GLAO @ Subaru

Globular Clusters & the Galactic Centre

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with thanks to Harvey Richer (UBC)

Globular Clusters & GLAO Imaging

1. Proper motion cleaning

2. IMBH at cluster centres?

2. White dwarf cooling curve (ages & EoS)

3. WD debris disks & planets?

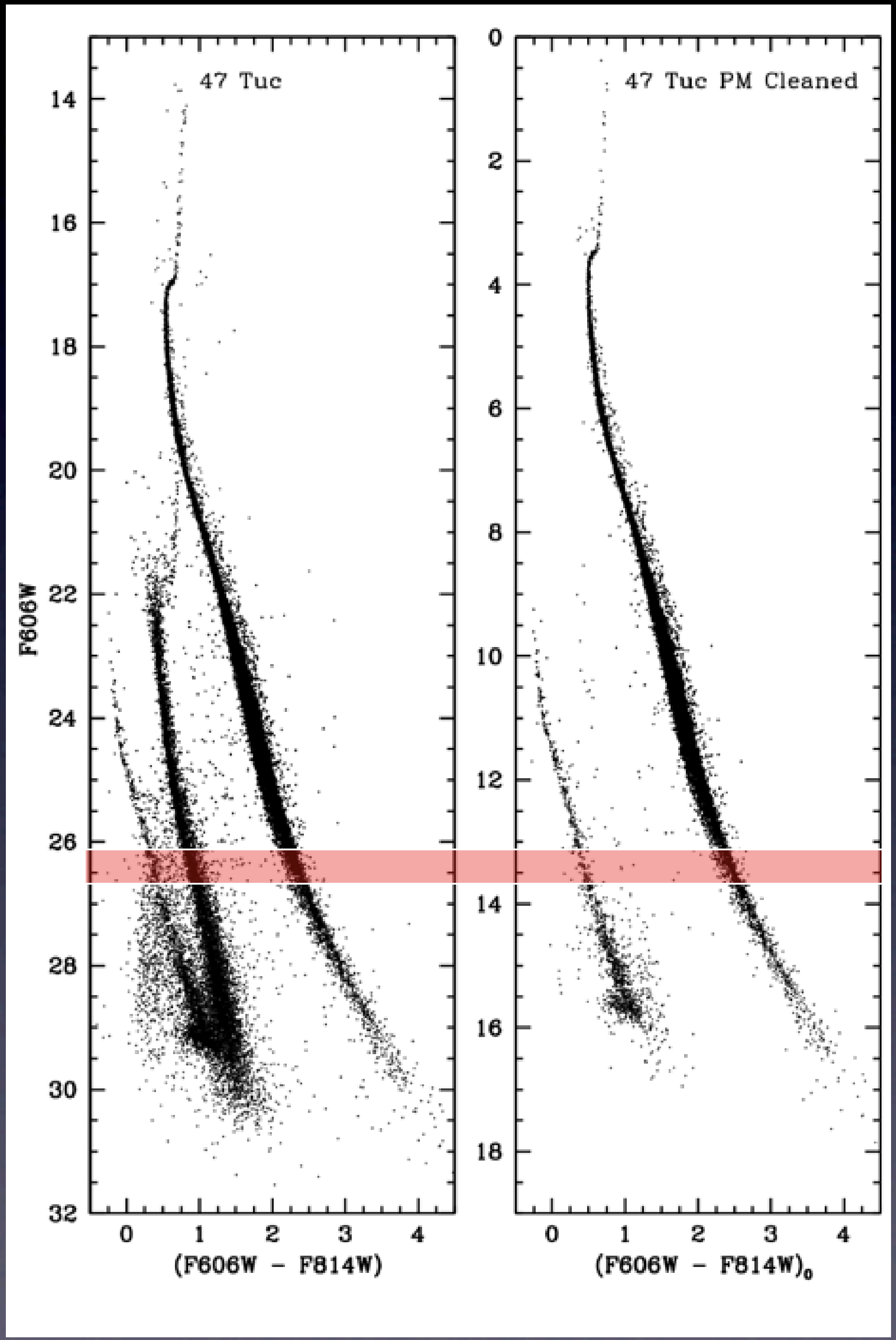
HST 0.04” imaging of 47 Tuc

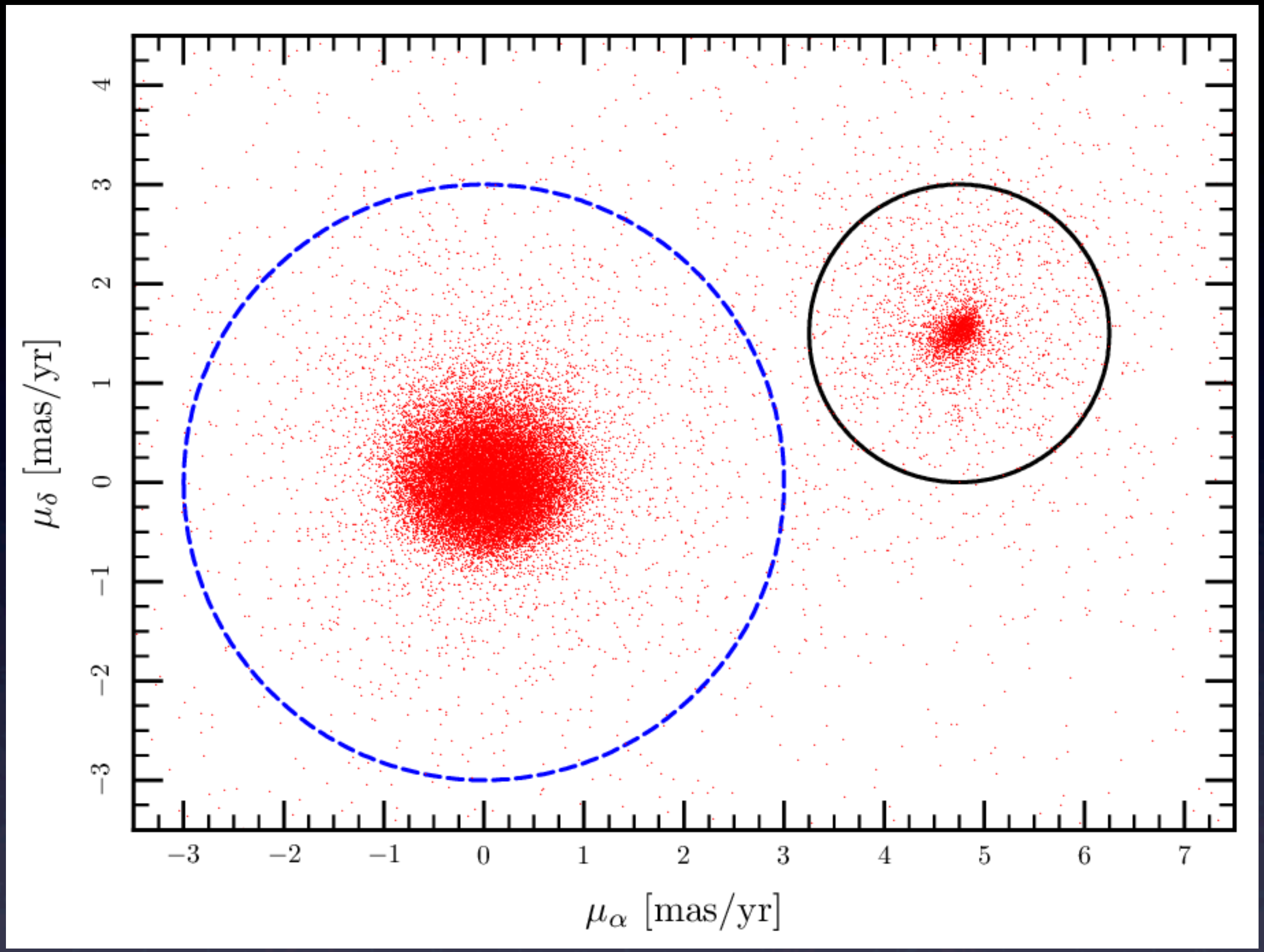
Nearby globular clusters at distances of <5 kpc

Velocity diff.s of the cluster to the field ~100 km/s, thus proper motion > 4 mas/year
Easily separate cluster from field with <1” resolution.

With good S/N (70) proper motions measurable to ~ 0.5 mas/year
Internal kinematics

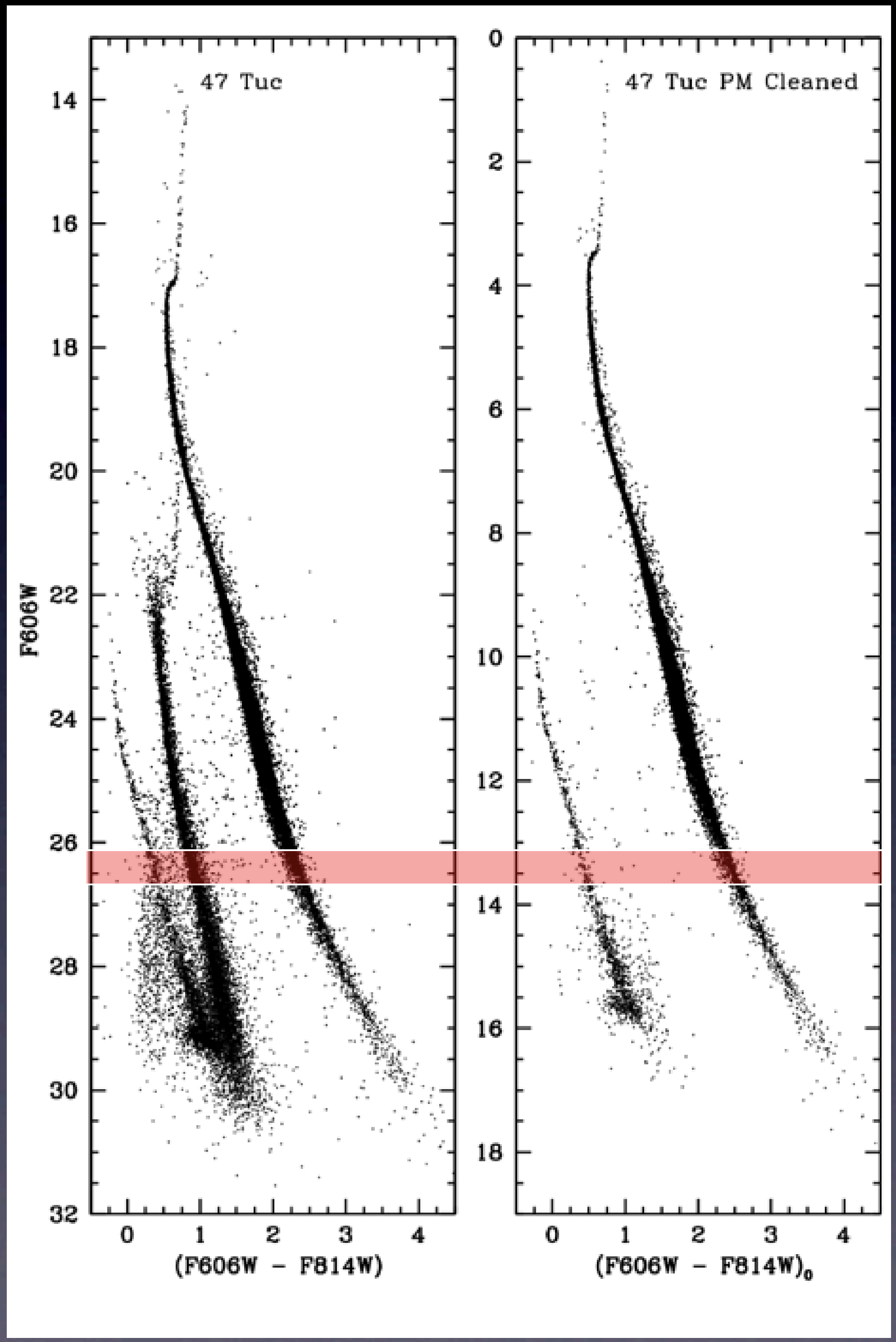
Cleaning 47 Tuc of foreground & SMC stars:
larger GLAO FOV helps!

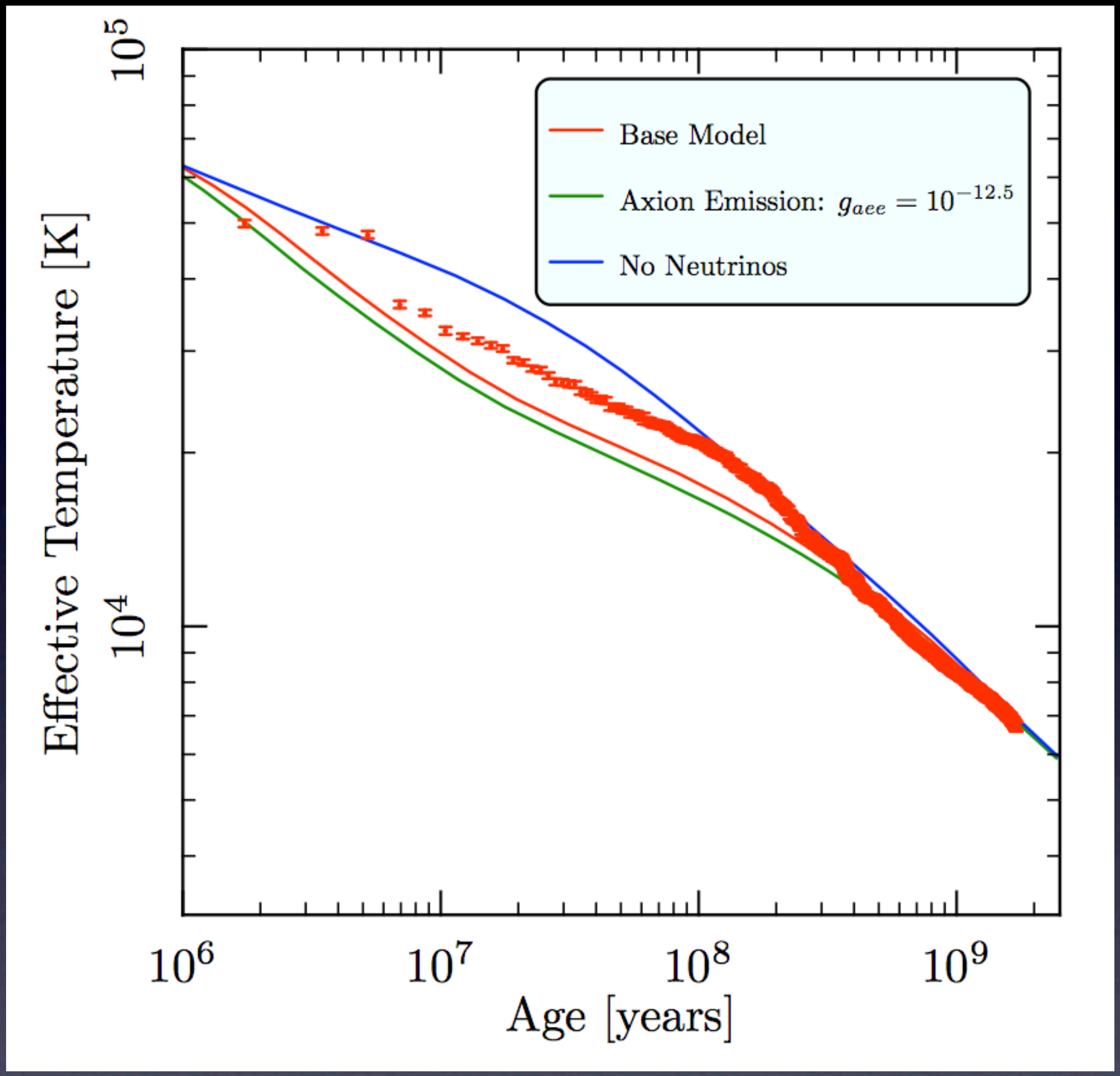




remove foreground, etc.
lower main sequence dynamical cleaning.
binary frequency
Multiple populations / Helium rich branch?
internal kinematics

Cleaning 47 Tuc shows ends of the WD cooling curve:
Larger FOV helps!





Empirical WD cooling sequence does not fit the hottest WD models (MESA, Paxton et al.)

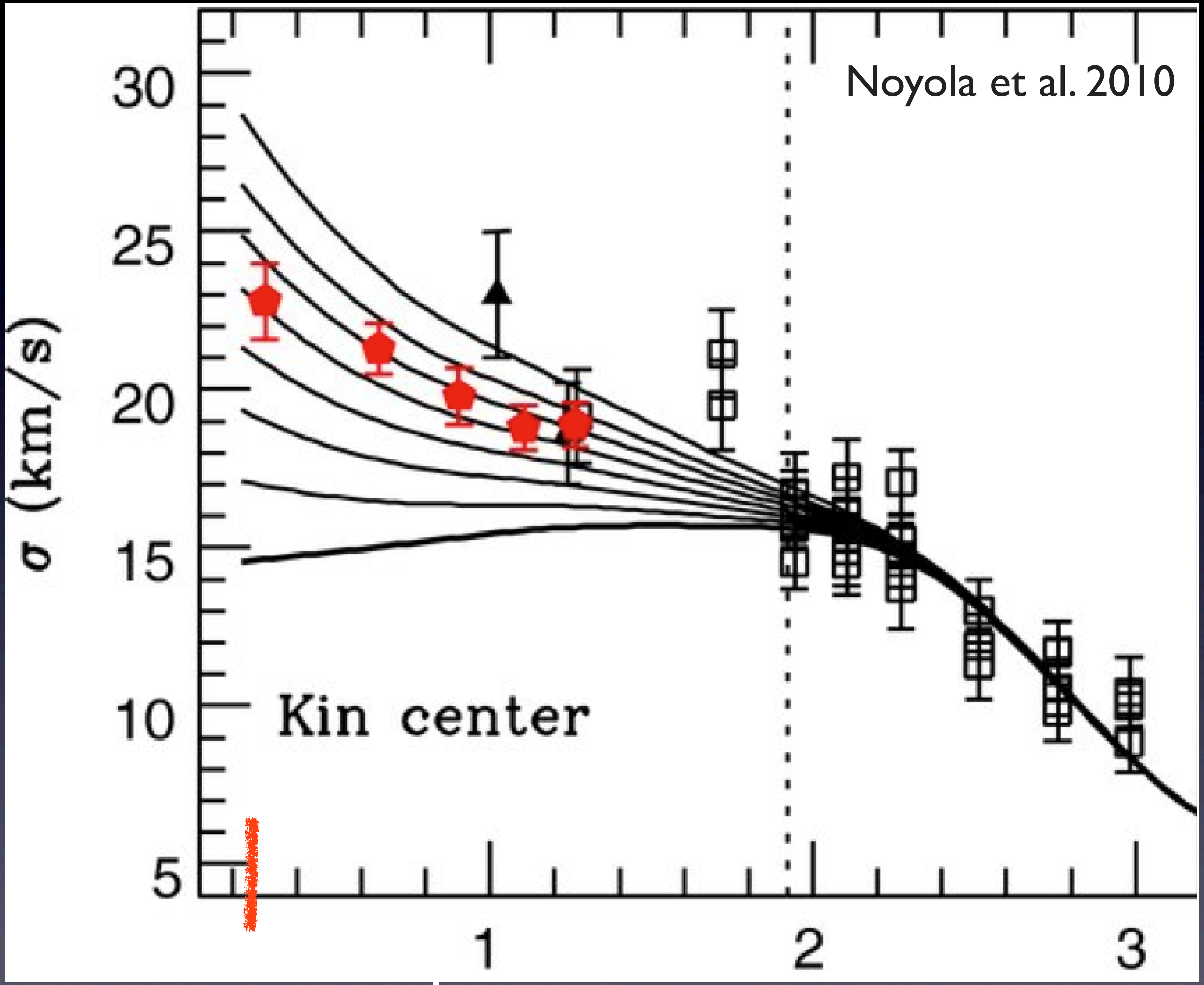
Neutrino or axion cooling important?

Predictions for IMBH in centre of Omega Cen *(M10, etc.)*

From IFS spectra, Noyola et al. 2010 report higher velocity dispersions in their central fields,

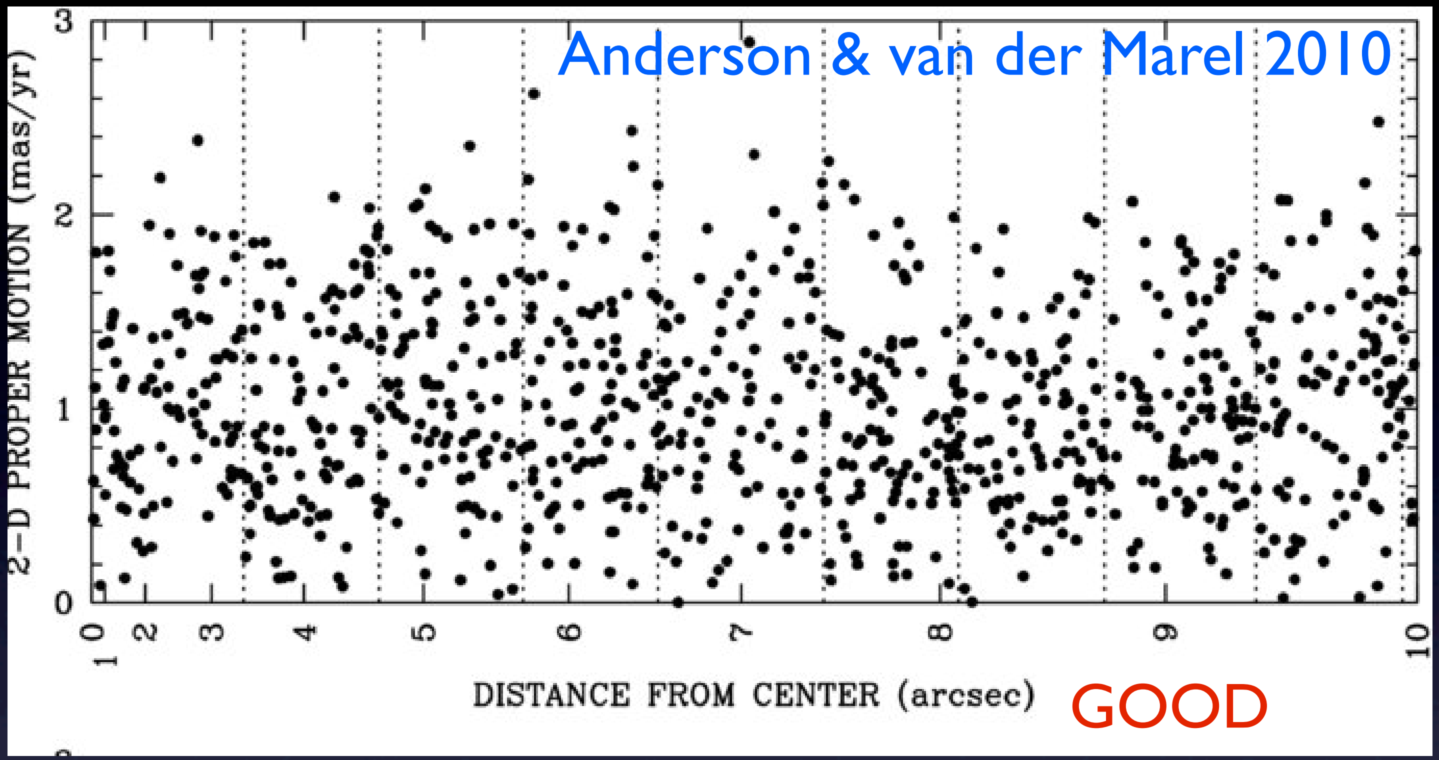
consistent with a 10^4 $M_\odot$ blackhole.

Surface brightness profile also consistent with a shallow central cusp consistent with an IMBH.



log r *(arcseconds)*

Yet, no change in proper motion kinematics of inner Omega Cen



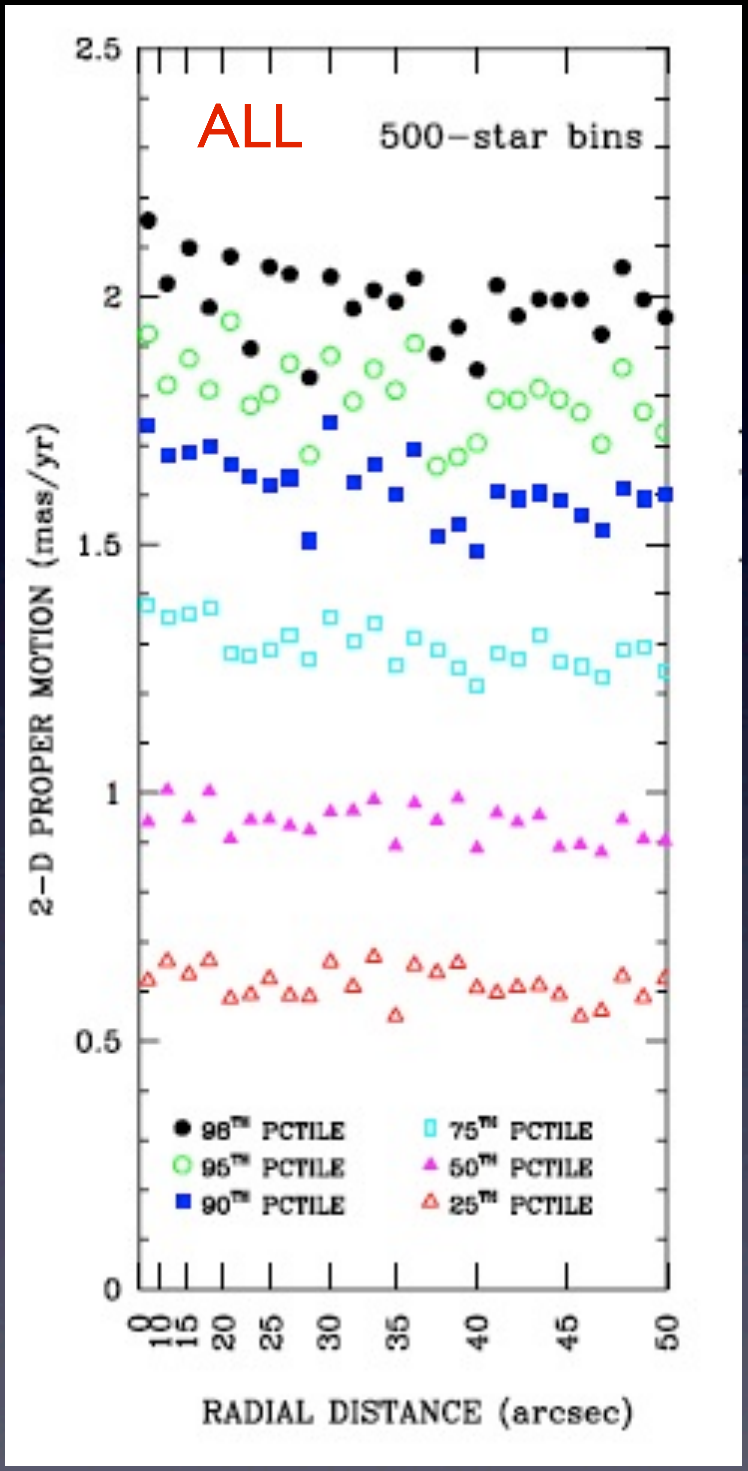


Figure shows there are the same number of high velocity stars in the centre of the cluster as at 10".

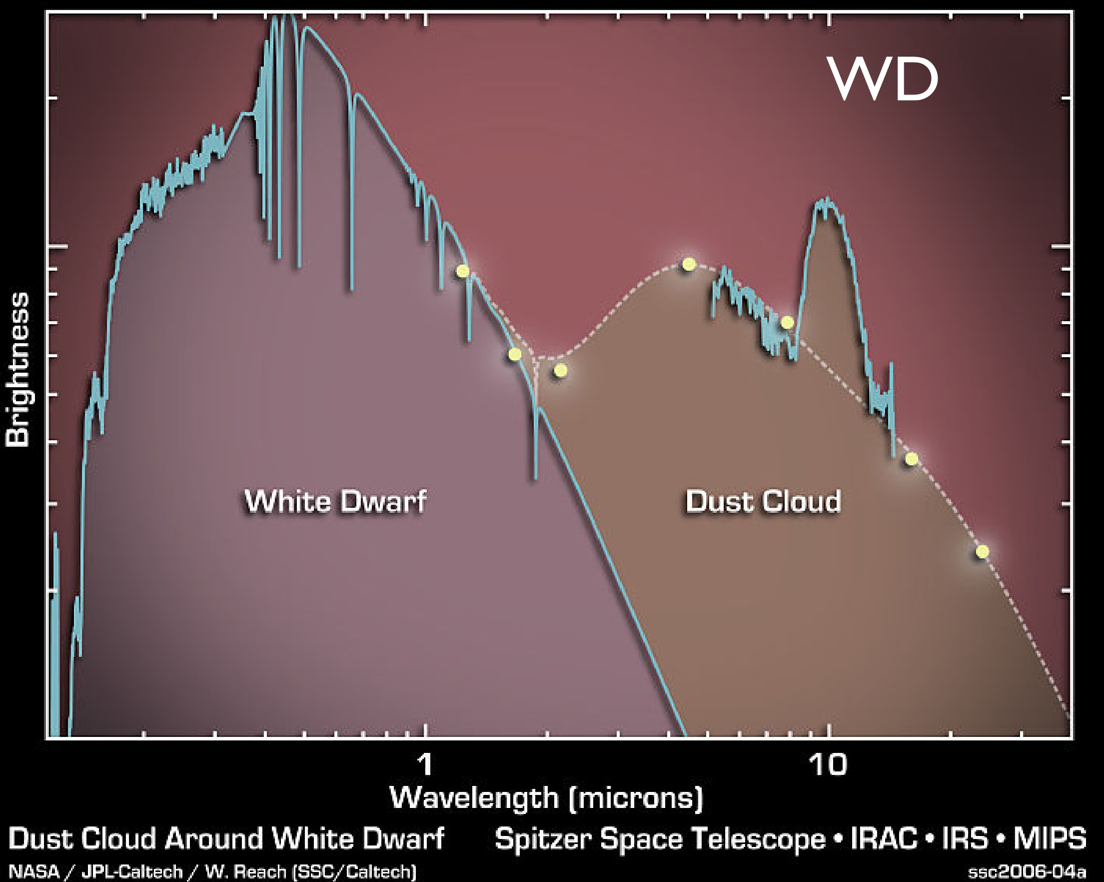
An IMBH would have induced increasing velocities towards the center with RMS α $R^{-1/2}$.

Also, they relocated the centre of Omega Cen by 12" from Noyola, Gebhardt, and Bergmann 2010

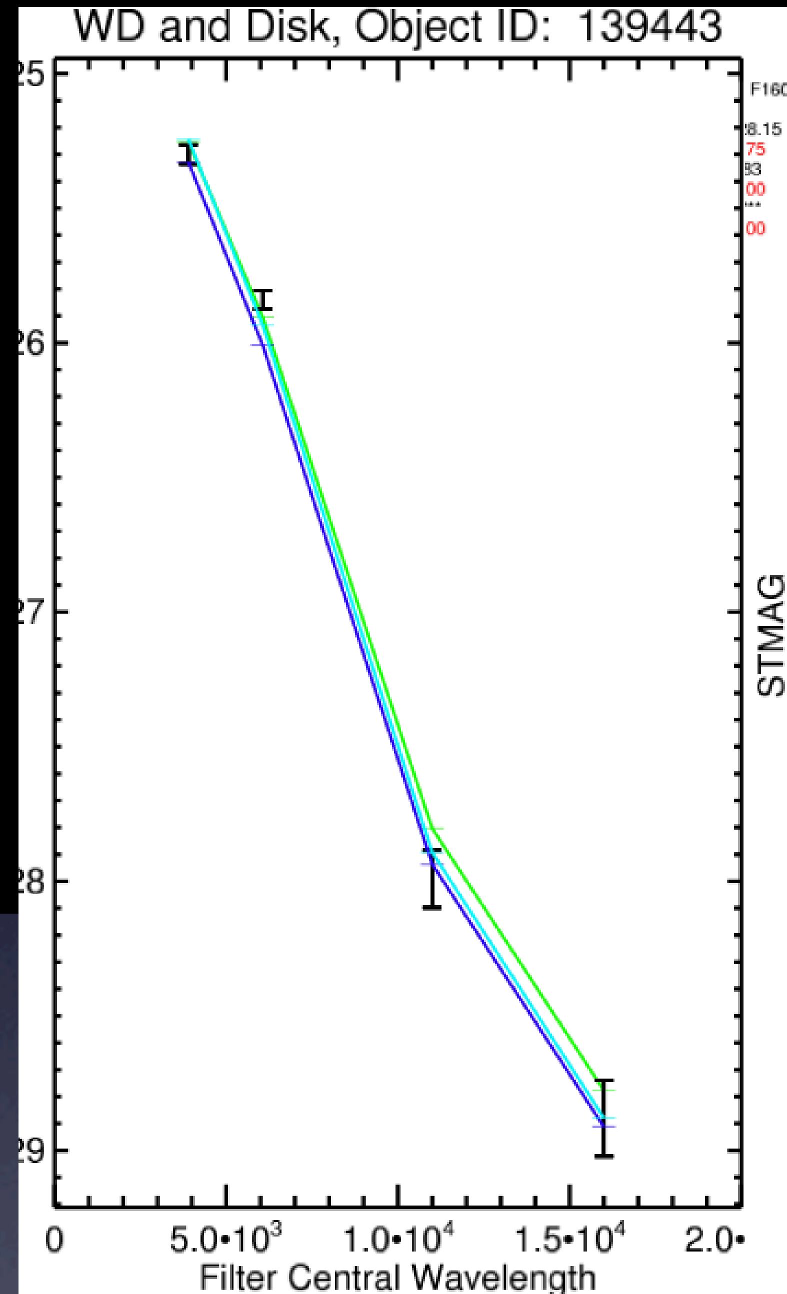
Are IR excesses Exoplanets, Debris Disks, QSOs, noise?

WDs in 47 Tuc

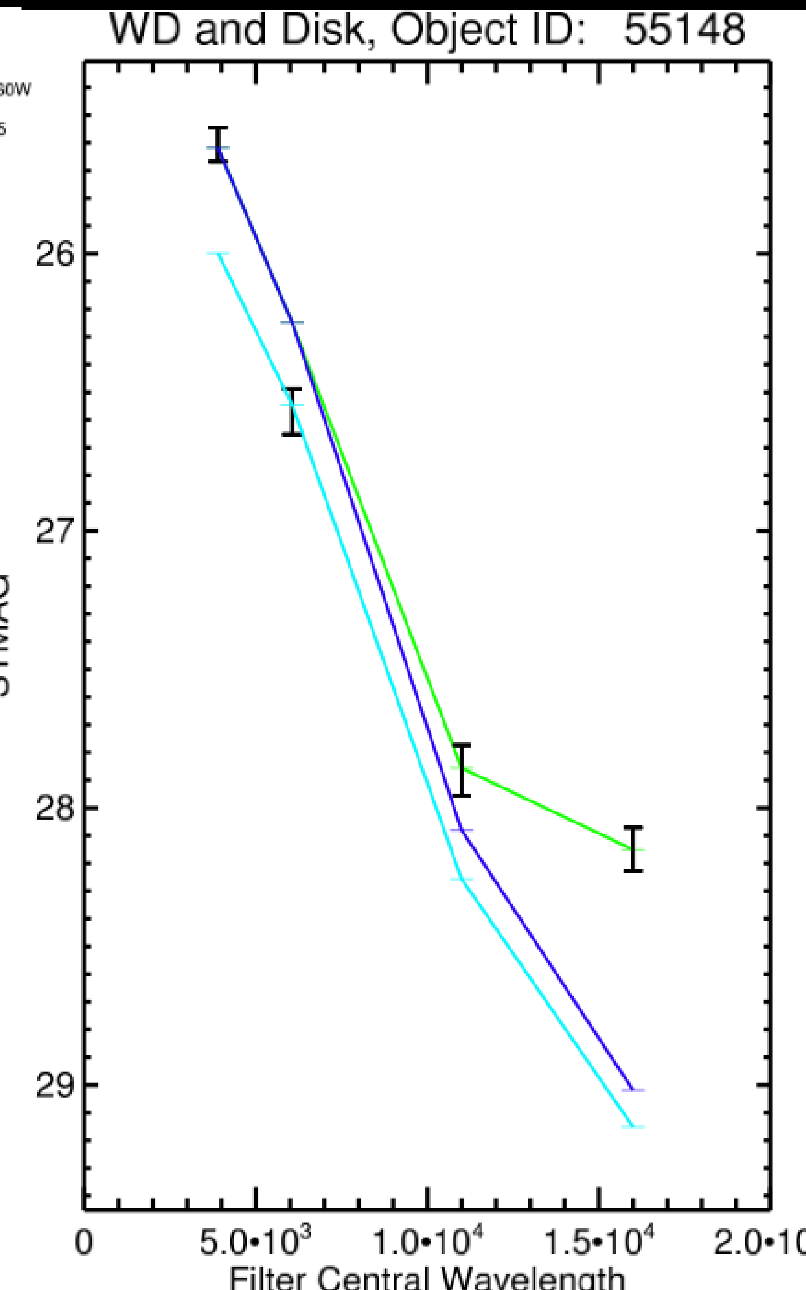
Field WD



pure WD



WD with IR excess



WDs with IR excesses in GCs?
Are these debris disk?, planets?, or just backgnd quasars, binaries, etc.?

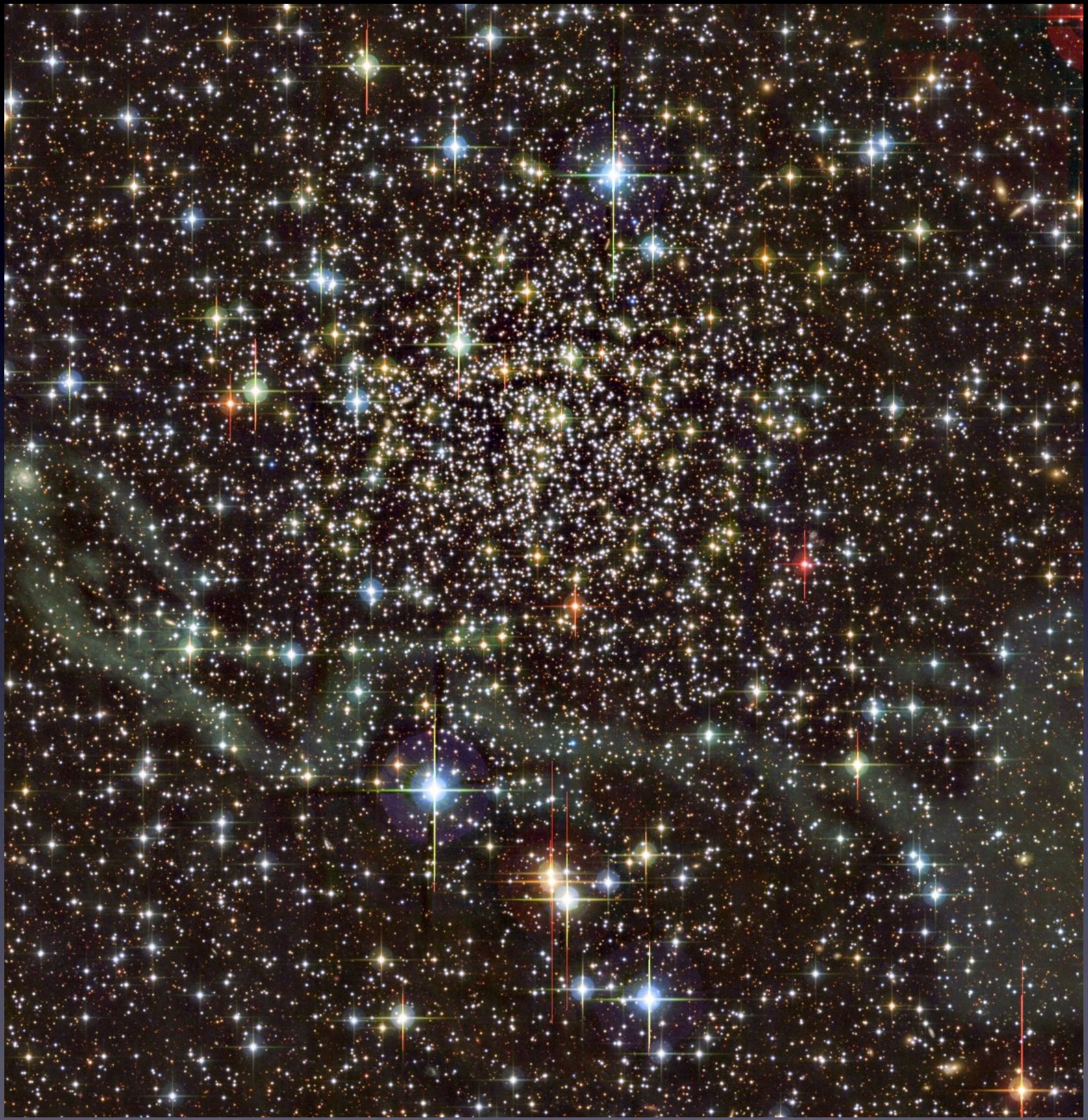
Metal-poor systems would require a new way to form planets, e.g., perhaps through disk instabilities.

Globular Clusters

Open Clusters

Galactic Centre

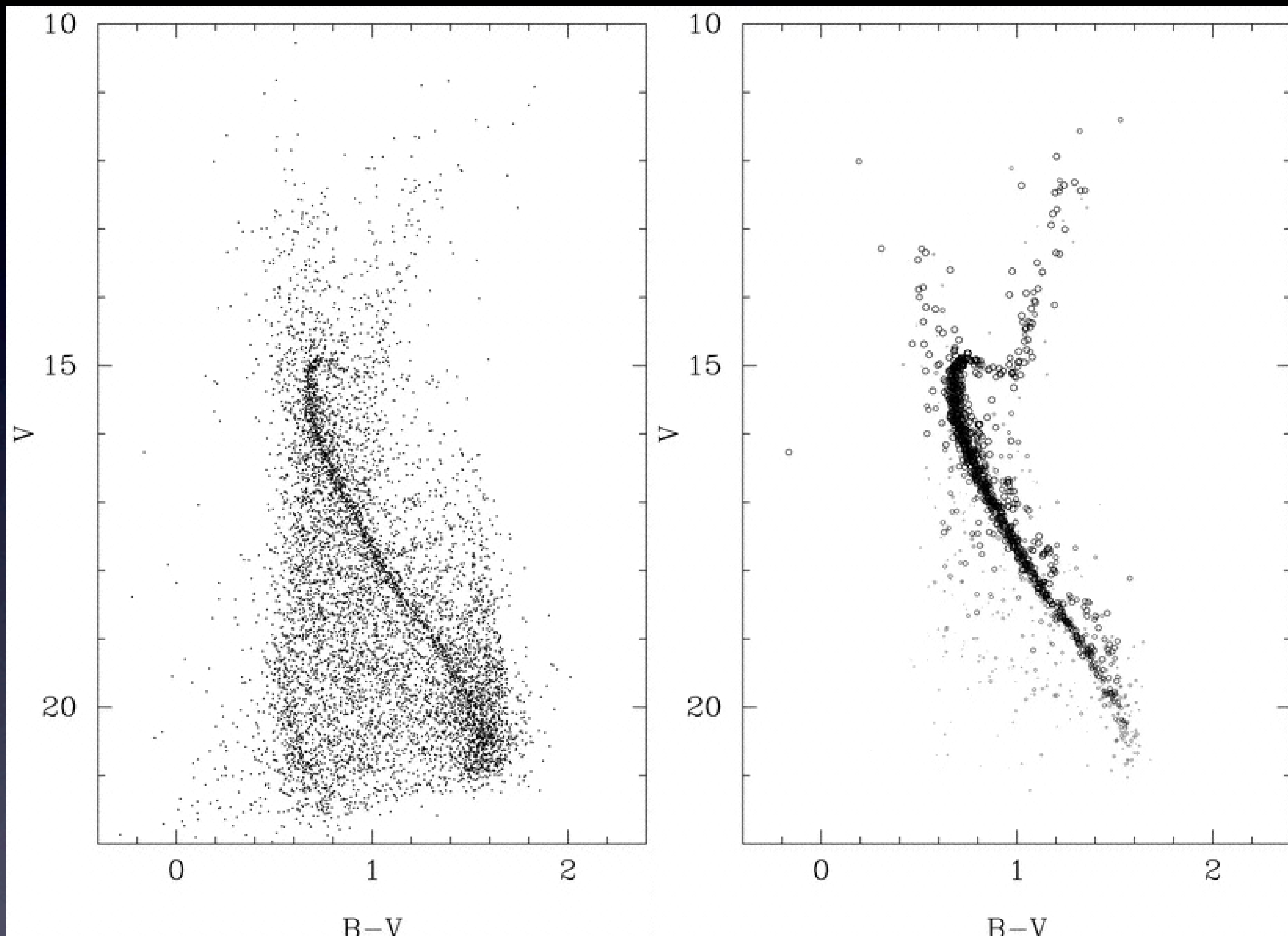
Proper motion cleaning of Galactic Open Clusters too:
Larger FOV helps!



Harder since OCs more embedded in the disk, velocities differences with the field stars is less.

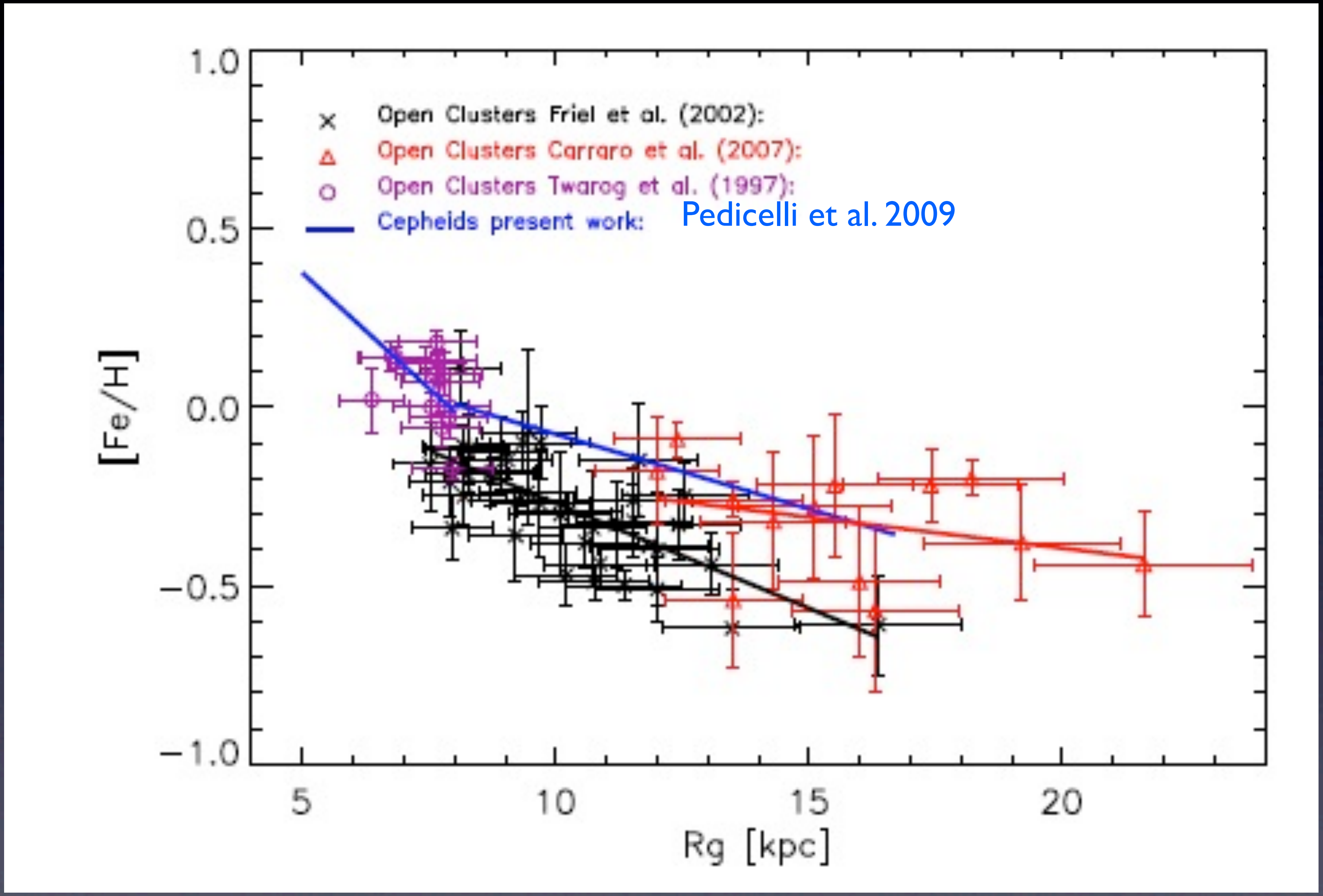
- Disk holds 3/4 of baryonic mass.
- Star Formation History of the disk?
- Gradients in the Galactic disk?
- Changes in gradients with age?
- Universal IMF?
- Universal binary fractions?
- Outer warps, structures, kinematics.
  (e.g., warp vs CMaj dwarf)

Proper Motion Cleaning of open cluster NGC 188



shows binary sequence very nicely.

Open Clusters indicate metallicity gradients steeper in the inner Disk, but difficulties in comparing the datasets.



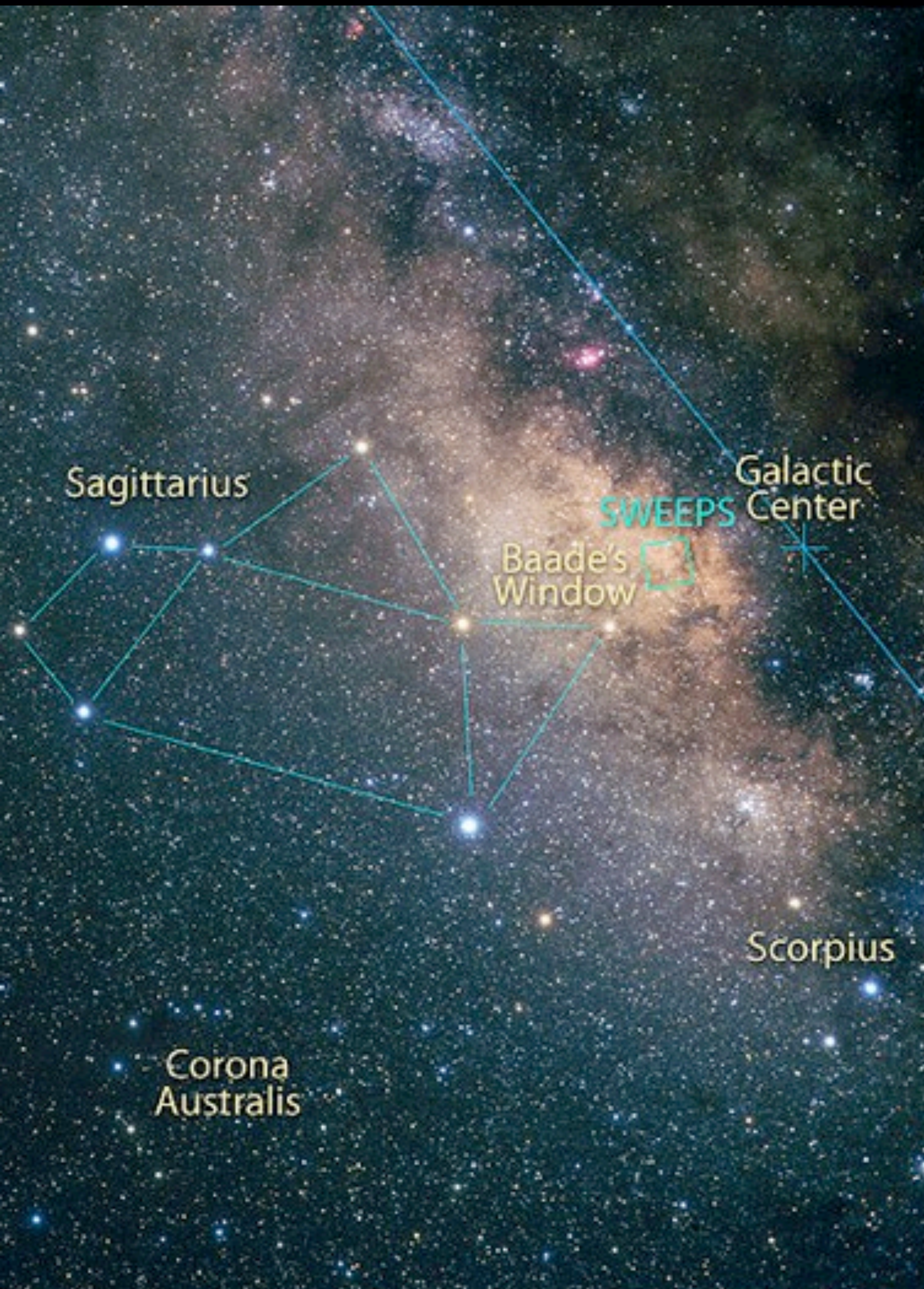
Galactic Centre & GLAO with *Spectroscopy*

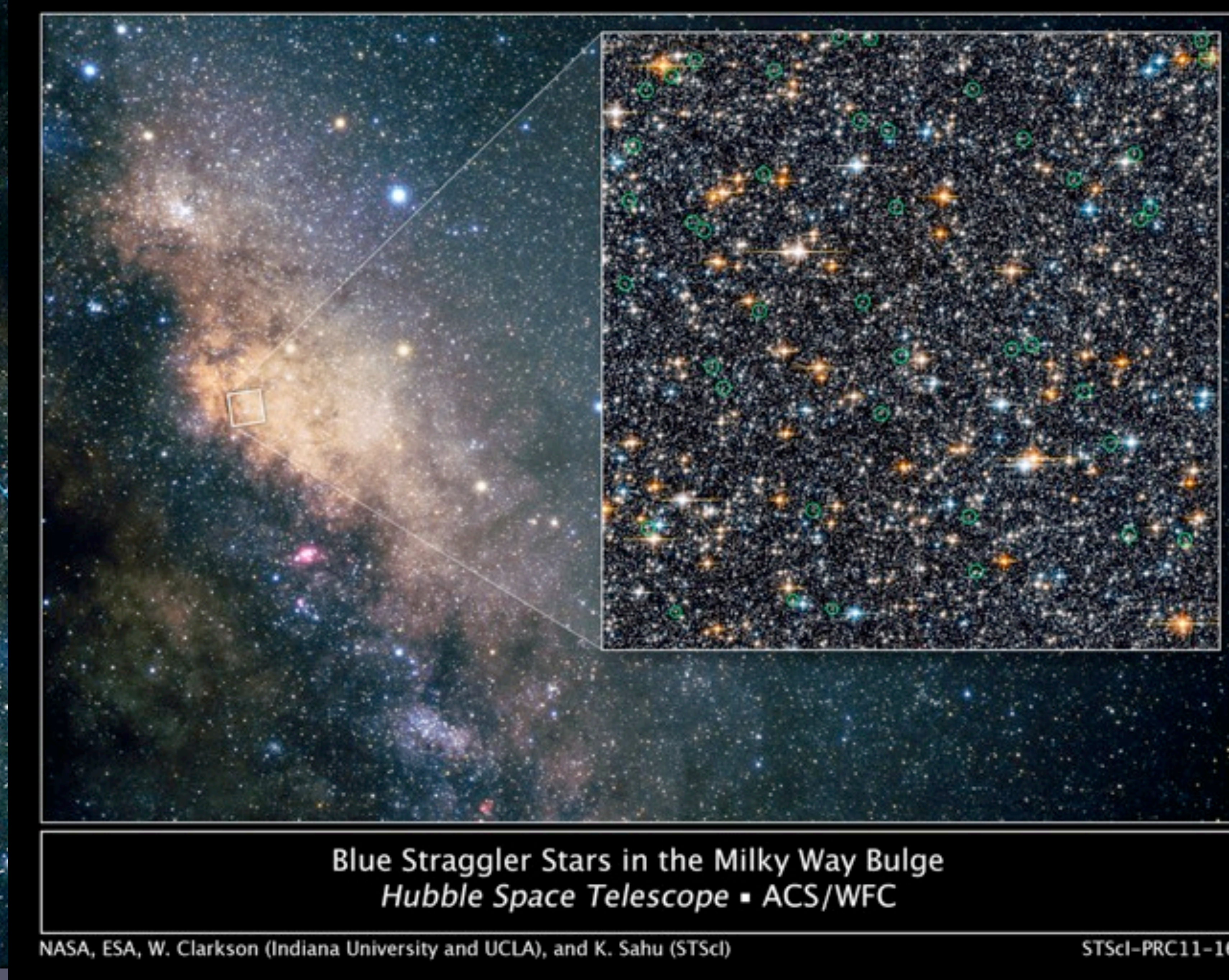
1. 3D kinematics (RV with p.m.)
2. SMBH - asymmetries?
3. Properties of stars in the Galactic Centre
4. Search for First Stars, remnants, earliest evolution.

SWEEPS FOV in the Galactic Bulge:

Sagittarius Window Eclipsing Extrasolar Planet Search

ACS/WFC FOV ~ 200” x 200”





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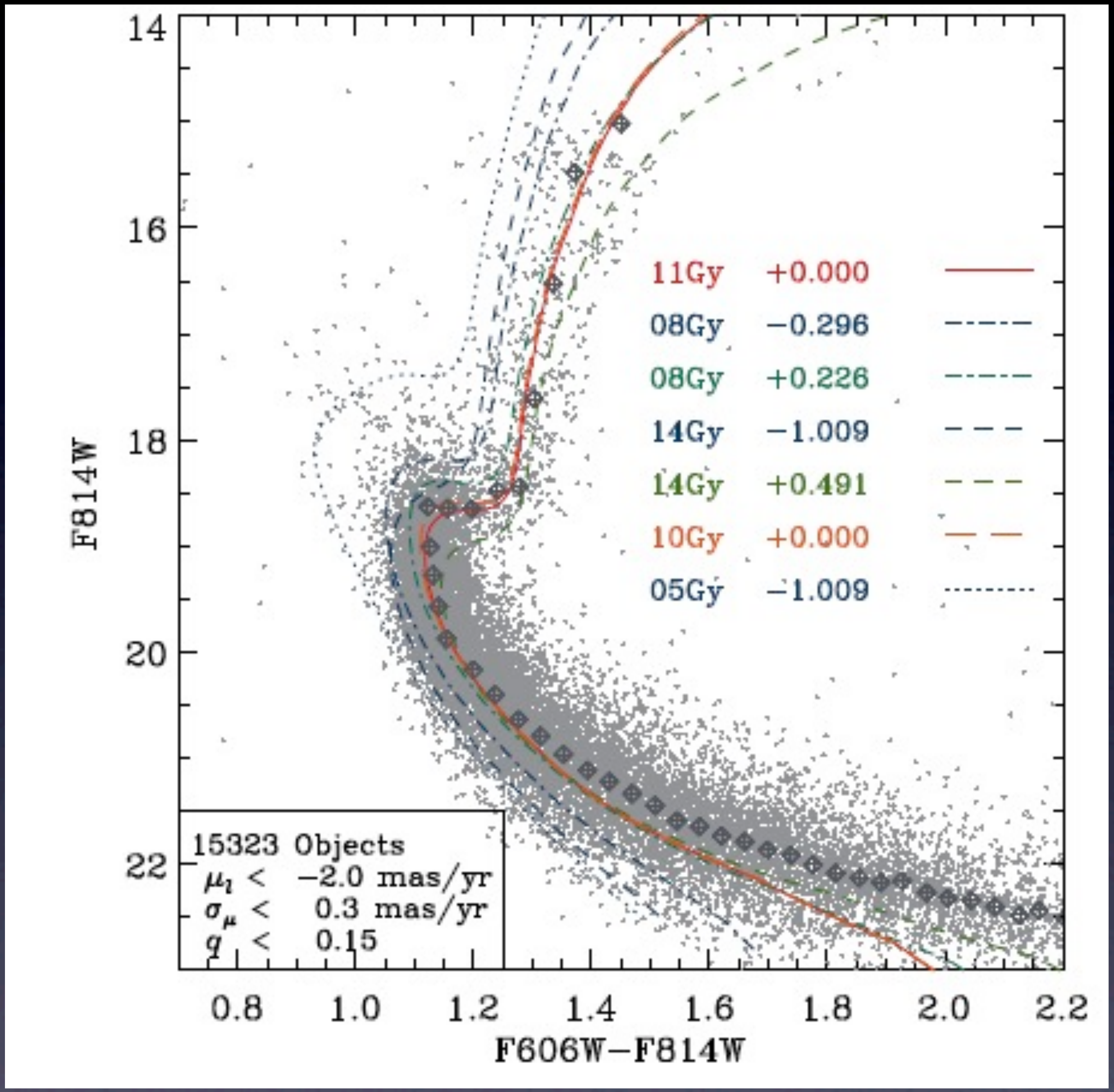

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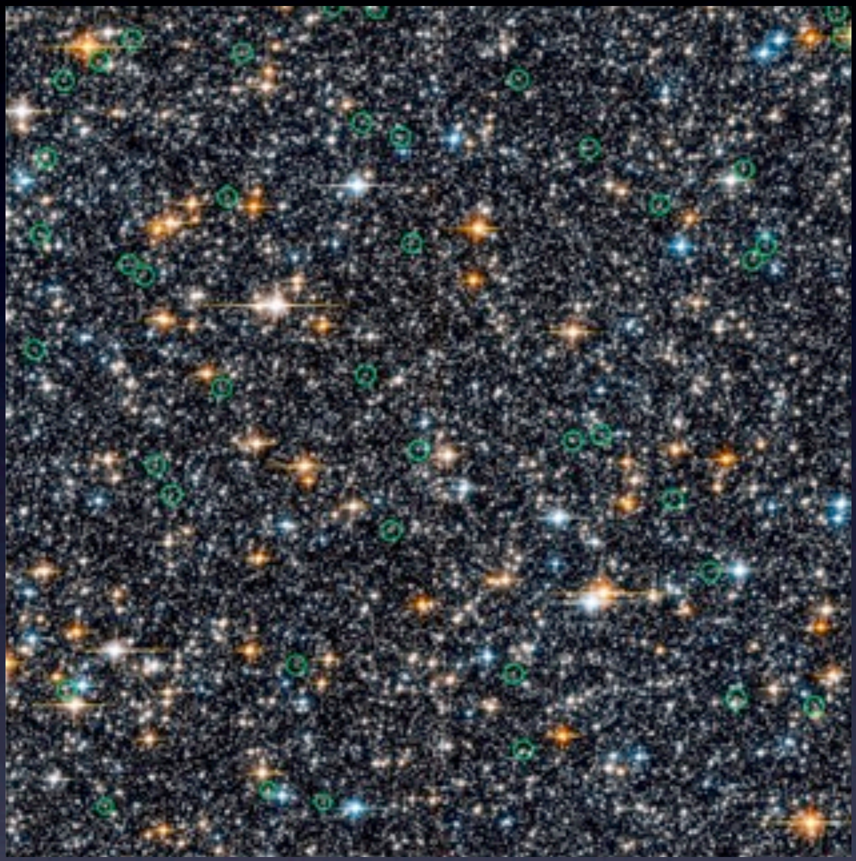
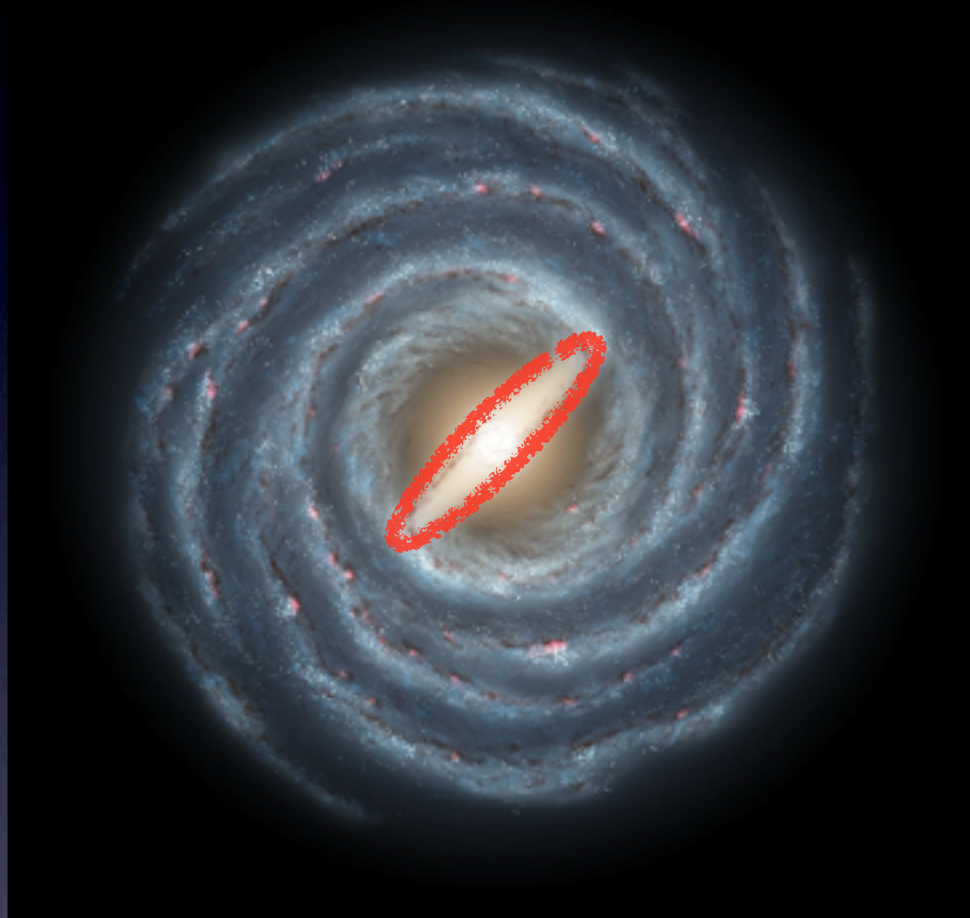
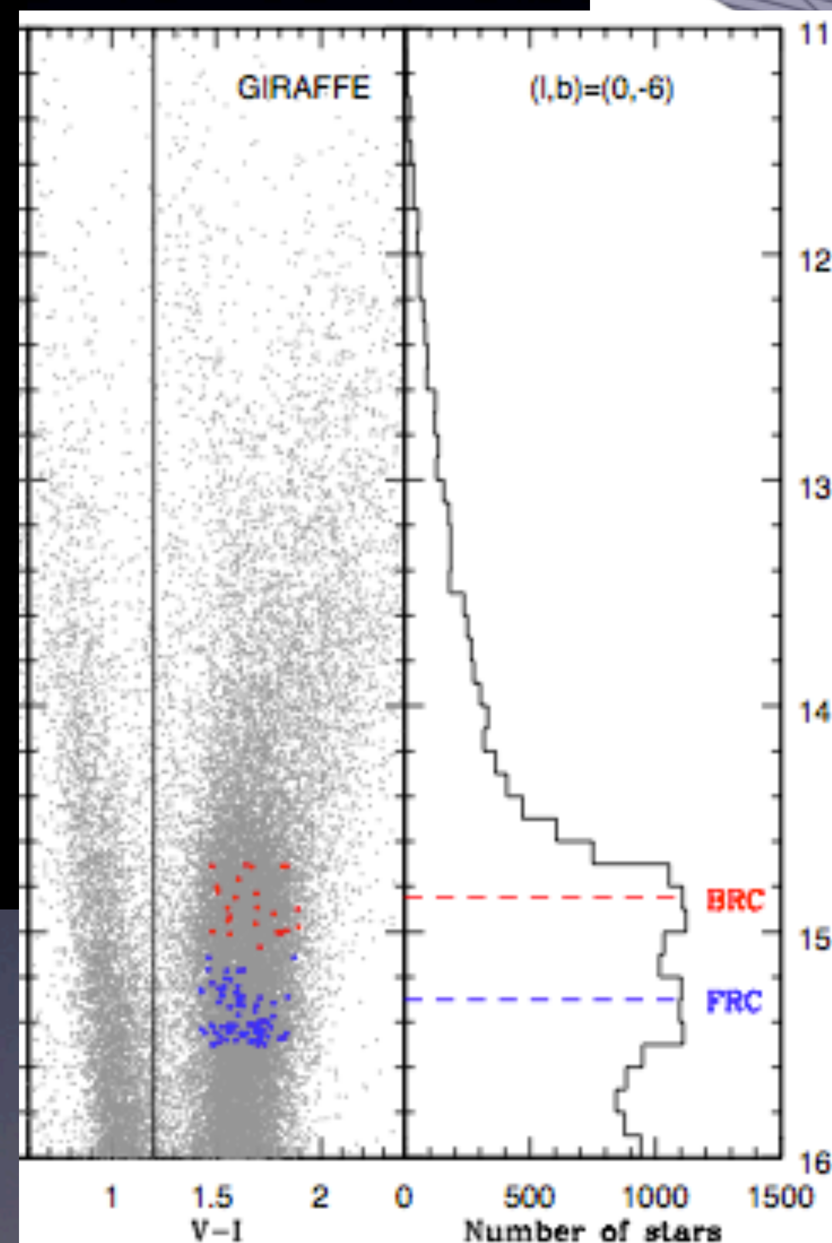


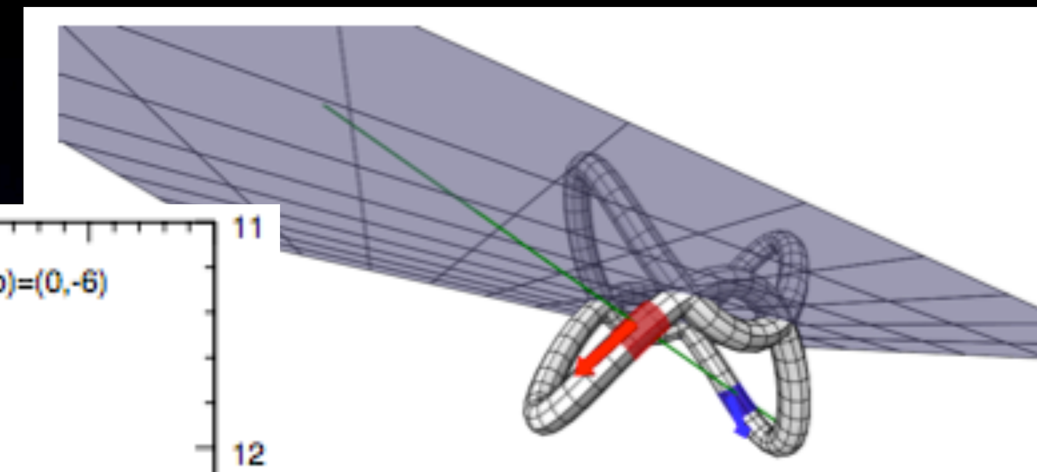
Proper Motion cleaned CMD of Galactic Bulge (tiny FOV) shows old & metal-rich (Clarkson et al. 2008)

But the Galactic Bulge has Structure
Bar and X-shape



Bissantz & Gerhard 2002
Babusiaux & Gilmore 2005
Cabrera, Lavers, et al. 2008
etc.





Red clump stars show two overdensities along the minor axis:

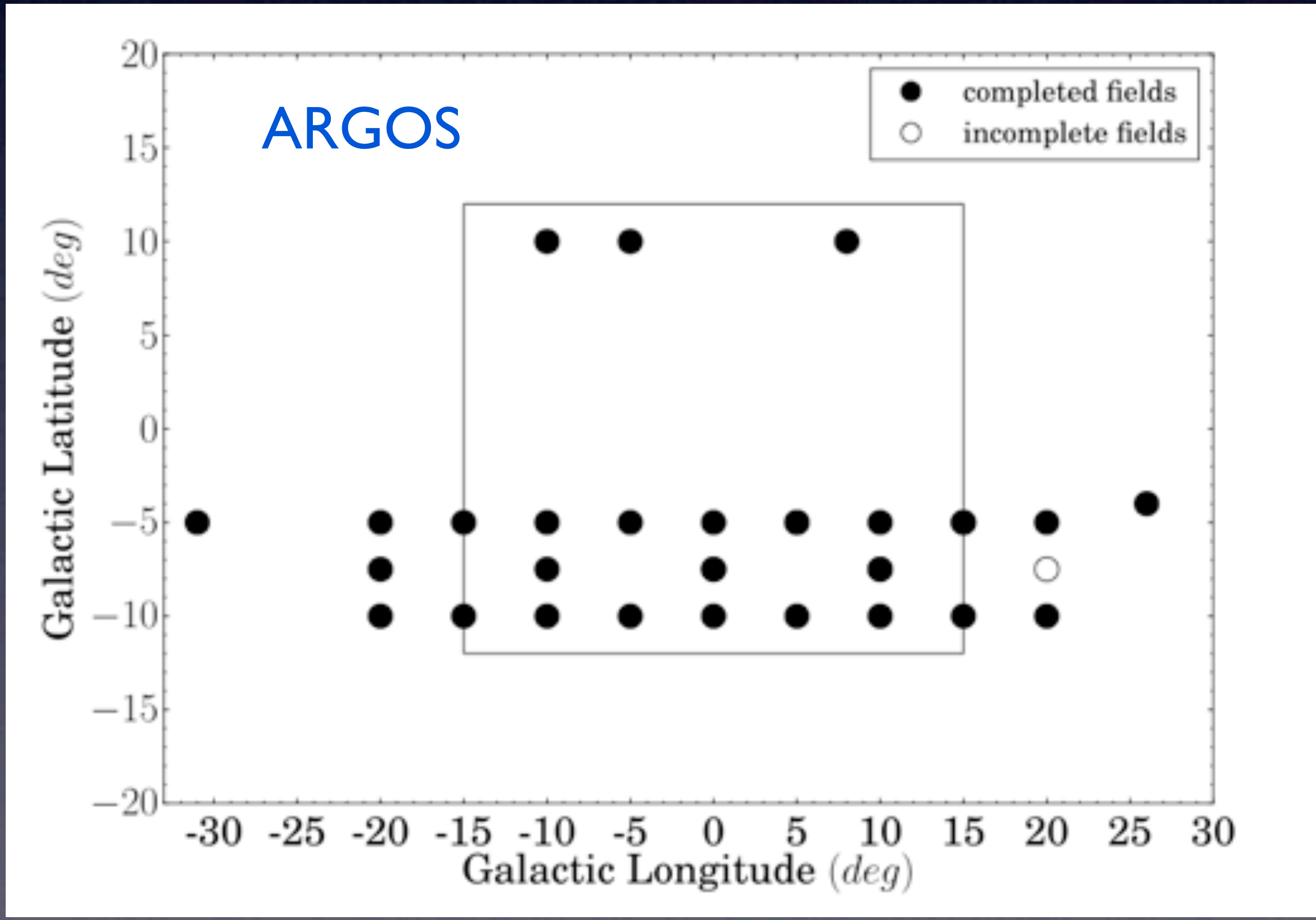
McWilliam & Zoccali 2010
Nataf et al. 2010
Saito et al. 2011

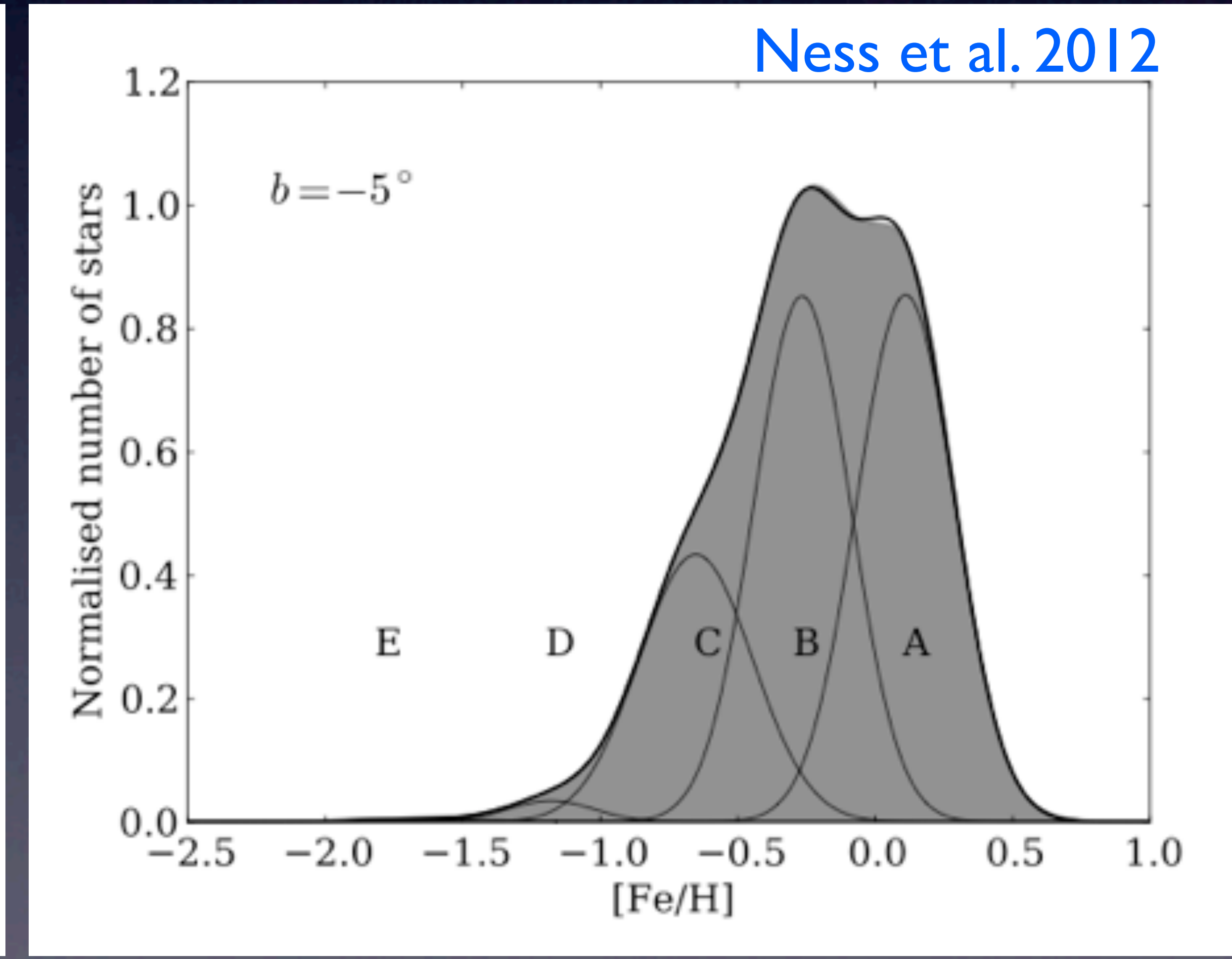
ARGOS survey of Galactic Bulge

metallicities, [alpha/Fe], velocity dispersions

Freeman (*March 2013 ngCFHT meeting*) suggests:

A: thin disk interlopers
B: true boxy/peanut bulge
C: old thick disk which may be part of the bulge





Bulge Spectral Surveys

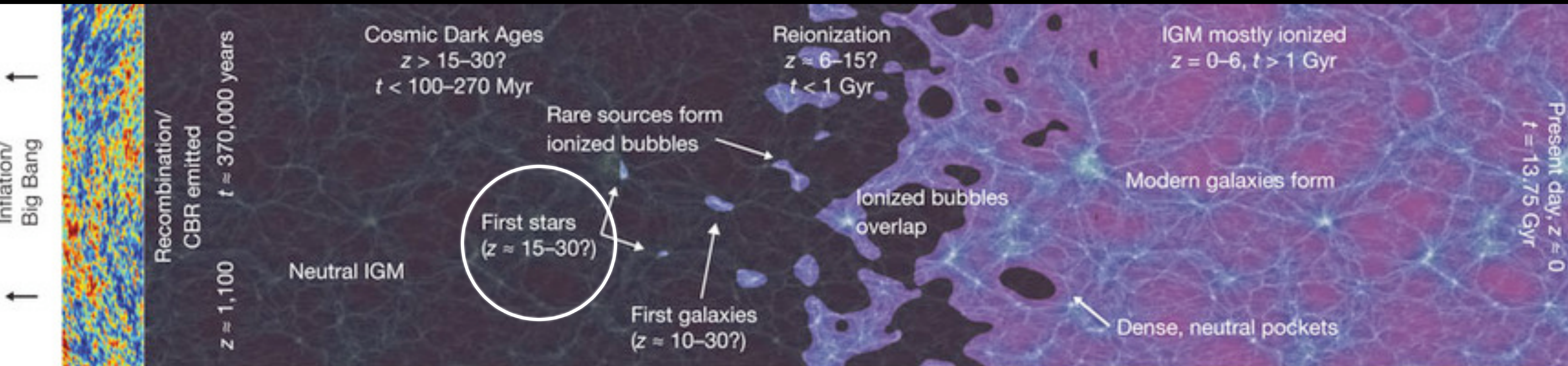
ARGOS (AAO)	R ~10,000 optical
ESO Bulge LP (ESO)	R ~ 5000 & 20,000 optical
APOGEE (SDSS-III)	R ~ 20,000, H-band
MOSFIRE ??	R ~ 5000

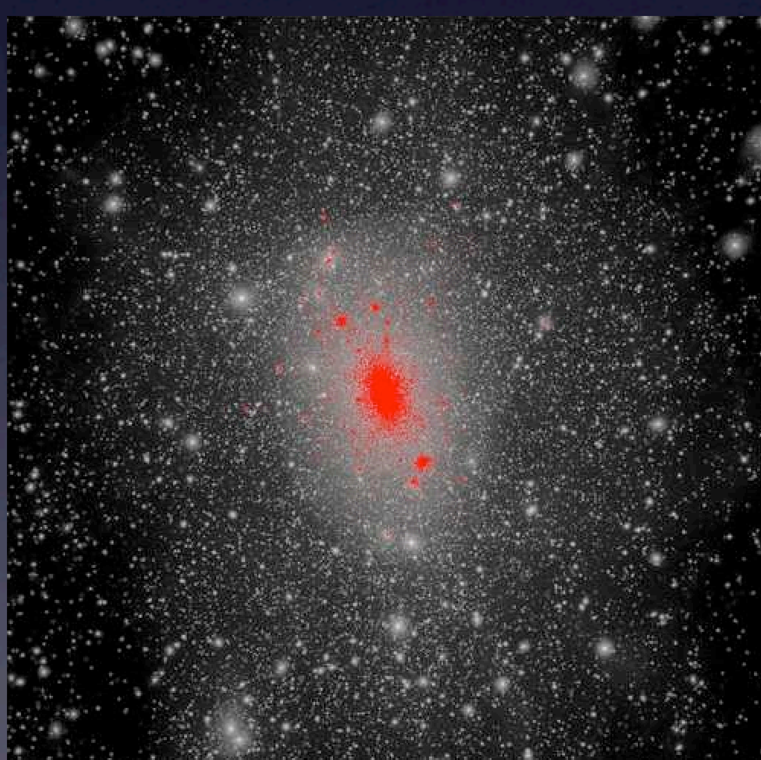
APOGEE only one that uses fibers:

300 low-OH ('dry') fused silica fibers with 2" FOV at focal plane, using VPH gratings & H2RG CCDs (loan from JWST NIRCam)

- Yet these surveys cannot go into crowded fields (no AO),
- Optical surveys have to deal with variable reddening (bad Av)
- All have bright limiting magnitudes (V<19, H<12).

Reason to Survey Stars *in* the Galactic Centre



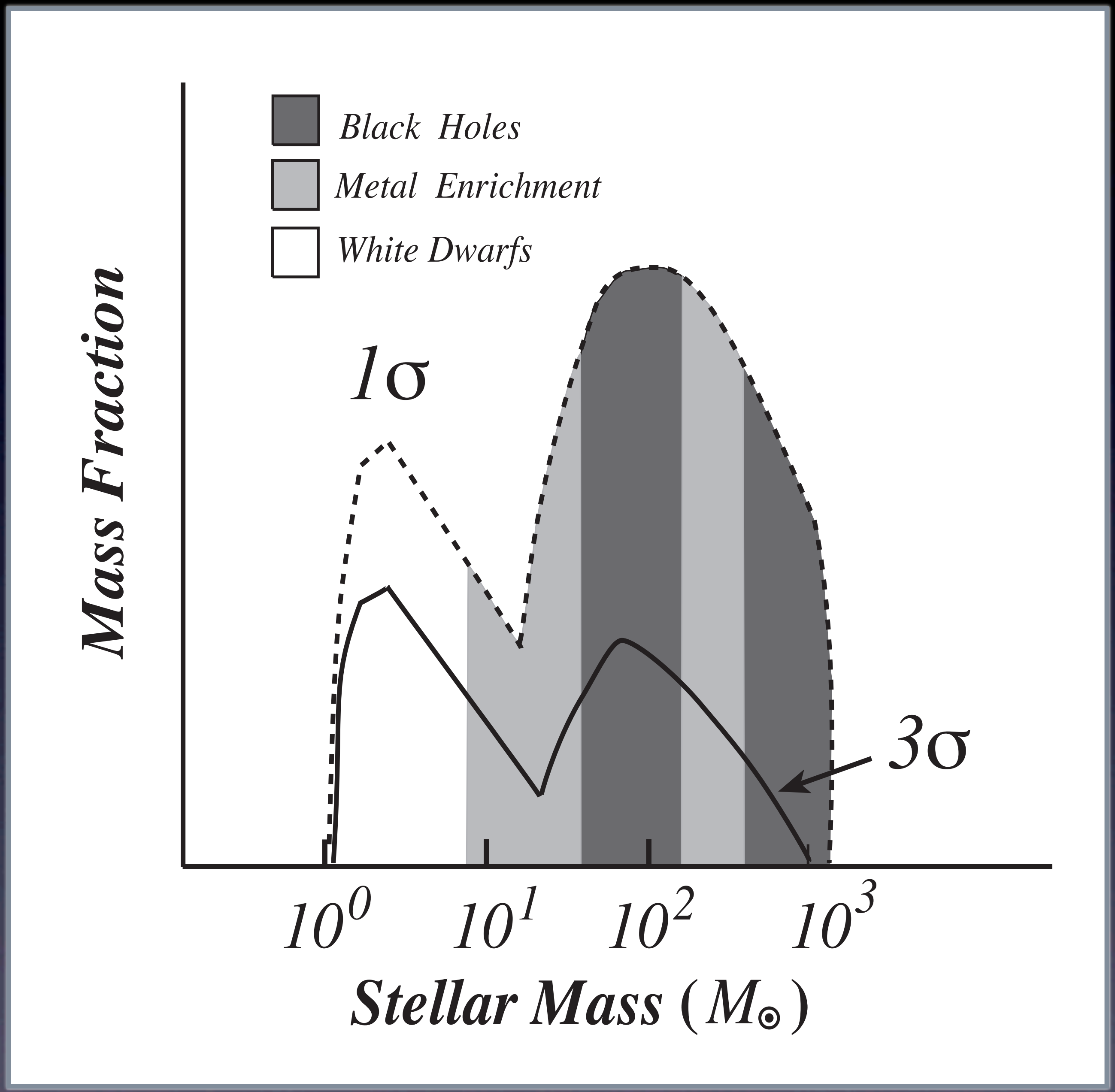


Gao et al. 2010

Search for remnants of the First Stars:

- *linked to Cosmic Dawn, reionization*
- *early chemical evolution in the Universe*
- *remnants may at centres of galaxies*

First Stars may have bimodal mass distribution



Nakamura & Umemura 2001

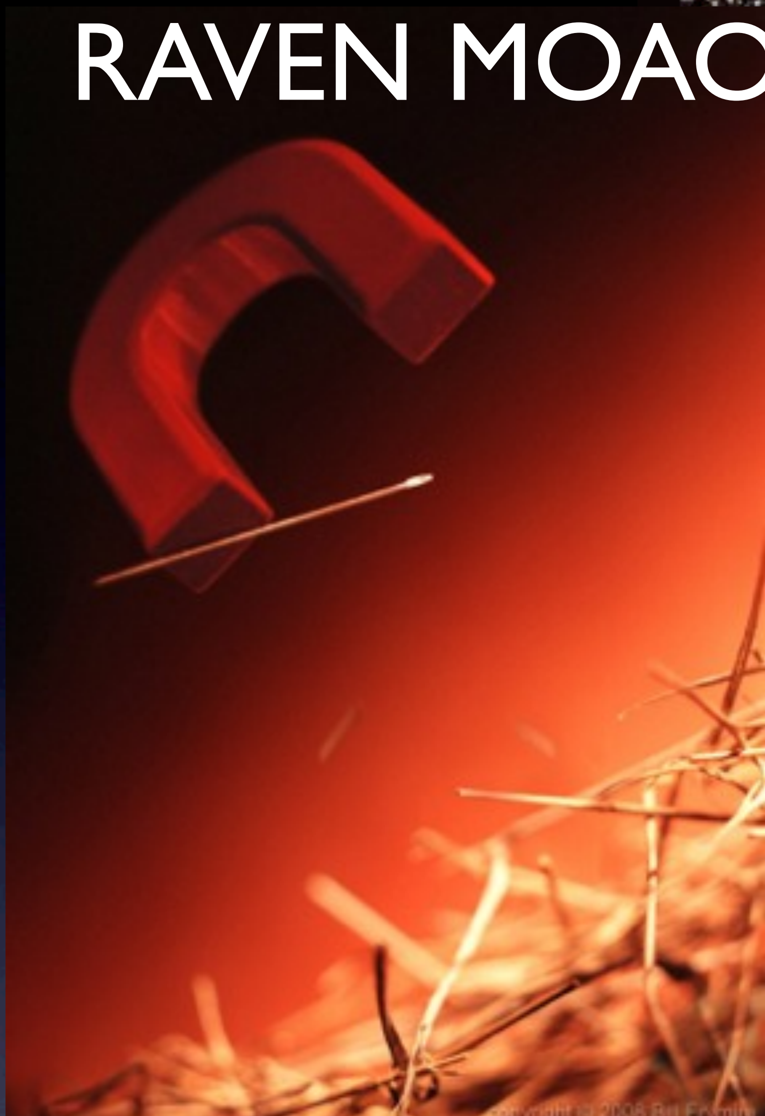
If fractionation occurs:
(e.g., Schneider 2004, 2006, Clark et al. 2008).

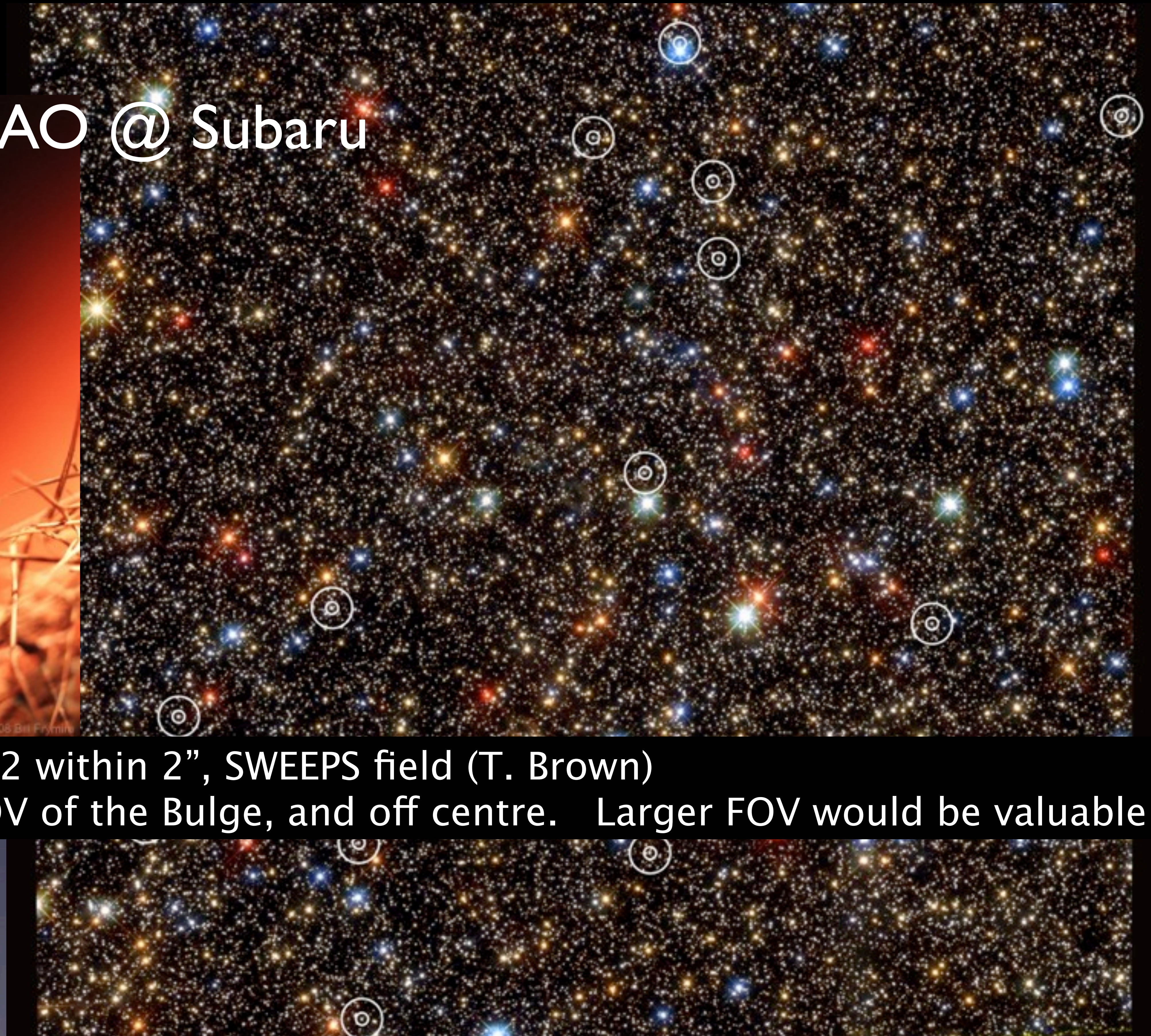
in high density regions, H_2 cooling becomes optically thick and the cloud fragments

or, dust formation in pair instability supernovae can lead to efficient cooling and fragmentation

0.08 Mo stars would still exist today

RAVEN MOAO @ Subaru

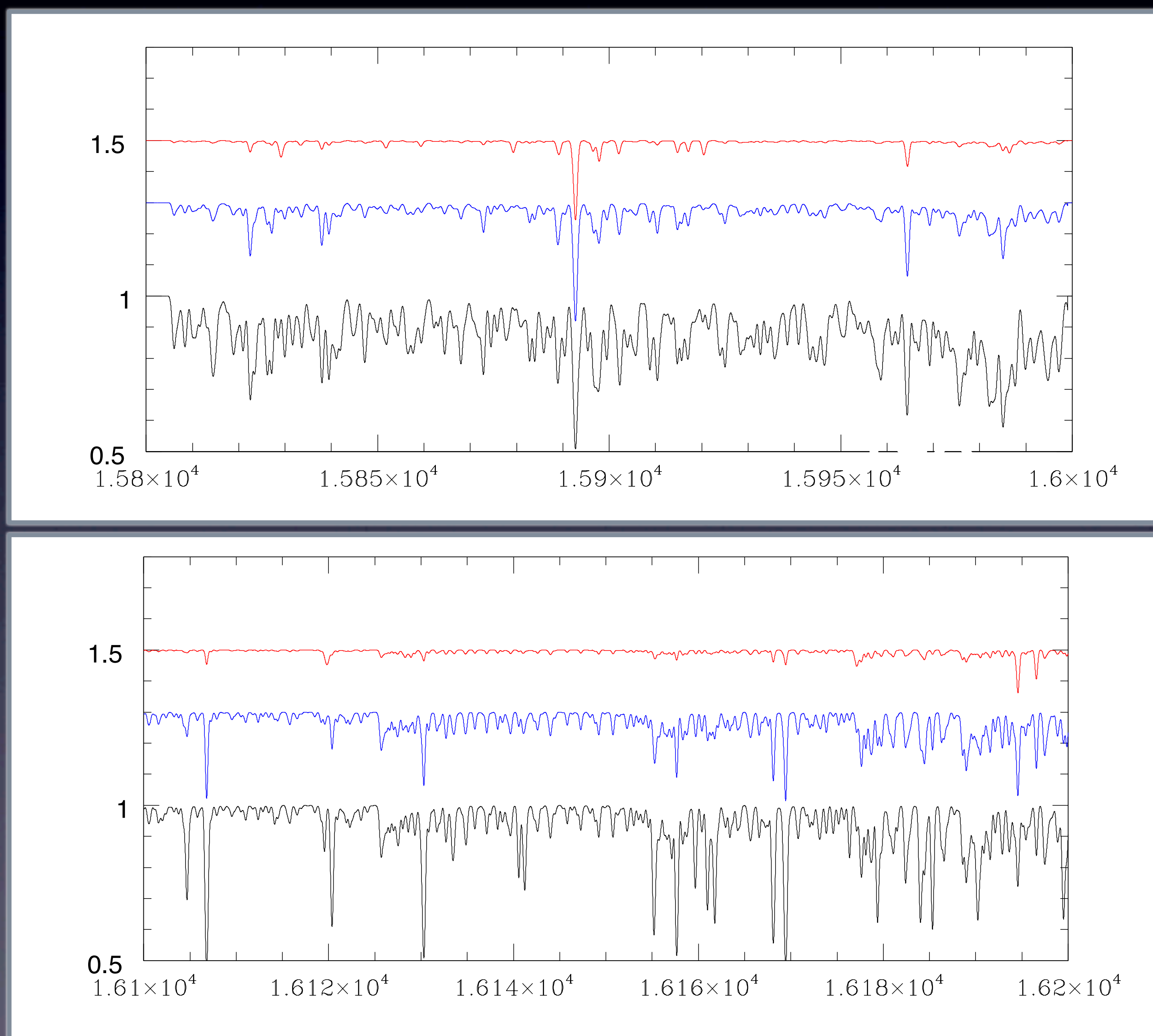




e.g., H < 16, ΔH > 2 within 2”, SWEEPS field (T. Brown)
but this is a tiny FOV of the Bulge, and off centre.   Larger FOV would be valuable!

Thus, AO-IR spectroscopic survey of the Galactic Bulge

R=2000 will be okay for [Fe/H] > -2.5 --> an IR SDSS?
R=5000 okay for [alpha/Fe] in the IR? --> unknown if features available or errors
R>20,000 for [X/Fe] --> APOGEE (bright) calibrations.



[Fe/H] = -2.5

[Fe/H] = -1.5

[Fe/H] = -0.5

How do you know if you got a First Star?

Heger & Woosley 2010

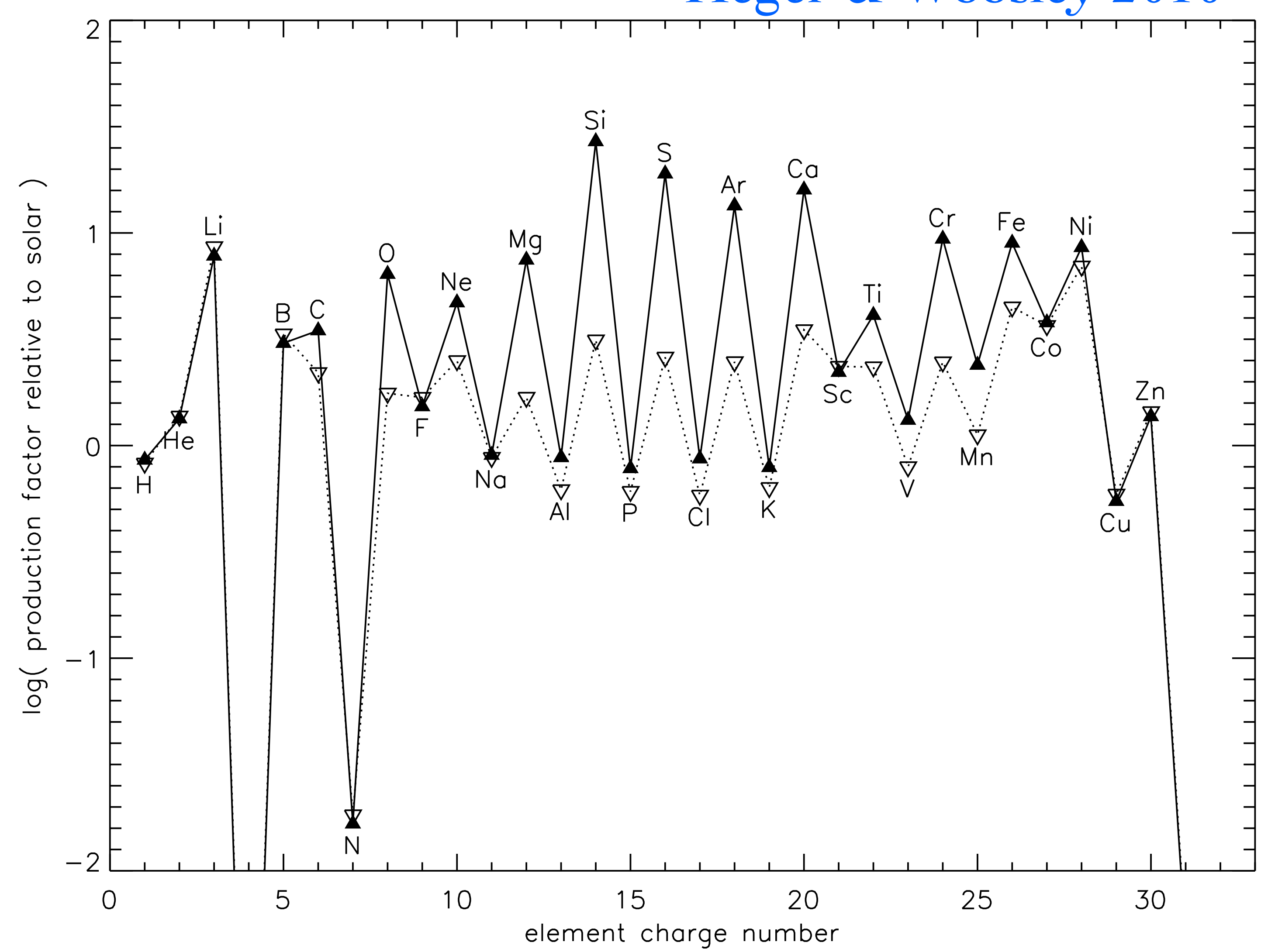
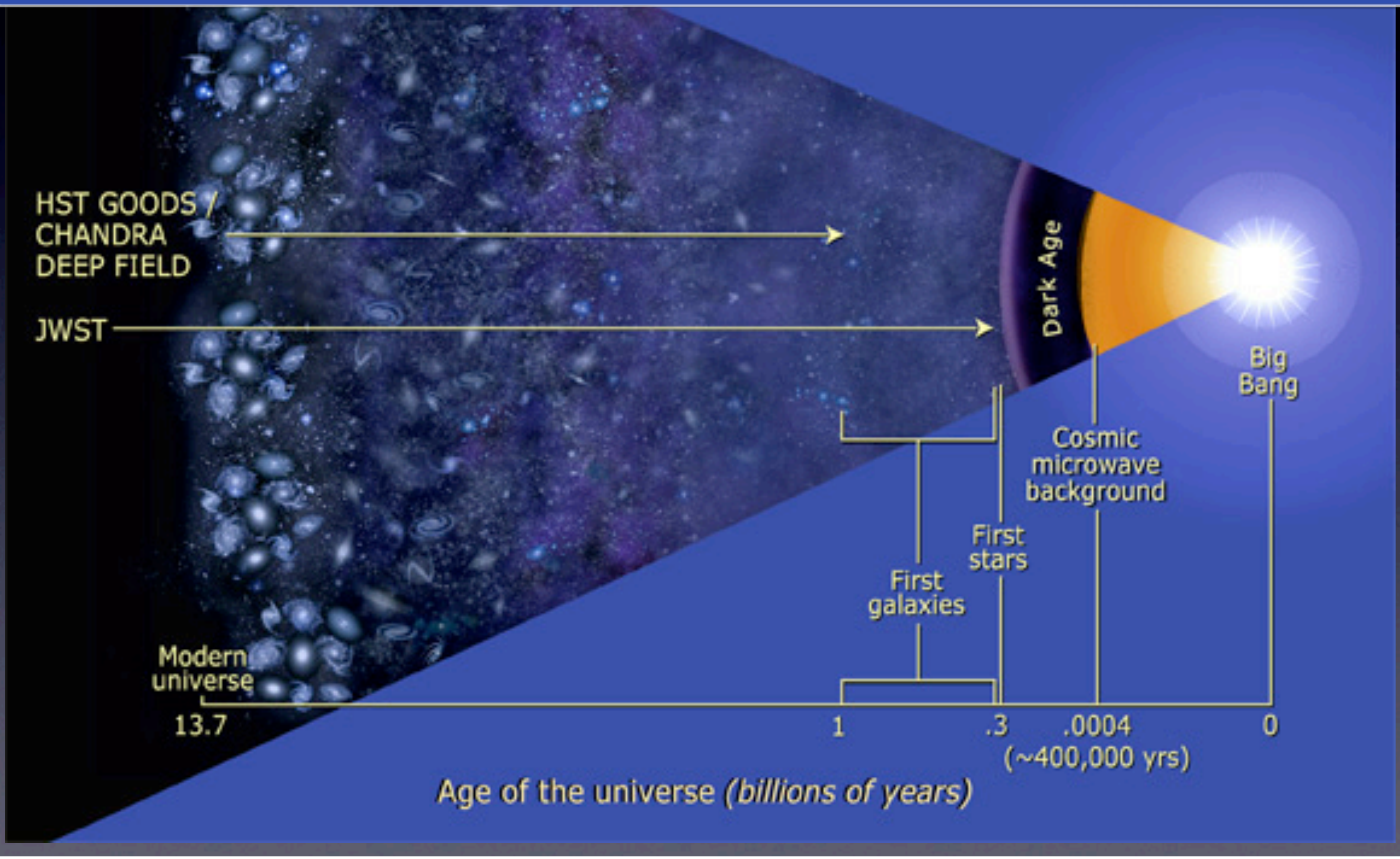


FIG. 4.—Production factors for massive stars (12–40 $M_\odot$; *dotted line, open triangles*) integrated over IMF and compared with solar abundances as a function of element number. The yields are taken from Woosely &

Predict a unique chemical pattern : no elements > Zn

First Star Candidates will require TMT HRS but GLAO + IR spect would identify candidates and connect us to Cosmic Dawn.



GLAO Workshop questions:

Two science cases: - proper motion cleaning (WF imaging)
- first star remnants (spectroscopy)

Q1. WF imager (p.m.) & MOS (R~5000, GCentre)
Q2. prefer <0.1" for proper motion cleaning
Q3. GLAO & TMT (preselect first star candidates)
Q4. GLAO & JWST (IMBH easier with JWST).

Qa. Will need spectroscopy for GCentre.
Not MOIRCS, too low spectral resolution (+other cons)