The BAckground universe (TBA)

MARUŠA BRADAČ

DARK SIDE OF THE UNIVERSE

Austin Hoag, Kuang-Han Huang, Russell Ryan, Brian Lemaux, Tommaso Treu,
Anja von der Linden, Adriano Fontana, Anthony Gonzalez, Dennis Zaritsky

Breaking Cosmic Dawn

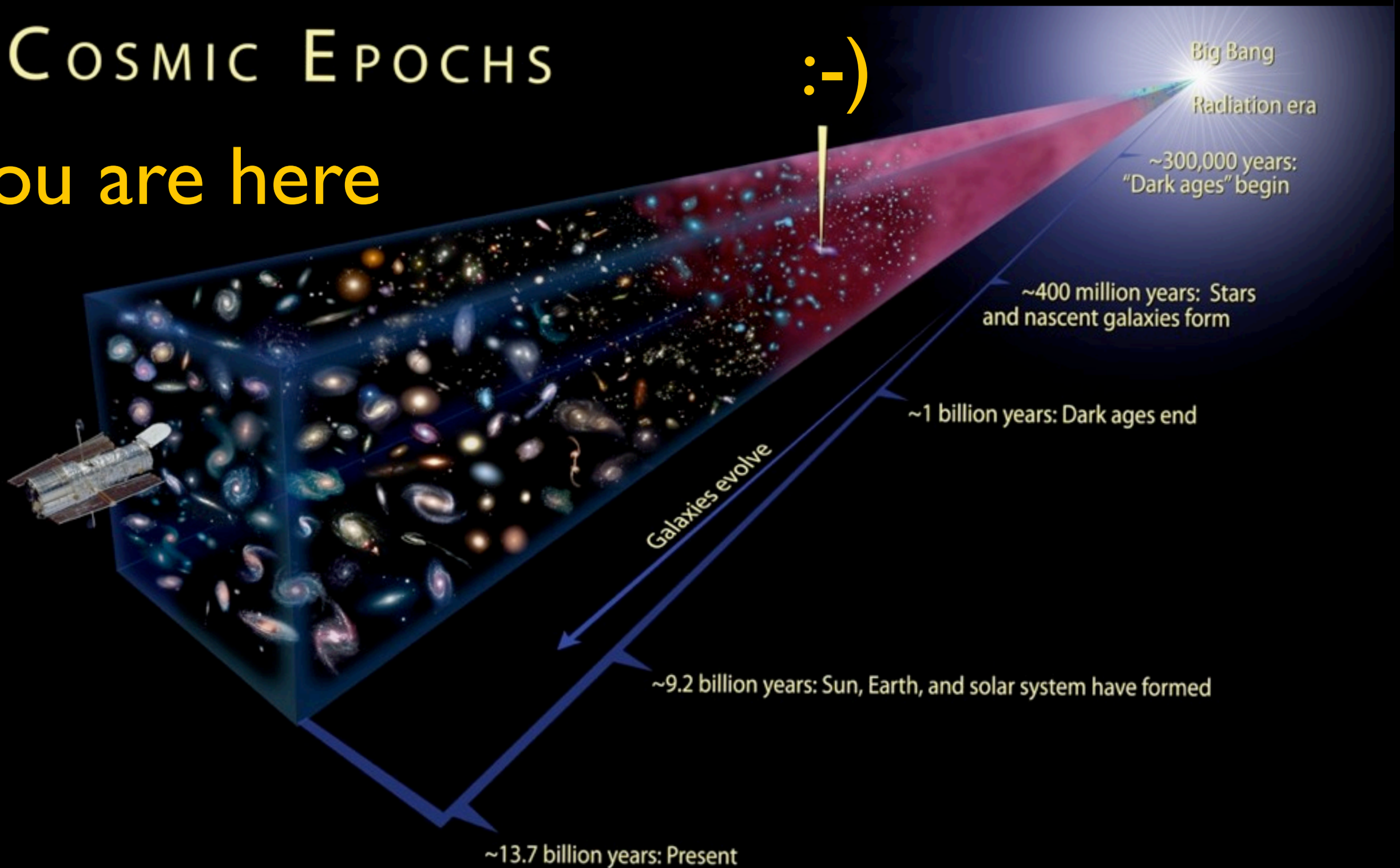
MARUŠA BRADAČ

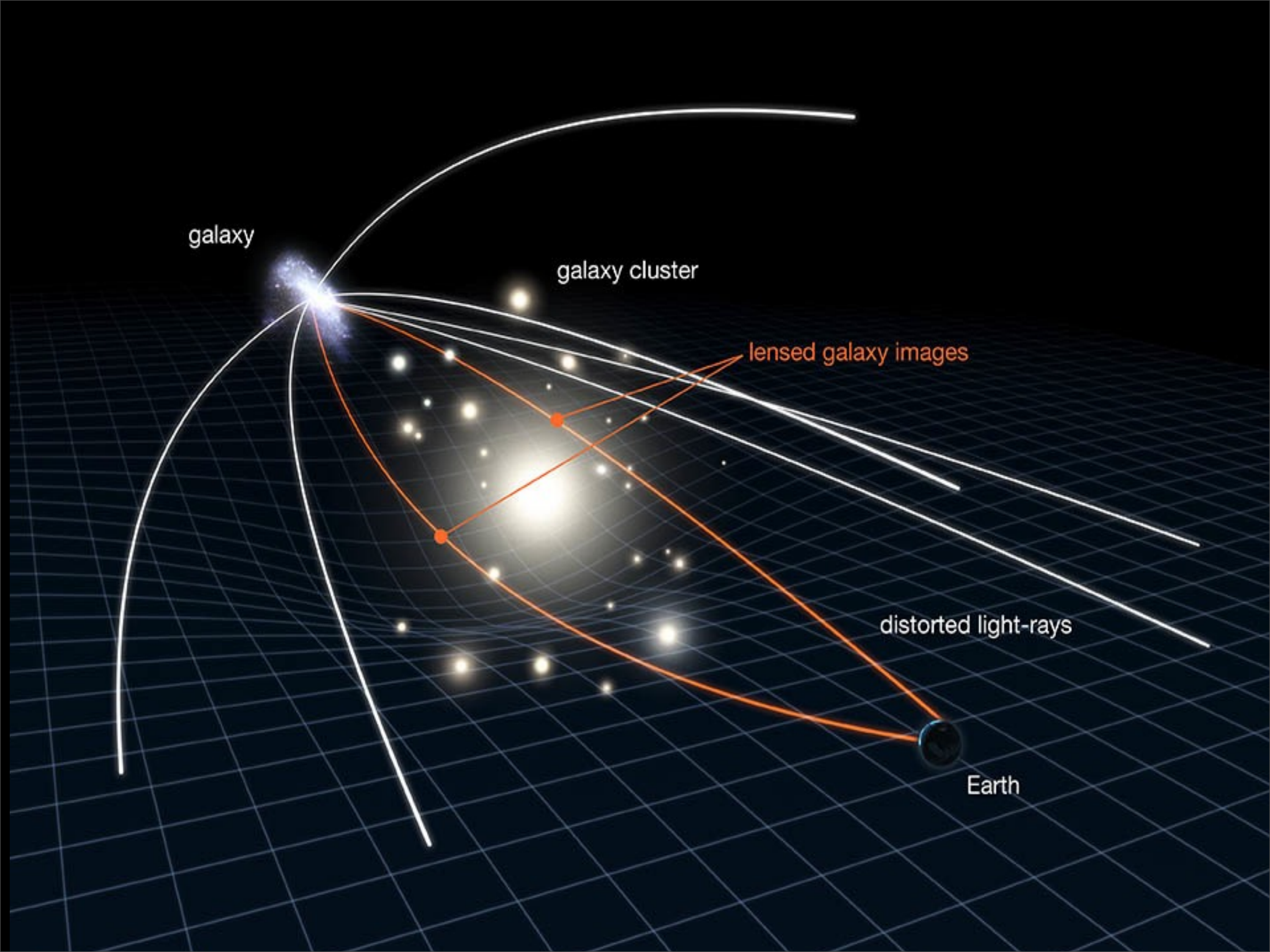
DARK SIDE OF THE UNIVERSE

Austin Hoag, Kuang-Han Huang, Russell Ryan, Brian Lemaux, Tommaso Treu,
Anja von der Linden, Adriano Fontana, Anthony Gonzalez, Dennis Zaritsky

Cosmic Epochs

You are here




galaxy
galaxy cluster
lensed galaxy images
distorted light-rays
Earth

LENSING IS FANTASTIC™

galaxy

galaxy cluster

lensed galaxy images

distorted light-ra

th

DETECT + YOUNG STELLAR POPULATION

OLD STELLAR POPULATION

TOPOLOGY OF REIONIZATION, Z CONFIRMATION

LENSING IS FANTASTIC™

galaxy

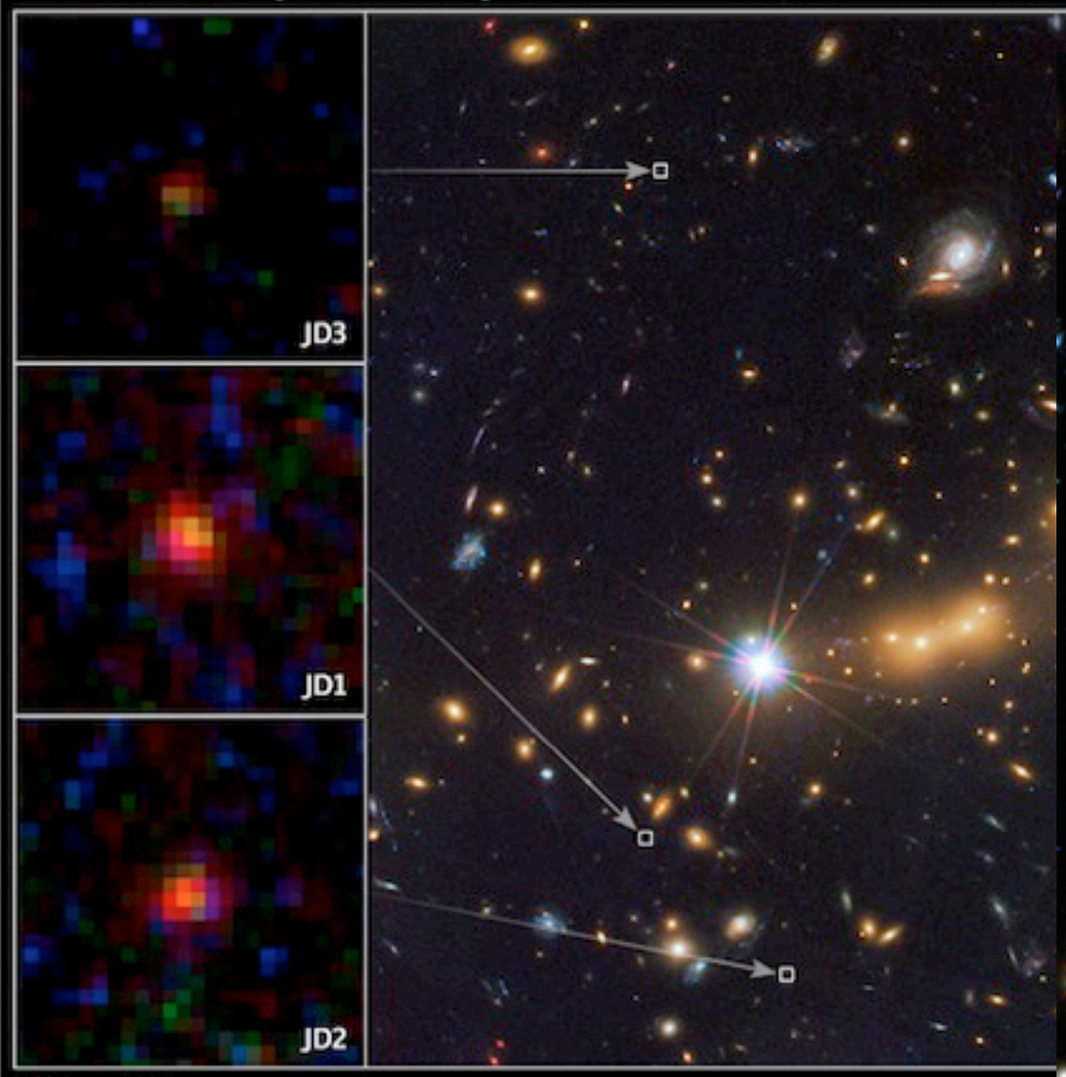
YOUNG STELLAR POPULATION

galaxy cluster

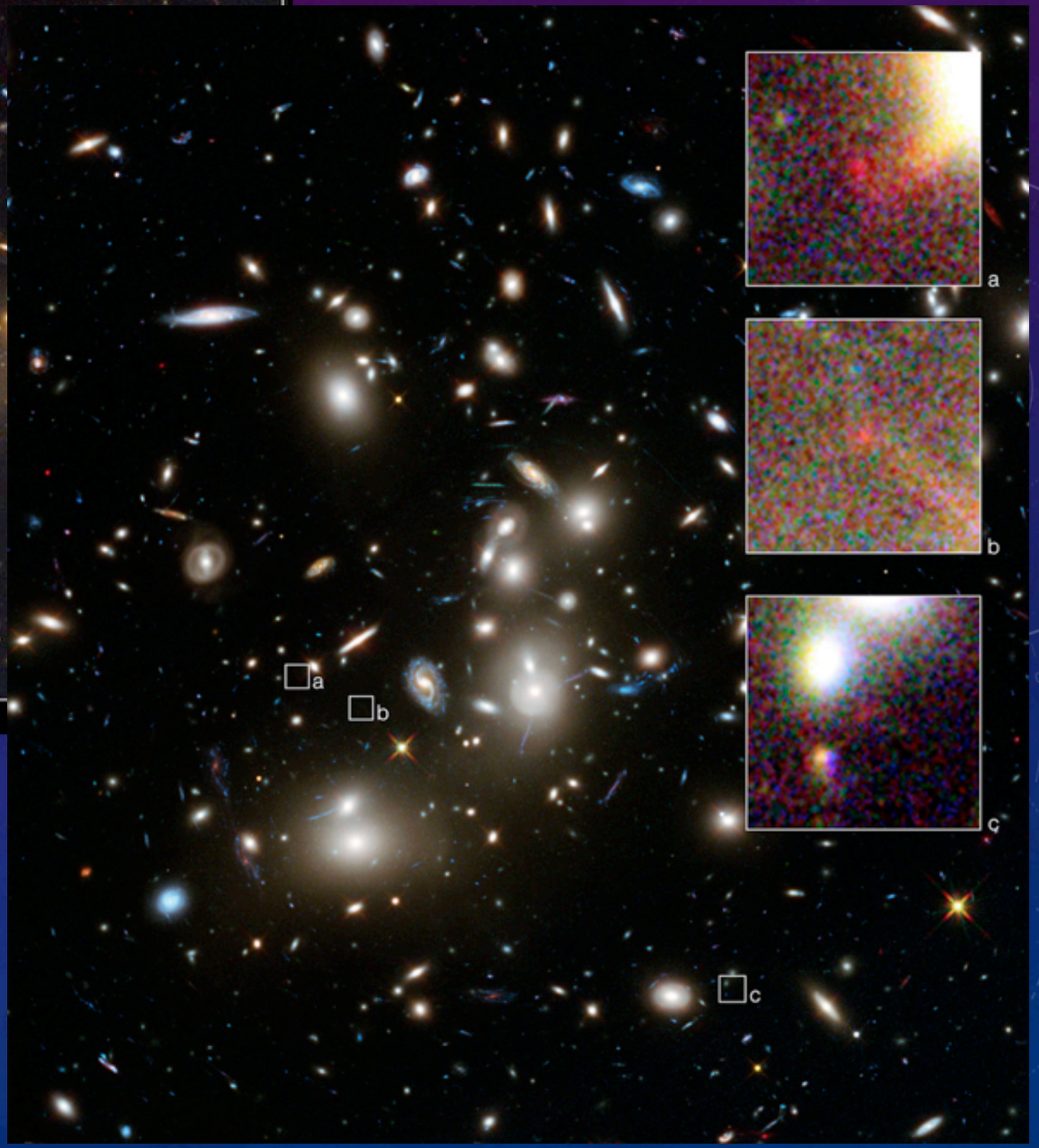
images

distorted light-rays

Earth



Coe et al. 2013
z=11



z=9.8

Zitrin et al. 2014

Breaking Cosmic Dawn

- Count the sources
- Ability of sources to reionize the universe depends upon the ρ_{SFR}
  - Rest-frame UV information is not sufficient

LENSING IS FANTASTIC™

galaxy

OLD STELLAR POPULATION

galaxy cluster

lensed galaxy images

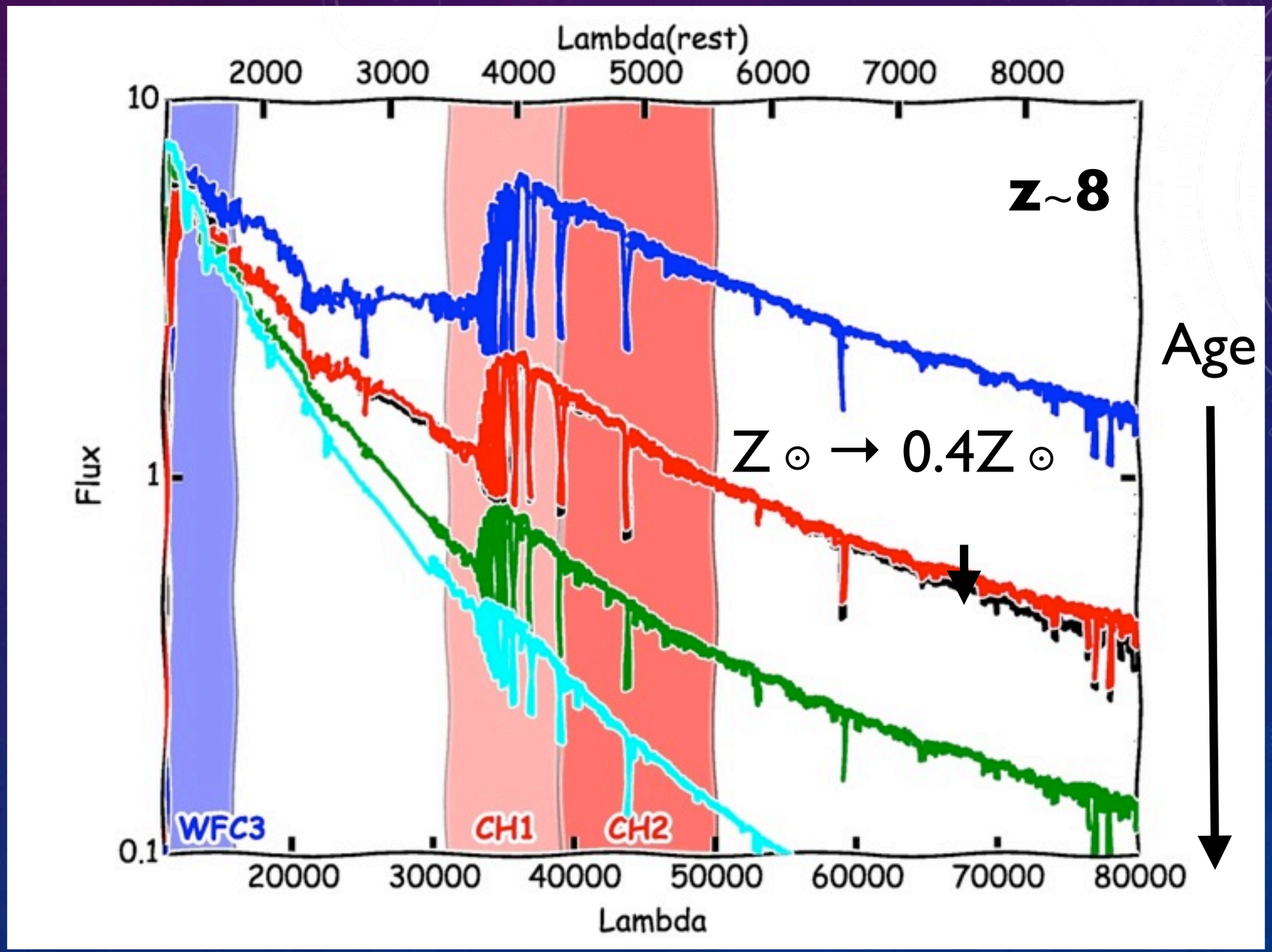
SPITZER SPACE TELESCOPE

distorted light-rays

Earth

Spitzer

- Star formation at z>7



SURFS UP: Spitzer UltRa Faint SUrvey Program

Exploration Science Spitzer Program for Cycle 9 (PI Bradač)

Over 550 hours with Spitzer for 10 clusters

Think Spitzer-UDF depth, but assisted by lensing!

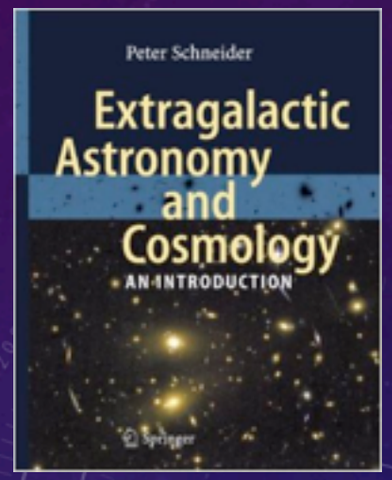
http://www.physics.ucdavis.edu/~marusa/SurfsUp.html

Bradač et al. 2014 (ApJ)
Ryan et al. 2014 (ApJL)

SURFS UP Cast

- Bullet Cluster
- MACSJ0454.1−0300

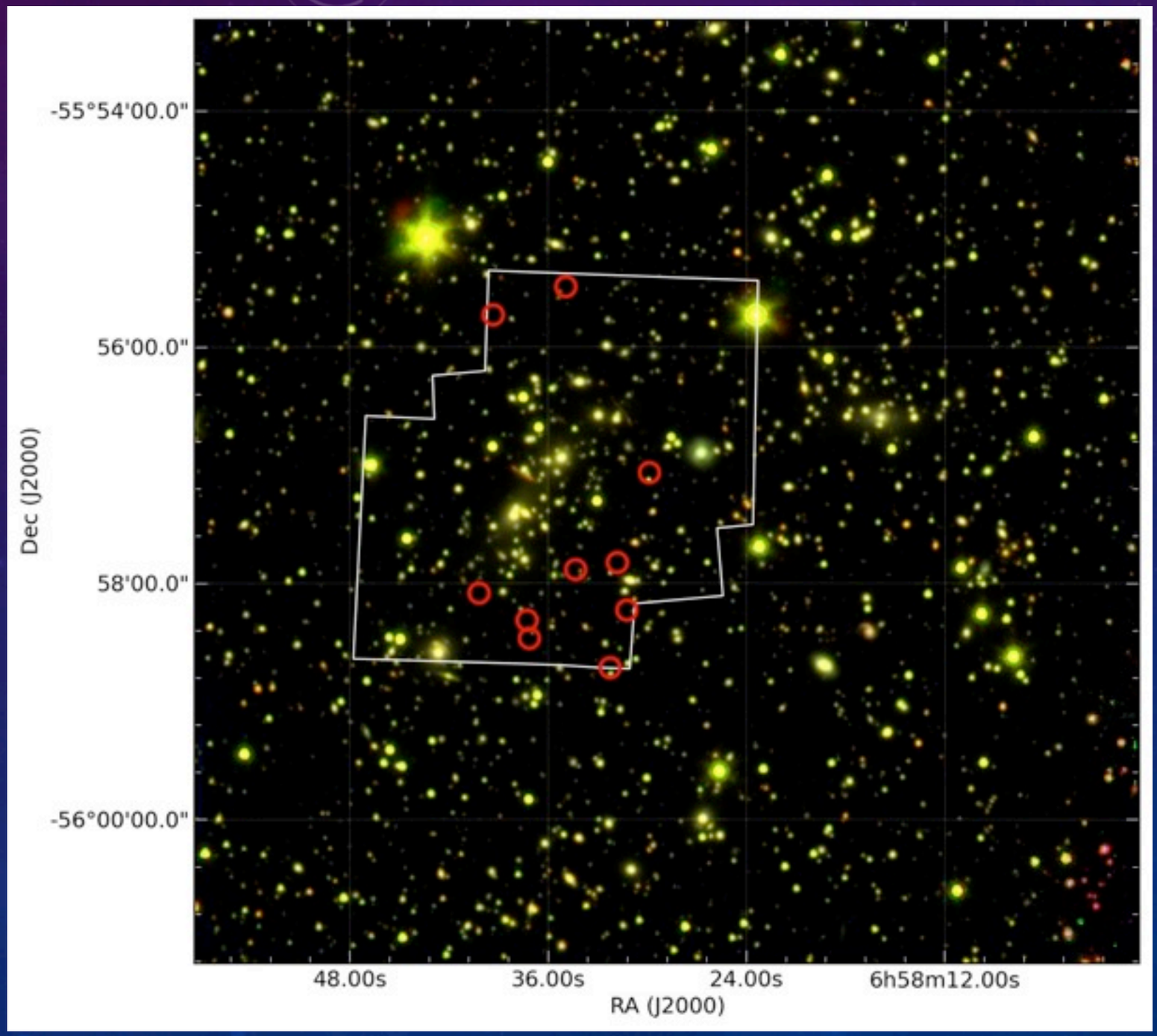
- MACSJ0717.5+3745
- MACSJ0744.8+3927
- MACSJ1149.5+2223



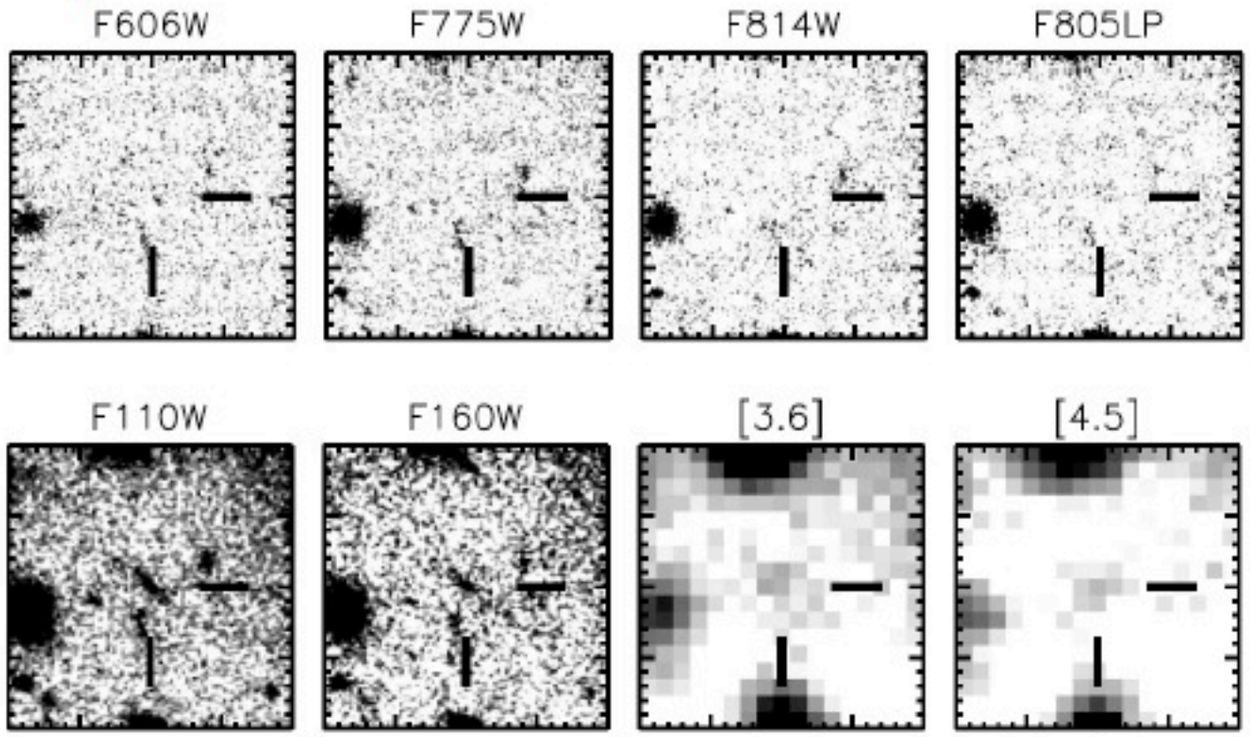
- RXJ1347−1145
- MACSJ1423.8+2404
- MACSJ2129.4−0741
- MACSJ2214.9−1359
- RCS2−2327.4−0204

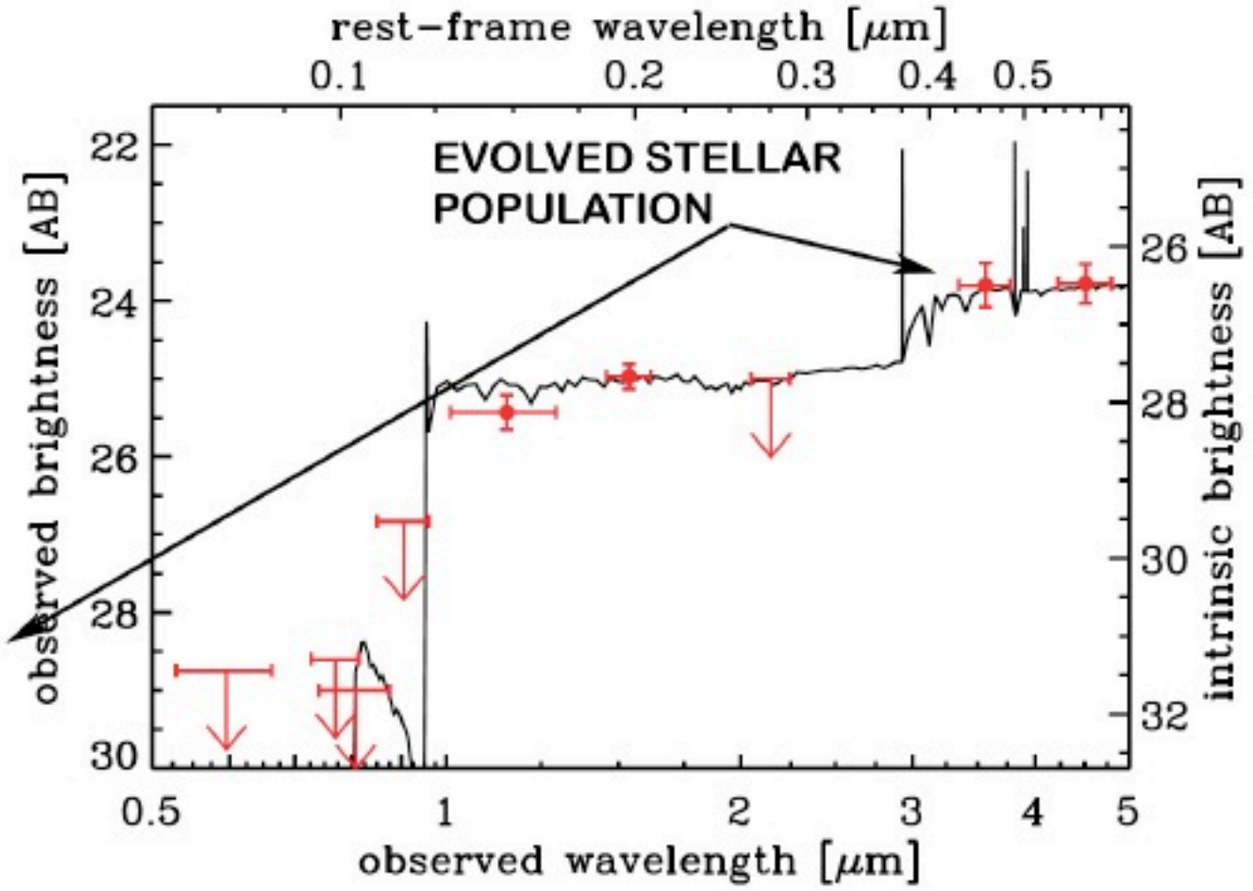
SURFS UP: Spitzer UltRa Faint SUrvey Program

Bullet Cluster with Spitzer



Object # 3





	μ	z	Age [Myr]	μSFR$[M_\odot \mathrm{yr}^{-1}]$	$\mu M^*[M_\odot]$	$\mu L_{\mathrm{IR}}[L_\odot]$
# 3	12±4	6.8 ± 0.2	600^{160}_{-230}	16^{+16}_{-8}	$2.4^{+0.7}_{-1.0} \times 10^{10}$	$1.3^{+1.8}_{-0.8} \times 10^{12}$

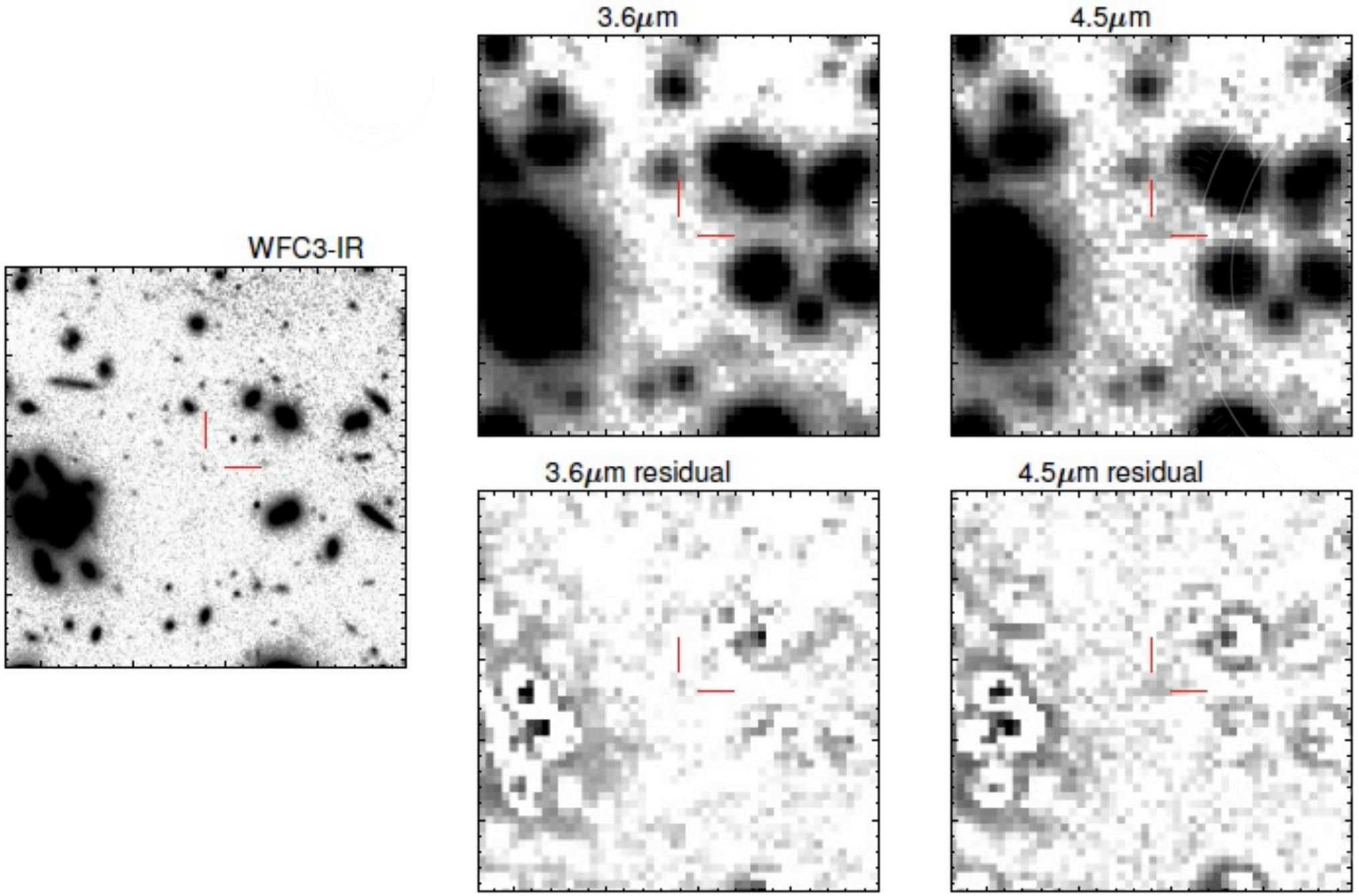
z=6.8

SFR~16M$_\odot$/yr (**lensed**)

SFR~1M$_\odot$/yr (**intrinsic**)

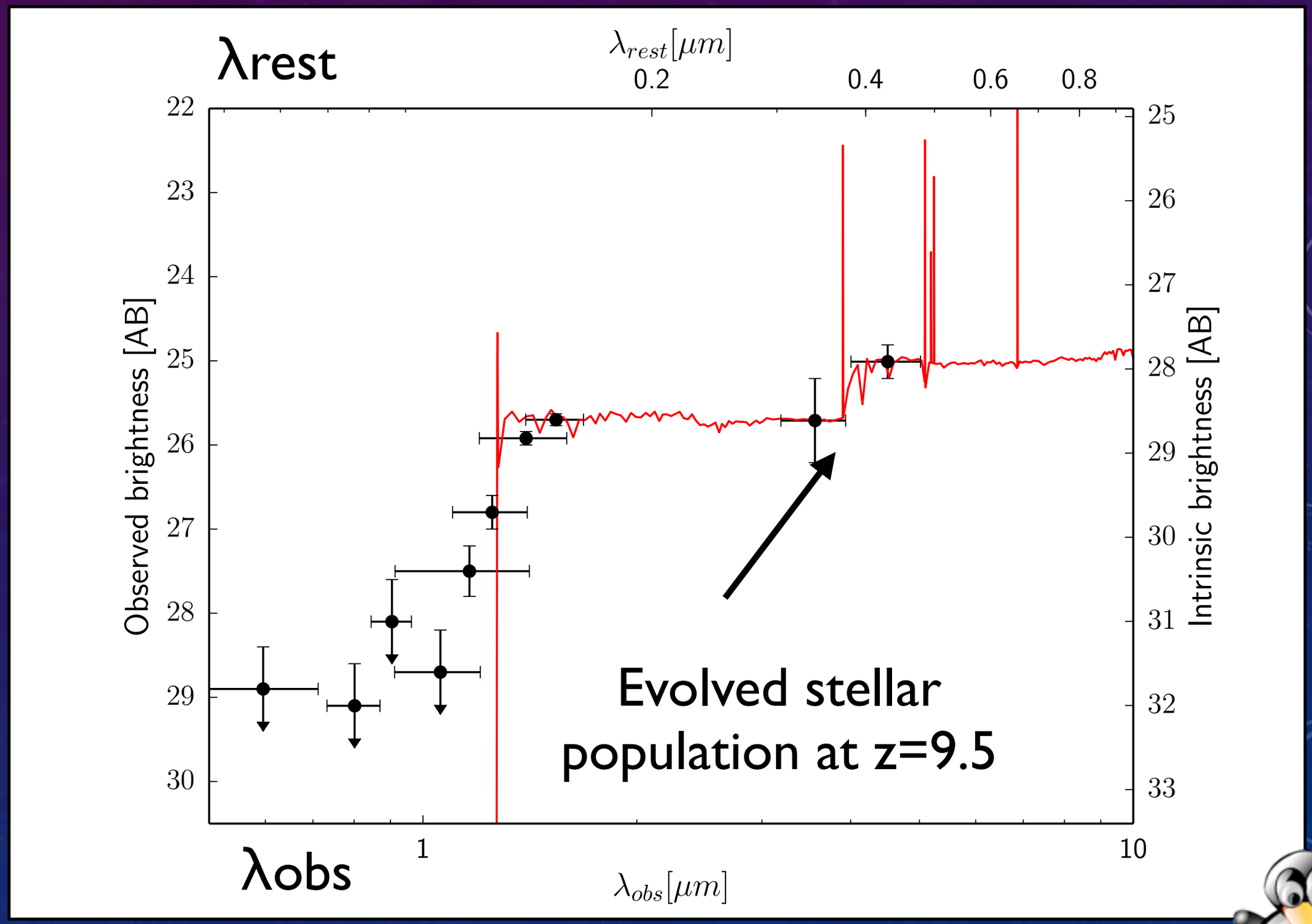
Ryan et al. 2014

MACS1149-zD



Zheng et al. 2012, Bradač et al. 2014

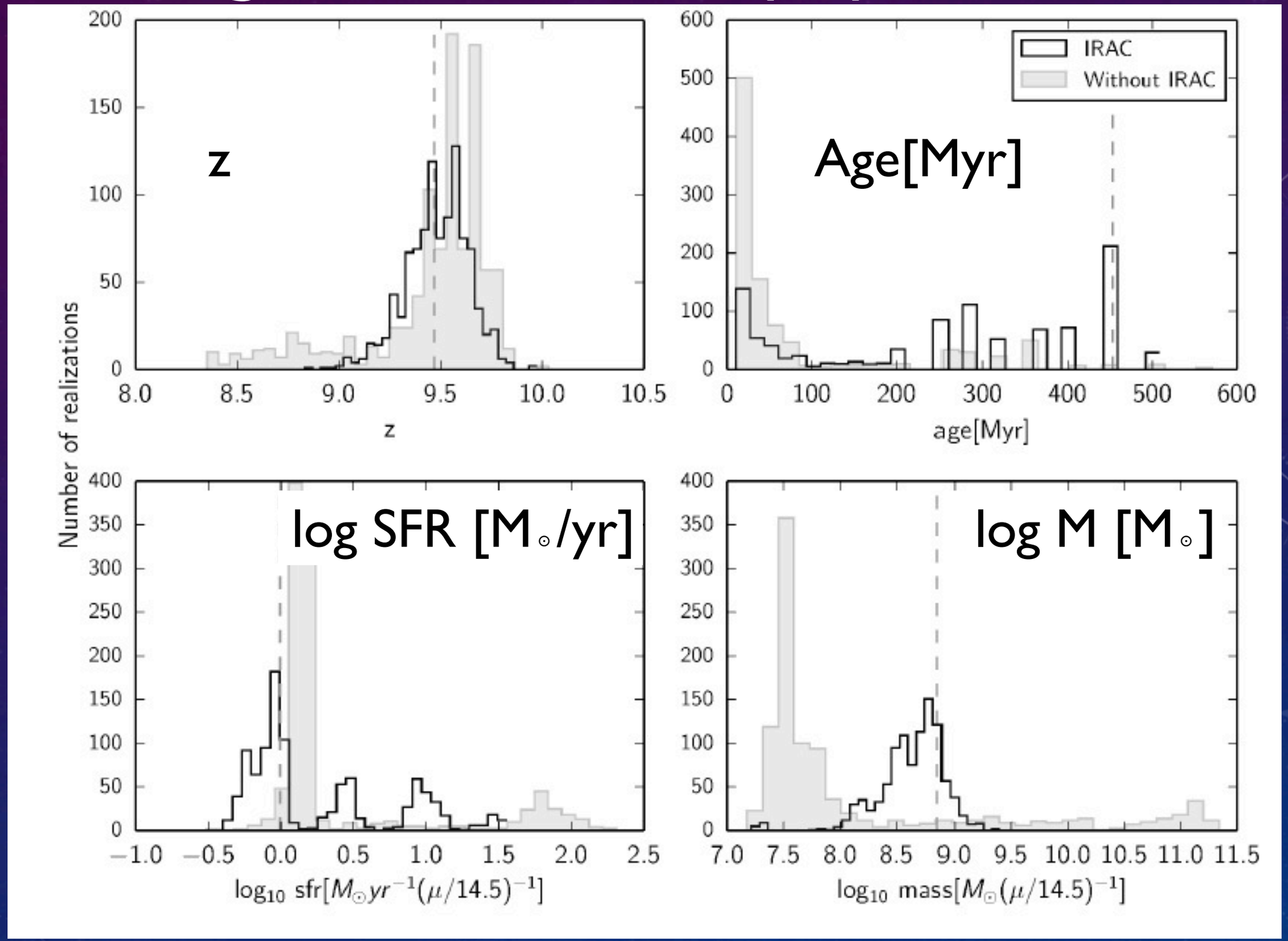
MACS1149-zD



Zheng et al. 2012, Bradač et al. 2014

“Distinguished” stellar populations

MARUŠA BRADAČ



The age of the universe at z~9.5 is ~520Myr.

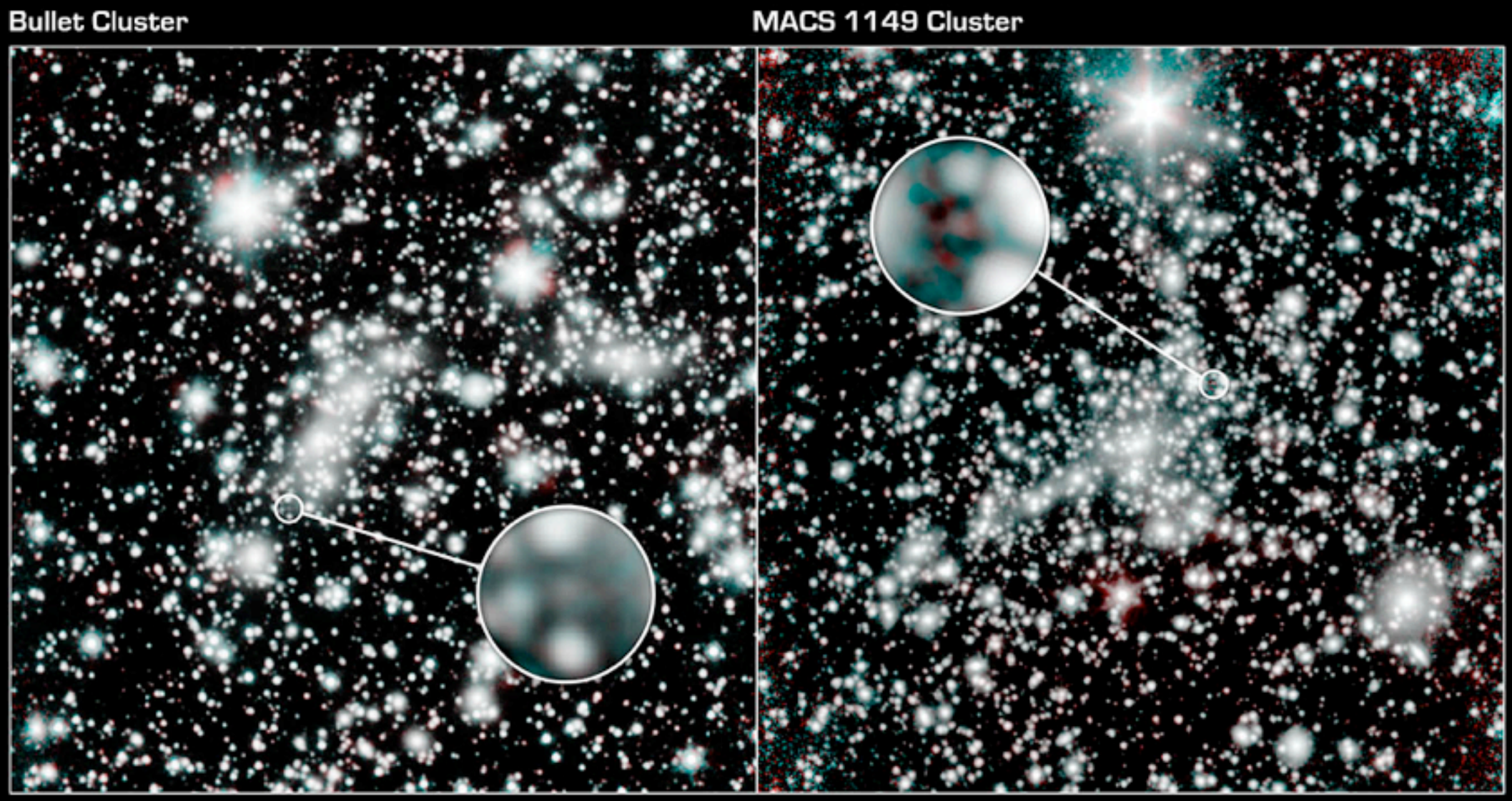
LePhare + Monte Carlo

BREAKING COSMIC DAWN

SURFS UP

MARUŠA BRADAČ

SURFS UP: Spitzer UltRa Faint SUrvey Program



www.spitzer.caltech.edu/news/1669-feature14-13-Catching-a-Wave-of-Galaxies-Ending-the-Dark-Ages

BREAKING COSMIC DAWN

Bradač et al. 2014 (ApJ)
Ryan et al. 2014 (ApJL)

SURFS UP

SURFS UP Status

- We have several more objects detected by Spitzer at z≳ 7 (Huang et al. 2014 in prep.)
  - → 20 z-band droputs with 3-sigma detection in at least one IRAC filters
- We are making data public: currently images, catalogs in the future.

Cluster	Number	Cluster	Number
MACS0454	2	RXJ1347	2
Bullet	1	MACS1423	8
MACS0717	0	MACS2129	1
MACS0744	2	MACS2214	n/a
MACS1149	3	RCS2327	1

Huang et al. 2014 in prep.

SURFS UP marches on....

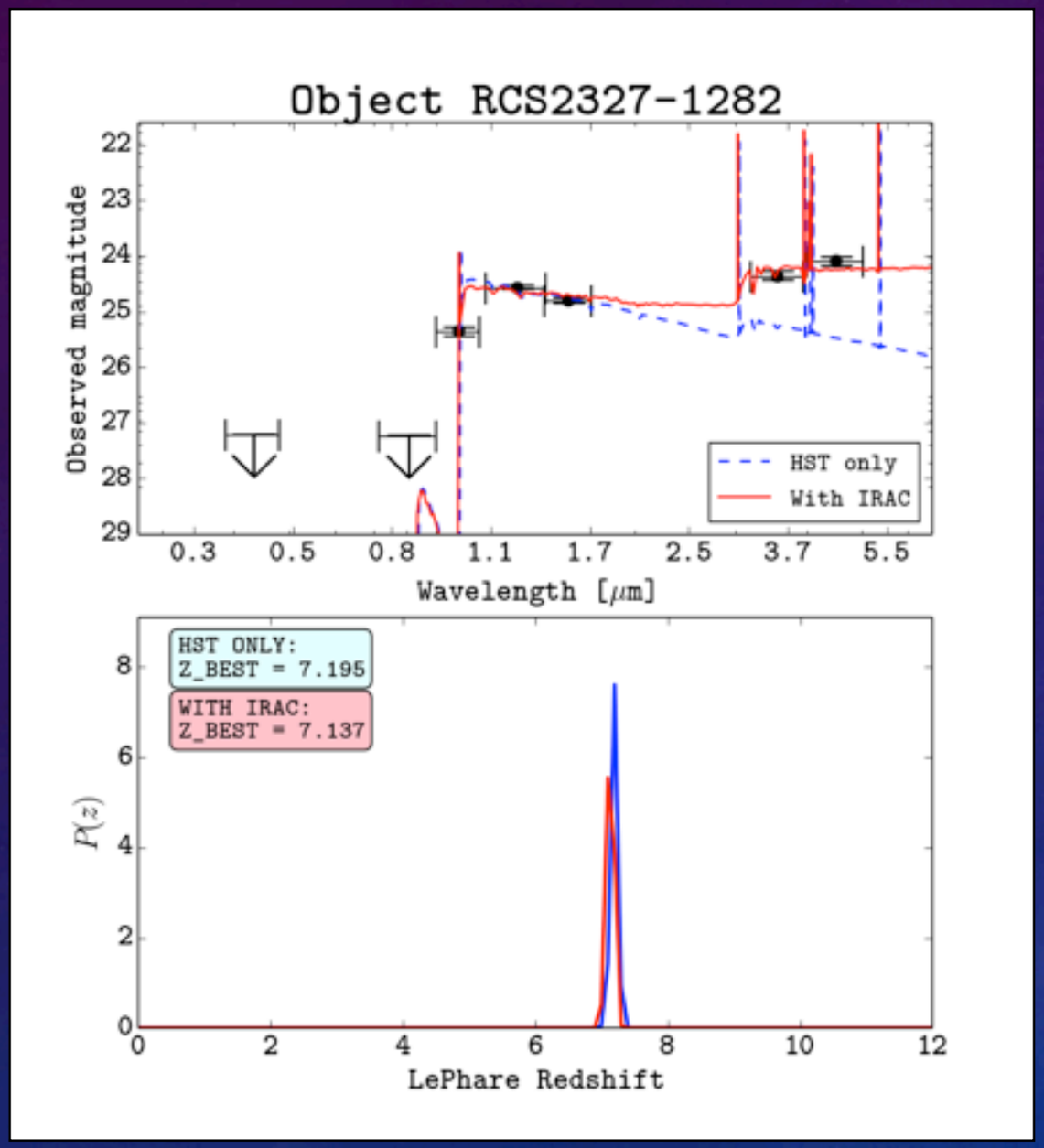
z~7 galaxies behind RCS2-2327

ID	$m_H(AB)$	μ	photo-z (best fit)	L ($L_\star$)
RCS2327-1914	25.6	$4.52^{+0.54}_{-0.23}$	6.9	$0.22^{+0.03}_{-0.02}$
RCS2327-1282	24.8	$4.30^{+0.37}_{-0.33}$	7.1	$0.46^{+0.04}_{-0.04}$
RCS2327-2068	26.6	$27.53^{+23.82}_{-9.66}$	6.8	$0.01^{+0.01}_{-0.01}$
RCS2327-1412	27.0	$12.00^{+2.09}_{-0.18}$	6.8	$0.02^{+0.01}_{-0.01}$

All sub-L_*

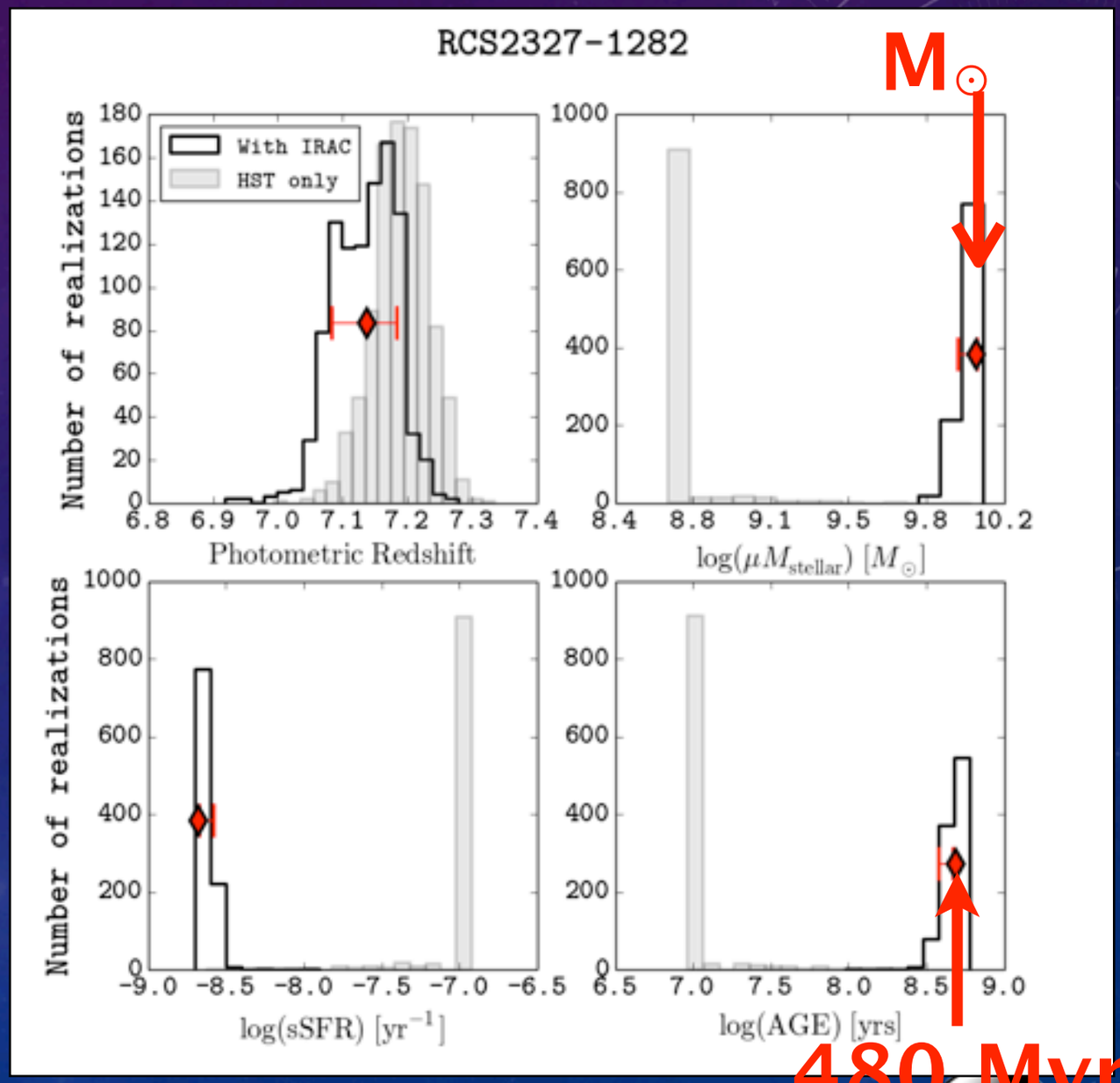
A. Hoag et al. 2014 in prep

SURFS UP marches on....



z=7.1

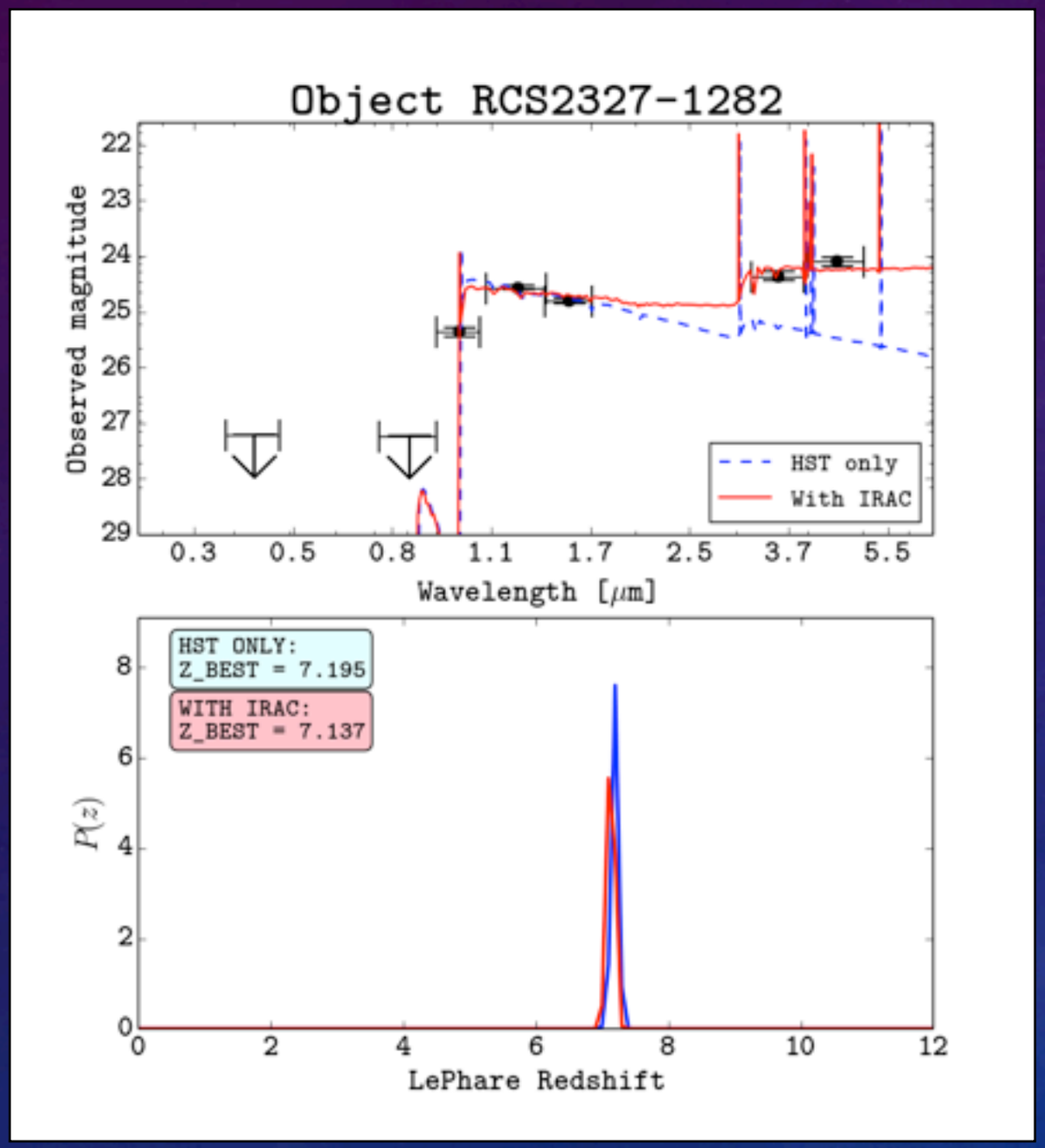
2.7×10⁹ $M_\odot$



480 Myr

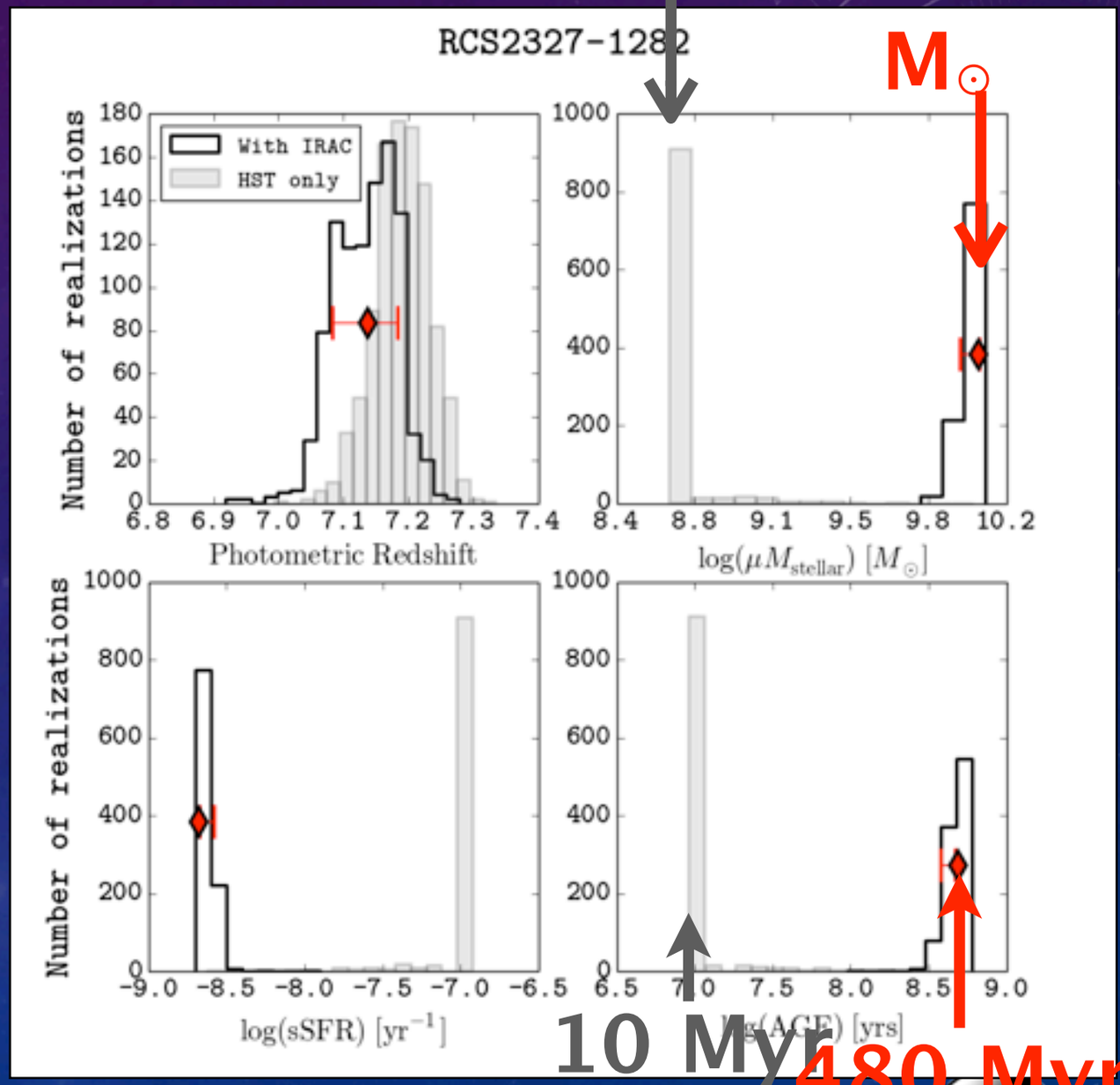
Huang et al. 2014 in prep.

SURFS UP marches on....



1.2×10^8 $M_\odot$

2.7×10^9 $M_\odot$



10 Myr

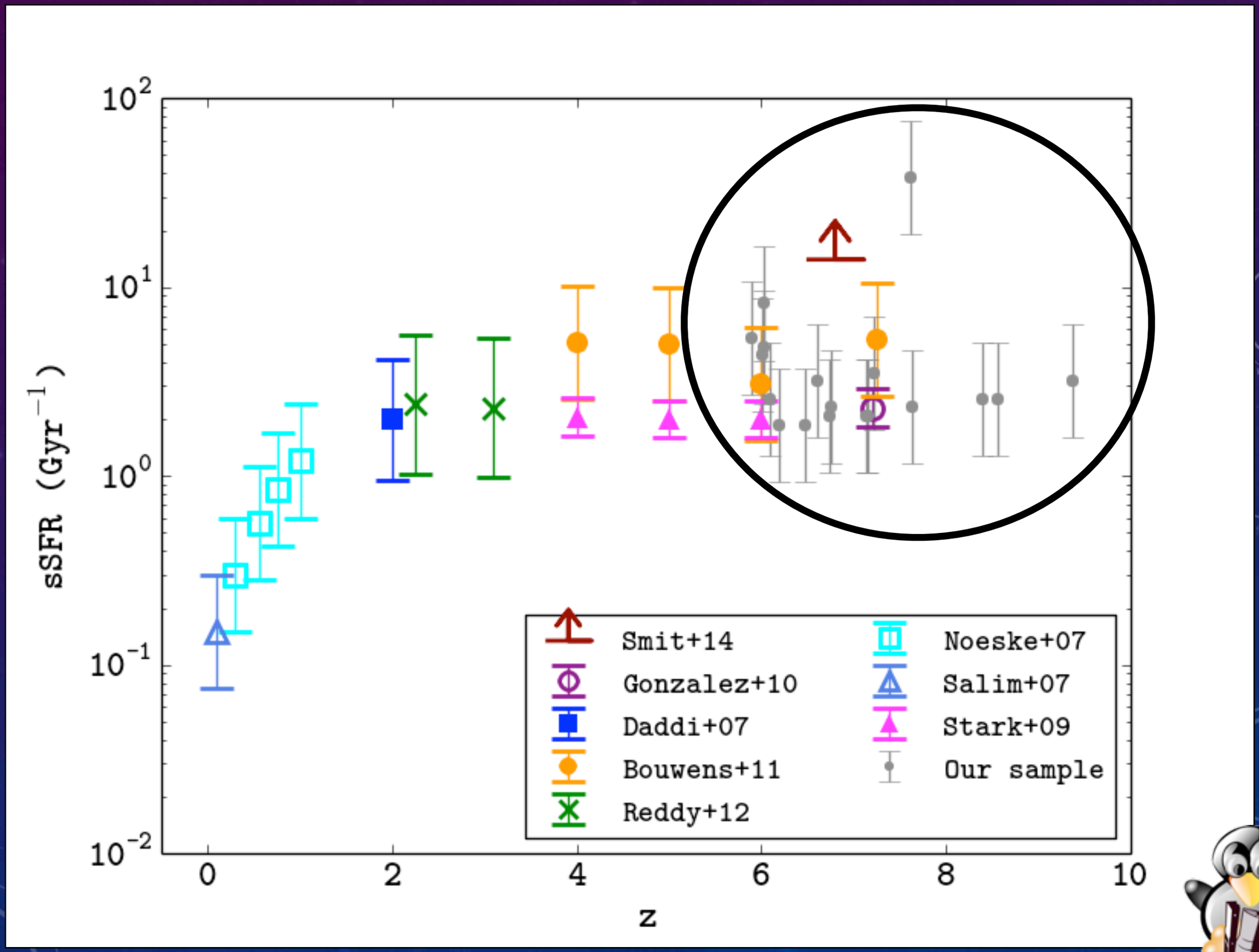
480 Myr

z=7.1

BREAKING COSMIC DAWN

Huang et al. 2014 in prep.

SURFS UP



Huang et al. 2014 in prep.

LENSING IS FANTASTIC™

TOPOLOGY OF REIONIZATION
Z CONFIRMATION

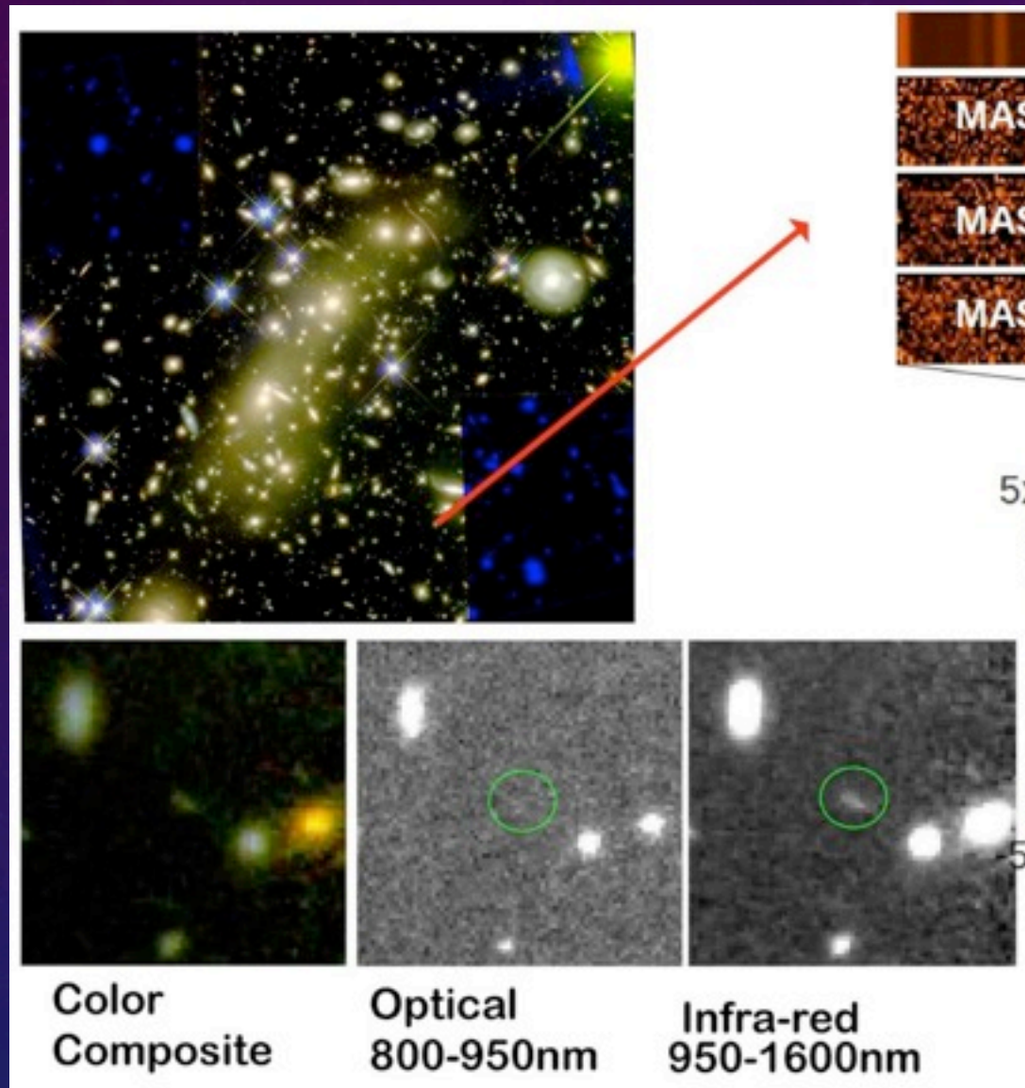
How do we capitalize on deep cluster imaging?

THE GOOD

- HST, Spitzer give us great imaging.
- Need spectra:
  - → Ultimate redshift determination.
- → Reionization.
- → Study SFR (young stellar population)

Spectroscopy at z > 7 is hard

THE BAD



The faintest high-z galaxy ever detected spectroscopically - 16 hours on VLT

z=6.740 LAE (0.5L* LBG)

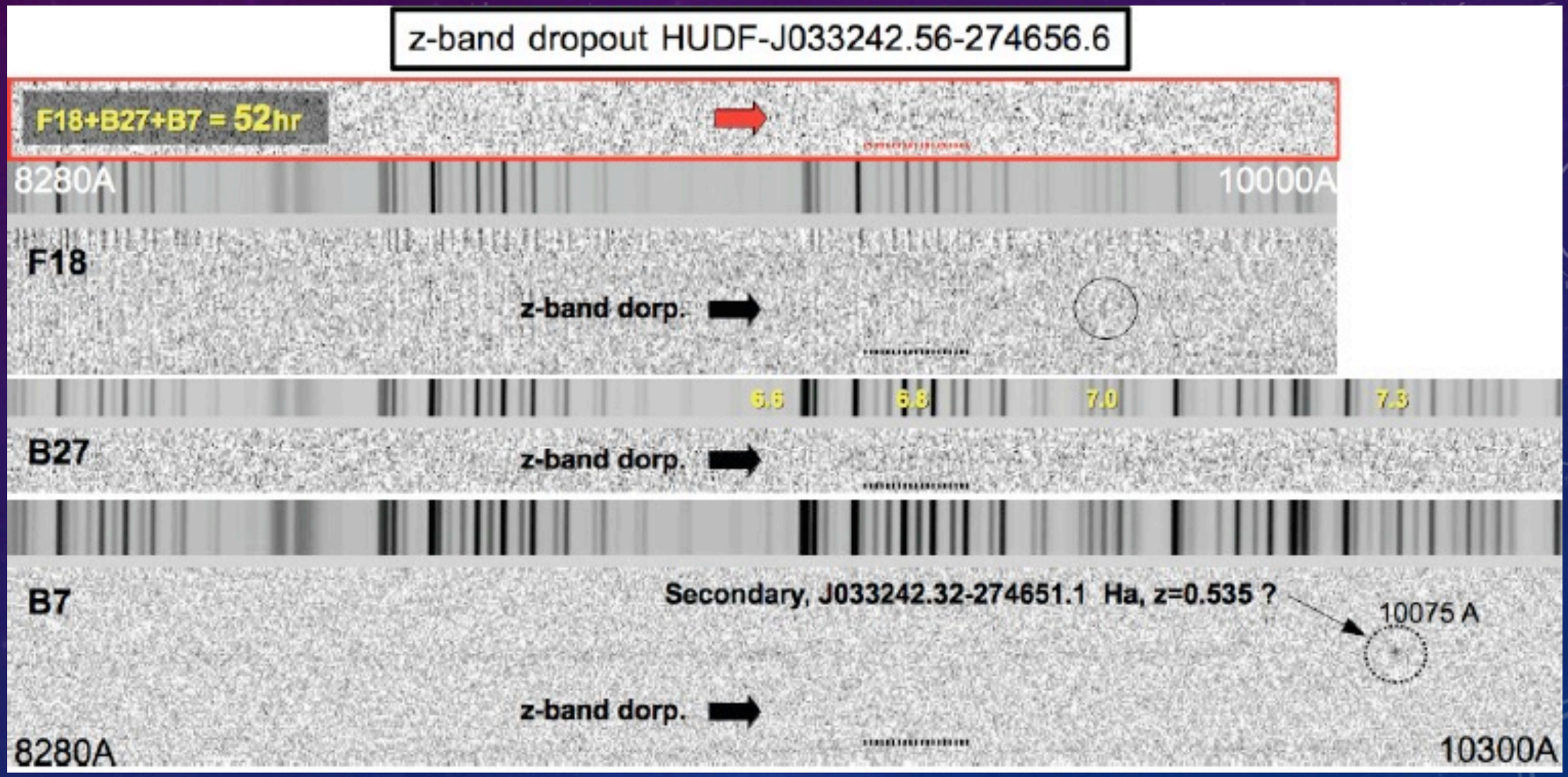
BREAKING COSMIC DAWN

Bradač et al. 2012

Spectroscopy at z > 7 is hard

THE UGLY

A 52 hours VLT/FORS2 spectrum of a bright z ~ 7 HUDF galaxy

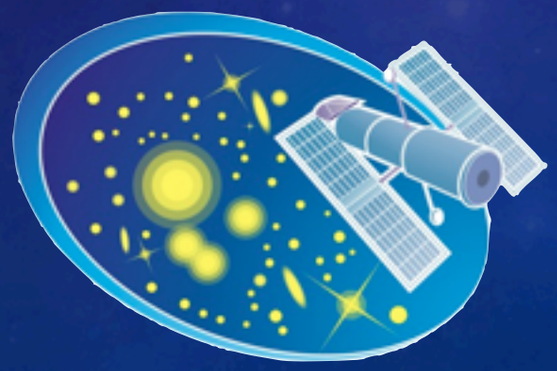


Vanzella et al. 2014

No lya published so far beyond z=7.6 (Schenker et al. 14) despite many attempts (e.g. Pentericci et al. 14).

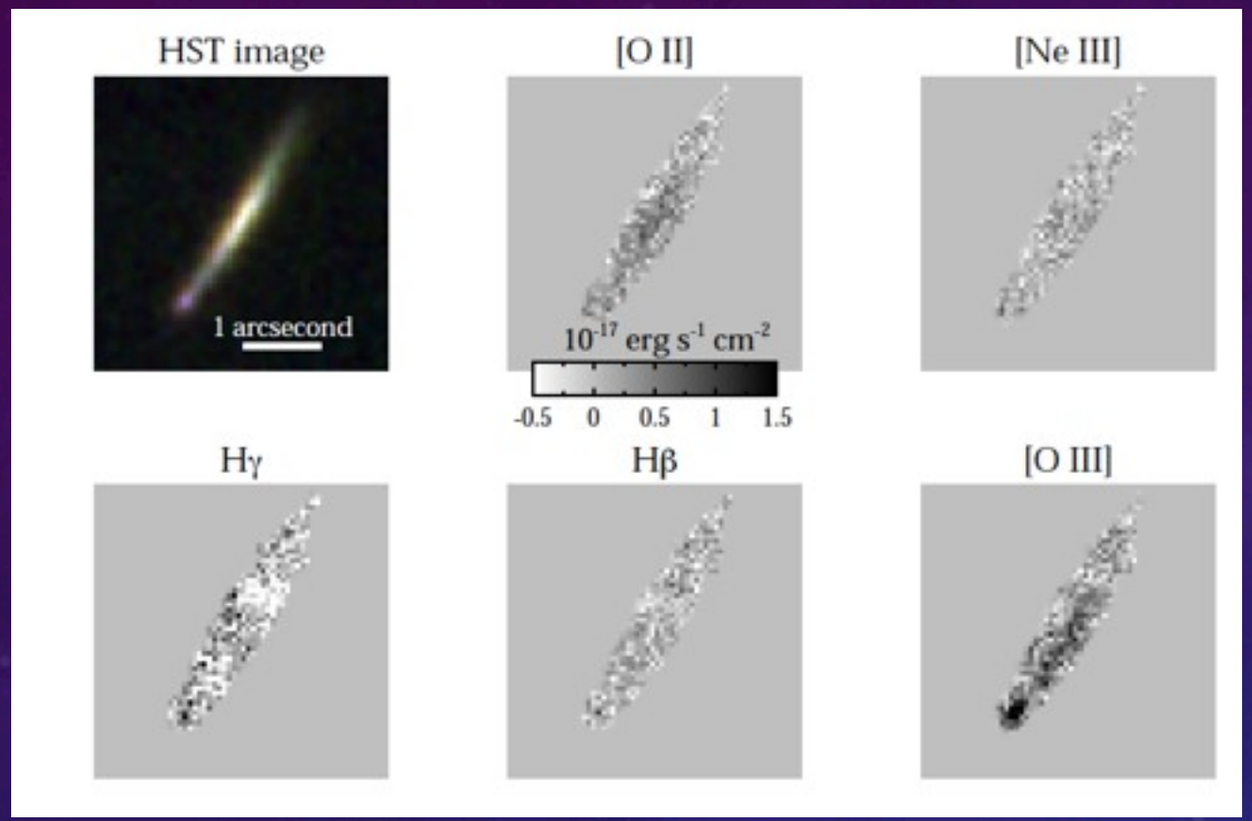
Grism Lens-Amplified Survey from Space

- PI Treu, 140 orbits prime + 140 orbits parallel with grism
  - Spectrum of everything in the field of view
- High sensitivity owing to lensing magnification
- Uninterrupted wavelength coverage, potentially able to detect weaker and redder nebular lines



GLASS

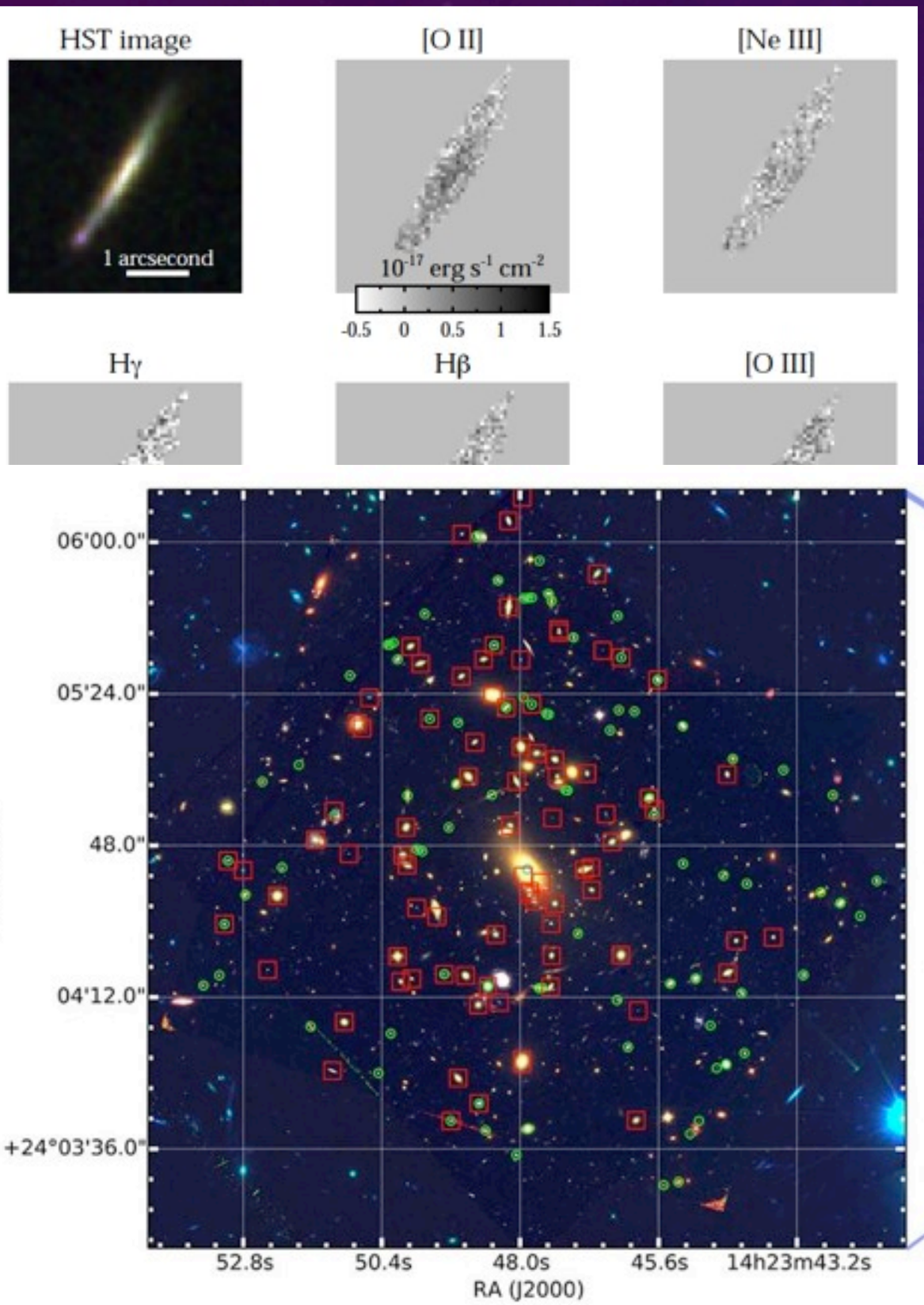
From Cosmic Dawn till Cosmic Dusk



Cycling of gas in galaxies
Jones et al. 2014

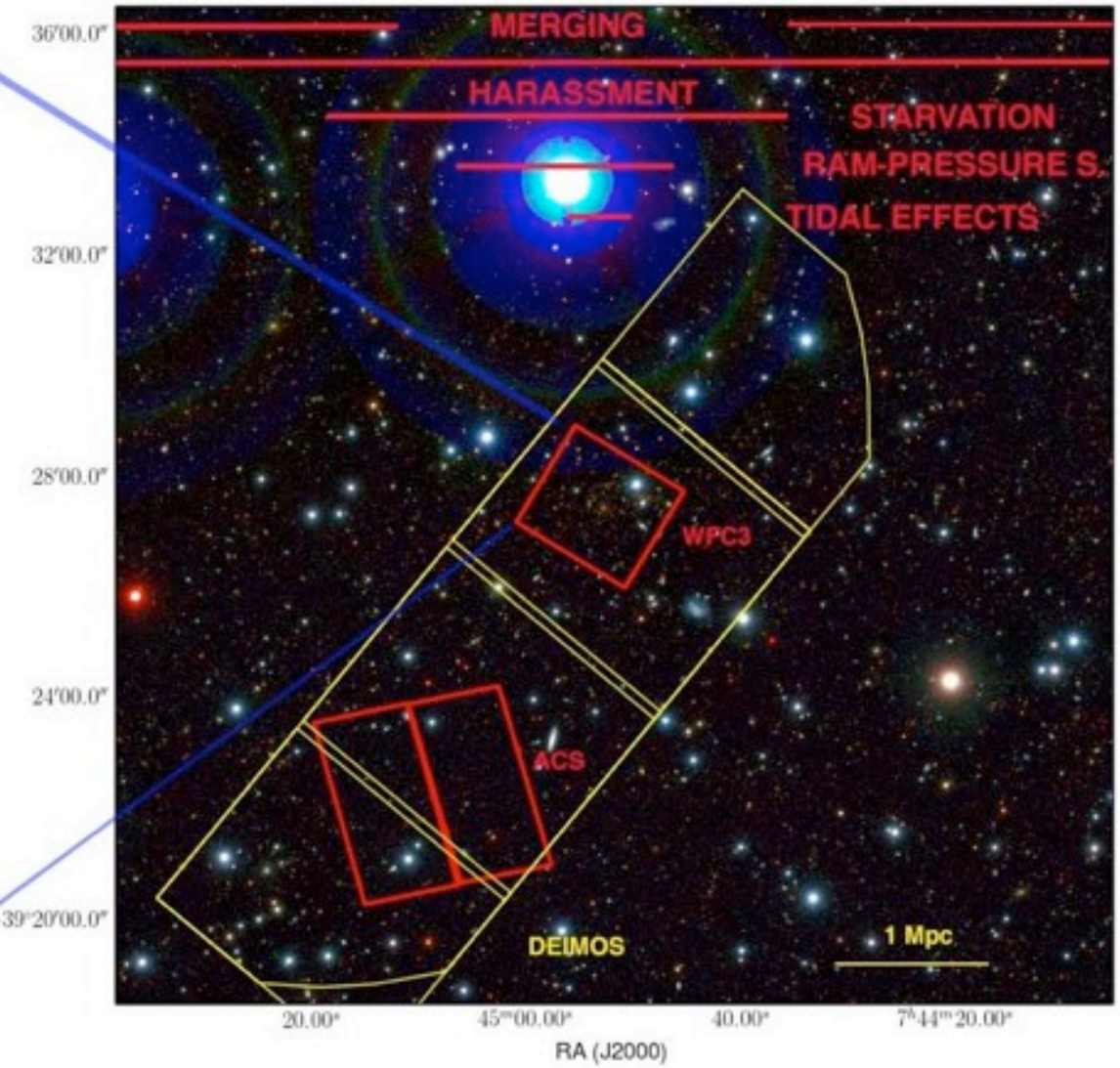
MARUŠA BRADAČ

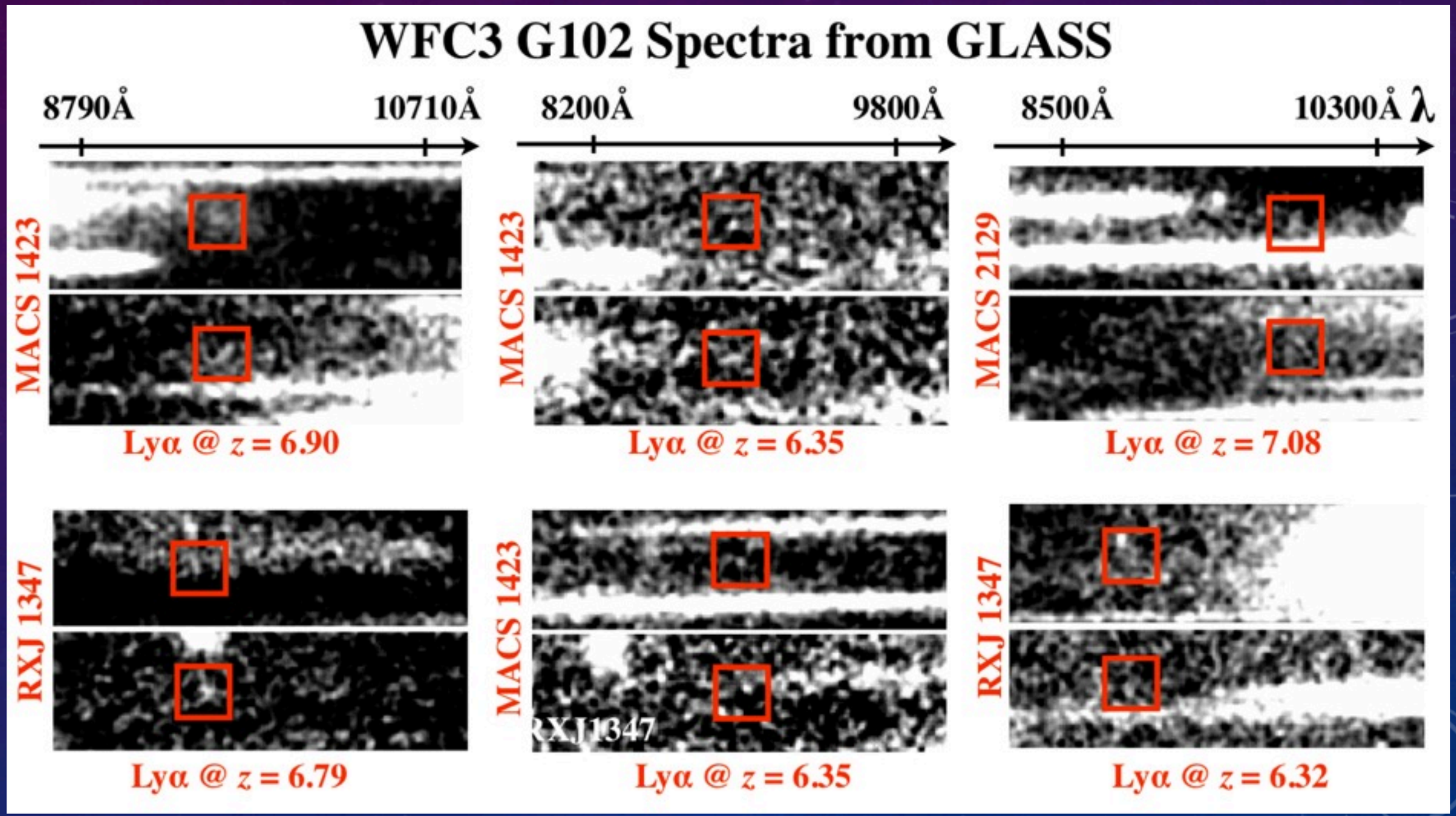
From Cosmic Dawn till Cosmic Dusk



Cycling of gas in galaxies
Jones et al. 2014

Environment and star formation
Vulcani et al. in prep

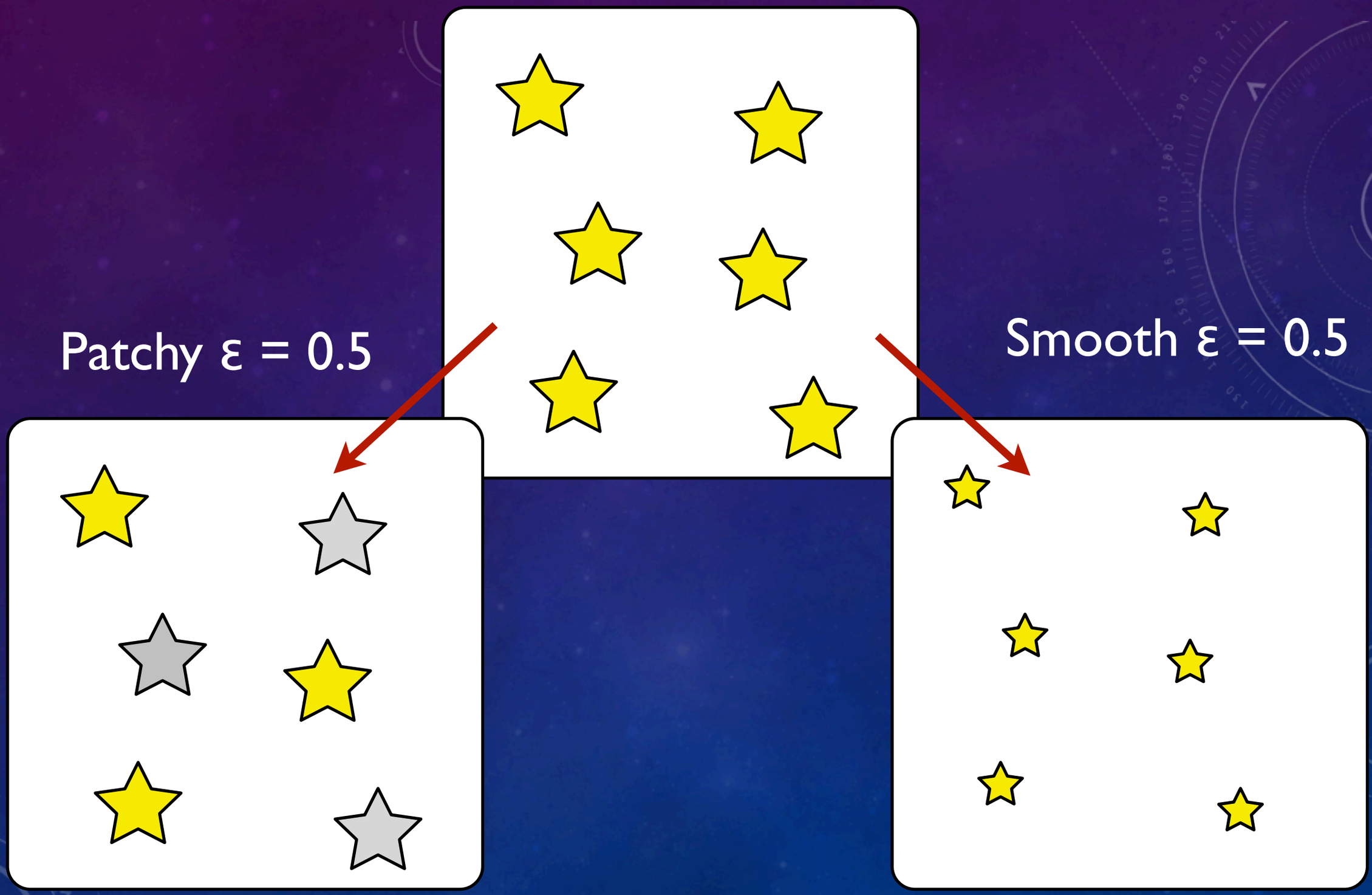




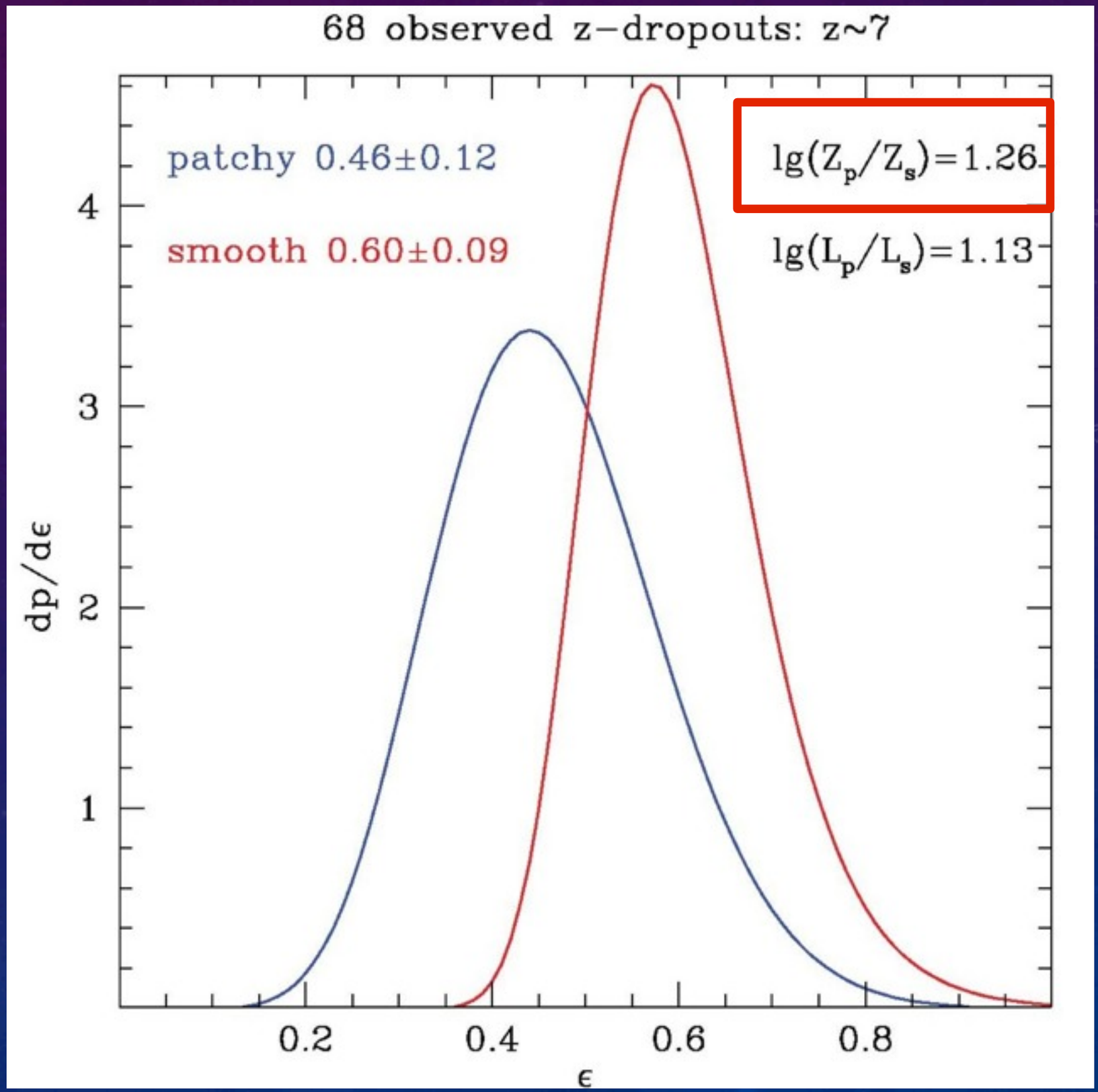
Schmidt et al. in prep.

GLASS

Breaking cosmic dawn



Patchy vs. smooth

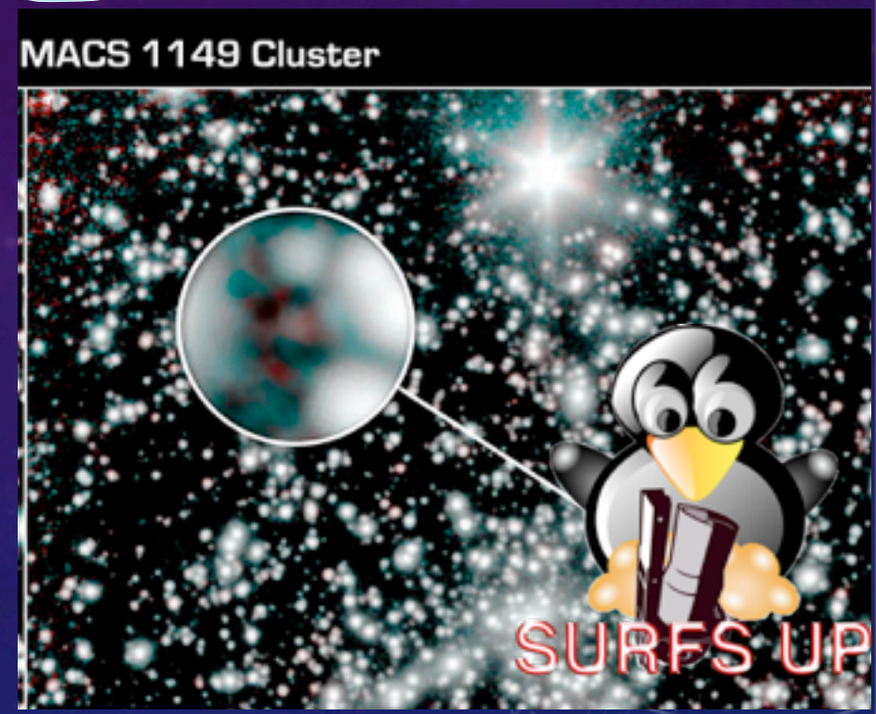


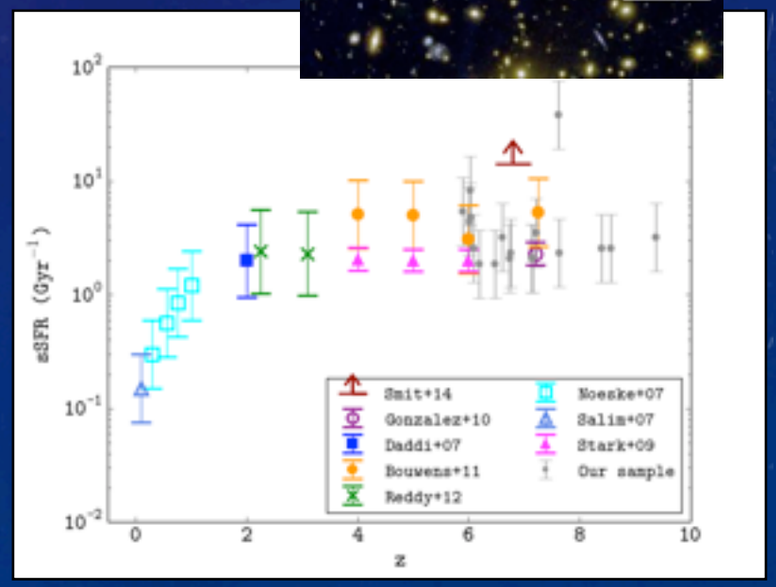
Pentericci et al. 2014, Treu et al. 2013

Summary

GLASS

- Star formation might proceed in a different way than previously thought at z > 7: exciting opportunities for Spitzer observations ahead!
- There seem to exist evolved stellar population at z>7
- Lensing is allowing us to push into until now unexplored territory
  - → study sources close to reionization (UV LF, old stellar population, topology of reionization with LAEs, etc.)
  - → first look of the sources that will be bread and butter for JWST

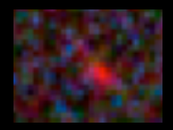


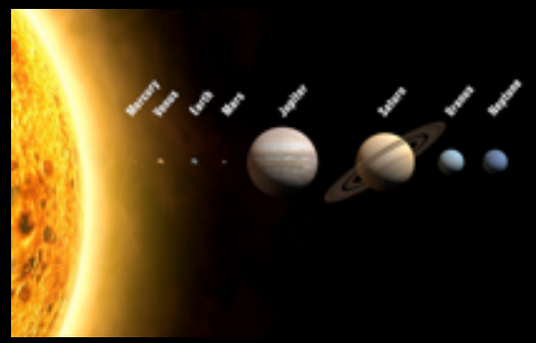


LENSING IS FANTASTIC™

13.3 billion years and counting….

Big Bang





Now

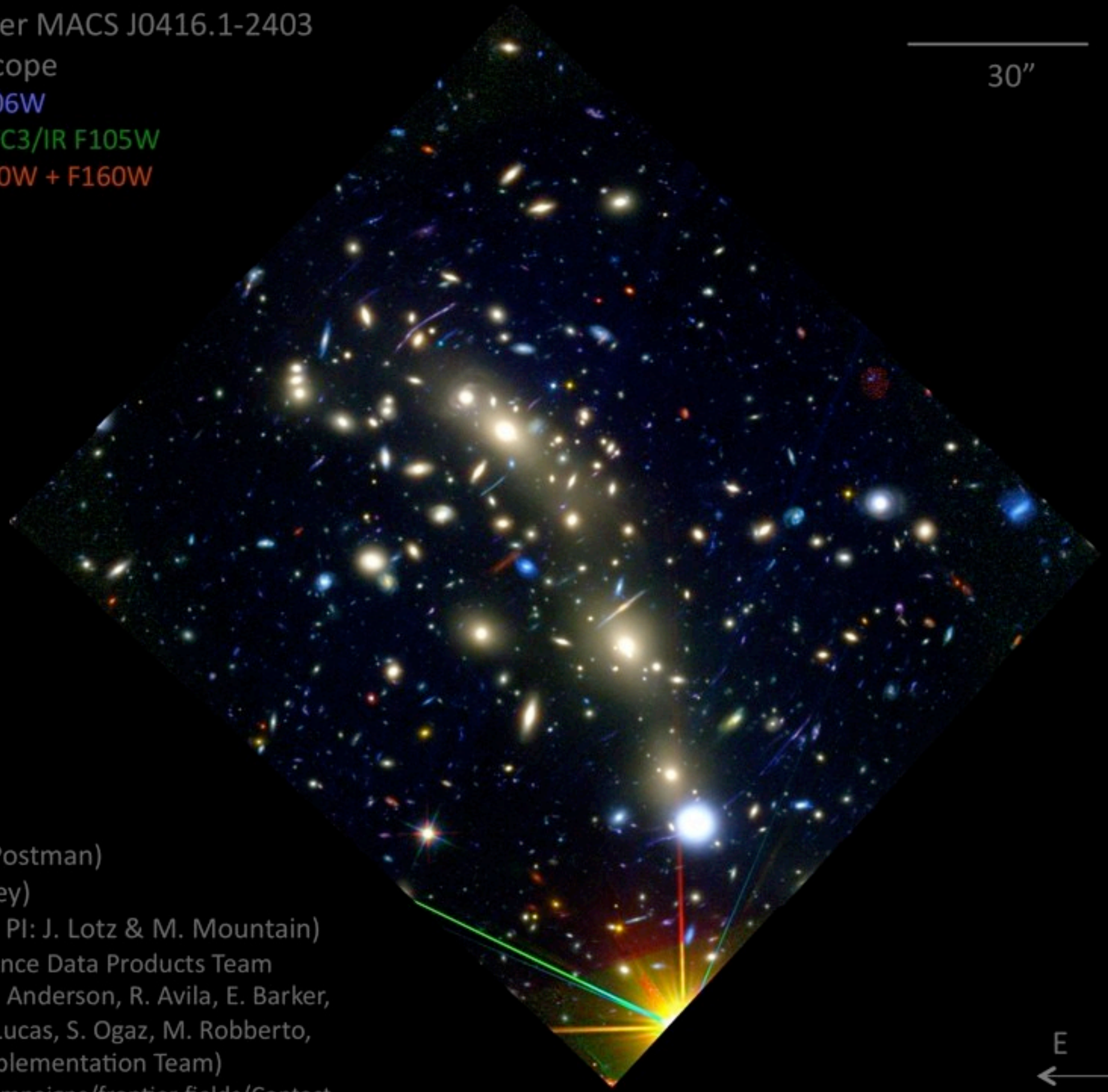
Jan

Dec

Wikipedia

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