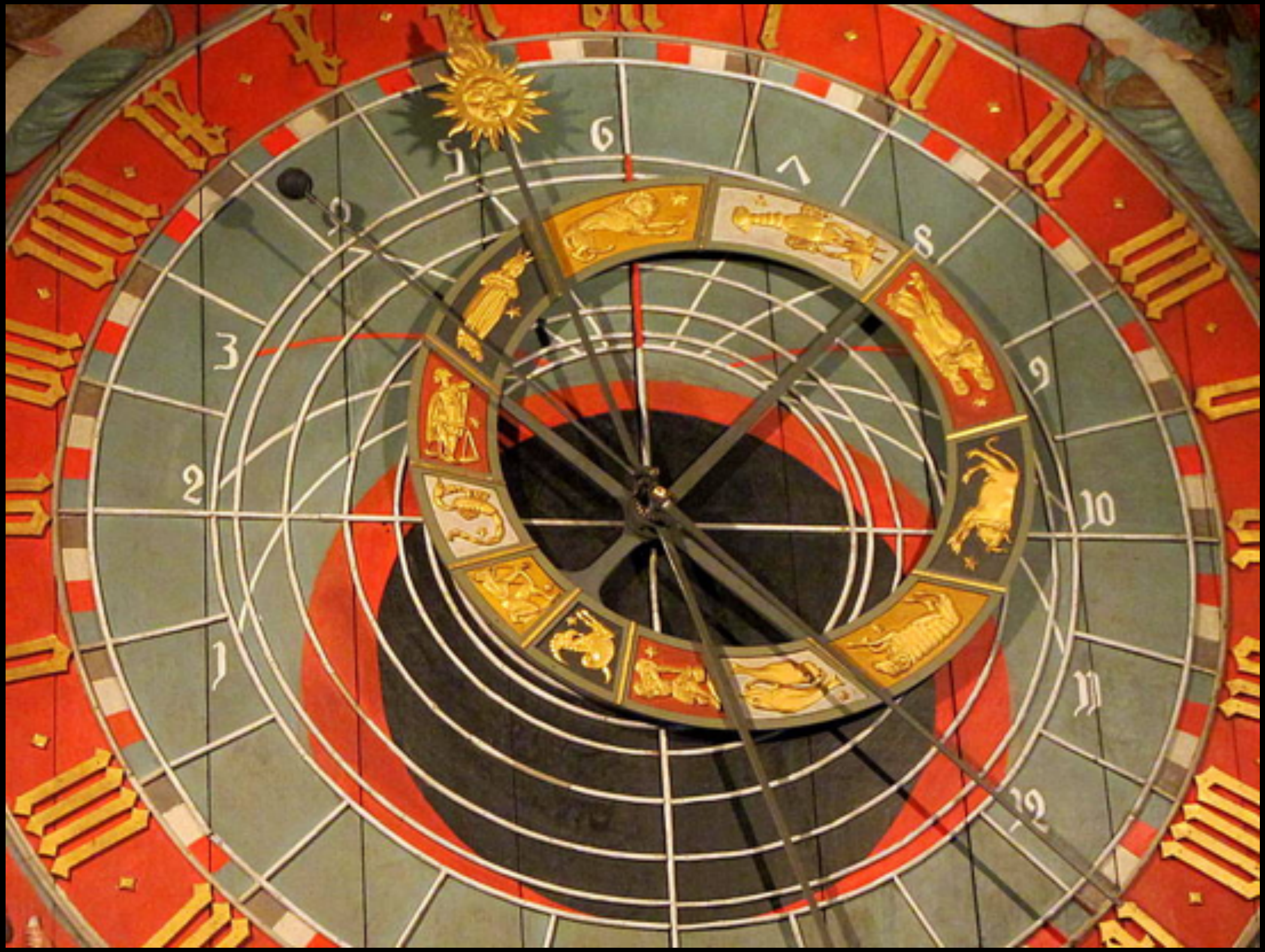
Resolved Stellar Populations in the JWST Era



Julianne Dalcanton
University of Washington

Stellar Populations

Resolved Stellar Populations

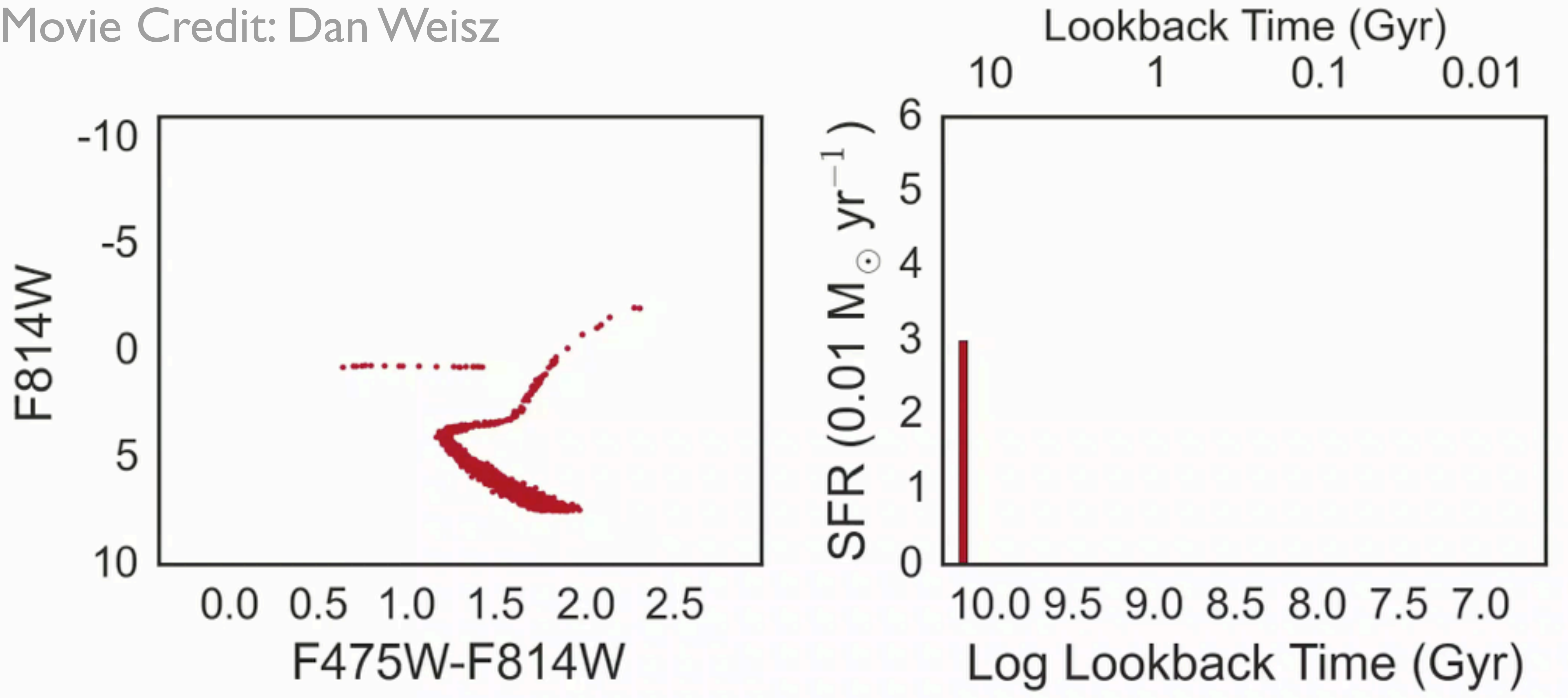
Science from Collections of Individual Stars

Colors & magnitudes

Encode information about stars' temperatures, luminosities

Color-Magnitude Diagrams (CMDs)

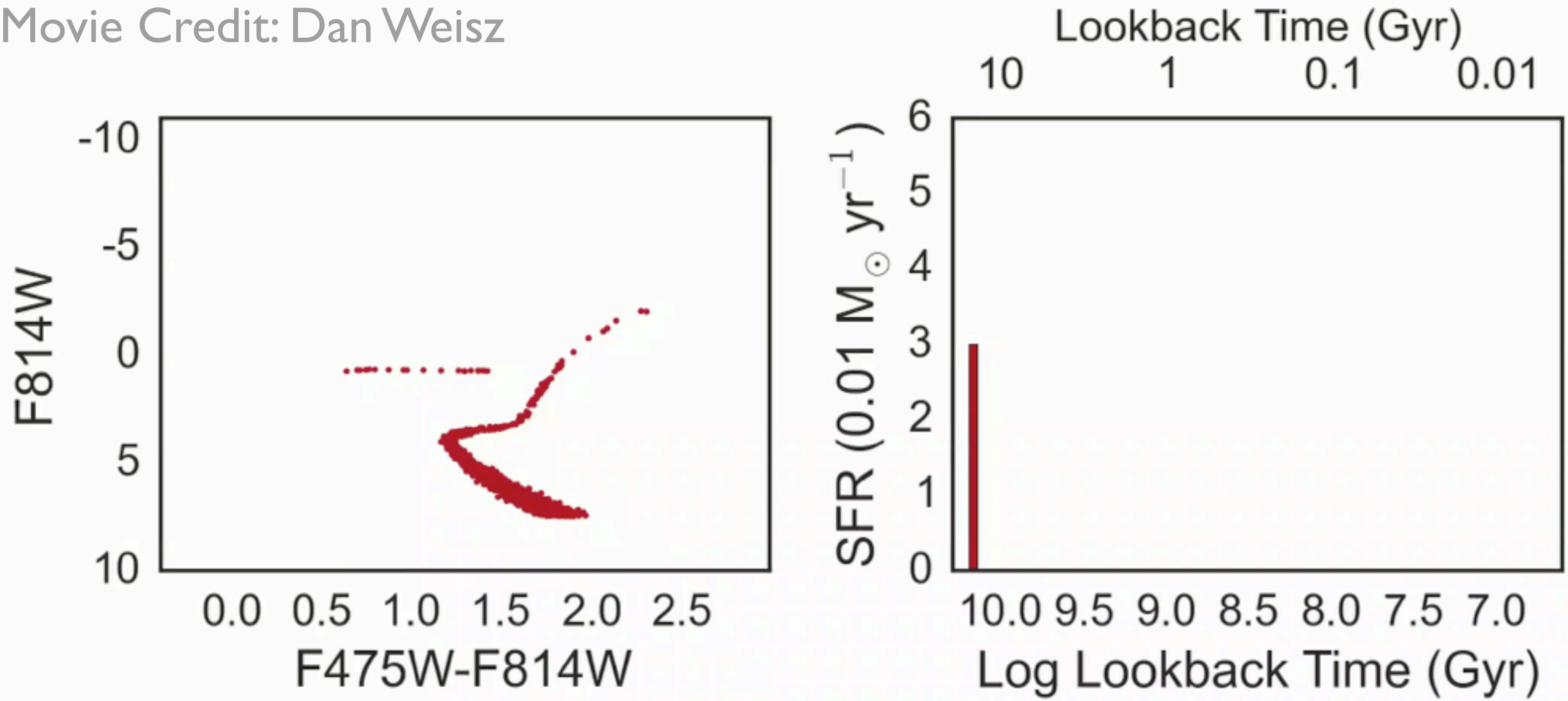
Movie Credit: Dan Weisz



Shaped by ages of underlying stellar populations

Color-Magnitude Diagrams (CMDs)

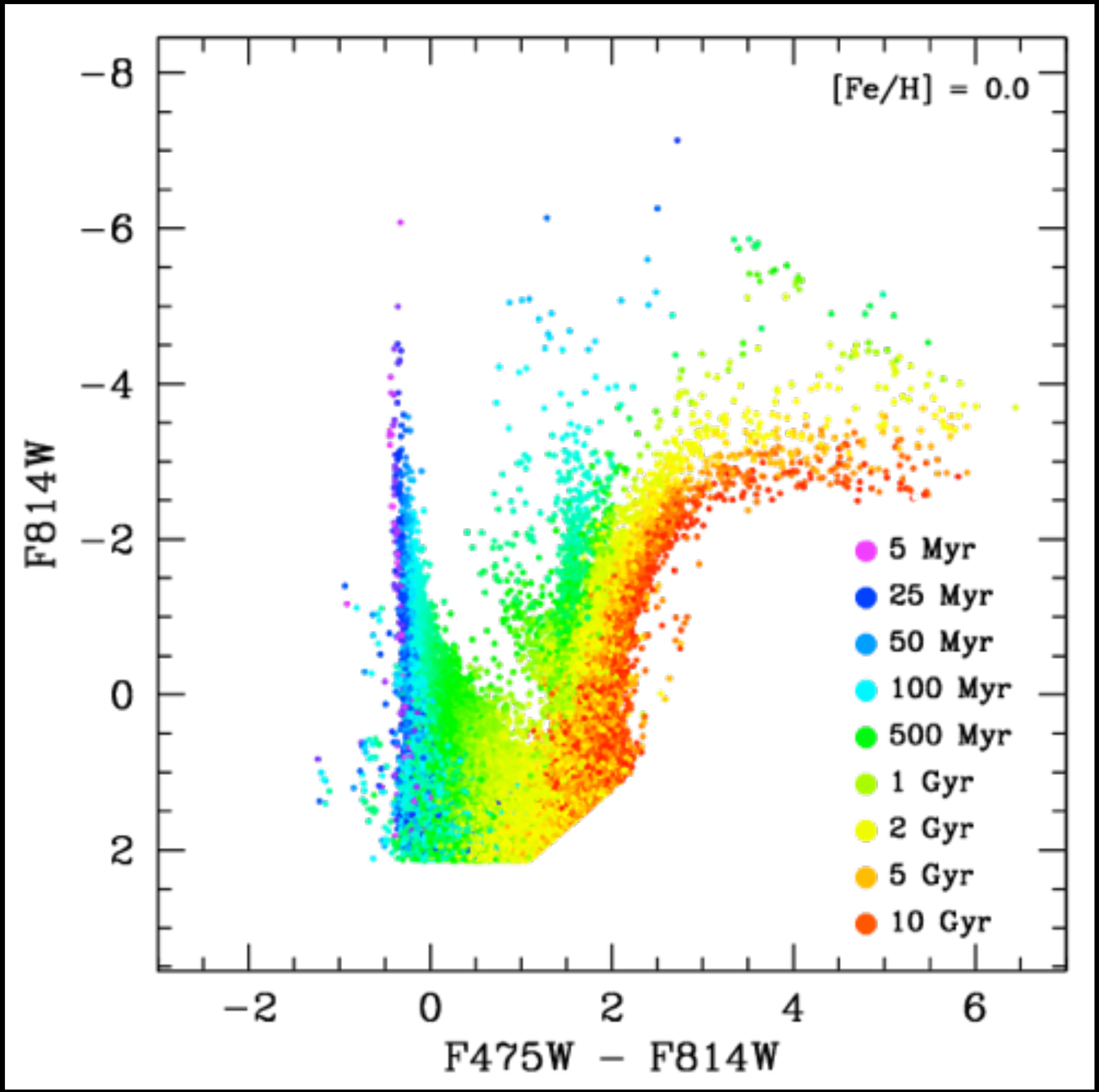
Movie Credit: Dan Weisz



Unique, redundant information at *all* epochs.

Main sequence turnoff is least ambiguous.

Stars are a clock.

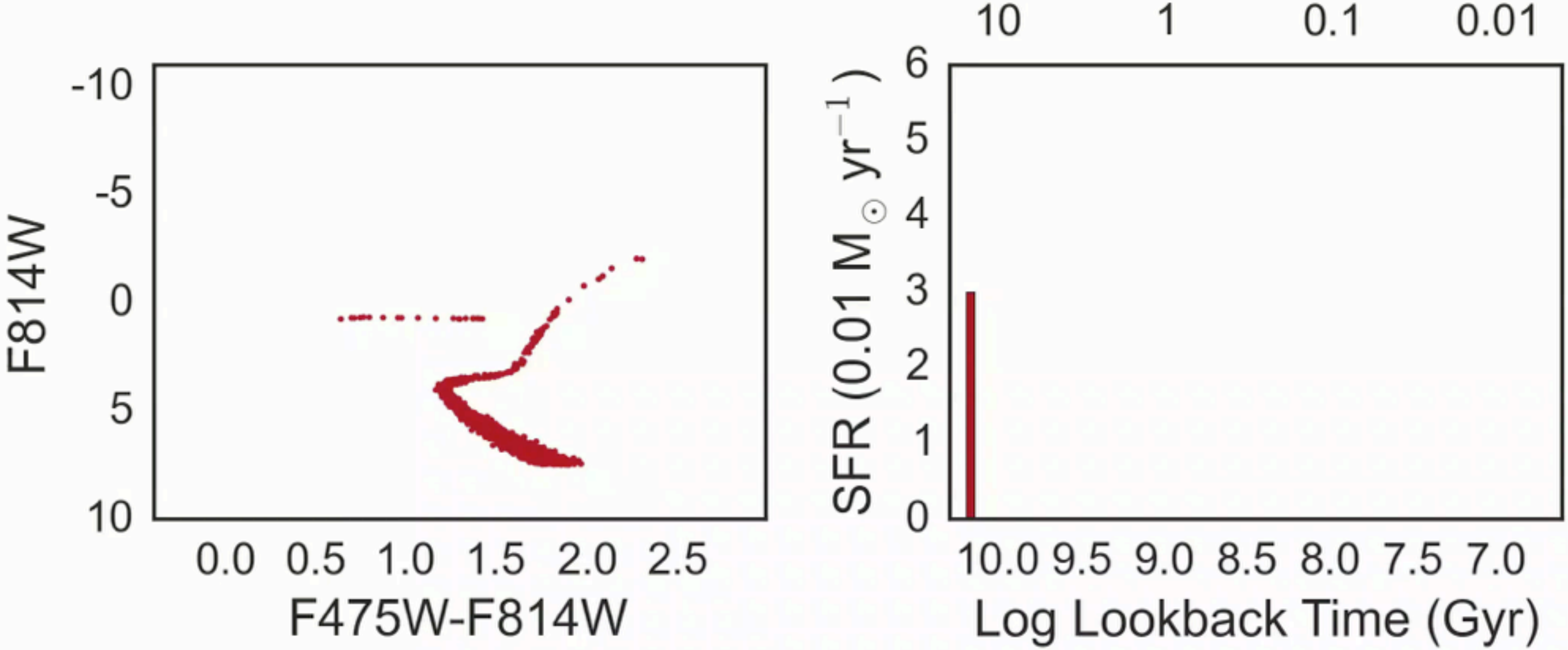


HST optical CMD, color-coded by age

They generically tag the ages of past events, along with the associated masses and energies

Decode CMDs by fitting both location of features and relative #'s of ★s

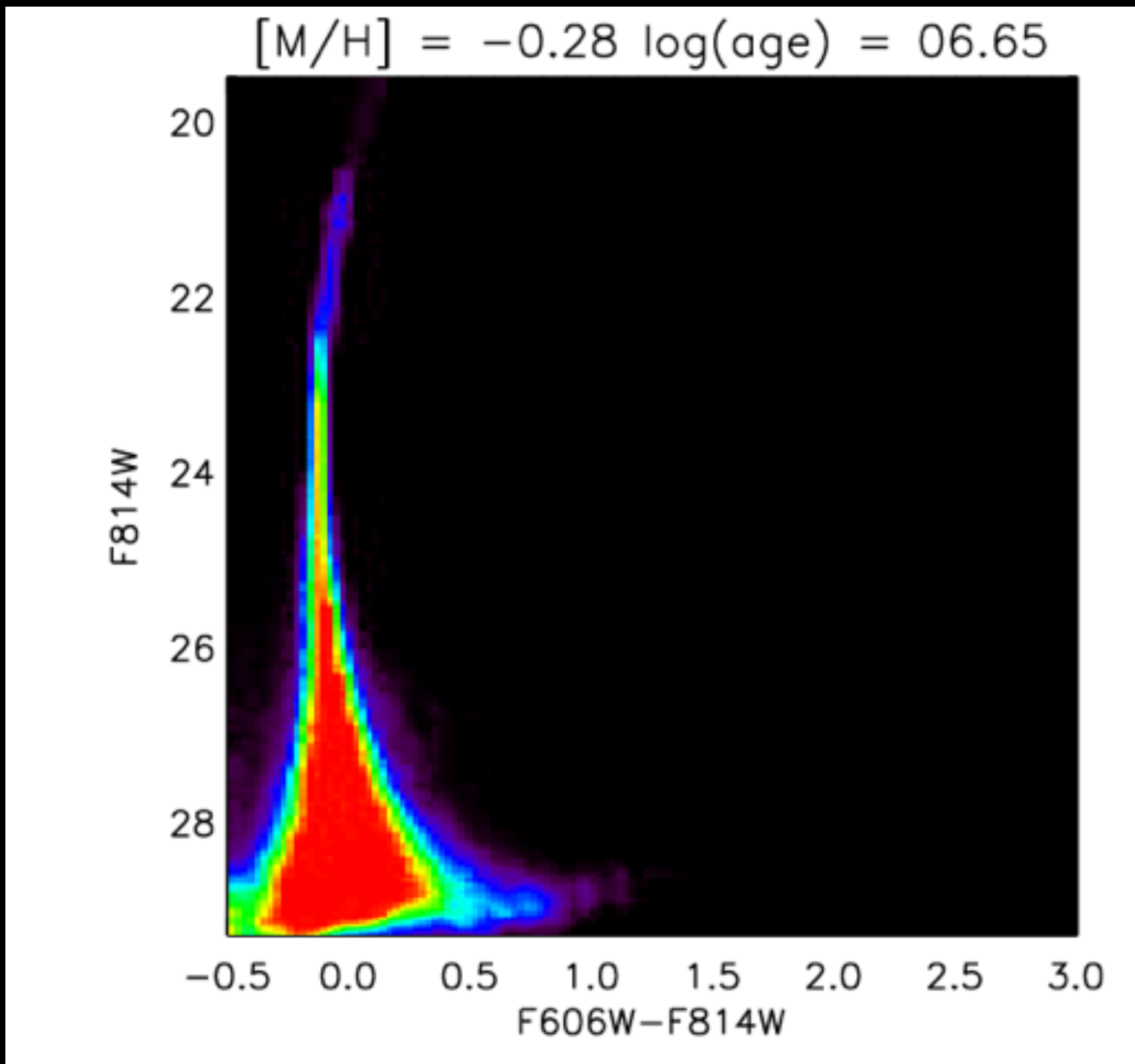
Movie Credit: Dan Weisz

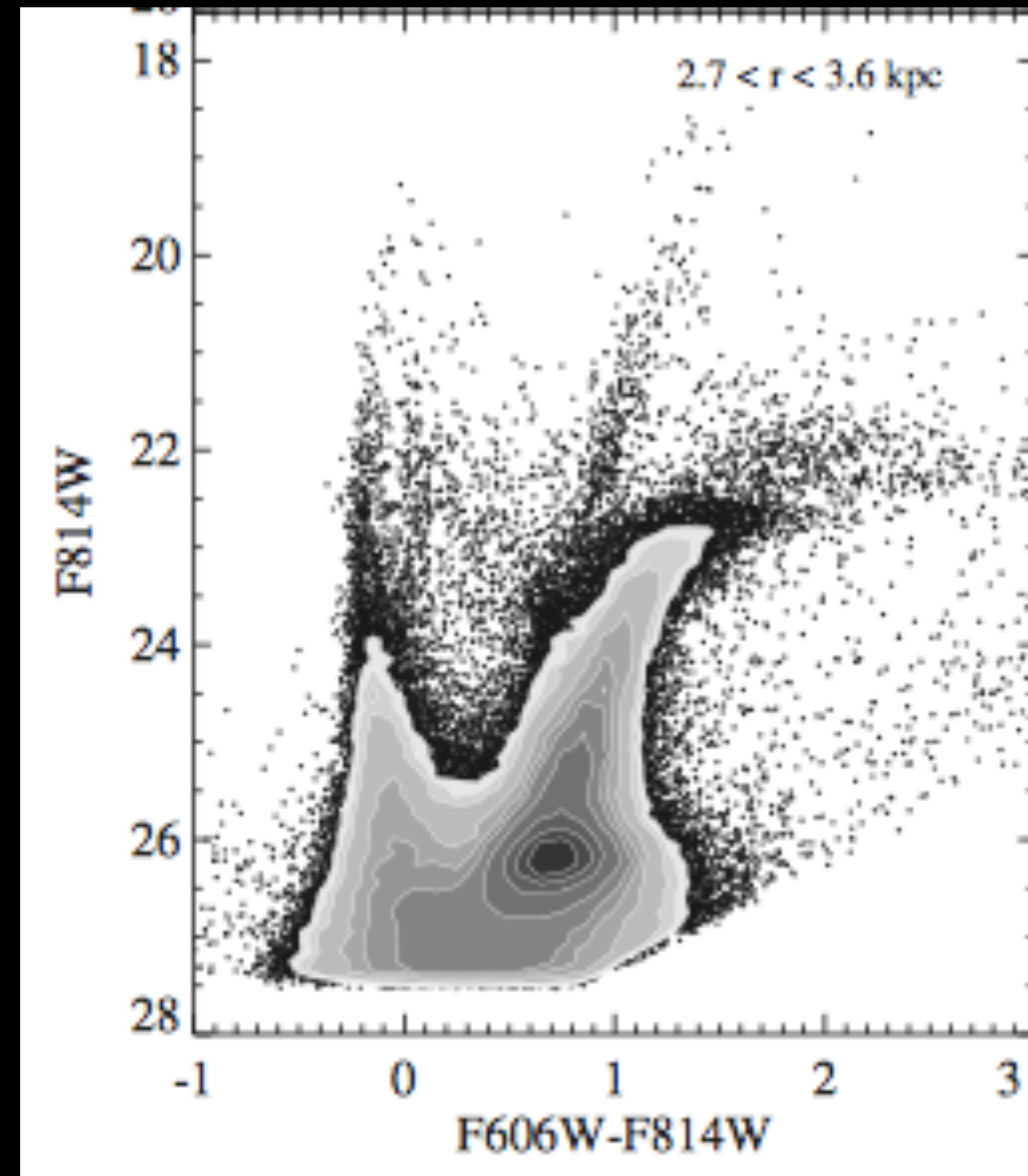


Derive star formation histories (SFHs)

Caveat: sensitive to stellar interiors, atmospheres, winds, & lifetimes

Use different age, Fe/H models as a basis set for modeling the CMD

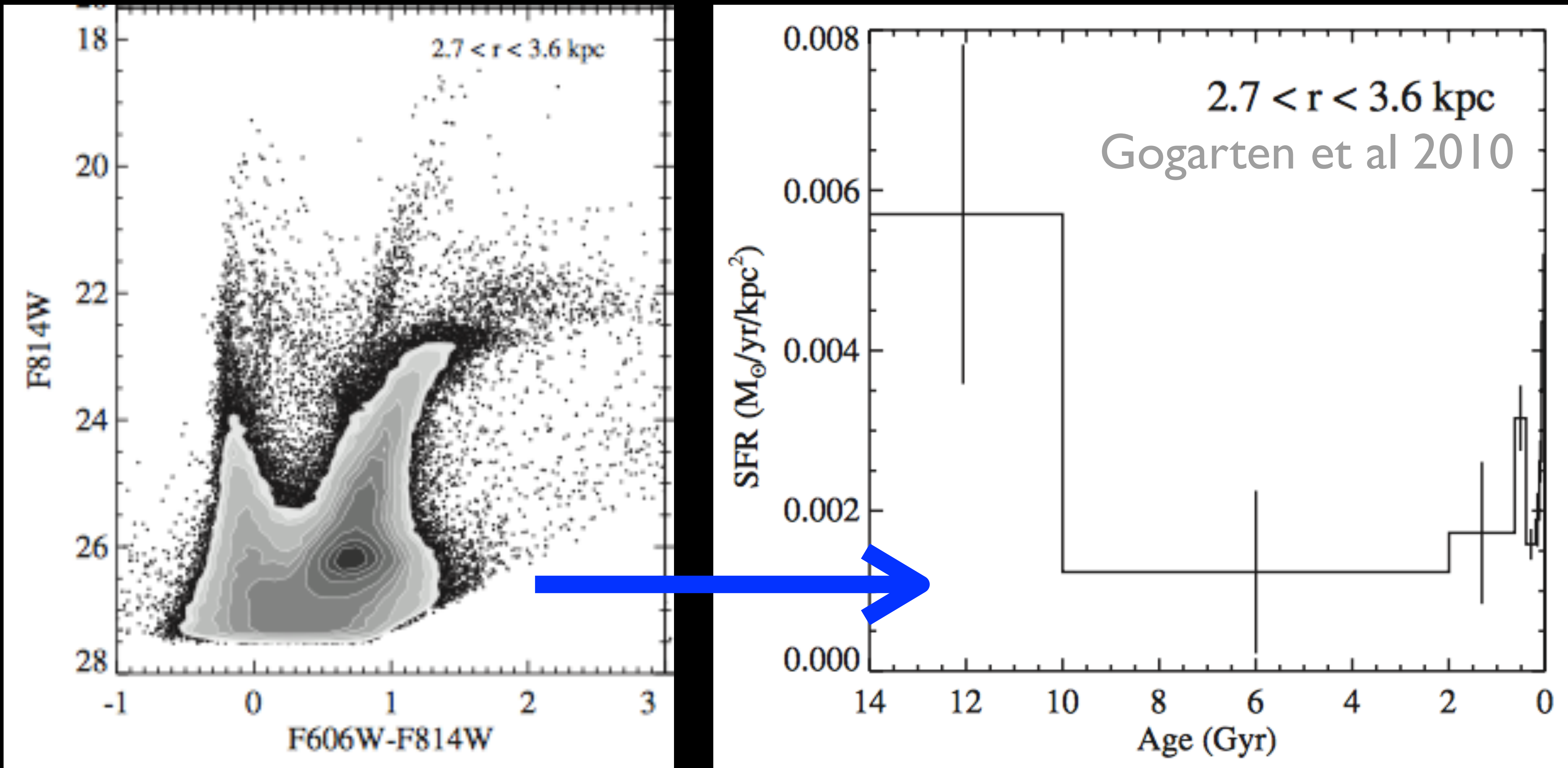




Weights give SFR, Fe/H at each time

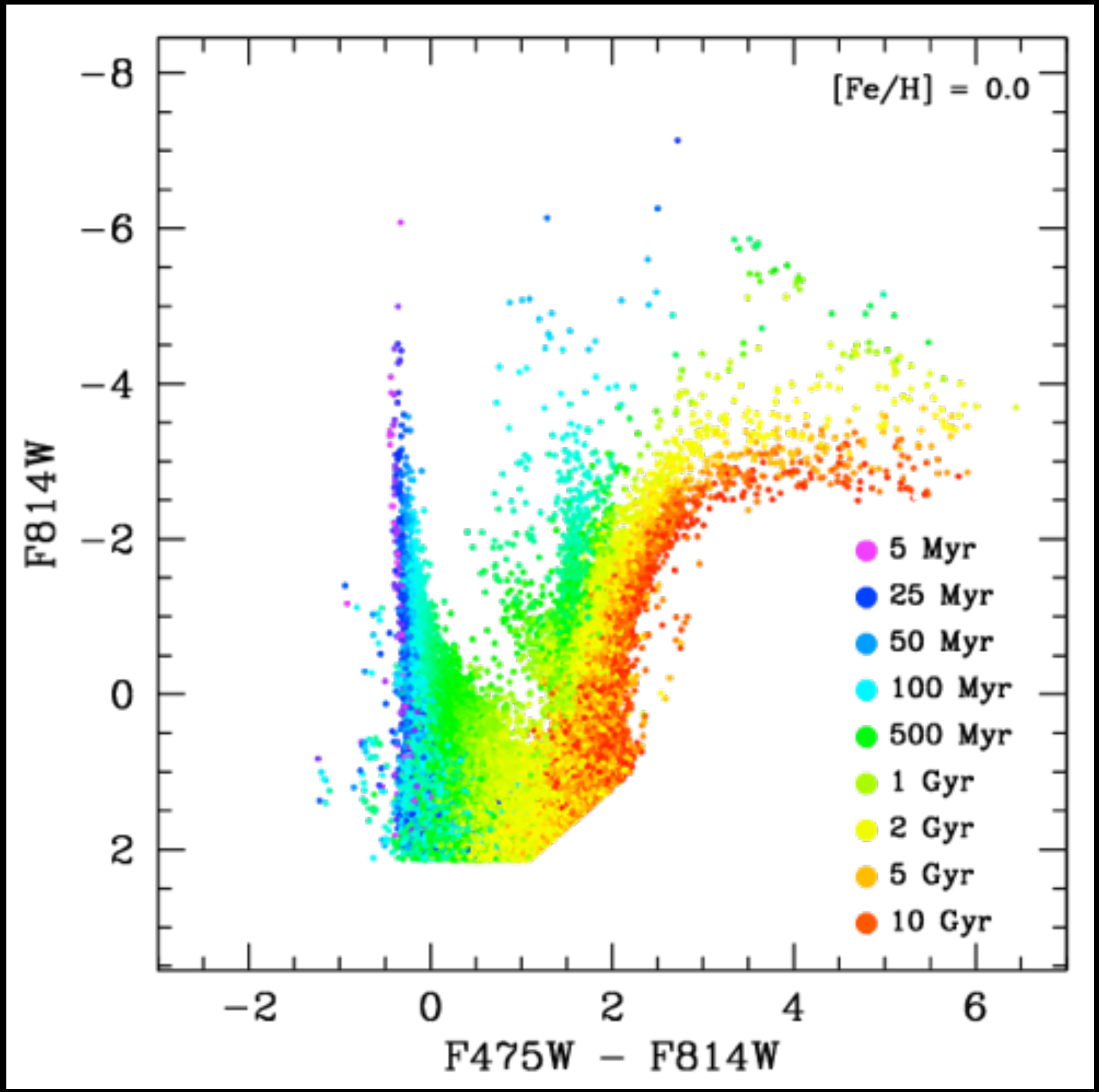
"MATCH", by Andy Dolphin

Star Formation History: SFH = SFR(t)



Constrains: Galaxy formation, metal enrichment,…

New questions about fundamental astrophysical quantities

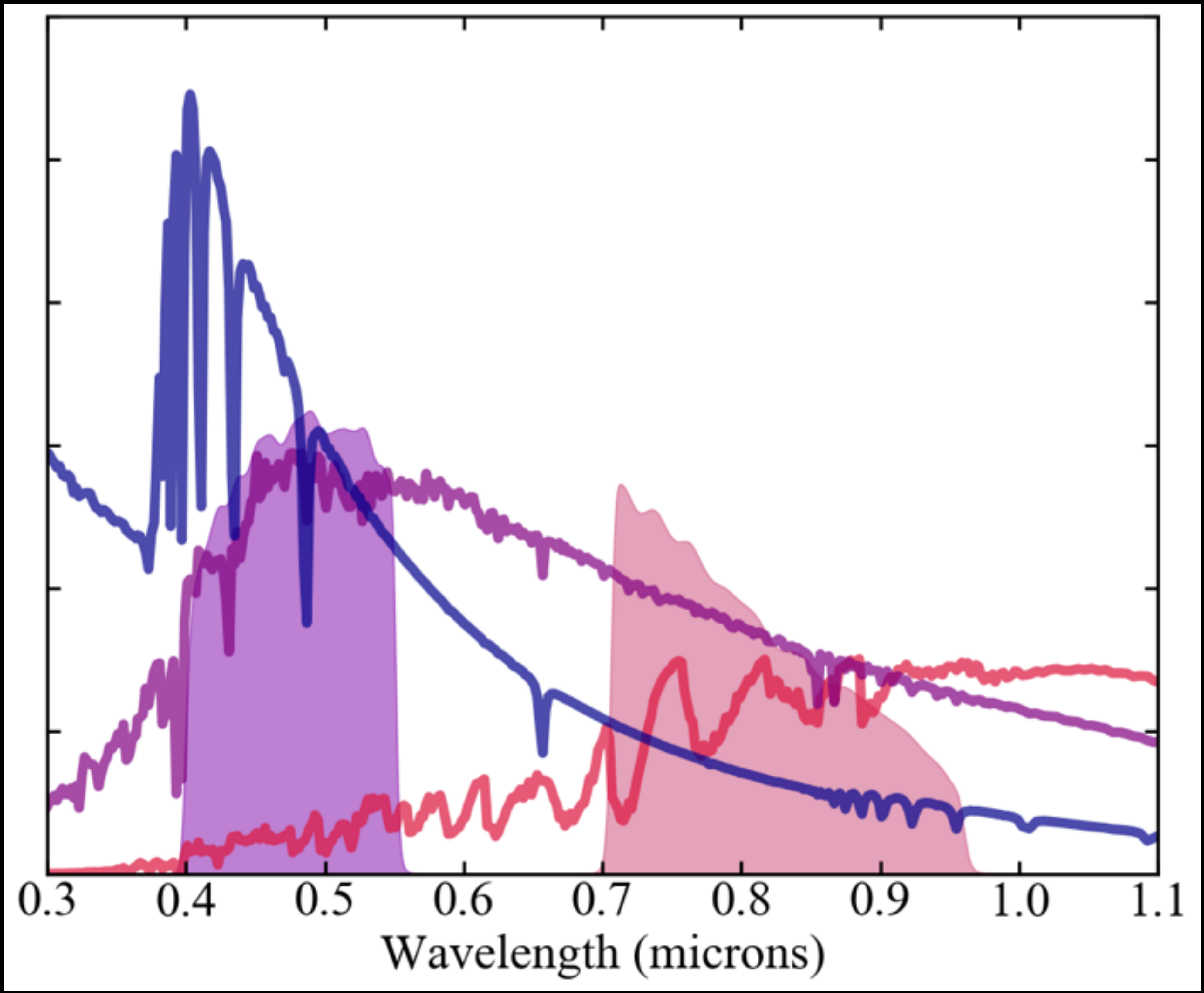


- What ionizing flux and kinetic energy was deposited by stars, and when?
- What stellar masses are evolving at the present time?
- What are timescales for forming unusual systems (HMXB, Be stars, etc)?

What do resolved stellar population studies require?

- Wavelength coverage (colors)
- Depth (more CMD features)
- Resolution (more stars)

Wavelength coverage: needed to probe stellar temperature



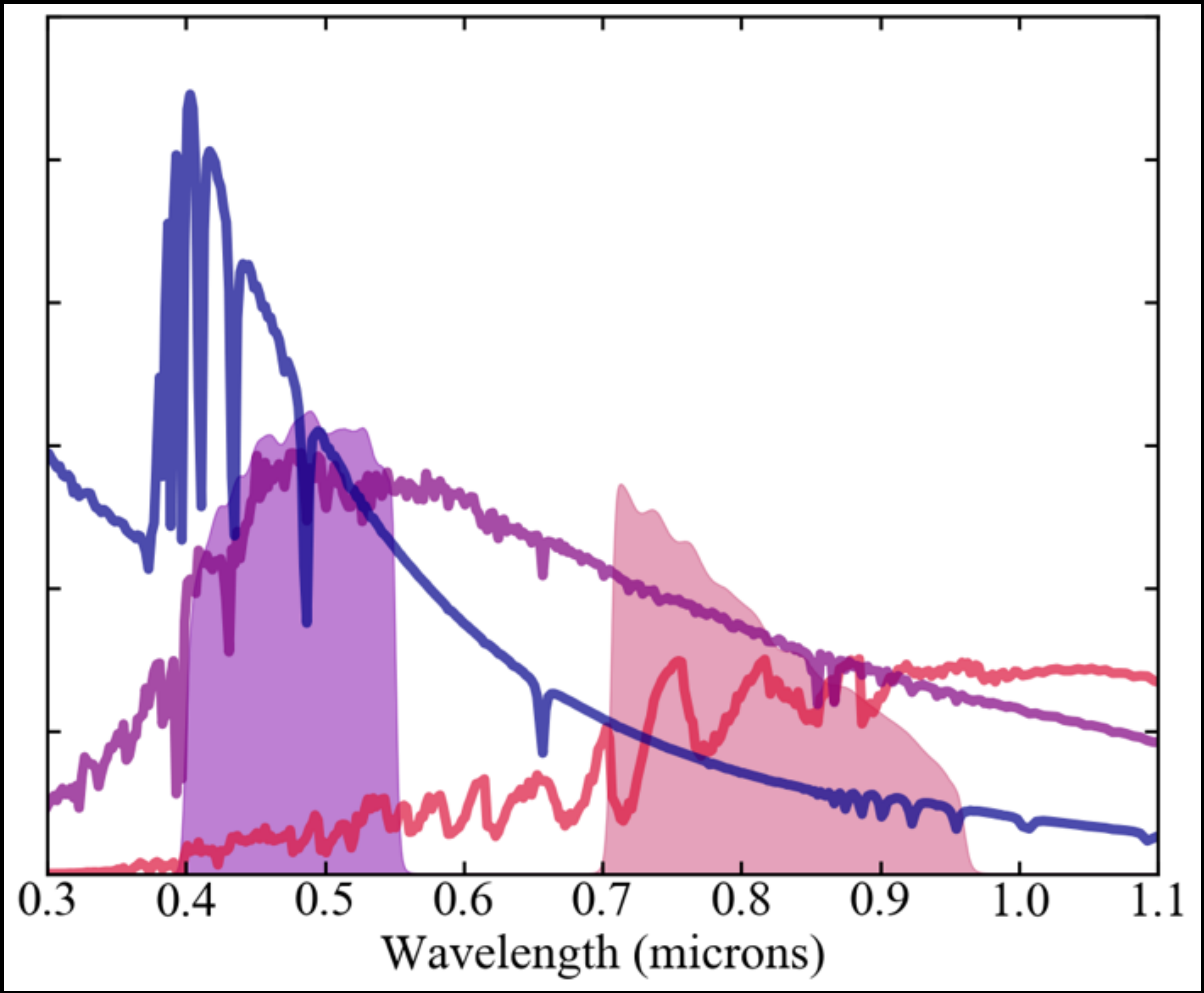
10,000K

5,500K

3,500K

F475W + F814W

Requires detectability in both filters, different relative fluxes for different T_{eff}



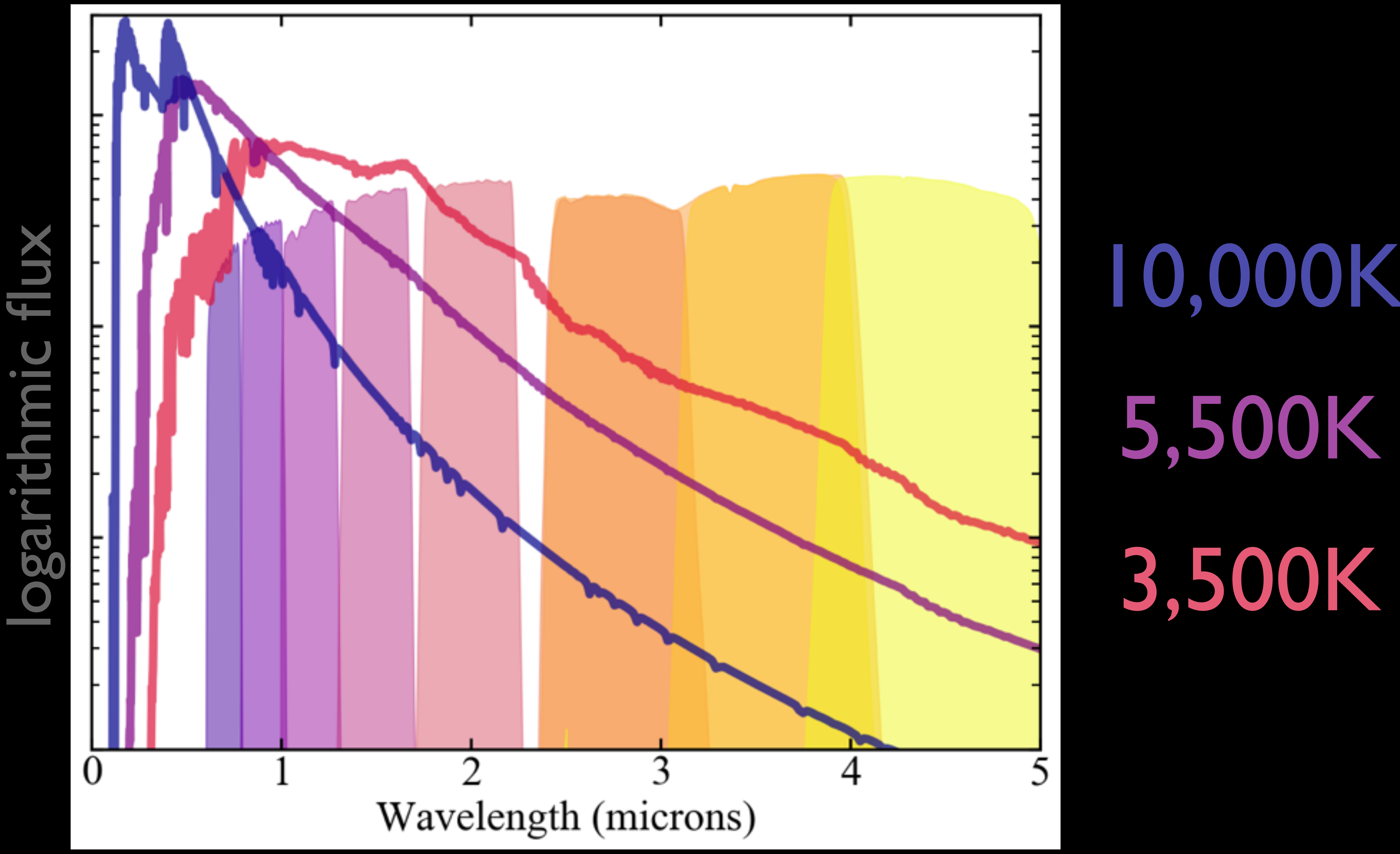
10,000K

5,500K

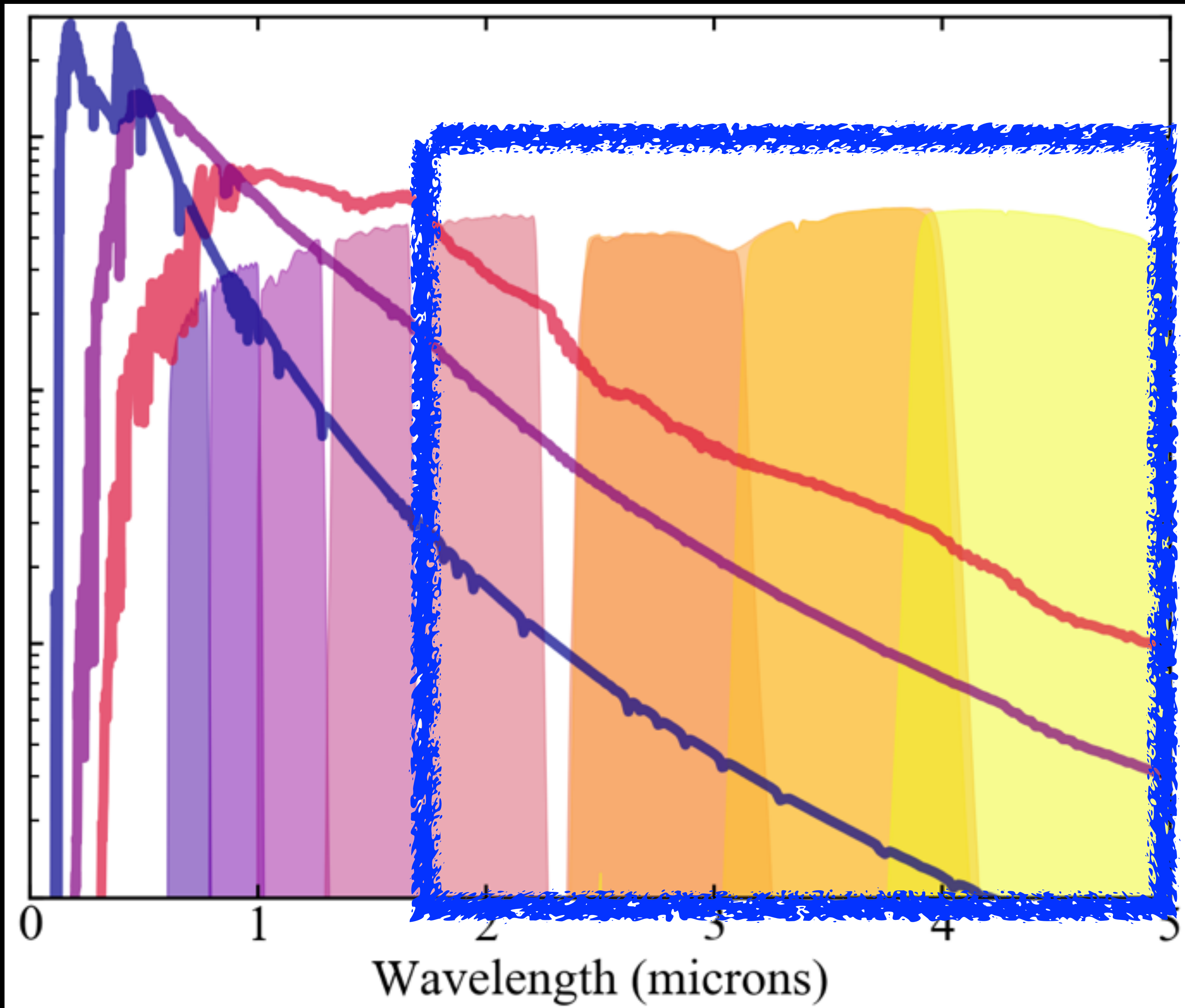
3,500K

F475W + F814W

JWST NIRCAM Wide Filters



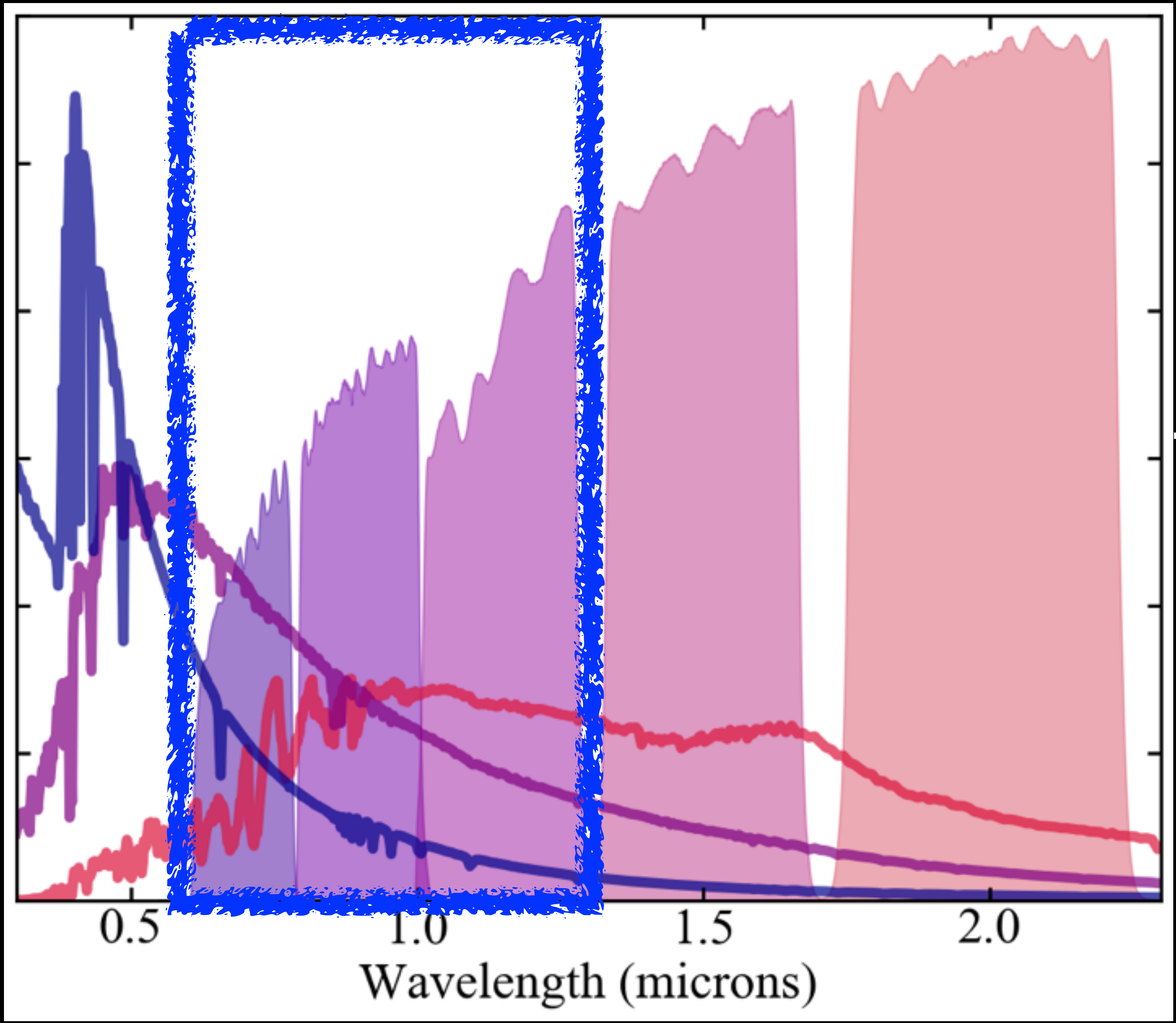
Long-wavelength broad-band colors less informative



Relative fluxes similar for all stars

10,000K
5,500K
3,500K

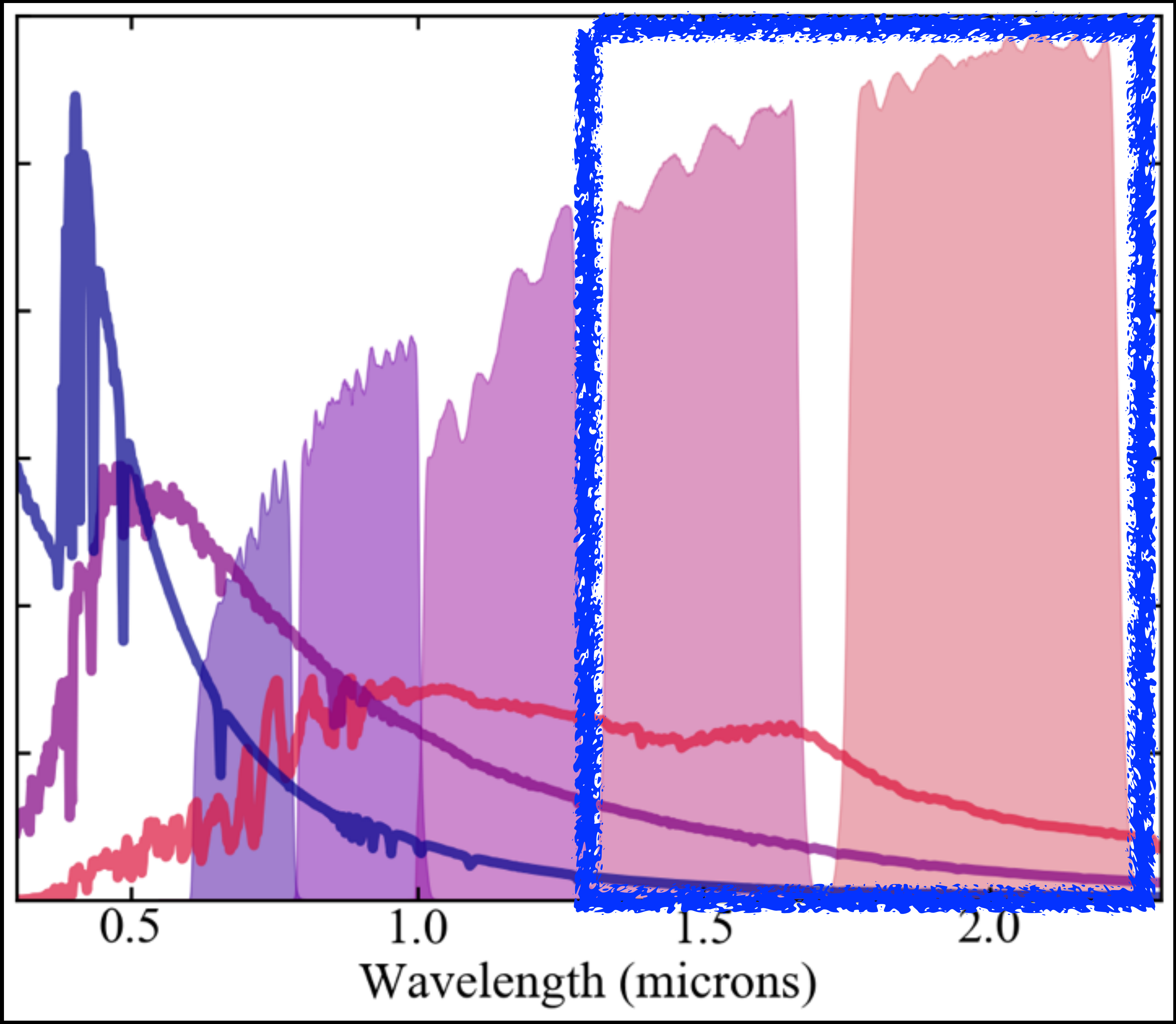
Short-channel NIRCAM Filters



Bluer bands have better T_{eff} sensitivity and brighter fluxes for hot young stars

10,000K
5,500K
3,500K

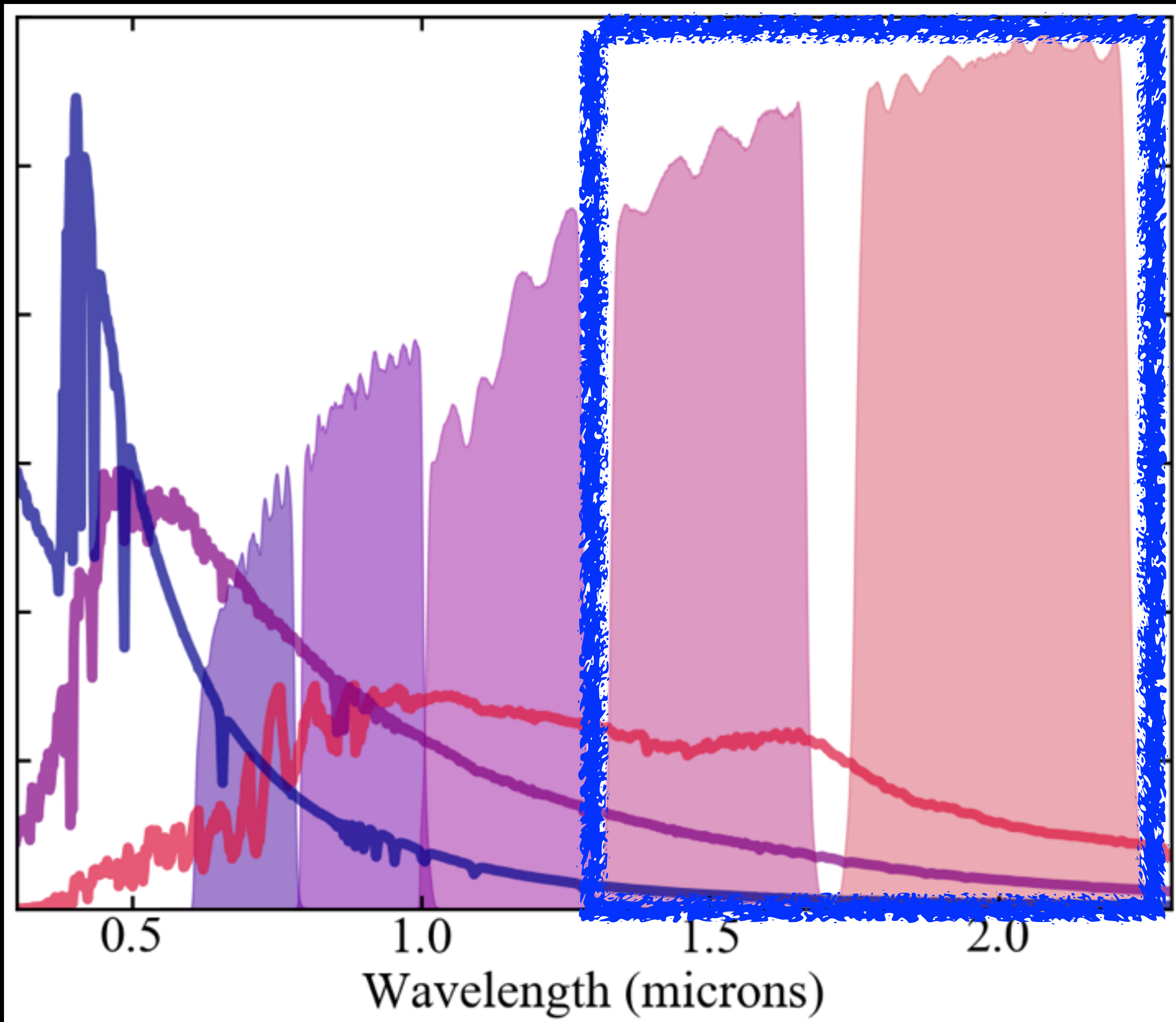
Short-channel NIRCAM Filters



Hot stars will be much harder to detect in redder bands

10,000K
5,500K
3,500K

Flip side: Great for cool stars

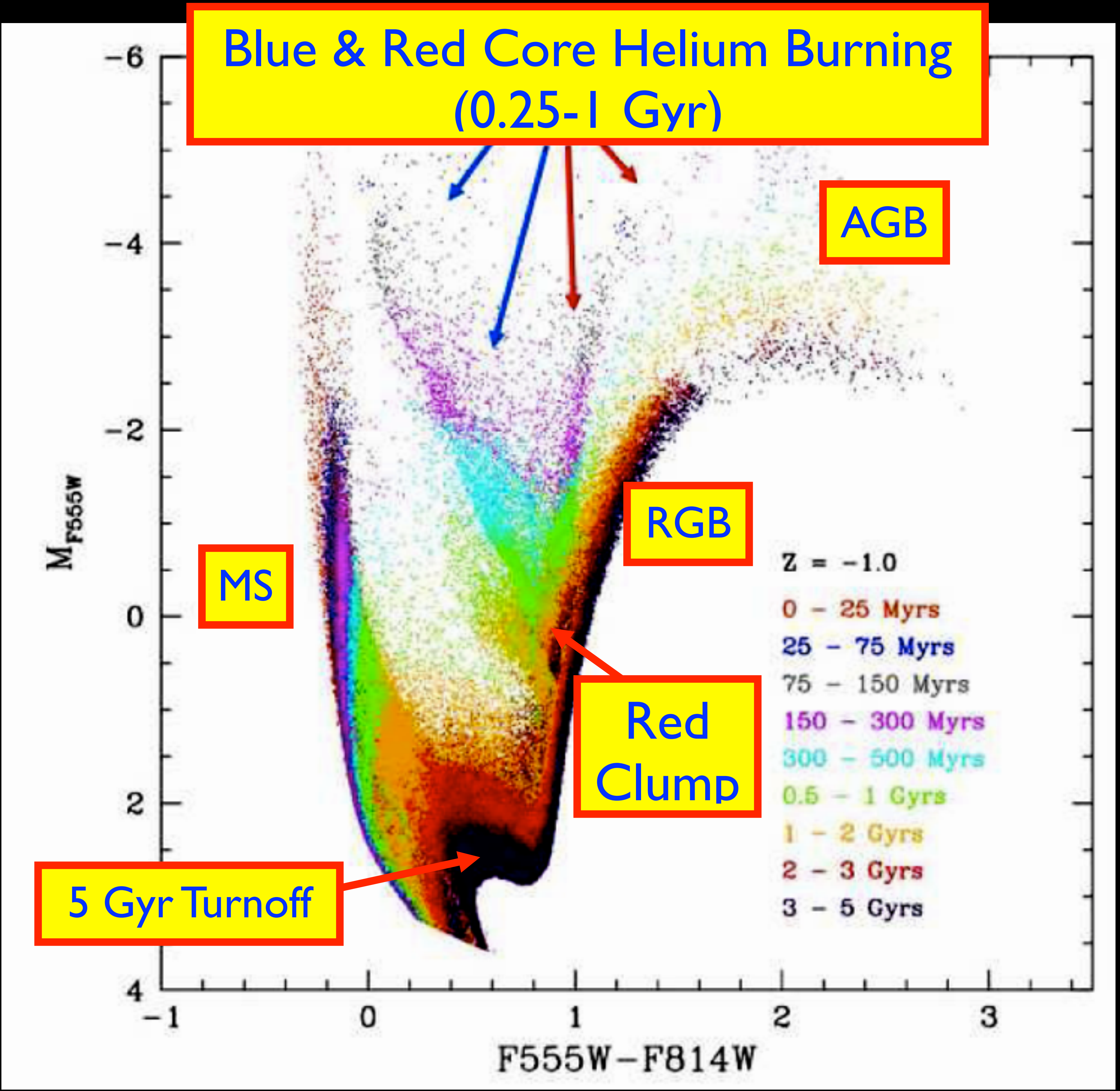


AGB,
RGB,
RSG

10,000K
5,500K
3,500K

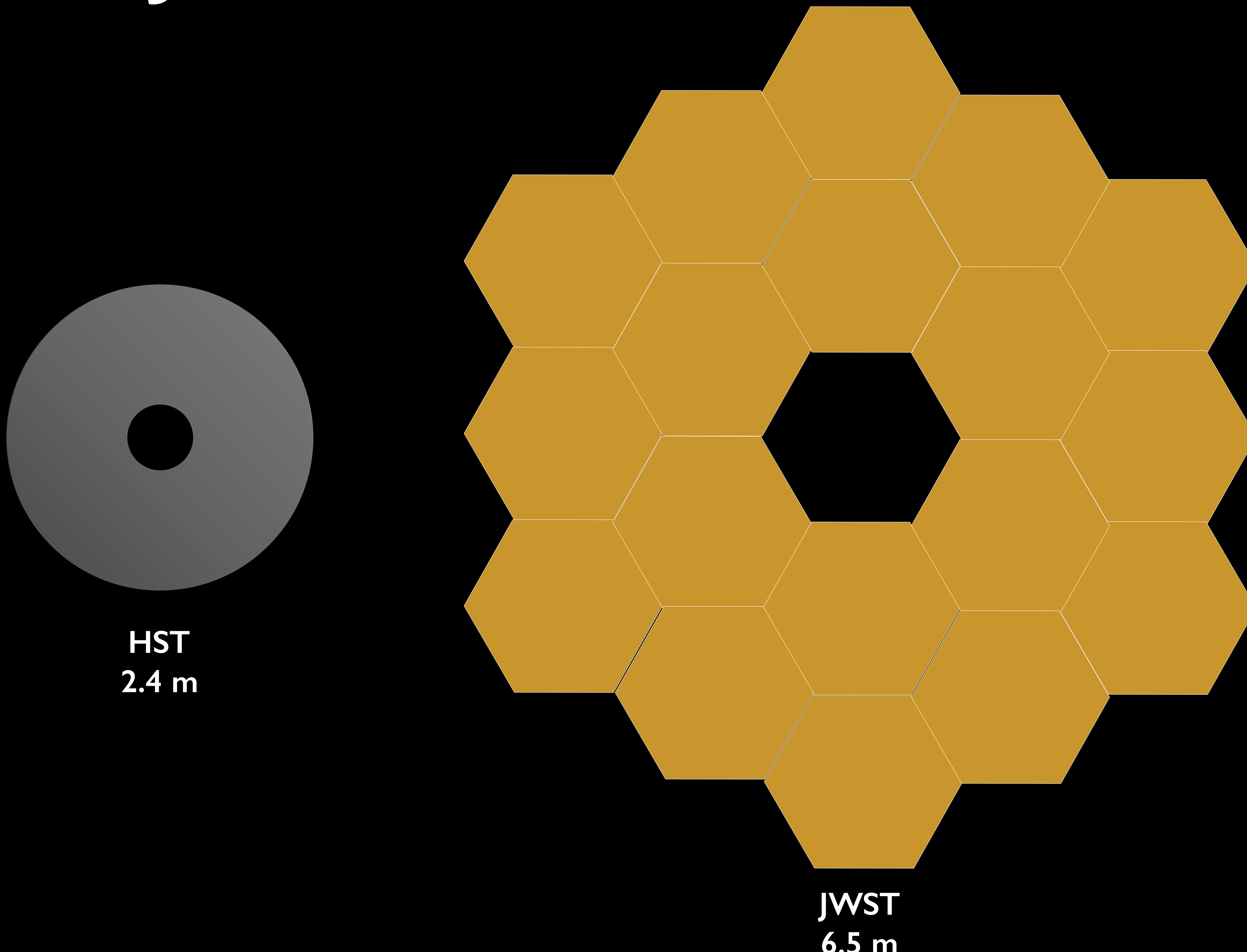
What do resolved stellar population studies require?

- Wavelength coverage (colors)
- Depth (more CMD features)
- Resolution (more stars)



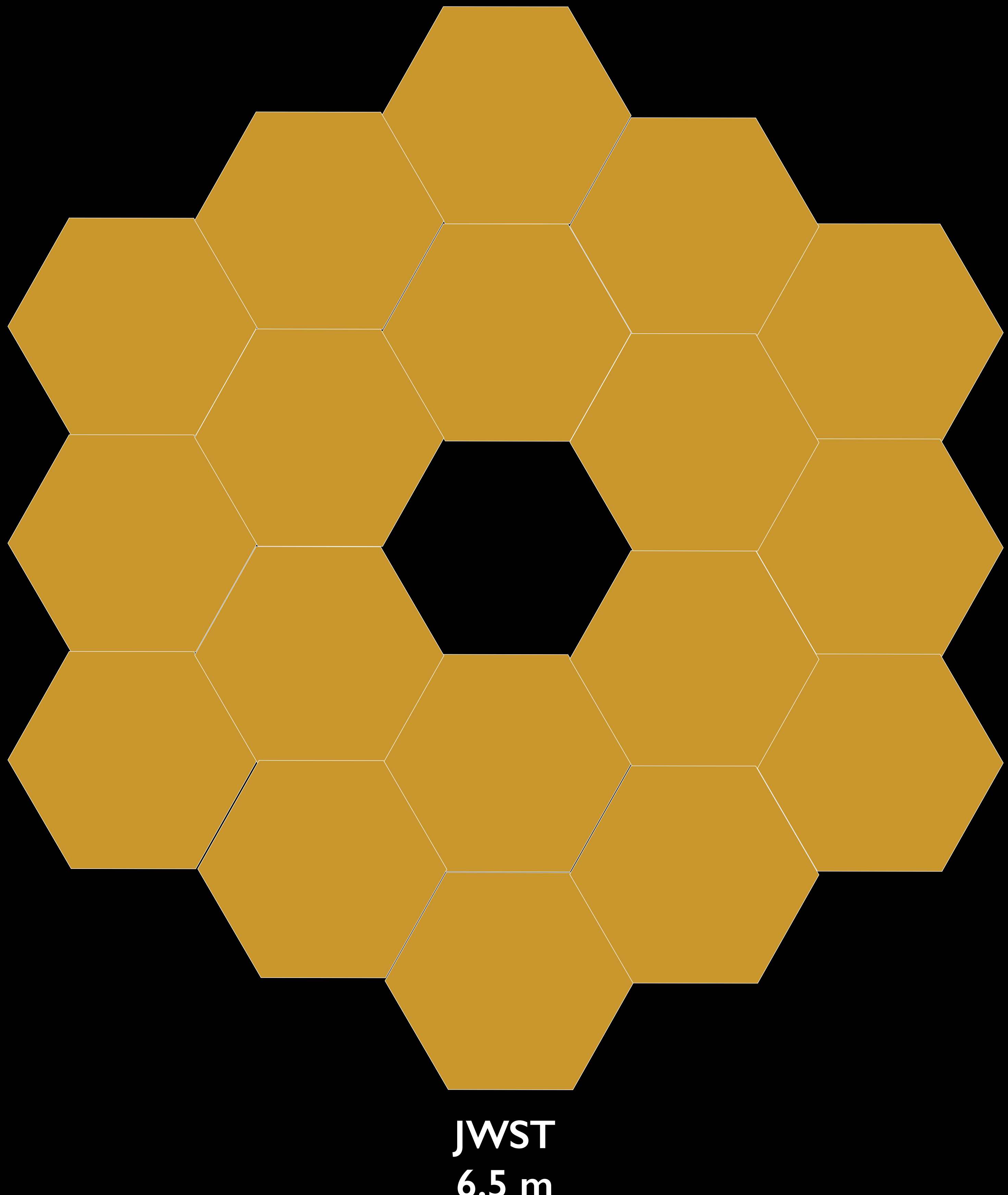
More information, especially for old ages

JWST will be *fast*



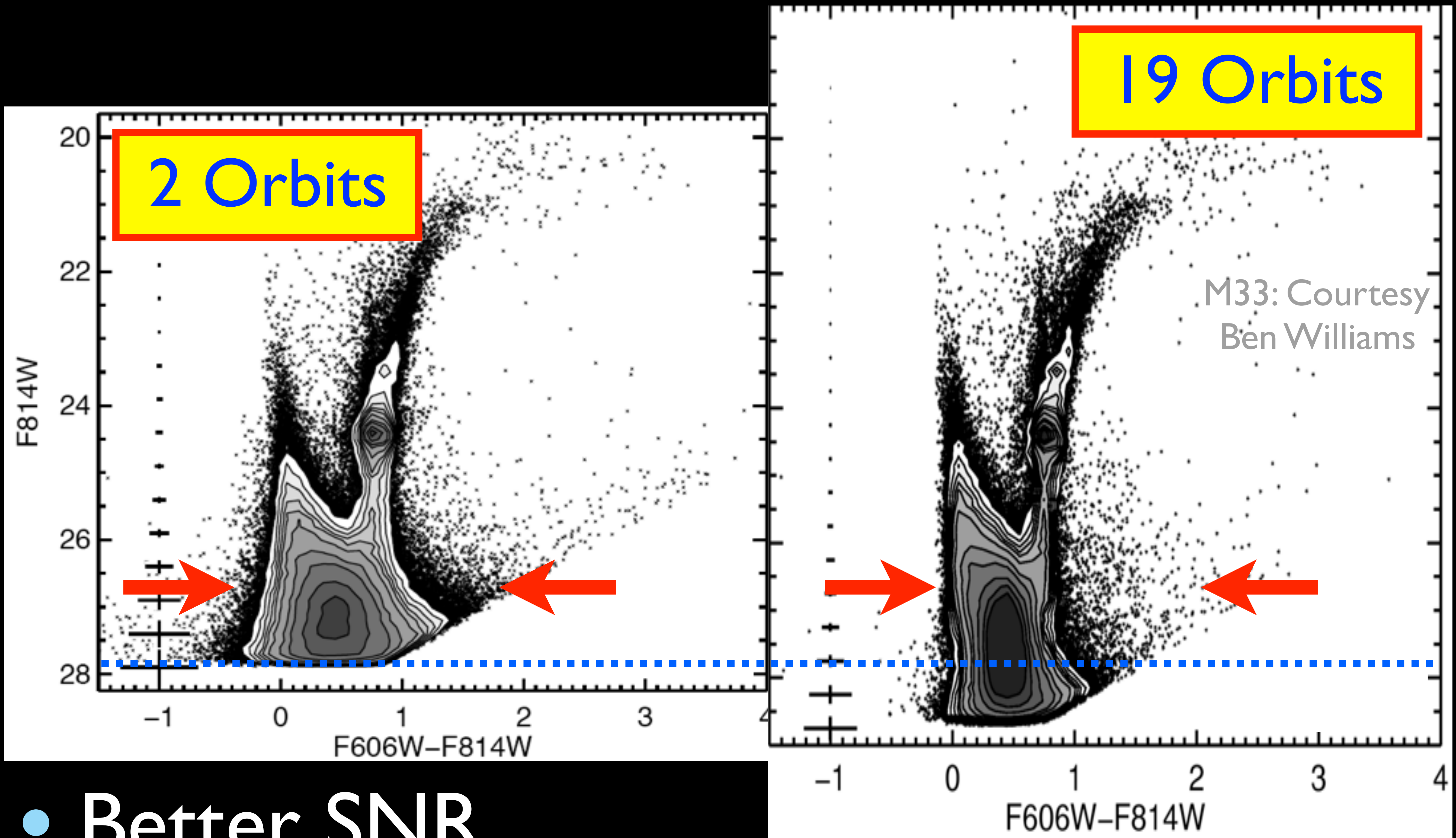
JWST will be *fast*

- 7.3x more photons/s
- 7.3x smaller PSF area = less noise from background



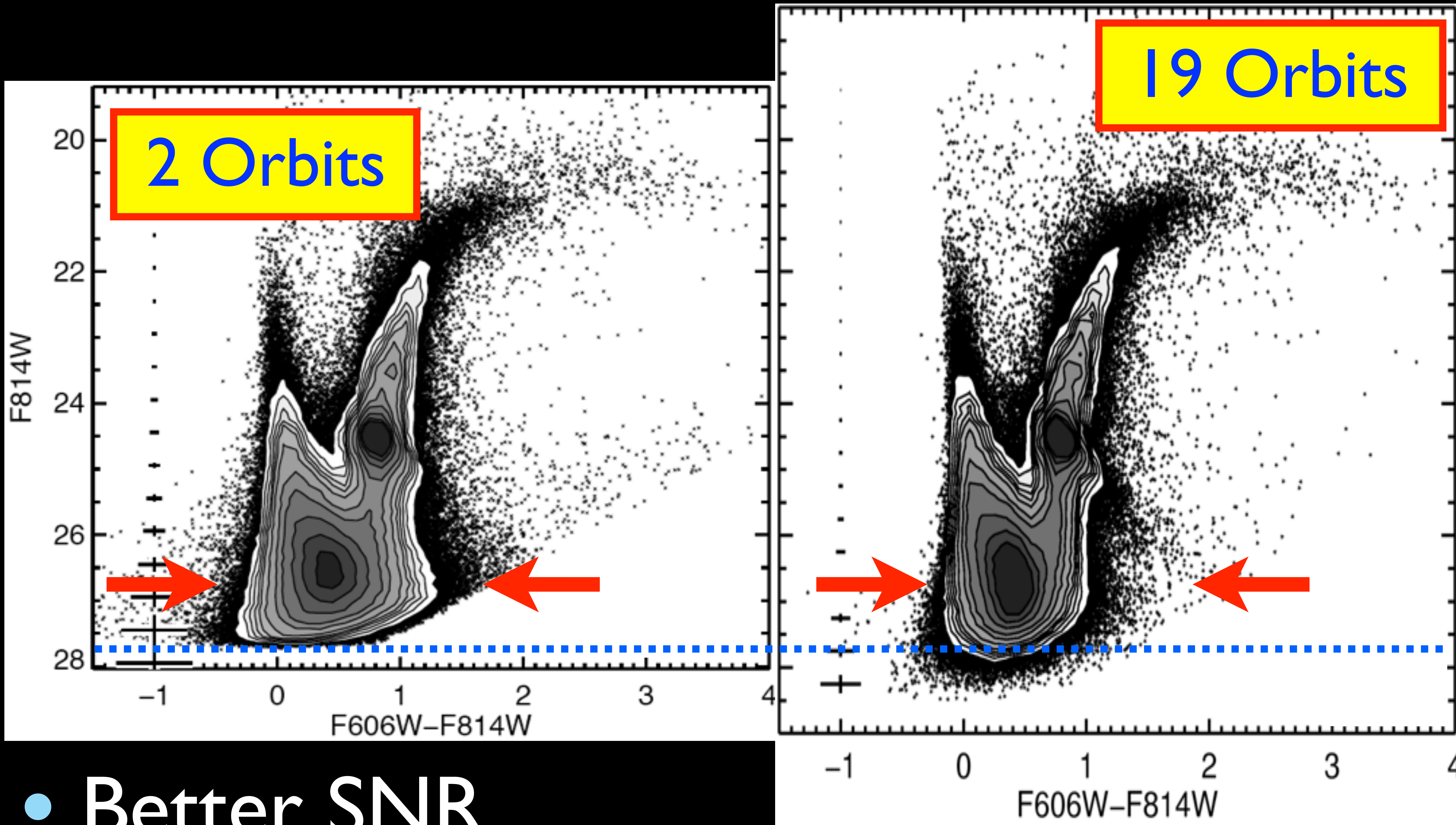
...but depth per integration time only increases for "*uncrowded*" or "*photon-limited*" observations

"Photon-Limited" Regime



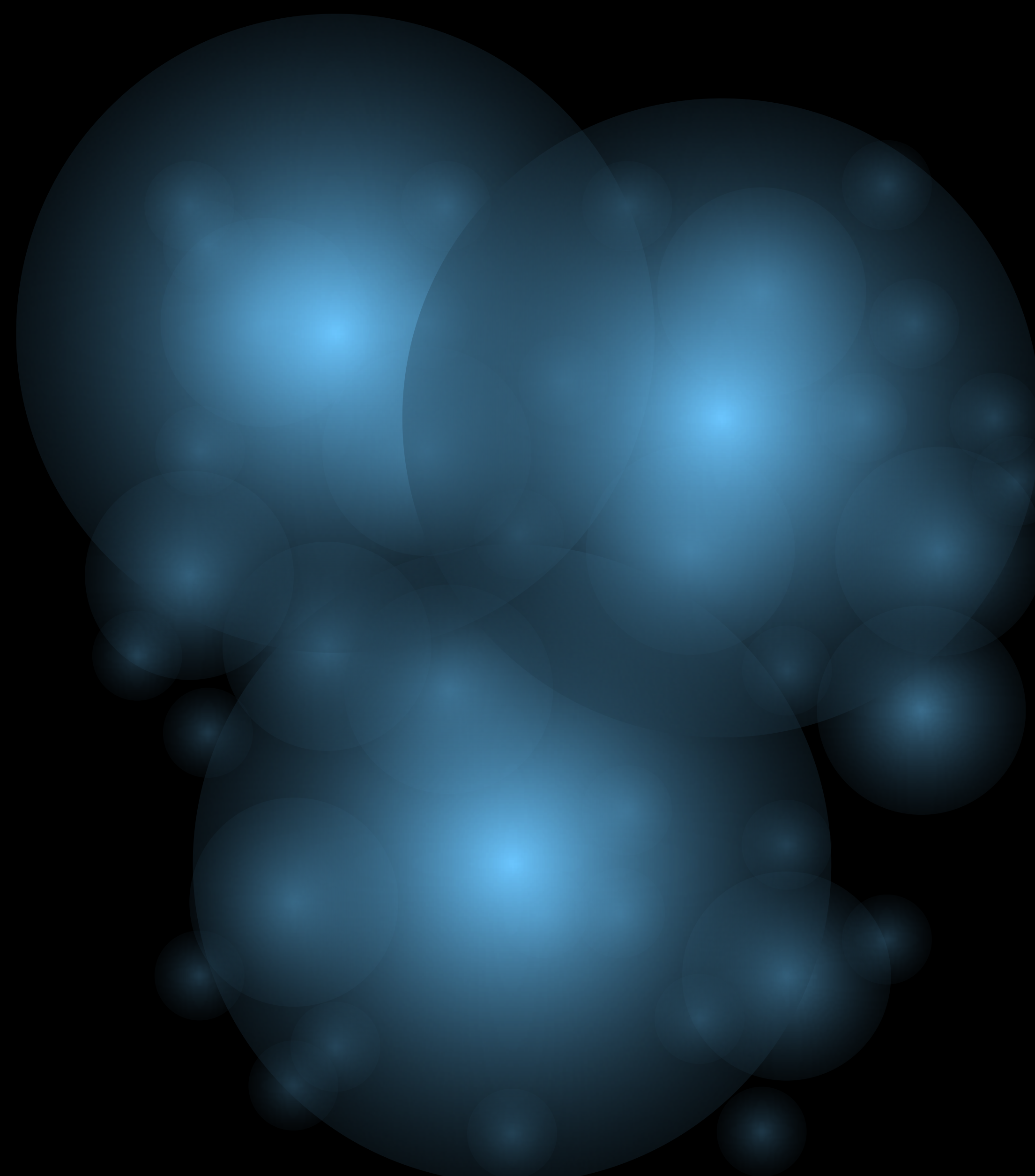
- Better SNR
- Deeper (more, fainter stars)

“Crowding-Limited” Regime

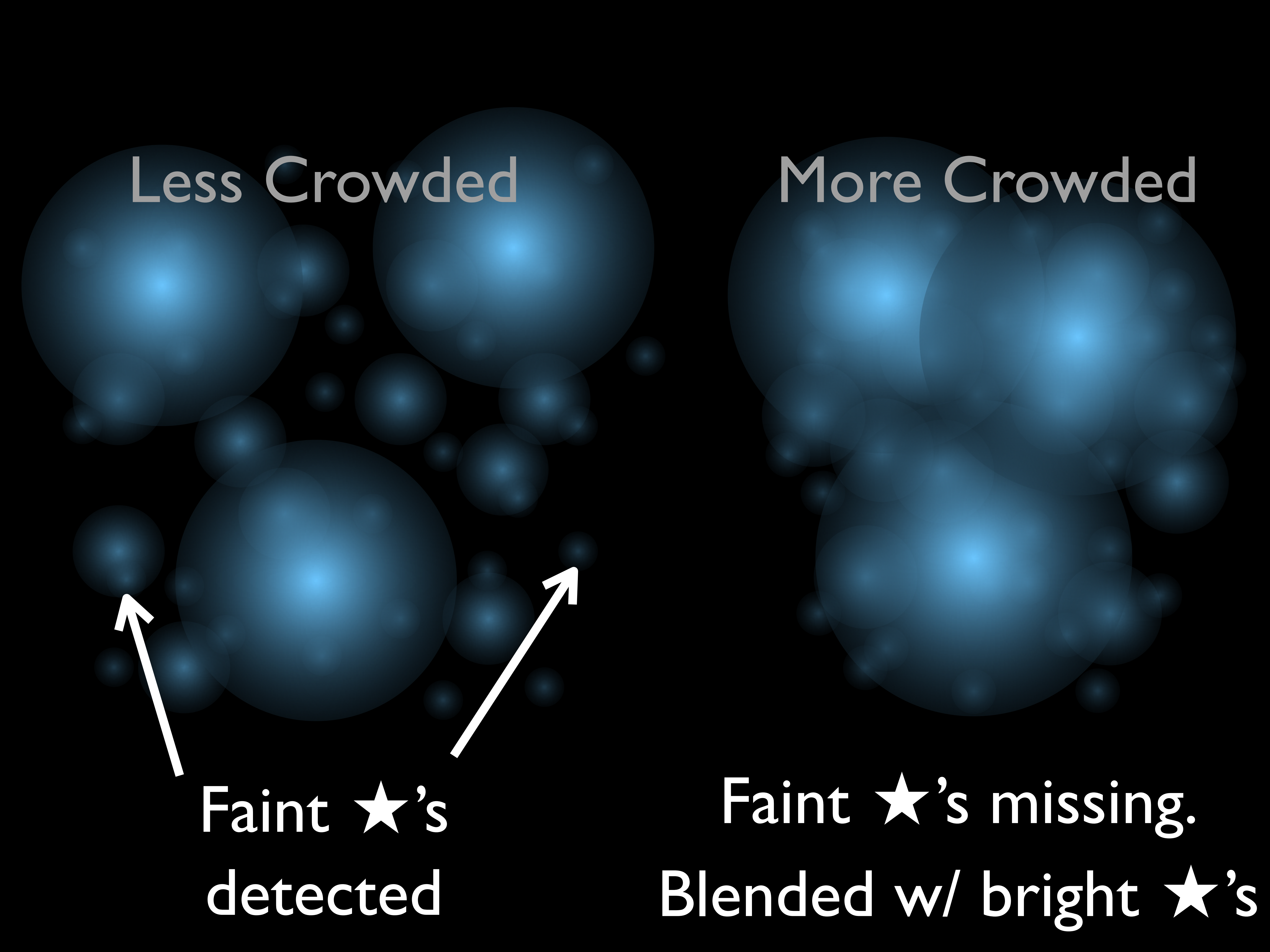


- Better SNR
- No increase in depth (no addt’l stars)

In “crowding-limited” images…

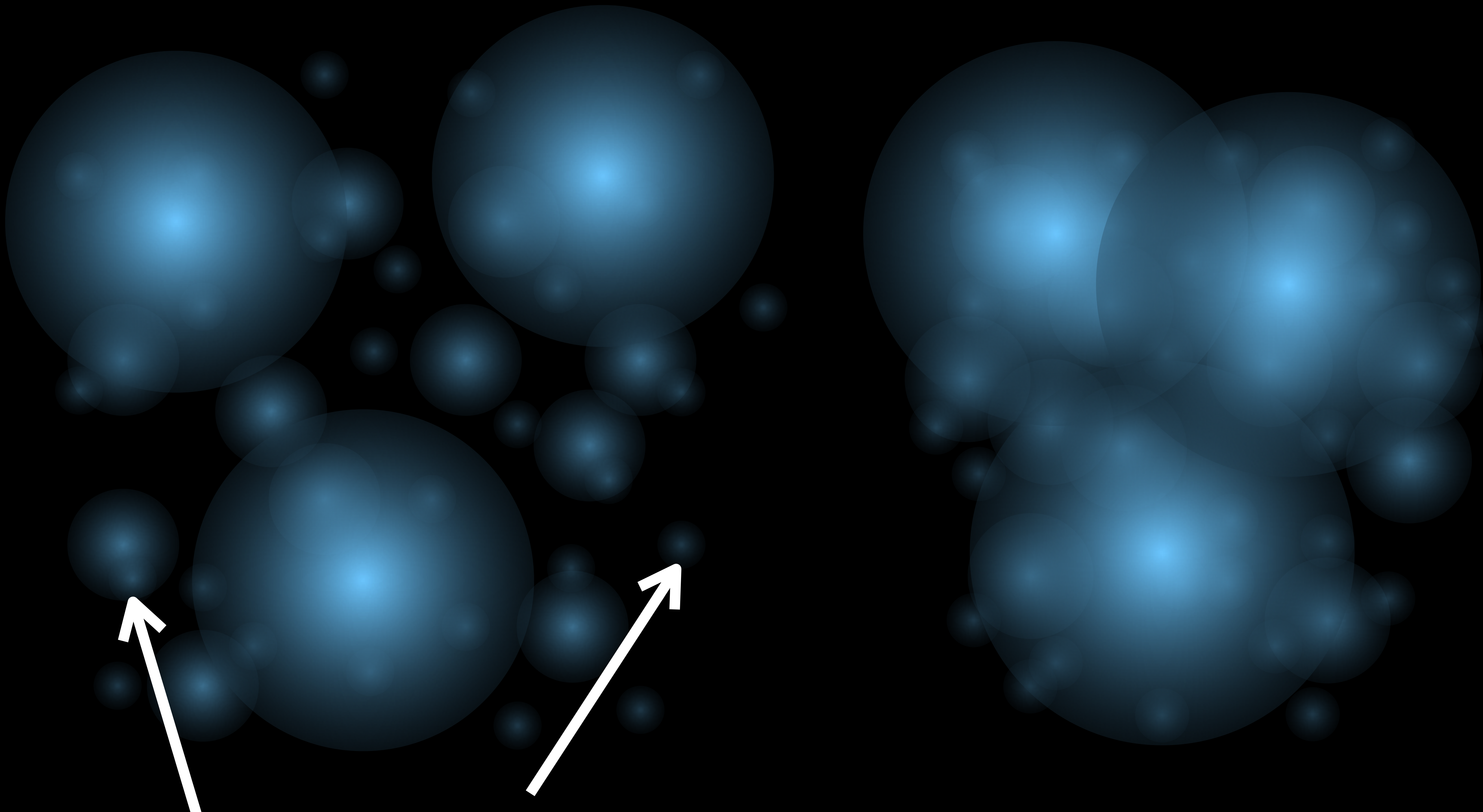


…how faint you see depends on how tightly stars are packed



Less Crowded
More Crowded
Faint ★'s detected
Faint ★'s missing.
Blended w/ bright ★'s

What sets the depth of crowded images?

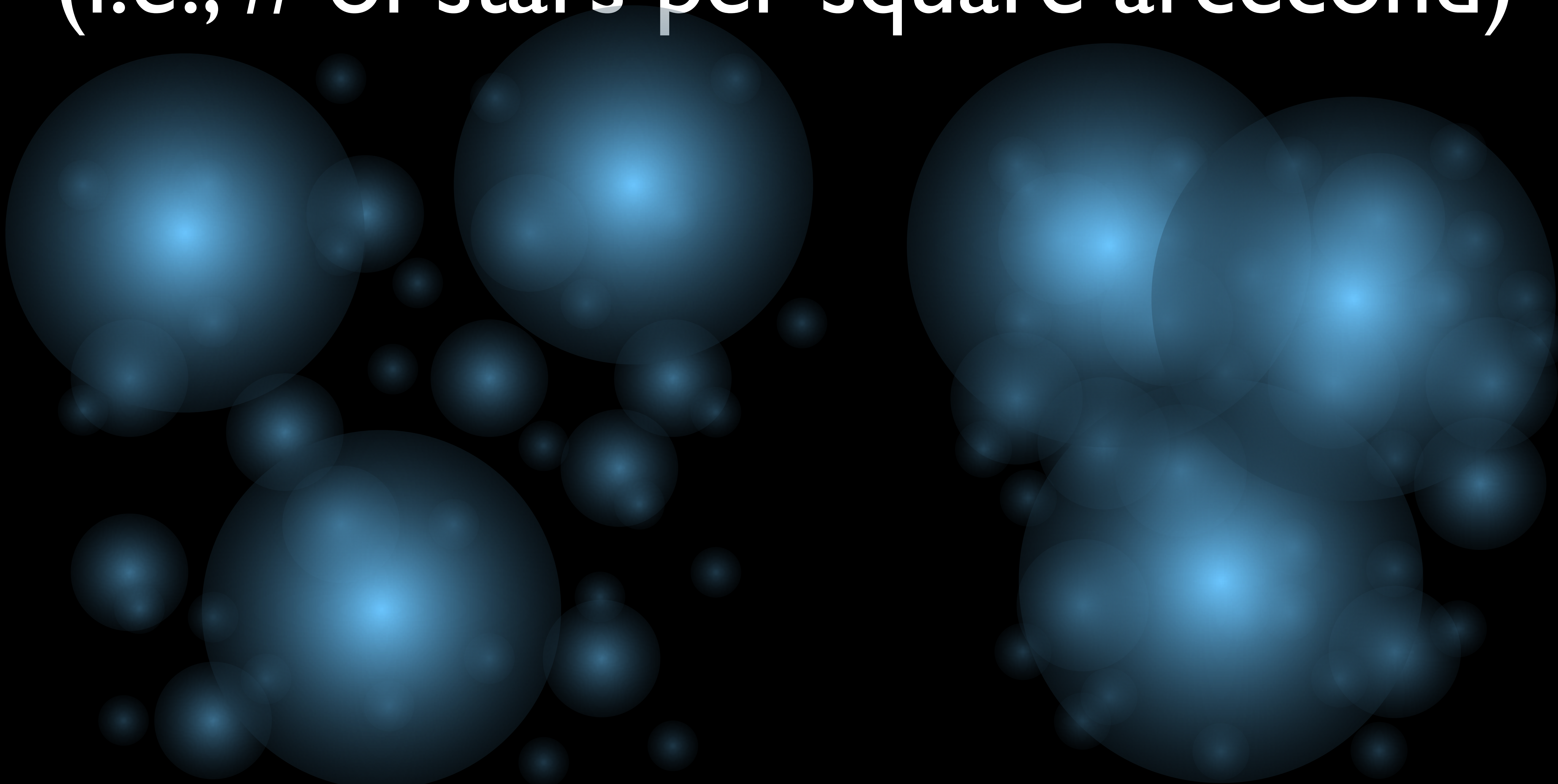


Faint ★'s detected

Faint ★'s missing.
Blended w/ bright ★'s

See simulations by Knut Olsen et al 2003

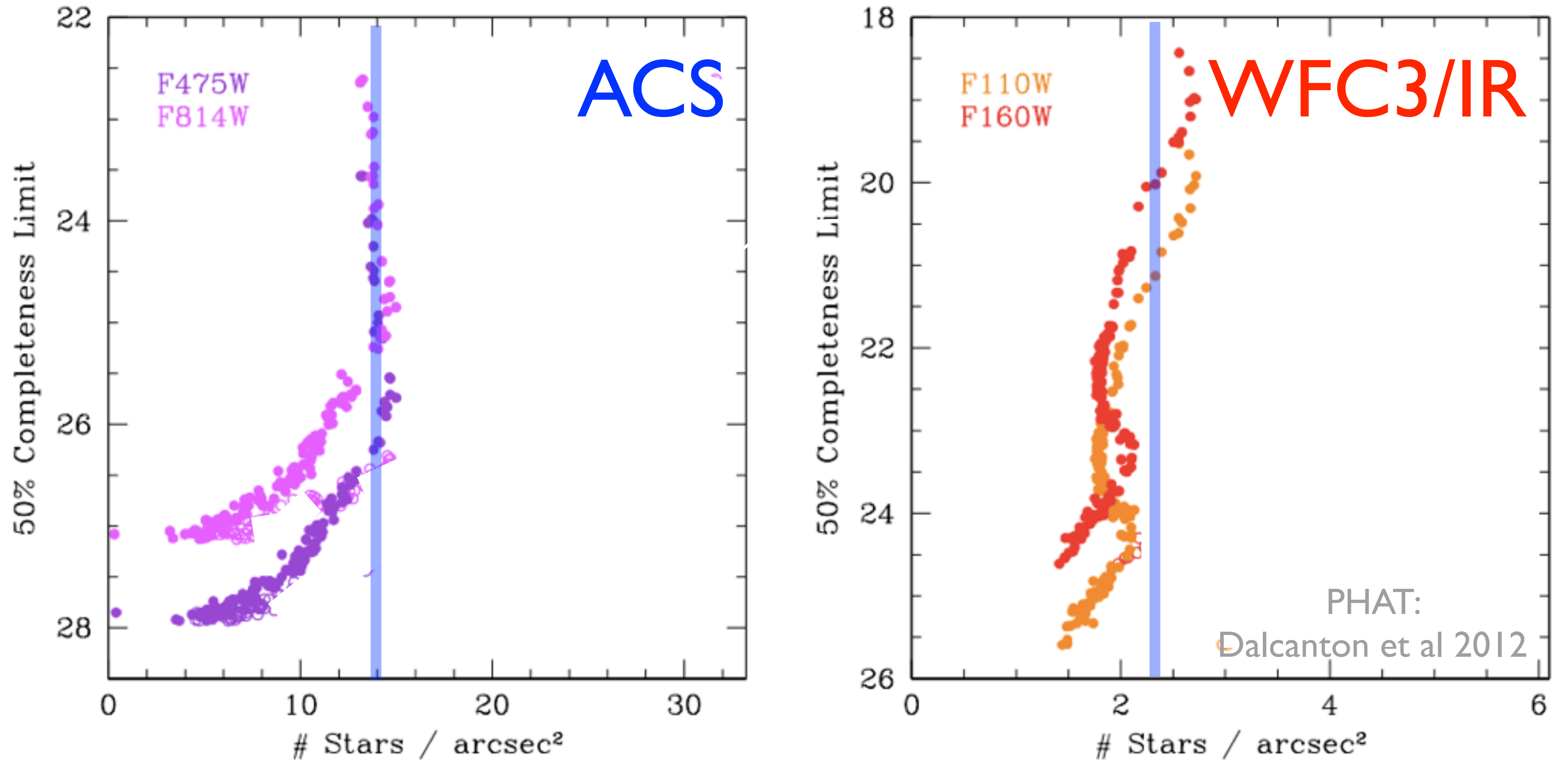
1. Crowding depends on stellar density (i.e., # of stars per square arcecond)



- Intrinsically diffuse
- Close

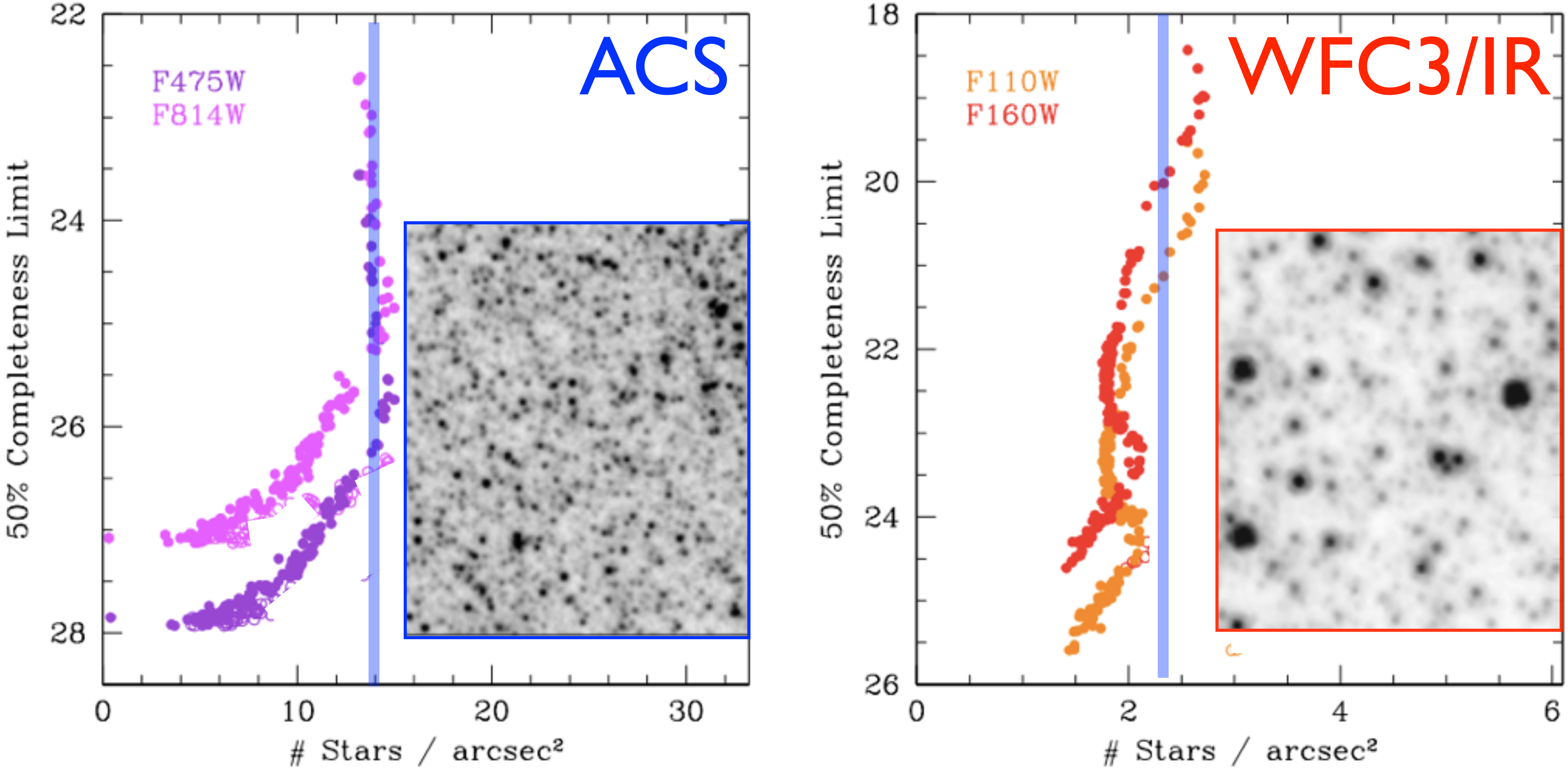
- High ☆ surface density
- Distant

2. Depth depends on maximum # of stars that can be resolved for telescope+instrument



Stellar density vs depth for fields in PHAT

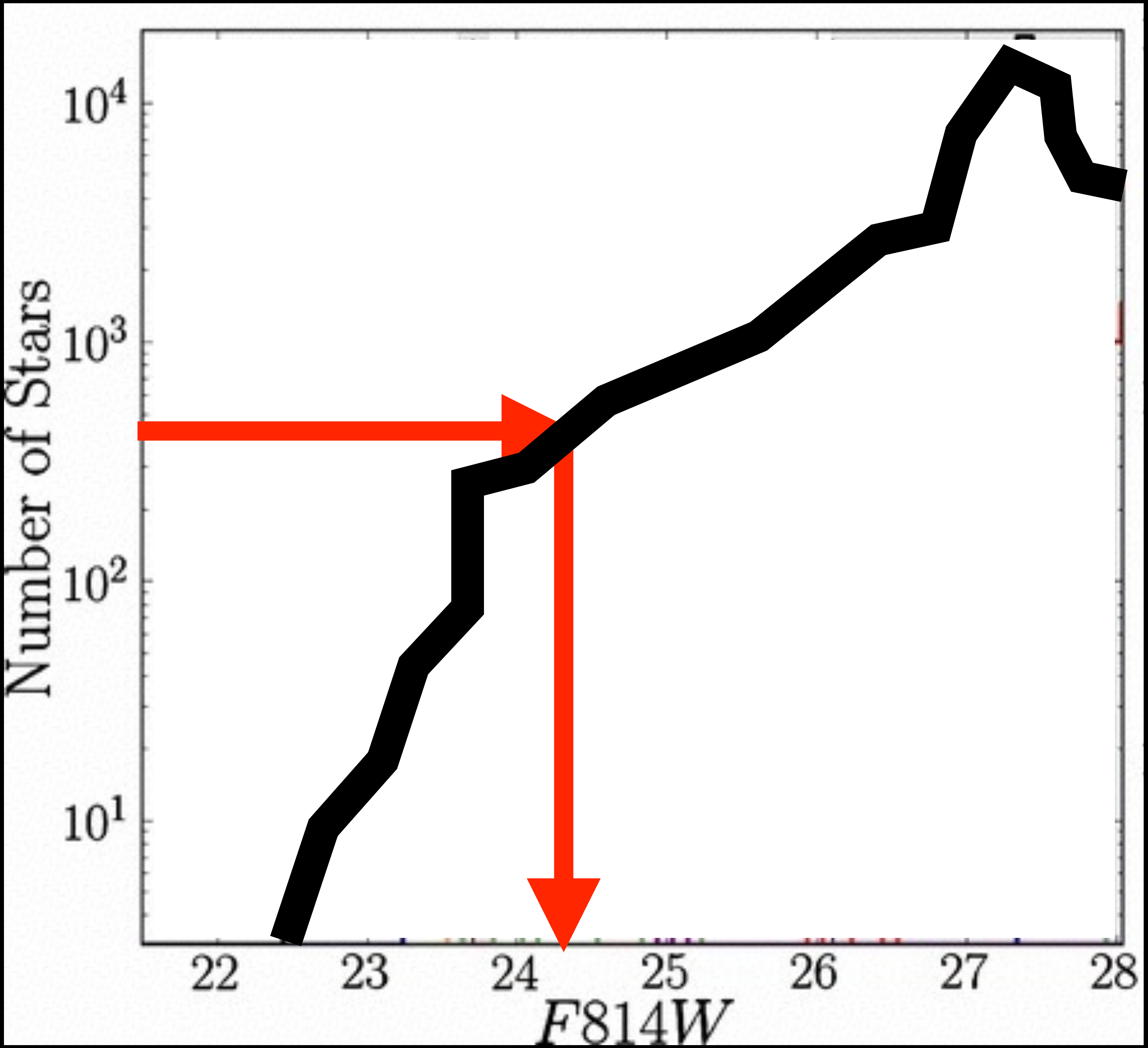
The max # of stars/□” is set by the resolution of telescope+instrument



Smaller PSF, pixels Larger PSF, pixels

Depth ("crowding-limit") depends on the stellar luminosity function.

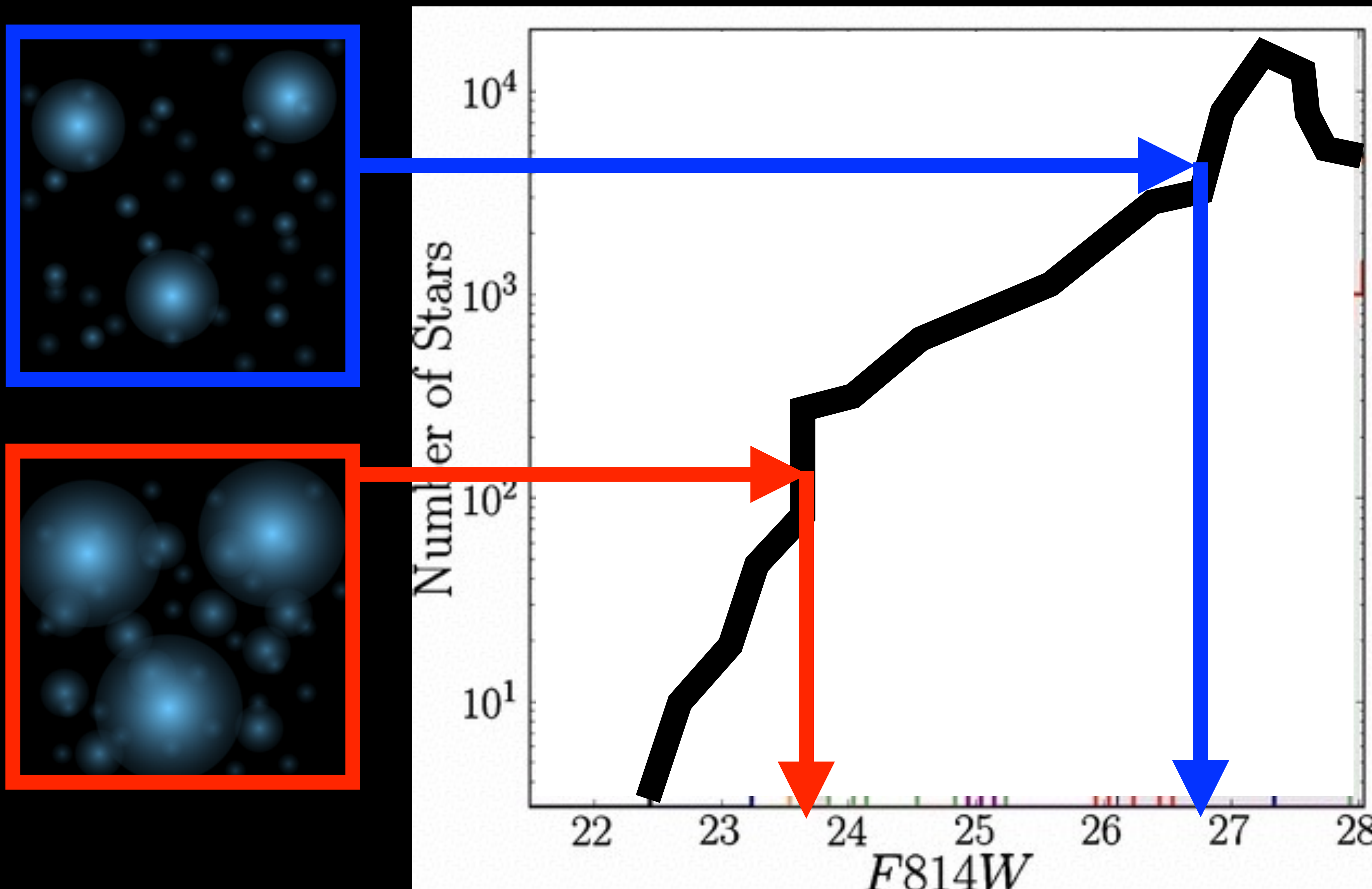
When this axis reaches the maximum stars/□"…



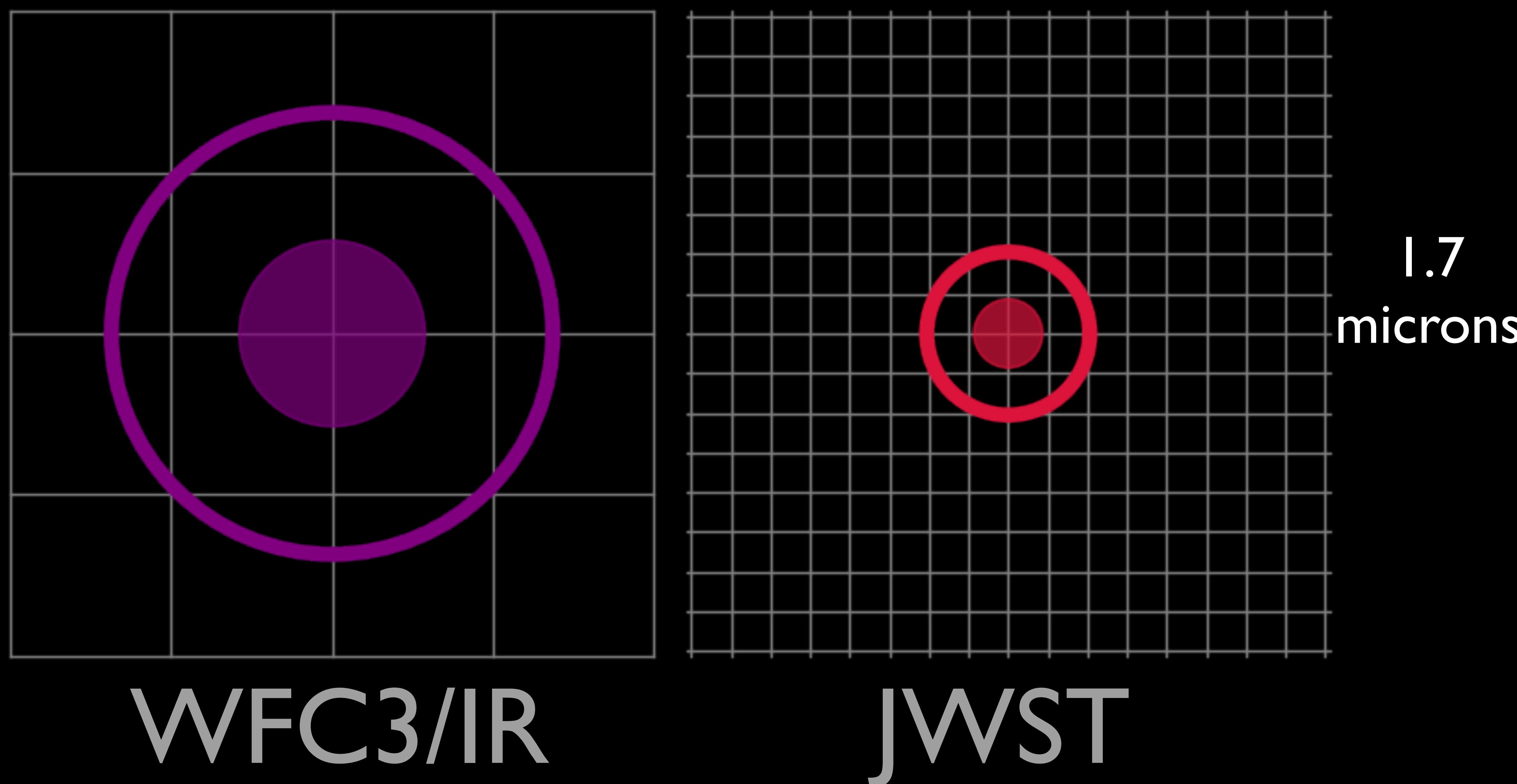
…what is the associated magnitude?

Old stellar population: Rosenfield et al 2014

For fixed surface density, better resolution leads to more depth

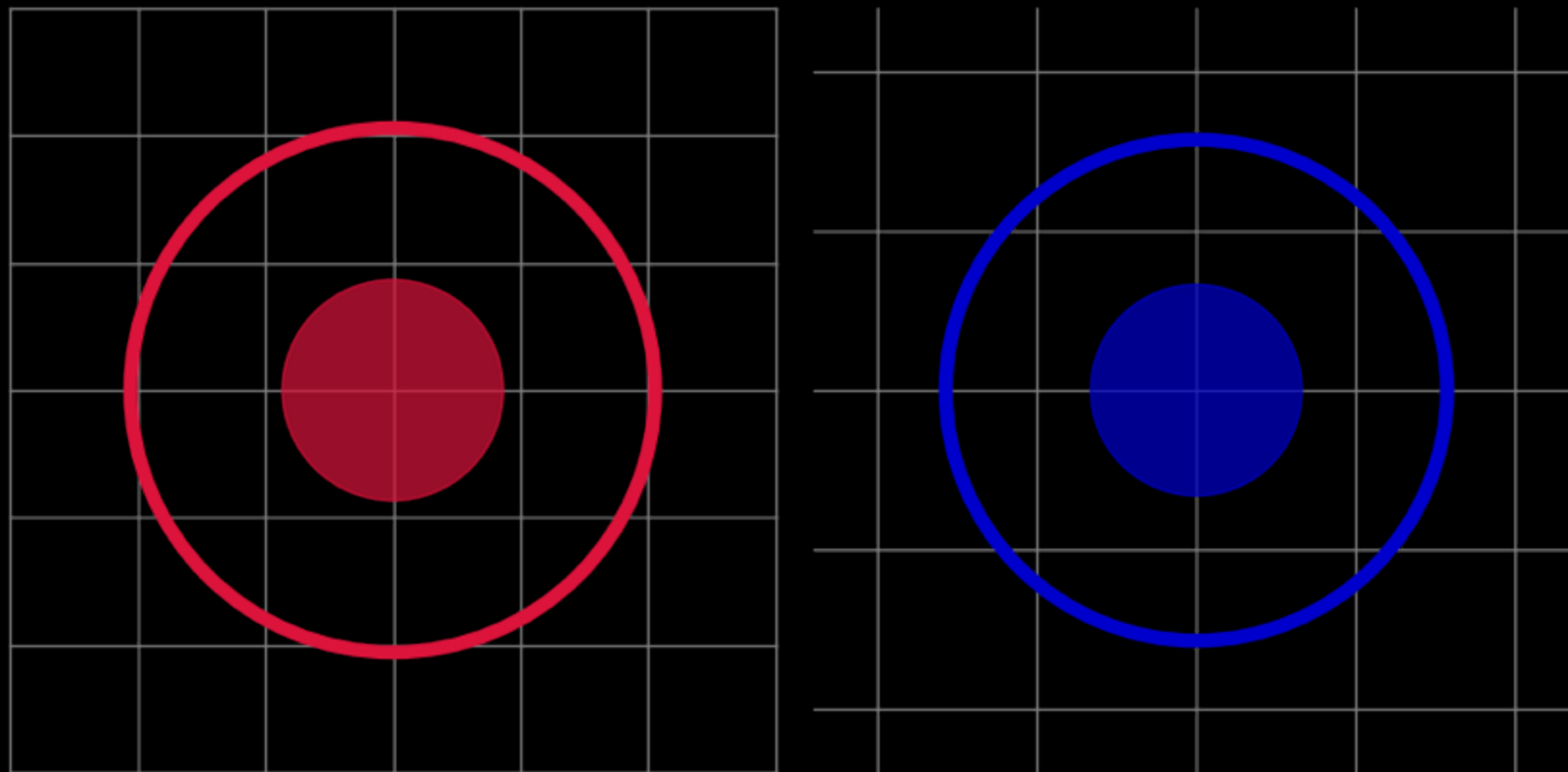


JWST: Large gain in NIR resolution



Crowded regions will be deeper in NIR

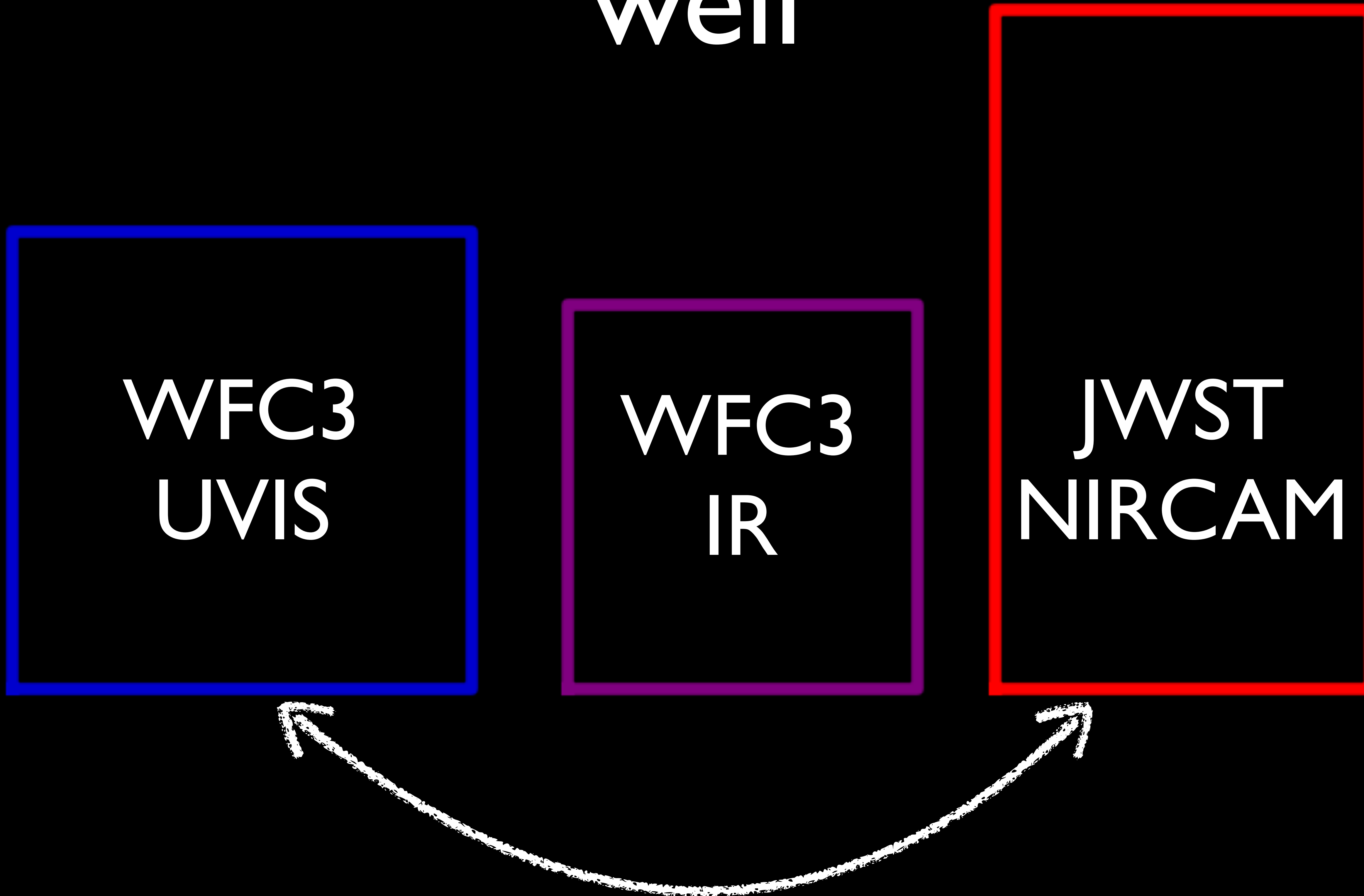
But, resolution *comparable* to HST optical



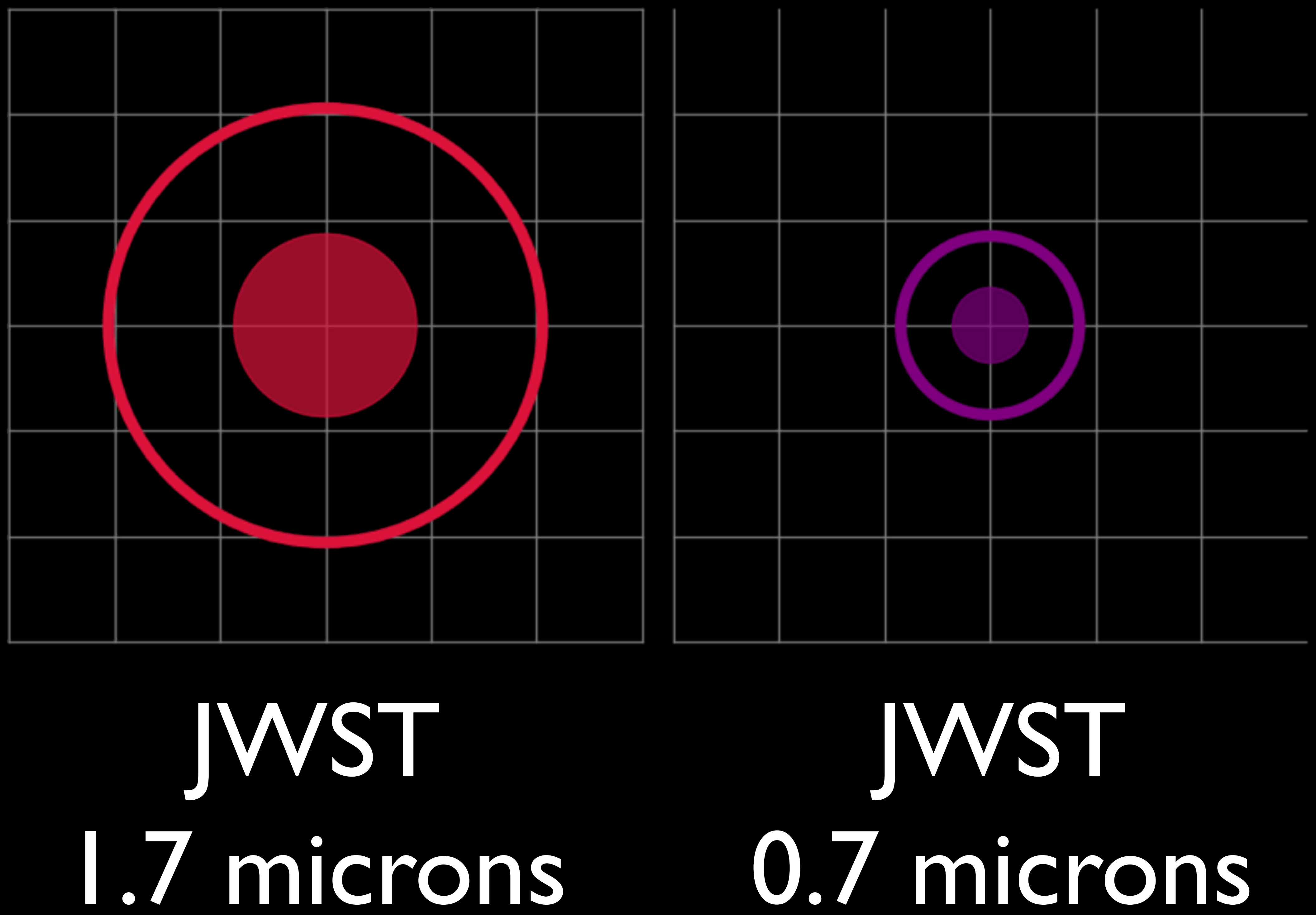
JWST
1.7 microns

WFC3/UVIS
0.6 microns

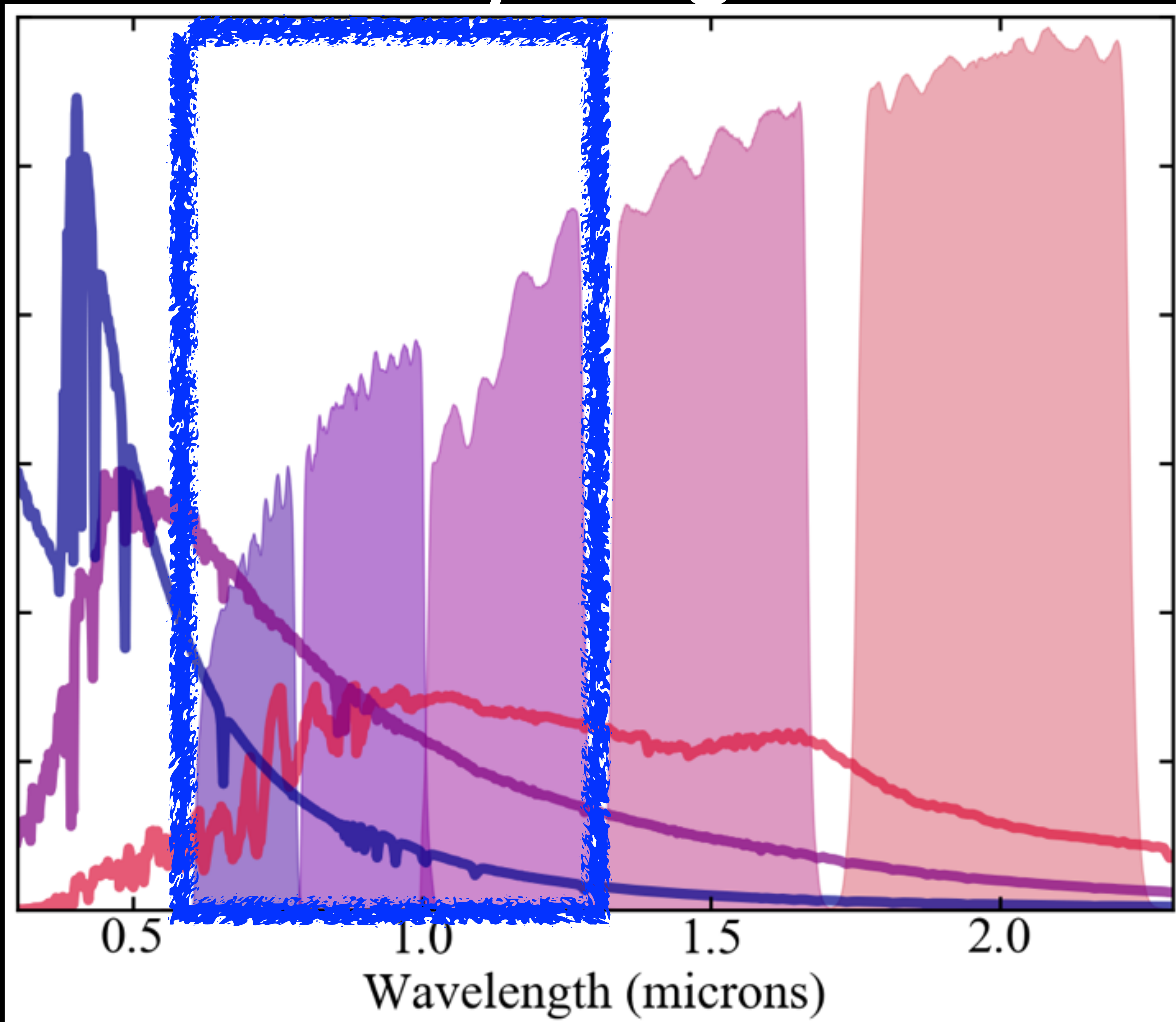
Fields of view comparable as well



In the optical, JWST *highly* undersampled



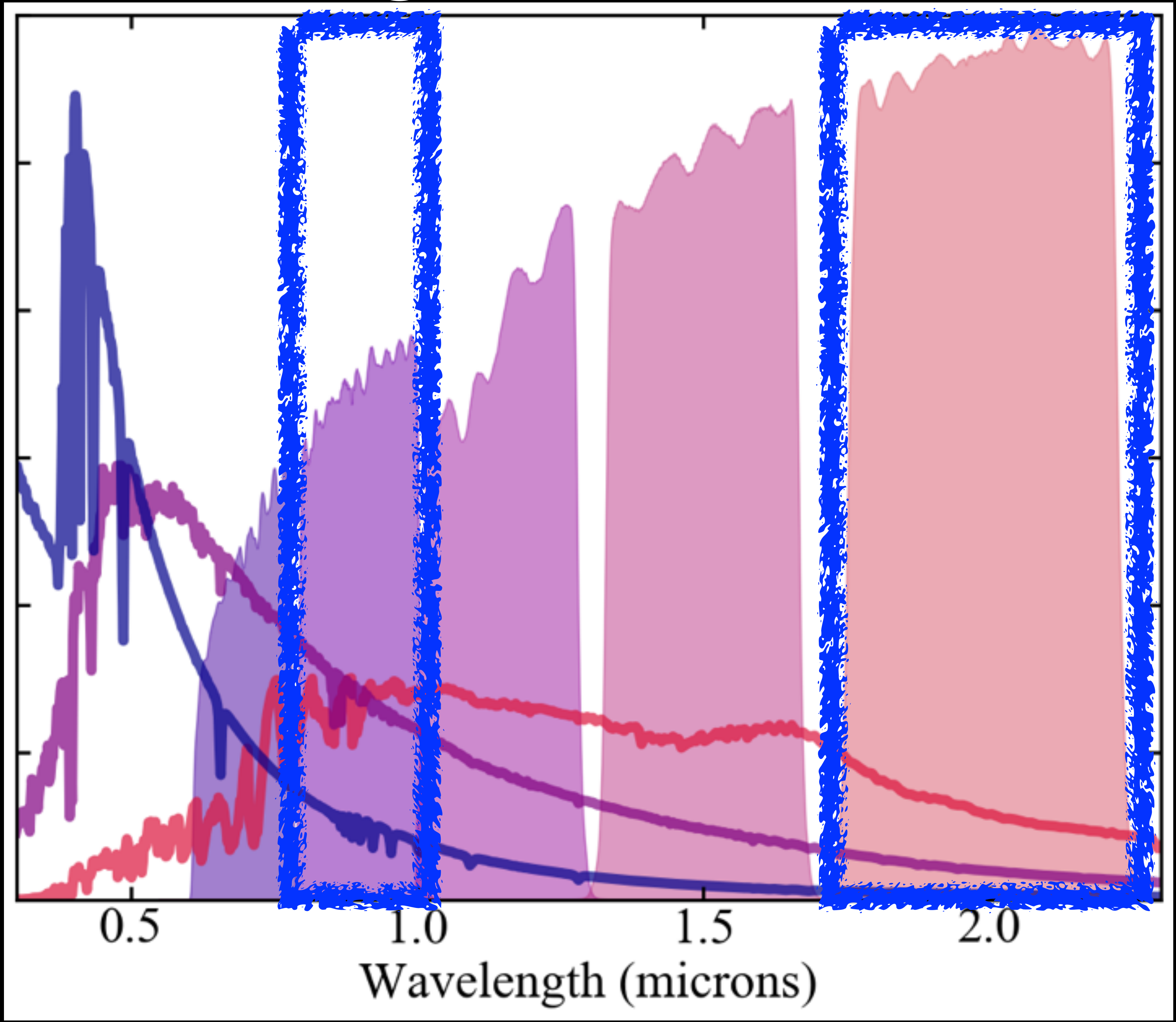
PSF undersampling will hurt detection of hot, young, massive stars…



Helps with dust, but limits resolution gains

10,000K
5,500K
3,500K

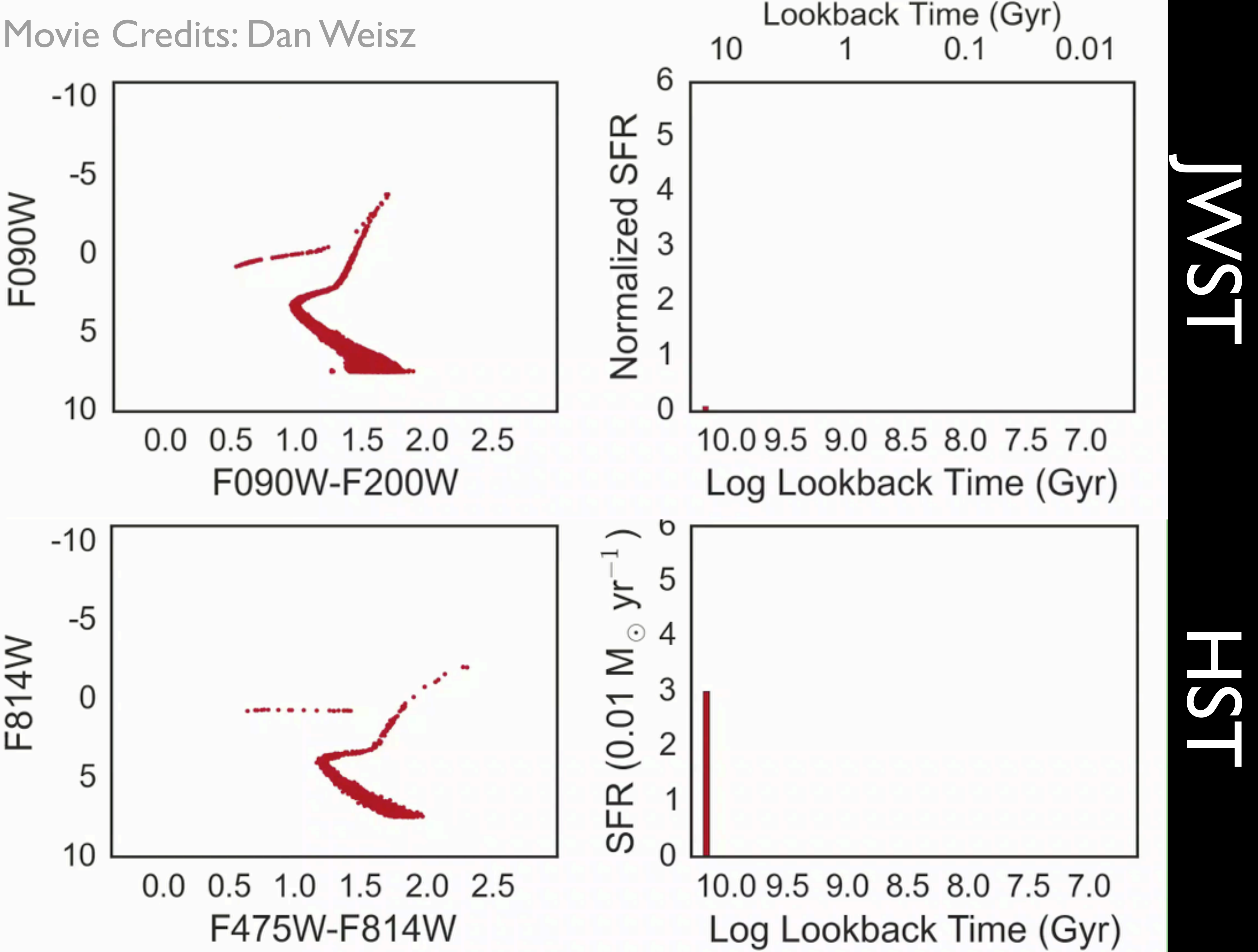
Best trade-off of throughput, color-leverage, dust, and PSF sampling?



F090W + F200W

10,000K
5,500K
3,500K

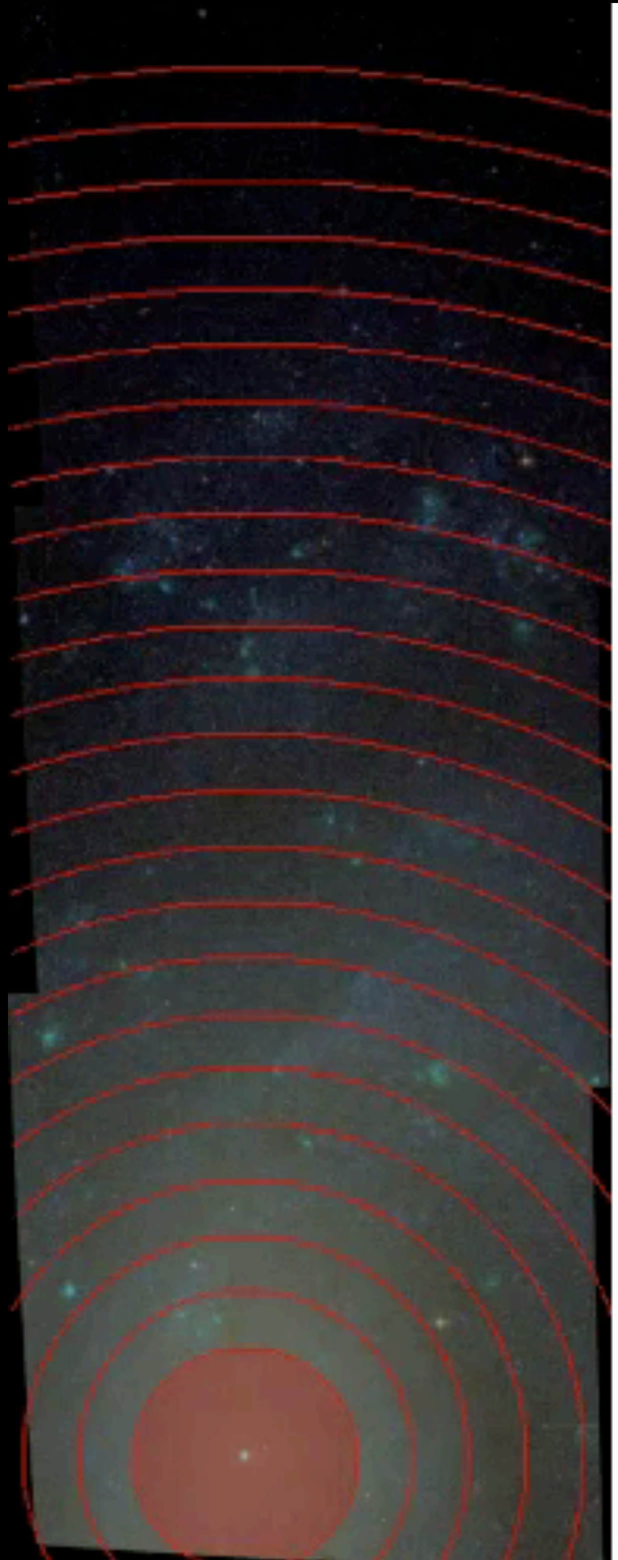
Movie Credits: Dan Weisz

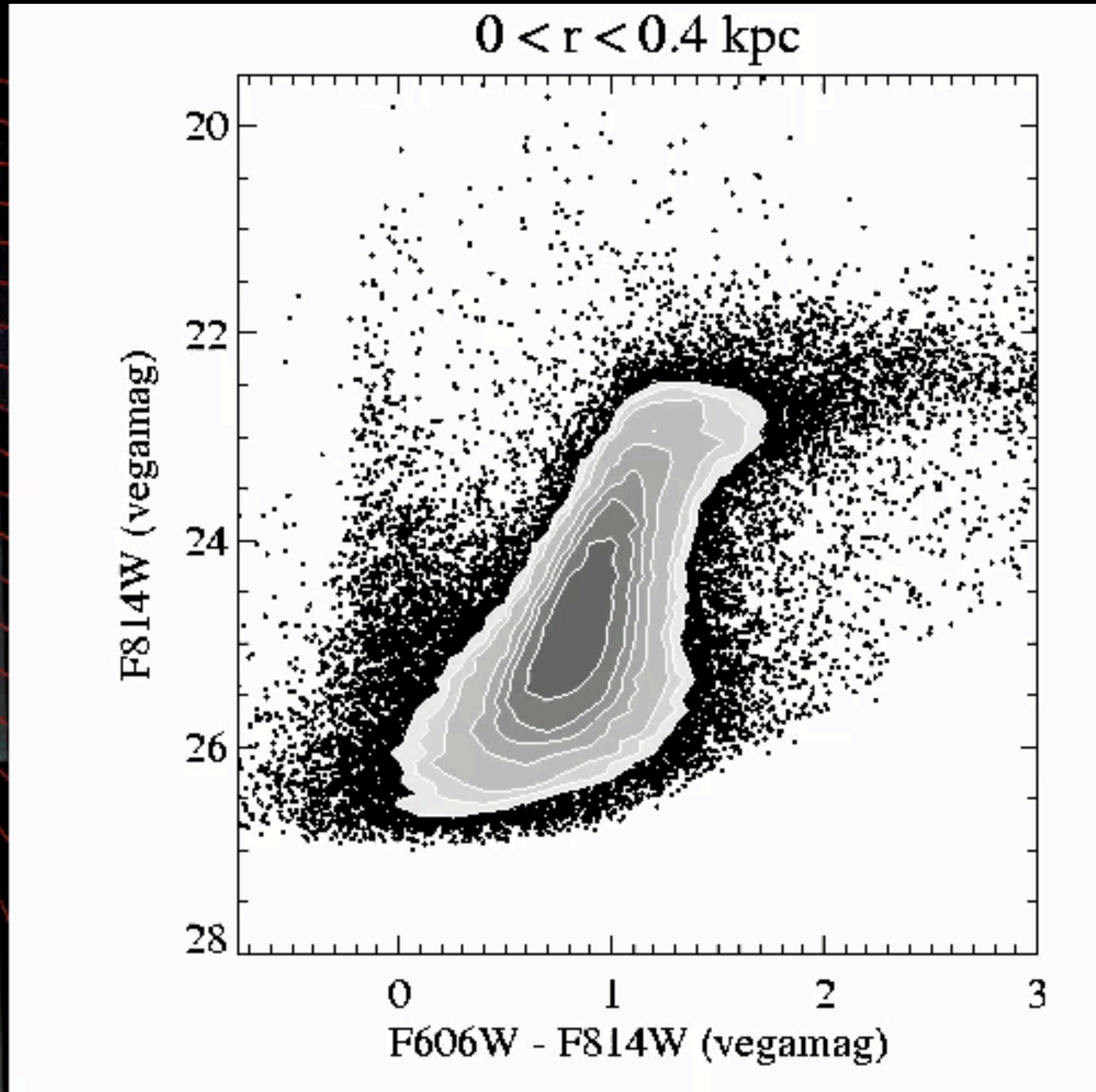


Prospects for JWST

- Huge gains in diffuse, uncrowded regions (galaxy halos, outer disks, Local Group, dwarfs)
- Vastly better CMD depth+area compared to HST's WFC3/IR
- Comparable CMD depth+area as WFC3/UVIS, but with better SNR / exposure time
- Challenges for younger stellar populations, but gold mine for old populations and cool stars

How do we go from this…



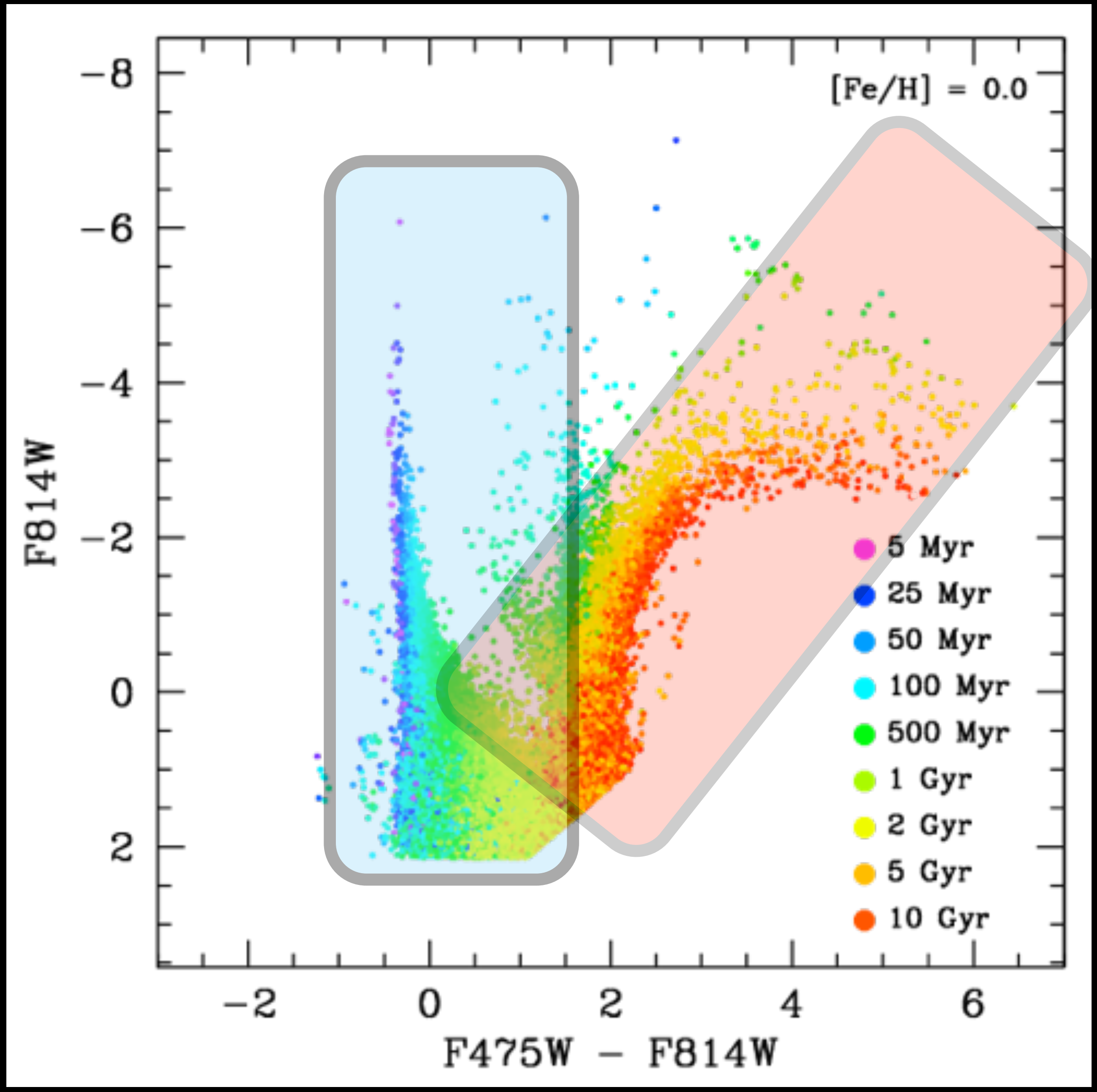


NGC 300;
Gogarten et al 2010

…to *SCIENCE!*

Age resolution is ~logarithmic

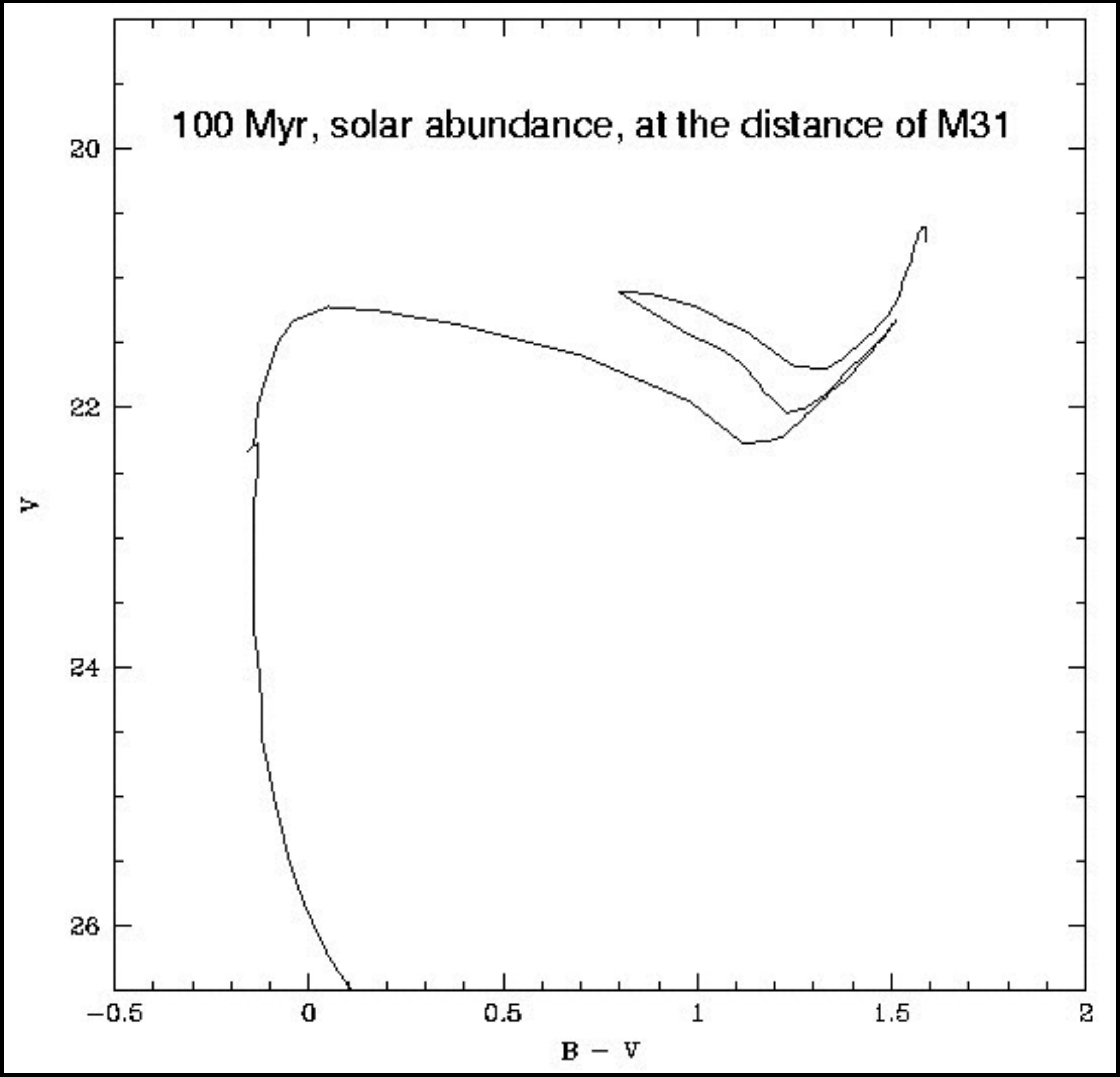
Younger



Older

High temporal resolution at recent times, lower resolution at older times

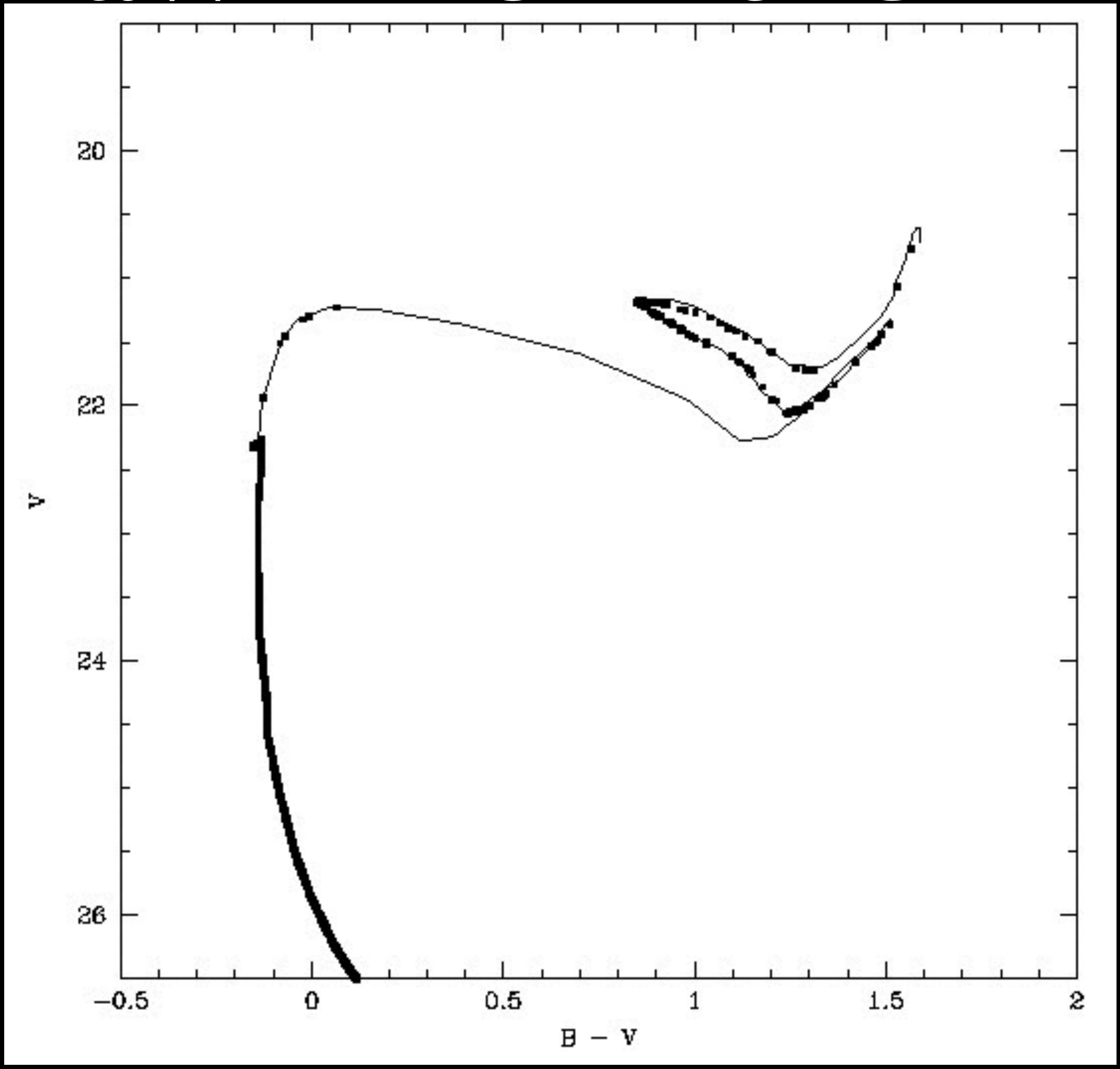
Building model CMDs



*CMD = "Color-Magnitude Diagram"

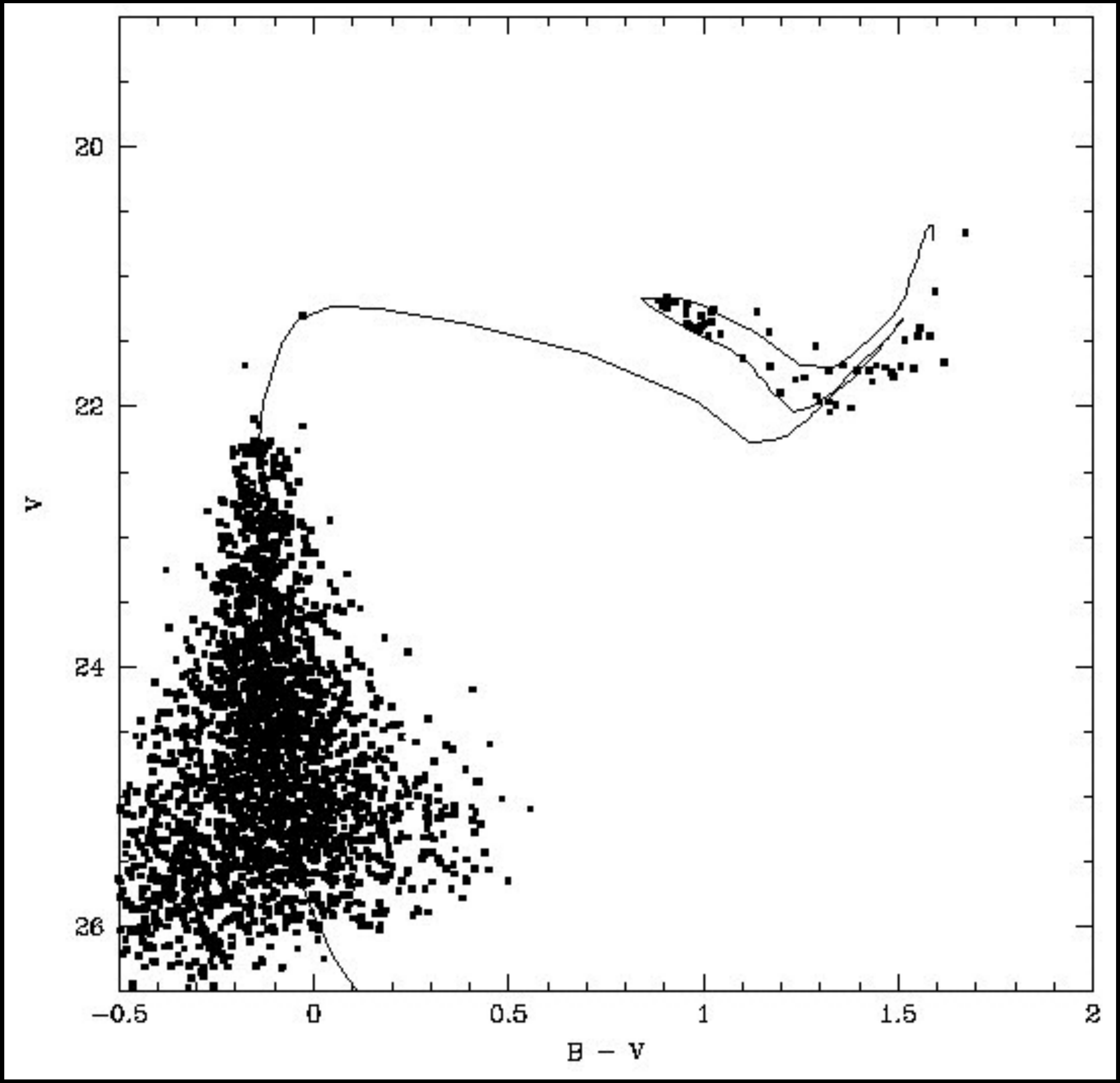
Theoretical isochrones

Populate isochrone with ★'s, drawn from the IMF



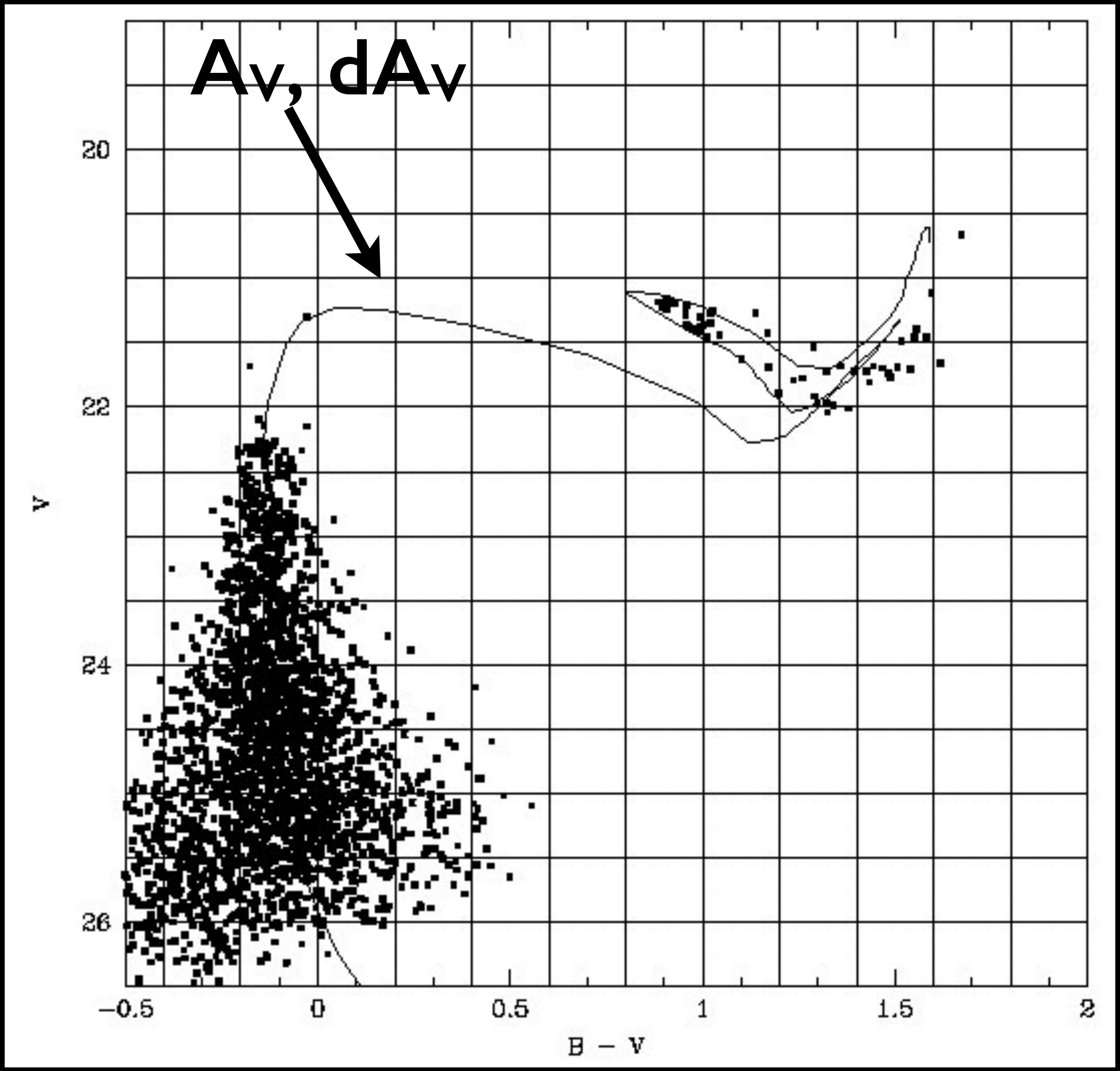
*IMF = "Initial Mass Function"

Convolve model points with errors & completeness



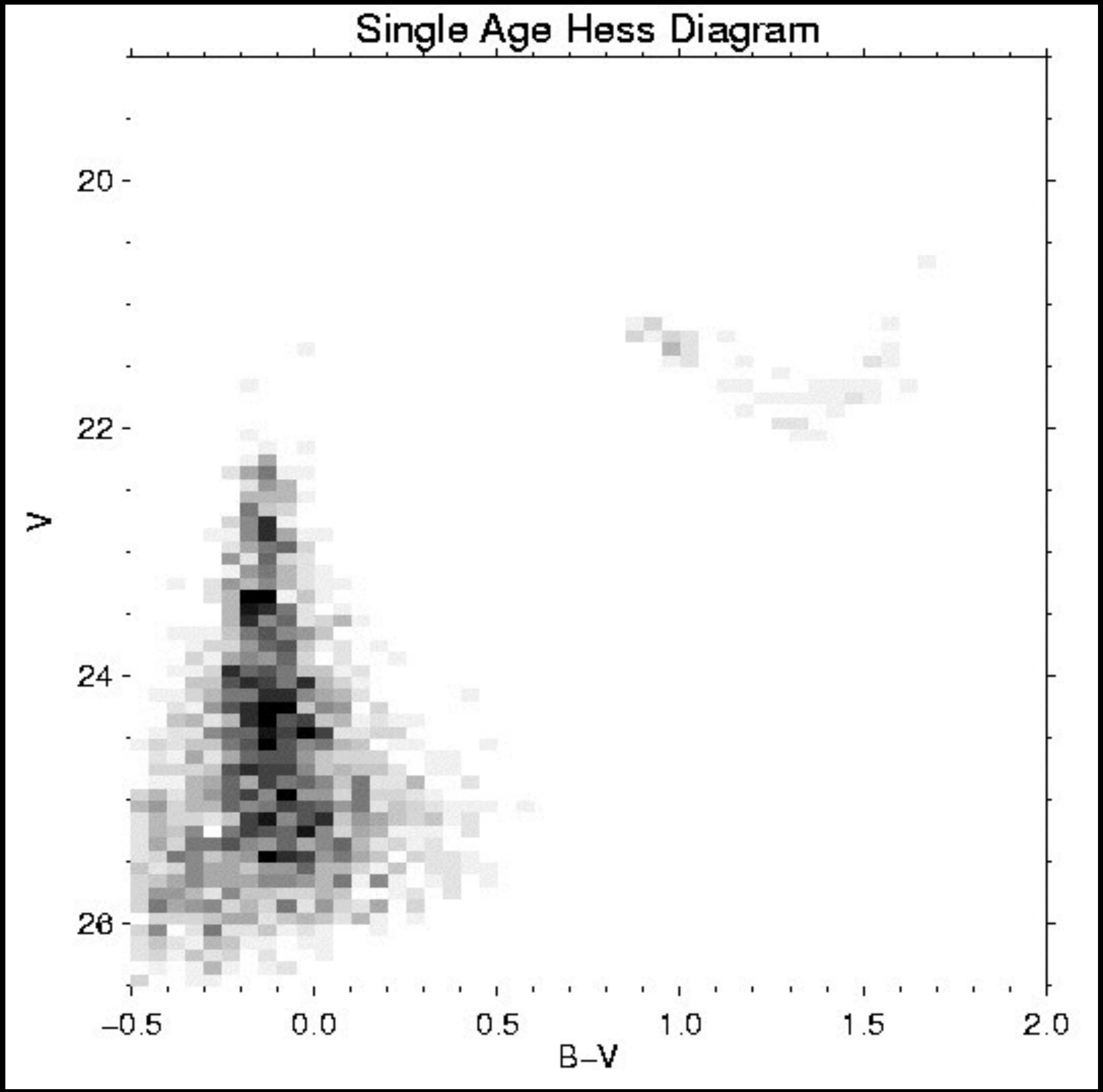
From artificial star simulations

Add foreground & internal (differential) reddening



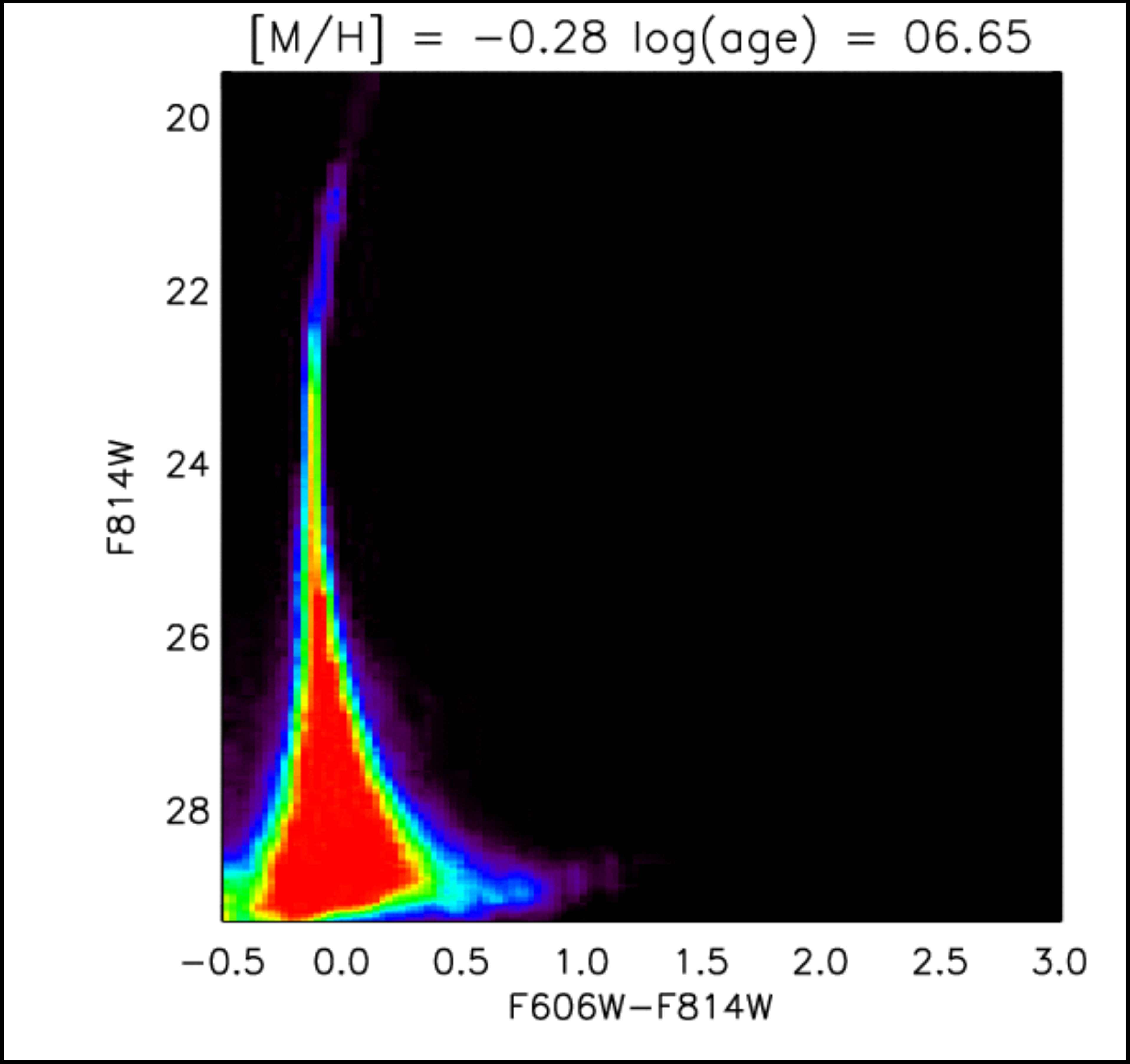
Can also fit for distance

Bin to produce probability distribution for that age bin

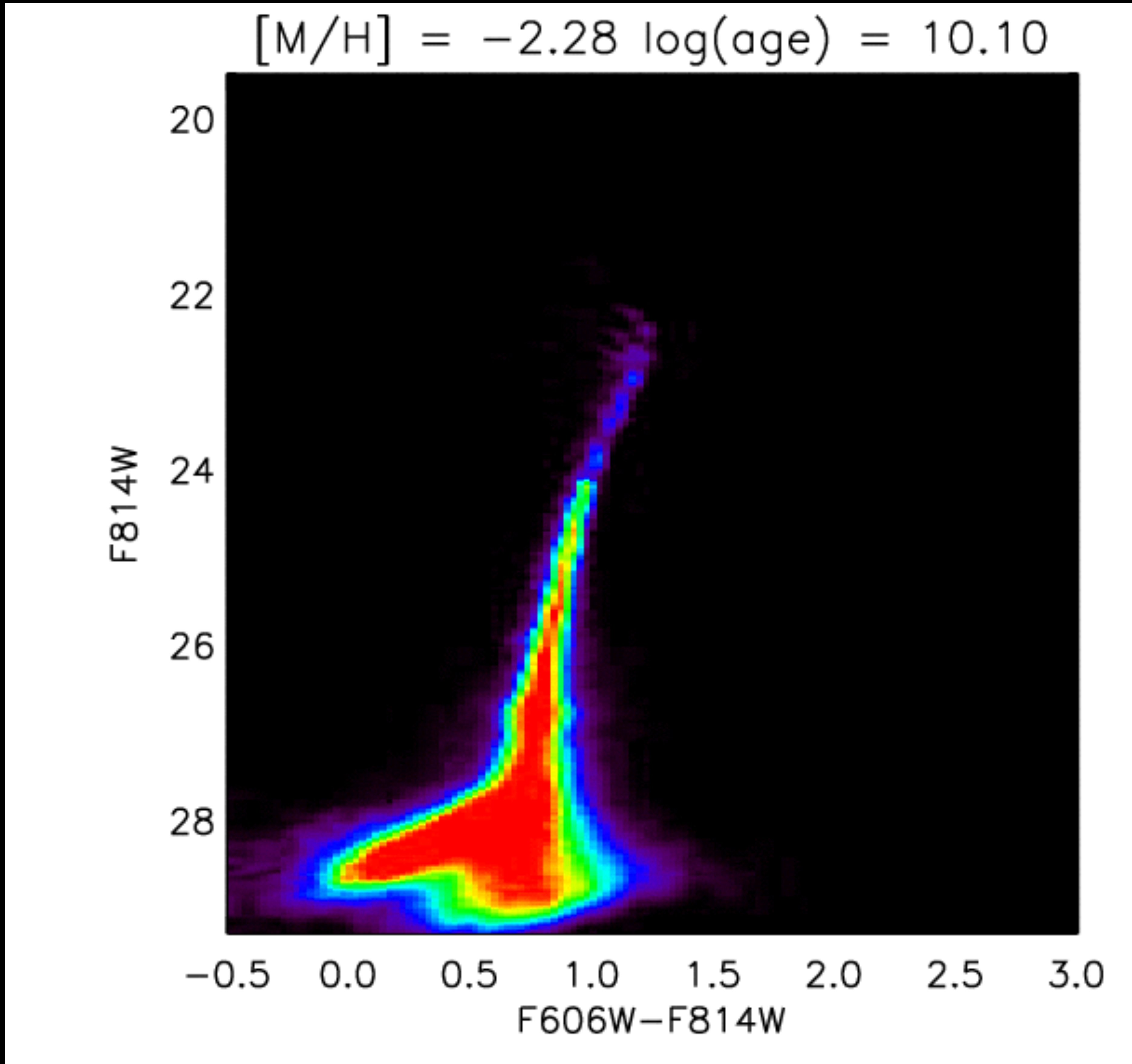


Binned CMD = "Hess diagram"

Increasing Age

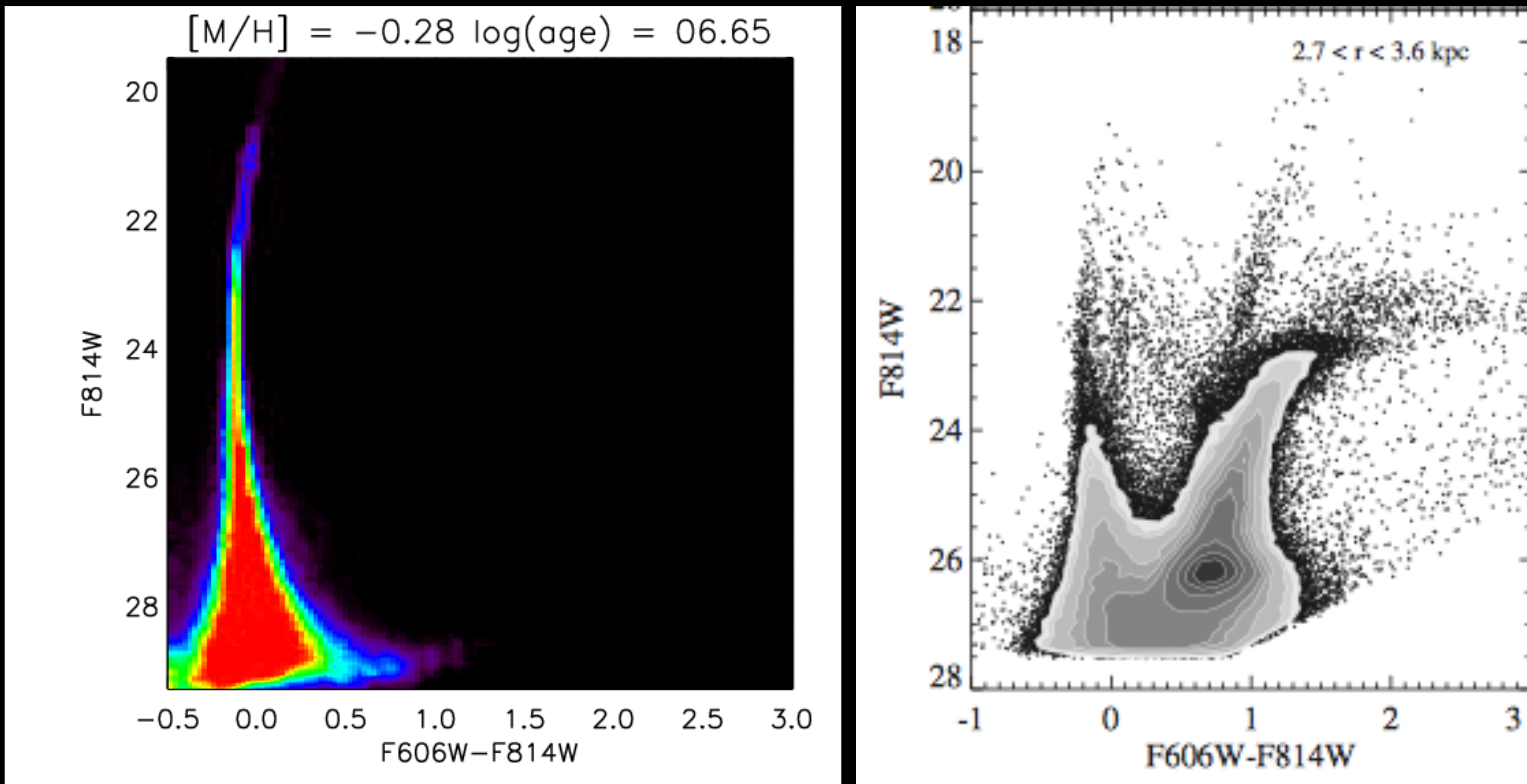


Repeat for Metallicity



More metals = more line blanketing in the blue, and back-warming to the red

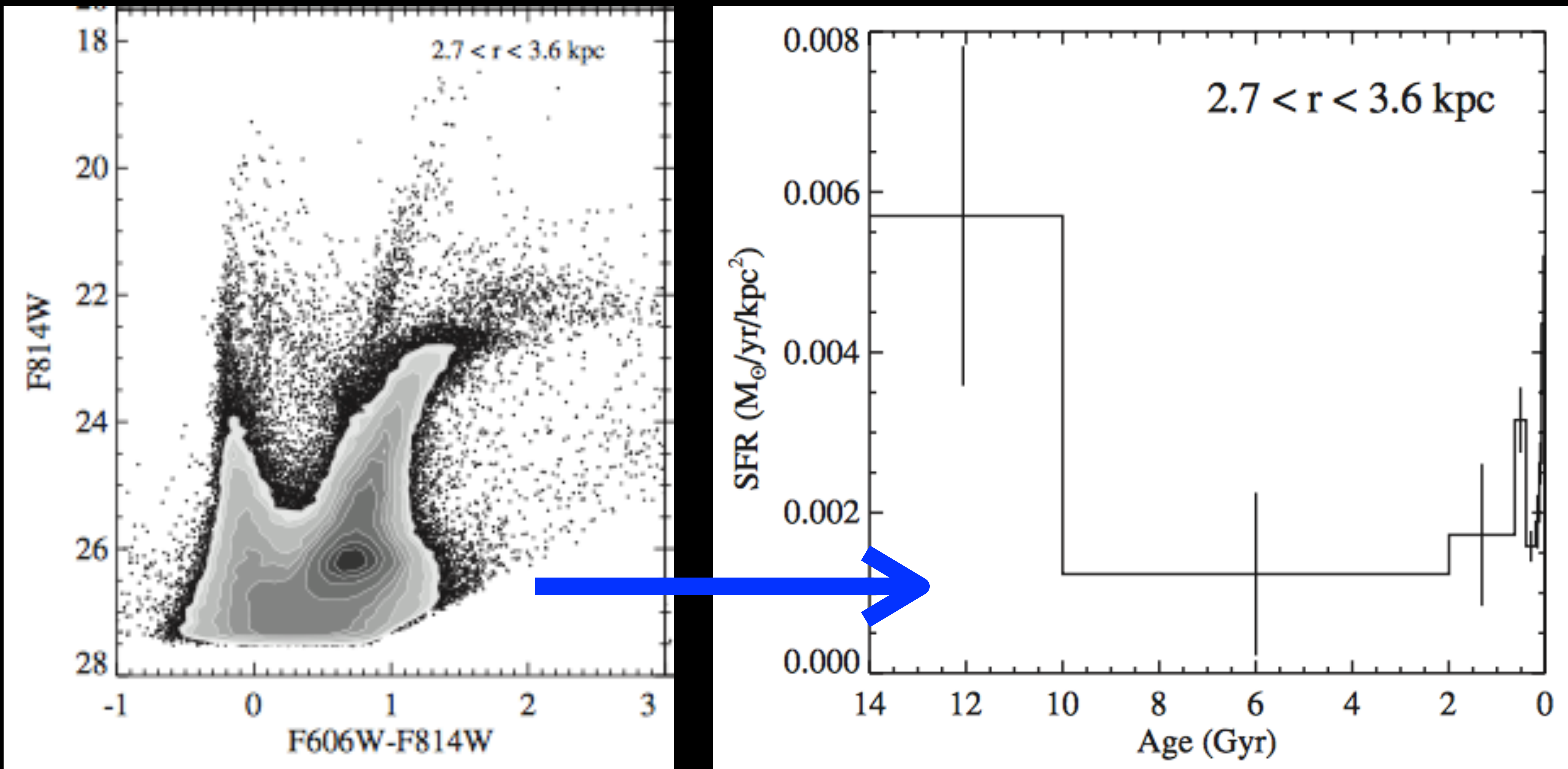
Use different age, Fe/H models as a basis set for modeling the CMD



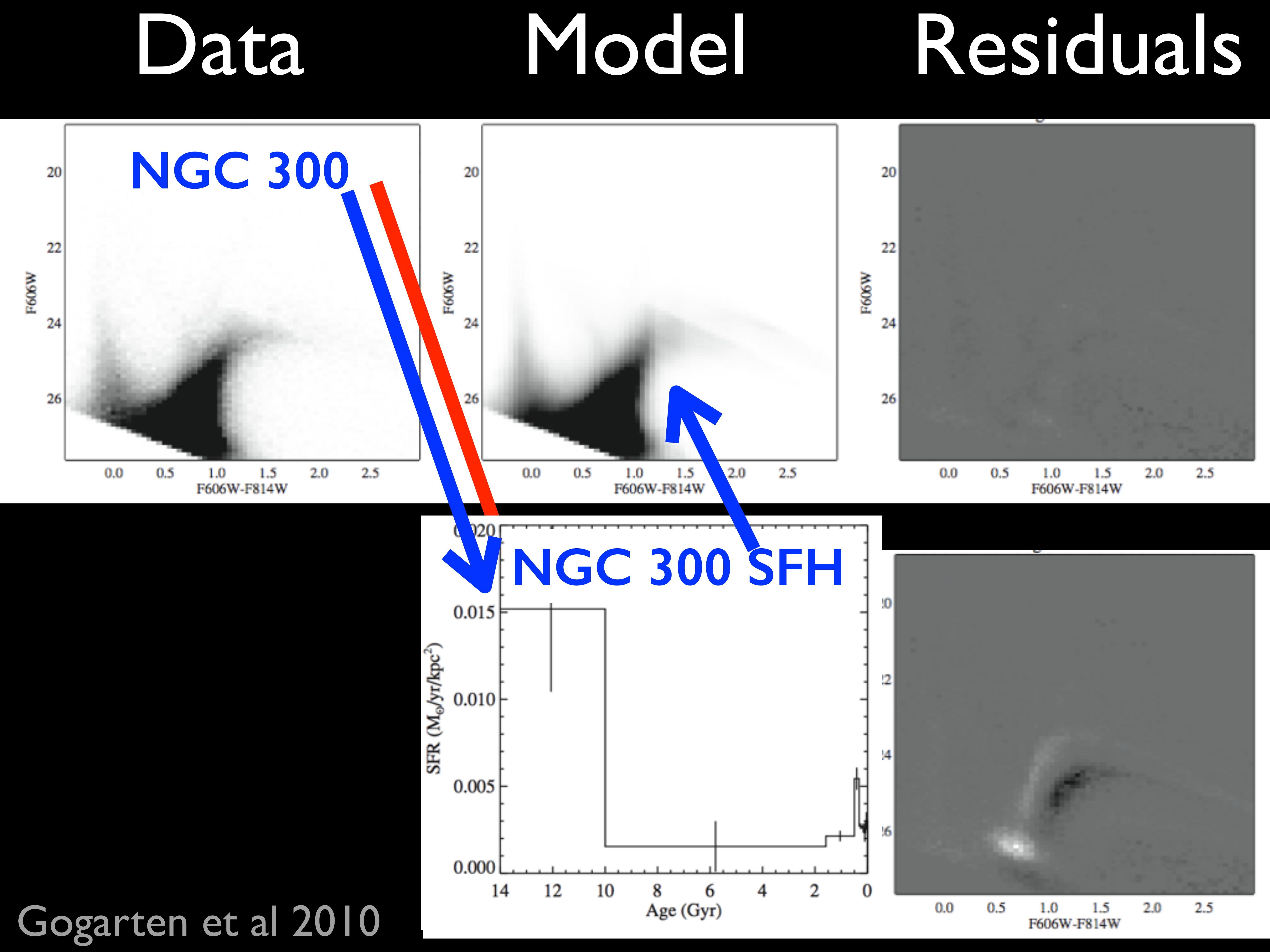
Weights give SFR, Fe/H at each time

"MATCH", by Andy Dolphin

Derive the "Star Formation History" (SFH)

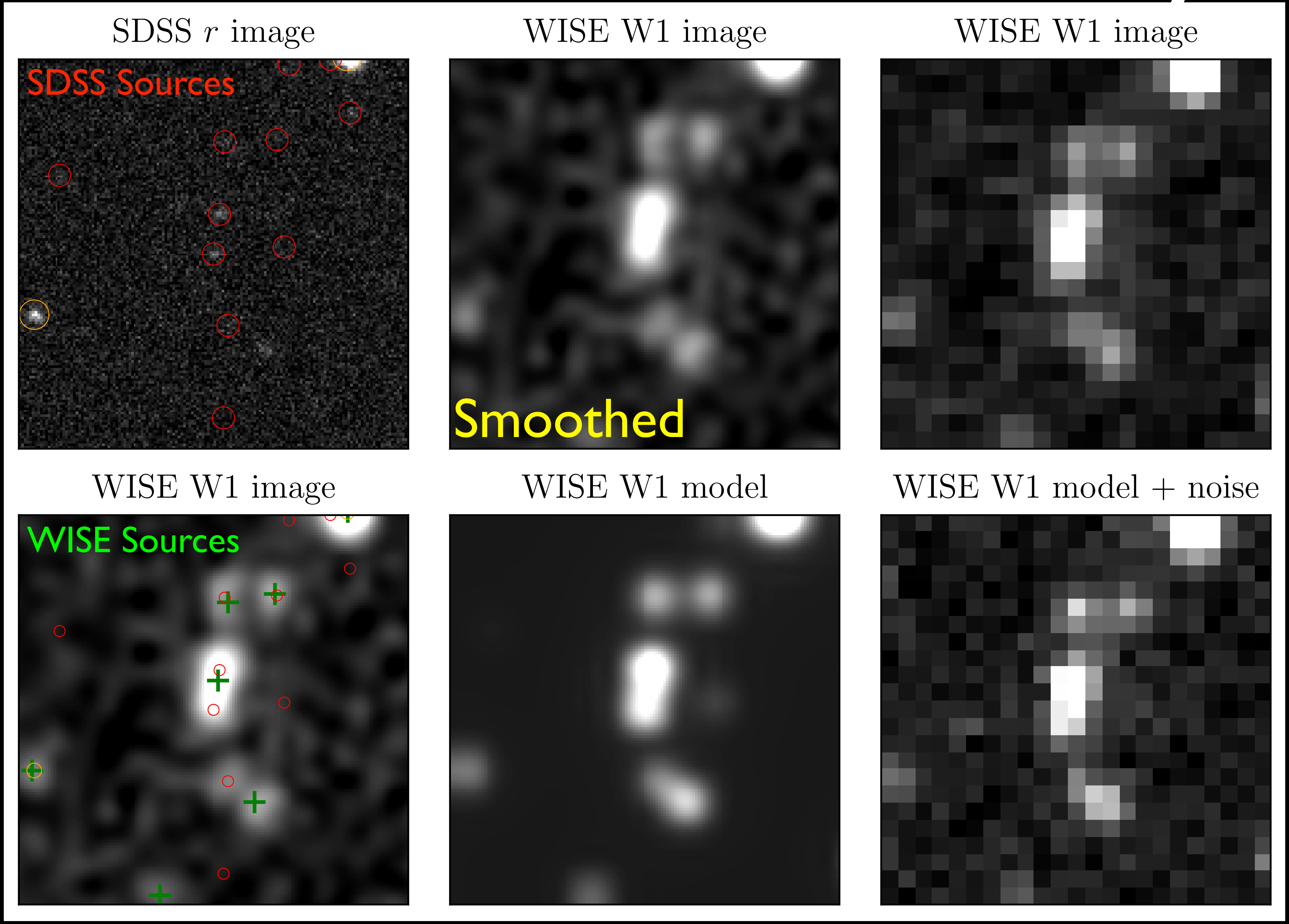


SFH = SFR(t)



Data
Model
Residuals
NGC 300
NGC 300 SFH
F606W
F606W-F814W
SFR ($M_\odot$/yr/kpc^2)
Age (Gyr)
Gogarten et al 2010

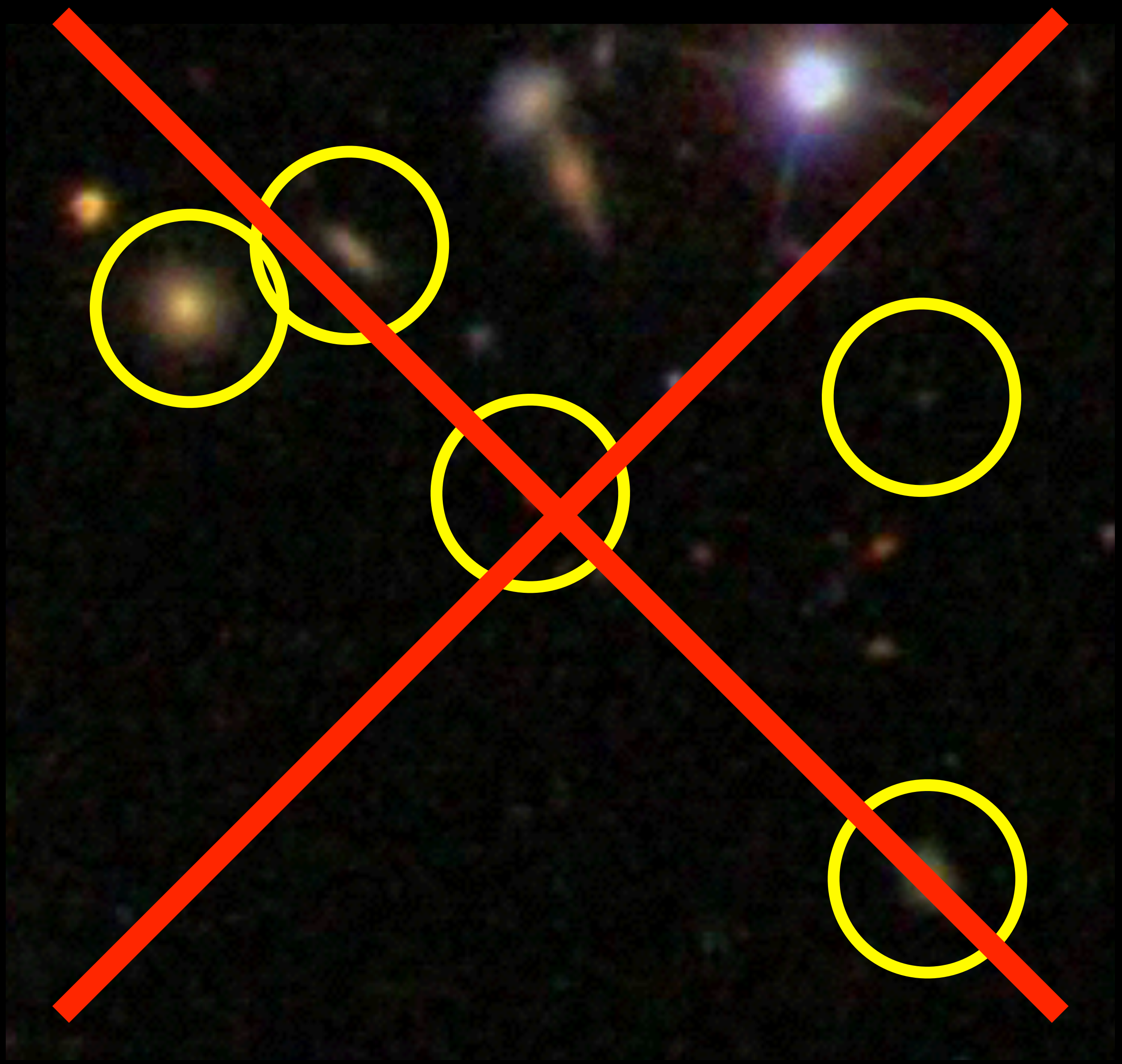
"Forced" Photometry

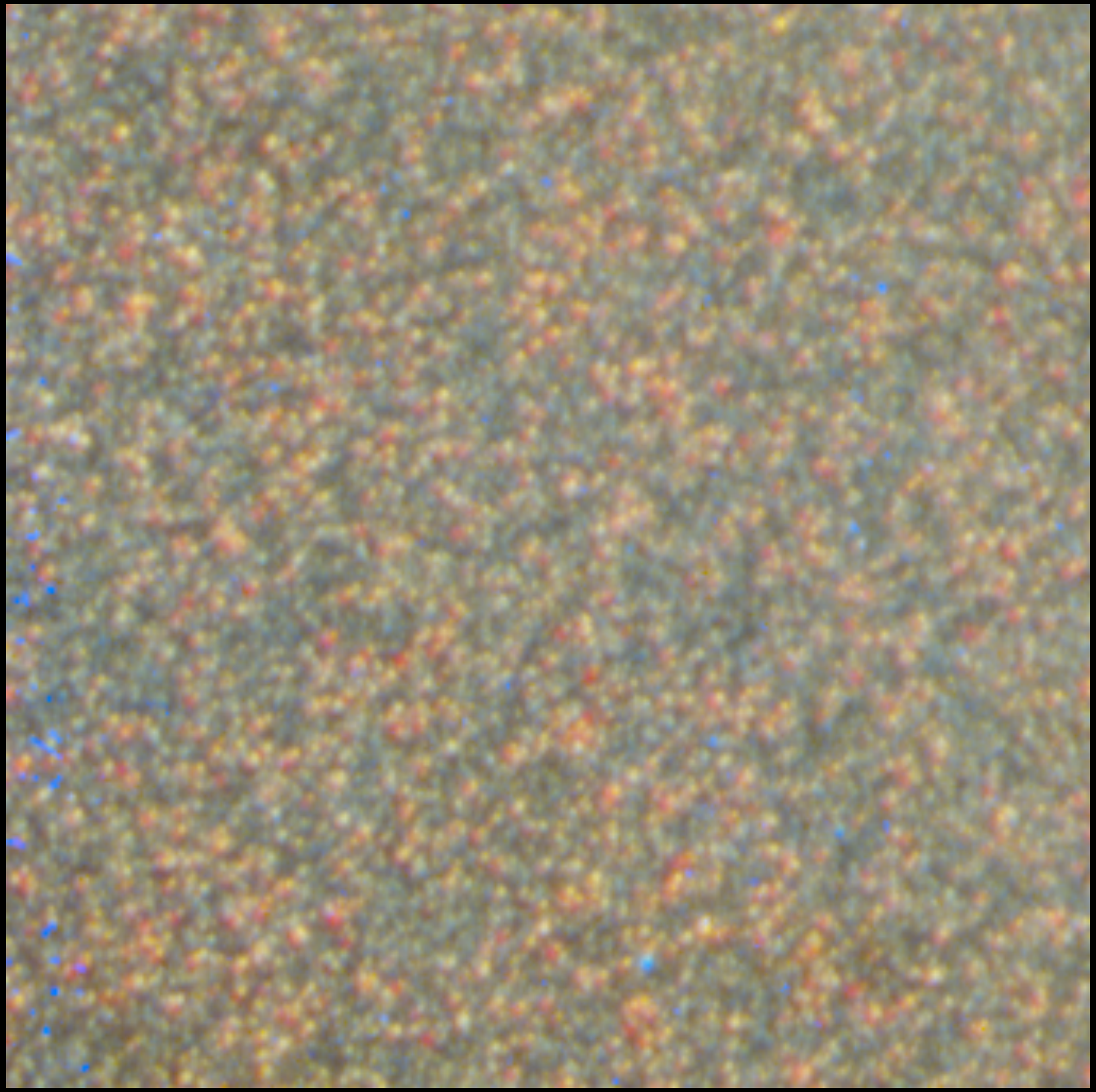


Lang et al 2014: "The Tractor"

Use catalog from one survey to force model fits at those positions.

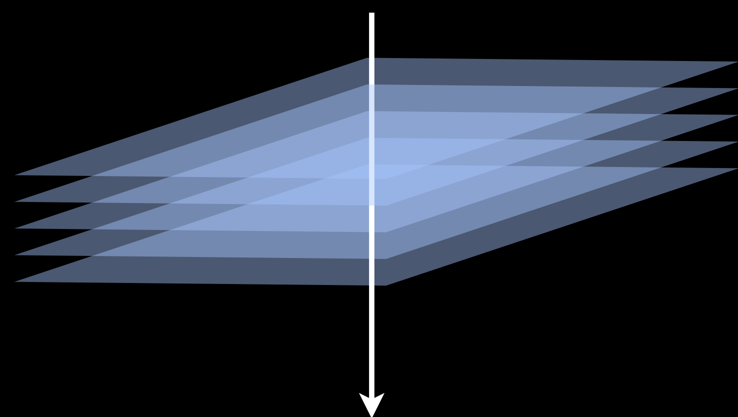
Crowded field photometry analogous to “forced” photometry



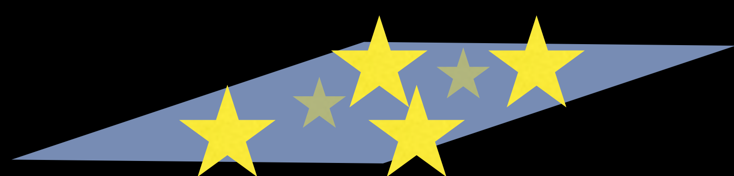


*Will focus on HST, which is state of the art.

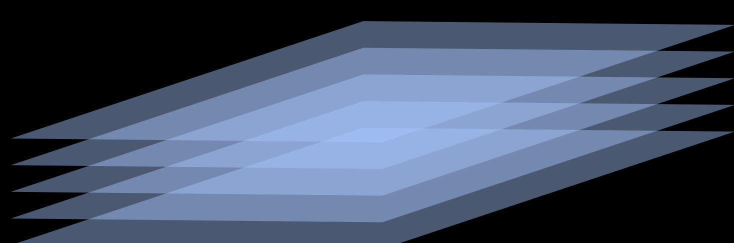
Crowded field photometry overview



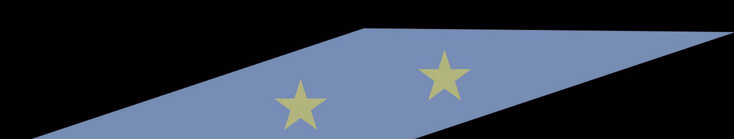
Align images, then combine deepest, highest resolution set



Find All Stars



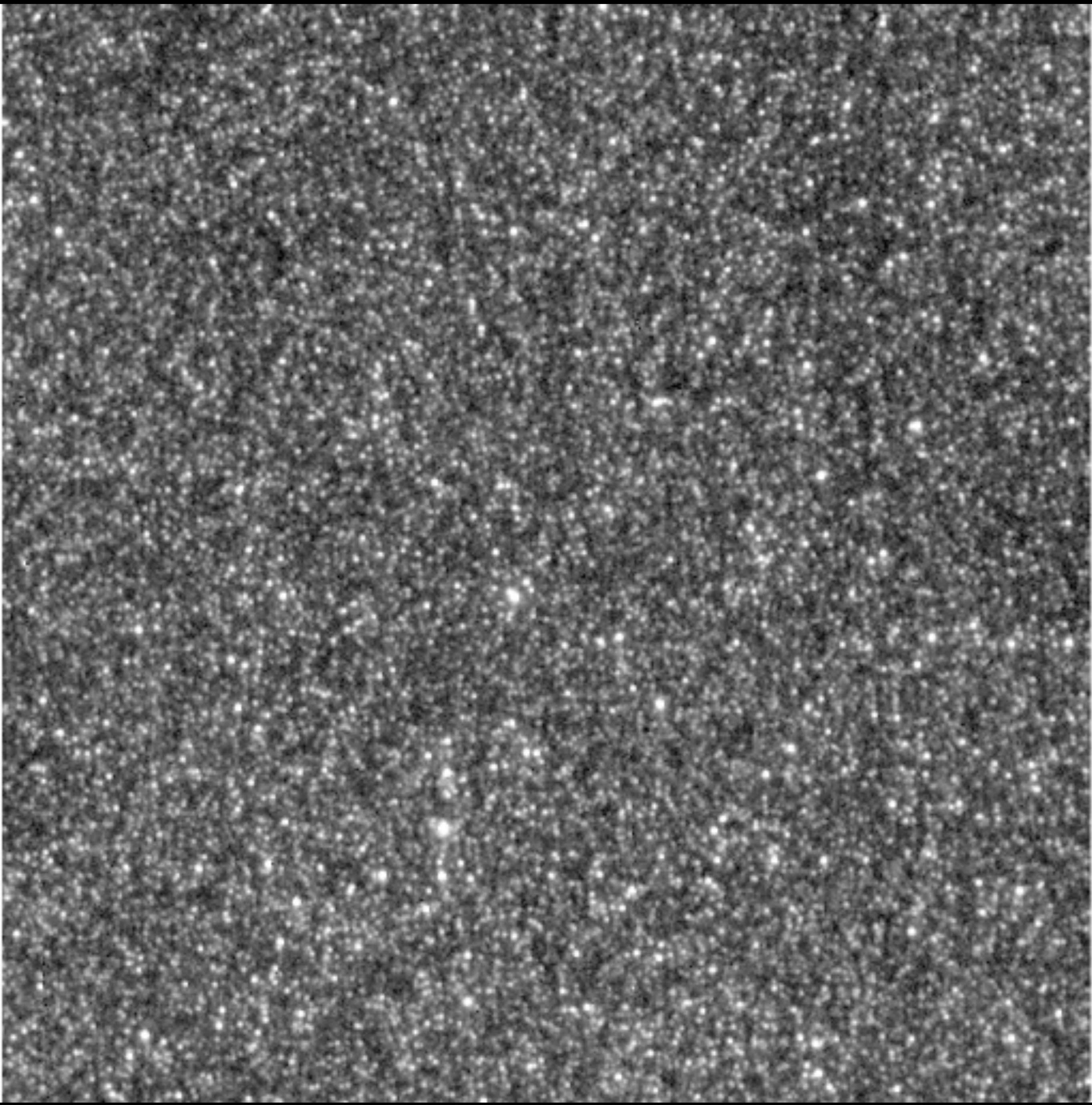
Fit PSF Amplitude in Individual Images



Subtract Stars & Repeat

"DOLPHOT", by Andy Dolphin

Crowded Field Photometry



Image

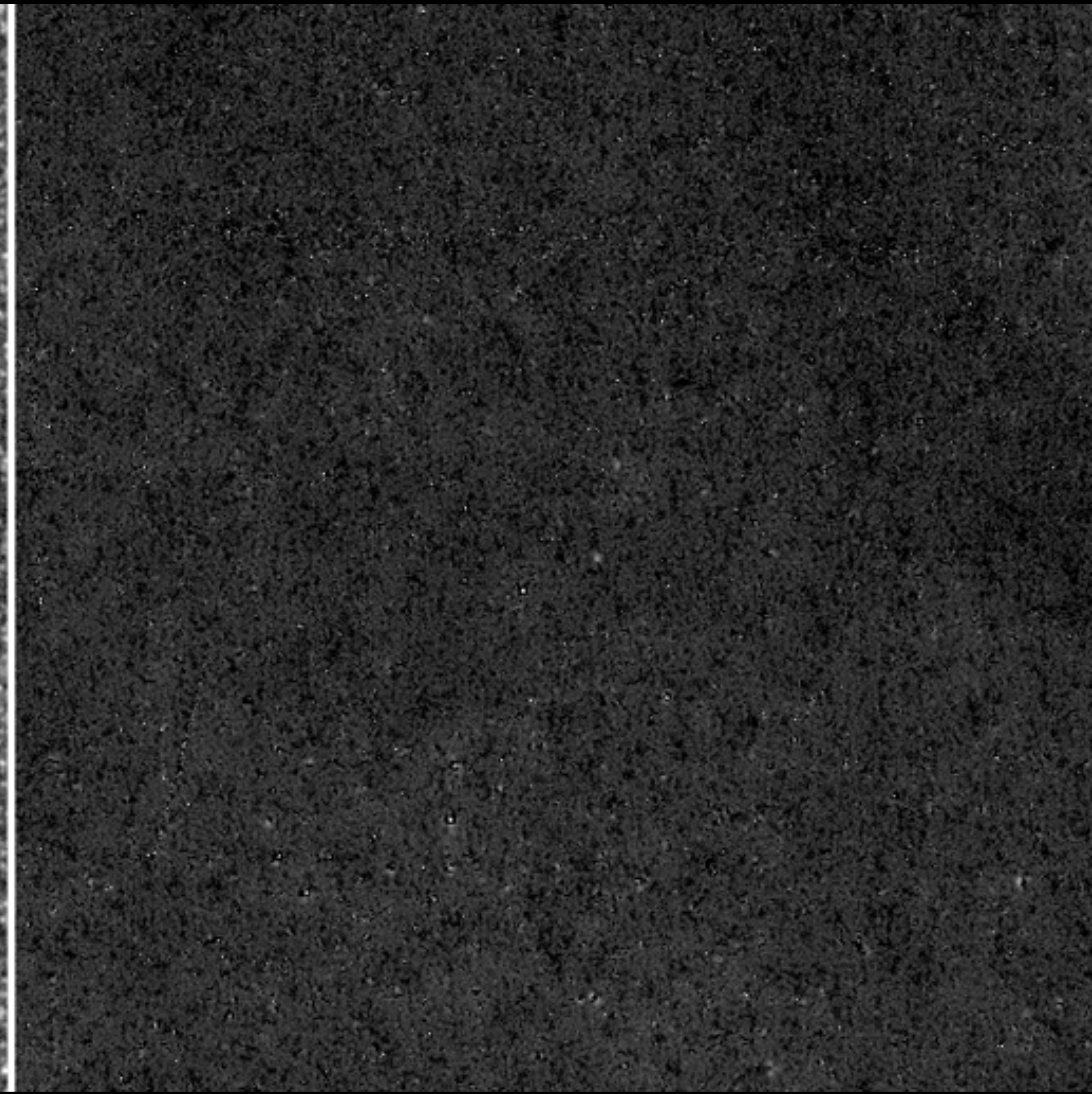
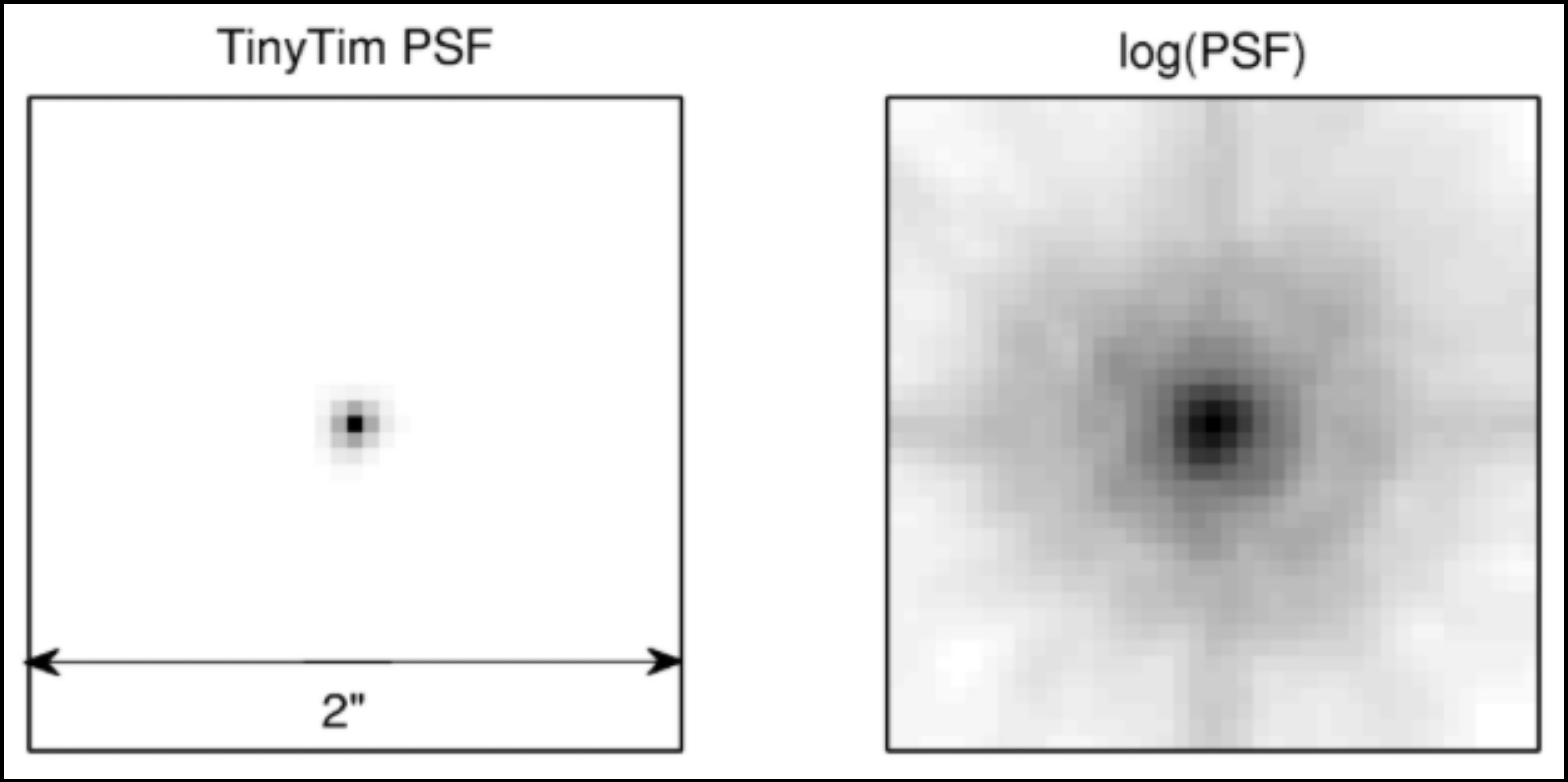


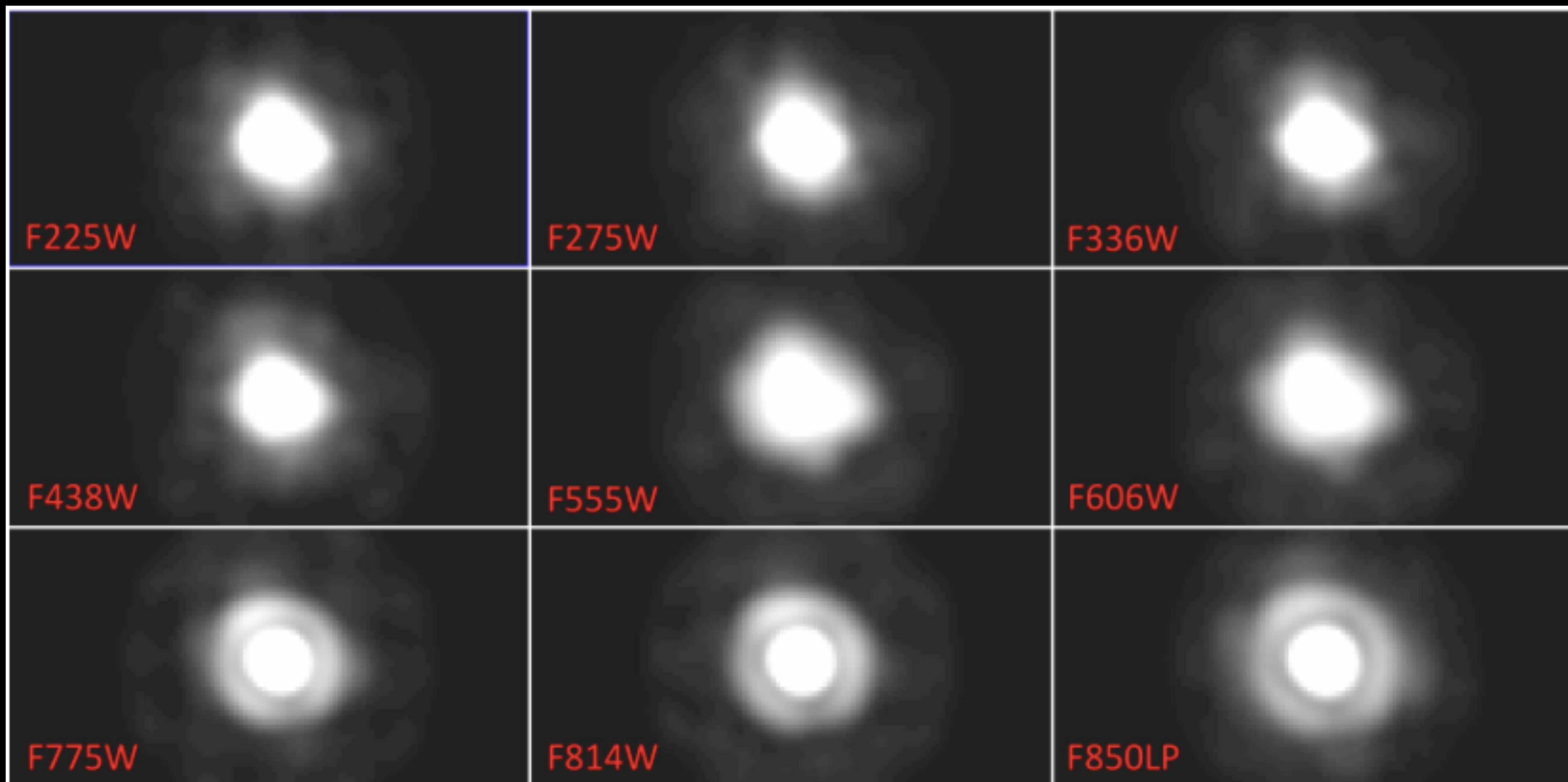
Image-Model
x a big number

Photometric accuracy depends *critically* on the point-spread function



Brewer & Lewis 2008

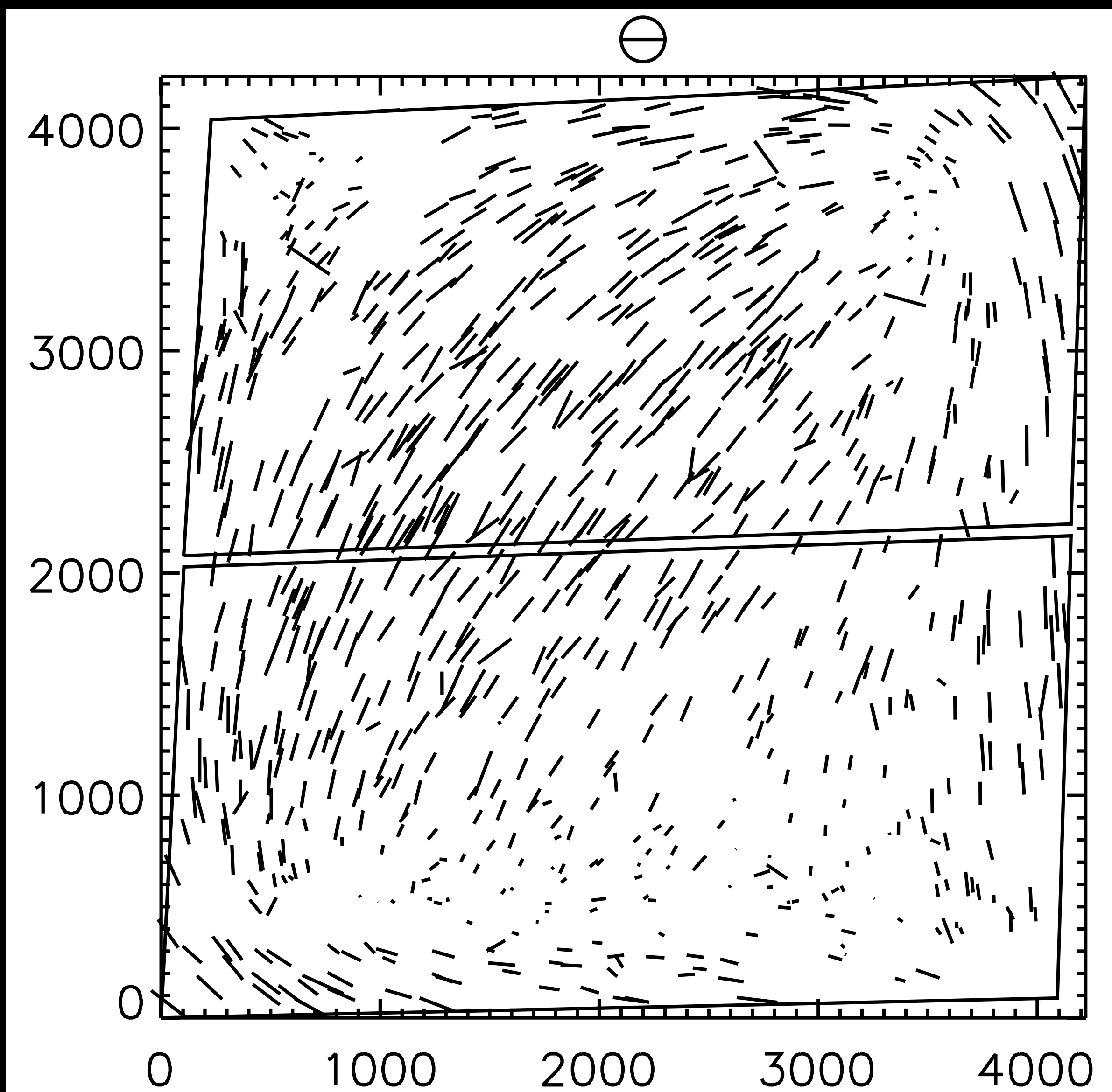
Point-Spread Function



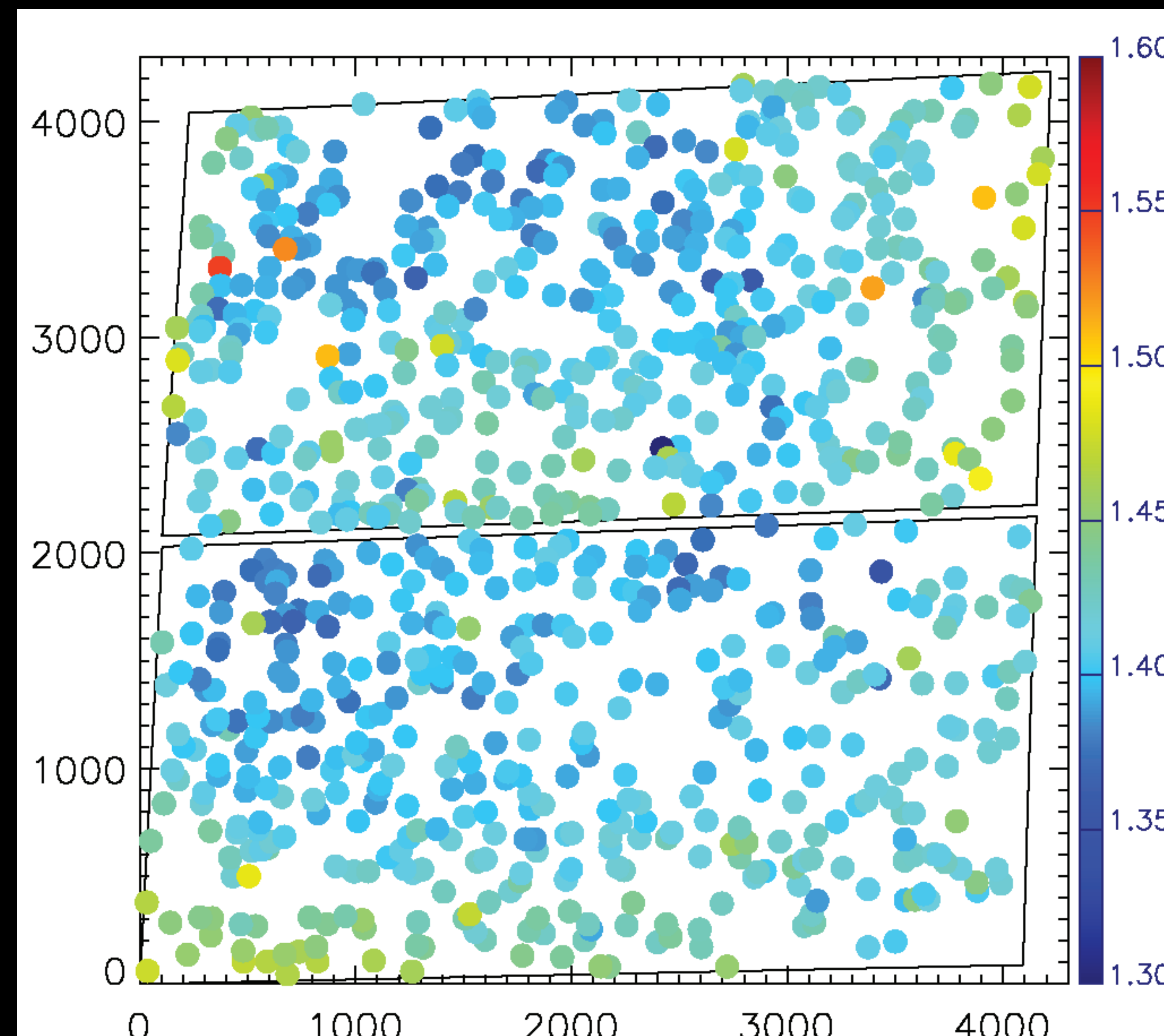
Sabbi & Bellini (ISR-2013-011)

Varies w/ wavelength
(Wider at long wavelengths)

Point-Spread Function: Varies with position



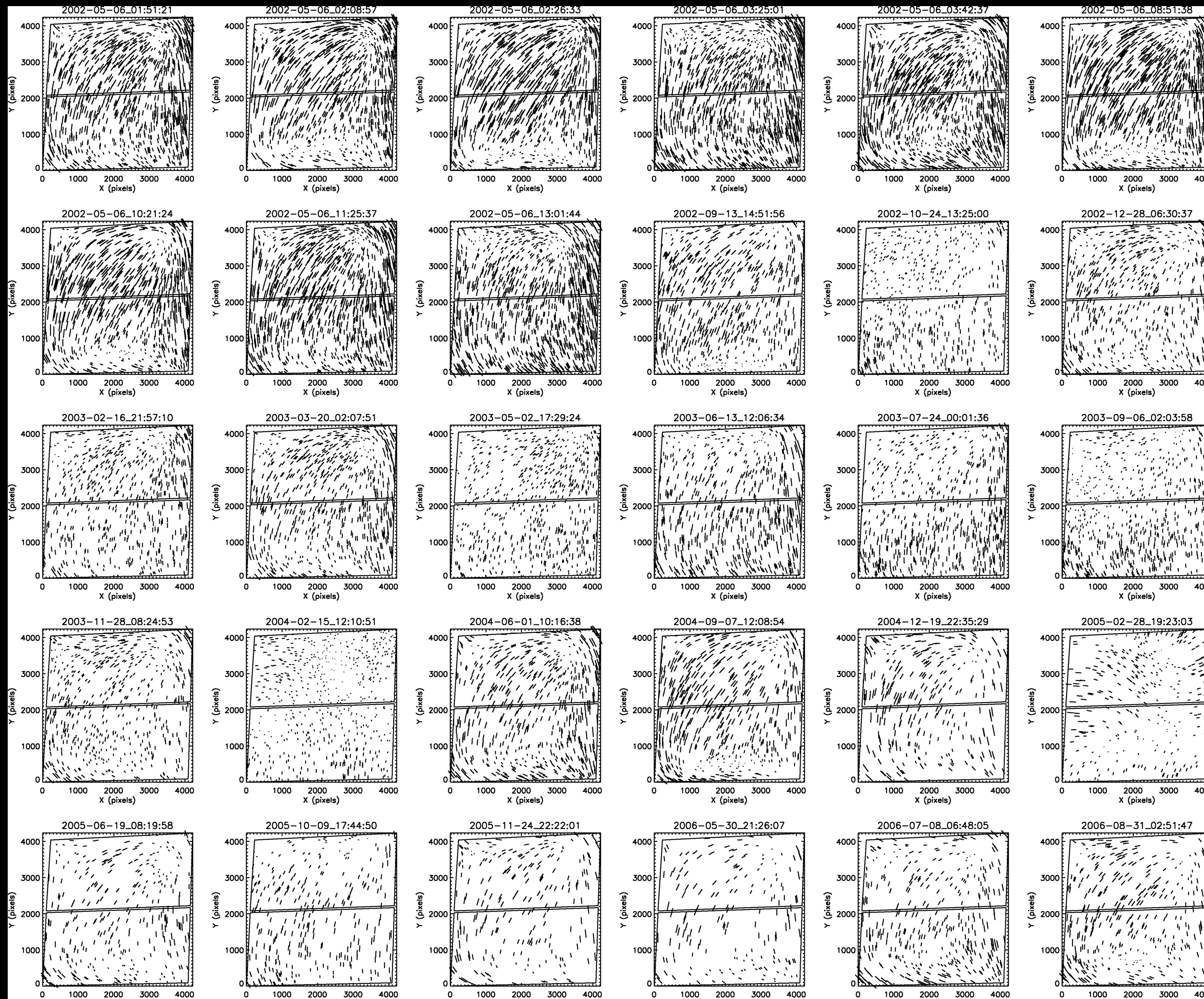
Ellipticity



Width

HST ACS Camera in F814W filter: Jee et al 2007

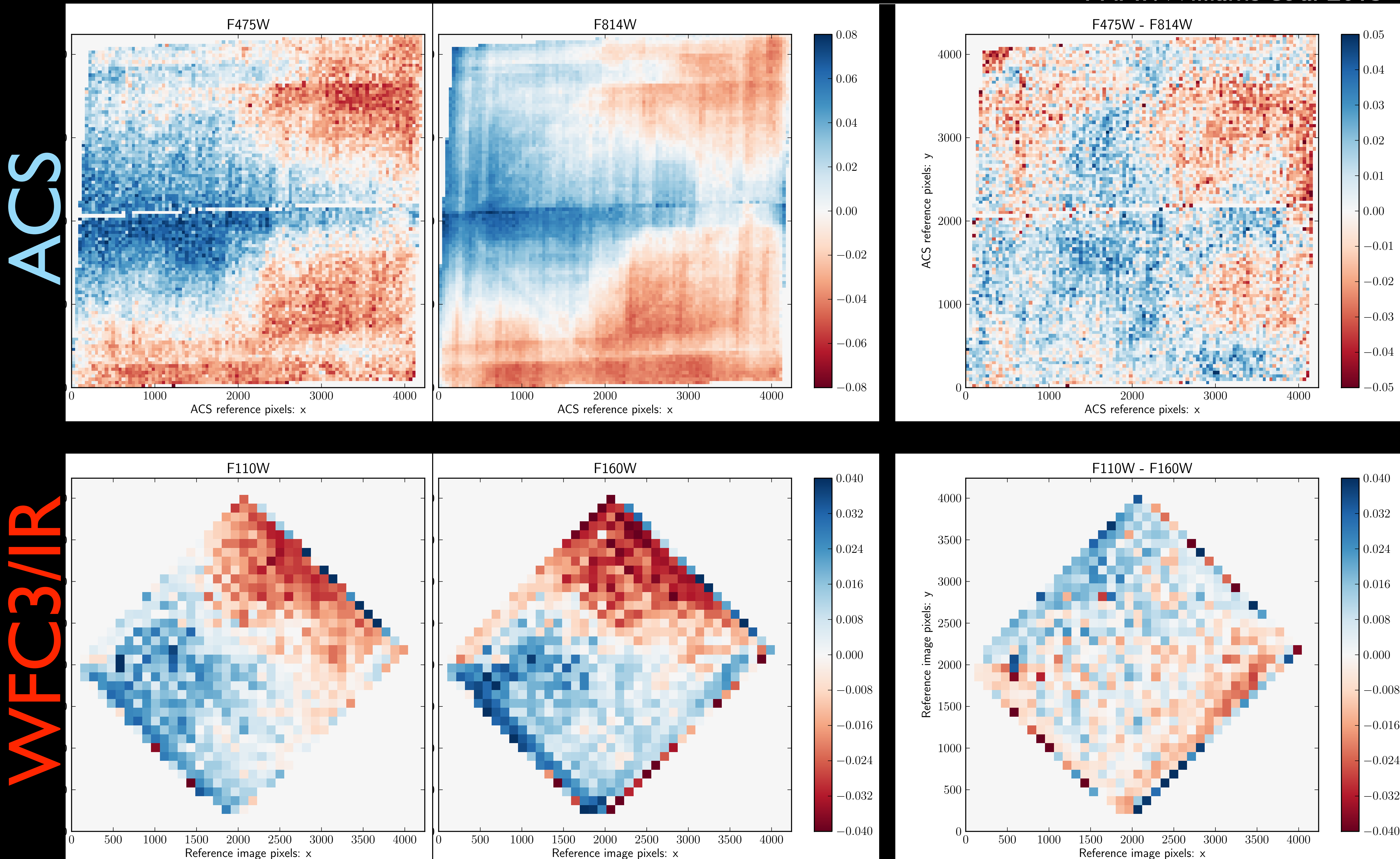
Point-Spread Function: Varies with time



Jee et al 2007

PSF errors affect magnitudes

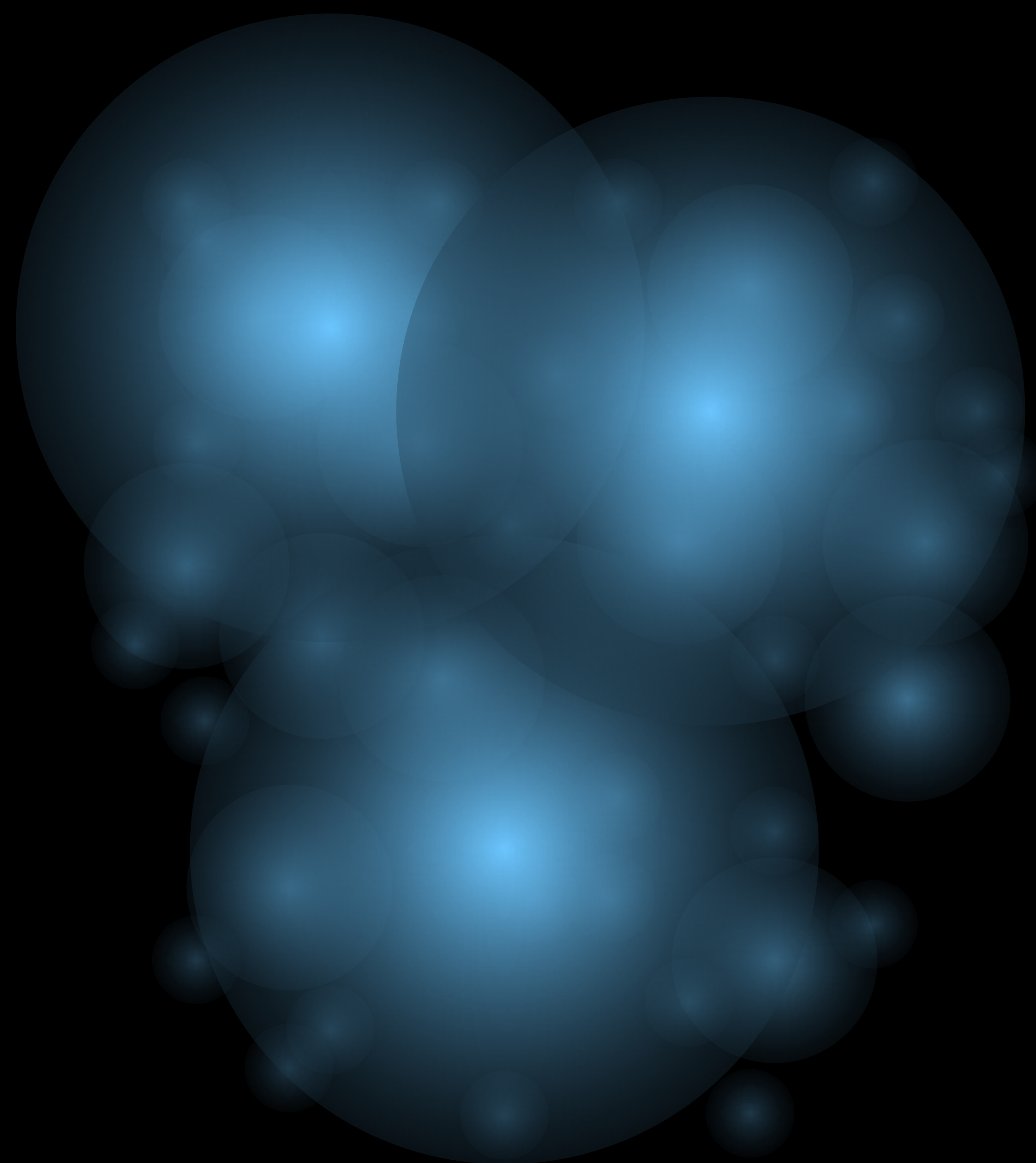
PHAT: Williams et al 2015



Magnitudes (4-8%)

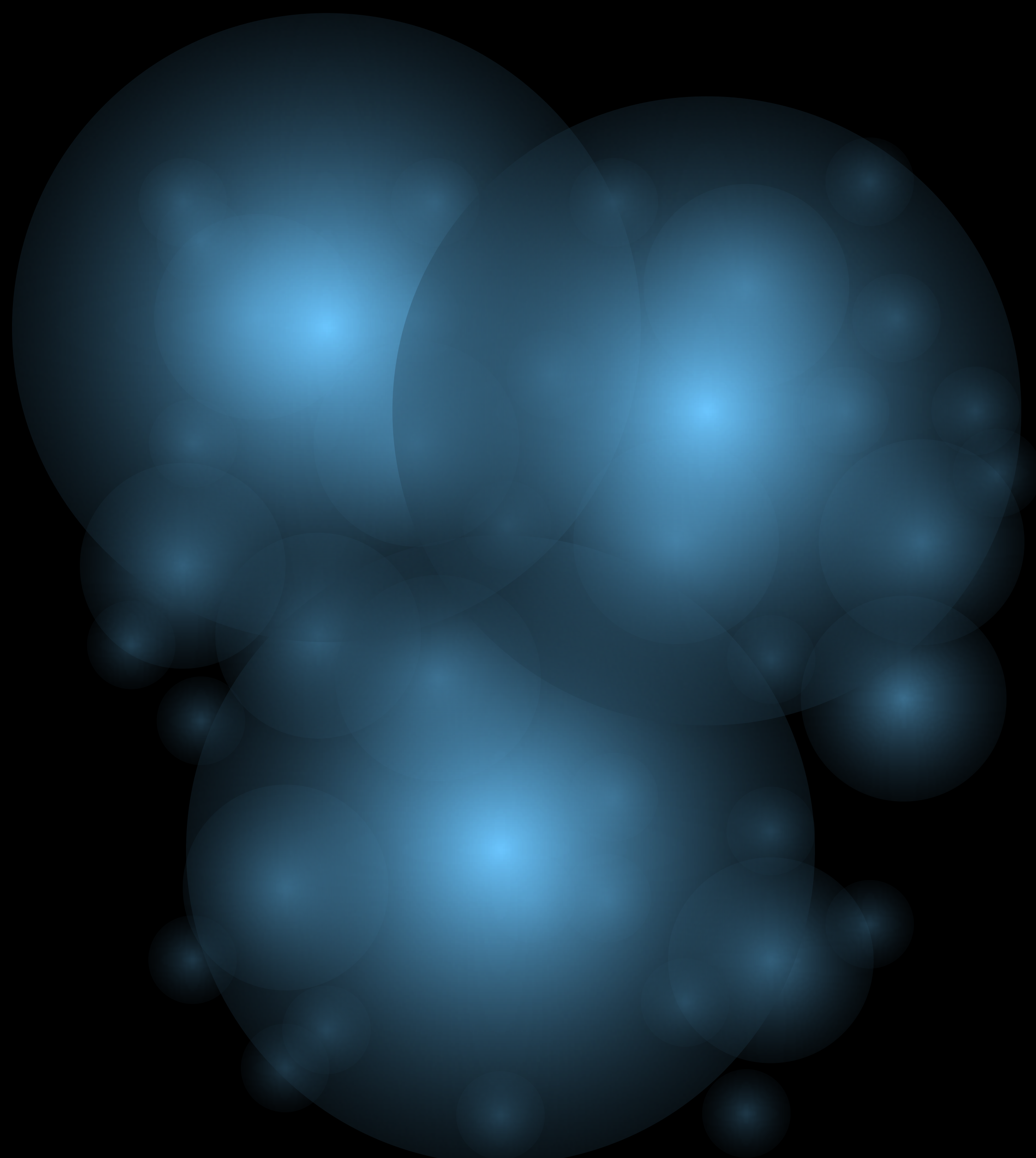
Color (5%)

Crowding biases photometry



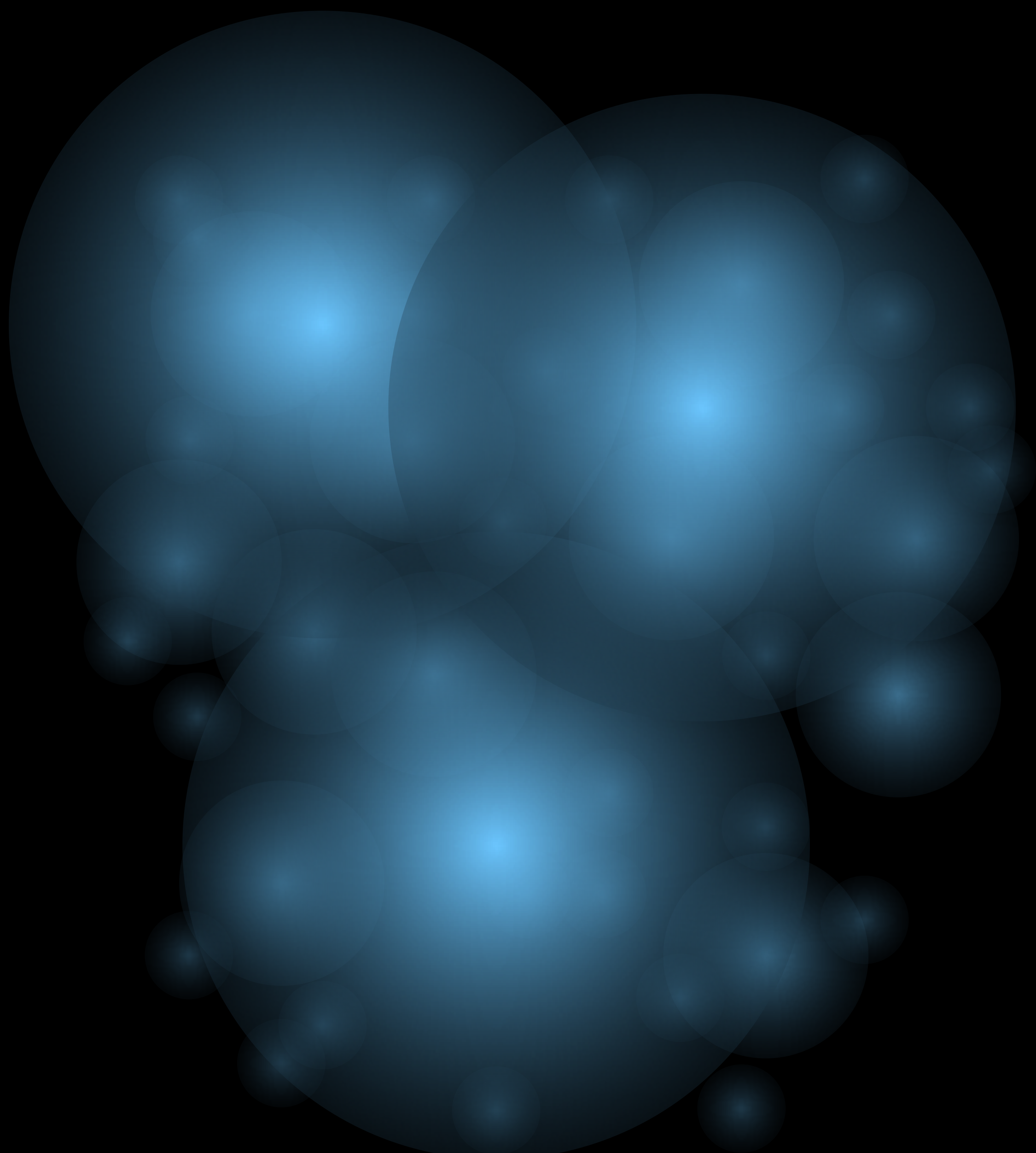
Undetected faint stars are blended with brighter, detected stars

Crowding biases:



- Magnitudes
  - Biased *brightward* from blended, undetected ★s

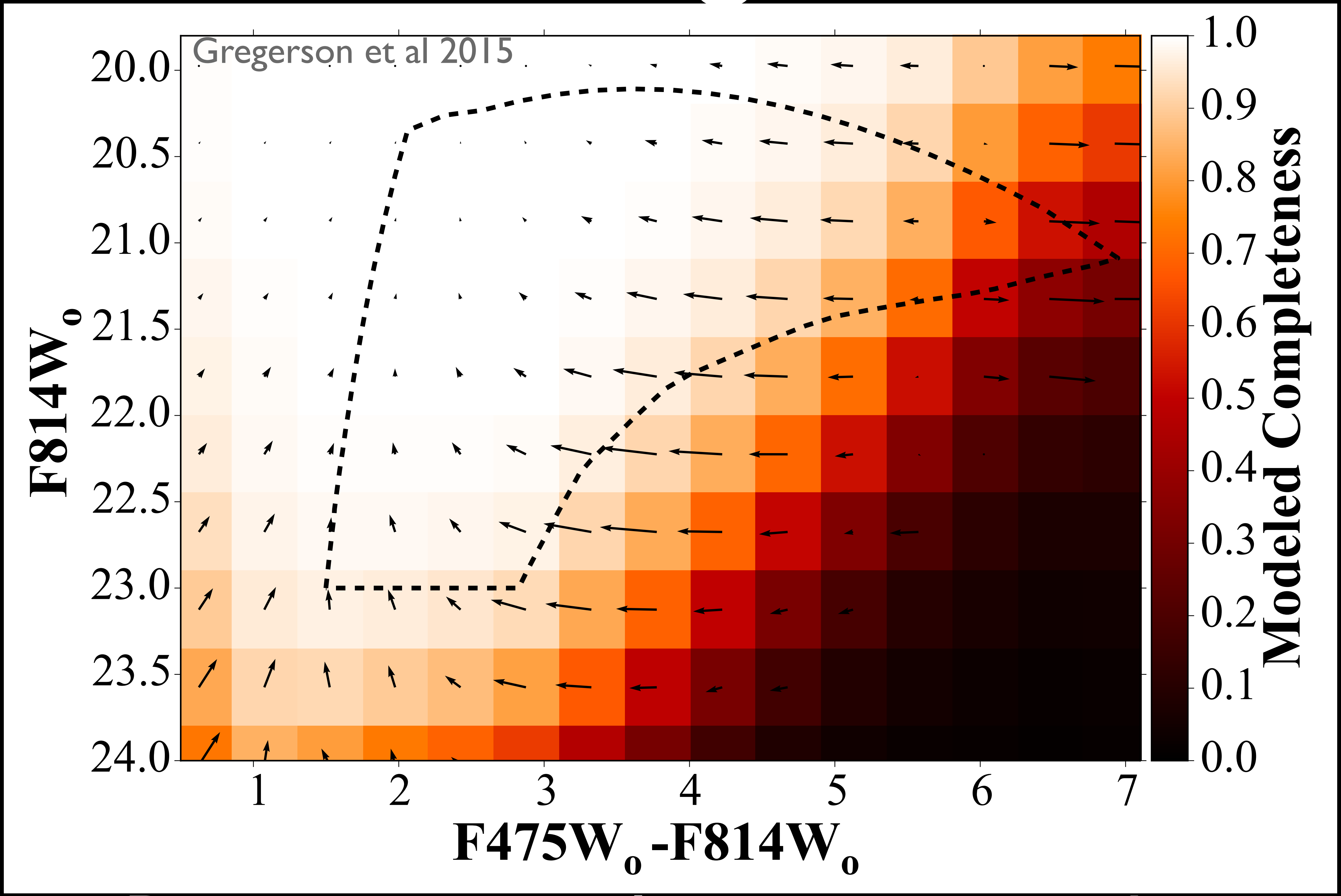
Crowding biases:



- Colors
  - Less biased, because blended ★s add flux to all bands

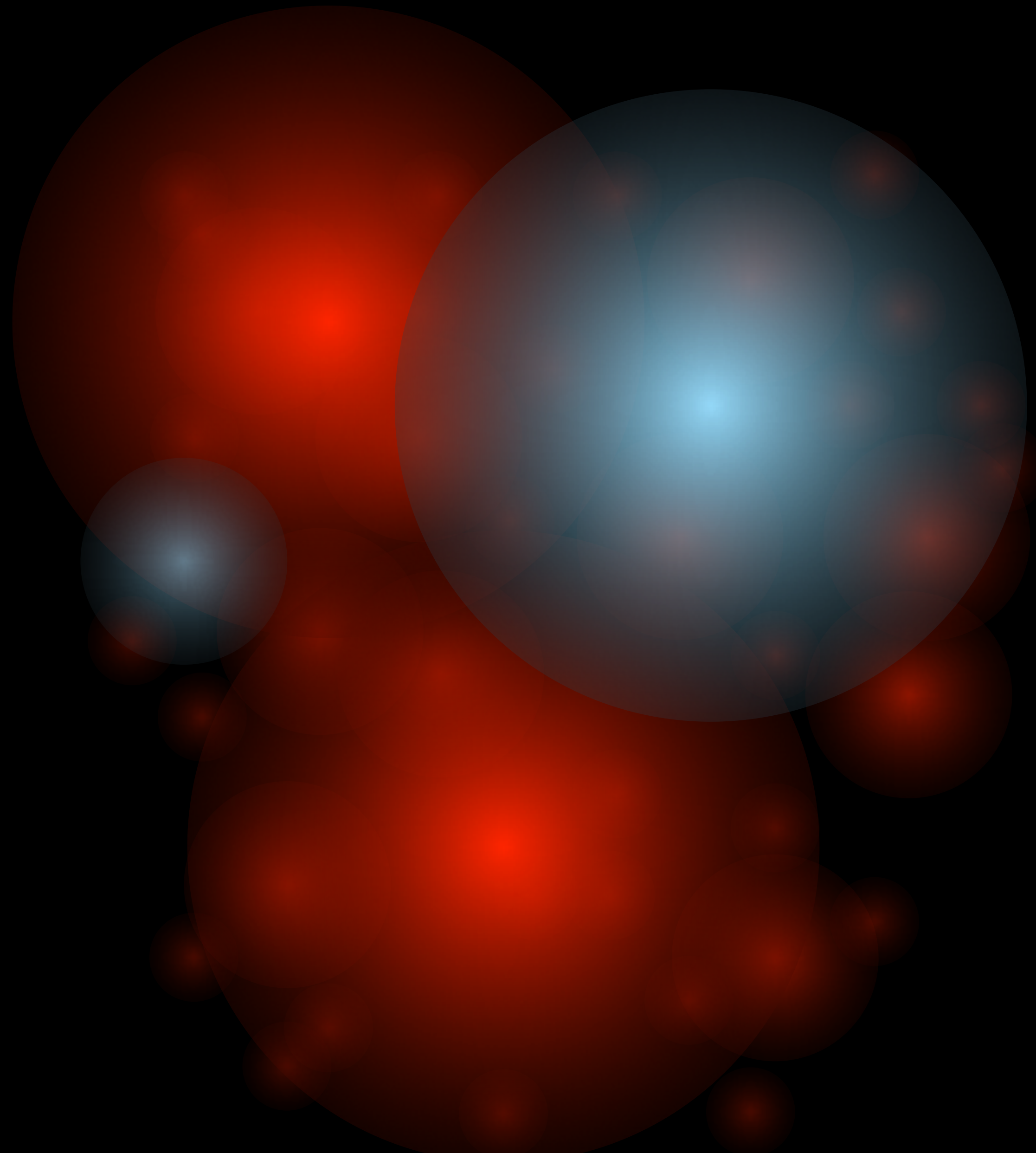
Bias can be large if typical unresolved stars have radically different colors, however

Crowding biases



Biases & completeness must be characterized w/ "artificial star tests"

Crowding dominates uncertainties



Uncertainties set by accuracy with which neighbors are subtracted, for all but the brightest stars