Population III Stars and Direct Collapse Black Holes with the *Roman Space Telescope*

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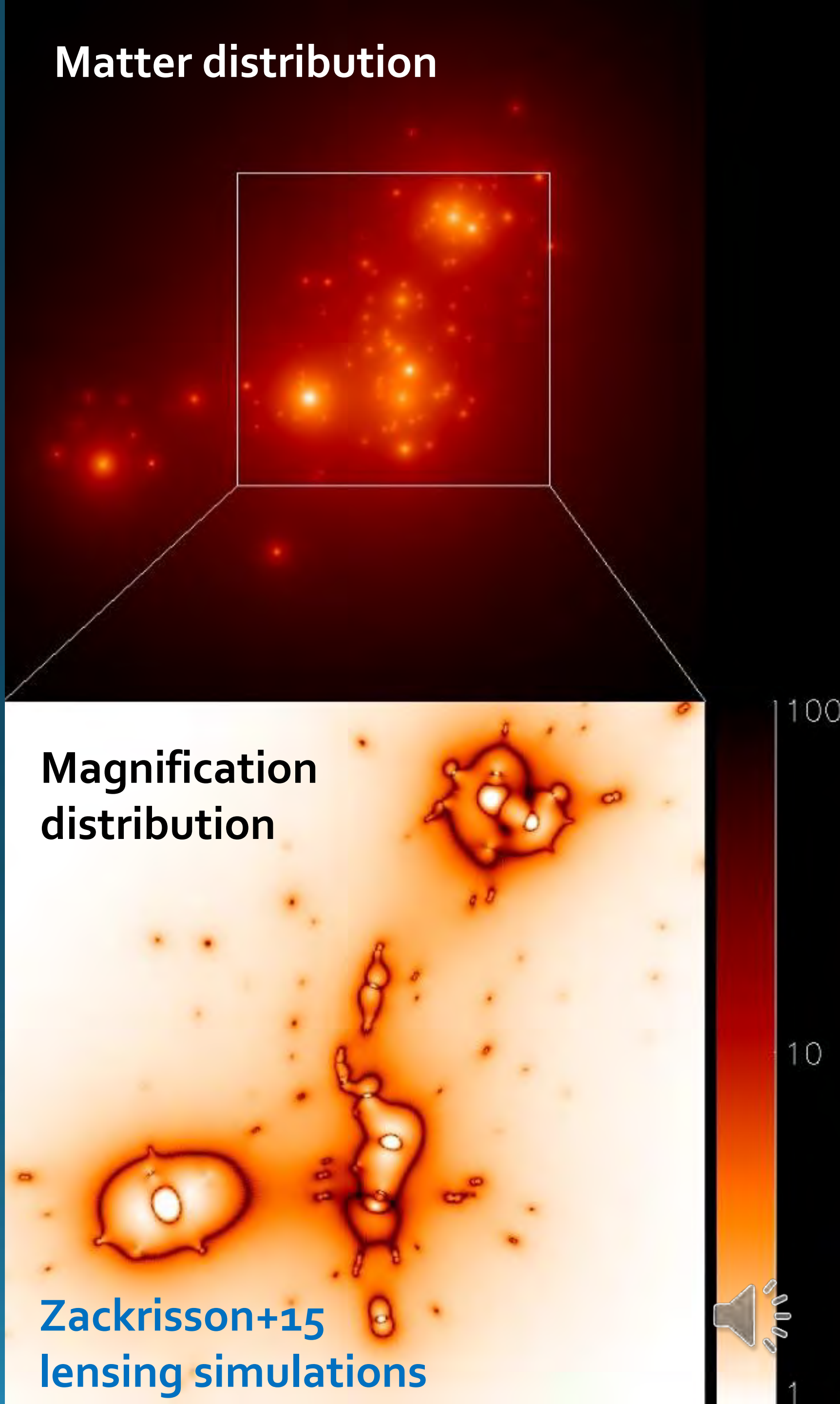
Fantastic beasts of the high-redshift Universe

- Population III stars
- Population III galaxies
- Supermassive Population III stars
- Direct collapse black holes
- Population III supernovae
- Population III gamma-ray bursts
- Hybrid Population III+II galaxies

Not covered in this talk

Hunting gear: Gravitational lensing

- Many species of high-z exotica too faint for detection, even with JWST, without significant gravitational magnification (μ)
- Probability of high magnifications: $P(>\mu) \propto \mu^{-2} \rightarrow$ **Extreme magnfications (μ>100) are very rare**
- High magnification not just produced by galaxy clusters, but also by individual field galaxies, galaxy groups, groups behind groups etc.
- The large survey area of *Roman* means lots of high-magnification sightlines $\rightarrow$ *Roman* can detect some types of objects that JWST cannot

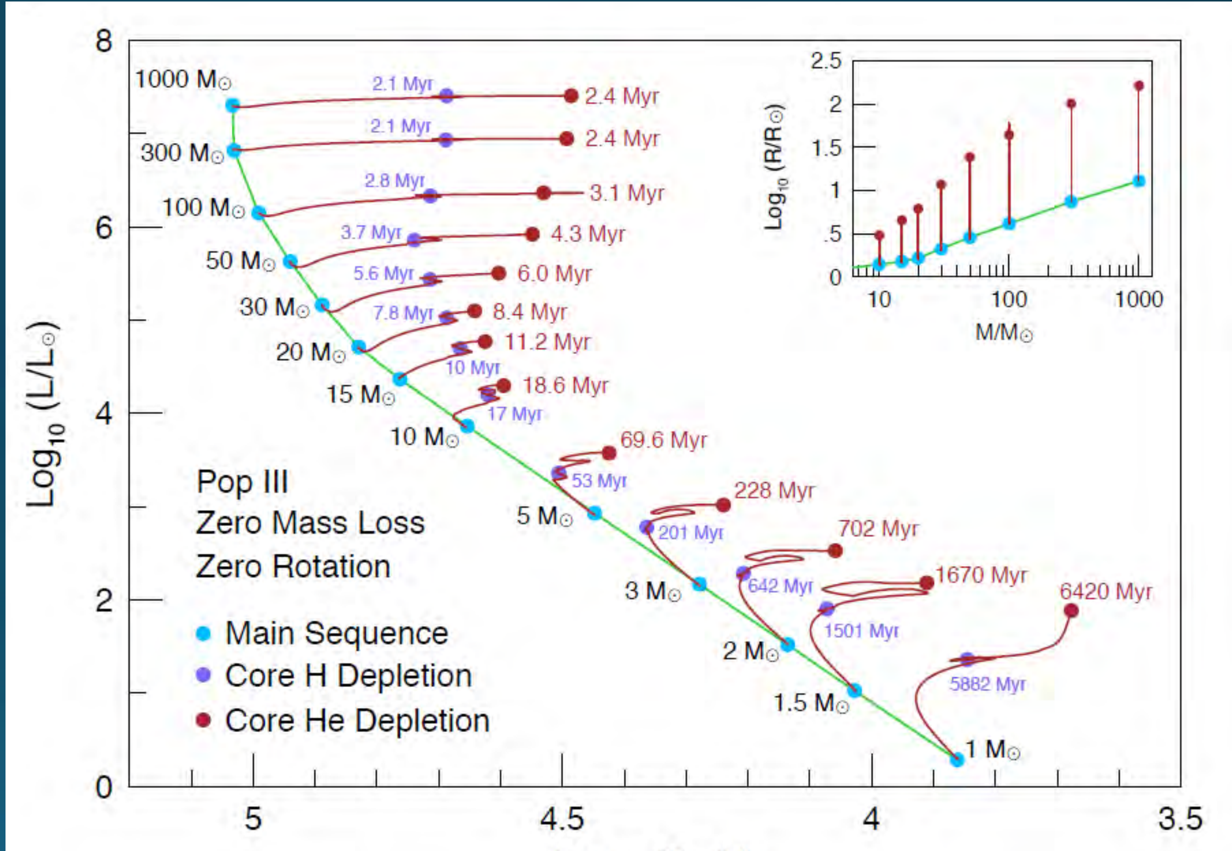


Population III stars

- The very first generation of stars – started forming in minihalos, before the first galaxies
- Formed from gas of primordial composition (H,He + trace amounts of Li; metallicity $Z \approx 0$)
- Produces the metals required for the metal-enriched stars seen today (Pop II & I)
- Cooling properties of $Z \approx 0$ gas $\rightarrow$ These stars should be ***very massive***, ***hot (~10^5 K)*** and ***short-lived***.
- Characteristic mass expected to be ~10^1-10^3 $M_\odot$ (but predictions are shaky)

Lensed Pop III stars at high redshifts

- A ≈ 100 Msolar Pop III star has intrinsic AB mag ≈ 38-40 AB mag at z≈10 → Detectable with JWST (or *Roman*) at magnification $\mu \sim 10^4$
- Windhorst+18: $\mu \sim 10^4$ Pop III stars (or the accreting black hole they leave behind) may be detectable due to caustic crossings in galaxy cluster fields
- Any deep *Roman* high-z photometric survey covering strongly-lensed fields could continue this effort, but JWST is likely better for this



Windhorst+18

Population III galaxies

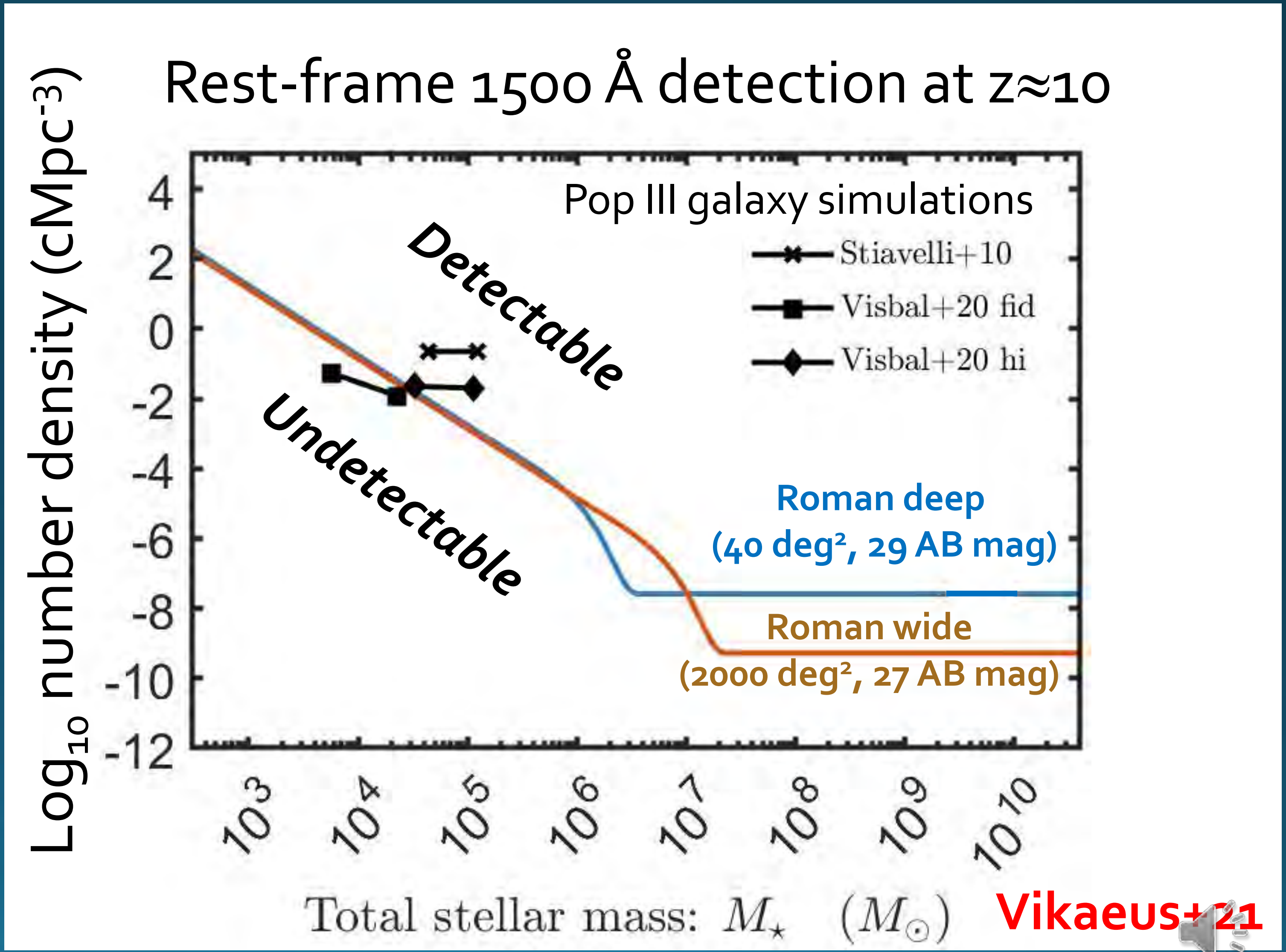
- Galaxy definition (in the high-z community): Stellar population with its own dark matter halo, sufficiently massive to sustain prolonged star formation → Minimum dark halo mass ~10^7-10^8 $M_\odot$
- Combined stellar mass in Pop III stars may be ~10^3-10^5 $M_\odot$
  (Note: the mass of a star cluster!)
- Pop III galaxies are brighter than individual Pop III stars (hence likely easier to detect) but very rare

Credit: ESO/M. Kornmesser

Detecting lensed Pop III galaxies with *Roman*

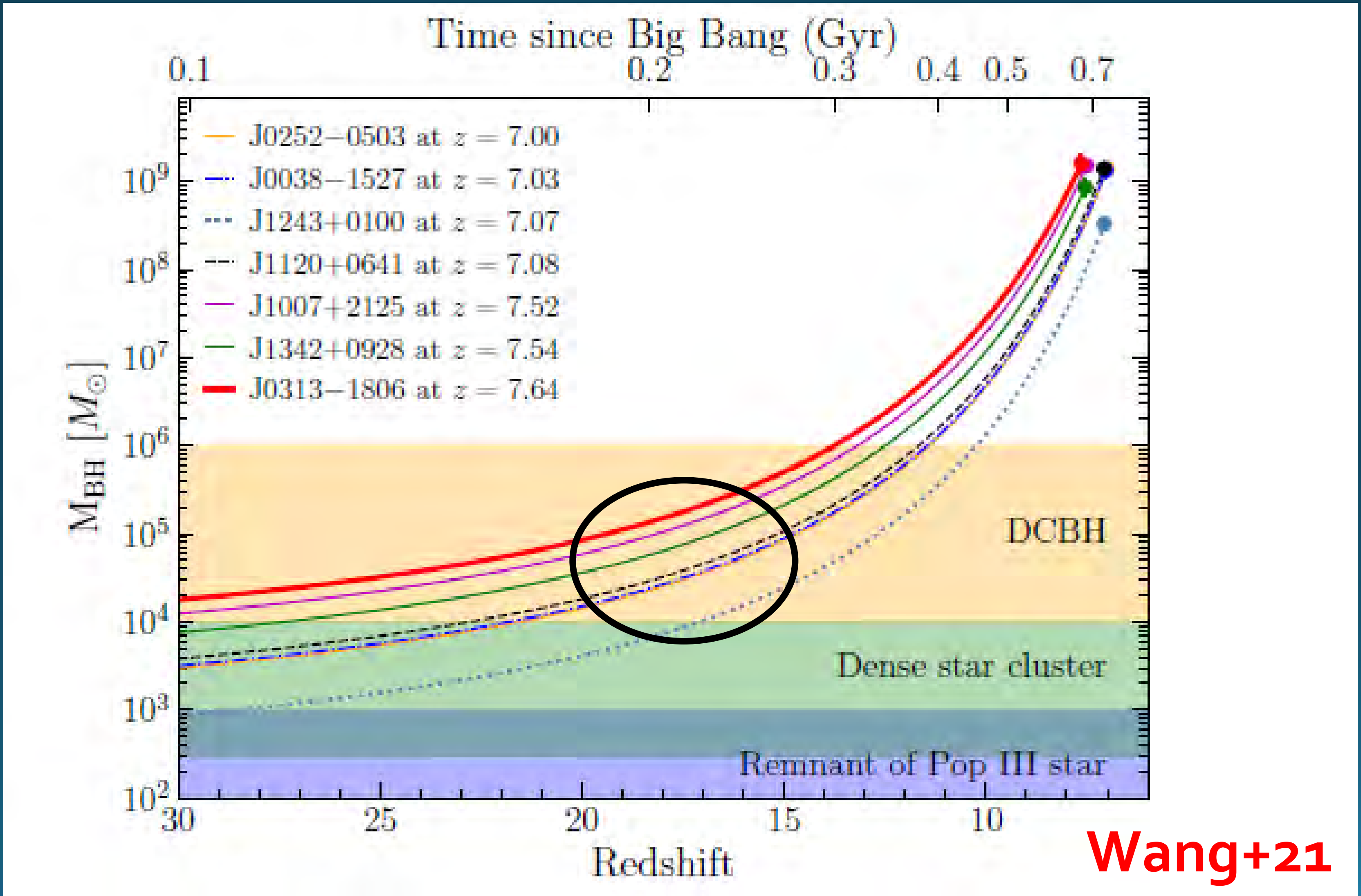
- Detection prospects set by combination of Pop III galaxy number density and Pop III galaxy mass

- <u>Vikaeus+21:</u>
  Some (not all) Pop III simulations predict that a small number of Pop III galaxies may turn up in *Roman* photometric surveys



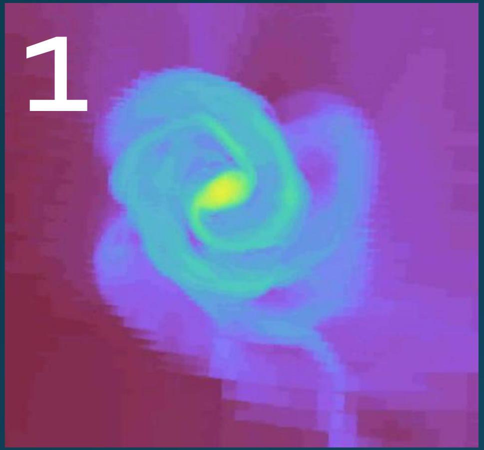
Vikaeus+21

Where do the first supermassive black holes come from?

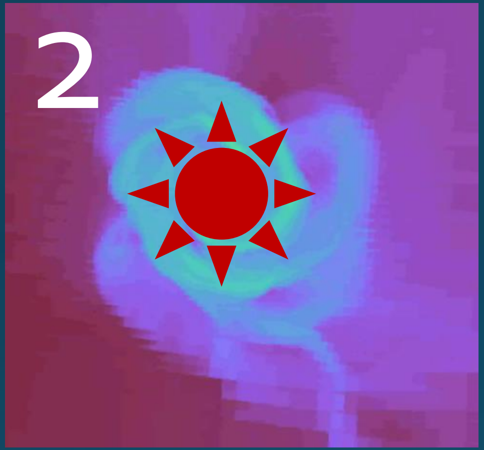


Wang+21

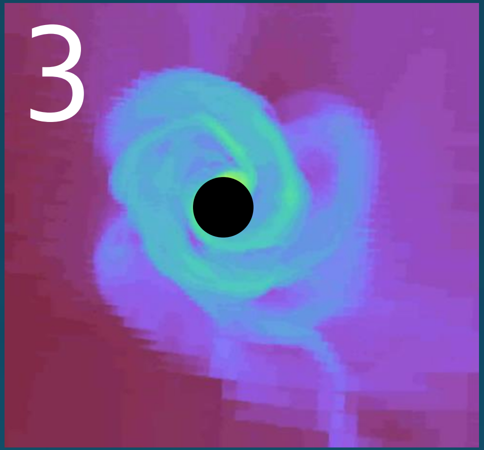
Supermassive Pop III stars and Direct Collapse Black Holes



Extreme accretion (0.1-$1\ M_\odot$/yr) of zero-metallicity gas into center of starless HI-cooling halo



Formation of supermassive Pop III star ($\sim 10^5\ M_\odot$) with very short lifetime ($\sim 10^5$ yr)



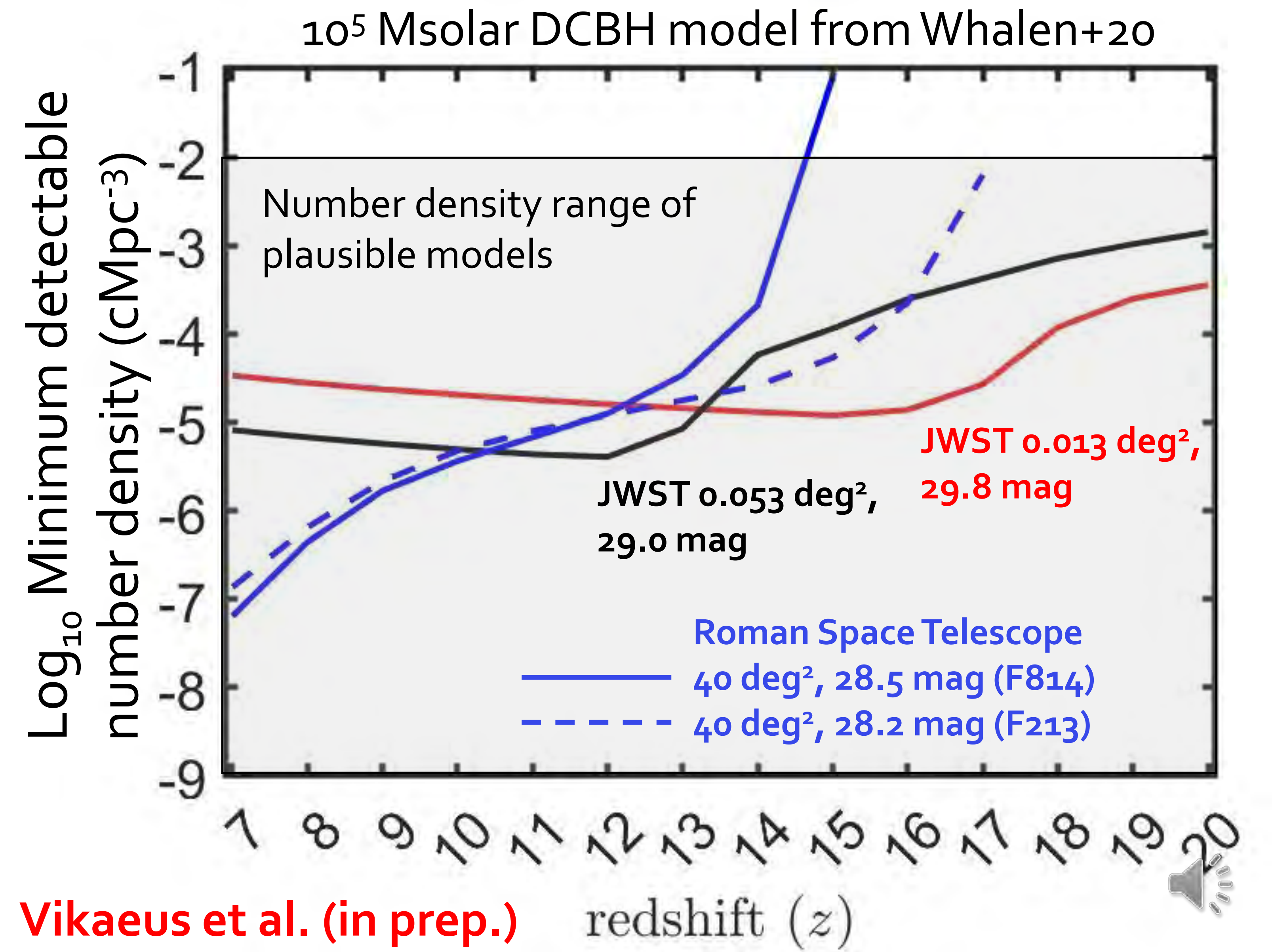
Direct collapse to $\sim 10^5\ M_\odot$ black hole without supernova

Accretion radiation onto black hole reprocessed by surrounding gas → More long-lived ($\sim 10^7$ yr) light source than the supermassive Pop III star

See Volonteri+21, Haemmerlé+20 , Woods+19 for recent reviews

Detecting Direct Collapse Black Holes

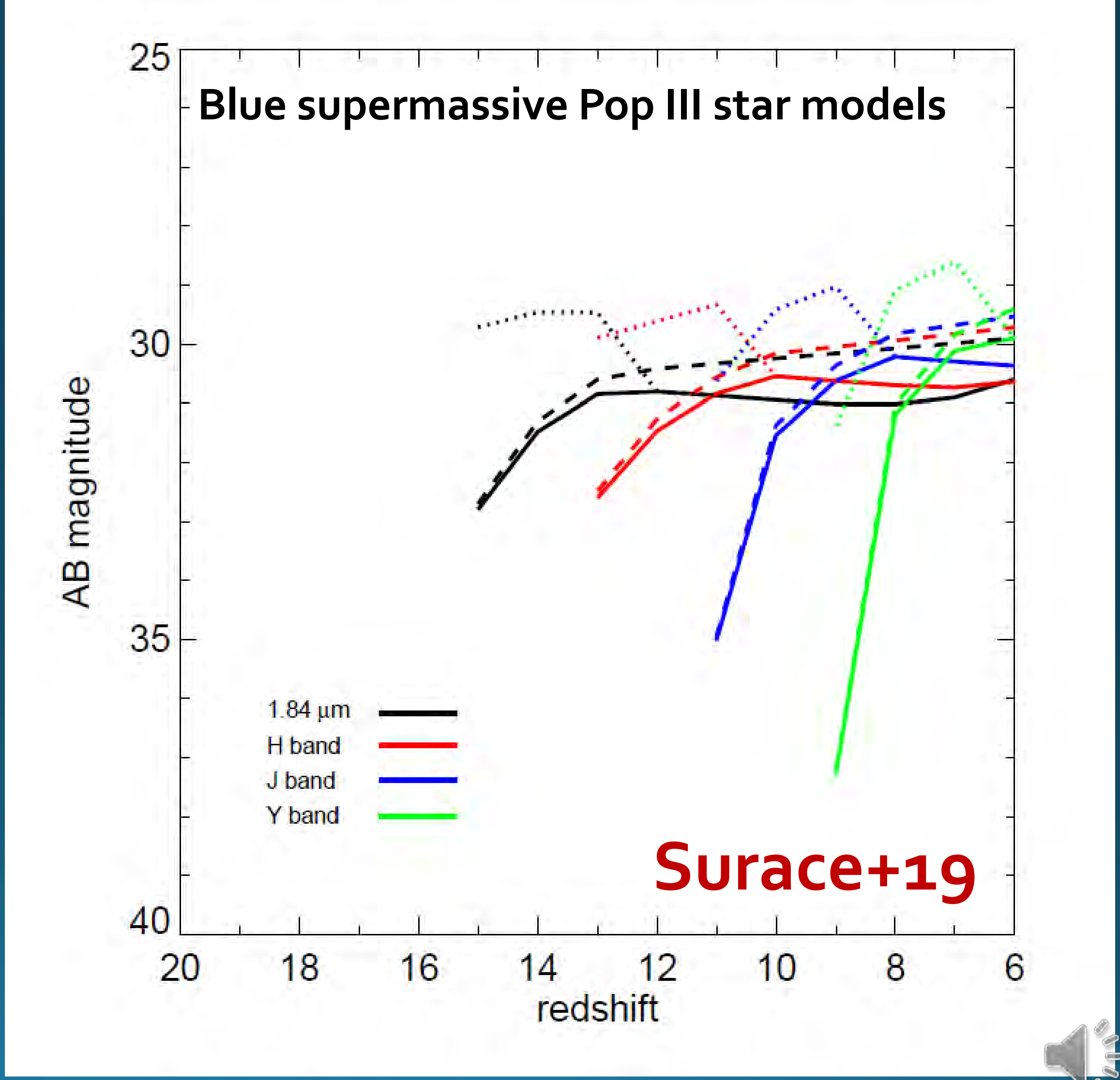
- DCBH comoving number density and typical formation redshift highly uncertain
- DCBHs are intrinsically "bright" (29.5 AB mag at z≈10 with *Roman* F184) → Not too extreme lensing required
- *Roman* does better than JWST at z<10



Vikaeus et al. (in prep.)

Detecting Supermassive Pop III stars

- Unlensed 30-31 AB mag at z≈10 and very short-lived (~10^5 yr) → Production rate would need to be very high for lensed detection
- RST 40 deg², 28.5 AB mag survey can probe production rates ≈10 times lower than JWST



Summary

- Due to the large field of view of the Roman Space Telescope, it becomes possible to detect classes of lensed high-z objects that are out of reach of both JWST and Euclid

- Lensed Pop III stars, supermassive Pop III stars and Pop III galaxies at high magnification are all potentially detectable with *Roman*, but the prospects are model-dependent

- Direct collapse black holes are both intrinsically bright and long-lived → Best detection prospects