Observations of the Galactic Center with WFIRST

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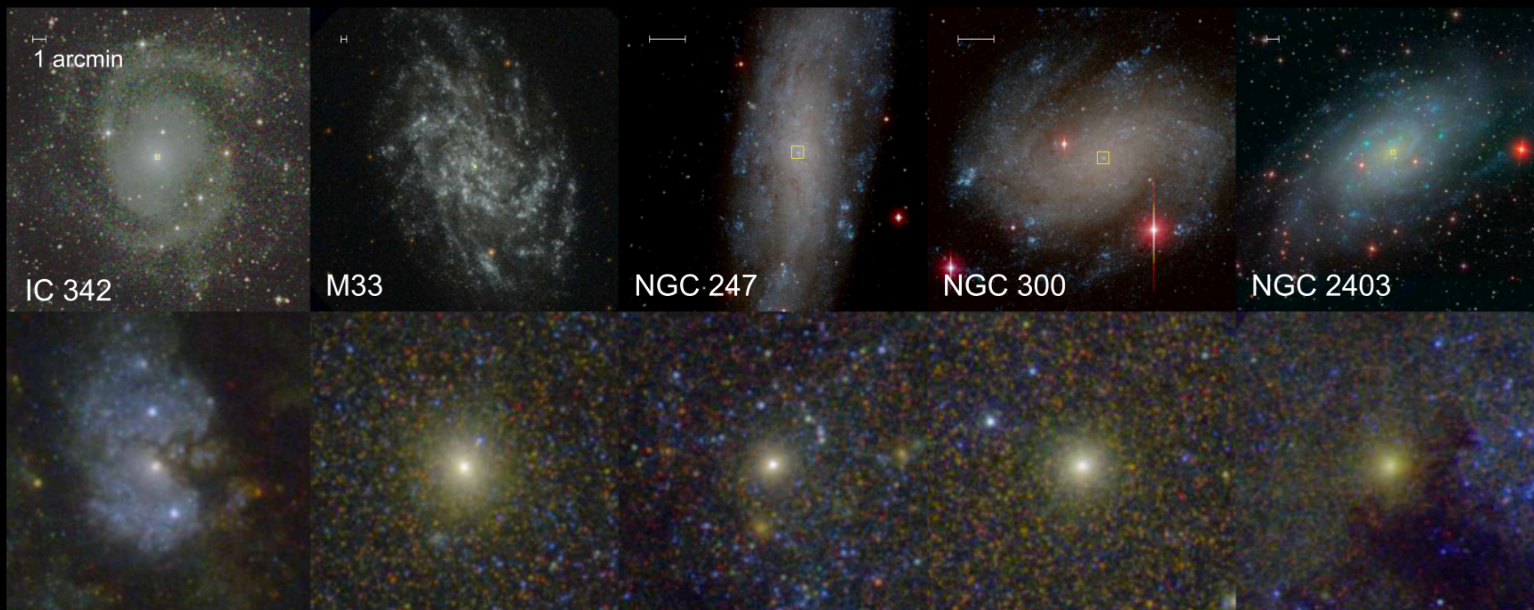
(UCLA)

Science in our own Backyard: Exploring the Galaxy and the Local Group with WFIRST, Caltech, Pasadena, 2019-06-18

What is the origin of the Milky Way Nuclear Star Cluster?

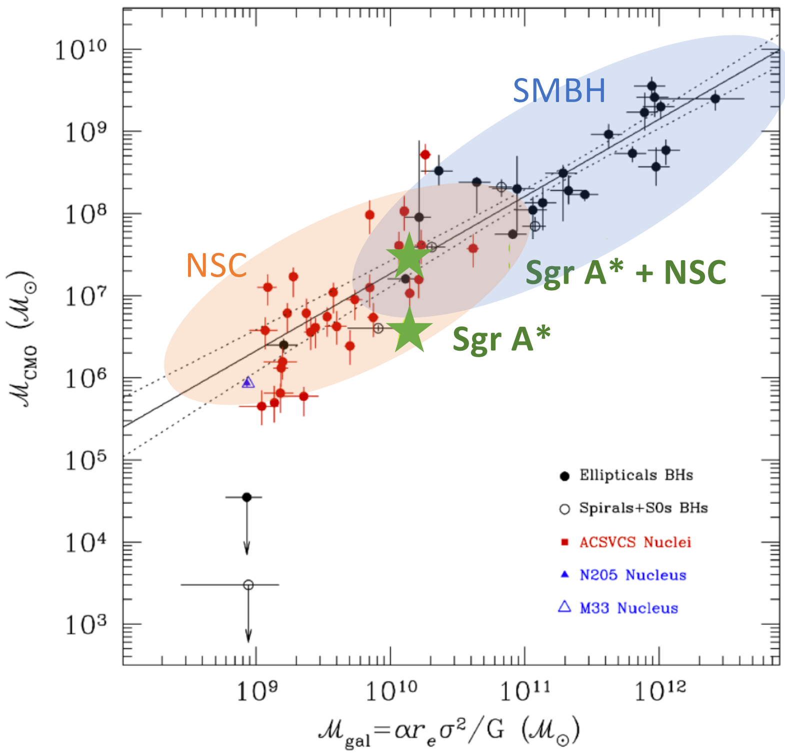
Nuclear star clusters are massive, & dense star clusters at the centers of many galaxies



HST images of NSCs from Carson et al. (2015)

See also: Böker et al. 1999, 2002, Walcher et al. 2005, Georgiev et al. 2014

The formation and evolution of nuclear star clusters, massive black holes, and galaxies are likely related



How do supermassive black holes and the formation of galactic nuclei relate to galaxy evolution?

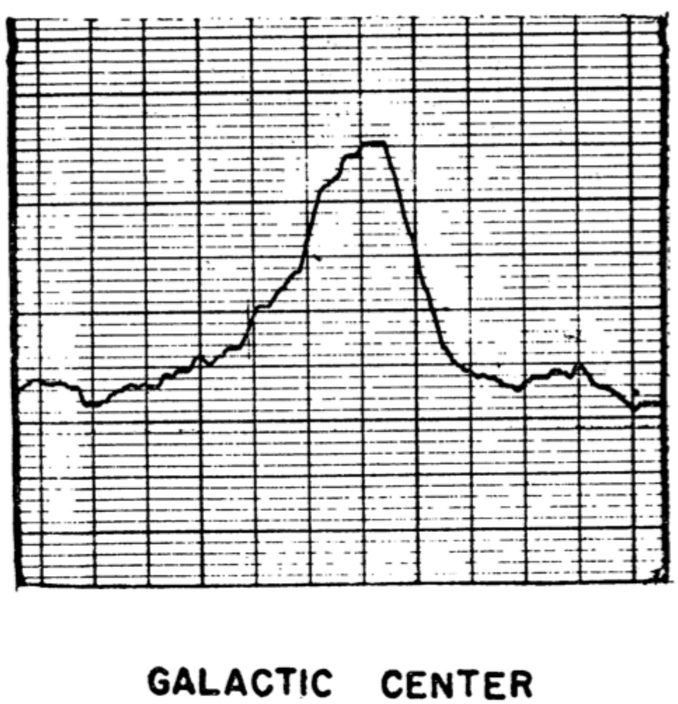
From Ferrasese et al. 2006, Schoedel 2011

See also: Wehner & Harris 2006 , Graham 2012, McConnell & Ma 2013, Capuzzo-Dolcetta et al. 2017

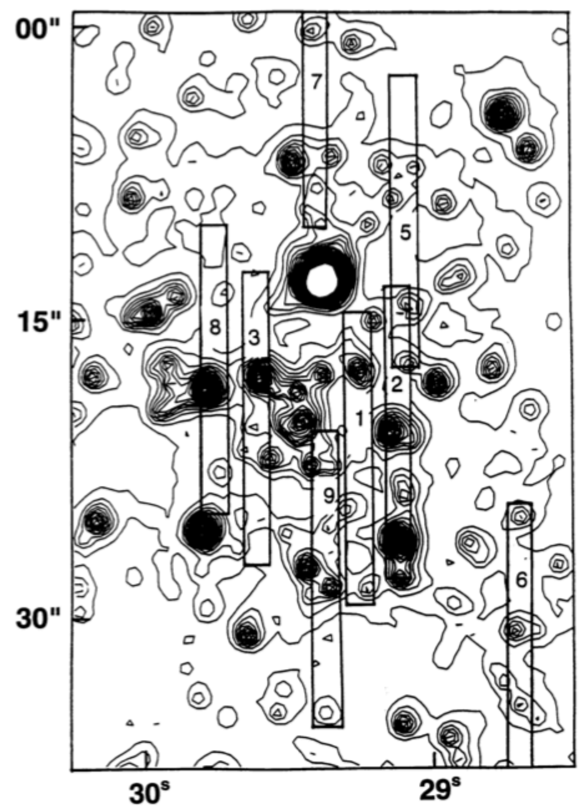
NASA/ESA/UCLA Galactic Center Group/T. Do/M. Williams/S. Sakai

Early infrared measurements discovered the Milky Way nuclear star cluster

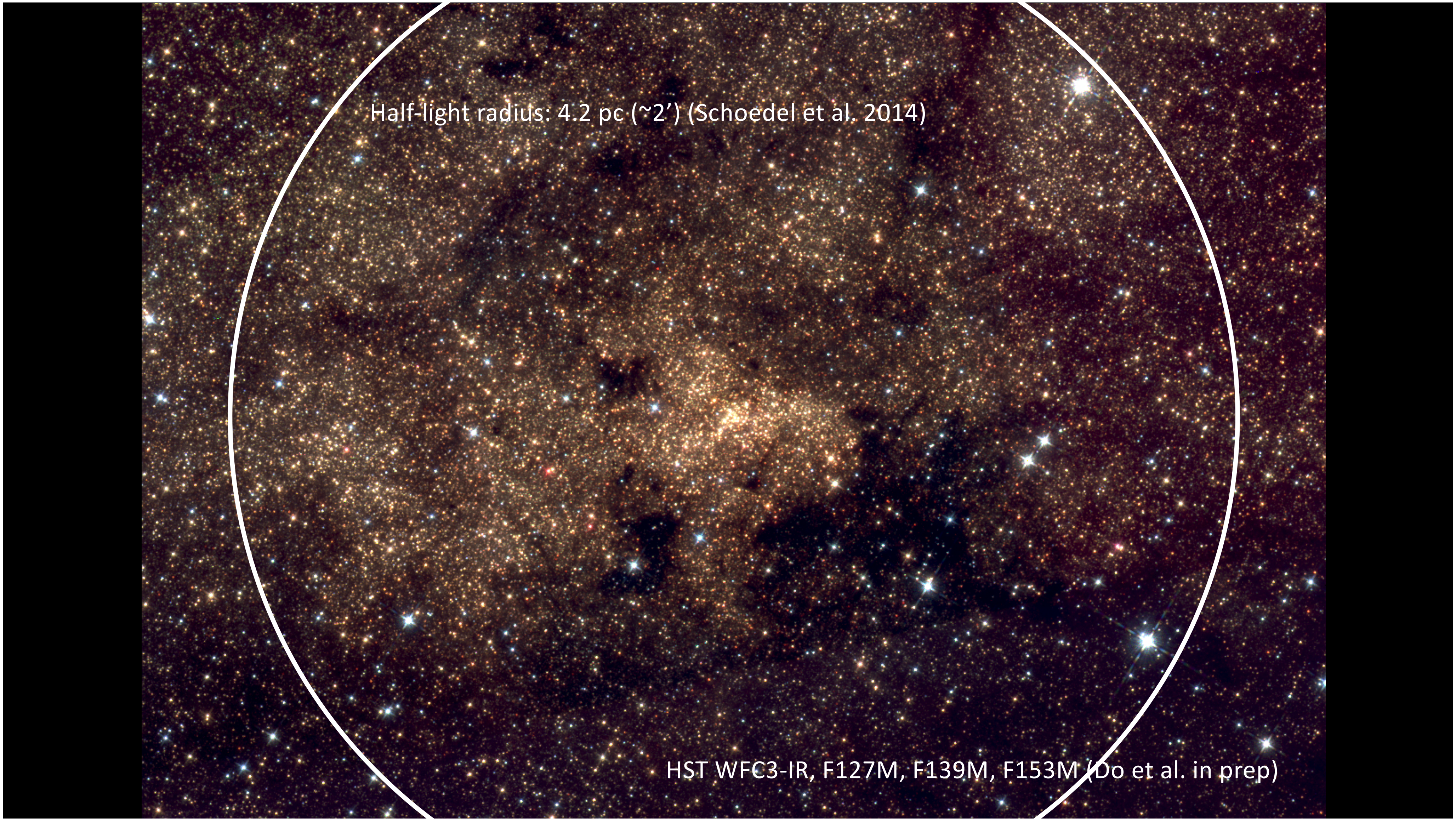
(7 pc) |←3'→|



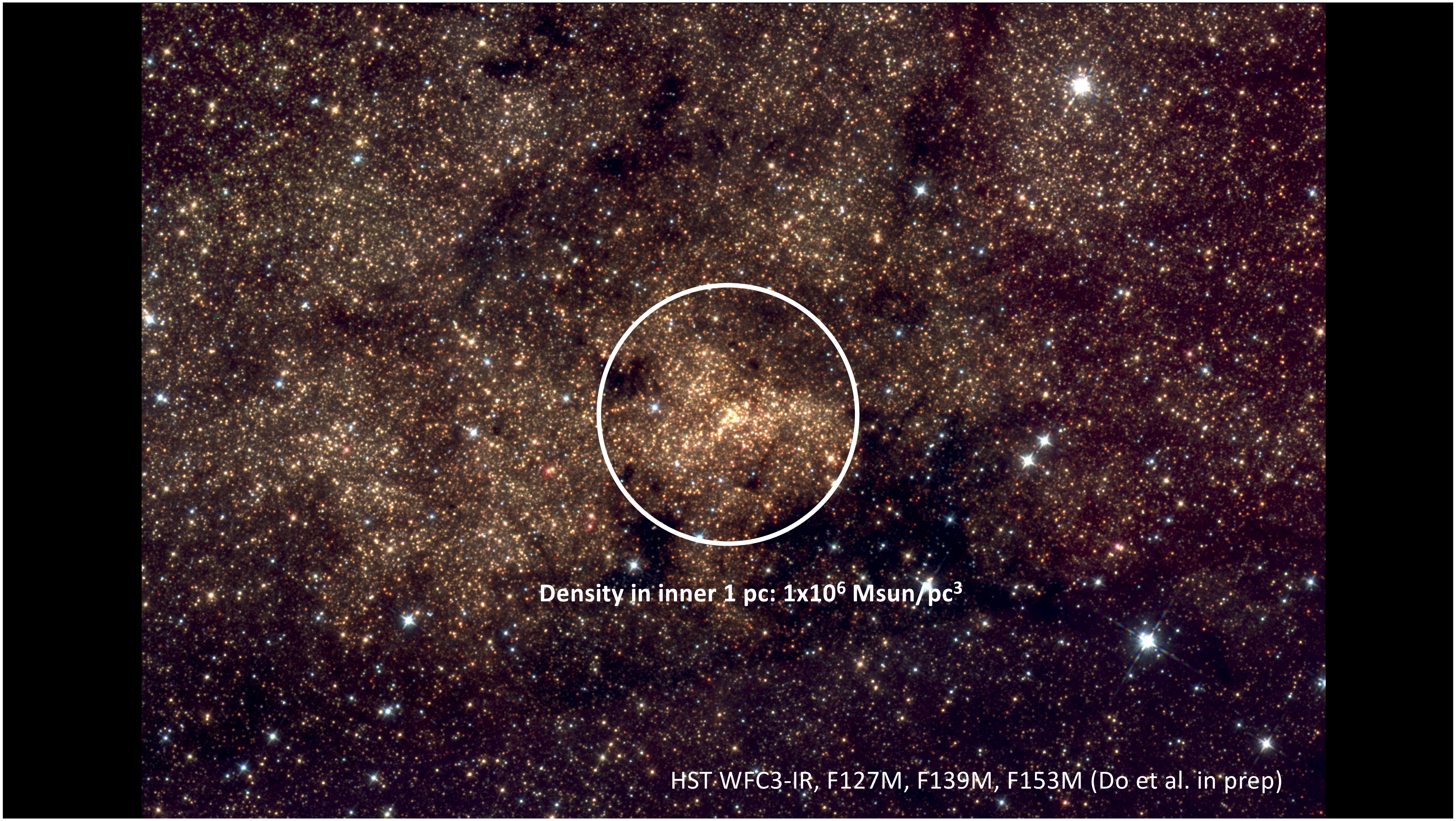
Becklin & Neugebauer 1968



Haller et al. 1996

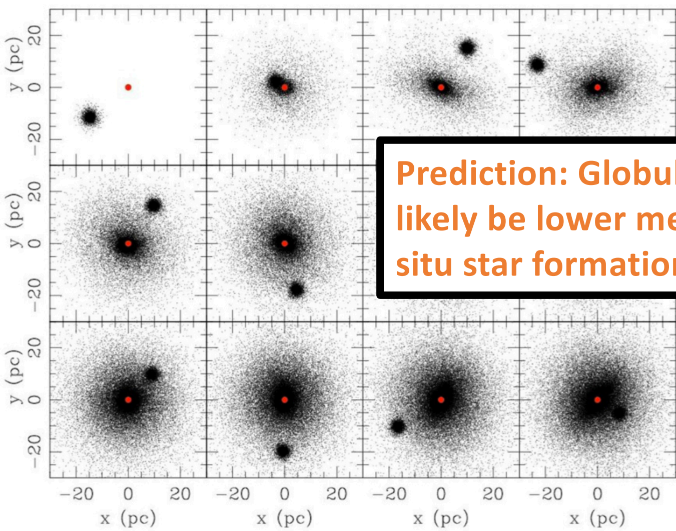

Half-light radius: 4.2 pc (~2') (Schoedel et al. 2014)
HST WFC3-IR, F127M, F139M, F153M (Do et al. in prep)


Total Mass: ~10^7 Msun, 5-10 Gyr old
(Chatzopoulos et al. 2014, Schoedel et al. 2009, Pfuhl, et al. 2011)
HST WFC3-IR, F127M, F139M, F153M (Do et al. in prep)


Density in inner 1 pc: 1x10^6 Msun/pc^3
HST WFC3-IR, F127M, F139M, F153M (Do et al. in prep)

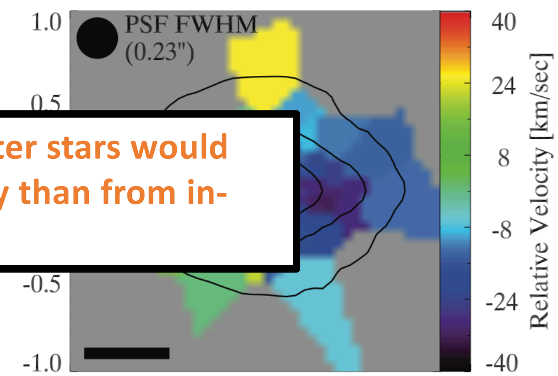
Dynamics and metallicities are ways to constrain the formation mechanisms of NSCs

Cluster in-fall builds NSC



(Antonini et al. 2014)

In-situ star formation from gas from the disk

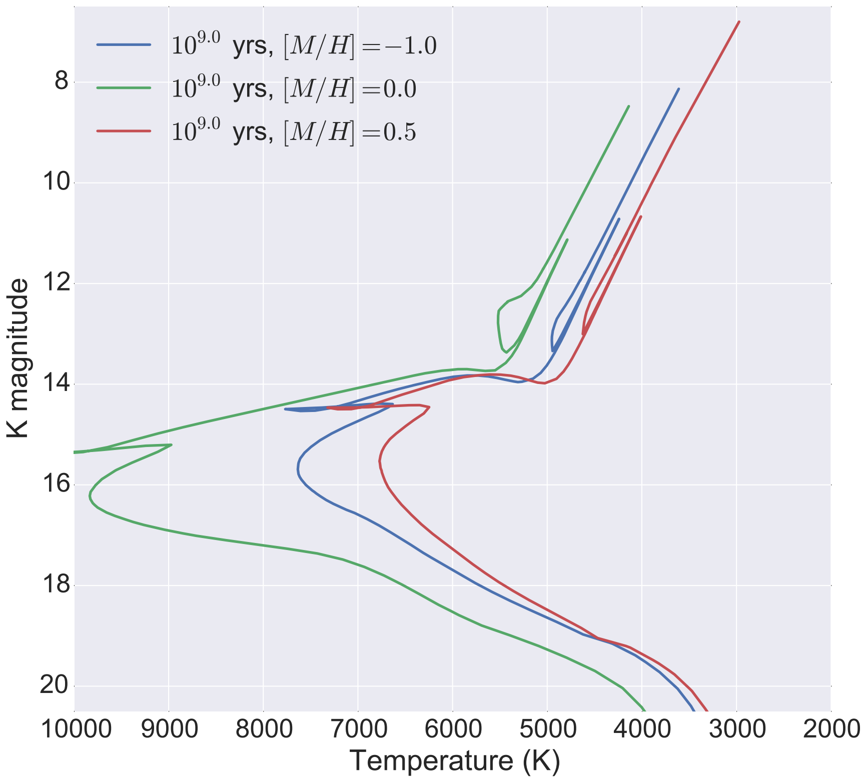


Rotating nuclear cluster in NGC 4244 (Seth et al. 2008)

Prediction: Globular cluster stars would likely be lower metallicity than from in-situ star formation

e.g., Tremaine et al. 1975; Capuzzo- Dolcetta & Miocchi 2008; Antonini et al. 2012, 2014; Perets & Mastrobuono-Battisti 2014

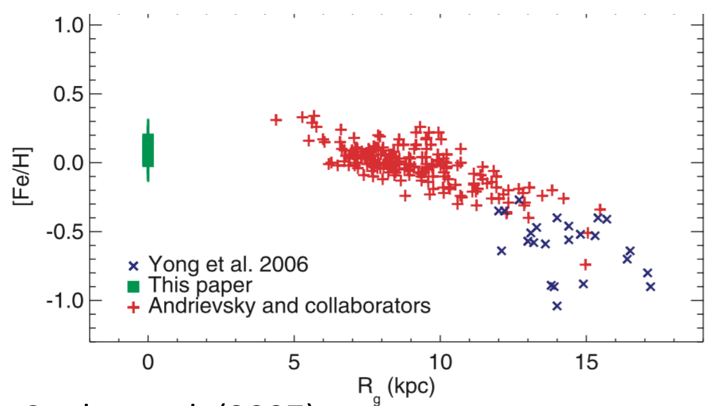
Metallicity is important to our interpretation of star formation history and origin of the MW NSC



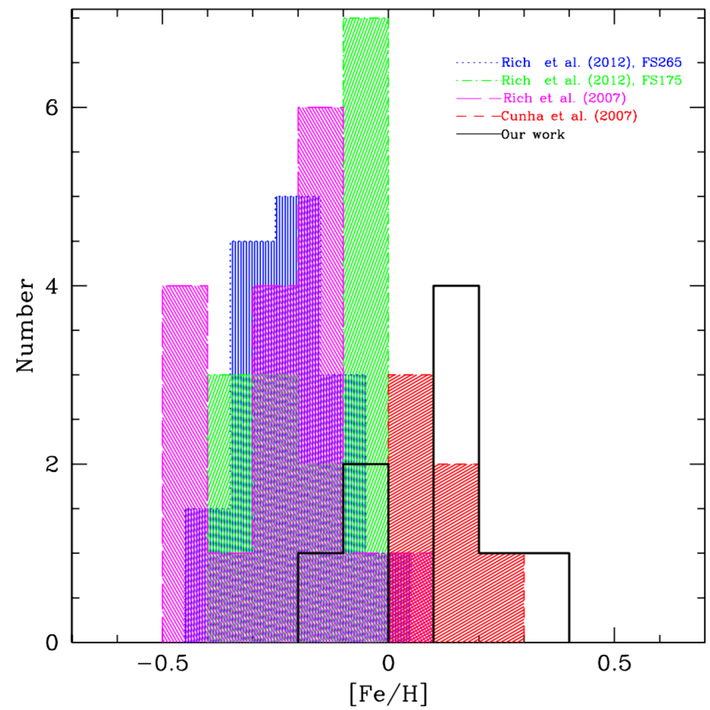
Do et al. (2015)

PARSEC isochrones (Bressan et al. 2012)

The nuclear star cluster was thought to be mainly solar metallicity



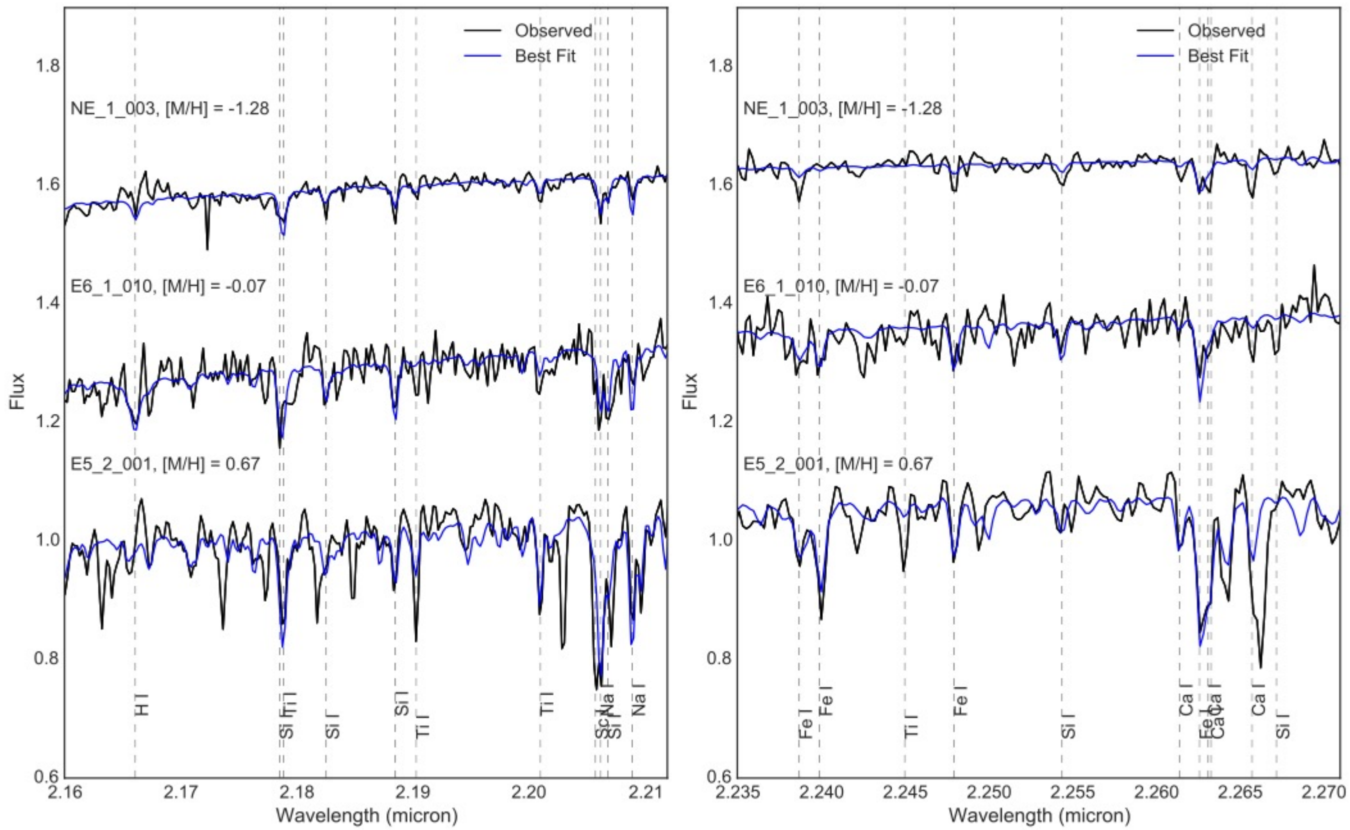
Cunha et al. (2007)



~ 12 stars have metallicity measurements in the MW NSC

Ryde & Schultheis (2015)

AO observations show large variations in metallicity at the Galactic center

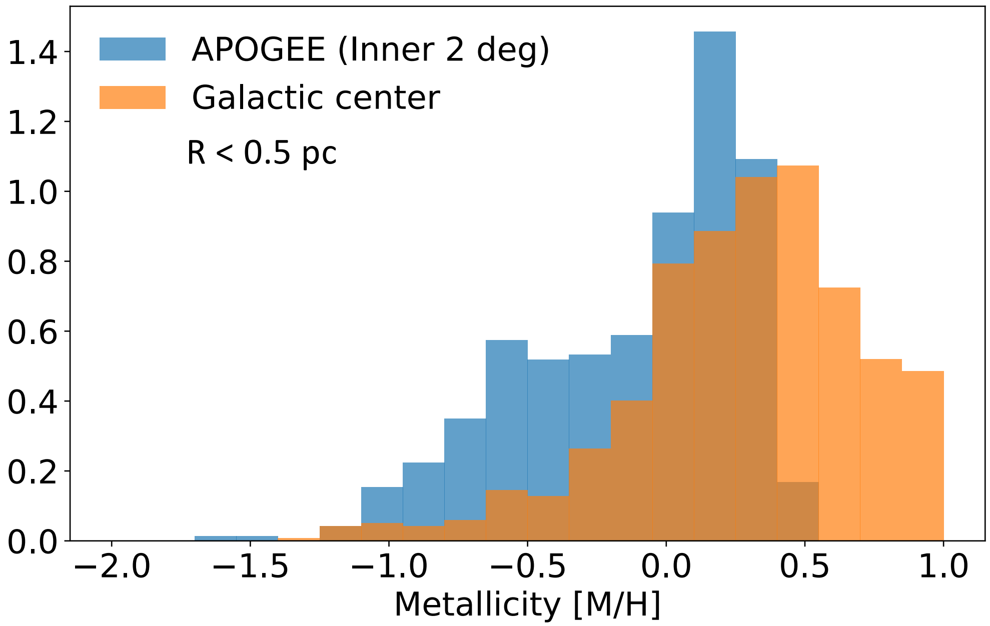


There are low metallicity stars!

Also, super-solar metallicity stars!

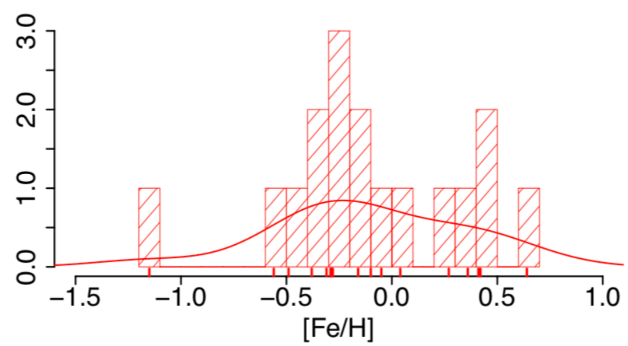
Do et al. (2015)

The NSC is likely very, metal-rich even compared to the inner bulge



Do et al. (2015, 2018)

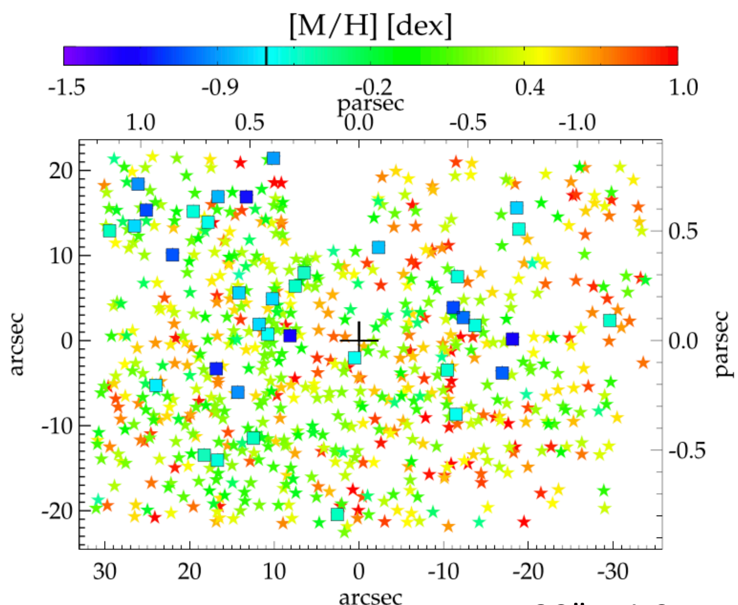
1.2 < R < 3.2 pc



From high-resolution observations (Rich et al. 2017)

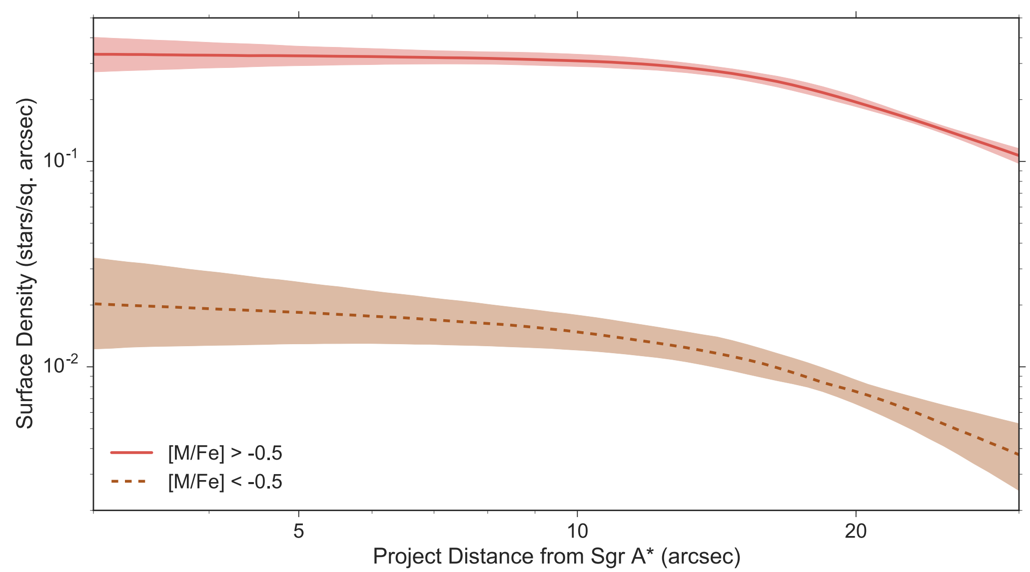
Also: Ryde et al. (2015, 2016), Do et al. (2015), Feldmeier-Krause et al. (2017), Rich et al. (2017), Garcia Perez et al. (2018)

Radial distribution of low metallicity stars are consistent with those of higher metallicity



30" ~ 1.2 pc

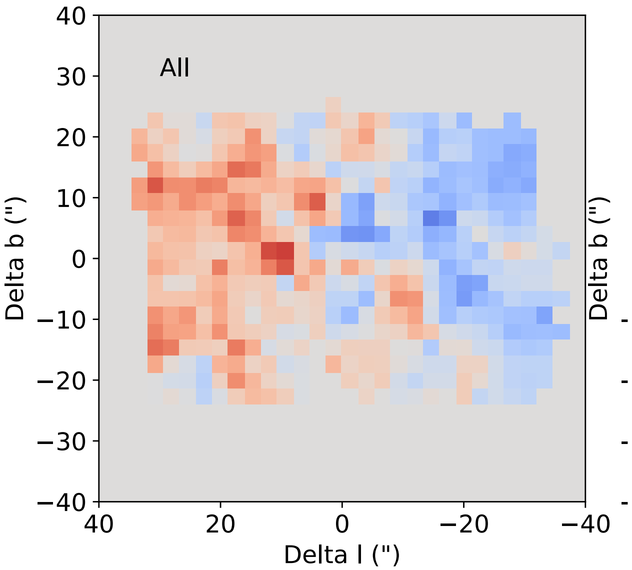
KMOS data, sample: 800 stars
Feldmeier-Krause et al. (2017)



Do et al. (2017)

Different kinematic signatures for different metallicity populations?

Average radial velocity maps



Do et al. in prep

Data from Feldmeier-Krause (2017)

Mixture modeling can be used to constrain the properties of multiple populations

The likelihood is consists of two parts, representing the two populations:

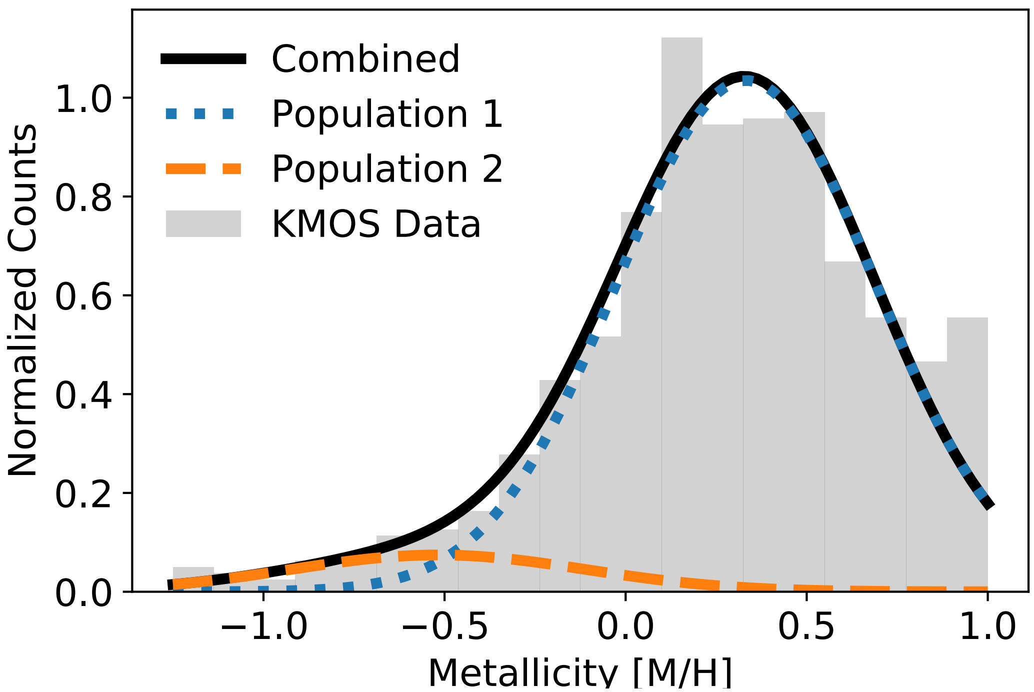
$$P(Data|Models) = fP_1(Data|Model_1) + (1-f)P_2(Data|Model_2)$$

f = Fraction of stars in population 1

Model:
Mean velocity
Rotational Velocity
Velocity dispersion
Metallicity
Metallicity dispersion

Total: 13 parameters: 6 parameters per population + fraction of populations

Metallicity and velocity data are consistent with having two distinct chemical-dynamical populations



Comparison of model distribution to data
(convolved with measurement uncertainty)

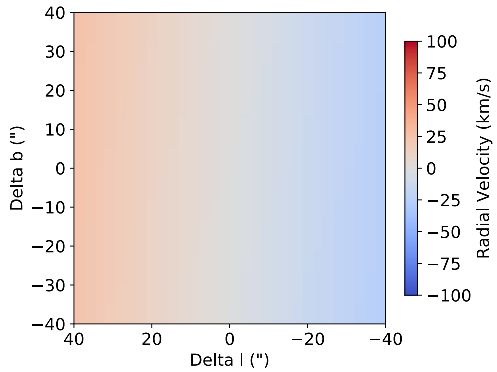
Pop. 1
[M/H] = 0.3+-0.1 dex
Intrinsic [M/H] dispersion = 0.2+-0.1 dex
N ~ 720 stars

Pop. 2
[M/H] = -0.5+-0.3 dex
Intrinsic [M/H] dispersion = 0.3+-0.1 dex
N ~ 80 stars

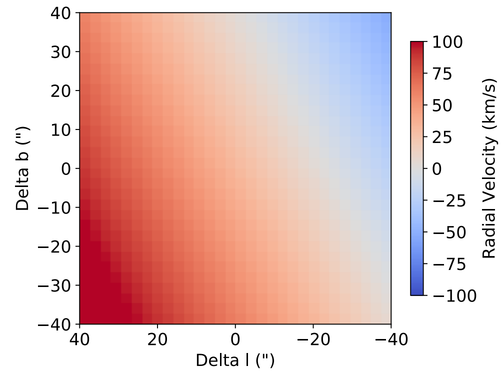
About 8% of total

Do et al. in prep

Metallicity and velocity data are consistent with having two distinct chemical-dynamical populations

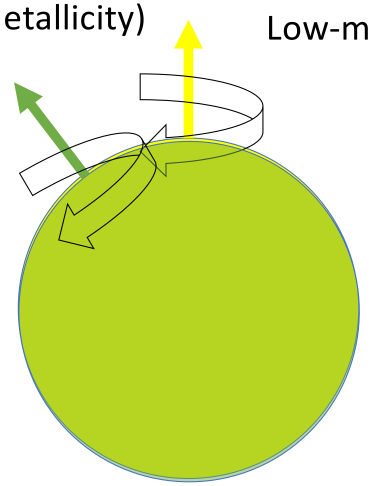


Main population (high-metallicity)



Low-metallicity population

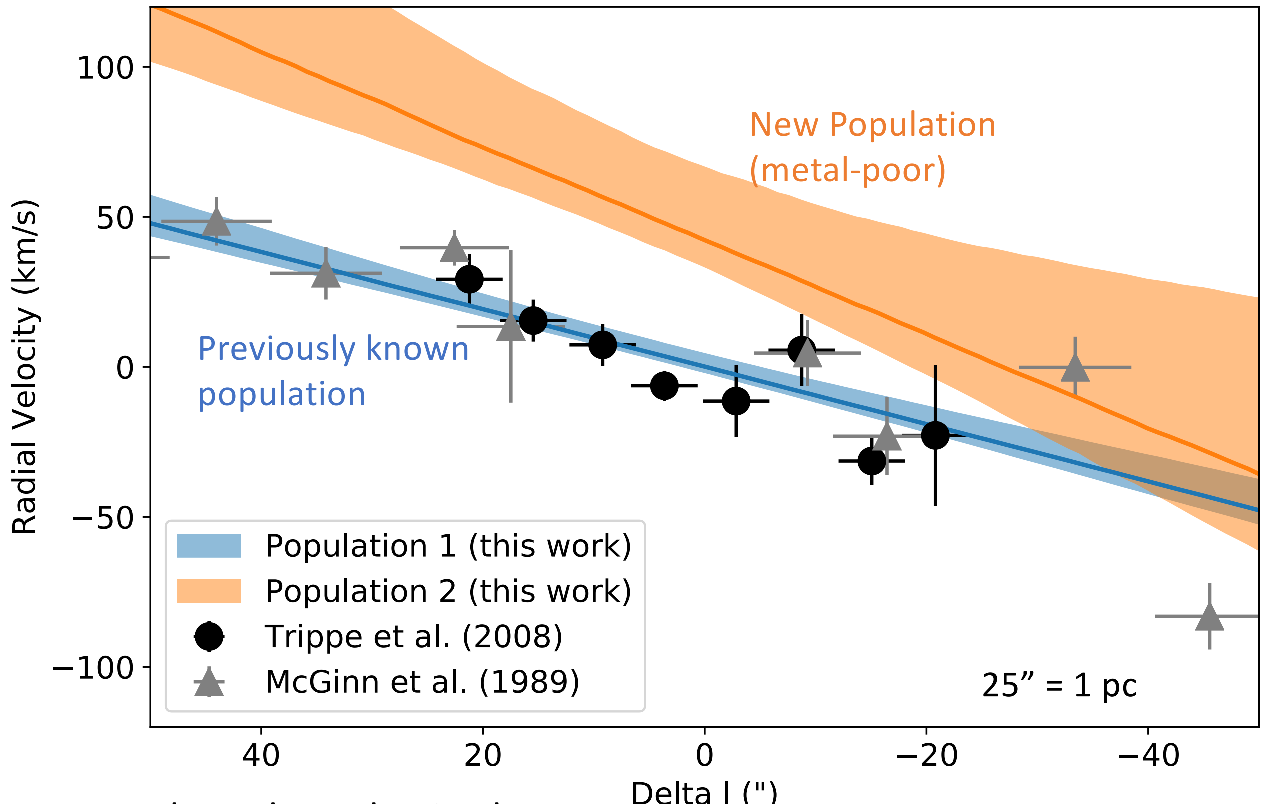
Do et al. in prep



Is this an infalling cluster?

Additional measurements helpful to confirm differences in rotation direction and extent of sub-components

Can we constrain the presence of a stellar stream or infalling cluster?



1D cut along the Galactic plane

Do et al. in prep.

Can we constrain the presence of a stellar stream or infalling cluster?

- Ability to differentiate metallicity
- High-precision kinematic measurements
- Probe spatial scales of 1 pc to tens of parsecs

How do star clusters interact with supermassive black holes?

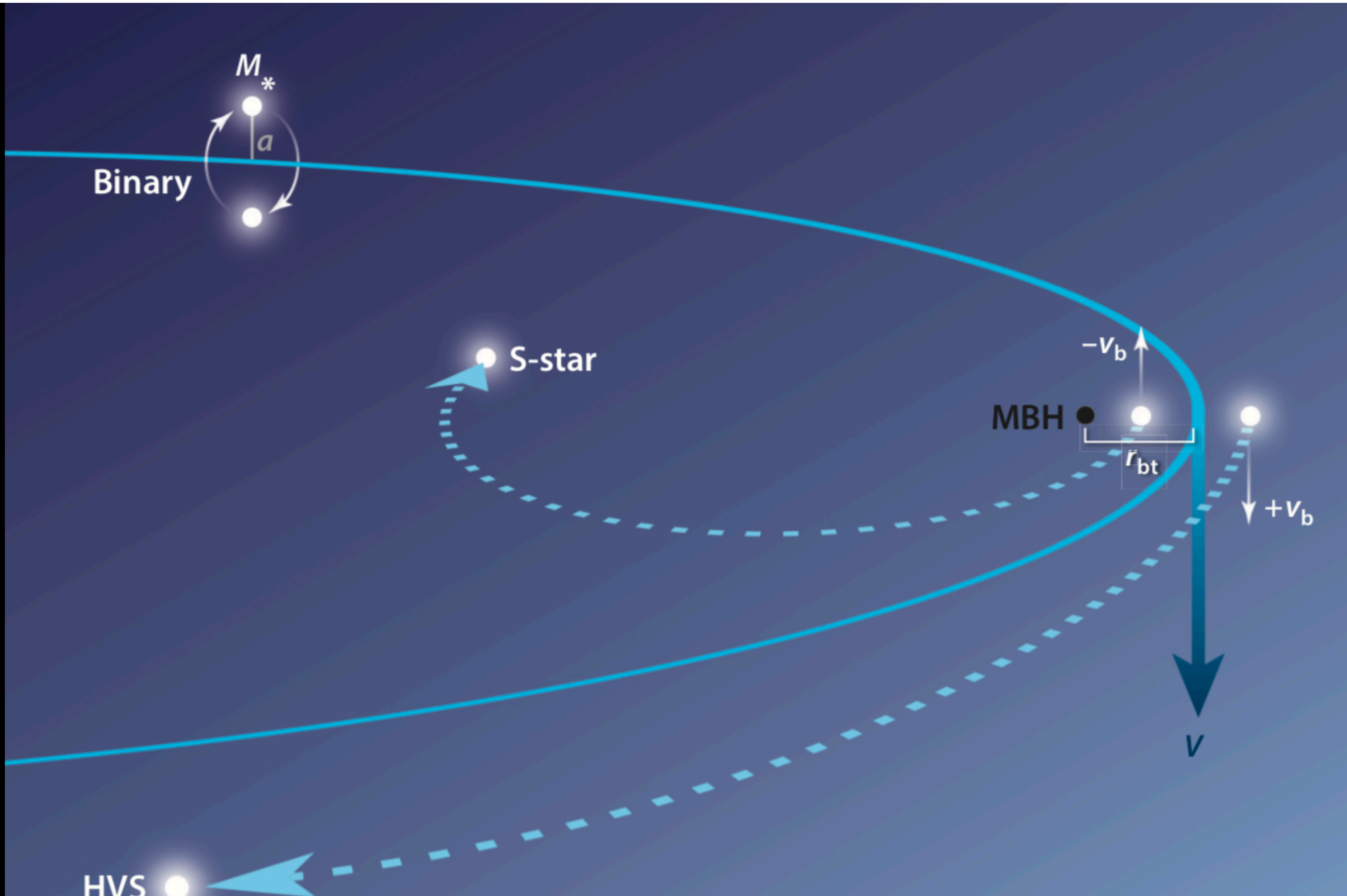
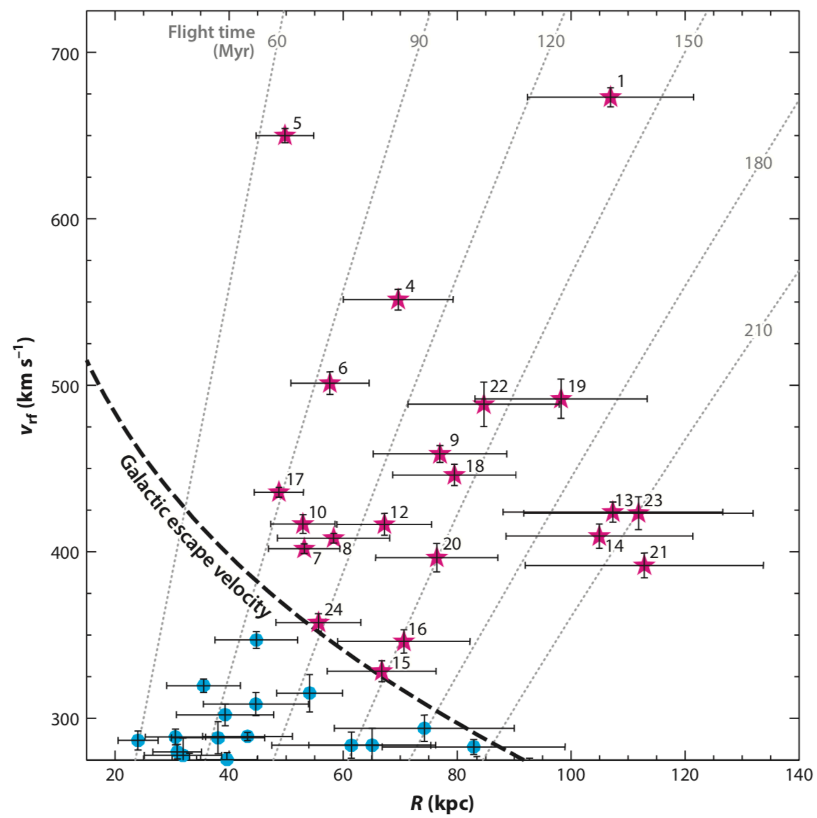


Figure from Brown (2016), See also: Hills 1988, Yu & Tremaine 20013

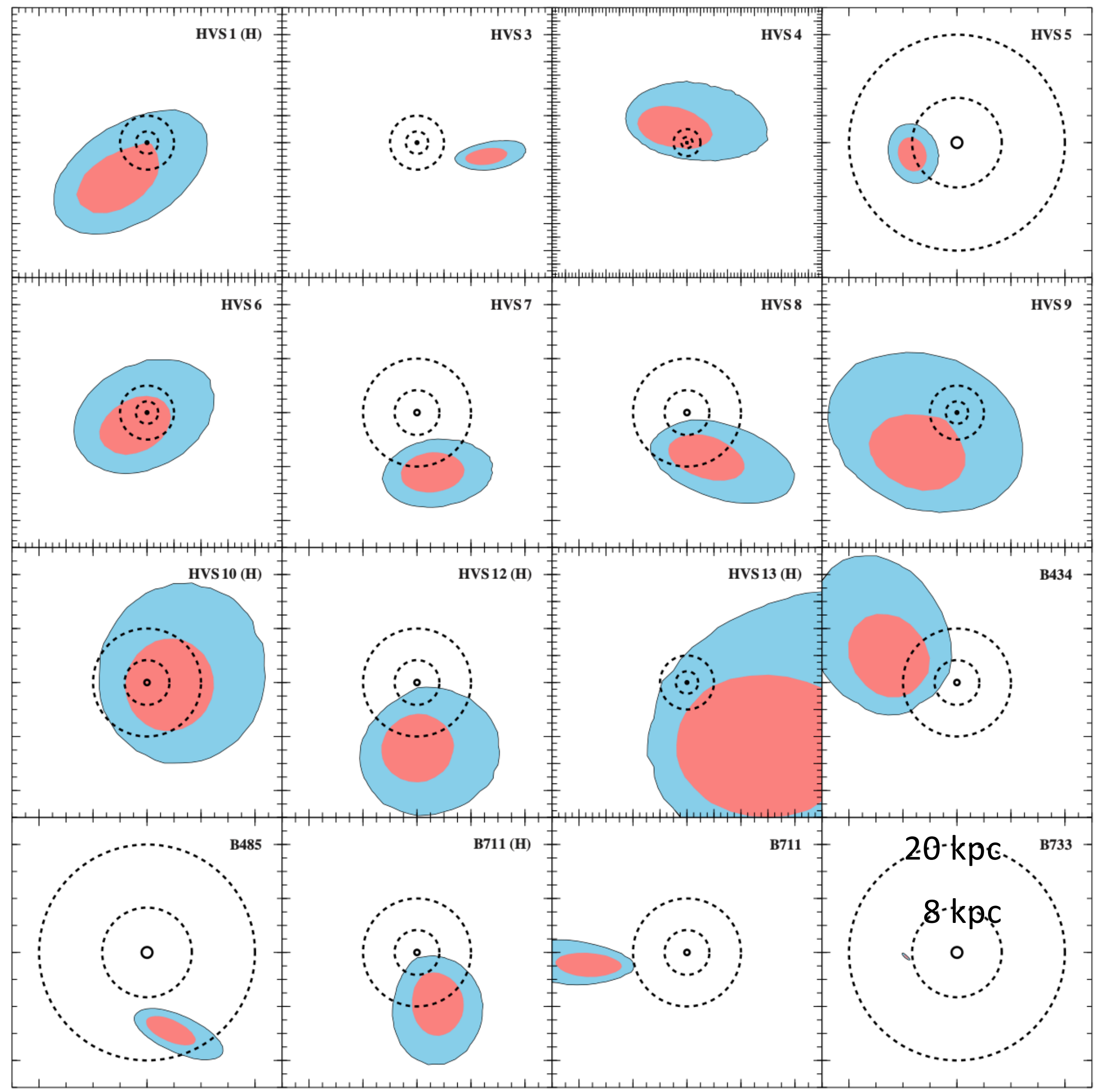
Hypervelocity stars are mainly detected in the MW halo



Many are B-type stars with lifetimes about consistent with travel time from the Galactic center

From Brown et al. (2016)

It is not clear where hypervelocity stars come from

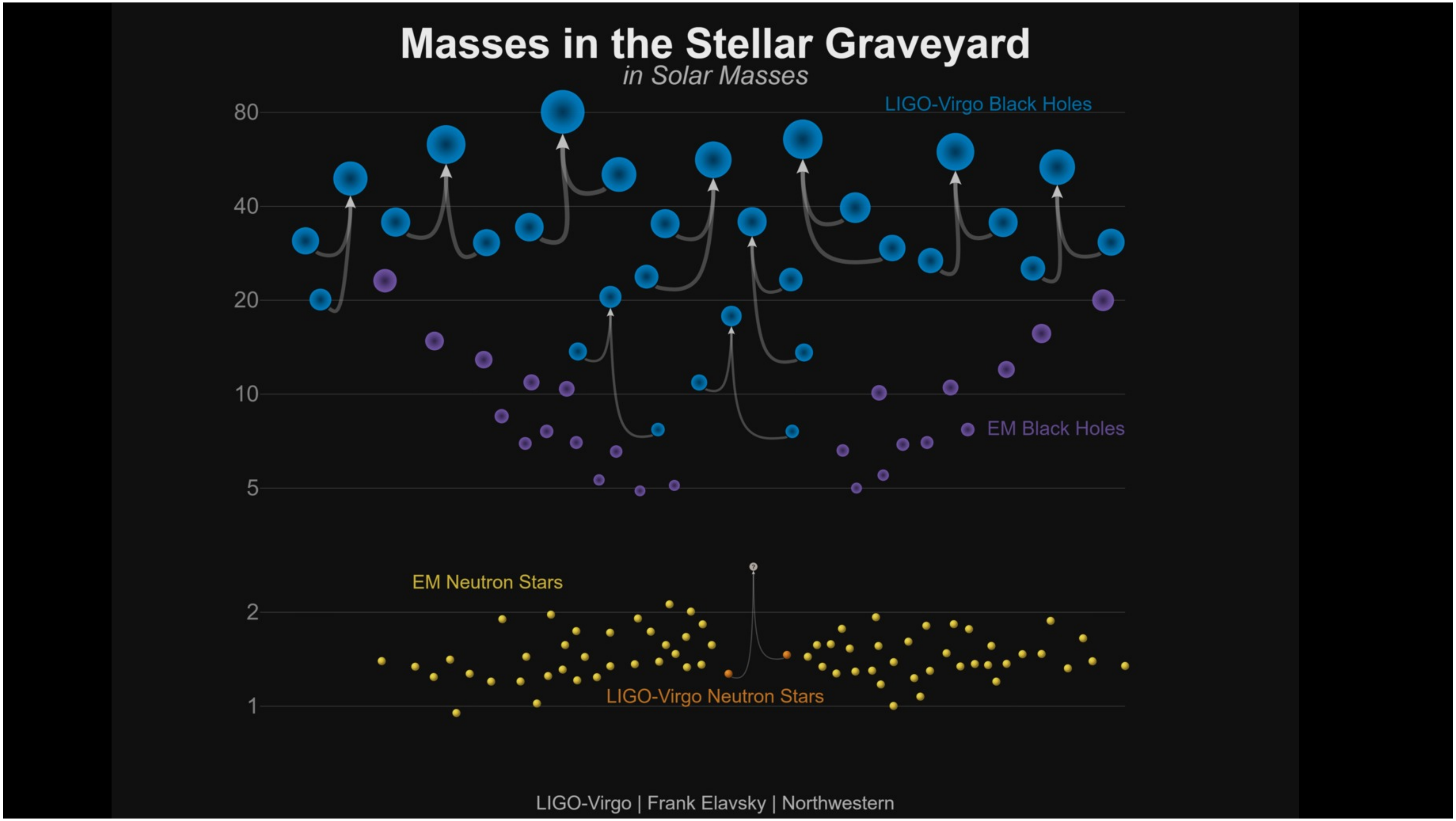


Recent constraints on HVS origin using GAIA proper motions (Irrgang et al. 2019)

We need to find hypervelocity stars at the Galactic center to determine their physical origin

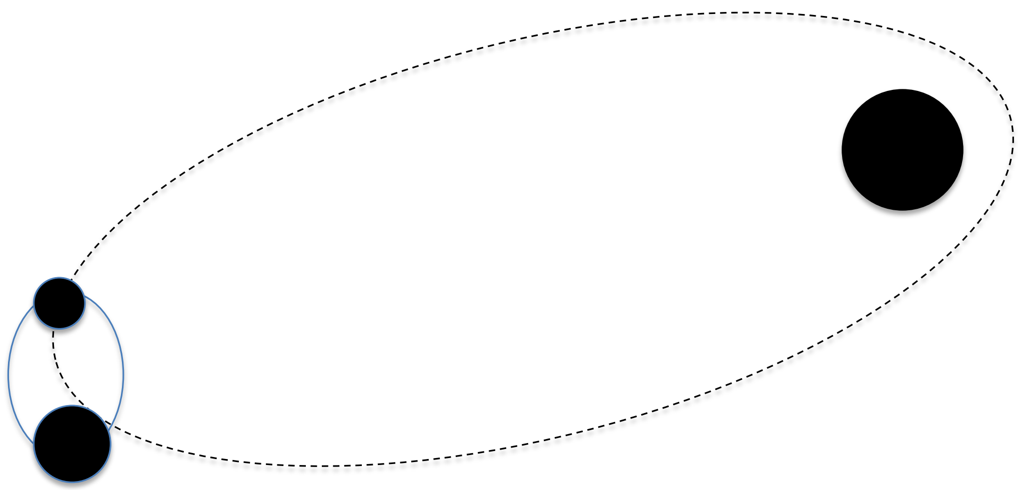
- We can localize HVSs to within < 0.1 pc of the BH: **10^9 times** better localization in area than with halo stars.
- Ejection rates of ~10^{-4} to 10^{-5} stars/yr (for 1000 km/s stars)
- Lower velocity ejections are significantly more likely

Where & how do black holes mergers form?



Masses in the Stellar Graveyard
in Solar Masses
80
40
20
10
5
2
1
LIGO-Virgo Black Holes
EM Black Holes
EM Neutron Stars
LIGO-Virgo Neutron Stars
LIGO-Virgo | Frank Elavsky | Northwestern

Binaries can merge through dynamical interactions with the black hole and each other



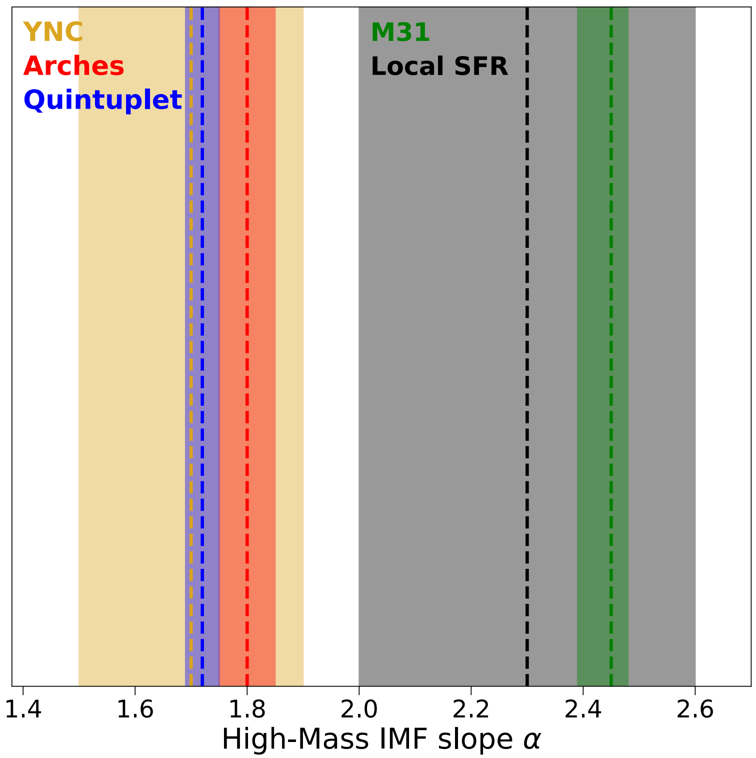
Nuclear star clusters can greatly enhance merger rates by holding on to black holes.

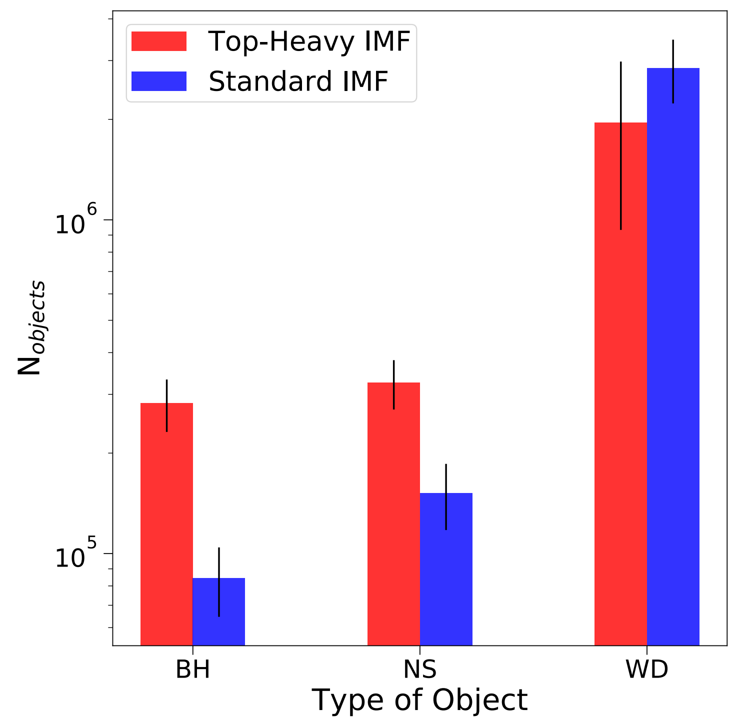
Eccentric Kozai-Lidov mechanism, see review: Naoz (2016)
Also e.g.: Antonini & Rasio (2016), Stephan et al. (2016), VanLandingham et al. (2016), Hoang et al. (2018)

We need to understand the compact object population at the Galactic center

Chandra X-Ray Image

Estimating the black hole population requires knowing the initial mass function and star formation history



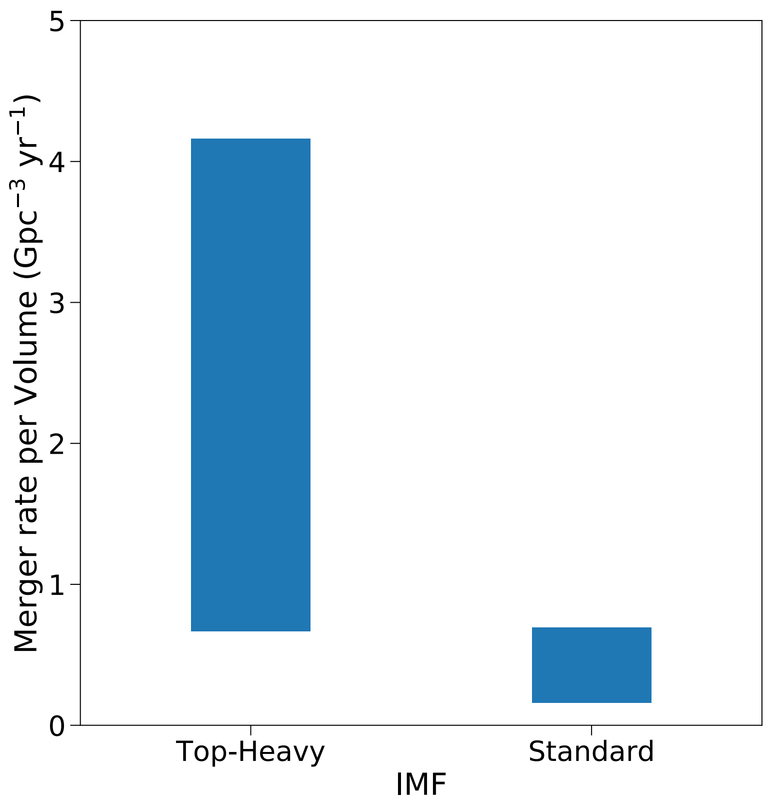


Observations at the Galactic center show generally more top-heavy IMF (e.g. Bartko et al. 2012, Do et al. 2013, Lu et al. 2013, Hosek et al. 2018)

Hosek et al. in prep

Black hole merger rates vary strongly with initial mass function and density profile

Estimate of nuclear star cluster BH binary merger rates



LIGO estimate of merger rate:

30-170 /Gpc^3/ yr
(Abbott et al. 2019)

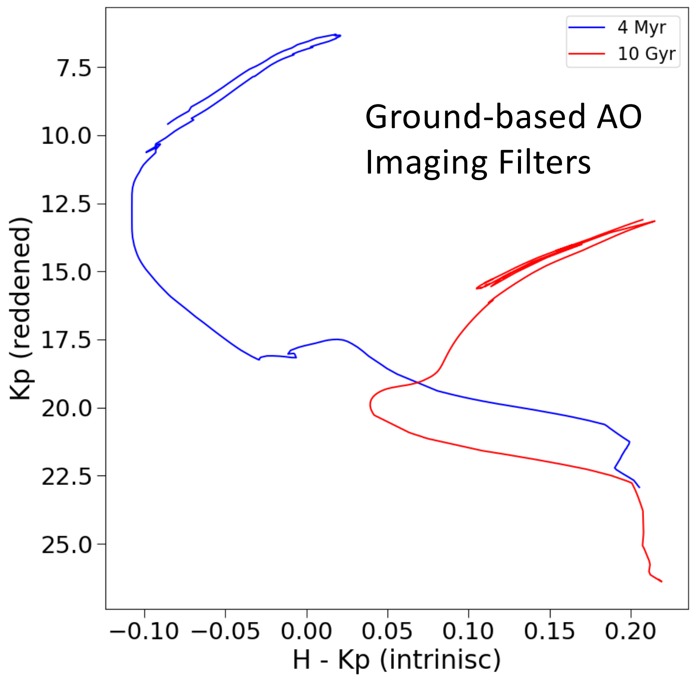
Hosek et al. in prep.
(See also: Rodridgez et al. 2017, Petrovich et al. 2018)

What limits our current studies?

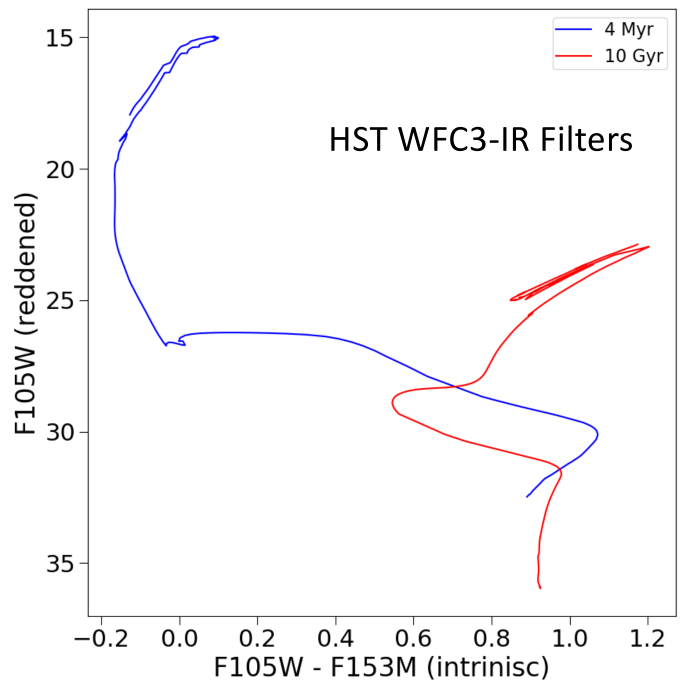
Knowledge of the stellar population via photometry is limited by measurements of the extinction


HST WFC3-IR, F127M, F139M, F153M (Do et al. in prep)

Wide wavelength coverage & deep observations helps to disentangle the young and old populations



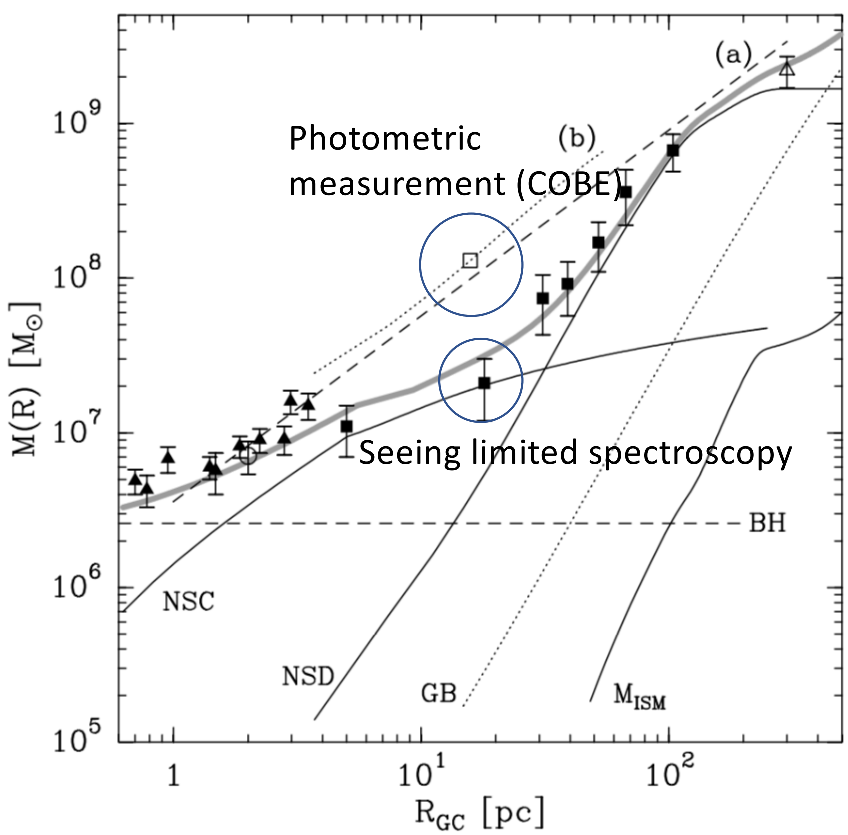
Small intrinsic color differences means uncertainty in extinction dominates



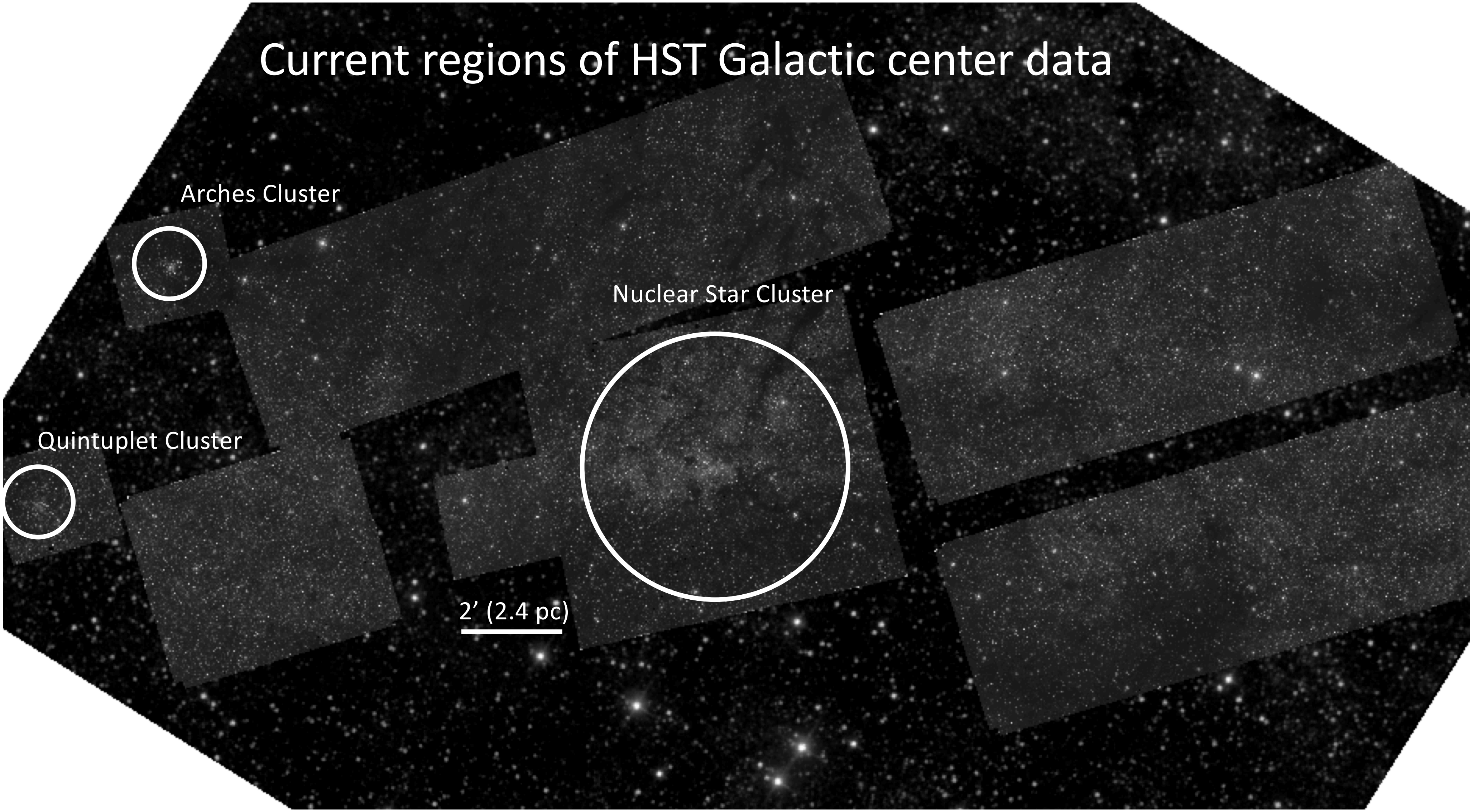
Large intrinsic color differences

Hosek et al. in prep

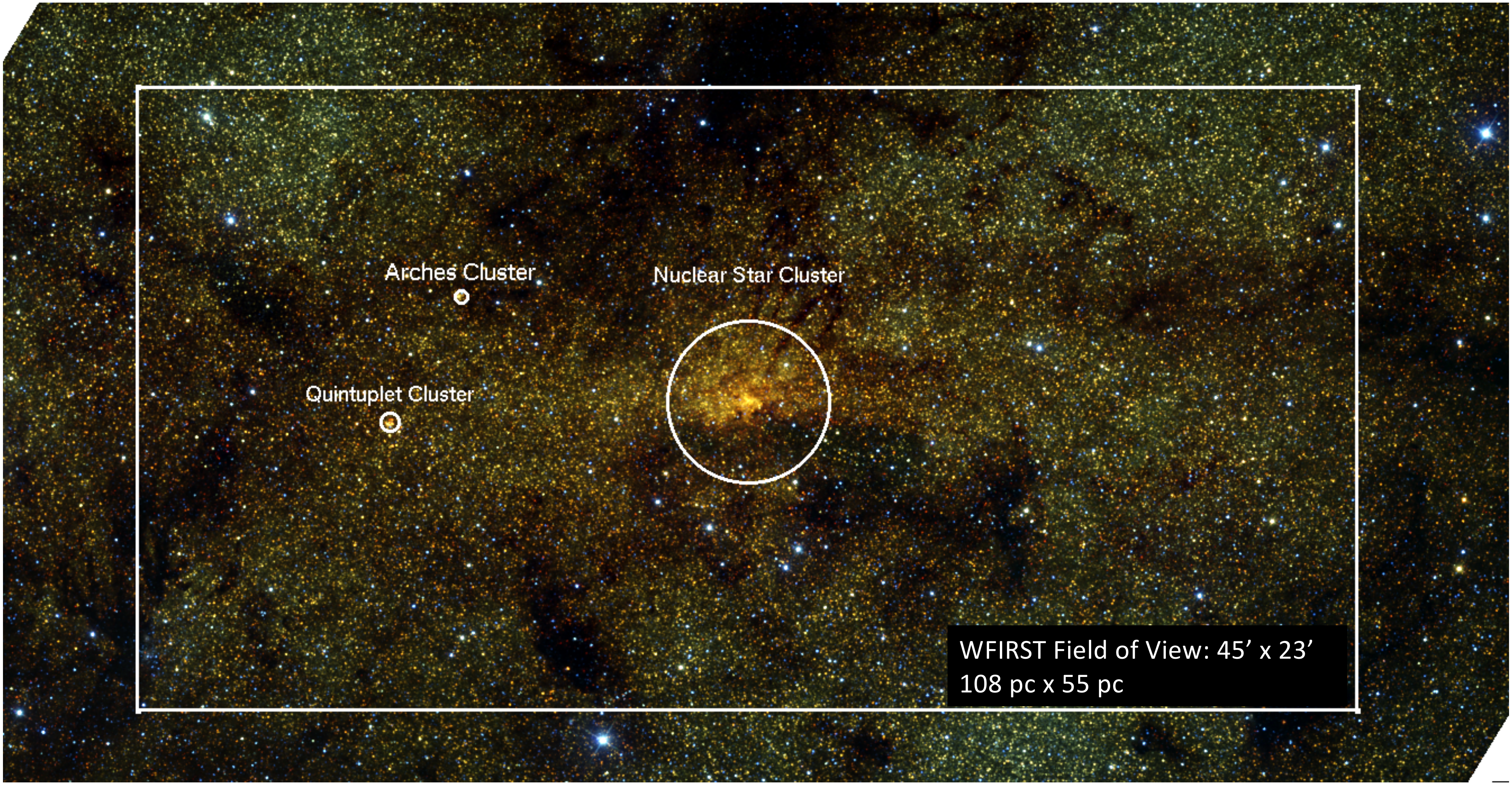
Mass distribution in the inner 50 pc is poorly known

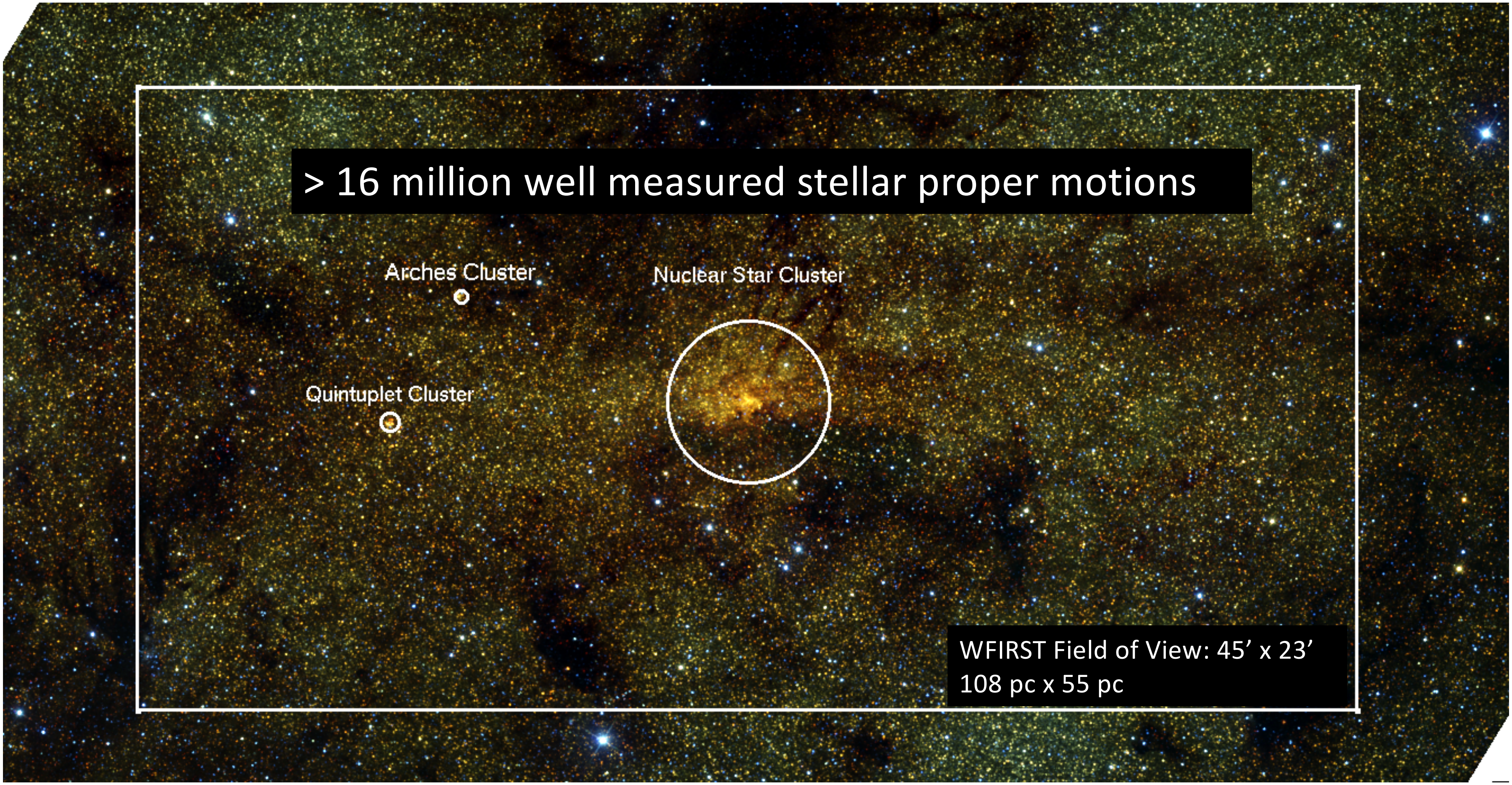


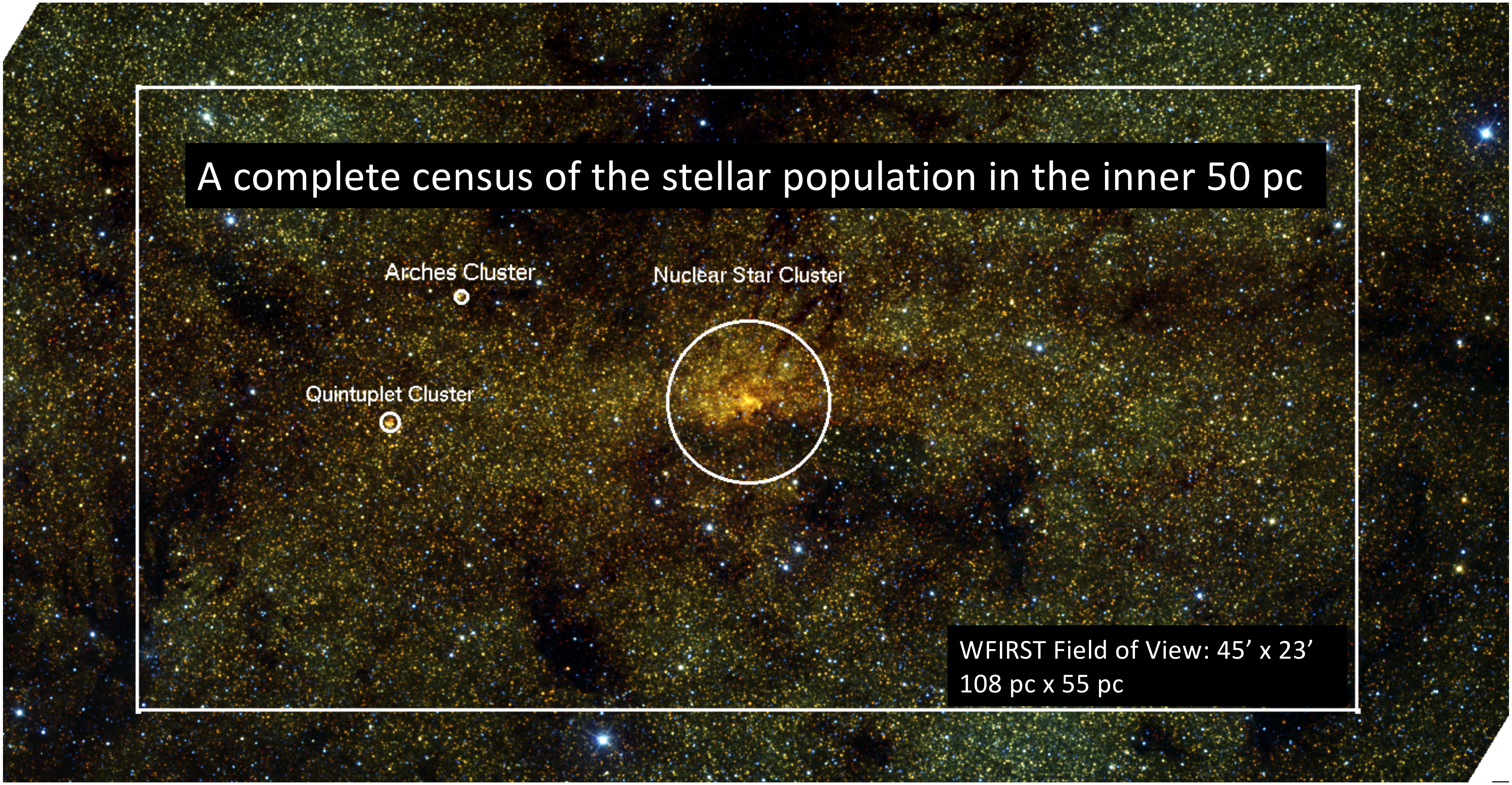
From Launhardt et al. (2002)



Current regions of HST Galactic center data
Arches Cluster
Nuclear Star Cluster
Quintuplet Cluster
2’ (2.4 pc)


Arches Cluster
Nuclear Star Cluster
Quintuplet Cluster
WFIRST Field of View: 45’ x 23’
108 pc x 55 pc


> 16 million well measured stellar proper motions
Arches Cluster
Nuclear Star Cluster
Quintuplet Cluster
WFIRST Field of View: 45’ x 23’
108 pc x 55 pc


A complete census of the stellar population in the inner 50 pc
Arches Cluster
Nuclear Star Cluster
Quintuplet Cluster
WFIRST Field of View: 45’ x 23’
108 pc x 55 pc

WFIRST has the potential to transform our understanding of the Galactic center.