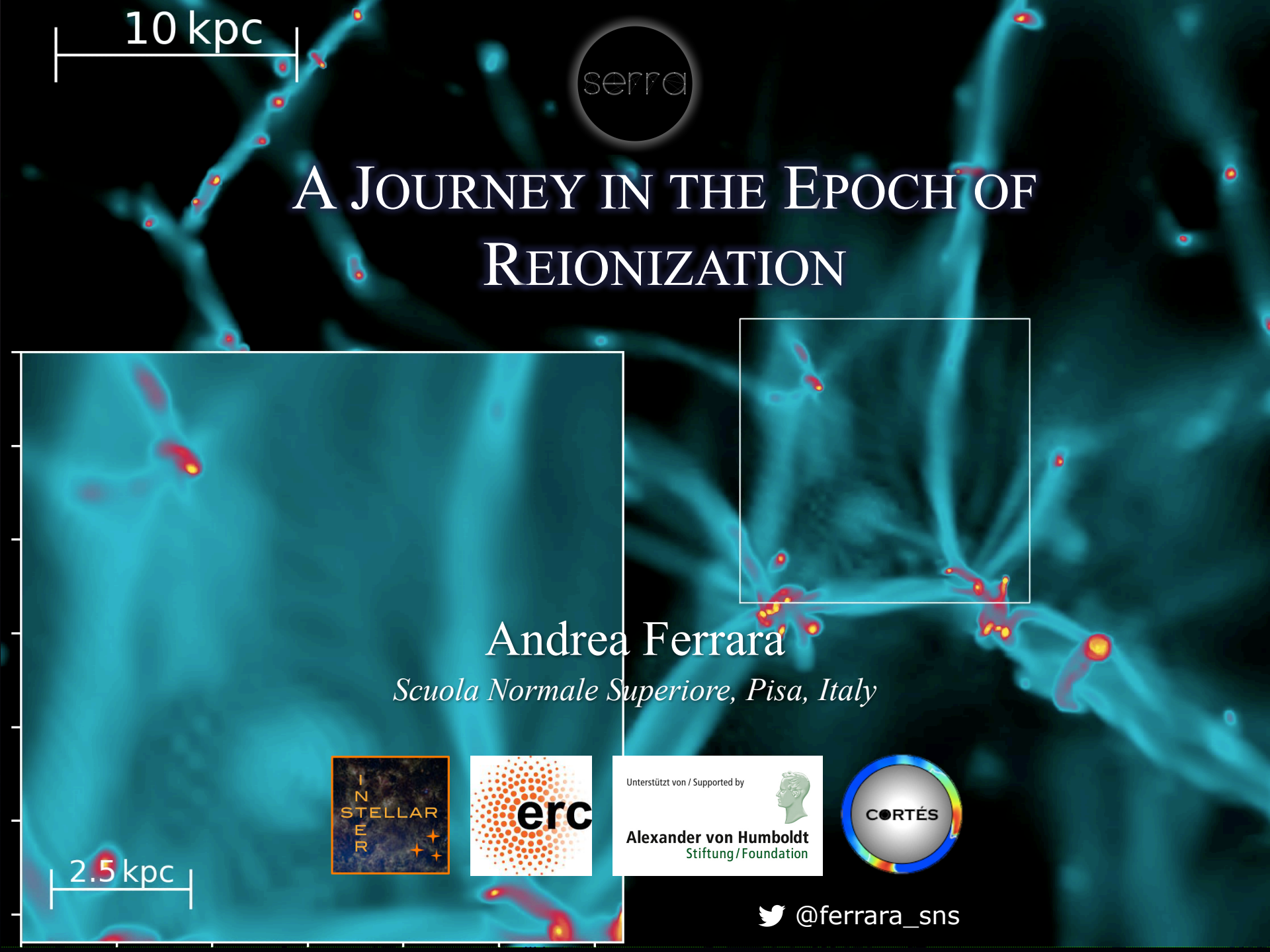

A Journey in the Epoch of Reionization

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Unterstützt von / Supported by
Alexander von Humboldt Stiftung/Foundation

@ferrara_sns

Sequence of events

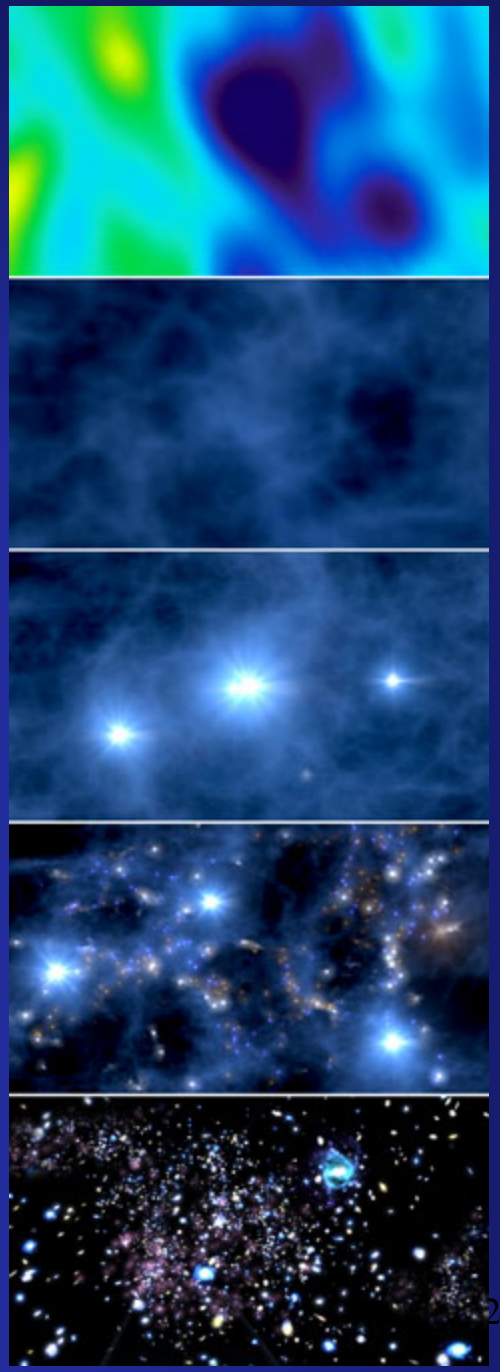
At z=1000 the Universe has cooled down to 3000 K. Hydrogen becomes neutral ("Recombination").

At z < 40 the first "PopIII" star (clusters)/small galaxies form.

At z ~ 6-15 these gradually photo-ionize the hydrogen in the IGM ("Reionization").

At z<6 galaxies form most of their stars and grow by merging.

At z<1 massive galaxy clusters are assembled.

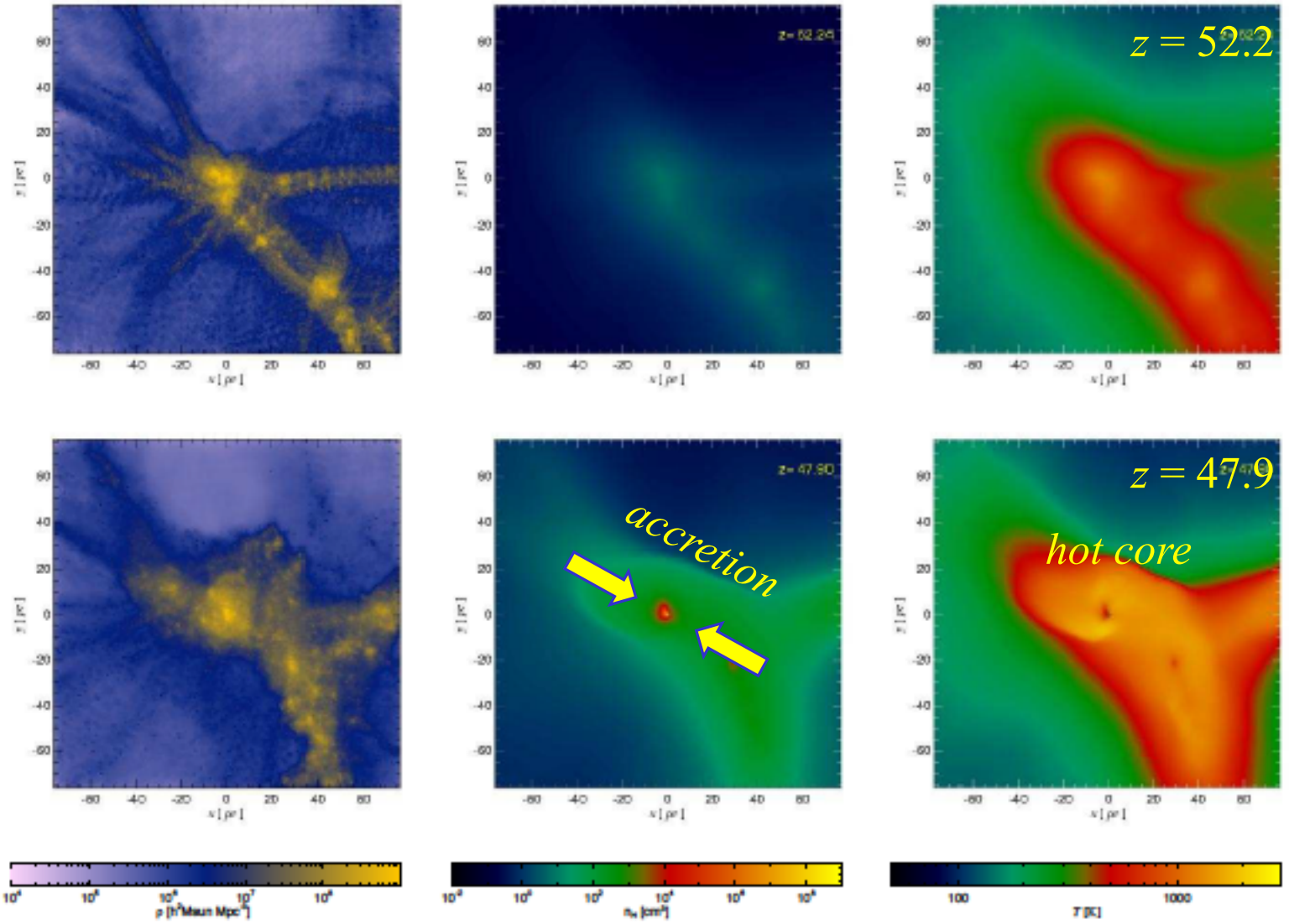


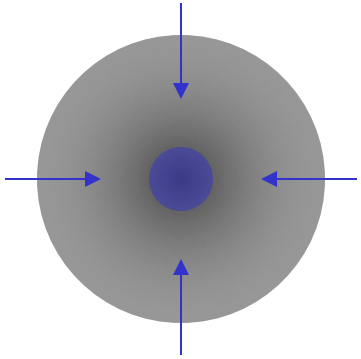
Time

Halo mass = $2.2 \times 10^5\ M_\odot$

Gao+07

dark matter density | *gas density* | *gas temperature*





- *Run-away collapses produces a core + accreting envelope structure*
- *Initial conditions: $M_c \approx 10^{-3}\ M_\odot$, $M_{env} \approx 10^{3}\ M_\odot$*

Accretion rate

$$dM/dt \approx M_J / t_{ff} \propto \lambda_J \rho / t_{ff} = \alpha_s \rho / t_{ff} \propto \alpha_s^3 G^{-1}$$

Numerical estimate

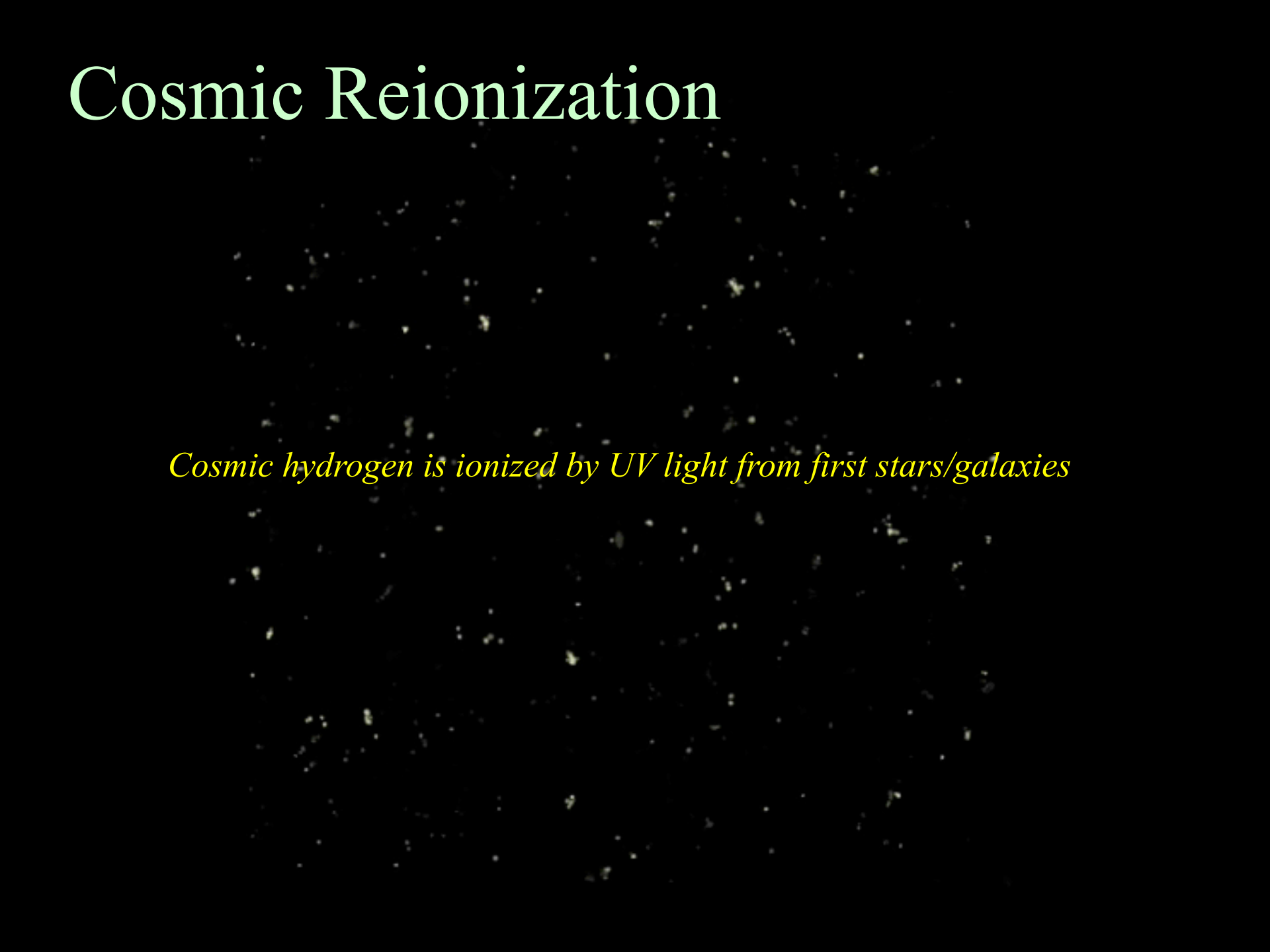
$$dM/dt \approx 4.4 \times 10^{-3} M_\odot / yr \quad (T = 300\ K)$$

KEY POINTS

It takes only 70,000 years to build a 300 $M_\odot$ star

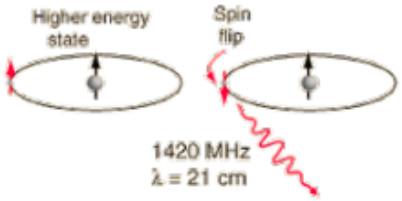
Was the Initial Mass Function of the first stars top-heavy?

Cosmic Reionization



Cosmic hydrogen is ionized by UV light from first stars/galaxies

BASIC PHYSICS



$$n_1/n_0 = 3\exp(-T_\star/T_S)$$

$$T_S{}^{-1} = \frac{T_\gamma{}^{-1} + x_\alpha T_\alpha{}^{-1} + x_c T_K{}^{-1}}{1 + x_\alpha + x_c}$$

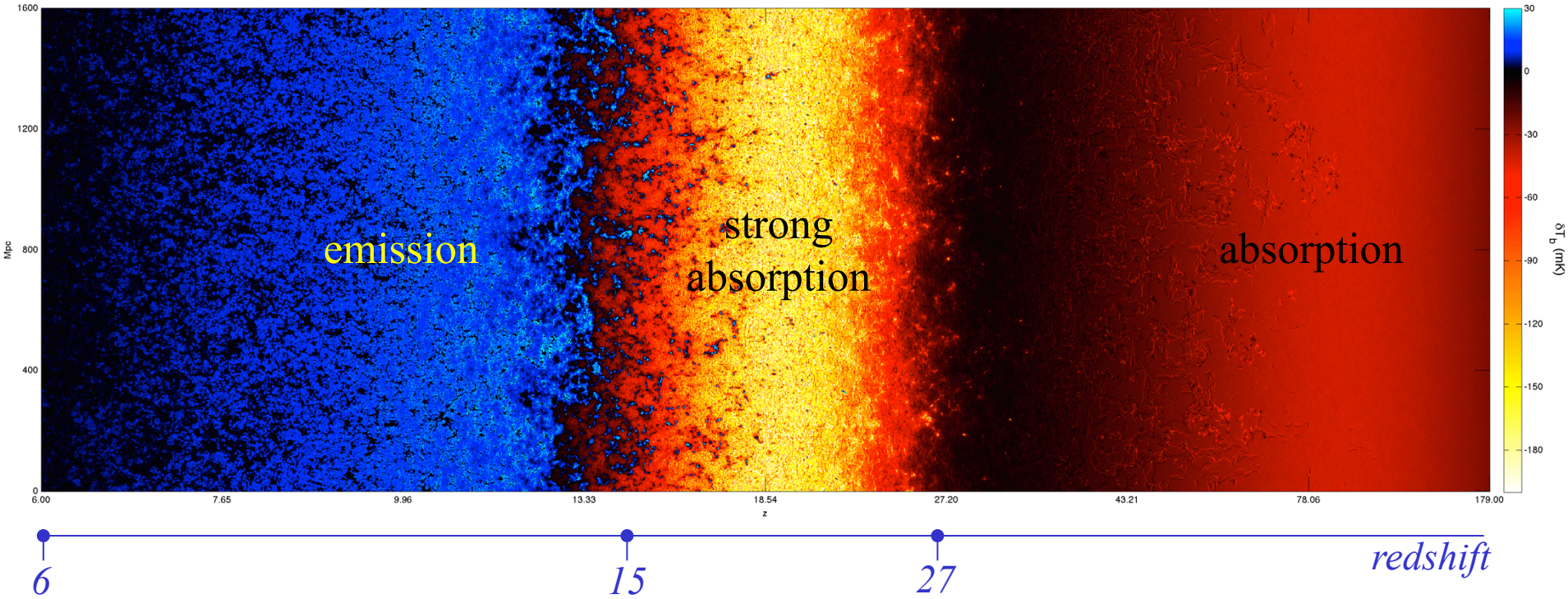
$$\delta T_b = \frac{T_S - T_\gamma}{1+z}\,\tau$$

$$\delta T_b \simeq 27 x_{\rm HI}(1+\delta_{\rm nl})\left(\frac{H}{dv_r/dr + H}\right)\left(1 - \frac{T_\gamma}{T_S}\right)\left(\frac{1+z}{10}\frac{0.15}{\Omega_M h^2}\right)^{1/2}\left(\frac{\Omega_b h^2}{0.023}\right)\,{\rm mK}$$

Mesinger, AF & Spiegel 2013; Pacucci+14

HI 21CM LINE VIEW

Brightness Temperature Evolution



6 *15* *27* *redshift*

Epoch of Reionization

- *IGM warmer than CMB*
- *Strong $T_s - T_k$ coupling*

Cosmic Dawn

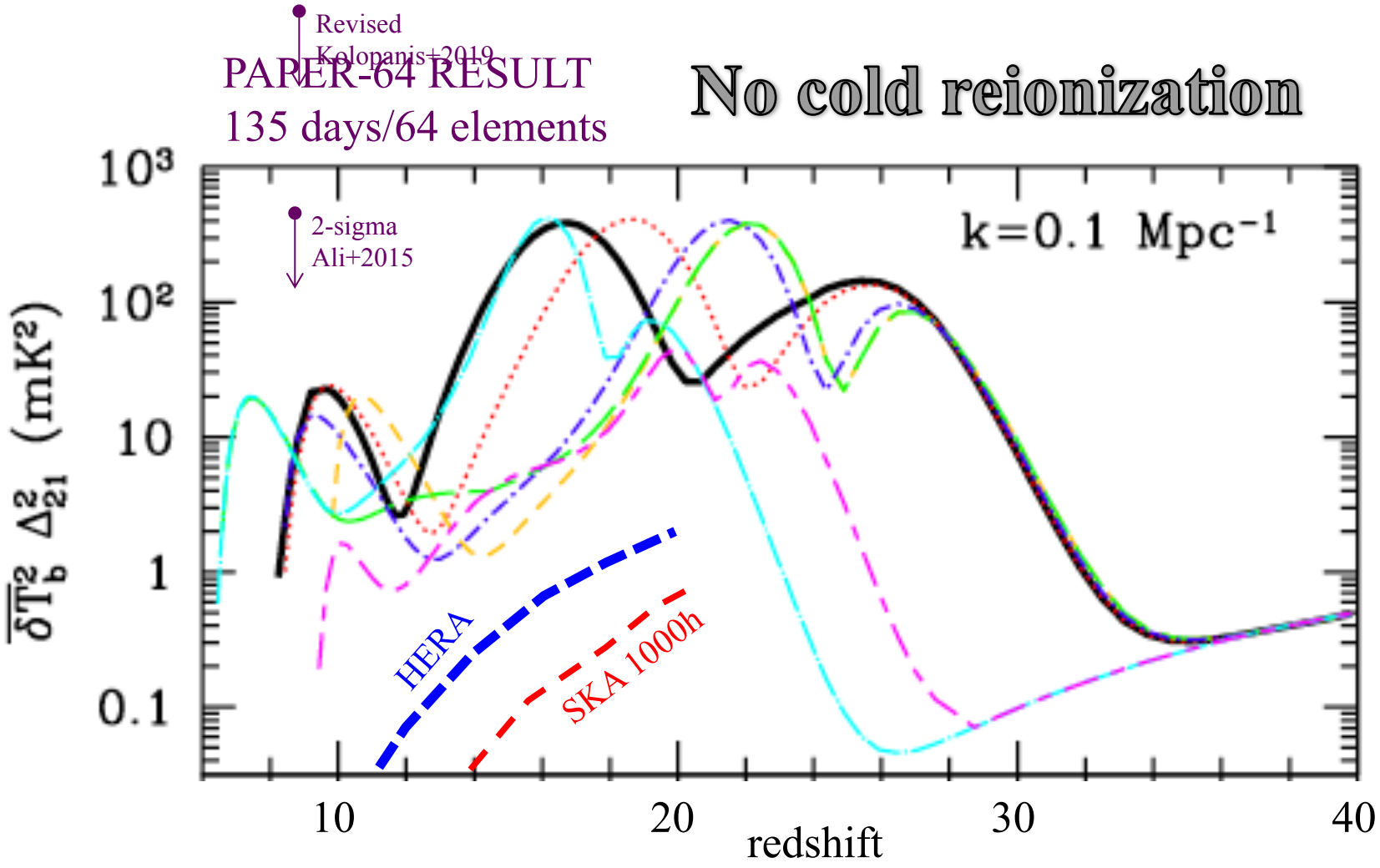
- *IGM colder than CMB*
- *Lya coupling (WF effect)*
- ***X-ray preheating***

Dark Ages

- *IGM colder than CMB*
- *Weak $T_s - T_k$ coupling*

Mesinger, AF & Spiegel 2013

21CM POWER SPECTRUM

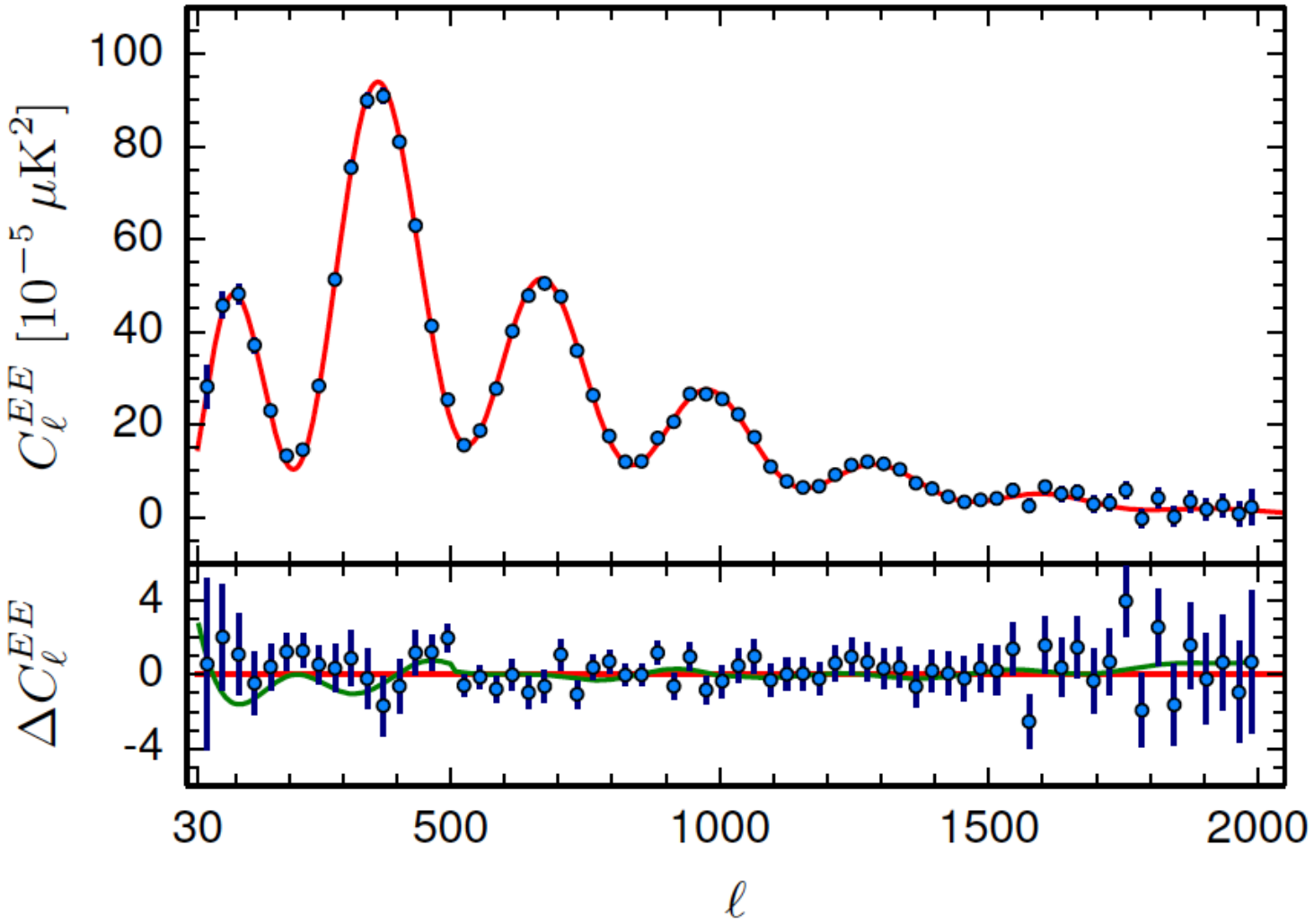


Diving in a hydrogen sea

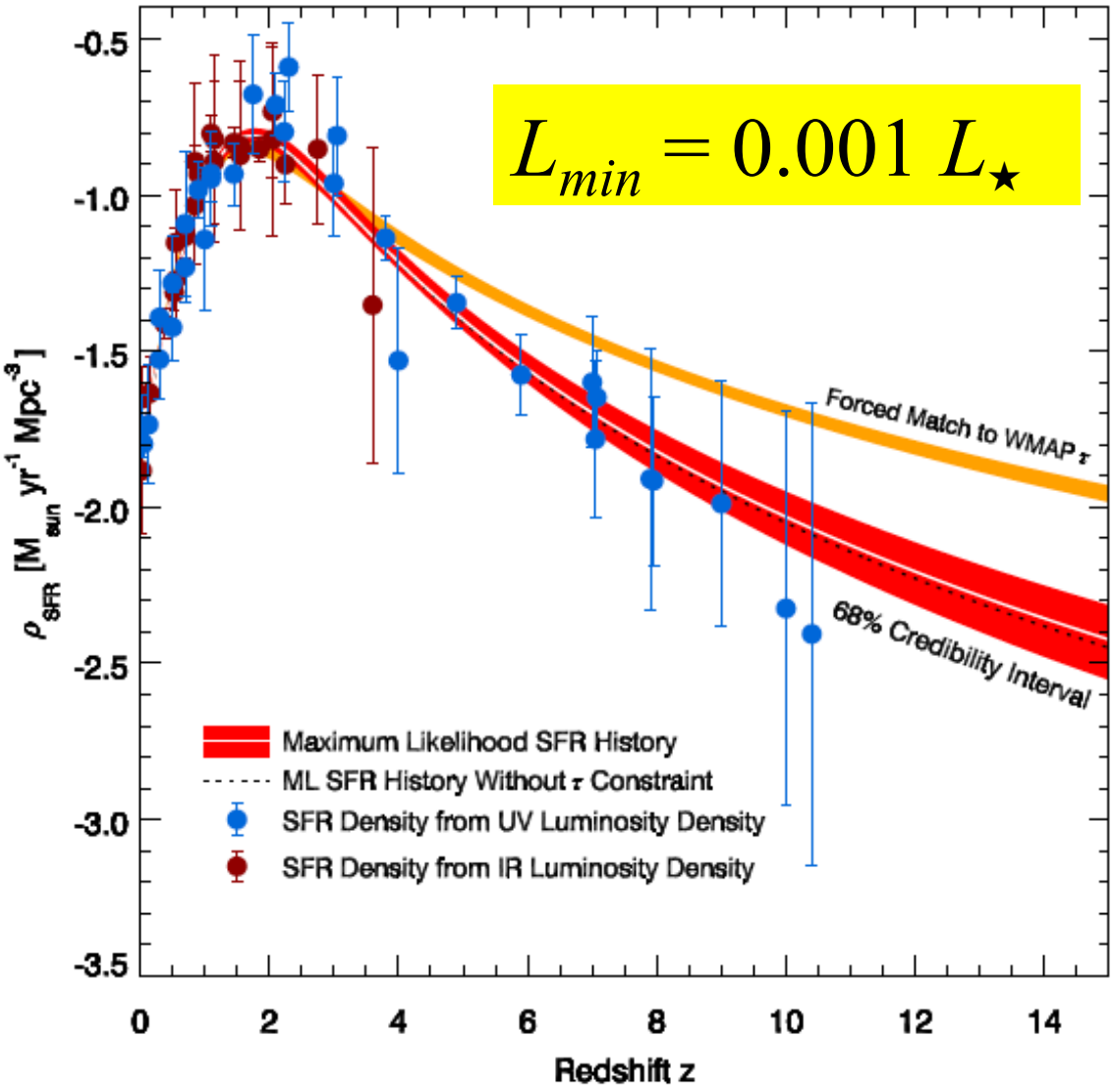
The world's largest radiotelescope

Planck Collaboration 2018

PLANCK POLARIZATION DATA



Robertson+15

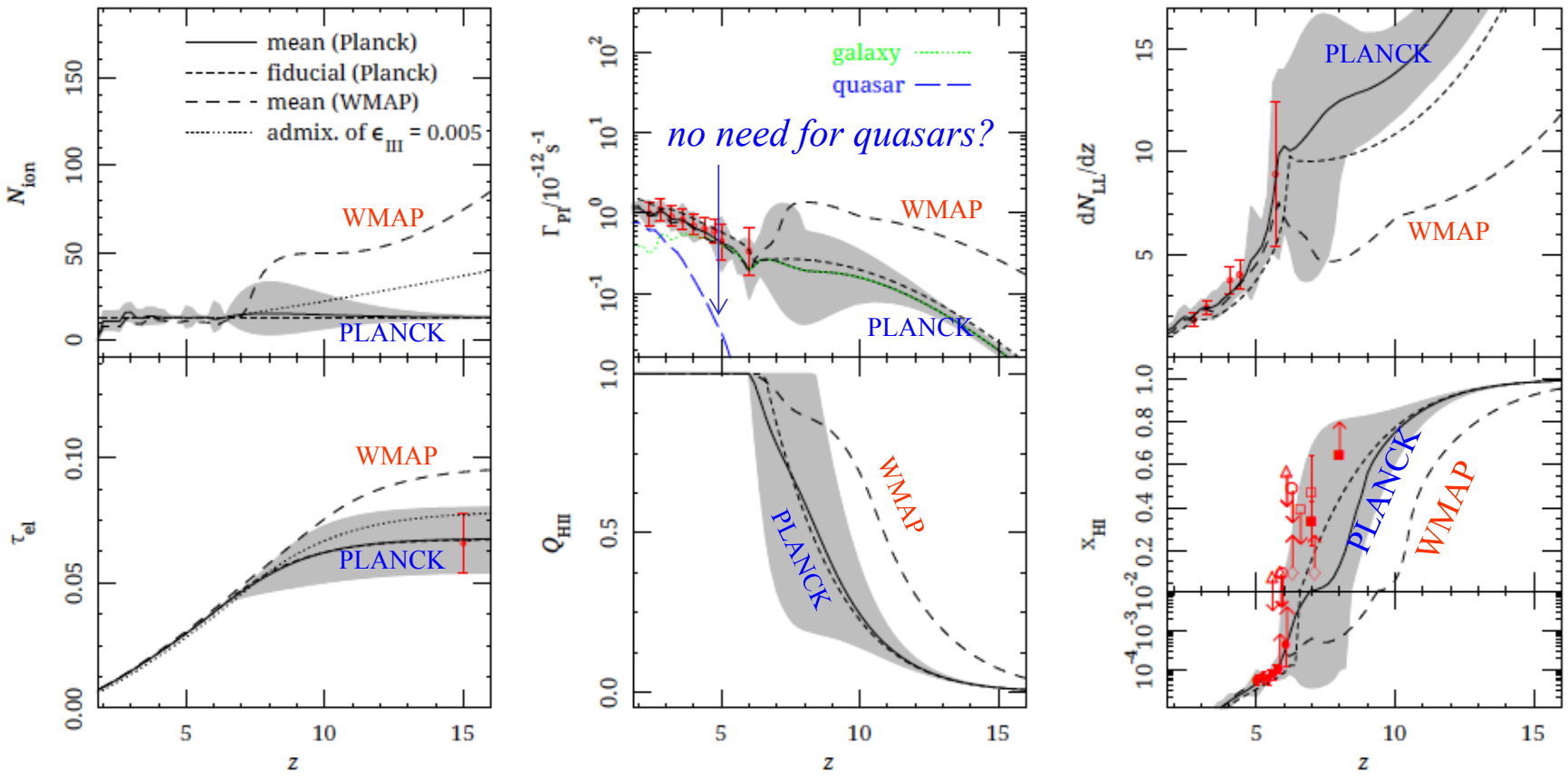


$f_{esc} = 0.2$

DATA-CONSTRAINED REIONIZATION

Mitra, Choudhury & AF 2015

$$N_{\rm ion} = \epsilon_* f_{\rm esc} N_\gamma$$

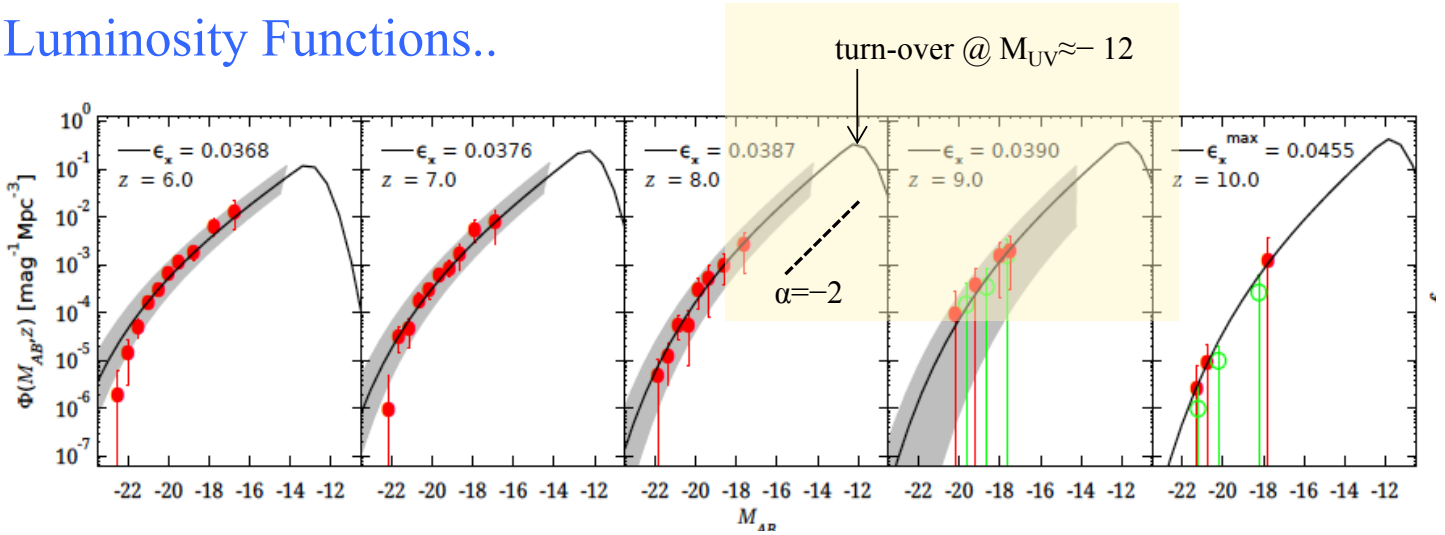


Reionization after *PLANCK – MCMC Analysis*

DATA-CONSTRAINED REIONIZATION

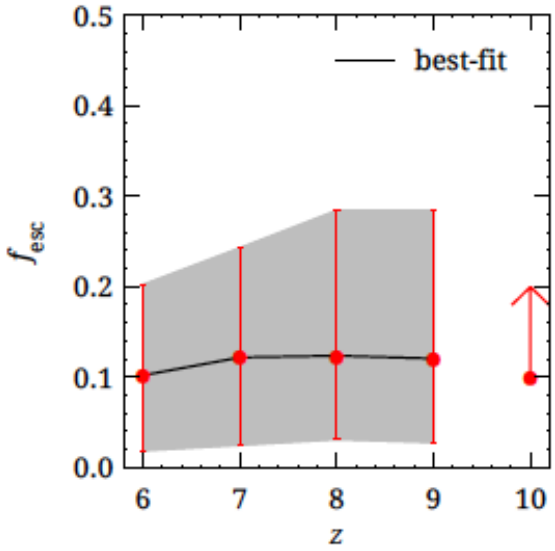
Mitra, Choudhury & AF 2015; Yue+16

Add Luminosity Functions..



.. get escape fraction

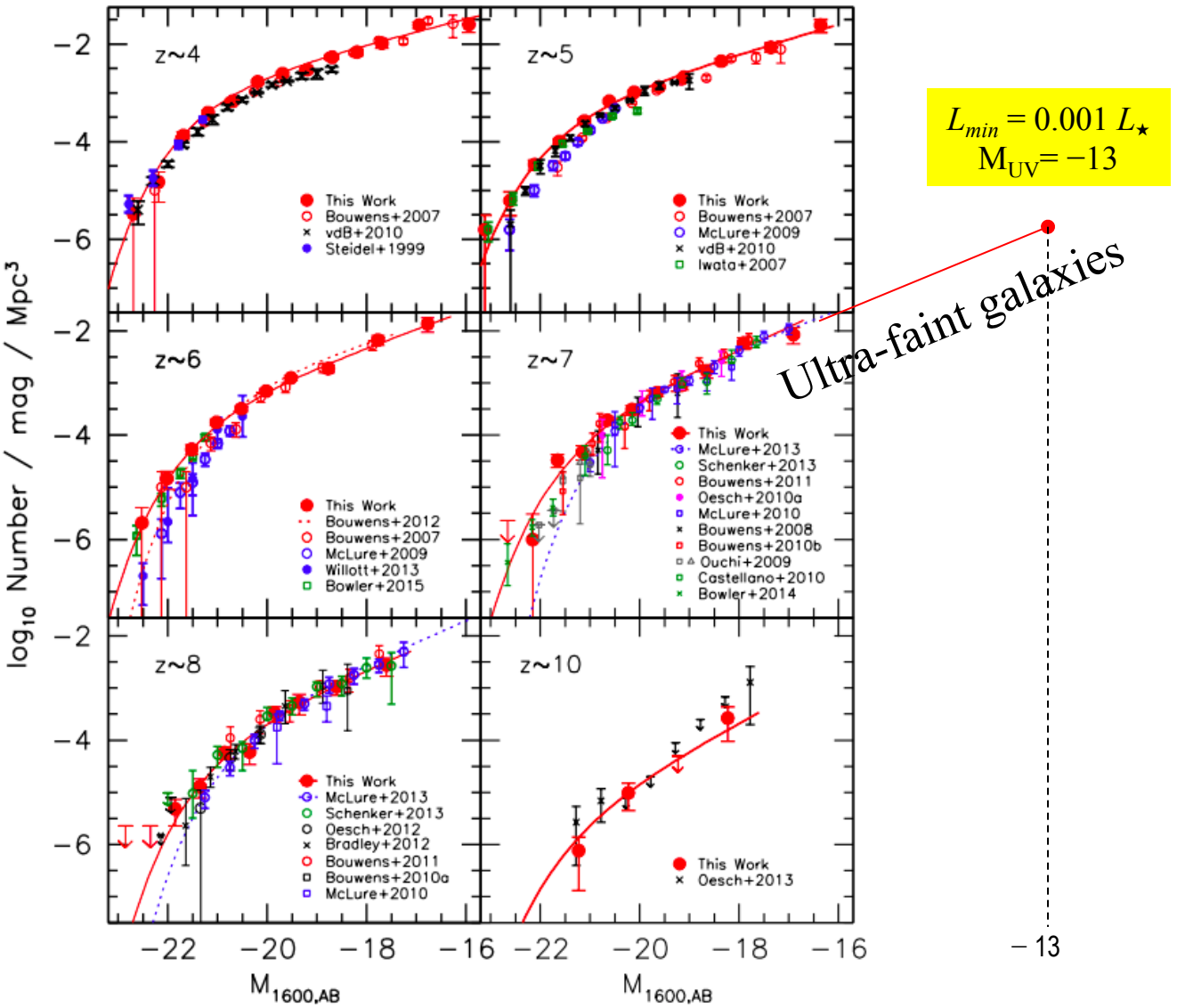
$$N_{\rm ion} = \epsilon_* f_{\rm esc} N_\gamma$$



✓*AF & Loeb 2013*

LUMINOSITY FUNCTIONS

Salvaterra+11, Bouwens+15, +21



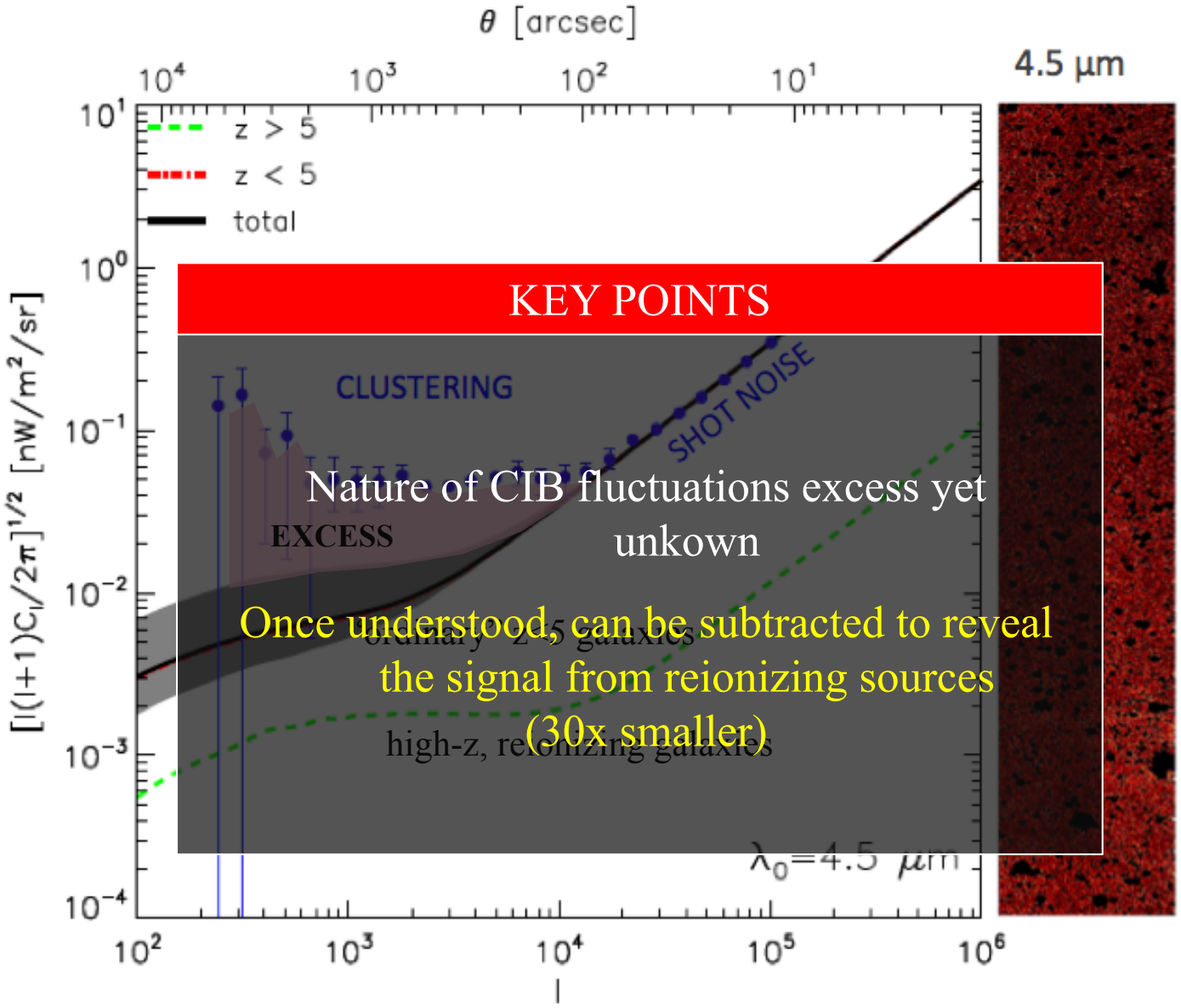
$L_{min} = 0.001\ L_{\star}$
$M_{UV} = -13$

Ultra-faint galaxies

−13

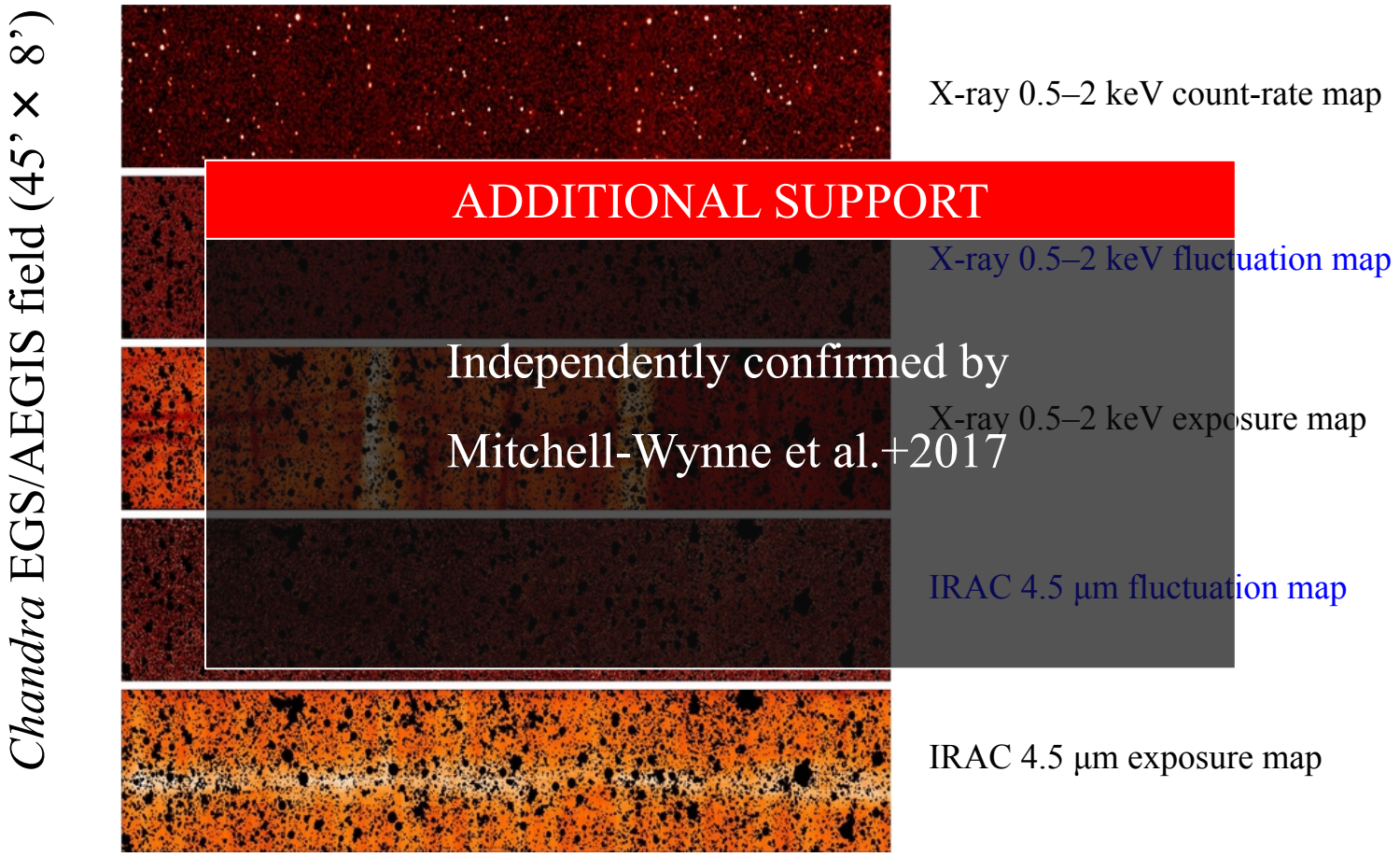
CIB FLUCTUATIONS

Kashlinsky+12, +18; Helgason+12; Yue+12



Cappelluti+12,+19

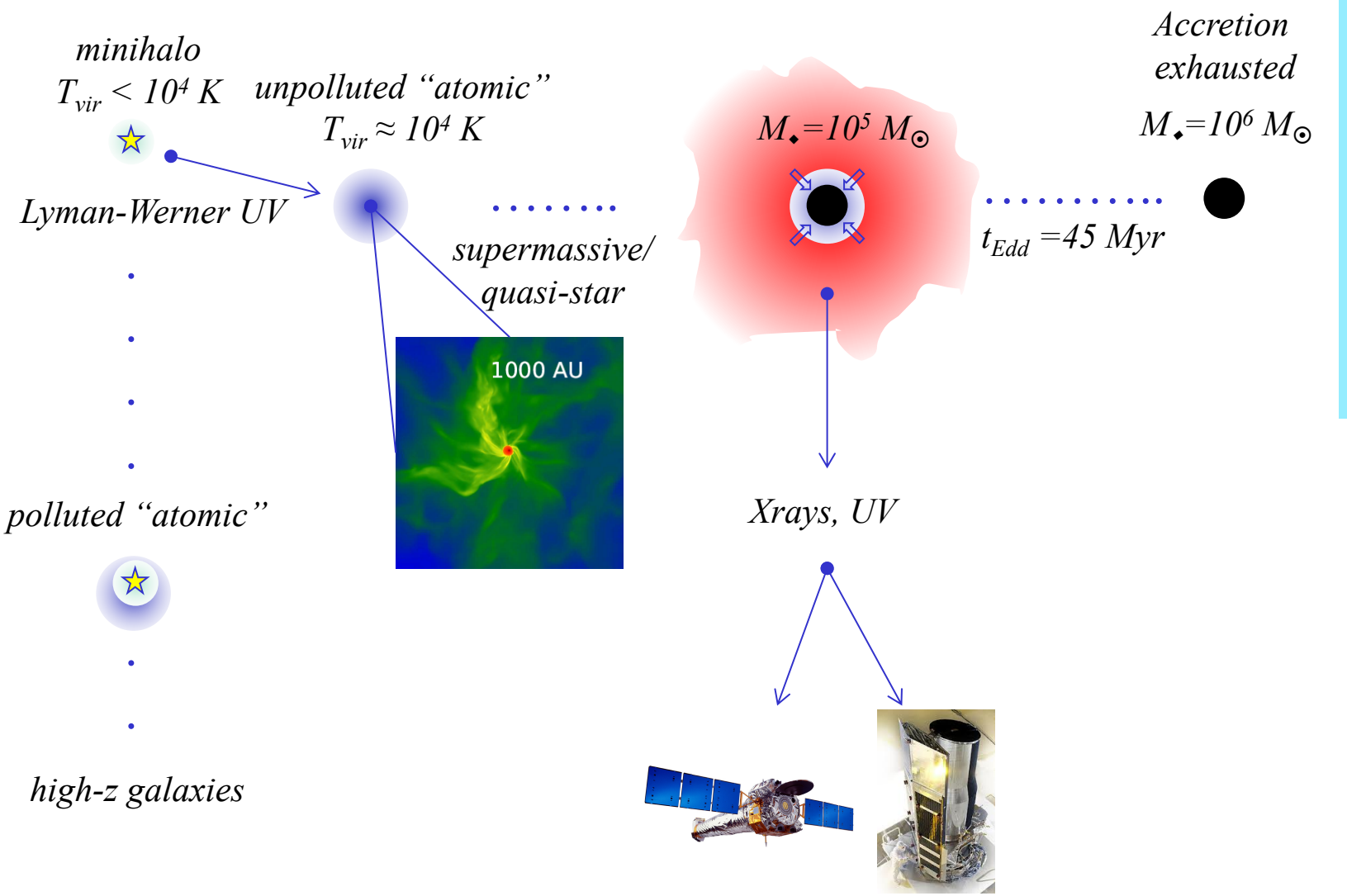
CIB-CXB CORRELATION



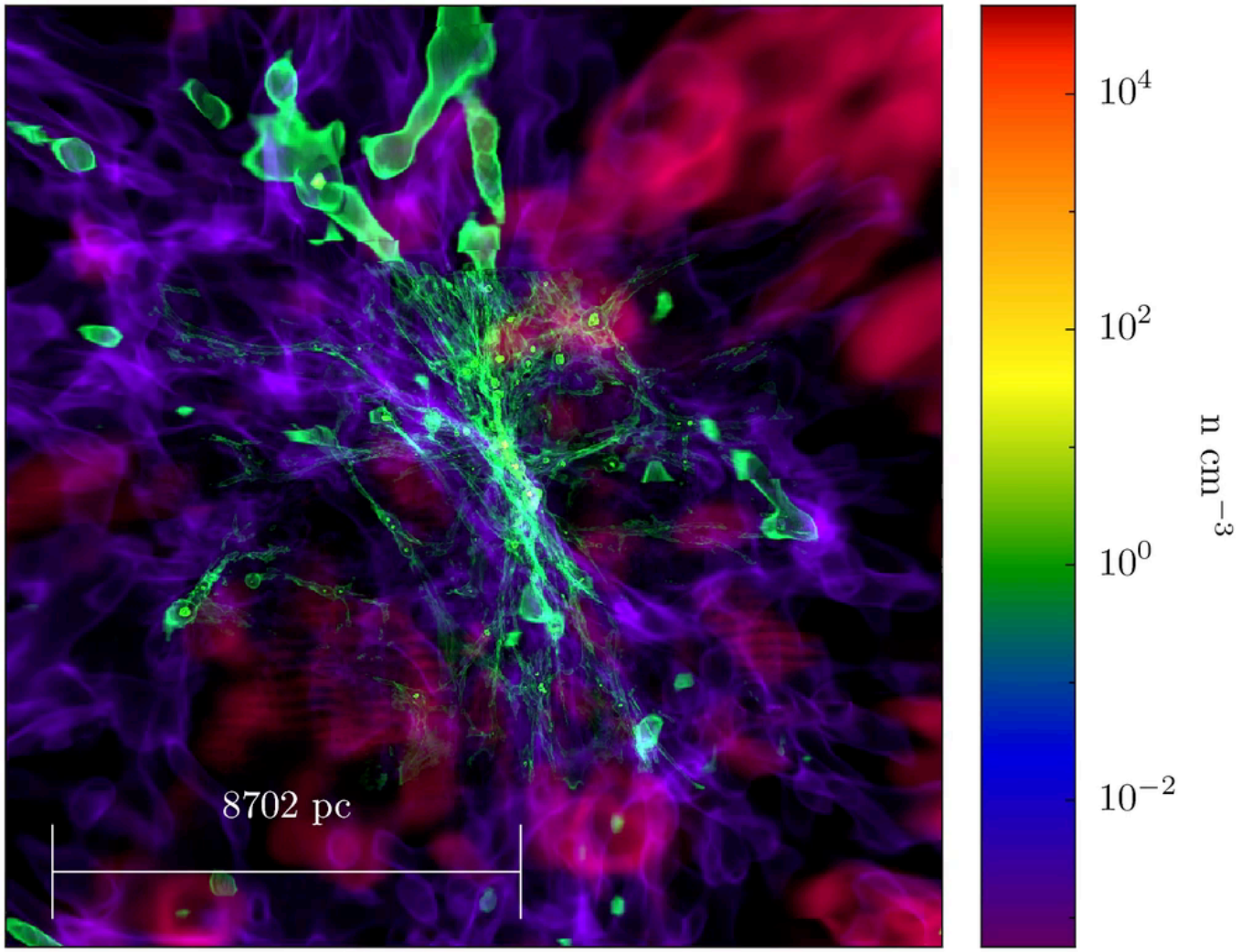

First Black Holes ?

Yue, AF+2013, AF+14

FIRST BLACK HOLE ERA



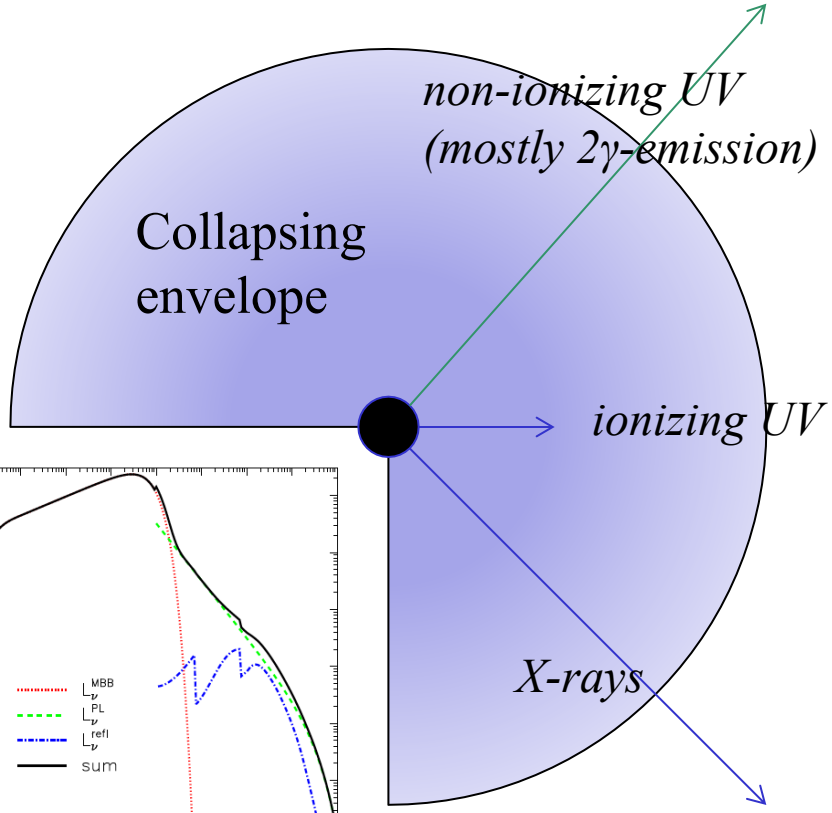
DCBH FORMATION

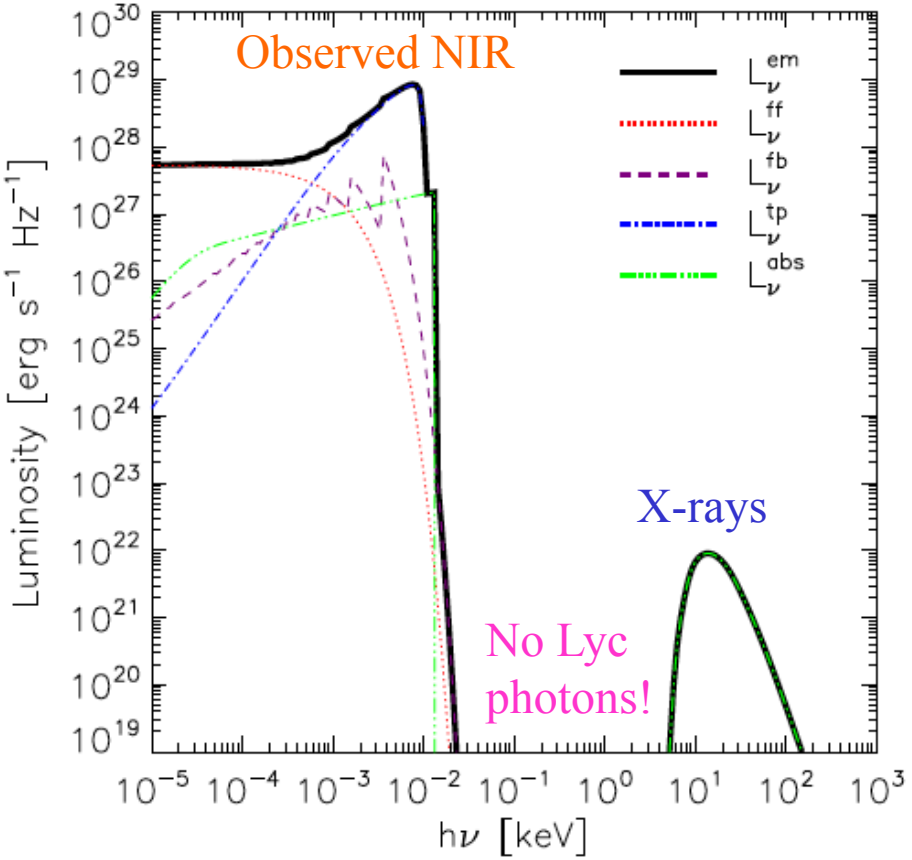


Courtesy: C. Regan, Univ. of Helsinki

ABSORBED SPECTRUM

$N_H=1.5x10^{25}$ cm^{-2}
(Compton thick)



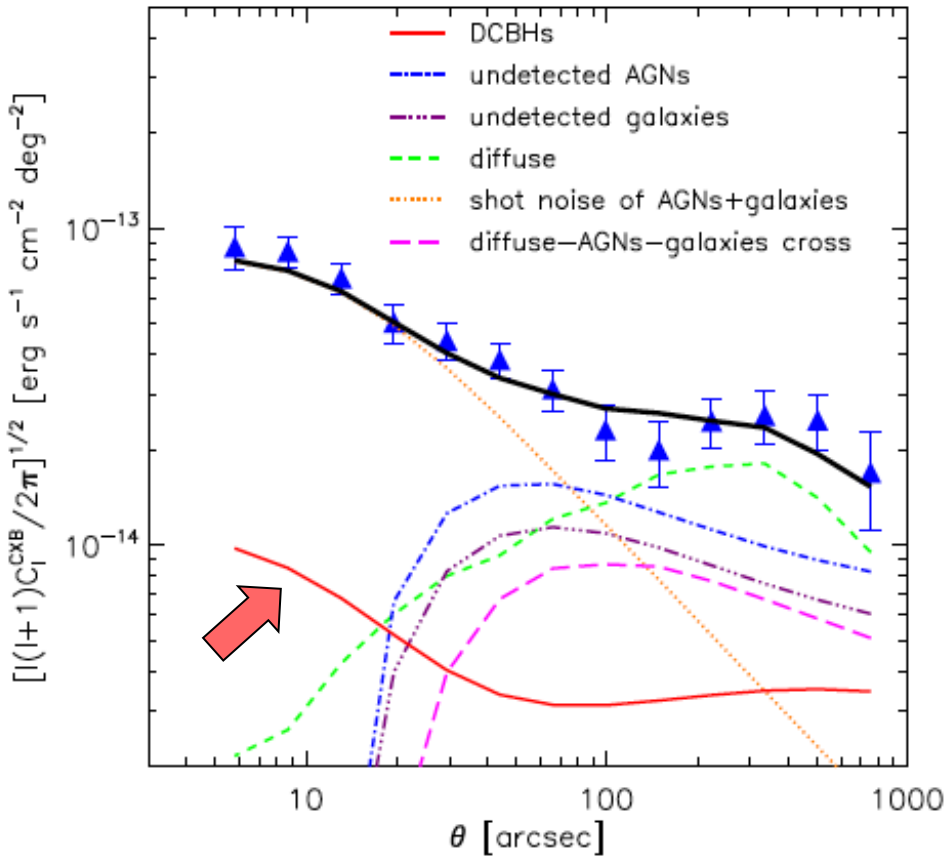


$M_\bullet=10^6\ M_\odot$
(Direct collapse black hole)

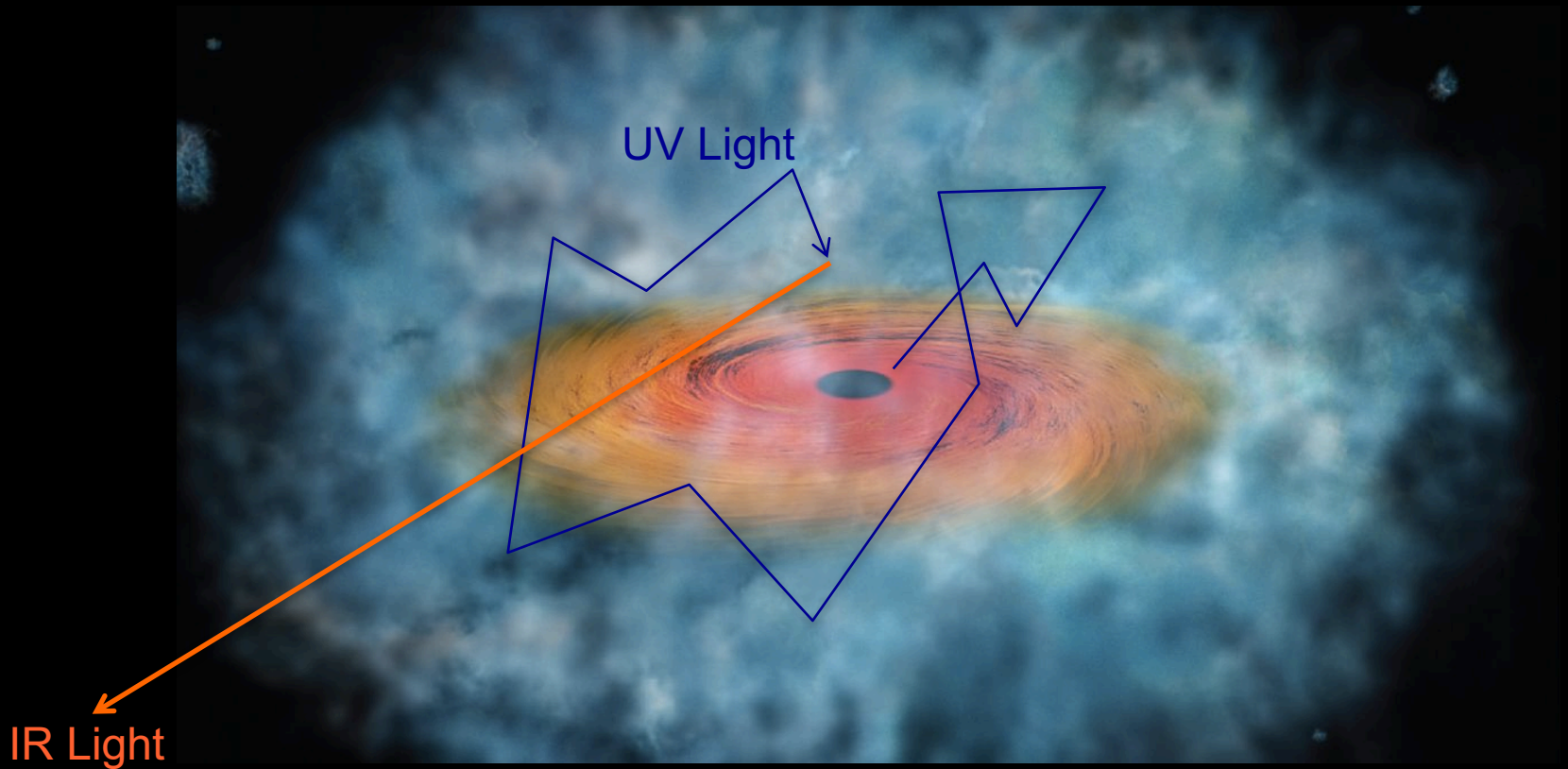
Yue, AF & Salvaterra 13

SEEDS EXPLAIN CIB-CXB CORRELATION

CXB Power spectrum



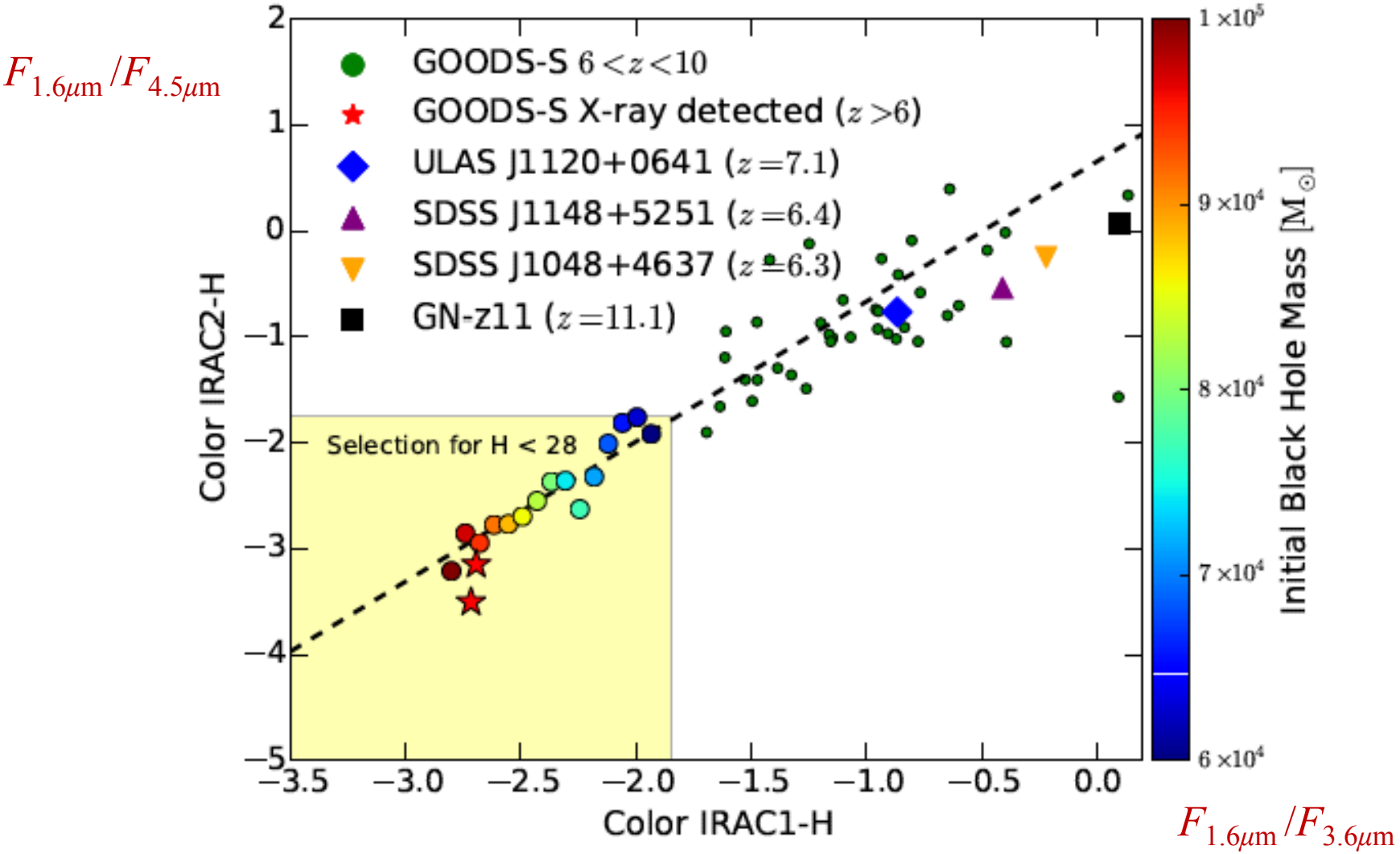
A growing DCBH



DCBH ACCRETING ITS PARENT HALO GAS

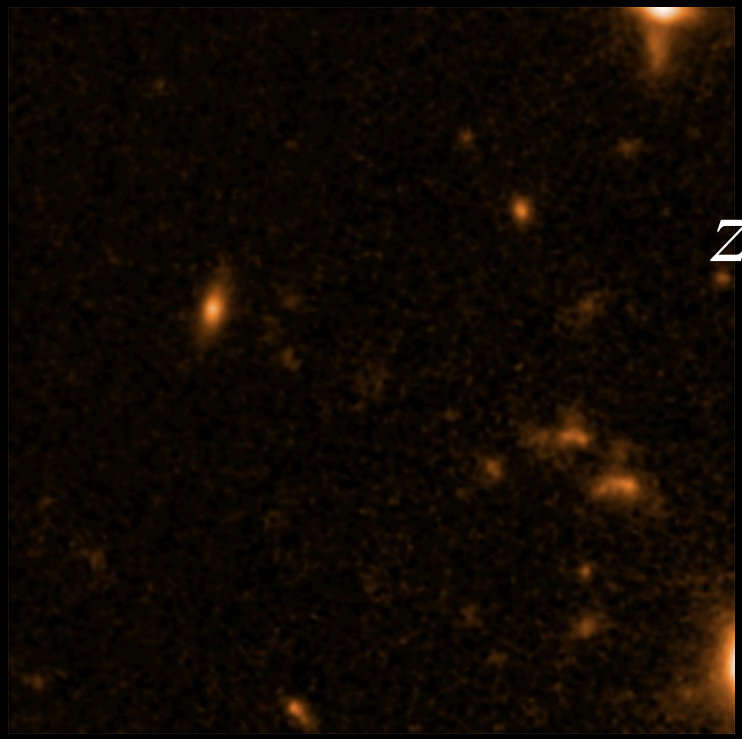
Pacucci+16

SELECTING DCBH BY COLORS

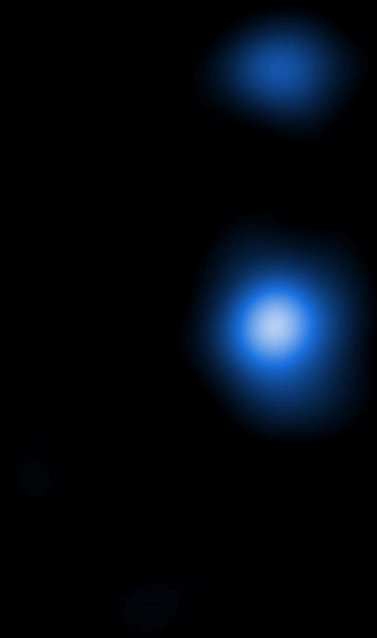


Do DCBHs exist? Yes!

Pacucci+16



$z = 9.7$



H-band Image
(Hubble Space Telescope)

X-ray Image
(Chandra Space Telescope)

hubble

esa

Pacucci+16

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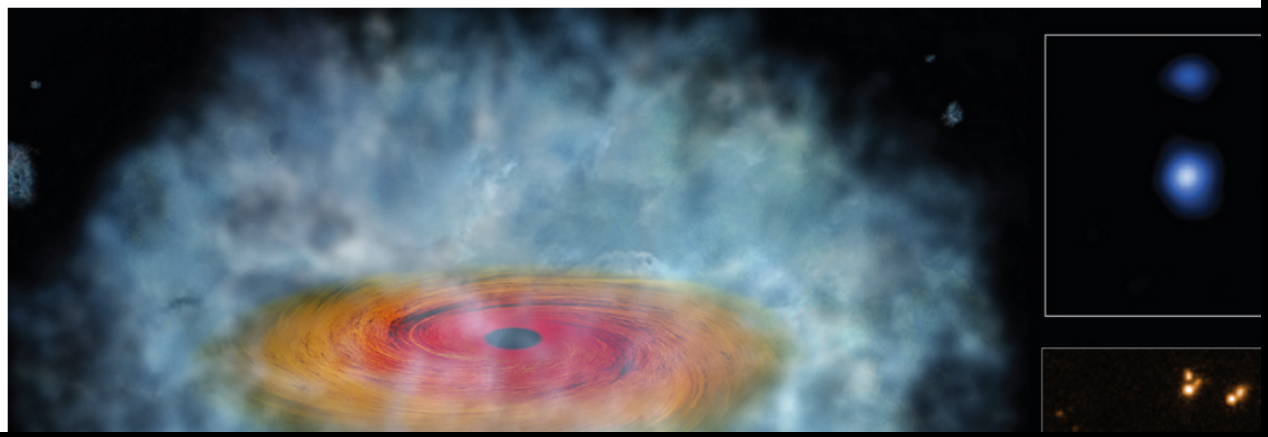
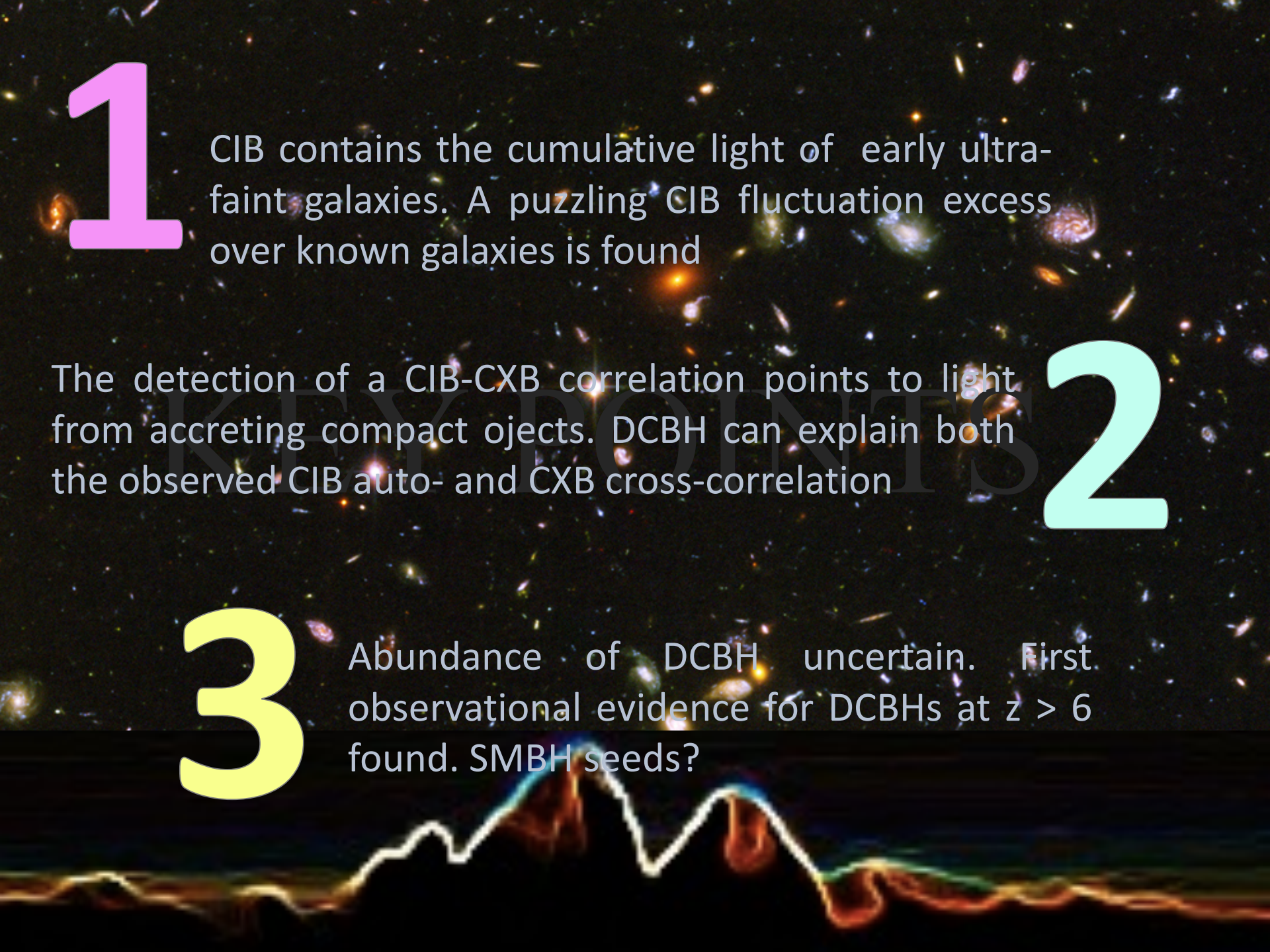
Jet Propulsion Laboratory
California Institute of Technology

NEWS | MAY 24, 2016

NASA Telescopes Find Clues For How Giant Black Holes Formed So Quickly




1
CIB contains the cumulative light of early ultra-faint galaxies. A puzzling CIB fluctuation excess over known galaxies is found
KEY POINTS
The detection of a CIB-CXB correlation points to light from accreting compact ojects. DCBH can explain both the observed CIB auto- and CXB cross-correlation
2
3
Abundance of DCBH uncertain. First observational evidence for DCBHs at z > 6 found. SMBH seeds?