Exploring the z~10 Universe through Massive Cosmic Lenses

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LETTER

nature

doi:10.1038/nature11446

A magnified young galaxy from about 500 million years after the Big Bang

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Re-ionization of the intergalactic medium occurred in the early Universe at redshift $z \approx 6$–11, following the formation of the first generation of stars[1]. Those young galaxies (where the bulk of stars formed) at a cosmic age of less than about 500 million years ($z \lesssim 10$) remain largely unexplored because they are at or beyond the sensitivity limits of existing large telescopes. Understanding the properties of these galaxies is critical to identifying the source of the radiation that re-ionized the intergalactic medium. Gravitational lensing by galaxy clusters allows the detection of [redacted]

prominent hydrogen absorption features in the spectra of faint galaxies. At $z > 7$, the hydrogen Lyman α break, at a wavelength of $\sim 0.12(1 + z)$ μm, is redshifted out of the optical bands, and the hydrogen Balmer break, at $\sim 0.38(1 + z)$ μm, is redshifted into the range of the Infrared Array Camera (IRAC) on board Spitzer.

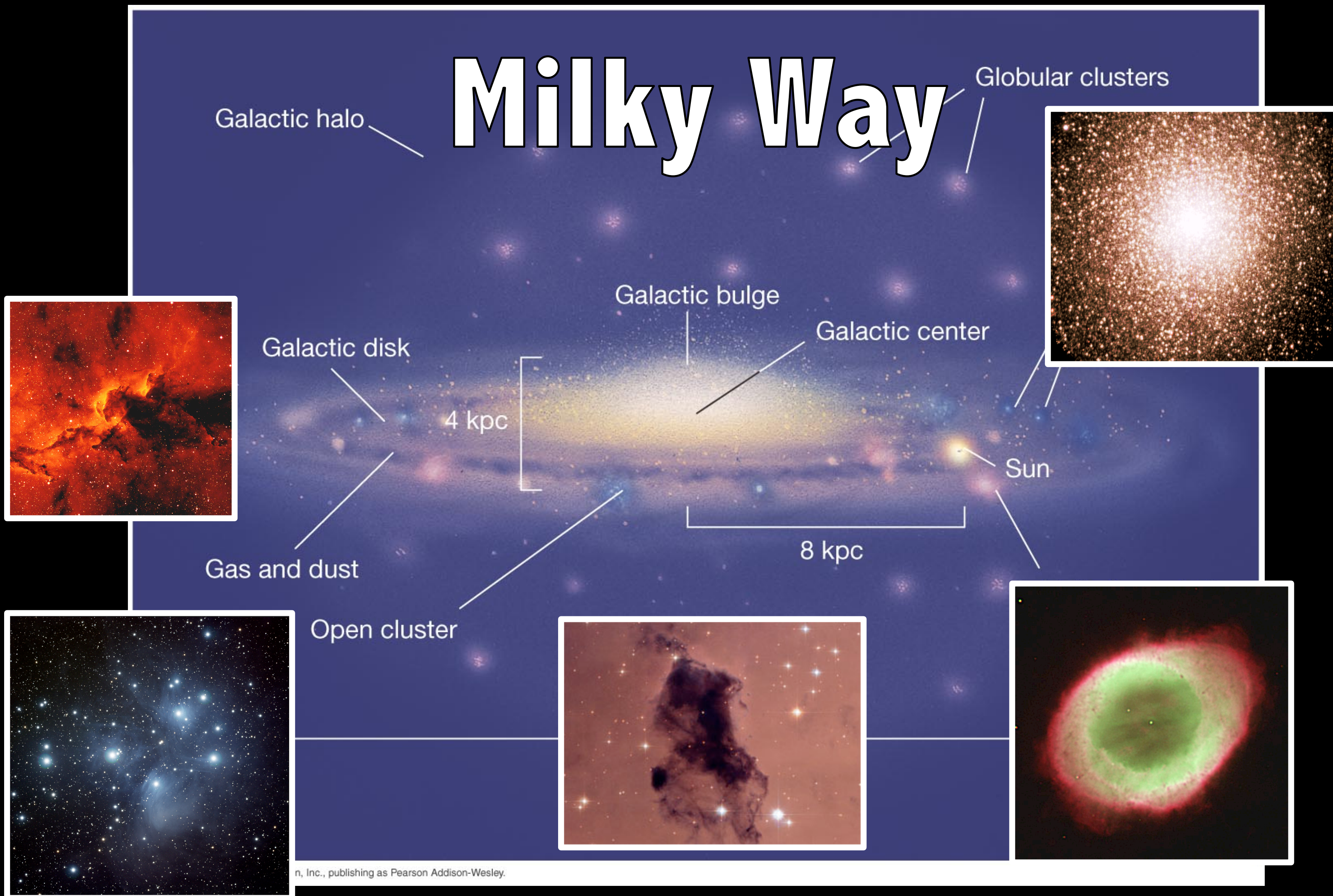
We have discovered a gravitationally lensed source whose most likely redshift is $z \approx 9.6$. The source, hereafter called MACS 1149-JD, is selected from a near-infrared detection image at a significance of 22σ. MACS 1149-JD has a unique flux distribution characterized by no

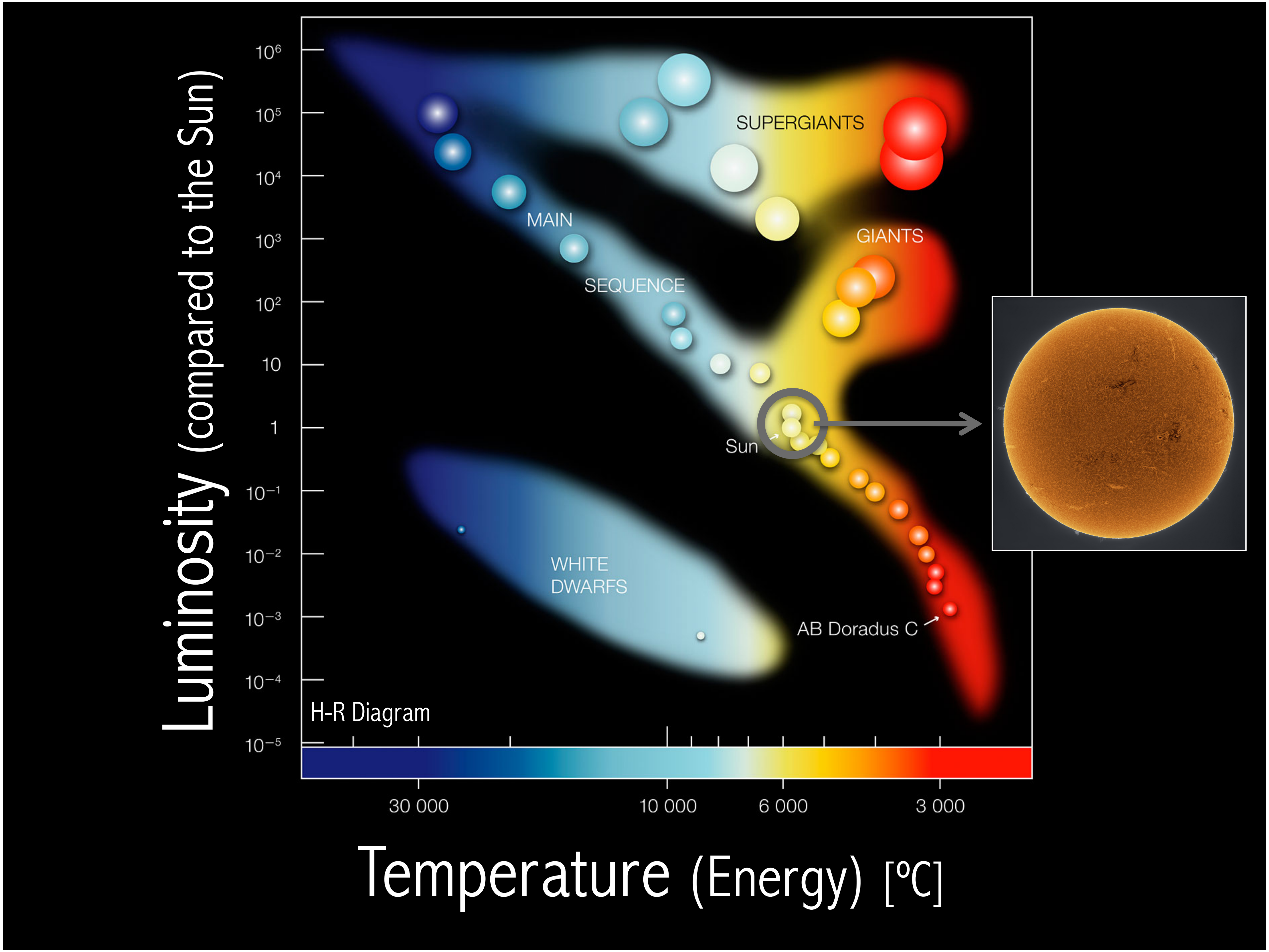
The GOAL for this talk:

- **How** do we do to observe those extremely faint sources?

- **Why** is it so important to study very distant galaxies in the Universe?

Exploring the **z~10** Universe through Massive Cosmic Lenses




Luminosity (compared to the Sun)
10^6
10^5
10^4
10^3
10^2
10
1
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
SUPERGIANTS
MAIN
SEQUENCE
GIANTS
Sun
WHITE
DWARFS
AB Doradus C
H-R Diagram
30 000
10 000
6 000
3 000
Temperature (Energy) [ºC]

$$E_\star = m_\star c^2$$

$$E_\gamma = h\nu$$

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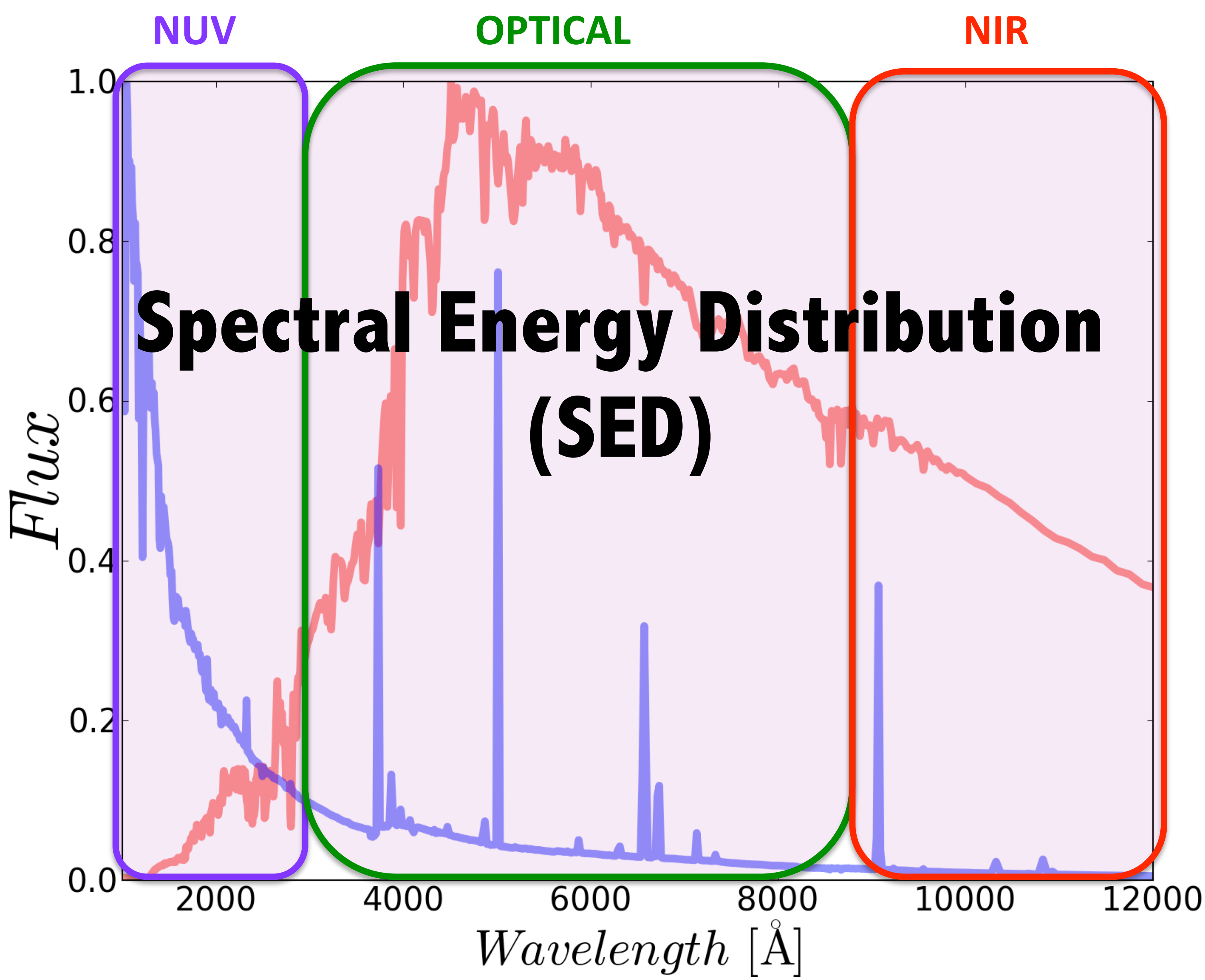

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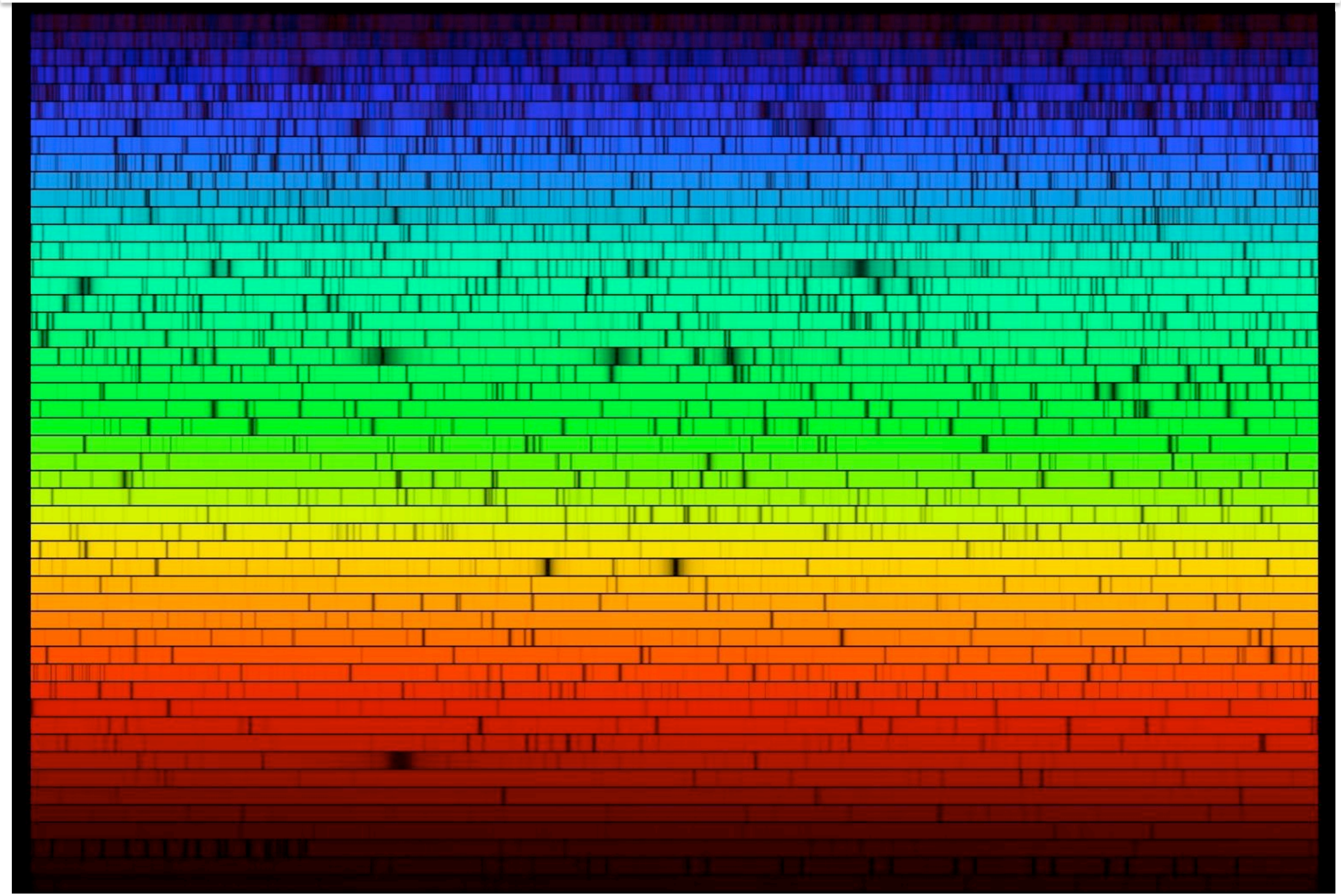
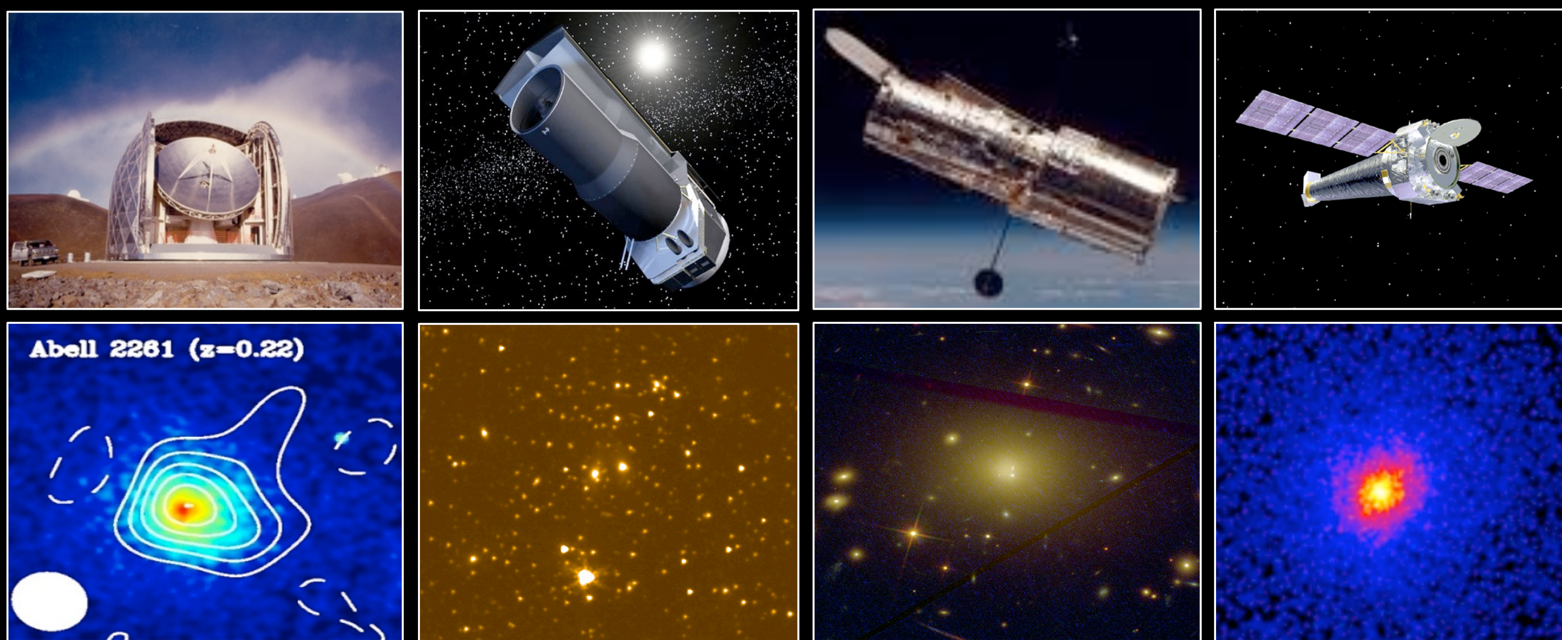


Different Telescopes



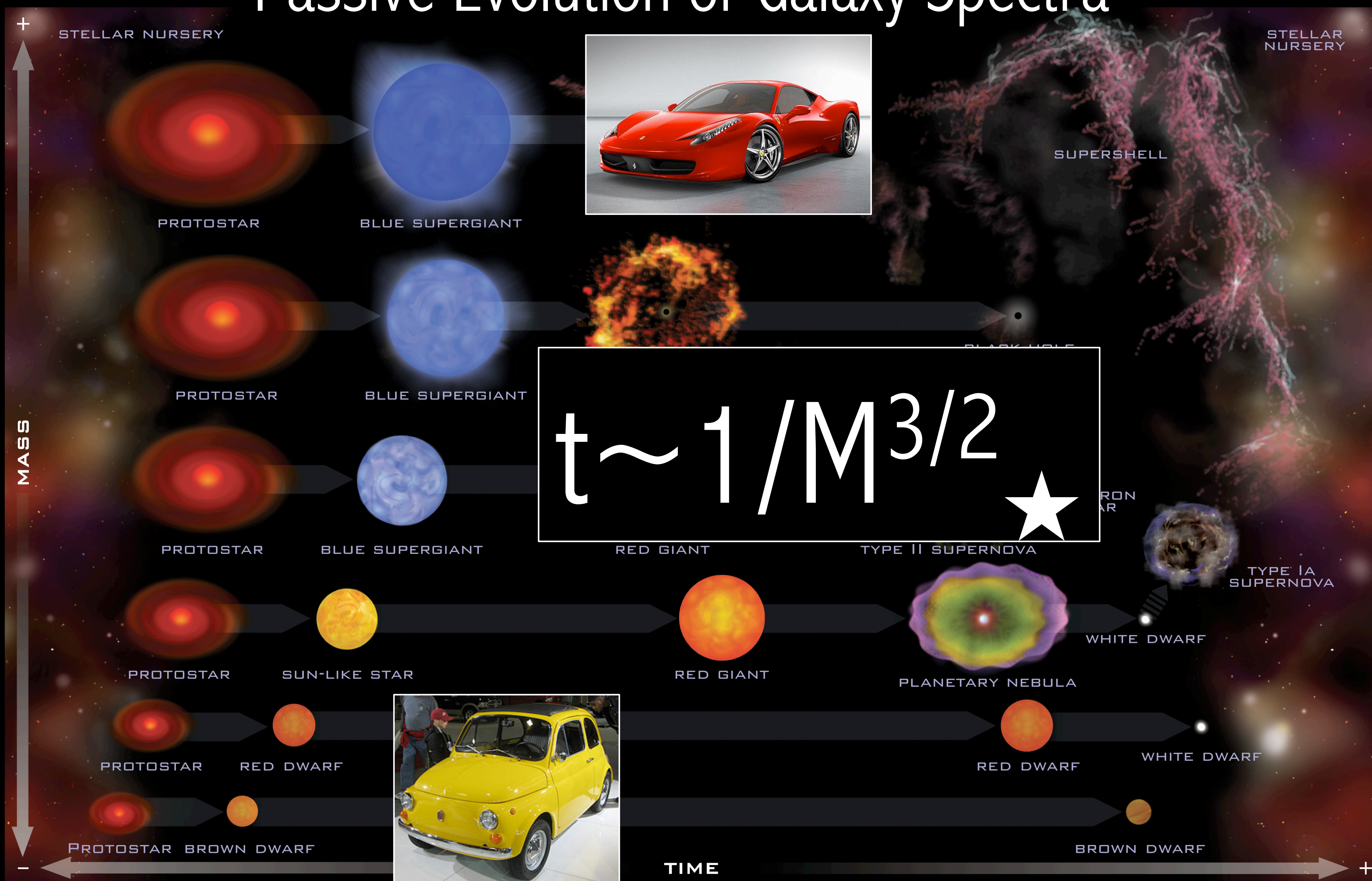
RADIO IR OPTICAL X-RAYS

Different Physical Information

Even although we use the SED to characterize the galaxies, these distributions are not constant across Time…

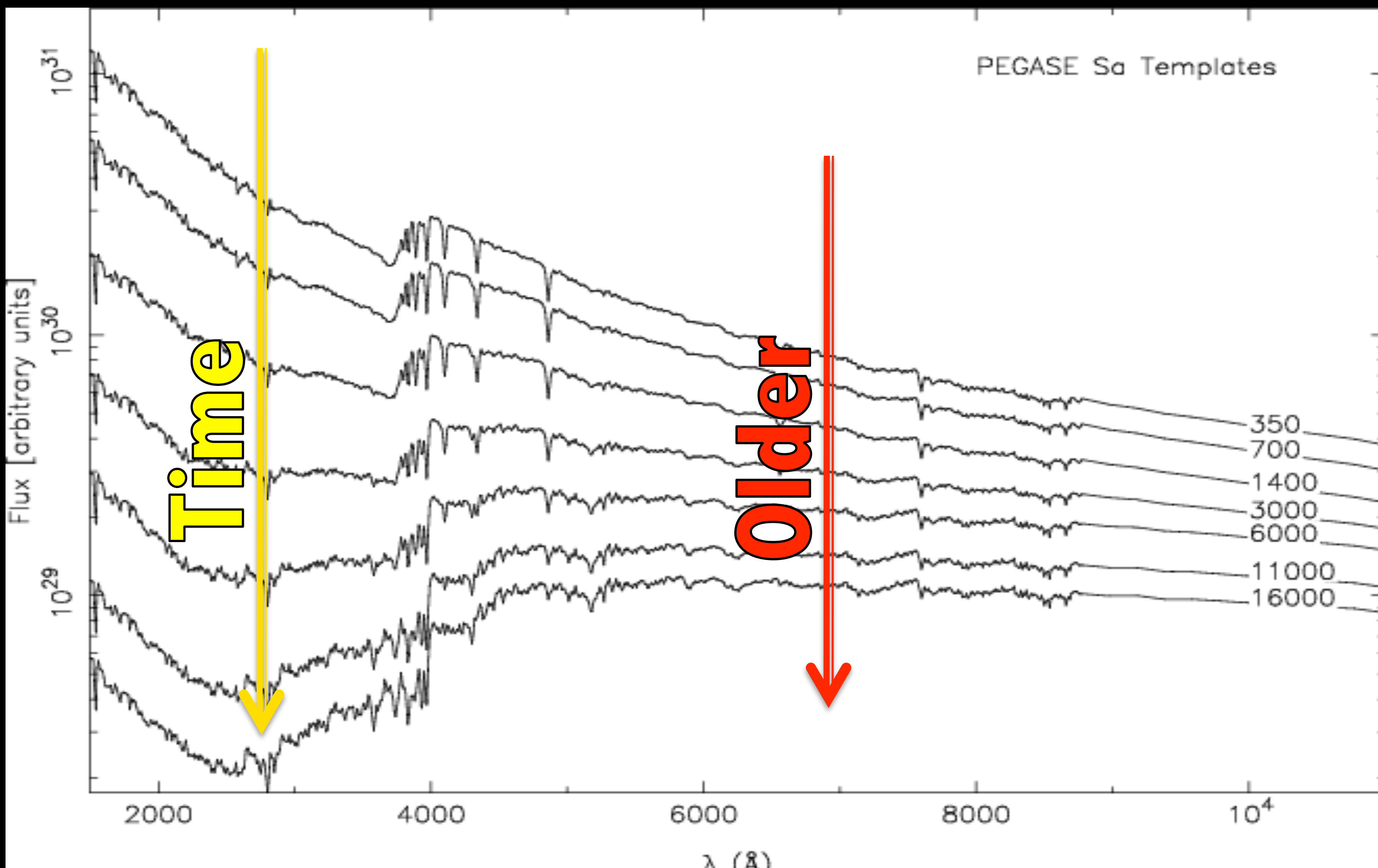
So we need to understand HOW and WHY they are changing??

Passive Evolution of Galaxy Spectra



$$t \sim 1/M^{3/2}_{\star}$$

Passive Evolution of Galaxy Spectra



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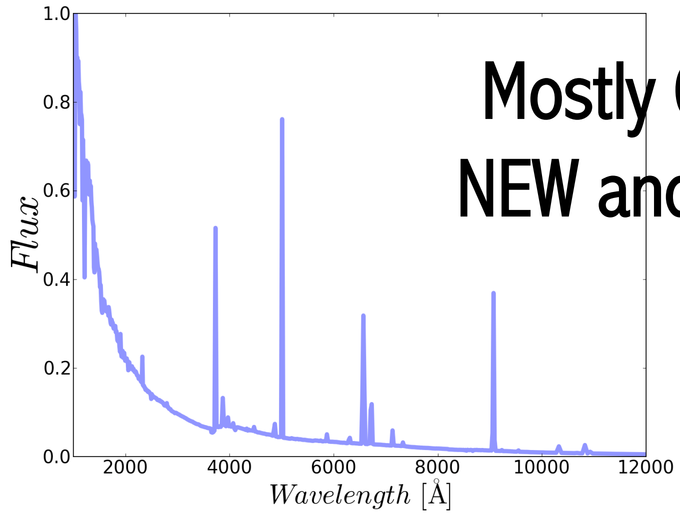
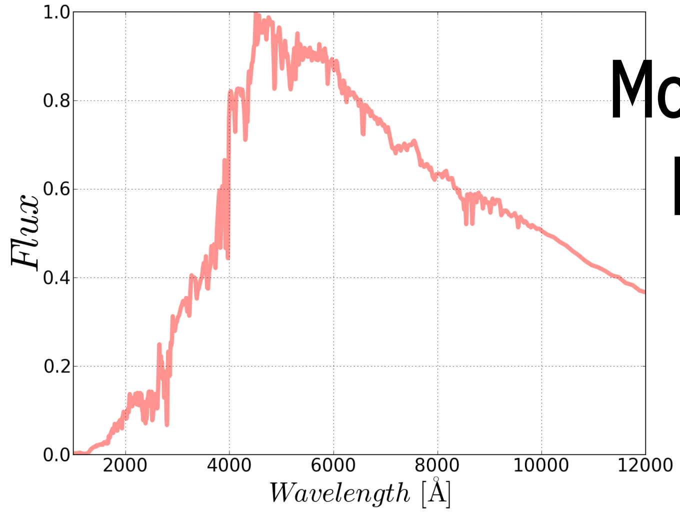


Mostly Composed by NEW and YOUNG stars



Mostly Composed by OLD stars

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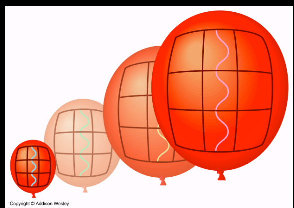
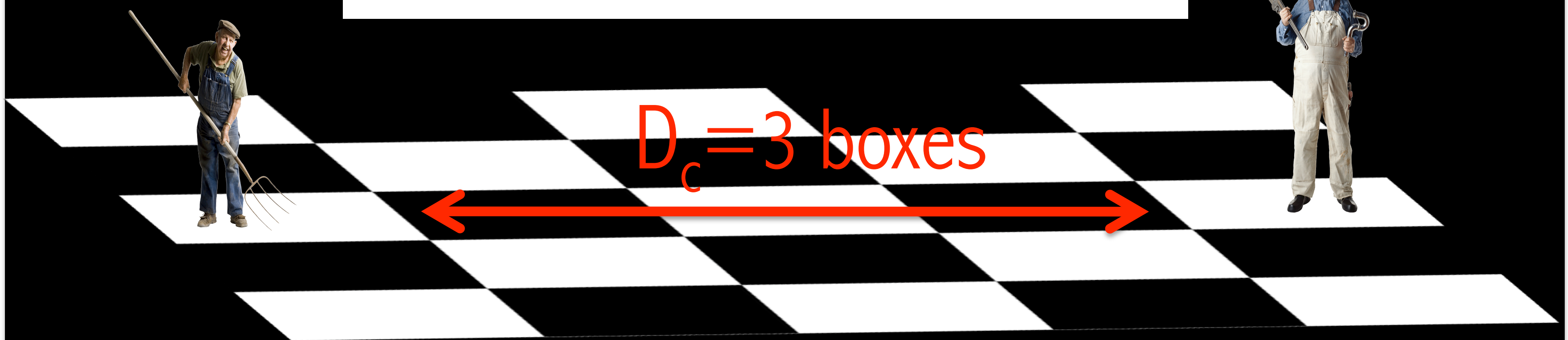


The Expansion of the Universe also makes galaxies look differently across Cosmic Time.

$$\frac{D_{p_0}}{D_p} = \frac{\lambda_0}{\lambda} = \frac{E_\gamma}{E_{\gamma_0}} = 1 + z$$

Redshift



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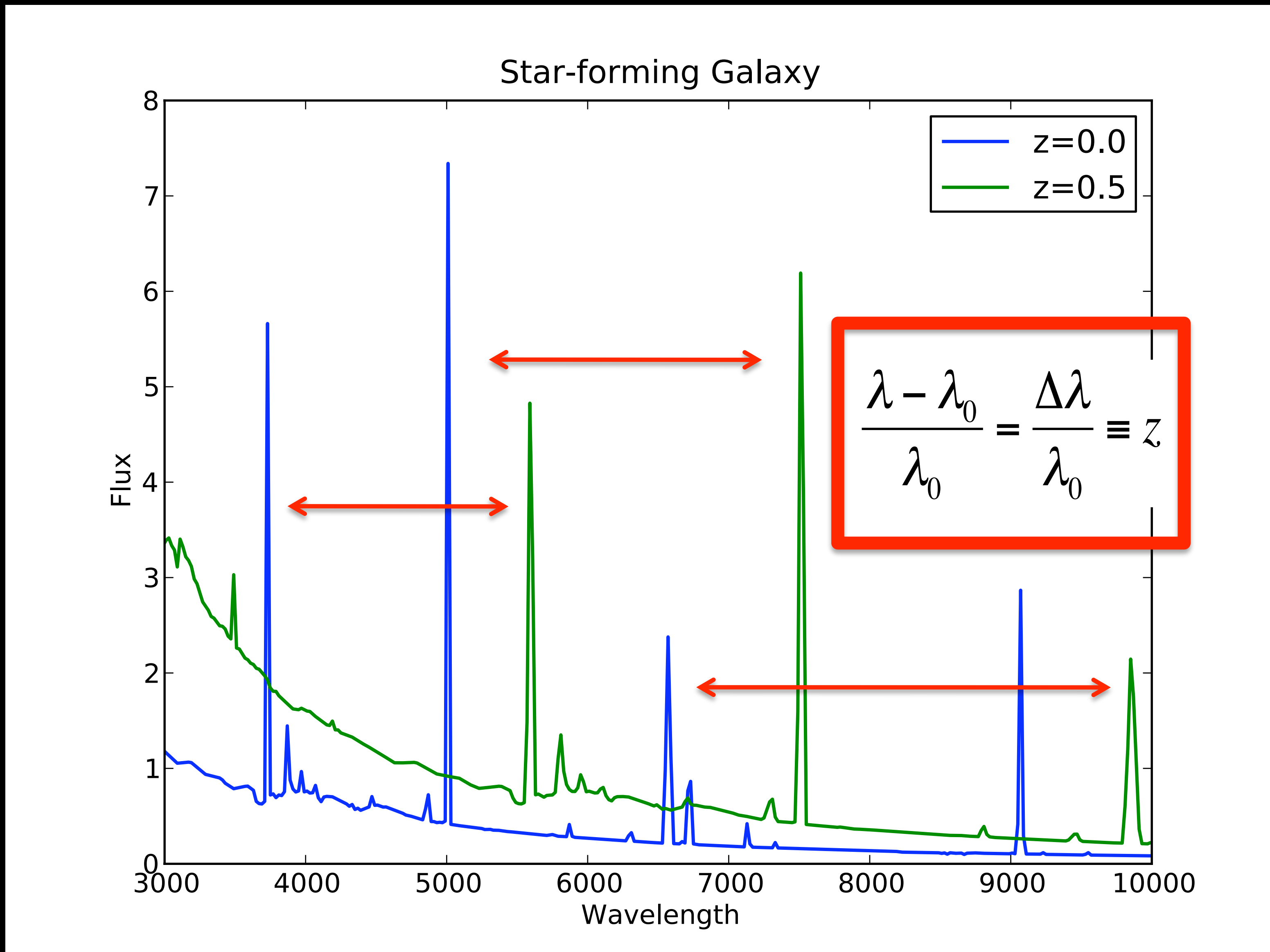

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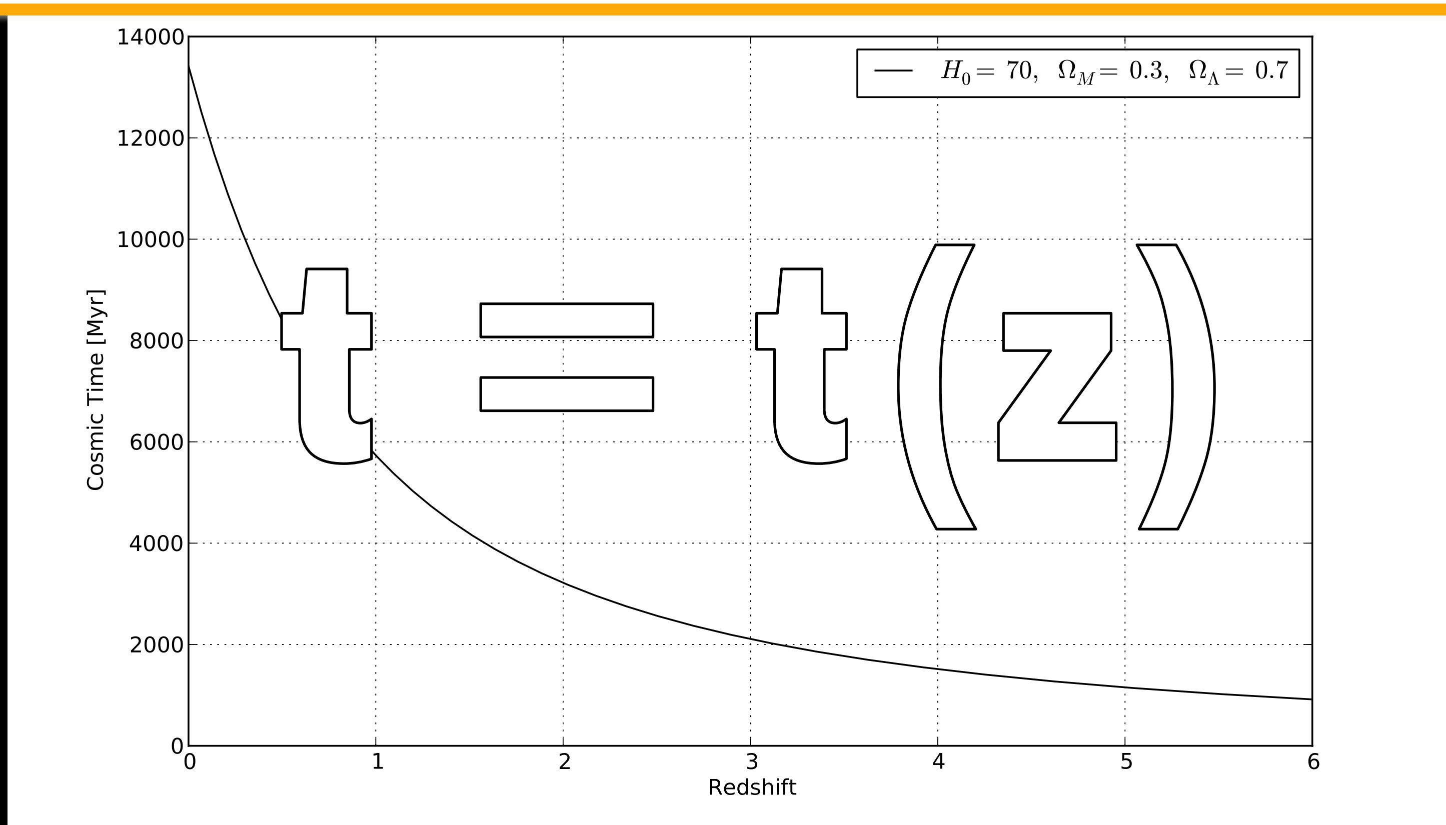
$$t = \int_0^t d_t = -\int_0^z \frac{dz}{H_0(1+z)\sqrt{\sum_i \Theta_{i0}(1+z)^{3(1+\omega_i)}}}$$



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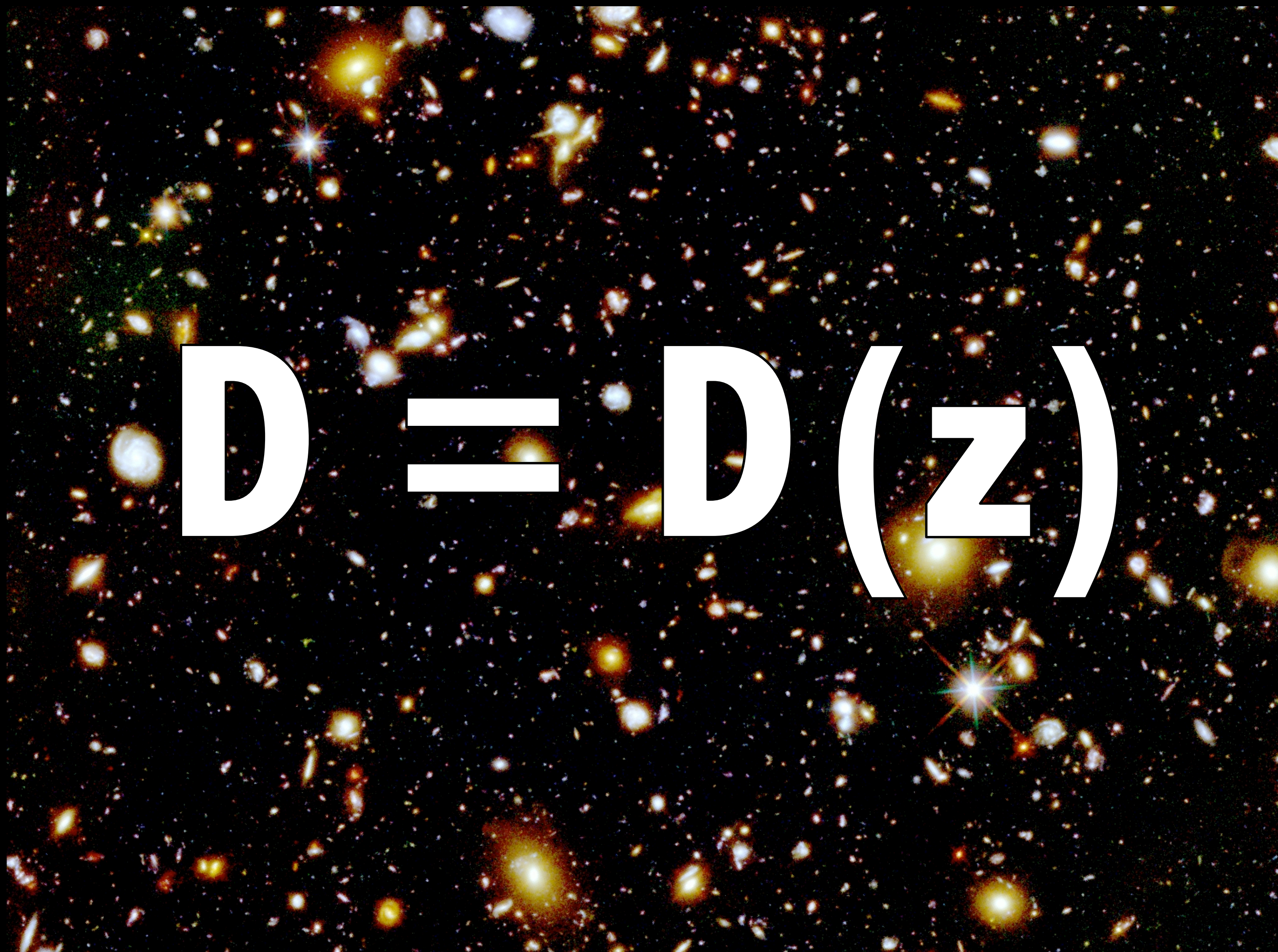
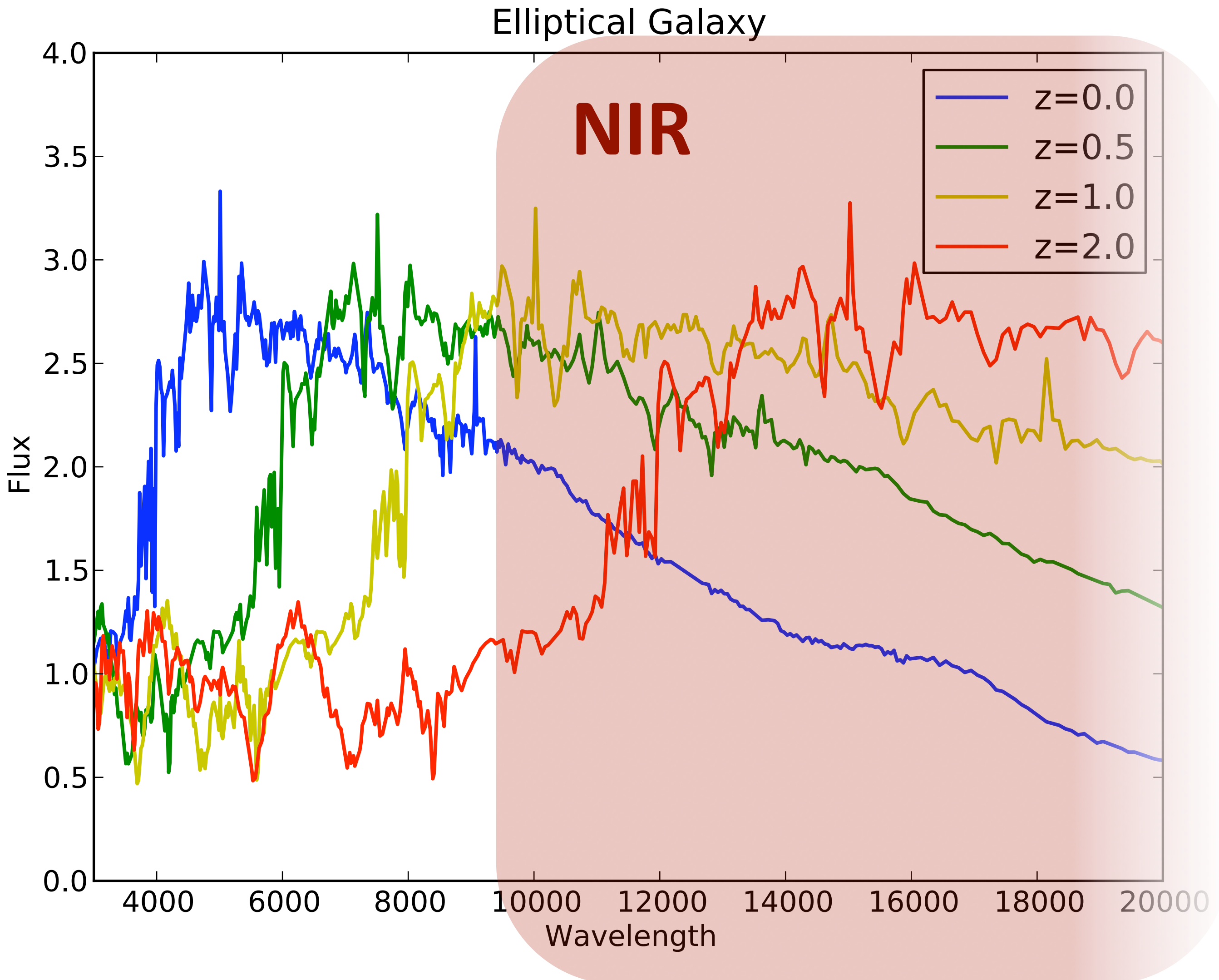




Elliptical Galaxy
NIR
z=0.0
z=0.5
z=1.0
z=2.0
Flux
Wavelength
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
4000
6000
8000
10000
12000
14000
16000
18000
20000

Exploring the **z~10** Universe through Massive Cosmic Lenses

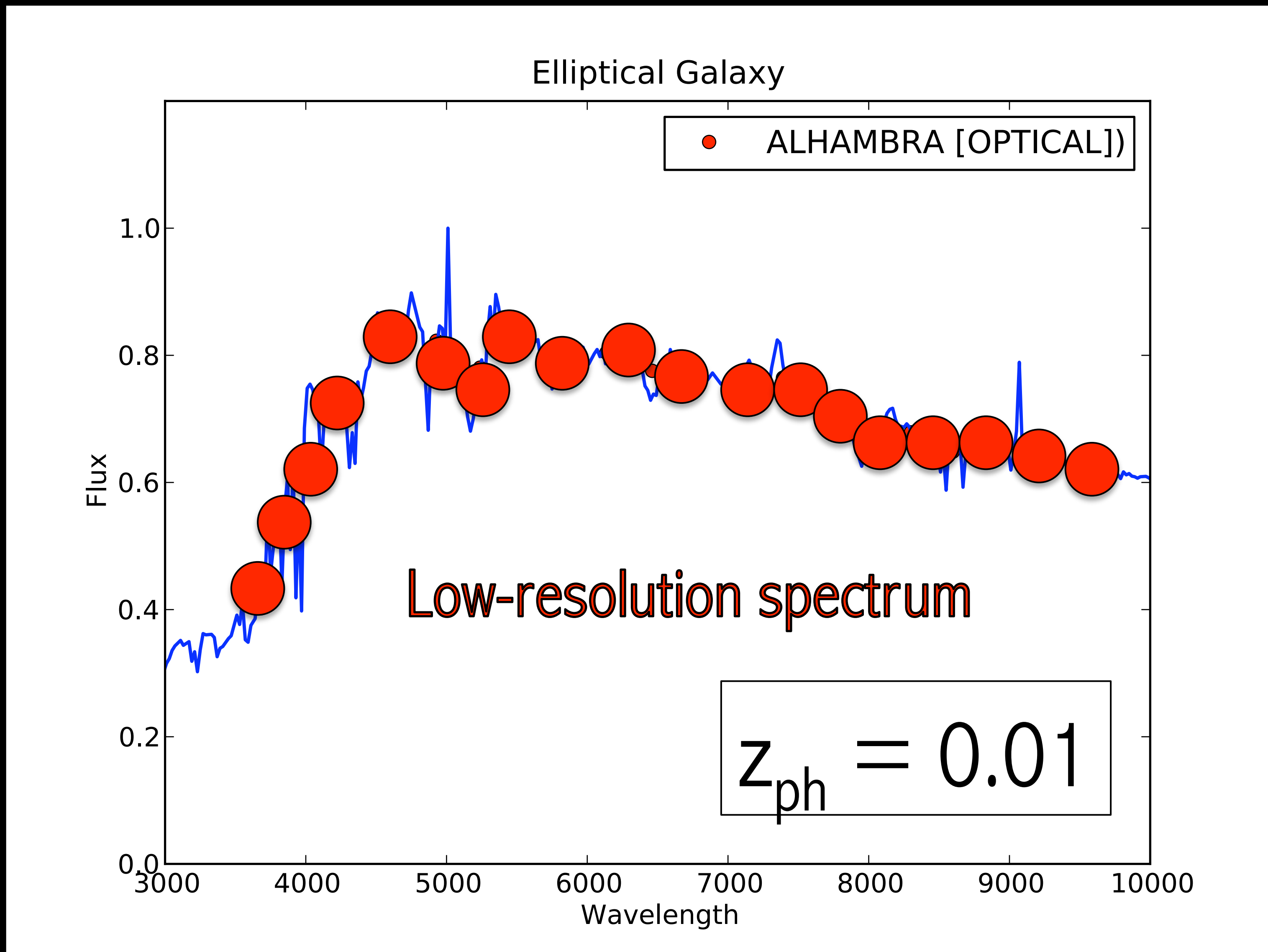
• So, If we want to know when a galaxy emitted its light, we just need to know which is its spectral redshift !

• To know the spectral redshift we just need its spectrum.

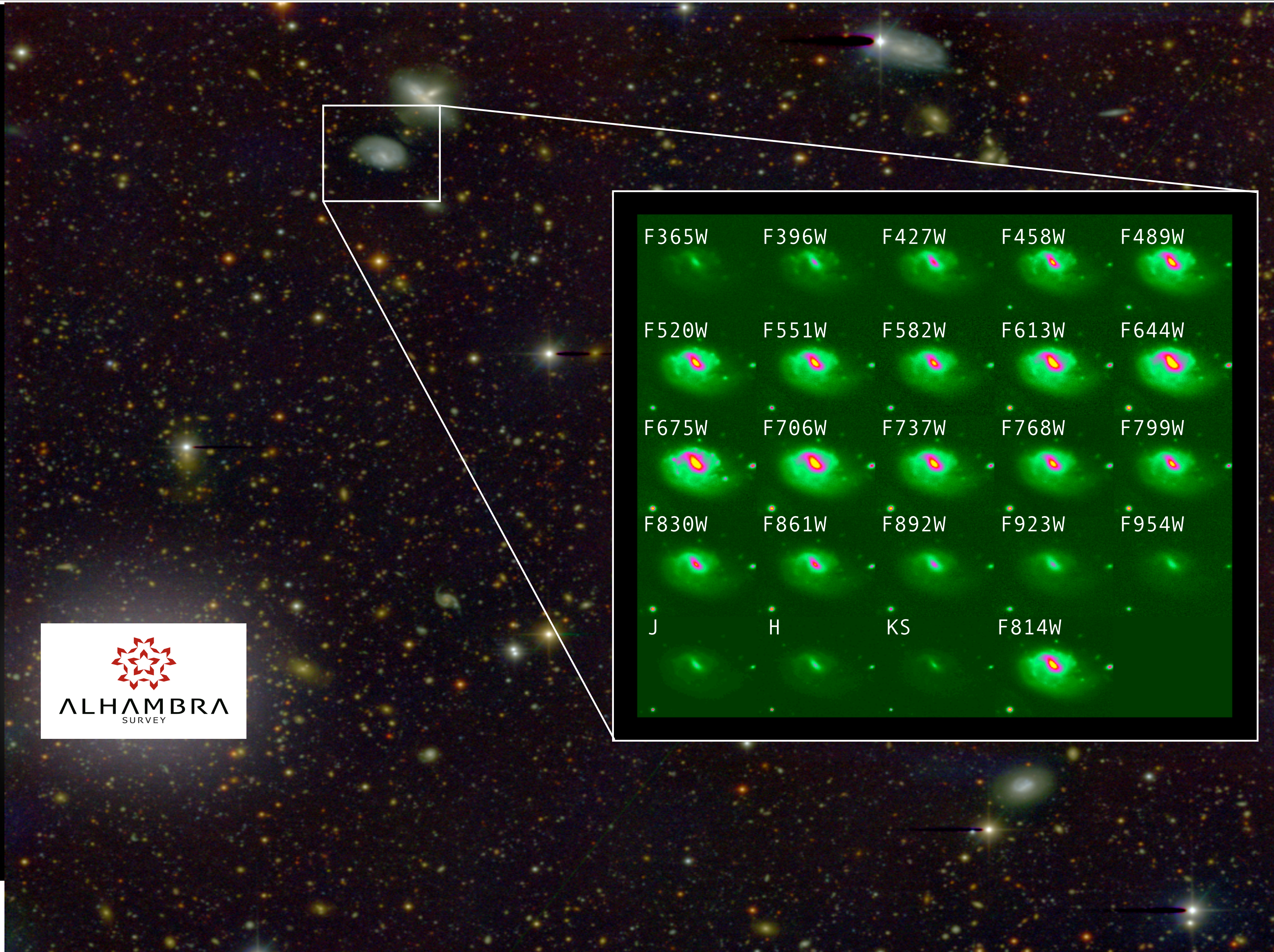
•However for very faint galaxies retrieve a spectrum is not always feasible as it would require very long exp. times.

• Therefore it becomes necessary to rely on other alternatives like the photometric redshifts.

Exploring the **z~10** Universe through Massive Cosmic Lenses



Exploring the **z~10** Universe through Massive Cosmic Lenses



ADVANTAGES:

• Using photometry fainter galaxies can be observed and derive an estimation of its spectral redshift.

DRAWBACKS:

• To be accurate it is necessary a large number of filters.

• To observe very faint sources it is necessary:

- Space-based Telescopes
- Observe in the NIR (or longer)

but… What about the very distant galaxies in the Universe?

We have good and bad news…

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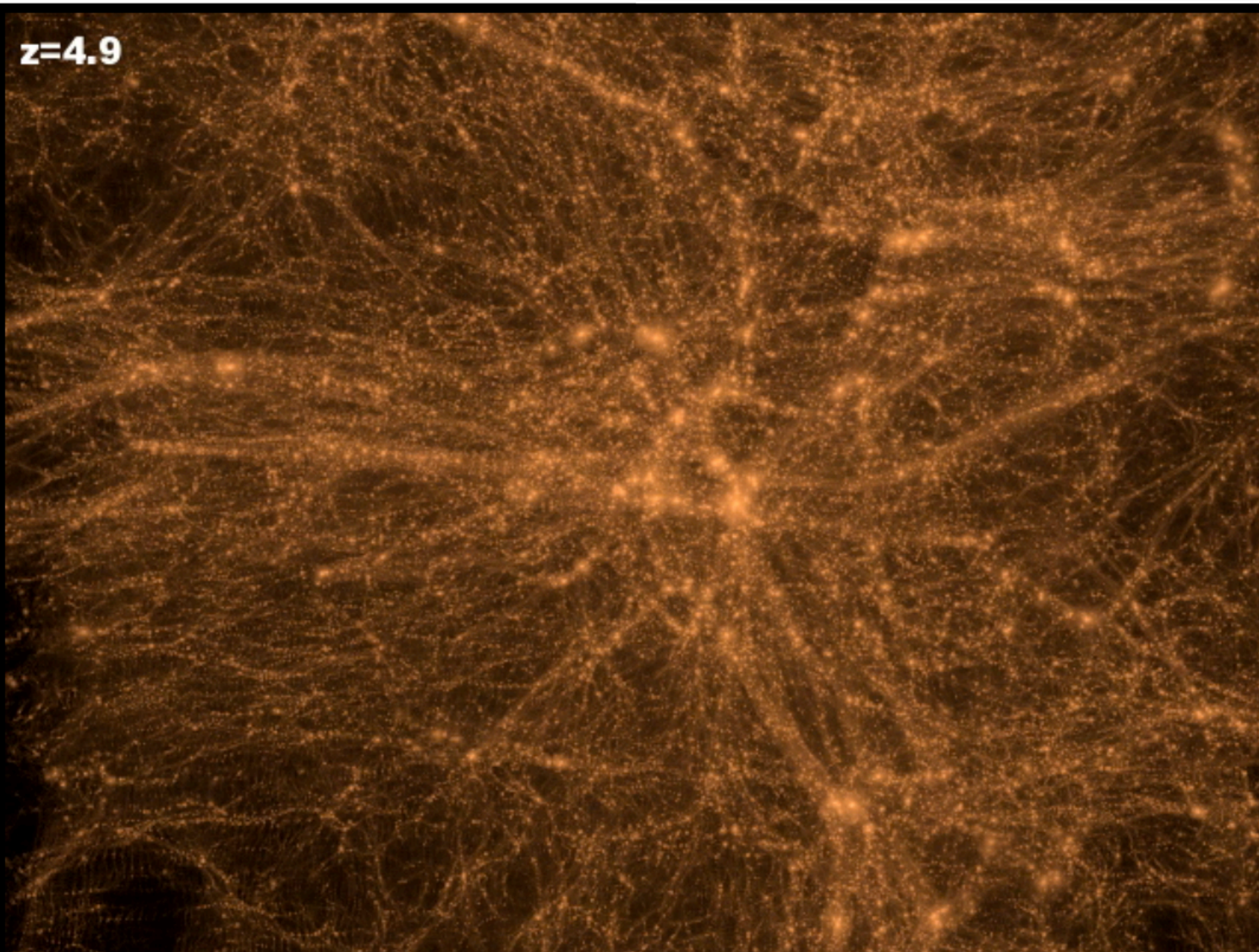
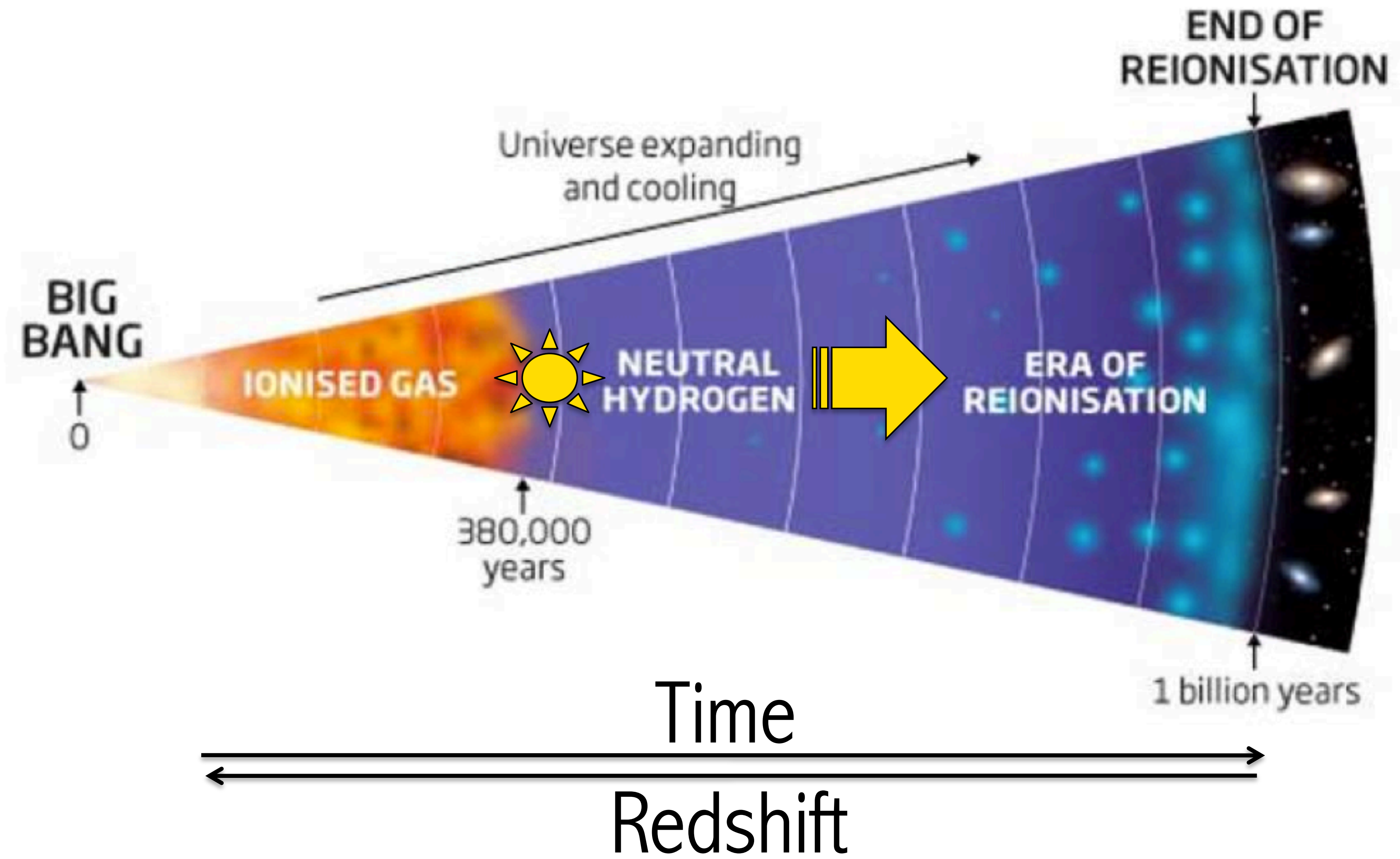
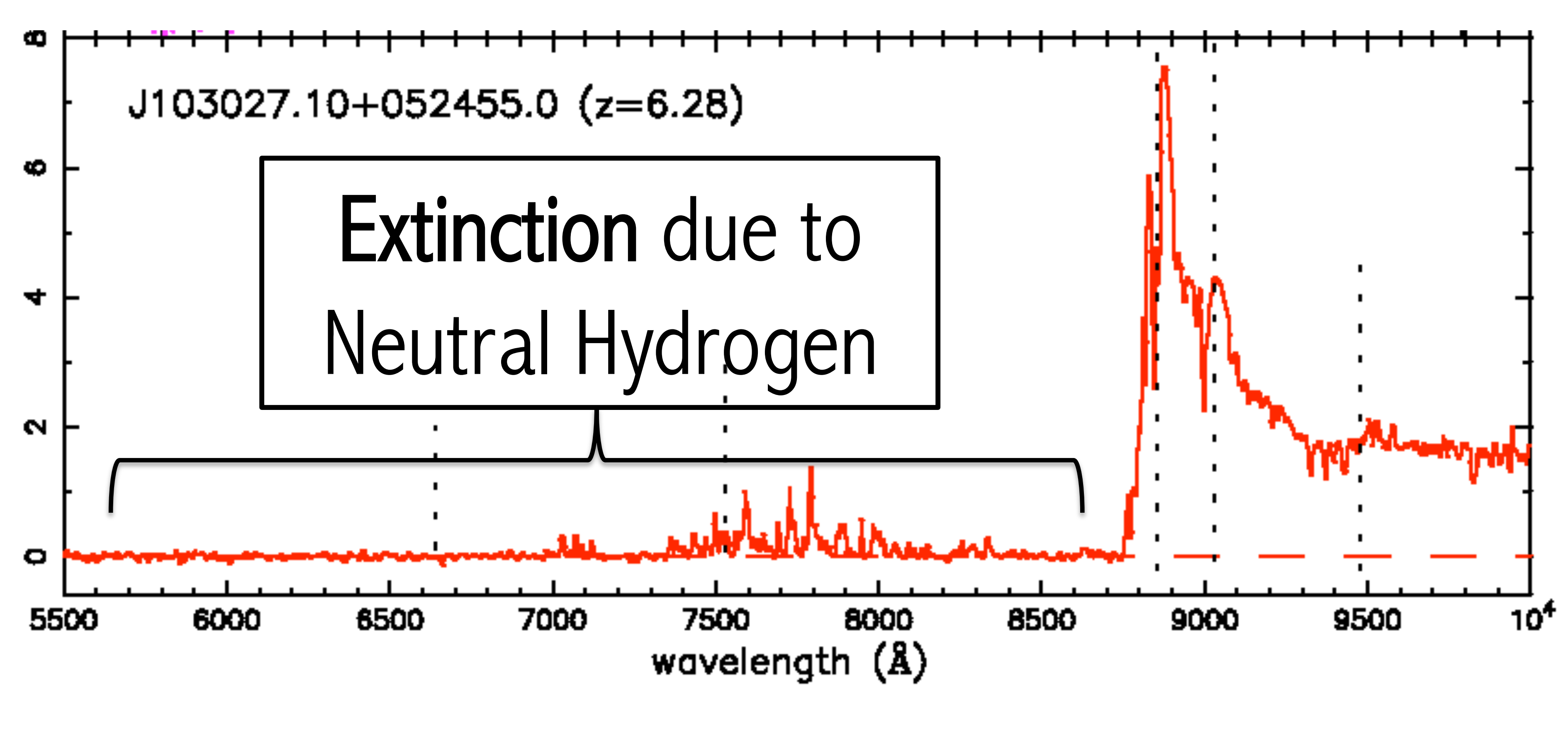


Exploring the **z~10** Universe through Massive Cosmic Lenses



Exploring the **z~10** Universe through Massive Cosmic Lenses

- There was a time where the Hydrogen was neutral and most of emitted light with $\lambda < 1000(1+z)$Å was absorbed (extinguished).
- This particular spectral feature makes galaxies to "disappear" at certain wavelengths (as there is no emission left to reach us).



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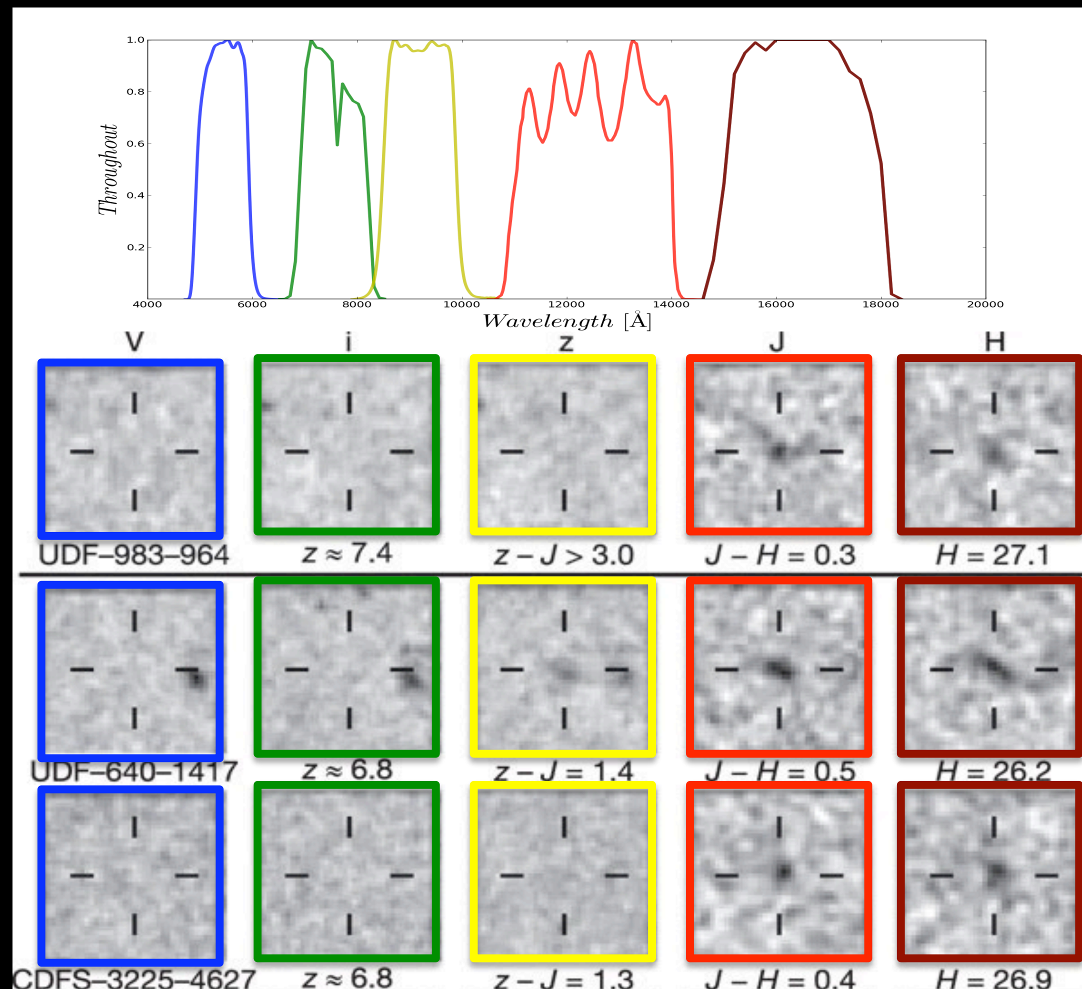
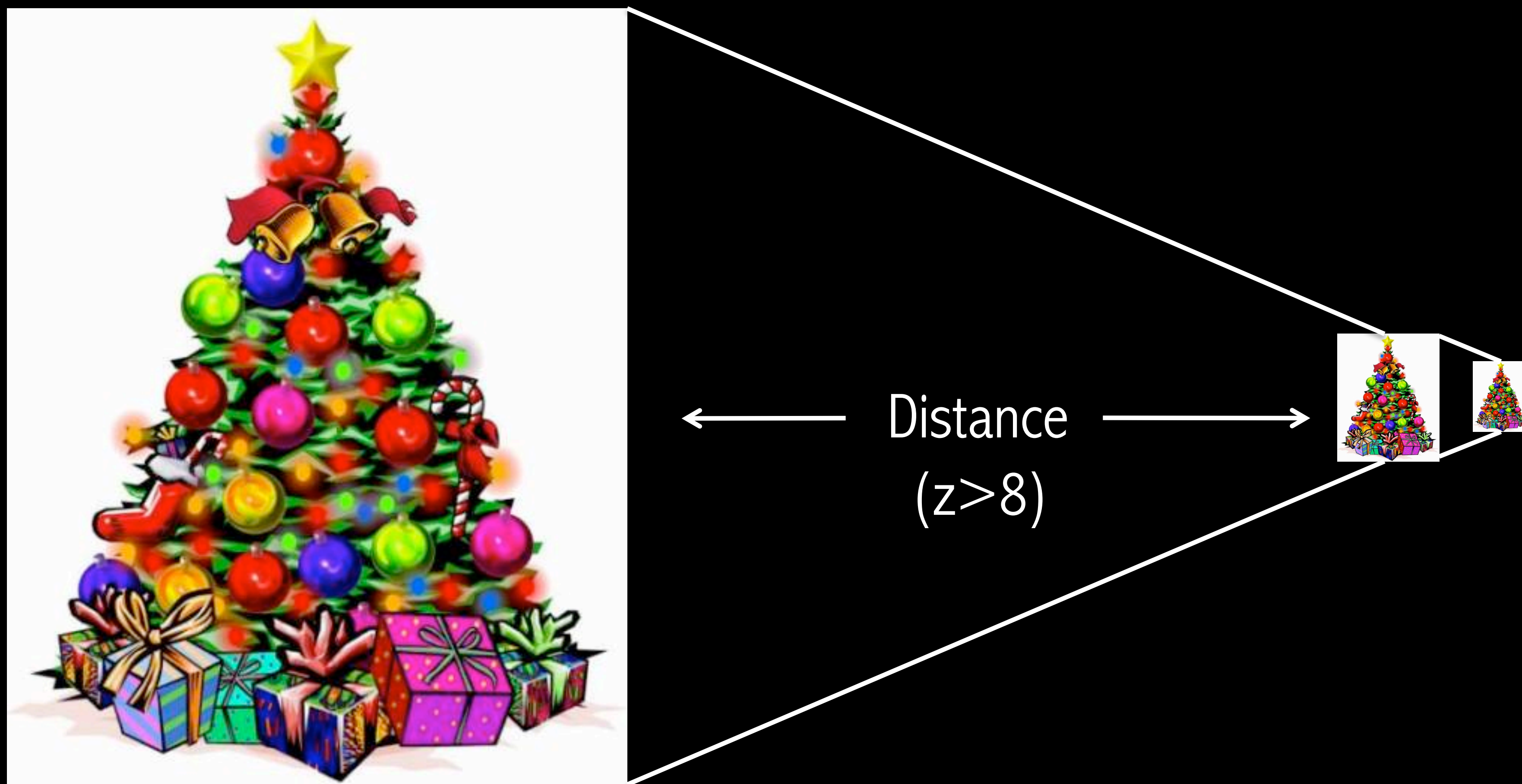
- Depending on the redshift of the galaxy this is re-observed at a wavelength $\lambda > 1000(1+z)$Å, taking the name of "DROP-OUT".

- This methodology serves to select potential candidates at high-z.

- For galaxies at z>7 they are only observable in the NIR bands.

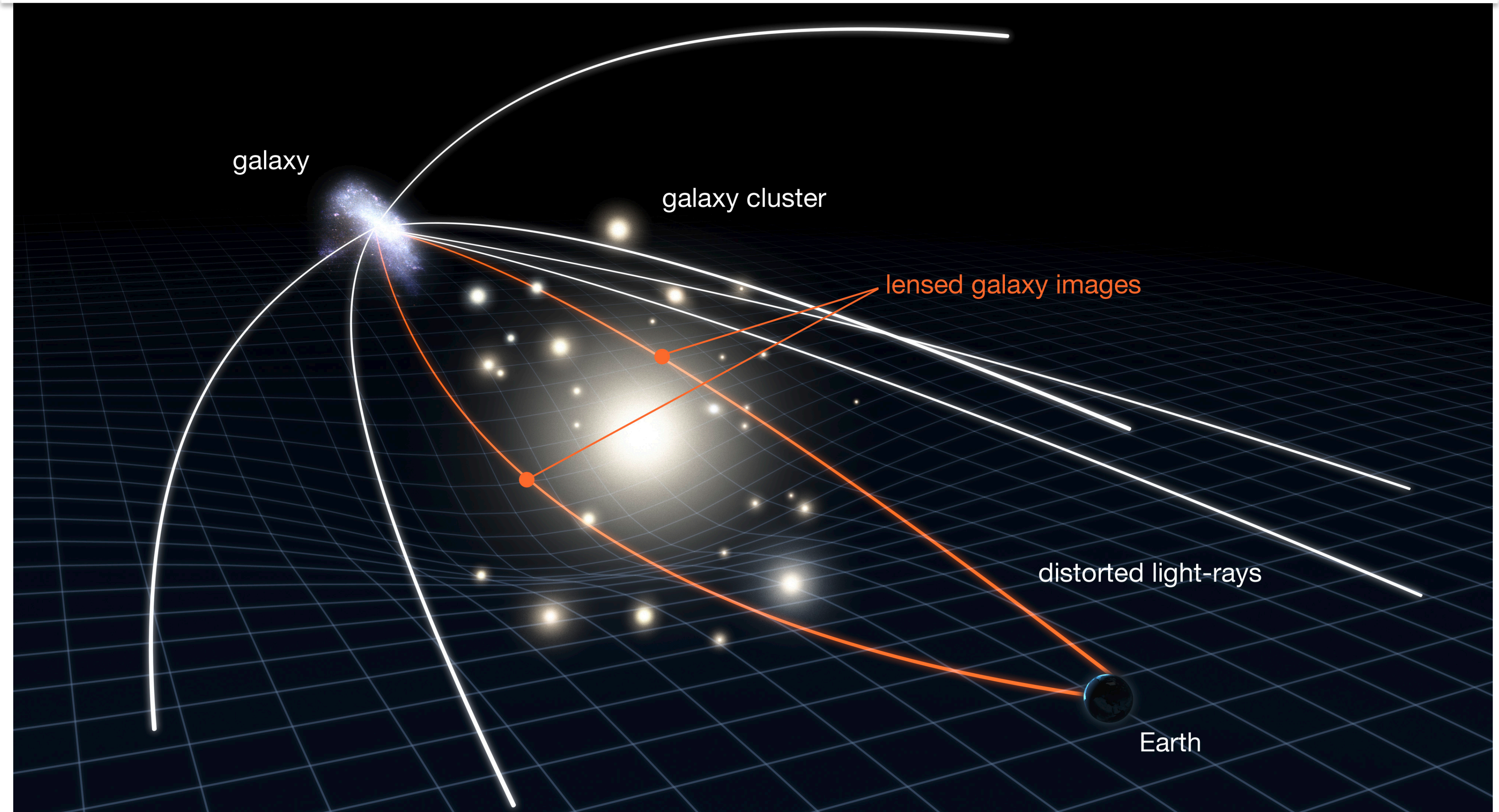


Exploring the **$z\sim10$** Universe through Massive Cosmic Lenses



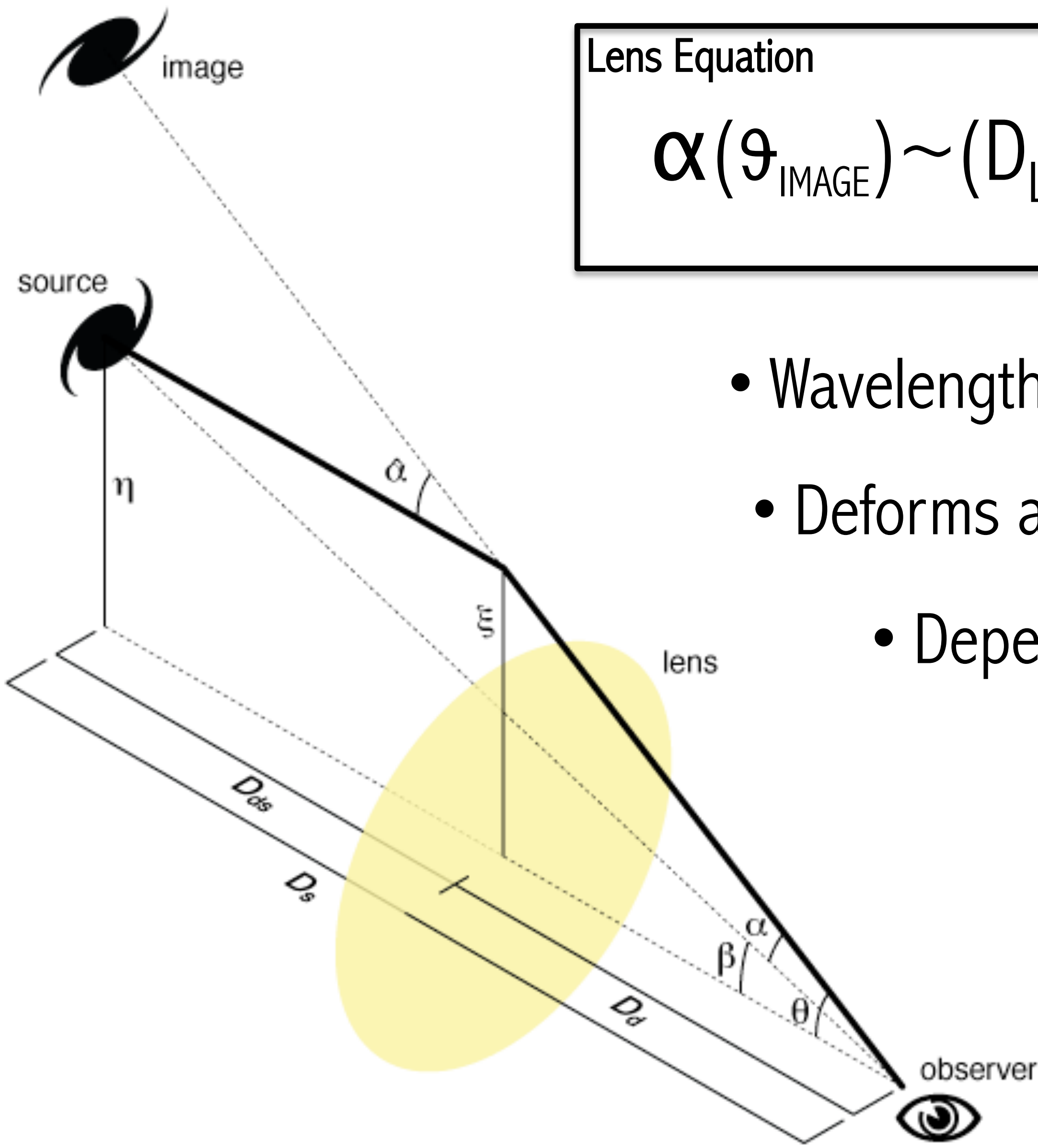
Very distant galaxies will not be reachable by our telescopes.
Only Future Generations of telescope or **NATURAL TELESCOPES**

Exploring the **z~10** Universe through Massive Cosmic Lenses



The light emitted by a distant source will be distorted while traversing a galaxy cluster which locally deforms space-time due to its large mass.

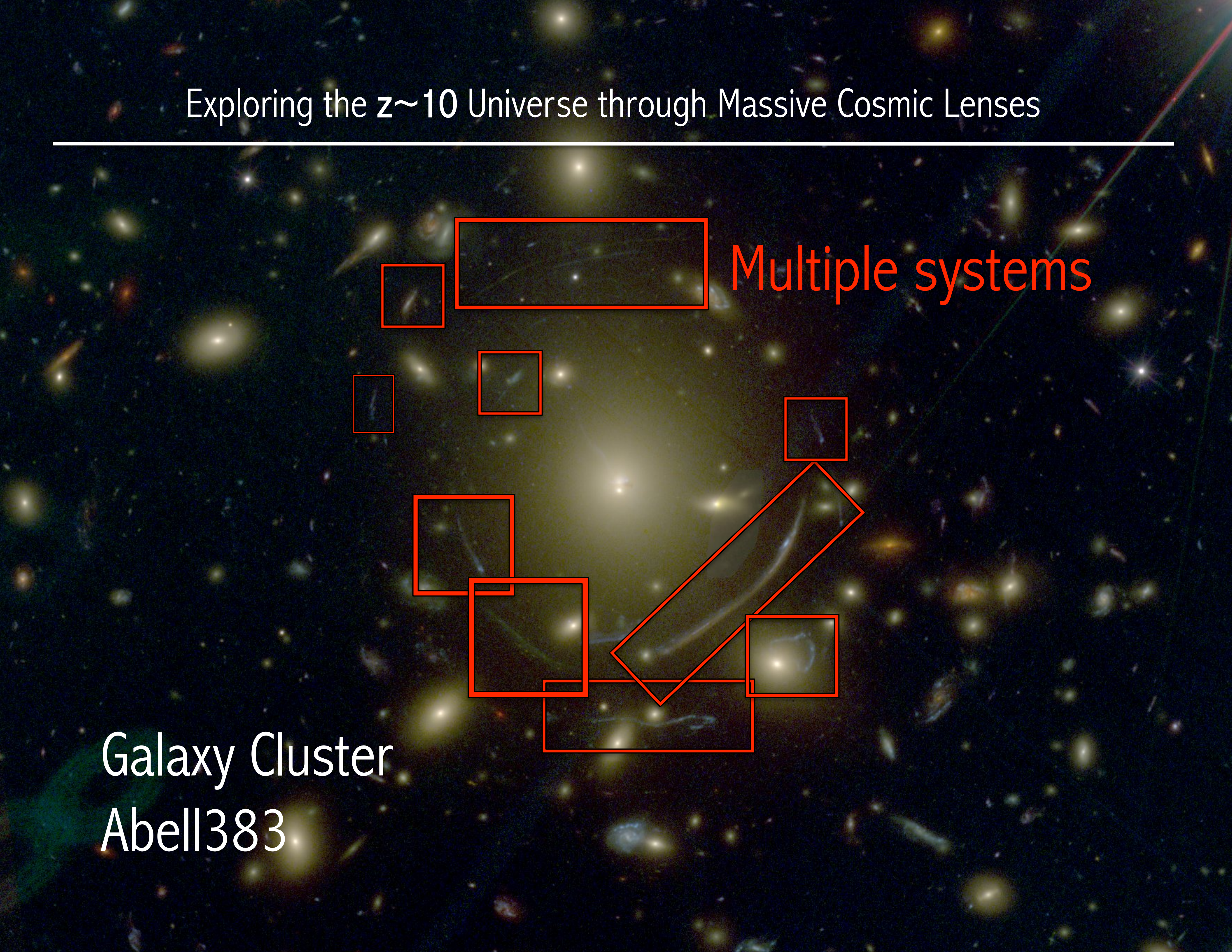
Exploring the **z~10** Universe through Massive Cosmic Lenses



Lens Equation

$$\alpha(\vartheta_{IMAGE}) \sim (D_{LS}/D_{OS}) \cdot \Phi_{NEWT}(\vartheta_{IMAGE})$$

- Wavelength-independent (geometry)
- Deforms and magnifies the galaxies
- Depends on Relative Distances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Multiple systems
Galaxy Cluster
Abell383

Exploring the **z~10** Universe through Massive Cosmic Lenses

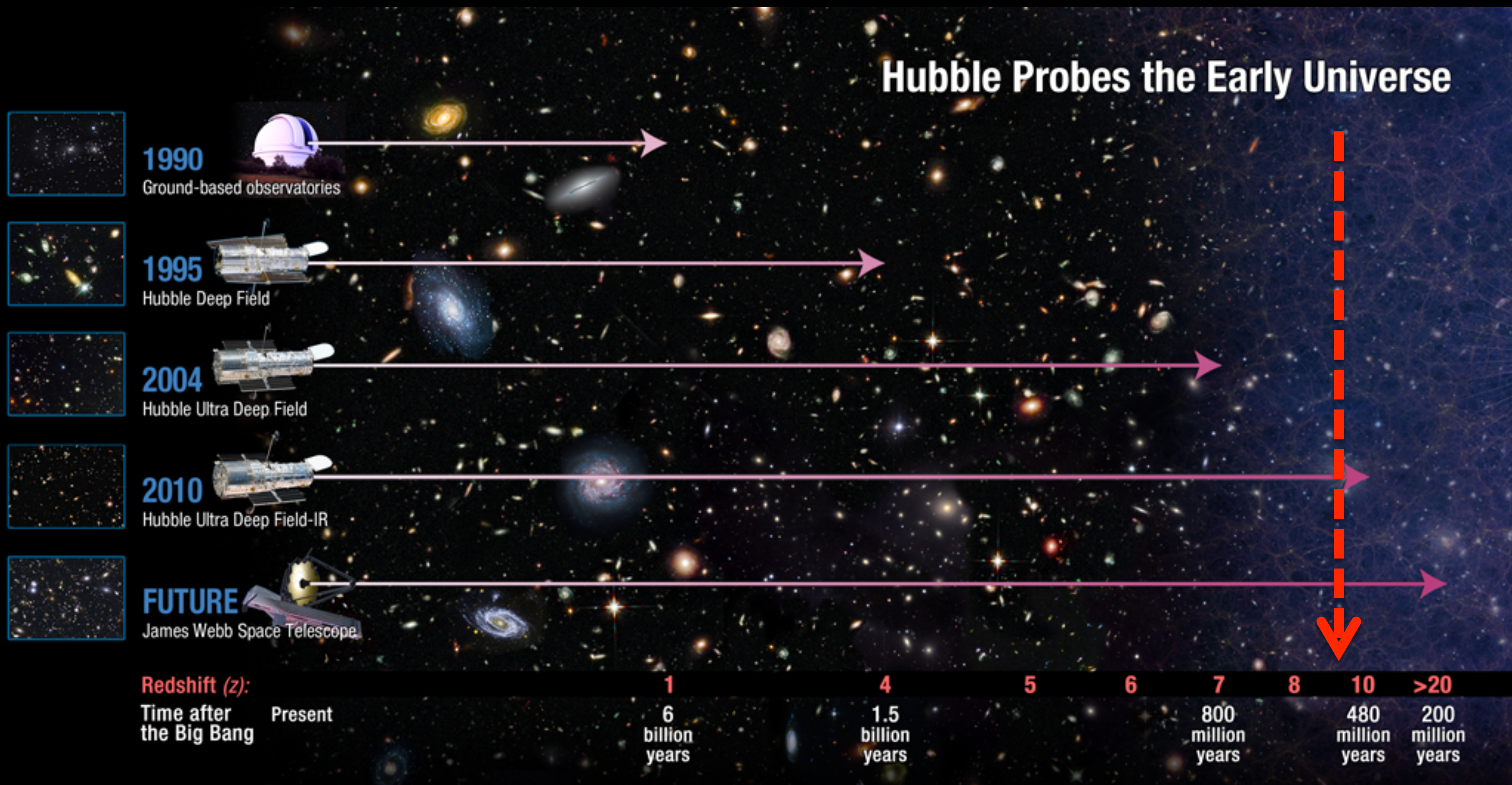
- Strong Lensing Regime (~1arc-minute)
- Weak Lensing Regime (~15arc-minutes)

- **Study of the Lens(es)**: understanding cluster (dark) matter distributions along with insights into galaxy cluster formation and evolution.

- **Study of the Lensed Objects**: providing properties of stellar populations of the lensed background galaxies (at higher-z & fainter).

- **Study of the Geometry of the Universe**: the strength of lensing depends on the ratios of angular diameter distances (D_{LS}, D_{OS} & D_{OL}).

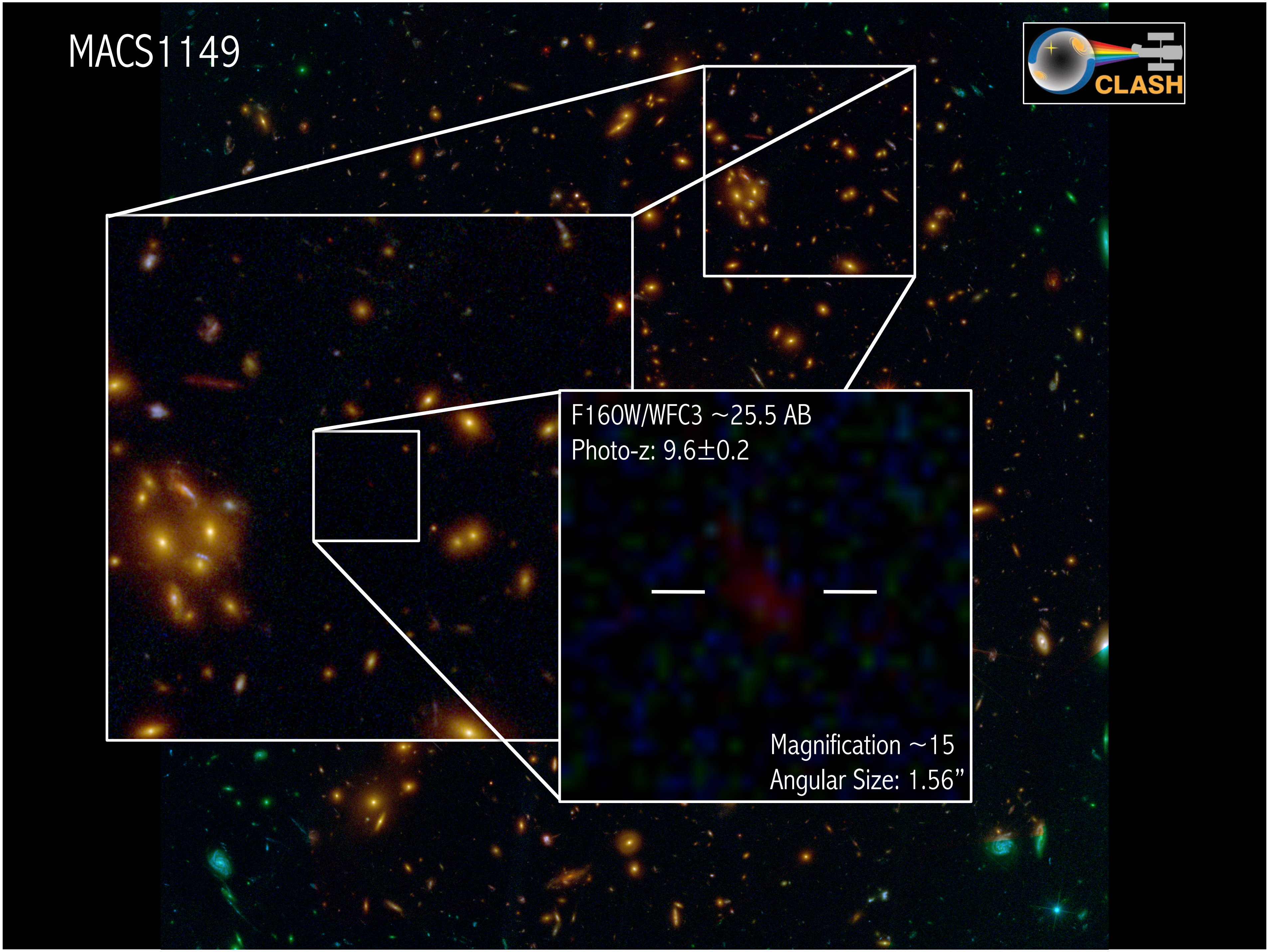
Exploring the **z~10** Universe through Massive Cosmic Lenses

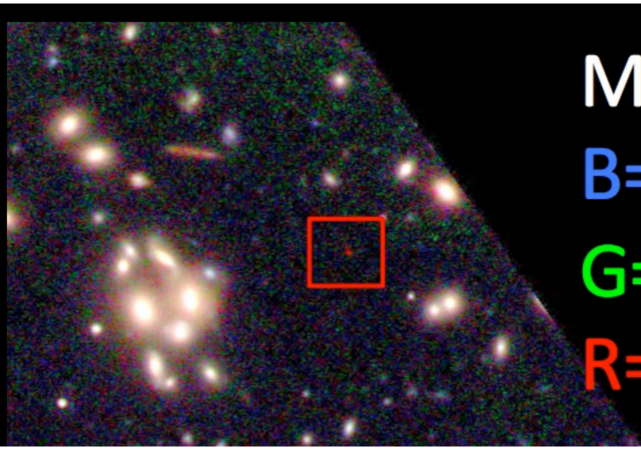


The Magnification effect makes galaxies much brighter and therefore observable photometrically !!

The Discovery of the most Distant galaxy (z~10) in the Universe

(when it was ~4% aged)


MACS1149
CLASH
F160W/WFC3 ~25.5 AB
Photo-z: 9.6±0.2
Magnification ~15
Angular Size: 1.56"



MACS1149 selected for high-magnification (z=0.54)

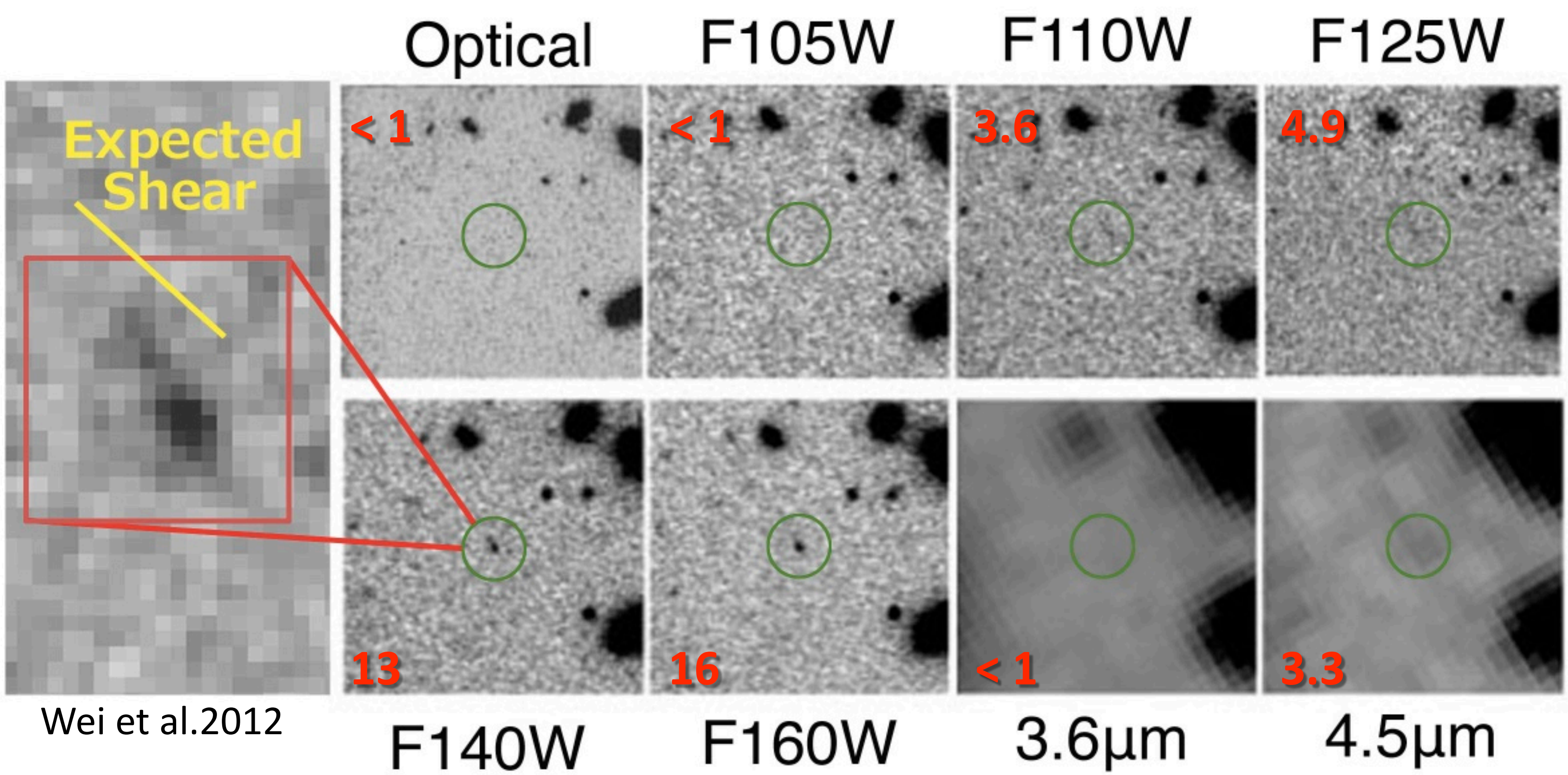
J-band dropout criteria:

F110W – F140W > 1.3

F140W – F160W < 0.5

<2σ detection in F105W

<1σ detection in optical detection image



Wei et al.2012

Object's position and flux does not vary significantly over course of 80 days

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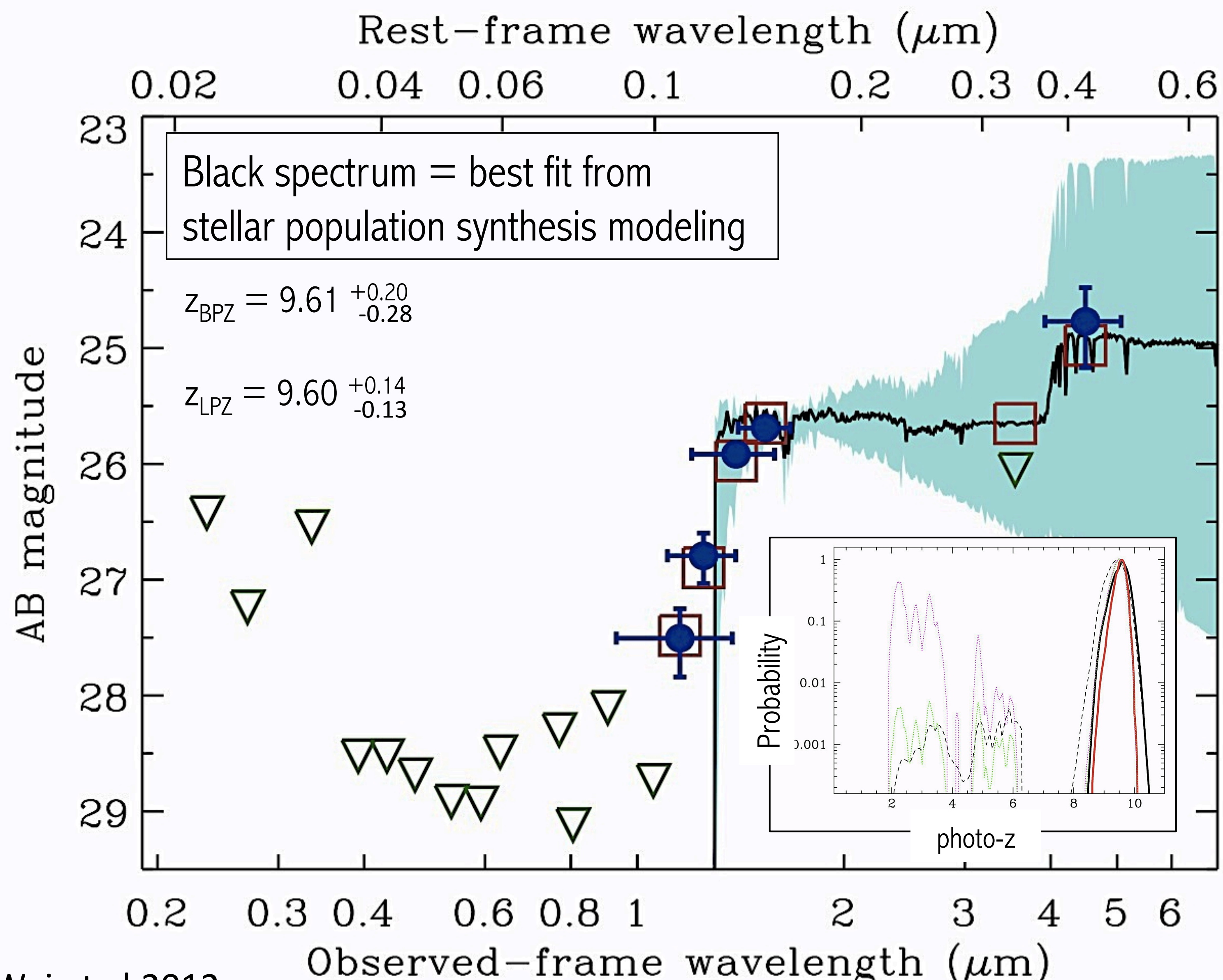
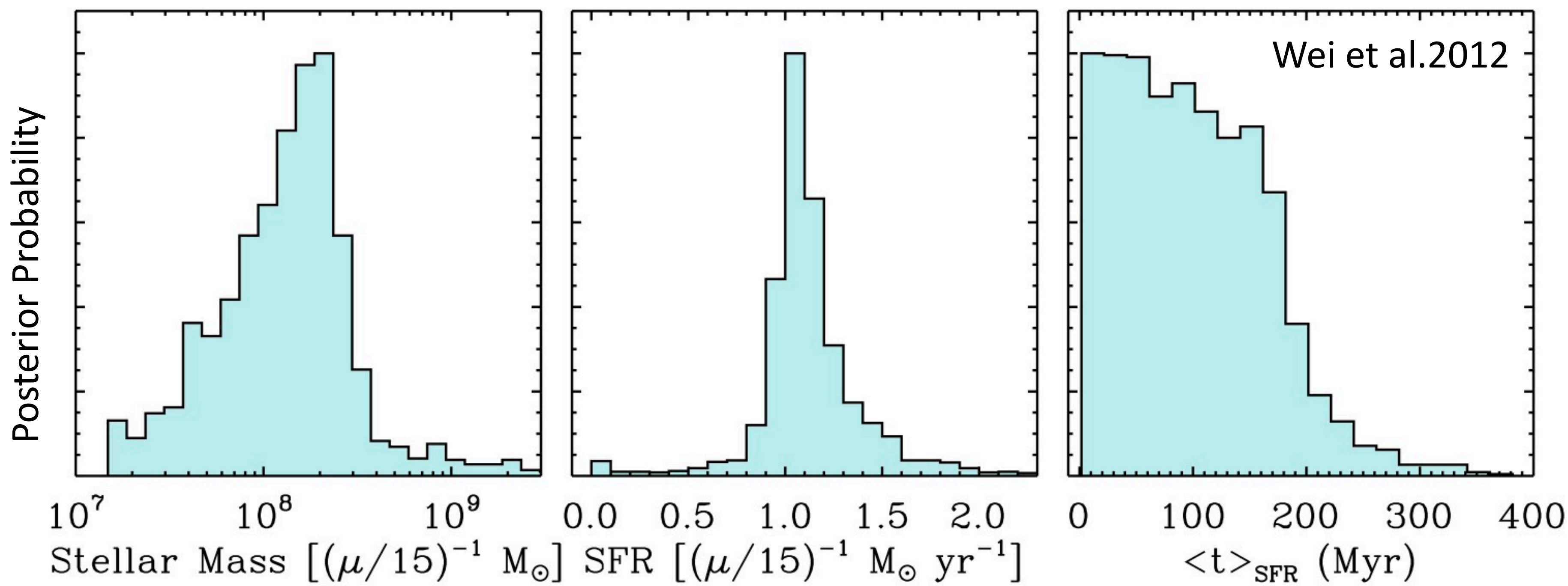


Wei et al.2012

Results based on 50,000 models assuming fixed z=9.6 with delayed star formation model $\psi(t) \sim t \exp(-t/\tau)$, where t = time since onset of star formation

Drew τ from a uniform distn between 10 Myr and 1 Gyr, t uniformly from 5 – 500 Myr, and Z = 0.002 – 0.02 (10% - 100% solar)



Stellar Mass ~1.5 x 10^8 $(\mu/15)^{-1}$ Msun

SFR ~ 1.2 $(\mu/15)^{-1}$ Msun/yr

SFR-weighted age < 200 Myr (95% CL) → formation z < 14.2

Stellar mass and SFR estimates have been de-magnified assuming a magnification μ =15. $\langle t \rangle_{SFR}$ is independent of magnification. IRAC photometry uncertainties are a major contributor to the large uncertainty in the age estimate.

SUMMARY:

- Galaxies in the Universe can be described by their SEDs (DNI)
- The expansion of the Universe distorts the original SEDs.
- The amount of distortion is defined by the Redshift (z).
- The z is a function of Time and Distance, so we can put in order galaxies across Time by measuring this quantity.
- For distant galaxies z has to be derived photometrically.
- These galaxies, so called "DROP-OUT", are missing in the Optical wavelengths due to the Neutral Hydrogen at the epoch that emitted their light. It makes its identification much easier.

SUMMARY:

• Very far away galaxies ($z>9$) are only observable by means of Massive Galaxy Clusters that Magnify (making brighter) the sources.

• With Space-based Telescope and High-quality observation in the NIR was possible to detect and characterize the $z\sim10$.

• This galaxy serves to understand when the First Galaxies were formed and which are their properties.

• New insights about the Re-ionization epoch of the Universe.

• This serves to constrain Cosmological Models.

Thanks!