The Observational Signatures of High-Redshift Dark Stars

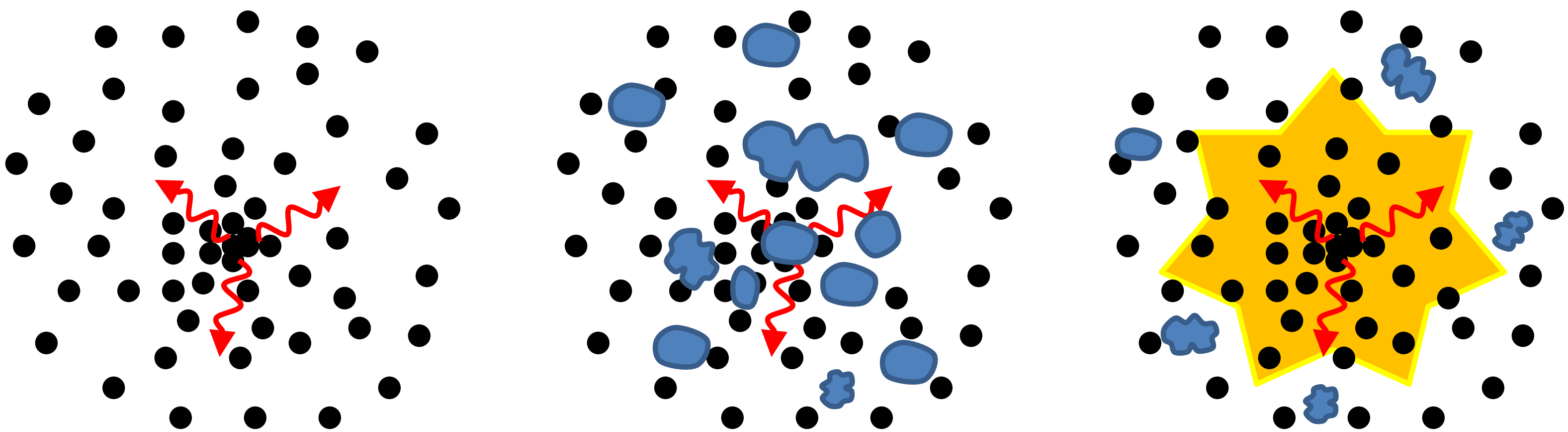
Erik Zackrisson
Department of Astronomy
Stockholm University

Pat Scott, Claes-Erik Rydberg, Fabio Iocco, Sofia Sivertsson, Paolo Gondolo, Göran Östlin, Bengt Edvardsson, Adi Zitrin, Tom Broadhurst, Garrellt Mellema, Ilian Iliev, Paul Shapiro

Outline

- Dark stars – what, when, where?
- How to detect individual, dark stars at high redshifts
  – How bright? How many?
  – What telescope?
  – How will we identify them?
- Dark stars within the first galaxies

Dark stars – What? Where?



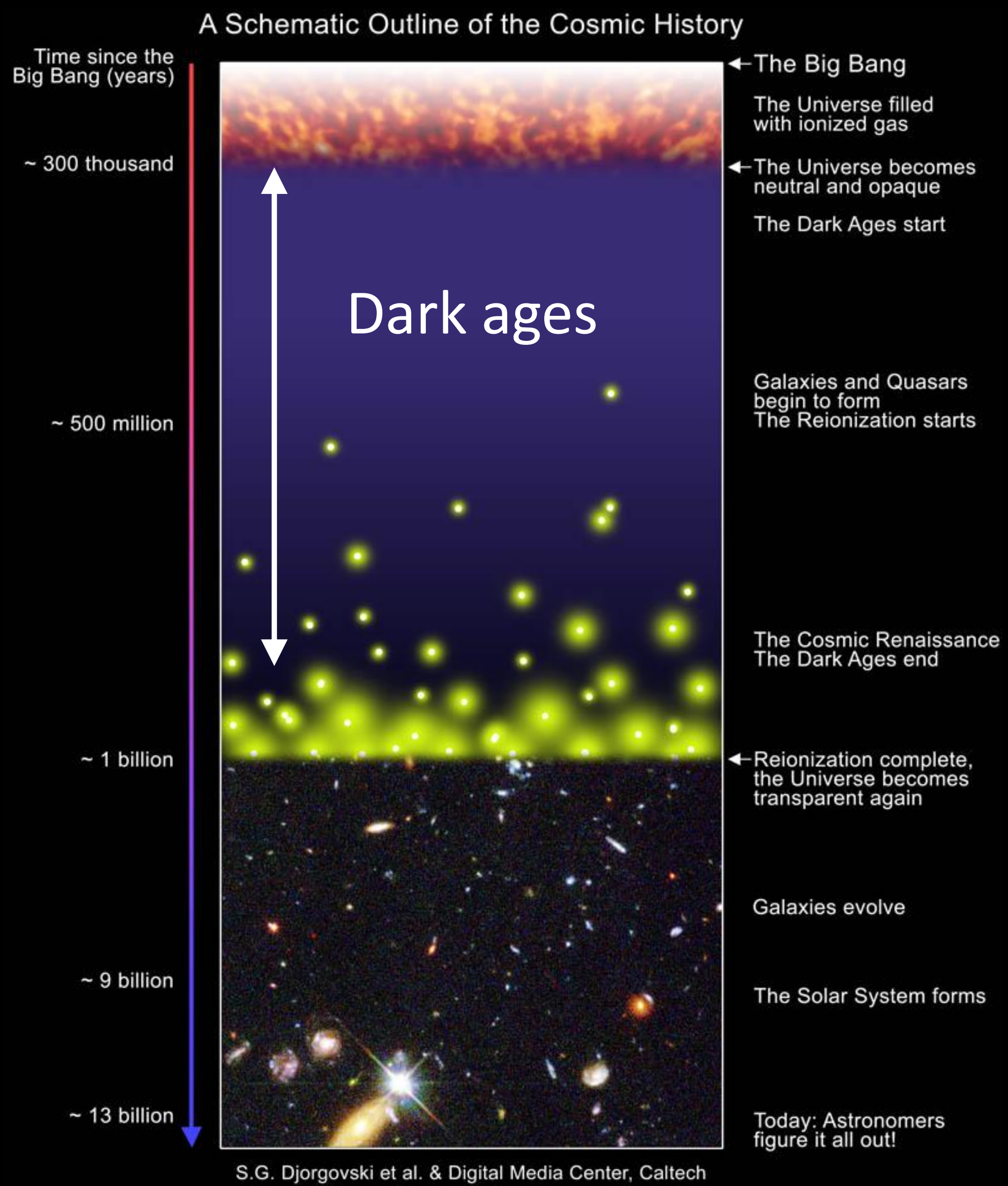
WIMP annihilation in centre of CDM halo

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

Dark stars – When?



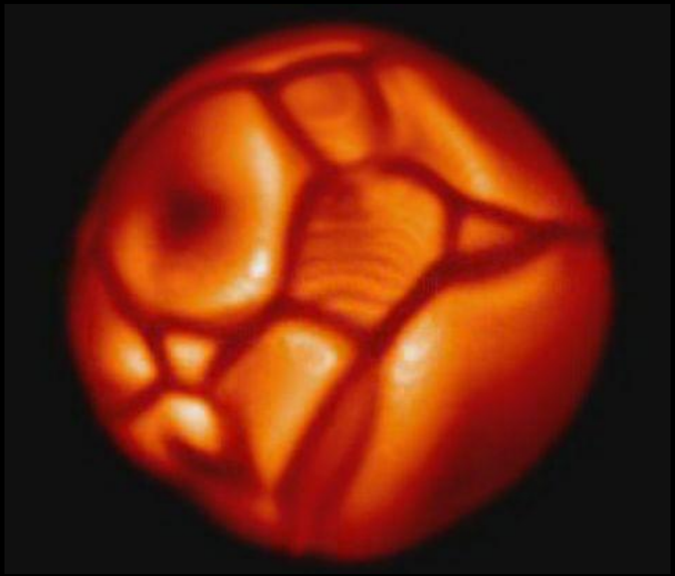
First stars
$z \approx 20\text{-}30$
$t_{Univ} \approx 100\text{-}200$ Myr

First galaxies
$z \approx 10\text{-}15$
$t_{Univ} \approx 300\text{-}500$ Myr

Current observational limit:
HST and Keck can detect
light sources up to $z \approx 10$

Dark star properties

- Conventional Pop III stars
  - Teff ~ 100 000 K
  - M ~ 10^2 Msolar
  - Lifetime $\tau \sim 10^6$ yr
- Pop III 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???



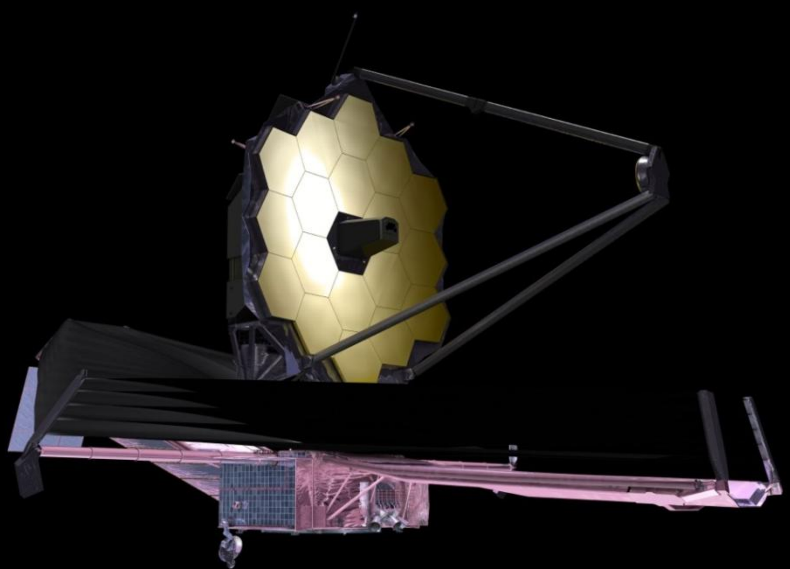
Problem: Still no consensus on likely masses or life times of dark stars (see talks by Spolyar and Sivertsson)

How can we detect high-z dark stars?

- Indirect methods:
  - Contribution to cosmic reionization (Schleicher et al. 2009)
  - Delay in pair-instability supernova rate (Iocco 2009)
  - Contribution to extragalactic background (talk by Maurer)
  - Black hole remnants (talk by Sandick)
- Direct methods:
  - Detecting them in deep infrared photometric surveys (Zackrisson et al. 2010ab, Freese et al. 2010)

The detection of dark stars would confirm that CDM is in the form of self-annihilating WIMPs (see Gondolo et al. 2010 and the talk by Kim for details)

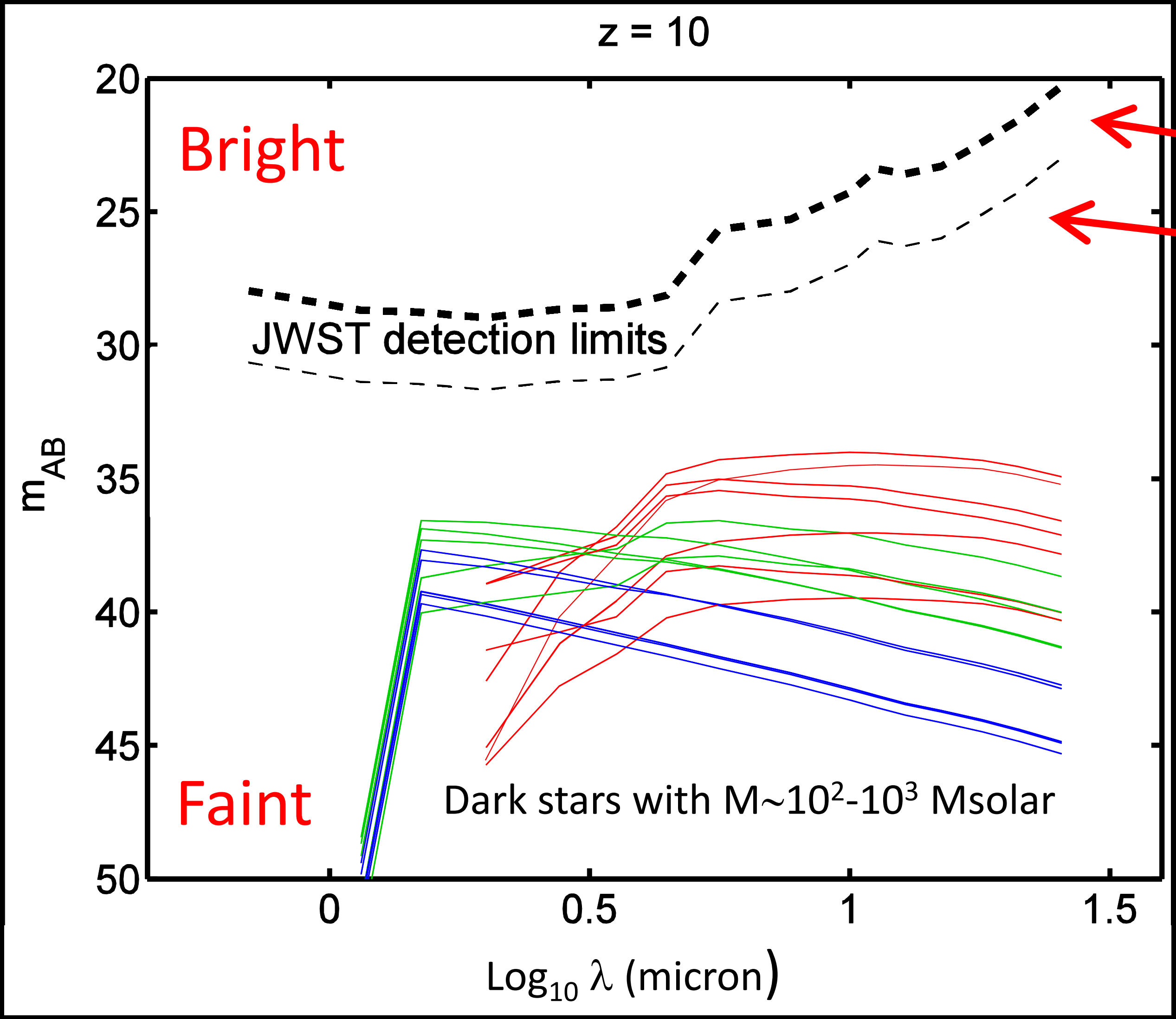
The James Webb Space Telescope



'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

JWST fluxes of dark stars

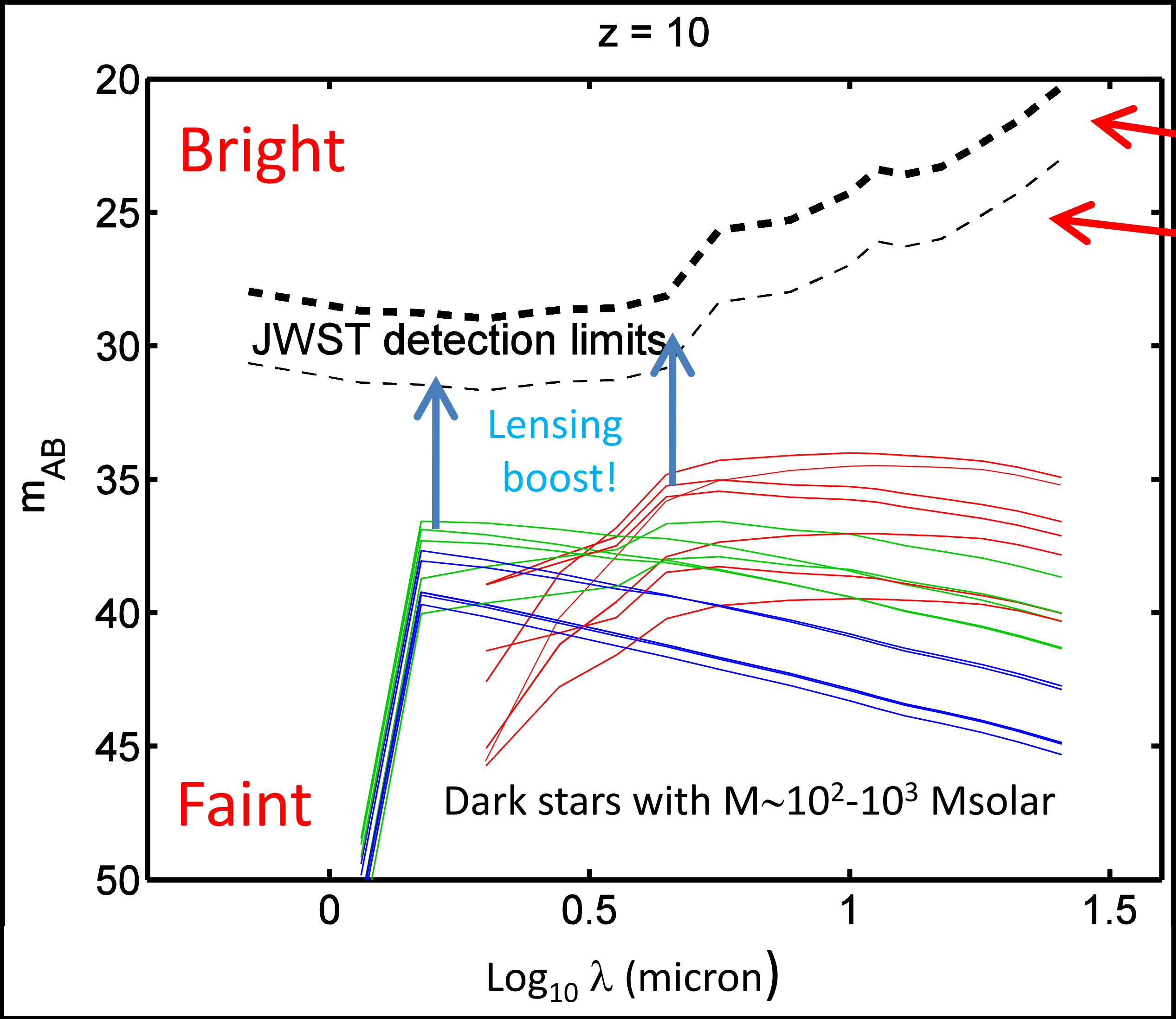


Bad news:

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

Zackrisson et al. 2010, ApJ 717, 257

Gravitational lensing



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

Zackrisson et al. 2010, ApJ 717, 257

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

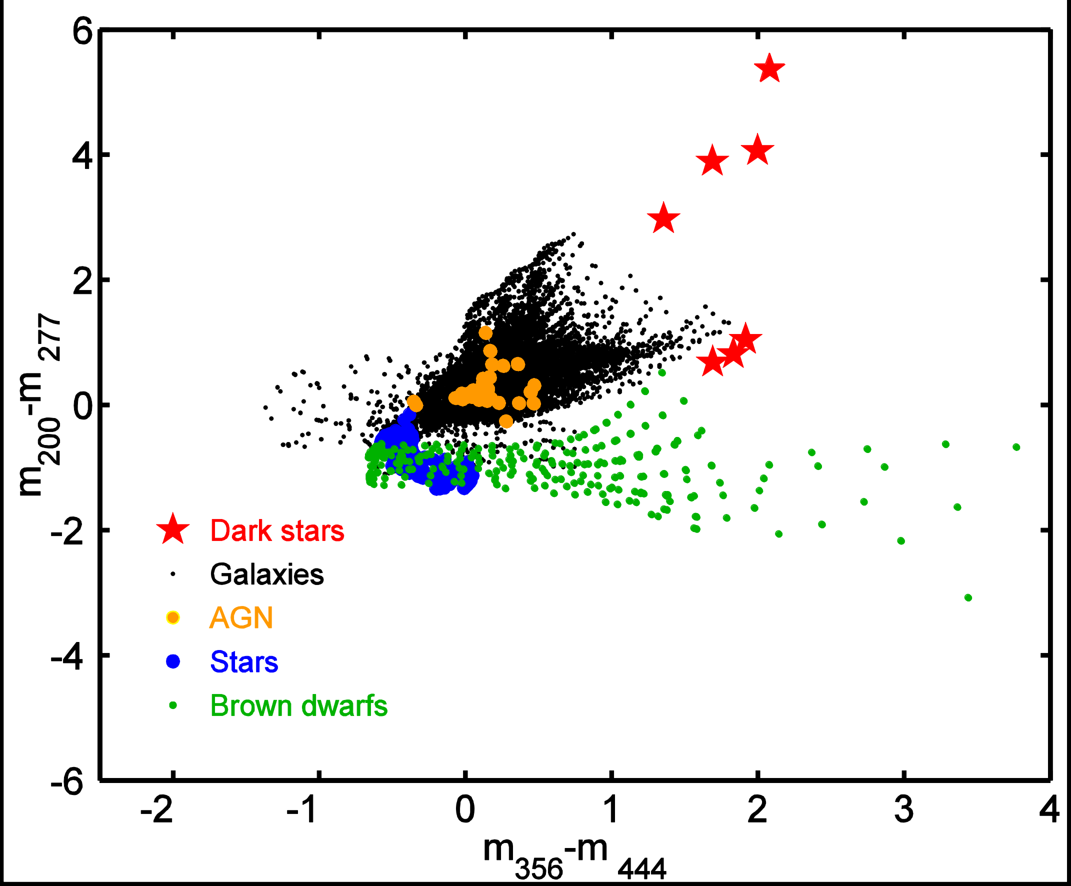
Can Palantir detect z ≈ 10 dark stars?

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 this may be ***the only way*** to detect these objects

How will we find them?

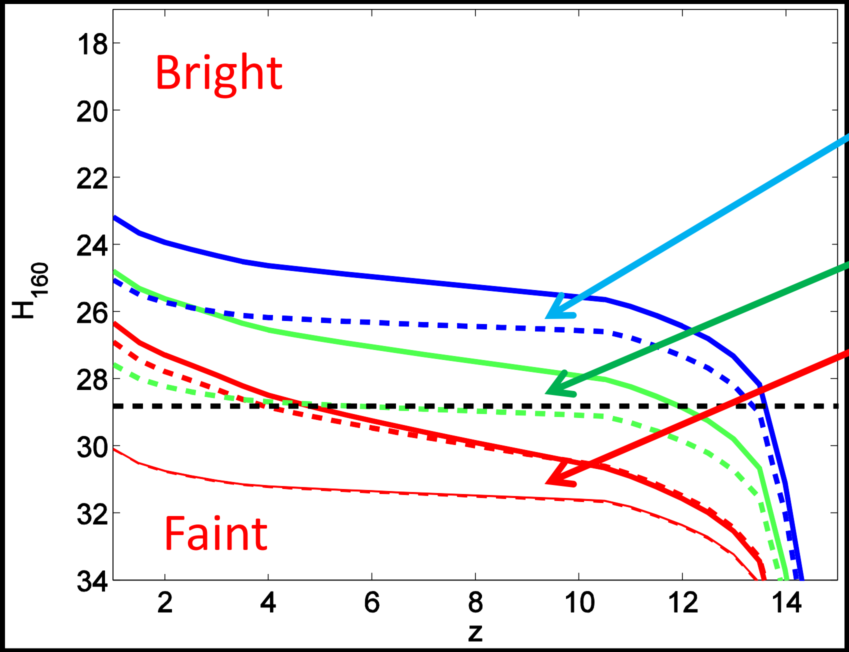


Zackrisson et al. 2010, ApJ 717, 257

Low-temperature dark stars at $z \approx 10$ 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 (see talk by Spolyar)
- 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!

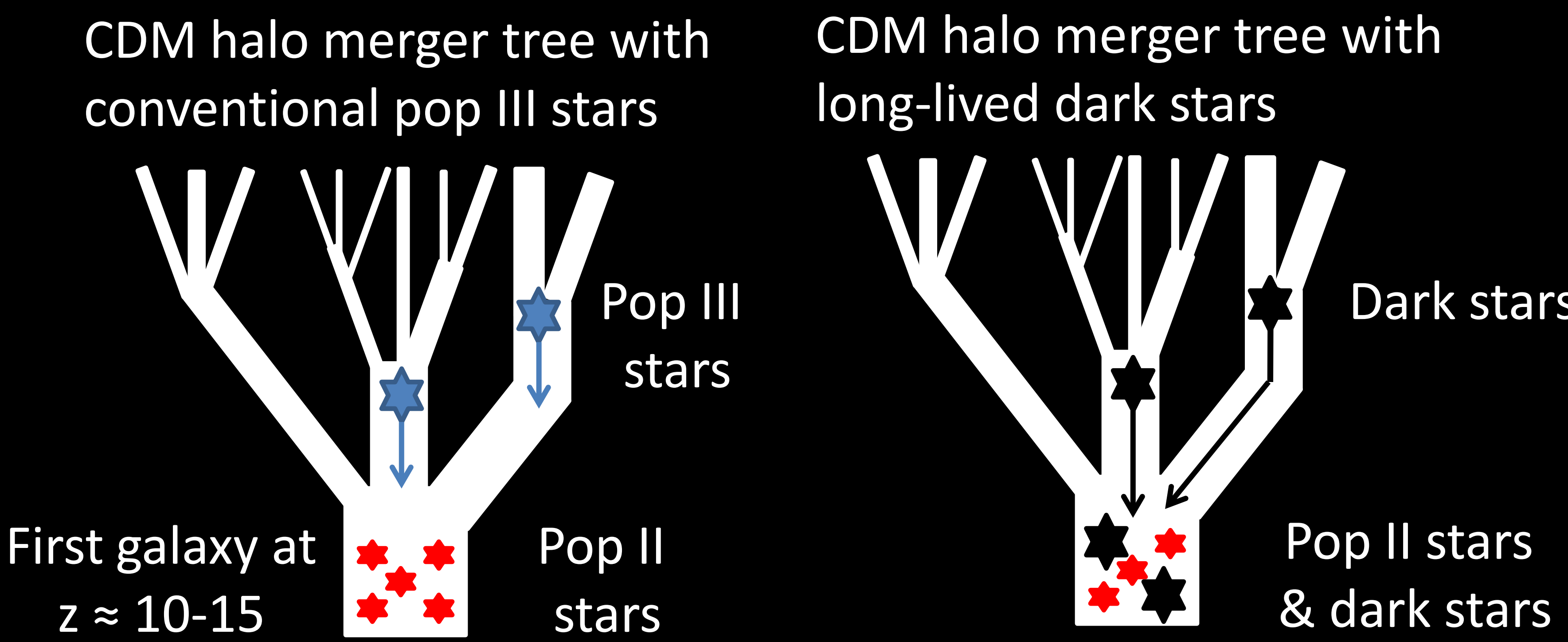
10^6 Msolar dark stars

10^5 Msolar dark stars

HST WFC3 detection limit

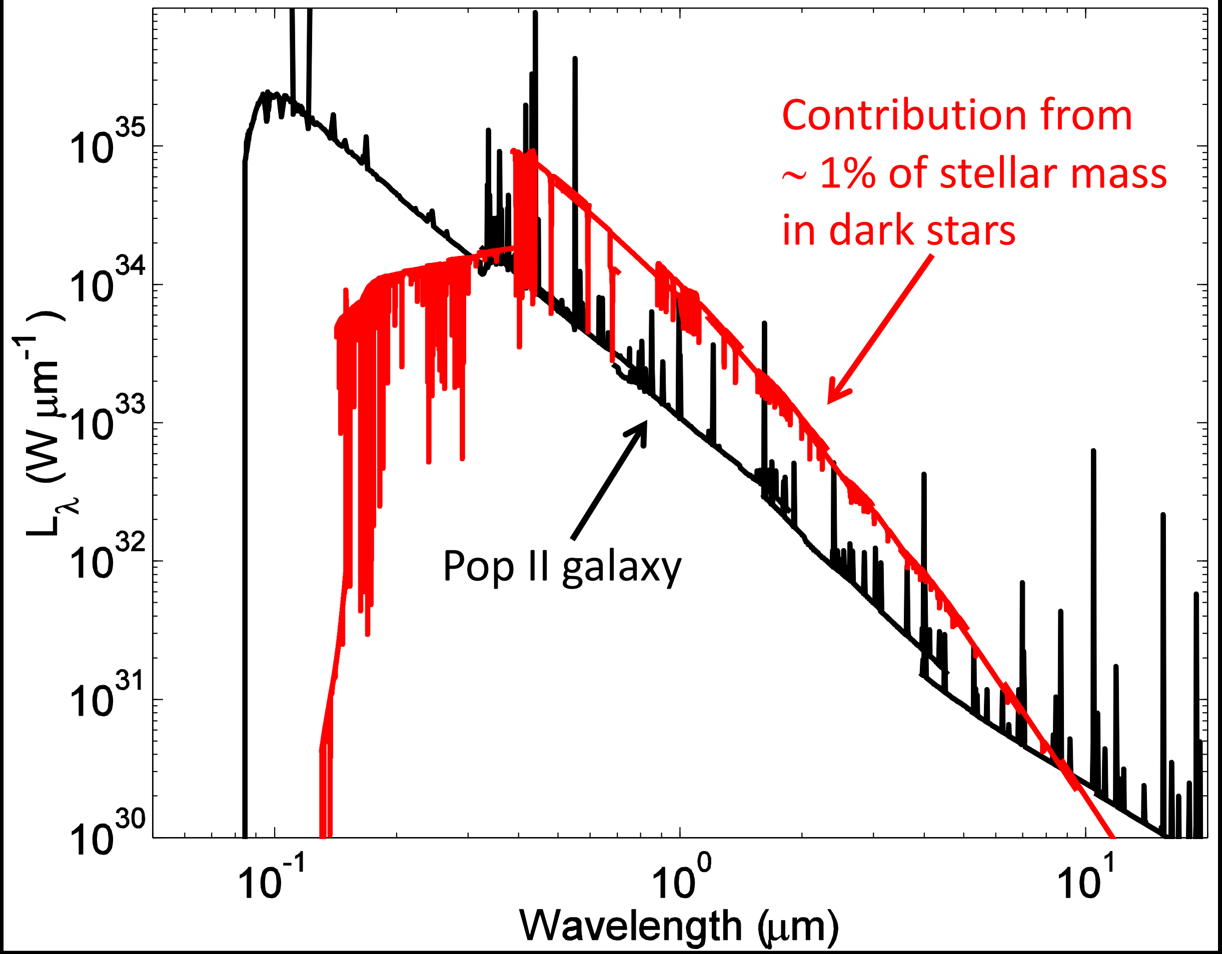
Zackrisson et al. 2010, MNRAS, in press (arXiv1006.0481)

Dark stars in the first galaxies I



Long-lived dark stars may accumulate inside the first galaxies → "dark star galaxy" (Zackrisson et al. 2010, ApJ, 717, 257)

Dark stars in the first galaxies II



Zackrisson et al. 2010, ApJ 717, 257

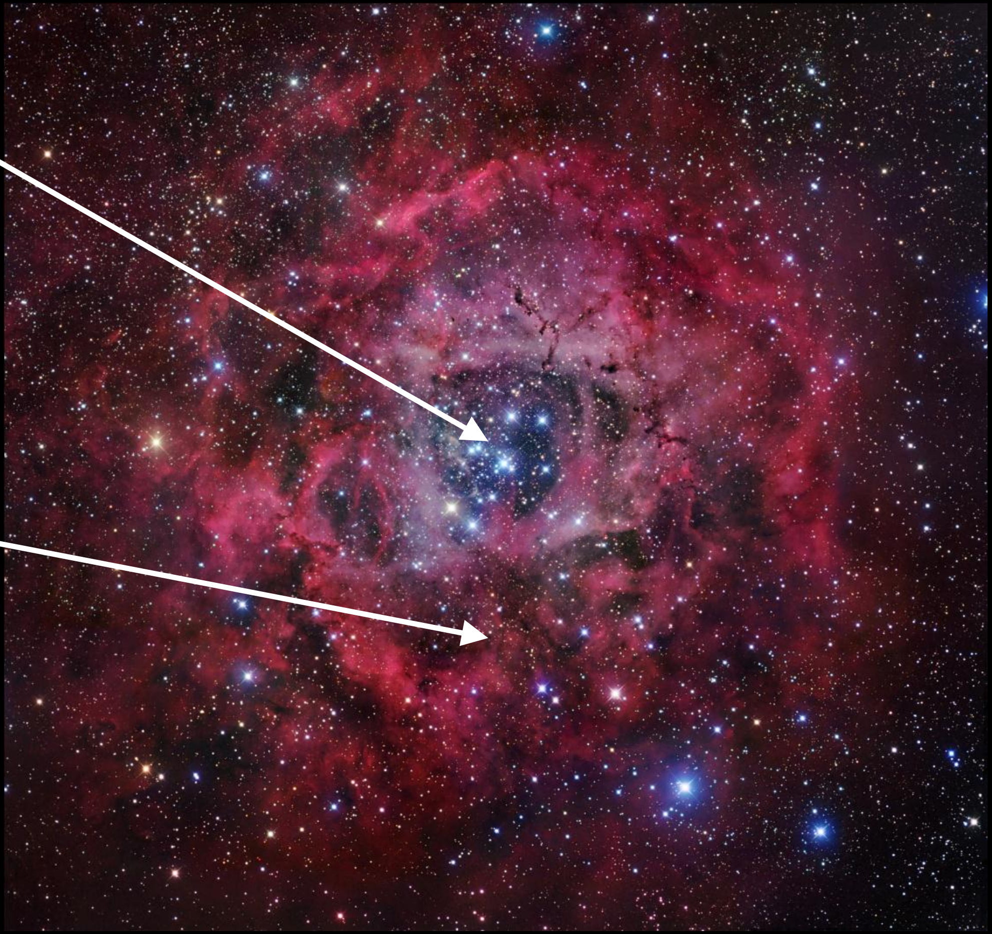
Long-lived ($\tau \sim 10^8$ yr) dark stars may produce telltale signatures in the spectra of the first galaxies

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

The HII regions of dark stars I

Young stars

Photoionized gas

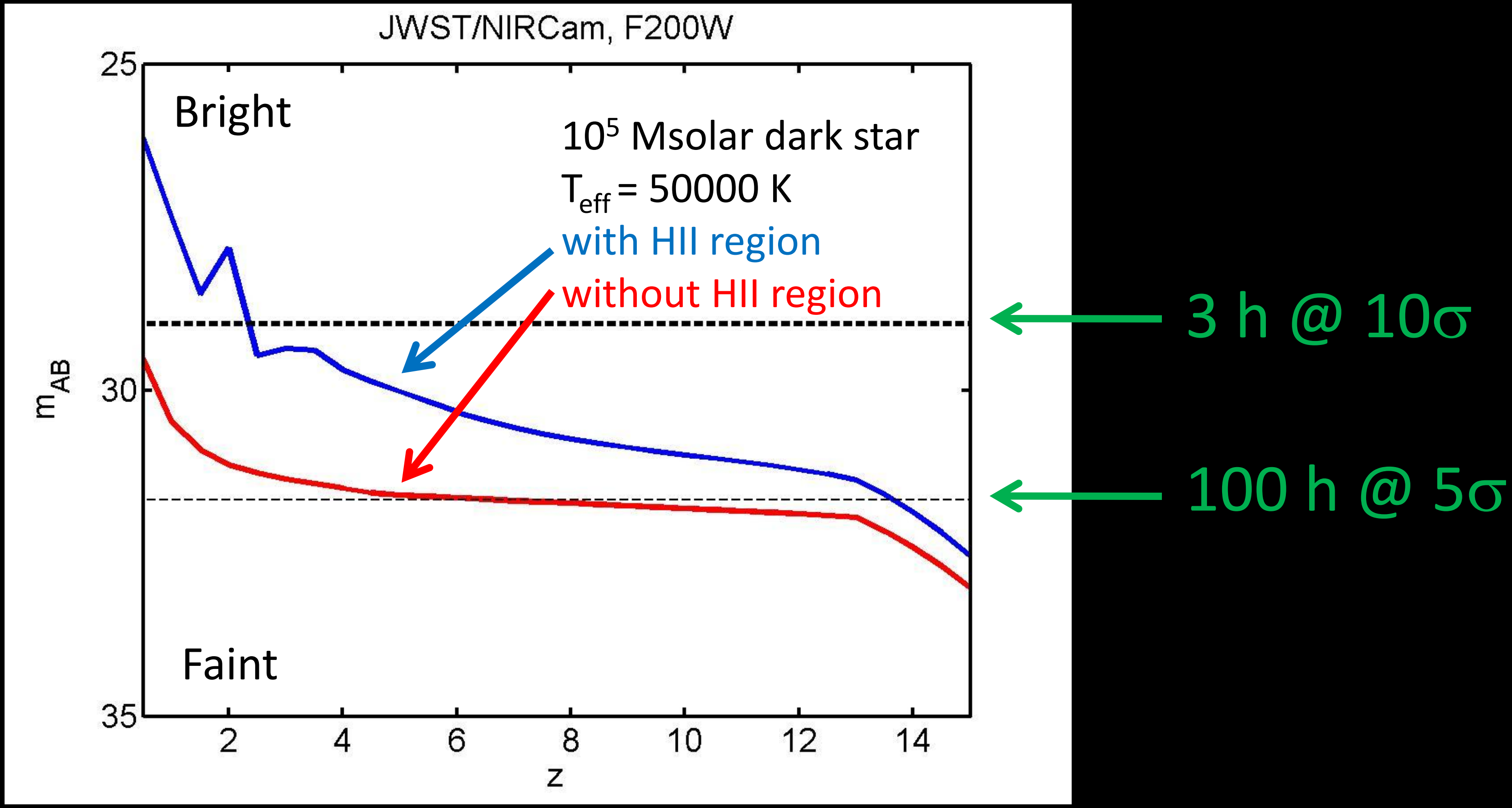


The nebula can be much brighter than the stars!

HII region around a young star cluster

The HII regions of dark stars II

The hottest (T_{eff} > 30000 K) dark stars should be surrounded by bright HII regions → Substantially boosted HST/JWST fluxes



Zackrisson et al., in preparation

Summary

- The detection of dark stars would confirm that CDM is in the form of self-annihilating WIMPs
- Dark stars with $M<10^3$ Msolar can be detected with JWST at $z \approx 10$ through lensing clusters
- Some "Supermassive dark stars" are already constrained by existing HST/VLT observations
- Long-lived dark stars may congregate inside the first galaxies $\rightarrow$ telltale spectral signature
- Dark star model spectra and JWST fluxes available at: www.astro.su.se/~ez