

Detecting the first stars and galaxies with the James Webb Space Telescope

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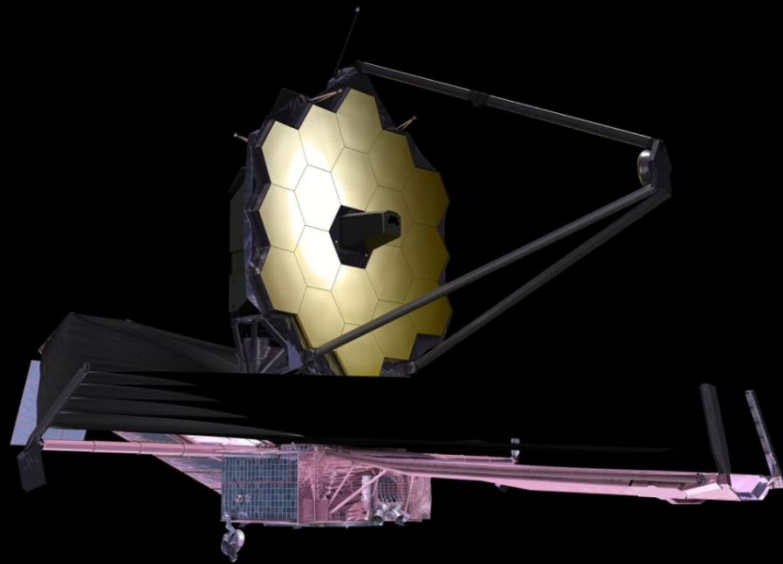
Stockholm University



Outline

- James Webb Space Telescope
 - Solving the puzzles of the high-redshift Universe
 - New window on the first stars and galaxies
- Extragalactic JWST projects in Stockholm:
 - The Palantir Survey
 - Population synthesis models for the first galaxies

James Webb Space Telescope



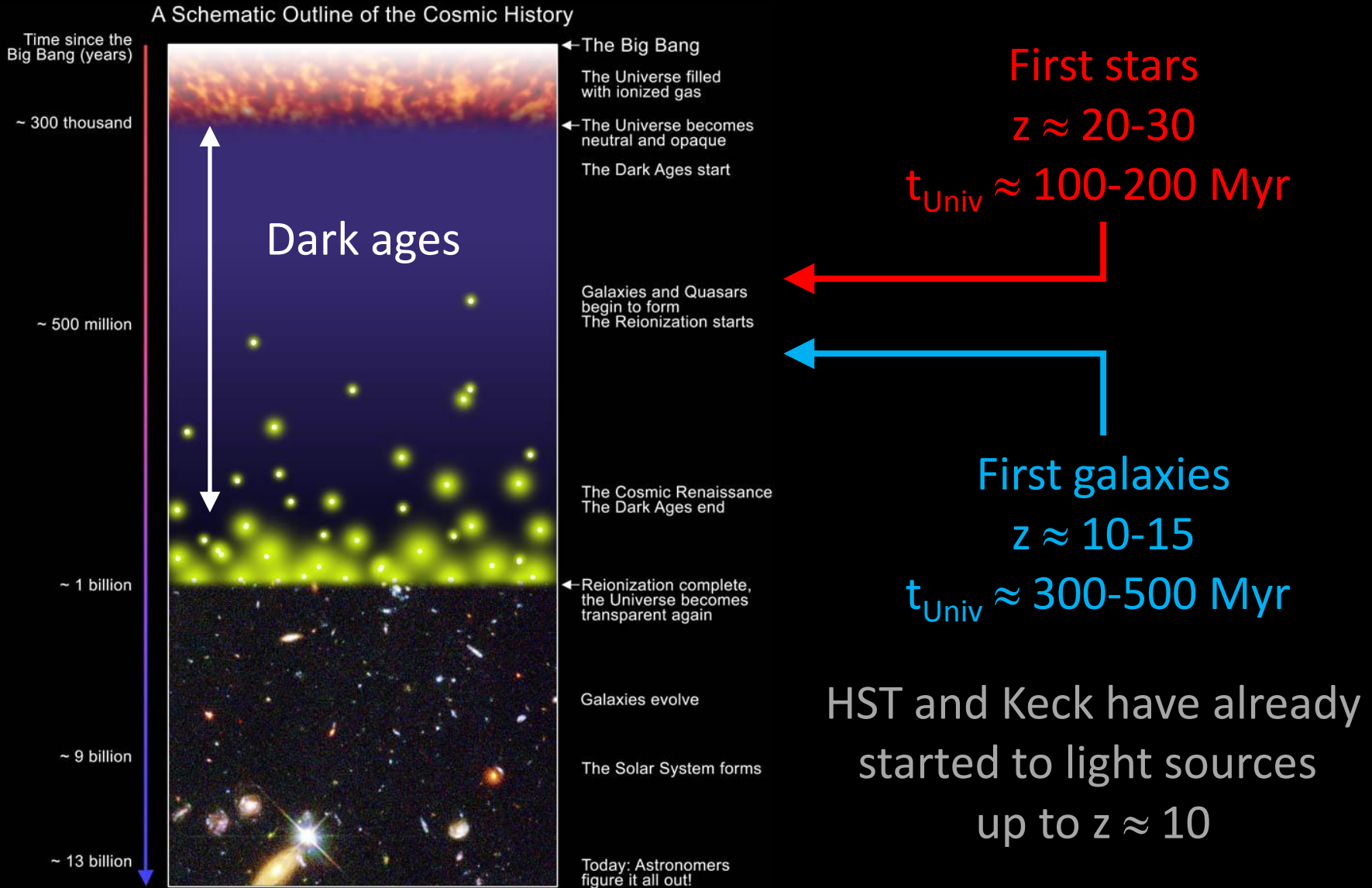
'The first light machine'

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

Sweden & Denmark are involved in
the development of one of the instruments (MIRI)

The End of the Dark Ages



What can we learn from observations at redshifts $z > 10$?

Unsolved puzzles:

- Reionization sources
- Seeds for supermassive black holes
- Origin of the first metals
- Origin of the near-IR extragalactic background light

Exotic beasts

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



Exotic beasts

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The JWST Ultra Deep Field

- JWST Ultra deep field:
 - Will reach AB mag ≈ 31.3 @ $2\mu\text{m}$ with $S/N=5$ in ≈ 100 hours per filter
- Our proposal:
 - Survey that will reach a factor of 10 deeper in just 1 hour per filter

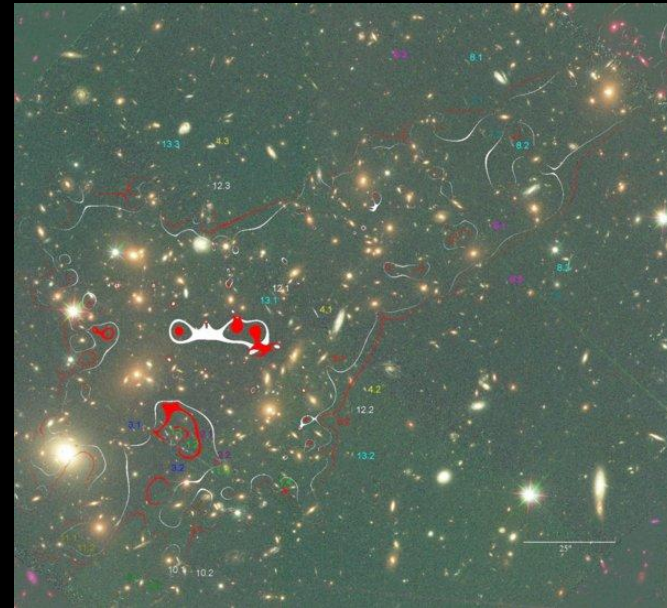
How is this possible?

The Palantir Survey

- Channeling the magic of gravitational lensing -

Collaboration:

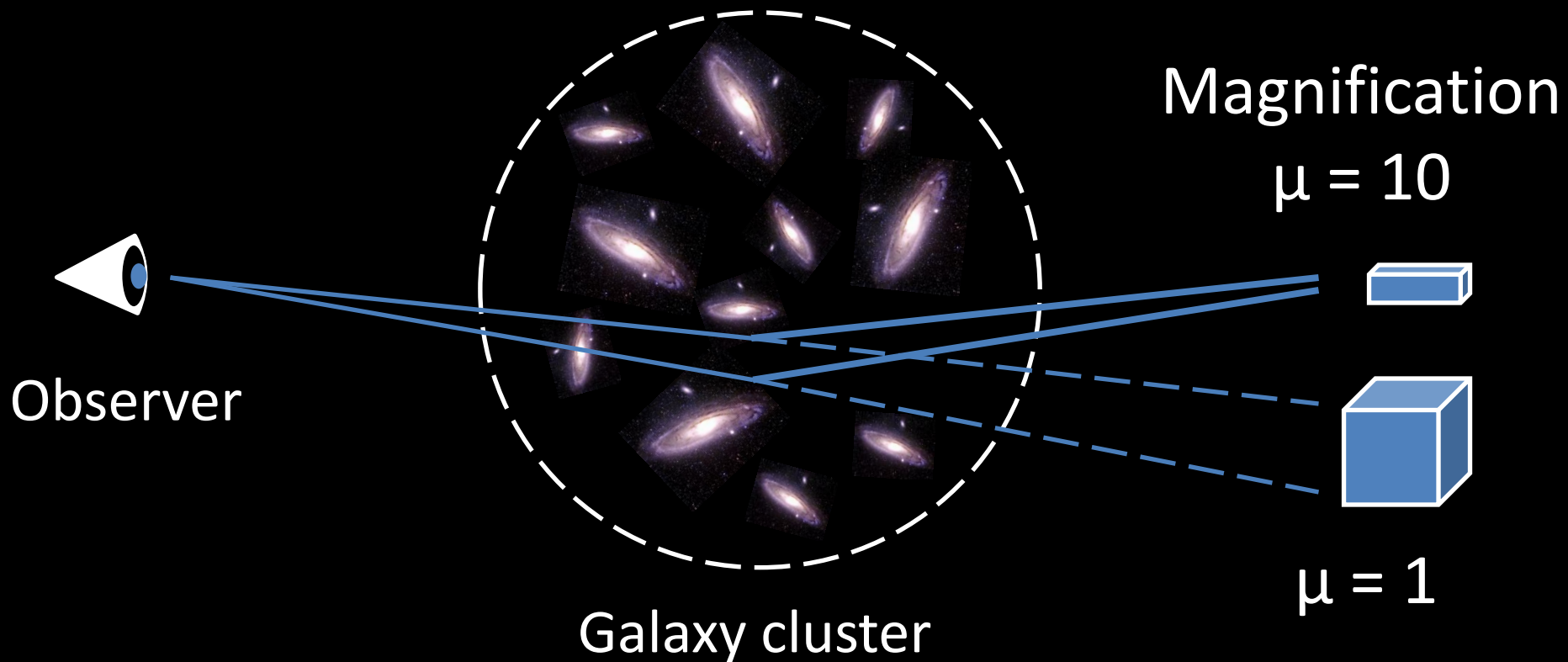
Erik Zackrisson
Claes-Erik Rydberg
Göran Östlin
Adi Zitrin
Tom Broadhurst
Daniel Schaerer
Michele Trenti
Massimo Stiavelli



Primary target: MACS J0717+3745
Largest Einstein radius known!
 $\mu > 10$ region is 3.5 arcmin²
 $\mu > 100$ region is 0.3 arcmin²

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

Pros and Cons of Gravitational Lensing



- + Background sources appear brighter by a factor μ
- The volume probed becomes smaller by a factor μ

Bottom line: Lensed survey fields can be superior for sources that are very faint, not too rare and not too highly clustered

Population III stars

Conventional population III stars

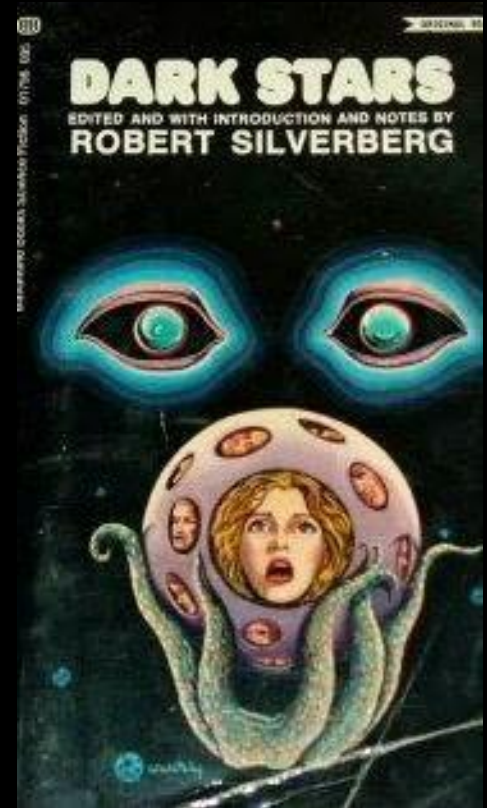
- Metallicity $Z \approx 0$
- First pop III stars form at redshift $z \approx 30$ in dark matter minihalos ($\sim 10^6 M_{\text{solar}}$)
- Very massive (10-300 M_{solar})
- Very hot ($T_{\text{eff}} \sim 10^5 \text{ K}$) and short-lived ($\sim 3 \text{ Myr}$)



Individual pop III stars are
most likely unobservable even with JWST 😞

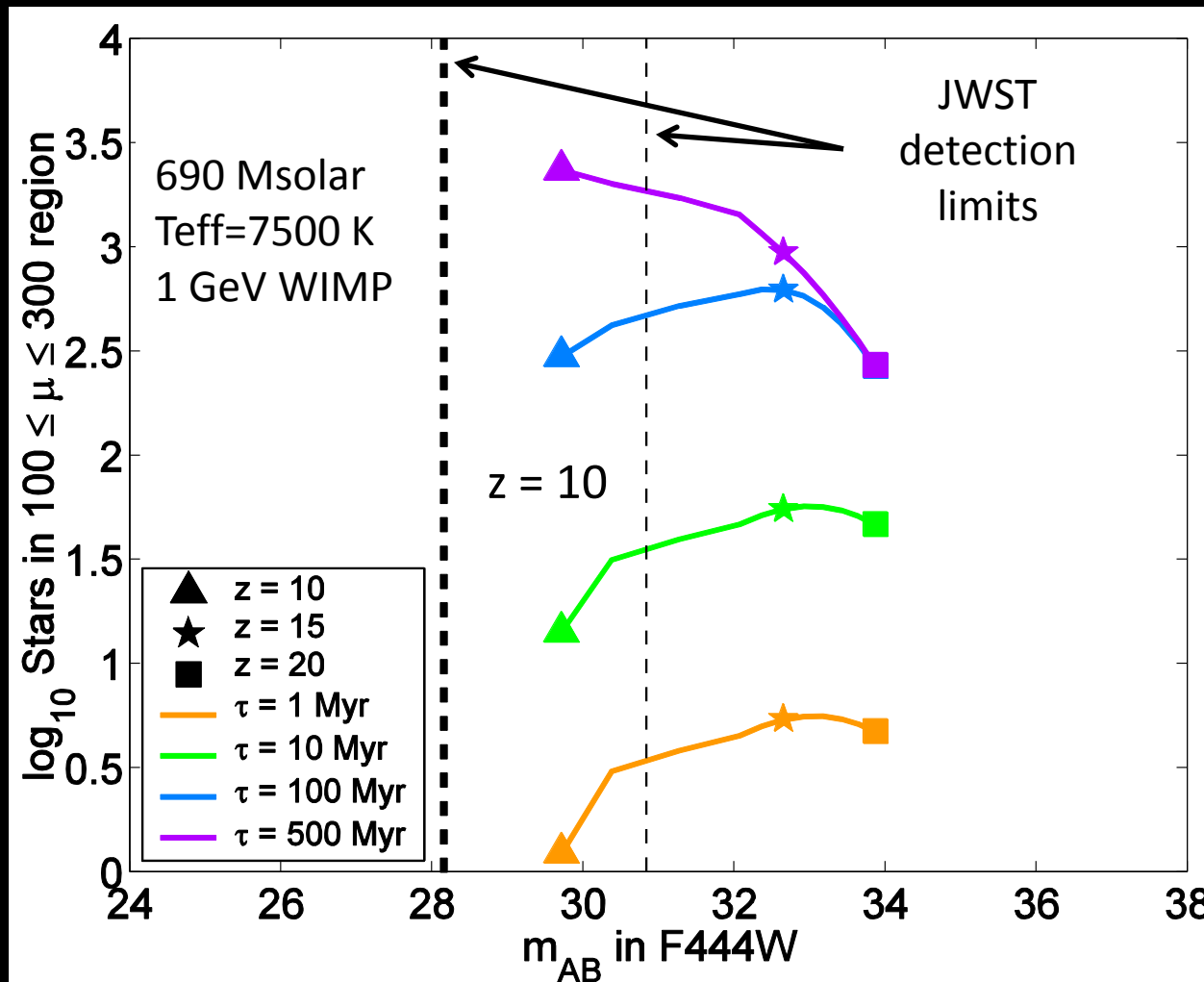
Dark stars

- WIMP annihilations may affect the evolution of stars forming in the centres of minihalos
→ Pop III star fueled by dark matter annihilation alongside hydrogen fusion (*Dark star*)
- Cooler, more massive and potentially more long-lived than conventional pop IIIs



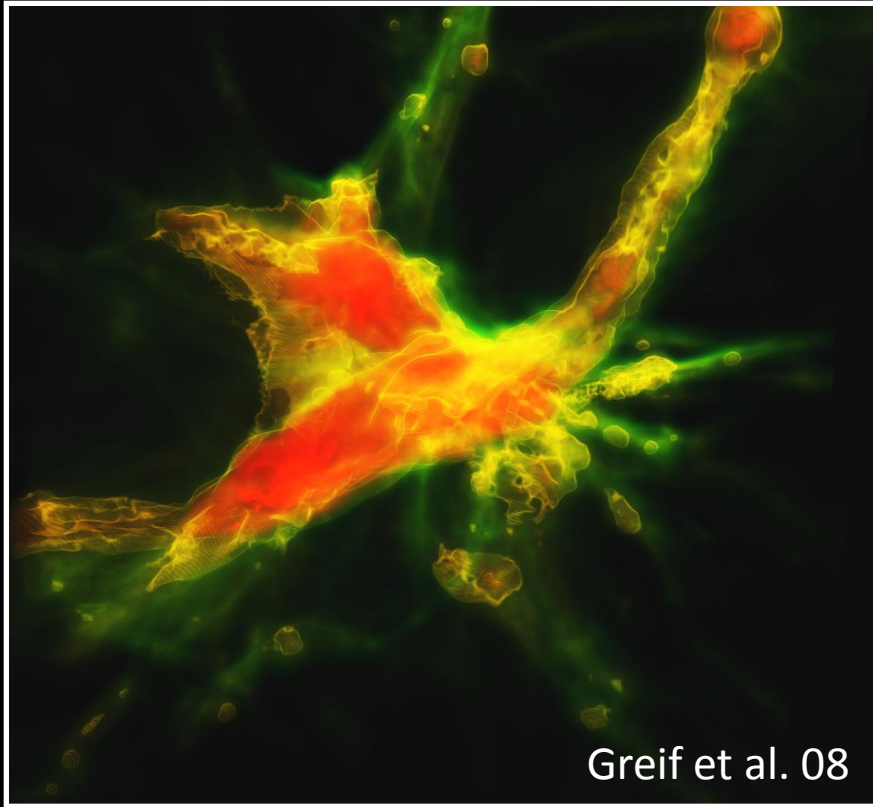
Detectable with JWST! 😊

Dark stars in the Palantir survey



Zackrisson, Scott, Rydberg, Iocco, Edvardsson, Östlin,
Sivertsson, Zitrin, Broadhurst & Gondolo (2010, ApJ, in press)

The First Galaxies



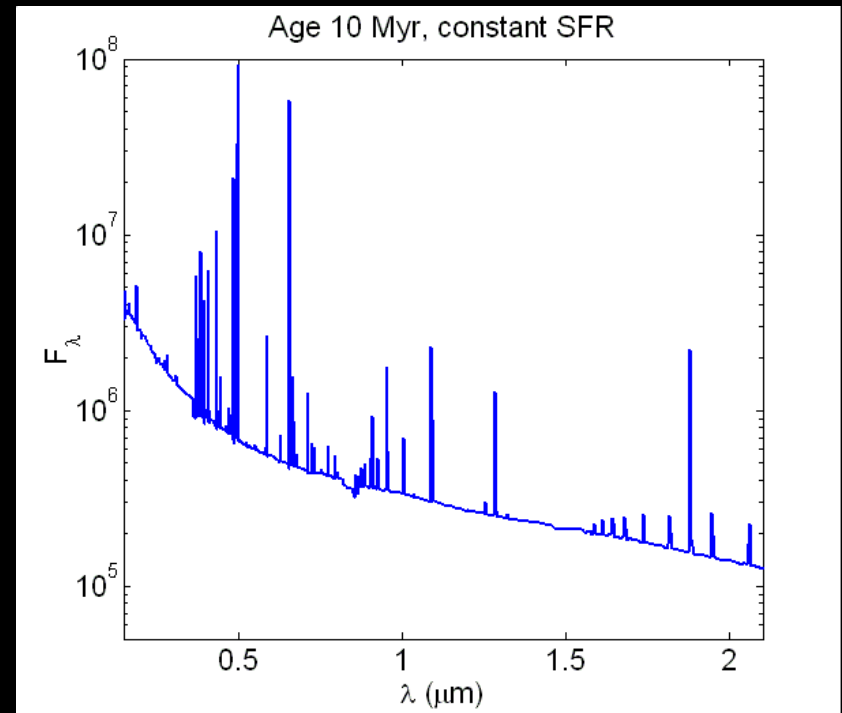
- Form at $z \approx 10-15$
- Irregular, starbursting dwarf galaxies
- Two types:
 - Population II galaxies
Normal stellar mass range
 - Population III galaxies
Only high mass stars?

Pop II galaxies may form before pop III galaxies!
Stiavelli & Trenti 2009 (arXiv0911.3368)

A spectral synthesis code for the first galaxies

Features:

- Population I, II, III stars
- Dark stars
- Nebular emission
- Dust extinction

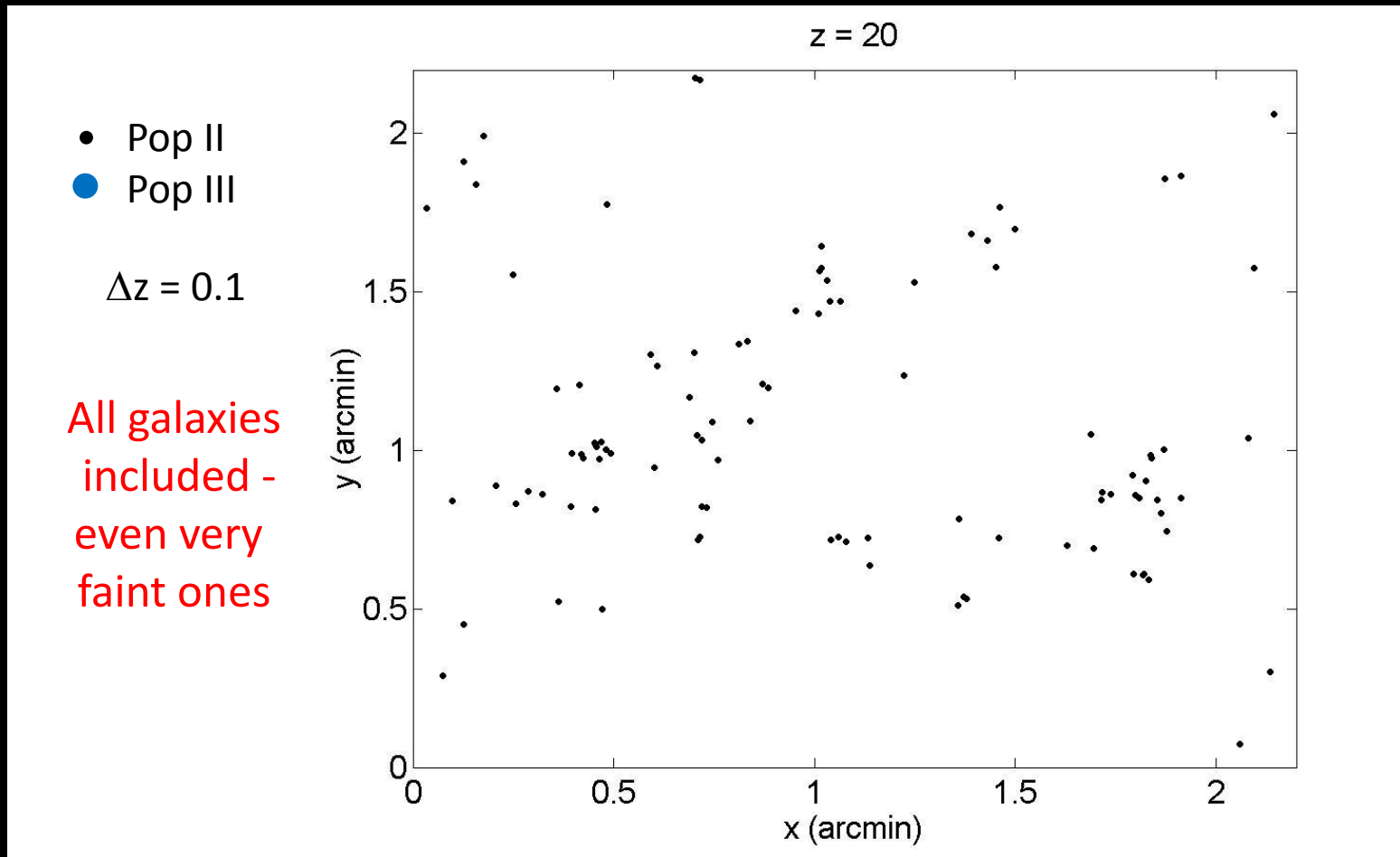


Zackrisson, Rydberg, Schaerer & Östlin (2010, in prep.)

A few model predictions already available at:

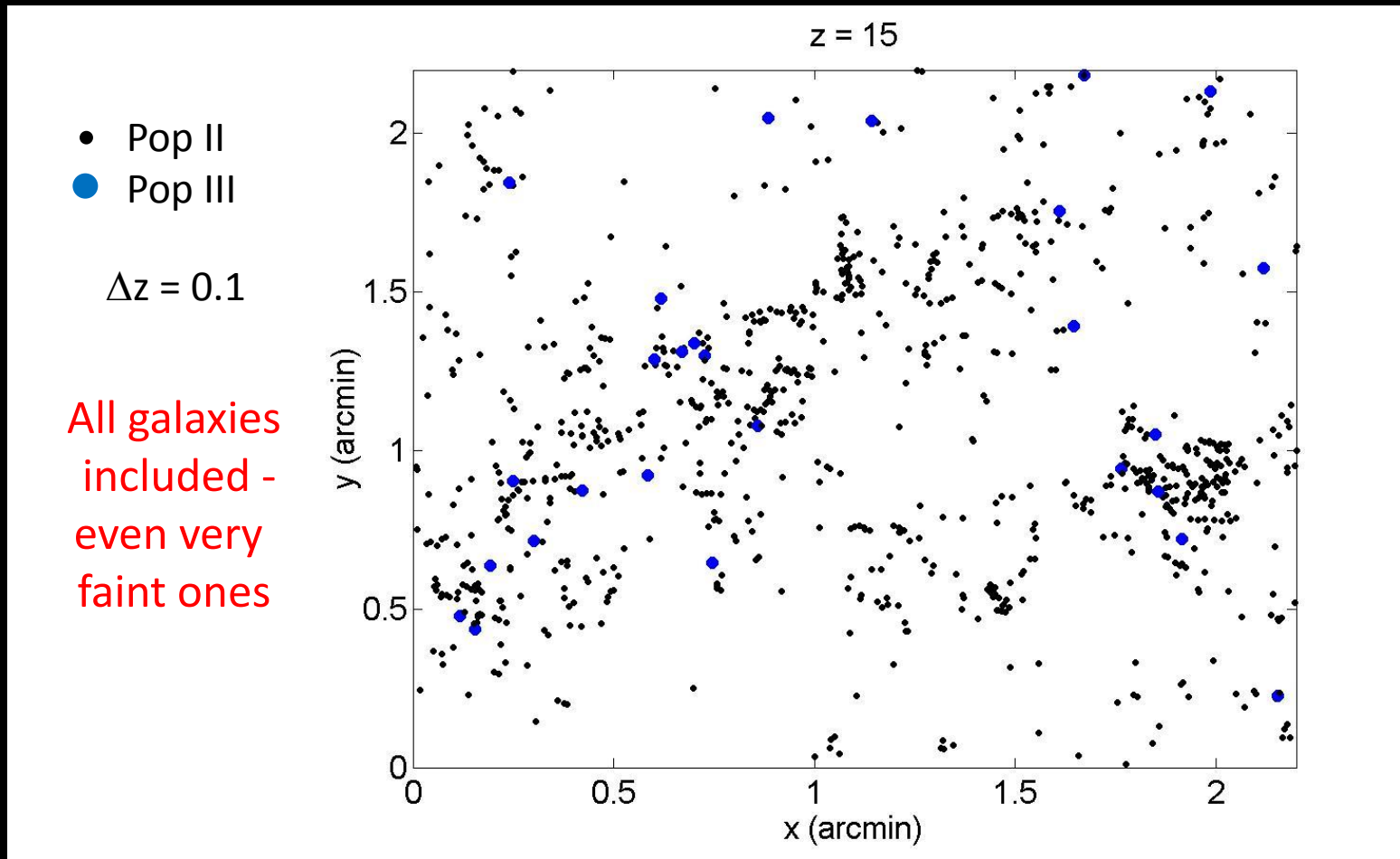
www.astro.su.se/~ez

First Galaxies in the JWST field of view



Simulations by Trenti, Stiavelli & Shull (2009)

First Galaxies in the JWST field of view



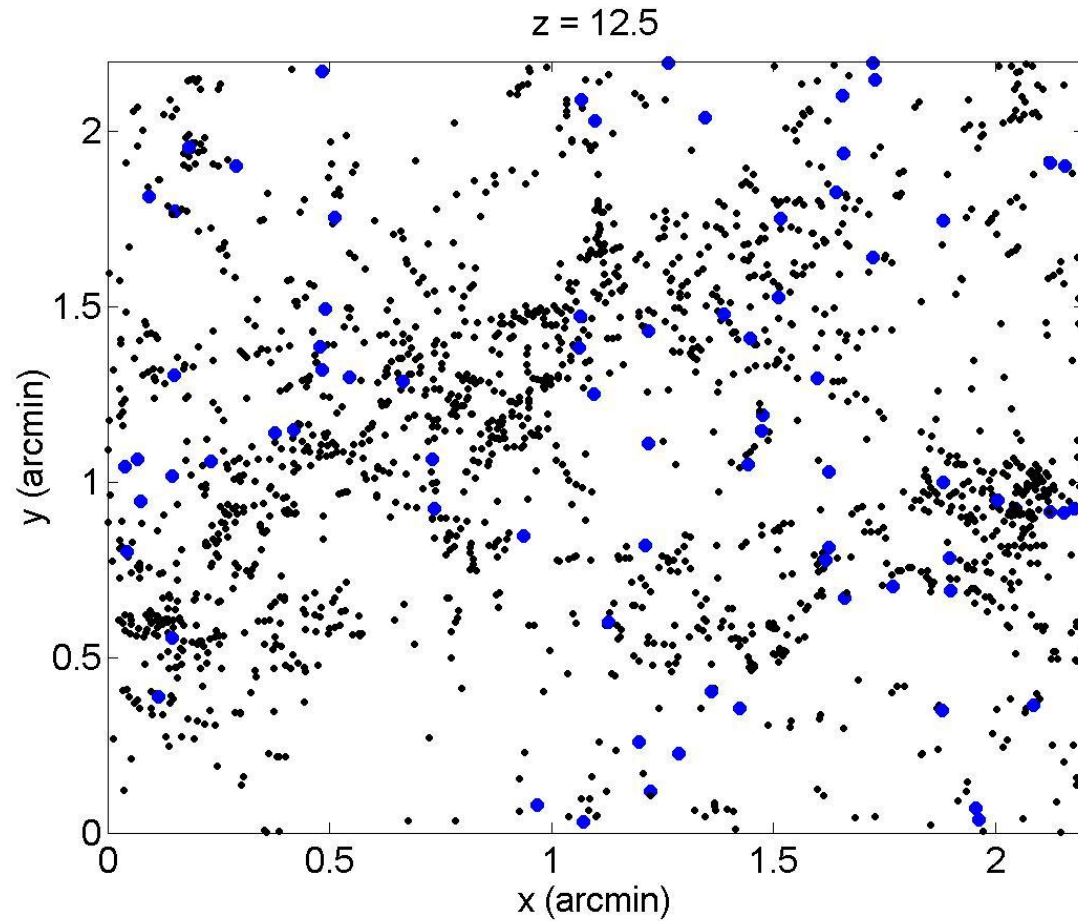
Simulations by Trenti, Stiavelli & Shull (2009)

First Galaxies in the JWST field of view

- Pop II
- Pop III

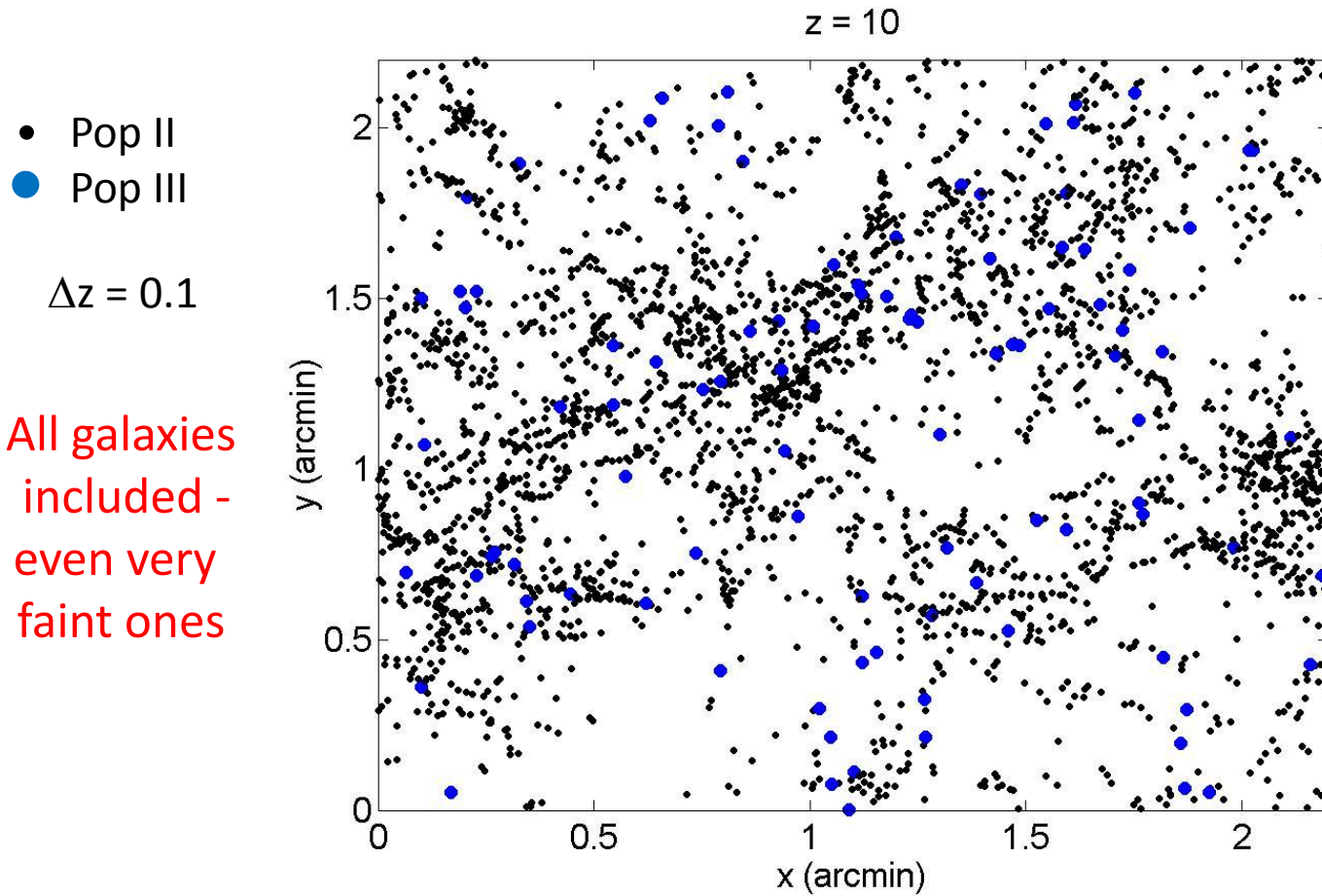
$\Delta z = 0.1$

All galaxies
included -
even very
faint ones



Simulations by Trenti, Stiavelli & Shull (2009)

First Galaxies in the JWST field of view



Simulations by Trenti, Stiavelli & Shull (2009)

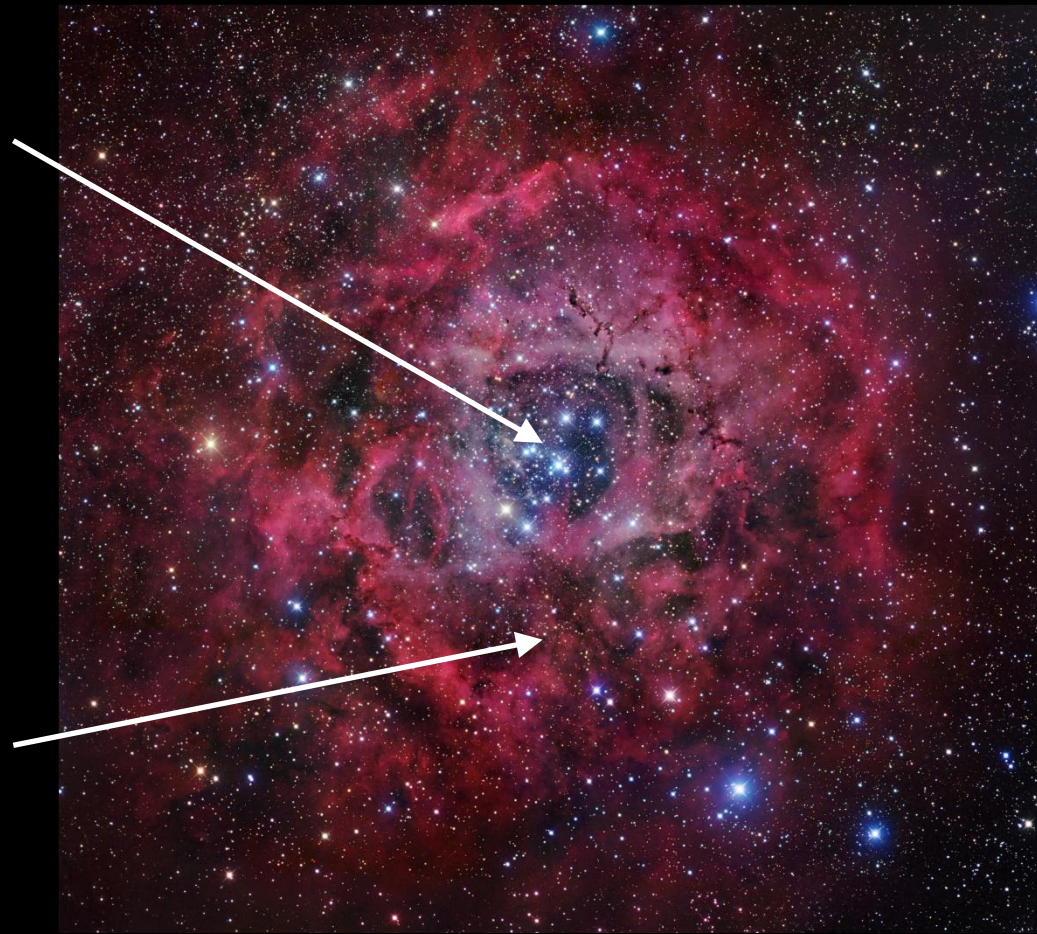
How many $z > 10$ galaxies will JWST actually detect?

- Depends on astrophysics way below the resolution limit of current simulations
- Population synthesis models + reasonable assumptions about burst length and star formation efficiency →
 - A few tens of pop II galaxies in JWST ultra-deep field (100 h exposure)
 - Pop III galaxies can only be detected in Palantir

Work in progress...

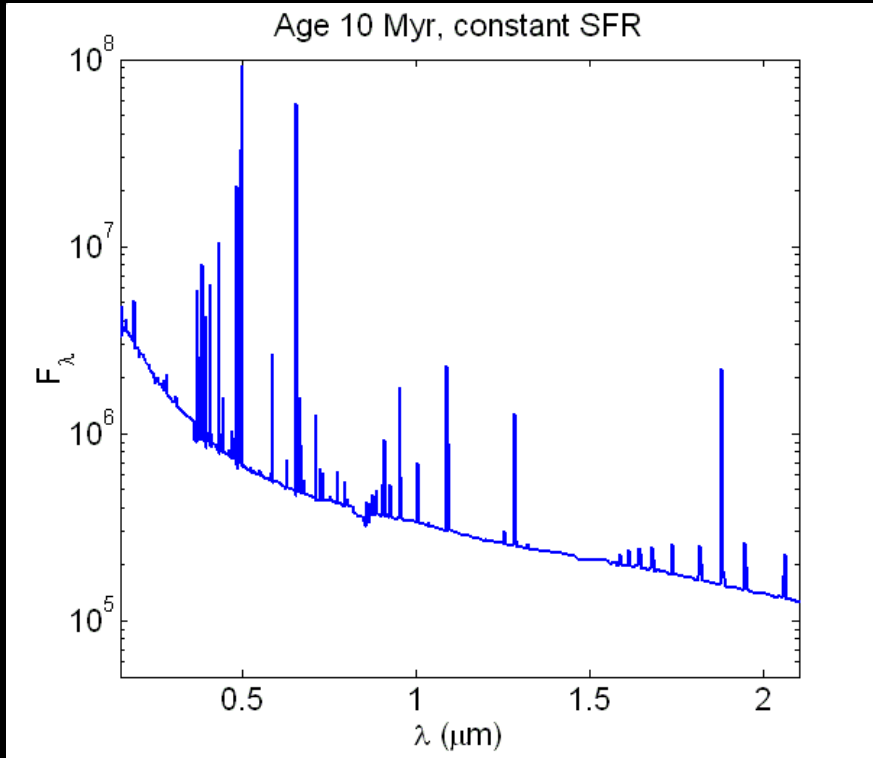
Nebular Emission from high-z galaxies

Young stars

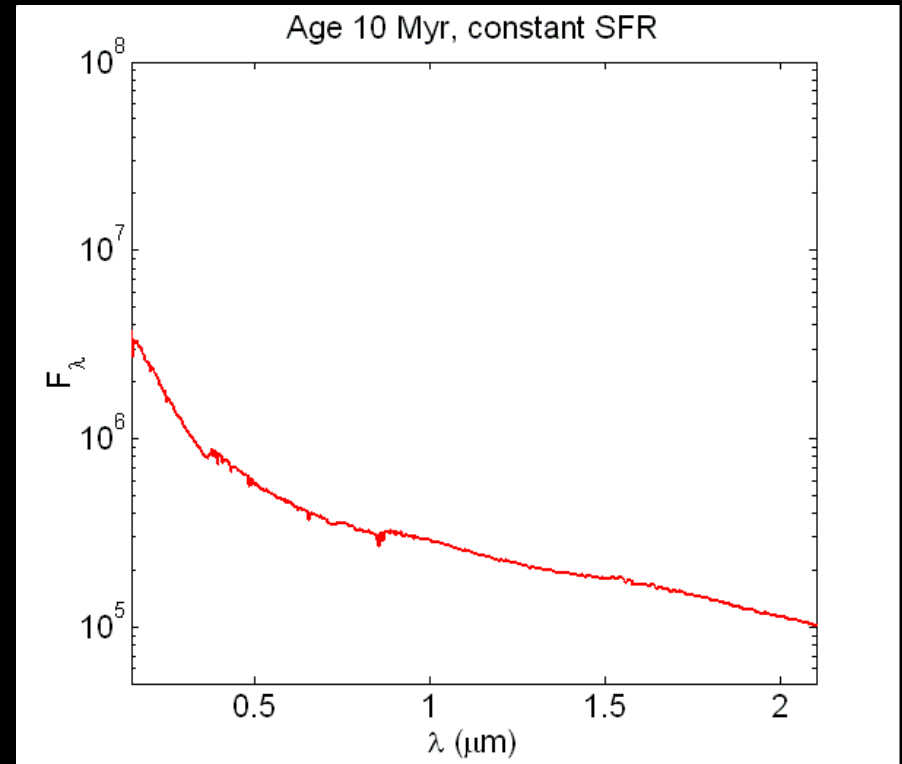


Photoionized gas

Nebular Emission from high-z galaxies II

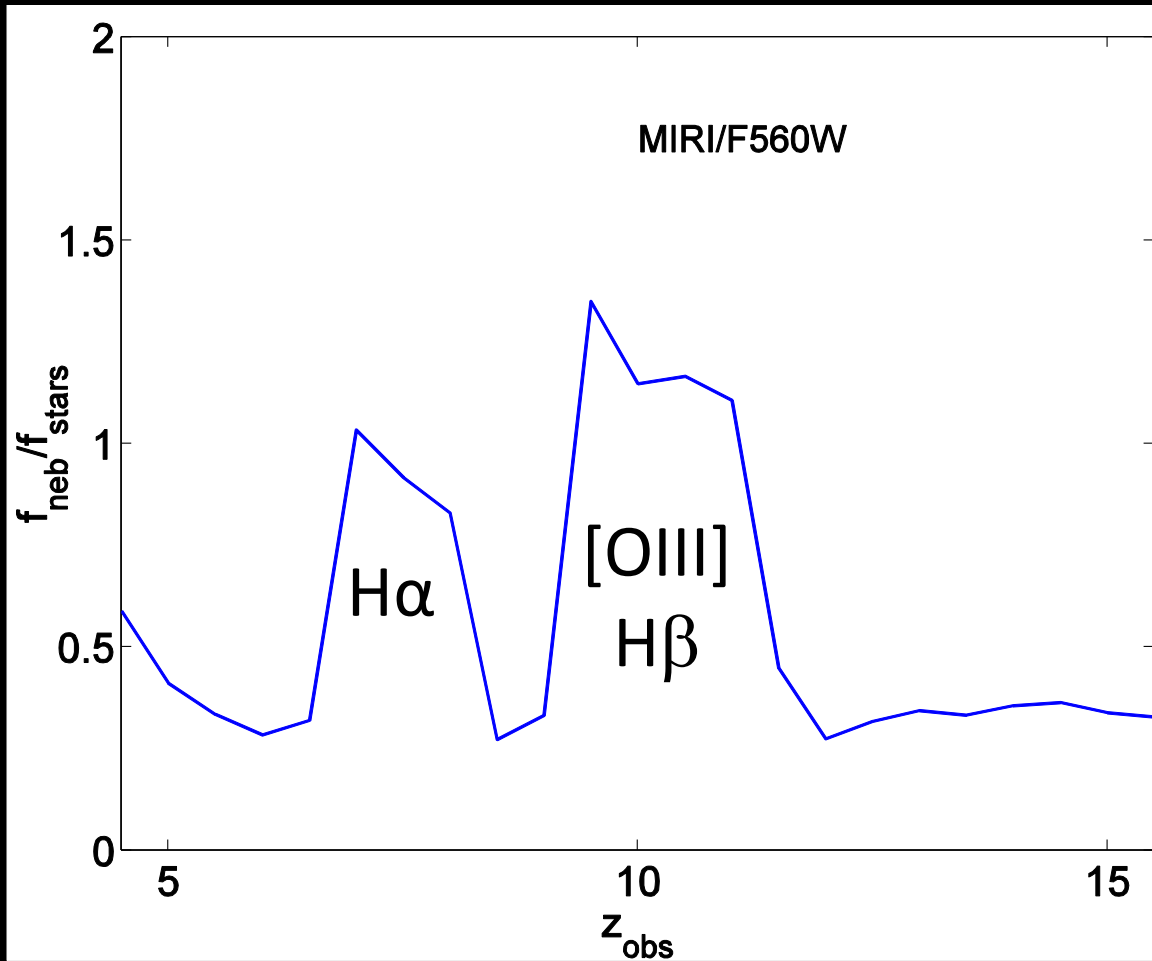


Stars + nebula



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 the only 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