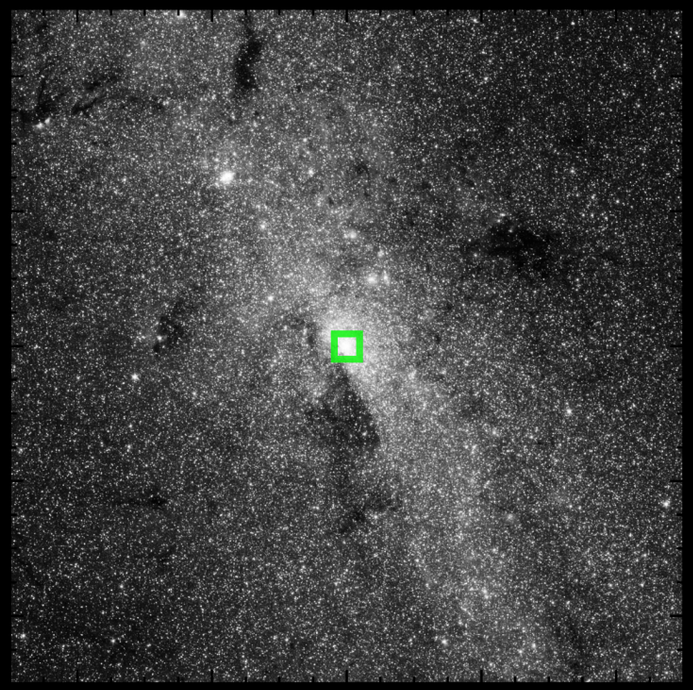
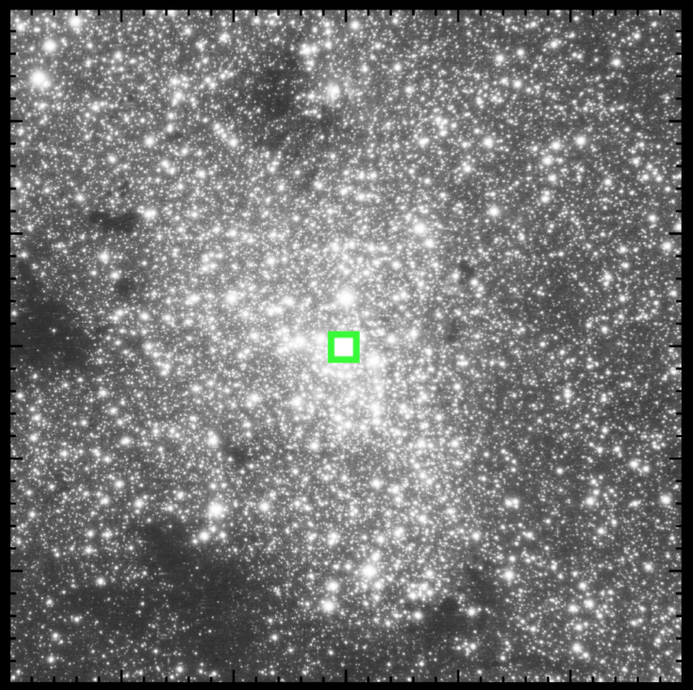
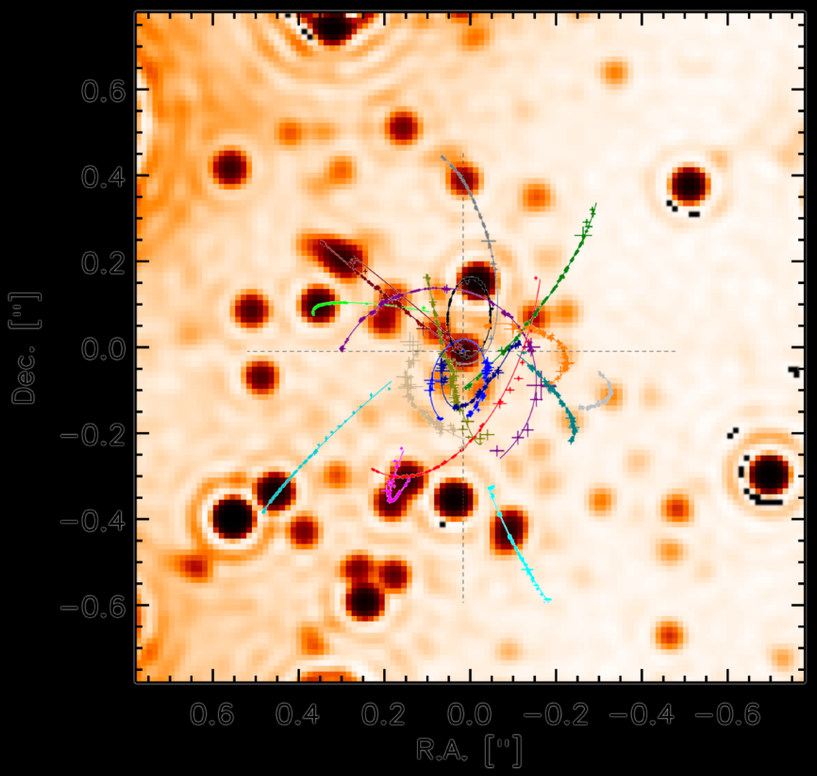
The Galactic Centre KSP







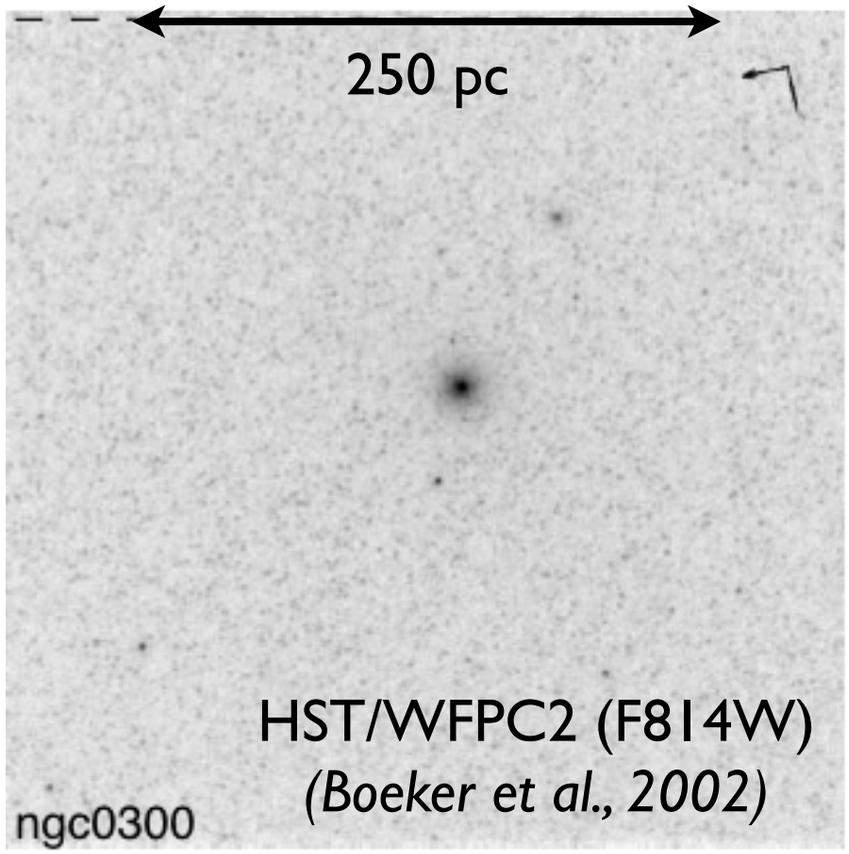
Rainer Schödel & Antxón Alberdi &
Grazia Umana
IAA(CSIC)
SKA "Our Galaxy" Meting, 11 july 2018

European Research Council
Established by the European Commission

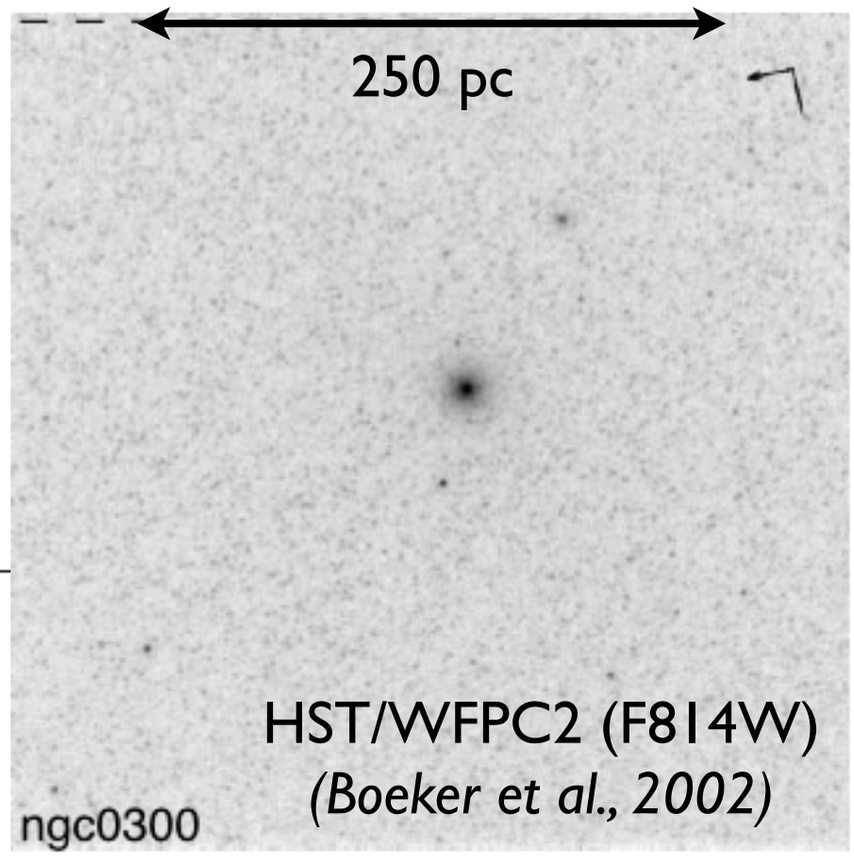
INSTITUTO de ASTROFISICA de ANDALUCIA
CSIC
I·A·A

High-resolution view of a nearby nucleus

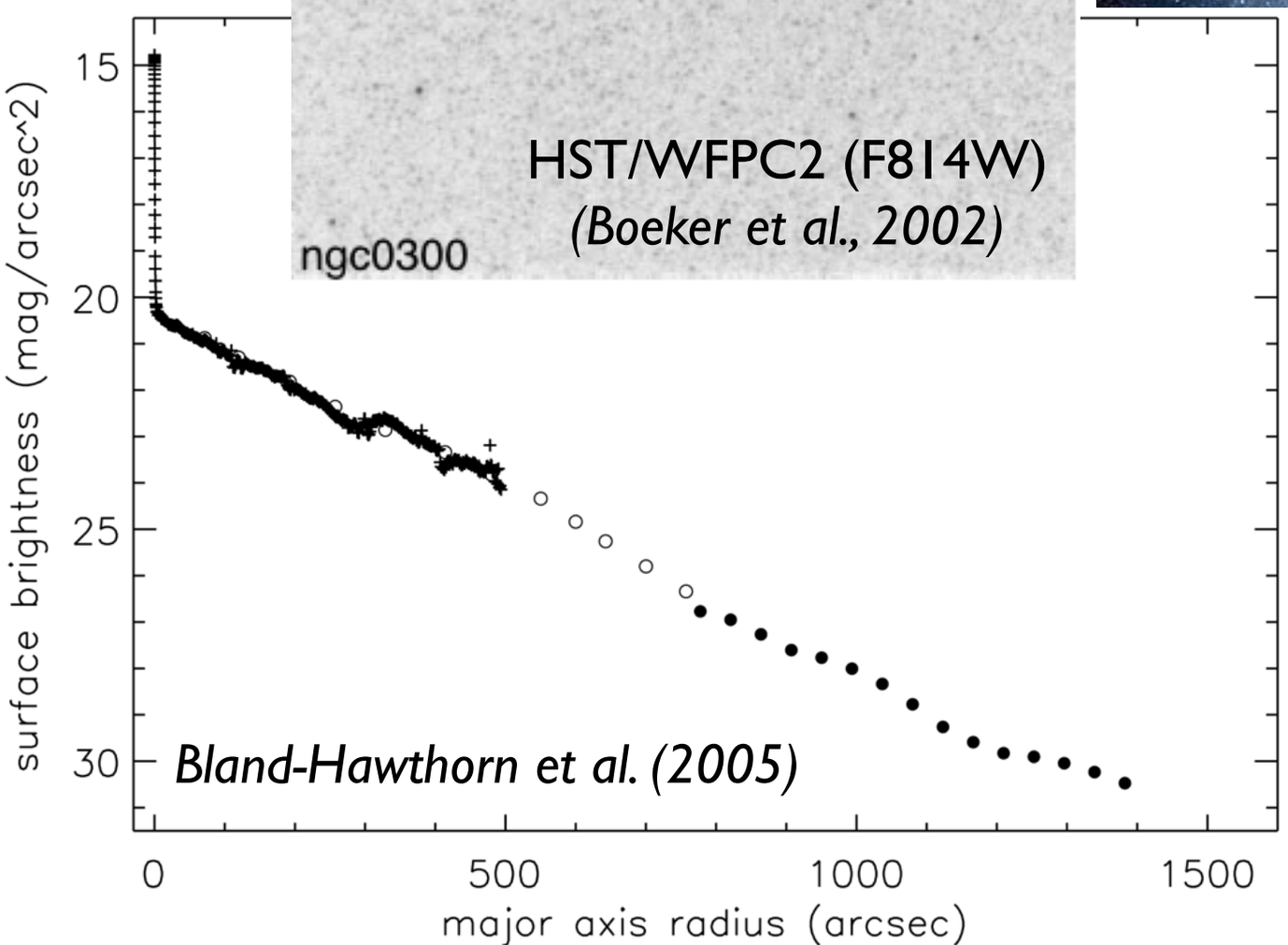
High-resolution view of a nearby nucleus



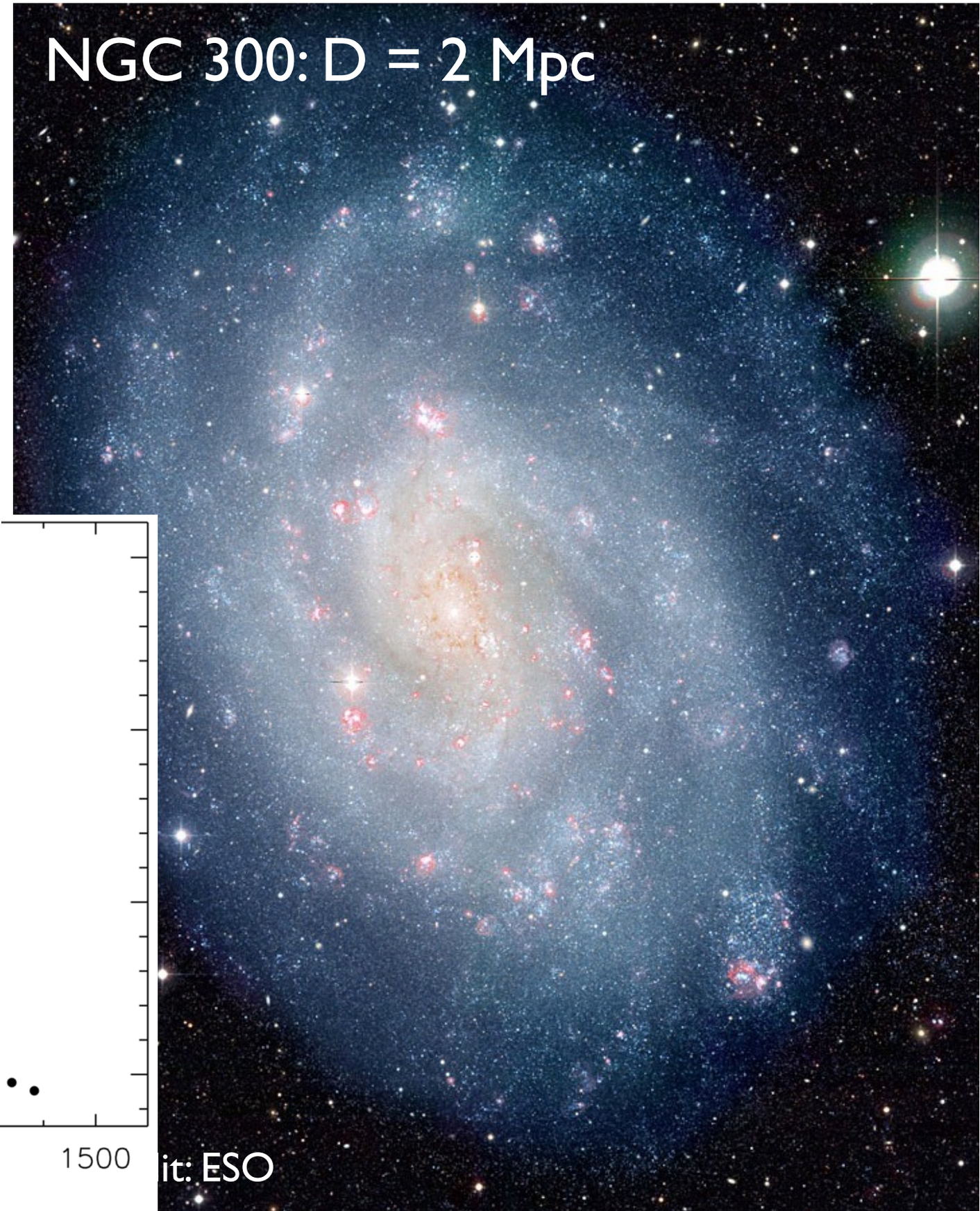
High-resolution view of a nearby nucleus



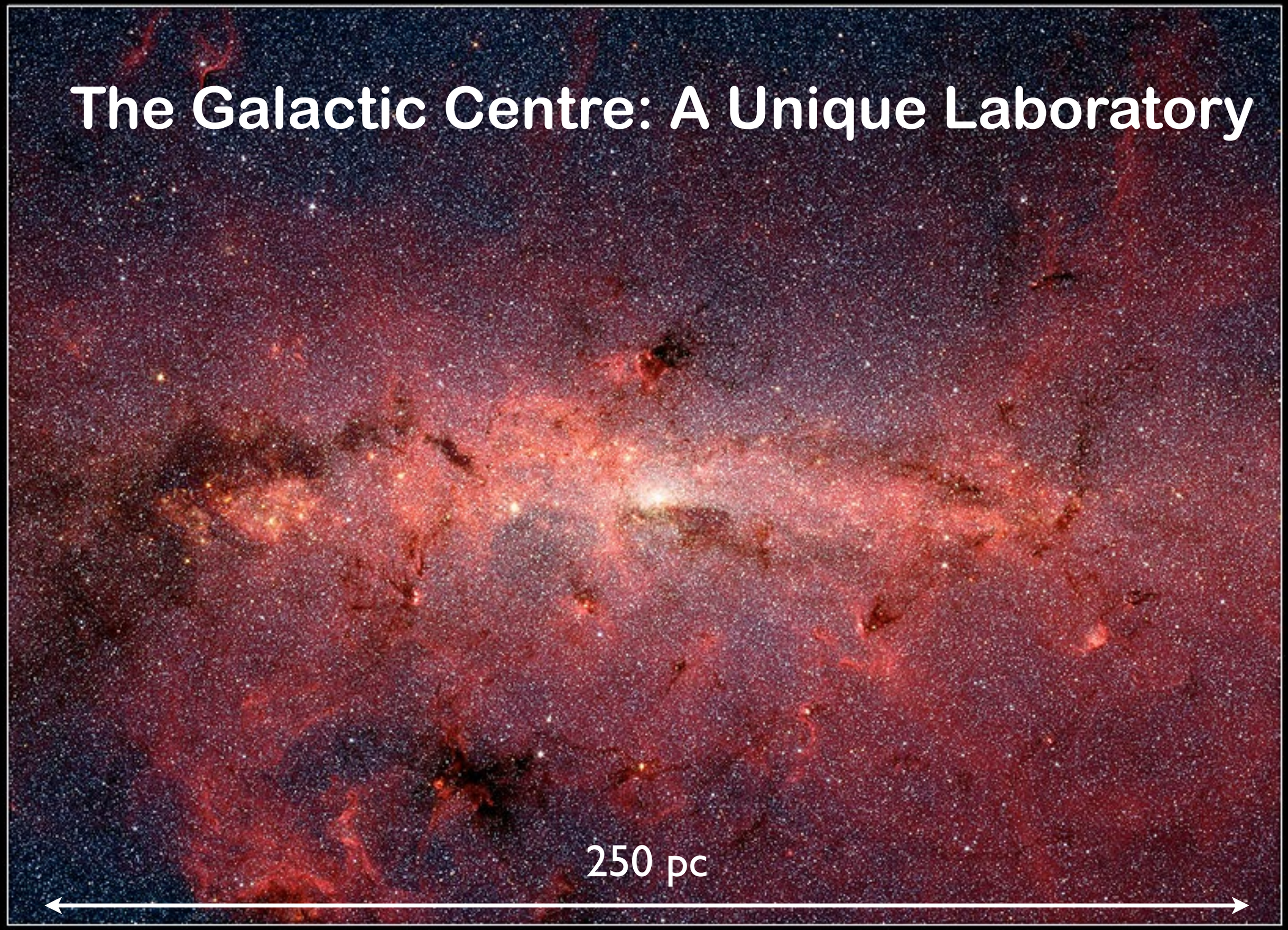
HST/WFPC2 (F814W)
(Boeker et al., 2002)



Bland-Hawthorn et al. (2005)



The Galactic Centre: A Unique Laboratory



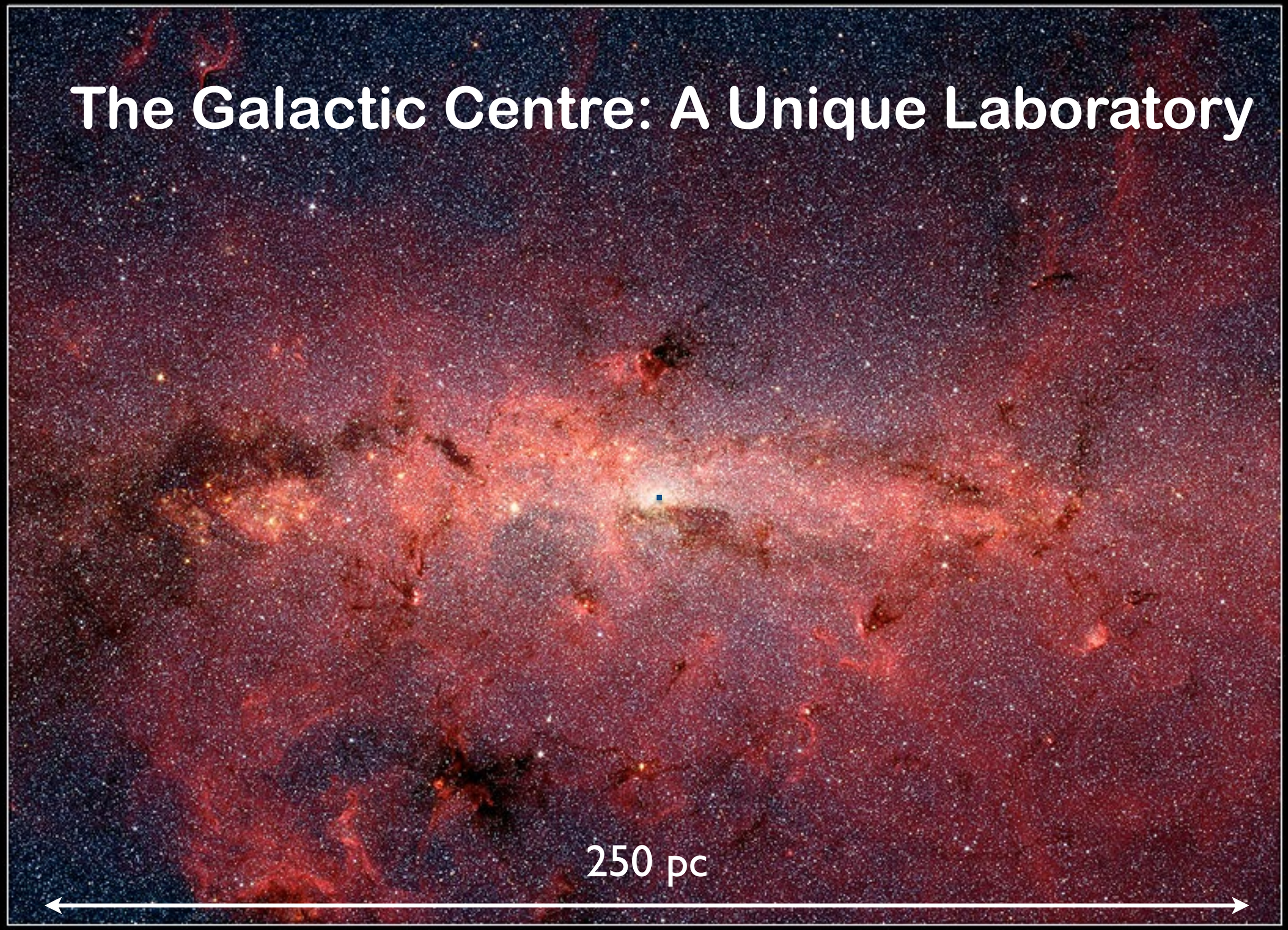
The Center of the Milky Way Galaxy

NASA / JPL-Caltech / S. Stolovy (Spitzer Science Center/Caltech)

Spitzer Space Telescope • IRAC

ssc2006-02a

The Galactic Centre: A Unique Laboratory



The Center of the Milky Way Galaxy

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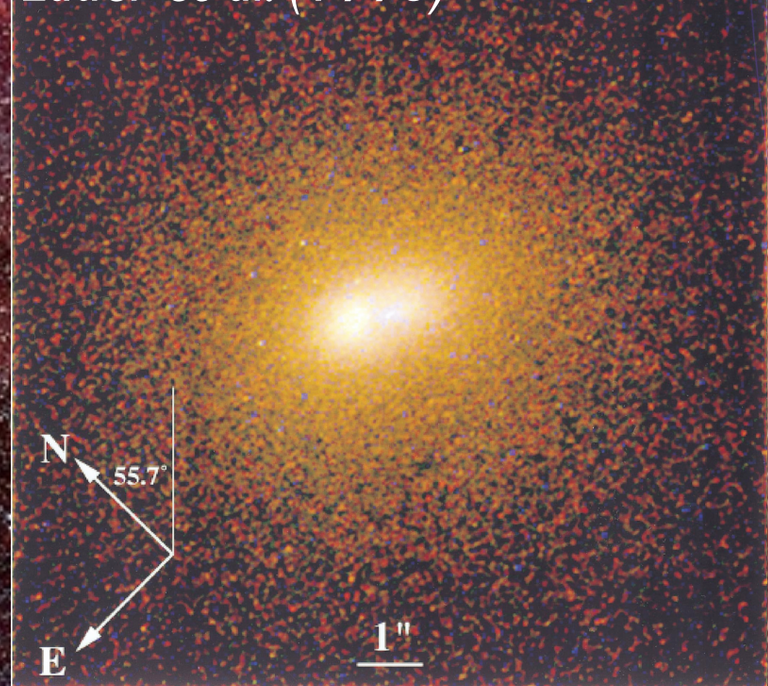
The Galactic Centre: A Unique Laboratory

Andromeda: HST/WFPC2 UBI

Lauer et al. (1998)



45 pc

250 pc

The Center of the Milky Way Galaxy

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Andromeda: HST/WFPC2 UBI

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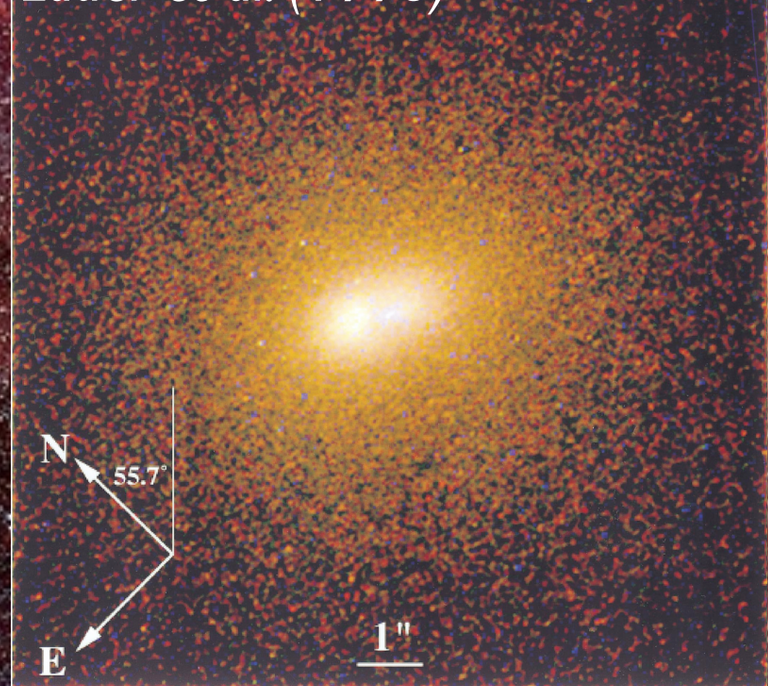

45 pc

Same FOV

11.65" ×11.65"

250 pc

The Center of the Milky Way Galaxy

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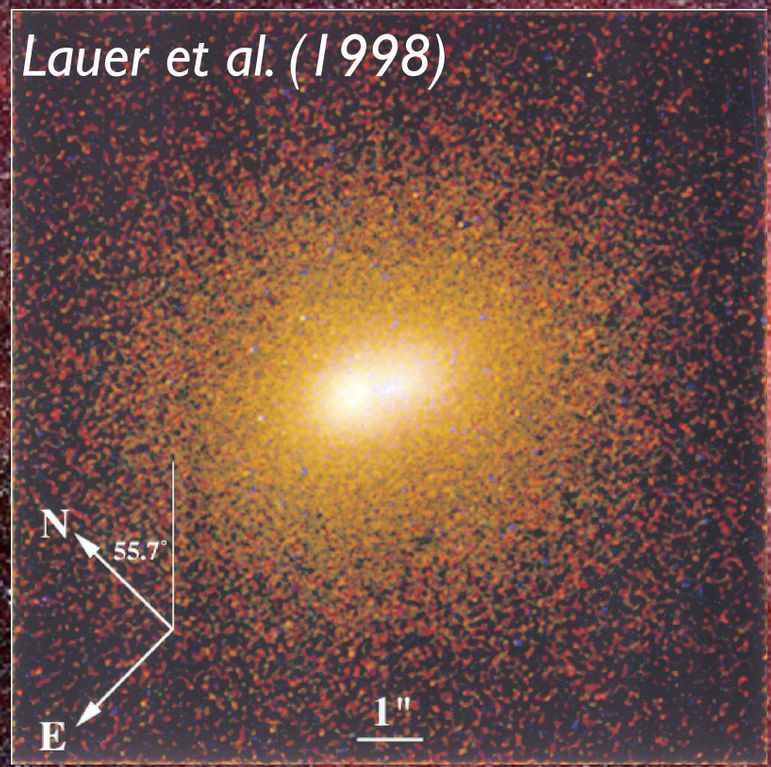
The Galactic Centre: A Unique Laboratory

Andromeda: HST/WFPC2 UBI

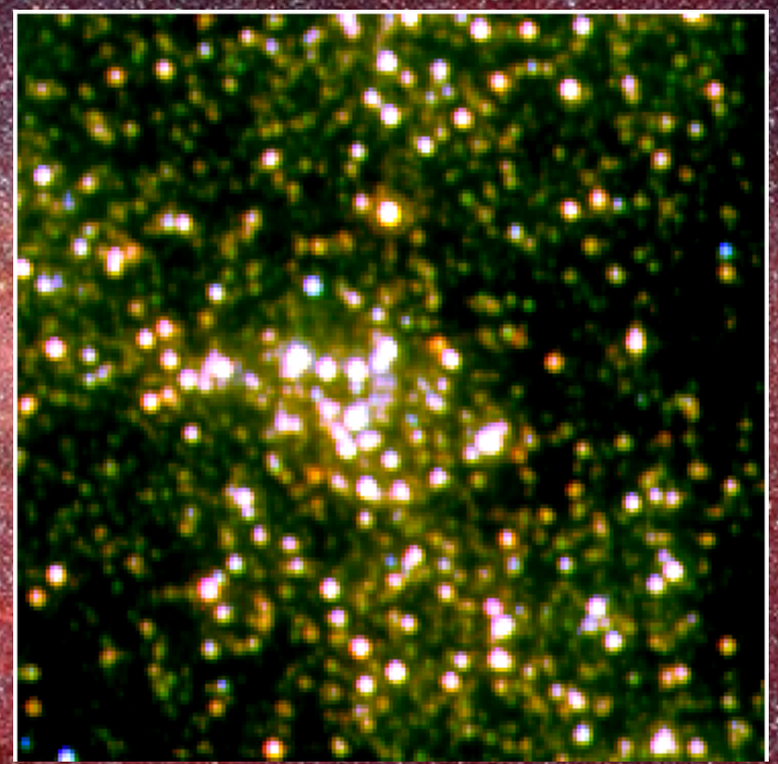


45 pc

Same FOV

11.65" ×11.65"

Milky Way: HST/WFC3 NIR



0.45 pc

250 pc

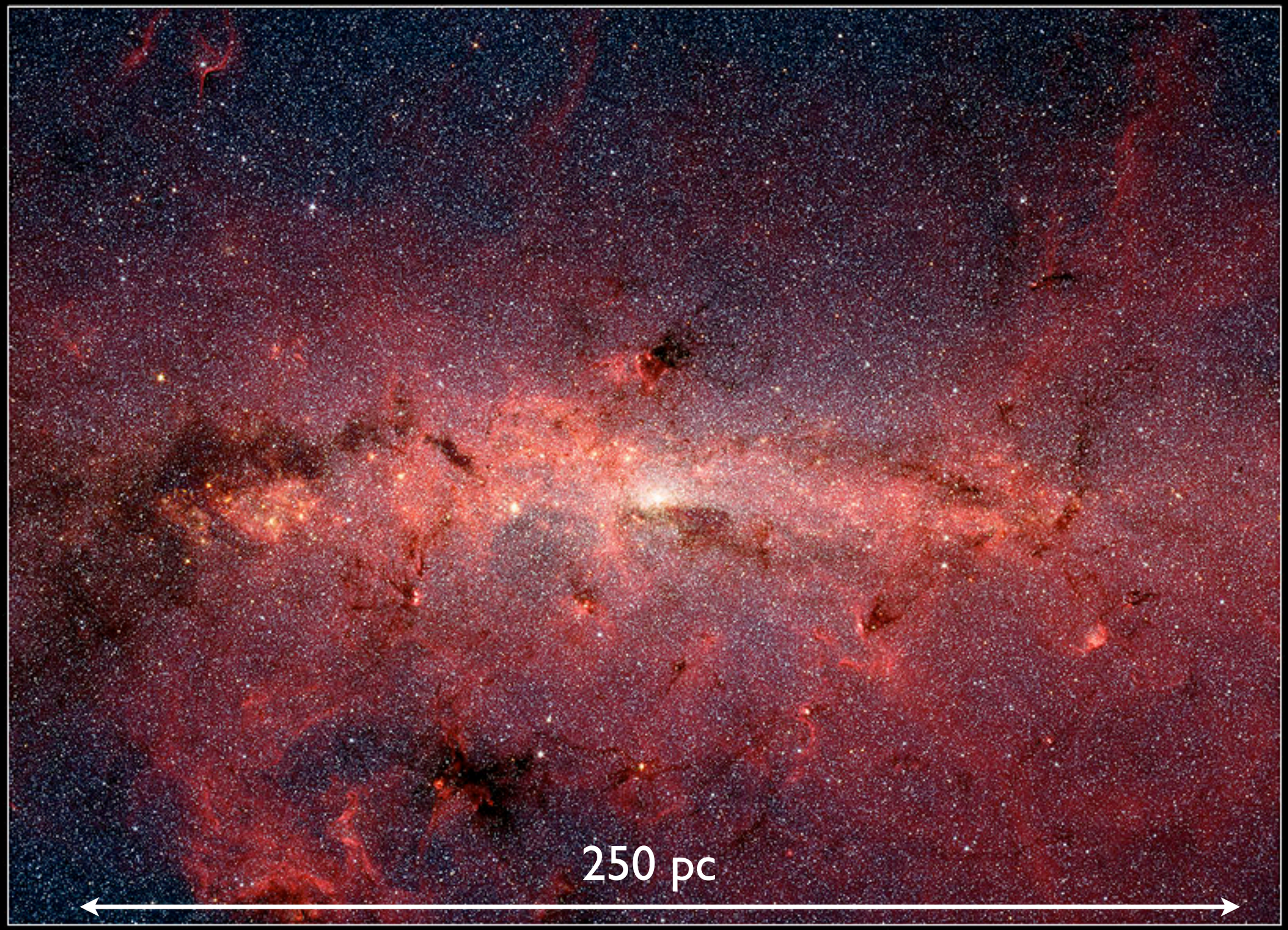
The Center of the Milky Way Galaxy

NASA / JPL-Caltech / S. Stolovy (Spitzer Science Center/Caltech)

Spitzer Space Telescope • IRAC

ssc2006-02a

Low-resolution view of the Galactic Center



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Spitzer Space Telescope • IRAC

ssc2006-02a

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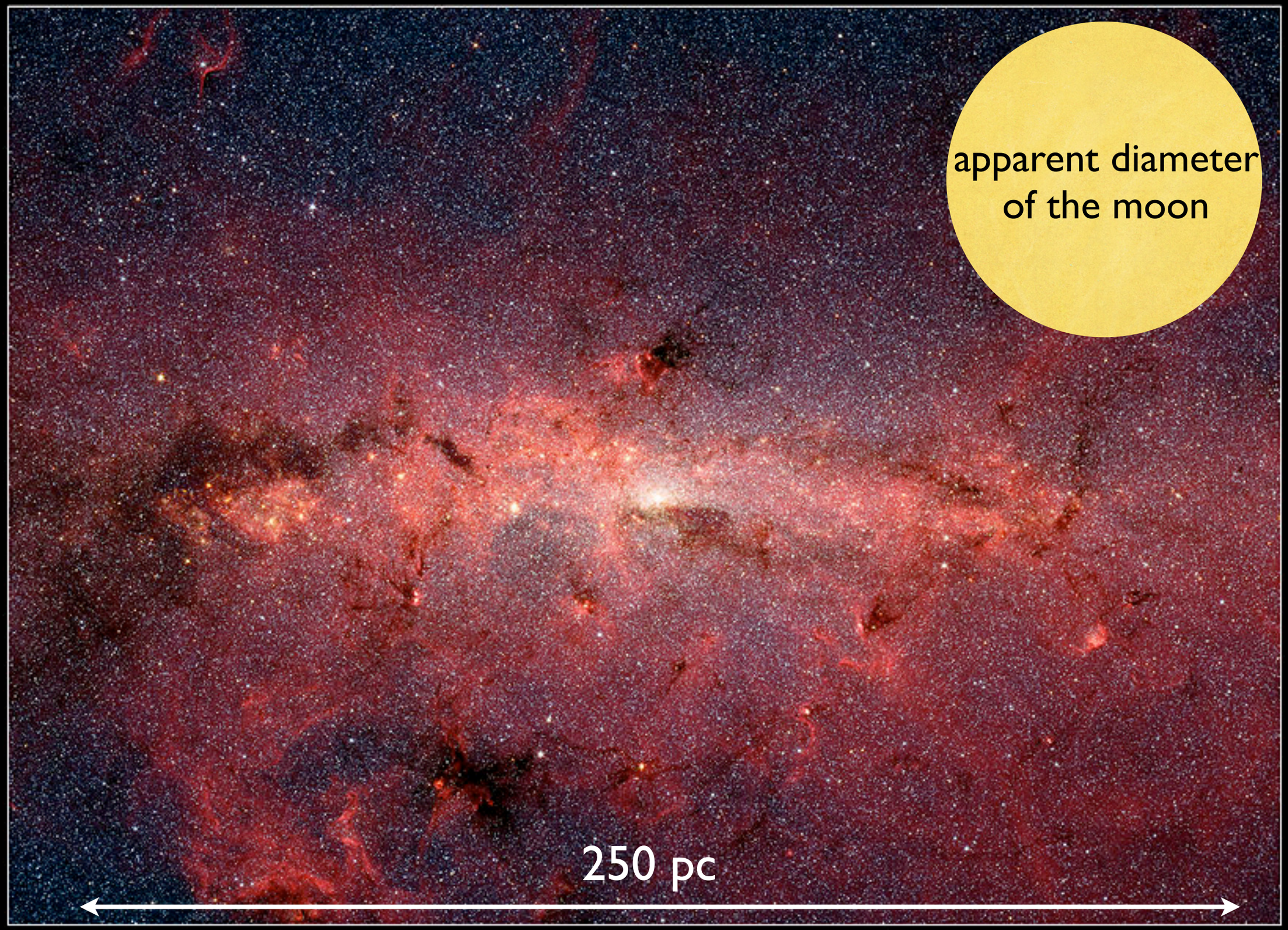

The Center of the Milky Way Galaxy

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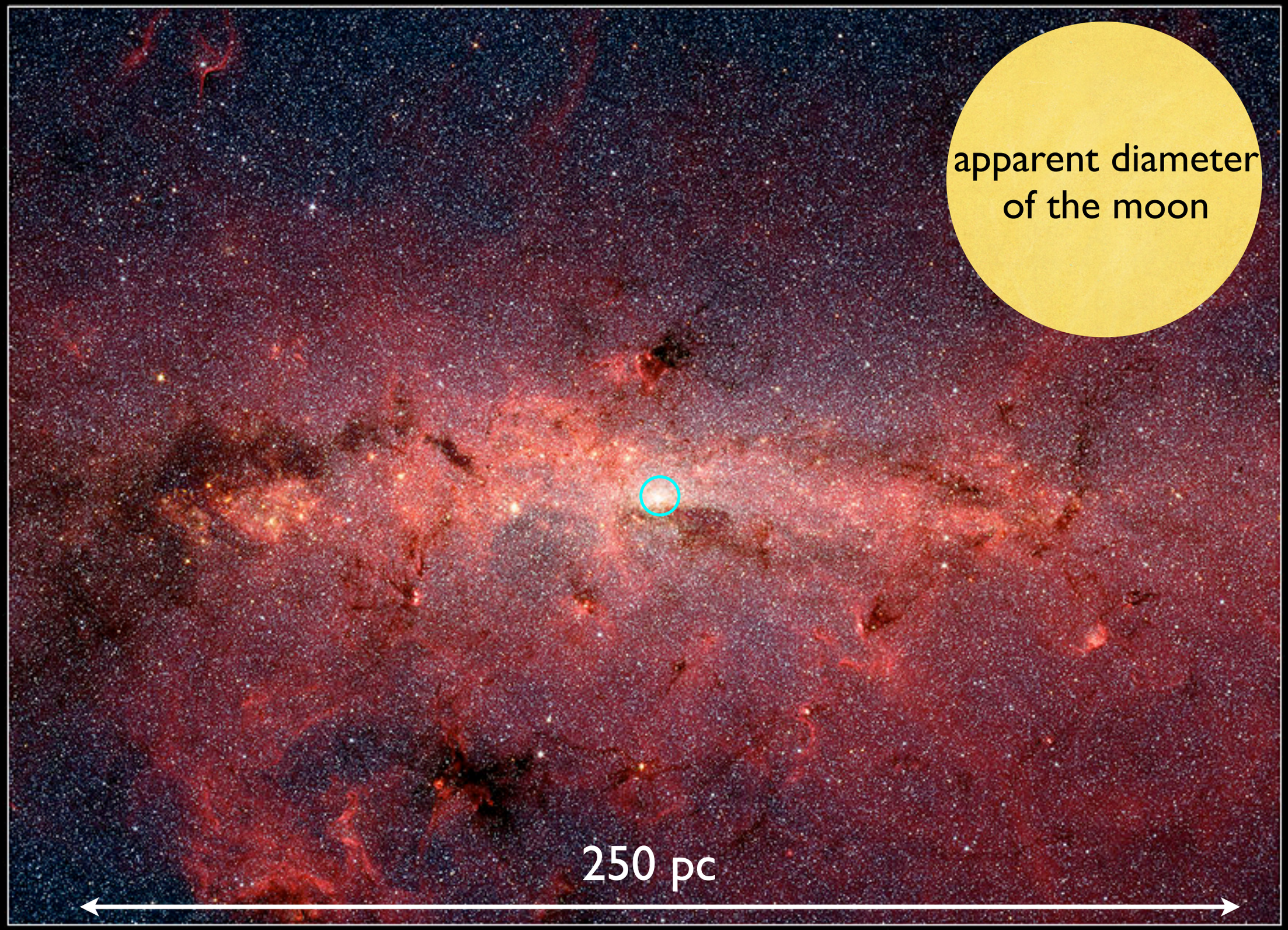

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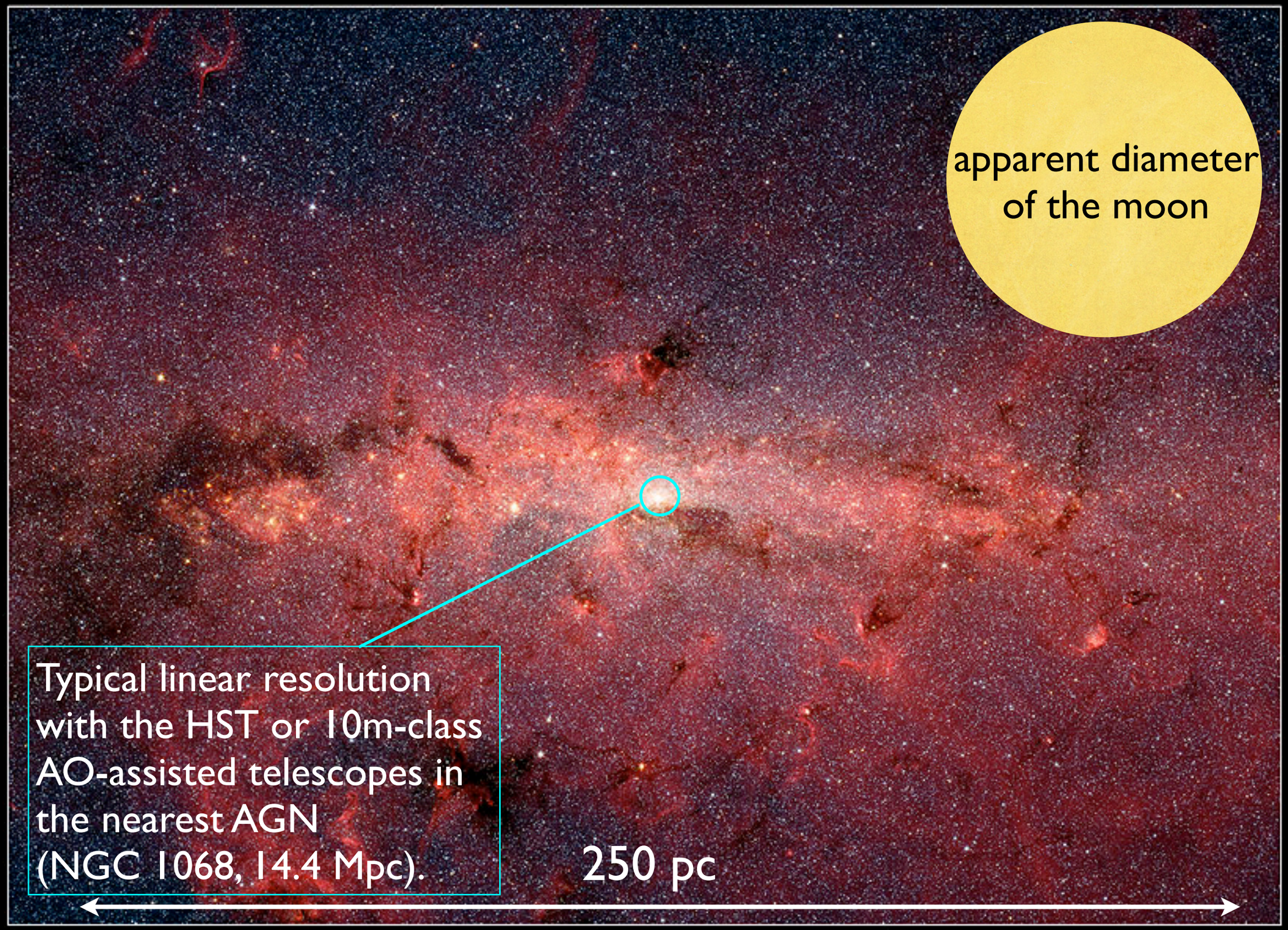

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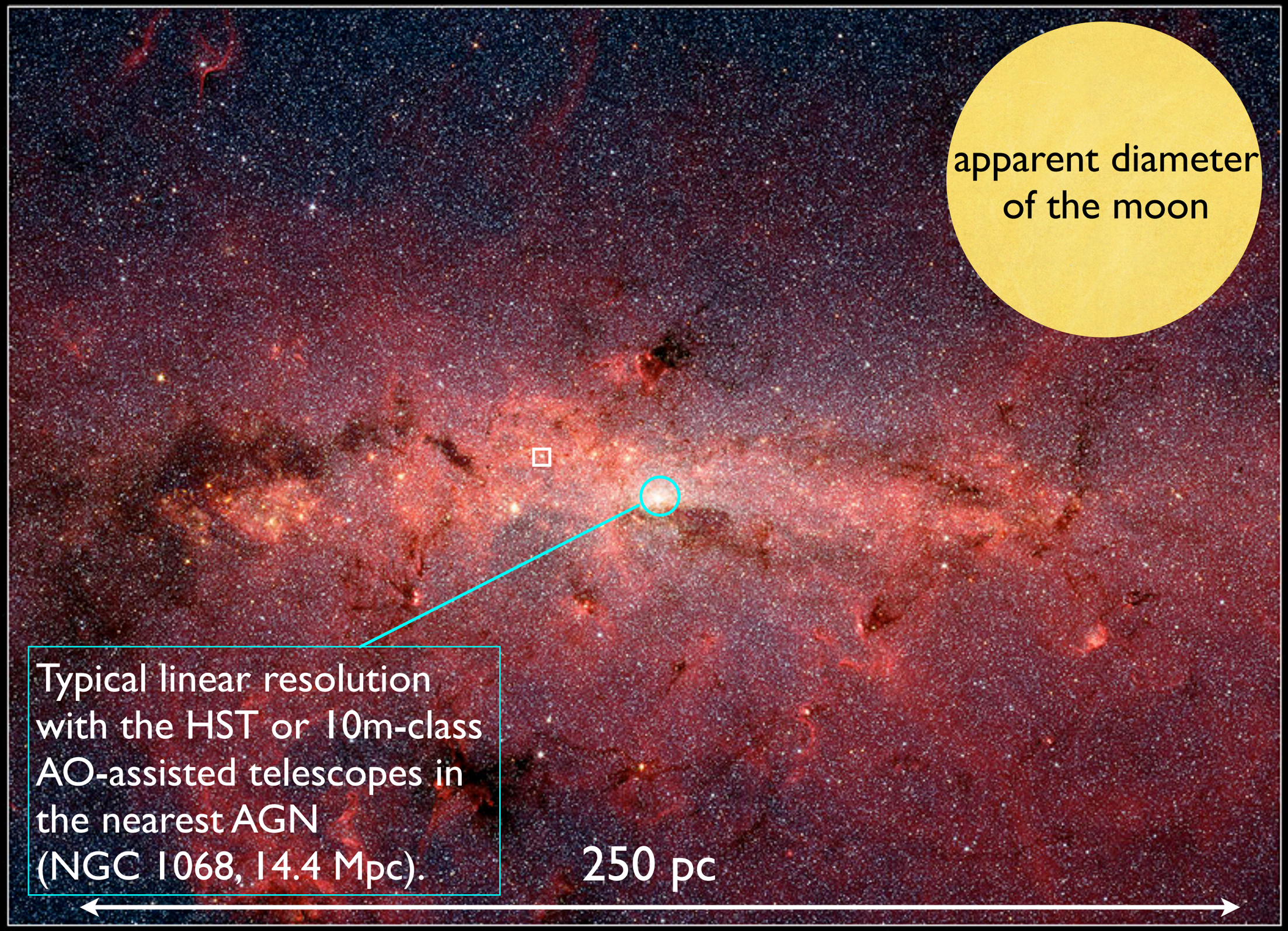

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ssc2006-02a

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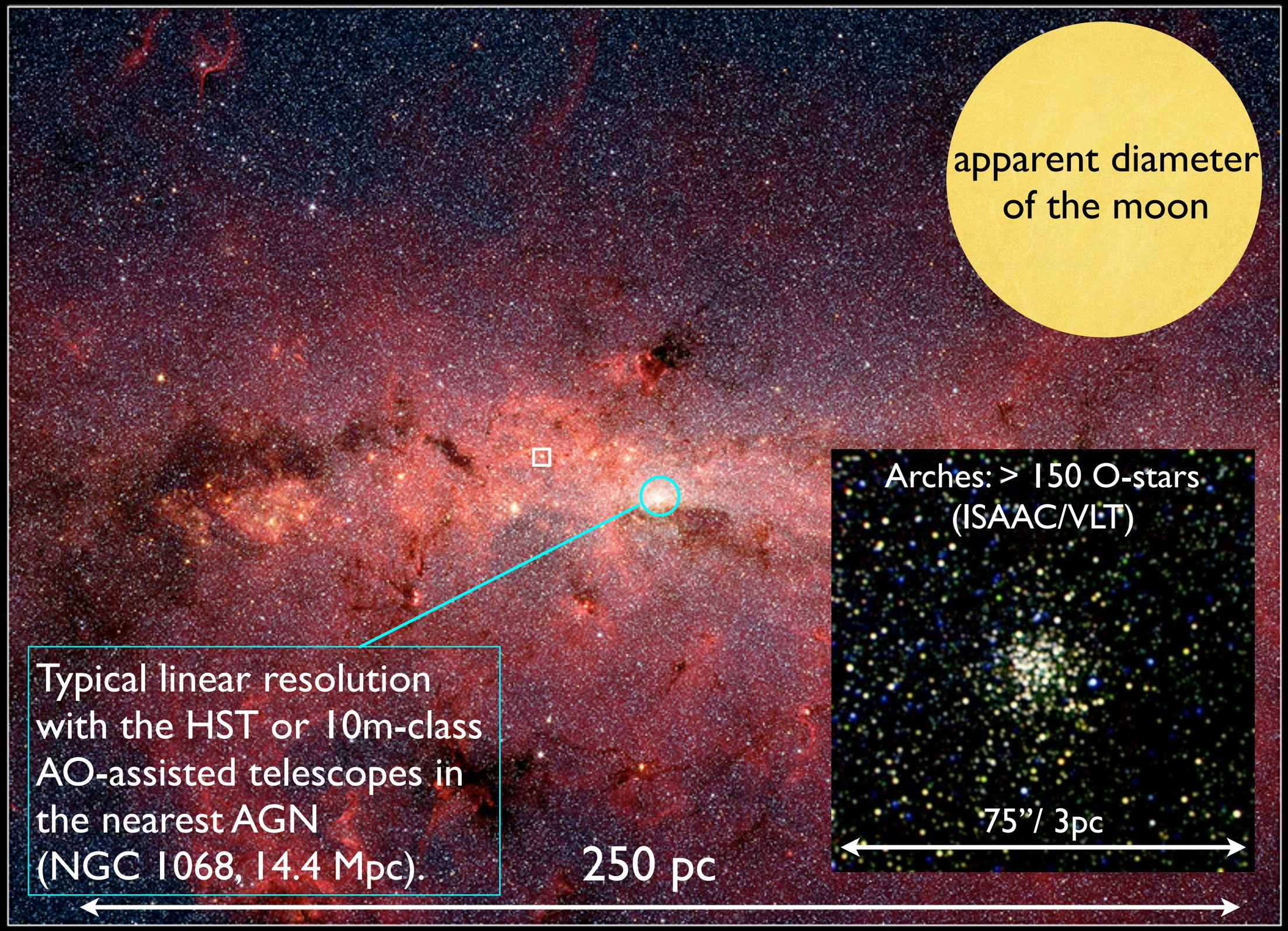

The Center of the Milky Way Galaxy

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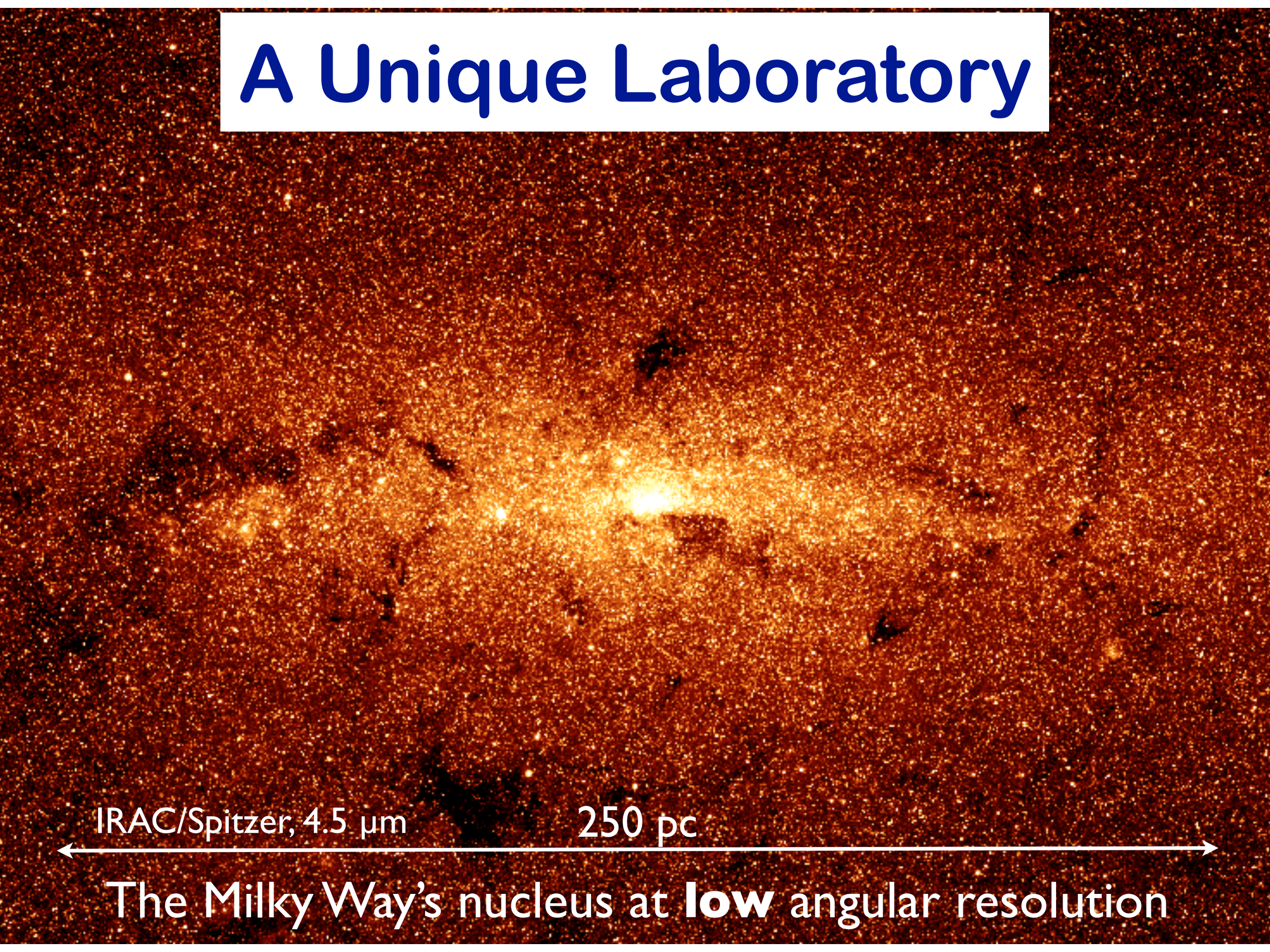
Spitzer Space Telescope • IRAC

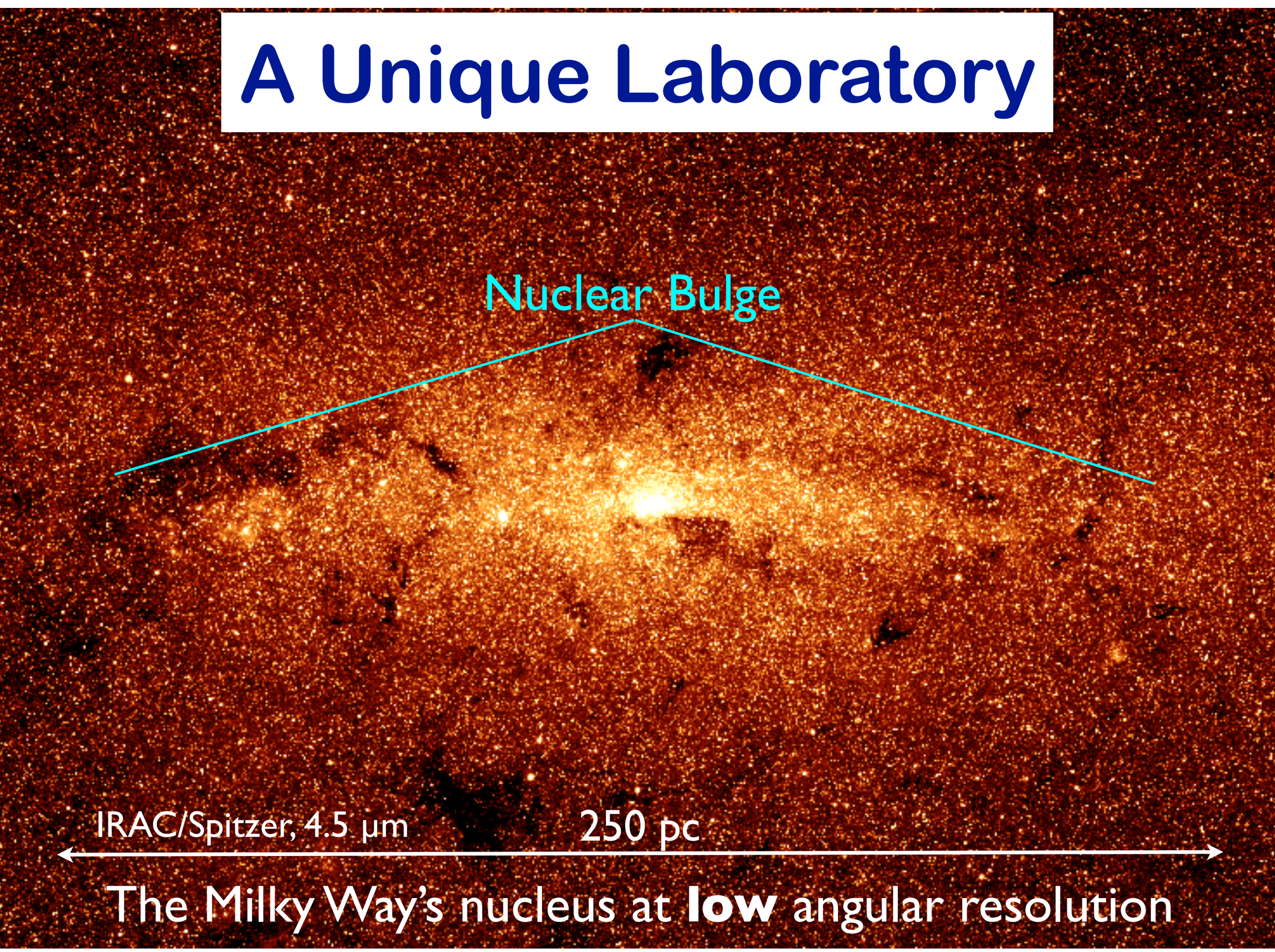
ssc2006-02a

A Unique Laboratory



The Milky Way's nucleus at **low** angular resolution

A Unique Laboratory



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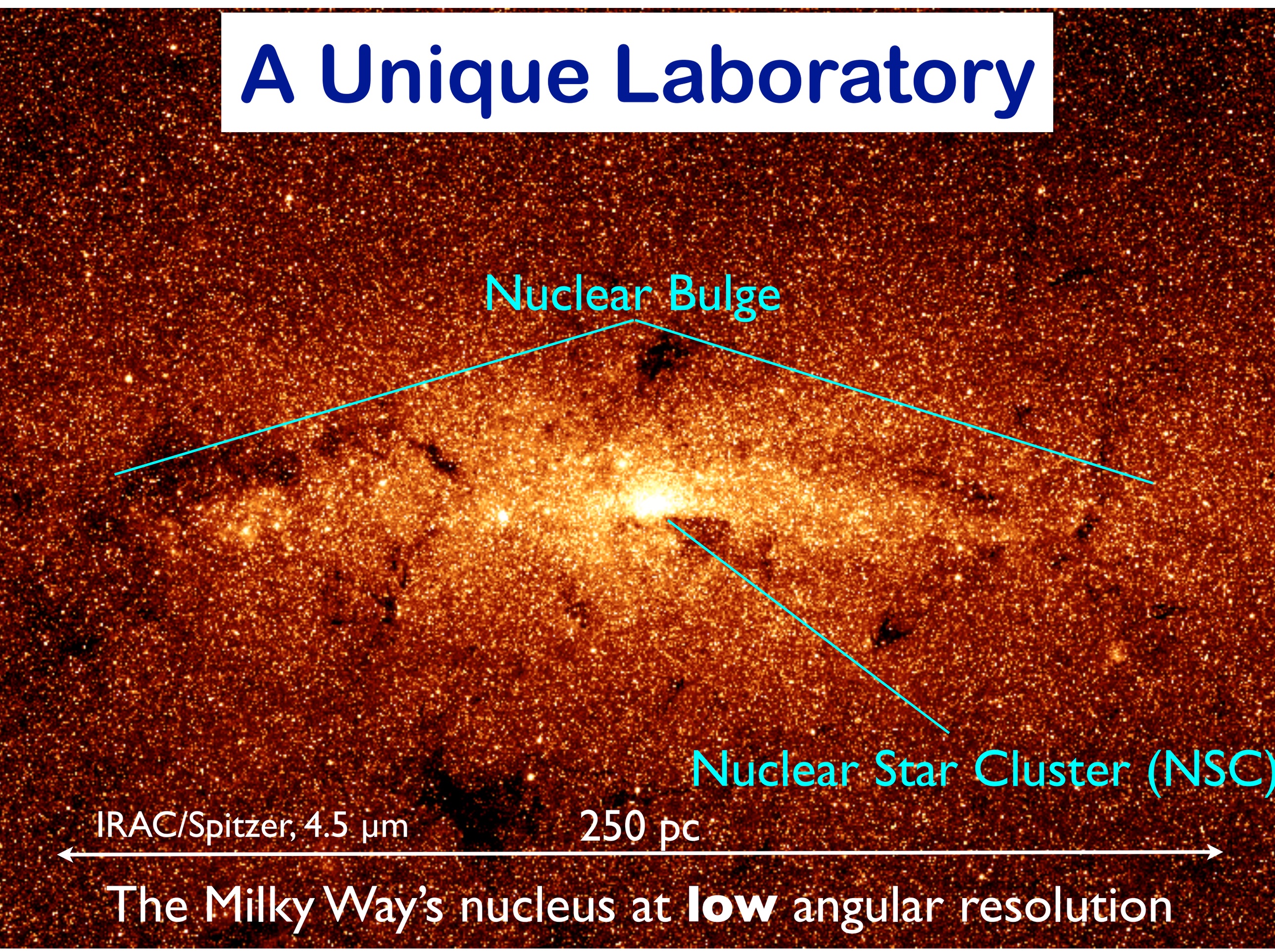

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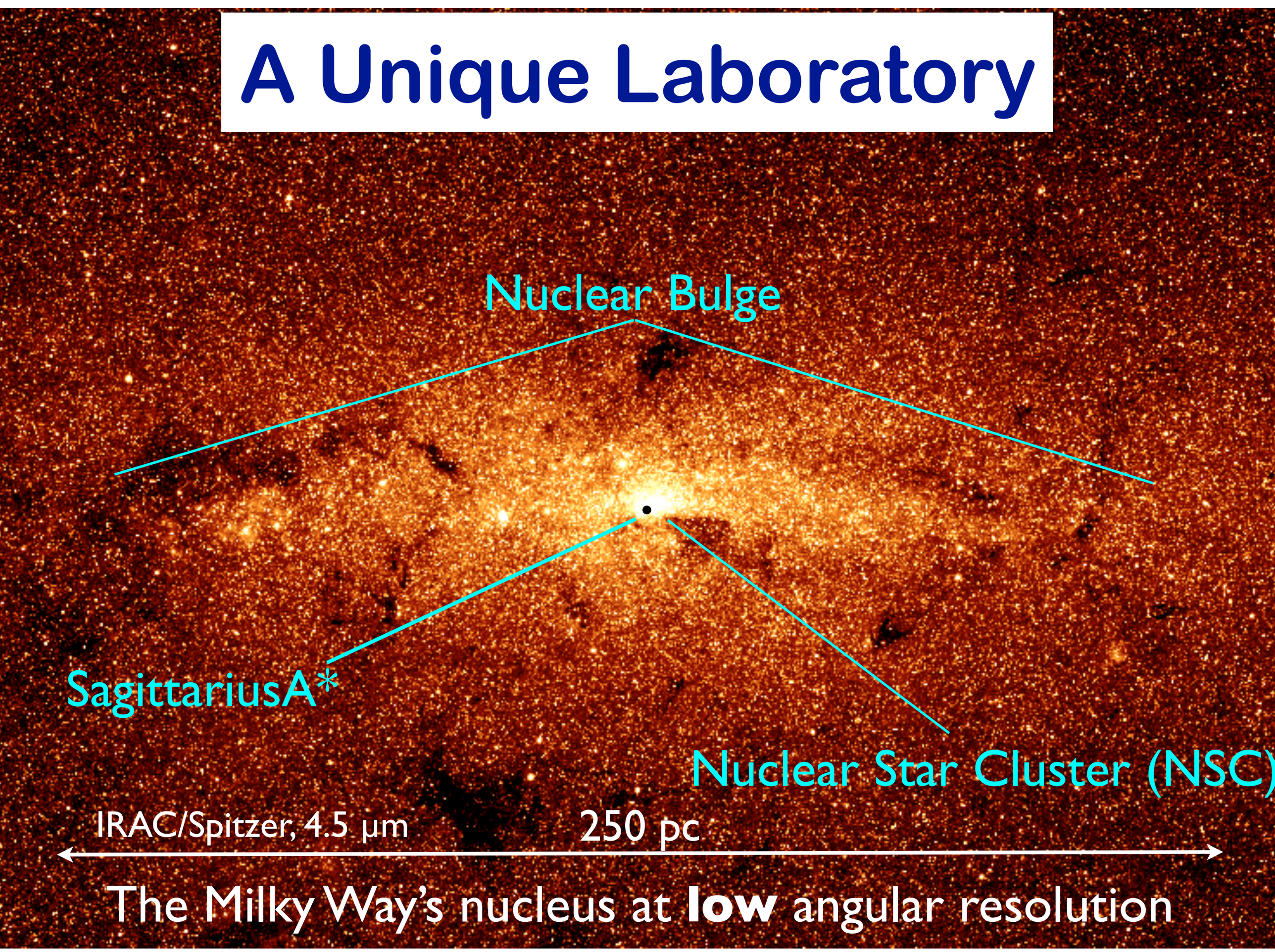

The Milky Way's nucleus at **low** angular resolution

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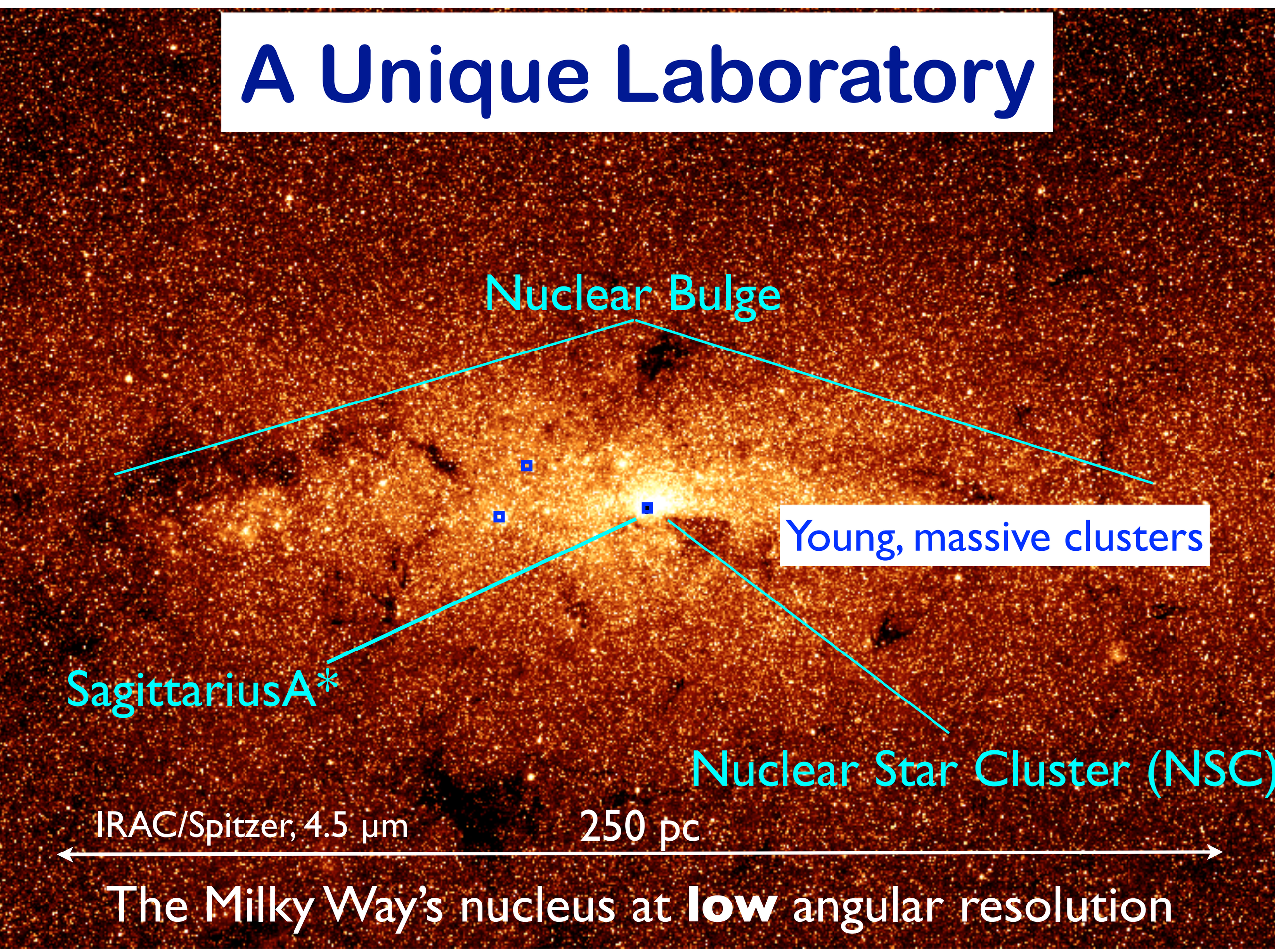
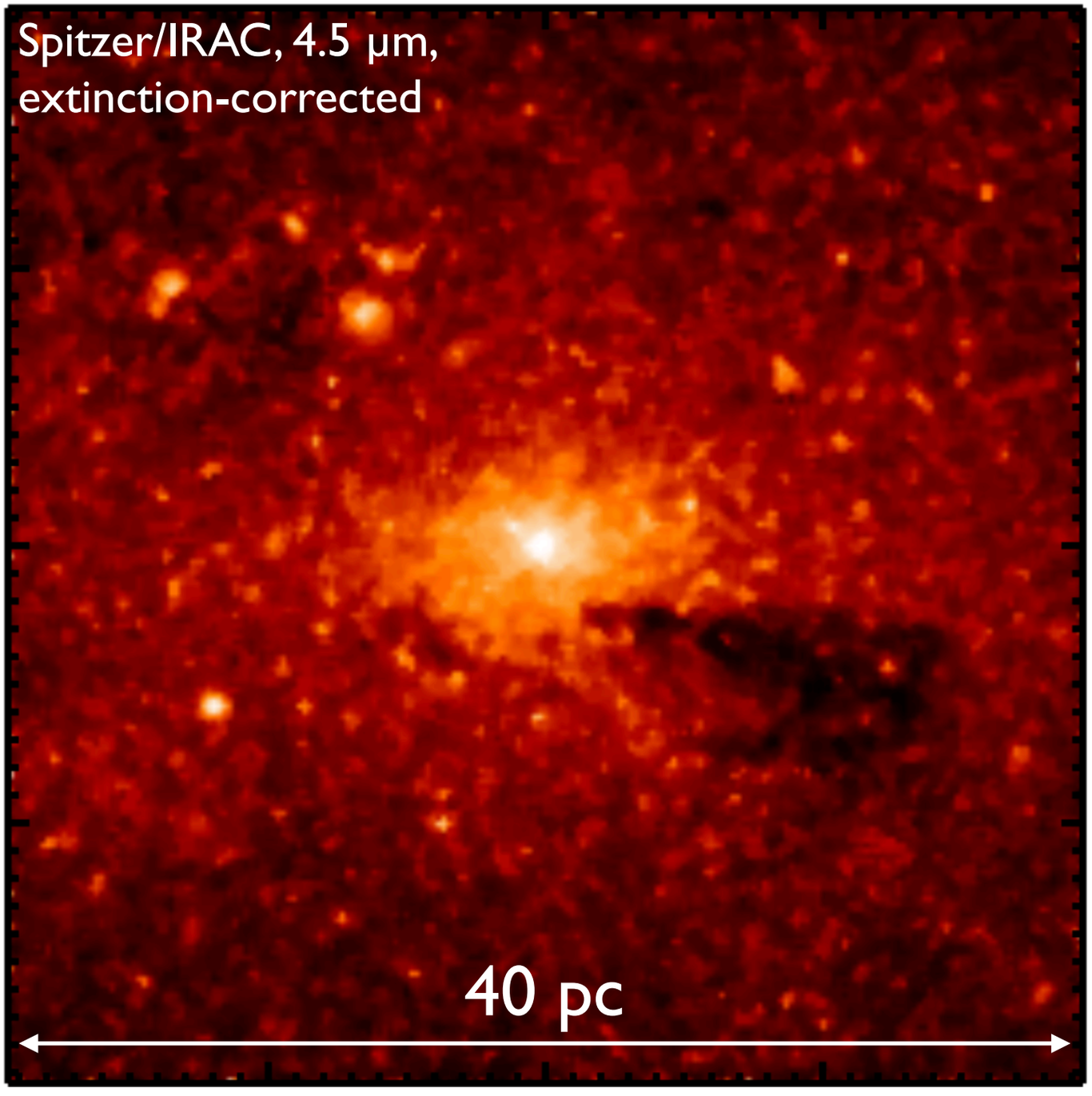


The Milky Way's nucleus at **low** angular resolution

Nuclear Star Cluster and MBH



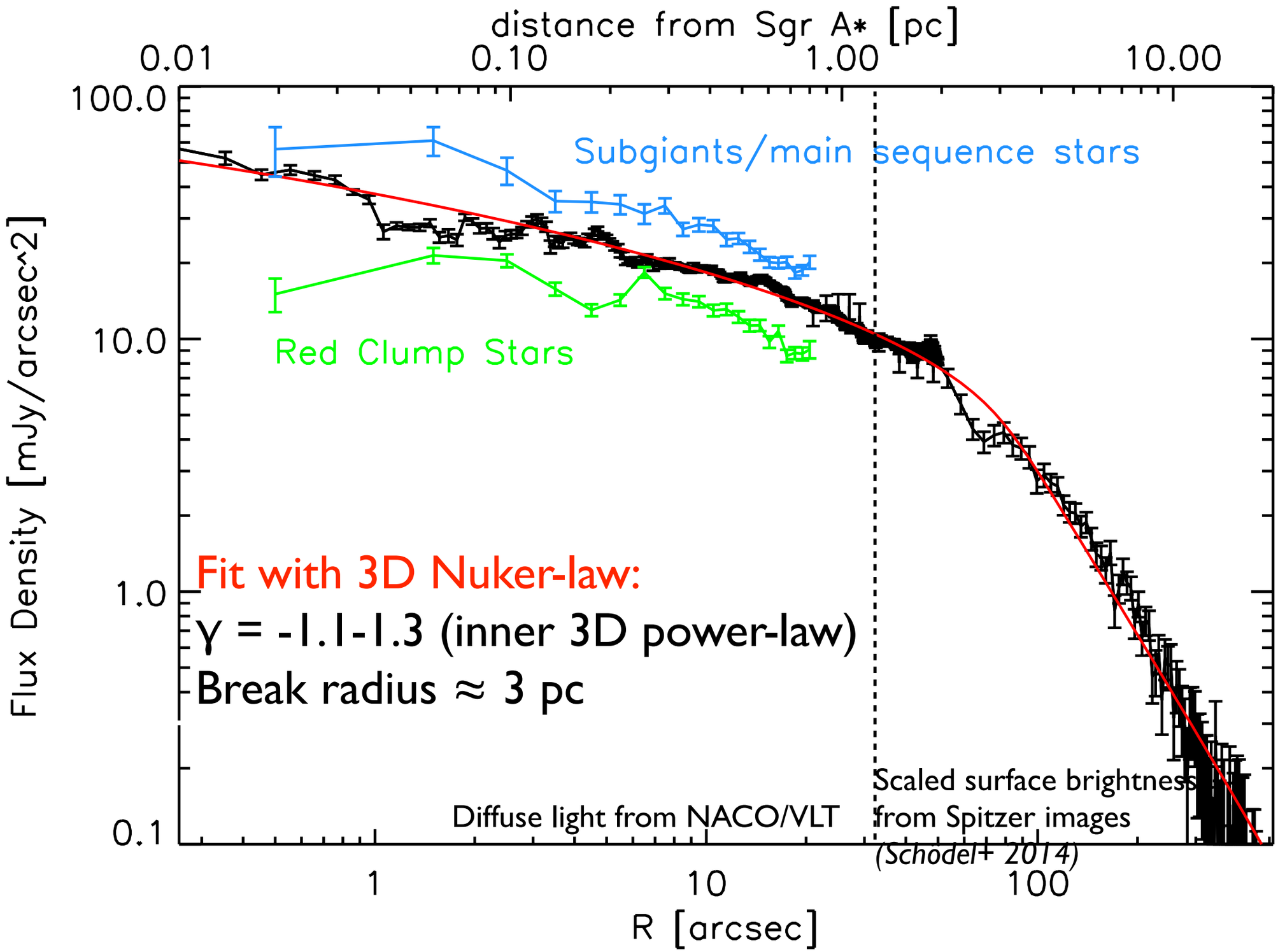
- Centred on Sgr A*
- Flattened along Galactic Plane
- Half light radius = 4.2 ± 0.4 pc
- Mass $2.5 \pm 0.4 \times 10^7\ M_\odot$
- $M_{MBH} = 4 \times 10^6\ M_\odot$

Schödel, et al. 2014; Feldmeier et al. 2014;
Fritz et al. 2016; Gallego-Cano et al. (in prep.)

The GC Laboratory

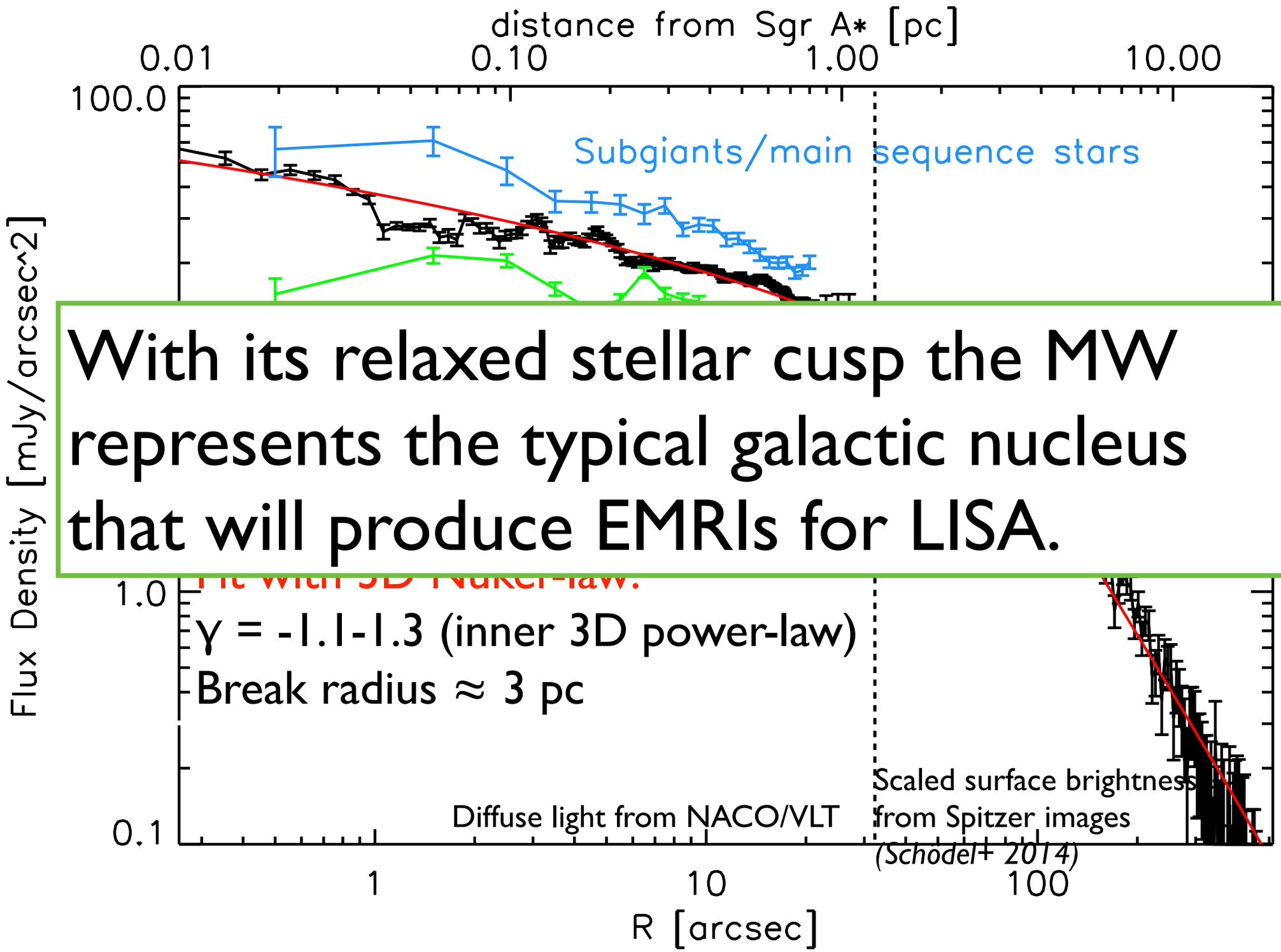
1. Densest stellar structures in the Milky Way
2. Massive black hole
3. Prolific massive star forming region/supernova+TDE factory
4. High-metallicity environment (~2x solar)
5. Potentially different (top-heavy) IMF
6. Contains ~10% of Milky Way's molecular gas
7. Contains three of the most massive young clusters in the Milky Way
8. High temperature and turbulence of the IMF
9. Magnetic field 10-100 times higher than in Milky Way disc
10. Typical galactic nucleus for Gravitational Wave emission (Milky Way equivalent galaxies - MWEGs)
11. Large population of stellar BHs and neutron stars expected
12. Pulsars excellent tracers of dynamics

The stellar cusp around Sagittarius A*



Gallego-Cano et al. (2018), Schödel et al. (2018), Baumgardt et al. (2018)

The stellar cusp around Sagittarius A*



With its relaxed stellar cusp the MW represents the typical galactic nucleus that will produce EMRIs for LISA.

Gallego-Cano et al. (2018), Schödel et al. (2018), Baumgardt et al. (2018)

A cusp of stellar mass BHs

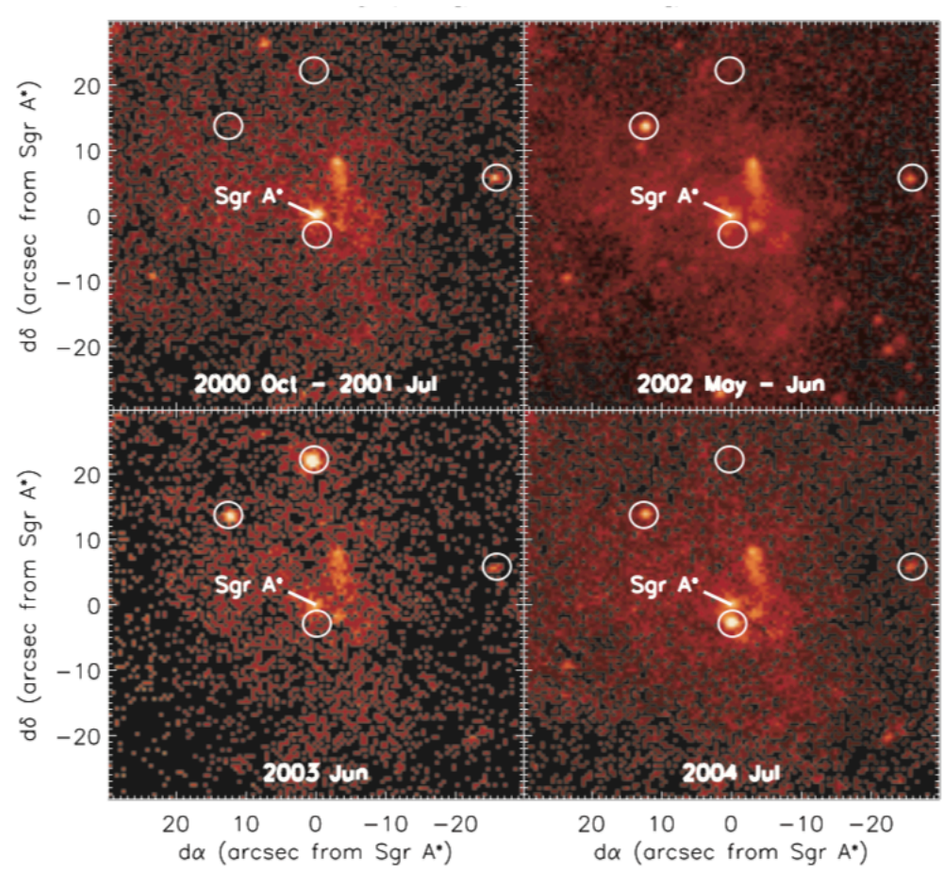
THE ASTROPHYSICAL JOURNAL, 622:L113–L116, 2005 April 1

AN OVERABUNDANCE OF TRANSIENT X-RAY BINARIES WITHIN 1 PARSEC OF THE GALACTIC CENTER

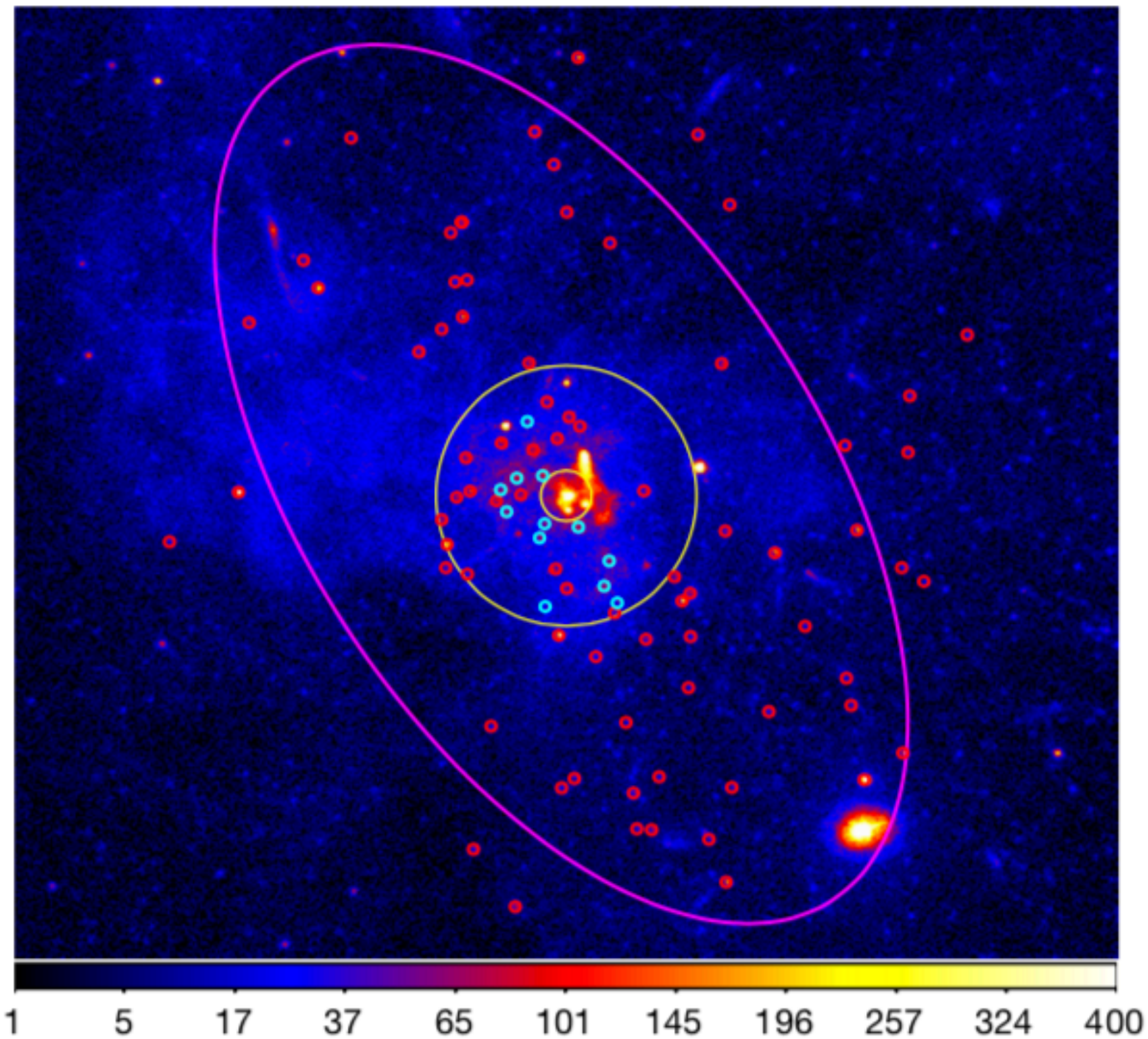
M. P. MUNO,[1,2] E. PFAHL,[3] F. K. BAGANOFF,[4] W. N. BRANDT,[5] A. GHEZ,[1] J. LU,[1] AND M. R. MORRIS[1]
Received 2004 December 17; accepted 2005 February 17; published 2005 March 11

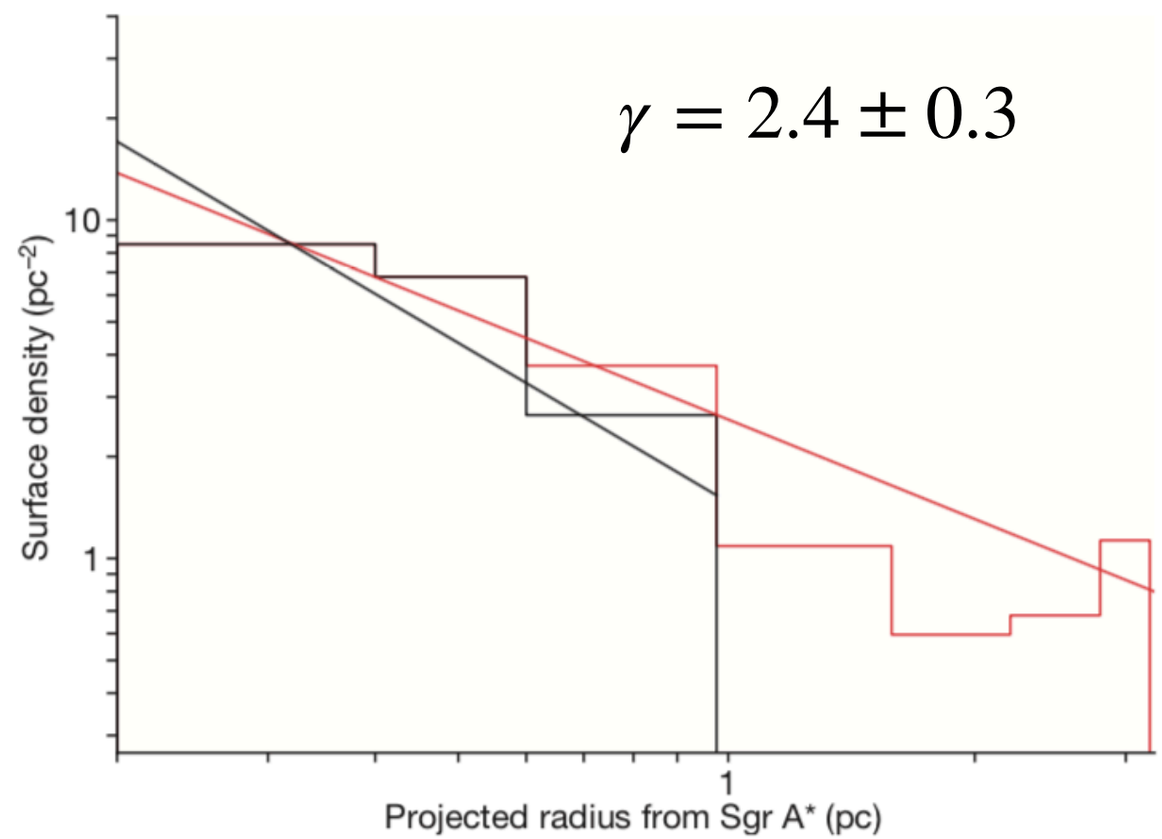
ABSTRACT

During 5 years of *Chandra* observations, we have identified seven X-ray transients located within 23 pc of Sgr A*. These sources each vary in luminosity by more than a factor of 10 and have peak X-ray luminosities greater than 5×10^{33} ergs s^{-1}, which strongly suggests that they are accreting black holes or neutron stars. The



A cusp of stellar mass BHs





Hailey et al. (2018)

IMBHs in the GC?

1. Intermediate-mass BHs may form in stellar clusters
2. IMBHs may be seeds of MBHs
3. Will sink to the GC due to dynamical friction

<u>Two claims for IMBHs in GC environment:</u>

1. Maillard et al. (2004): IMBH in IRS 13E, 0.13pc from Sgr A*
2. Oka et al. (2016, 2017): IMBH in molecular cloud at ~60 pc from Sgr A*

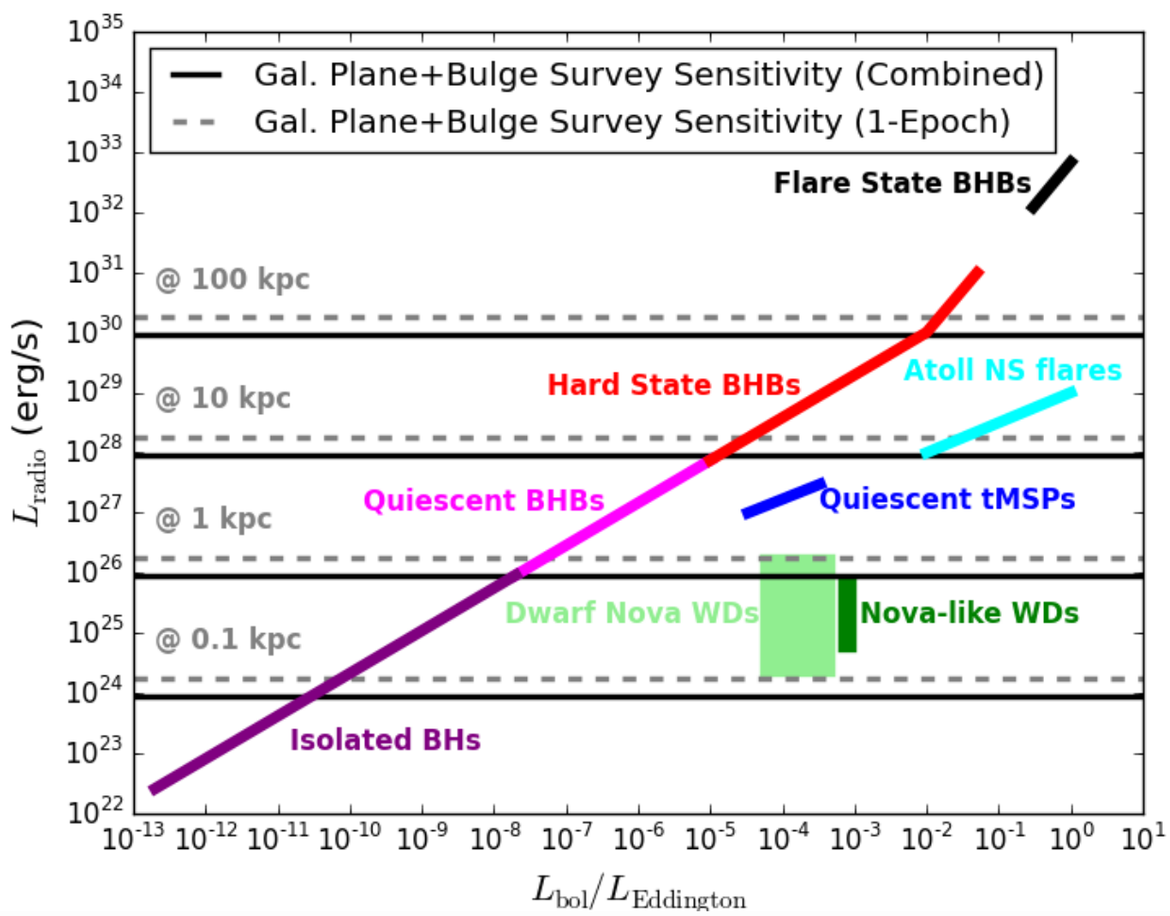
However, see counterarguments in Schödel et al. (2005), Fritz et al. (2010), Tanaka (2018): **No smoking gun!**

Extraordinary claim requires extraordinary evidence.

GC KSP - Scientific Aims

1. State of the ISM and conditions for star formation
2. Extreme SF environments: SgrB2
3. Current star forming activity: YSOs
4. Number and distribution of stellar remnants: Dark cusp, GW sources, IMF
5. Post-MS evolution of (massive) high-metallicity stars
6. Transients
7. Measurement of recent SFH through complete sample of OB stars
8. Intermediate mass black holes(?)
9. Astrometry: GAIA blind toward GC, reference for relativistic dynamics
10. …

Tier 2 Accreting Compact Objects



Detect large numbers of accreting compact objects across wide ranges of mass accretion rate and compact object.

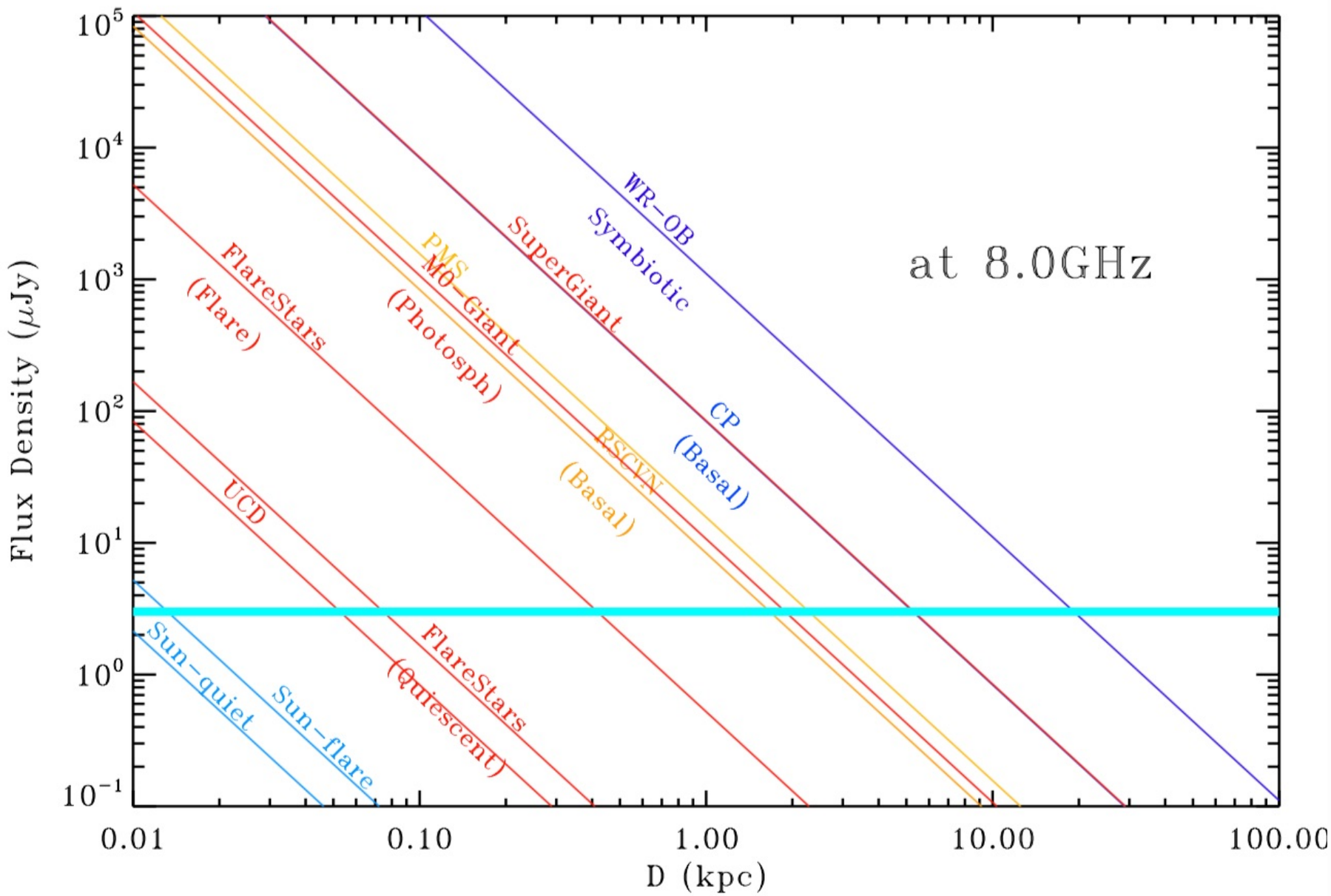
Wide implications for understanding the connected physics of accretion and outflow, as well as the evolution of binary systems.

Courtesy G. Sivakoff

Combined= 4 epochs

Slide from Thompson et al.

Tier 2 Detections forecast: Radio Stars



Flaring Sun @ 10pc

OB-WRs @GC

Slide from Thompson et al.

GC KSP - Precursors

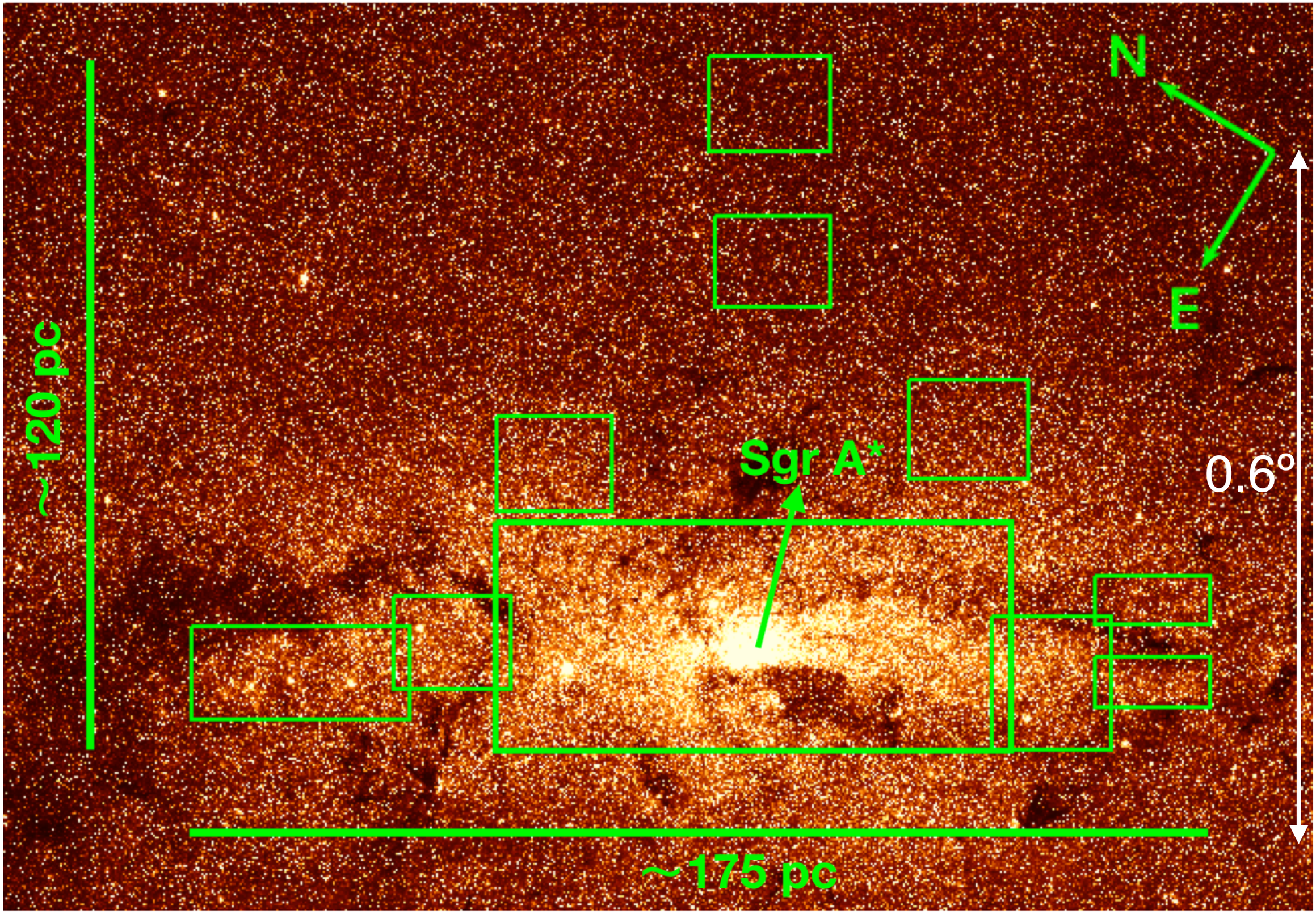
(1) GALACTICNUCLEUS:

0.2”resolution FWHM JHK survey of > 3000 pc^2 of the GC
Photometric uncertainty < 5%
> 10^6 stars

(2) Radio+NIR studies of young, massive stars in the GC:

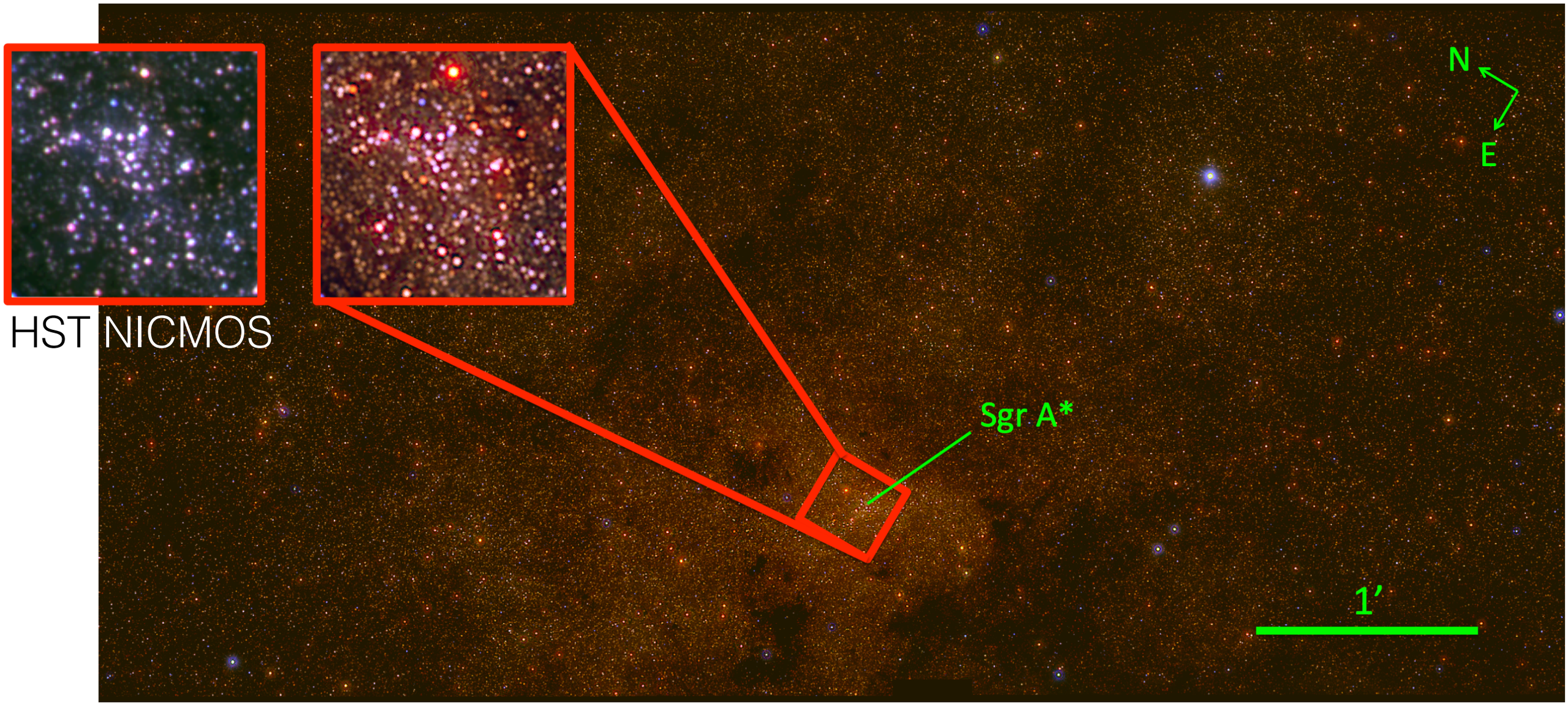
Arches and Quintuplet clusters (JVLA, in prep.)
Radiostars near Sagittarius A* (Yusef-Zadeh et al. 2014, 2015)

GALACTICNUCLEUS



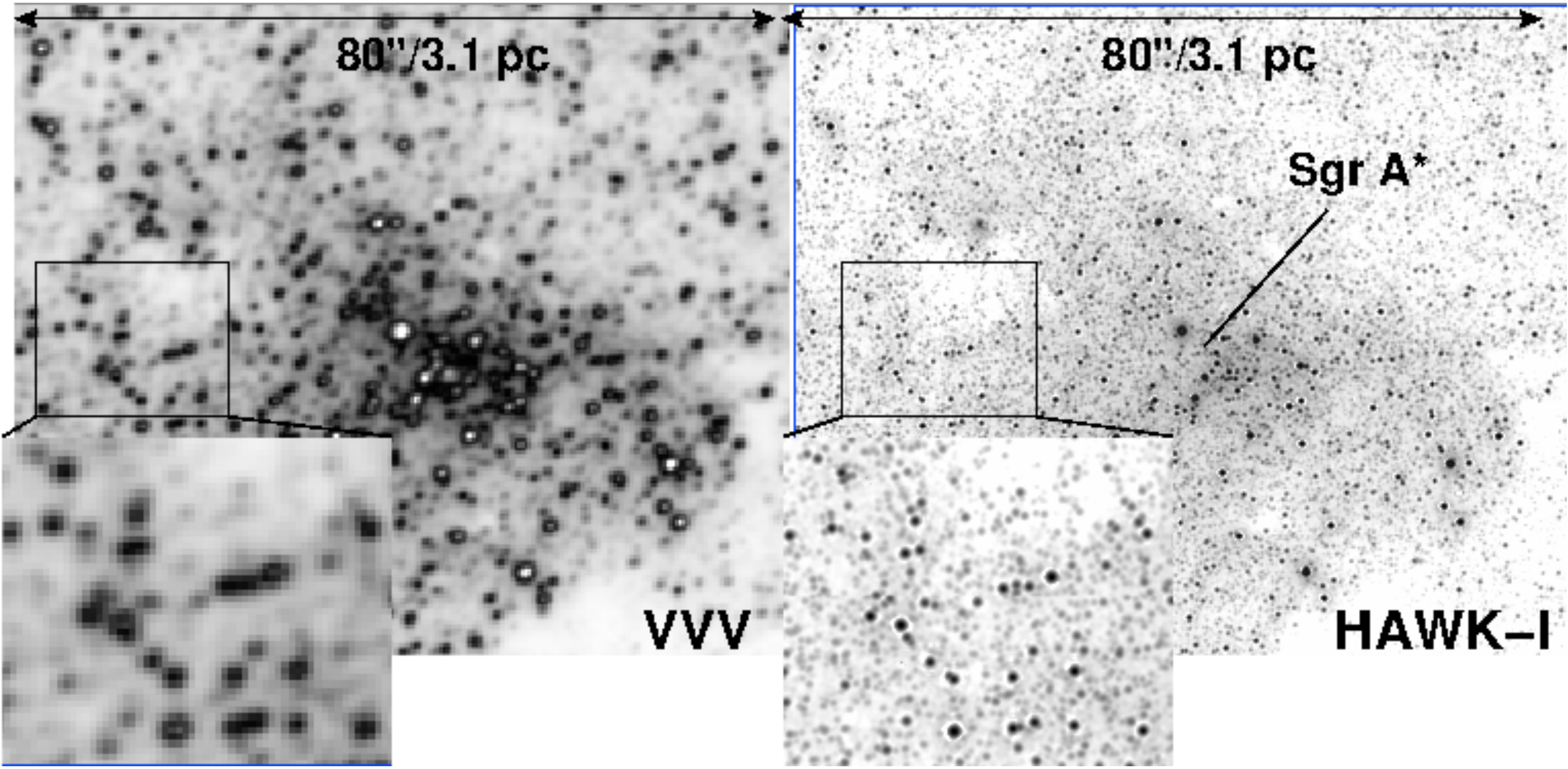
see gc.iaa.es

RGB image using JHKs bands



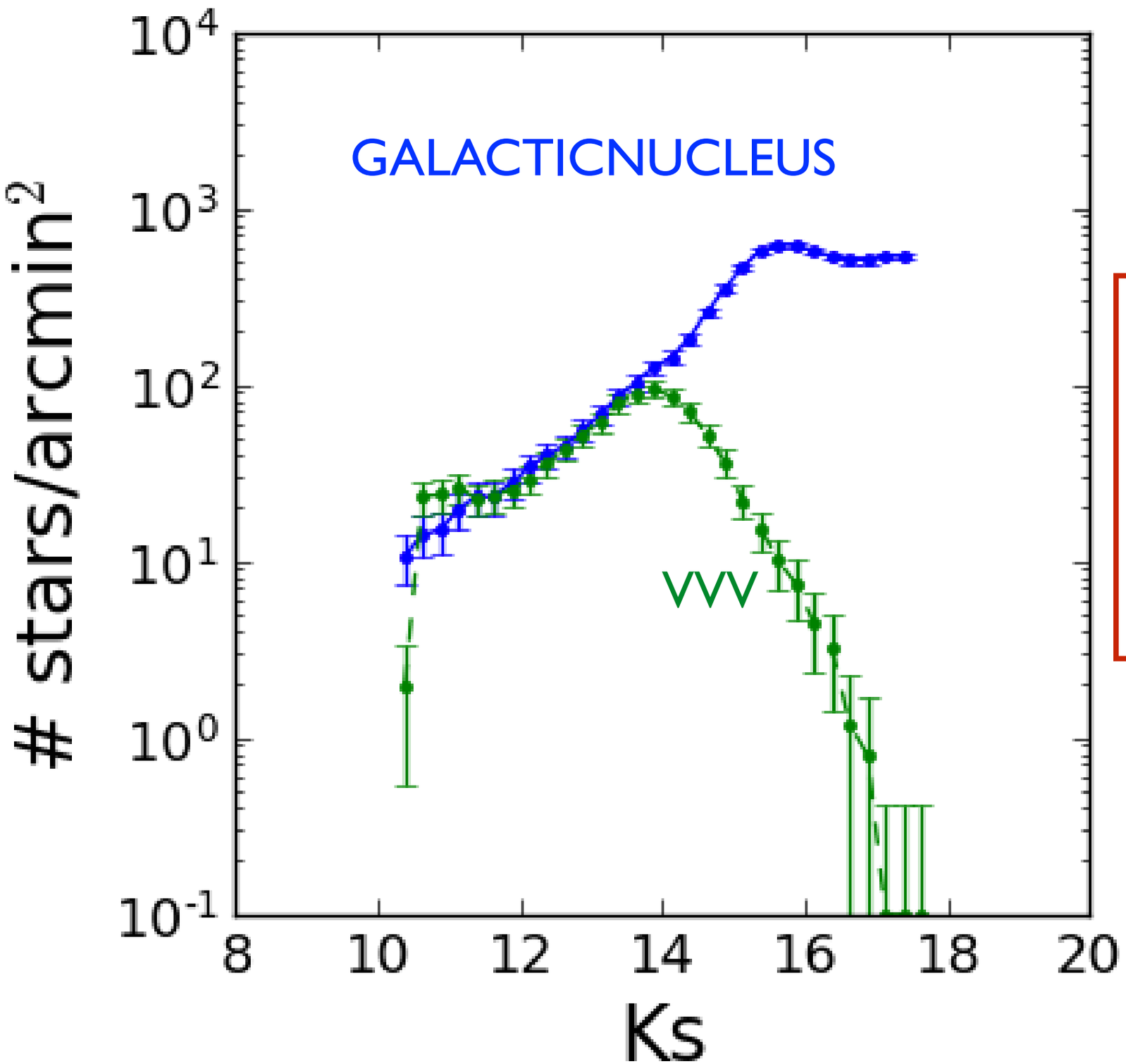
Nogueras-Lara et al. (2017)

GALACTICNUCLEUS vs VVV



Nogueras-Lara et al. (2017)

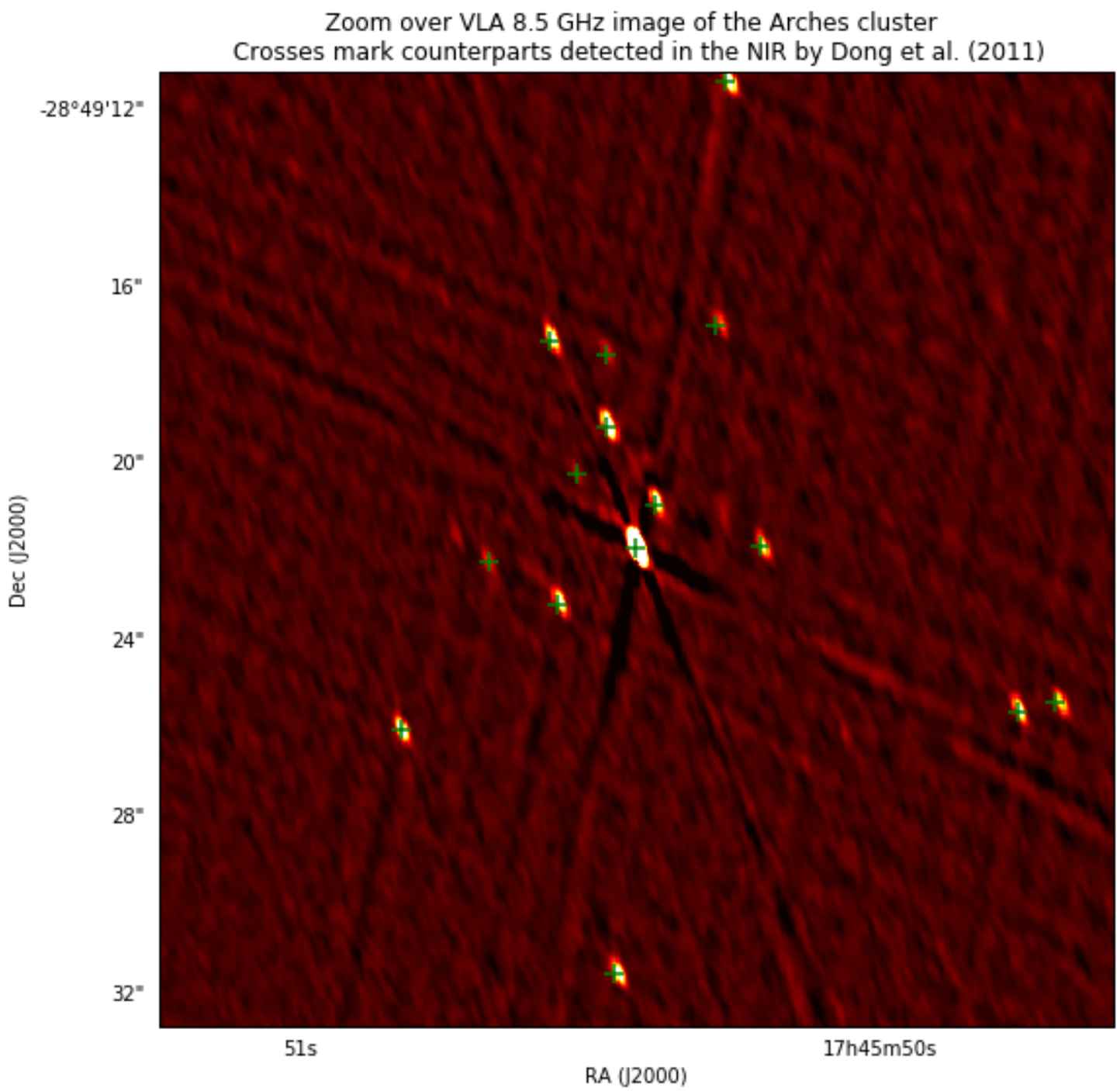
GALACTICNUCLEUS vs VVV



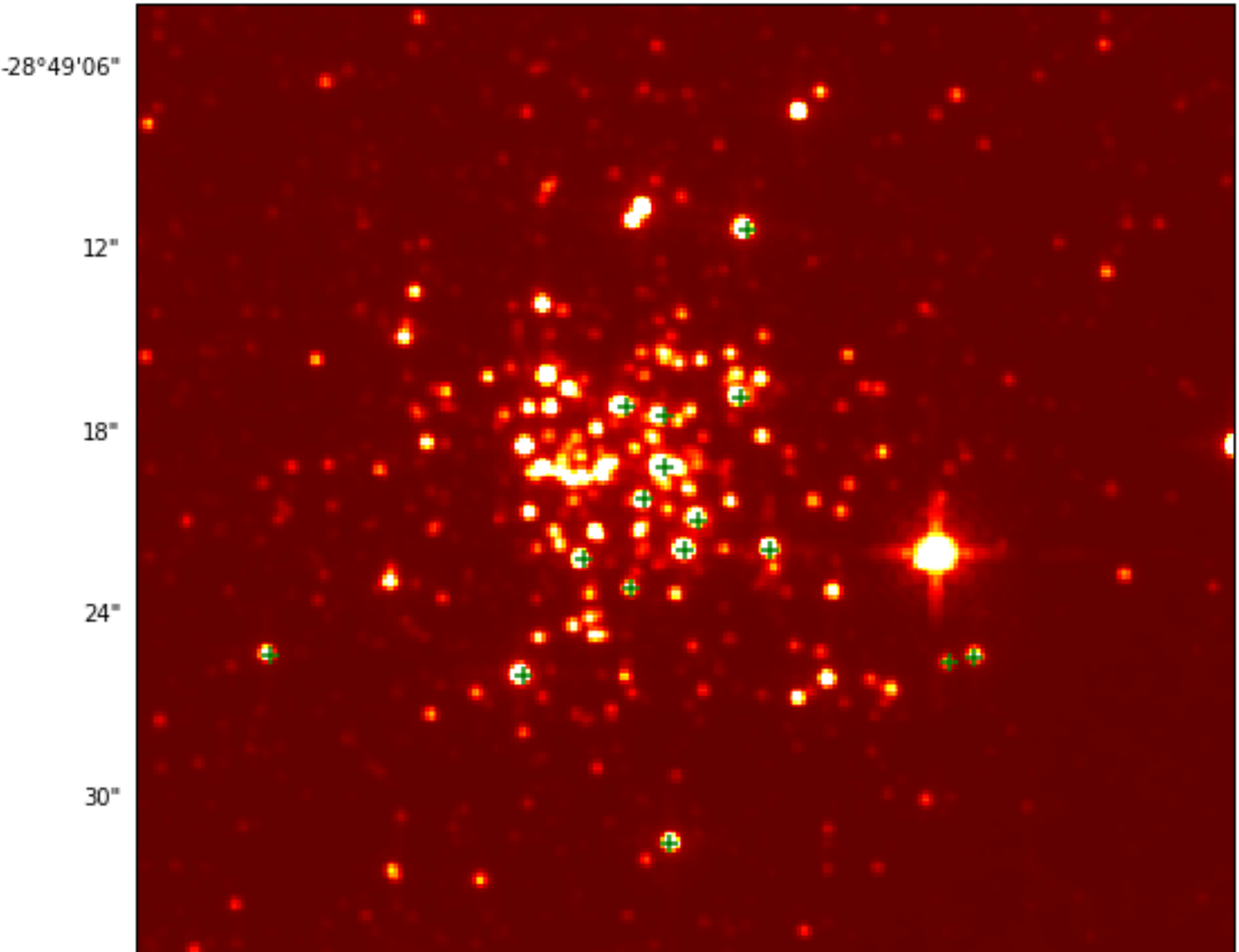
GALACTICNUCLEUS reaches well below the Red Clump and contains all potential O/B stars.

Nogueras-Lara et al. (2017)

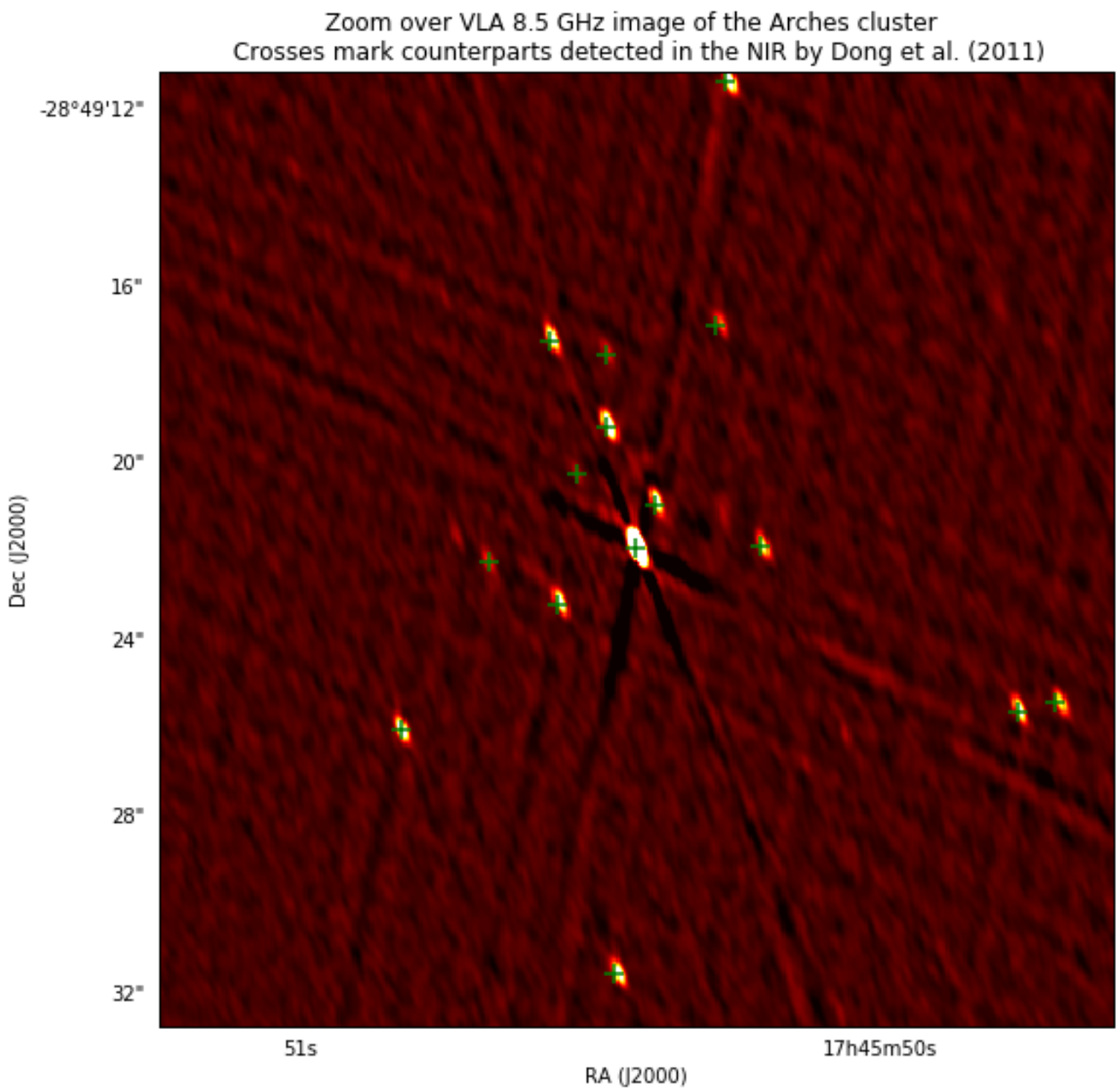
Radio + NIR studies of massive young clusters



Zoom over HST/WFC3 image of the Arches Cluster
Crosses mark radio-detected sources



Radio + NIR studies of massive young clusters



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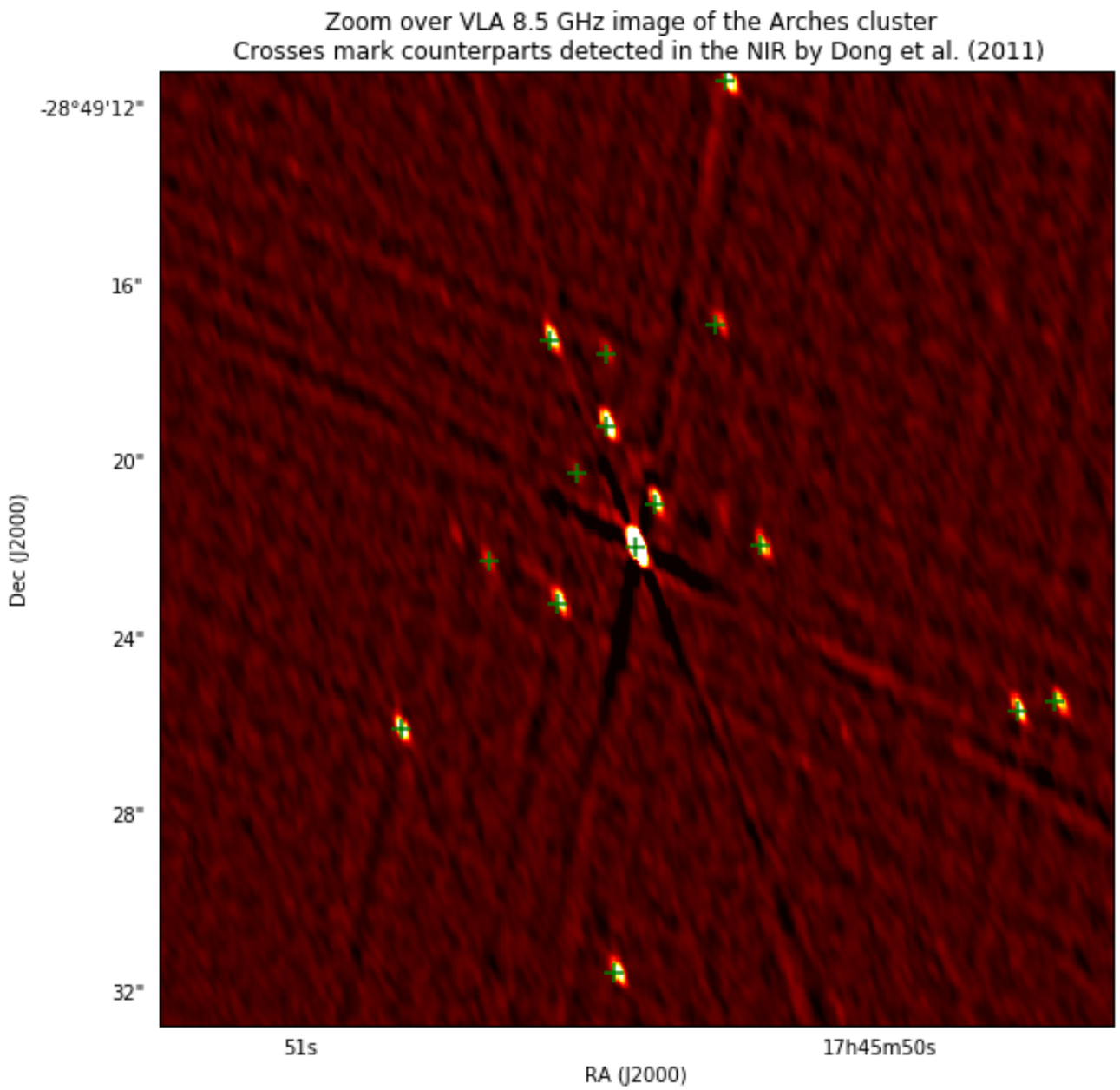
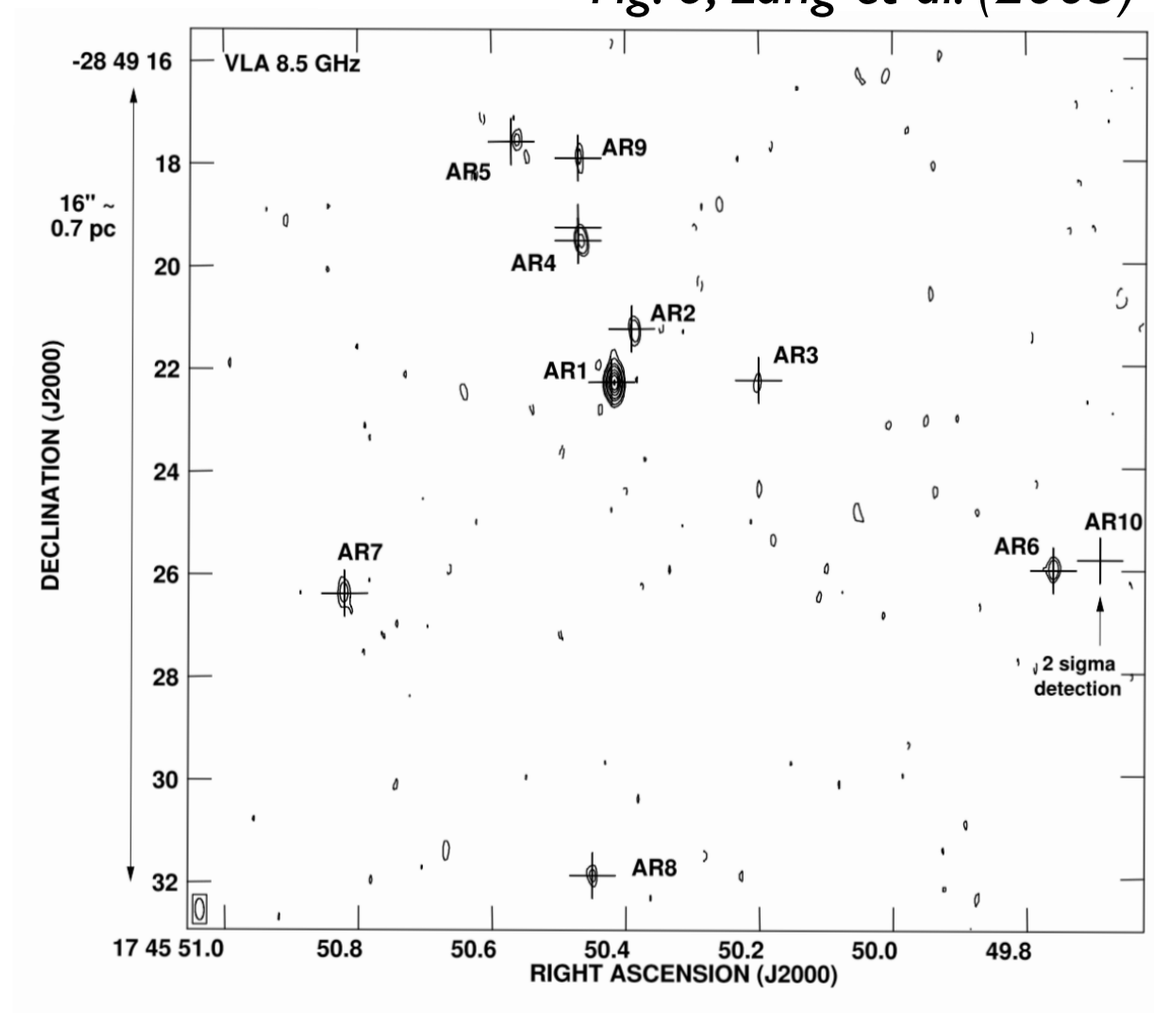


rms 5 μJy/Beam

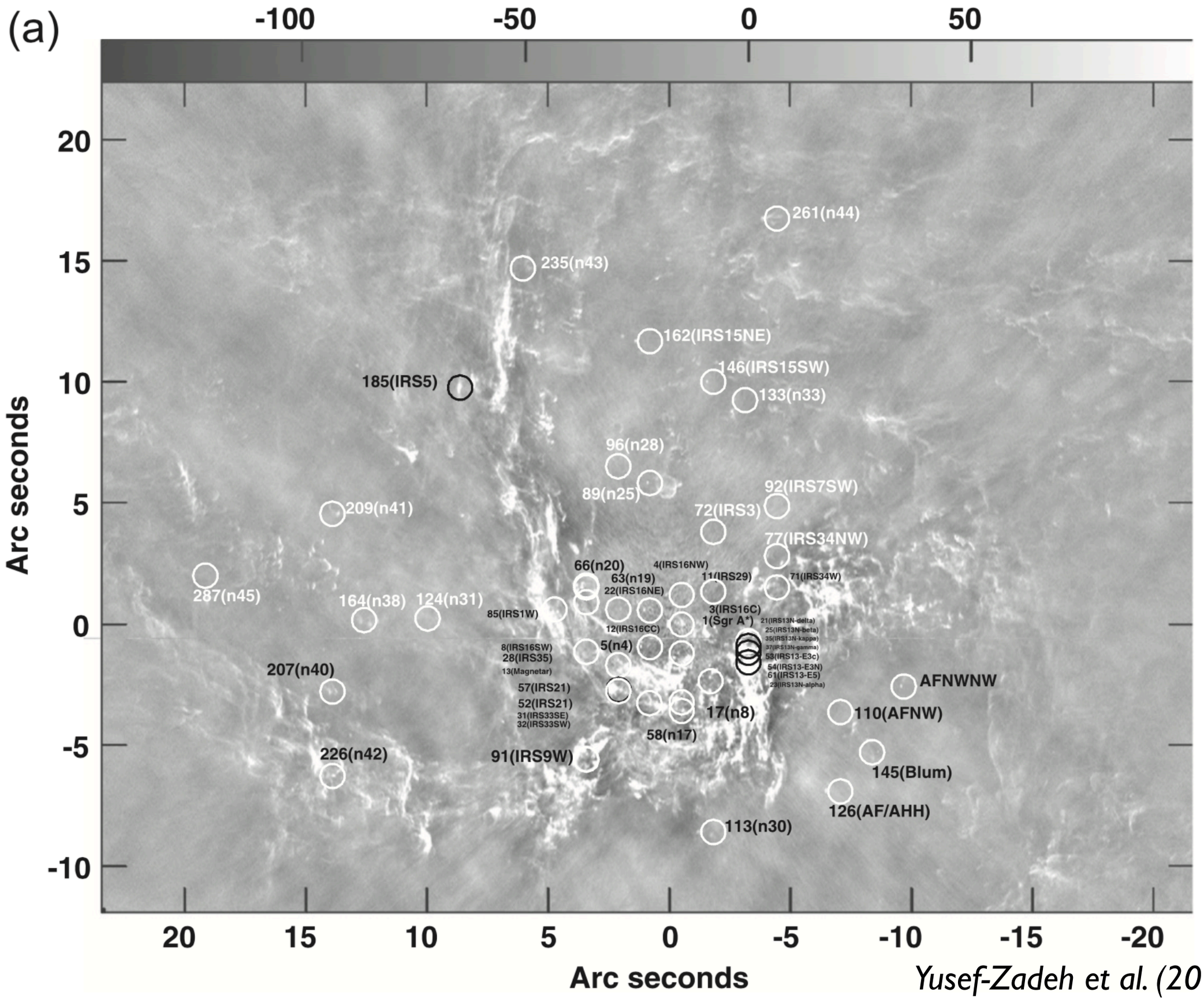
Fig. 6, Lang et al. (2005)



rms 25 μJy/BEAM

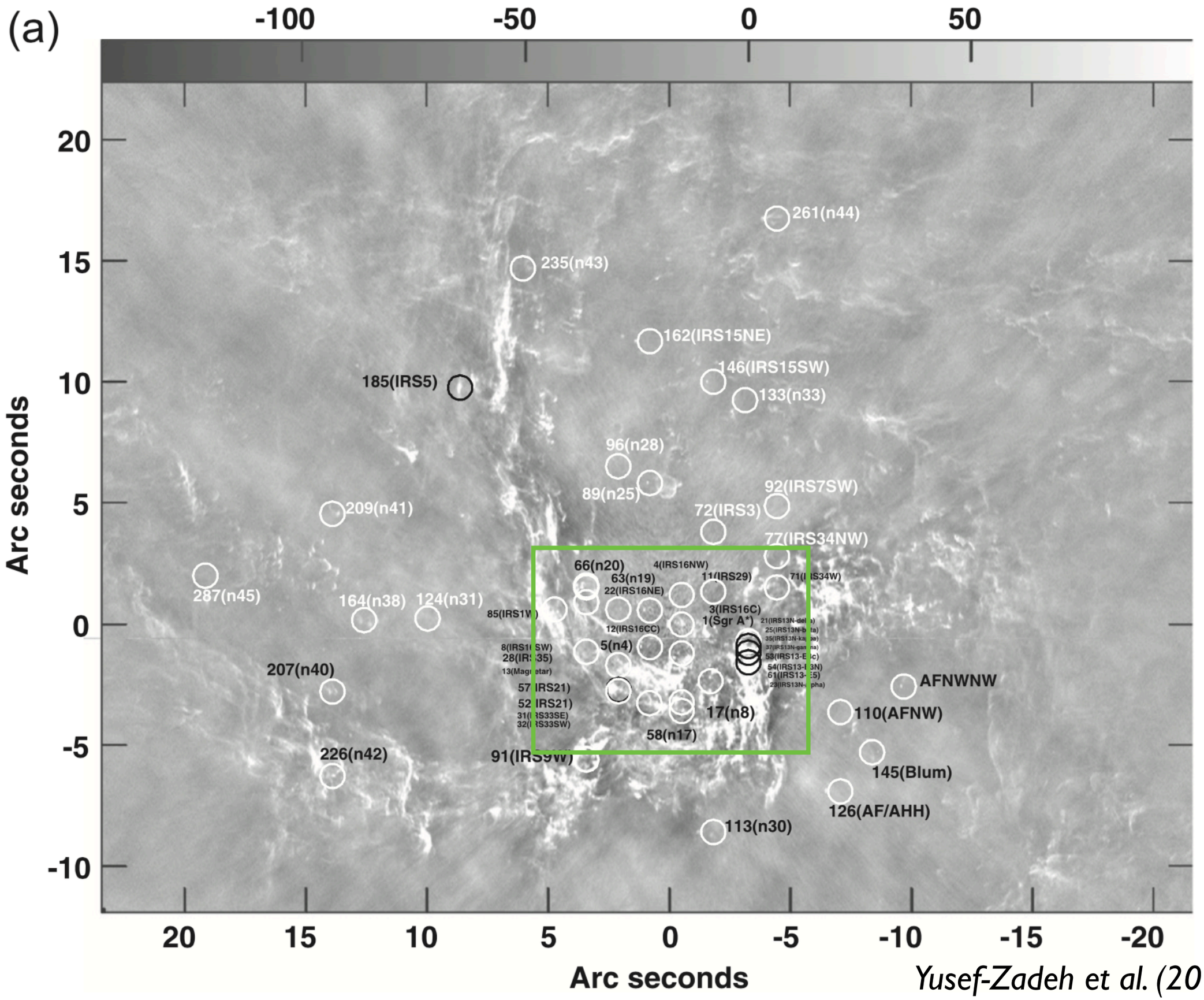
Gallego et al., in prep.

Radio stars near Sagittarius A*



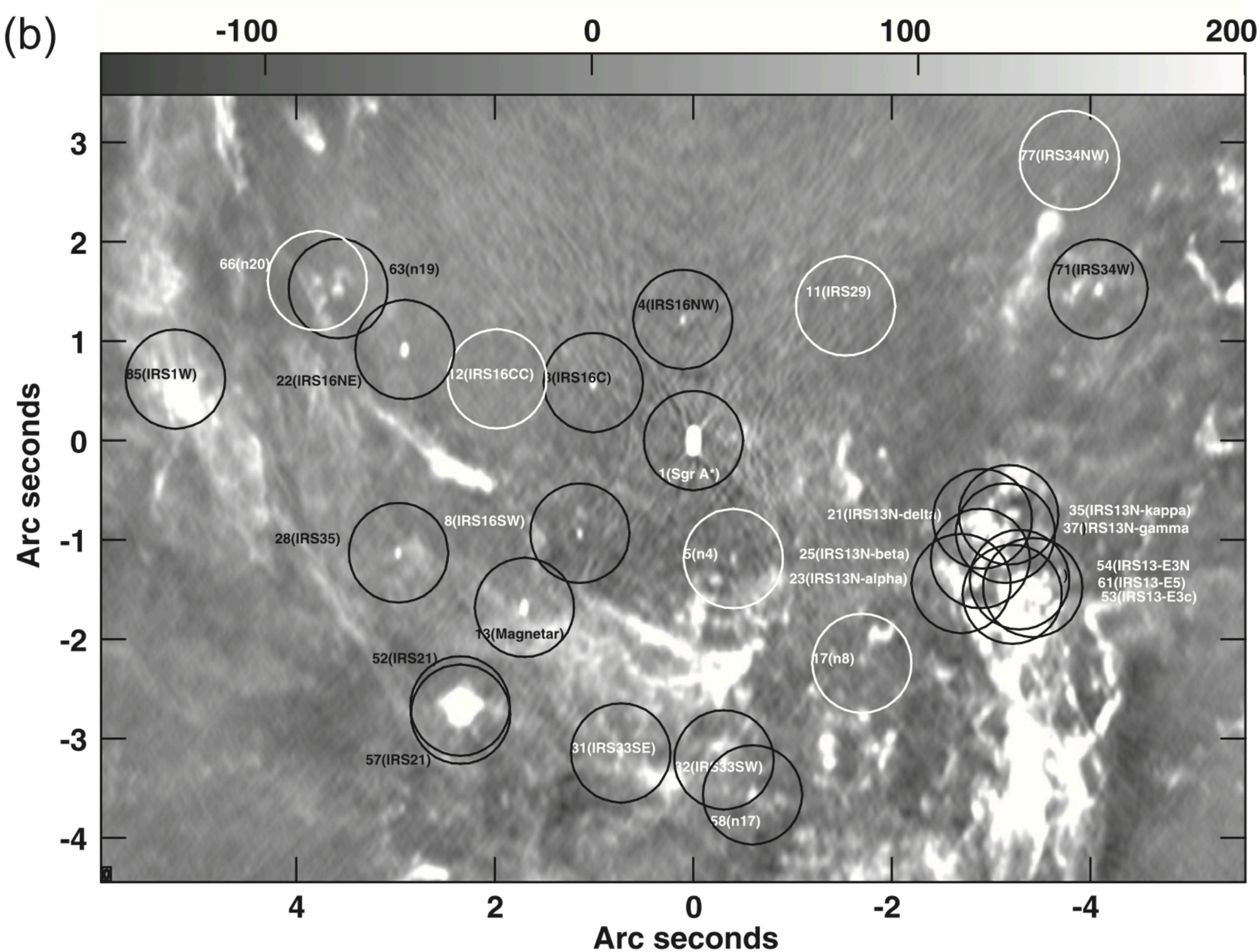
Yusef-Zadeh et al. (2014,2015)

Radio stars near Sagittarius A*



Yusef-Zadeh et al. (2014,2015)

Radio stars near Sagittarius A*



Yusef-Zadeh et al. (2014,2015)

Radio stars near Sagittarius A*

Radio stars in the GC provide insight into mass-loss at high metallicities and post-MS evolution.

They can serve as astrometric standards for high-precision proper motion measurements in particular to probe GR near Sagittarius A*.

GC KSP - Some numbers

"Continuum" Key Science Project Ideas

Science Objective	SWG	High Priority Science Objective Number	SKA1 Component	Band	Mode	Frequency	Sensitivity	Observing Area		Integration
						Range Low - High	RMS Noise Min:Max @ Beam @ Bandwidth	Total Area	Angular Resolution Min:Max	Total
Magnetism - RM-grid AASKA14:092	Magnetism	27	**SKA1-MID**	**SPF2**	**Imaging**	1000 - 1700 MHz	7 µJy/Beam @ 2 arcsec Cont	31000 deg2	2 arcsec	10000 hr
Cosmology - ISW, Dipole AASKA14:018, 032	Cosmology	33	**SKA1-MID**	**SPF2**	**Imaging**	1000 - 1700 MHz	7 µJy/Beam @ 2 arcsec Cont	31000 deg2	2 arcsec	10000 hr
Continuum - SFR(z) AASKA14:067	Continuum	37 + 38	**SKA1-MID**	**SPF2**	**Imaging**	1000 - 1700 MHz	1.3 µJy/Beam @ 0.5 arcsec Cont	1000 deg2	0.5:1 arcsec	10000 hr
			SKA1-MID	**SPF2**	**Imaging**	1000 - 1700 MHz	0.25 µJy/Beam @ 0.5 arcsec Cont	7.8 deg2	0.5:1 arcsec	2000 hr
			SKA1-MID	**SPF2**	**Imaging**	1000 - 1700 MHz	65 nJy/Beam @ 0.5 arcsec Cont	0.38 deg2	0.5:1 arcsec	2000 hr
			SKA1-MID	**SPF5**	**Imaging**	**7 - 11 GHz**	400 nJy/Beam @ 0.05 arcsec Cont	0.5 deg2	0.05:1 arcsec	1000 hr
			SKA1-MID	**SPF5**	**Imaging**	**7 - 11 GHz**	50 nJy/Beam @ 0.05 arcsec Cont	30 arcmin2	0.05:1 arcsec	1000 hr

- HPSOs distilled from much broader package of survey ideas and goals

Robert Braun, Science Director

21 October 2015

GC KSP - Some numbers

"Continuum" Key Science Project Ideas

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			SKA1-MID	**SPF5**	**Imaging**	**7 - 11 GHz**	50 nJy/Beam @ 0.05 arcsec Cont	30 arcmin2	0.05:1 arcsec	1000 hr

- HPSOs distilled from much broader package of survey ideas and goals

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GC KSP - Some numbers

- Band 5, continuum
- Wide field ~0.5 deg^2: 100h (~ 1.3 μJy rms)
- Deep field 30 $arcmin^2$ on Sgr A*/NSC: 100h (~0.16 μJy rms)
- angular resolution 0.05”

Synergies with other instruments/projects

- GALACTICNUCLEUS survey and follow up (variability)
- JWST ~2022 - 2027
- ESO ELT from 2025 on
- ALMA

Thank you!