Perspectives at Detecting Globular Clusters in Formation at High Redshift (z~3-10)

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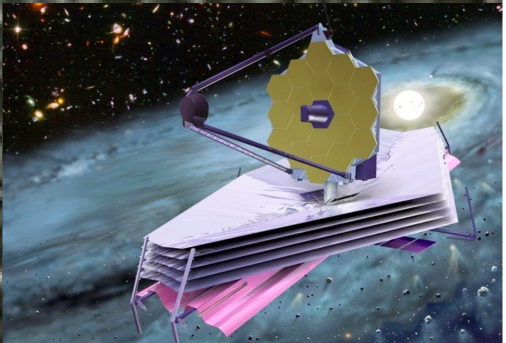
From Pozzetti, Maraston & AR, MNRAS, 2019

- Most (metal poor) GCs formed before their today host galaxies
- Perspectives at observing GC Progenitors at high redshift (z>~3)
- From JWST to the ELT
- What can we learn by finding (many of) them?

Observatoire de la Cote d'Azur, July 2, 2019

& Laboratoire Lagrange

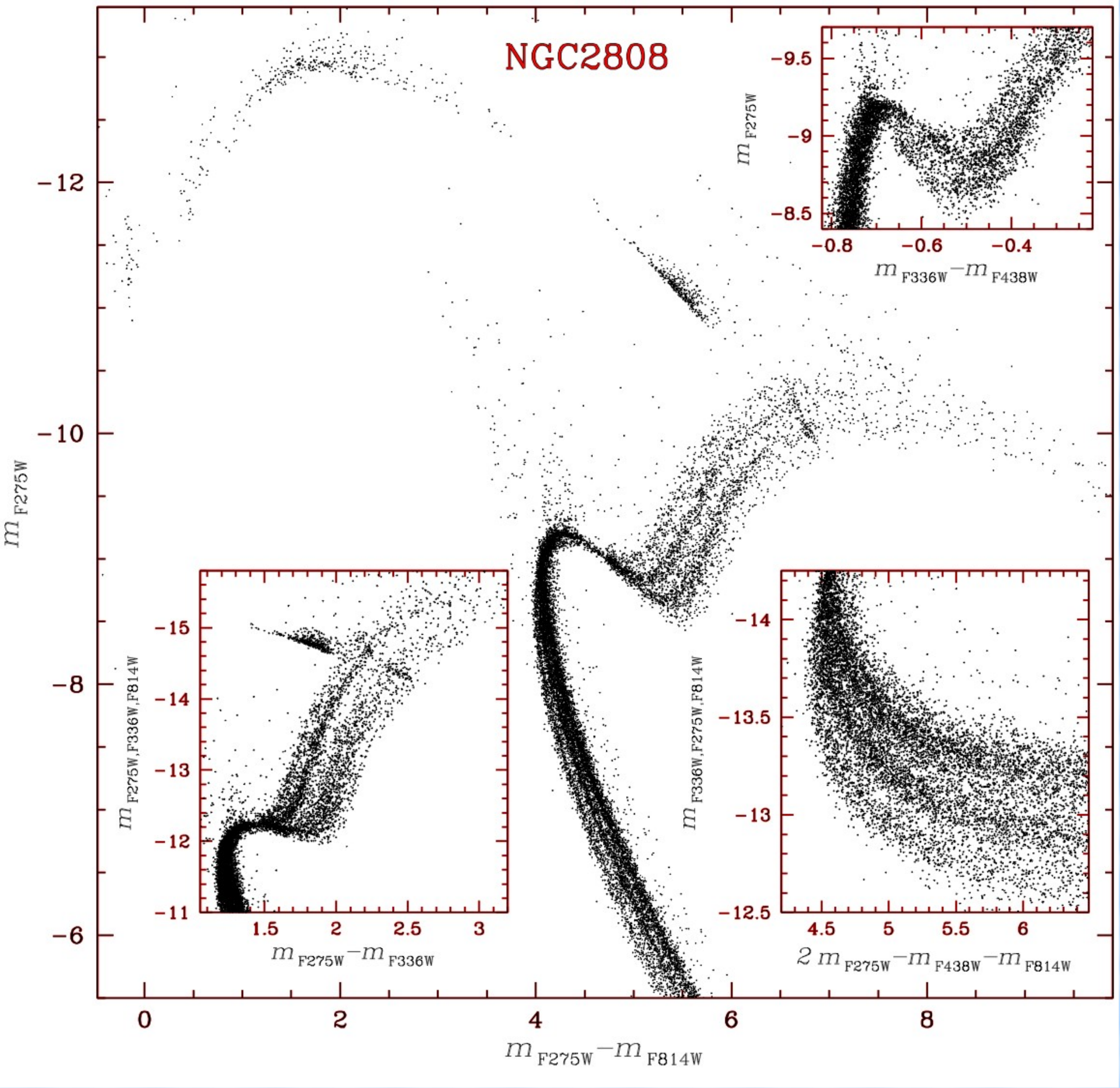


Globular Clusters

- Are the oldest objects in the MW with accurate ages (<~10%)
- ~half of them are very metal poor (<~1/10 solar)
- Host multiple stellar populations we still don't understand
- Honestly, we don't know how they formed
- For all these reasons, that's why it is tantalizingly interesting to see them in formation at (very) high redshifts,

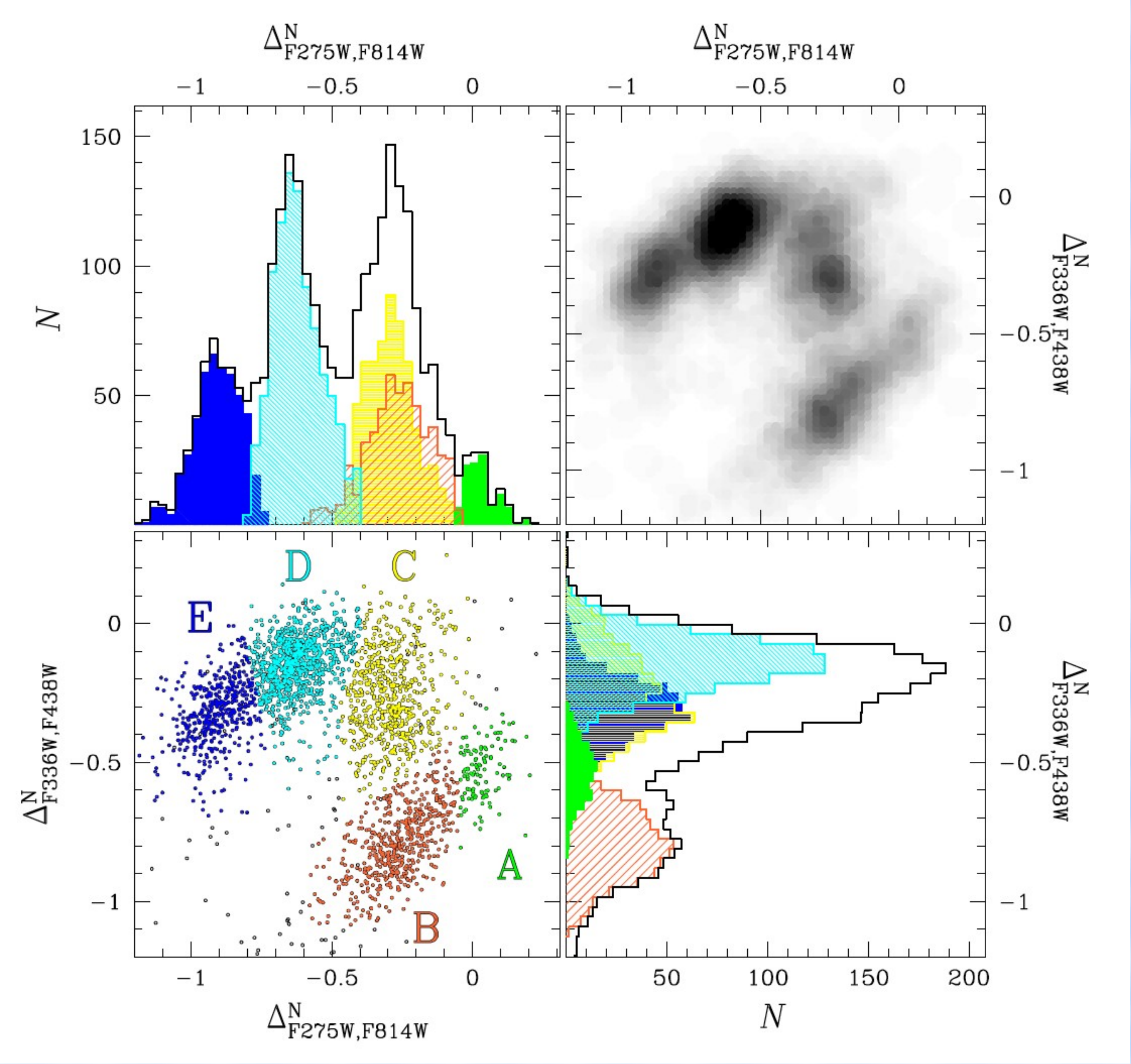
  in particular with next coming facities such as JWST & ELT

Multiple Stellar Populations in GCs



Milone et al. 2015

A GC “Chromosome Map”



Milone et al. 2015

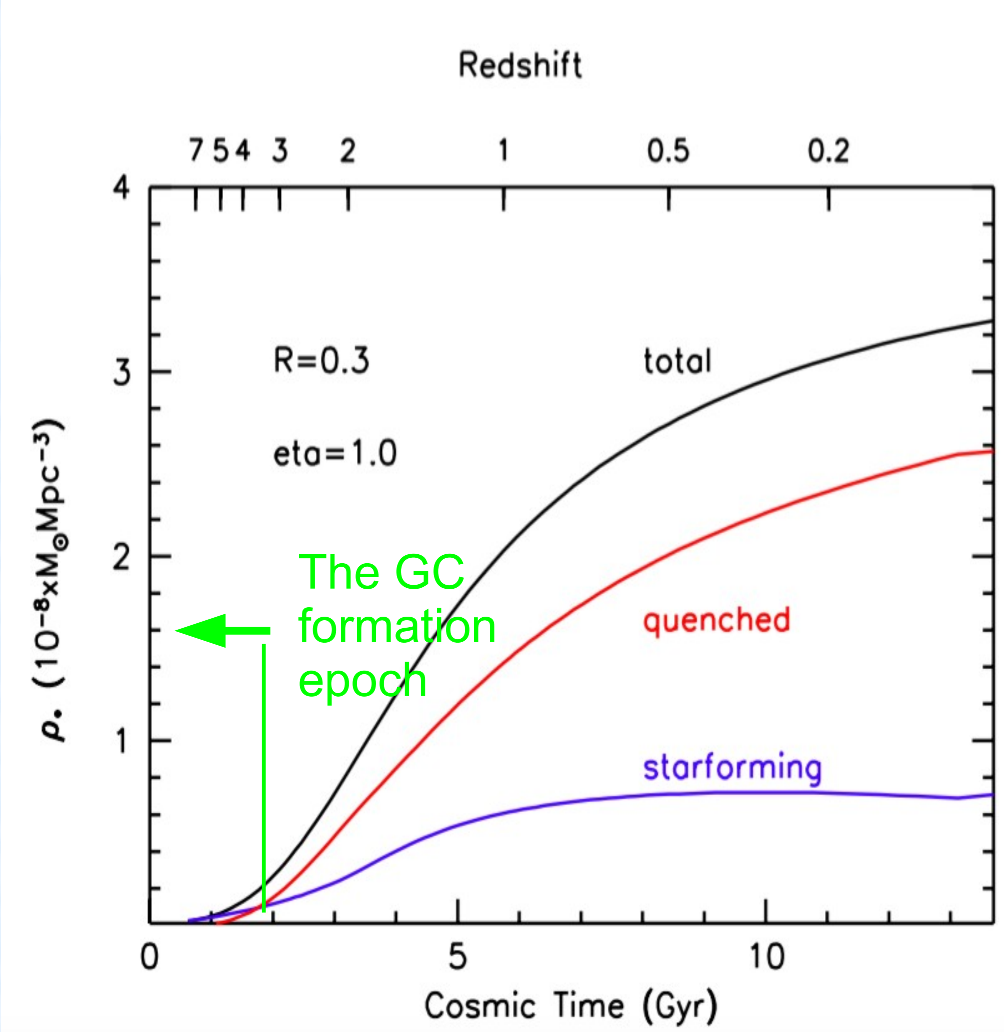
The possibility of seeing Globular Clusters in formation at high redshift and their possible role on reionization

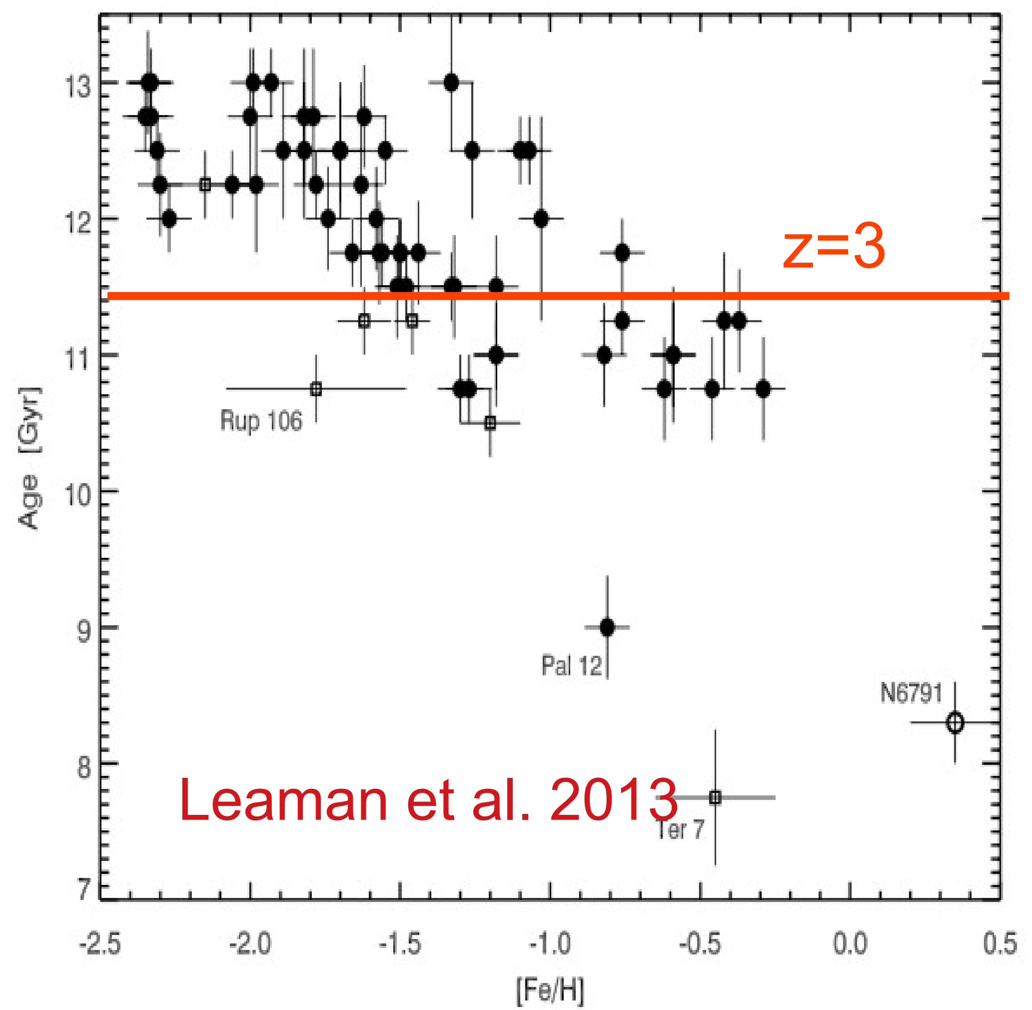
- Carlberg (2002), Ricotti (2002), Schraerer & Charbonnel (2011), Katz & Ricotti (2013, 2014), Trenti et al. (2015) Renzini (2017), Zick et al. (2018), Boylan-Kolchin (2018)
- First hints at objects that may be them: Vanzella et al. (2016, 2017a,b, 2019), Elmegreen & Elmegreen (2017), Bouwens et al. (2017, 2018)

- Next: search instructions for GCs in formation at high redshift

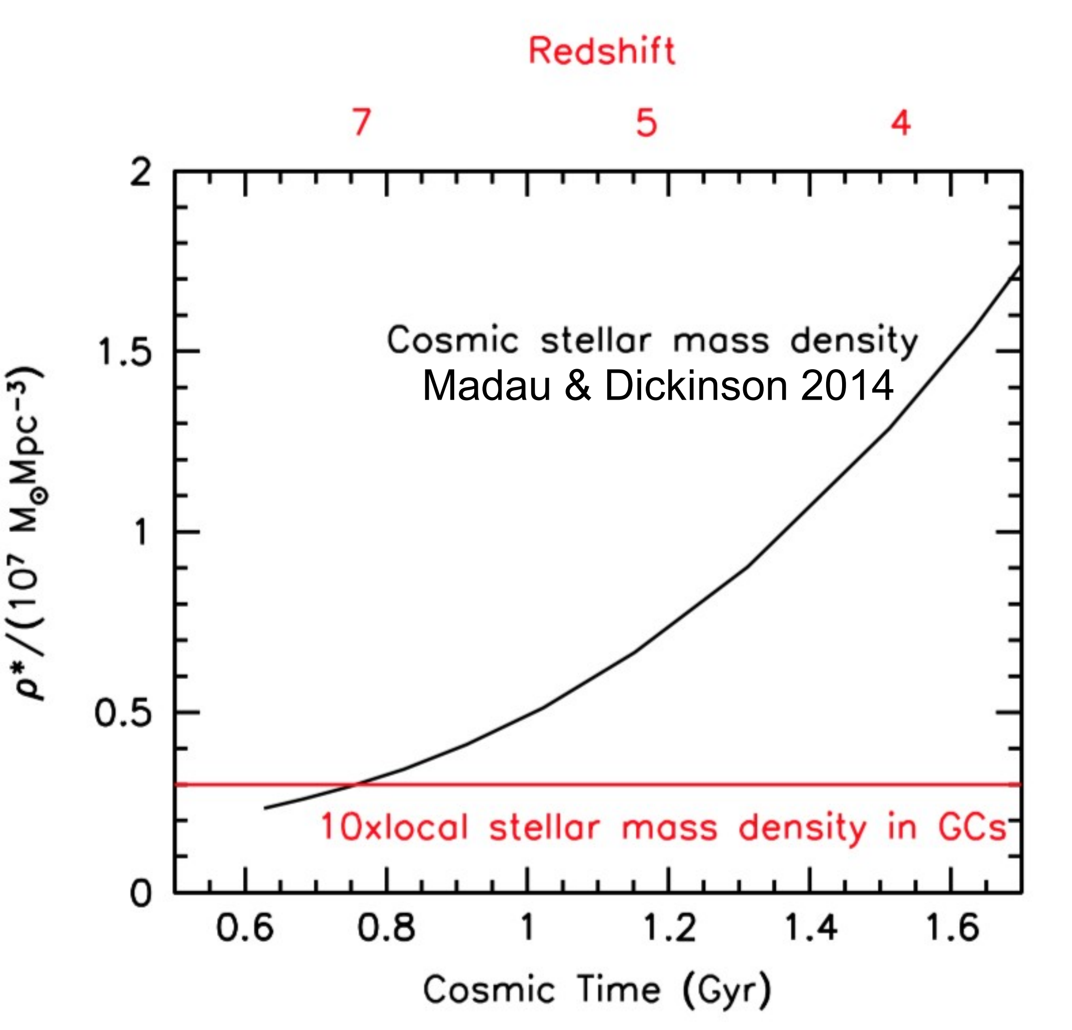
Most MW Globular Clusters formed ~12.5±1 Gyr ago, equivalent to 3<z<10, when there was no major Galaxy, yet

The ages of MW GCs





Did GC Progenitors have a role on reionization? Or did it the (metal poor) GC "generation"?



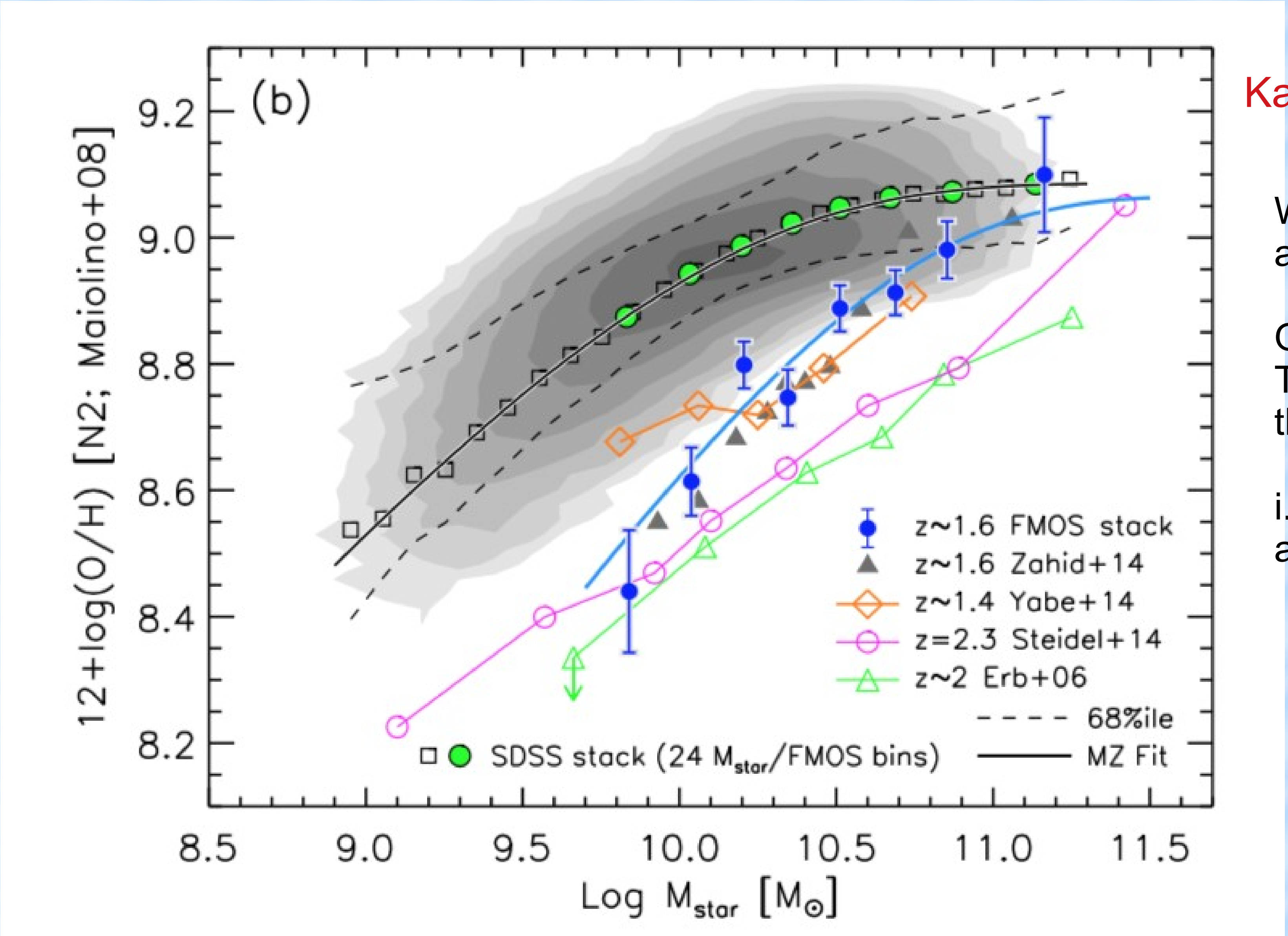
In the MW:

The metal poor halo$10^9 M_\odot$

The MP GCs: few $10^7 M_\odot$

The mass of the (**halo) GC Generation is >30x the mass in MP GCs

The Mass-Metallicity Relation as a Function of Redshift



Kashino et al. 2018

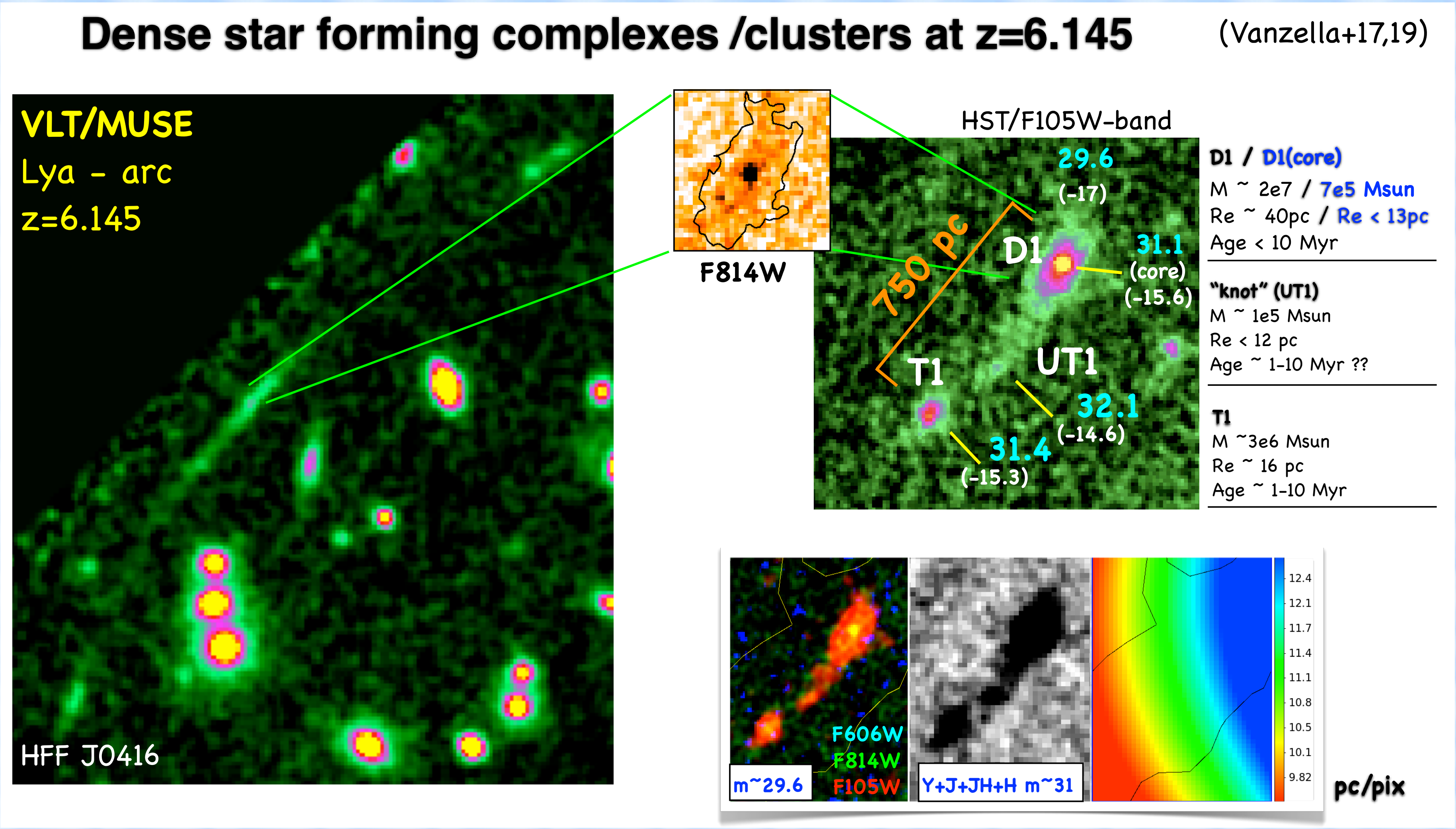
Were metal-poor GCs accreted by the MW?

Or rather, more likely, The MW grew around the GC generation?

i.e., the MW was accreted ....

Some 50% of GCs have metallicities below this plot

The best example so far of a Globular Cluster in formation at high redshift



What to Find at z>3 in a NIRCam Frame ~10 $arcmin^2$

Number of precursors = (Sampled comoving volume) x (Local number density)

Sampled comoving volume = ~130,000 cubic megaparsecs

Objects	Local Number density (Mpc^{-3})	Number of precursors in a NIRCam Frame
Galaxy Clusters & BCGs	10^{-5}	~1
$M^*>10^{11}\ M_\odot$ Galaxies	2×10^{-3}	~200
Globular Clusters	1.5	~200,000
GCPs within 10 Myr from peak Luminosity		~1500

Local number density of GCs: ~1.5 Mpc^{-3}; $\langle M_{GC}\rangle \sim 2\times10^5\ M_\odot$

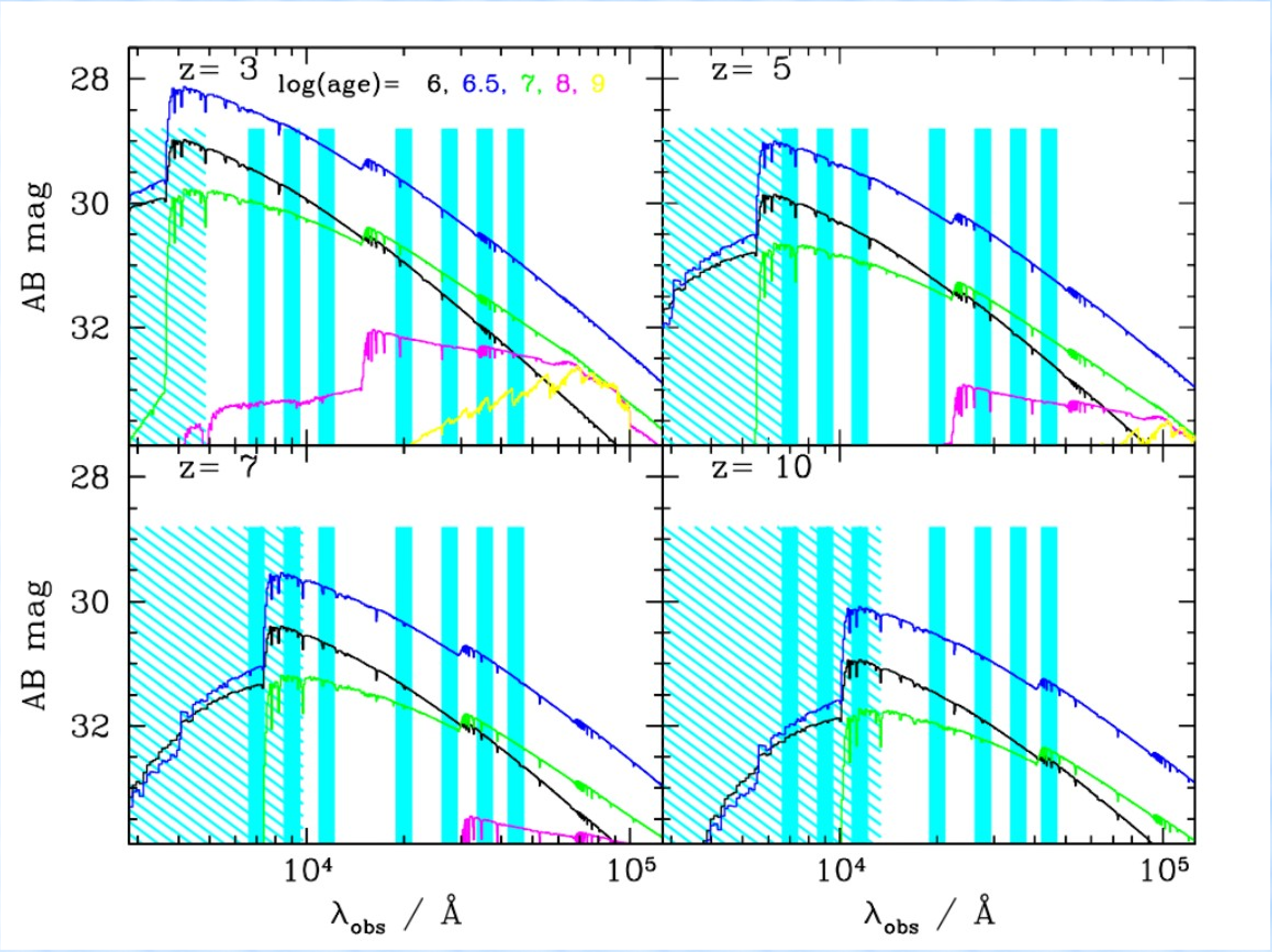
Local mass density in GCs: ~ $3\times10^5\ M_\odot Mpc^{-3}$

(GCs make only ~0.1% of the total mass in stars today)

Assumptions to estimate the Number Counts of "Classical" GCPs at z>3

- The Milky Way is not atypical (so most GCs in the Universe formed within the first ~2 Gyr from the BB).
- The mass function of the forming GCs in the early Universe is either 1) identical to the local GC mass function: a Gaussian with log M*=5.3 and σ=0.52 dex (Harris+2014), or 2) a scaled-up version of it with log M*=6.3 (i.e., 10x local M*): Mass budget factor = 1 or 10, hoping to braket reality.
- GCPs are approximated as unreddened SSPs No EL
- (Yes, many caveats about these assumptions..)

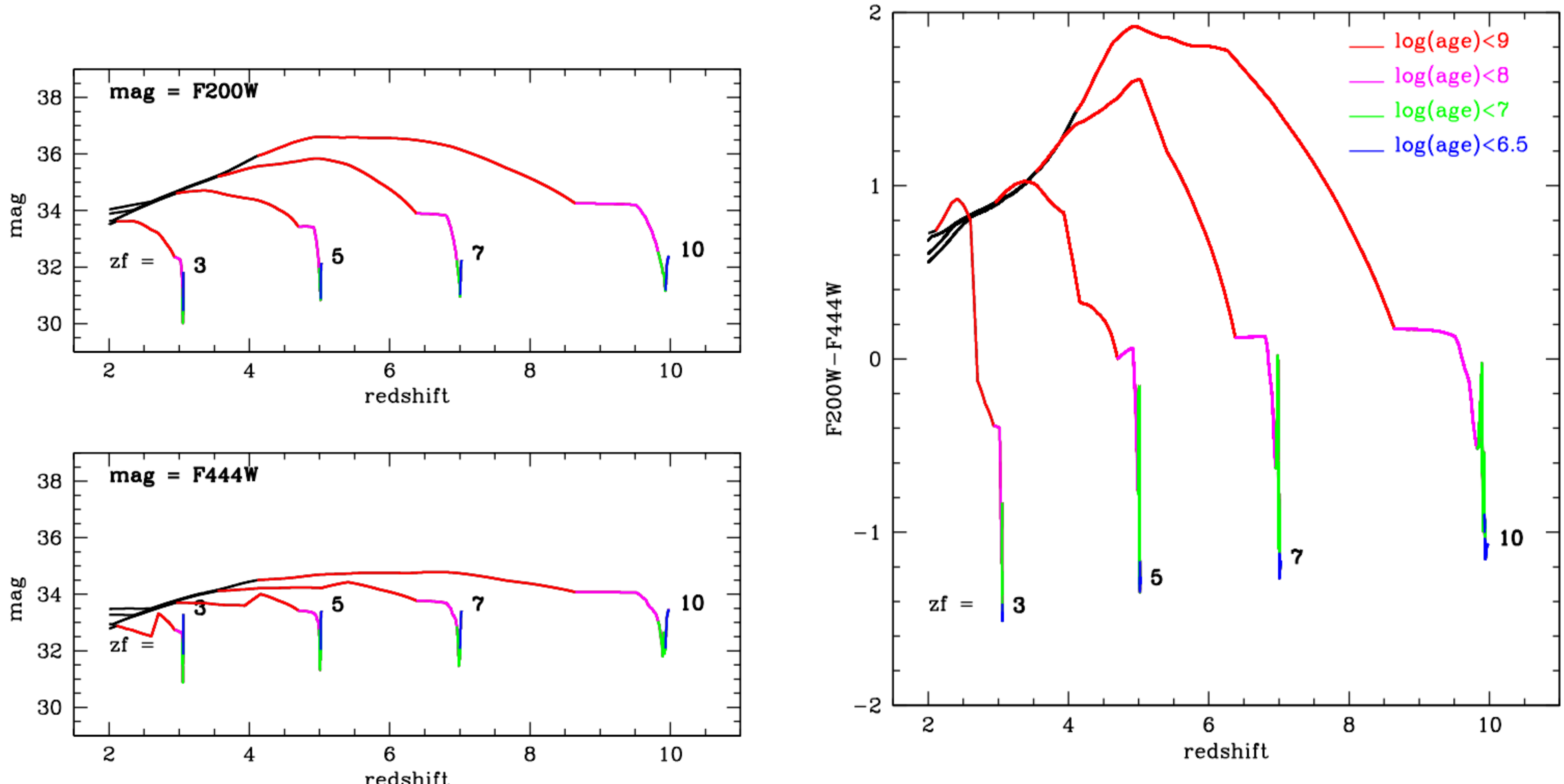
The Spectral evolution of GCPs as Sampled by NIRCam



Expected Peak Luminosity and NIRCam Color of GC Progenitors are almost independent of their formation redshift!

A 10^6 $M_\odot$ burst (SSP)

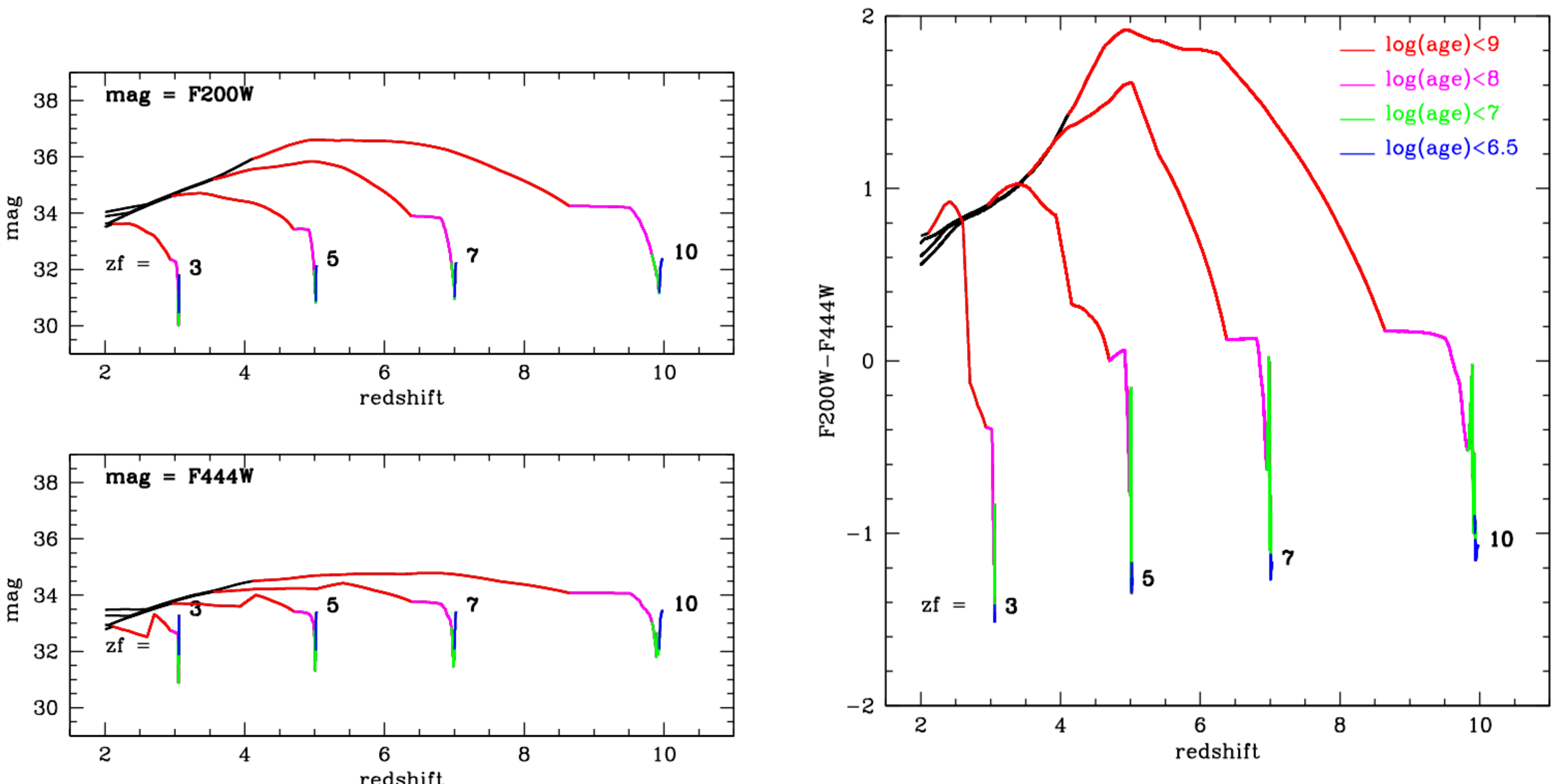
Pozzetti, Maraston & A.R. (2019)



This is so because NIRCam will sample the rest-frame UV, which is close to a power law. Hence colors (flux ratios) are ~independent of redshift and so are luminosities, because flux increases with decreasing wavelength (a negative K correction)

A $10^6\ M_\odot$ burst (SSP)

$F(\lambda) \propto \lambda^{-\beta}$ β~2.5-3

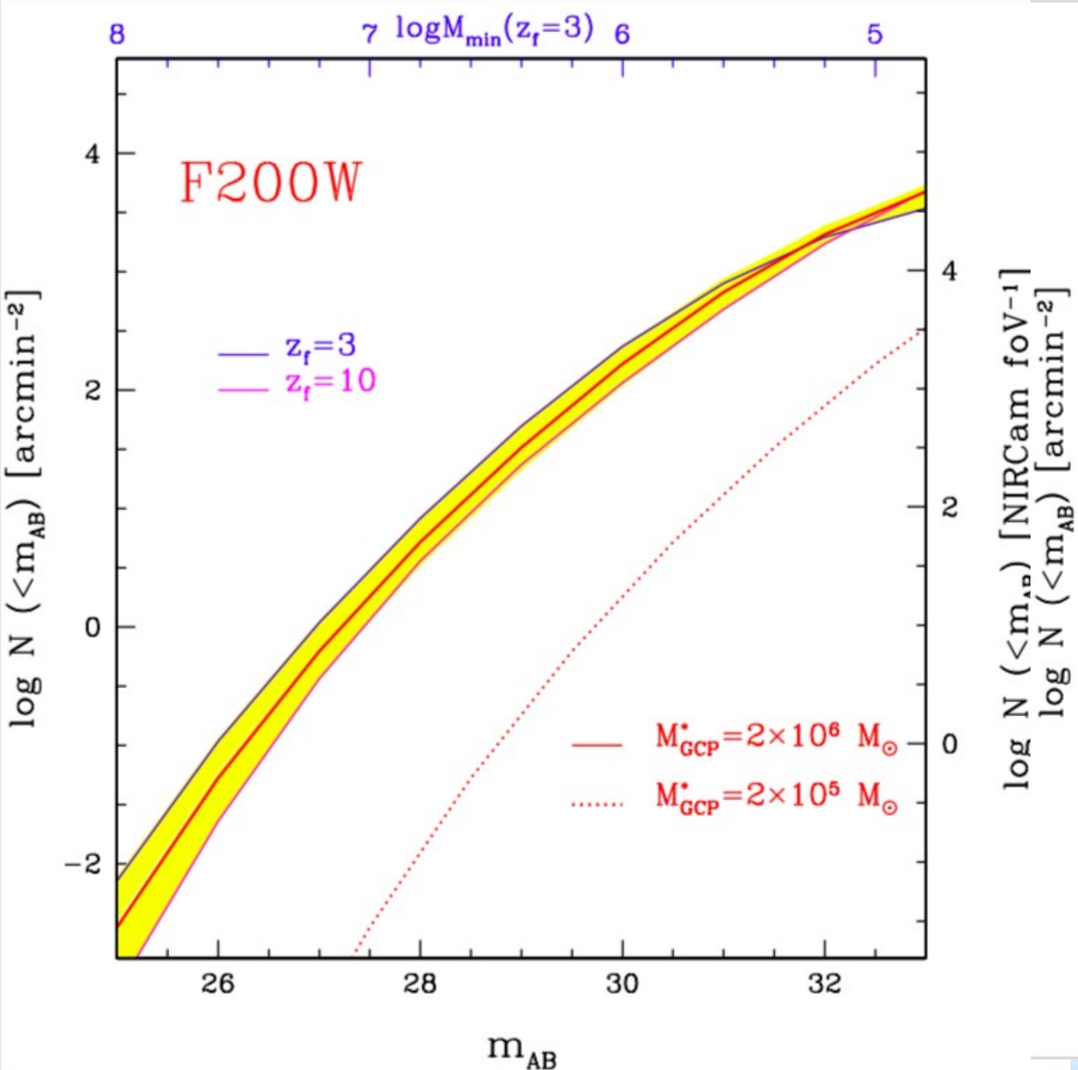


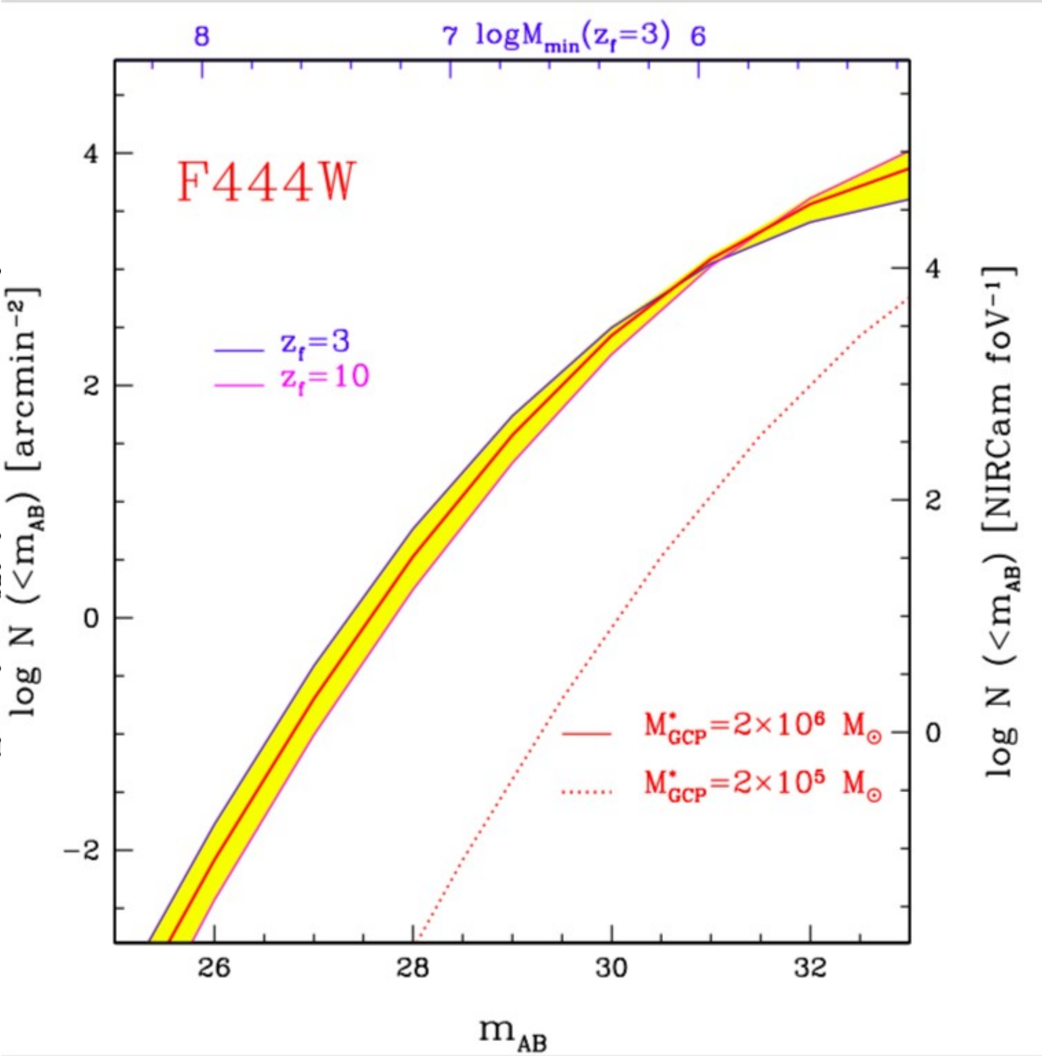
Expected Number Counts of GC Progenitors

Constant formation rate within 3<z<10

Log M* = 6.3
σ = 0.52 dex

This assumes GCPs were 10x more massive at formation





$$N_{\rm tot}(< m_\lambda) = \int_{t_{\rm lb}^{\rm inf}}^{t_{\rm lb}^{\rm sup}} \int_{z_{\rm min}}^{z_{\rm f}(t_{\rm lb})} \int_{M_{\rm min}(m_\lambda, z, z_f)}^{\infty} \mathcal{F}(t_{\rm lb}) \frac{dN}{d{\rm log}M} \frac{dV}{dz}\, d{\rm log}M\, dz\, dt_{\rm lb},$$

Log M* = 6.3
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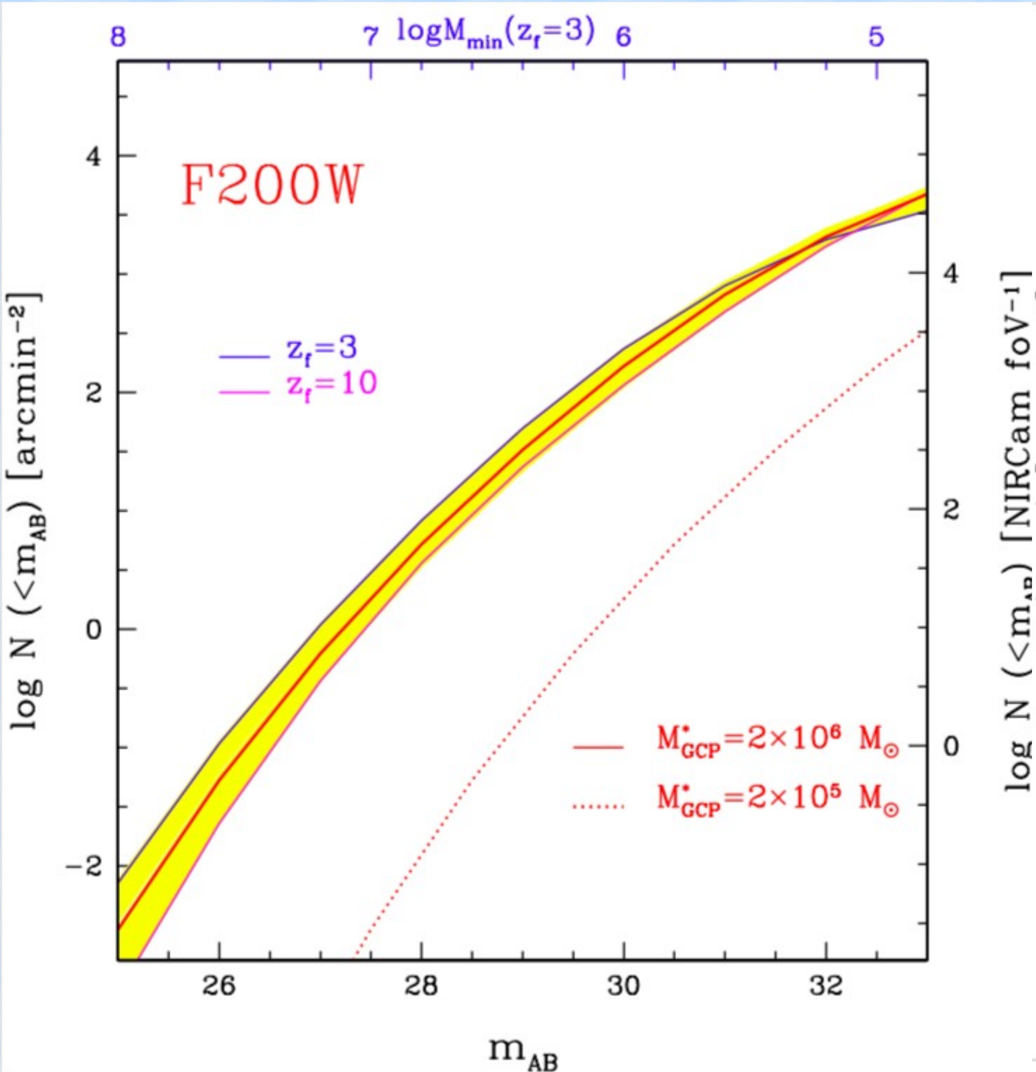

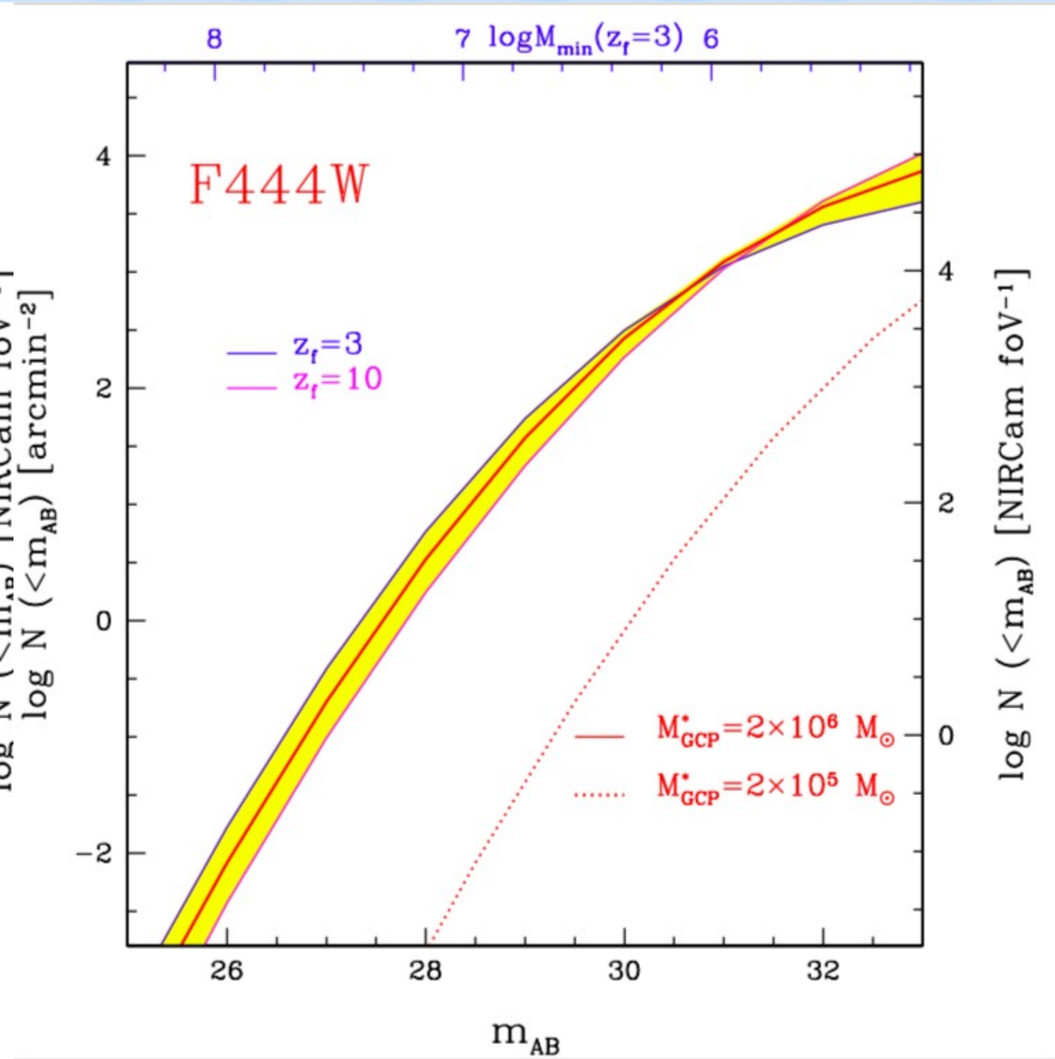

Expected Number Counts of GC Progenitors

Constant formation rate within $3<z<10$

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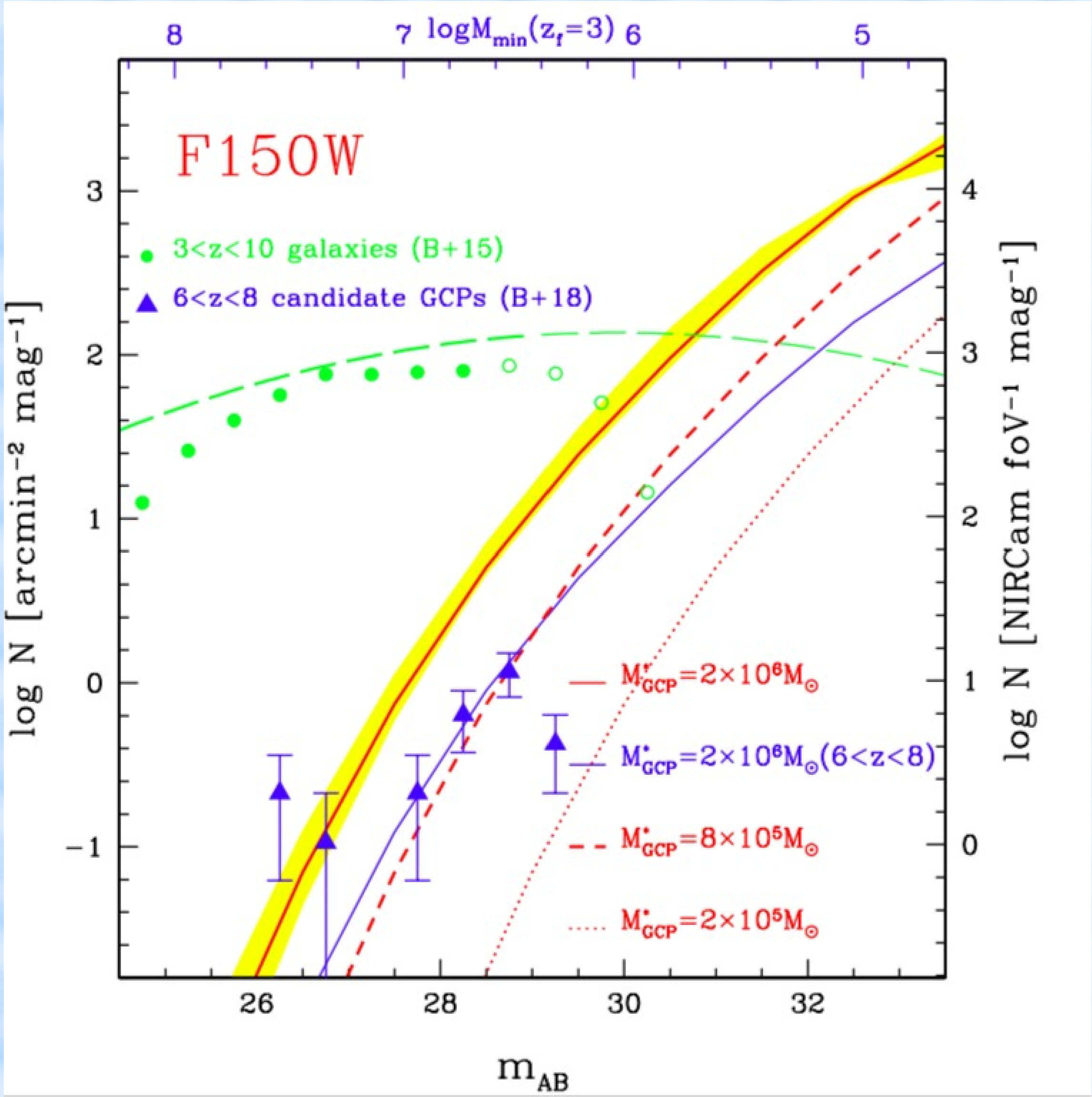
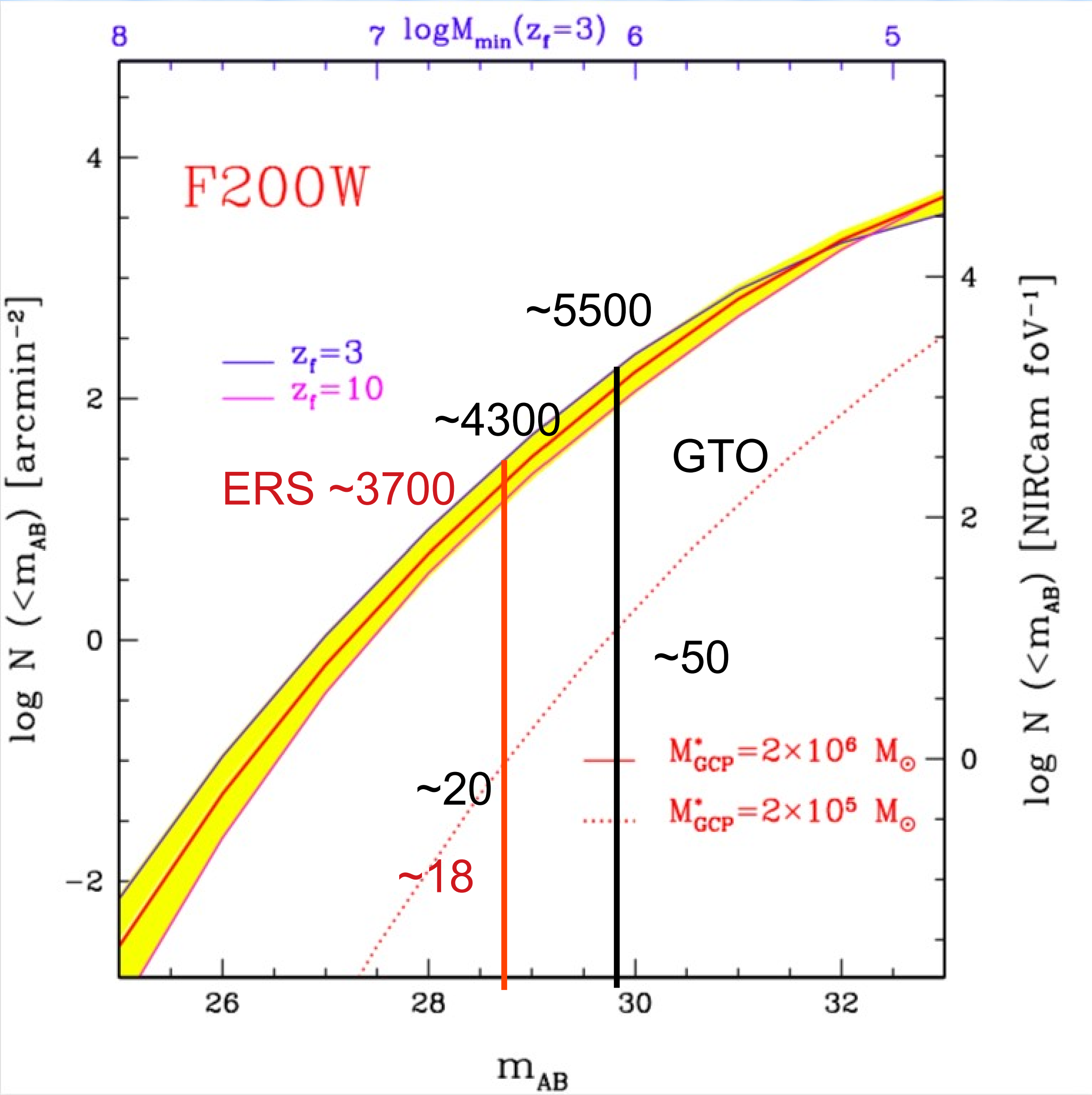


Blue triangles: (F160W) candidate GCPs (size <~40 pc) at $6<z<8$ from Bouwens+2018

Expected Number Counts of GCPs In NIRCam ERS & GTO Frames



First JWST/NIRCam checks of these numbers will come from the JWST/NIRCam "Early Release Science" (ERS) observations:

~100 arcmin^2 down to mag ~29

Followed by NIRCam GTO Team obs.s

GTO Plans:

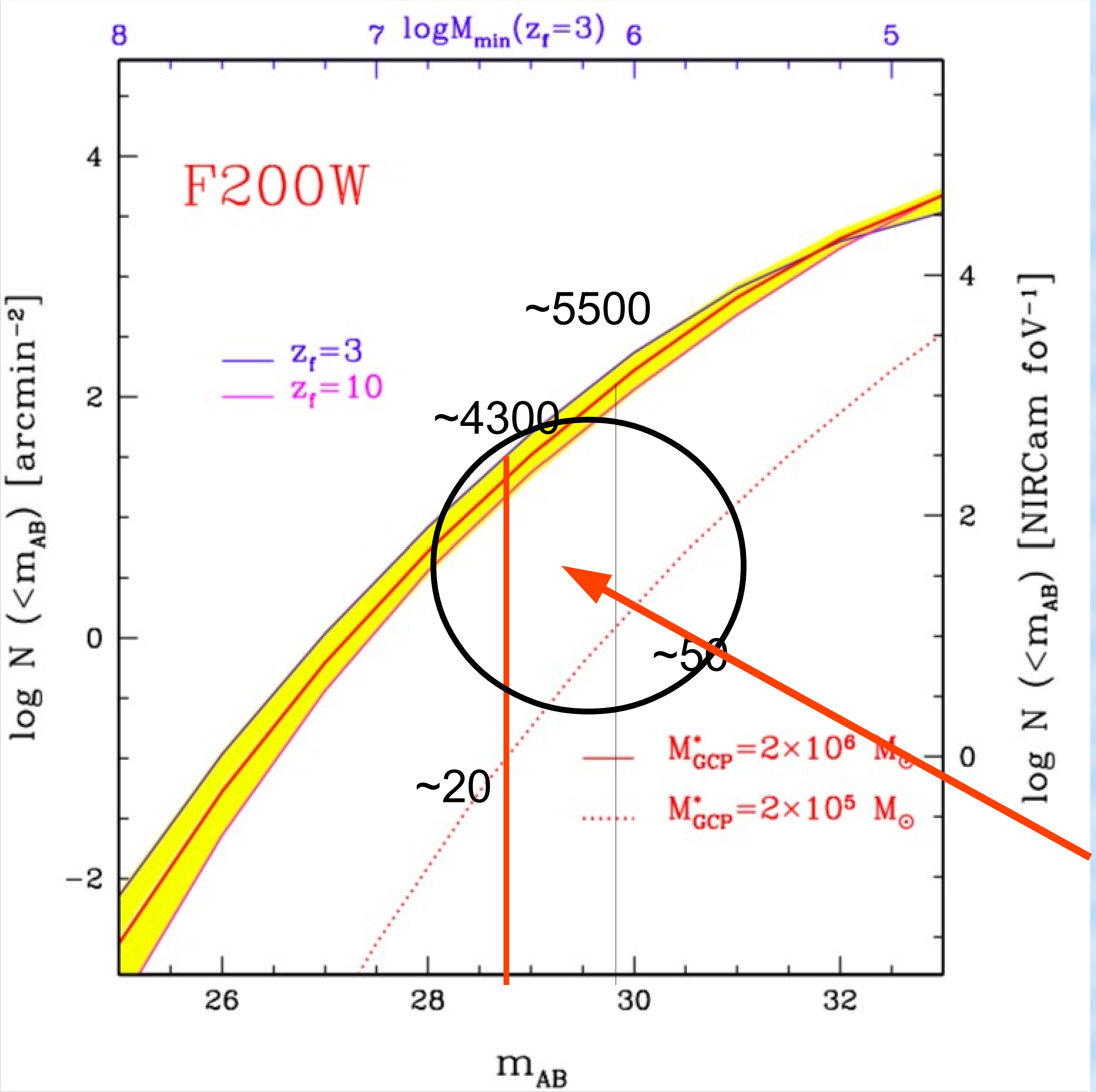
Down to mag < 29.8 (10σ for p.s.)

Over 46 arcmin^2 and

Mag < 28.8 Over 190 arcmin^2.

Alltogether, they should detect (F200W) ~ 90 or ~13,500 GCPs for mass budget factor 1 or 10, respectively

Expected Number Counts of GCPs In NIRCam GTO Frames



First JWST/NIRCam checks of these numbers will come from the NIRCAM GTO Team

GTO Plans:

Down to mag < 29.8 (10σ for p.s.)

Over 46 arcmin^2 and

Mag < 28.8 Over 190 arcmin^2.

Alltogether, they should detect ~ 70 or ~10,000 GCPs for mass budget factor 1 or 10, respectively

The battle is going to be faught here

Among NIRCam Candidates, how to Distinguish True GCPs from Dwarfs or Clusters of GCPs?

- At these redshifts, NIRCAM Spatial Resolution is ~200 pc (largely insufficient!)
- Lensing already can! (See Eros Vanzella)
- MICADO@ELT will have ~30 pc resolution: it should do a great job following-up NIRCam candidates!
- MICADO FoV is 53”x53” (~0.8 arcmin^2) and on average should include ~80 mag<29.8 GCPs for MBF=10, or just ~1 for MBF=1.
- But ERS+GTO will also give ~30 z>3 progenitors of M87-like galaxies, each with its ~10,000 GCPs ...

- MICADO Narrow Slit (16 mas ~ 80 pc) single-object Spectroscopy, of emission lines: [OIII] at z~2, [OII] up to z <4.4, CIV up to z<12, Lyα for z>5.5

- HARMONI: single object, ~30 pc resolution IFU. Spectroscopic separation of GCP from Host Dwarf. Very fast on point-like sources such as GCPs would be.

- MOSAIC HMM-NIR, 0".1 (~500 pc) spaxels, (MOAO) multiplex ~100, patrol field 40 arcmin^2 will contain ~4,000 galaxies at 3<z<10 mag<28, & <~40 GCPs

- MOSAIC HDM: 0".08 (~400 pc) resolution, again, good for (dwarf) galaxies, not for GCPs.

MOSAIC spectral range if <1.8 μm [OIII] @ z<2.6

What can we learn once (many) GCPs will be found?

- Measure how more massive were GCPs compared to their GC progeny and see how they formed
- GCP clustering: ~ 200 progenitors of today $\sim 10^{11} M_\odot$ galaxies in each NIRCam FoV, each with ~500 GCPs
- Relative timing of GC and bulk of galaxy formation
- Do GCPs play a role in cosmic reionization?

  (not a new possibility, e.g., Ricotti 2002, Carlberg 2002; Katz & Ricotti 2013; Schraerer & Charbonnel 2011; Bowens+2017; Zick+2018)
- Are you looking for "first galaxies"? beware of globular clusters in formation!
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CAVEATS

- Is an SSP a fair representation for GCPs? Multiple stellar generations will reduce the peak luminosity if separated by more than a few Myr
- If GCPs are ~kpc sized dwarfs, then their SFH may extend ~100 Myr, resulting in fainter luminosities compared to an SSP of the same mass. Its GCs can overshine the dwarf when forming (Zirk+2018)
- Metal rich GCPs ($Z>0.1Z_\odot$) must have formed inside more massive galaxies, with extended SFHs, hence will be affected by high extinction and may not be detectable at all.
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Thank You!