Massimo Capaccioli

University of Naples Federico II

INAF - National Institute of Astronomy

on behalf of E. Iodice, P. Schipani, and the broad VST team

VST

an overview

Excusatio non petita

I am not a
radioastronomer
&
I know nothing about
radioastronomy

Rationale of this talk

I will talk of a successful technological project based on a general scientific idea:

1. to describe how we succeeded;

2. to present one example of scientific results (drives);
3. to tell you about possible intersections with other projects, including radio.

1997: OAC proposal to ESO

for a wide-field optical & ~~IR~~ facility

then VISTA came …

European Southern Observatory - Cerro Paranal, Chile

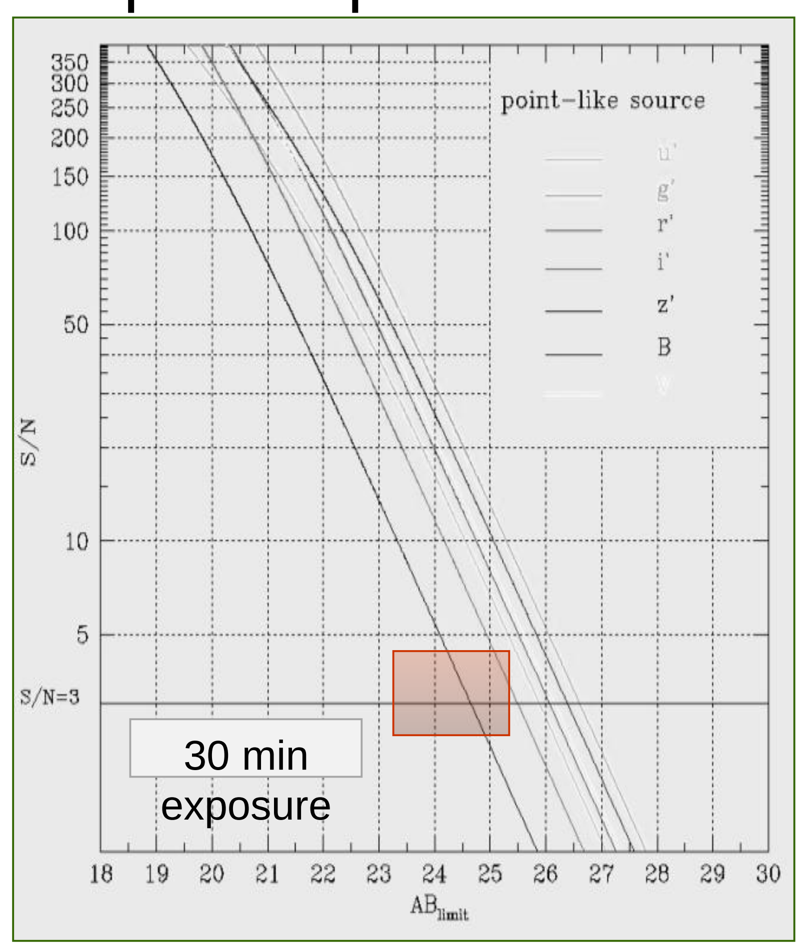
INAF-Capodimonte Astromonical Observarory
Naples

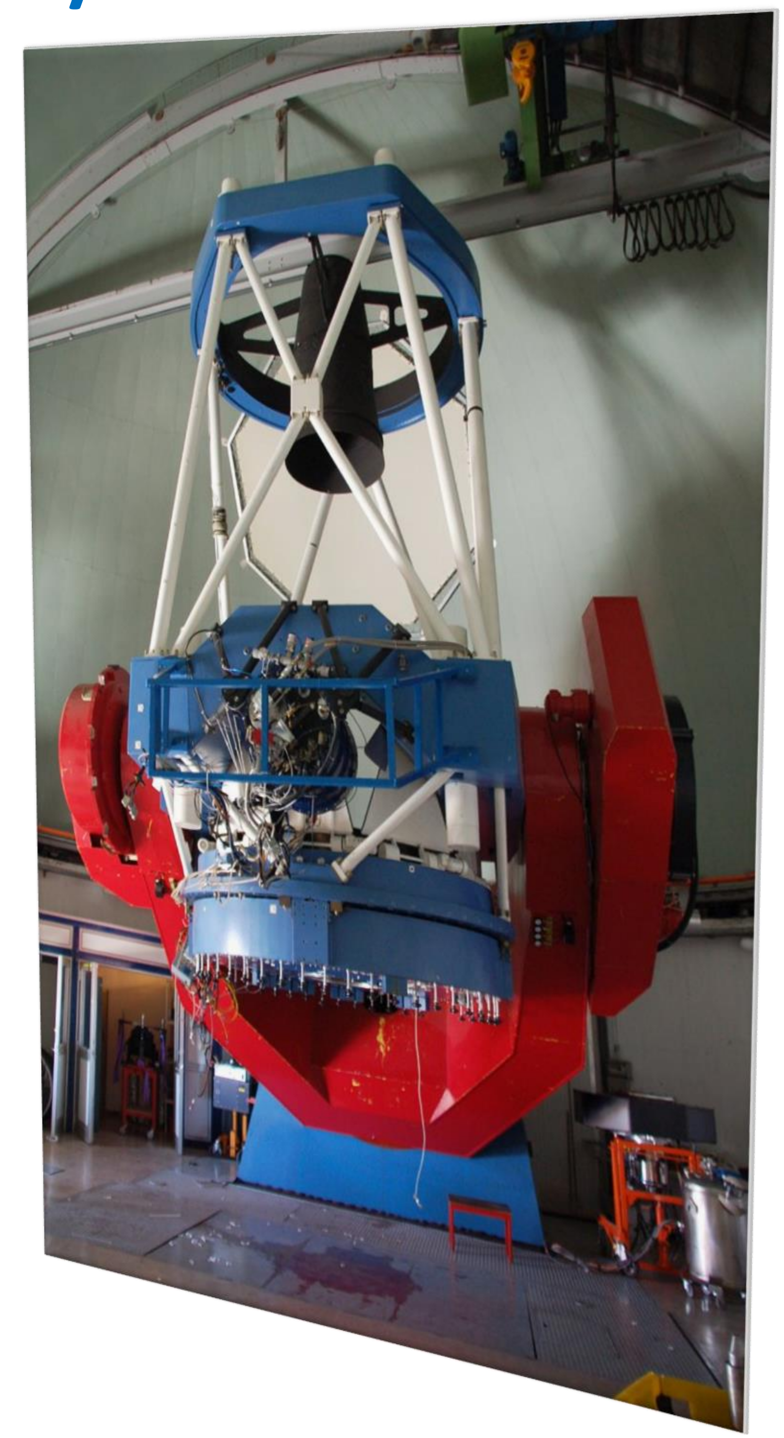
1997: OAC proposal to ESO

for a wide-field optical facility
performing 10 times better than WFI @ ESO/MPI2.2m

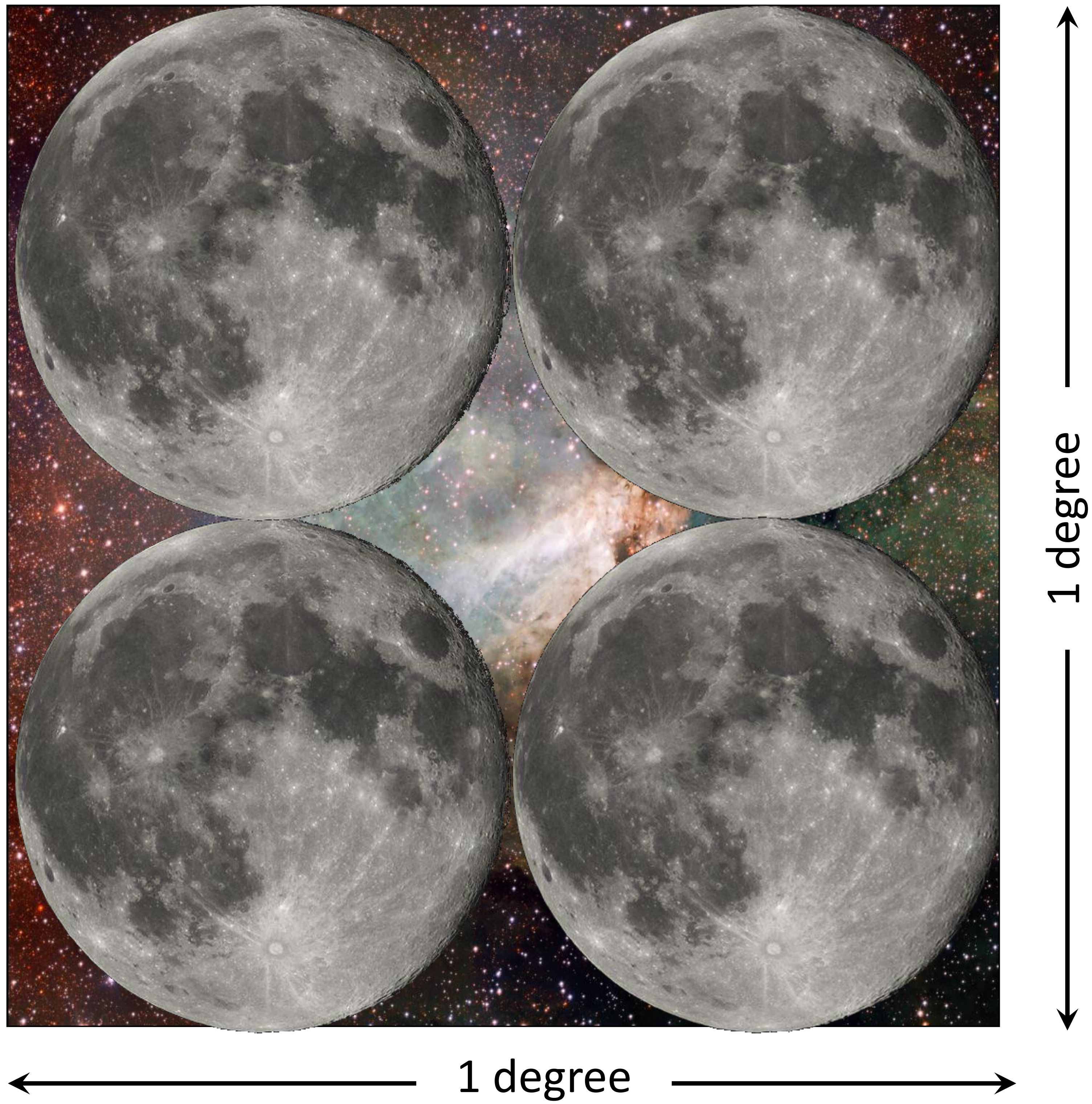
- class 2.5 m
- NTT type mount (new technology)
- active optics
- 1.46 deg corrected FoV (∅)
- 80% EE in 0.4″
- scale ~ 0.2″
- spectral range from *U* to *I*

Expected performances





VST: a wide-field telescope for surveys in the best site for optical astronomy



Where is Cerro Paranal?

Chajnantor plateau

Cerro Armazones

Cerro Paranal

Las Campanas

Cerro Tololo

Cerro La Silla

Cerro Pachon

Why sky surveys?

The sky is:

- **wide** (40,000 square degrees)
- **deep** (50 billions light-years)
- **variable** with time (evolution)
- **full** of objects & phenomena
- **full** of transients (astrometric & photometric)

Objects/phenomena are:

- **color sensitive** (fourth coordinate)

One has to take WF images with a **<u>fast enough telescope</u>**
in order to cope with the need of mapping and monitoring the sky

1998: ESO accepted OAC proposal

and the VST project started with the following commitments and returns

OAC: **procurement of the telescope at Paranal**
in exchange of some GTO @ VST & VLT

ESO: **civil work and operation of the facility for at least 10 years;**

OmegaCam: **procurement of the 16k×16k camera**
in exchange of some GTO @ VST.

Let a glass mirror free fall …

VST M1 delivery @ Lytkarino Glass Factory on September 7, 2001

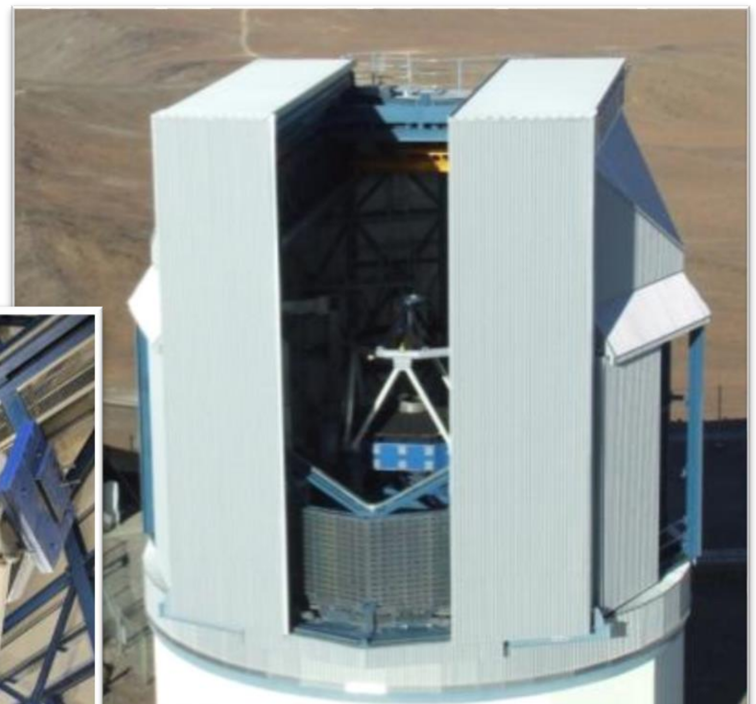
VST completion significantly delayed

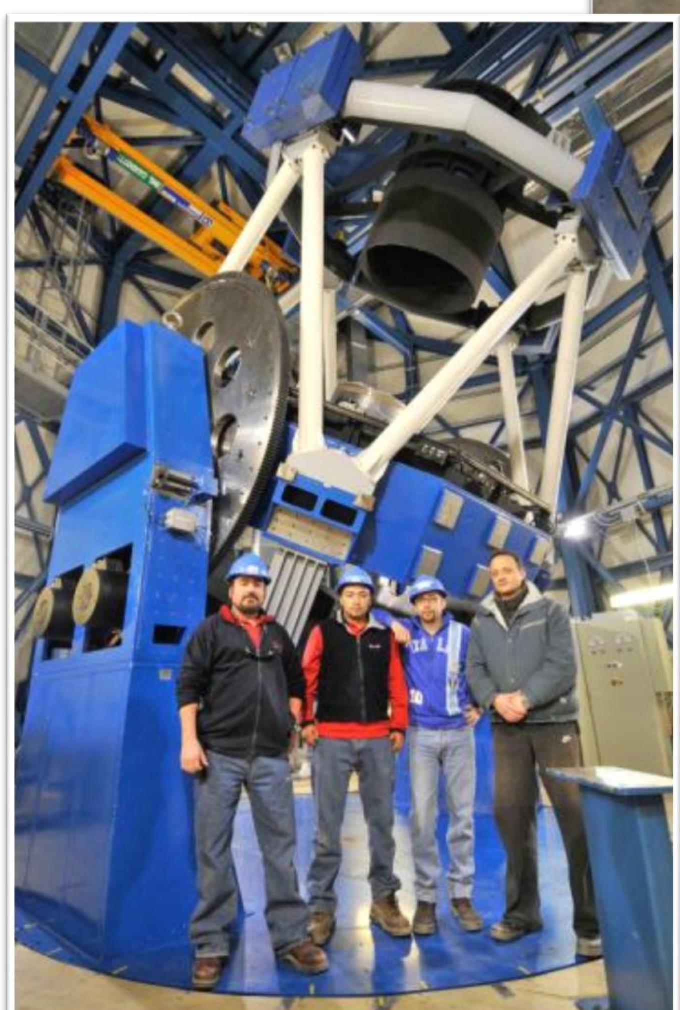
June 2002: the first BIG problems along the VST route

ЛЗОС

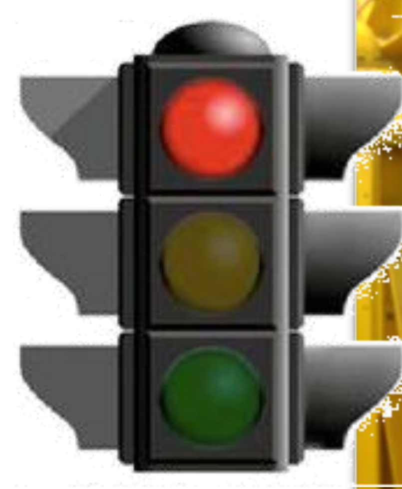
VST completion significantly delayed

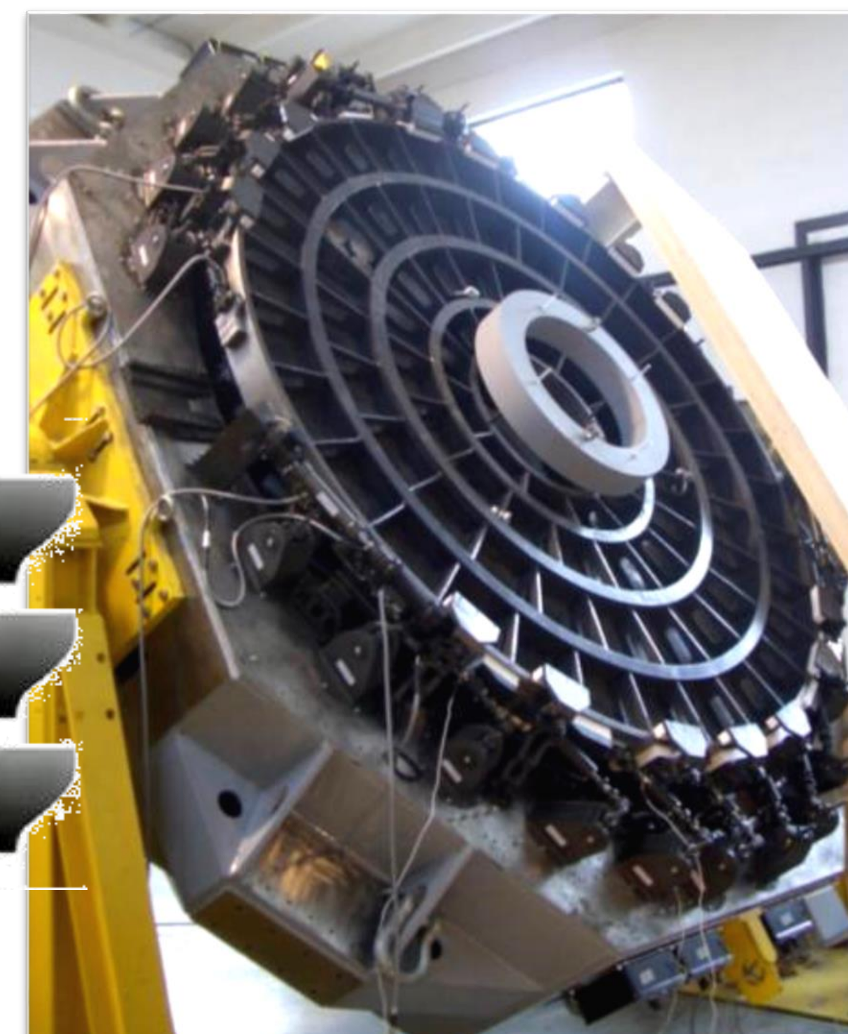
March 2007: failed CDR – unreliable active optics subsystems





While the telescope structure was already mounted and working at Paranal, the M1 and M2 subsystems and the auxiliary units, still in Italy, did not pass the Critical Design Review and had to be substantially refurbished.



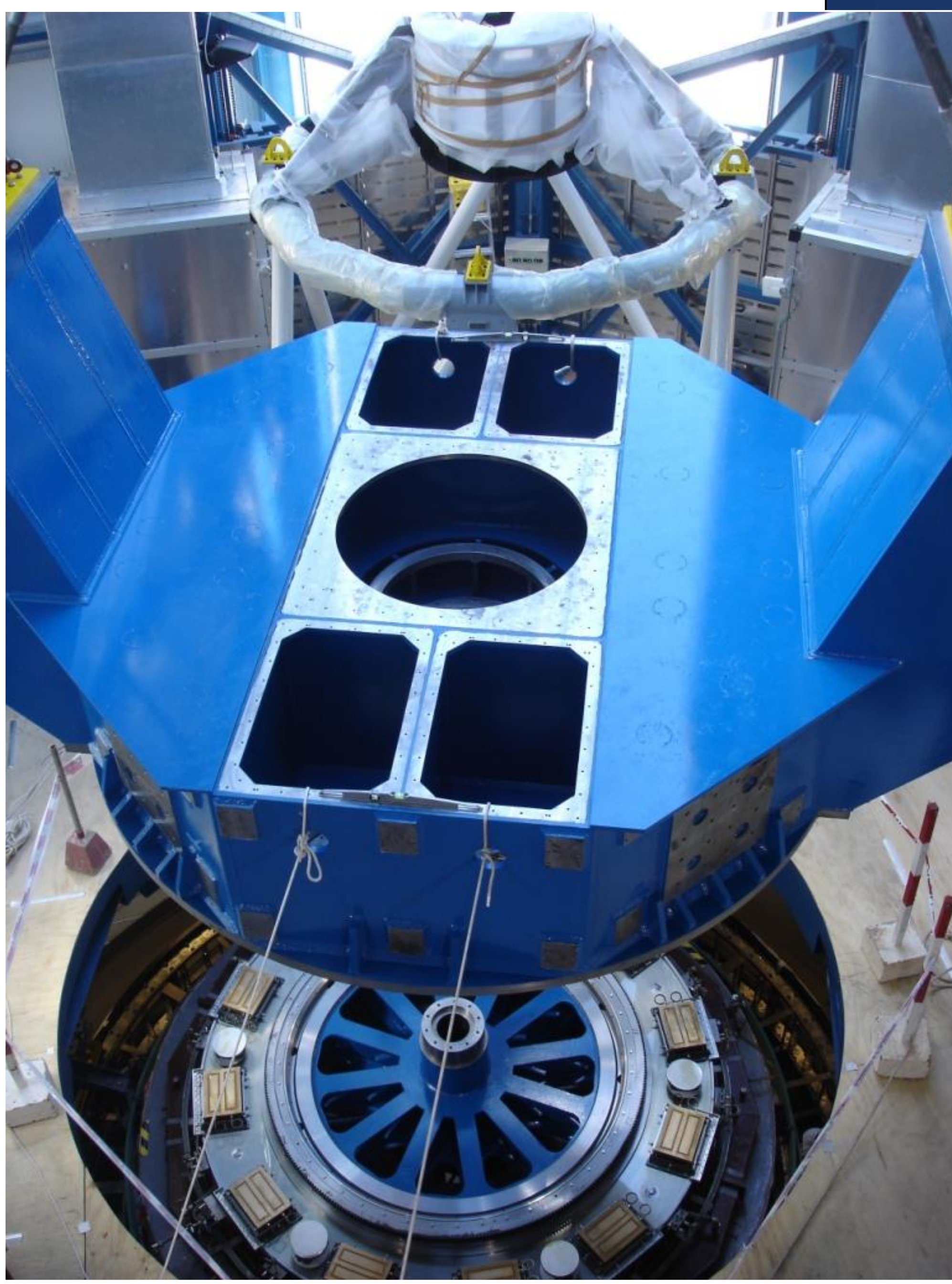


The refurbished M1 cell
@ Tomelleri premises

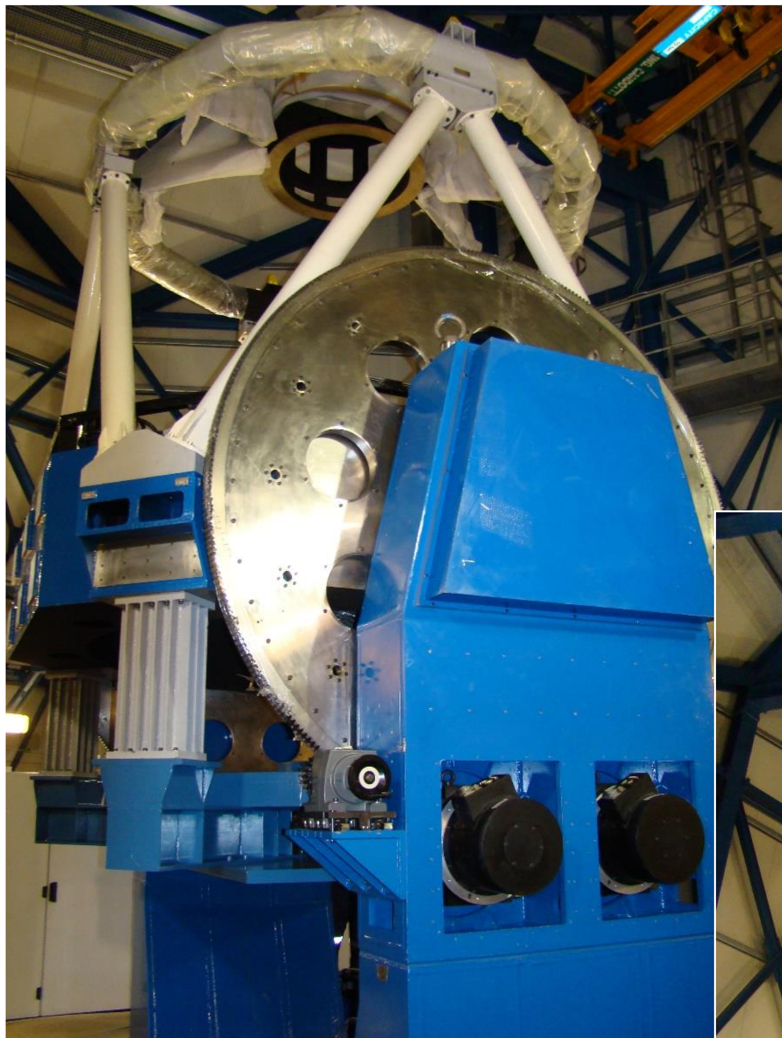
August 2007:
VST components on their way to Paranal

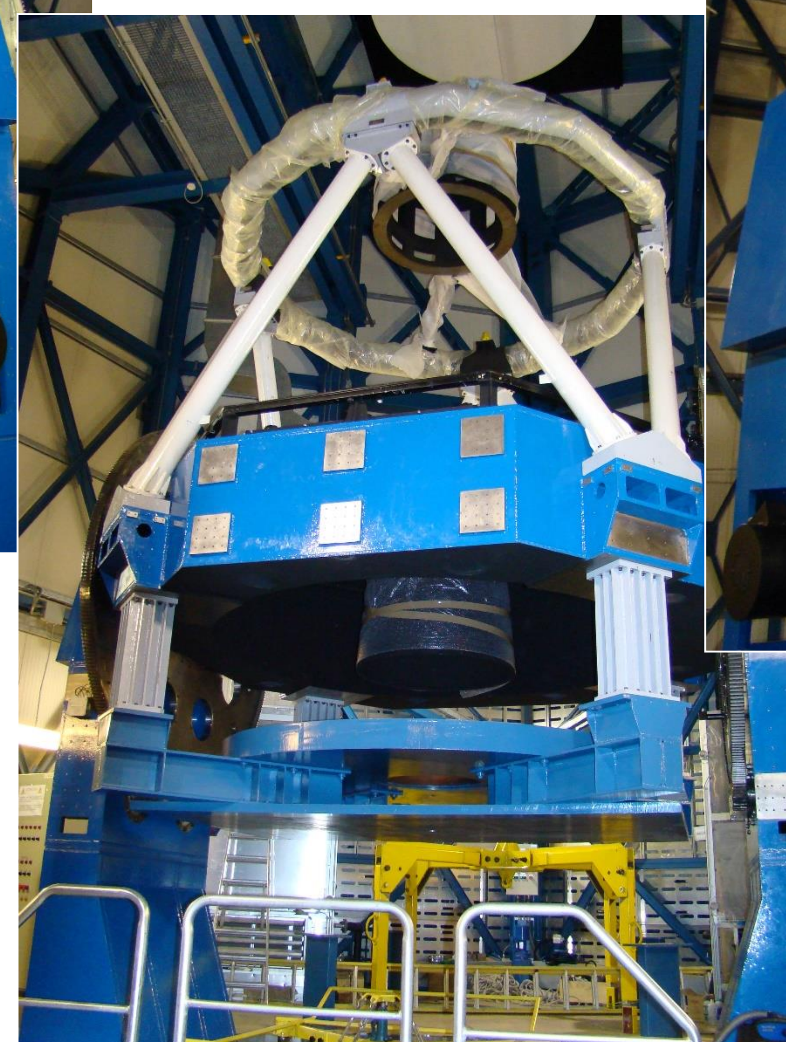
October 2007:

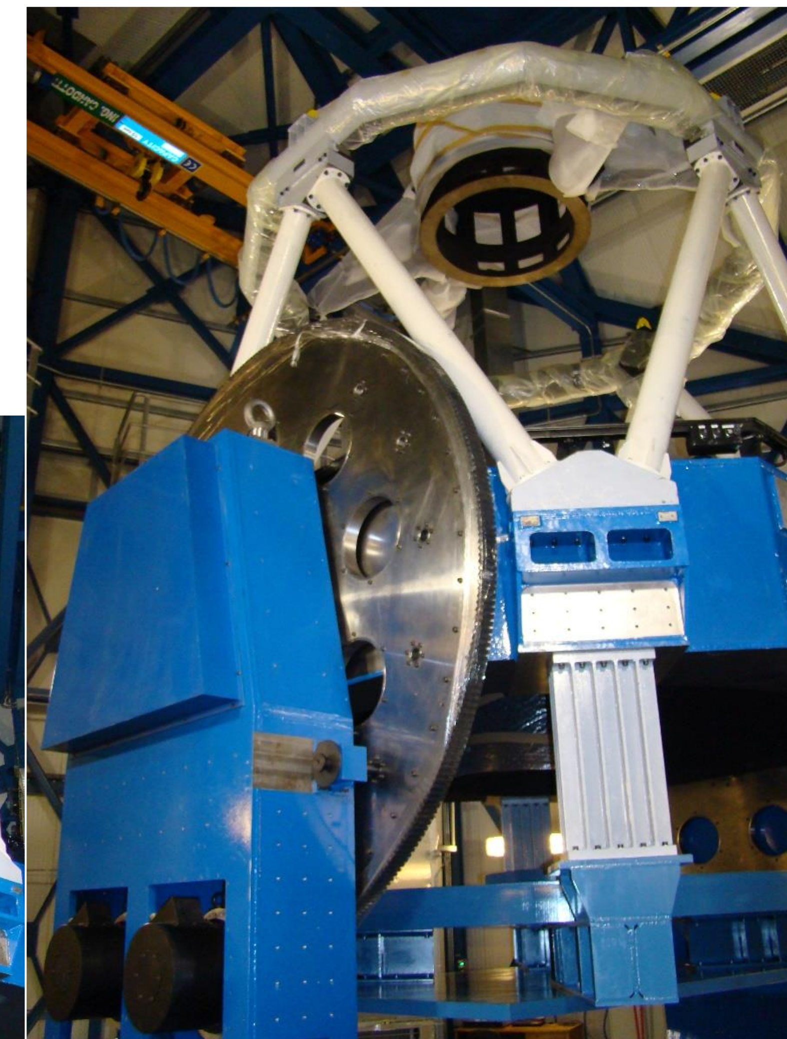
re-assembly of the telescope in Chile



December 2007:
telescope re-assembly successfully completed







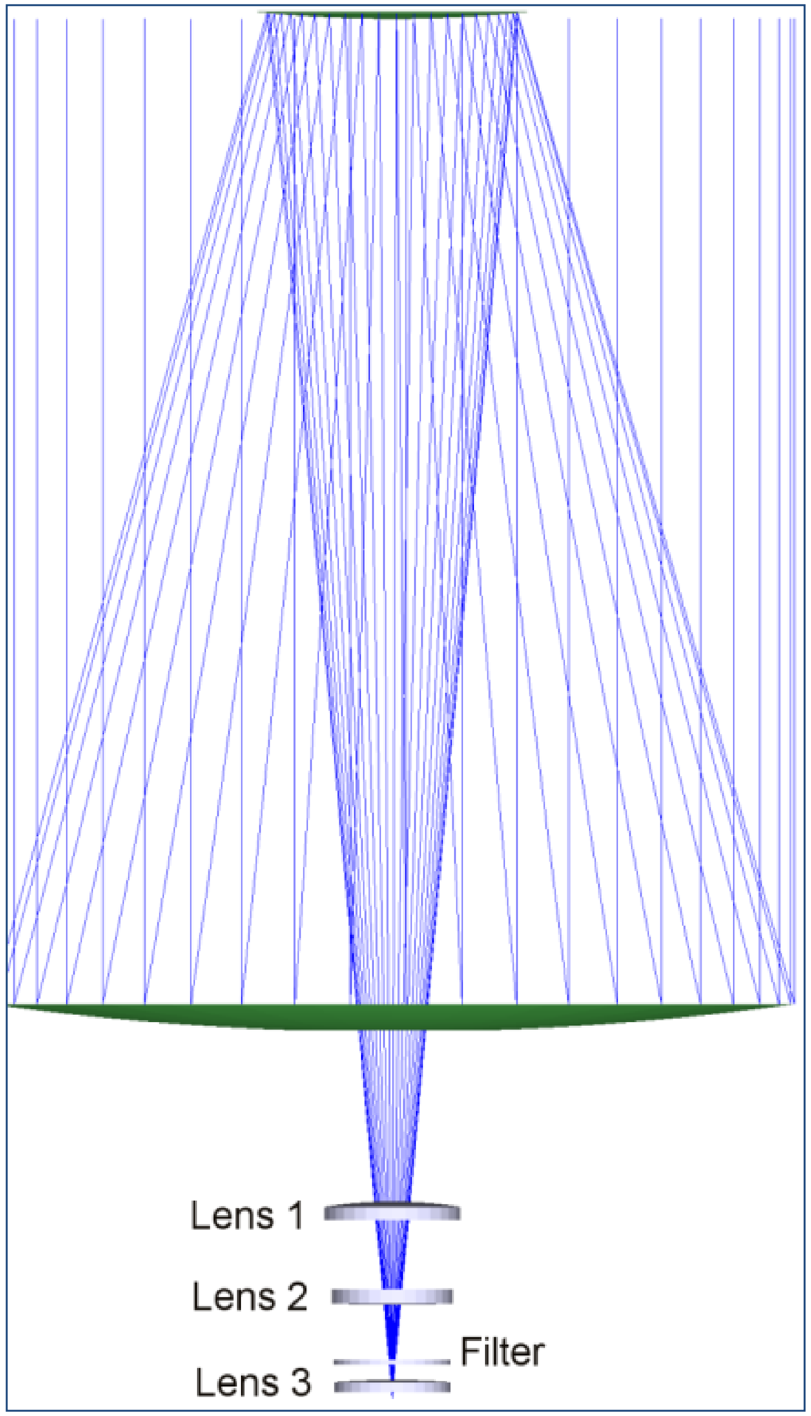
VST in its dome
at Cerro Paranal

April 2009:
M1 cell completed in Verona, Italy

VST as it is, in a nutshell

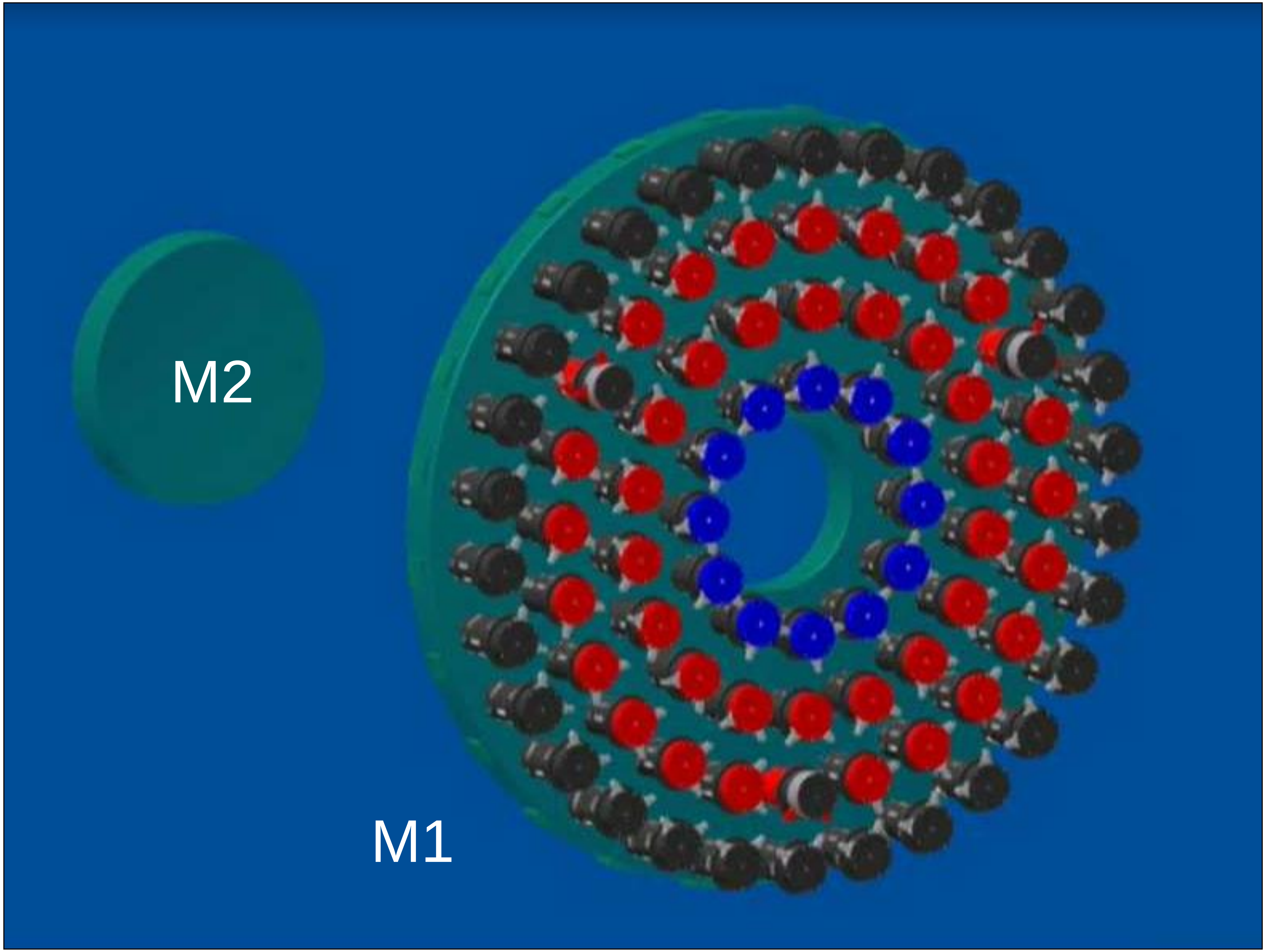
Optical System

- Primary mirror: 2.6 m
- Secondary mirror: 0.9 m
- F# 5.5
- Field corrector with 3 lenses
  (2 in the telescope + 1 in the camera)
- Field of view: 1°×1°
- Shack-Hartmann wavefront sensor
- Active M1 shape control
  (81 active axial supports + 3 axial fixed points)
- Active M2 positioning in 5 dof (hexapod)
- Autoguiding with probe in R, θ coordinates

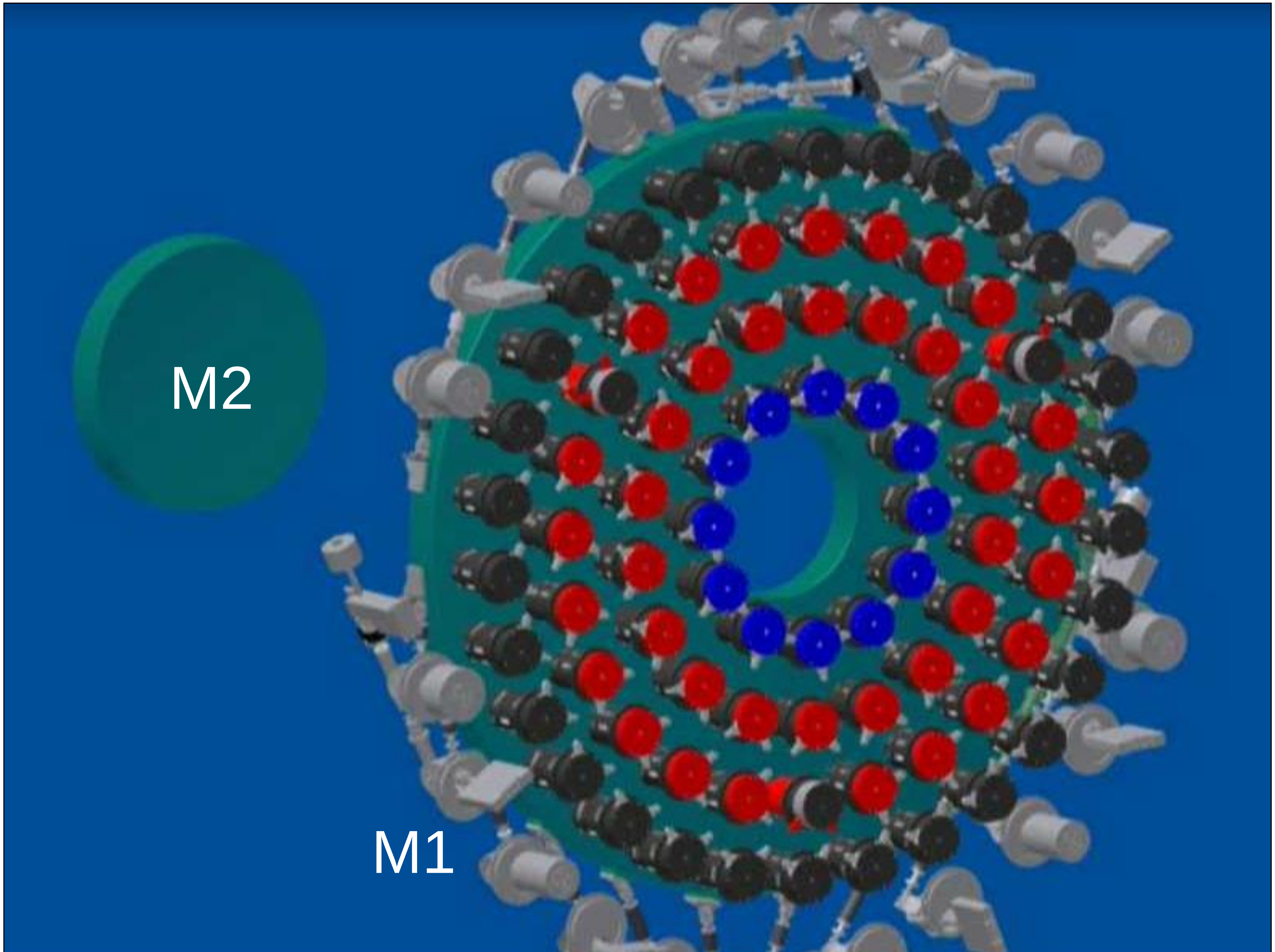


VST active optics:

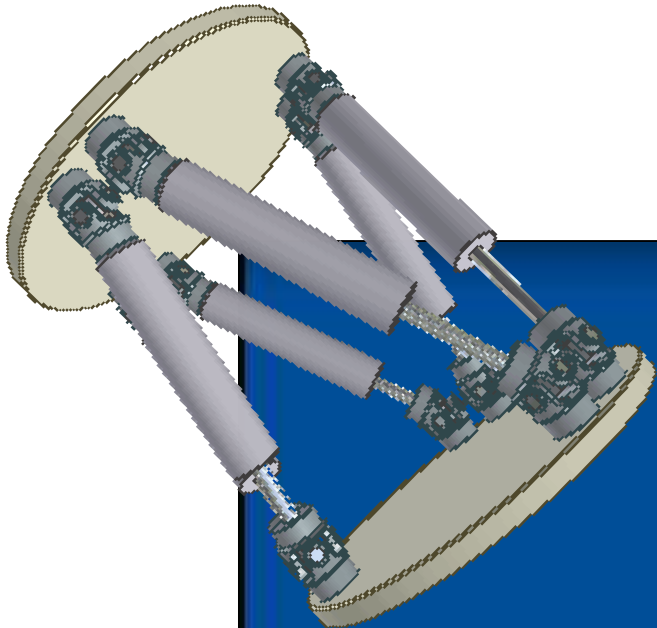
M1 axial actuators & fixed points

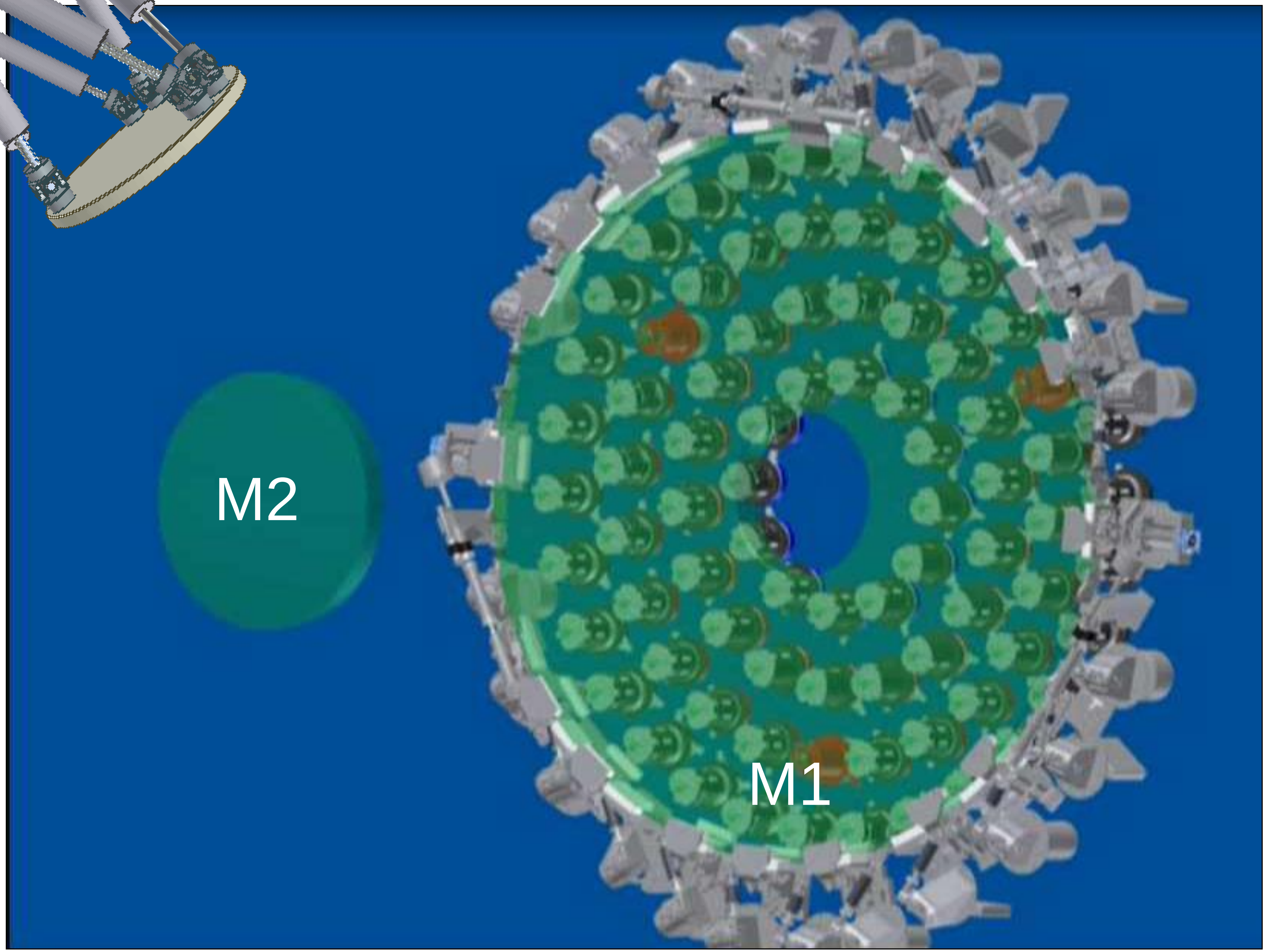


VST active optics:
M1 axial & radial actuators

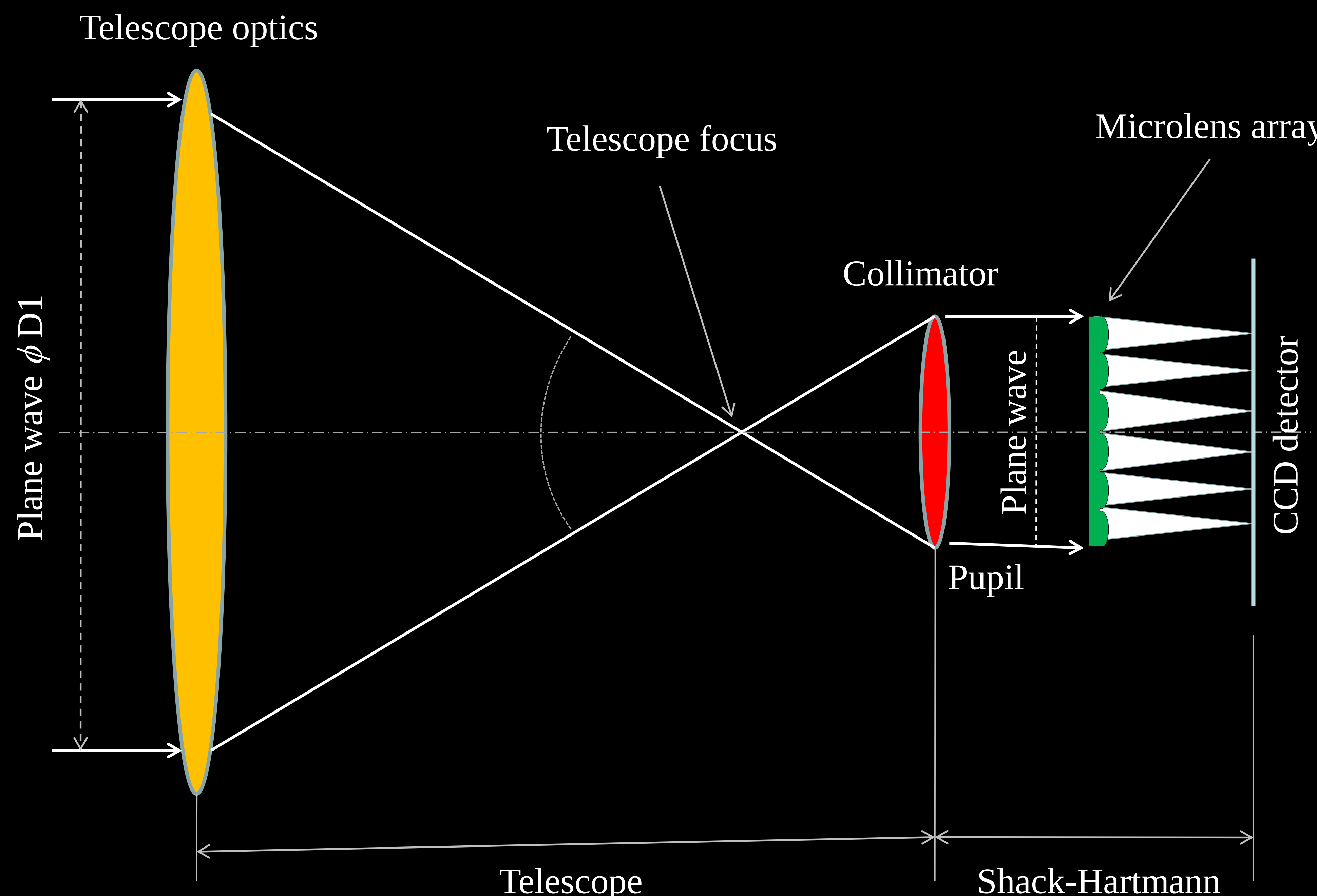


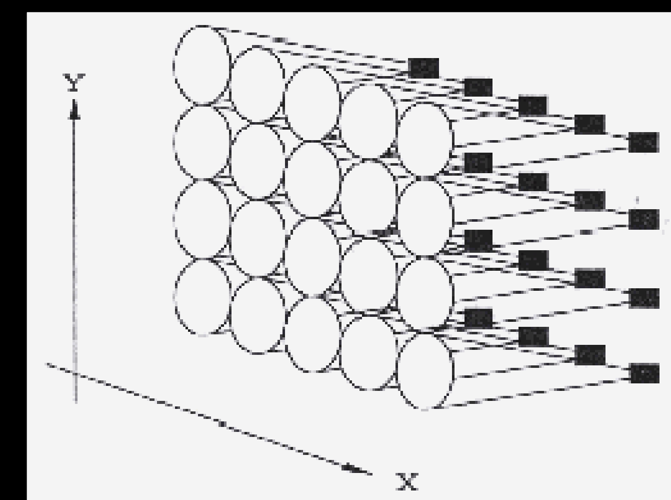
VST active optics:
hexapod at M2

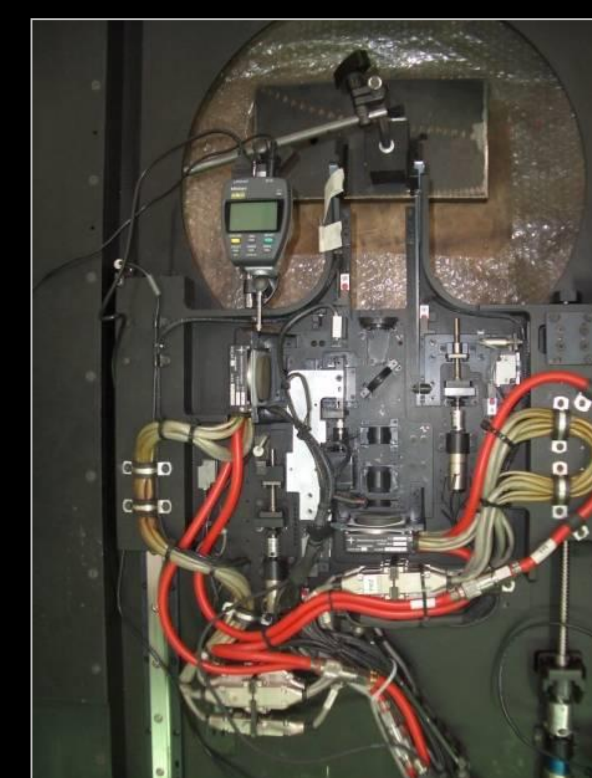




Active M1: Shack-Hartmann system

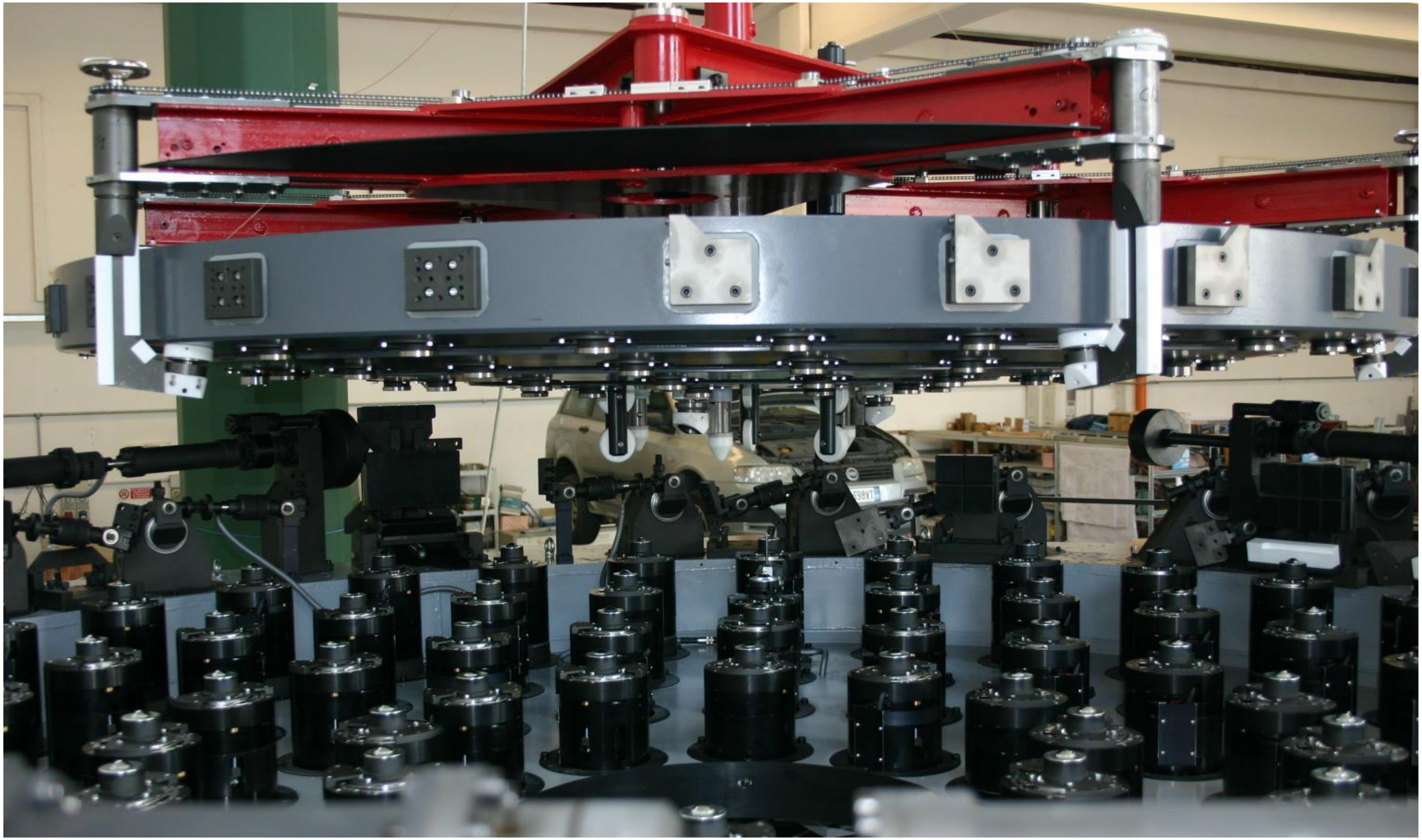






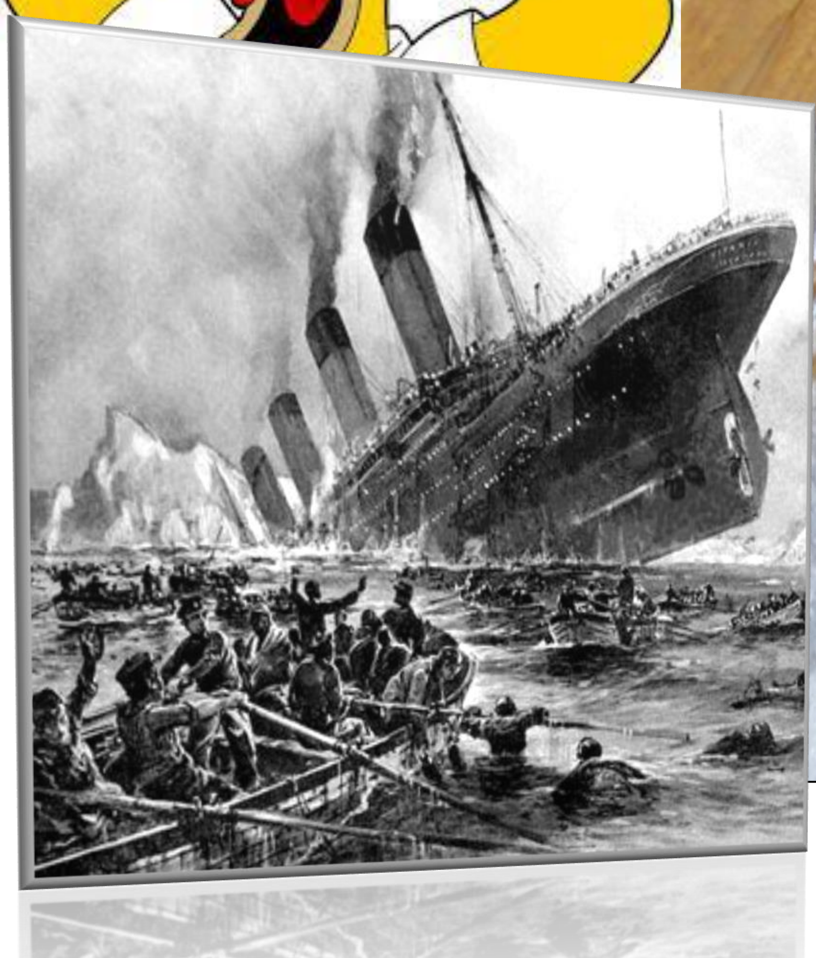
VST: the active M1 cell as it must be

April 2009:
M1 cell completed in Verona, Italy



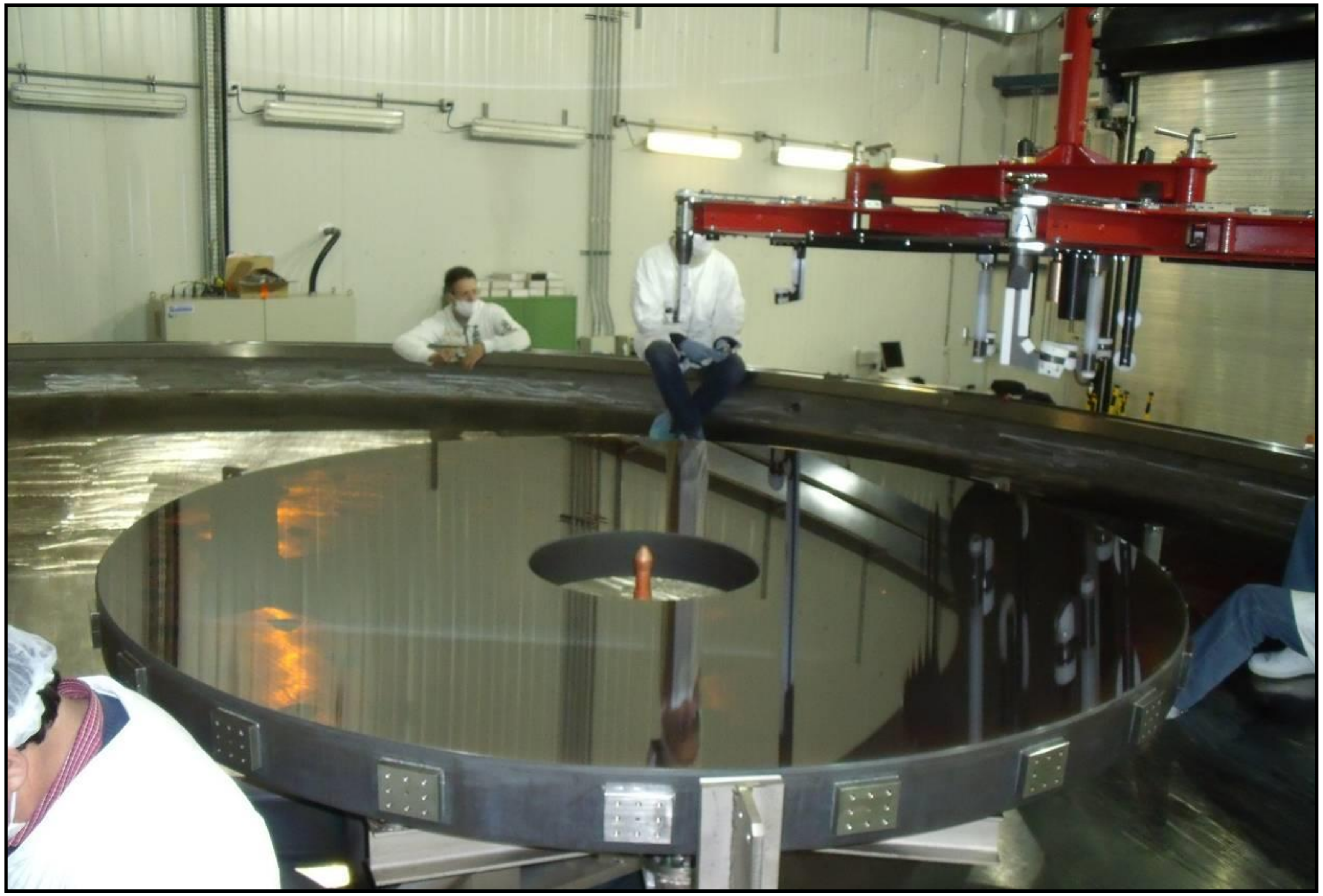
VST completion significantly delayed

July 2009: the second **BIG** disaster – damage of M1 cell



One year later:
arrival of the new cell at Paranal

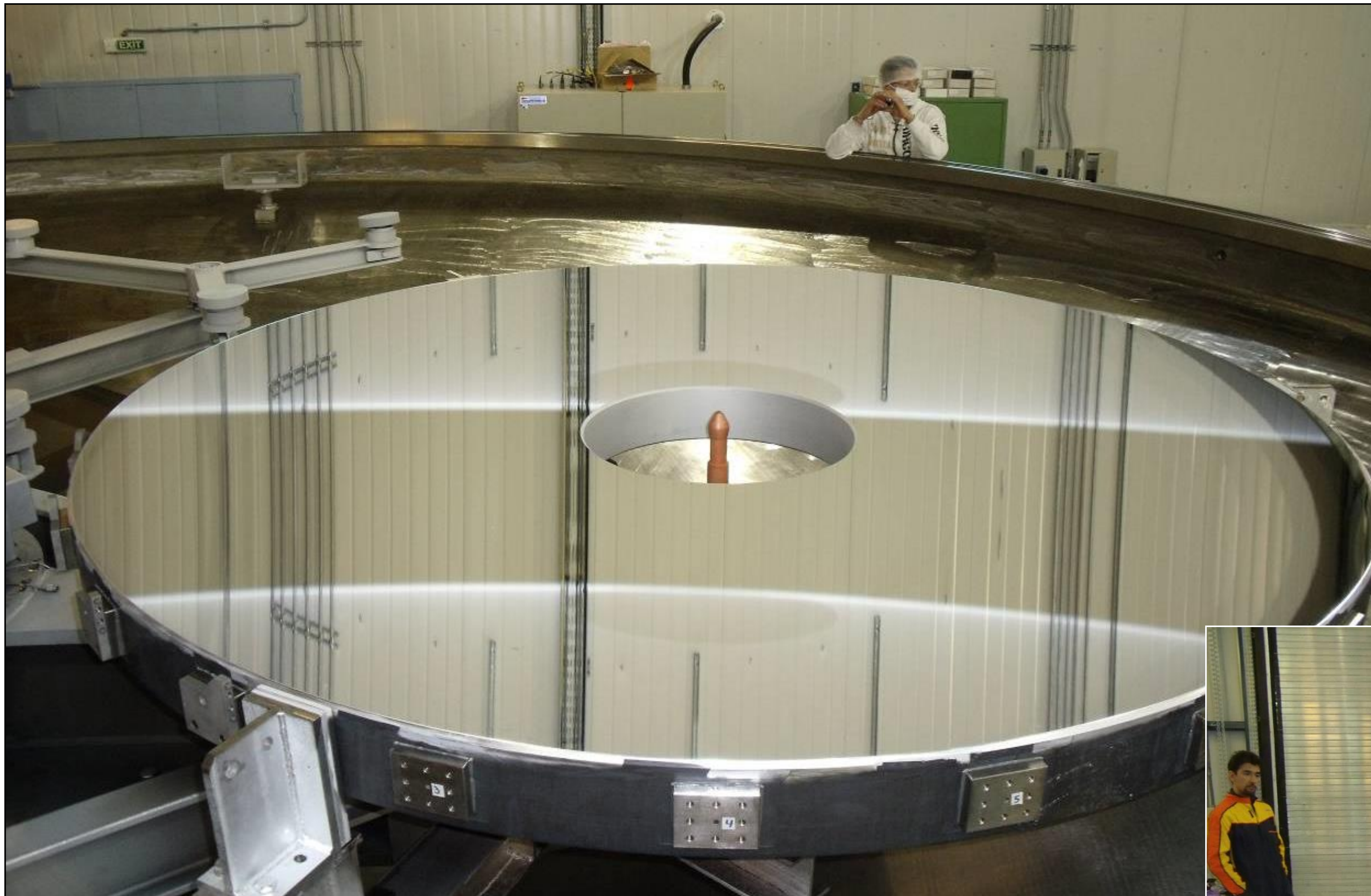
In the mean time:
preparation of the NEW optics at Paranal



M1 in the washing chamber to be prepared

In the mean time:

preparation of the NEW optics at Paranal



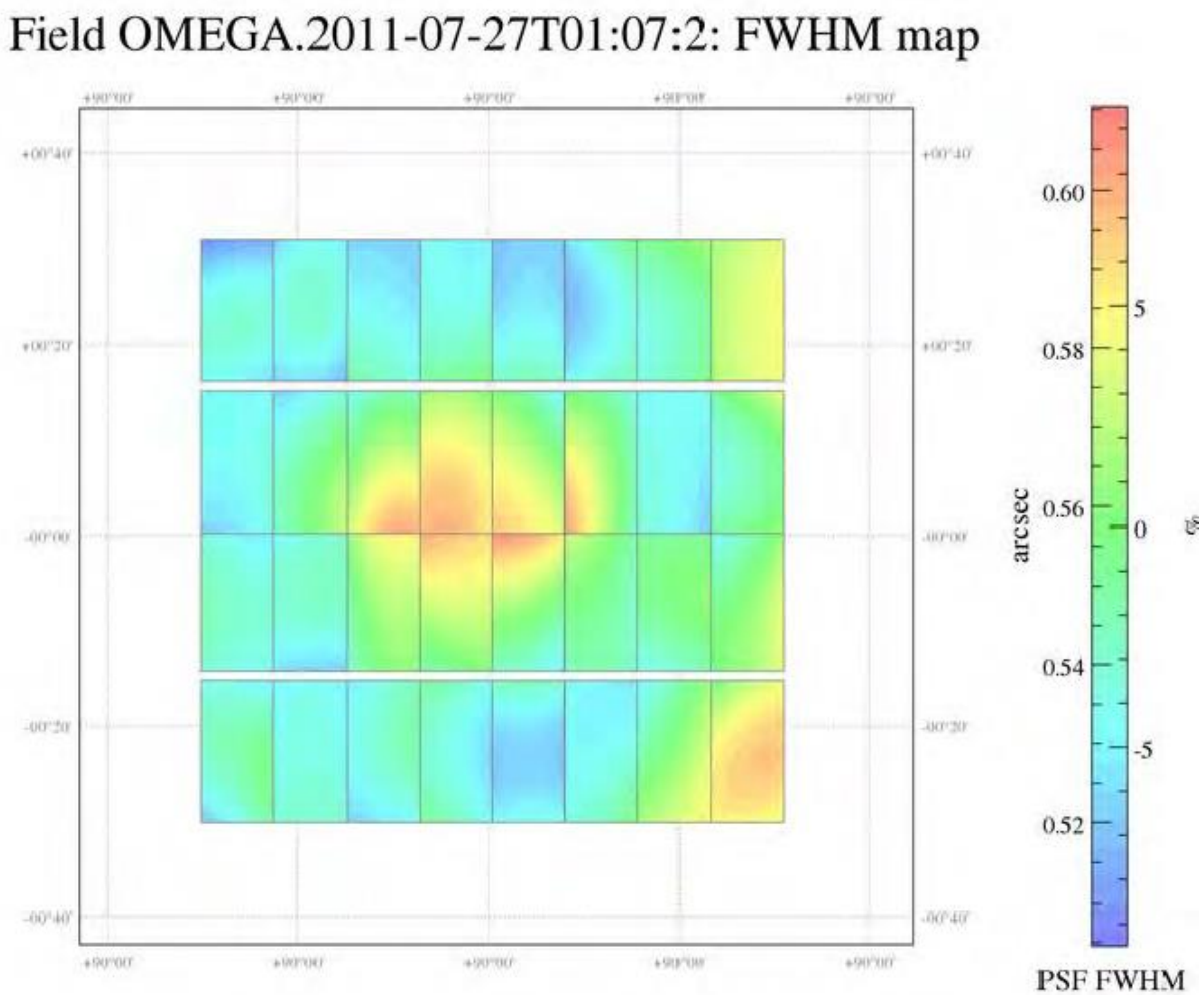
M1 aluminized and back in its
LZOS box
June 25, 2010

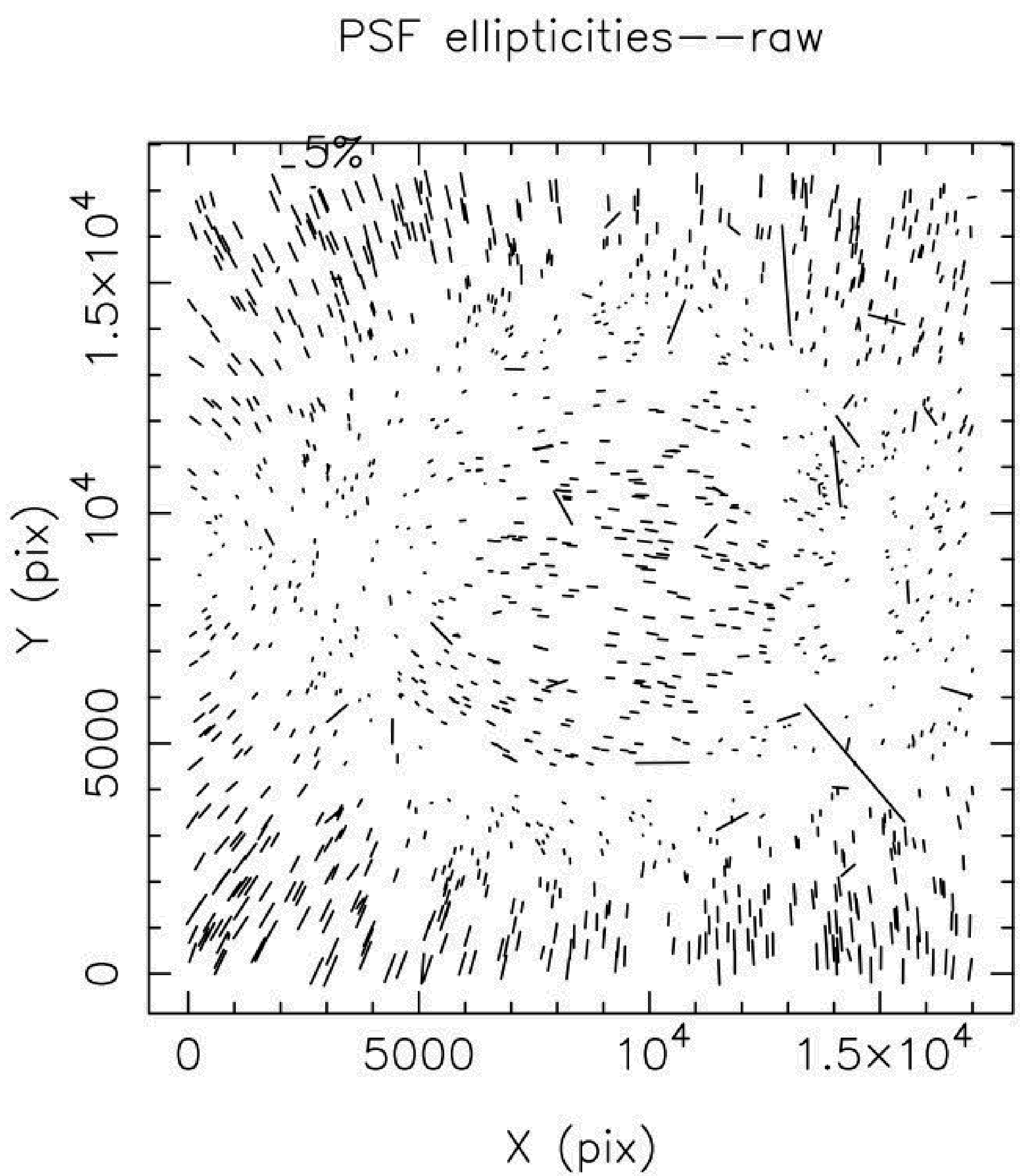
June 2010:

the mounting of the **new** M1 cell

October 15, 2011: VST facility is operational

VST Image Quality performance

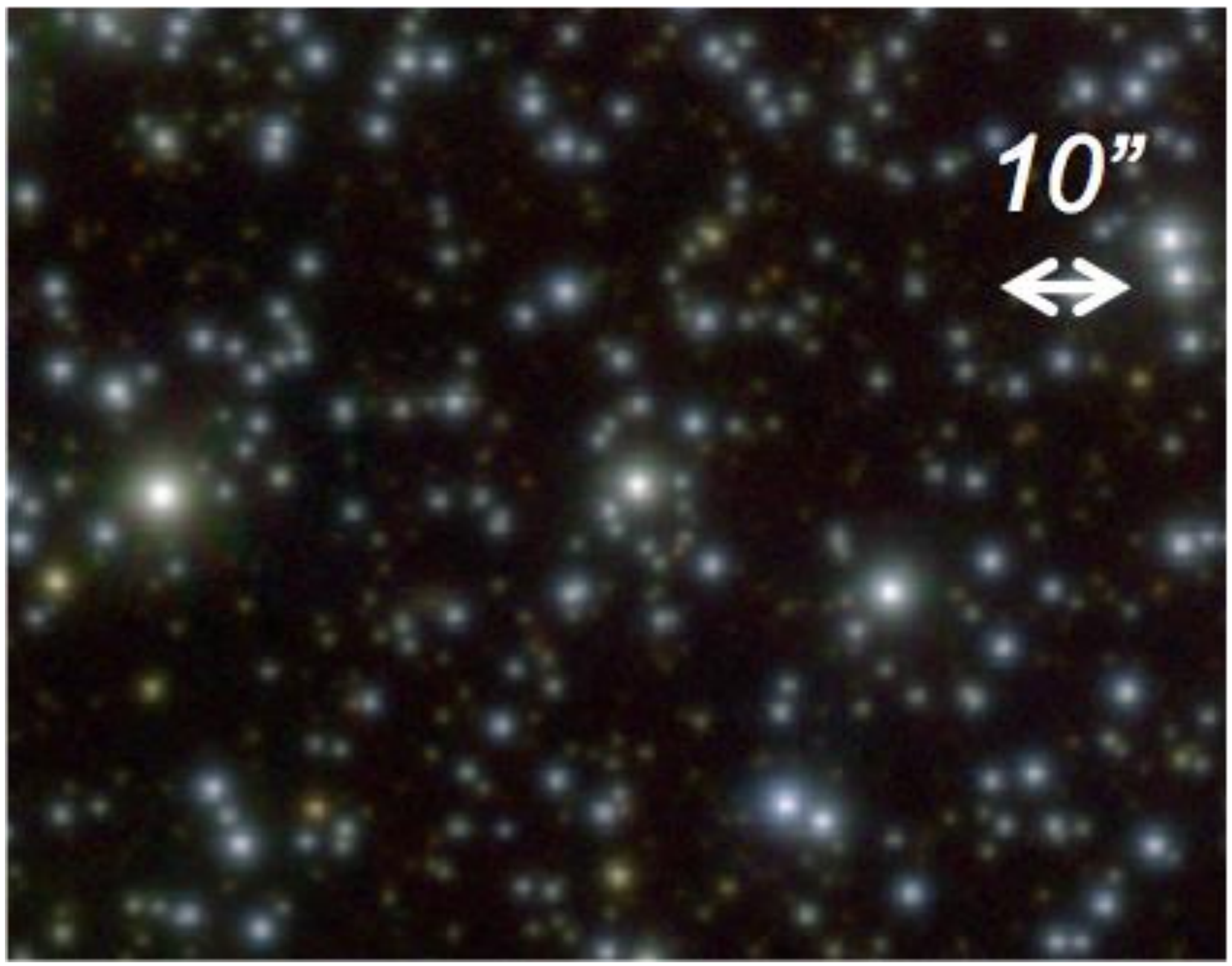


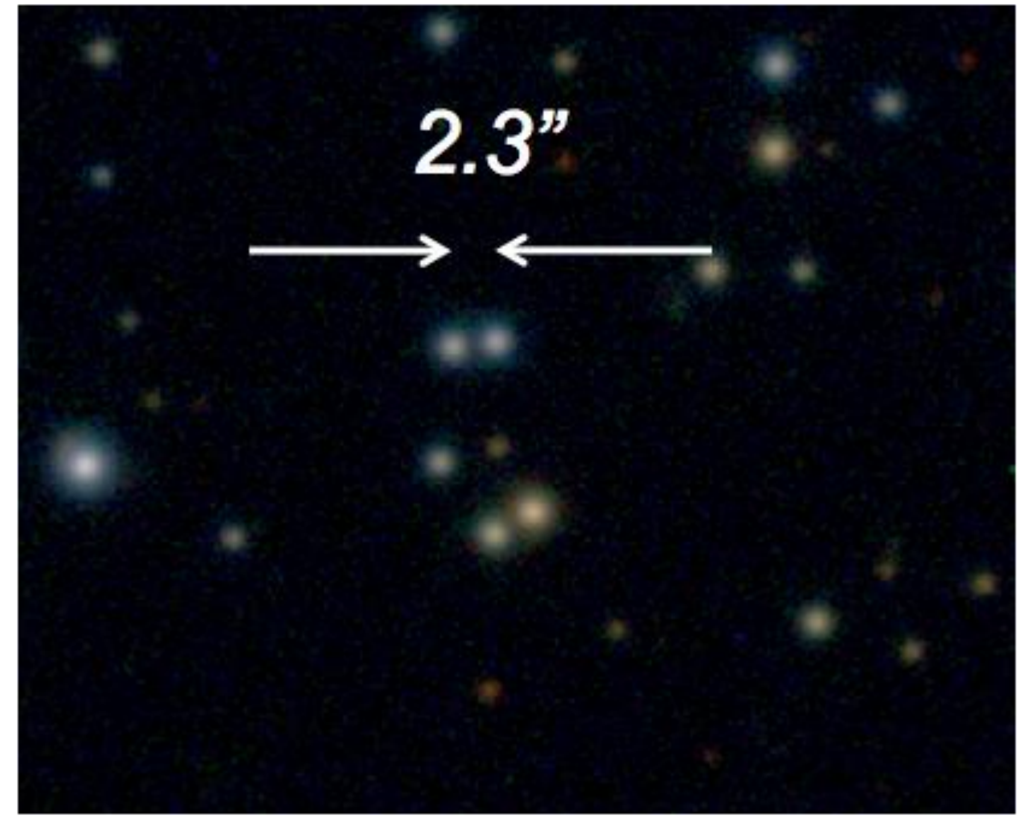


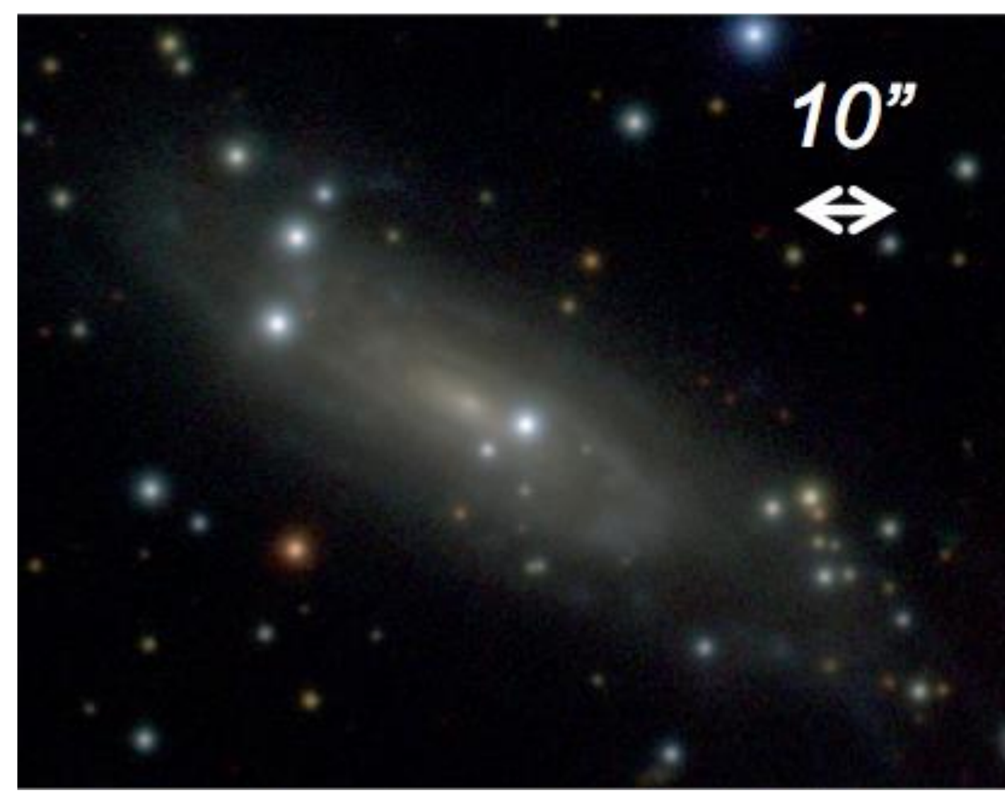
PSF FWHM = 0.5 arcsec, constant within <10% over the whole field
ellipticity ~ 10%

VST Image Quality performance: resolution

0.8” seeing image of OmegaCen
ESO press release (VST Tube)







VST camera OmegaCam

P.I. Konrad Kuijken

OmegaCAM Consortium: the Netherlands, Germany, Italy, ESO

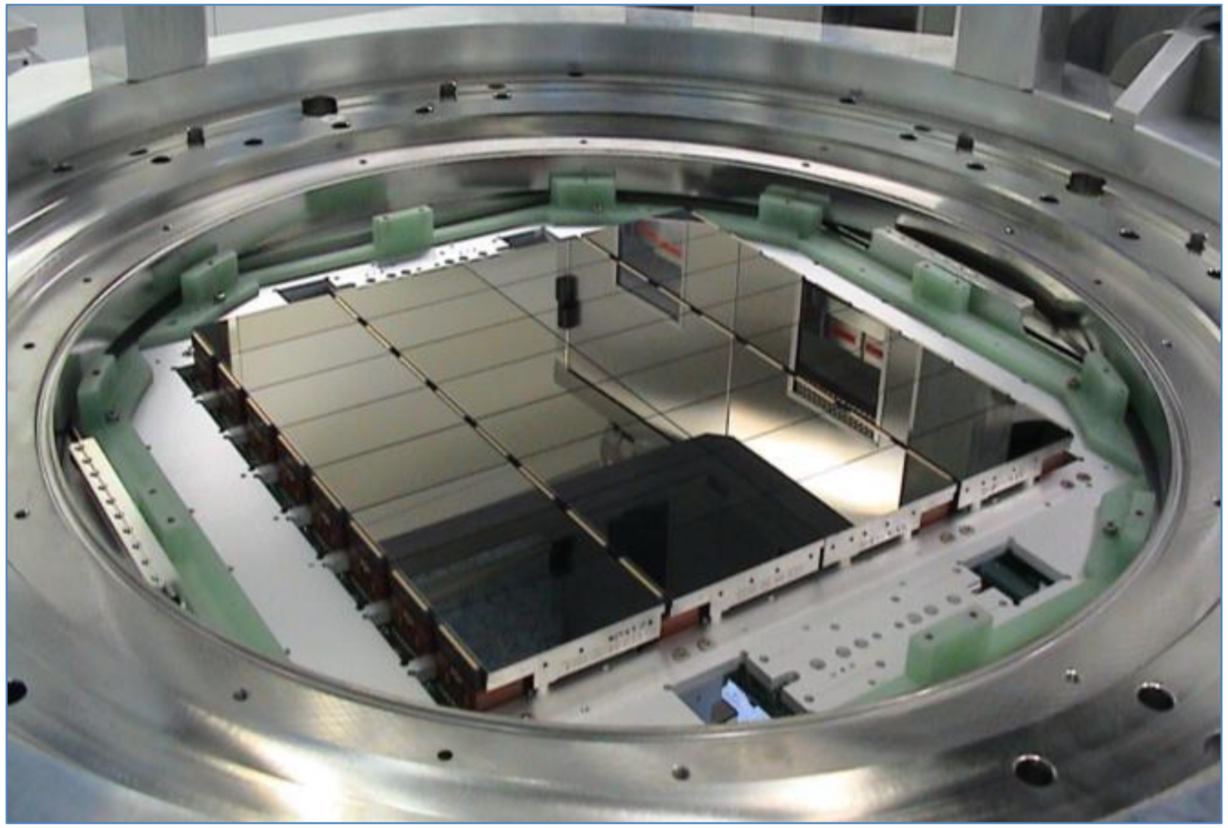
Format: 268 Mpixel mapping a $1^\circ \times 1^\circ$ field

Scale 0.21 arcsec/pixel

32 scientific CCDs + 4 outer CCDs

Autoguiding

Image analysis curvature sensor



Telescopes within INAF

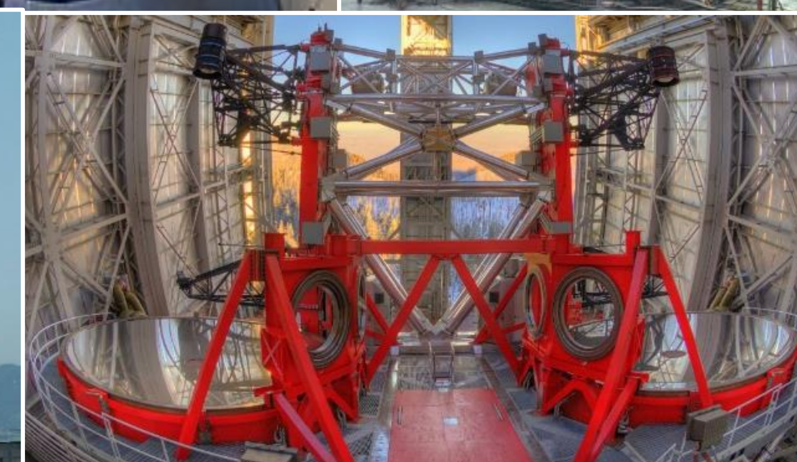
Optical-NIR Medium – Large

- Telescopio Nazionale Galileo (3.5-m)
- ***VST (2.6-m) operated by ESO***
- 25% of LBT (2x8.4-m)


Radio

- SRT (64-m)
- Medicina (32-m)
- Noto (32-m)





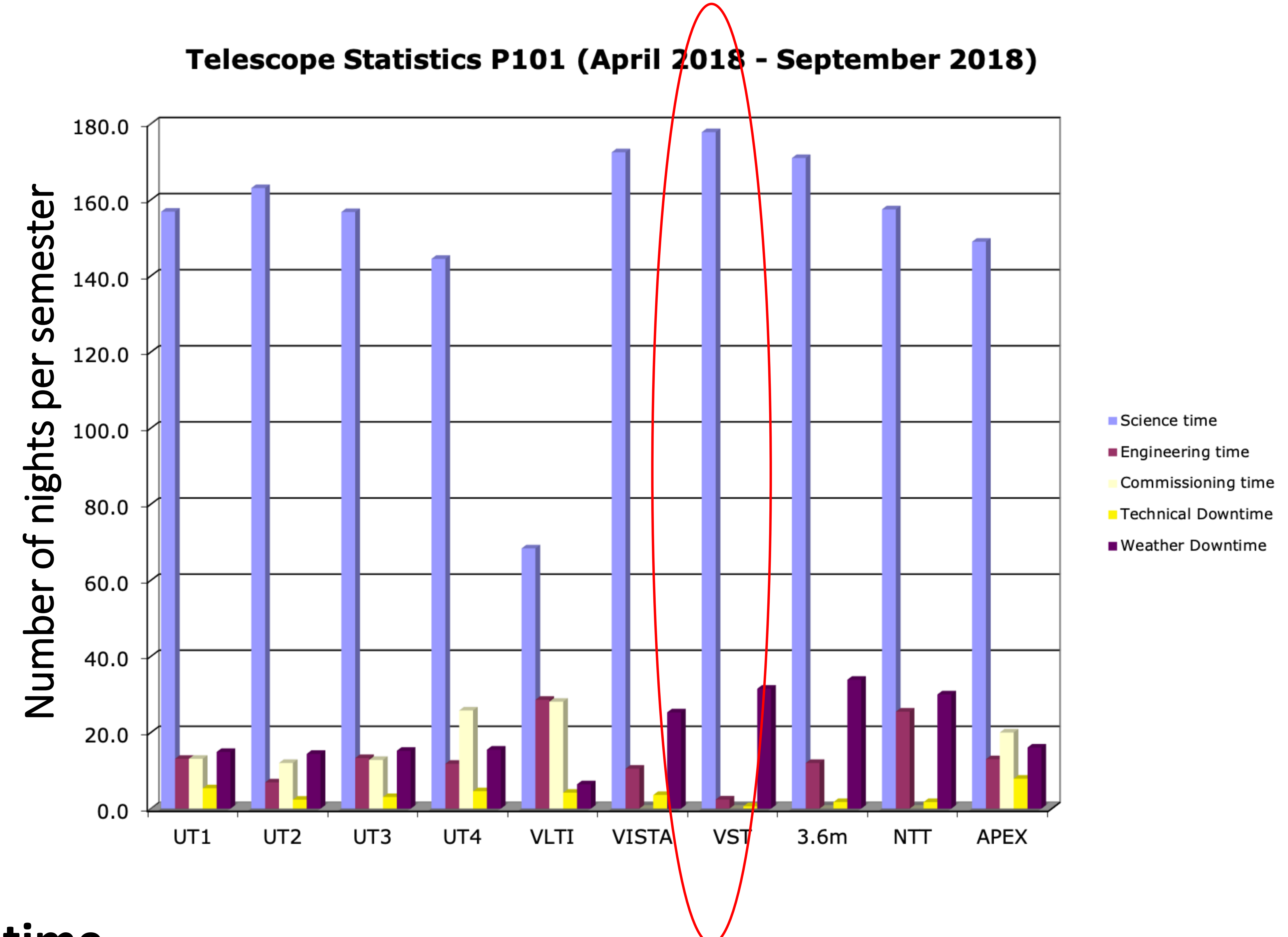
Cherenkov

- Astri (4-m)


***only telescopes *owned* by INAF**

Small telescopes not included

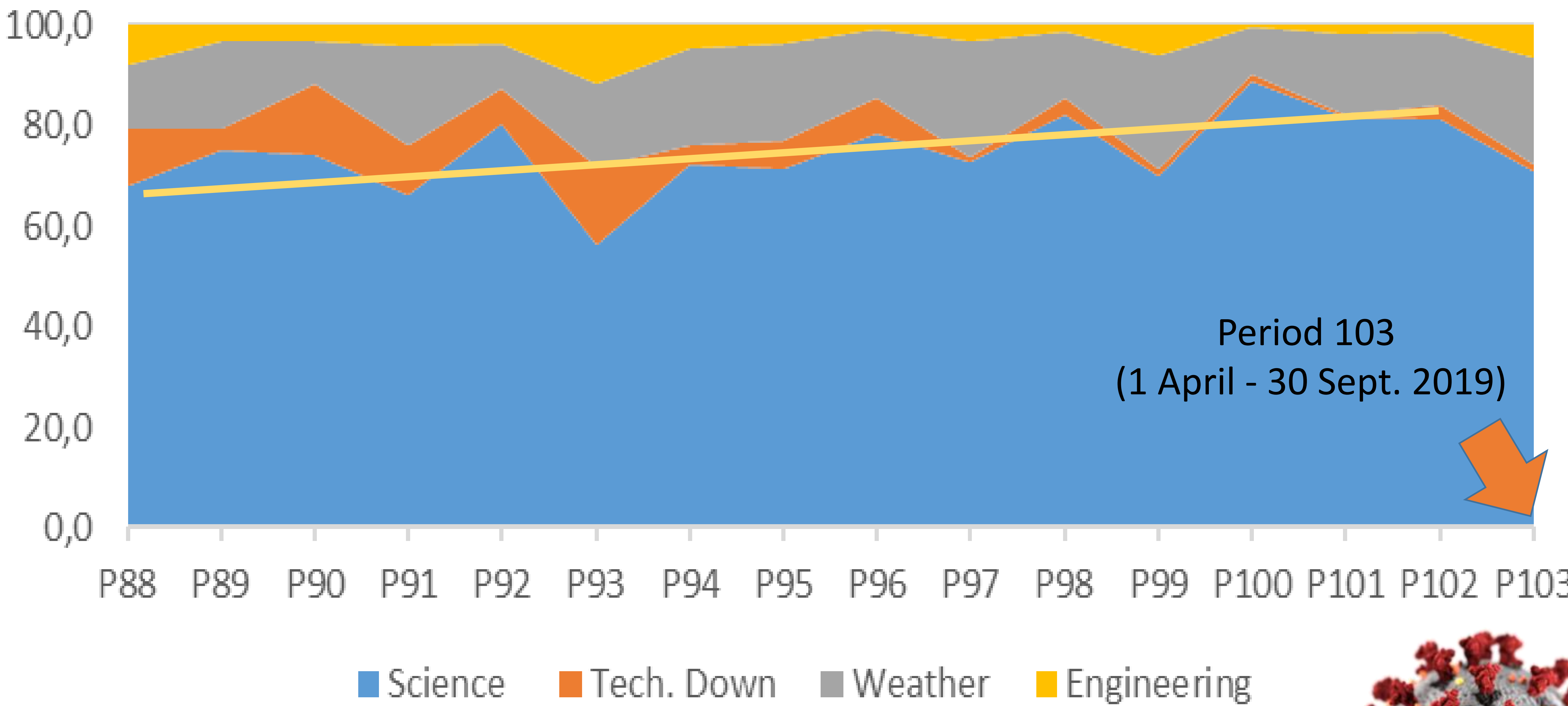
Reliability for ESO telescopes



Small downtime

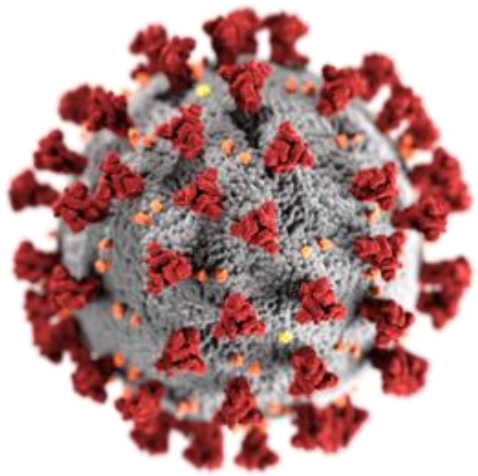
Especially good as VST features a single instrument only

VST statistics



Reliable!

In the last few years it has been often the ESO telescope with the longest time available for science



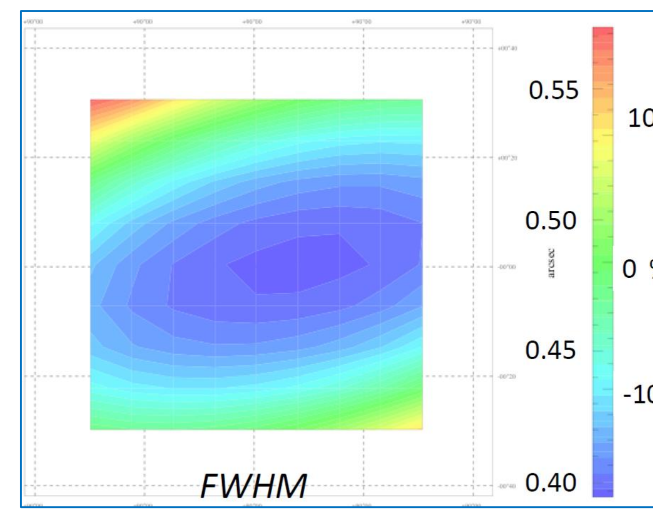
Only COVID could stop it.

VST image quality

2 Tom Shanks

Survey	Type	Epoch	Bands	Lim. Mag.	deg^2	N/S	Seeing (arcsec)
DENIS	NIR	1997-03	iJK	$K \approx 12$	20000	South	3
SDSS	Visible	2000-05	*ugriz*	$r \approx 22.7$	14500	North	1.2
CFHT RCS2	Visible	2002-09	*grz*	$r \approx 24.8$	830	N+S	0.9
CFHTLS Wide	Visible	2003-12	*ugriz*	$r \approx 25$	157	North	0.9
2MASS	NIR	1997-01	*JHK*	$K \approx 14.3$	All sky	N+S	1.5
UKIDSS	NIR	2005-12	*YJHK*	$K \approx 18.4$	7500	North	0.9
WISE	Mid-IR	2010-12	$3.4-22\mu m$	$W1 \approx 17$	All Sky	N+S	6
Pan-Starrs 3π	Visible	2010-14	*grizy*	$r \approx 22.8$	30000	N+S	1.1
SkyMapper	Visible	2009-	*uvgriz*	$r \approx 22.0$	20000	South	2.5
VST ATLAS	Visible	2011-	*ugriz*	$r \approx 22.7$	4700	South	0.9
VST KiDS	Visible	2011-	*ugri*	$r \approx 24.6$	1500	South	0.7
VISTA VHS	NIR	2010-	*YJK*	$K \approx 18.4$	18000	South	0.7
VIKING	NIR	2010-	*zYJHK*	$K \approx 19.5$	1500	South	0.9
DES	Visible	2013-	*grizy*	$r \approx 25.0$	5000	South	0.9
DECaLS	Visible	2015-	*grz*	$r \approx 23.6$	9000	North	1.2
HSC Wide	Visible	2015-	*grizy*	$r \approx 26.0$	1400	South	0.7

Table 1 Recent Optical and NIR extragalactic imaging sky surveys with an area of $> 100\text{deg}^2$. Magnitude limits are quoted in r_{AB} and K_{Vega}.



VST+OmegaCAM regularly delivers images down to **0.45'' FWHM** uniformly over the whole field, small ellipticities

VST data & operation center

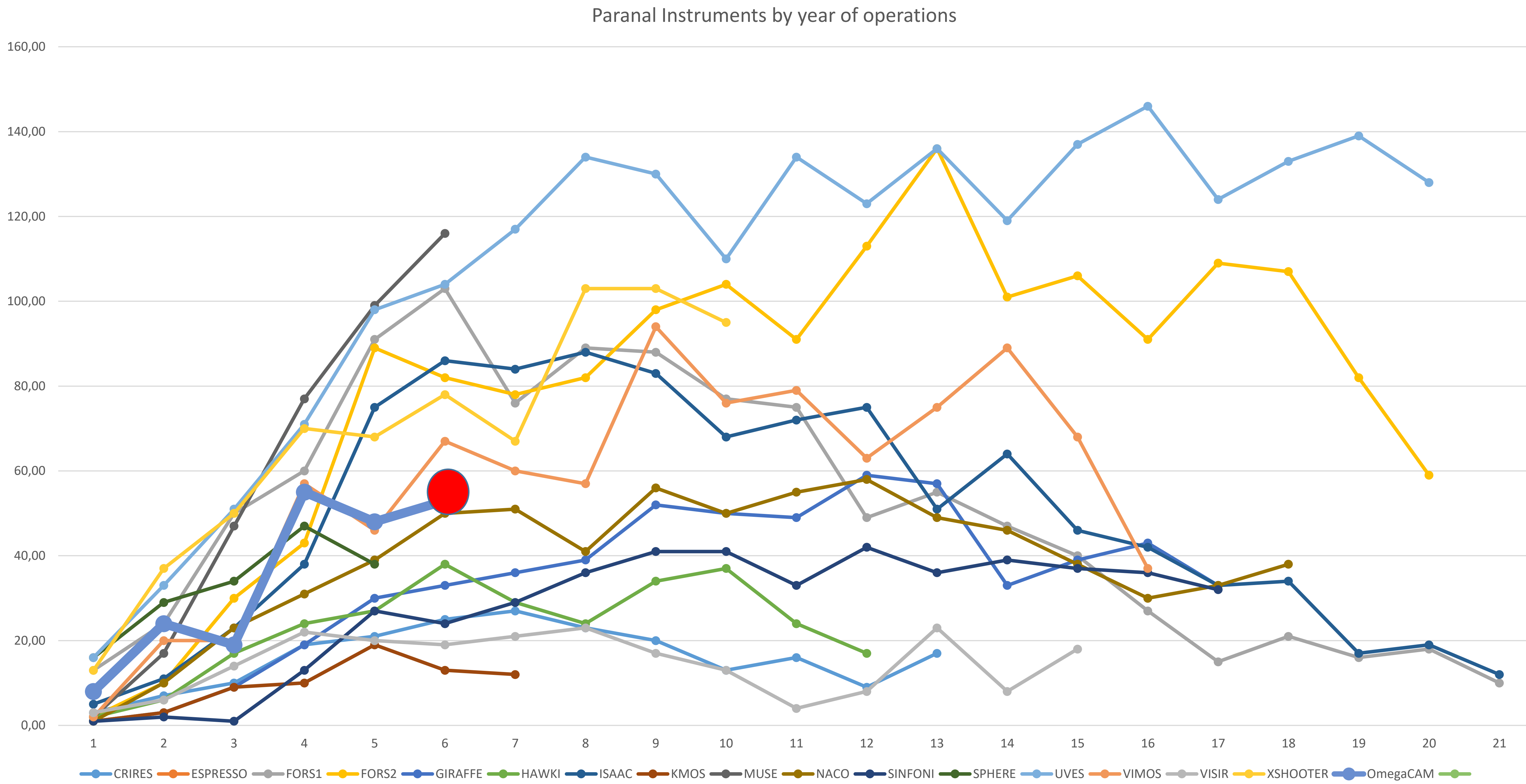
Data Reduction

- Based @INAF – Capodimonte, operational since 2011
- Pipeline: fully moved to **AstroWISE** (KiDS and other projects). INAF – Capodimonte is one of AstroWISE founders node
- Data Center dimensioned few years ago, still good for current needs (GTO=20% of time). To be expanded for future needs.
- VST data reduction of a large program is *extremely* time consuming. Any potential user should consider this seriously.
- Skills, software, computational capabilities and (lot of) time

Future

- The VST Data & Operations Center is available to assist the community in the future scenario

Publications: VST vs VLT instruments

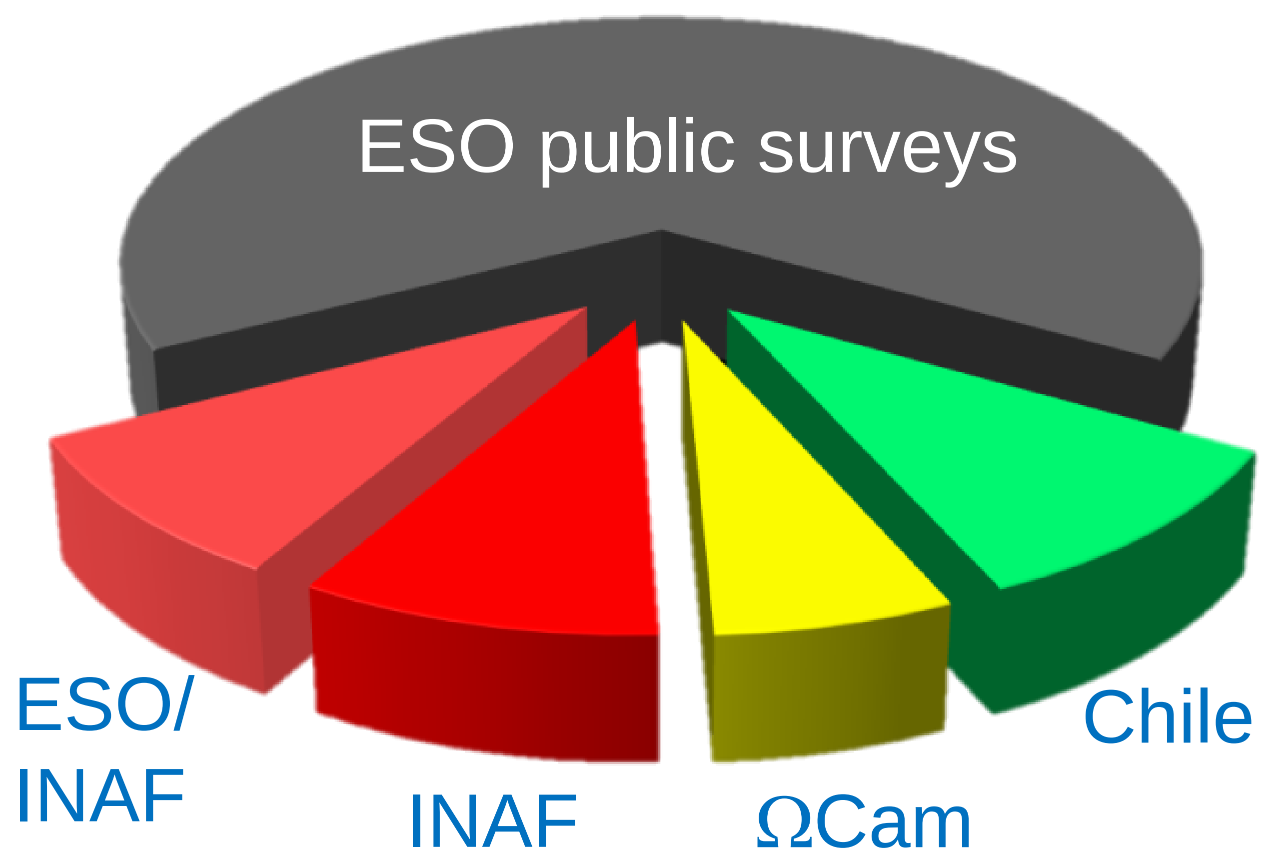


Red circle: VST+OmegaCAM papers (vs **VLT** instruments)

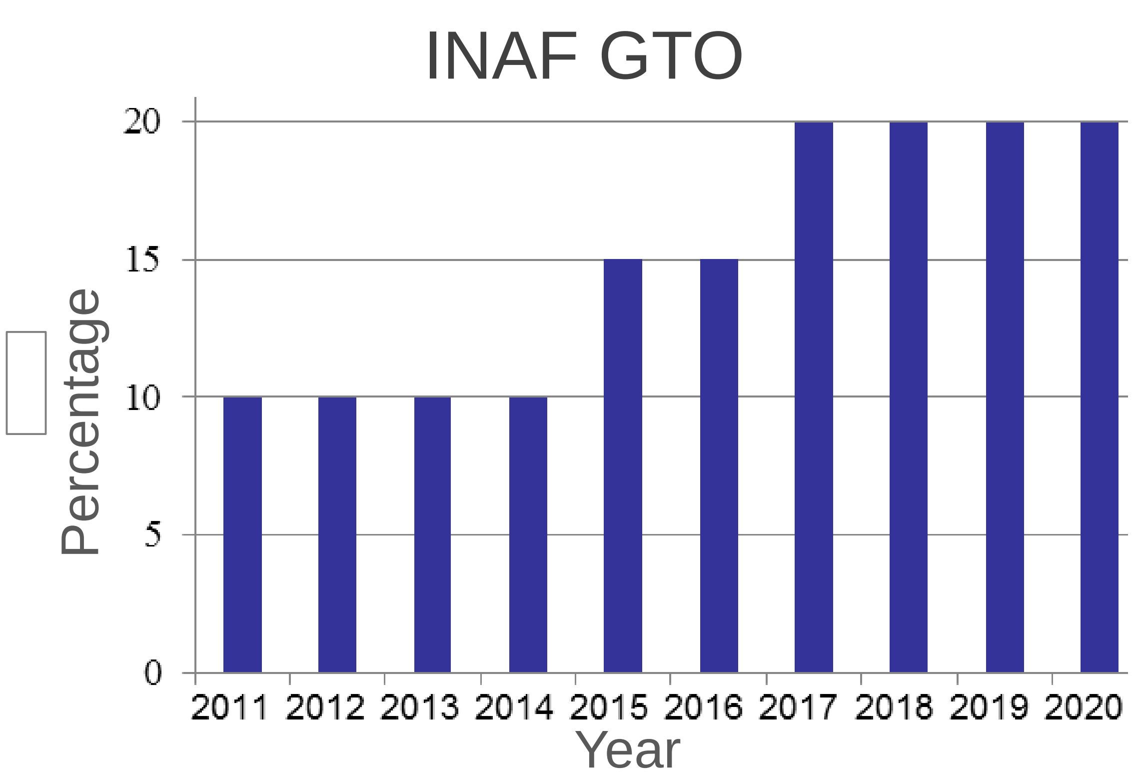
- ❑ Part of the most productive observatory of the planet (LPO)
- ❑ Contributes with more than 50 papers/yr in the last 3 years

Share of VST observing time and scientific policy

for the first 10 years of operation



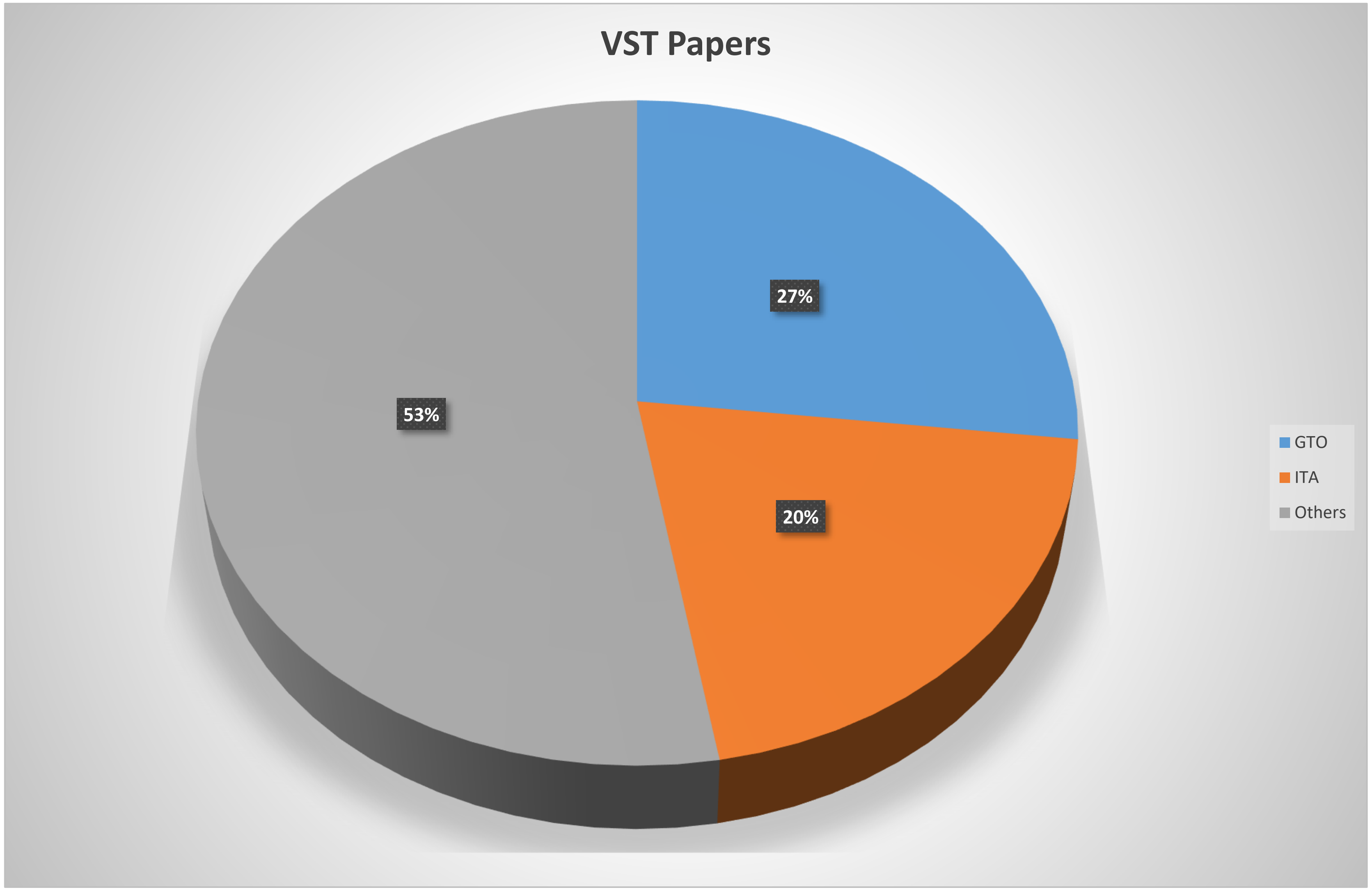
+
3 VST nights/yr



Observations:
service mode

Impact on Italian community

- Overall INAF GTO is now 25% (20% VST, 5% OmegaCAM)
- Many GTO programs (galactic, extragalactic, transients, ToO)
- Deep Italian involvement in KiDS public survey



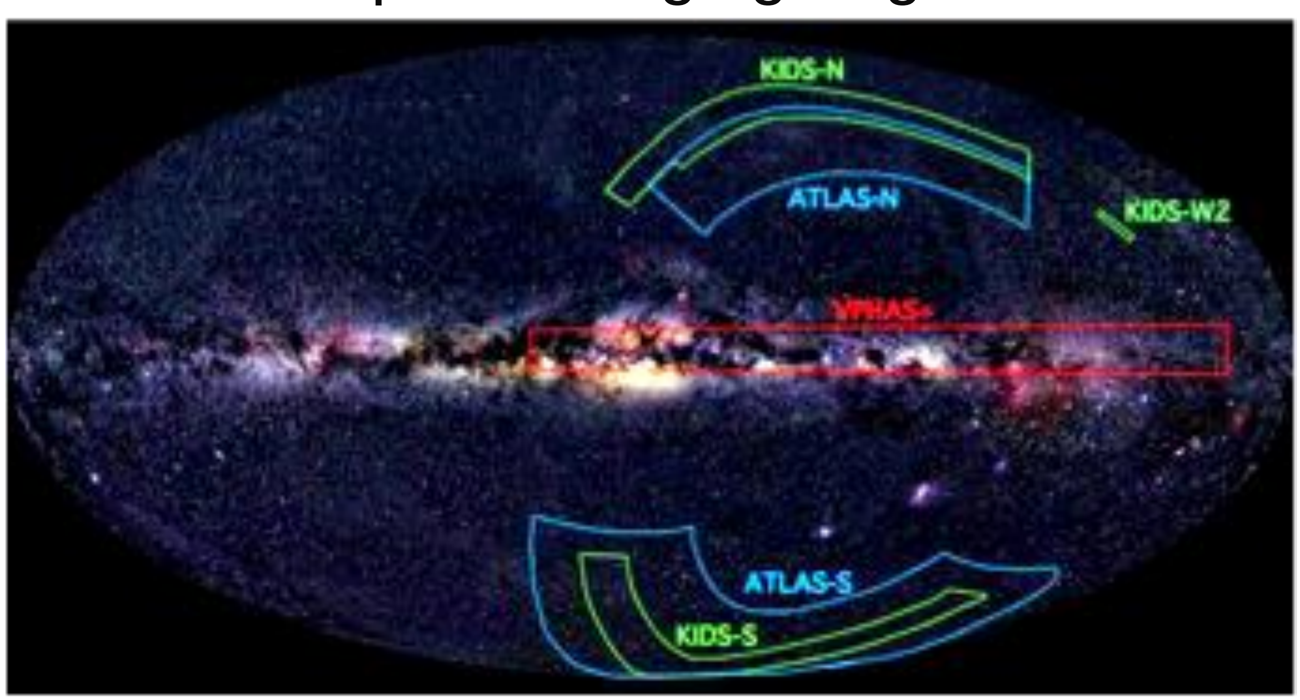
VST ESO Public Surveys

1) KIDS = Kilo-Degree Survey; P.I. Konrad Kuijken (Leiden)

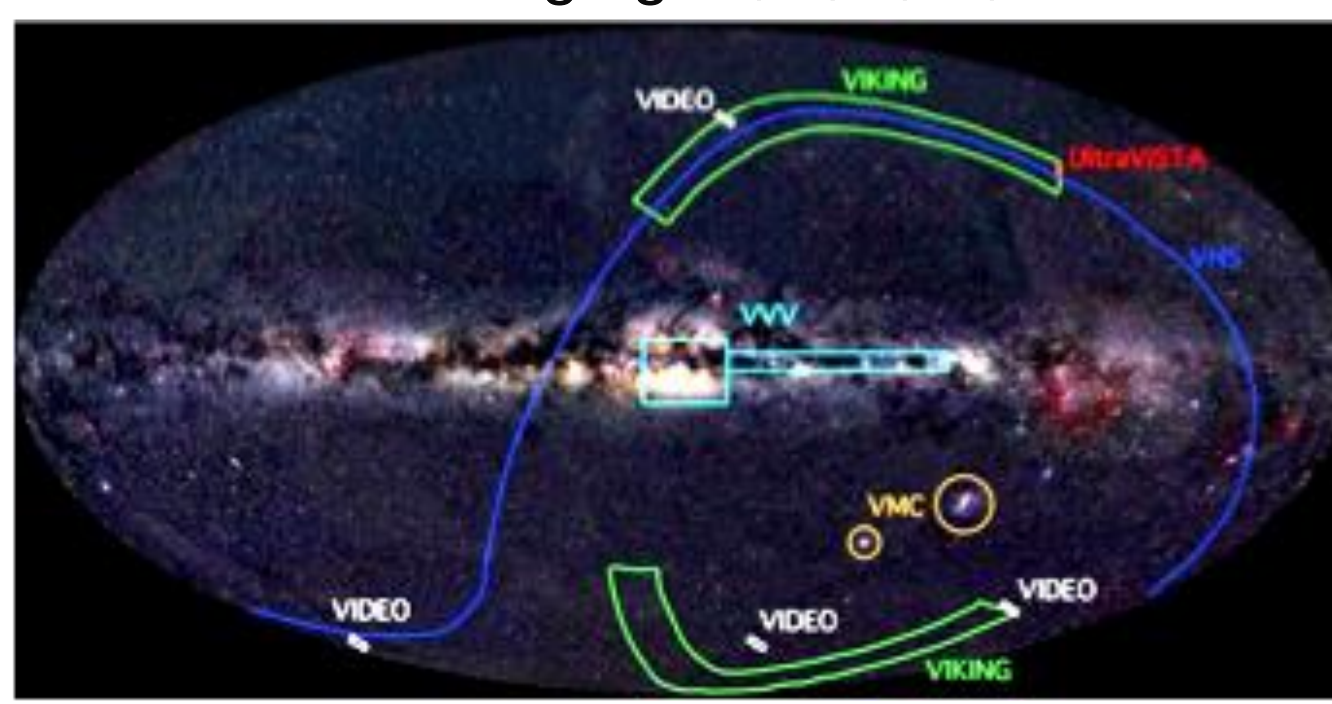
1500 square deg in 4 bands (+ NIR VISTA/VIKING survey)
2.5 mag deeper than the Sloan Digital Sky Survey

- weak gravitational lensing: studying DM halos and DE with weak lensing,
- investigating galaxy and cluster evolution, large-scale angular power spectrum, and the equation of state of the dark energy;
- high redshift quasars.

Optical imaging: u g r i



NIR imaging: Z, Y, J, H, Ks



VST ESO Public Surveys

2) The VST ATLAS;
P.I. Tom Shanks (Durham)

4500 square deg survey of the Southern Sky in 5 filters to depths comparable to the SDSS + NIR from the VHS VISTA survey.

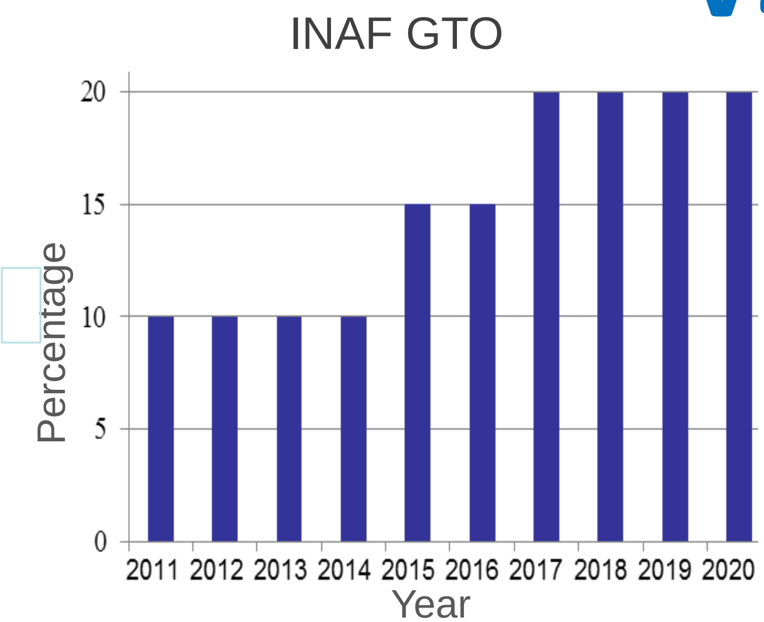
- dark energy equation of state by examining the 'baryon wiggles' in the matter power spectrum;
- high redshift galaxies and quasars;
- imaging base for many other future spectroscopic survey (VLT AAOmega).

3) VPHAS+ - The VST Photometric Hα Survey of the Southern Galactic Plane;
P.I. Janet Drew (Imperial College, London)

1800 square deg survey in H-α and broadband u'g'r'i' covering the whole of the Southern Galactic Plane within the latitude range |b| < 5 deg.

- VPHAS+ will facilitate detailed extinction mapping of the Galactic Plane
- and will be used to map the structure of the Galactic disk and to investigate its star formation history.

VST – Italian GPO projects



redshift

1) **STREGA**: STRucture and Evolution of the Galaxy (PI Marconi)

2) **STEP**: The Small Magellanic Cloud in time evolution of a prototype interacting dwarf galaxy (PI Ripepi)

3) **VST-Omegacam Local Group Dwarf** survey (PI Held)

4) **VEGAS**: VST survey of Early-Type Galaxies (PI Capaccioli → Iodice)

5) **WINGS** Wide field Imaging of Nearby Galaxy clusters Survey (PI Poggianti & D'Onofrio)

6) **VST-ACCESS:** Complete CEnsus of Star-formation in Shapley (PI Merluzzi)

7) **VOICE**: The VST optical imaging of the CDFS and ES1 fields (PIs: Covone, Vaccari)

8) **SUDaRE**: SUpernova Diversity and Rate Evolution (PI Cappellaro)

VEGAS

VST Early-type GAlaxy Survey

beyond $\mu_g \sim 28$ mag/arcsec^2






Science

Why VEGAS

What to we know about galaxy formation?

What do we know about morphological segregation?

What do we know about galaxy types?

What do we know about mass assembly?

What do we know about primary/secondary evolution?

What do we know about galaxy outskirts?

Science

Which are the observables?

- morphology

  ➥ to constraints the processes in the mass assembly history (i.e. detection of diffuse halos *vs* fine LSB features)

- azimuthally-averaged SB profiles

  ➥ to set the scales of the different components in the galaxy (in-situ *vs* ex-situ)

- color gradients

  ➥ to procure hints on the stellar populations in the cluster/group members

- fraction of ICL

  ➥ to constraint the look-back time of the mass assembly in the cluster and/or group of galaxies

- kinematics & metallicity

  ➥ to constraint the structure & stellar population

Science

Which are the obser…s?

- morphology

  ➥ to constraints the process… mass assembly history (i.e. detection of diff…s *vs* fine LSB features)

- azimuthally-averaged SB profiles

  ➥ to set the sc…e different components in the galaxy (i…ex-situ)

- color gradients

  ➥ to …nts on the stellar populations in the clus… members

- fraction of ICL

  ➥ …onstraint the look-back time of the mass …embly in the cluster and/or group of galaxies

- kinem…etallicity

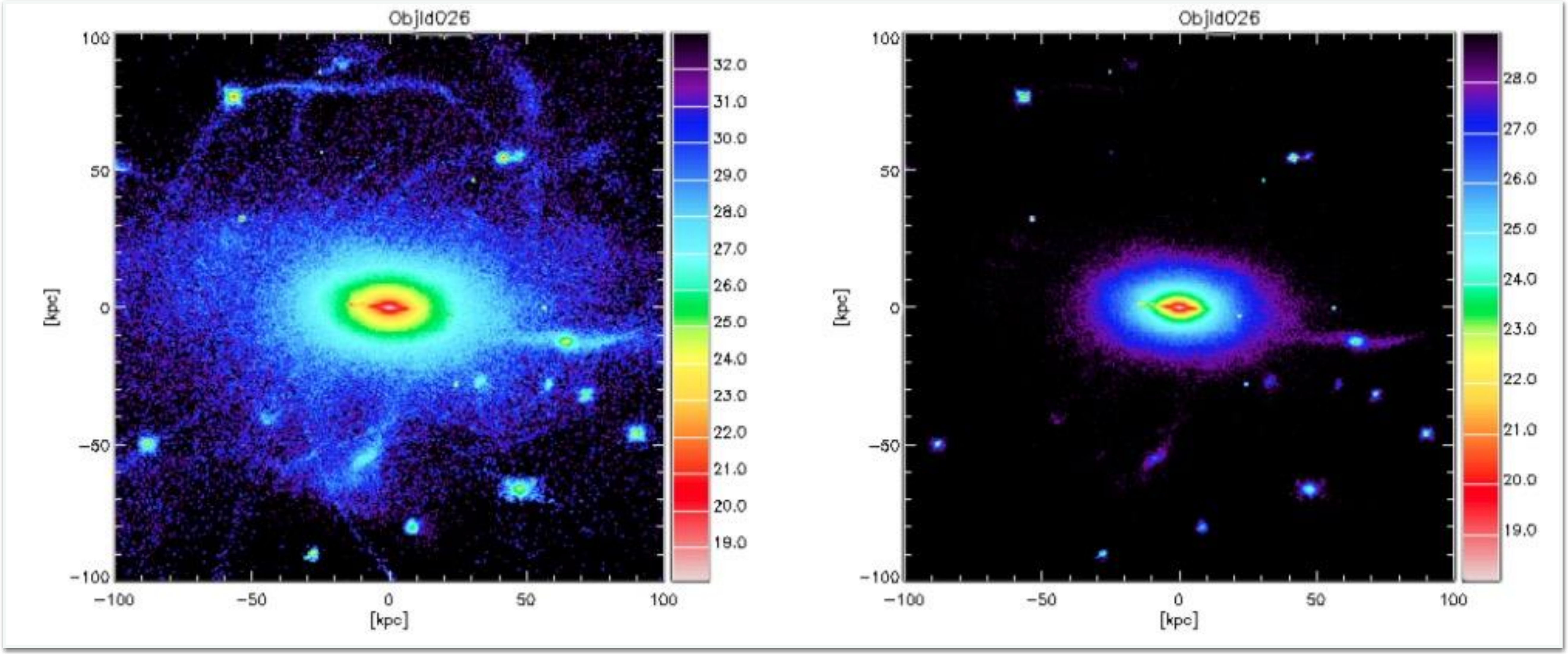
  ➥ to constraint the structure & stellar population

GO AS FAINT AS POSSIBLE

Science

Why deep images?

Mancillas et al. 2019



$\mu_g \sim 33$ mag/arcsec^2

$\mu_g \sim 29$ mag/arcsec^2

Science

Which are the requirements for the real data?

- deep multi-band imaging & spectroscopy
  - ➡ to study the galaxy structure out to region of the stellar halos + detect the LSB features & ICL plus hints on the stellar populations of progenitors
- large covered area (several square degrees)
  - ➡ map the extended stellar envelope of BCG & ICL in nearby clusters of galaxies (< 50 Mpc)
- arcsec-level angular resolution (scale < 0.3 arcsec/pixel)
  - ➡ characterize the LSB features (tidal tails, shells, streams & UDG)

VST in the panorama of deep imaging surveys

Using:

- **LSB optimised small telescope** & **telescope arrays**: μ_g ***~ 29.5 mag/arcsec^2***
  Burrell Schmidt (Mihos et al. 2017),
  Dragonfly image array (Abraham & van Dokkum 2014; Merritt et al. 2016)

- **3m-class telescope**: μ_g ***~ 28.5 - 29 mag/arcsec^2***
  NGVS@CFHT (Ferrarese et al. 2012); ATLAS3D@CFHT (Duc et al. 2015); CFHT Legacy Survey (Gwyn 2012); **FDS&VEGAS@VST** (Iodice et al. 2019)

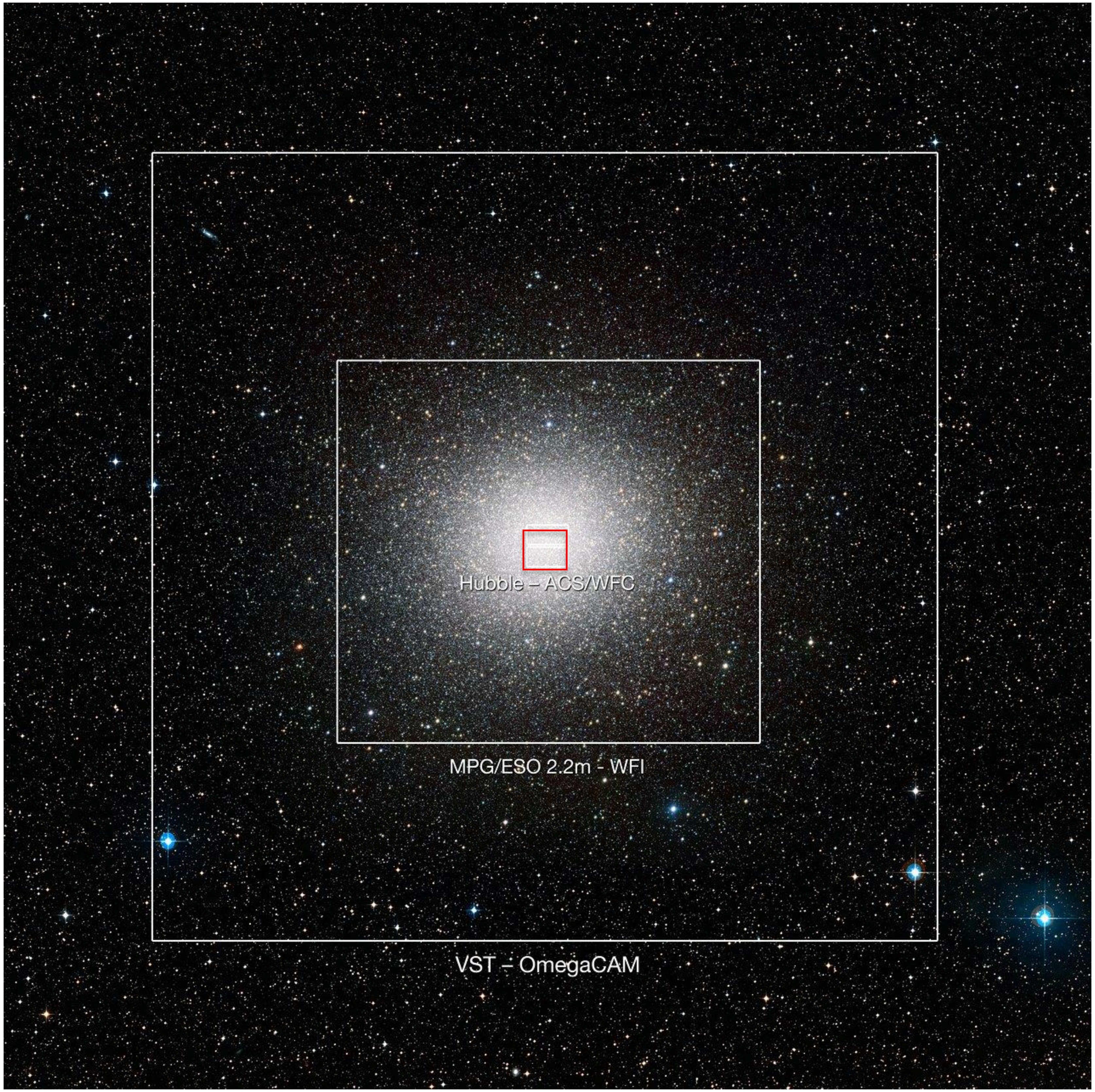
- **4m-8m class telescope (wider area)**: μ_r ***~ 27.5 - 28.5 mag/arcsec^2***
  DECam@CTIO (Dey et al. 2019); Hyper Suprime-Cam Subaru Strategic Program@Subaru (Aihara et al. 2018)

- **10m GTC telescope (FOV = 5')**: μ_r ***~ 31.5 mag/arcsec^2***
  (Trujillo & Fliri 2016)

- **HST**: μ ***~ 31 mag/arcsec^2***
  (ICL in Hubble Frontiers Fields by Montes & Trujillo 2018)

FoV of VST/OmegaCAM compared to other telescopes

VST covers an area of sky more than 300 times greater than the imager on HST with the widest field.



VST survey of Early-type GAlaxieS (VEGAS)

deep, multi-band (*ugri*) imaging survey of
early-type galaxies in groups & clusters at VST

Limiting integrated magnitudes at 5σ:
m_g = 27.3 mag; m_r = 28.9 mag; m_i = 26.2 mag
Tot. int. time: 2.5 hrs in g & r bands; 1 hr i band

➞ **INAF-GTO large program**: **500 hrs** (2016-2021), P.I. **E. Iodice**

➞ by the end of the survey (2022), VEGAS will collect:
a **total of 55 targets,**
with a **spatial coverage of 110 deg^2**,
spanning **halo mass range** ~ **10^{12} to 10^{15} $M_\odot$**

http://www.na.astro.it/vegas/VEGAS/Welcome.html

VEGAS team

INAF

& collaborations

E. Iodice (PI) - **INAF-OAC**

- M. Spavone (co-PI & head of data center) - **INAF-OAC**
- P. Schipani - **INAF-OAC**
- R. Ragusa (PhD 2020-2023)- **INAF-OAC**
- A. La Marca (MSc 2020-2021) - Univ. of Naples & **INAF-OAC**
- M. Mirabile (MSc 2020-2021) - Univ. of Naples & **INAF-OAC**
- M.Paolillo - Univ. of Naples & **INAF-OAC**
- C. Spiniello - Oxford & **INAF-OAC**
- A. Pasquali - Univ. of Heidelberg & **INAF-OAC**
- G. D'Ago - PUC Chile & **INAF-OAC**

- INAF-OATeramo (M. Cantiello)
- INAF-OARoma (M.A. Raj)
- INAF-IRA Bologna (I. Prandoni)
- INAF-OAPadova & Univ. of Padova (E.M. Corsini, E. Dalla Bontà, L. Greggio, M. Gullieuszik, E. Held, P. Mazzei, A. Pizzella, R. Rampazzo)
- INAF-OACagliari (P. Serra)

M. Arnaboldi, E. Emsellem, D. Gadotti, M. Hilker, M. Rejkuba, S. Mieske

K. Dolag, S.R. Remus

D. Forbes

S. Brough

J. Falcòn-Barroso

G. van de Ven

R. Peletier

D. Krajnović

30% of the VEGAS observing time

The Fornax Deep Survey

26 deg^2 out to R_{vir}

Virial radius: where the density equals the critical density of the Universe at the redshift of the system, multiplied by an overdensity constant

Effective radius: that of the isophote encircling half of the total light

- **Joint project** based on:
  - ★ INAF GTO for VEGAS (P.I. E. Iodice)

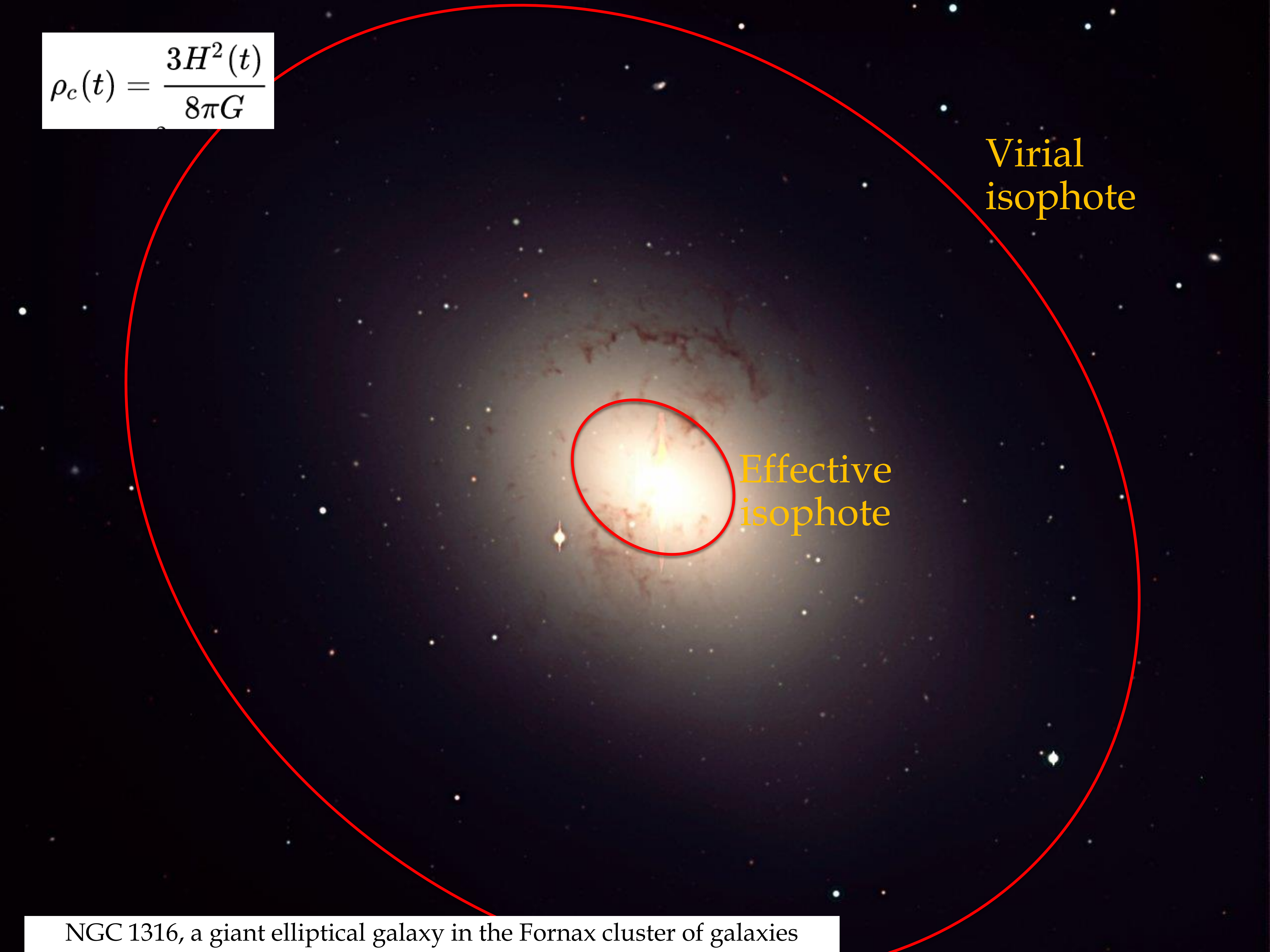
    &
  - ★ OmegaCam GTO (FOCUS, P.I. R. Peletier)
- New, multi-imaging (*u*, *g*, *r*, *i* bands) survey of the Fornax Cluster
- Tot. exp. times: 3 hrs (*u*), 2.3 hrs (*g*&*r*), 1.8 hrs (*i*)
- Unprecedented limits reached in mapping light and color distribution:

$$R \geq 10 - 15\ R_e$$
$$\mu_g \geq 28\text{-}30\ \mathrm{mag/arcsec^2}$$

SUNDIAL

2020 Innovative Training Network

$$\rho_c(t) = \frac{3H^2(t)}{8\pi G}$$



NGC 1316, a giant elliptical galaxy in the Fornax cluster of galaxies

30% of the VEGAS observing time

The Fornax Deep Survey

26 deg^2 out to $R_{\rm vir}$

Virial radius: where the density equals the critical density of the Universe at the redshift of the system, multiplied by an overdensity constant

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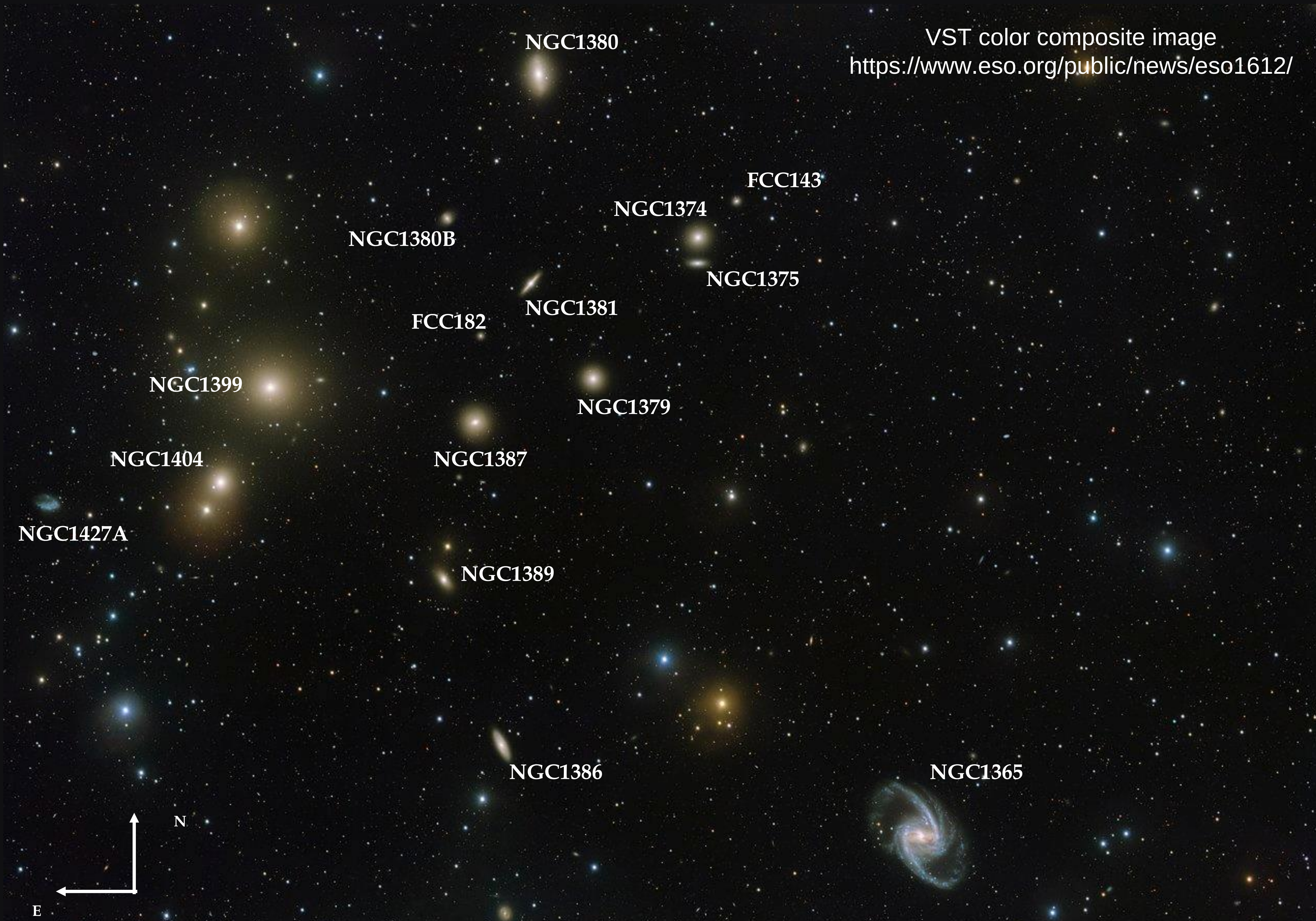
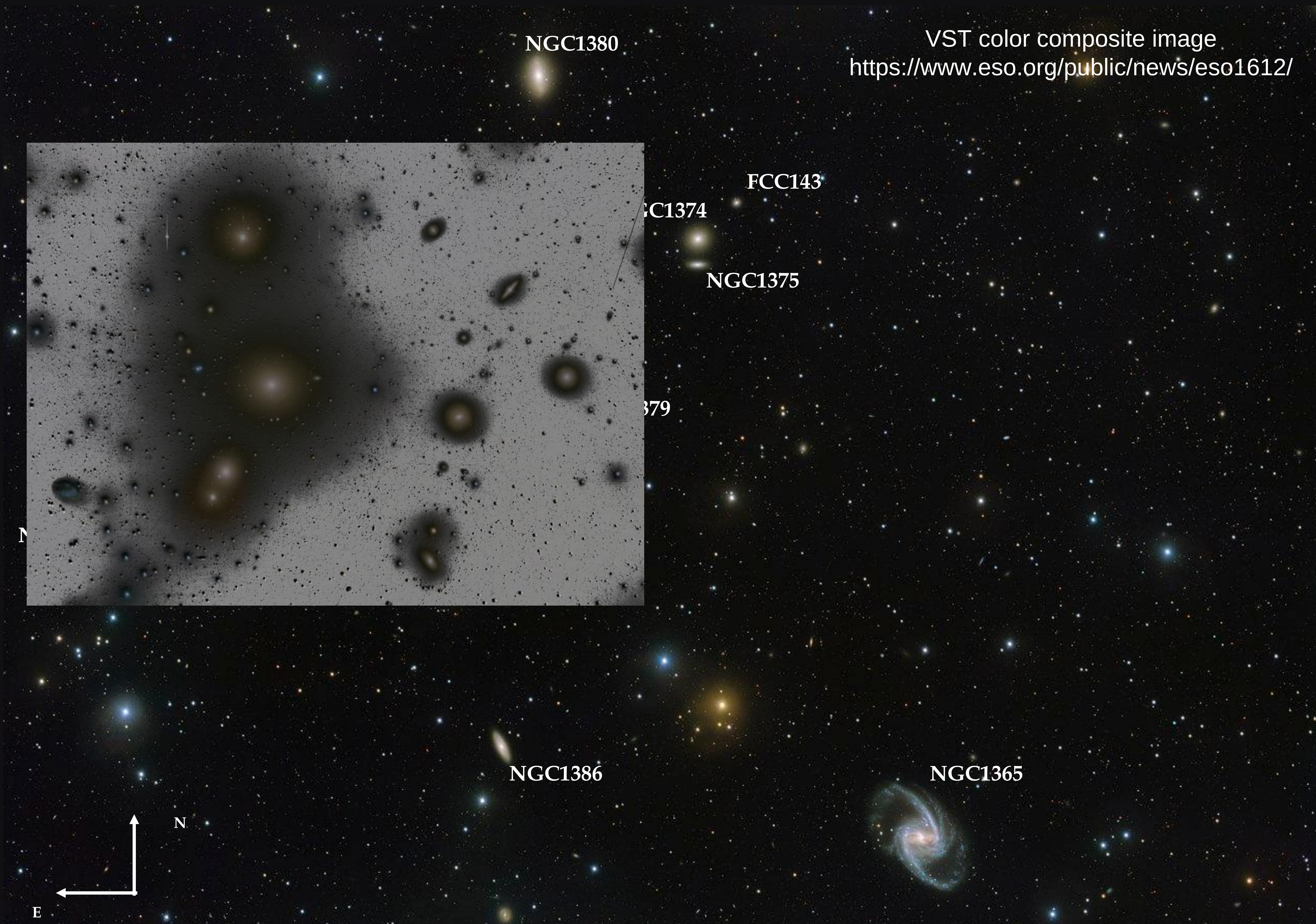
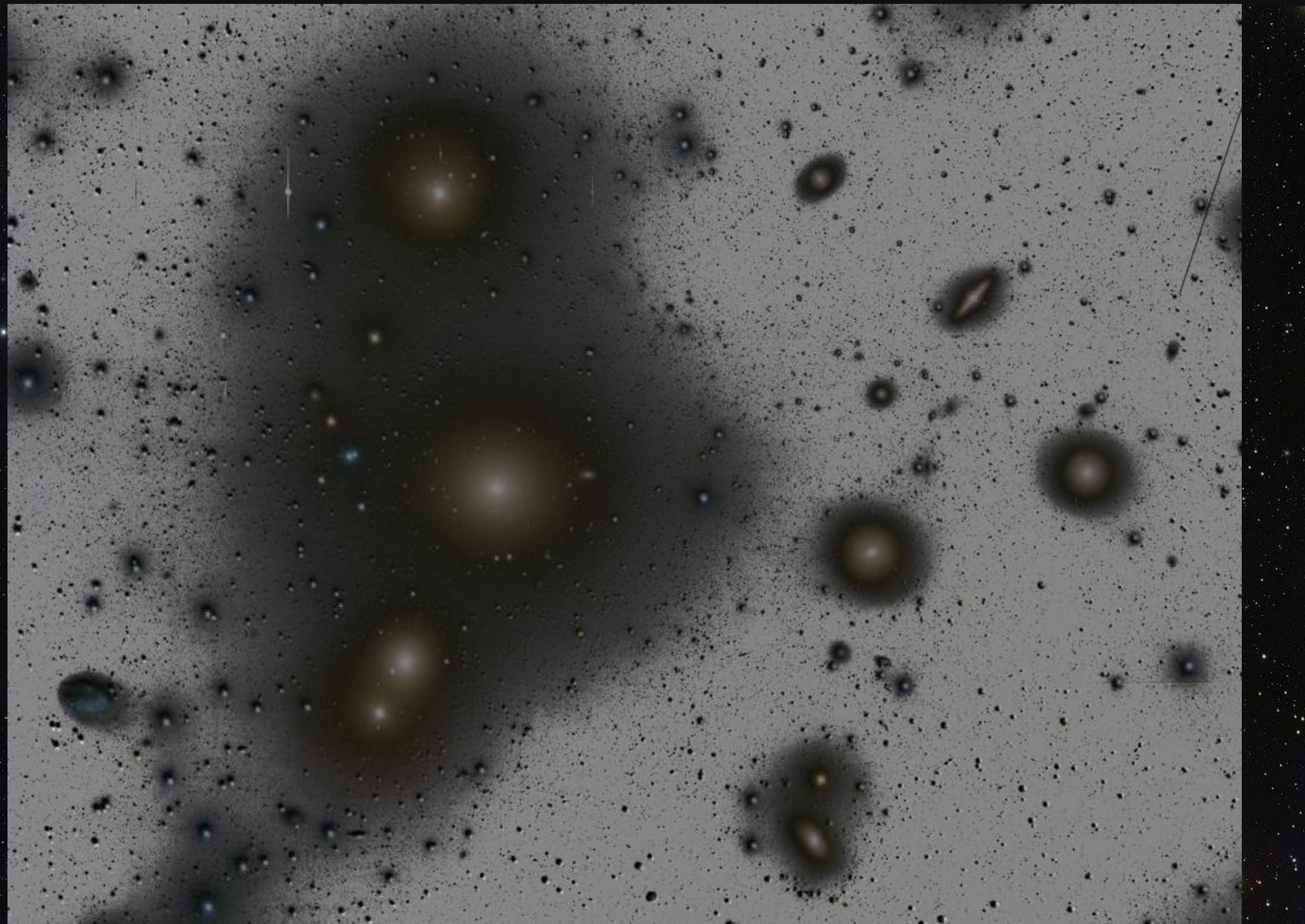
FDS: the core of the cluster



FDS: the core of the cluster



FDS: the core of the cluster



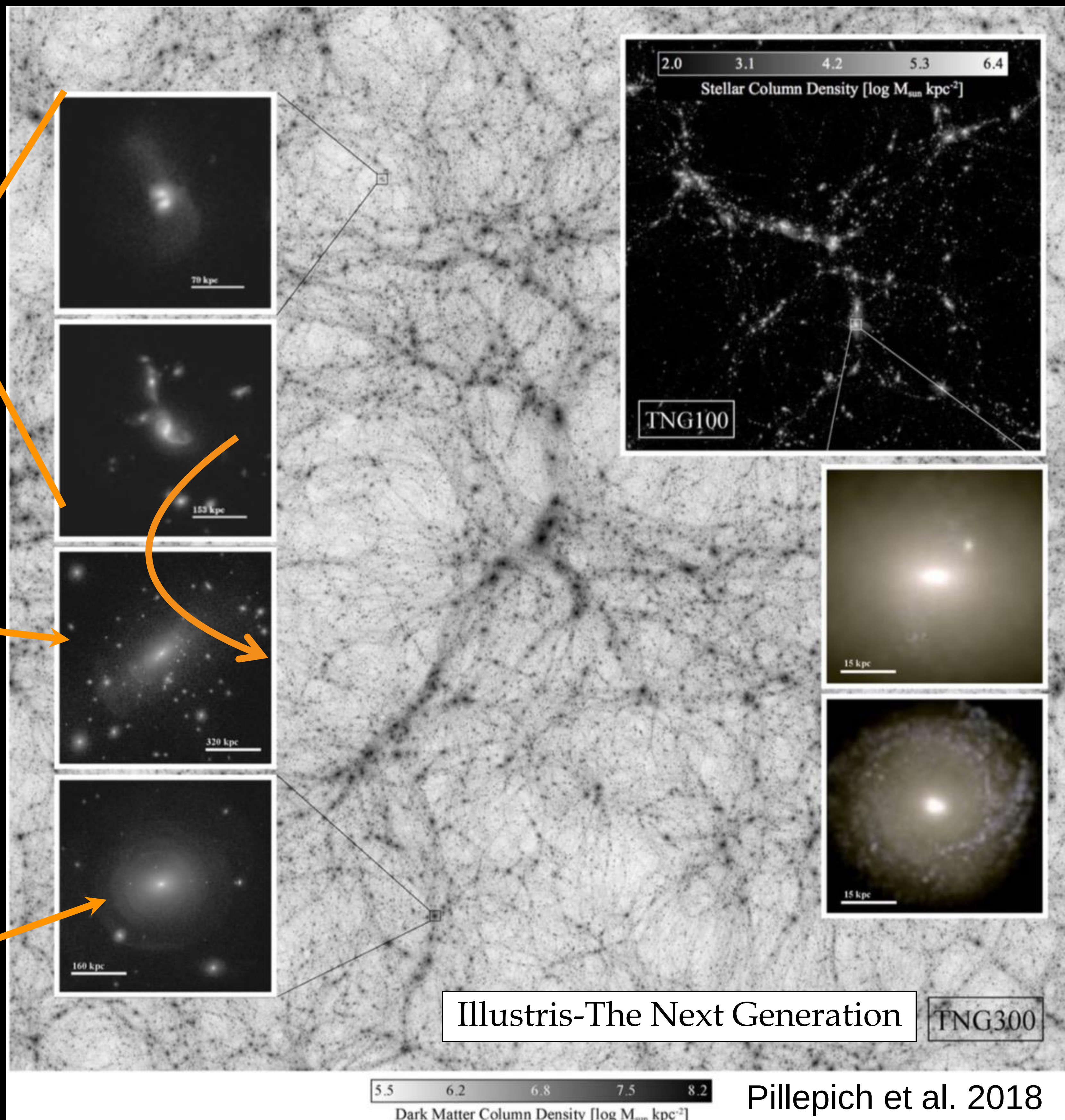
Science context

Study the mass assembly of galaxies in all environments to constrain their formation within the ΛCDM paradigm

Interactions & mergers

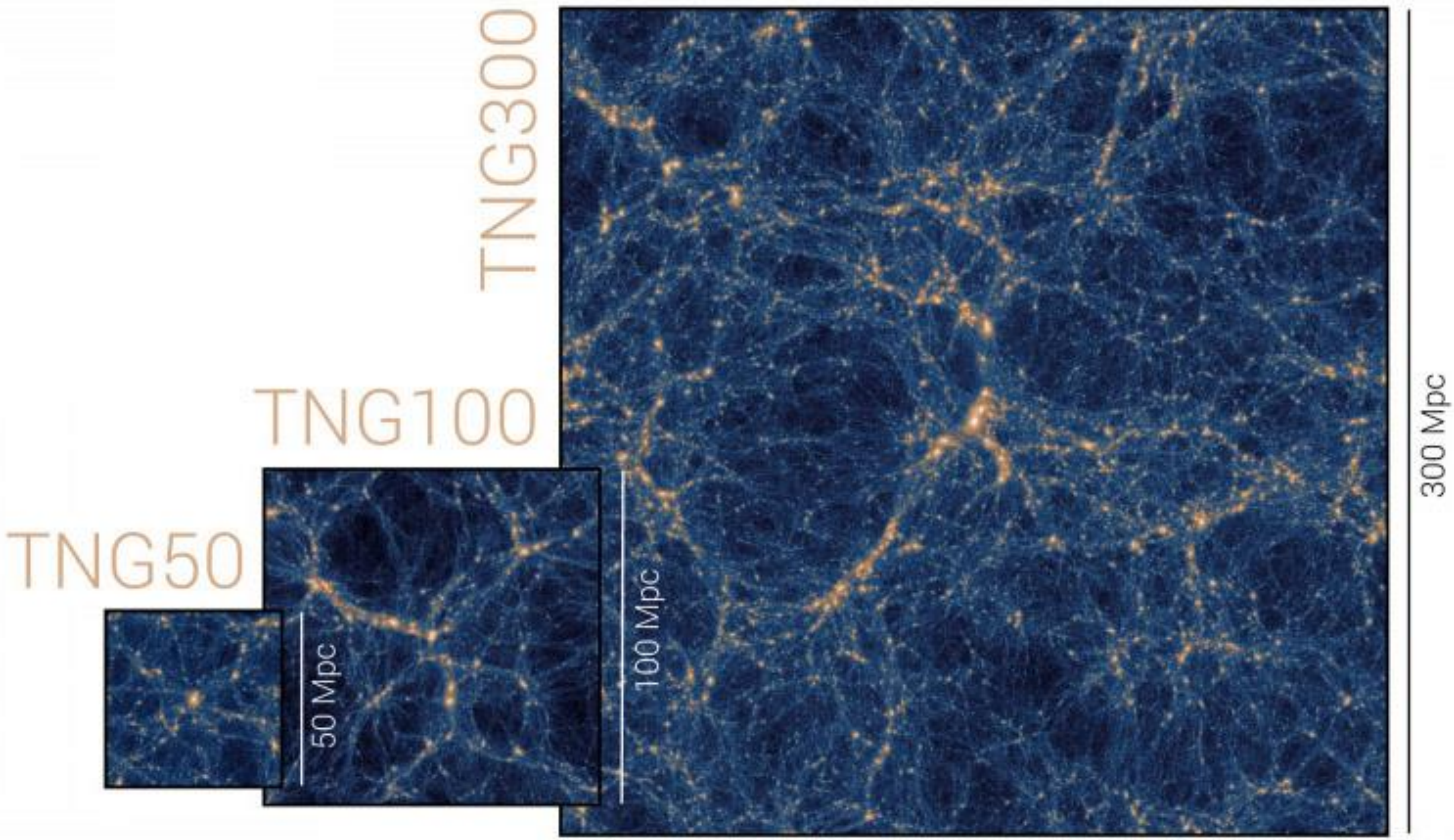
ICL

Accretion of small satellites



Numerical Simulations

Illustris TNG hydrodynamic simulations and their DM-only (DMO) counterparts



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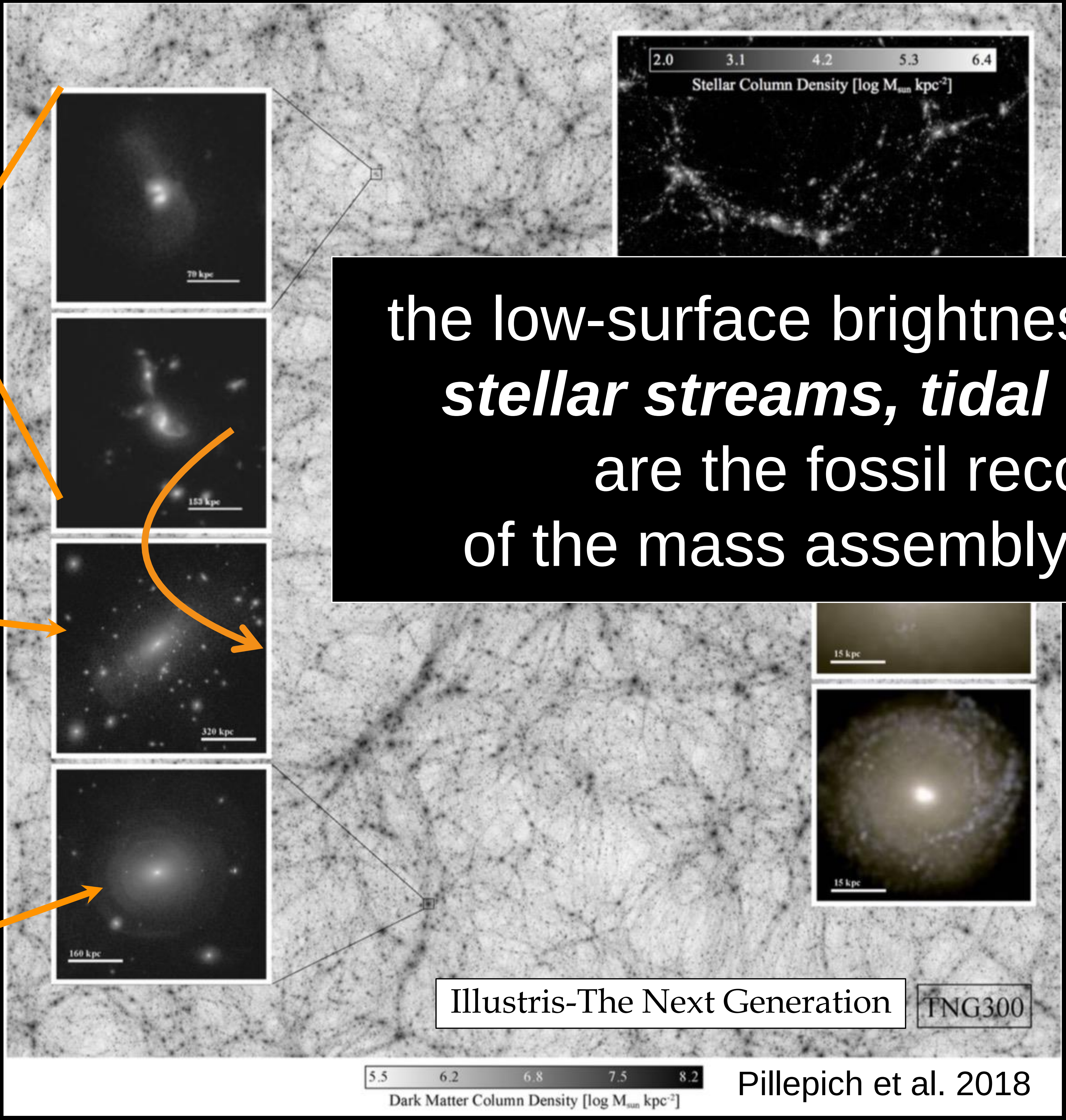
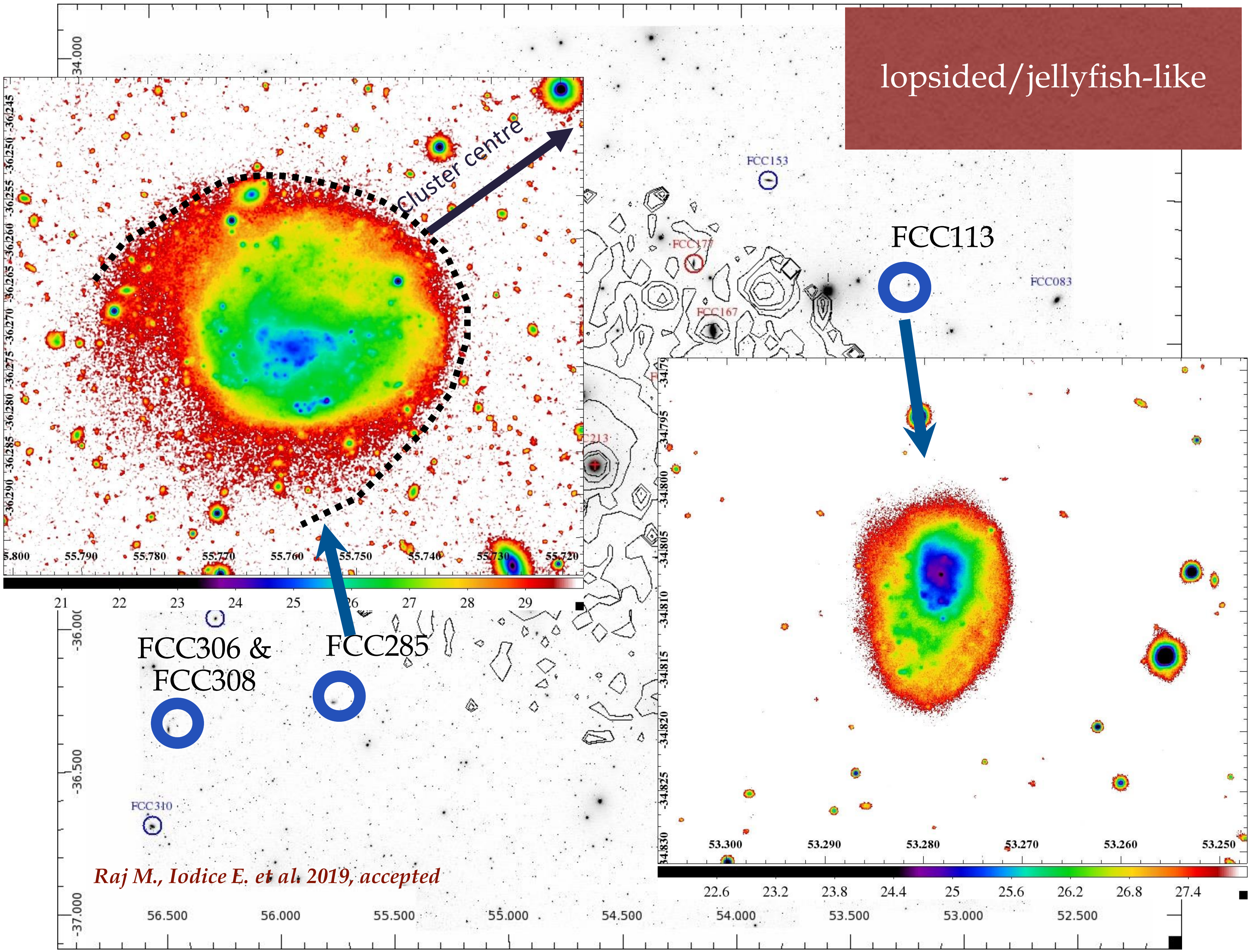


Pillepich et al. 2018

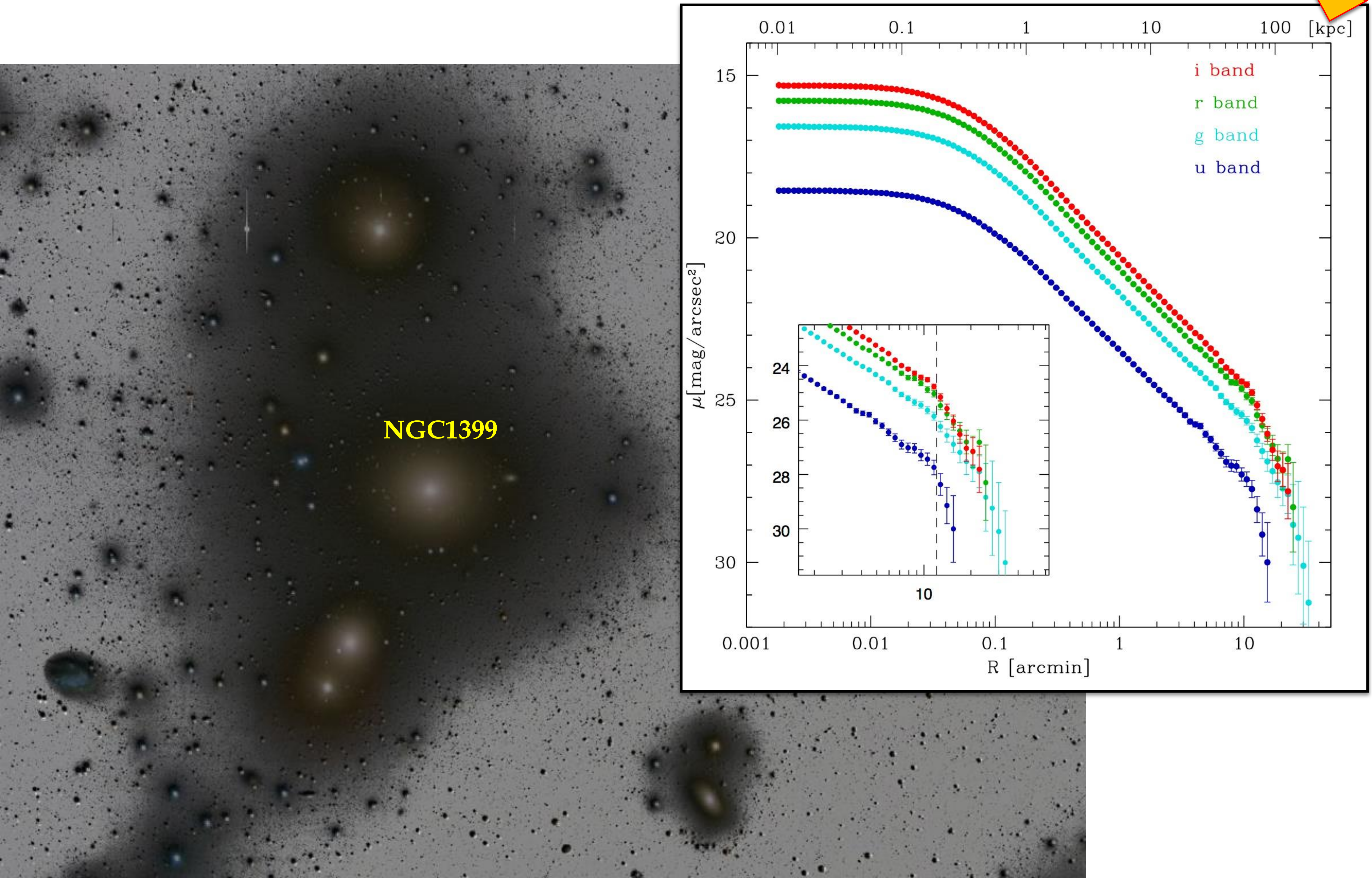
the low-surface brightness features,
stellar streams, tidal tails, ICL
are the fossil records
of the mass assembly process

Nu
mulations

Morphology:
the bright LTGs in the R_{vir} of the cluster (FDS)

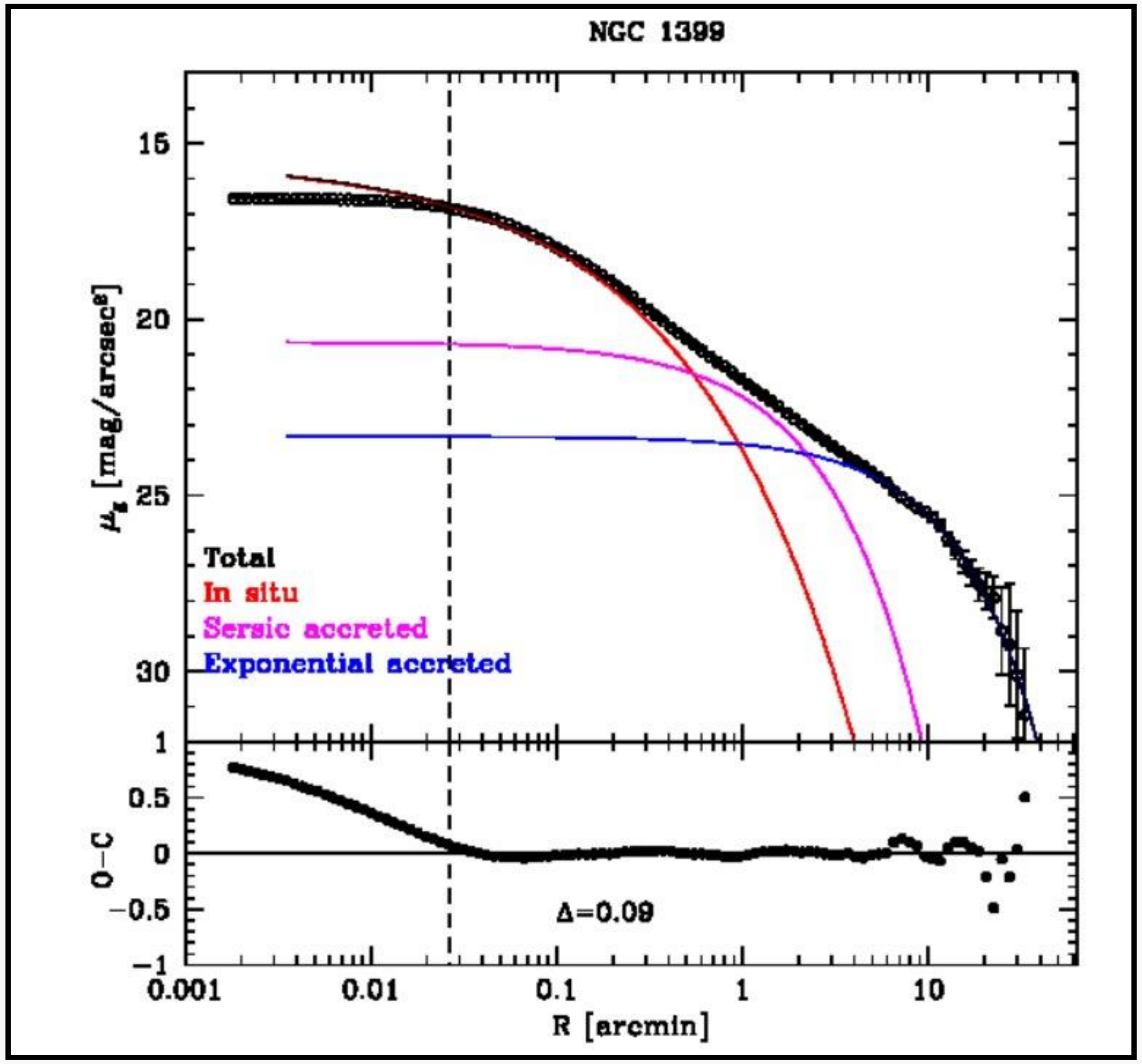


Light profiles of NGC 1399 out to ~6 R_e



Observations vs theoretical predictions: accreted mass fraction

Fit of the SB profiles
to identify the main components dominating the galaxy light

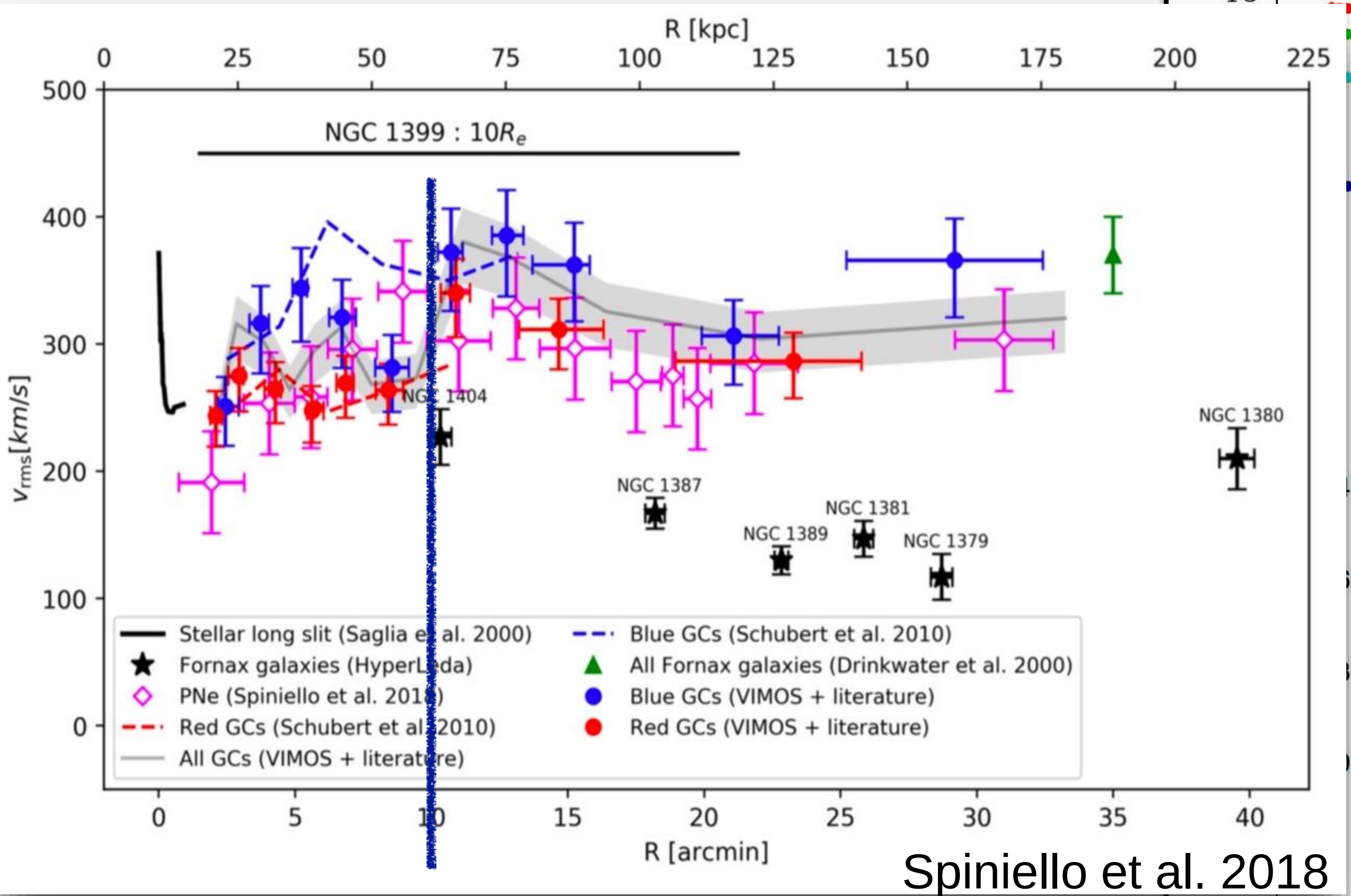


– 1D fit –

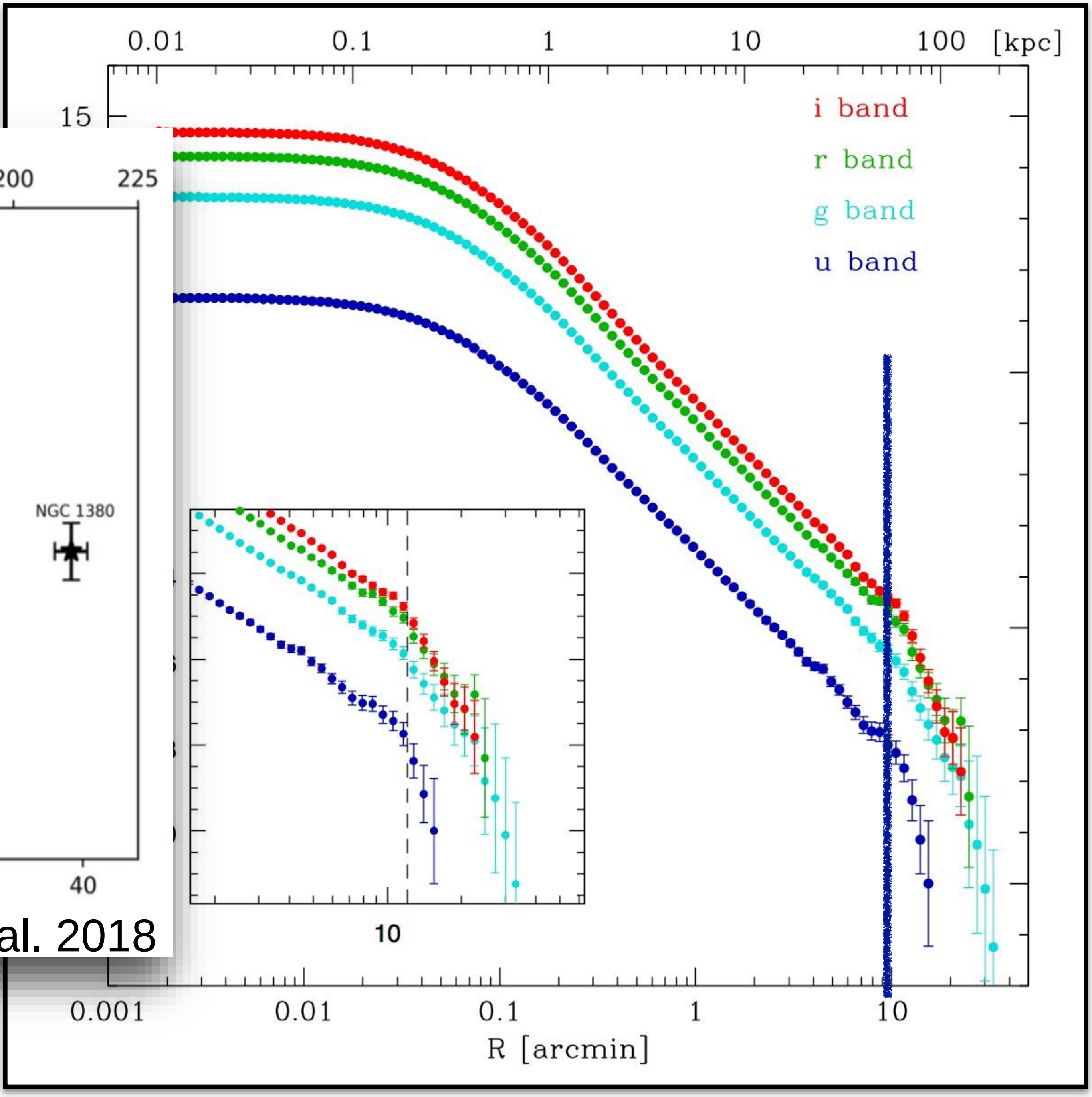
in-situ
+
accreted "relaxed"
+
accreted "unrelaxed" envelope

Spavone et al. 2017, A&A, 603, 38

Kinematics



Spiniello et al. 2018



stellar envelope in NGC1399

Iodice et al. 2016, ApJ, 820, 42

R>60 kpc: evidence for the transition radius from the gravitationally bounded to unbound accreted material

Science

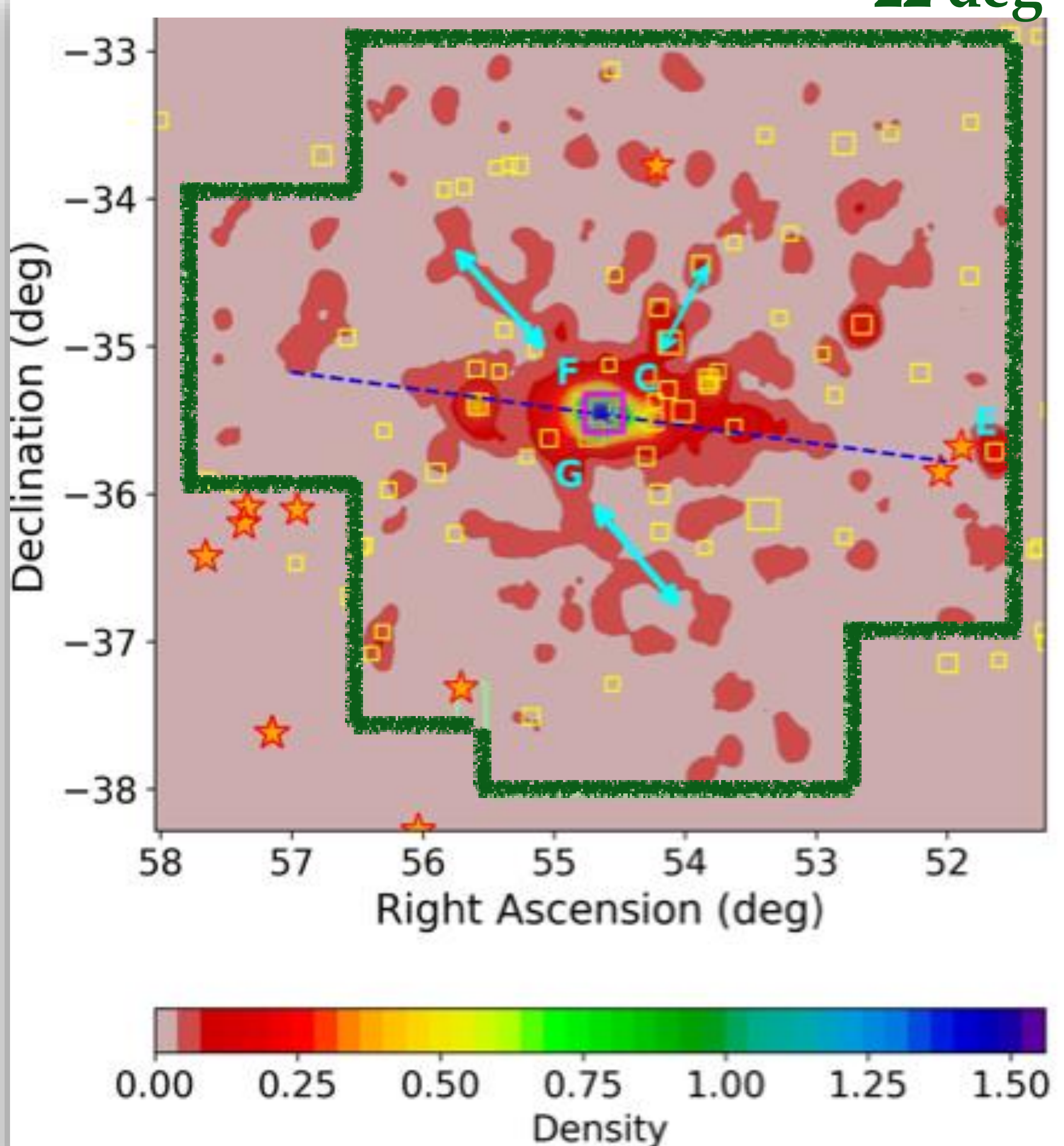
Dwarfs & GCs

VEGAS-SSS

led by M. Cantiello (INAF-OATeramo) +
Fellow A. La Marca + MsC M. Mirabile

- **inventory of GCs & dwarf galaxies**
- **number density, structural properties**

2D GC surface distribution over the FDS area **22 deg^2**



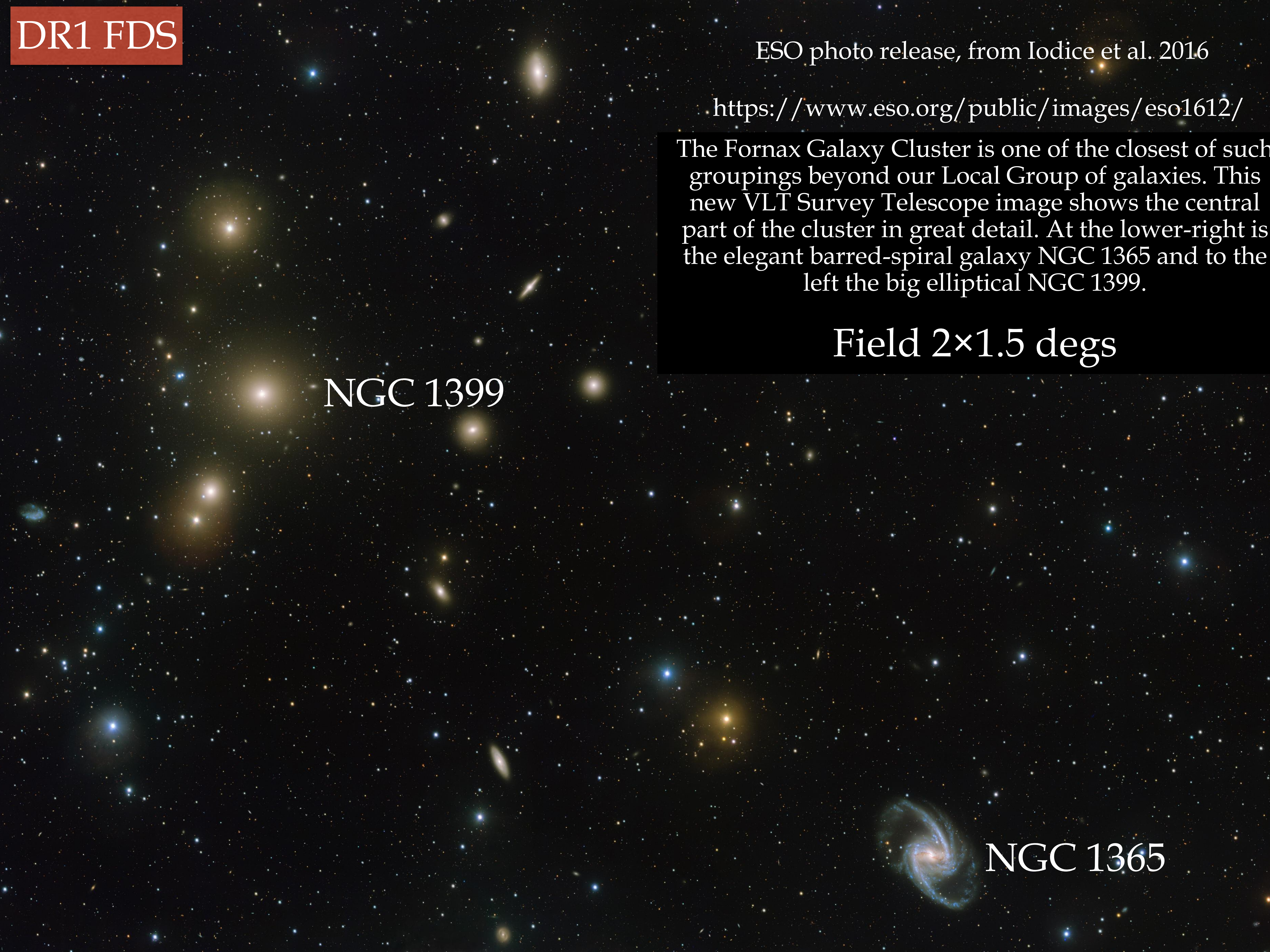
Publications:

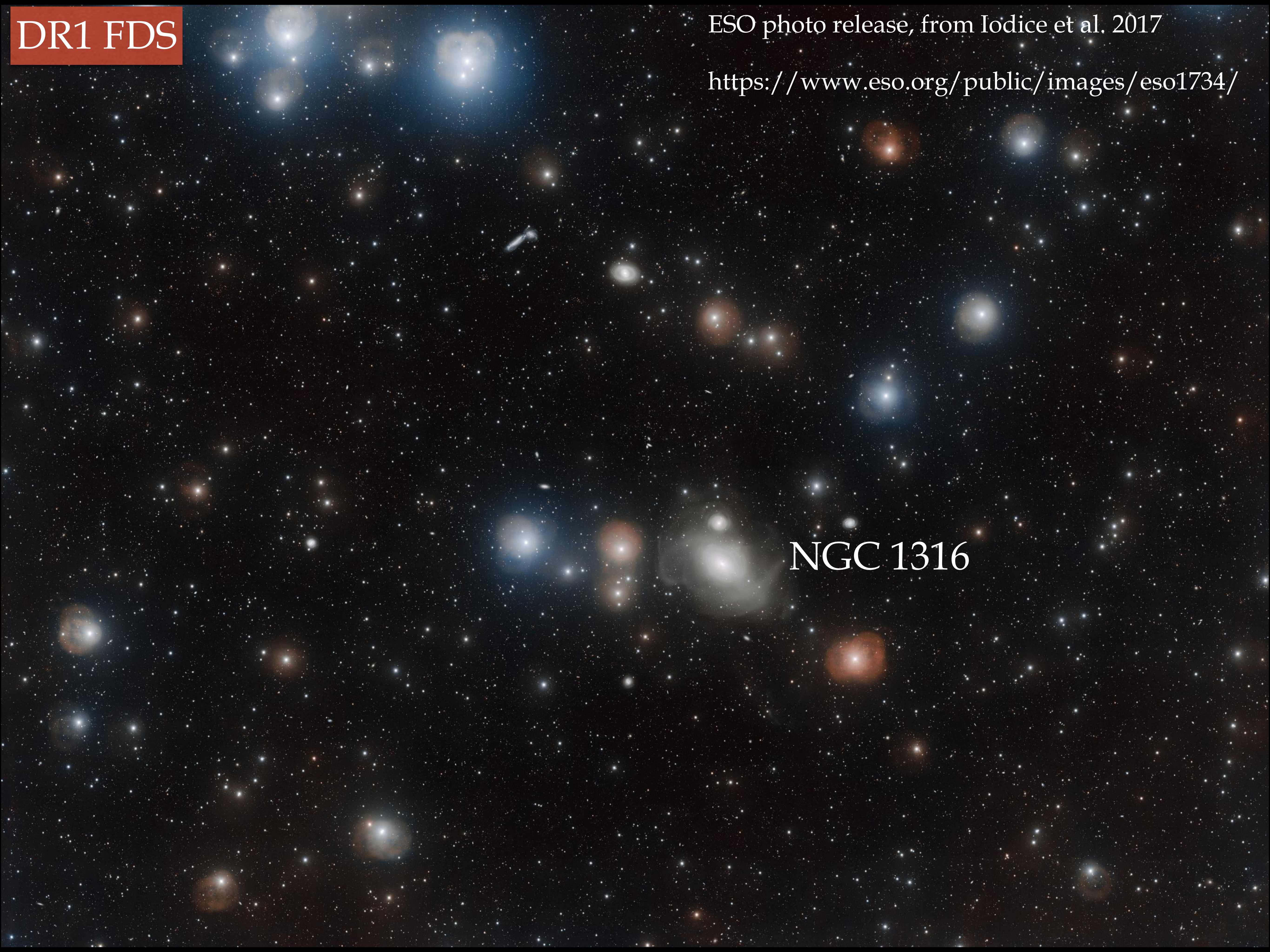
- Cantiello et al. 2020, A&A 639, 36
- Venhola et al. 2019, A&A 625, 143
- Cantiello et al. 2018, A&A 611, 93
- Venhola et al. 2018, A&A 620, 165
- Venhola et al. 2017, A&A 608, 142
- D'Abrusco et al 2016, ApJL 819, 31
- Cantiello et al. 2015, A&A 576, 14

DR1 GCs in FDS area
by M. Cantiello

41 photometric & morphometric parameters
for ~3.1 million sources (*gri* bands)

https://www.eso.org/rm/api/v1/public/releaseDescriptions/162


DR1 FDS
ESO photo release, from Iodice et al. 2016
https://www.eso.org/public/images/eso1612/
The Fornax Galaxy Cluster is one of the closest of such groupings beyond our Local Group of galaxies. This new VLT Survey Telescope image shows the central part of the cluster in great detail. At the lower-right is the elegant barred-spiral galaxy NGC 1365 and to the left the big elliptical NGC 1399.
Field 2×1.5 degs
NGC 1399
NGC 1365


DR1 FDS
ESO photo release, from Iodice et al. 2017
https://www.eso.org/public/images/eso1734/
NGC 1316

ESO photo release, from Spavone et al. 2018

https://www.eso.org/public/images/eso1827a/

DR1 VEGAS

This deep image of the area of sky around the elliptical galaxy NGC 5018 offers a spectacular view of its tenuous streams of stars and gas. These delicate features are hallmarks of galactic interactions, and provide vital clues to the structure and dynamics of early-type galaxies.

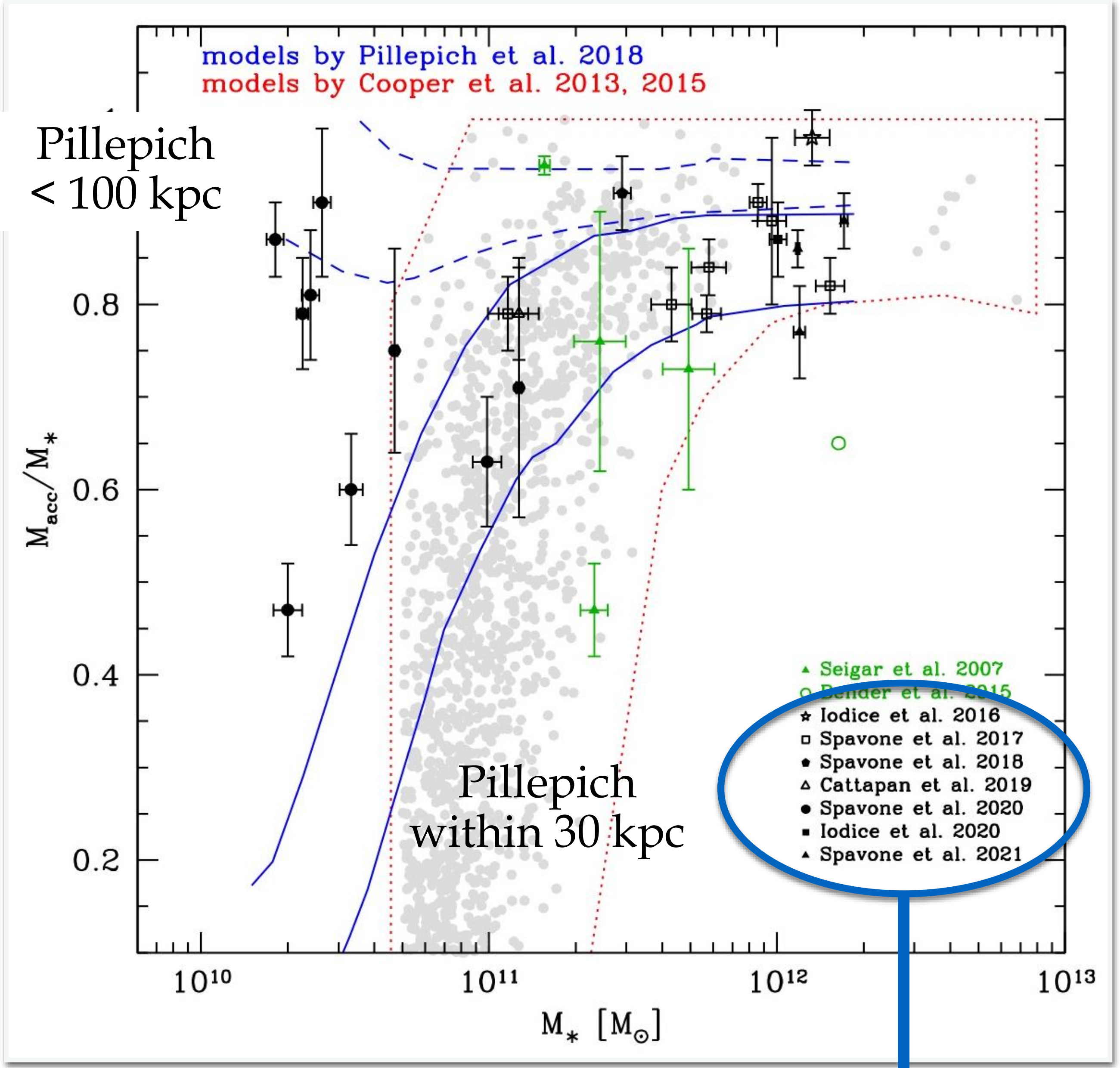
Science

LSB universe

led by M. Spavone (INAF-OAC) + PhD R. Ragusa

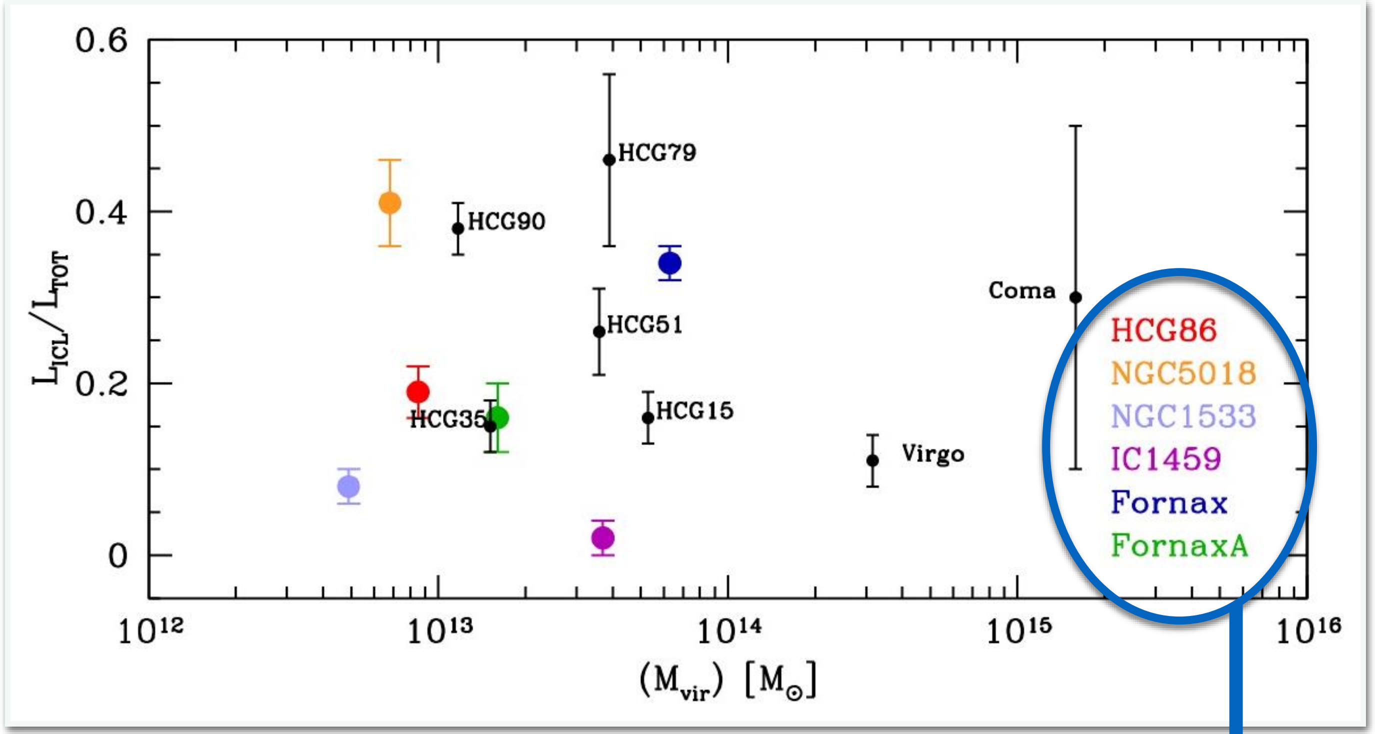
- **build-up history of the stellar halos**
- **accreted mass fraction**
- **contribution of the ICL**

Cluaster



BCG: accreted vs stellar mass

From VEGAS



Group-Clusters: ICL light vs virial mass

From VEGAS

Publications:
- Spavone et al. 2021, A&A in press
- Ragusa et al. 2021, A&A in press
- Spavone et al. 2020, A&A 639, 14
- Spavone et al. 2017, A&A 603, 38
- Raj et al. 2020, A&A 604, 137
- Iodice et al. 2017, ApJ 851, 55
- Capaccioli et al. 2015, A&A 581, 10

Science

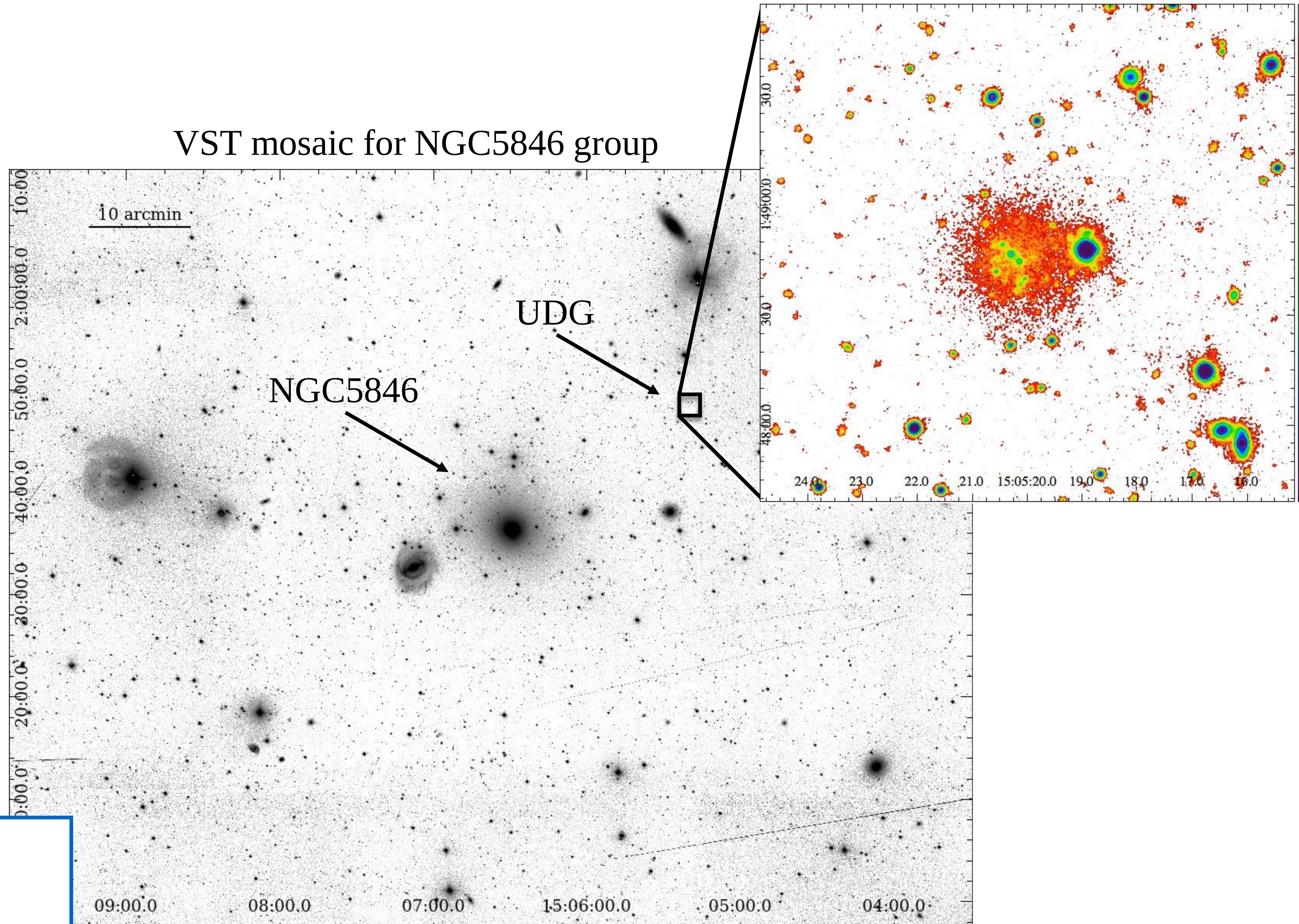
Ultra Diffuse Galaxies

Ultra-VEGAS

led by E. Iodice (INAF-OAC) + Fellow A. La Marca + PhD project approved INAF&IAC

- **build of statistically large sample (~1300) of newly discovered UDGs in groups & clusters**
- **structure & formation of UDGs**

VST mosaic for NGC5846 group



Publications:
- Iodice et al. 2021, A&AL sub
- La Marca et al. 2021, in prep
- Iodice et al. 2020, A&A 642, 48
- Forbes et al. 2020, MNRAS 494, 5293
- Forbes et al. 2019, A&A 626, 66

Science

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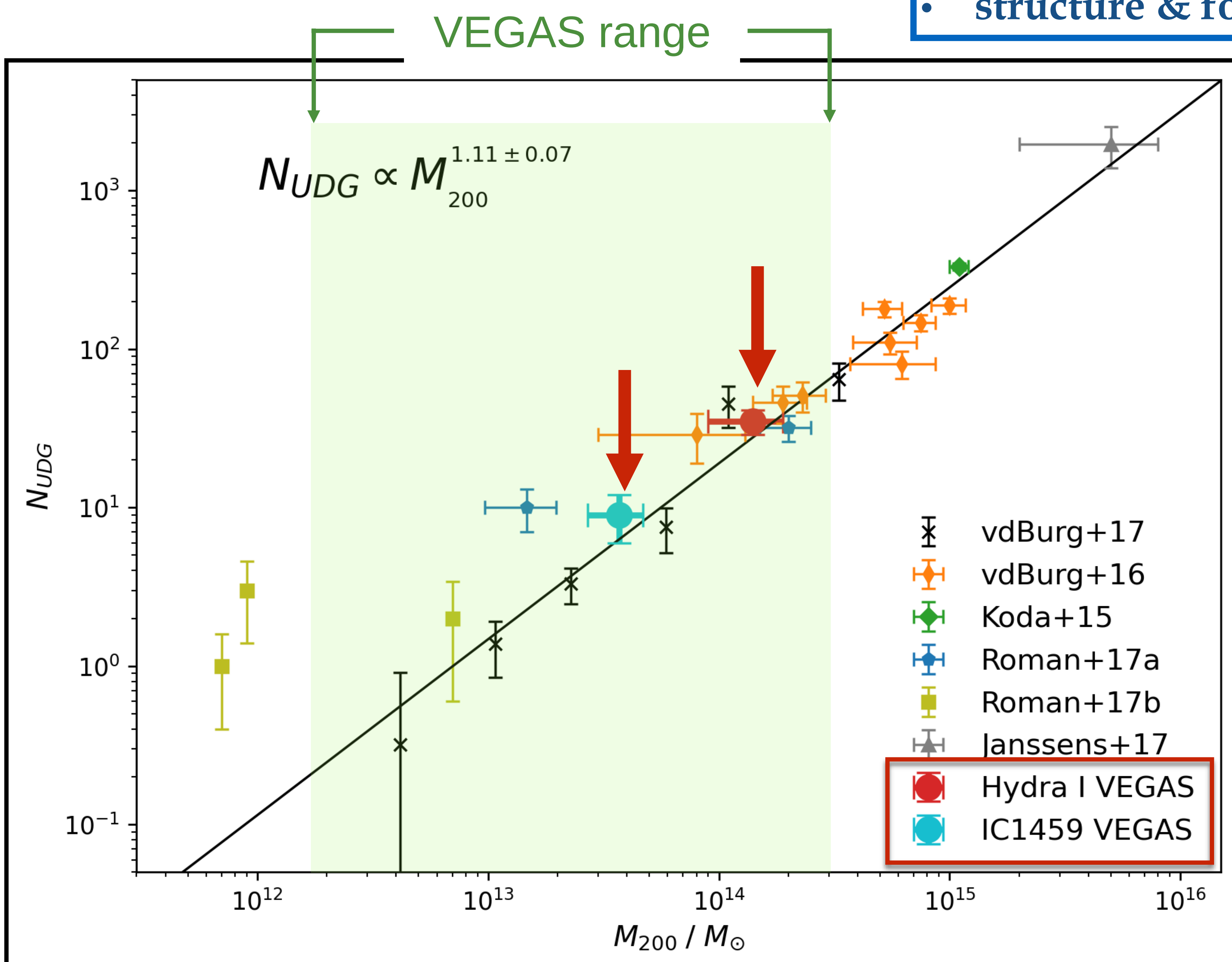

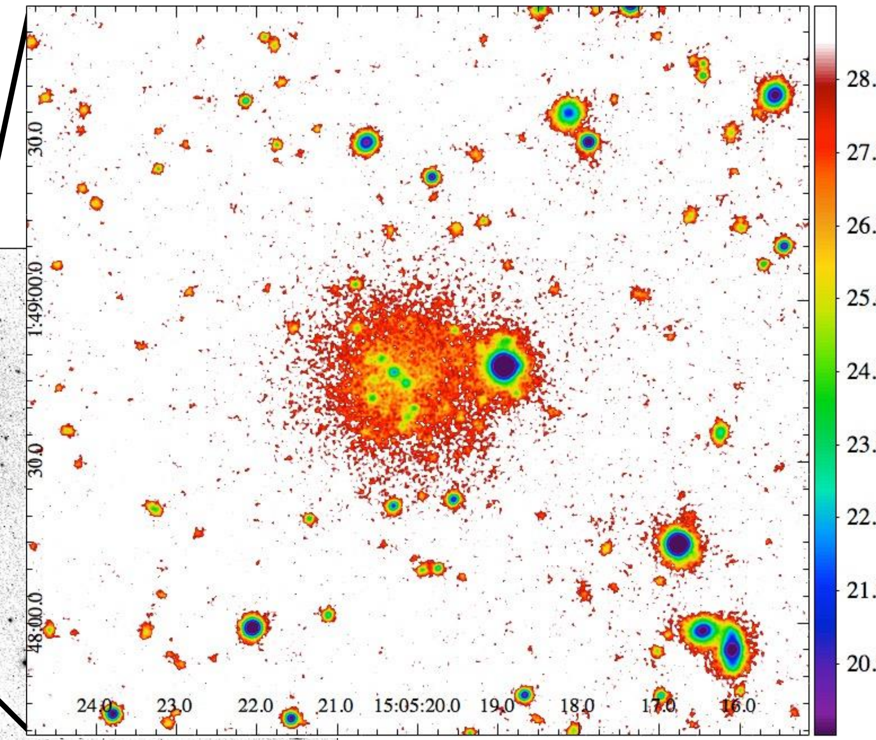

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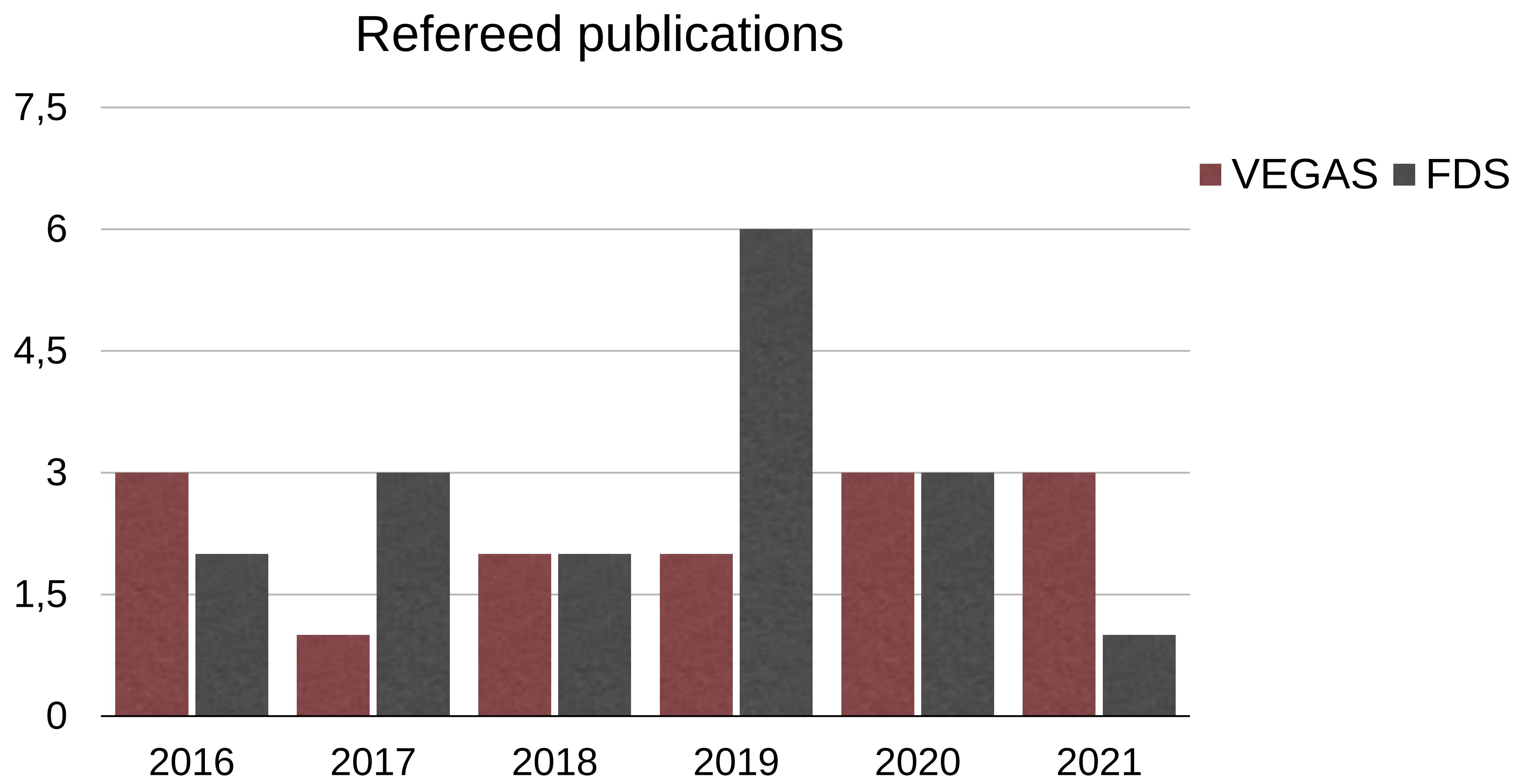
- Iodice et al. 2020, A&A 642, 48
- Forbes et al. 2020, MNRAS 494, 5293
- Forbes et al. 2019, A&A 626, 66

Publications & press coverages

2016-2021

- →31 papers on refereed journals
- →4 invited talks (2018-2021)
- →3 ESO Messenger papers + 1 by May 31st
- →3 ESO photo releases



VST has completed its lifetime
(10 years)

What to do next?


THANKS