Large-scale observations of the Milky Way Nuclear Star Cluster

Image: Spitzer Space Telescope

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ESO

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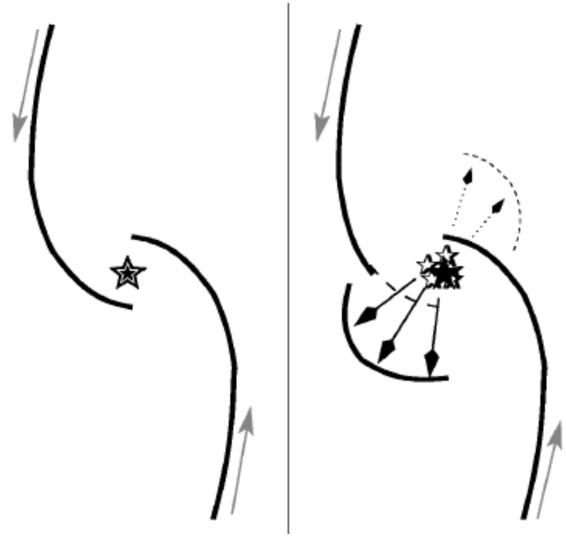
There are two scenarios for NSC formation

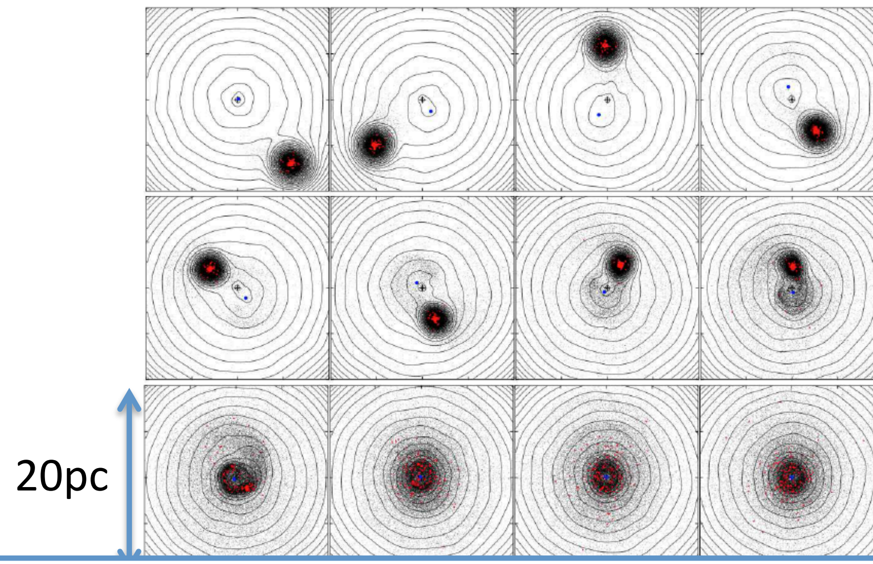
1) Gas is accreted and stars form in situ

(e.g. Loose et al. 1982, Schinnerer et al. 2008)



2) Star clusters migrate to the center and merge

(e.g. Tremaine et al. 1975, Antonini 2014)



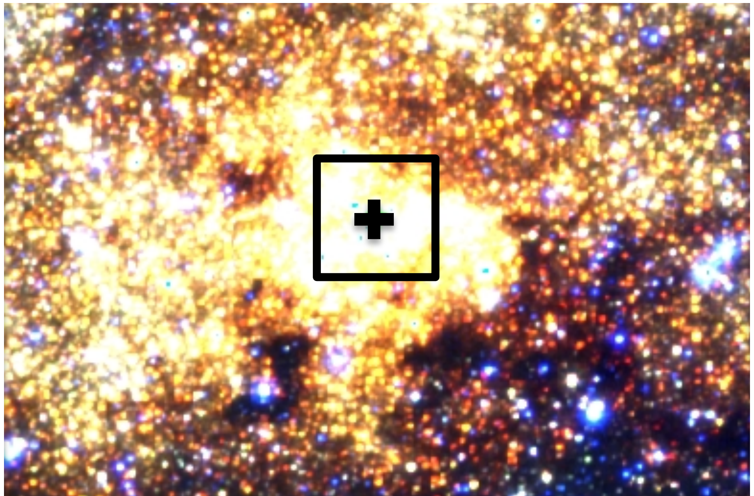
Both mechanisms can work in parallel in other NSCs

(e.g. Neumayer et al. 2011, den Brok et al. 2014),

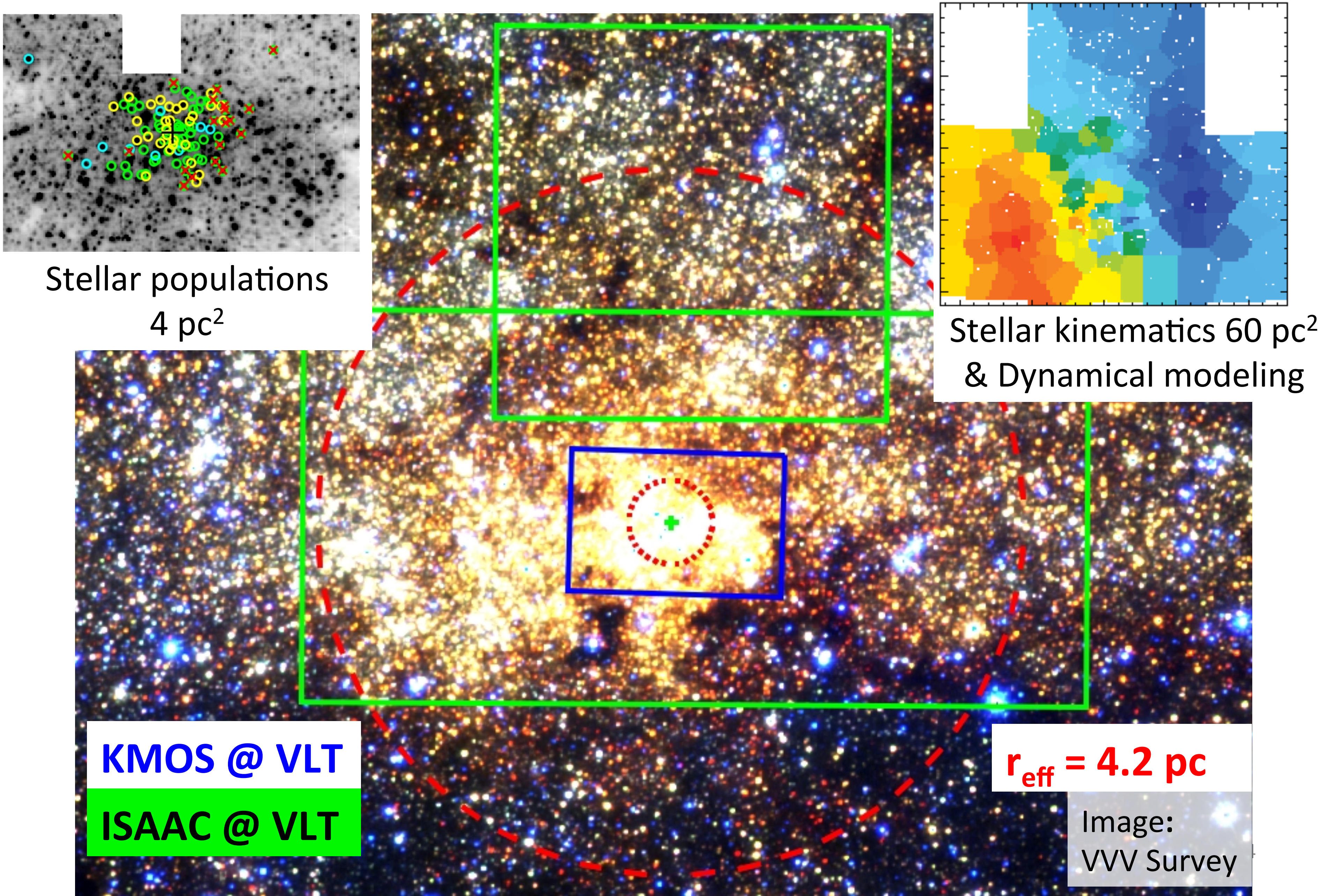
but which mechanism dominates in the Milky Way?

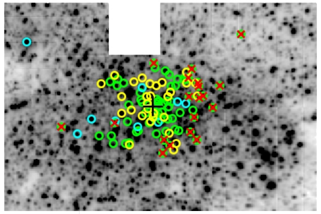
The central Milky Way nuclear star cluster

- **SMBH:** 4 x 10^6 $M_\odot$ (Boehle et al. 2016, Gillessen et al. subm.) in the center
- S-Star cluster in the central 1" (0.04pc) Eisenhauer et al. 2005, Talk by M. Habibi on Friday
- Young massive stars (3-8 Myr) at 0.8-12" (0.03-0.5pc) distance from the SMBH e. g. Paumard et al. 2006, Støstad et al. 2015
- Some intermediate-age stars (50-500 Myr) out to r=3 pc e.g. Maness et al. 2007, Nishiyama et al. 2016
- Cool, older (>5 Gyr) red giant stars out to 2.5pc; 75% of the stars (Blum et al. 2003, Pfuhl et al. 2011)

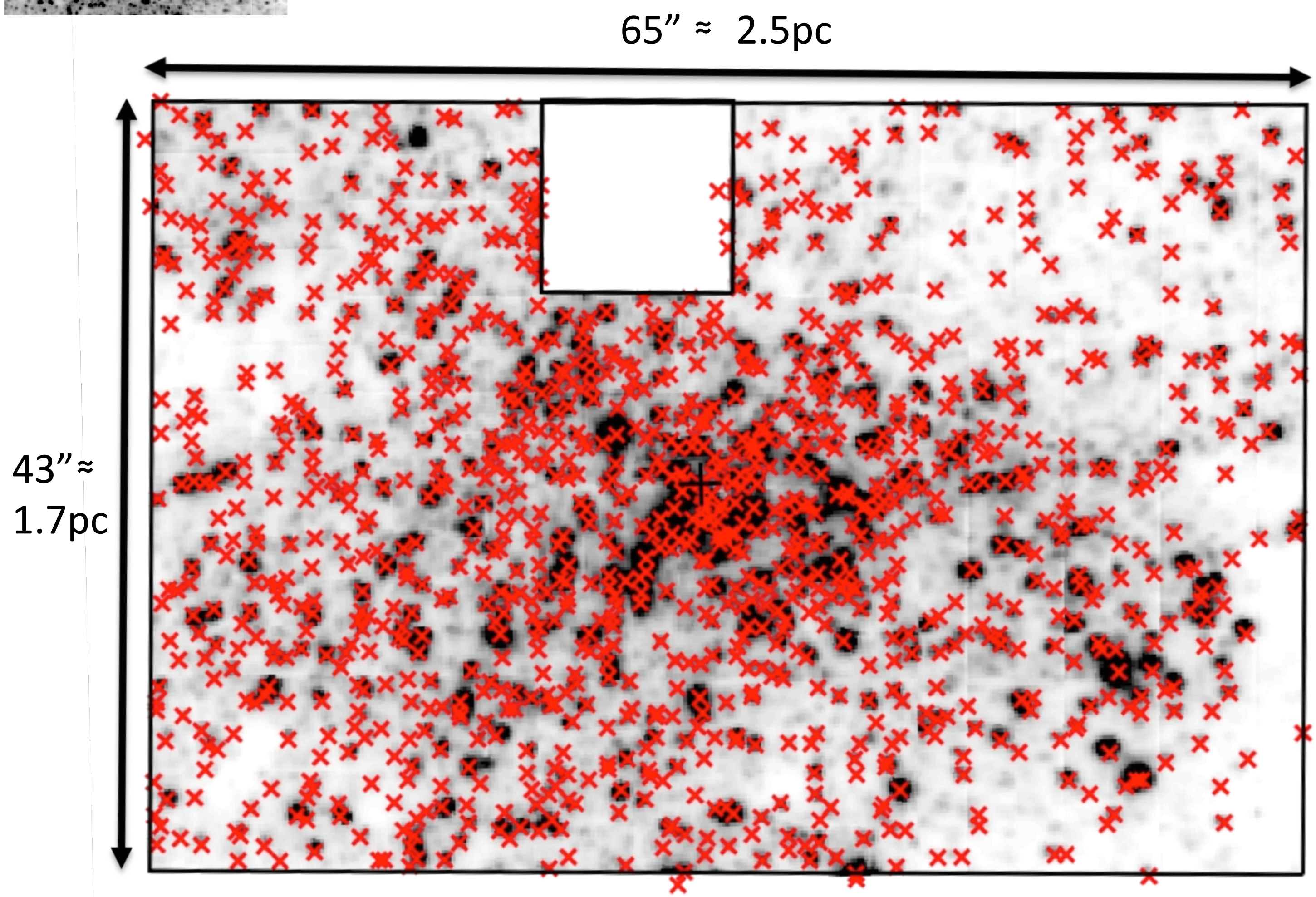


The extended Milky Way nuclear star cluster



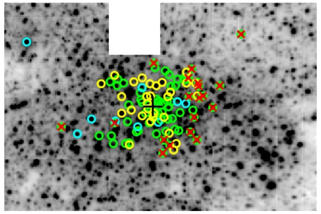


Stellar populations with KMOS

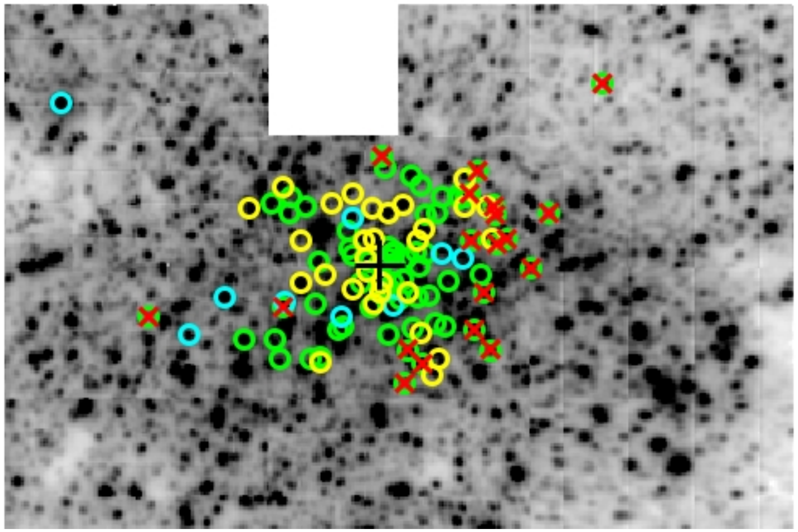


Area: 4pc^2
R ≈ 4000
Seeing limited

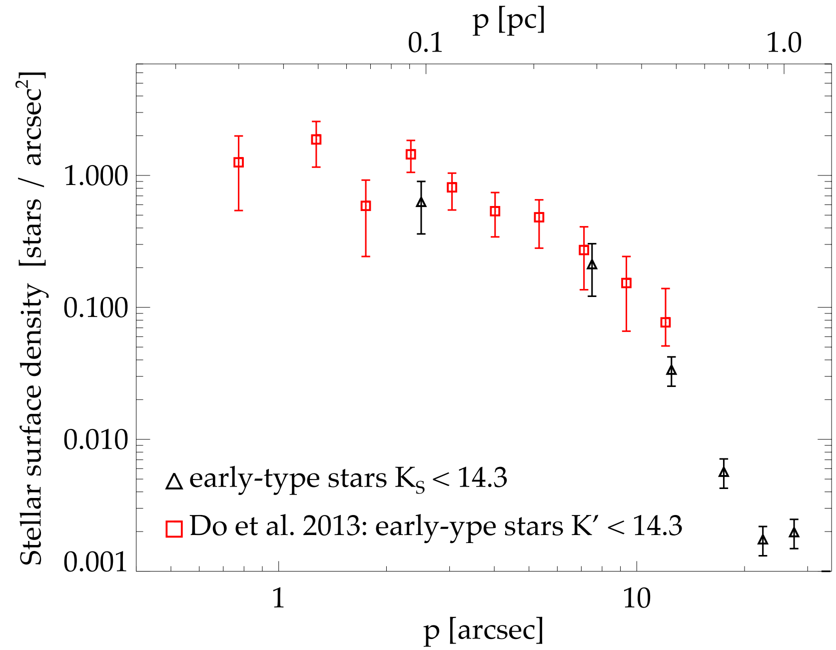
K-band Spectra of >1,000 stars



Young massive stars in the center



Feldmeier-Krause et al. 2015

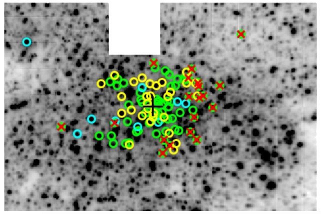


We detected 19 new young O/B type stars (red crosses).

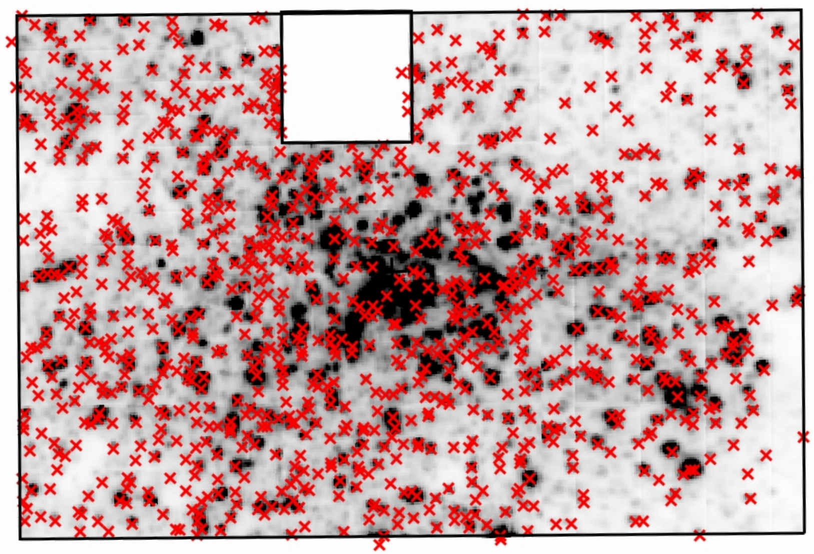
Young stars are centrally concentrated in r = 0.5 pc.

An infalling cluster would have left behind young stars at large radii (see also Støstad et al. 2015).

→ Young stars formed in-situ



Most stars are cool red giants

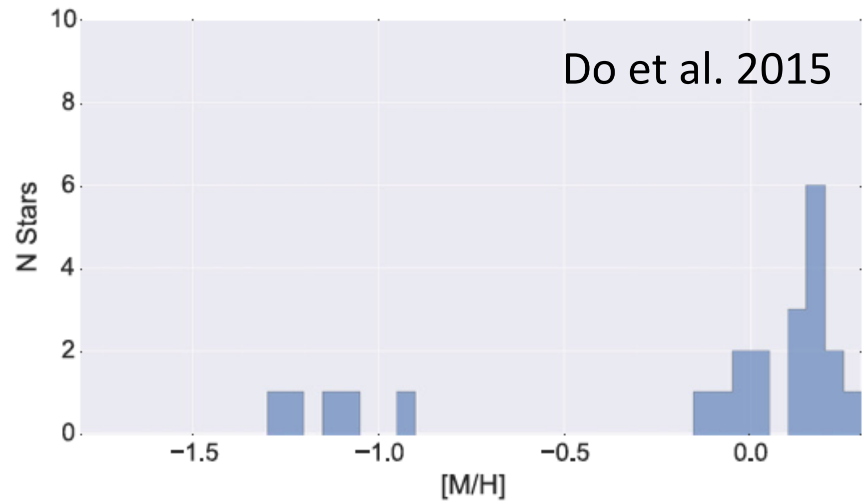


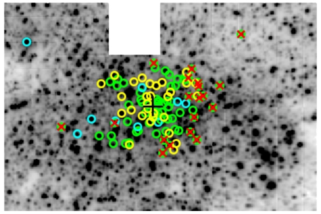
We can constrain the stellar metallicity distribution.

Previous studies:

- Metallicities of **< 100 stars.**
- **Mean [M/H]** range: +0.1 to +0.4 dex

(Ryde & Schultheis 2014, Do et al. 2015, Schultheis et al. 2016, Ryde et al. 2016)



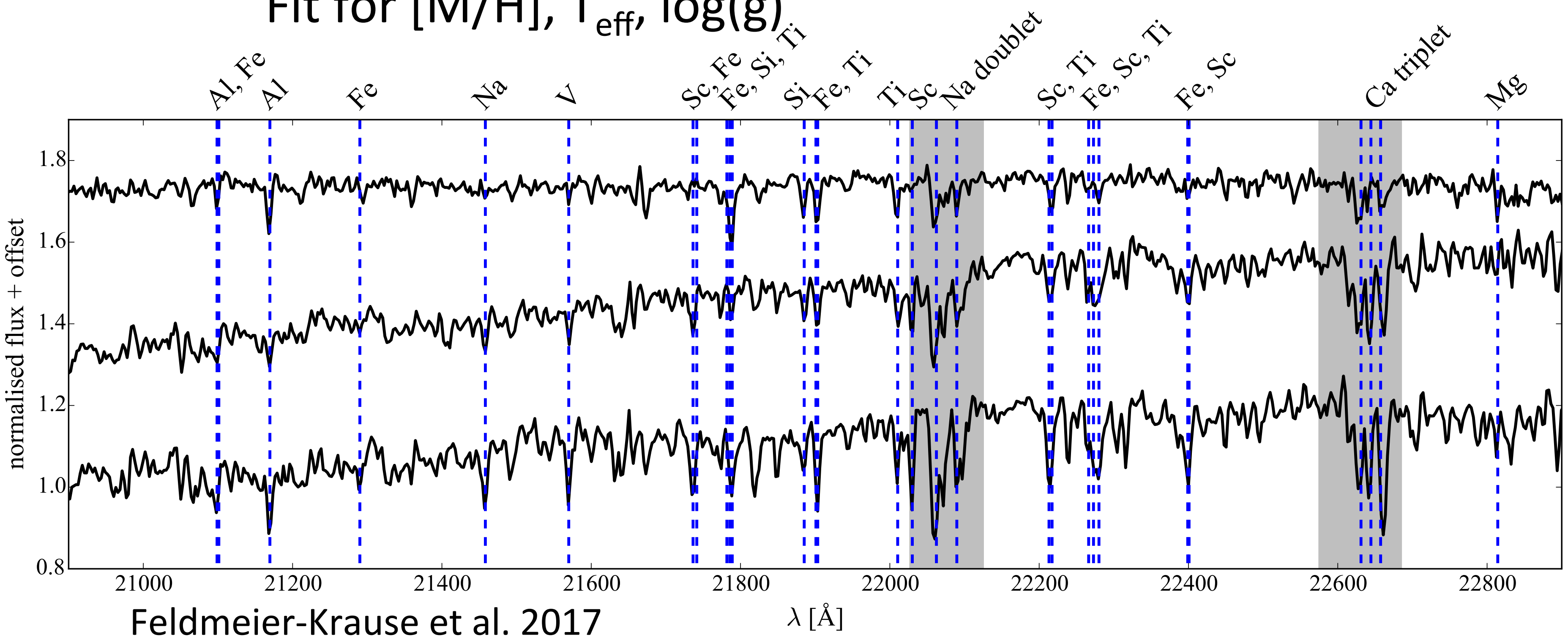


Metallicity distribution of red giant stars

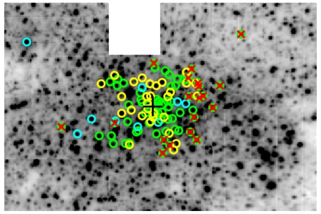
Method:

- ✧ Full Spectral fitting with STARKIT (Kerzendorf & Do 2015) for >700 stars
- ✧ PHOENIX library of synthetic spectra as templates (Husser et al. 2013)

Fit for [M/H], T_{eff}, log(g)



Feldmeier-Krause et al. 2017



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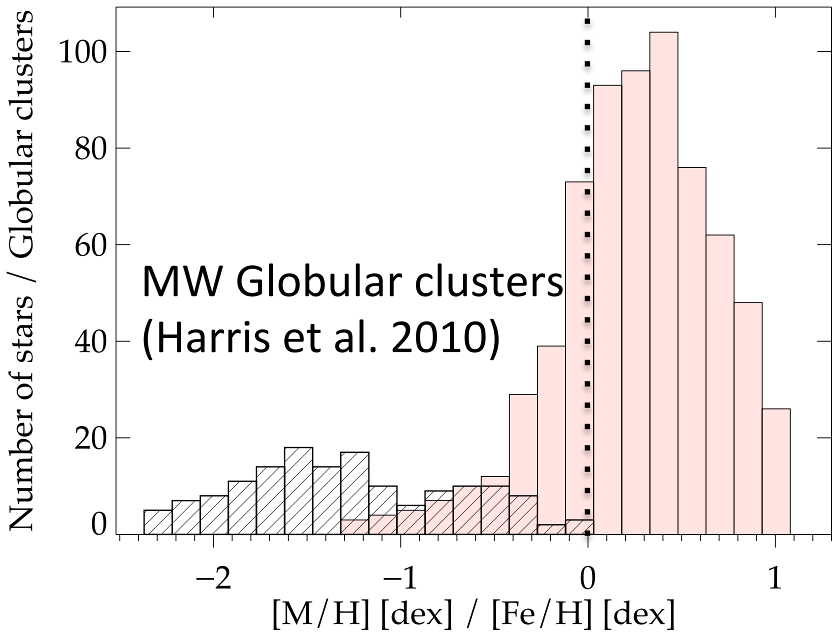
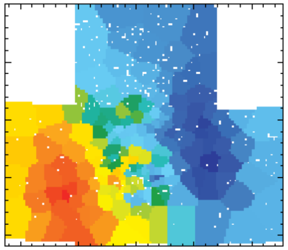


Feldmeier-Krause et al. 2017

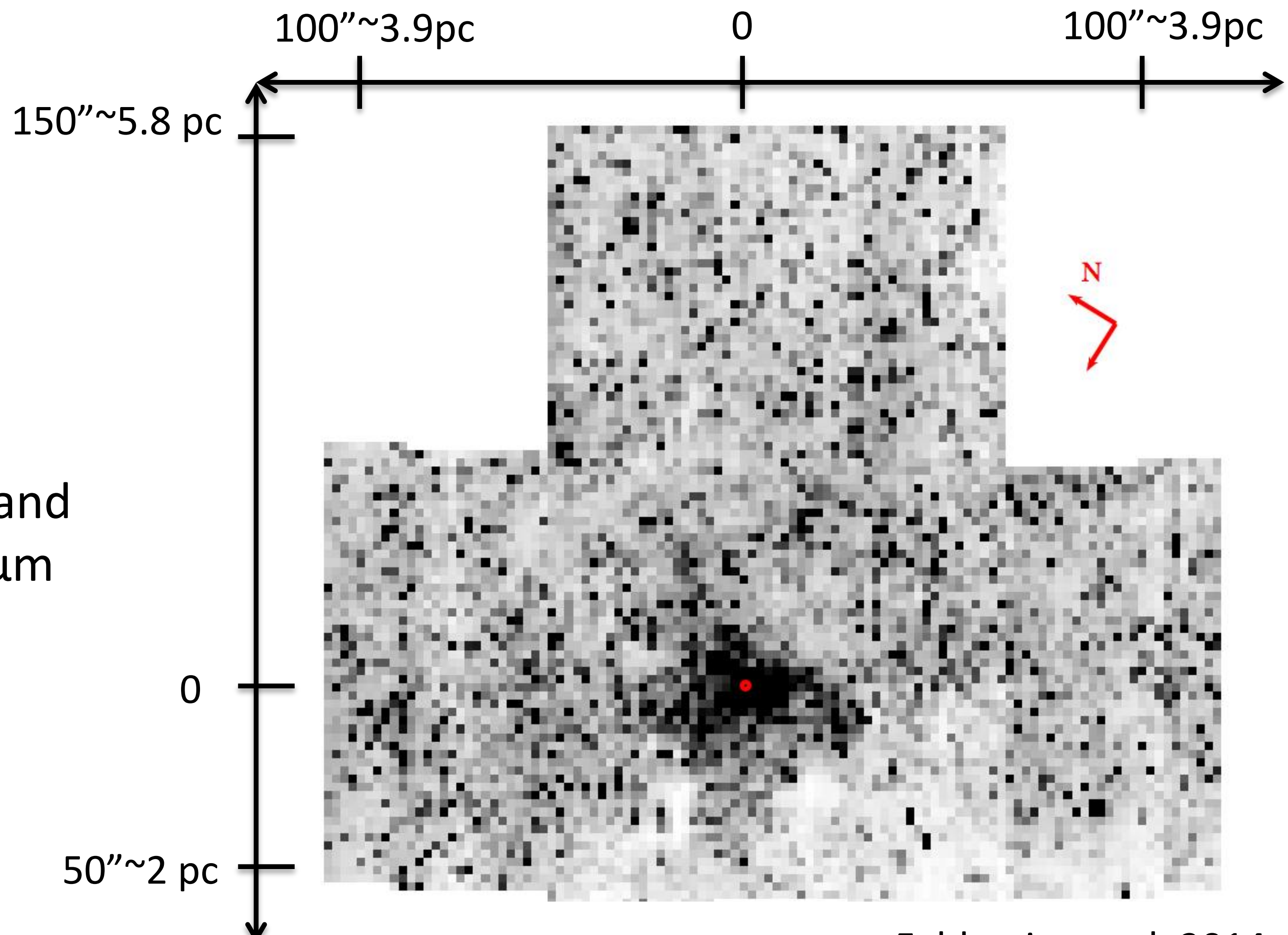
- ✧ Mean metallicity [M/H] = +0.26dex
- ✧ 25% of stars are metal-poor (< 0.0 dex).
- ✧ The metal-poor stars are consistent with globular cluster stars, but also with inner bulge stars (Ryde et al. 2016).



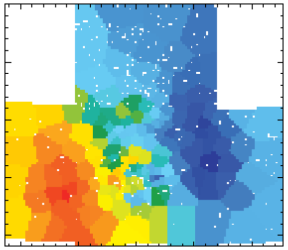
Stellar kinematics of red giants

60 pc^2
ISAAC (VLT)
R ≈ 4 400

Red end of K_S-band
λ = 2.29 – 2.41 μm

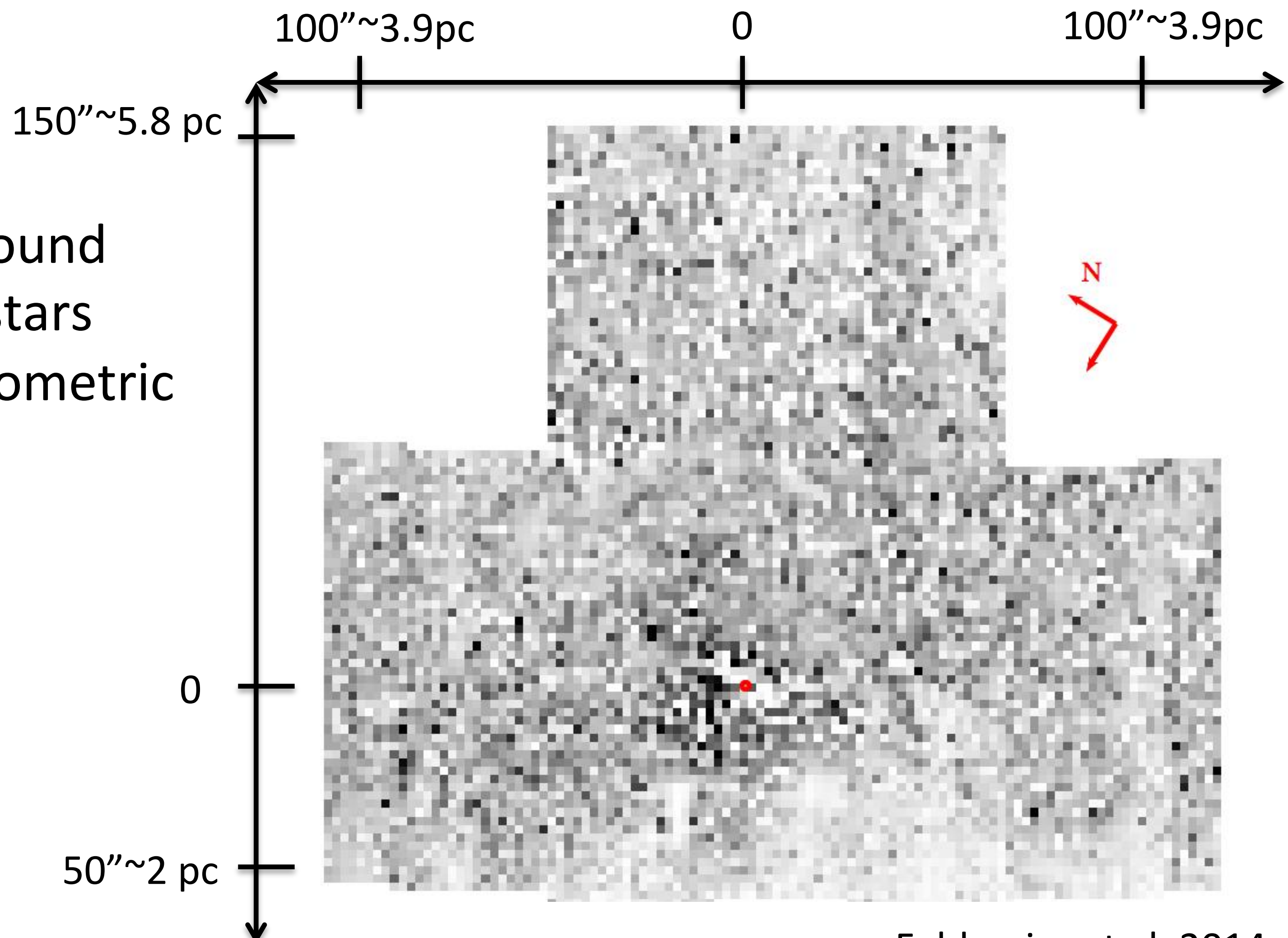


Feldmeier et al. 2014

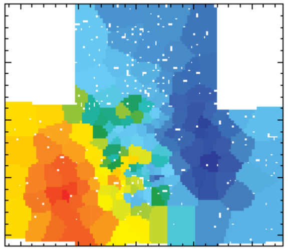


Stellar kinematics of red giants

Cut out foreground and brightest stars based on photometric catalogs

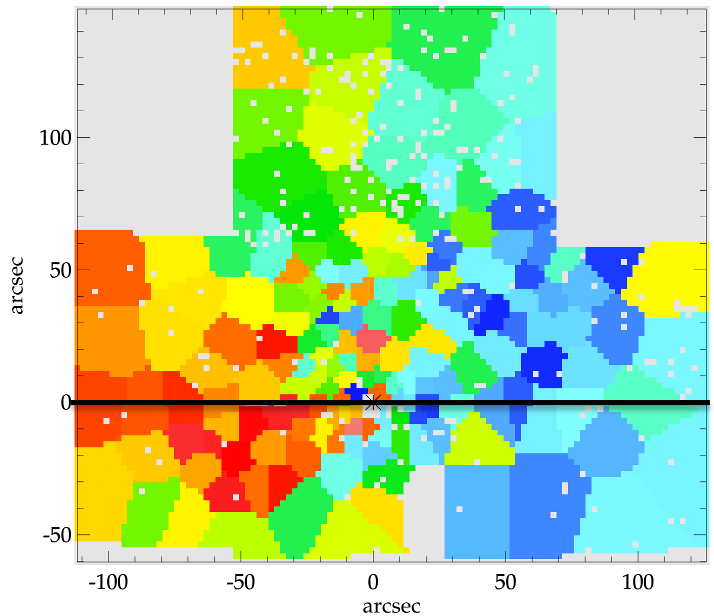


Feldmeier et al. 2014



The two-dimensional kinematics of red giant stars reveals unexpected structures

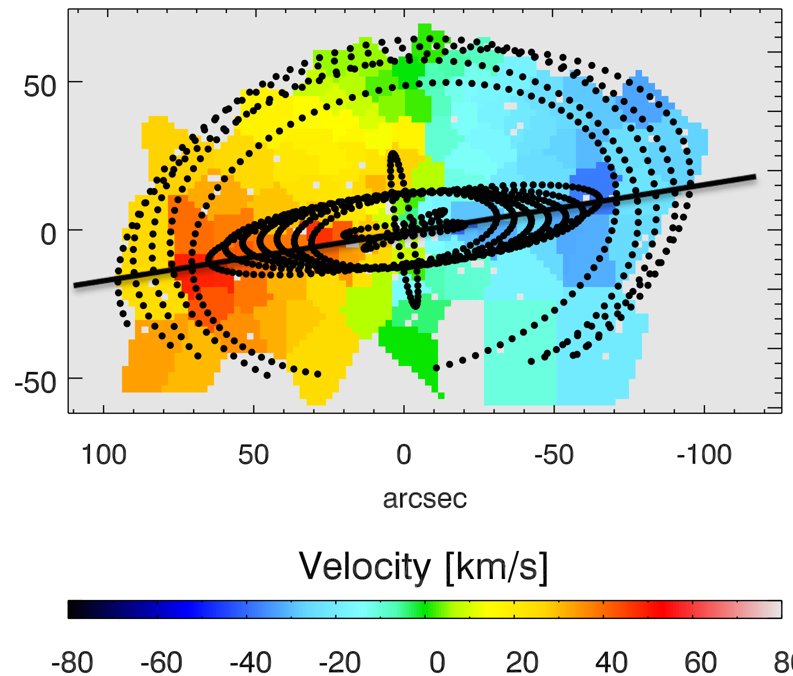
1. Position angle offset



Feldmeier et al. 2014

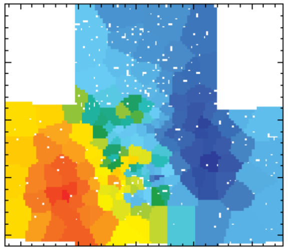
Kinemetry model

(Krajnovic et al. 2006)



Rotation axis is offset by ≈ 9° from photometric minor axis

(see also Fritz et al. 2016)



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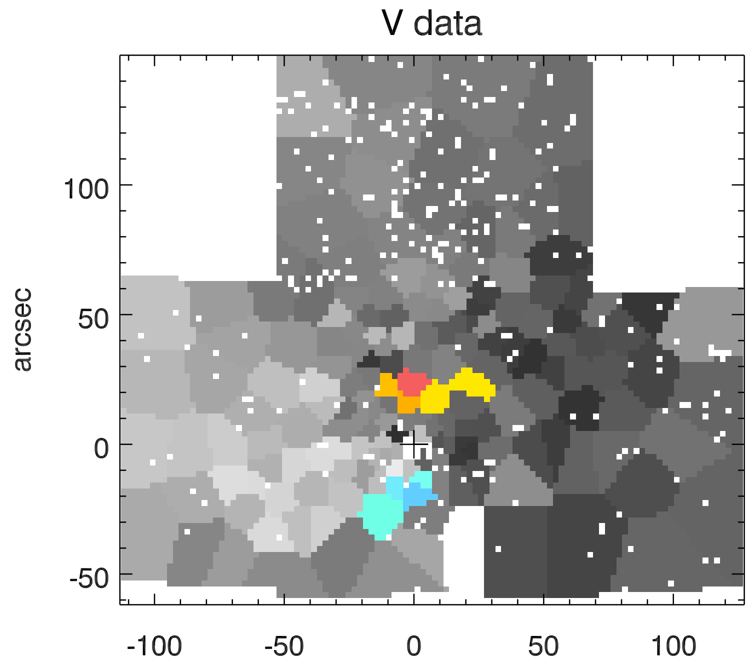
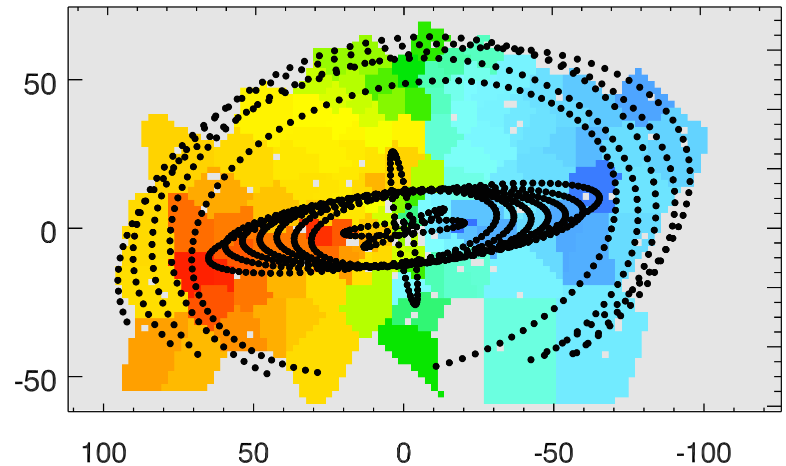


2. Perpendicular rotating substructure

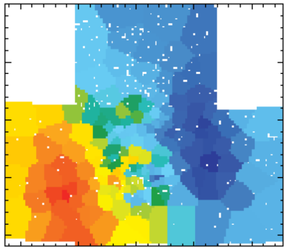
Kinemetry model
(Krajnovic et al. 2006)



Complex kinematics, hint at accretion of star clusters

(Tsatsi et al. 2017, Talk by A. Mastrobuono-Battisti)

The Milky Way nuclear star cluster is not an axisymmetric system?

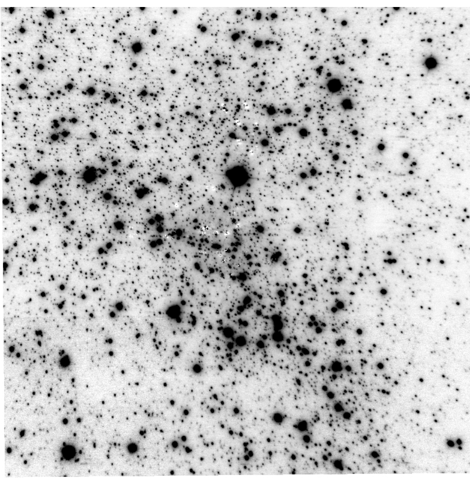


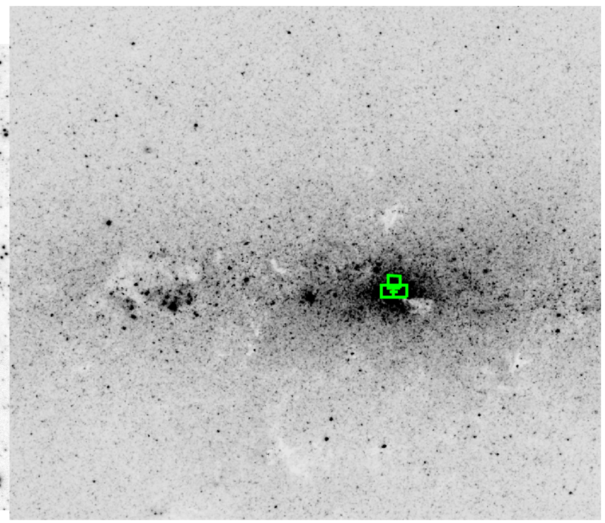
Axisymmetric surface brightness distribution for dynamical modeling

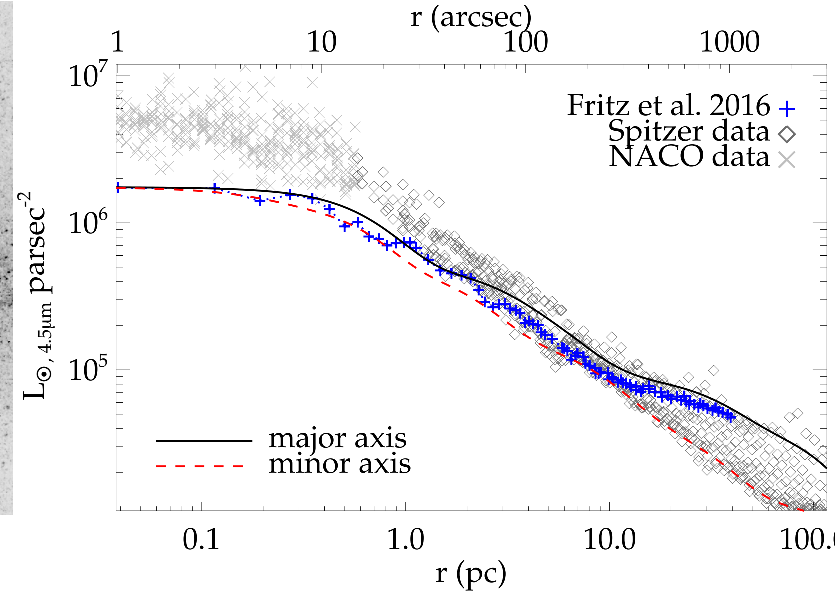
H-band NaCo mosaic
(Schödel et al. 2009)
1.6 pc x 1.6 pc

4.5µm Spitzer
~ 270 pc x 200 pc

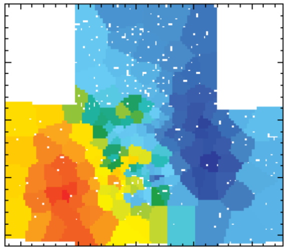
Surface brightness distribution
Multi-Gaussian expansion fit
(Cappellari 2002)







- ✧ Young stars were cut out
- ✧ Dust emission and extinction corrected (Schödel et al. 2014)
- ✧ Central flux scaled to Fritz et al. 2016



Triaxial dynamical Schwarzschild modeling

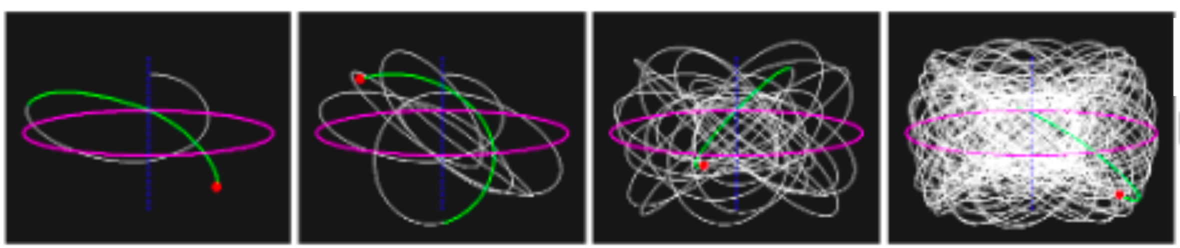
Models by van den Bosch et al. (2008)

Compute a gravitational potential $\Phi_{tot} = \Phi_{\star} + \Phi_{\bullet}$

Assuming

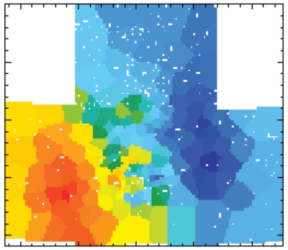
- 3 Shape parameters q, p, u
- Constant mass-to-light ratio M/L
- Black hole mass $M_{\bullet}$

Compute an orbit library



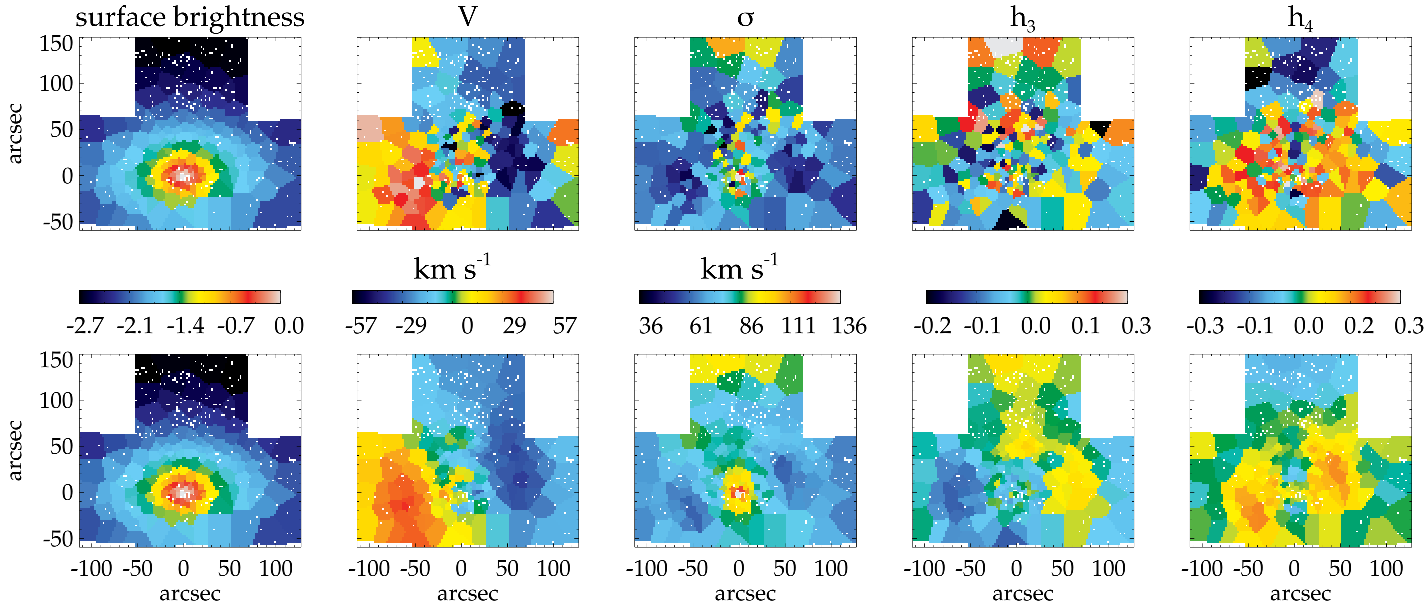
Cappellari 2015

Find orbit superposition that recovers the kinematic data



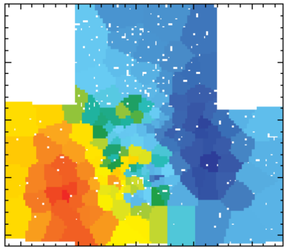
Triaxial dynamical Schwarzschild modeling

Best fit:

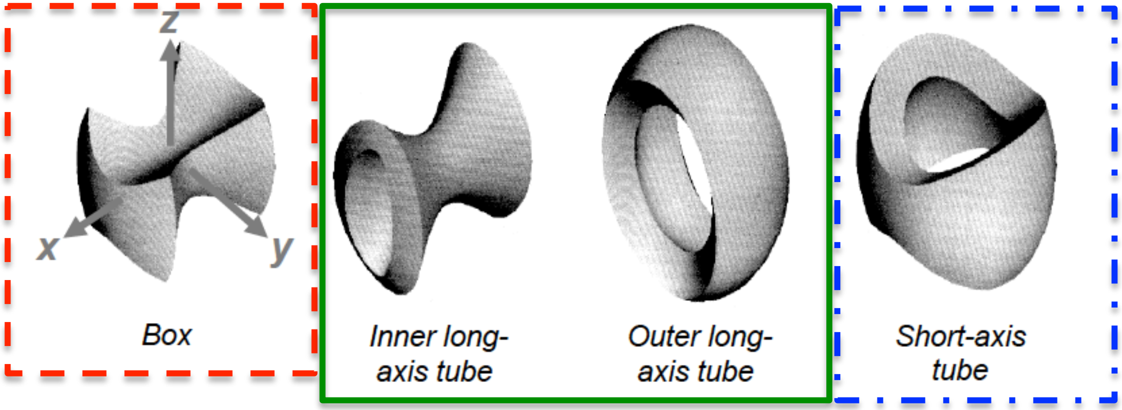


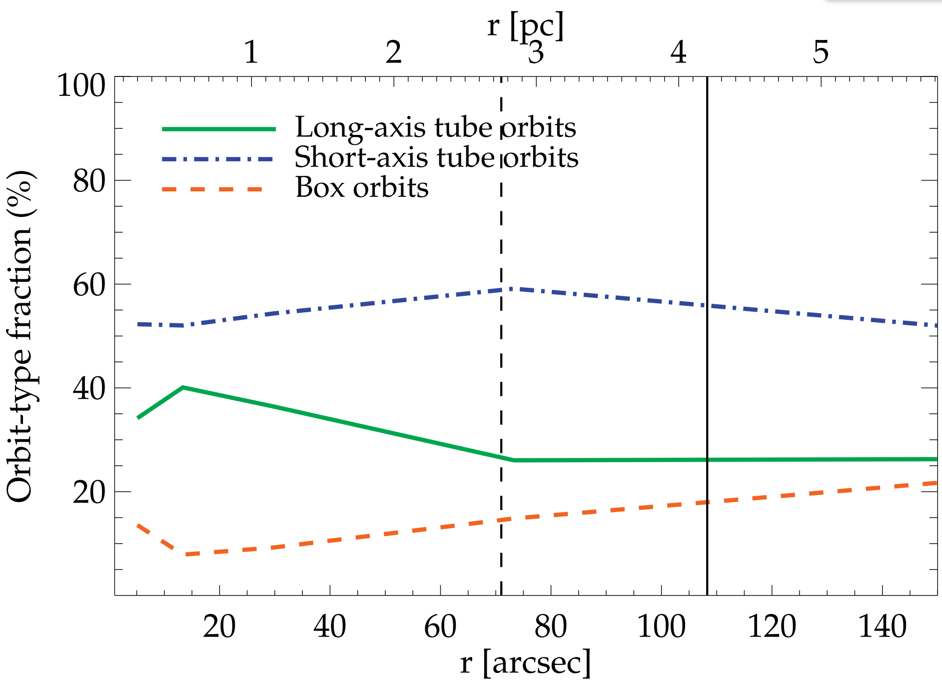
χ^2_{red}	M/L $[M_\odot/L_{4.5\mu m,\odot}]$	q (Minor/major axis ratio)	p (Intermed./major axis ratio)	$M_\bullet$ $[x10^6\ M_\odot]$
0.42	$0.90^{+0.76}_{-0.08}$	$0.28^{+0.0}_{-0.02}$	$0.64^{+0.18}_{-0.06}$	$\mathbf{3.0^{+1.1}_{-1.3}}$

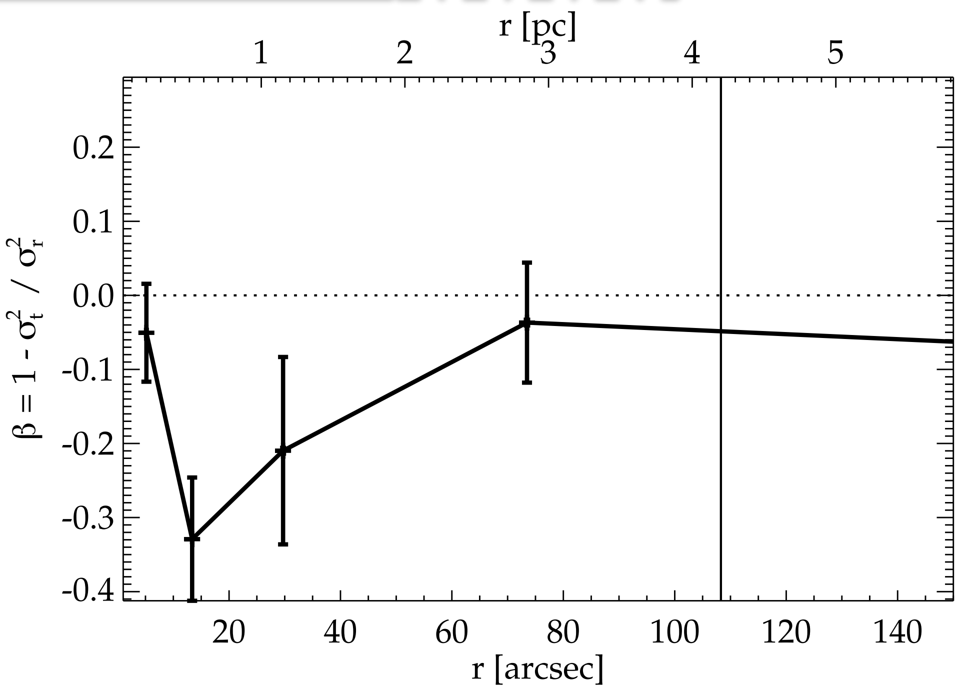
Feldmeier-Krause et al. subm.



Orbital structure of the MWNSC

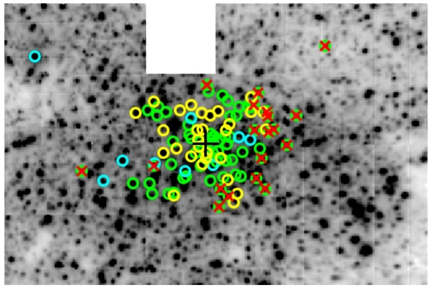


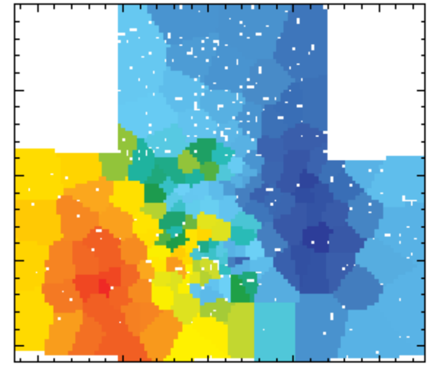




Feldmeier-Krause et al. subm.

Large-scale observations of the MWNSC





1. Stellar populations in 4 pc^2

- Young stars formed in-situ
- 75% of red giants are metal-rich stars, inconsistent with a globular cluster origin
- Metal-poor red giants may originate from globular cluster infall

2. Stellar kinematics in 60 pc^2 & Dynamical modeling

- Complex kinematic structures are signatures of different accretion events
- Large-scale triaxial dynamical models recover the SMBH mass