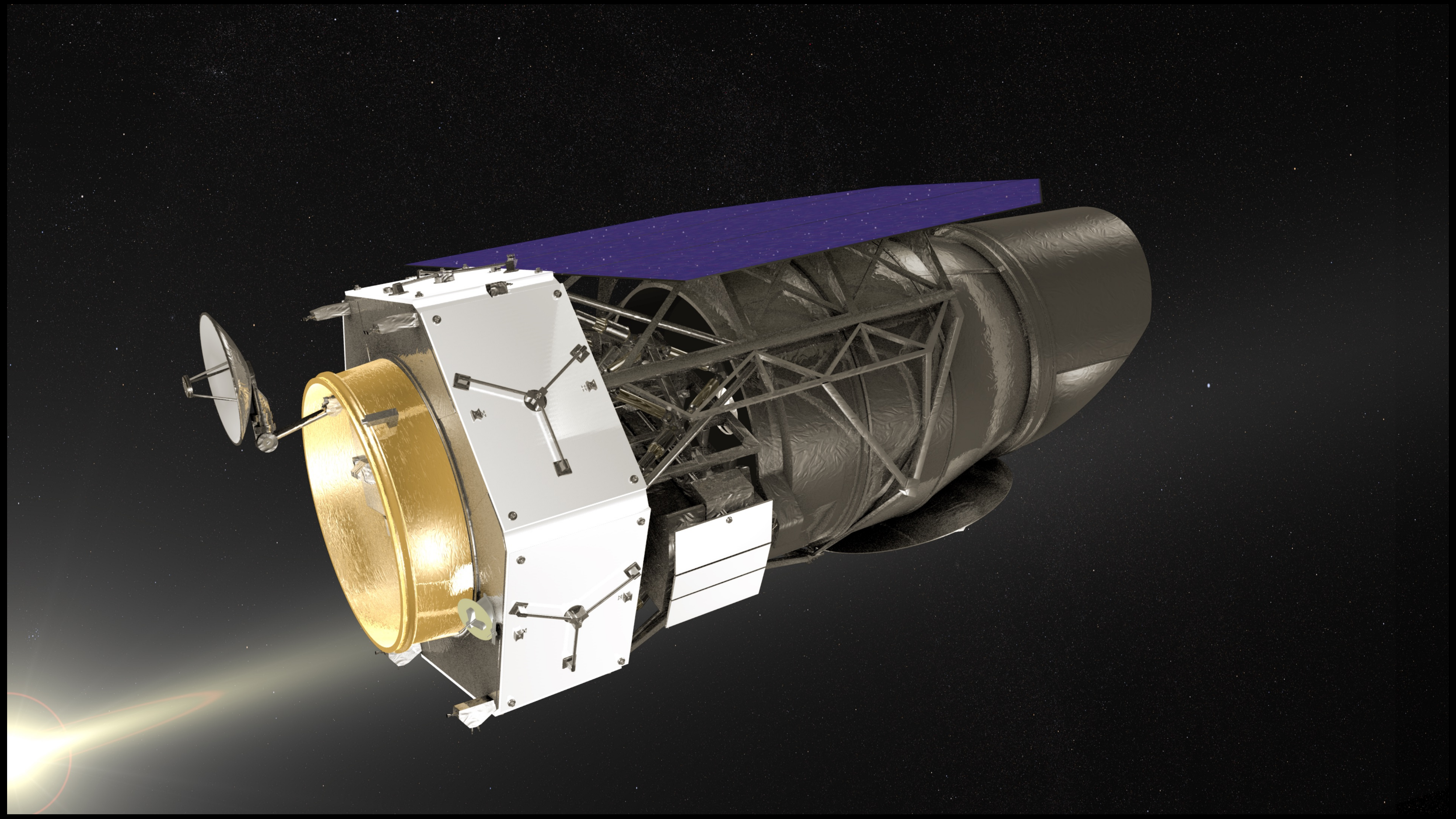
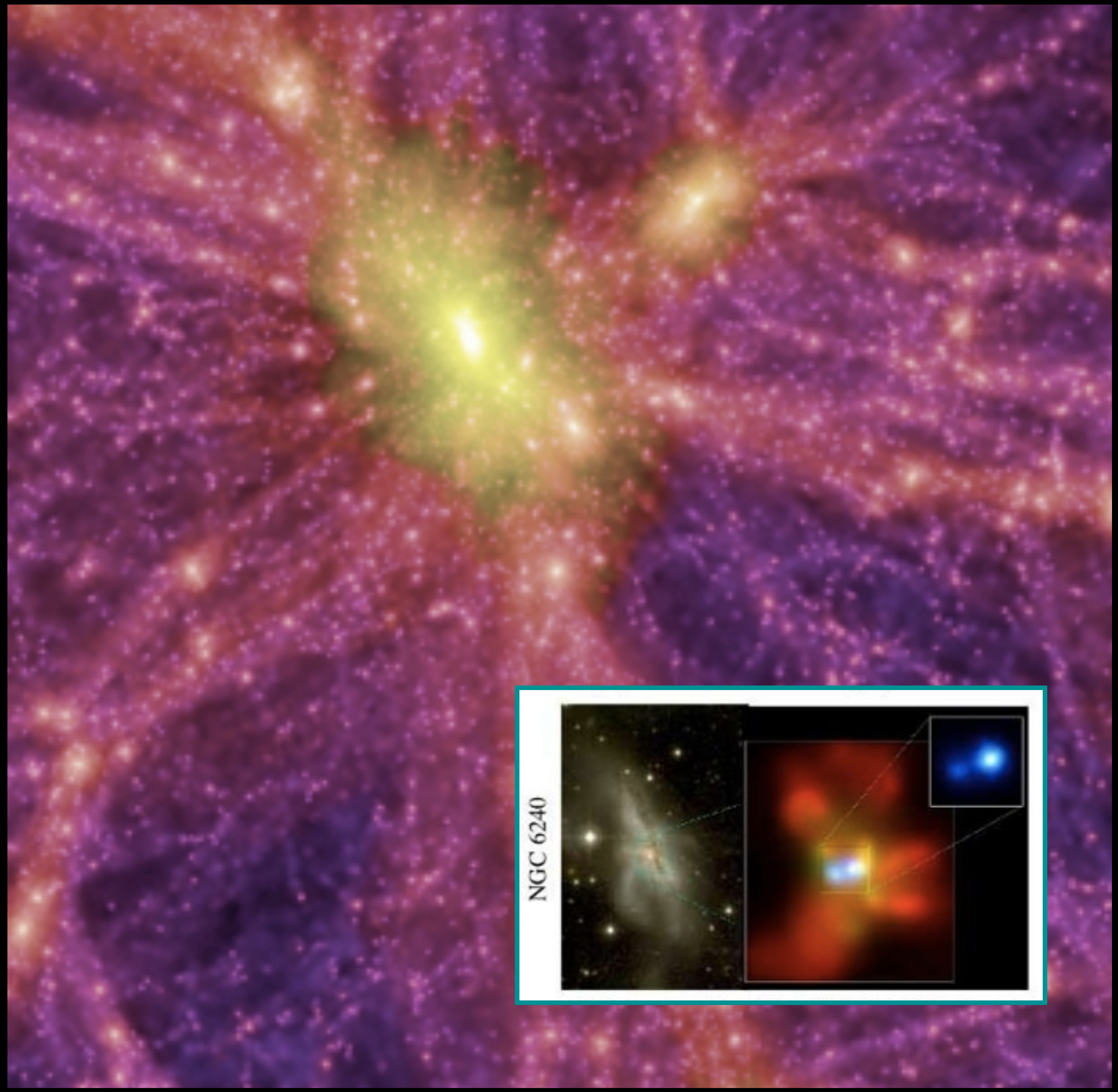
Black Holes in the Cosmic Web: Evolution of AGN, Galaxies, and Large-Scale Structures in the Era of *WFIRST*





Ryan C. Hickox
Dartmouth College
AAS Splinter Meeting
10 January 2018

Hubble Sized Mirror with a Survey Sized Camera

Hubble Space Telescope

- 14,000+ research publications w/ > 600,000 citations
- 2.5 new published papers per day
- 1000+ scientific proposals per year
- Training of over 1000 grad students and 600 PhD thesis
- Countless scientific breakthroughs

The Sloan Digital Sky Survey

- 5000+ research publications, w/ > 245,000 citations
- 1000+ astronomer user community
- 14,000 sq deg survey cataloged >1 billion objects
- Created the most detailed map of the Universe to date

Sloan Digital Sky Survey

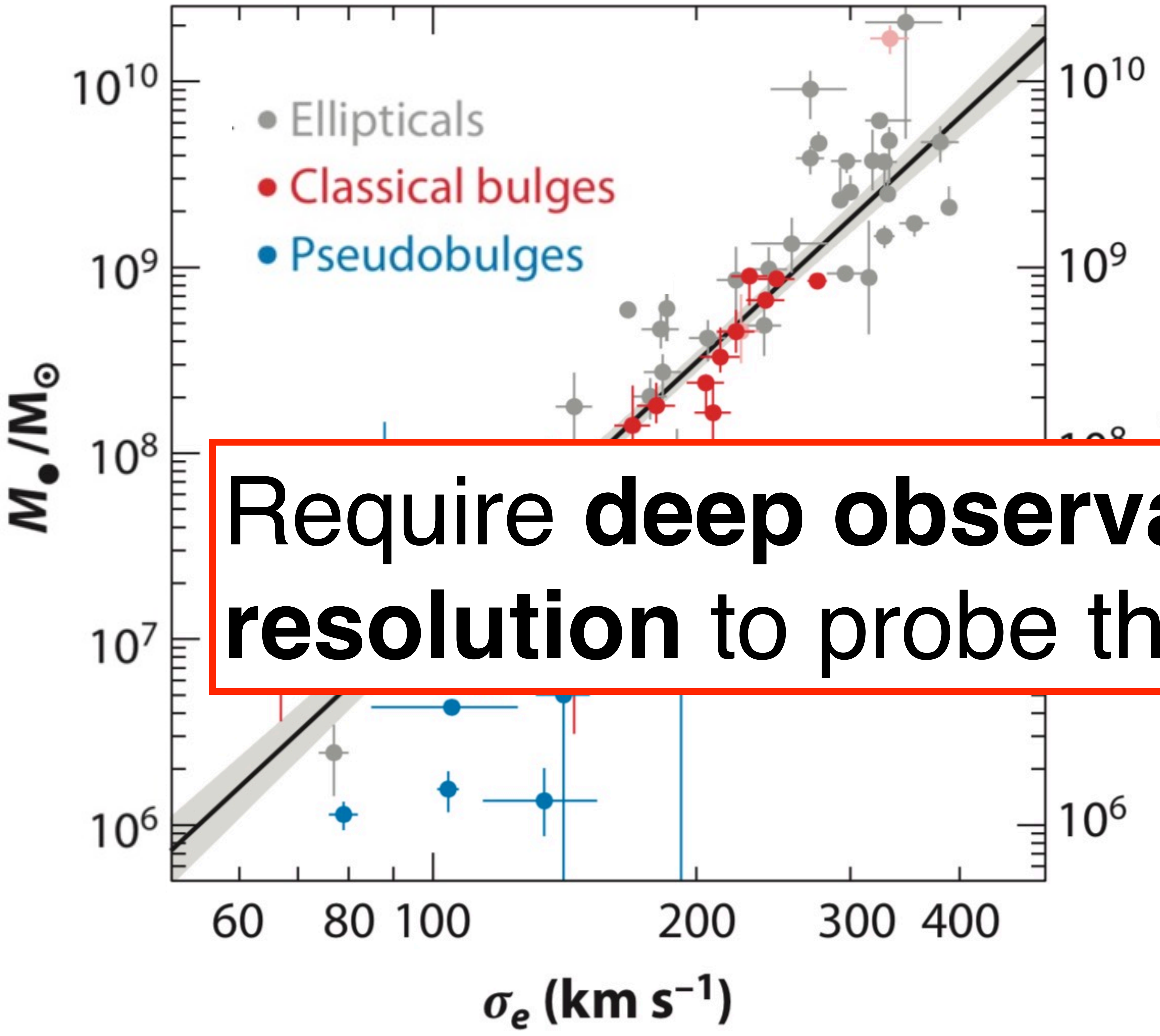
Miguel A Aragon (JHU), Mark Subbarao (Adler P.), Alex Szalay (JHU)

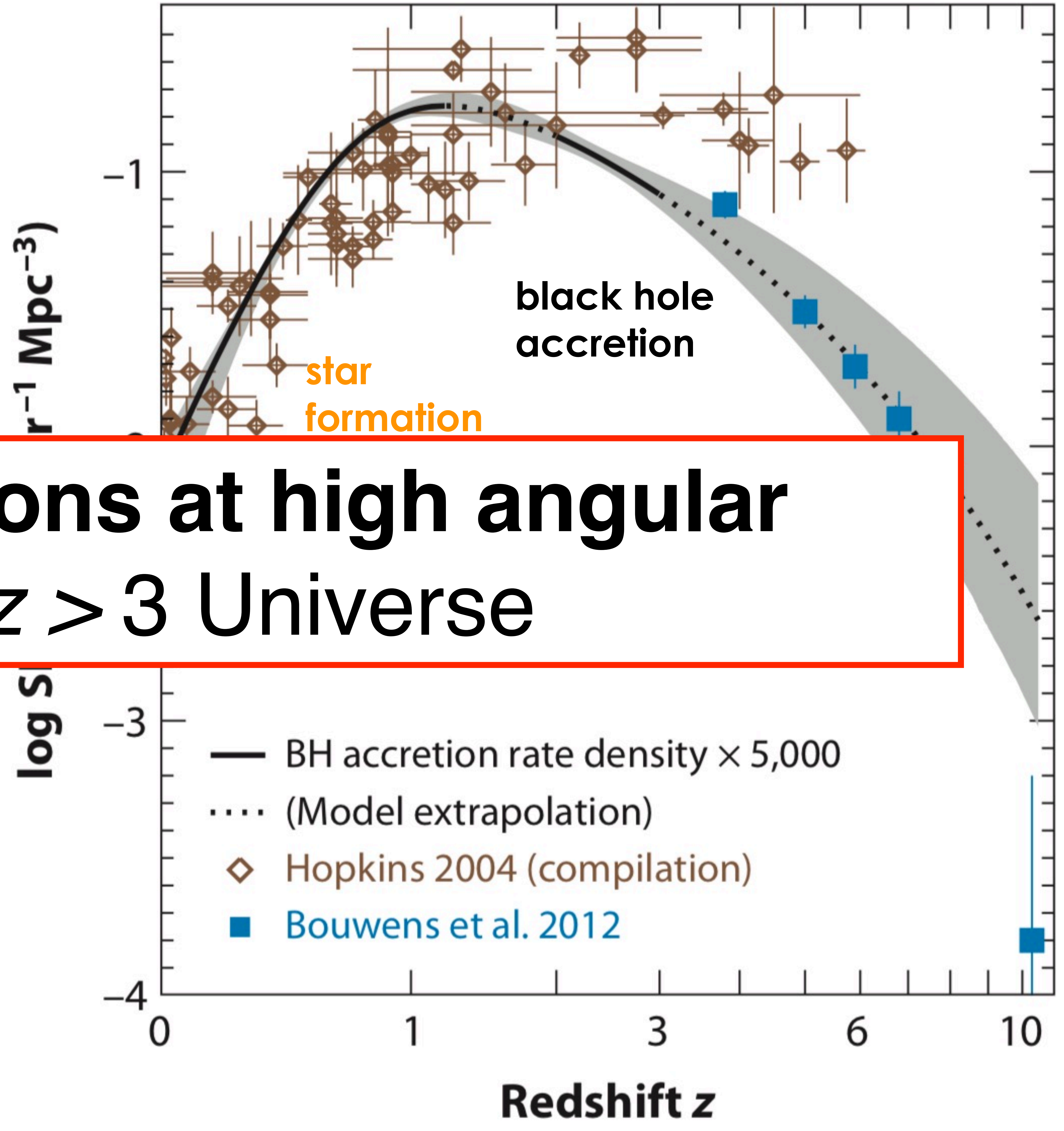

Time since the Big Bang: 5.1 billion years
ILLUSTRIS

Evolution of supermassive black holes

What is the origin of supermassive black holes?

What is their role in the evolution of galaxies and large-scale structuers?



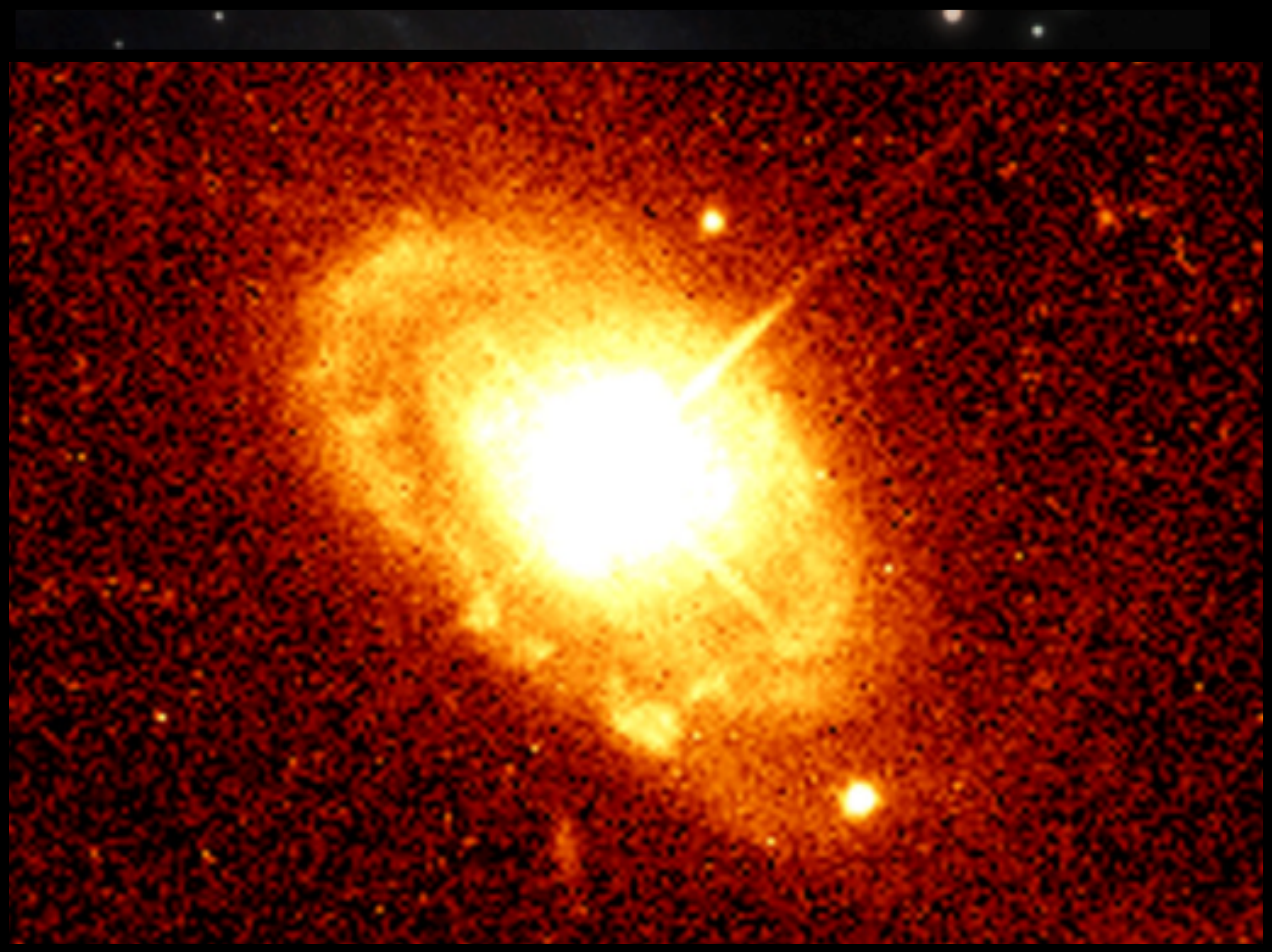


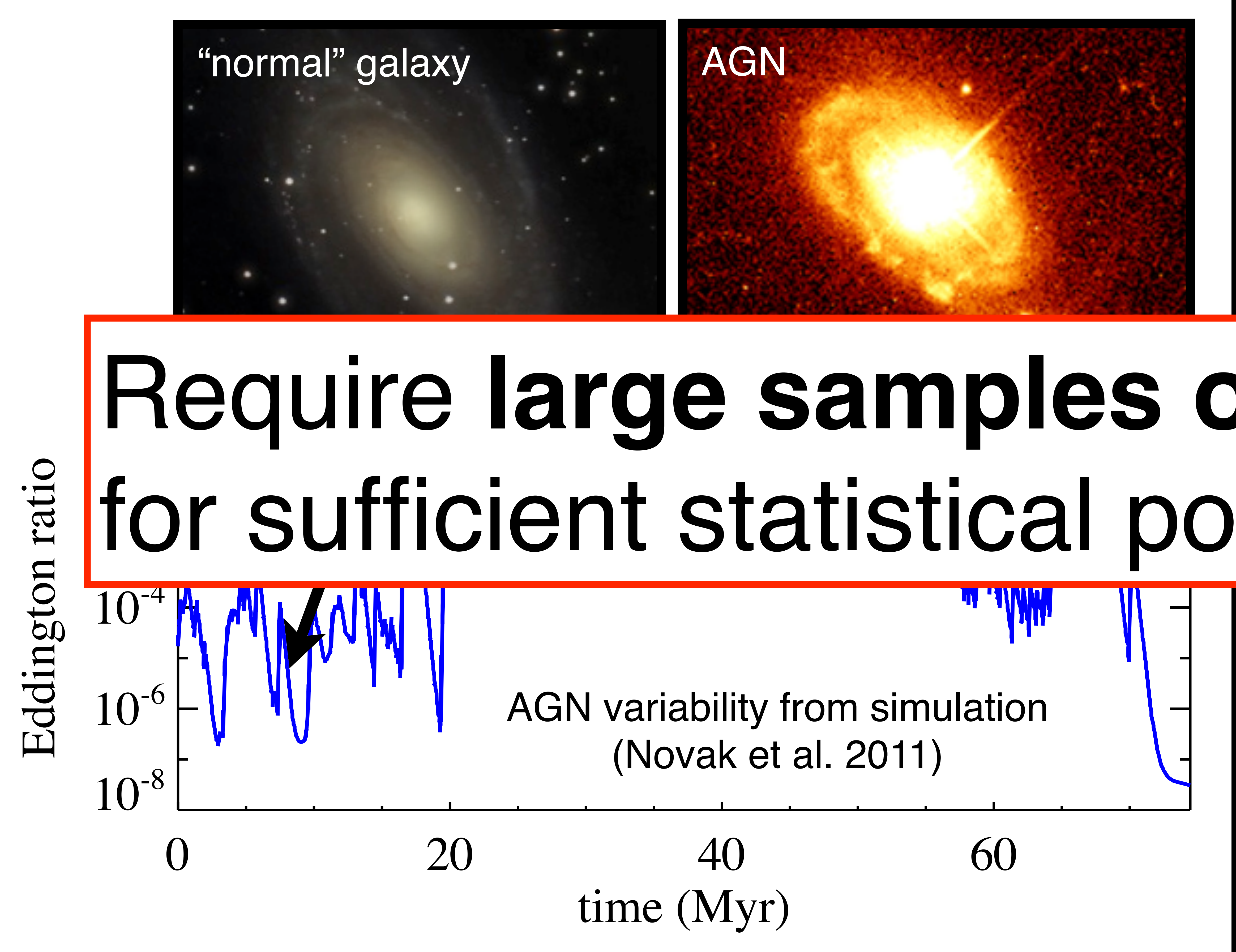
Require **deep observations at high angular resolution** to probe the $z > 3$ Universe

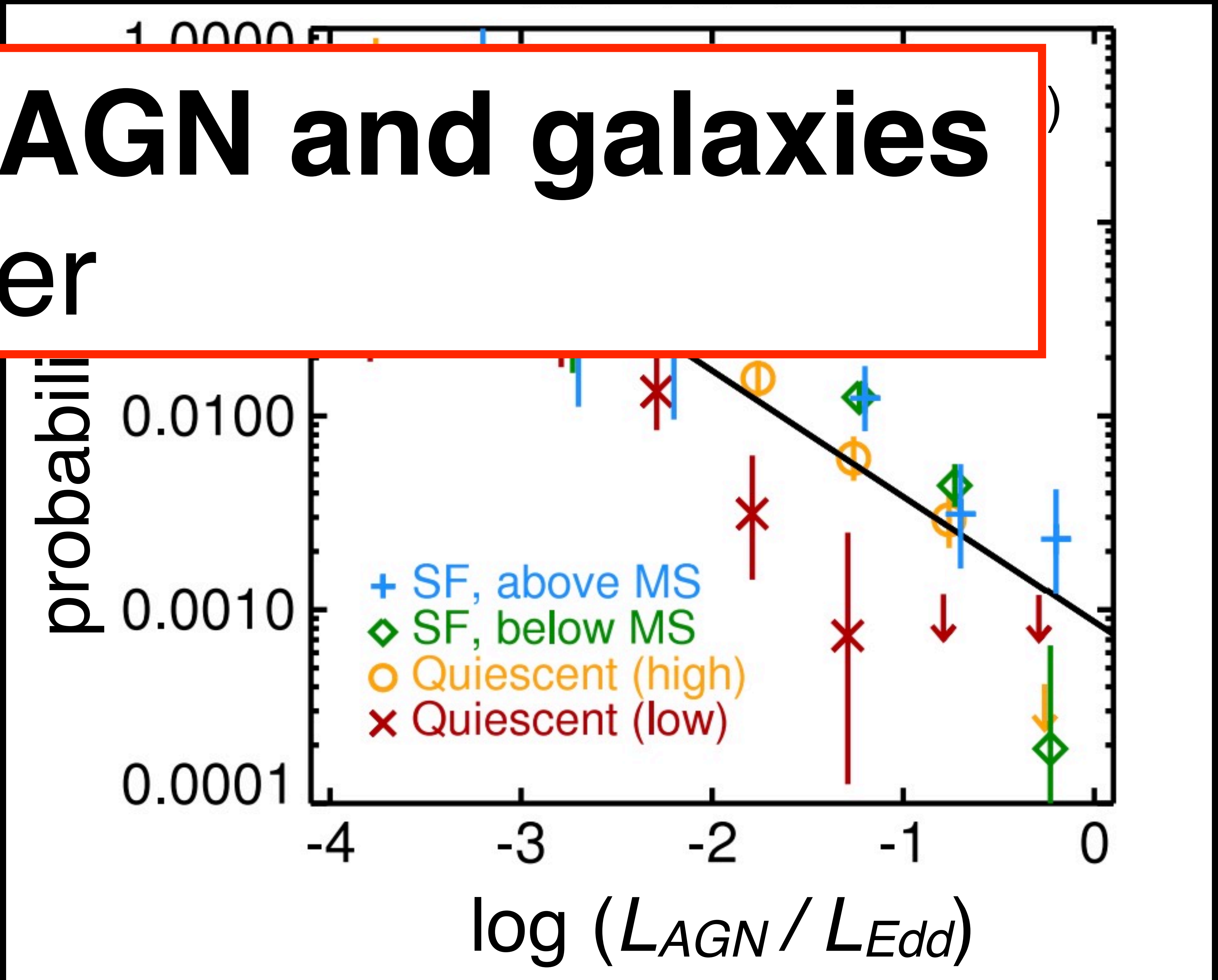
Kormendy & Ho (2013)

AGN are rare!

AGN are stochastic!







Require **large samples of AGN and galaxies** for sufficient statistical power

Hickox et al. (2014)

Probing the distant Universe at high resolution

Studying large samples of objects

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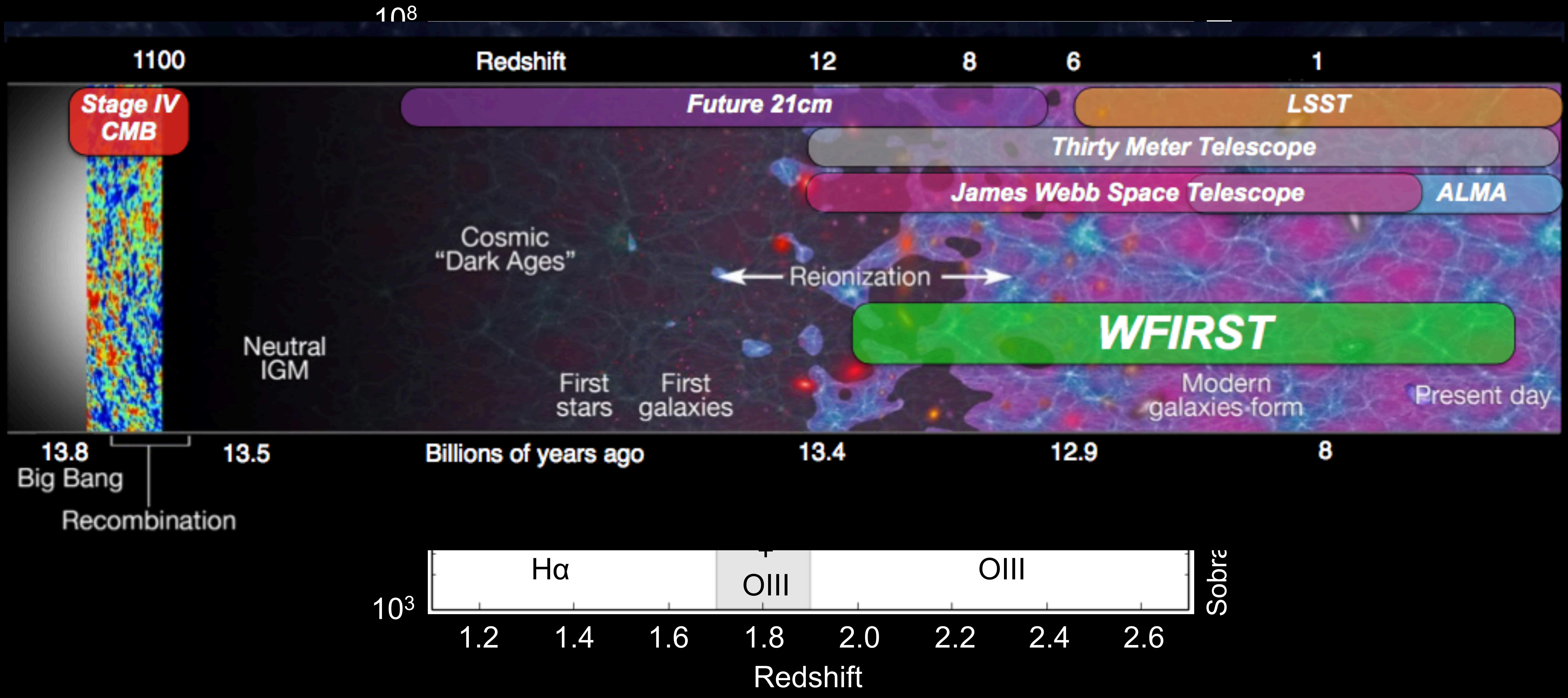
WFIRST

WFIRST Spectroscopy at the Peak of Cosmic Star Formation

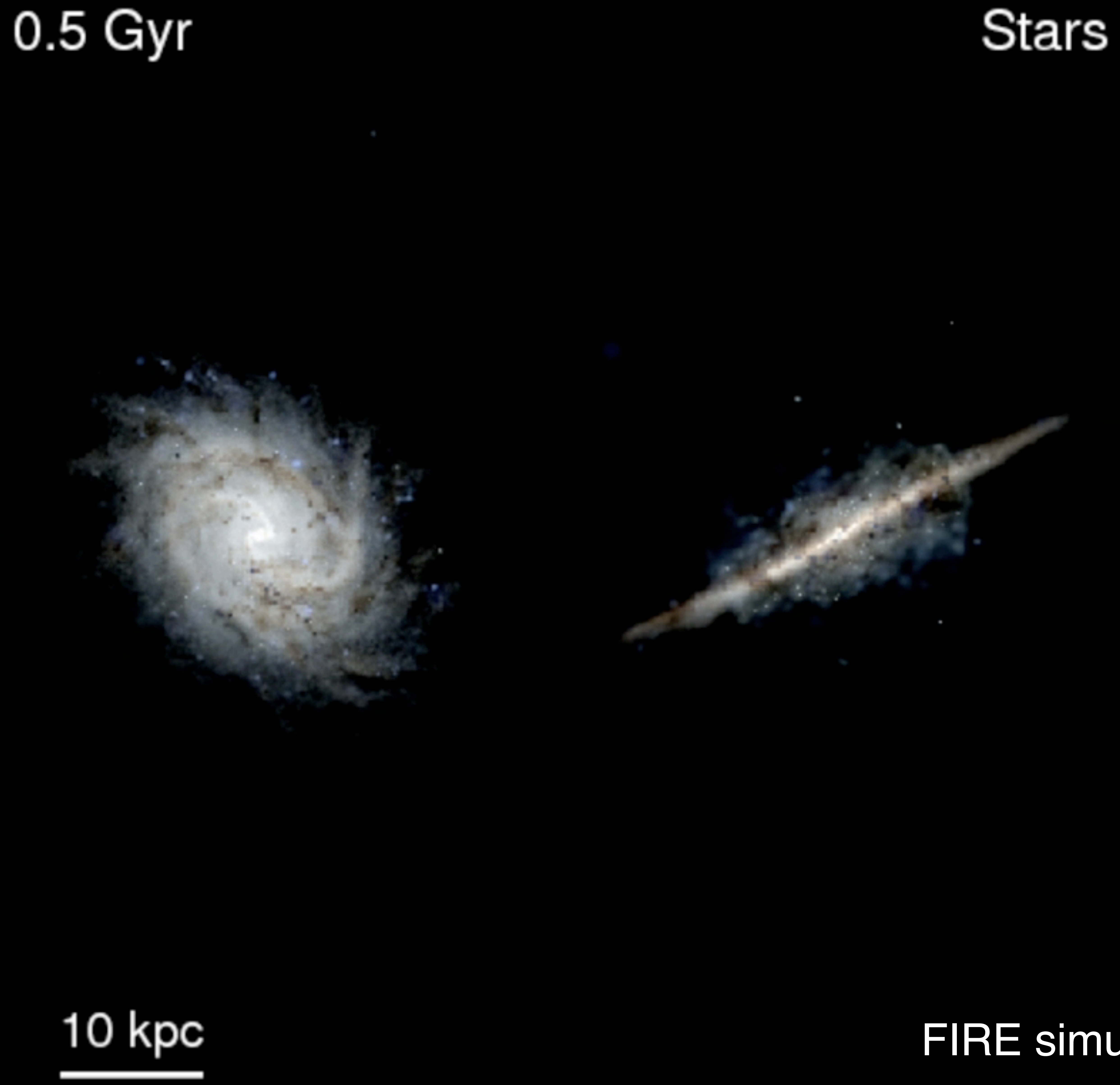


1. Black hole fueling in galaxy mergers

2. Black hole growth and large-scale structures

3. The dawn of black holes

1. Black hole fueling in galaxy mergers



FIRE simulations (courtesy P. Hopkins)

Are AGN more likely to be found in mergers than "normal" galaxies?

YES

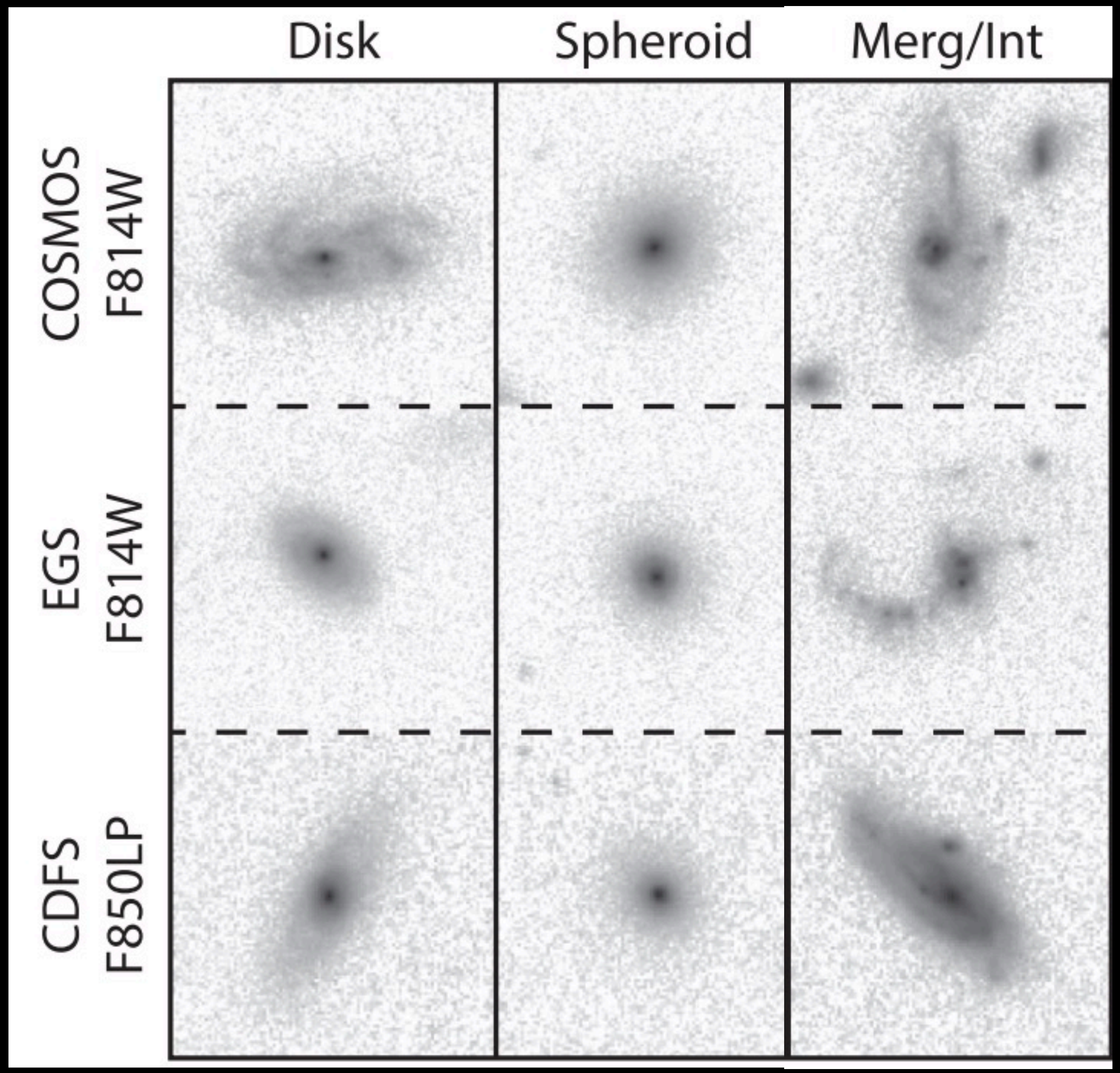
Urrutia et al. (2008)
Treister et al. (2012)
Glikman et al. (2015)

NO

Cisternas et al. (2010)
Schawinski et al.
Kocevski et al. (2012)
Villforth et al. (2014, 2017)

IF OBSCURED

Kocevski et al. (2015)
Ricci et al. (2017)



Kocevski et al. (2015)

Are **all** mergers more likely to host AGN than **all** "normal galaxies"

YES

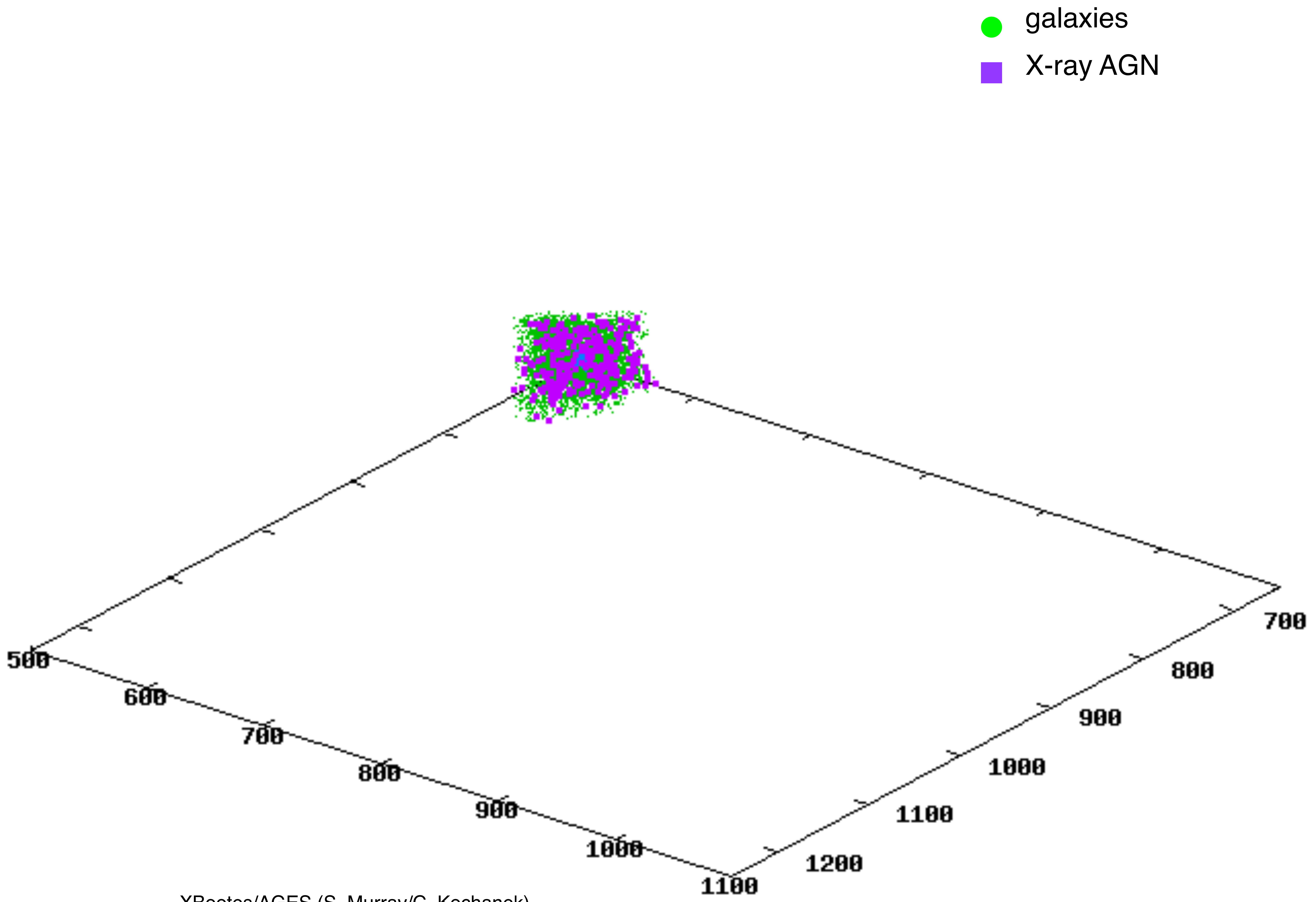
SDSS (Ellison et al. 2011, 2013; Weston et al. 2017) ***z* < 0.1**

Subaru Hyper-Suprime Cam (Goulding et al. 2017) ***z* < 0.9**

See discussion in Hickox et al. (2014)

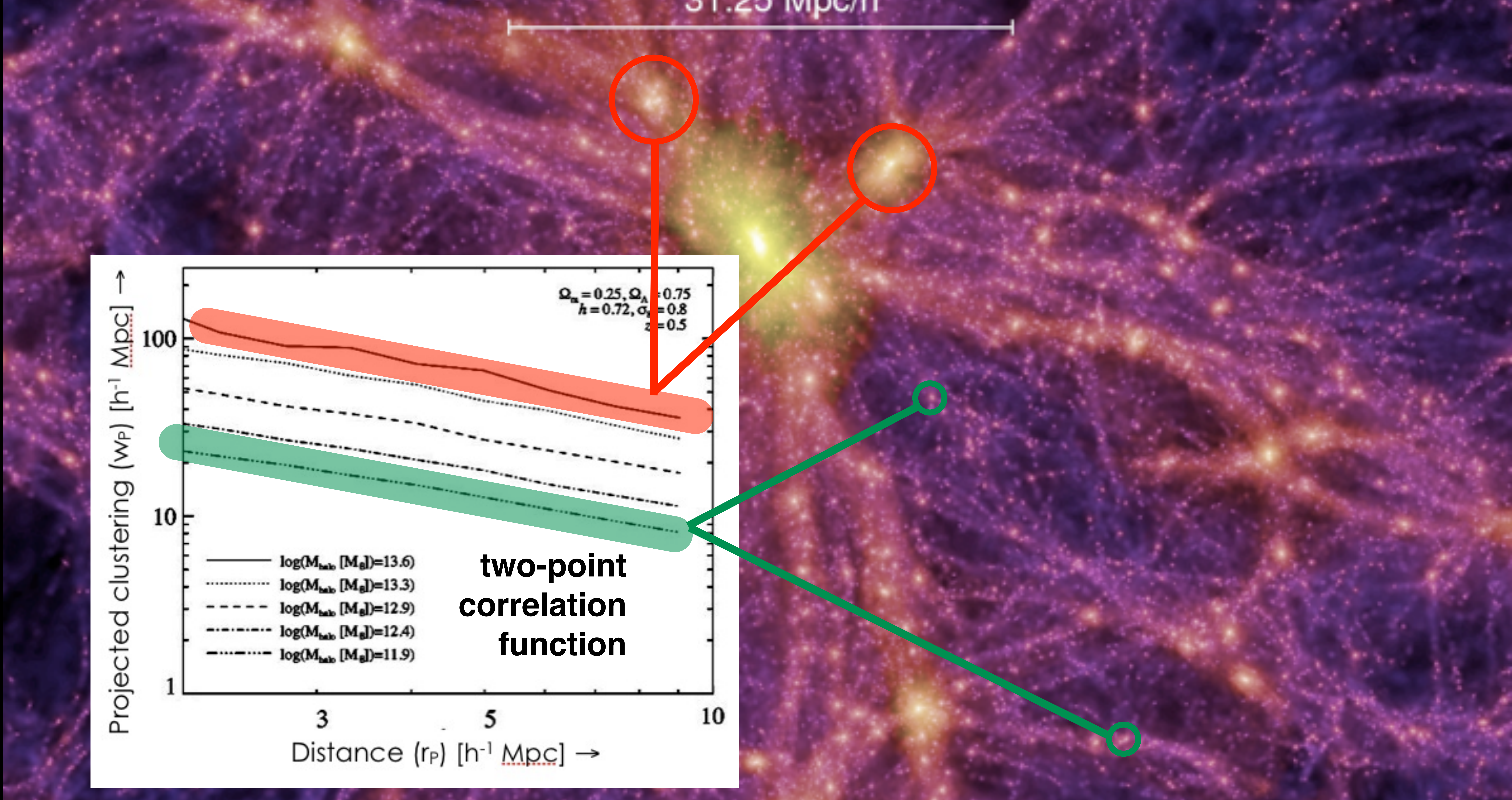
Simulated *WFIRST* HLS image
Power of using **kinematic pairs**
$\Delta V < 300$ km/s (Ellison et al. 2013)
AGN Excess
1
2
3
4
5
0
20
40
60
80
Projected separation (kpc/h)

2. Black hole growth and large-scale structures



XBootes/AGES (S. Murray/C. Kochanek)

Clustering tells us dark matter halo mass

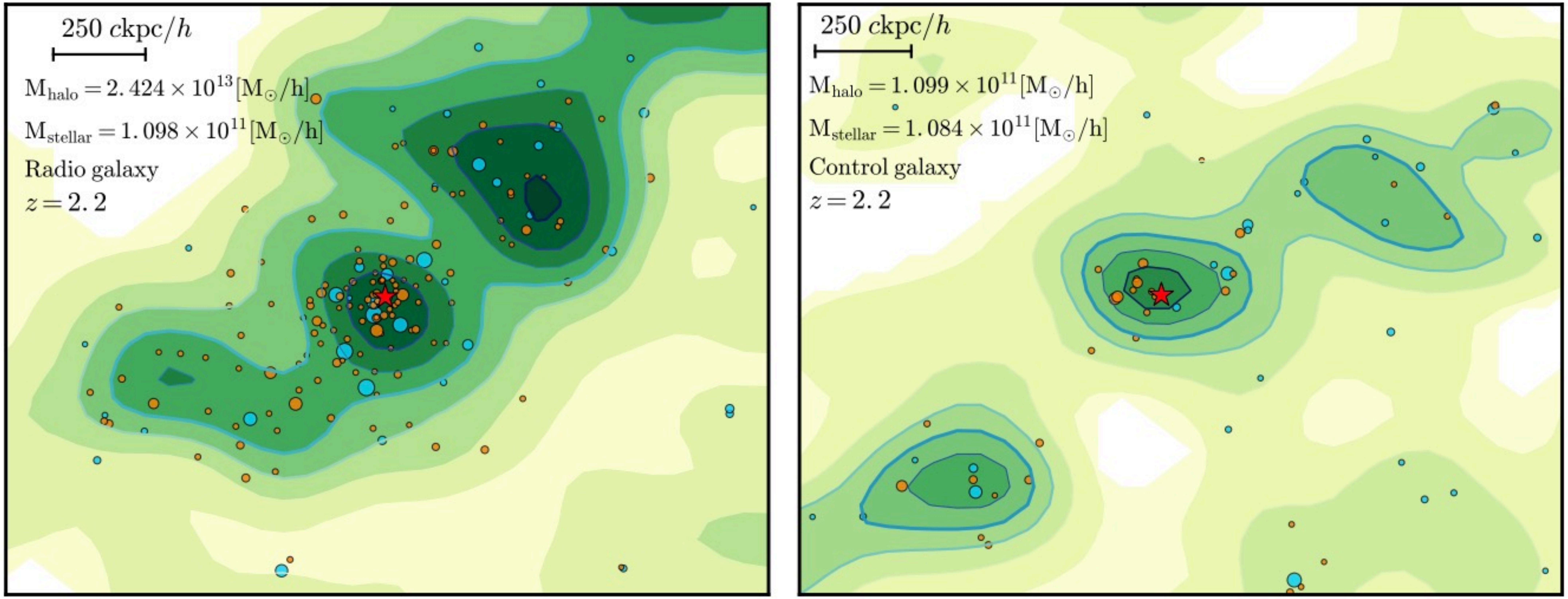


The What happens at **higher *z*?**

(Hick

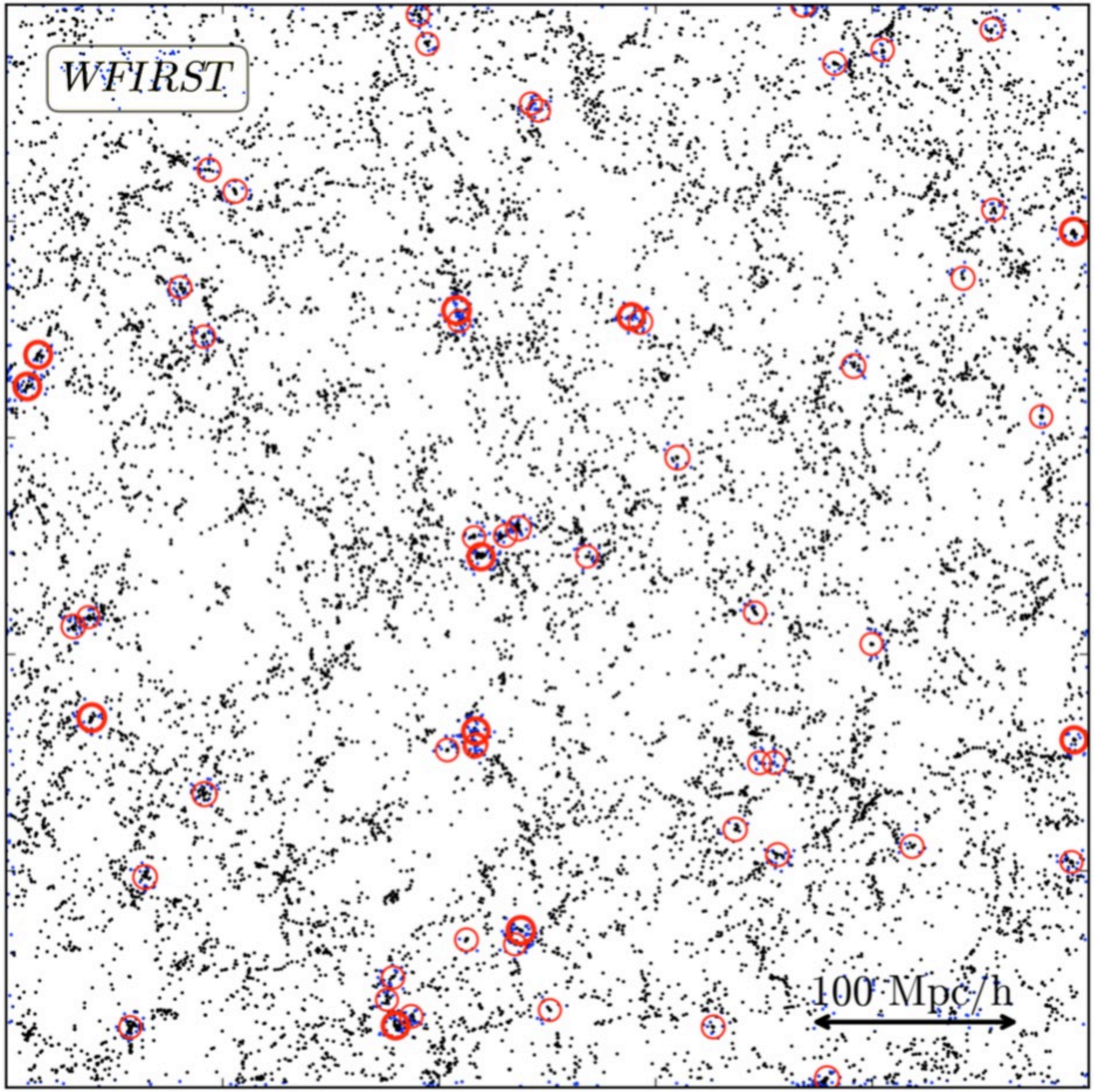
AGN clustering and environment provides an important constraint on black hole feedback models (e.g., Izquierdo-Villalba 2017)

me
fe
m
ra
gr
m



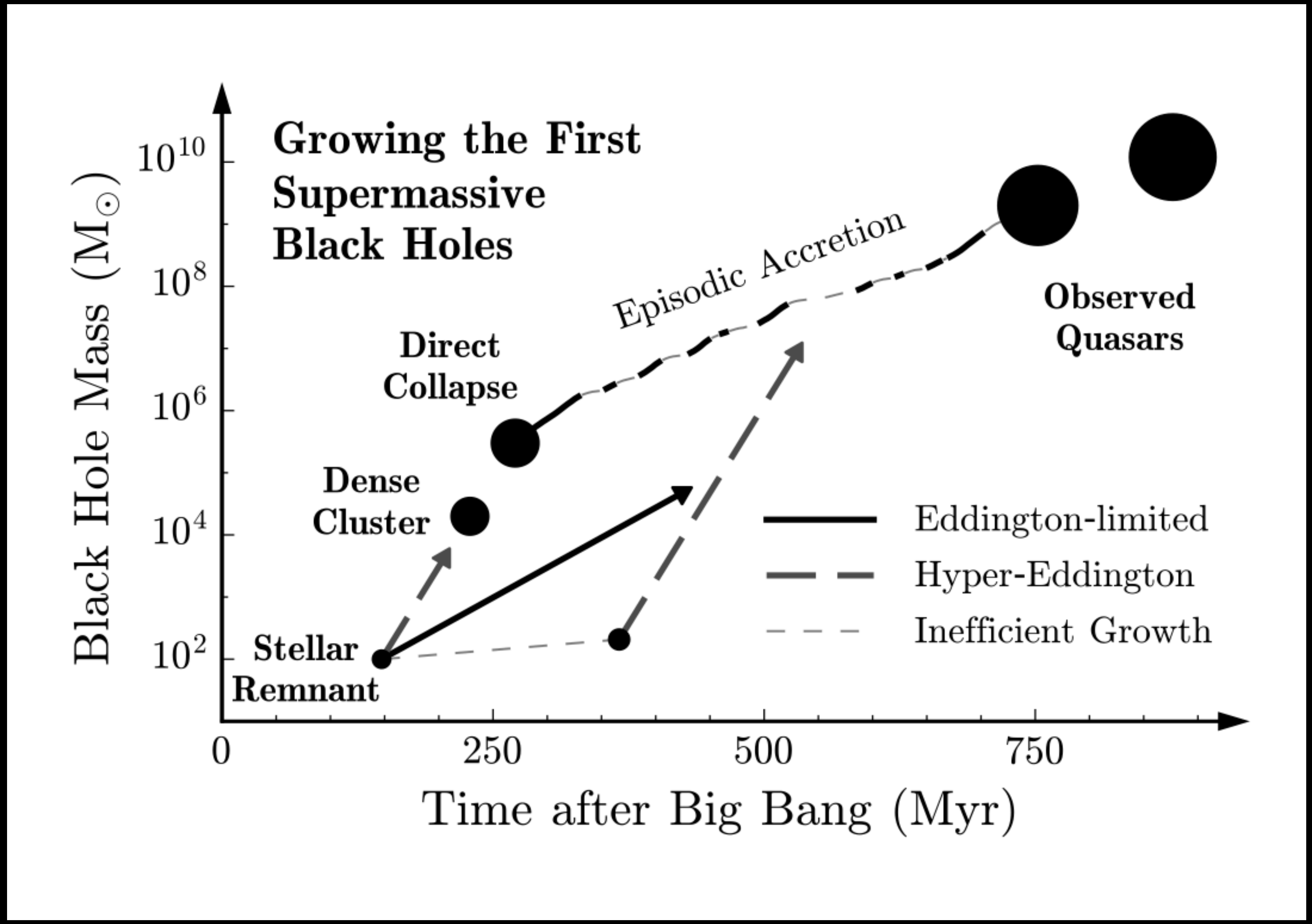
Redshift

Alexander & Hickox (2012)

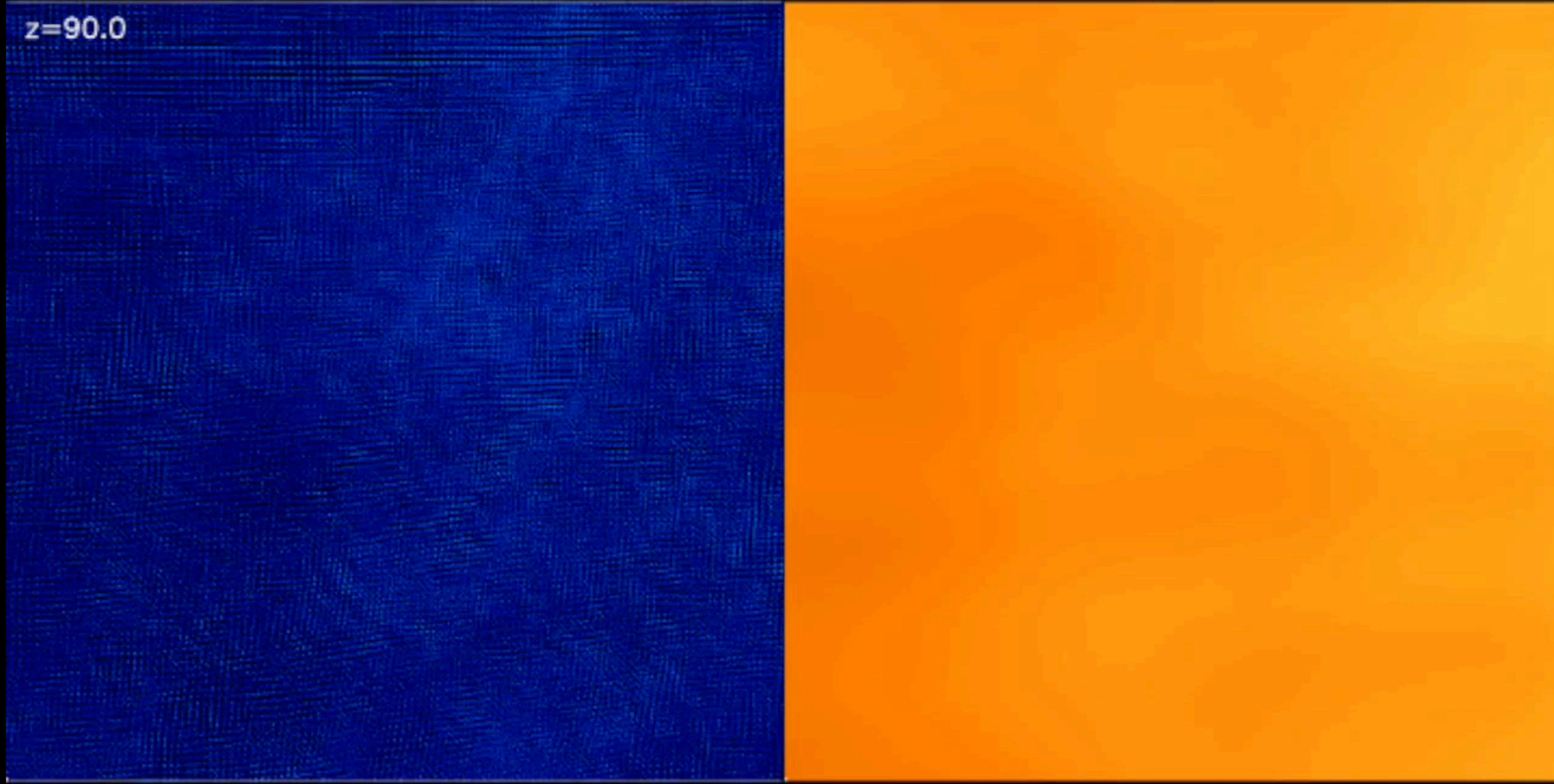


Also, **weak lensing** can provide a valuable independent constraint on AGN halo masses (e.g. Mandelbaum et al. 2009; DiPompeo et al. 2017)

3. The dawn of black holes



Smith, Bromm & Loeb (2017)



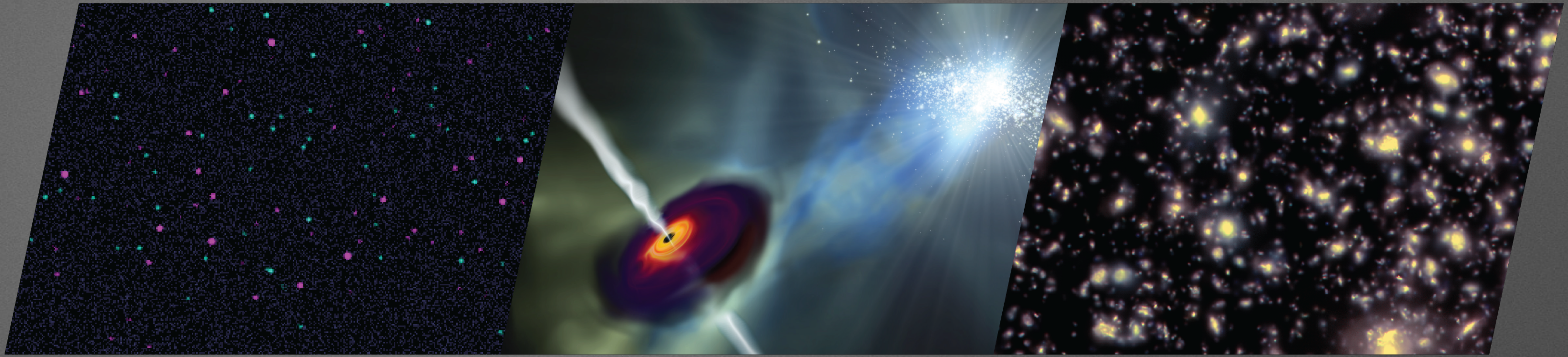
Hirano et al. (2017)

The earliest supermassive black holes, more than 1 billion times more massive than the Sun, are observed when the Universe is less than a billion years old. **How did these black holes form?** There are many potential pathways.

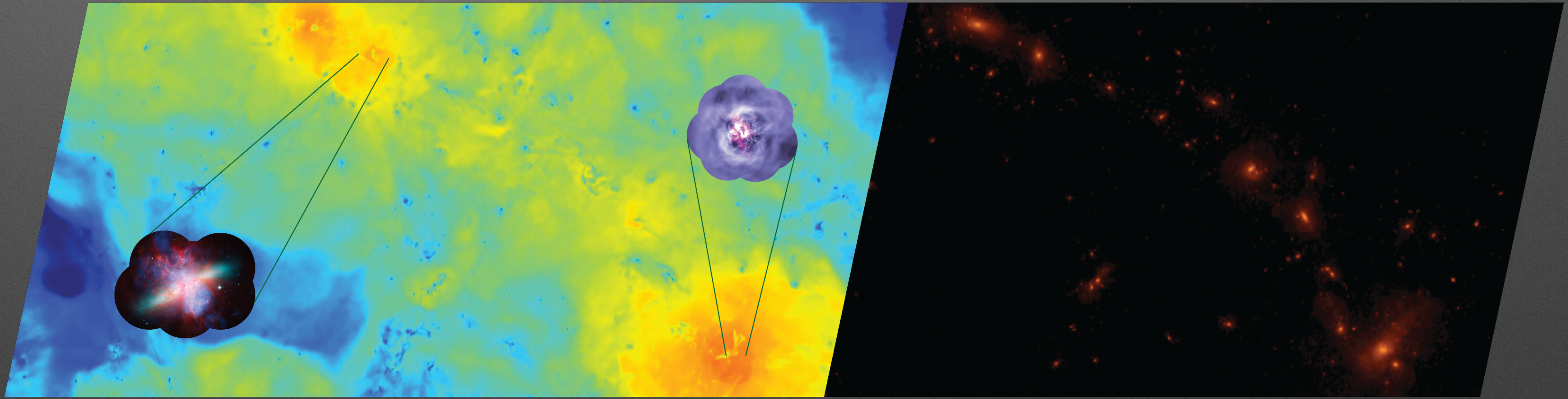
X-RAY OBSERVATORY

LYNX

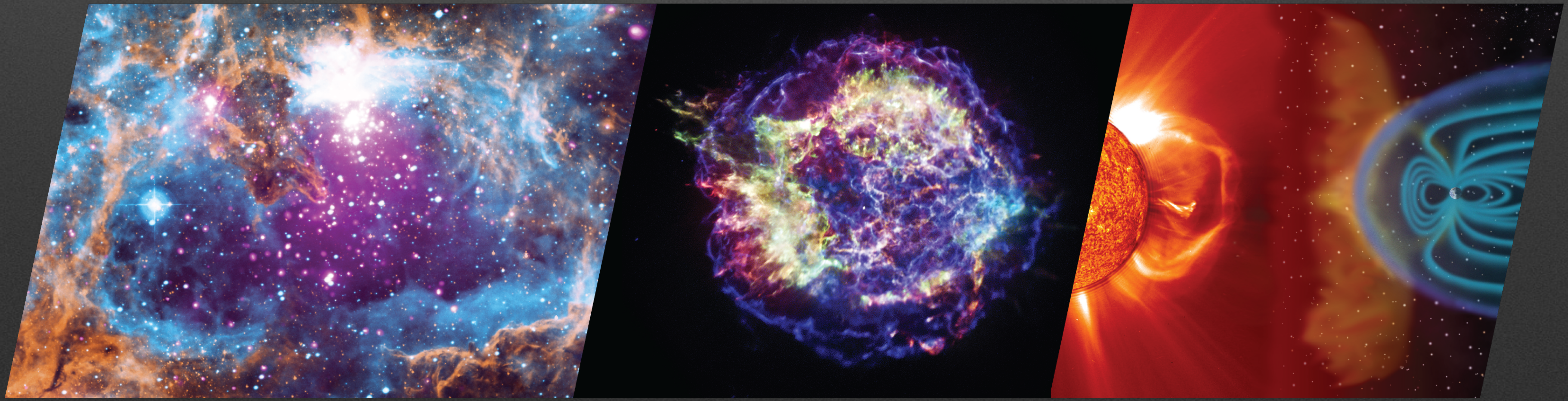
The Dawn of Black Holes

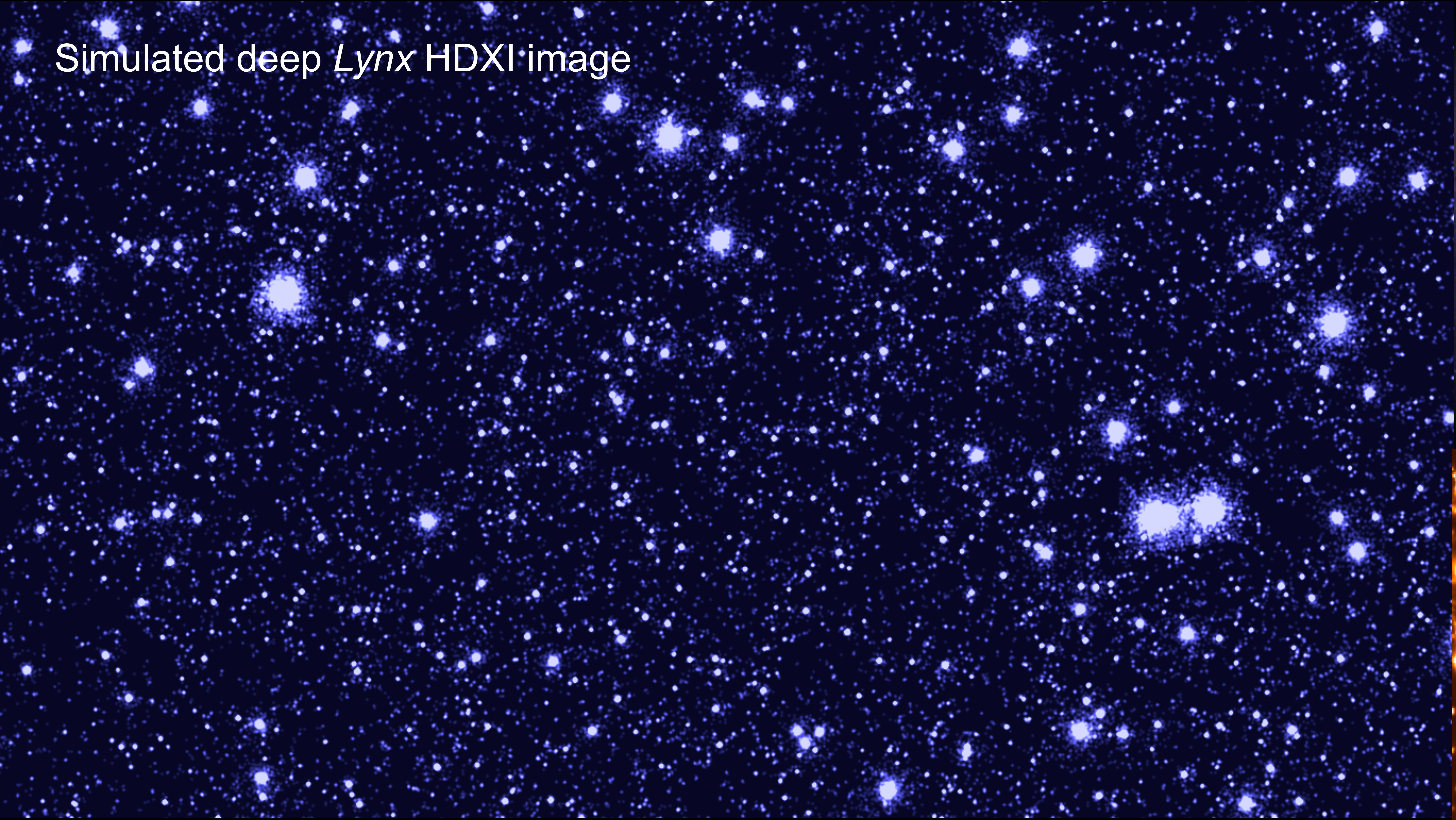


The Invisible Drivers of Galaxy and Structure Formation



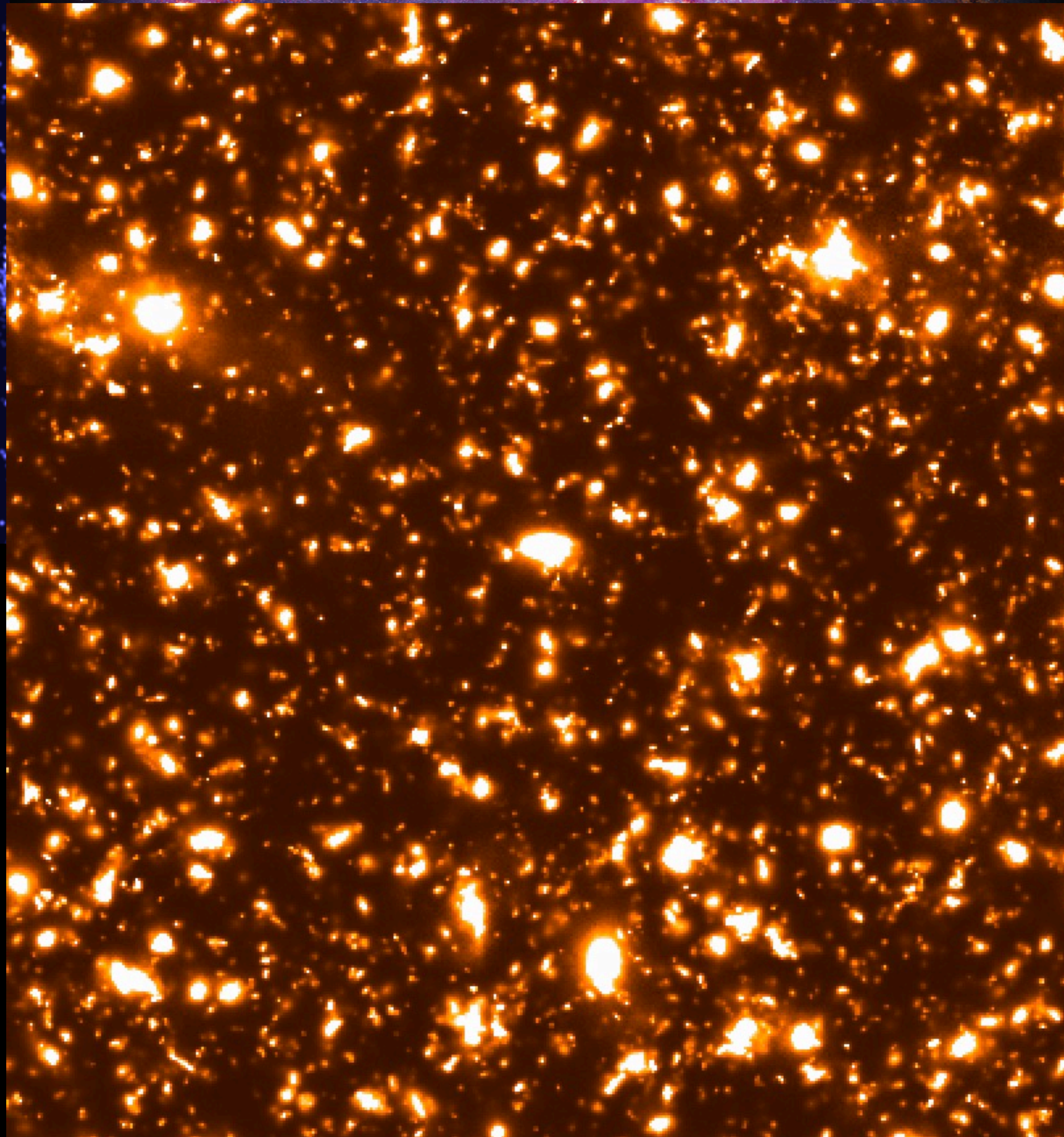
The Energetic Side of Stellar Evolution and Stellar Ecosystems




Simulated deep *Lynx* HDXI image

X-ray observations with *Lynx* can find the **earliest growing black holes**, at redshift up to 10 or higher, covering up to a **full square degree.**

Infrared observations with *WFIRST* will be critical for associating high redshift


Simulated WFIRST deep field (illustris; Snyder et al. (2017)

To understand the co-evolution of black holes and galaxies we need to:

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WFIRST