Optical and IR astronomy - and its relation to CTA

@GalacticRAVE

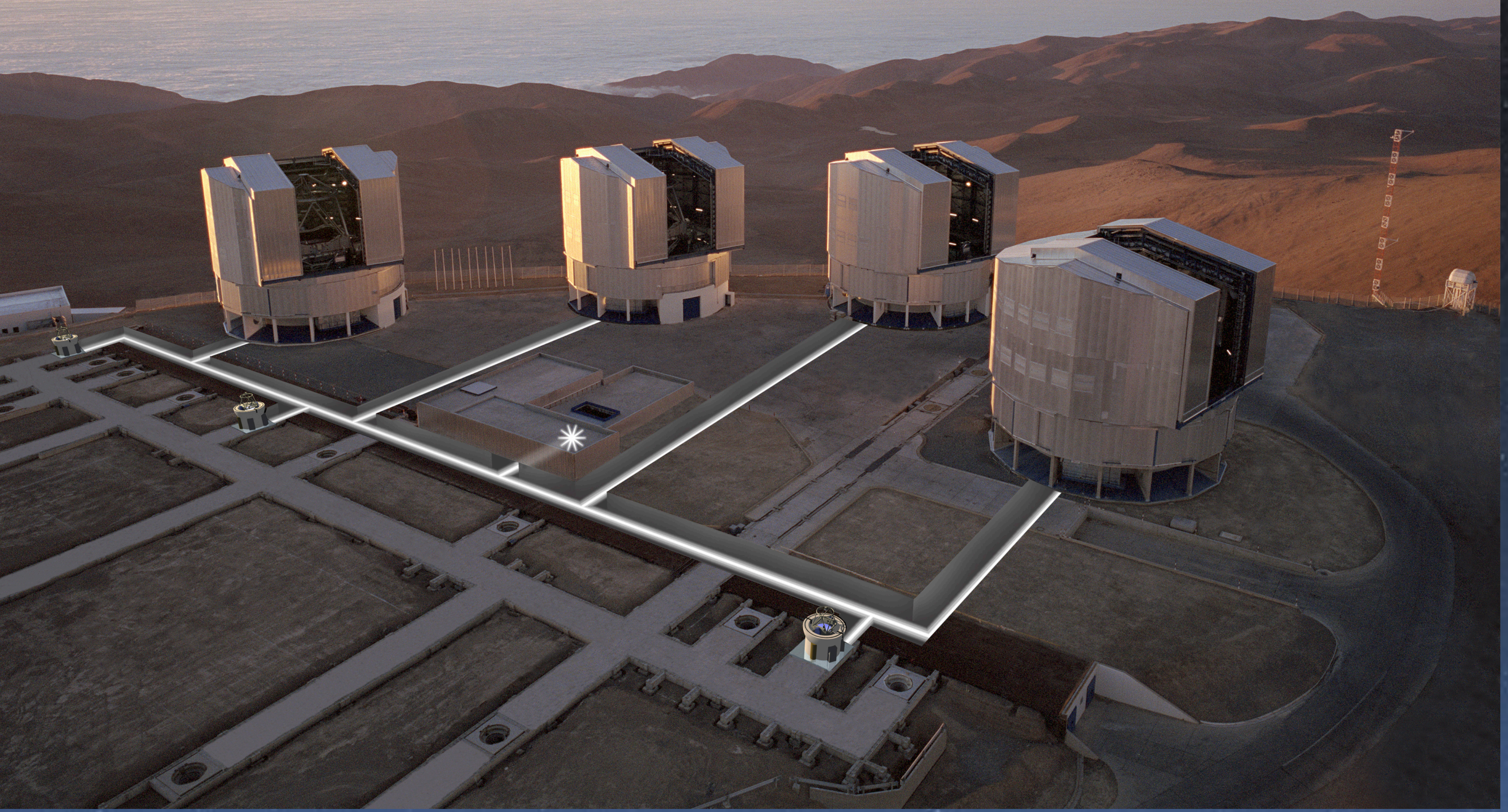
Matthias Steinmetz

„Traditionally, the overlap between optical/infrared (OIR) astronomy and gamma-ray astronomy has been considered to be fairly small.“

- Dark Matter Programme
- Galactic Centre
- Galactic Plane Survey
- LMC Survey
- Extragalactic Survey
- Transients
- Cosmic Ray PeVatrons
- Star Forming Systems
- Active Galactic Nuclei
- Clusters of Galaxies

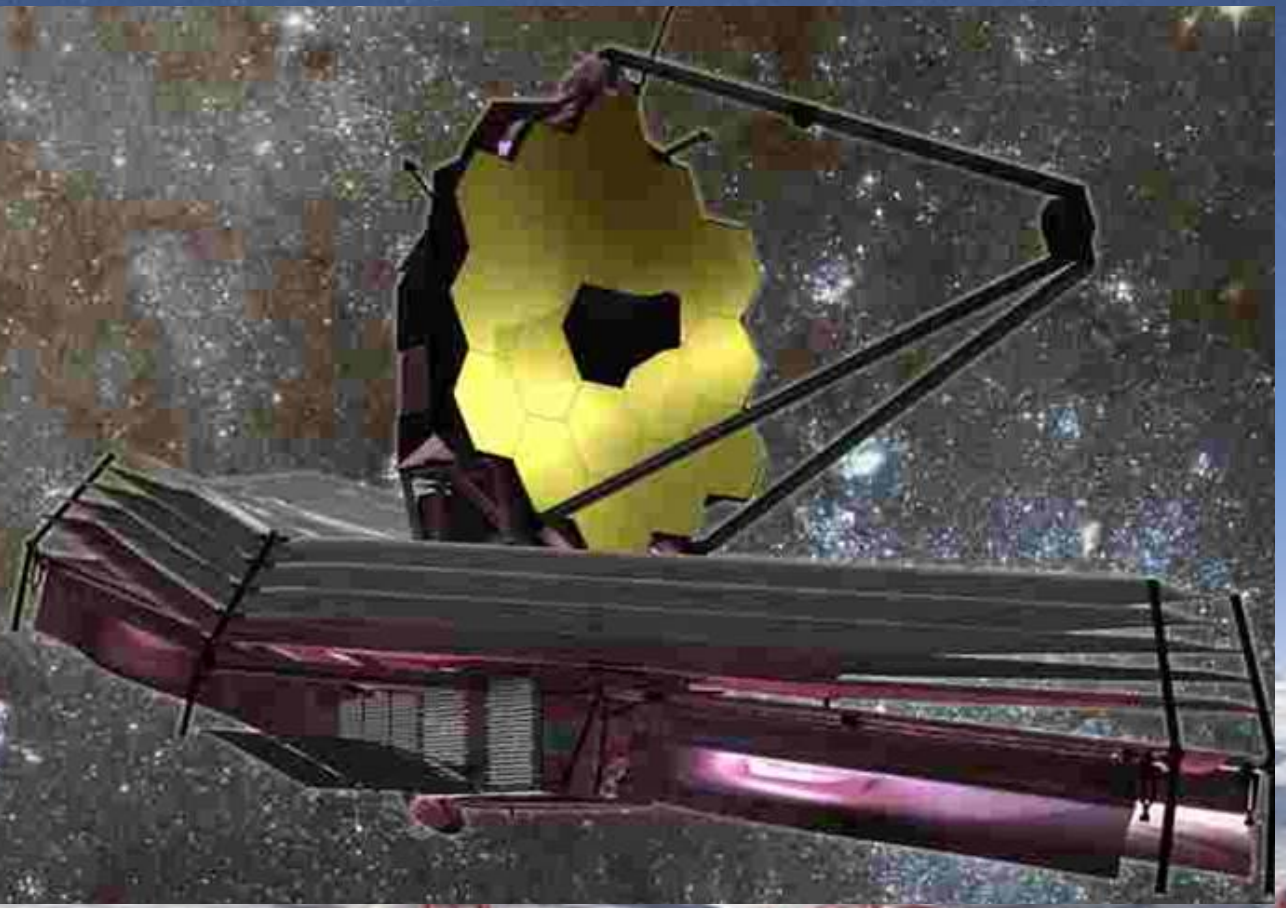
„Traditionally, the overlap between optical/infrared (OIR) astronomy and gamma-ray astronomy has been considered to be fairly small.“

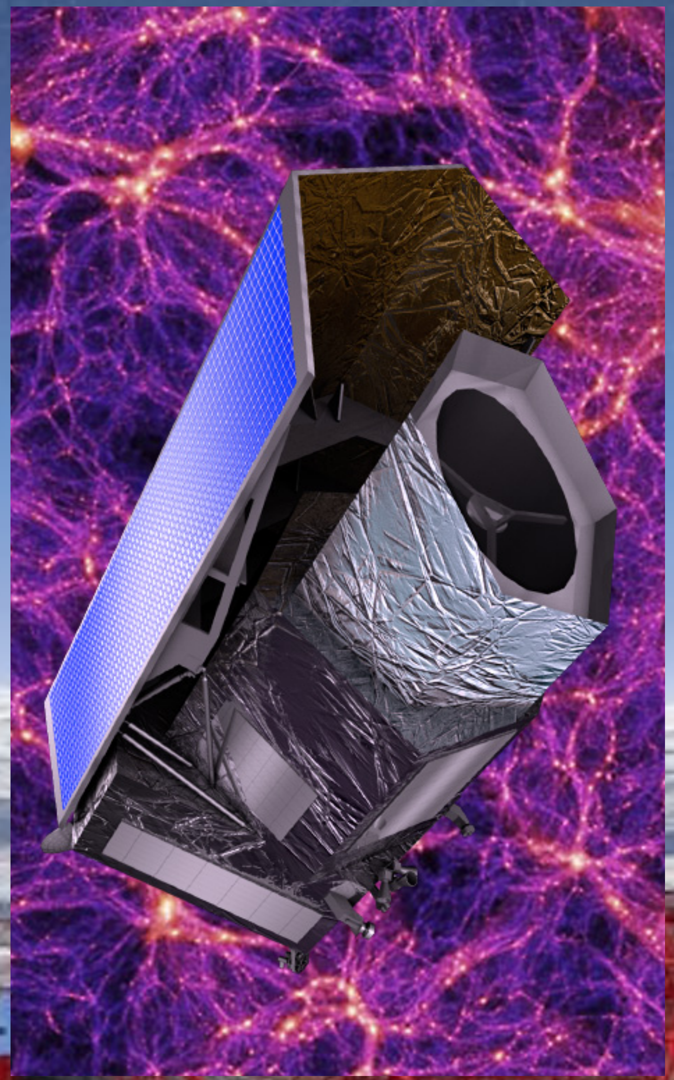
- Dark Matter Programme
- Galactic Centre
- Galactic Plane Survey
- LMC Survey
- Extragalactic Survey
- Transients
- Cosmic Ray PeVatrons
- Star Forming Systems
- Active Galactic Nuclei
- Clusters of Galaxies

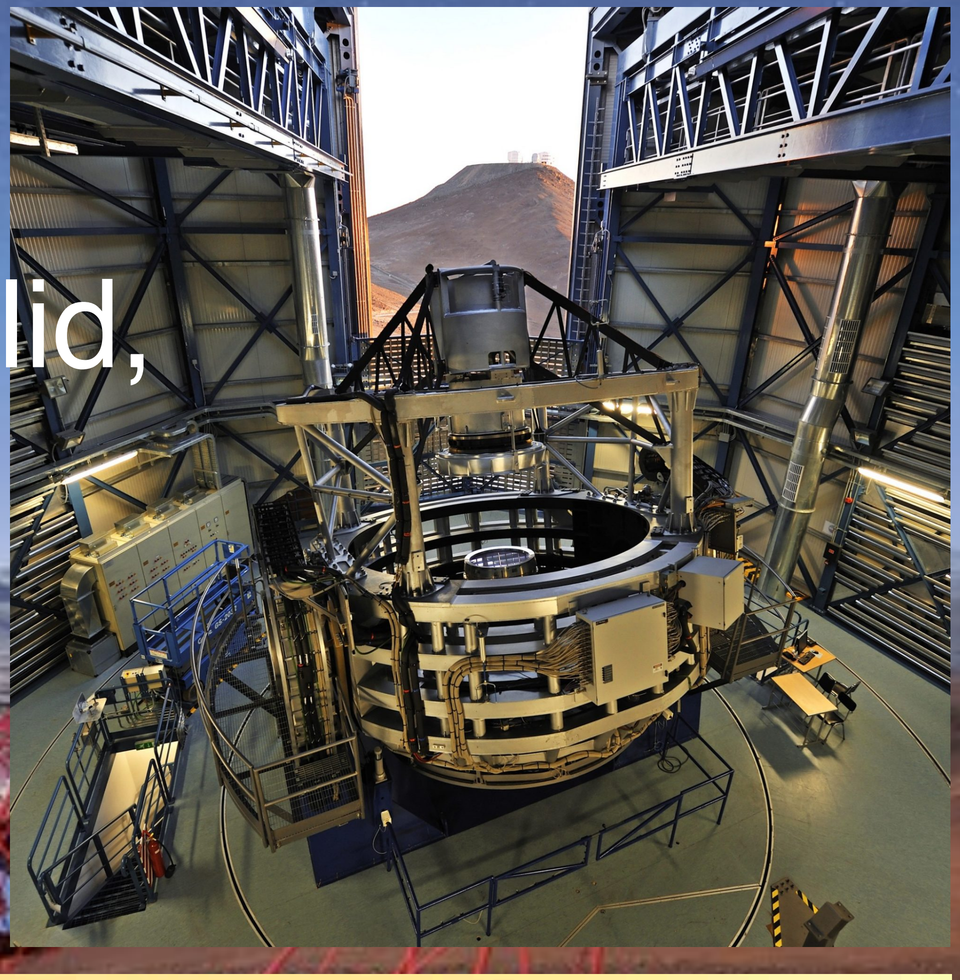


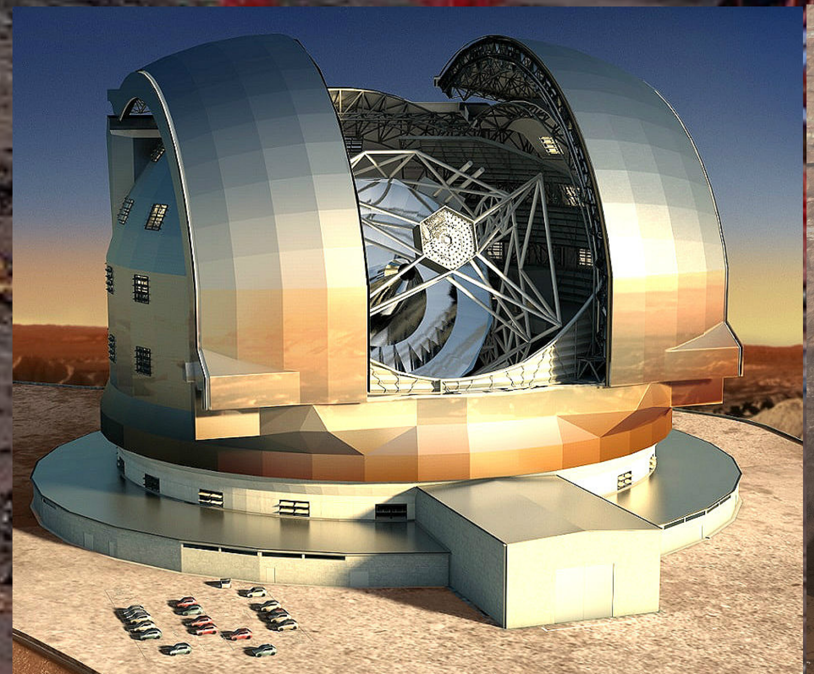
The main facilities & surveys

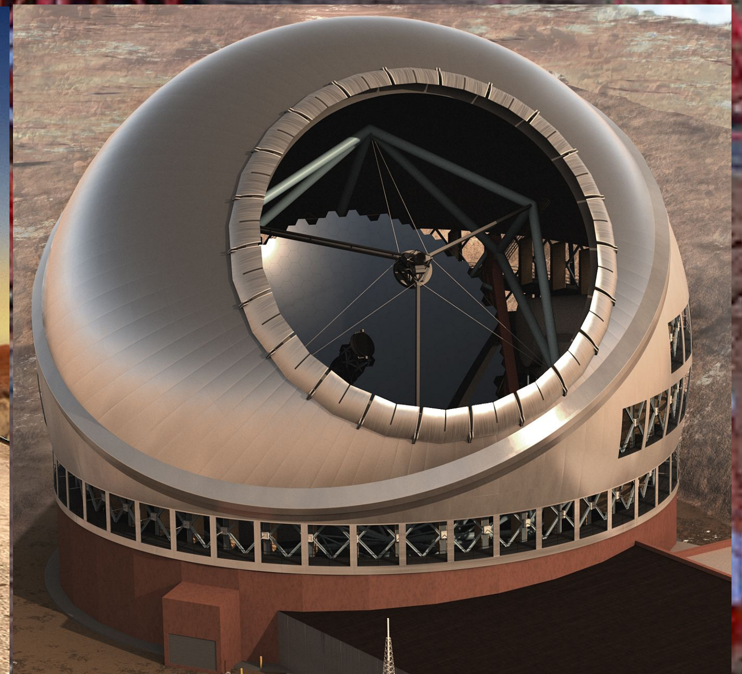
- Current Generation of 8m telescopes
- JWST
- ELTs
- Ground based survey like LSST (imaging) and 4MOST, DESI, WEAVE, SDSS (spectroscopic)
- Space based surveys like Gaia, Euclid, and WFIRST

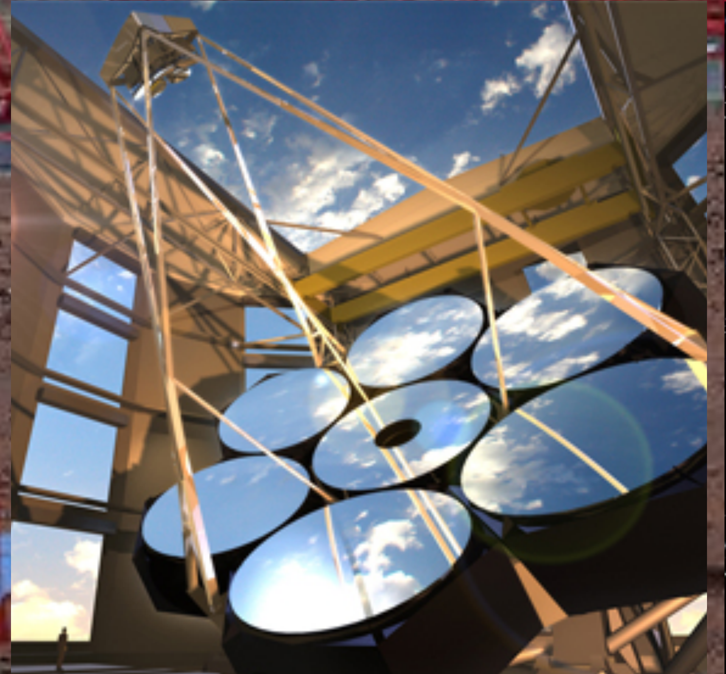


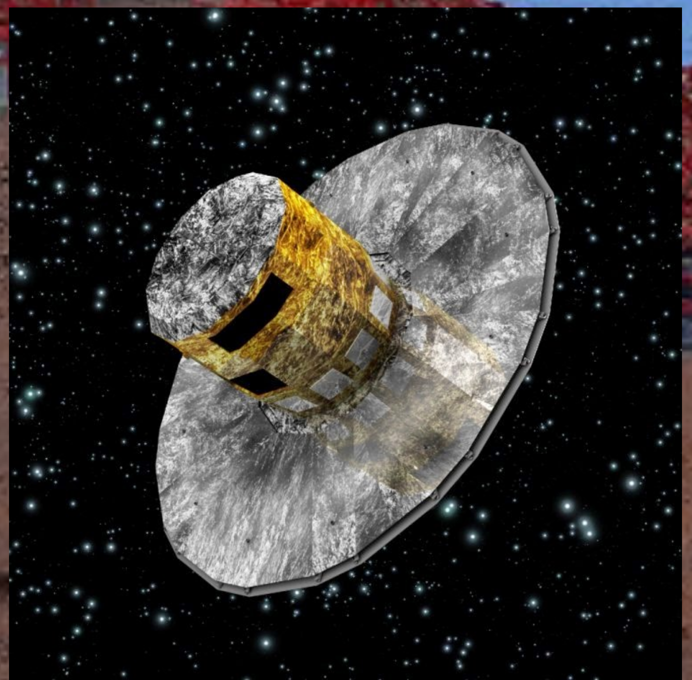












Gaia is rewriting stellar & Galactic evolution

Detailed spectroscopy + astrometry (+ astroseismology) of large samples

⟹ precision samples with good masses, ages and abundances

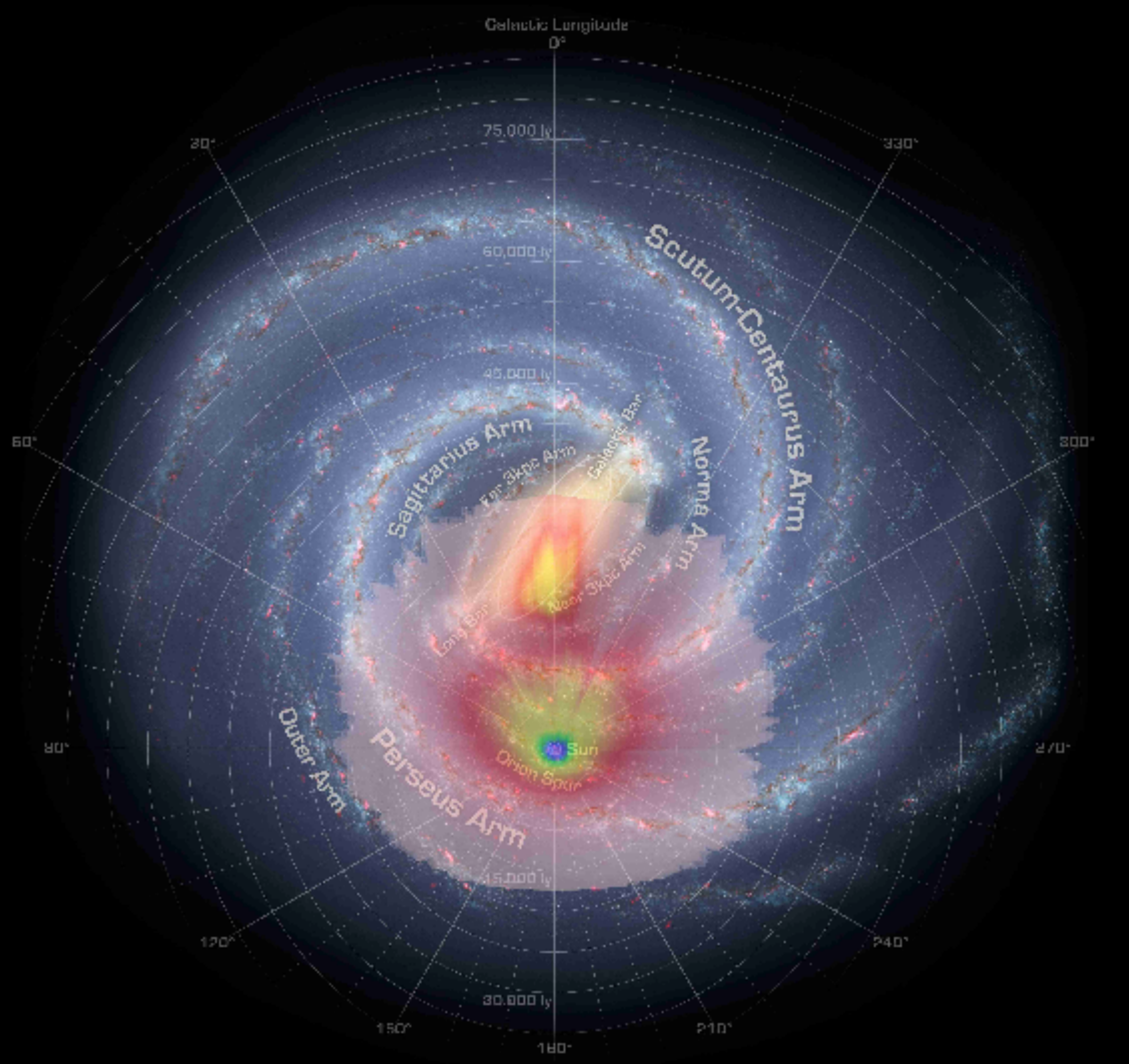
⟹ stellar and Galactic evolution cannot be separated

⟹ affects binaries, SNR remnants …

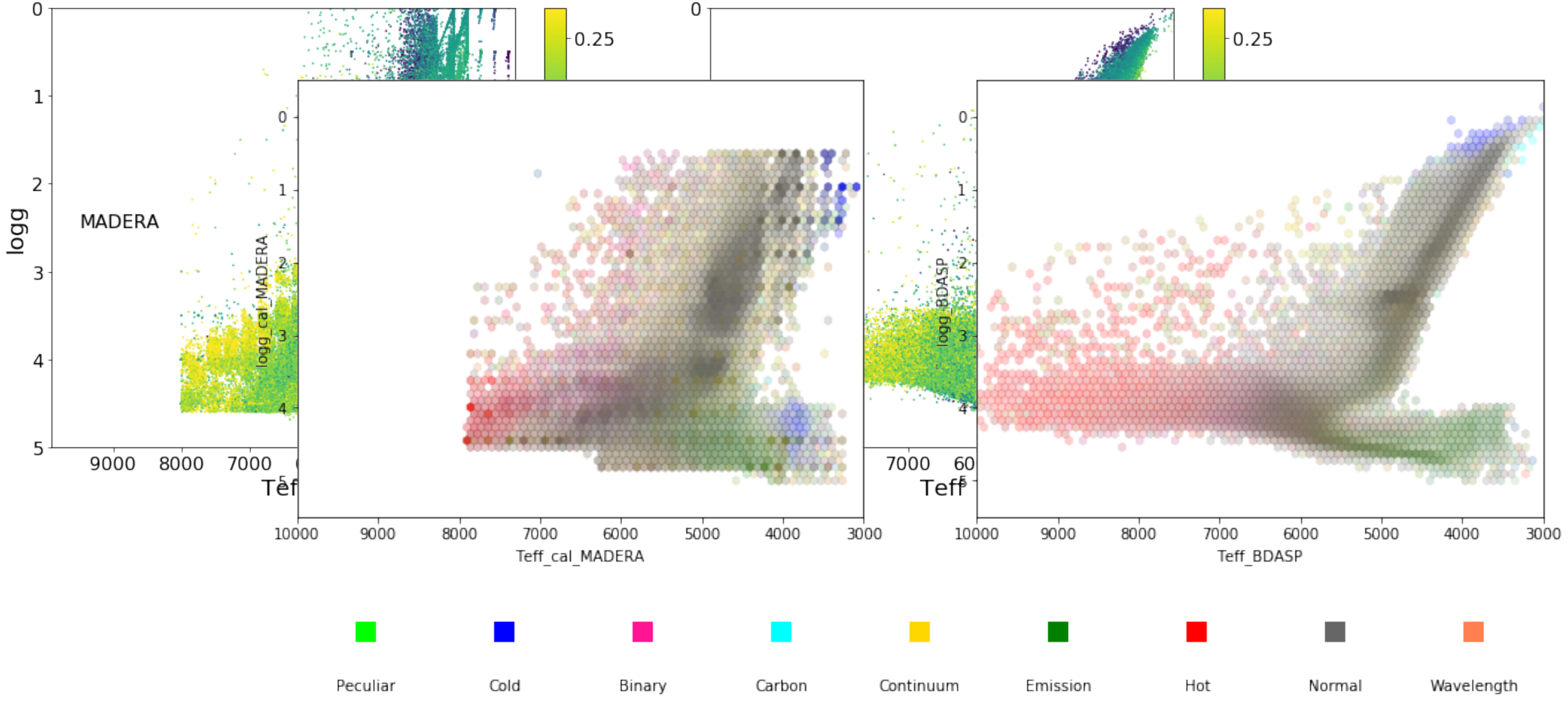
- distance no longer a „fiddle“ parameter
- embedding into general stellar evolution history + chemical enrichment

⟹ Signatures of formation history can be found in the kinematics of the stellar system

⟹ new mass estimates for the Milky Way and its satellite system



Gaia is rewriting stellar & Galactic evolution



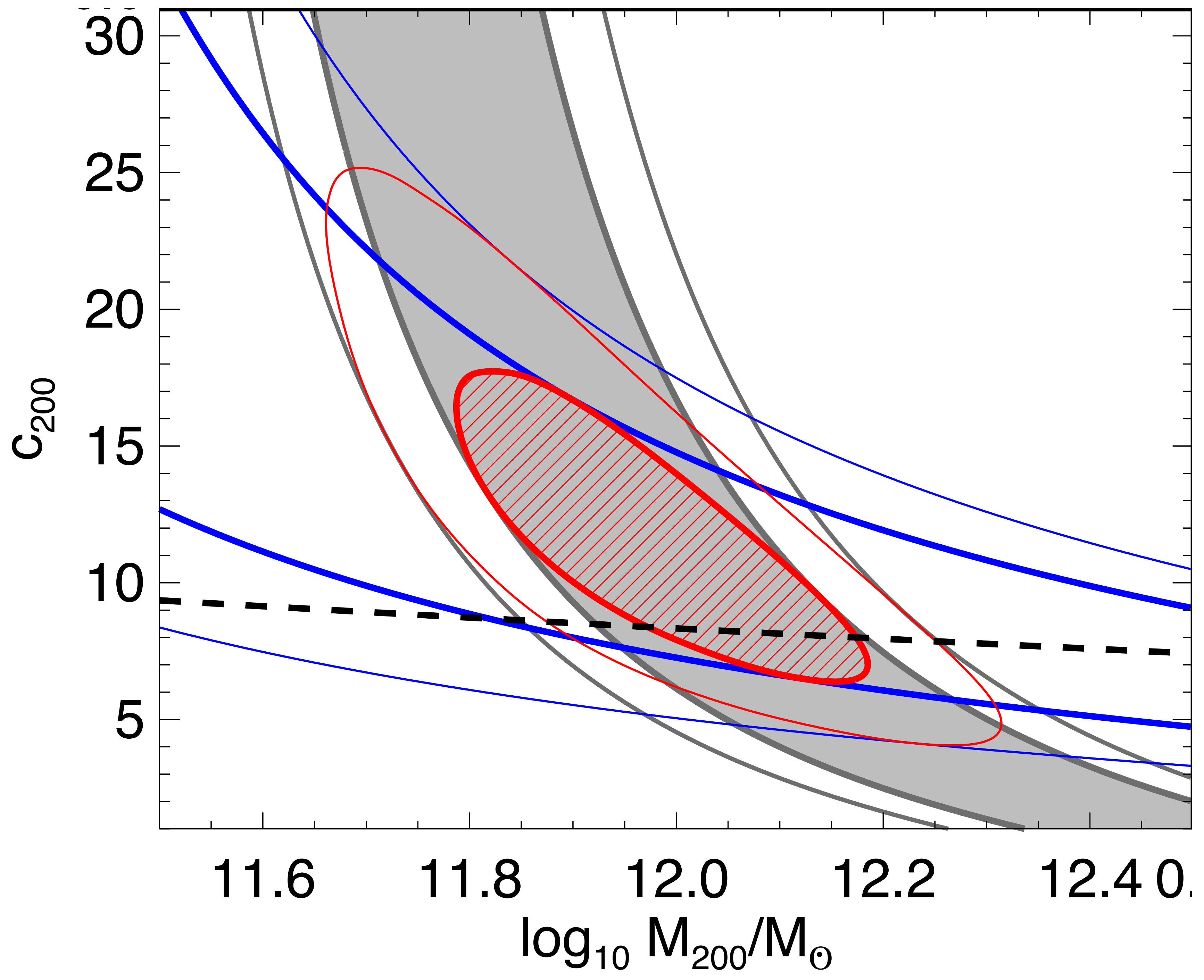
MS & RAVE (2019)

Milky Way may be considerably less massive

Over the past 15 years:

- naive extrapolation from rotation curve gives $M_{MW} > 2.5\times10^{12}\ M_\odot$
- spectroscopic surveys (RAVE, SEGUE) modelling the overall velocity distribution $M_{MW} > 1 - 1.5\times10^{12}\ M_\odot$
- recent Gaia data taking into account the local velocity distribution reveals considerable anisotropy

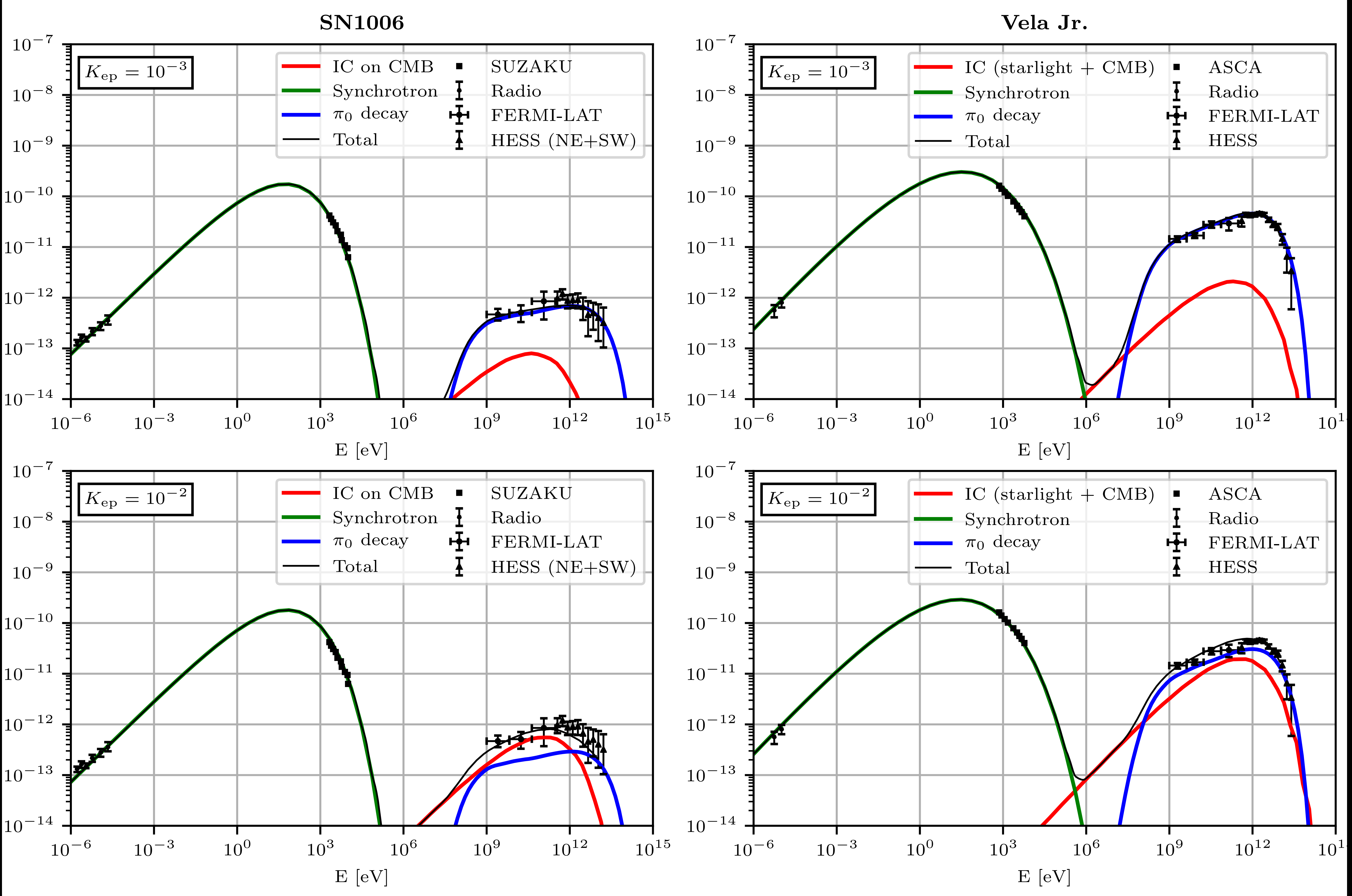
$\Longrightarrow M_{MW} \approx 10^{12}\ M_\odot$



Deason et al (2019)

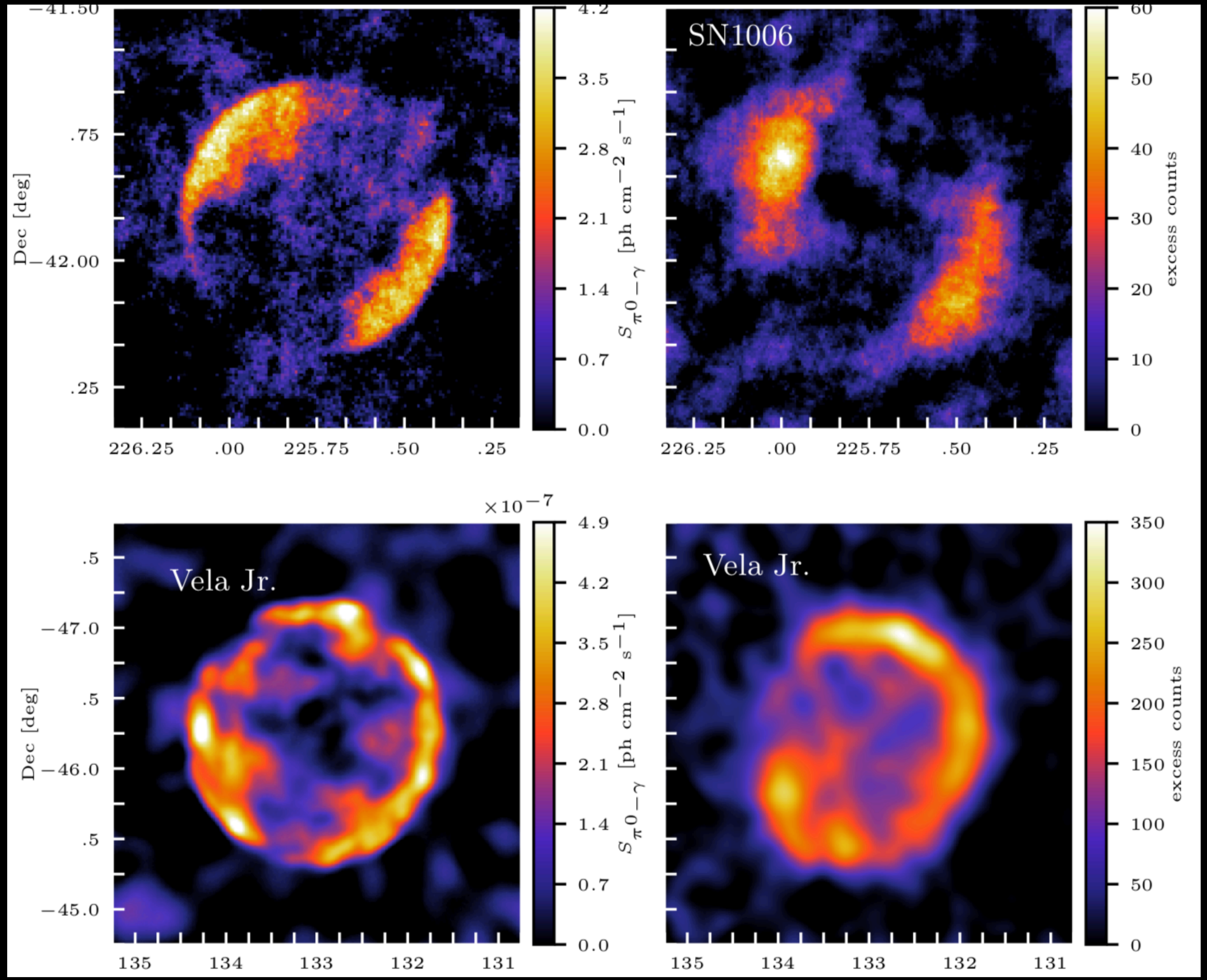
Cosmic ray acceleration in SNRs

3D simulation with cosmic ray acceleration depending on magnetic obliquity (Pais, Pfrommer+ 2019)

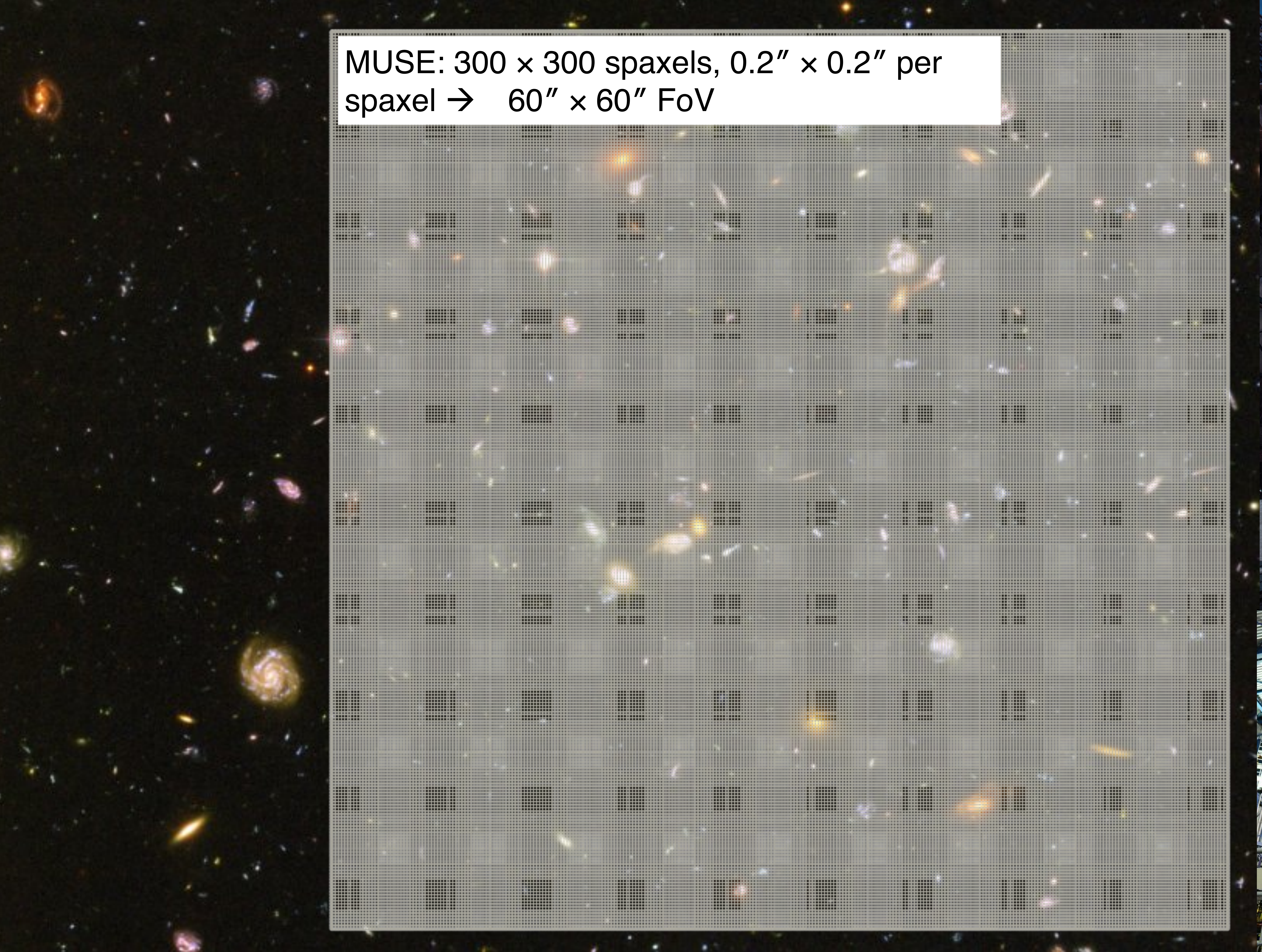
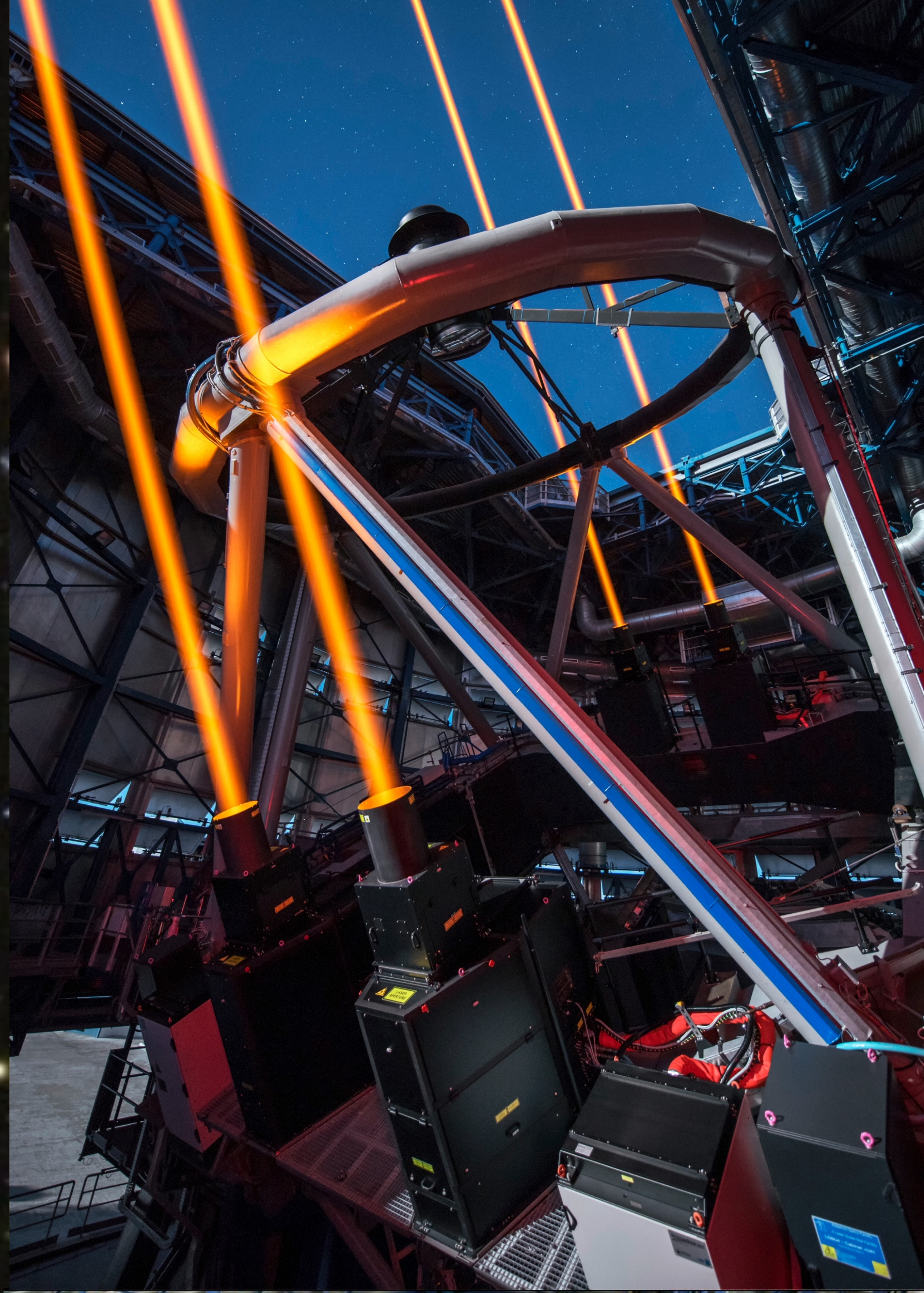
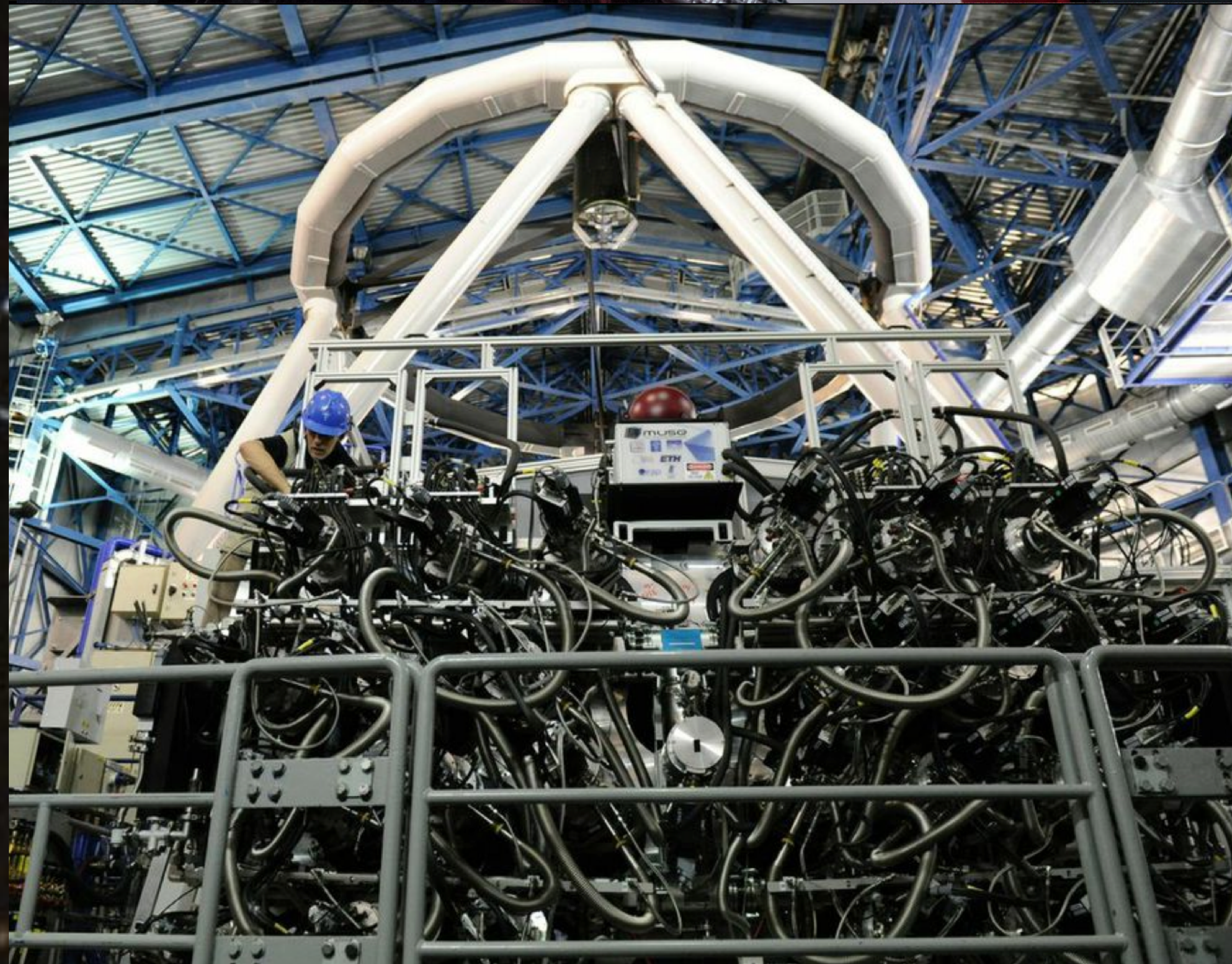


Gaia distances help breaking parameter degeneracies of hadronic and leptonic models

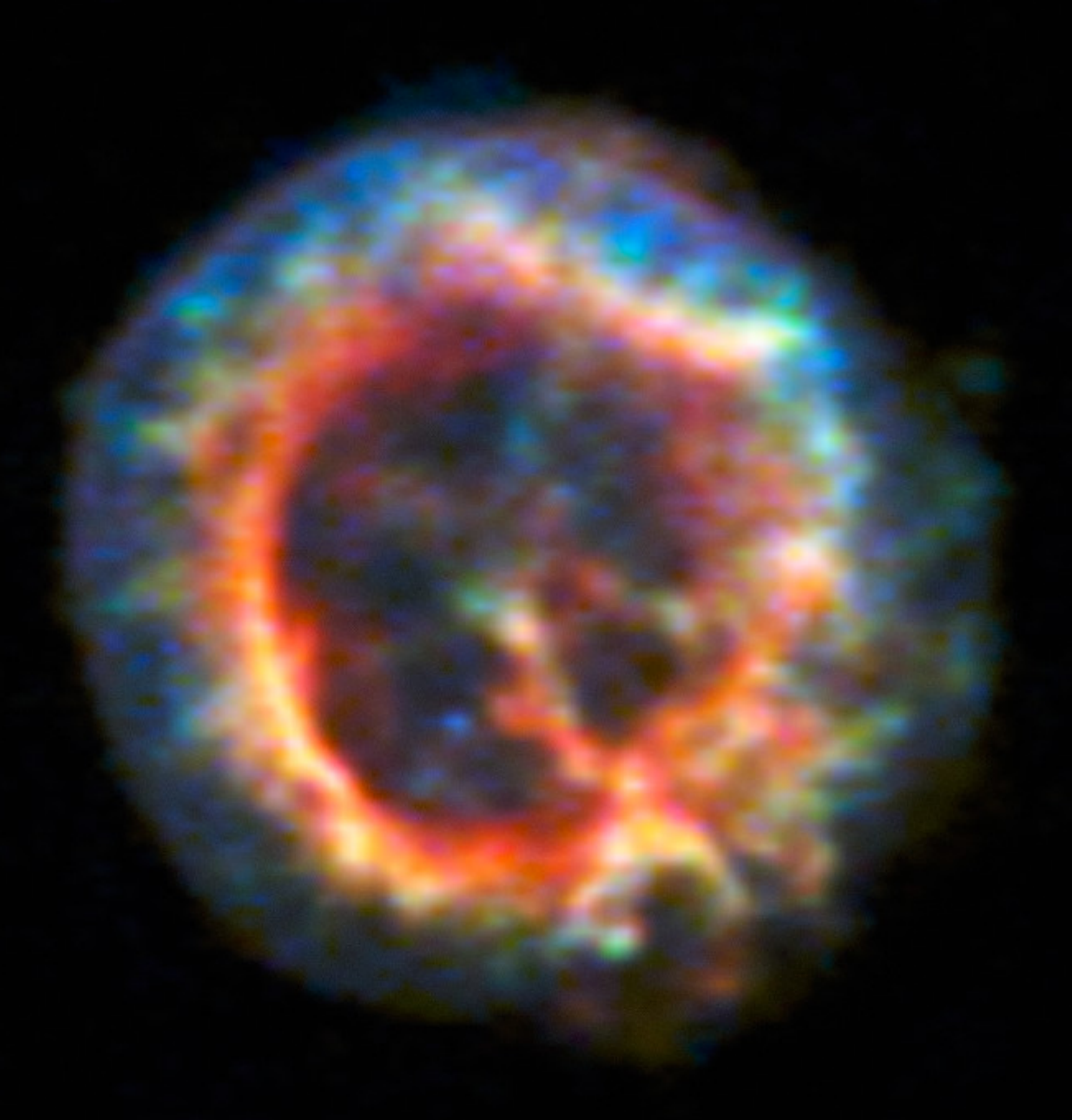
Simulation H.E.S.S. Observation



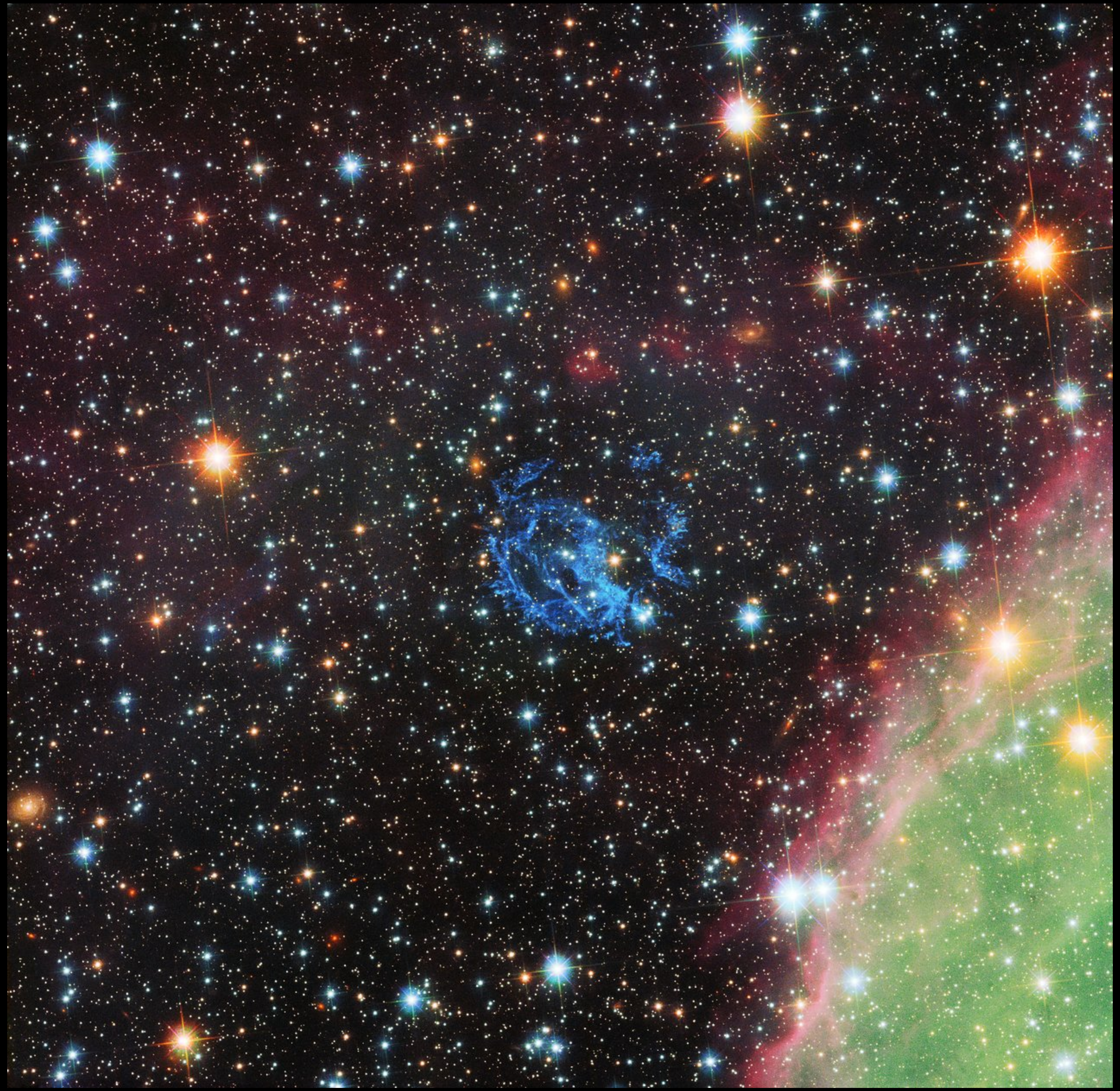
SN1006 (top) expands into homogeneous field, Vela Jr. (bottom) expands into a turbulent field


MUSE: 300 × 300 spaxels, 0.2″ × 0.2″ per spaxel → 60″ × 60″ FoV



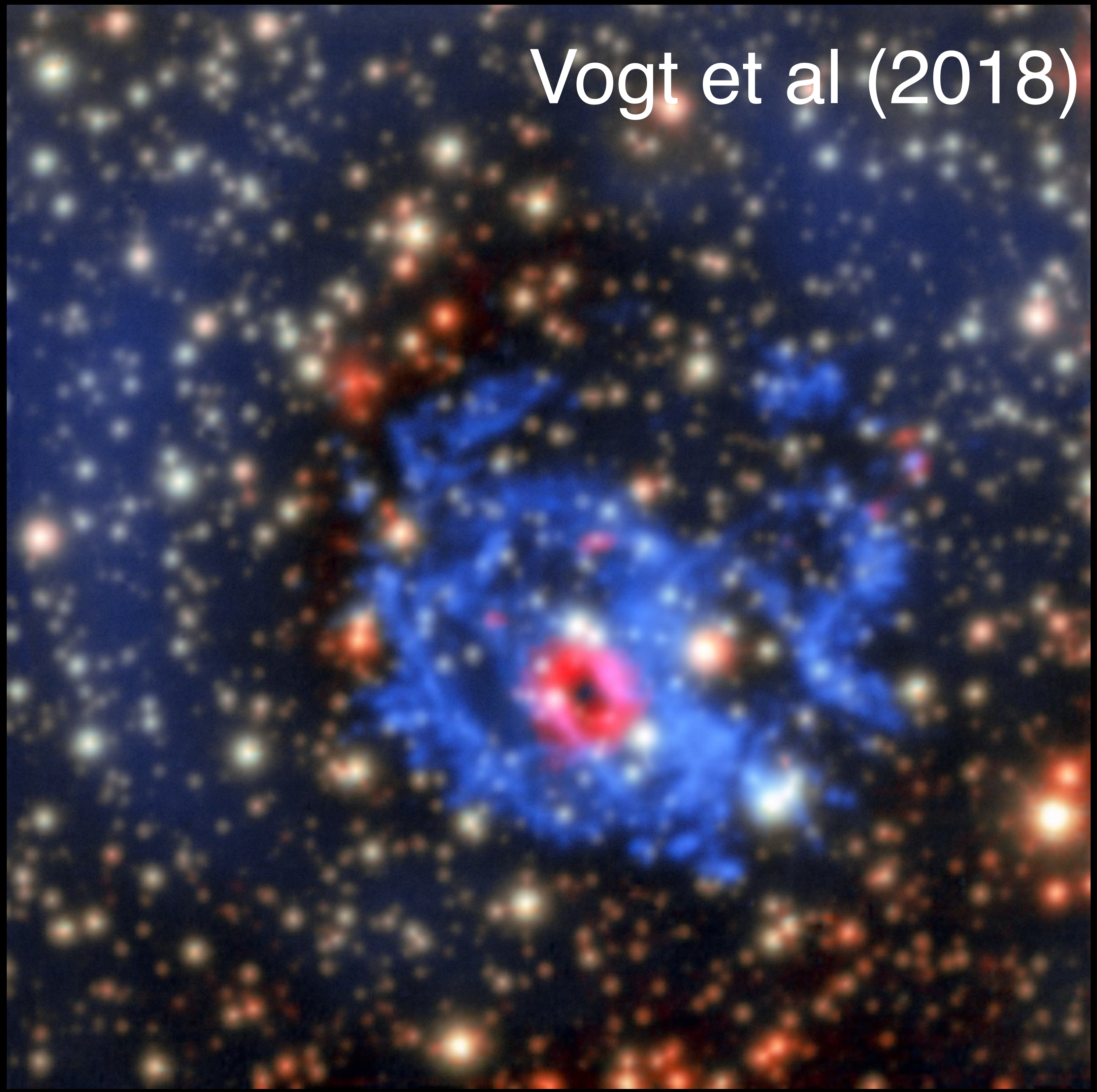
Neutron star in SNR 1E0102.2-7219 in the SMC



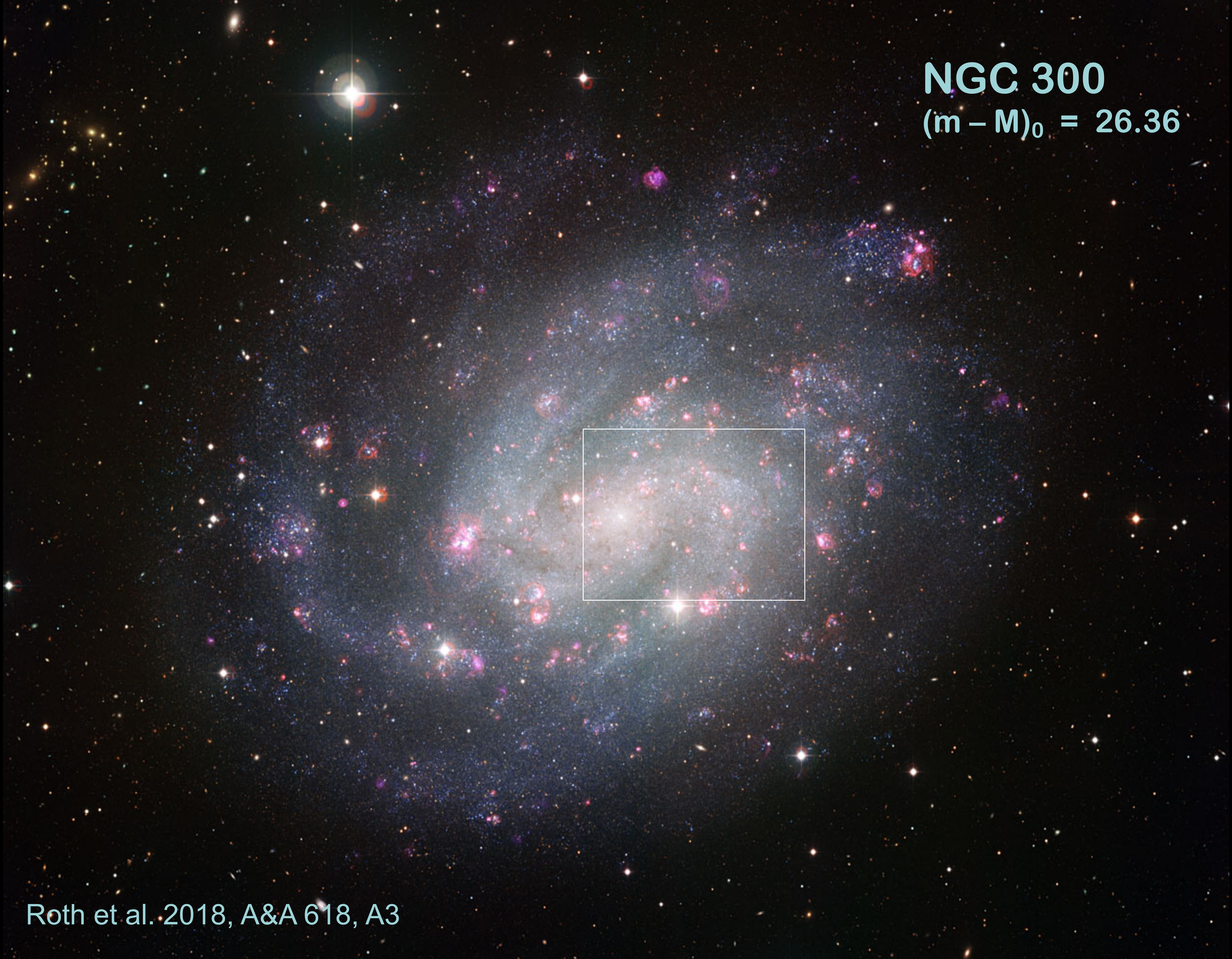
Chandra



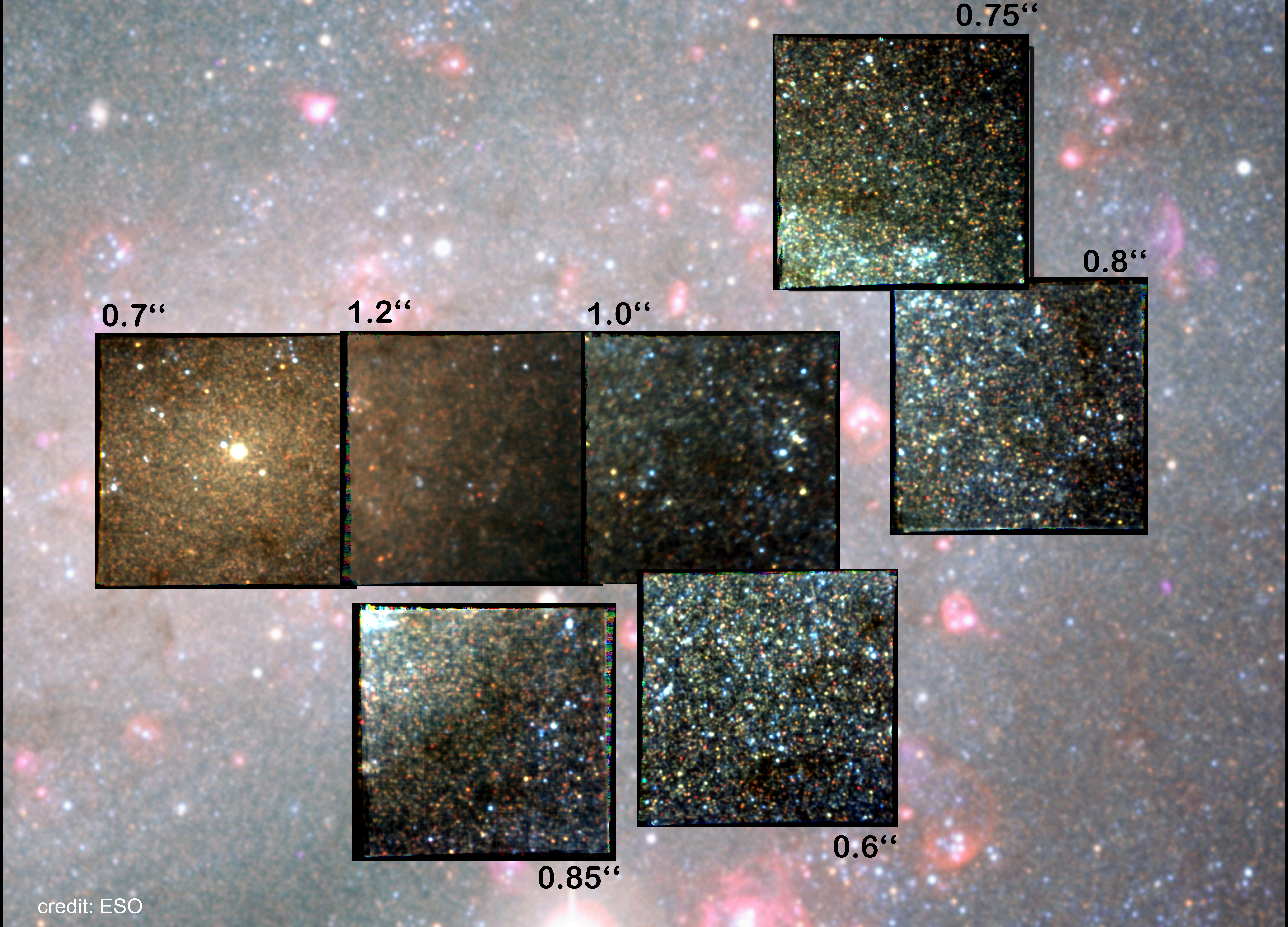
HST

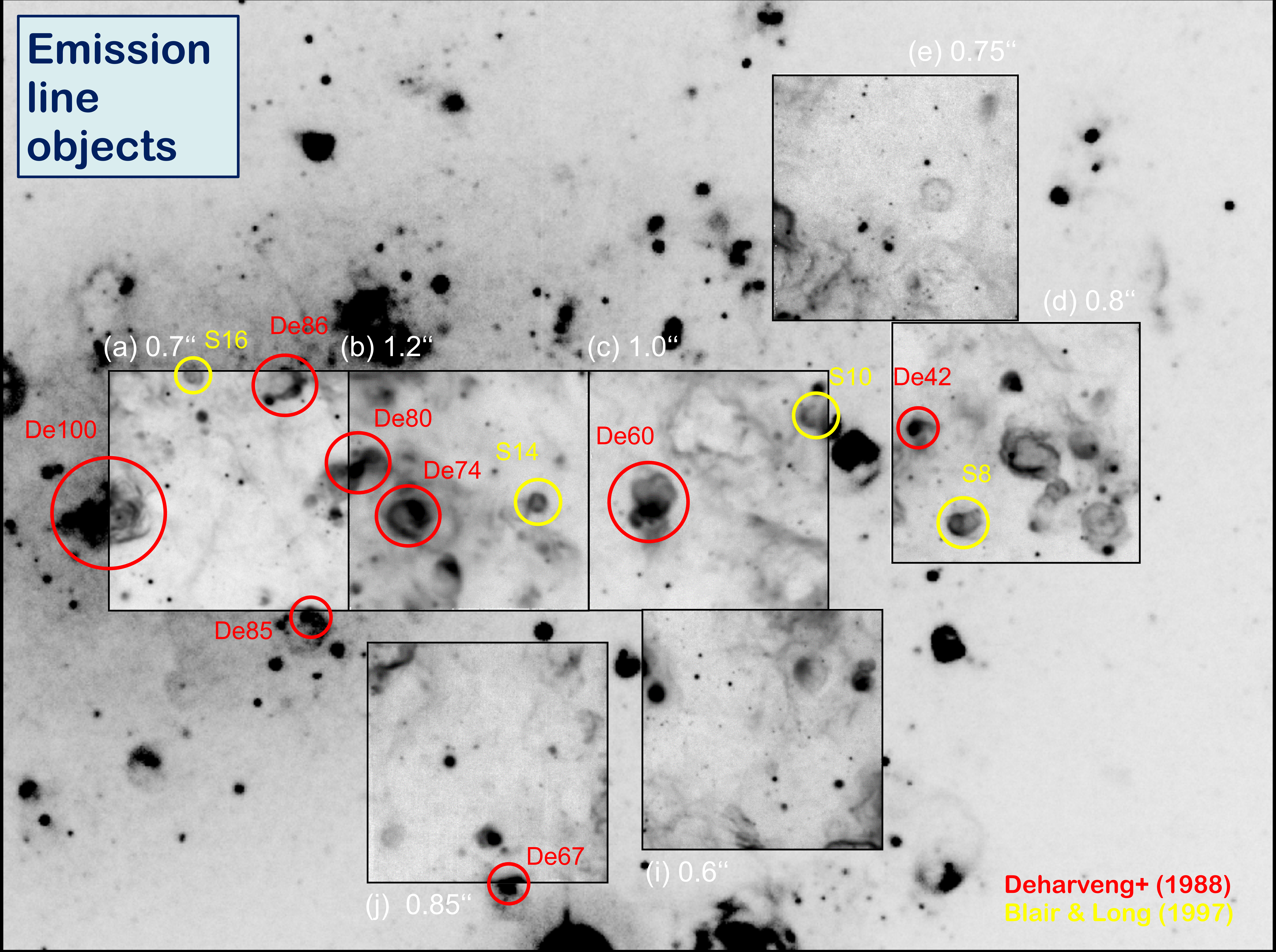


MUSE@VLT



Roth et al. 2018, A&A 618, A3

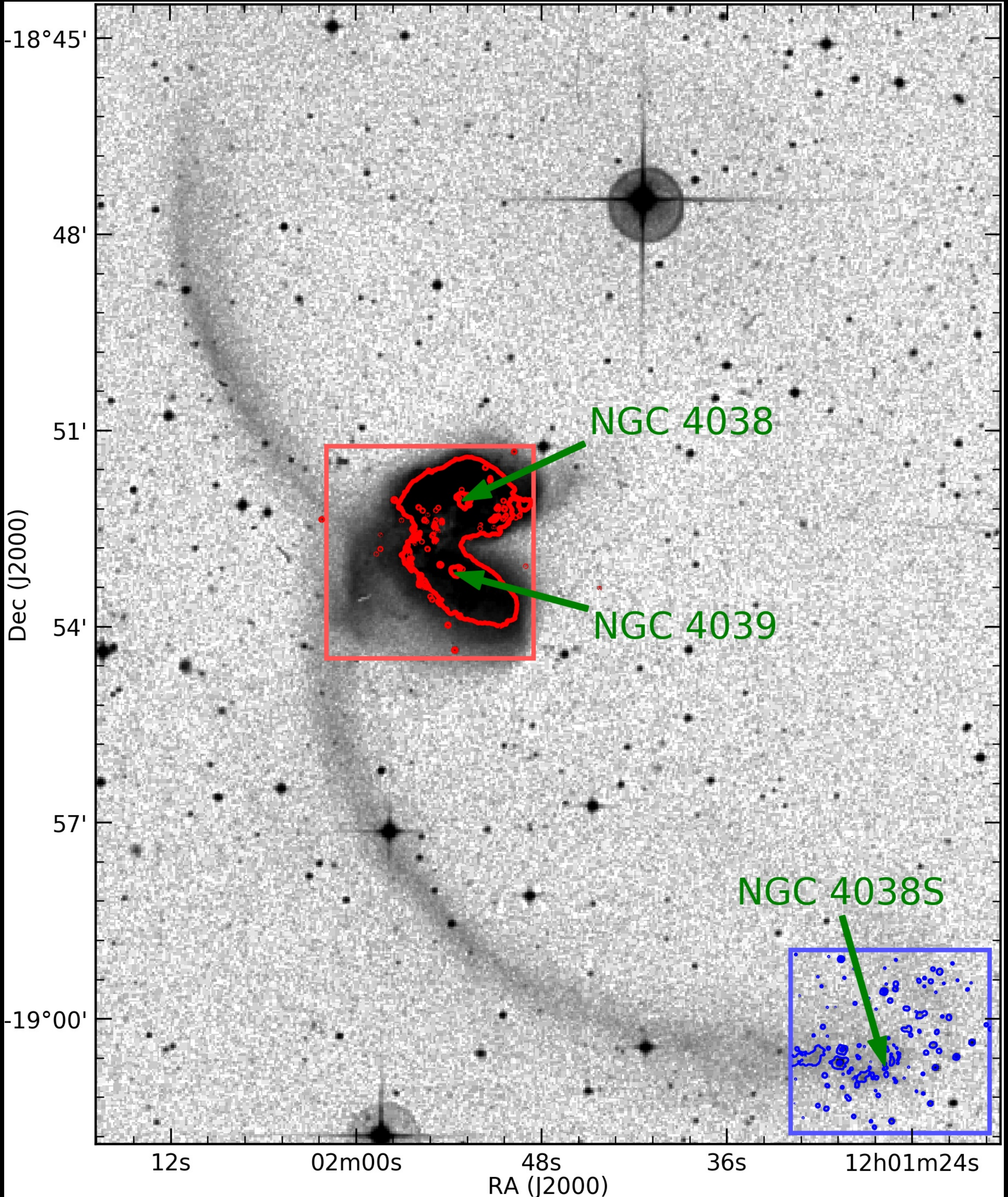

0.75''
0.8''
0.7''
1.2''
1.0''
0.85''
0.6''
credit: ESO


Emission line objects
(a) 0.7“
S16
De86
(b) 1.2“
(c) 1.0“
(e) 0.75“
(d) 0.8“
S10
De42
De100
De80
De74
S14
De60
S8
De85
De67
(i) 0.6“
(j) 0.85“
Deharveng+ (1988)
Blair & Long (1997)

Summary (from 9 hrs exposure time)

	a	b	c	d12	e1	i	j	
Seeing	0.7“	1.2“	1.0“	0.8“	0.75“	0.6“	0.85“	
PN	5	7	6	4	9	3	2	36
PN candidates	4	0	0	1	4	0	0	9
HII regions	10	11	5	13	4	13	5	61
cHII regions 1)	8	4	5	19	5	2	8	51
SNR	14	5	3	5	3	6	2	38
emStars 2)	18	4	4	15	30	40	7	118
bgr. Galaxies 3)	4	3	1	6	2	8	4	28
Stars 4)	445	77	152	265	299	517	91	1846

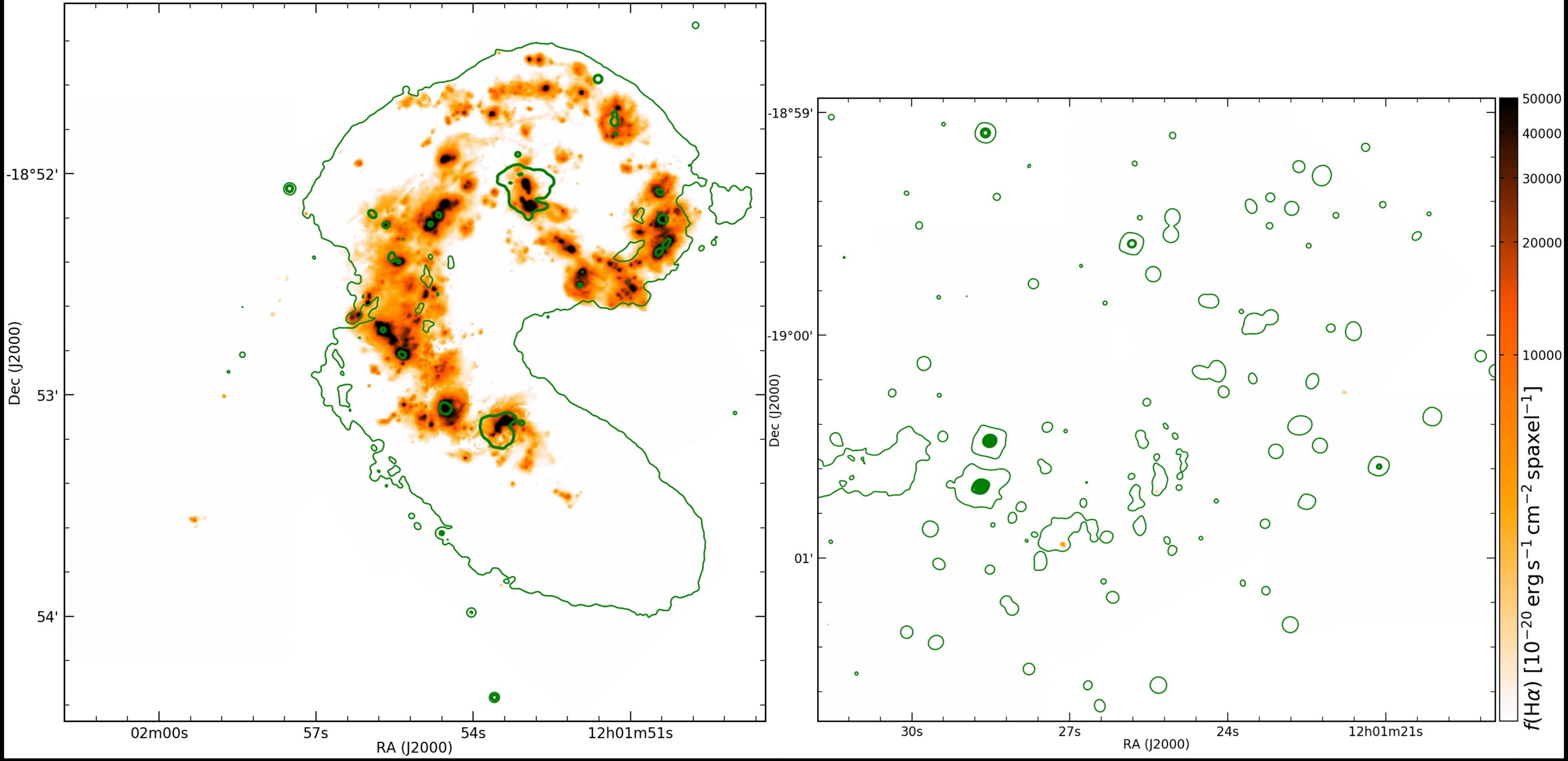
1) compact HII regions
2) emission line stars
3) background galaxies
4) stars with spectral type



MUSE
data
locations

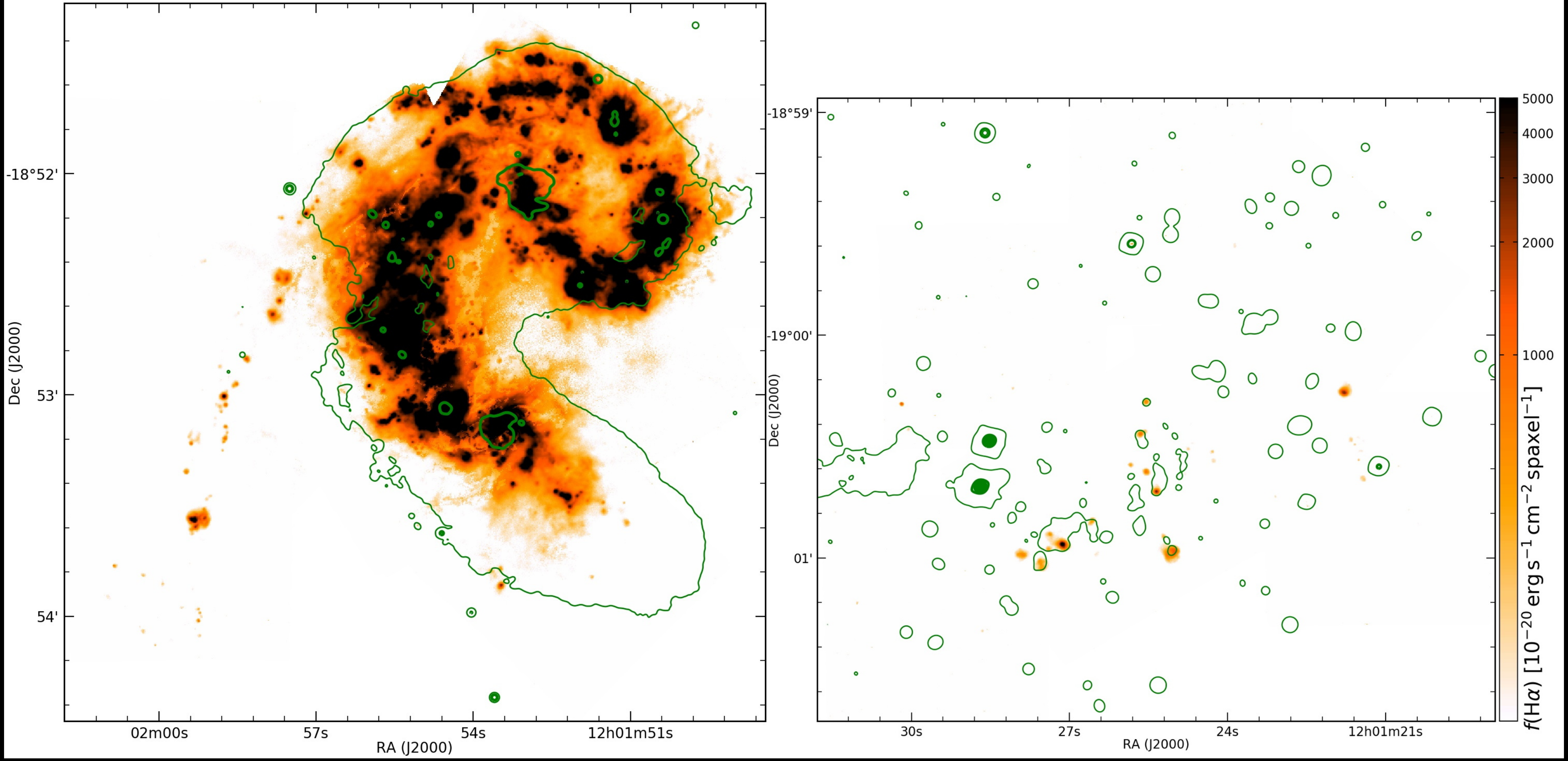
Weilbacher, MS et al (2018)

MUSE Hα maps



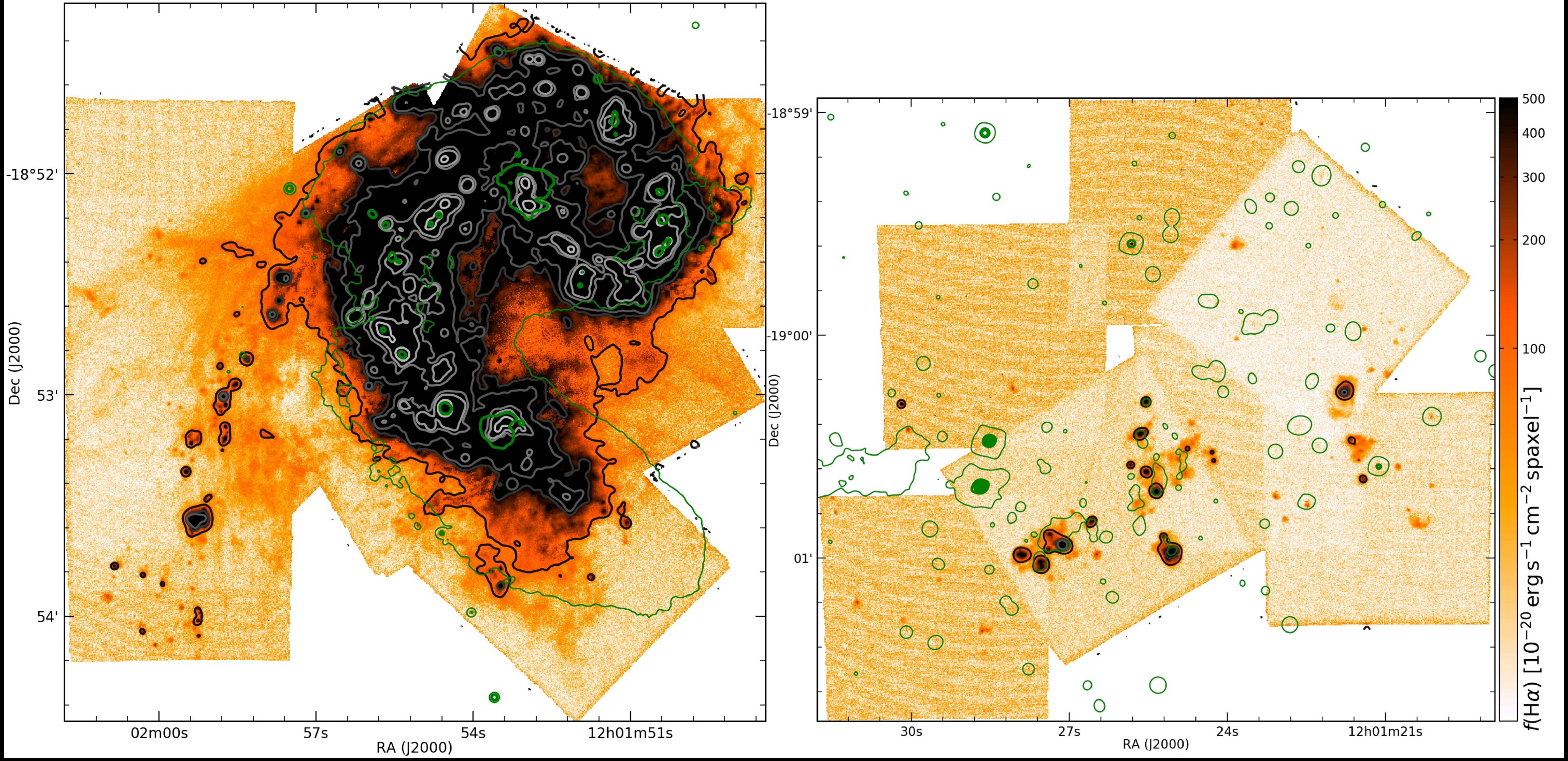
Weilbacher, MS et al (2018)

MUSE Hα maps



Weilbacher, MS et al (2018)

MUSE Hα maps



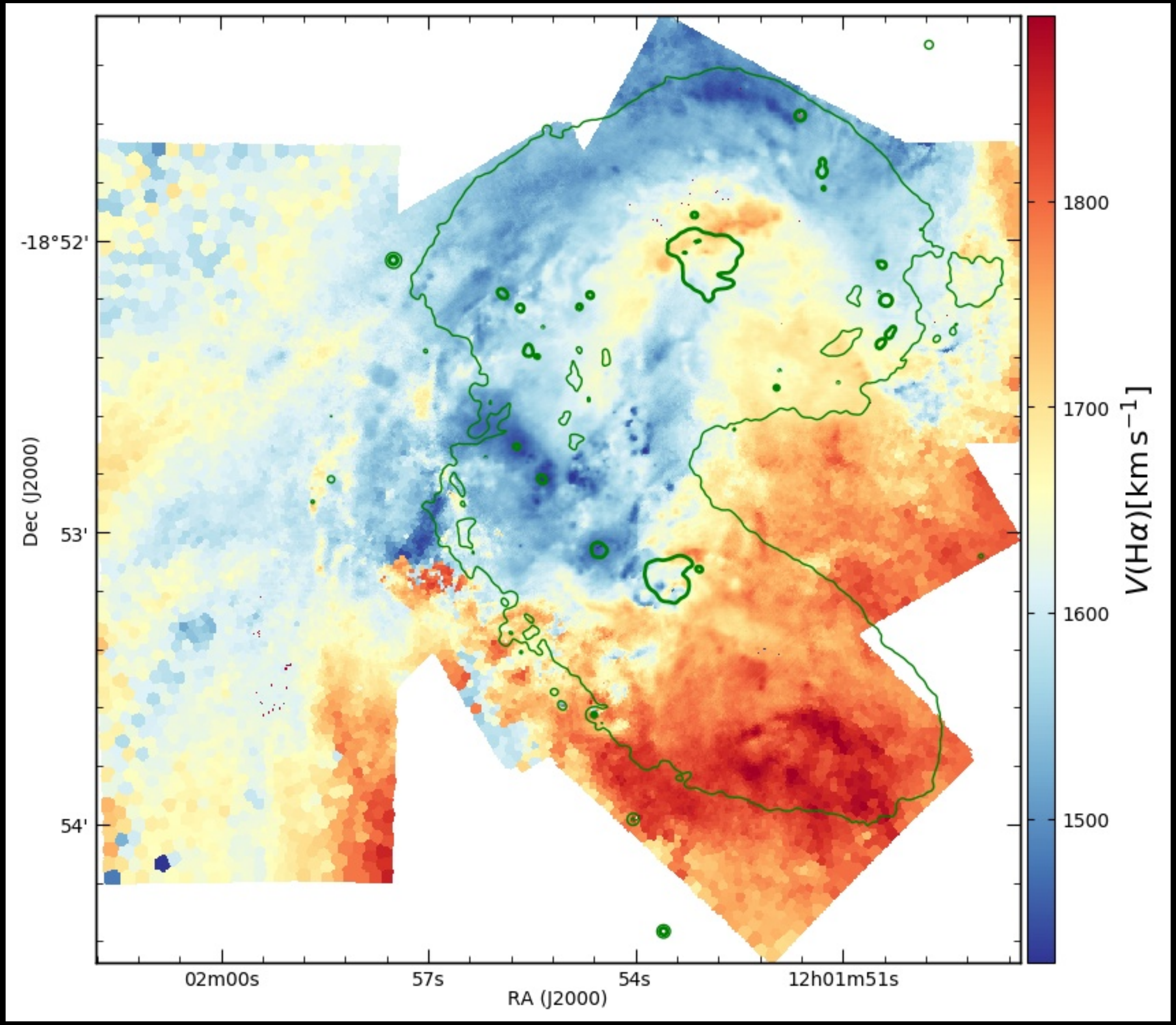
$\sim$1.5h depth → $1\sigma \approx 3\times10^{-20}$ erg s^{-1}cm^{-2}pix^{-1}

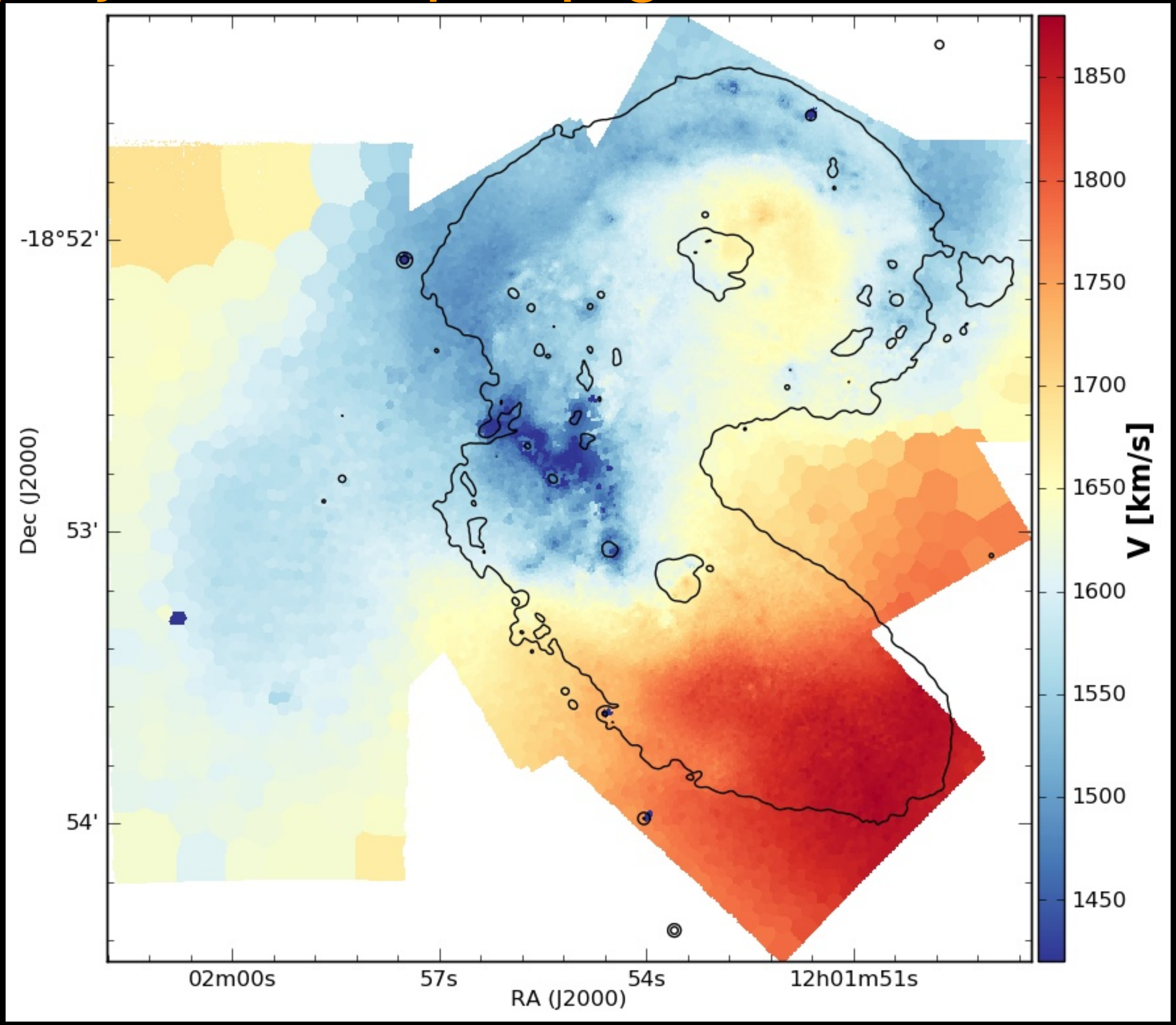
$=7.5\times10^{-19}$ erg s^{-1}cm$^{-2}\square''$

Weilbacher, MS et al (2018)

Velocities

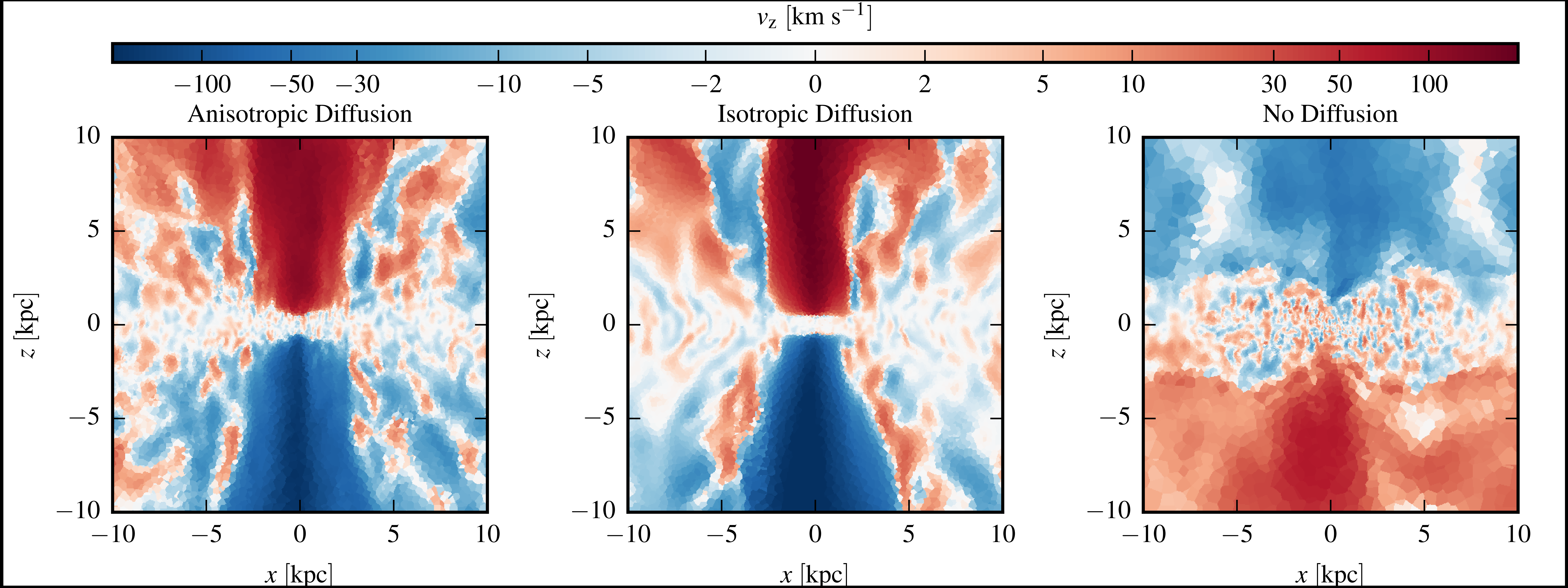
Kamann et al: ongoing project to map Arp galaxies with MUS





Weilbacher, MS et al (2018)

MHD galaxy simulation with cosmic rays

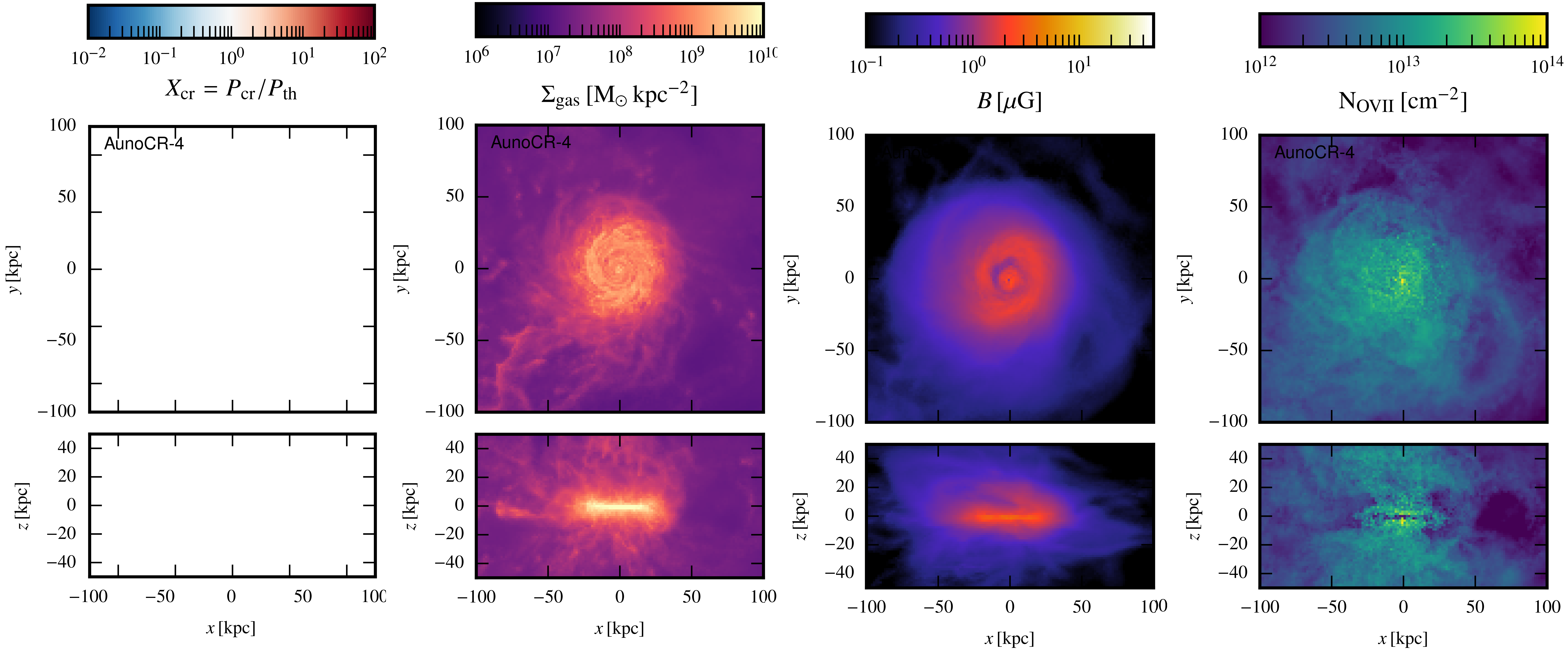


*

CR diffusion launches powerful winds (Pakmor, Pfrommer+ 2016)
Simulation without CR diffusion exhibits only weak fountain flows

Cosmic rays in cosmological simulations

Fiducial cosmological simulations: AURIGA MHD simulations (Grand+ 2017)



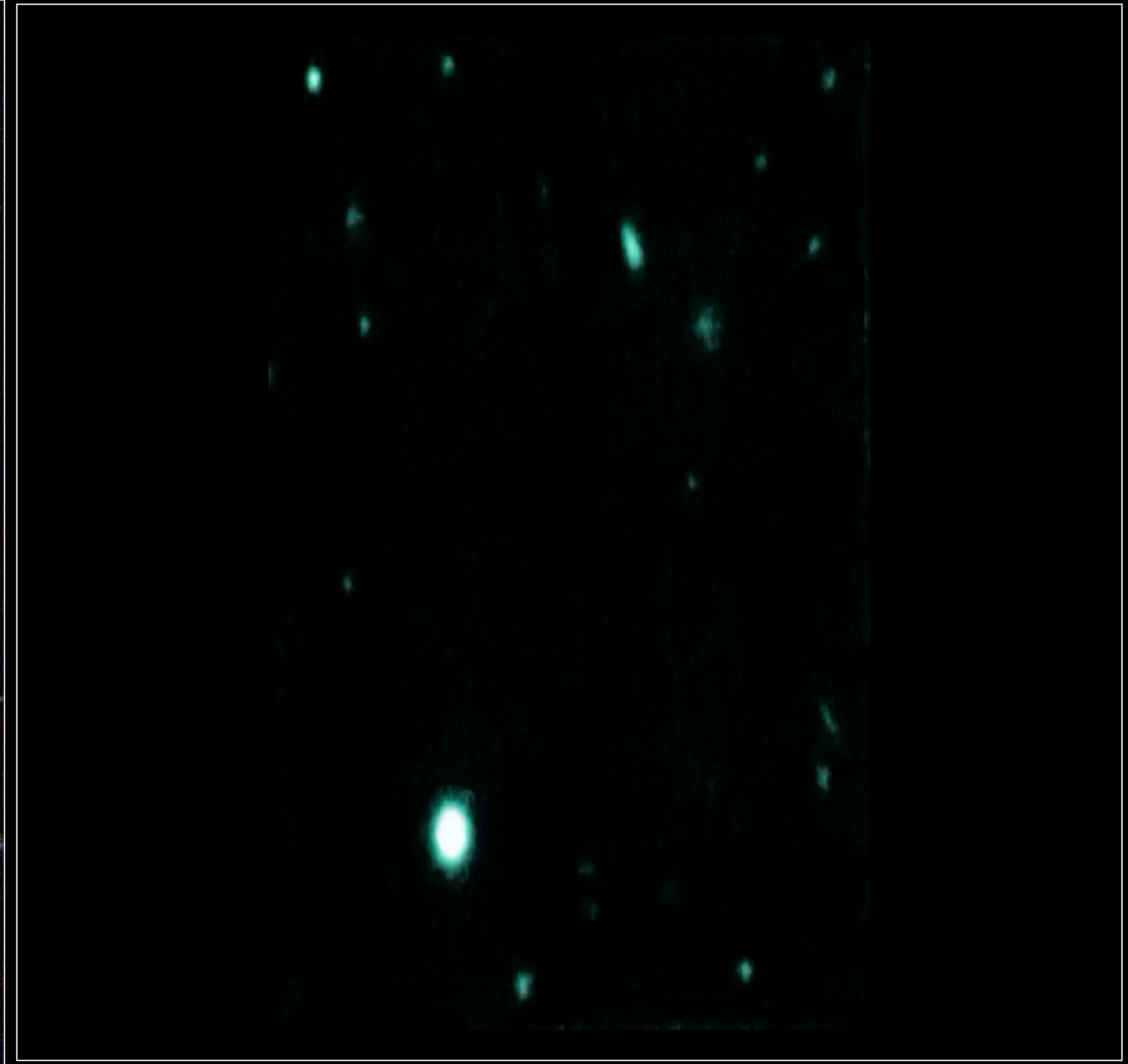
Cosmic rays in cosmological simulations

Fiducial cosmological simulations: AURIGA MHD + CR simulations (Buck, Pakmor, Pfrommer+)

The Hubble Deep Field South, seen by MUSE

Hubble:

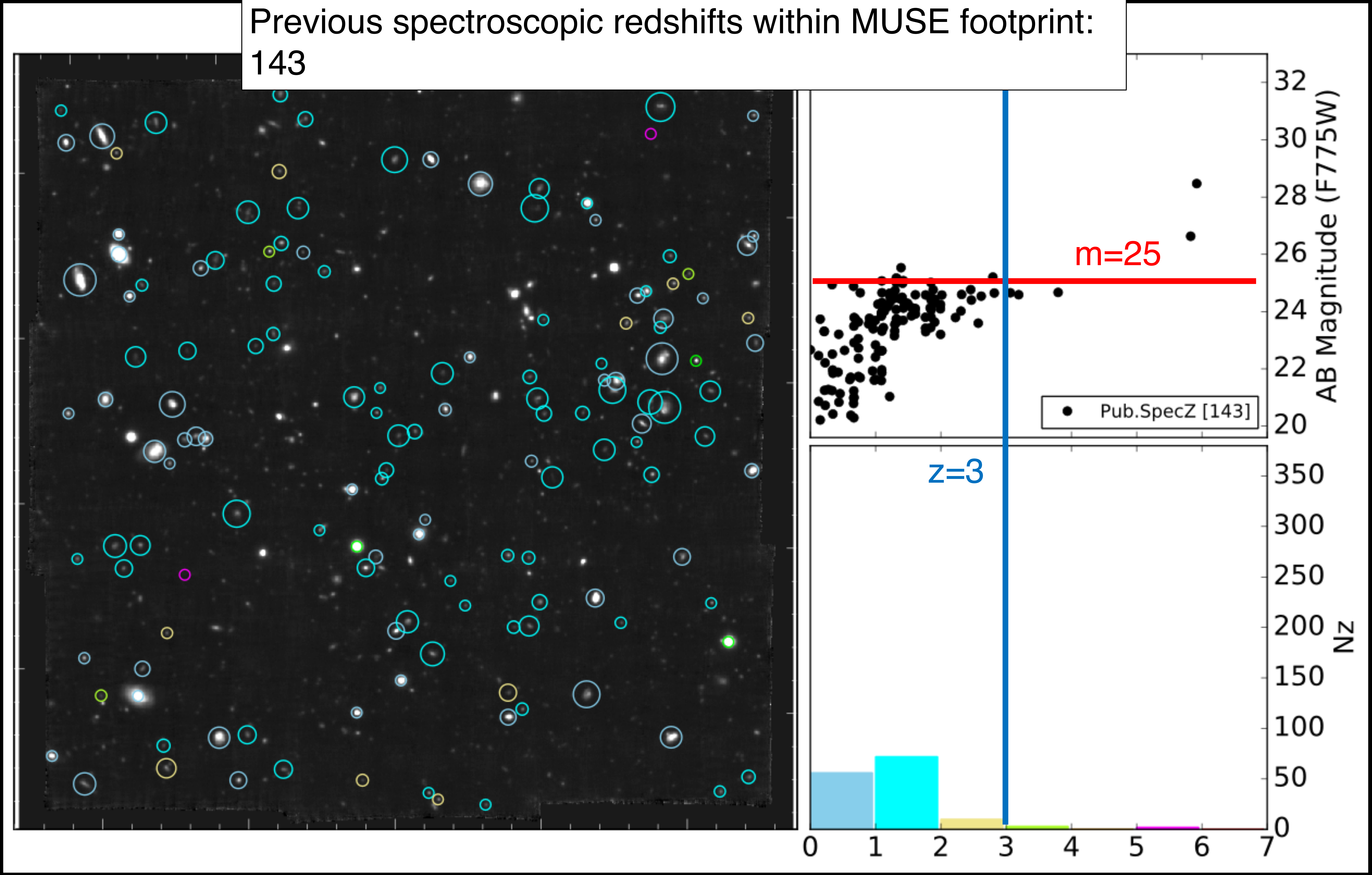
MUSE:



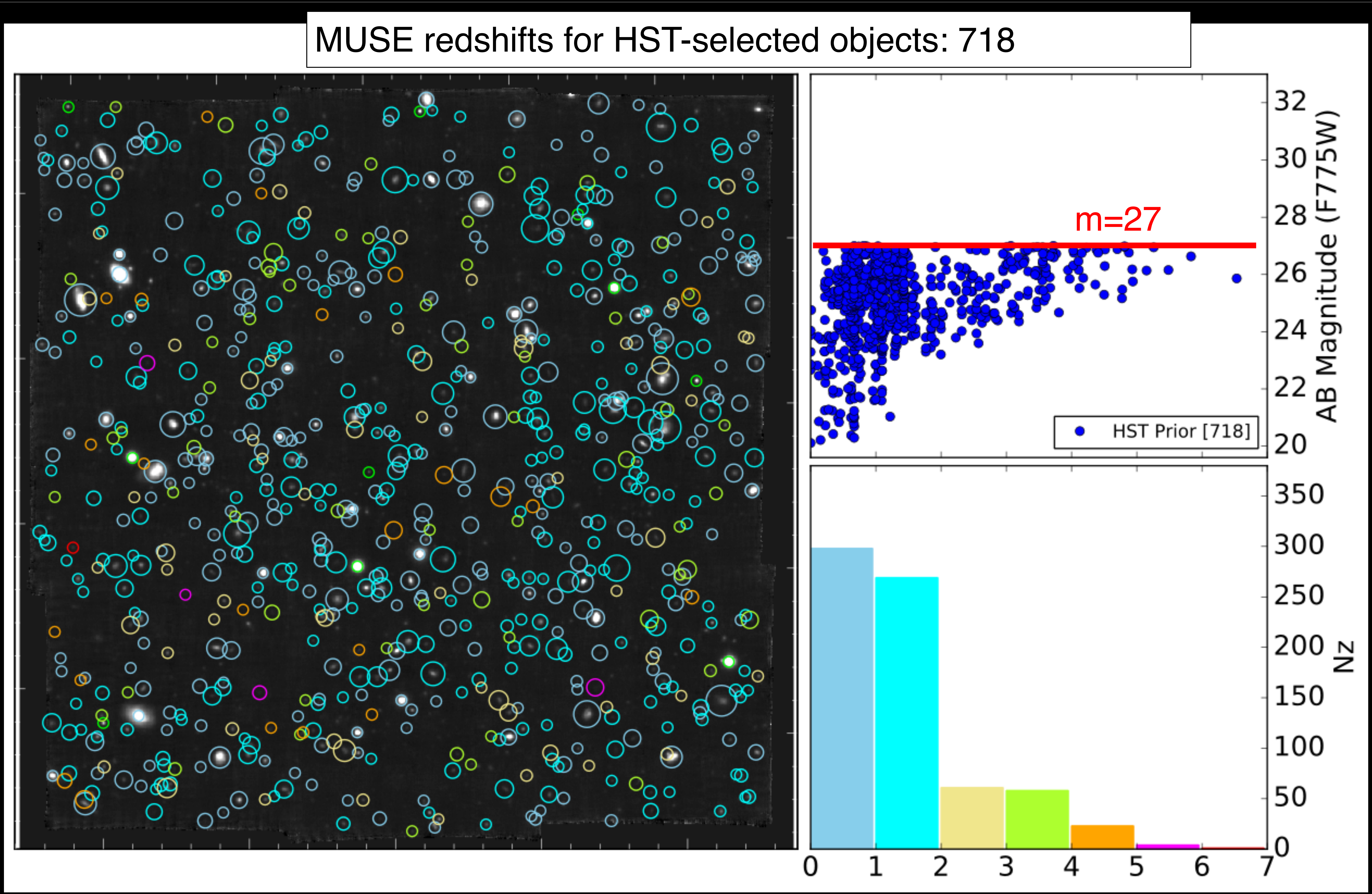
Urrutia, MS et al (2018)

Redshifts in the MUSE-Deep UDF mosaic

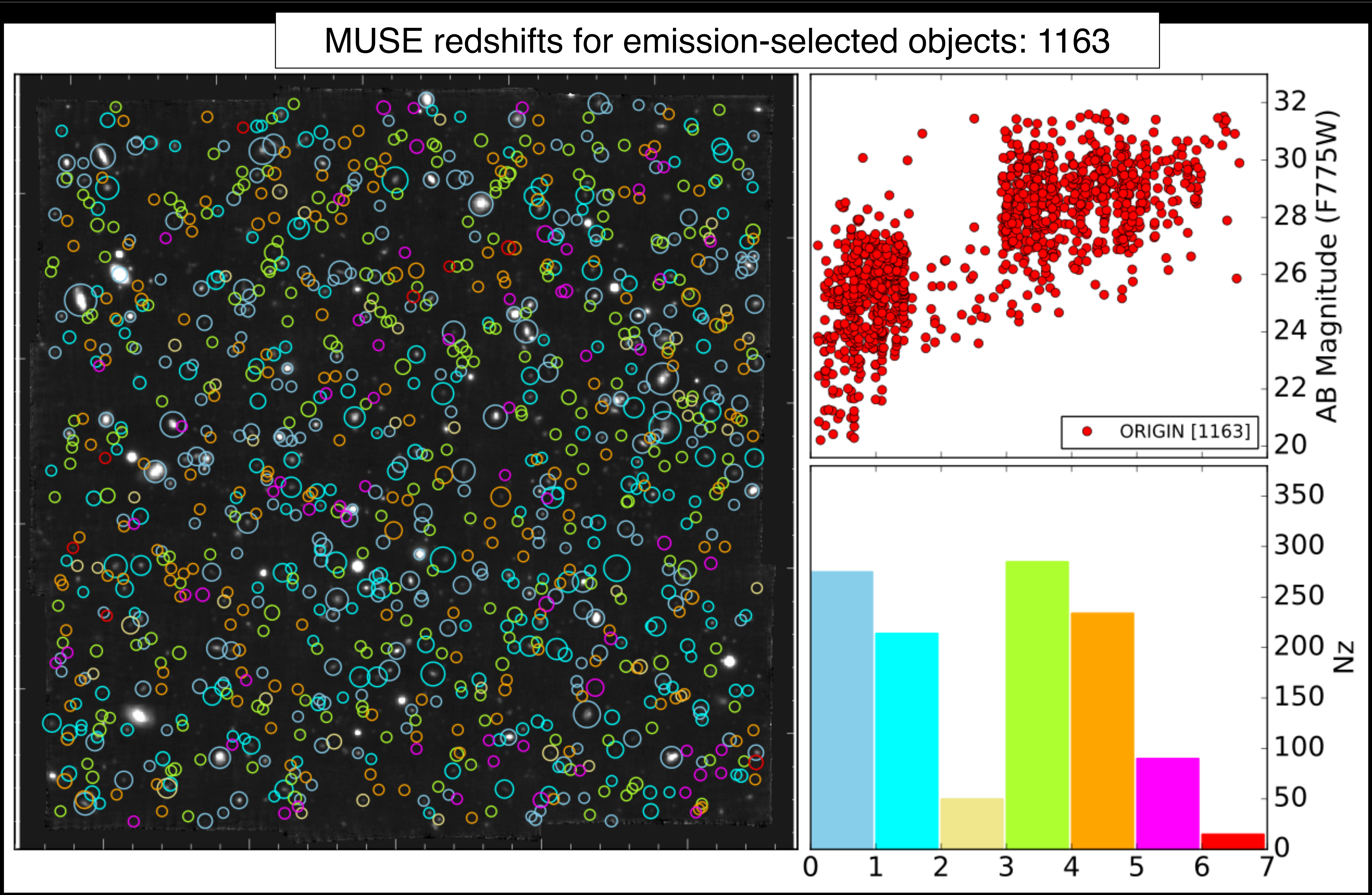
Previous spectroscopic redshifts within MUSE footprint: 143



Redshifts in the MUSE-Deep UDF mosaic

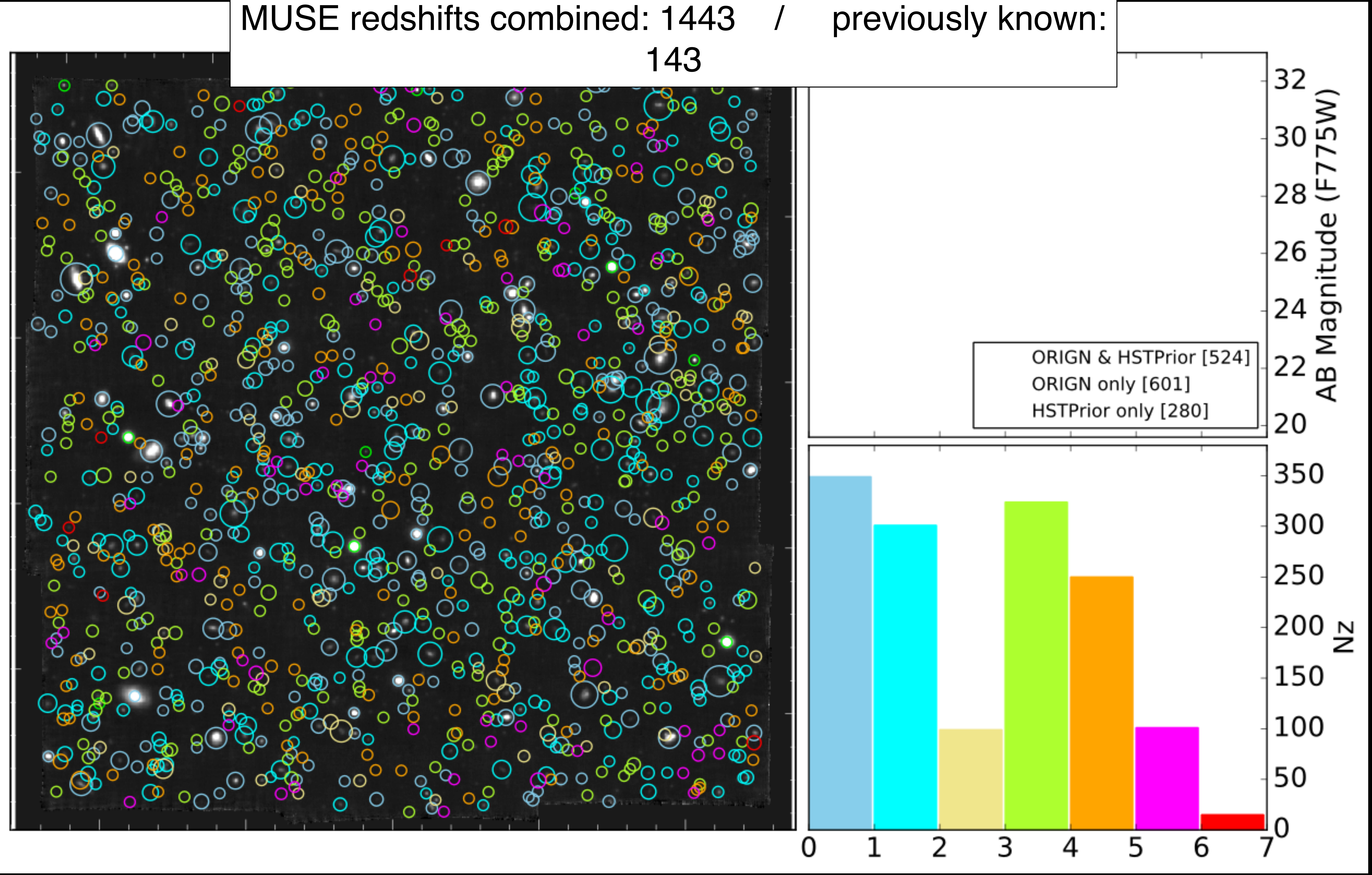


Redshifts in the MUSE-Deep UDF mosaic

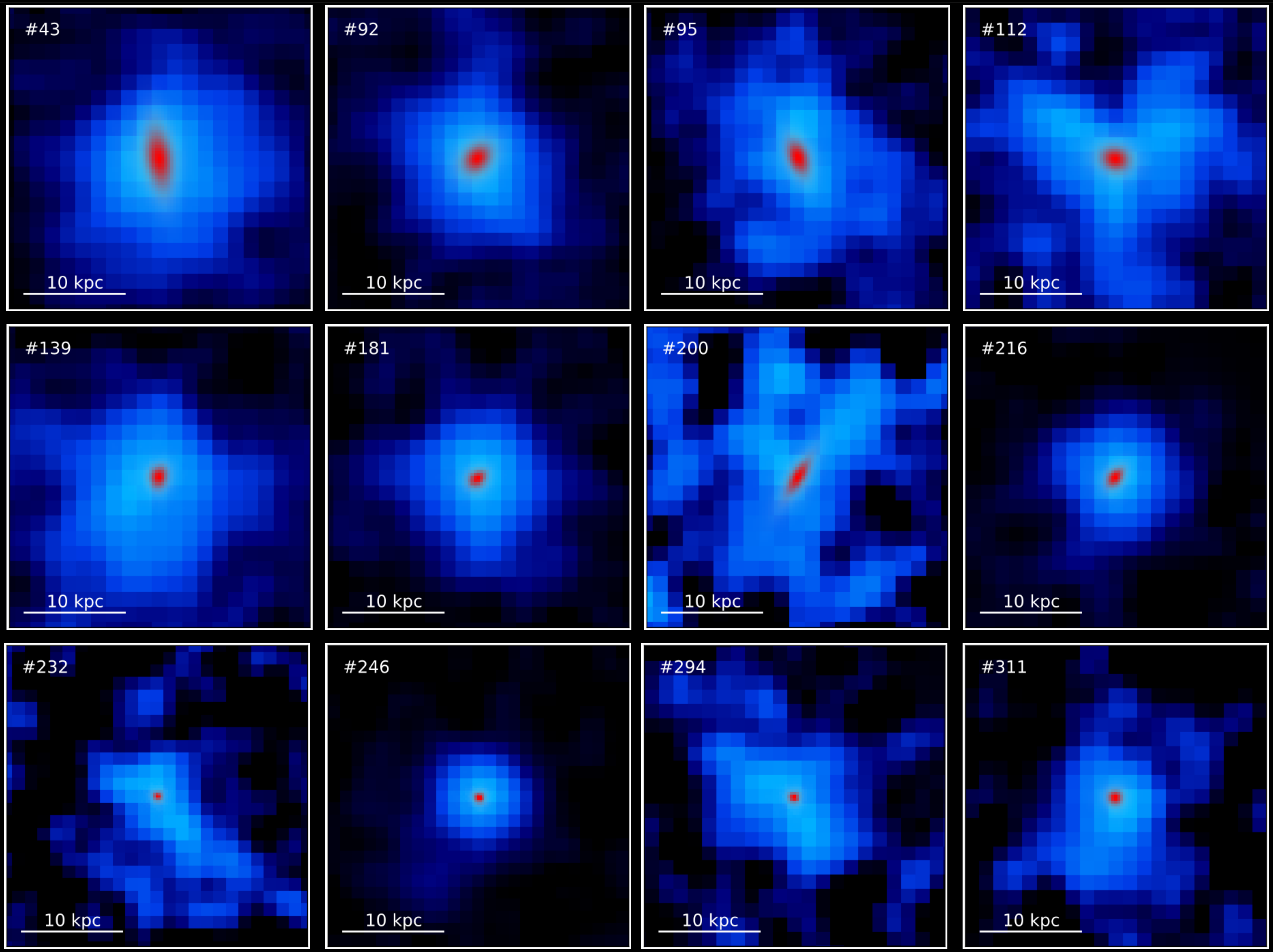


Redshifts in the MUSE-Deep UDF mosaic

MUSE redshifts combined: 1443 / previously known: 143

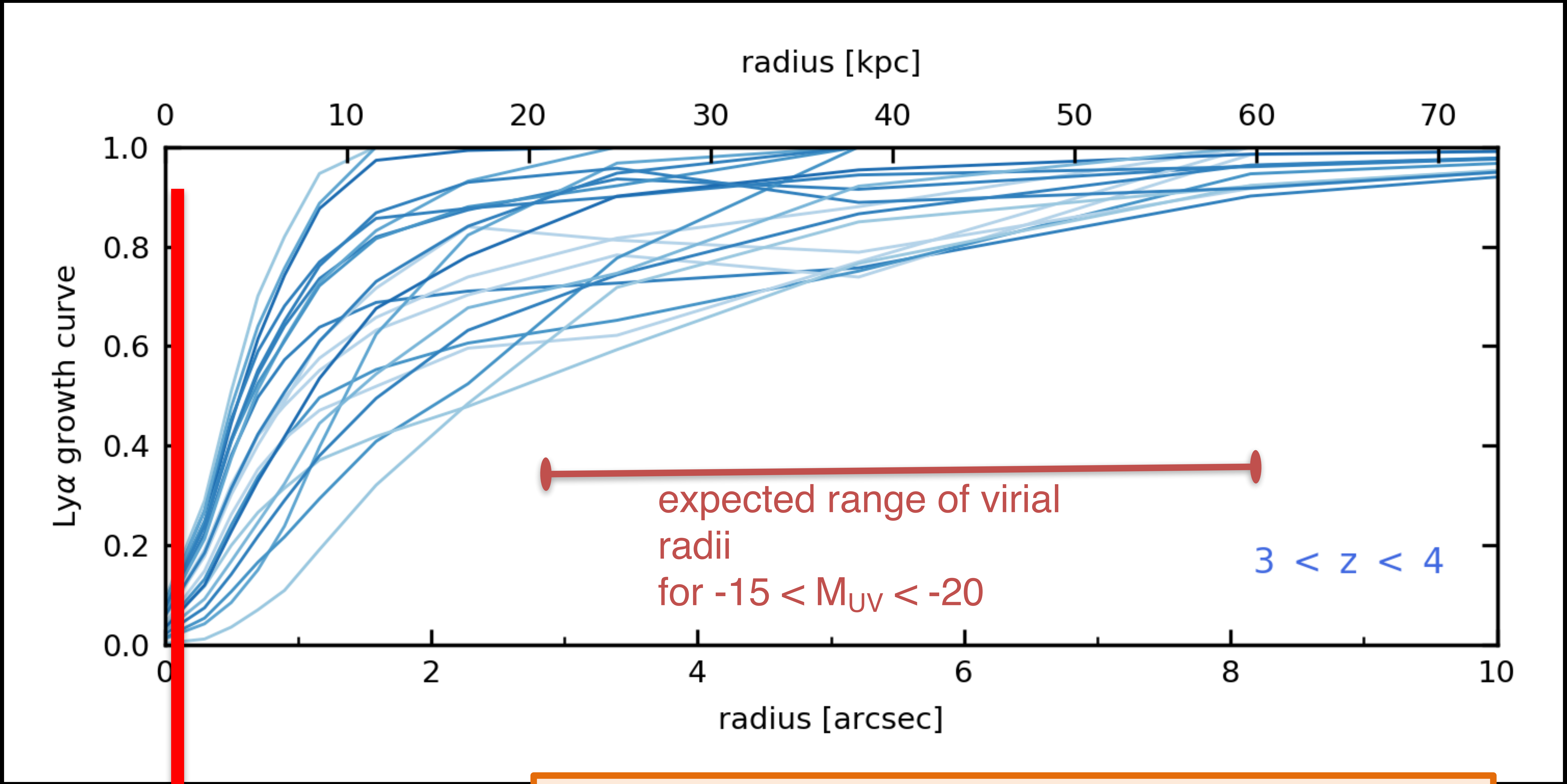


Ly-α haloes around individual galaxies at z>3 are ubiquitous!



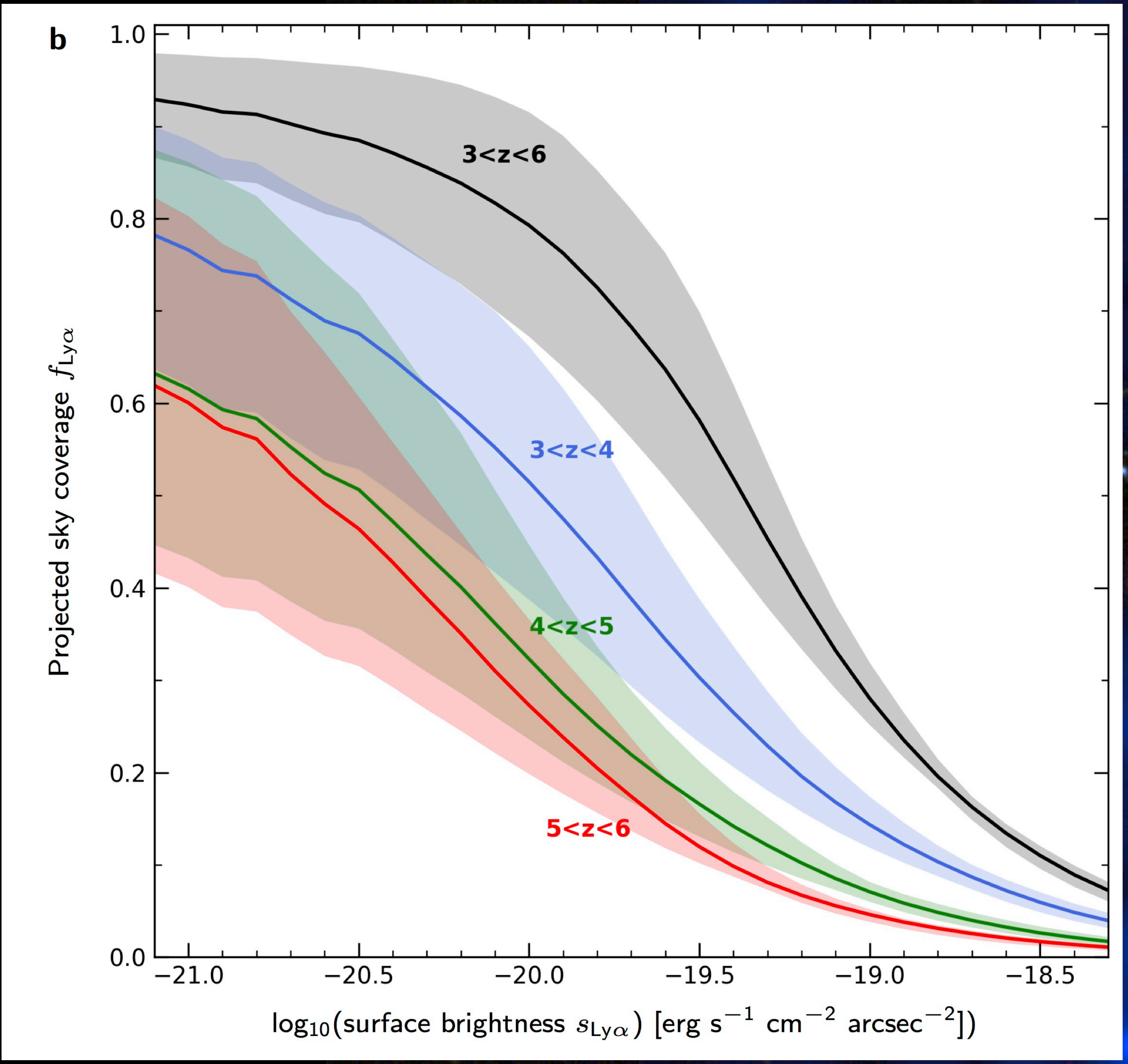
Wisotzki, MS et al (2016)

Growth curves of Lyman-α haloes in MUSE deep data



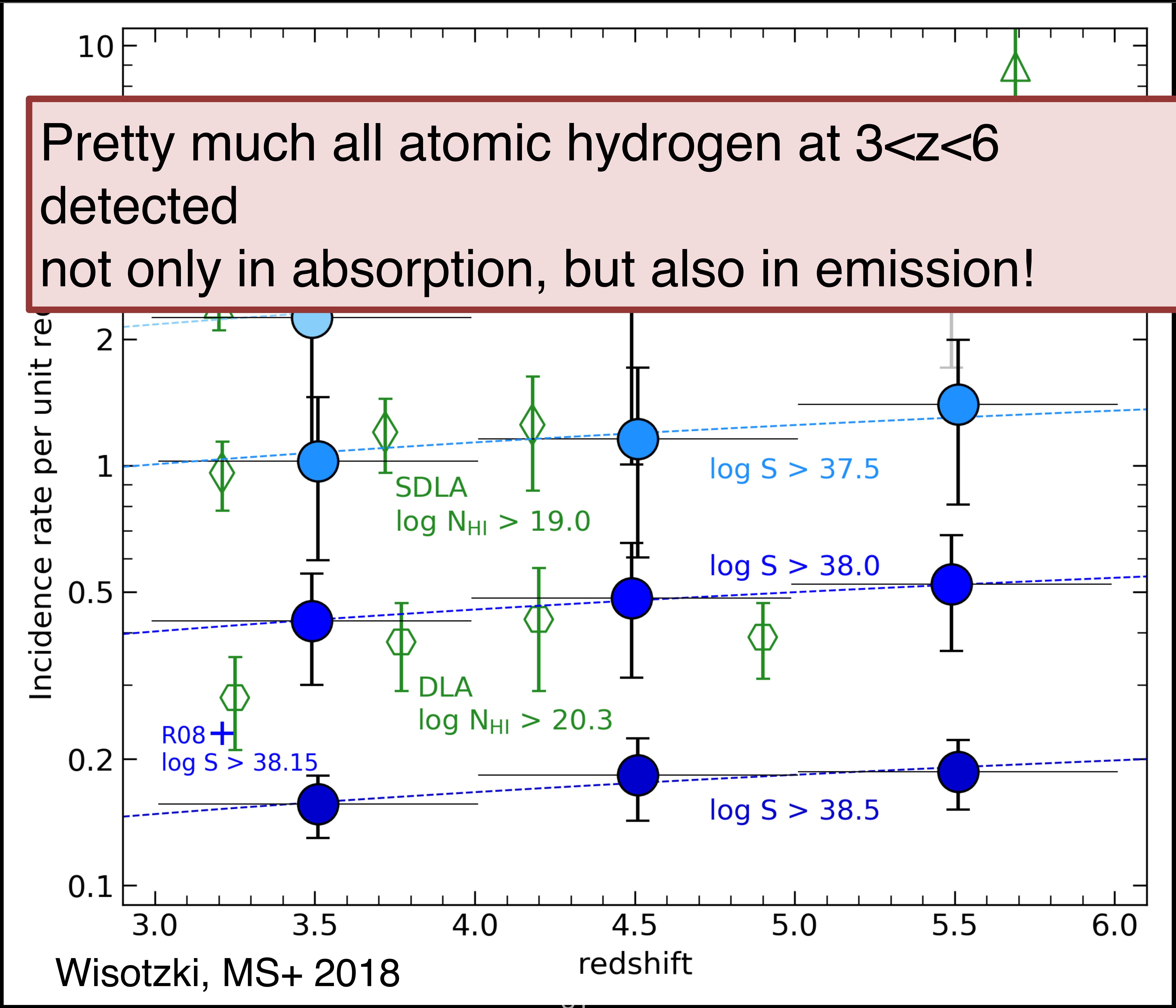
Intrinsic sizes
of UV continuum

Total extent ≈ giant Lyα nebulae around AGN
– but 10...100 × fainter



Already from individual z>3 sightlines:
≈50% at SB > 10^{-19} erg s^{-1} cm^{-2} $arcsec^{-2}$

Redshift evolution of dn/dz in Lyα emission ... and in HI absorption



Pretty much all atomic hydrogen at 3<z<6 detected
not only in absorption, but also in emission!

Wisotzki, MS+ 2018

Studying the CGM in emission and in absorption

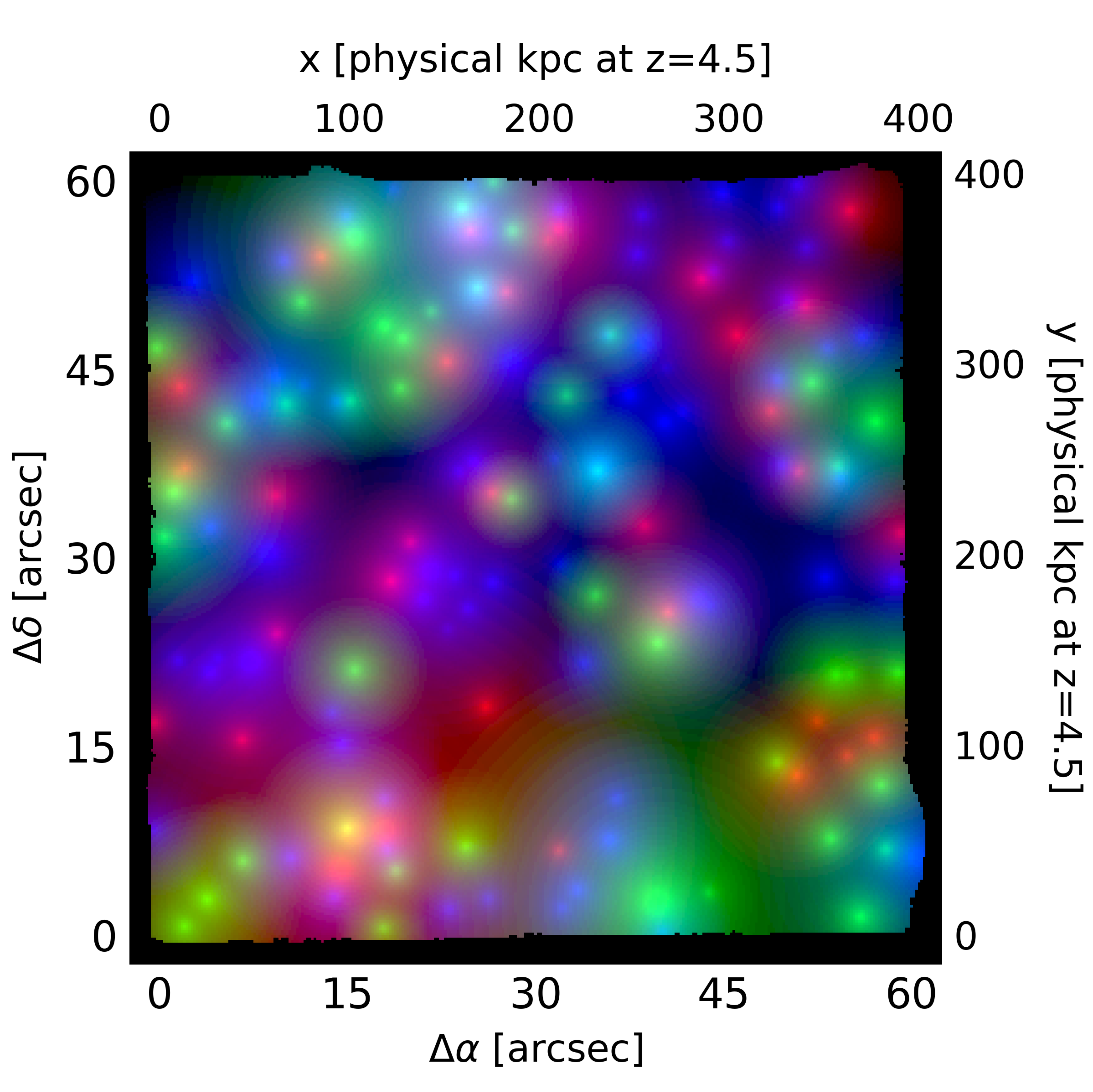
To combine diagnostics we have to measure N(HI) for known Ly_α haloes of high-z galaxies.

→ absorption spectra of back–ground galaxies close to LAEs!

Not feasible with MUSE!
typical $m_{AB} \approx 26 \dots 28$

E-ELT + MOS can do this!

(science case related to IGM tomography, but on scales of 10–100 kpc)




~32 arcmin² field of view
VIS spectrograph 0.4 - 0.8 μm
NIR spectrograph 0.8 - 1.8 μm
B V R I Z Y J H
Fibres
Slit
Array of microlens + fibres = Integral Field Unit
Data cube
y
x
λ
~32 arcmin² field of view
Integral field unit (IFU)
Natural guide star for adaptive optics
NIR spectrograph 0.8 - 1.8 μm
B V R I Z Y J H
M2
M4
M5
M3
MOSAIC

LSST in one sentence:

An optical/near-IR survey of half the sky in ugrizy bands to r~27.5 based on ~1000 visits over a 10-year period:

More information at www.lsst.org and arXiv:0805.2366

A catalog of 20 billion stars and 20 billion galaxies with exquisite photometry, astrometry and image quality!

First light: 2020

Prompt Data Products

- A stream of ~10 million time-domain events per night, detected and transmitted to event distribution networks within 60 seconds of observation.
- A catalog of orbits for ~6 million bodies in the Solar System.

Level 1

Yearly Data Releases

- A catalog of ~37 billion objects (20B galaxies, 17B stars), ~7 trillion single-epoch detections ("sources"), and ~30 trillion forced sources, produced annually, accessible through online databases.
- Deep co-added images.

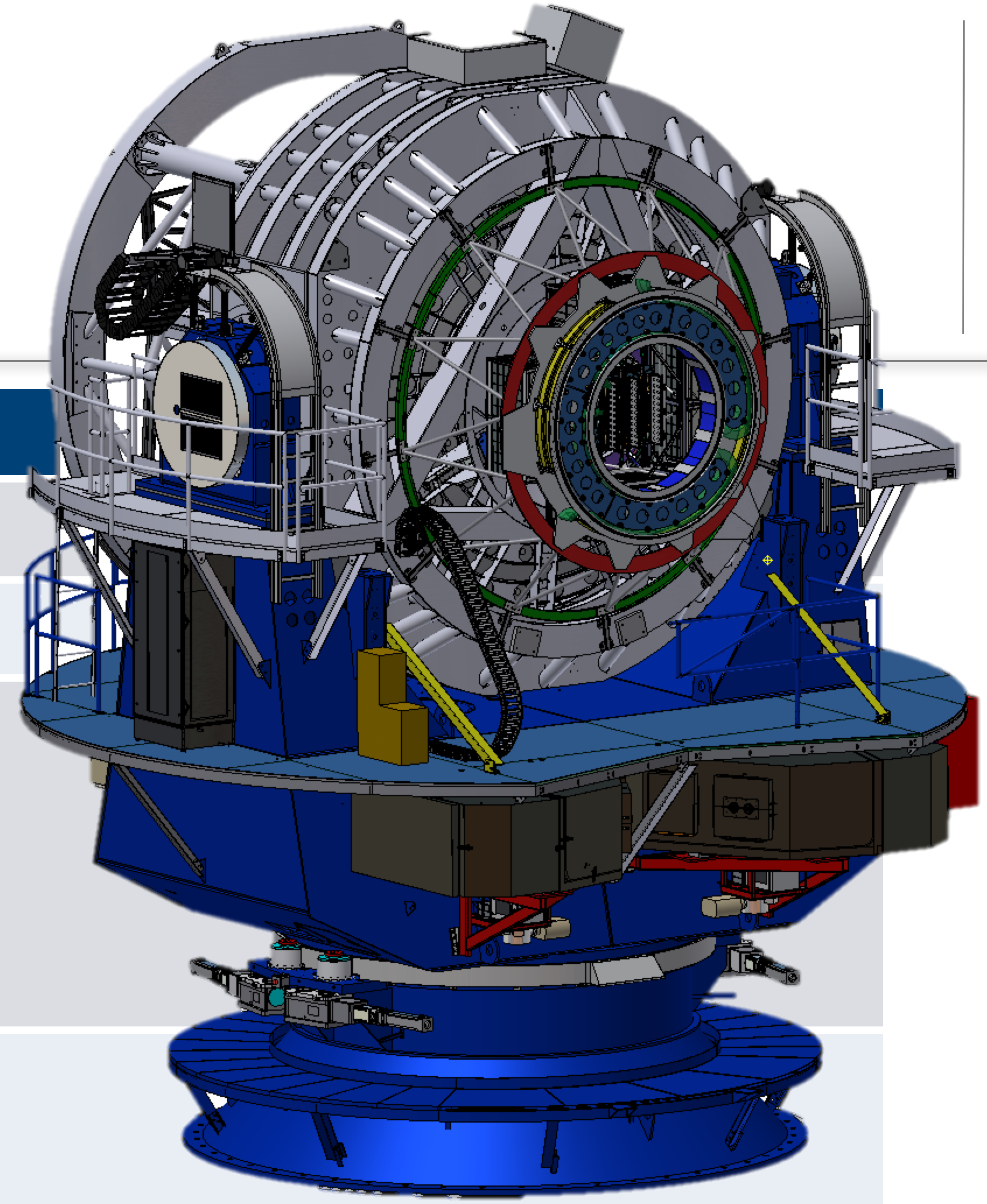
Level 2

User Contributed Data Products

- Services and computing resources at the Data Access Centers to enable user-specified custom processing and analysis.
- Software and APIs enabling development of analysis codes.

Level 3

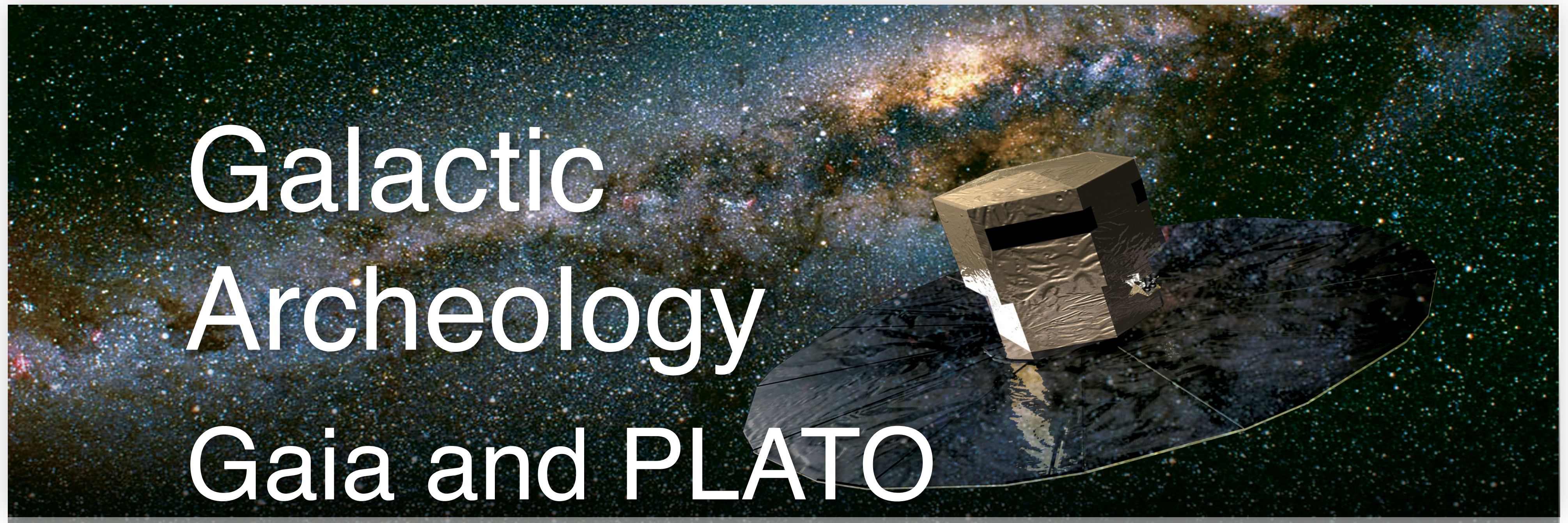
Instrument Specification

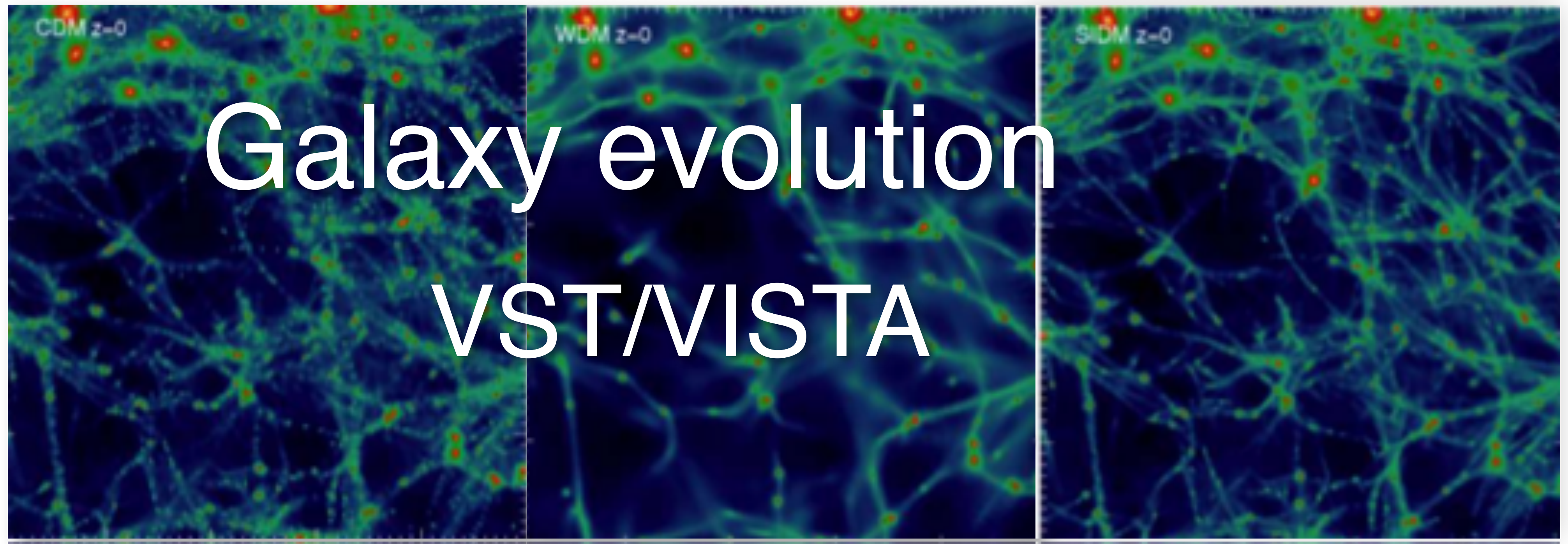


Specification	Design value
Field-of-View (hexagon)	~4.2 degree^2 (⌀>2.6°)
Multiplex fiber positioner	2436
Medium Resolution Spectrographs (2x) \# Fibres Passband Velocity accuracy	R~4000–7500 812 fibres (2x) 370-950 nm < 1 km/s
High Resolution Spectrograph (1x) \# Fibres Passband Velocity accuracy	R~20,000 812 fibres 392.6–435.5 nm, 516–573 nm, 610–679 nm < 1 km/s
# of fibers in ⌀=2' circle	>3
Fibre diameter	⌀=1.45 arcsec
Area (first 5 year survey)	>2h x 18,000 deg^2
Number of science spectra (5 year)	~75 million of 20 min

4MOST Science Themes

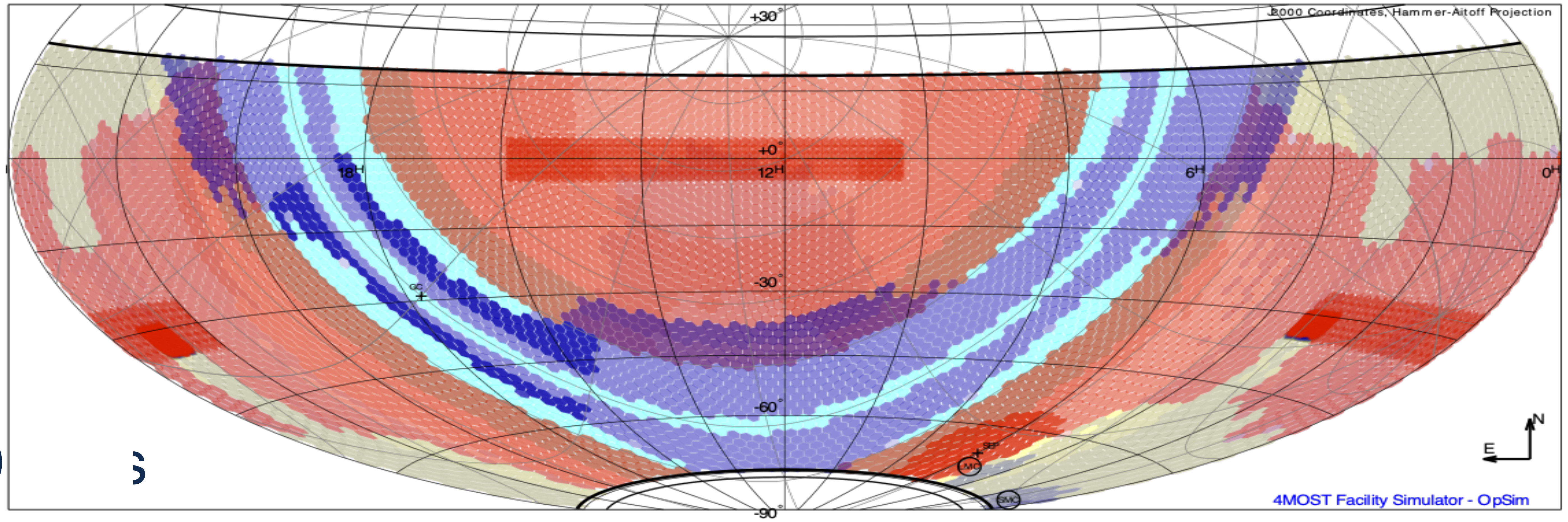
R>5000 spectra over the full optical range





4MOST Operations

- Unique operations model for MOS instruments suitable for most science cases
- 4MOST program defined by Public Surveys of 5 years
- Surveys will be defined by Consortium and Community
- All Surveys will run in parallel: Surveys share fibres per exposure for increased efficiency
- Consortium Key Surveys will define observing strategy
  - Millions of targets all sky
  - Fill all fibres
- Add-on Surveys for smaller surveys
  - Small fraction fibers all sky or
  - dedicated small areas
  - 10^3 to 10^6 targets
- Several passes of sky with 2, 10, 20, 30 s
- Wedding-cake distribution for total time 1h to 10h



Opportunity to get spectra of some 10k objects spread over large areas of the sky

Summary and conclusions

- Gaia is rewriting stellar and Galactic evolution - implication of late stages of stellar evolution and dark matter
- Spatially and spectroscopically resolved analysis of the hosts of γ-ray sources in the Galactic plane and (nearby) extragalactic source
- Detailed spatially resolved analysis of interplay of galaxy formation, feedback and cosmic rays throughout cosmic evolution
- Follow-up with large imaging and spectroscopic surveys