Pointing the JWST Through Lensing Clusters
– Can the First Stars and Galaxies be Detected?

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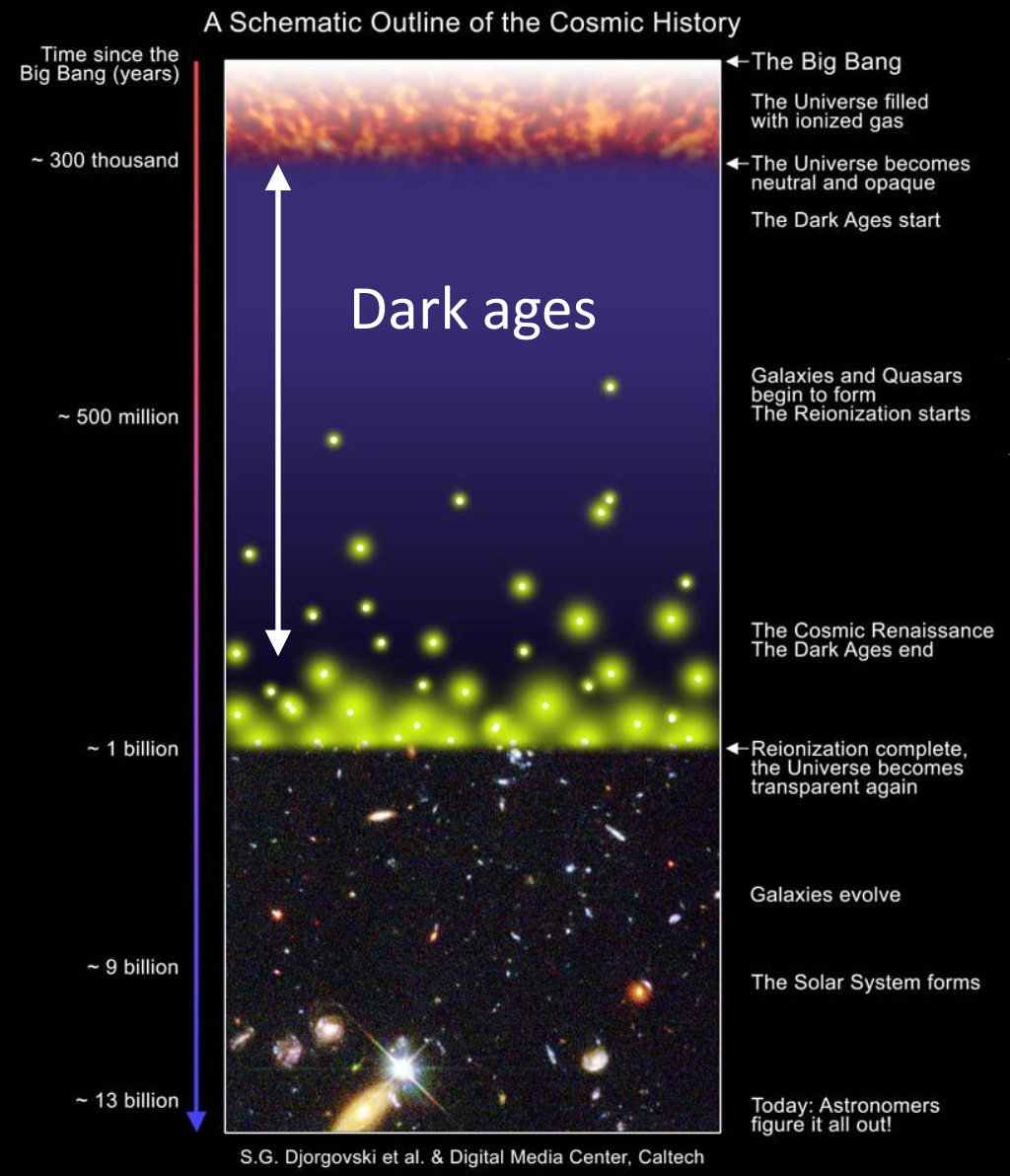
Outline

- Introduction
  - The first stars and galaxies
  - The James Webb Space Telescope
- The Palantir Survey
  - Hunting for the first stars and galaxies behind lensing clusters
- The Yggdrasil Spectral Synthesis Code
  - The spectral signatures of the first galaxies

The end of the dark ages



First stars

$z \approx 20\text{-}30$

$t_{Univ} \approx 100\text{-}200$ Myr

First galaxies

$z \approx 10\text{-}15$

$t_{Univ} \approx 300\text{-}500$ Myr

Current observational limit: HST and 8-10 m telescopes on the ground can detect light sources up to $z \approx 10$

Exotic beasts awaiting discovery

- Population III stars
- Dark stars
- Quasistars
- First galaxies
  - Population III
  - Population II/I

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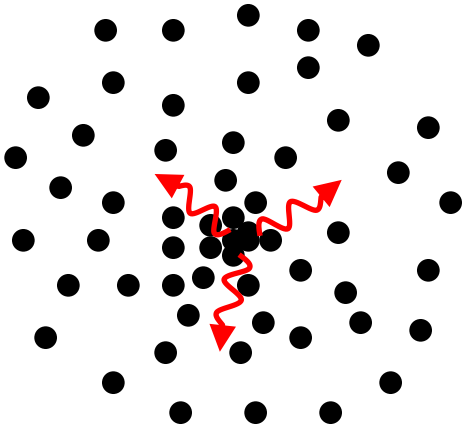
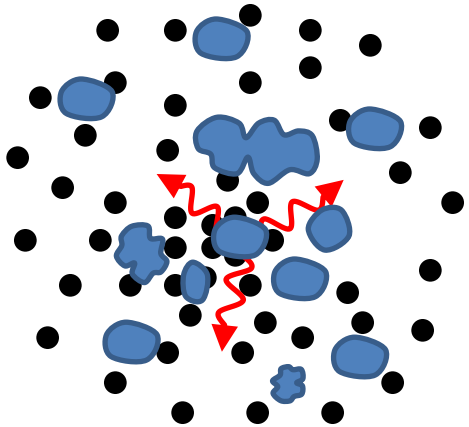
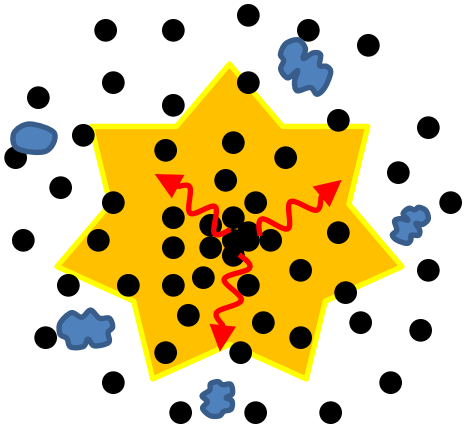
Dark stars



WIMP annihilation in centre of CDM halo



Gas cools and falls into the centre

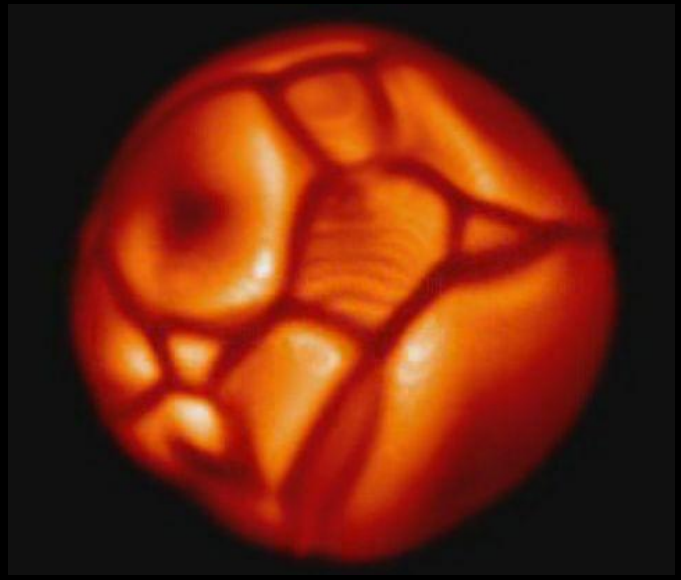


Star fueled by WIMP annihilation rather than hydrogen fusion

This scenario may apply to the formation of the very first stars (population III):
Spolyar et al. 08/09, Iocco 08, Freese et al. 08/09/10, Yoon et al. 08, Taoso et al. 08, Natarajan et al. 09, Umeda et al. 09, Ripamonti et al. 10, Gondolo et al. 10, Sivertsson & Gondolo 10

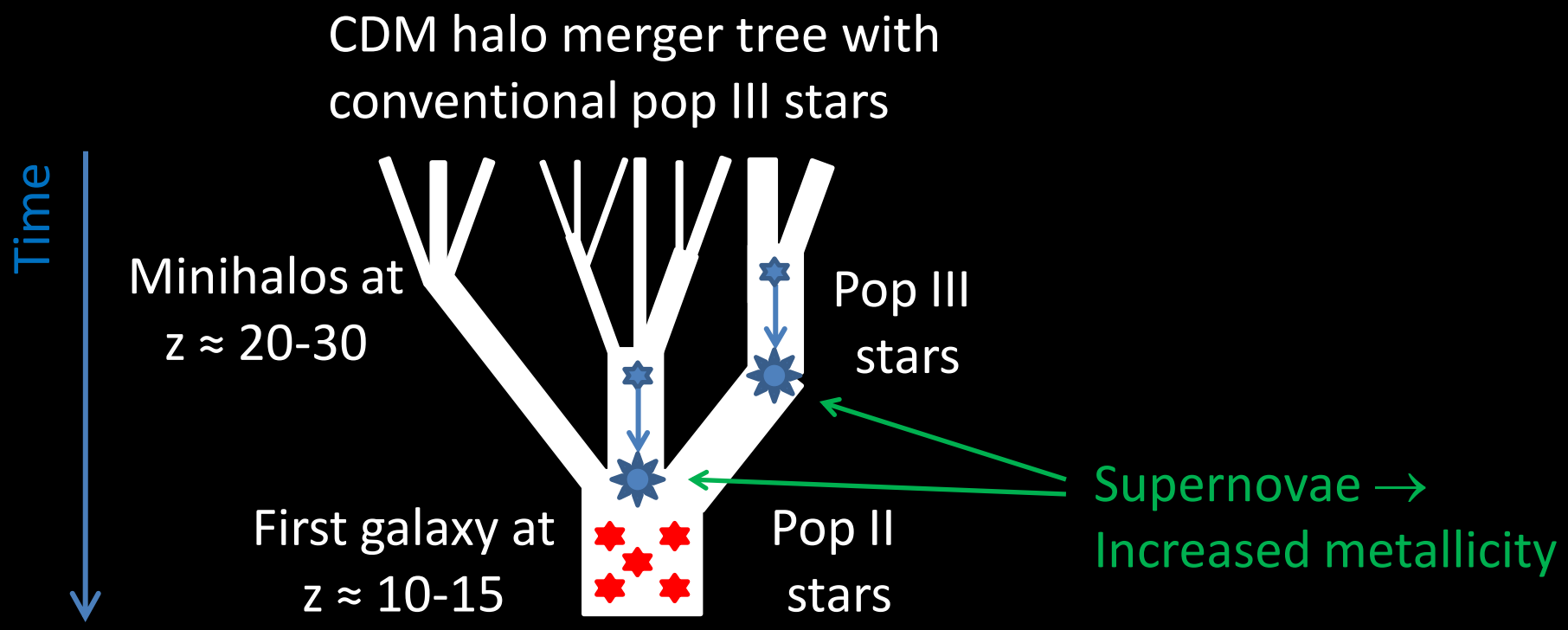
Conventional pop IIIs vs. dark stars

- Conventional Pop III.1 stars
  - Teff ~ 100 000 K
  - M ~ 10^2 Msolar
  - Lifetime $\tau \sim 10^6$ yr
  - Probably not detectable with JWST (see poster by Rydberg et al.)



- Pop III.1 dark stars
  - Teff ≈ 4000-50000 K — Cooler!
  - M ~ 10^2-10^7 Msolar — More massive???
  - Lifetime $\tau \sim 10^6$-10^{10} yr — More long-lived???
  - Possibly detectable with JWST (Zackrisson et al. 2010, ApJ, 717, 257)

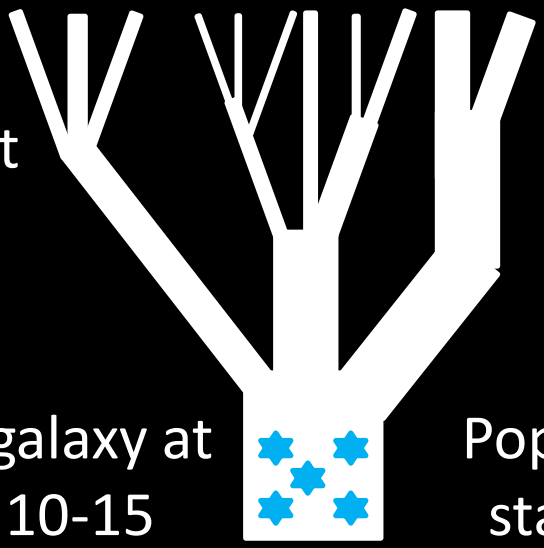
The stellar content of the first galaxies I



End result: z ≈ 10-15 population II galaxy
(see e.g. simulations by Greif et al. 08)

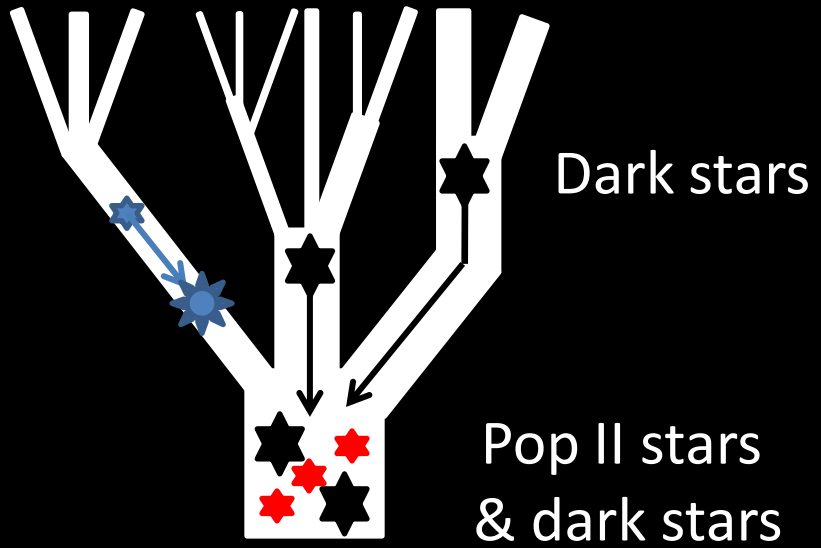
The stellar content of the first galaxies II: Other options

Merger tree with no pop III stars in progenitor minihalos



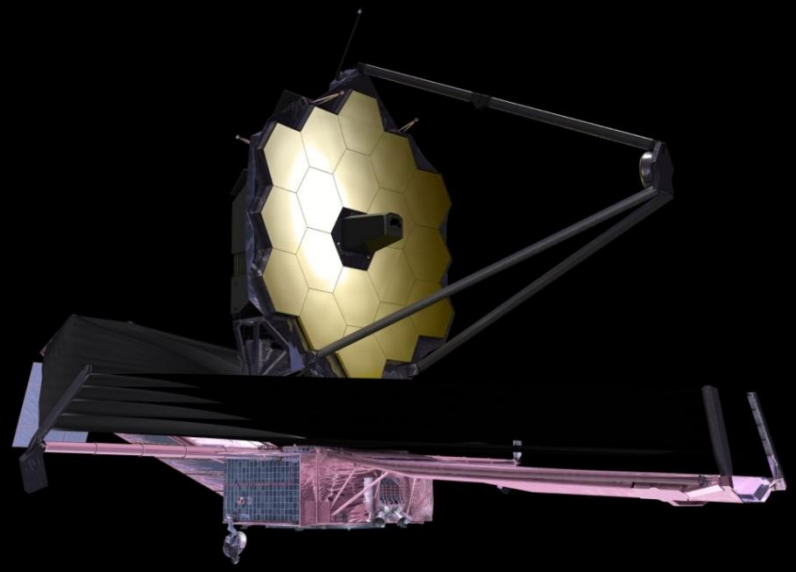
Population III galaxy
Stiavelli & Trenti (2010) →
1 % of all z > 6 galaxies

Merger tree with pop IIIs and long-lived dark stars



'Dark star galaxy'
Zackrisson et al. (2010)

The James Webb Space Telescope



'The first light machine'
To be launched by
NASA / ESA / CSA in 2014

- 6.5 m mirror
- Observations @ 0.6-29 μm
- Expected to revolutionize our understanding of the z = 6 - 15 Universe

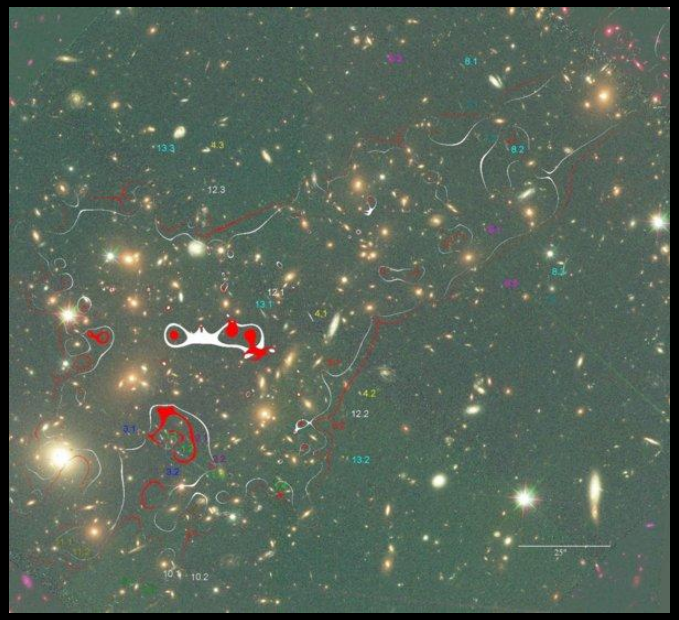
The JWST Ultra Deep Field

- JWST Ultra deep field:
  - Will reach AB mag ≈ 31.3 @ 2μm with S/N=5 in ≈ 100 hours per filter
- Our proposal:
  - Survey that will reach up to a factor of 10 deeper in just 1 hour per filter

How is this possible?

The Palantir Survey

A proposed JWST survey to search for the first stars and galaxies through lensing clusters



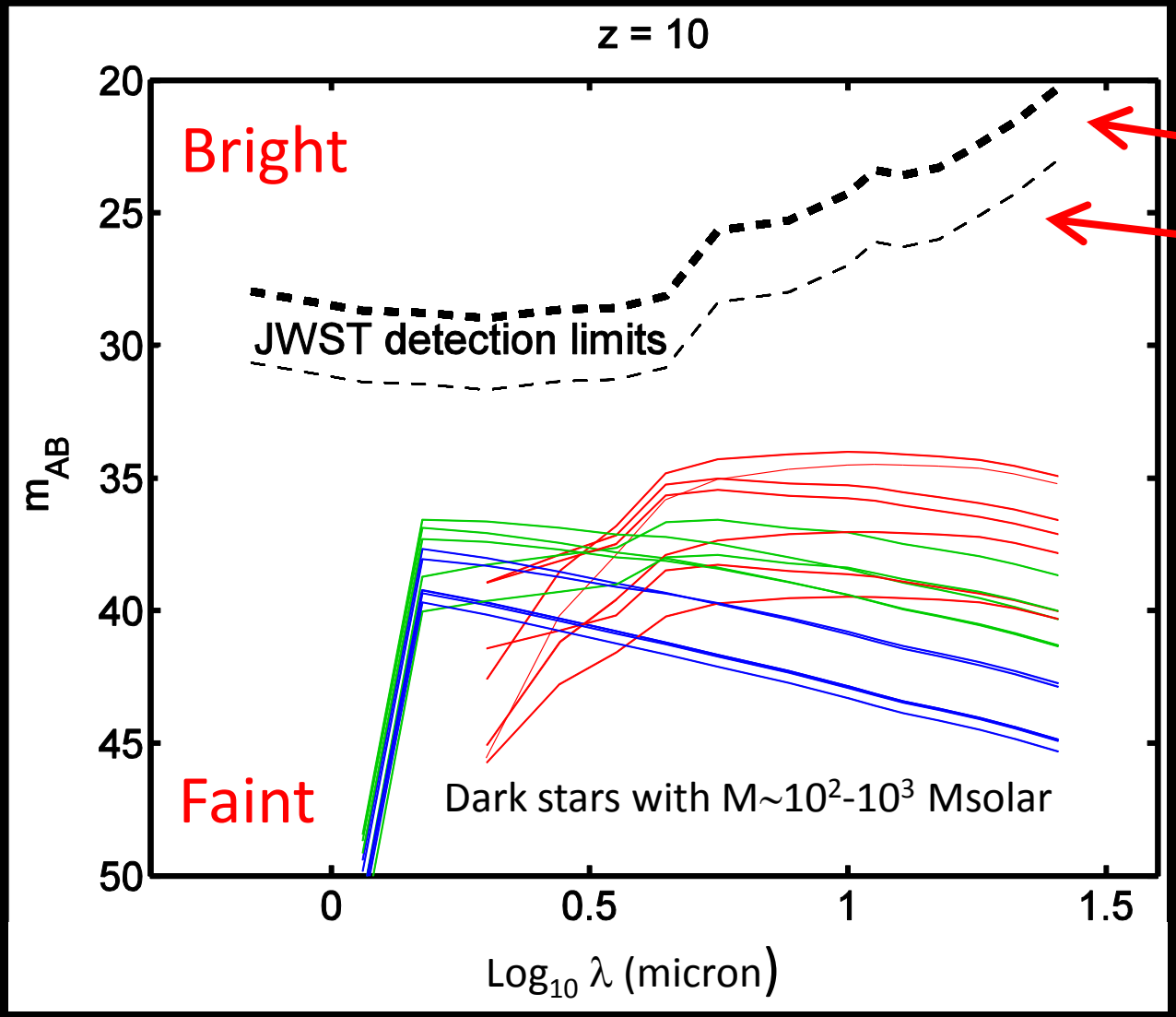
Primary target: MACS J0717+3745
Largest Einstein radius known!
$\mu > 10$ region is 3.5 arcmin^2
$\mu > 100$ region is 0.3 arcmin^2

Palantir: A magical object from Lord of the Rings that allows the user to see distant events

Collaboration:

Erik Zackrisson, Claes-Erik Rydberg, Göran Östlin, Adi Zitrin, Tom Broadhurst, Daniel Schaerer, Michele Trenti, Massimo Stiavelli

JWST fluxes of 10^2-10^3 Msolar dark stars



3 h @ 10σ

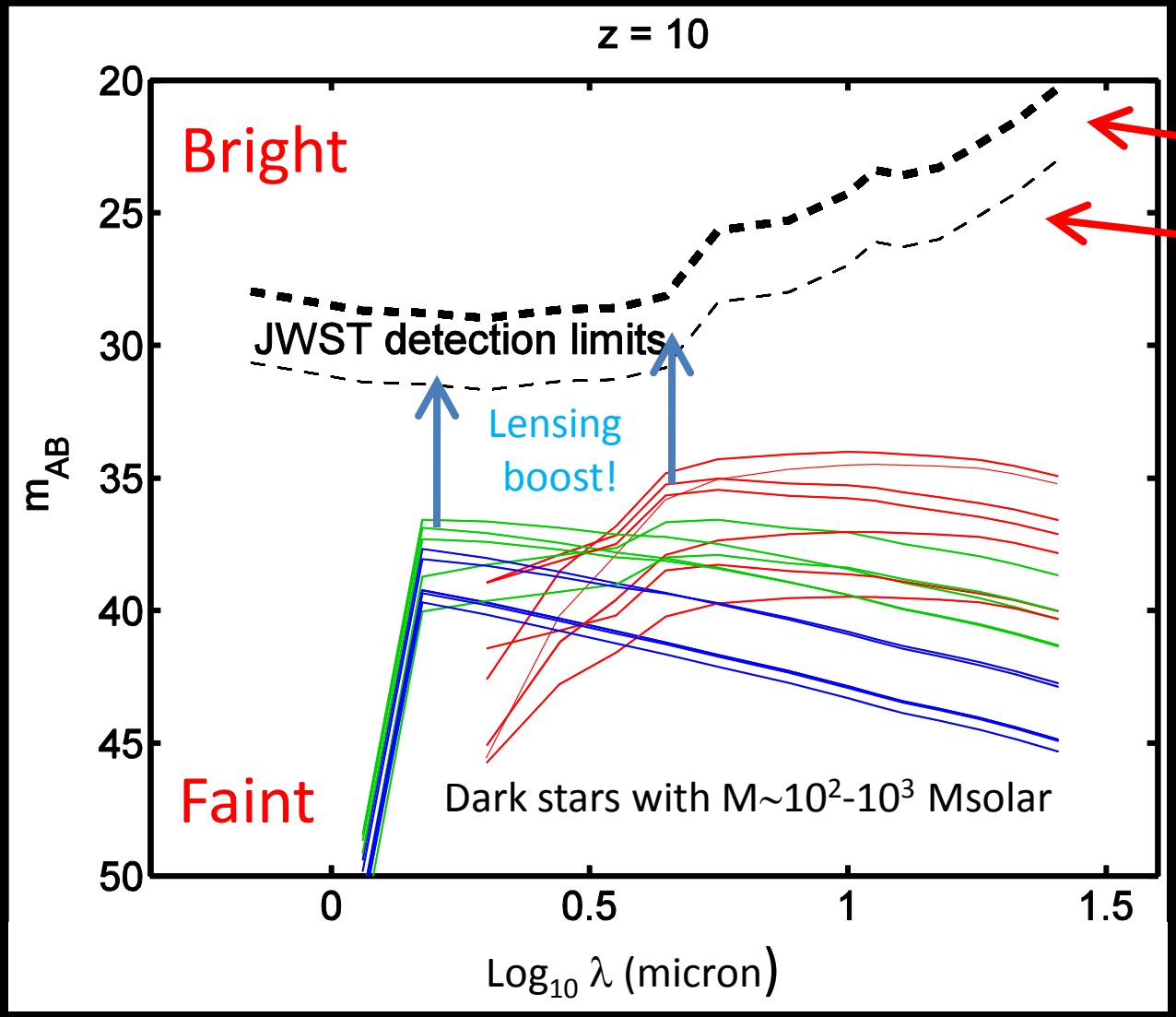
100 h @ 5σ

Bad news:

Dark stars in the 10^2-10^3 Msolar range are intrinsically much too faint! ☹

Zackrisson et al. 2010, ApJ 717, 257

Gravitational lensing



3 h @ 10σ

100 h @ 5σ

Good news: Gravitational lensing will make *some* of these dark stars sufficiently bright! ☺

Zackrisson et al. 2010, ApJ 717, 257

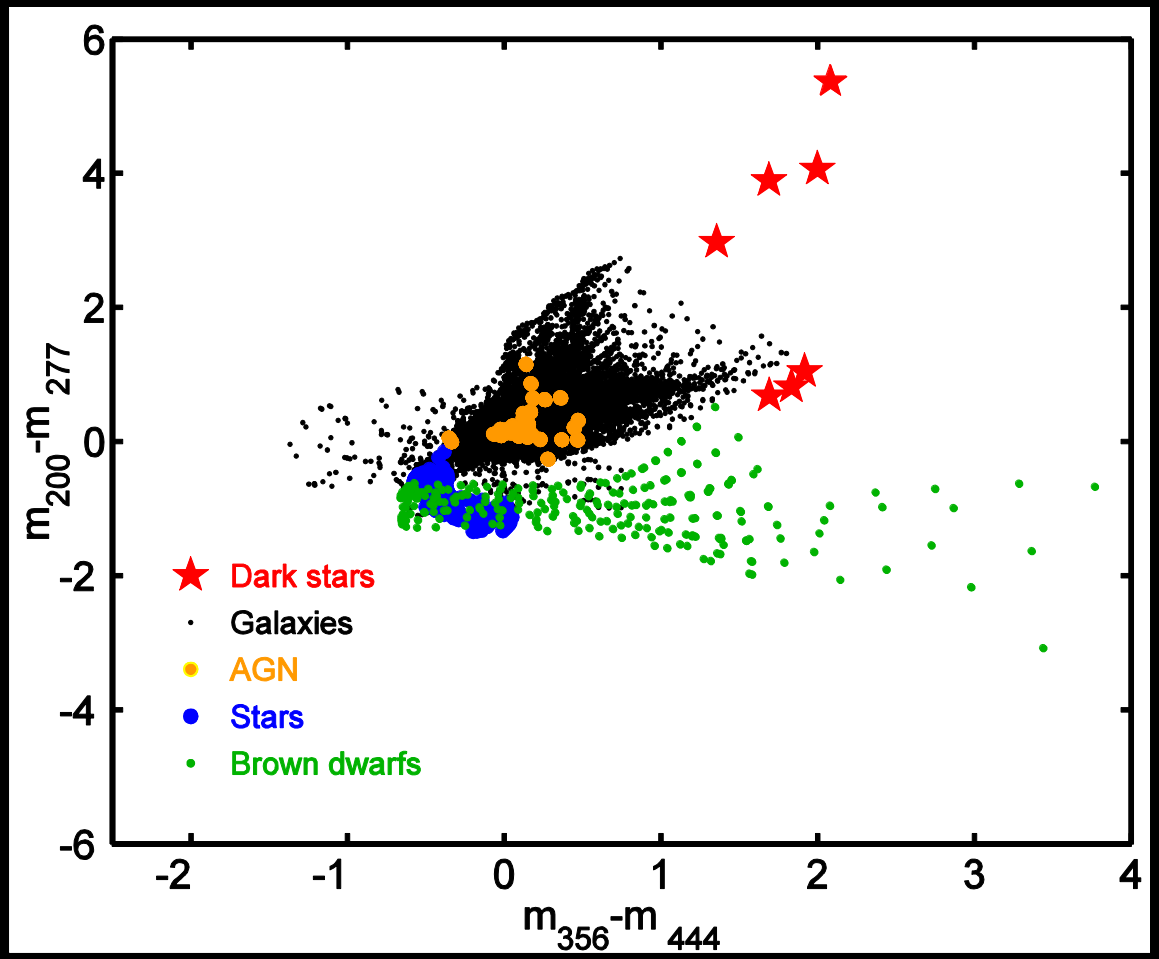
Can Palantir detect z ≈ 10 dark stars?

Requirements for detection of 10^2-10^3 Msolar dark stars:

- The typical dark star lifetime is long (≥ 10 Myr)
- The fraction of pop III.1 stars that become dark stars is high (~ 0.1-1)
- Very long JWST exposures (≈ 30 h per filter)

Bottom line: Very challenging, but Palantir may be *the only way* to detect these objects

How will we find them?

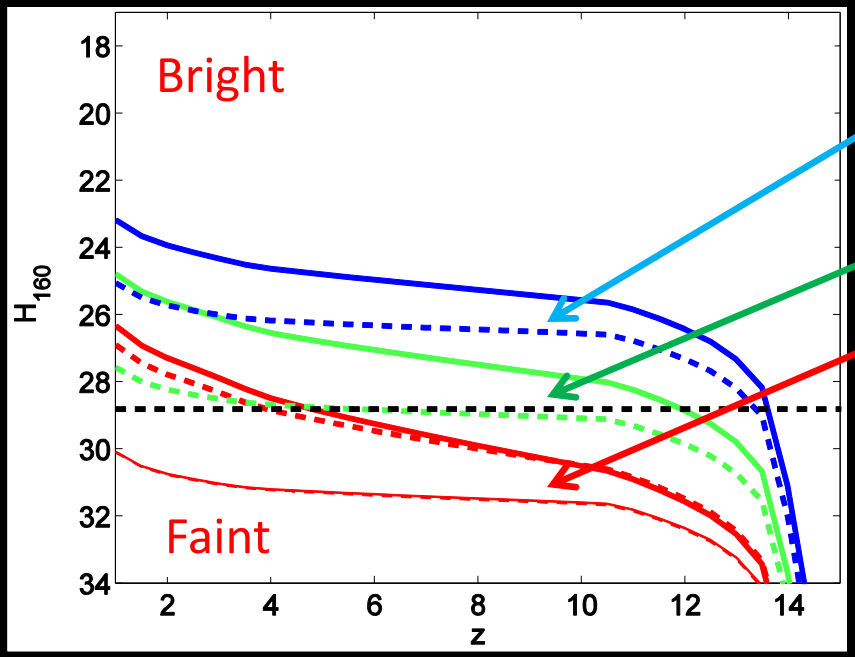


Zackrisson et al. 2010, ApJ 717, 257

Low-temperature dark stars at z ≈ 10 will stand out in photometric surveys due to their very red spectra

Supermassive dark stars

- Freese et al. (2010) argue that dark stars may attain masses of 10^4-10^7 Msolar and should be detectable by JWST even without lensing
- But: Potential fueling/stability problems + 10^7 Msolar dark stars are already strongly constrained by HST/VLT data



10^7 Msolar dark stars
Should have been detected already!

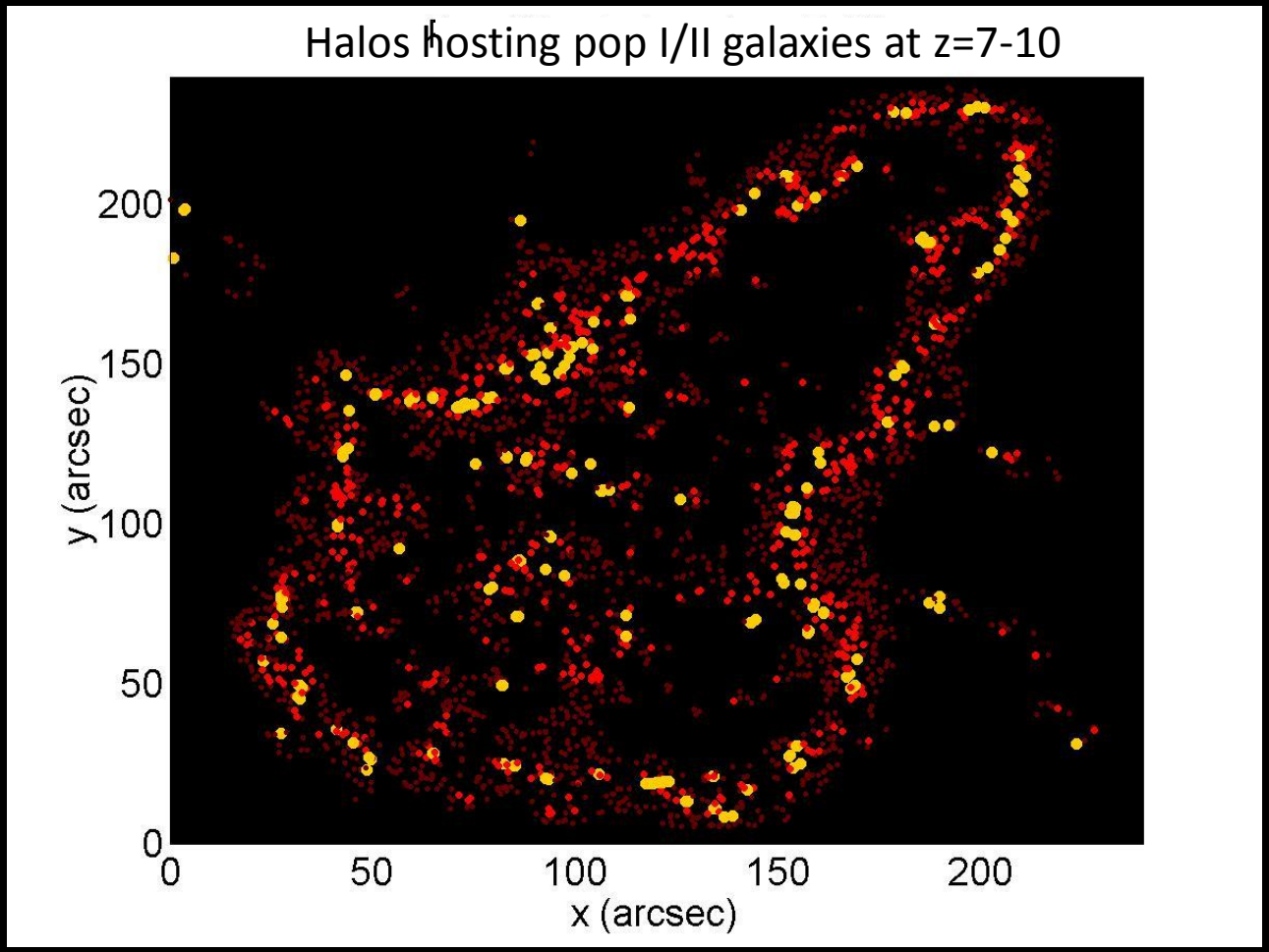
10^6 Msolar dark stars

10^5 Msolar dark stars

HST WFC3 detection limit

Zackrisson et al. 2010, MNRAS 407, L74

Detecting the first galaxies in Palantir I

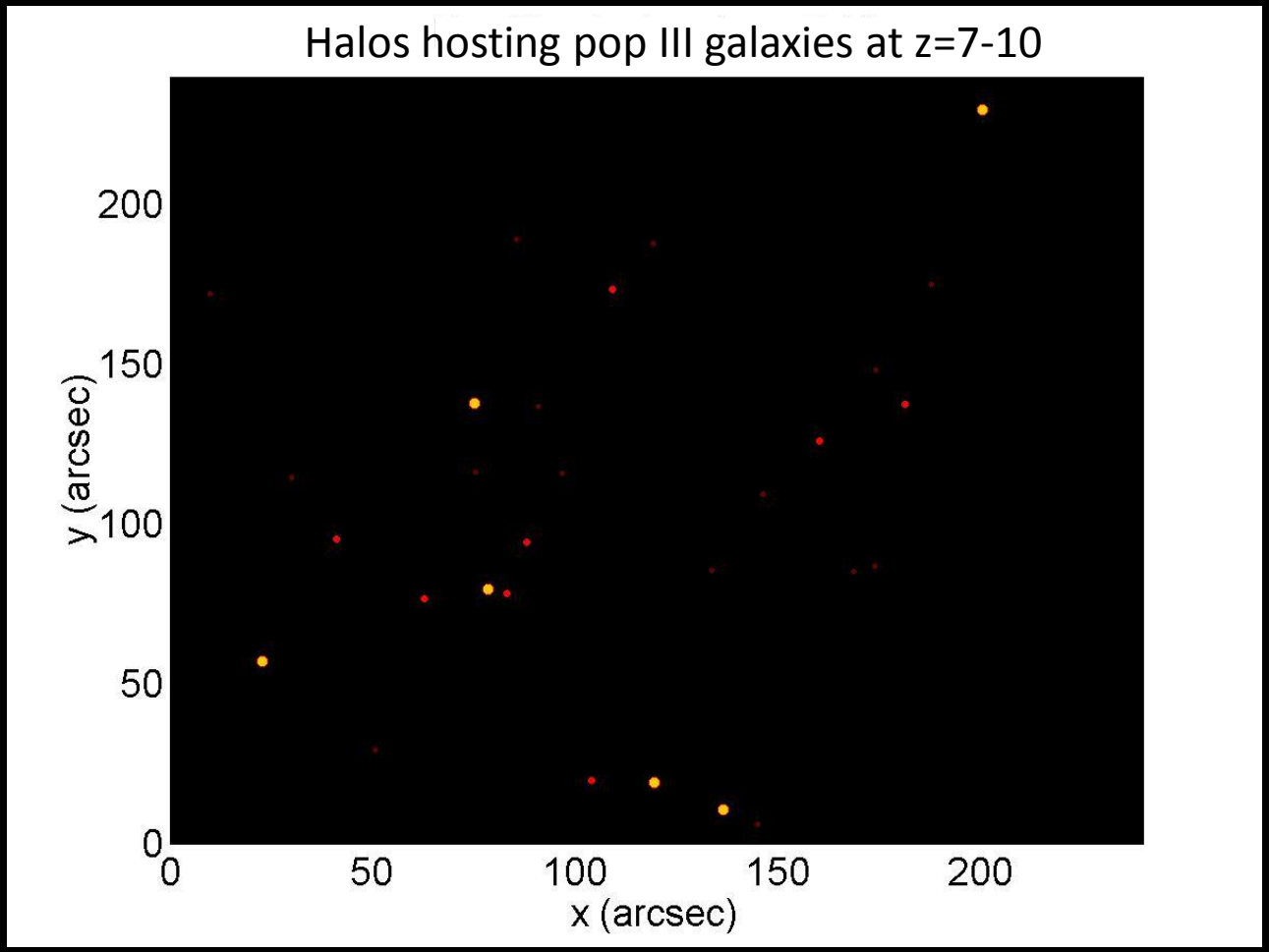


- μ >10
- μ >30
- μ >100

Halo catalogs based on the Trenti et al. (2009) simulations

Zackrisson et al. 2011, in prep.

Detecting the first galaxies in Palantir II



- μ >10
- μ >30
- μ >100

Result: ≈ 30 highly magnified pop III halos

Zackrisson et al. 2011, in prep.

Will Palantir detect more pop III galaxies than the JWST UDF?

- Conditions favouring detection in the UDF:
  - Short burst duration (~1 Myr)
  - High star formation efficiency
  - Extremely top-heavy IMF (pop III.1; M~100 Msolar)

→Rare but intrinsically bright objects

- Conditions favouring detection in Palantir:
  - Long burst duration (~10-100 Myr)
  - Low star formation efficiency
  - Moderately top-heavy IMF (pop III.2; M ~10 Msolar) or normal IMF

→Common but intrinsically faint objects

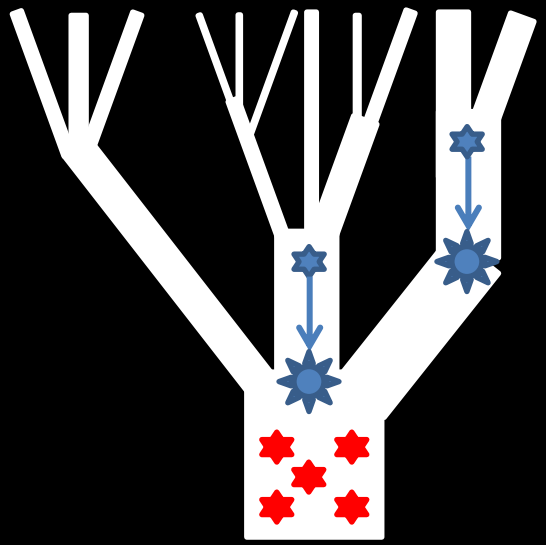
Bottom line: Impossible to say a priori – both approaches should be attempted!

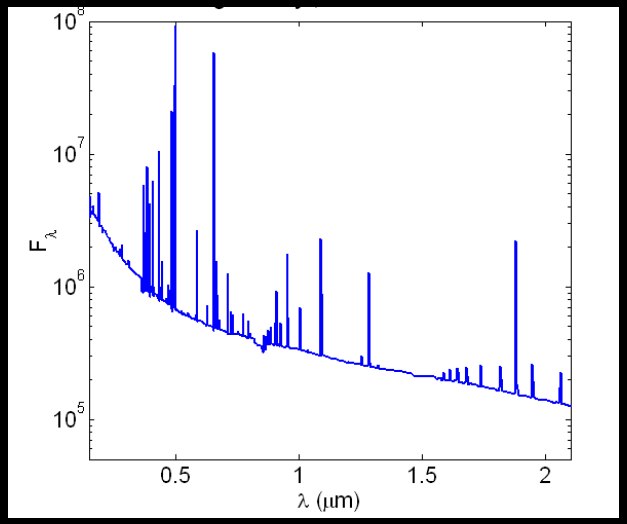
But: Palantir is far less expensive in terms of observing time…

Collaboration:
Erik Zackrisson, Claes-Erik Rydberg, Göran Östlin, Daniel Schaerer

The Yggdrasil code

A spectral synthesis model for the first galaxies





The Yggdrasil code

Features:

- Pop I/II/III stars
- Nebular emission
- Dust extinction
- Dark stars

} *No other model can do this!*

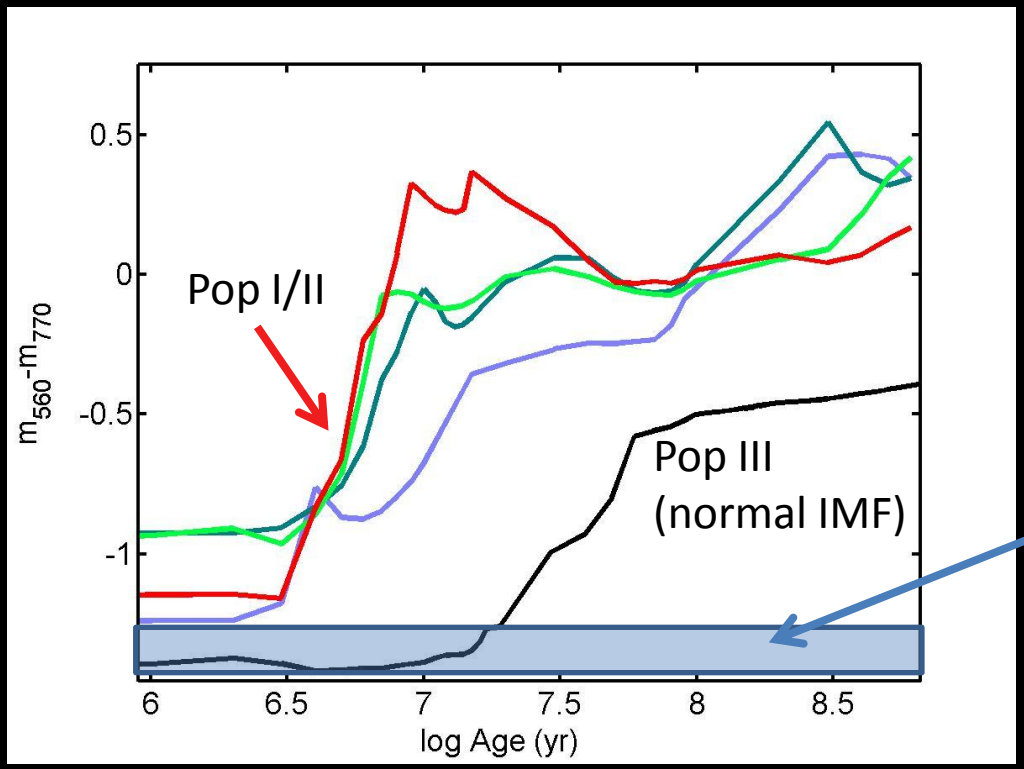
Grids of publicily available model data available at:

www.astro.su.se/~ez

Paper in preparation (Zackrisson et al. 2011)

New spectral signatures of pop III galaxies

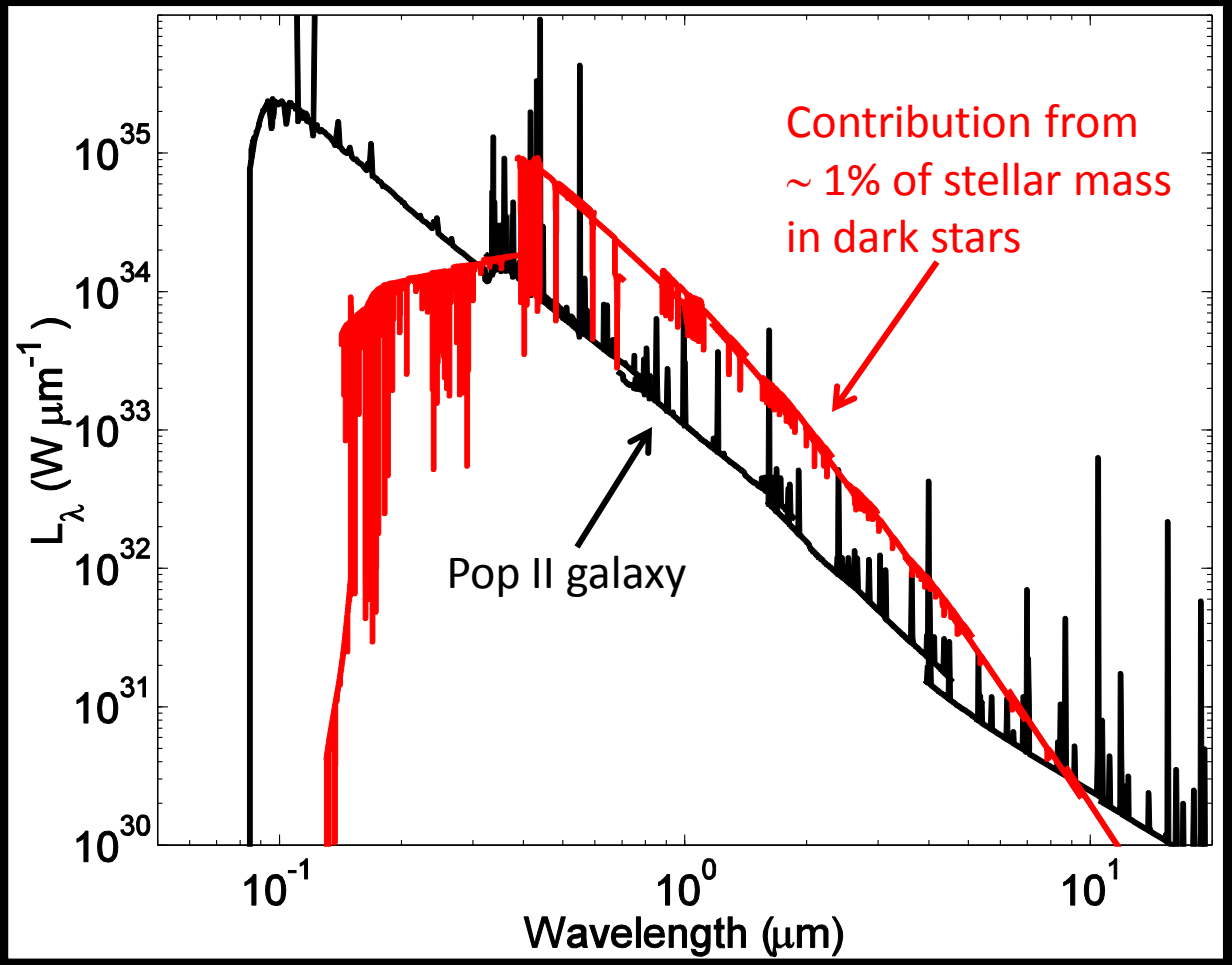
- Conventional strategy:
  Look for anomalously strong HeII line @ 1640 Å
- But plenty of other options, e.g. very strong
  Hα @ 6563 Å, yet absent [OIII] @ 5007 Å
  → potential signatures in JWST *broadband* filters



Only pop III galaxies expected here

Zackrisson et al. 2011, in prep.

Dark stars in the first galaxies



Long-lived ($\tau \sim 10^8$ yr) dark stars may produce telltale signatures in the spectra of the first galaxies

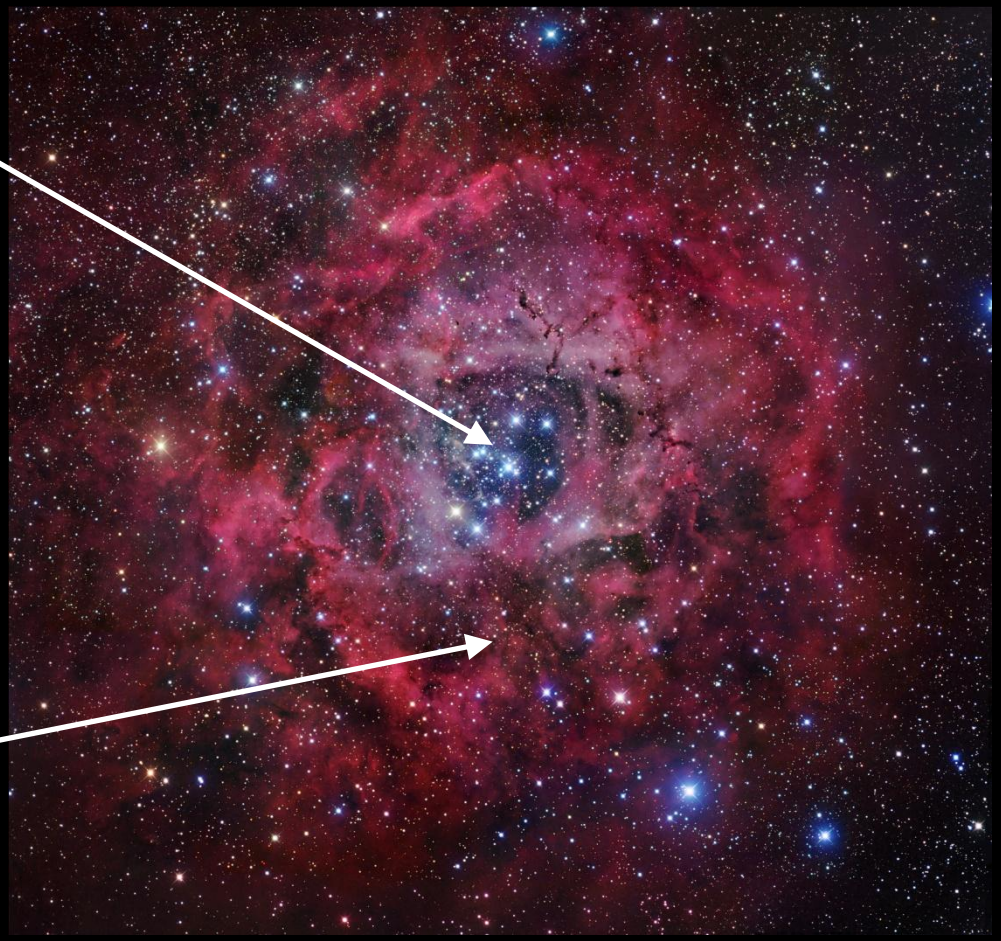
Readily detectable with JWST at $z \approx 10$!

Zackrisson et al. 2010, ApJ 717, 257

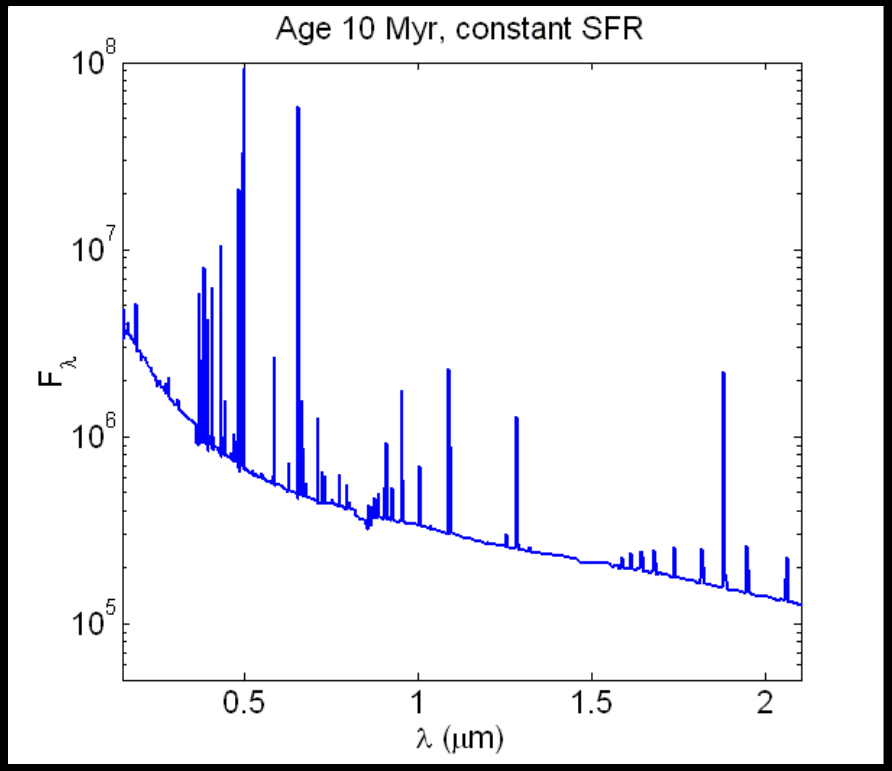
Nebular Emission from high-z galaxies

Young stars

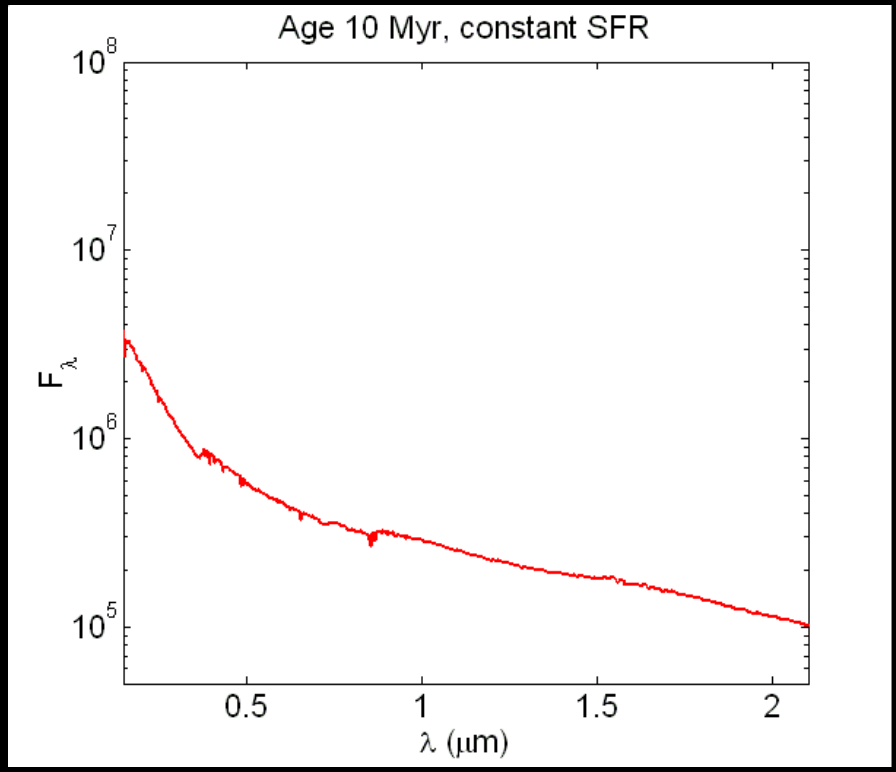
Photoionized gas



Nebular Emission from high-z galaxies II

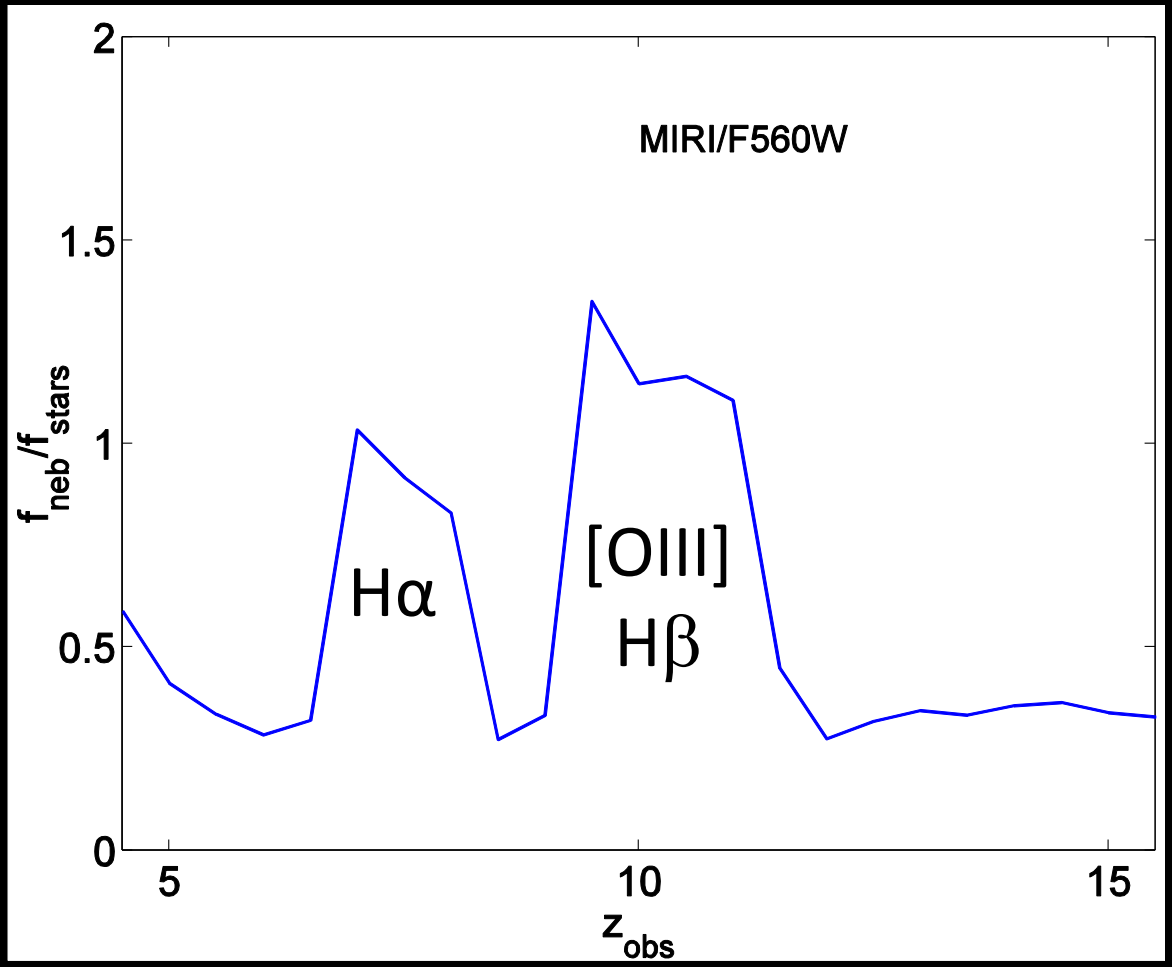


Stars + nebula



Stars only

Nebular Emission from high-z galaxies III



Pop II galaxy
Age: 50 Myr
SFR: Constant

Zackrisson et al. (2001, 2008) models

Summary

- JWST scheduled for launch in 2014
- New window on the z = 6 -15 Universe
- Lensed survey fields (e.g. Palantir) may be an excellent way to detect very faint, high-z objects (dark stars, pop III galaxies)
- New population synthesis models for the first galaxies: *www.astro.su.se/~ez*