Herschel Lensing Survey (HLS)

Beyond the Confusion: Exploiting Gravitational Lensing by Galaxy Clusters

Tim Rawle

ESA Research Fellow

Survey Paper: Egami+10

High-z sources: Rex+10, Pérez-González+10, Boone+11, Combes+12,
Boone+13, Rawle+sub, Sklias+sub, Egami+prep, Rawle+prep

Cluster sources: Rawle+10, Rawle+12a, Rawle+12b, Rawle+prep, Walth+prep

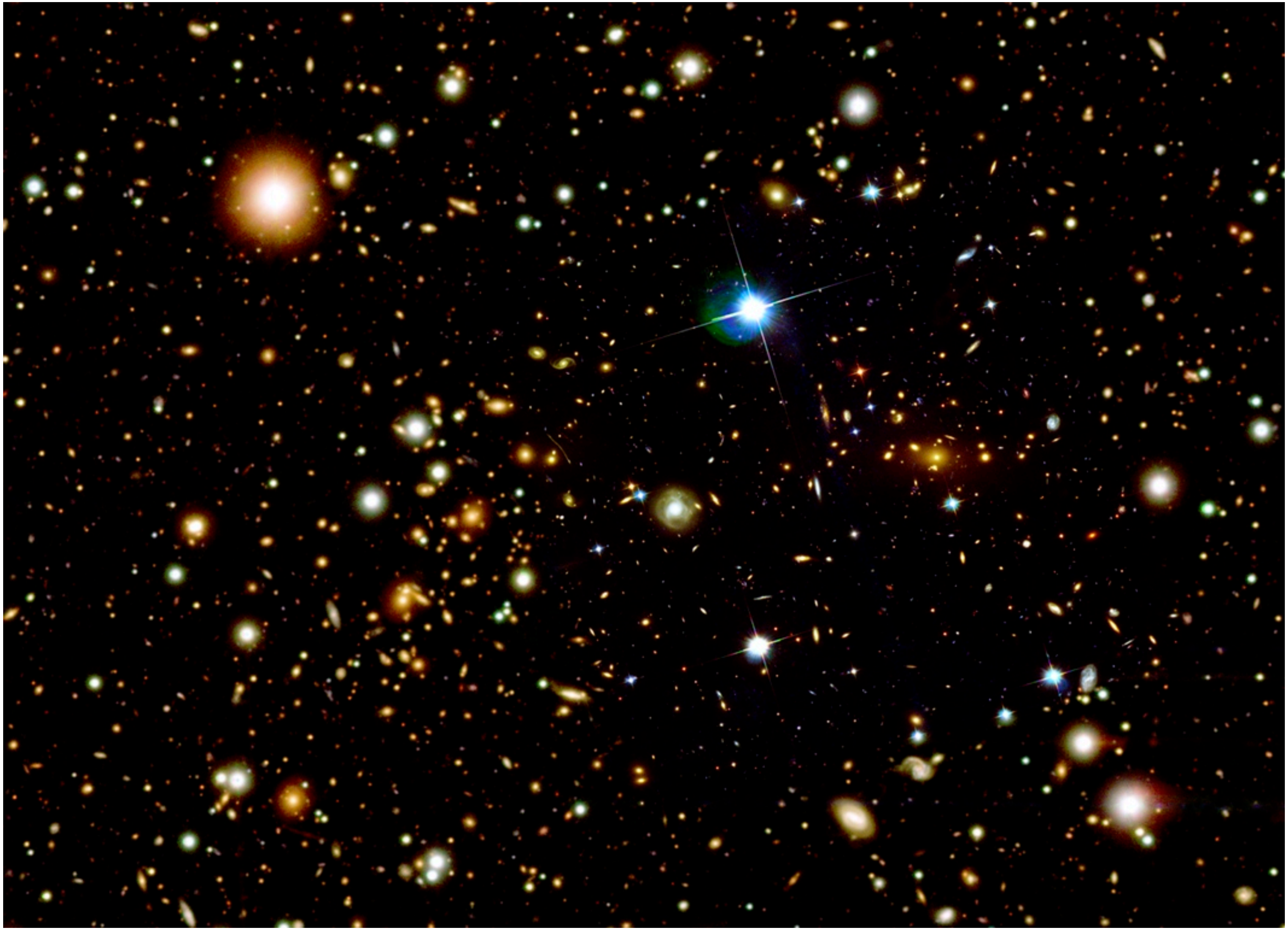
SZ effect: Zemcov+10, Prokhorov+12, Sayers+13

E. Egami (PI; Arizona)

B. Altieri (ESAC)
L. Metcalfe (ESAC)
J. Santos (ESAC...)
I. Valtchanov (ESAC)

A. Blain (Leicester)
J. Bock (JPL/Caltech)
F. Boone (Toulouse)
C. Bridge (Caltech)
S. Bussmann (CfA-Harvard)
A. Cava (Geneva)
S. Chapman (Dalhousie)
B. Clement (Arizona)
F. Combes (Paris)
M. Dessauges (Geneva)
D. Dowell (JPL/Caltech)
H. Ebeling (Hawaii)
A. Edge (Durham)
R. Ellis (Caltech)
D. Fadda (IPAC/NHSC)
O. Ilbert (Marseille)
R. Ivison (Edinburgh)
M. Jauzac (SALT)
T. Jones (UCB)
J.-P. Kneib (Geneva)
D. Lutz (MPE)
A. Omont (IAP)
R. Pello (Toulouse)
M. Pereira (Arizona)
P. Pérez-González (Madrid)
J. Richard (Lyon)
G. Rieke (Arizona)
G. Rodighiero (Padova)
D. Schaerer (Geneva)
P. Sklias (Geneva)
I. Smail (Durham)
G. Smith (Birmingham)
M. Swinbank (Durham)
G. Walth (Arizona)
P. Van der Werf (Leiden)
M. Werner (JPL/Caltech)
M. Zamojski (Geneva)
M. Zemcov (JPL/Caltech)

Bullet Cluster 1E0657-56 (z=0.296)



Optical: NASA/STScI; Magellan/U.Arizona/Clowe et al.

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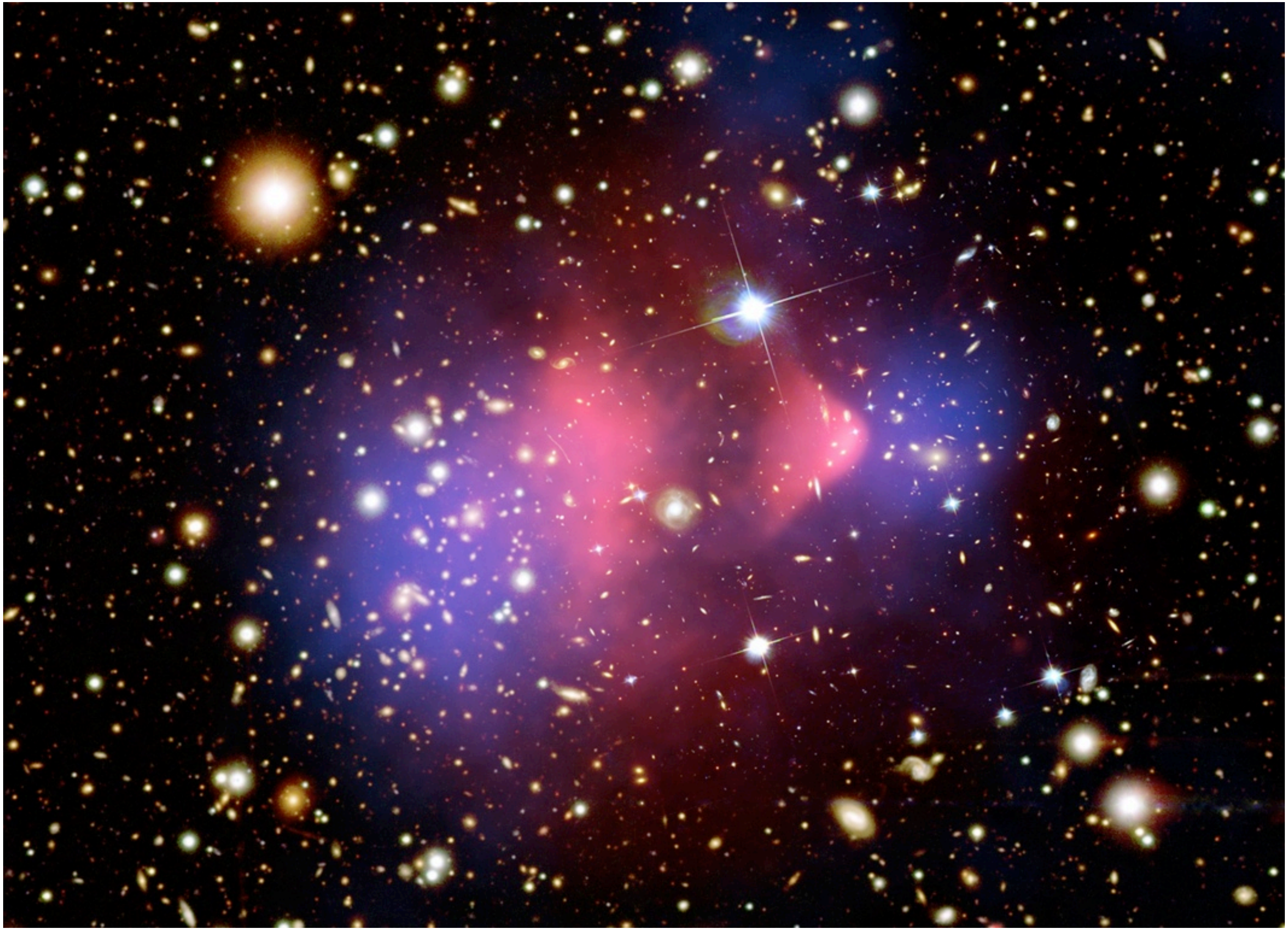

X-ray: NASA/CXC/CfA/ Markevitch et al.

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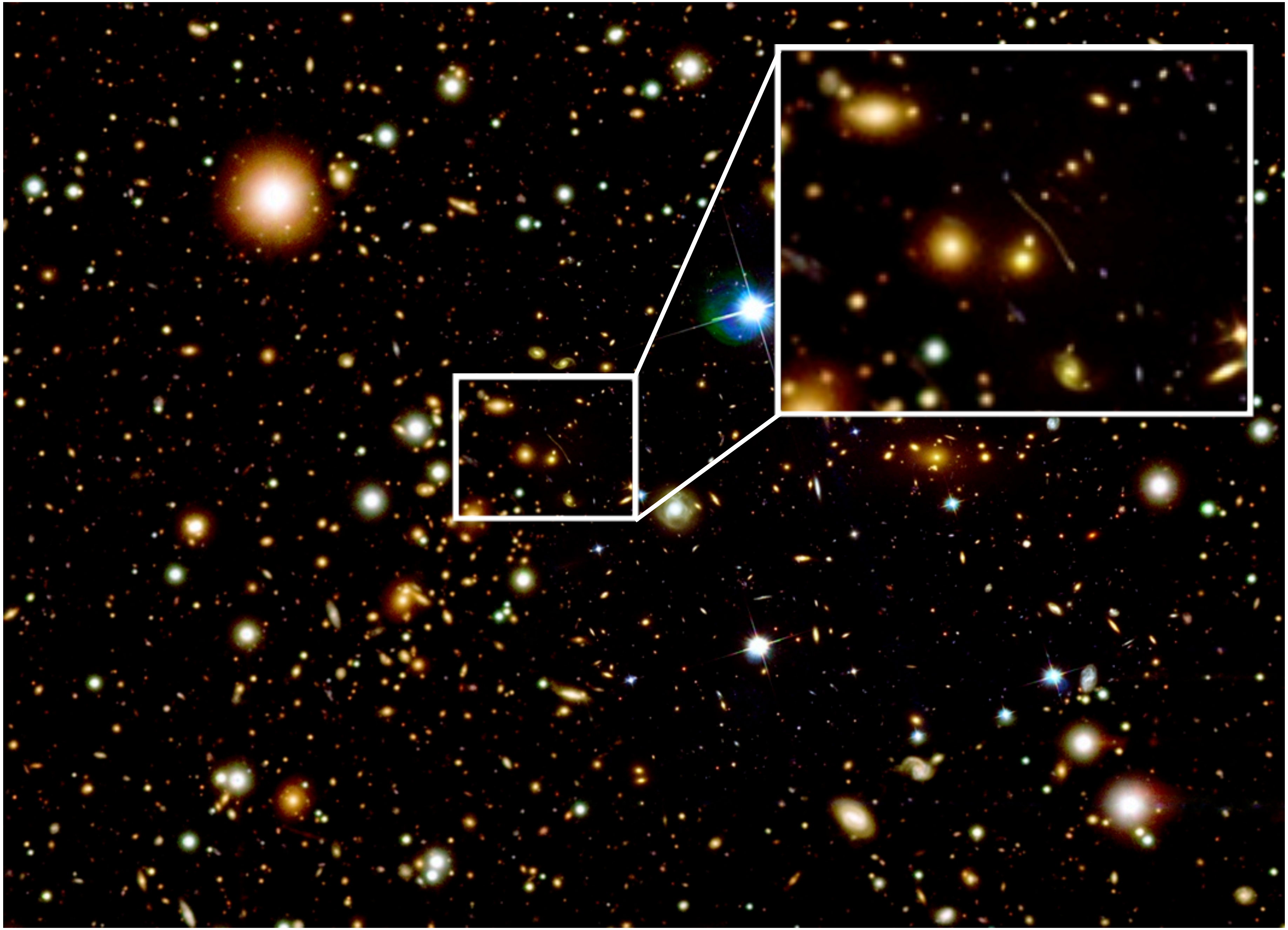
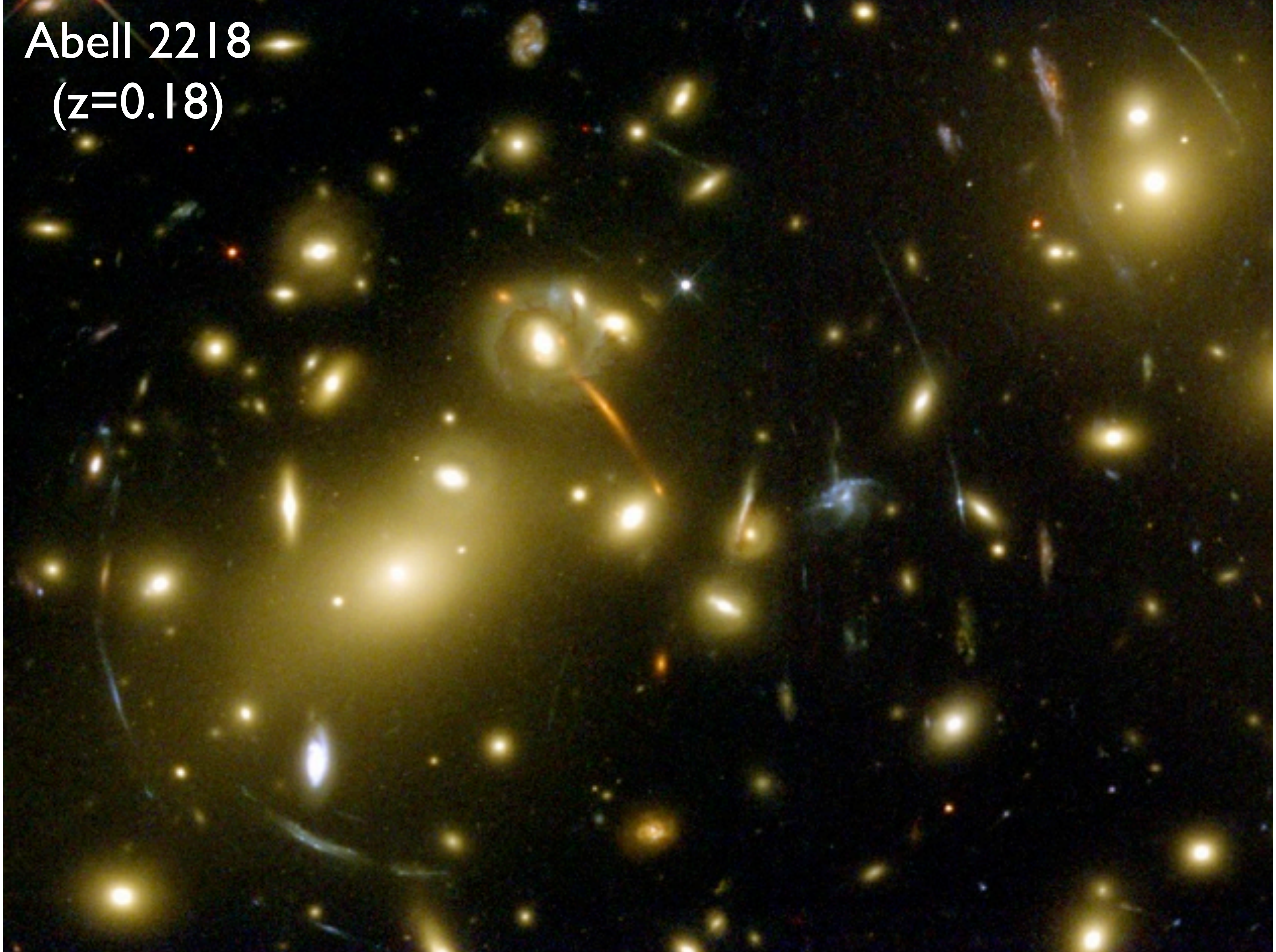
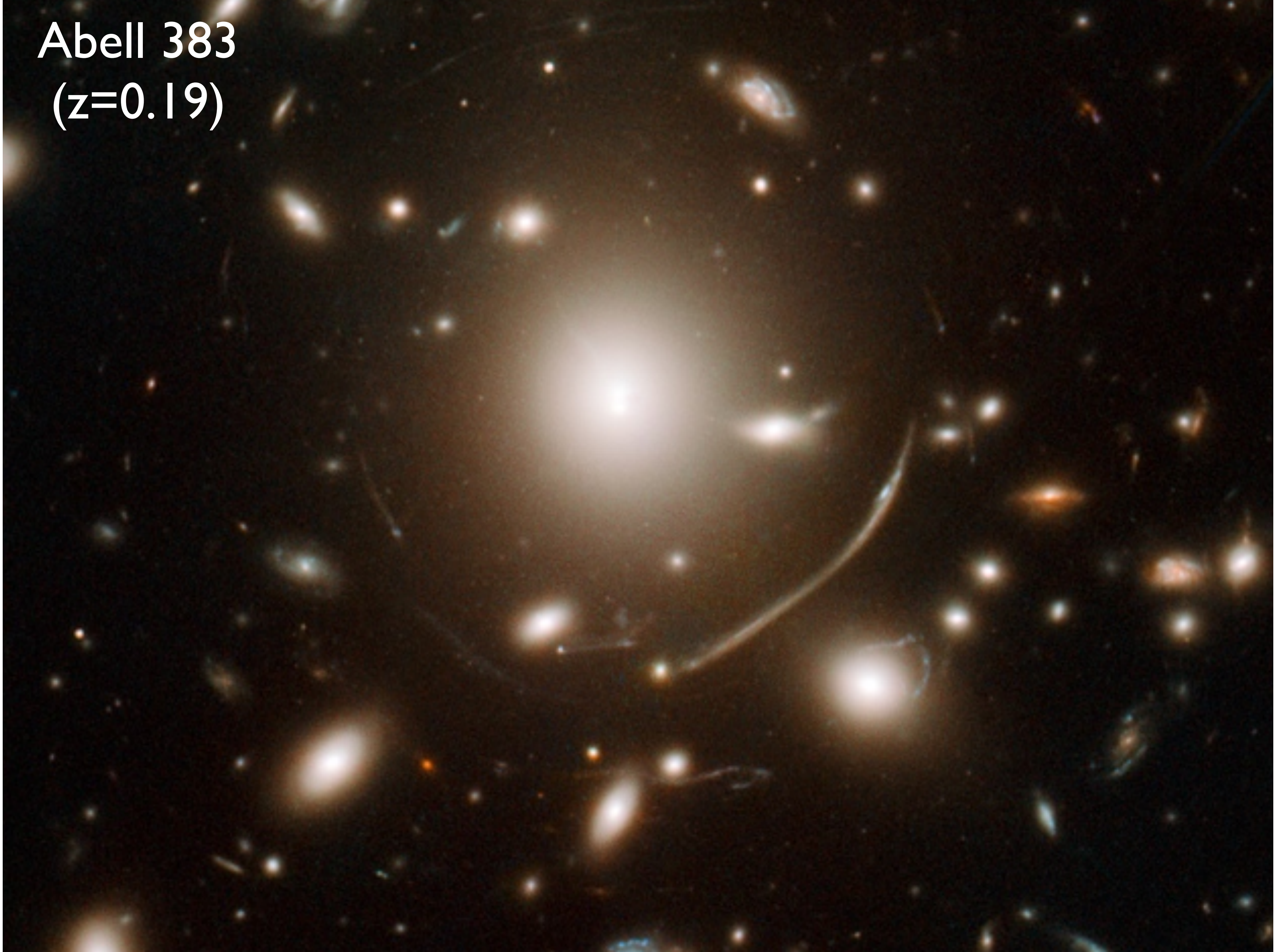
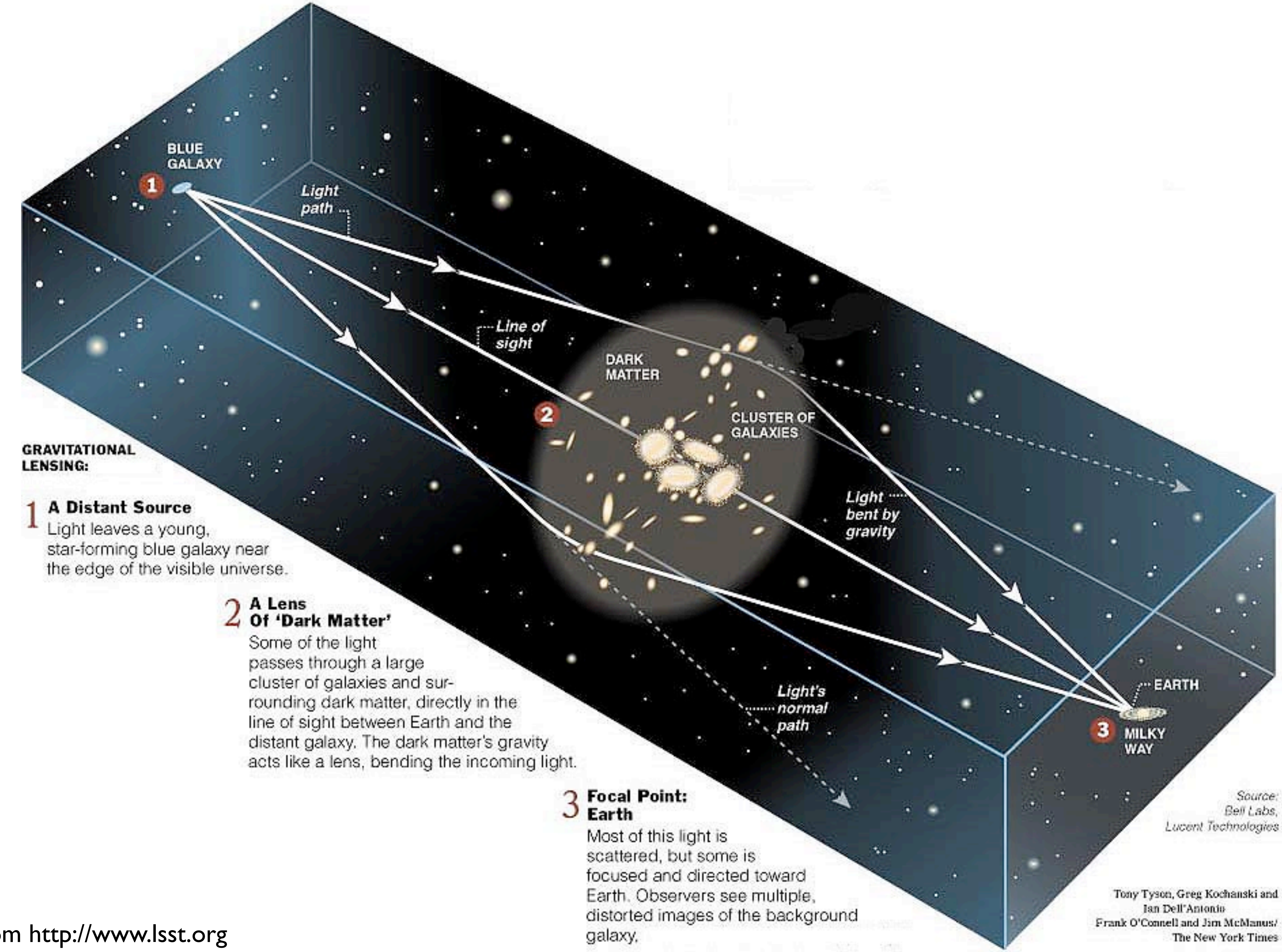



Abell 2218
(z=0.18)

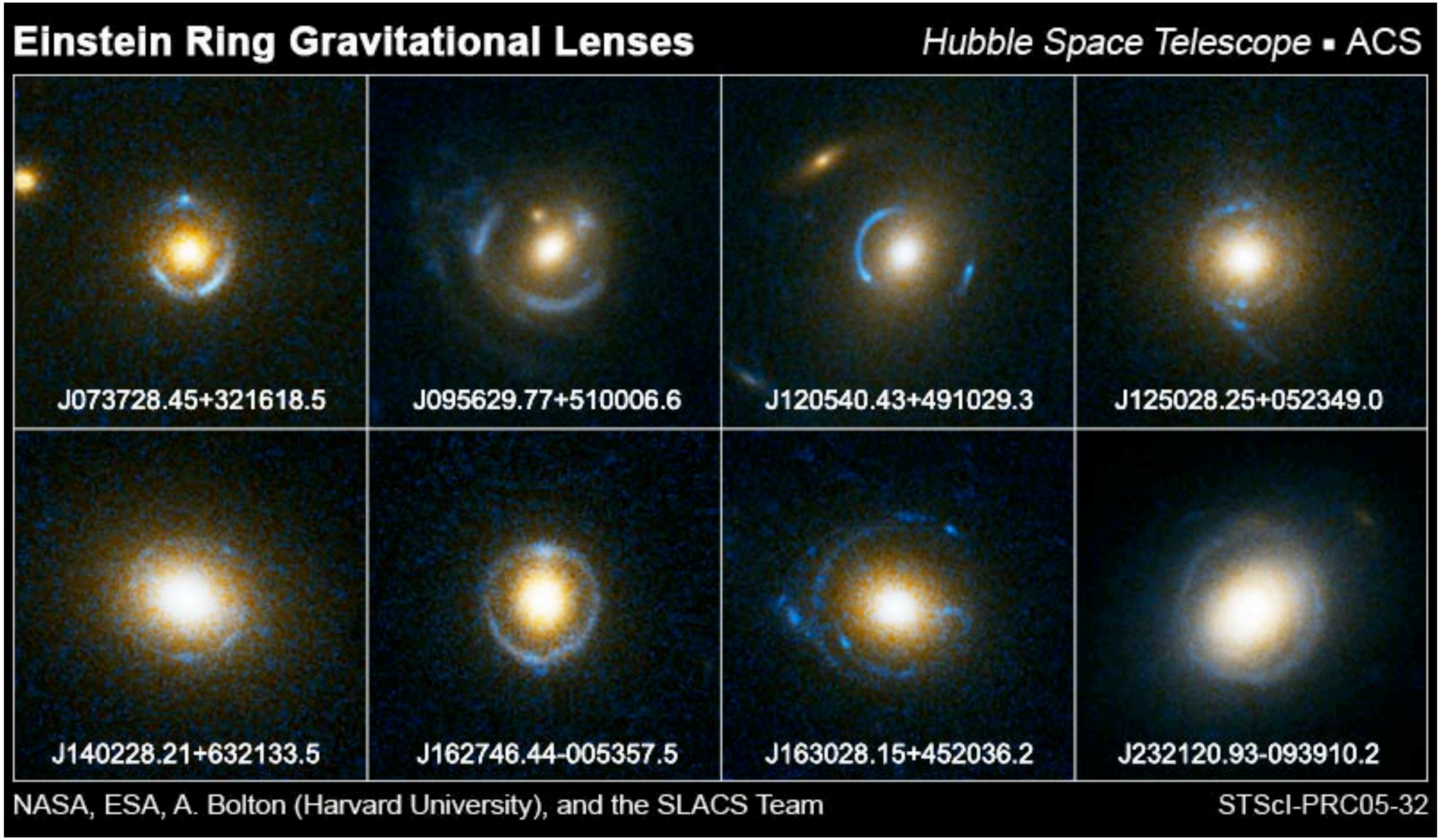

Abell 383
(z=0.19)

How does gravitational lensing work?



from http://www.lsst.org

Do you need a cluster of galaxies?

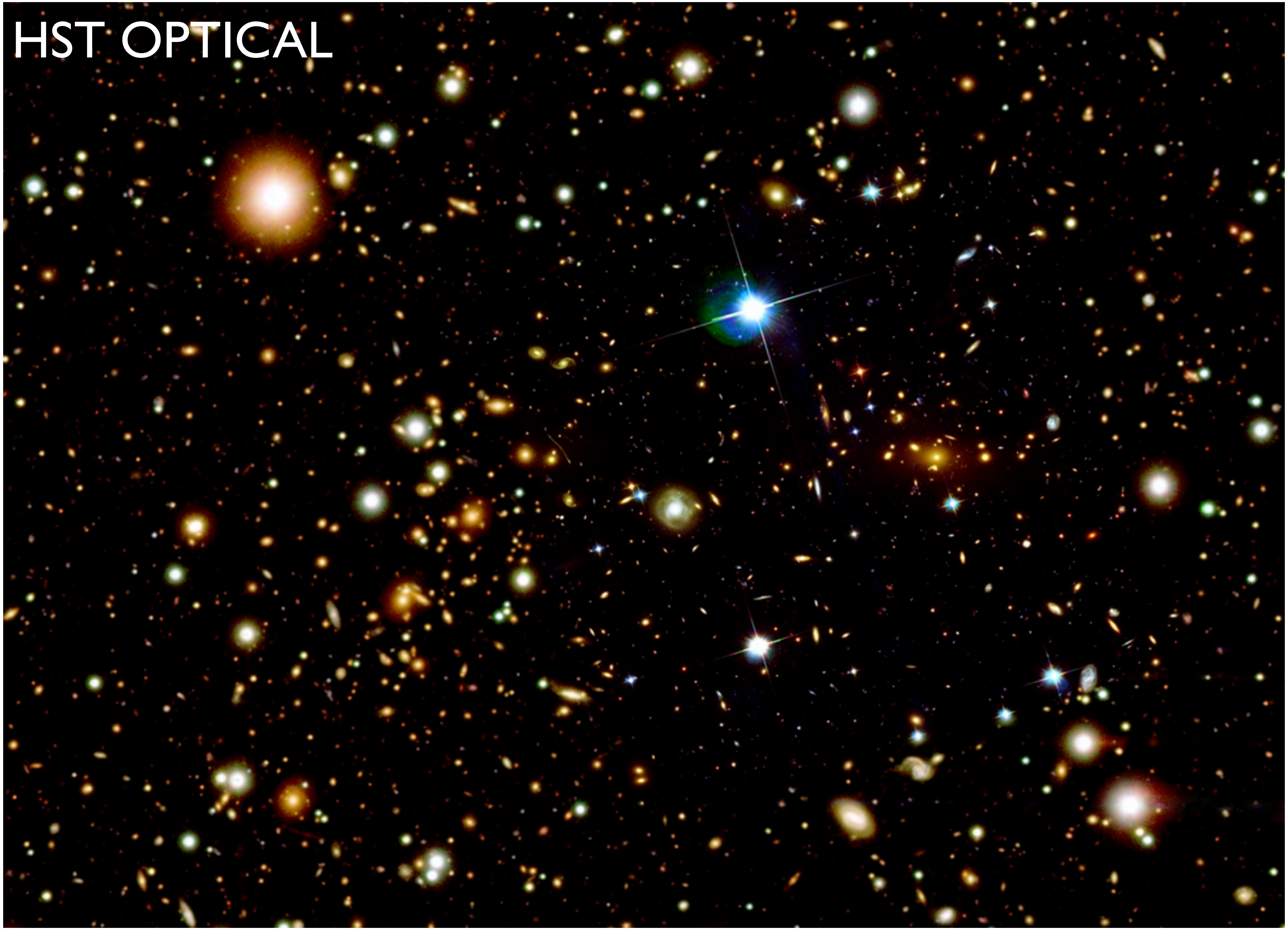


No, individual galaxies can be lenses too... BUT...

1) galaxy-galaxy lenses are only discovered serendipitously in large blank-field surveys
2) the lens and background source can be hard to disentangle

Cluster lensing: - allows selection of most likely lensing locations
- often no line-of-sight foreground object

Bullet Cluster 1E0657-56 (z=0.296)



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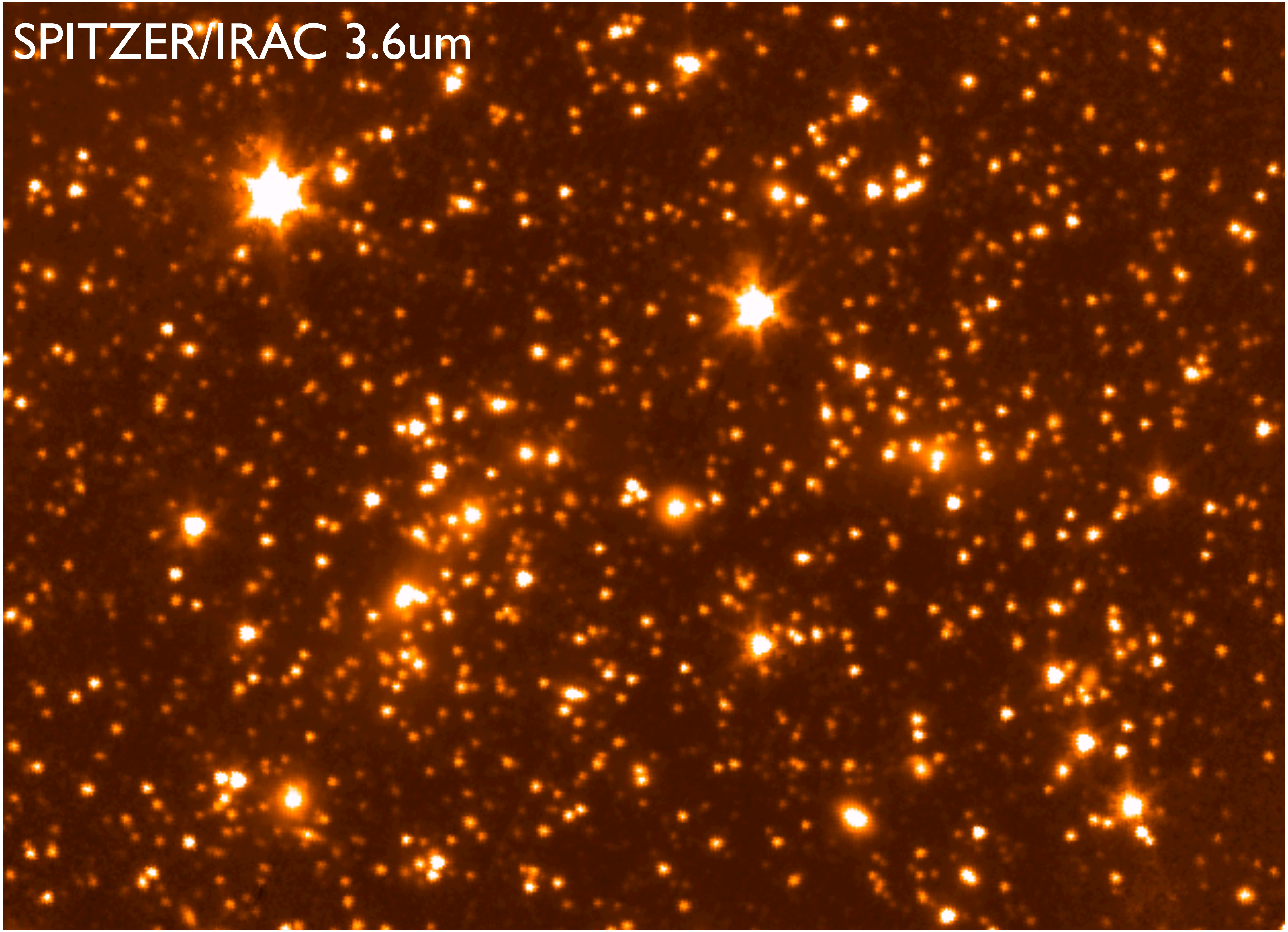

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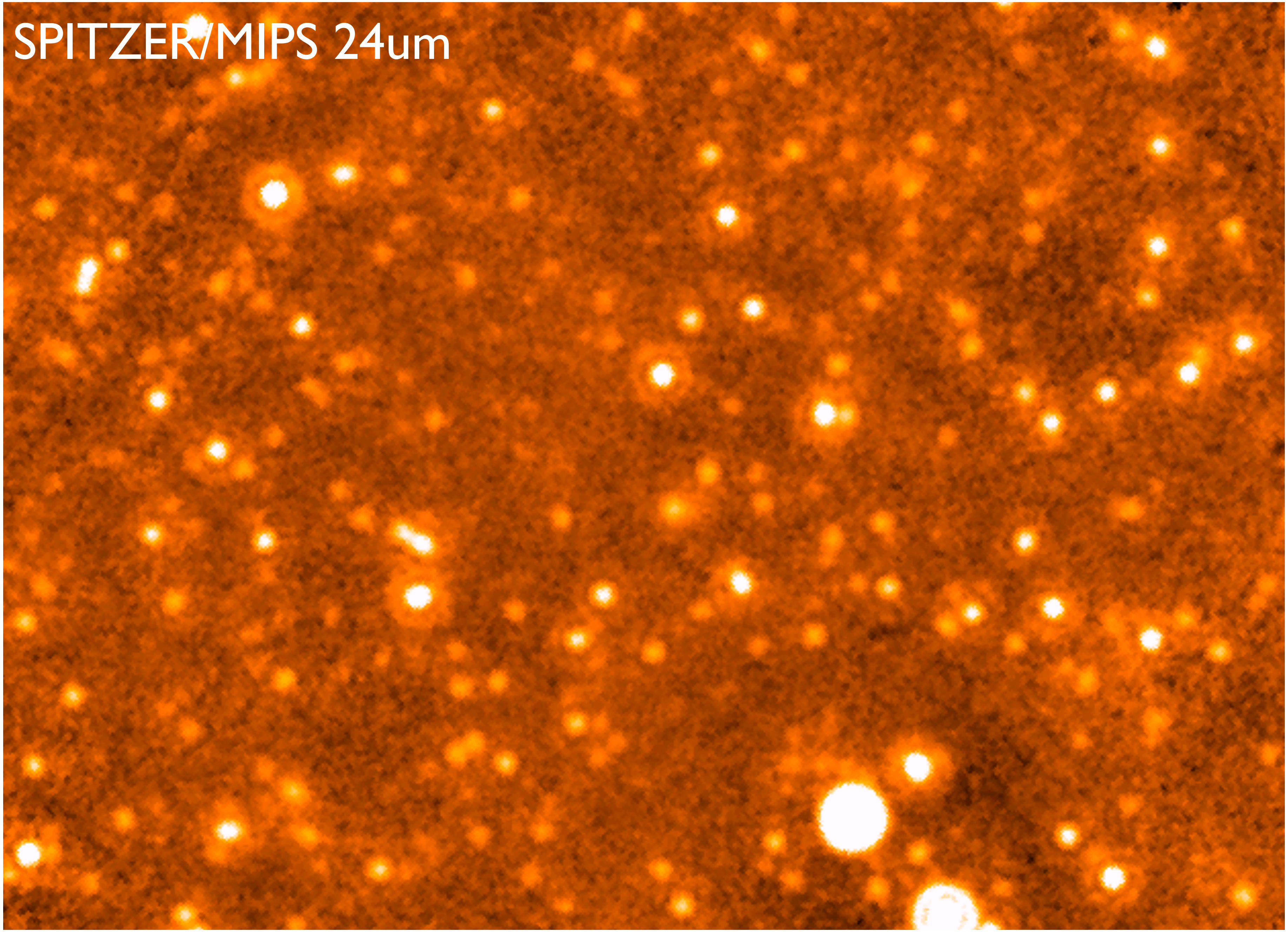
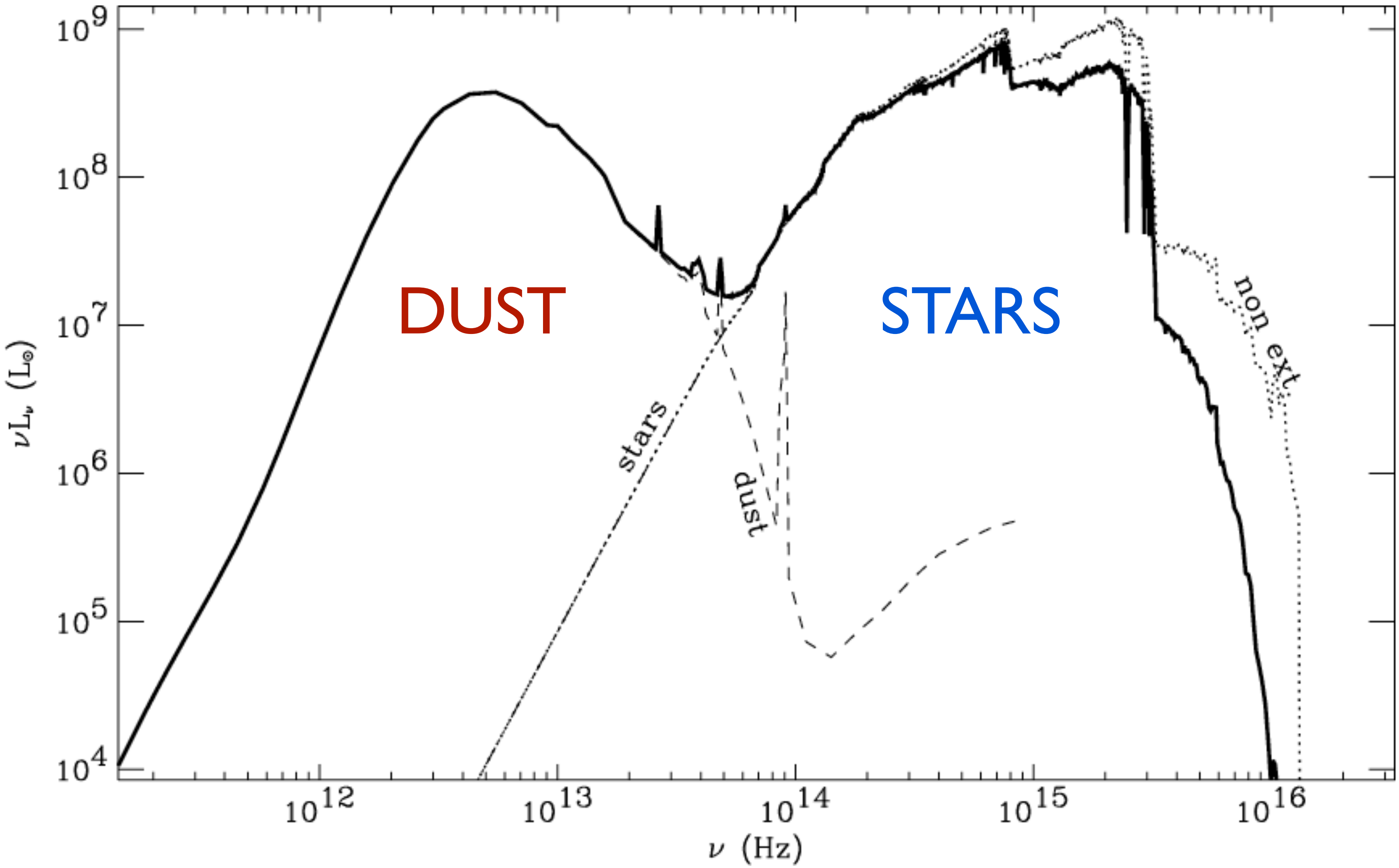


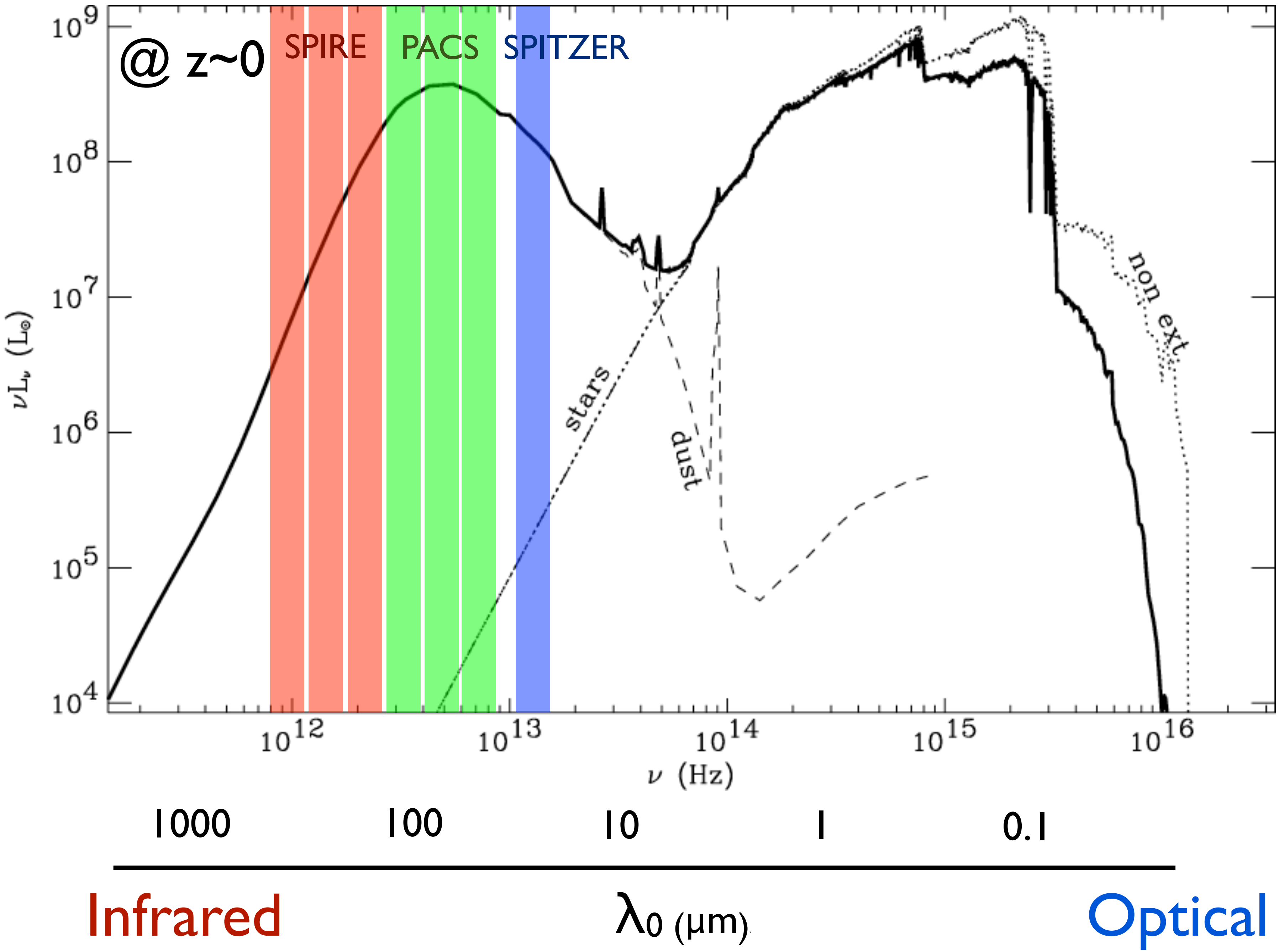
Galaxy spectrum



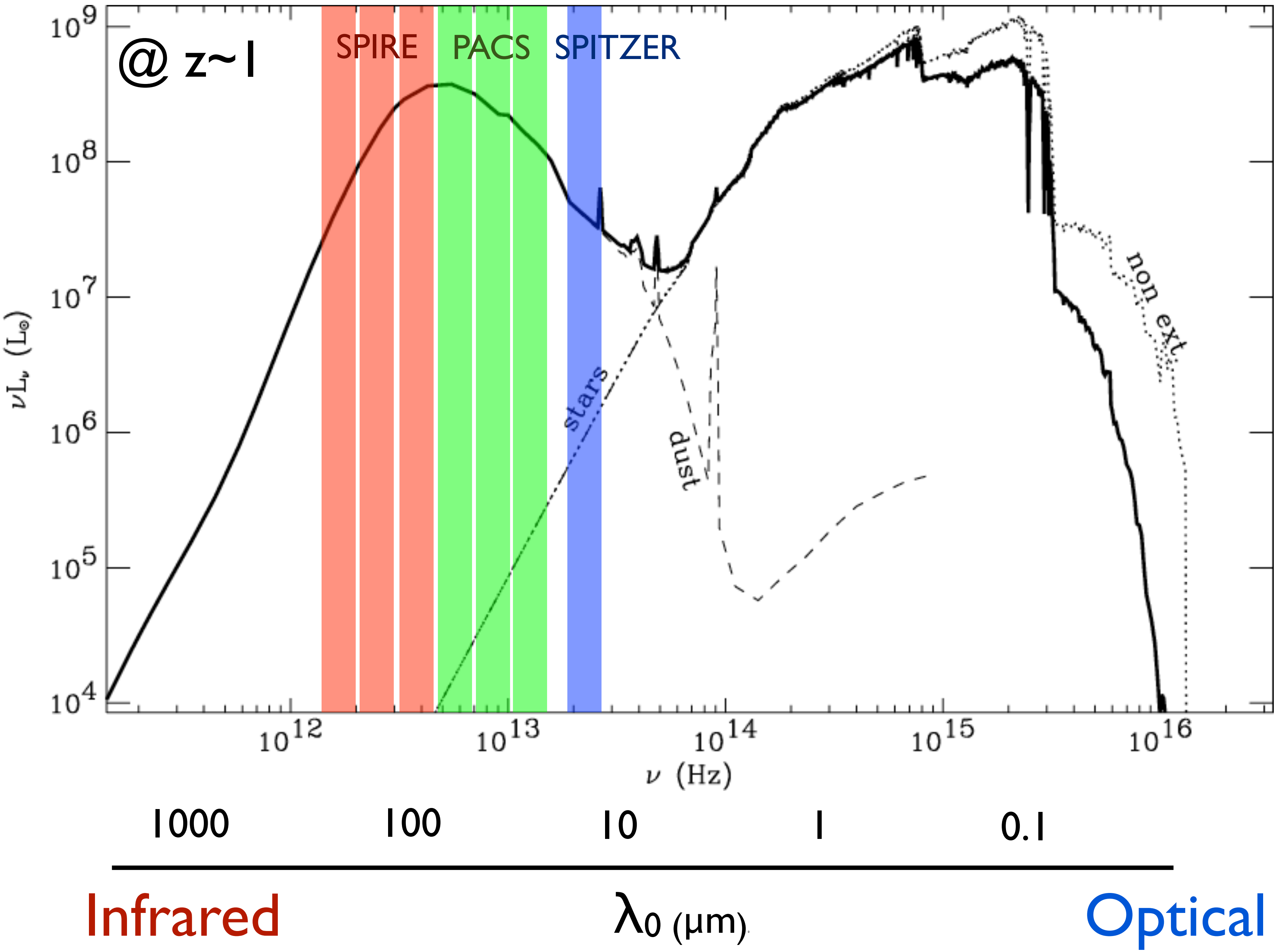
1000 100 10 1 0.1

Infrared λ_0 (μm) Optical

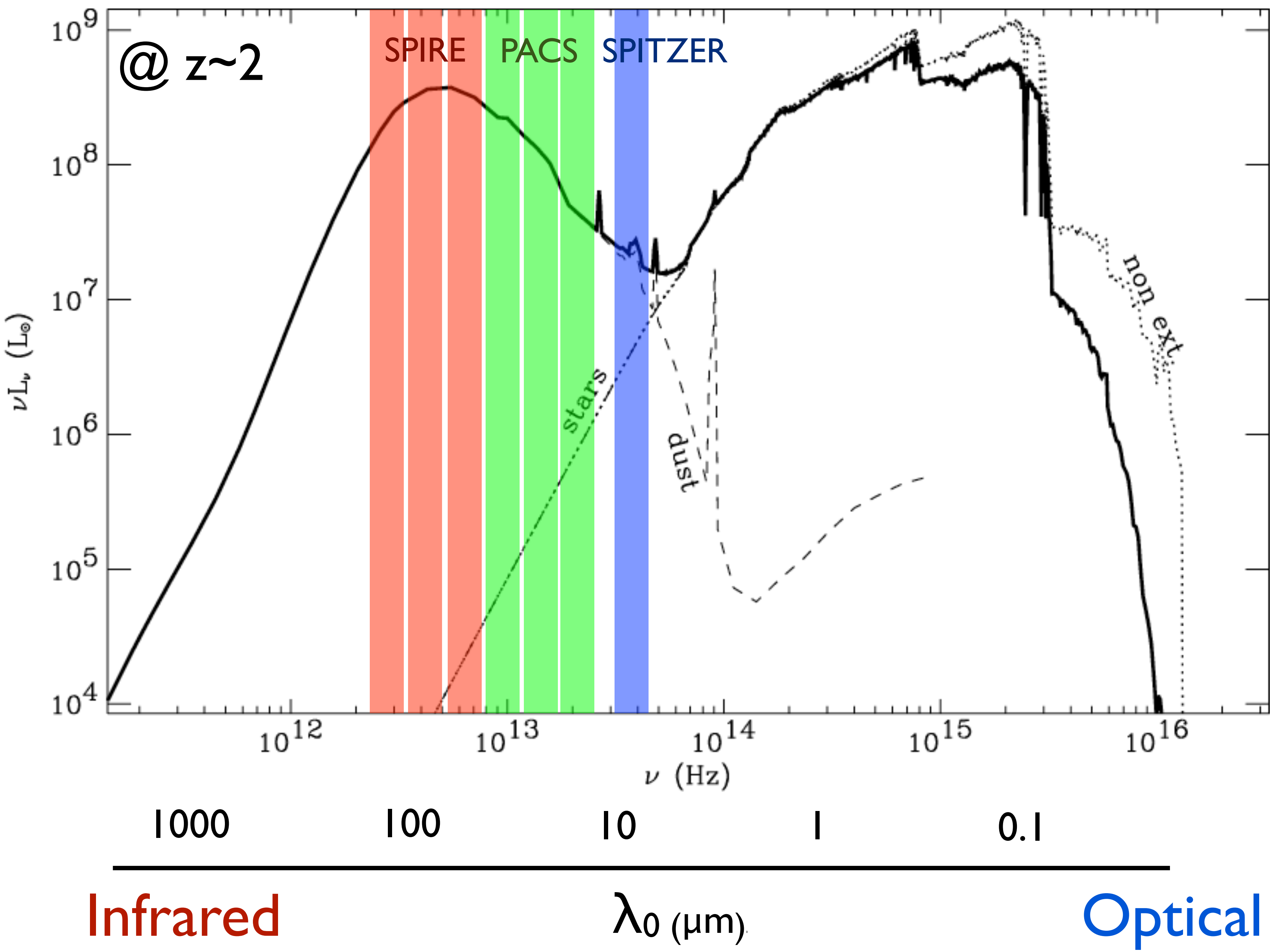
Galaxy spectrum



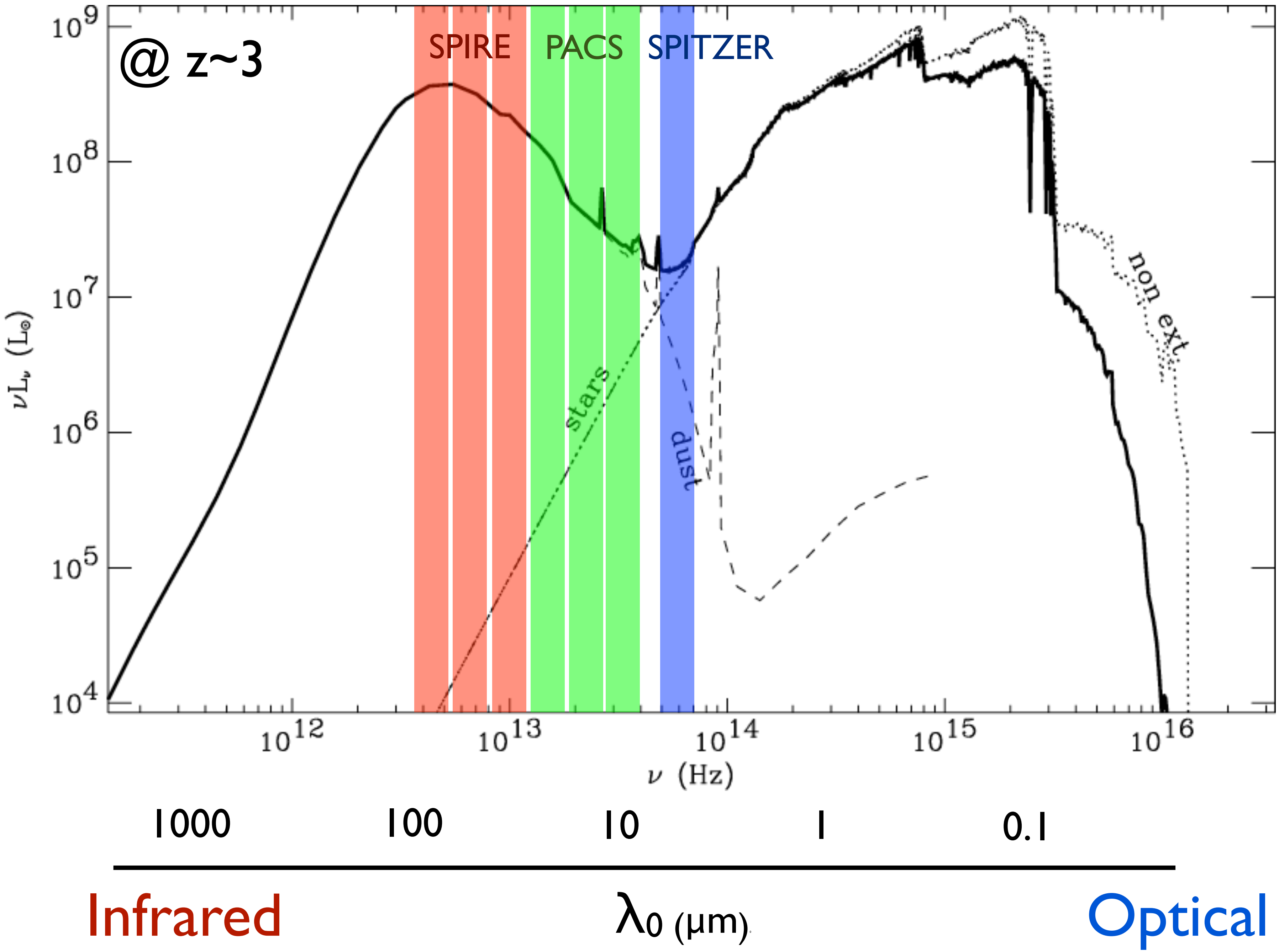
Galaxy spectrum



Galaxy spectrum



Galaxy spectrum



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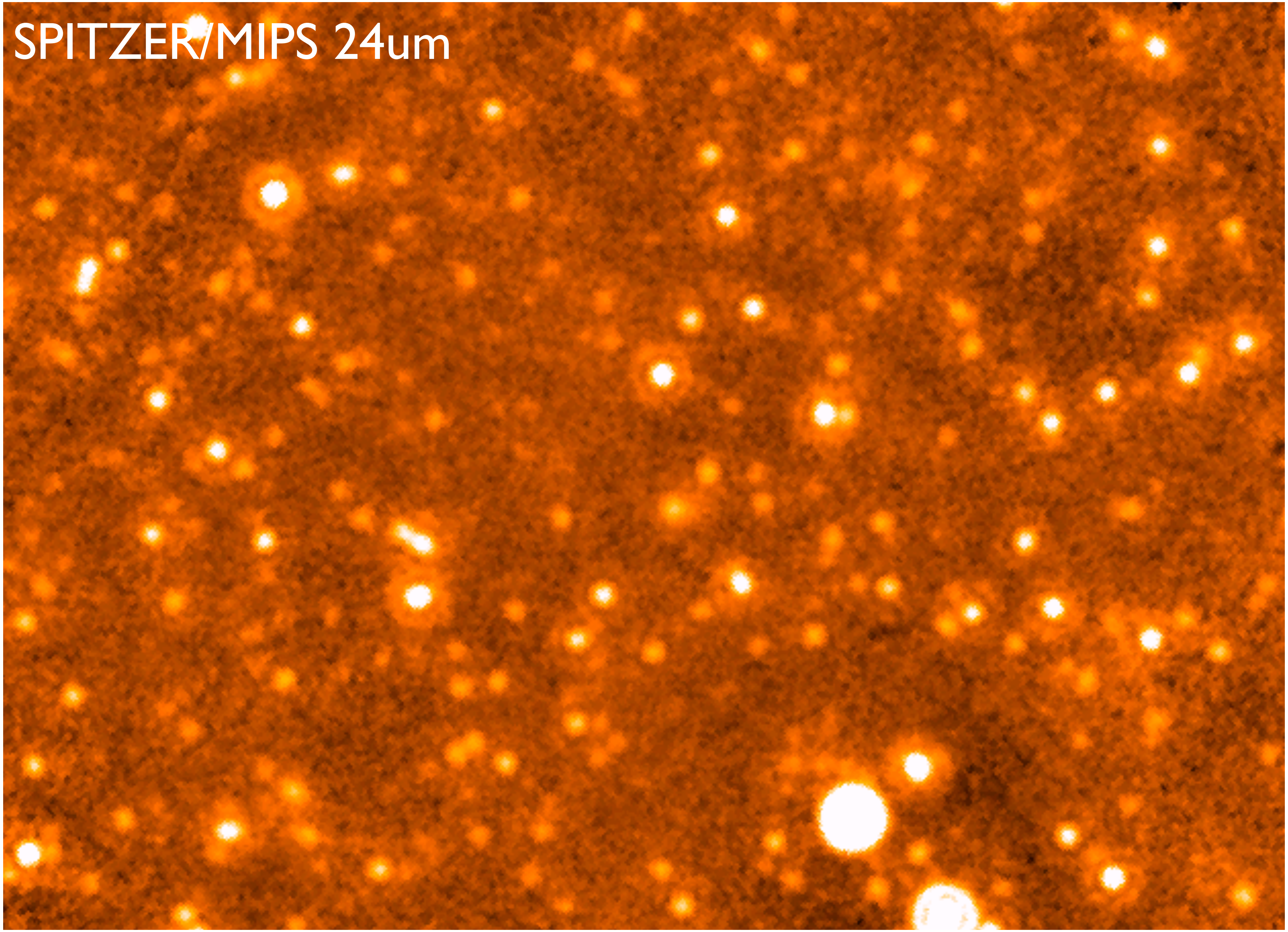

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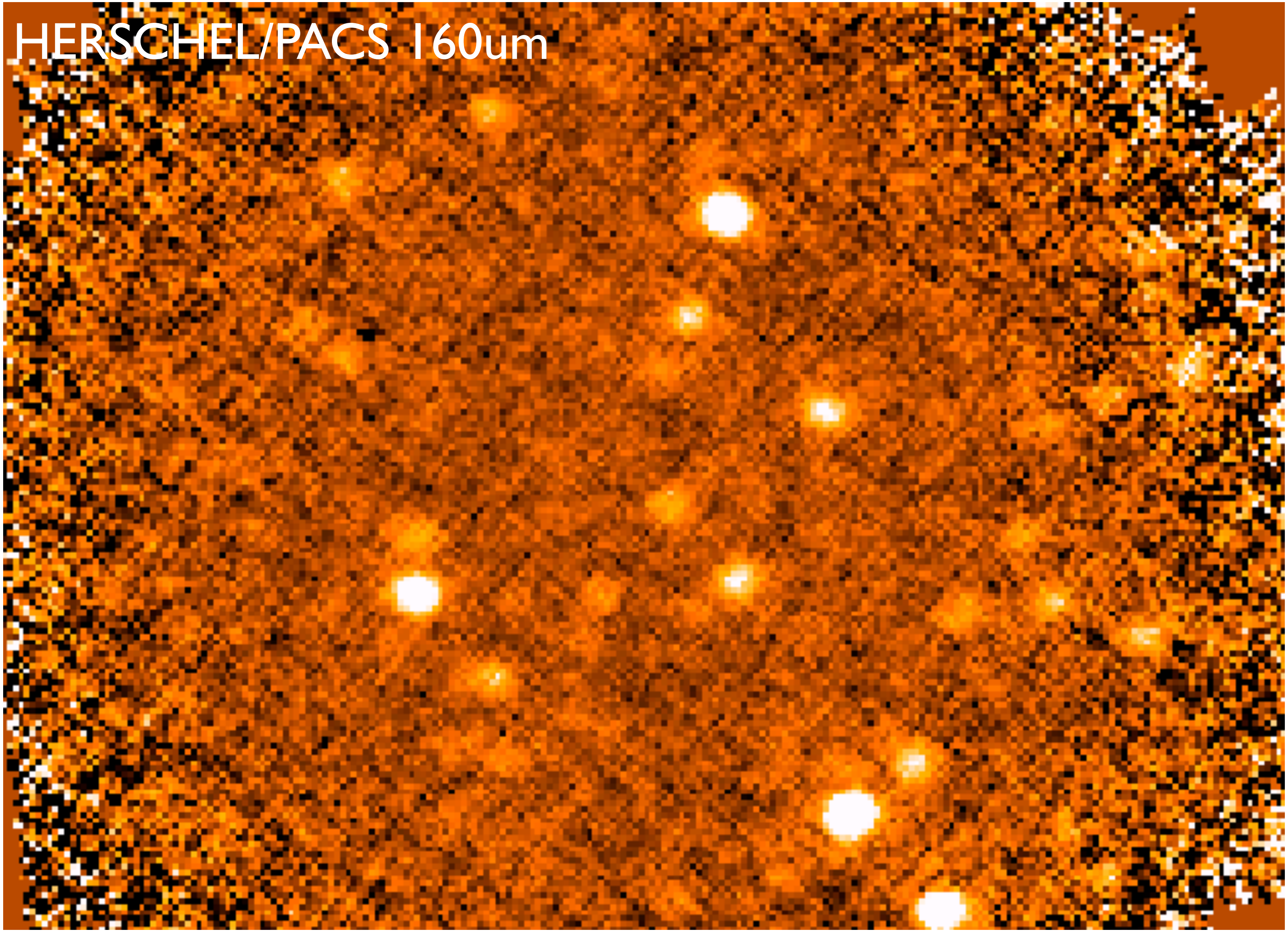

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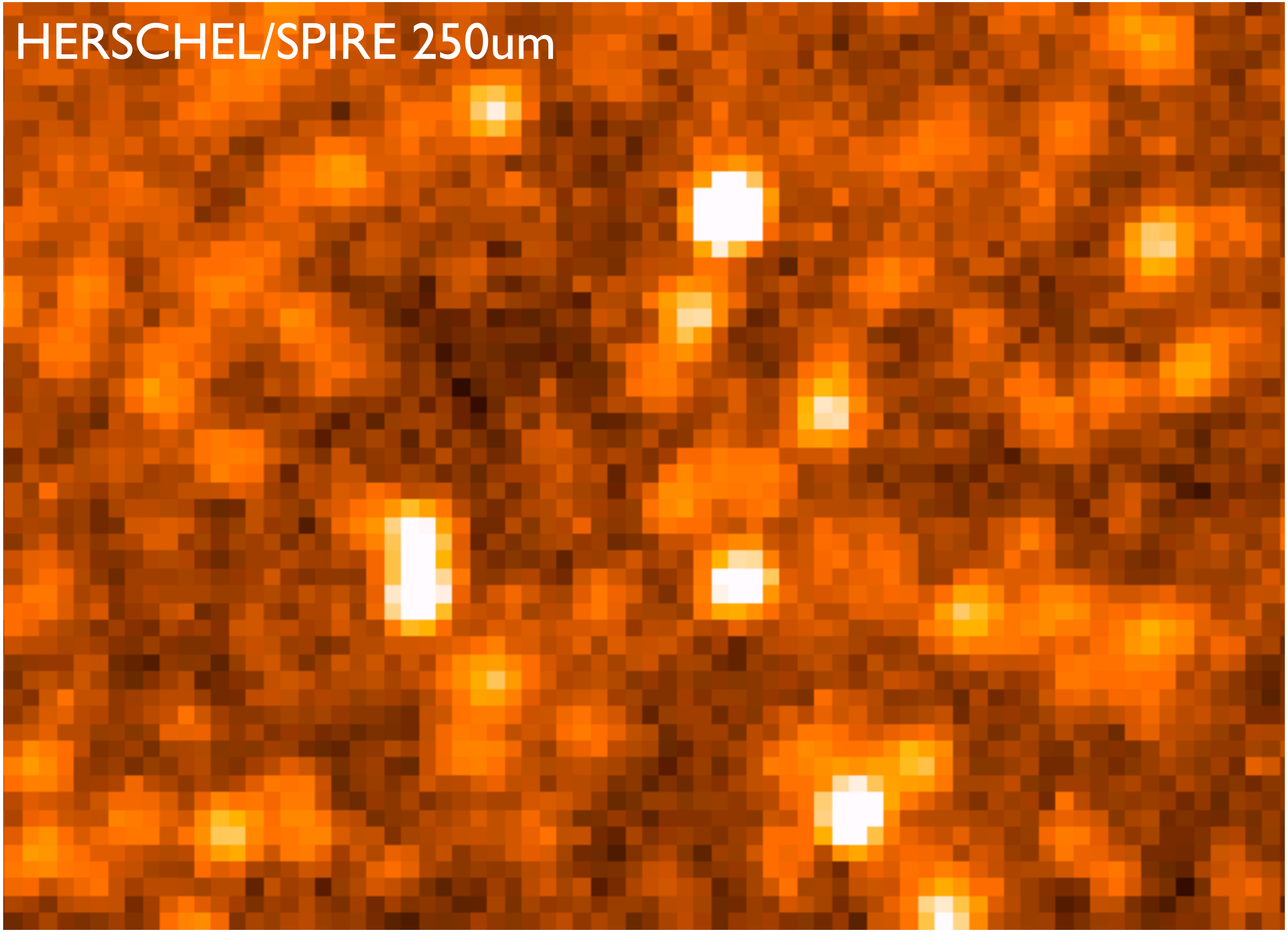

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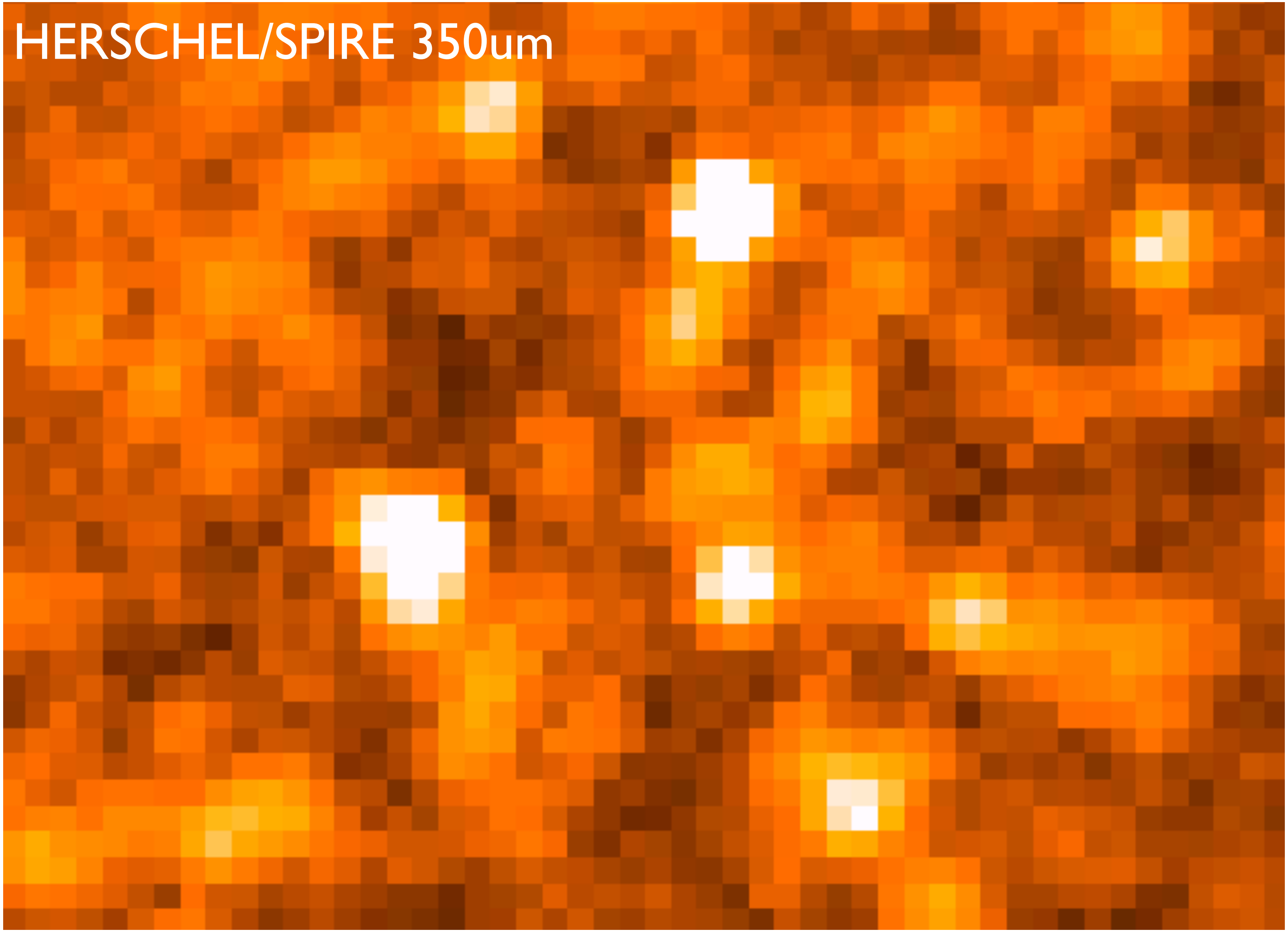
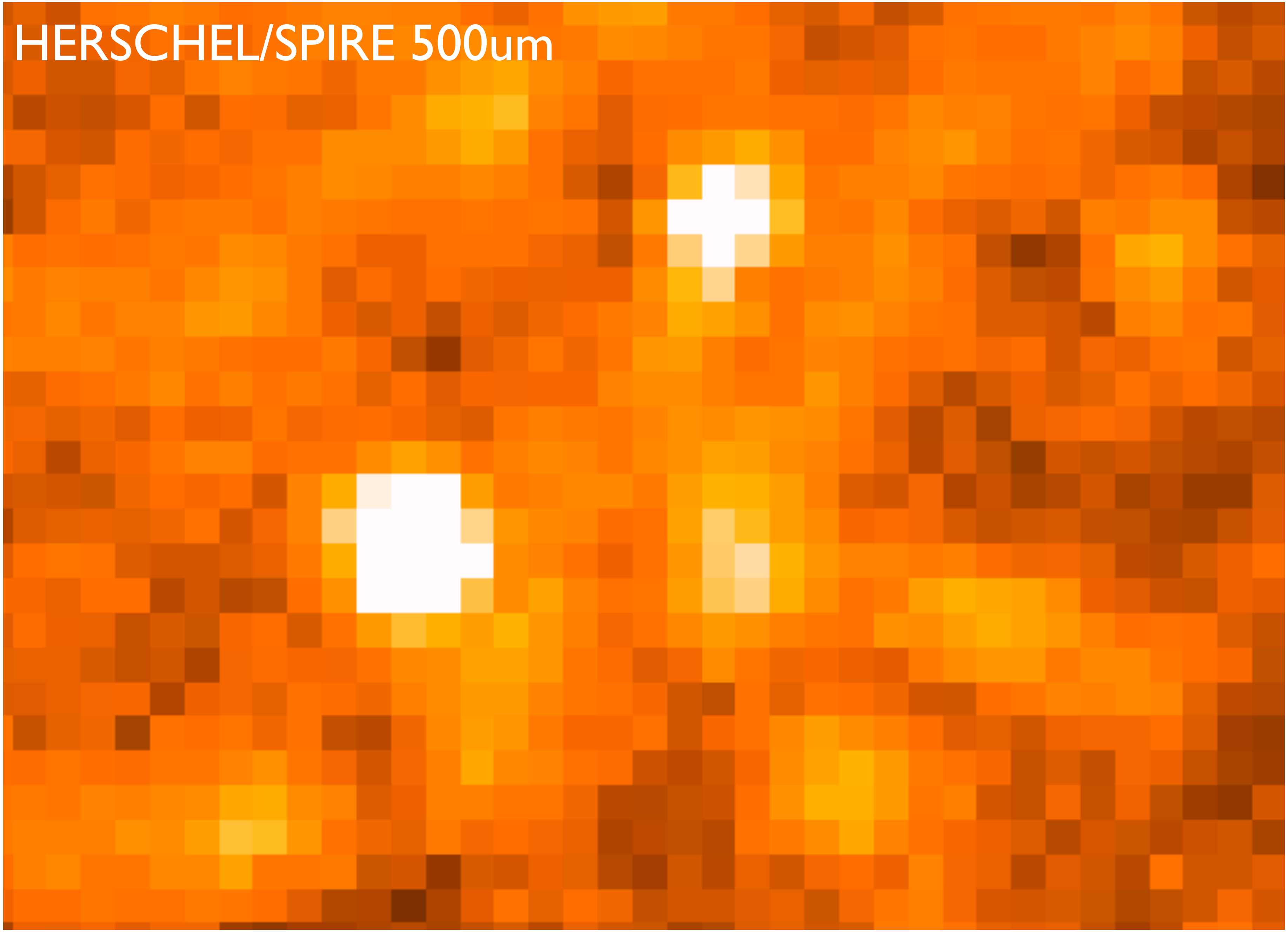
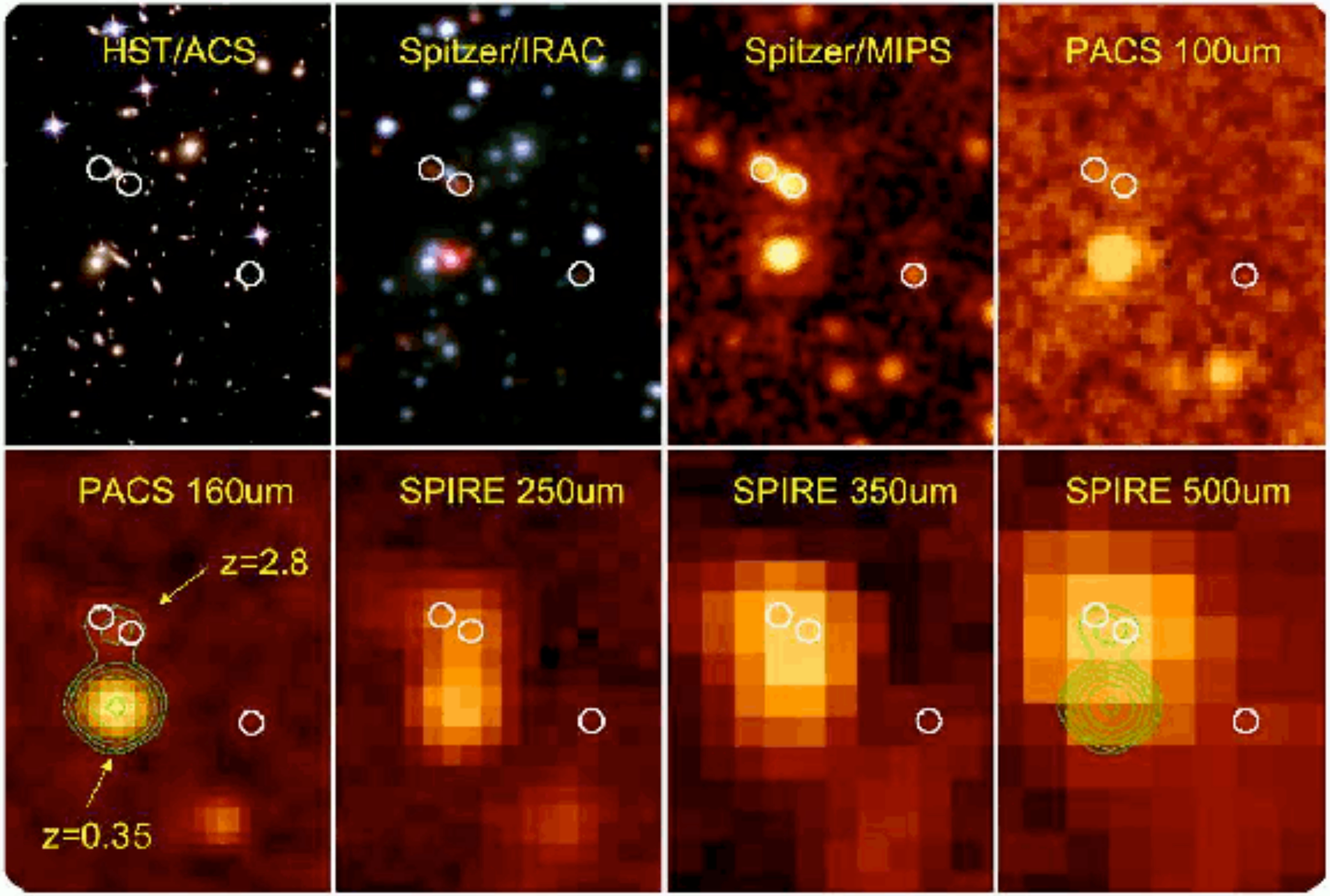


Bullet Cluster 1E0657-56 (z=0.296)



Faint (LIRG; $5 \times 10^{11}\ L_\odot$) lensed source at z=2.8



[Rex+10]

Magnification factor of ~75x

Observed Herschel flux densities:	7.0, 24.5, 65.3, 98.6, 101.4 mJy
Corrected for lensing:	0.09, 0.3, 0.9, 1.3, 1.4 mJy

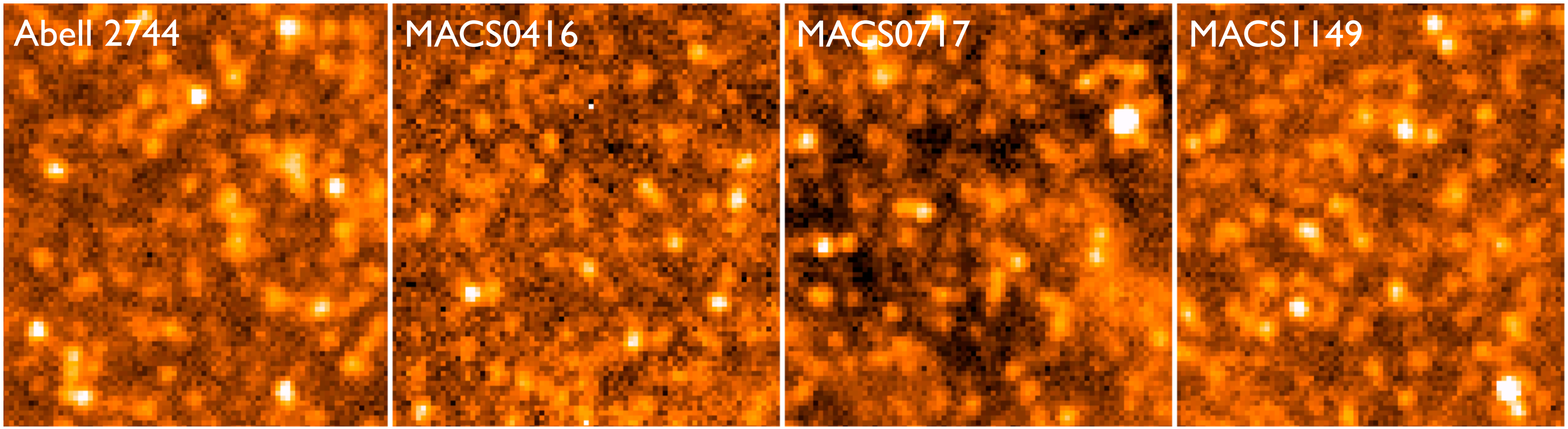
Such a source would be impossible to observe without lensing

The Herschel Lensing Survey (HLS)

PI: Eiichi Egami (Steward Observatory, Arizona)

- HLS-deep
    - 64 clusters (0.1<z<1.0); previously well-studied massive galaxy clusters
    - Deep 100-500μm PACS+SPIRE imaging (~2.4, 4.7, 9.4, 10.6, 12.0 mJy)... ~5 deg^2
    - Full IRAC coverage and ~75% MIPS 24μm coverage
    - Sample includes all 25 CLASH clusters (HST Treasury Survey with 16 UV-NIR bands)
    - Sample includes all 4 HST Frontier Fields (ultra-deep HST DDT program)

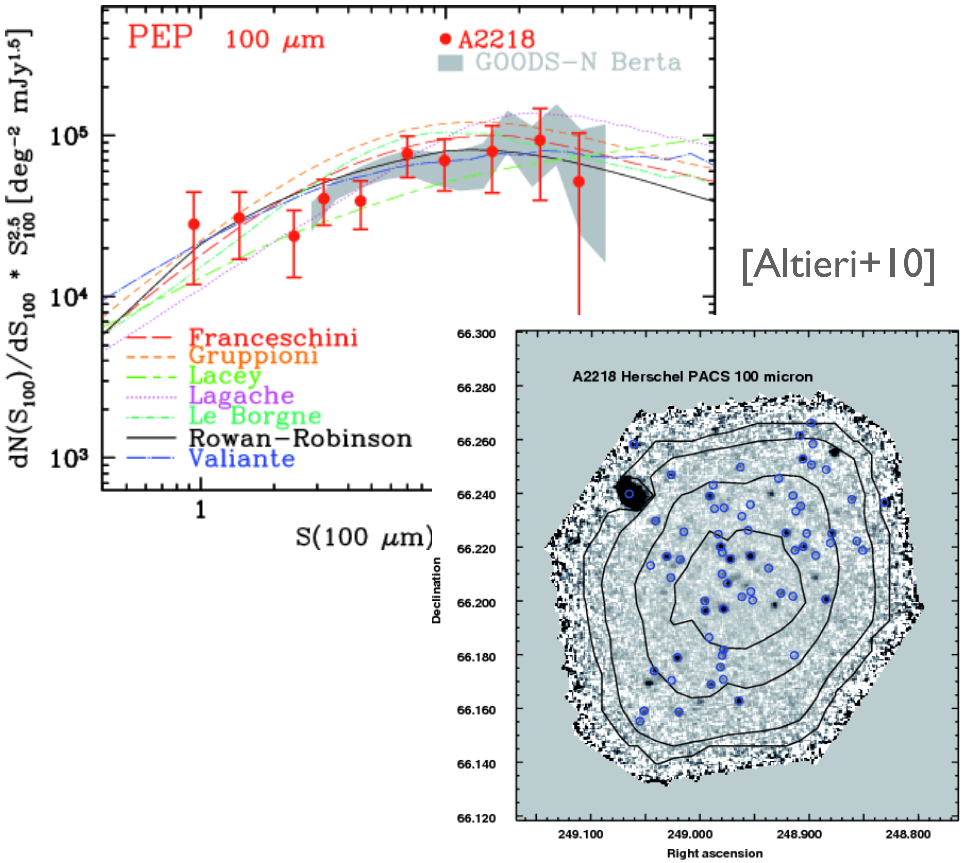
- HLS-snapshot
    - 527 clusters (0.1<z<1.0) from the MACS (ROSAT), SPT and CODEX samples
    - Shallower (but near confusion) 250-500μm SPIRE imaging (~14, 19, 20 mJy)... ~10 deg^2



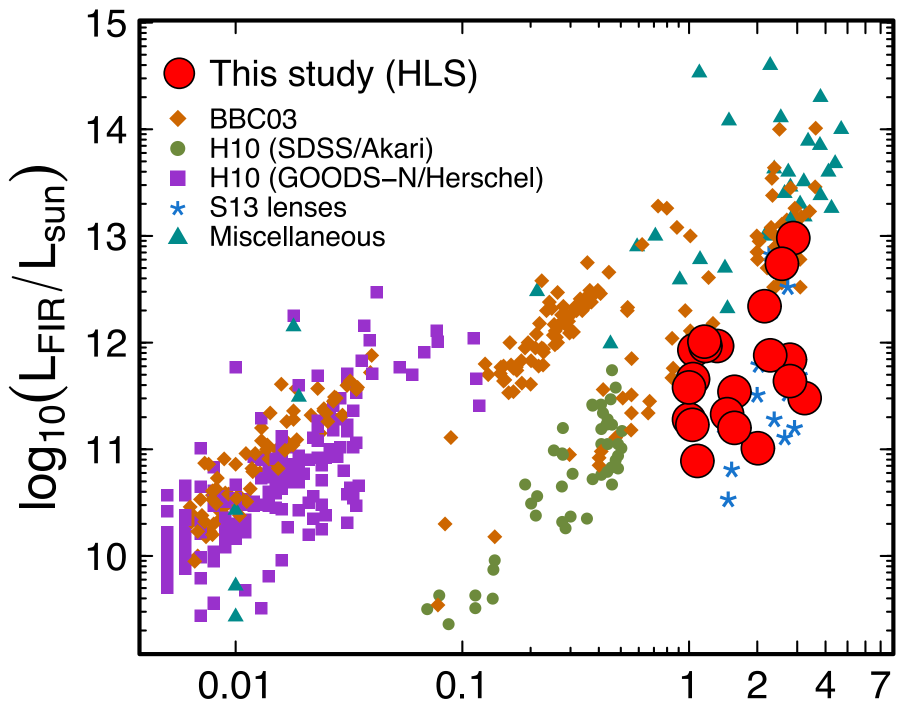
The Herschel Lensing Survey (HLS)

- Large sample of lensed galaxies

Herschel number counts (Abell 2218 only)



[Altieri+10]



[Rawle+in prep.]

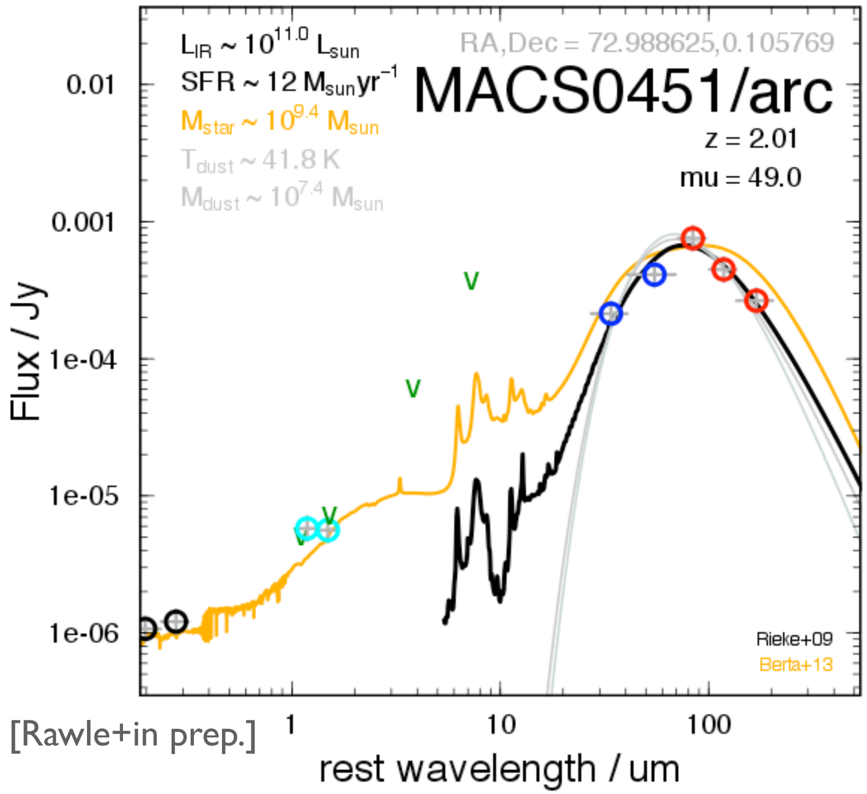
In-depth view of Herschel-detected cluster-lensed sources with spectroscopically-confirmed redshifts (20 sources; 8 @ z>2)

LIRG-types in the early Universe (z=1−4)

The Herschel Lensing Survey (HLS)

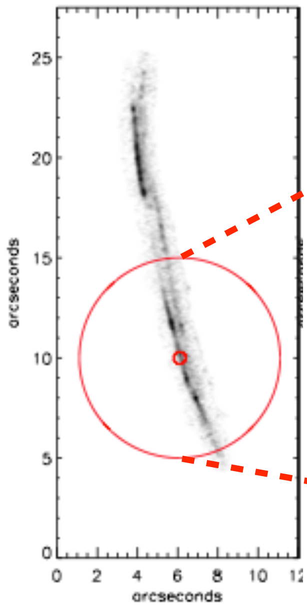
- The brightest lensed galaxies in amazing detail
  - Locate the brightest star-forming (submm) galaxies at high redshift
  - Ideal for exciting follow-up of individual sources using the next generation of observatories (ALMA, JVLA, JWST...)

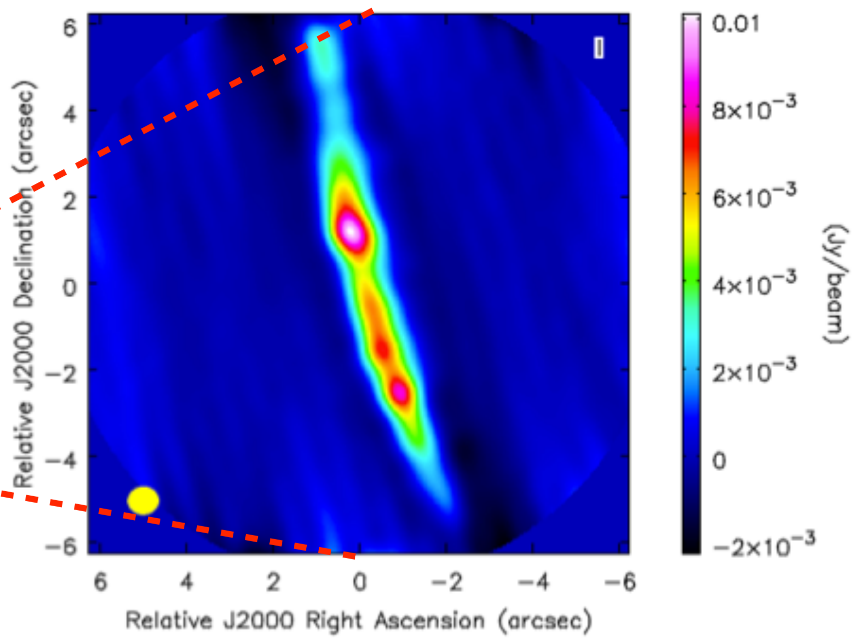
MACS0451: giant arc @ z=2 (49x mag)



[Rawle+in prep.]

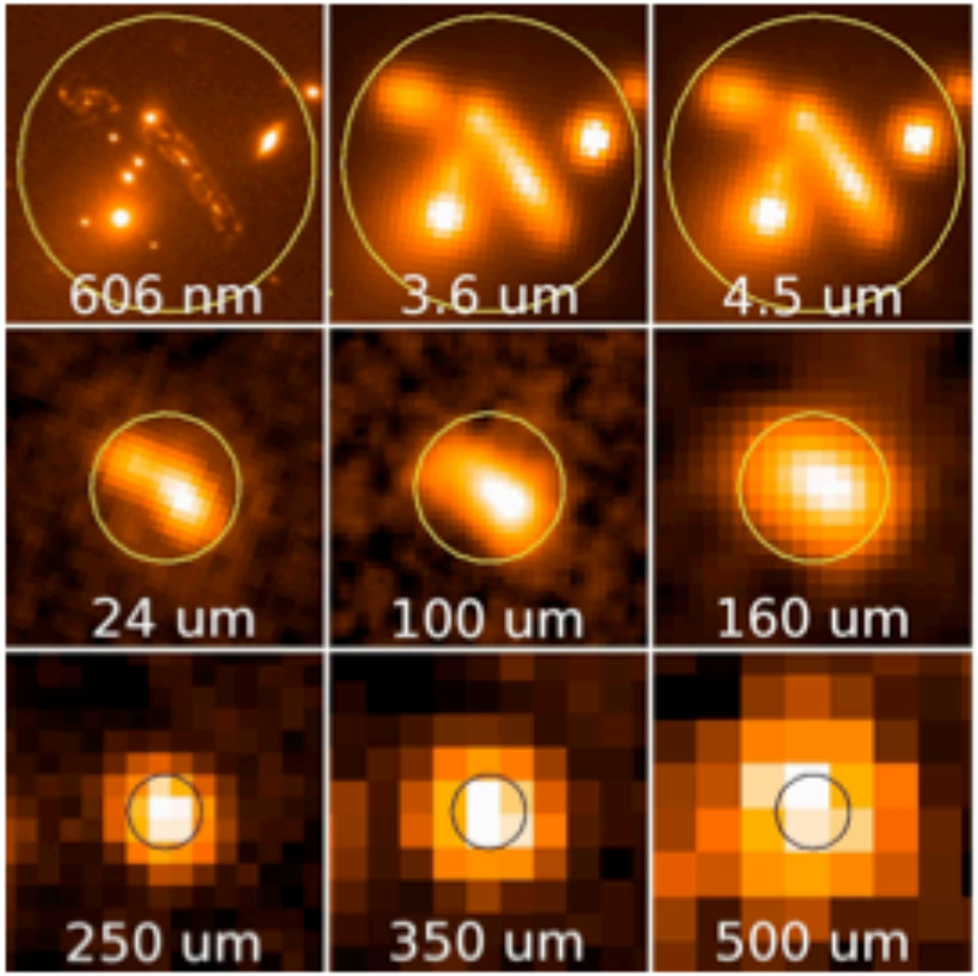
optical, [CII] ALMA resolution < 200pc !



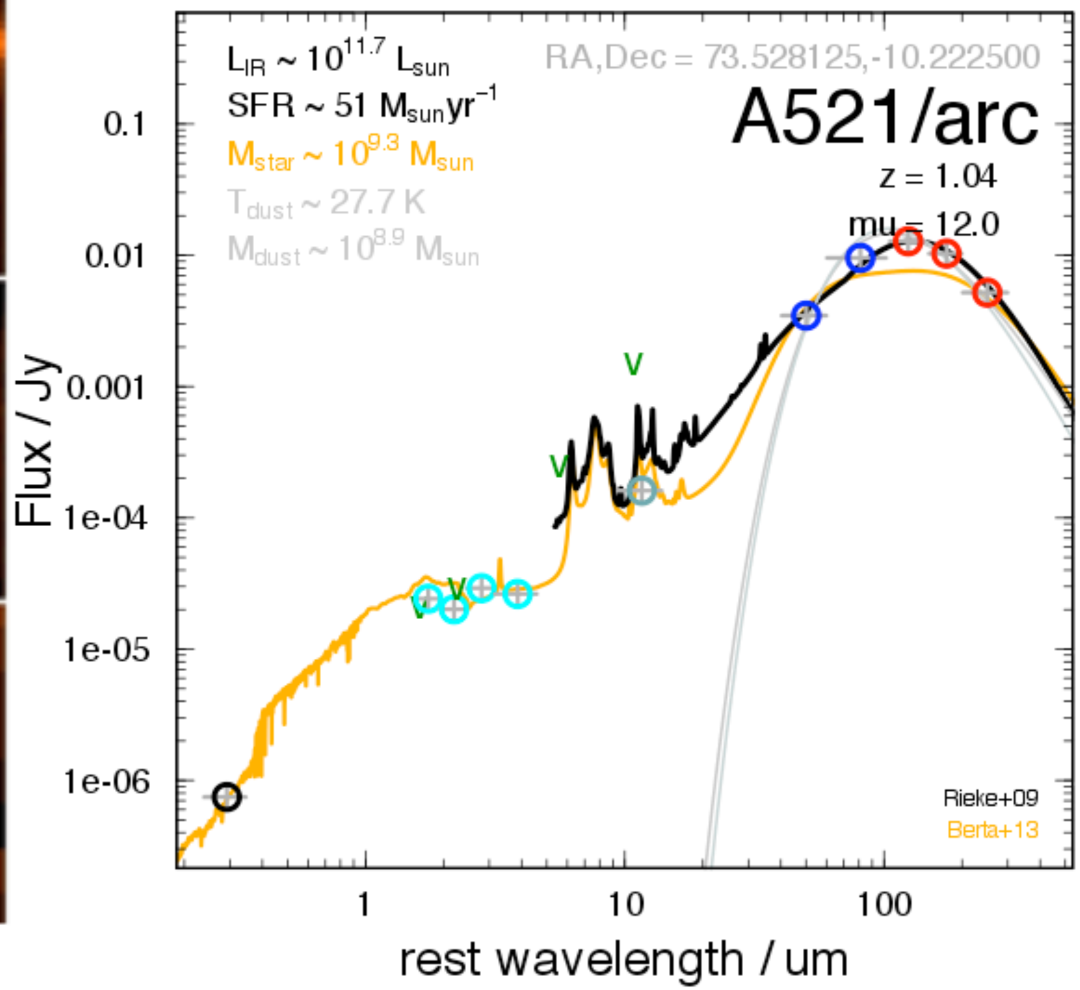


The Herschel Lensing Survey (HLS)

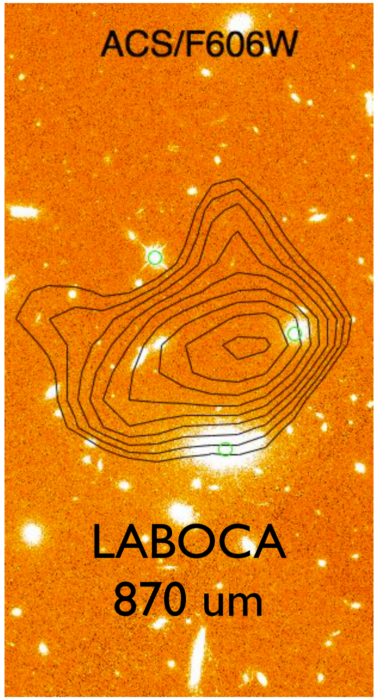
Abell 521: giant arc @ z=1 (12x mag)

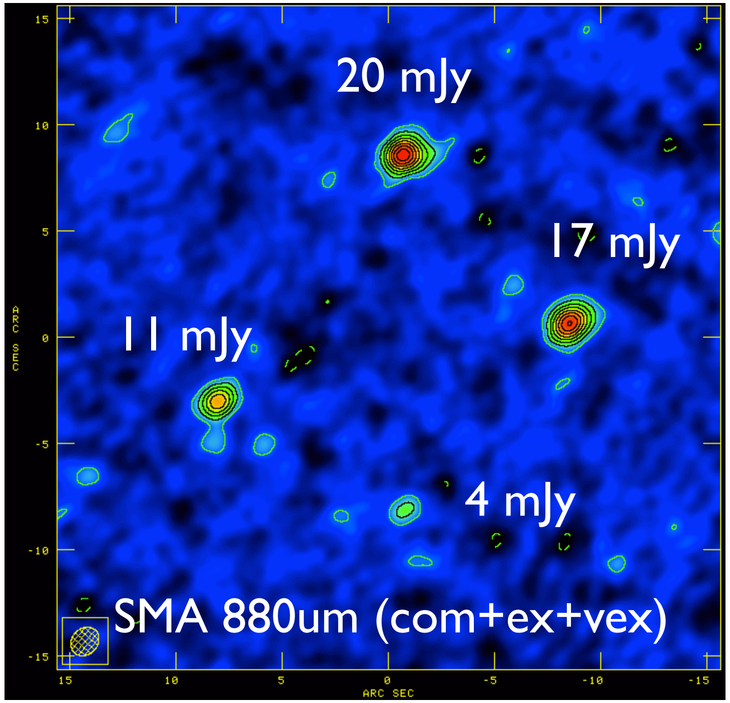


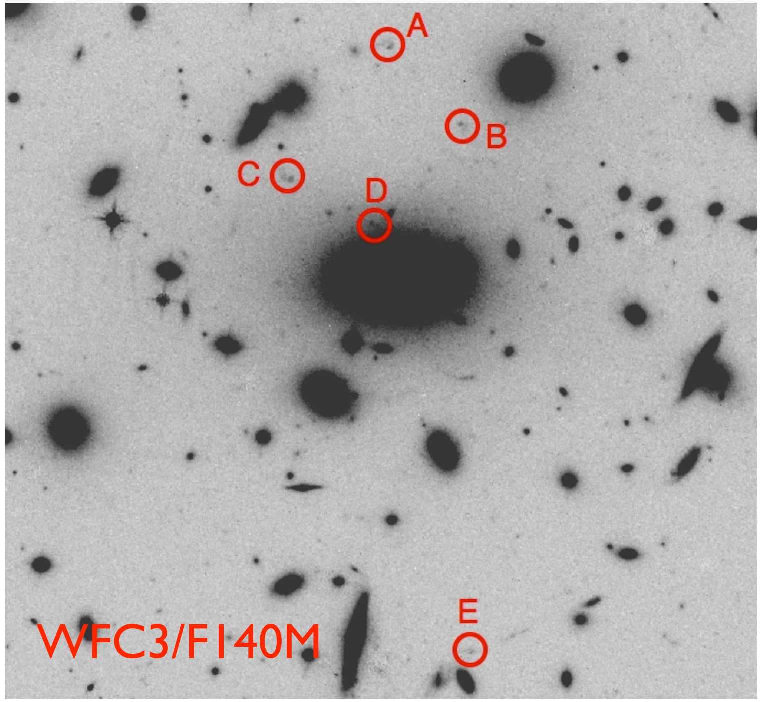
[Rawle+in prep.]



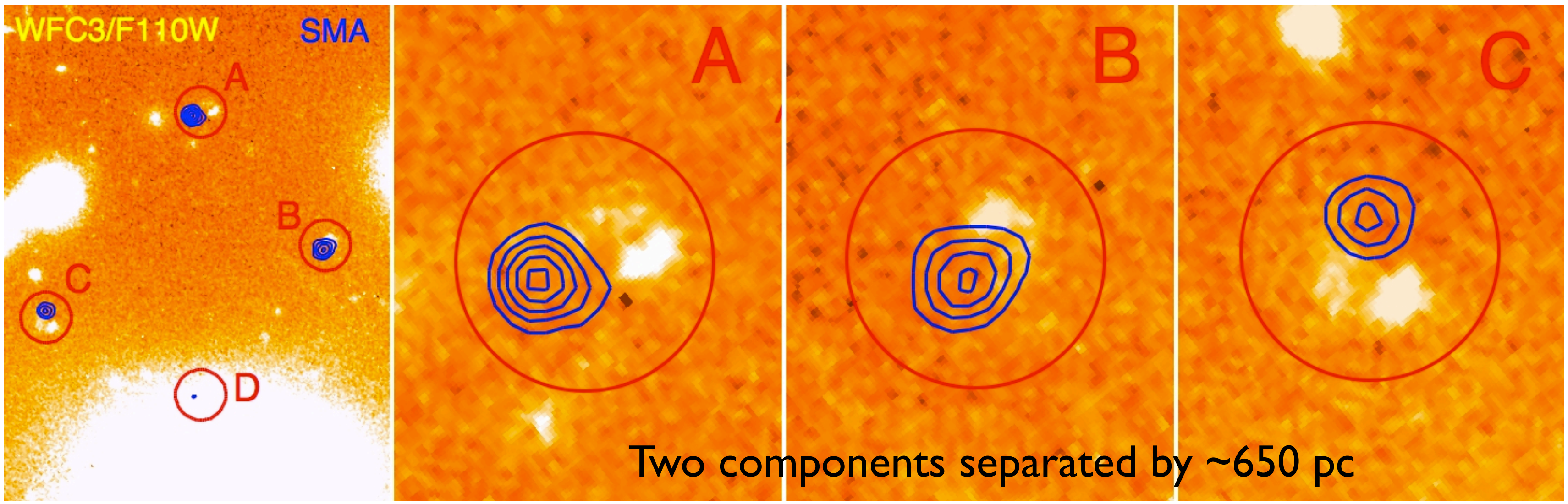
z=4.7 SMG behind MACS0257





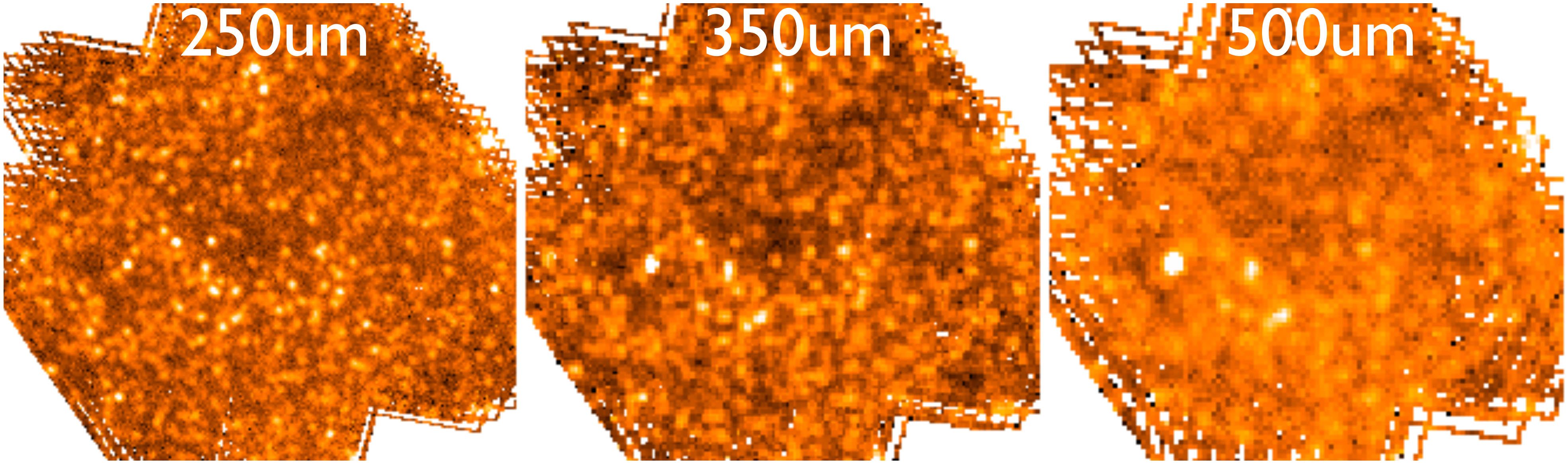


Magnification factor >130 for A+B+C+D→ $L_{IR} < 5 \times 10^{11} L_{\odot}$



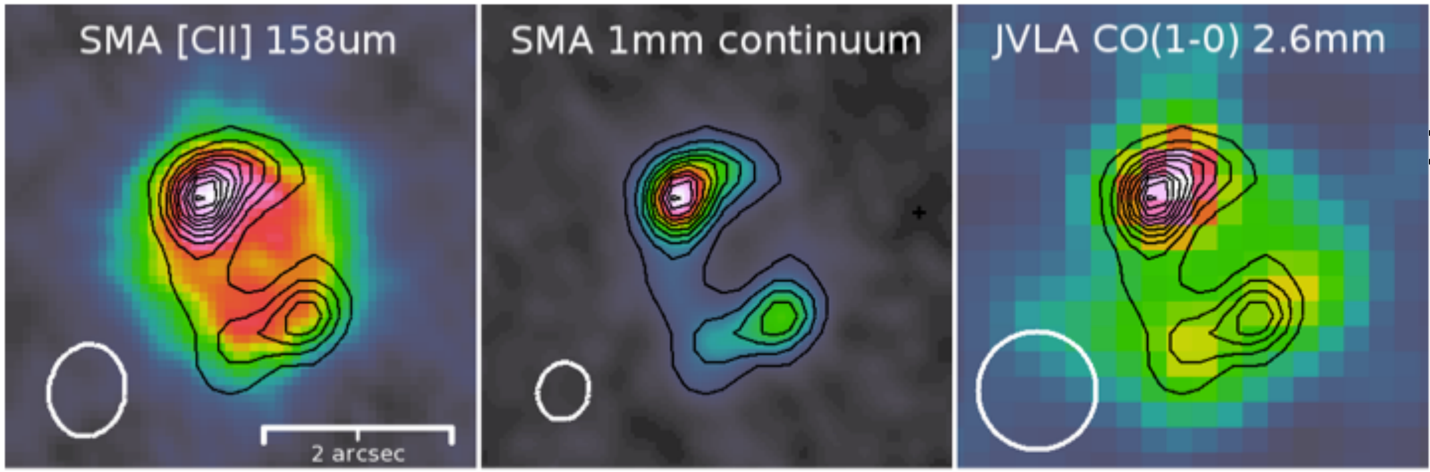
z=5.2 merging system behind Abell 773 (1)

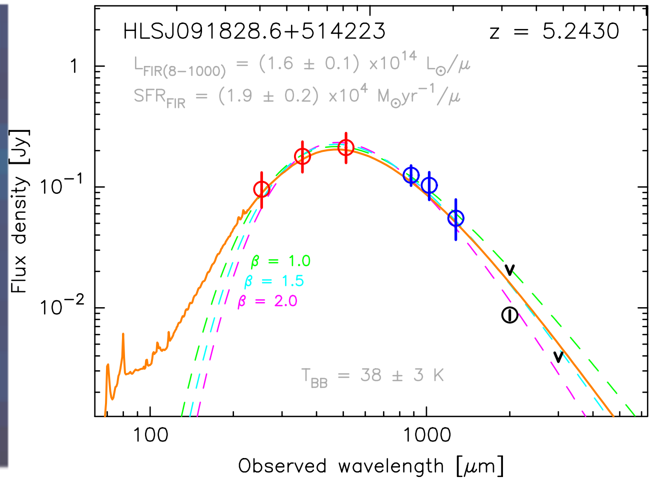
Combes+12 - Discovery paper



~200mJy @ 500um

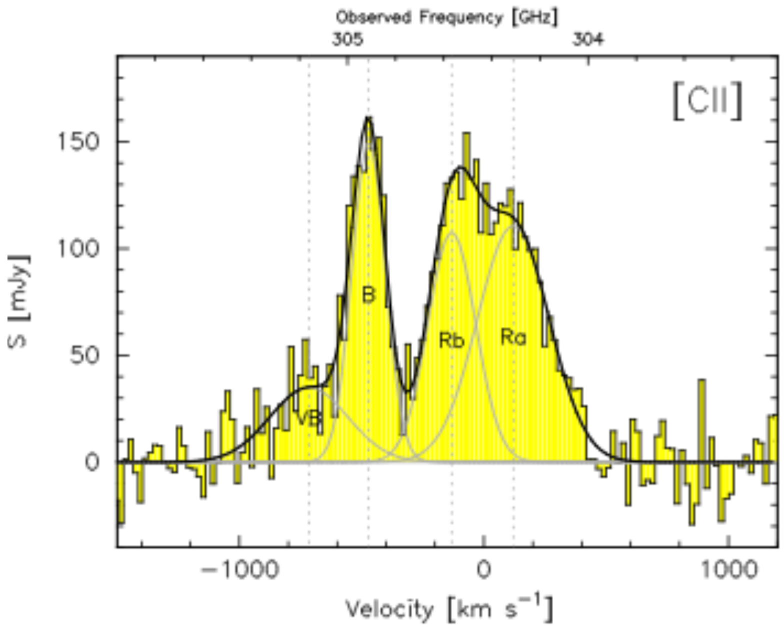
Rawle+13 (arXiv:1310.4090) - Resolved spectroscopy

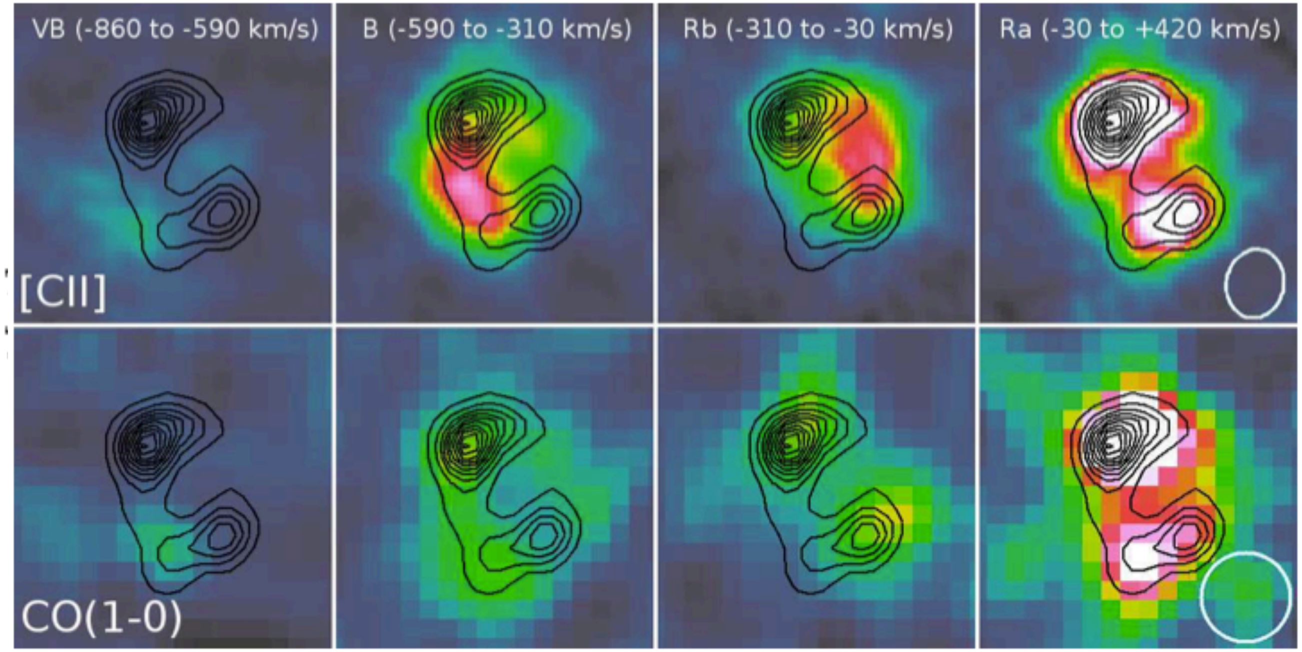




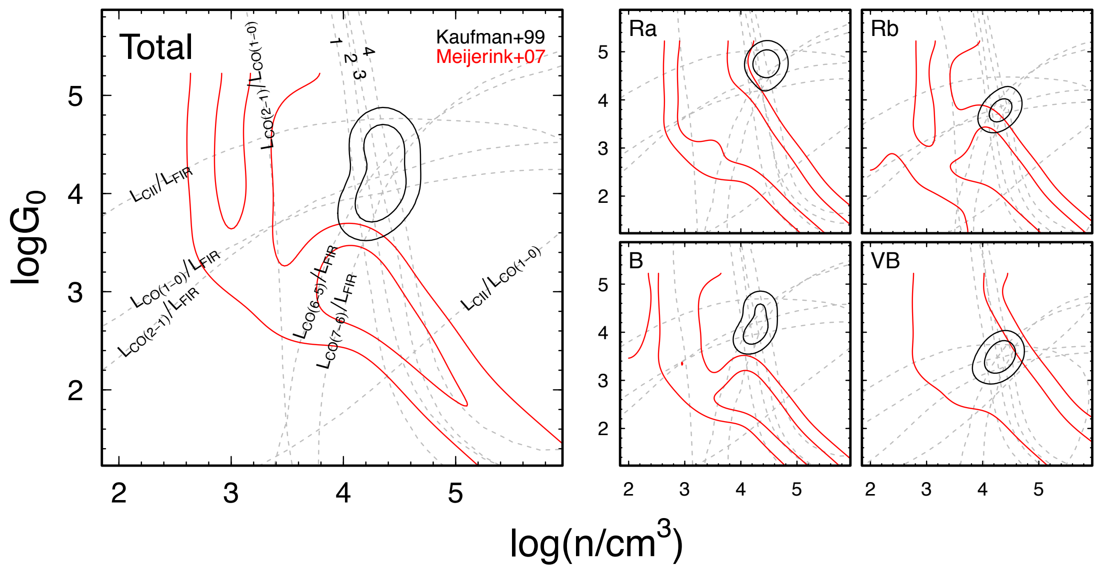
z=5.2 merging system behind Abell 773 (2)

Rawle+13 (arXiv:1310.4090) - Resolved spectroscopy





- Magnification ~ 15x
- Components separated by < 4 kpc in source plane
- Line observations of [CII], [CI], [NII], ^{12}CO (J_{upper}=1,2,5,6,7,8), H_2O to help constrain the chemical and physical parameters of the star-forming regions (photo-dissociation regions)

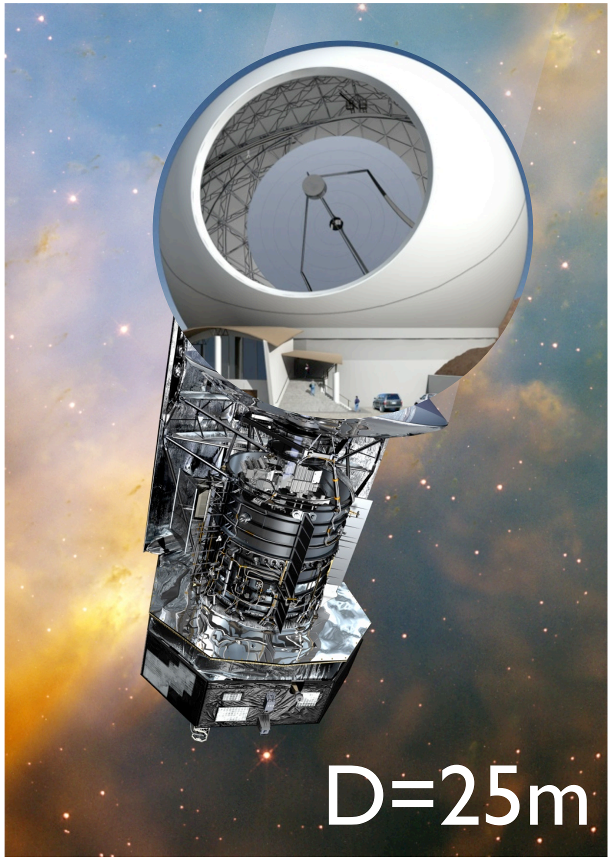


Summary

Gravitational cluster lensing

- Enormous gain in sensitivity for free
- Extraordinary spatial resolution at high redshift

x7 magnification turns Herschel into CCAT in Space



Summary

Gravitational cluster lensing

- Enormous gain in sensitivity for free
- Extraordinary spatial resolution at high redshift

Investigating high-z lensed sources is efficient in clusters in FIR

HLS probes faint lensed galaxies

↓

perfect for ALMA follow-up

Next frontier (ALMA / JWST):
aided by lensing magnification, resolve lensed galaxies into individual star-forming regions (HII regions, molecular clouds)