VST Beyond 2021

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Revision Record

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1.0	Initial version	2020-11-25

List of Acronyms

ADC Atmospheric Dispersion Corrector
CTA Cherenkov Telescope Array
GTO Guaranteed Time Observations
KiDS Kilo-Degree Survey
LSST Legacy Survey of Space and Time
RRM Rapid Response Mode
SOXS Son of X-SHOOTER
SKA Square Kilometre Array
SM Service Mode
ToO Target of Opportunity
VLT Very Large Telescope
VPHAS VST Photometric Hα Survey
VST VLT Survey Telescope
VM Visitor Mode

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1 Scope of this document

1.1 VST beyond 2021

The VLT Survey Telescope (VST) is one of the largest telescopes in the world designed for surveying the sky in the optical band. The telescope has a 2.6-m aperture and is designed specifically for wide-field imaging. It is equipped with a single dedicated focal plane instrument: OmegaCAM. With OmegaCAM it is possible to carry out optical (0.3 - 1.0 microns) imaging over a field of view of 1 square degree. The VST is located at the ESO Paranal Observatory, one of the best astronomical sites in the world, in an enclosure immediately adjacent to the four ESO-VLT Unit Telescopes, where it is operated to high technical standards, providing excellent image quality and efficiency at negligible technical down time.
The VST is the result of a joint collaboration between the INAF–Osservatorio Astronomico di Capodimonte (Italy) and ESO. INAF has designed and built the telescope, OmegaCAM was designed and built by a consortium including institutes in the Netherlands, Germany and Italy (with major contributions from ESO). The enclosure and the civil engineering works at the site were under ESO responsibility. Following the original INAF-ESO agreement, since its first light (June 2011) the whole facility has been operated by ESO, which also archives and distributes data from the telescope, while INAF obtained Guaranteed Time Observations (GTO: initially 10%, increasing to 20% over time), keeping the property of the telescope.
The international scientific panorama changed a lot in the past decade, since the telescope was conceived and built. On the one hand, new observational infrastructures have been or will soon be introduced, first of all the Vera C. Rubin Observatory (formerly known as LSST), expected to open a new era in the field of synoptic surveys. On the other hand, the development of transient and multi-messenger astrophysics has introduced innovative scientific cases, where a telescope such as VST can be particularly productive.
In October 2021, after 10 years of activity the current INAF-ESO contract will expire (this date has been postponed to April 2022 due to the COVID19 pandemics) and the VST management and operations will evolve into a different INAF-ESO agreement, which is still to be discussed.

1.2 The VST beyond 2021 Working Group

In view of this approaching deadline, in November 2019 the Optical/NIR Division of the INAF Scientific Directorate appointed the "VST beyond 2021" working group to study the possible science cases and management options for the VST future. The working group is composed by:

- Paolo D’Avanzo, INAF - Osservatorio Astronomico di Brera (chair)
- Maria Teresa Botticella, INAF - Osservatorio Astronomico di Capodimonte
- Marco Gullieuszik, INAF - Osservatorio Astronomico di Padova
- Alessandro Papitto, INAF - Osservatorio Astronomico di Roma
- Pietro Schipani, INAF - Osservatorio Astronomico di Capodimonte

The main task of the “VST beyond 2021” working group is to explore the scientific potential of the VST telescope and to present to the INAF management a written report where a set of options for the future of telescope management and operations is described and discussed (this document).
During its activity, the working group “VST beyond 2021” issued a call for ideas, aimed at surveying the INAF community interest in the use of the VST for the next decade. The call for ideas was open to the INAF community, including the possibility of international collaborations and synergies. Even though it was not a call for awarding observing time, the response from the community has been very good, providing the “VST beyond 2021” working group an

effective tool to shape its recommendations concerning the VST future. All the submitted projects have been presented and discussed in a dedicated workshop held in June 2020. The presentations are available on the website:
https://indico.ict.inaf.it/e/VST2021

The report is structured as follows: in Sect. 2 we present an overview of the present status of the telescope, its instrumentation and operations. In Sect. 3 we present a summary of the main scientific results. In Sect. 4 we discuss the VST in the scientific panorama of the next decade. In Sect. 5 we present and discuss the results of the call for ideas. In Sect. 6 we list the possible and realistic short and long term scenarios for what refers to the telescope management and operations. Finally, we report our recommendations and concluding remarks (Sect. 7).

2 VST: the present

2.1 The telescope

The 2.6-m VST is one of the telescopes of the Paranal Observatory (Chile), the most productive astronomical observatory of the world, installed on the same platform of the four 8.2-m UTs composing the ESO Very Large Telescope (Fig. 1a,b). It is operative and fully offered to the astronomical community since 2011, observing nightly with a reliability which has increased over the years (Fig. 2). Unlike in the usual ESO scheme, where the instrument consortium is rewarded with observing time and the instrument becomes an ESO property, the VST remains an INAF property.

The telescope has been designed, built and commissioned by INAF, under the terms of an agreement with ESO. It is one of the two telescopes (together with the UK VISTA) not designed and built directly by ESO, operating in the Paranal observatory, where the exceptional quality of both the sky and the other telescopes (the VLT, flagship facility of the European astronomy) generates the tightest requirements in terms of performance and reliability.

The involvement of INAF researchers in its design, realization and commissioning makes the telescope well known and with no company-built black-boxes. It is worth mentioning it is the only INAF optical telescope of its class ever fully designed and realized in Italy, as the TNG itself was largely based on the ESO-NTT optomechanical design. A by-product of the project has been the development of a INAF know-how in systems engineering, management and technical aspects in ESO projects. So far, it is the only Italian-led instrument realized for ESO, with INAF having the full responsibility (several instruments will join it in the next decade: SOXS, MAORY, HIRES; still, it will be the only telescope), a precious heritage for INAF.

The basic technical features are summarized in the following sections.

Fig. 1a: ESO Paranal, the most productive astronomical observatory in the world. VST in the middle of the VLT Unit Telescopes on top of the platform.

Fig. 1b: The VST

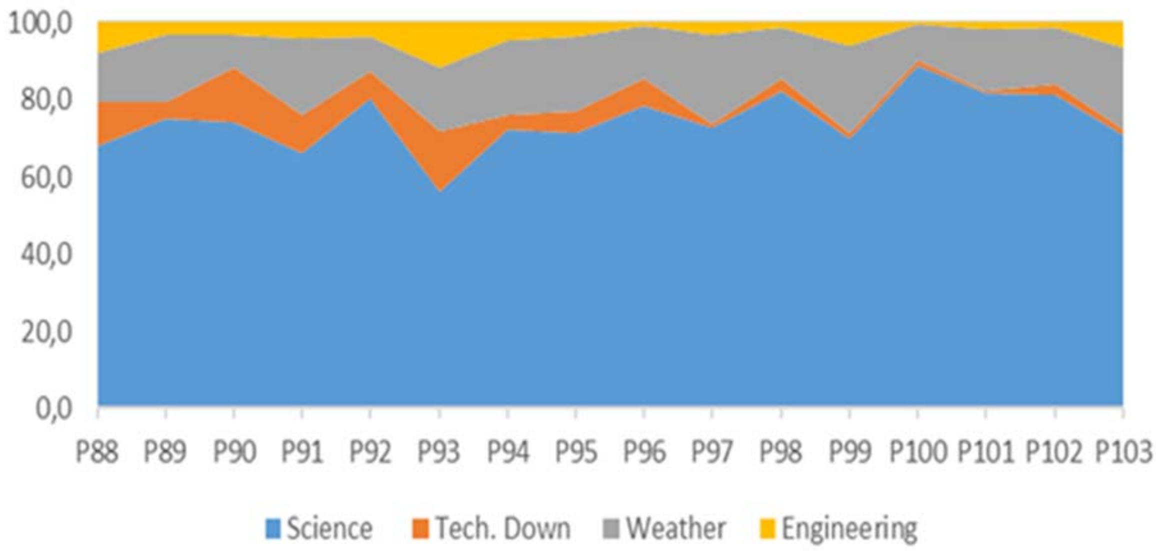

Fig. 2: VST statistics (Px= Period no. x; 1 period = 6 months). The technical downtime is at negligible levels in the last years.

2.1.1 Optical Design and Active Optics

The VST is an F/5.5 two mirror telescope with a lens corrector designed to flatten the field dependent aberrations, improving the image quality on a wide field of view. The primary mirror is a concave 2.6-m hyperbolic meniscus with a 60 cm central hole and 140 mm thickness, the 0.9-m secondary mirror is convex and hyperbolic.

It operates from the ultraviolet to the z'-band with a corrected field of view of 1.42 degrees in diameter, allowing for an inscribed square field of a net 1 degree in size. The wide-field corrector is composed of two lenses with the dewar window of the camera acting as a third lens.

The telescope is equipped with an active optics system, based on wavefront sensing and correcting devices, which are actuators for modifying the shape of the primary mirror and for the positioning of the secondary mirror. Two wavefront sensors were built, one in the telescope and another in the camera. The one in the telescope is a Shack-Hartmann sensor installed on a probe system, which can be positioned anywhere in the field, using a motorized probe. The camera sensor is based on the curvature principle. After the commissioning of the telescope, the camera wavefront sensor has been adopted for night operations, because it has no moving parts and provides a way quicker measure.

The correction system is composed of a hexapod, which moves the secondary mirror, and four rings of force actuators supporting the primary mirror, which is also protected by a safety system from possible damages caused by earthquakes. The commands to the actuators can come from an online computation of corrections coming from the wavefront sensor, or from the interpolation of look-up tables containing calibrated values depending on zenith angle and temperature. Normally, the telescope works in closed active optics loop mode, with corrections applied in between the science exposures.

It is worth noticing the VST is the only telescope based on active optics completely designed from scratch in Italy, i.e. not partially based on replicas of other telescopes. This allowed for the development of a full Italian know-how in the design of active optics systems, a different and complementary field with respect to the adaptive optics.

2.1.2 Pointing and Tracking System

The telescope has an alt-azimuthal mount and is hosted within a relatively small enclosure to minimize the effects of dome seeing.

Both azimuth and altitude axes are driven by four motors controlled in pairs, applying a constant preload torque bias that prevents backlash problems at almost zero speeds. The position feedback is provided by high quality glass disc encoders, customized for astronomical telescopes. The velocity feedback is provided by differentiating the encoder signal. Two nested control loops (position and speed) are implemented in order to provide a high quality pointing and tracking.

The pointing accuracy was measured at the level of 1 arcsecond root-mean square (RMS), with a best score of 0.8 arcseconds. The tracking axes have a blind tracking error against their own encoders of the order of a few x 0.01 arcseconds RMS, smaller than specification. The VST guiding system enables an image centroid error smaller than 0.1 arcseconds. Good performance has been measured also during windy nights, with wind speed up to the operational limit of 18 m/s. As for wavefront sensing, the guiding is performed using the camera auxiliary CCDs rather than the telescope probe.

The pointing and tracking system has the same level of performance of the other telescopes in Paranal.

2.1.3 The Engineering Plant

The VST is also a complex engineering plant. It includes a control system based on workstations and real-time computers based on the VME bus and the VxWorks operating system. About 60 software modules run in parallel on 10 computers to control the whole telescope, a factor 5 more complex than the control system of a typical ESO instrument. More than 100 control loops simultaneously operate during the operations. A Hydrostatic Bearing System supports the telescope and allows for a frictionless azimuth rotation.

All the heat sources are cooled in order to prevent any dome seeing effect. The whole telescope is hosted inside a rotating enclosure which is totally decoupled from the telescope to avoid interference. Last but not least, the whole system operates in a remote environment (a desert) and is designed to be extremely reliable and easy to maintain.

It is worth noticing that in the official ESO statistics of the last years, including all Paranal and La Silla telescopes, the VST has often been the telescope with the smallest technical downtime and/or with the largest time available for science activities (Fig. 2-3).

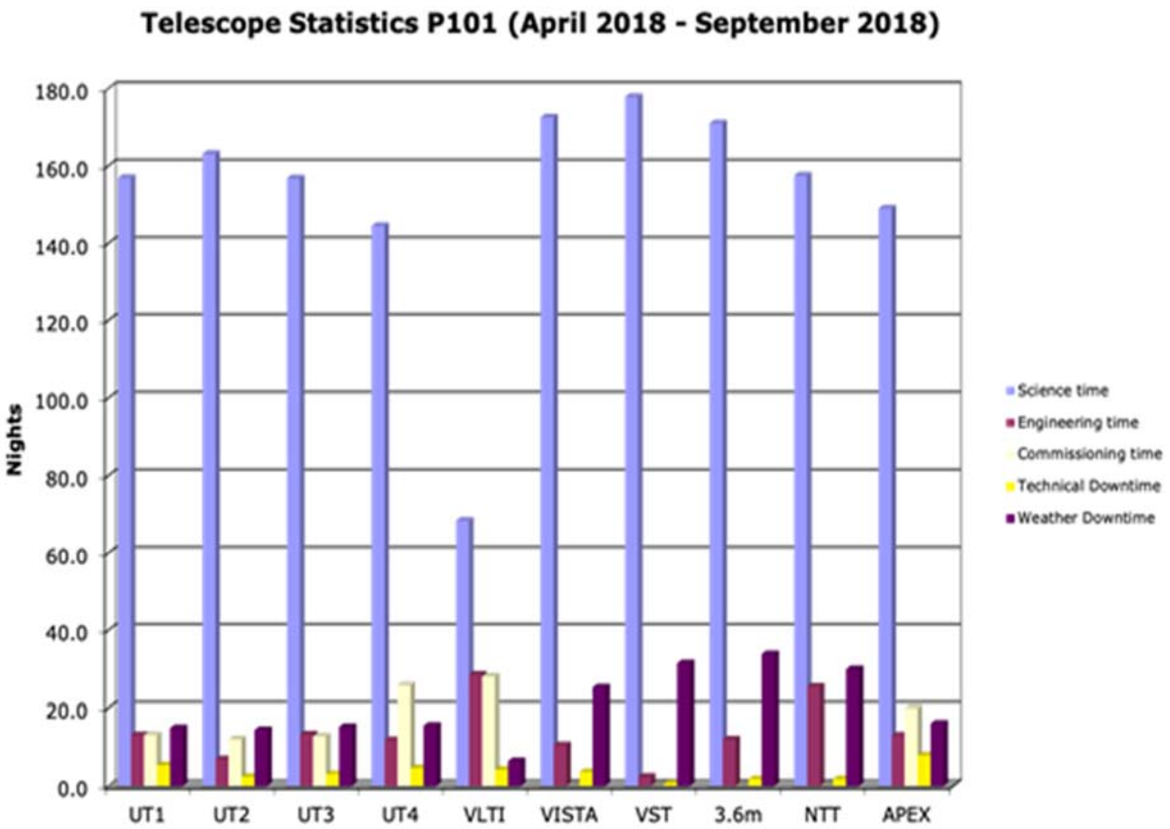

Fig. 3: Statistics of ESO La Silla Paranal Observatory for one recent semester, with the VST having the smallest technical downtime and the highest science time.

2.1.4 Telescope Image Quality

The ideal performance for a wide-field telescope like VST is to be seeing-limited. This means the degradation due to imperfections of the instrument itself shall be negligible with respect to the disturbance caused by the atmospheric turbulence. As the atmospheric turbulence effect is exceptionally small in the Paranal site (considered one of the best in the world for its “seeing”), this was a very ambitious goal for VST, harder to achieve than in any other site. Therefore the requirements in the error budget for the individual subsystems were very tight.
After a successful commissioning, the VST regularly provides seeing-limited images, with FWHM of 0.5 arc seconds across the whole 1°x1° field in nights of good seeing. This is one of the best image quality among the wide-field imagers operating in visible bands, which has been key to the success of some of its main science programmes (see Section 3.1).
At the start of the operations in 2011, it was the largest telescope in the world specially designed for surveying the sky in visible light. Still today, its combination of image quality, wide-field and depth makes it competitive and attractive for the community inside and outside Italy.

2.1.5 Unused subsystems

Several years into telescope operations, two telescope subsystems are daily unused. This can be important for planning instrumentation upgrades (see, e.g., Sect. 5.2). Their current functionality and reliability is not assessed (INAF staff last used them 8 years ago):

- Probe
  It was successfully commissioned, providing telescope autoguiding and wavefront sensing, essential for the telescope commissioning and the calibration of the equivalent camera systems. After commissioning, the VST, OmegaCAM and ESO teams agreed the best for the integrated telescope+camera system was the adoption of autoguiding and wavefront sensing on the camera side (having no moving parts). Thus, now the probe is never used in normal operations. Still, it is needed to update the telescope pointing model. This is a rather rare activity at the VST for the Paranal staff.

- Atmospheric Dispersion Corrector (ADC)
  An error in optical manufacturing emerged during commissioning, making the system unusable. Thus, the telescope was never fully characterized with the ADC in place. No user complained and no recovery plan was scheduled.

2.2 OmegaCAM

The VST has only one (Cassegrain) focus for instruments, hosting the OmegaCAM (K.Kuijken, The Messenger 146, 8-11). It is a large format (16Kx16K pixels) CCD camera contributed by the OmegaCAM consortium (Netherlands, Germany, Italy, ESO), composed by a mosaic of 32 2Kx4K two edge buttable scientific CCDs manufactured by E2V, arranged in a 8x4 matrix for almost 300 millions pixels in total. The array samples a full square degree at 0.21 arcsecond per pixel resolution, with minimal gaps between the devices.
The optical design of the telescope and camera was integrated. The dewar entrance window of the camera is actually a spherical lens with optical power, belonging to the 3-lens telescope field-corrector.
A filter exchange mechanism permits observations through any one of the filters, that are significantly large, about 30x30cm. OmegaCAM comes with broad Sloan u,g,r,i,z,B,V filters, as well as a Strömgren-v and several narrow-band filters. Many of the narrow-band filters are segmented, with four quadrants that each have a different band-pass; a special calibration filter with u,g,r,i quadrants for extinction measurements is also part of the set. Liquid nitrogen is used to cool the detectors.
Removing and reinstalling the instrument is a quite long operation, because it is surrounded by many cables and tubes.
OmegaCAM is still one of the largest wide-field imager in the southern hemisphere. The *u-band* sensitivity is high, because of the choice of CCDs; other optical wide-field imagers sacrifice *u-band* sensitivity for near-infrared.
In addition to the science CCDs, the focal plane also contains four auxiliary CCDs used for guiding and wavefront sensing. The wavefront sensor works by registering out of focus star images. Two auxiliary CCDs are mounted out of the focal plane, one 2mm above and one 2mm below for this purpose. Aberrations are measured during scientific exposures from the way the donuts are distorted, and as soon as the shutter is closed the telescope is corrected, ready for the next exposure.
The other two auxiliary CCDs are mounted in focus, implementing an autoguider that guides using two stars either side of the field (so that the center of the image remains on track), providing corrections to azimuth, altitude and rotation axes.
Unlike the telescope, the OmegaCAM is owned by ESO (the camera has followed the traditional scheme for ESO instruments realized by external consortia: the property of the instrument was transferred to ESO in return of some GTO).
All other details are available in the user manual being maintained by the ESO user support group.

Fig. 4a: OmegaCAM at the VST Cassegrain focus

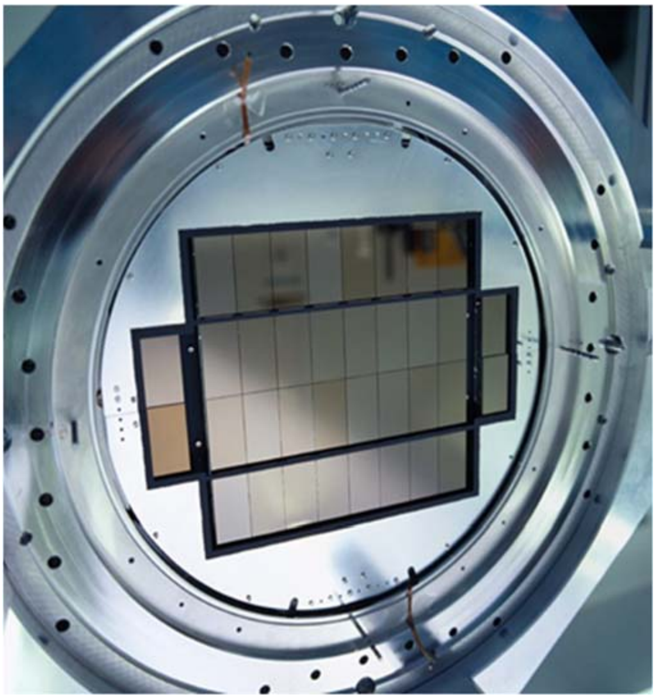

Fig. 4b: OmegaCAM array of detectors

2.3 Enclosure

According to the original MoU agreement between ESO and INAF-Capodimonte, the civil works including the enclosure were part of the ESO delivery. Thus, within the VST project collaboration, the enclosure is owned by ESO.
ESO placed a contract to design and manufacture the VST enclosure, following the same strategy adopted for all other telescopes in Paranal. The control system of the enclosure is fully integrated with the telescope.

Fig. 5: Inner view of the enclosure

2.4 Operations & Data Flow

The VST Data Flow System is based on the standard ESO Data Flow Model (Peron, ASP Conf. Series 461, 2012; Mieske, DOI:10.5281/zenodo.1303284, 2018) represented in Fig. 6 and summarized here.

The ESO Data Flow System is a distributed system which provides all necessary components involved in the observation life-cycle to support the operations of the telescopes:

- Phase 1: assist external users in the preparation and submission of their proposals, and the Observing Programme Committee to assess and select the proposals.
- Phase 2: Observation handling to prepare and schedule the Observation Blocks.

- An archive system to store the raw data acquired by the instruments.
- Pipelines to reduce the raw data in order to check the quality of the observations and monitor the health of instruments.
- Phase 3: the process of preparation, validation and ingestion of science-ready data products (usually carried out by the PIs of the ESO observing programmes, in particular those related to public surveys).

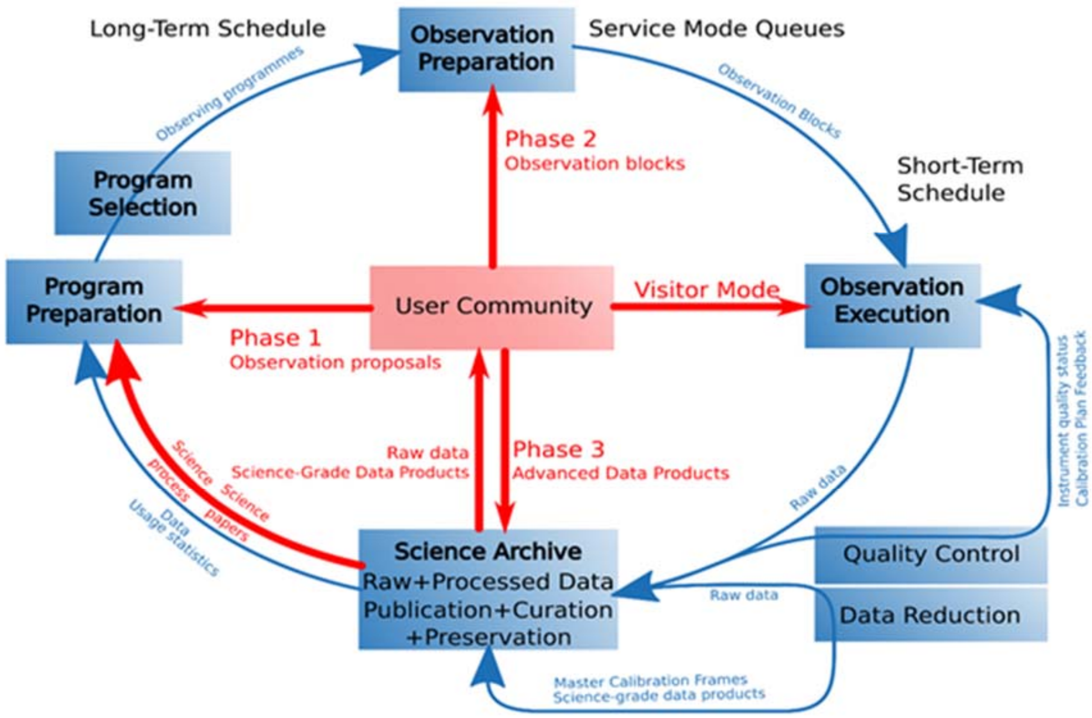

Fig. 6: The ESO Data Flow Model

At the moment, many people in Paranal and Garching contribute to the VST Data Flow System implementation.

- ESO staff periodically updates the instrument User Manual and prepares Call for Proposals (common to all telescopes).
- The OPC panels approve or reject the proposals submitted by the community.
- The ESO User Support Department (based in Garching) monitors the execution of the programmes, provides statistics, checks the right balance of time sharing (GTOs, Chilean time, etc.) and assists the community acting as a help-desk.
- The ESO Quality Control group (based in Garching) ensures that a complete set of good quality calibrations is available to calibrate science data, monitors performance of the instrument, provides continuous feedback to the Observatory about the status of the data and of the instrument, and provides information to the community through web pages.
- The ESO Paranal Team takes care of night operations, providing a semi-automatic detailed log of the activities. The Paranal Team is in charge of all instrument and telescope issues affecting the normal execution of the science programmes. An issue tracker (Paranal Problem Reporting System – PPRS) is in place, to track any issue, related to the quality or at the functionality of the instrument. In Paranal many sub-

teams are involved: the TIOs, the Maintenance, Support and Engineering Department, the Instrument Scientist, etc.
- The ESO Science Archive (based in Garching) provides the storage of the VST data. An instrument specific query page is publicly accessible. Statistics are prepared on publications, archive usage, etc.

2.4.1 Program handling

During the first years of operations, the VST time available for the ESO community has been extensively used for its three public surveys (see section 3.1). Only recently, these surveys have been completed and more time has been offered to the European community twice a year. Similarly, the Italian GTO (20% of the time) has been assigned only for programmes with duration of few years, selected by a panel appointed by the INAF Scientific Directorate after a public call.
With reference to the time offered to the ESO community, the proposals for observations at VST follow the normal ESO evaluation process. They are invited twice a year and contain a scientific case, a summary of the proposed observing programme, a list of desired instrument modes as well as a definition of the observing conditions. Proposals are submitted through the ESO P1 web application. They are reviewed by the Observing Programmes Committee (OPC), which evaluates the scientific merit of the proposals and provides recommendations that serve as a basis for the final decision on the telescope time allocation by the ESO Director General.
The observations at the VST are carried out almost exclusively in **Service Mode (SM)**: observations are carried out by ESO staff with the goal of maximizing the scientific efficiency by executing first the programmes with the highest scientific priorities under the required observing conditions. The other option, discouraged by ESO for survey telescopes whose programs are intrinsically very long, is the **Visitor Mode (VM)**: the astronomers travel to the Observatory and conduct their observations themselves. This allows them to take decisions on the execution of their programmes in quasi-real time on the basis of the results obtained so far, with the drawback of taking the risk of bad weather. The Visitor Mode has been allowed for VST only in very specific cases, in case the program PI could demonstrate the Service Mode scheme couldn't allow for the successful execution of their program based on a specific observing strategy.
A long-term schedule is prepared by ESO for each six-month semester, simply allocating blocks of time for the few Visitor Mode runs and for engineering nights, if any. However, in the large majority of the time the VST works in pure Service Mode with no schedule at all (see the following Section).
A further observing mode that is sporadically used at the VST is the **ToO (Target of Opportunity)**, very useful for science related to the study of transient sources. So far, this has been used for a minimal amount of time for the search of electromagnetic counterparts of gravitational waves. ToO observations can be scheduled with short advice (hours), overcoming any other Service Mode operation, as well as for the other ESO telescopes.

2.4.2 Observation handling

Users who have obtained observing time must provide a detailed description of their observations in the form of **Observation Blocks**. The web based Phase 2 tool (P2) is used by the ESO user community for the preparation of their observations, both in VM and SM mode. The tool is not VST specific, it is used for all ESO telescopes.
The nighttime operations of the VST are performed in Service Mode for the vast majority of the time. It is worth mentioning the Service Mode implementation is based on a flexible system which uses no schedule at all. In other words, with this system nobody exactly knows what will

be observed the next night. A Service Mode tool (Fig. 7) filters the OBs by matching their constraints with the current environmental conditions. It is based on a ranking algorithm that presents the next Observation Block to be observed to the telescope operator on the basis of the observing strategy defined in the scheduling constraints, the visibility of the targets as well as the various observing constraints (e.g. Moon distance, seeing, etc.). It provides a list of observable OBs which are then selected and executed by the Telescope Operator.
This system is not adopted in the few cases of Visitor Mode or ToO observations, which must be handled differently by the observatory.

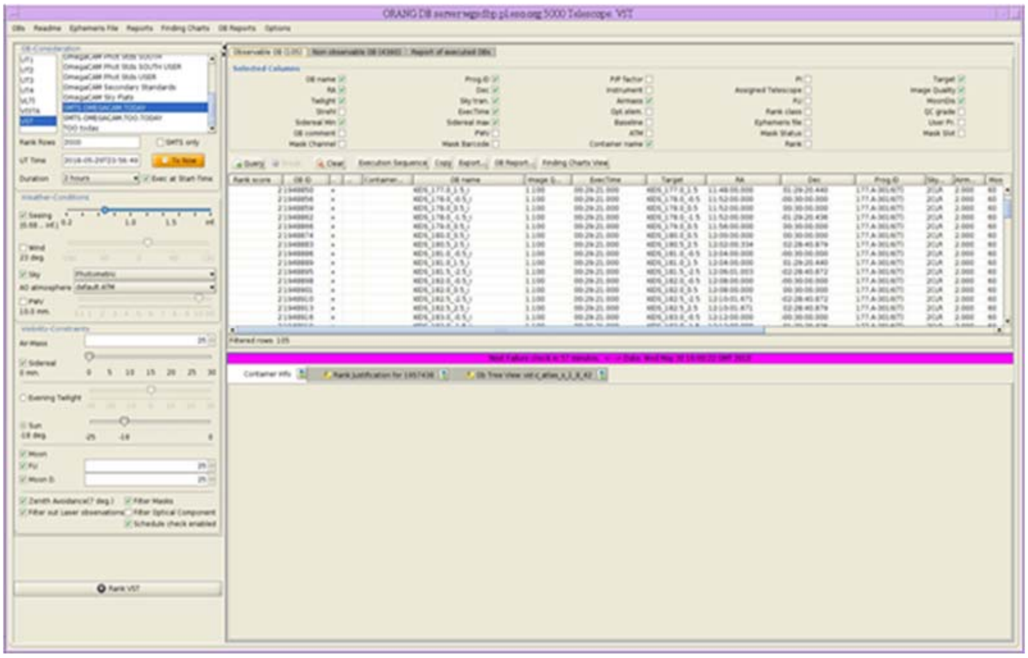

Fig. 7: Service Mode tool

Fig. 8: VST & VISTA area in the Paranal Control Room

Nighttime operations of the VST are performed by a single TIO (Telescope Instrument Operator), who is shared with VISTA since June 2018, thanks to the proven stability of the two systems. There is no night astronomer support, except for the managing of ToO requests, where an ESO astronomer provides support to the requester and to the TIO (Fig. 8 shows the Paranal Control Room area for the survey telescopes).
Quality Control (QC) grading is provided by a script analyzing average Image Quality (IQ), ellipticity and IQ variation across the field. The Quality Control loop works like this: data are acquired at Paranal, transferred to Garching where they are processed and checked, then the results are fed back to Paranal. The certified calibrations are saved in the Archive.

2.5 VST Data Center

The VST Data Center is based at INAF – Capodimonte. It was established to take care of data reduction for the GTO programmes. Indeed, it has also provided some support to the KiDS public survey using the Astro-WISE (http://www.astro-wise.org/) pipeline.
The VST machines, mostly based on DELL equipment, are hosted in a dedicated room in the Capodimonte laboratories. Hardware and human resources were dimensioned for the Italian GTO, i.e. for a limited amount of data: the VST GTO time percentage was initially 10%, increasing to 20% over time.
The data center was established a few years before the start of the operations. The first machines were purchased in the period 2006-2009, then a partial upgrade was done in 2013-2014.
The number of FTE dedicated to data reduction has been on average 1.5; data were not reduced in parallel with the acquisition, anyway all queues were absorbed with time. The very limited percentage of GTO dedicated to multi-messenger astronomy, requiring prompt reaction, was handled differently, i.e. promptly served. Personnel and software have partially changed over time.
The VST Data Center is based on the Astro-WISE pipeline. Astro-WISE was created by the Astro-WISE Consortium, a partnership of OmegaCEN-NOVA at the Kapteyn Institute in Groningen, INAF - Osservatorio Astronomico di Capodimonte, Terapix at IAP in Paris, ESO, Universitats-Sternwarte Munchen. As such, it is a private pipeline but publicly available to the members of the consortium or under request by single users. Astro-WISE was conceived to handle the vast amounts of astronomical data generated by all-sky surveys, particularly those to be observed with OmegaCAM on the VST, but it has also been used for several other instruments. It is the pipeline of the KiDS public survey, the program receiving more time by far at the VST, and of several other programs.
The other two public surveys ATLAS and VPHAS+, led by UK astronomers, adopted the private British pipeline CASU (http://casu.ast.cam.ac.uk/).
An example of a public pipeline, used in specific cases also at the VST Data Center, is THELI (https://www.astro.uni-bonn.de/theli/).
Some programs, way smaller than a public survey, provided data reduction with their own resources and software. At variance with other ESO facilities, a public, ESO-released (and maintained) pipeline is not available for OmegaCAM.
However, it shall be noted that for long and large programmes, taking the majority of time at the VST, the data reduction is extremely time consuming and not comfortably affordable for a science team with no assistance from a dedicated structure, as it has been the case for most of the programmes done at the VST in the last decade.

3 Science with the VST in the years 2011 - 2020

3.1 Scientific Programs

The aim of this section is to give an overview of the scientific activity and output of the VST in the last decade. Unavoidably, this will be done by mentioning some programs, but this description does not want to be exhaustive. Historical programs, which have already produced published papers, have clearly received more attention. More recent programs, still not well documented, have not been mentioned. A good overview of the science programs at the VST is the Zenodo repository of the “VST in the era of the large sky surveys” conference held in 2018, inspiring much of this section, accessible from the conference website:
https://indico.ict.inaf.it/event/549/timetable/#all

The observing time at the VST was shared between:

- ESO Public Surveys (~67%)
- GTO VST and OmegaCAM (~23%)
- Chilean Time (10%)

The three public surveys (KiDS, ATLAS, VPHAS+) have been by far the largest programs at the VST. They started in 2011 and ended recently (2018-2019), fully executed in Service Mode. The Data reduction has been done by using the two pipelines Astro-WISE (with the contribution of the VST Data Center at INAF - Capodimonte) and CASU (for the British surveys). The main features of the Public Surveys are outlined in the following.

KiDS, the Kilo-Degree Survey (de Jong et al. 2013, Exp. Astron., 35, 25D) has mapped two areas of extragalactic sky for 1350 square degrees of the night sky in four broad-band filters (ugri), working in parallel with the infrared survey VIKING (Arnaboldi et al. 2007, The Messenger, 127, 28) at VISTA to get a wide wavelength coverage (u-K, 9 bands) that is unique for surveys of its size and depth. The integration times are chosen so that the survey reaches a median redshift of 0.7. The central science case for KiDS is mapping the matter distribution in the Universe through weak gravitational lensing and photometric redshift measurements. However, the enormous data set of KiDS can also be used for many different applications.
To be successful, KiDS needed an excellent image quality, better than any previous similar survey with other wide-field imagers. The reason is that weak lensing is in principle an excellent method to act as a cosmological probe, but lensing measurements need to be free of systematics to better than 1% accuracy, and photometric redshifts unbiased to a similar level. The expectations have been fulfilled to a point unmatched by any other similarly wide-field cameras. The combination of excellent natural seeing at the site, fully active optics in the telescope and a specially designed real-time curvature sensing system were fully exploited by KiDS (as well as by smaller extra-galactic programs observed on GTO time, e.g. VEGAS, FDS, etc.). Image quality is the key, because one of the central requirements for weak lensing surveys is to be able to measure the intrinsic shapes of faint, small galaxies accurately, and any blurring of the images degrades the accuracy to which this can be done.

The VLT Survey Telescope **ATLAS** survey (Shanks et al. 2015 MNRAS, 451, 4238) is an optical survey in five bands (ugriz) covering ≈4700 deg2 of the southern sky to similar depths as the Sloan Digital Sky Survey (SDSS) in the Northern Hemisphere. ATLAS has been extended with u-band observations in Chilean time.
The median seeing ranges from 0.8 arcsec FWHM in i to 1.0 arcsec in u, significantly better

than the 1.2–1.5 arcsec seeing for SDSS. The 5σ mag limit for stellar sources is rAB = 22.7 and in all bands these limits are at least as faint as SDSS. SDSS and ATLAS are more equivalent for galaxy photometry except in the z band where ATLAS has significantly higher throughput.
The ATLAS survey is particularly aimed at survey cosmology but can be exploited for many other branches of extragalactic and Galactic astronomy. ATLAS science highlights range from quasar redshift surveys in the range 0.5<z<6.5, including quadruply lensed quasars and investigations of the Cosmic Microwave Background (CMB) Cold Spot via ATLAS based galaxy redshift surveys, to the discovery of dwarf Milky Way satellite galaxies including the crucial Crater 2 dwarf and new catalogues of thousands of white dwarf stars in the Milky Way.

The VST Photometric Hα Survey of the Southern Galactic Plane and Bulge (**VPHAS+**, Drew et al. 2014, MNRAS, 440, 2036) has surveyed the southern Milky Way in ugri and Hα (segmented narrow-band filter) at ∼1 arcsec angular resolution. Its footprint spans the Galactic latitude range −5° < b < +5° at all longitudes south of the celestial equator. Two extensions around the Galactic Centre to Galactic latitudes ±10° bring in much of the Galactic bulge. This survey reaches down to ∼20th magnitude (10σ) and provides single-epoch digital optical photometry for ∼300 million stars. Thanks to its excellent imaging performance, the VST/OmegaCAM combination used by this survey is a perfect vehicle for automated searches for reddened early-type stars, and for the discovery and analysis of compact binaries, white dwarfs and transient sources.

Initially, the Public Surveys took all the time offered to the ESO community. Recently (2018-2019), the Public Surveys have been completed. As ESO didn't own the telescope, the expiration of the agreement with INAF in 2021 was not far, and no new agreement with INAF had been signed yet, ESO couldn't issue a new call for long Public Surveys. Thus, in the very last semesters ESO simply offered an increasing amount of time at the VST, made free by the completion of the Public Surveys. These programs started recently and as such are not mentioned here, because generally no public description exists yet. However, it is worth mentioning several large programs embracing more semesters were approved by the OPC.

The GTO time was shared among Galactic, extra-galactic and transient astronomy programs. All of them were planned initially in Service Mode. Starting in 2015, the ToO mode was implemented for a multi-messenger astronomy program related to the beginning of science operations of the advanced LIGO/Virgo gravitational wave interferometers (since 2015, still ongoing); it was adopted for a relatively small amount of time. A non-exhaustive description of the programs (several programs are here neglected as they started recently and still did not arrive to publications) is reported in the following.

Galactic astronomy
Stellar programs ranging from STREGA (STRucture and Evolution of the GAlaxy, Marconi et al. 2014, MNRAS, 444, 3809), aimed at investigating the formation and evolution of the galactic halo, to STEP (the SMC in Time: Evolution of a Prototype interacting late-type dwarf galaxy, Ripepi et al. 2014, MNRAS, 442, 1897) and YMCA (Yes, Magellanic Clouds Again), looking into the Magellanic system stellar populations, were executed or are still running.

Extragalactic astronomy
The VEGAS (VST survey of Early-type GAlaxies in the Southern hemisphere, Capaccioli et al. 2015, A&A, 581, 10) team performed a survey of early-type galaxies (ETGs) taking advantage of the deep photometry, addressing the study of stellar halos and faint structures. Oher

program highlights are about globular clusters within the same fields, as well as a look at galaxies in the Dorado group and the post-merger evolution of ETGs. The same VEGAS team worked also on the Fornax Deep Survey (FDS, Iodice et al 2016, ApJ, 820, 42) publishing many papers with results on the evolution of dwarf galaxies, the automated searches for low surface brightness galaxies and the surface photometry of late type galaxies inside the virial radius of the Fornax cluster.
The WINGS/OmegaWINGS (Wide-field Imaging Nearby Galaxy clusters Survey with OmegaCAM, Gullieuszik et al. 2015, A&A, 581, 41) surveys studied nearby galaxy clusters originating follow-ups with the AAOmega spectrograph, Alma, Meerkat, VLA, HST and including a Large Programme with MUSE (GASP; Poggianti et al. 2017, ApJ, 844, 48).
The Shapley Supercluster Survey (Merluzzi et al. 2014, MNRAS, 446, 803) conducted with VST, VISTA and the AAOmega spectrograph observed the transformations of galaxies in a stormy environment.

Transients and multi-messenger astronomy
The evolution of the supernova rate with cosmic time was studied by the SUDARE (SUpernova Diversity And Rate Evolution; Cappellaro et al. 2015, A&A, 584, A62) program, monitoring the two Chandra Deep Field South (CDFS) and Cosmic Evolution Survey (COSMOS) sky fields in a joint effort including Italian and Chilean time and the VOICE (VST Optical Imaging of the CDFS and ES1) program. In addition, the multi-epoch survey of the COSMOS field allowed to test the optical variability as a tool to identify Active Galactic Nuclei (AGN).
The GRAWITA (GRAvitational Wave Inaf TeAm) collaboration uses the VST in the search for electromagnetic counterparts of gravitational wave events in reaction to LIGO/Virgo alerts. This program triggered the introduction of the ToO mode at the VST. In particular the kilonova AT2017gfo, optical counterpart of the neutron star merger GW 170817, was observed by the GRAWITA team with the VST (Pian et al., 2017, Nature, 551, 67). The parallel use of more interferometers is going to produce alerts way better localized in the sky. This makes the field of view / depth combination of the VST a powerful tool for the search.

GAIA support
Among the ESO community time programs other than Public Surveys, it is worth mentioning the VST Ground Based Optical Tracking (GBOT) campaign, essential to improve the astrometric precision of GAIA. The main GAIA papers are also partially based on VST data. As a by-product, additionally this program discovered lots of new asteroids.

3.2 Scientific Results

The list of VST papers published on refereed journals, maintained officially by ESO, is available here:

http://telbib.eso.org/index.php?&flimiti=off&fq[]=instrument:OMEGACAM

Hereinafter we report absolute metrics of the VST in terms of published articles, as well as a comparison with the other ESO instruments.

- To date, 232 refereed papers based on VST observations have been published by international refereed journals, according to the official ESO statistics, with about 15000 citations and h-index = 43.

- After an initial ramp-up phase, in the last 3 years more than 50 papers/yr based on VST data have been published in refereed journals.

The comparison with other ESO instruments is carried out in terms of number of papers normalized by years of operations, i.e. shifting all the initial times to start together. We note explicitly that this comparison is done between the VST and the most productive telescopes worldwide.

- Fig. 9 shows the VST and VLT instrument papers by years of operations. VST/OmegaCAM is in the middle of the group, giving its contribution to make Paranal the most productive observatory in the world.

- Three VST papers are in the “ESO Top 20” 2020 ranking (see http://telbib.eso.org) for number of citations all time (4^{th},7^{th},14^{th}).

- Fig. 10 reports the VST and VISTA papers normalized by years of operations, showing approximately the same slope in the first years, where the comparison can be done. VISTA is the other ESO survey telescope, working at IR wavelengths, with a larger aperture of 4.2-m. VISTA is acknowledged as a successful project and an asset for ESO, that decided to start a 2nd generation instrument project (4MOST).

In short, the VST is highly productive in absolute terms, holding up the comparison with the best telescopes of the world.

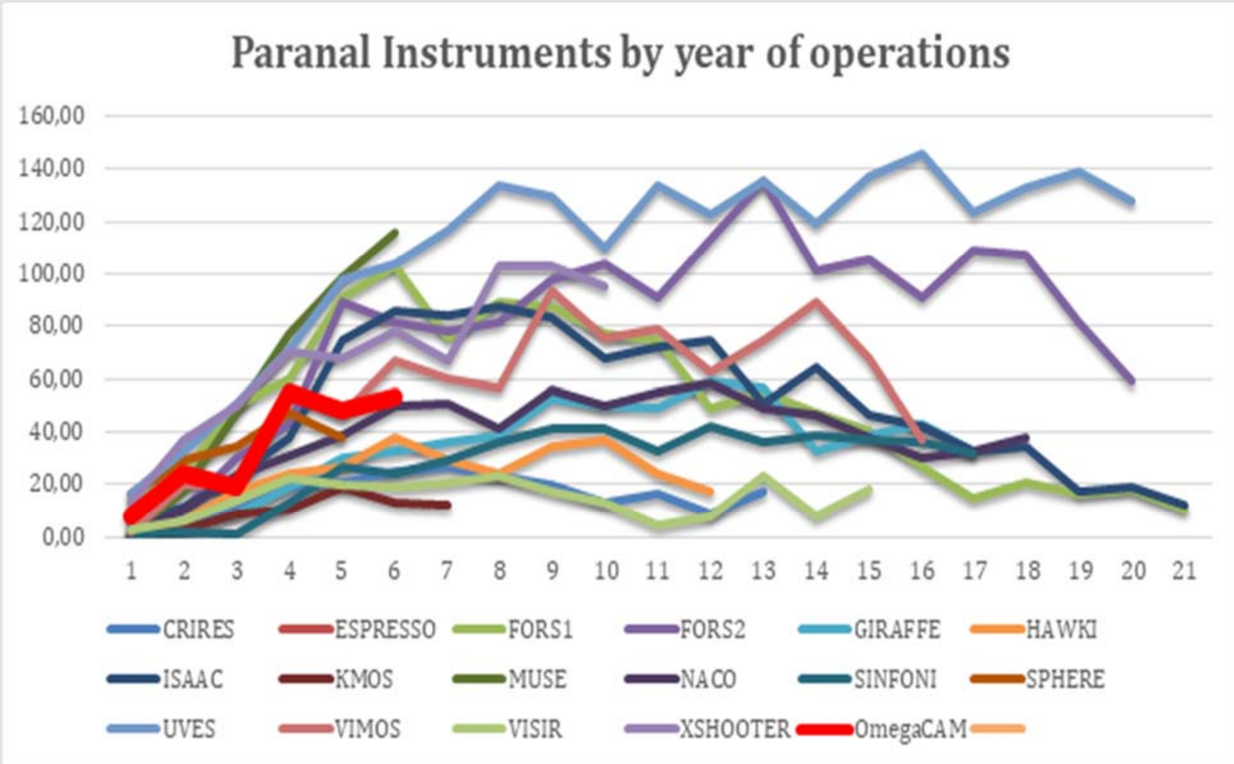

Fig. 9: Papers with VST and VLT instruments, normalized by year of operations

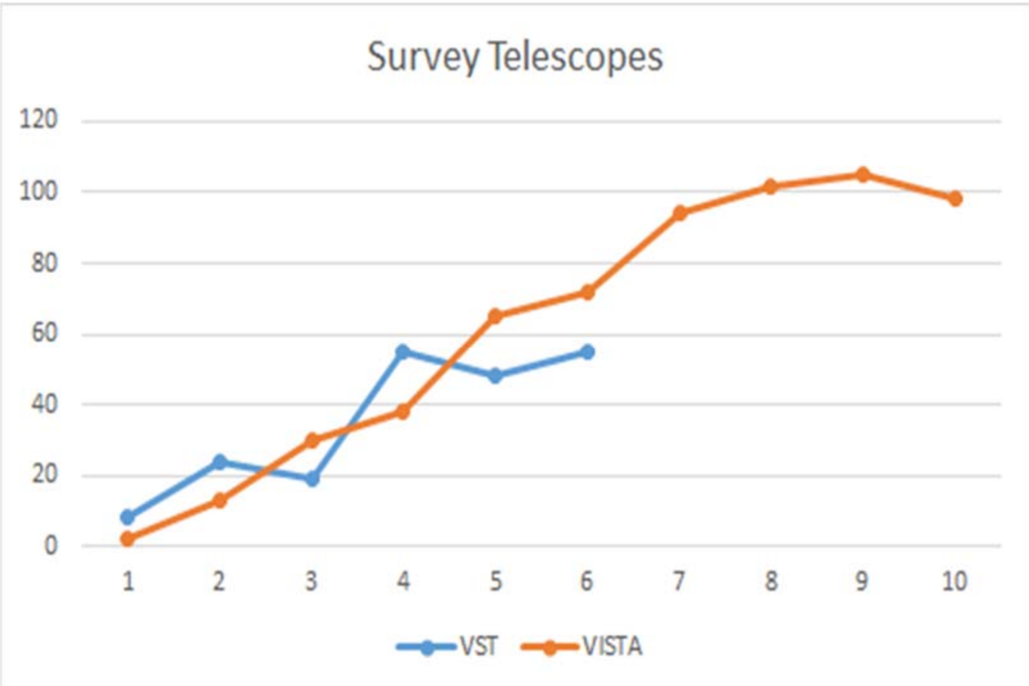

Fig. 10: Papers with VST and VISTA instruments, normalized by year of operations

Not surprisingly, the three public surveys (Figure 11) resulted in the highest number of publications since their size is not comparable with respect to the other programmes.

Figure 12 shows the impact of the Italian community on the VST production. Overall, about 40% of the papers have been authored or co-authored by astronomers affiliated to Italian institutions (INAF and universities), through the GTO programmes but also, with non-negligible percentage, through the involvement in KiDS and other programmes on community time. The percentage of GTO papers is higher than the percentage of GTO time, but in reasonable agreement. Thus, the Italian GTO time has been used at least as effectively as the community time.

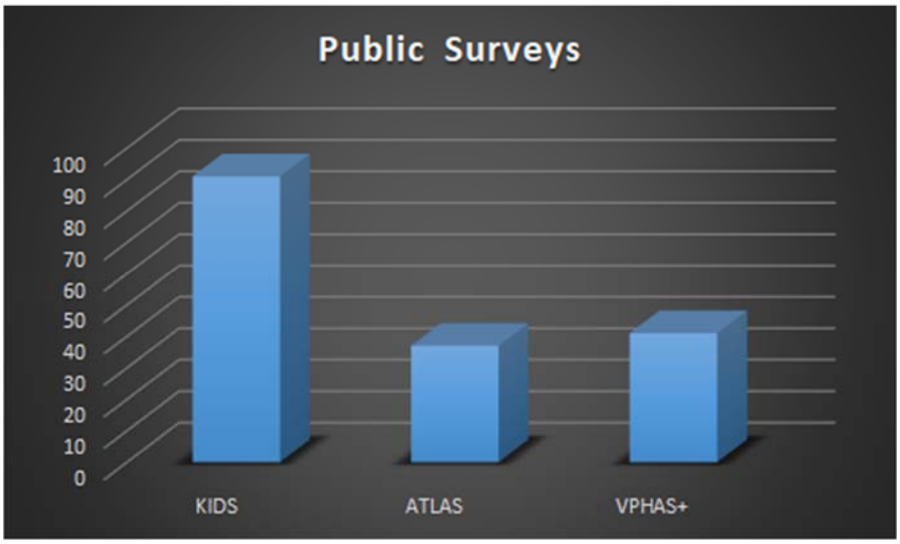

Fig. 11: Papers produced by public surveys (ESO Telbib data)

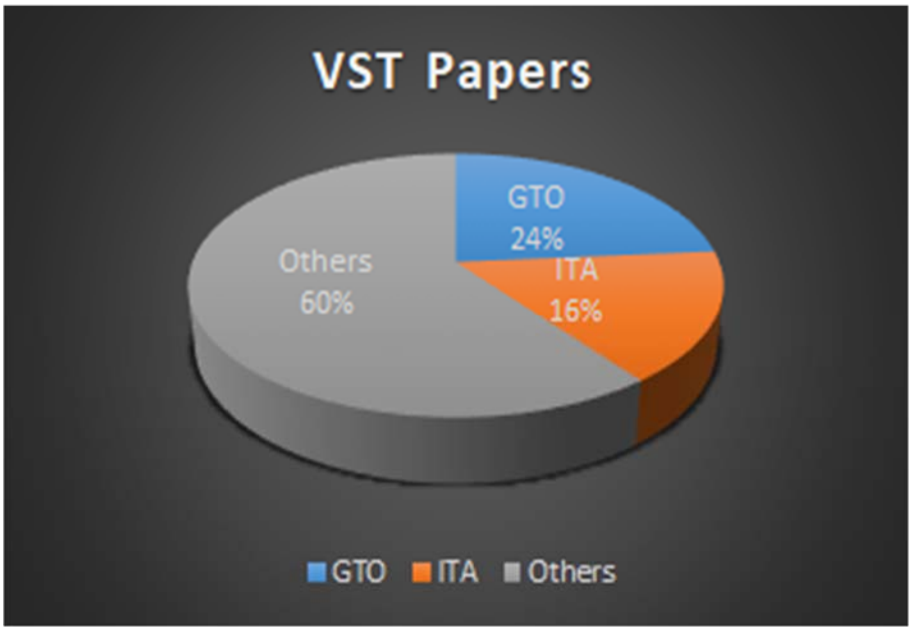

Fig. 12: Blue - papers from GTO time; Red - other papers with Italian authors (mainly through the participation to KiDS); Gray- all other papers

Figure 13 reports the sharing of GTO papers among the various programmes. We note explicitly that they were granted a different amount of observing time and did not start all at the same time; however, an analytic description is outside the scope of this report.

Figure 14 shows that all the VST papers have been published on high impact journals for the astronomical community, with a strong prevalence of MNRAS, A&A, ApJ and a paper on Nature (on GTO time: Pian et al. Nature 551, 67-70, 2017).

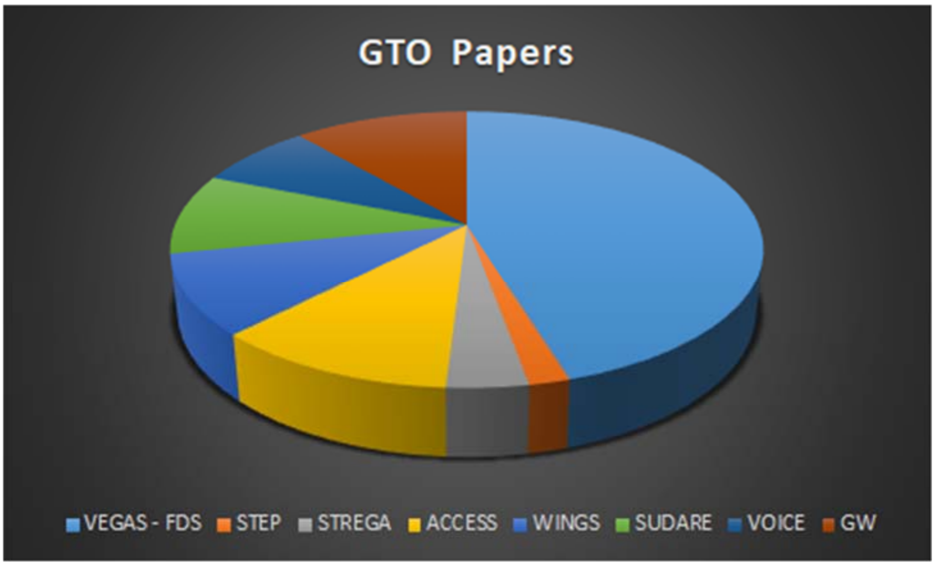

Fig. 13: Papers on GTO time

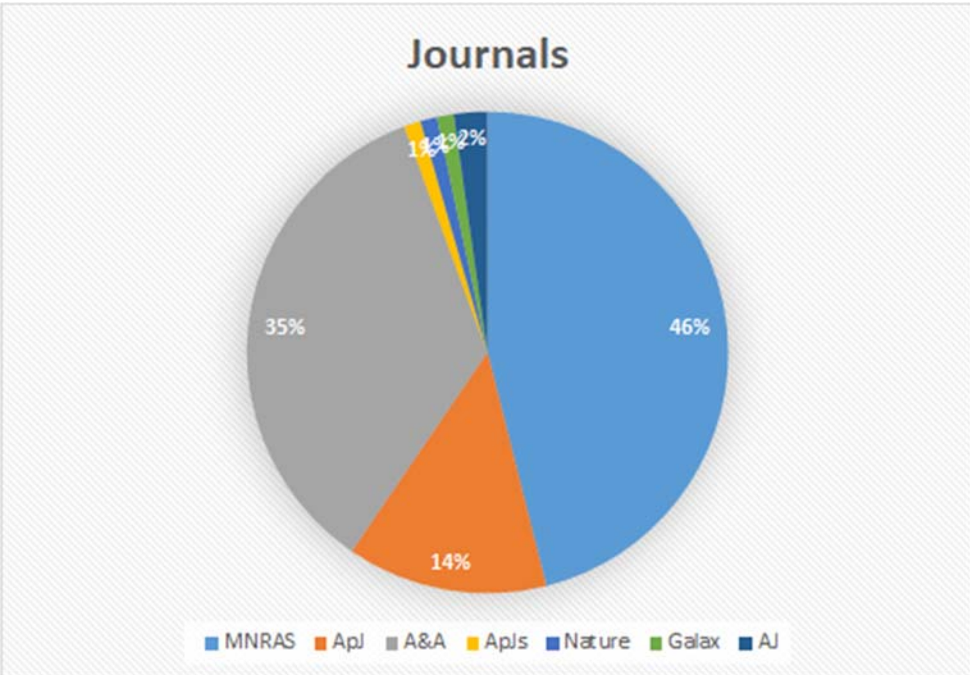

Fig. 14: VST Papers: journals

4 VST in the post-2021 scientific panorama

The next decade will be characterised by the advent of a series of ground and space-based facilities that will advance the frontiers of all fields of astronomy and astrophysics. Large facilities will enable to map and characterise the sky at an unprecedented level at all wavelengths, ranging from the radio band (SKA and its precursors) to the very high energies (CTA), passing through the optical/NIR (LSST, Euclid, e-ELT, JWST) and the X-rays (eROSITA, Athena). At the same time, we will enter the golden age of time-domain and multi-messenger astronomy having in place existing and forthcoming high energy satellites (Swift, SVOM, HERMES, Einstein Probe) together with gravitational waves (advanced LIGO/Virgo) and neutrino (IceCube, KM3Net) experiments. In order to exploit these facilities at their best, the astrophysical community will have to face challenges related to big data handling, multi-wavelength and multi-messenger source characterisation, temporal studies of transient sources. At the same time, it will be fundamental to re-invent the role and objectives of existing facilities, in light of the evolving scientific context.
INAF has a heavy interest and/or direct involvement in most of the key facilities listed above, it is therefore desirable (and recommendable) that any future VST science plan will take into due account a synergic approach.
The case of the Vera C. Rubin Observatory and of the Cherenkov Telescope Array are discussed separately in the following sections.

4.1 The Vera C. Rubin Observatory and Legacy Survey of Space and Time

The Vera C. Rubin Observatory, previously referred to as the Large Synoptic Survey Telescope, will perform an unprecedented deep all-sky survey every few nights, and generate significant advances in several science areas, from large-scale structures to the study of minor bodies in the Solar System (https://www.lsst.org/scientists). So far, the Rubin observatory has recognized eight LSST Science Collaborations, with hundreds of members in each one. These scientists have developed science plans, roadmaps, and detailed tasks lists for their work (https://www.lsst.org/scientists/science-collaborations). The observatory is being built on the Cerro Pachón, close to Paranal, and will become operational in 2023-2024.
The observatory is a US-funded and Chilean supported project, and only scientists from those countries will enjoy full rights to access the data from its Legacy Survey of Space and Time (LSST; which it will carry out during the first ten years of its operations). However, the observatory is actively soliciting involvement from international partners, in which LSST data rights for named individuals will be given in exchange for in-kind contributions to Rubin Observatory operations themselves, or to the LSST science effort in the US. LSST data rights will be established through institutional Memoranda of Agreements with the NSF and DOE (or one of their designates) and international members. Examples of the type of in-kind contribution that are likely to be acceptable in exchange for a certain number of named Principal Investigators with data rights include (i) Observing time, dedicated to proposals led by US PIs, at key non-US facilities, and (ii) Access to surveys or proprietary datasets of high value to the US community, including (but not restricted to) datasets complementary to the LSST survey and which enable high priority LSST science. A call for letters of interests and proposals of in-kind contributions has been issued in September 2020 with a deadline in November 2020. The Contribution Evaluation Committee (CEC) will likely give its recommendations and possible acceptance by March 2021.

Although to date INAF has not yet agreed upon a formal participation in the LSST project, many of its scientists have a marked interest in the LSST science and are heavily involved in a few LSST science collaborations (such as Galaxies, Solar System, Milky Way and Local Volume, Transients and Variable Stars). For its characteristics, the VST can be considered a key asset that is able to satisfy both the conditions reported above to access LSST data rights through in-kind contributions. In addition, a few proposals submitted to the VST Call for Ideas demonstrated that VST surveys and future observing time would be very beneficial for LSST science, and could be offered as a valuable in-kind contribution under option (ii) above (Sect. 5.4). Given the significant involvement and interest of INAF scientists in LSST, the INAF OPT/NIR division has proposed VST time and datasets as an in-kind contribution to LSST to the Contribution Evaluation Committee along the policies described above. The evaluation of the proposal is pending. If the in-kind contribution is evaluated positively, we estimate that 10-15% of the time could be awarded to observational programs to be performed during LSST commissioning (currently foreseen in the years 22-23 but highly uncertain due to the COVID pandhemics). During LSST operations, the time awarded to LSST-programs could be as high as ~30%, (e.g. 35 nights/year made available to the US and Chilean communities for follow-up observation of LSST targets or other scientific investigations and 65 nights/year for surveys that will be executed from late 2023 and will share the results with LSST community) the exact value depending on the outcome of the negotiations.

4.2 The Cherenkov Telescope Array

The Cherenkov Telescope Array (CTA) is the next generation ground-based observatory for gamma-ray astronomy at very-high energies (VHE, 20 GeV – 300 TeV) . With more than 100 telescopes located in the northern (La Palma, Canary Islands) and southern (Paranal, Chile) hemispheres, CTA will be the world’s largest and most sensitive high-energy gamma-ray observatory. It will characterize the VHE sky, joining the multi-messenger revolution through the detection of VHE transients. Currently, 200 INAF researchers (out of a total of 328 Italian scientists and more than 1400 overall members) are currently part of the CTA consortium that is responsible for directing the science goals of the Observatory and is involved in the array design and supplying components. The CTA observatory (CTAO) gmbH is the interim legal entity responsible for the preparation and implementation of the CTA Observatory until the final legal entity, a European Research Infrastructure Consortium (ERIC), is achieved. INAF is currently involved in the multilateral negotiations to establish the ERIC. Although not yet settled, in-kind contributions by the ERIC partners are a concrete possibility to consider.

The “optical taskforce” of the Transients/MultiWavelength working group of the CTA consortium has largely recognized that coordinated observations in the optical band will play a crucial role to achieve the CTA goals (Barres de Almeida et al. 2019). An optical support is crucial to identify the nature of VHE sources discovered by CTA and the physical processes involved through the identification of a low-energy counterpart, the measurement of a broad band spectra energy distribution, and the determination of polarimetric properties. Optical observations will be also required to monitor the evolution of transient events (such as gamma-ray bursts and double NS mergers). The optical taskforce working group defined the requirements of the optical support needed by CTA. These include (i) a medium sized field of view (5’x5’) for transients identification, (ii) polarimetric accuracy of 0.5-1%, (iii) limiting magnitude of ~20 for photometry and ~17 for polarimetry, (iv) intranight cadence and fast repointing.

5 Call for ideas

The call for ideas was open to the INAF community, including the possible synergies with working groups of broader international collaborations, for large and/or long term scientific projects, innovative ideas, an upgrade of the existing instrumentation or new scientific instruments. The aim of the call was to survey the science programmes that the INAF researchers wish to carry out with VST and was not to allocate time for the next decade with scientific assessment and ranking of the proposals.

The feedback from the INAF community has been extremely positive and reflects a strong interest in the use of VST for the next decade. A large group of researchers has been involved (about 340 researchers + Coordinamento Italiano Burst Ottici + GRAWITA collaboration) from all INAF institutes (Fig. 15) in collaboration with several ASI and IAPS institutes and Universities (Torino, Bologna, Milano, Ferrara, Napoli, Salerno, Pisa) and international institutions (Dark Niels Bohr institute,Observatoire de Paris, Laboratoire Lagrange, Institute Liverpool John Moores University, University of Cambridge, University of Edinburgh, The Open University, University of St Andrew, Observatoire de la Cote d'Azur Nice, Las Cumbres Observatory, Universitat Heidelberg, Universidad de Chile Cerro Calan, Instituto de Astrofísica de Canarias, Univ. of Hertfordshire, Amherst University of Massachusetts, Centro de Astrobiología, Univ. California San Diego, Max Planck Institute, IMPRS Garching,ESO Garching, ESO Chile, Ecole Polytechnique Fédérale de Lausanne, UCLA, DARK University of the Western Cape, SunYat-sen University, Northern Arizona University,University of Helsinki, JHU APL, ASU-CAS, Armagh, Leiden).

The proposals submitted to the VST2021 working group are 25 and have been presented and discussed in a workshop on June 11-12 2020. The workshop presentations are accessible on the event webpage:
https://indico.ict.inaf.it/event/1014/contributions/

Many letters of intent suggested new science cases for the VST (e.g. VSTPLANES and FAST) while few proposed programmes are the extension of completed or ongoing surveys (e.g. WINGS survey, GW, VEGAS, GBOT-Gaia). Some programmes aim to put the Italian community at the forefront for the exploitation of multi-wavelength (e.g. Euclid and SKA precursors) and multi-messenger data (e.g. CTA, Fermi and LIGO-Virgo) from international projects. Some others are ancillary to the future Legacy Survey of Space and Time (LSST). Other ideas proposed an upgrade of the current VST instrumentation (e.g. narrow band filter and polarizing filter, grism/gren for slitless spectroscopy) or new instrumentation for VST, preserving the wide field imaging capability (beating the seeing limit with new generation CMOS Imaging Sensors) or not (installing a SHAO Speckle Imaging Camera or a next-generation extremely precise radial velocity spectrograph). Some projects take a few years, others are long term programmes. Moreover synergies may be found between different letters of intent (e.g. CTA and VSTPOL, VST SMASH and VEGAS-LSS).

The following analysis based on the 25 letters of intent received in response to the Call for Ideas aims to give an indicative but not exhaustive overview of the INAF community interest in the use of the VST in the next decade.

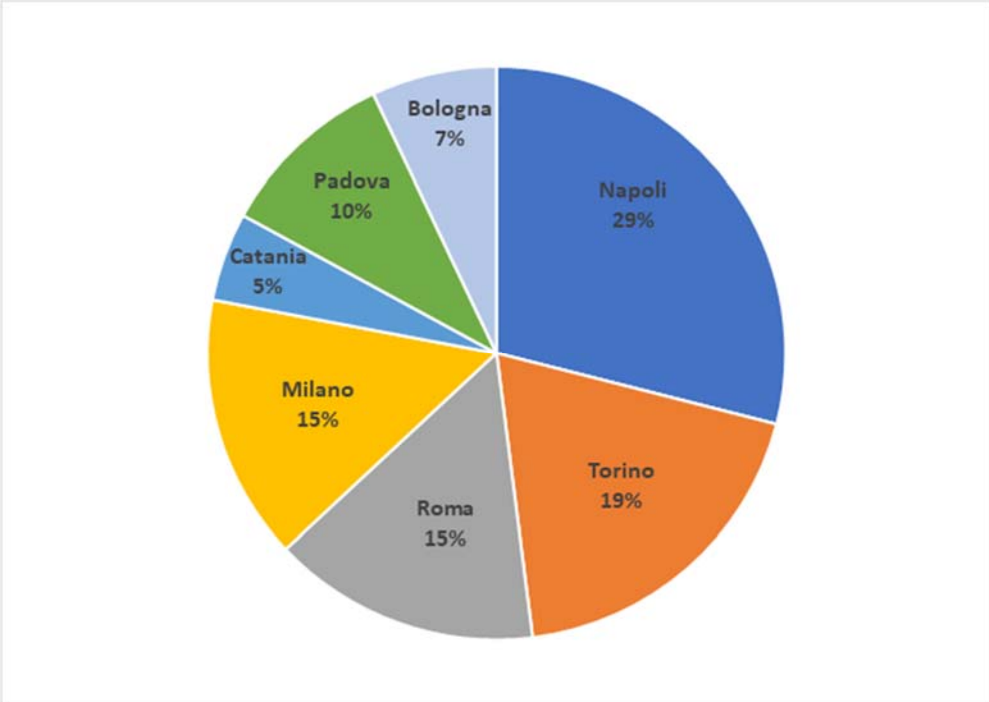

Fig. 15: Fraction of INAF institutes to which PIs belong

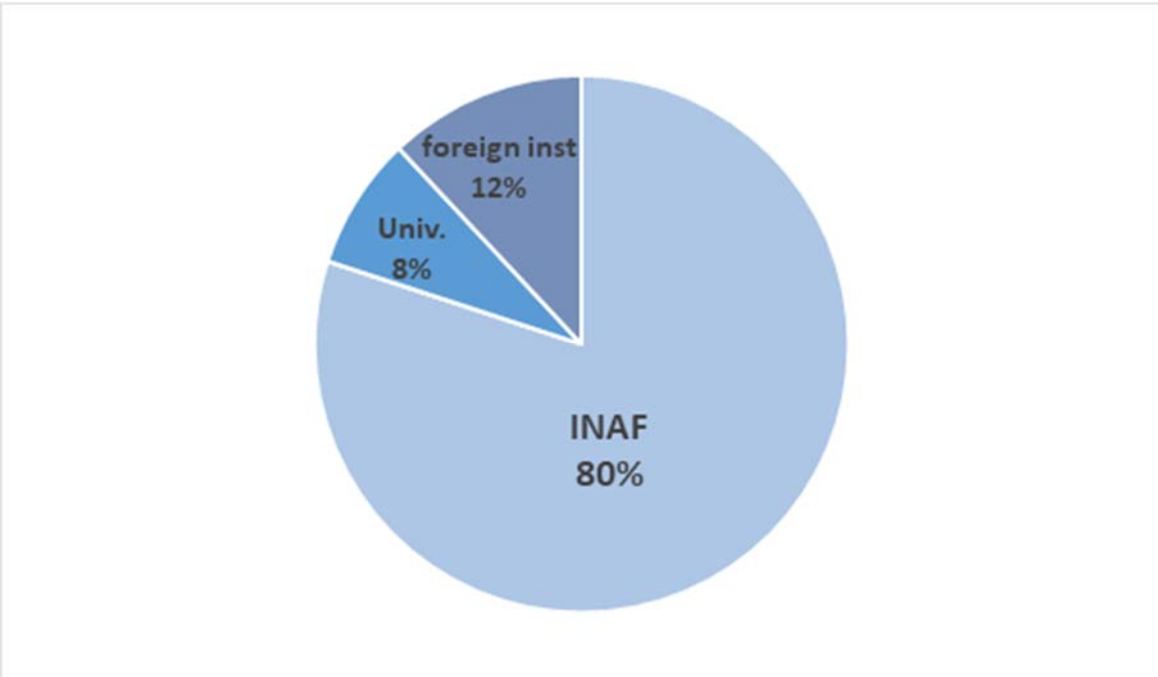

Fig. 16: Principal Investigator affiliation

5.1 Scientific projects

5.1.1 Science cases

The science cases that have been illustrated in the proposals submitted to the Call for Ideas cover all main research areas in which the INAF community is contributing (Fig. 17).

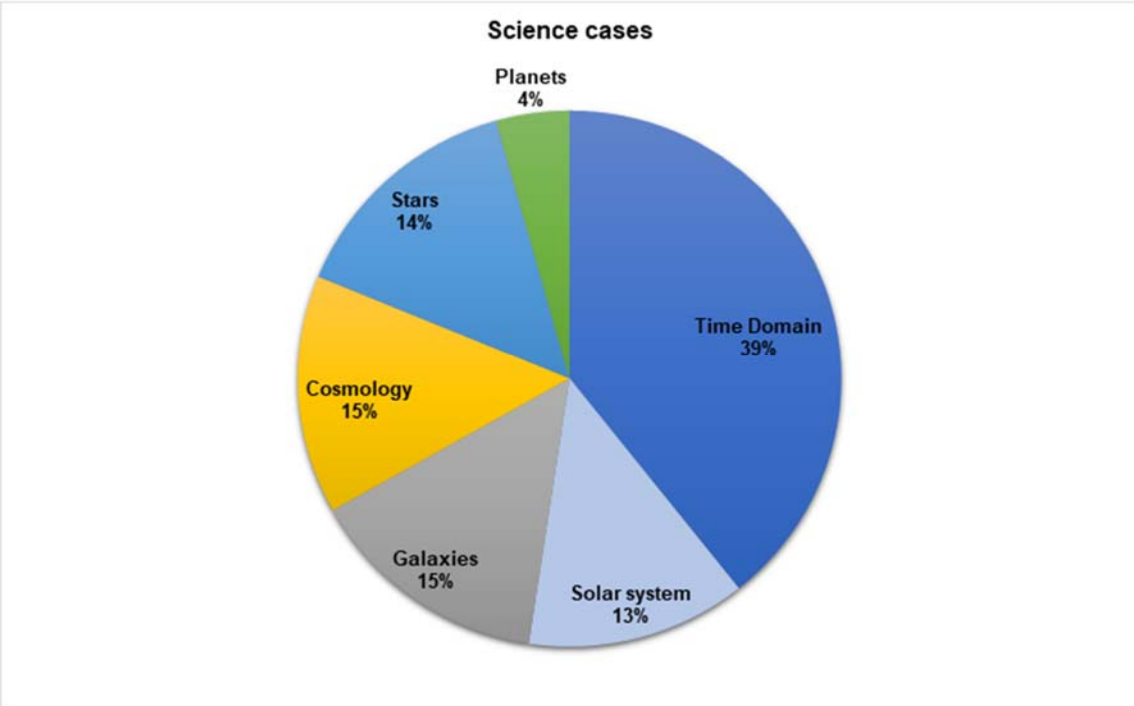

Fig. 17: Science cases presented for the call for ideas

In the following table (Tab. 1) the proposed programmes have been color coded based on the research area.

Table 1: Letters of intent in response to the Call for Ideas

	Title	PI
1	Near-opposition observations of asteroids to extend, complement and improve Gaia and WISE results	A. Cellino
2	Uncovering the "high-priority" near-Earth objects: NEOROCKS and beyond	D. Perna
3	"A day in the life". Observations of DART impact on Dimorphos	E. Mazzotta Epifani
4	Finding the next Earth. A extreme-precision radial velocity spectrograph on a dedicated telescope	A. Sozzetti
5	International Binary Speckle Survey – IBiSS	R. L. Smart
6	Formation origins of low mass objects from rotation rates	R. L. Smart
7	VST-PLANES VST - PLAnetary NEbulae Survey	M. Arnaboldi
8	VST-SMASH: The VST Survey of Mass Assembly and Structural Hierarchy	C. Tortora, L. Hunt
9	VEGAS-LSS: Mapping the large scale structure of the Fornax-Eridanus & Hydral-Centaurus	E. Iodice,M. Spavone
10	DWINGS: an extension of the WINGS survey to the dwarf galaxies domain	M. D'Onofrio
11	Fate of massive stars in nearby galaxies	N. Elias-Rosa
12	Search for SN explosions from Pop III analogs in the local Universe	M. Della Valle
13	Hunting for afterglows of short GRBs detected with Fermi	CIBO
14	Searching for kilonovae associated with sub-threshold Fermi short GRBs using VST	L. Izzo &GRAWITA team
15	GROWN-UP GRavitatiOnal Waves and Neutrino follow-UP	A. Grado
16	An LSST Time Domain precursor survey	M. Paolillo
17	VST as Vera Rubin observatory Support Telescope	M.T.Botticella
18	Unveiling the very energy sky with VST and CTA	A.Papitto
19	FAST monitoring of the optical sky	S. Campana
20	u for Euclid	M. Bolzonella & M. Radovich
21	Exploiting the synergy between LSST and VST to investigate the cosmos	C. Grillo
22	Cosmology beyond the reach of the LSST	A. Agnello
23	VST4SKA – Mapping SKA precursor's fields with VST	I.Prandoni, G.Umana, E. Iodice, V. Ripepi
24	The Very Sharp Telescope (VST)	P. Schipani, J. Skottfelt
25	VSTpol: the first large survey telescope for optical polarimetry	S. Covino, F. Snik, A.Smette

In the following we report a brief summary of the proposed programmes grouped according to their science cases.

❑ Solar system

Near-opposition observations of asteroids (PI A. Cellino)
A large group of researchers in collaboration with Gaia Follow- up Network proposed to carry out multi-band follow-up observations of asteroids detected by the GAIA Ground Based Optical Tracking campaign (GBOT) about 48 hours from first detection. This will be crucial to obtain information about the absolute magnitudes of already known objects and to obtain preliminary astrometric data sufficient to perform further follow-up activities of newly detected asteroids to extend, complement and significantly improve Gaia and WISE studies.

Uncovering the "high-priority" near-Earth objects (PI D. Perna)
The VST telescope can be exploited to observe newly-discovered "high-priority" small near-Earth objects (NEOs) securing their orbits (most of small NEOs have sky position uncertainties of several arcminutes) and characterising their physical nature thanks to multi-band photometry in collaboration with H2020 "NEO Rapid Observation, Characterization and Key Simulations" (NEOROCKS) project.

Observing the NASA Double Asteroid Redirection Test (DART) (PI E. Mazzotti Epifani)
DART will be the first space experiment to demonstrate asteroid impact hazard mitigation by using a kinetic impactor. The target of the mission is the binary near-Earth asteroid (65803) Didymos. The DART spacecraft will impact in September 2022 Dimorphos, the secondary member of the system, and will change the mutual orbit of the two members of the binary system. VST can be exploited for a short-and-intense observing campaign to observe the Didymos system immediately before, during and immediately after the impact to constrain the possible impact effects and to get a framework for context interpretation of the in- situ Light Italian Cubesat for Imaging of Asteroids (LICIACube) data.

❑ Planets

Finding the next Earth (PI A. Sozzetti)
The VST could be dedicated solely, providing the required high cadence of observations, to discover temperate Earth-mass planets around the brightest solar-type stars in the sky and measure the mass of transiting exoplanets discovered by ESA's PLATO Mission (2026) through a next-generation extremely-precise radial velocity spectrograph. Planets discovered in such a survey will forever be the targets that next-generation telescopes will observe in search of biosignatures.

❑ Stars

International Binary Speckle Survey (IBiSS) (PI R. L. Smart)
A half-a-sky, volume-limited, speckle survey of binary systems and multiple stellar systems brighter than 11th magnitude identified in the Gaia data processing pipeline could be performed with VST. VST speckle observations of the individual components will enable the possibility of obtaining precise orbital elements and a mass sum for the system, complementing and

enhancing the value of the Gaia observations. At this aim a speckle camera provided by the Shanghai Astronomical Observatory should be adapted and mounted at VST.

Formation origins of low mass objects from rotation rates (PI R. L. Smart)
This monitoring programme will probe the short timescale photometric variability from young substellar dwarfs to the lowest mass stars in two star-forming regions, three young moving groups and two open clusters spanning a wide range in ages (2-150 Myr) to investigate the rotation rates over a mass and age range and to study the low-mass extreme of the star formation process over the lifetime of the Galaxy.

VST PLAnetary NEbulae Survey (VSTPLANES) (PI M. Arnaboldi)
VPLANES aims to observe planetary nebulae in the galaxies in the Local volume (9 -10 Mpc) to link the late phases of the stellar evolution with the star formation histories, ages and metallicities of their parent stellar populations. This survey will be carried out via the narrow band plus off band imaging technique by equipping the VST with a narrow band [OIII] filter. The proposed narrow band survey of the MW halo, Local Group & Volume complements programmes like the STEP/YMCA and VEGAS, plus the parallel proposal VST-SMASH (optical counterparts).

- **Galaxies**

VST Survey of Mass Assembly and Structural Hierarchy (VST-SMASH) (PIs C.Tortora & L. Hunt)
VST-SMASH aims to observe a sample of 56 galaxies selected from the Nearby Galaxies Catalogue within a distance of 11 Mpc and to map stellar streams and tidal remnants in the outskirts of galaxies reaching m≥29 mag arcsec2 in order to obtain a systematic and homogeneous census of these features and to derive a coherent picture of hierarchical assembly in the Local Volume. This multiband survey will allow to characterize the galaxy stellar populations by inferring stellar mass, age, and dust extinction from galaxy SEDs, to probe the stellar and globular cluster halo populations by tracing galaxy surface brightness to the outskirts, to obtain for Milky Way satellites and the closest external galaxies resolved colour-magnitude diagrams of the stars and to study of stellar and structural parameters of the background galaxy population in terms of mass, redshift and environment.

VST Early-type GAlaxy Survey large-scale structure (VEGAS-LSS) (PIs E. Iodice & M. Spavone)
Following in the footsteps of the VEGAS survey that has already observed 40 groups and clusters of galaxies for a total of 90 deg^2 VEGAS-LSS is a short-term (3 years) deep multi-band survey focused on two large scale structures rich of groups of galaxies with a wealth of multi-wavelength observations: the Fornax-Eridanus and the HydraI-Centaurus super-clusters. The main goals of VEGAS-LSS are to obtain a complete coverage of two super-clusters mapping the unexplored regions connecting filaments and voids between all the dense structures; to study the pre-processing of the galaxies in filaments and voids before they fall into clusters; to constrain the assembly history of the superclusters by connecting the main properties of the infalling subgroups.

An extension of the WINGS survey to the dwarf galaxies domain (PI M. D' Onofrio)
The aim of this proposed extension of the WIde-field Neary Galaxy-cluster Survey (WINGS) is the systematic analysis of the properties as such as stellar population properties and

morphology of dwarf galaxies in nearby clusters, spanning a wide range of cluster environments, from the center out to the virial radius. While WINGS has covered galaxies of magnitudes MV < -19 in the redshift range 0.04 < z < 0.07, Dwarf-WINGS aims to target the galaxies in the magnitude range -19 < MV < -14. The study of dwarf galaxies is essential to understand the evolution of galaxies and clusters in the framework of the hierarchical mass assembly, because these objects are at the lowest mass scale of the assembly and the role and weight of physical mechanisms involved in their transformations in much large galaxies are still poorly understood

- **Time domain**

Fate of massive stars in nearby galaxies (PI N. Elias-Rosa)
VST could be exploited to monitor for 3 years with one-month cadence, a sample of nearby (< 10-15 Mpc) galaxies to identify the pre-explosion outburst that seems to characterize the last stage of massive star evolution just before SN explosion. The stacked images can be used as template images for hunting SN progenitors, for the possible identification of dark collapses (i.e. the disappearance of massive stars), for the search of electromagnetic counterparts of gravitational wave and neutrino events and transients as Luminous Red Novae or Intermediate-Luminosity Red Transients. This survey can be carried out in synergy with MeerKAT surveys to explore the connection between optical and radio transients. Simultaneous observations in optical and radio wavelengths can be used to reconstruct the recent stellar mass-loss activity of the massive SN progenitors and to derive a dust-free complete census of core collapse SNe.

Search for SN explosions from Pop III analogs in the local Universe (PI M. Della Valle)
This pilot programme over two years aims to search for Pop III analog SN events and to study the properties of these events within z<2. Such Pop III SNe analogs should be detected as superluminous pair-instability SNe with a slowly evolving plateau in at least two flavours: i) pulsational pair-instability SNe and ii) classical pair-instability SNe. This VST search has the potential to provide: i) a few Pop III SN analogs per year that could become suitable targets for 8m class telescopes; ii) the properties exhibited by nearby Pop III SN analogs to be compared with genuine SN explosions from Pop III stellar populations that will be observed by JWST at z~10-20; iii) an independent estimate (in synergy with LSST) of the rates of different classes of transients (see above) characterized by shorter times scale.

Hunting for afterglows of short GRBs detected with *Fermi* (PI CIBO)
The main problem with the study of *Fermi* gamma-ray bursts (GRBs) is that the poor positional accuracy (tens to hundreds of deg^2) makes extremely tough the follow-up campaigns aimed at the detection of afterglows and host galaxies. This program aims to exploit the large field of view of VST in order to follow every short GRB (sGRB) detected by *Fermi* and localised within ~50 deg^2 providing a firm sGRB – host galaxy association and, consequently the measure of sGRB redshifts. The observed sGRB sample will enable to derive a reliable SGRB redshift distribution and the burst rest-frame properties. As a byproduct, it will be possible to select a sample of host galaxies for accurate studies with 8-m class telescopes, *HST*, and, in the near future, *JWST* and *e-ELT*.

Searching for kilonovae associated with sub-threshold *Fermi* sGRBs using the VST (PI L. Izzo, on behalf of the GRAWITA team)

The aim of this survey consists in identifying possible kilonova optical counterparts of the sub-threshold *Fermi*-GBM sGRBs with the highest confidence value that their origin is astrophysical. The 50% credible region can be covered by the VST using a strategy based on multiple adjacent pointings. A positive detection will then permit to identify the presence of a rising kilonova component and at same time to study the afterglow emission in order to understand if their observed low- luminosity originates from an off-axis jet emission. Optical counterparts will immediately trigger spectroscopic observations at larger telescopes, as well as multi-wavelength observations with space detectors like Swift-XRT and on-ground with radio telescopes.

GRavitatiOnal Waves and Neutrino follow-UP (PI A. Grado)
GROWN-UP is the prosecution and extension of the ongoing program at VST (GW) to search and follow up the optical counterpart of gravitational waves and neutrinos. This project aims to use a sample of GW events as standard sirens for cosmology. The improved sensitivity of the GW detectors in the observing run O4 and the contribution of the fourth detector KAGRA will reduce the expected localization area to few square degrees and will perfectly match the VST observational capability. Also the typical > 100 TeV neutrino error box from IceCube is ~ one deg^2 match perfectly the VST field of view.

A LSST Time Domain precursor survey (PI M. Paolillo)
A precursor monitoring survey of some of the LSST Deep Drilling Fields can be performed with the VST Telescope in two bands, with a uniform cadence, until the beginning of LSST operations, in order to: 1) obtain deep template images as well as precursor light curves that will be crucial to detect and characterise variable and transient sources (AGN, TDE, blazars) thus significantly increasing LSST performance in the first years of the surveys; 2) extend the temporal coverage of LSST monitoring studies, thus increasing the detection efficiency of variable sources characterised by red-noise variability, as demonstrated by our previous VST-based studies. This survey has been proposed as an in-kind contribution for the LSST community.

VST as Vera Rubin Observatory Support Telescope (PI M. T. Botticella)
The distribution of visits over time of the same sky field in the same filter currently planned for the LSST survey, prevents the sampling of the transient light curves suitable for deriving a photometric robust classification LSST observations can greatly benefit from auxiliary data aimed at improving the accuracy of photometric typing for all classes of transients.. The VST can be exploited as an in-kind contribution to LSST observing selected sky fields in one or two filters with an optimized rolling cadence in order to secure high cadence multi-band and pre-LSST discovery observations for the transients discovered in these fields. The collection of these data will be essential to measure the frequencies of occurrence of different classes of transients on the basis of an homogeneous data set.

Unveiling the very high energy sky with VST and CTA (PI A. Papitto)
CTA is the next generation ground-based observatory for gamma-ray astronomy at very high energies (VHE). A few CTA key science projects (e.g., Active Galactic Nuclei, Transients and Gamma-ray Bursts), require optical photometric and polarimetric coordinated observations to achieve their goals. Optical observations are needed to (i) locate with a sub-arcsecond accuracy the low-energy counterpart of both transient and steady VHE sources discovered by CTA, allowing to identify their nature, (ii) build a broad-band spectral energy distribution, (iii) monitor the evolution of any transient event to search for multiwavelength correlation, (iv) perform polarimetric observations to measure the role played by magnetic field in particle

acceleration and disentangle between different emission components. VST could support CTA to identify, follow-up and monitor transient VHE sources. The possibility of robotization and remote controlling of operations to allow fast follow up of transients and polarimetric capabilities should be also assessed.

FAST monitoring of the optical sky (PI S. Campana)
The aim of this ideal proposal is to explore the short-timescale transient sky with a dedicated high-cadence (nightly and sub-nightly) survey at VST. Short-timescale transients include, for example, SN shock breakout, disk outflow from black-hole-forming a SN, accretion- induced collapse of white dwarfs, new class of luminous, rapidly evolving SNe possibly related to the shock break out in a dense medium surrounding the progenitor. In addition to these, there might also be unknown kinds of transients with a short duration since our knowledge of short-timescale transients is still limited, and never probed observationally in depth. Two different strategies have been suggested on a 30 deg^2 area: i) follow one field for 2-3 hr continuously acquiring with 60-90 images per field; ii) perform a search on a 1 hr timescale on several close-by fields repeating the pattern 3-5 times per night (best visibility window), and over several nights.

- **Cosmology**

u for Euclid (PIs M. Bolzonella & M. Radovich)
VST can be exploited to observe 2000 deg^2 in *u*-band where the Best Euclid Southern area overlaps with *grizy* public data from the DES survey. This will help to guarantee the effective achievement of scientific goals of Euclid, providing at the same time an enduring legacy to the whole community for a very wide range of studies in in cosmology and galaxy evolution: photometric redshifts and SFR derivation, separation of quiescent and star-forming galaxies, the evolution of dust, galaxy and AGN evolution studies, clusters of galaxies and Large Scale Structure analyses. The availability of *u*-band data from VST can put the Italian Euclid collaboration at the forefront for the exploitation of the Euclid Wide Survey in the south. LSST data, even if they will be subject to a future agreement, will be unlikely available for all these analyses.

Exploiting the synergy between LSST and VST to investigate the cosmos (PI C. Grillo)
The proposed high-cadence r band monitoring campaign targeting the 40 brightest time-varying sources multiply lensed by galaxies and galaxy clusters, discovered by LSST in 10 years, aims to accurately measure their light curves, thus their time delays. The time delay is an important and complementary tool to measure the expansion rate and the geometry of the Universe. The results of this study will help clarify whether the current, hotly debated tension on the value of H must be ascribed to intriguing new physics or to significant systematic effects neglected so far, and improve by 40% the Figure of Merit of any stage-IV cosmological survey (LSST, Euclid, etc.). The same data will provide deep imaging, in good seeing conditions, that will allow to build high-quality weak lensing mass maps.

Cosmology beyond the reach of the LSST (PI A. Agnello)
This proposal consists of two experiments in observational cosmology that are beyond the capabilities of the *Vera Rubin Observatory: i)* a nightly monitoring of gravitationally lensed quasars for time-delay cosmography, continuing the successful endeavour by TDCOSMO; ii) a sparse, wide-field, slitless spectroscopy (R~100, <700nm) to aid the calibration of photo-

z determination in the LSST-*Euclid* synergy, by mounting a dispersive element in the ADC housing.

❑ **Collections of different science cases**

Mapping SKA-precursor's fields with the VST (VST4SKA)
(PIs I. Prandoni, G. Umana, E. Iodice, V. Ripepi)
The proposed projects, based on ongoing galactic and extragalactic/cosmology RC and HI surveys with two SKA precursors MeerKAT and ASKAP, will maximally benefit from deep VST imaging and will serve the Italian SKA community, in its diverse scientific interests: study of the Galactic plane, galaxy formation and evolution, cosmic magnetism, cosmology.

Mapping the Galactic Plane in Hα
The project is aimed at observing the southern Galactic plane. As a pilot project, 40 deg^2 of the SCORPIO field already observed with ASKAP at three different frequencies can be observed with the Hα filter. The main science goals of the project are the following:

1. *Classifying stellar objects and studying their variability* (led by F. Bufano, S. Riggi)
2. *Studying diffuse emission and filamentary structures observable both in emission and in absorption on the Galactic plane both in radio and in optical* (led by C. Trigilio, A. Ingallinera)
3. *Study of the complex regions in the galactic plane* (led by G. Umana, F. Cavallaro)
4. *Regions showing radio emission and Hα absorption* (led by A. Ingallinera, C. Trigilio)
5. *Supernova remnants (SNRs)* (led by S. Loru, F. Bufano)
6. *Cosmic Rays (CRs)* (led by I. Busà, F. Leone)

Detailed studies of the local Universe
This project aims to obtain deep imaging of extragalactic fields observed as part of ongoing ASKAP and MeerKAT surveys. Their optical observation is essential to better understand transformation processes of galaxies in different environments, as well as the non thermal properties of the intergalactic medium. The main science goals of the project are the following:

1. *Galaxy transformation in different environments in the nearby Universe* (led by P. Serra, E. Iodice)
2. *Magnetic fields in galaxy clusters* (led by F. Govoni, V. Vacca)
3. *Gas scaling relations in nearby galaxies* (led by G. Rodighiero)

Cosmology, Large Scale Structure and galaxy evolution
This project aims to perform deep observations of one of the extragalactic fields observed as part of the optical GAMA spectroscopic survey, which is also targeted by RC, polarization and HI surveys as part of the ongoing ASKAP surveys. Very deep multi-band VST imaging of this field will enable the following science projects:

1. *Baryon and Dark Matter Assembly* (led by N. Napolitano, P. Serra)
2. *Tracing Star formation and Black Hole Accretion History* (led by I. Prandoni, M. Vaccari)
3. *Weak lensing or cosmic shear* (led by N. Napolitano, M. Radovich)
4. *The non-Thermal Cosmic Web* (led by F. Govoni, V. Vacca)

The Very Sharp Telescope (VST) (PI P. Schipani & J. Skottfelt)
The idea is building a new wide field imager capable to deliver images sharper by a factor 2.5, adopting new generation high performance CMOS Imaging Sensors characterized by a fast readout (about 10-30 Hz) and very low readout noise levels (~1 electron RMS). Using a shift-

and-add technique with real-time processing, the tip-tilt component of the atmospheric turbulence can be effectively contrasted, using 100% of the frames with no loss of photons. The new instrument goal is getting 1 deg^2 wide-field imaging with a median seeing of about 0.3 arcsec (0.2 arcsec in good seeing nights). The VST+GravityCam can be exploited to detect planets with the mass of the Earth, compact object binaries, tight binaries and their eclipse features, to obtain proper motion measurements for kinematic studies, to resolve the orbits of binary asteroids, discovery of small bodies in the Kuiper Belt and Oort Cloud, to analyze stellar variability and asteroseismology, sub-second variability from accretion onto compact objects, microlensing events and weak gravitational lensing.

VSTpol: the first large survey telescope for optical polarimetry (PIs S. Covino, F. Snik, A. Smette)
Replacing its ADC by a polarizing filter would transform the VST into the first large polarimetric optical survey telescope, without affecting the current capabilities of the VST+OmegaCAM system. The design of the VST limits the technical implementation of the polarimetric unit to a single-beam system: therefore, data-driven calibration methods can be developed to achieve a sub-percent polarimetric sensitivity and accuracy that fulfils the specifications for the CTA Optical Support Telescope. The proposed implementation is of low cost as polarizing filters of the needed size are readily available. The currently offered capabilities of the VST+OmegaCAM are preserved as the polarizing filter can be removed from the optical beam. Scientific cases include: 3D mapping of the magnetic fields of the Milky-Way and Magellanic clouds, surveys of quasar polarization, polarimetric characterization and mapping of solar-system objects, follow-up of CTA sources and transients, polarisation measurements of bright transients identified by transient factories, such as bright GRB afterglows.

5.1.2 Scientific project's timelines

Short term programmes (2022-2024)
Few programs need to start as soon as possible to be effective before the beginning of LSST operations (e.g. a LSST time domain precursor survey) and for a brief period (< 5 years) due to the lifetime of external projects (e. g. until the end of the operational phase of the Gaia satellite).

Programme	Nights per year	Survey timescale	Survey start
Observations of DART impact on Dimorphos	3	1	2022
Near-opposition observations of asteroids	6	3	2022-2024
Uncovering the "high-priority" near-Earth objects	20	1	2022
Formation origins of low mass objects	35	2	
VST-SMASH	19	4	2022-2024
VEGAS -LSS	90 +40 in grey time	3	2022-2024
DWINGS	55		2022-2024
Search for SN explosions from Pop III analogs	12	2	2023-2024
Fate of massive stars in nearby galaxies	14-20	3	2022-2024
An LSST Time Domain precursor survey	45	3	2022-2024

Long Term Surveys (> 5 years)
Many programs need a substantial amount of telescope time for a long period to execute surveys that are complementary to LSST, CTA and Euclid science or are dedicated solely to a unique science case such as searching Earth-like planet candidates.

Programme	Nights per year	Survey timescale	Survey start
Finding the next Earth	every night	5	2024?
Unveiling the very high energy sky with VST and CTA	75	10 ?	2025
VST as Vera Rubin observatory Support Telescope	180	10	2023-2024
u for Euclid	30	5	2022
Cosmology beyond the reach of the LSST	90-120	10	2023-2024
Exploiting the synergy between LSST and VST to investigate the cosmos	81	10	2023-2024

ToO programmes

Three programmes dedicated to the search of optical counterparts of LIGO-VIRGO signals and Fermi discovers can start in 2022 and last ten years (depending on if LSST will operate in ToO mode and how many events will follow per year) so they are a mix between short term and long term programme types.

Programme	Nights per year
Hunting for afterglows of short GRBs detected with *Fermi*	4-5
Searching for kilonovae associated with sub-threshold Fermi short GRBs using VST	4
GROWN-UP	22

Other programmes

Finally few programmes do not require strict constraints on the start and/or duration of surveys but report the total amount of the telescope time they need.

Programme	Total amount of nights
VSTPLANES	22
IBiSS	30
VST4SKA	400
FAST	10 (consecutive)

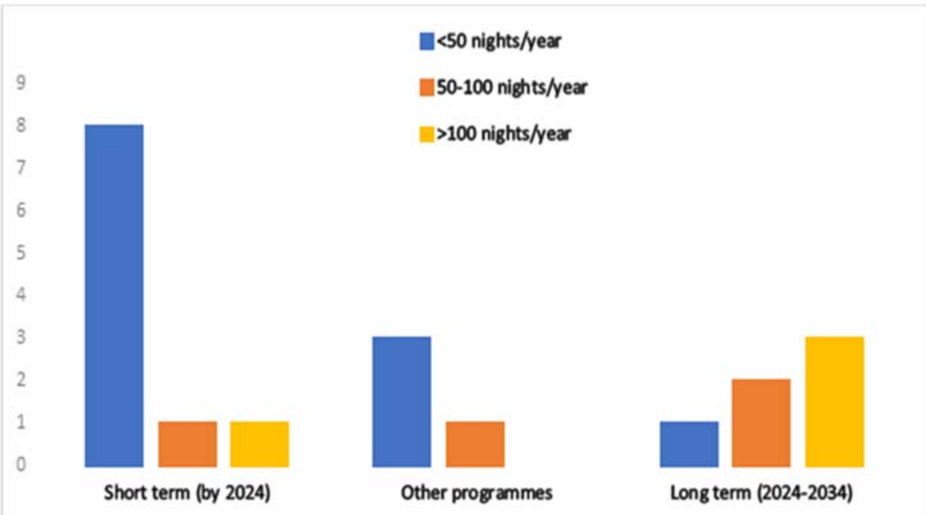

Fig. 18: Number of short term (by 2024), long term (2024-2034) and other projects divided by requested night per year.

5.1.3 Requested number of nights

The projects proposed in response to the Call for Ideas firmly prove the interest of the INAF community for the VST. It is reasonable to assume that an even larger number of projects would be submitted to an official call for proposals. The submitted projects alone suggest that also in the next decade the pressure on the VST, in terms of requested *vs.* available nights will be maintained large enough to justify a substantial investment from INAF.

The estimate of the requested telescope time from the proposed programs is rather rough (due to missing or incomplete information) and should be considered as indicative. In addition, the amount of time requested by the projects submitted to the Call for Ideas should be evaluated in the time frame set by the possibility of signing agreements that yield VST time as an INAF in-kind contribution to third parties.

In the short term (2022-2024), the projects submitted to the Call for Ideas requested about 345 nights per year. Considering that 10-20% of the time could be awarded to Chilean Time and possibly ESO, and that 15-20% could be spent for LSST commissioning operations, executing these projects would result in an oversubscription factor larger than 1.5. This clearly justifies the offer of a large fraction of VST science time (60%) to an open call for proposals, possibly with some restrictions to ensure the involvement of the Italian community.

In the long term (2024-2034), the weight of projects related to external projects and consortia (e.g. 175 nights/year for LSST and CTA) increases compared to other projects (180 nights/year, of which 26 nights for Target of opportunity). Awarding ~50% of the time to external projects would then result in a slightly higher, although still manageable oversubscription factor of ~3.

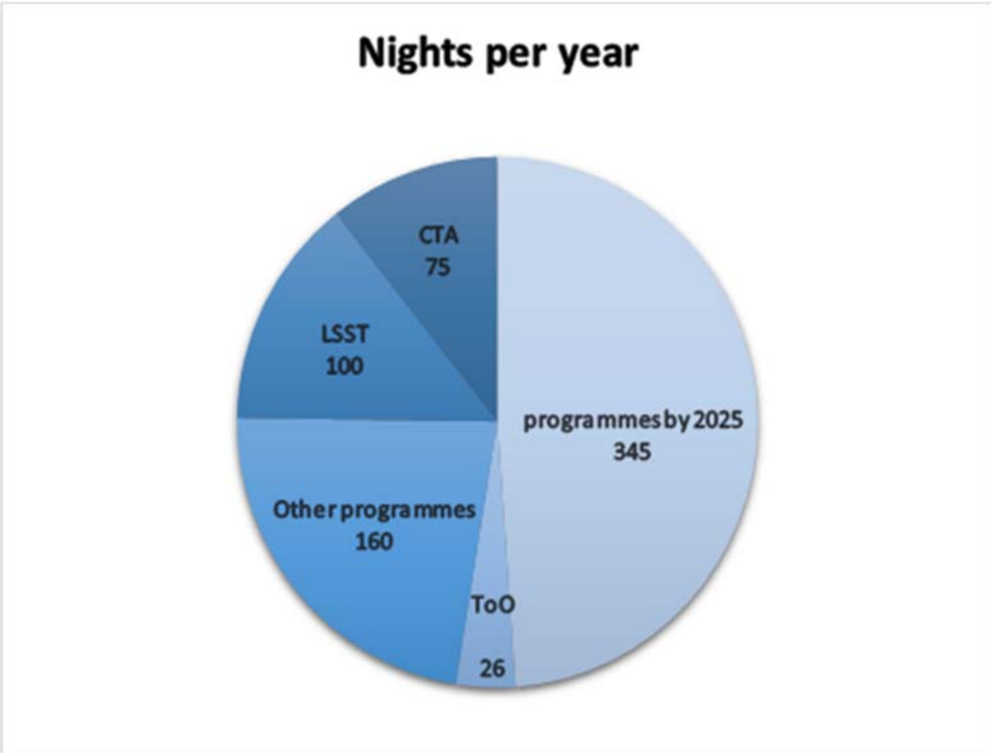

Fig. 19: Number of nights per year requested by different programs

We have not counted in this exercise those programs that would require the almost complete dedication of the telescope, such as a survey to search for Earth-like planets and the survey VST4SKA that needs 450 nights (150 for galactic surveys and 300 for extragalactic programmes) over a period not defined.

5.2 Instrumentation

Several letters of intent suggested either upgrades of the current instrumentation (still maintaining the OmegaCAM), or the installation of new instruments.

Within the category of upgrades, these proposals were associated to specific science cases:

- the addition of a [OIII] narrow band filter to discover planetary nebulae (VSTPLANES),
- the replacement of the ADC with a dispersing optics to implement low resolution slitless spectroscopy to aid the calibration of photo-*z* determination (Cosmology beyond the reach of LSST),
- the replacement of the ADC with polarimetric optics to make the VST a wide-field polarimetric telescope within the (but not limited to) context of CTA (VSTPOL).

Within the new instruments category, two new instruments were proposed:

- an extremely-precise radial velocity spectrograph to discover temperate planets similar in mass to the Earth (EPRV finding a next Earth)
- an innovative CMOS based wide-field camera for delivering images of a 2.5 factor better than seeing-limited (Very Sharp Telescope)

Finally, one existing instrument has been proposed for a part-time installation at the VST:

- a speckle camera to study of binary and multiple stellar systems (IBiSS)

Within this context, an additional idea was received from Alex Kim on behalf of a large collaboration led from the Lawrence Berkeley National Laboratory, expressing interest for building an IFU spectrograph for VST to dedicate to SN Ia studies, independently of the call for ideas.

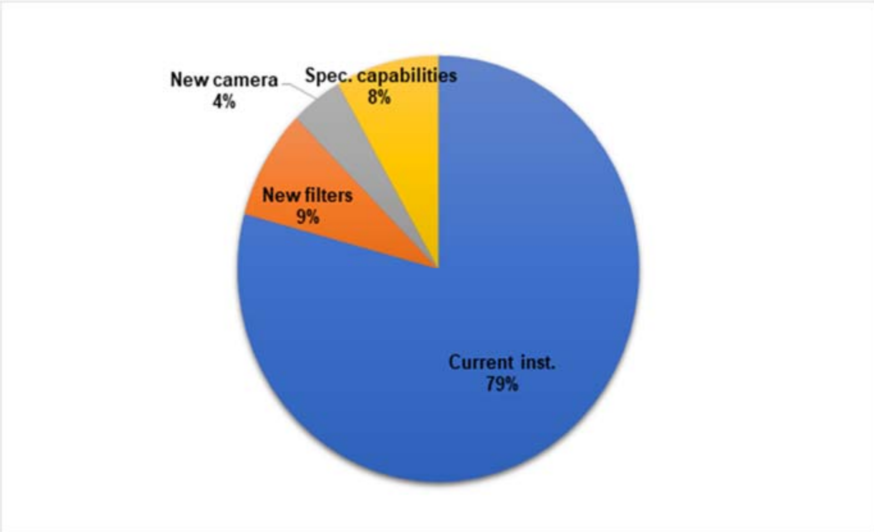

Fig. 20: The fraction of proposals that plan to exploit the current VST instrumentation, new filters, a new camera and spectroscopic capabilities.

Programme	Upgrading inst.	New inst.	notes
VSTPLANES	OIII filter		
VSTPOL	Polarizing filter		in the ADC unit
IBiSS		Speckle imaging Camera	provided by the Shanghai Astronomical Observatory
Very Sharp Telescope		GravityCam	CMOS imaging sensors atmospheric dispersion corrector, autoguiding and wavefront sensing
Finding the next Earth		extremely precise radial velocity spectrograph	
Cosmology beyond the reach of LSST	dispersive element		in ADC unit

5.3 Telescope management & operations

In the majority of cases a service observing mode (SM) is adequate for the successful execution of the program (Fig. 21). Few projects need rapid Target of opportunity Observations (ToO) and a Rapid Response Mode (RRM) capability (hours) to enable an immediate reaction for optical counterpart location, photometric and polarimetric follow-up.

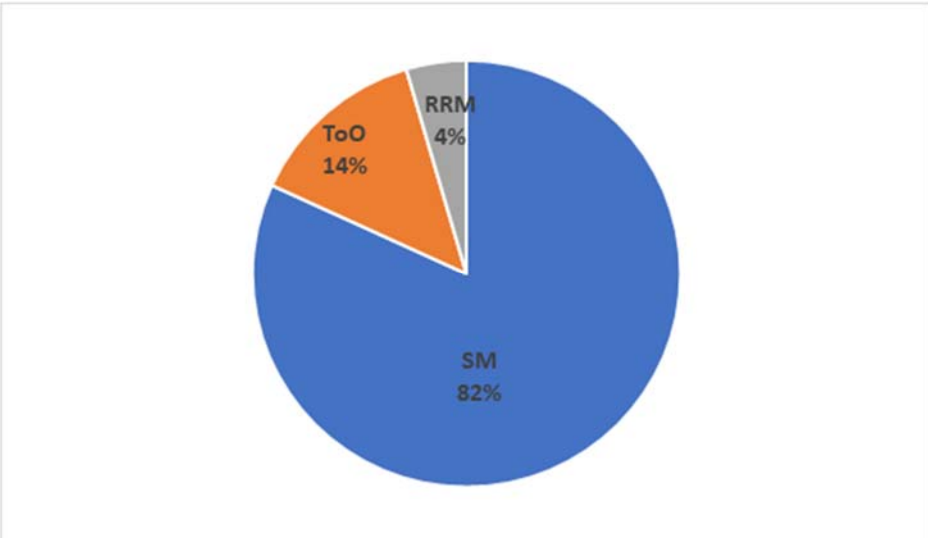

Fig. 21: Fraction of proposals requiring service, ToO and RRM mode for observations.

Several letters of intent proposed to implement remote operations at VST to maximize the operation efficiency and science return of the project.

5.4 External synergies

The Call for Ideas highlighted a great interest from the INAF community in programs that foresee joint activity between VST and main future key astronomical facilities. Indeed, more than the 50% of letters of intent reflects synergies with other facilities and international projects. We give more details in the following.

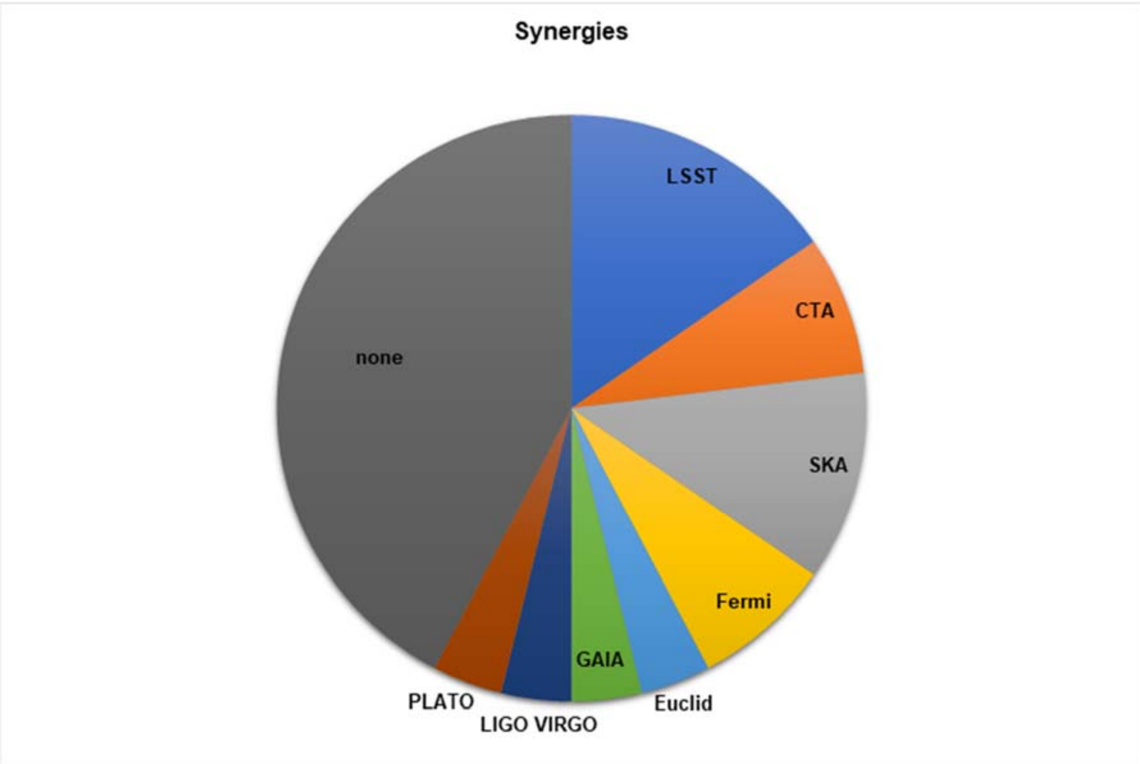

Fig. 22: The fraction of proposals that exploit synergies with other facilities.

5.4.1 LSST

For its characteristics, the VST can be considered a key asset able to satisfy both the conditions reported in sect. 4.1 to access LSST data rights through in-kind contributions: observing time, dedicated to proposals led by US PIs, as well as access to surveys or proprietary datasets of high value to the US community. Indeed, the LSST CEC provided the highest rank to VST telescope. Several INAF scientists devised possible future VST surveys with a complementary role for LSST, which could be offered as a valuable in-kind contribution. The following projects were submitted to the VST Call for Ideas:

- a precursor monitoring survey of a few LSST drilling fields with VST, to extend the LSST temporal baseline and to produce template images (PI: M. Paolillo);
- high-cadence multi-band VST observations to detect transients in synergy with LSST, to improve the light curve sampling in all bands and derive a robust photometric identification and classification (PI: M. T. Botticella);
- a follow-up of the brightest variable sources lensed by galaxies and galaxy clusters to provide a complementary tool to measure the expansion rate and the geometry of the Universe (PI: C. Grillo).

5.4.2 CTA

In response to the VST call for ideas, a proposal (PI: A. Papitto) analyzed the possible use of VST as an optical support facility to CTA south. VST would share the same site, provide a large field of view that would highly beneficial for transient detection at the low end of the CTA energy band, and ensure the required photometric accuracy in ~ a minute thanks to the larger mirror size compared to most other robotic telescopes considered by the CTA consortium.
Additional features to be implemented that would let VST almost completely match the CTA needs are (i) polarimetric capabilities and (ii) robotization with the possibility of being operated remotely to allow a repointing within a few minutes.
The polarimetric requirement would be addressed by a polarimetric filter to the unused ADC (project VSTpol, PIs: S. Covino,F. Snik, A. Smette). This would make VST the first large survey telescope for optical polarimetry. The need to respond timely to ToO observations could be addressed remotely e.g. using an infrastructure similar to that developed for SOXS (Sect. 6.1.1). The implementation of the capability of pointing a target within a few minutes and/or performing observations of the same field covered by CTA, now not possible, should be also assessed.

5.4.3 SKA precursors

Deep, wide field optical surveys of sky regions already selected for ongoing large radio continuum and/or HI surveys performed by MeerKAT and ASKAP are potentially extremely beneficial for SKA-related science. A collection of VST scientific projects related to ongoing radio surveys has been submitted in response to the call for ideas (PIs: I. Prandoni, G. Umana, E. Iodice, V. Ripepi). These would refine the SKA science case, contribute to develop an interpretative framework, widen the involvement of the Italian community in MeerKATplus and SKA and reinforce Italian leaderships in the context of SKA-driven international projects.

5.4.4 Euclid

LSST is expected to perform deep observations in the southern sky, but its data policy currently does not allow the free exploitation of photometry and derived quantities, and the MoU with Euclid is still to be defined. In this context, a complementary VST survey using the u filter in a region where *grizy* data are already available from the Dark Energy Survey survey, has been proposed by INAF scientists in response to the call for ideas (PIs: M. Bolzonella & M. Radovich). The availability of u-band data from VST can put the Italian Euclid collaboration at the forefront for the exploitation of the Euclid Wide Survey in the south.

5.4.5 PLATO

The VST equipped with a EPRV instrument could become a strategic synergy facility for PLATO mission capable of playing a key role in the confirmation of PLATO detections as suggested in a letter of intent in response to the call for ideas (PI A. Sozzetti).

6 VST beyond 2021

The starting point of our working group was the analysis of all the possible options for the future of the VST in terms of telescope, operations and data management, hardware/instrumentation. This section describes all the different scenarios we took into consideration, together with our recommendations, that are based on the astronomical scientific context of the next decade and on the feedback we received from the Italian astronomical community as response to our Call for Ideas (Sect. 5).

6.1 General telescope management

After the expiration of the current agreement with ESO the VST maintenance and operation will be in charge of INAF. The agreement between INAF and ESO was due to expire in October 2021. This date has been postponed to April 2022 due to the COVID19 pandemics. Considering that VST is owned by INAF, but the rotating enclosure and the instrument are ESO properties, in all cases INAF shall sign a new agreement with ESO after the expiration of the current one. Alternatively, as per current agreement INAF should bring the cost for the uninstallation of the telescope. Given the high interest of the INAF community and the clear downside in terms of costs and benefits, this hypothesis is not considered here. In principle INAF could take care of the whole management of the telescope and use the VST as a National facility. Alternatively, INAF could make an agreement with ESO to jointly manage the telescope. Both options keep open the possibility to provide a fraction of the VST time to international facilities and consortia (through in-kind contribution, MoUs or similar types of agreements). As said above, in principle the conditions of the new agreement are totally open. The ESO counterpart position is to wait for INAF, owner of the telescope, to do the first step in this negotiation. In general, the new ESO-INAF agreement shall regulate different matters like:

- the operational model, or how the whole facility is operated;
- the sharing, if any, of the observing time between the partners;
- the fee to pay at ESO to keep having the VST in Paranal.

The points above are of course closely related one to each other. Although there is no formal decision yet, the fractions of INAF and ESO time will very likely change under the future agreement and this will likely have an impact on the responsibility of the telescope operations.

6.1.1 Operations & Scheduling

The current organization of the operations, including not only the scheduling but also other essential tasks like the monitoring of the program executions, the monitoring of time sharing, the user support, the development and maintenance of the infrastructural software for user interaction, and OB creation is fully under ESO control. The operational model involves some activities to be performed on site (e.g. telescope night operations, ordinary and extraordinary maintenance) and others which are performed remotely at ESO-Garching. (e.g. selection of proposals, scheduling, assistance to observers, archiving).
For the future of the VST, at this stage INAF might propose anything, but some basic considerations are developed in the following. For what concerns the on-site activities, in principle the two possible options are:
1. INAF sends his personnel to Paranal to operate and maintain locally the telescope
2. ESO Paranal staff keeps on operating the telescope nightly, providing maintenance

In terms of comparison, INAF already operates and maintains the TNG, an optical telescope of similar diameter, in a remote location (although less remote than Paranal) employing about 25 people working exclusively on the TNG, at a cost of several M€/yr. But unlike the TNG, the VST is fully integrated into the Paranal observatory, hosting 6 major telescopes + 4 auxiliary telescopes, where the same staff is shared for all telescopes. This makes the current local operations of the VST way cheaper than for a "single" telescope in a desert, as the cost of all Paranal is almost identical to all Paranal without the VST. We estimate the option of maintaining the ESO personnel operations on site, rather than sending INAF people, is by far the most cost-effective, cheaper of a factor 5. Last but not least, Paranal staff has now 9 years of experience on the telescope, while new INAF staff should start from scratch. The two reasons of smaller cost and higher experience and efficiency lead us to consider only the option no.2 as a realistic and desirable solution. At the same time it should be taken into account that, as a matter of fact, ESO is moving the operations load for its smaller telescopes (2-4m class) to consortia (e.g. NTT-SOXS, VISTA-4MOST). It is therefore realistic that the same will happen for VST, in particular if INAF will claim most (if not all) of the telescope time. Therefore, any future plan concerning operations should take into due account which activities can be handled on-site and which remotely, which responsibilities should be shared with ESO and which should fall under INAF direct control. About scheduling, so far the telescope has been operated by ESO in Service Mode. This configuration has been particularly well suited for the execution of large programs like the ESO Public Surveys, where a fine control of the next night schedule was not needed. The current implementation of Service Mode does not allow for a strict control of the observations on a short term: it is the Service Mode software tool, rather than the observatory, to decide on the fly what is observed during the night, as explained in Sect. 2.4.2. ToO observations can fit within such a framework (as they actually do at present) under the condition that they are executed for a relatively small amount of time (indicatively, 5%) and that an astronomer on the mountain can manually schedule them, once the request is received. The above scheme works effectively for big surveys or, more in general, for non time-critical observing programs scheduled on a semestral basis but is unfit for situations where time-critical programs (e.g. for time domain science or simultaneous/coordinated observations with other facilities) represent a significant fraction of the observing time.

Although not fully representative, the call for ideas highlighted the interest of the community science programs that go beyond the traditional survey approach, such as synergies with the main forthcoming facilities and time-domain astronomy studies. Besides, it is worth noticing that the VST support (through e.g., specific MoU and/or in-kind proposals) to the main future facilities is under discussion, with possible agreements with international partners, (e.g. CTA and LSST). These considerations highlight that a control over the night operations, that goes beyond the current ESO scheme (but goes towards the ESO approach of transferring the management of 2-4m class telescopes hosted in its premises), with the possibility of having a flexible schedule under INAF control can be an asset (if not a need) for the future management of the VST observations. This is a new activity which needs to be prepared in advance in order to be ready before April 2022 and able to define all the terms in the new agreement to be signed with ESO for the next decade. Something very similar is currently under study within the context of NTT-SOXS, where the SOXS consortium (led by INAF) and ESO are developing an operation model suited for a facility hosted in a ESO premise (La Silla) and operated by the consortium. In addition to the service mode tool, the ESO infrastructure includes the support for a Visitor Execution Sequence, a night scheduling born to be used in Visitor mode with the astronomer on site, but also available to be programmatically filled from remote. This mechanism will be used by the SOXS consortium to prepare day-by-day the night schedules. An ESO Telescope Operator will execute on site the SOXS observations which have been scheduled remotely, having the possibility to reprogram automatically the schedule during the

night with the same software. Although we acknowledge this is an extreme case, given that SOXS is heavily focused on study of transients, it can constitute a useful roadmap also for the VST operations. Indeed, a discussion with ESO was started in parallel for the VST future operations, agreeing to explore a SOXS-like approach (where no INAF astronomers will travel to Chile but can maintain a full remote control), to be tailored according to the VST future needs. Thus, a parallel development effort for the VST should start as soon as possible, as the system shall likely be ready well before April 2022. Under the above scheme the INAF VST Center should be upgraded consequently to handle the operations of the telescope, i.e. evolving from a Data Center to a Data & Operations Center.
As the start of this process requires the agreement with the ESO counterpart, it is recommended to discuss the terms of the general agreement with ESO as soon as possible. Within this context, it is useful to remind that ESO has been working a lot over the last years to provide tools for remote control like G-RAF (Garching - Remote Access Facility), to allow ESO staff to remotely connect to the instrument workstations and the POEM (Paranal Observatory Eavesdropping Mode) for observers in Designated Visitor Mode, with the clear aim to facilitate remote operations, offering possibilities for limiting long travels.

6.1.2 Data archiving & reduction

The size of a single OmegaCAM raw frame is ~500Mb. A typical observing block of 1 hour in general consists of a few exposures; the corresponding dataset will include both the raw science frames and all associated raw calibration frames and will require 5-10Gb to be stored. The data reduction process generally creates a large number of intermediate files and therefore the total disk space required to reduce a single OB can be easily of the order of a few 100Gb; the total amount of space to store the raw frames and the intermediate and final data products is >1Tb/night. These figures are consistent with the actual data-flow produced by the VST data center in the past years.
Small observing projects with OmegaCAM will therefore produce dataflows of the order of a few Tb, which can be handled and archived using machines and storing solutions that are relatively affordable by small research groups. The disk space for data storage and computing power required for larger Observing Programmes (e.g. new surveys) can however be easily beyond the availability of many research groups.
An easily accessible data archive and an efficient facility for data reduction could therefore play an extremely critical role to maximize the scientific outcome of VST and OmegaCAM observing.
For data archiving we consider two possible solutions:

1. Keep using the ESO structure. This would of course require to set up an agreement with ESO)
2. Use the INAF IA2 services. INAF infrastructures already store data for a number of projects

The most natural choice would be of course to keep the current structure (option 1), which already demonstrated, over the years, to be highly effective and reliable for the VST needs. Indeed, to date, ESO provides its community with an extremely efficient data archiving facility for raw data. In some specific cases (e.g., MUSE or Large Programmes) the final user has even the option to either directly download the final calibrated and science-ready data products or retrieve the raw dataset and reprocess it using the official ESO pipeline. This opens the possibility also to relatively small research groups to fully exploit the scientific potential of the observations.

To this end, an agreement with ESO is considered recommendable. Under these considerations, option 2 is anyway a viable alternative, given that the INAF archives demonstrated too to be a reliable infrastructure for effectively archiving and managing large datasets from advanced facilities (e.g. TNG and LBT).
Concerning data reduction, to date the VST data center hosted at the Capodimonte Observatory offers data reduction support to INAF GTO programmes and also to other VST observing projects. As already discussed in Sect 2.5, in principle the existing data center infrastructure could be upgraded to take care of the whole data-flow from VST. To this end, there is an ongoing activity to partially dedicate to the VST data center some machines that INAF is getting for free from CINECA. Of course, this kind of upgrade of the VST Data Center infrastructure would be particularly cost-effective for INAF, if feasible. Besides the expansion of the current hardware infrastructure, the allocation of extra man-power to maintain and run the data-center has also to be accounted for. As a reference currently 1.5 FTE/yr are allocated to the VST data-center. Since, as previously discussed, the current data-center should be increased by a factor x5 to take care of the whole VST data (Sect. 2.5) extra man-power is required. The existing Astro-WISE pipeline (used for the KiDS survey, see Sect. 2.5) already proved to be robust and efficient for the needs of the INAF GTO and is therefore expected to work effectively also under a future upgrade of the VST-Data center tasks. To this end, a key asset will be to have a Data Center able to provide all the VST users with science-ready data, together with photometric catalogues over a relatively short (days/weeks) time-scale.
Besides the above considerations, it is worth to mention the need, typically shared by small groups/projects and/or of specific science programs (e.g. time-domain ones) to have effective, user-friendly tools for rapid data reduction (or quick-look). Such a need is typically satisfied by the existence of public, instrument-dedicated pipelines. As reported in Sect. 2.5, for the specific case of OmegaCAM there are a number of public (or publicly available under request) pipelines but, at variance with other ESO facilities, a public, ESO-released (and maintained) pipeline is not available. In principle, such a gap can be filled with a relatively modest investment (basically man-power). However, while such a solution can be undoubtedly cost-effective and useful for small projects (as public, dedicated pipelines always are), it is important to keep in mind that the absence of a dedicated data center able to provide users with science-ready data can discourage the execution of large programs for groups that are not used and equipped to handle large photometric datasets. This aspect is of particular importance as a large fraction of the VST projects carried out so far are large; similarly, also most of the projects presented in reply to the call for ideas are medium/large ones, accordingly with the survey vocation of the VST. Therefore, although the development of a public, OmegaCAM-dedicated pipeline (following the route already established for all ESO VLT instruments) can have clear advantages (quick-look) and is worth to be explored (although the existing ones proved to work effectively), the upgrade of the VST Data Center capabilities and services remains the essential step needed to maintain VST as an effective and competitive facility in the next decade.

6.2 Time allocation

After ten years of operations, with the telescope still in good efficiency and the GTO programs successfully accomplished, it would be highly desirable and effective in terms of scientific return to keep a significant fraction of VST time assigned through an open call for Proposals, to be held with a six months cadence. This recommendation is also supported by the positive response to our Call for Ideas (see Sect. 5) that confirms the strong scientific interest from the INAF community for the VST.
Under such a scenario one can expect that on a short timescale (with the telescope still in the

current instrumental configuration), the requests will mainly be for the finalisation/upgrade of surveys carried out under GTO programs, explorative studies from new users to test the VST capabilities, programs in synergy with existing (e.g. advanced LIGO/Virgo) and forthcoming facilities (e.g. pathfinder programs for LSST). Such a situation, already virtuous in its expectations, is expected to dramatically evolve and improve on a few years timescale, as the main facilities of the next decade will begin their science operations (see introduction of Sect. 4). This will introduce a healthy injection of novelty and vitality that can be fully exploited by having, at the same time, an open call for proposals and a fraction of time dedicated to programs developed under specific MoUs / agreements with the consortia operating those facilities. We note that, in the overall budget of the observing time, the ESO and Chilean fractions should be taken in due account. So far ESO has not asked for maintaining a part of the VST observing time for the ESO community. However, it is not a-priori excluded that ESO might be interested to maintain a fraction of time (although likely in a smaller percentage with respect to the current agreement). Awarding ESO a percentage of the observing time (≥10%) for open calls is an option which should be promoted (or, at least, not excluded) in proposing the terms of a new agreement. Concerning Chilean time, this will be in any case 10% as per ESO rules.
In conclusion, an indicative (though reasonable) scenario for the management of the VST time allocation in the next decade could be the following:

- on a short term timescale (2022 + 2-3 years) a fraction up to 20% for the ESO and Chilean time, up to 20% for programs in synergy with forthcoming facilities (e.g. support to the LSST commissioning under a dedicated agreement) and the remaining fraction ($\gtrsim$ 60%) for an open call for proposals;
- on a longer term timescale (> 2024/2025) a fraction up to 20% for the ESO and Chilean time, up to 50% for synergies regulated by specific MoUs / agreements and the remaining fraction ($\gtrsim$ 30%) for an open call for proposals.

The possibility of applying national restrictions (along the lines and procedures already established for the time allocation of the TNG and REM telescopes and for the INAF fraction of time at the NOT and LBT telescopes) to the time awarded through the open call for proposal should be taken into account, in particular under the (likely) hypothesis that a fraction of time will be assigned under the ESO usual procedures. Finally, we remark the importance of keeping implemented the possibility of carrying out VST observations in Target of Opportunity mode, possibly improving the reaction times (see Sect. 2.4.2 and Sect. 6.1.1) and for the users to submit large programs (with an horizon of multiple semesters).

6.3 Instrumentation

The VST in its present-day configuration has been in operation since 2011 without any major upgrade. Taking this fact into consideration it is mandatory to envision the future of VST on a time scale of 10 years or longer. Under a more general point of view we highlight that, given the tight relationship between the VST and the OmegaCAM, any new plan for instrumentation shall include the design of the integration with the telescope. For the same reason, any plan for a future replacement of the OmegaCAM, or the addition of a new instrument, shall be developed jointly with the VST team.

6.3.1 Telescope & Instrument maintenance

Over the last years, both the telescope and the camera have proved to be in good health status, demonstrating a high reliability. Starting from this ideal situation, however, it is wise to look at the future. A plan of the future telescope and instrument maintenance cannot neglect that they will be 10 years old in 2021. A study (F. Gonté et al., The Messenger 157, 17-25, 2014) on the reliability of ESO instruments in Paranal shows a statistical increase of problems approximately after about 9 years; the time span of that study is only 11 years, as at that time the vast majority of instruments was less than 11 years old. Thus, albeit so far the VST+OmegaCAM system is still working remarkably well, an increase of problems may reasonably happen in the next decade, due to aging.

At the moment, the ESO Paranal staff detains obviously the best knowledge of the system status. In the following we report two issues which would be worth fixing before starting a new decade of VST+OmegaCAM life.

An important preventive maintenance intervention, planned years ago by Paranal, should be the replacement of the main axes electronic drives, motivated by the lack of spares. The cost of the parts would be only a few tens of k€, but the work is highly delicate, as it affects the tracking system which must maintain the same high quality current performance. Although this work was proposed by ESO and INAF agreed to sustain part of the cost, ESO has not done it yet, likely because of the uncertain future of the telescope.

The pointing model update procedure is based on the telescope guiding camera, that is out of order. It has not been fixed as it is not used (the guiding corrections comes from the scientific camera). Although the telescope operations are proceeding reasonably well with the old pointing model, it would be wise to restore the system, or move to a procedure using one of the OmegaCAM CCDs with no hardware intervention, if possible.

Overall, apart from specific issues, after a decade of experience in Paranal the local ESO staff knows the system in detail and is able to perform ordinary and extraordinary maintenance efficiently on the telescope and the camera. Thus, the obvious requirement of the continuity of the service makes the option of keeping the local Paranal staff for maintenance the most (if not the only) reasonable solution. In case of specific preventive maintenance interventions, INAF might decide to participate.

The most likely scheme currently under study is the one adopted by ESO for the hosted telescopes in La Silla, e.g. an agreement with ESO billing the cost of extraordinary maintenance performed on site, with details to be agreed. As the agreement has not been worked out yet, for the moment only a very rough yearly budget (about 50k€) can be guessed. Besides this extraordinary work, the ordinary part will be included in a yearly fixed cost that ESO will bill, still to be agreed.

6.3.2 Upgrade of the current instrumentation

Given that the development of second-generation instrumentation takes several years, it is extremely important to consider in parallel possible developments for the available VST instrumentation before the replacement of OmegaCAM.

On a short or medium time-scale of a few years it is possible to upgrade the current instrumentation. There are a number of possible options to explore that do not require extremely large investments and/or major modification of the existing hardware; these would extend the current scientific capabilities and/or increase the current performances of the VST and could allow it to keep being competitive. An example of a possible upgrade that would require no major modifications of the existing instrumentation is the installation of new filters on OmegaCAM. For example narrow bands filters would open completely new scientific possibilities for the VLT that no other telescope of the same class can offer at the moment. A

few examples of possible solutions and science cases for new filters were proposed by the community and have been described in Sect. 5.
Other interesting options involving minor modifications of VST and OmegaCAM could be considered. For example, the unused ADC can be replaced by a polarizing filter that would transform the VST into the first large polarimetric optical survey telescope or by a grism that would enable slitless spectroscopy over the entire field of view (Sect. 5).
Clearly, when considering what are the best options for an upgrade of the current instrumentation, it is fundamental to consider what will be the general use of the telescope and its instrumentation in a close future (i.e. in the next ~5 years), carefully evaluating possible synergies with other instruments and projects.

6.3.3 Plans for new instrumentation

Up to now the VST with OmegaCAM is one of the most efficient survey machines at optical wavelength available for the international community but upcoming facilities, in particular the Vera C. Rubin Observatory, will soon dramatically change the situation. Besides, OmegaCAM has been in operation for about 10 years and therefore it is now time to consider possible second generation instrumentation for the VST. The time required to develop, build and install a new instrument for a telescope like the VST is 5-10 years, depending on the complexity of the instrument.
The VST was designed as a survey telescope and the large field of view of OmegaCAM has been one of its main key characteristics. It would therefore be natural to consider second-generation instrumentation solutions that would keep the VST as one of the best surveying machines for the international communities. This solution was for example adopted for the VISTA telescope; it started its operation in 2009, just before the VST, and its only instrument, VIRCAM, a NIR wide-field imaging camera, will be replaced with 4MOST a 2400-object fibre-fed multi-object spectrograph that will be in operation in 2022.
Since 4MOST will be soon available and other major telescopes of the same class of the VST will be soon equipped with wide field spectrographs with high multiplexing capabilities (e.g. WEAVE at the WHT), a MOS spectroscopic option for the VST may not be the best option and, therefore, alternative solutions can be explored. Proposals for maintaining the wide-field vocation have been presented in response to the Call for Ideas, ranging from building a new high-spatial resolution camera, to implementing a simple polarimetric filter, keeping the OmegaCAM (Sect. 5).
Maintaining the wide-field vocation for the VST is however not a mandatory option for second generation instrumentation and alternative solutions should also be considered. As an extreme case of a possible radical change in the scope of the VST, we cite another example taken from the proposals submitted to the call for ideas (Sect 5); a single object extreme-precision radial velocity spectrograph mounted at the VST would allow to discover exoEarths orbiting solar-type host stars. This would turn the VST from a wide-field survey telescope that can be efficiently used for an extremely broad range of scientific applications into a telescope used for a single very narrow highly rewarding scientific goal.
It is necessary to evaluate any option for next-generation instrumentation for the VST in the general context of the facilities that will be available in the early 2030's; the evaluation of possible options for replacing the current instrumentation is therefore strongly connected with what collaborations and synergies INAF (and ESO) would like to set up on ~10 years time-scale.

7 Summary and conclusions

After ten years of successful operations, the VST keeps being a productive telescope, holding a great potential to face the main science challenges in astronomy and astrophysics of the next decade. This is highlighted by the impressive scientific production of the telescope (chapter 3) and by the extremely positive response to the Call for Ideas (Chapter 5). The scientific activity carried out during the past decade testifies the success in accomplishing the goals related to carry out large public surveys, together with the capability of tackling a wide range of science cases, including frontier topics such as time-domain and multi-messenger astronomy (Sect. 3.1). Key assets for this success have been the stability of the instrument, the excellent quality of the obtained data and the location in an outstanding observing site like Paranal (Chapter 2), that enabled it to reach a level of scientific productivity that can hold up the comparison with the best telescopes of the world (Sect. 3.2). At the same time, there is a great potential for the future. The quantity, high quality and diversity of the projects presented in response to the Call for Ideas remarks the great interest of the community towards the VST (Sect. 5.1). A significant fraction of these projects foresees synergies with the main future key astronomical facilities, demonstrating that the telescope is perceived as a vital and competitive scientific asset also for the next decade (Sect. 5.4). Besides, the proposed plans for next generation instruments make it possible to project and extend the telescope activities over a long-term horizon (sect. 5.2). The above summary emphasizes that it is strategic for INAF to keep the VST in operation through a negotiation with ESO that should start as soon as possible. This will be the opportunity to discuss the terms of a new agreement, in light of the approaching expiration of the current one (April 2022). To this end, it is important to remember (as discussed in Sect. 6.1) that the ESO policy of the recent years is to move the management of the 2-4 meter class telescopes to consortia. With this in mind, INAF should consider and prepare a series of actions and initiatives (both organizational and operational). These actions have been discussed in this document (Chapter 6), outlining the possible scenarios for the telescope operations, the data flow and time allocation, also taking into account synergies with external consortia and upgrade/changes in the instrumentation. The outcome is summarized below:

- The terms of a new agreement must be discussed with ESO as soon as possible, so that any preparatory activity can start in due time. Such an agreement should consider the future managerial aspects, as well as the sharing of time (between INAF, ESO and Chilean community). An agreement of at least 5 years is recommended, thus enabling to plan the activities on a reasonably long term. The transition towards a new INAF-ESO agreement for the VST management should be prepared well in advance, especially if commitments with international partners are taken by the Italian community.

- Given the full integration of the VST in the Paranal observatory and the history of the last ten years of operations, the ESO partnership will be fundamental in the future. To this end, it is recommended that all the workload in Chile remains under ESO responsibility. At the same time, options where ESO maintains a scientific interest in the VST should be explored and pursued (e.g. time for the ESO community, involvement in joint projects using the VST, support to other facilities with ESO partnership like the CTA).

- A new INAF infrastructure for handling proposals and observations, together with a sound plan for operations, should be ready months before the start of the new agreement, now planned on 1st April 2022. Under the terms of a possible new agreement moving to INAF the responsibility of the operations, with a significant increase of the fraction of the observing time to be managed, the INAF VST Center should be adequately expanded in terms of extra-manpower and computational capabilities, evolving to a Data and Operations Center. At the same time, the possibility of keeping relying on the existing ESO infrastructure for raw data flow and archiving should be explored and possibly implemented, as it demonstrated to be highly effective.

- Even with the advent of next-generation facilities, a telescope of the VST class, in a site like the Paranal Observatory, can keep being competitive if dedicated to specific science cases and adequately upgraded over time. A long term plan for the instrument replacement should start relatively soon. With the aim of replacing the OmegaCAM around 2030 when it will be 20 years old, the process of selecting a new instrument idea should start in 2022-2023 to leave time for selection, design and realization of the instrument. It is recommended to issue a call for new instrument ideas in 2022-2023.

- Any change to the telescope-instrument setup shall be designed and implemented jointly with the INAF VST team, given the specific tight relationships between the instrument and the telescope, not obvious for external teams. This systems engineering approach is key to maintaining the functionality and reliability of the telescope.

- It is recommended to explore the possibility of agreements and synergies with external large projects, agencies, observatories, to exploit the scientific niches where the VST will still be highly useful in the era of next generation multi-wavelength synoptic surveys. More in general, the new upcoming facilities (e.g. LSST, CTA, SKA) are going to open new perspectives for a synergic use of the VST as well. As highlighted by the Call for Ideas, within the context of an astronomy continuously evolving towards multi-instrument, multi-wavelength and multi-messenger projects, the VST can be an asset for the Italian community, complementing larger facilities.

- Within these possible agreements, it is recommended to pursue strategies aimed at providing to the Italian researchers the highest scientific return and the full exploitation of the VST data.

- Depending on the agreements possibly signed with external consortia/observatories, slight changes to the instrumentation, or to the telescope operations, might be needed or desired (e.g. addition of polarimetric filter, narrow-band filters, fast reaction time to triggers). Any modification should be planned carefully and ahead of time.

- Given the strong interest of the Italian community, in response to the Call for Ideas, for many science cases with potentially high scientific return for which the characteristics of the VST are unique, it is recommended to always keep a percentage of open time to the community assigned through regular call for proposals.

- Within a new context where INAF directly manages the telescope, a Time Allocation Committee should be appointed to award the INAF share of the observing time, similarly to the TNG. A Call for Proposals should be issued, e.g. twice a year maintaining the ESO cadency. Target of Opportunity and large programs (spanning over more than 1 semester) should be allowed.