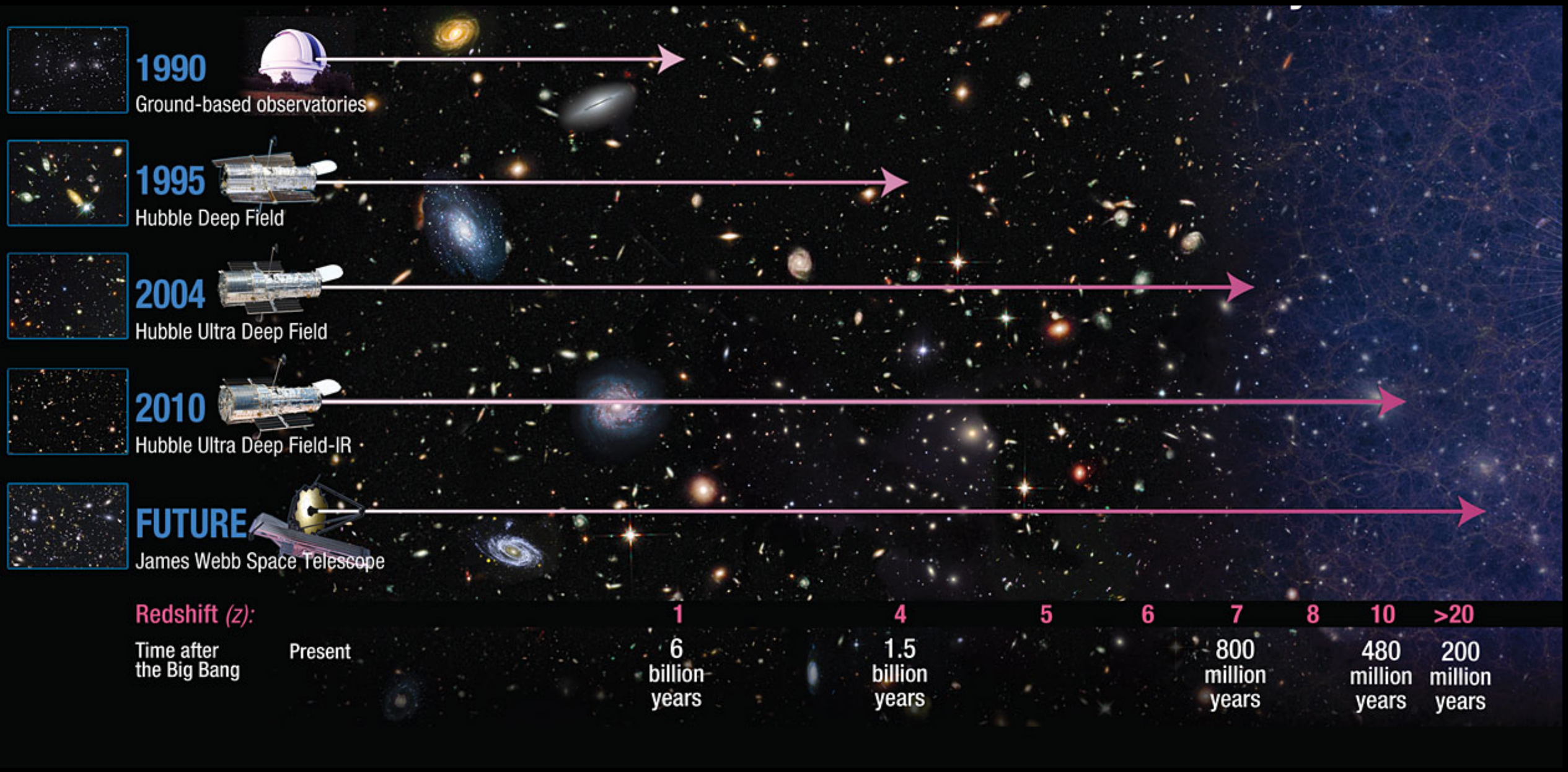
The Frontier Fields:
past, present, and future

Jennifer Lotz, STScI
with Matt Mountain and the Frontier Fields Team

the history of deep fields



Challenge: Can we peer deeper into the Universe
than the Hubble Ultra Deep Field
before the launch of the James Webb Space Telescope?

ANSWER:

use Hubble +
nature's telescopes x 6
(strong lensing clusters)

⇒ Go intrinsically deeper than HUDF

⇒ Go wider than HUDF+parallels

6 Lensed Fields +
6 parallel "Blank Fields"
= New Parameter Space

Hubble Deep Fields Initiative Science Working Group:
James Bullock (Chair, UCI), Mark Dickinson (NOAO), Steve Finkelstein (UT), Adriano Fontana (INAF, Rome), Ann Hornschemier Cardiff (GSFC), Jennifer Lotz (STScI), Priya Natarajan (Yale), Alexandra Pope (UMass), Brant Robertson (Arizona), Brian Siana (UC-Riverside), Jason Tumlinson (STScI), Michael Wood-Vasey (U Pitt)

Brammer, VLT/Hawk-I K

6 strong-lensing clusters

+ 6 adjacent parallel fields

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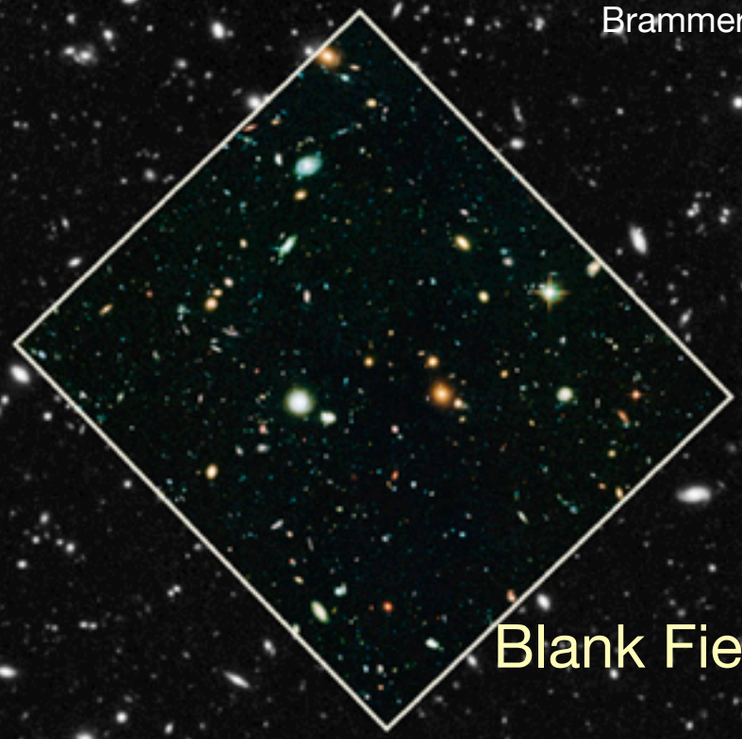
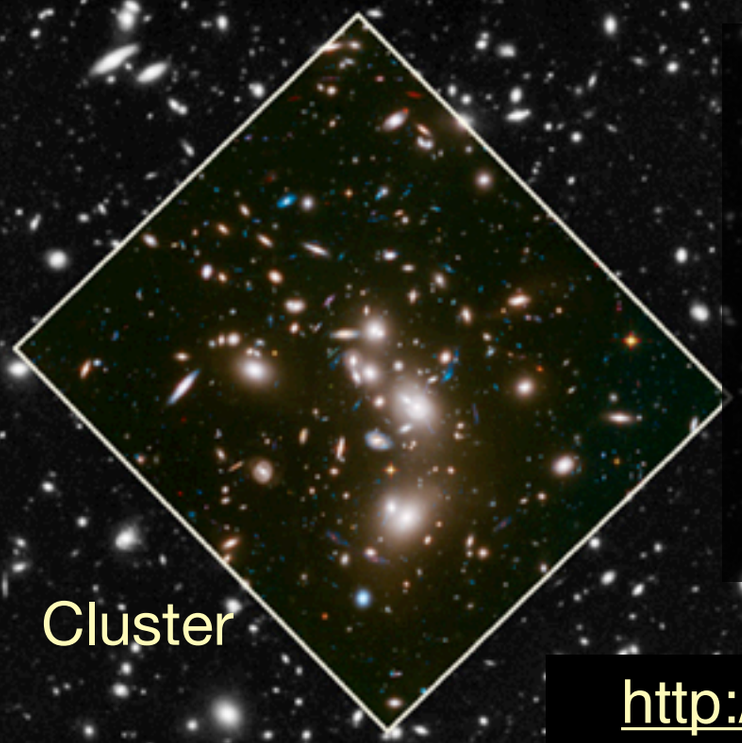
140 HST DD orbits per pointing

ACS/ WFC3-IR in parallel

~29th ABmag in 7 bands



Blank Field



Cluster

2 clusters per year x 3 years

→ 840 total orbits

1000 hours Spitzer DD time for

~26.5 ABmag in IRAC 3.6, 4.5 μm

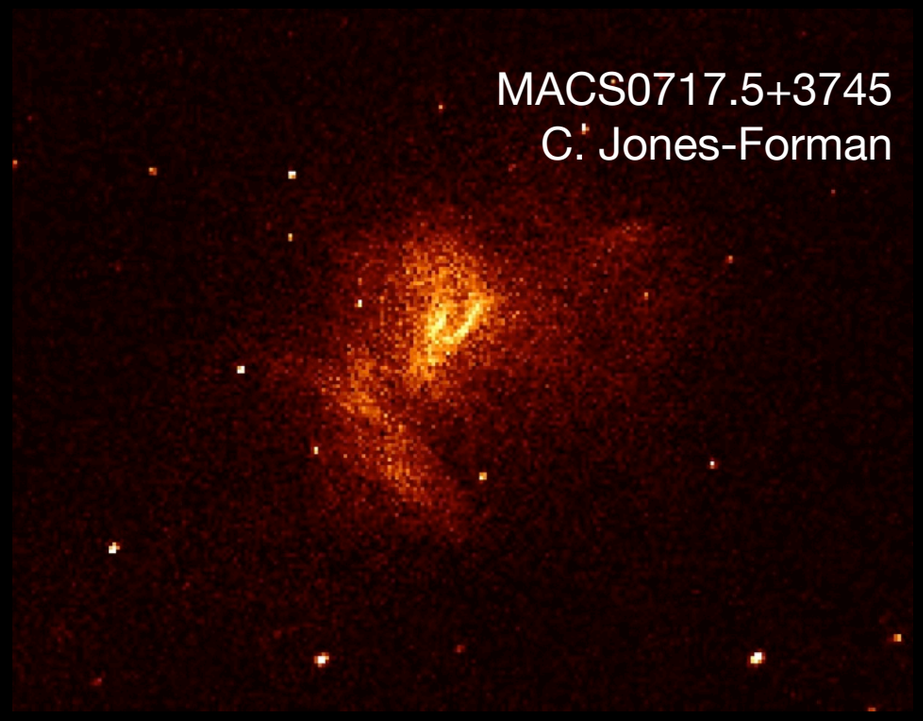
http://www.stsci.edu/hst/campaigns/frontier-fields/

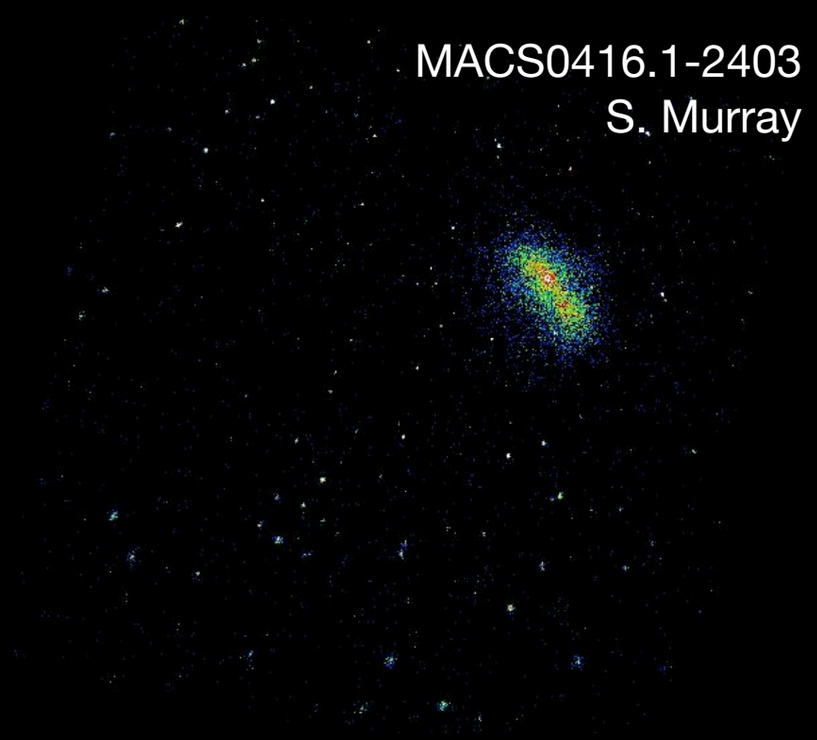
Spitzer Frontier Fields

Infrared Spitzer Space Telescope will look at Frontier Fields at wavelengths redder than Hubble can see (but not as deep)

crucial for distances, measuring total amount of stars

Chandra Frontier Fields





X-rays see hot cluster gas and gas accreting onto massive black holes

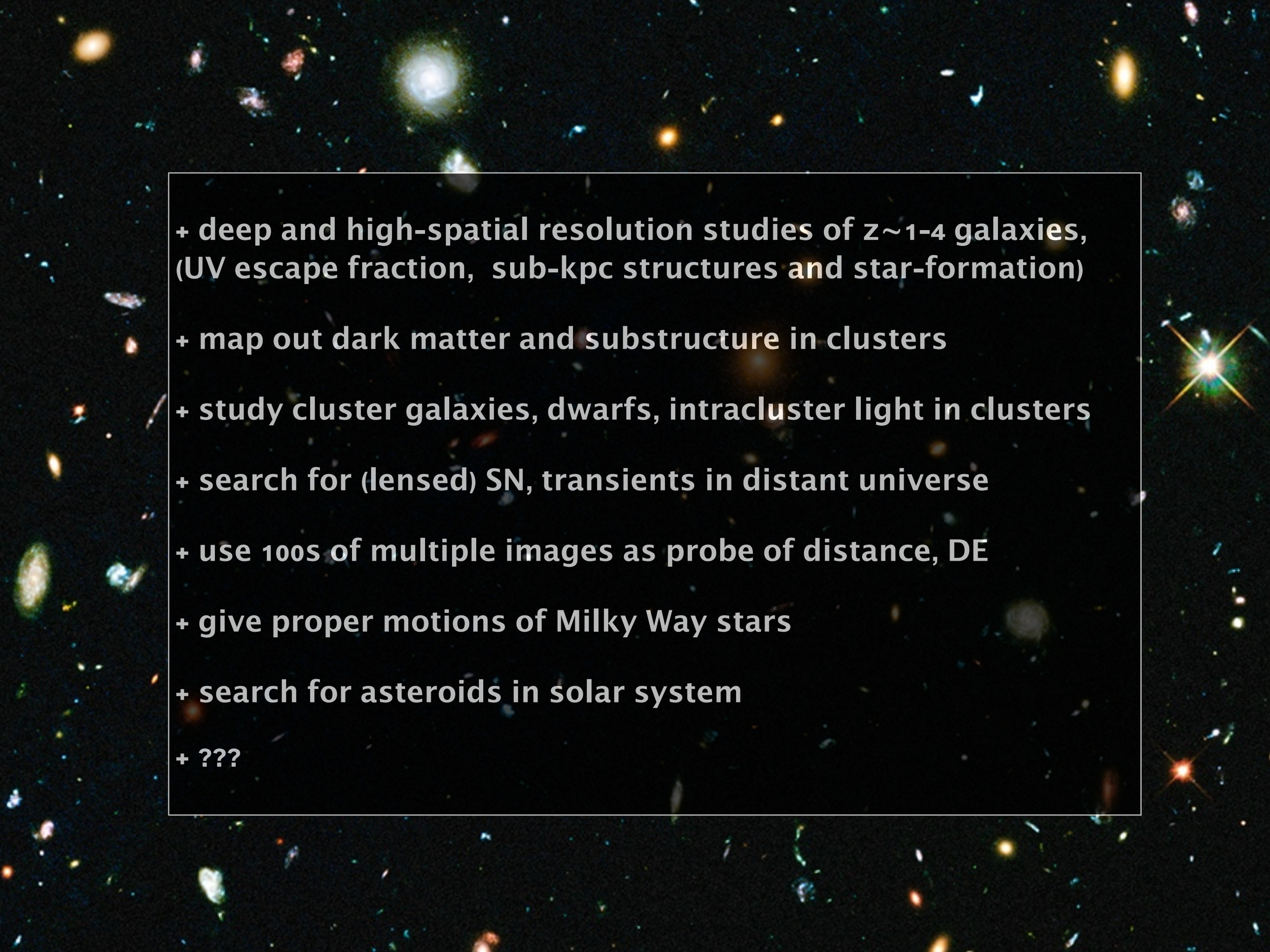
Deep observations of the Frontier Fields will:

- probe galaxies 10-50x intrinsically fainter than any seen before, particularly those before and during reionization

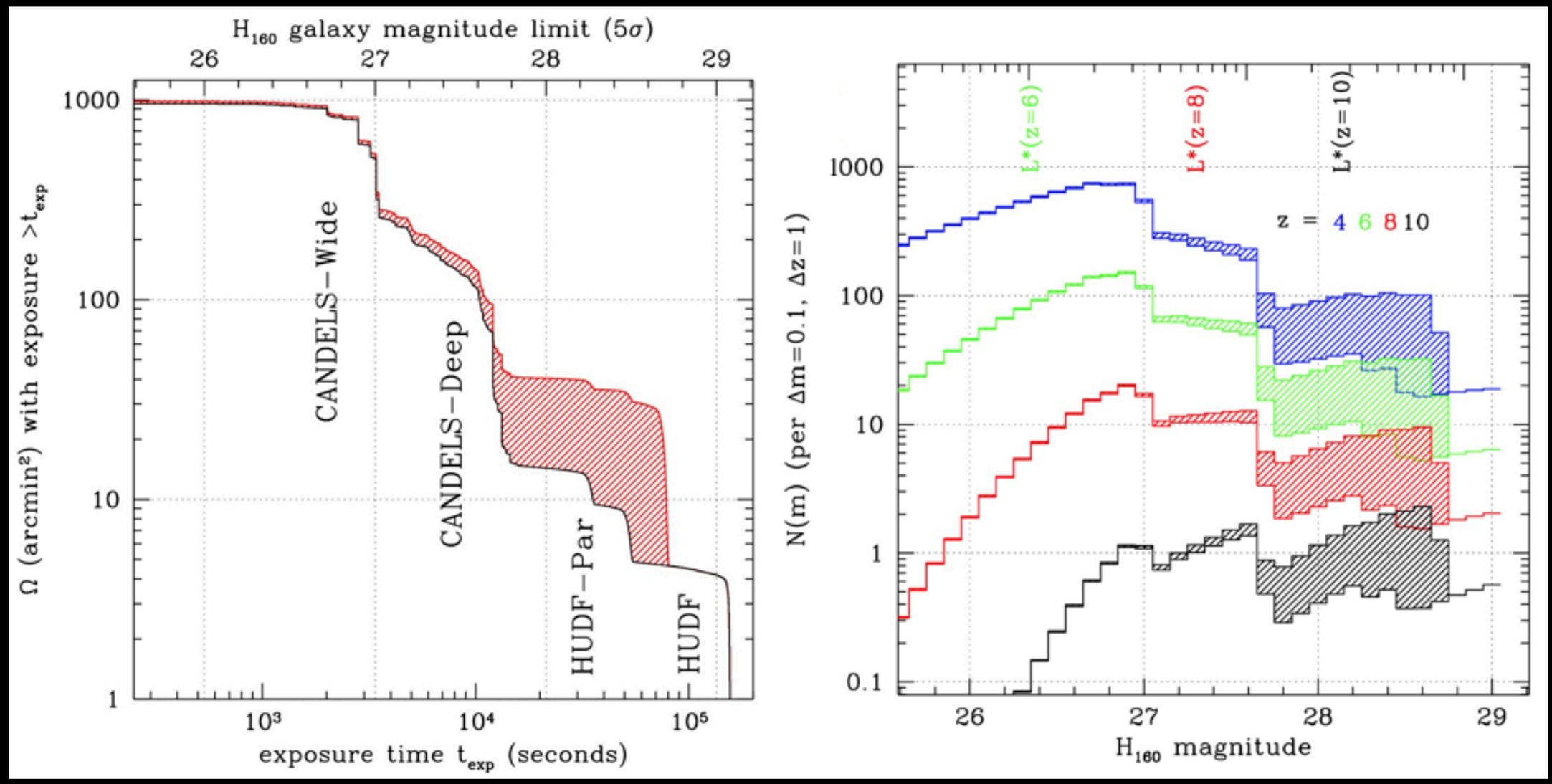
- study the early formation histories of galaxies intrinsically faint enough to be the early progenitors of the Milky Way

- study highly-magnified high-z galaxies in detail: structures, colors, sizes and provide targets for spectroscopic followup

- provide a statistical picture of galaxy formation at early times


+ deep and high-spatial resolution studies of z~1-4 galaxies,
(UV escape fraction, sub-kpc structures and star-formation)
+ map out dark matter and substructure in clusters
+ study cluster galaxies, dwarfs, intracluster light in clusters
+ search for (lensed) SN, transients in distant universe
+ use 100s of multiple images as probe of distance, DE
+ give proper motions of Milky Way stars
+ search for asteroids in solar system
+ ???

why 6 clusters + 6 parallels?

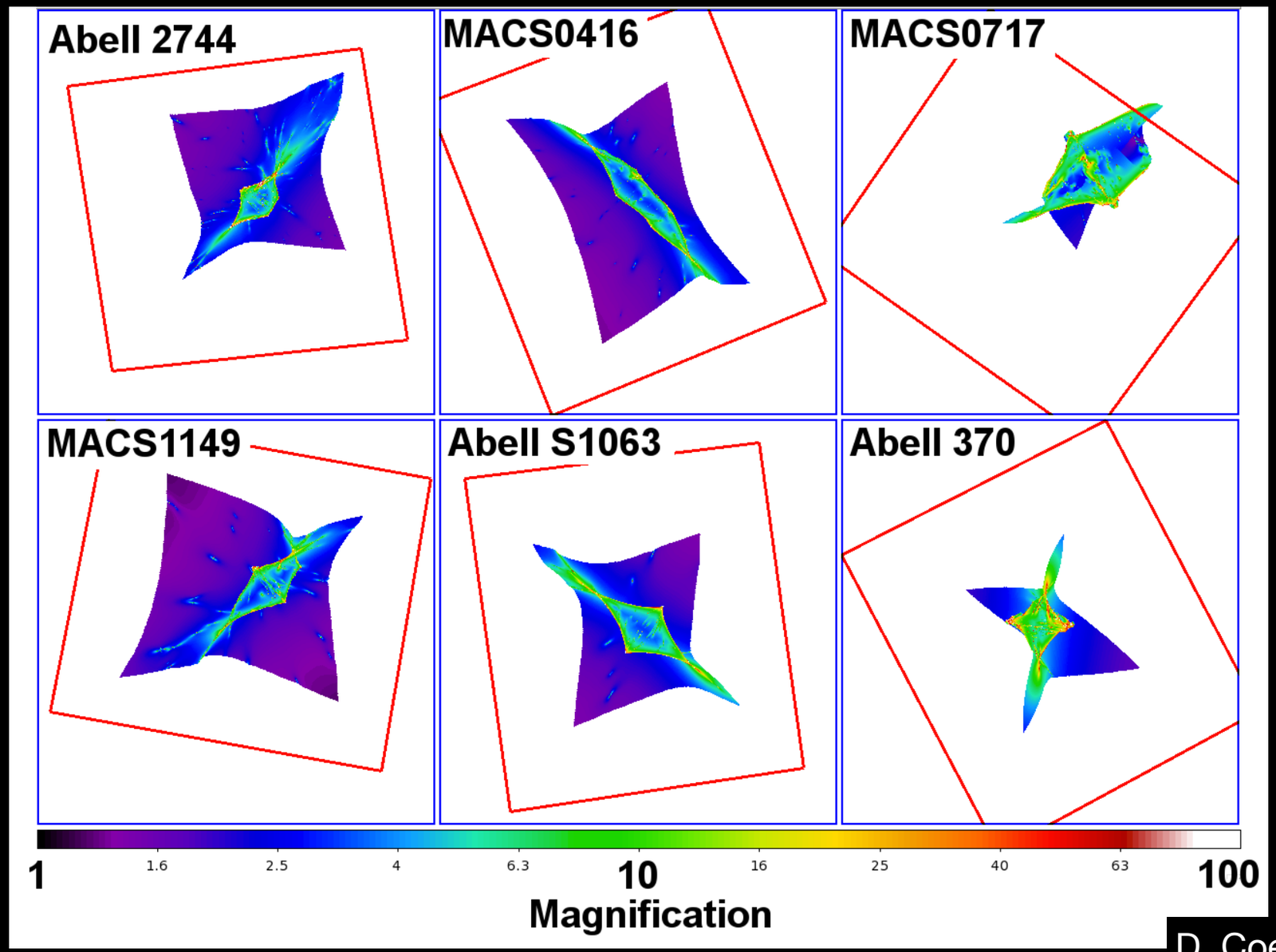


HDFI SWG report 2012:

Six "blank" parallel fields give you 3x more area than existing HUDF+pars

⇒ "3-5x more faint galaxies + doubling of numbers of z~8-10 galaxies"

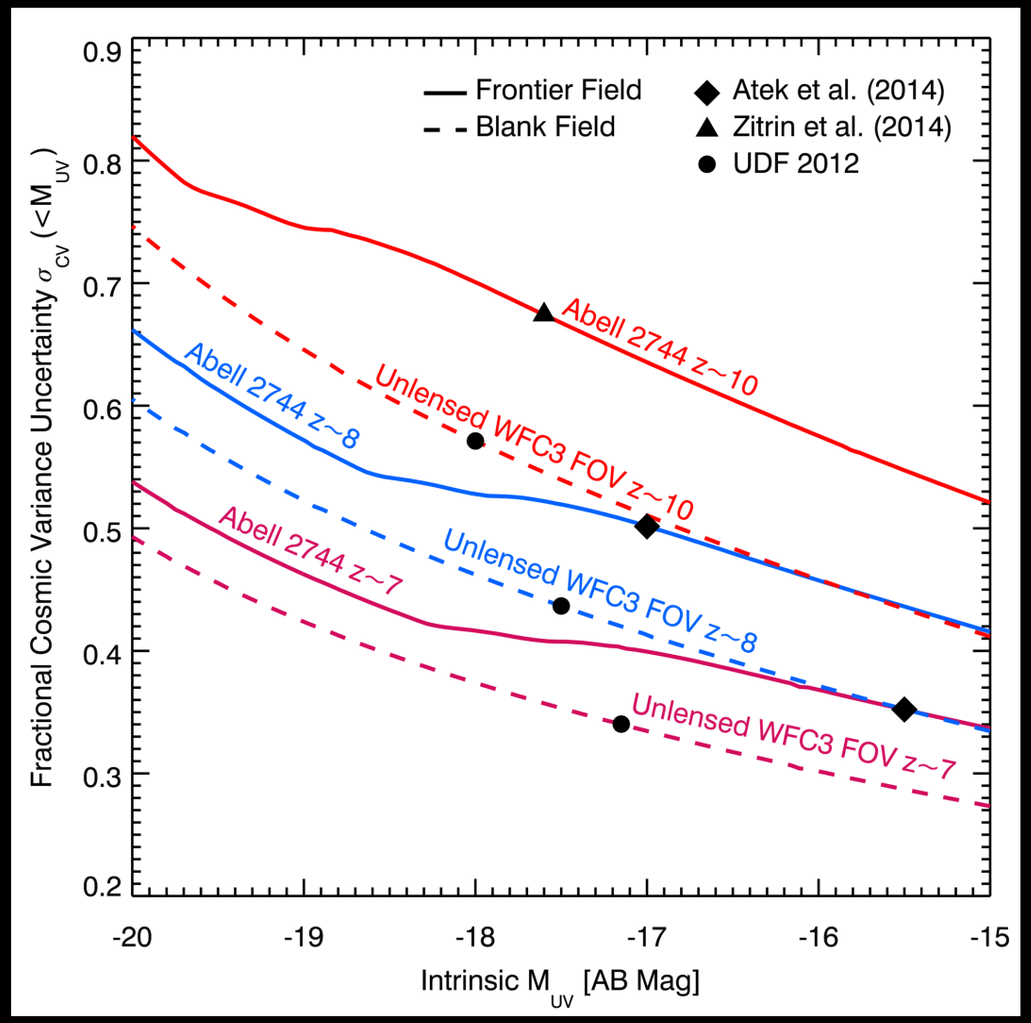
why 6 clusters + parallel fields?

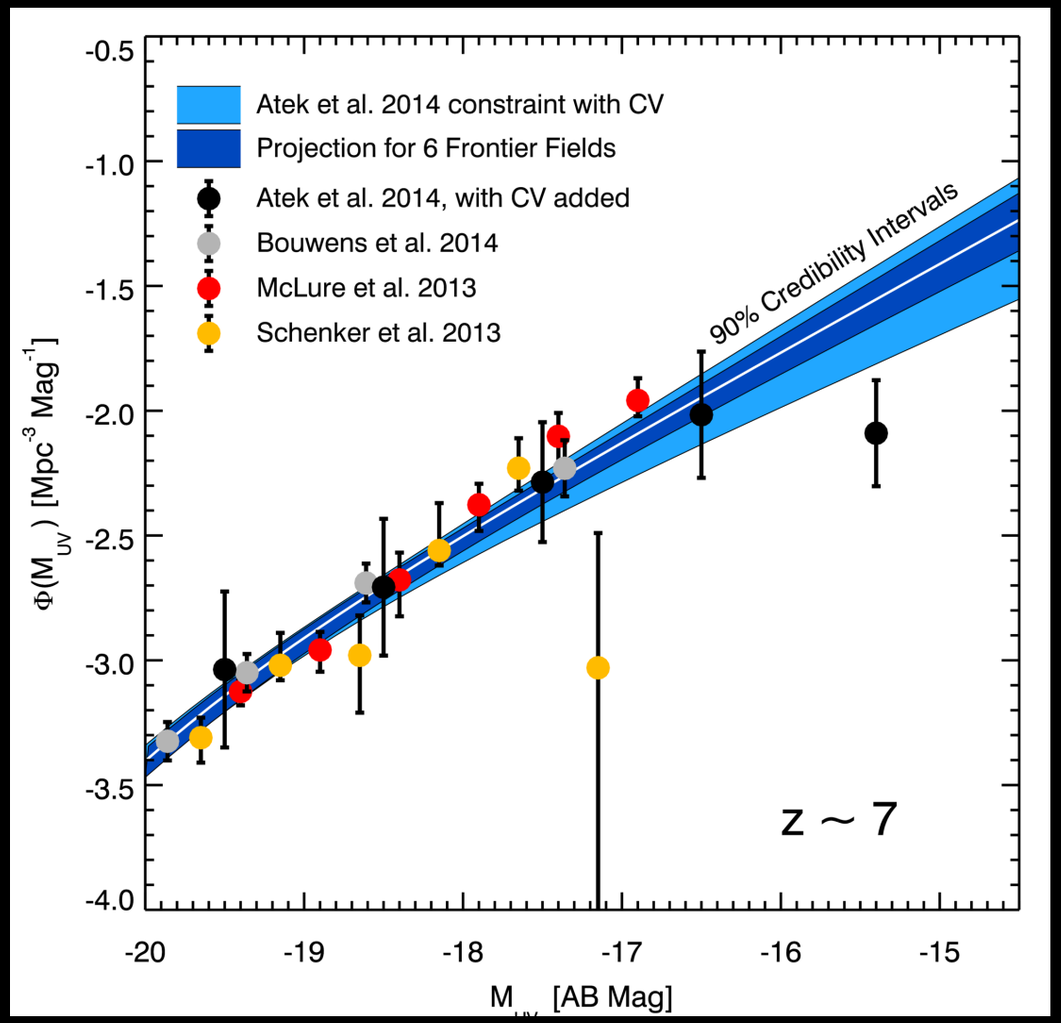


D. Coe et al, 2014

high-redshift volumes probed by strong lensing is small

why 6 clusters + parallel fields?

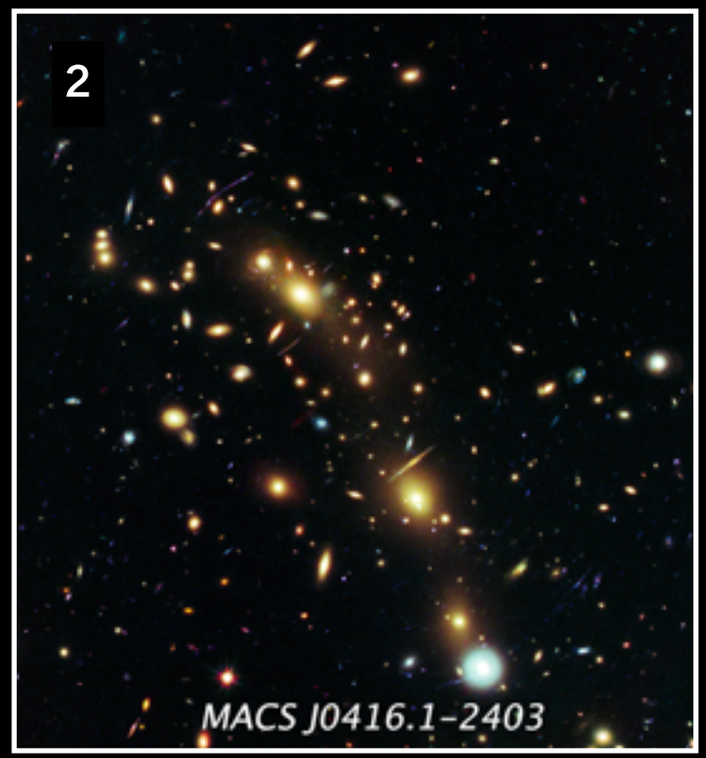


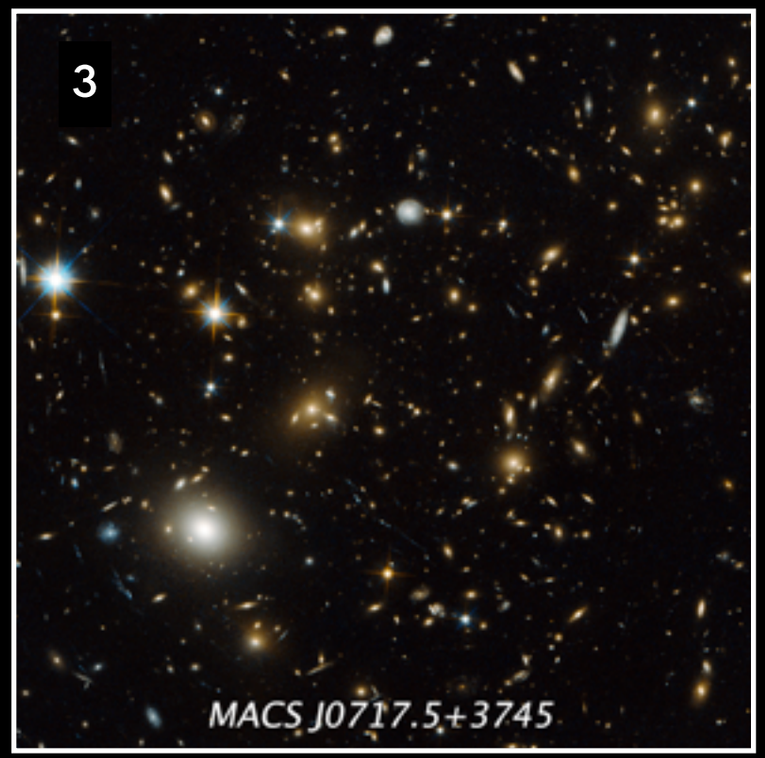


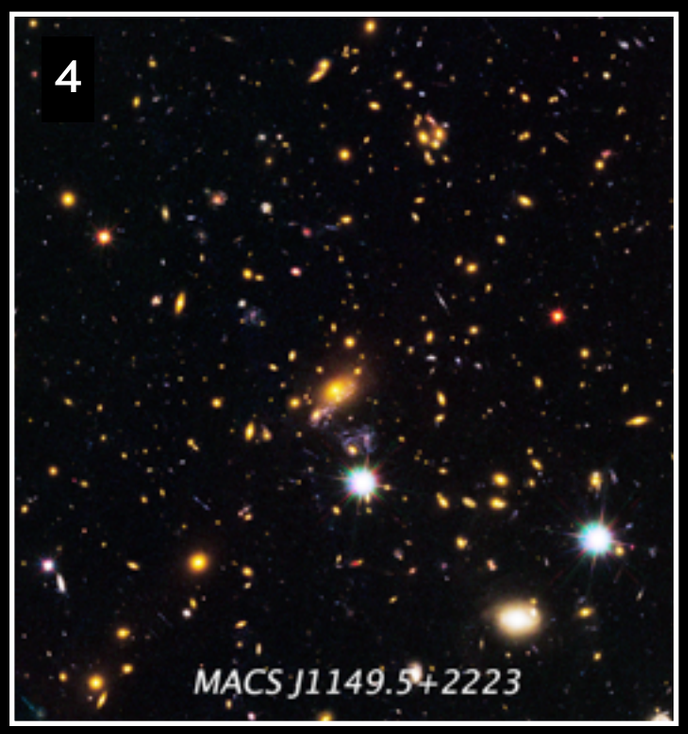
B. Robertson et al, 2014

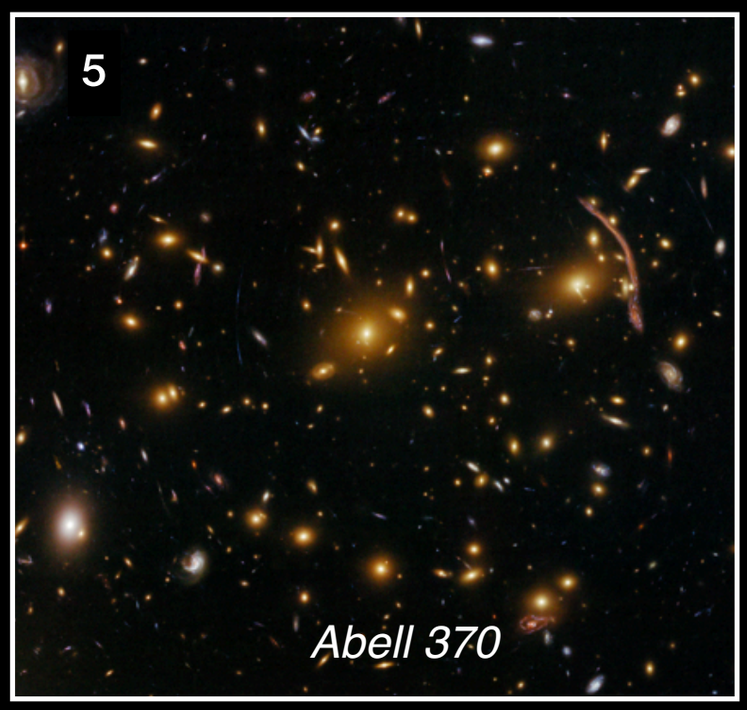
cosmic variance 10-30% higher in 1 lensed field vs. HUDF;
but 6 fields can provide critical constraints
on faint galaxies required to reionize the universe

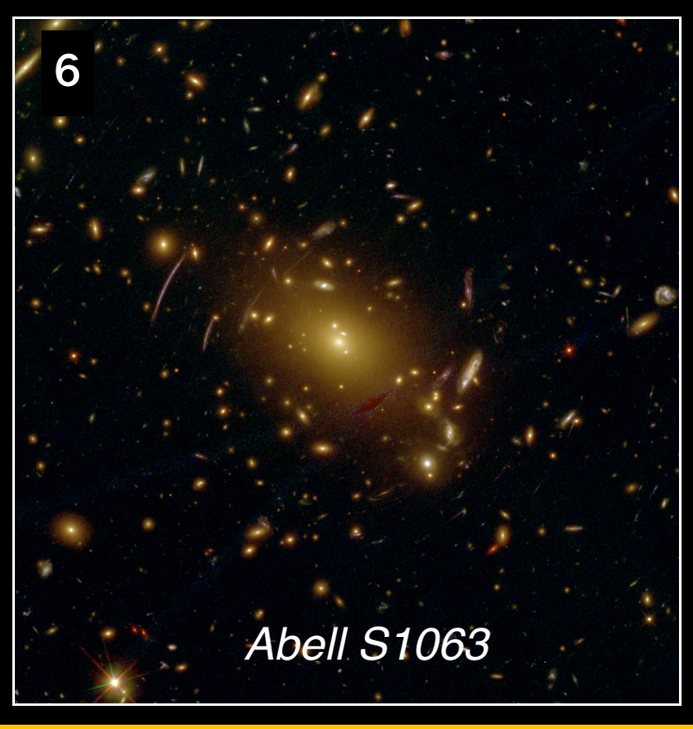
HST Frontier Fields





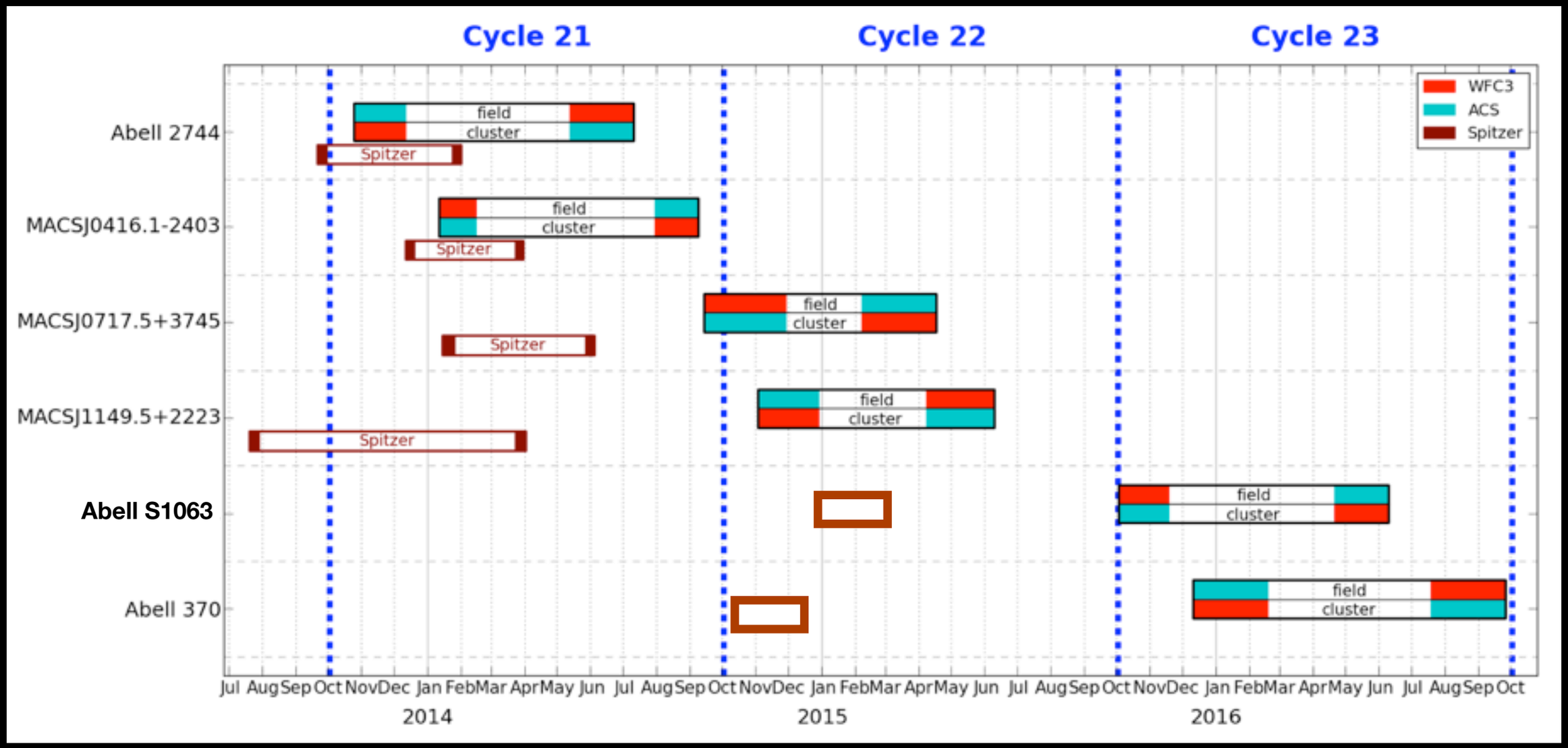






chosen based on known lensing strength, sky location, ancillary data

Frontier Fields Schedule



year1 observations Abell 2744, MACS0416 are complete
Spitzer observations of 1st four clusters complete

MACS0717, MACS1149 HST observations starting now
AbellS1063, Abell 370 Spitzer observations planned Winter 2015

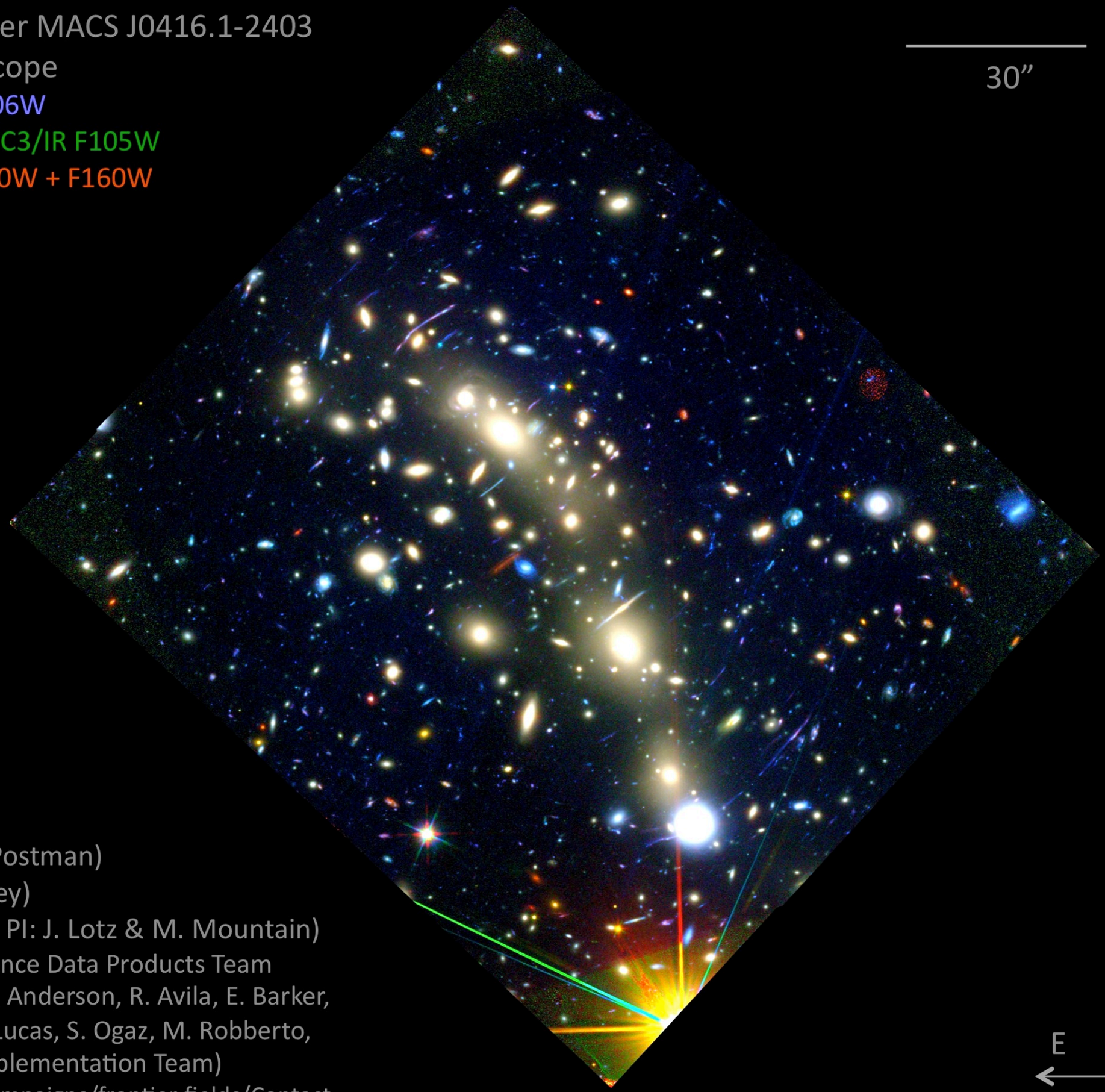
Abell 2744
Cluster

Abell 2744
Cluster
WFC3/IR

Abell 2744
Cluster
ACS/optical

Frontier Fields Cluster MACS J0416.1-2403
Hubble Space Telescope
ACS/WFC F435W + F606W
ACS/WFC F814W + WFC3/IR F105W
WFC3/IR F125W + F140W + F160W

30”



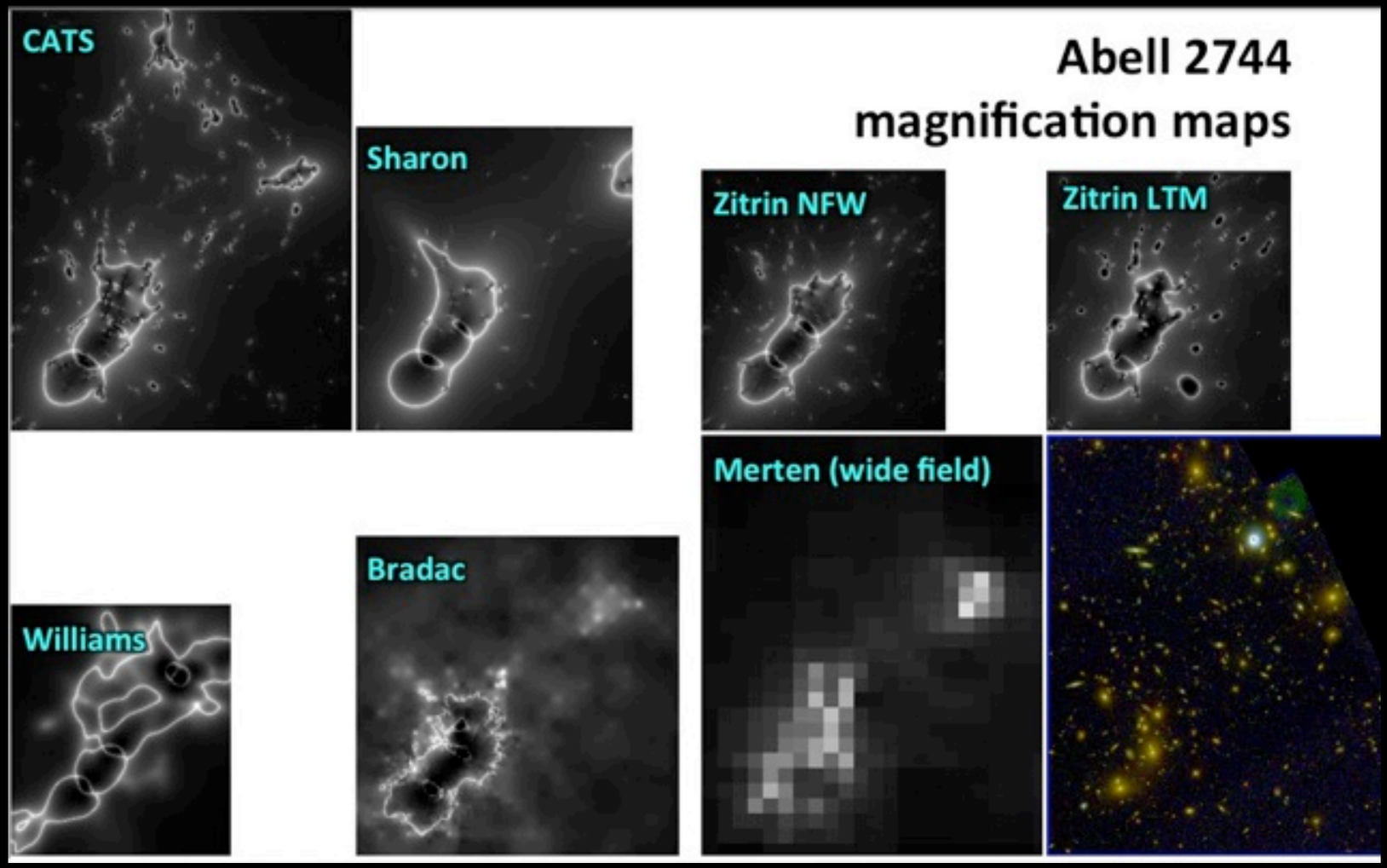
HST Data from:
- 12459 (CLASH; PI: M. Postman)
- 13386 (SN: PI: S. Rodney)
- 13496 (Frontier Fields: PI: J. Lotz & M. Mountain)

Image: Frontier Fields Science Data Products Team
(A. Koekemoer, J. Mack, J. Anderson, R. Avila, E. Barker, D. Hammer, B. Hilbert, R. Lucas, S. Ogaz, M. Robberto, and the Frontier Fields Implementation Team)
http://www.stsci.edu/hst/campaigns/frontier-fields/Contact

N
E

MACS0717.5+3745
Cluster
ACS/optical

Frontier Fields Lensing Maps



lensing models are key to interpreting luminosities of background galaxies

5 groups have made magnification maps for FF before 1st observations

100s of arcs expected in FF data ⇒ tighter constraints on lensing models

http://archive.stsci.edu/prepds/frontier/lensmodels/

Early science (lensing maps)

- improved lensing models based on >150 lensed images;
  give factor 2.5x improved statistical uncertainty (Jauzac +14 a, b)

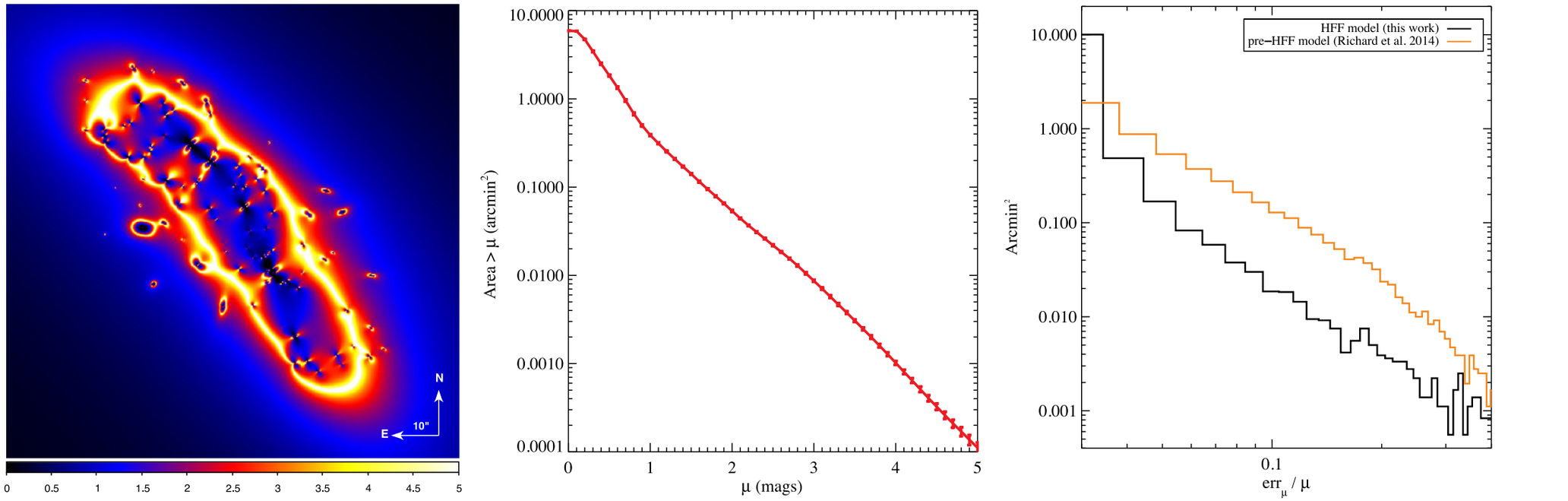
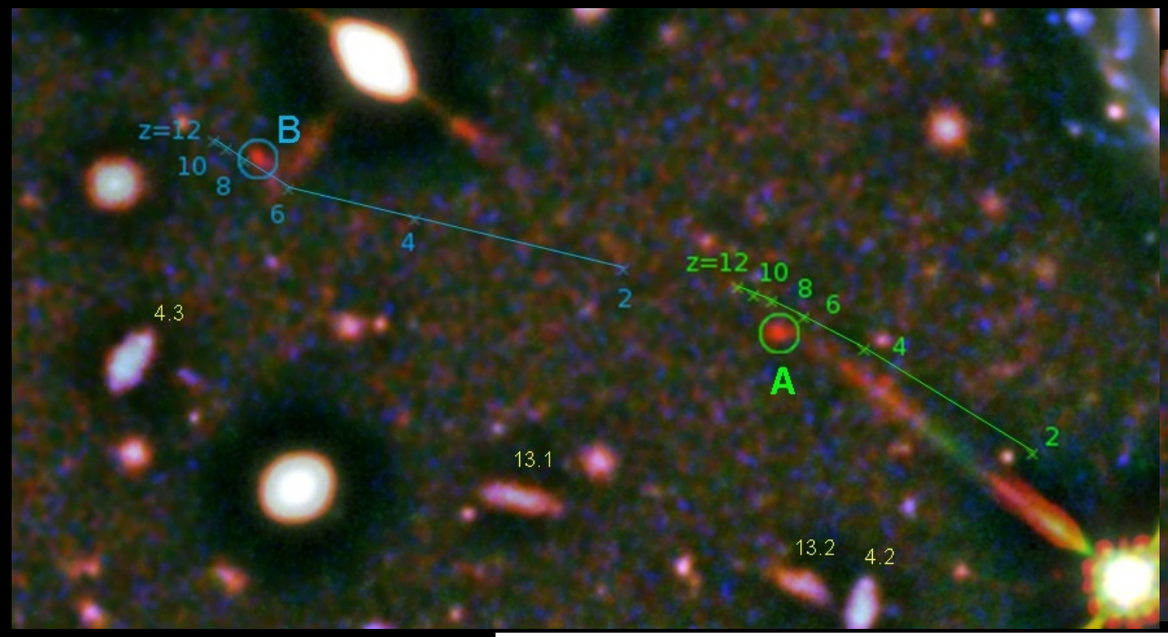


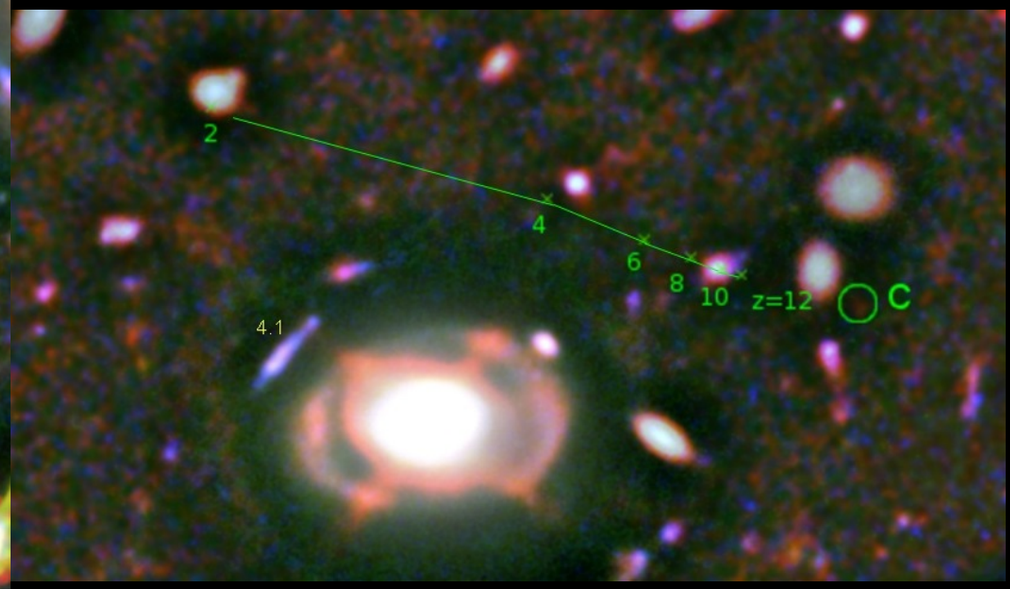
Figure 2. Left-hand panel: magnification map obtained from our *HFF* lens model for a source at $z_S = 9$. Middle panel: surface area in the source plane covered by ACS at a magnification above a given threshold μ. Right-hand panel: histograms of the relative magnification errors (in linear units) for the pre-*HFF* lens model of Richard et al. (2014, orange) and our new mass model (black).

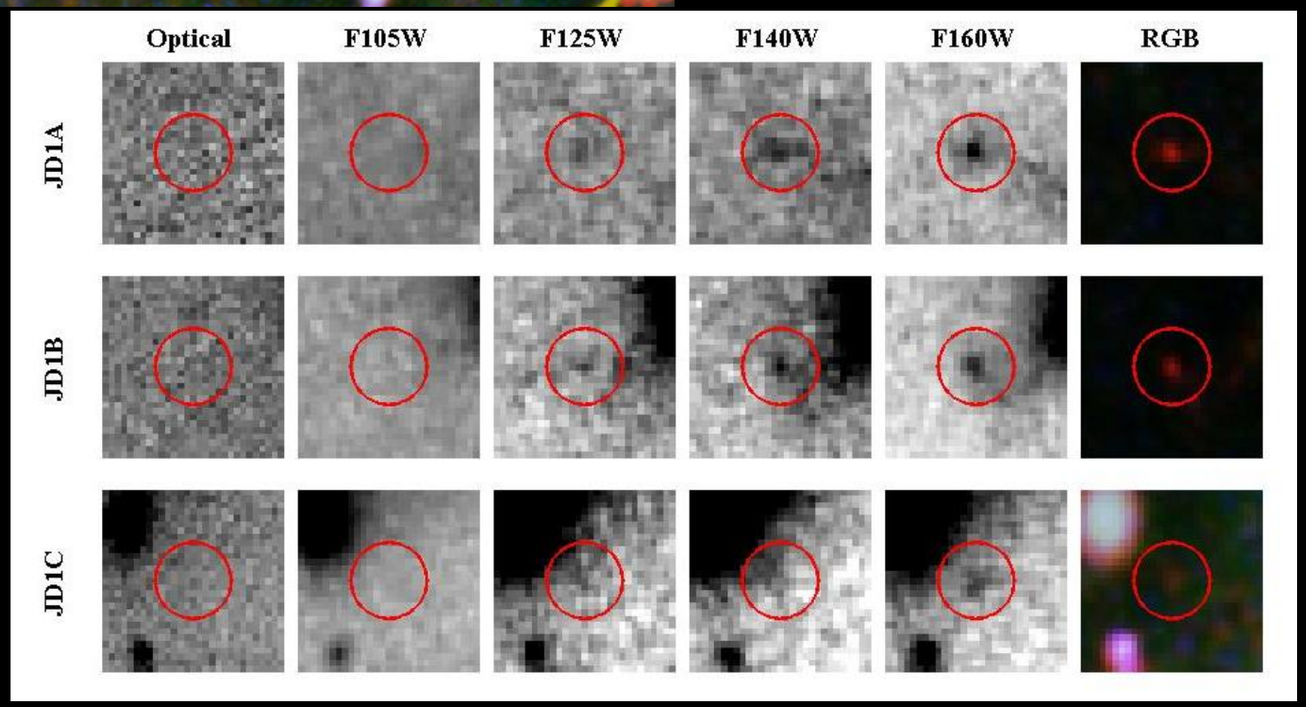
- Abell 2744 dark matter substructure detected by lensing (Grillo+ 14)

Early science (Abell 2744)

- triply imaged z~10 galaxy candidate (Zitrin +14)

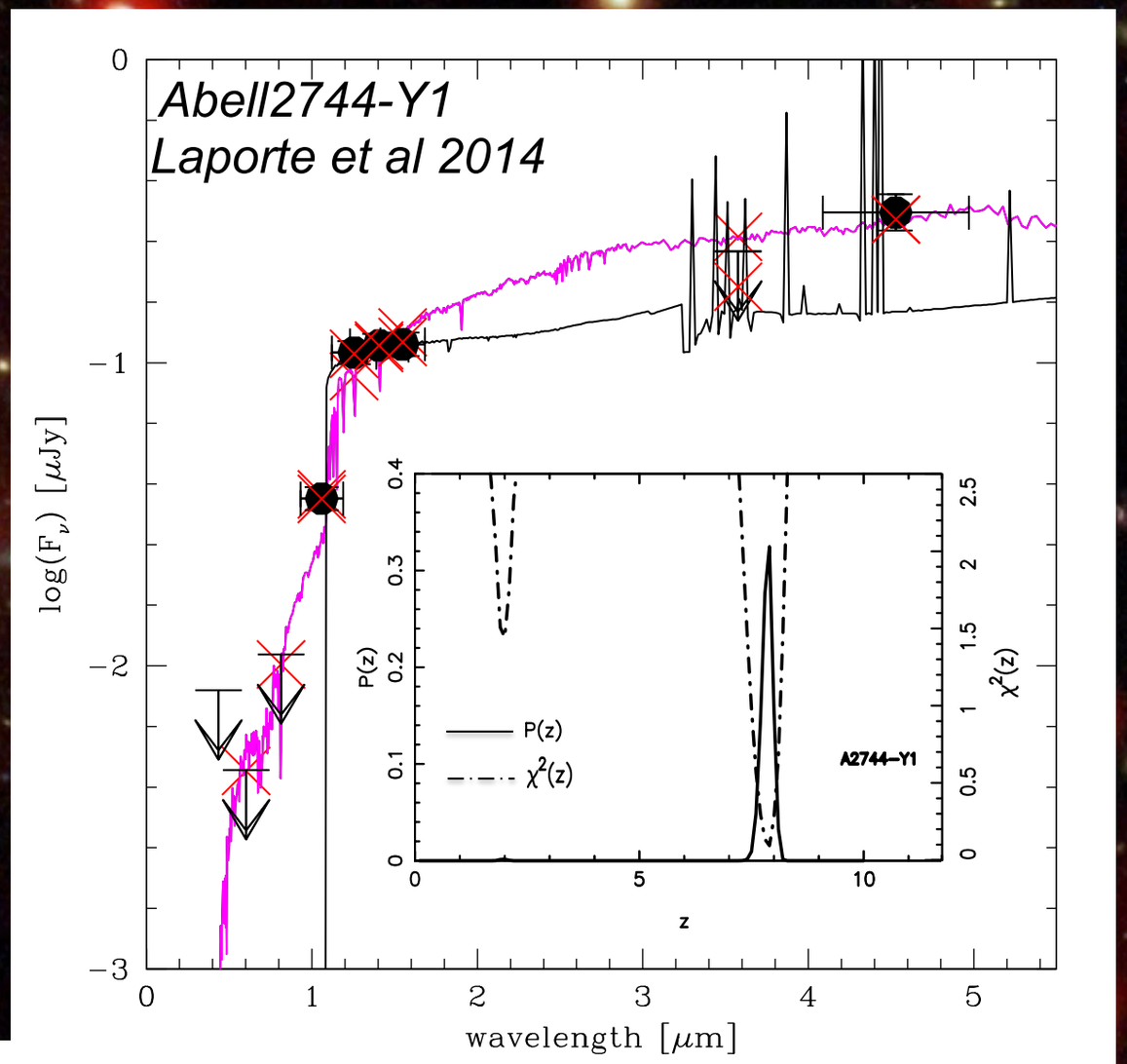


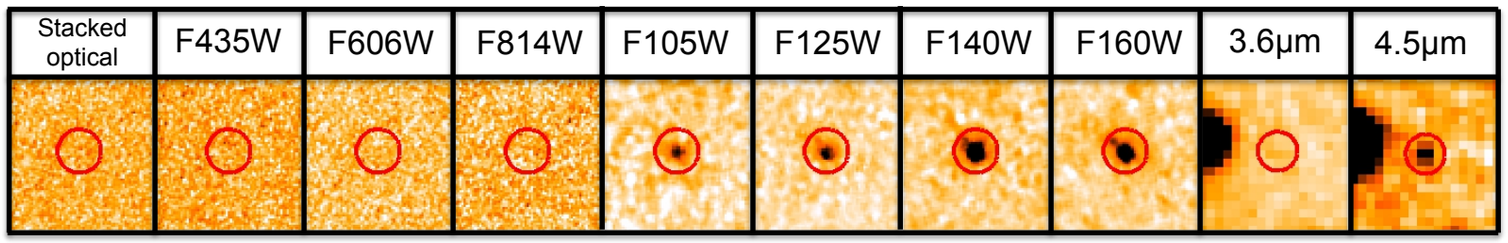




Spitzer Frontier Fields

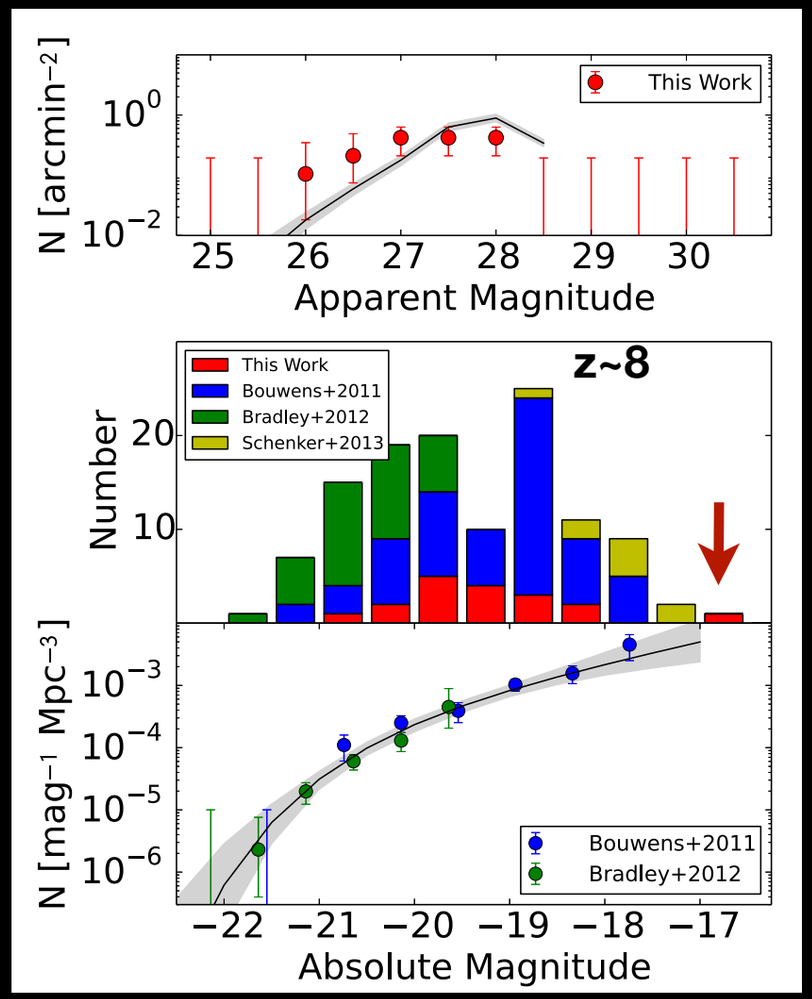
IRAC 4.5 micron detection
⇒
strong optical emission lines
at z~8.0

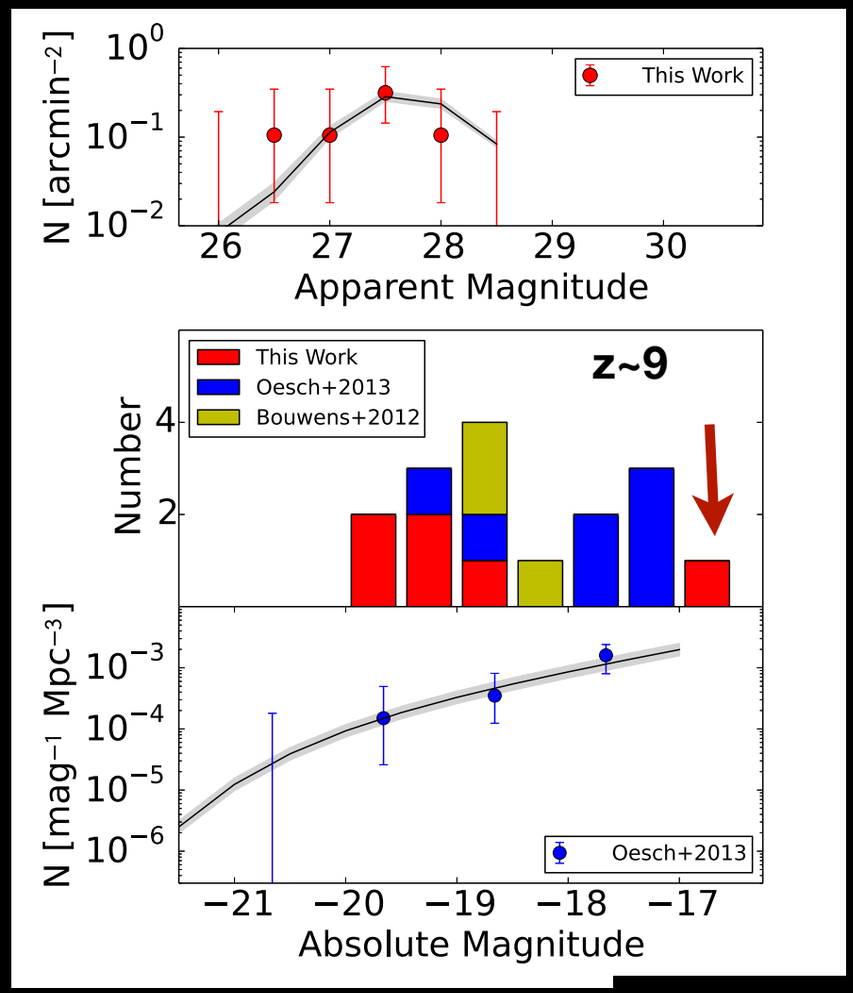




Laporte et al. 2014

Early science (high-z galaxies)





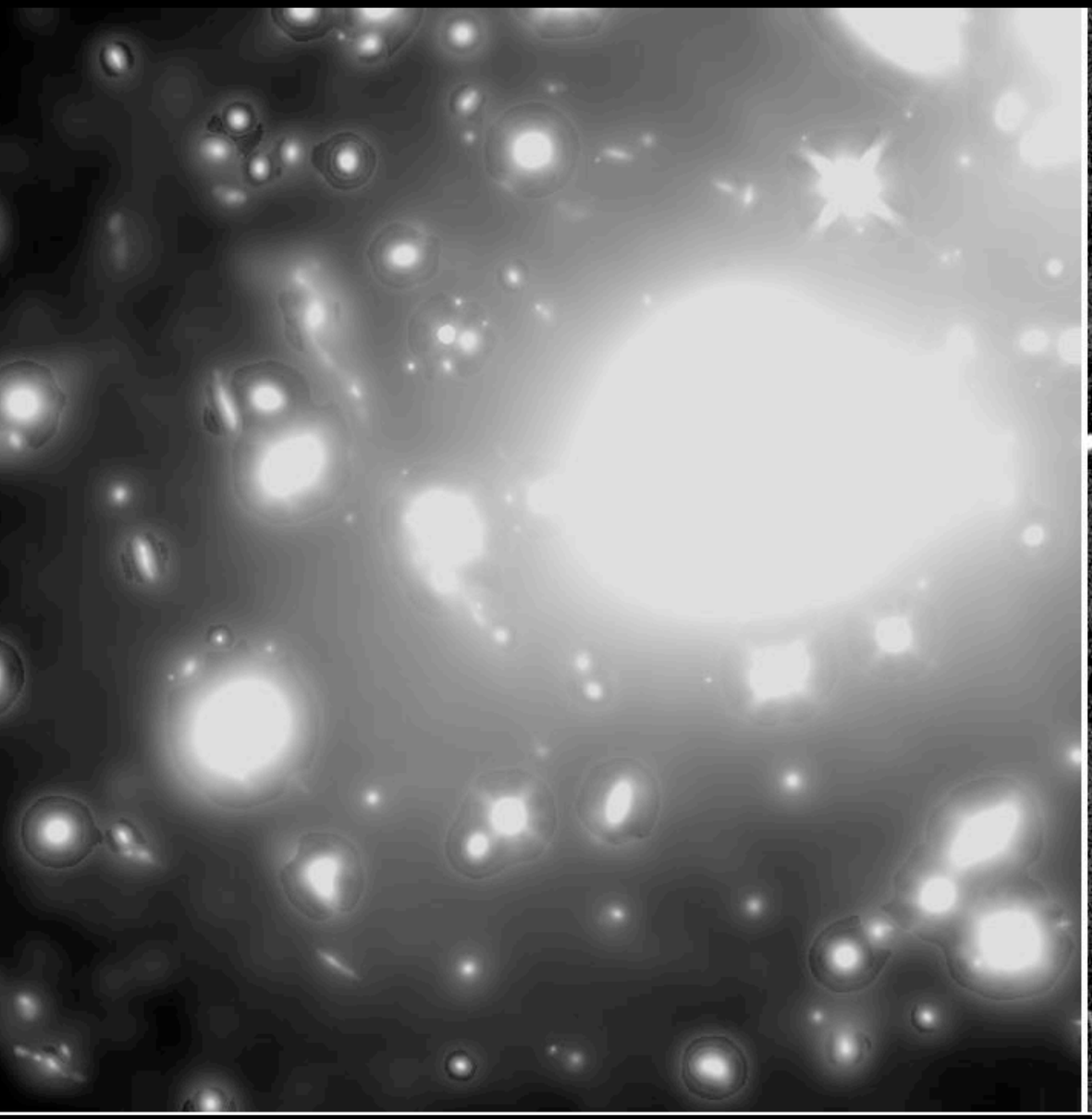
Ishigaki et al, 2014

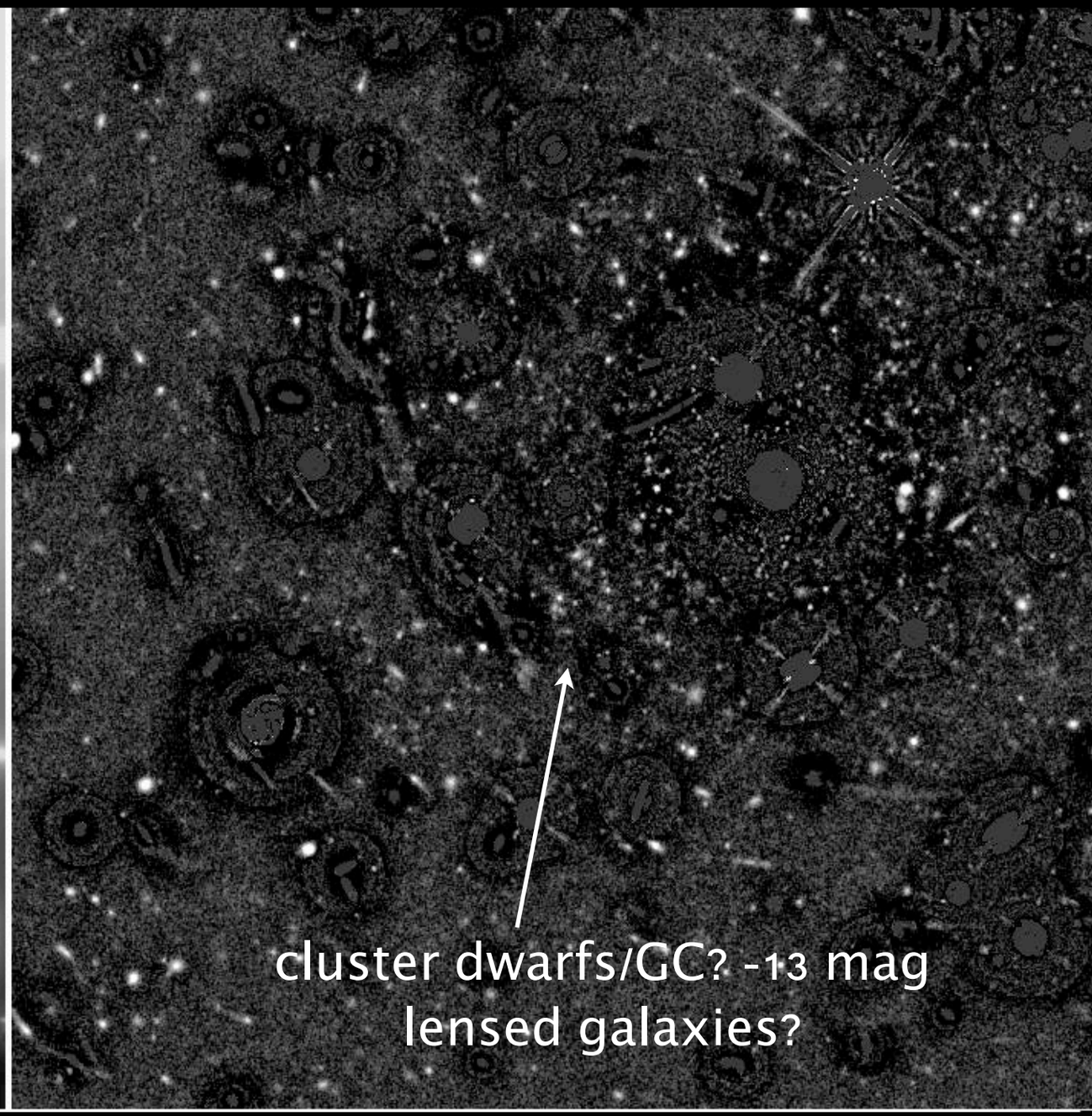
54+ z~5-10 objects detected in Abell 2744 + parallel,
including 3 with magnifications >10
(Ishigaki; Atek; Zheng; Coe; Laporte; Zitrin; Oesch)

deficit of z~9 objects ?

standard Source Detection in Cluster highly incomplete (Oesch et al.2014)
⇒ need to subtract large-scale “foreground” (cluster + ICL)

+ identify small-scale structures

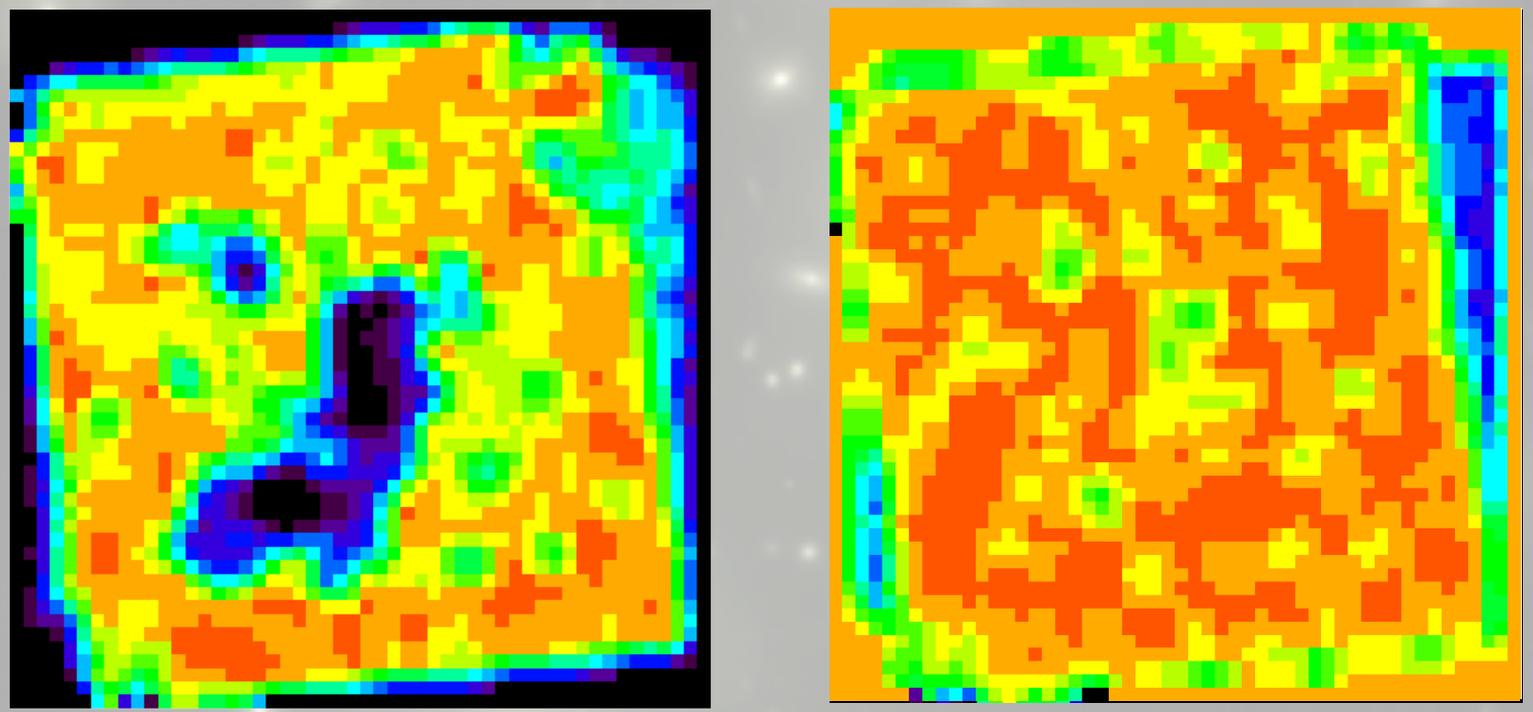




Wavelet subtraction improves depth across the field, particularly the crucial central region

Original image

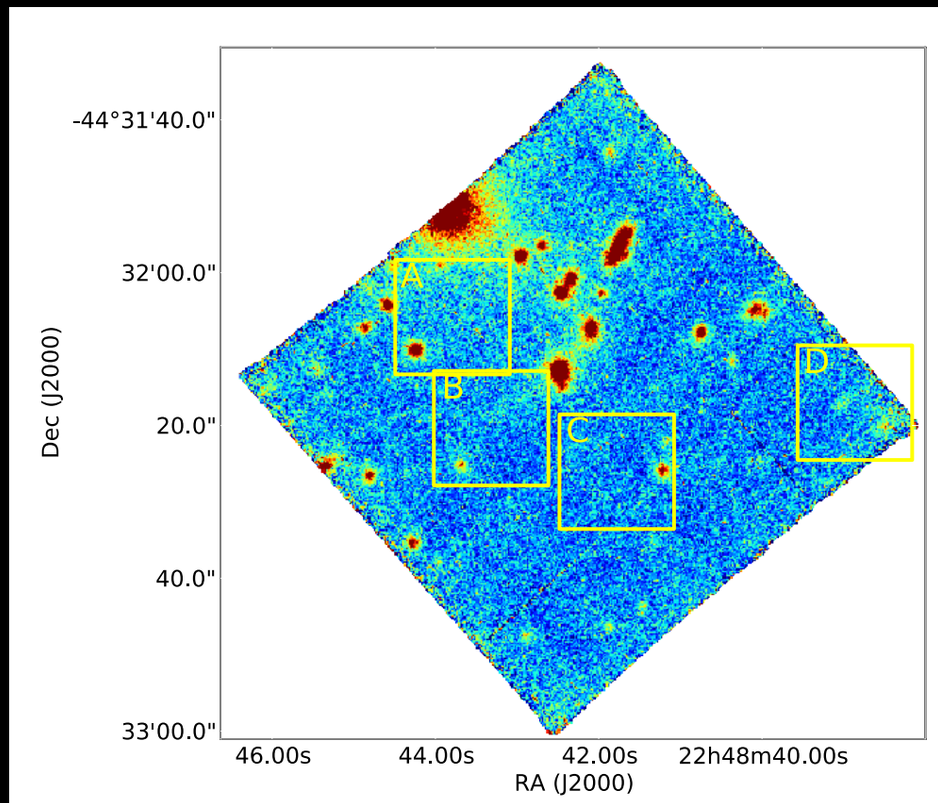
Subtraction scale 5



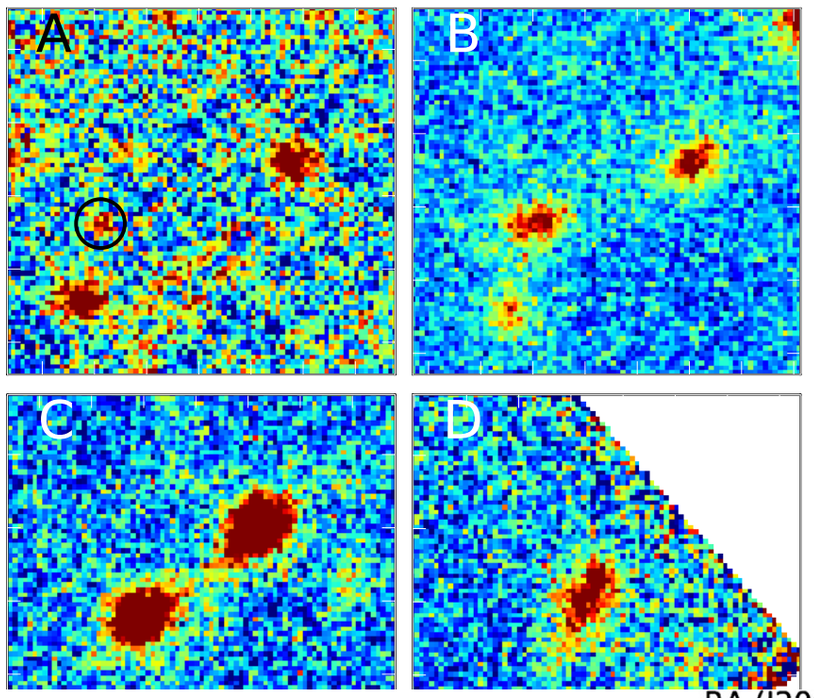
more high-redshift galaxies yet to found?

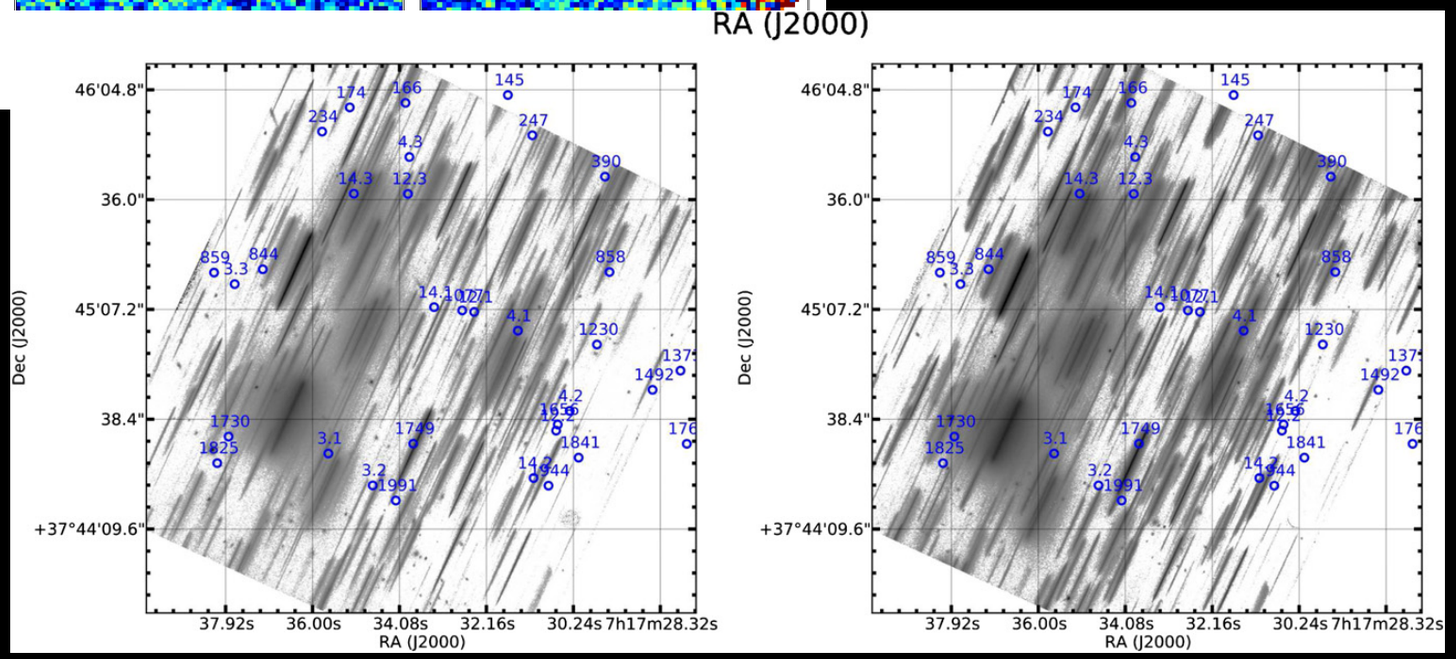
Livermore et al. in prep

Early science (spectroscopy)



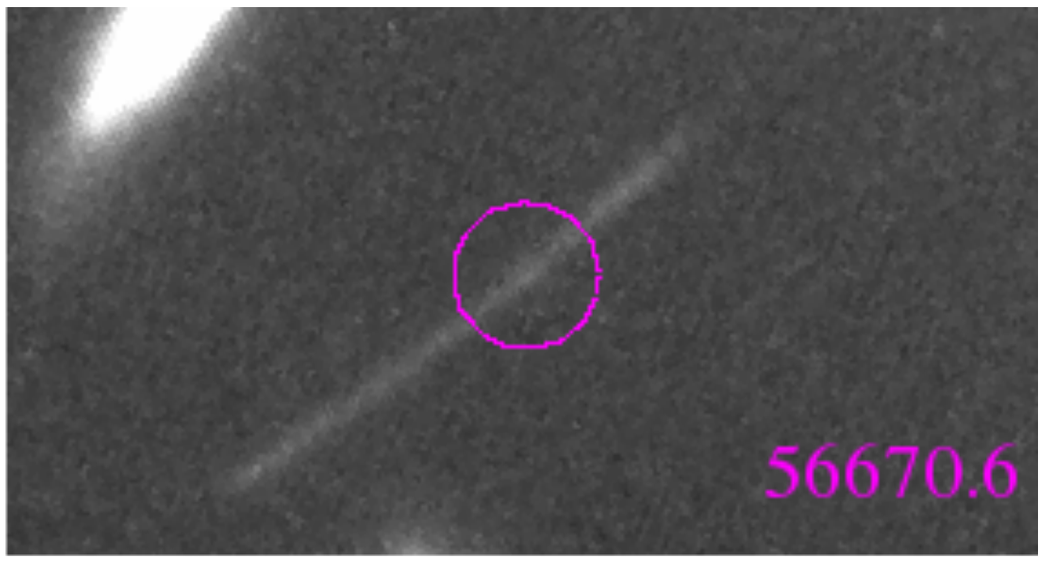
MUSE/VLT: Karman et al. 2014

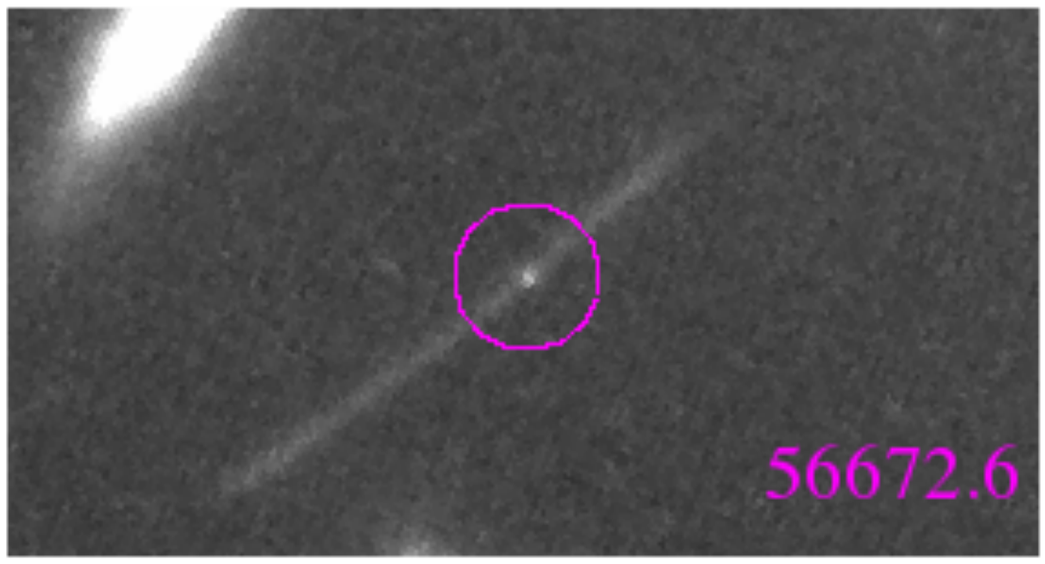




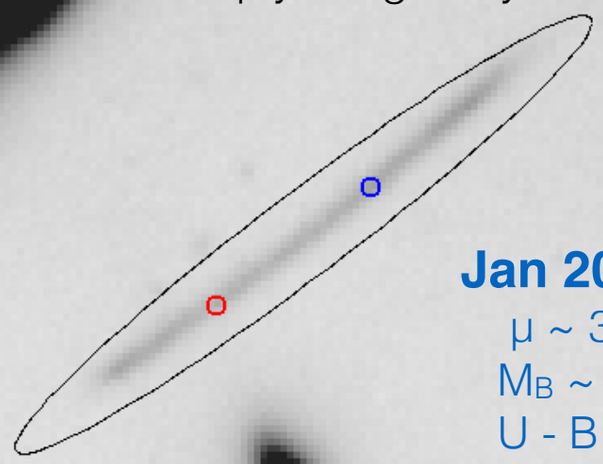
GLASS: Schmidt et al. 2014

Early science (transients)





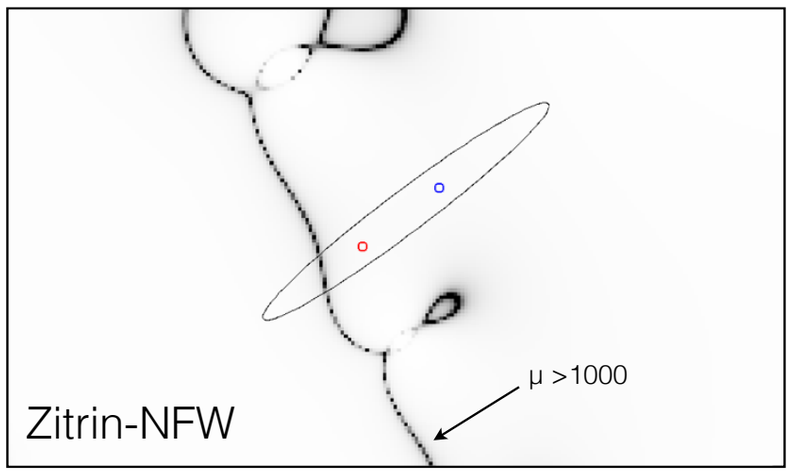
Host Galaxy :
photoz = 1.00 +- 0.02
triply-imaged by MACSJ0416

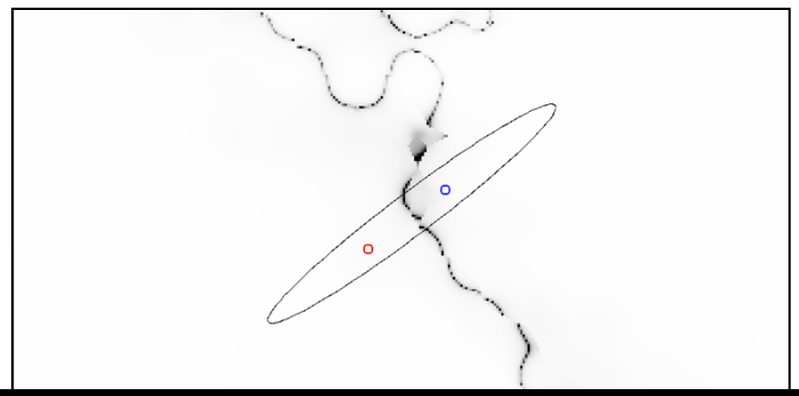


Spock-SE
Aug 2014 IR flare
μ ~ 20 [5,60]
M_I ~ -14.4 [-13, -16]
R - I ~ 0.4
τ < 1 wk rest-frame

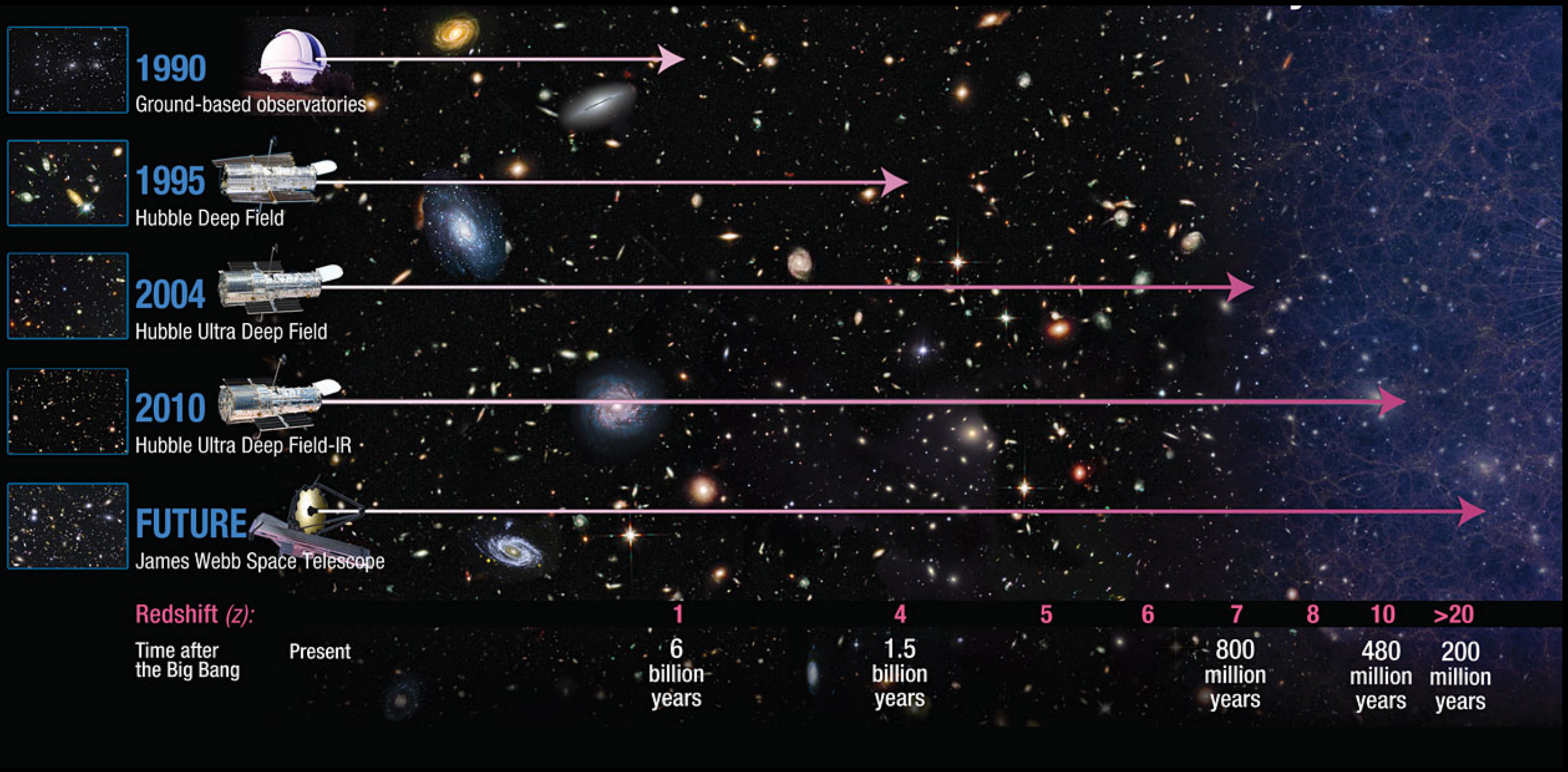
Spock-NW
Jan 2014 optical flare
μ ~ 30 [5,1100]
M_B ~ -14.3 [-10, -16]
U - B ~ 0.5
τ ~ 2.5 days rest-frame

Rodney et al. in prep





the history of deep fields



JWST Deep Field Science

NIRCam imaging-

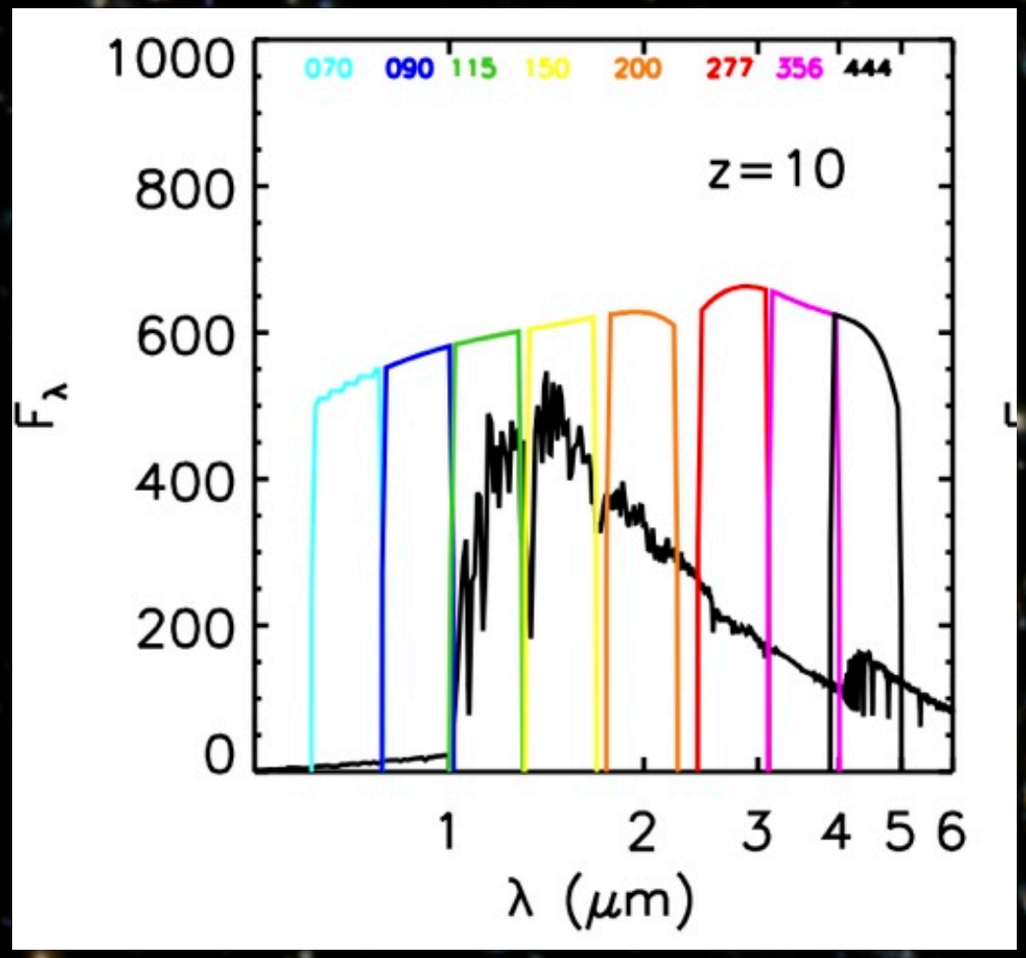
use broadband imaging to detect Balmer break at z~10!

5σ 29th ABmag F150W ~ 2 hrs
(vs. 15 hrs HST WFC3/IR F160W)

5σ 30.5th ABmag F150W ~ 15 hrs
(HFF exptime -> UDF depths)

5σ 31.2th ABmag F150W ~ 70 hrs
(UDF exptime -> 1.2 mag deeper)

http://jwstetc.stsci.edu/etc/



simulated JWST NIRCam deepfield - G. Snyder, Illustris team

lensing clusters with JWST?

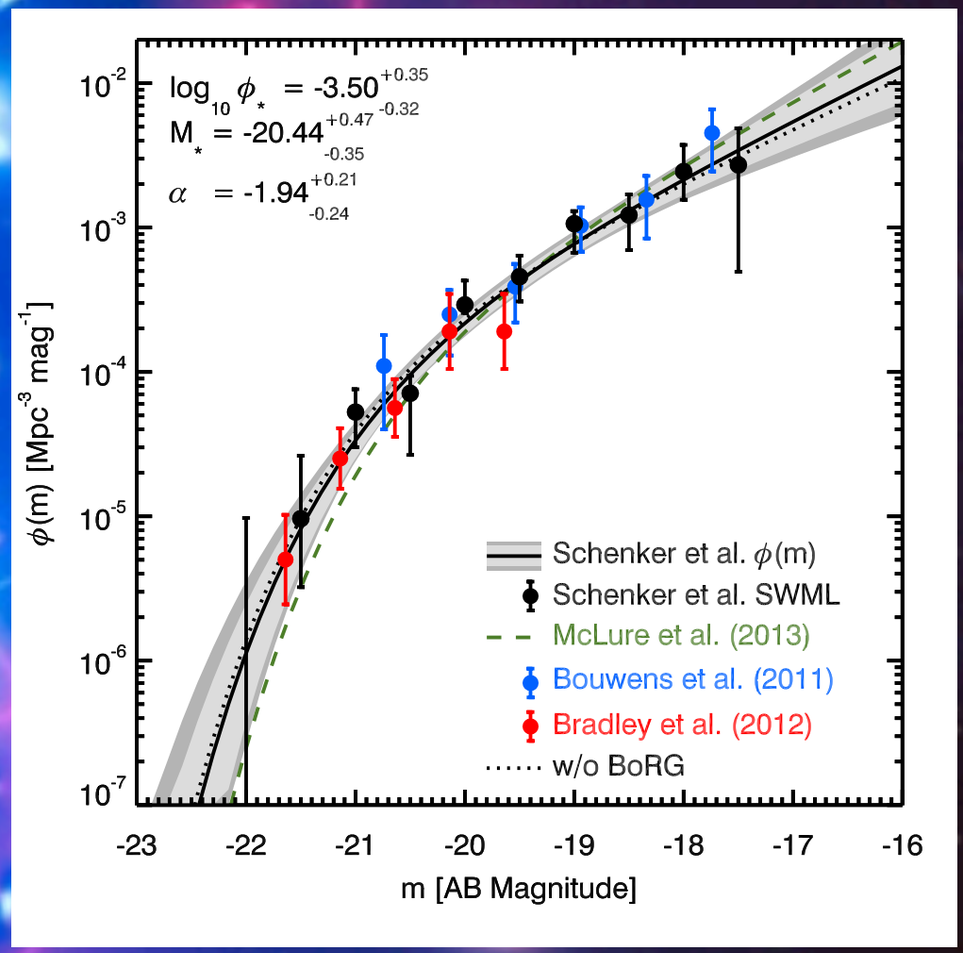
NIRCam -

5σ 29th ABmag F150W ~ 2 hrs
-> 30-31 ABmag intrinsic

5σ 30.5th ABmag F150W ~ 15 hrs
-> 31.5- 32.5 ABmag intrinsic

5σ 31.2th ABmag F150W ~ 70 hrs
-> 32.2 - 33.2 ABmag intrinsic

to observe M_{UV} ~ -15 galaxies responsible for re-ionization; need depths ~ 32 ABmag intrinsic



HUDF12 z~8 luminosity function - Schnenker et al. 2013