MESSIER

Unveiling galaxy formation

David Valls-Gabaud
on behalf of the MESSIER consortium

Challenges in UV astronomy
ESO - 2013 Oct 09

Two driving science cases

for critical tests of the ΛCDM paradigm on non-linear scales

- How galaxies accrete their satellites ?
- What are the properties of the cosmic web ?

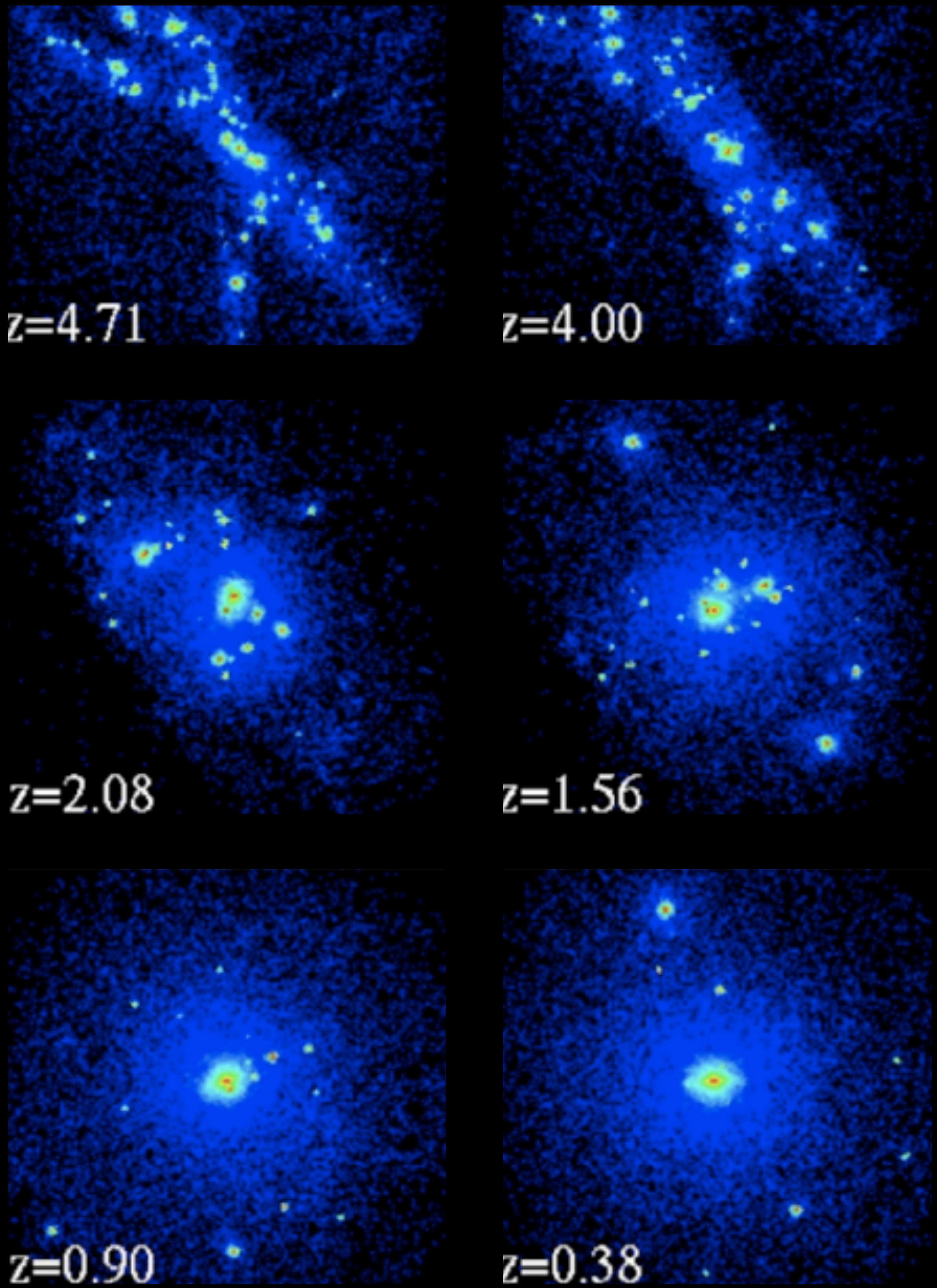
Mission summary

To understand the galaxy formation processes by:

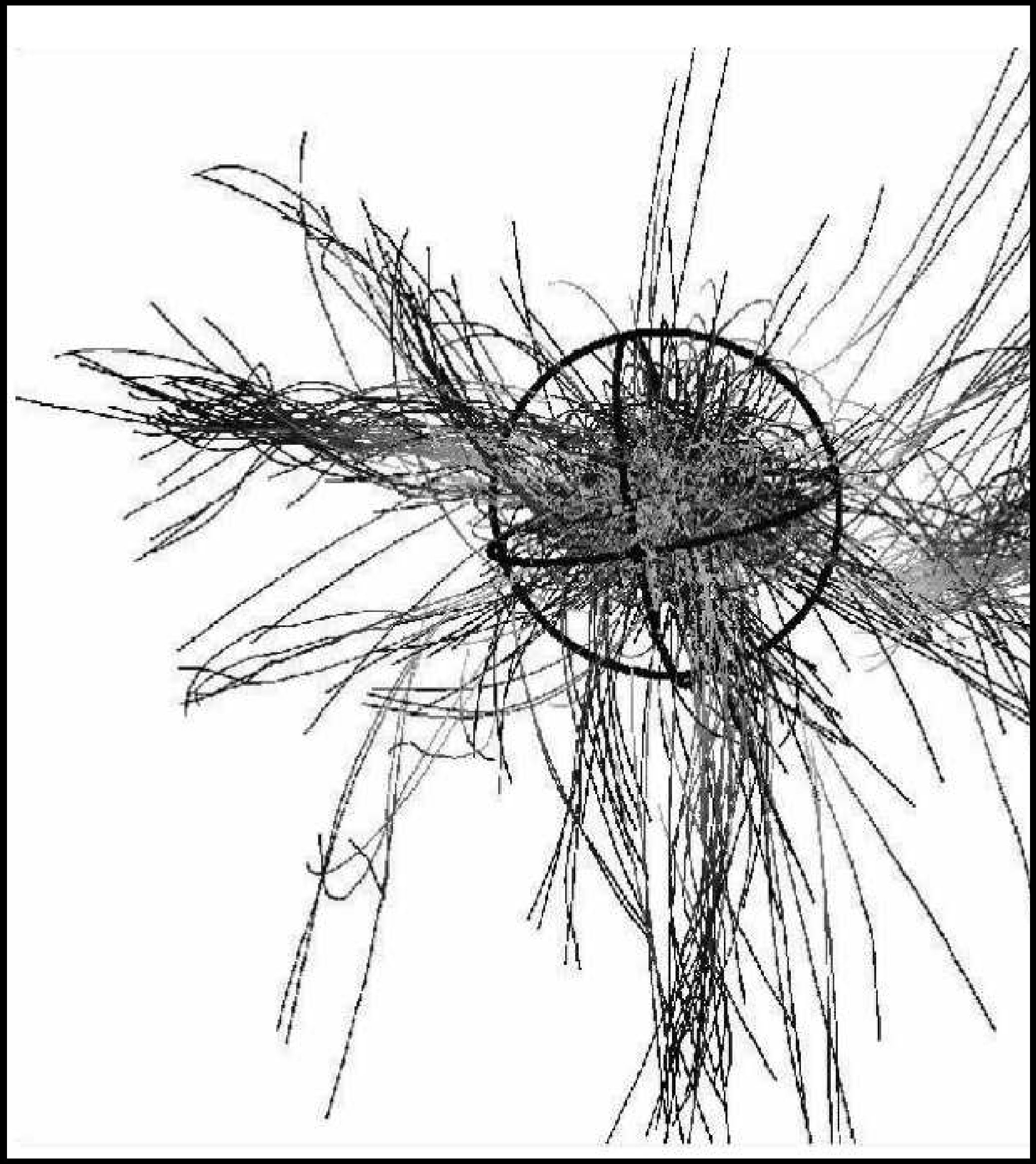
- measuring the local accretion history of baryons
- characterising the cosmic web :
  low-density outskirts, Lyman-α emission
- measuring the diffuse light in clusters of galaxies
- measuring the cosmological UV/optical background

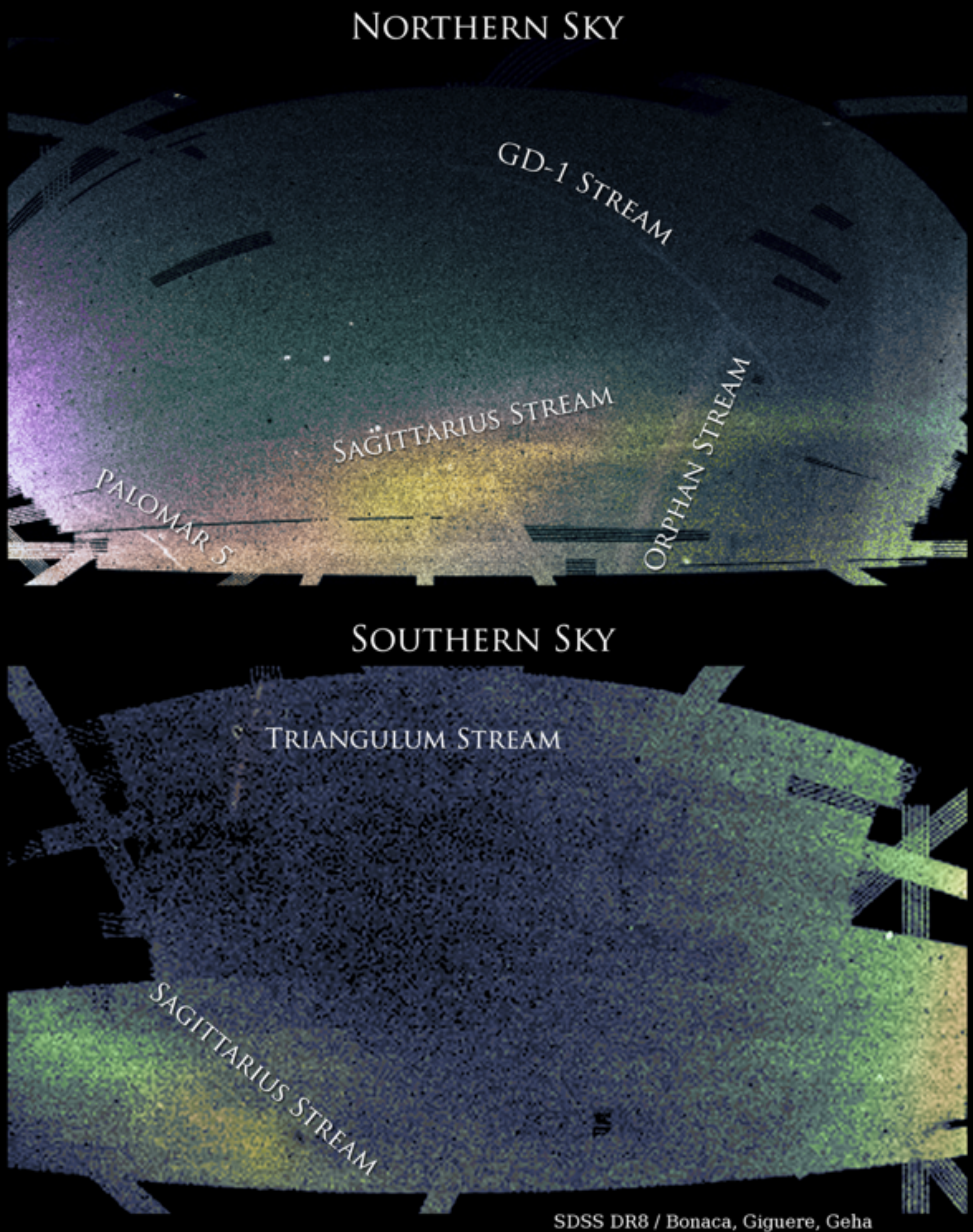
Multi-band all-sky survey down to $SB(V)$~33 mag arcsec^{-2}

Payload 45 cm mirror, f/2.5, off-axis design
Stable PSF with very low wings
8 4K×4K CCD, scale : 1 arcsec/pixel
Drift scan mode (TDI) : <0.05% flat-fielding
6 optical + two UV filters: *ugrizW IB200 NB200*



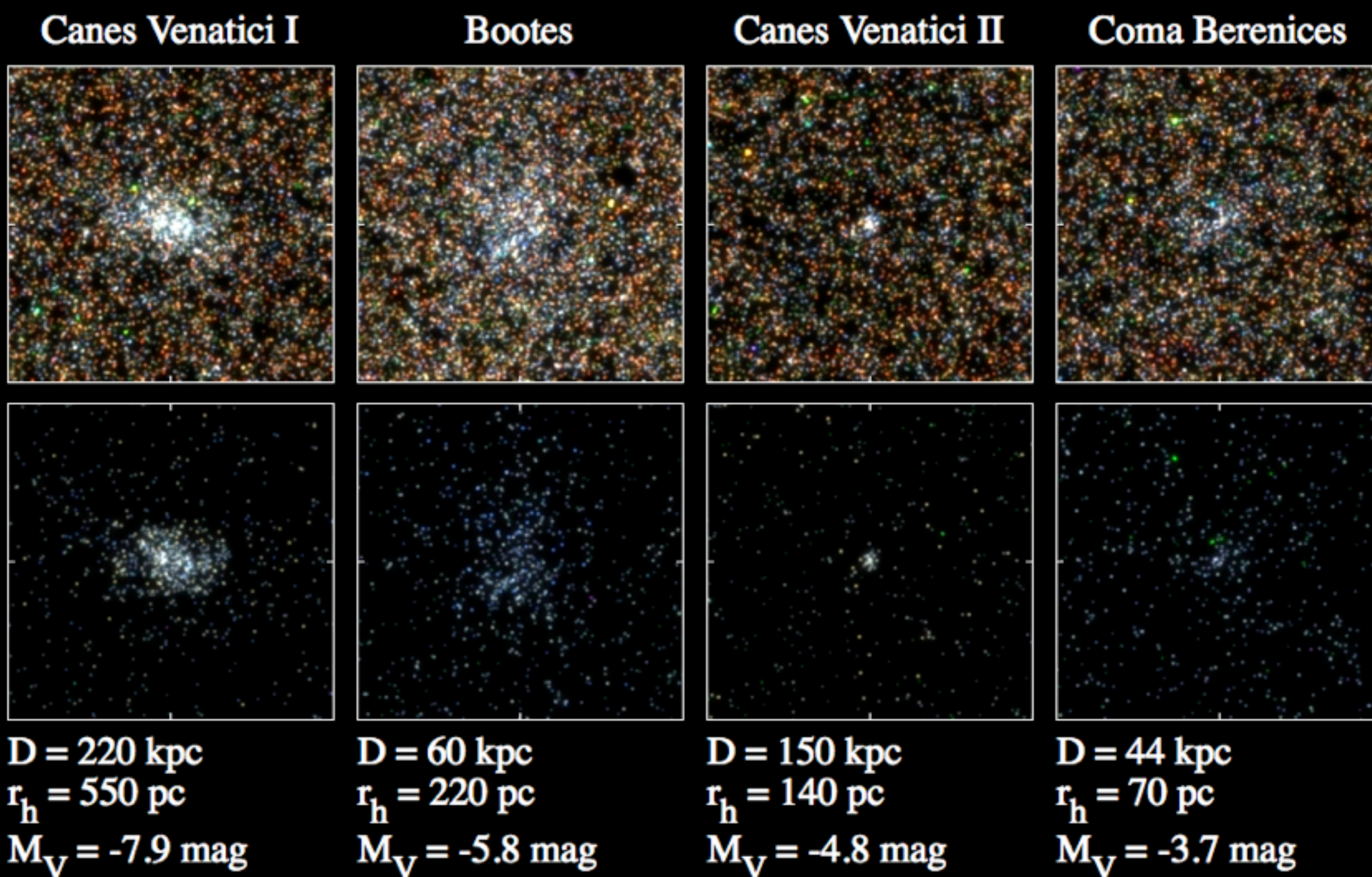
Formation history
of galactic haloes





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

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

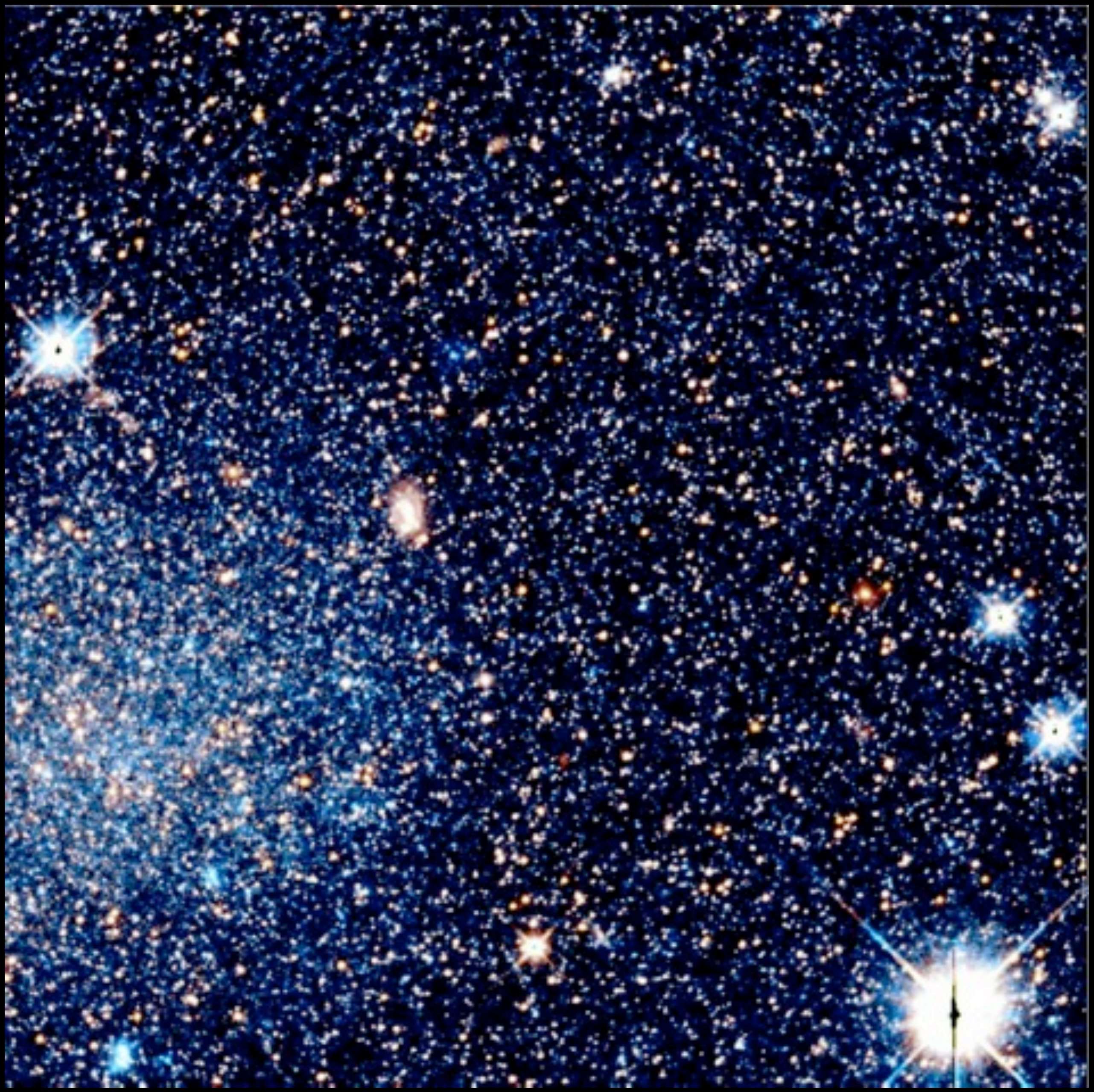


Belokurov et al. (2008)

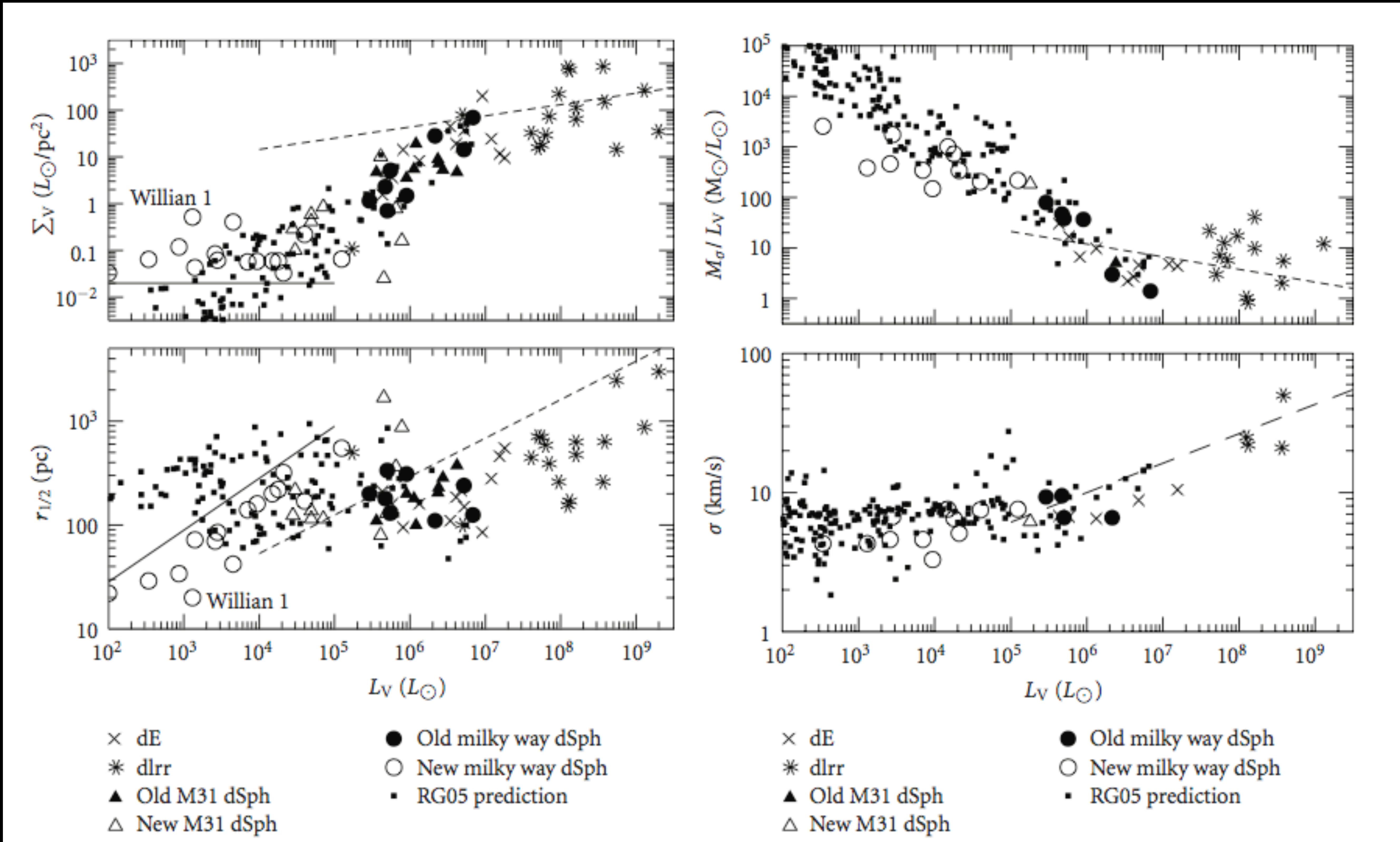
Leo T

Ground-based

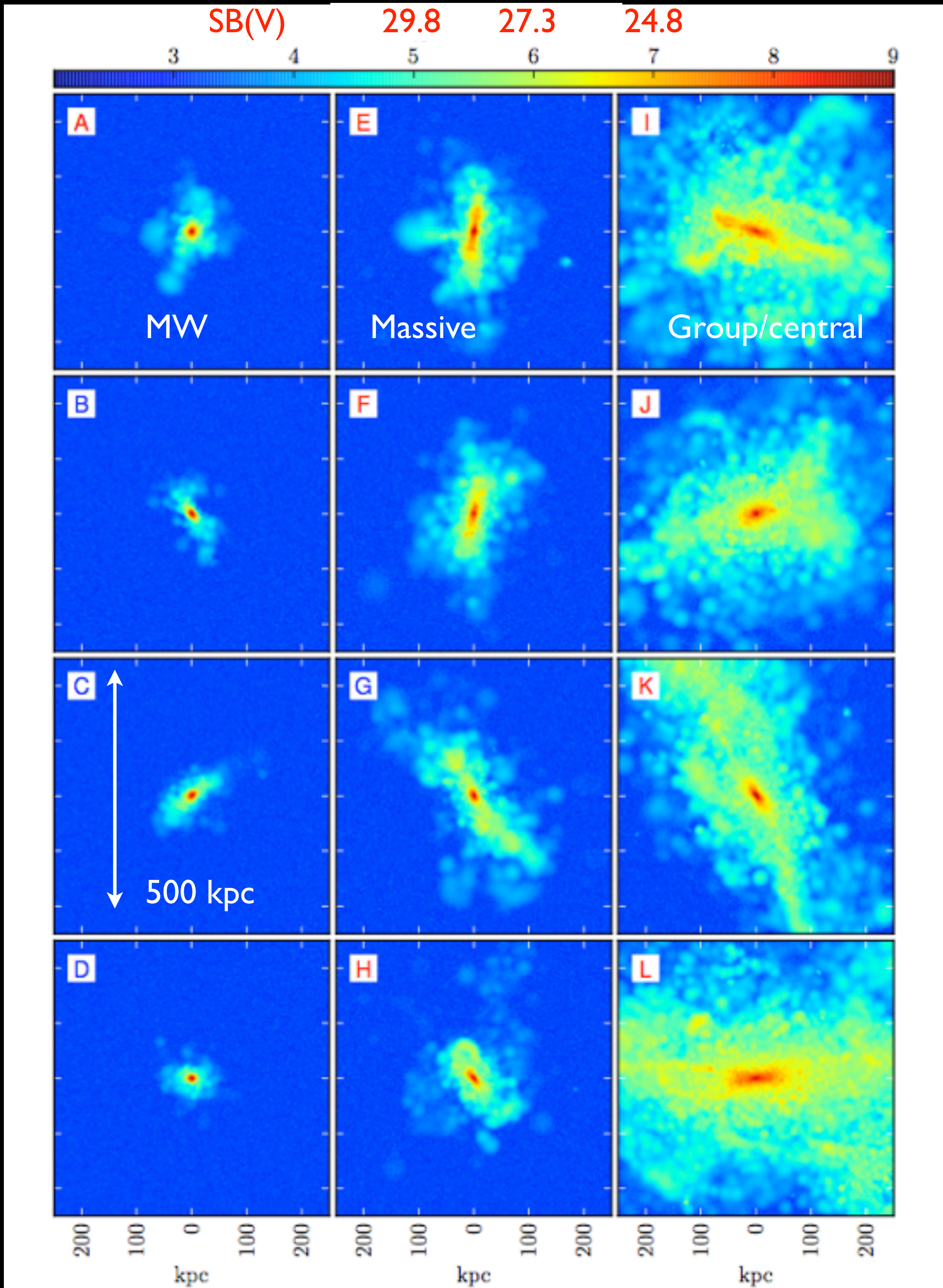
And IV

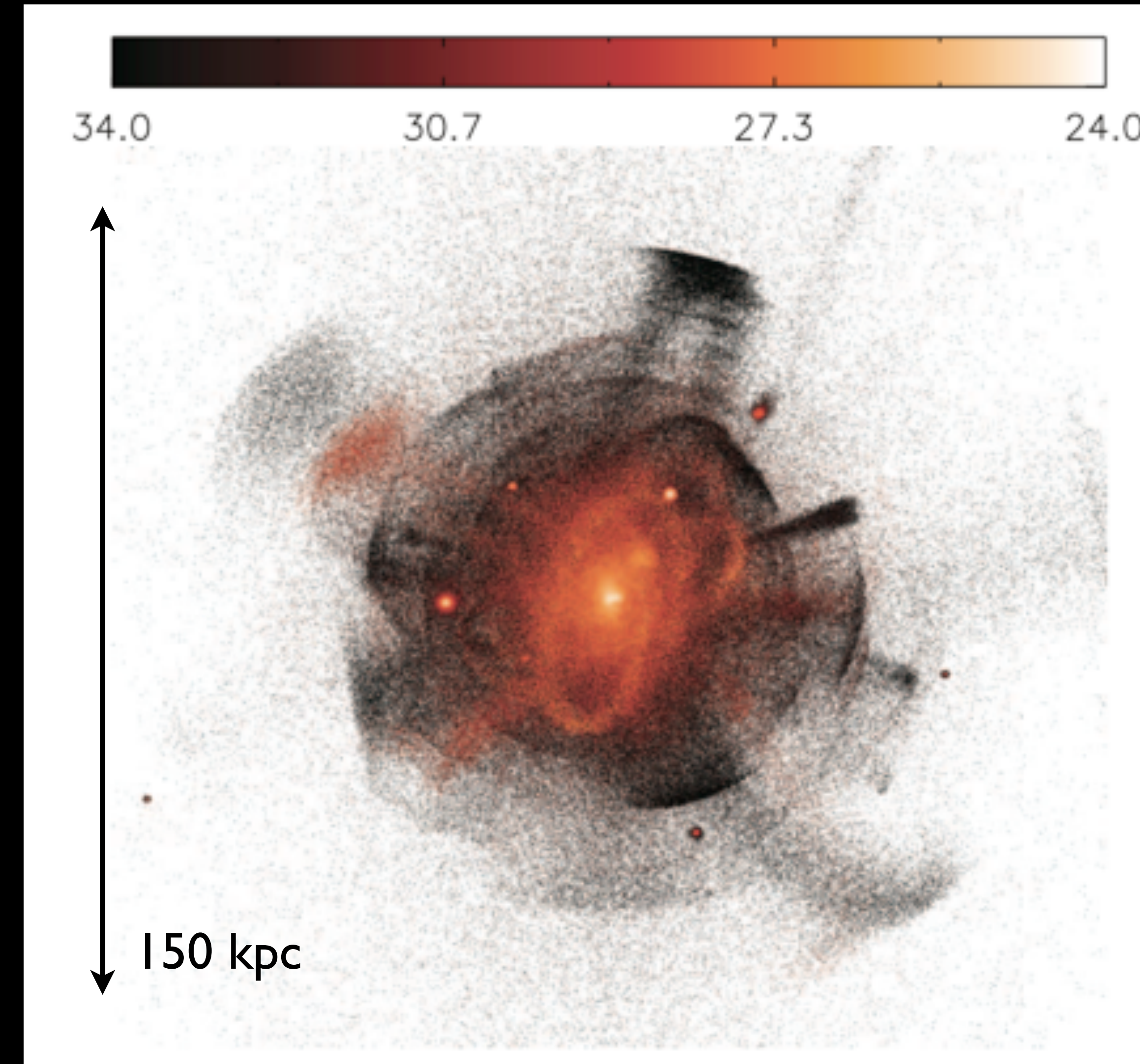


HST



Ricotti (2011)





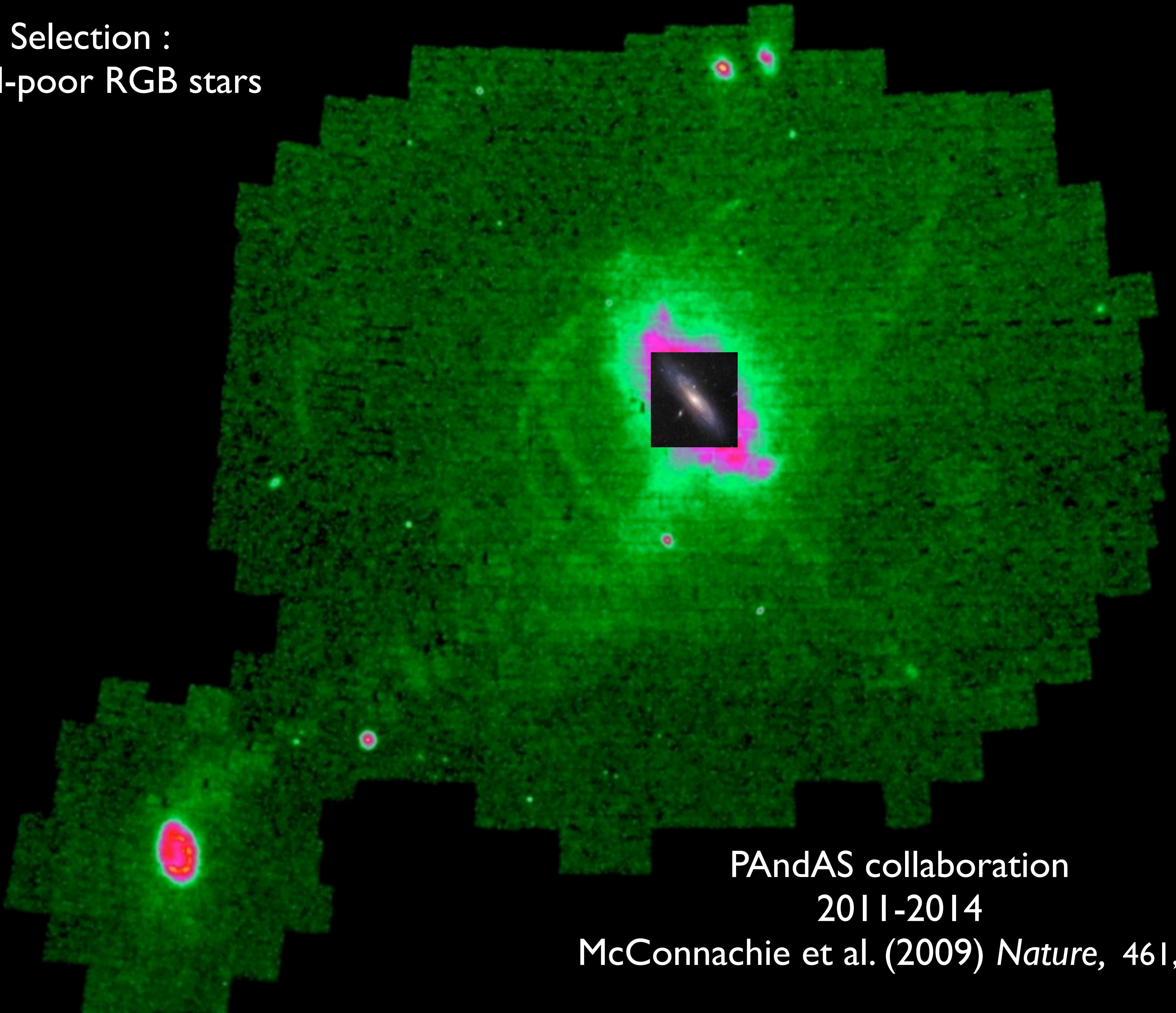
Font et al. (2008)

Most predicted key structures lie at SB below 30 mag arcsec^{-2}

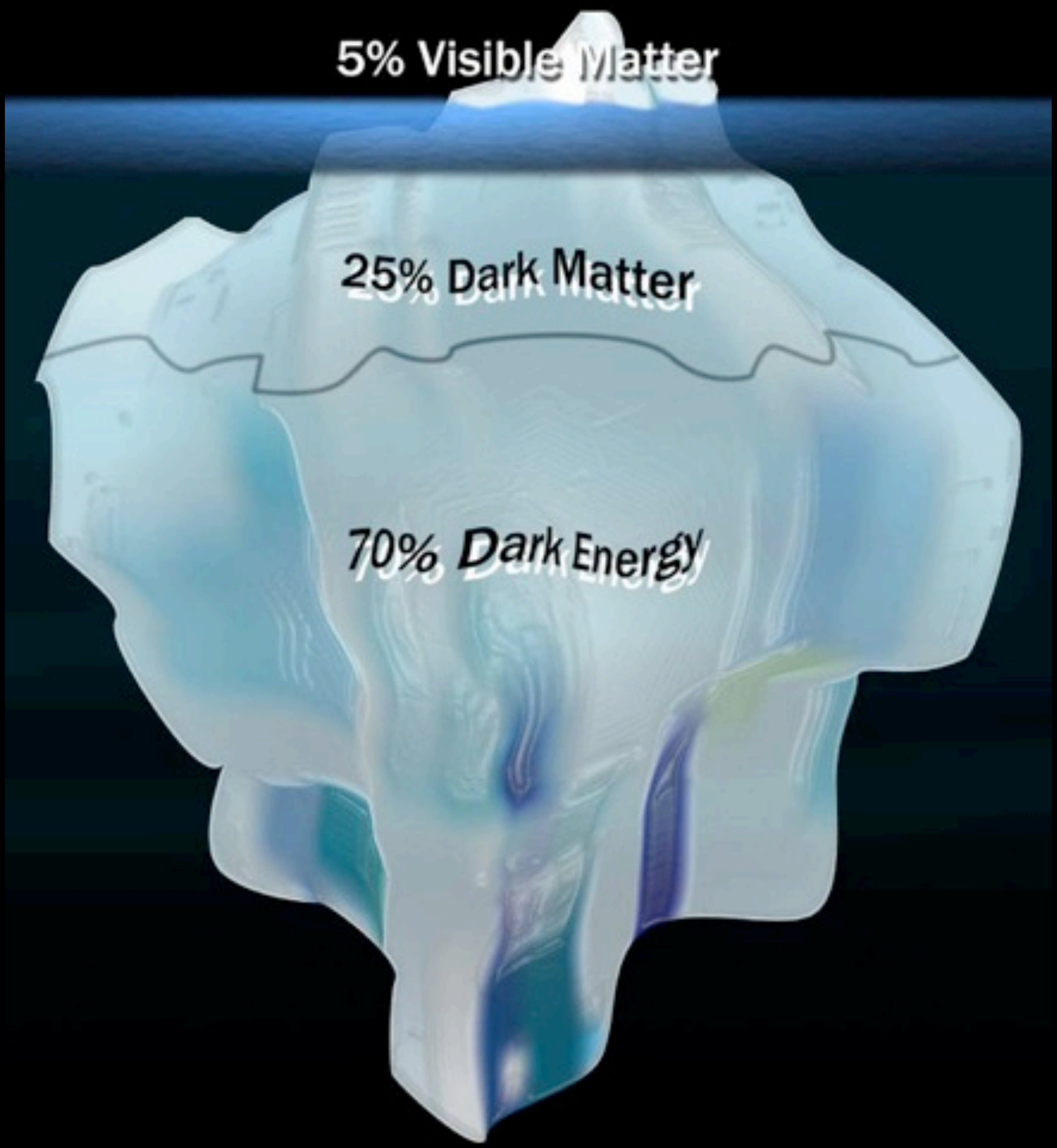
Unreachable from the ground

Cooper et al. (2013)

Selection :
metal-poor RGB stars



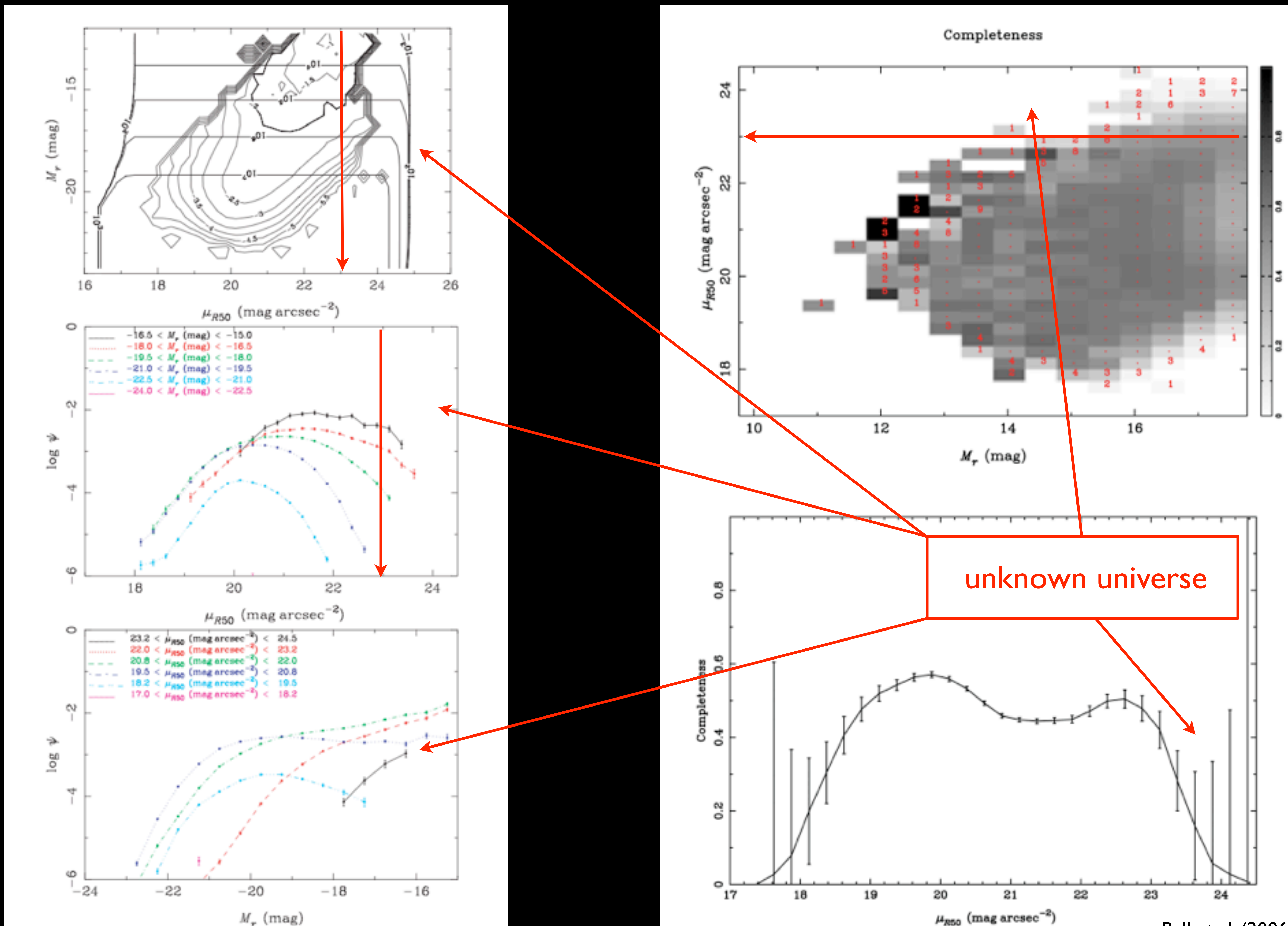
PAndAS collaboration
2011-2014
McConnachie et al. (2009) *Nature,* 461, 66



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

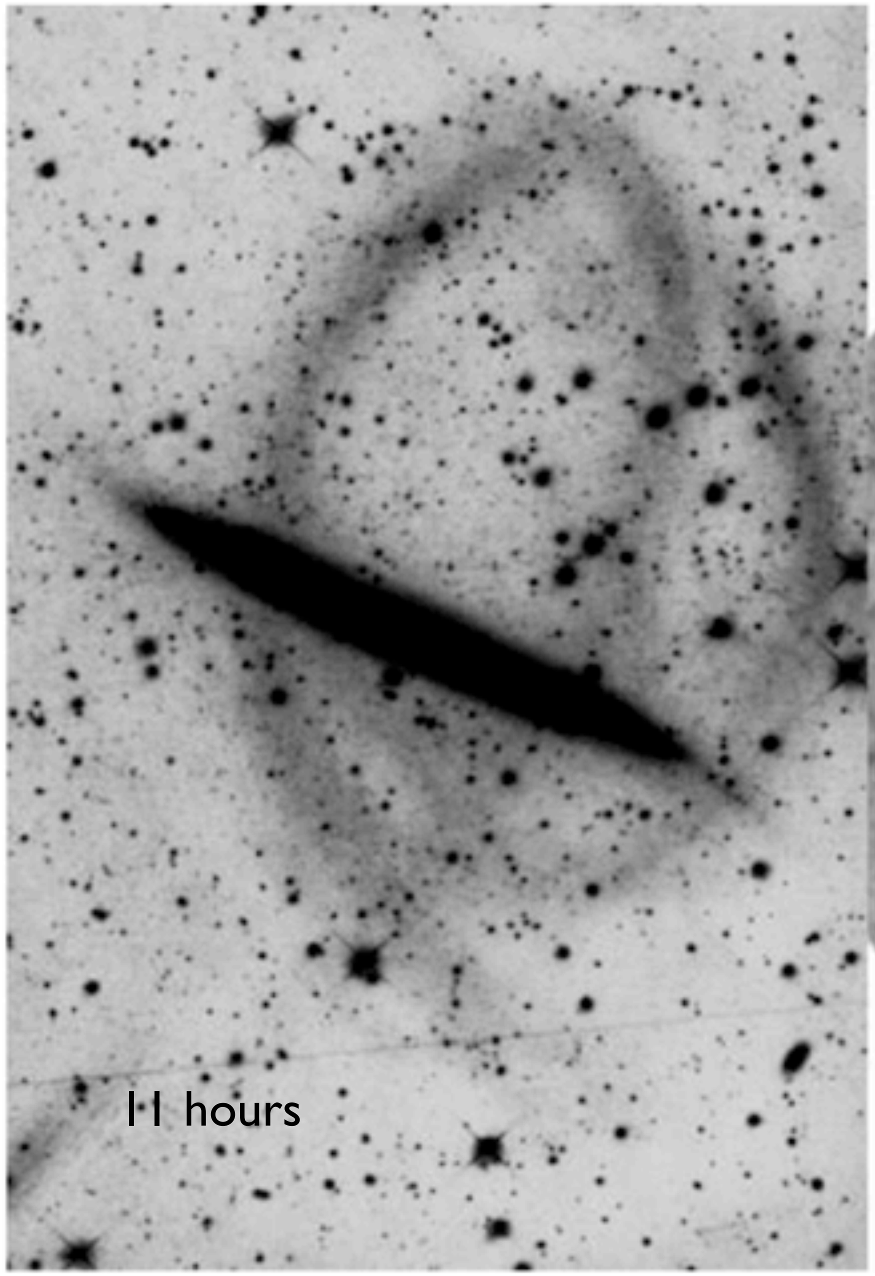
M. Disney (1976)

Surface brightness completeness issues

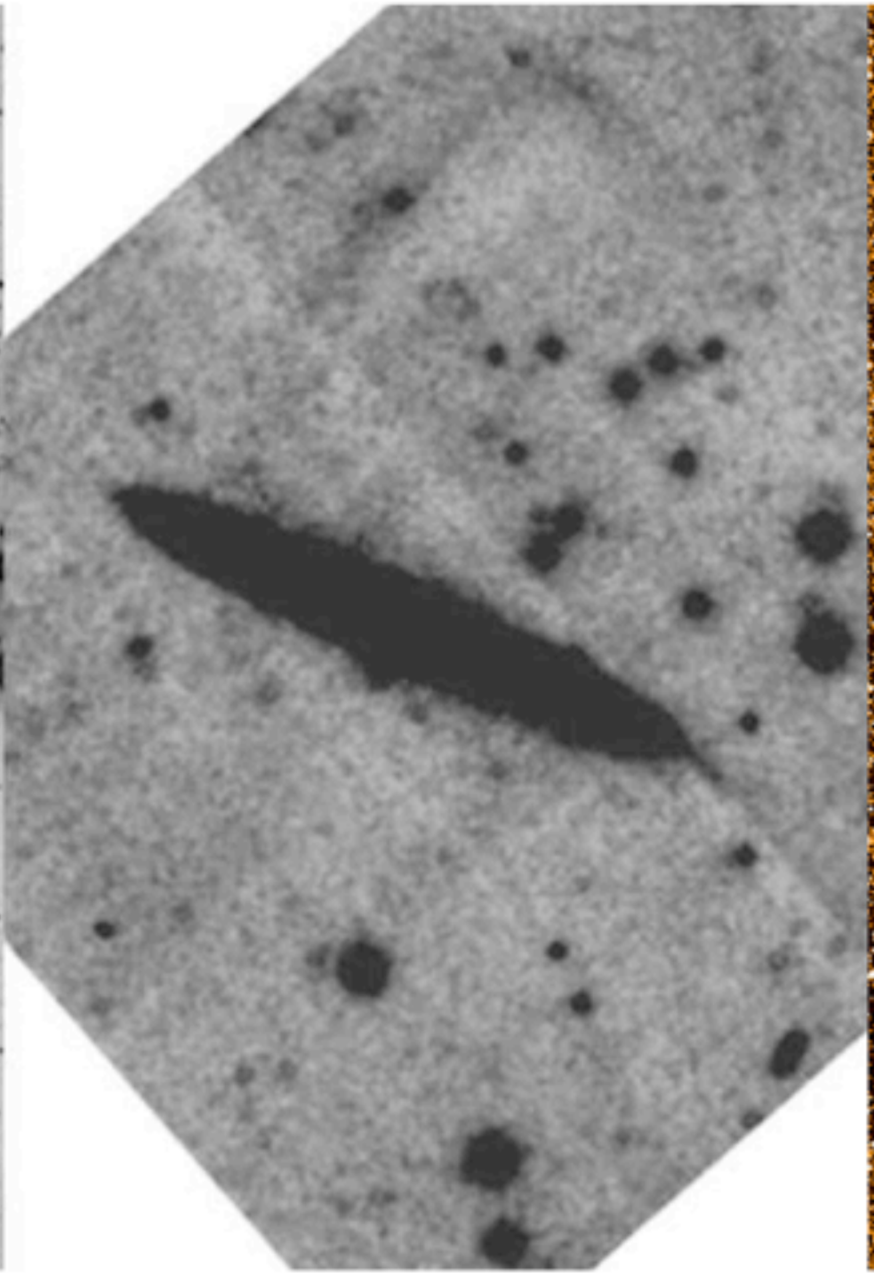


Ball et al. (2006)

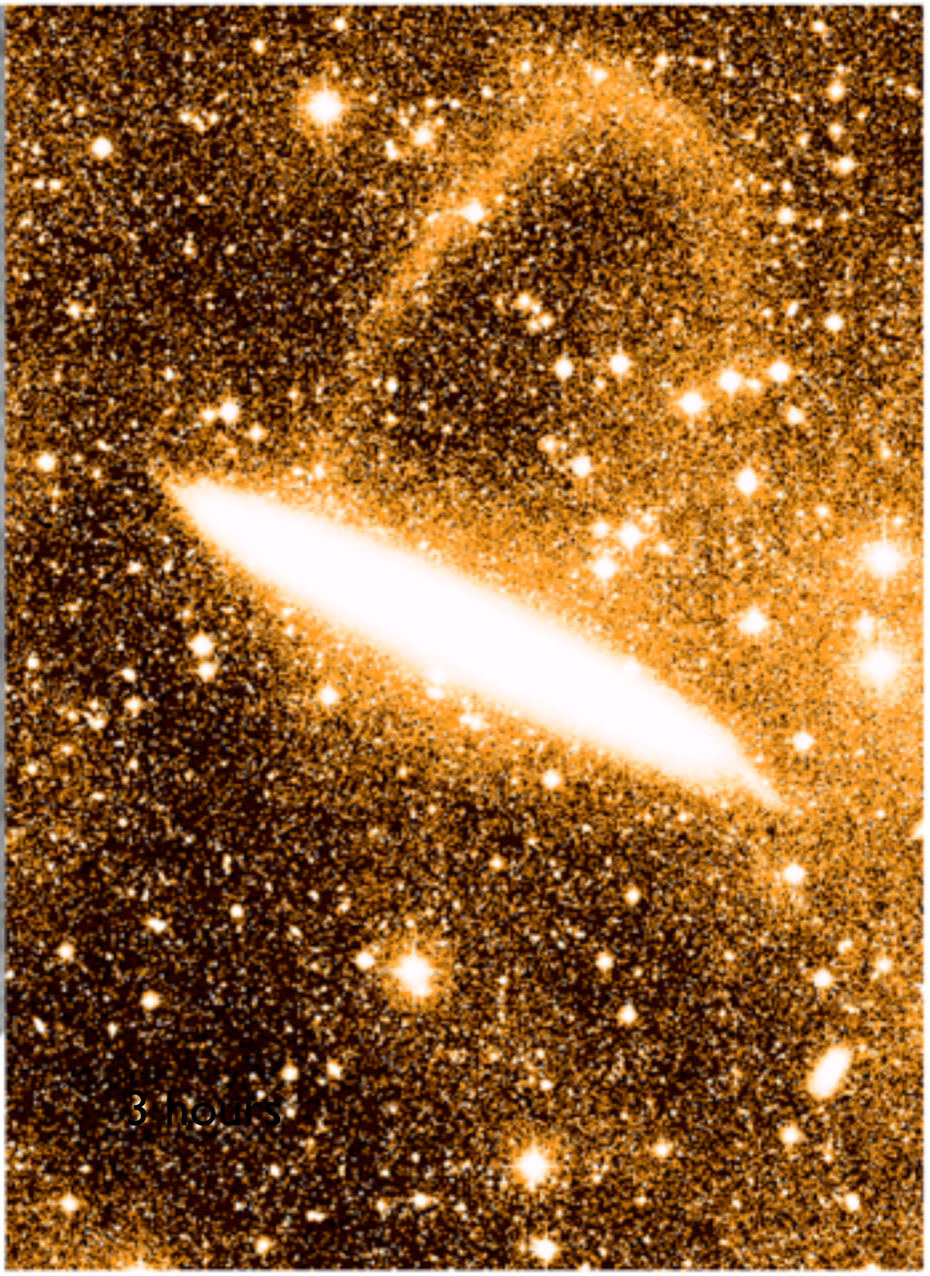
The paradigmatic case of NGC 5907



0.5m f/8.1
Martinez Delgado et al. 2008



SDSS
Miskolczi et al. 2011



CFHT
Ibata et al. 2011

Signal received by an unresolved source:

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

→ drives large diameter telescopes and large focal distances

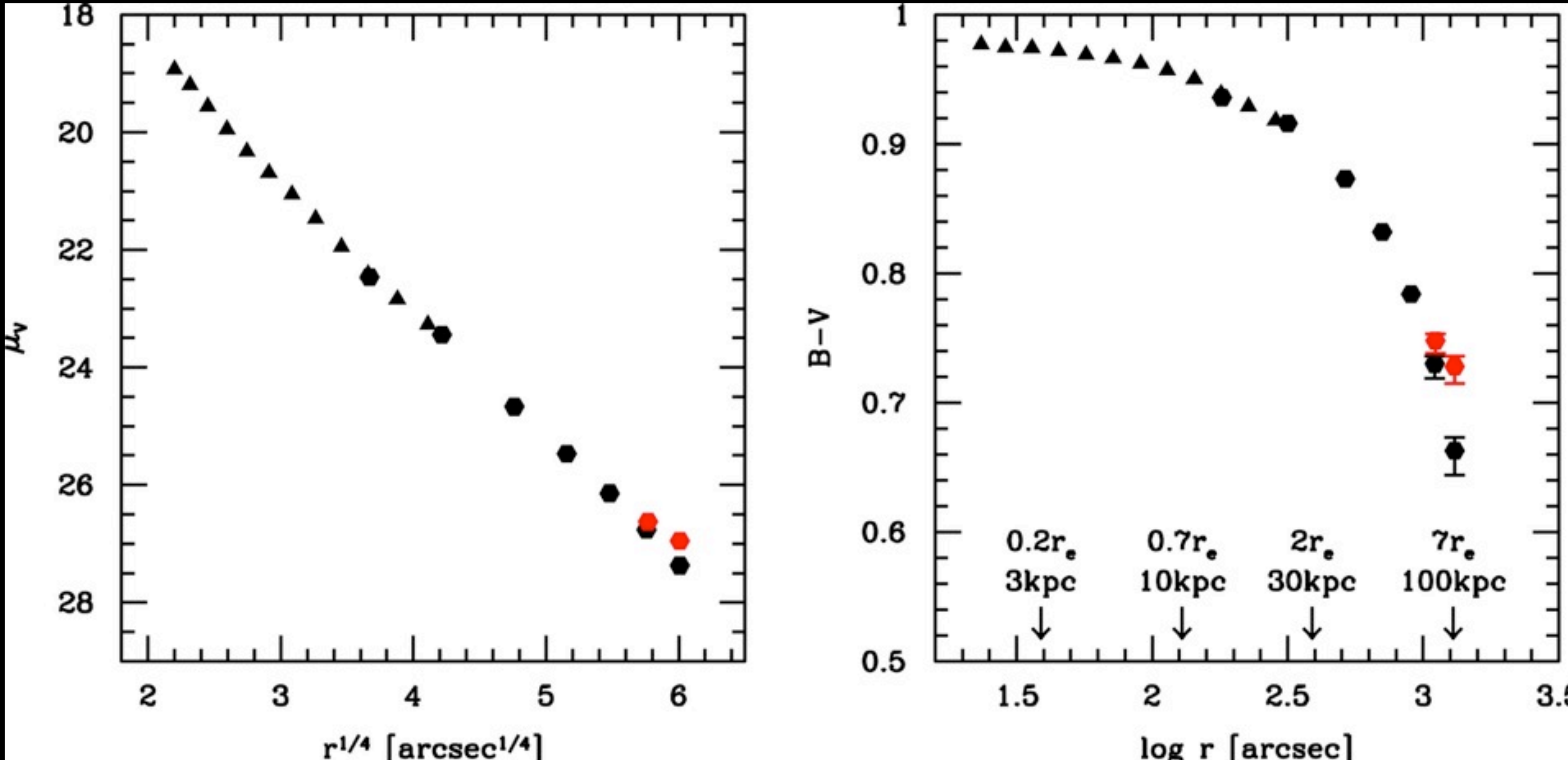
Surface brightness received by a resolved source:

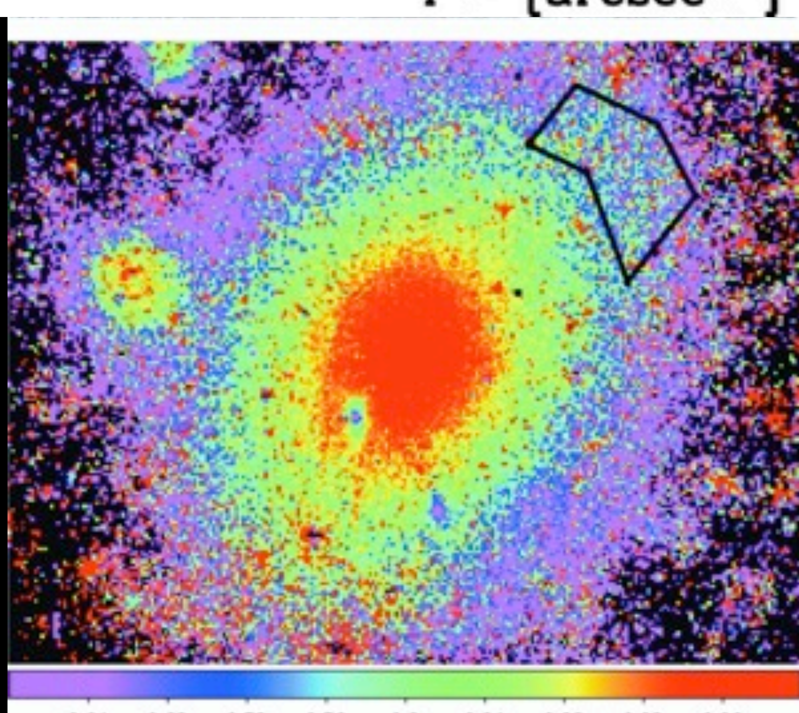
$$SB_{\rm extended} \;\propto\; \left(\frac{D}{f}\right)^2 \epsilon\,t_{exp}\;s_{pix}^2\;N_{pix}\;10^{-0.4\,\mu}$$

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

The unprobed realm of the low surface brightness universe

Mihos et al. (2005)





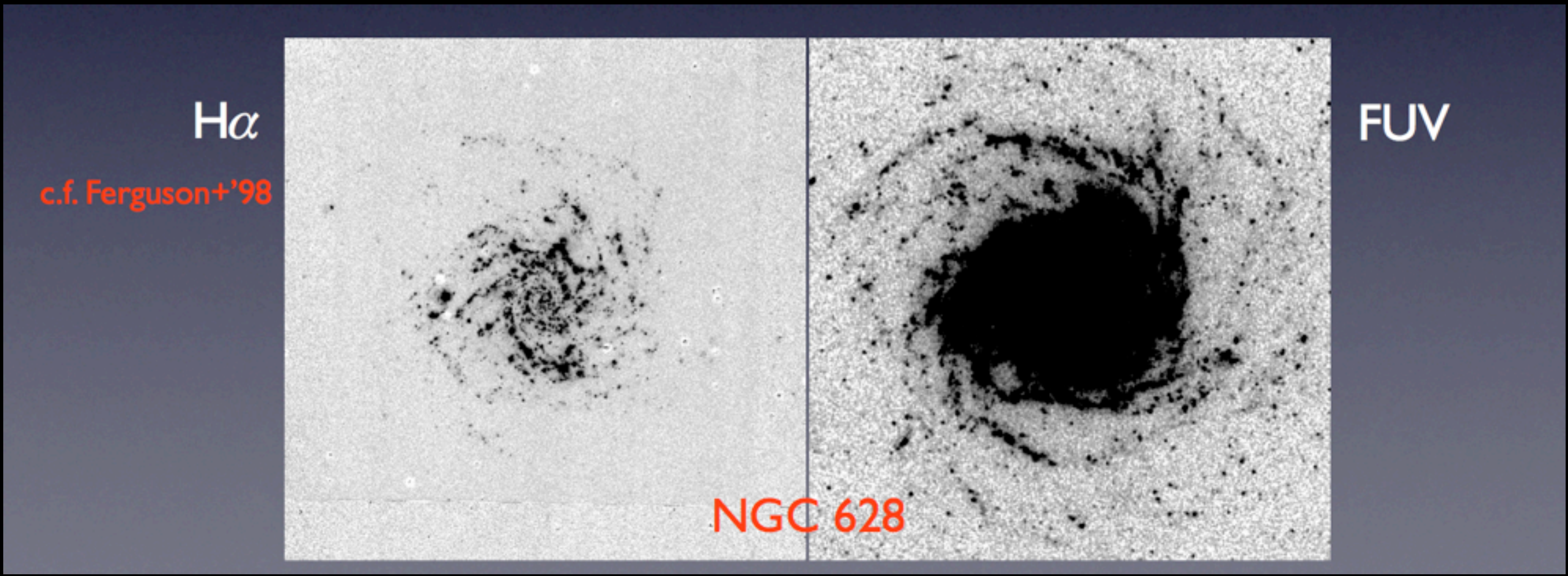
Mihos et al. (2013)

M49 massive elliptical in Virgo

Blue outskirts → blue filters
(old) stellar streams → red filters

SDSS *vs* Strömgren/Washington?

UV channels



Outer, low density star formation activity

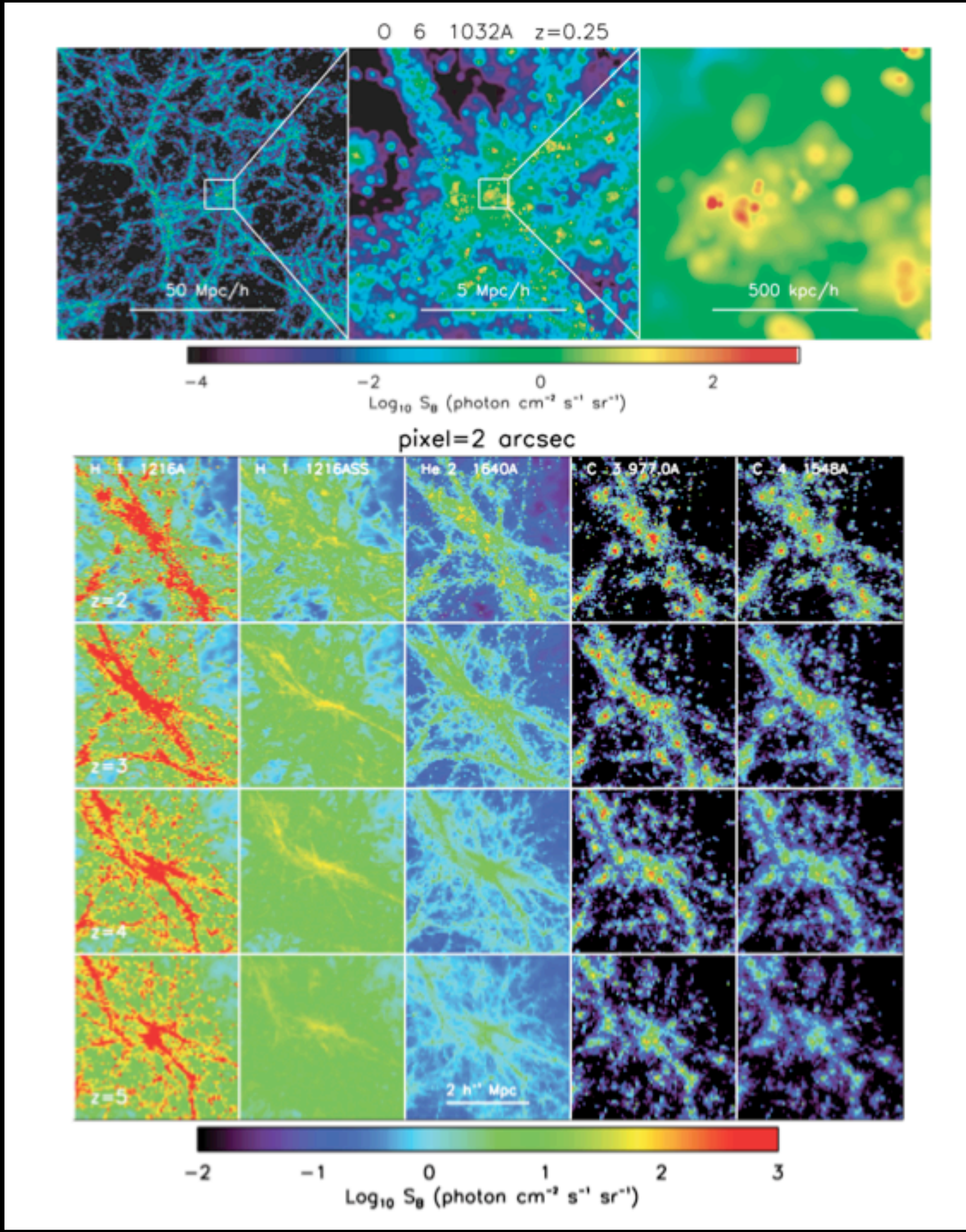
UV is a better tracer of low-level SF

XUV discs: galaxies are still growing today

Science case #2

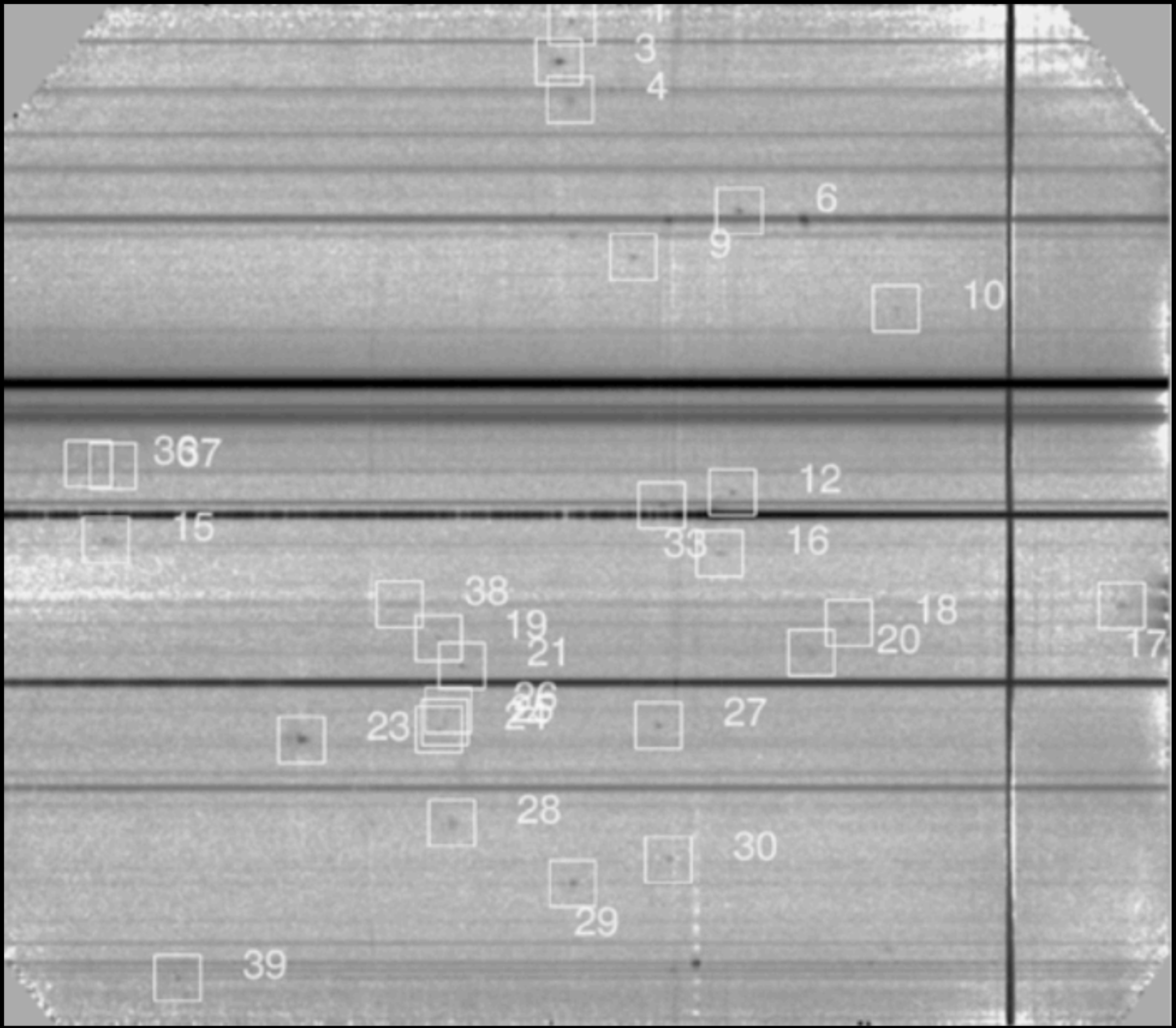
The Cosmic Web

Strongest
in Lyman α
by 1000 x



Bertone + Schaye (2012)

Low surface brightness Lyman-α emitters

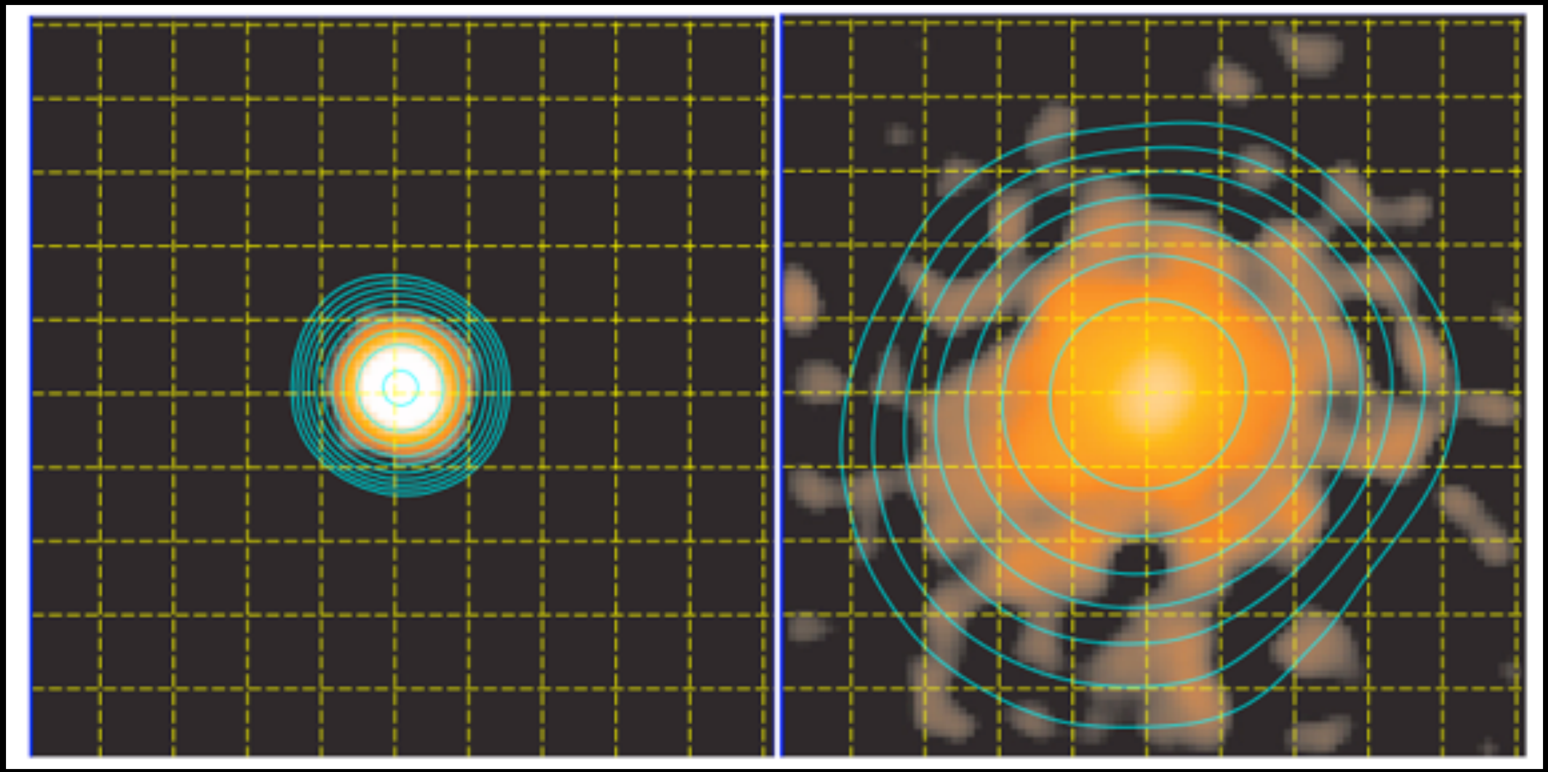


VLT
92 hours exposure

Rauch et al. (2010)

Extended Lyman-α emission from z ~ 2.65 galaxies

UV continuum



Lyman-α

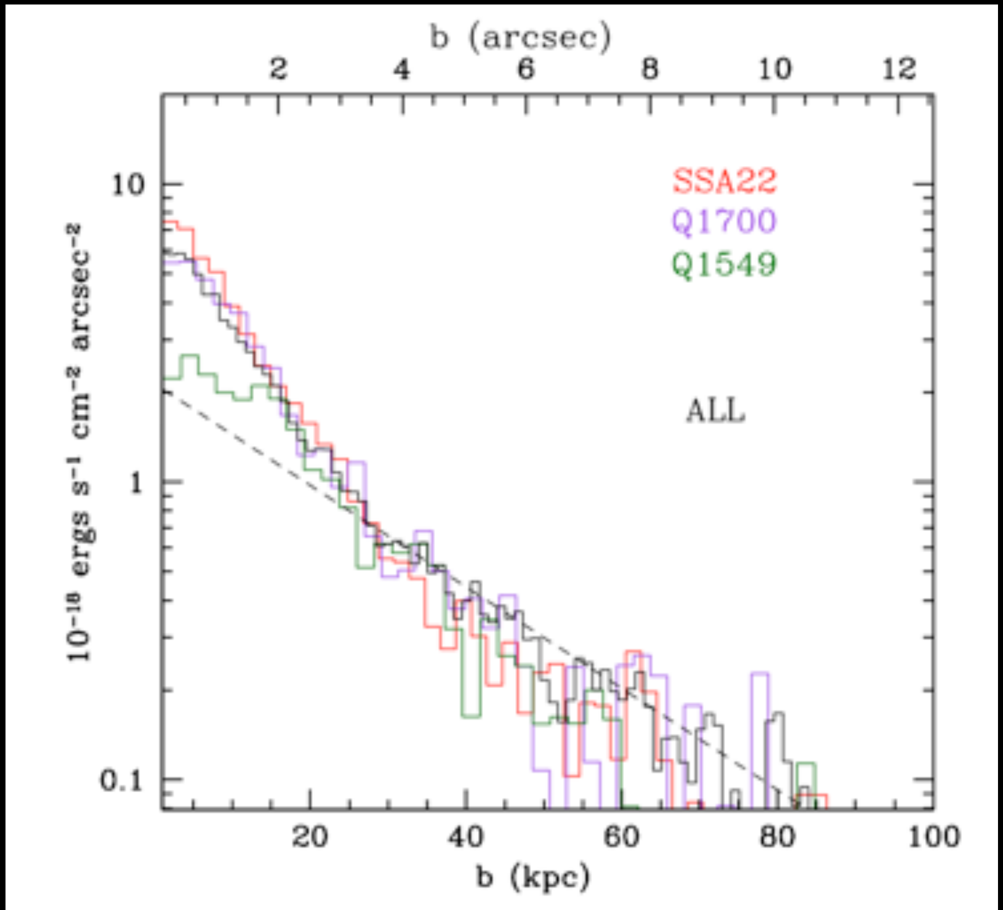
92 UV-selected galaxies with <z>=2.65

Extended haloes to ~ 80 kpc (when stacked)

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

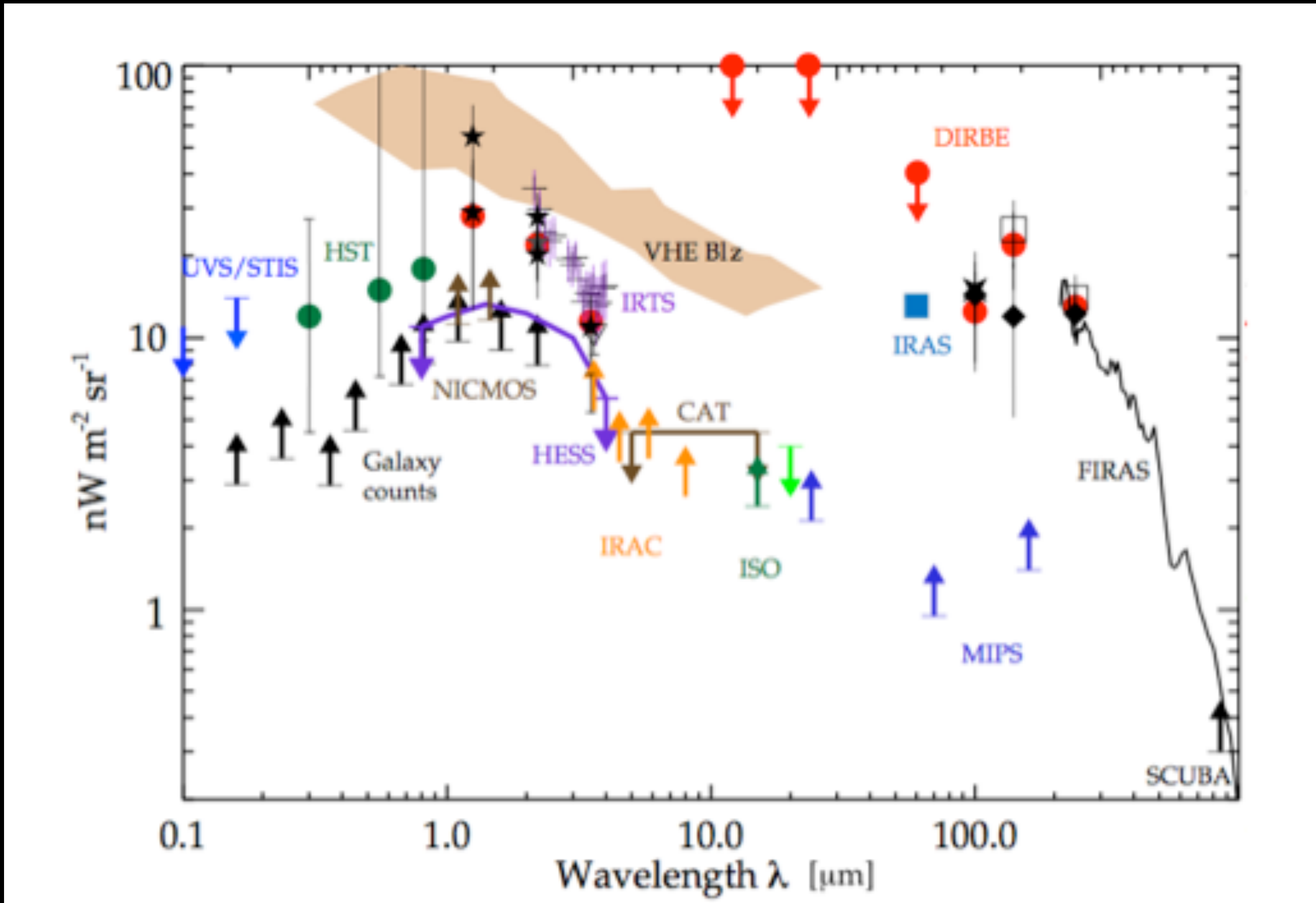
900 hours integration at 8-10m class telescopes

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



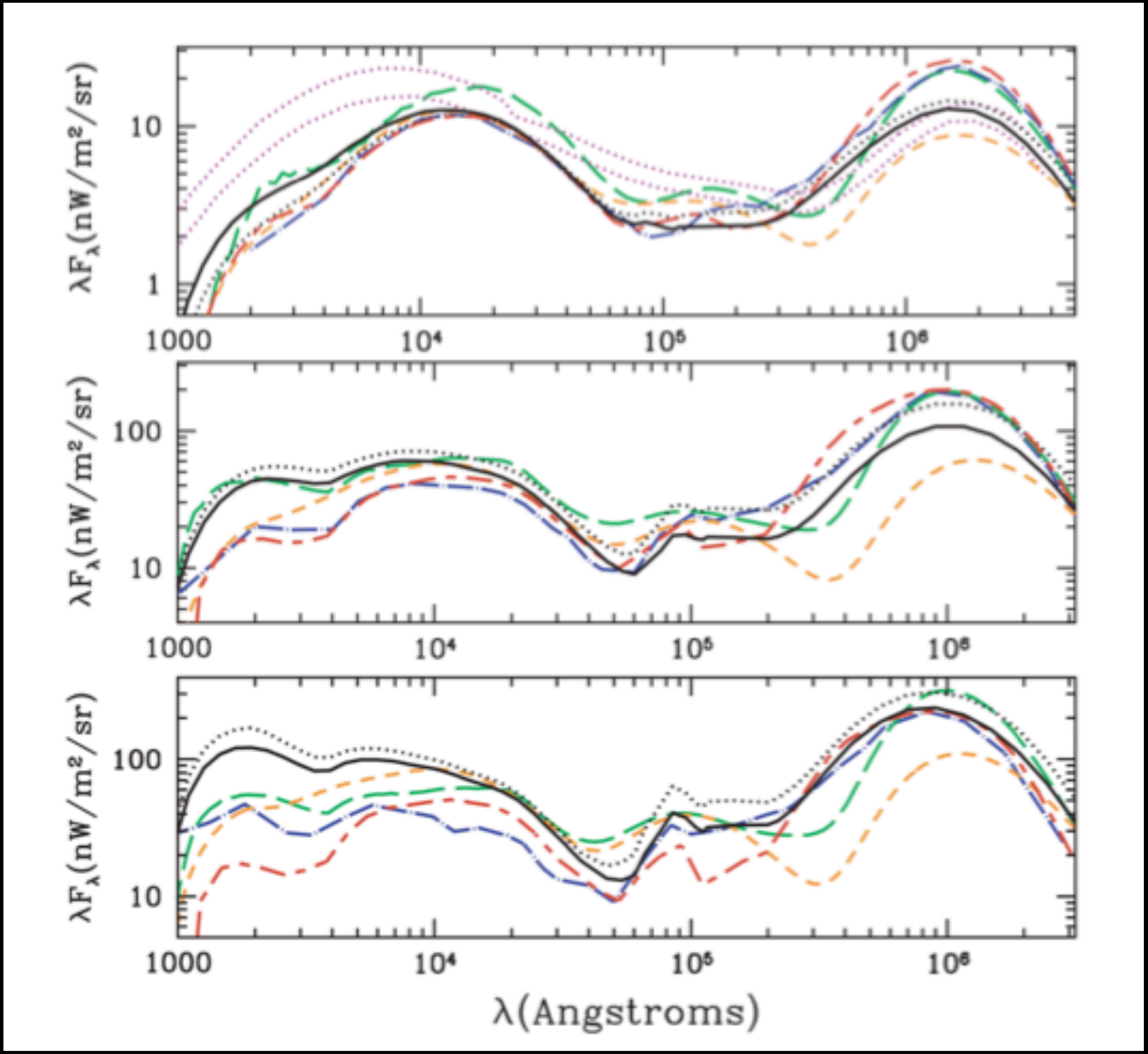
Steidel et al. (2011)

The optical/UV cosmological background radiation



Cooray et al. (2009)

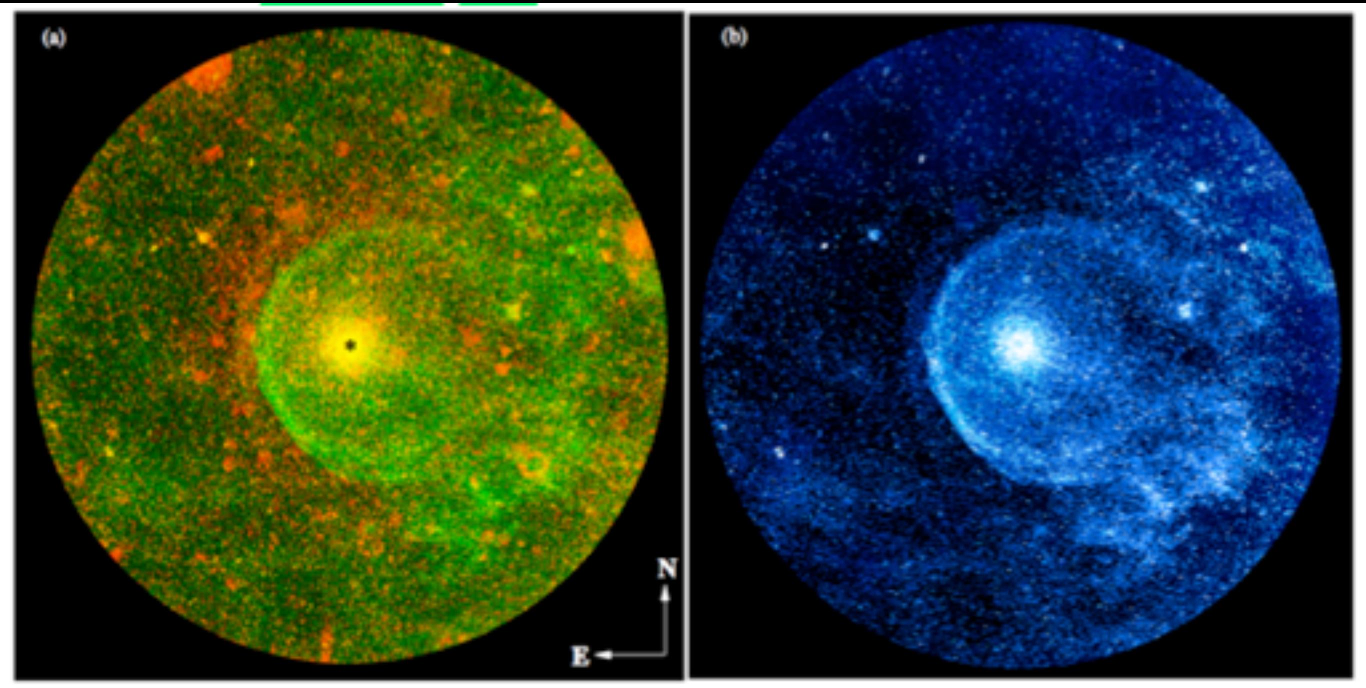
The optical/UV cosmological background radiation



Gilmore et al. (2012)

Other science cases

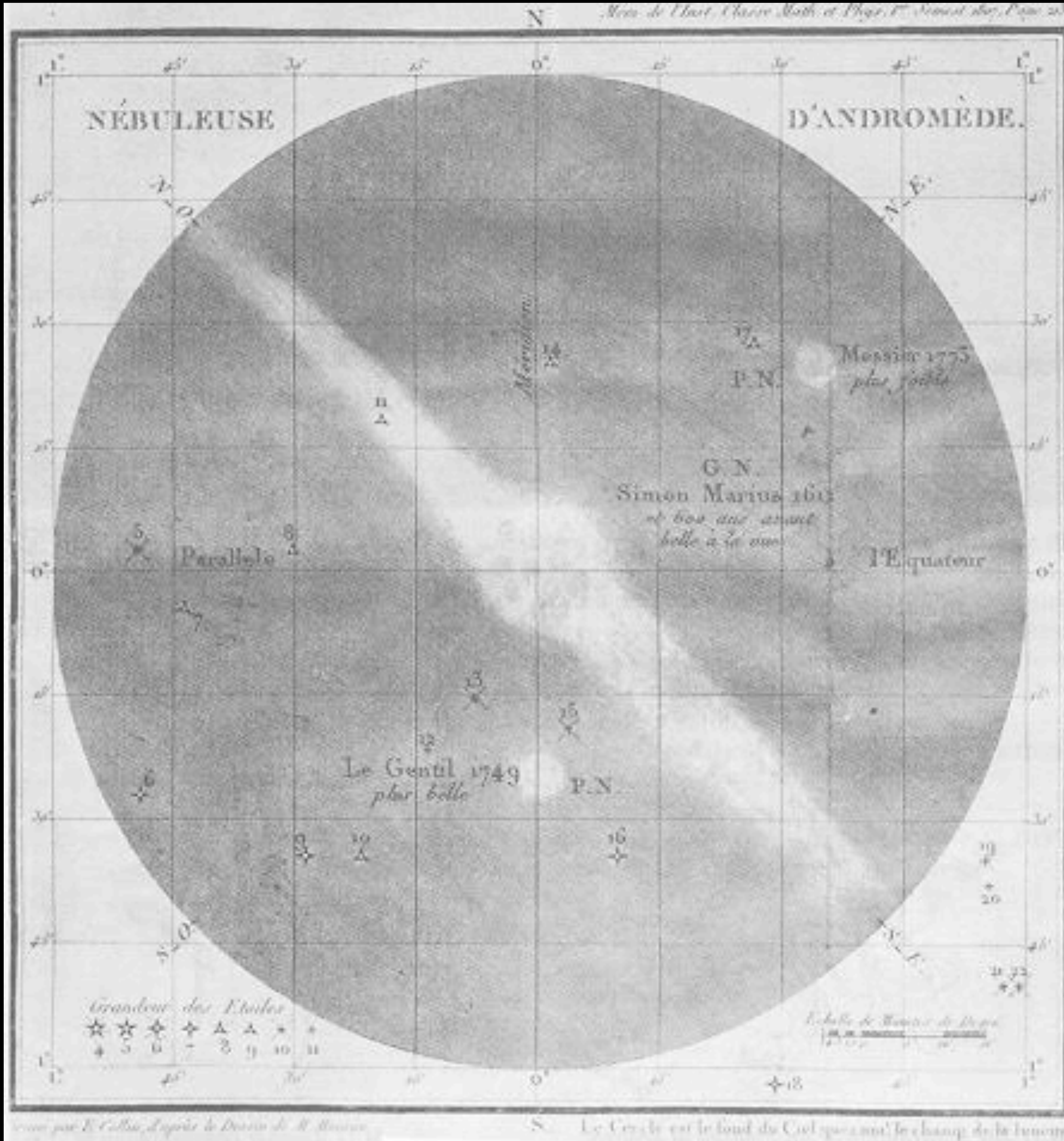
- Fluorescent emission from molecular hydrogen (Lyman-Werner bands)
- SB fluctuations and extragalactic distances
- Intracluster light and the accretion history in galaxy clusters
- Time domain astronomy: multi-wavelength variability
- Zodiacal disc
- Mass loss from stars



Sahai + Chronopoulos (2012)

Scientific and technical challenges

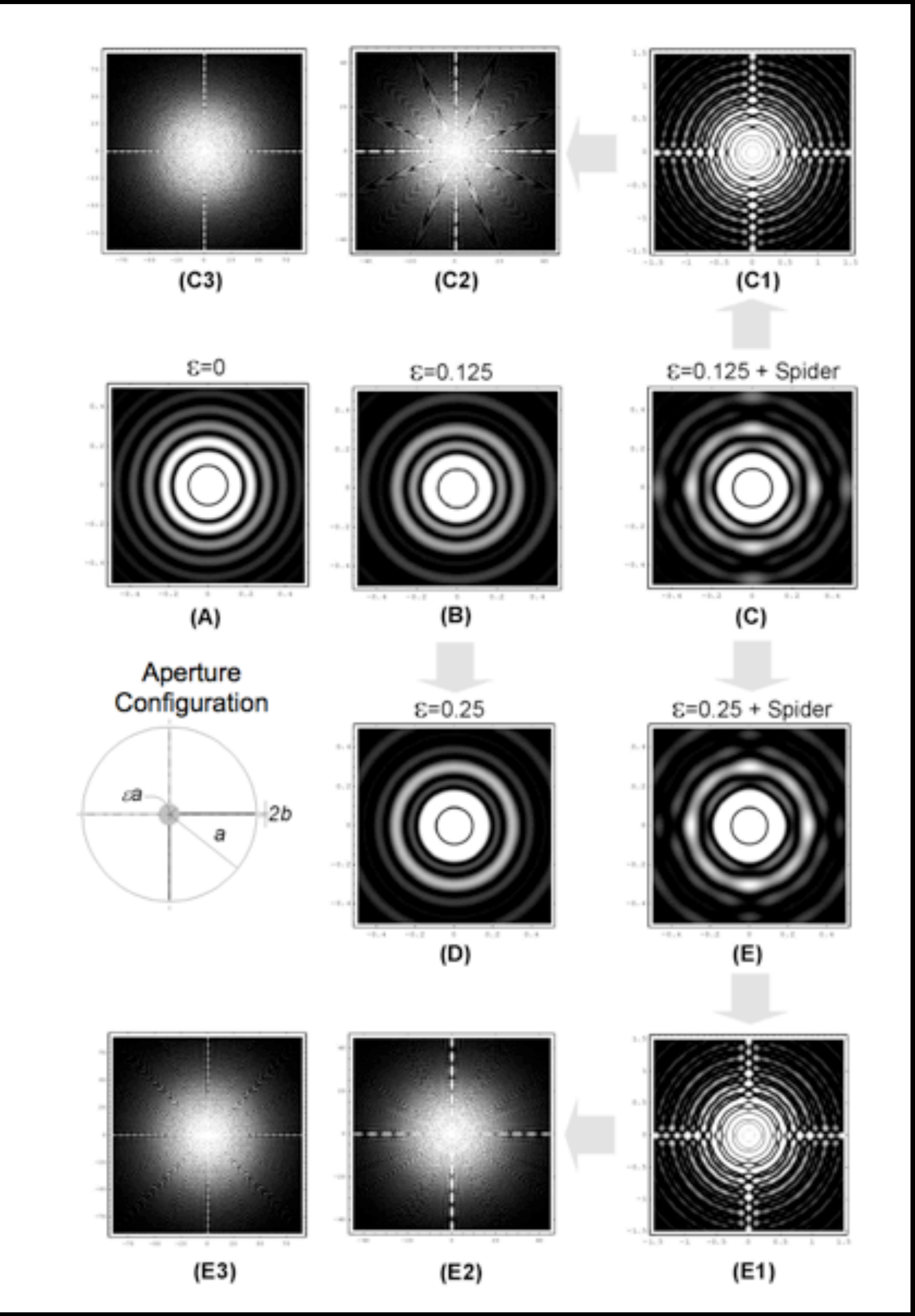
The MESSIER proposal

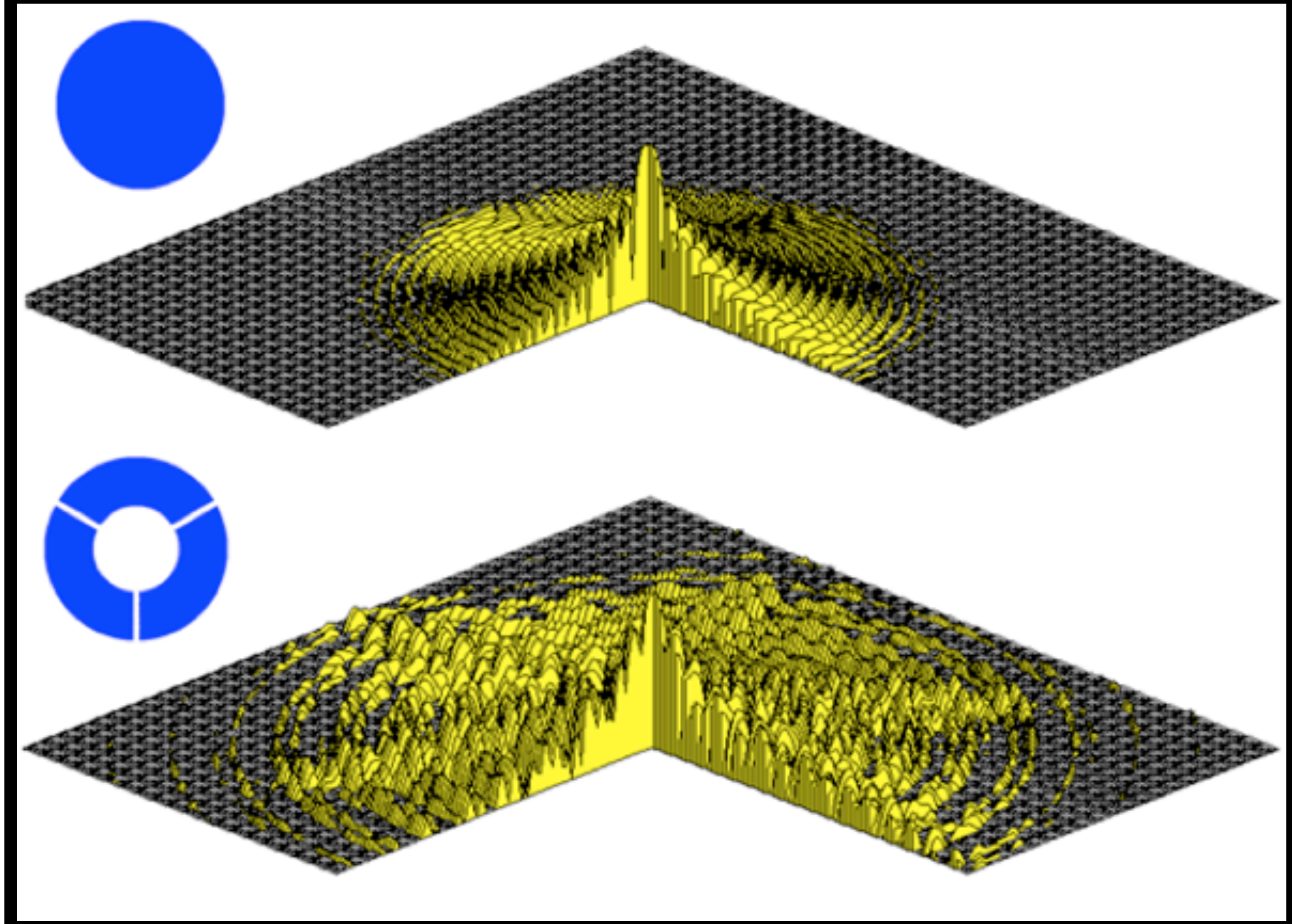


First catalogue of diffuse objects

Messier (1771)
Mem. Acad. Sci. Paris
Messier (1780)
Conn. Temps

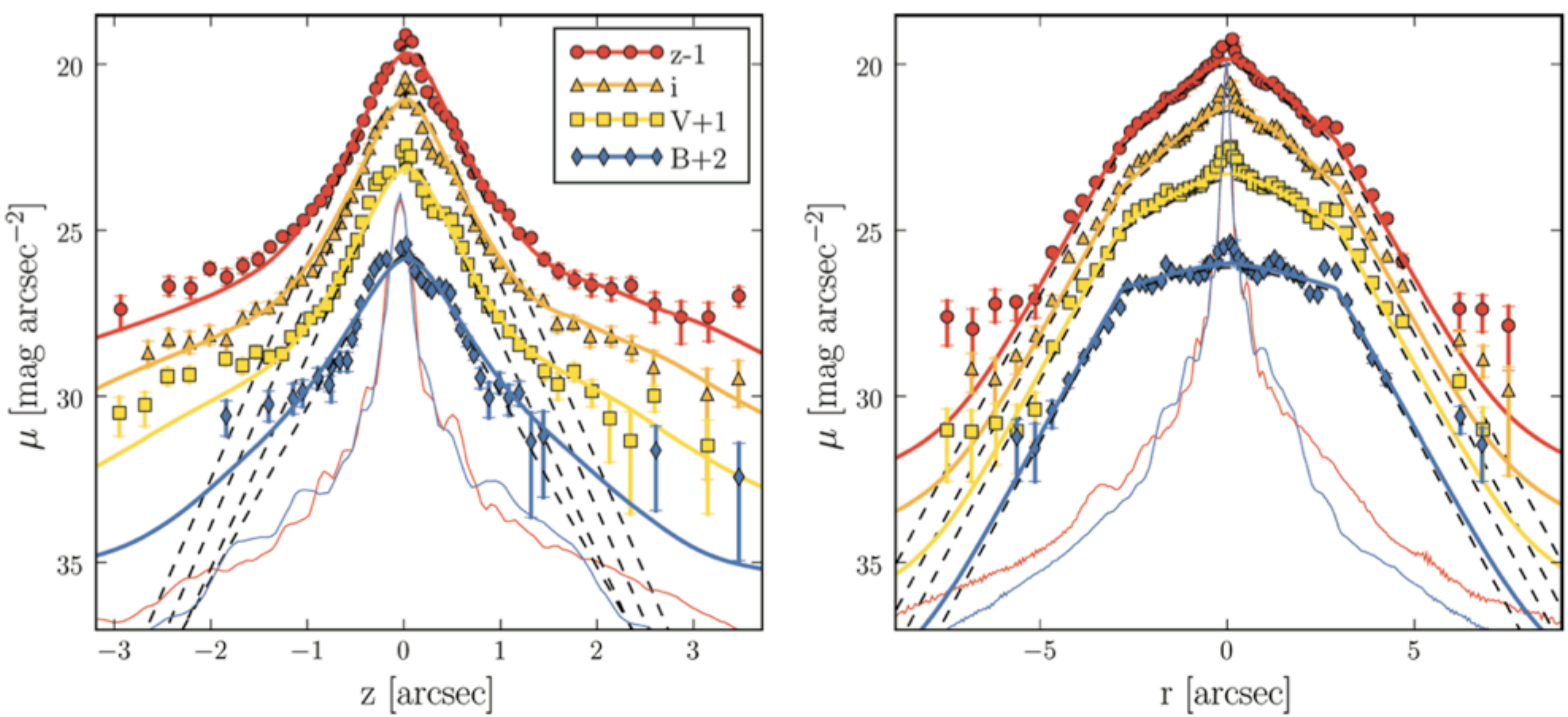
LSST: Large obstruction M1/M2 yields very extended PSFs



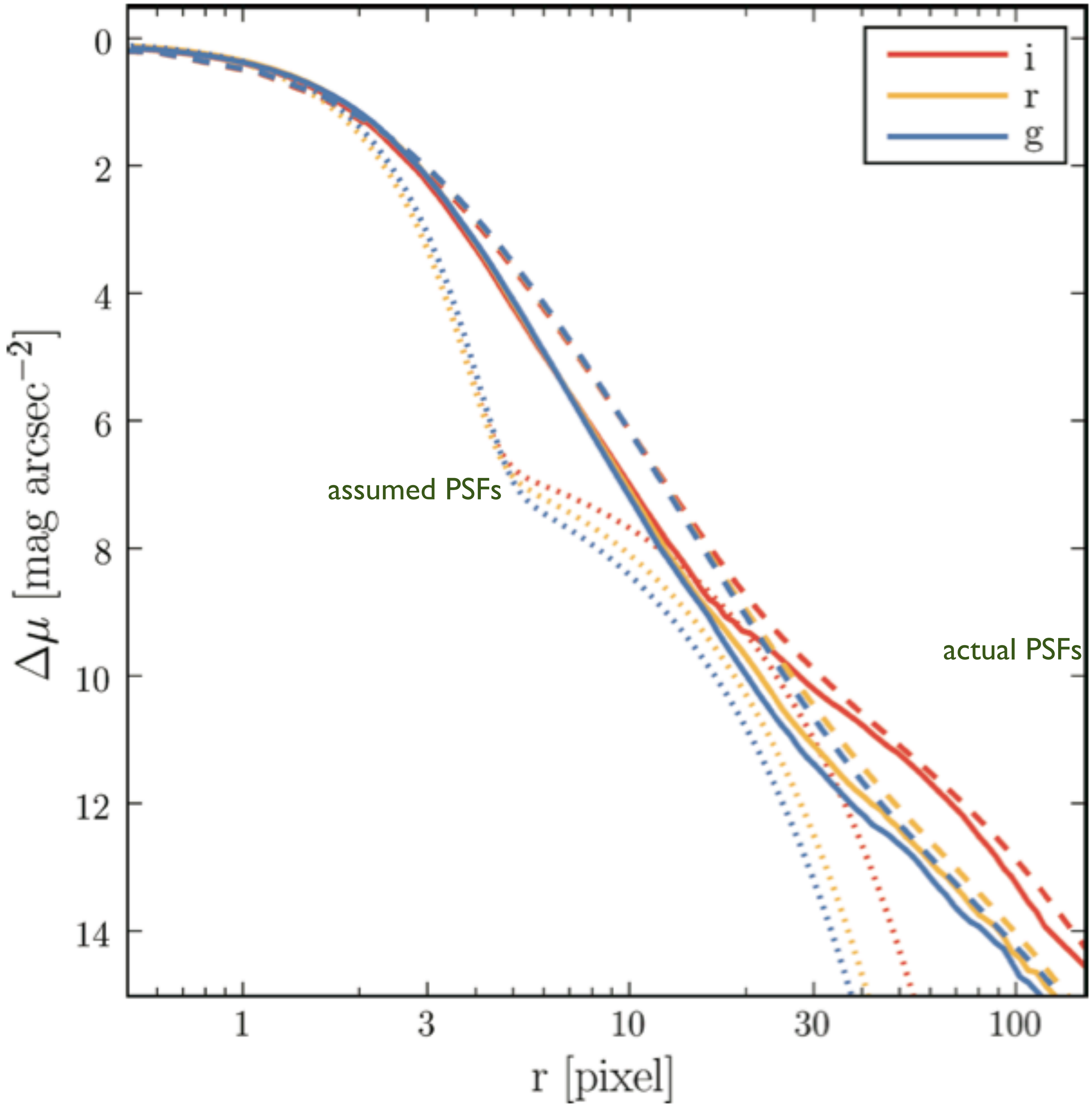


Zero obstruction is required

Stability and wings of the PSF



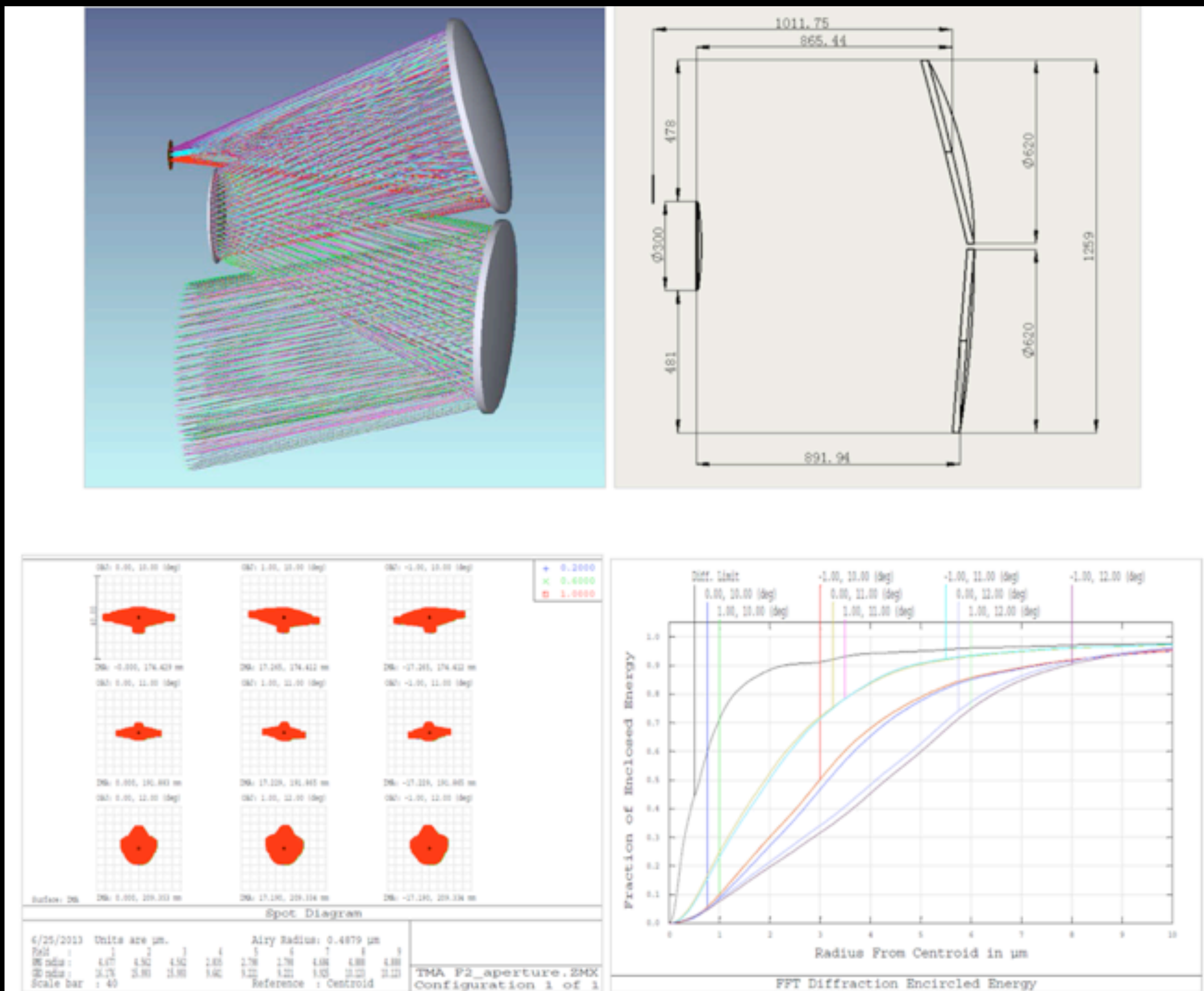
Extended red haloes ??
Zibetti et al. (2004, 2009)


i
r
g
assumed PSFs
actual PSFs
0
2
4
6
8
10
12
14
Δμ [mag arcsec⁻²]
1
3
10
30
100
r [pixel]

De Jong (2008)

Design issues

— wide-field
— flat(ish) focal plane
— no lenses (Cerenkov radiation)



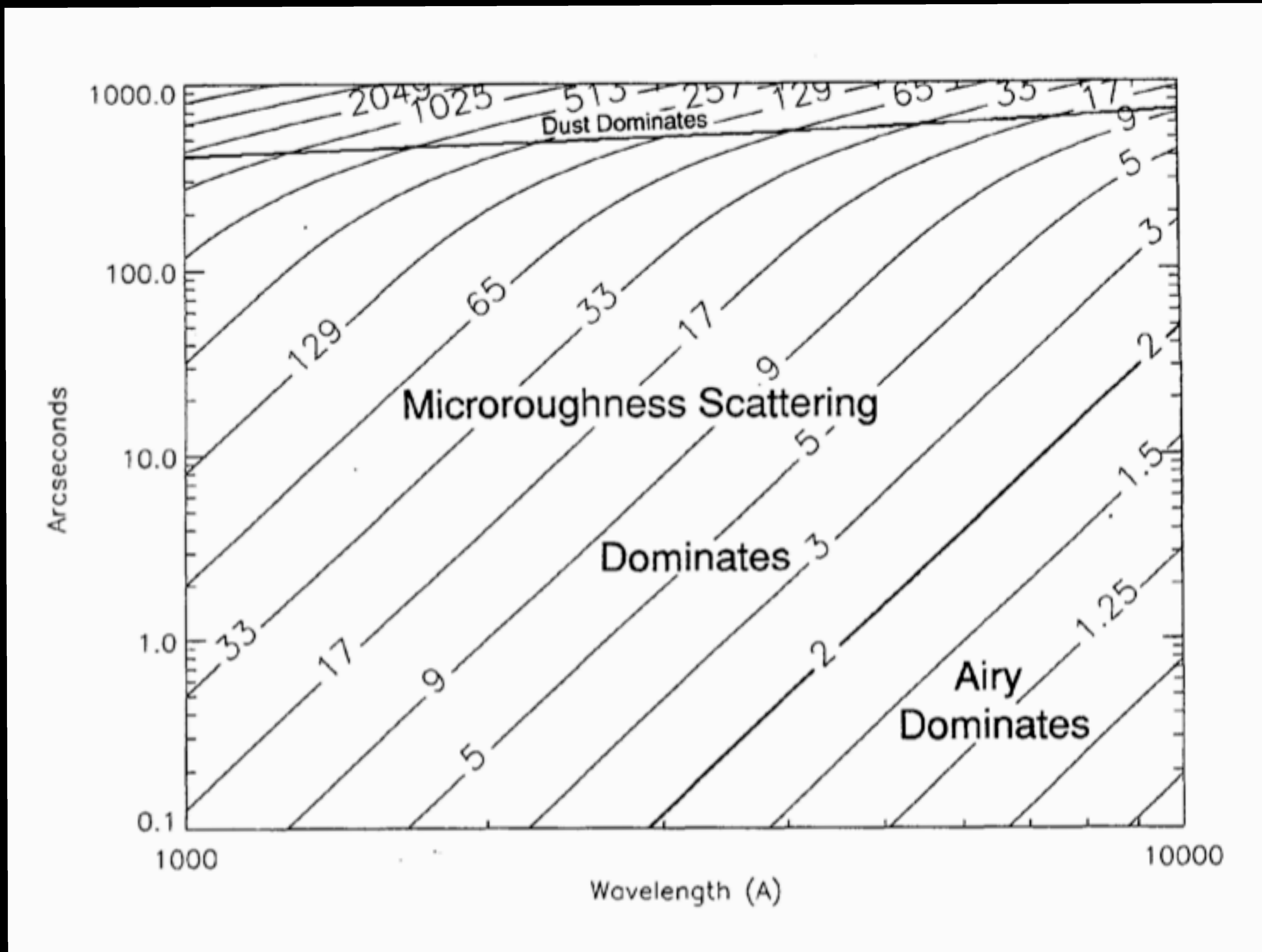
Current solution

TMA
unobscured, off-axis
flat FP
f/2
3° x 2°
TRL9 (optics/FP)
alignment issues TBD

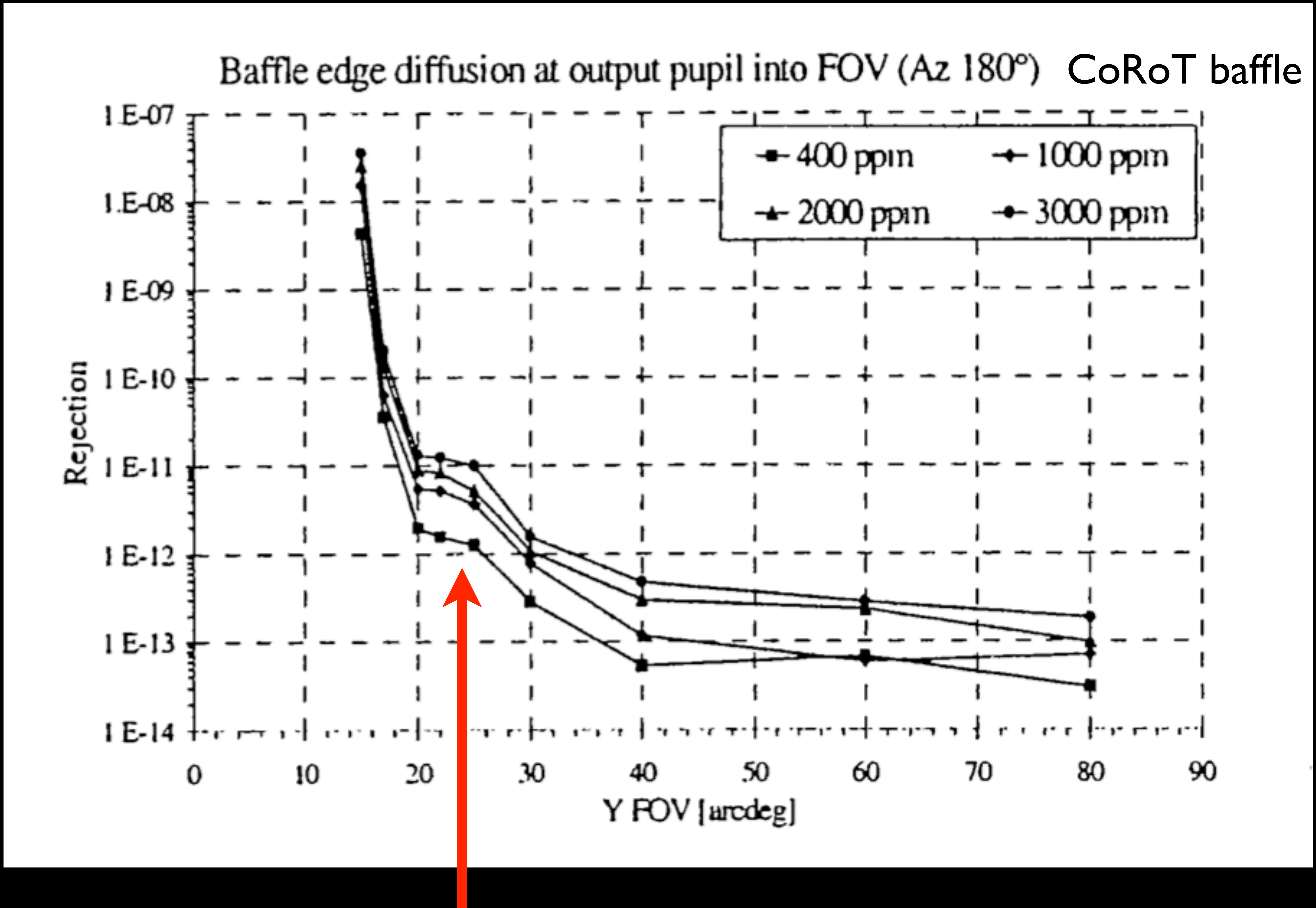
Mirrors + coatings issues

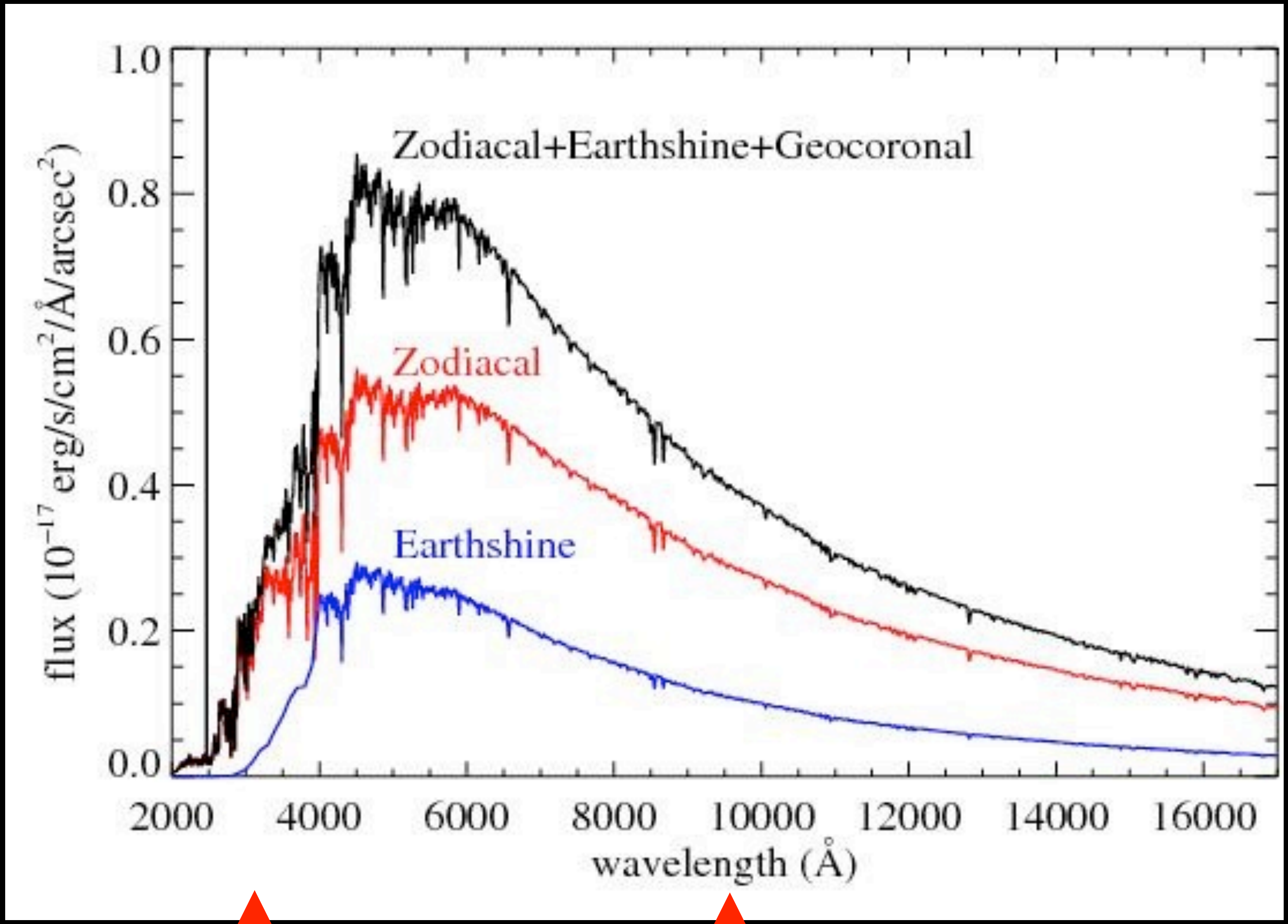
PSF WINGS

PSF CORE



Stray light contamination

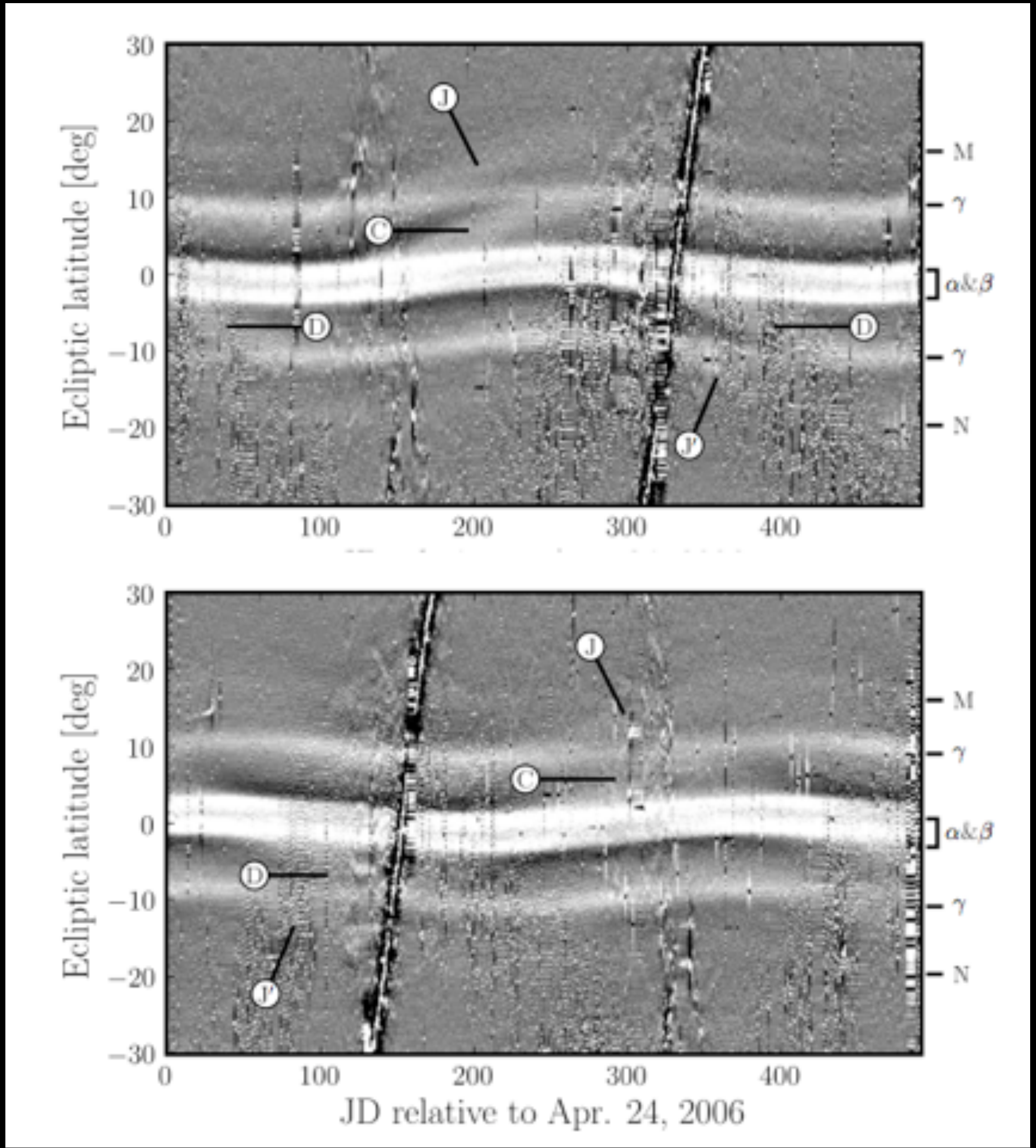




No sky variability but
many foregrounds:

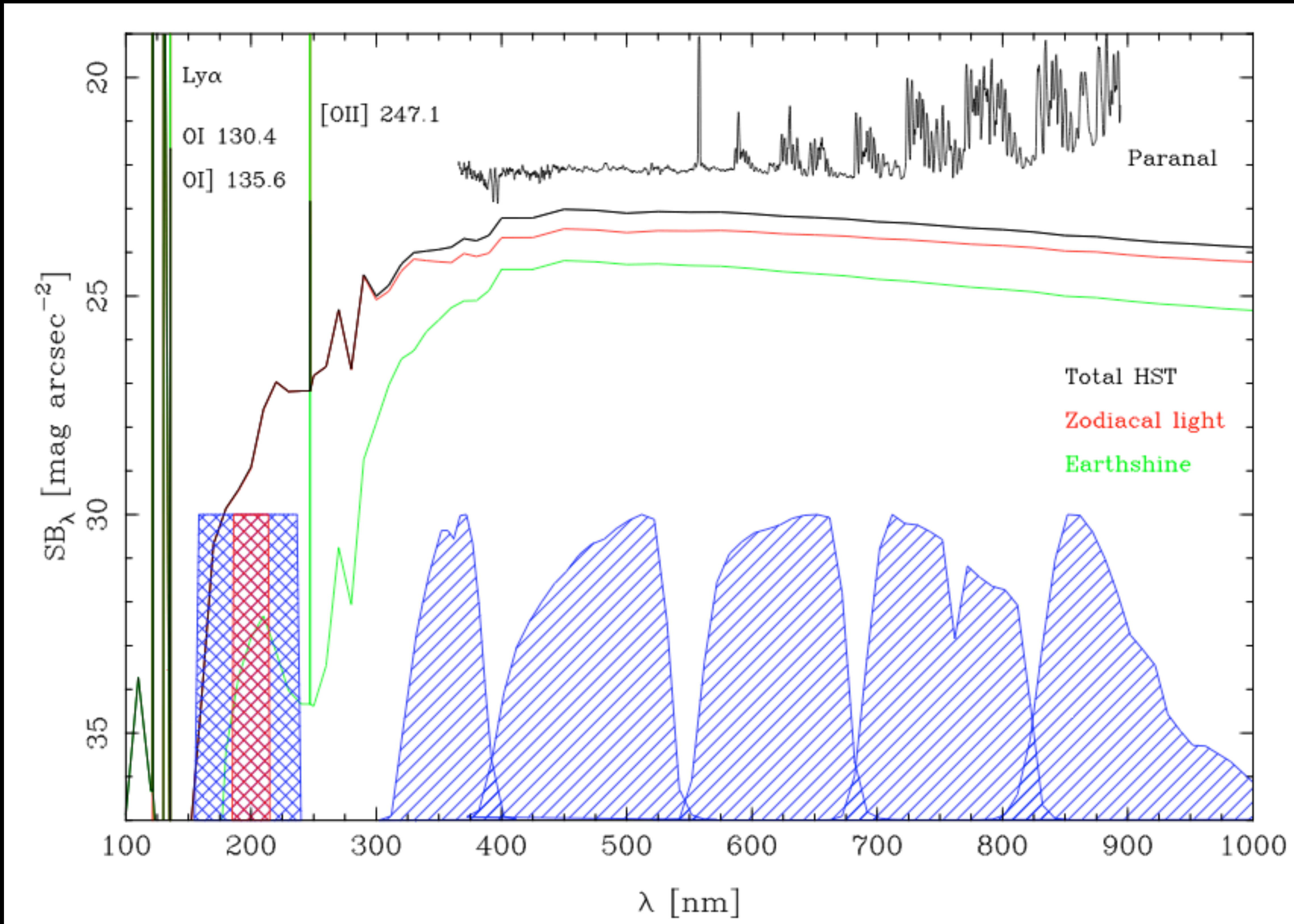
- zodiacal light
- stray light contamination
- geocoronal/airglow emission
- optical emission from dust

Zodiacal
light variability
as observed
by AKARI



Minimise zodiacal contamination
while keeping key information
on stellar populations

Filters


Lyα
OI 130.4
OI] 135.6
[OII] 247.1
Paranal
Total HST
Zodiacal light
Earthshine
20
25
30
35
SB$_\lambda$ [mag arcsec^{-2}]
100
200
300
400
500
600
700
800
900
1000
λ [nm]

Focal plane configuration

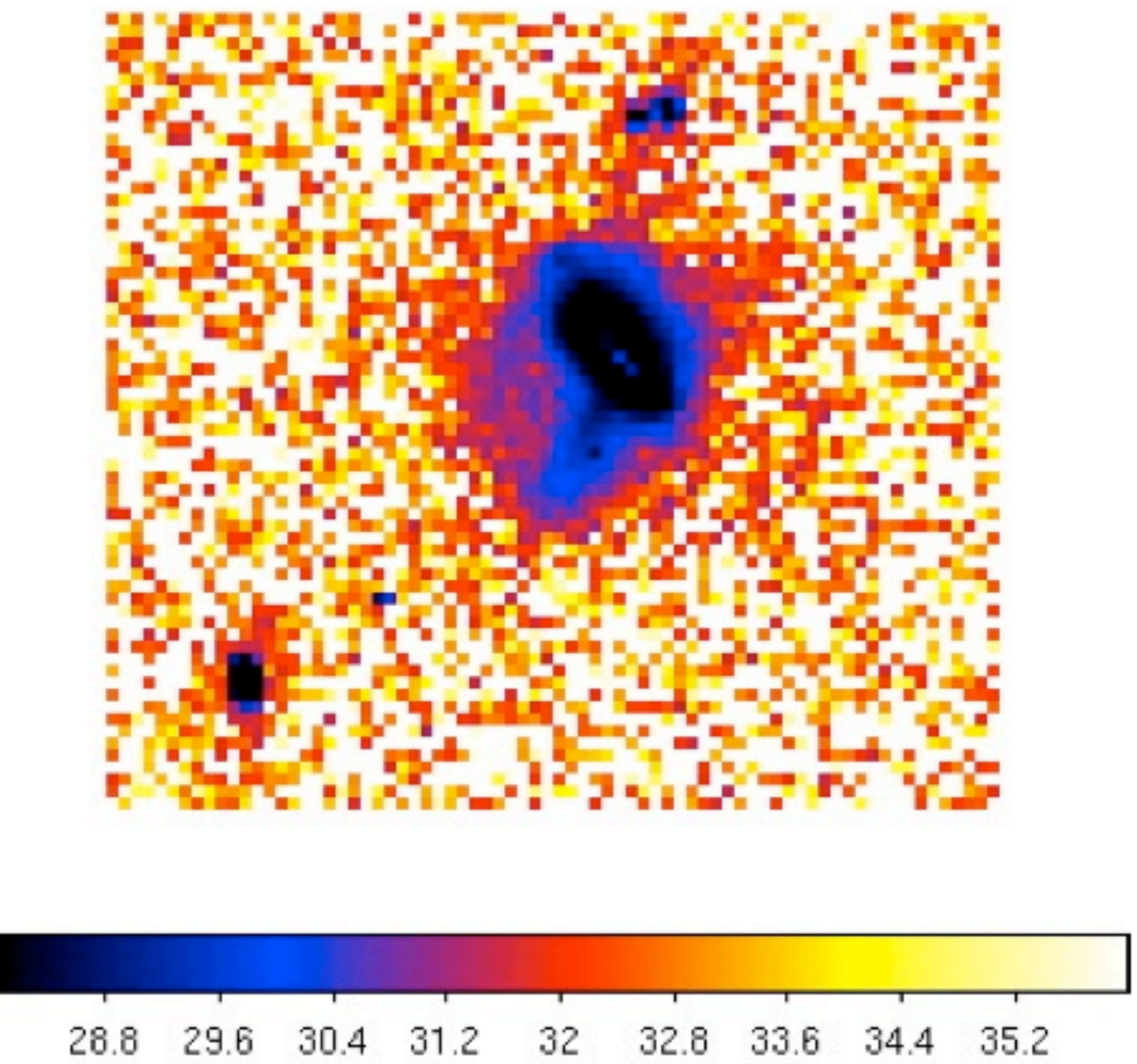
8 independent CCD controllers in drift-scan mode

QE of each detector optimised for each filter/band

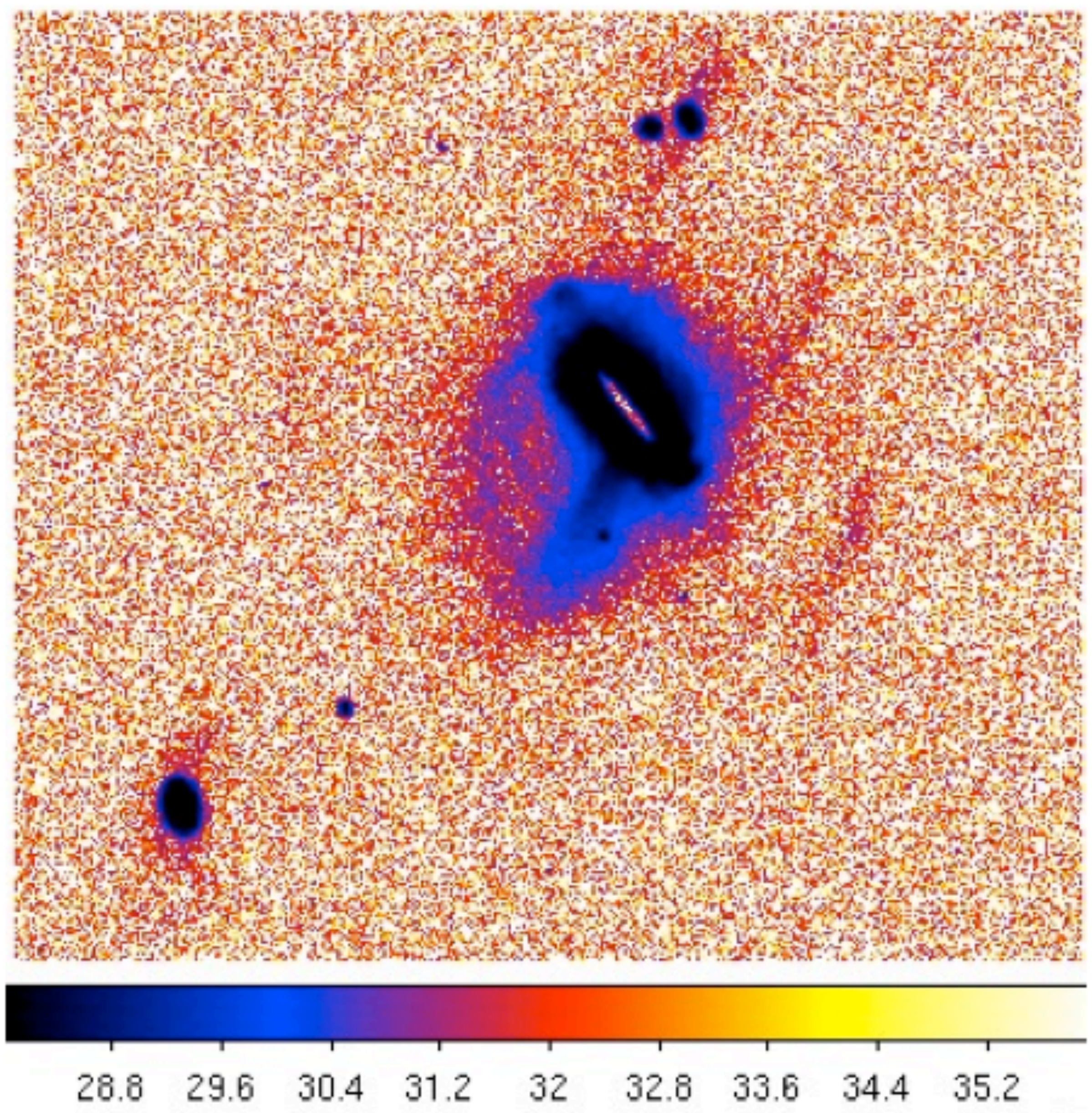
No moving parts

r / T1	g / C	u / M	IB200 Lyα
Extra broad	i / T2	z / T2	NB200 Lyα

Simulated MESSIER images of a galaxy at 15 Mpc

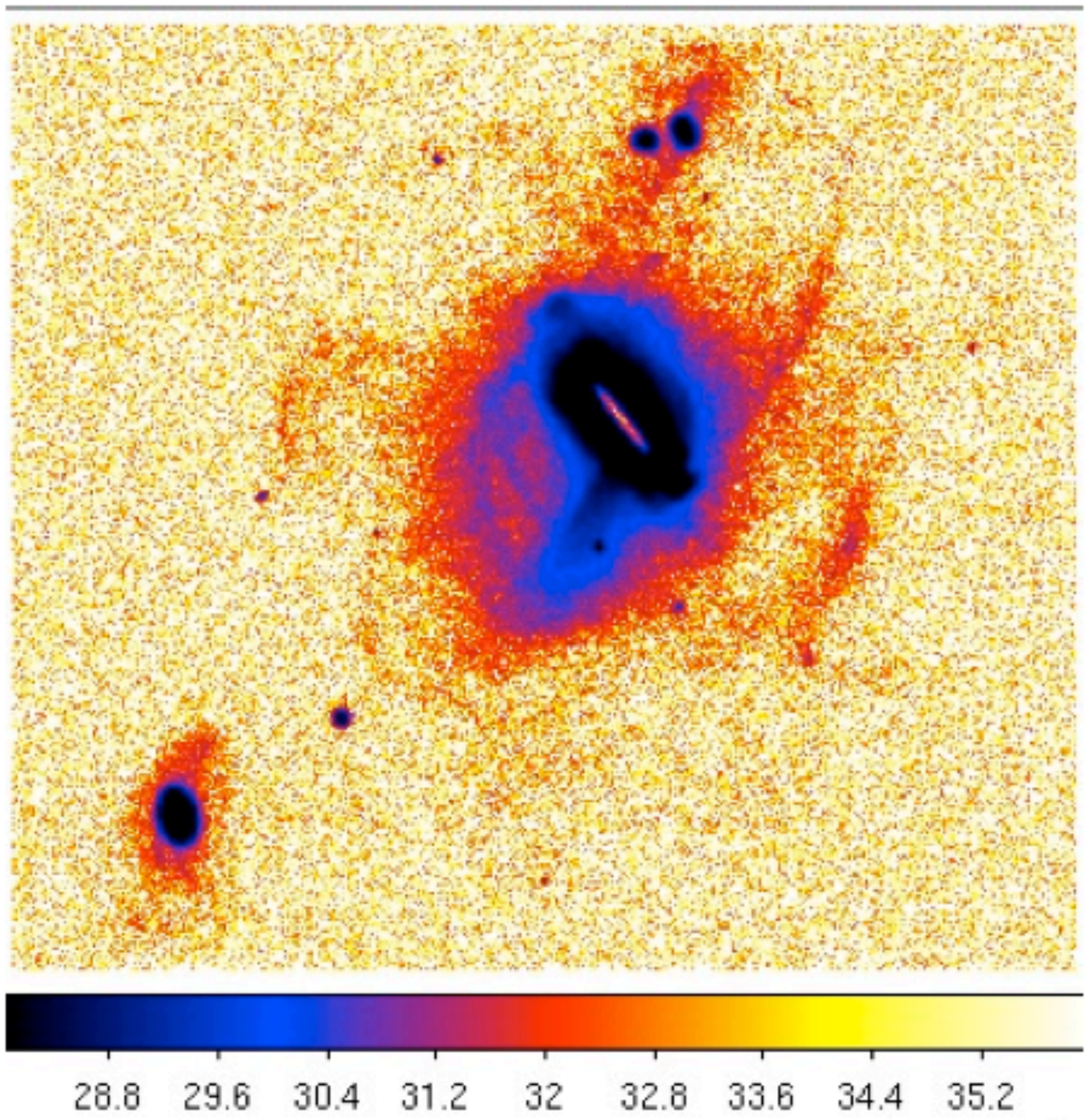


10 ksec
5 kpc × 5 kpc

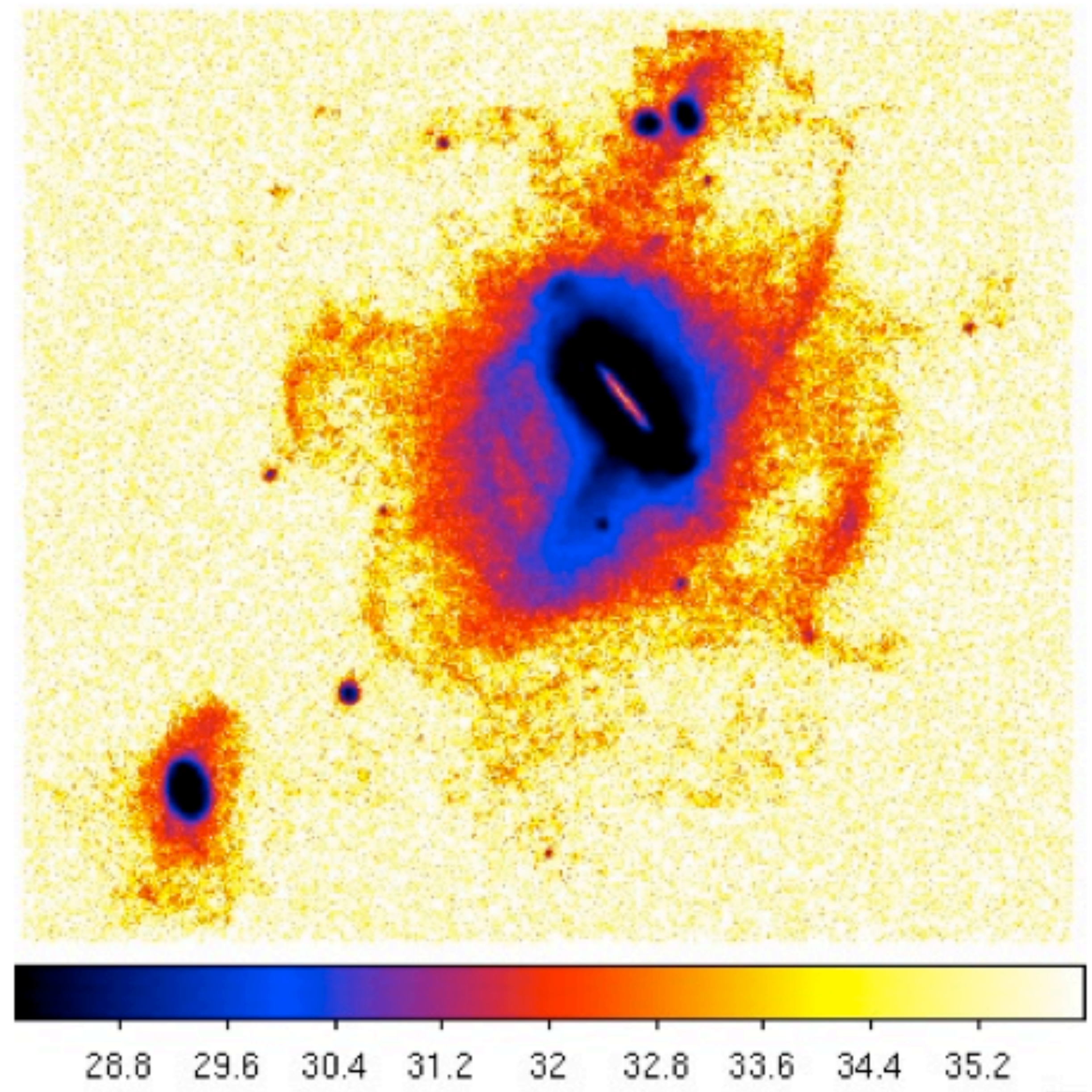


100 ksec
1 kpc × 1 kpc (14″ × 14″)

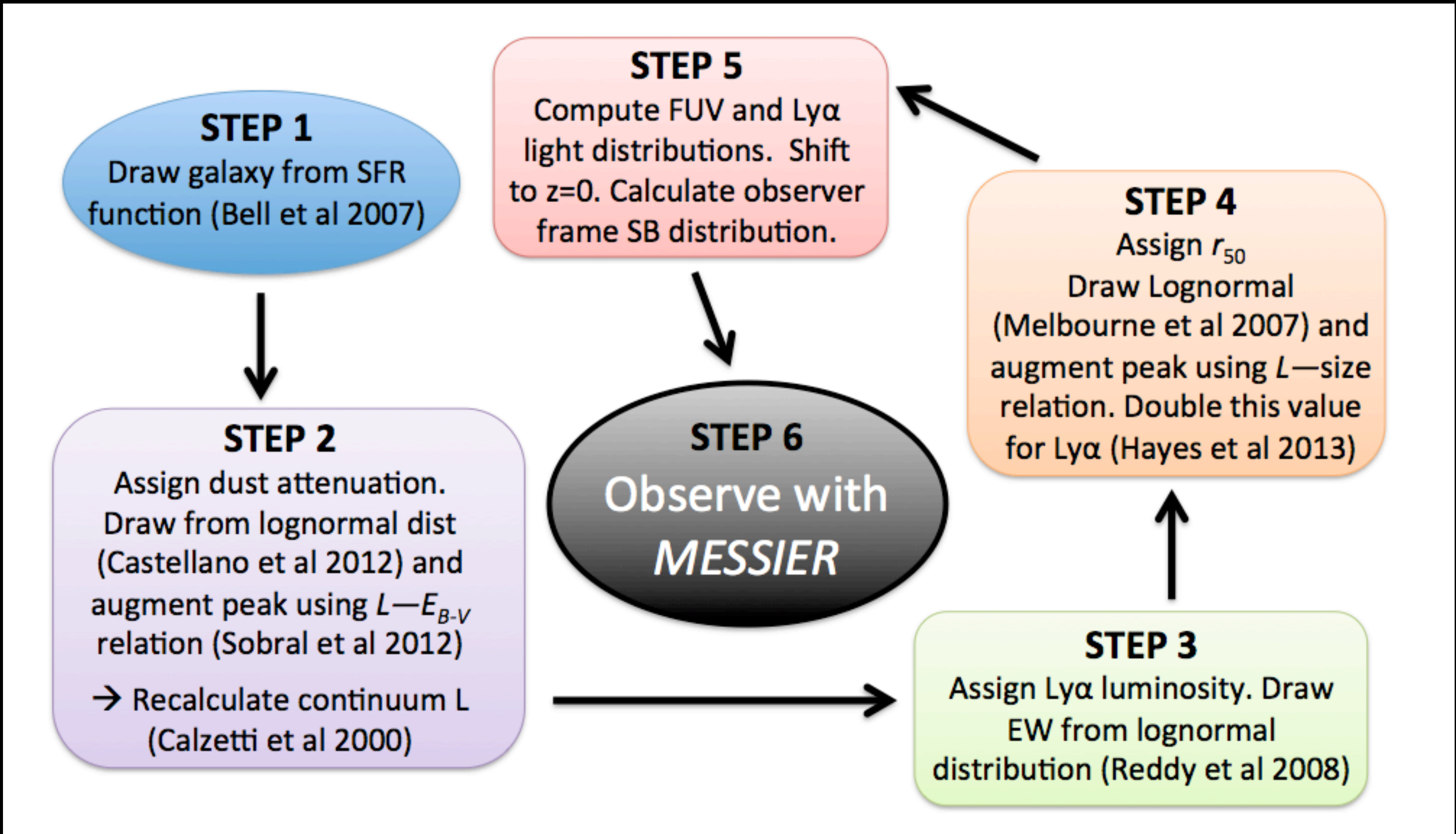
Simulated MESSIER images of a galaxy at 15 Mpc

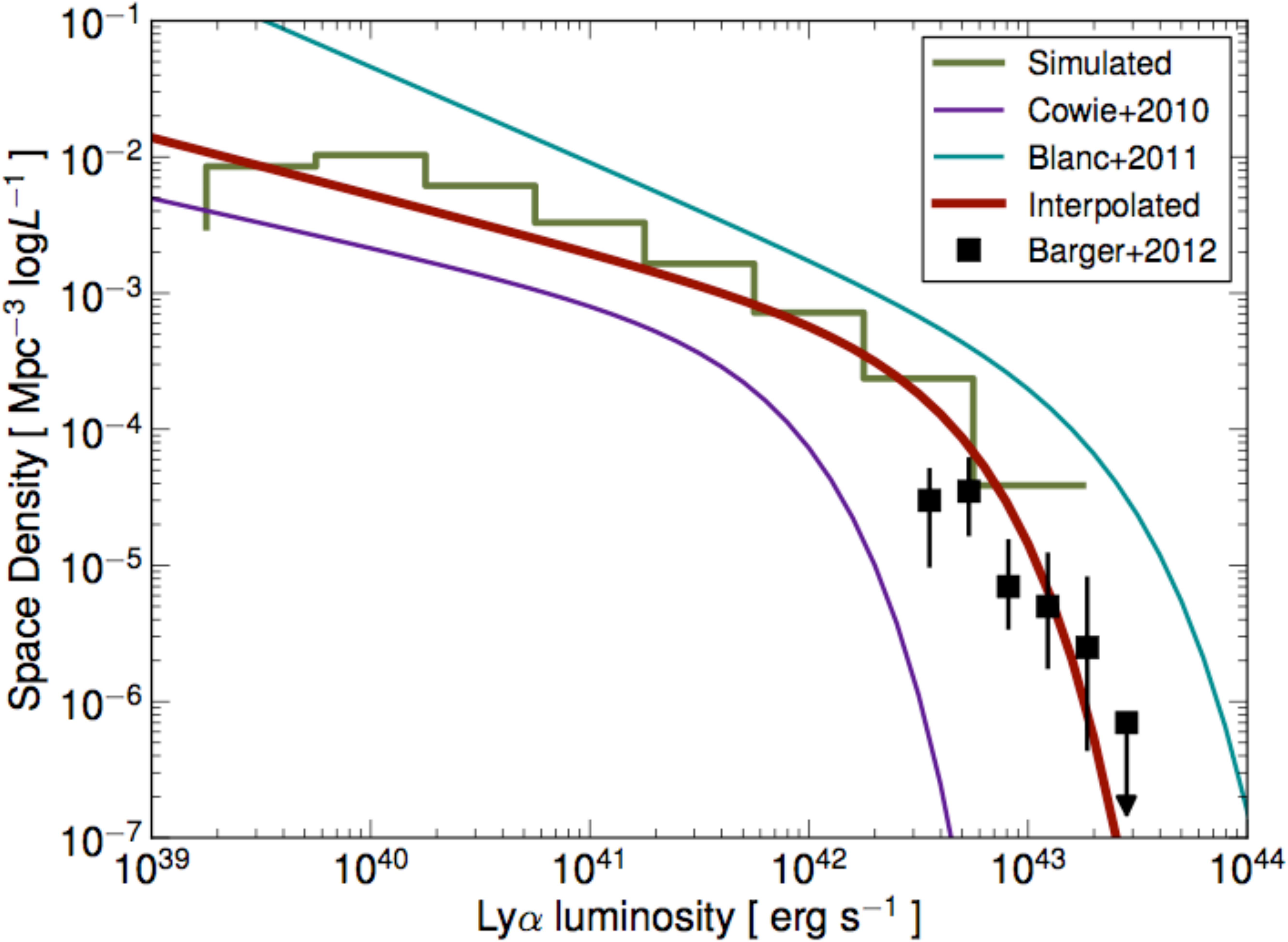


1 Msec
1 kpc × 1 kpc



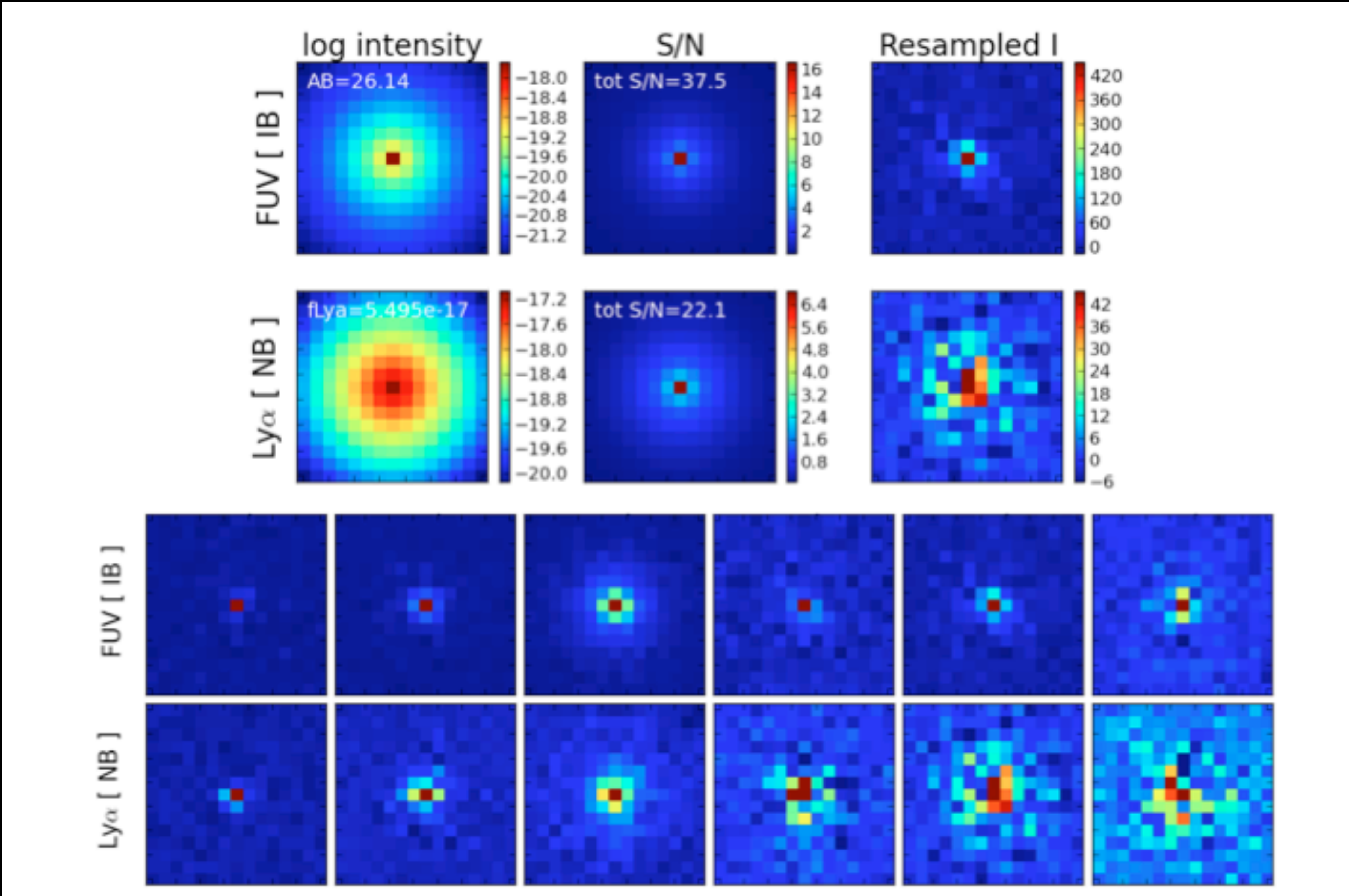
10 Msec
1 kpc × 1 kpc


STEP 1
Draw galaxy from SFR function (Bell et al 2007)
STEP 2
Assign dust attenuation. Draw from lognormal dist (Castellano et al 2012) and augment peak using L—E_{B-V} relation (Sobral et al 2012)
→ Recalculate continuum L (Calzetti et al 2000)
STEP 3
Assign Lyα luminosity. Draw EW from lognormal distribution (Reddy et al 2008)
STEP 4
Assign r_{50}
Draw Lognormal (Melbourne et al 2007) and augment peak using L—size relation. Double this value for Lyα (Hayes et al 2013)
STEP 5
Compute FUV and Lyα light distributions. Shift to z=0. Calculate observer frame SB distribution.
STEP 6
Observe with *MESSIER*

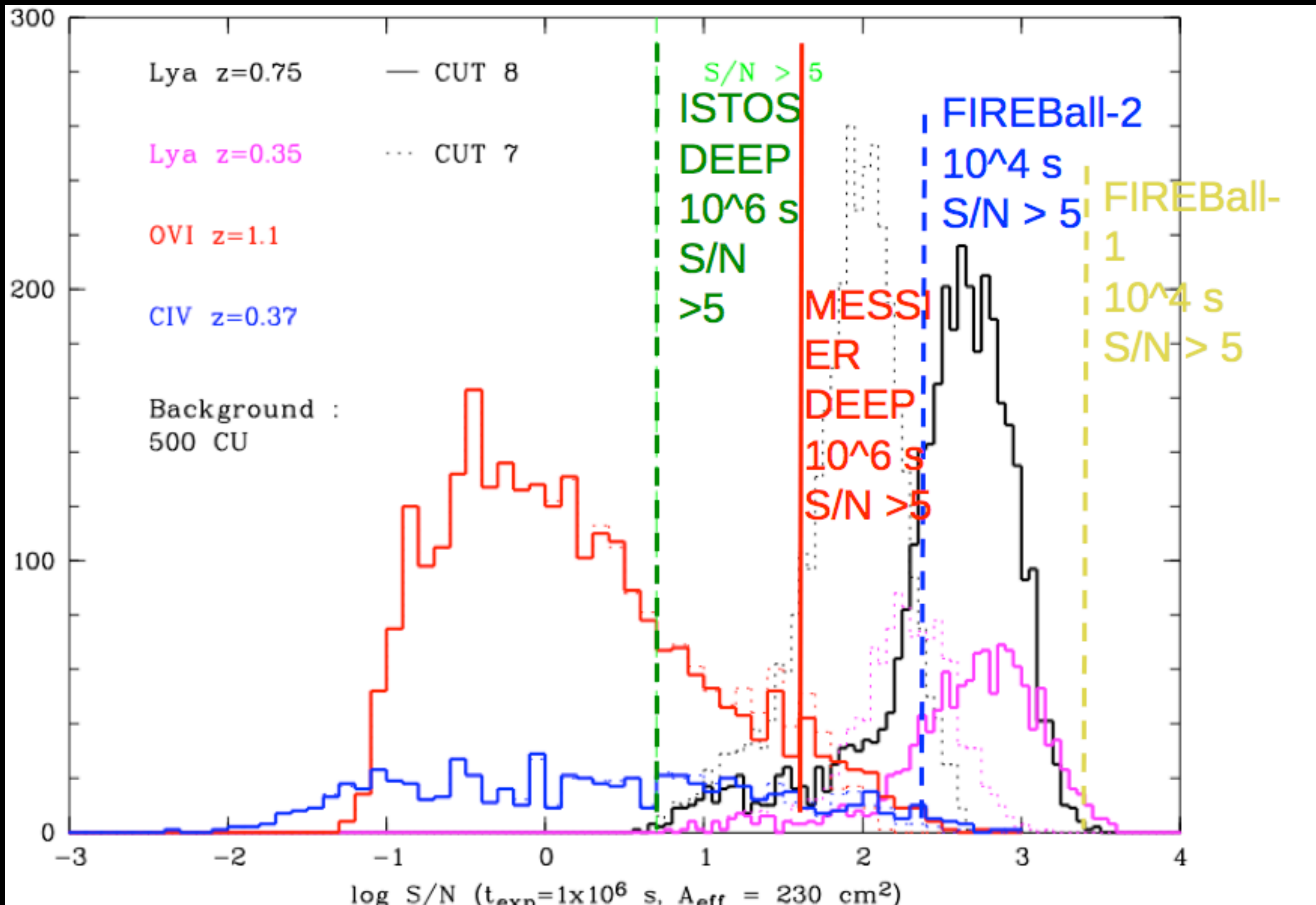


Simulated
Cowie+2010
Blanc+2011
Interpolated
Barger+2012
Space Density [Mpc^{-3} logL^{-1}]
Lyα luminosity [erg s^{-1}]
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{39}
10^{40}
10^{41}
10^{42}
10^{43}
10^{44}

Simulated Lyman-α images in MESSIER

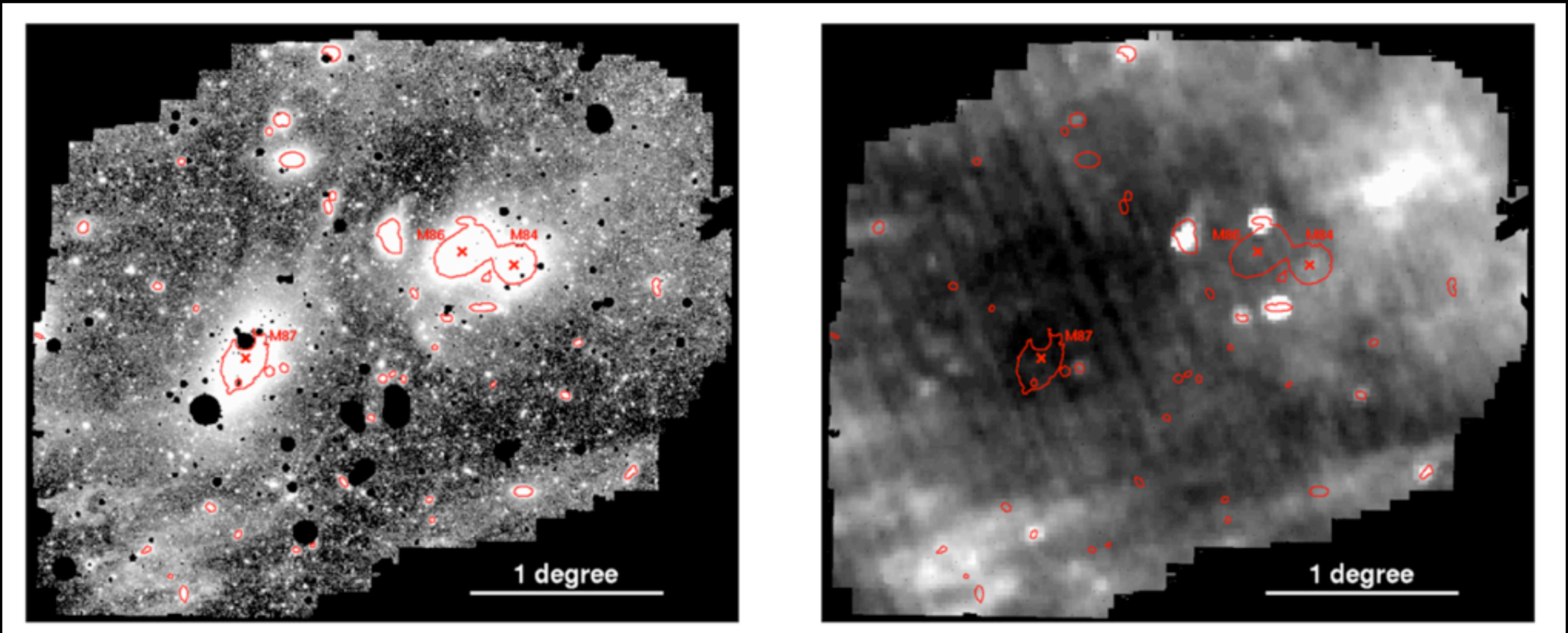


Simulated MESSIER images of the cosmic web at z=0.65



Optical

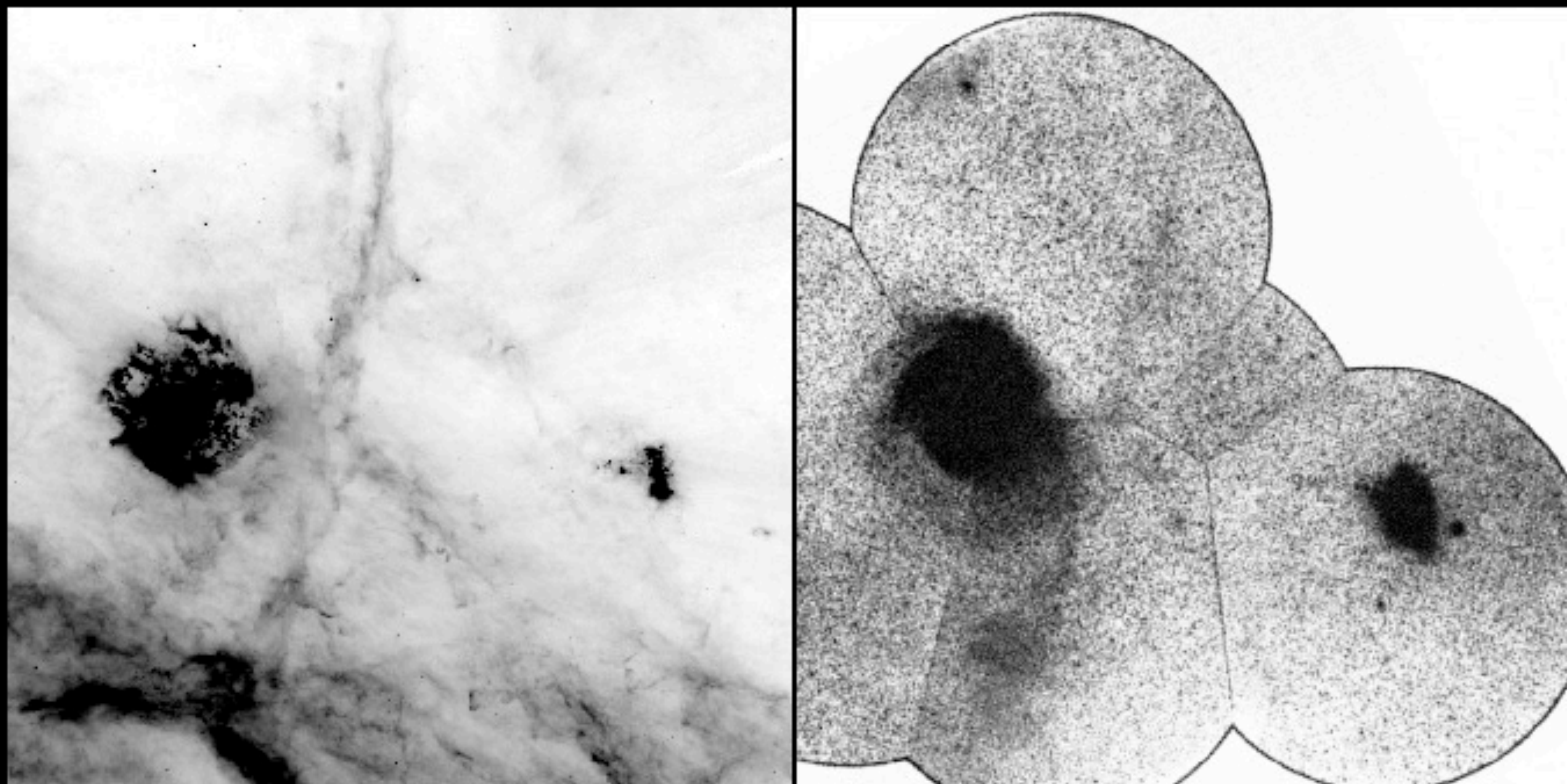
IRAS 100μm emission



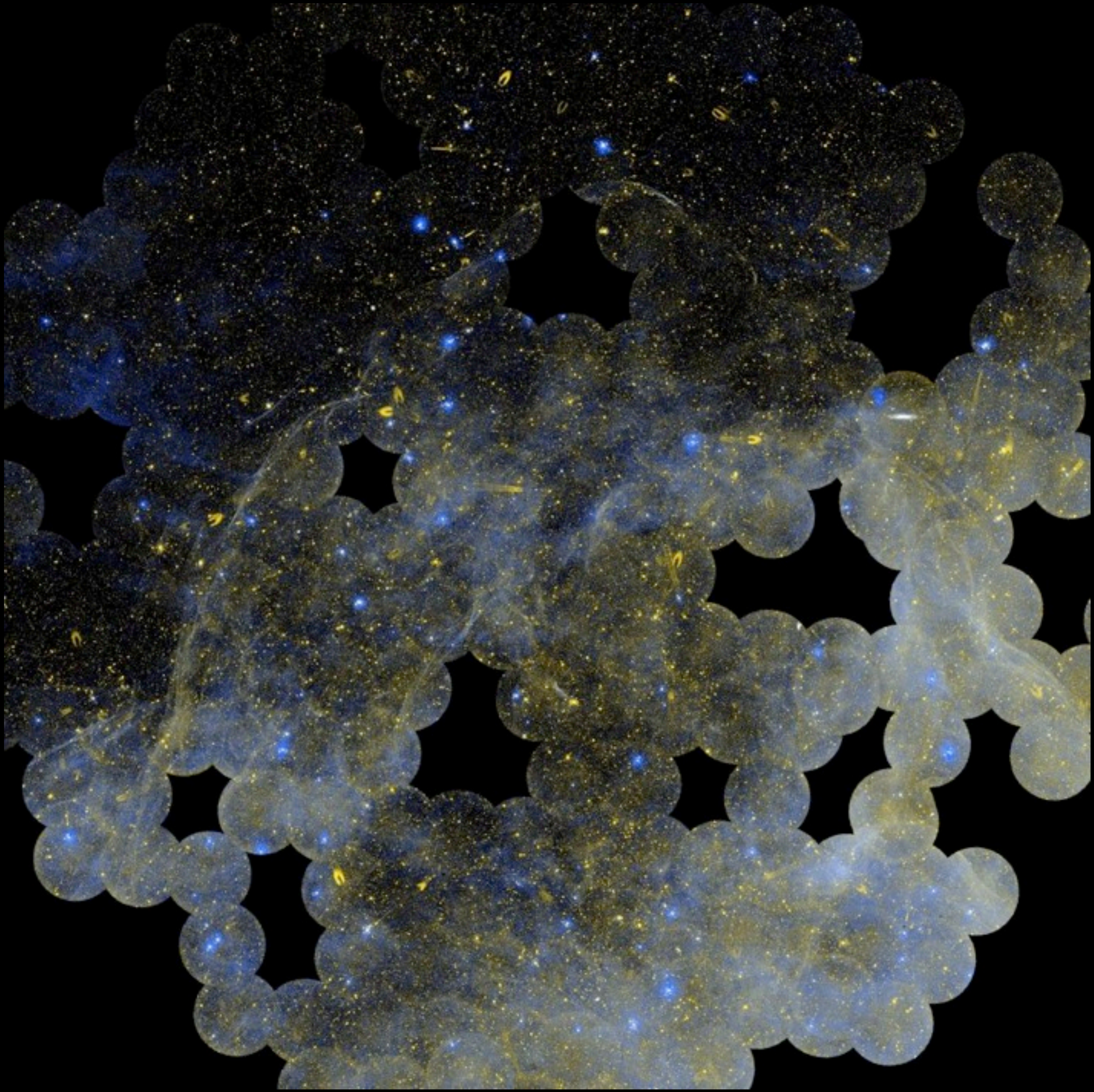
Mihos et al. (2009)

Virgo cluster field

100μm (IRAS) | Optical (de Vaucouleurs 1955)



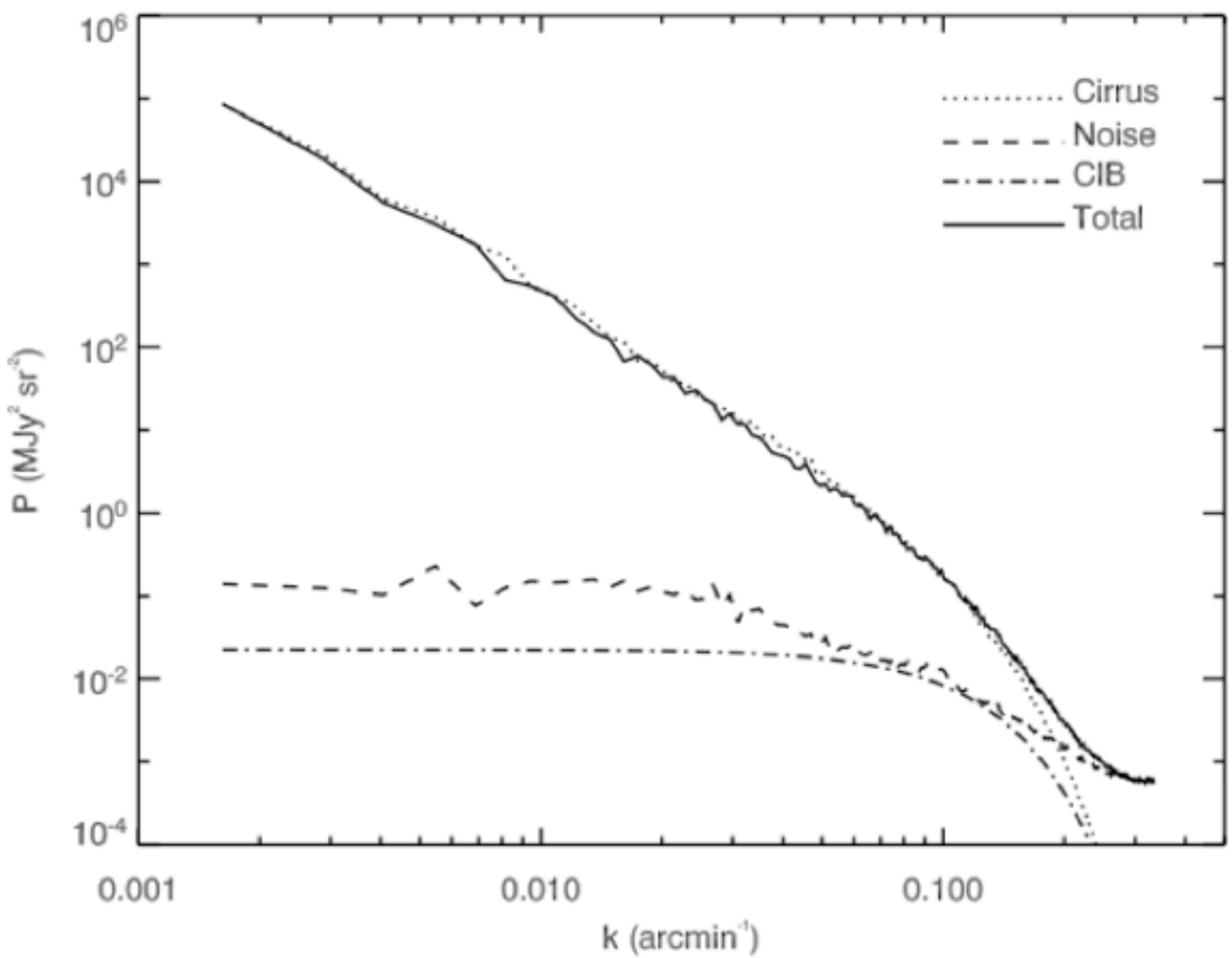
Magellanic Clouds



GALEX

Angular power spectrum of IR cirri

angular distribution



the smaller
the scale,
the smaller
the fluctuations

IRAS 100um
Miville-Deschênes et al., 2007

PLANCK 857 GHz
Dole et al., 2013

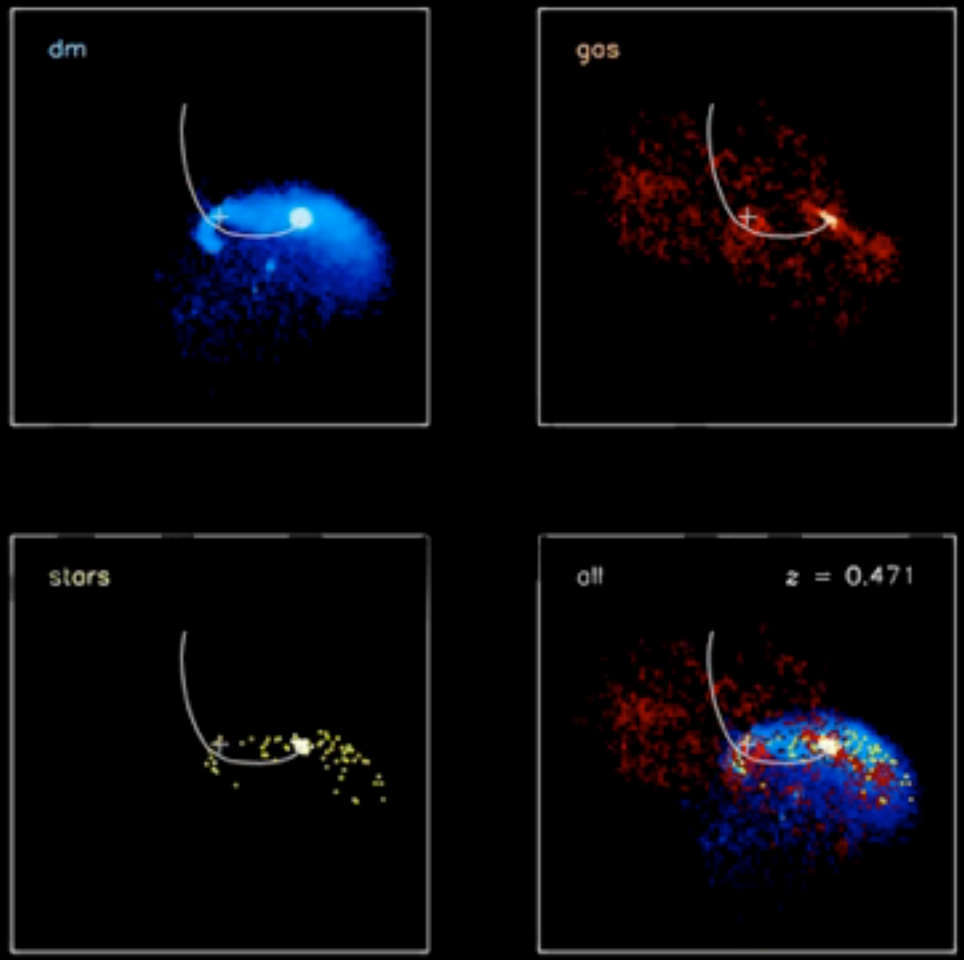
Critical technical issues

- Optics
  - optical design: flat focal plane, FOV ~ 8 square degrees
    ultra-stable PSF with ultra-low wings
  - no lenses (to avoid Cerenkov radiation)
  - extreme baffling to limit straylight contaminations
- Detectors
  - time delay integration controllers + data flow to ground
  - optimise detector/QE for each UV/optical filter
- Orbit
  - orbit stabilisation: great circle drift scan within pixel
  - orbit design: avoiding Moonshine and Earthshine

Synergies

- GAIA
  MESSIER provides extension of star counts to fainter levels than G=20
  Use GAIA astrometry as prior for MESSIER detections
  Problem: pixel size to separate dwarf galaxies from stars down to g~25
  Solution: use EUCLID astrometry as prior
- EUCLID
  Requires multi-band follow-up for photometric redshifts
  Use EUCLID astrometry as prior for MESSIER detections
- Time-domain astronomy
  Transients, transits, etc
  Complements UV-based projects (Ultrasat, JUST) on longer timescales
- Reference catalogue for space-based photometry

MESSIER



Proposal for a CNES satellite
S/M-class, 150M€, 2020 horizon
Phase 0 to start in 2013/4

Uncovering the unobserved
low surface brightness universe

The last unexplored niche
in observational space

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

International partners welcome