

Hubble Space Telescope Imaging of Bulge Stellar Populations

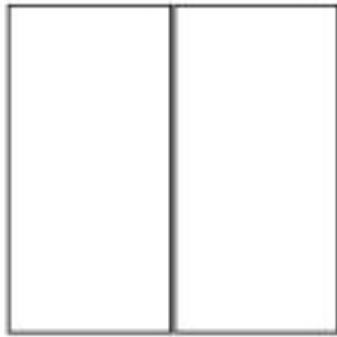
Roger E. Cohen (STScI)

Dec. 11, 2018

GBX2018: Pucon, Chile

- HST Imagers: Is HST optimal for bulge stellar pops?
How do current/future imagers compare?
- Science output so far:
 - White dwarfs
 - Binaries
 - Extinction Law
 - Clusters
 - IMF
 - Kinematics
 - Galactic Center
 - SFH/AMR
- Bulge stellar pops: Some general considerations
- The future: Complimentary facilities, outstanding questions

- HST Imagers: **Is HST optimal for bulge stellar pops?**



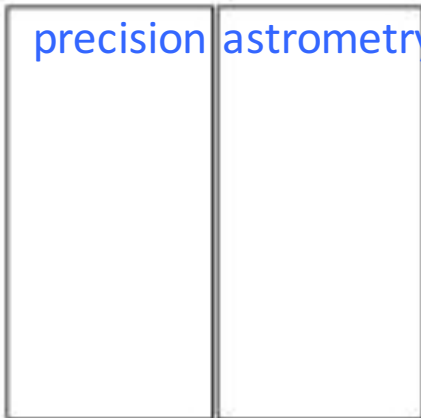
WFC3/UVIS

2×2051×4096

0.04"/pix

162"×162"

Better for
precision astrometry



ACS/WFC

2×2048×4096

0.05"/pix

202"×202"

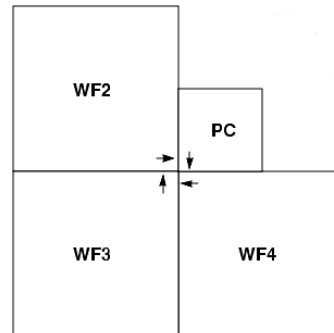


WFC3/IR

1014×1014

0.13"/pix

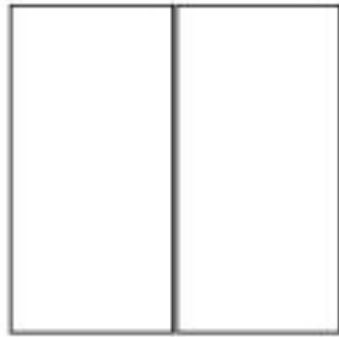
136"×123"



WFPC2

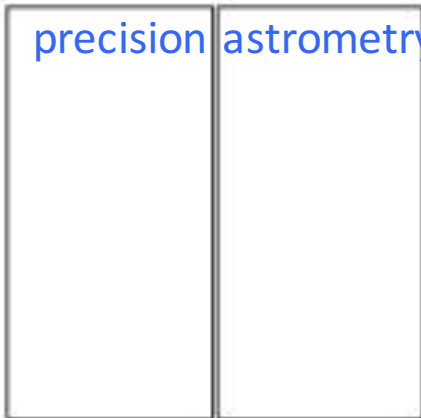
0.046" (PC) or 0.100" (WF) per pix
160" per side

- HST Imagers: **Is HST optimal for bulge stellar pops?**



WFC3/UVIS
2×2051×4096
0.04"/pix
162"×162"

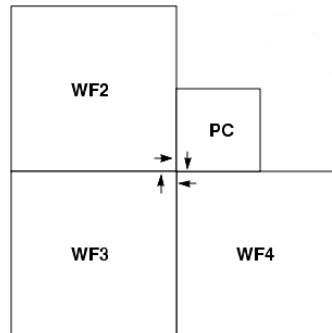
Better for
precision astrometry



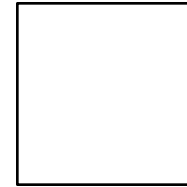
ACS/WFC
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202"×202"



WFC3/IR
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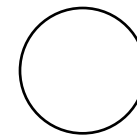
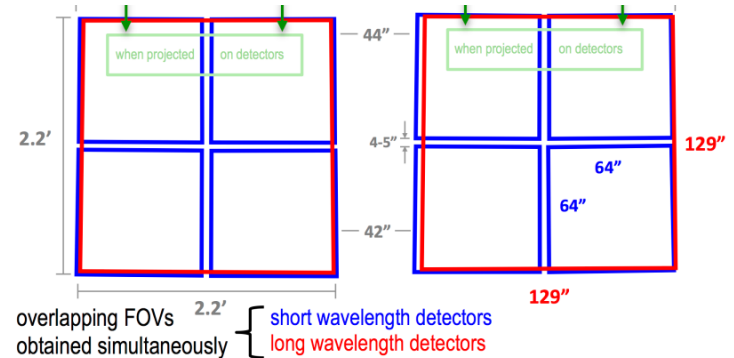


WFC2
0.046" (PC) or 0.100" (WF) per pix
160" per side



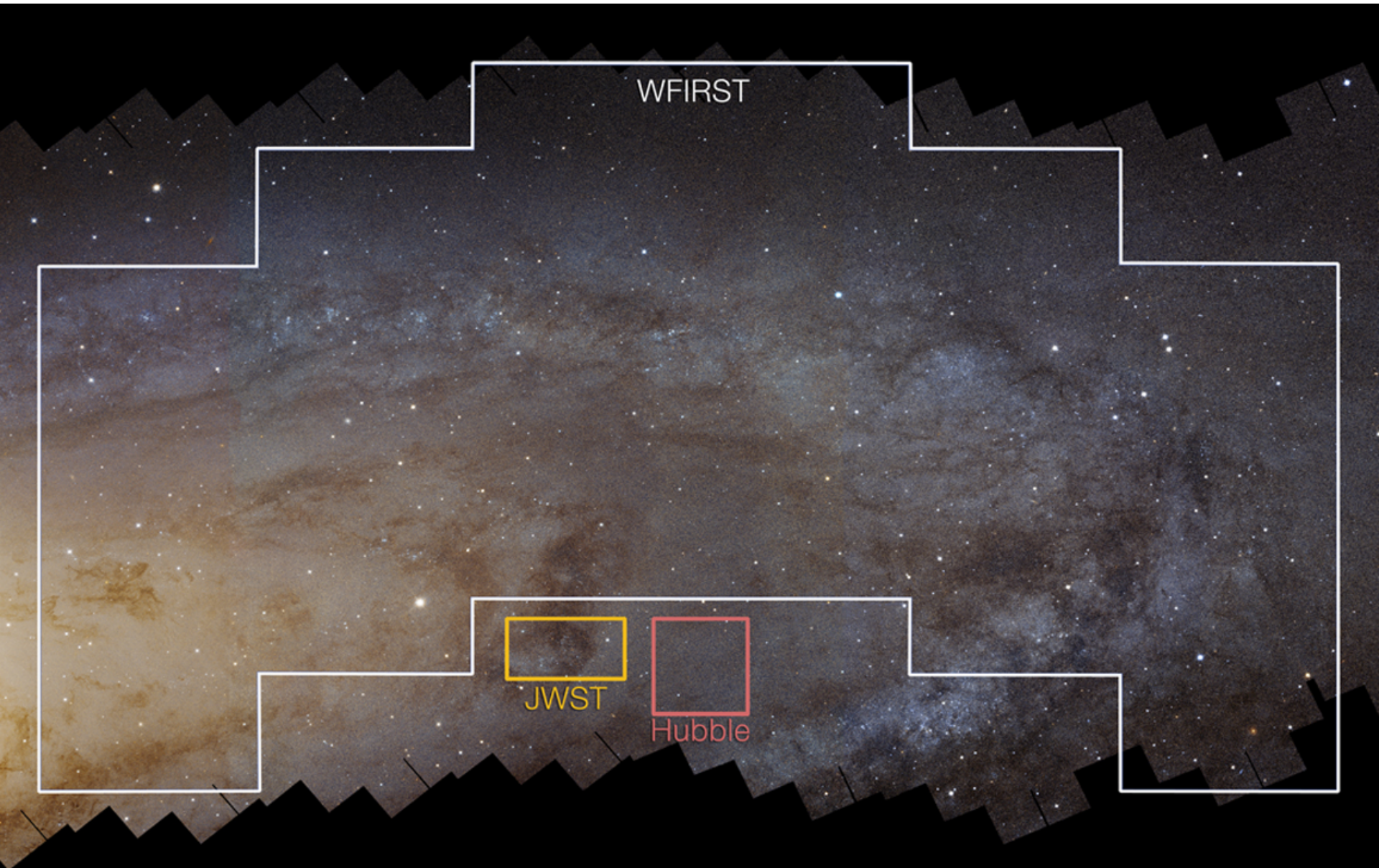
GeMS+GSAOI@Gemini-S:
0.02"/pix

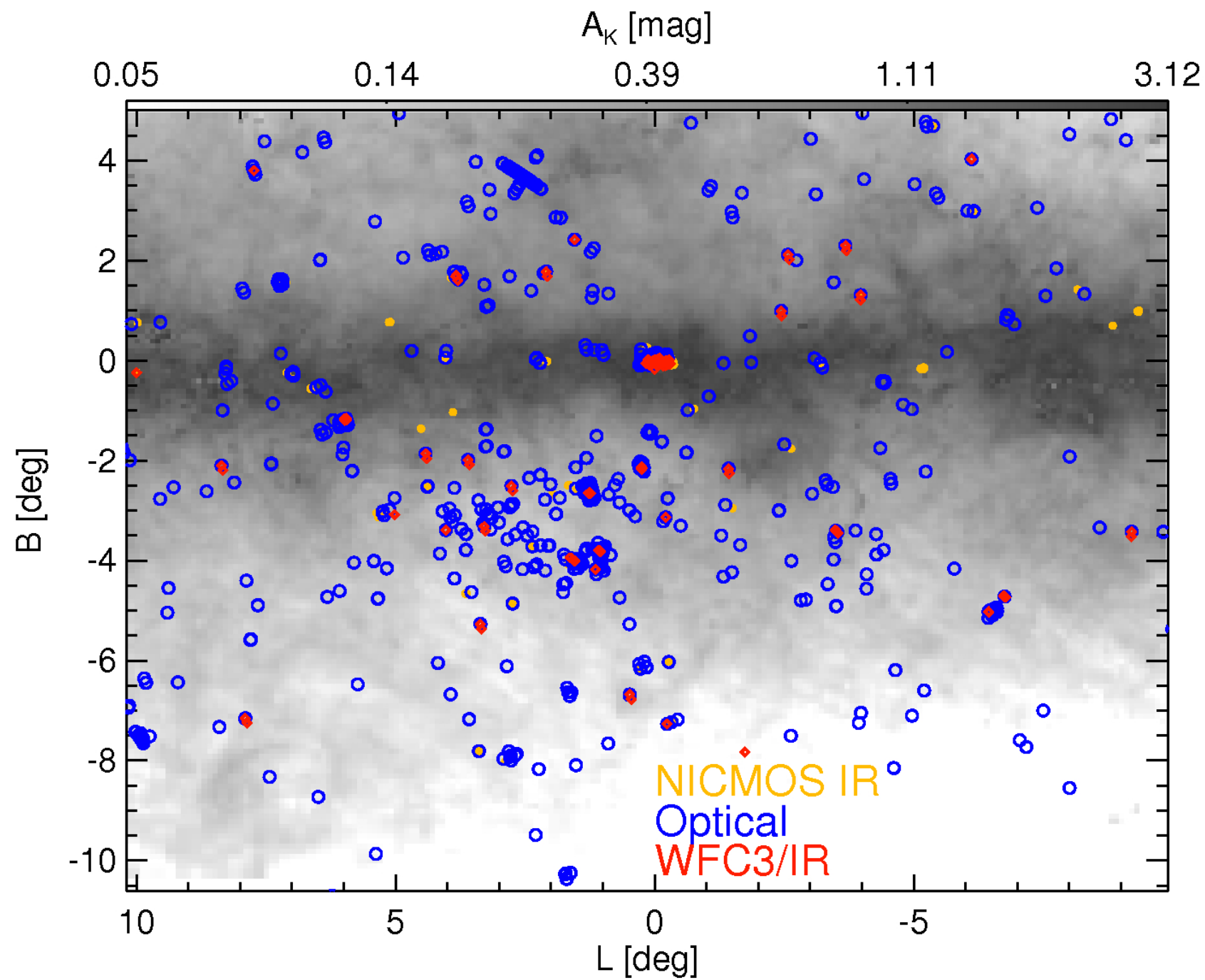
JWST NIRCAM: 0.031/0.063"/pix

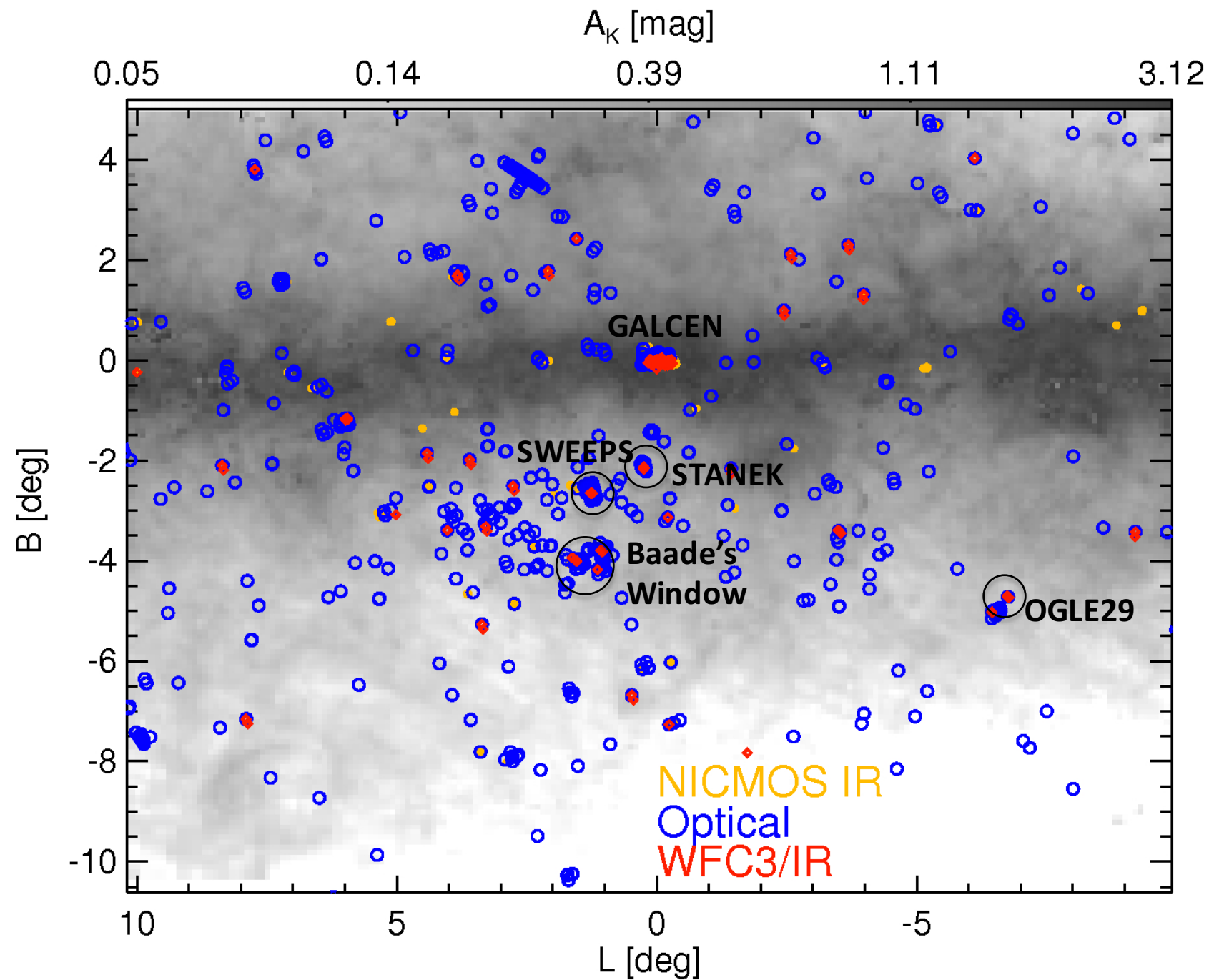


MICADO@E-ELT:
Diff. limited over ~1 arcmin
0.003"/pix

WFIRST: $0.11''/\text{pix}$







- HST Imagers: **Is HST optimal for bulge stellar pops?**

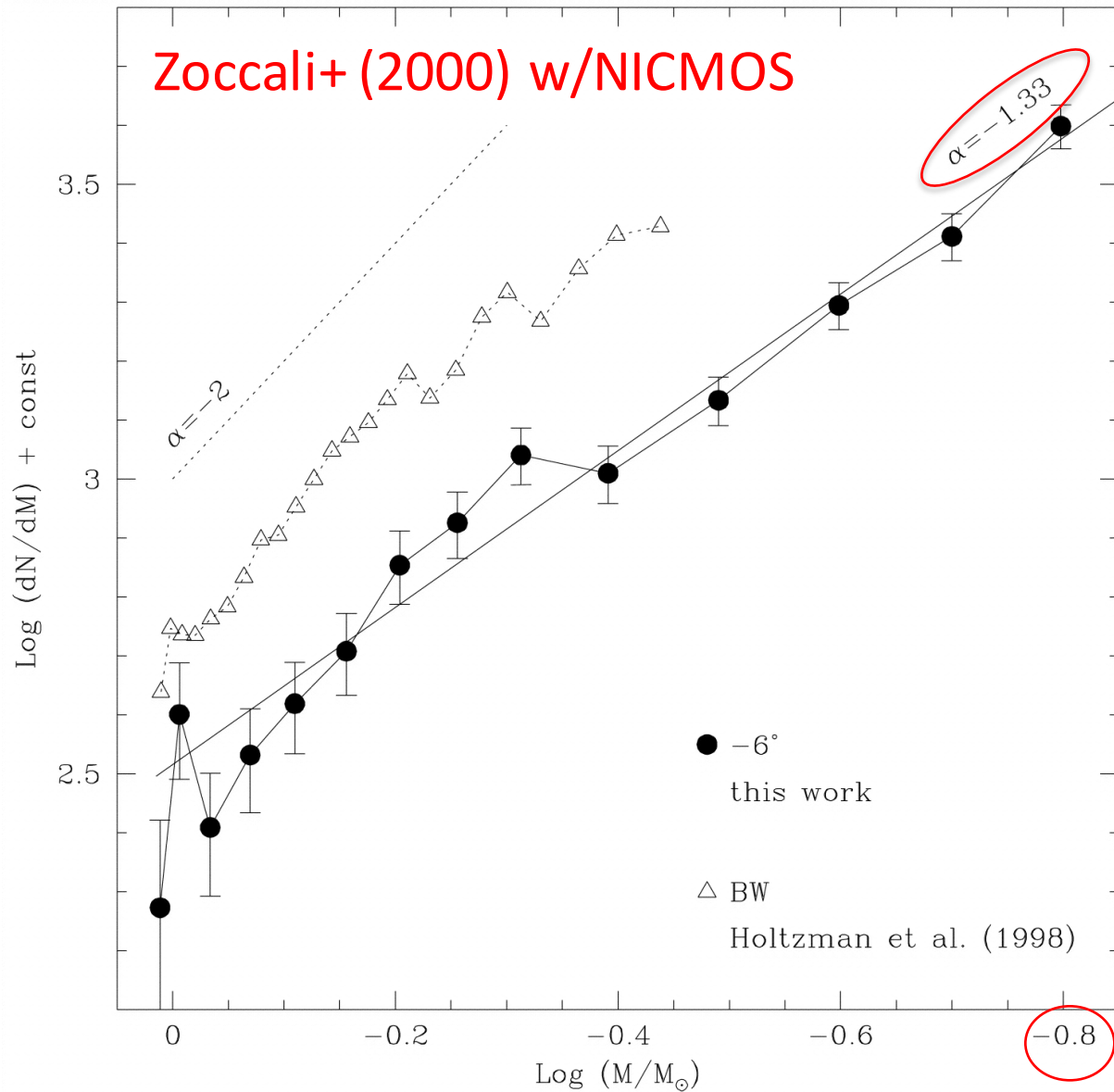
Provides combination of photometric depth PLUS astrometric precision:
Enables study of main sequence samples: High N, large mass range

BUT

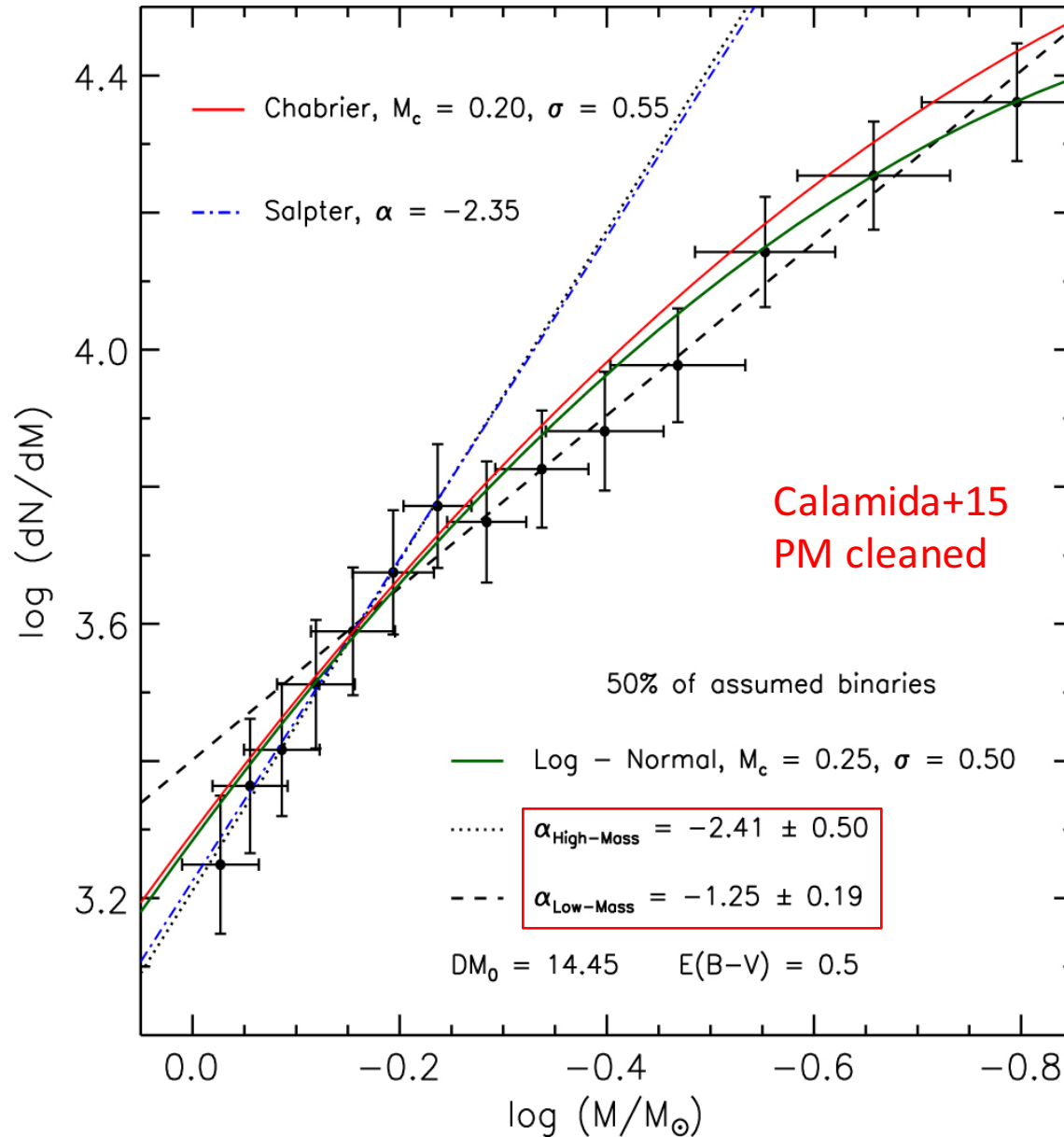
Small FOV: “Pencil beam” studies

Optical imagers better for astrometry: Requires lower extinction

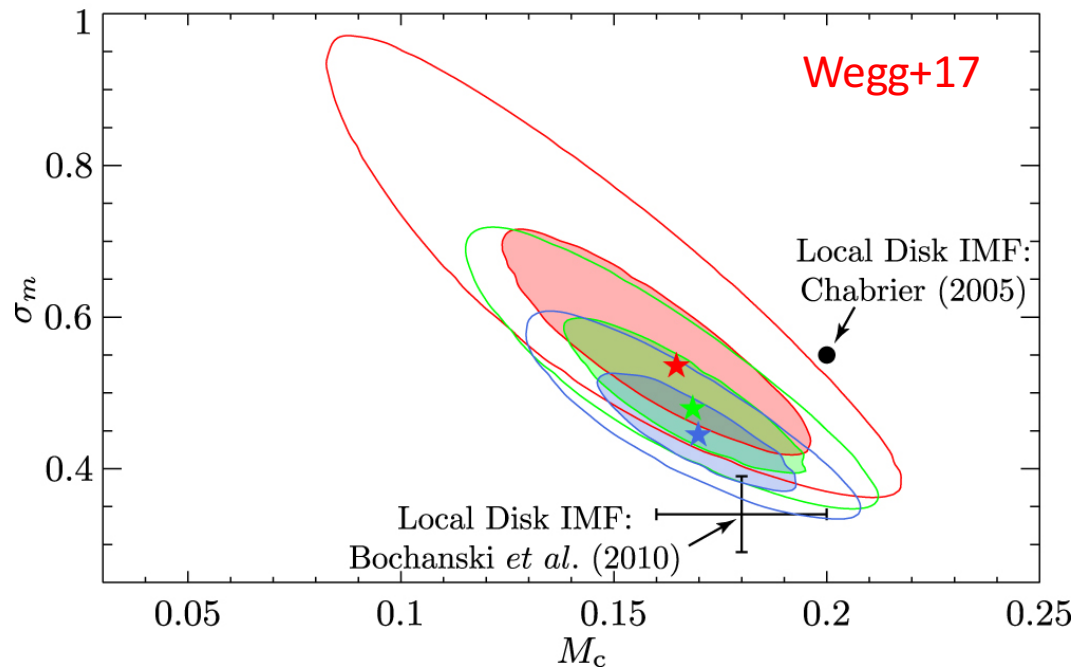
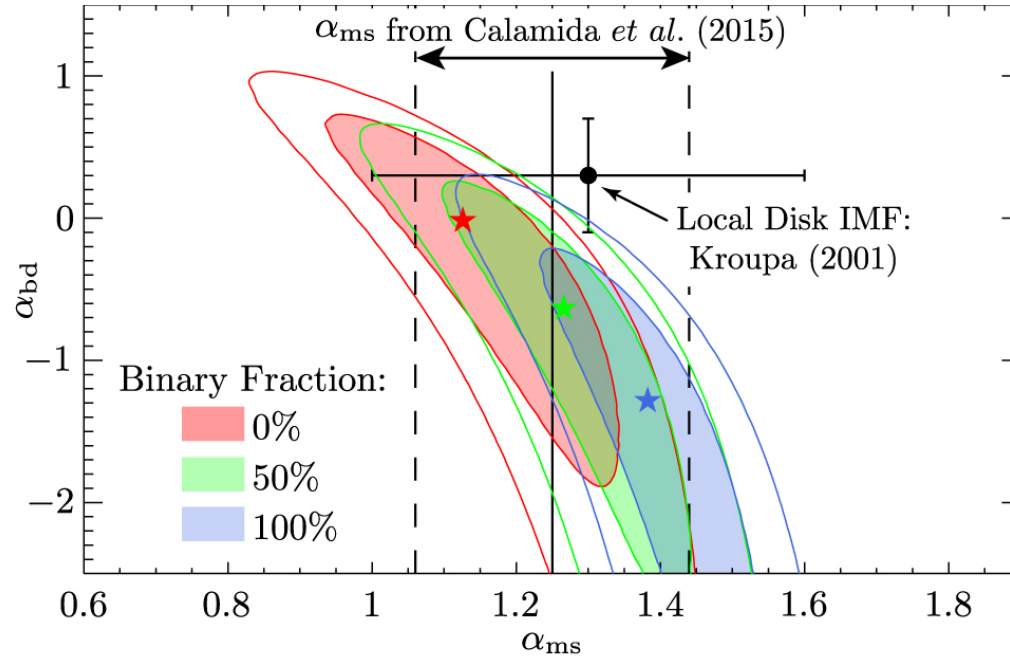
Bulge Stellar Pops With HST: IMF



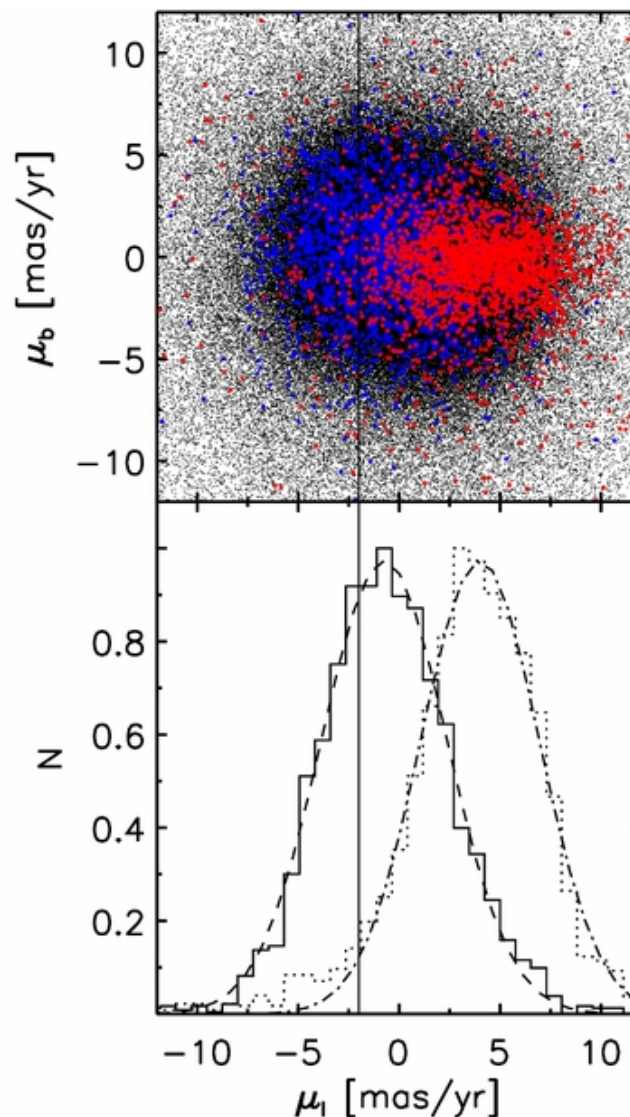
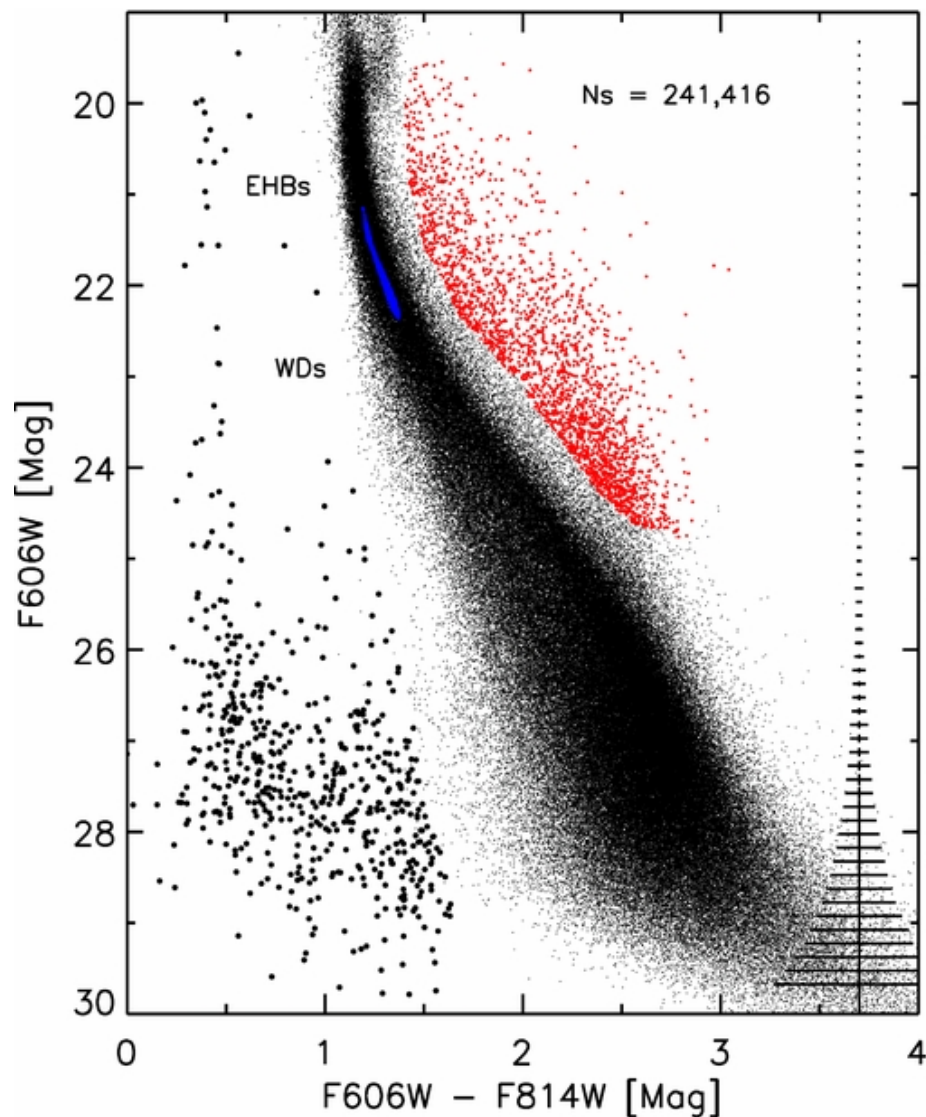
Bulge Stellar Pops With HST: IMF



Bulge Stellar Pops With HST: IMF

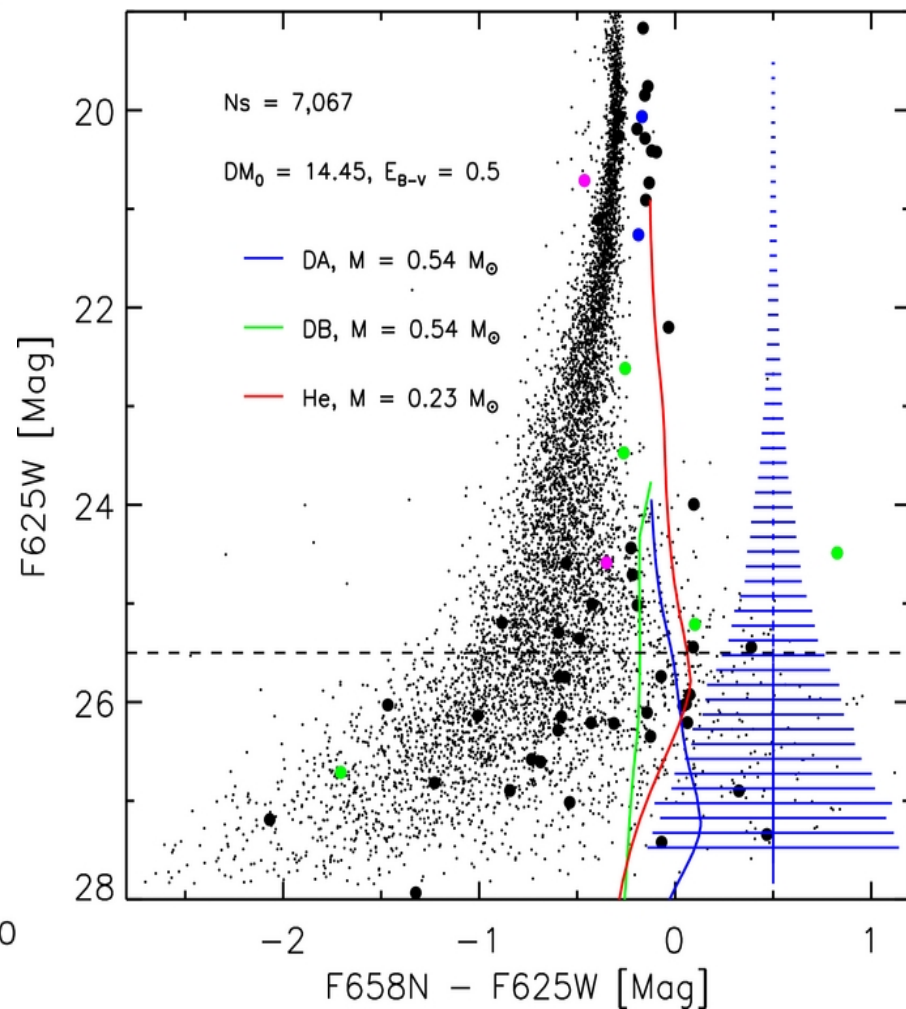
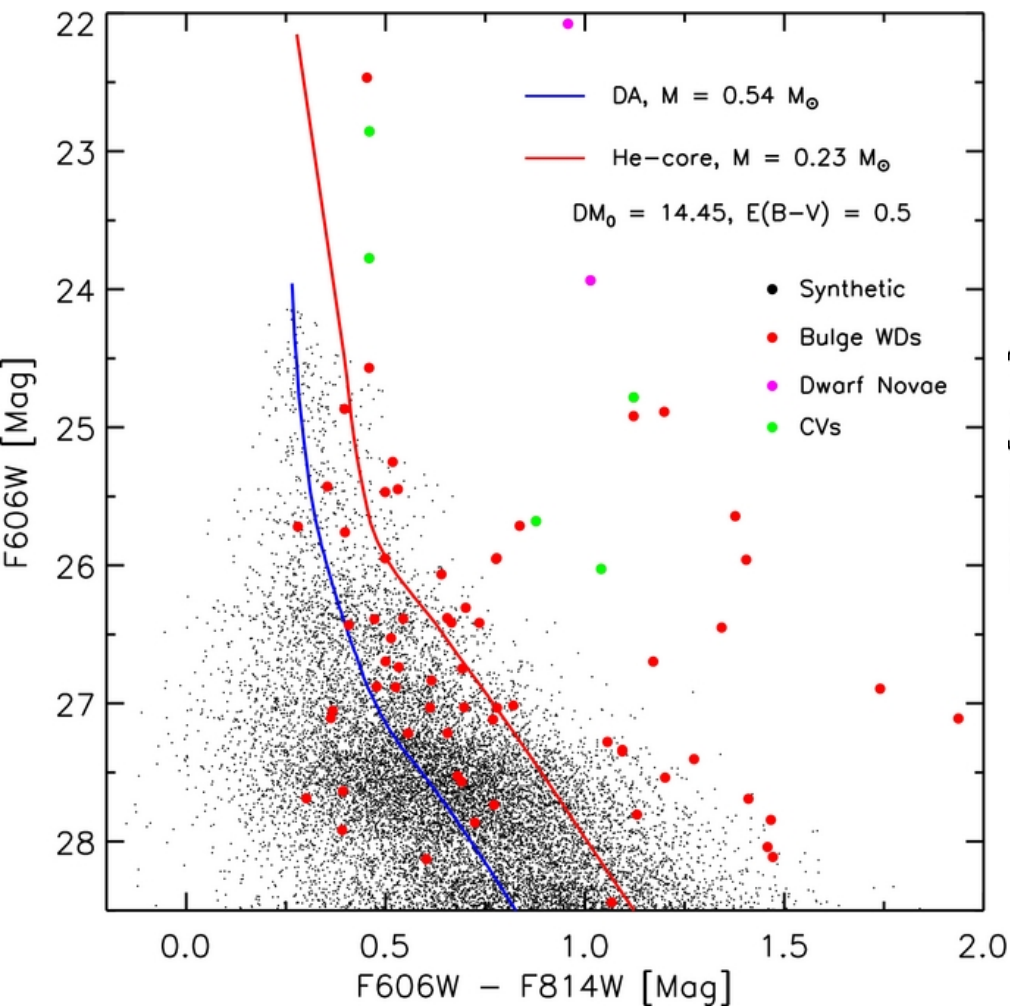


Bulge Stellar Pops With HST: White Dwarfs



Calamida+14: PM Cleaned

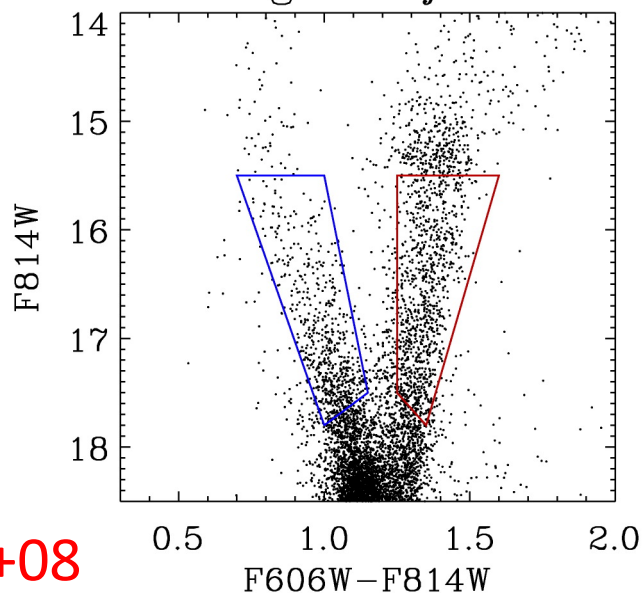
Bulge Stellar Pops With HST: White Dwarfs



Calamida+14: PM Cleaned

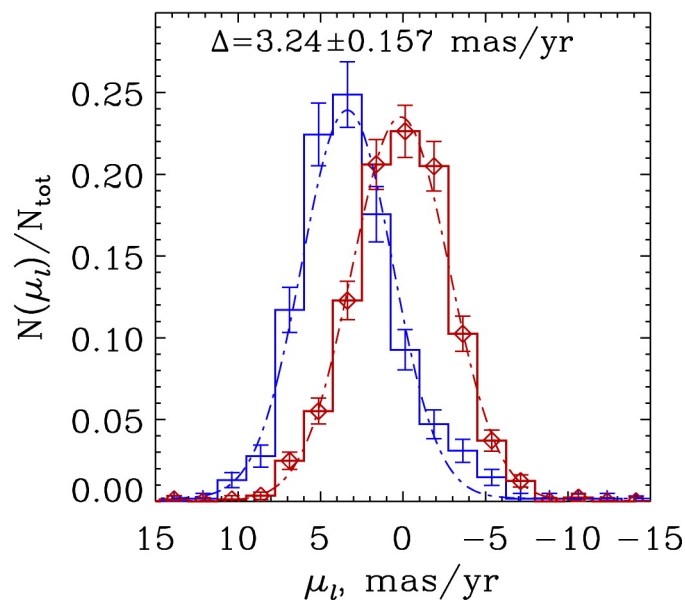
Bulge Stellar Pops With HST: Kinematics

Bright Objects

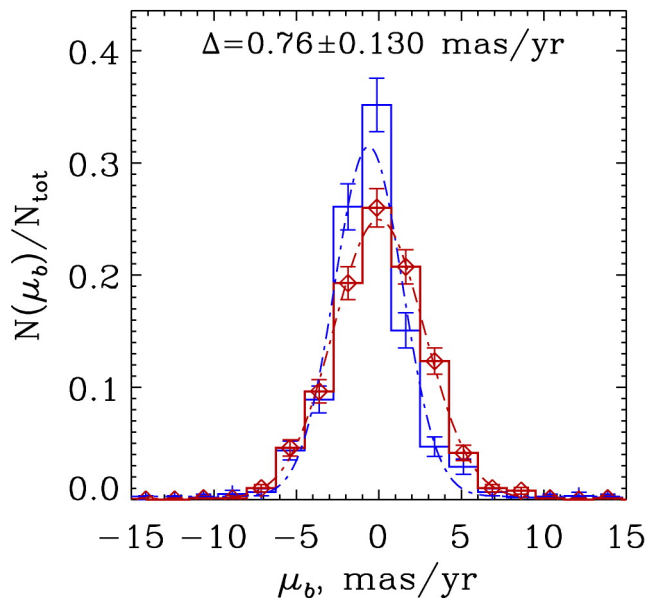


Clarkson+08
SWEEPS field

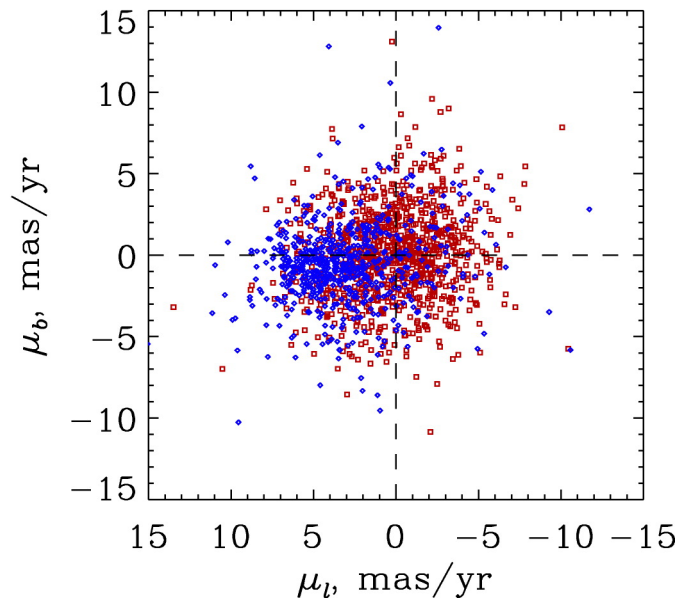
l



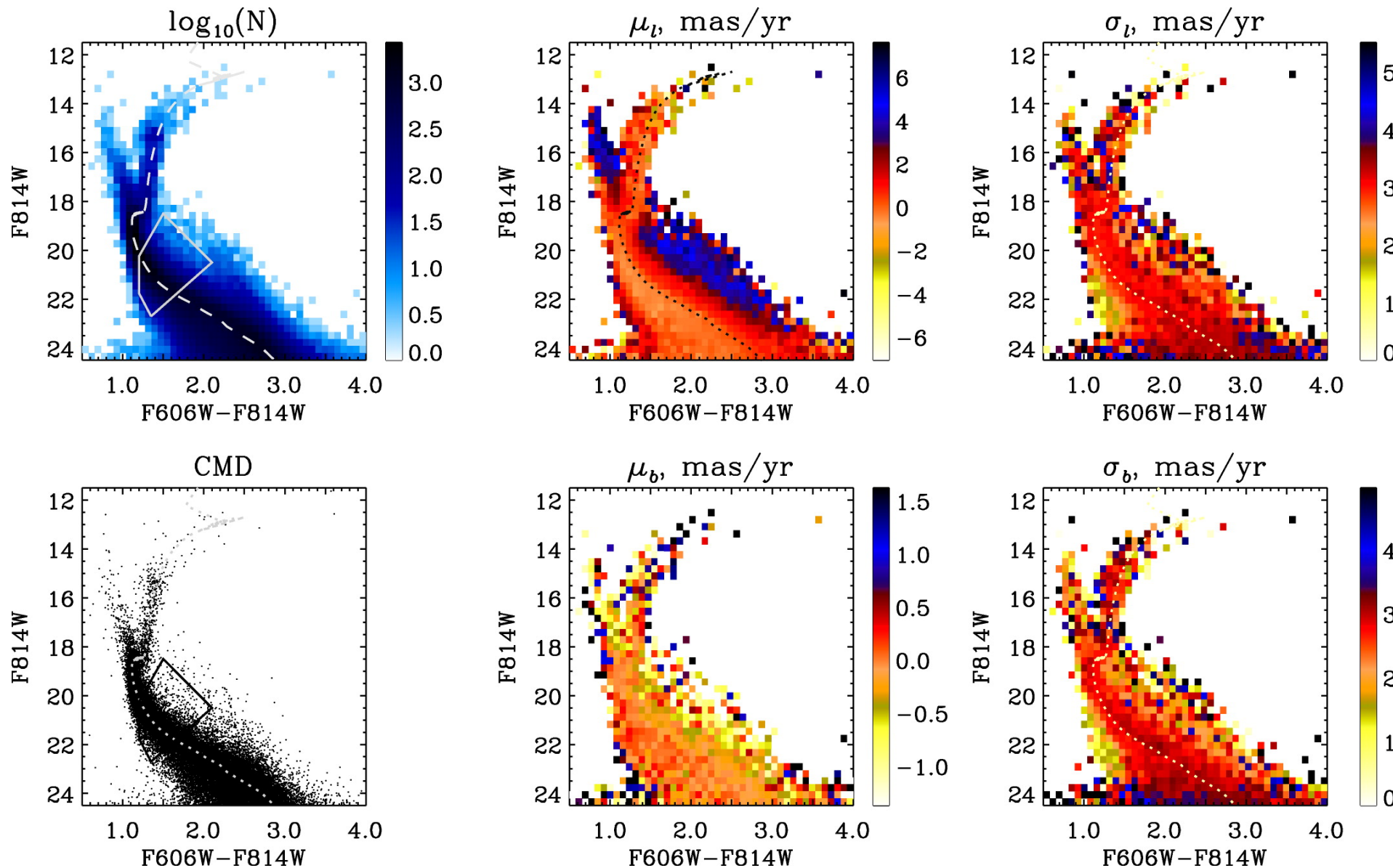
b



Vector Points

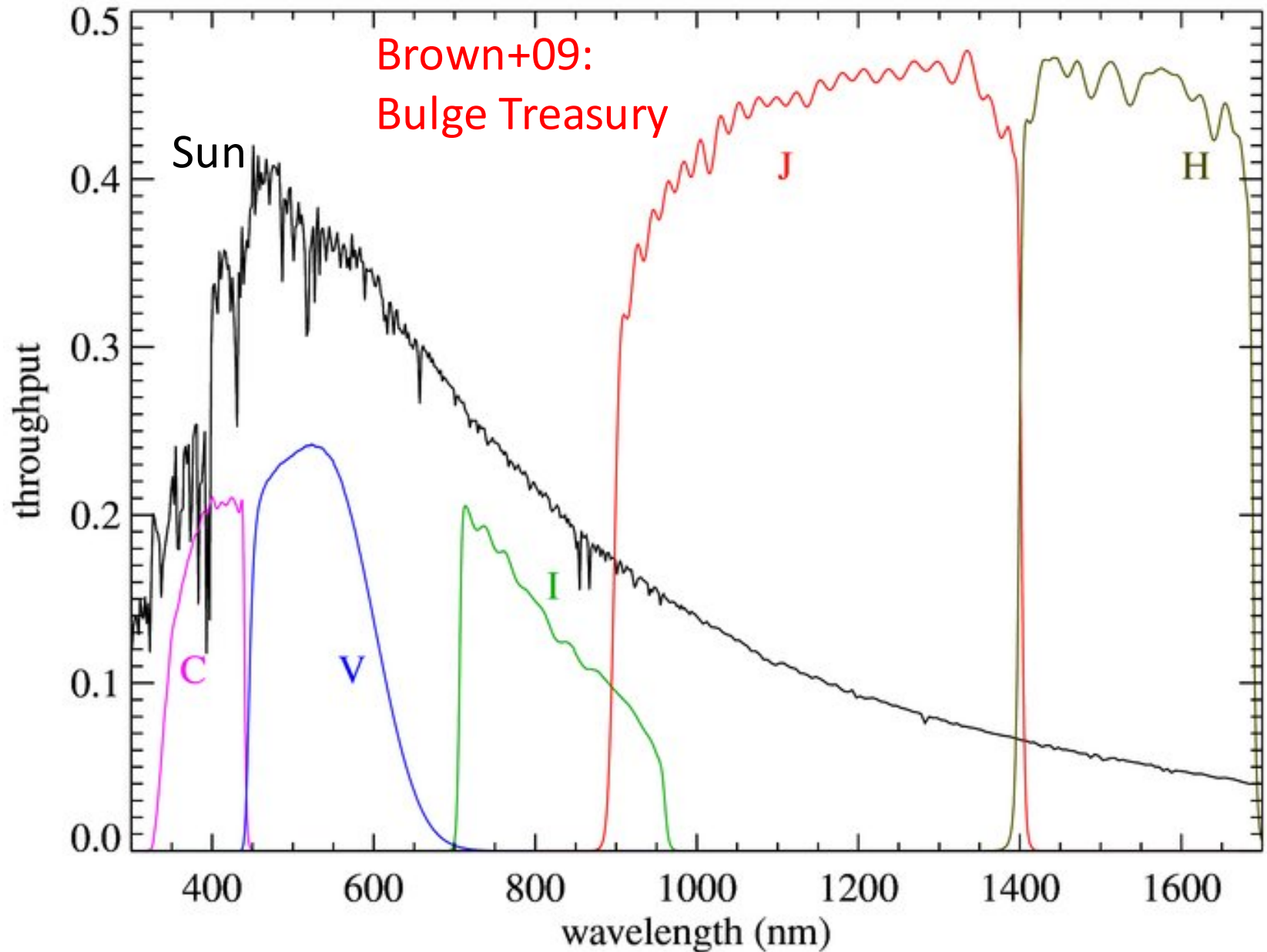


Bulge Stellar Pops With HST: Kinematics

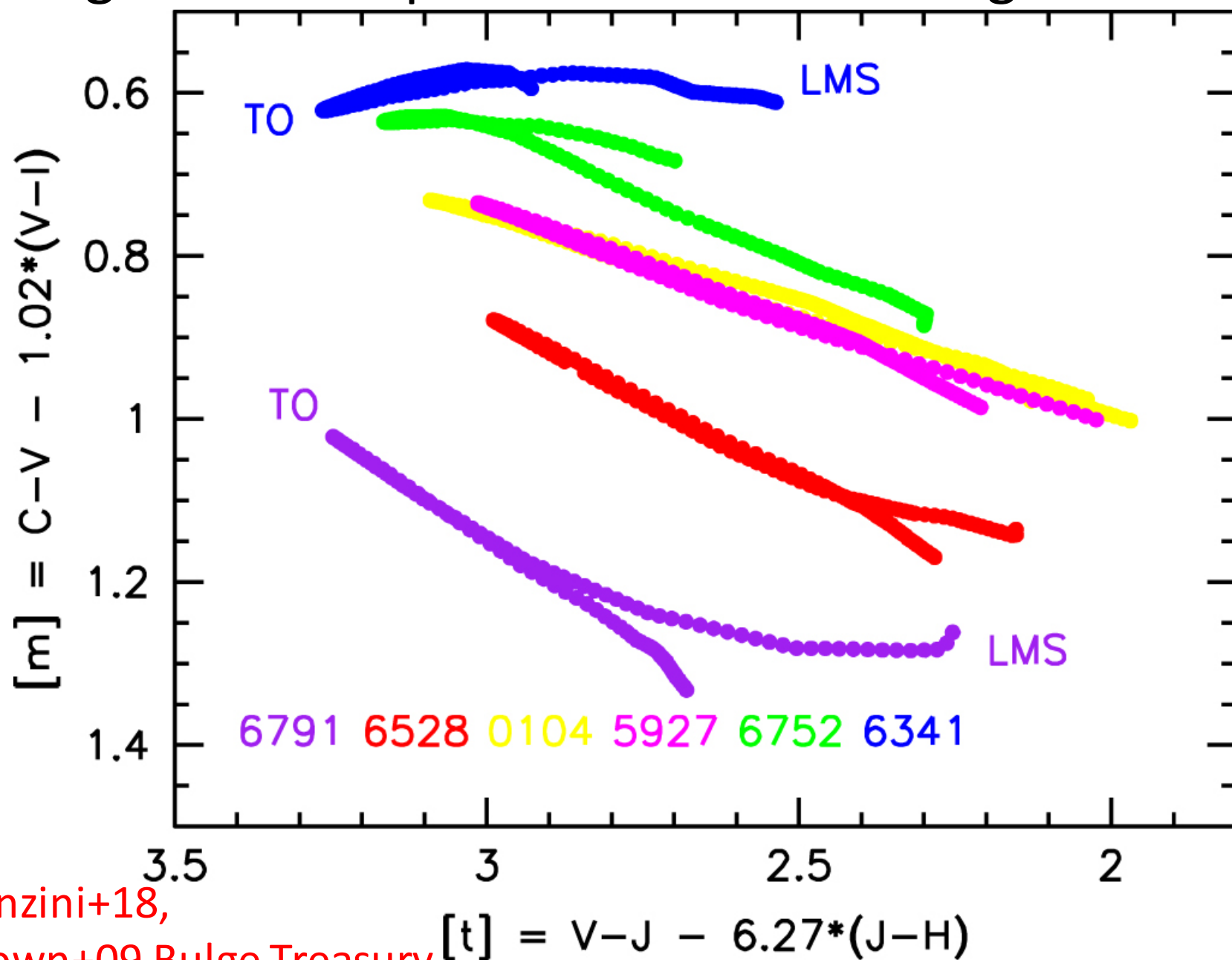


Clarkson+08 SWEEPS field

Bulge Stellar Pops With HST: Reddening-Free Indices

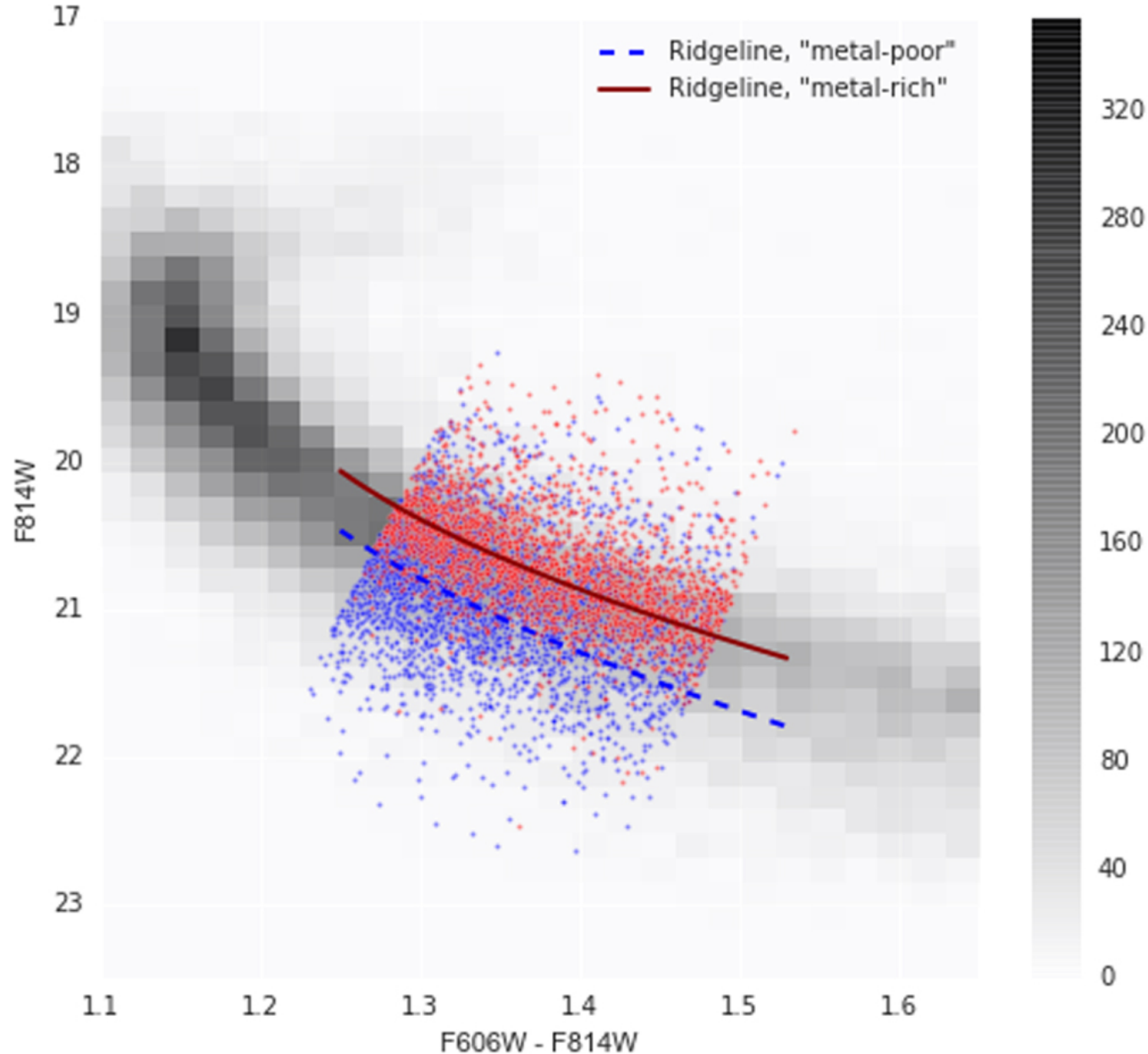


Bulge Stellar Pops With HST: Reddening-Free Indices



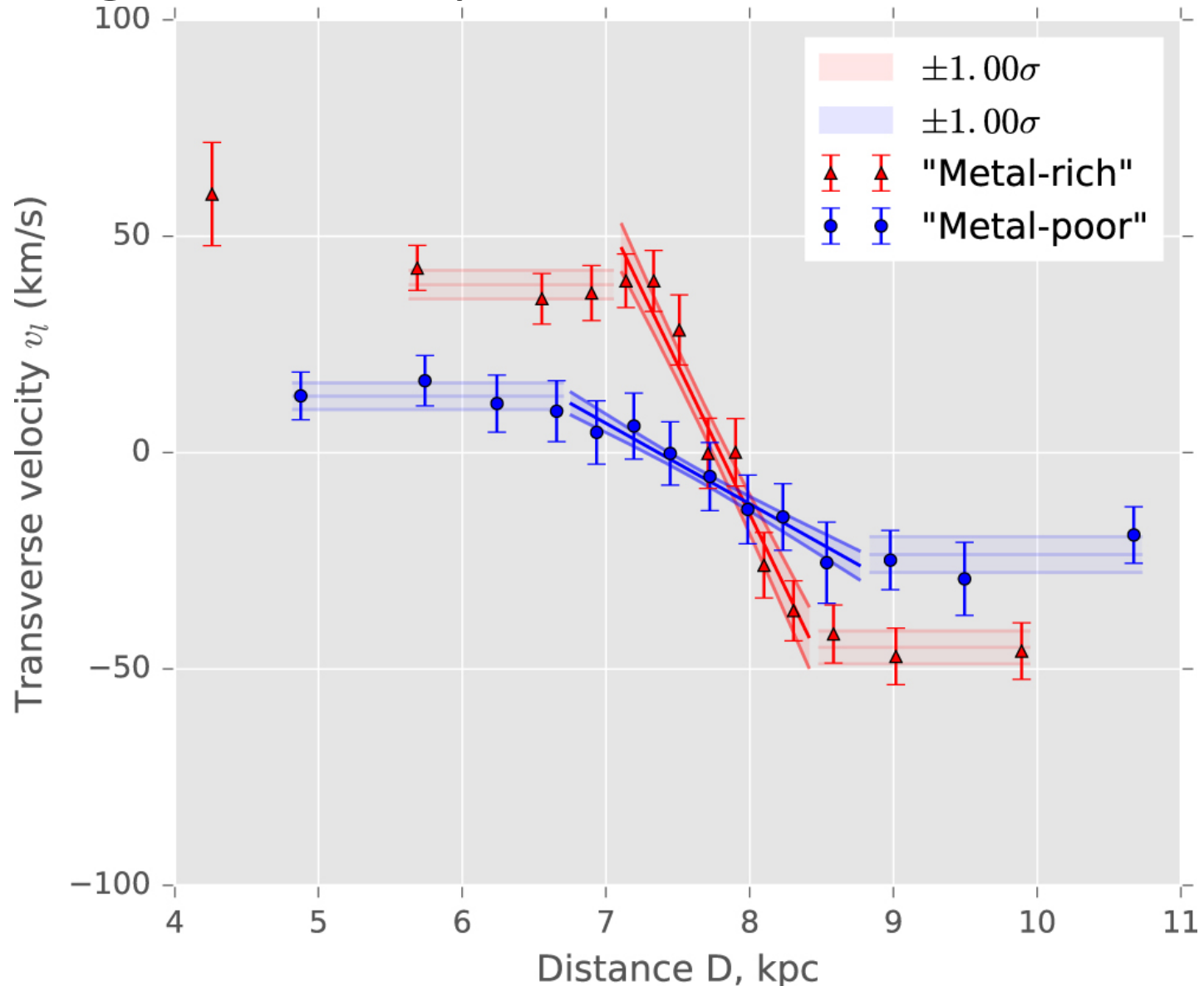
Renzini+18,
Brown+09 Bulge Treasury

Bulge Stellar Pops With HST: Kinematics



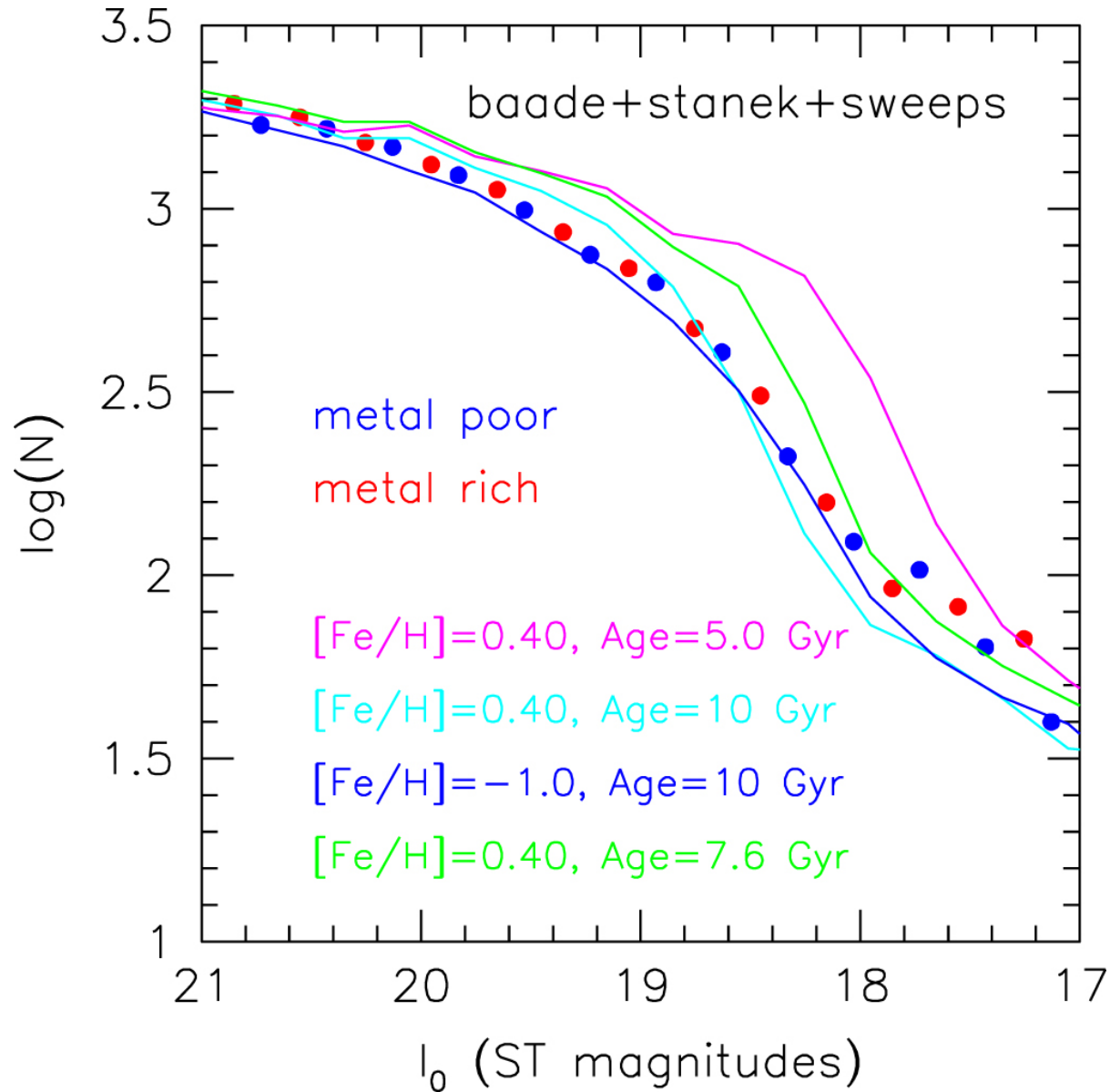
Clarkson+18 SWEEPS+Bulge Treasury

Bulge Stellar Pops With HST: Kinematics



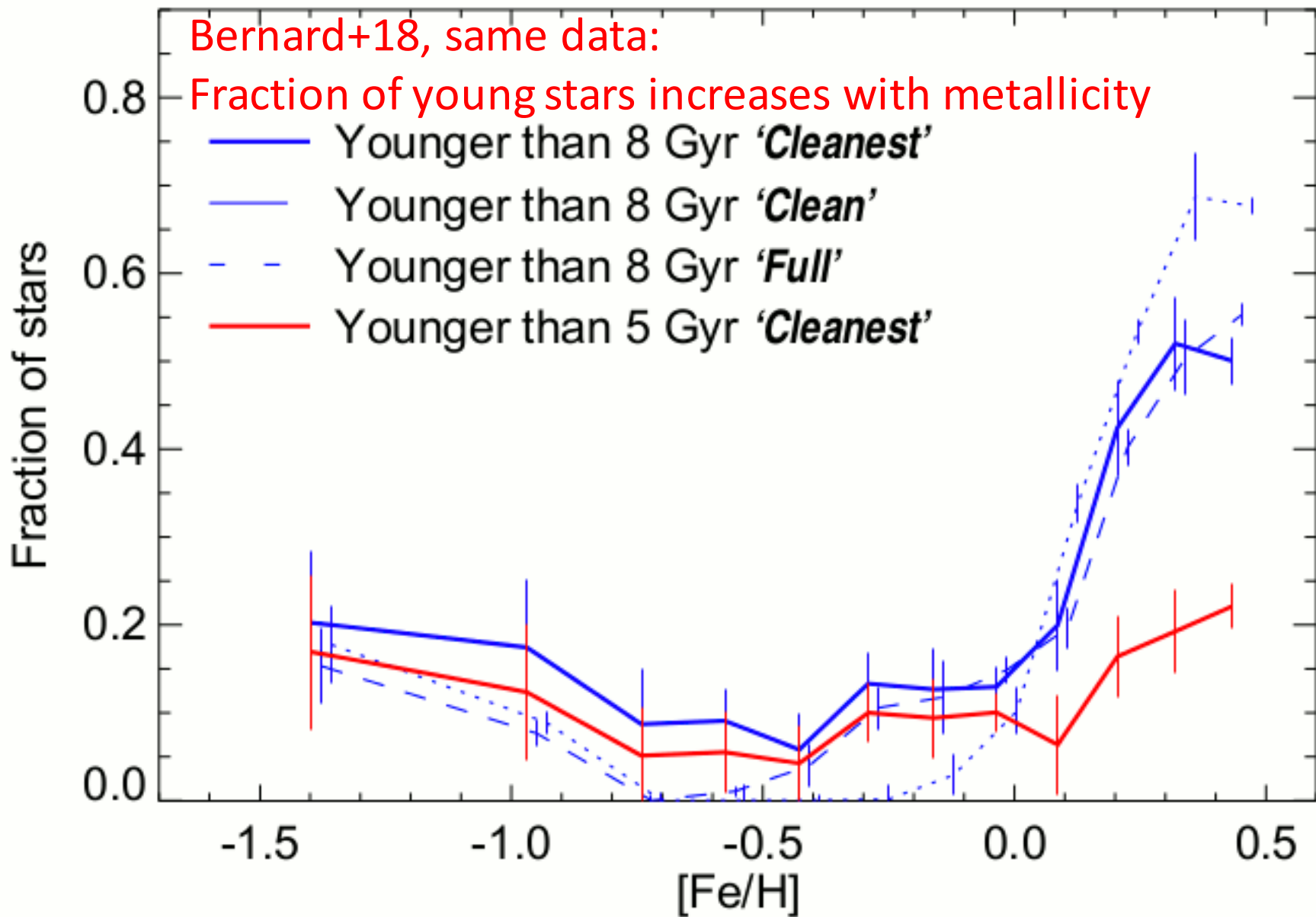
Clarkson+18 SWEEPS+Bulge Treasury

Bulge Stellar Pops With HST: SFH/AMR

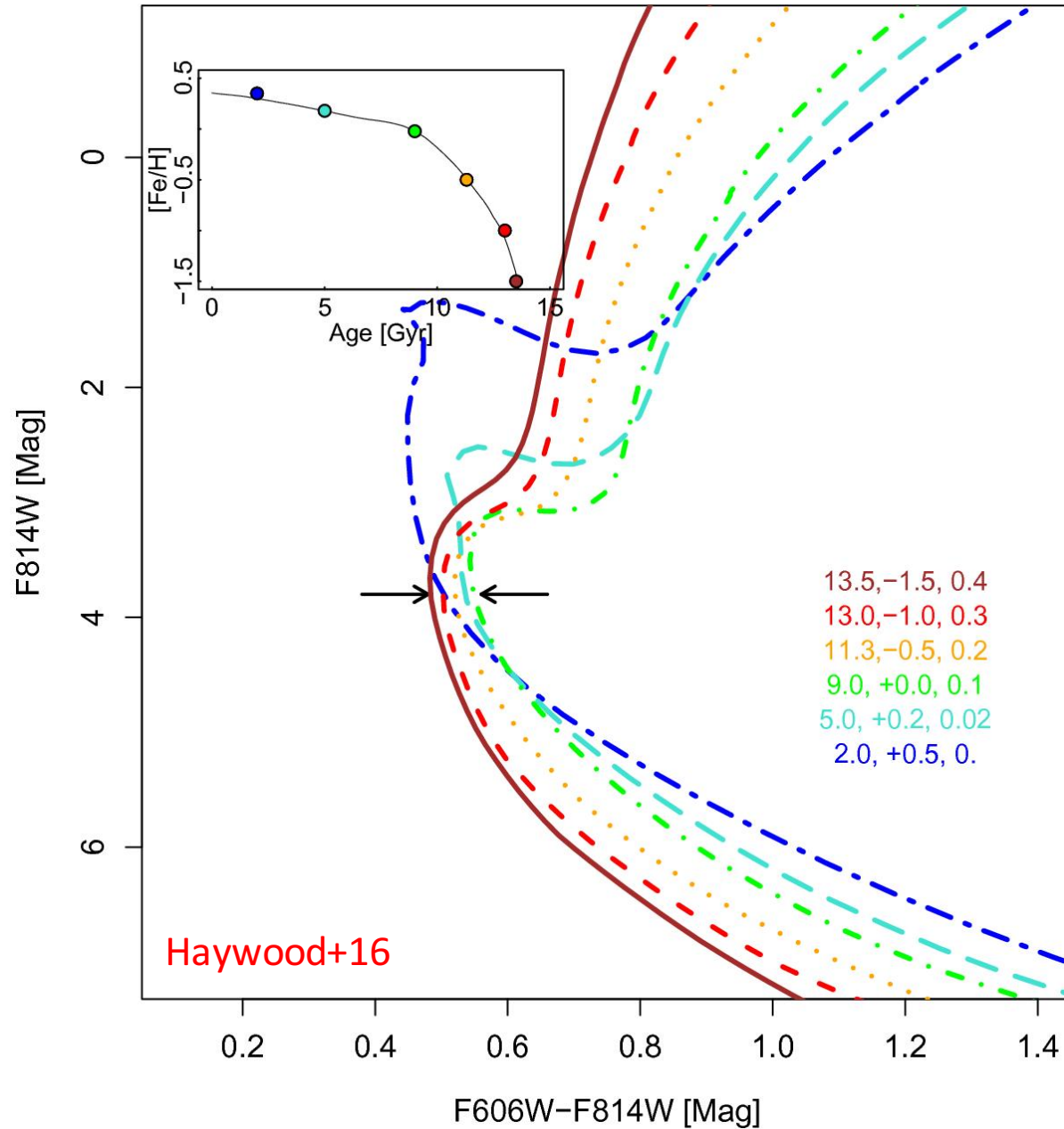


Renzini+18 using Bulge Treasury

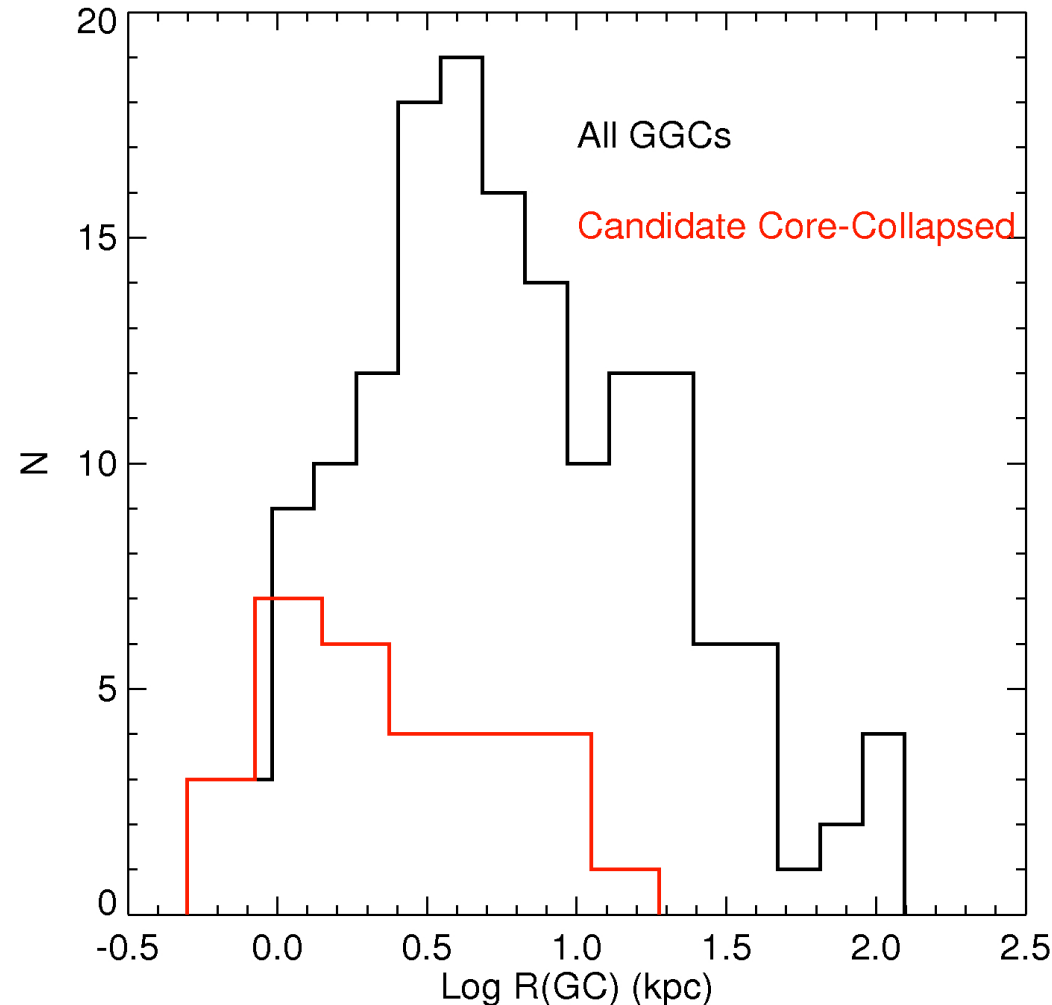
Bulge Stellar Pops With HST: SFH/AMR



Beware assumptions based on MSTO morphology!



Bulge Globular Clusters



Bulge GGC formation/evolution is an open issue.

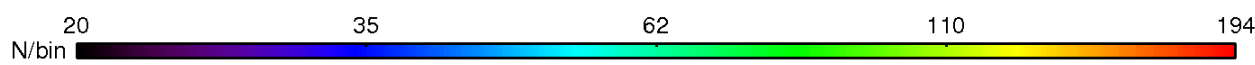
- 24/26 inside 2 kpc have no systematic age measurement!

De Angeli+05, Marin-Franch+09, Dotter+10, VandenBerg+13, O'Malley+17

- Bulge GGCs give us access to unique parts of parameter space!

[X/H], mass, R(GC), concentration

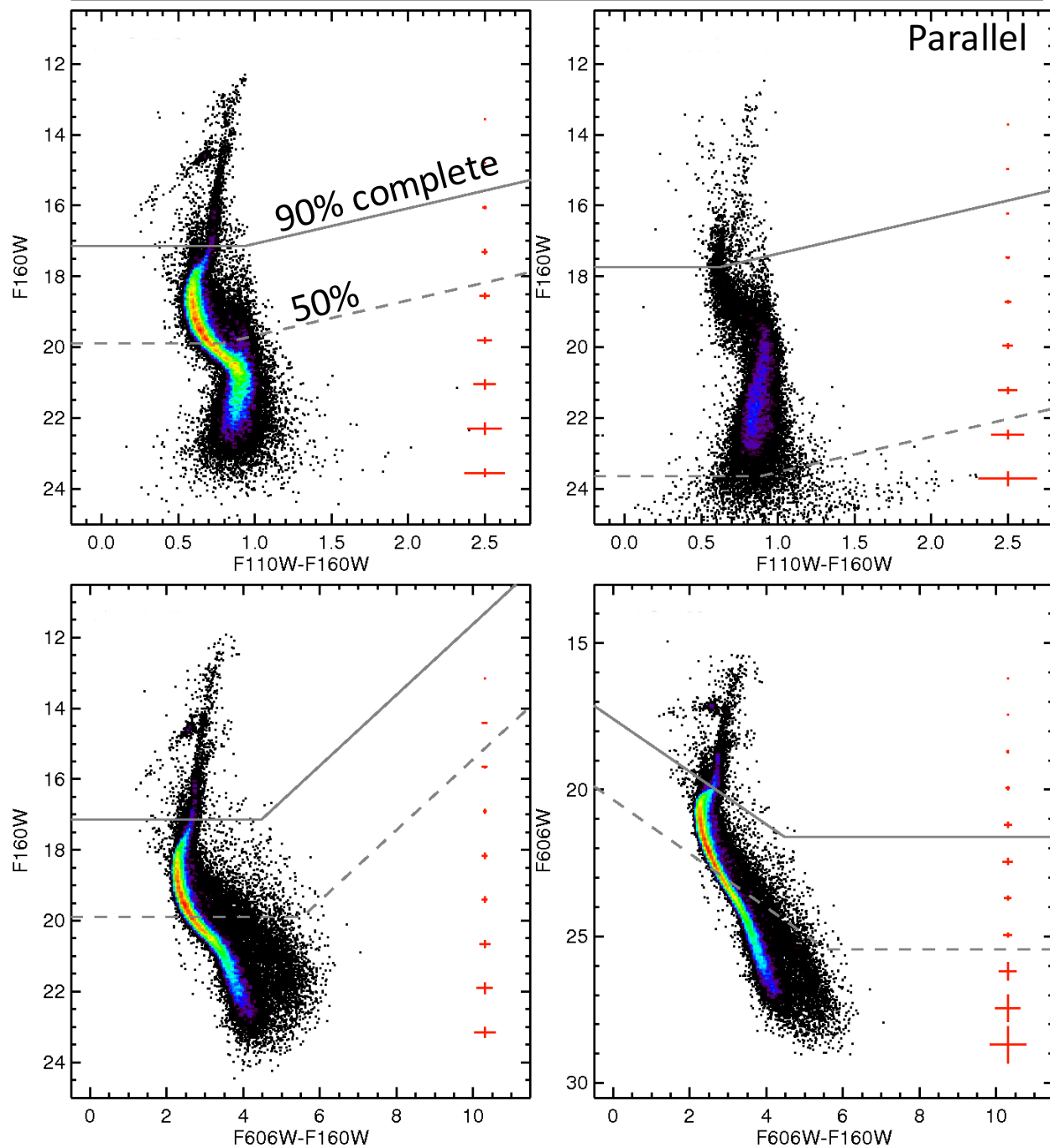
Use the population of GGCs towards the bulge ***as an ensemble*** to study Galactic (bulge,disk..) formation and evolution



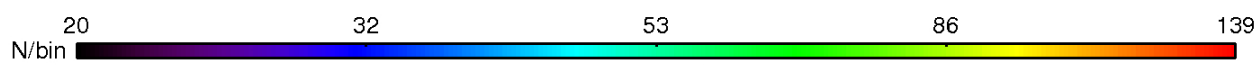
GO-14074

WFC3/IR:
F110W+F160W

ACS/WFC:
F606W



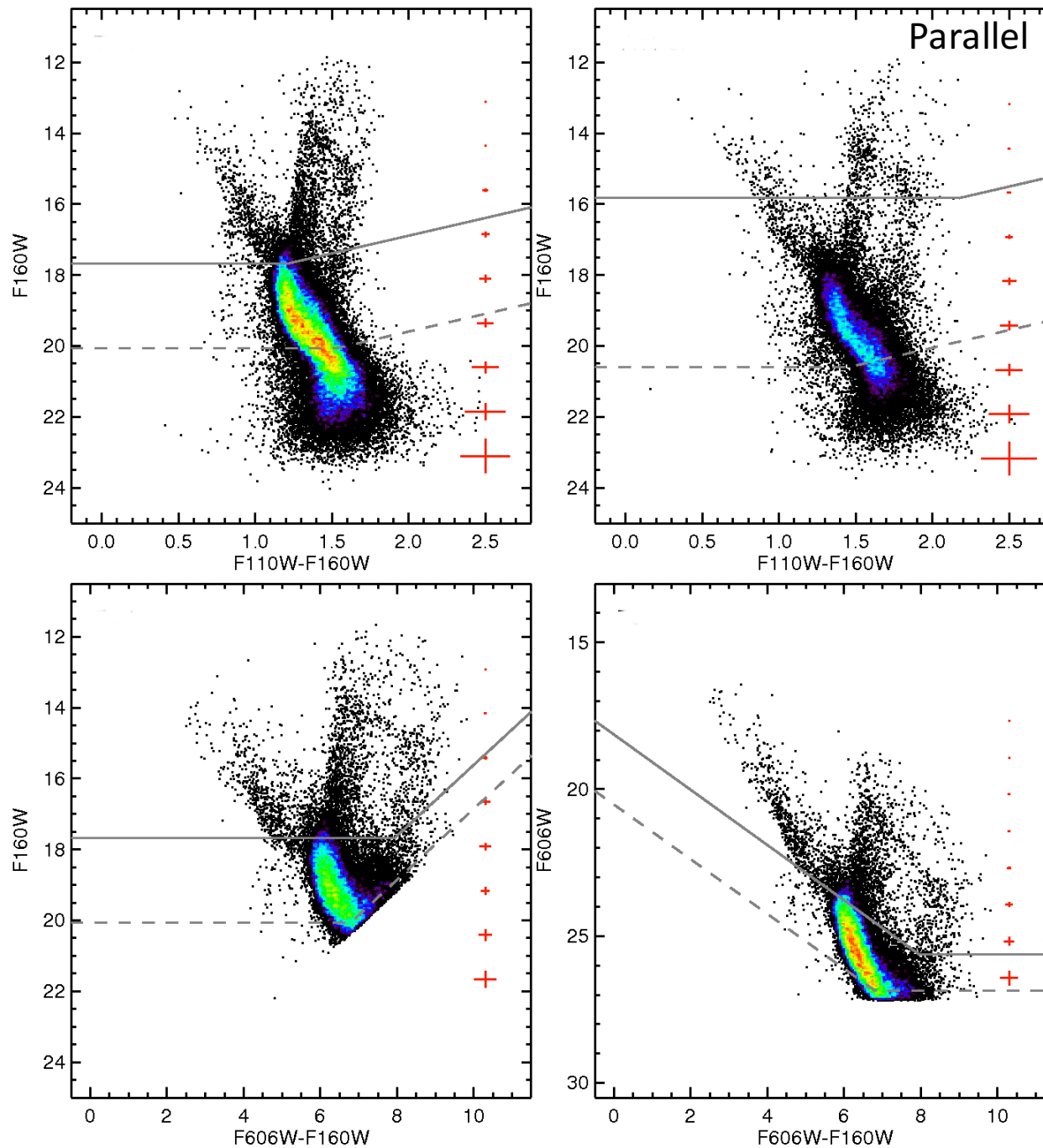
Cohen+18



GO-14074

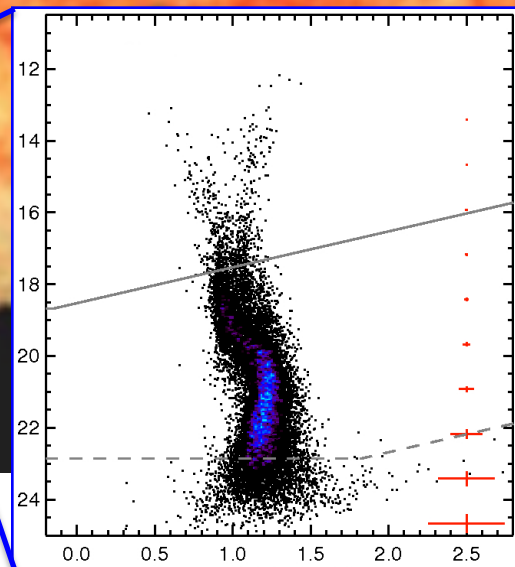
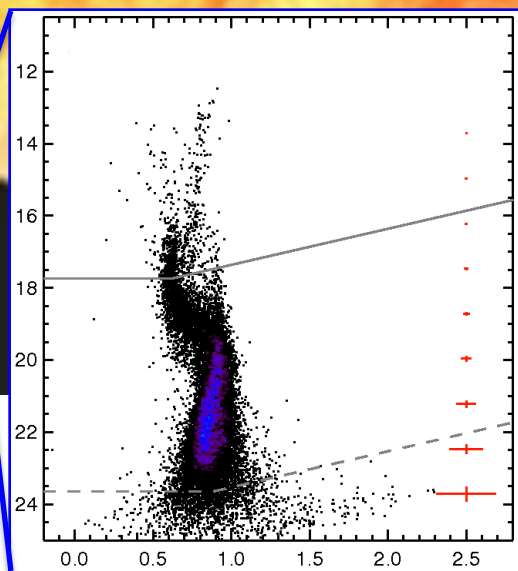
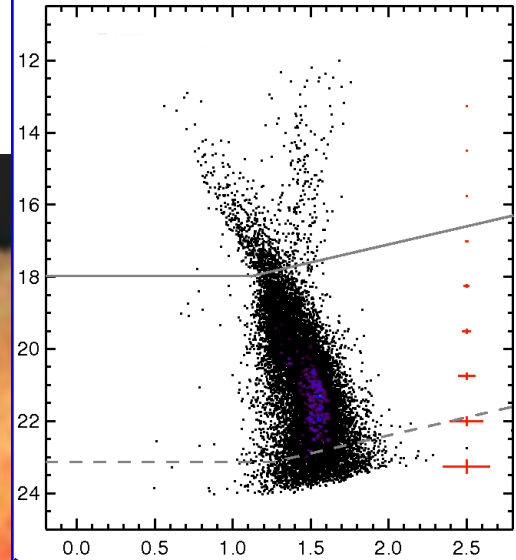
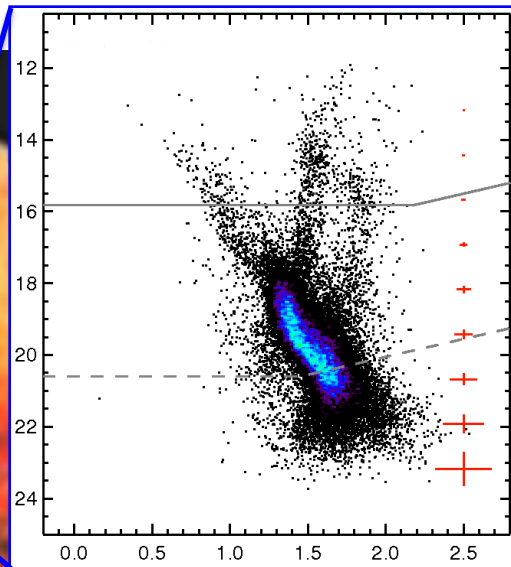
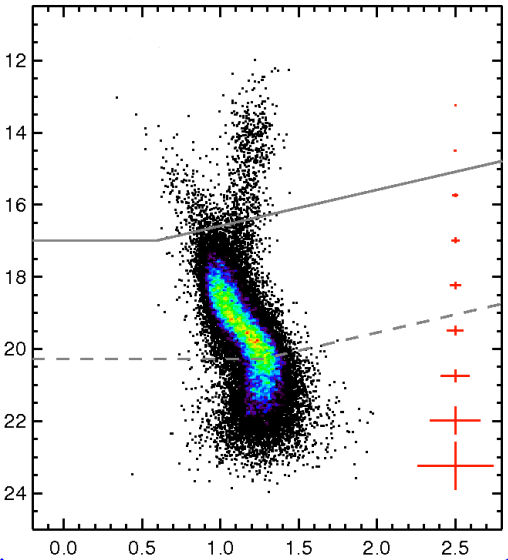
WFC3/IR:
F110W+F160W

ACS/WFC:
F606W



Cohen+18

WFC3/IR: (F110W-F160W),F160W



B
L

GO-14074
Cohen+18

decaps.legacysurvey.org, Schlafly+17

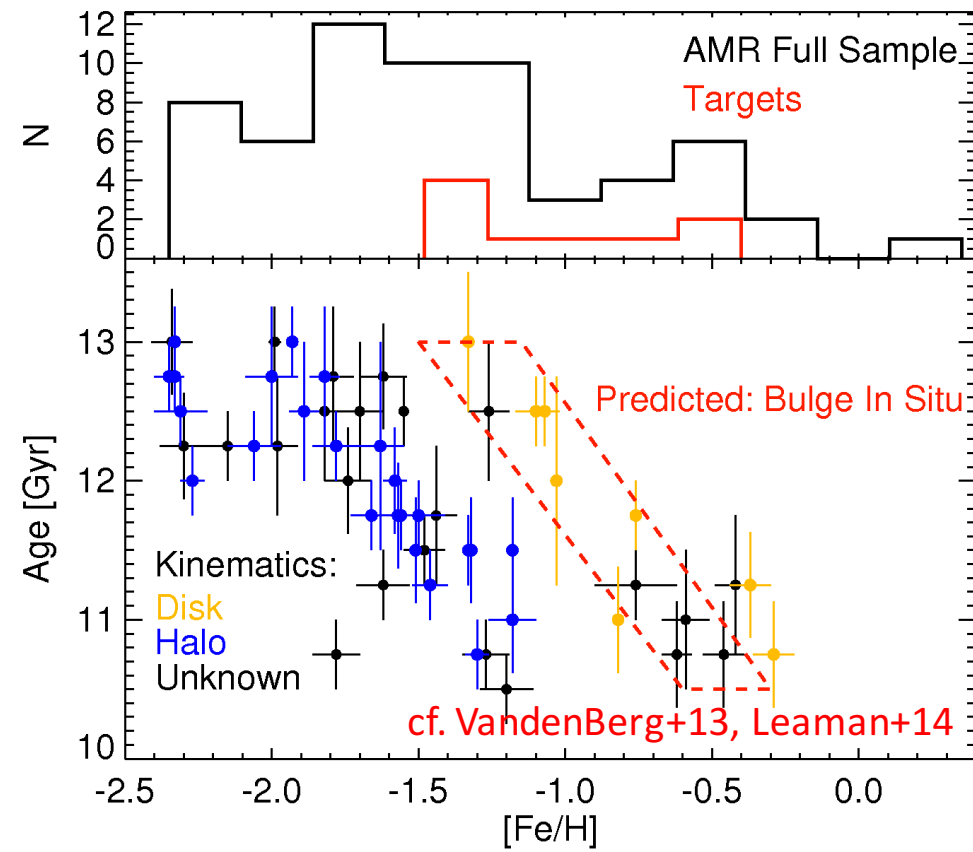
Bulge GGCs with HST: Cleaned CMDs

Gaia PMs not good enough to identify **unevolved** pops

Individual cases: NGC 6528 (LaGioia+14), NGC 6544 (Cohen+14),
NGC 6522, 6626 (Kerber+18),

More on the way using HST + Gemini AO (Kerber, Saracino talks etc)

But: Self-consistent analysis needed to compare to other GGCs!

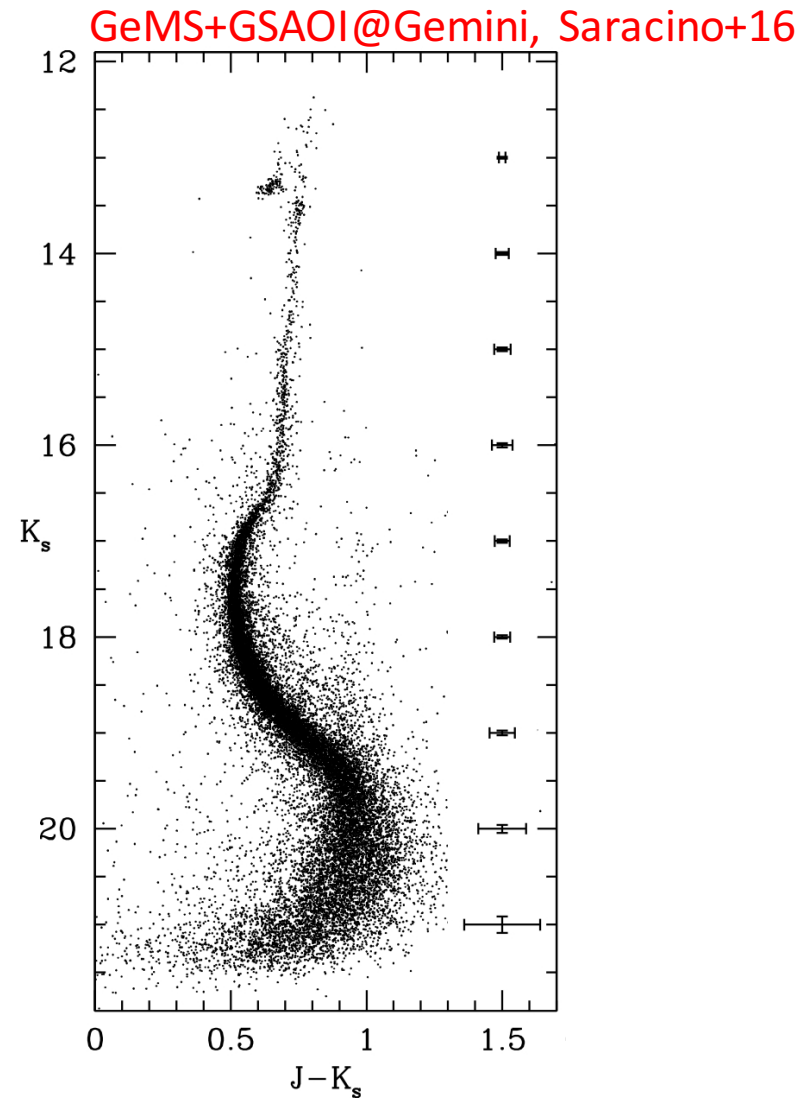
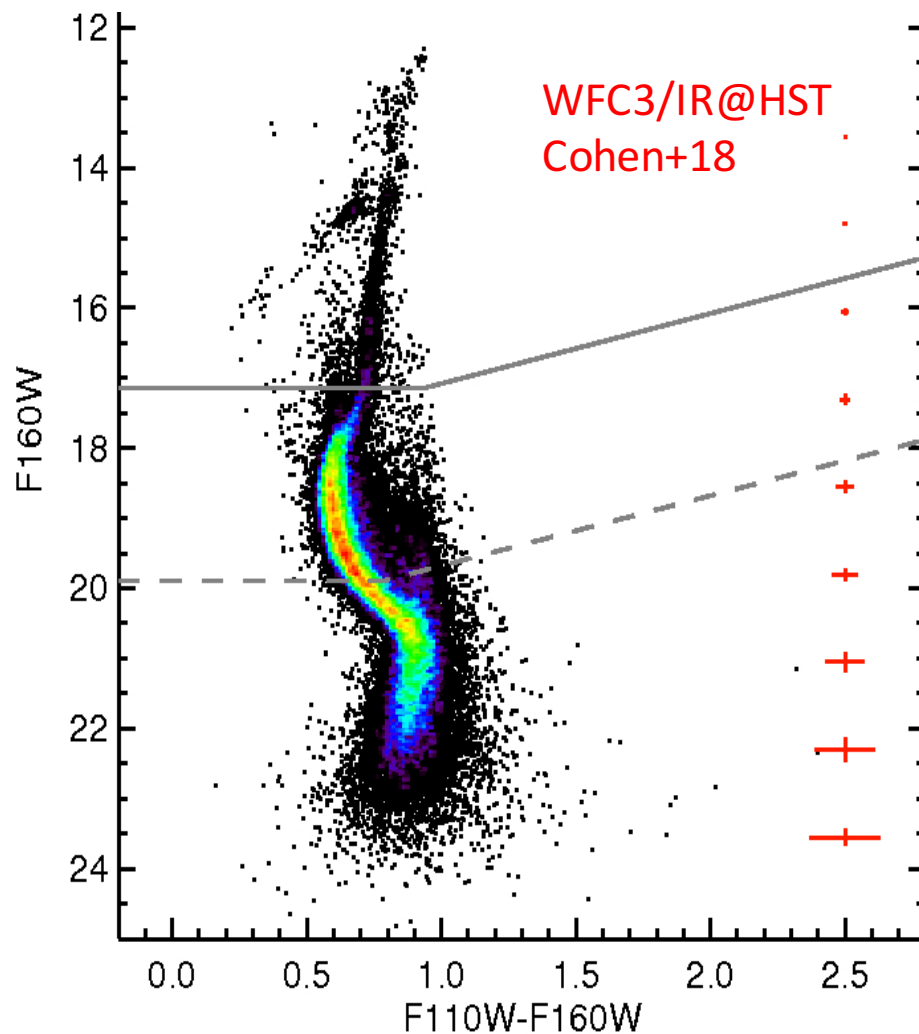


Coming in 2019:

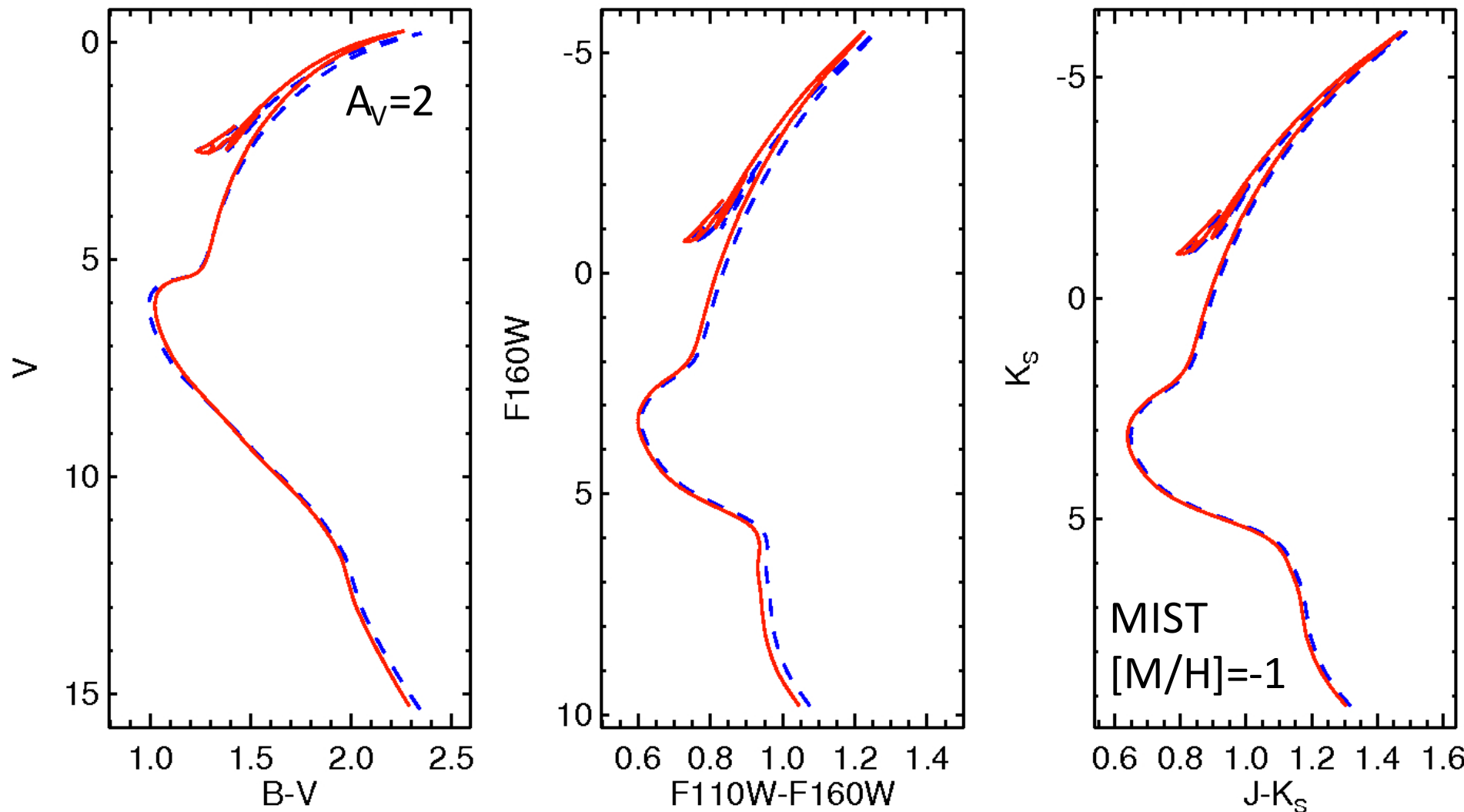
Direct, empirical age comparison:
Metal-intermediate BHB GGCs

HST vs Ground-Based MCAO

~1.5 hours of telescope time **(including overheads!)**



GC Parameters and Extinction

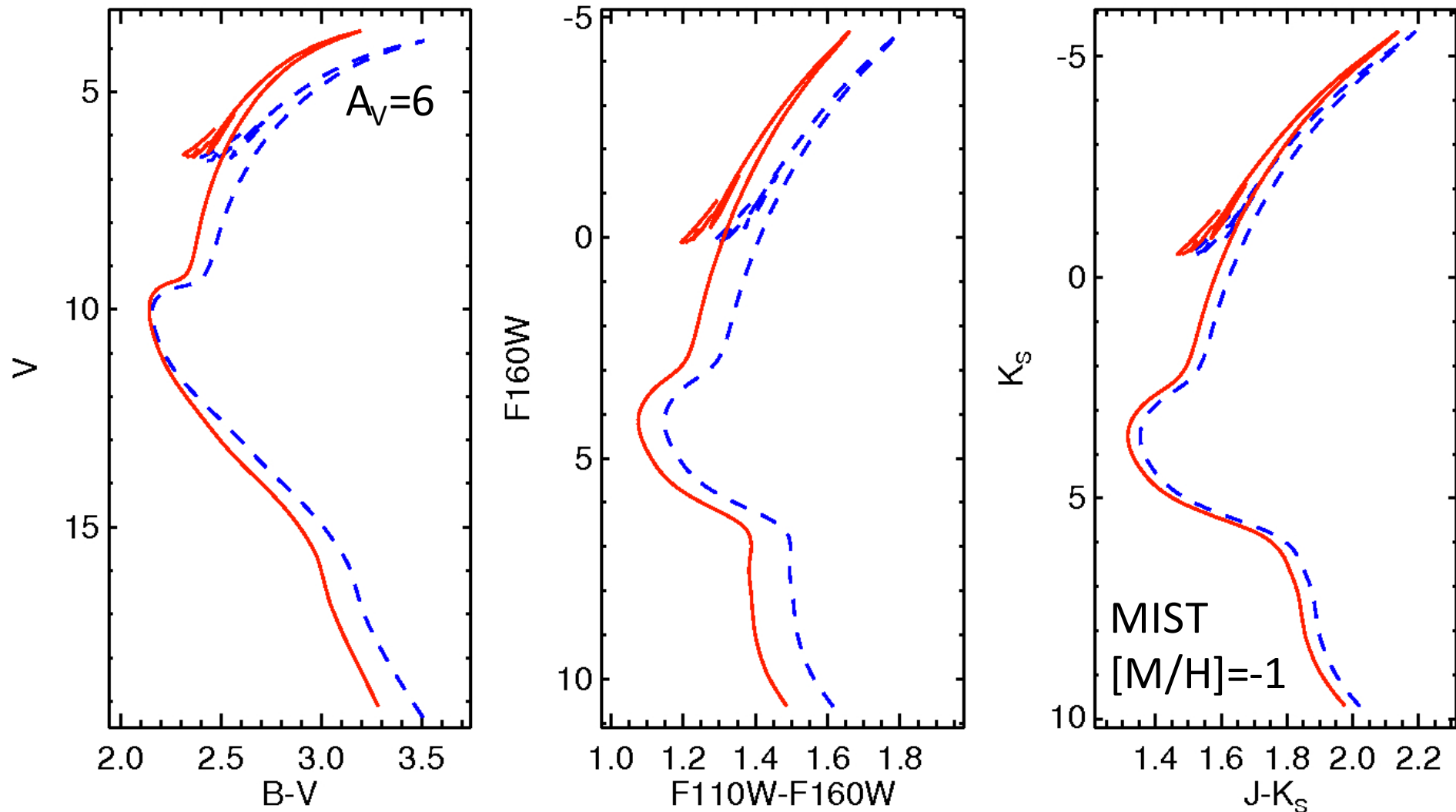


Reddened source spectrum

vs

shifted $A_V=0$ isochrone

GC Parameters and Extinction



Reddened source spectrum

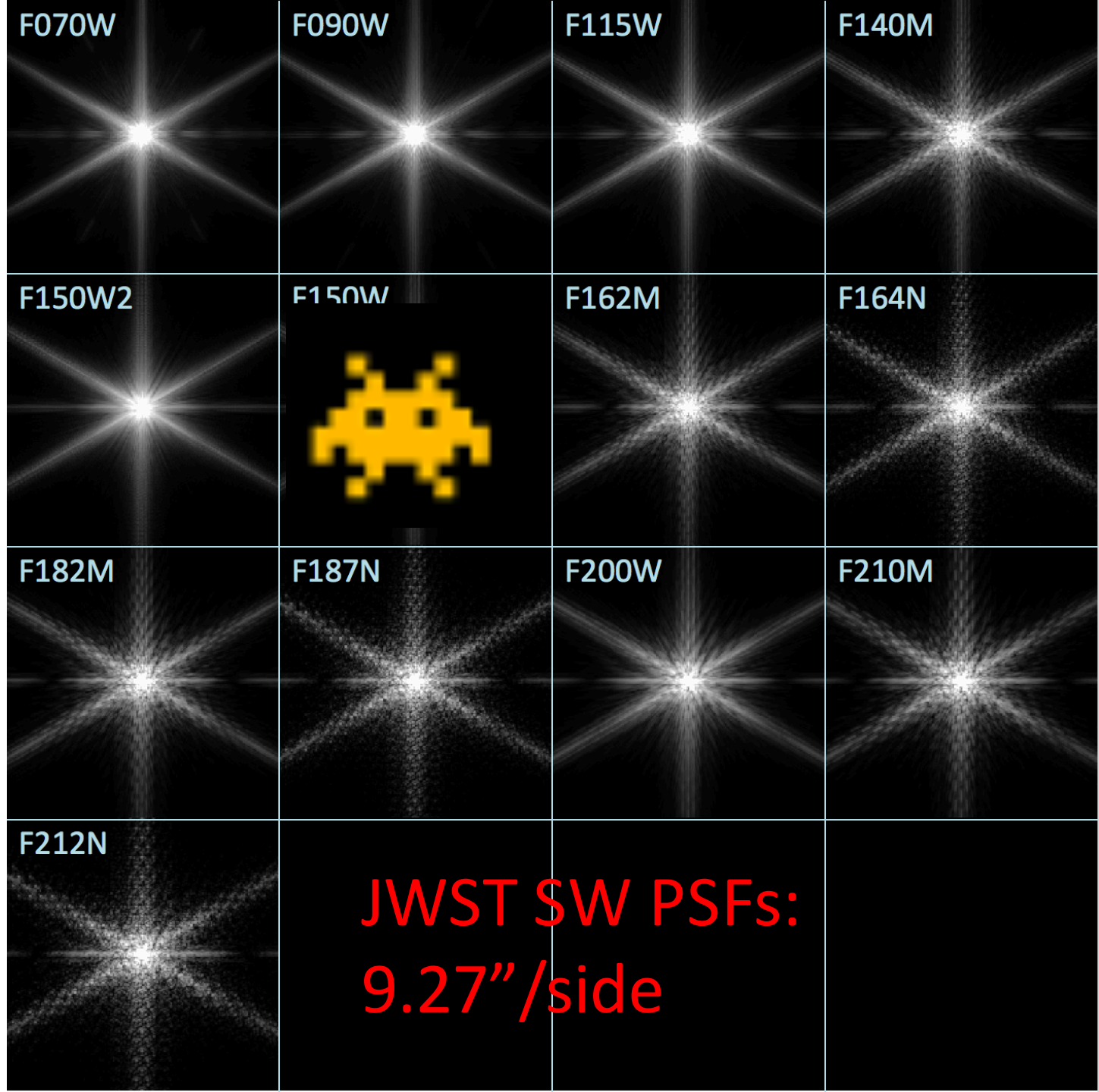
vs

shifted $A_V=0$ isochrone

The Future: Synergy With Other Facilities

- Ground-based: Many bands: SED fitting, reddening law, etc
 - Lots already there: DECam, VVV(X), OGLE etc.
 - Lots on the way: LSST, ELT, 4MOST, MOONS, ...
- Space-based: Long-term PSF stability, astrometric precision
 - Gaia DR2+: Optical, field crowding limited in bulge
 - JWST, WFIRST: Near- to mid-IR





Summary

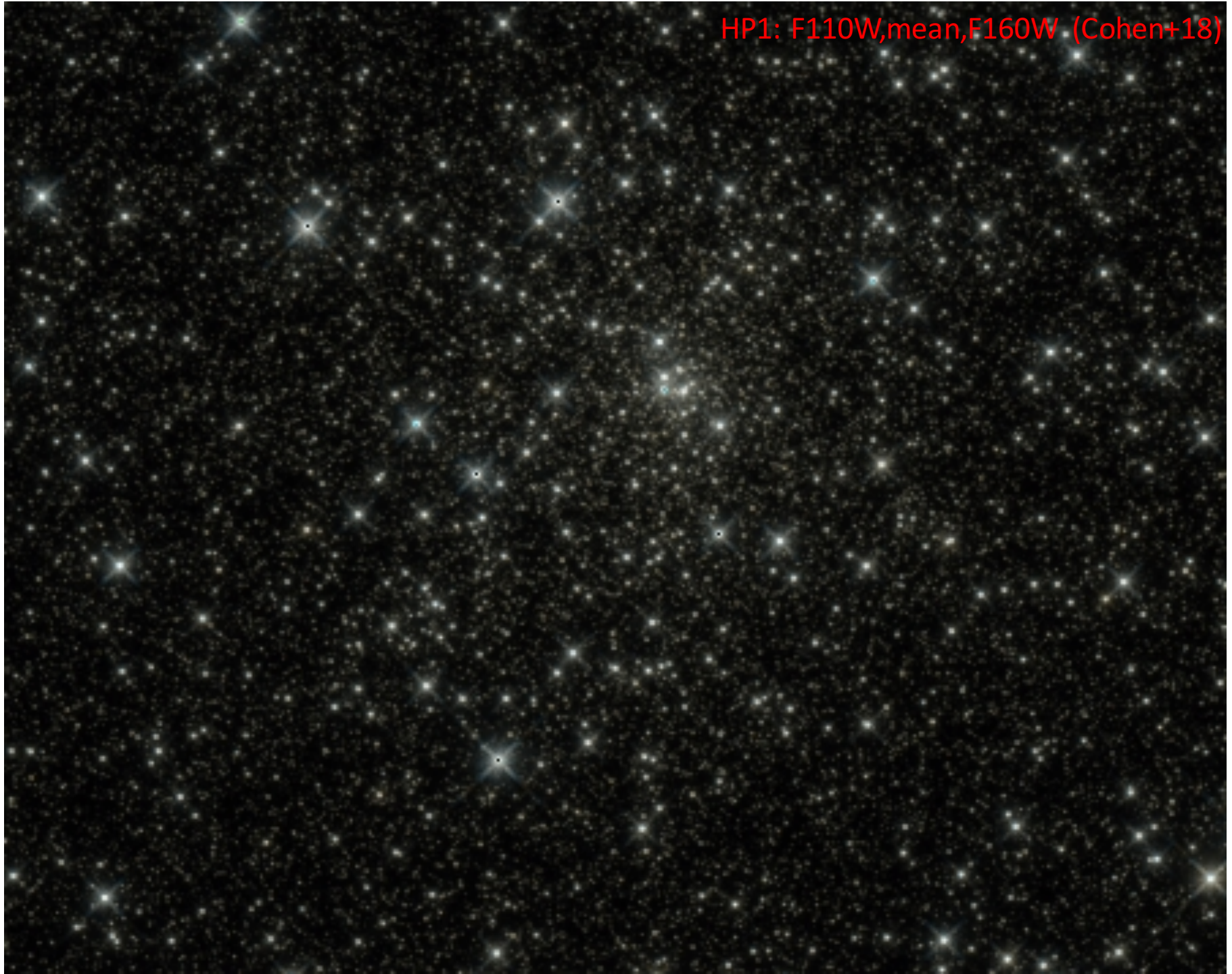
- Most of what we know about the bulge main sequence (and WDs) is due to HST observations:

Combination of photometric AND astrometric precision

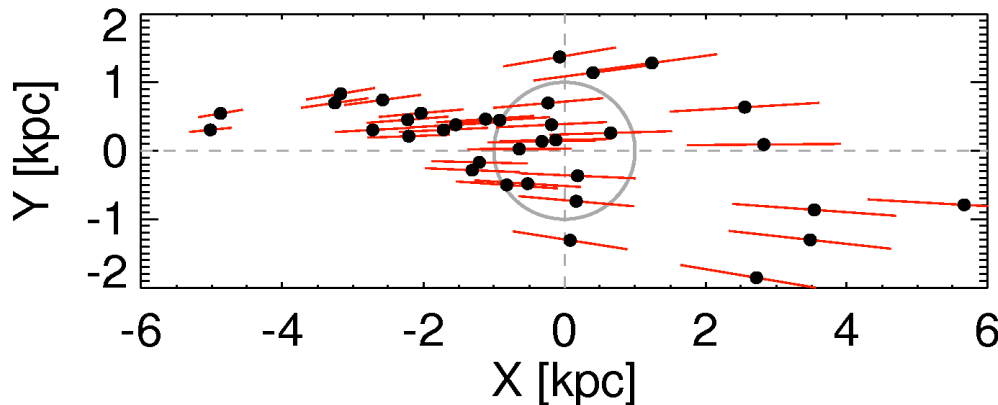
BUT: These are mostly from optical imaging, so only sample low reddening windows

- RGB/HB/RC: Already lots of complimentary data (imaging, spectra) at other wavelengths, much more on the way
- Also coming soon: Astrometric precision of HST + Deep IR imaging

HP1: F110W,mean,F160W (Cohen+18)



Distances, Reddening and the IR



“Standard” $R(V)=3.1$: (Cardelli+89)

IR: $A(\lambda) \sim \lambda^{-\alpha}$, $\alpha=1.61$

$A(K)/E(J-K) \sim 0.687$

Meanwhile, towards the bulge:

Two-parameter curves? (Nataf+12)

Single parameter? (Schlafly+16)

IR: $A(K)/E(J-K) \sim 0.53$ (Nishiyama+06)

VVV Inner Bulge: $A(K)/E(J-K) < 0.40$

(Alonso Garcia+14,17)

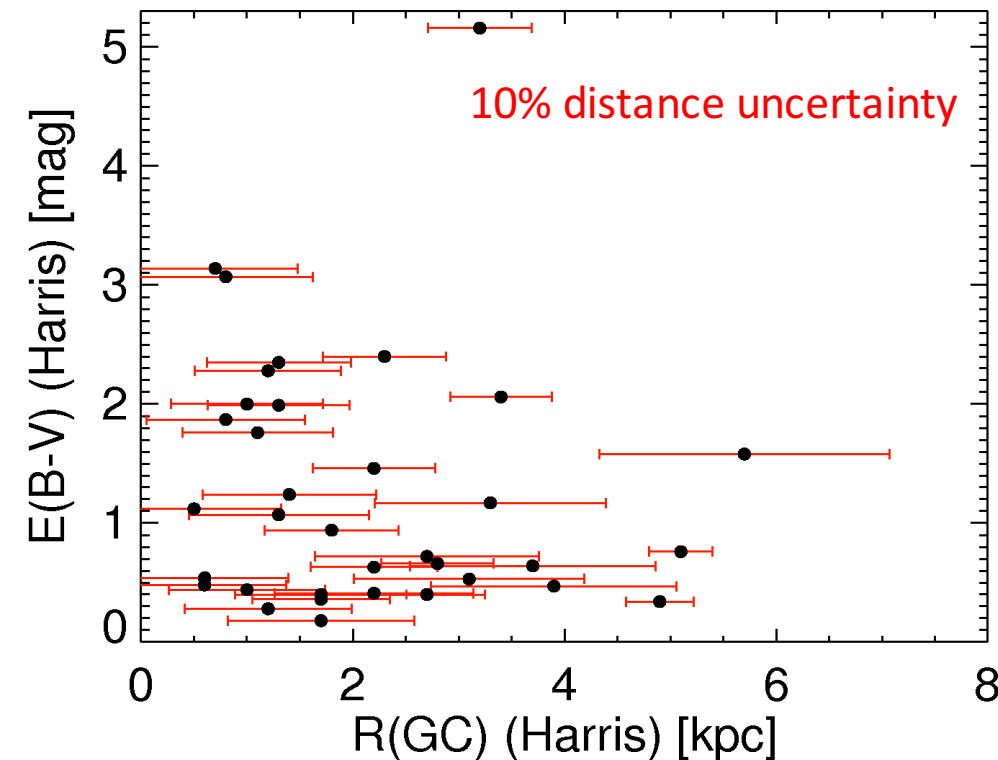
For example of $E(B-V)=1$, $d=8\text{kpc}$:

$\Delta R(V)=0.6$: 25% error in distance!

$A(K)/E(J-K) \sim 0.40$: <8% error

Extinction depends on many things:

- Extinction curve (family)
- Stellar parameters (= source SED)
- Total extinction



WFIRST: $0.11''/\text{pix}$, 2.81 sq. degrees

WFIRST

- Disk/bulge proper motions,
- BG quasar ref frame
- Faint satellites
- Substructure
- (Sub)stellar pops in SFRs

JWST

Hubble

