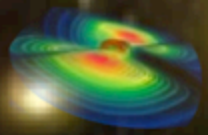
GRAWITA
follow-up of GW150914



Enzo Brocato

&

Grawita collaboration

Istituto Nazionale di AstroFisica
Osservatorio Astronomico di Roma

GRAWITA: GRAvitational Wave Inaf TeAm

Goals

The present research group is committed to taking part in the search and the study of electromagnetic counterparts of the GW events by using different observational facilities.

Project milestones

05-12-2013...Monte Mario meeting INAF – LVC
2014……...MoU INAF-LVC signed / early Team submitted PRIN INAF
2014……...VST as ToO facility
2015.....Early activities Proposals / fund raising (Unsolicited / Premiale)
07-07-2015…Unsolicited project “Gravitational Wave Astronomy …” approved
15-09-2015... First operational meeting
17-09-2015... VST observations of GW150914
01-2016..... PRIN MIUR 2015 (INAF-RU) *submitted*
03-2016..... Joint paper with LVC

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Who we are

INAF OA Roma: **E.Brocato (P.I.)**, L. Pulone, V.Testa, G. Iannicola, L. Stella, M. Lisi, S. Piranomonte, S. Ascenzi, G. Israel, P. Casella
INAF OA Napoli: **A. Grado**, F. Getman, L. Limatola, M. della Valle, M Botticella, M. Capaccioli
INAF IASF Bologna: **L. Nicastro,** E. Palazzi, L. Amati, L. Masetti, D. Vergani, A. Bulgarelli, G. De Cesare, A. Rossi
INAF OA Milano: **S. Campana**, S. Covino, G. Tagliaferri, P. D'Avanzo, A. Melandri
INAF OA Padova: **E. Cappellaro**, L. Tomasella, S. Yang
University of Urbino: **M. Branchesi**, G. Stratta, G. Greco
SNS Pisa: **E. Pian**, A. Stamerra, F. Longo, M. Razzano, G. Pivato, B. Patricelli, G. Cella
ASI Science Data Center: **L.A. Antonelli**, G. Giuffrida, S. Marinoni, P. Marrese, V. D'Elia

Know-how: Time Domain Astronomy, Observational Strategy, Image analysis, Accurate Photometry in crowded fields, GRB astronomy, Supernovae, Data Interpretation, Theoretical models

> 1800 referred papers in 2010−2015

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Multi-wavelength Observing Facilities:

Visible: *VST, LBT, TNG, NOT, NTT, VLT + small telescopes [REM, 1.82m (Asiago, IT), 1.52m (Loiano, IT), 0.9m C. Imperatore, IT)] + HST (coll.)*
Near-mid IR: *1.1m AZT-24 (C. Imperatore,IT), IRAIT (Antarctica)*
Radio: *64m SRT (Cagliari, IT), 2x 32m (Medicina and Noto, IT)*
High energy (coll.): *space(coll. Swift, Chandra) + ground (coll. MAGIC, future ASTRI, CTA)*

Collaboration: *SWIFT, Magic, VISTA (contacts started)*
Positive interaction during O1: Pan-Starrs, iPTF, VISTA, J-GEM

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STEP 1

Search & Detect

Transients in the error box provided by LVC have to be discovered and measured *as soon as possible*

Telescopes with large FoV distributed at different latitudes/longitudes

STEP 2

Observe & Characterize

The detected transients have to be observed to infer their nature

Computing Facilities with fast and smart software to select a handful of transients

STEP 3

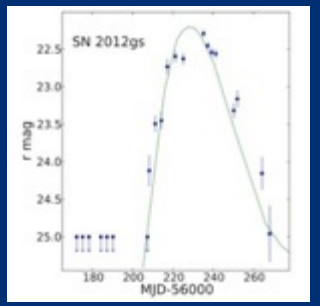
Follow & Study

Follow-up at all observable λ for an adequate time to study the physical properties of the **EM counterparts of GW**

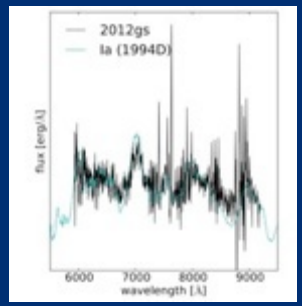
Telescopes with large collecting area to obtain light curves and spectral features of transients

Telescope	Proposal approved	Proposal Submitted PI
VST	ToO 30h	Cappellaro \Grado
LBT	ToO 7h	Palazzi
TNG	ToO 12h	Piranomonte
NOT	ToO 8h	Pian
VLT	ToO 20h	Pian
SRT	ToO	Possenti
REM	ToO	Campana
It Antartic Tel	yes	Col Brocato

Note: *HST, VISTA, Swift - proposals accepted with INAF CoIs.*



time



λ

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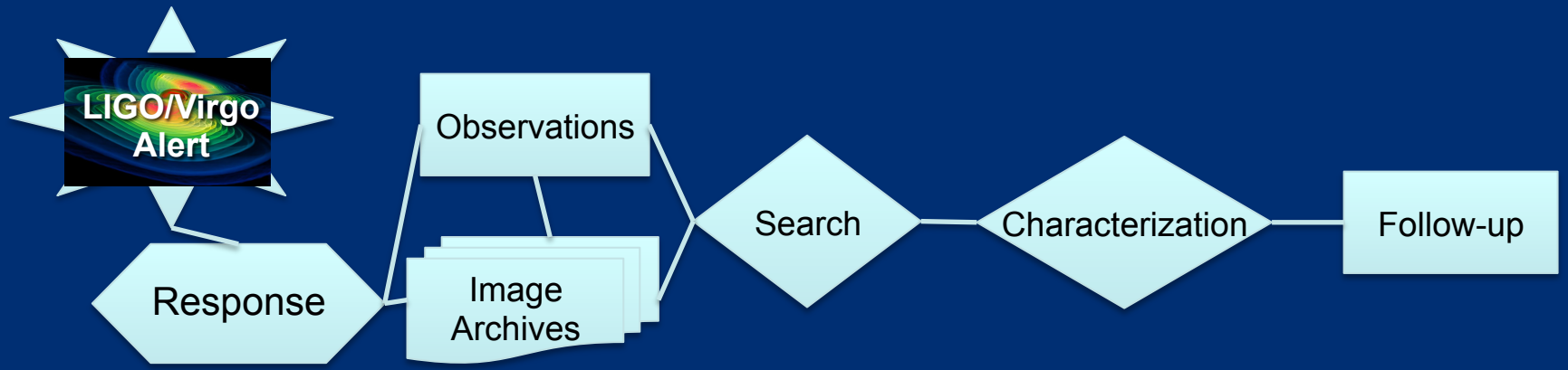

Work Groups	Leader	Task	People
WG1	M. Branchesi	**Observational Strategy** Simulation and observational strategies for the INAF instruments. Contact with LVC researchers.	G. Greco, G. Stratta, E. Brocato
WG2	A. Grado	**Observations:** VST observational operations following GW alerts. Pre-reduction of VST images. Sextractor catalogs. Difference images production	F. Getman, L. Limatola
WG3	S. Covino	**Search** of counterpart candidates in wide field images by VST. Procedures/pipelines to identify transients using Sextractor catalogs and comparison with archive of known objects available in literature. Procedures/pipelines to identify transients using image difference techniques	L. Pulone, G. Iannicola, G. Giuffrida, V. Testa, S. Marinoni, E. Palazzi, L. Nicastro, P. D'Avanzo, A. Melandri, E. Cappellaro S. Yang, E. Brocato, G. Iannicola, S. Ascenzi, , S. Piranomonte
WG4	E. Palazzi	**Characterization and follow-up** of the candidate counterparts found by WG3 (or by other LVC partners) to identify a few possible astrophysical objects most likely emitting the GW signal. Spectroscopic and multi-wavelength observations and their data analysis. Managing ToO activation. Preliminary data analysis.	E. Pian, E. Cappellaro, L. Tomasella, S. Covino, D'Avanzo, A. Melandri, S. Piranomonte
WG5	E. Pian	**Follow-up & proposals** Planning and observing time request at ESO-VLT, LBT, SRT, TNG, NOT, etc to obtain spectroscopy, light curves, multi-wavelength observations from ground and space	E. Palazzi, E. Cappellaro, G. Grado, S. Piranomonte, E. Brocato, S. Campana, A. Possenti
WG6	P. D'Avanzo	**24H Alert team** Response to GW alerts by LIGO/VIRGO Collaboration. Activation of ToO at available telescopes	M. Branchesi, E. Palazzi, G. Greco, S. Piranomonte, A, Melandri, L. Tomasella, G. Stratta S. Covino, L.A. Antonelli e V. D'Elia
WG7	L. Nicastro	**Archiving activities.** Software implementation on gravitown. DataBase construction and management WEB and wiki for GRAWITA	M. Lisi, G. Giuffrida, P. Marrese
WG8	E. Brocato	**Networking.** Link to other group and experiments, funding proposals writing	A. Antonelli, A. Stamerra, S. Campana, G. Tagliaferri, E. Pian, E. Palazzi, A. Possenti

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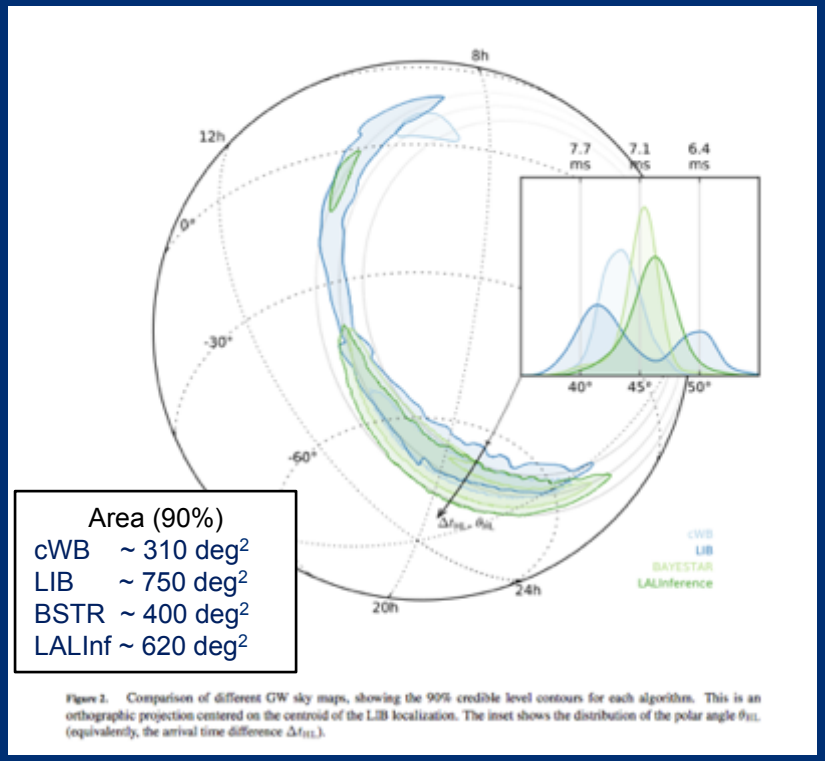
GW150914 : LVC Skymaps



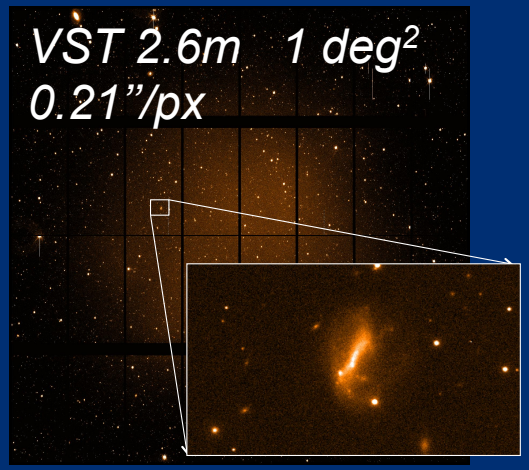
Area (90%)
cWB ~ 310 deg^2
LIB ~ 750 deg^2
BSTR ~ 400 deg^2
LALInf ~ 620 deg^2

Figure 2. Comparison of different GW sky maps, showing the 90% credible level contours for each algorithm. This is an orthographic projection centered on the centroid of the LIB localization. The inset shows the distribution of the polar angle θ_{HL} (equivalently, the arrival time difference Δt_{HL}).

Observational strategy
OB definition

Galaxy targeting?

Aasi et al. 2014, ApJS, 211



VST campaign on GW150914

- 90 deg^2 to be repeated at six epochs:
  t_0 , t_0+1d, t_0+5d, t_0+8d, t_0+15d, t_0+ 60d [t_{REF}]
- Filters: r
- 2 dithered exposure per pointing, 40 s each, limiting mag r ~ *22.4*

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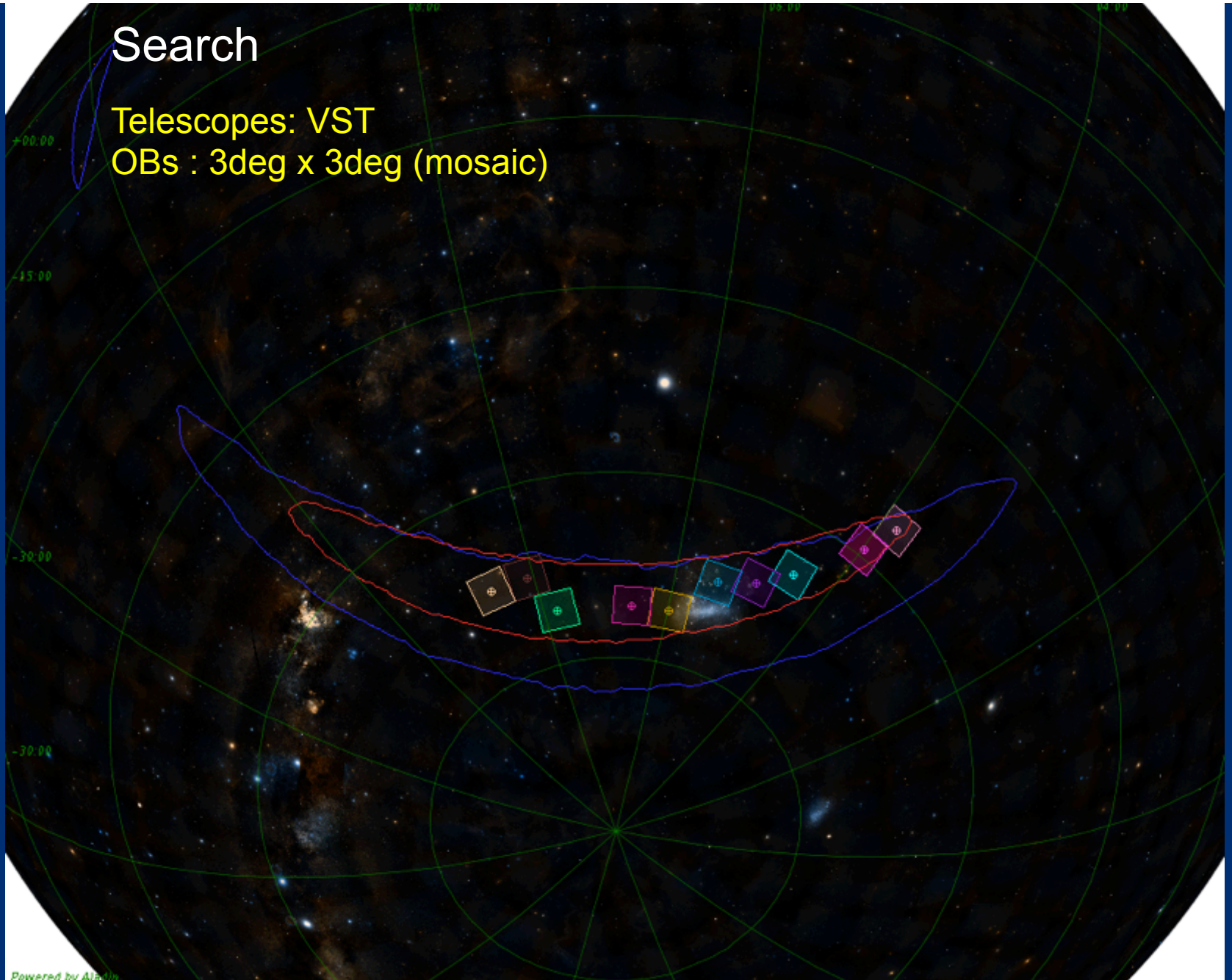

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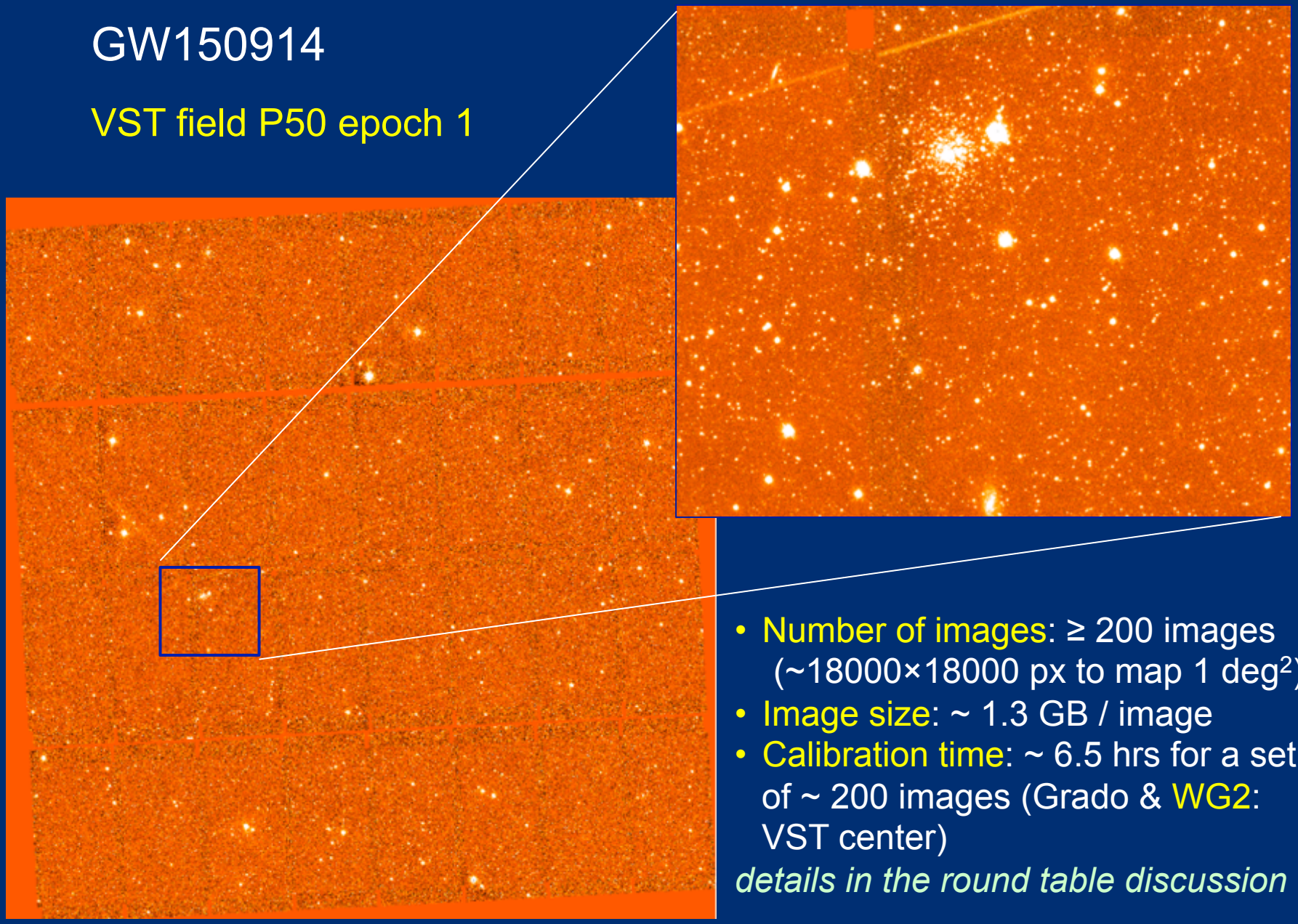
GW150914

VST field P50 epoch 1



- Number of images: ≥ 200 images (~18000×18000 px to map 1 deg^2)
- Image size: ~ 1.3 GB / image
- Calibration time: ~ 6.5 hrs for a set of ~ 200 images (Grado & WG2: VST center)

details in the round table discussion

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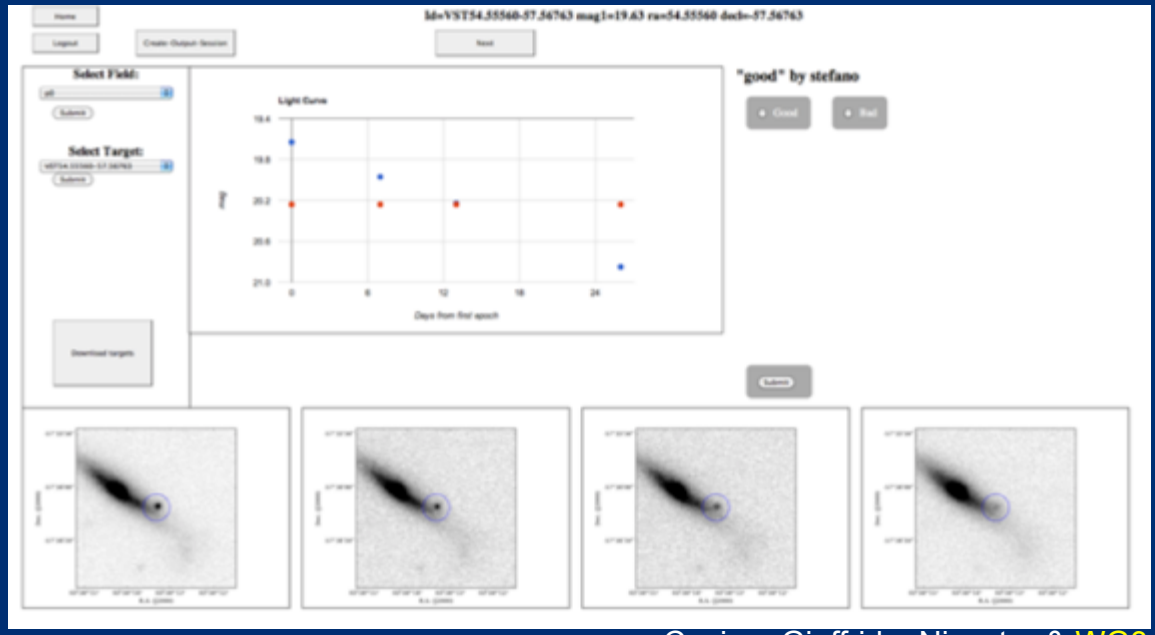
Search

I. Photometry of sources

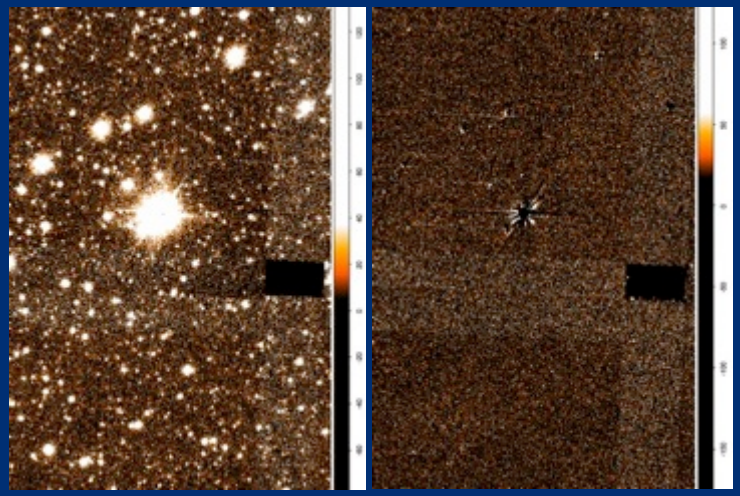
- Sextractor -> object ident.
- mag_{diff} @ each epoch (7σ)
- check with available catalogs
  (Initial GAIA Cat.. Simbad, Min. Planet..)
- PSF fitting single object
- Check by eye (LC +images)

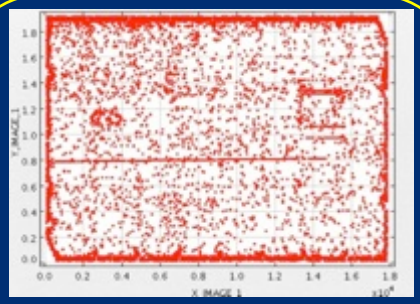


Covino, Giuffrida, Nicastro & WG3

II. Image subtractions

SUDARE@VST
Cappellaro et al. 2013





~10^4 transients in 1 deg^2

~10 transients in 1 deg^2

(III.) Feature analysis

RMN - neuroimaging
(coll. INFN – Ge)

Server for data analysis: Gravitown@OARoma (Lisi, Nicastro & WG7)
details in the round table discussion

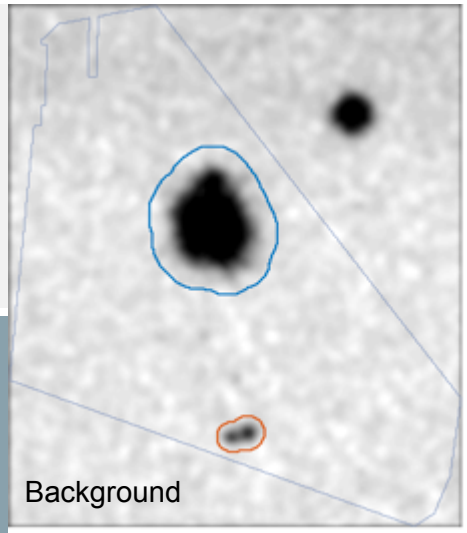
Collab. INFN-GE / INAF-Roma

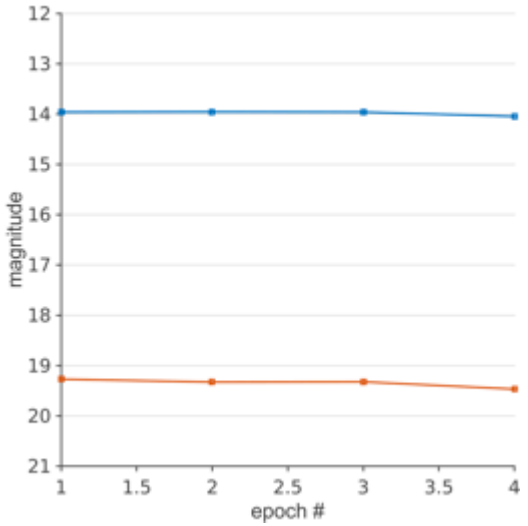
Andrea Chincarini
Gianluca Gemme

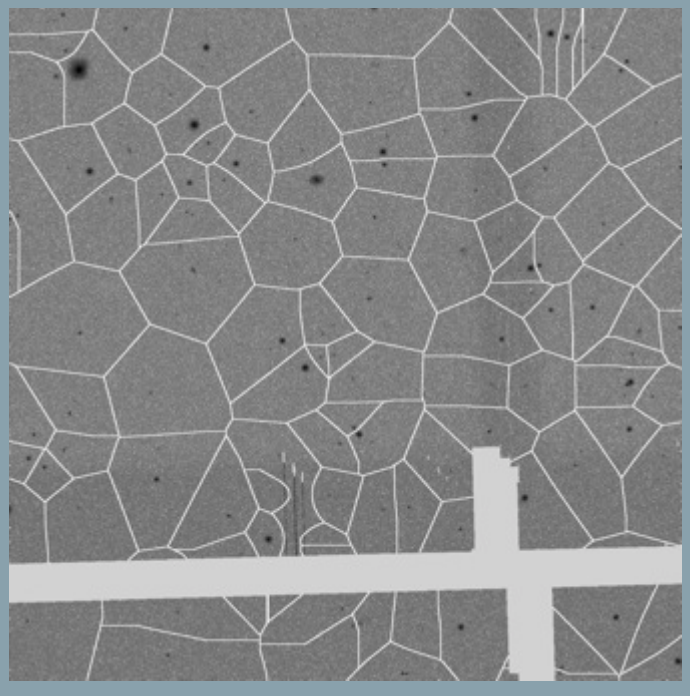
Francesca Badaracco (laur.)

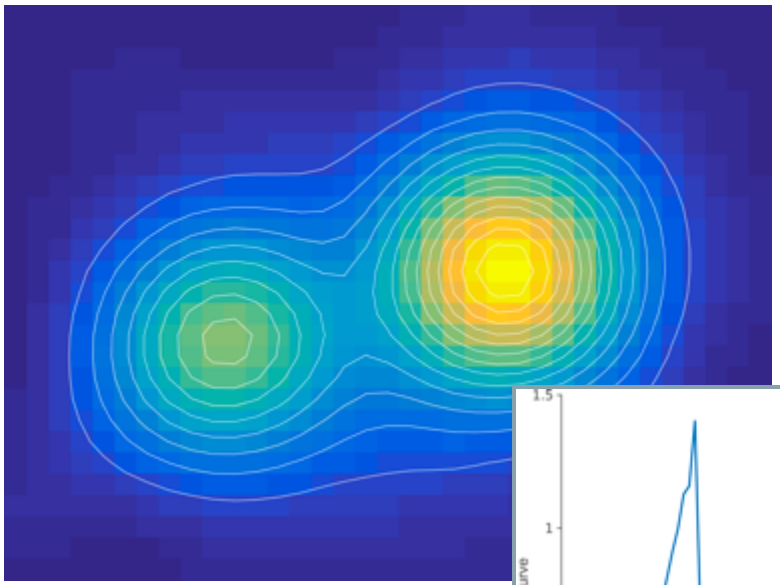
Feature-based analysis
(a technique already implemented in neuroimaging)

1. rough S/N estimation
2. Voronoi tessellation
3. patch extraction & local photometry
4. ELBA analysis (isophotes geom. properties)
5. candidates

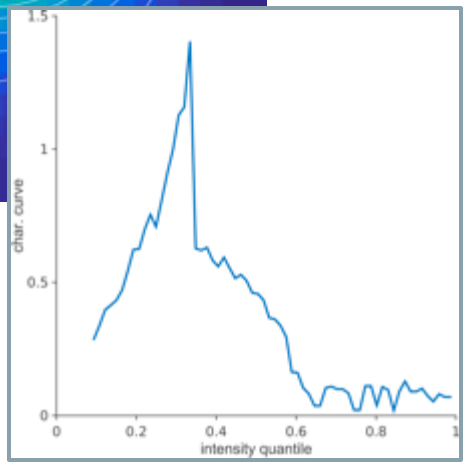








profile characteristic curve
- Intensity
- Topology



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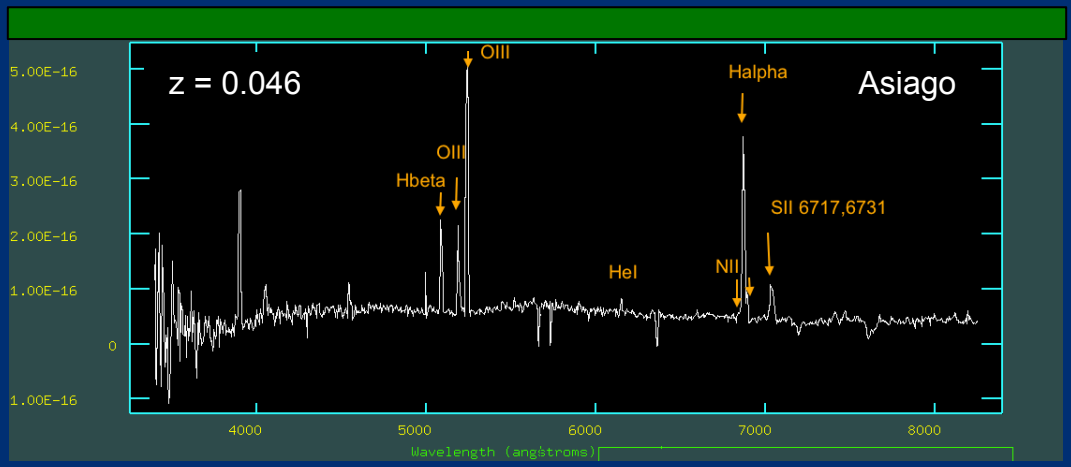
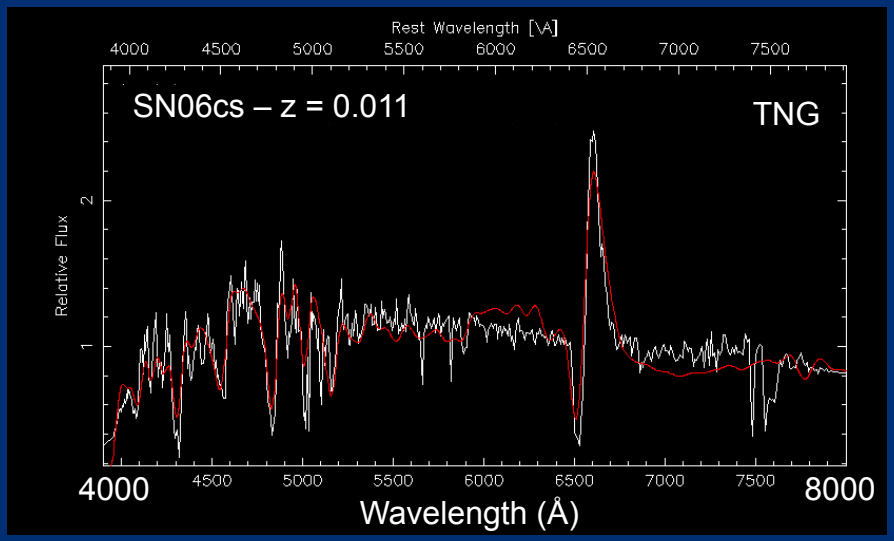
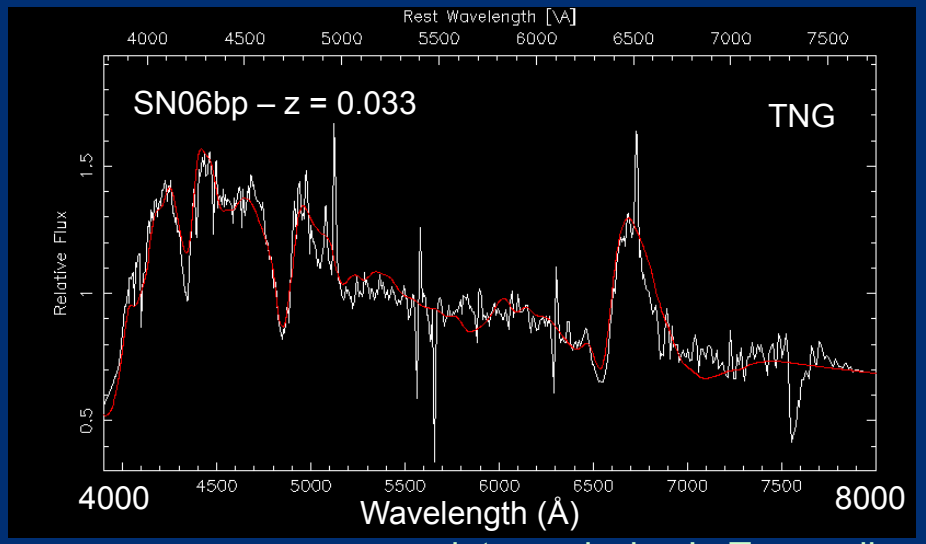
Characterization

Telescopes: LBT / NTT / TNG / NOT / Asiago
Collaborations: IPTF and PanSTARSS/PESSTO







data analysis : L. Tomasella

GW150914 : EM follow-up

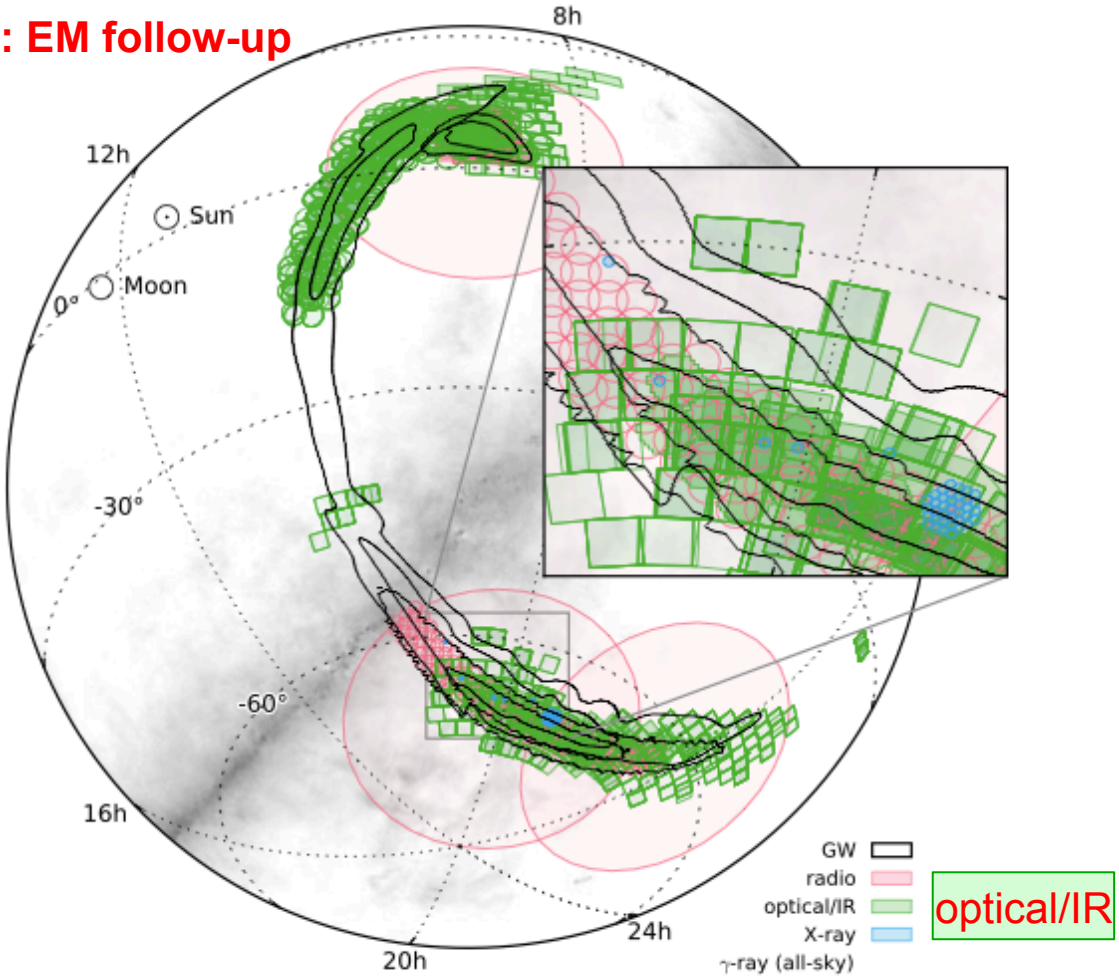


Figure 3. Footprints of observations in comparison with the 50% and 90% credible levels of the LIB GW localization. Radio fields are shaded red, optical/infrared fields are green, and XRT fields are blue circles. The all-sky *Fermi* GBM, LAT, *INTEGRAL* SPI-ACS, and MAXI observations are not shown. Where fields overlap, the shading is darker. The initial cWB localization is shown as thin black contour lines and the refined LIB localization as thick black lines. The inset highlights the *Swift* observations consisting of a hexagonal grid and a selection of the *a posteriori* most highly ranked galaxies. The Schlegel et al. (1998) reddening map is shown in the background to represent the Galactic plane. The projection is the same as in Fig. 2.

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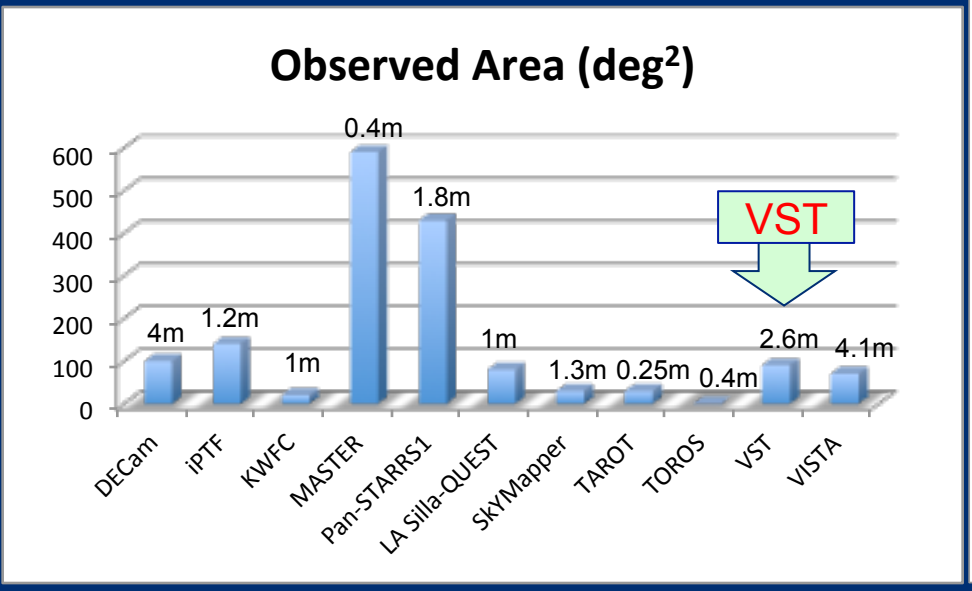

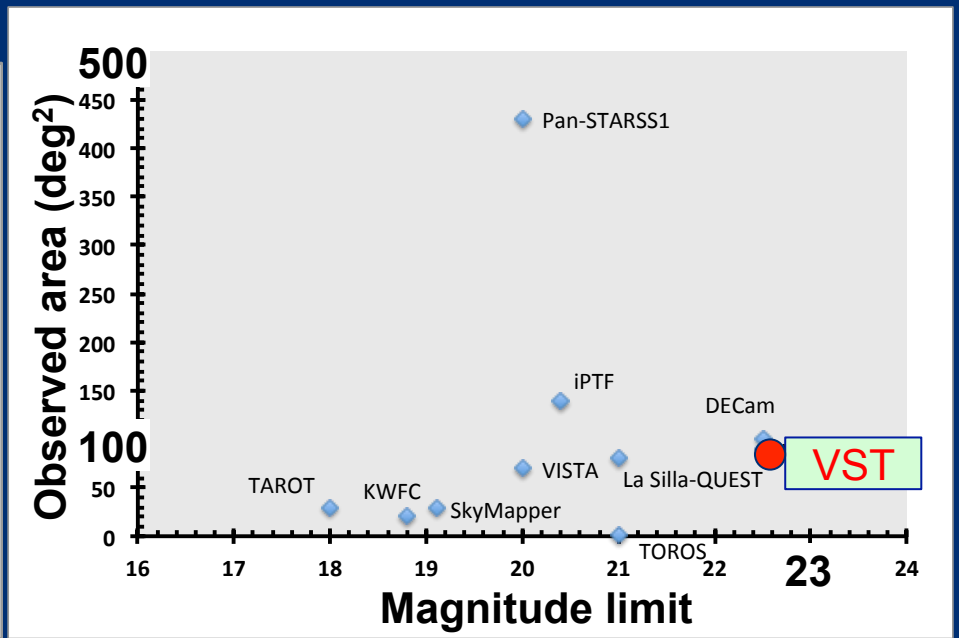

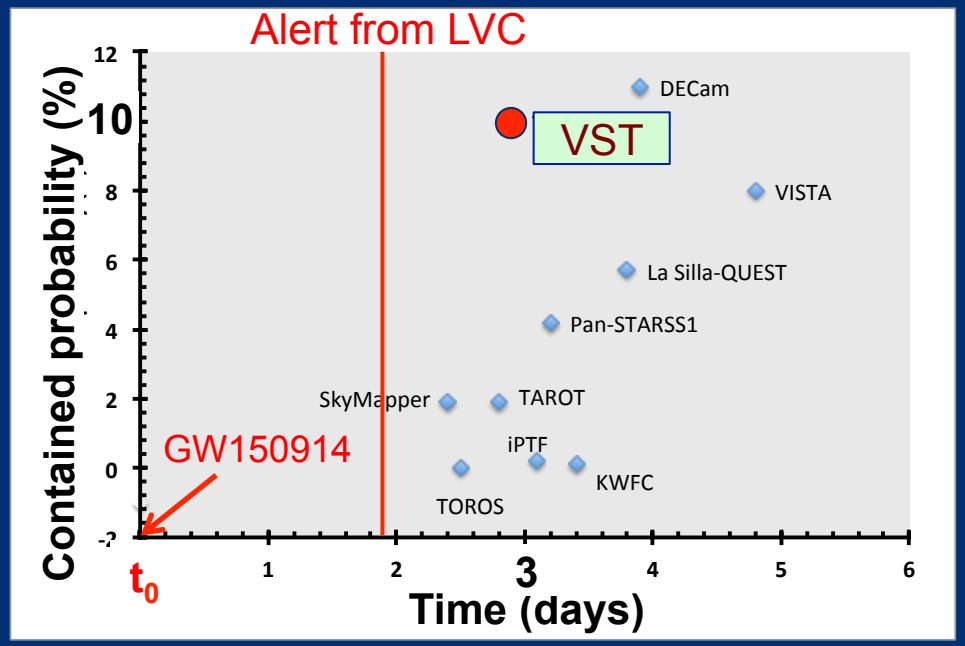

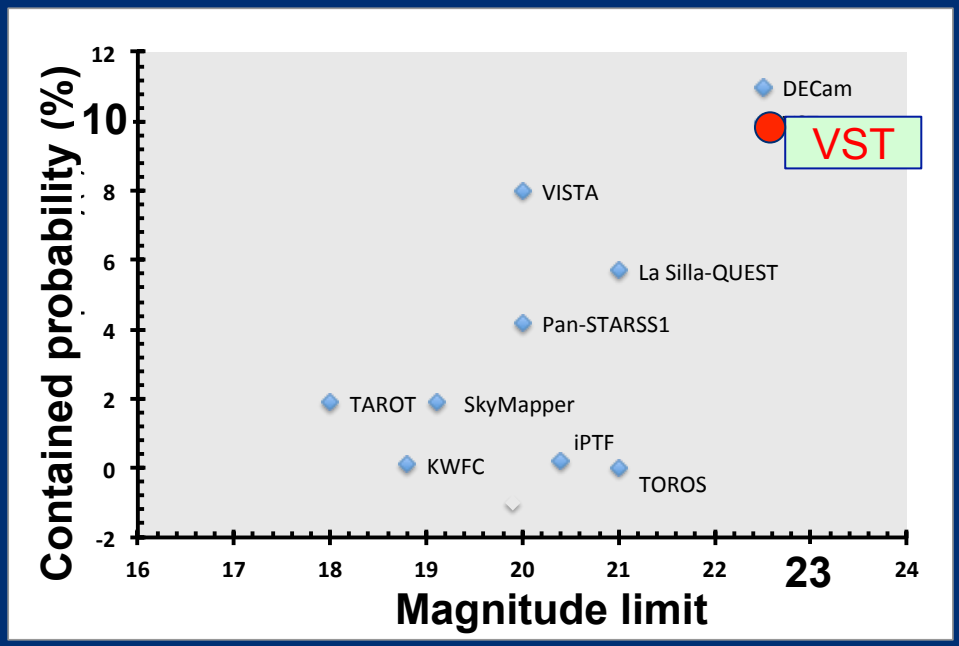

Some open issues

- several 10−100 deg^2 sky areas to cover
- EM follow-is facing the well known problem of balancing large sky coverage with sufficient depth
- Info on Distances + Progenitor would greatly help in adopting efficient observational strategies for optical follow-up
- large number of false positive events (background SNe, stellar flares, AGN flares, etc.)
- unknown EM counterpart in many cases (e.g. off-axis GRB, kilonova, BBH)
- unknown timing (e.g. light curve morphology of transients)

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Next future:

- support for networking
- support for training (now 2 PhD supported by Univ. RM + Cina)
- balanced development (post-doc + TD + staff)
- synergy with SOXS + NTE

GRAWITA and the next LVC runs:

- Prepare to Virgo impact
- Faster alerts from LVC
- Faster data analysis of VST image (photometry pipeline + image subtraction)
- Make agreements with other groups