The WFC3 Galactic Bulge Treasury Program

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Outline

- Historical perspective
- Overview of program
- Images, photometry, astrometry
- Preliminary ages & metallicities in the bulge populations
- Metallicities of exoplanet hosts
- Implications

Bulge Formation - Historical Paradigm

Protogalactic collapse

Galaxy mergers, RAM-pressure stripping of gas

fast

internal

common processes
star formation, gas recycling,
metal enrichment,
energy feedback via SNe,
etc.

external

slow

Internal secular evolution

driven by bar instabilities, dark matter halos, bars and oval distortions, spiral structure, nuclear black holes, galactic winds & fountains, etc.

Environmental secular evolution

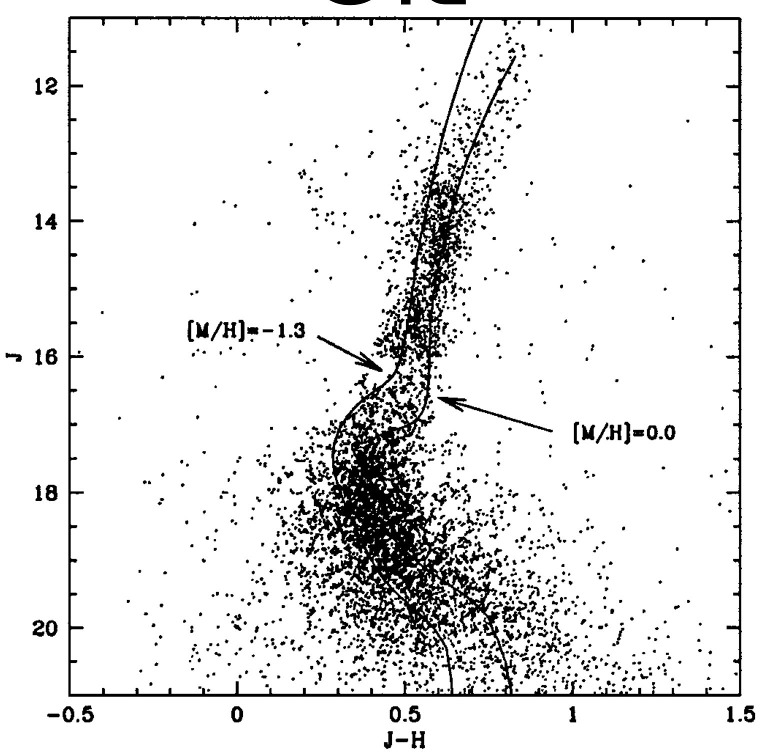
driven by prolonged gas infall, minor mergers, galaxy harassment, etc.

Kormendy & Kennicutt (2004)

Conflicting evidence

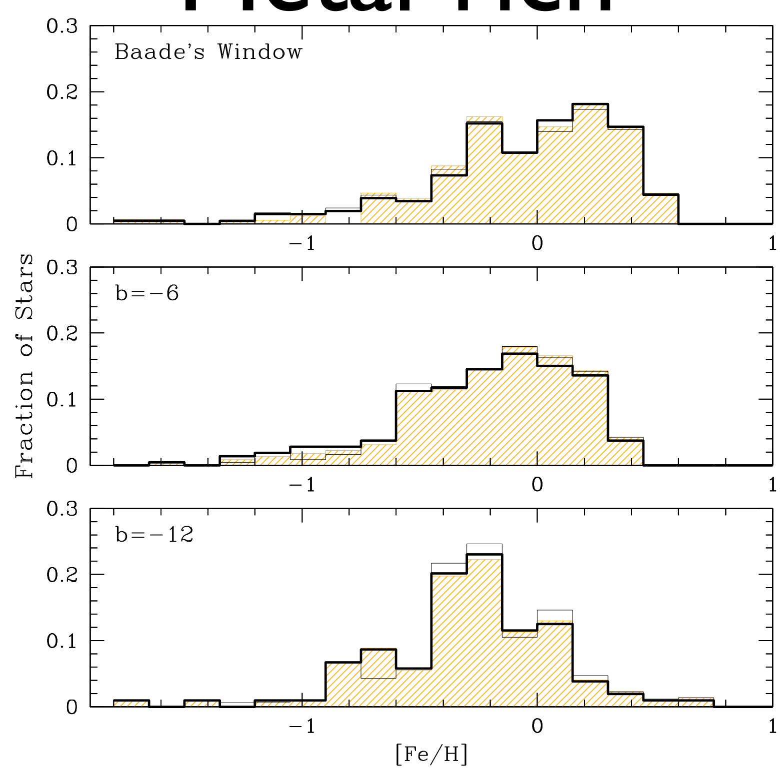
- Bulge morphology implies prolonged evolution from secular instabilities

Old



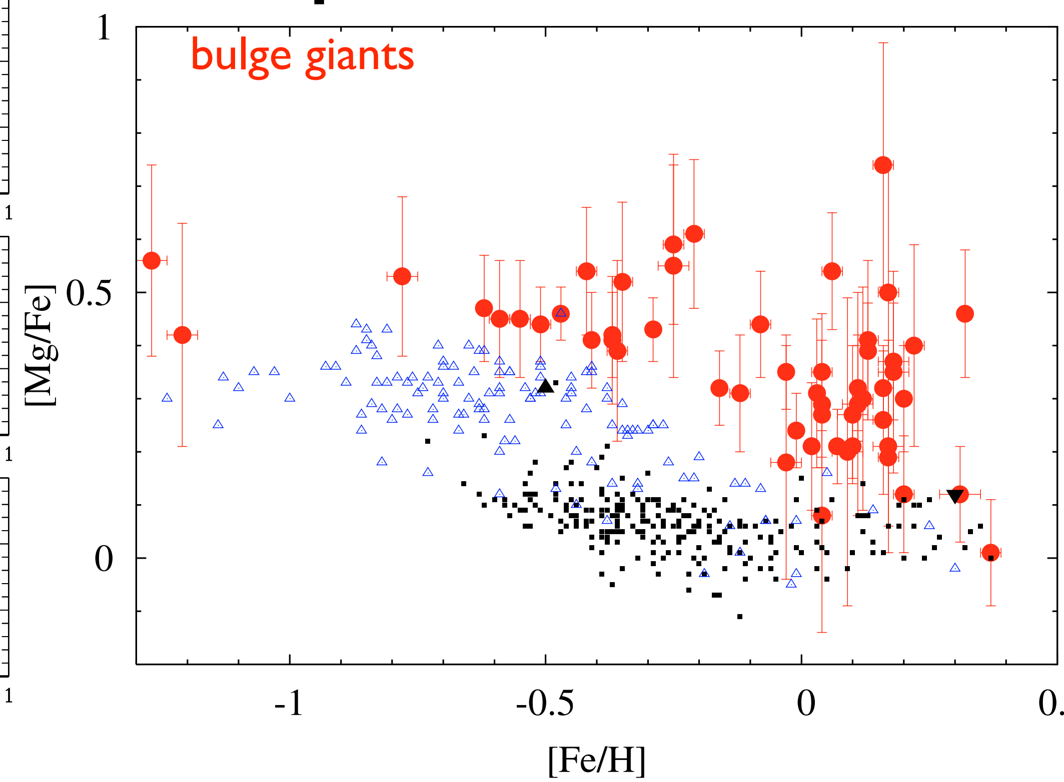
Zoccali et al. (2003)

Metal-rich



Zoccali et al. (2008)

Alpha-enhanced

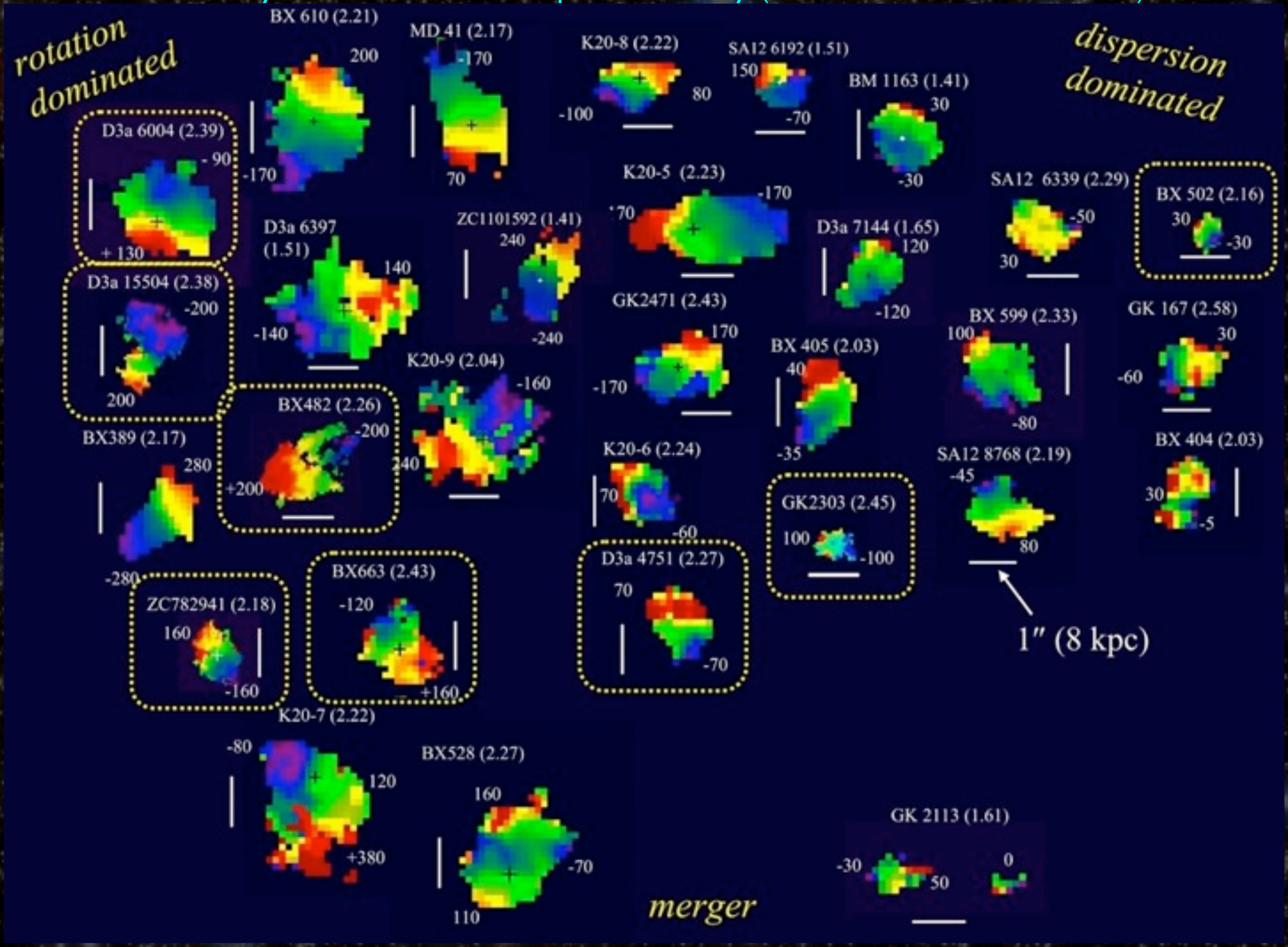


Lecureur et al. (2007)

- Bulge populations imply rapid formation (see also Ferreras et al. 2003)

New paradigm emerging

Velocity fields from SINS H-alpha IFU survey (Forster Schreiber et al. 2009)



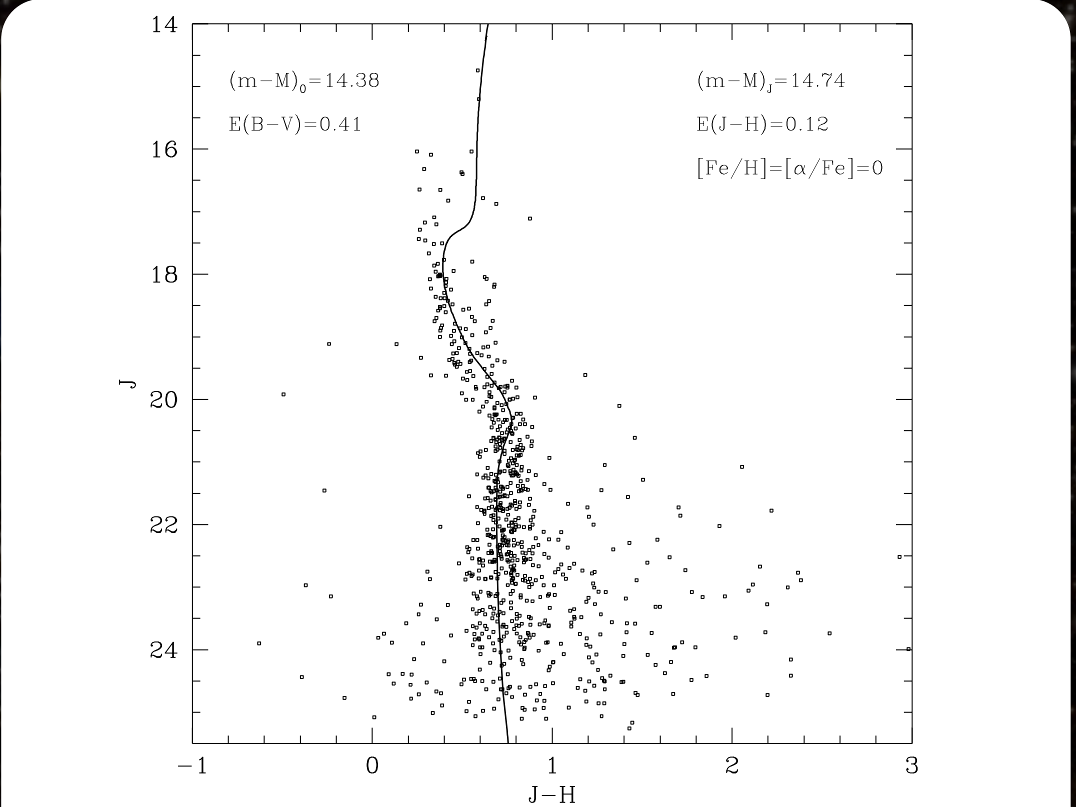
- IFU observations of z~2 galaxies reveal large, rotating, gas-rich, disks (Genzel et al. 2008; Forster Schreiber et al. 2009)
- Gas-rich & clumpy disks prone to instabilities that can drive bulge formation faster & earlier than traditionally associated with secular processes (Immeli et al. 2004; Elmegreen et al. 2009)

Program Goals

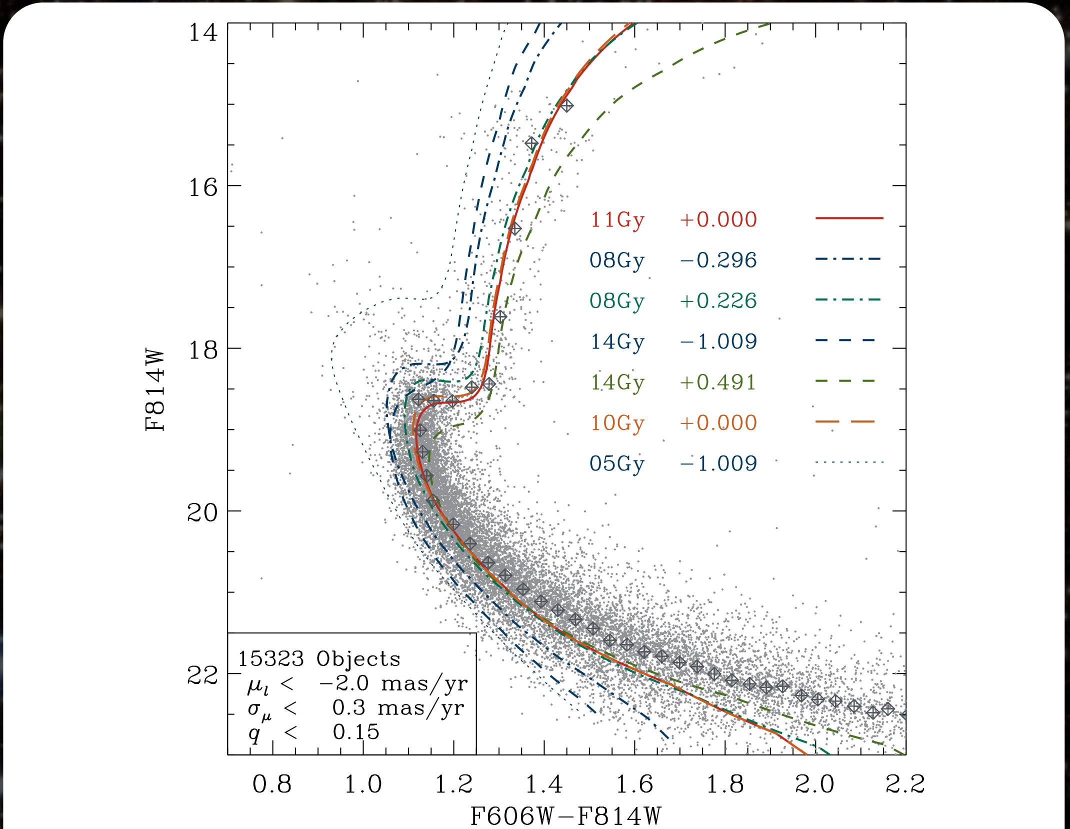
- Map the detailed star-formation history of the Galactic bulge in four distinct windows
- Calibrate a new HST photometric system for stellar population studies, using star clusters
- Measure accurate temperatures and metallicities for tens of thousands of stars in each bulge field, including 11 exoplanet hosts
- Calculate stellar mass function of a pure bulge population as a function of metallicity and position
- Obtain proper motions in each field for bulge/disk decomposition and kinematics

Deep HST bulge observations already exist
- why do we need new ones?

- Observations did not provide wide wavelength coverage
- Bands could not distinguish the effects of reddening, age, and metallicity
- Different fields observed in different bands
- Most fields have single-epoch observations (no proper motions)

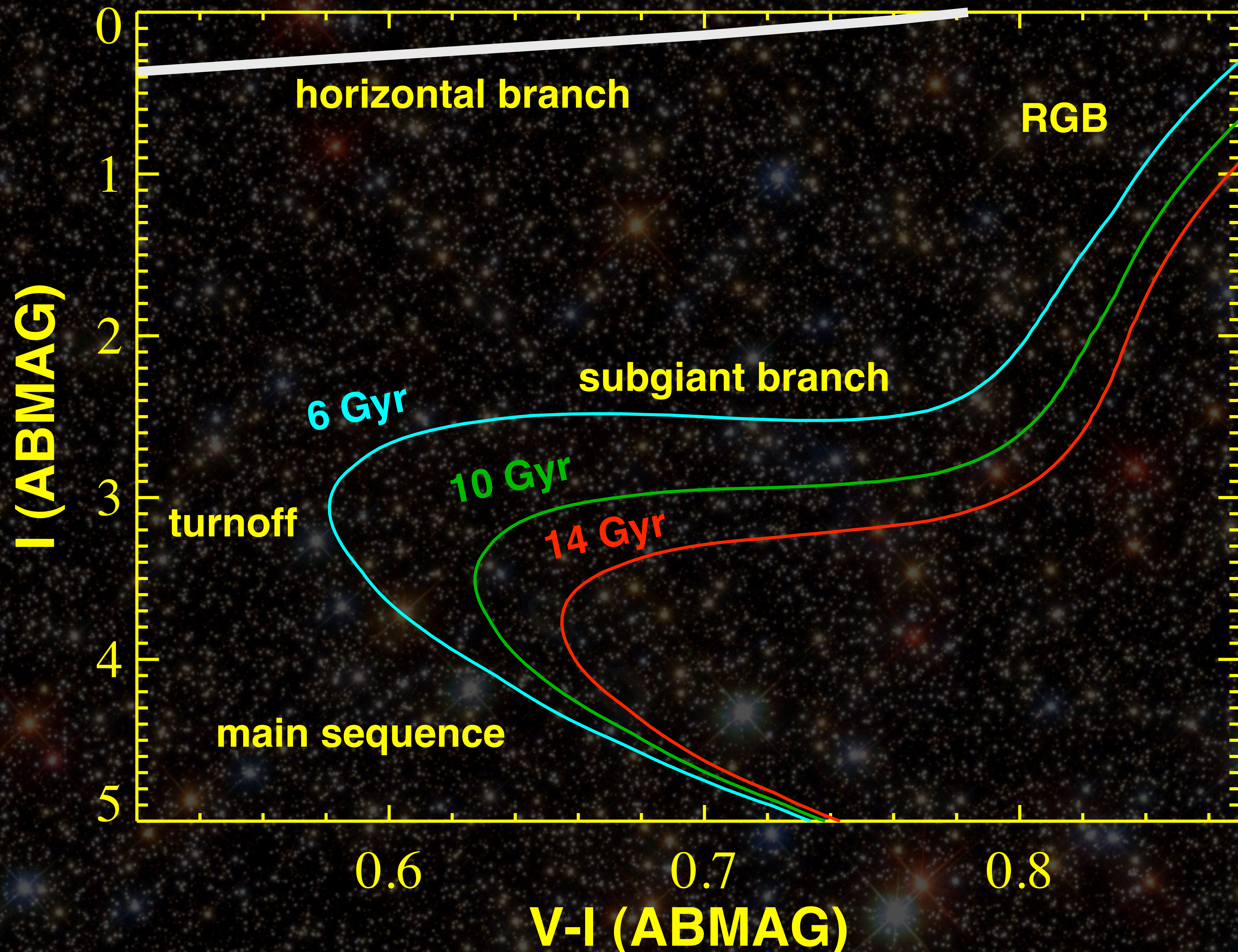


HST/NICMOS - Zoccali et al. (2010)

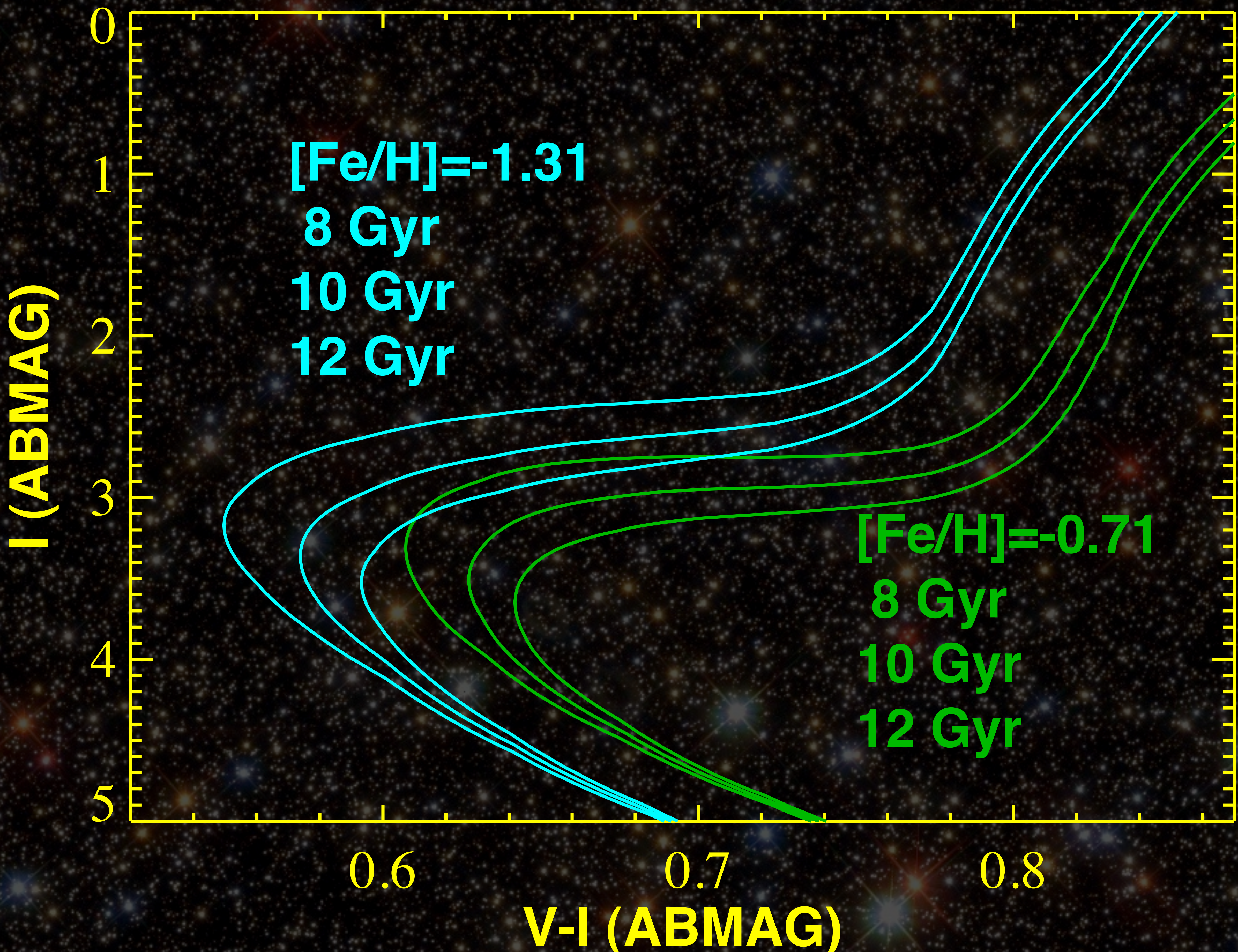


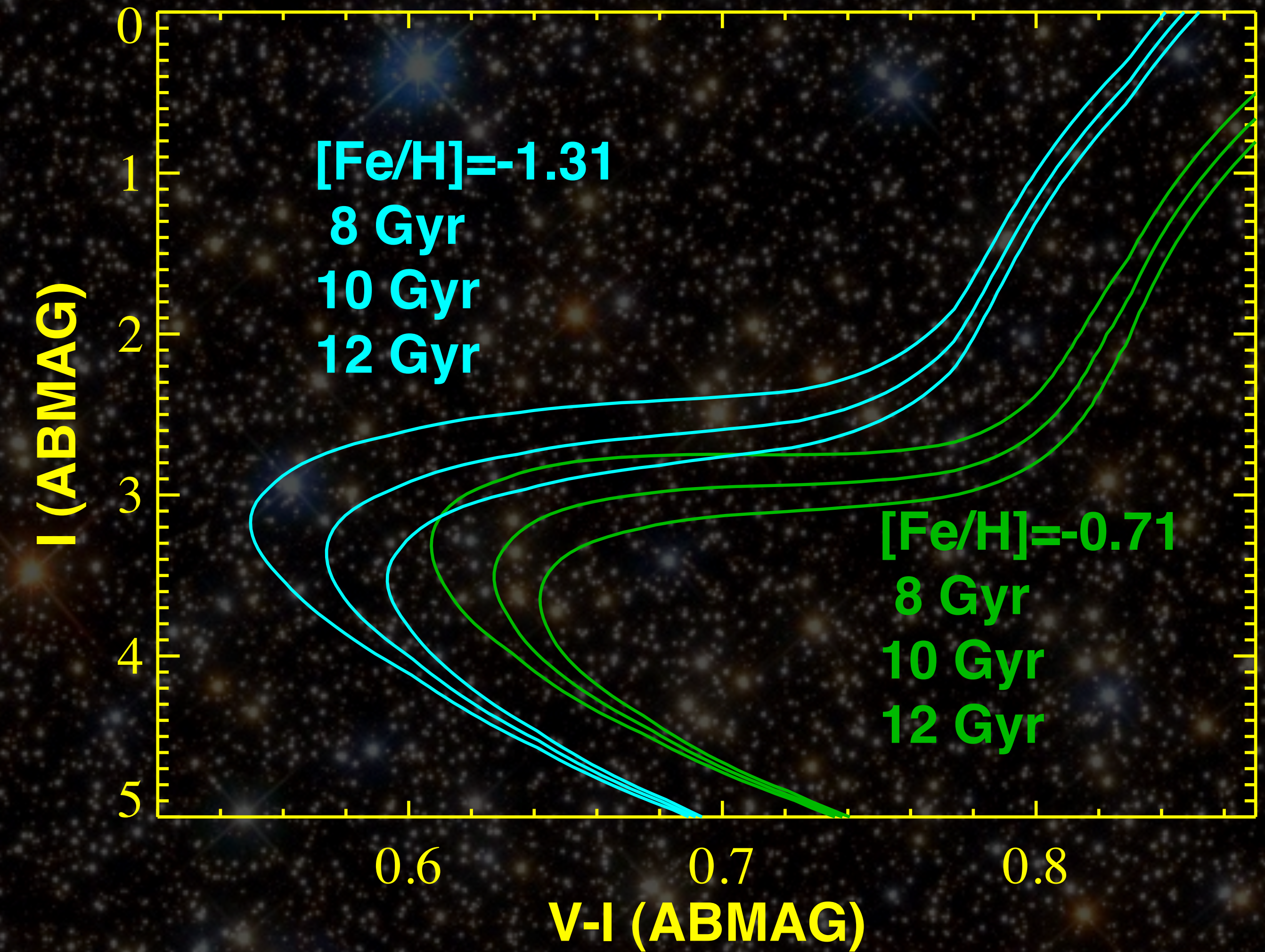
HST/ACS - Sahu et al. (2006), Clarkson et al. (2008)

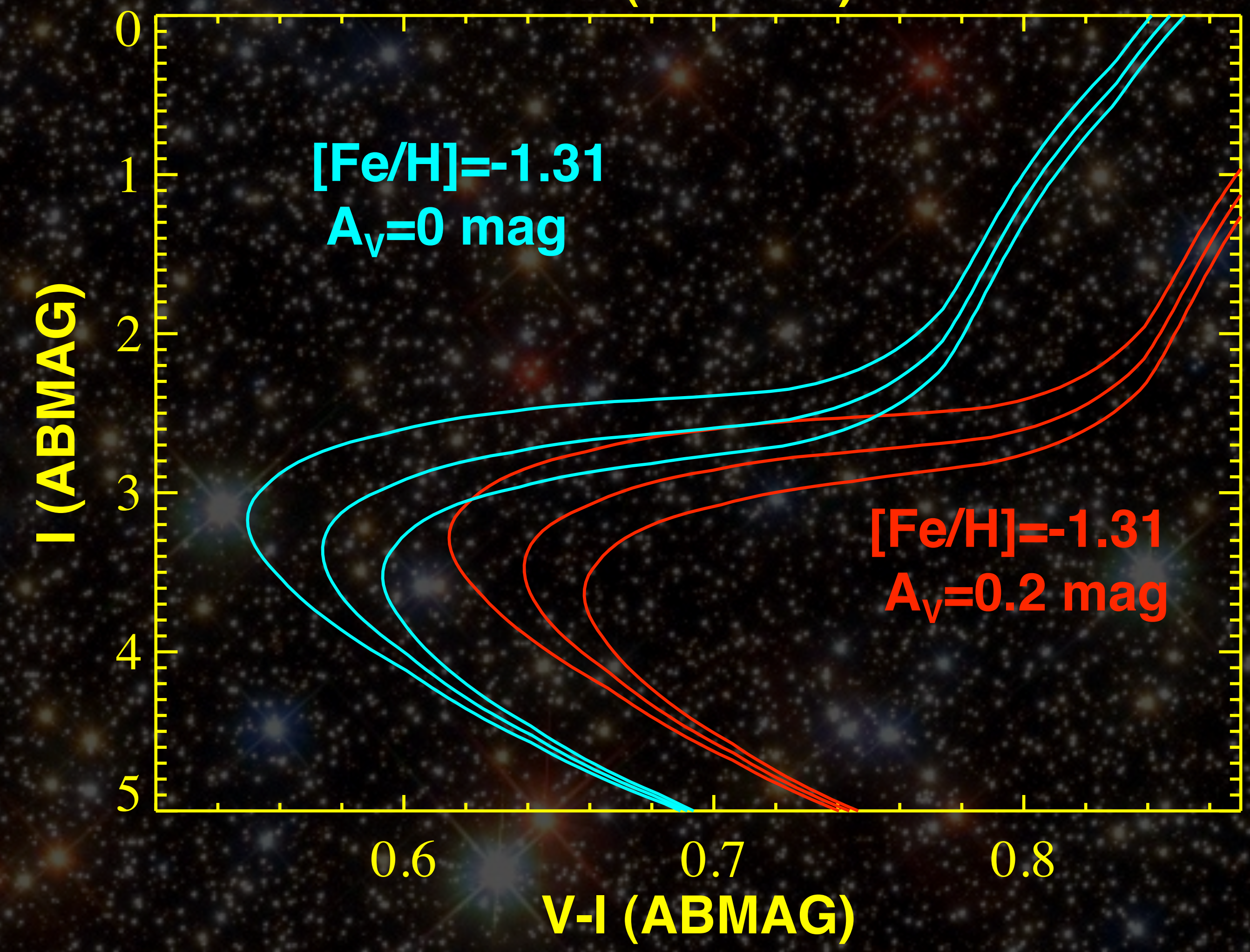
Main sequence = clock



CMD also indicates metallicity

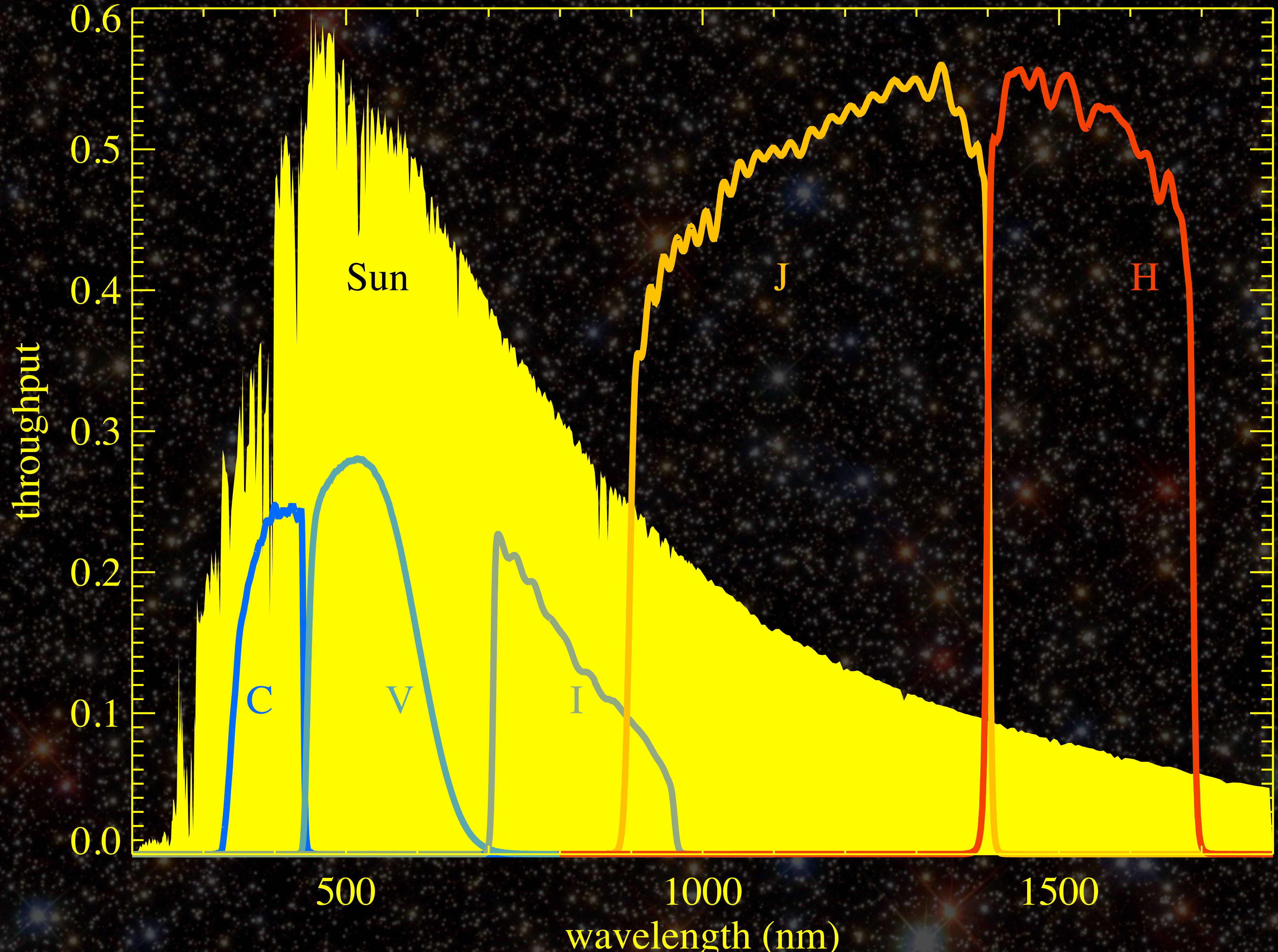






With only 2 bands, it is difficult to disentangle age and metallicity in a highly reddened environment like the bulge

WFC3 Filters



Brown et al. (2009, AJ, 137, 3172)

Reddening-free indices of temperature & metallicity

- Temperature index using: V J H

$$[t] = (V - J) - (J - H)\, E(V\text{-}J) / E(J\text{-}H)$$

$$[t] = (V - J) - 5.8\, (J - H)$$

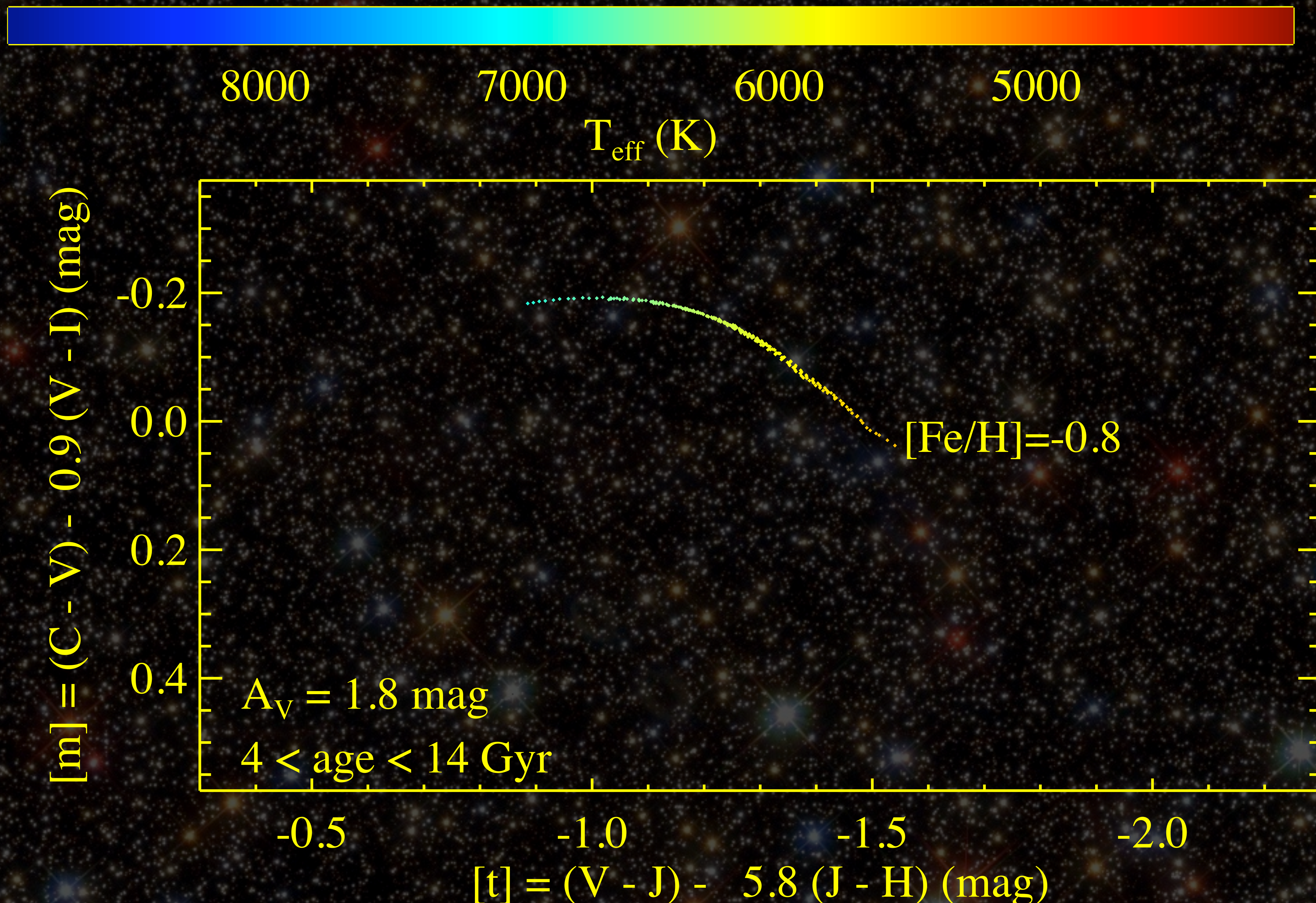
- Metallicity index using: C V I

$$[m] = (C - V) - (V - I)\, E(C\text{-}V)/E(J\text{-}H)$$

$$[m] = (C - V) - 0.9\, (V - I)$$

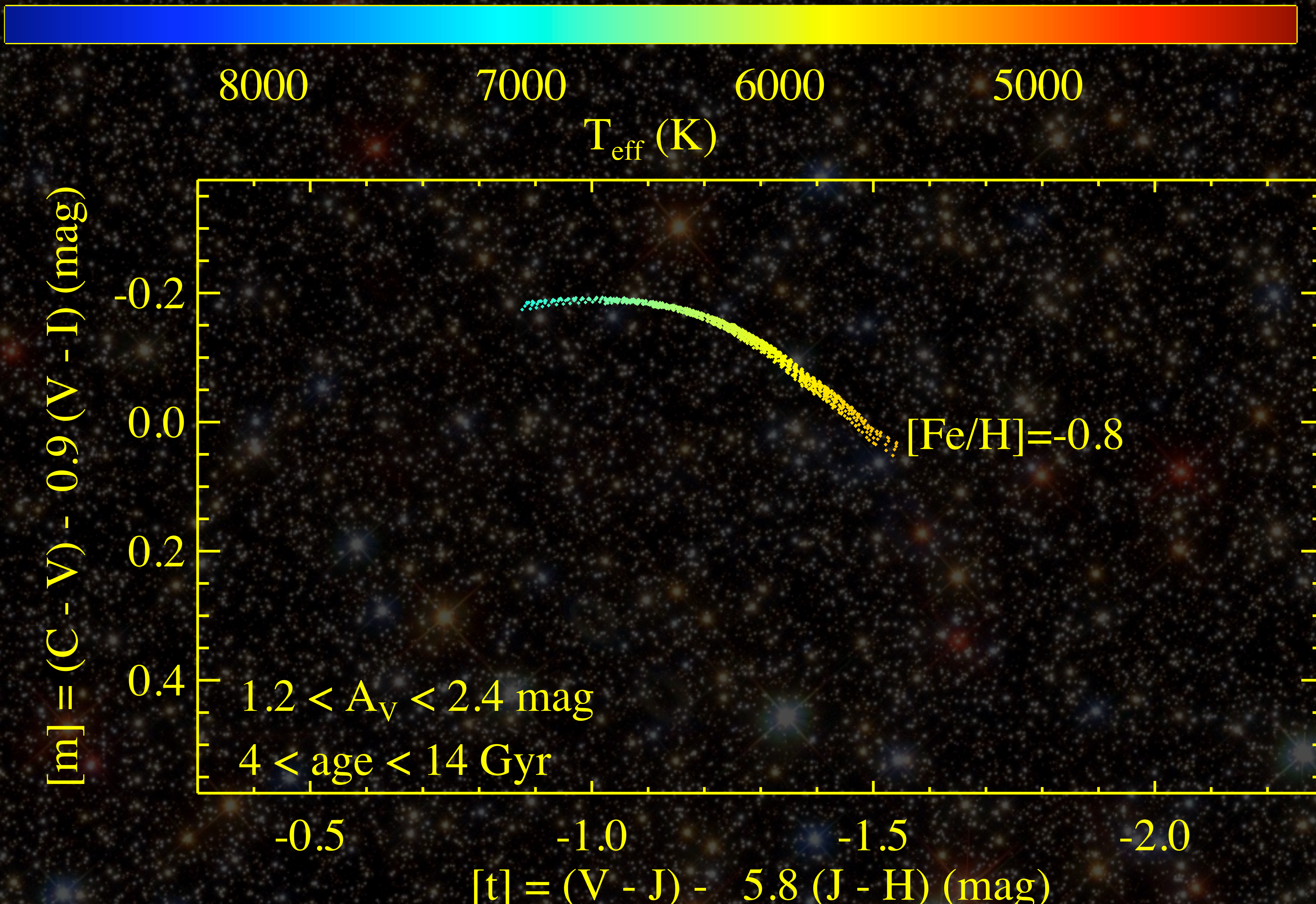
Brown et al. (2009, AJ, 137, 3172)

Reddening-free indices of temperature & metallicity



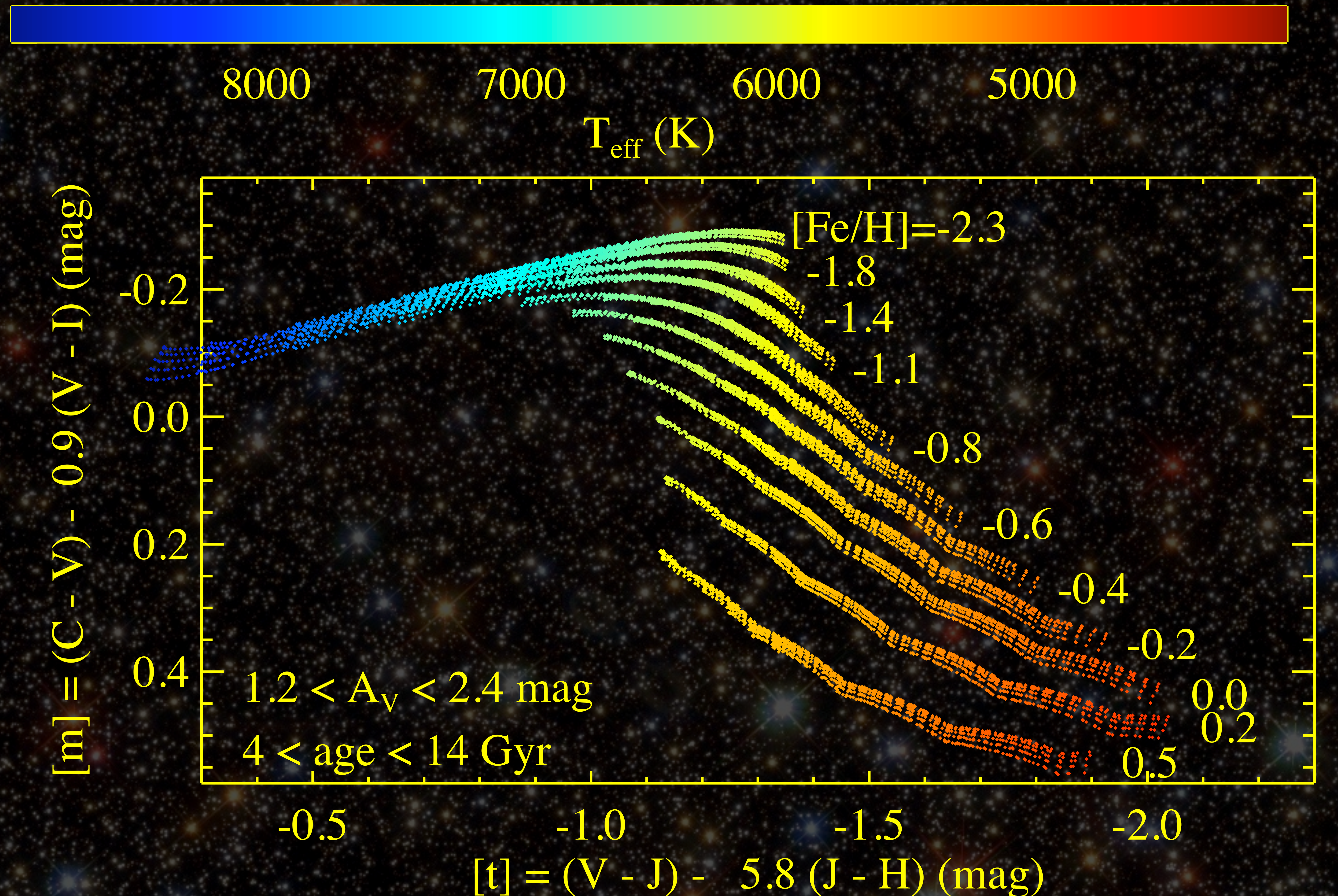
Brown et al. (2009, AJ, 137, 3172)

Reddening-free indices of temperature & metallicity



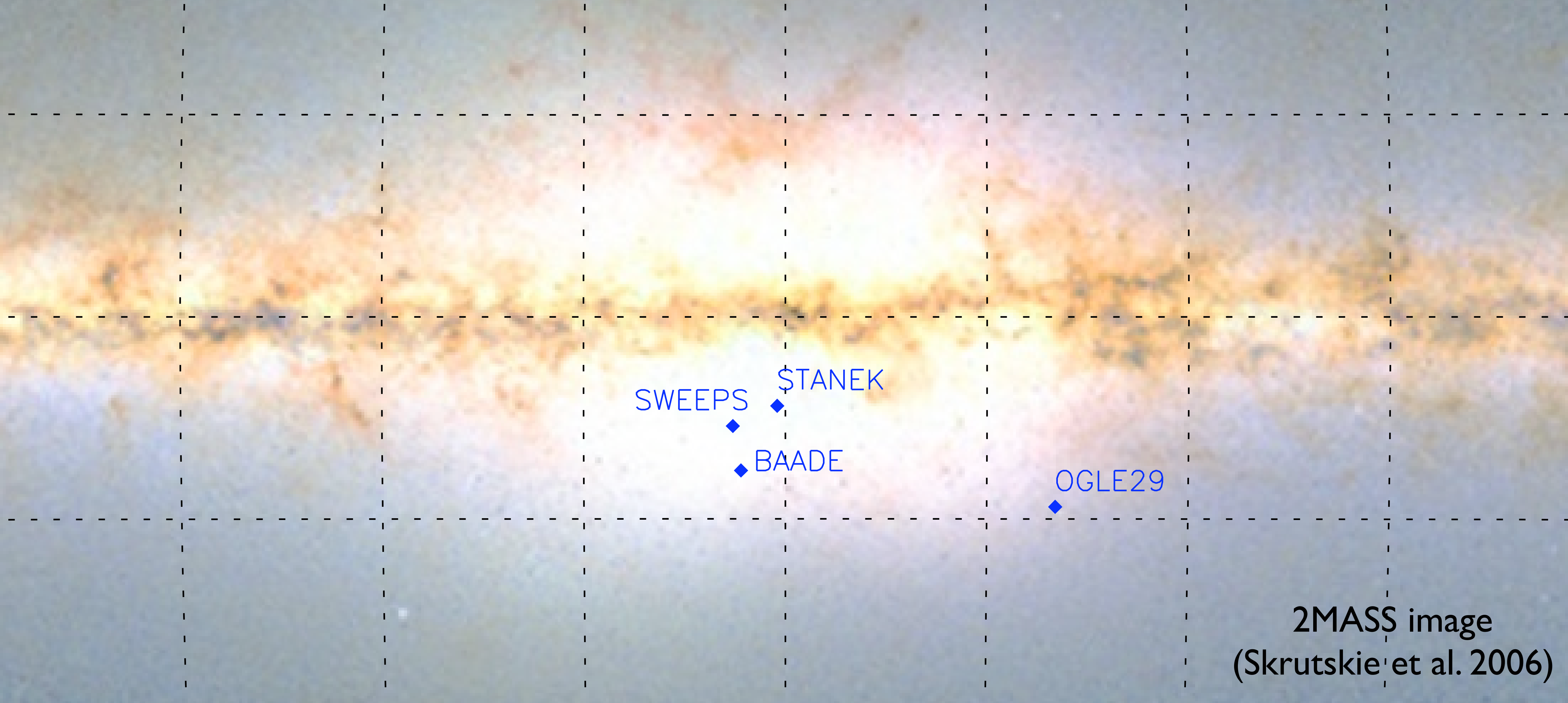
Brown et al. (2009, AJ, 137, 3172)

Reddening-free indices of temperature & metallicity

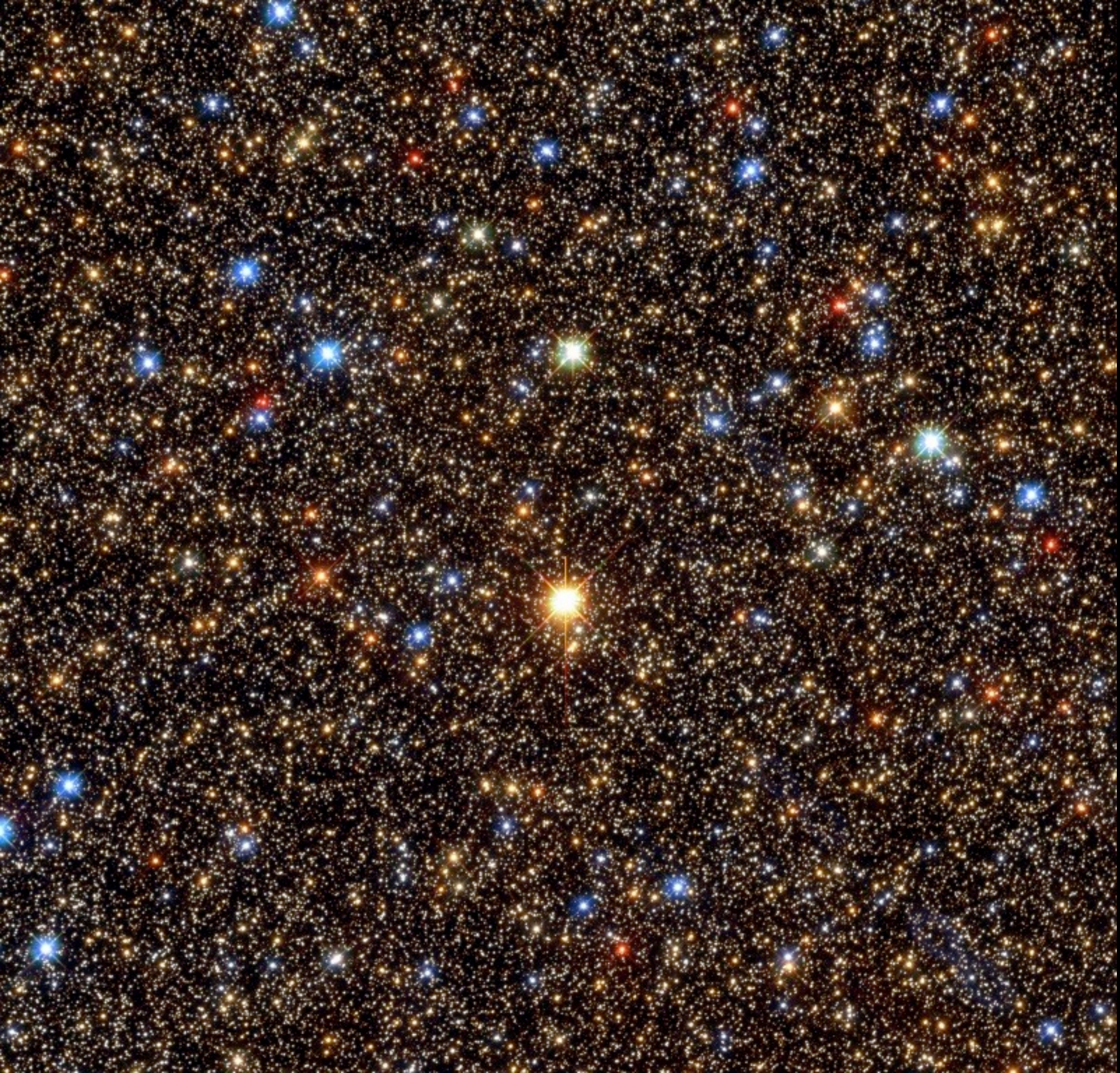


Brown et al. (2009, AJ, 137, 3172)

WFC3 Fields



Field	l (deg)	b (deg)	R_{min} (kpc)	A_V (mag)
Stanek's Window	0.25	-2.15	0.32	2.6
SWEEPS	1.25	-2.65	0.43	2.0
Baade's Window	1.06	-3.81	0.58	1.6
OGLE29	-6.75	-4.72	1.21	1.5



Stanek's Window

156x150 arcsec

6.5x6.1 pc

R_{min}=0.32 kpc

A_V=2.6 mag

SWEEPS

156x150 arcsec

6.5x6.1 pc

R_{min}=0.43 kpc

A_V=2.0 mag

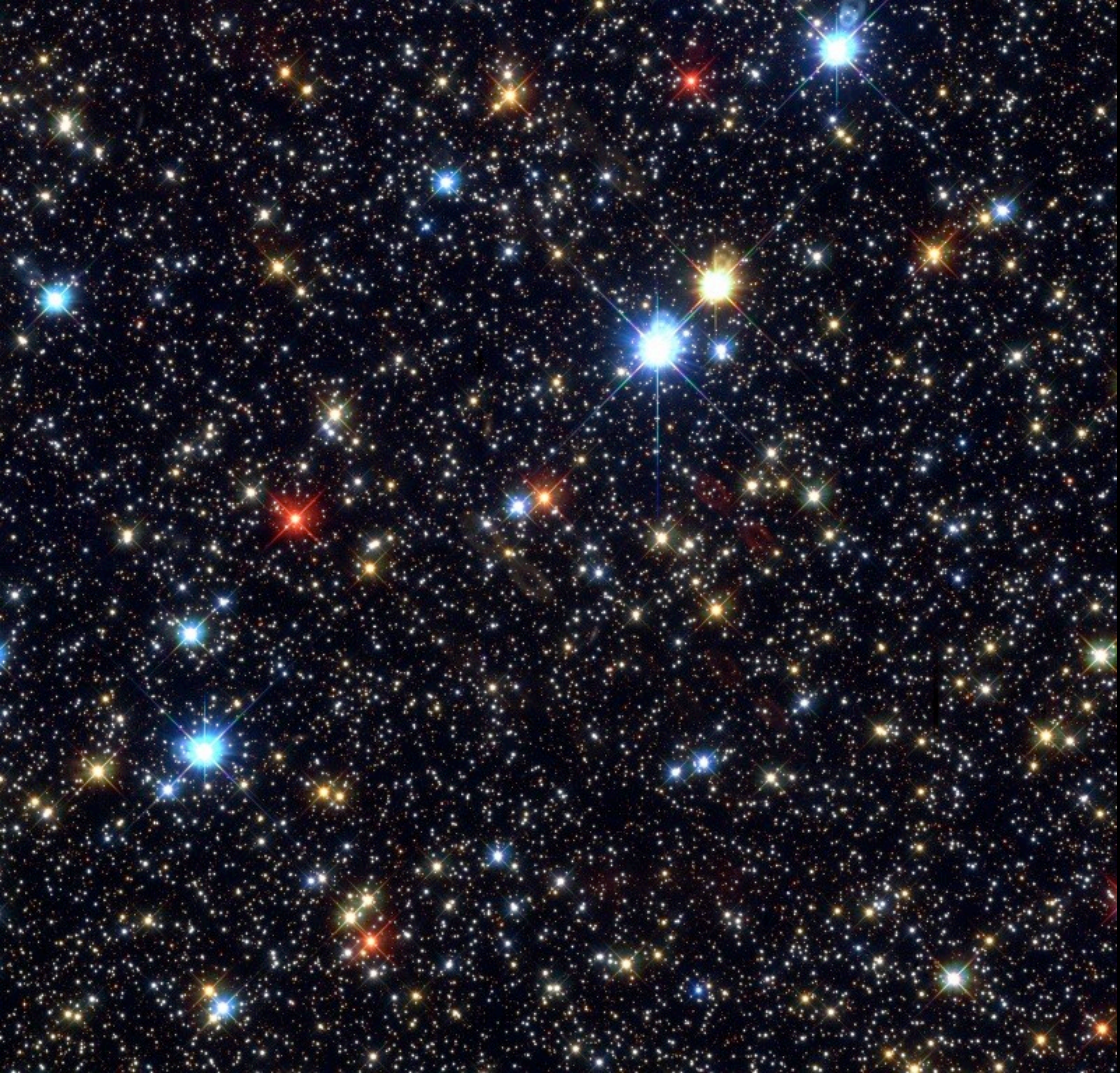
Baade's Window

156x150 arcsec

6.5x6.1 pc

R_{min}=0.58 kpc

A_V=1.6 mag



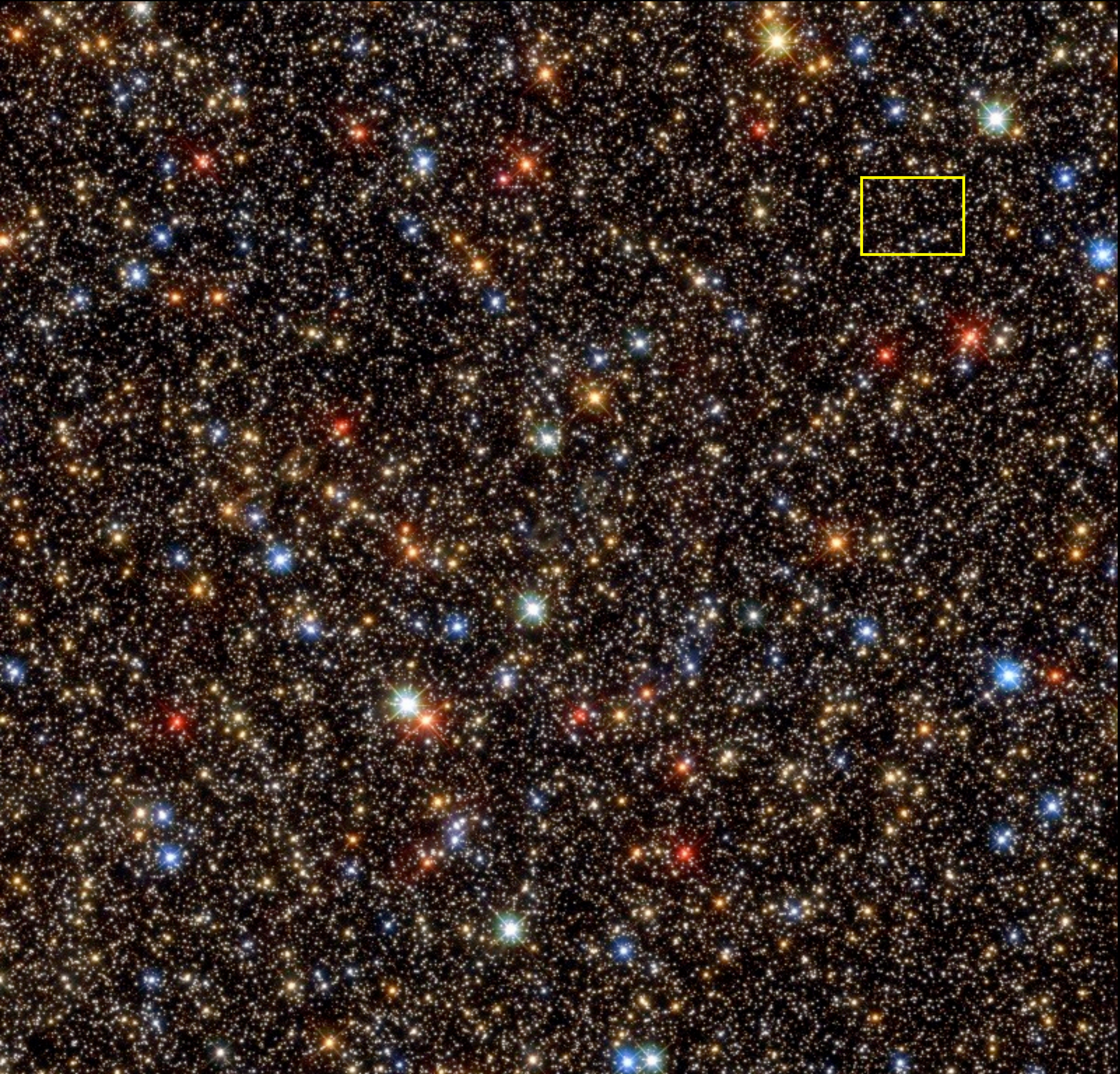
OGLE29

156x150 arcsec

6.5x6.1 pc

R_{min}=1.21 kpc

A_V=1.5 mag



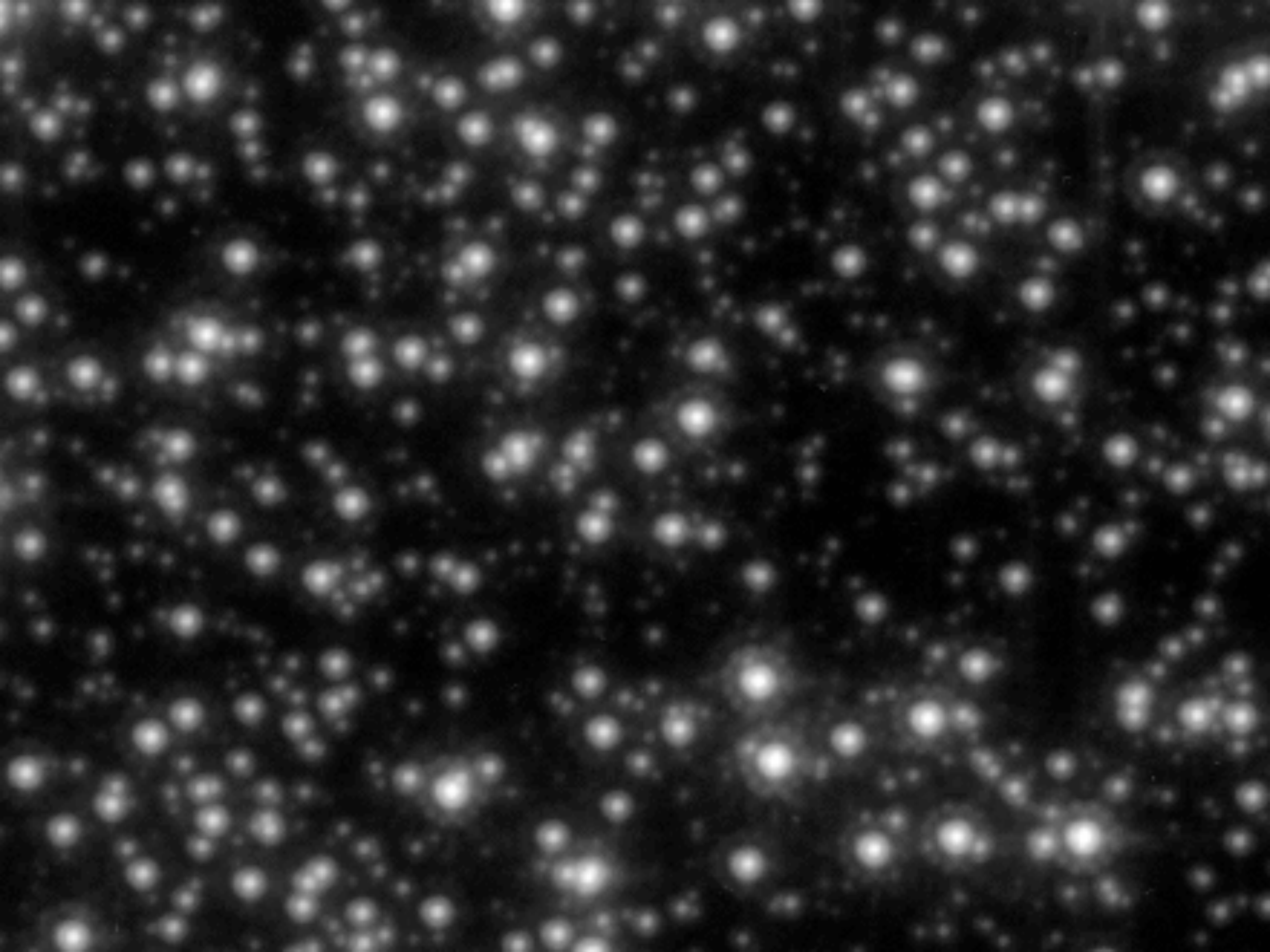
SWEEPS

156x150 arcsec

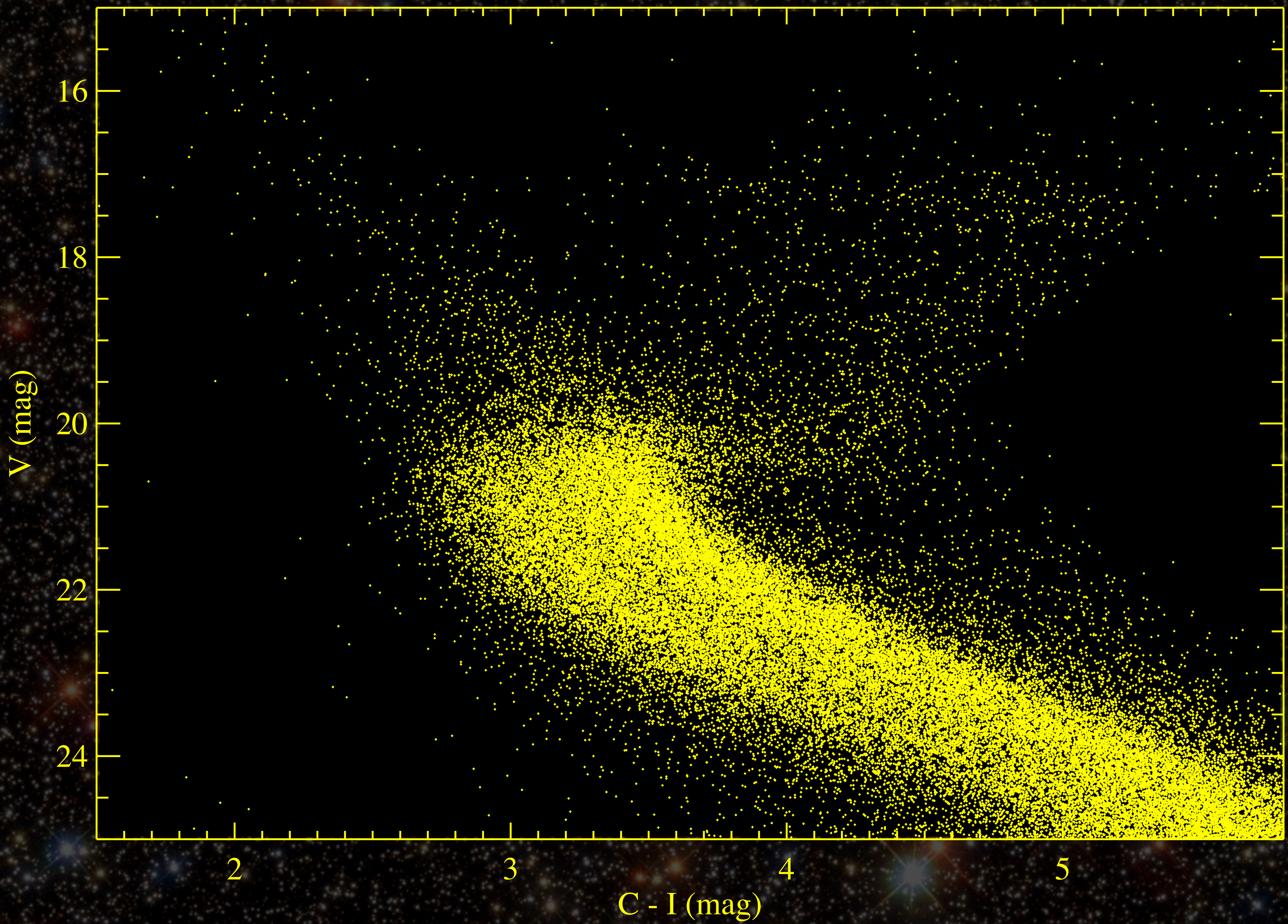
6.5x6.1 pc

R_{min}=0.43 kpc

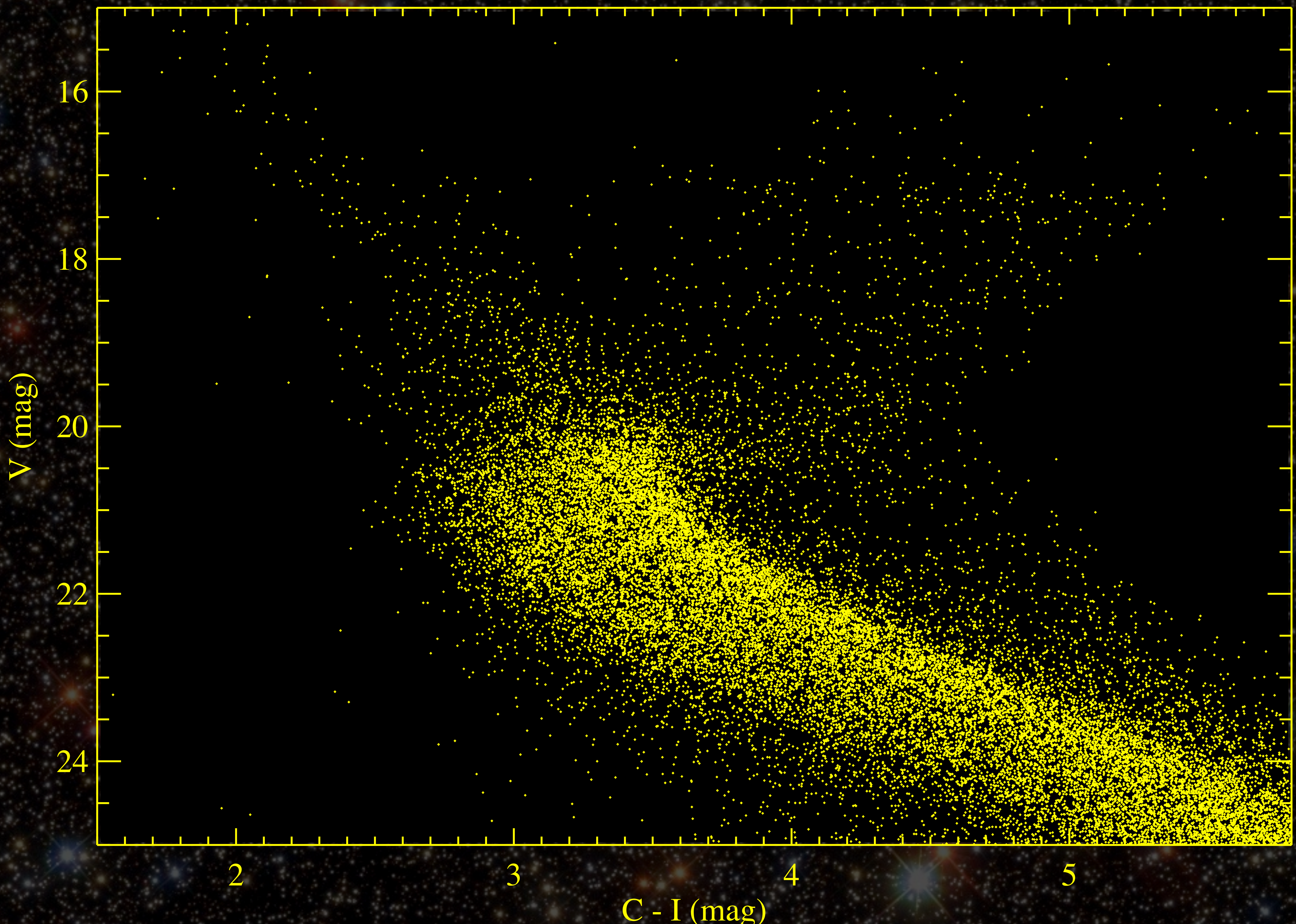
A_V=2.0 mag



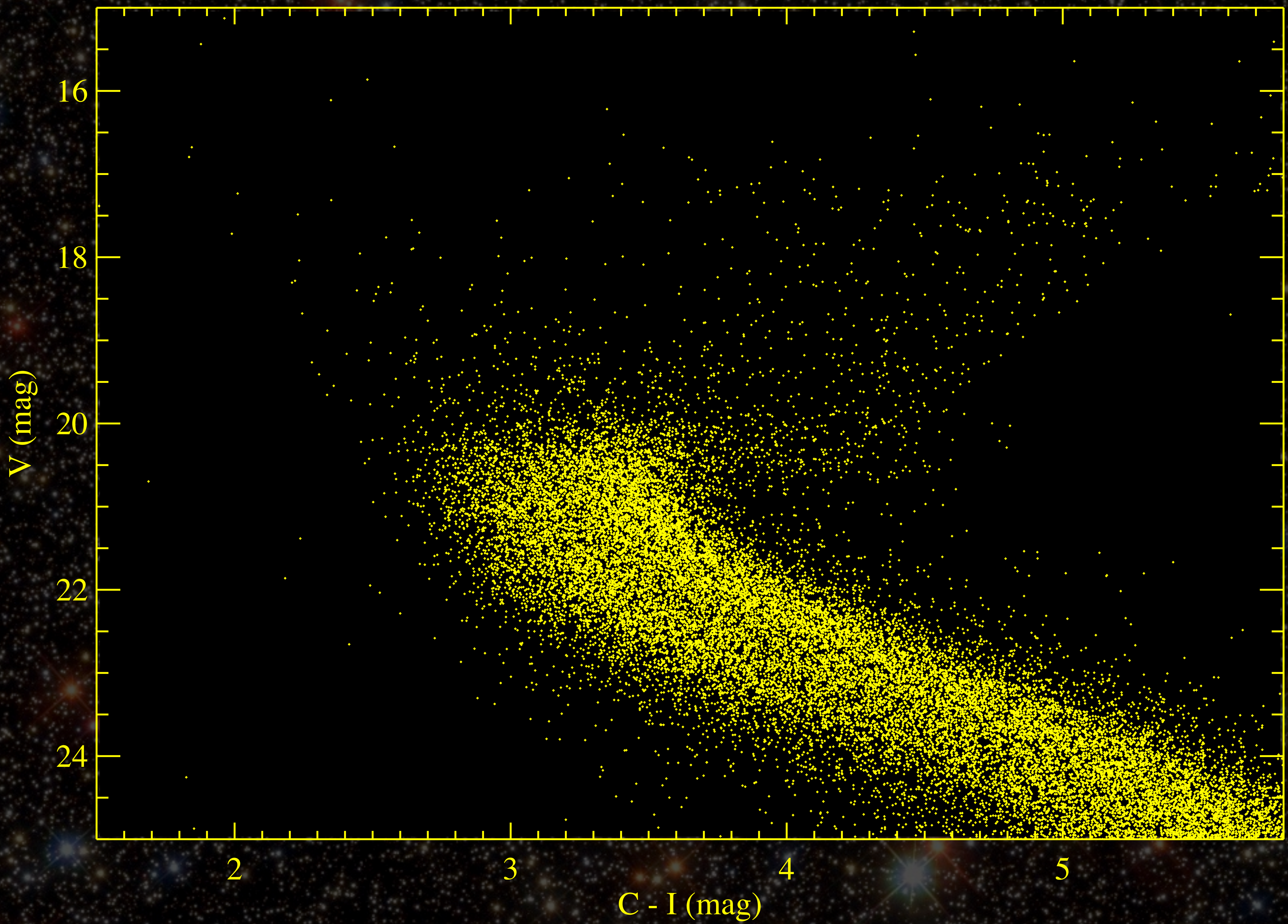
SWEEPS CMD



SWEEPS CMD (motions in disk direction)

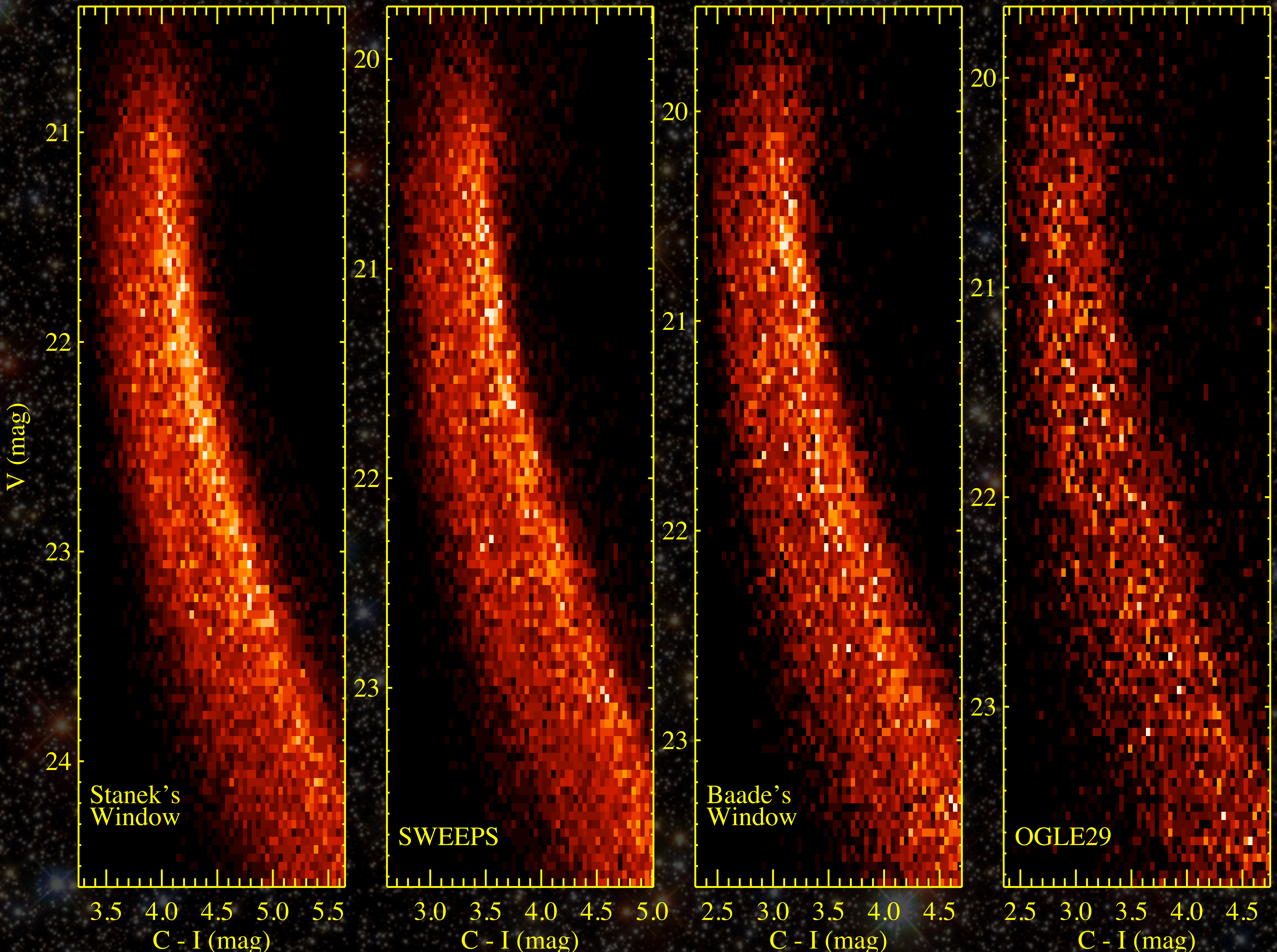


SWEEPS CMD (motions opposite disk direction)



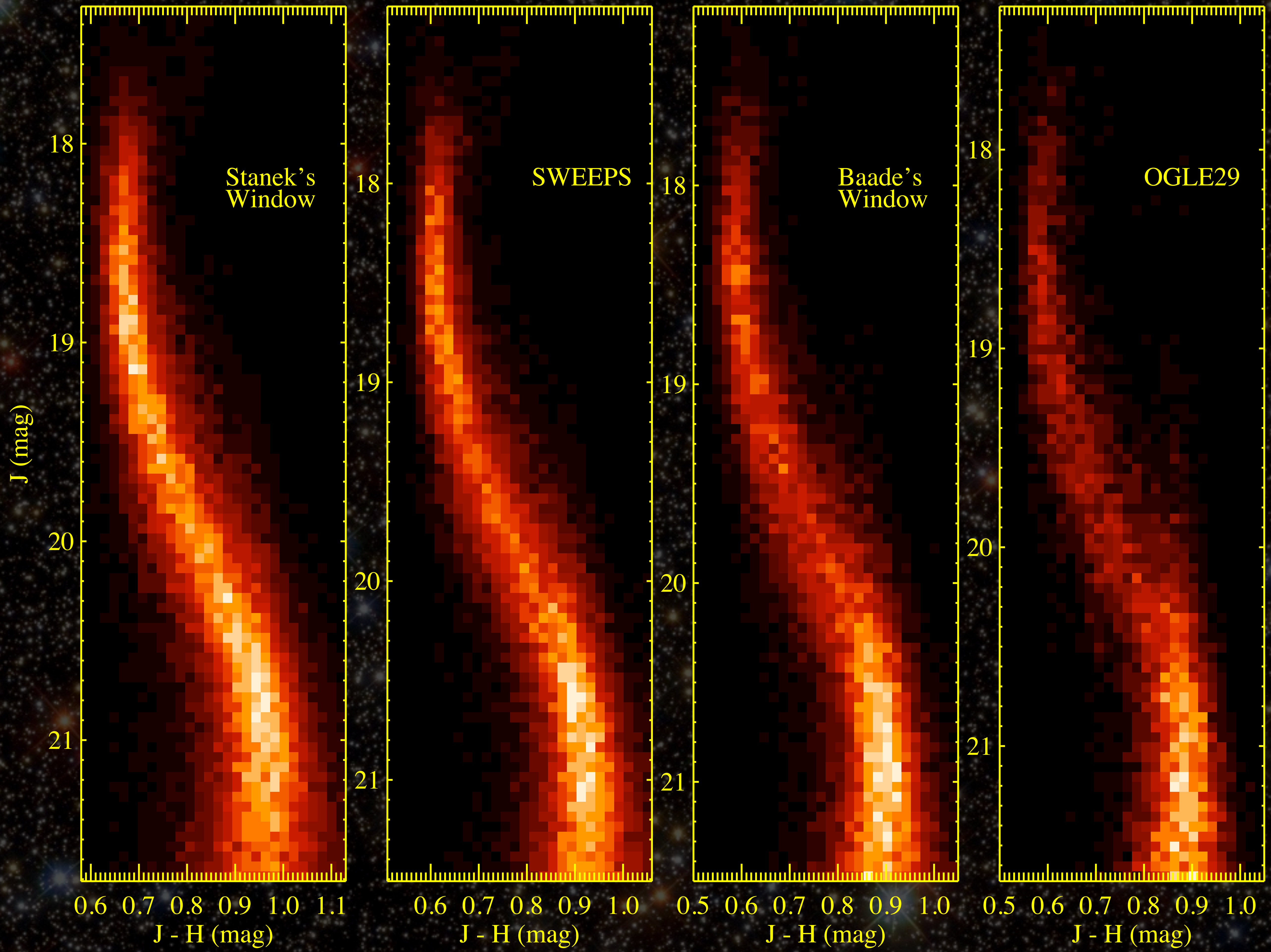
All fields (UV/optical)

Brown et al. (2010, ApJL, sub.)



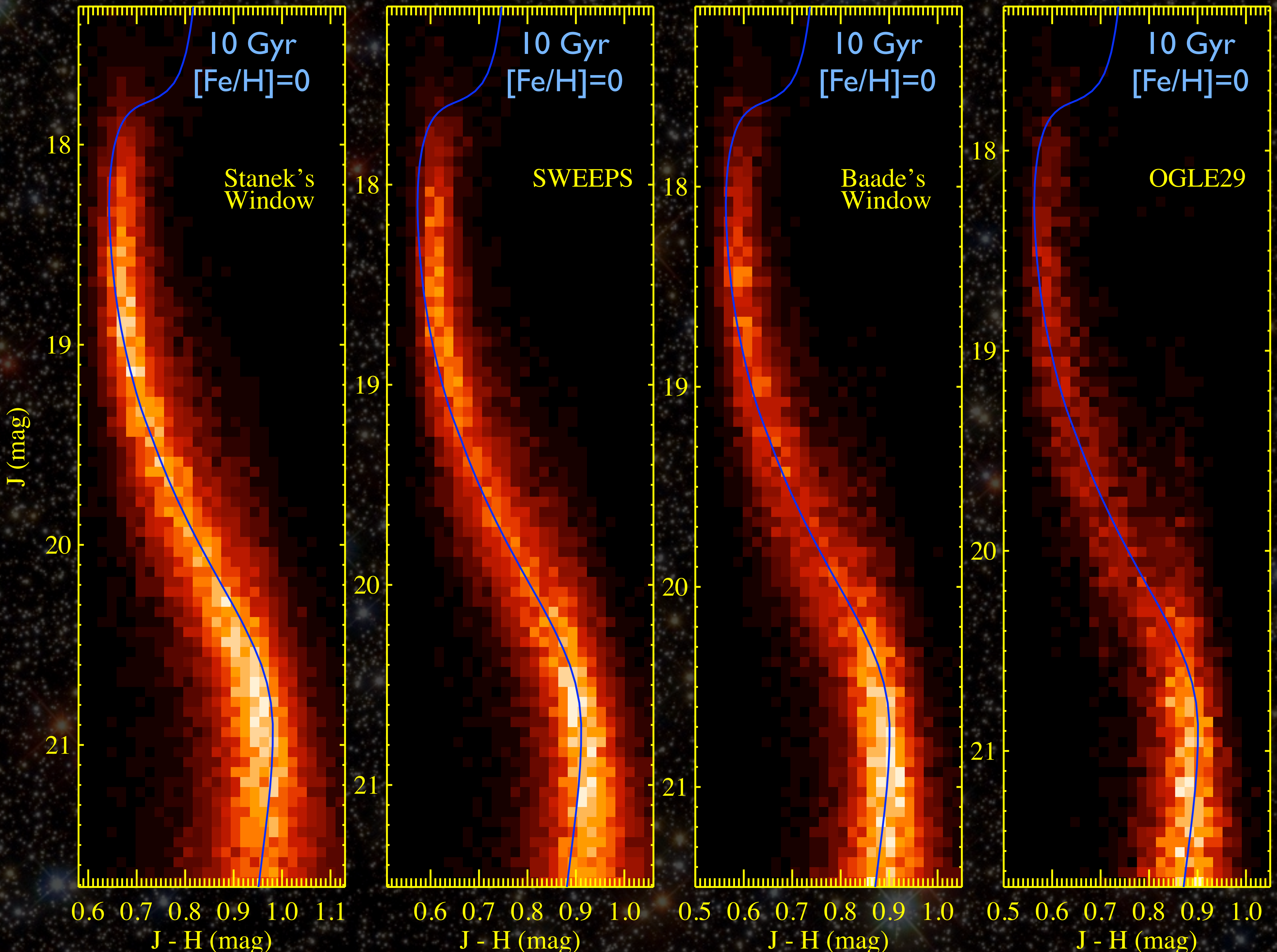
All fields (IR)

Brown et al. (2010, ApJL, sub.)

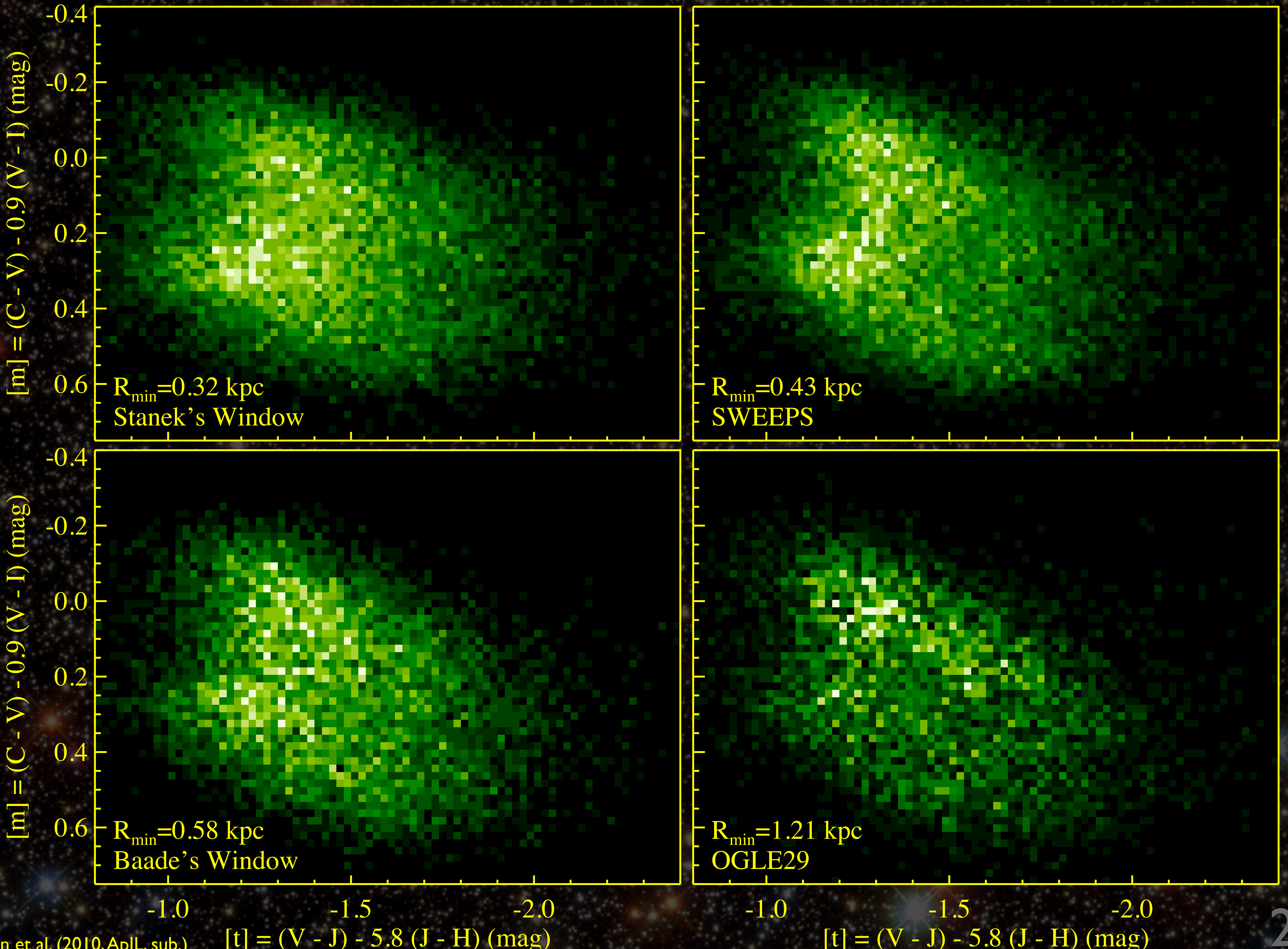


All fields (IR)

Brown et al. (2010, ApJL, sub.)

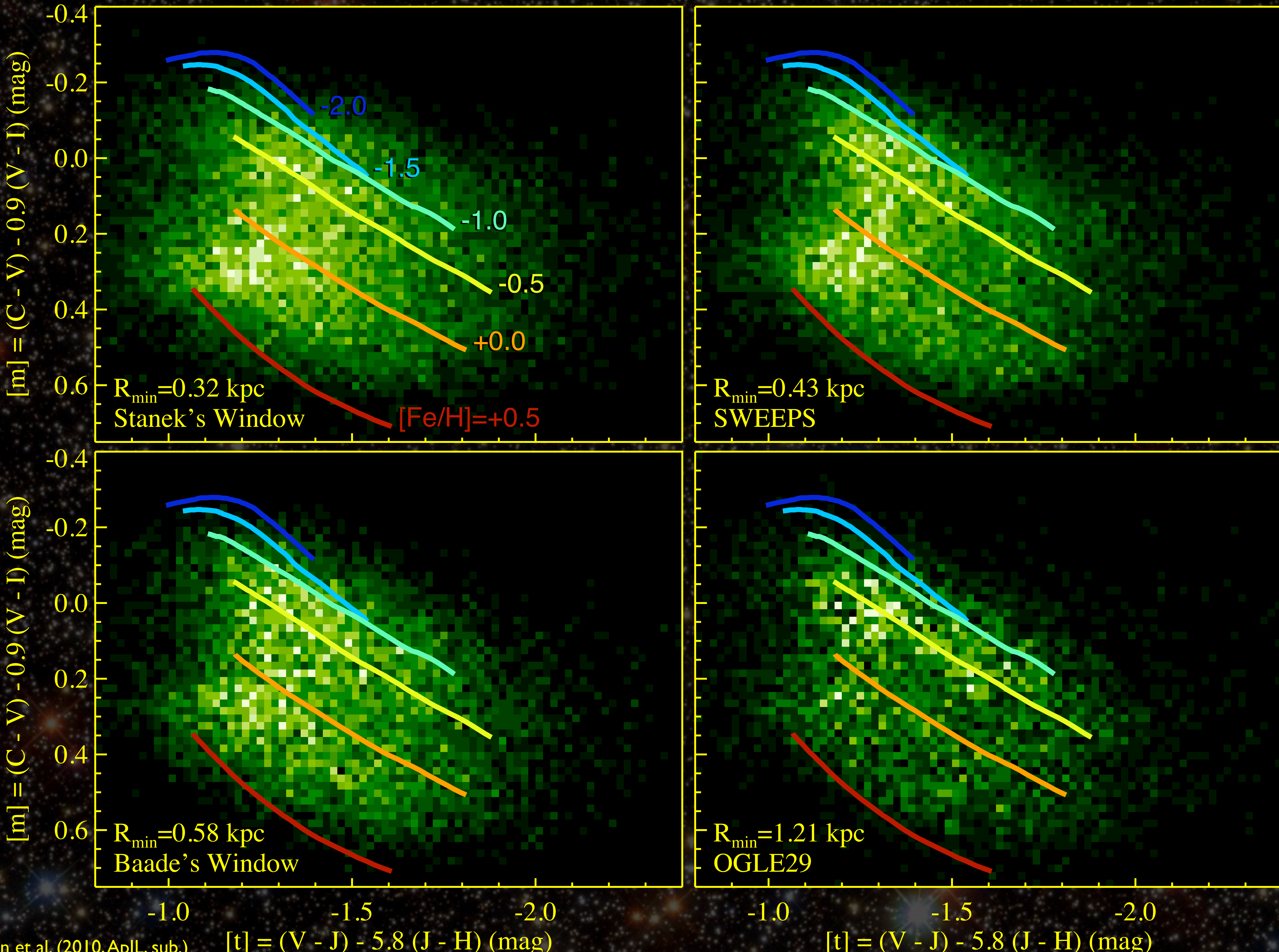


Bulge stars on upper main sequence



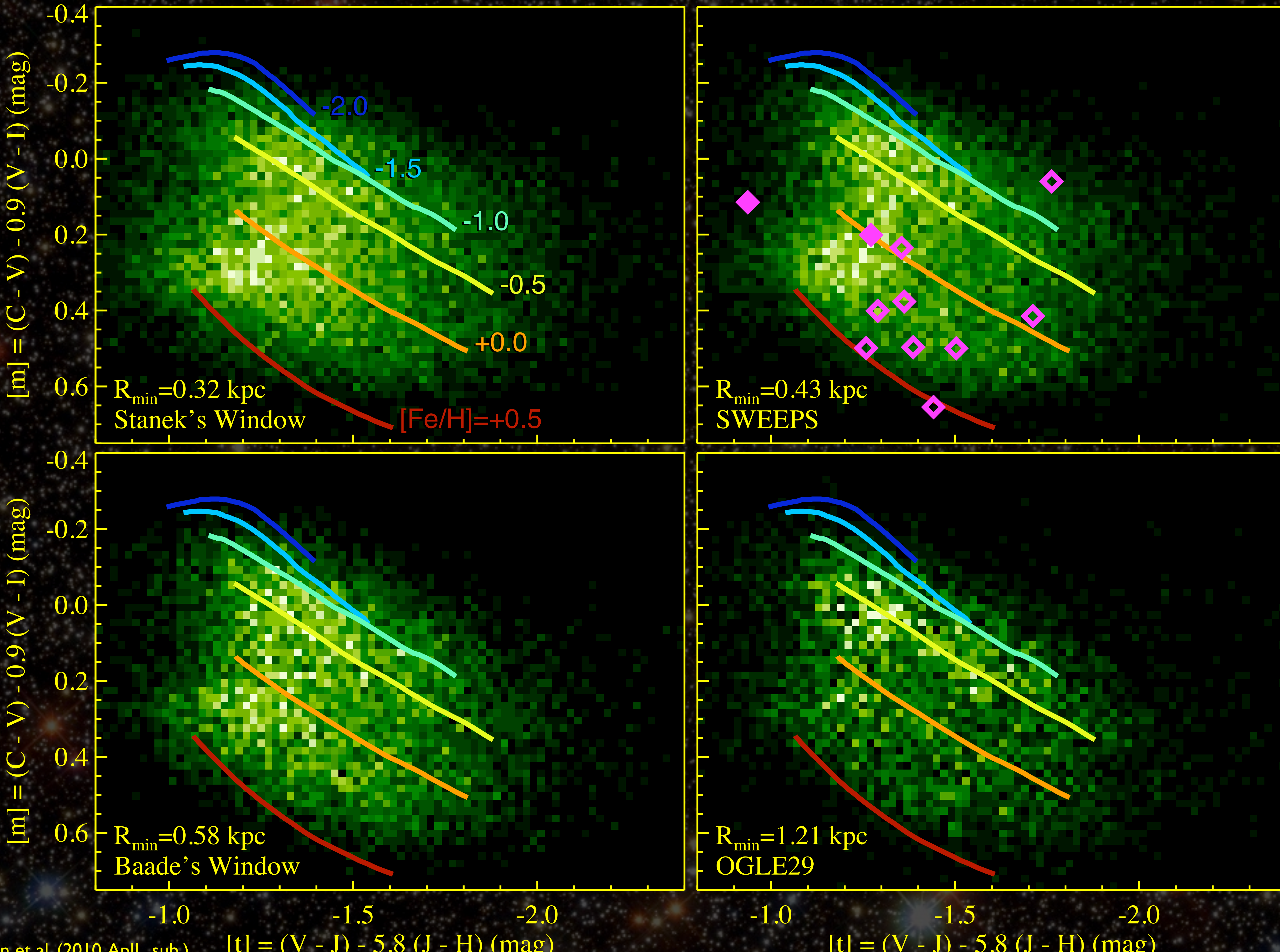
Brown et al. (2010, ApJL, sub.)

Bulge stars & isochrones on upper main sequence



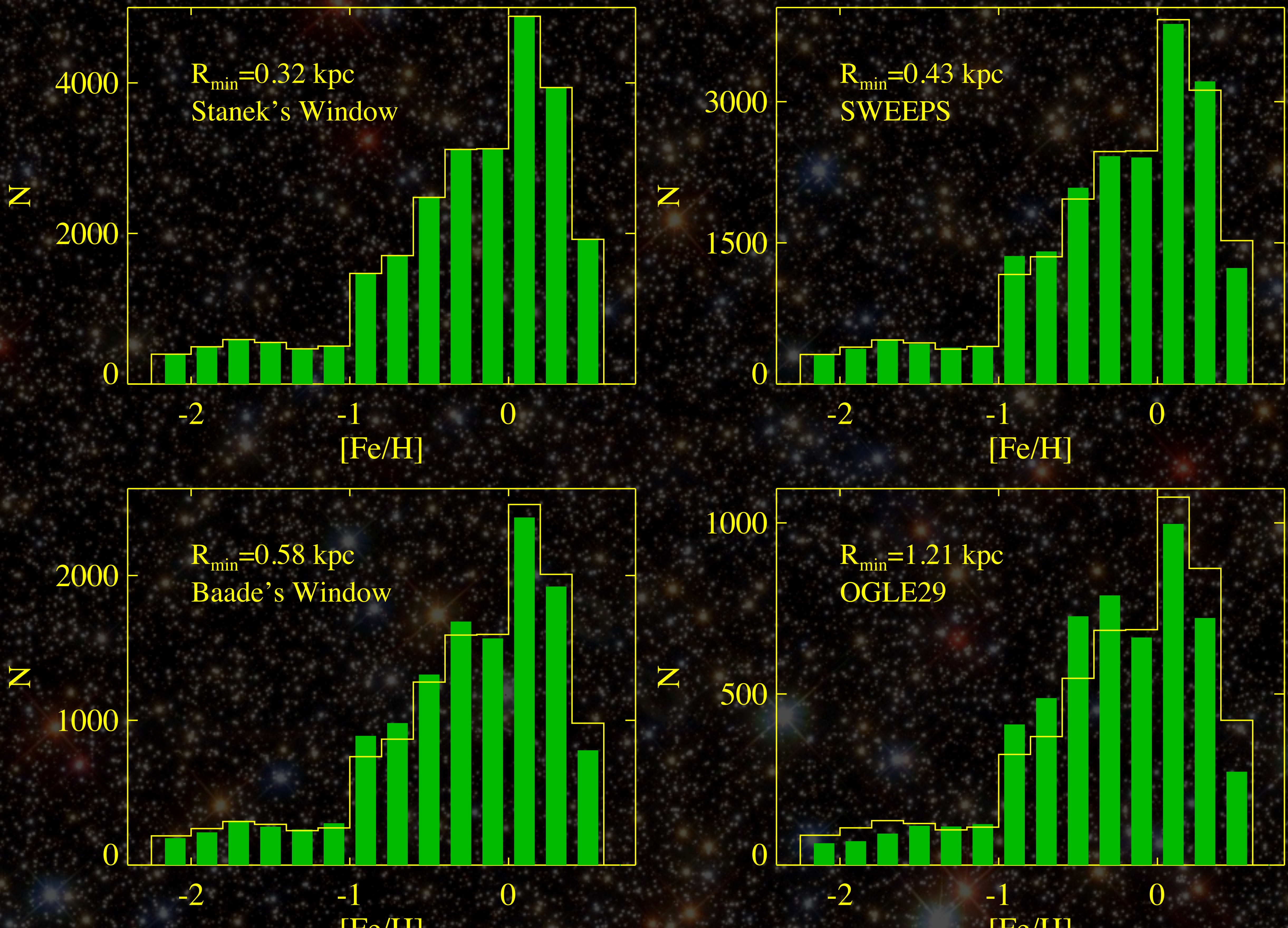
Brown et al. (2010, ApJL, sub.)

Metal-rich exoplanet hosts in SWEEPS field



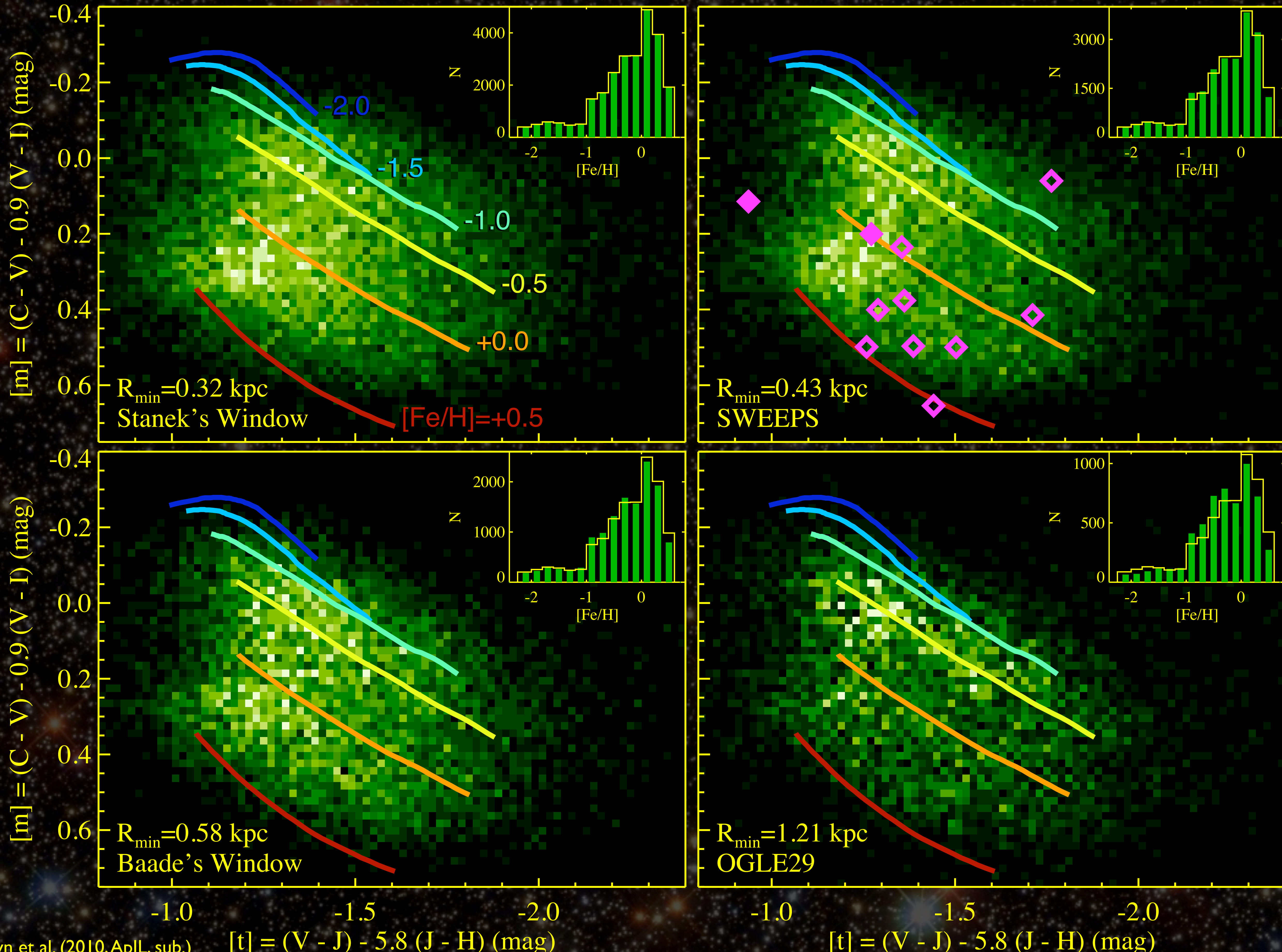
Brown et al. (2010, ApJL, sub.)

Implied metallicities for bulge fields



Brown et al. (2010, ApJL, sub.)

Bulge fields and metallicities



Brown et al. (2010, ApJL, sub.)

Implications

- Bulge is dominated by old (10 Gyr) stars at all positions
- Bulge exhibits declining metallicities at increasing radius
- Preliminary analysis of bulge consistent with
  - Classical dissipative collapse, or
  - Early, rapid evolution driven by instabilities in a gas-rich clumpy disk
- Inconsistent with secular processes traditionally associated with peanut-shaped bulge
- Exoplanets preferentially found at high metallicity in bulge (as in solar neighborhood; Fischer & Valenti 2005)
- Exoplanets may preferentially form in metal-rich environment