LSST FOR DUMMIES

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OUTLINE

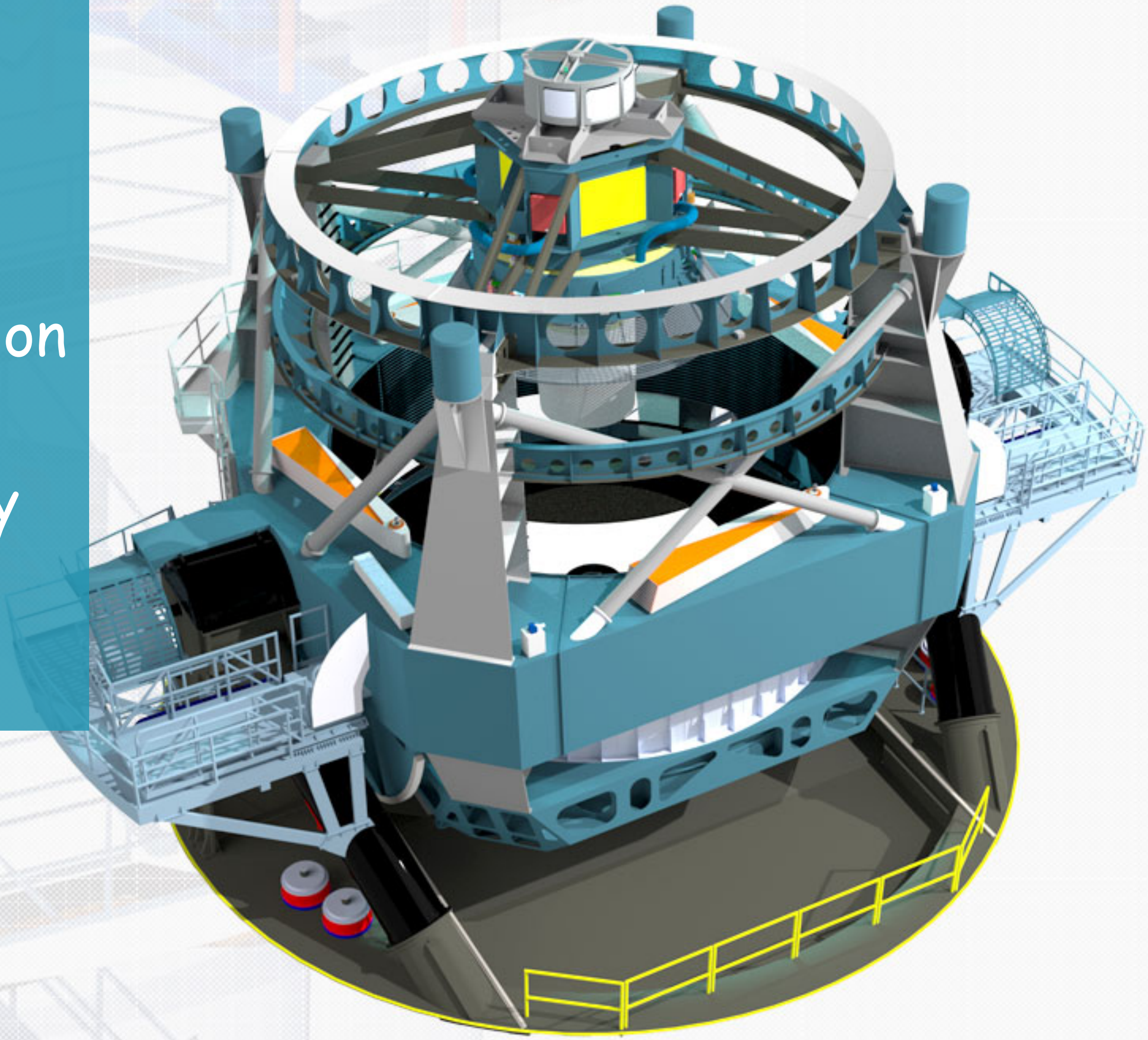
→ Multi-band photometry

→ Astrometry

→ LSST Science Collaboration

→ Ancillary data & Crowded field photometry

→ Conclusions



LSST@INAF

July 14th, 2016

Circumstantial evidence

Single epoch (5σ) measurements

u=23.9 -- g=25.0 -- r=24.7 -- i=24.0 -- z=23.3 - y=22.1

Final mean magnitudes

u=26.1 -- g=27.4 -- r=27.5 -- i=26.8 -- z=26.1 - y=24.9

Number of visits x band

u=56 - g=80 - r=184 - i=184 -- z=160 - y=160

Median number of visits x field in all bands → 824

Two 15 sec exposures x visit

90% survey + 10% special programs

A few crucial numbers

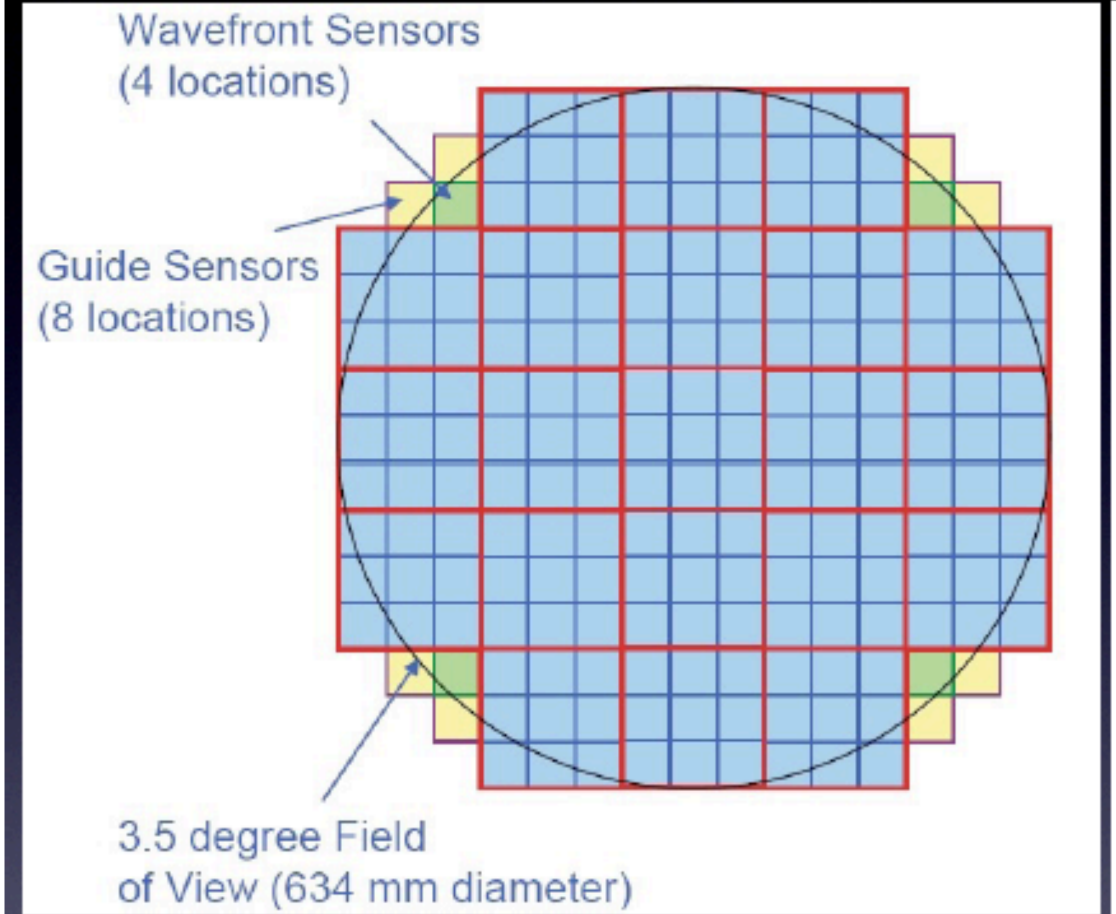
t_vis→ exposure time x visit → 20-40 sec

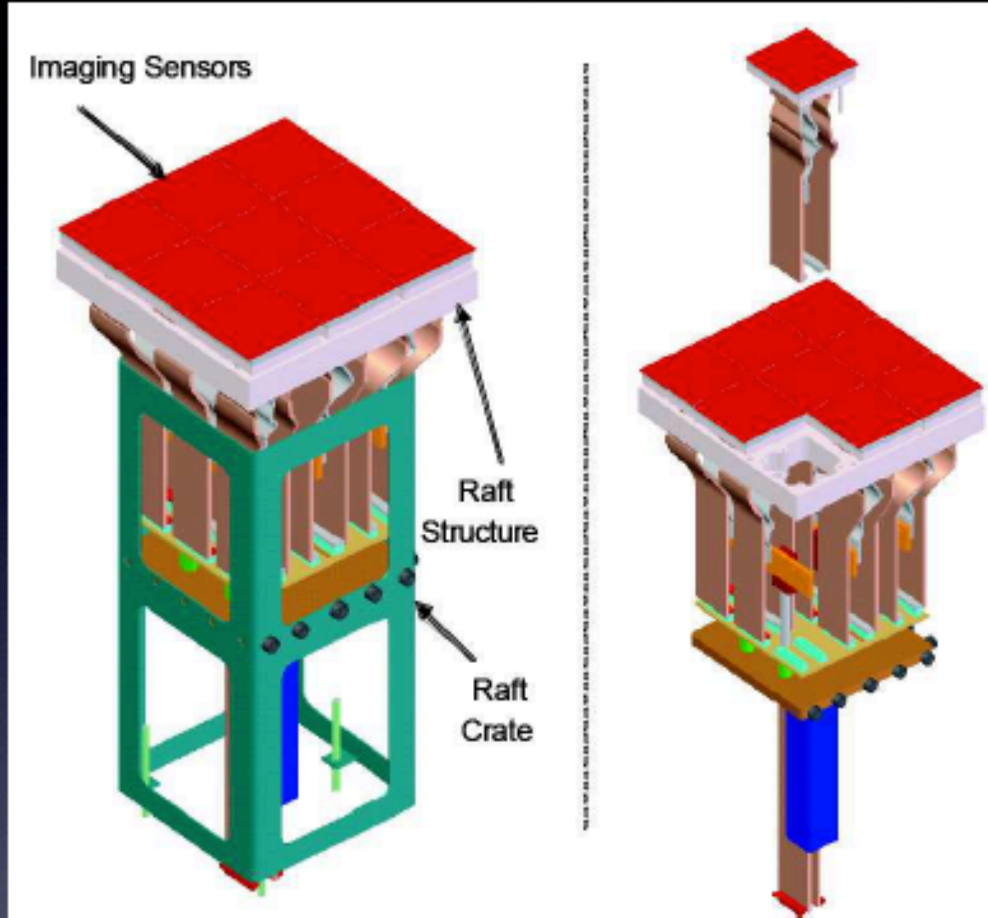
m5 → single visit depth
24.7+1.25*log(t_vis / 30 sec)

n_rev → mean revisit time
3 days * (t_vis / 30 sec)

n_vis → number of visits
1000 * (30 sec / t_vis) * (T / 10 years)

LSST camera





Modular design: 3200 Megapix = 189 x16 Megapix CCD

9 CCDs share electronics: raft (=camera)

Problematic rafts can be replaced relatively easily

FoV 10 square degrees

"0.20 arcsec/pixel"

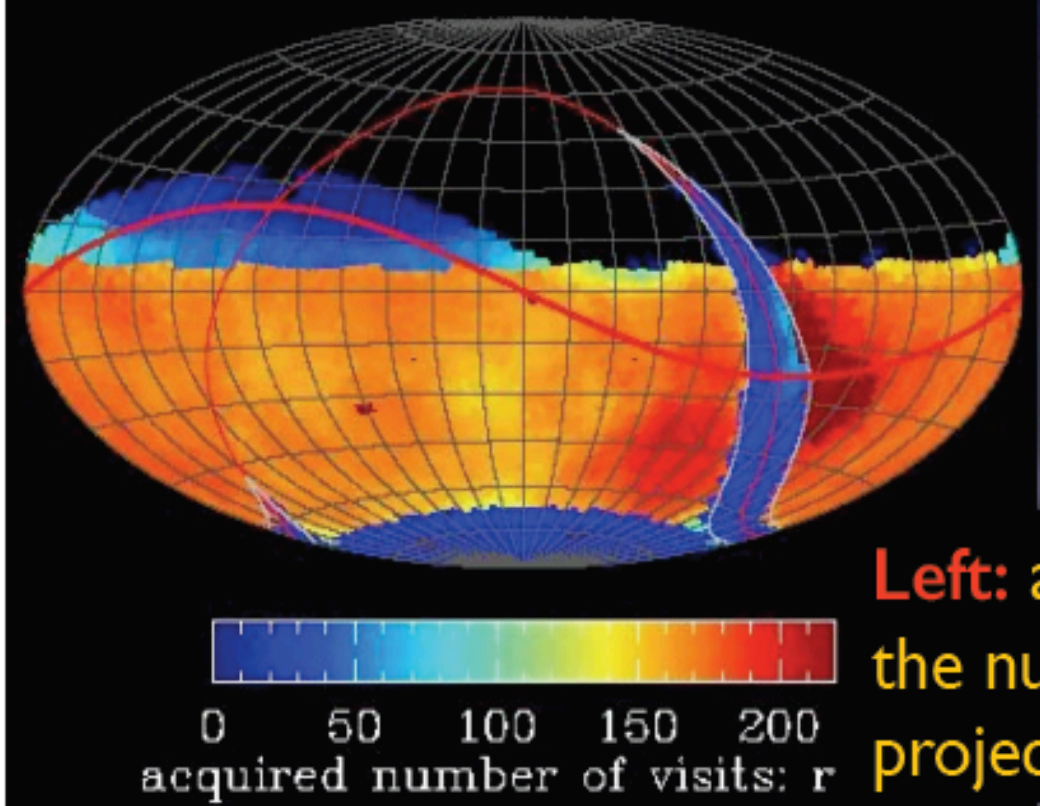
5.5 million images, with 189 CCDs (4k x 4k)

One **billion 16 Megapixel images of the sky**

Proprietry time of the data 2 years

Basic idea behind LSST: a uniform sky survey

- 90% of time will be spent on a uniform survey: every 3-4 nights, the whole observable sky will be scanned twice per night
- after 10 years, half of the sky will be imaged about 1000 times (in 6 bandpasses, ugrizy): a digital color movie of the sky
- ~100 PB of data: about a billion 16 Mpix images, enabling **measurements for 40 billion objects!**



LSST in one sentence:
An optical/near-IR survey of half the sky in ugrizy bands to r~27.5 (36 nJy) based on 825 visits over a 10-year period: deep wide fast.

Left: a 10-year simulation of LSST survey: the number of visits in the r band (Aitoff projection of eq. coordinates)

LSST Science Themes

- Dark matter, dark energy, cosmology (spatial distribution of galaxies, gravitational lensing, supernovae, quasars)
- Time domain (cosmic explosions, variable stars)
- The Solar System structure (asteroids)
- The Milky Way structure (stars)

LSST Science Book: arXiv:0912.0201

Summarizes LSST hardware, software, and observing plans, science enabled by LSST, and educational and outreach opportunities

245 authors, 15 chapters, 600 pages

Galaxies:

- **Photometric redshifts:** random errors smaller than 0.02, bias below 0.003, fewer than 10% >3σ outliers
- These photo-z requirements are one of the primary drivers for the photometric depth and accuracy of the main LSST survey (and the definition of filter complement)

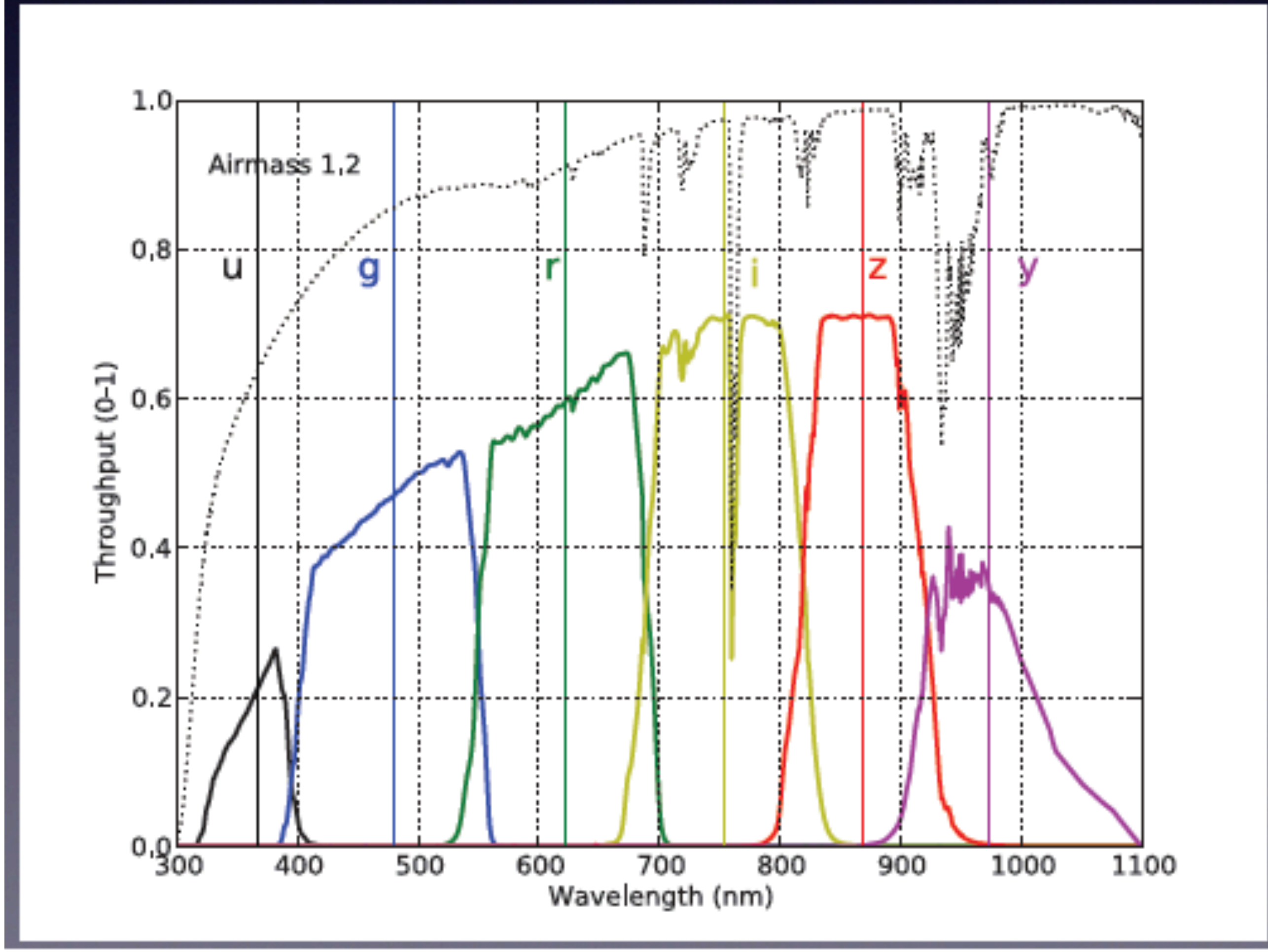


Photo-z requirements correspond to r~27.5 with the following per band time allocations:

u: 8%; g: 10%

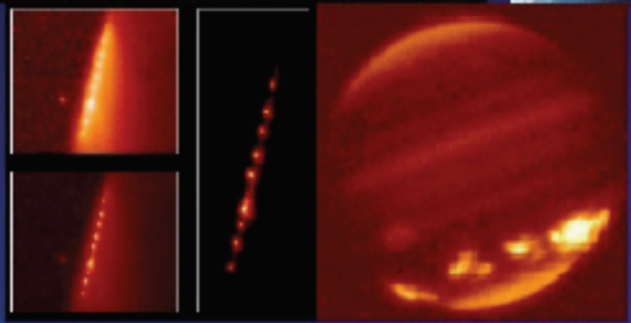
r: 22%; i: 22%

z: 19%; y: 19%

Consistent with other science themes (stars)

Killer asteroids: the impact probability is not 0!

photomontage!



Shoemaker-Levy 9
(1994)

Tunguska
(1908)

LSST is the only survey capable of delivering completeness specified in the 2005 USA Congressional NEO mandate to NASA (to find 90% NEOs larger than 140m)

The Barringer Crater, Arizona: a 40m object 50,000 yr. ago

Milky Way & Local Group

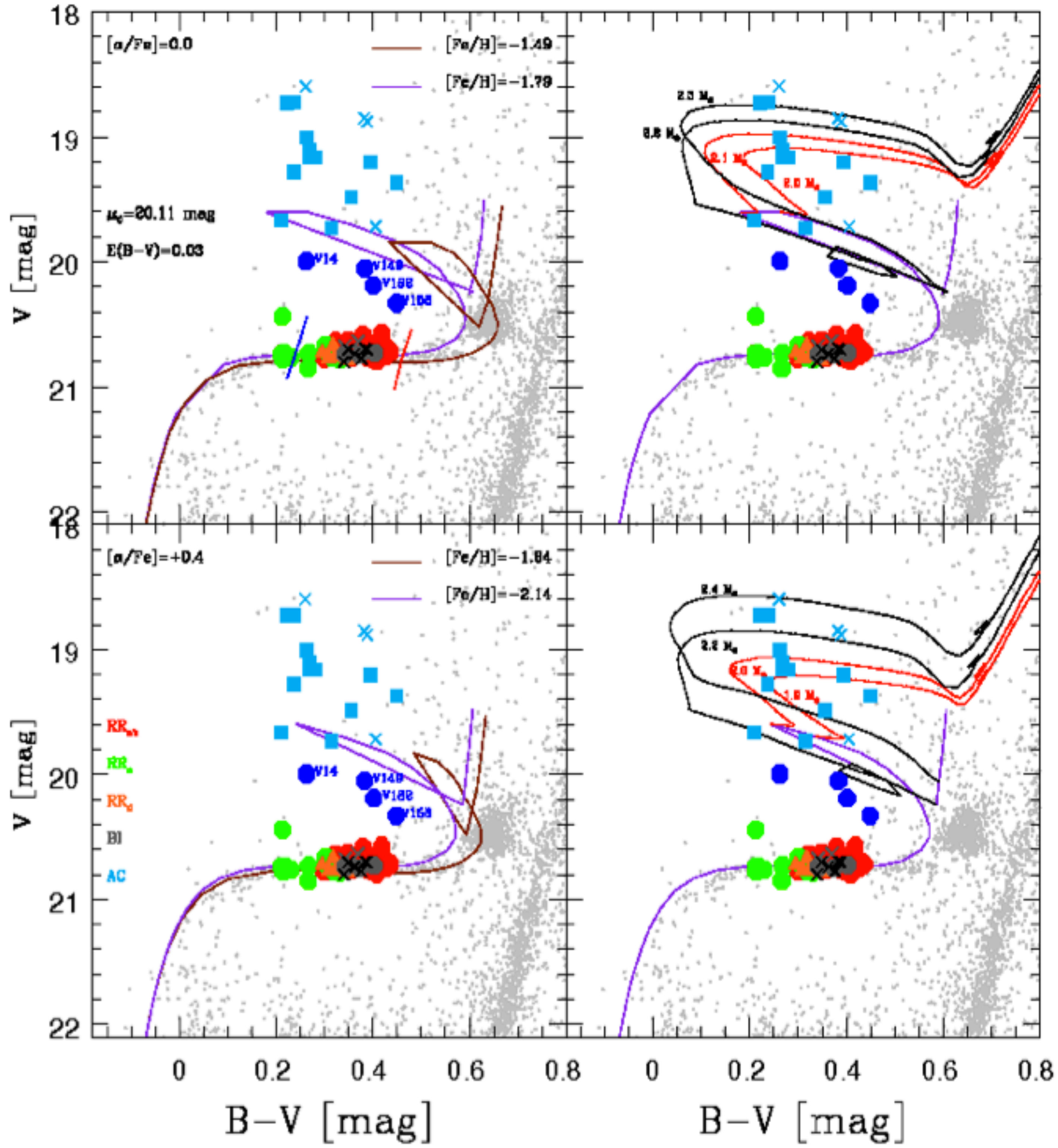
Carina dSph

Coppola et al. 2015

More than ten yrs data collection

Complete census evolved variables

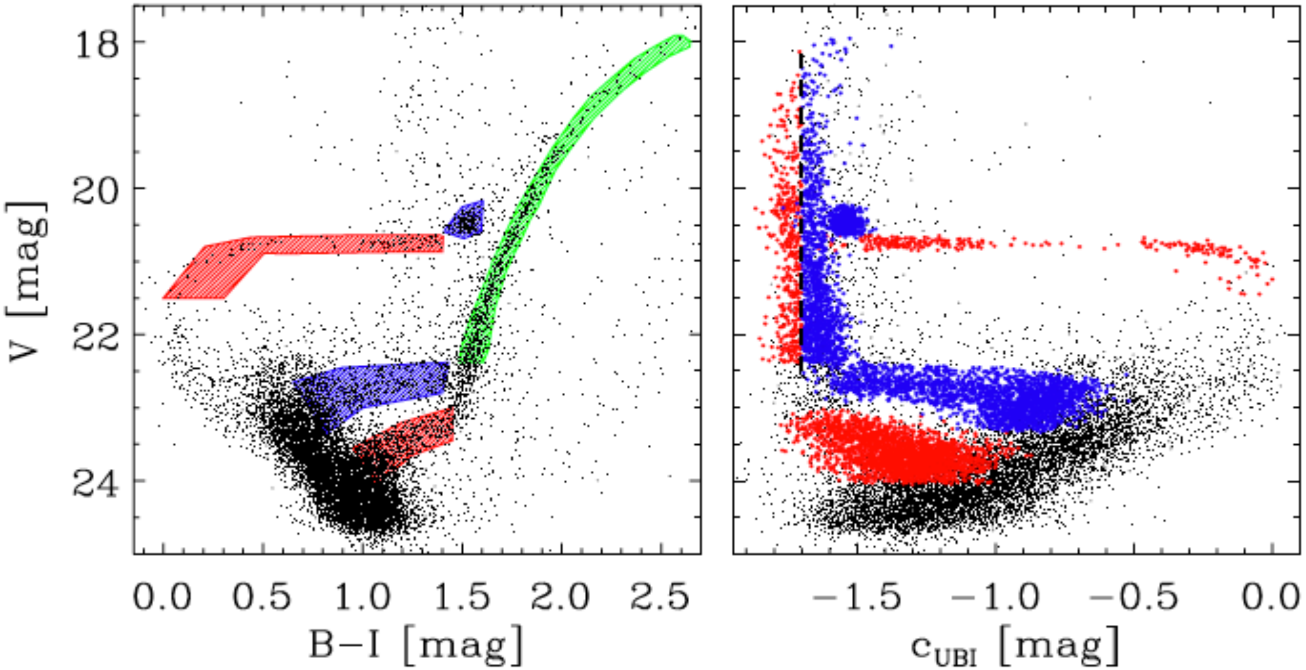
distance,
metallicity distr,
Evol. & Puls.
SFH

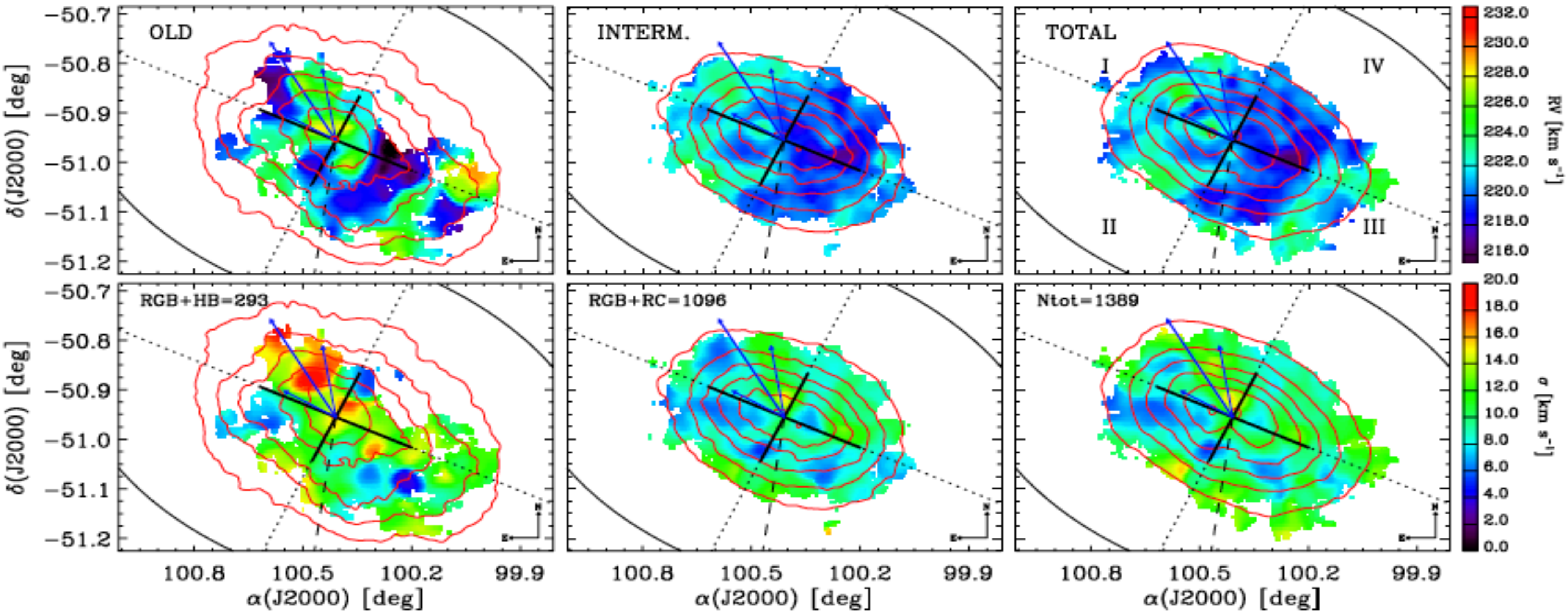


Carina dSh

Fabrizio et al. 2016

Looking for deep u-band photometry





Carina dSph: metallicity distribution
Old & intermadiate-age stars

[Fe/H]
μ(int) =−1.74±0.38±0.20

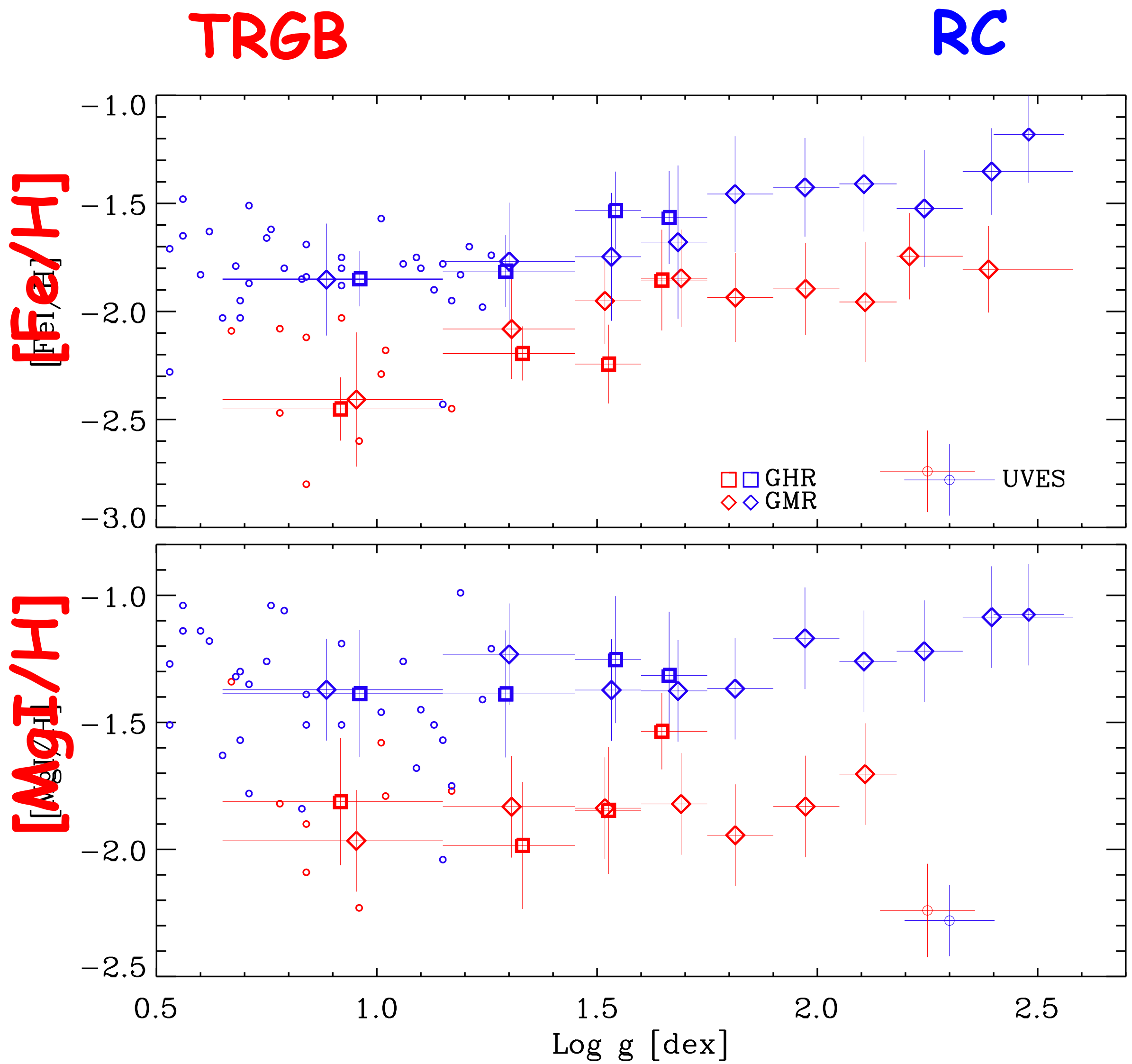
μ(old)=−2.13±0.06±0.28

They differ 75% c.l.

[Mg/H]
μ(int) =−1.37±0.04±0.27

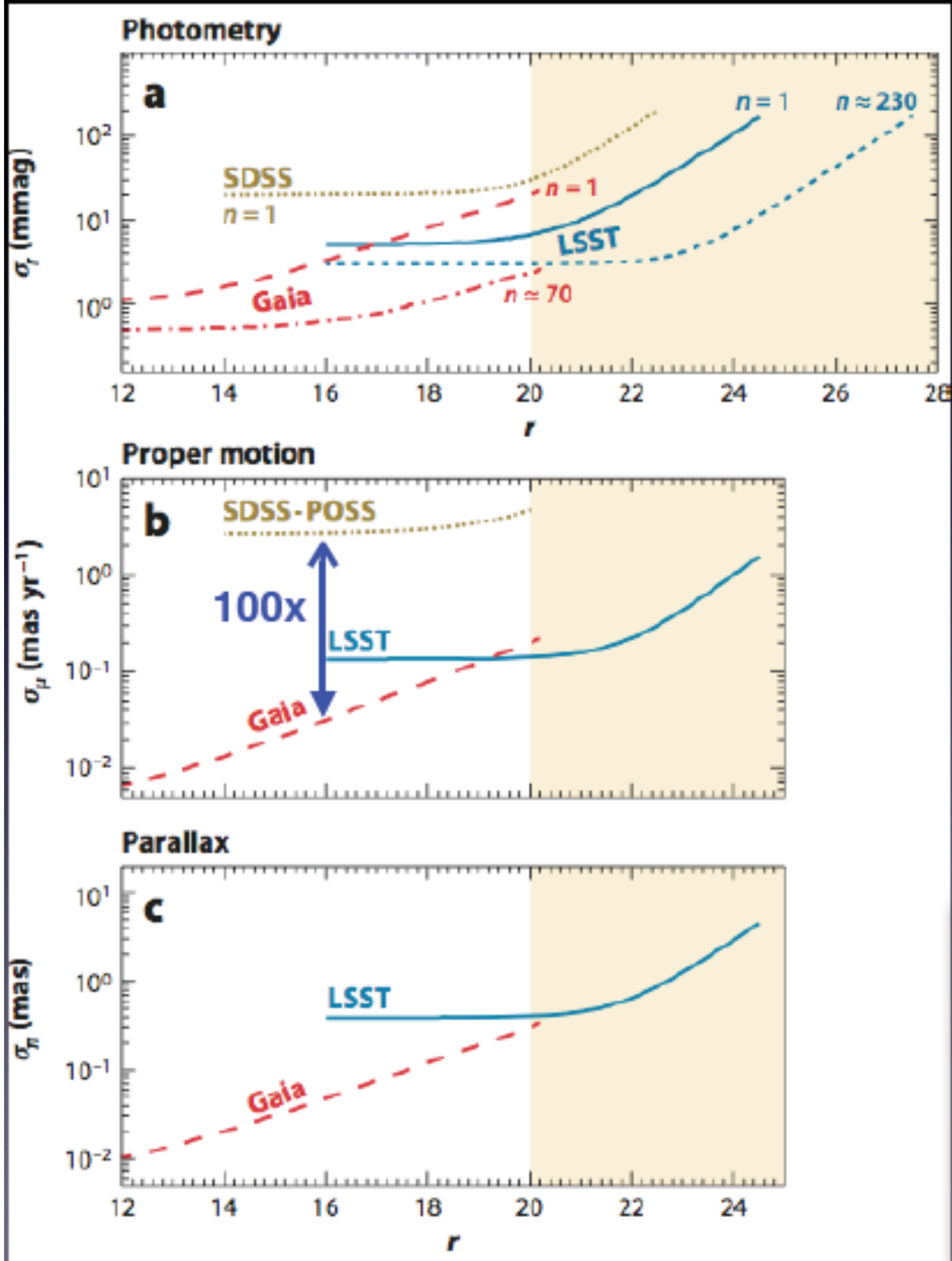
μ(old)=−1.77±0.08±0.36

They differ 83% c.l.



Fabrizio + 2015

Gaia vs. LSST comparison



Ivezić, Beers, Jurić 2012, ARA&A, 50, 251

- **Gaia:** excellent astrometry (and photometry), but only to r < 20
- **LSST:** photometry to r < 27.5 and time resolved measurements to r < 24.5
- Complementarity of the two surveys: photometric, proper motion and trigonometric parallax errors are similar around r=20

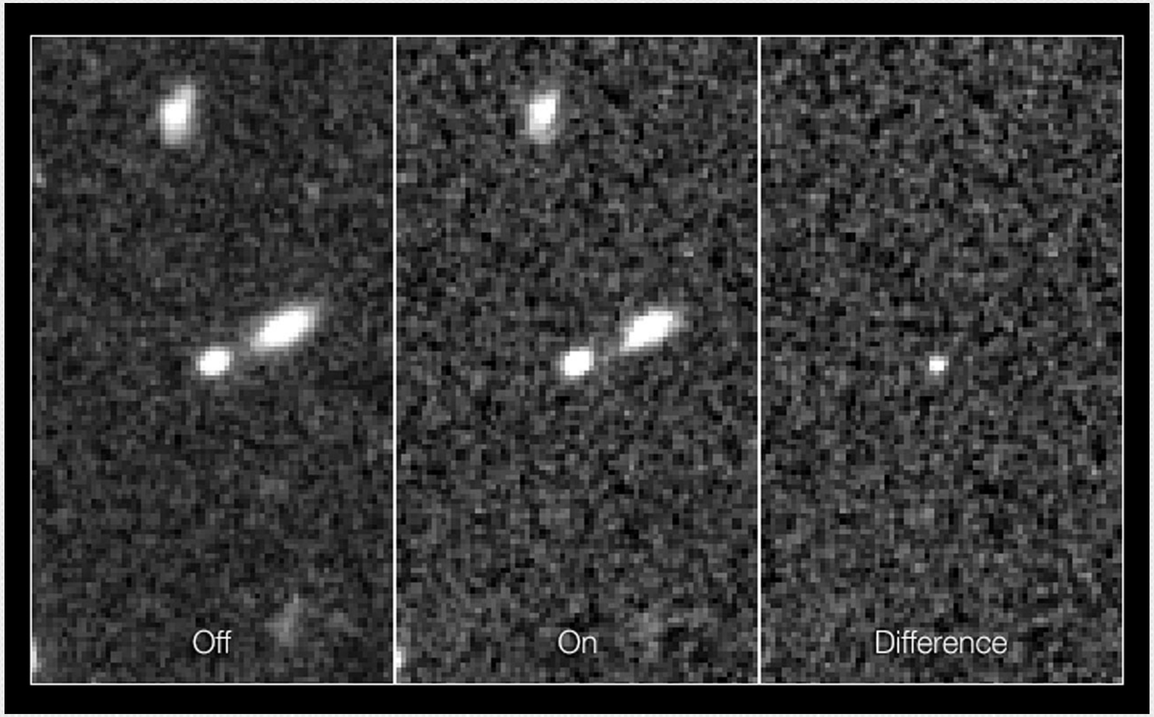
The Milky Way disk "belongs" to Gaia, and the halo to LSST (plus very faint and/or very red sources, such as white dwarfs and LT(Y) dwarfs).

DATA PRODUCTS

Level 1 Data Products: Time Domain

- **Real-time image differencing as observing unfolds each night**
- Detection performed on image differenced against a deep template
- Measurement performed on the difference image and direct image
- Associated with pre-existing observations and stored in a database
- For every source detected in a difference image, we will emit an "Event Alert" within 60 seconds of observation.

  The primary use case is to enable real-time recognition and follow-up of transients of special interest.



CANDELS (http://www.spacetelescope.org/images/heic1306d/)

Level 1: Time-Domain Event Alerts

- **Each alert will include the following:**
  - Alert and database ID: IDs uniquely identifying this alert.
  - The photometric, astrometric, and shape characterization of the detected source
  - 30x30 pixel (on average) cut-out of the difference image (FITS)
  - 30x30 pixel (on average) cut-out of the template image (FITS)
  - The time series (up to a year) of all previous detections of this source
  - Various summary statistics ("features") computed of the time series

- **The goal is to transmit nearly everything LSST knows about any given event, enabling downstream classification and decision making *without* the need to call back into LSST databases (thus introducing extra latency)**

- We expect a high rate of alerts, **approaching 10 million per night**.

Level 2: Annual Data Releases

- **Well calibrated, consistently processed, catalogs and images**
  - Catalogs of objects, detections, detections in difference images, etc.

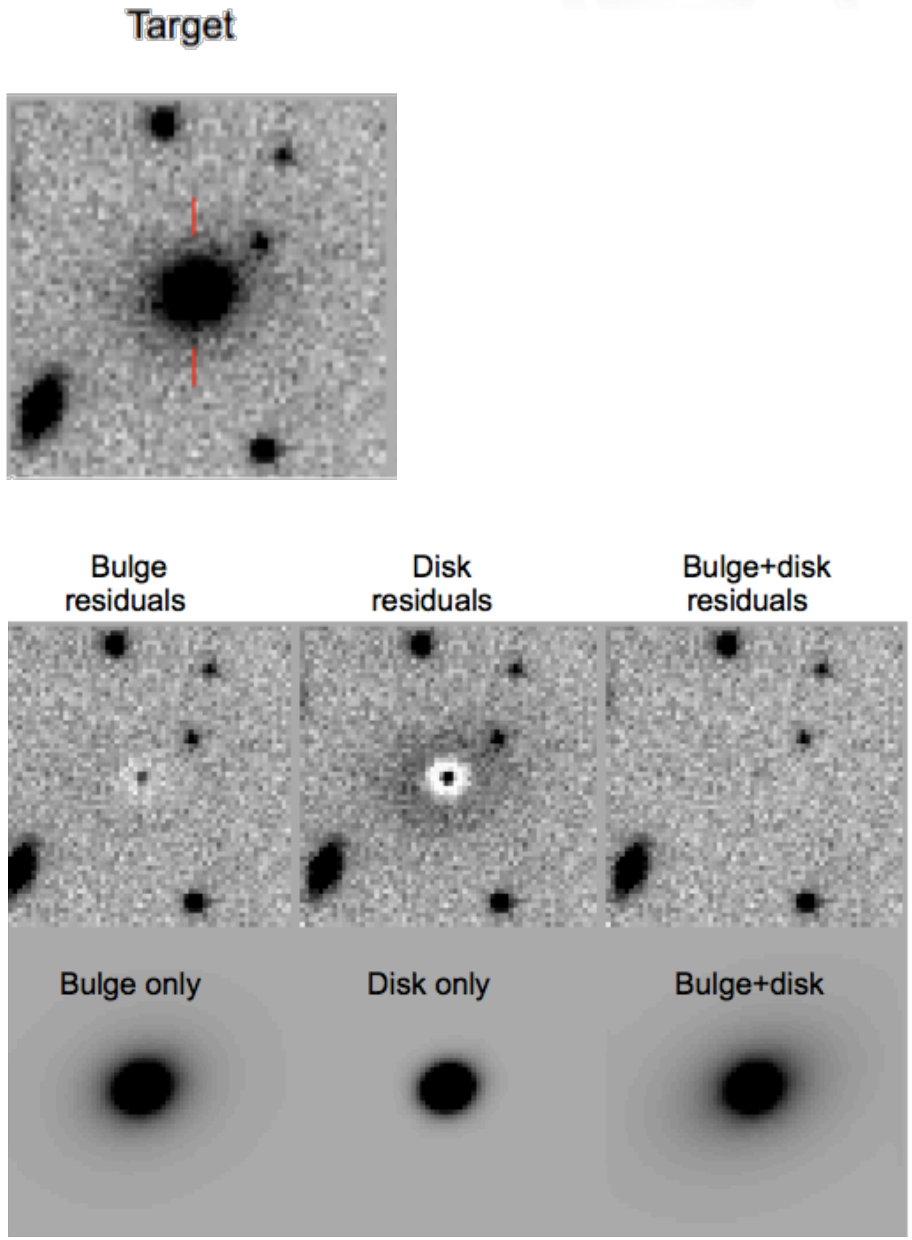
- **Made available in *Data Releases***
  - Annually, except for Year 1
    - Two DRs for the first year of data

- **Complete reprocessing of all data, for each release**
  - Every DR will reprocess ***all*** data taken up to the beginning of that DR

- **Projected catalog sizes:**
  - **18 billion objects** (DR1) → **37 billion** (DR11)
  - **750 billion observations** (DR1) → **30 trillion** (DR11)

LSST Catalog Contents (Level 2)

- **Object characterization (models):**
  - Moving Point Source model
  - Double Sérsic model (bulge+disk)
    - Maximum likelihood peak
    - Samples of the posterior (hundreds)
- **Object characterization (non-parametric):**
  - Centroid: (α, δ), per band
  - Adaptive moments and ellipticity measures (per band)
  - Aperture fluxes and Petrosian and Kron fluxes and radii (per band)
- **Colors:**
  - Seeing-independent measure of object color
- **Variability statistics:**
  - Period, low-order light-curve moments, etc.



Level 3: Added Value Data Products

- **Level 3 Data Products: Added-value products created by the community**

- **These may enable science use-cases not fully covered by what we'll generate in Level 1 and 2:**
  - Catalogs of SNe light echos
  - Characterization of diffuse structures (e.g., ISM)
  - Extremely crowded field photometry (e.g., globular clusters)
  - Custom measurement algorithms

- **The LSST wants to make it easier for the community to create and distribute Level 3 products**
  - Making the LSST software stack available to end-users
  - Enabling limited end-user analysis and processing at the LSST data center
  - User databases and workspaces ("mydb")

- Level 3 products may be migrated to Level 2 (with owners' permission); this is one of the ways how Level 2 products will evolve.

Enabling the creation of Level 3 Data Products

- We are engineering the LSST software stack to be modular, reusable, documented, supported, and end-user friendly. It will be available under free software or public domain licenses. (see Session 8 on Tuesday)

- We will enable user computing at the LSST archive, making available to the users ~10% of our storage and computing resources (~50-100 TFLOPS). We will use this to power a JupyterHub-type remote analysis environment and a small HPC-type processing cluster.

- LSST archive will be located in the National Petascale Computing Facility at National Center for Supercomputing Applications (NCSA). Significant additional supercomputing is expected to be available at the same site (e.g., NPCF currently hosts the Blue Waters supercomputer).

- Rights-holders may build their own computing facilities to support larger-scale processing, reusing our software (pipelines, middleware, databases) to the extent possible.

There are currently nine science collaborations

Galaxies

Michael Cooper (UC Irvine) & Brant Robertson (UCSC)

Stars, Milky Way & Local Volume

John Bochanski (Rider); John Gizis (U Delaware); Nitya Kallivayalil (U VA)

Solar System

Lynne Jones (UW); David Trilling (NAU)

Dark Energy

Rachel Bean (Cornell); Jeff Newman (Pitt)

AGN

Niel Brandt (Penn State)

Transients & Variable Stars

Federica Bianco (NYU); Ashish Mahabal (Caltech)

Large-scale Structure

Eric Gawiser (Rutgers); Anže Slosar (BNL)

Strong Lensing

Phil Marshall (KIPAC)

Informatics & Statistics

Tom Loredo (Cornell); Chad Shafer (CMU)

Ancillary data

Data available in public archives on which the LSST software is tested

Are available to LSST corporation

TUTORIALS for the entire LSST community

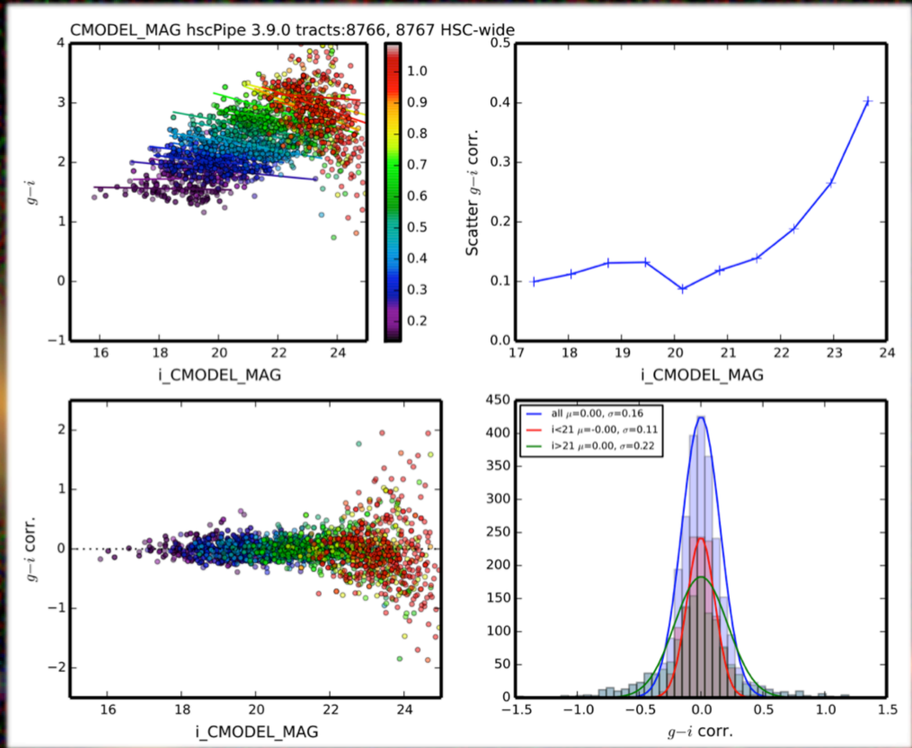
Prototype LSST Science Pipelines Are Running on HSC Survey …

HSC "ultra deep" gri imaging in COSMOS, with a total of 1.5 hours in g and r and 3 hours in i; (280/550 LSST visits).

The visits were processed, calibrated, registered, added, and the resulting coadds processed using the LSST stack.

These catalogues are being used to carry out first-year HSC science.

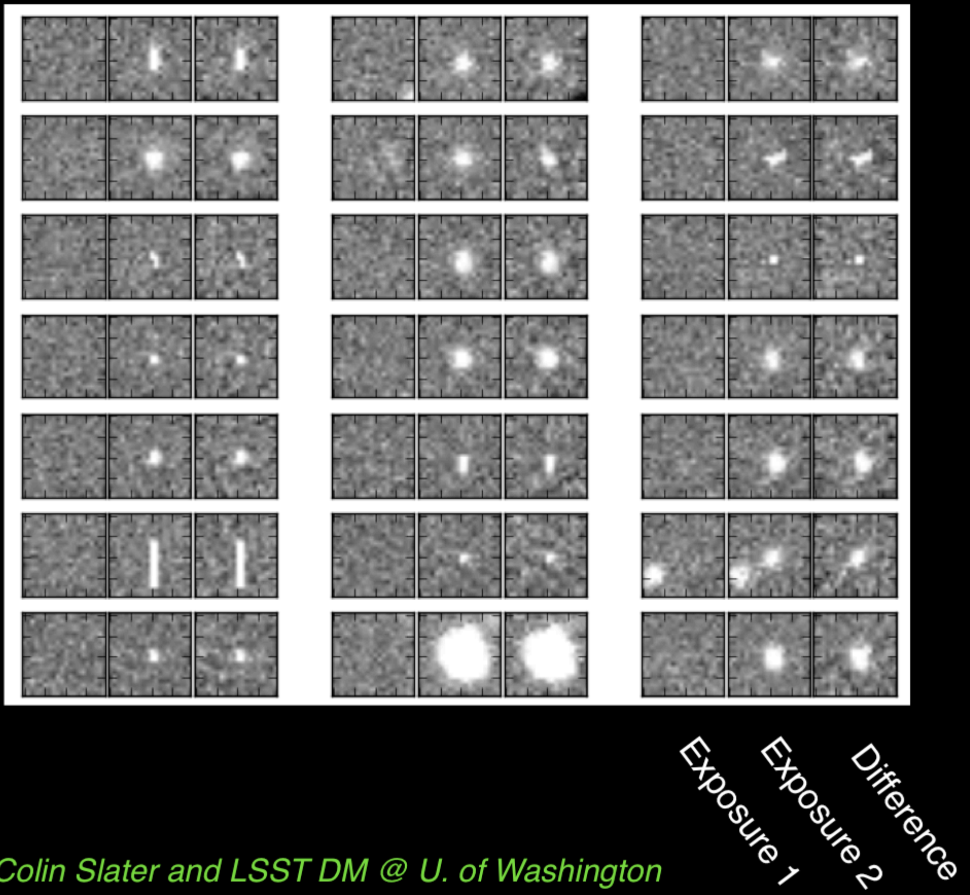
Credit: HSC collaboration, Robert Lupton and LSST DM @ Princeton.



Width of the E-S0 red sequence for SDSS `red mapper' galaxies, measured from the HSC `wide' data. The results are comparable to those from SDSS; the small extra scatter is attributed to problems with deblending data going several magnitudes deeper than SDSS.

Credit: Bob Armstrong, Atsushi Nishizawa, and the HSC collaboration.

LSST Time Domain Pipelines: Testing on DECam



Credit: Colin Slater and LSST DM @ U. of Washington
Data courtesy of L. Allen, NOAO

- We've begun running the LSST image differencing pipelines on data acquired by DECam.
- The immediate goal is to characterize LSST's asteroid detection capabilities. This requires low false positive rate. Preliminary runs are showing performance rates known to be clean enough for MOPS.
- Left: A representative set of 21 detections. Only dipoles were identified and rejected; no machine-learning afterburners were applied. Note the low instrumental artifact rates.

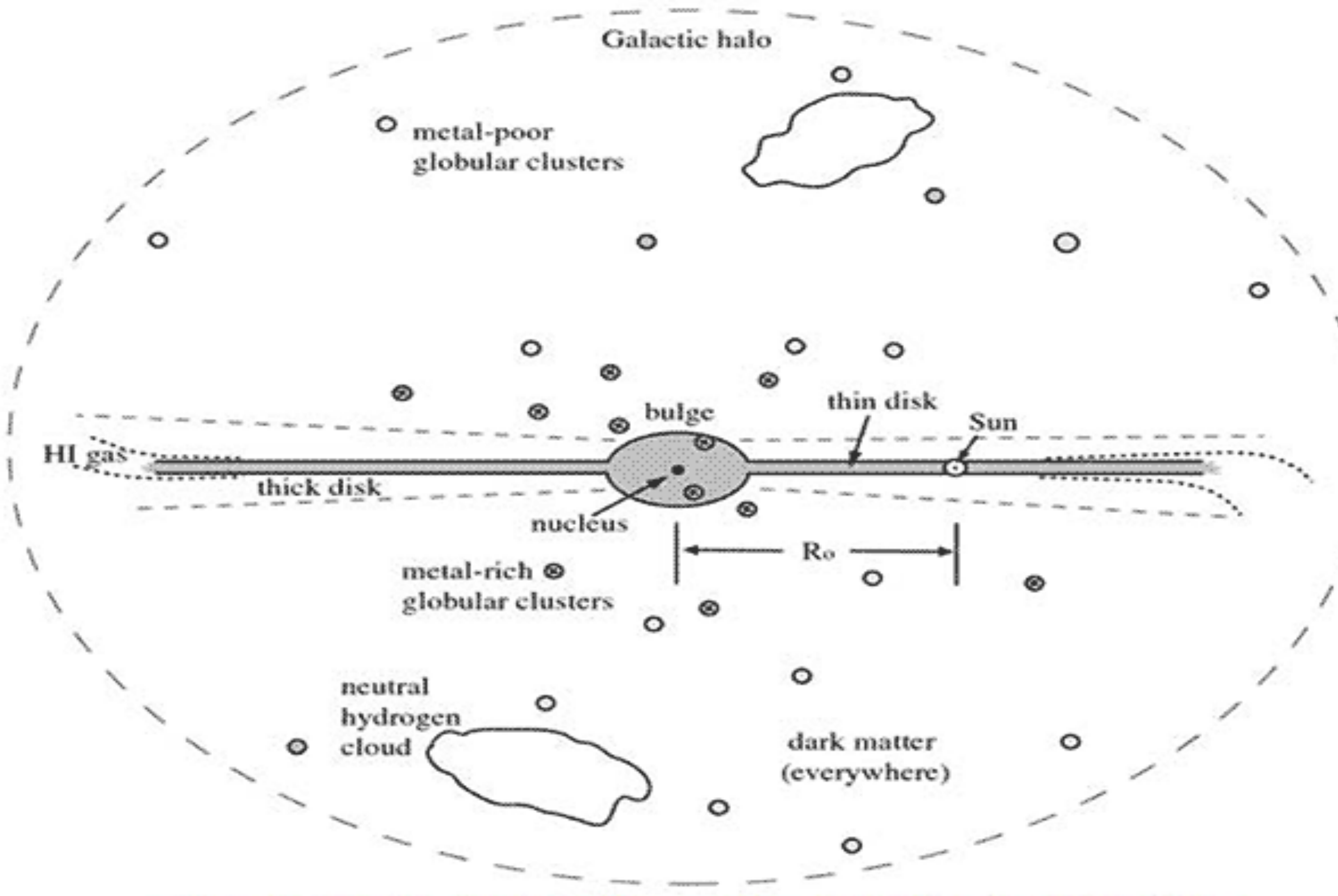
A fundamental issue:

Differential photometry

versus

PSF photometry

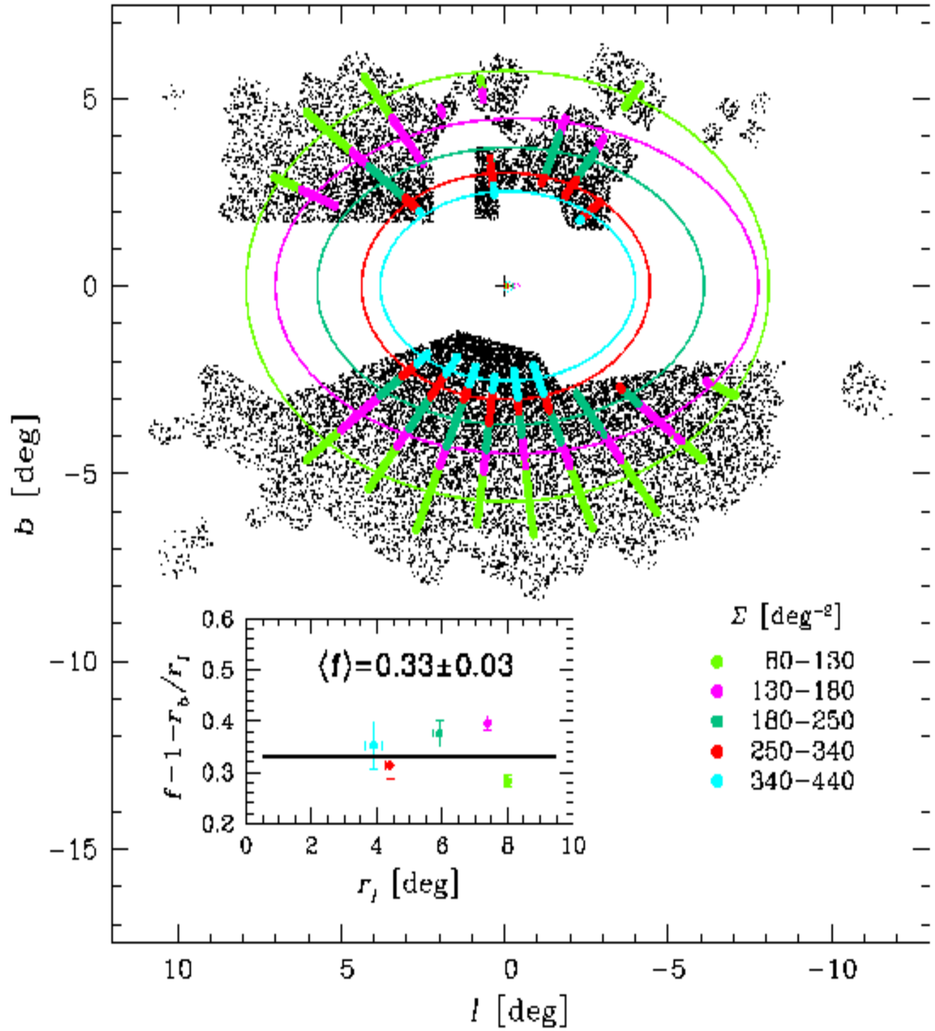
The Galactic thin disk & bulge



Disk → Gaia Halo → LSST

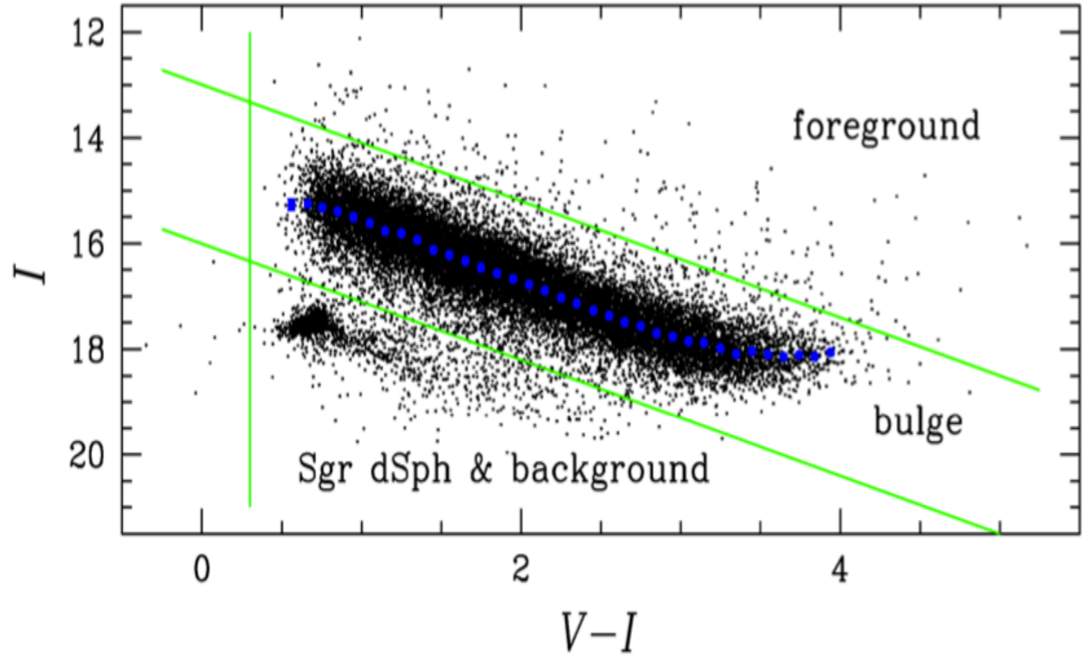
Crowded stellar photometry!!

Unveiling the inner bulge



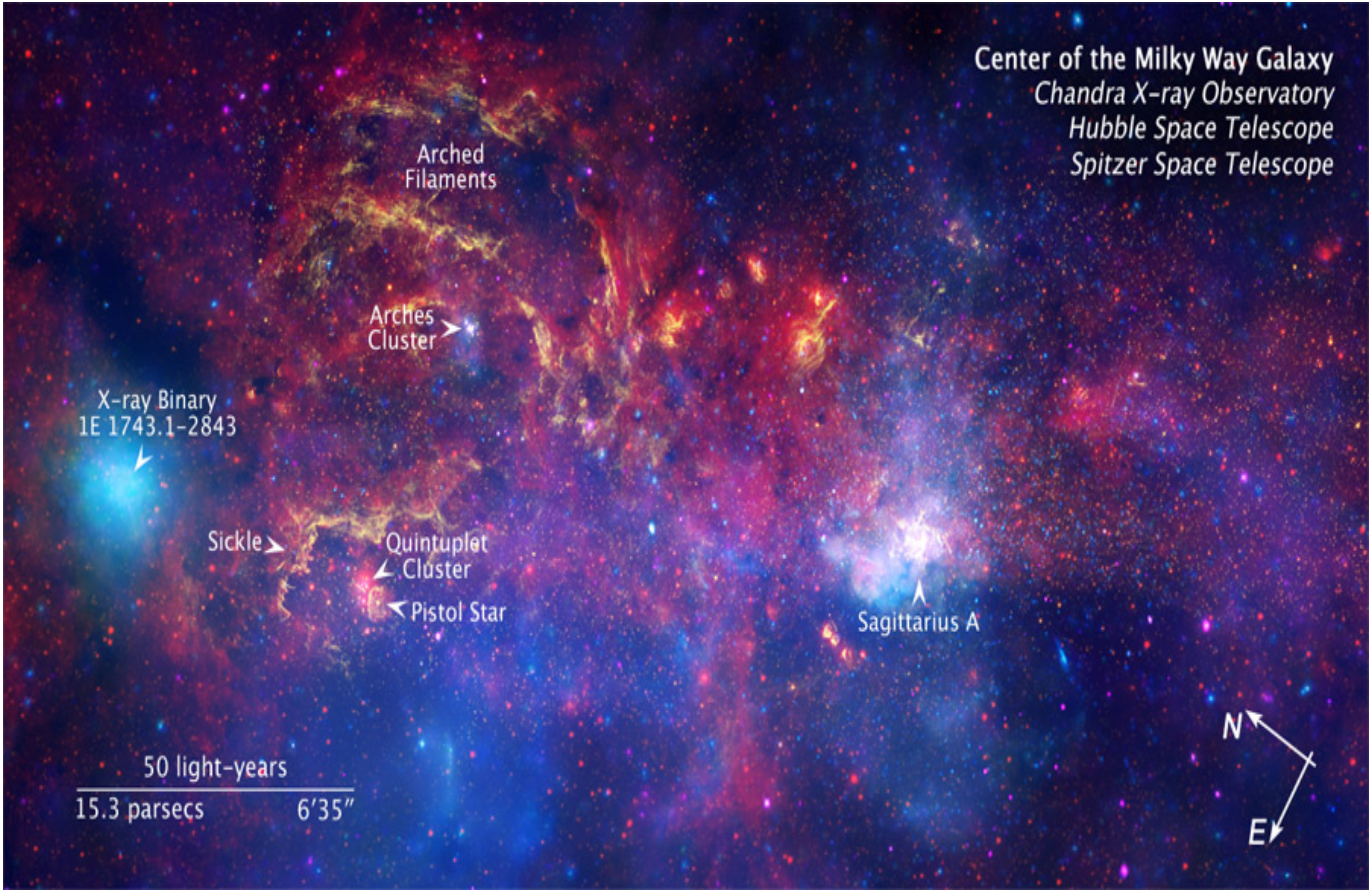
~25,000 RR Lyrae by OGLE IV

Census far from being complete!

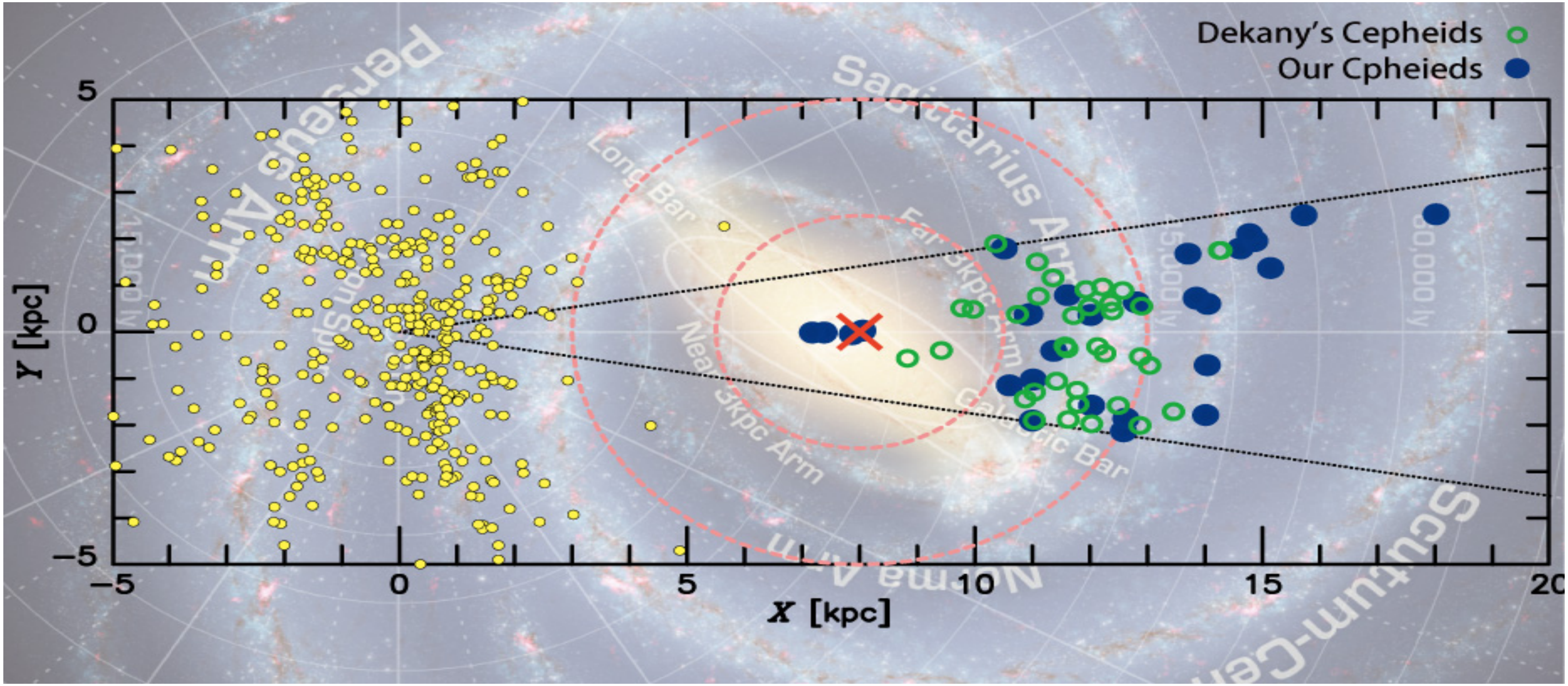


Pietrukowicz + (2015)

VVV → JHK~16-18


Center of the Milky Way Galaxy
Chandra X-ray Observatory
Hubble Space Telescope
Spitzer Space Telescope
Arched Filaments
Arches Cluster
X-ray Binary 1E 1743.1-2843
Sickle
Quintuplet Cluster
Pistol Star
Sagittarius A
N
E
50 light-years
15.3 parsecs
6′35″

Beyond The Galactic Centre: classical Cepheids



New constraints on stellar populations & Kinematics beyond the Nuclear bulge

Matsunaga + (2016, accepted)

Added value in joining LSST corporation

VLT:
K-MOS, AOF+MUSE, CRIRES

MOONS

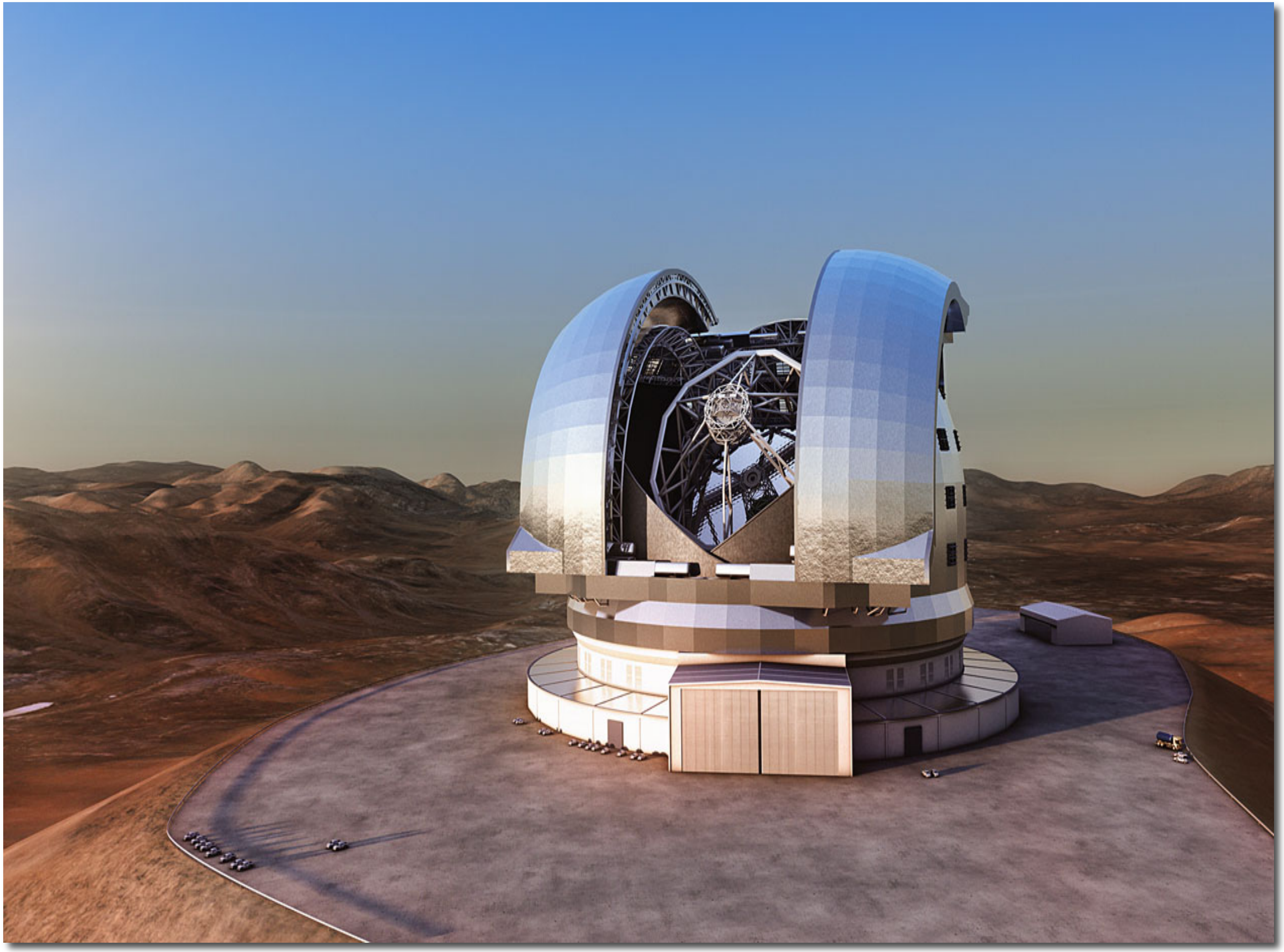
VLT:
AOF+HAWK-I

ERIS

4MOST@VISTA

Superb use of GTO!!

…. and even more → E-ELT



First Generation E-ELT Instruments

First Light

E-ELT--CAM (MICADO): R. Davies

E-ELT--IFS (HARMONI): N. Thatte

E-ELT–MIR: L, M, N: B. Brandl

MAORY (AO module): E. Diolaiti

NGS → y~22--23

4) E-ELT–HIRES (Optical – NIR) –> r~21

5) E-ELT–MOS: Fib/ + IFUs (Opt./NIR) →r~25

6) E-ELT – Not defined yet

… and furthermore .. space

EUCLID
JWST
WFIRST

+

PLATO

CONCLUSIONS

LSST is one of the most challenging & rewording ground-based optical experiment for the next 20 years

We have in our genetics the tools to compete & collaborate with the International community

A great opportunity to shape new ideas & Projects → Community Growth

Credits

Young researchers pushing & supporting for new adventures

Z. Ivezic M. Juric L. Walkowicz
for many slides