Searching for gravitationally lensed population III galaxies with HST and JWST

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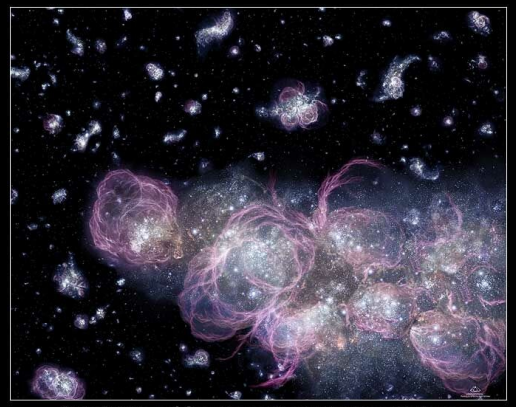
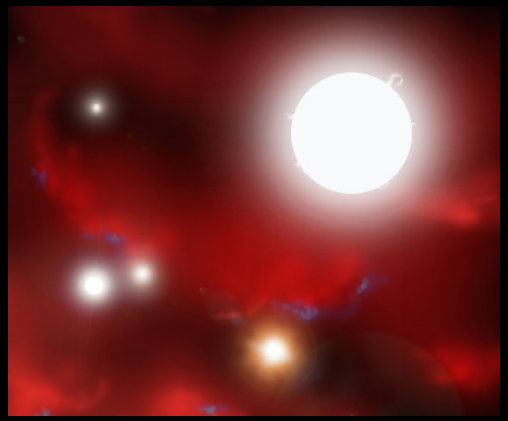
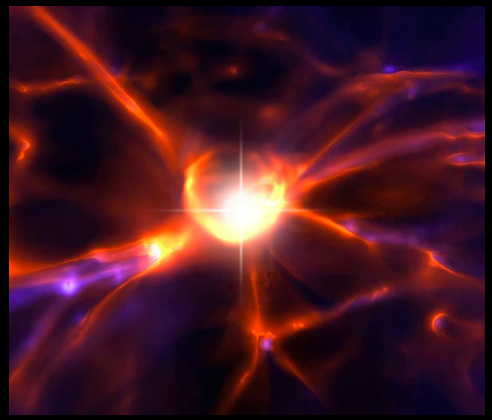
Outline

- Population III stars and galaxies – what, when, why?
- Cluster lensing – we're chanceless without it!
- Population III galaxy candidates in CLASH
- A glimpse of the future (JWST)



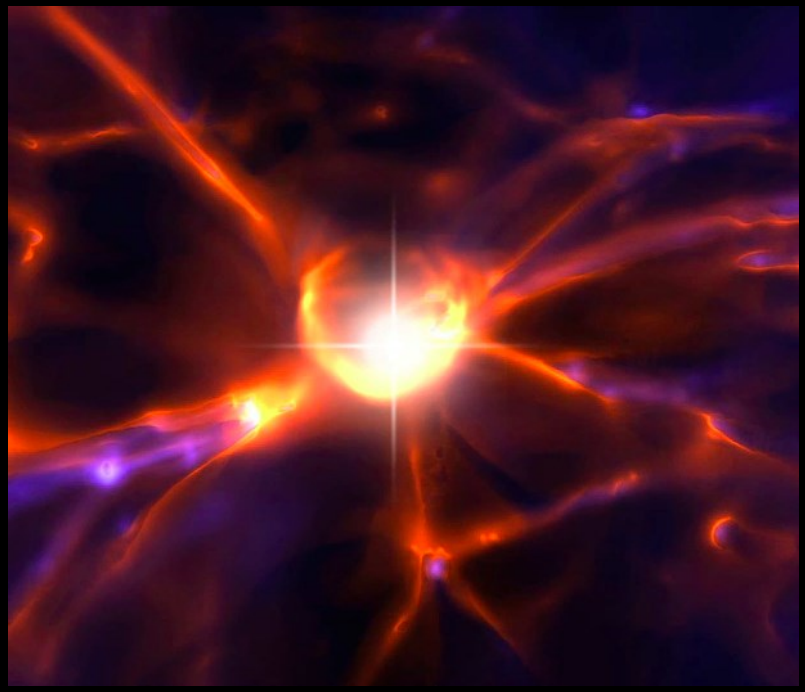
Artist's View of Star Formation in the Early Universe
Painting by Adolf Schaller • STScI-PRC02-02





Population III stars

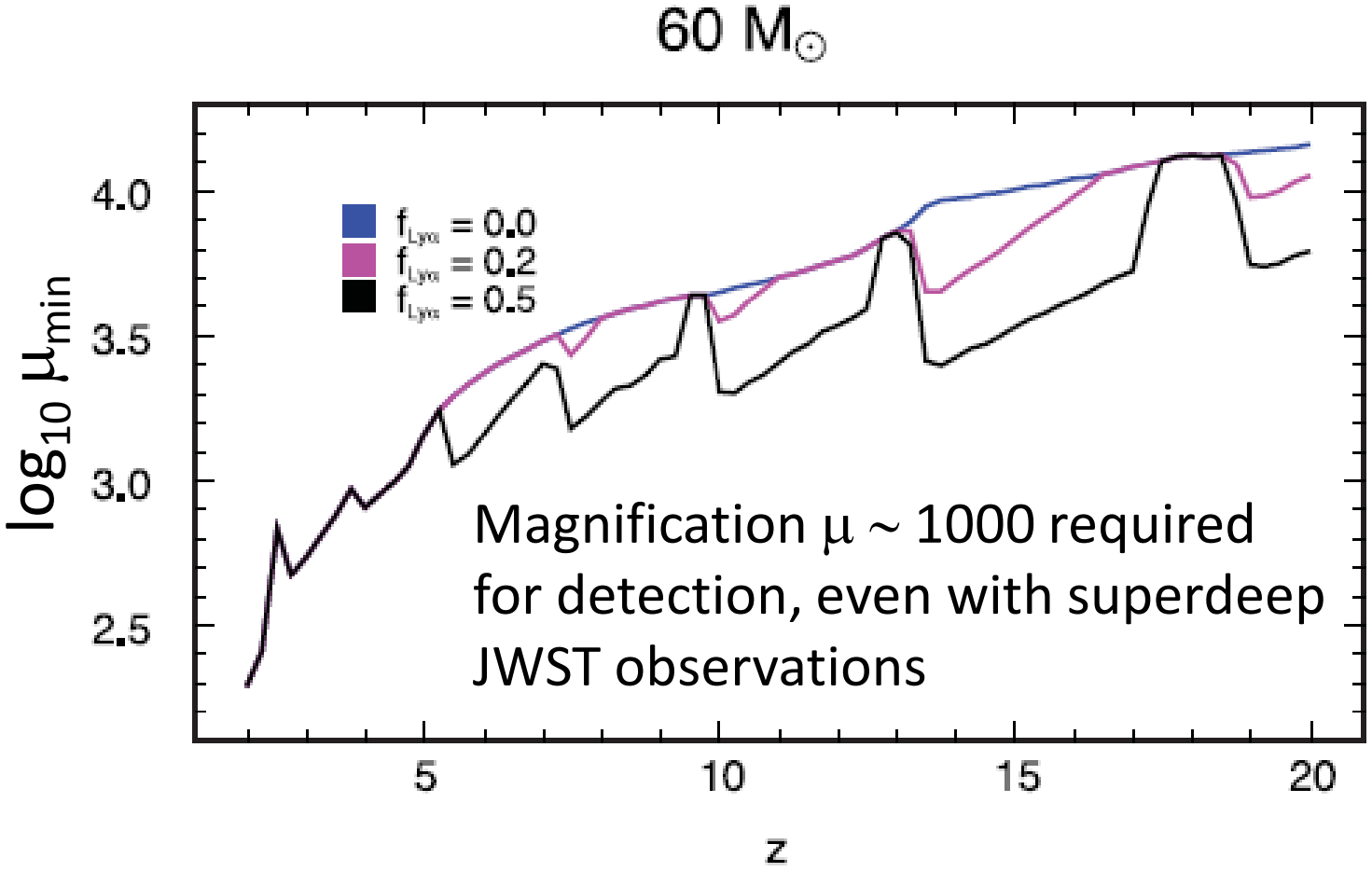
- First generation of stars
- Metallicity $Z \approx 0$
- Start forming at $z \approx 30$, in 10^5-10^6 M_{solar} minihalos
- Typical mass ~ 10 M_{solar} (very top-heavy IMF)
- Very hot (Teff ~ 10^5 K)
- A few stars per minihalo



All theory and simulations!

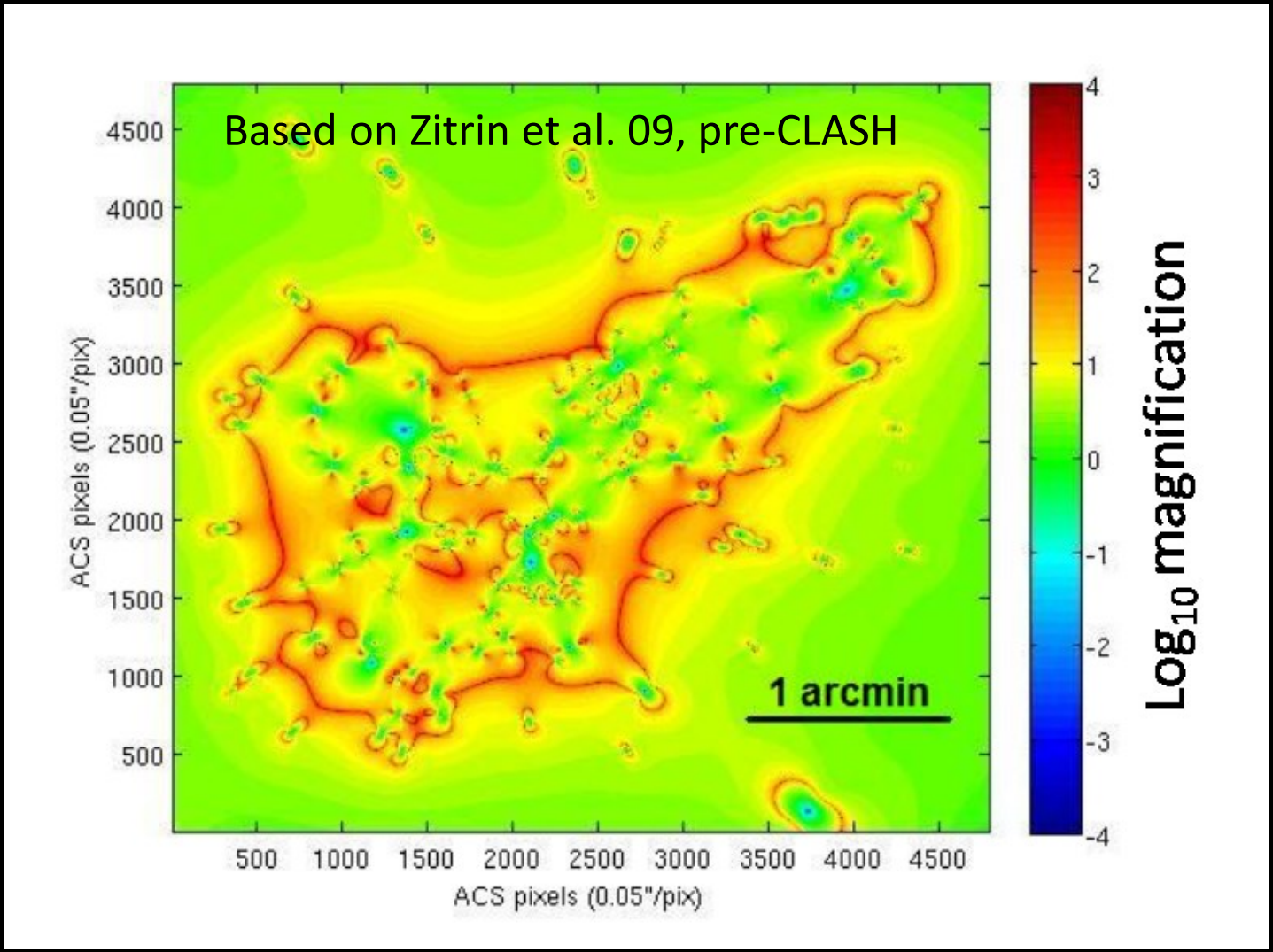
No observational confirmation so far!

Not even JWST can detect individual pop III stars



Rydberg et al. 2013, MNRAS, 429, 3568

Magnification map of J0717.5+3745



Zackrisson et al. 2012, MNRAS 427, 2212

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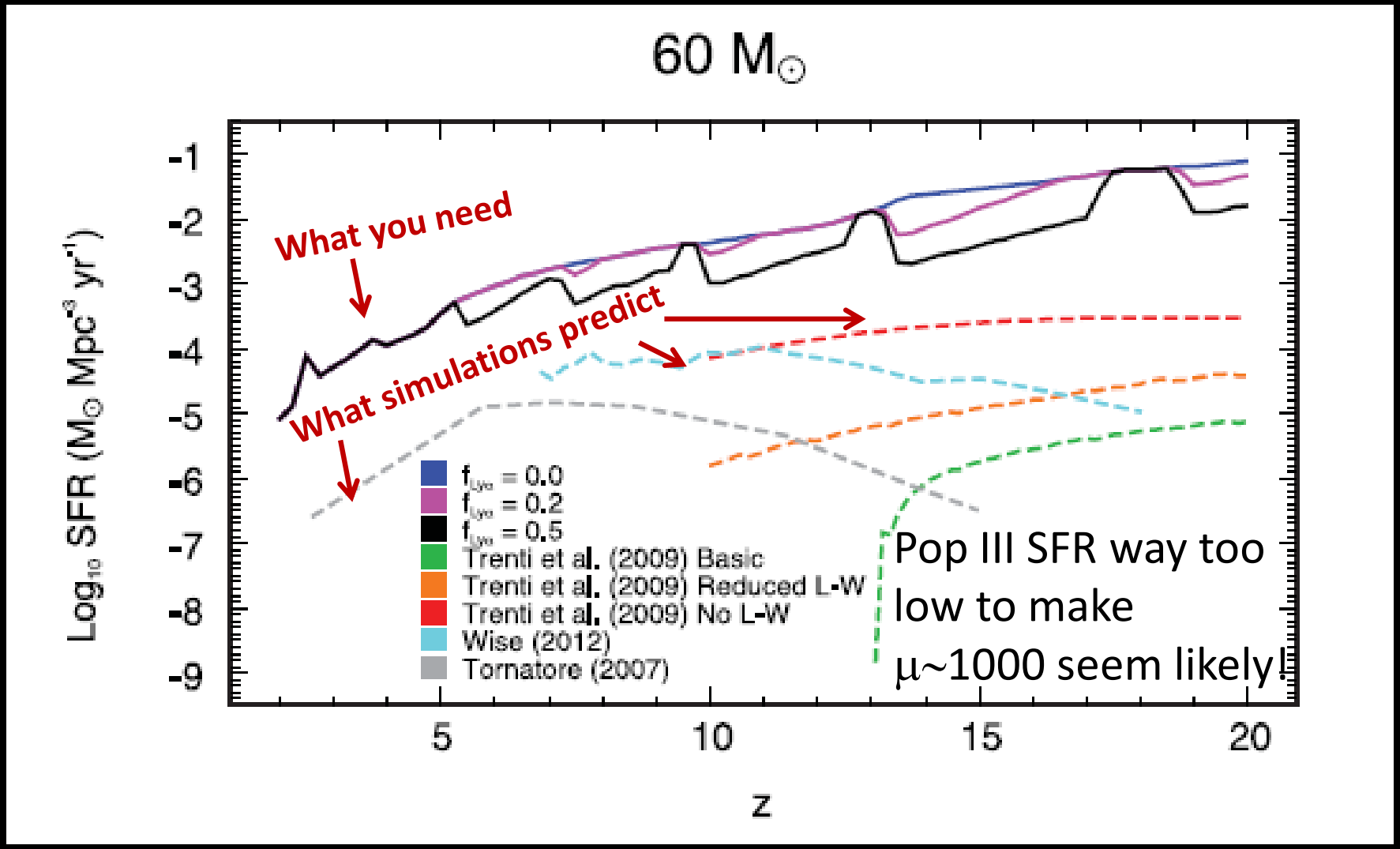
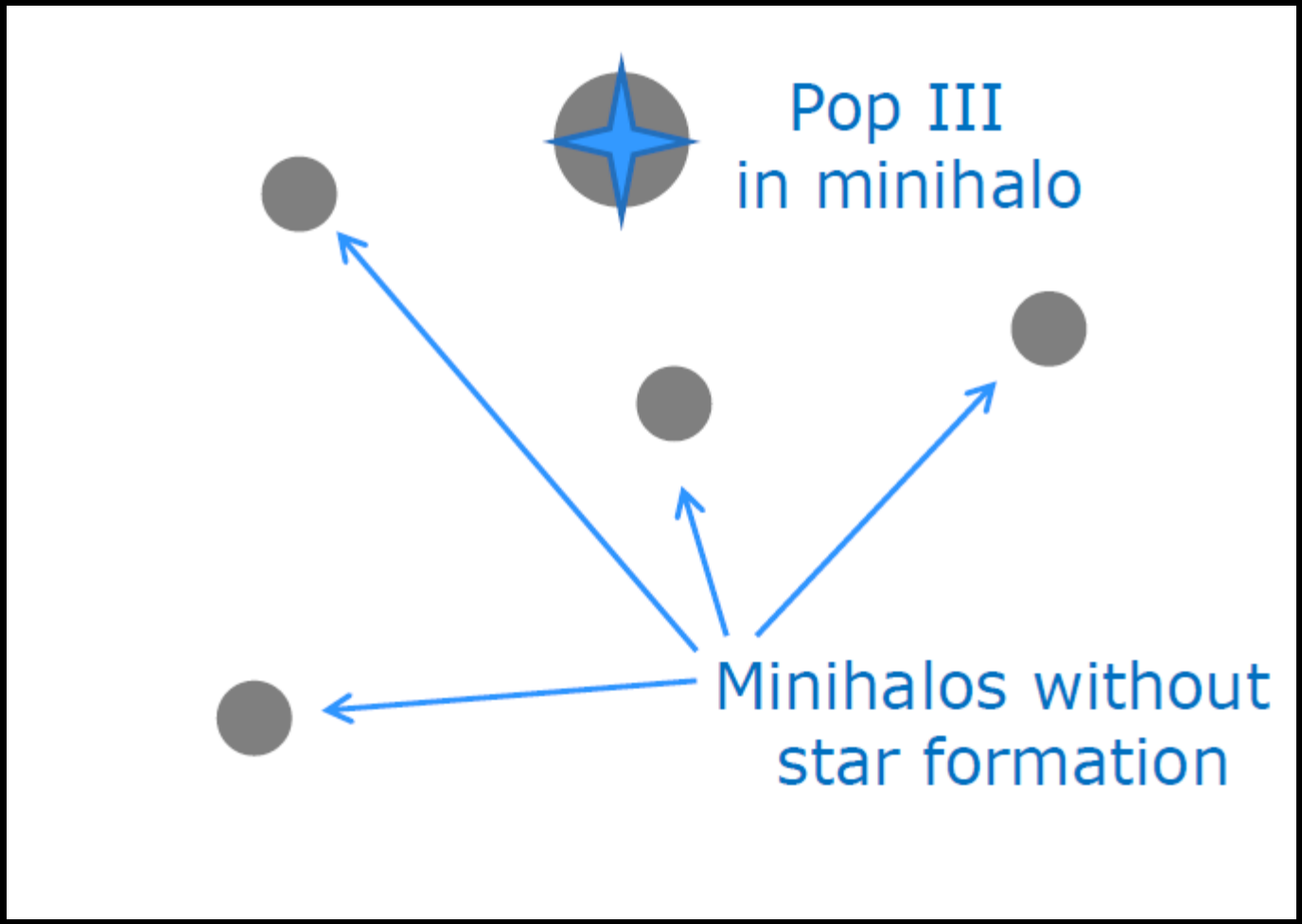


Rydberg et al. 2013, MNRAS, 429, 3568

Other Probes of Population III Stars

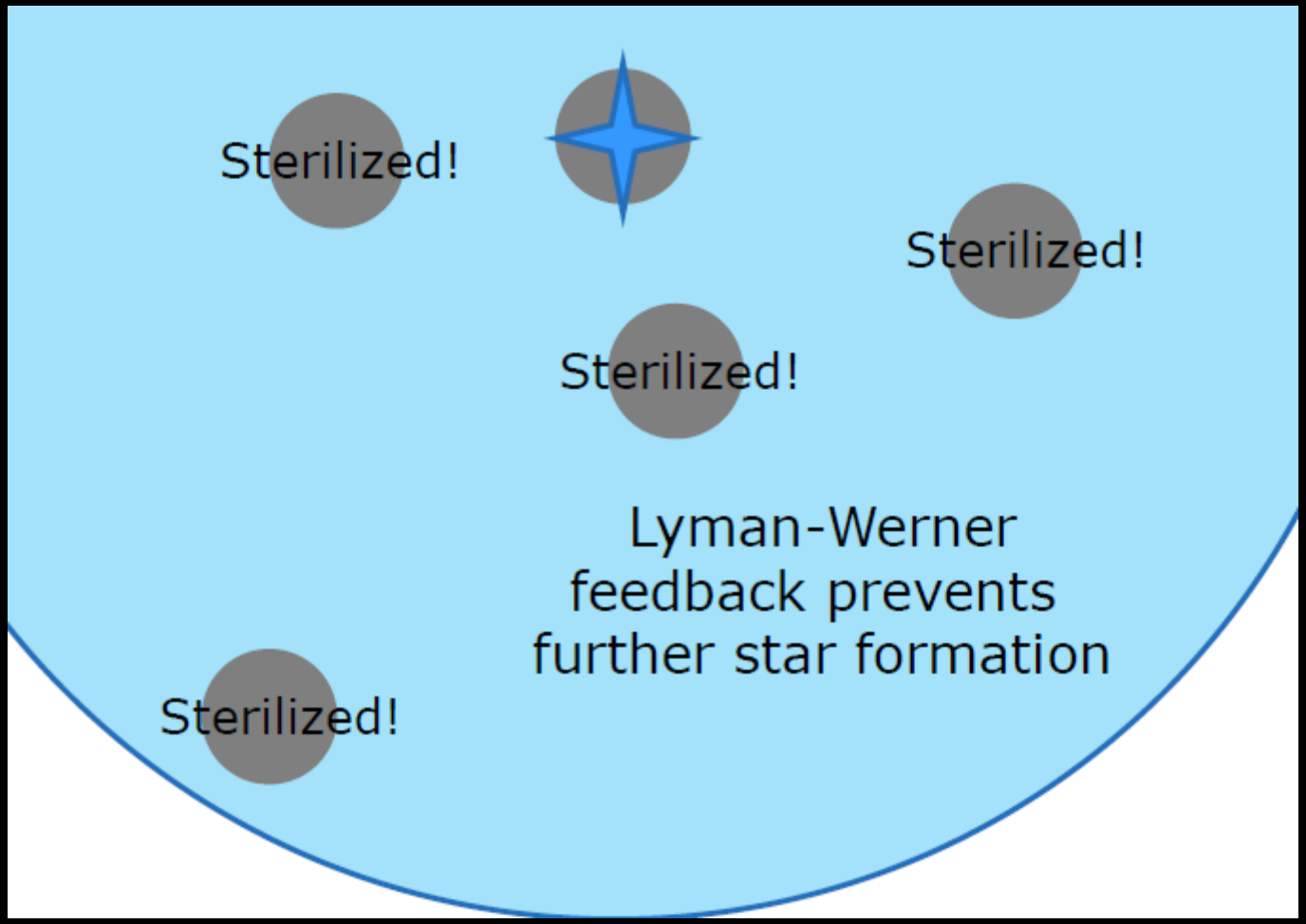
- Pop III supernovae
- Pop III gamma-ray bursts
- Low-mass pop III stars surviving until z=0
- Cosmic infrared background
- Chemical enrichment signatures in low-metallicity MW stars
- **Pop III galaxies – many pop III stars in a single halo $\rightarrow$ bright!**

How to form a Pop III galaxy



E.g. Stiavelli & Trenti (2010)

How to form a Pop III galaxy



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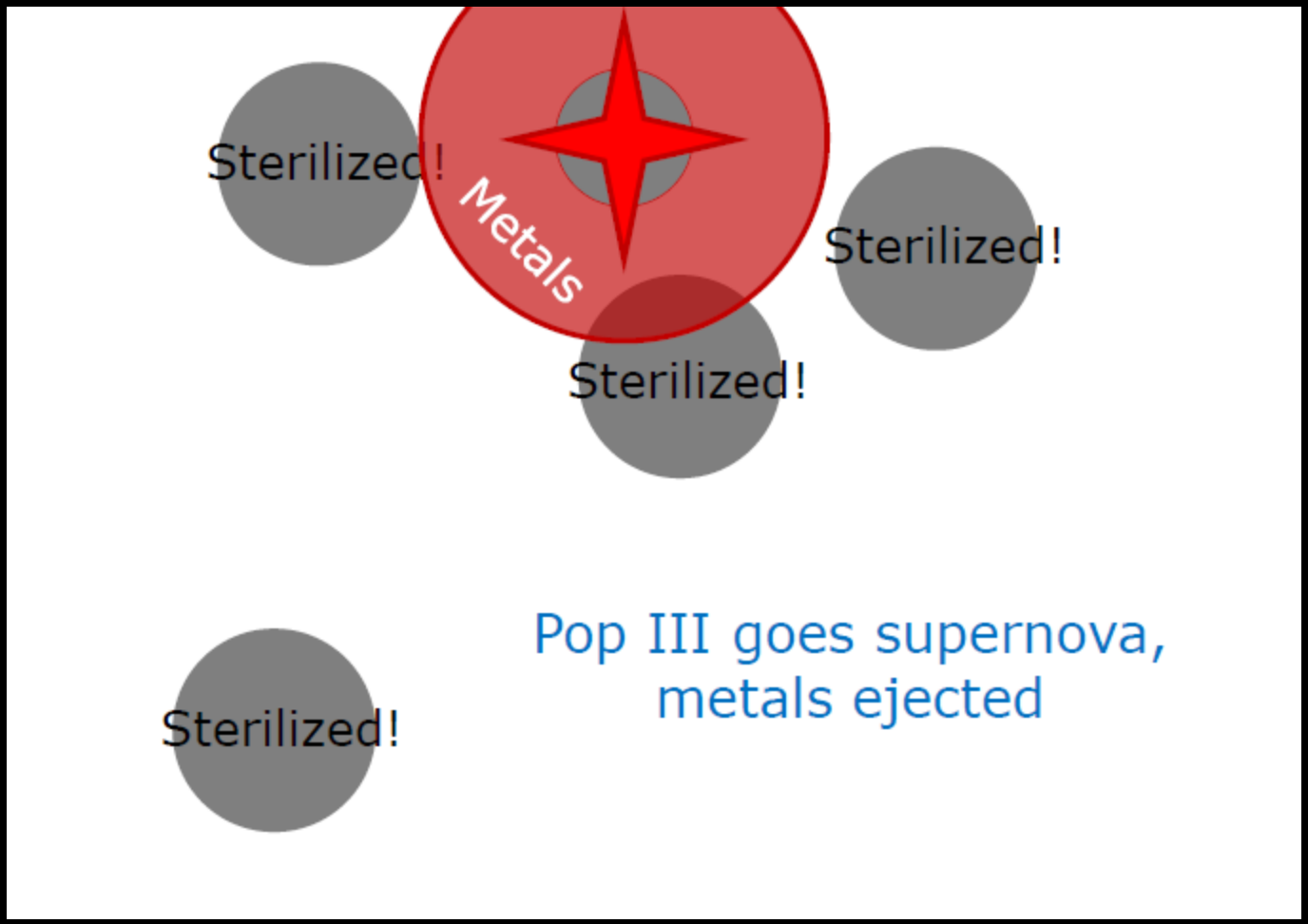

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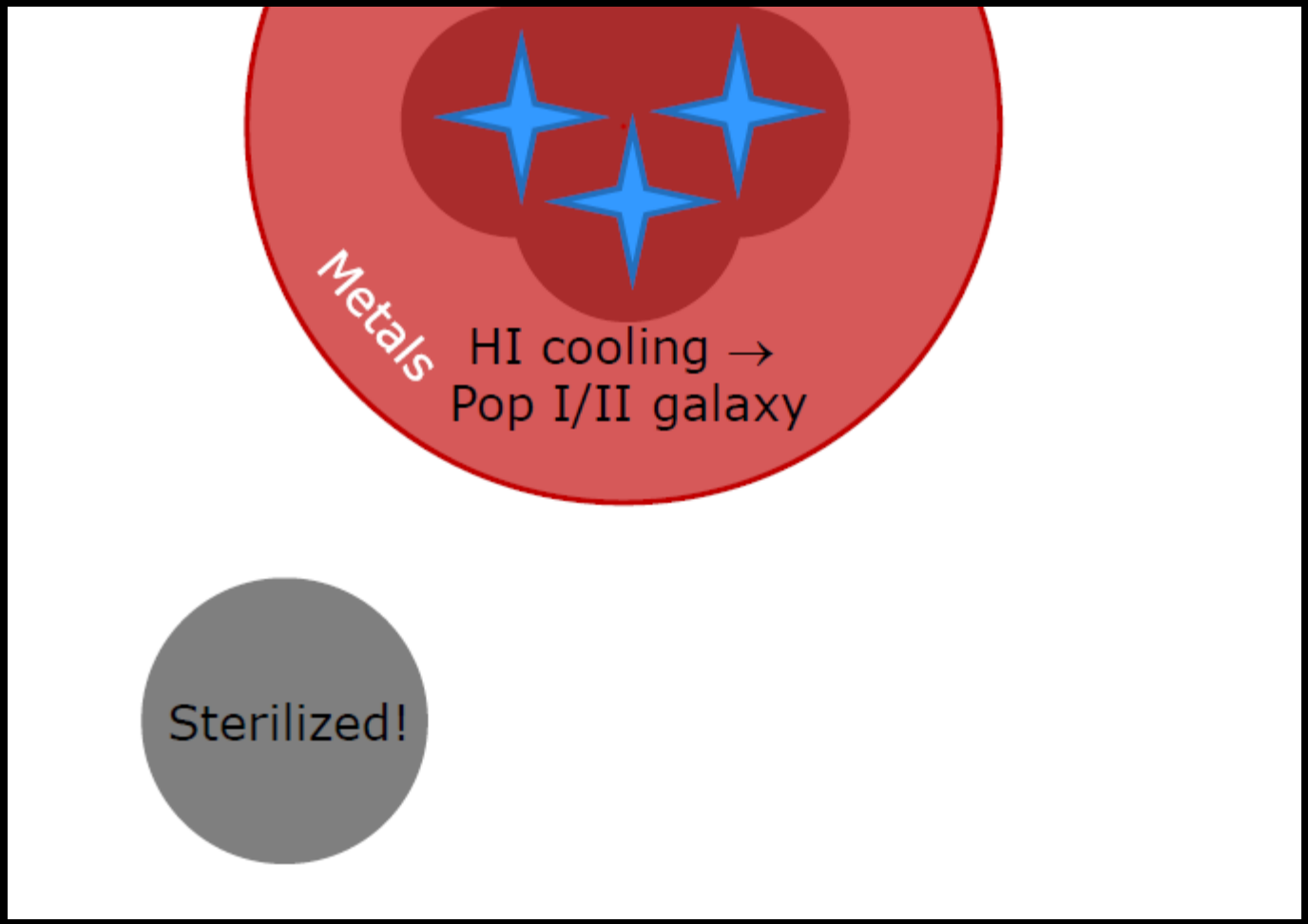

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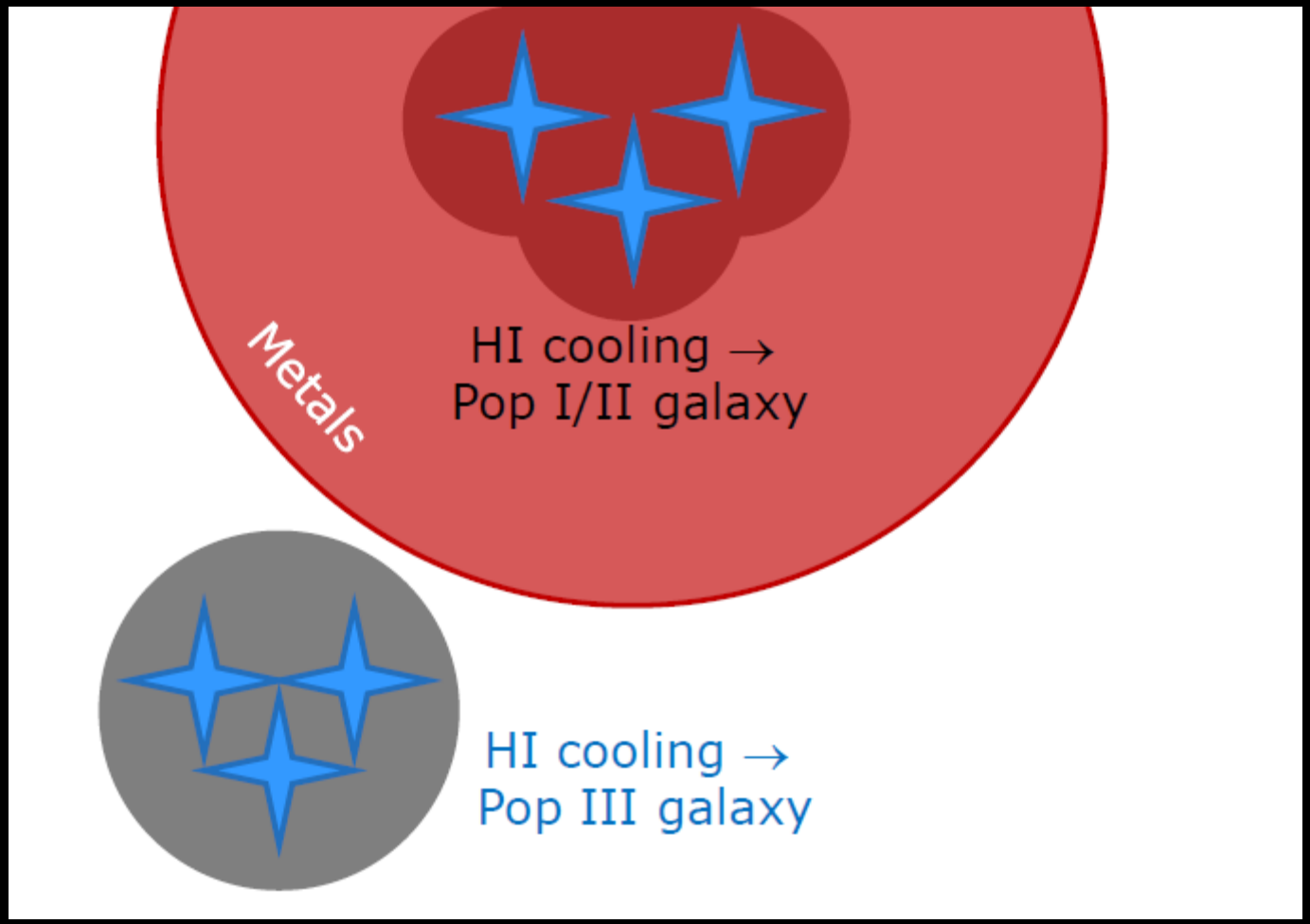
How to form a Pop III galaxy



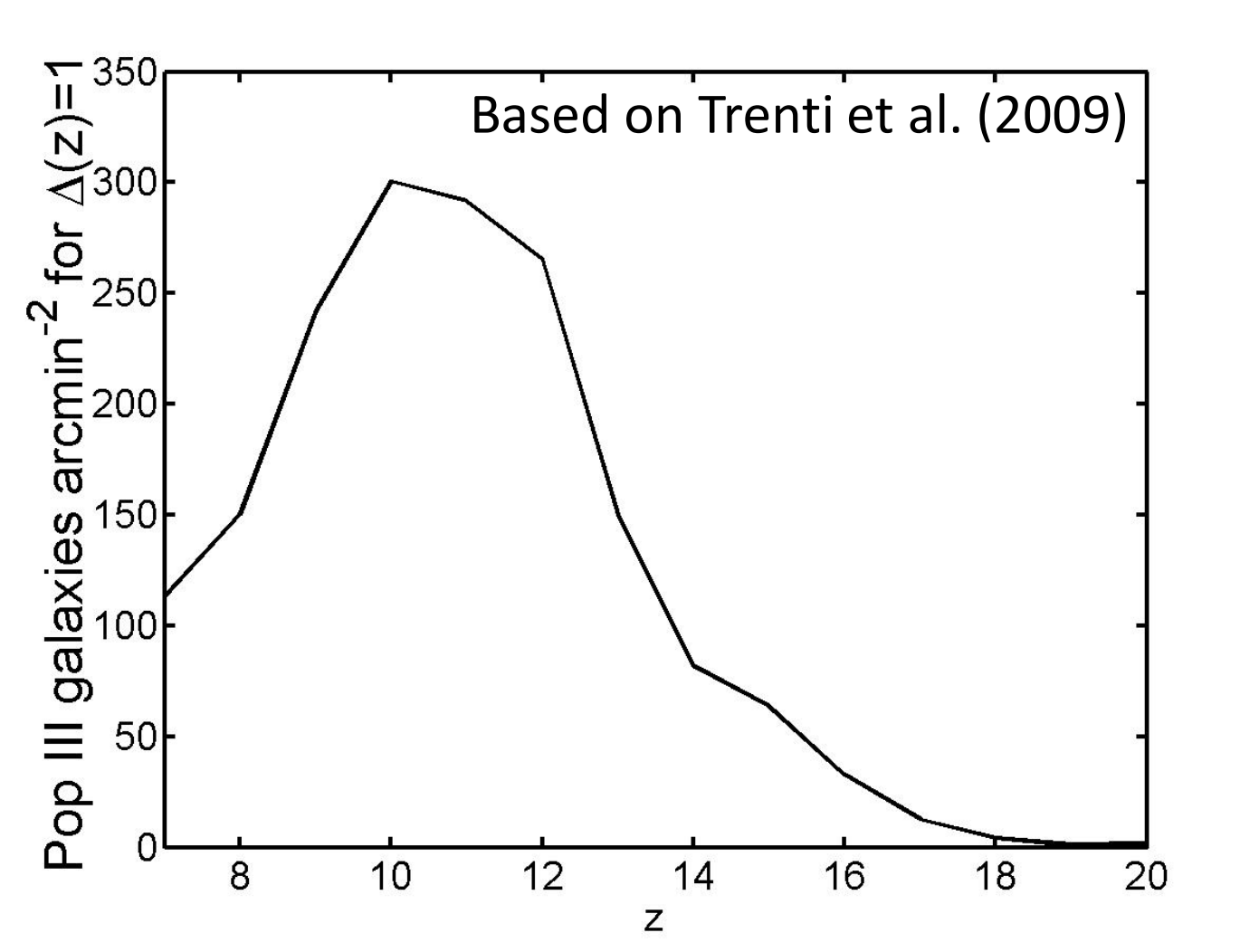
E.g. Stiavelli & Trenti (2010)

Population III galaxies – general

- How massive?
  - Halo mass ~10^7–10^8 Msolar
- How many?
  - Stiavelli & Trenti (2010): Lots @ z > 7 ☺
  - Johnson et al. (2010): Some even @ z ≈ 2-7 ☺
  - Salvaterra et al. (2011): None! ☹
- Star formation efficiency?
  - Safranek-Shrader et al. (2012): ~0.1% of halo baryons → pop III stars — Detectable ☺
  - Muratov et al. (2012ab): <0.01% of halo baryons → pop III stars — Undetectable ☹

The jury is still out…

The formation history of pop III galaxies

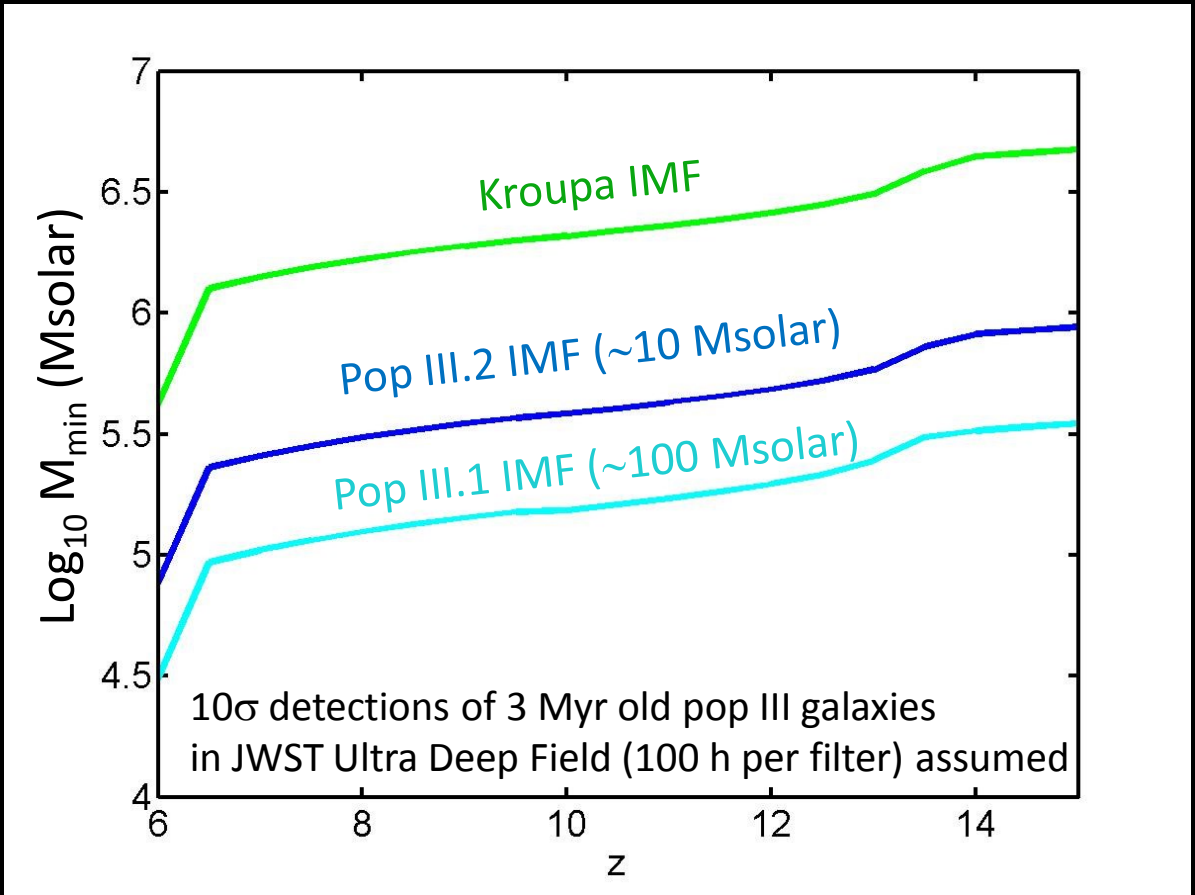


Zackrisson et al. (2012)

Can we identify them? Sure!

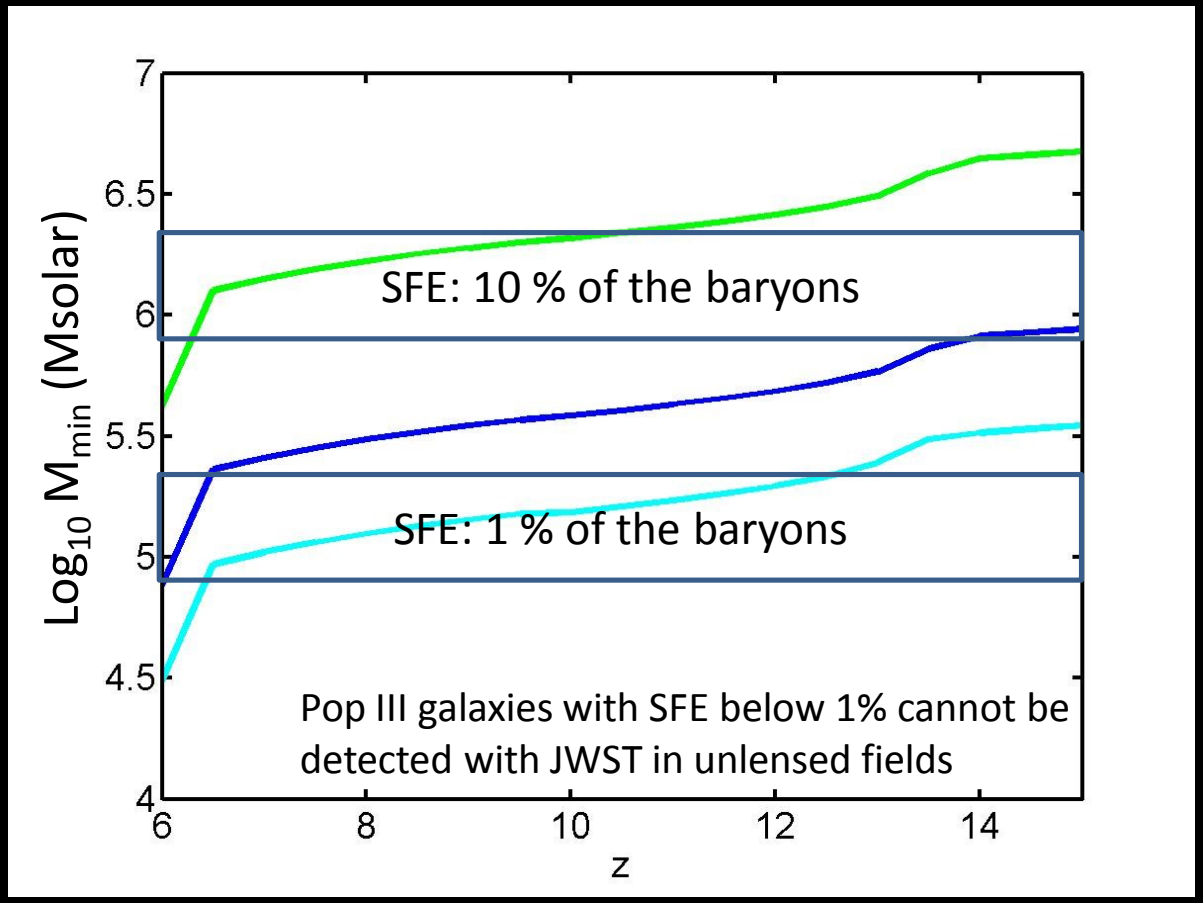
- Very strong Lyα line (e.g. Schaerer 02, Zackrisson 11b)
  - Good: Detectable with HST + 8-10m telescopes at current time!
  - Bad: IGM absorption @ z > 6-7 & non-pop III contributions (AGN, cooling, anisotropic escape)
- Metal-free nebular spectrum (Inoue 11, Zackrisson 11a)
  - Good: Lack of [OIII] @ 5007 Å $\rightarrow$ strange colours
  - Bad: Requires JWST at z > 3
- He II line @ 1640 Å (e.g. Schaerer 02, Johnson 09, Raiter 10)
  - Good: Can be strong despite significant Lyman continuum leakage
  - Bad: Too weak for colour signatures, requires JWST spectroscopy (i.e. *very* bright pop III galaxy)
  - Bad: WR-galaxies also display this line

JWST detection limits in unlensed fields



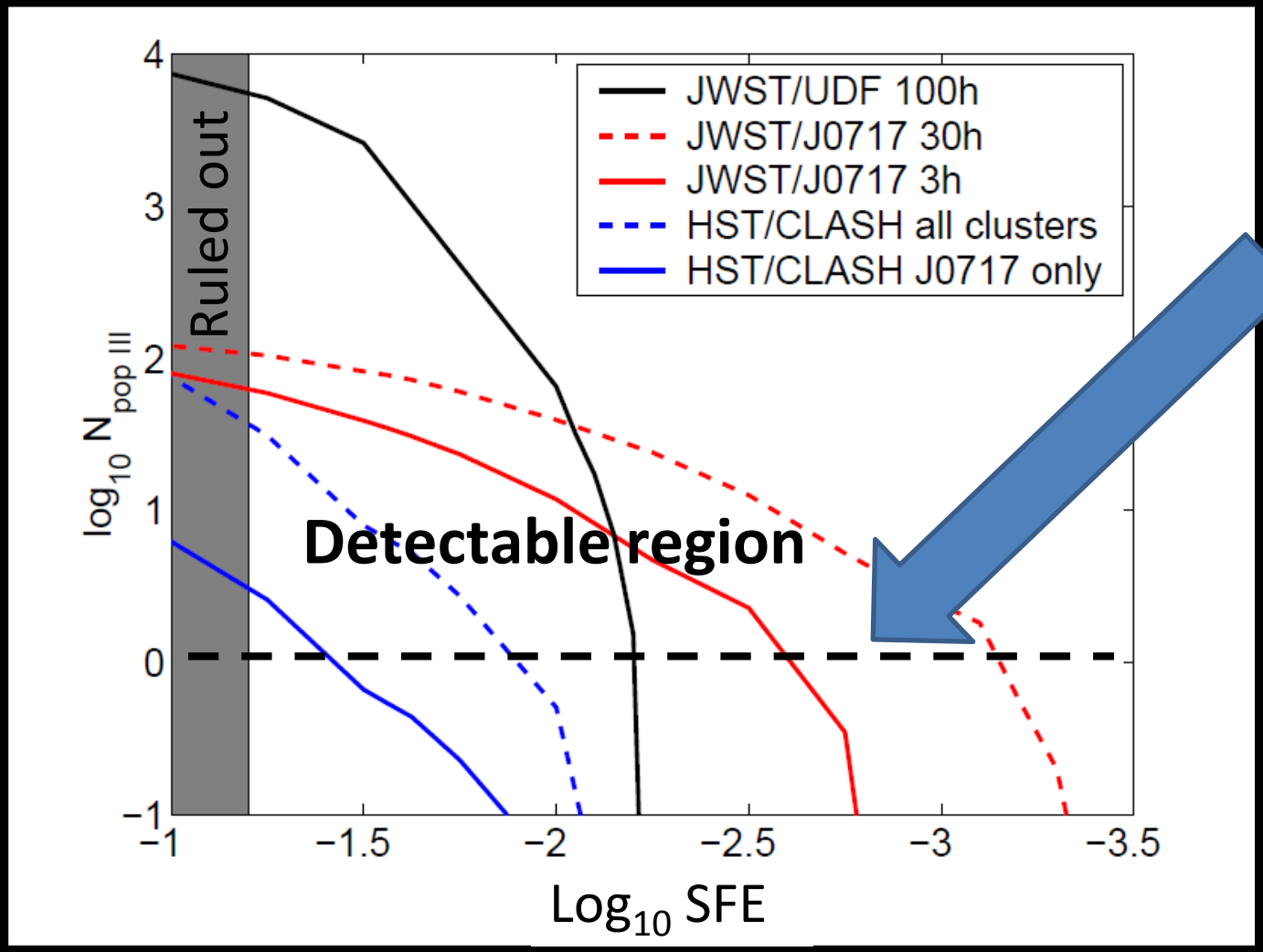
Zackrisson et al. 2011, ApJ, 740, 13

JWST detection limits in unlensed fields



You need lensed pop III galaxies to reach SFE ~ 0.1%

Lensed pop III galaxies - HST/JWST detection prospects @ z ≥ 7



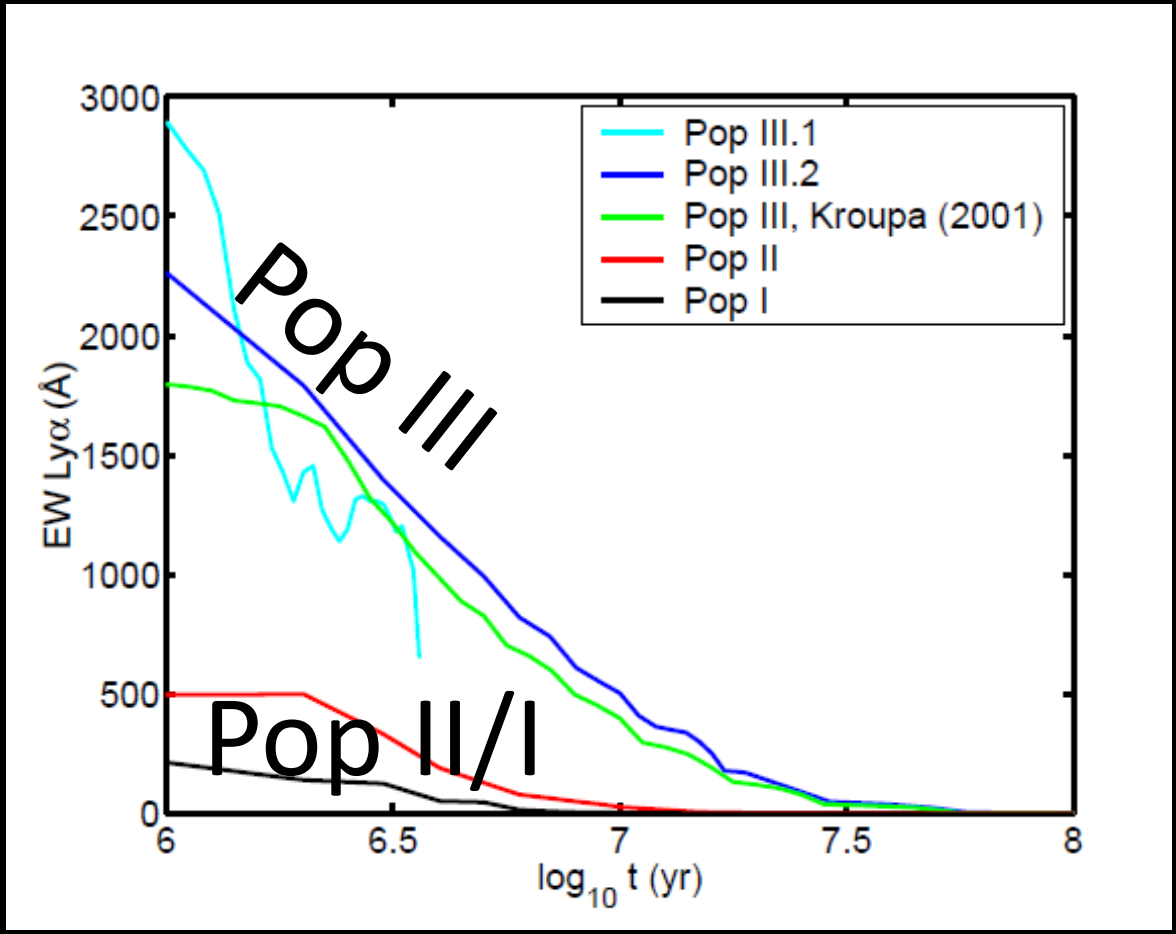
Pop III galaxies with SFE~10^{-3} detectable with JWST in deep images of single lensing cluster!

Magnification μ~30-100

Zero Lyα transmission through IGM assumed

Zackrisson et al. 2012, MNRAS 427, 2212

But JWST is years away…
What can we do at the current time?

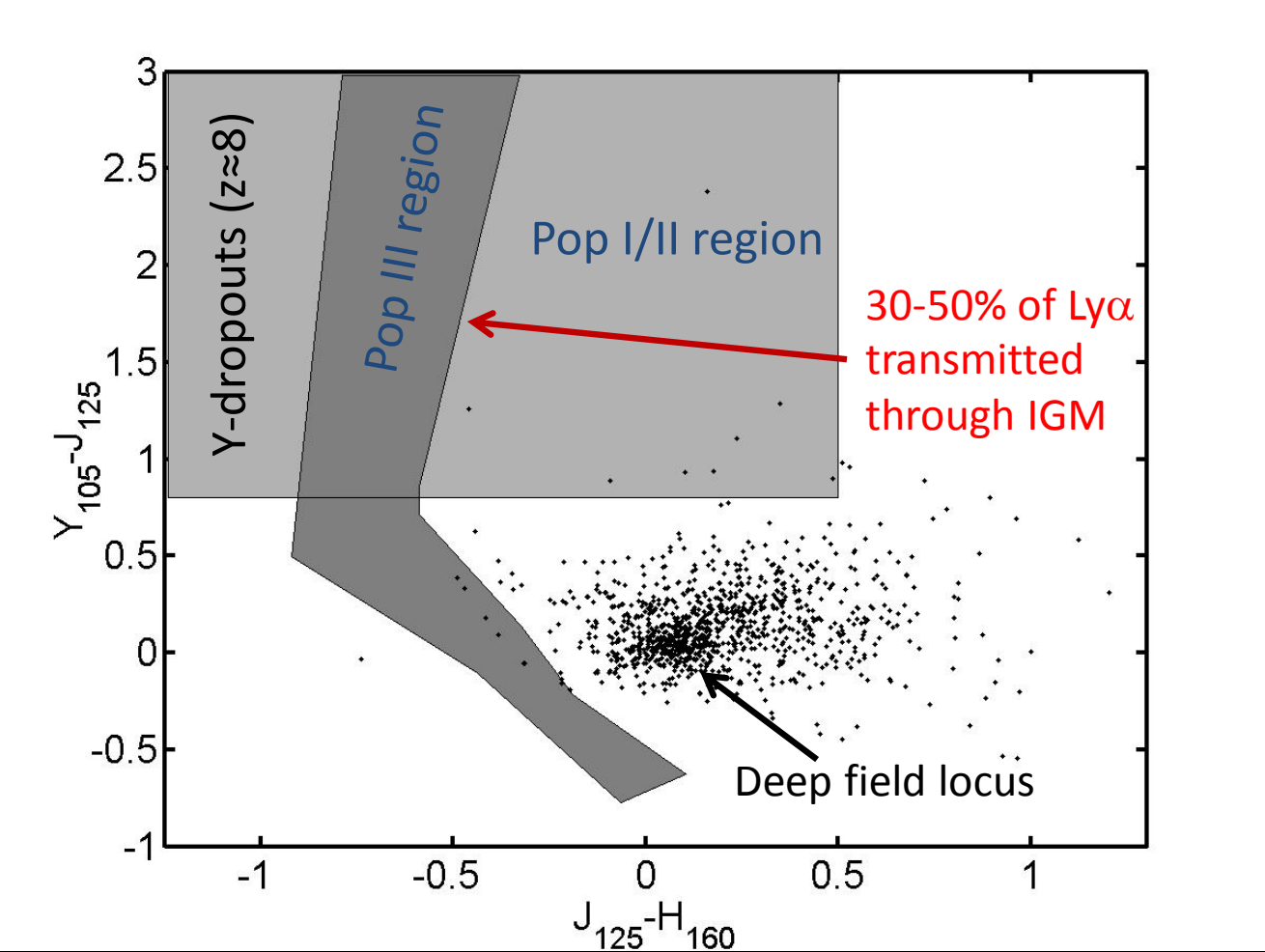


Lyα!

Lyα easily absorbed by neutral IGM at z > 6-7, but you could get lucky…

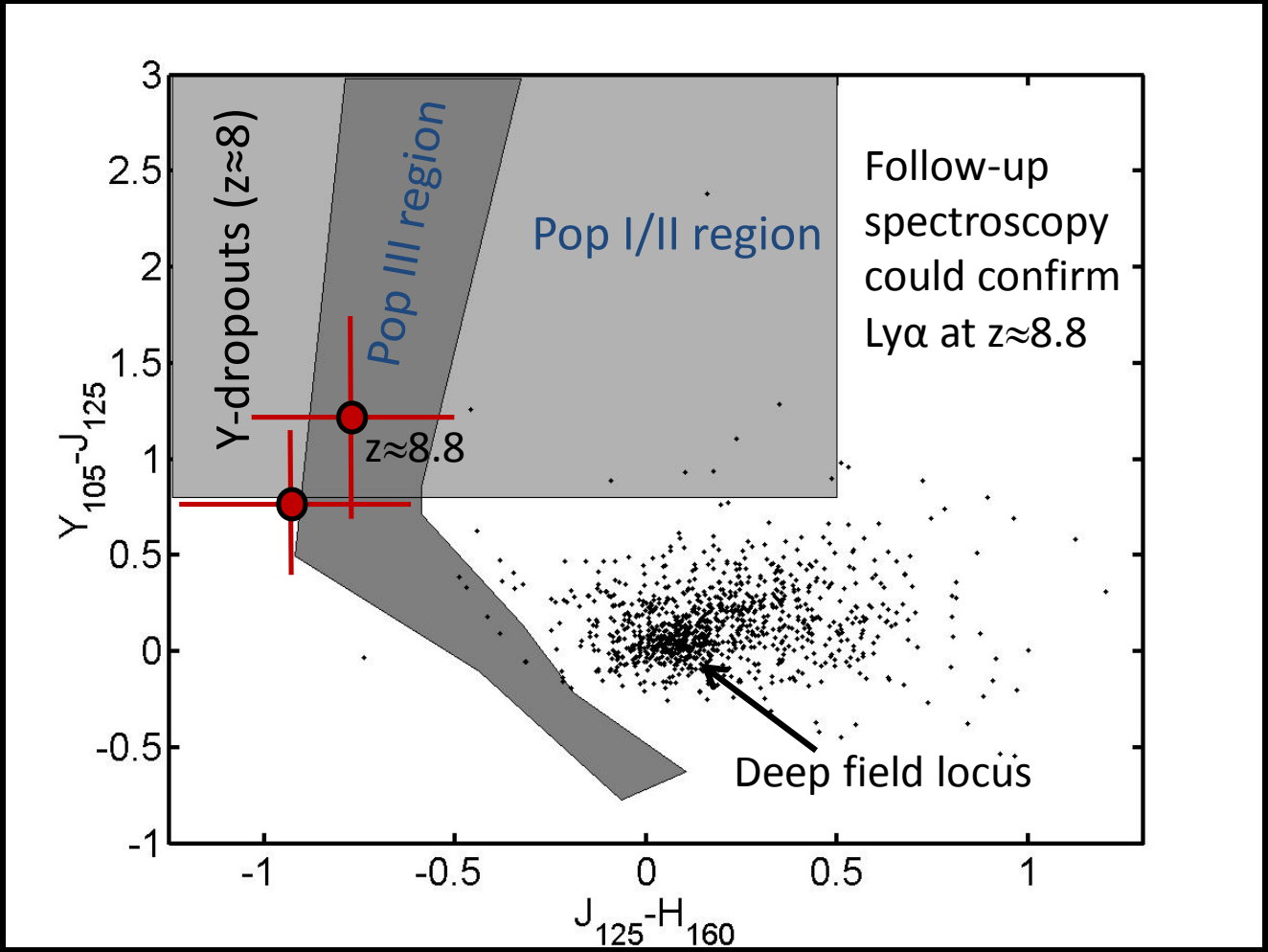
Outflows and patchy reionization → strong Lyα for a fraction of objects (Dijkstra 11, Dayal 11, Jeeson-Daniel 12)

The HST colour signatures of strong Lyα



Zackrisson et al. 2011, MNRAS 418, L104

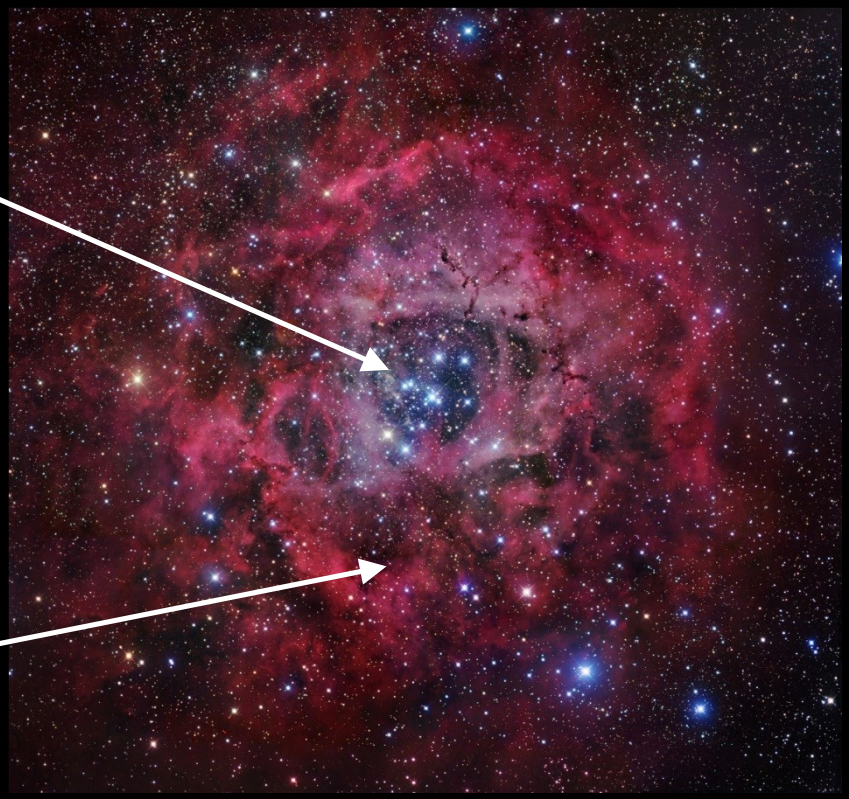
Lensed pop III galaxy candidates in CLASH



Rydberg et al. 2013, in prep.

Anatomy of a Pop III Galaxy

Pop III star cluster
~1-100 pc



Pop III nebula
~ 1000 pc

E.g. Johnson et al. (2009)

- Pop I, II, III stars + dark stars
- Nebular emission (Cloudy)
- Dust
- HST/JWST fluxes @ z=0-15

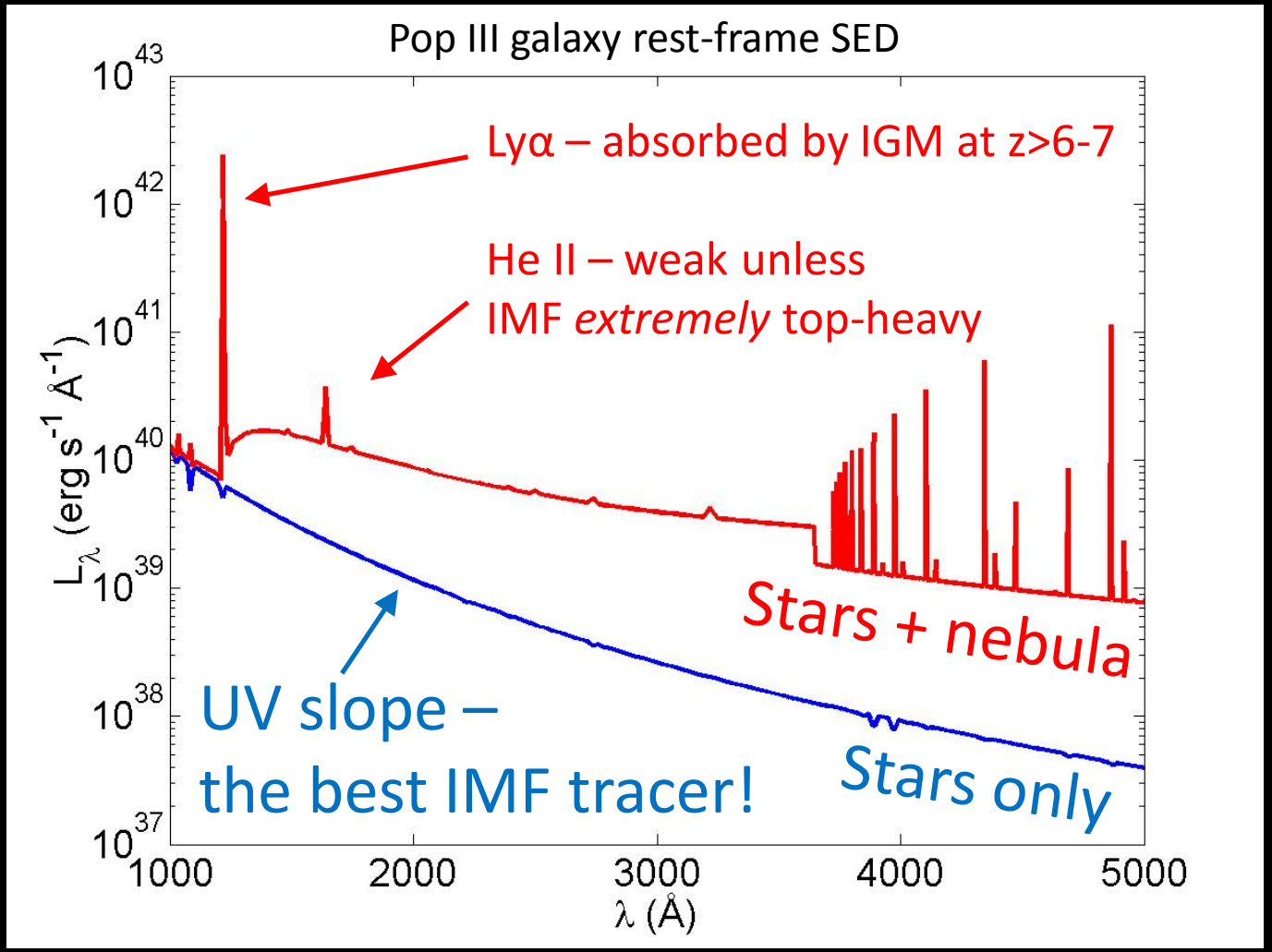
The Yggdrasil code

A spectral synthesis model for the first galaxies

Model grids available at: www.astro.su.se/~ez

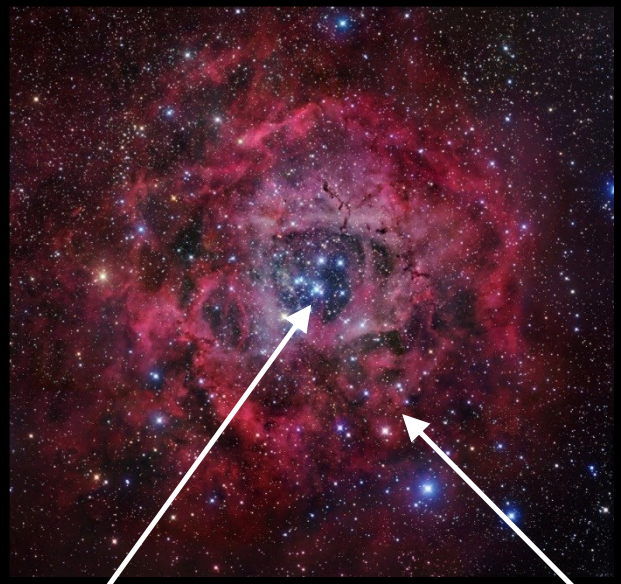
Zackrisson et al. 2011, ApJ, 740, 13

Pinning down the Pop III stellar IMF with JWST imaging



Pinning down the Pop III stellar IMF with JWST imaging

Problem:
This is what JWST will see @ z=1-9…

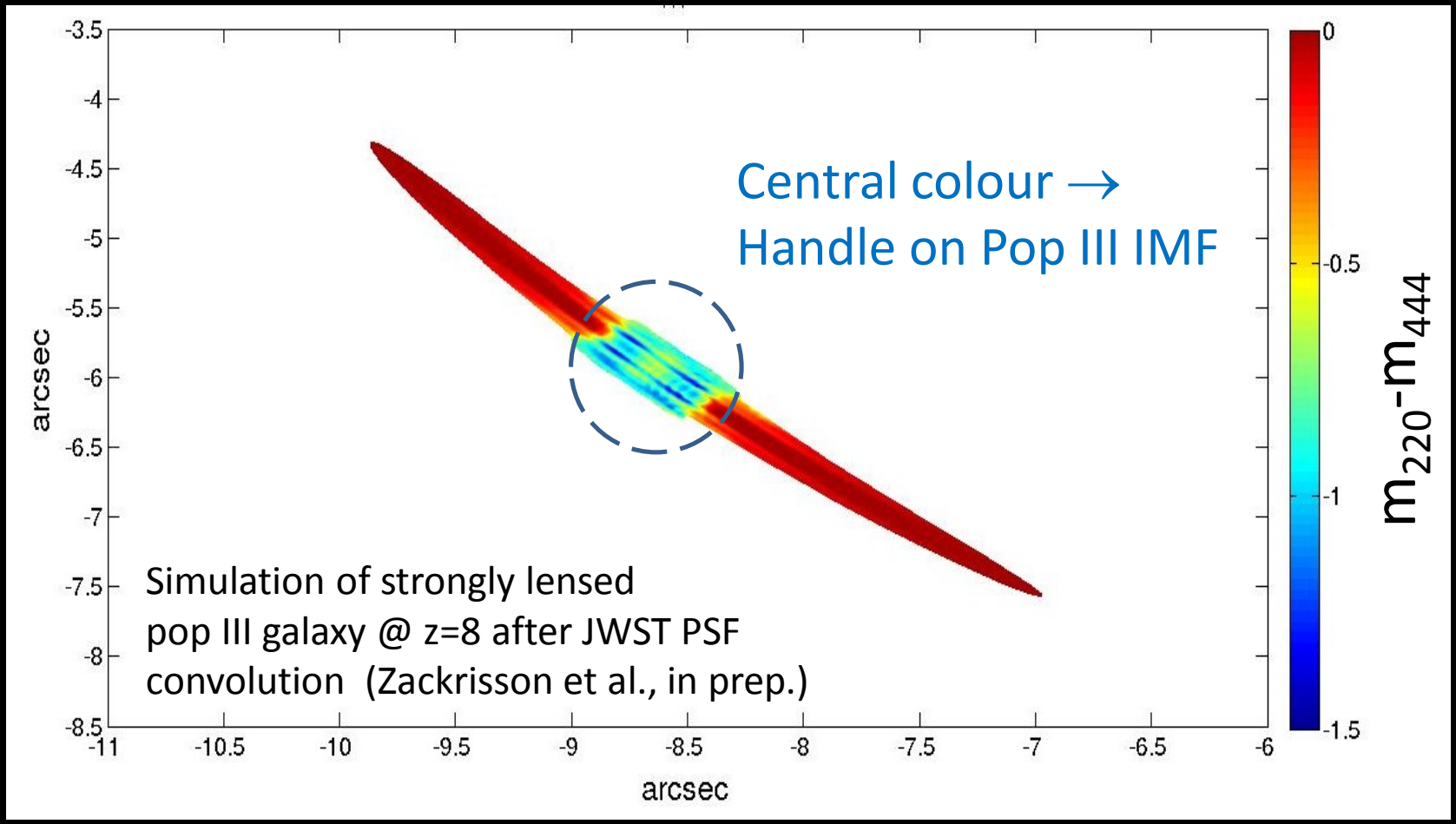


Very blue UV slope (IMF-sensitive)

Very red UV slope (not IMF-sensitive)

A ~ 0.1 arcsec reddish smudge! All IMF information lost!

Lensing helps!



Magnification ~ 100 → Blue, compact core and red arc

Great method, but many caveats

- Requires JWST imaging (launch in 2018)
- Requires extreme magnificaton ($\mu \approx 100$)
- Requires high star formation efficiency in pop III galaxies ($\log_{10}$ SFE > -3)
- Nebular surface brightness profile can't be too centrally concentrated

Will it work? Time will tell…

Summary

- Lensed pop III galaxies may be detectable with HST/JWST
- A few lensed pop III galaxy candidates in CLASH
- JWST imaging of lensed pop III galaxies can confirm top-heavy pop III stellar IMF