THE MESSIER SURVEYOR

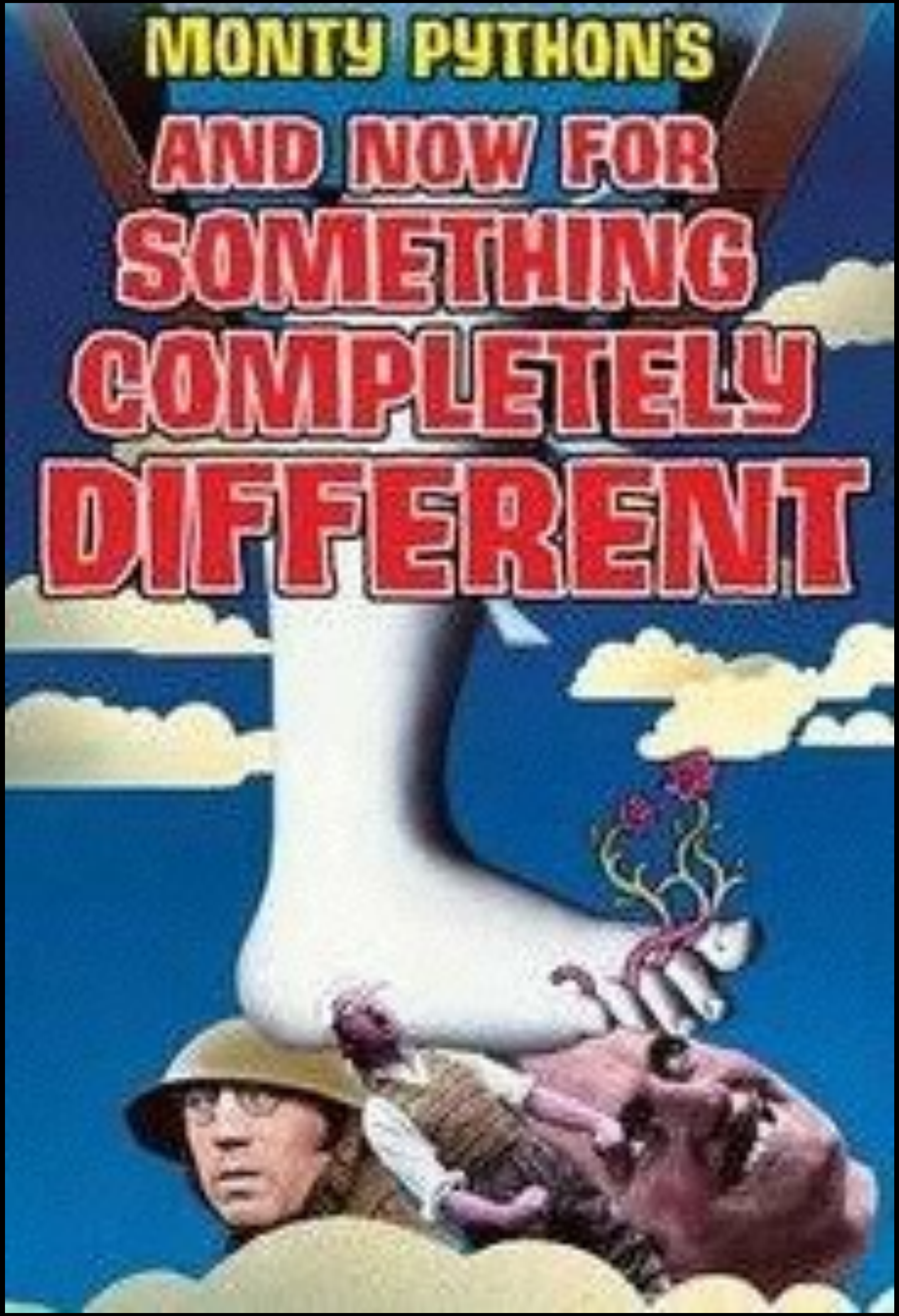
David Valls-Gabaud

LERMA - Observatoire de Paris

on behalf of the MESSIER collaboration

SF2A - Bordeaux

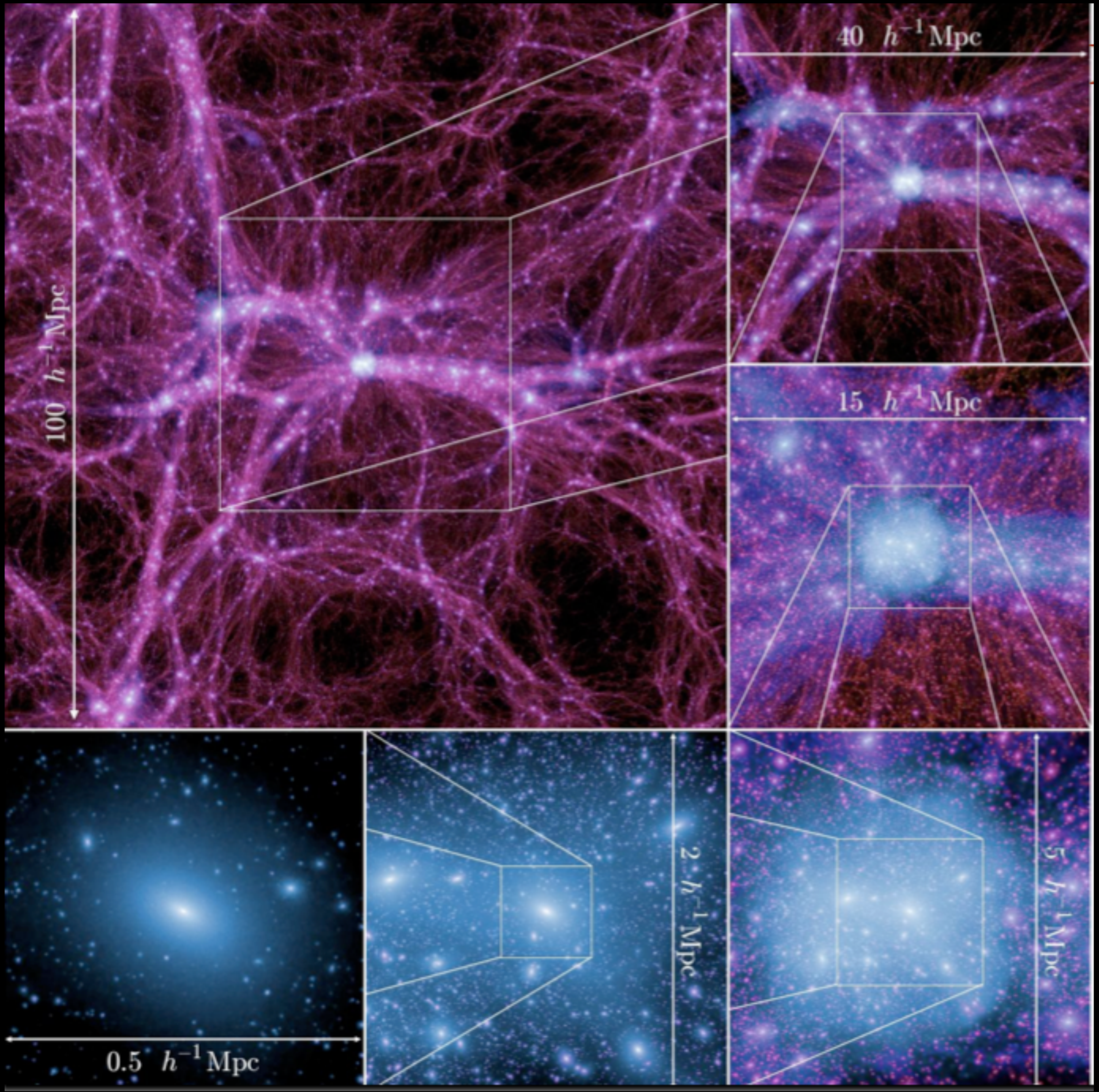
2018 July 6


MONTY PYTHON'S
AND NOW FOR
SOMETHING
COMPLETELY
DIFFERENT

linear

weakly nonlinear

highly
nonlinear

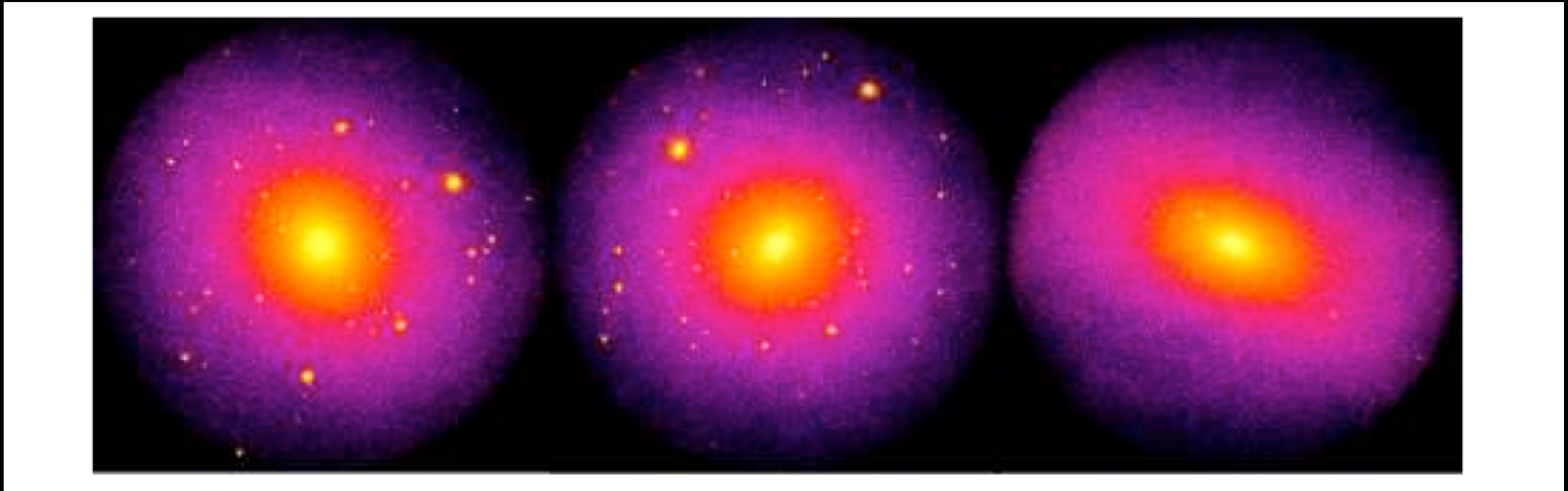


Boylan-Kolchin *et al.* (2009)

Untested

LCDM predictions

Tension in the CDM paradigm ?



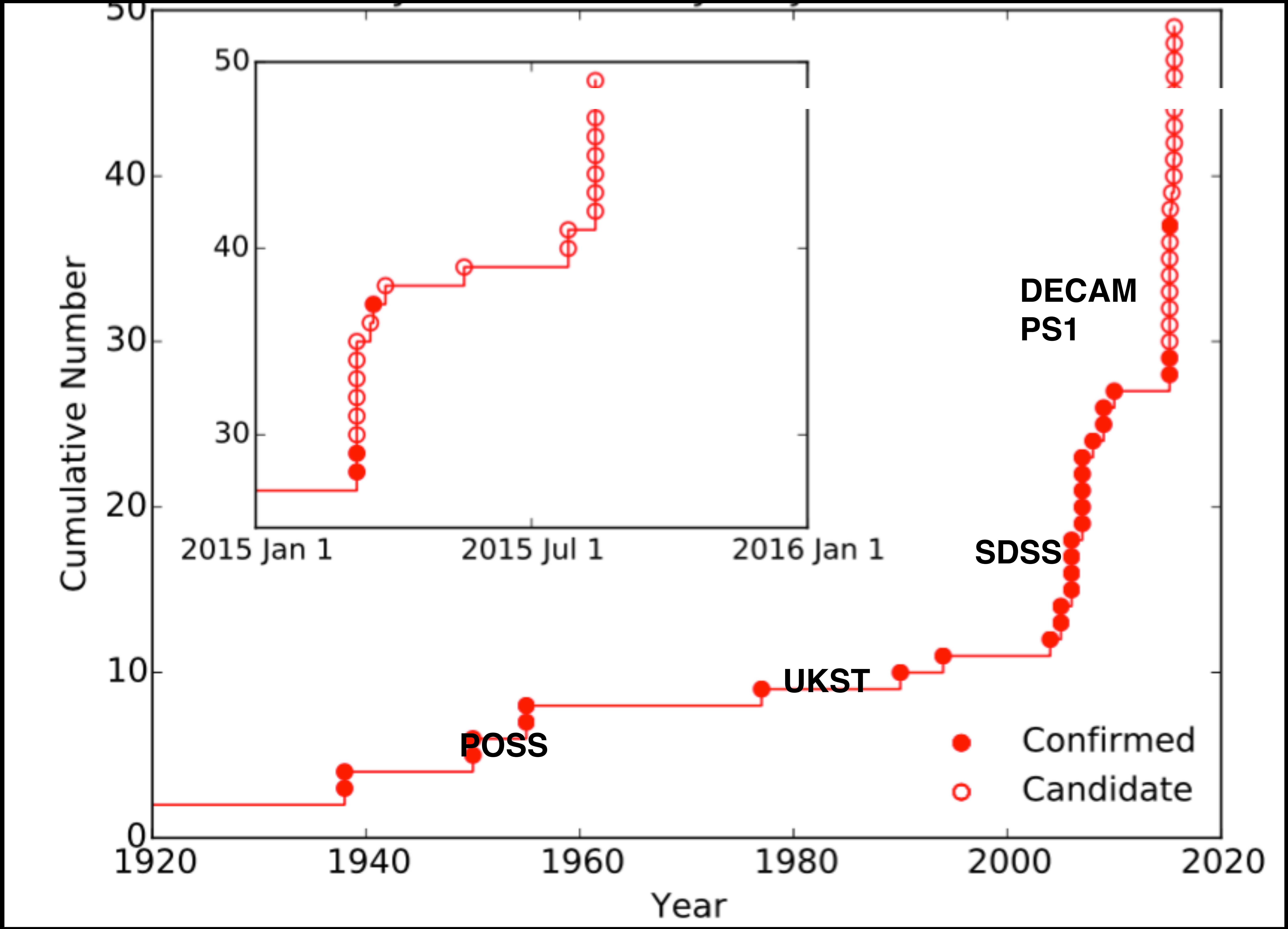
Brooks *et al.* (2014)

Self-Interacting
dark matter

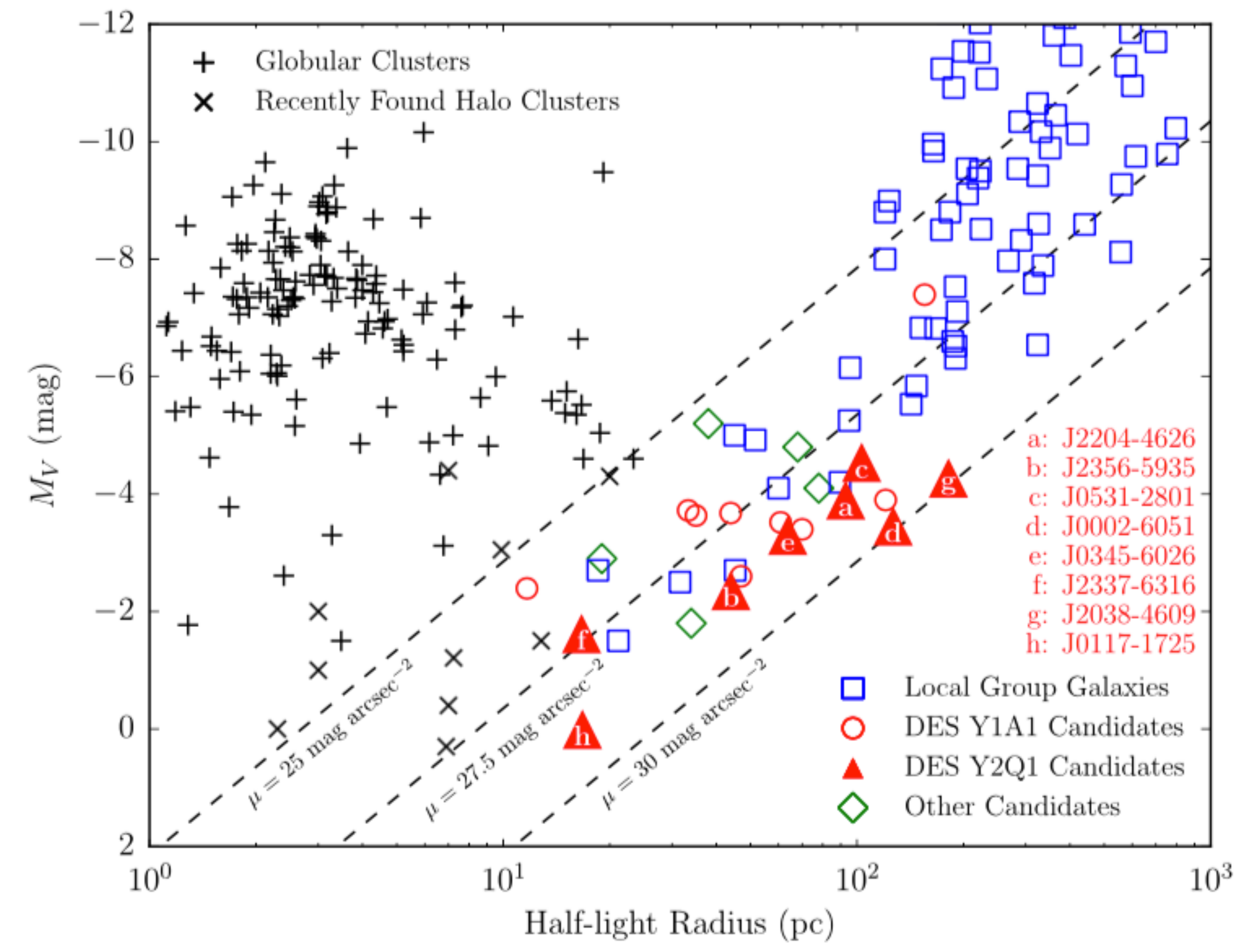
Cold
dark matter

Warm
dark matter

Discovery rate of Milky Way satellites



K. Bechtol (2015)



Drlica-Wagner *et al.* (2015)

Current instrumentation is *not* adequate for LSB science

Flux received by a *point* source:

$$F_{\mathrm{point}} = \epsilon\,\pi \left(\frac{D}{2}\right)^2 t_{exp}\, 10^{-0.4\,m}$$

→ drives telescopes with *large* diameters and *large* focal lengths

Surface brightness received by a *extended unresolved* source:

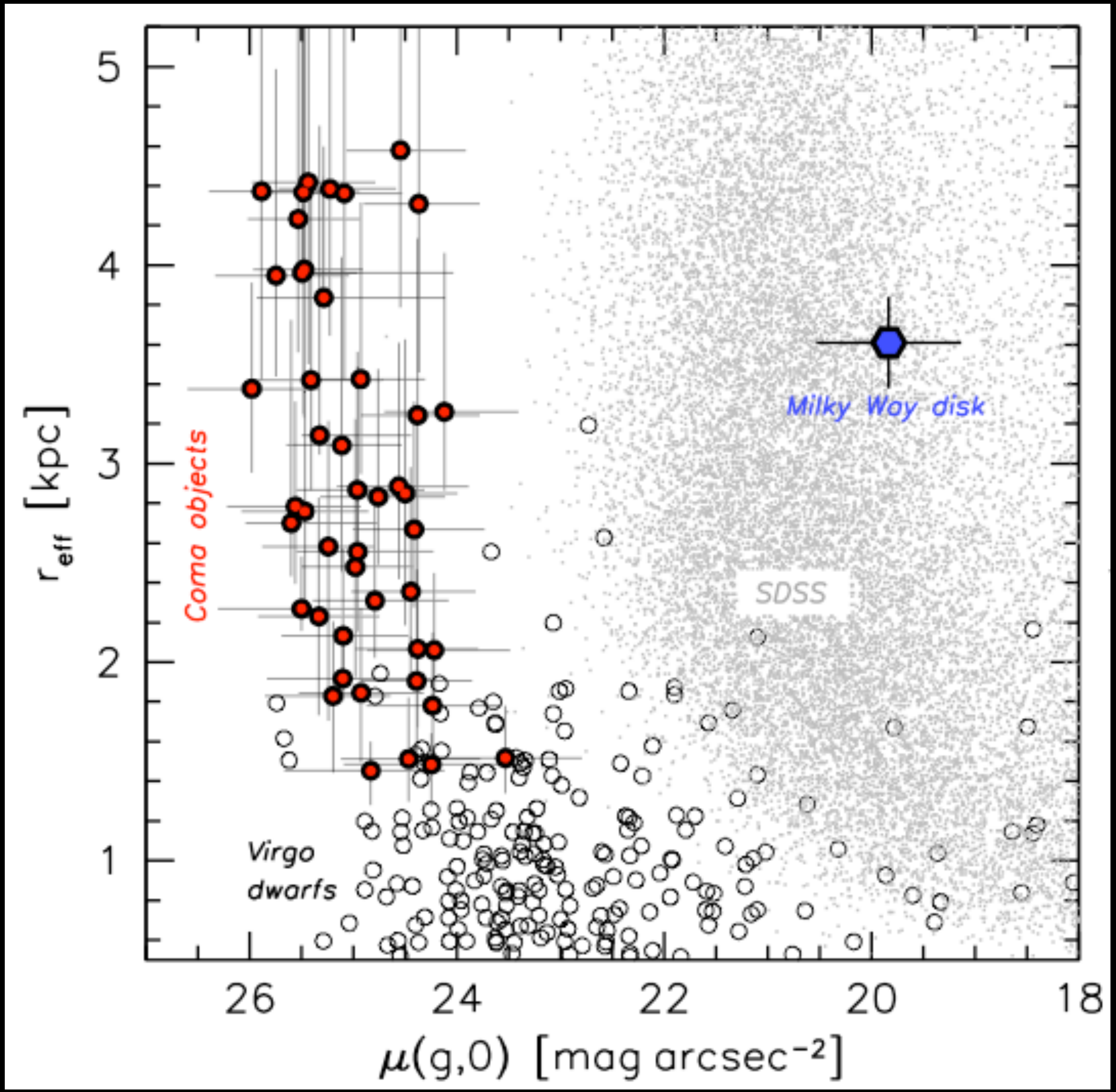
$$SB_{\mathrm{extended}} = \epsilon\,\pi^2 \left(\frac{f}{D}\right)^{-2} t_{exp}\, s_{pix}^2\, N_{pix}\, 10^{-0.4\,\mu}$$

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

The Dragonfly array telescope

Abraham & Van Dokkum (2014)

47 new Milky Way-sized galaxies in the Coma cluster



26 hours 6″ FWHM SB(g) ~ 29.3 mag arcsec^{-2} @ 10″ Van Dokkum *et al.* (2015)

The unprobed realm of the ultra-low surface brightness universe

Mihos *et al.* (2005)

Limited by *systematics*

- sky variability
- straylight
- flat field accuracy
- extended PSF wings

Foregrounds

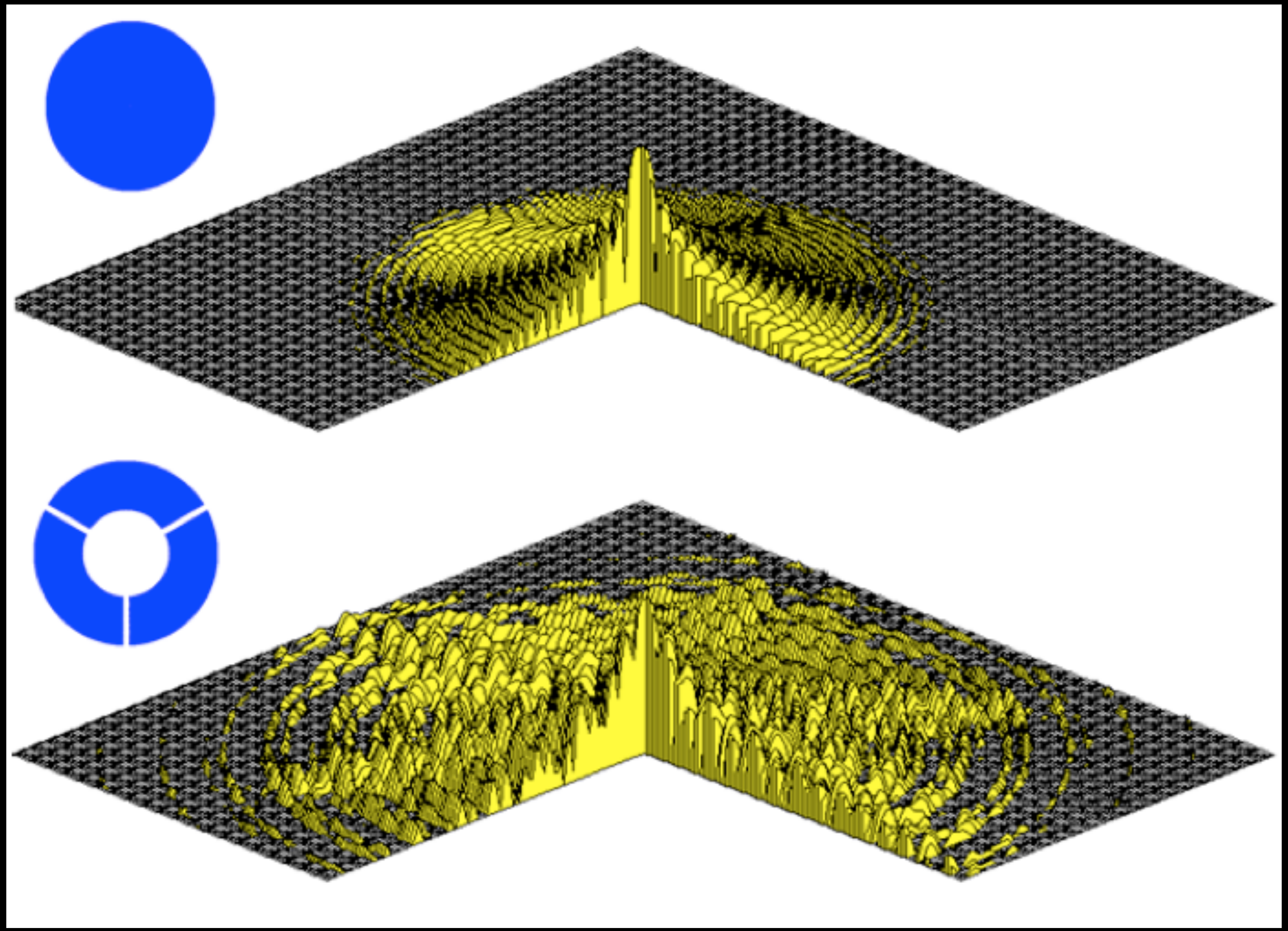
- zodiacal light
- cirrus (local ISM)

Obstruction by secondary mirrors yields very *extended* and *anisotropic* complex PSFs

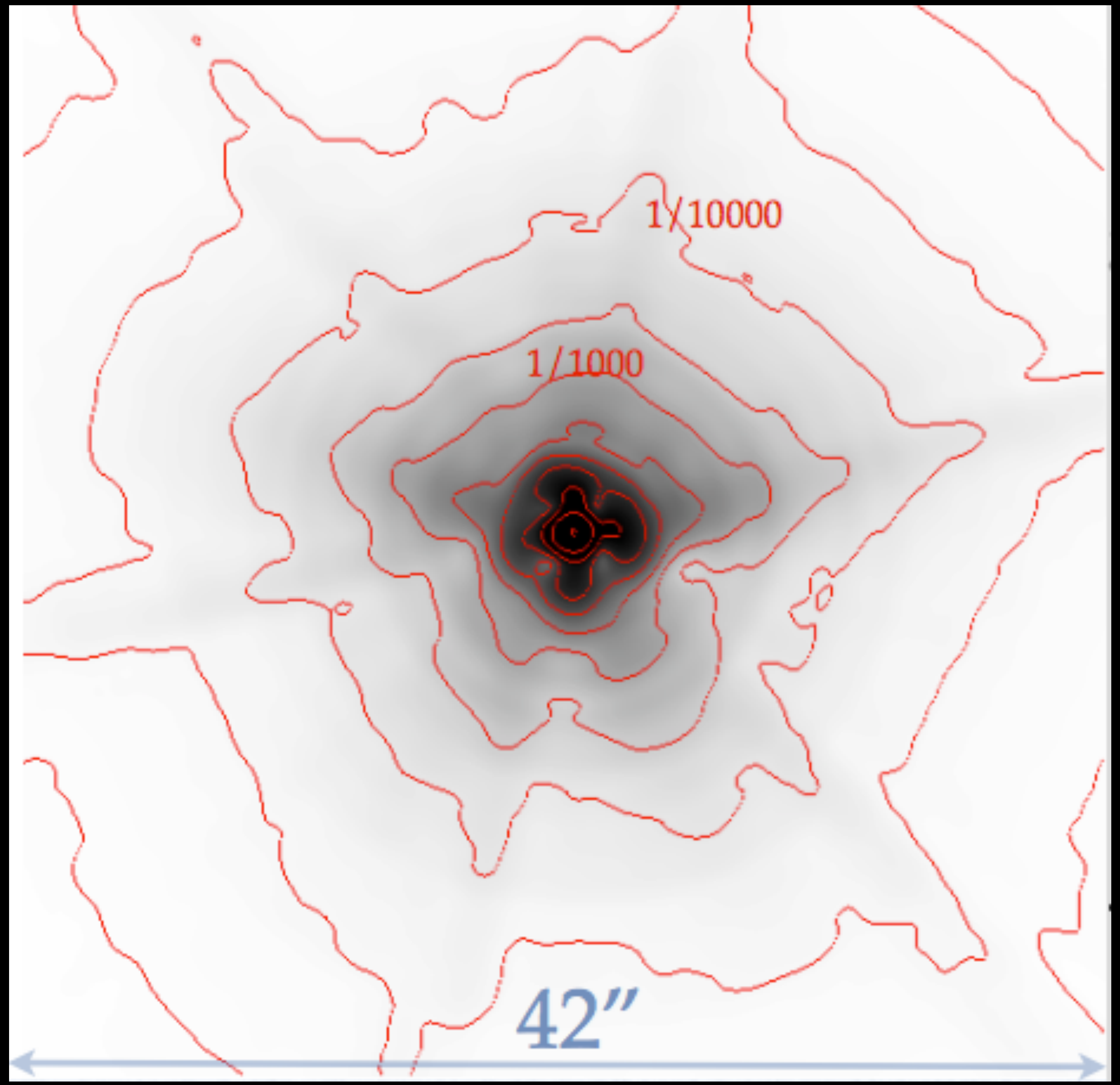
Large *f/D* optics are *inefficient* for LSB science

Requires *tailored* observational planning, incompatible with main science drivers

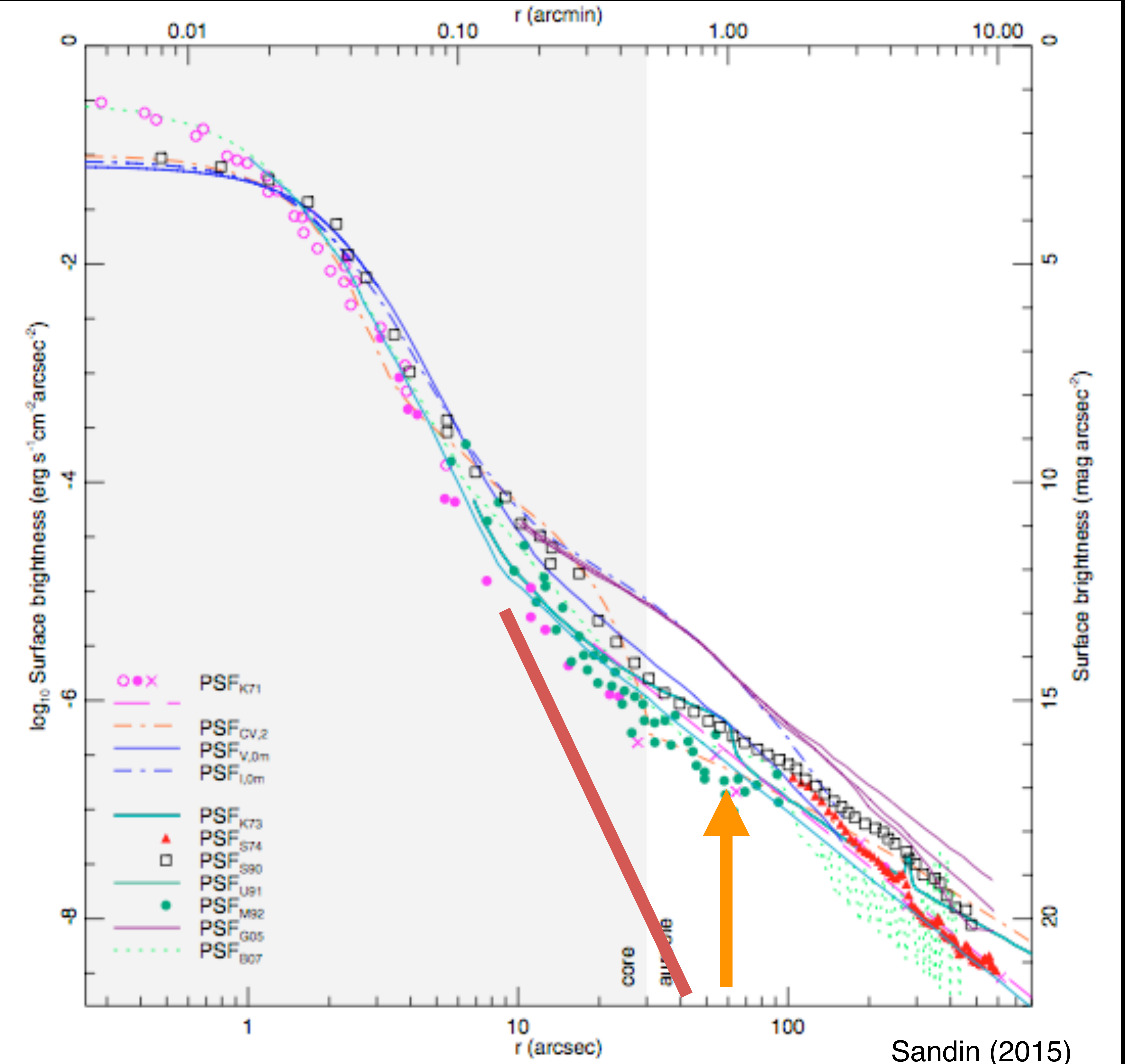
Yet, ideal for *resolved* stellar populations at low SB levels



LSST



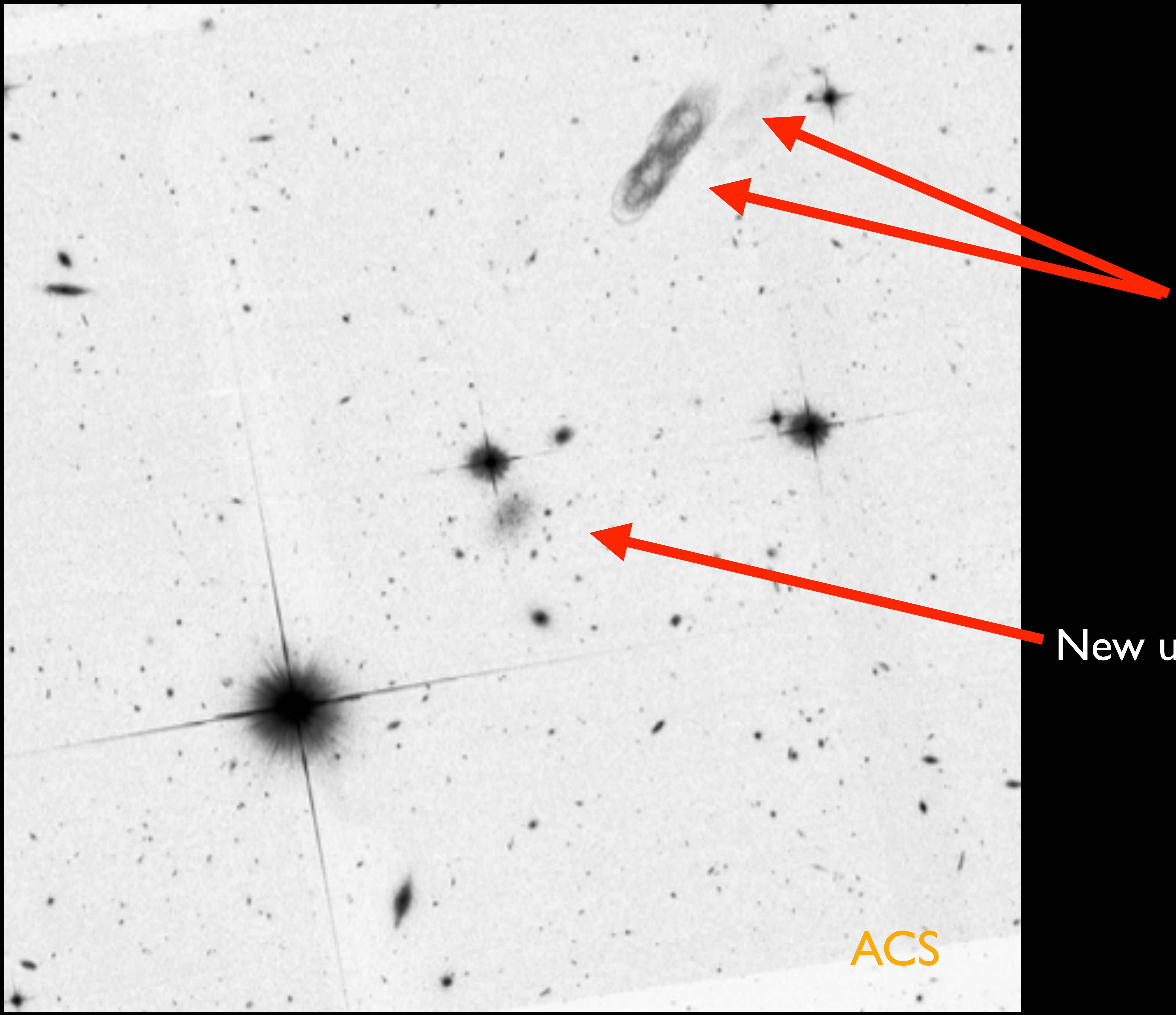
EUCLID



Sandin (2015)

Scattering by atmospheric molecules is the major limitation for ground-based detections

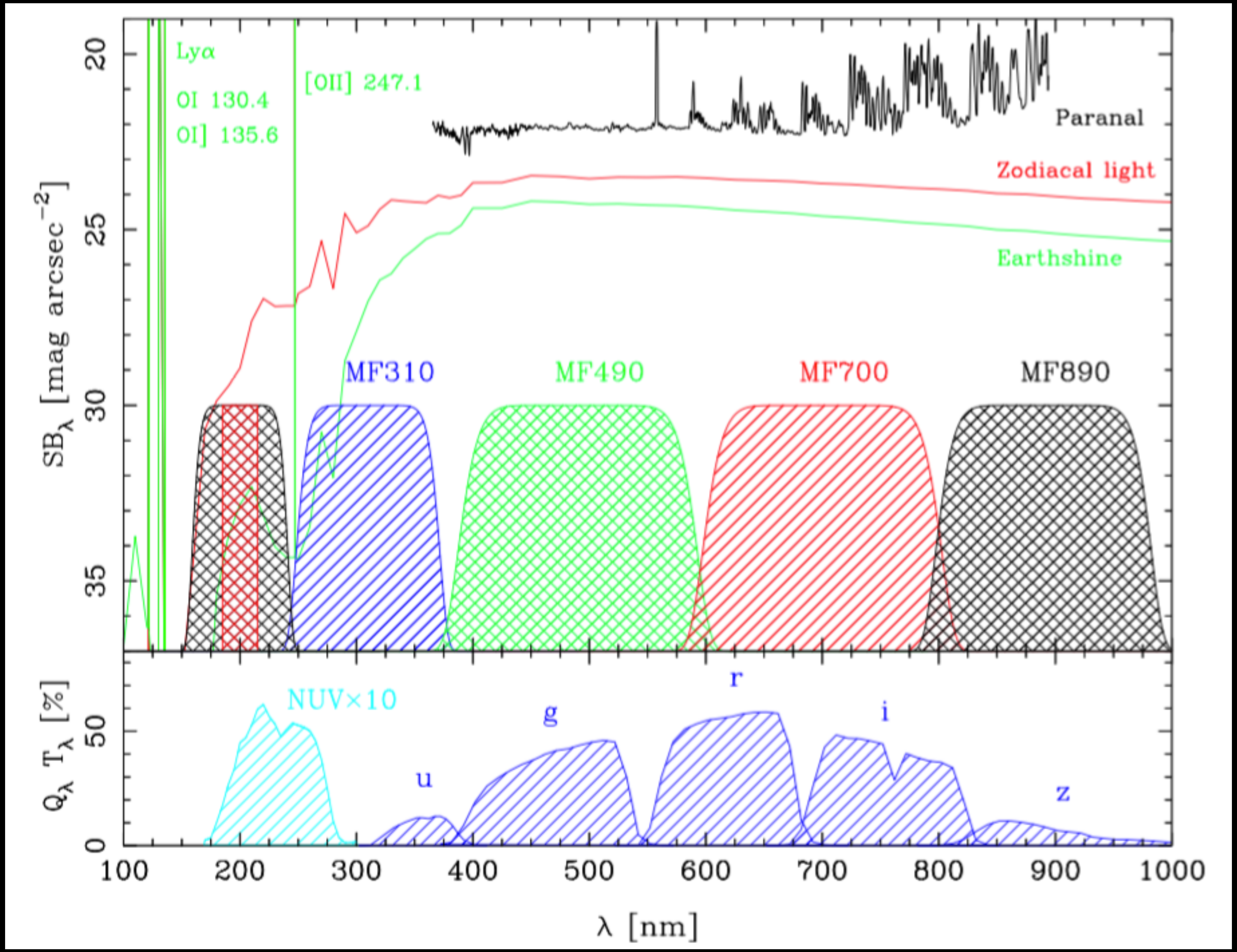
No lenses are allowed (1) internal scattering (2) Cherenkov emission



Top-level design requirements

• FOV	2° x 4°	*(lifetime of satellite)*
• Focal ratio	*f* / 2	*(200x better than HST / Euclid)*
• Central obscuration	none	*(minimal PSF wings)*
• Spatial resolution	1″ per pixel	*(matches ground)*
• Roughness	< 0.5 nm	*(UV to optical)*
• Flat field rms	< 0.0025%	*(TDI / drift scan)*
• Distortion	< 0.5%	*(in one direction)*
• Diameter	50 to 150 cm	*(set by platform)*
• Survey	all sky	*(unique)*

Requirements for filters



Broad-band UV/optical filters: characterise resolved/unresolved stellar populations

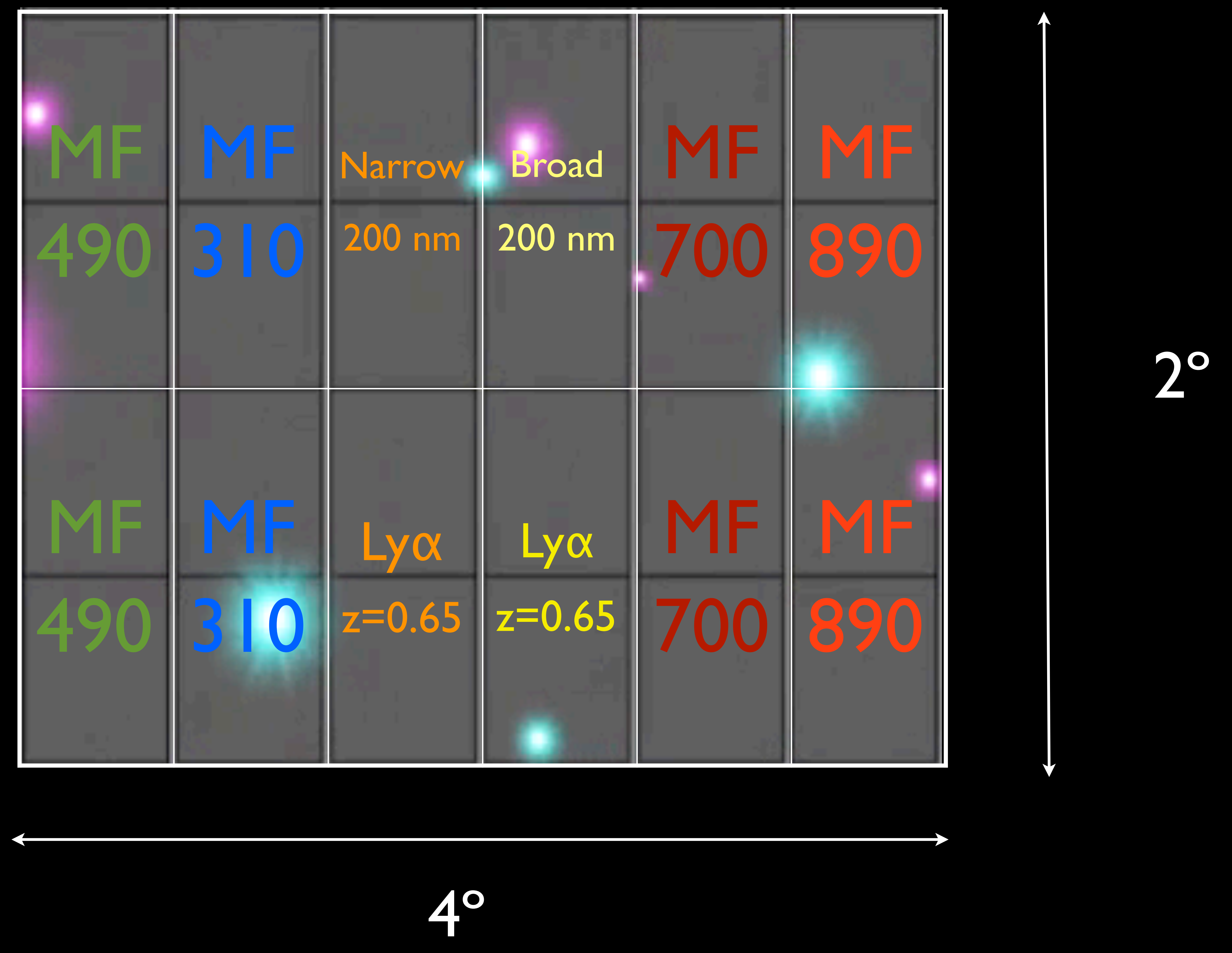
Narrow 200 nm filter: Lyα intensity mapping of cosmic web at z=0.64 Δz=0.03

(Curved) focal plane configuration

6 x 2 independent controllers in drift-scan mode

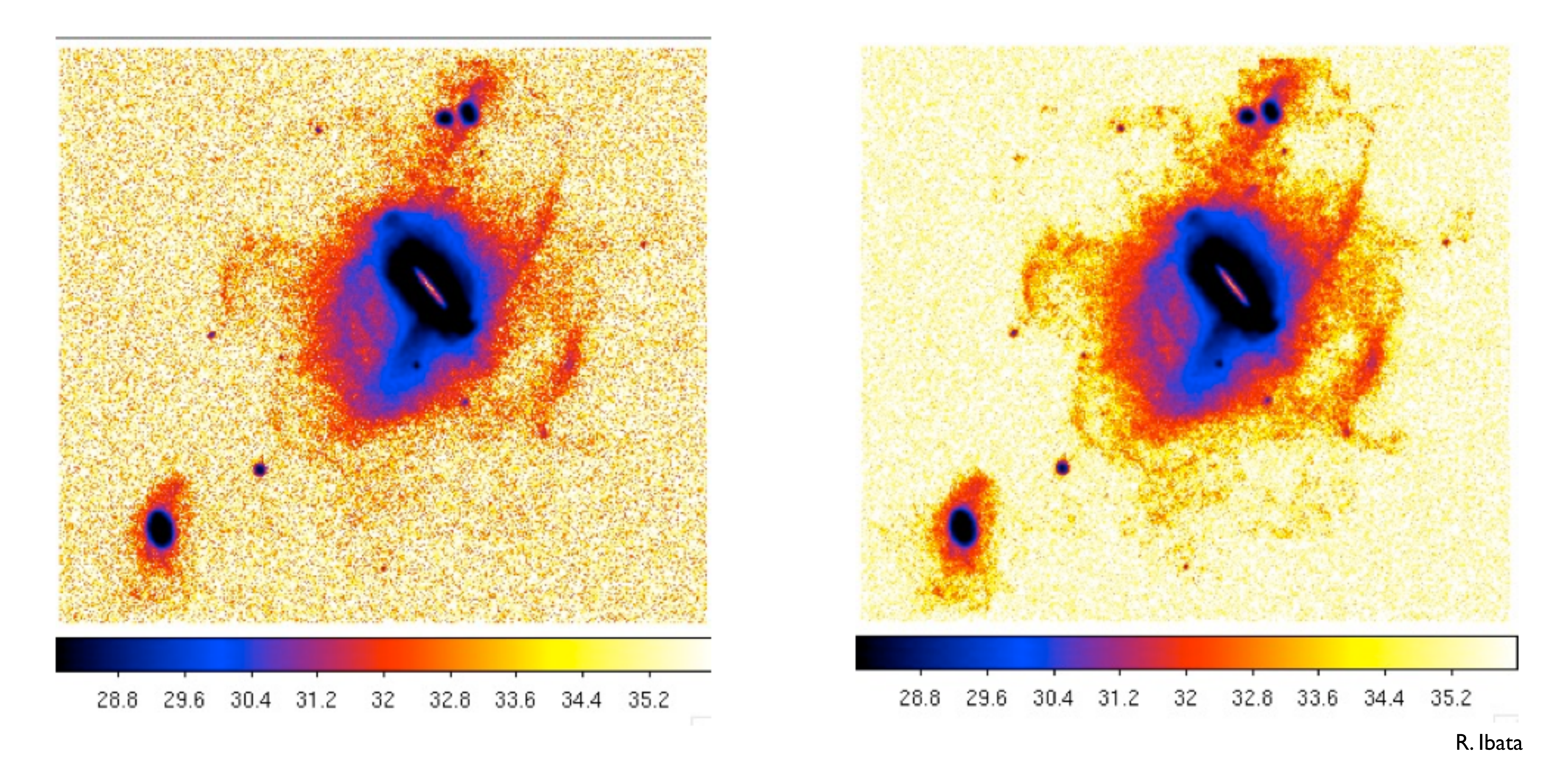
QE of each CCD optimised for each filter (TQ>85%)

Highly efficient: *no moving parts, passive cooling*



Expected performances - 1 Optical bands

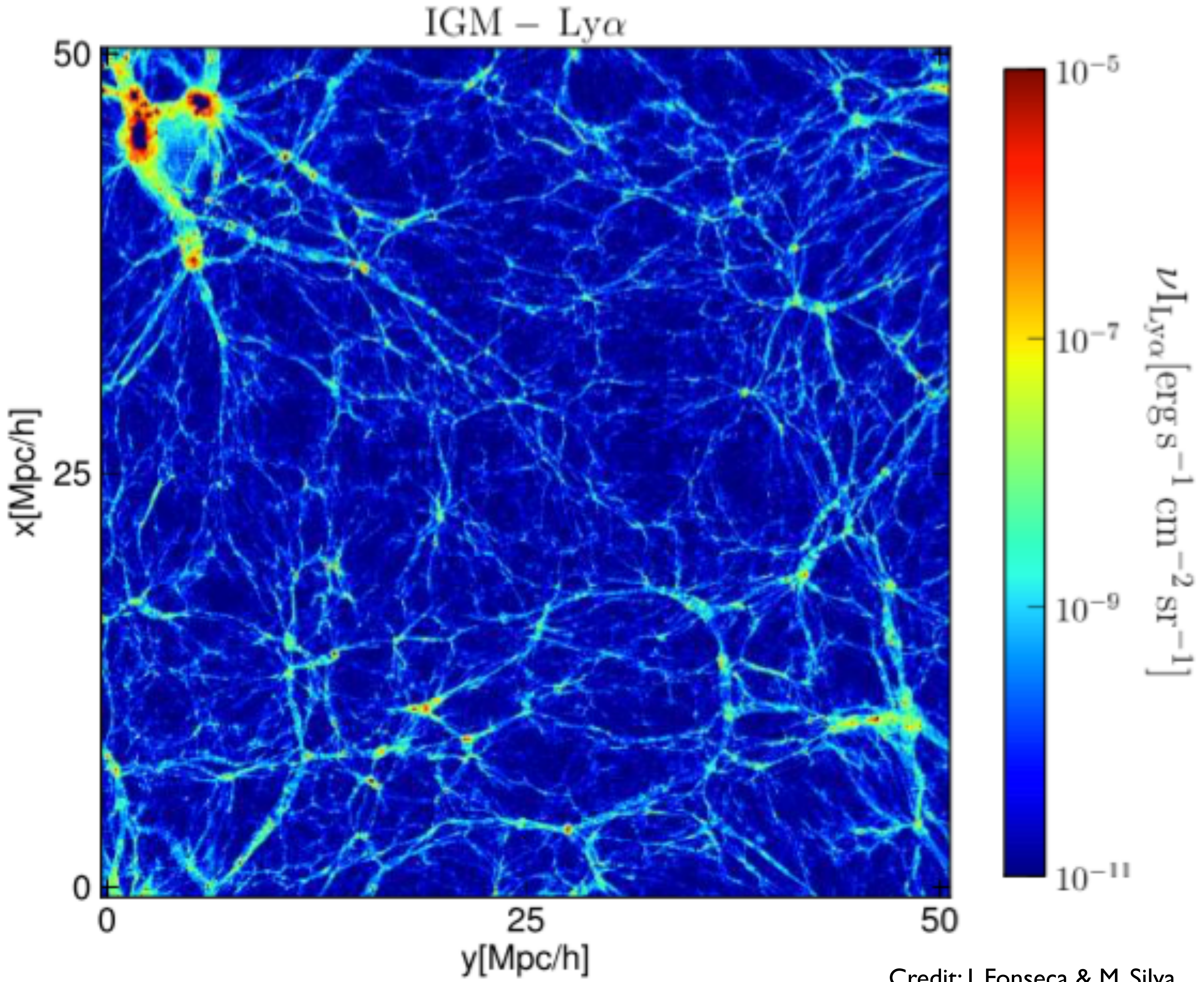
Simulated MESSIER images of a real galaxy (M31) seen at 150 Mpc



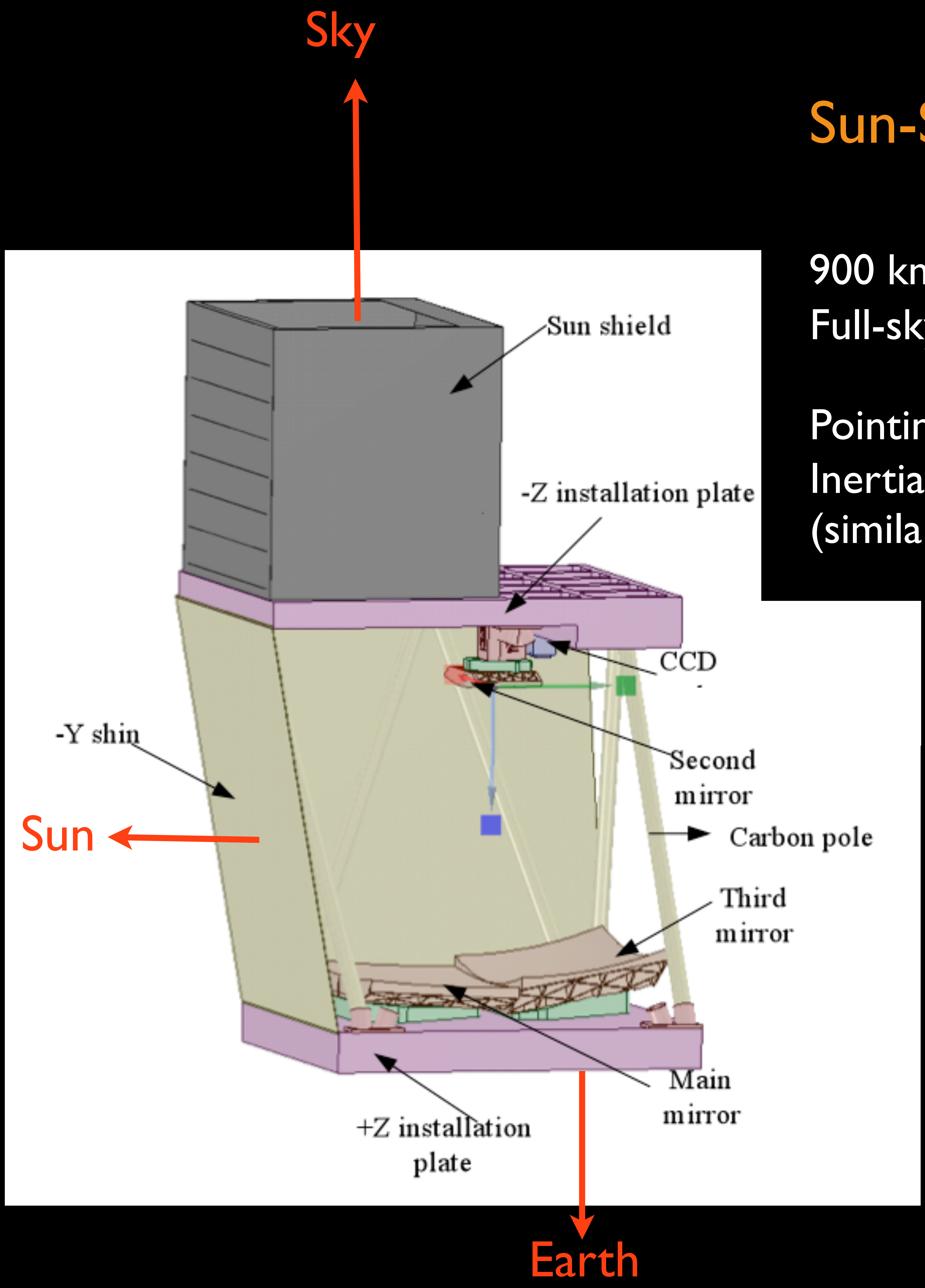
1 Msec
1 kpc × 1 kpc

10 Msec
1 kpc × 1 kpc

Expected performances - II   UV bands



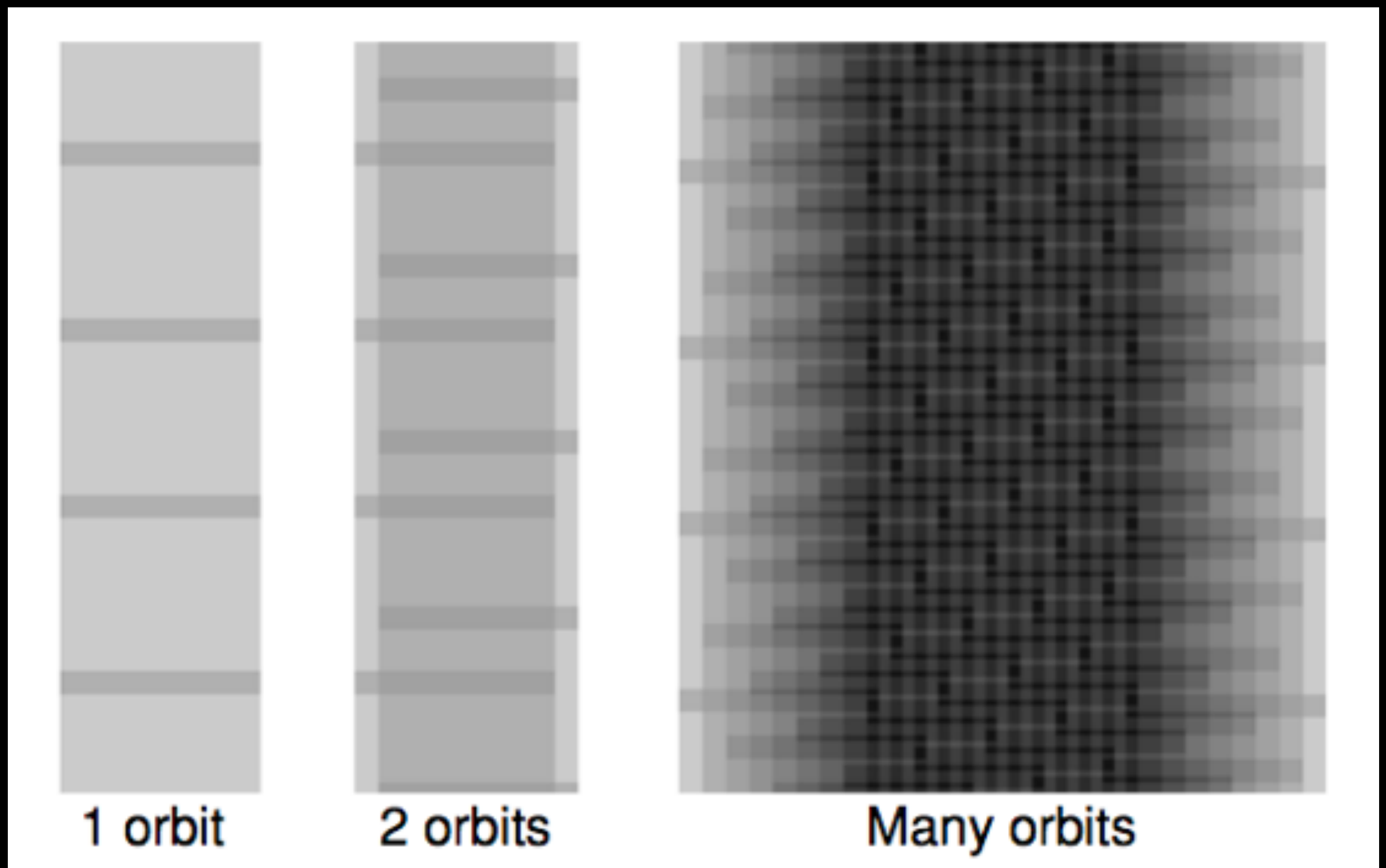
Credit: J. Fonseca & M. Silva

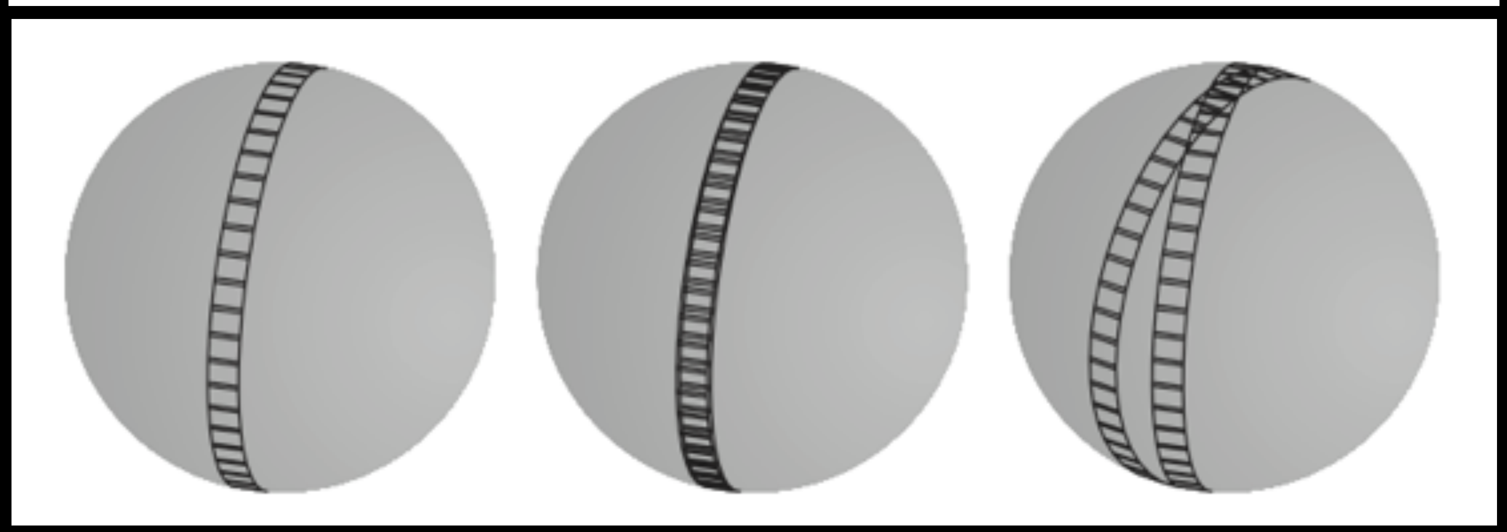


Sun-Synchronous Orbit

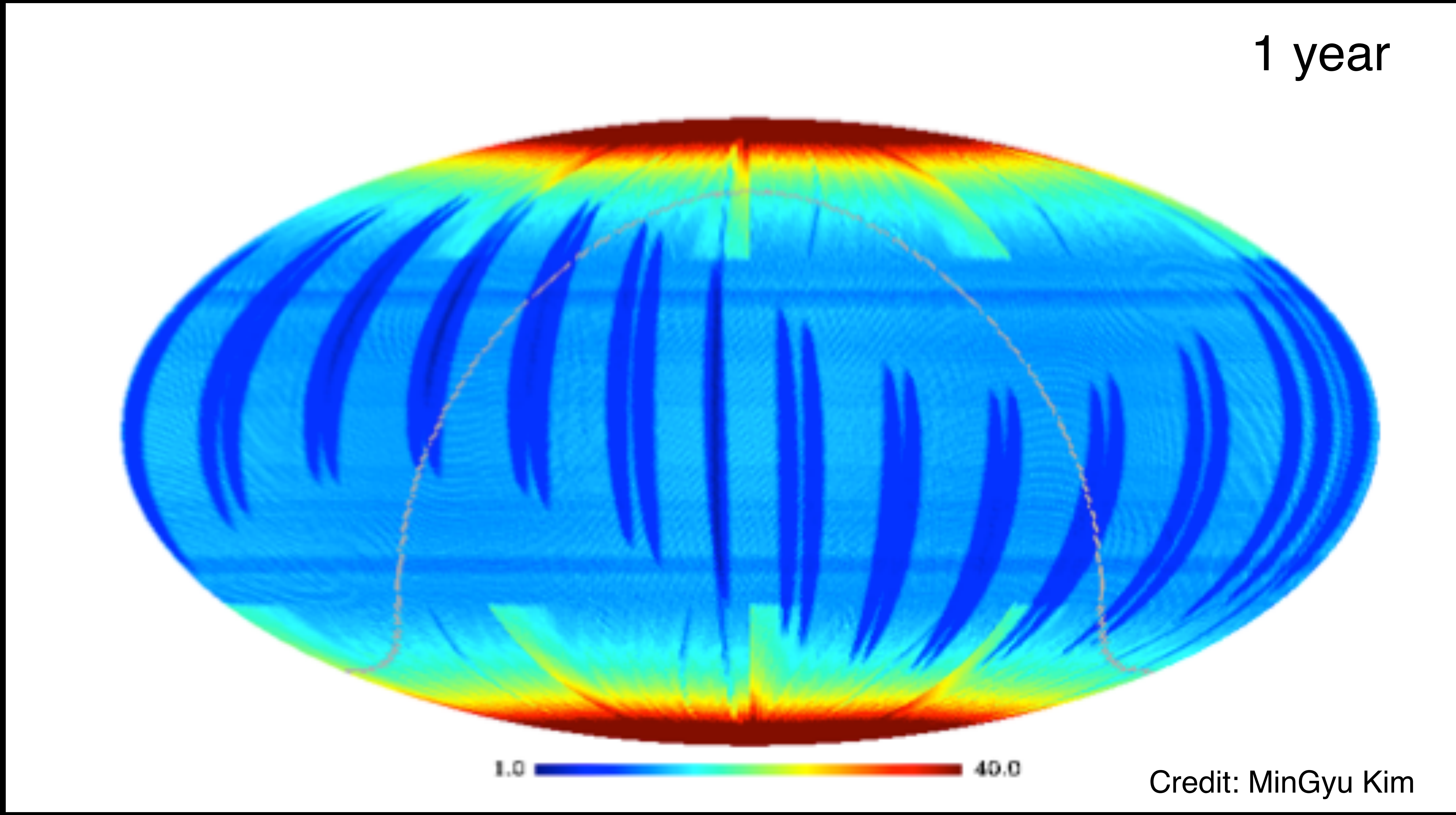
900 km, 98° inclination, LTAN 6h
Full-sky survey in 6 months

Pointing ⊥ Sun-Earth direction (no Earthshine)
Inertial great-circle drift scan centred at the Sun
(similar to COBE, WISE, PROBA-V)





Complete sky coverage every 6 months



Includes Moon avoidance angle (35 degrees) and South Atlantic Anomaly

Time sampling:

1 UV-optical measure/pixel every 90 minutes for 2 days at $\beta = 0$

1 UV-optical measure/pixel every 90 minutes at $|\beta| \geqq 80$ at all times

CSC Collateral Science Cases (*free* by-products)

Solar System

- Comet tails, interplanetary and cometary dust grains

Stellar physics

- What is the extent of mass loss in giant stars ?
- Debris discs
- Nature of orphan SN and GRB ?
- Time-domain stellar astronomy: simultaneous multi-wavelength variability disruption events, GW UV counterparts
- Legacy Ultimate multi-band photometric survey of point sources

Interstellar medium

- Properties of interstellar dust grains

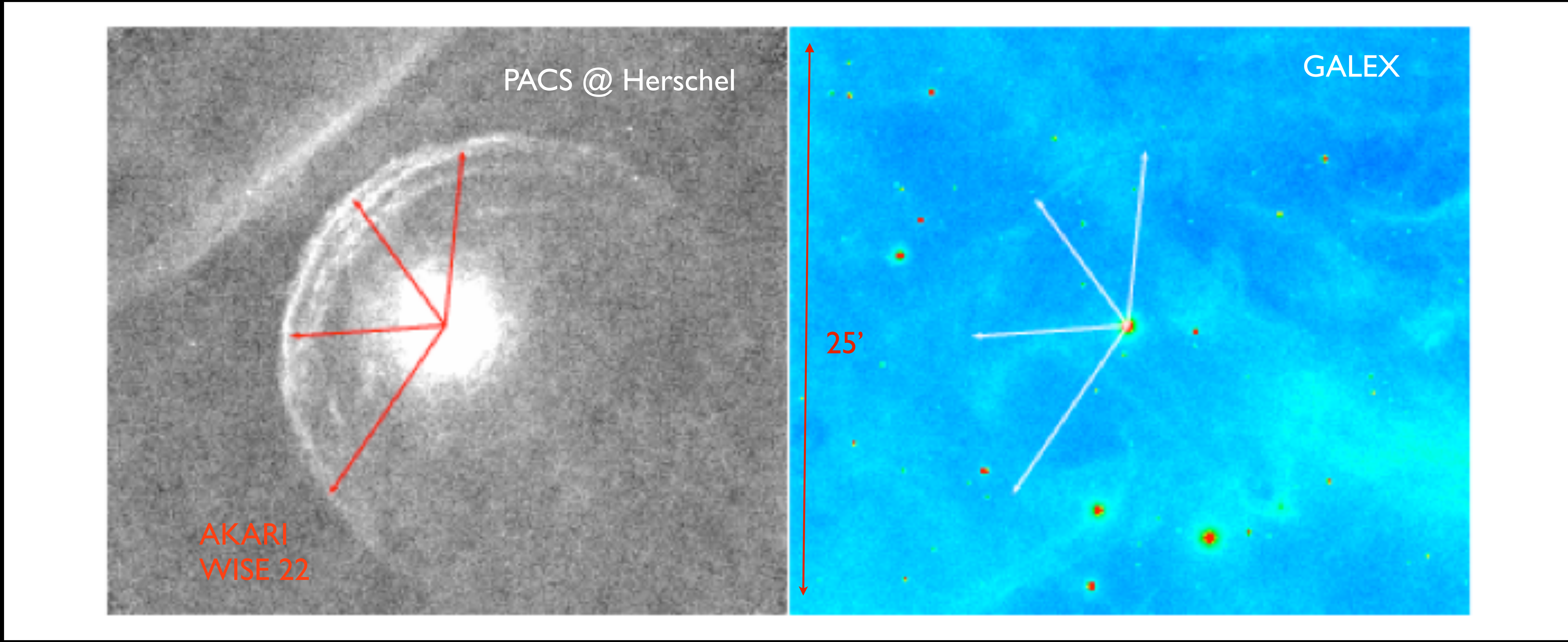
Extragalactic

- What is the true luminosity function of galaxies ?
- What is the molecular content of galaxies in the low-z universe ?
- What is the role of intracluster light and the accretion history in clusters ?

Cosmology

- The fluctuations of the optical / UV cosmological background radiation
- Calibration of the cosmological distance ladder with Surface Brightness fluctuations
- Baryonic acoustic oscillations with $3\ 10^6$ galaxies in a thin shell at z=0.65

CSC 7 Mass loss episodes from massive stars

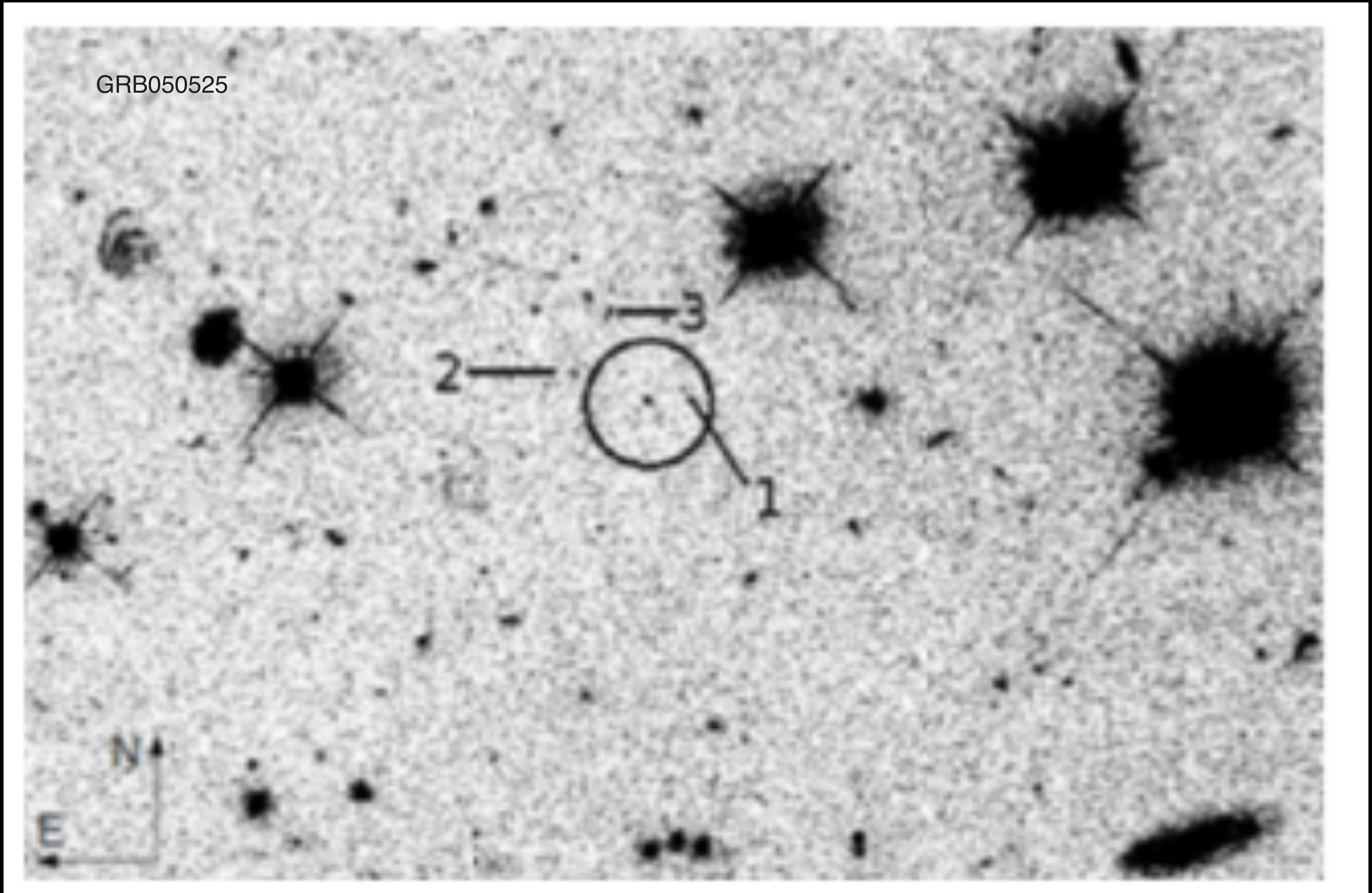


Betelgeuse

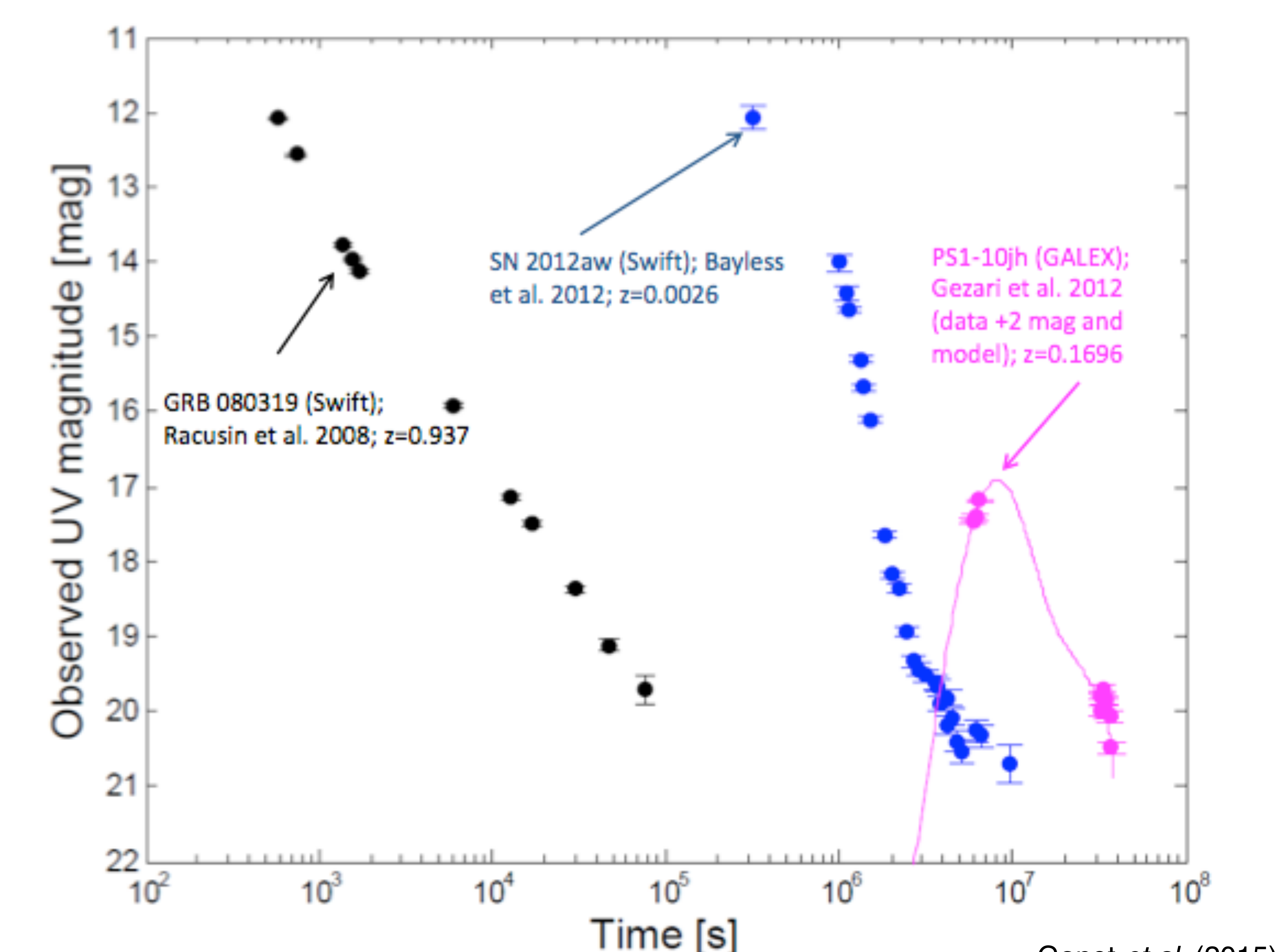
Decin *et al.* (2012)

→ enrichment of the interstellar medium in metals
→ chemical evolution of galaxies

CSC 9 Variability and transients from the UV to the optical
Orphan SN and GRB , Tidal disruption events, GW events

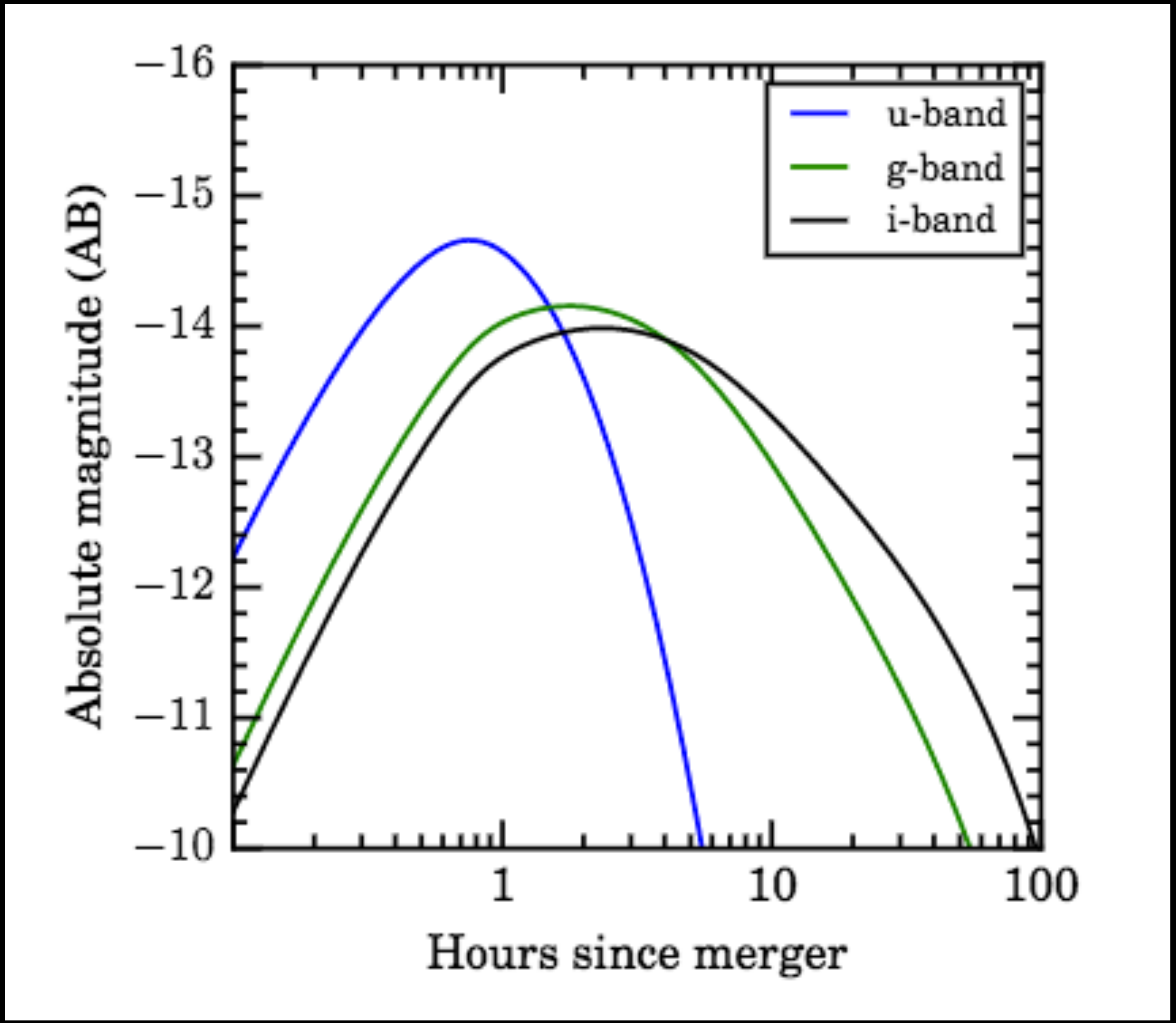


CSC 12 Time-domain astronomy
Variability and transients from the UV to the optical



Ganot *et al.* (2015)

CSC 16 UV counterparts of gravitational wave events



Ridden-Harper *et al.* (2017)

Photometric performance of MESSIER for point sources

Table 16: Properties of the MESSIER AB photometric system

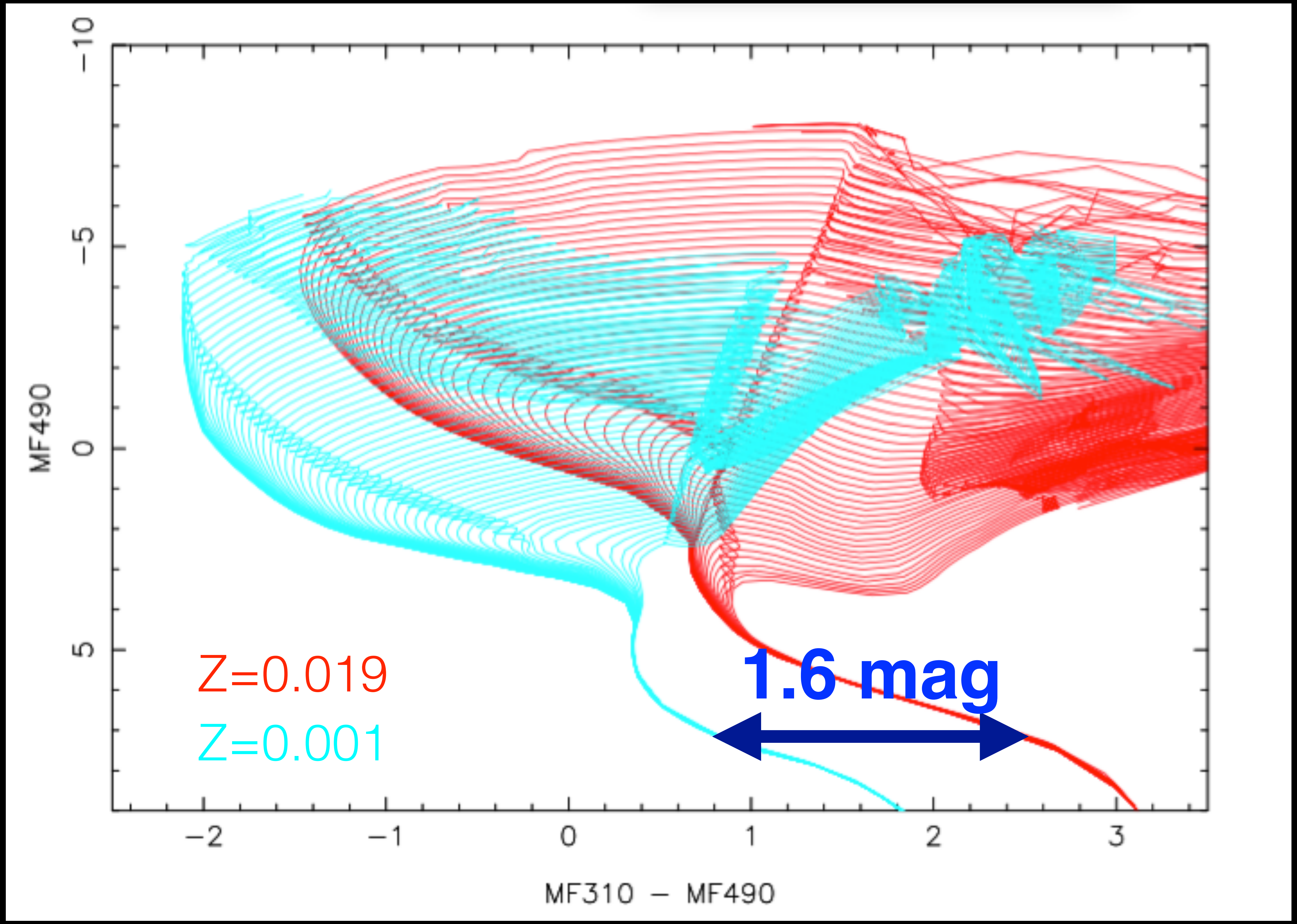
Filter	$\lambda_{\rm eff}$ [nm]	ZP (Flux)	ZP (photons)	ZP [Jy]
		[10^{-8} erg s^{-1} cm^{-2} Å^{-1}]		
IB 200	194·5282	2·836 78	2·759 17	3631
NB 200	199·2507	2·736 73	2·726 48	3631
MF 310	302·0625	1·177 59	1·147 43	3631
MF 490	476·0350	4·734 30	0·459 937	3631
MF 700	690·2802	0·226 857	0·223 707	3631
MF 890	883·8244	0·138 868	0·137 904	3631

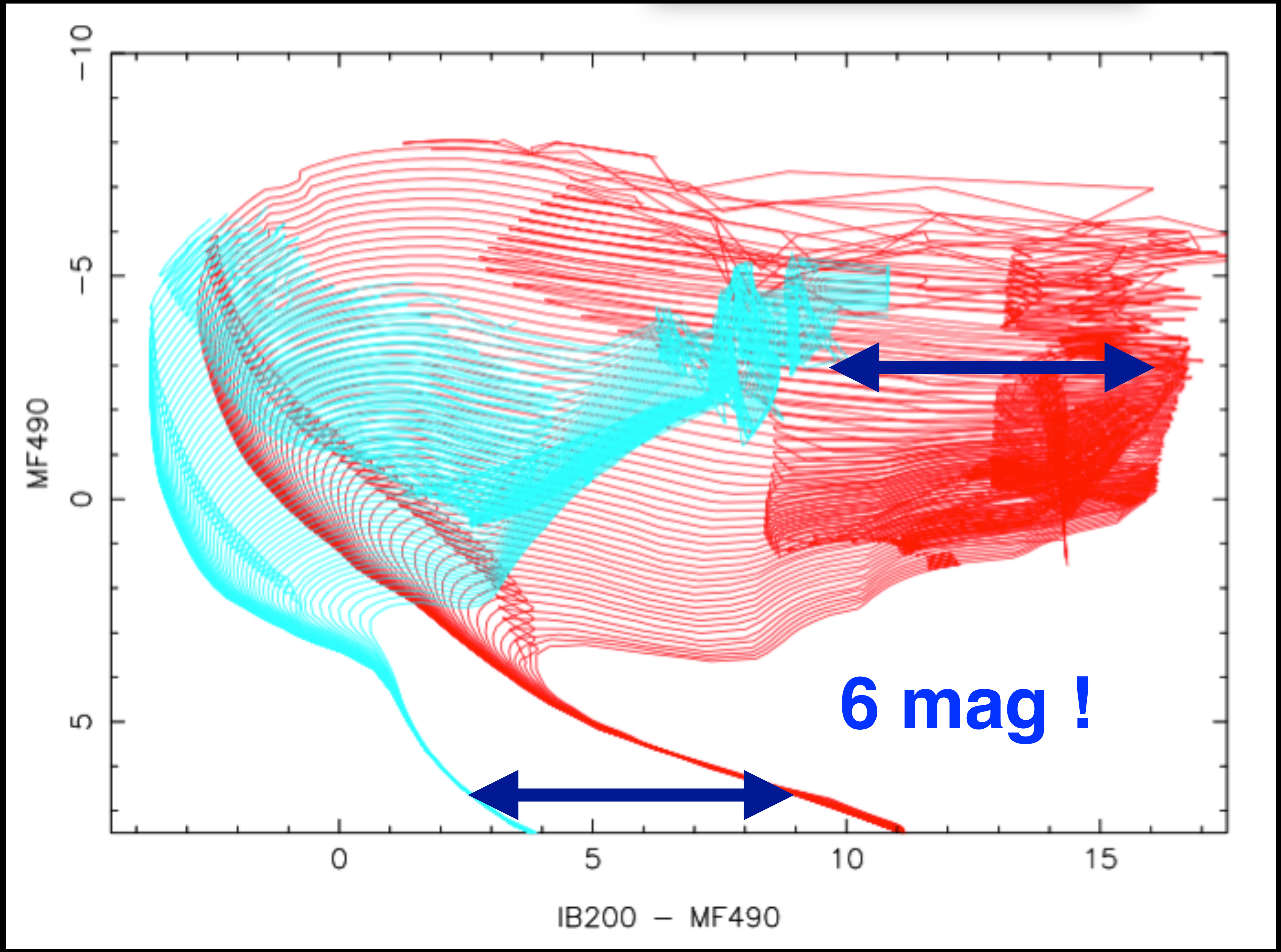
End of mission (5 years) sensitivity: 27.5 AB (3σ)

— limited by confusion (1 arcsec pixels)

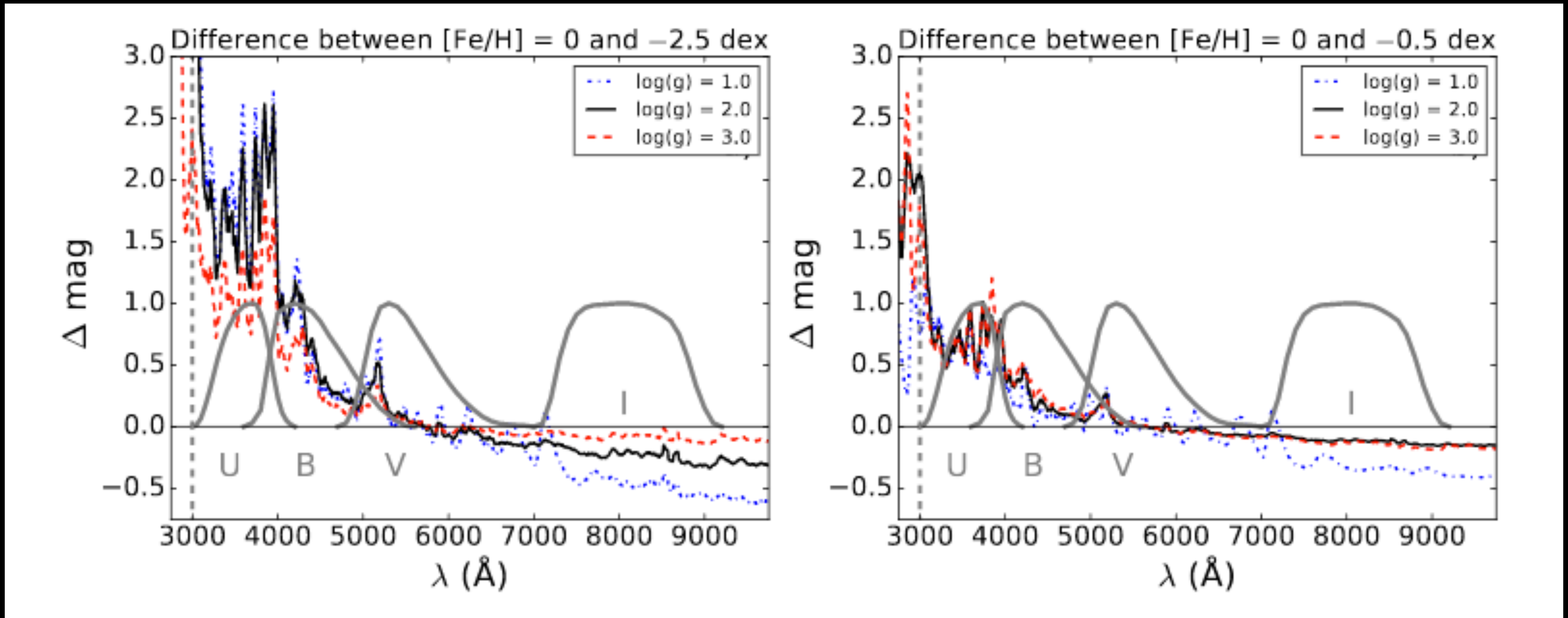
— strong dependence with ecliptic latitude

Isochrones in the MESSIER photometric system





Extreme sensitivity to metallicity with the UV filters



Bond (1999)

Extreme sensitivity to metallicity in filters (much) bluer than U

Designs by two competing industrial contractors

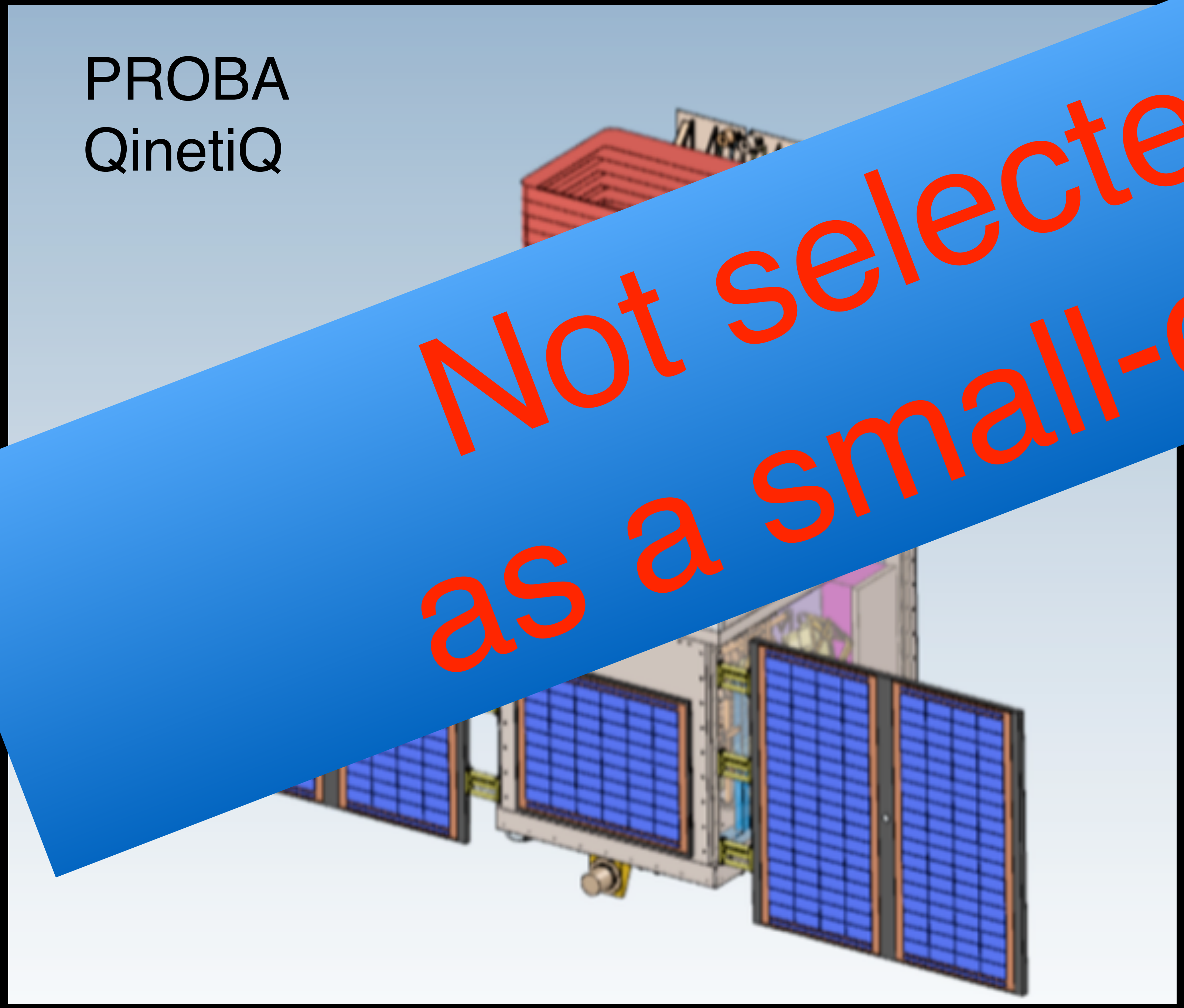
— Platform : heritage from CHEOPS *or* PROBA-V

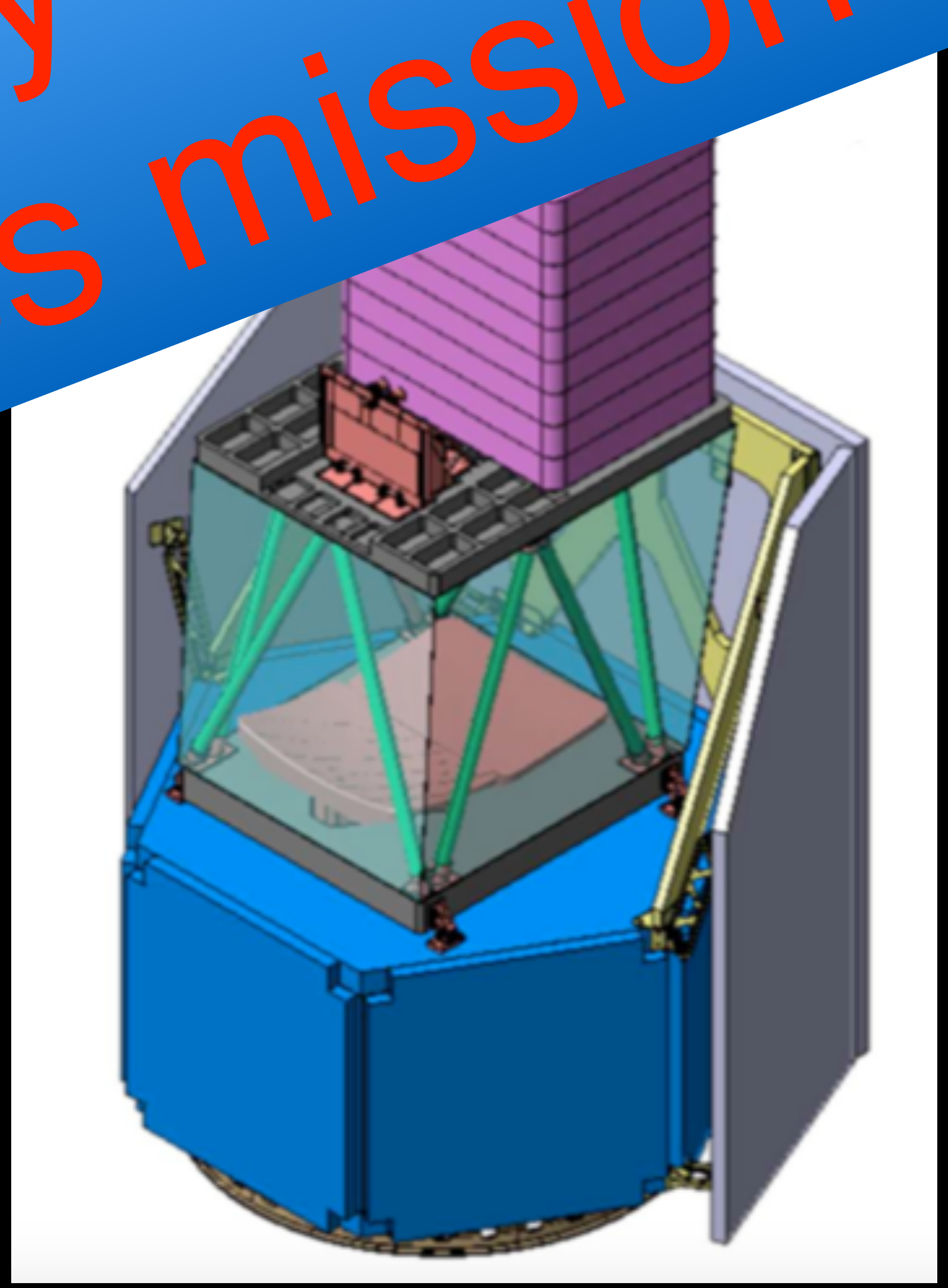
— Payload constraints: 65 kg and 60 W   TRL > 6

— Total budget : 120 M€

— 150+ scientists in 12 countries

Not selected by ESA
as a small-class mission





QinetiQ

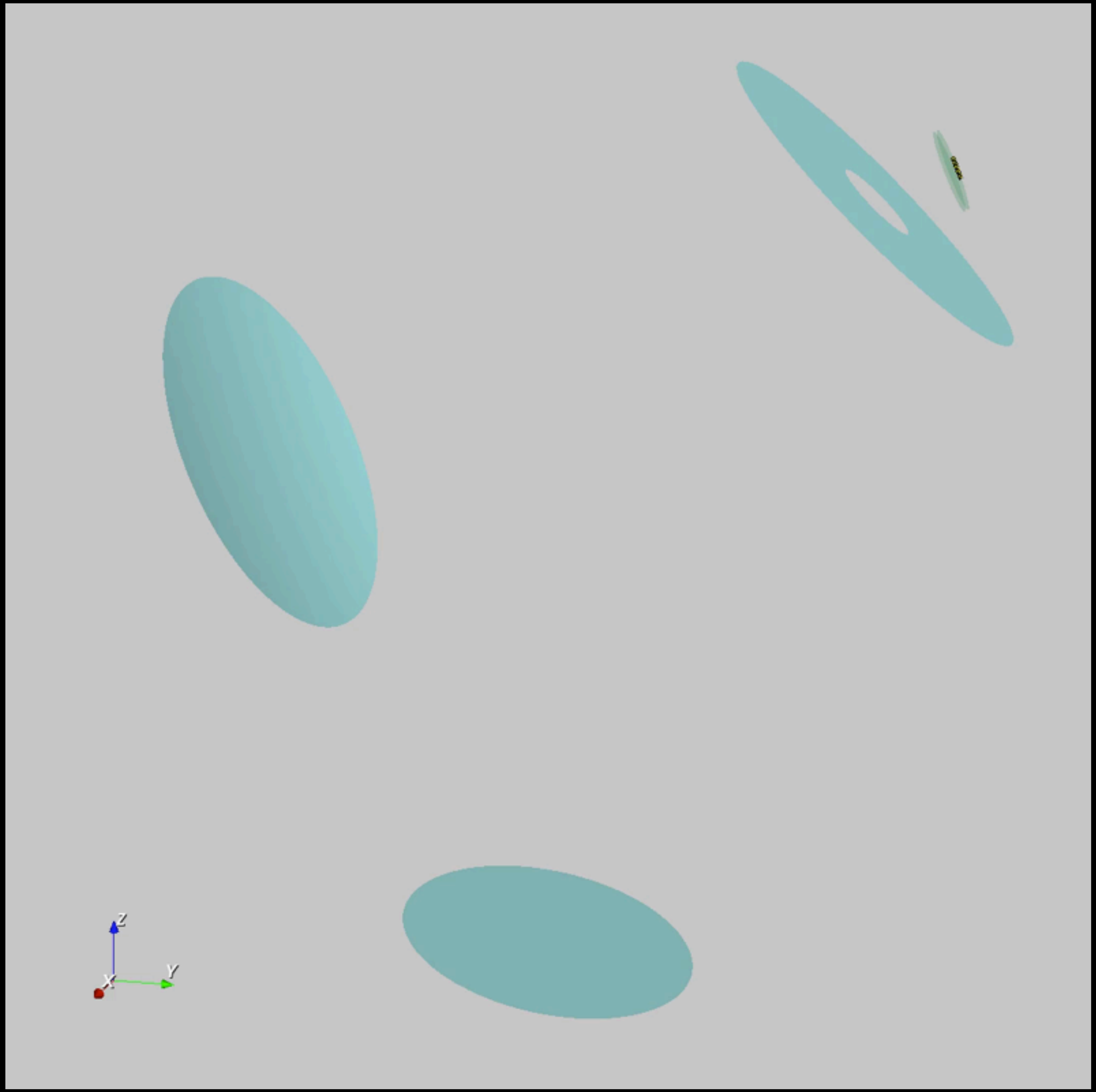
AIRBUS
DEFENCE & SPACE

Photon Monte Carlo for the new optical design with curved CCDs

Allows for the detailed modelling of *all* the physical processes involved

End-to-end simulation (from the atmosphere to CTE effects)

Quantifies the variability of the wings of the PSF across FOV



Lombardo *et al.* (2018)

The MESSIER pathfinder   (2018)

Demonstration of advanced technologies :

— fast optics with off-axis reflective Schmidt design (D>36cm)
— *curved* focal plane
— drift scanning with curved CCDs
— characterisation the PSF on large scales
— increase TRL level to 6

Demonstration of LSB science cases (with 2 filters)

✔ MOU signed with IAC
✔ Installation at Teide Observatory (dome, optical fibre ethernet, power)

MESSIER

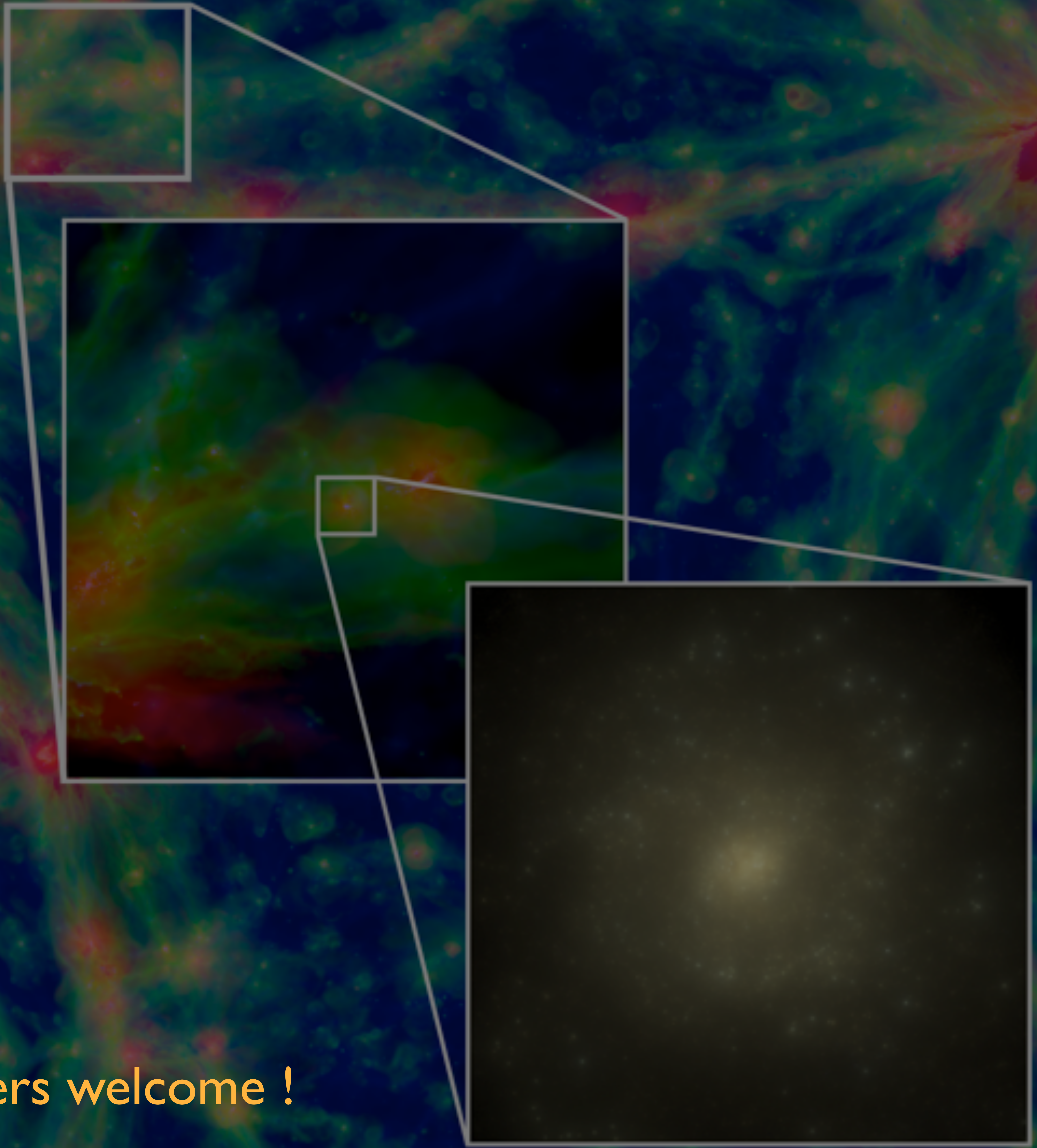
The ultimate survey of the ultra-low surface brightness universe

Unique international collaboration
built upon strong heritage

A fully unexplored niche remaining
in observational parameter space
— unprecedented discovery scope

Unique scientific returns in
cosmology, galaxy evolution, stellar physics

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



Further partners welcome !