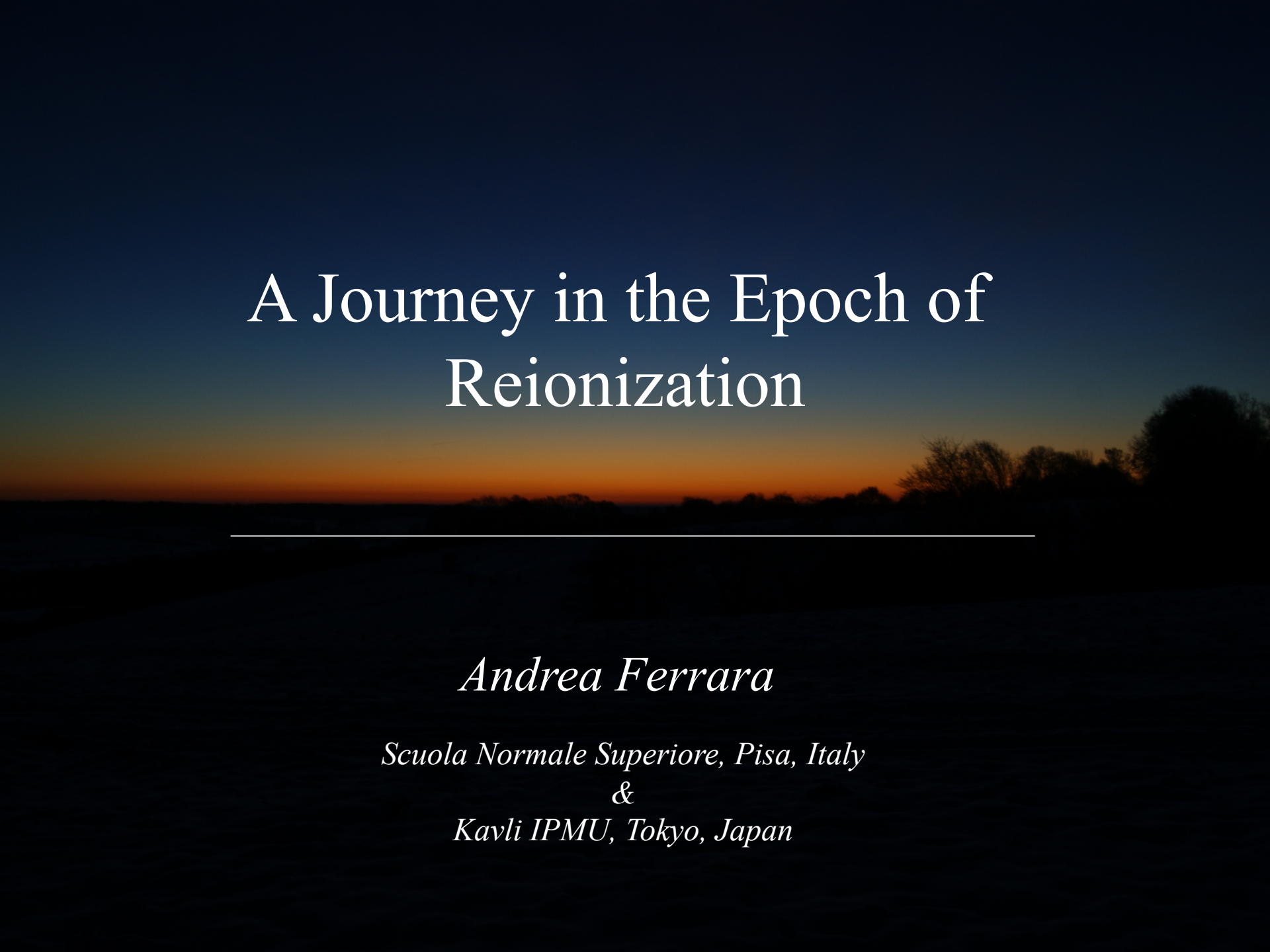


A Journey in the Epoch of Reionization

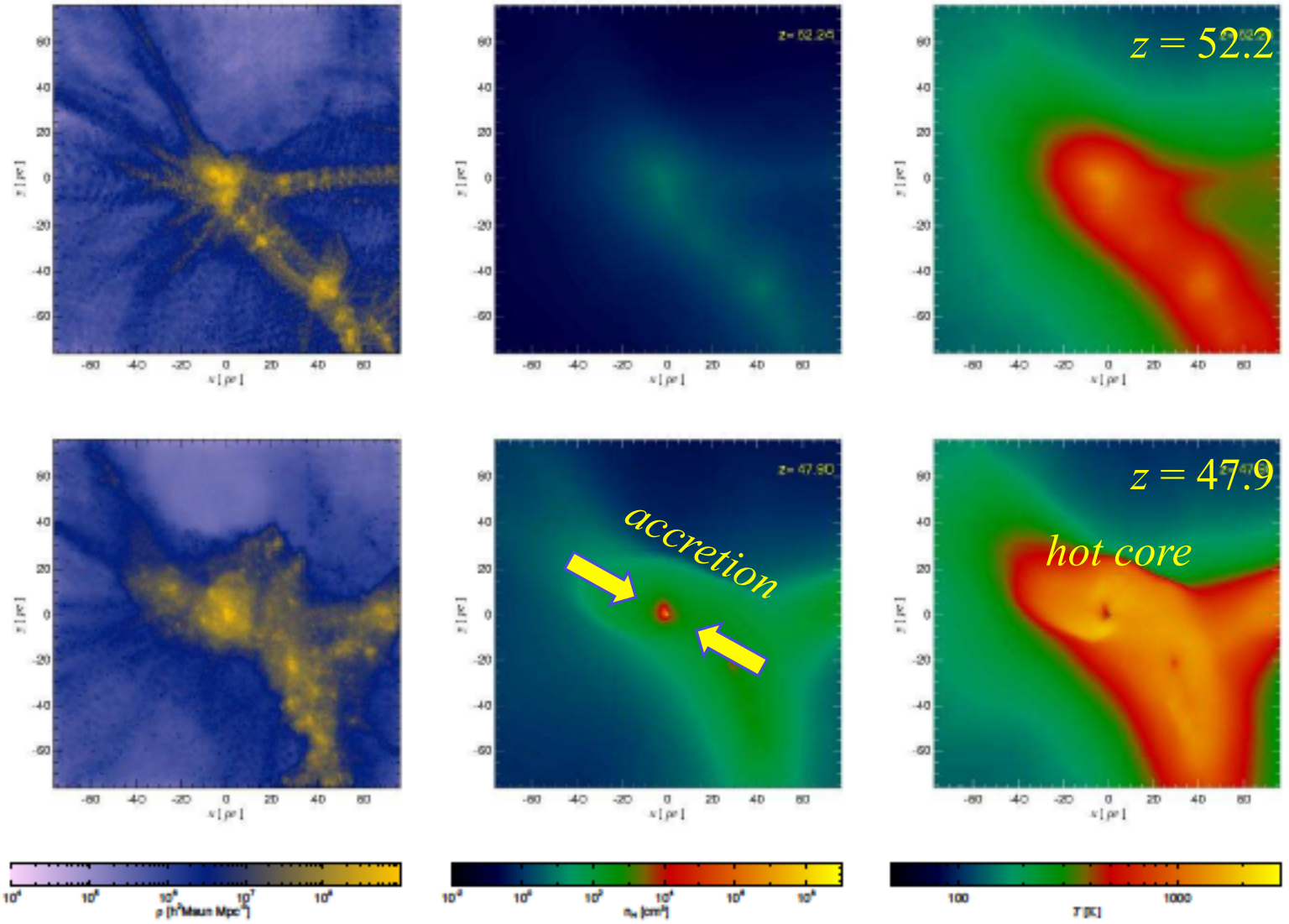
Andrea Ferrara

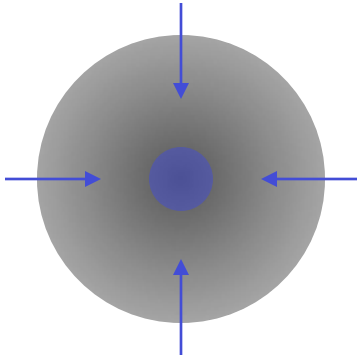
Scuola Normale Superiore, Pisa, Italy
&
Kavli IPMU, Tokyo, Japan

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

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

$$dM/dt \approx M_J / t_{ff} \propto \lambda_J \rho / t_{ff} \propto c_s^3 / G$$

Numerical estimate

$$dM/dt \approx 4.4 \times 10^{-3}\ M_\odot\ yr^{-1} \quad (T = 300\ K)$$

KEY POINTS

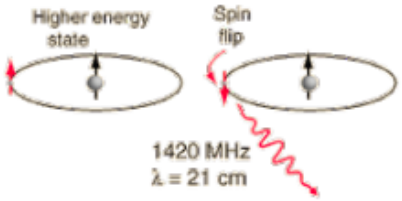
It takes only 70,000 years to build a 300 $M_\odot$ star

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



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

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

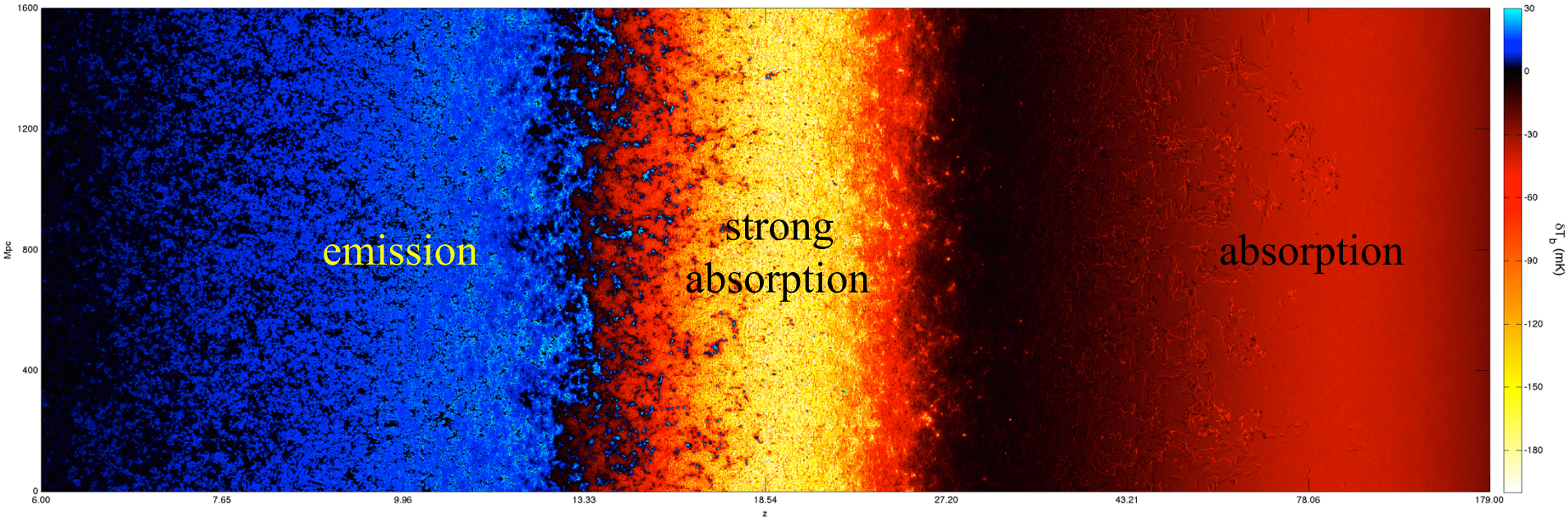
$$\delta T_b = \frac{T_S - T_\gamma}{1+z}\,\tau$$

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

Mesinger, AF & Spiegel 2013; Pacucci+14

HI 21CM LINE VIEW

Brightness Temperature Evolution



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***

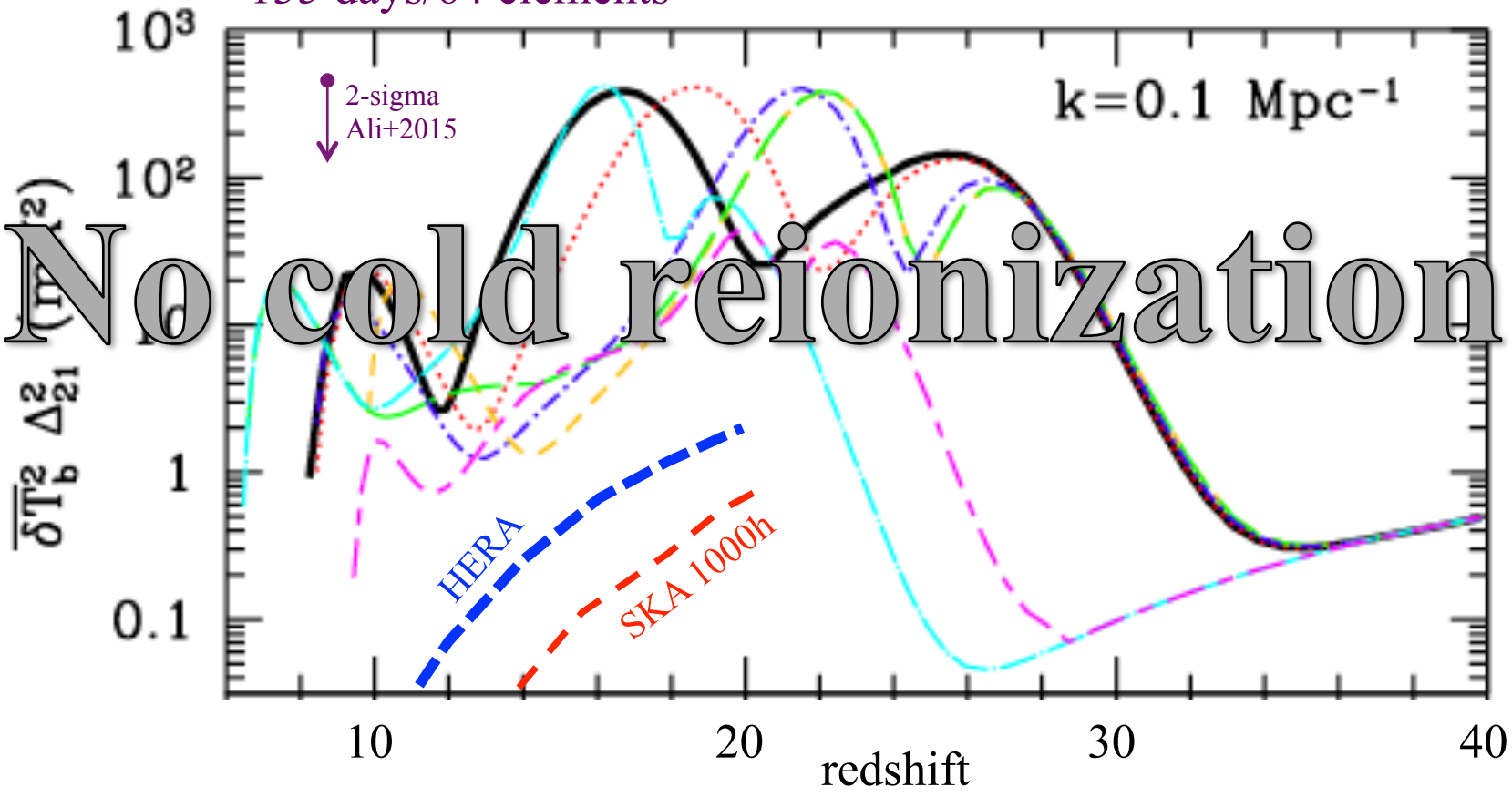
Dark Ages

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

Mesinger, AF & Spiegel 2013

21CM POWER SPECTRUM

PAPER-64 RESULT
135 days/64 elements



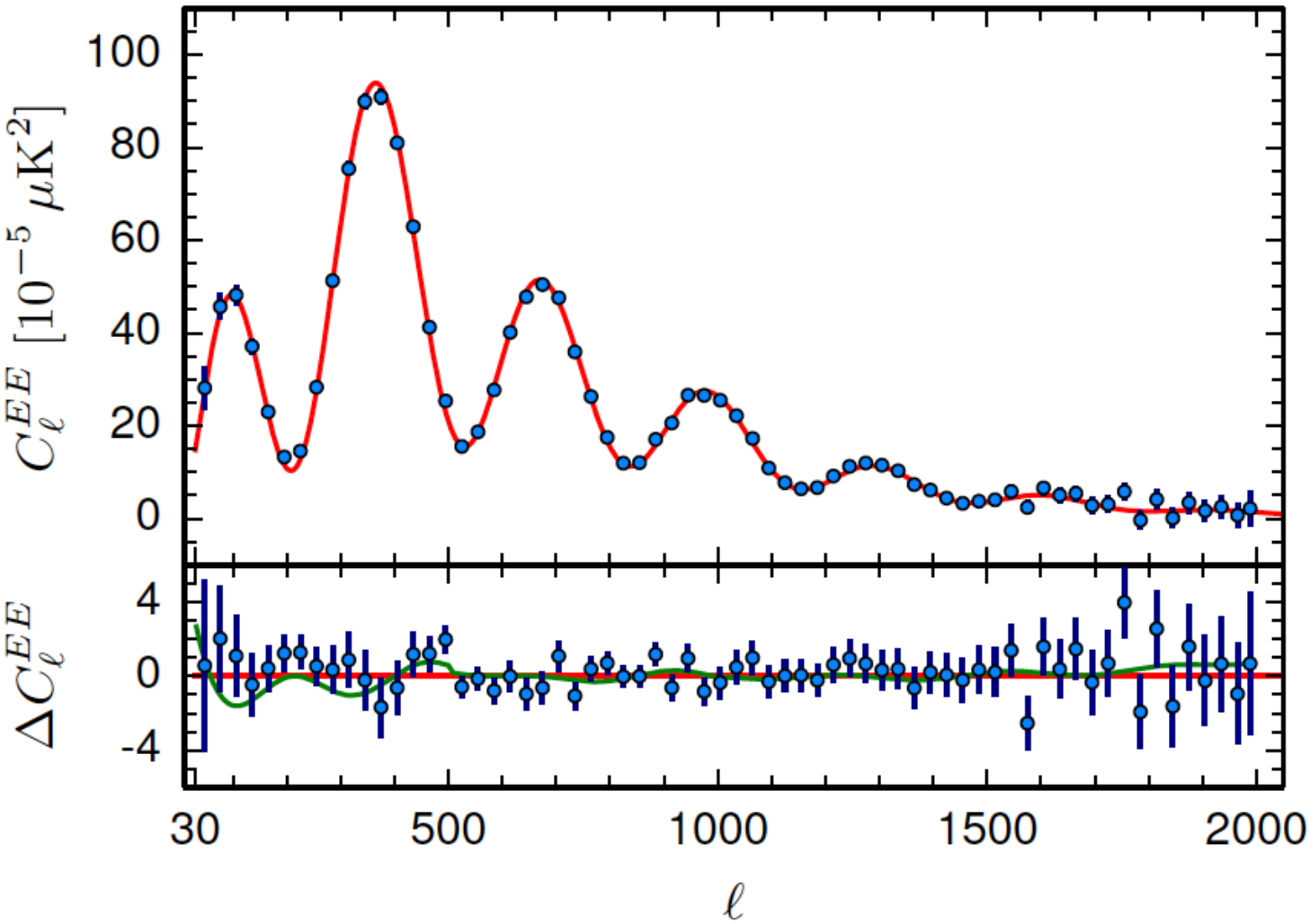
No cold reionization

Diving in a hydrogen sea

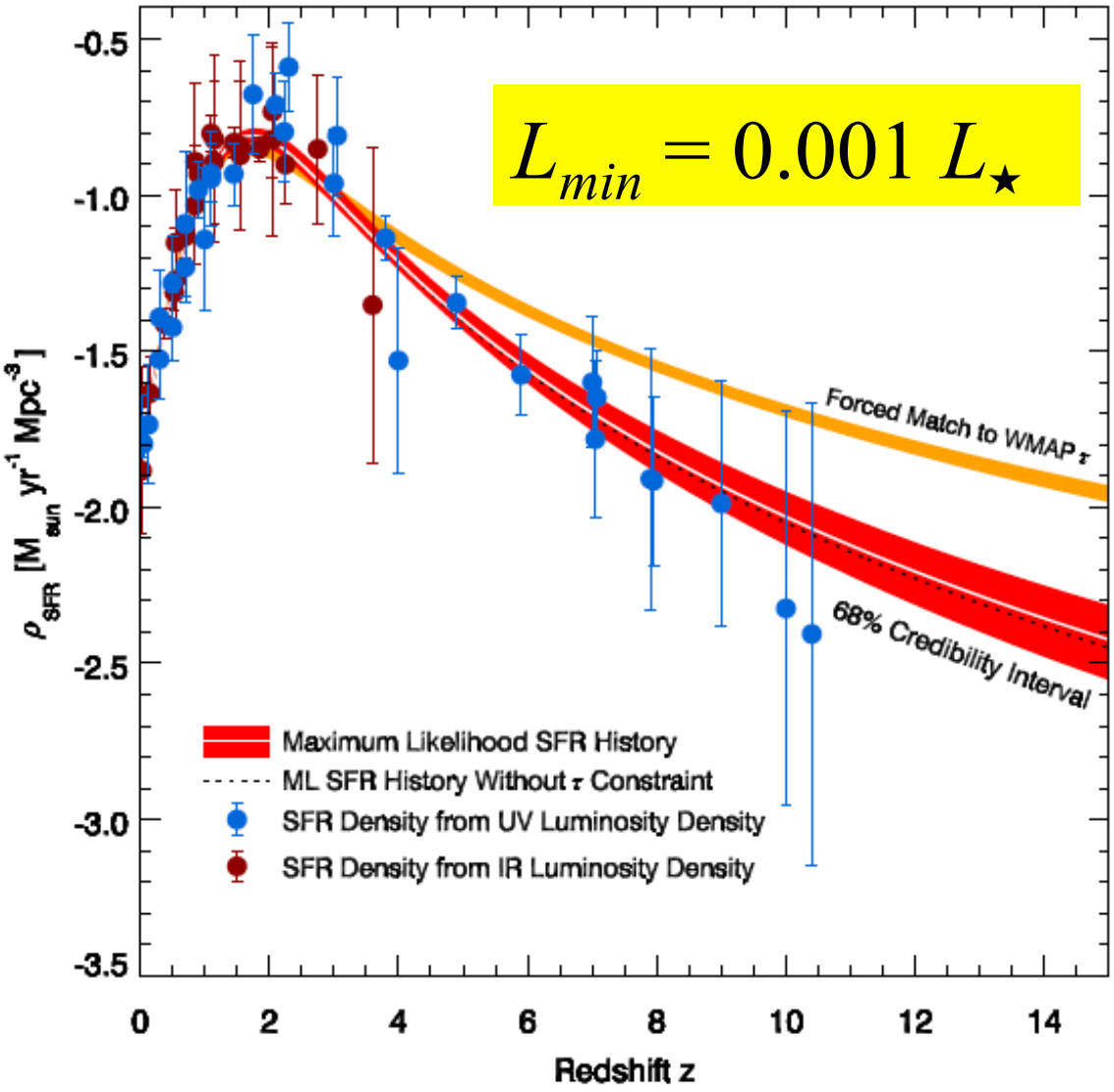
The world's largest radiotelescope

Planck Collaboration 15

PLANCK POLARIZATION DATA



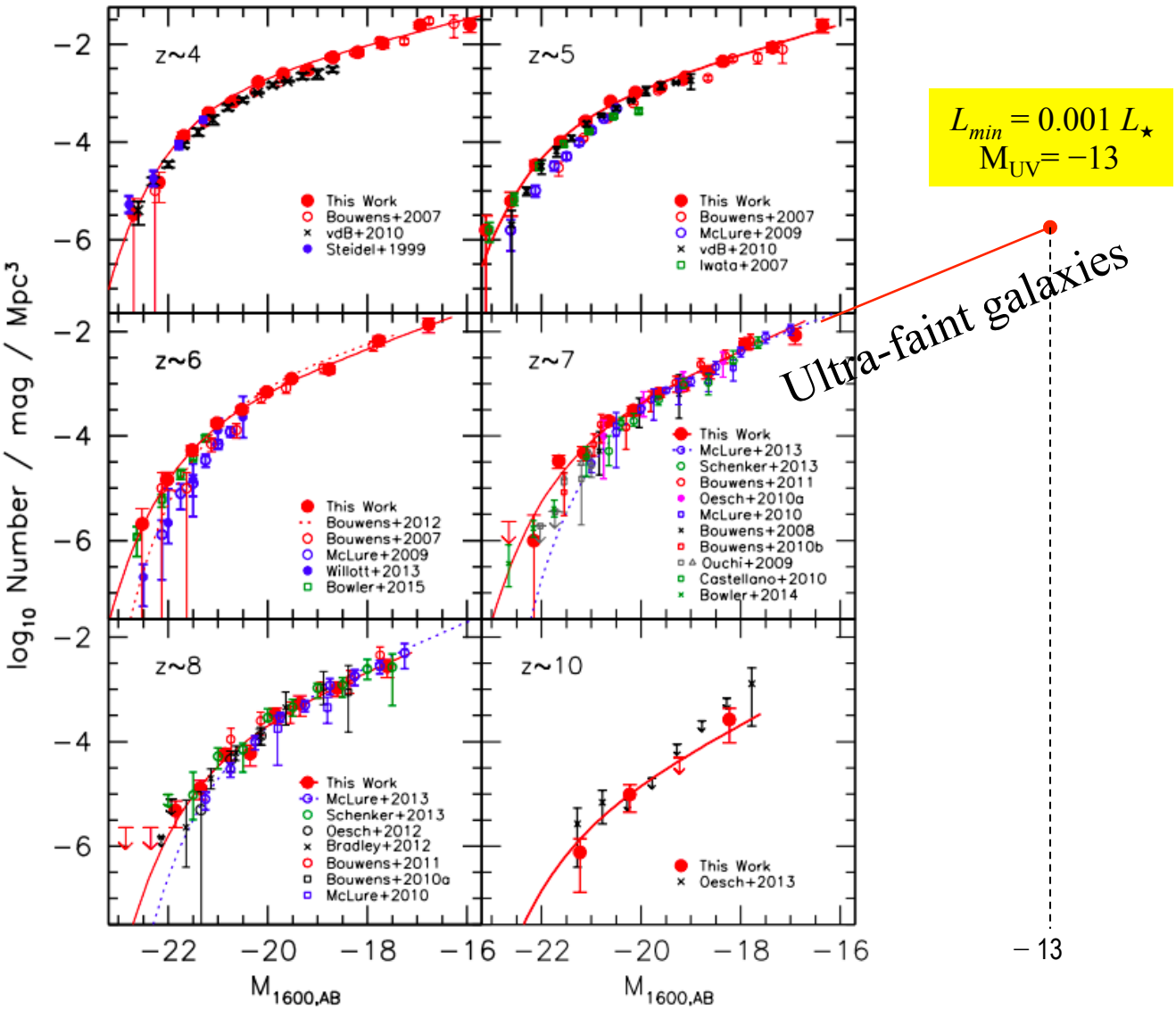
Robertson+15



$f_{esc} = 0.2$

LUMINOSITY FUNCTIONS

Salvaterra+11, Bouwens+14



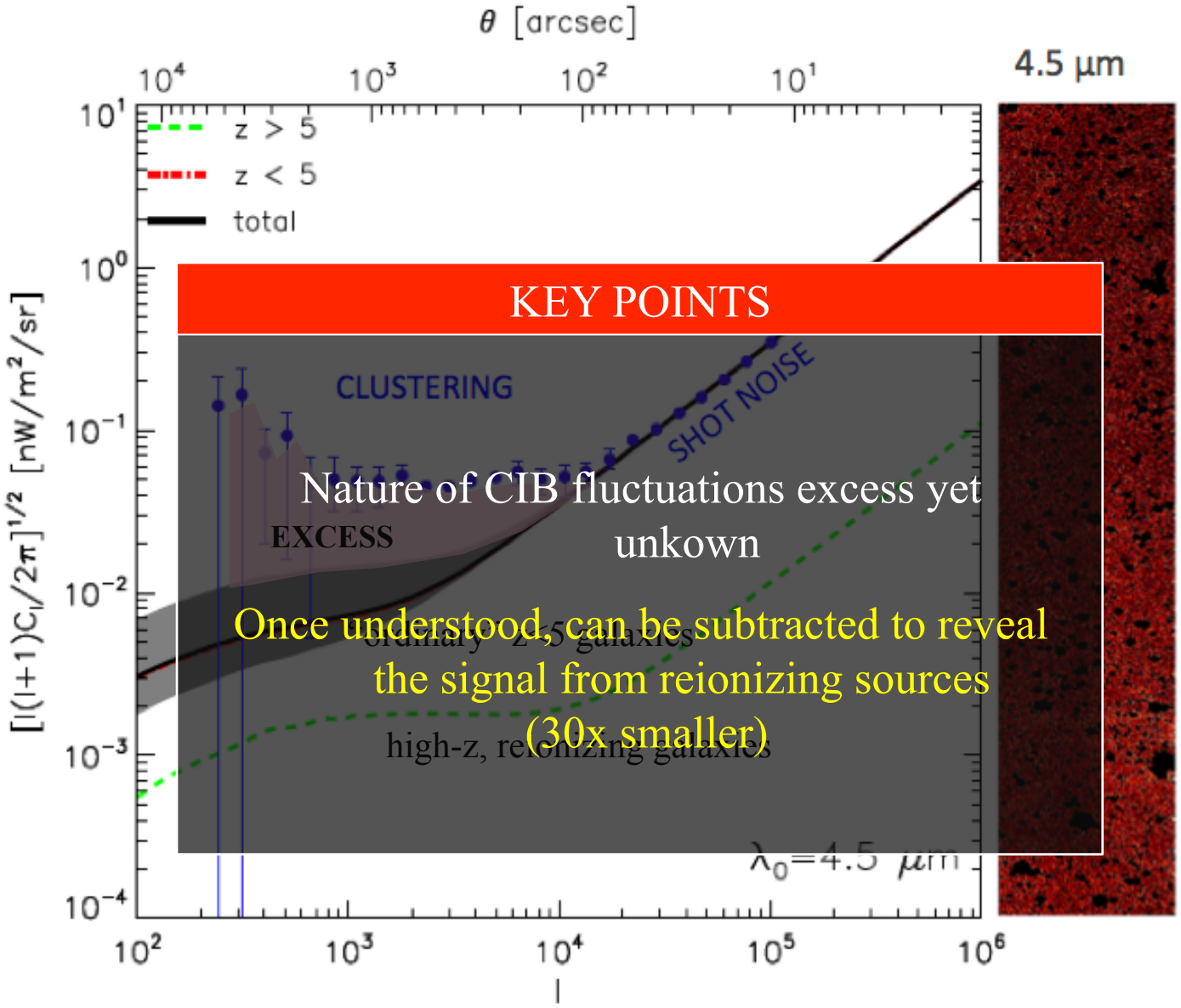
$L_{min} = 0.001\ L_{\star}$
$M_{UV} = -13$

Ultra-faint galaxies

−13

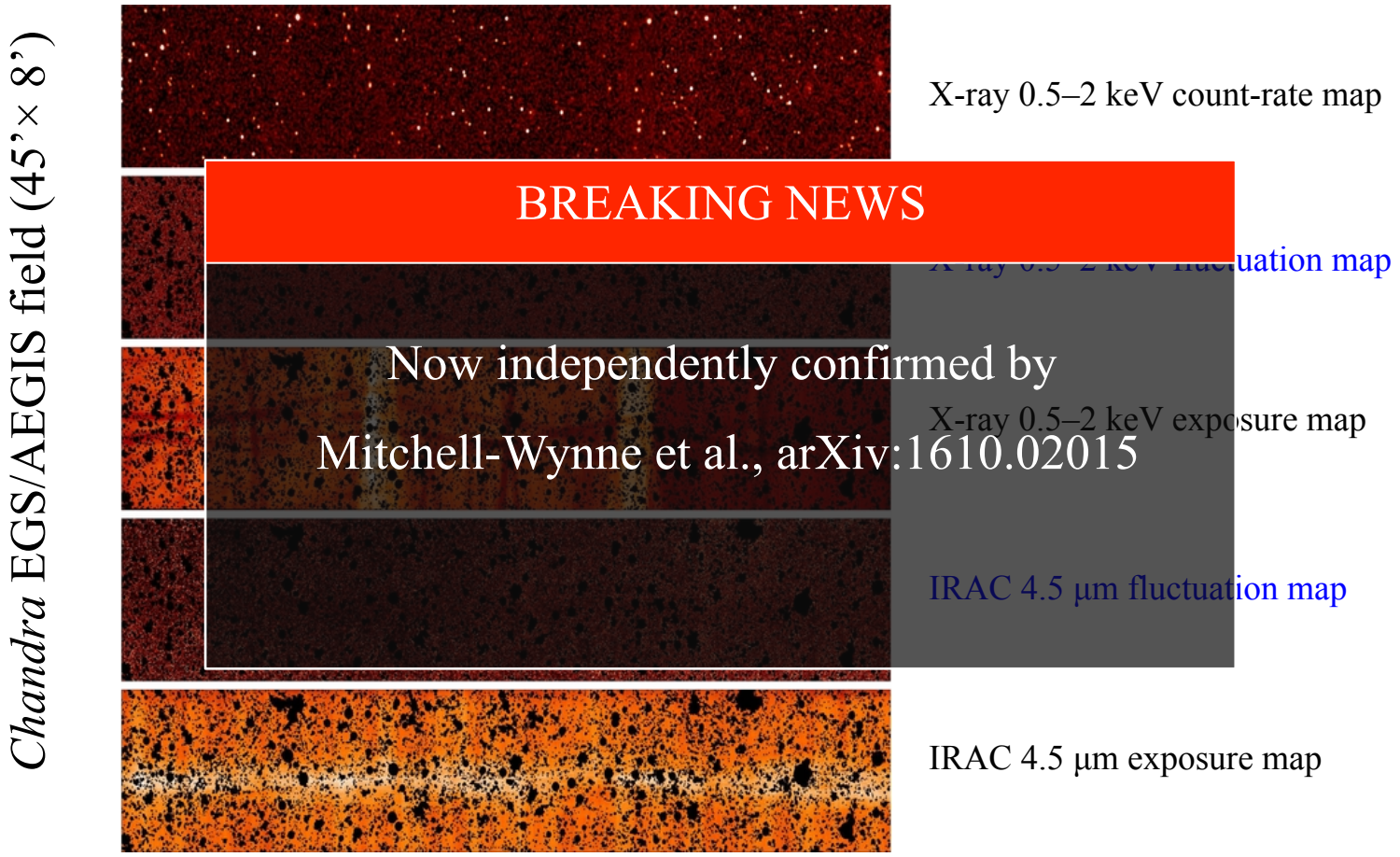
CIB FLUCTUATIONS

Kashlinsky+12; Helgason+12; Yue+12



Cappelluti+12

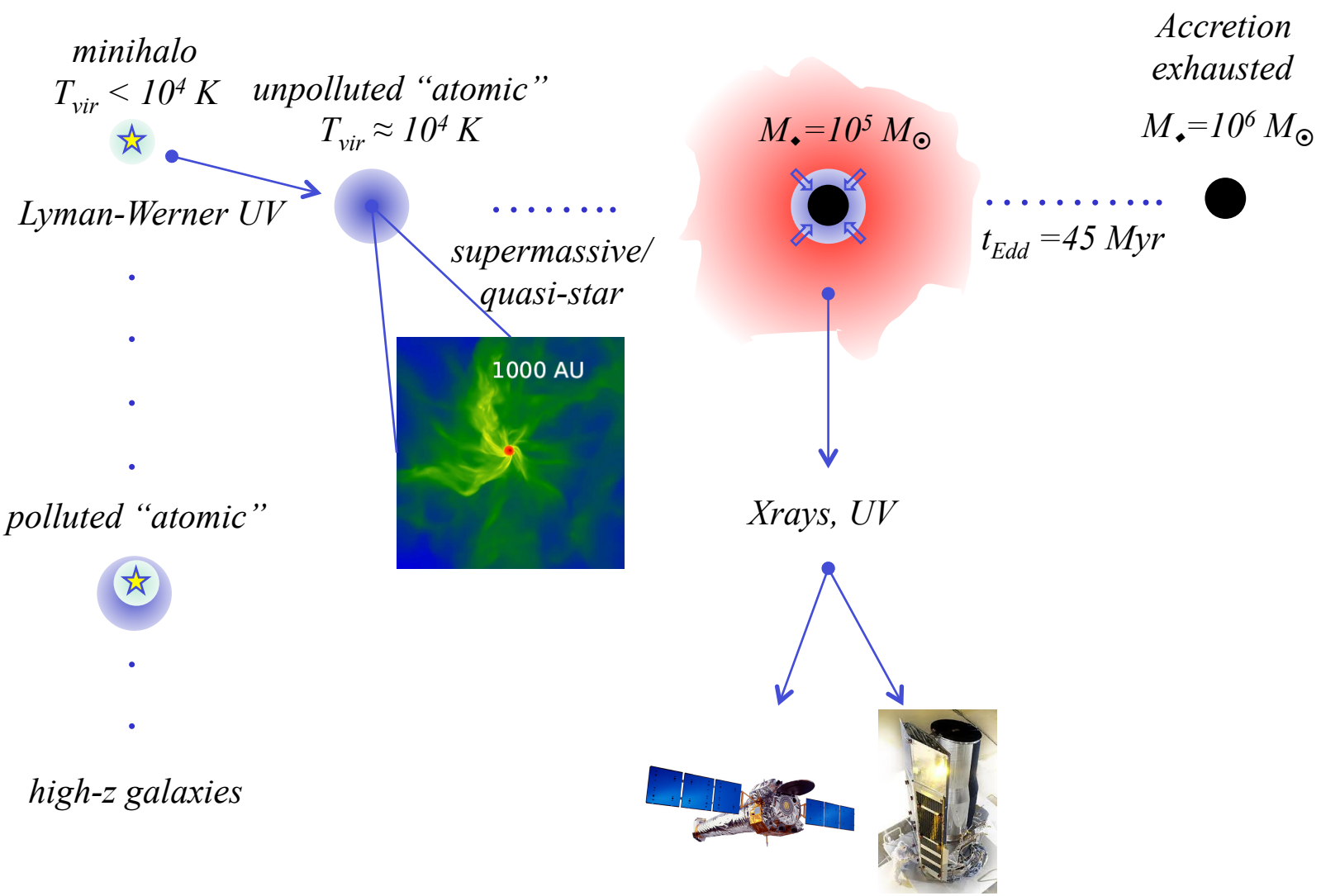
CIB-CXB CORRELATION



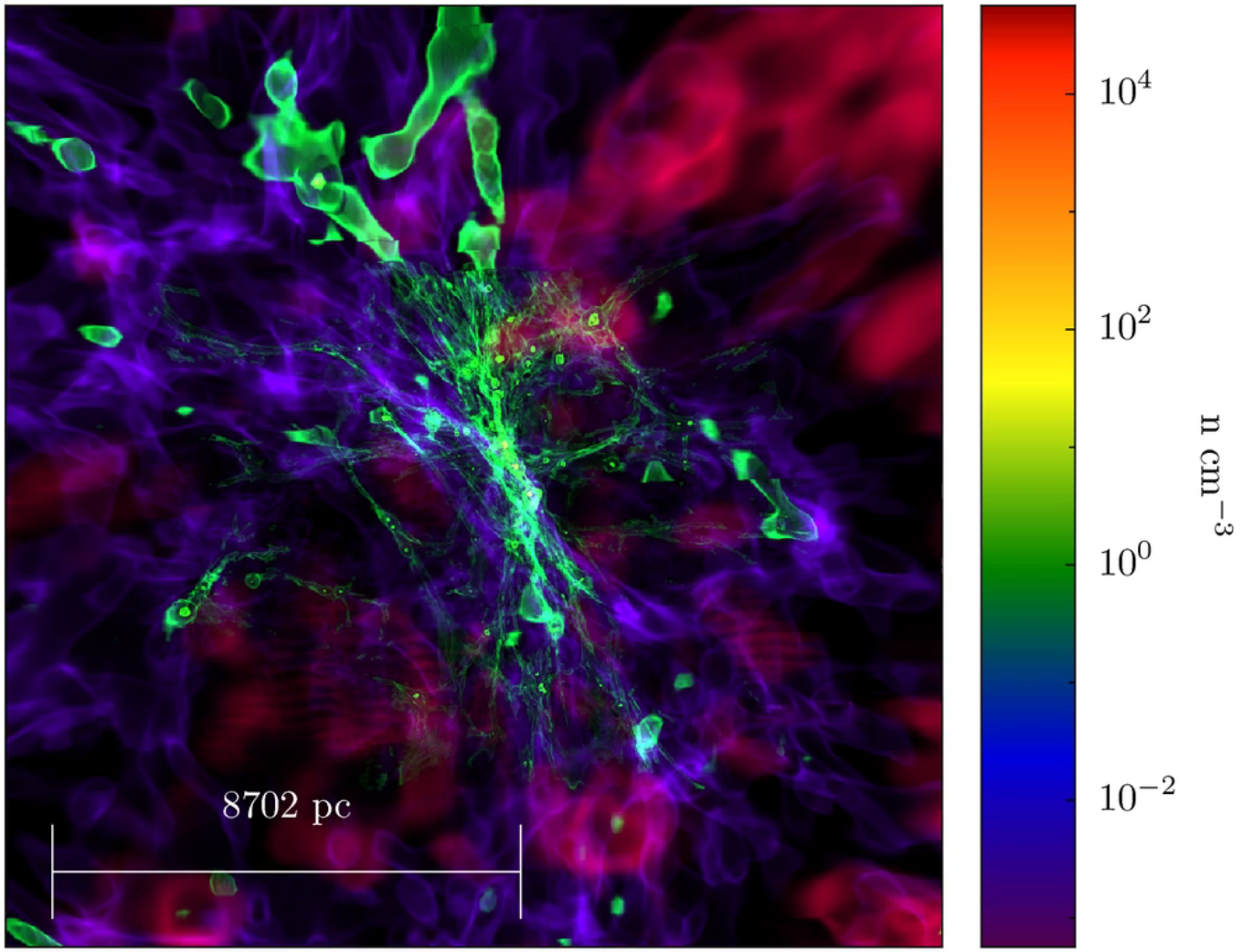

First Black Holes ?

Yue, AF, Salvaterra, Xu, Chen 2013

FIRST BLACK HOLE ERA



DCBH FORMATION

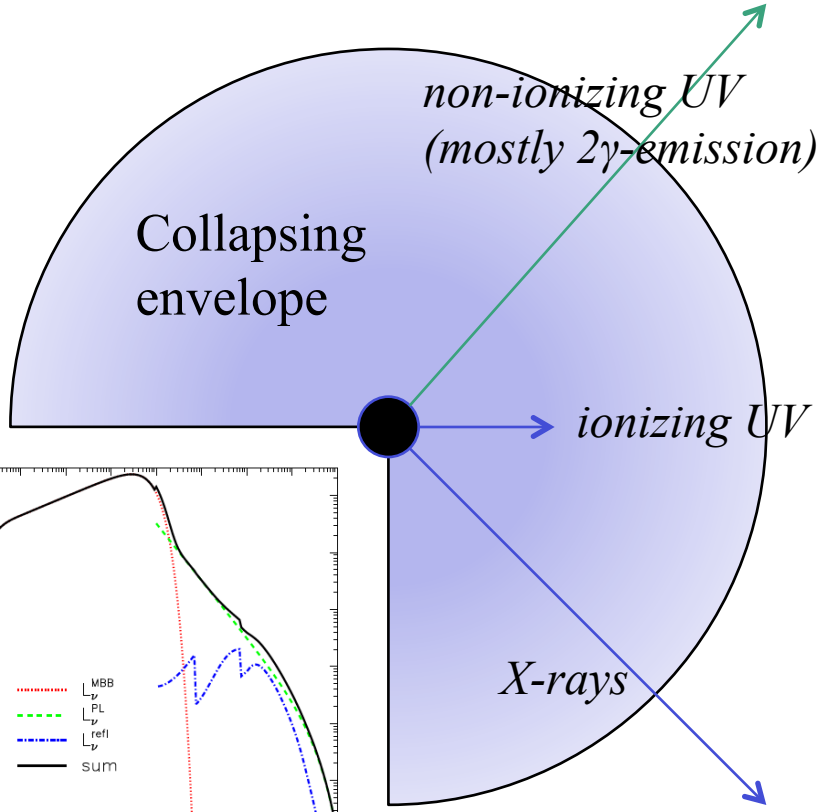


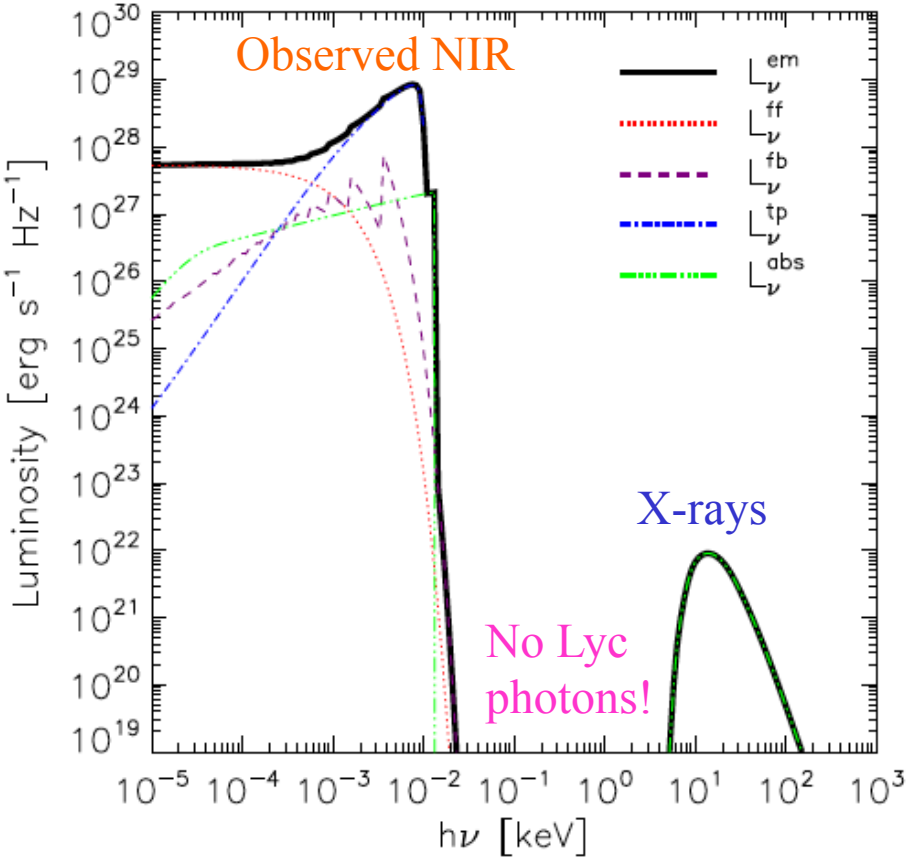
Courtesy: C. Regan, Univ. of Helsinki

Yue, AF & Salvaterra 13

ABSORBED SPECTRUM

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



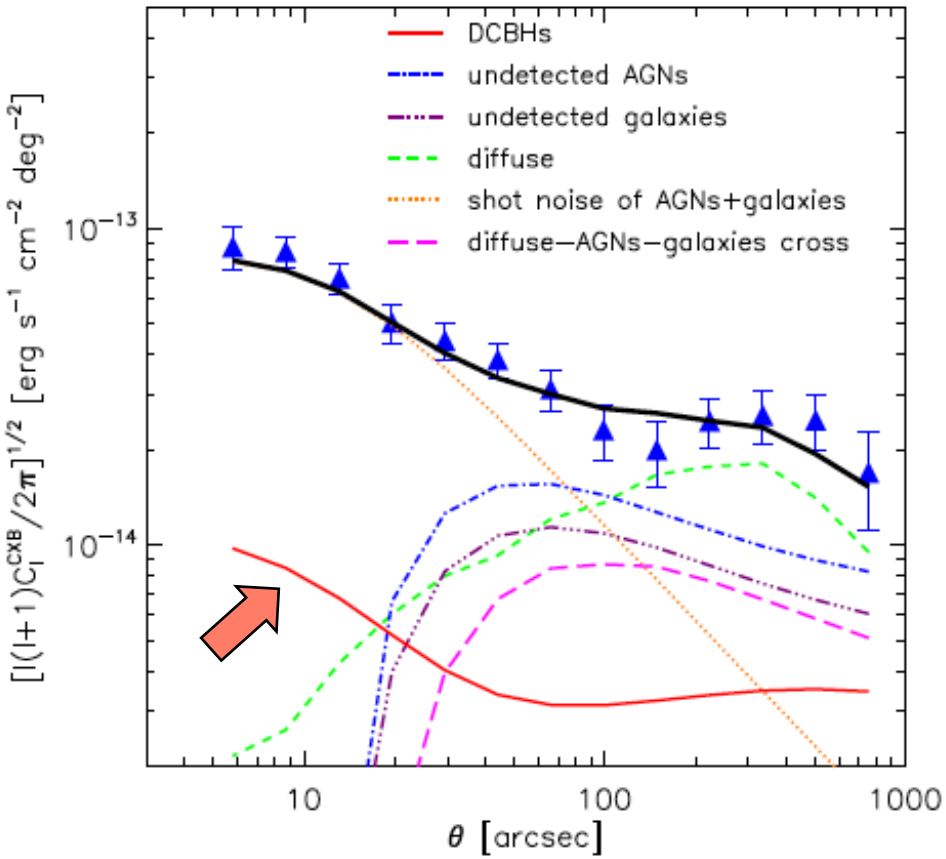


$M_\bullet=10^6\ M_\odot$
(Direct collapse black hole)

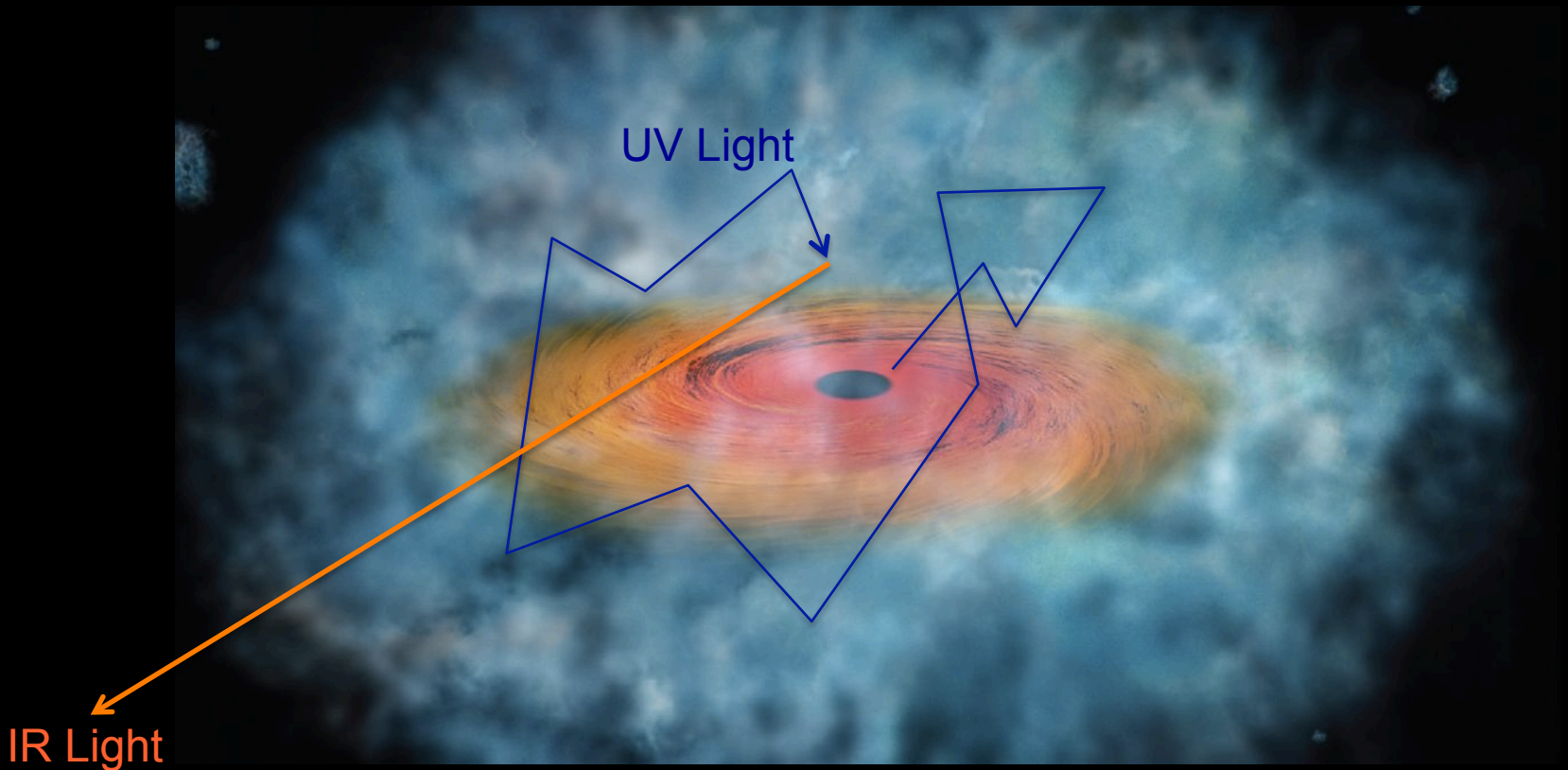
Yue, AF & Salvaterra 13

SEEDS EXPLAIN CIB-CXB CORRELATION

CXB Power spectrum



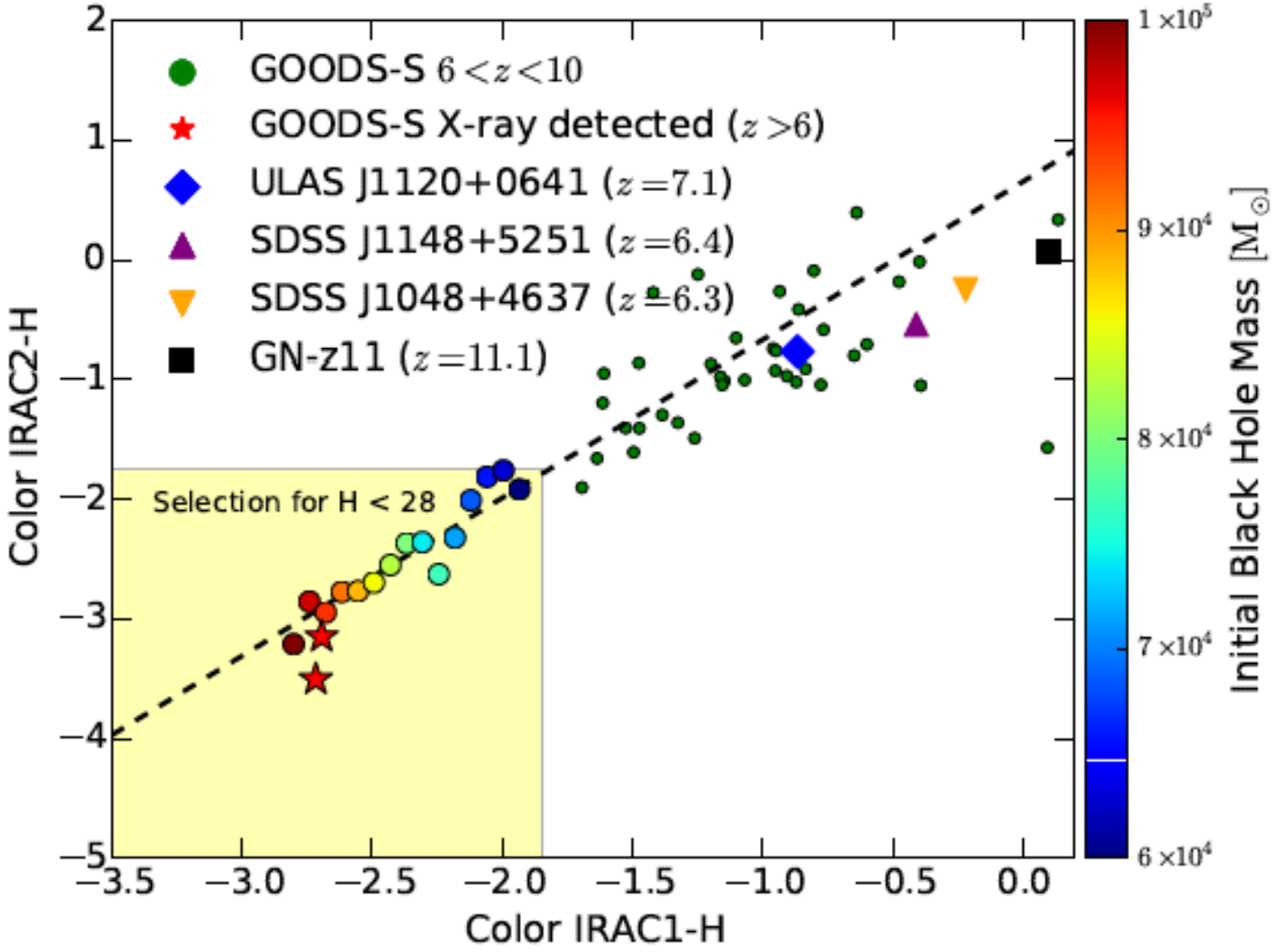
A growing DCBH



DCBH ACCRETING ITS PARENT HALO GAS

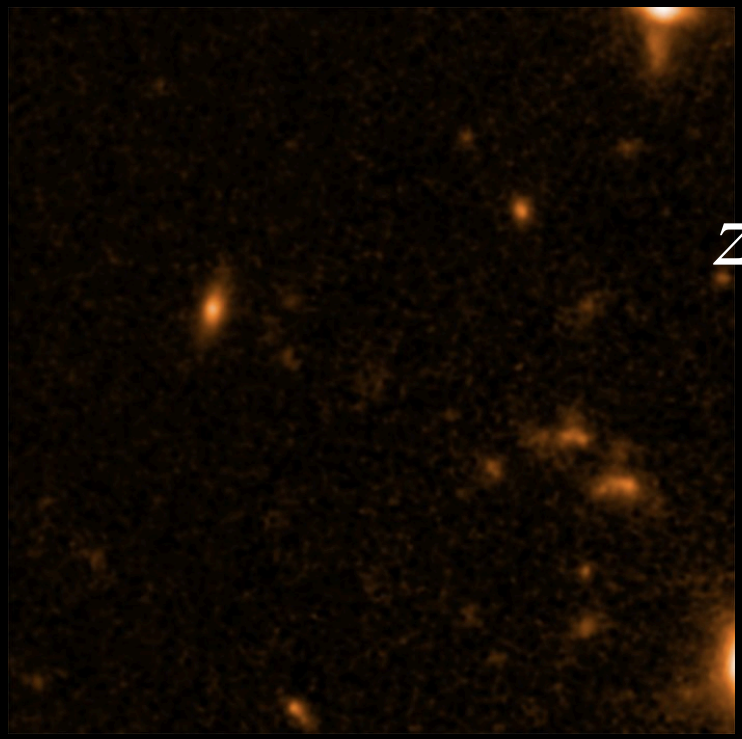
SELECTING DCBH BY COLORS

Pacucci+16



Pacucci+16

Do DCBHs exist? Yes!



$z = 9.7$

H-band Image
(Hubble Space Telescope)

X-ray Image
(Chandra Space Telescope)

Pacucci+16

hubble

esa

ESA

Missions
· Show All Mi

Mission Hom
· Summary
· Fact Sheet
· About Hubb
· Hubble histo

Spacecraft
· Spacecraft
· 3D Model
· Hubble instr
· Engineering

Mission Oper
· Operating H
· Launch
· SM 1
· SM 2
· SM 3A

MEDIA INAF

NOTIZIARIO ON-LINE DELL'ISTITUTO

Universo INAF

HOME

ASTRONOMI

Gli anter

Un gruppo di as

"semi" dei prim

di Giulia Bonelli

Esiste una vecc

quella apparter

celesti del cielo

il Big Bang. Co

scienziati non e

risposta; fino a

astronomi ital

di quelli che po

"semi" dei buch

ZOOM

25 maggio 201

Scuola

proger

Mail St

Consiglia

G+1 9

SULLO STESSO

DAL SITO

Le Scienze

LA RIVISTA IN EDI

Il nostro post

La Via Lattea è s

in uno dei più gra

la Repubblica

Quotidiano

Data 25-05-2016
Pagina 1+27
Foglio 1 / 3

PER SAPERNE DI PIÙ

L'ul

il tel

E

d

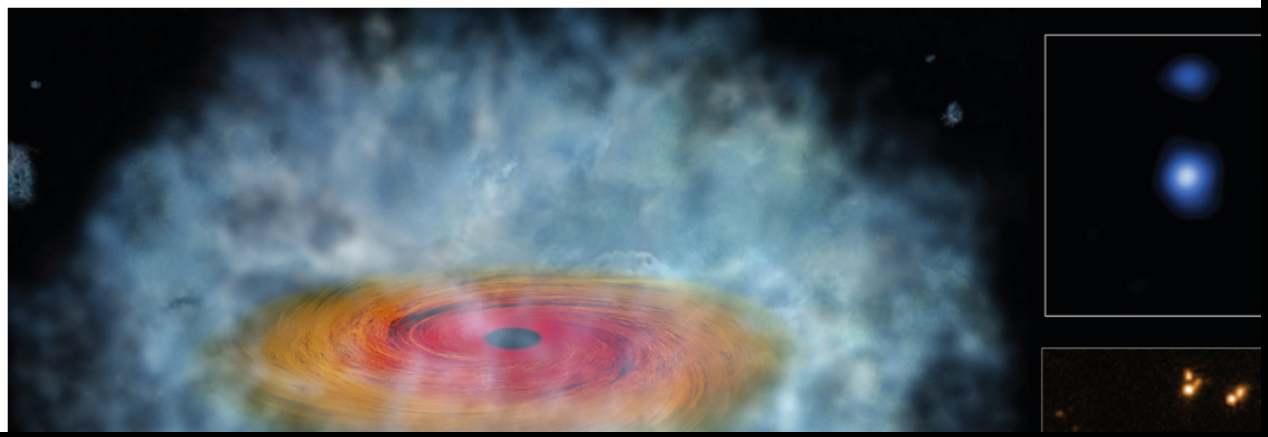
la

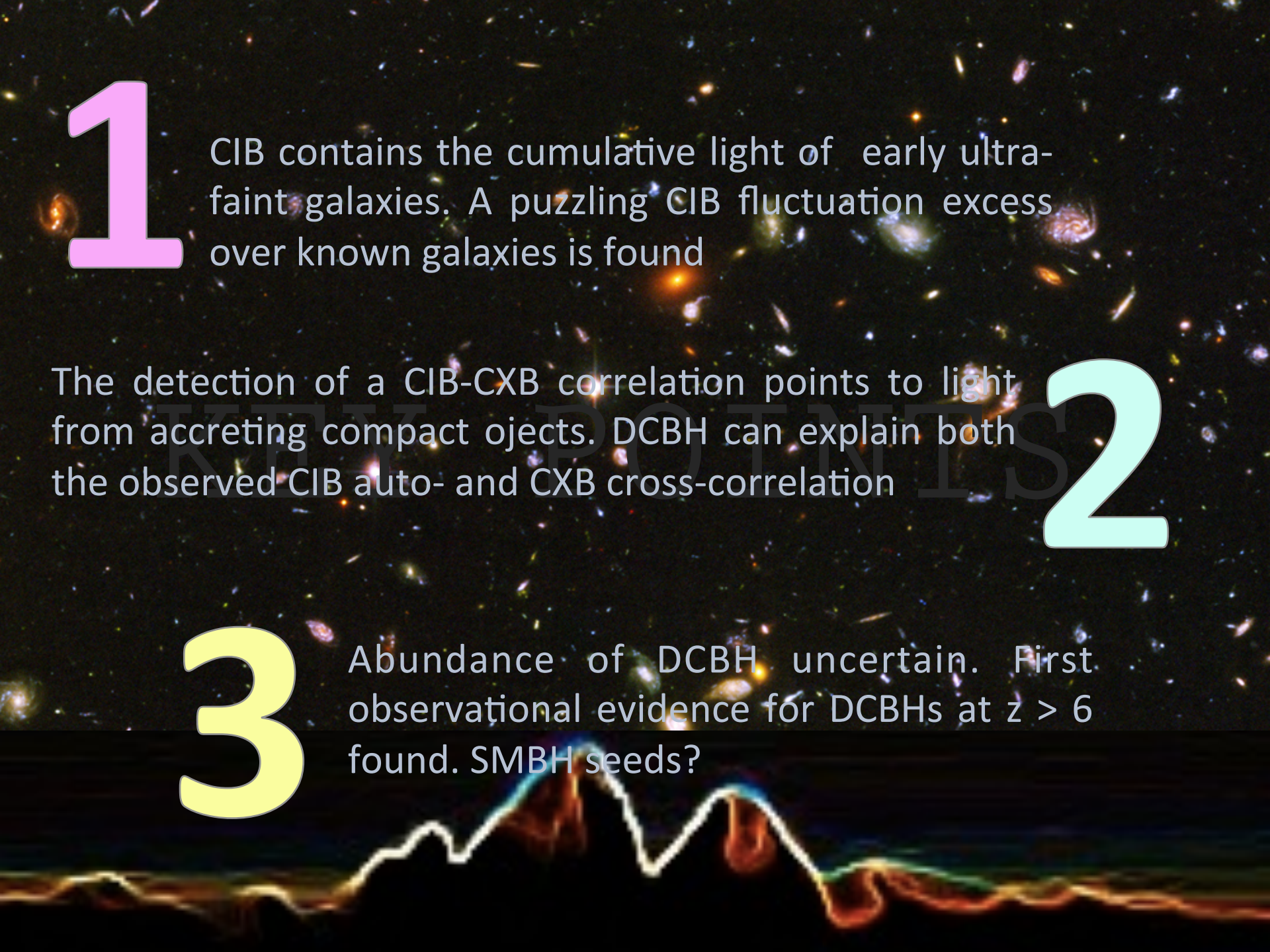
vi

NASA 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
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
KEY POINTS
3
Abundance of DCBH uncertain. First observational evidence for DCBHs at z > 6 found. SMBH seeds?