MESSIER
Unveiling galaxy formation

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on behalf of the MESSIER consortium

CAS-ESA First workshop
Chengdu - 2014 February 26

cnrs dépasser les frontières
l'Observatoire de Paris
中国科学院高能物理研究所
Institute of High Energy Physics Chinese Academy of Sciences
NAOC 中国科学院国家天文台
NATIONAL ASTRONOMICAL OBSERVATORIES ,CHINESE ACADEMY OF SCIENCES

Science working group

Core team

Paris Strasbourg Heidelberg Stockholm
Caltech Arizona Columbia

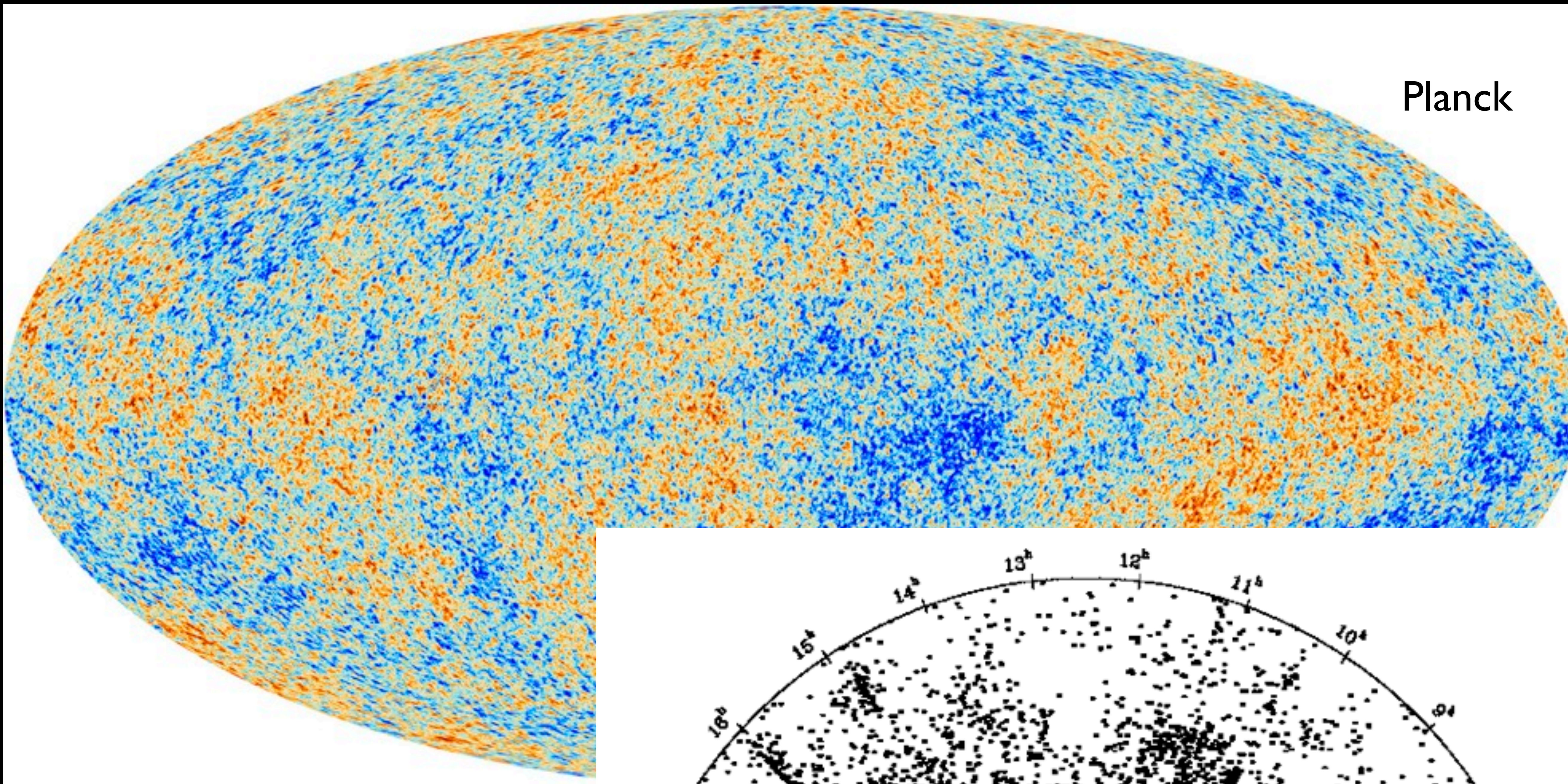
Technical team

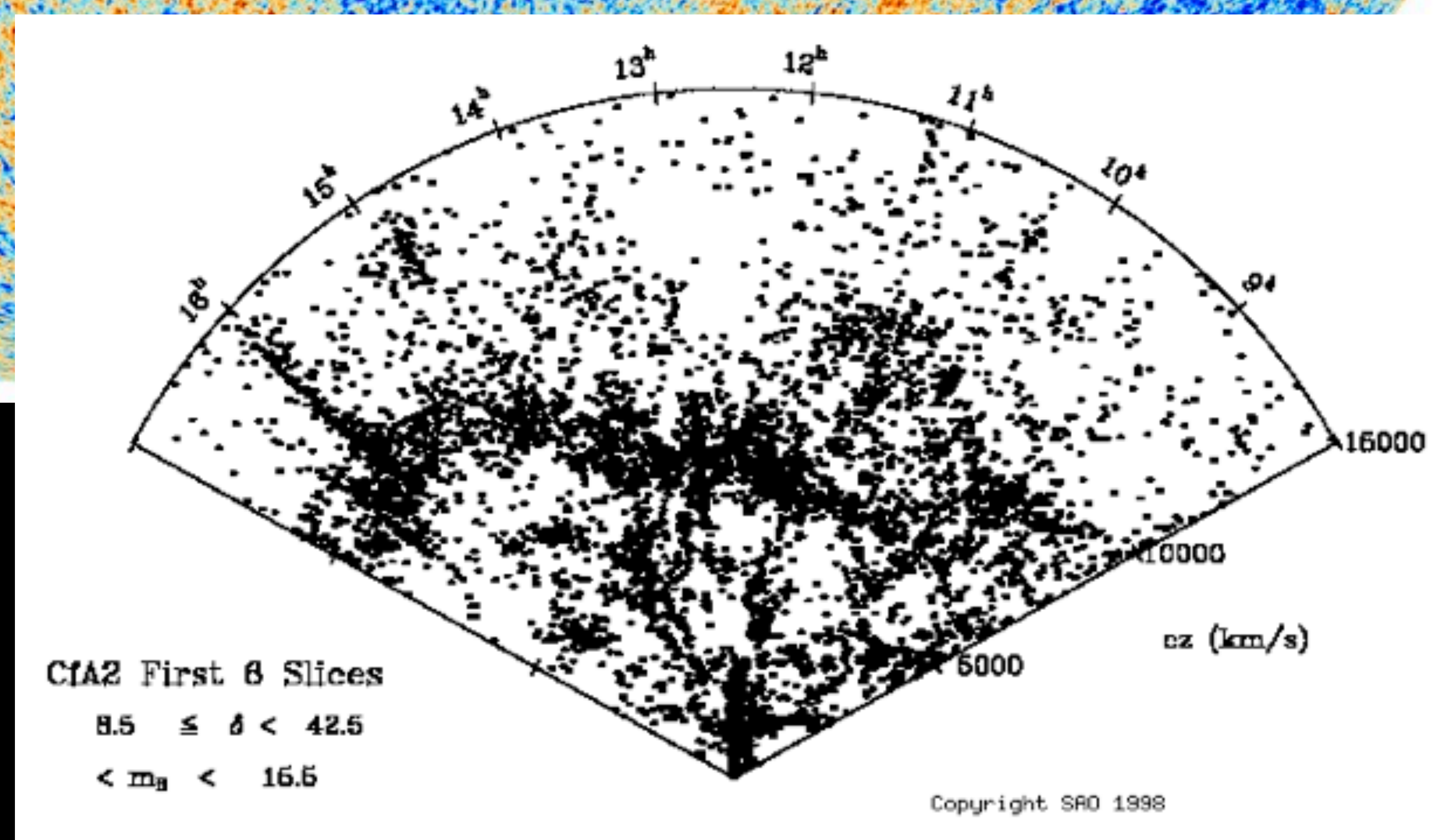
Paris Marseille Shanghai

Interested parties: >100 researchers over 30 institutes

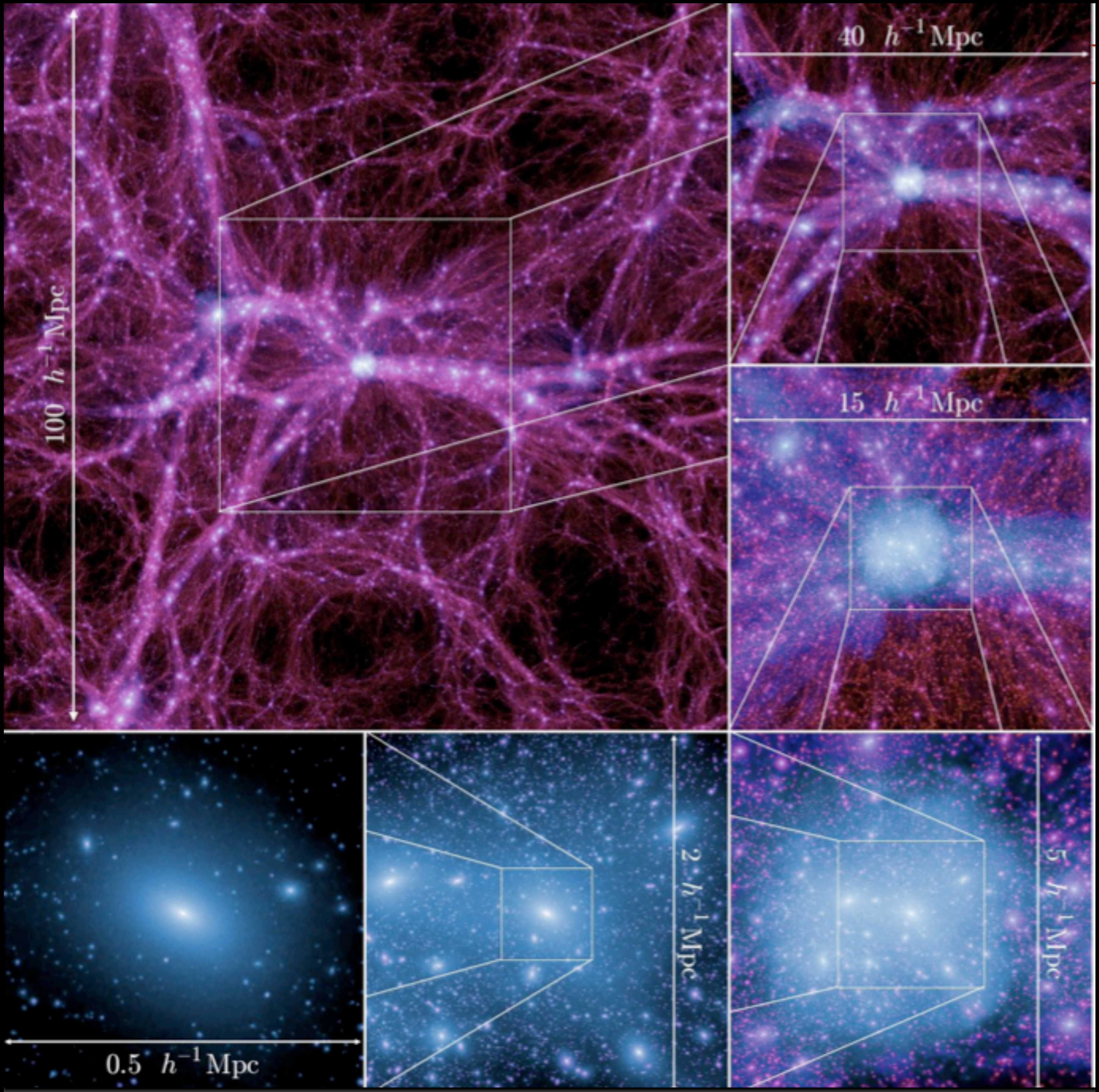
Standard cosmological model ΛCDM

... from initial conditions



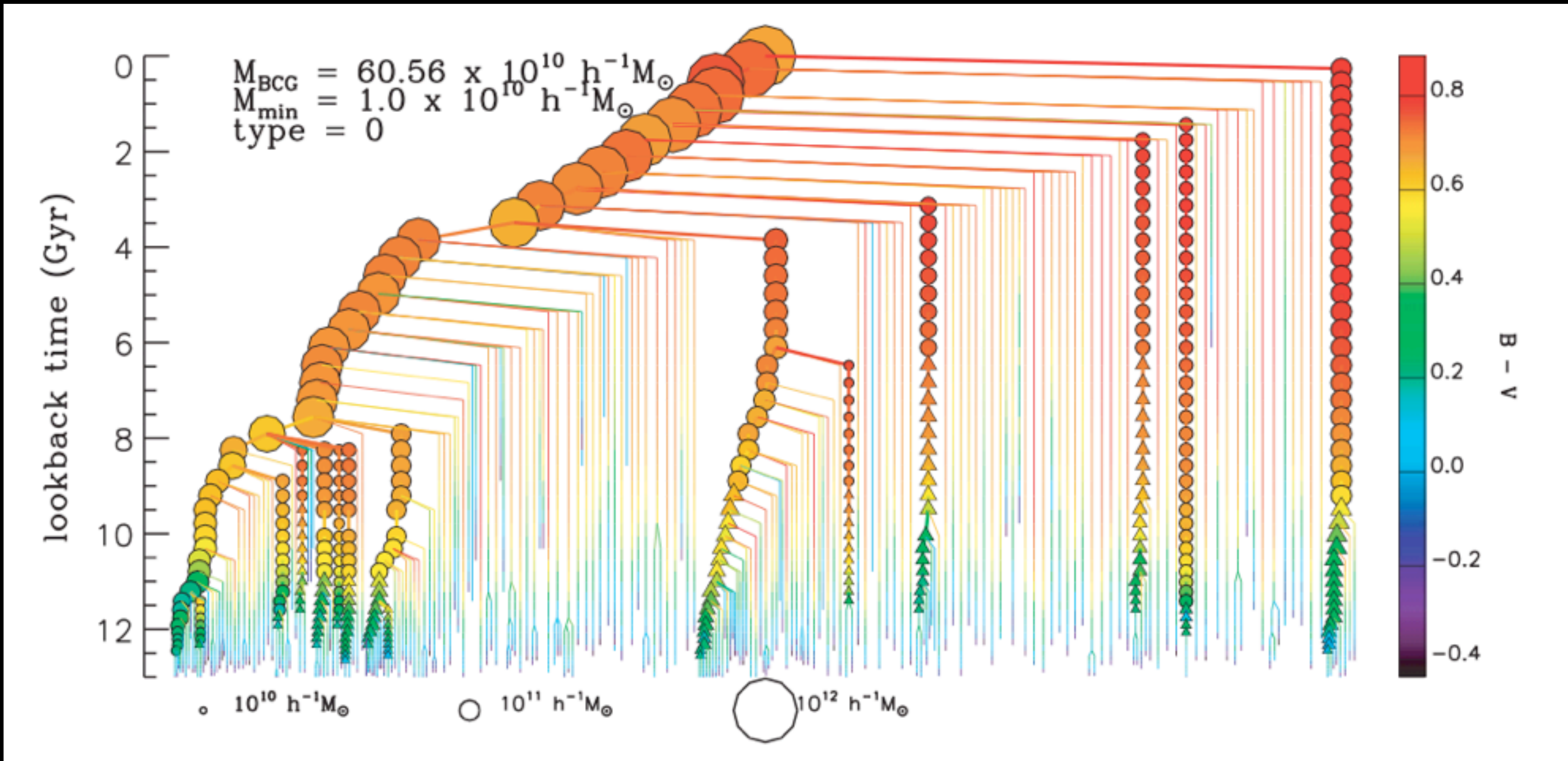


…. to non-linear structures:
filaments, clusters, galaxies

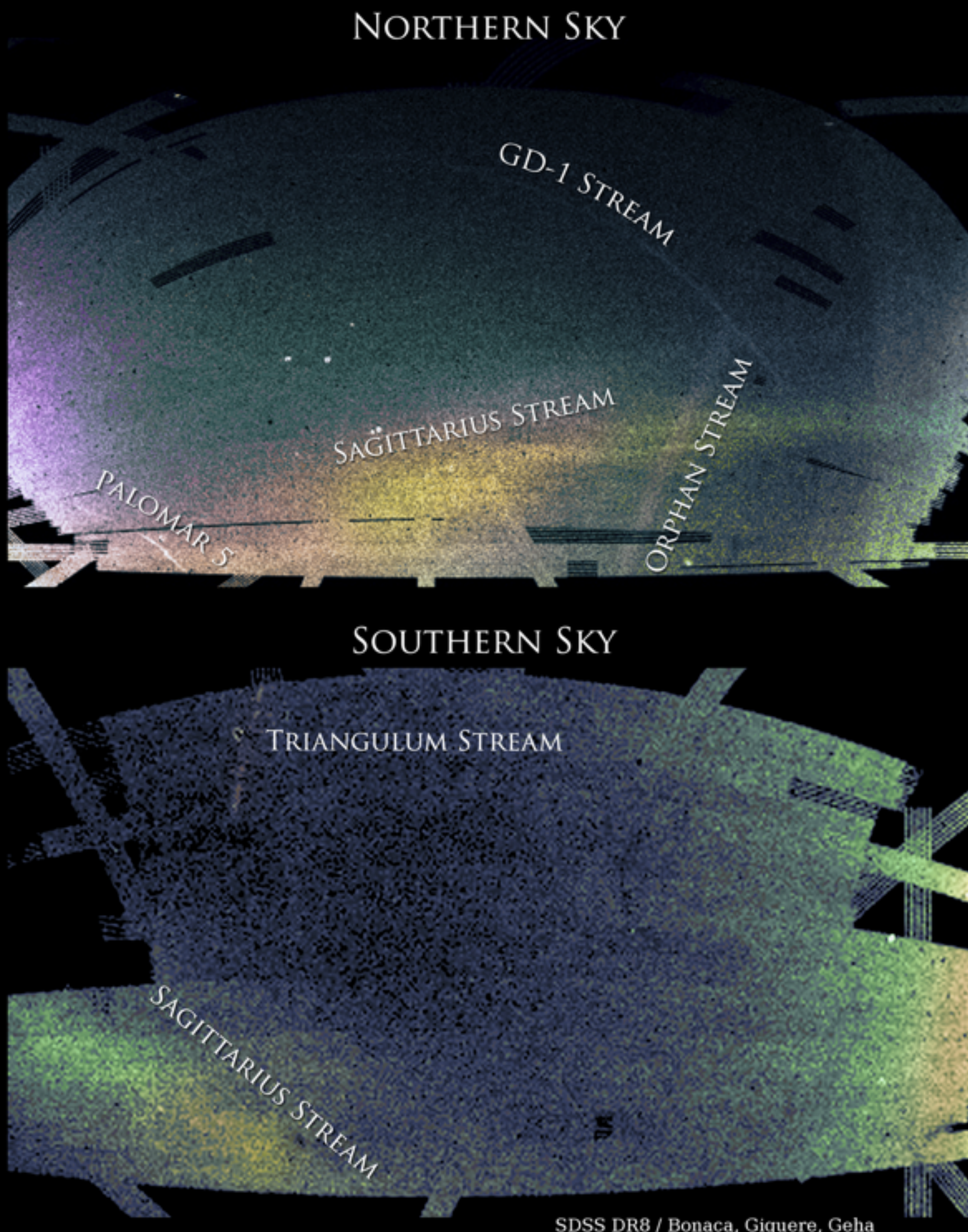


Boylan-Kolchin et al. (2009) *MNRAS* 398, 1150

Hierarchical bottom-up accretion/merging of cold dark matter (sub)haloes



De Lucia & Blaizot (2007) *MNRAS* 375, 2



Can we detect the fossil record of past accretion events in our Galaxy and beyond ?

MESSIER's two driving science cases

To critically test the ΛCDM paradigm on *non-linear* scales

- How do galaxies form by accretion?

  Anisotropic accretion from filaments? Mergers?

  Discs of satellites? Missing satellites ? Halo profiles?

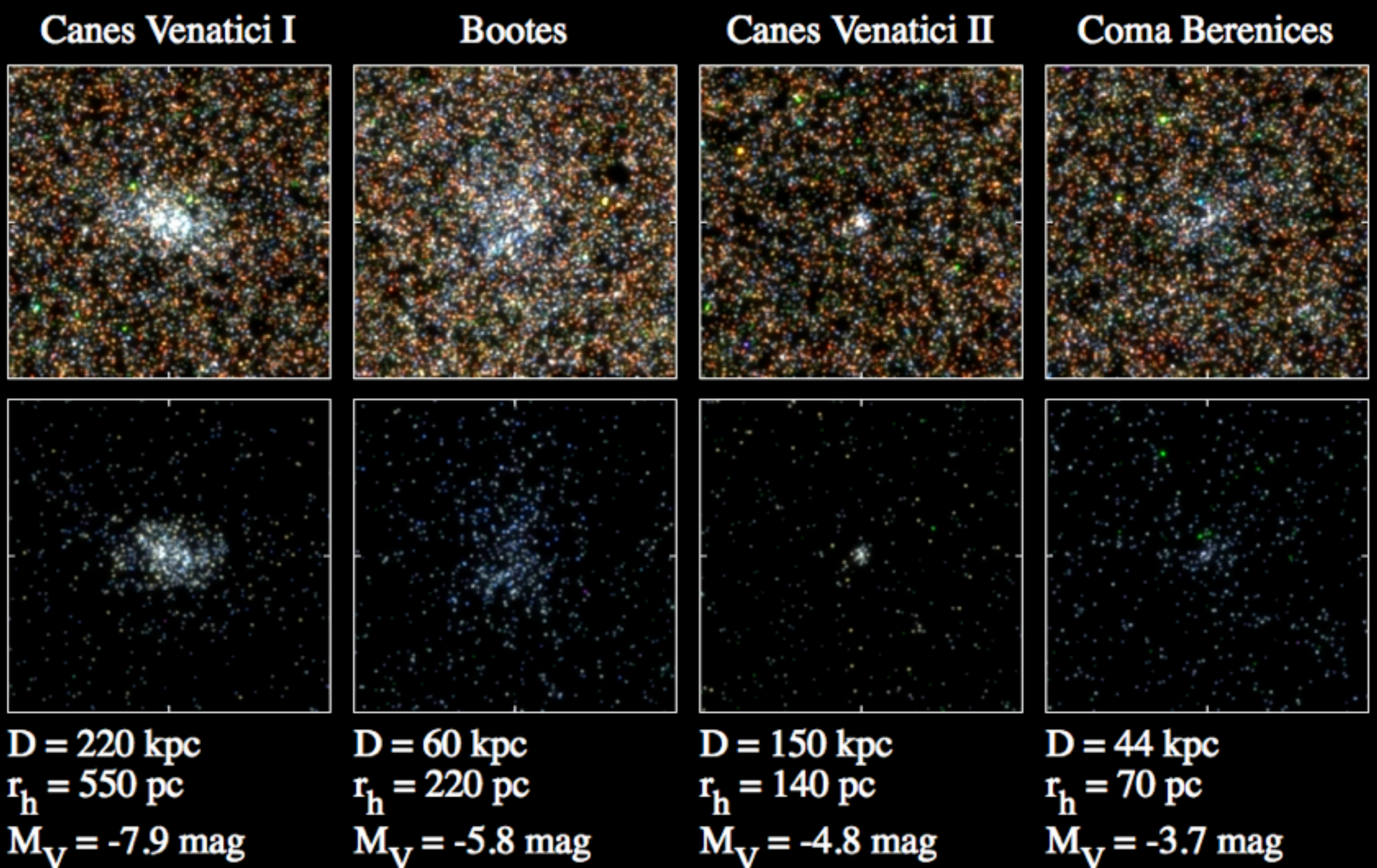
- What are the properties of the cosmic web ?

  Does it exist? Do baryons follow dark matter?

  Reservoir of missing baryons? Shock heated? Ionisation?

ESA *Cosmic Vision*:	4.2 The universe taking shape
NSF *Decadal Survey*:	How do cosmic structures form and evolve ?
Europe ASTRONET:	3.2 Cosmic web 3.4 How were galaxies assembled?

Key prediction of the ΛCDM paradigm
(over?) abundance of dwarf satellites



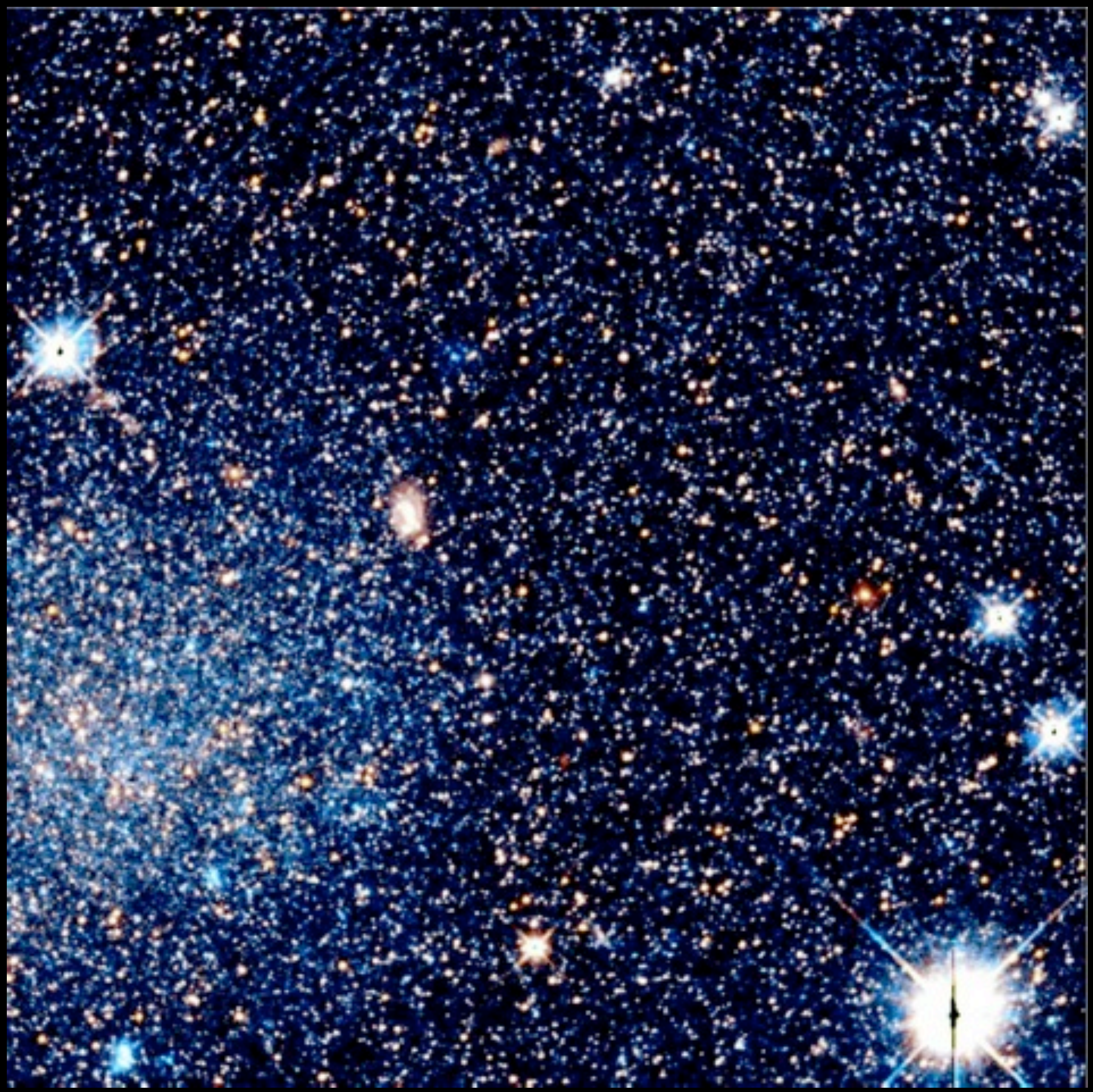
Belokurov et al. (2008)

All newly-discovered satellites of the Galaxy and Andromeda
are at the limit of surface brightness reachable by counting (resolved) stars

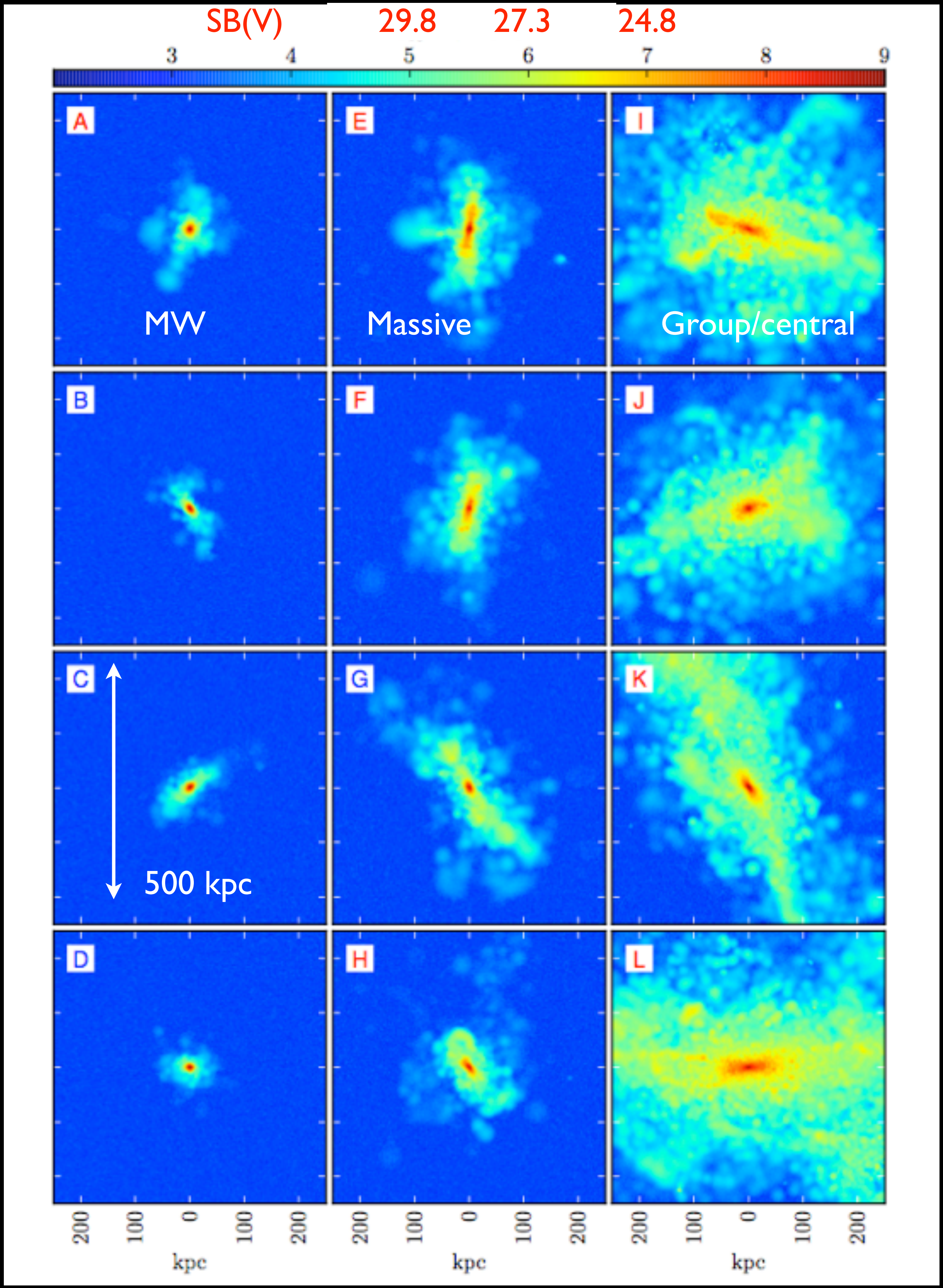
Leo T

Ground-based

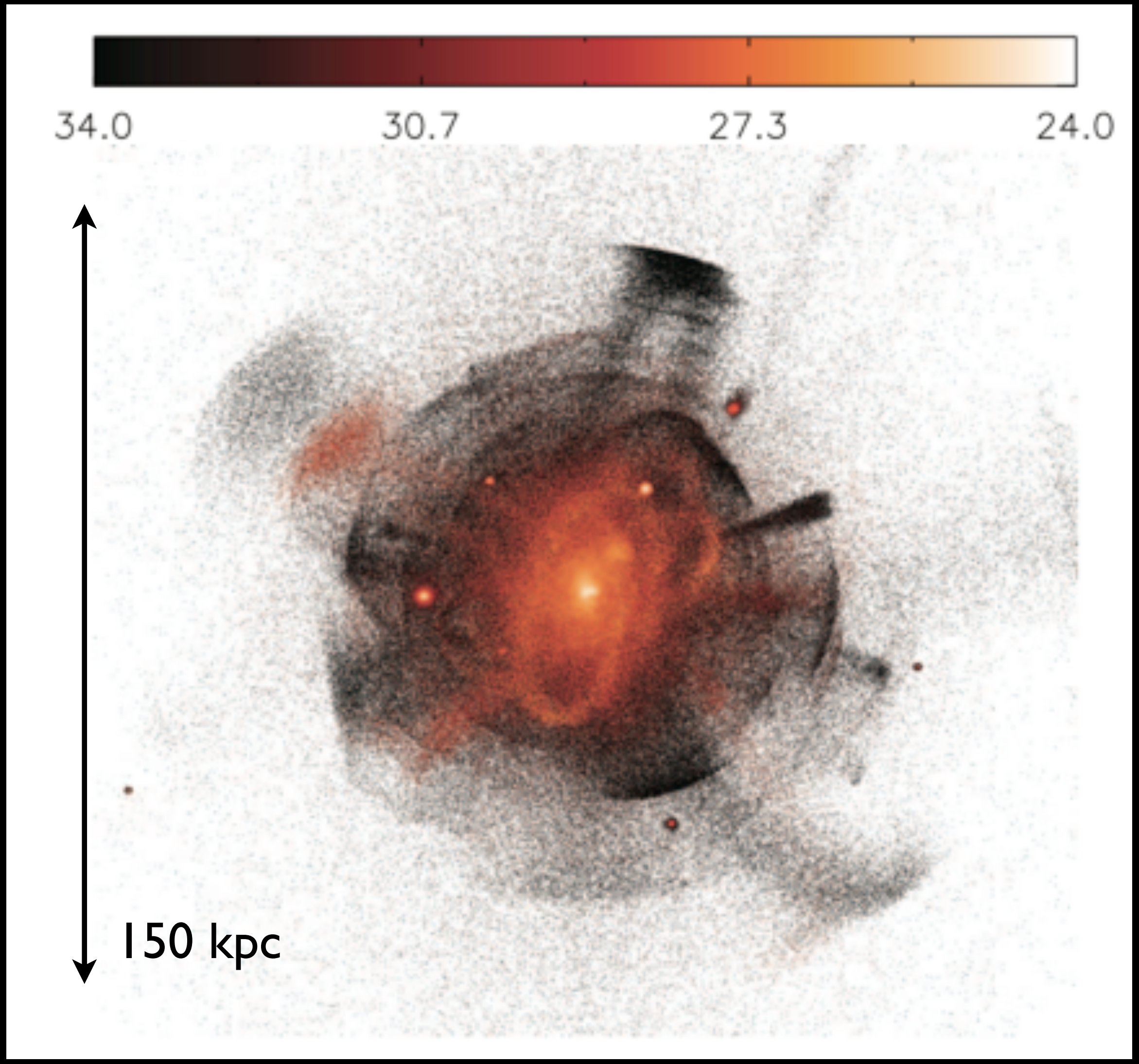
And IV



HST



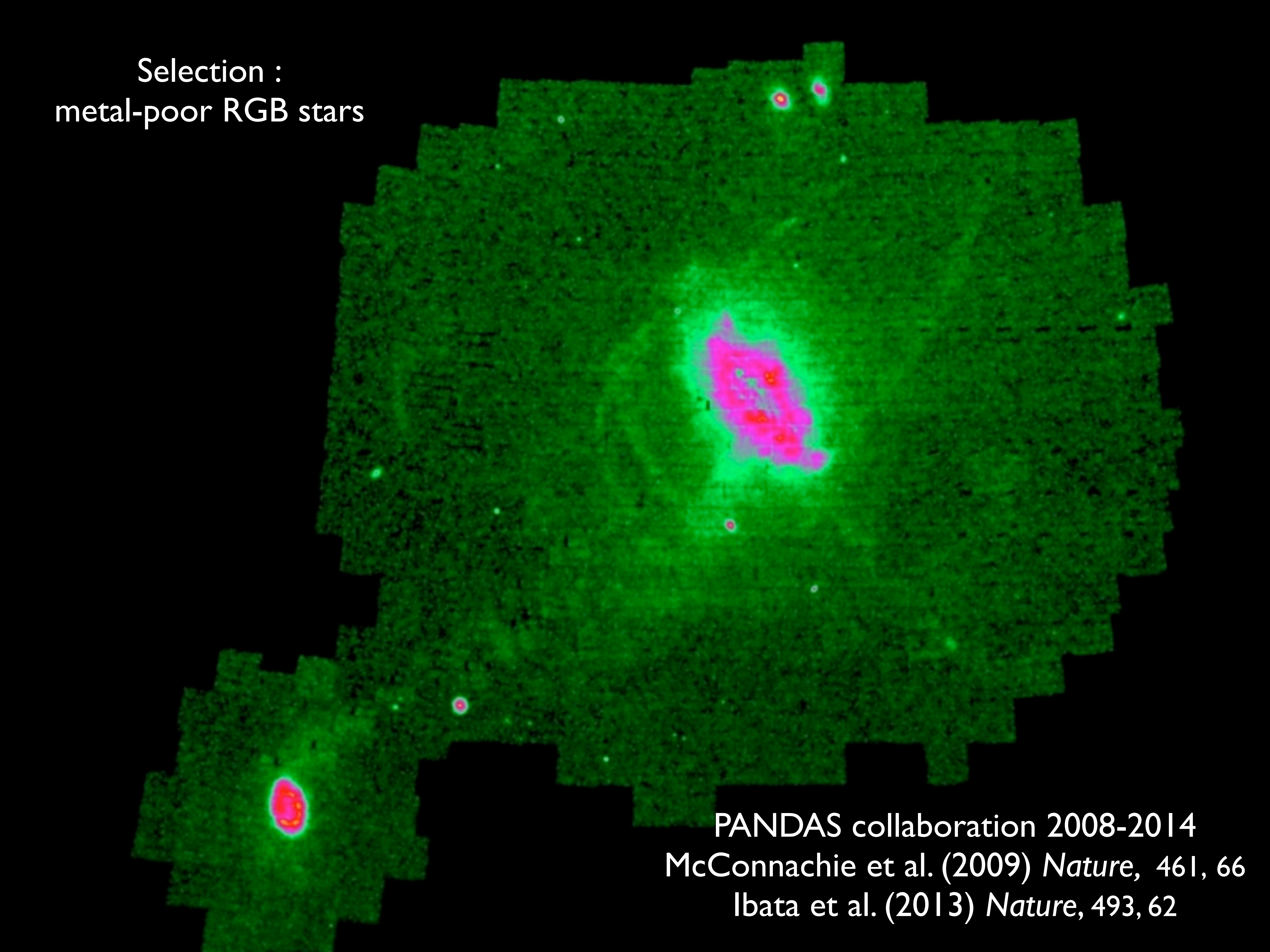
Cooper et al. (2013)

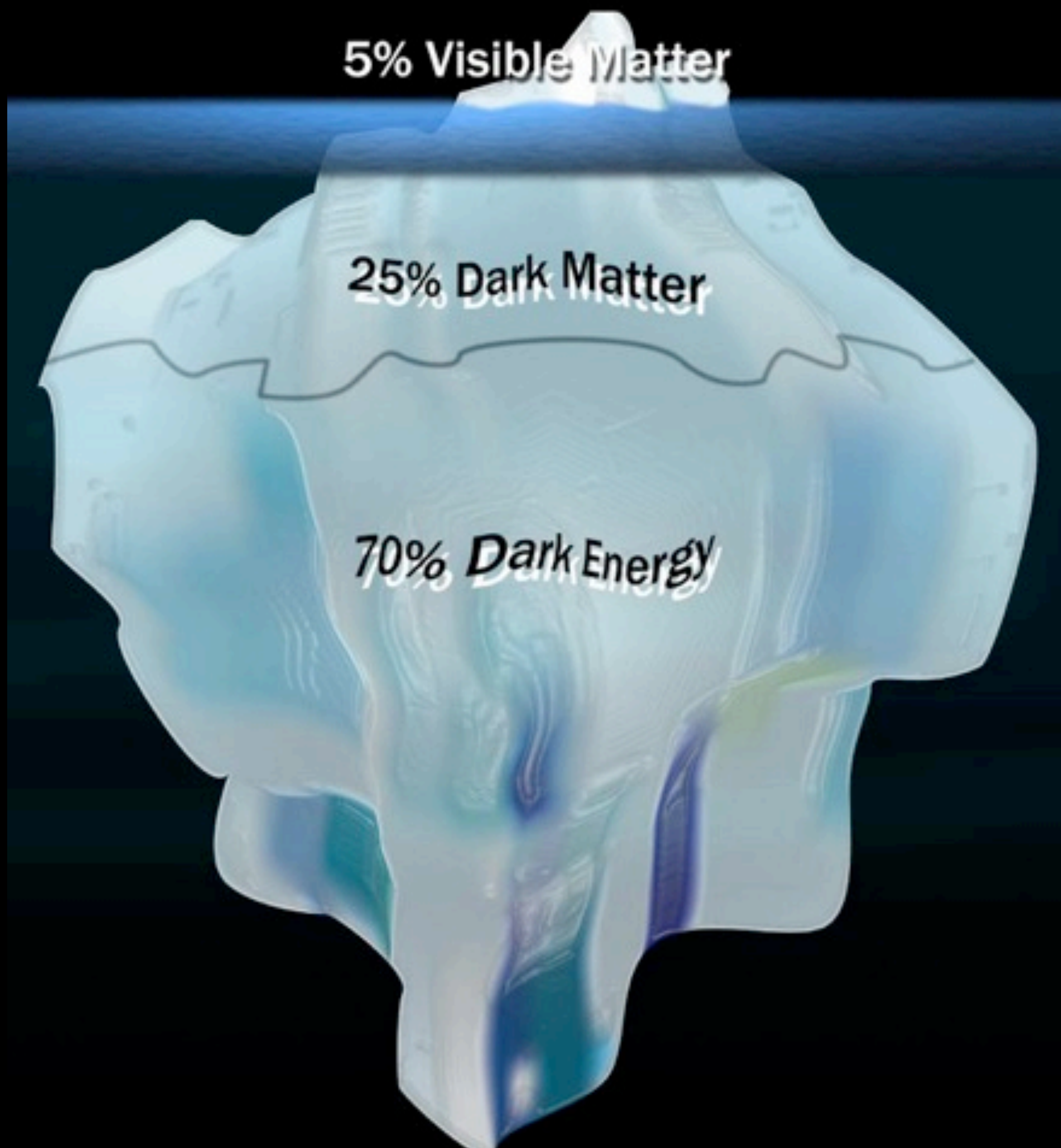


Font et al. (2008)

Most predicted key structures lie at surface brigtness levels below 30 mag arcsec^{-2}

Unreachable from the ground


Selection :
metal-poor RGB stars
PANDAS collaboration 2008-2014
McConnachie et al. (2009) *Nature*, 461, 66
Ibata et al. (2013) *Nature*, 493, 62



[...] *galaxies are like icebergs and what is seen above the sky background may be no reliable measure of what lies underneath.*

M. Disney (1976)

The unprobed realm of the low surface brightness universe

Mihos et al. (2005)

Limited by systematics
- sky variability
- straylight
- flat field accuracy
- extended PSF wings

Current instrumentation is not adequate

Signal received by an *unresolved* source:

$$F_{\rm point} \;\propto\; A\,\epsilon\,t_{exp}\,10^{-0.4\,m_{tot}}$$

→ drives telescopes with large diameter and large focal length

Surface brightness received by a *extended* source:

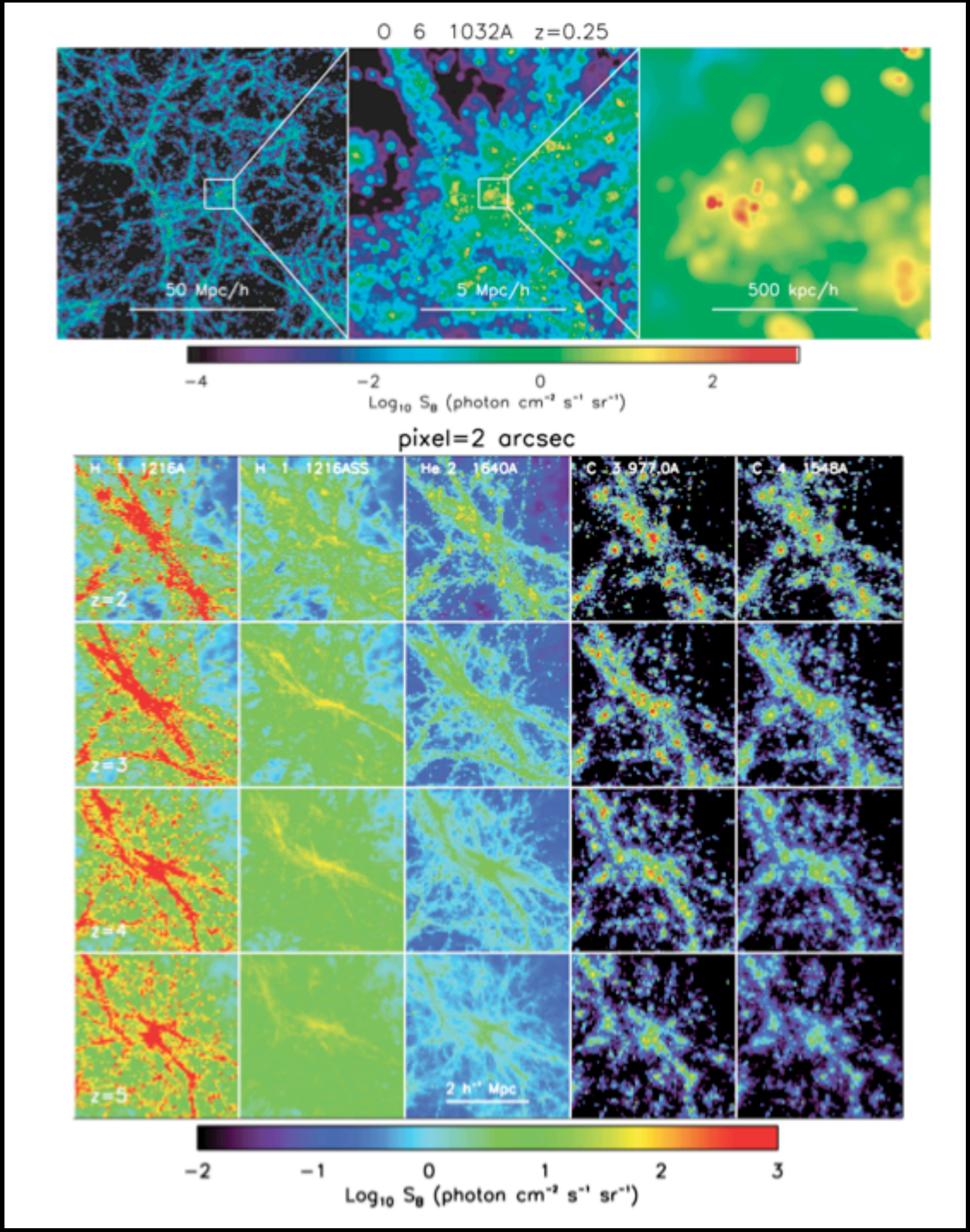
$$SB_{\rm extended} \;\propto\; \left(\frac{D}{f}\right)^2 \epsilon\,t_{exp}\,s_{pix}^2\,N_{pix}\,10^{-0.4\,\mu}$$

→ requires fast optics with minimal (f/D) ratio

Driving science case #2

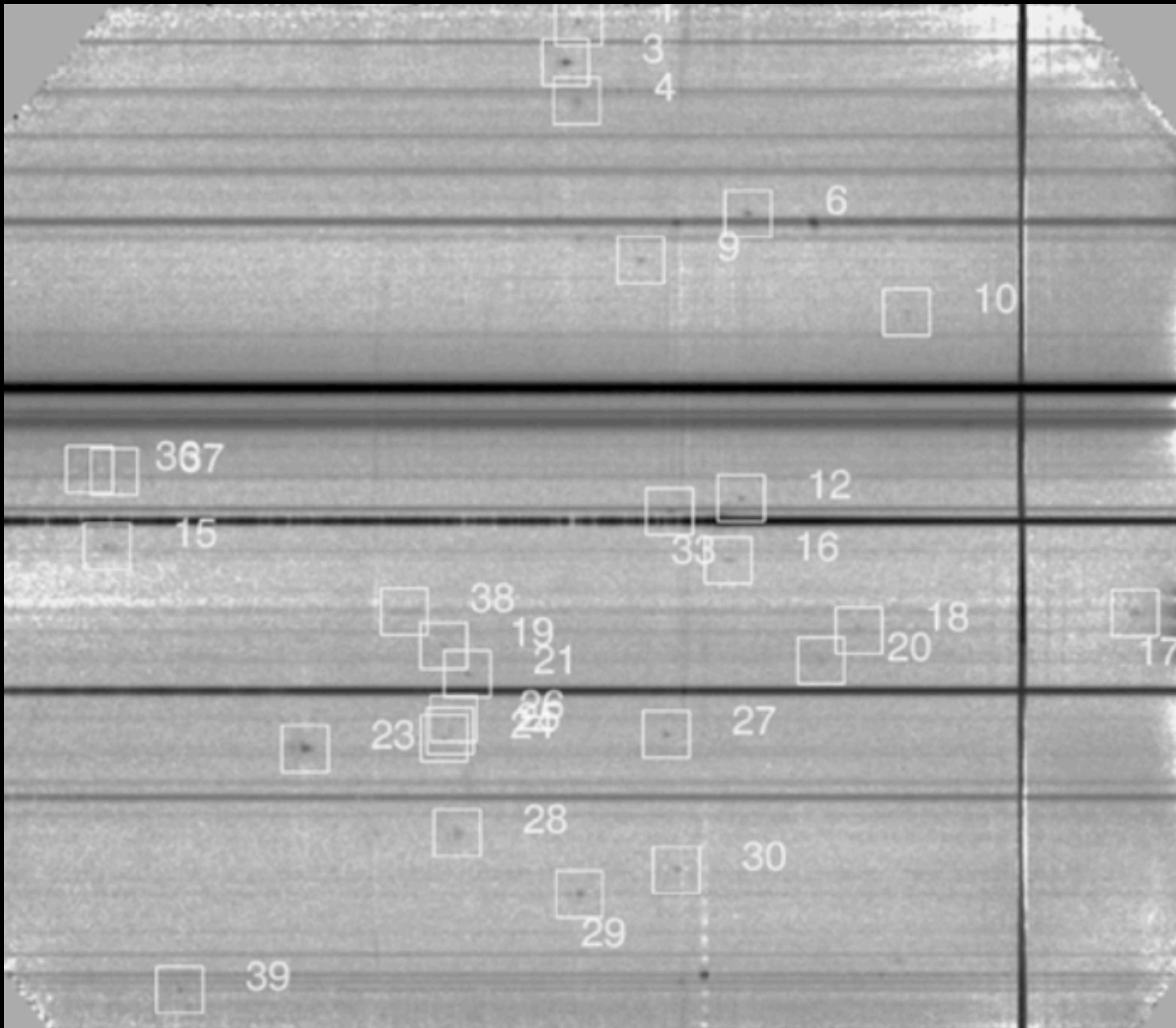
The Cosmic Web

Strongest in Lyman α by ~1000



Bertone + Schaye (2012)

Low surface brightness Lyman-α emitters

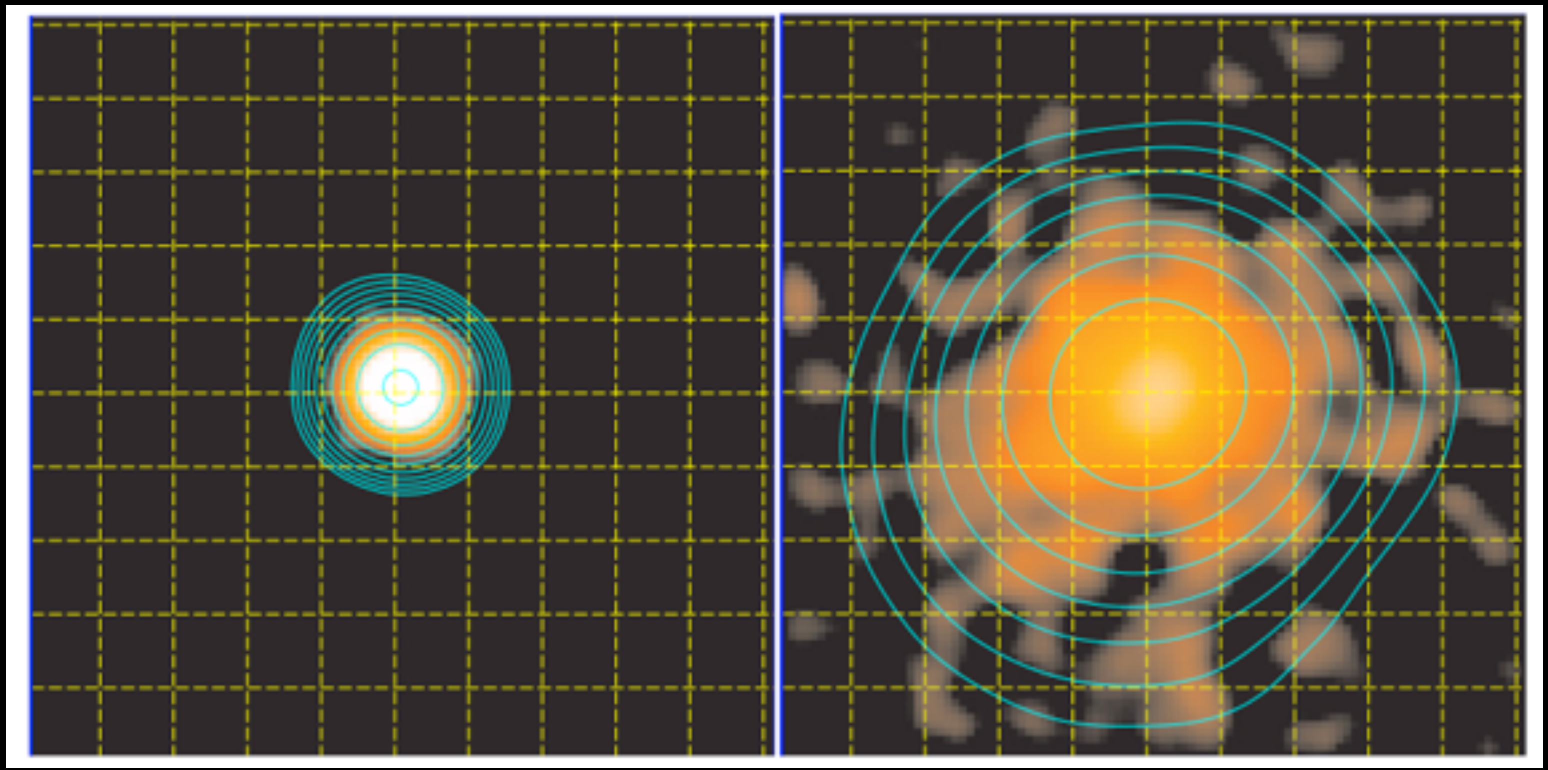


VLT
92 hours exposure

Rauch et al. (2010)

Extended Lyman-α emission from z ~ 2.65 star-forming galaxies

UV continuum



Lyman-α

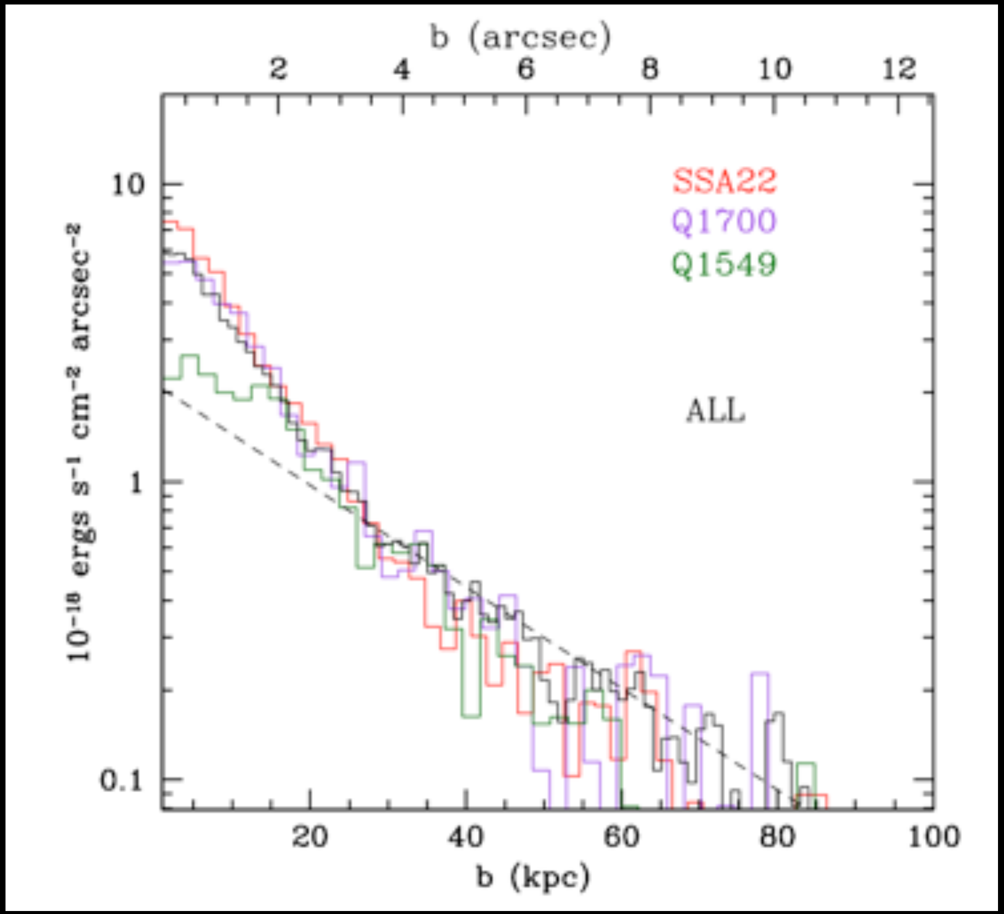
92 UV-selected galaxies with <z>=2.65

Extended haloes to ~ 80 kpc (when stacked)

SB ~ 10^{-19} erg s^{-1} cm^{-2} $arcsec^{-2}$

900 hours integration at 8-10m class telescopes

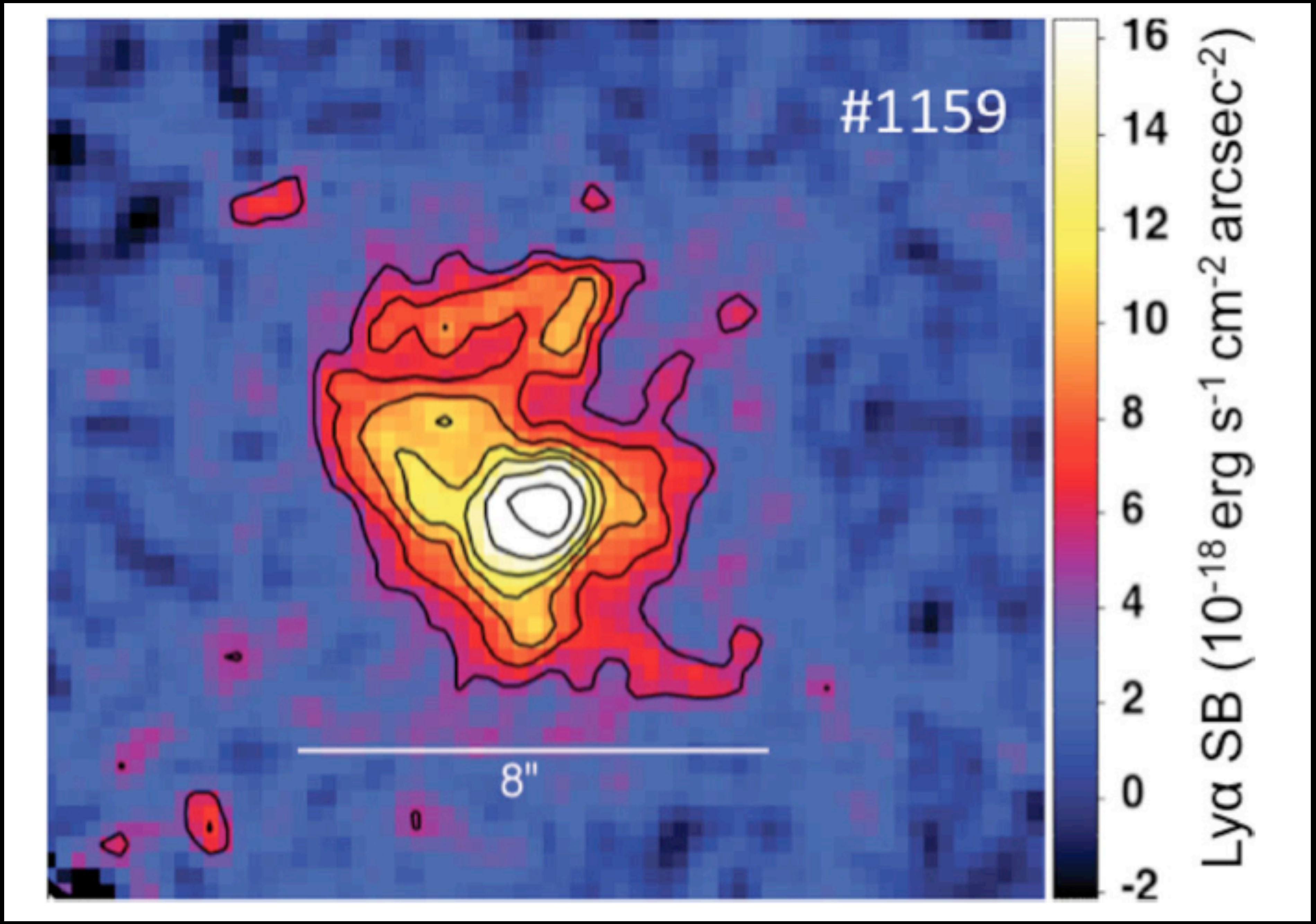
Lyman-α cooling?
Fluorescence by ionising radiation?
Scattering from circumgalactic gas?



Steidel et al. (2011)

Fluorescent Lyα emission of the circum-galactic medium around a quasar at z=2.4

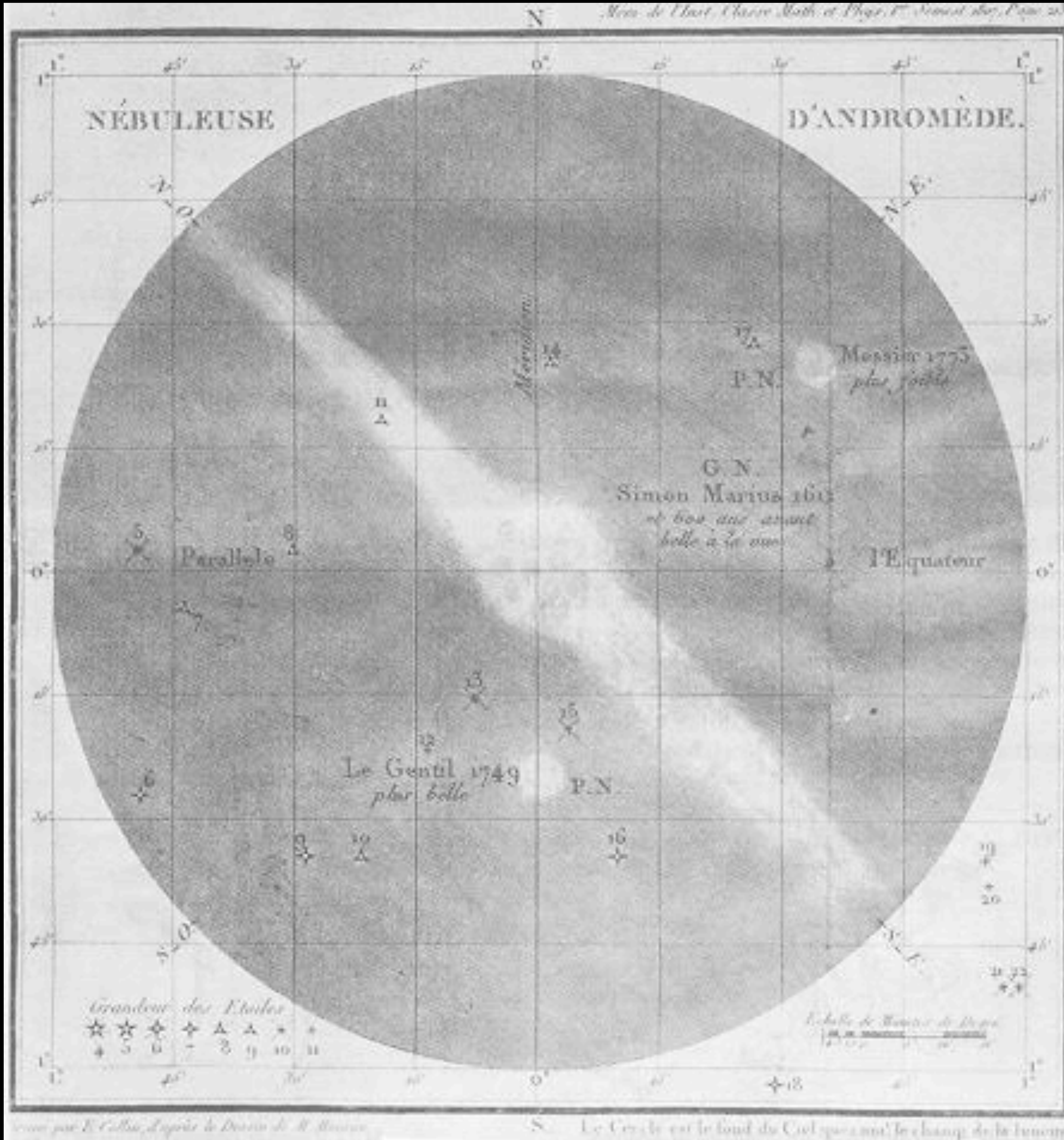
27 hours
VLT



Cantalupo, Lilly & Haehnelt (2012)

The MESSIER satellite

Scientific and technical challenges



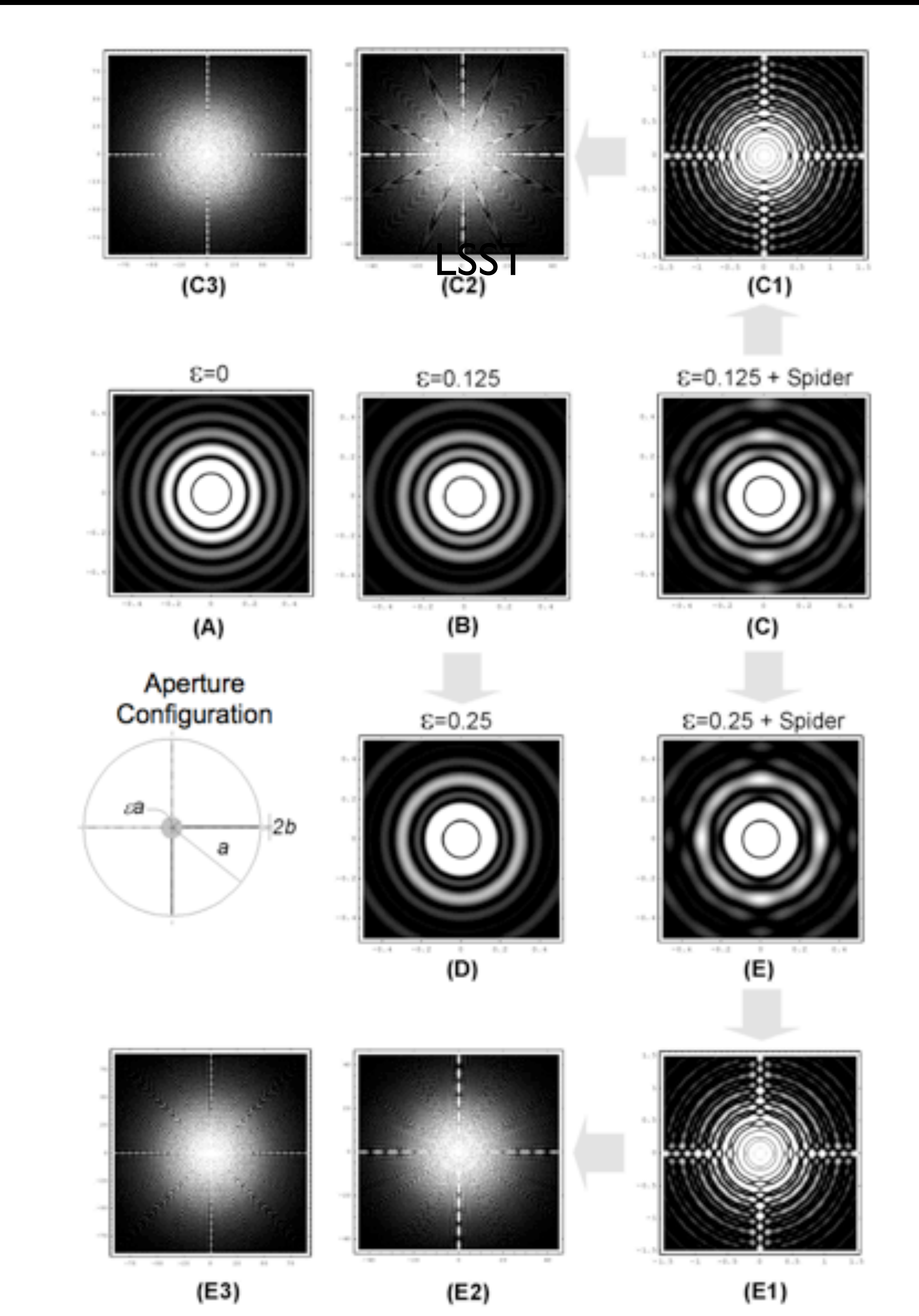
First catalogue of diffuse objects

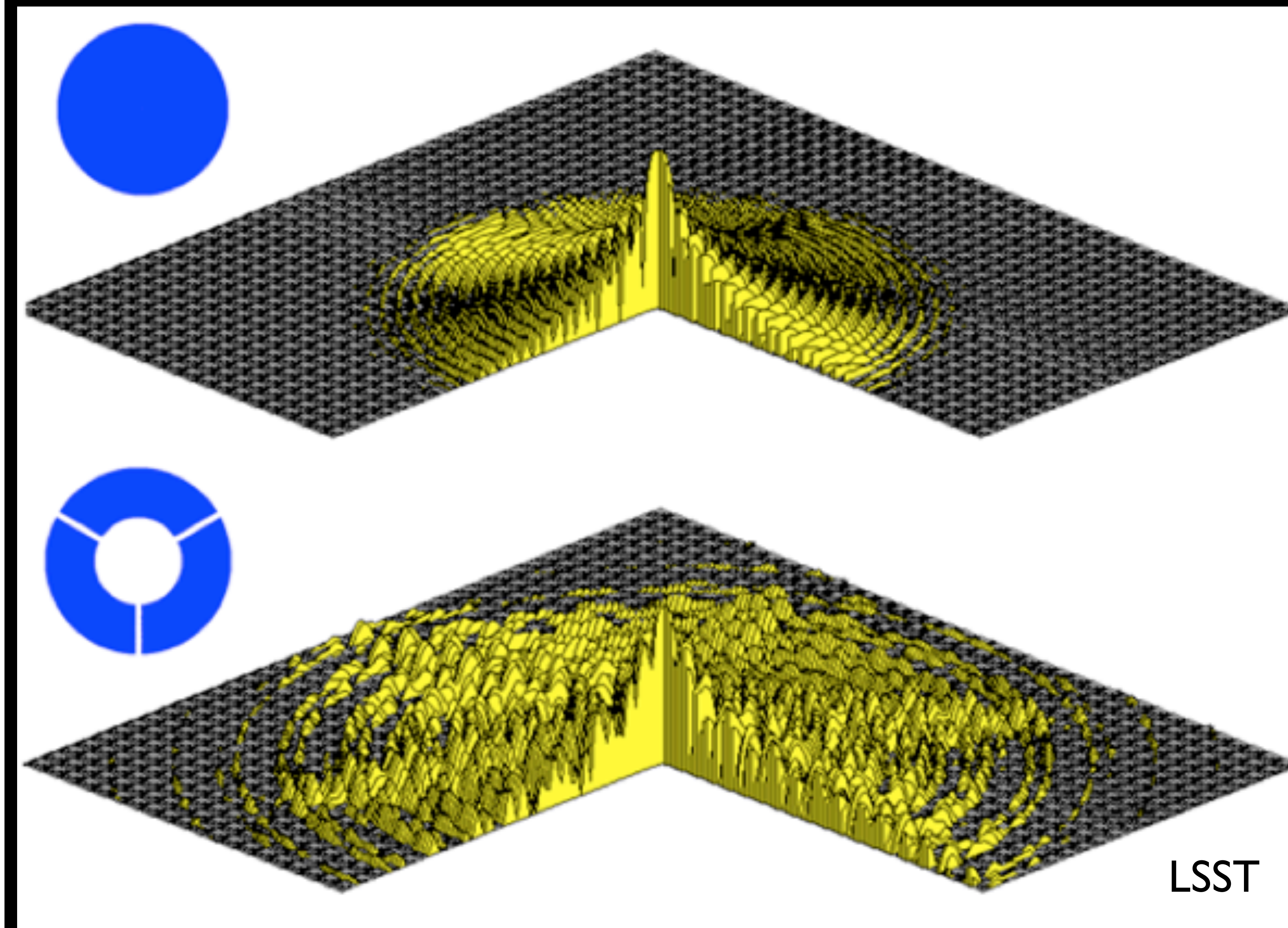
Messier (1771)
Mem. Acad. Sci. Paris

Top-level design requirements

- FOV 2°x4° (*lifetime of satellite*)
- Focal ratio f/2 (*200x better than HST*)
- Central obscuration none (*minimal PSF wings*)
- Spatial resolution 1-2″ per pixel
- Roughness < 0.5 µm (*UV to optical*)
- Flat field rms < 0.025% (TDI / *drift scan*)
- Distortion < 0.5% in one direction
- Diameter 40 cm (*set by platform/design*)

Obstruction by secondary mirrors yields very extended PSFs

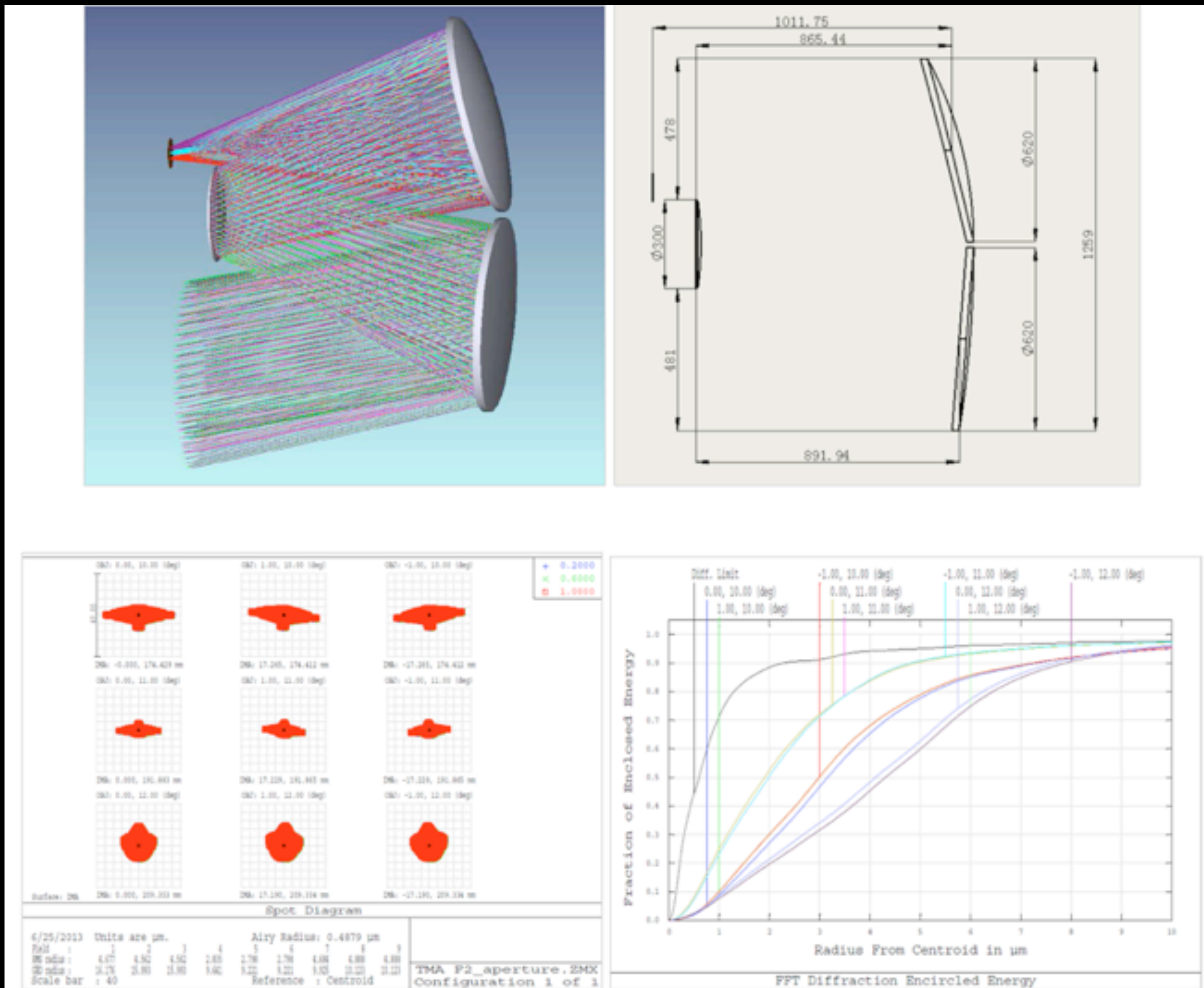




Zero obstruction is required

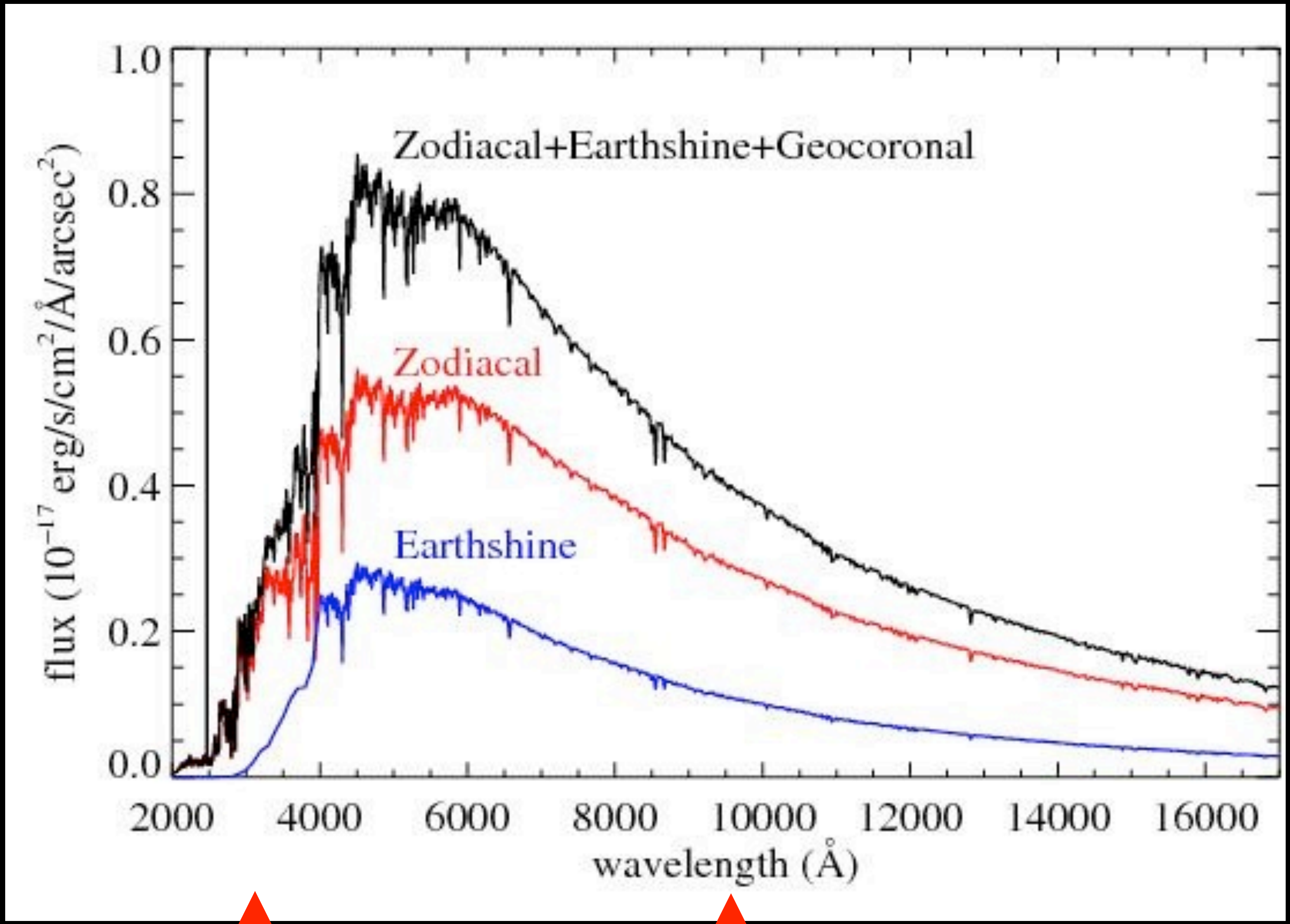
Additional requirements

— flat(ish) focal plane
— no lenses (Čerenkov radiation)



Current solution

TMA
unobscured, off-axis
easy baffling
flat focal plane
f/2
4° x 2°
TRL 9 (optics/FP)
alignment issues TBD

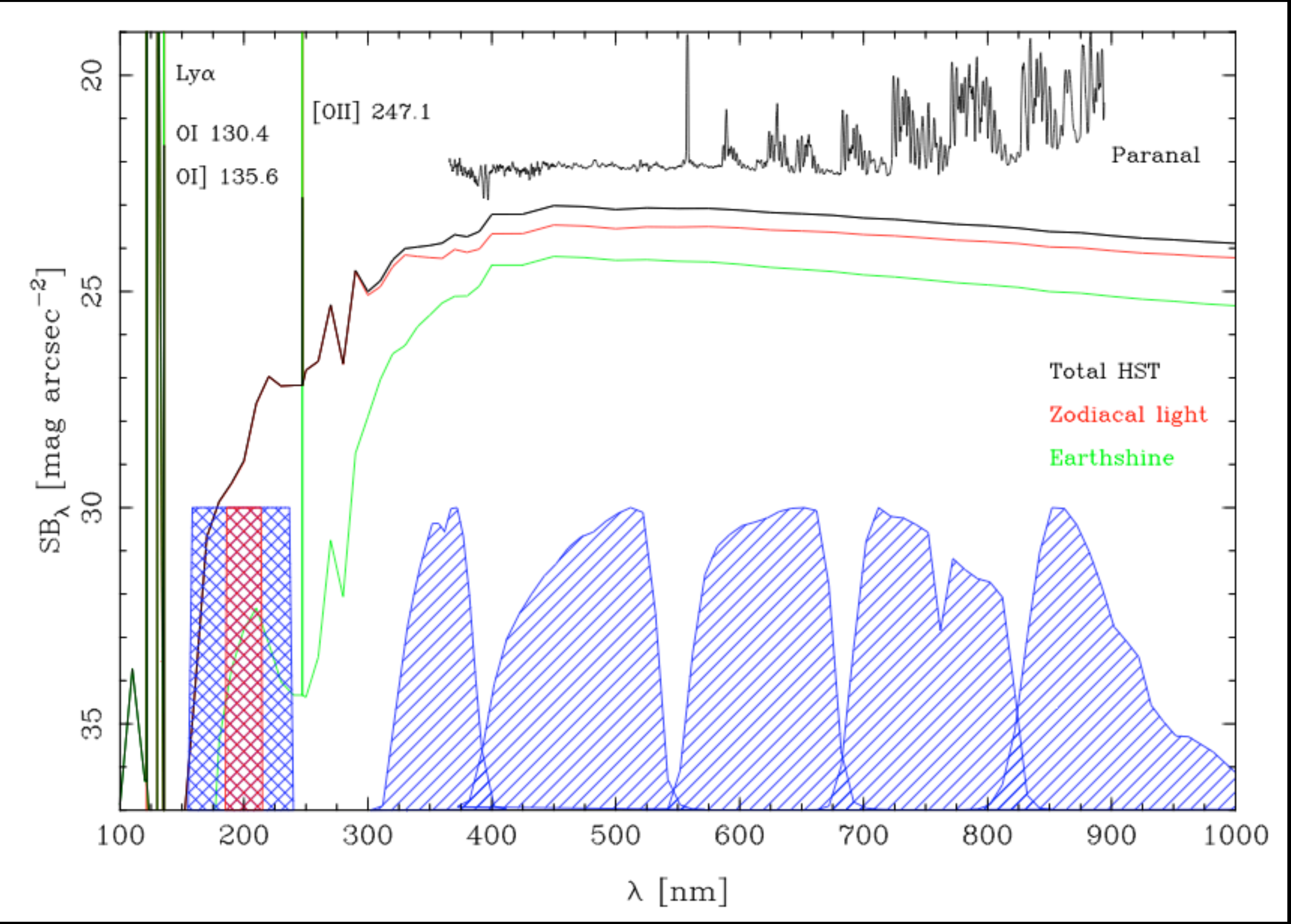


No sky variability but many foregrounds:

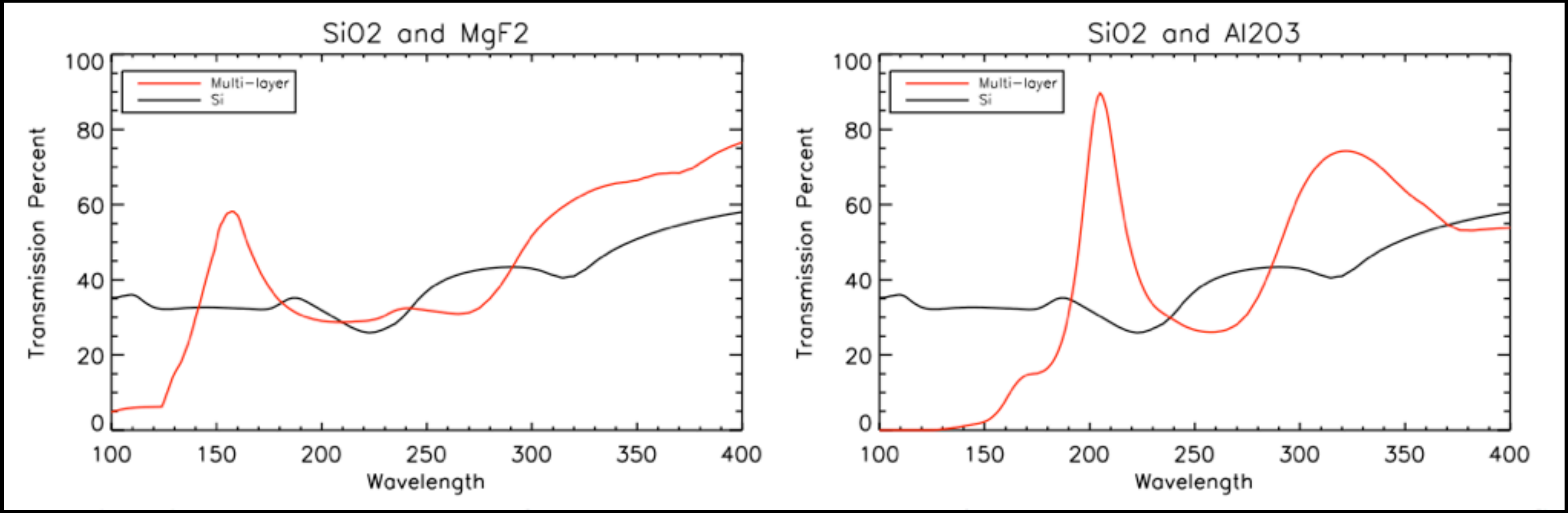
- zodiacal light (variable)
- stray light contamination
- geocoronal/airglow emission
- optical/UV emission from Galactic dust (cirrus)

Minimise zodiacal contamination while keeping key information on stellar populations

Requirement for filters



New generation of UV detectors



AR coatings allow to reach a quantum efficiency of 80-90%
Atomic Layer Deposition: multi-layer JPL/Columbia
ITAR free (in principle, TBC)

Focal plane configuration

4 x 2 independent CCD controllers in drift-scan mode

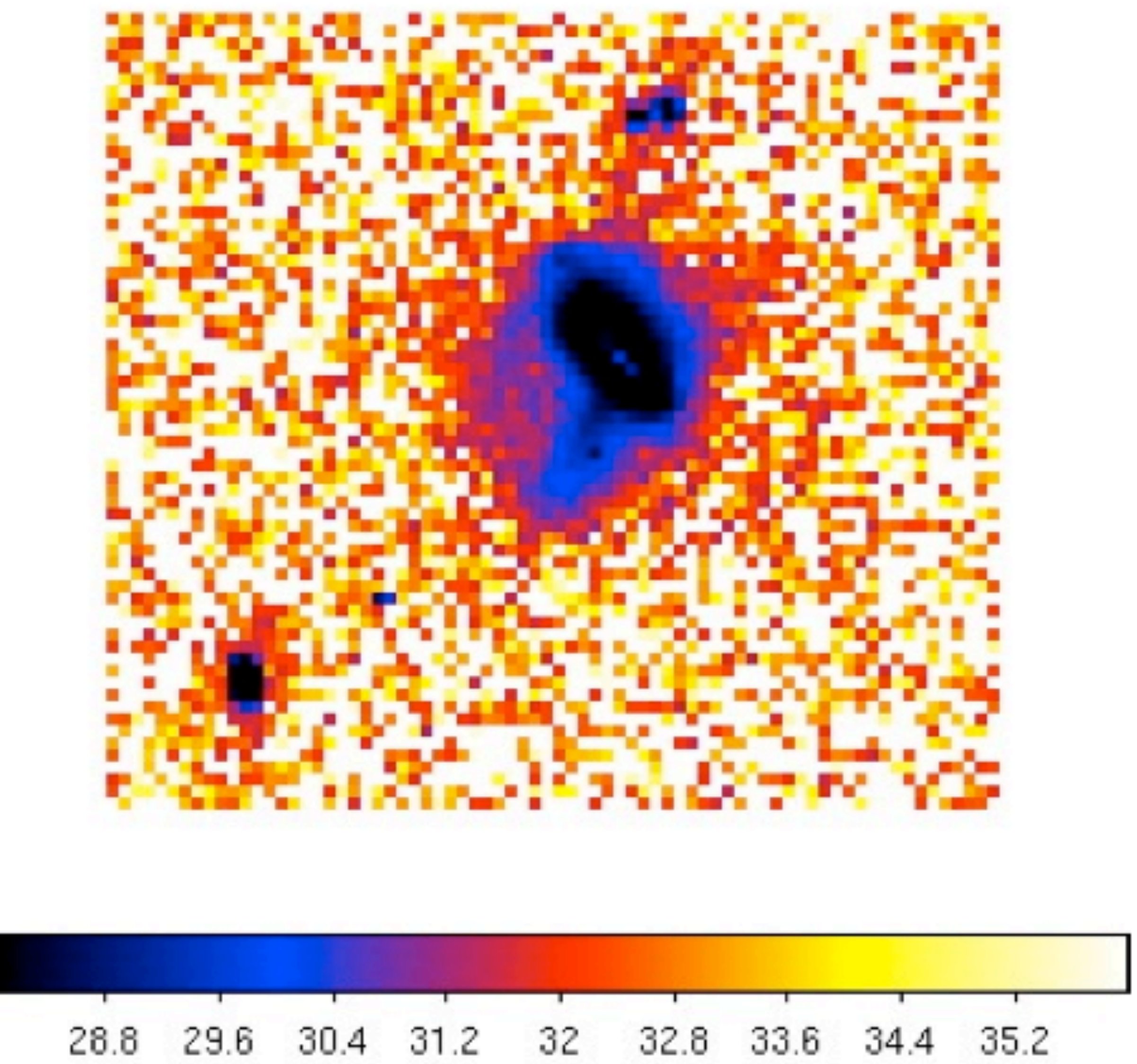
QE of each detector optimised for each filter

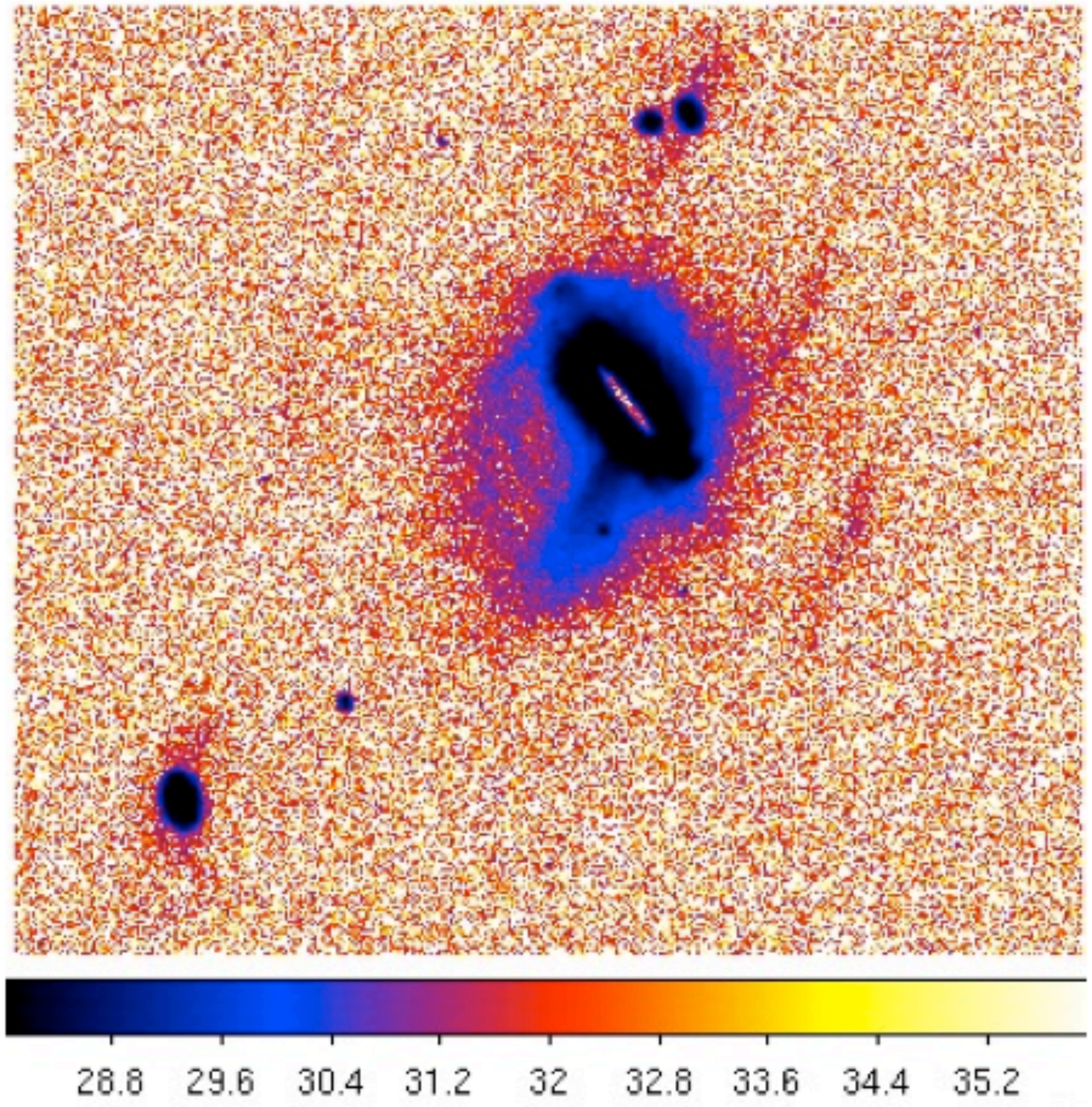
No moving parts; no coolants

r	g	u	Broad-band @200 nm Lyα
Extra broad	i	z	Narrow band @200 nm Lyα

Expected performances - I   Optical bands

Simulated MESSIER images of a galaxy at 15 Mpc



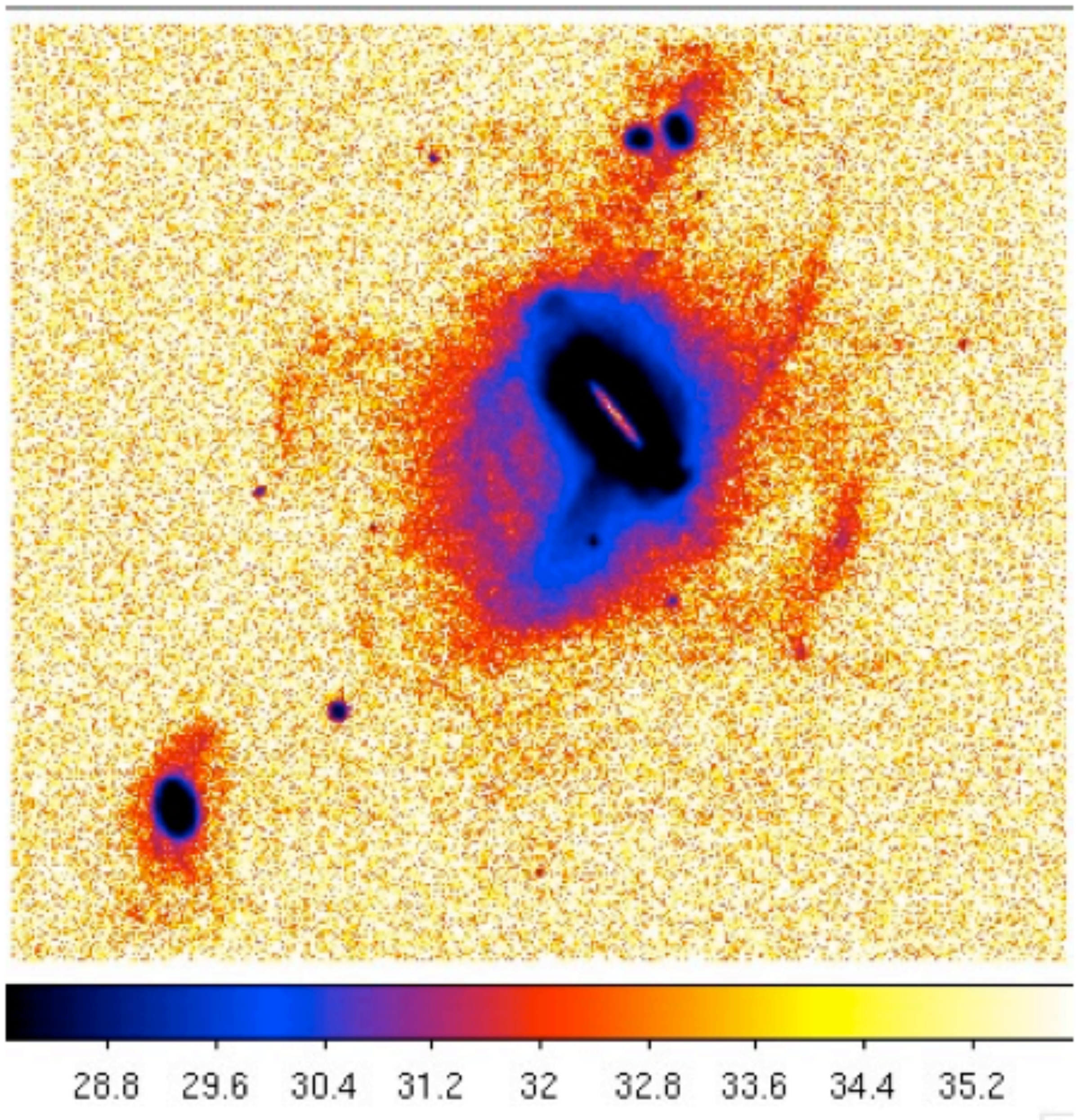


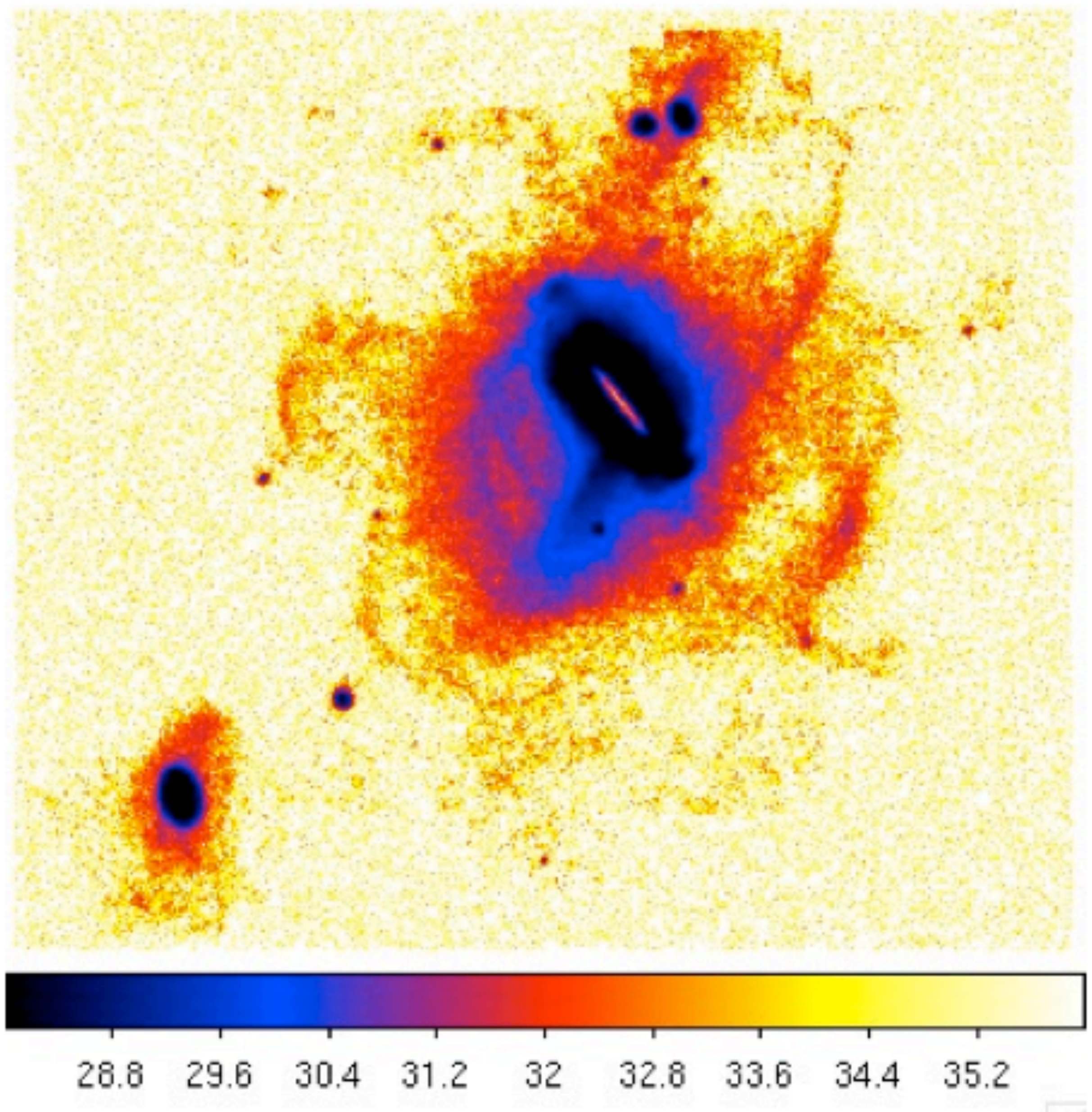
10 ksec
5 kpc × 5 kpc

100 ksec
1 kpc × 1 kpc (14″ × 14″)

Expected performances - 1 Optical bands

Simulated MESSIER images of a galaxy at 15 Mpc

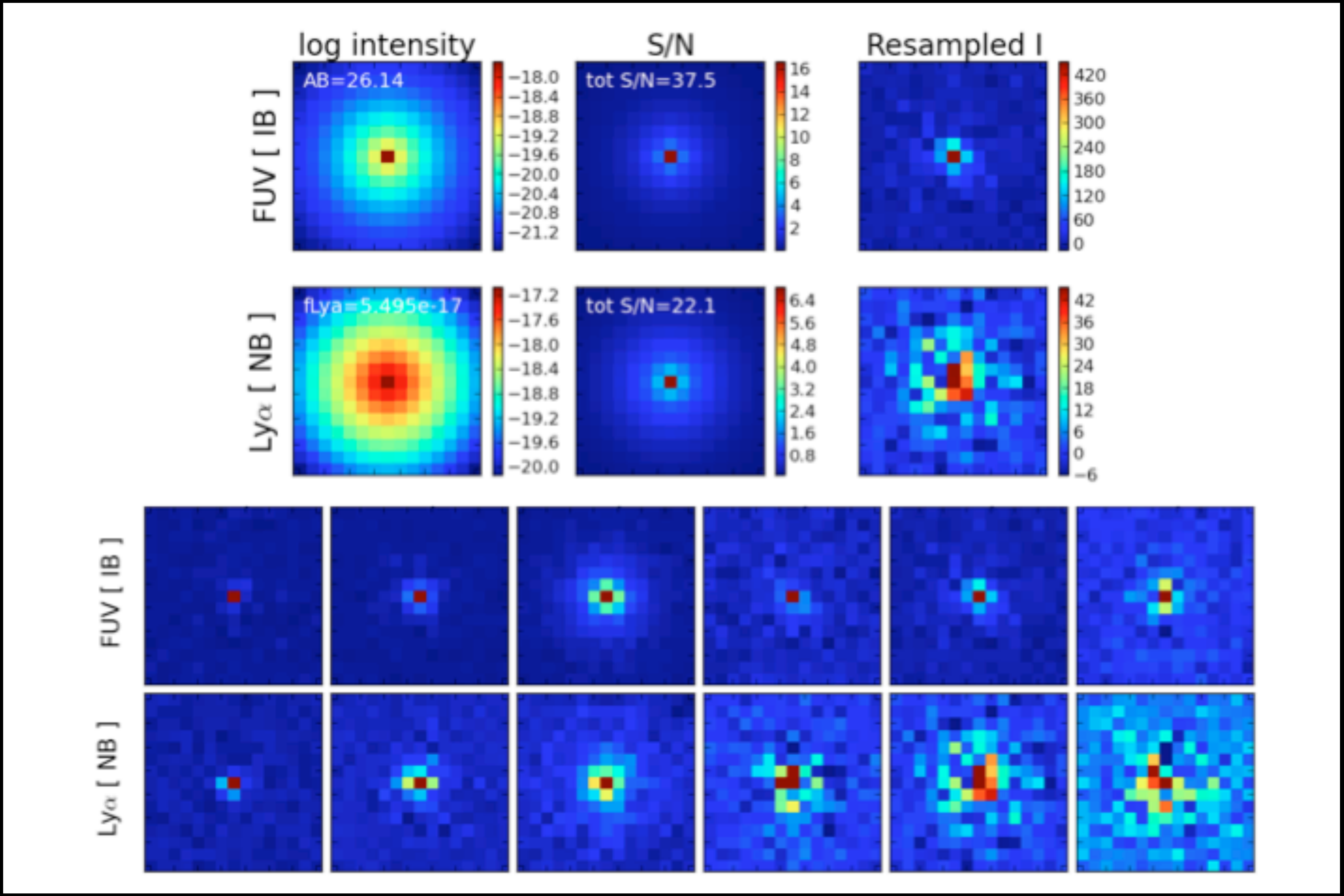




1 Msec
1 kpc × 1 kpc

10 Msec
1 kpc × 1 kpc

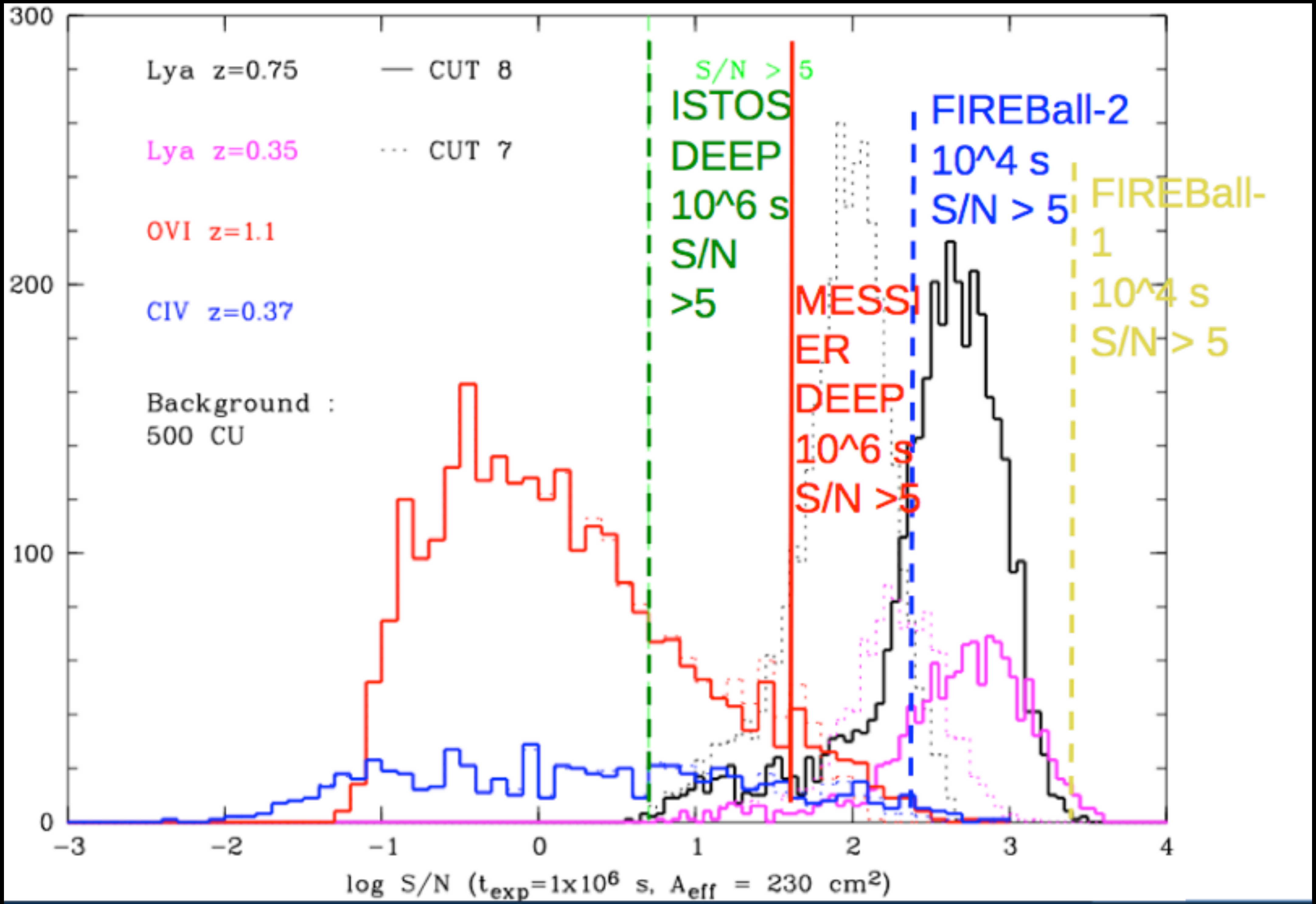
Expected performances - II   UV bands



Over 3 x10^6 galaxies detected in Lyα with S/N>30

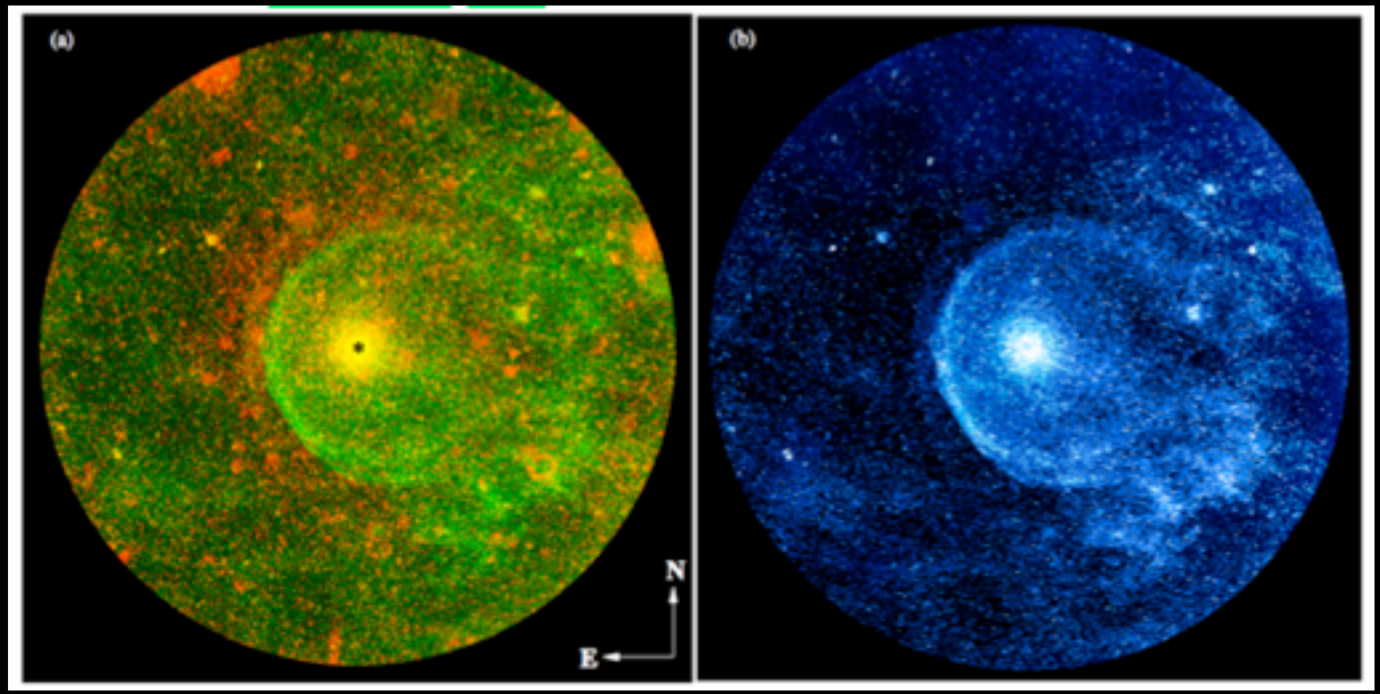
Expected performances - II UV bands

Signal / Noise for simulated MESSIER images of the cosmic web



Secondary science cases (free by-products)

- The optical / UV cosmological background radiation
- Fluorescent emission from molecular hydrogen (Lyman-Werner bands)
- Surface brightness fluctuations and extragalactic distances
- Intracluster light and the accretion history in galaxy clusters
- Time domain astronomy: multi-wavelength variability
- Zodiacal dust + comet tails
- Mass loss from stars
- Synergies with GAIA
  and EUCLID



Sahai + Chronopoulos (2012)

Mission concept - I

- Payload
  - Off-axis TMA f/2 telescope, 40 cm diameter
    - flat focal plane, FOV : 8 square degrees
    - ultra-stable PSF with ultra-low wings
    - no lenses (to avoid Čerenkov radiation)
    - extreme baffling to limit straylight contaminations
    - 8 UV / optical filters
    - no moving parts, passive cooling, low power
    - TRL 9 (but stability of FP TBD)

- Detectors
  - optimised QE > 80% for each UV/optical band
  - ITAR free (TBC)
  - time delay integration controllers + data flow to ground

Mission concept - II

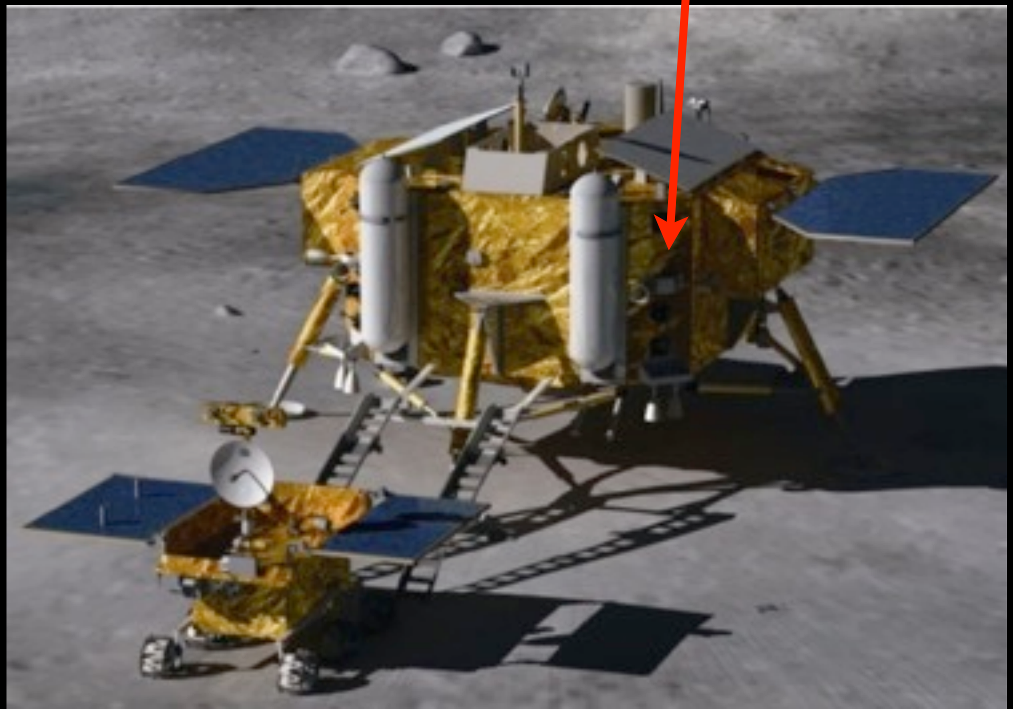
- Spacecraft
  similar to ESA's Proba-V (instrument: 40 kg, 43 W)
  platform: 40×60×80 cm; 95 kg
  MIDEX WISE (40 cm telescope, 200x285x173cm, 660 kg, 300 W, 540 km)
  VESTA dual-payload adapter @ Vega rocket
- Orbit
  SSO 700-900 km, precession 360°/year
  pointing ⊥ Sun-Earth direction avoiding Earthshine
  great circle drift scan with centre at the Sun
- Mission lifetime
  3 to 5 years
  full sky coverage to SB > 32 (optical) - 37 (UV) mag arcsec^{-2}

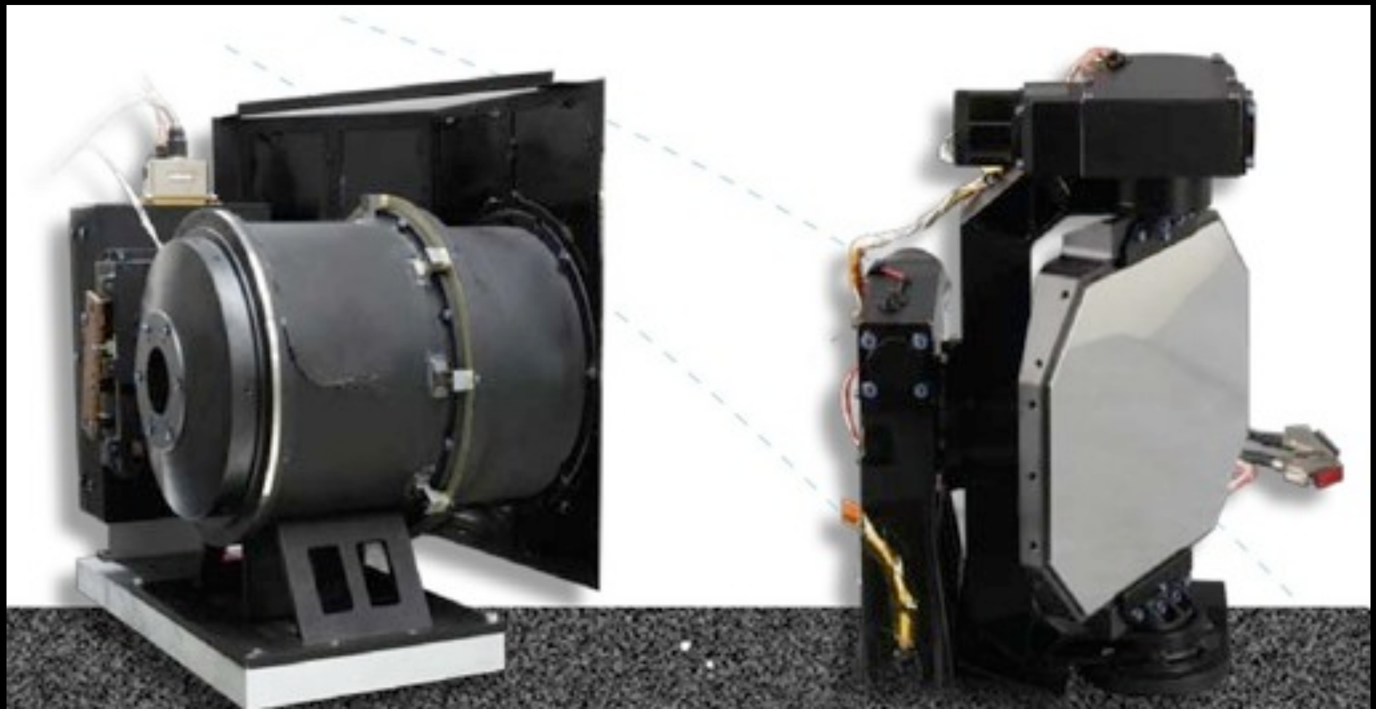
Contributions by China to MESSIER

- ✔ Innovative optical design of the off-axis *f*/2 TMA telescope
  Marseille + Shanghai

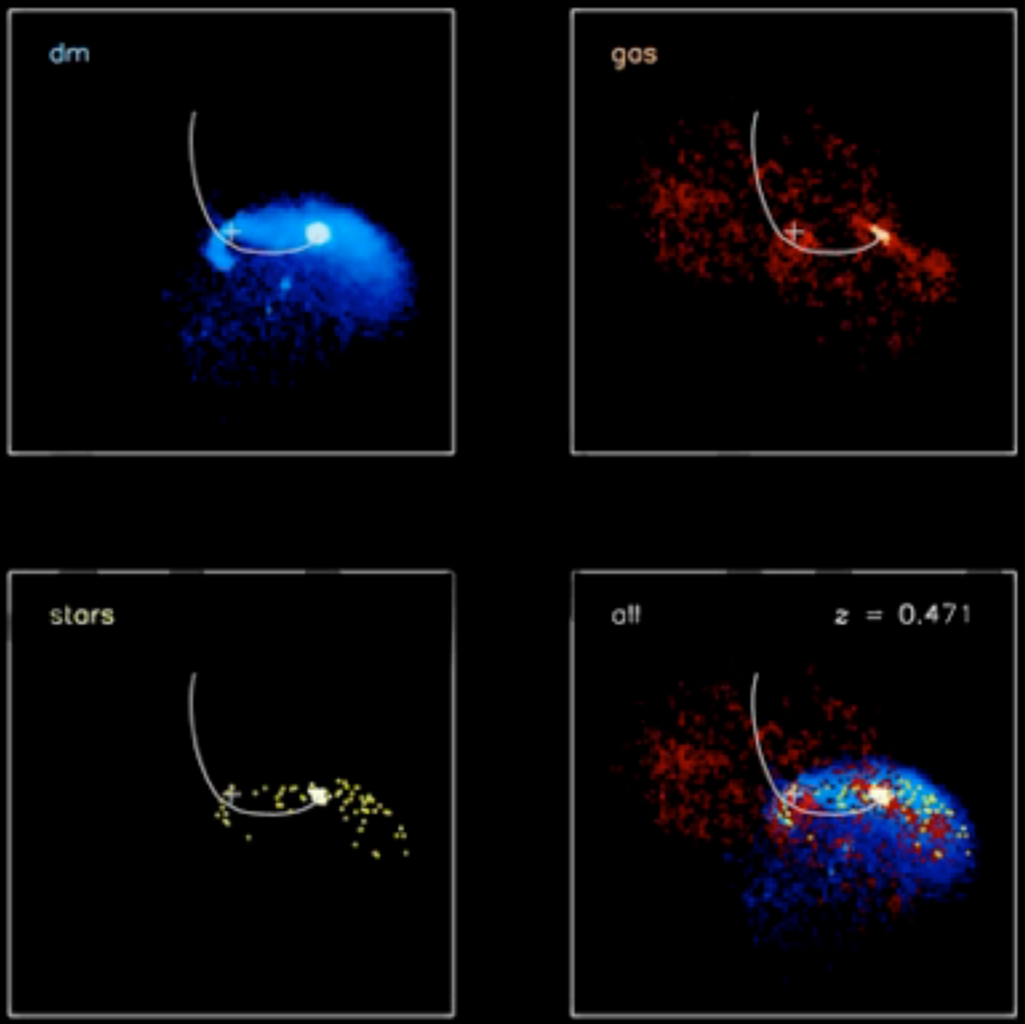
- ✔ Large community working in cosmology / galaxy evolution
  ample scope for science and technology collaborations

- ✔ Expertise in UV instrumentation: Lunar-based UV Telescope
  NAOC: LUT @ Chang'e 3 150mm RC 245-340 nm





MESSIER
a backpacker trip to the extremely low surface brightness universe



Proposal for a Proba-like satellite
2020 horizon

The last unexplored niche
in observational space

Legacy value: reference catalogue
for multi-band optical/UV photometry

Further international partners welcome