

A Journey in the Epoch of Reionization

Andrea Ferrara

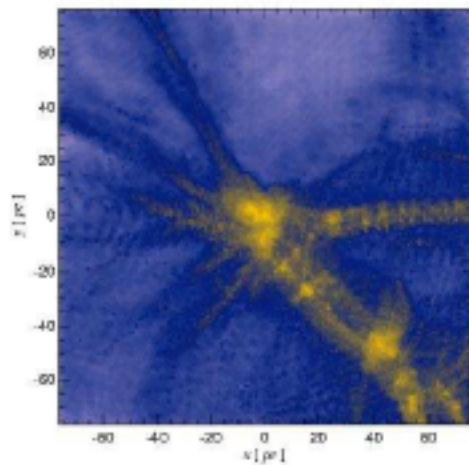
*Scuola Normale Superiore, Pisa, Italy
&
Kavli IPMU, Tokyo, Japan*

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

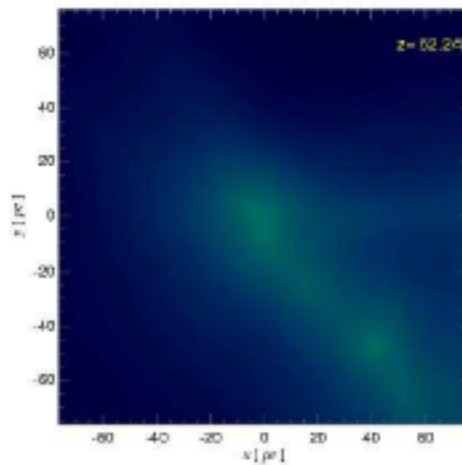
THE FIRST STAR

Gao+07

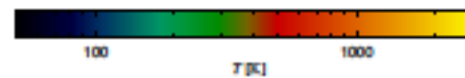
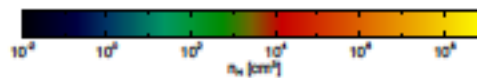
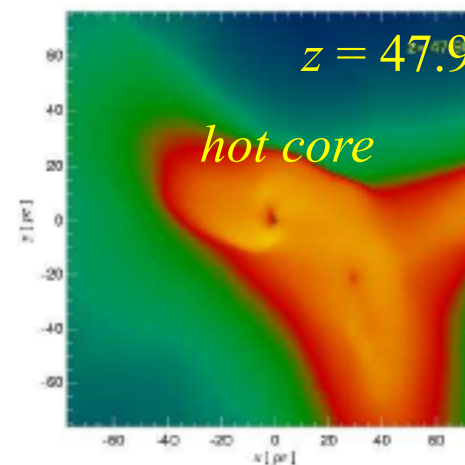
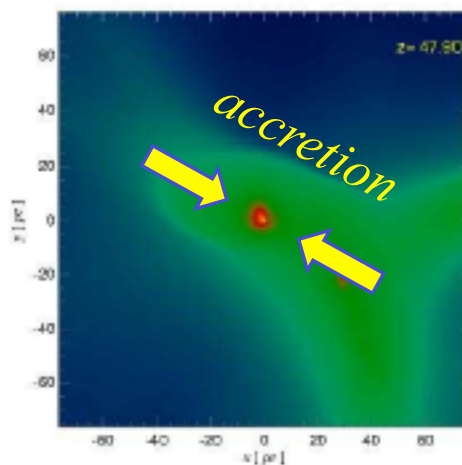
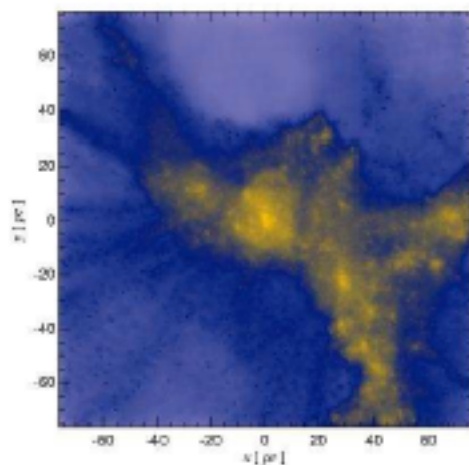
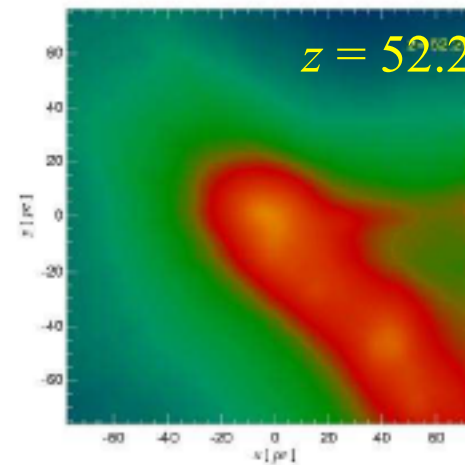
dark matter density

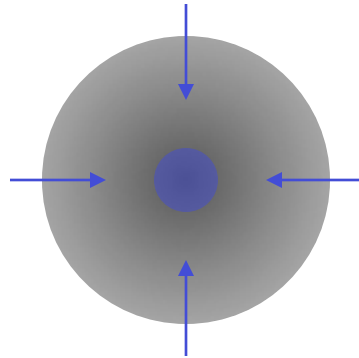


gas density



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

$$dM/dt \approx M_J / t_{ff} \propto \rho_s^{3/2} G^{1/2} R_s^{-1/2}$$

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

Numerical estimate

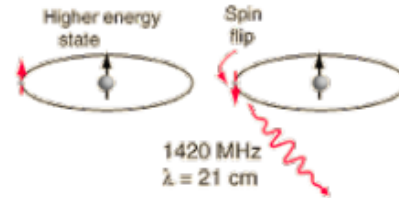
Was the Initial Mass Function of the first stars top-heavy?

$$dM/dt \approx 4.9 \times 10^{-4} M_\odot \text{ yr}^{-1} \quad (T \sim 600 \text{ K})$$

Cosmic Reionization

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

BASIC PHYSICS



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

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

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

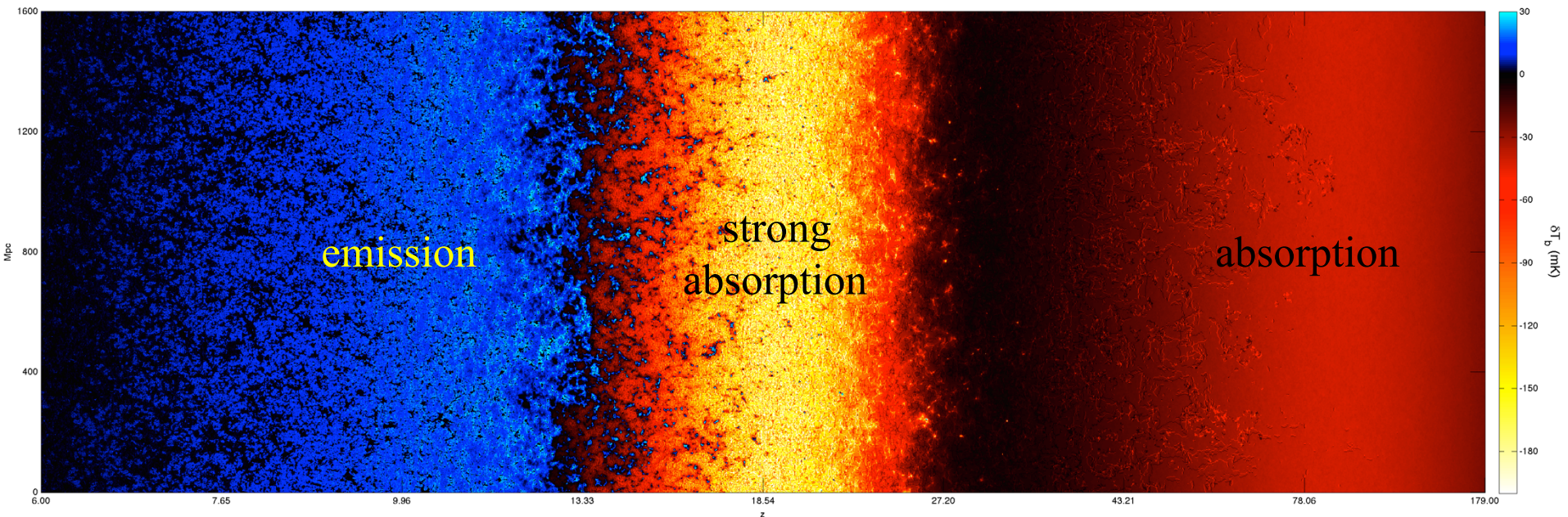
$$\delta T_b \simeq 27 x_{\text{HI}} (1 + \delta_{\text{nl}}) \left(\frac{H}{dv_r/dr + H} \right) \left(1 - \frac{T_\gamma}{T_S} \right) \left(\frac{1 + z}{10} \frac{0.15}{\Omega_M h^2} \right)^{1/2} \left(\frac{\Omega_b h^2}{0.023} \right) \text{ mK}$$

COSMIC REIONIZATION

Mesinger, AF & Spiegel 2013; Pacucci+14

HI 21CM LINE VIEW

Brightness Temperature Evolution



6

Epoch of Reionization

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

15

Cosmic Dawn

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

27

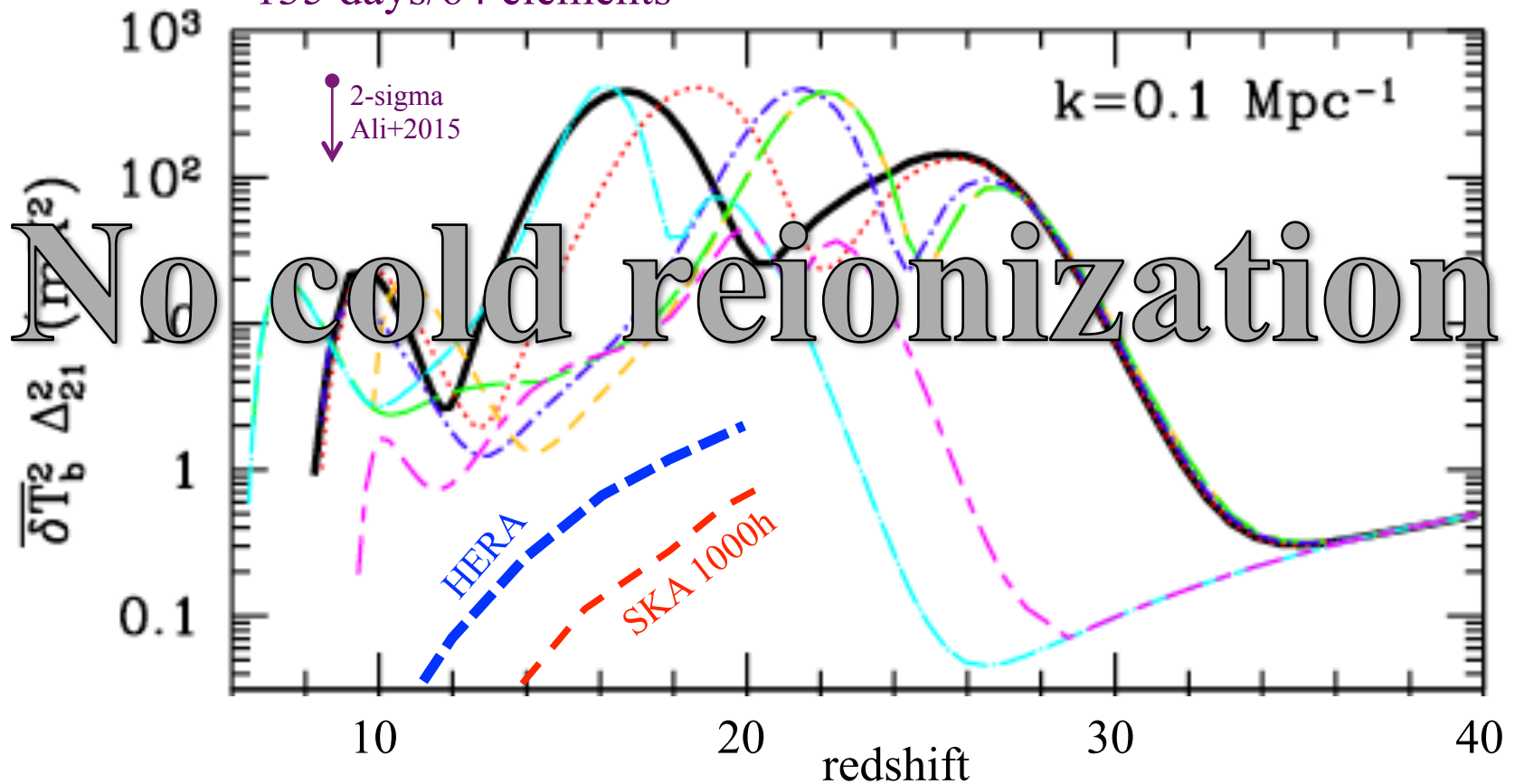
Dark Ages

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

redshift

21CM POWER SPECTRUM

PAPER-64 RESULT
135 days/64 elements



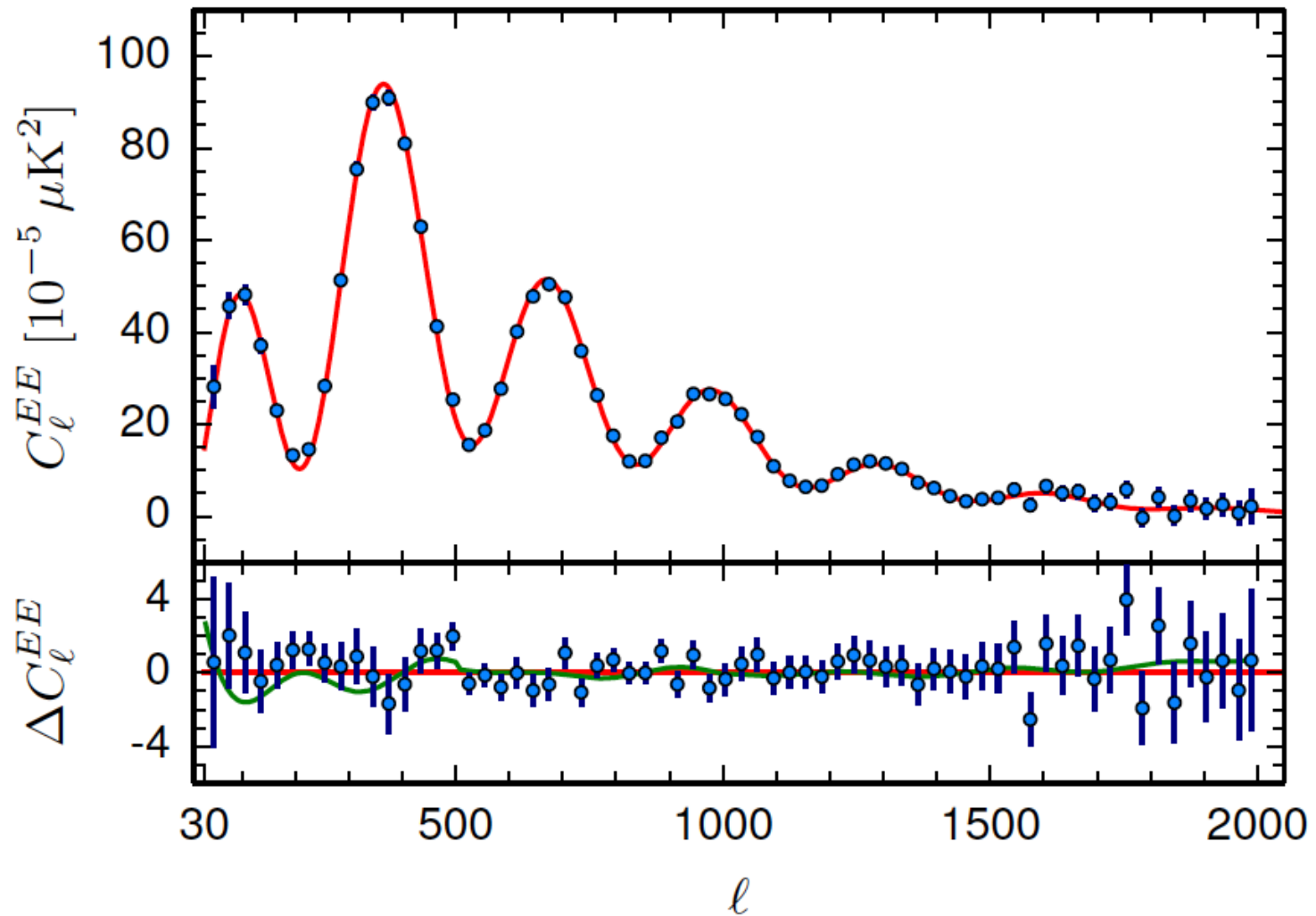
Diving in a hydrogen sea

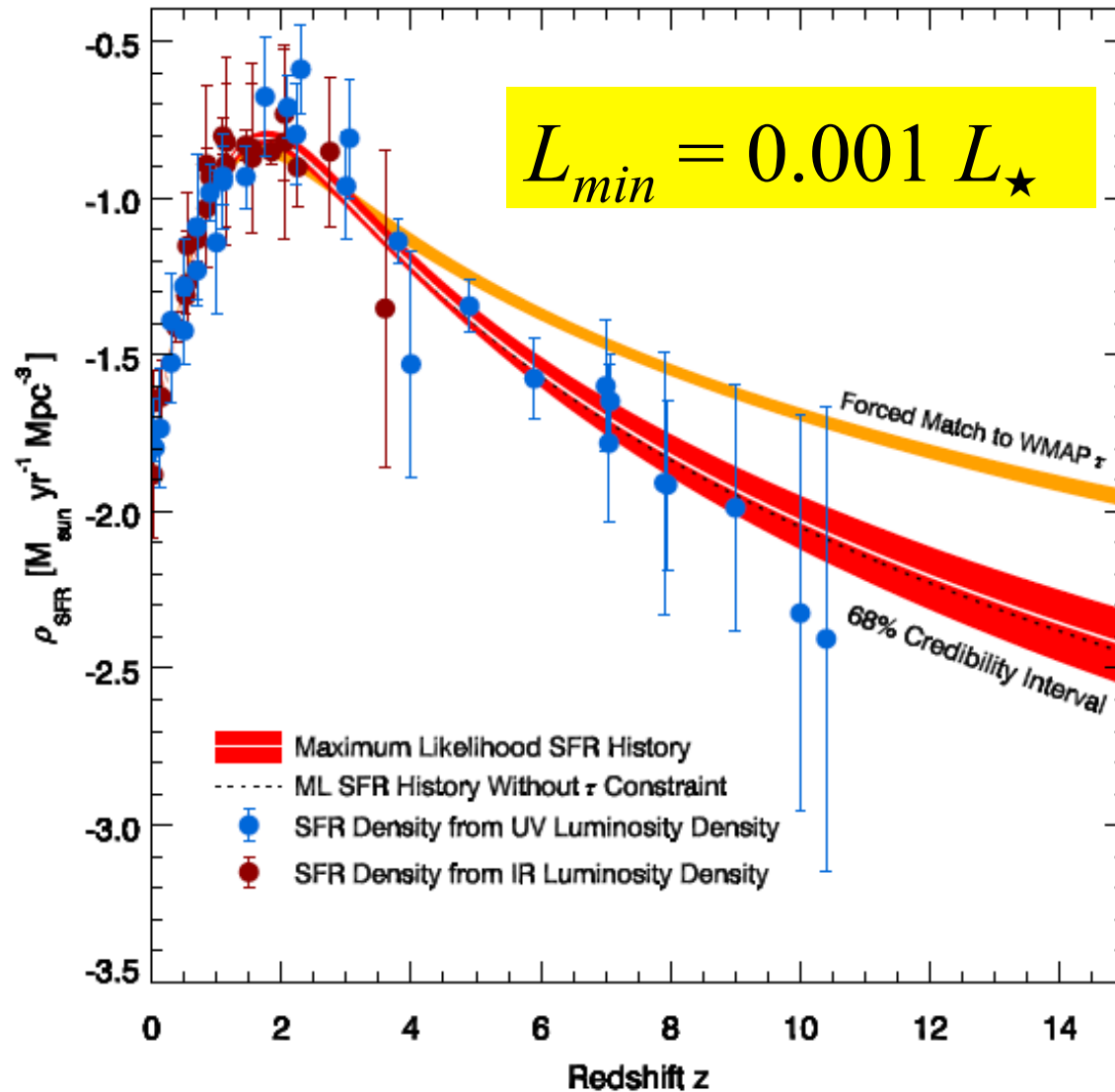


The world's largest radiotelescope



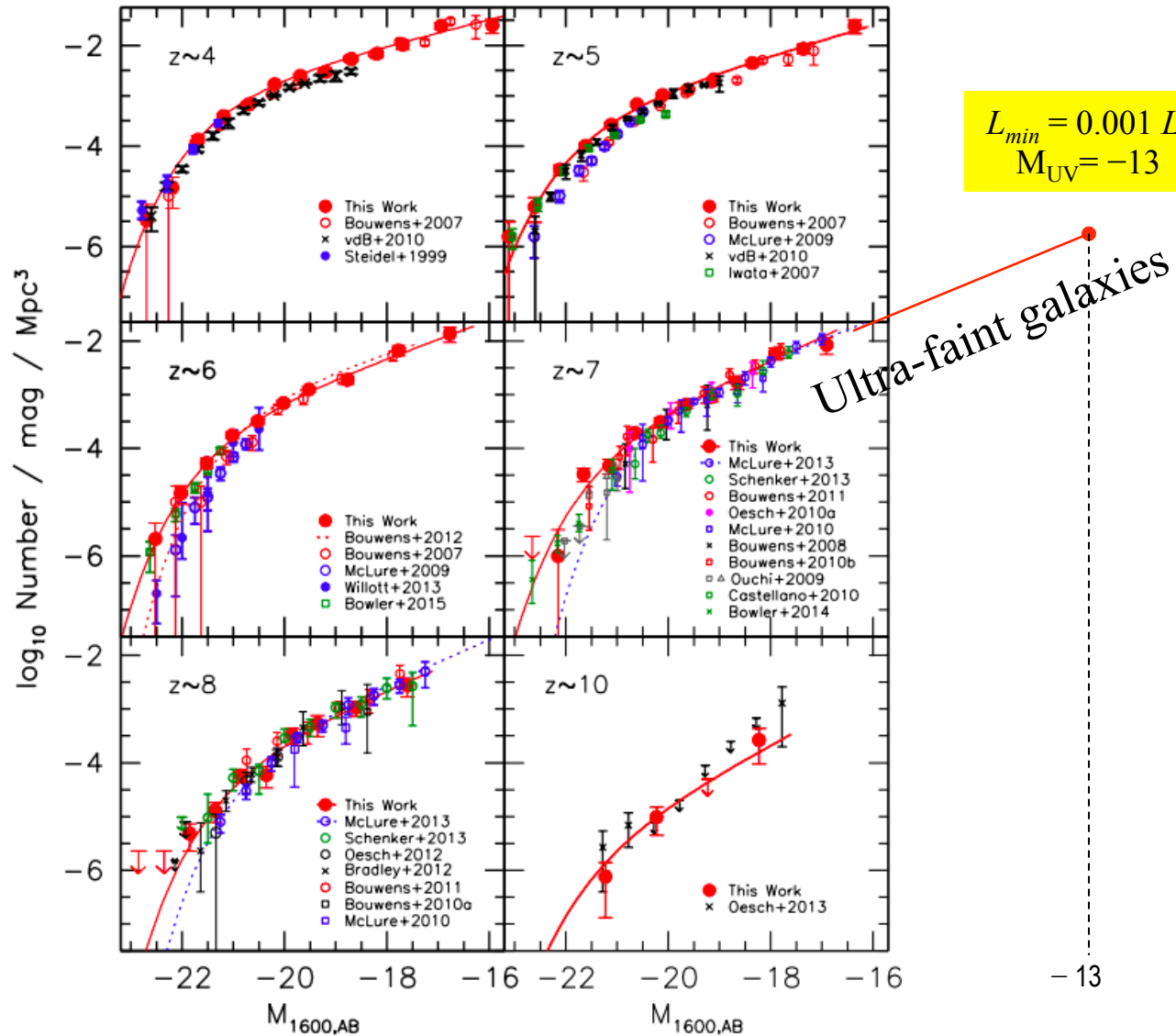
PLANCK POLARIZATION DATA



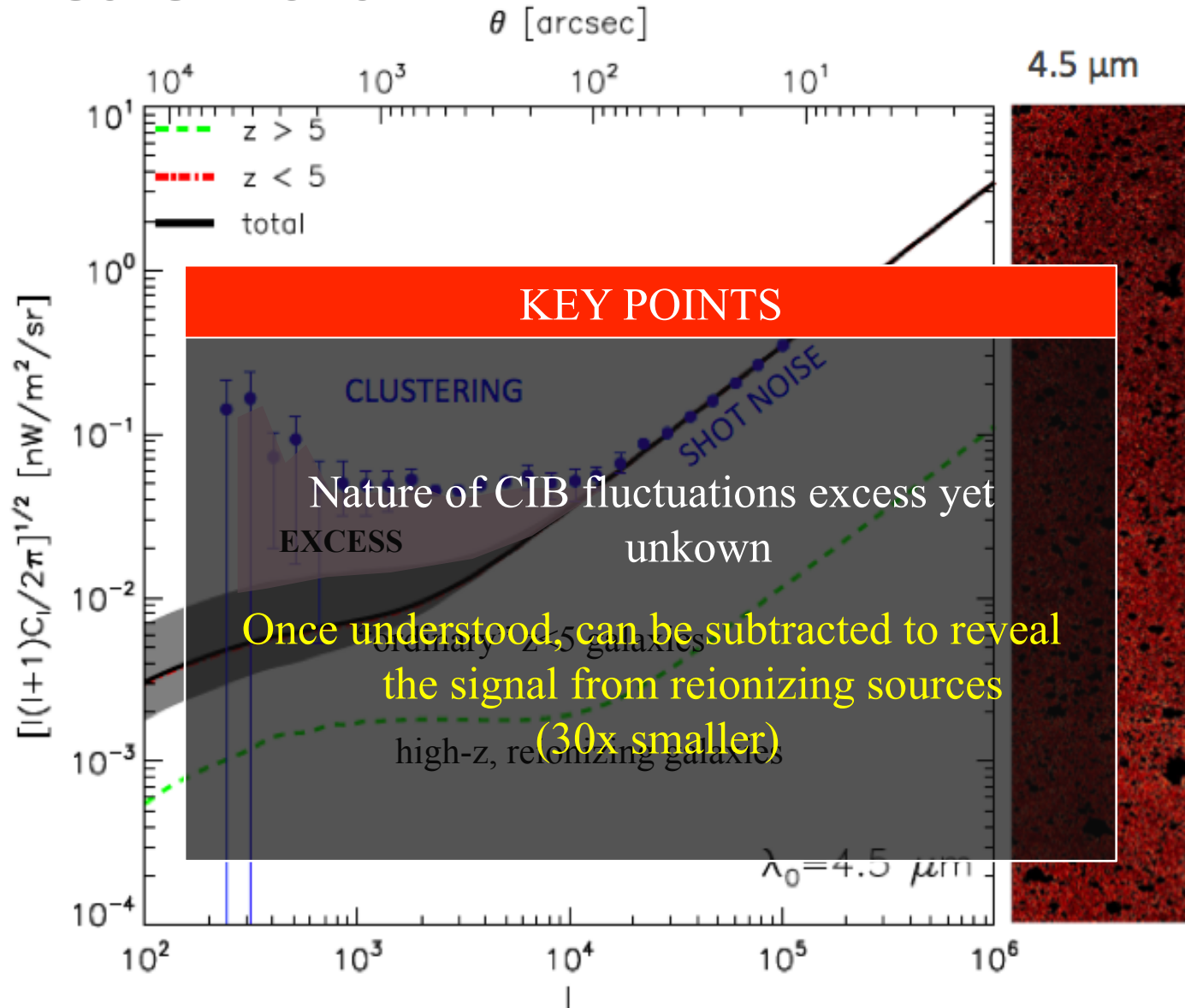


$$f_{\text{esc}} = 0.2$$

LUMINOSITY FUNCTIONS



CIB FLUCTUATIONS

Kashlinsky+12; Helgason+12; Yue+12

CIB-CXB CORRELATION

Chandra EGS/AEGIS field ($45' \times 8'$)



X-ray 0.5–2 keV count-rate map

BREAKING NEWS

X-ray 0.5–2 keV fluctuation map

Now independently confirmed by
Mitchell-Wynne et al., arXiv:1610.02015

X-ray 0.5–2 keV exposure map

IRAC 4.5 μ m fluctuation map

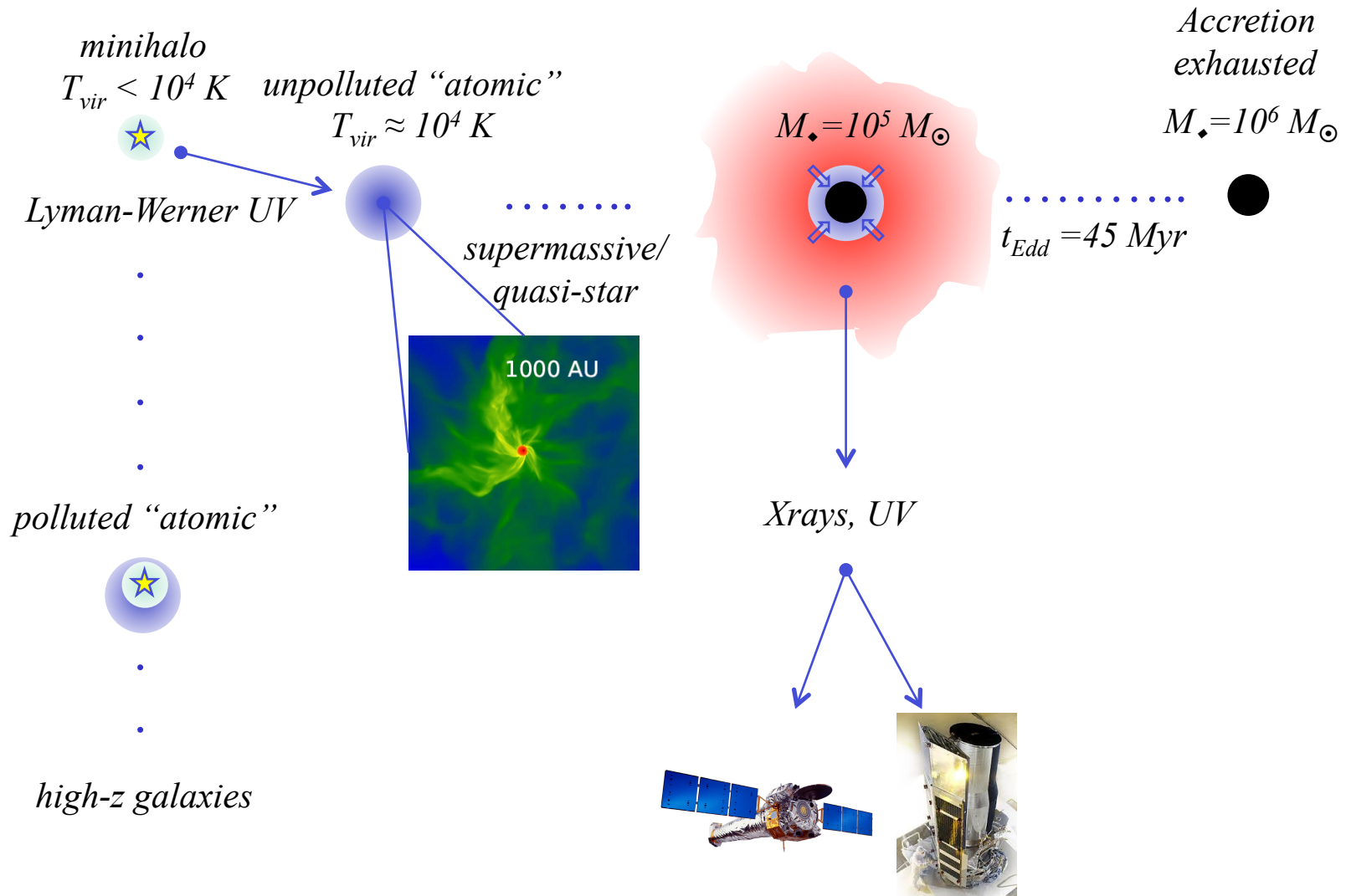
IRAC 4.5 μ m exposure map

A black hole is depicted as a dark, spherical object at the center. It is surrounded by a thick, glowing blue accretion disk that shows concentric rings of light. From the top and bottom of the black hole, bright blue jets of light and energy extend outwards into the surrounding space. The background is a dark, star-filled universe.

First Black Holes ?

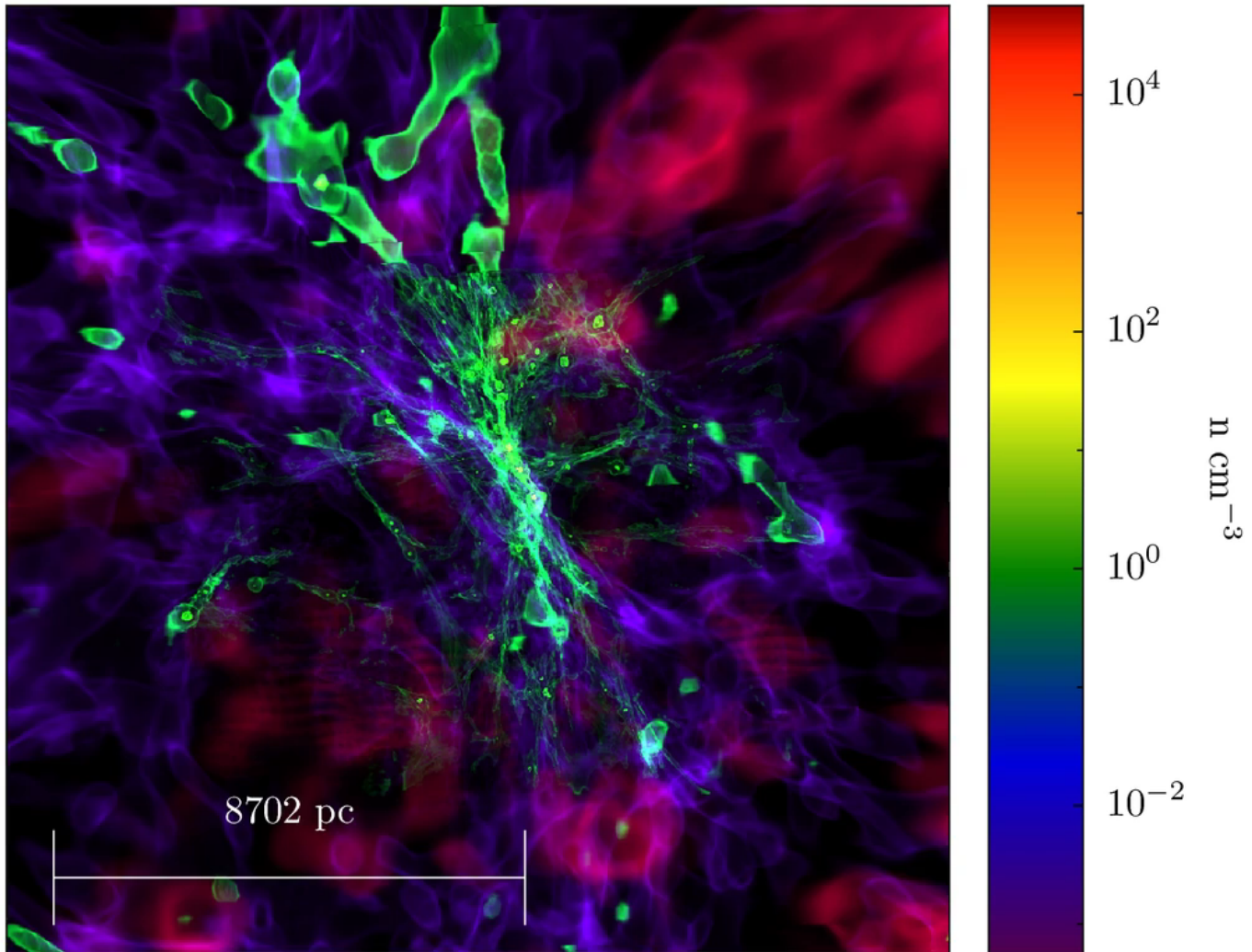
Yue, AF, Salvaterra, Xu, Chen 2013

FIRST BLACK HOLE ERA

BH ERA $z > 12$ 

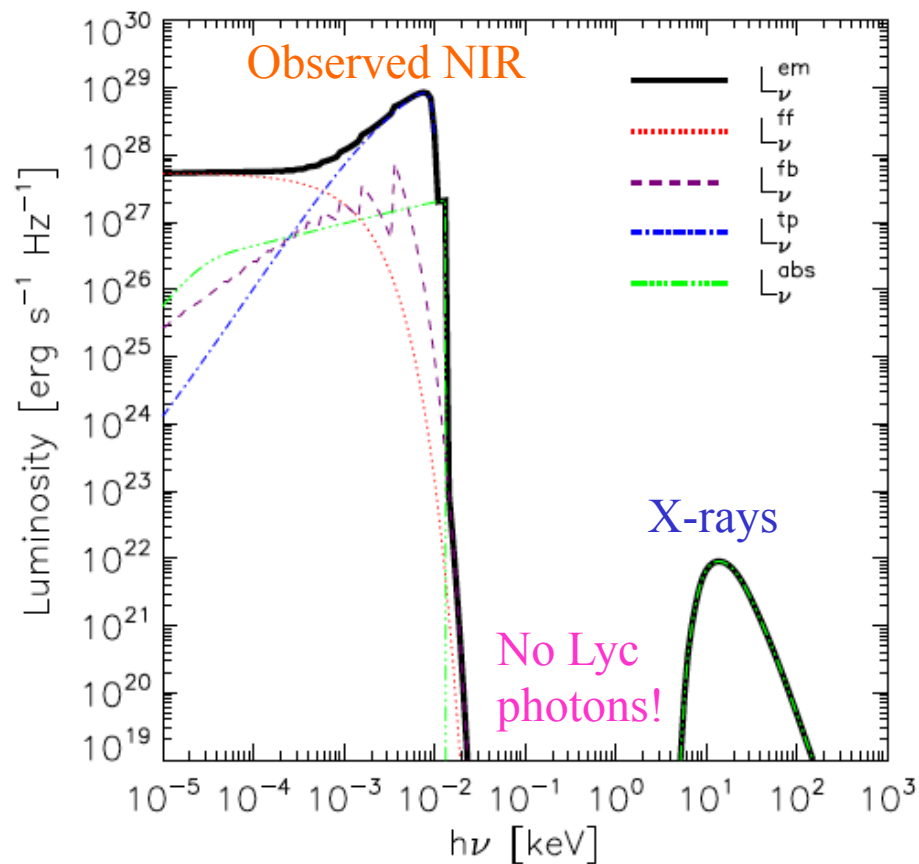
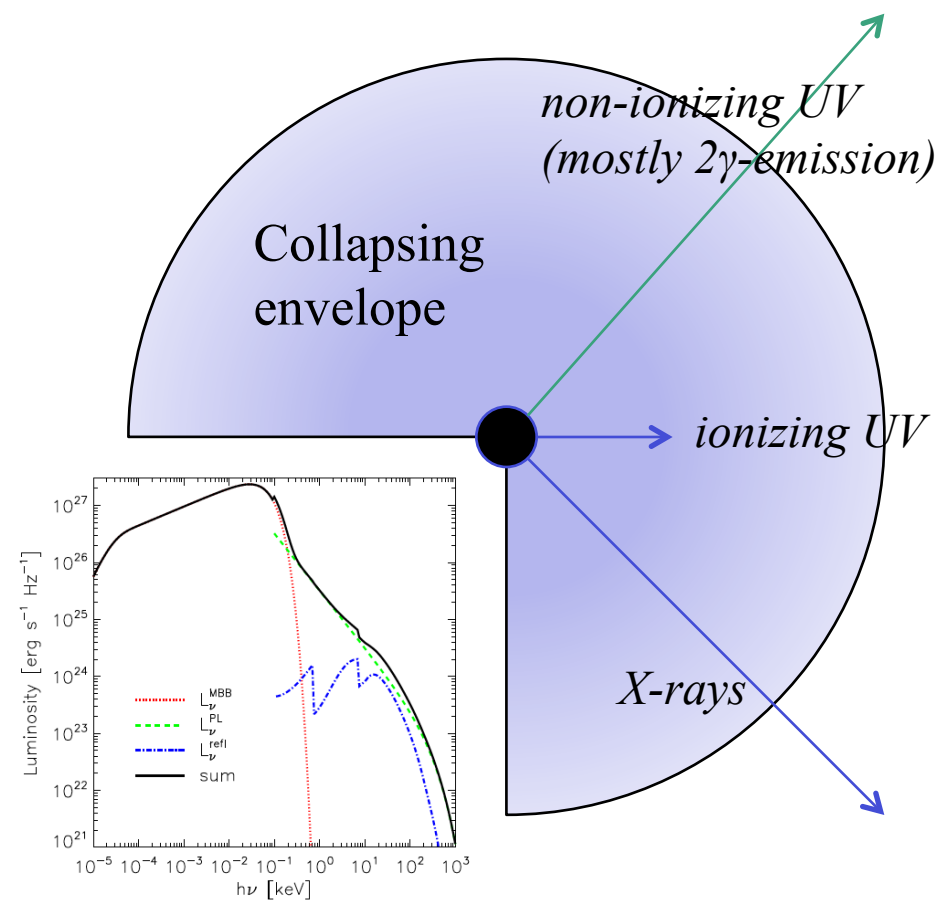
DCBH FORMATION

Courtesy: C. Regan, Univ. of Helsinki



ABSORBED SPECTRUM

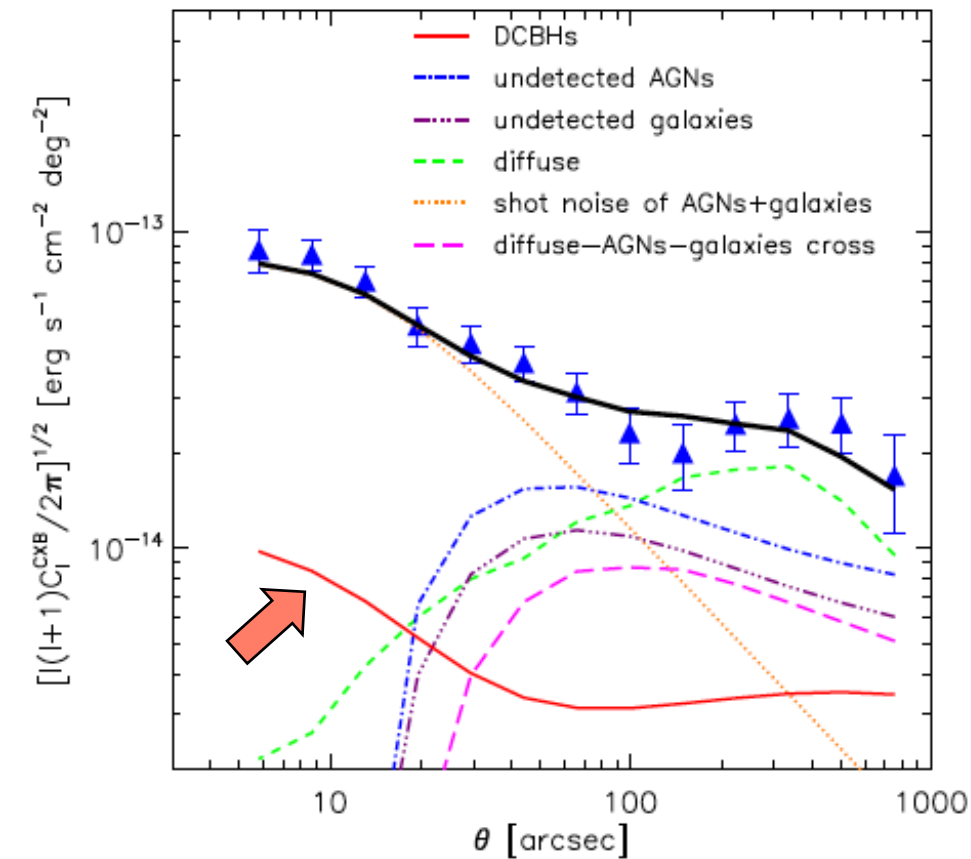
$N_H = 1.5 \times 10^{25} \text{ cm}^{-2}$
(Compton thick)



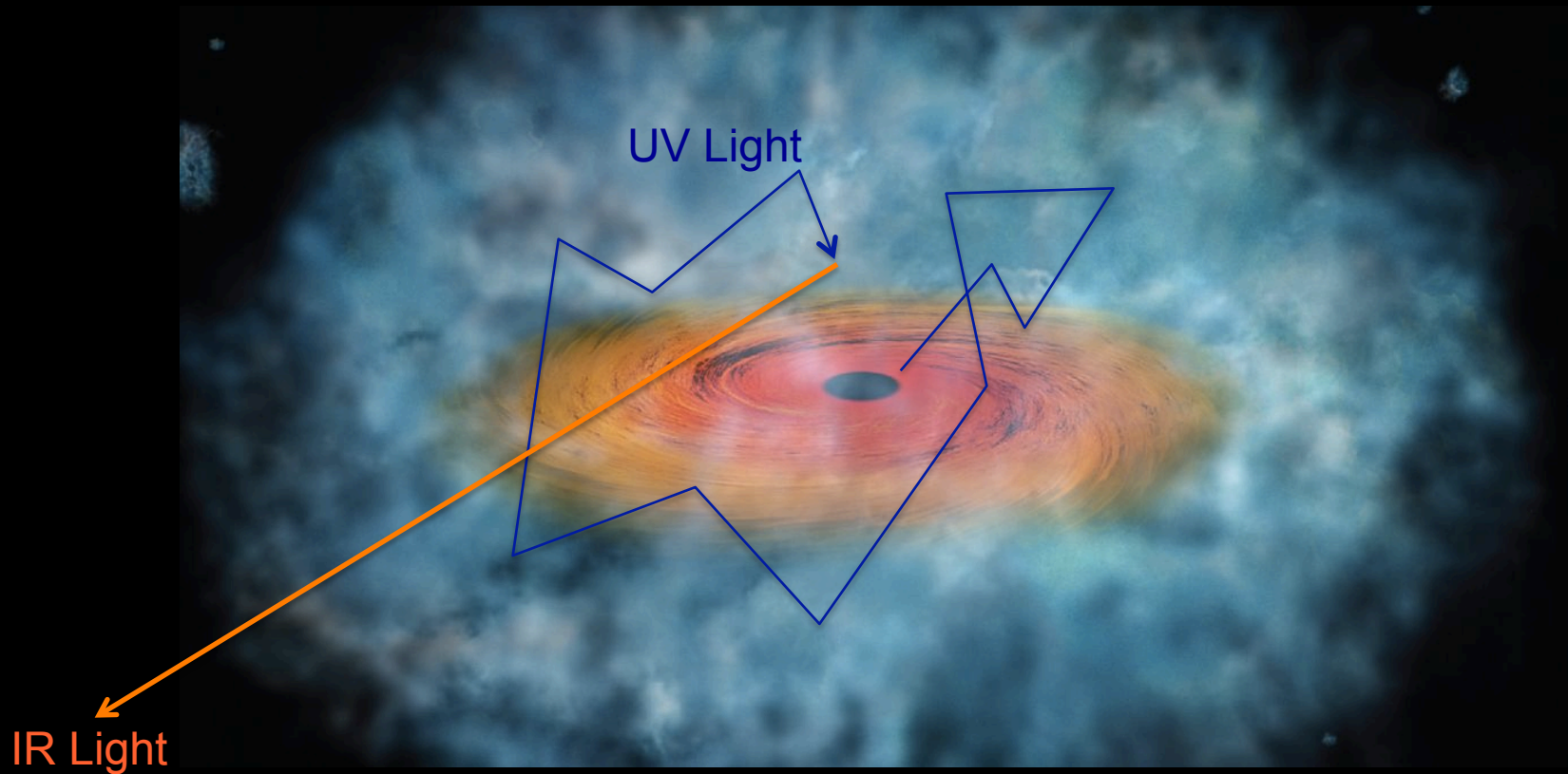
$M_{\bullet} = 10^6 M_{\odot}$
(Direct collapse black hole)

SEEDS EXPLAIN CIB-CXB CORRELATION

CXB Power spectrum

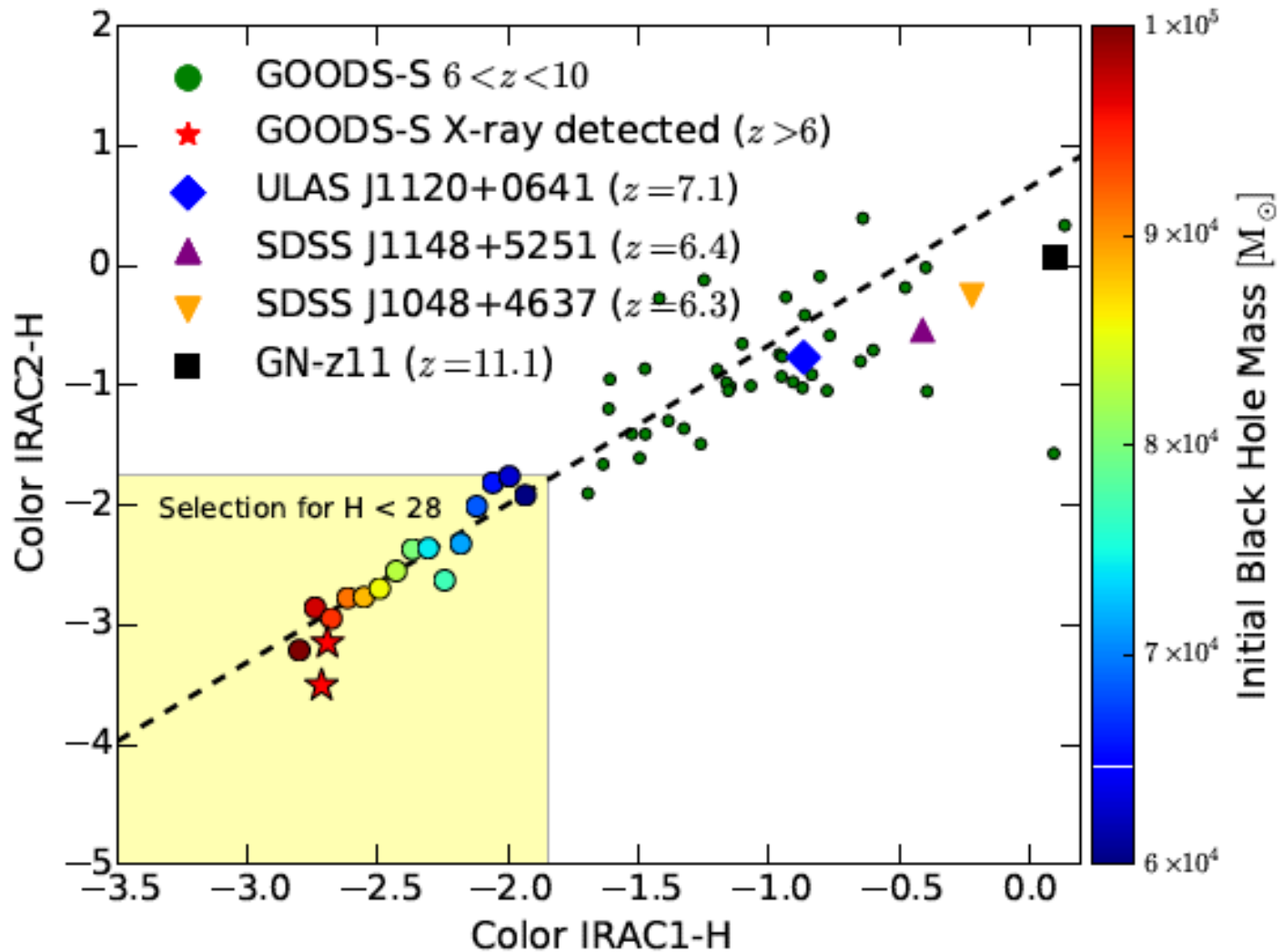


A growing DCBH

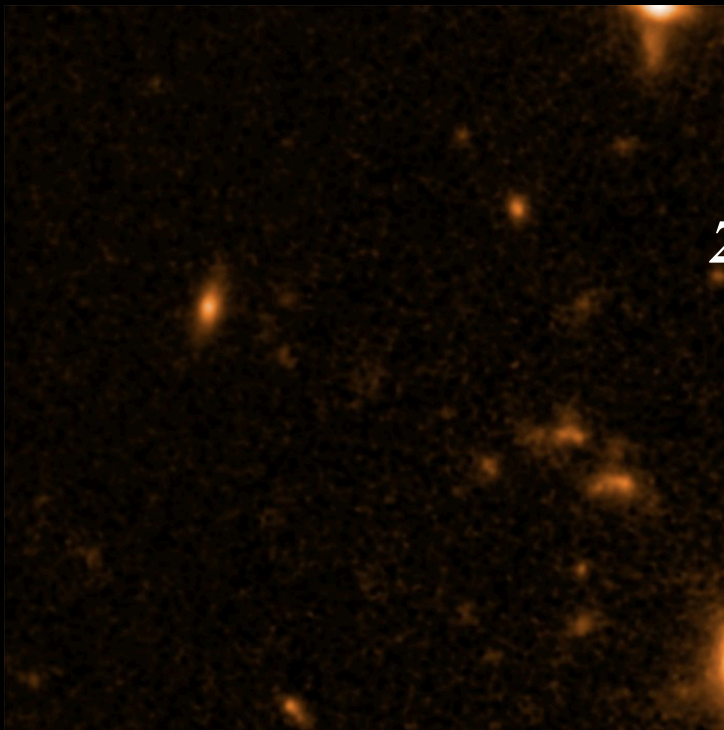


DCBH ACCRETING ITS PARENT HALO GAS

SELECTING DCBH BY COLORS

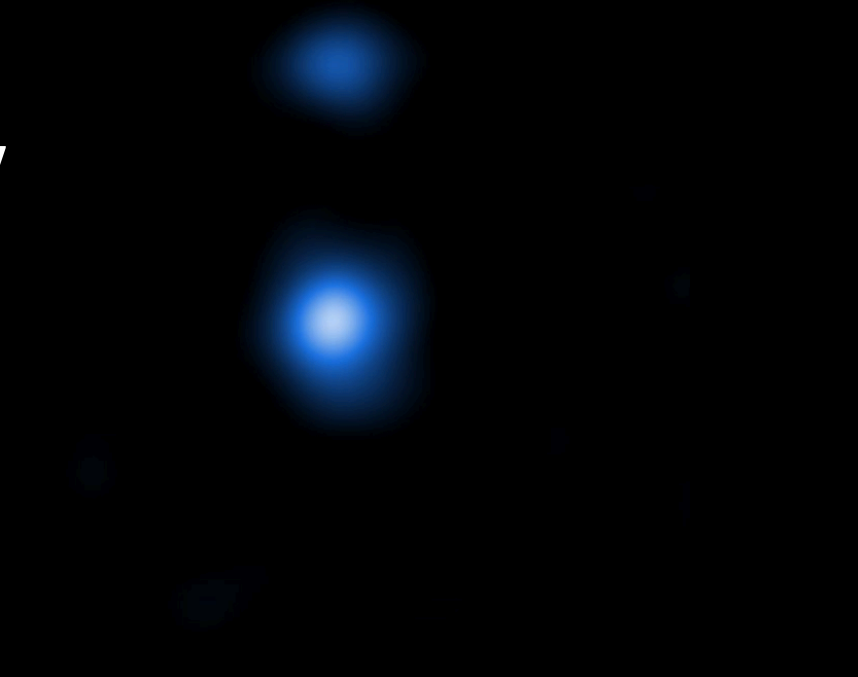


Do DCBHs exist? Yes!



H-band Image
(Hubble Space Telescope)

$z = 9.7$



X-ray Image
(Chandra Space Telescope)

hubble



Pacucci+16

ESA SCIENCE

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• SM 3A



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ASTRONOMIA

Gli antenati

Un gruppo di ast

"semi" dei primi

di Giulia Bonelli

Esiste una vecchia

quella apparten

celesti del cielo

il Big Bang. Co

scienziati non e

risposta; fino a

astronomi ital

di quelli che po

"semi" dei buchi

Lo Scienzo

LA RIVISTA IN EDIZIONE

Il nostro post

La Via Lattea è solo
in uno dei più arca

la Repubblica

Quotidiano

Data 25-05-2016

Pagina 1+27

Foglio 1 / 3

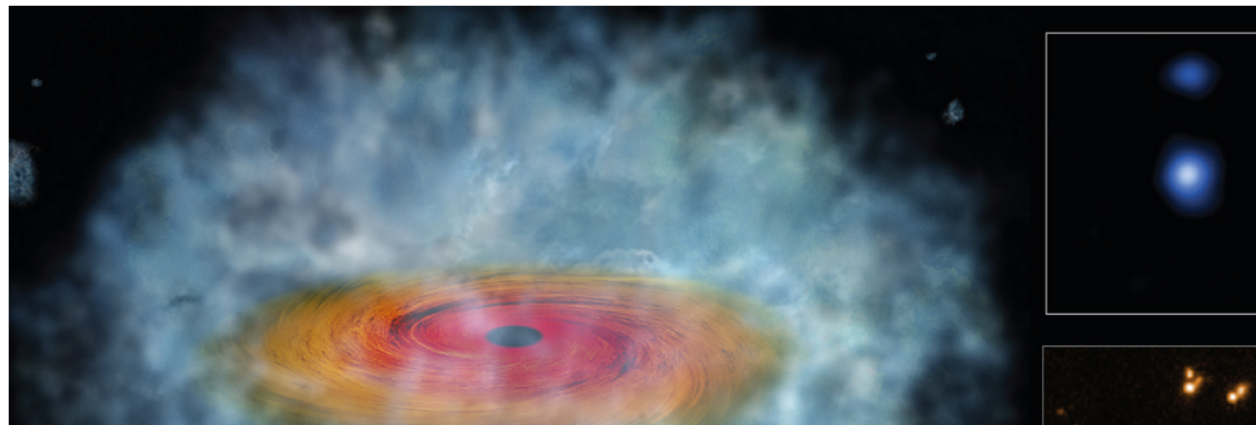
Il r
L'ul
il tel



Jet Propulsion Laboratory
California Institute of Technology

NEWS | MAY 24, 2016

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



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25 maggio 2016

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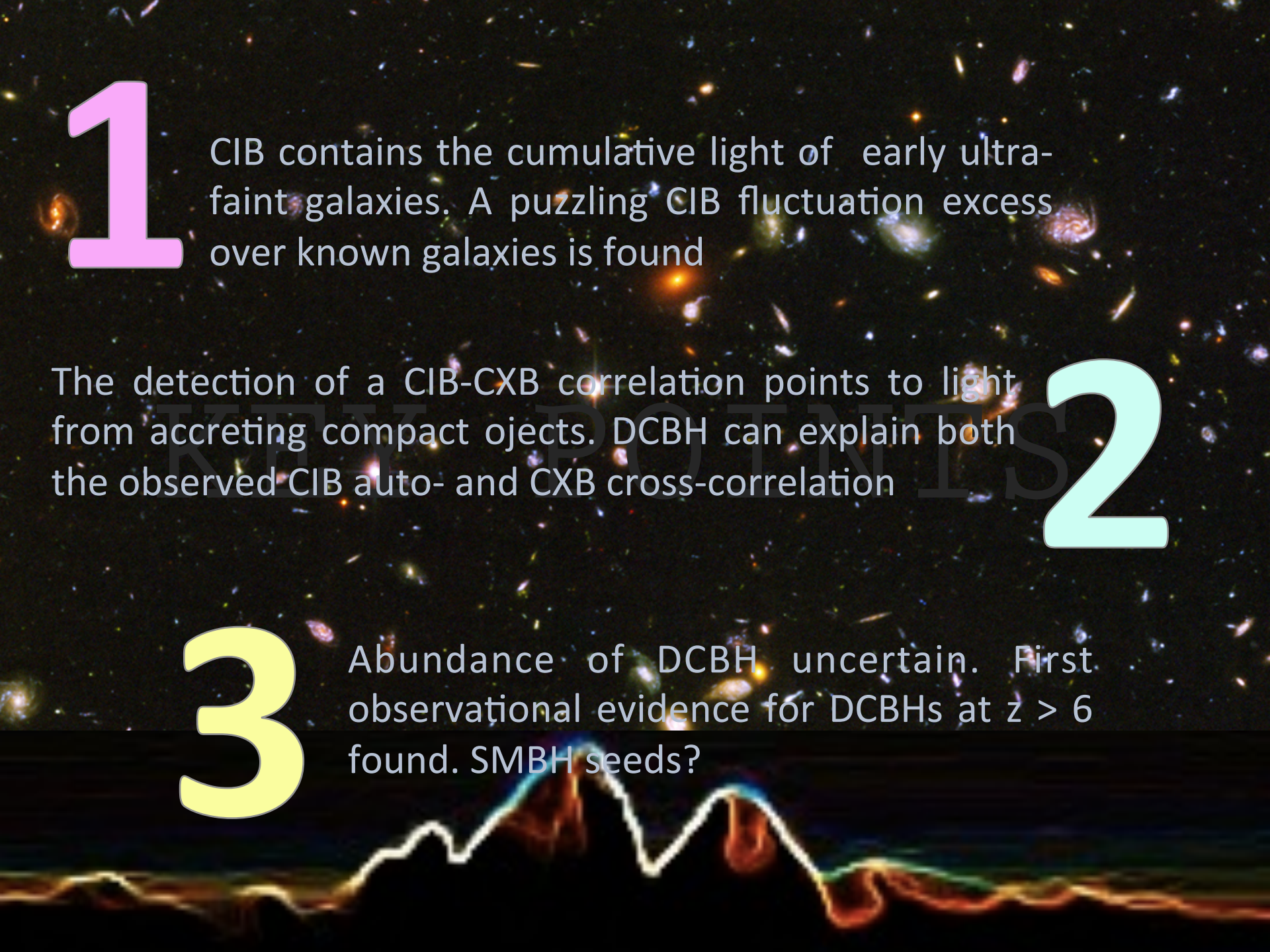
Consiglia

G+1 9

SULLO STESSO

DAL SITO



The background of the slide is a deep space image filled with numerous galaxies of various shapes and colors, including spirals, ellipticals, and irregulars. At the bottom of the slide, there is a horizontal strip showing a spectral energy distribution (SED) plot. The plot features a white line with several peaks and troughs, overlaid on a colorful gradient that transitions from blue on the left to red on the right, representing different wavelengths of light.

1

CIB contains the cumulative light of early ultra-faint galaxies. A puzzling CIB fluctuation excess over known galaxies is found

The detection of a CIB-CXB correlation points to light from accreting compact objects. 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?