How can SPHEREx select the best lensing clusters for JWST?

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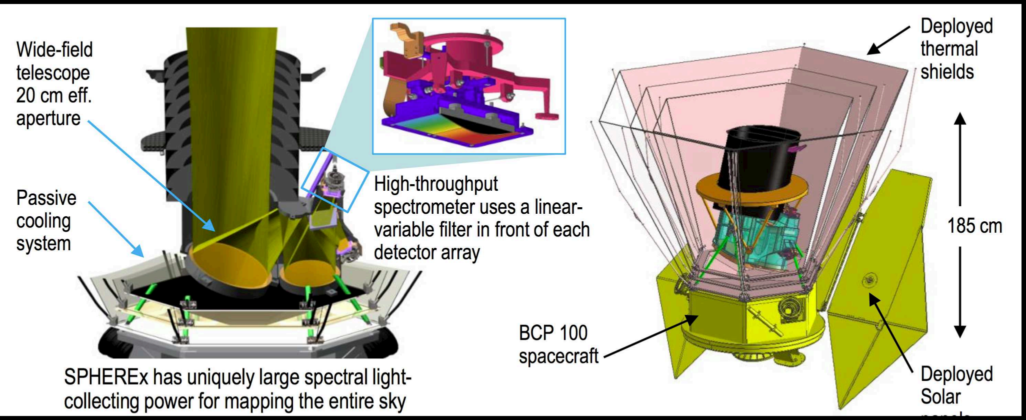

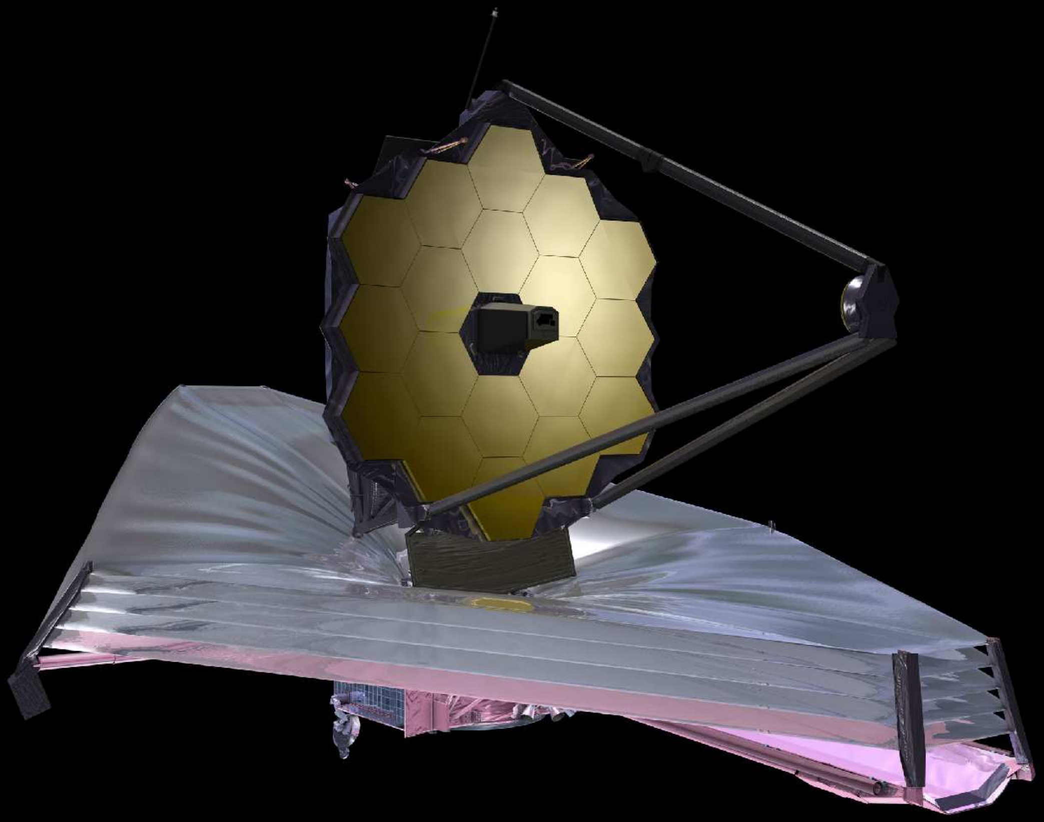

Talk at the SPHEREx Community Workshop, Jan. 29–31, 2018 Center for Astrophysics (Cambridge, MA)

ON THE OBSERVABILITY OF INDIVIDUAL POPULATION III STARS AND THEIR STELLAR-MASS BLACK HOLE ACCRETION DISKS THROUGH CLUSTER CAUSTIC TRANSITS

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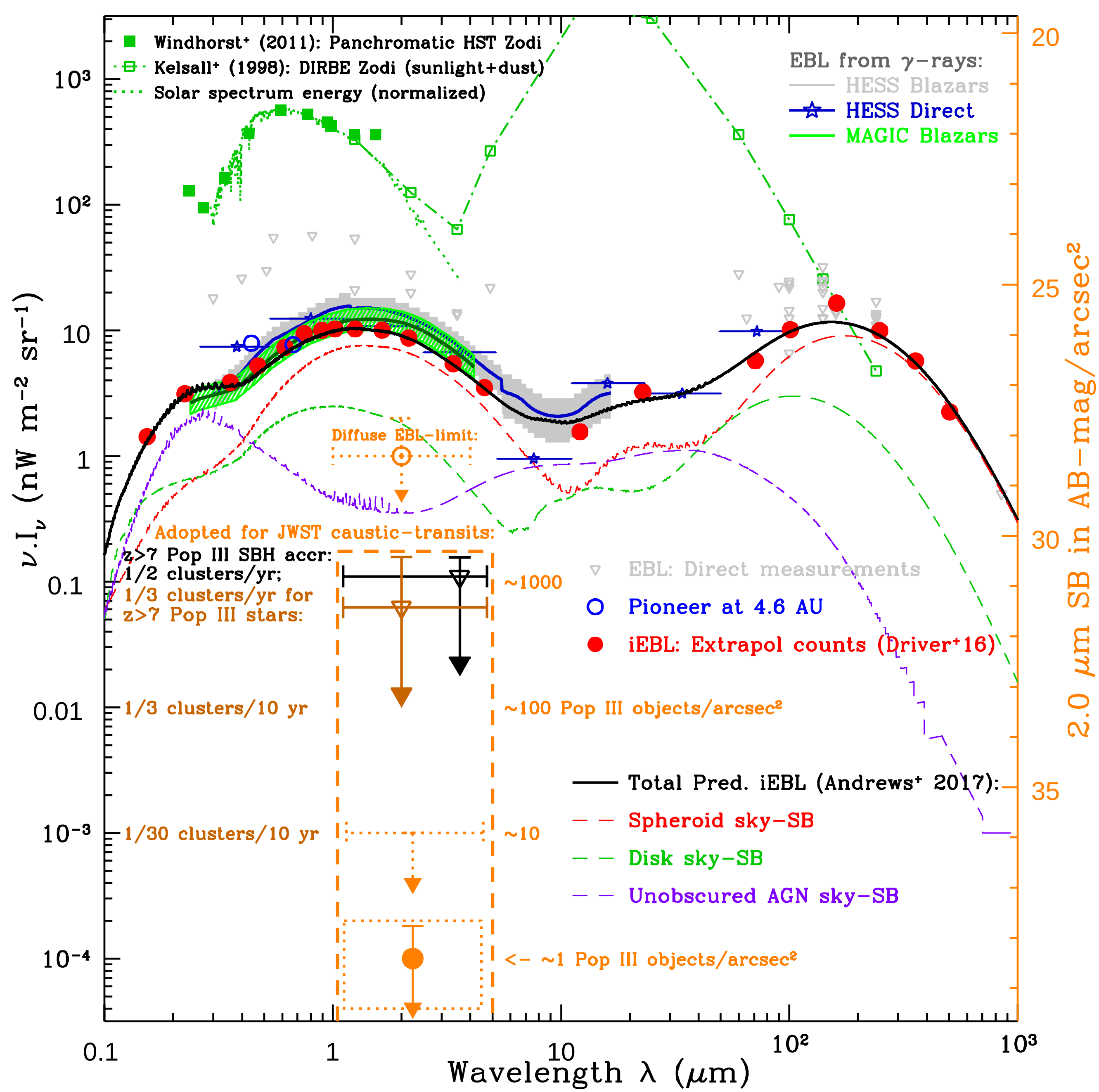
Abstract

We summarize panchromatic Extragalactic Background Light data to place upper limits on the integrated near-infrared surface brightness (SB) that may come from Population III stars and possible accretion disks around their stellar-mass black holes (BHs) in the epoch of First Light, broadly taken from $z\simeq7$–17. Theoretical predictions and recent near-infrared power-spectra provide tighter constraints on their sky-signal. We outline the physical properties of zero metallicity Population III stars from `MESA` stellar evolution models through helium-depletion and of BH accretion disks at $z\gtrsim7$. We assume that second-generation non-zero metallicity stars can form at higher multiplicity, so that BH accretion disks may be fed by Roche-lobe overflow from lower-mass companions. We use these near-infrared SB constraints to calculate the number of caustic transits behind lensing clusters that the James Webb Space Telescope and the next generation ground-based telescopes may observe for both Population III stars and their BH accretion disks. Typical caustic magnifications can be $\mu\simeq10^4$–10^5, with rise times of hours and decline times of $\lesssim1$ year for cluster transverse velocities of $v_T\lesssim1000$ km s^{-1}. Microlensing by intracluster medium objects can modify transit magnifications, but lengthen visibility times. Depending on BH masses, accretion-disk radii and feeding efficiencies, stellar-mass BH accretion-disk caustic transits could outnumber those from Population III stars. To observe Population III caustic transits directly may require to monitor 3–30 lensing clusters to AB$\lesssim$29 mag over a decade.

Keywords: accretion disks — clusters: general — gravitational lensing: strong — infrared: diffuse background — stars: black holes — stars: Population III

Windhorst et al. (2018, ApJS, in press; astro-ph/1802.03584) suggest that JWST (and 25–39 m ground-based telescopes) may detect Pop III stars and their stellar-mass black hole accretion disks *directly* to AB$\lesssim$28–29 mag via caustic transits in the right clusters. SPHEREx has the unique capability to identify just the right clusters.

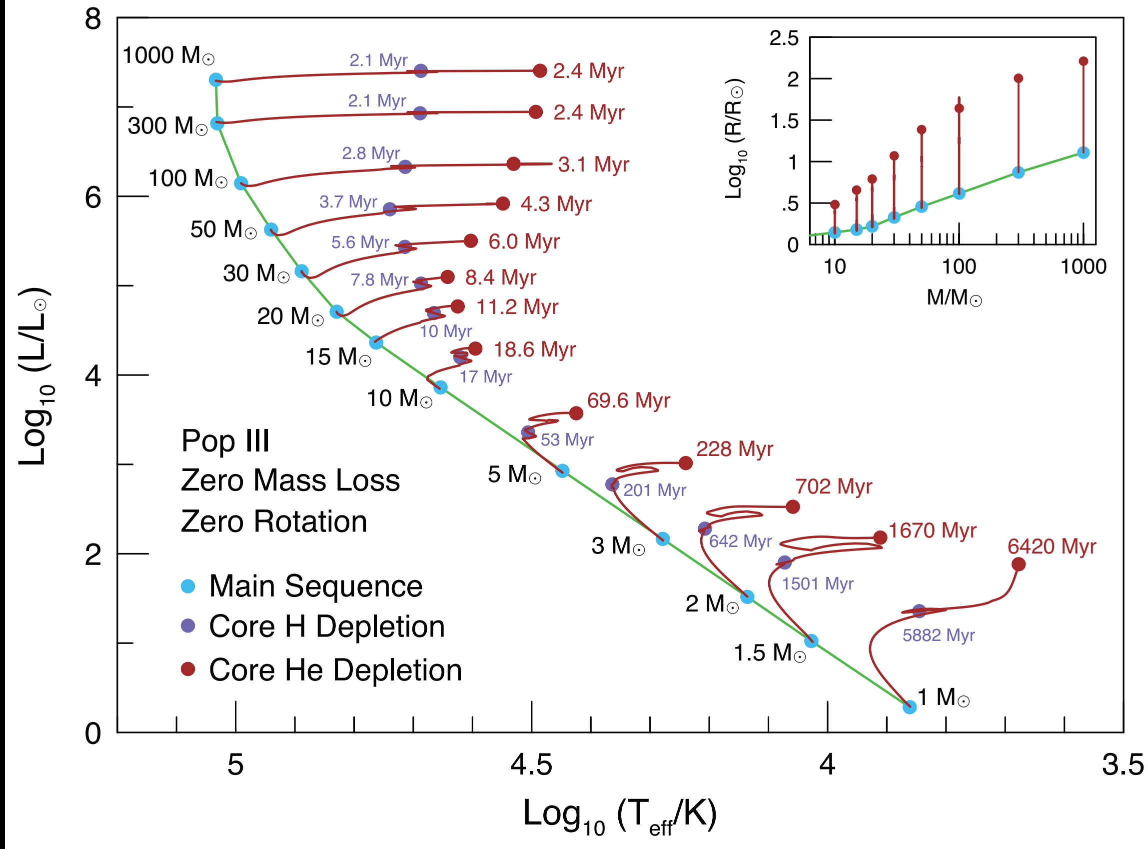


Using EBL constraints of Cappelluti+ (2013), Driver+ (2016), Kashlinsky+ (2012) & Mitchell-Wynne+ (2016), Windhorst+ (2018, ApJS) infer a limit of $\lesssim 0.1$ $nW\ m^{-2}\ sr^{-1}$ to the 1–4 μm diffuse light that may come from:

- 1) Pop III stars at z$\simeq$7–17, and
- 2) Their stellar-mass Black Hole accretion disks.

Depending on the level of diffuse SB from Pop III objects at z$\simeq$7–17, this can render Pop III stars or their BH accretion disks visible to JWST (and 25–39 m ground-based telescopes) at AB$\lesssim$28–29 mag.

- This requires using the best lensing clusters and monitoring caustic transits.
  - SPHEREx has the unique capability to identify just the right clusters.



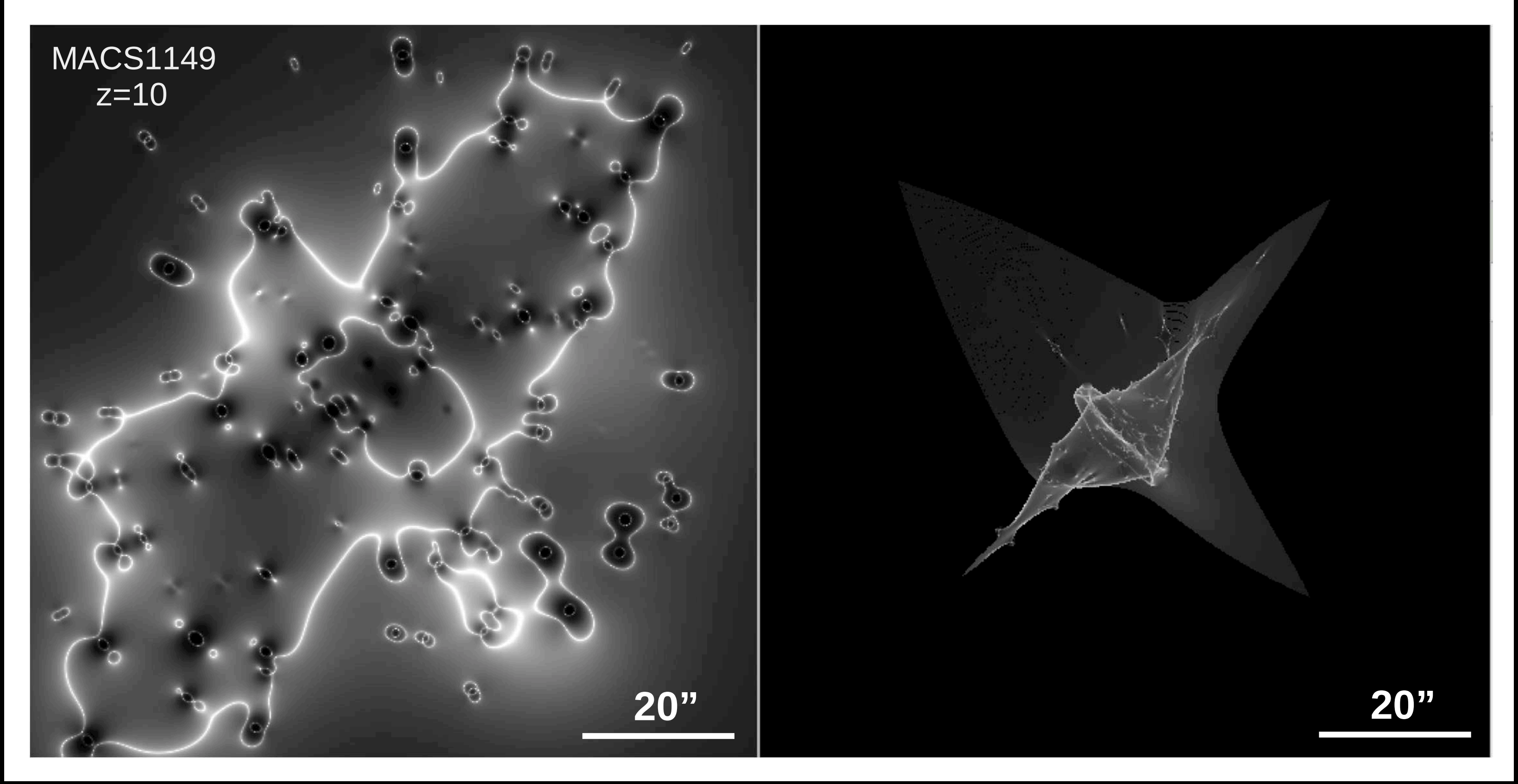
Windhorst et al. (2018) use:

- MESA stellar evolution models for z=0$Z_\odot$ Pop III stars [LEFT]: ZAMS and RGB–AGB Pop III stars with M$\gtrsim$20 $M_\odot$ can be detected at AB$\lesssim$28-29 mag via caustic transits for magnifications of $\mu\simeq 10^4$–10^5.
- Multicolor accretion-disk models for stellar-mass black holes [RIGHT]: For M_{BH} $\simeq$5–700 $M_\odot$, accretion disks radii and luminosities are similar to those of Pop III AGB stars, when the BH is fed by a Roche lobe-filling lower-mass companion star on the AGB (which live $\gtrsim$10$\times$ longer).

BOTH could thus be detected similarly via cluster caustic transits.

HFF A2744: JWST needs cluster caustic transits to see Pop III objects.

Need clusters with minimal ICL and microlensing near the main caustics.

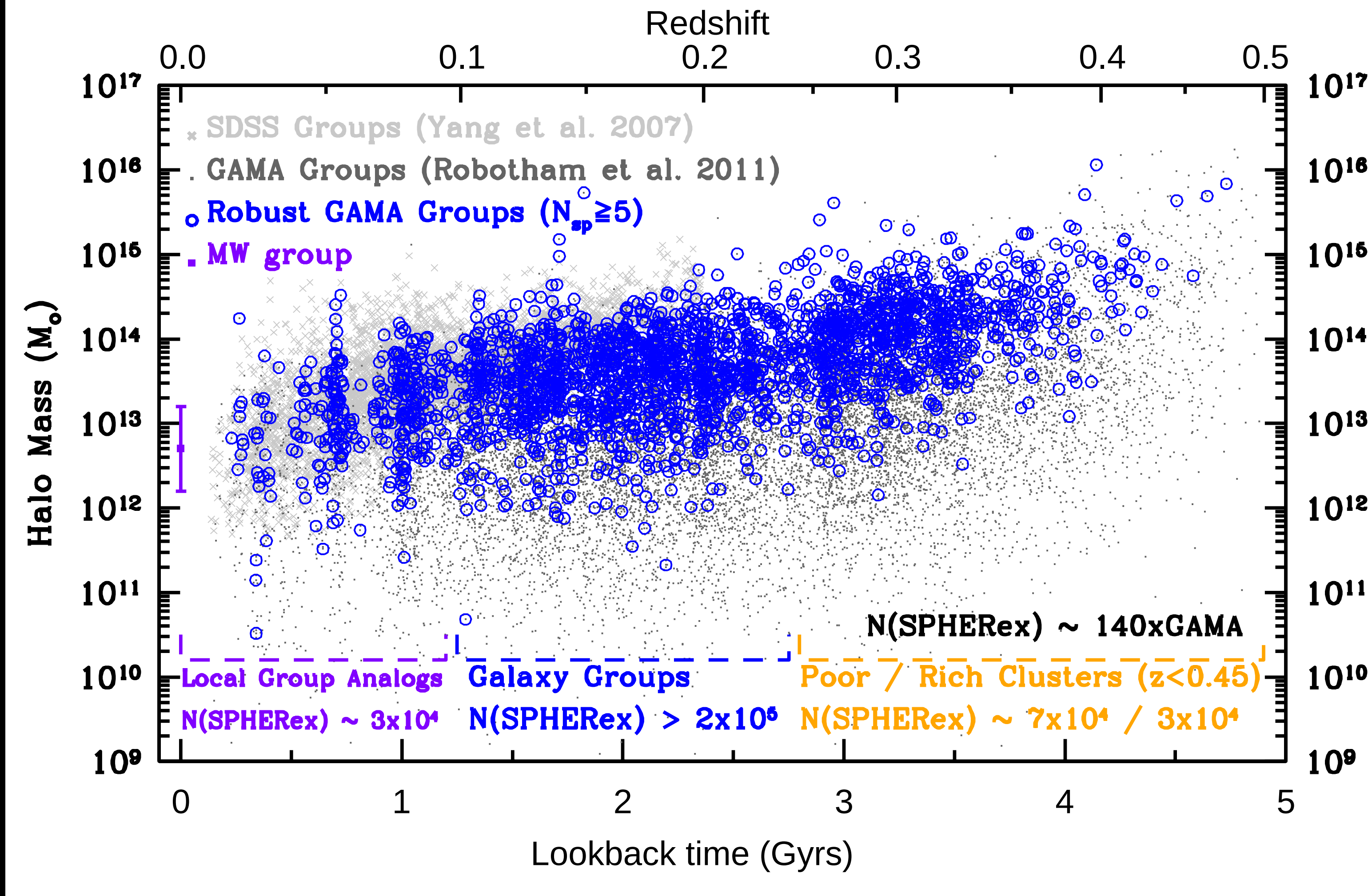


For a source at z=10, example of critical curves for HFF cluster MACS 1149 at z$\simeq$0.4 [LEFT], and its main cluster caustics [RIGHT].

- Typical transverse cluster (sub-component) velocities can be $v_T \lesssim$1000 km/s (Kelly$^+$ astro-ph/1706.10279; Windhorst$^+$ astro-ph/1801.03584).

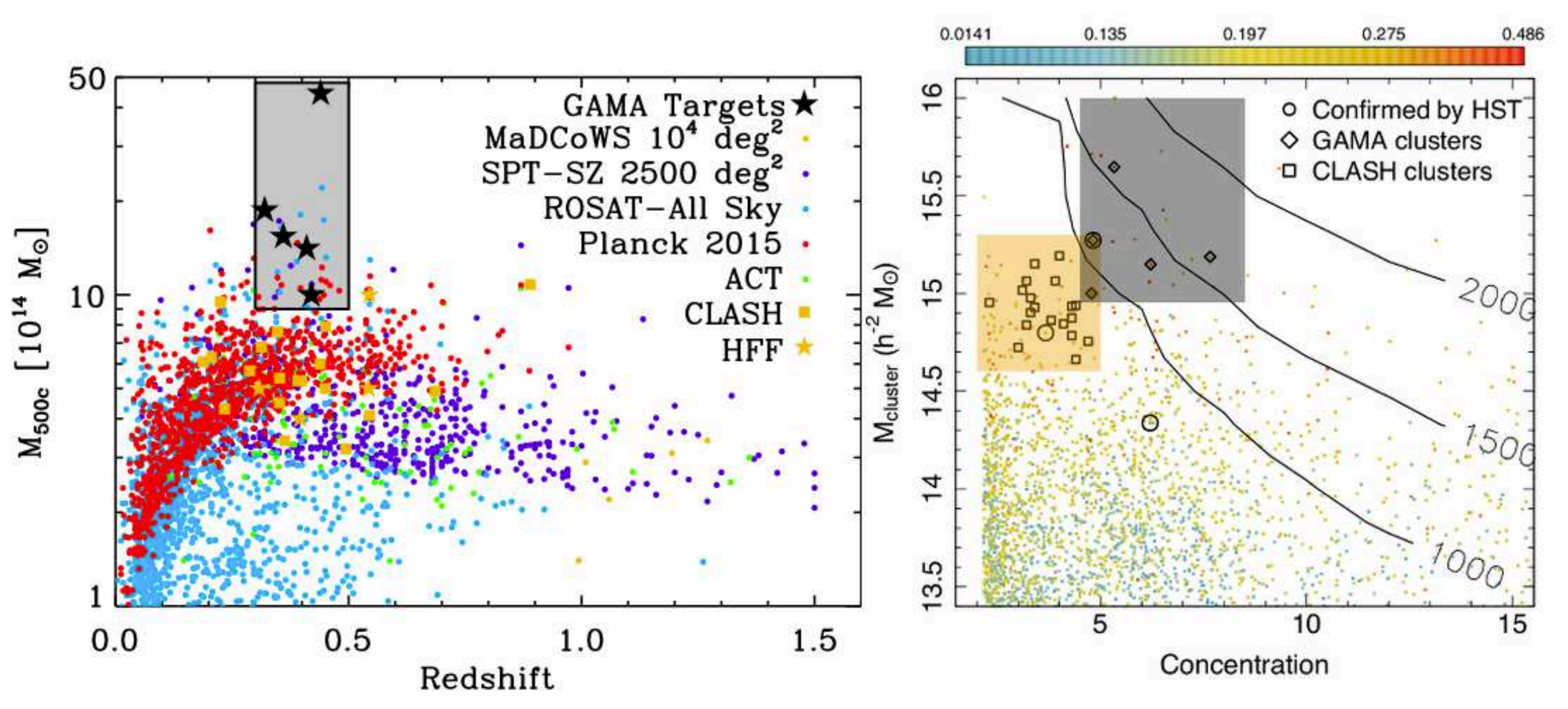
- Main caustic magnification $\mu \simeq 10\ (\mathrm{d}_{caustic}/'')^{-1/2}$. *For Pop III objects at z$\gtrsim$7 with 1–30 $R_\odot$, μ can be $\gtrsim 10^4$–10^5 for $\lesssim$1 year!*

- Must use clusters with minimal ICL near the main caustics, since ICL microlensing dilutes the main caustics (Diego$^+$ astro-ph/1706.10281).



- SPHEREx covers ≳100×GAMA area to similar depth at 0.7–4.8 μm.
- SPHEREx *stellar* masses for 3×10^4 Local Group Analogs to z≲0.1, 2×10^5 galaxy groups, 7×10^4 poor and 3×10^4 rich clusters to z≲0.5.
- SPHEREx selects those with *minimal* ICL near the modeled caustics.
- For these clusters, caustic transits observed with JWST at z≳7 will be the easiest to model (minimal ICL!). Only SPHEREX can select those.

SPARE CHARTS



What are the best lensing clusters for JWST to see First Light objects?:

[LEFT] Best lensing clusters vs. ROSAT, Planck, SPT, MaDCoWS.

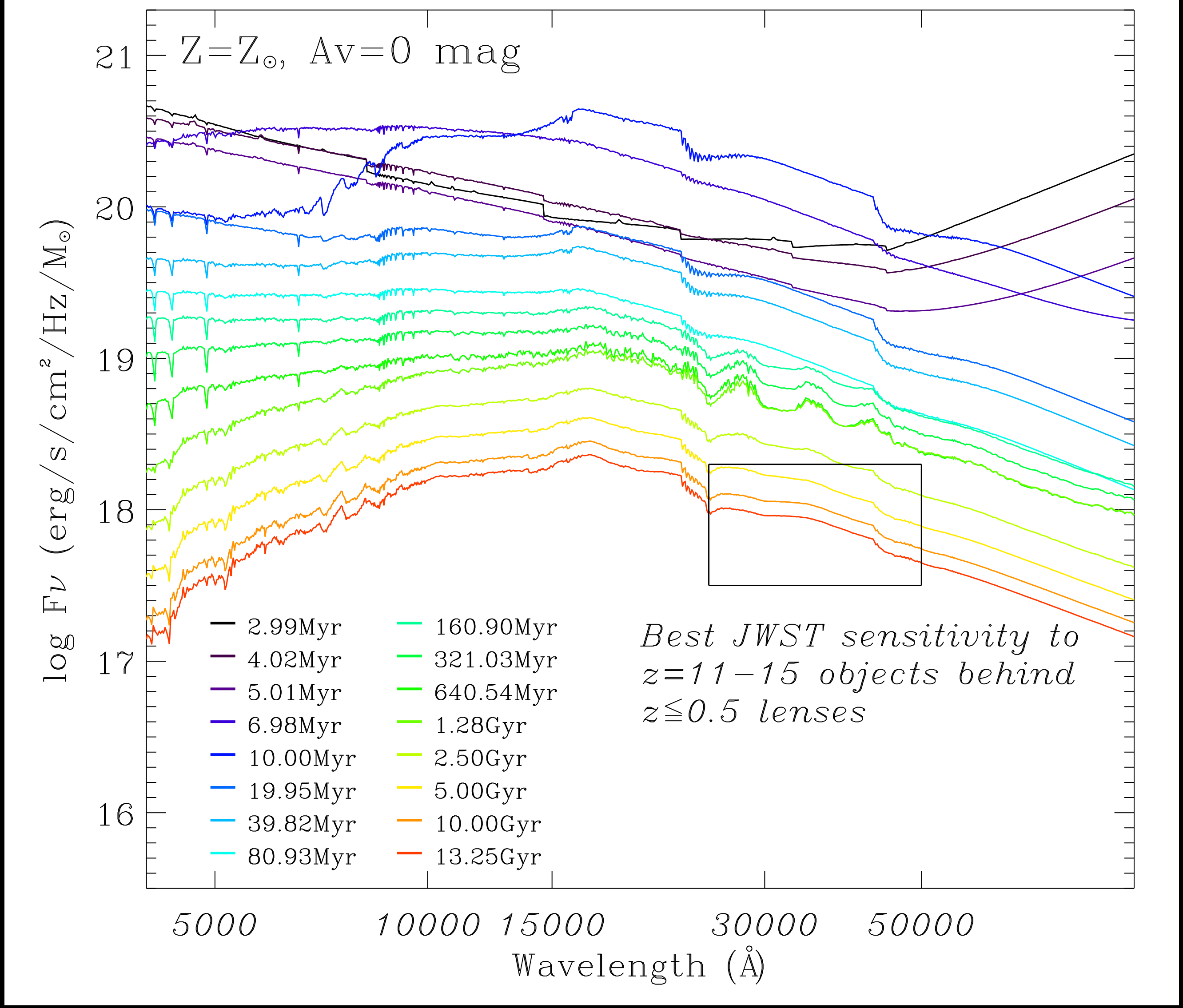
[RIGHT] Best lensing clusters vs. CLASH clusters.

(Contours: Number of lensed JWST sources at z$\simeq$1–15 to AB$\lesssim$31 mag).

- Resulting sweet spot for JWST lensing of First Light Objects (z$\gtrsim$10):

Redshift: 0.3$\lesssim$z$\lesssim$0.5; Mass: $10^{\mathbf{15-15.6}}$ $M_\odot$; Concentration: 4.5$\lesssim$C$\lesssim$8.5

SPHEREx selects those with *minimal* ICL near the modeled lensing caustics.



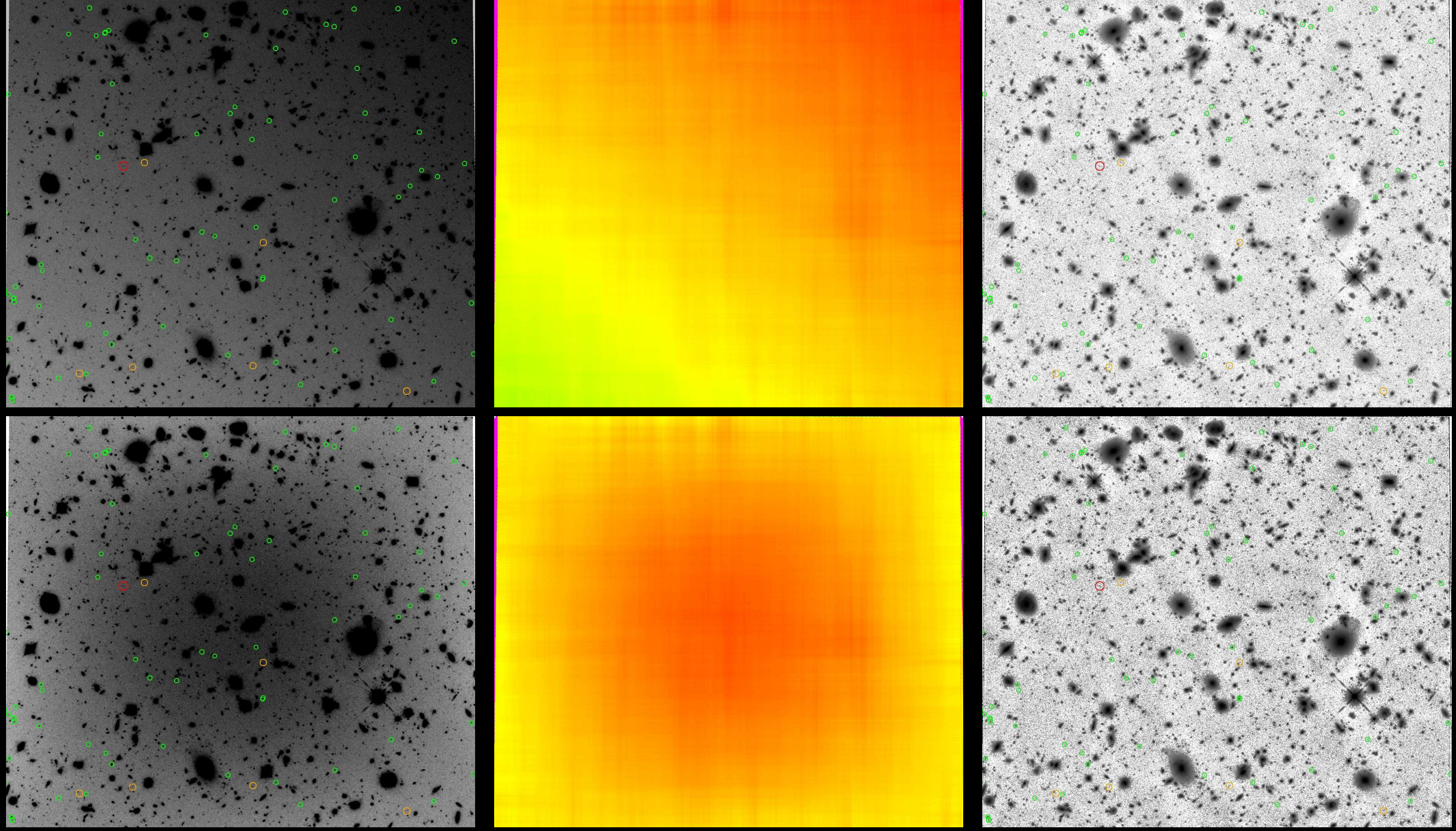
Galaxy SEDs for different ages: peak at $\lambda_{rest}\simeq$1.6μm (Kim et al. 2016).

JWST-NIRCam peaks in sensitivity for λ=3–5μm, where Zodi is lowest.

Sweet spot for JWST lensing cluster is z$\lesssim$0.5: Zodi-gain beats $(1+z)^4$.

- Minimizes effects from near-IR K-correction and ambient ICL!

SPHEREx to characterize total light of best lensing z$\lesssim$0.5 clusters for JWST.



[TOP]: [Left] HUDF F160W image with *worst case* (95% of Zodi) rogue-path amplitude imposed $\pm$ a 4% *linear gradient* from corner-to-corner.

[Middle]: Best fit to sky-background with R. Jansen's "rjbgfit.pro".

[Right]: HUDF image from left with best-fit sky-background subtracted.

[BOTTOM]: Same as top, but with *single-component 2D pattern* superimposed, modeled & removed.

- If JWST rogue-path straylight has slight or complex gradients, we must carefully plan JWST imaging of lensing clusters with strong ICL.

SPHEREx to characterize total light of best lensing z$\lesssim$0.5 clusters for JWST.