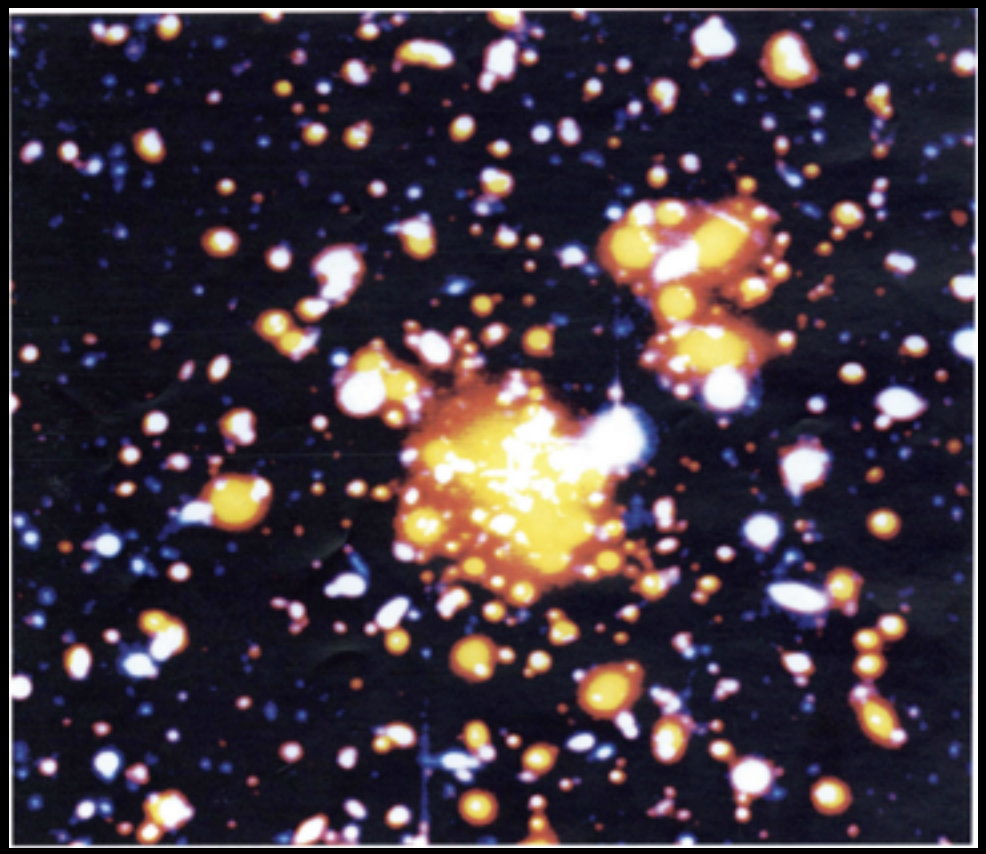
The Best 'Optics' for JWST: the *Planck* Connection



1. *Motivation: does lensing help to detect high redshift sources?*

2. *Which are the best 'optics' for JWST?*

3. *Are there any other worthy clusters: the Planck connection!*

By Brenda Frye, Yujing Qin, Massimo Pascale, Adam Bauer & Ramon Jaime-Frias (UA), Rogier Windhorst, Dan Coe, Chris Conselice, Stu Wyithe, Haojing Yan & Adi Zitrin

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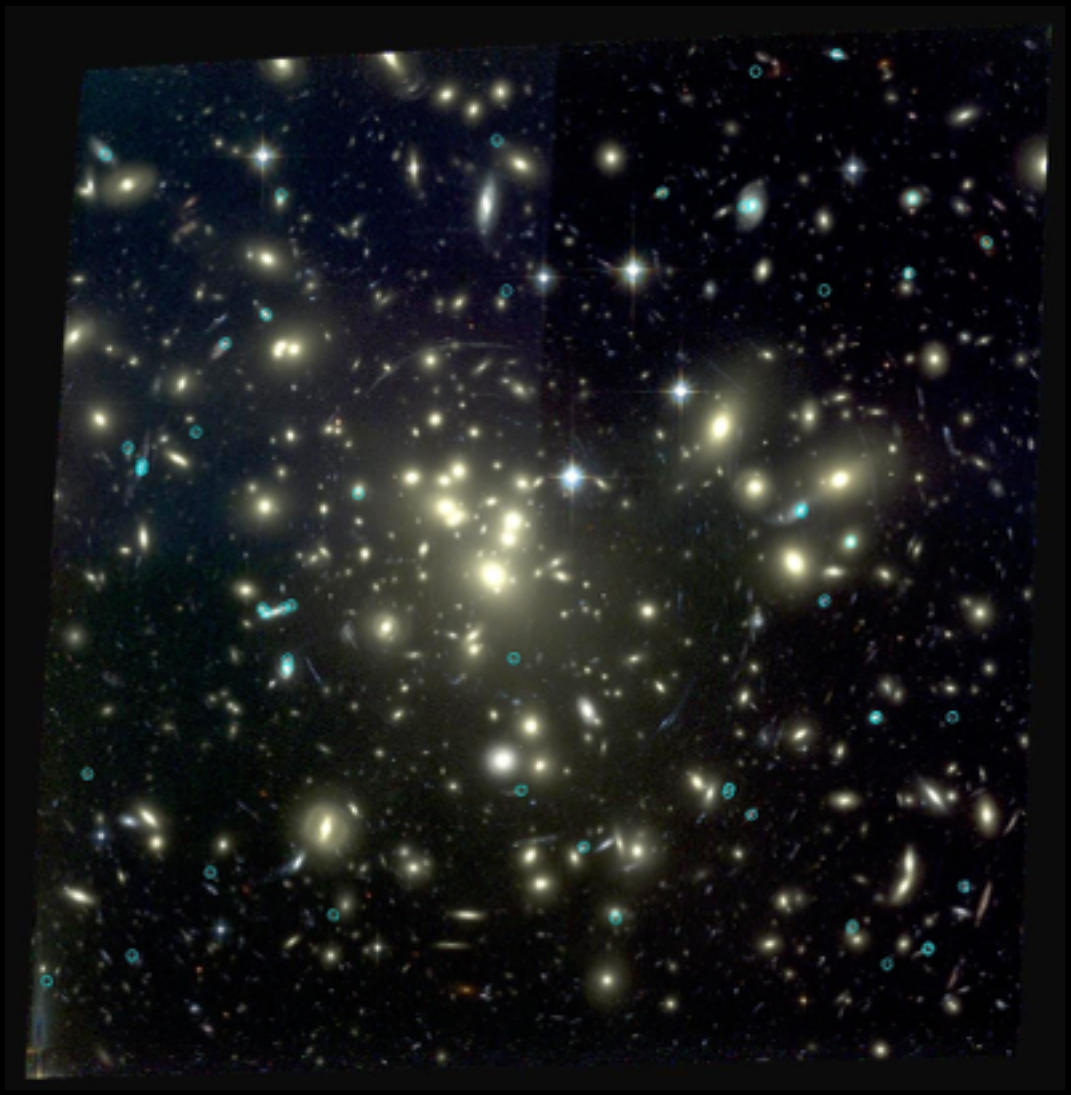

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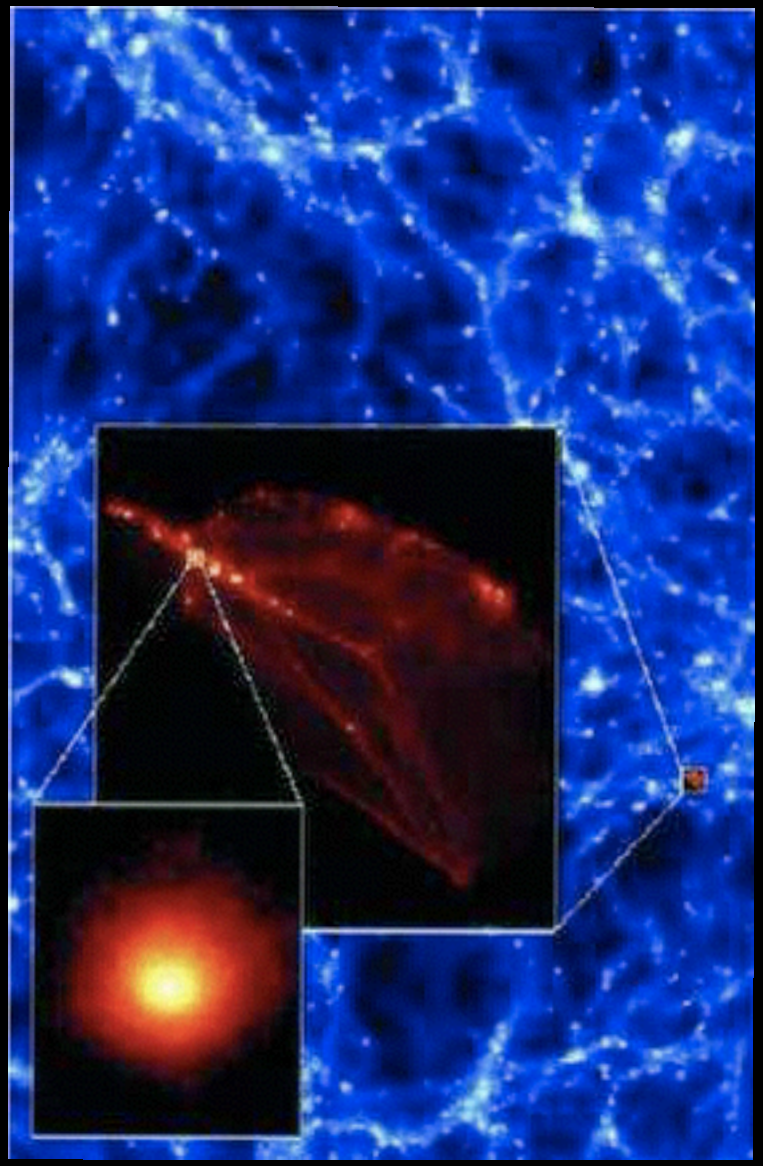
1. Motivation: Mass Assembly

✦ At early times, **gravity** amplifies tiny fluctuations in density

✦cosmic web assembles its filmentary structure during dark ages

✦ after 10^8 years of baryons infalling into the nodes, overdense regions collapse to make the first bound galaxies

✦ First stars and galaxies are FAINT and RED, requiring JWST for detection



Diemand, Moore, & Stadel 2005

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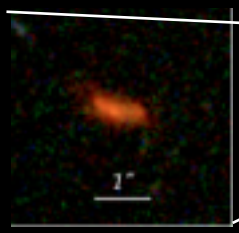

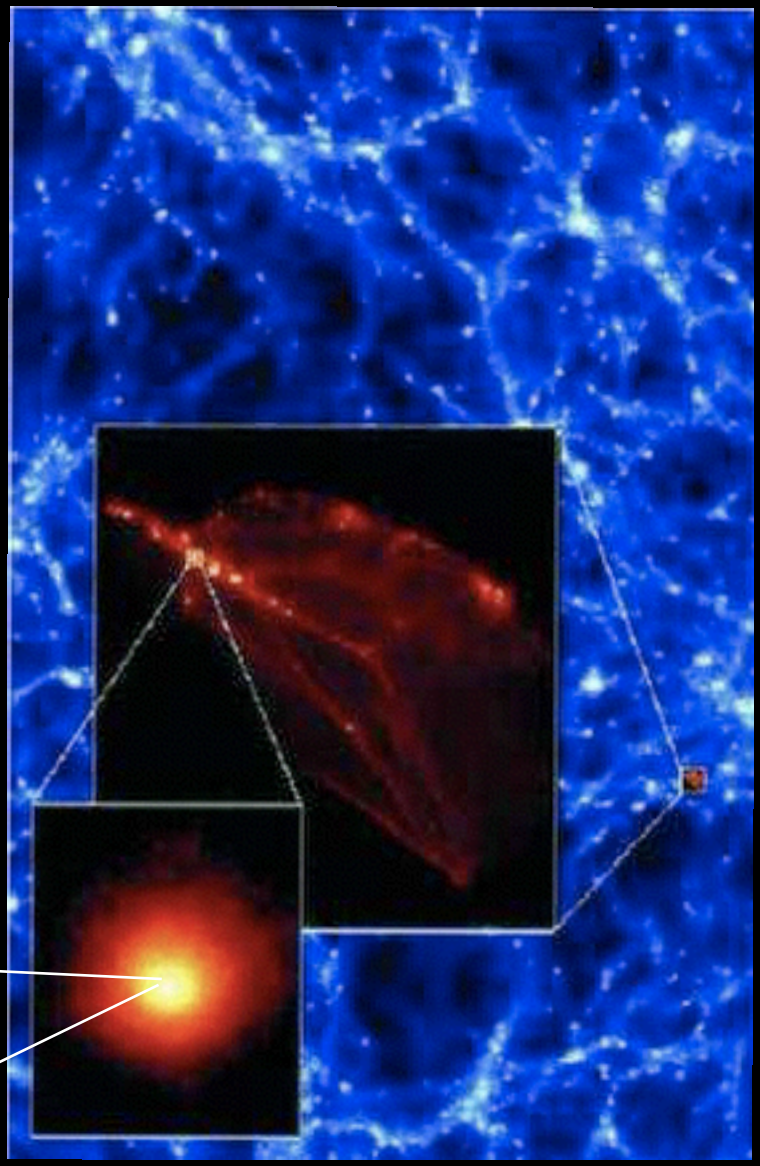

Frye et al. 2008

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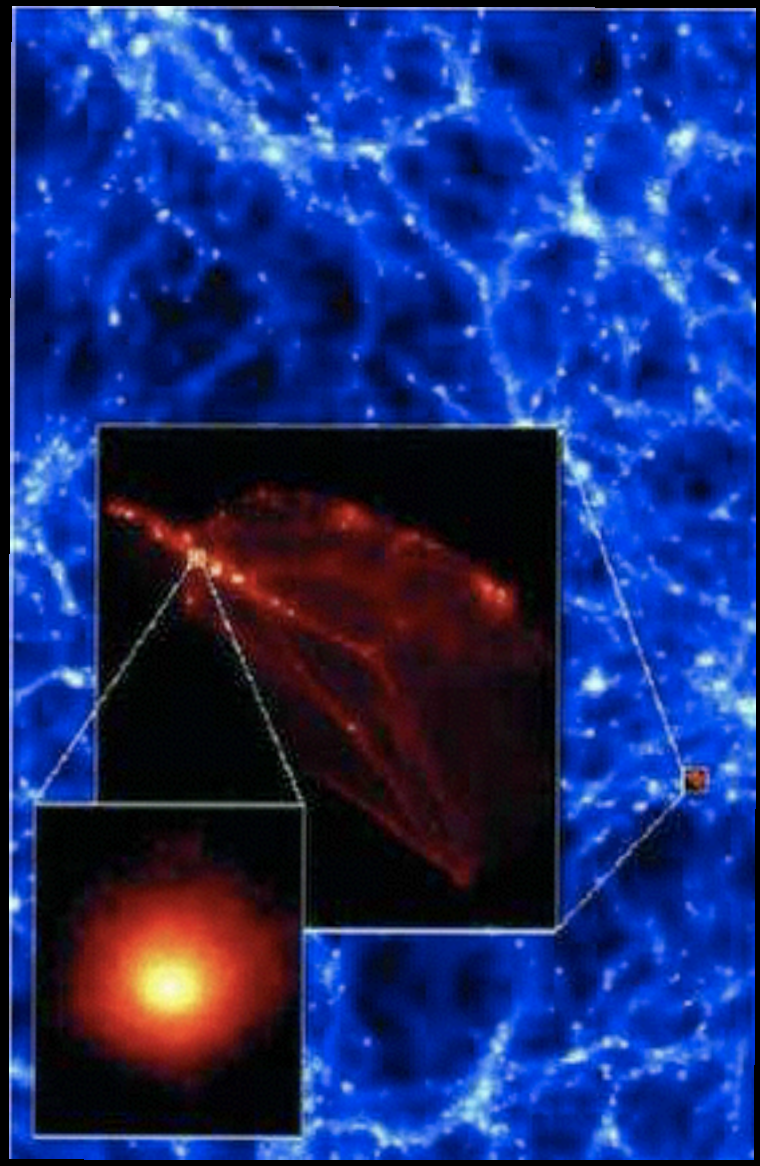
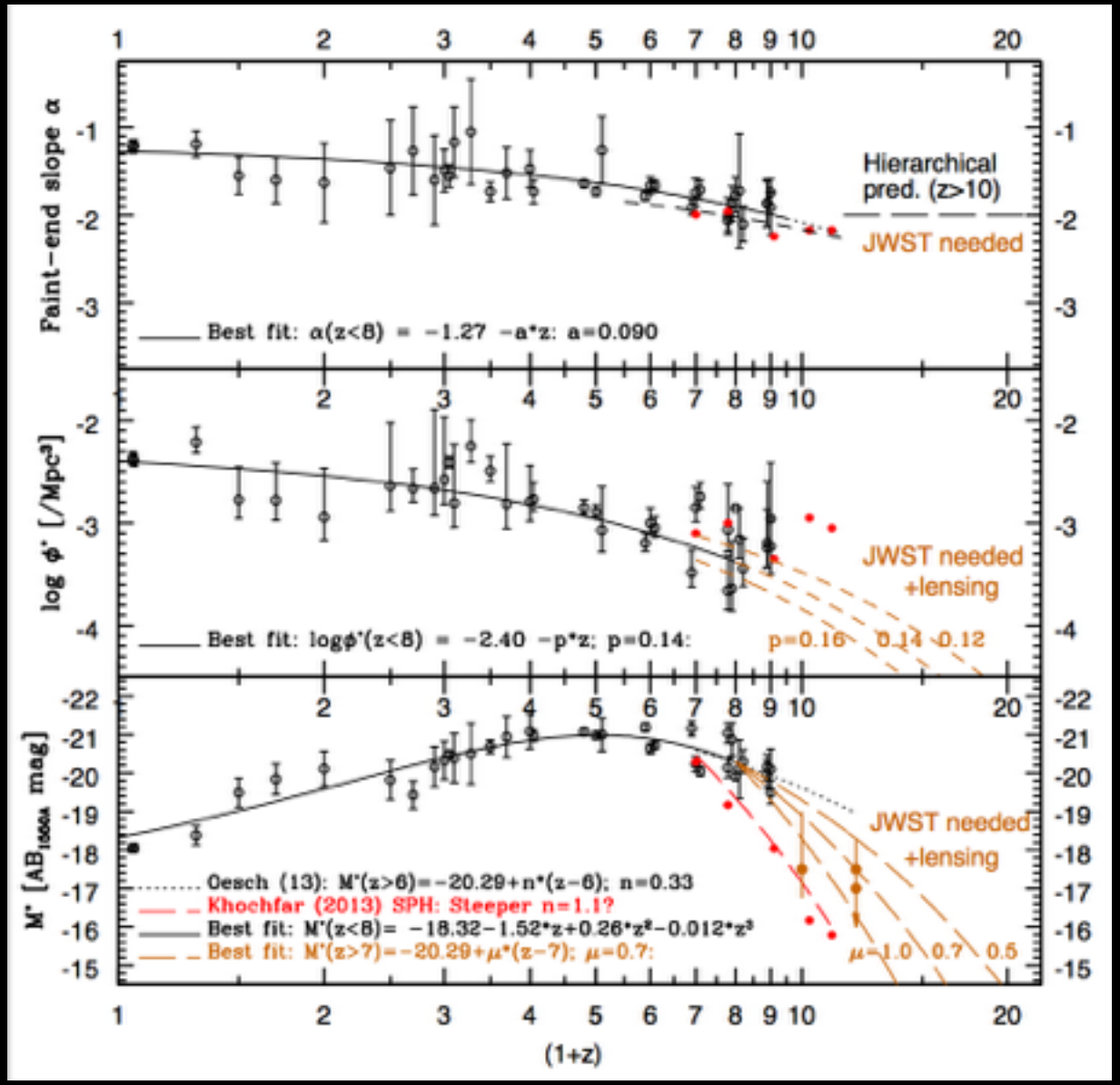


Diemand, Moore, & Stadel 2005

1. Motivation: How Lensing Helps at High-z

- For $z > 4$ we find:
  - numbers decline with z
  - low τ suggests $z_{reion} < 9$
- galaxies ramped up rapidly and are **rare**

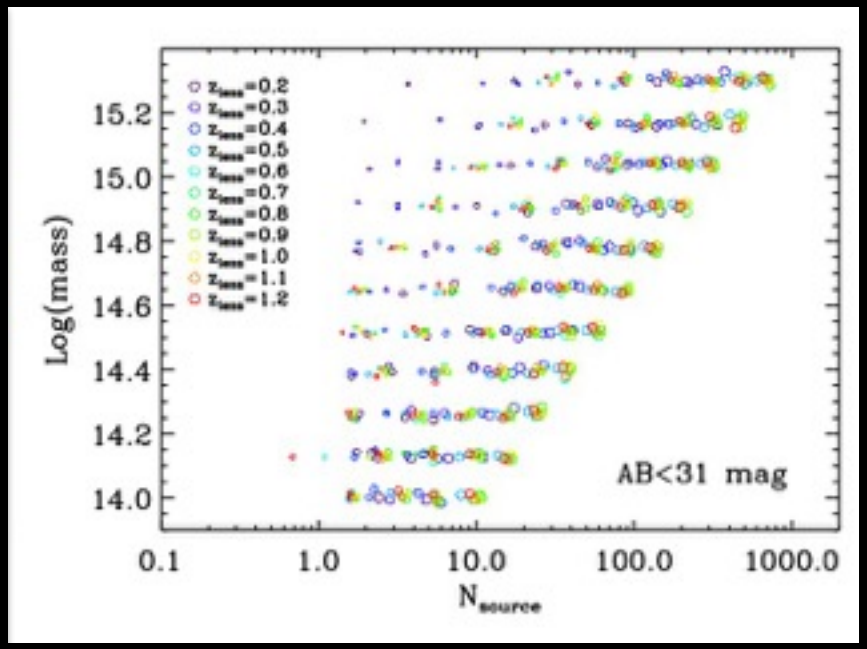
- ϕ^*, M* fall at high-z
- Significant consequences if M* as faint as -18 mags
- Meanwhile $\alpha \approx 2$ favors positive magnification bias
- We will see **more** galaxies behind lenses

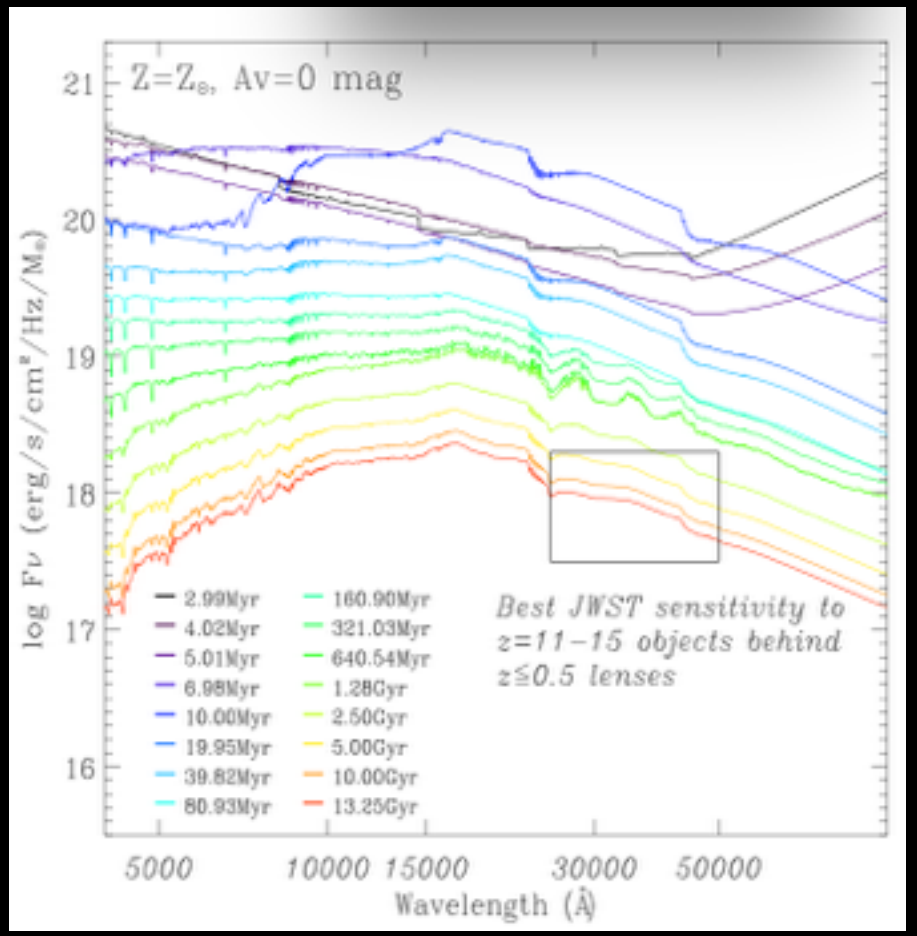


2. The Best Optics for JWST: the lenses

✦ clusters better studied, potentially more massive and highly concentrated at $z < 1$

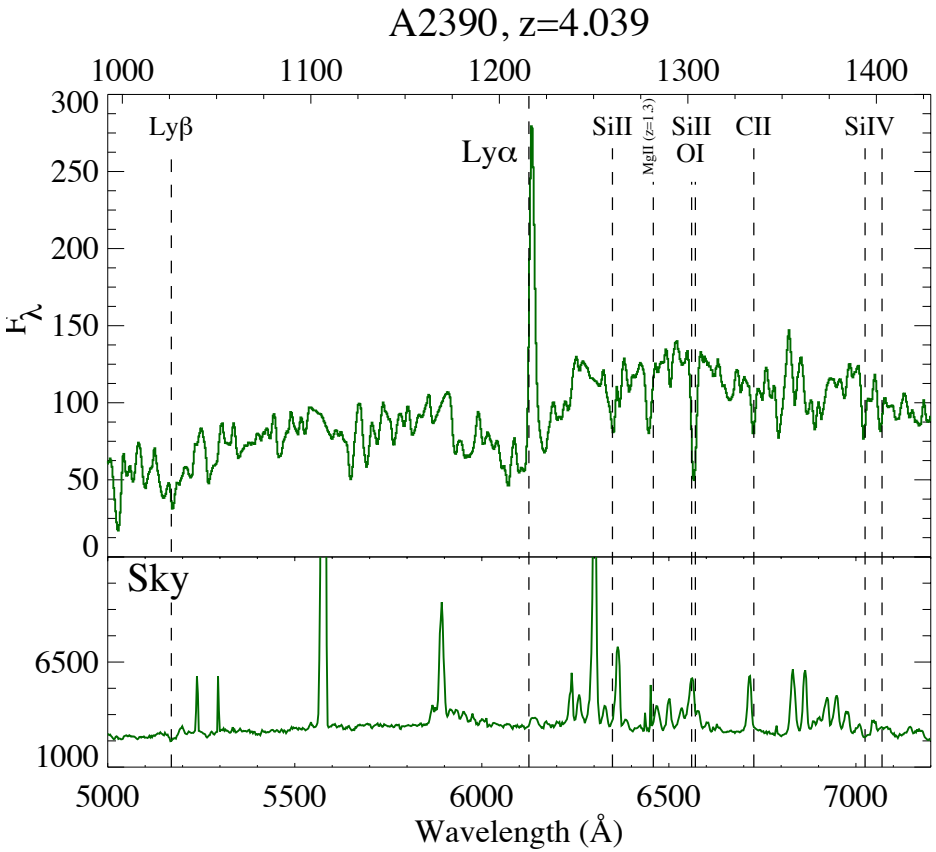
✦$z < 0.5$ so cluster light minimized at 2-4 microns where zodiacal light low & NIRCam sensitivity maximized

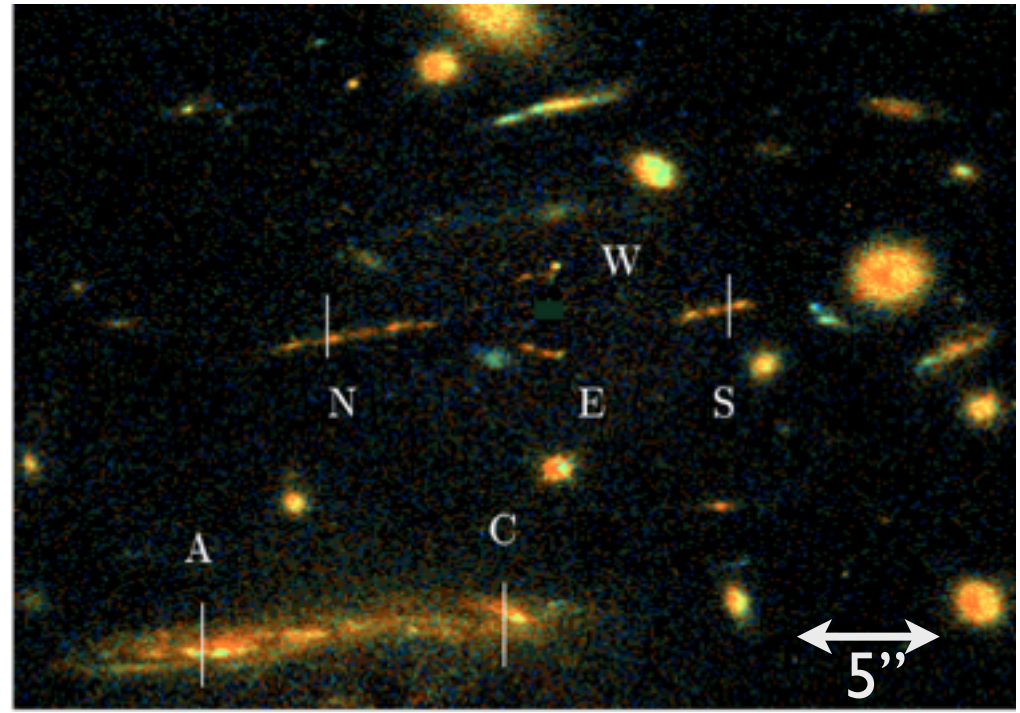


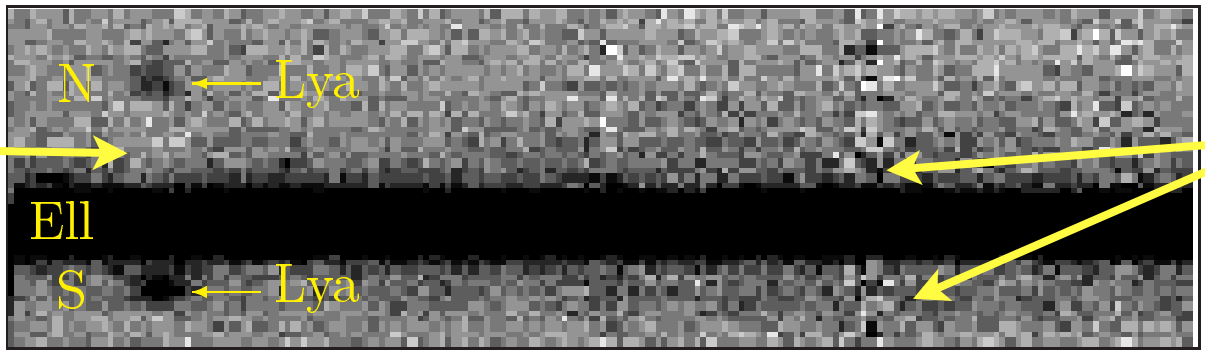


✦ high mass, high **concentration** lenses needed for magnified area to fill field of view in single pointing

2. The Best Optics for JWST: arclet families



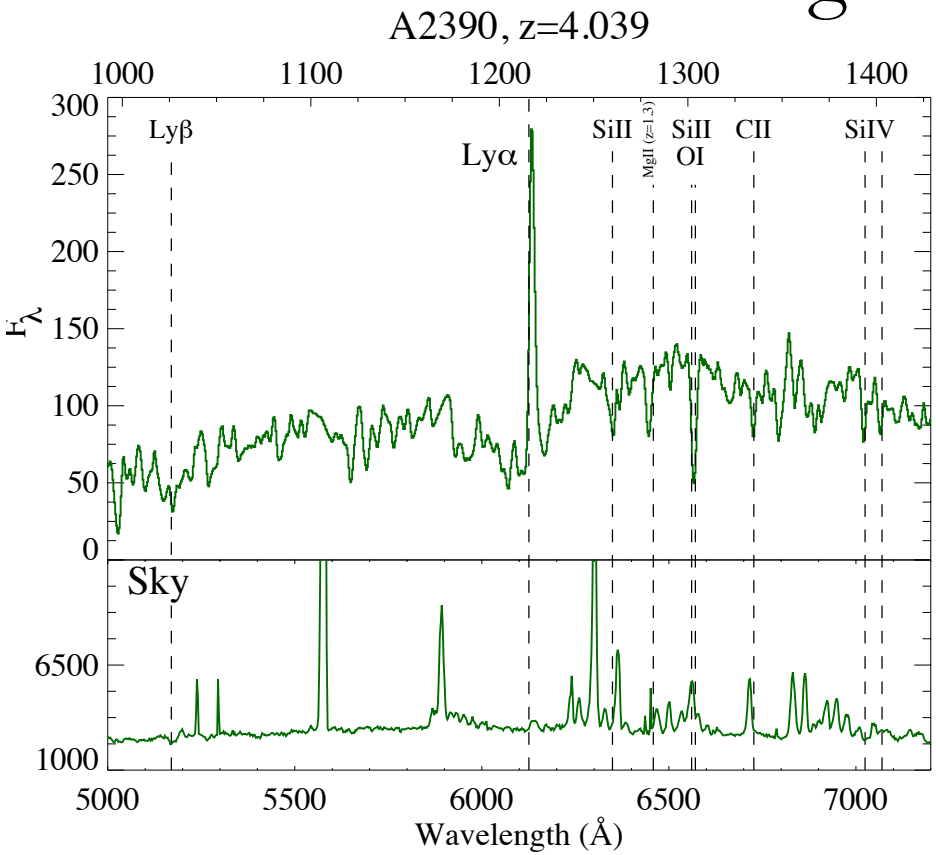


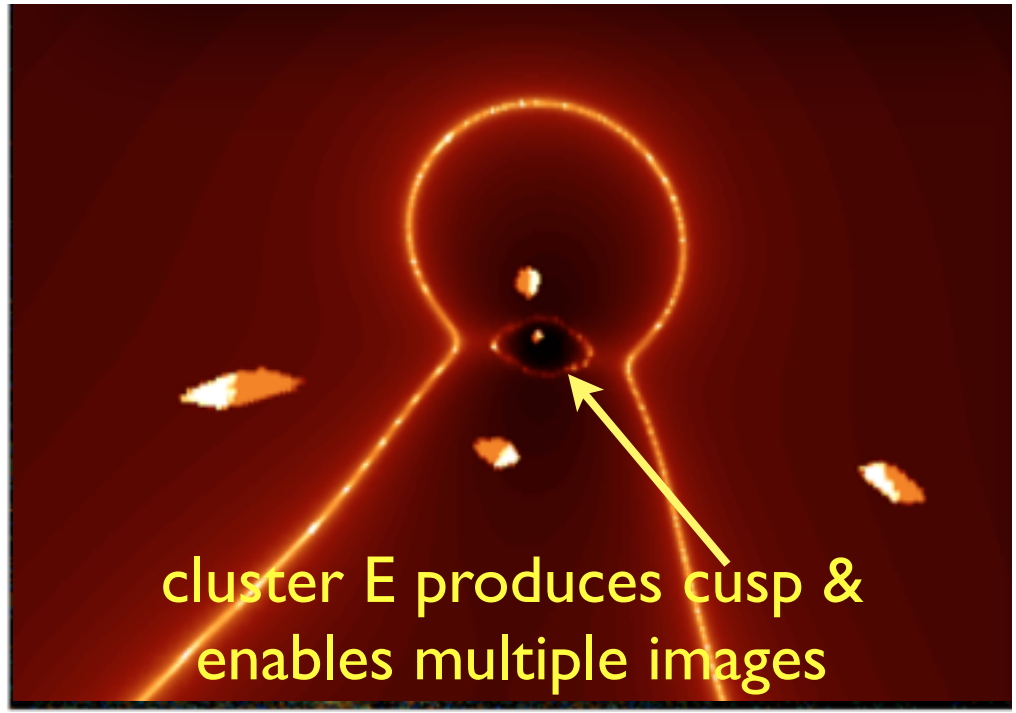


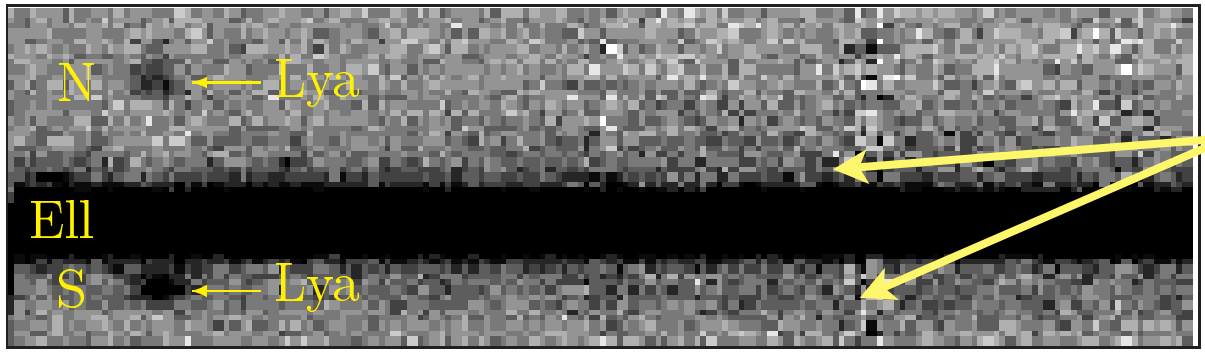
spatially-resolved
stellar continuum

Frye & Broadhurst 1998

2. The Best Optics for JWST: masses best measured using arclet families







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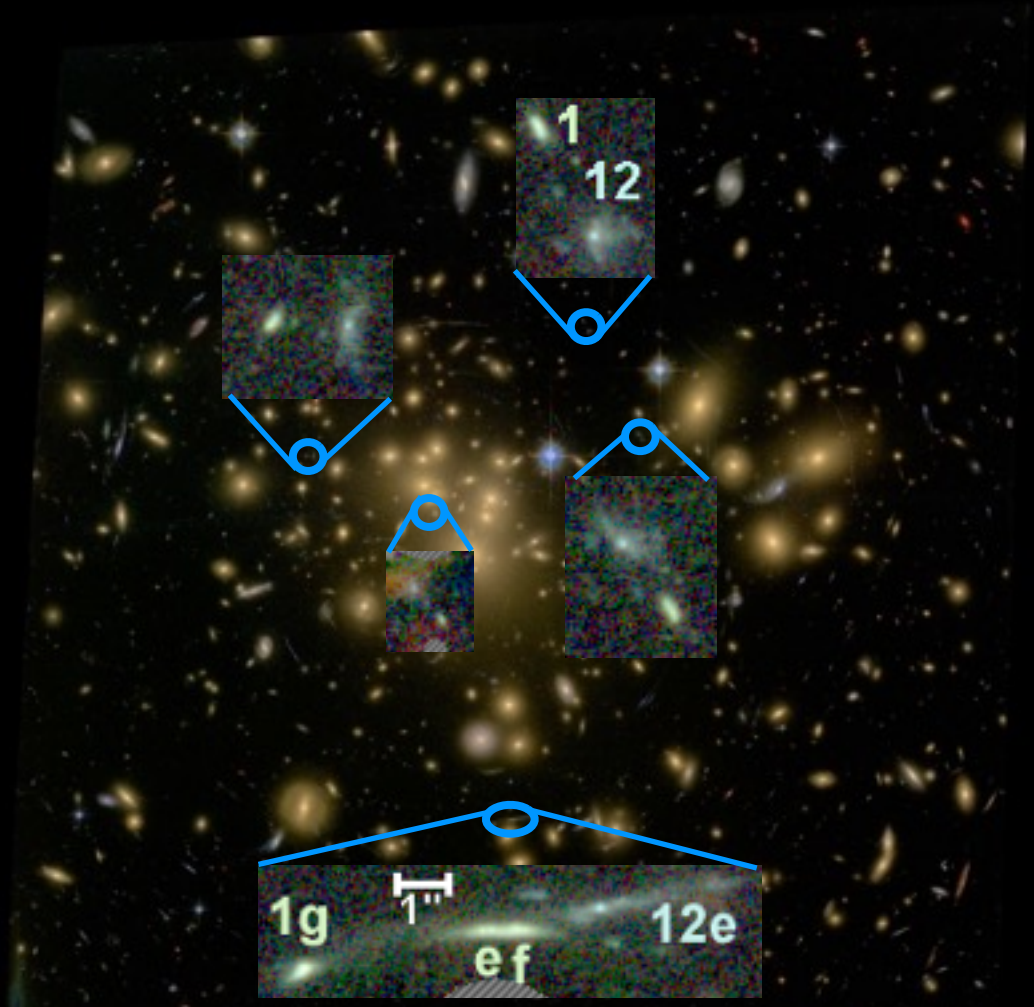
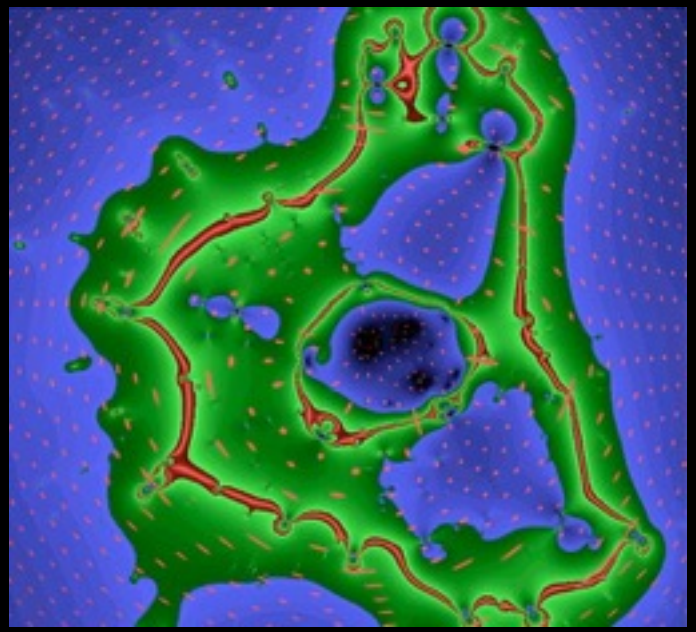
2. The Best 'Optics' for JWST: arclet families



("The Sextets"; Frye et al. 2002, 2007, 2012)

~8 clusters have robust mass maps for cosmography (Gilmore & Natarajan 2009) & to the LF!



(Broadhurst et al. 2005)

2. The Best 'Optics' for JWST: *worthy* clusters

large galaxy surveys

Best-studied

Classic

X-ray bright (CLASH)

Planck S-Z (RELICS)

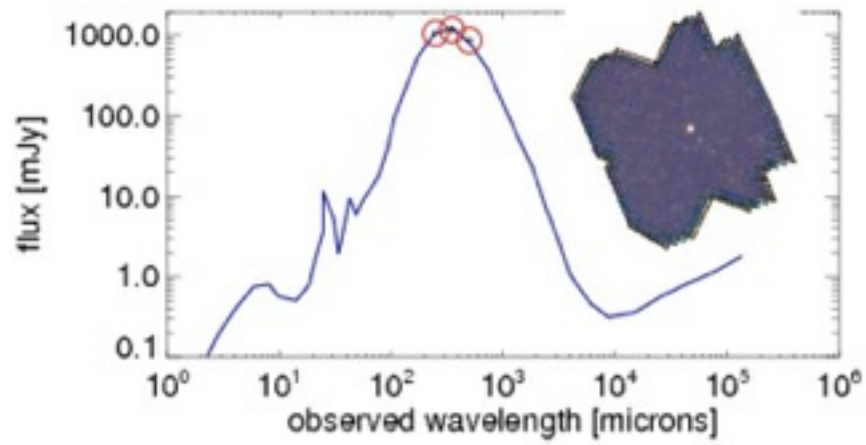
Large beams

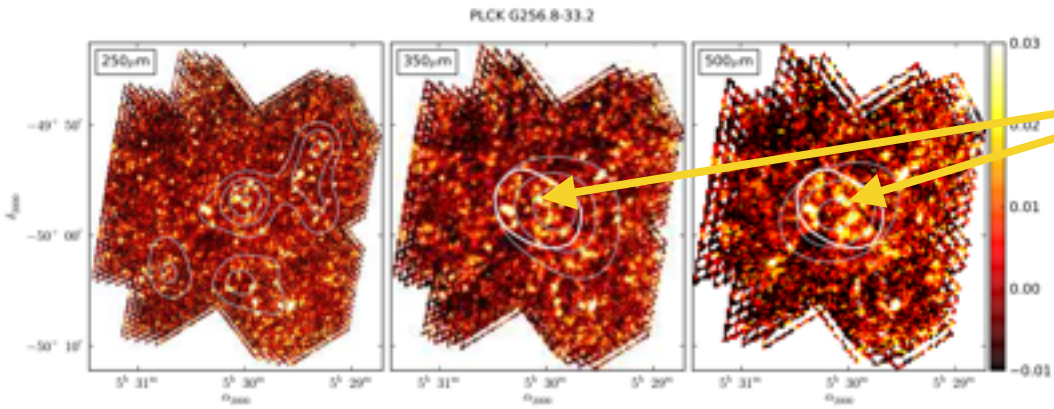
Planck by Color

"Poudrette" gem

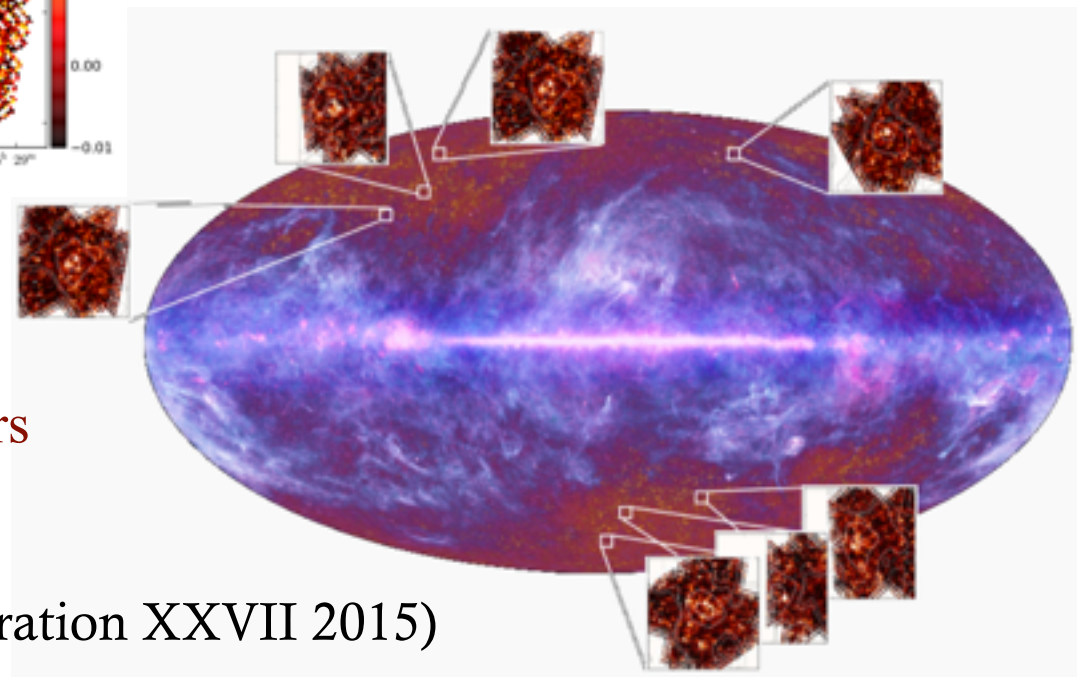
3. The *Planck Connection*

- apply novel approach to find brightest sources that are also red so potentially at high-z
- select compact *Planck/HFI* by rest-frame FIR **color** at z=1-3 (Montier+10)
- Image best 228 sources on *Herschel*
- match up 50% intensity contours, 'In' regions





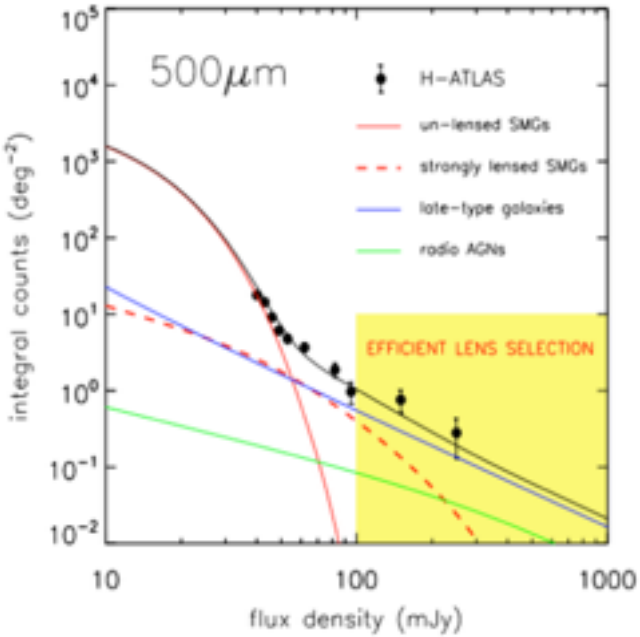
'In' regions for *Planck* sources



- So what are they?
  - Most are over densities of ~10 red galaxies as expected for protoclusters
  - 11 show only one red galaxy

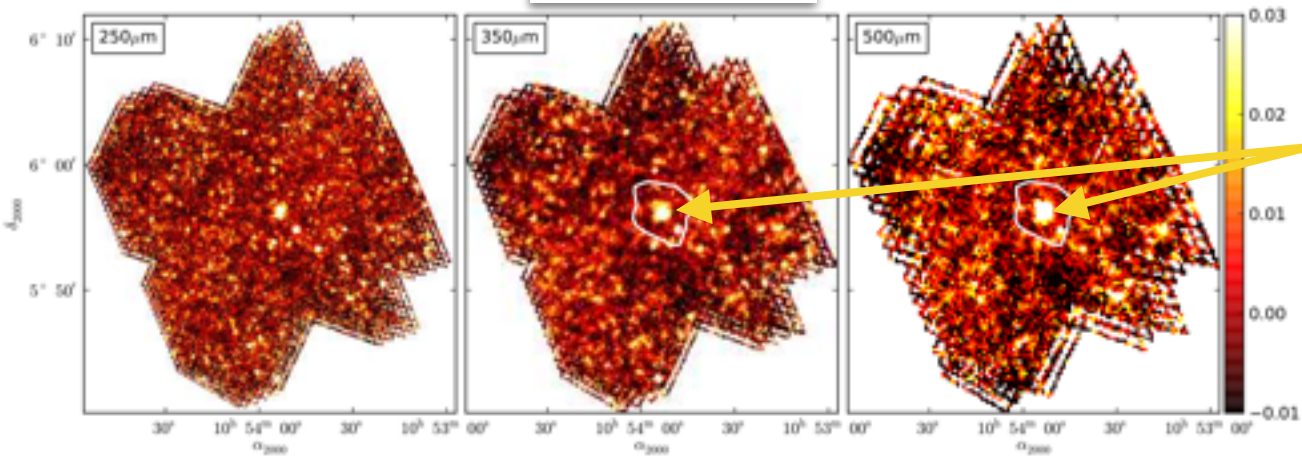
(Planck Collaboration XXVII 2015)

3. The *Planck Connection*



(Negrello et al. 2010)

- What are these 11 sources that are so bright (all have S_{500}>300mJy), new and **isolated?**
- Brightest sources also more likely to be *lensed*
- imaging in confirms strong lensing interpretation
- EL spec-z's demonstrate *z*=2-4 (Canameras+15)
- In sum, this subset of brightest Planck/Herschel sources are *giant arcs* !

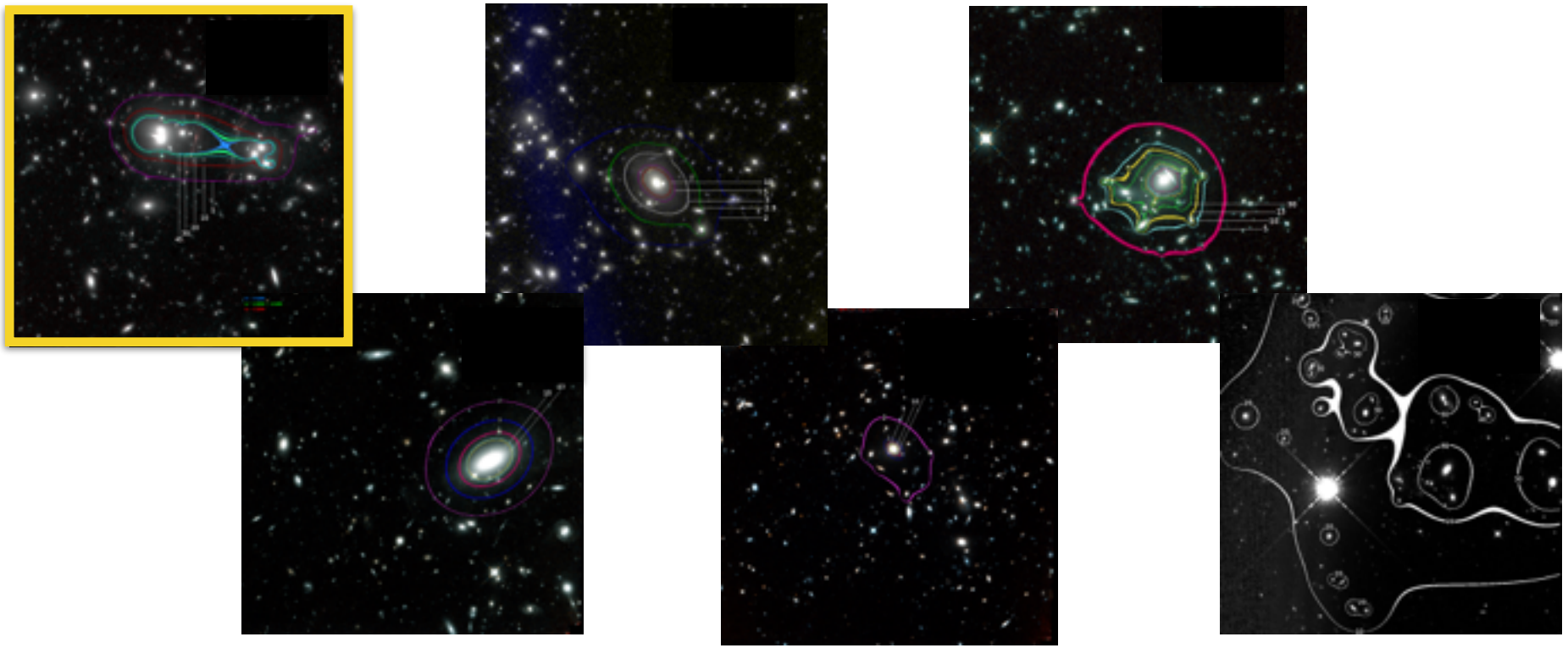


- 1 of the 11 ultra-bright sources showing single sub-mm galaxy

(Canameras et al. 2015)

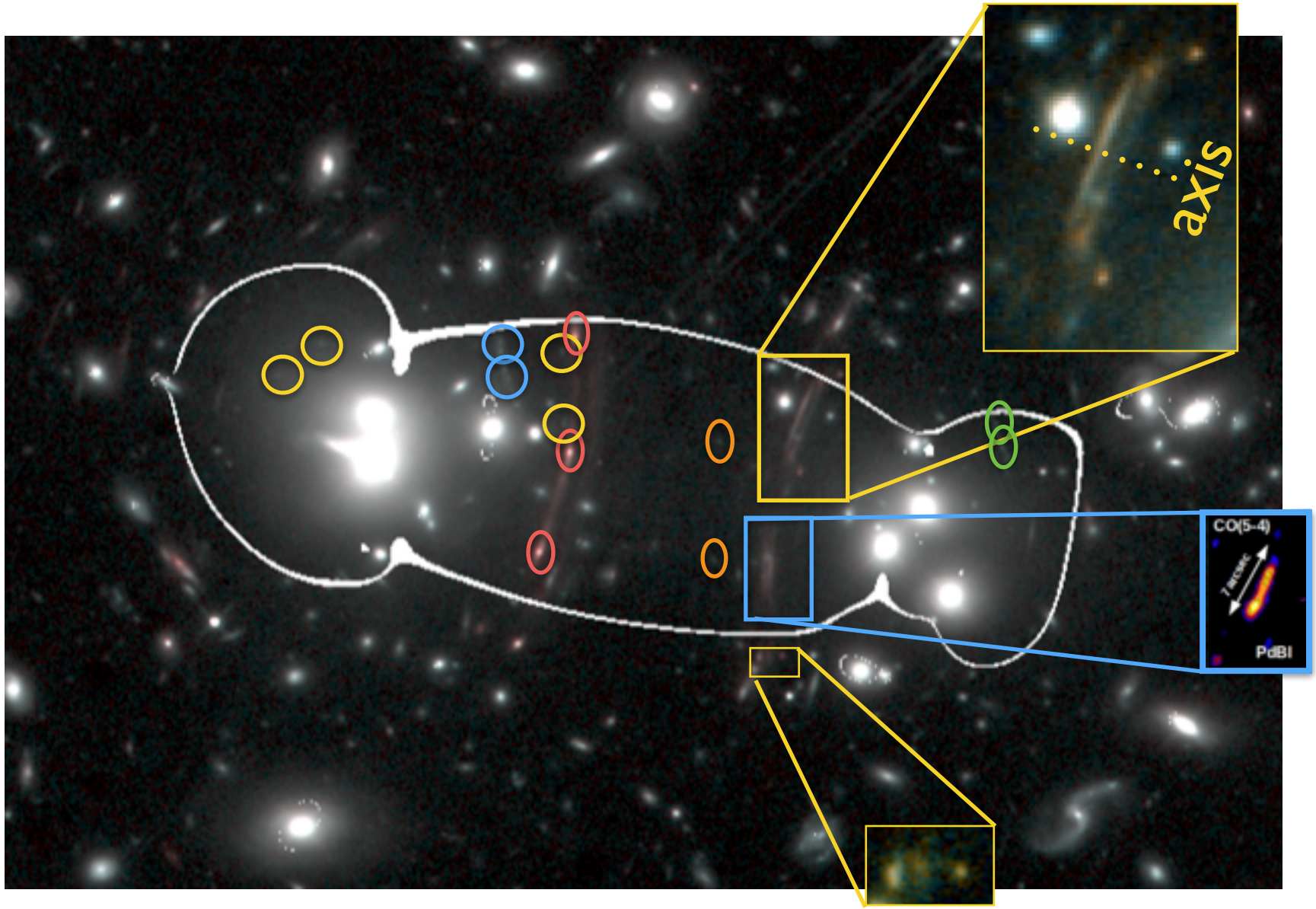
3. The *Planck Connection*: HST images (Cy23, PI: Frye)

- like field counterparts, lensed sources are dusty & clumpy: need NIR space-based imaging to resolve morphologies/construct lens models
- unlike field counterparts, lensed sources are ~spatially-resolved: need NIR to study high surface mass densities, radiation fields & turbulence
- Voila! We present new imaging for 6/11 fields in NIR on HST



Light-traces-mass lens models (Zitrin+09) by M. Pascale

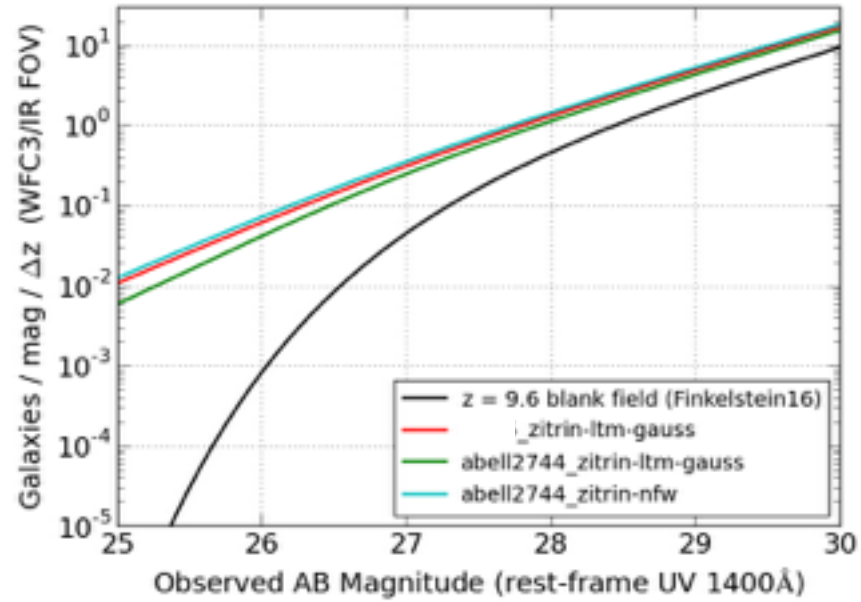
3. The *Planck Connection*: HST images of best lens field with z=9 critical curve overlaid (11 arclet families confirmed)

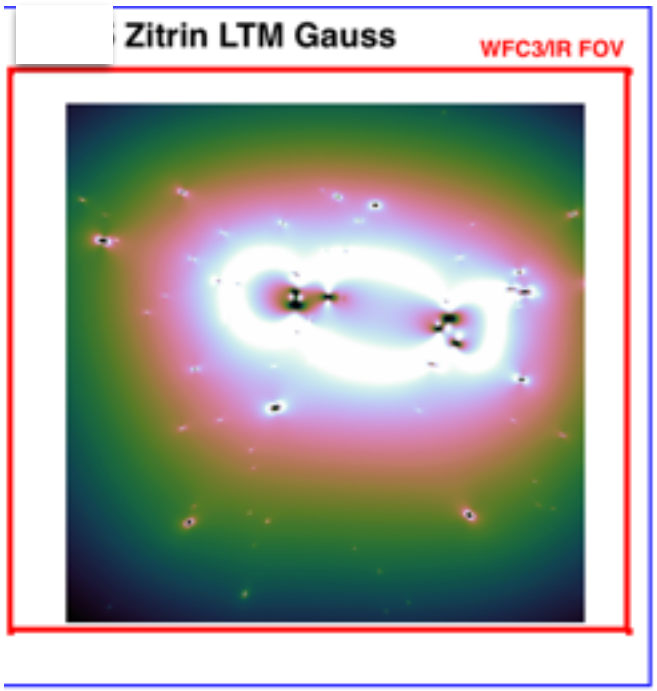


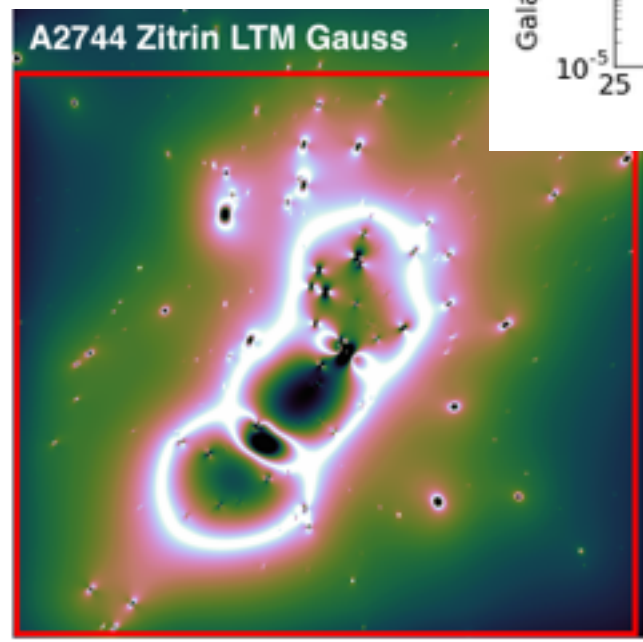
(Qin et al. 2016, *in prep*)

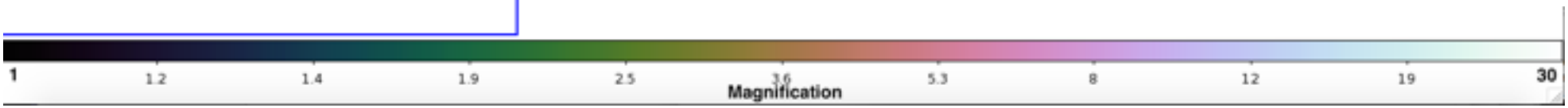
3. The *Planck Connection: a worthy cluster!*

- magnification map at $z = 9$ is large, will not overfill NIRCam field of view
- crucially high magnification region for covers larger locus of points so high DM *concentration*









- LF shows this one and A2744 both recover equal numbers of galaxies
- In sum: this cluster has significant lensing power!

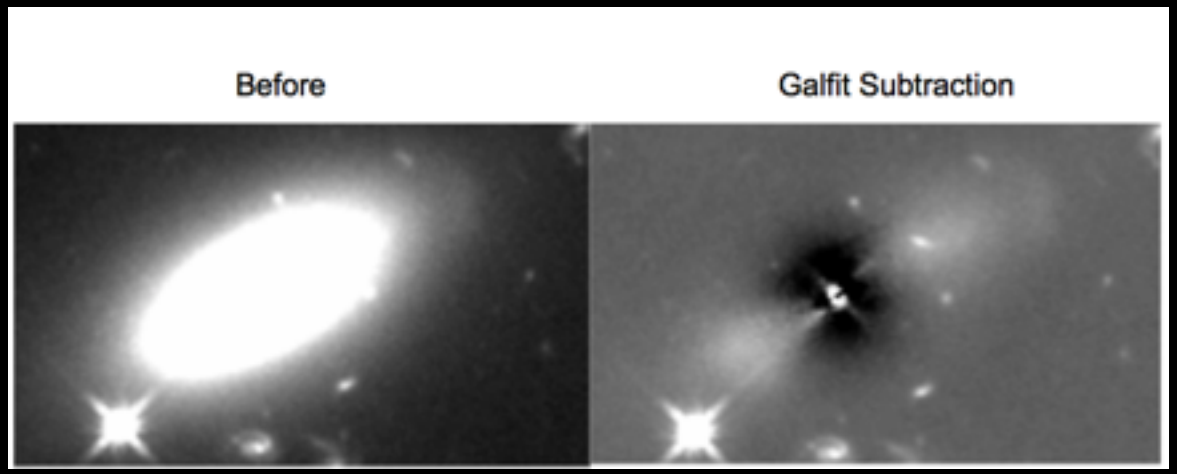
(Plots courtesy of Dan Coe)

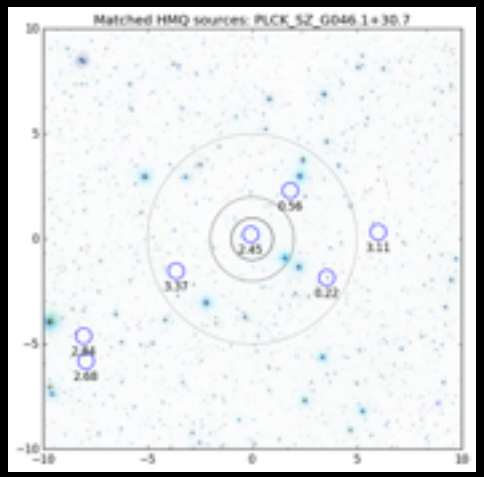
A Summary, and some thoughts..

- Yes - lensing approach may potentially be needed to find JWST high-z sources
- Yes, some 'optics' better than others to fill f.o.v. & not contaminate in NIR
- *Planck* color selection yields 11 sub-mm giant arcs, some with large critical curves

For the future:

- subtracting off cluster light in progress to yield additional arcs & assist to understand the ICL





- QSOs found behind the 200 galaxy overdense regions enable rare study of H I opacities of large structures

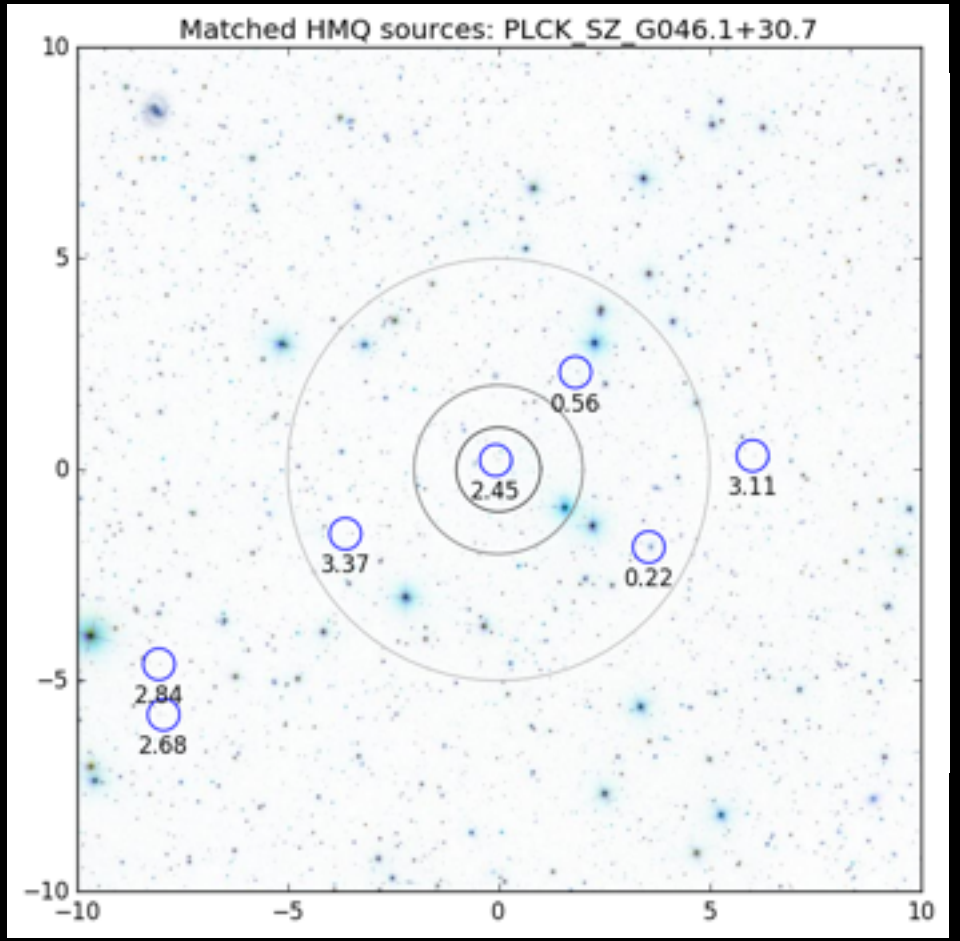
3. The *Planck* Connection: the galaxy overdensities

- ~200 Planck color-selected sources show red galaxy over densities at z=1-2.5 consistent with being *protoclusters*
- Of these, 23 sources have QSOs in SDSS DR13 data within $\theta \leq 2'$

- Example (right): G046 has 5 background QSOs in projection

- Question: Will QSO spectra show significant absorption along line of sight at the overdensity redshift?

- Observational program offers rare chance to measure τ_{HI} towards galaxy overdensities compared to the field



Qin et al. 2017, *in prep*