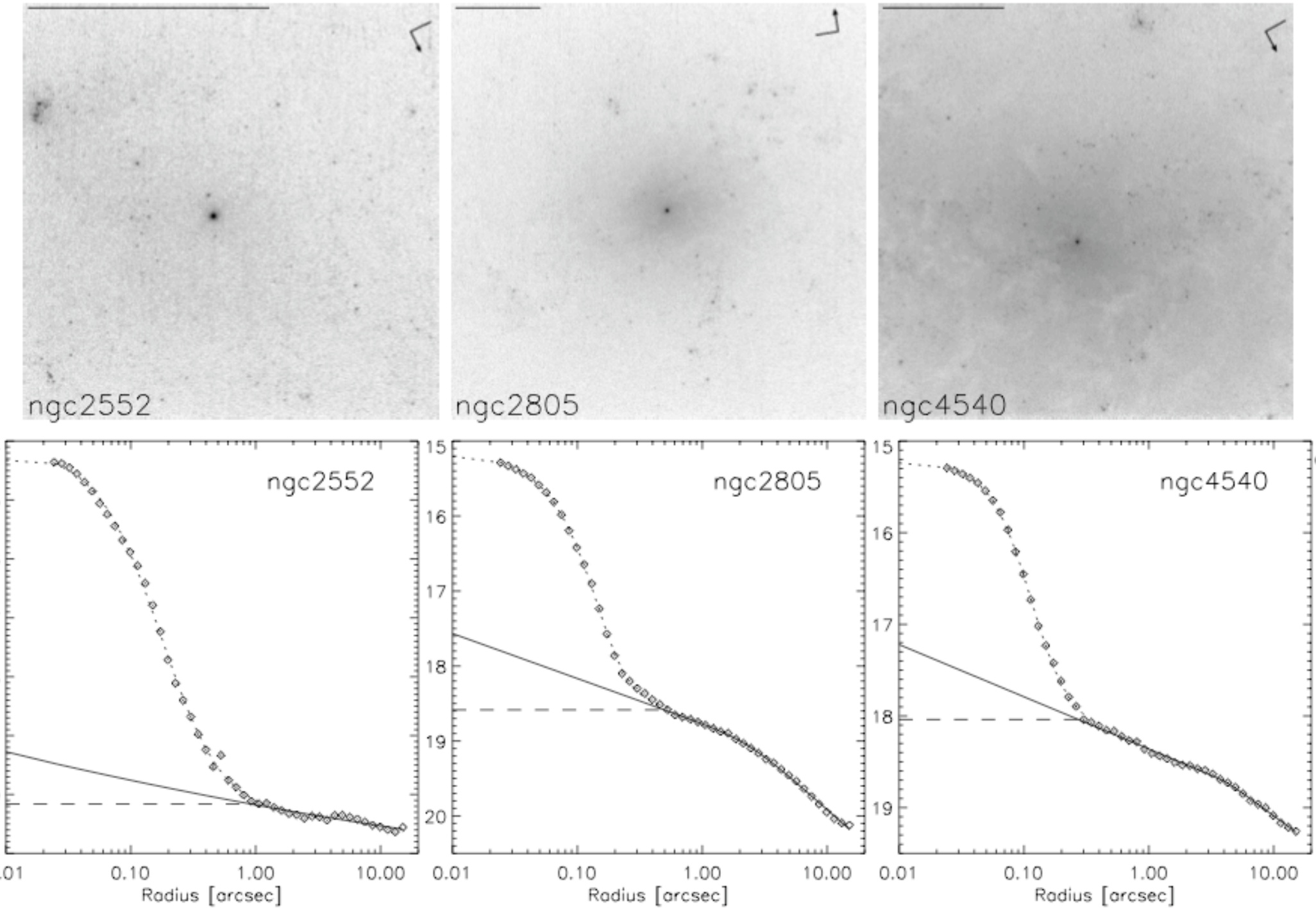
# The stellar cluster at the center of the Milky Way

Rainer Schödel, IAA-CSIC

CMO 2010, ESO, Garching,22 June 2010

# Nuclear Stellar Clusters

# Nuclear Star Clusters (NSCs)




*Böker et al. (2002)*

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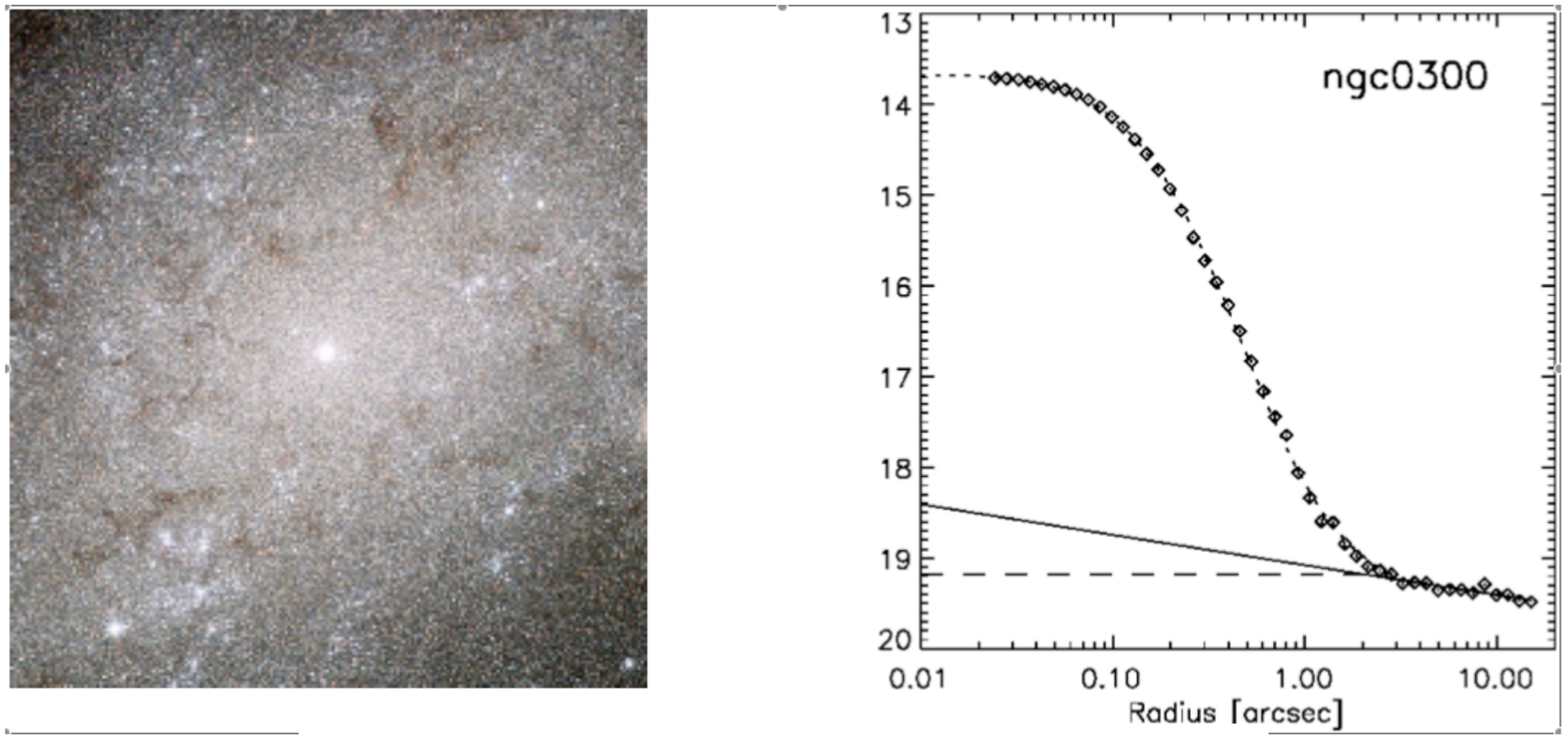



*van der Marel et al. (2007), image from the observations of Bresolin et a. (2005)*

# Nuclear Star Clusters (NSCs)

NSCs are detected *unambiguously* in 50%-75% of spiral, spheroids ("dwarf ellipticals"), and S0 galaxies. Their actual rate of occurrence in these galaxies may be close to 100%.

NSCs appear to be absent in elliptical galaxies (i.e. products of major mergers: coreless and extra-light ellipticals).

*see also, e.g., Phillips+ 1996; Carollo+ 1998; Matthews+ 1999; Böker+ 2002, 2004; Balcells+ 2003; Ferrarese+ 2006; Kormendy+ 2009*

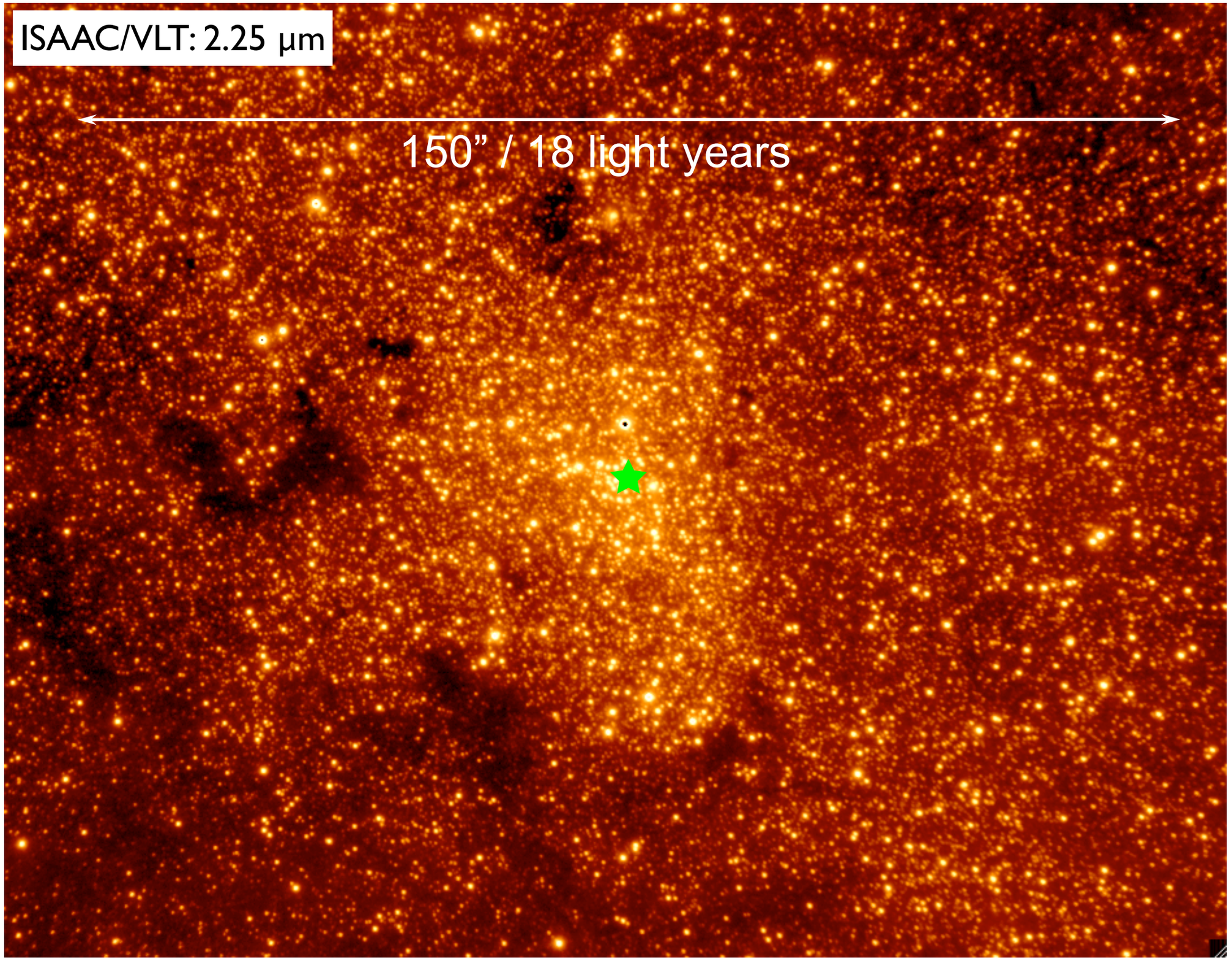
# Nuclear star clusters

- **Half-light radii** typically 2-5 pc
- **Masses** of $10^6$ - $10^7$ $M_\odot$
- **Complex star formation histories**: evidence for frequent and repetitive star formation episodes, most recent generation often younger than $10^8$ yr
- NSCs may obey similar **scaling relationships with properties of host galaxies** as do massive black holes

see, e.g., review by *T. Böker (2008)*

# The Nuclear Stellar Cluster of the Milky Way

# A Word about Extinction…



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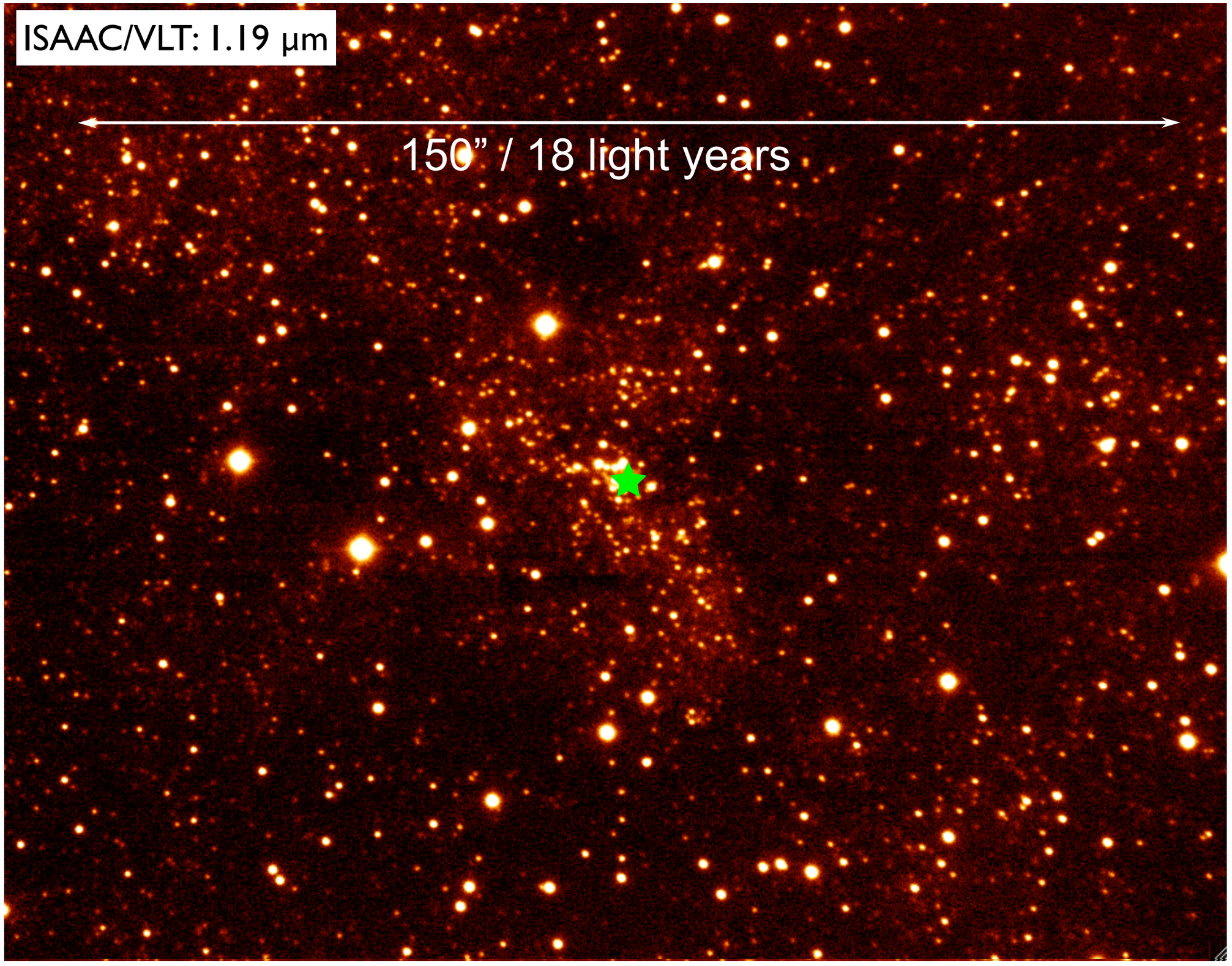

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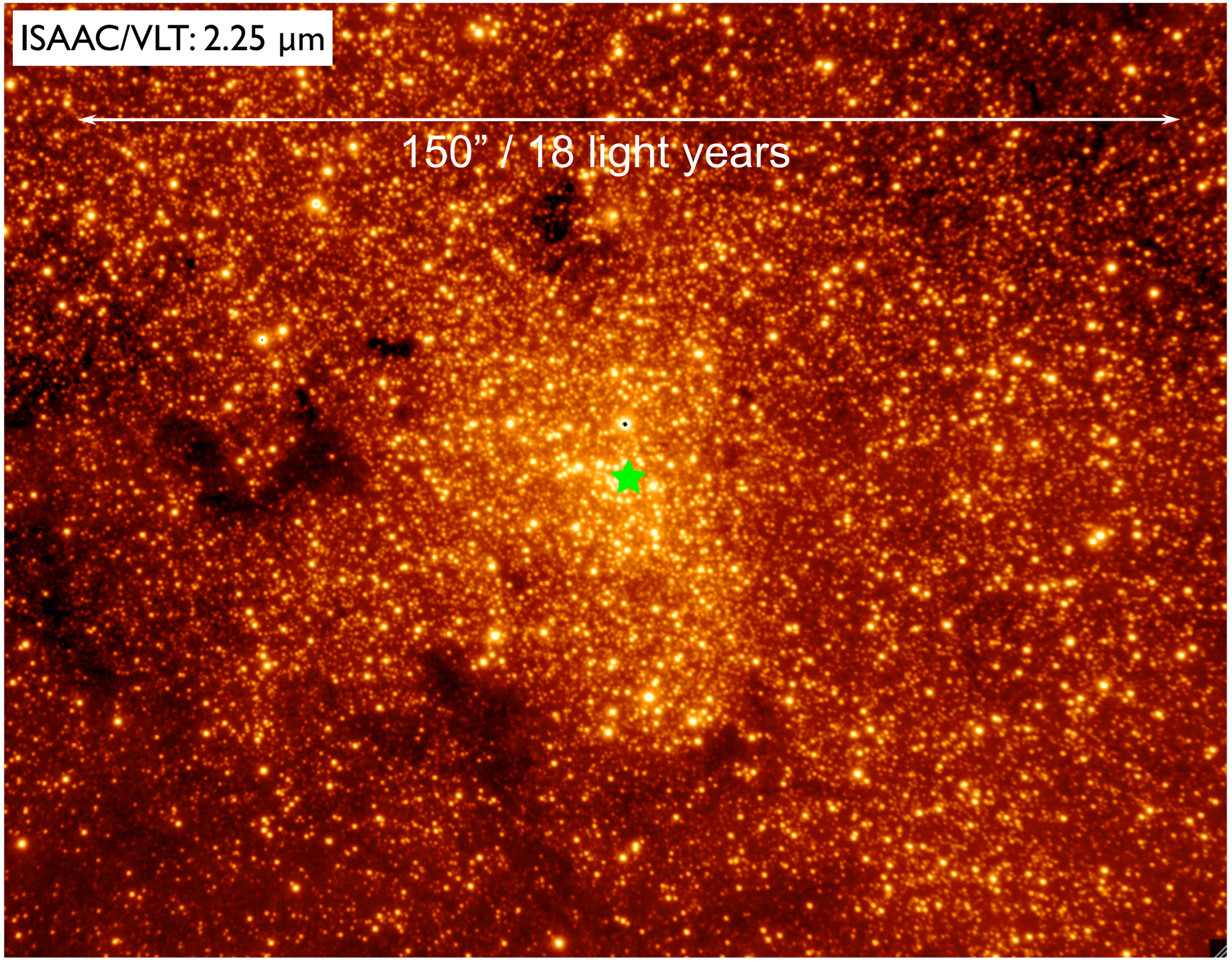

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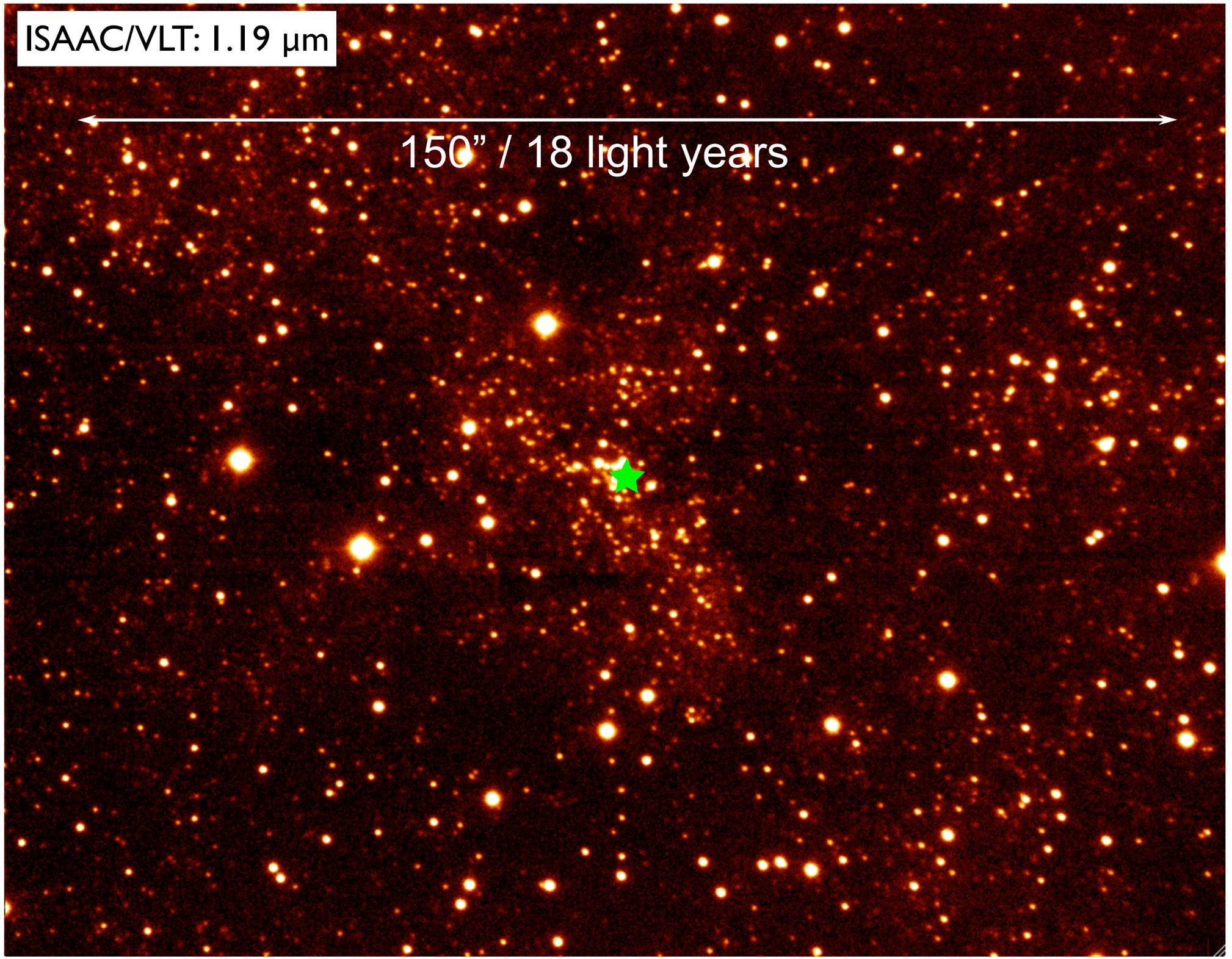

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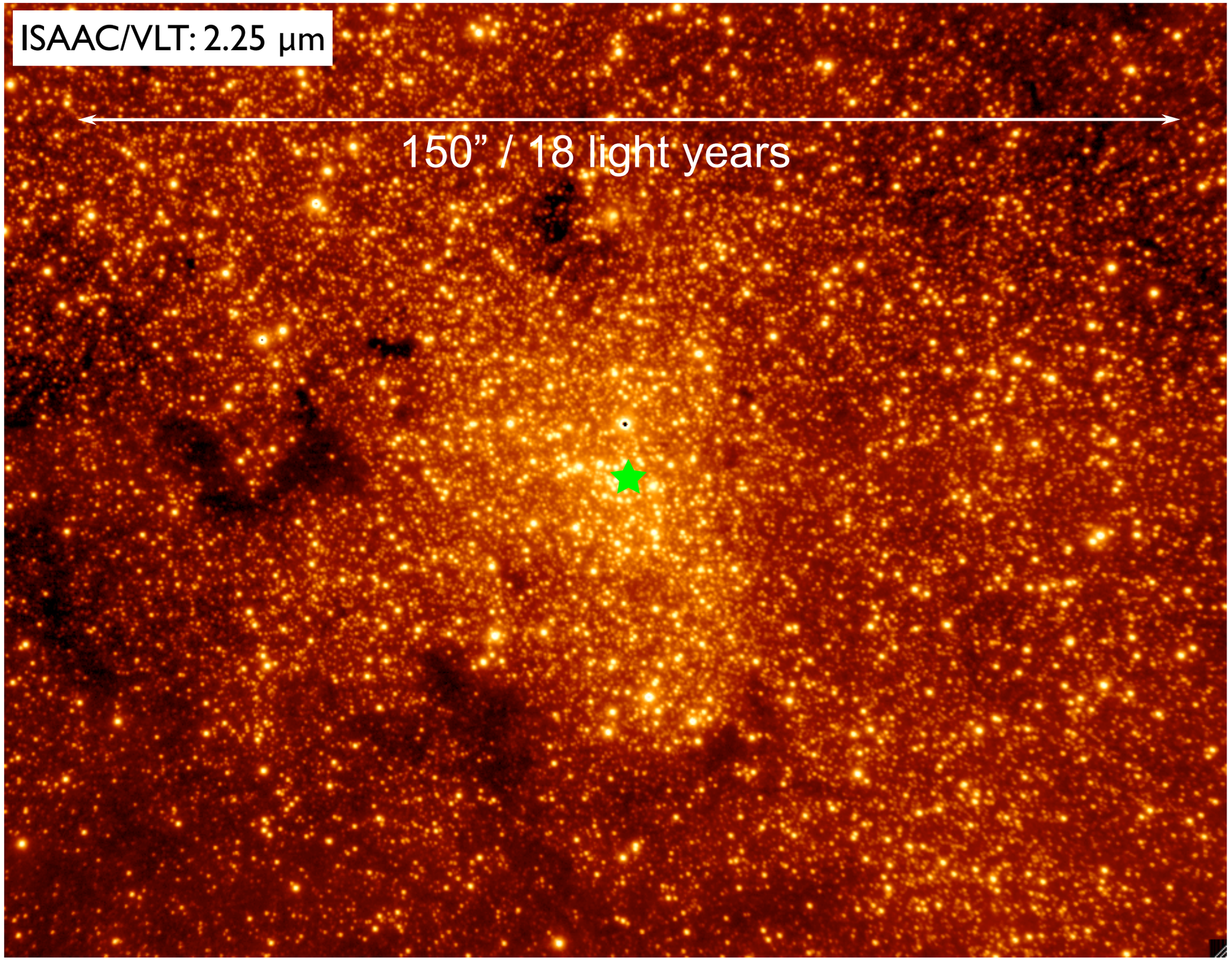

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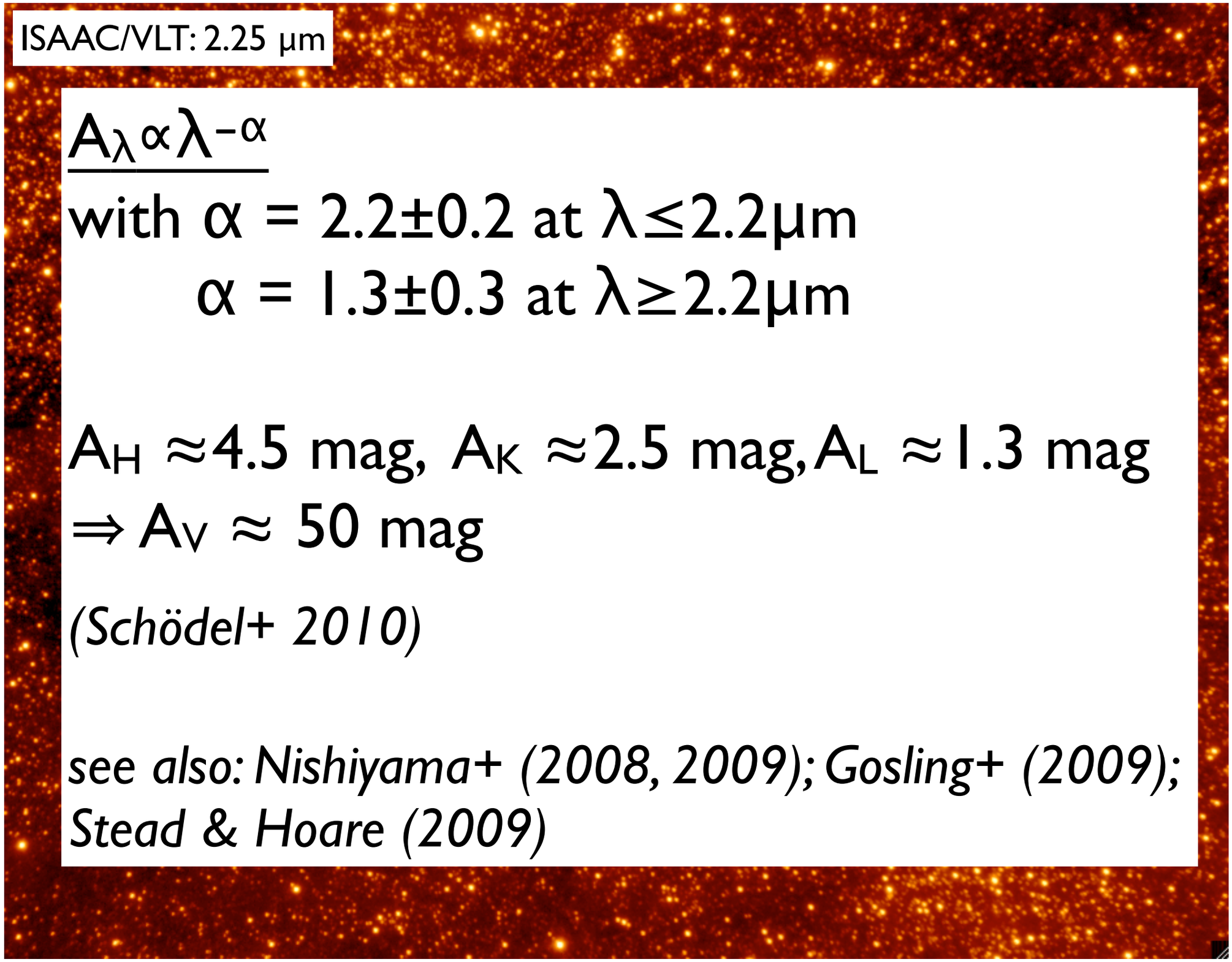



$\underline{A_\lambda \propto \lambda^{-\alpha}}$

with $\alpha = 2.2 \pm 0.2$ at $\lambda \leq 2.2\mu m$

$\alpha = 1.3 \pm 0.3$ at $\lambda \geq 2.2\mu m$

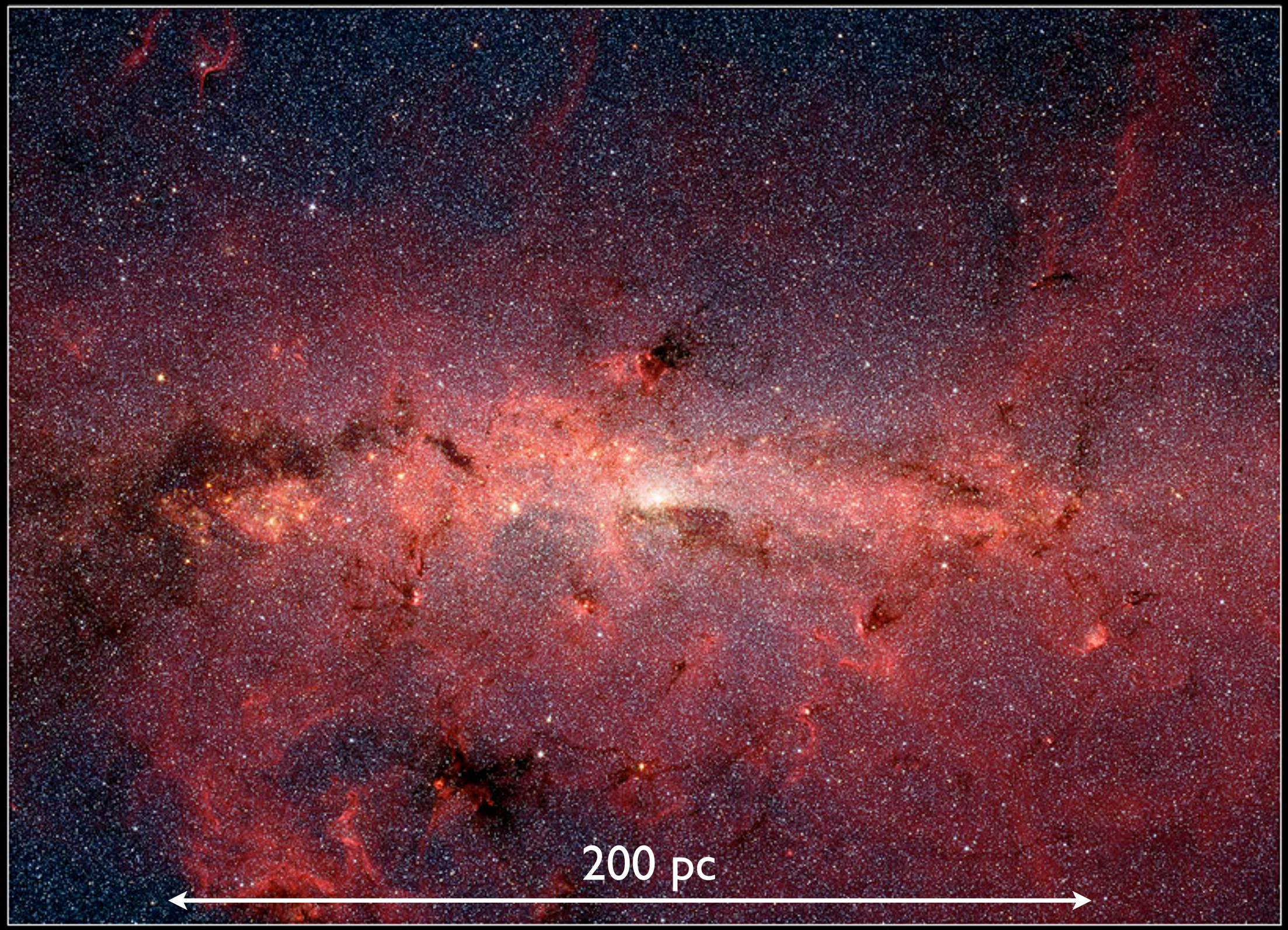
$A_H \approx 4.5$ mag, $A_K \approx 2.5$ mag, $A_L \approx 1.3$ mag

$\Rightarrow A_V \approx 50$ mag

*(Schödel+ 2010)*

see *also: Nishiyama+ (2008, 2009); Gosling+ (2009); Stead & Hoare (2009)*

# Contemporary view of the Galactic Center




The Center of the Milky Way Galaxy

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

Spitzer Space Telescope • IRAC

ssc2006-02a

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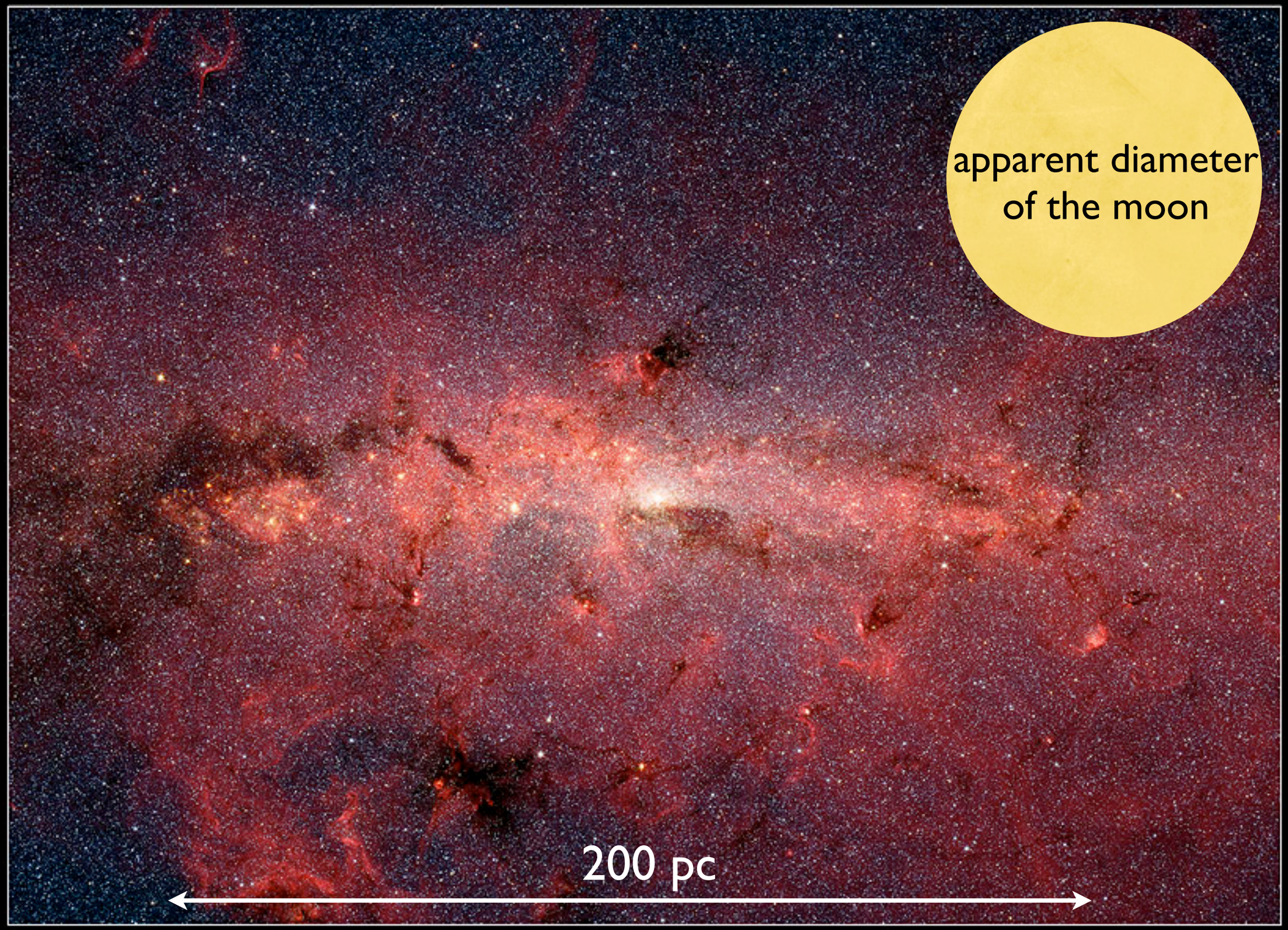


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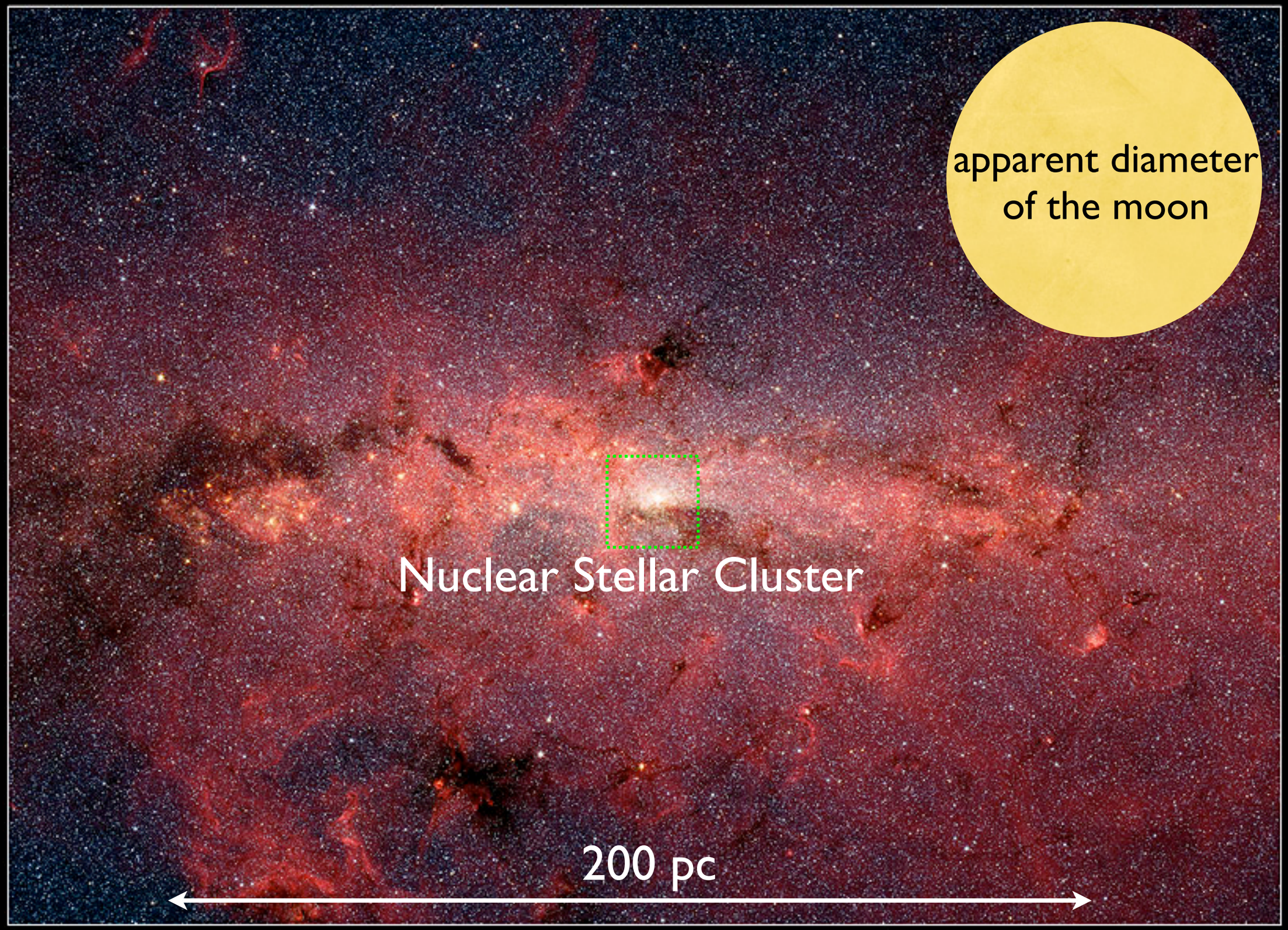


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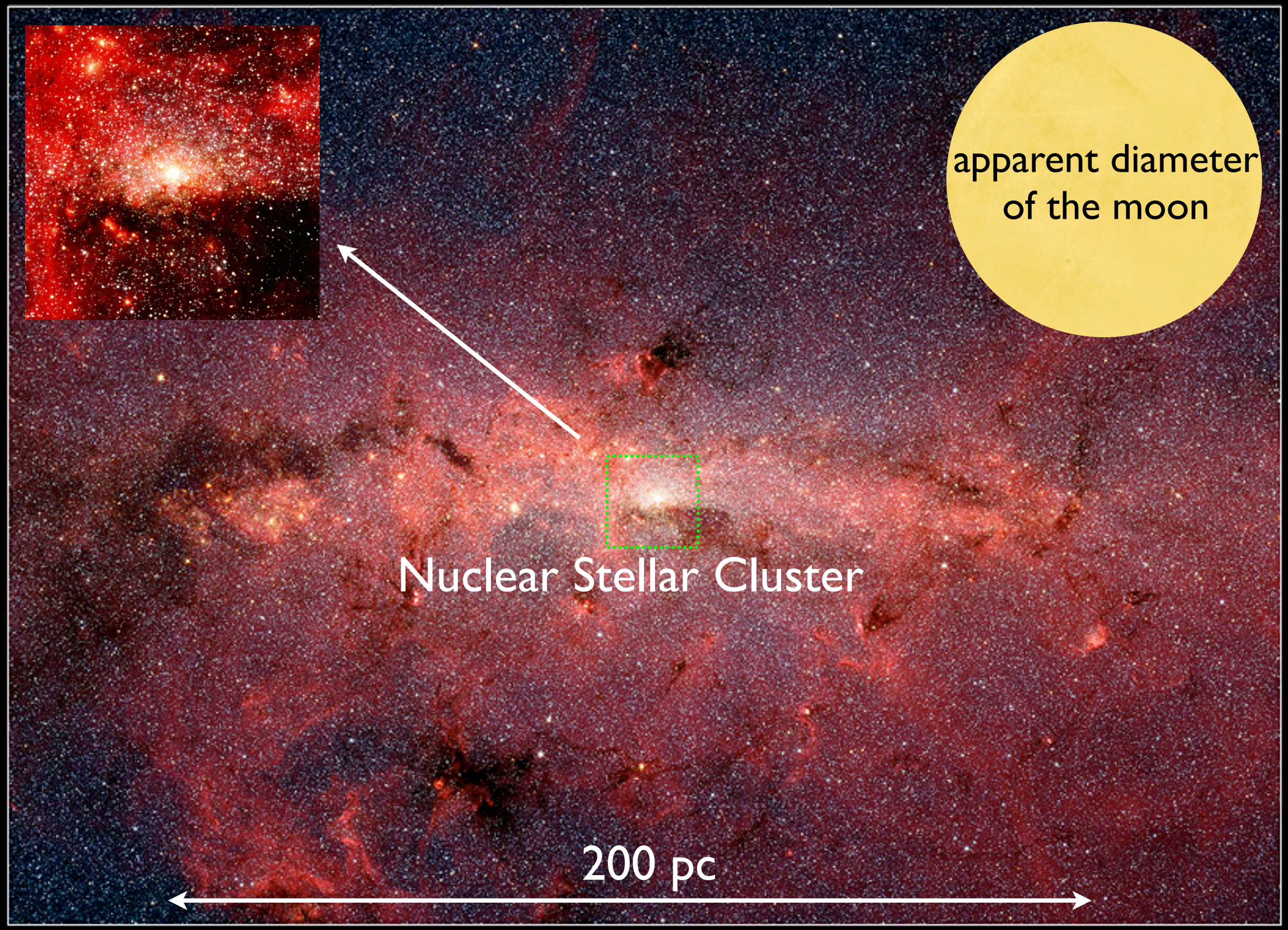


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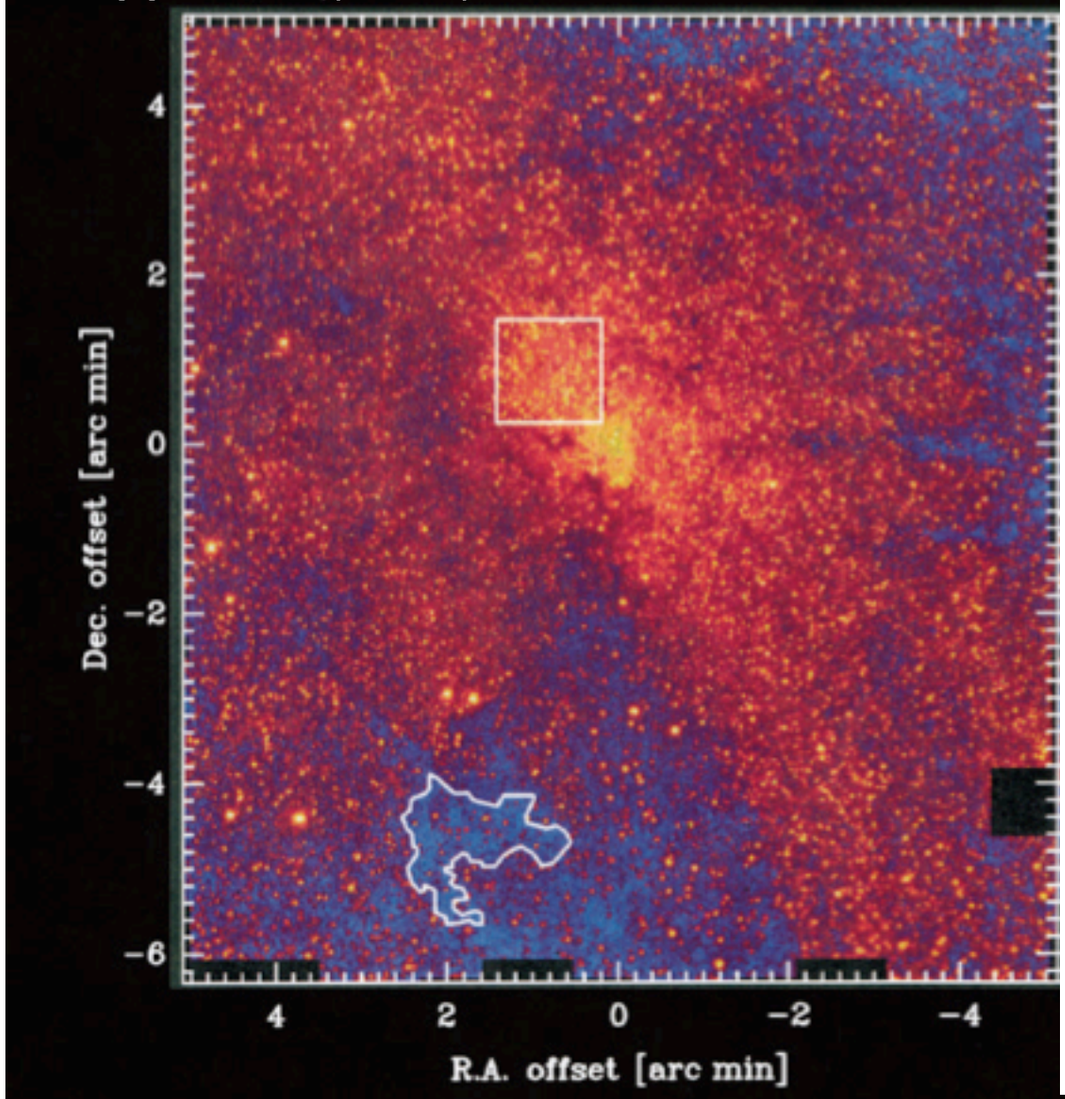
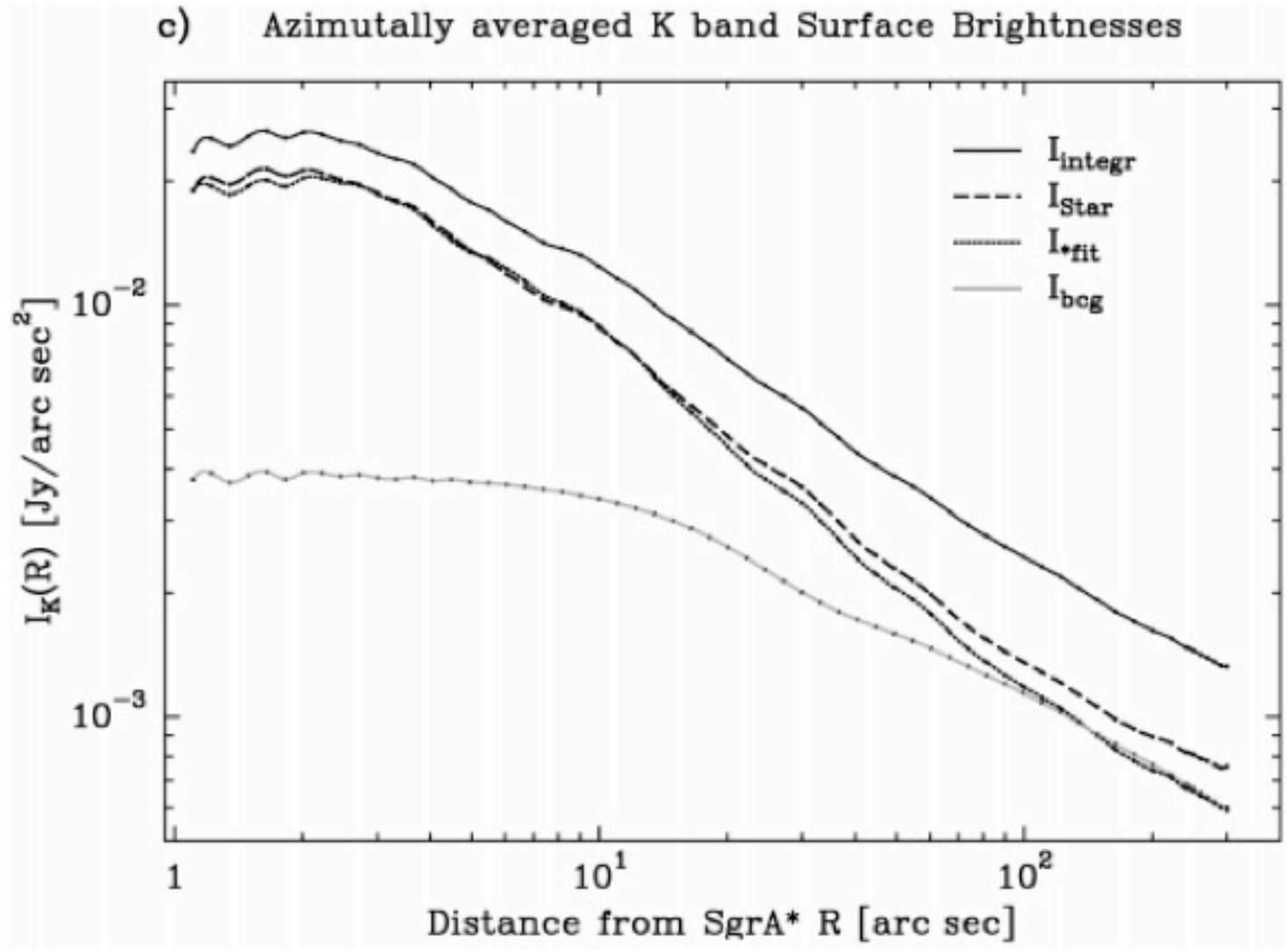
ssc2006-02a

Philipp et al. (1999)

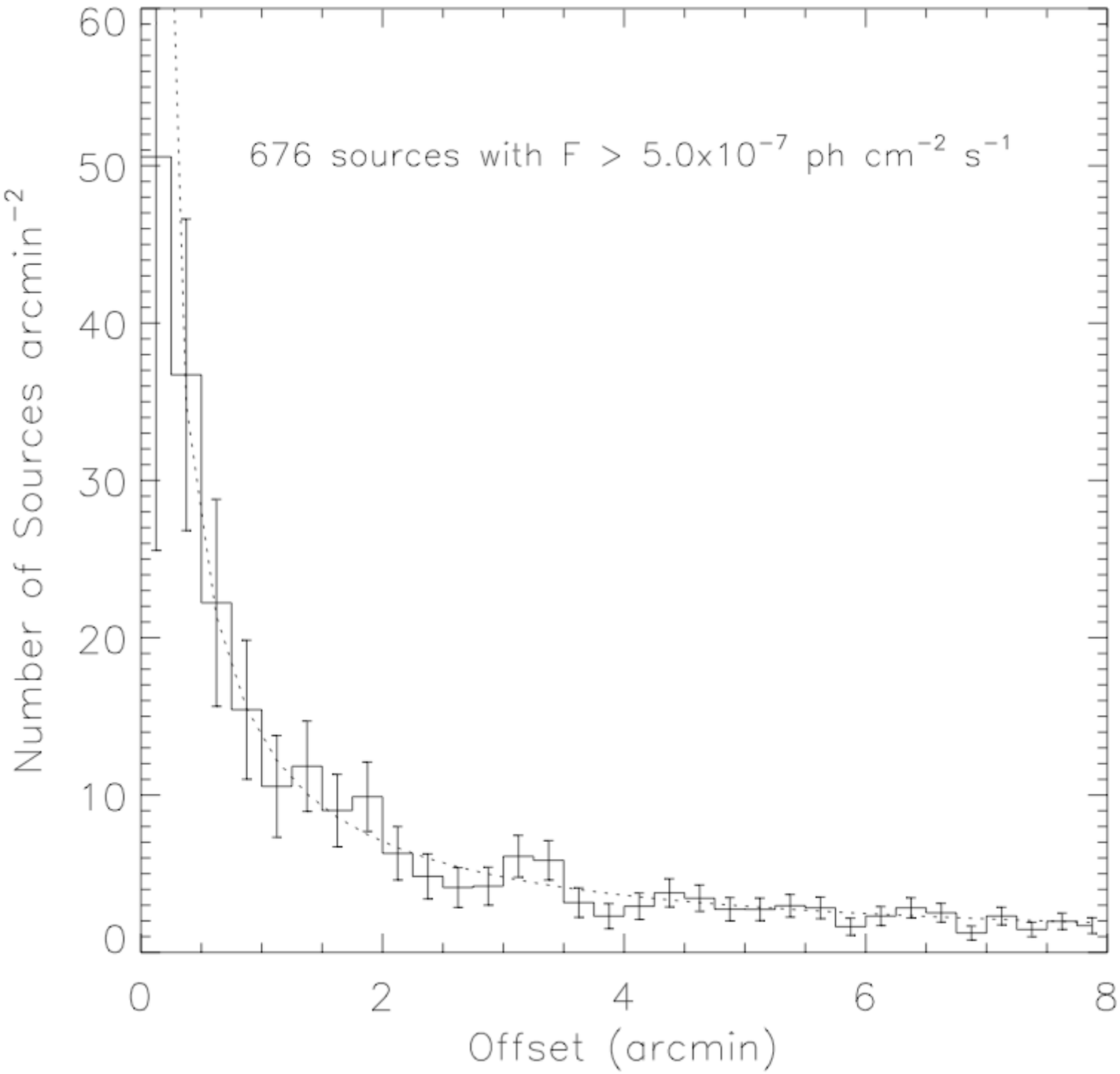



# Studies on stellar number and/or light surface density of NSC find $\rho(r) \propto r^{-1.5...-2}$ at distances r>~10”

e.g., *Becklin & Neugebauer, 1968* - $\rho \propto r^{-1.8}$ (bulge reference field subtracted); *Catchpole+, 1990; Eckart+ ,1993* - $\rho \propto r^{-1.8}$ (SHARP source counts, inner 15”); *Genzel+, 1996* - $\rho \propto r^{-1.8}$ (inner 20”, late-type stars); *Haller+ 1996; Genzel+, 2003; Schoedel+, 2007* - $\rho \propto r^{-1.75}$ (ISAAC+NACO, no bulge correction); *Graham & Spitler, 2009* - $\rho \propto r^{-2.0...2,7}$ (2MASS light density, bulge correction); *Oh +, 2009* - $\rho \propto r^{-1.5}$ *(various models and data)*

# Some help from X-ray observations...




Surface density of GC X-ray point sources $\propto R^{-1.0\pm0.1}$

*(*CHANDRA: *Muno et al. 2003)*

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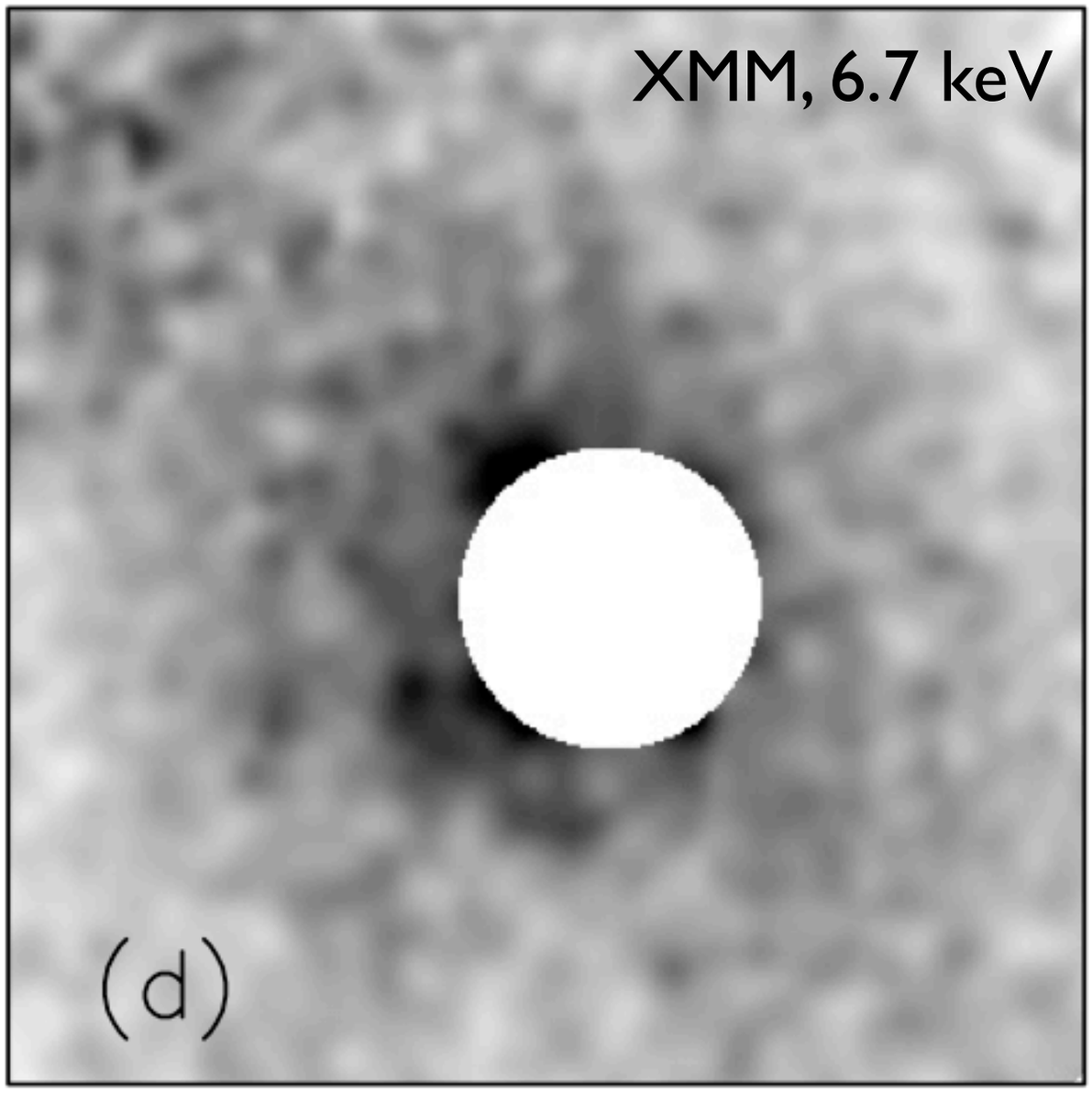

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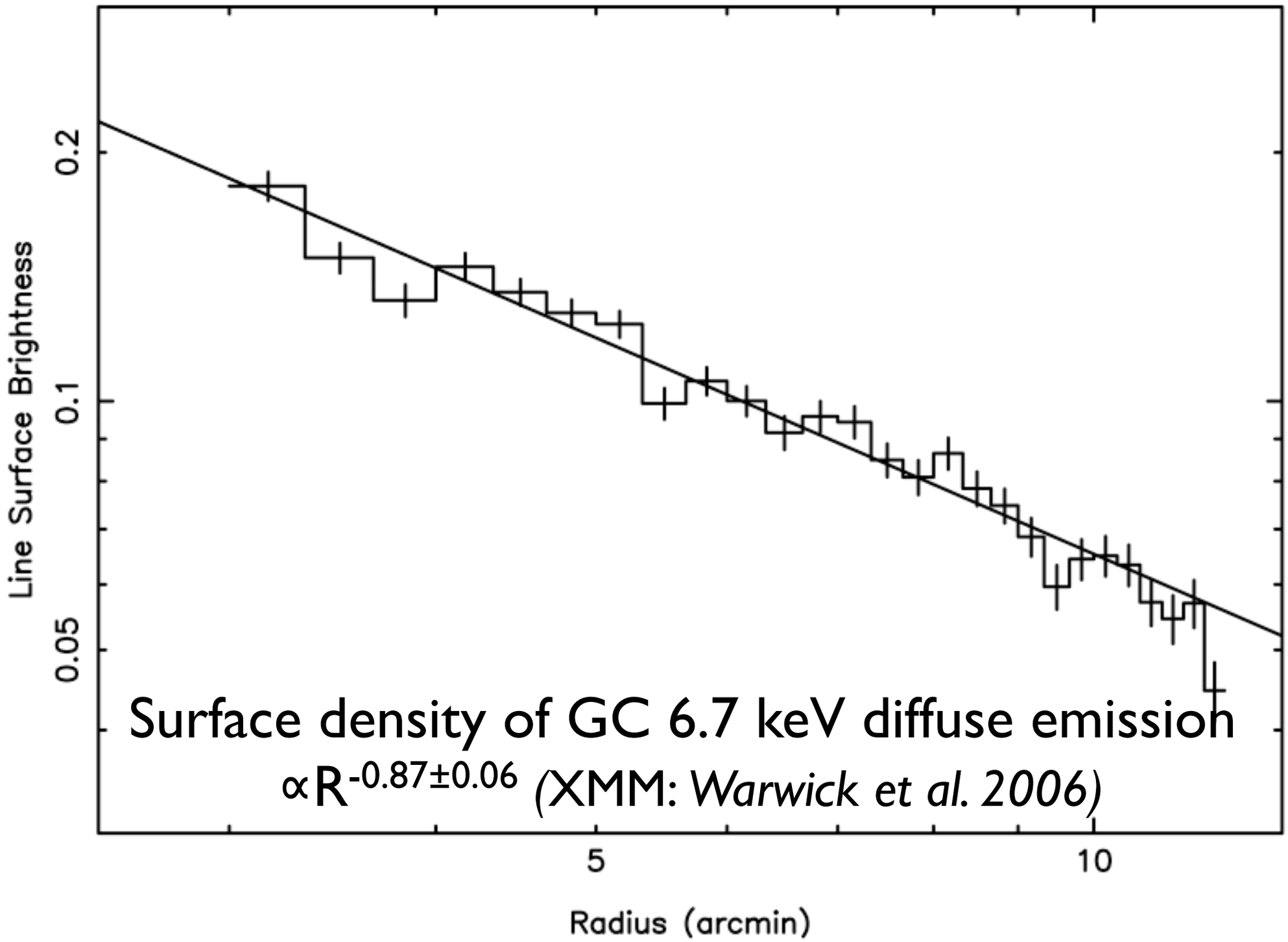
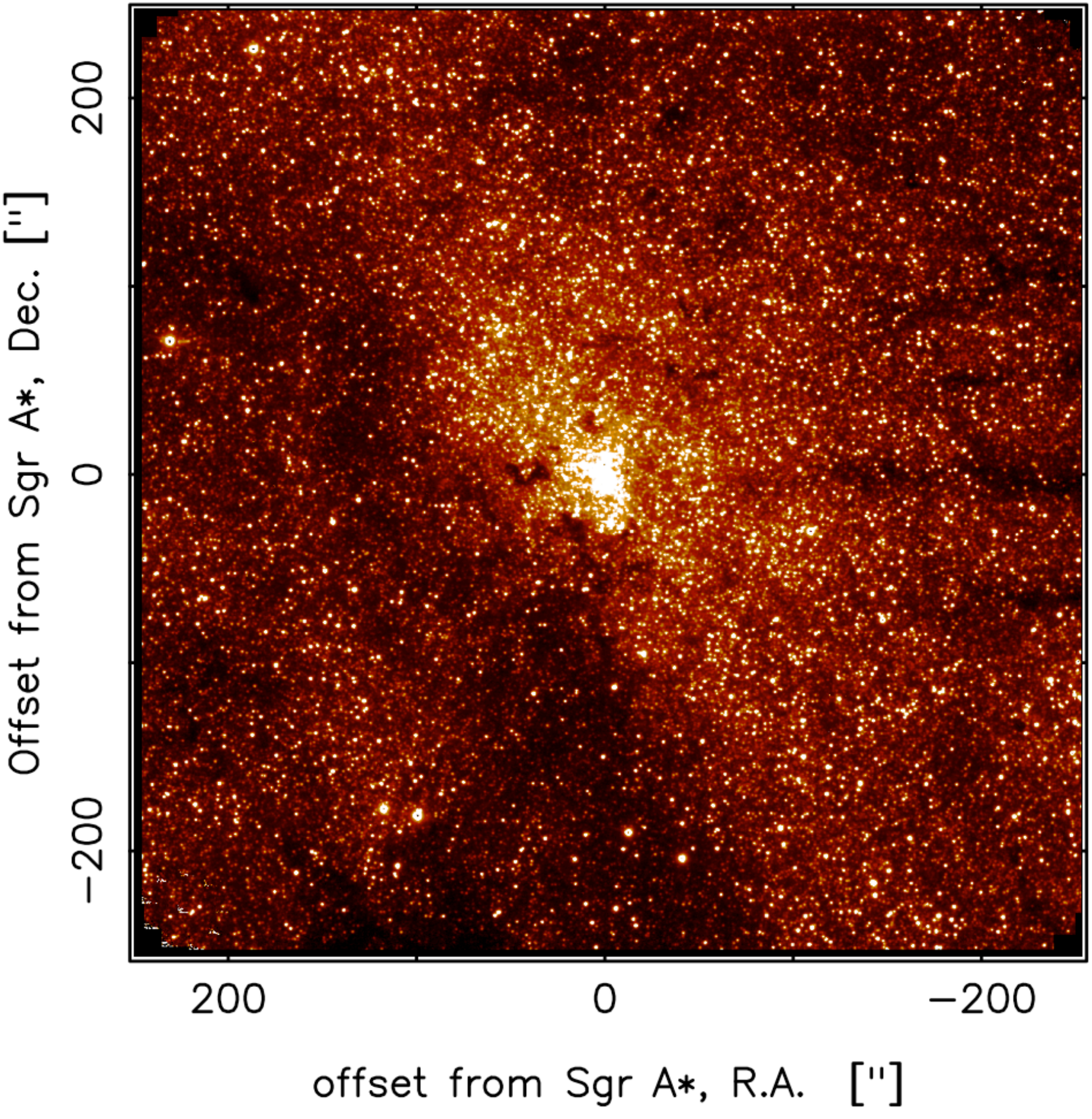


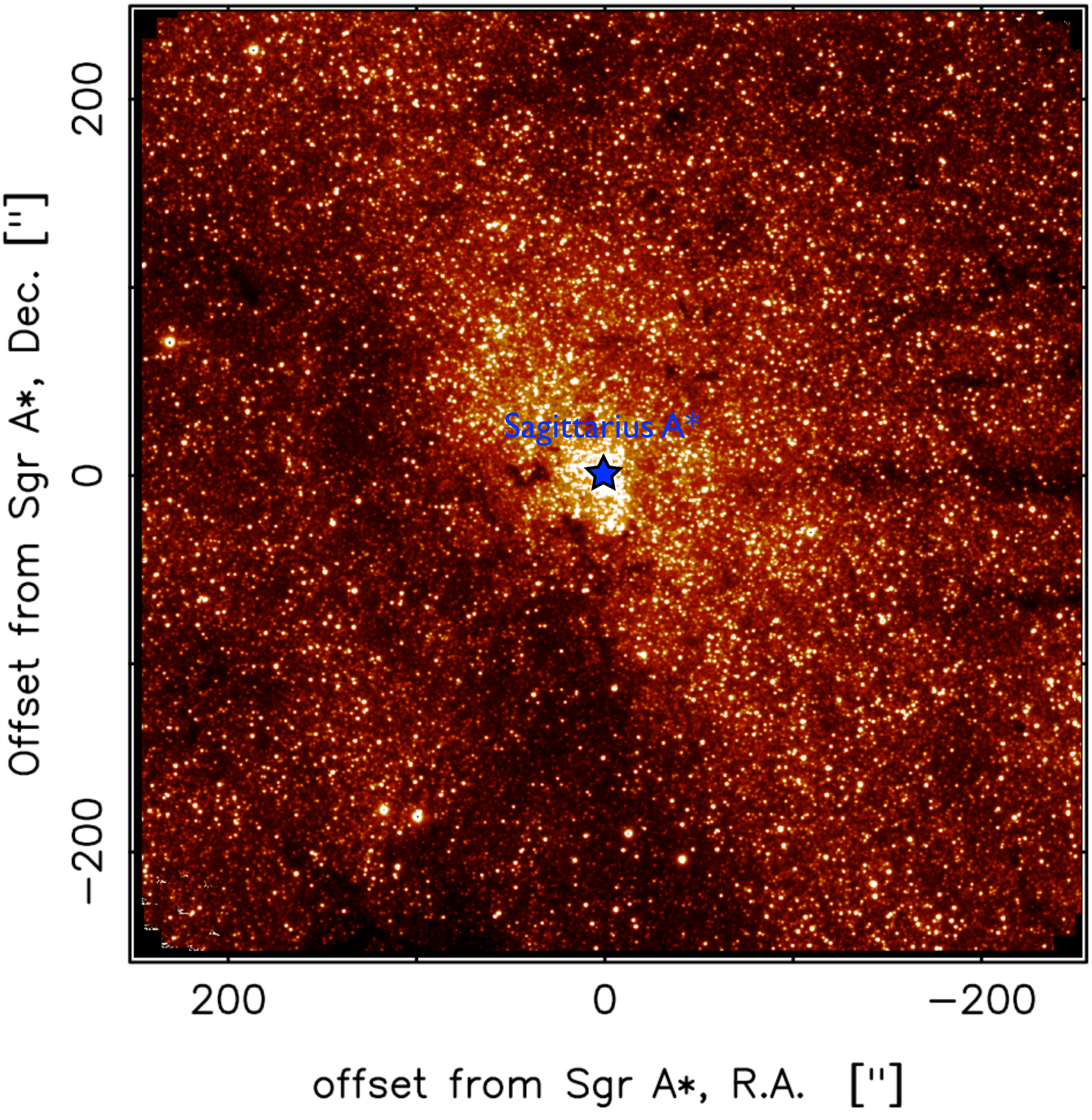

Surface density of GC 6.7 keV diffuse emission

$\propto R^{-0.87\pm0.06}$ *(*XMM: *Warwick et al. 2006)*




# IRSF/SIRIUS Ks

*Nishiyama et al. (2006, 2009)*

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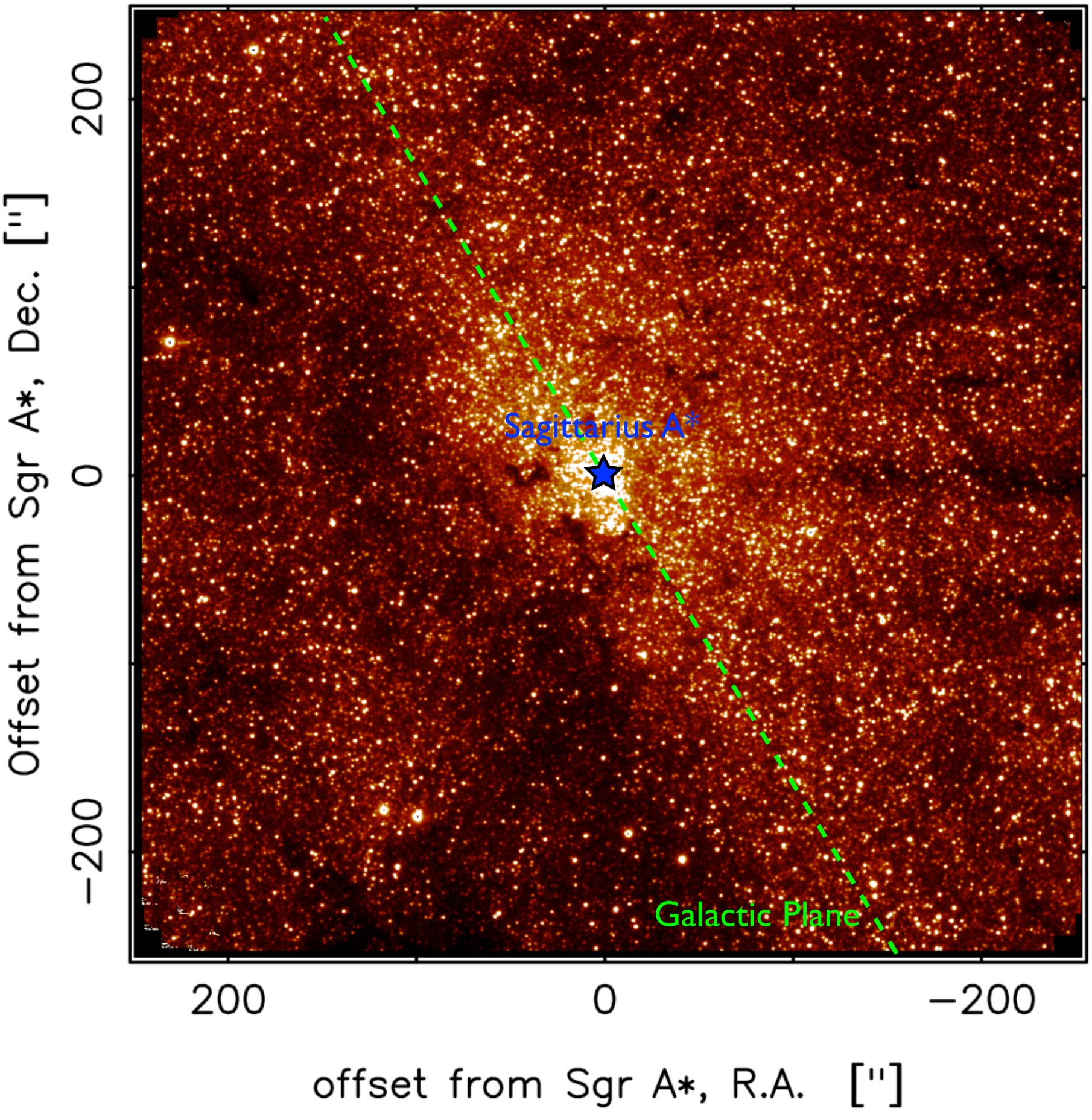



# IRSF/SIRIUS Ks

*Nishiyama et al. (2006, 2009)*

Fit with N~3.4 Sérsic profile
half-light radius, ~130 arcsec/5 pc
(Graham & Spitler, 2009: N~3/3pc)

$$I(r) = I_e \exp\left\{ -b\left[\left(\frac{R}{R_e}\right)^{1/n} - 1\right]\right\}$$

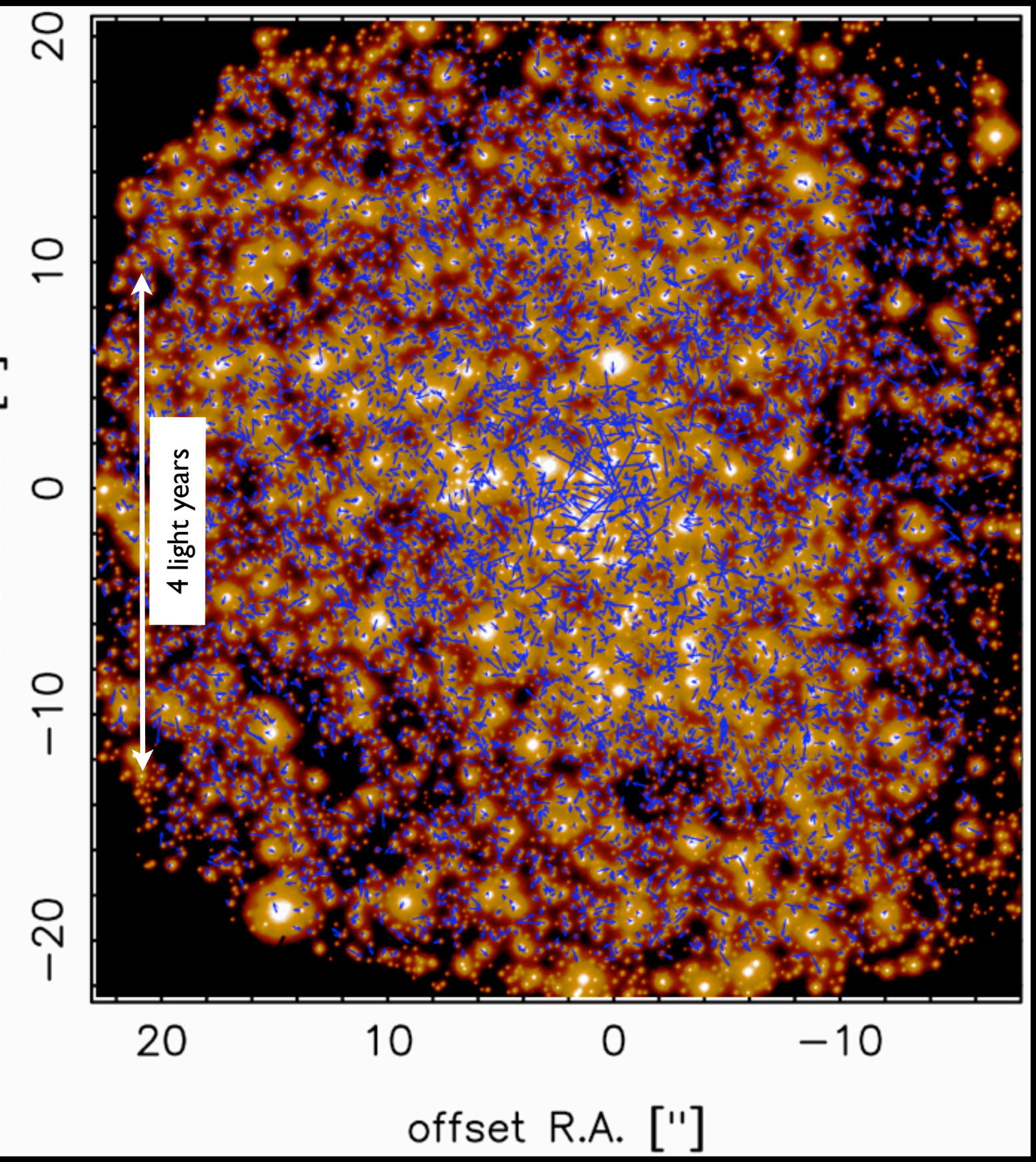
surface brightness [mag arcsec$^{-2}$]

11
12
13
14

0.1
1
10

distance from Sgr A* [pc]

# Kinematics




6000 proper motions within 1 pc of Sgr A*, data from Schoedel+ (2009) publicly available.

Based on 10 images taken between 2002 and 2008.

*Schödel, Merritt, & Eckart (2009); see also Trippe et al. (2008)*

# Kinematics

4 light years

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# Kinematics

4 light years

Sagittarius A*

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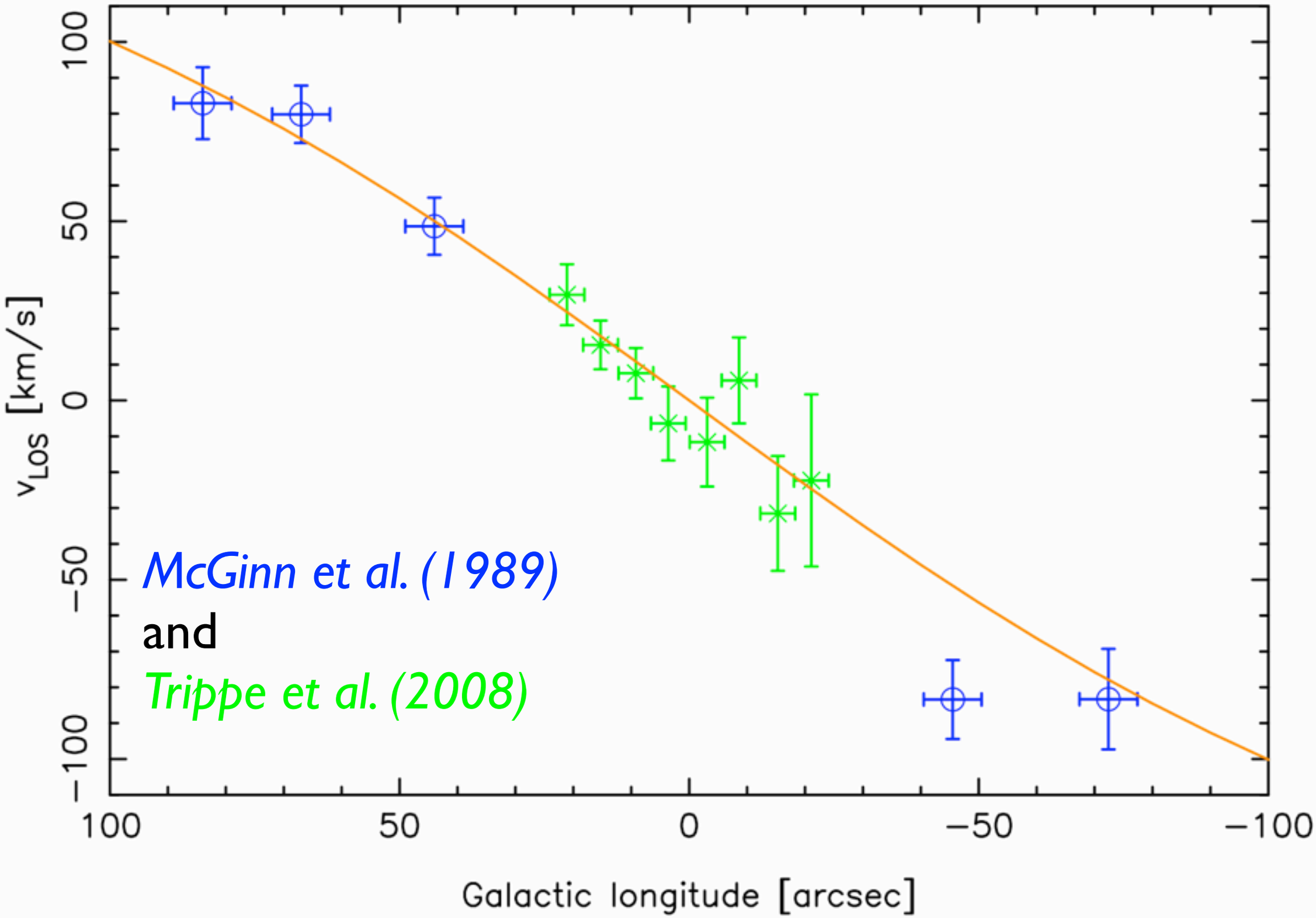
# Rotation of the NSC




see *Schödel, Merritt, & Eckart (2009, A&A)*

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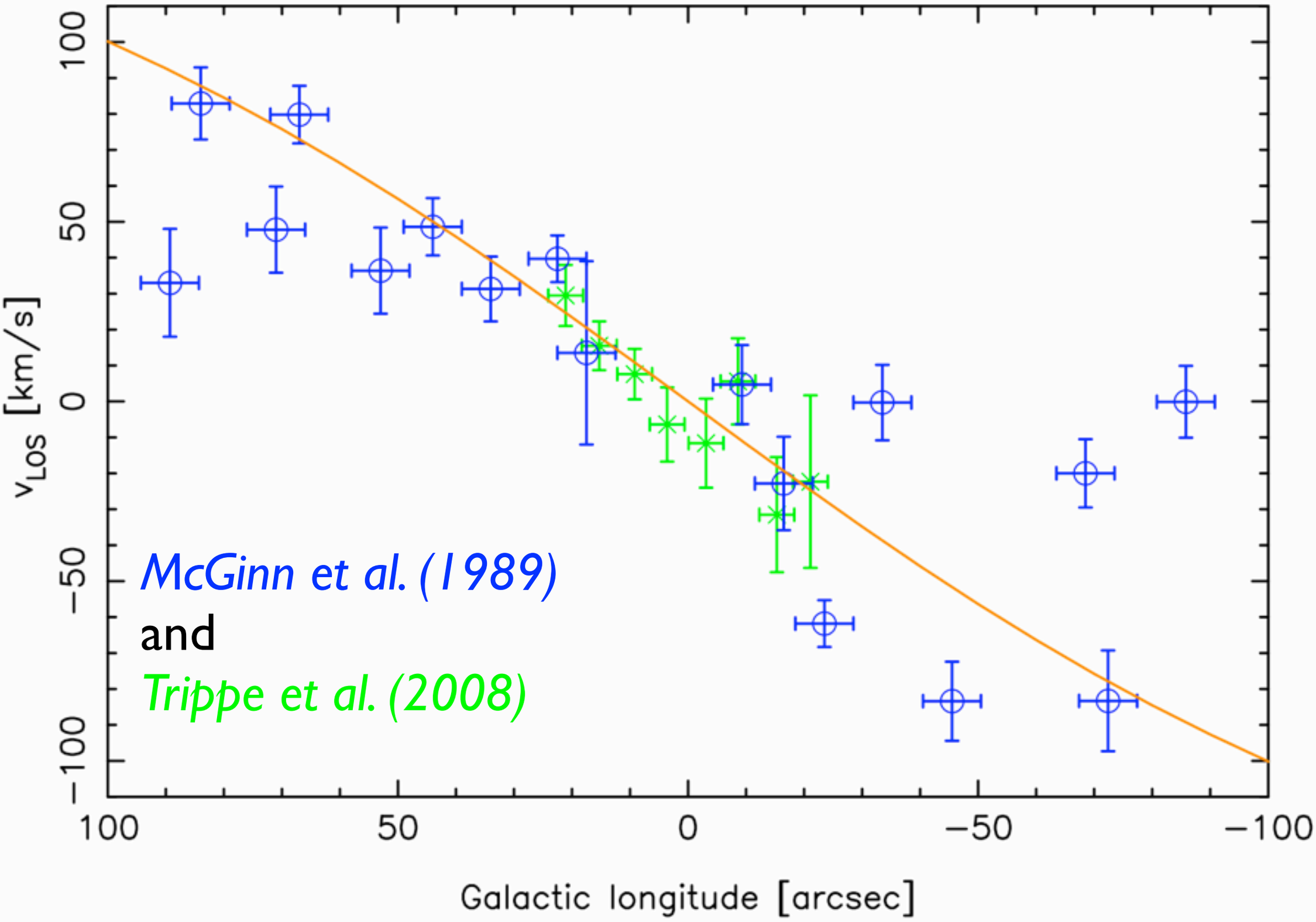


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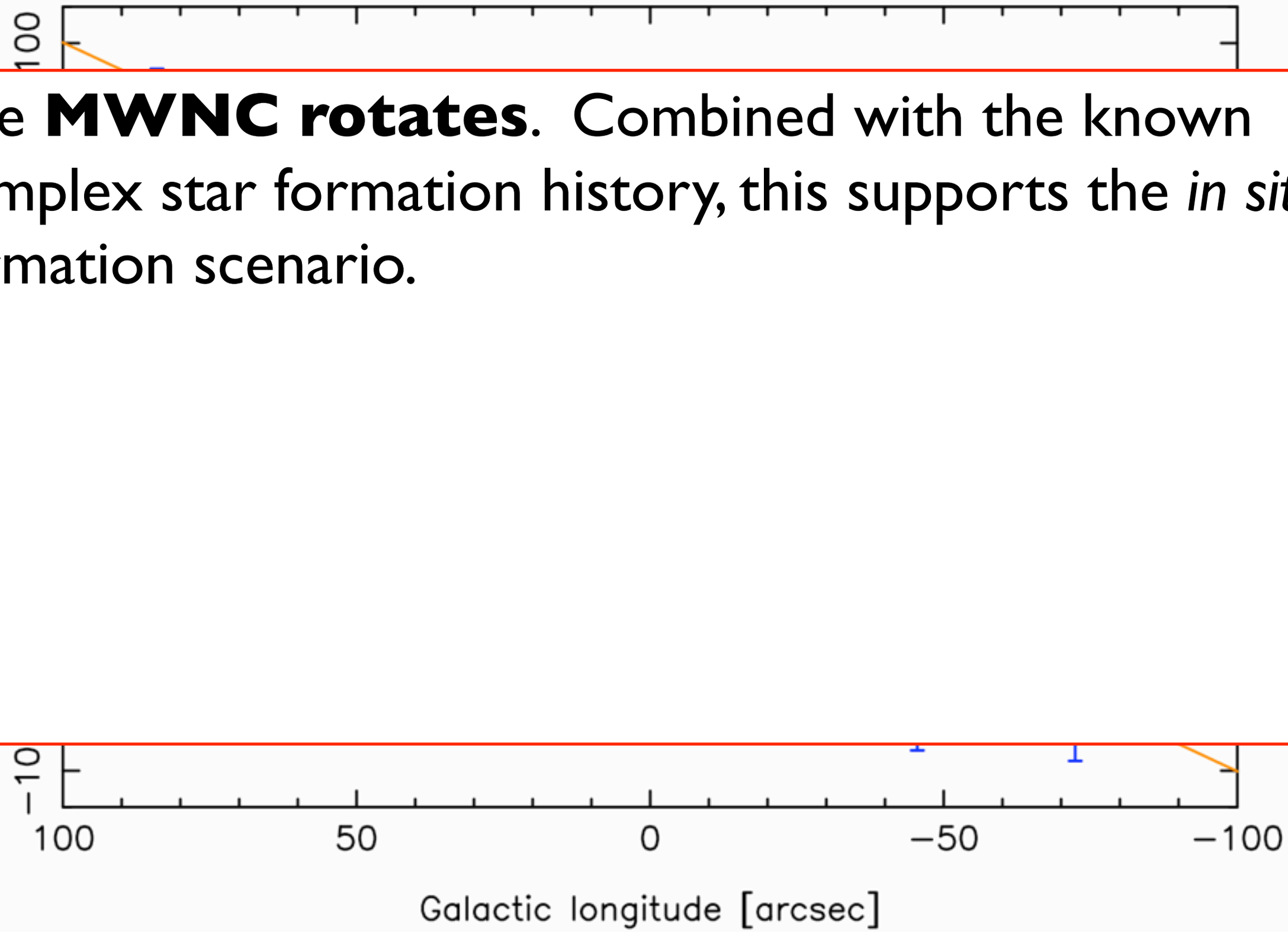


The **MWNC rotates**. Combined with the known complex star formation history, this supports the *in situ* formation scenario.

see *Schödel, Merritt, & Eckart (2009, A&A)*

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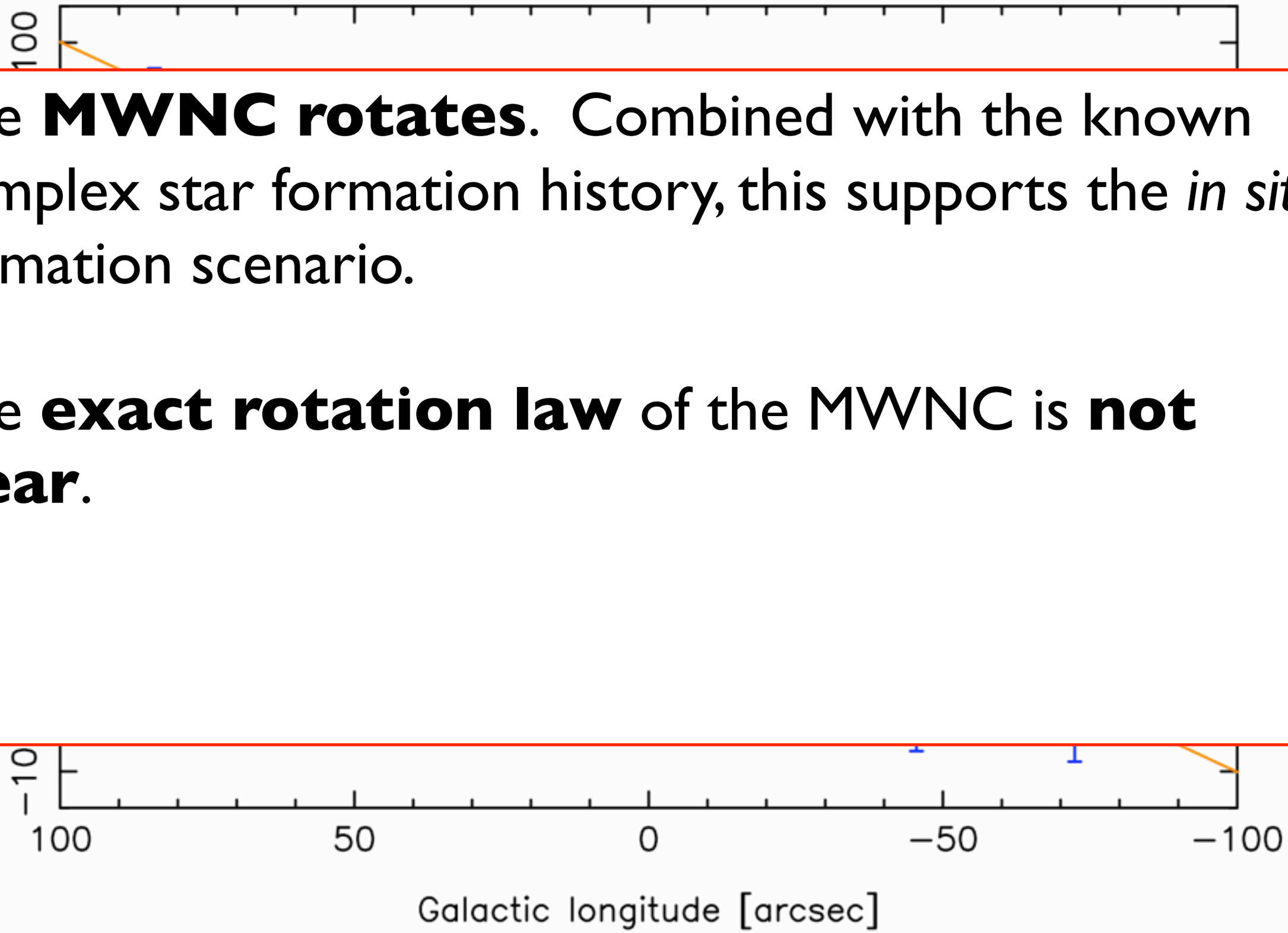
The **exact rotation law** of the MWNC is **not clear**.

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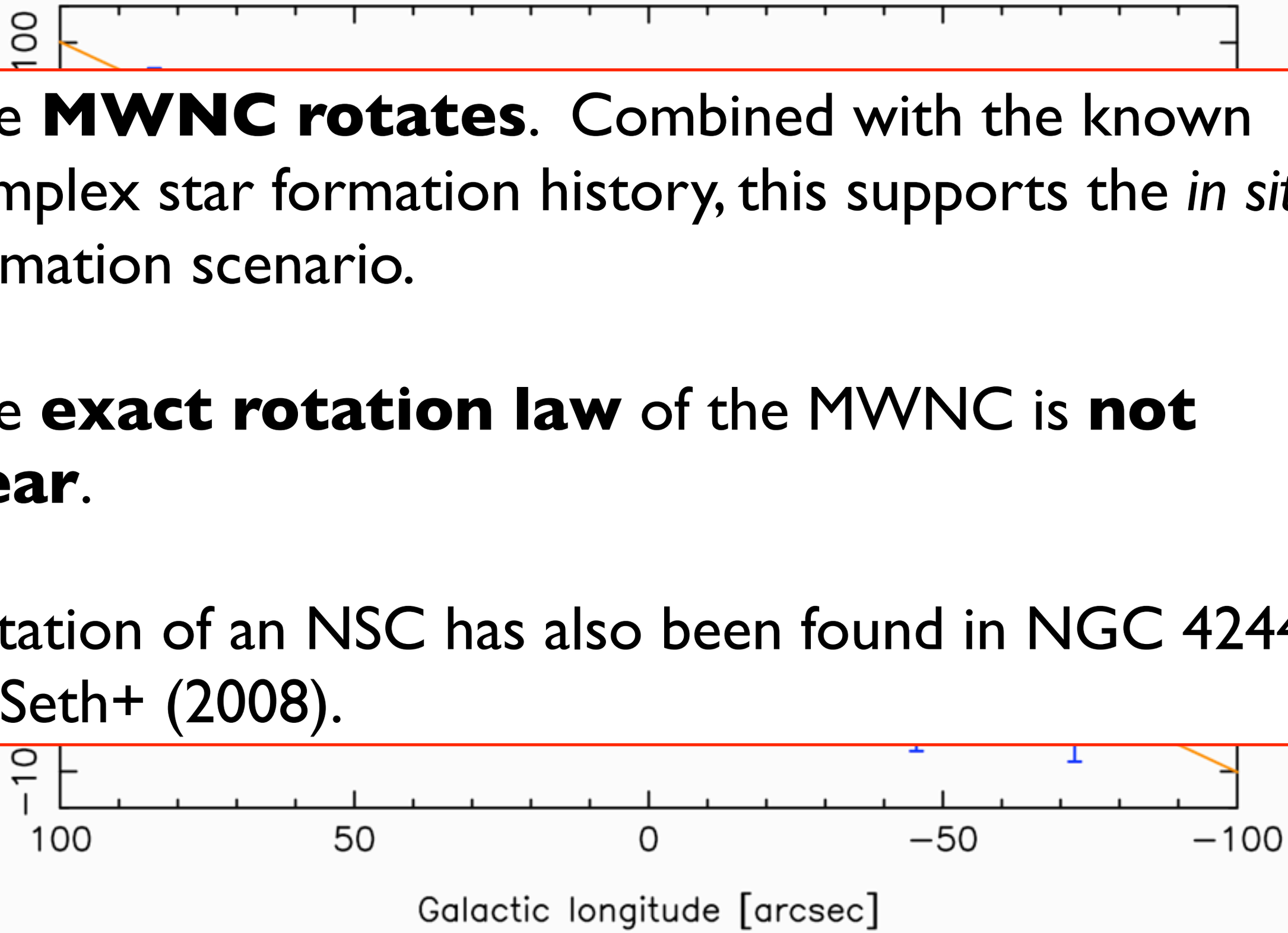


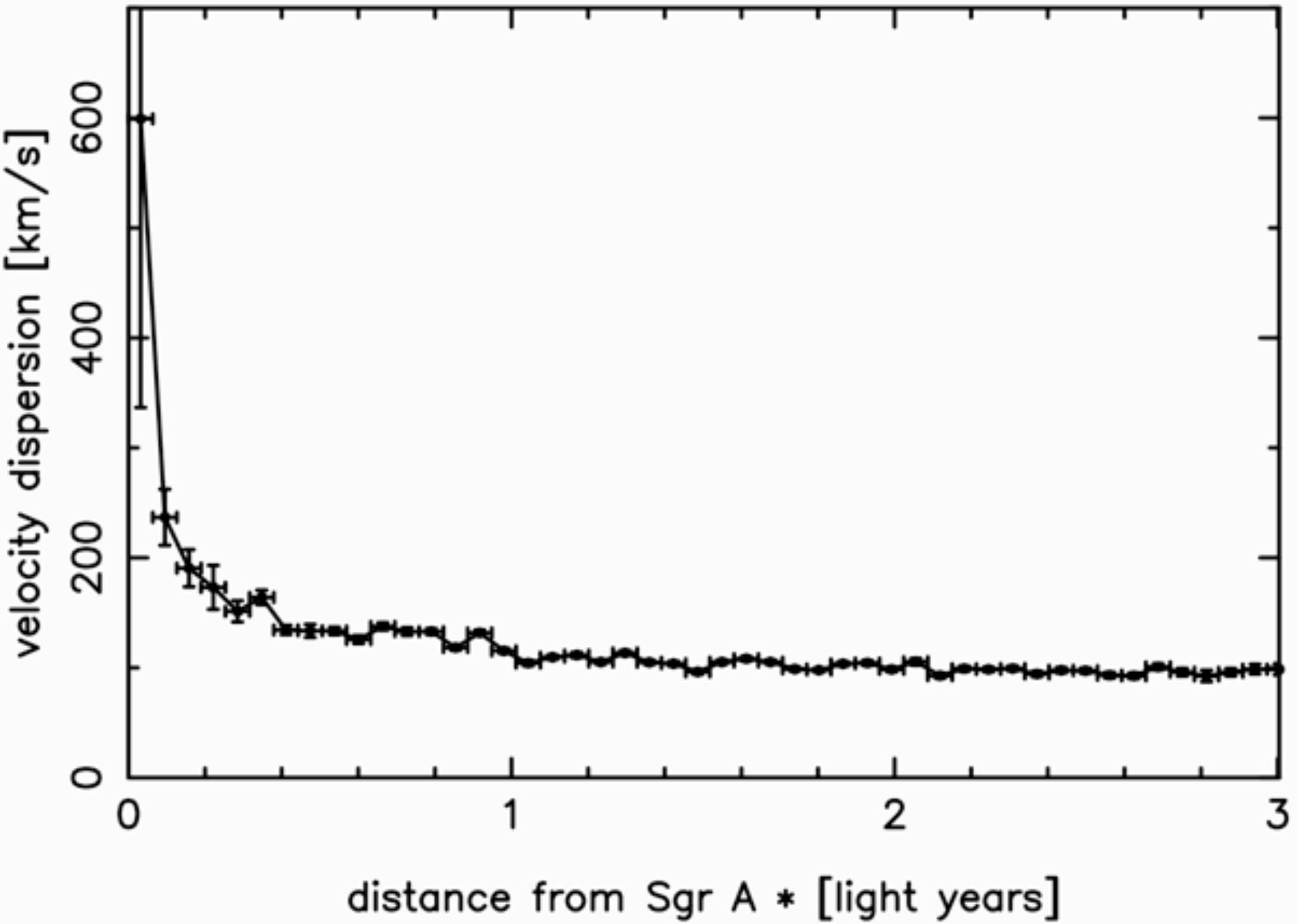

The **MWNC rotates**. Combined with the known complex star formation history, this supports the *in situ* formation scenario.

The **exact rotation law** of the MWNC is **not clear**.

Rotation of an NSC has also been found in NGC 4244 by Seth+ (2008).

see *Schödel, Merritt, & Eckart (2009, A&A)*

# Velocity dispersion at the Galactic Center



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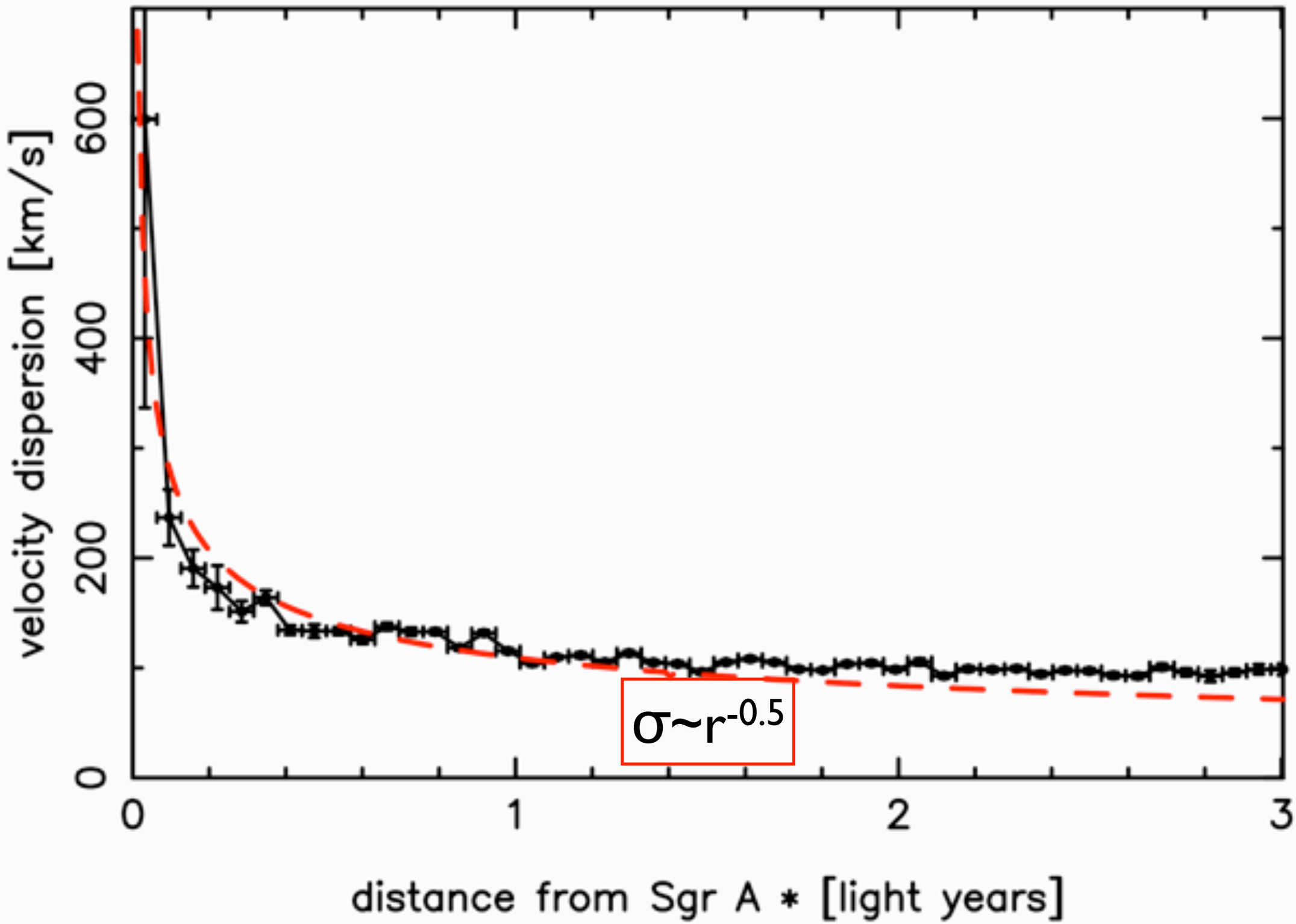

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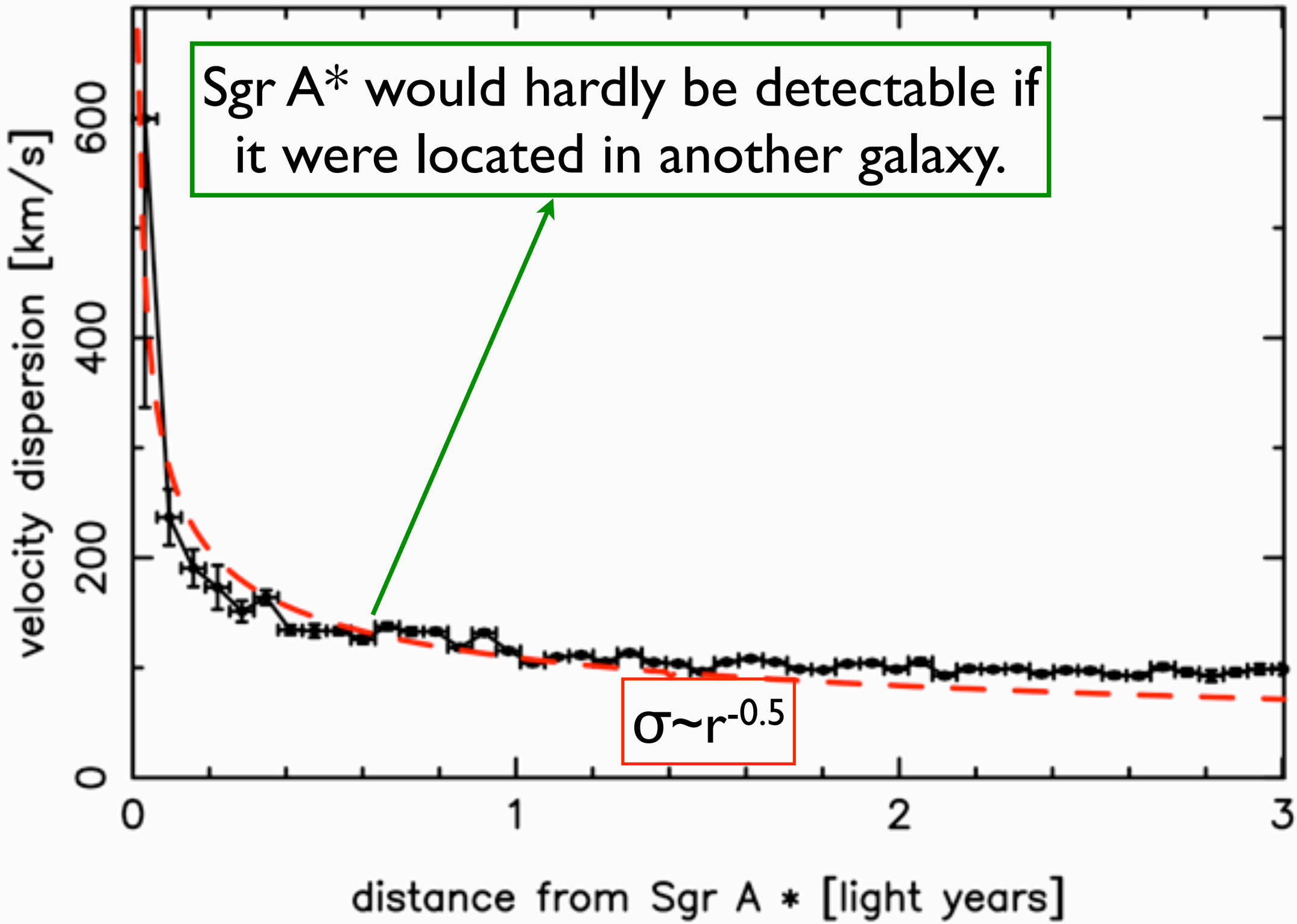

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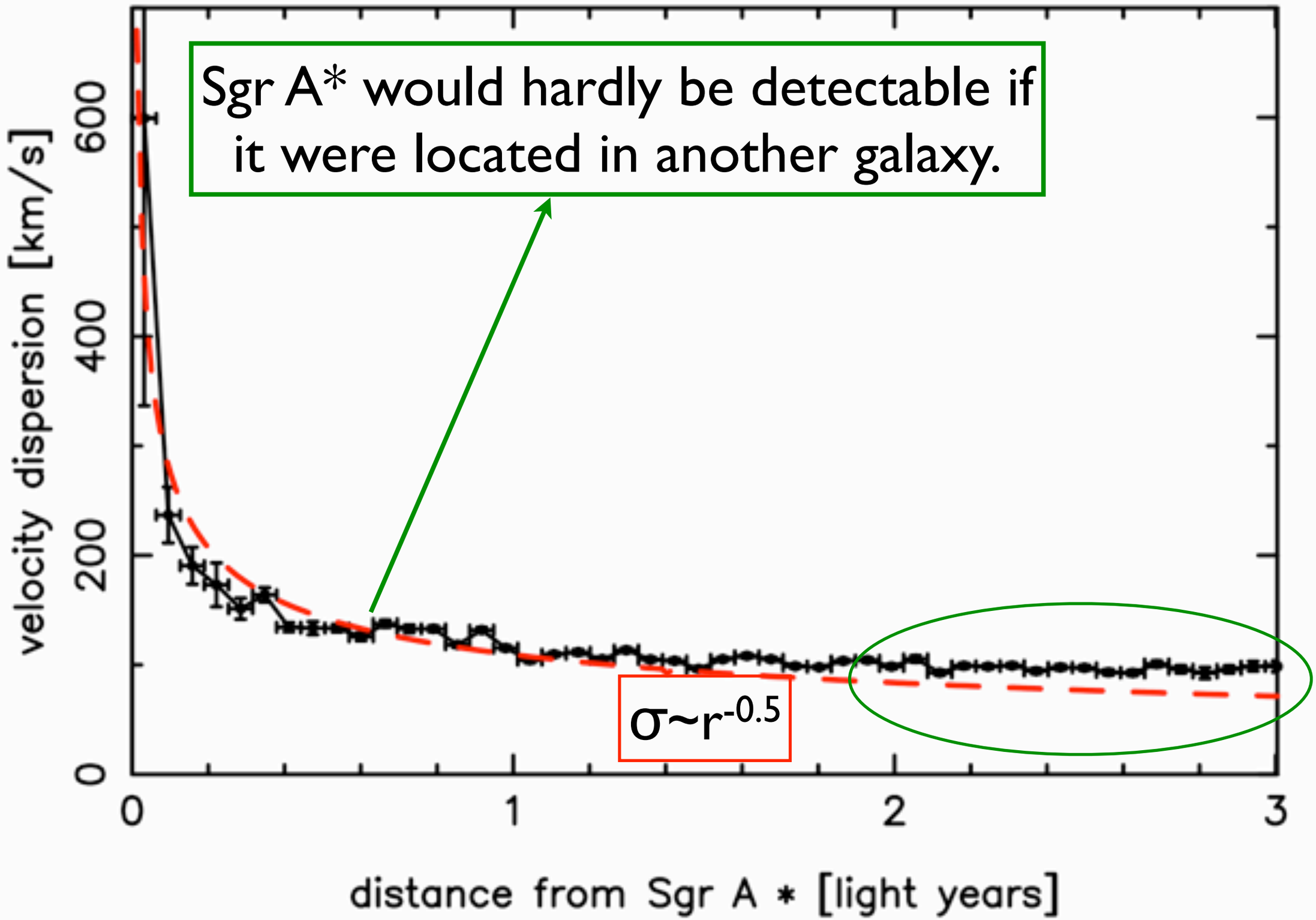

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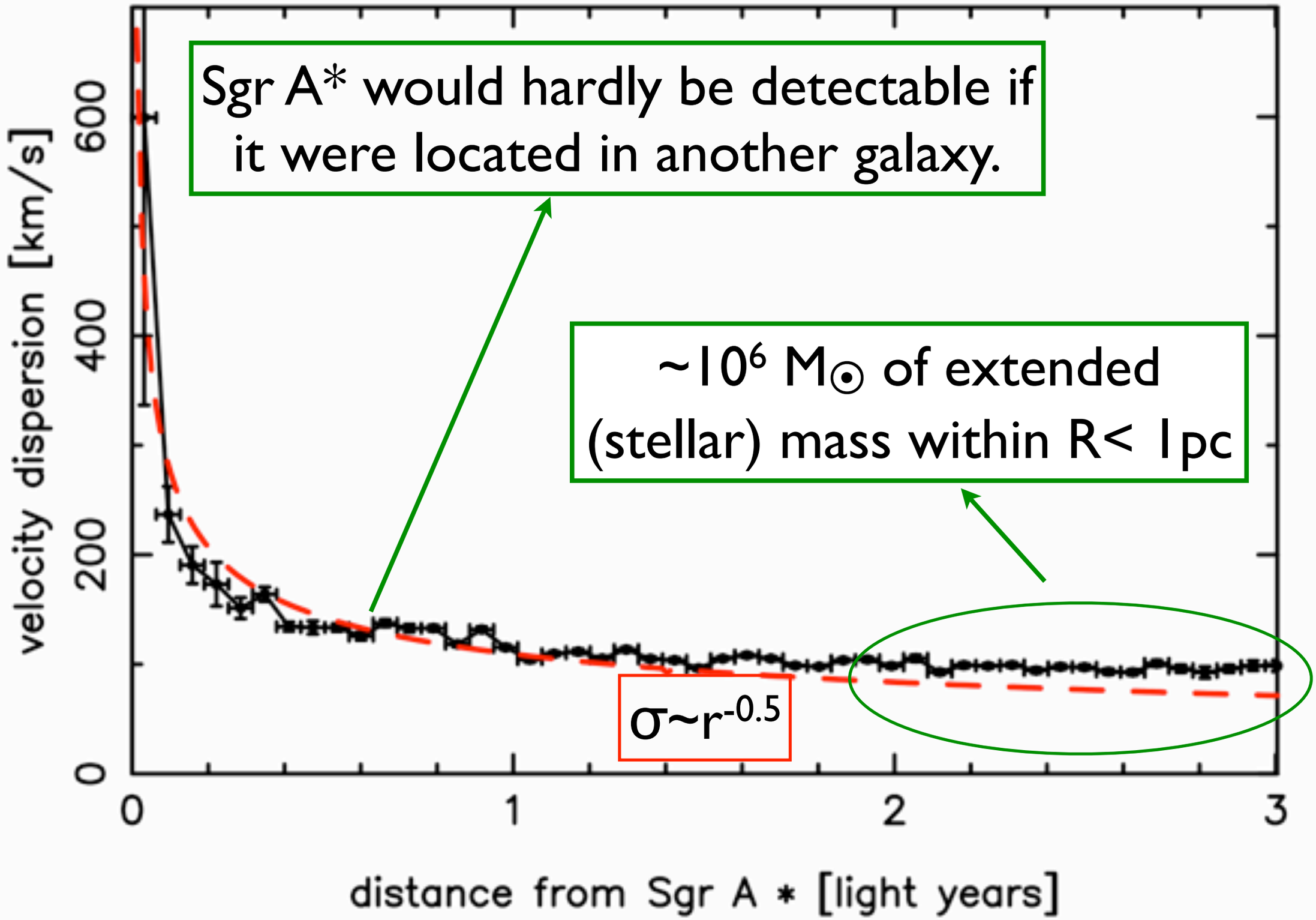

# Overall properties of the NSC

Shape:

- King/Sérsic/broken power-law models have been used
- spherically symmetric?
- $\rho$ (light, number density) $\propto r^{-1.8}$ found in most analyses
- power-law slope changes on scales of 5-10 pc

Star formation:

- significant overabundance of supergiants and bright giants as well as presence of young massive stars
- starburst-like activity in the central 1 pc about 4-6 Myr ago

Mass, total: $3 \pm 1.5 \times 10^7$ $M_\odot$ *(Launhardt+ 2002)*

Mass, central pc: $1 \pm 0.5 \times 10^6$ $M_\odot$ *(Schödel+ 2009)*

Size: half light radius of 3-5 pc (large uncertainties)

BH radius of influence: ~1-2 pc

Density: $\sim 1.5 \times 10^5$ $M_\odot$ $pc^{-3}$ at r=1 pc, $\sim 1 \times 10^{6...8}$ $M_\odot$ $pc^{-3}$ at r=0.1 pc

Rotation: The NSC rotates *(Trippe et al., 2008)*.

# Overall properties of the NSC

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- King/Sérsic/broken power-law models have been used
- spherically symmetric?
- [illegible]
- [illegible]

St[illegible]

- [illegible]

as[illegible]

- [illegible]

The overall properties of MW NSC are similar to extragalactic ones.
However, there are still major uncertainties concerning its shape and dynamics.

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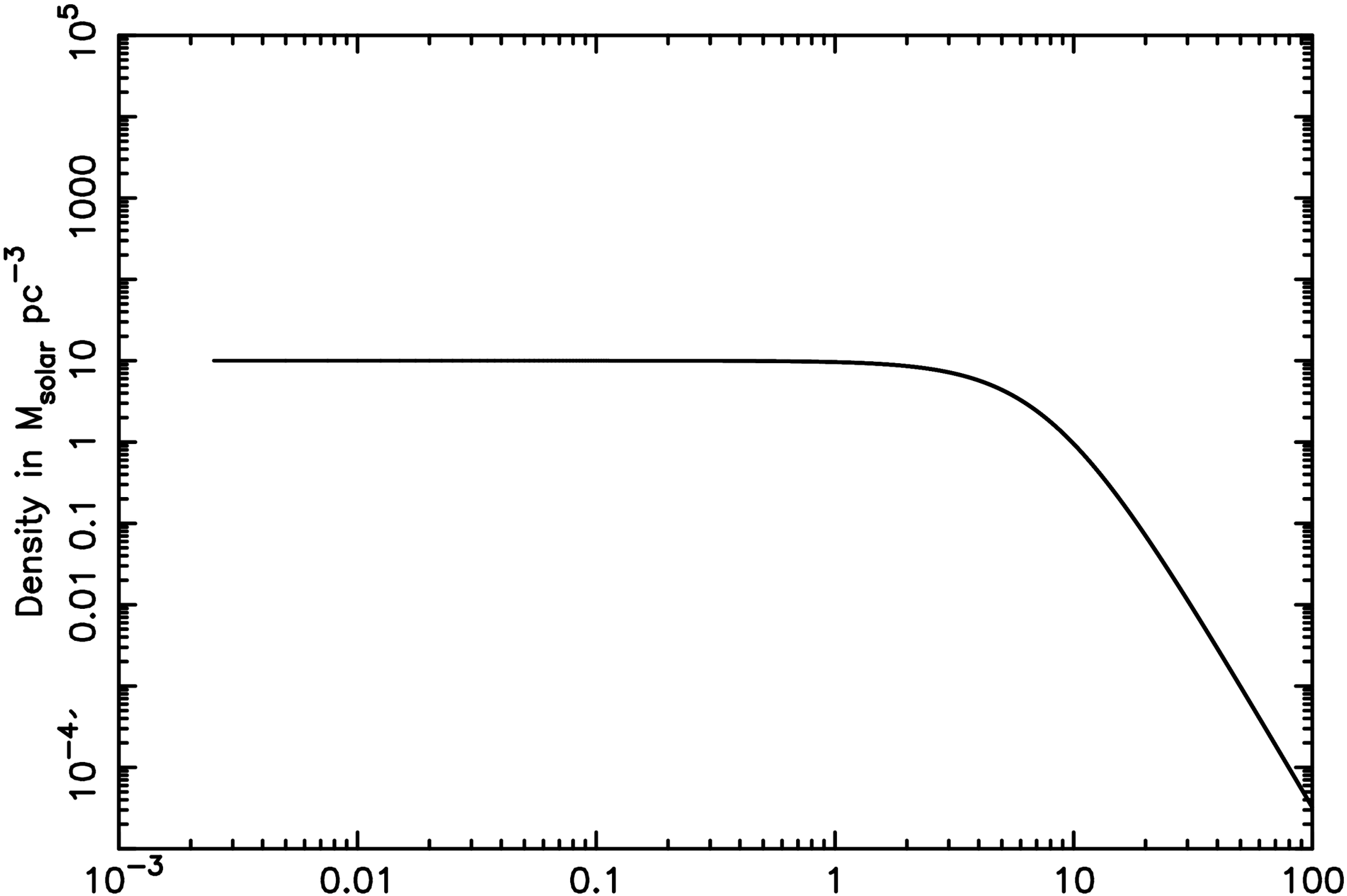
# Is there a cusp around the SMBH Sagittarius A*?

# Formation of a stellar cusp




Model/illustration based on/ taken from P. Amaro-Seoane's PhD Thesis (2004).

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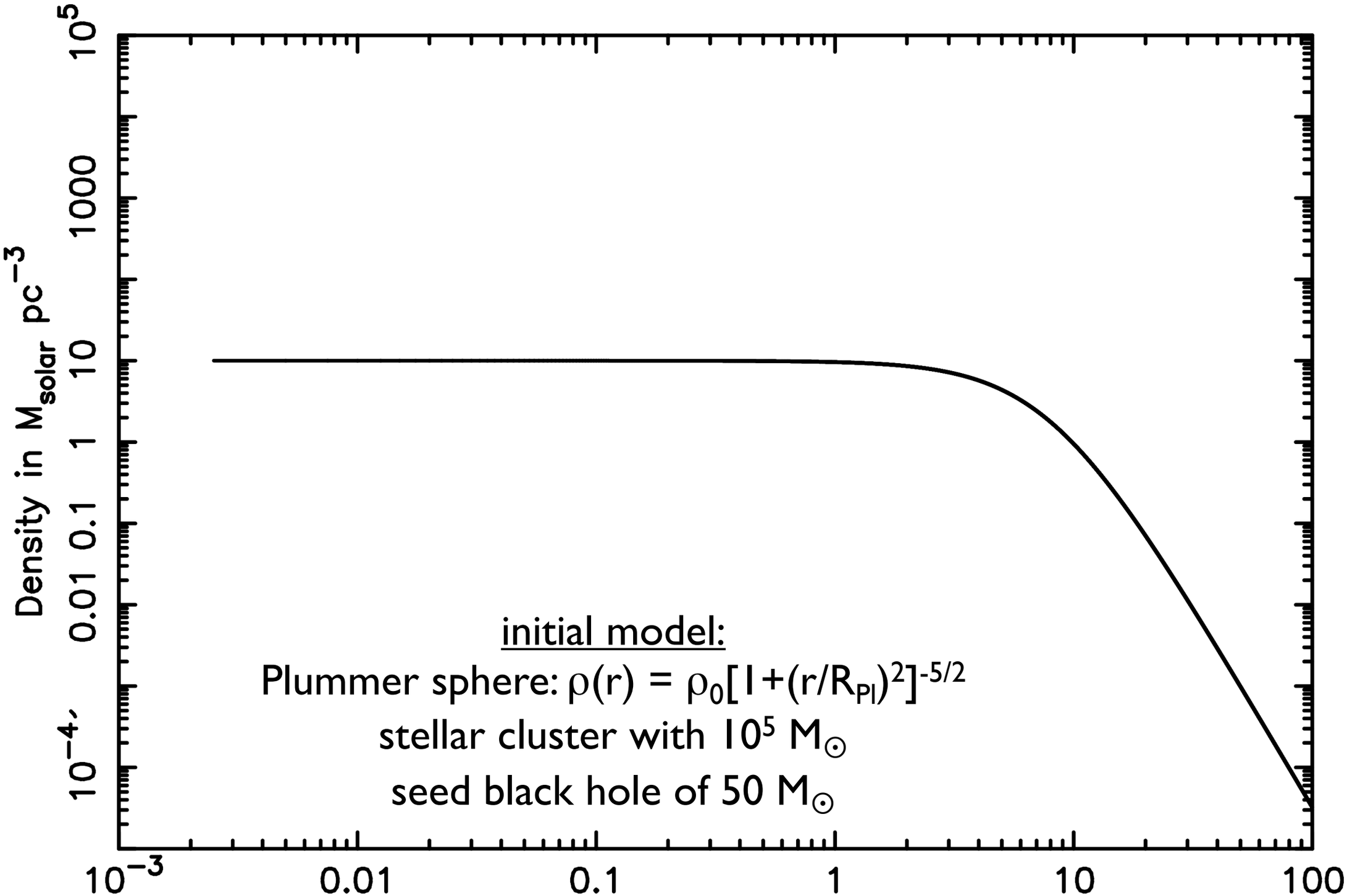


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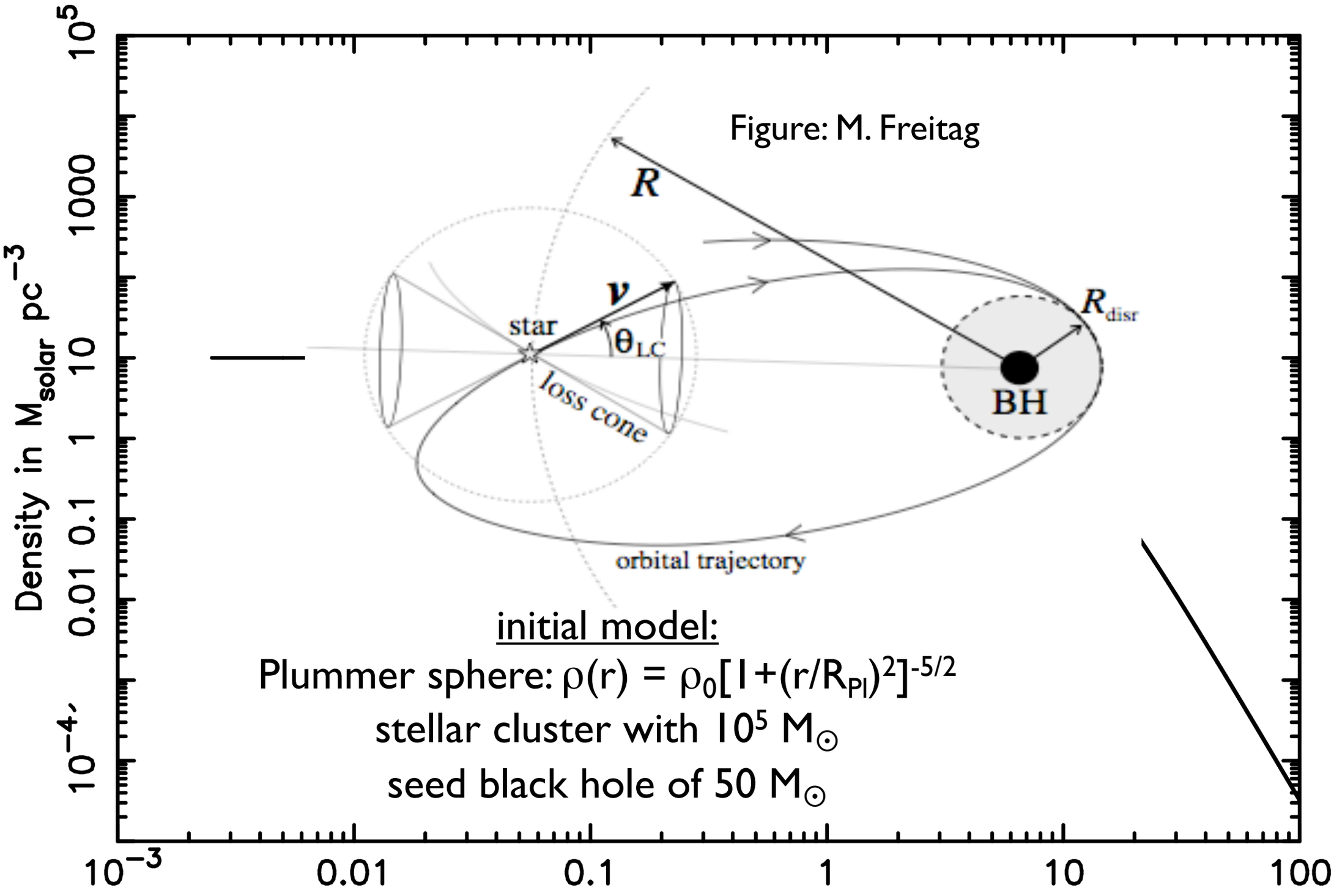


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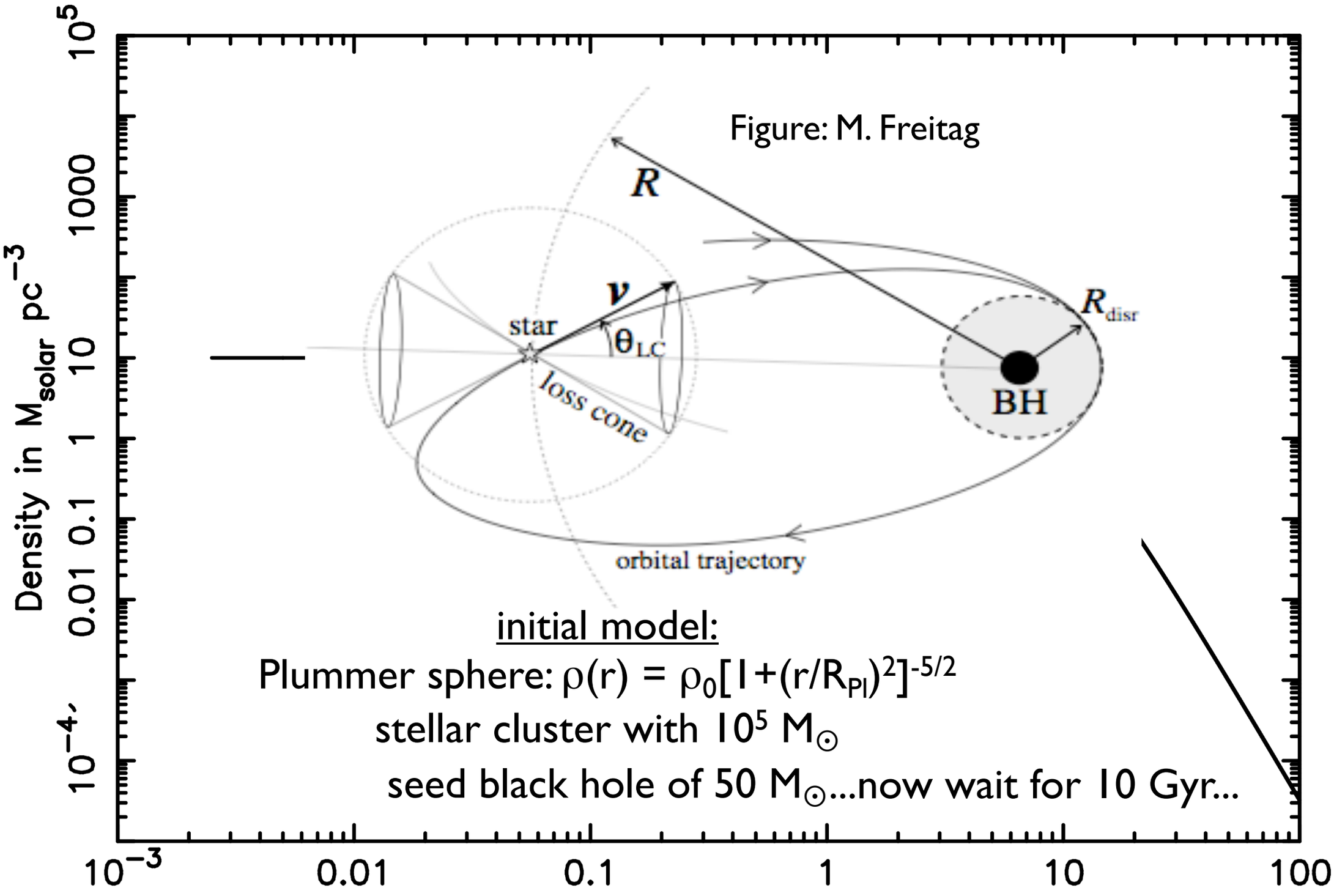


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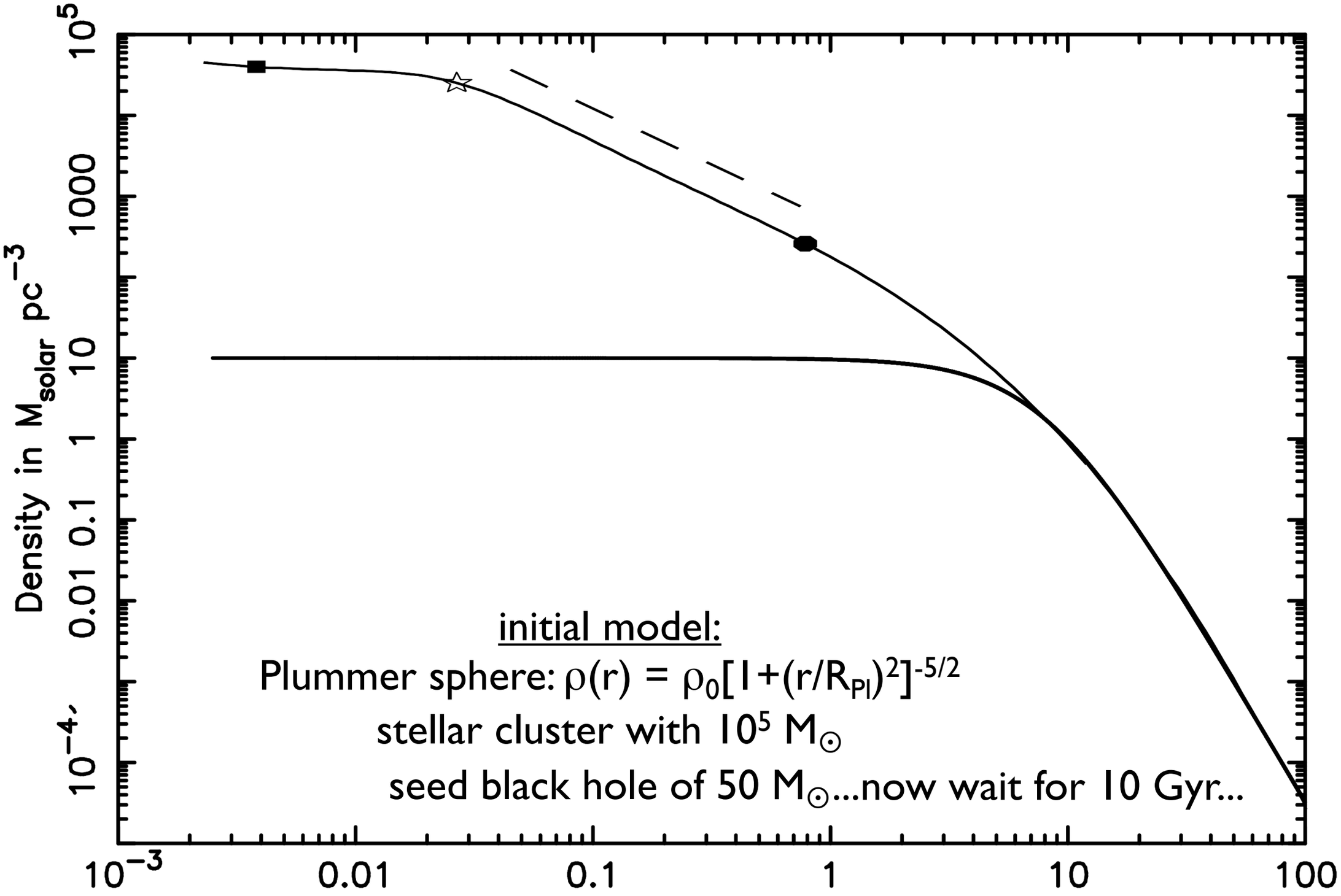


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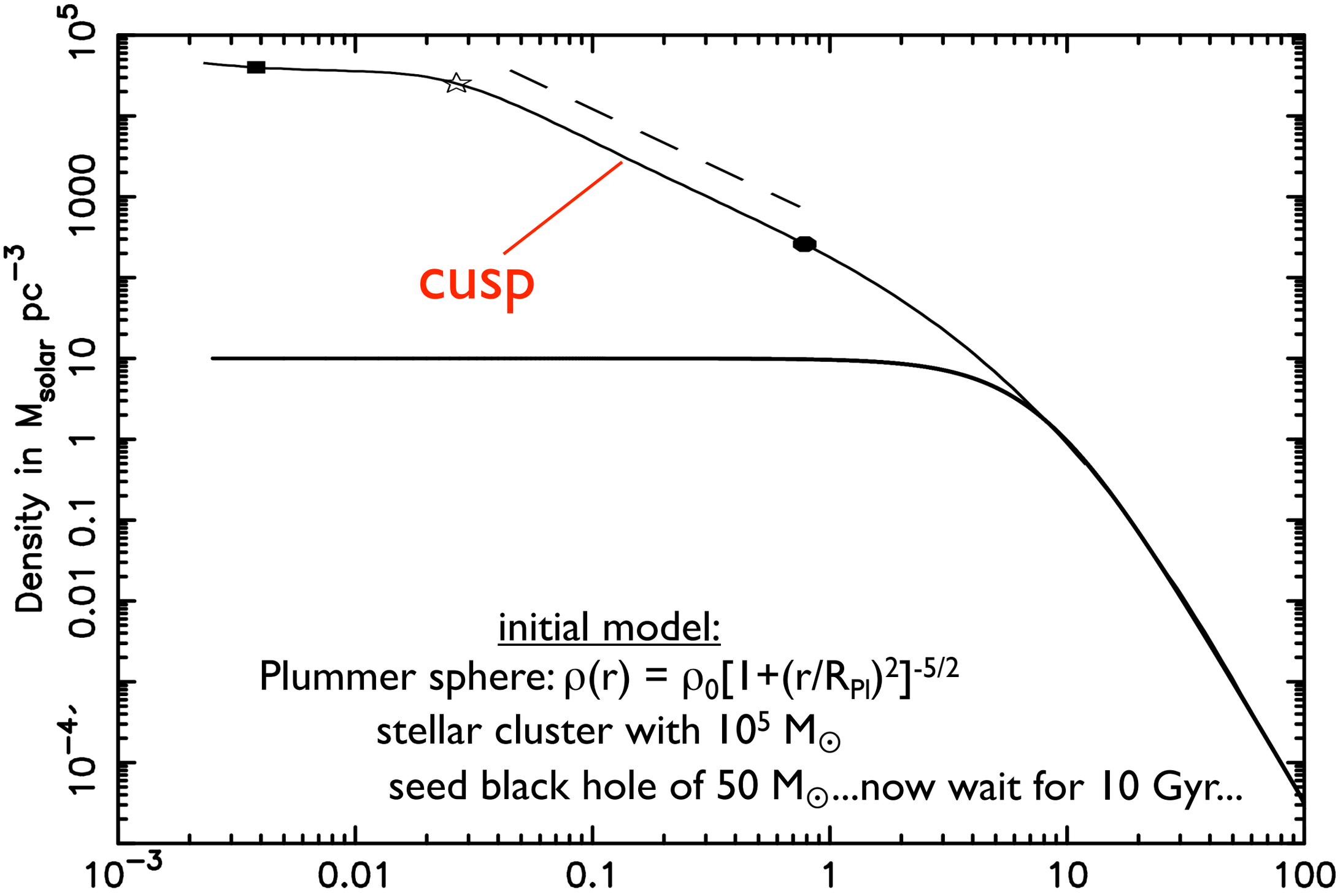


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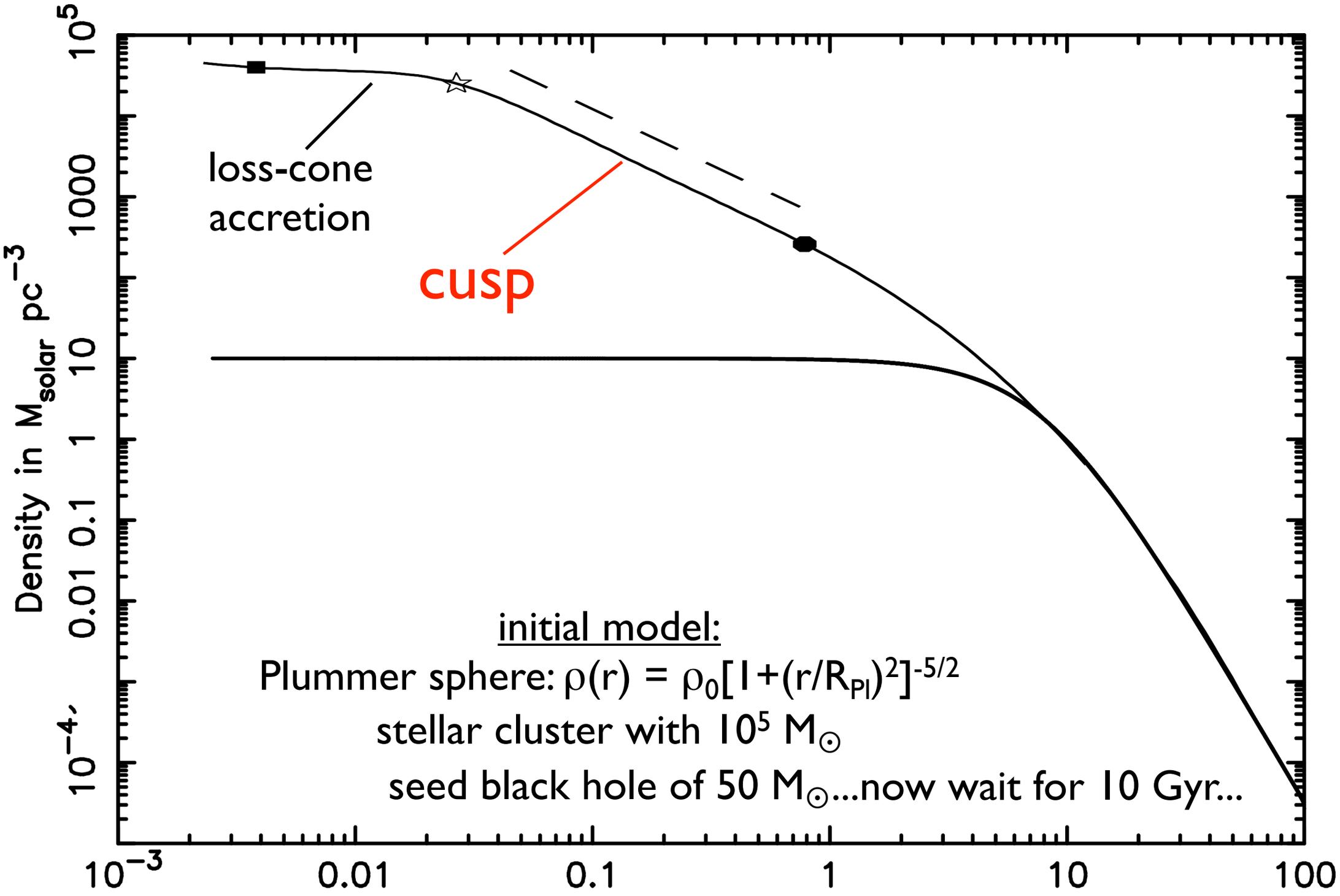


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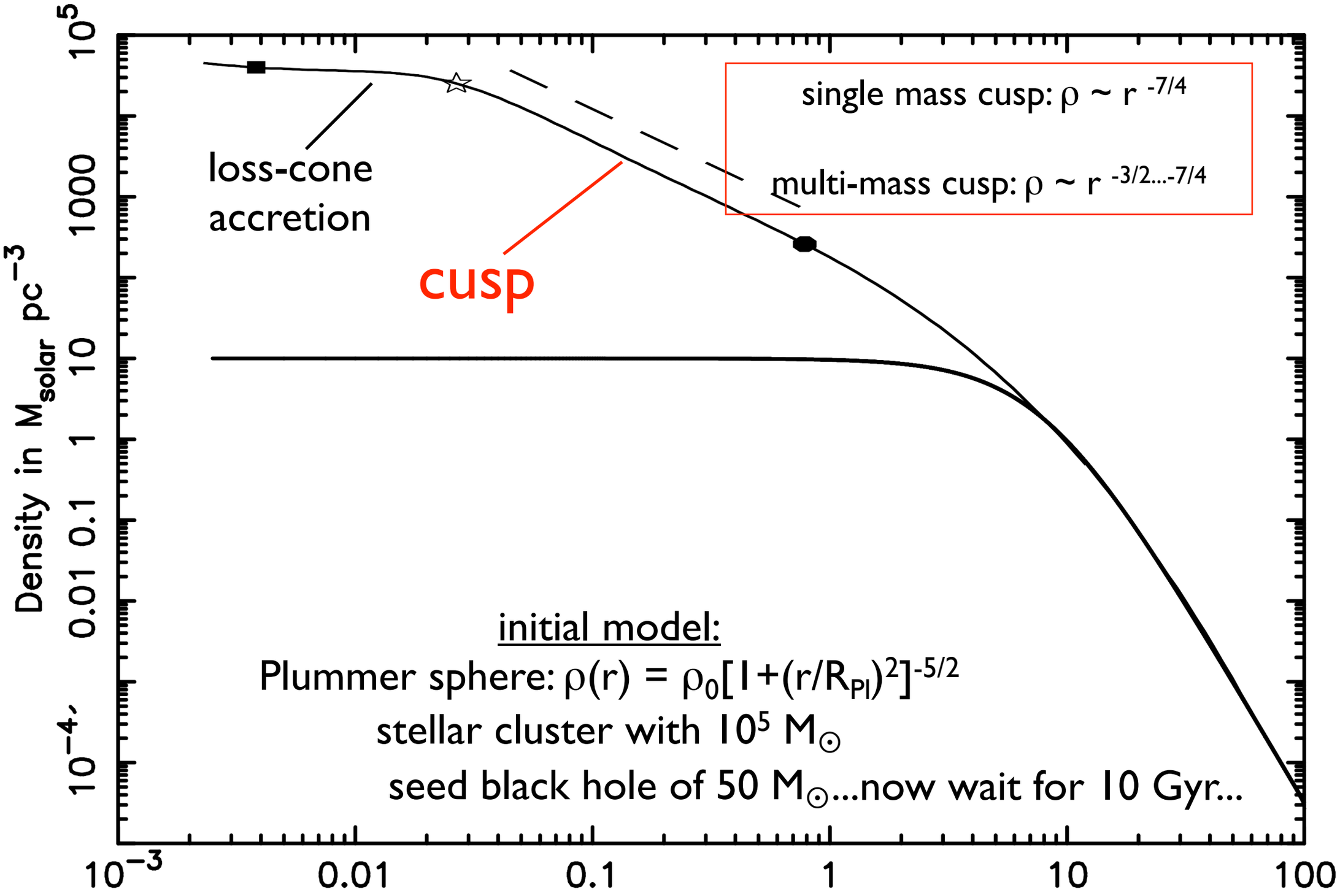


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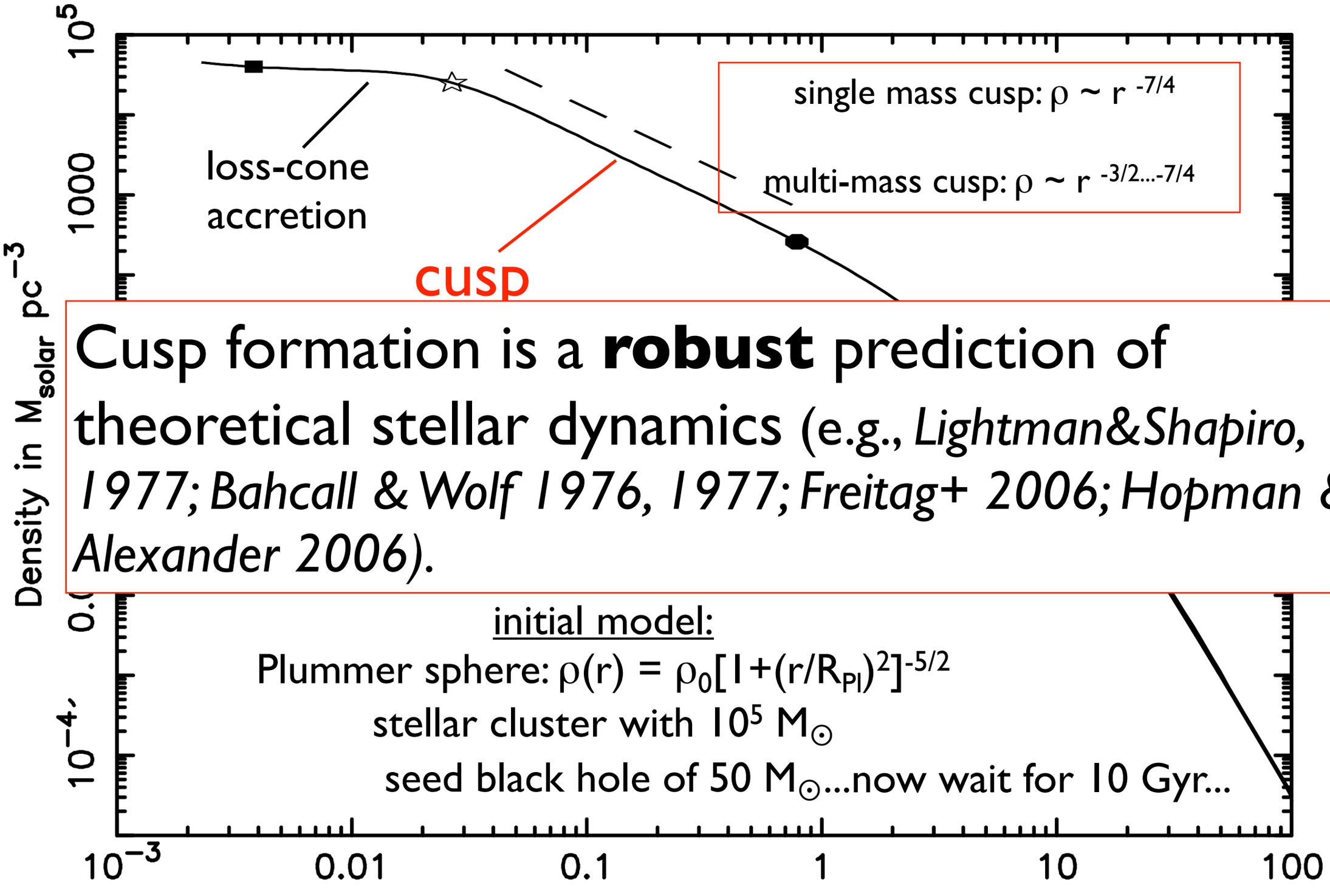


Cusp formation is a **robust** prediction of theoretical stellar dynamics (e.g., *Lightman&Shapiro, 1977; Bahcall & Wolf 1976, 1977; Freitag+ 2006; Hopman & Alexander 2006).*

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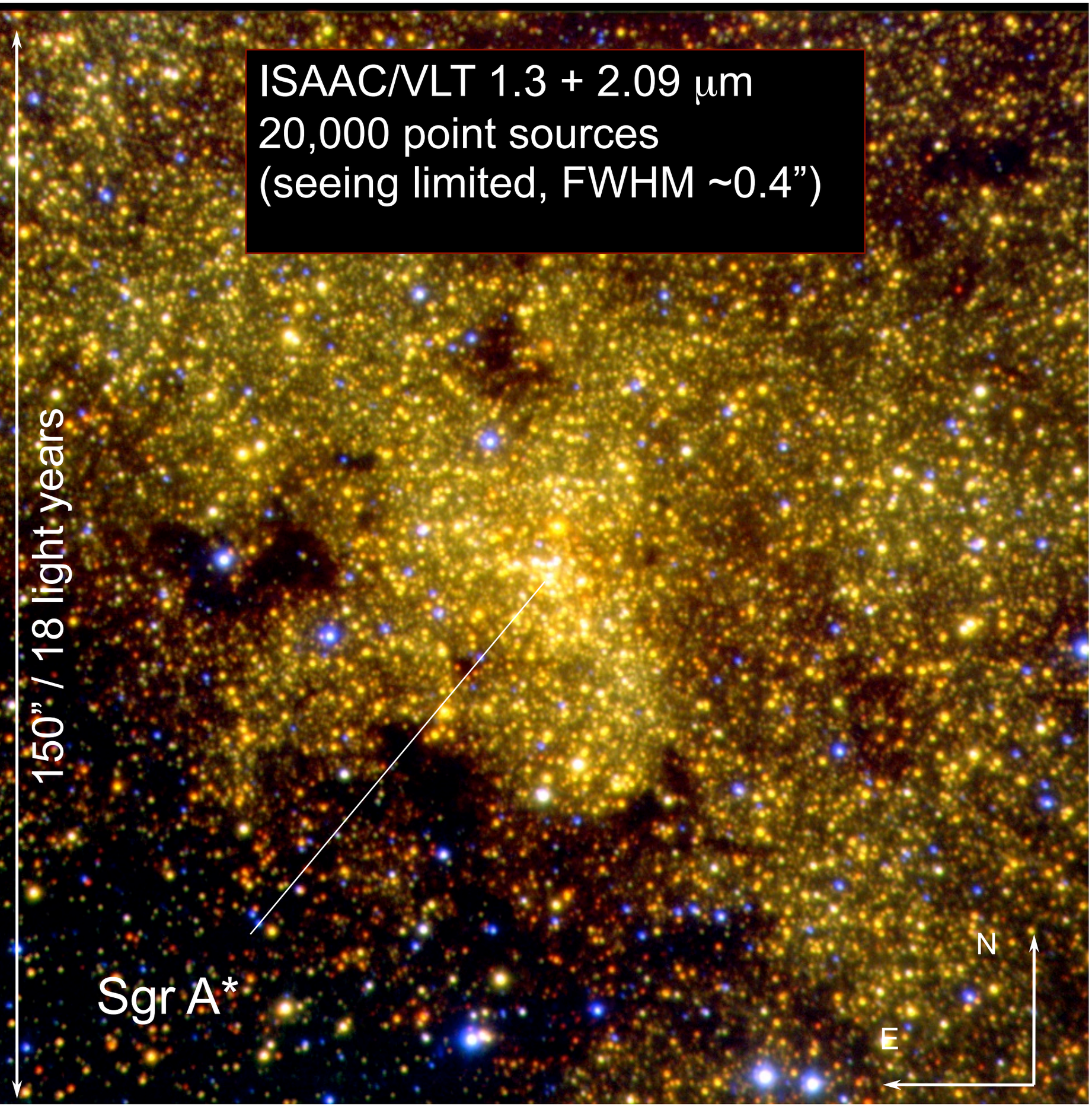
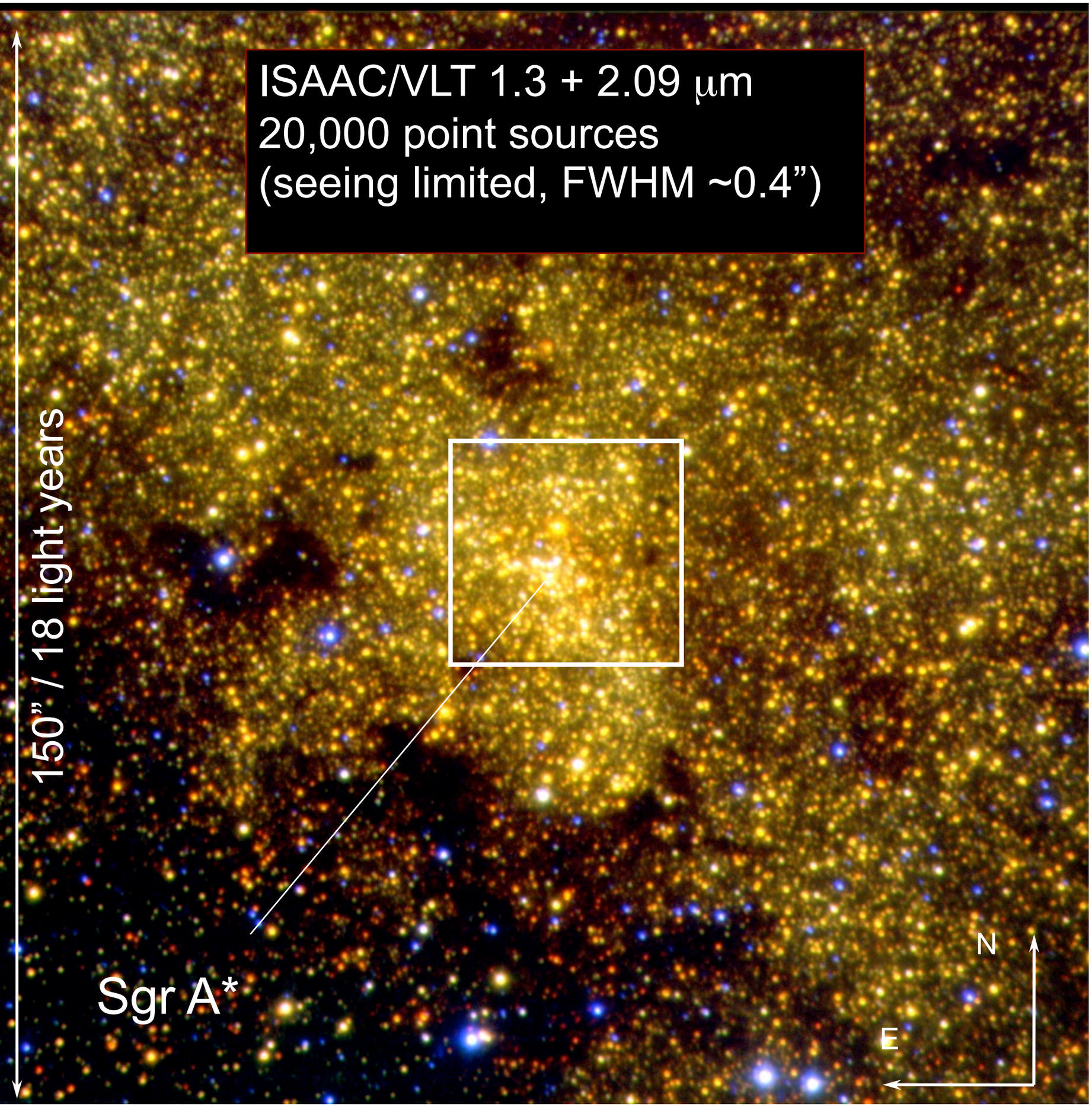

ISAAC/VLT 1.3 + 2.09 μm
20,000 point sources
(seeing limited, FWHM ~0.4”)
150” / 18 light years
Sgr A*
N
E

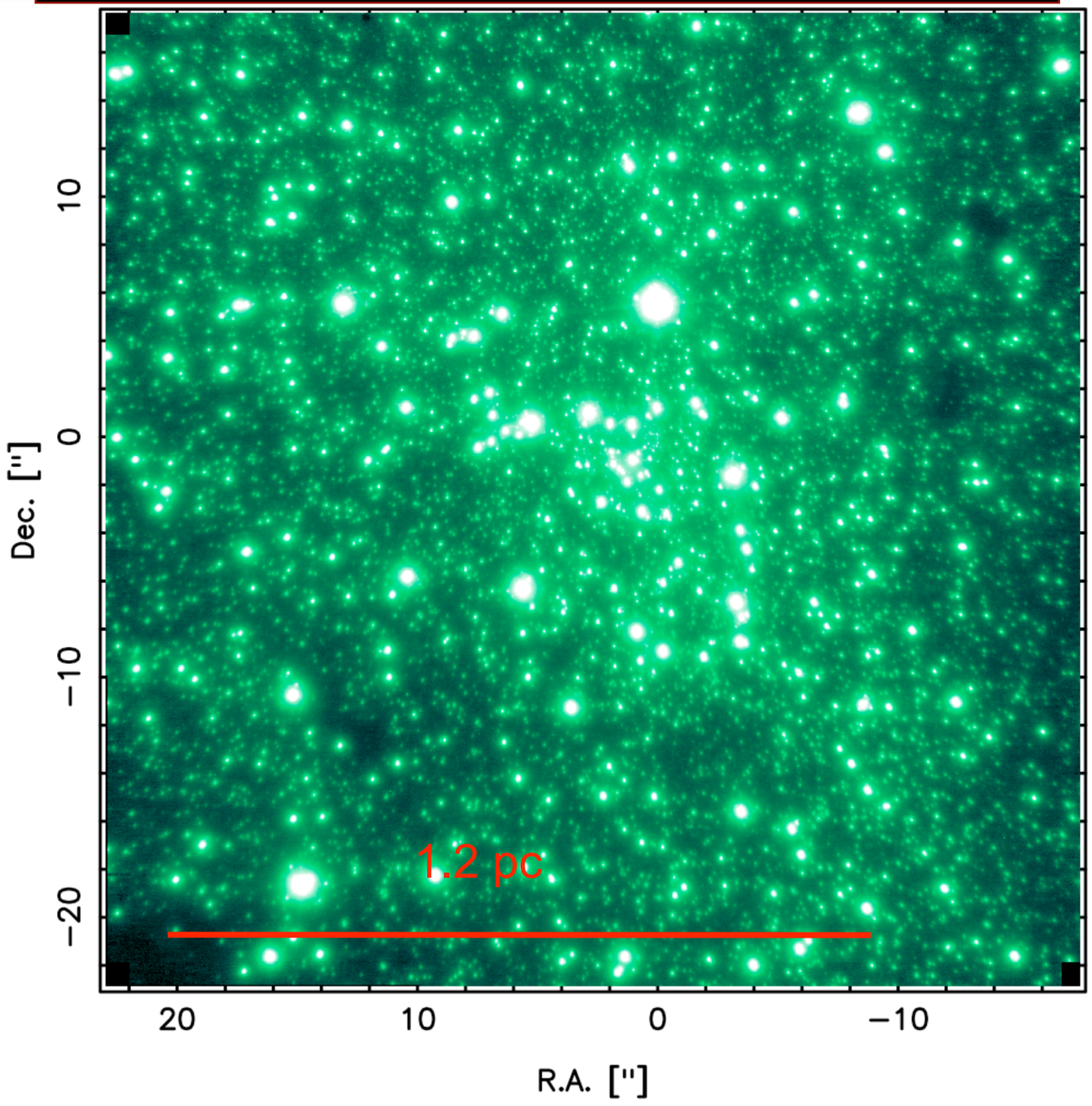

ISAAC/VLT 1.3 + 2.09 μm
20,000 point sources
(seeing limited, FWHM ~0.4”)
150” / 18 light years
Sgr A*
N
E

ISAAC/VLT 1.3 + 2.09 μ
20,000 point sources
(seeing limited, FWHM

NACO/VLT, 2.2 μm
adaptive optics, ~0.06” FWHM
10,000 point sources ($mag_K \leq 17.5$)

150” / 18 light years

Sgr A*



ISAAC/VLT 1.3 + 2.09 μ
20,000 point sources
(seeing limited, FWHM

NACO/VLT, 2.2 μm
adaptive optics, ~0.06" FWHM
10,000 point sources ($mag_K \leq 17.5$)

Count stars and correct for completeness (due to confusion) and for extinction...

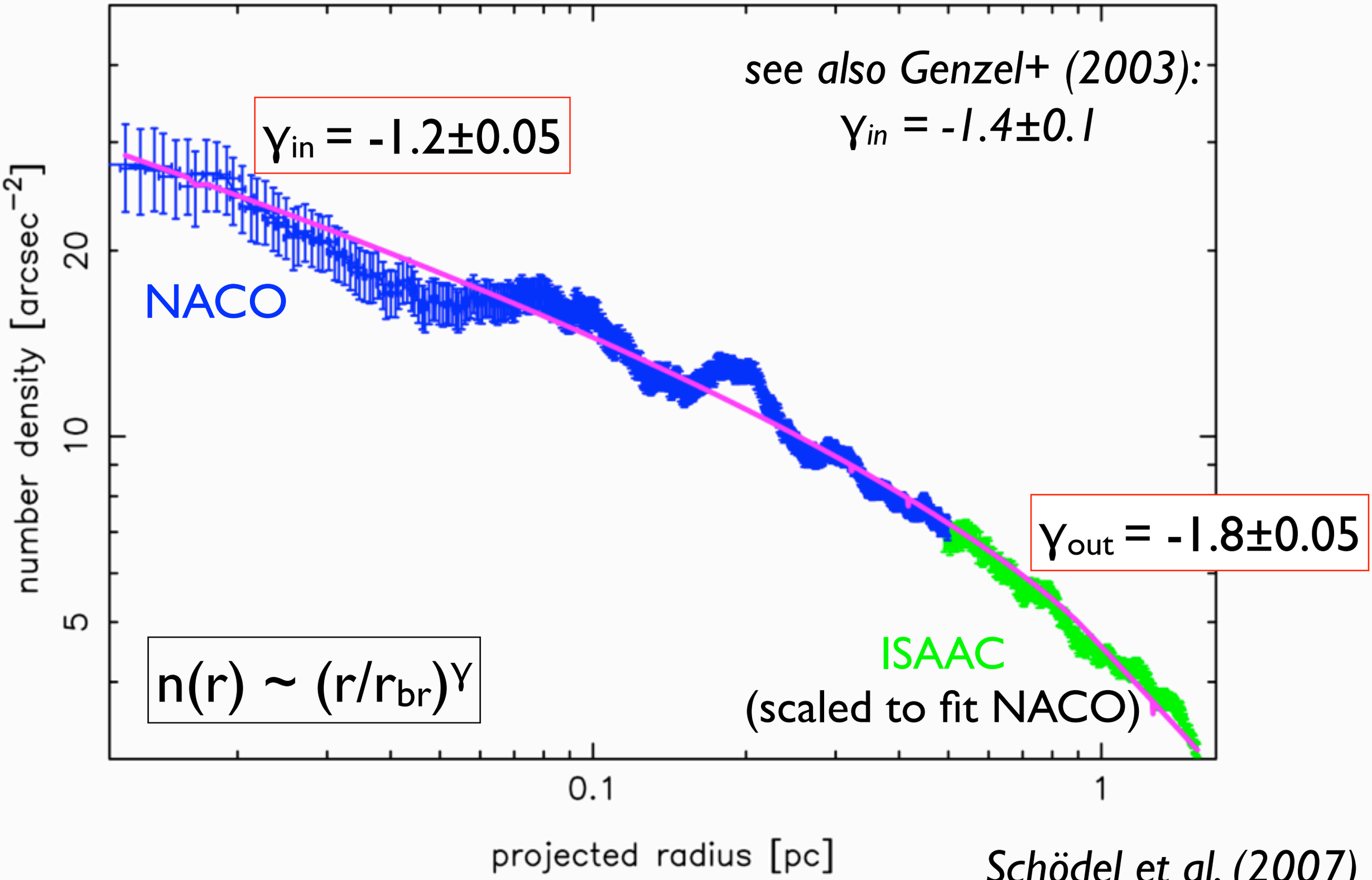
150" / 18 light years

Sgr A*

1.2 pc

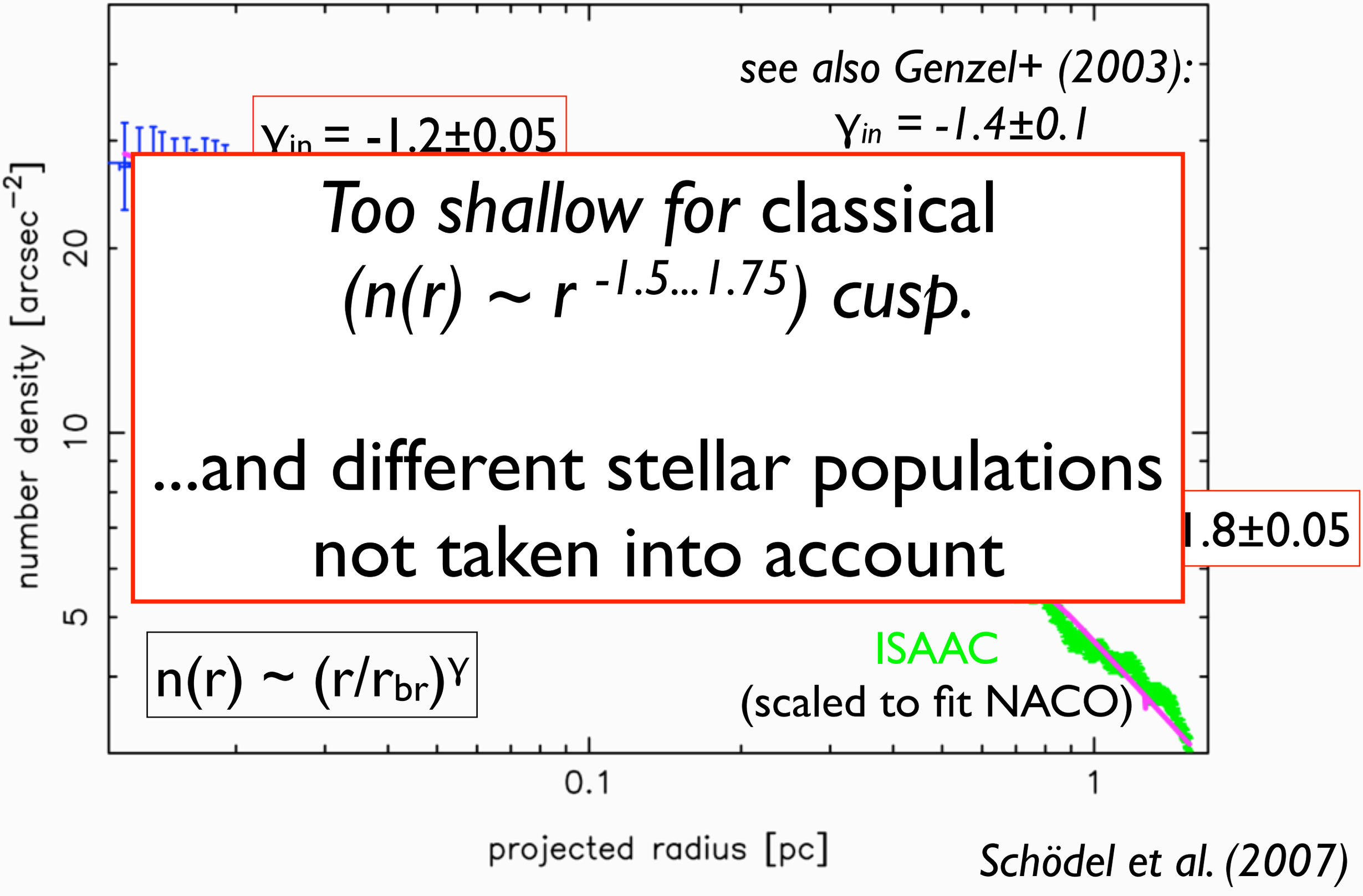
10
−10
−20
20
10
0
−10
R.A. ["]

# Stellar surface number density




*Schödel et al. (2007)*

# Stellar surface number density




*Schödel et al. (2007)*

# Young stars at the Galactic Center

Two recent star formation events in central pc: ~100 Myr and ~4 Myr ago (e.g., Krabbe et al. 1995).

Young, massive stars in central 0.5 pc:

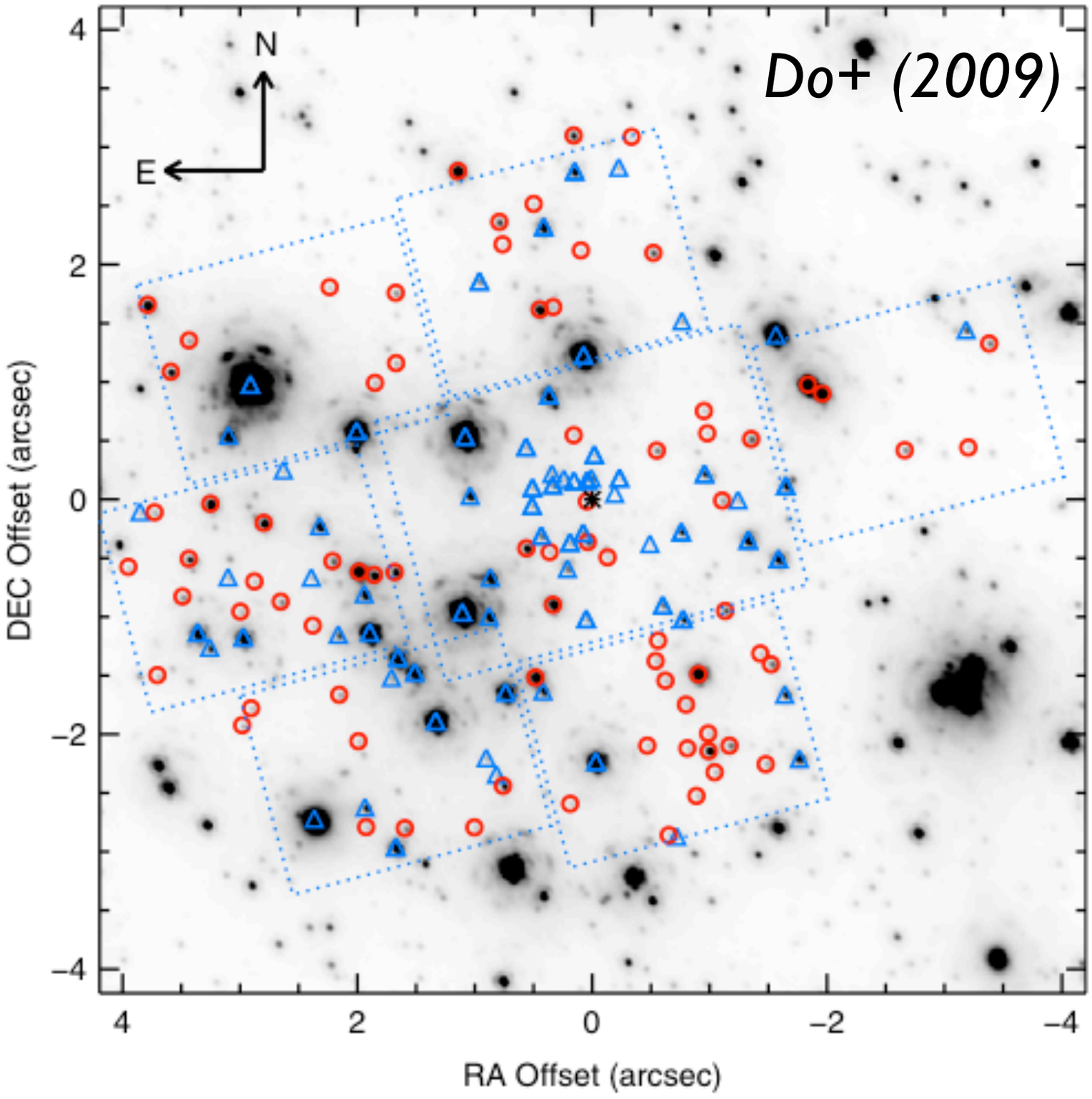
•O/B dwarfs within ~20 mpc of Sgr A* *("S-stars", "paradox of youth", e.g. Ghez et al., 2003: Eisenhauer et al., 2005 and others)*

• ~100 O/B supergiants/WR stars within 0.5 pc of Sgr A* *(e.g. Genzel et al., 2003; Paumard et al., 2006)*

• at least 50% of the young stars move within a disc *(e.g. Paumard et al., 2006; Lu et al., 2008)*

• surface number density of young stars rises steeply toward Sgr A* *(e.g., Paumard+ 2006; Lu+ 2009)*

# Young stars at the Galactic Center



# Classifying stars at the GC: Broad-band

main problems:

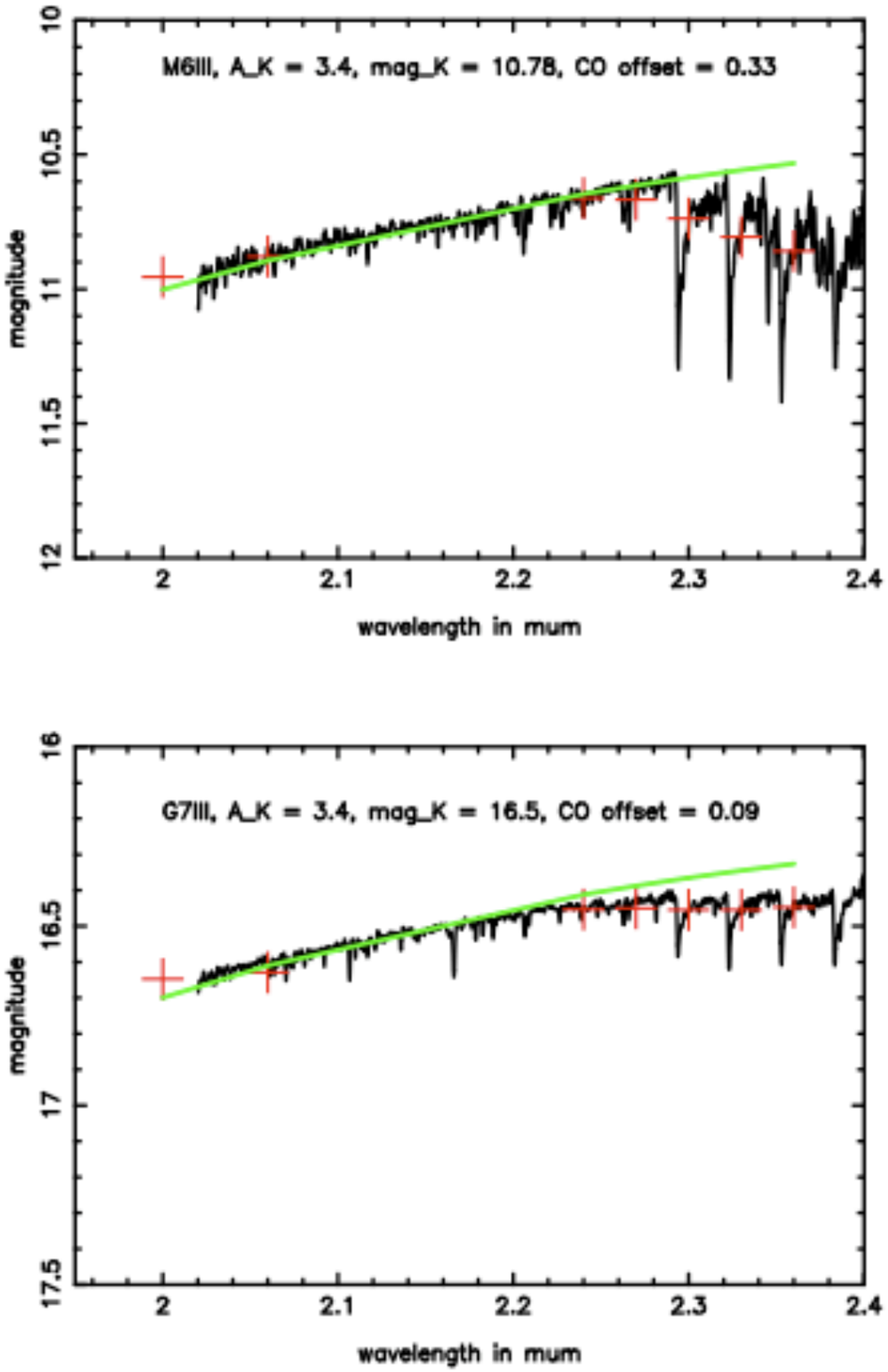
- high and variable extinction
- only H,K,L observations (narrow range of stellar colors)
- FOV of spectroscopy very small

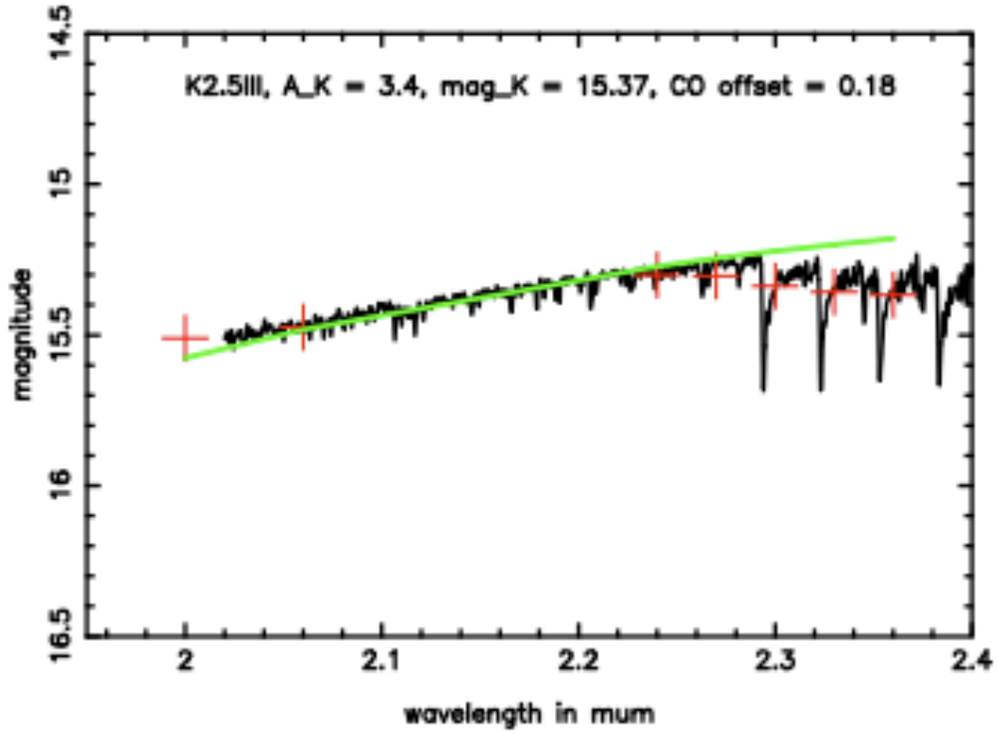
*see Schödel et al. (2010, A&A)*

# Classifying stars at the GC: Broad-band

*see Schödel et al. (2010, A&A)*

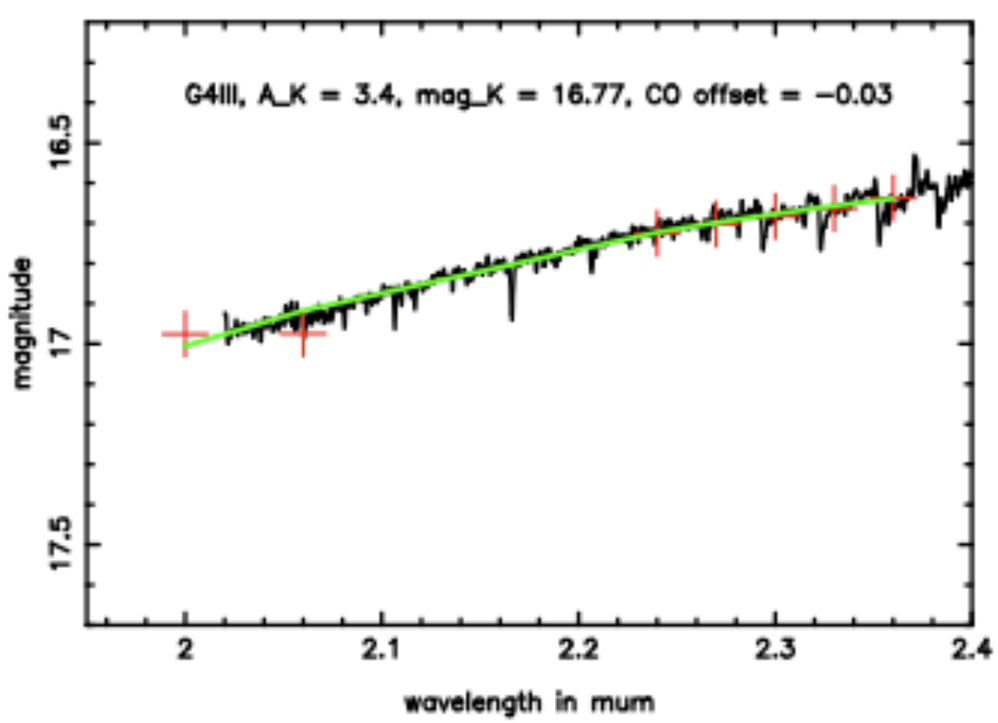
# Classifying stars at the GC: Narrow band



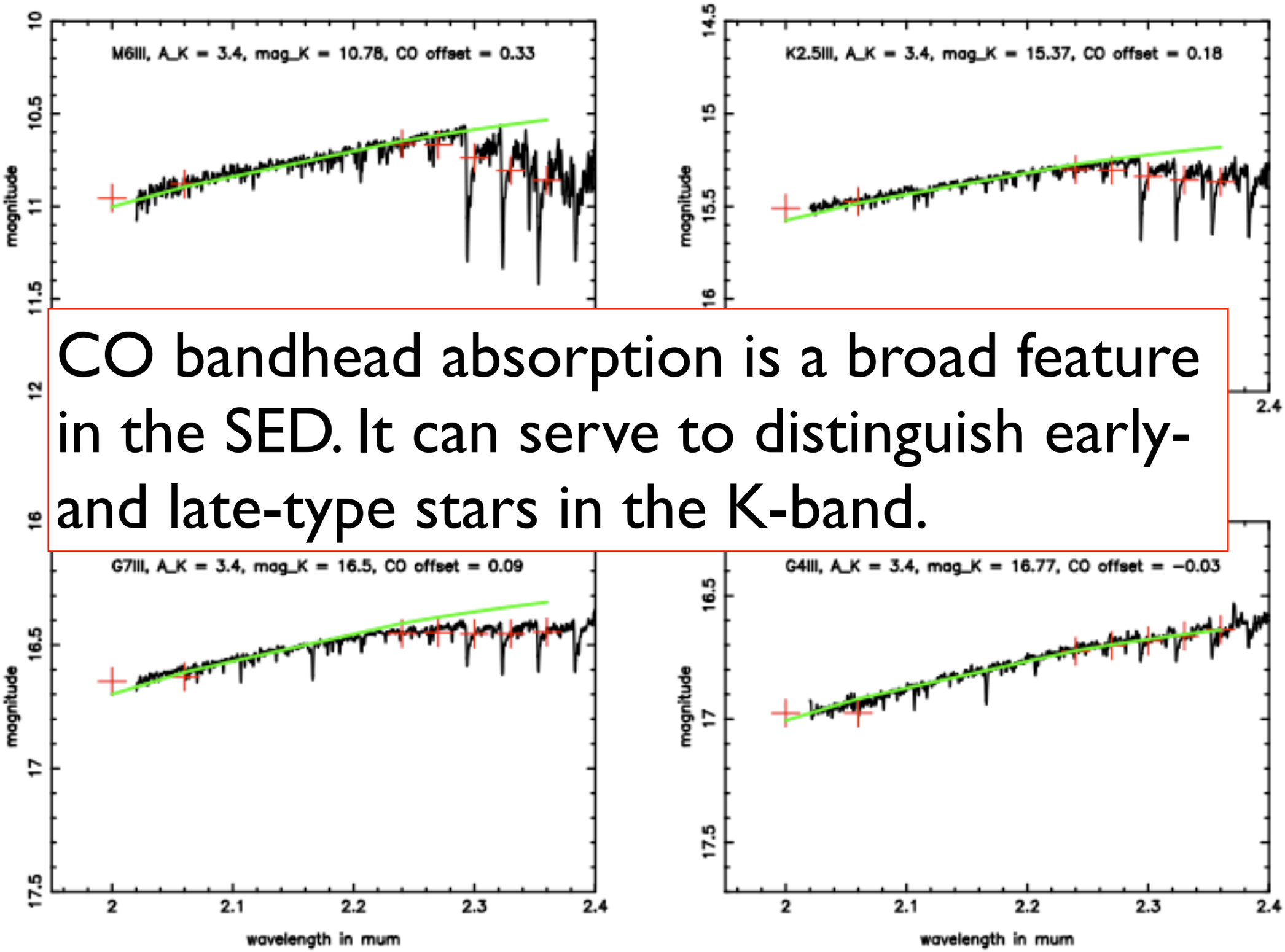







*Buchholz, Schödel, & Eckart (2009, A&A)*

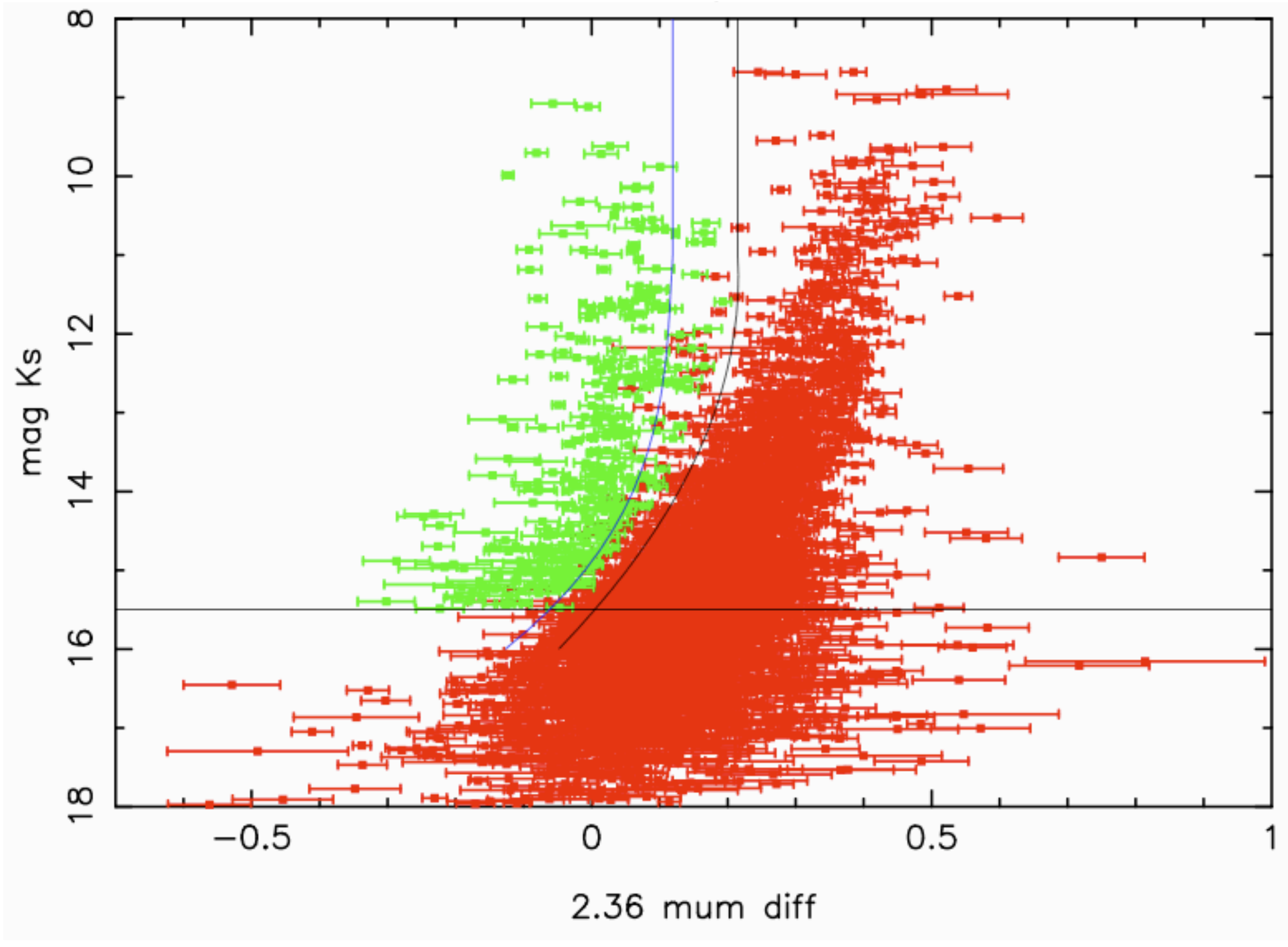
# Classifying stars at the GC: Narrow band




CO bandhead absorption is a broad feature in the SED. It can serve to distinguish early- and late-type stars in the K-band.

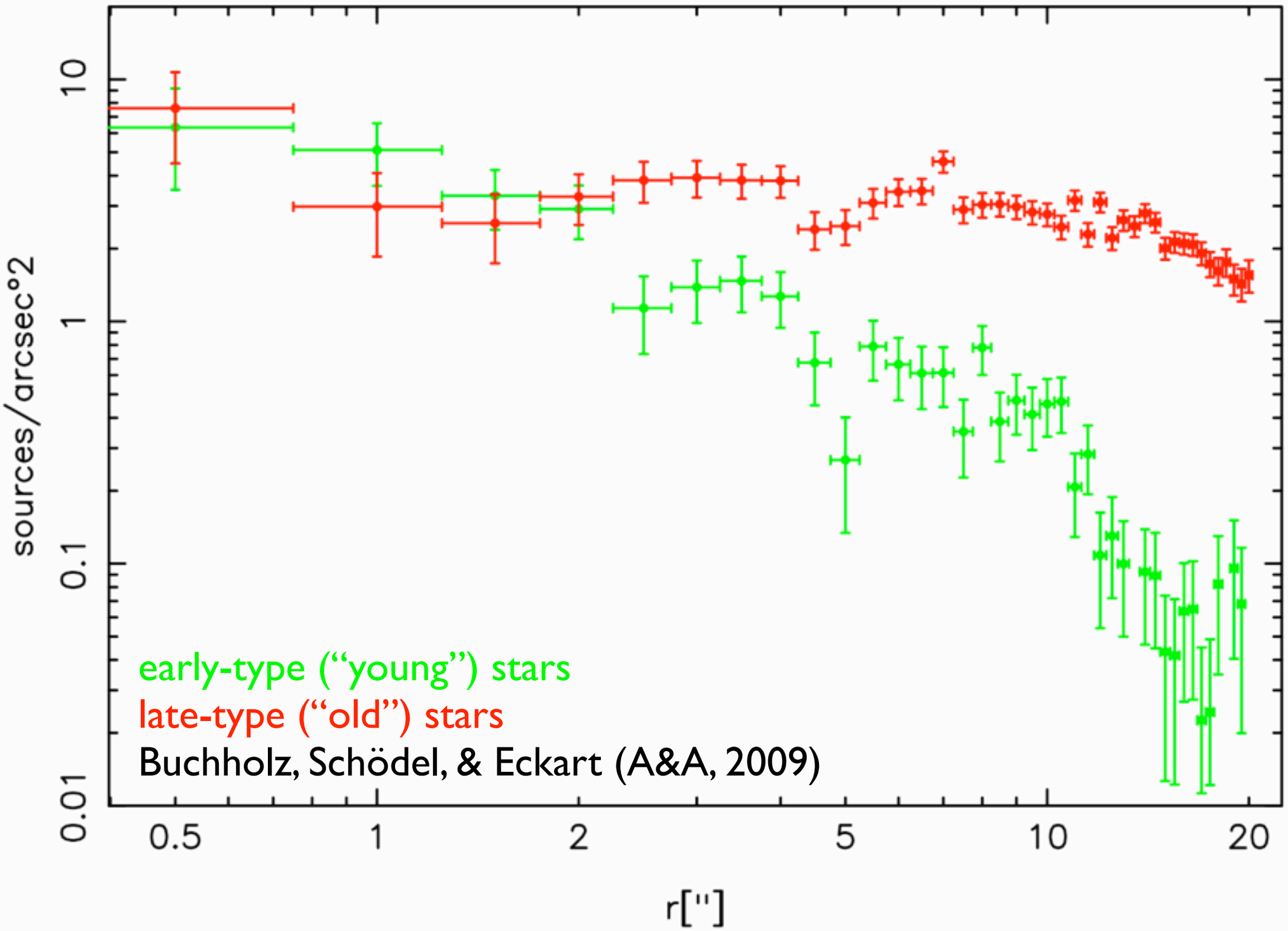
*Buchholz, Schödel, & Eckart (2009, A&A)*

# Classifying stars at the GC: Narrow band

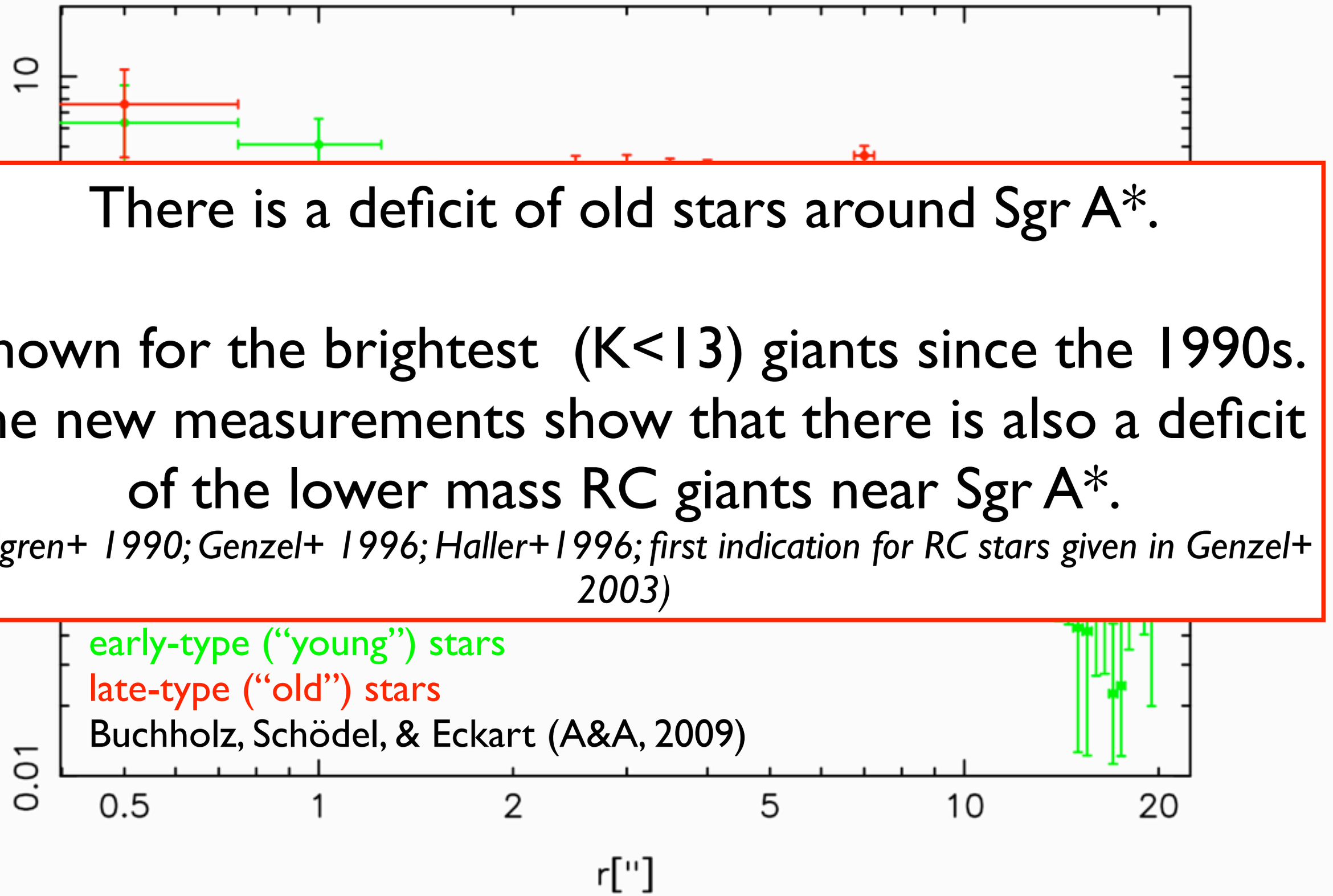



*Buchholz, Schödel, & Eckart (2009, A&A)*

# n(r) of old stars ≠ n(r) of young stars



# n(r) of old stars ≠ n(r) of young stars

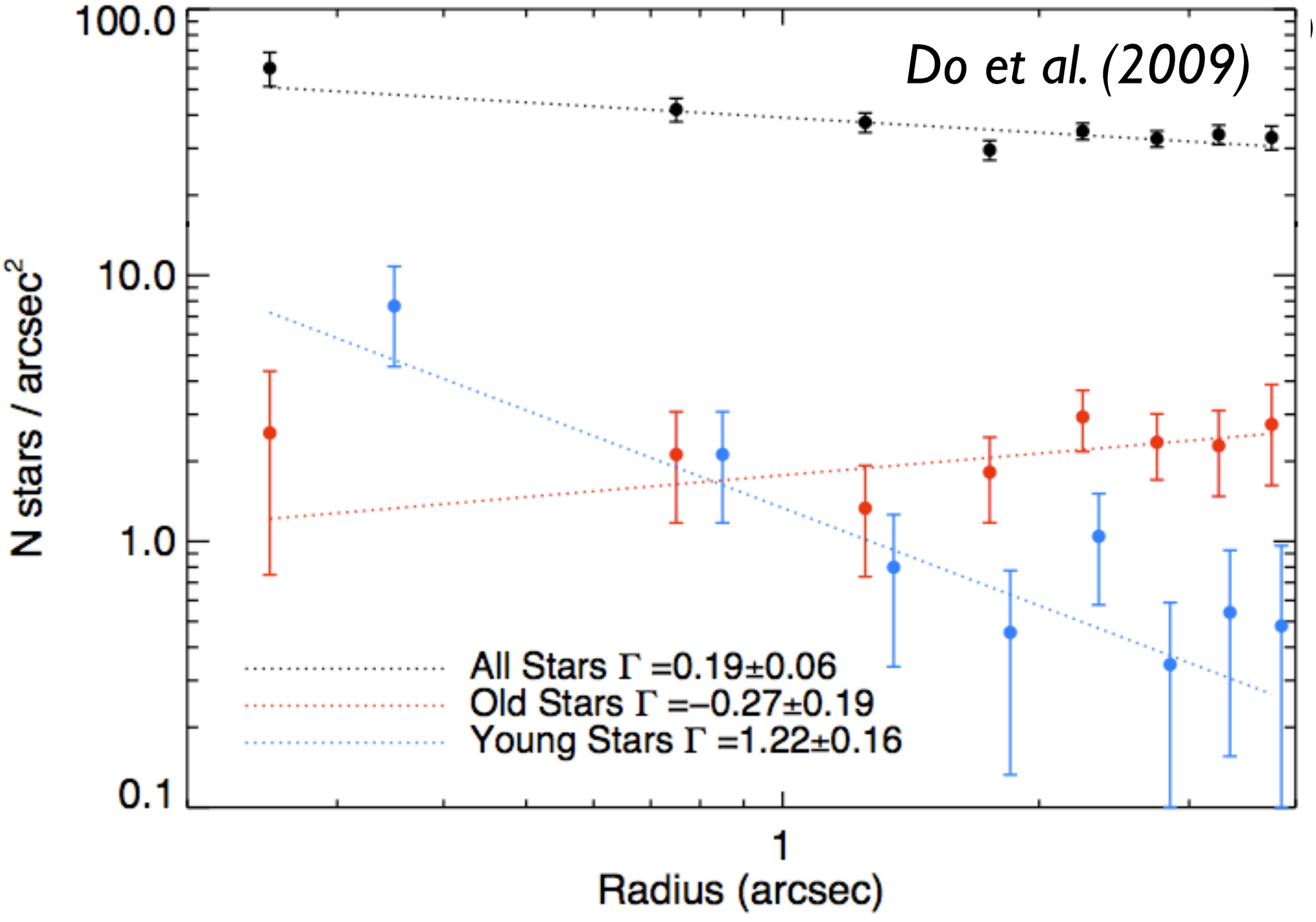



There is a deficit of old stars around Sgr A*.

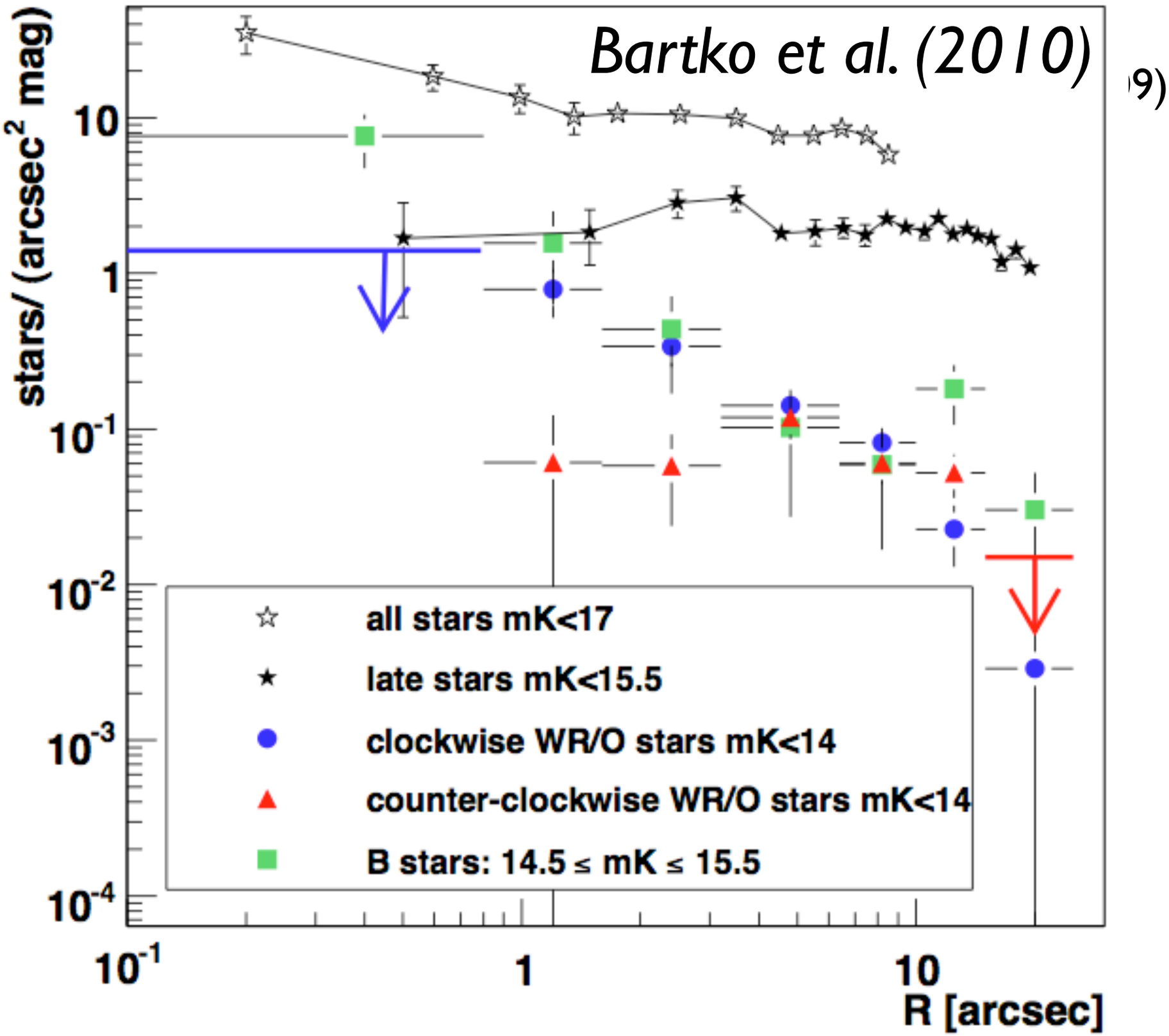
Known for the brightest (K<13) giants since the 1990s. The new measurements show that there is also a deficit of the lower mass RC giants near Sgr A*.

*(Sellgren+ 1990; Genzel+ 1996; Haller+1996; first indication for RC stars given in Genzel+ 2003)*

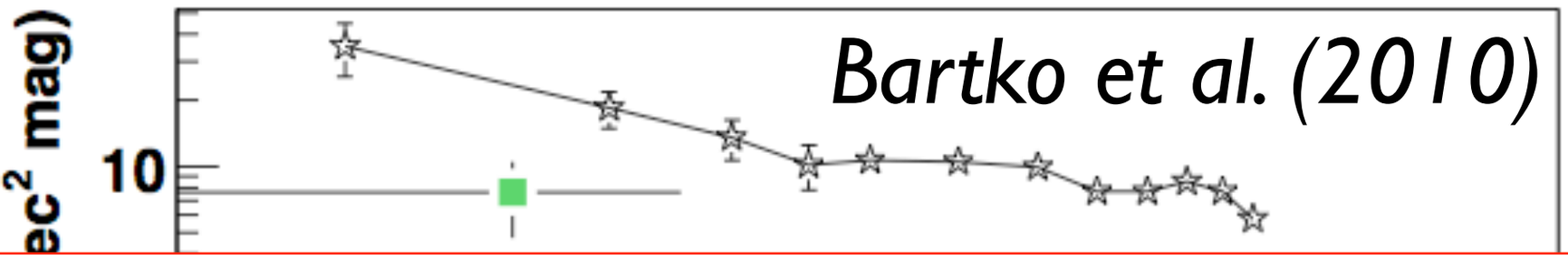
# Spectroscopic studies of late-type stars at the GC



# Spectroscopic studies of late-type stars at the GC



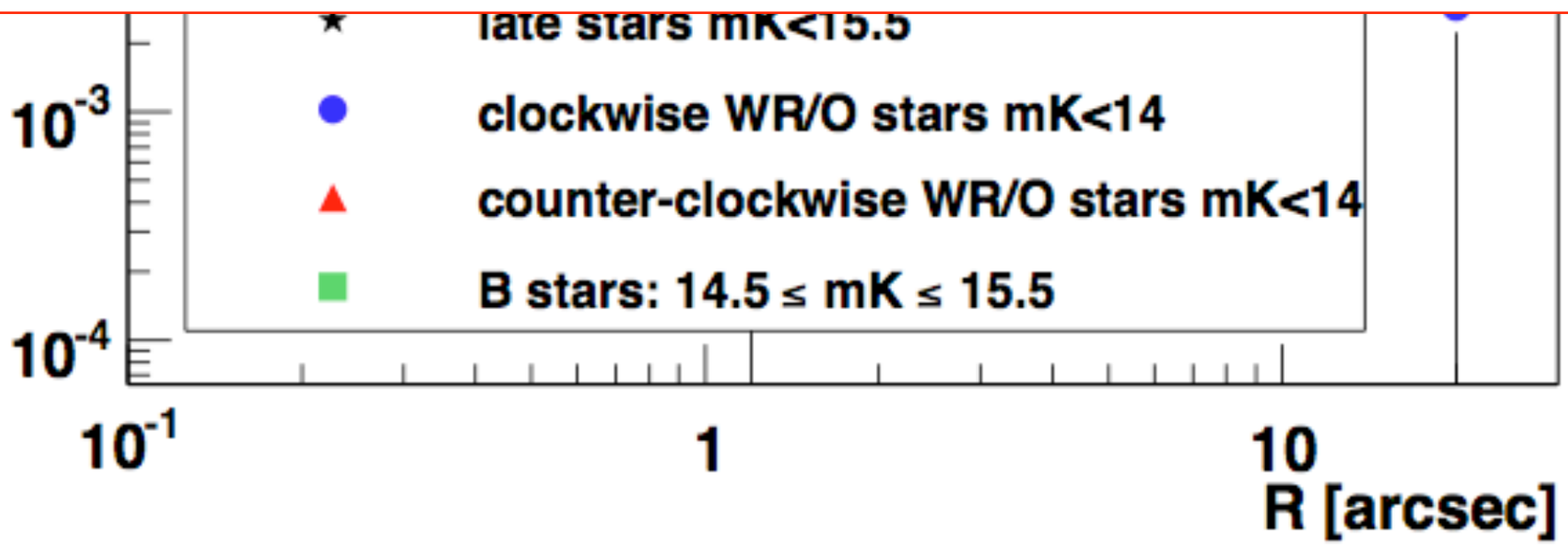
# Spectroscopic studies of late-type stars at the GC




*Decreasing* density of old stars toward Sgr A*.

→ γ < 1.0 with >99% probability *(Do et al., 2009)*

→ There is no observable cusp, there may be even a hole.



# Where is the stellar cusp at the GC?

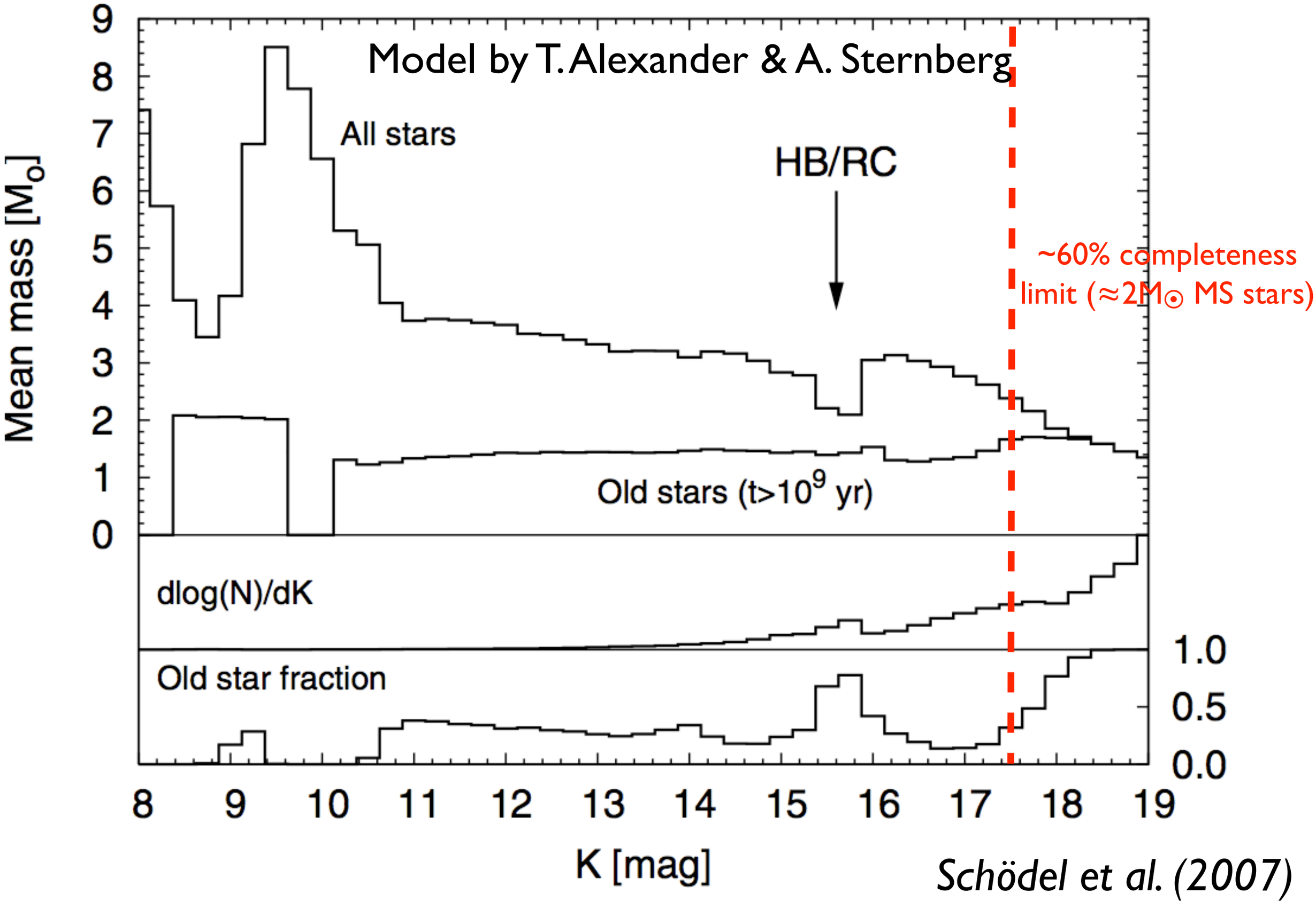
- Destroyed:
  e.g., by infall of IMBH up to a few $10^9$ yr ago

- Not yet formed:
  necessary time scale may be longer than ~$10^{10}$ yr *(Merritt 2009)*

- Invisible:
  giants could be destroyed by collisions with MS stars and BHs in dense cluster center; however, mechanism probably not effective enough *(Dale+ 2009)*

- Are our assumptions correct?
  Continuous star formation, cluster not old enough?, cluster embedded in nuclear bulge, fraction of disrupted star accreted onto BH?, etc.

# What do we observe at the GC?




*Schödel et al. (2007)*

# What do we observe at the GC?

*Source:Wikipedia*
*Created by Uwe Kils (iceberg) and User:Wiska Bodo (sky).*

# Thank you!