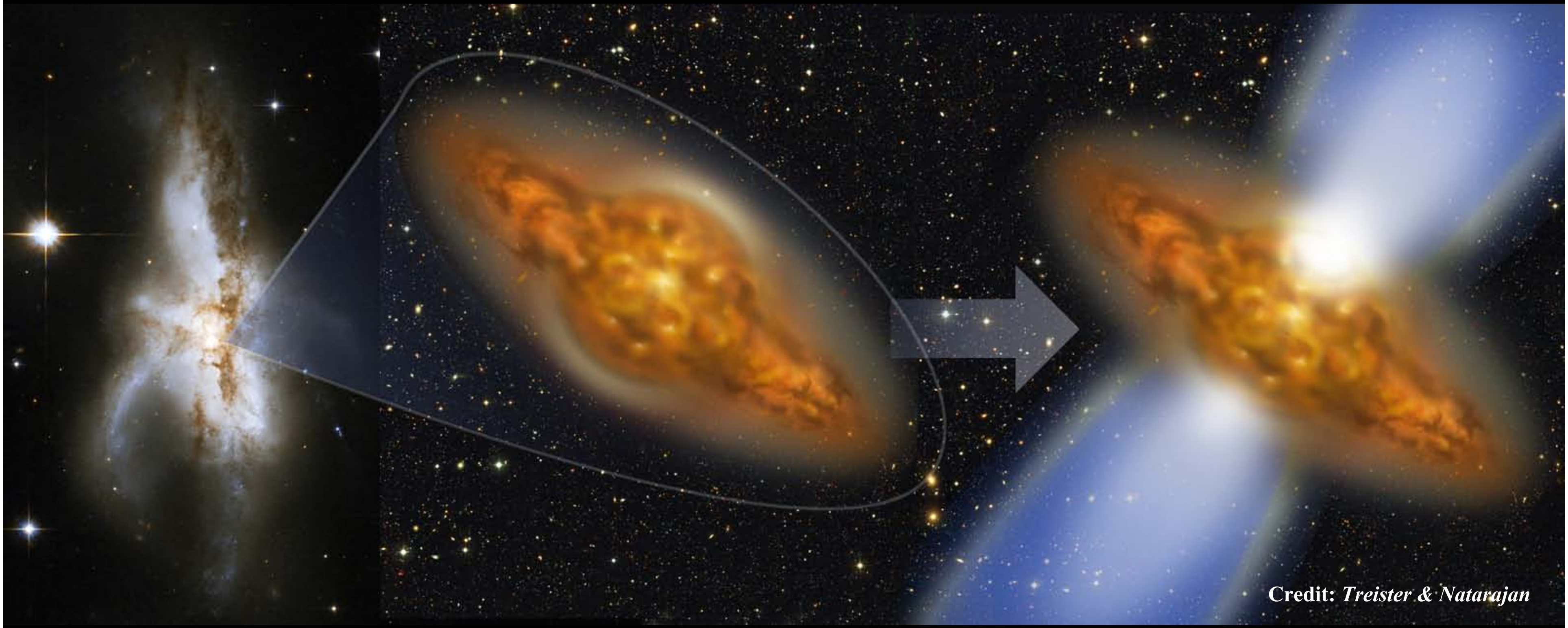
Super-massive Black Holes Across the Cosmic History



Ezequiel Treister

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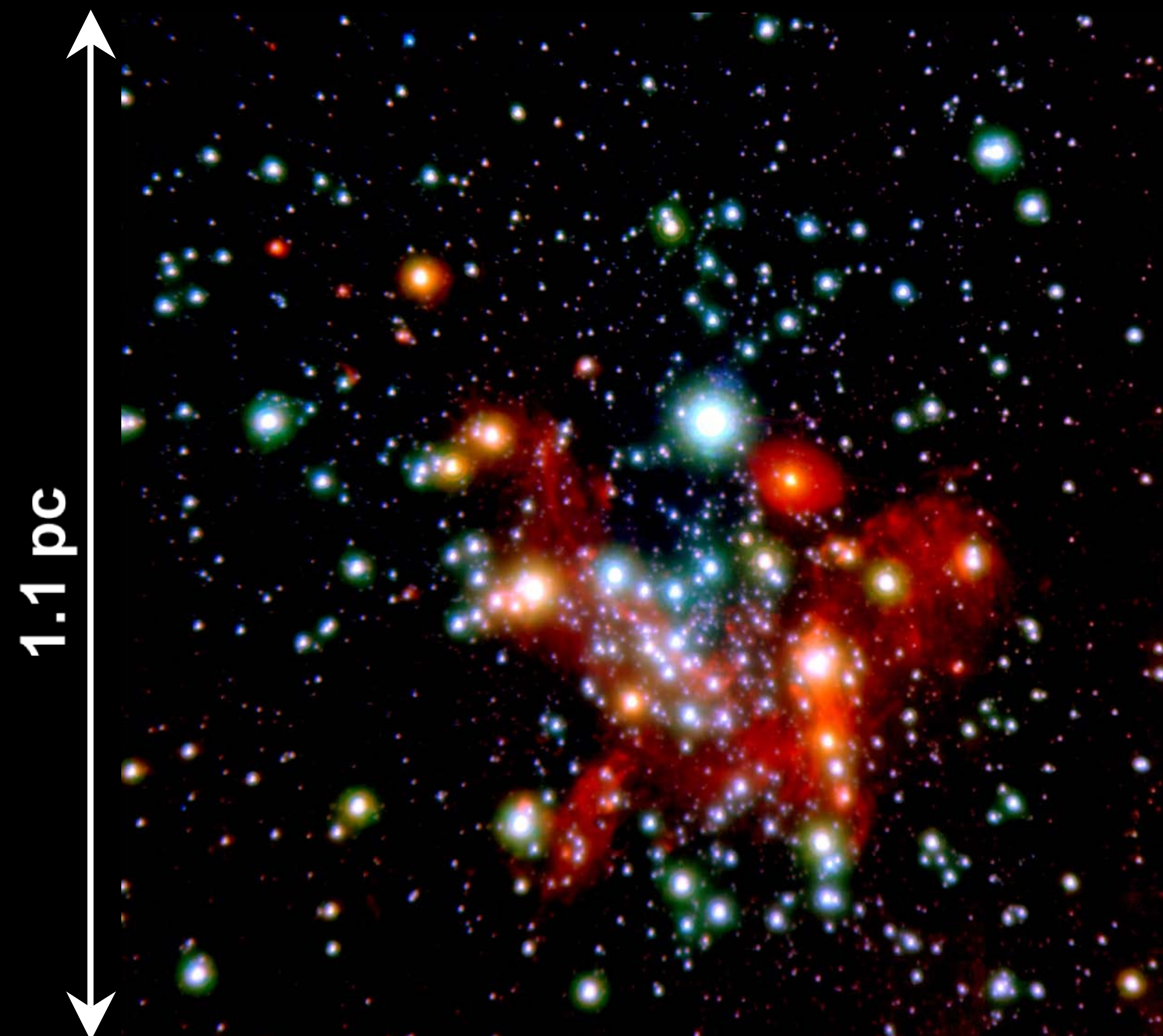
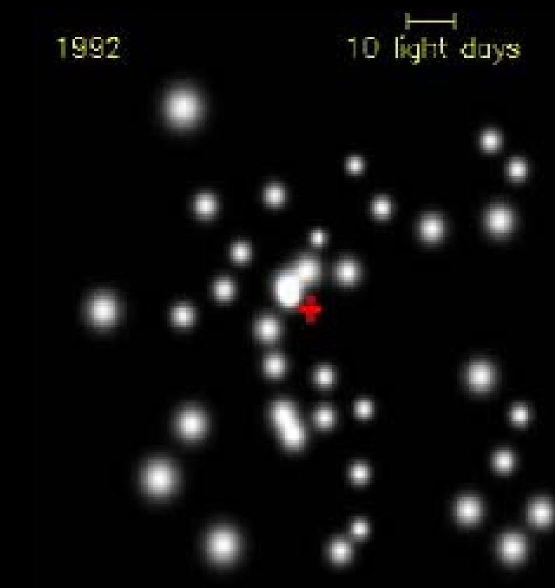
Collaborators: Meg Urry, Priya Natarajan, Kevin Schawinski (Yale), Carie Cardamone (MIT), Eric Gawiser (Rutgers), Dave Sanders (IfA), Marta Volonteri (Michigan)

Galactic Center

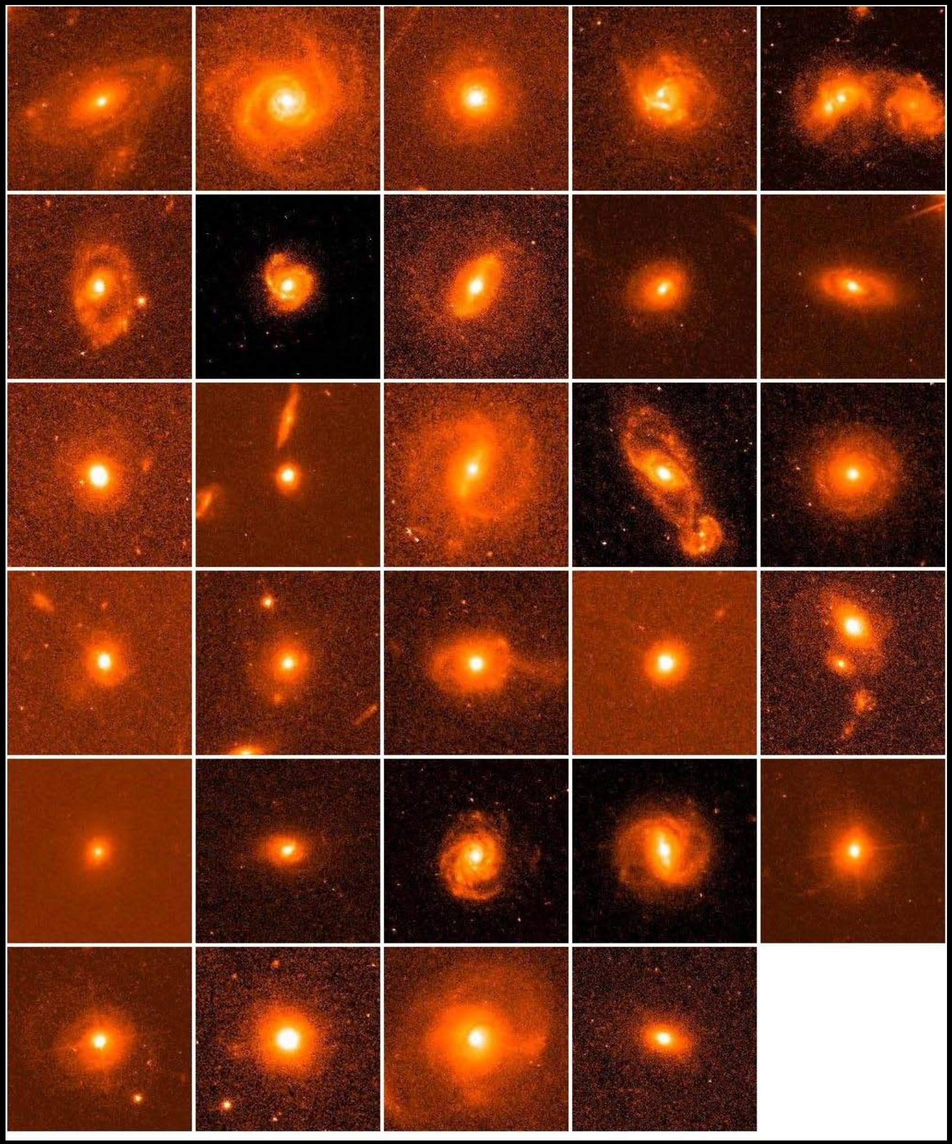




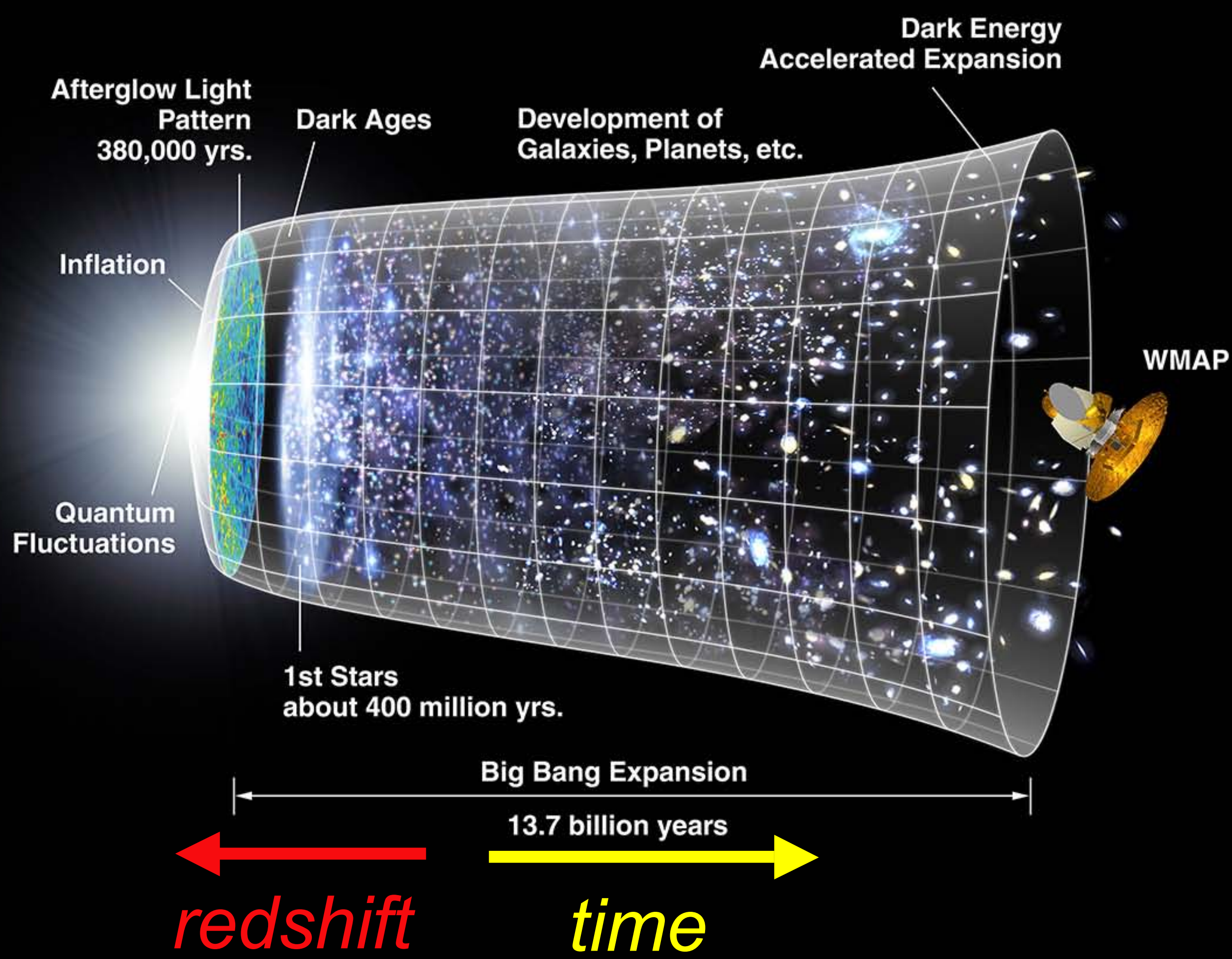
Mass: $4 \times 10^6\ M_{sun}$

Credit: Galactic Center Group at the University of Cologne

All (Massive) Galaxies have Super-Massive Black Holes



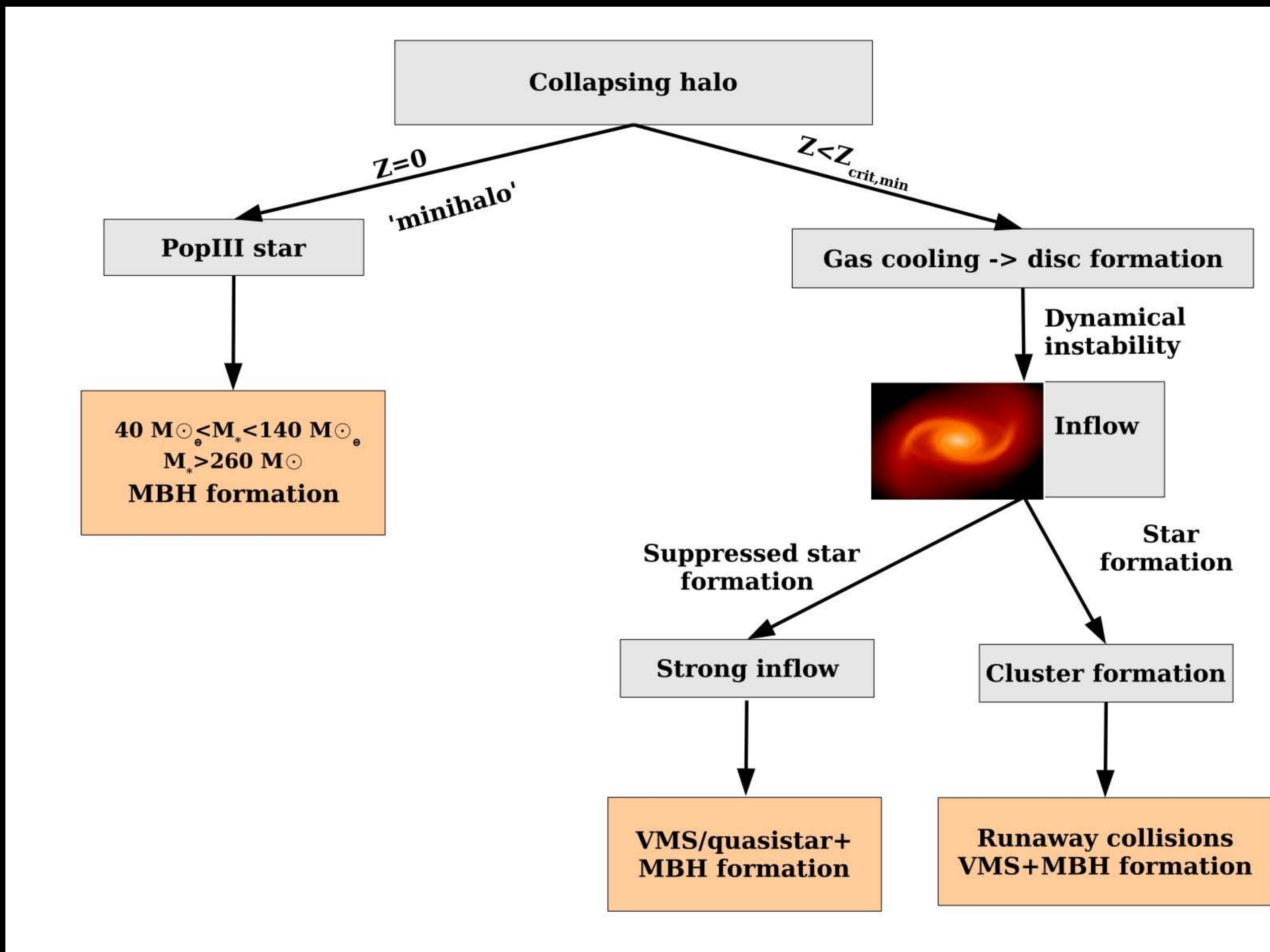
The First Black Holes



Credit: NASA / WMAP Science Team

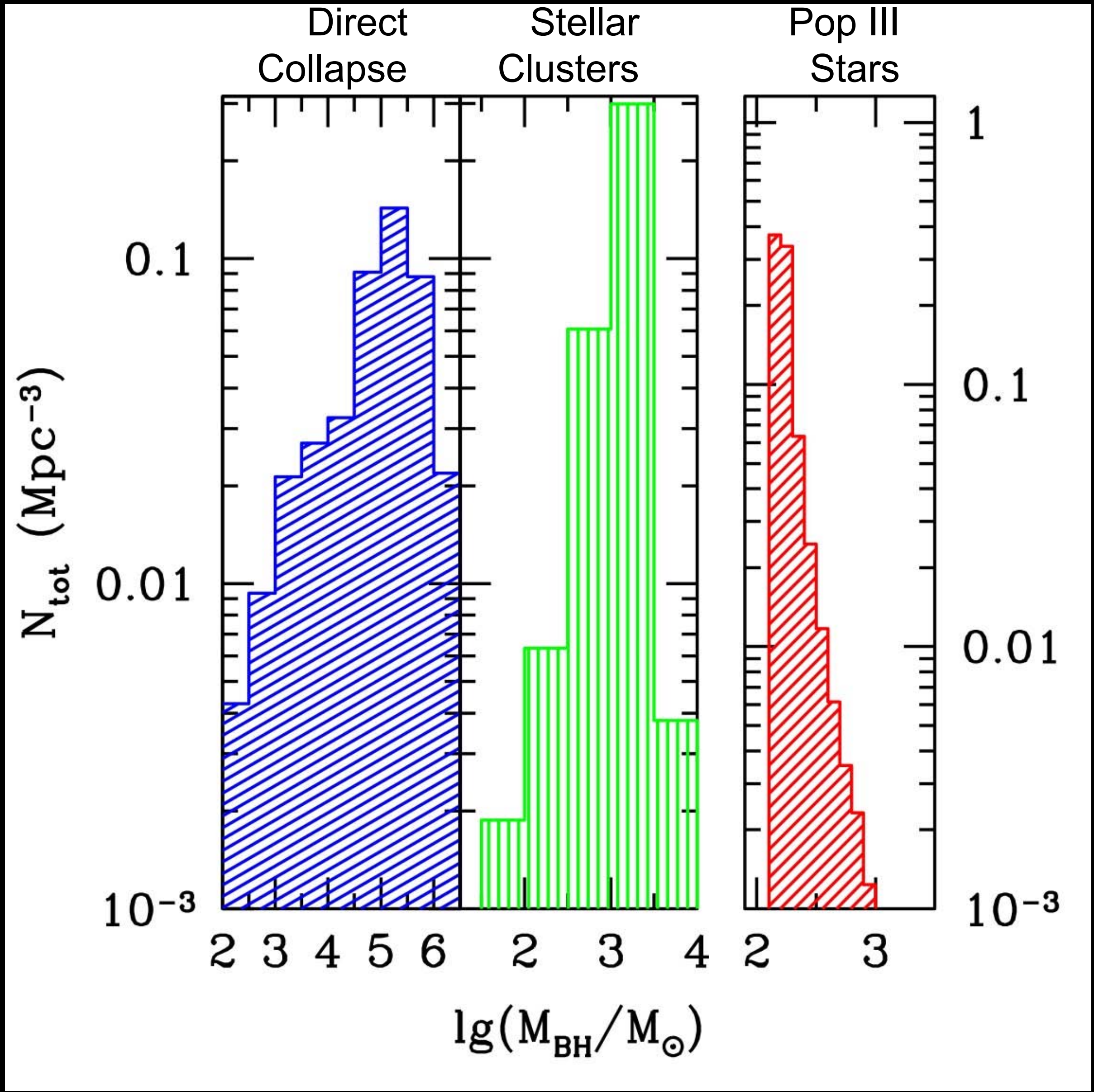
How to grow a SMBH?

The seeds:



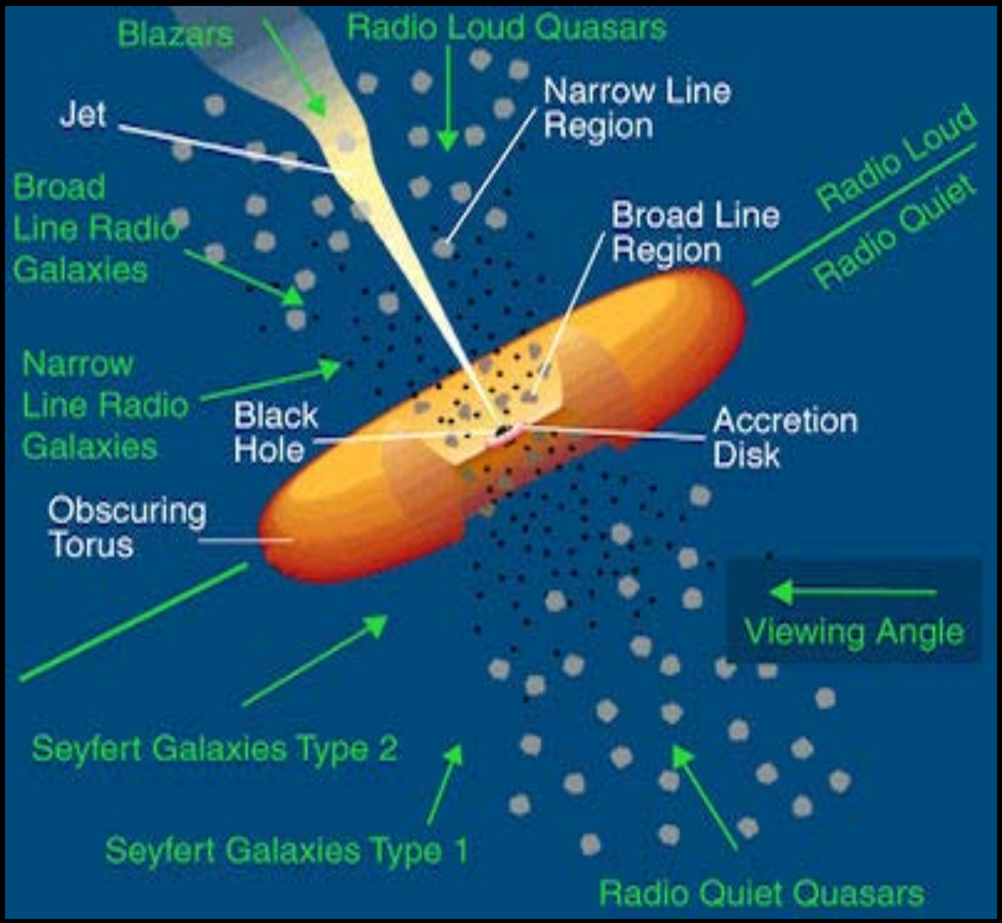
Volonteri (2010)

Seed Mass Functions



Volonteri (2010)

Further SMBH Growth: Active Galactic Nuclei (AGN)



Black hole:
10^{6}-10^{10} M_{sun}

Accretion disk:
- ~10^{-4}-10^{-2} pc (from variability)

Torus:
- 10^{5}-10^{7} M_{sun}
- ~few parsec (from IR spectrum)
- Geometry unknown
- Source of nuclear obscuration

Urry & Padovani (1995)

Black hole-Galaxy Connection

- ✓**All (massive) galaxies have black holes**
- ✓Tight correlation of M_{BH} with σ
- ✓Common BH/SFR Evolution
- ✓AGN feedback important

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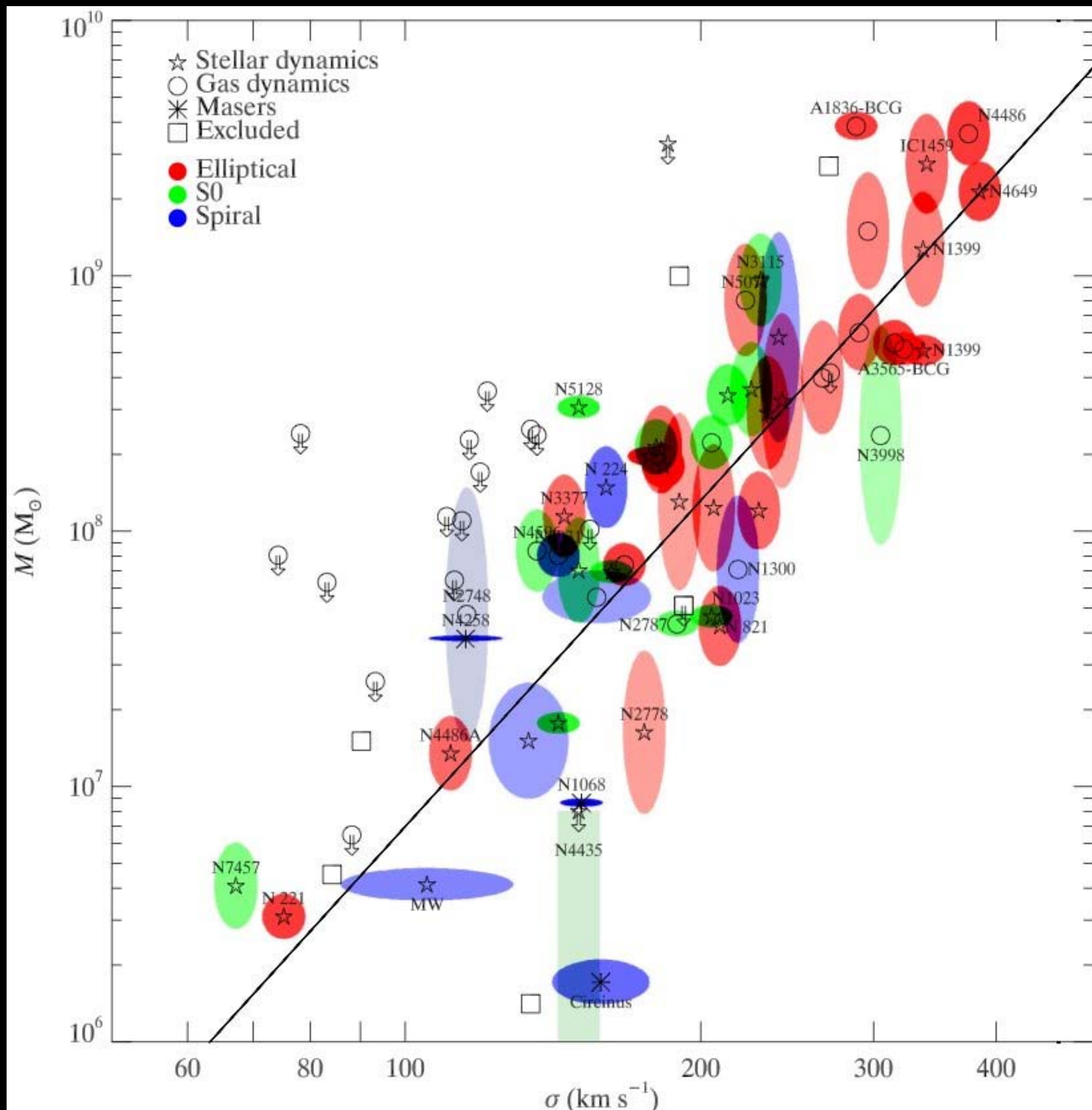
M-σ Relation

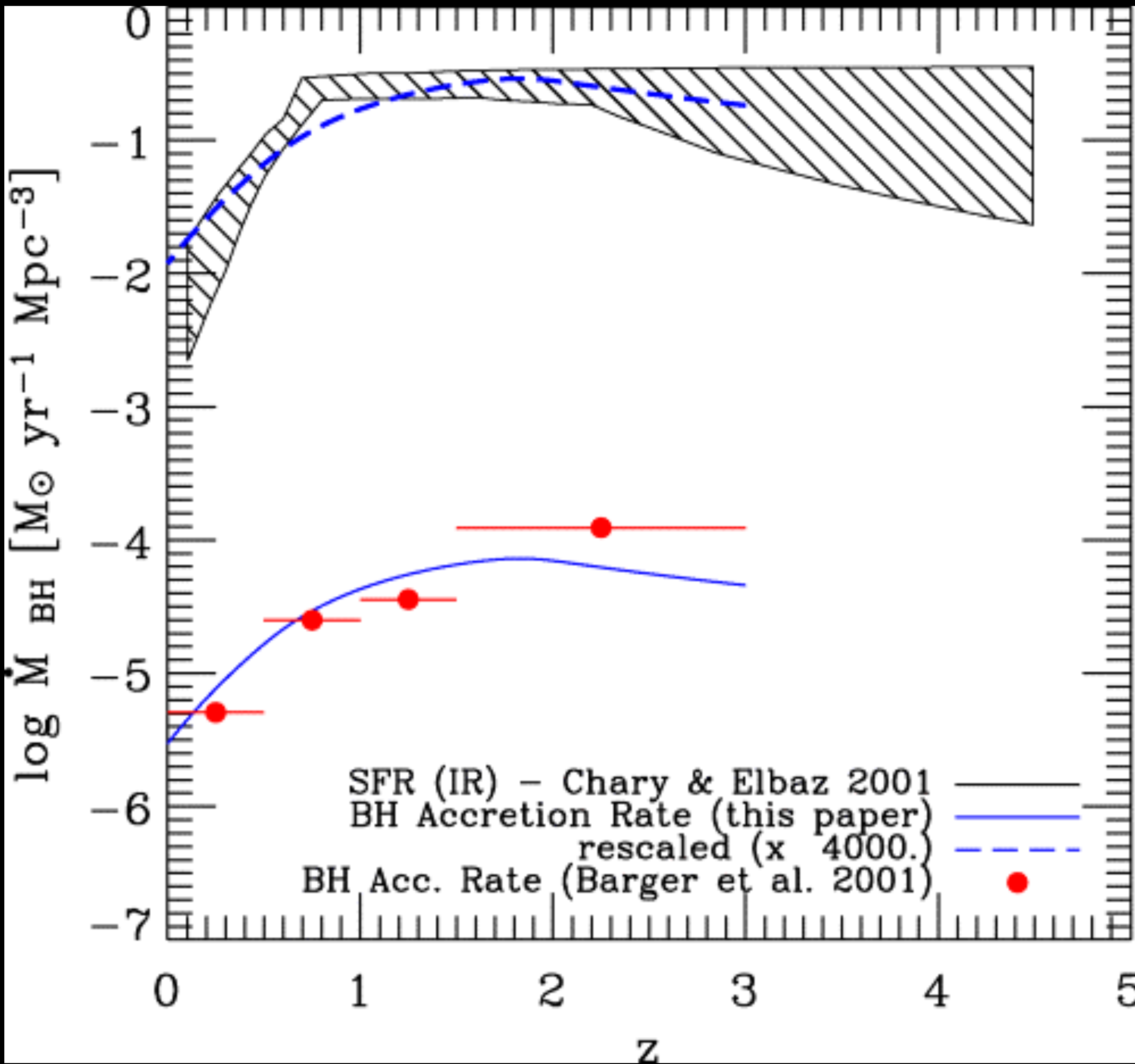


Gueltekin et al. (2009)

Black hole-Galaxy Connection

- ✓ All (massive) galaxies have black holes
- ✓ Tight correlation of M_{BH} with σ
- ✓ **Common BH/SFR Evolution**
- ✓ AGN feedback important

Common BH/Star Formation Evolution



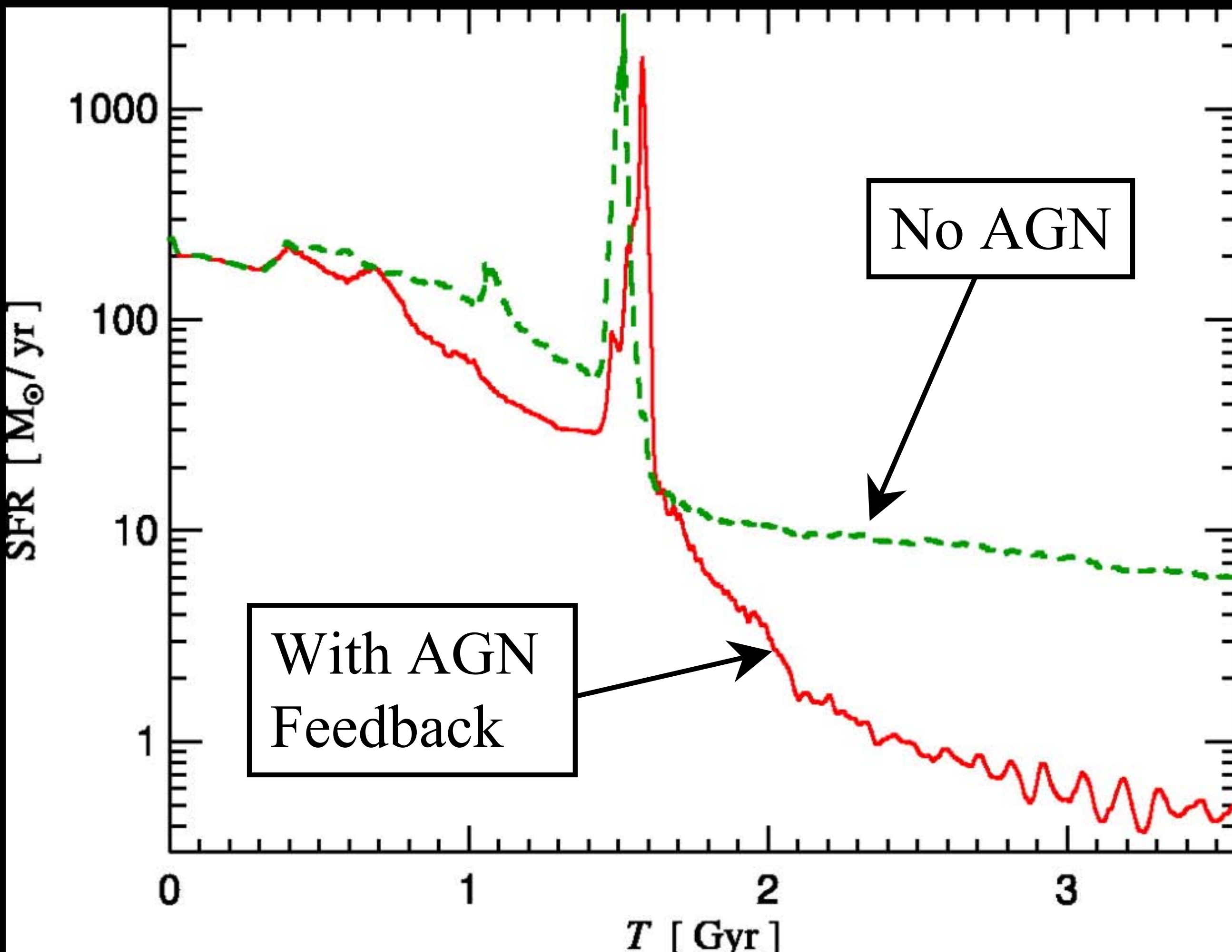
Both peak at z~2 and decline at low z.

Marconi et al. 2004

Black hole-Galaxy Connection

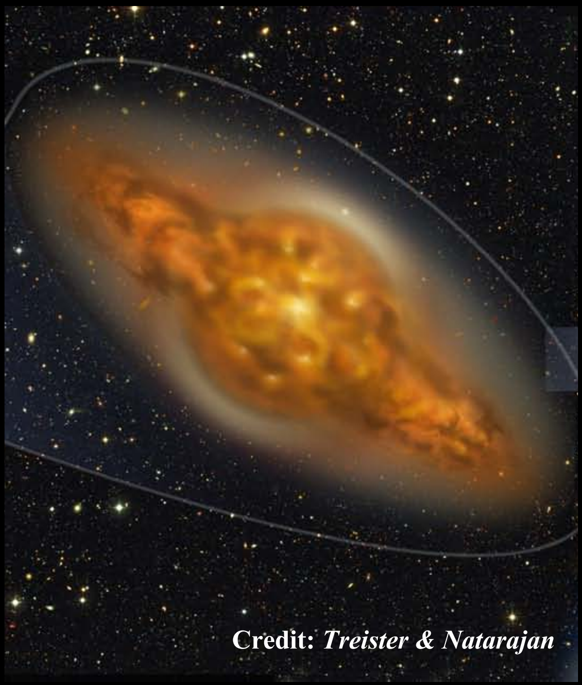
- ✓ All (massive) galaxies have black holes
- ✓ Tight correlation of M_{BH} with σ
- ✓ Common BH/SFR Evolution
- ✓ **AGN feedback important**

AGN Feedback



Springel et al. 2005

Obscured Accretion



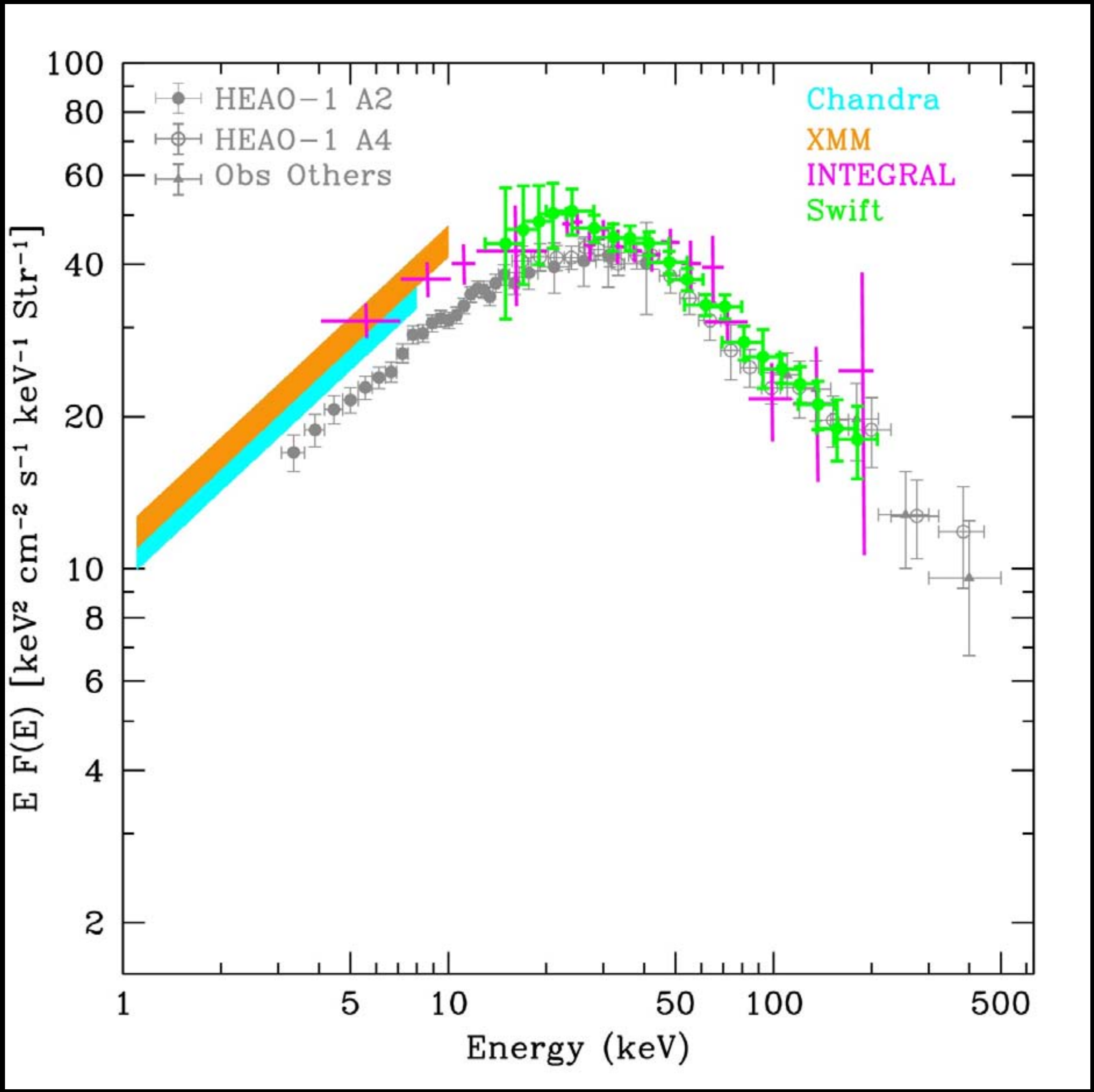
- Critical stage of BH-galaxy connection.
- Occurs when galaxies form most of their stars.
- Can represent up to 50% of matter accretion onto the central black hole.

How do we know that?

→ **Local AGN Unification**

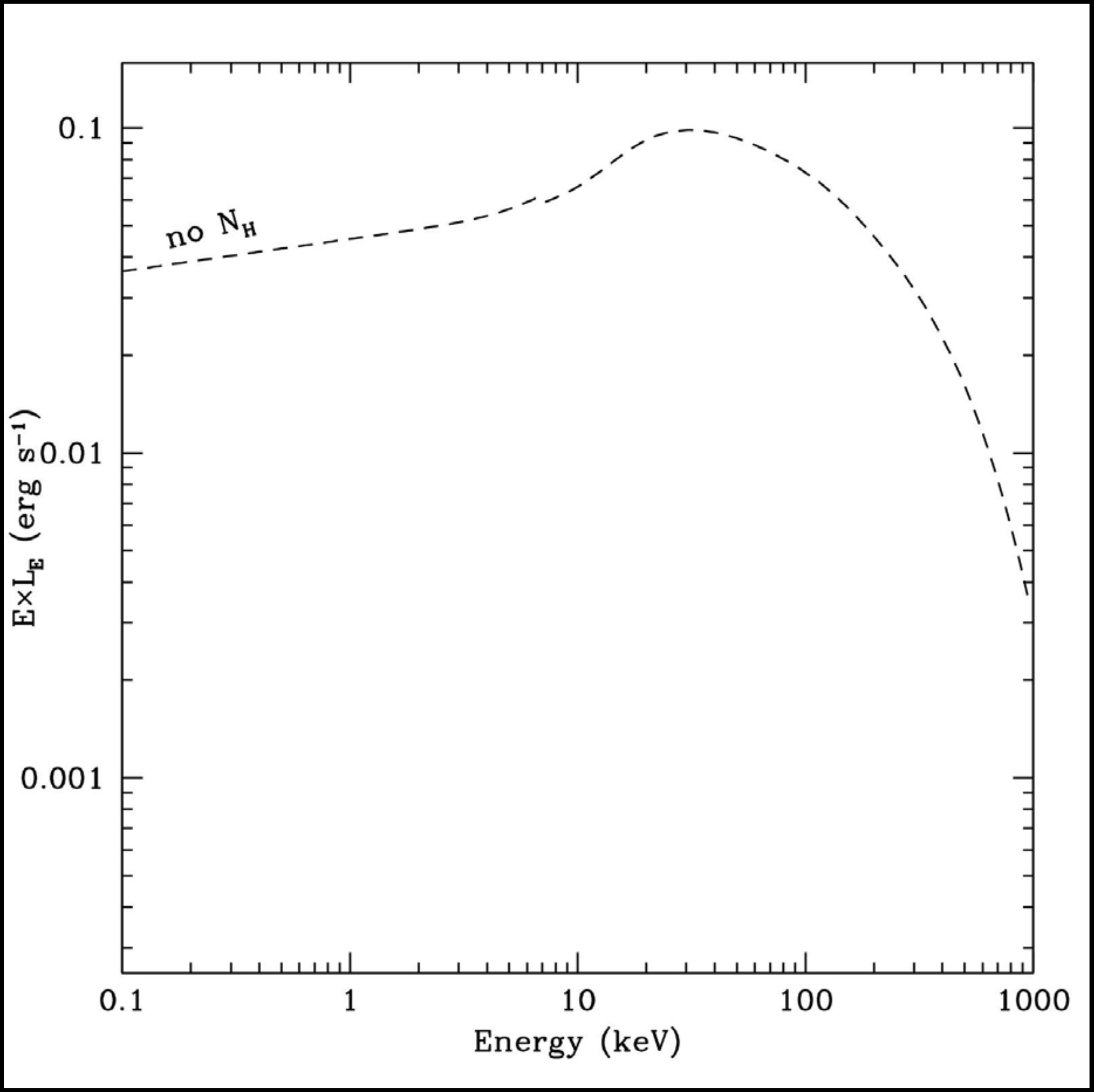
→ **Explain Extragalactic X-ray "Background"**

Observed X-ray "Background"



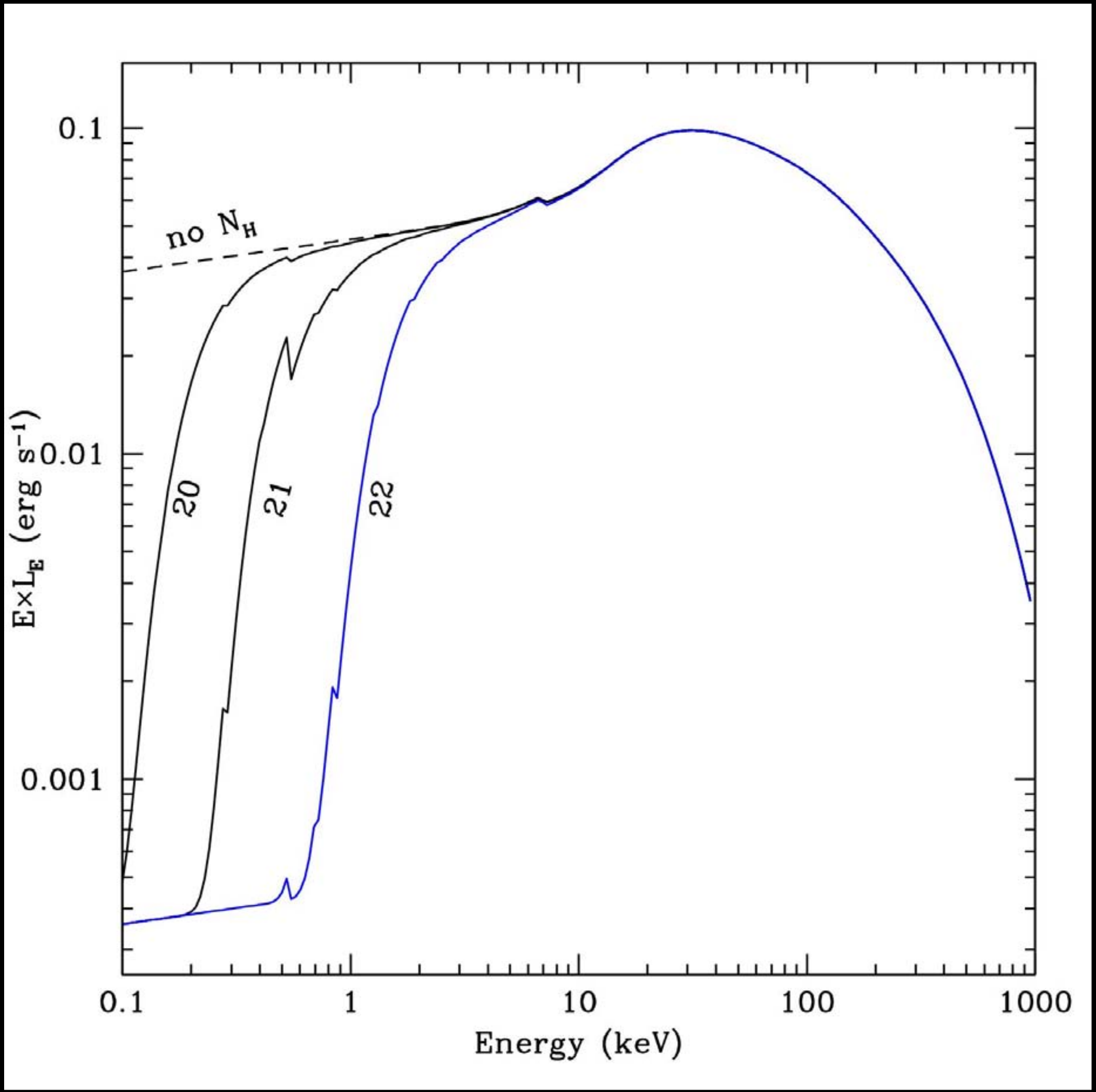
Treister et al. 2009

AGN in X-rays



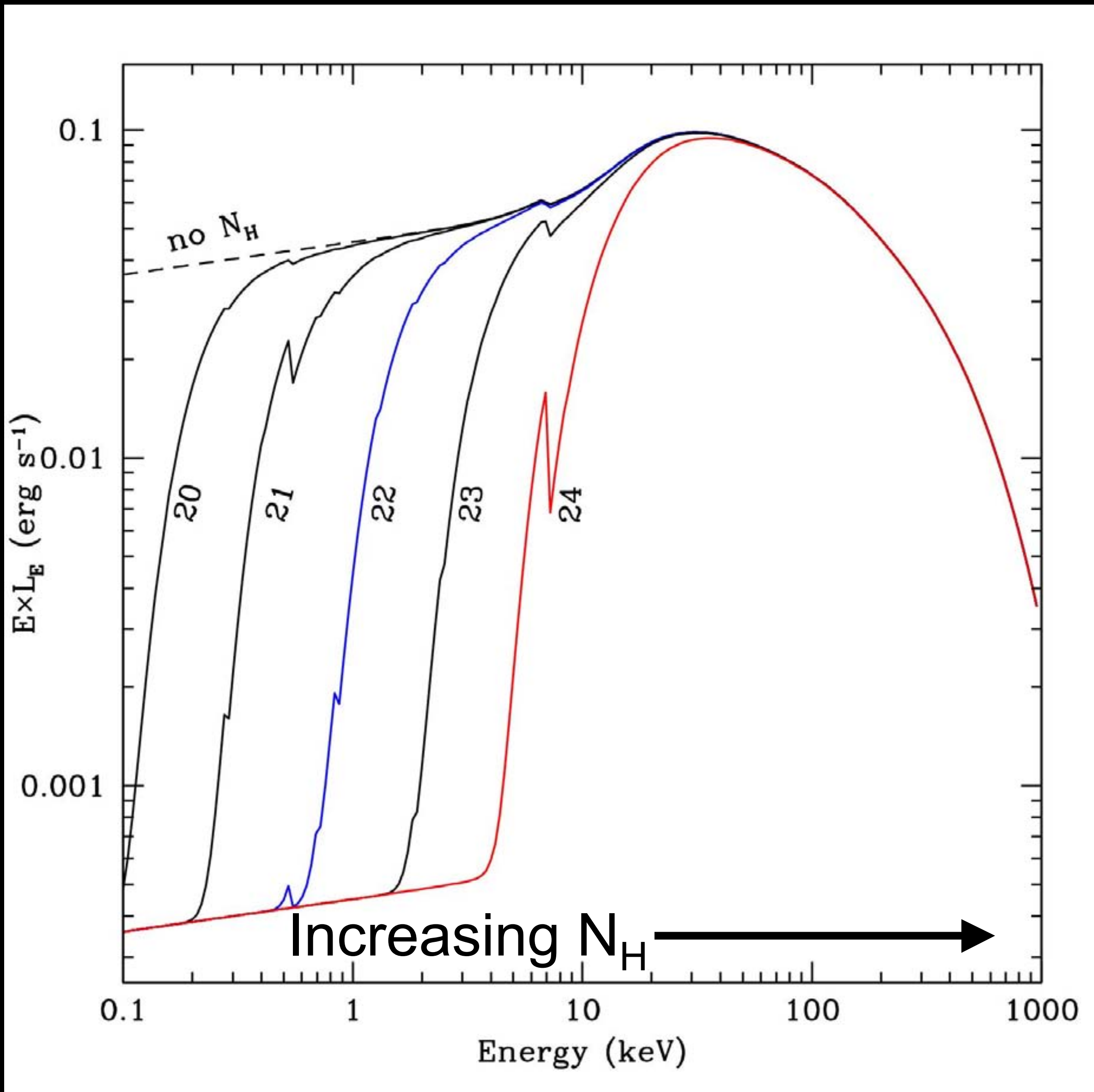
X-ray spectrum of unobscured AGN much softer than X-ray background.

AGN in X-rays



Photoelectric absorption affect mostly low energy emission making the observed spectrum look harder.

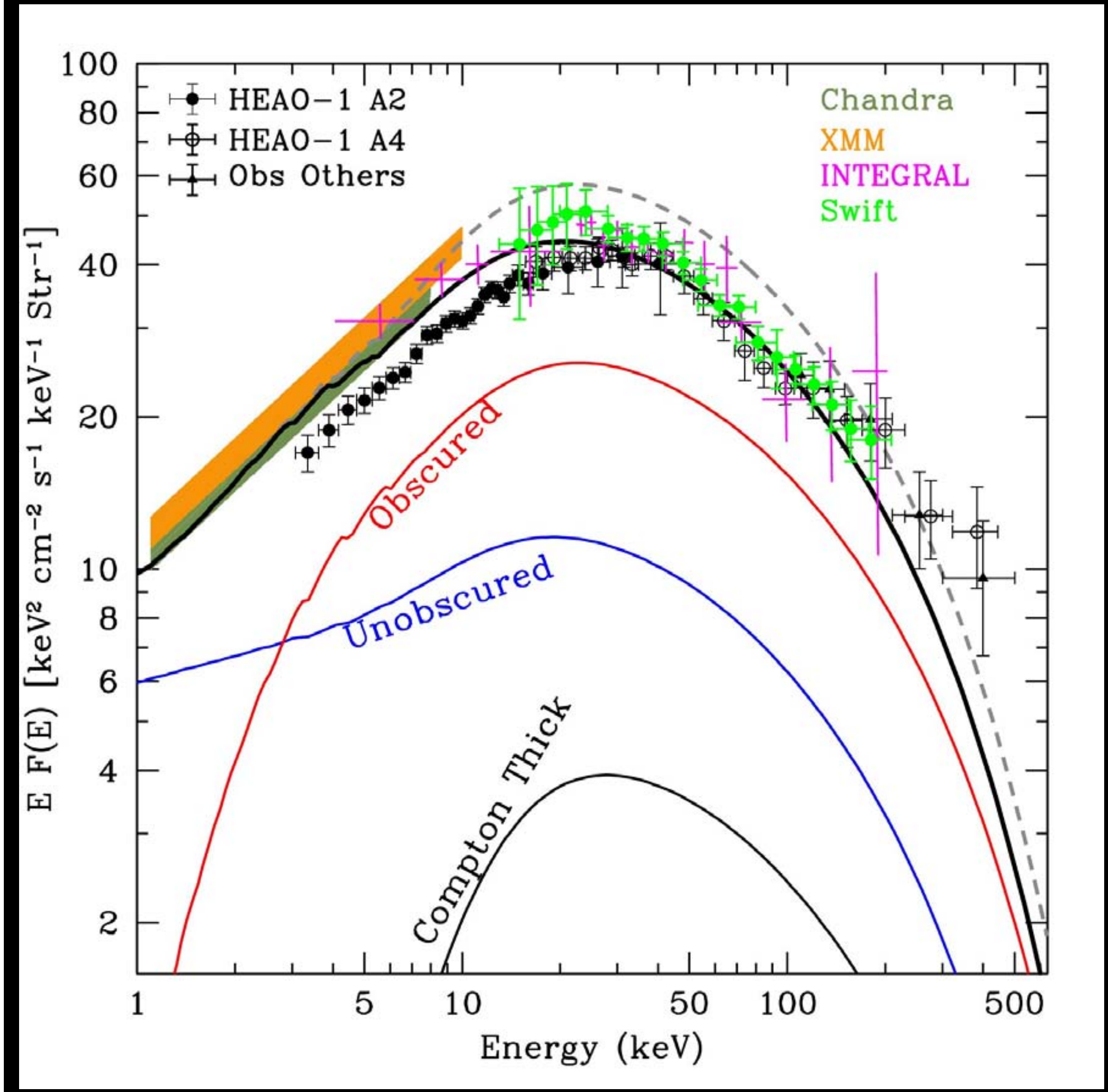
AGN in X-rays



Compton Thick AGN

- Defined as obscured sources with $N_H > 10^{24}$ cm^{-2}.
- Very hard to find (even in X-rays).
- Observed locally and needed to explain the X-ray background.
- Number density highly uncertain.

X-ray Background



Treister et al. 2009

XRB well explained using a combination of obscured and unobscured AGN.

- Setti & Woltjer 1989
- Madau et al. 1994
- Comastri et al. 1995
- Gilli et al. 1999,2001
- Ueda et al. 2003
- Treister & Urry 2005
- Gilli et al. 2007
- And others…

Only 0.1% of the XRB comes from CT AGN in the local Universe.

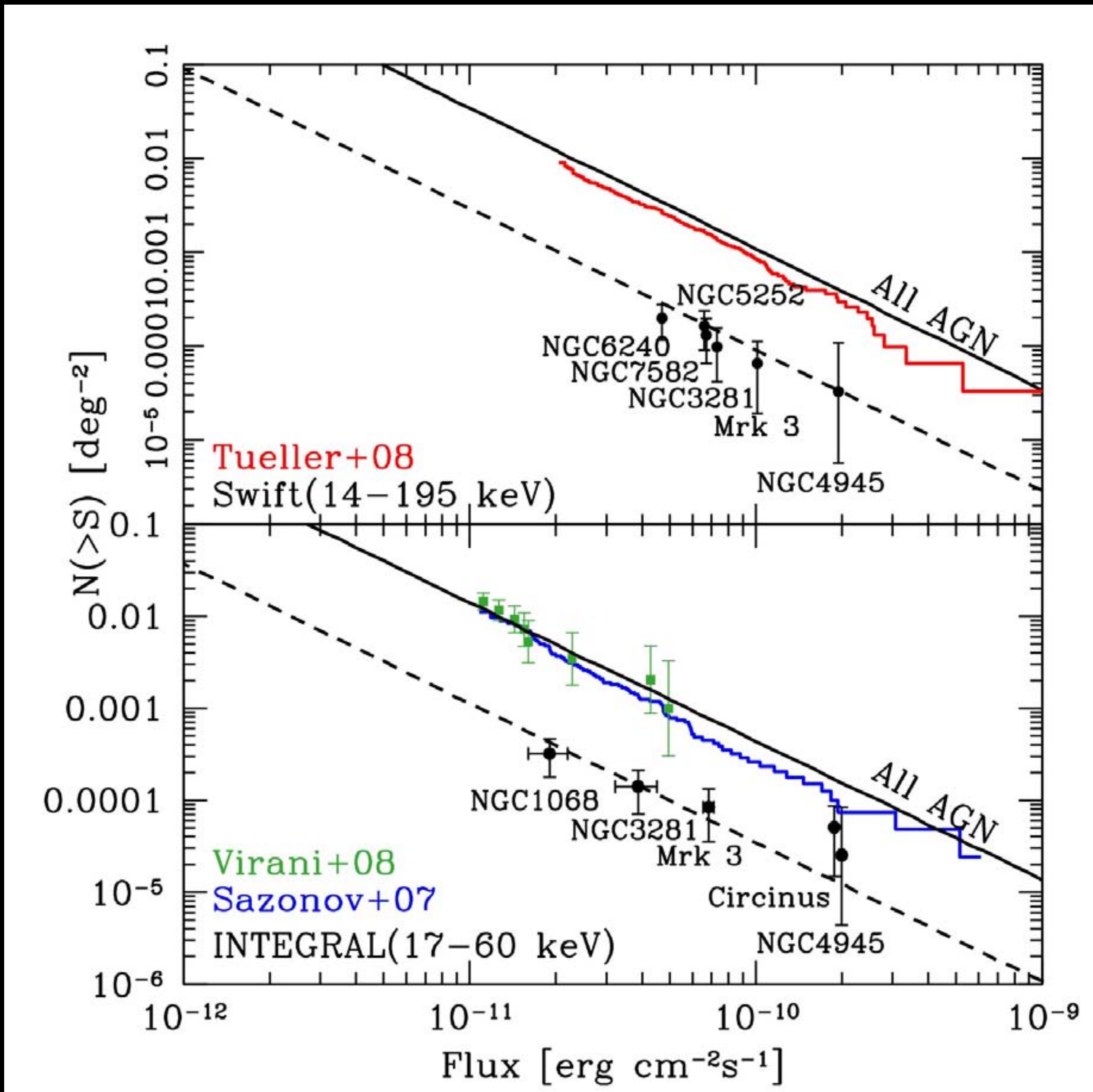
XRB not useful to constrain CT AGN at z>1

Local Universe (z~0)

Swift

INTEGRAL

Log N-Log S



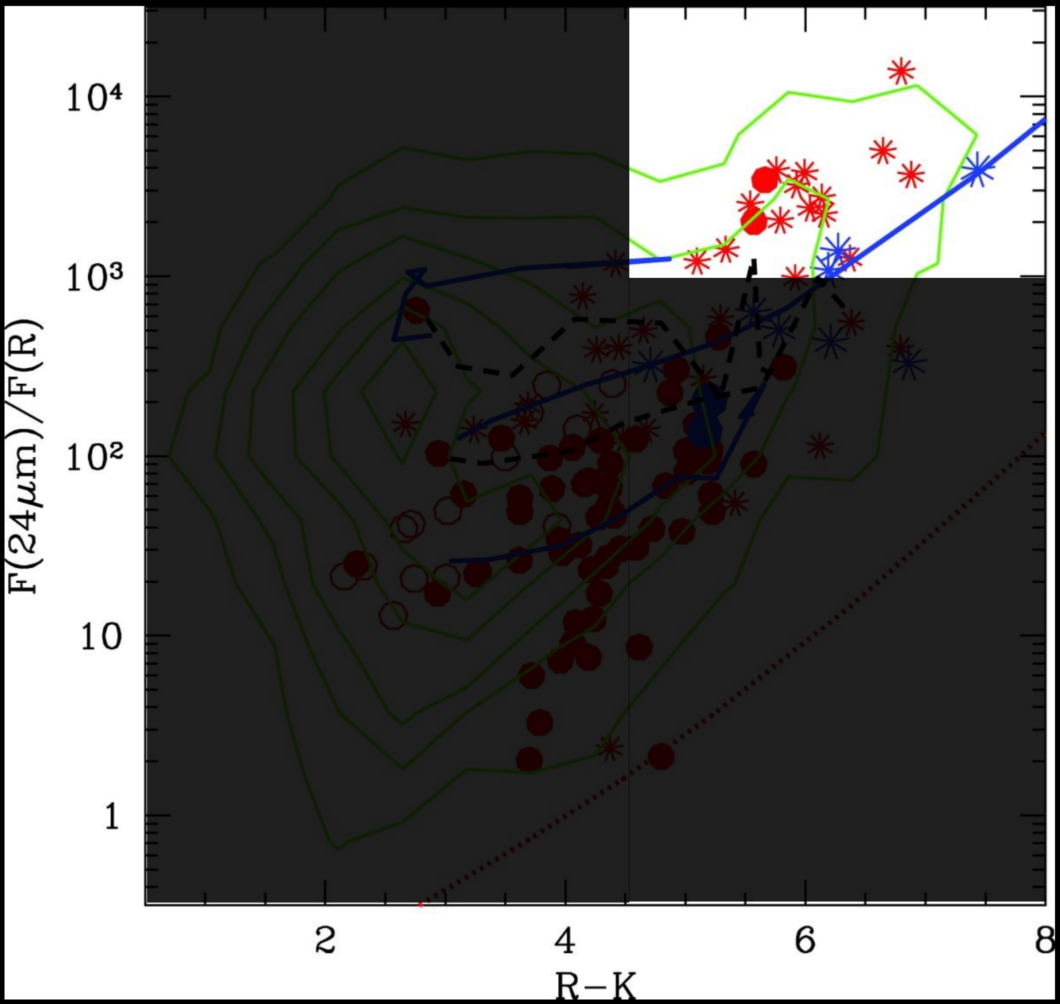
CT AGN fraction ~7%

Significantly lower than previous XRB pop. synthesis models

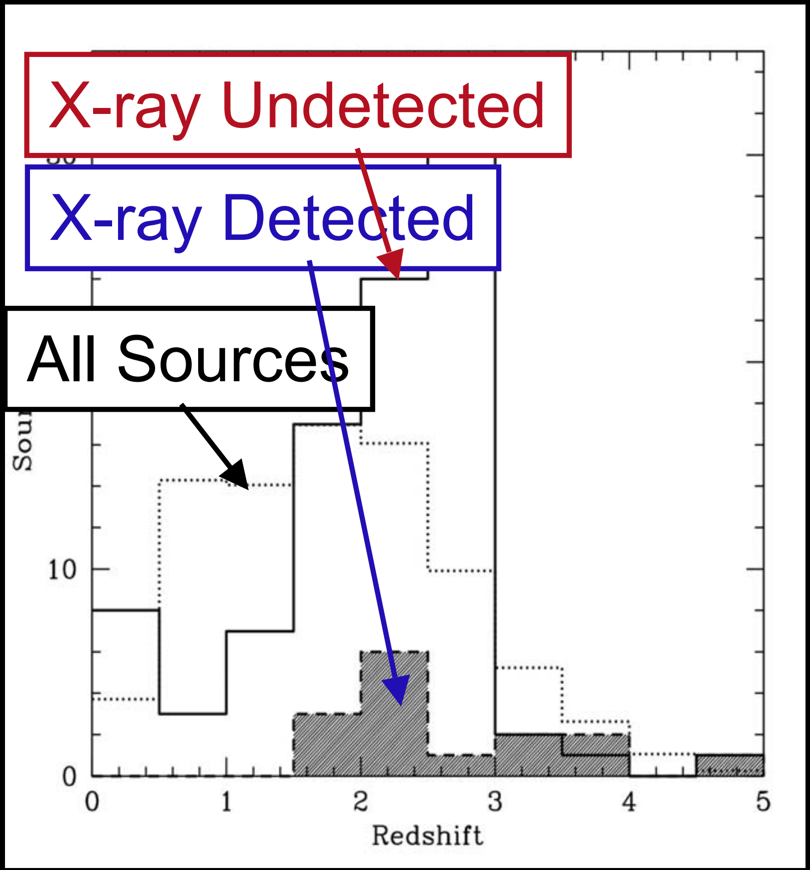
Consistent with more recent measurement 4.6% (Burlon+10)

Treister et al. 2009

Intermediate Redshifts (z~1-3)
Mid-IR Selection

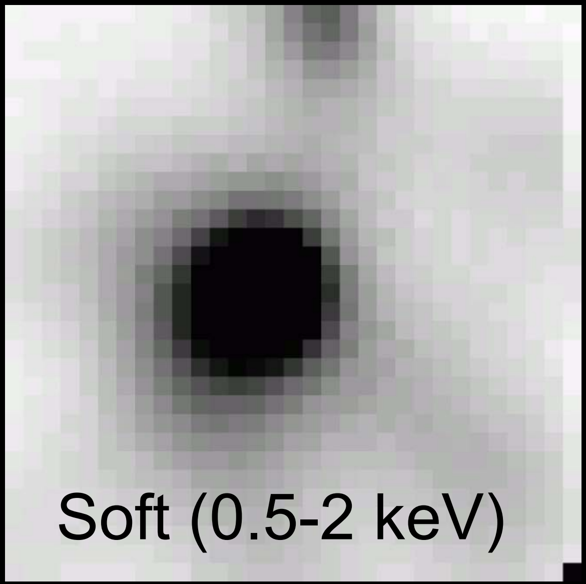


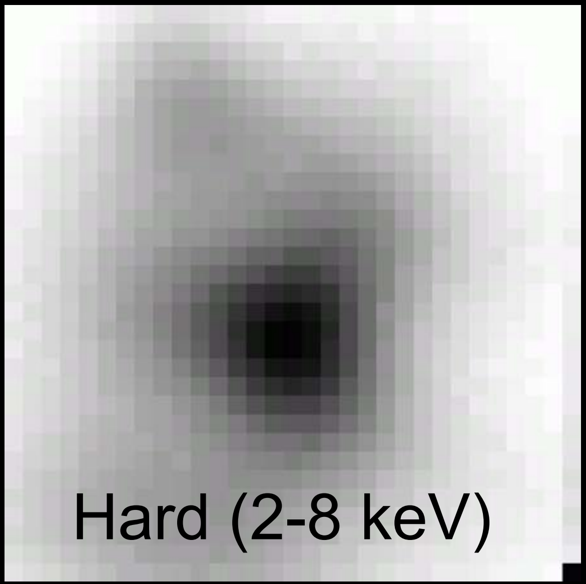
• This technique selects mostly high luminosity sources (quasars)



Fiore et al. 2008, Treister et al. 2009b

Stacking of $f_{24}/f_R > 10^3$ Sources

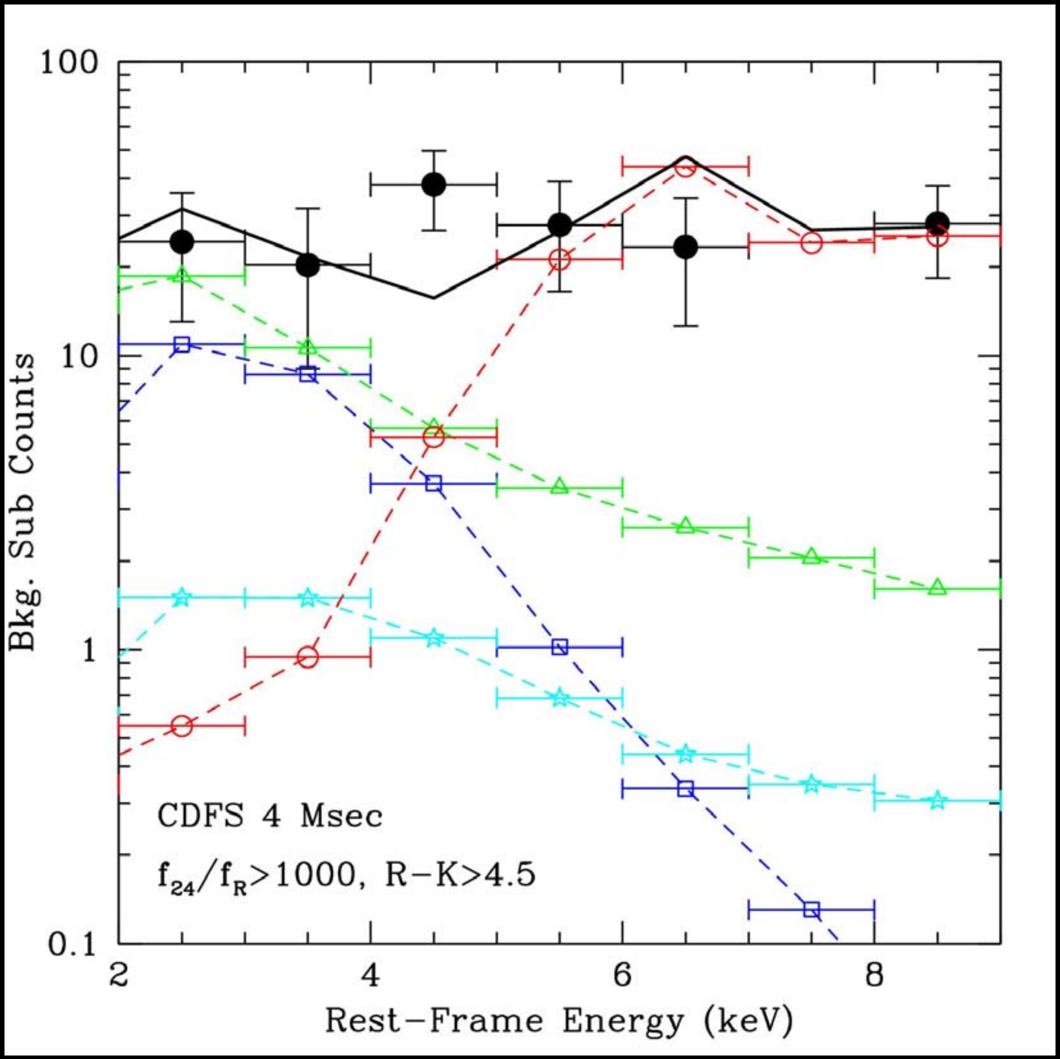




- ~4σ detection in each band
- $f_{soft}=2.1\times10^{-17}$ erg cm^{-2}s^{-1}. $f_{hard}= 8\times10^{-17}$ erg cm^{-2}s^{-1}
- Sources can be detected individually in ~10 Msec

Treister et al. 2009b

Rest-Frame Stacking

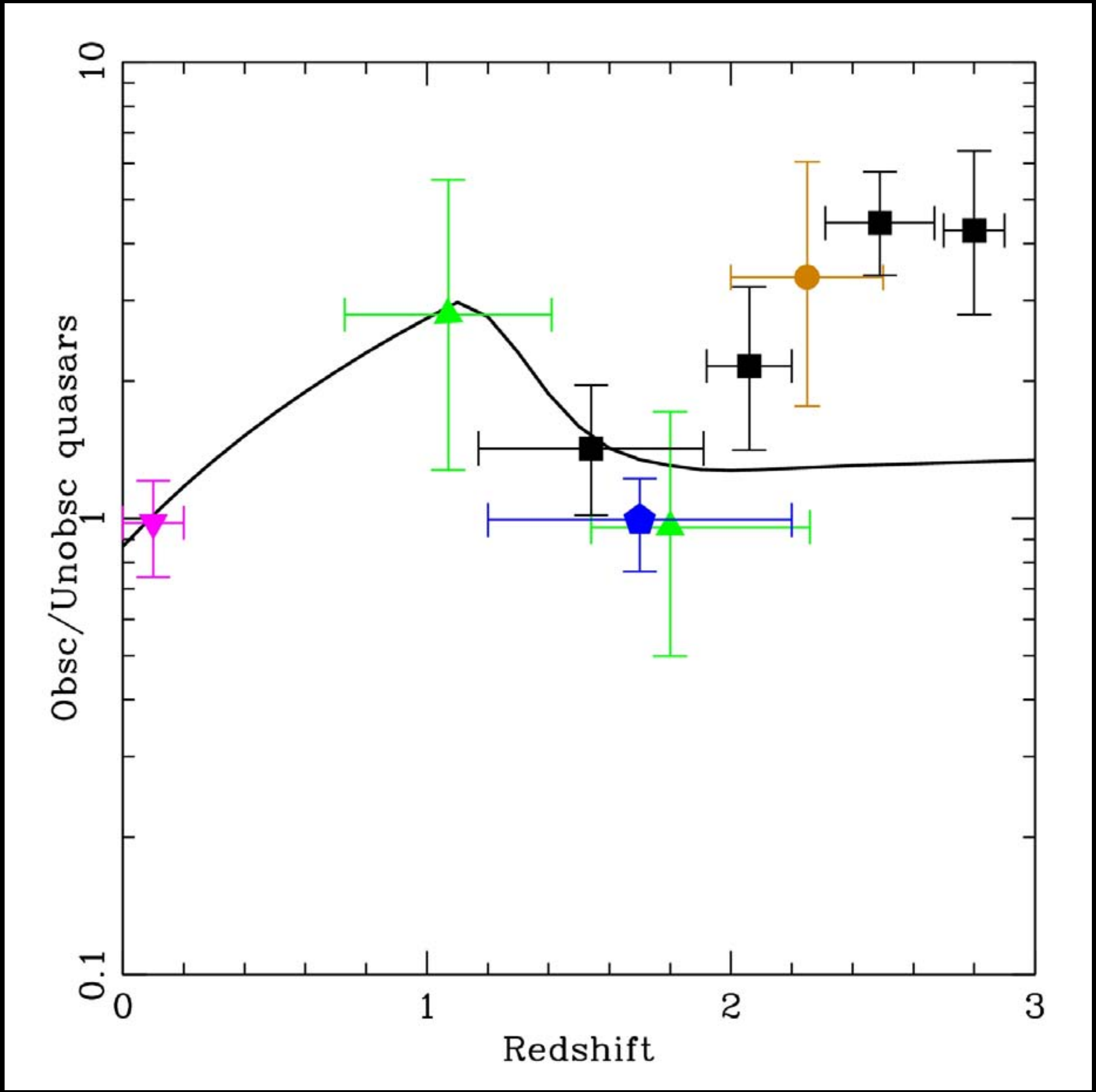


$N_H = 10^{24} cm^{-2}$ $\Gamma = 1.9$
$\Gamma = 1.9$ (reflected)
Thermal kT=0.7 keV
HMXBs

Combination of heavily-obscured AGN and star-formation

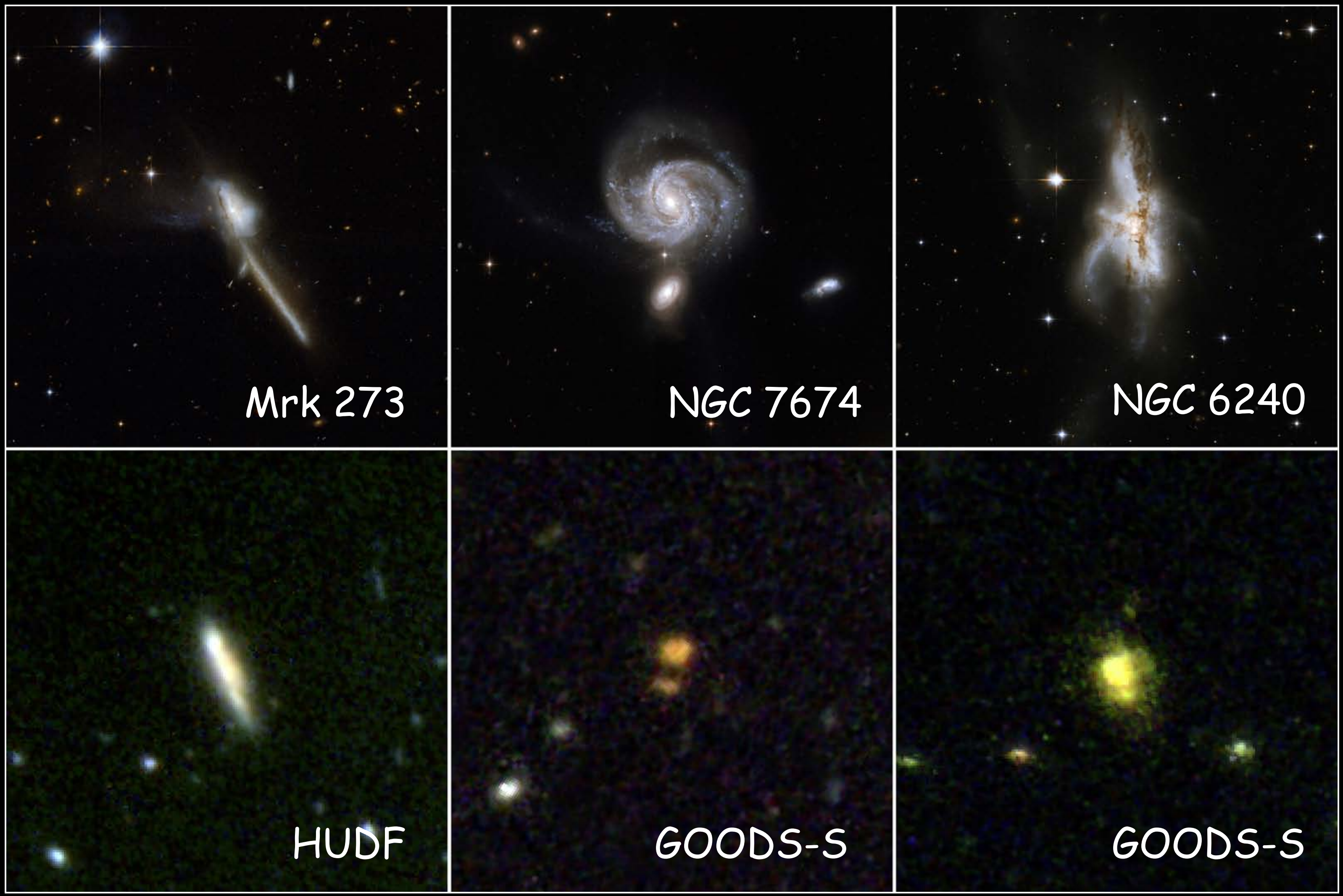
Treister et al. 2009b

The Merger-Quasar Connection



Treister et al. 2010a

Morphologies

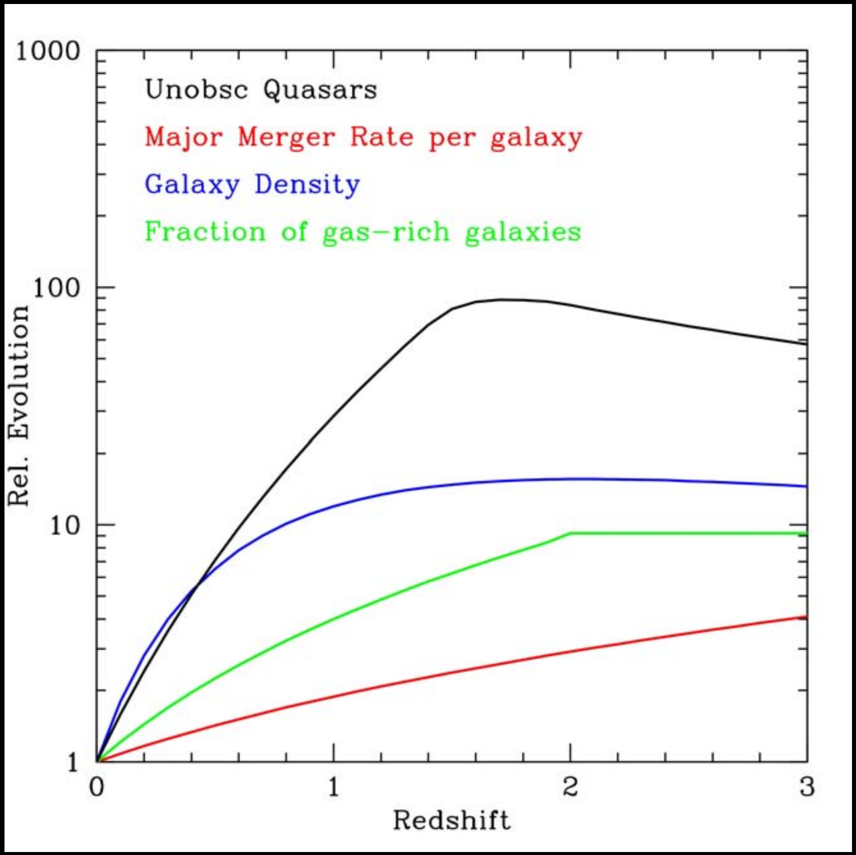


Treister et al. 2010a

Merger-Quasar Connection

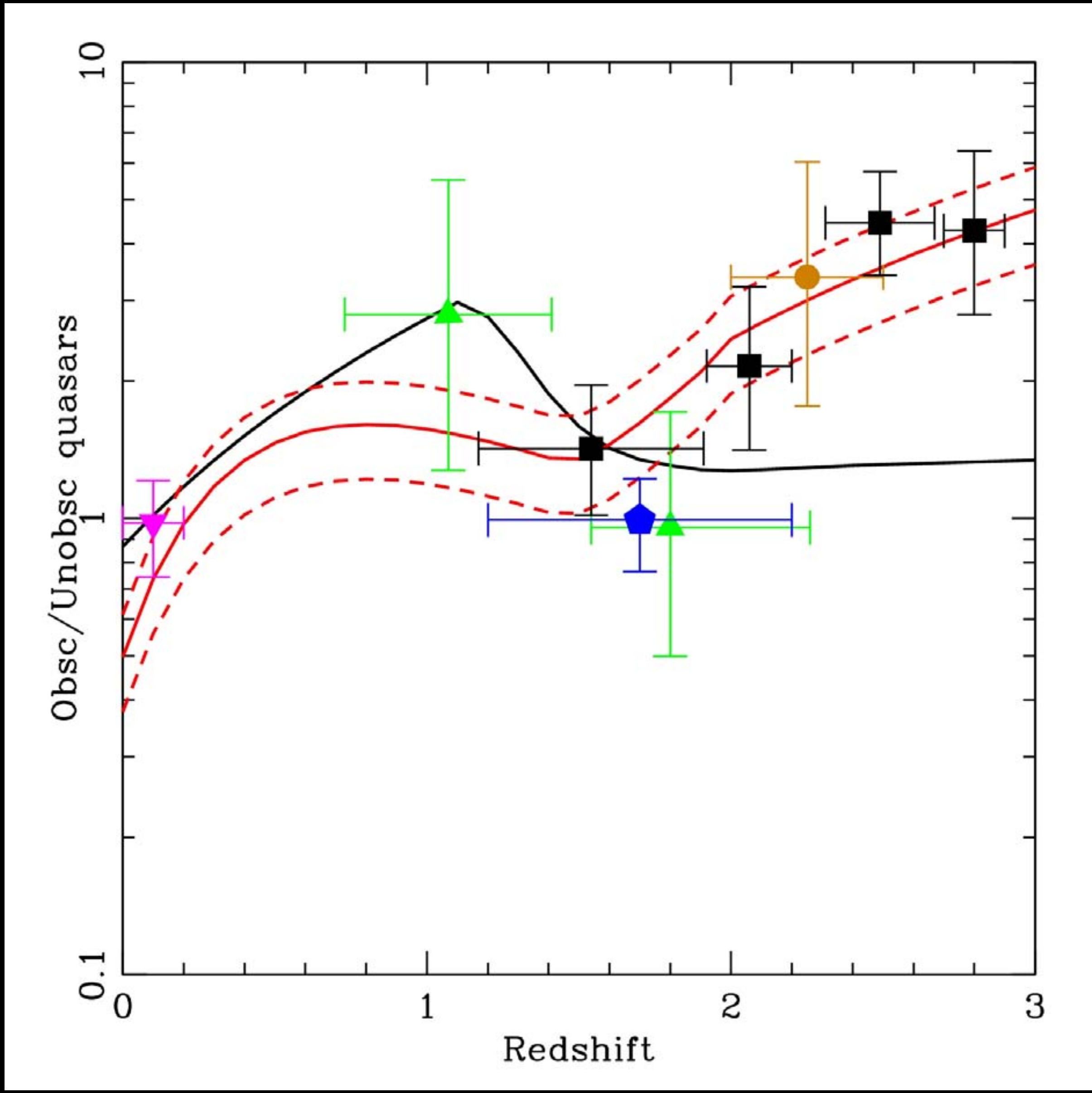
Obscured quasars are the product of the merger of two massive gas-rich galaxies. After a time Δt the quasar becomes unobscured

$$\frac{N_{obsc}}{N_{Unobsc}}(z) = \frac{\Delta t \frac{d^2 merger}{dtdN} N_{gal}(> M_{\min}(z)) f_{gas}(z)}{N_{Unobsc}(z)}$$



Treister et al. 2010a

The Merger-Quasar Connection



Treister et al. 2010a

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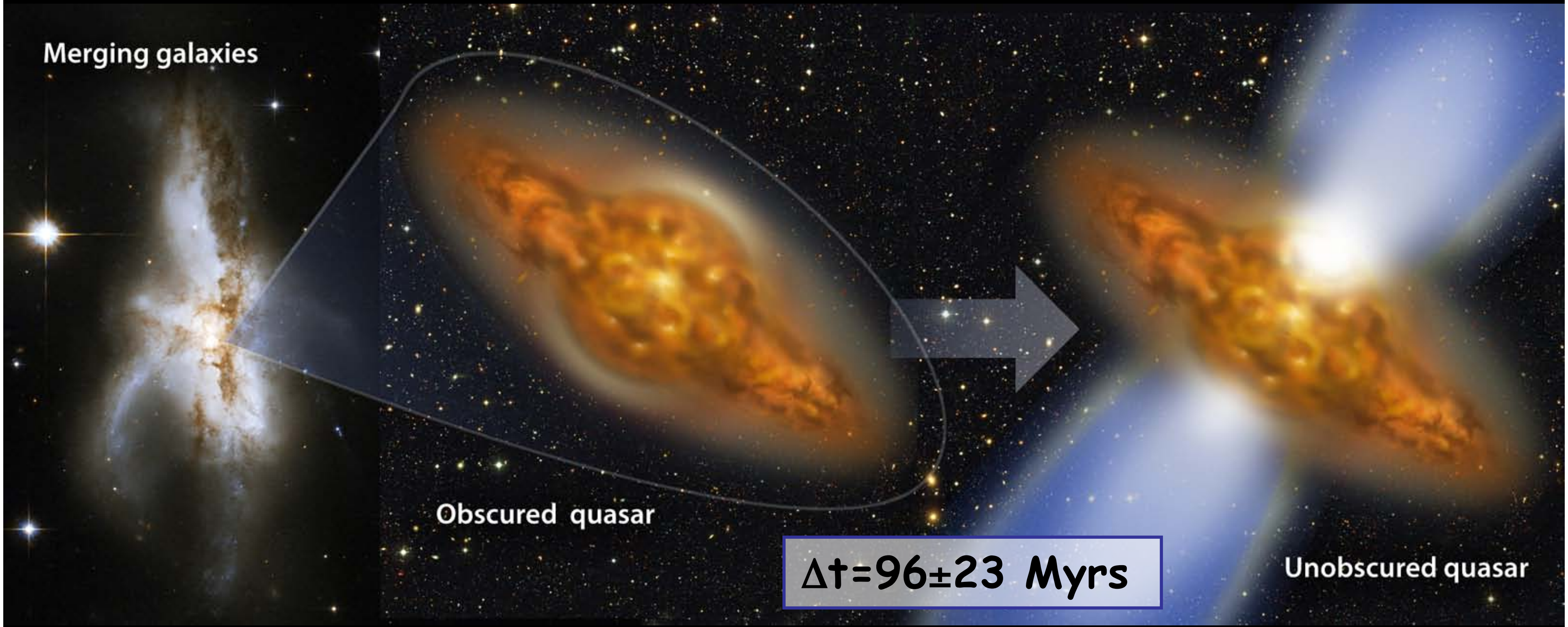


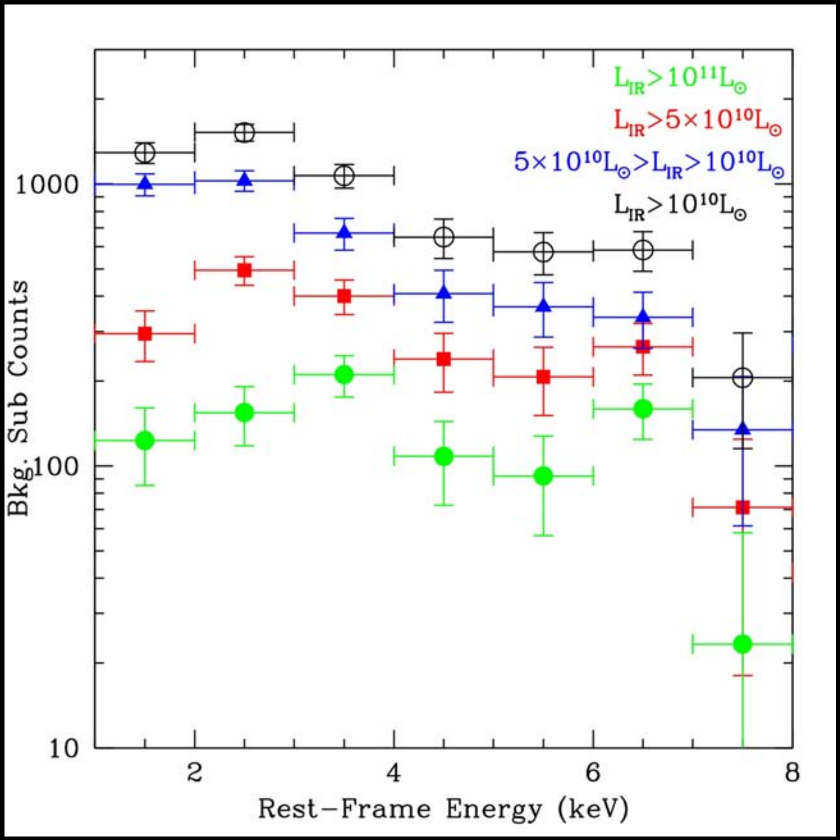
The obscured phase represents ~30% of total accretion onto supermassive black holes

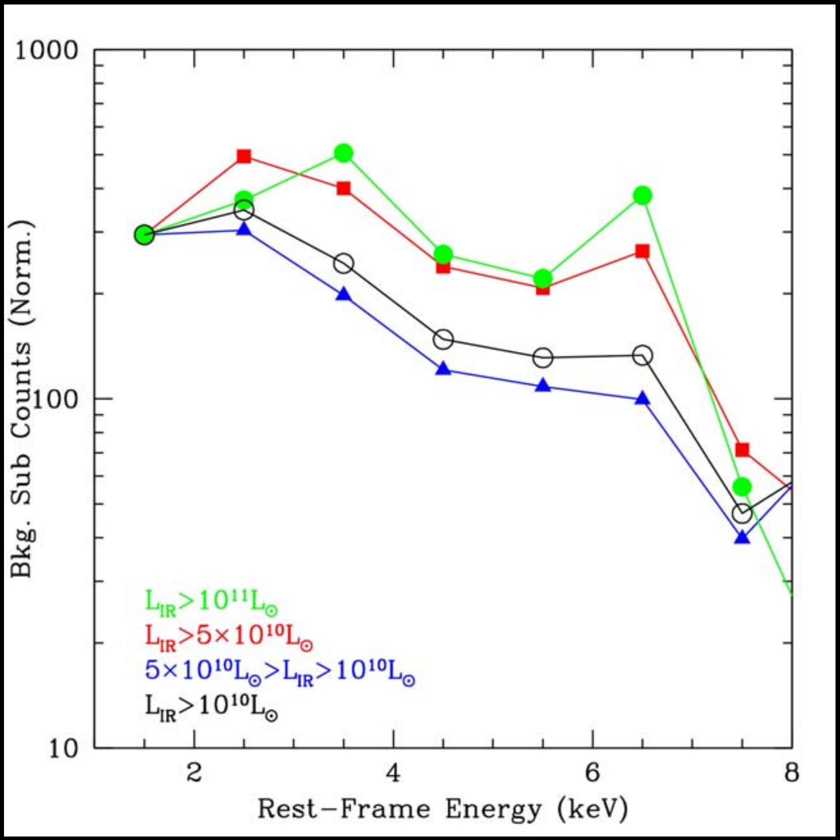
Quasars outflows can get rid of most of the surrounding material

Treister et al. 2010a

Lower Luminosity Obscured AGN

CDF-S 4 Msec data
X-ray stacking of IR-selected galaxies

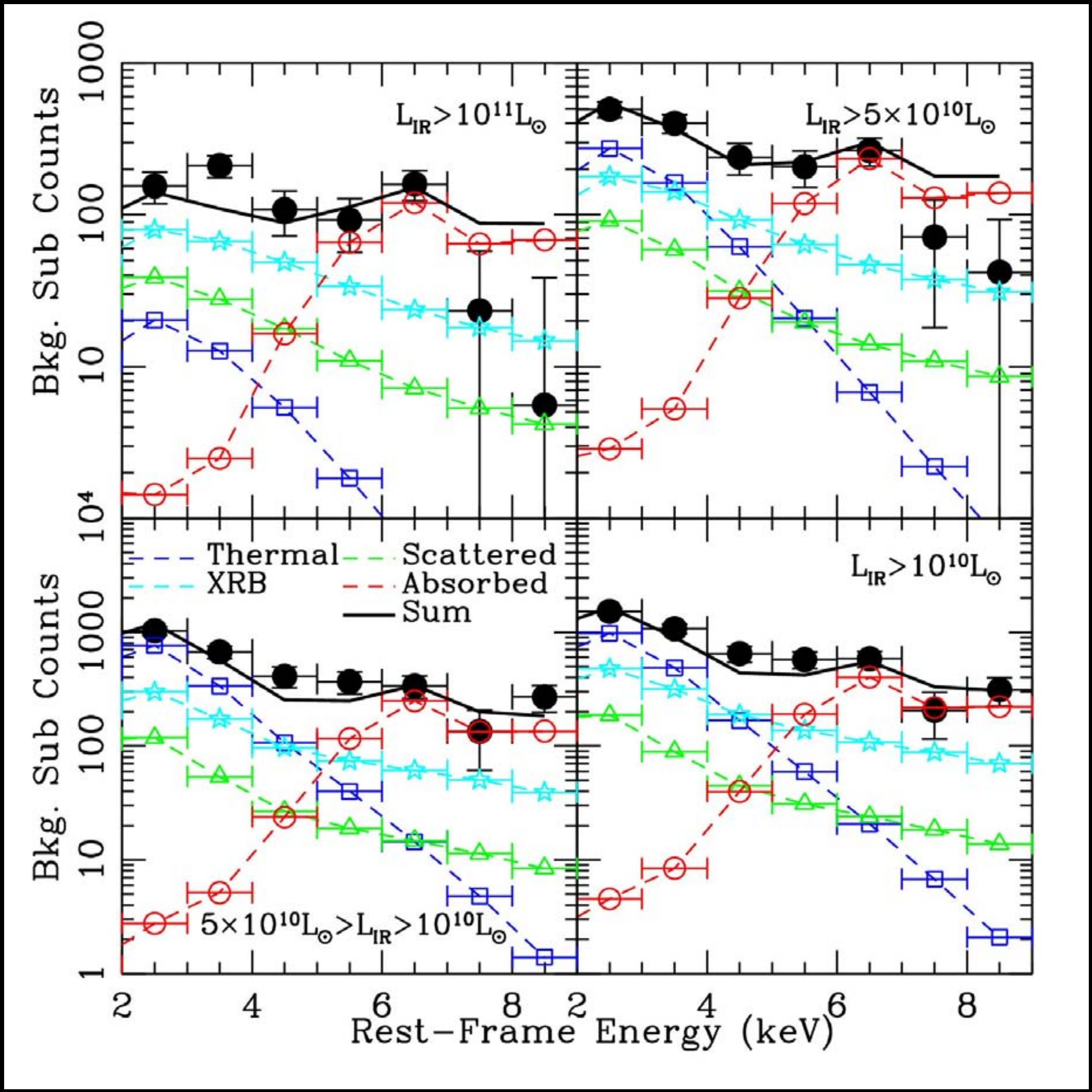




Harder X-ray spectrum for more luminous sources
-> More AGN in these samples

Treister et al. 2010b

Rest-frame Spectral Analysis



Combination of thermal emission, X-ray binaries and obscured AGN

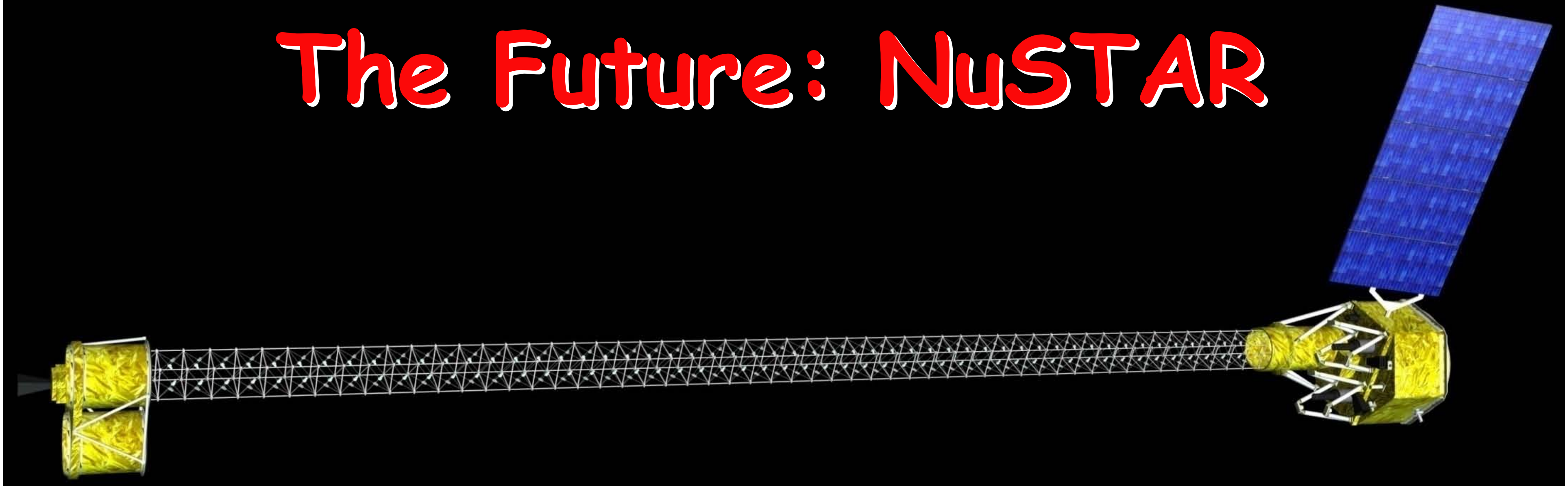
AGN Luminosities

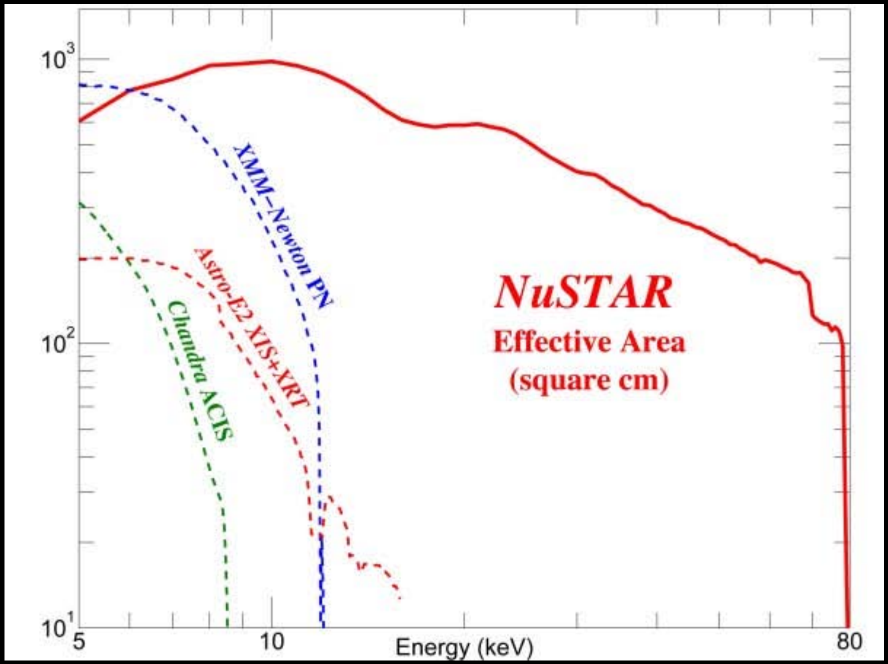
- 6×10^{42} erg/s $L_{IR}>10^{11}L_o$
- 3×10^{42} erg/s $L_{IR}>5\times10^{10}L_o$
- 5×10^{41} erg/s $5\times10^{10}>L_{IR}\ (L_o)>10^{10}$
- 7×10^{41} erg/s $L_{IR}>10^{10}L_o$

Much flatter evolution -> different triggering mechanism?

Treister et al. 2010b

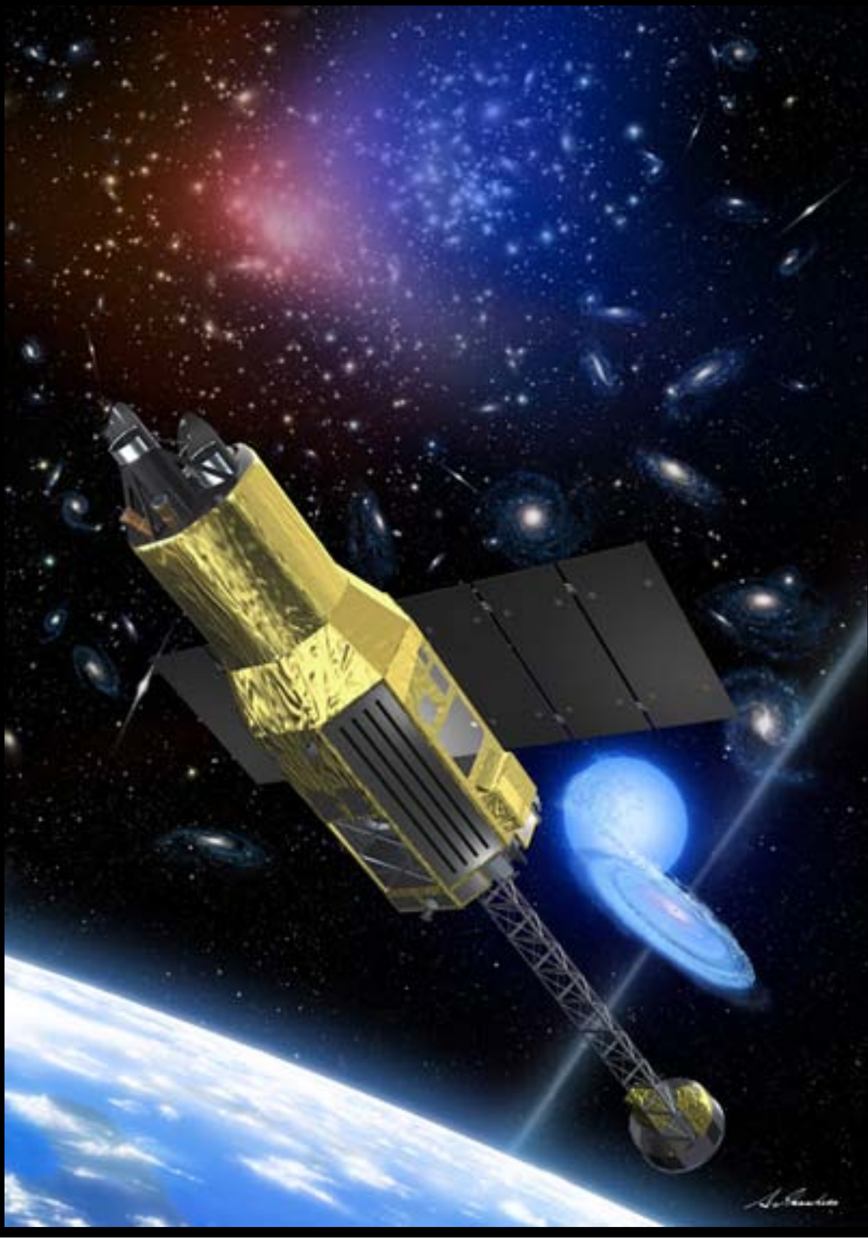
The Future: NuSTAR

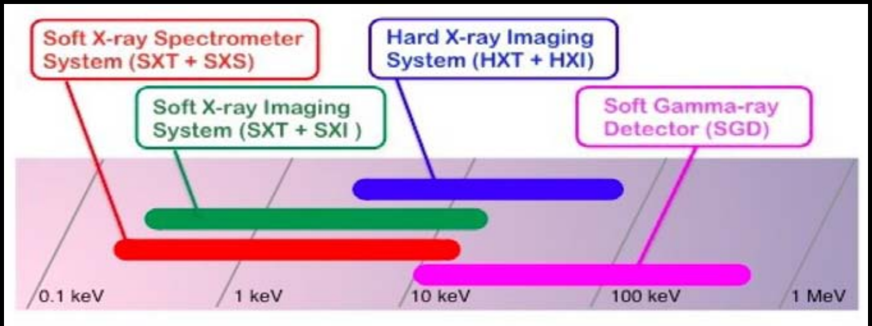


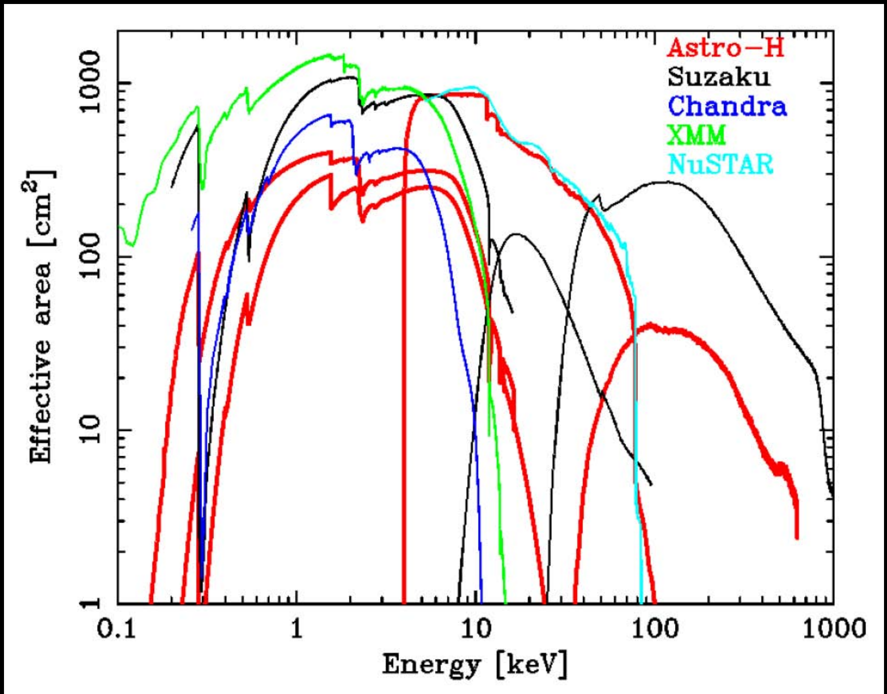


Energy Range	6-80 keV
Angular resolution	40″
Field of View	12′x12′
Flux Limit	~2×10^{-14} in 1 Msec
Launch Date	February 2012
PI	Fiona Harrison

The Future: ASTRO-H

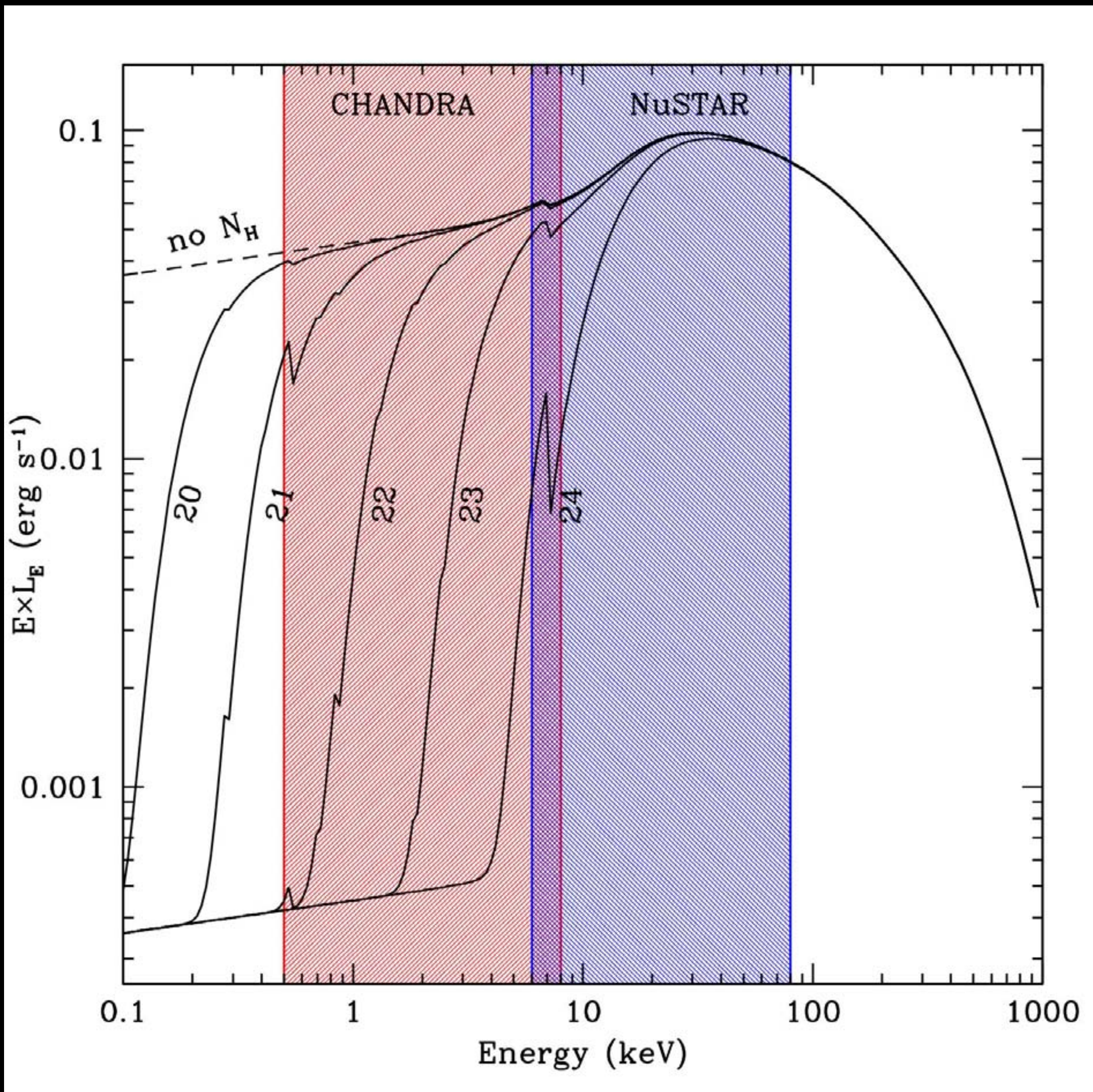






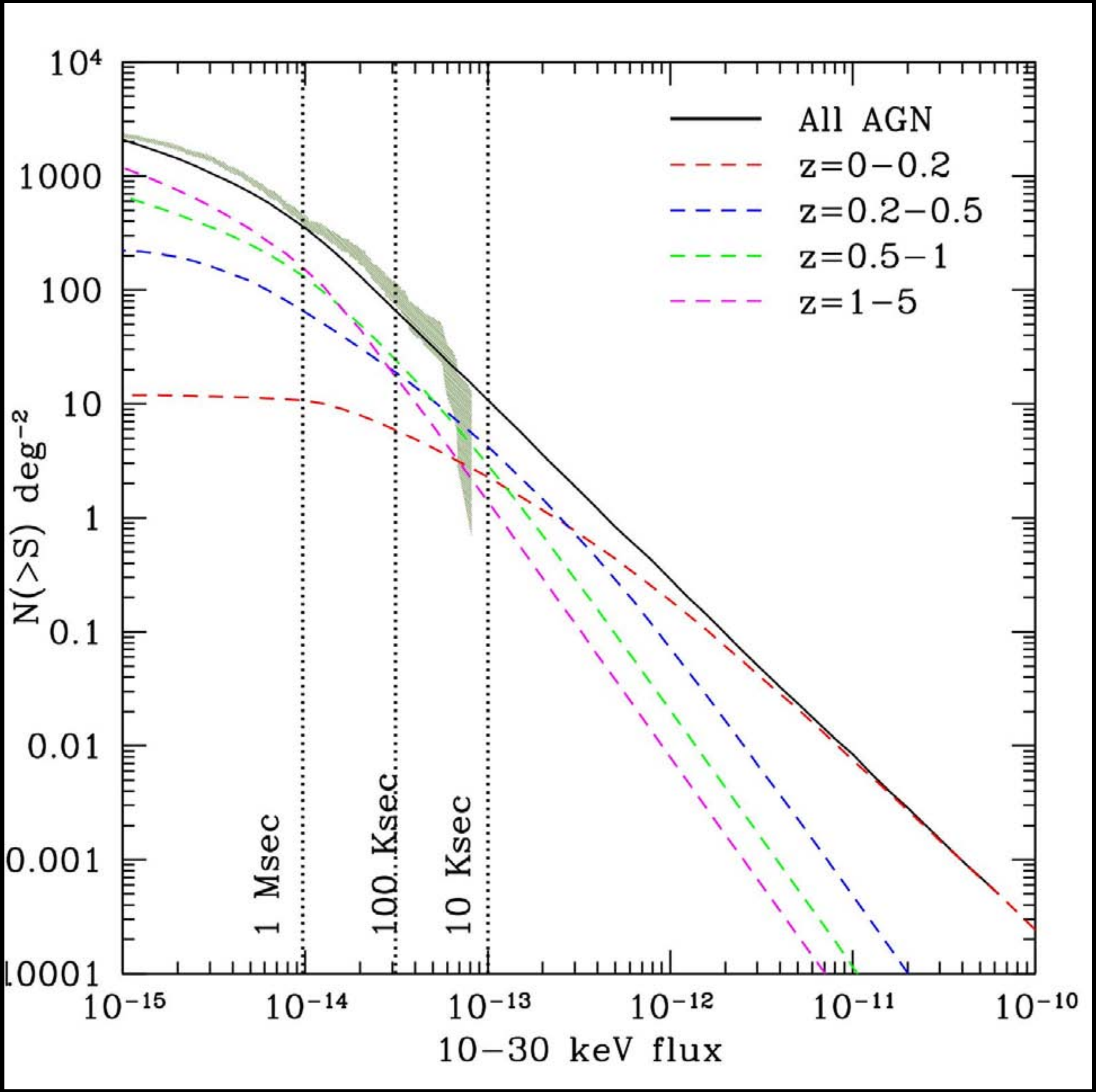
http://astro-h.isas.jaxa.jp

High Energy Observations



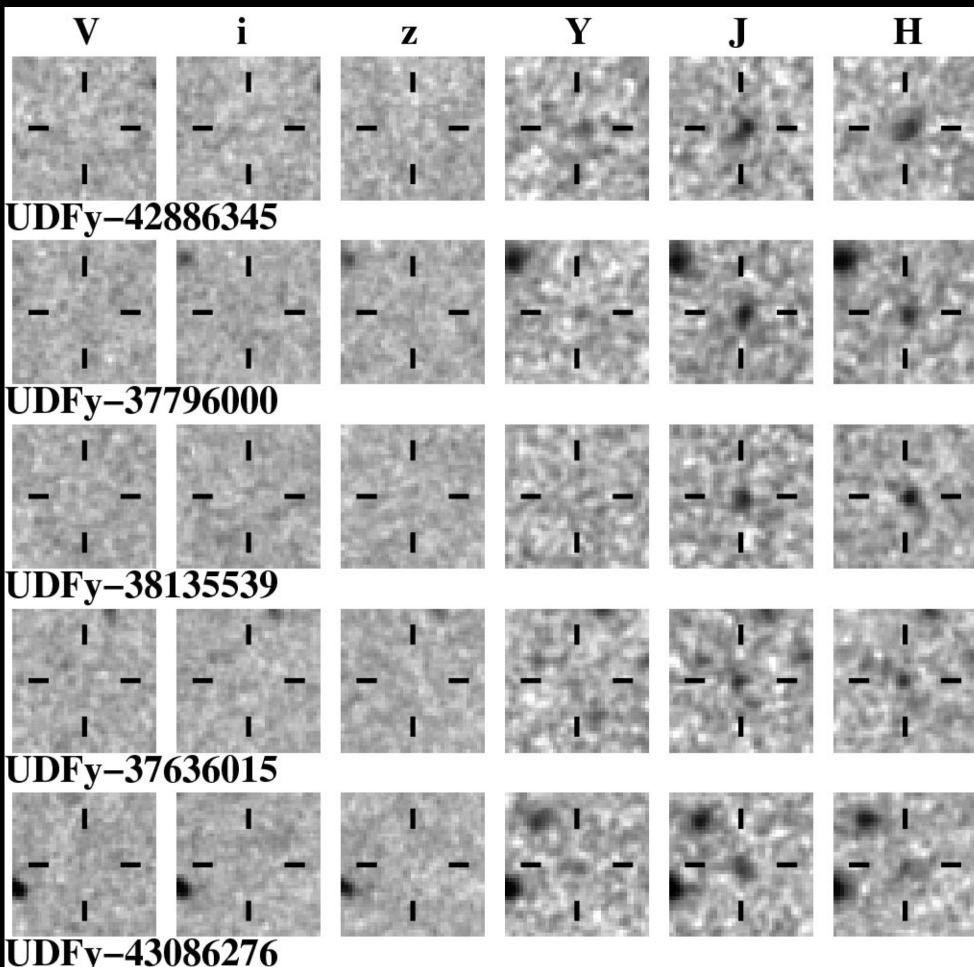
NuSTAR and astro-H will directly detect a large number of heavily-obscured AGN up to z~1-2

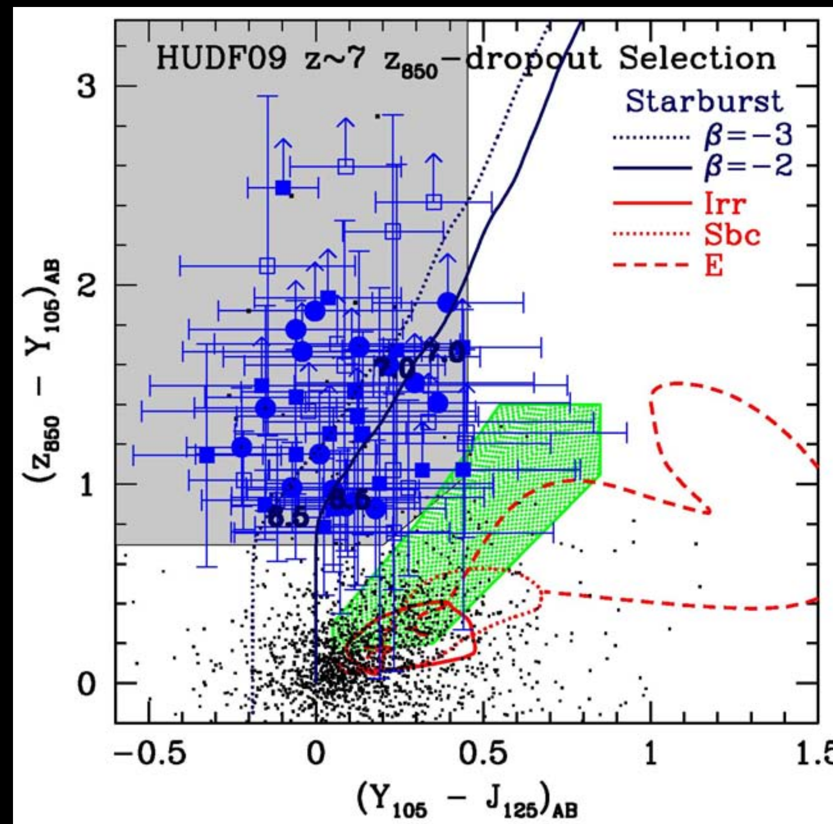
AGN Number Counts



High Redshift (z>6)

Lyman Break Selection



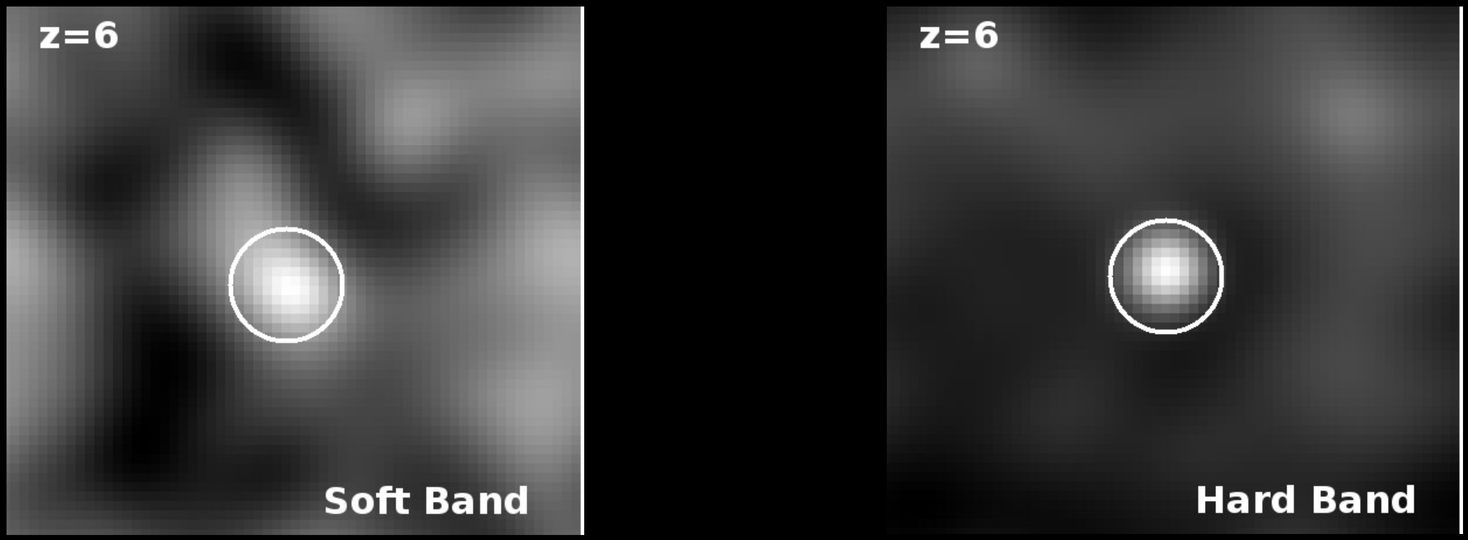


Bouwens et al. 2010

X-Ray Stacking

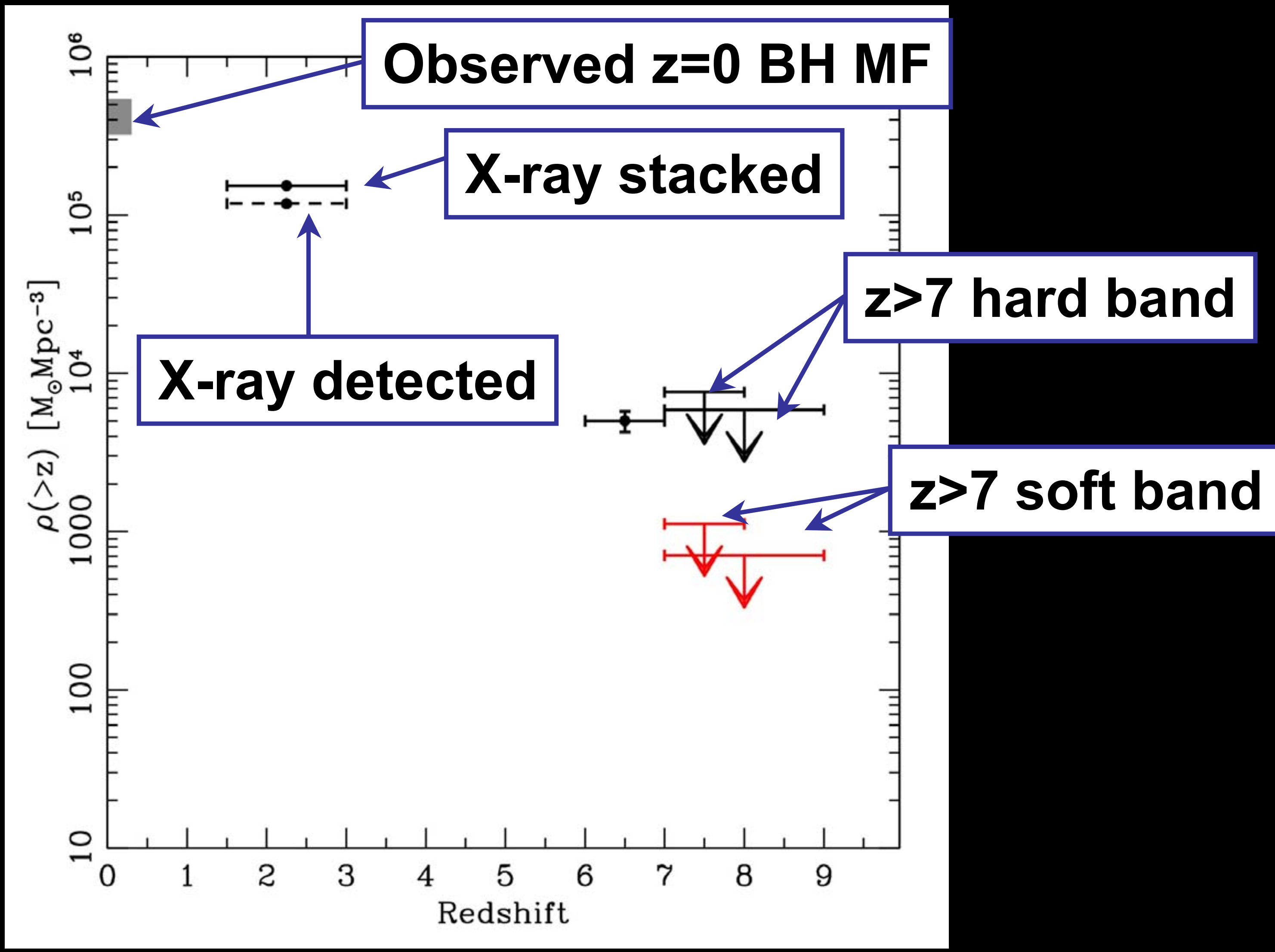
z~6

- ~5σ detection in the soft (3.5-14 keV rest frame) band
- ~7σ detection in the hard (14-56 keV) band
- Flux ratio ~9
- Need N_H~1.6x10^{24}cm^{-2} to explain it
- Vast majority of sources heavily obscured (4π obscuration)
- No detection in any band at z~7 and z~8 (or combined)



Treister et al. submitted

Accreted Mass vs Redshift



Treister et al. submitted

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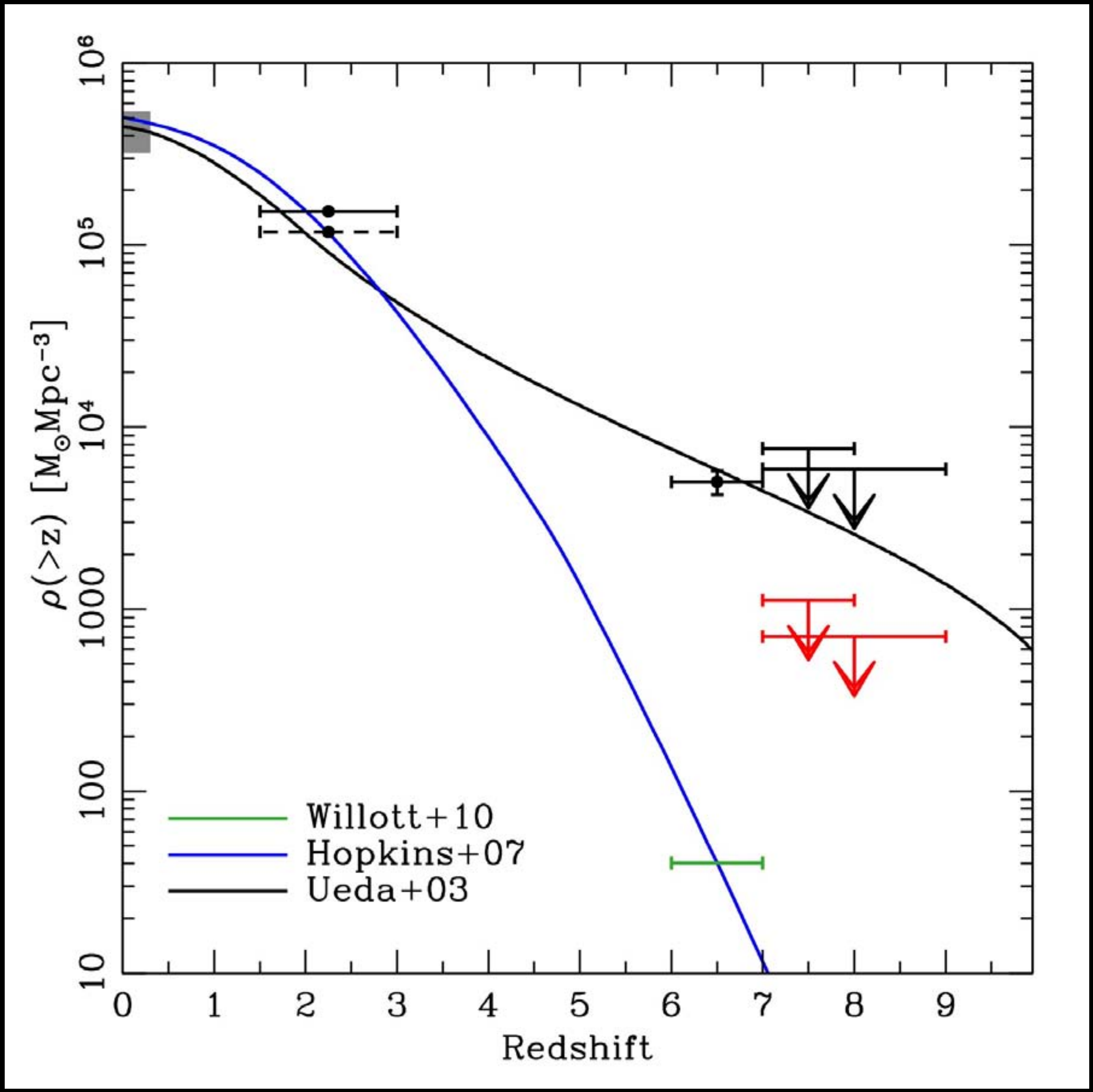

Treister et al. submitted

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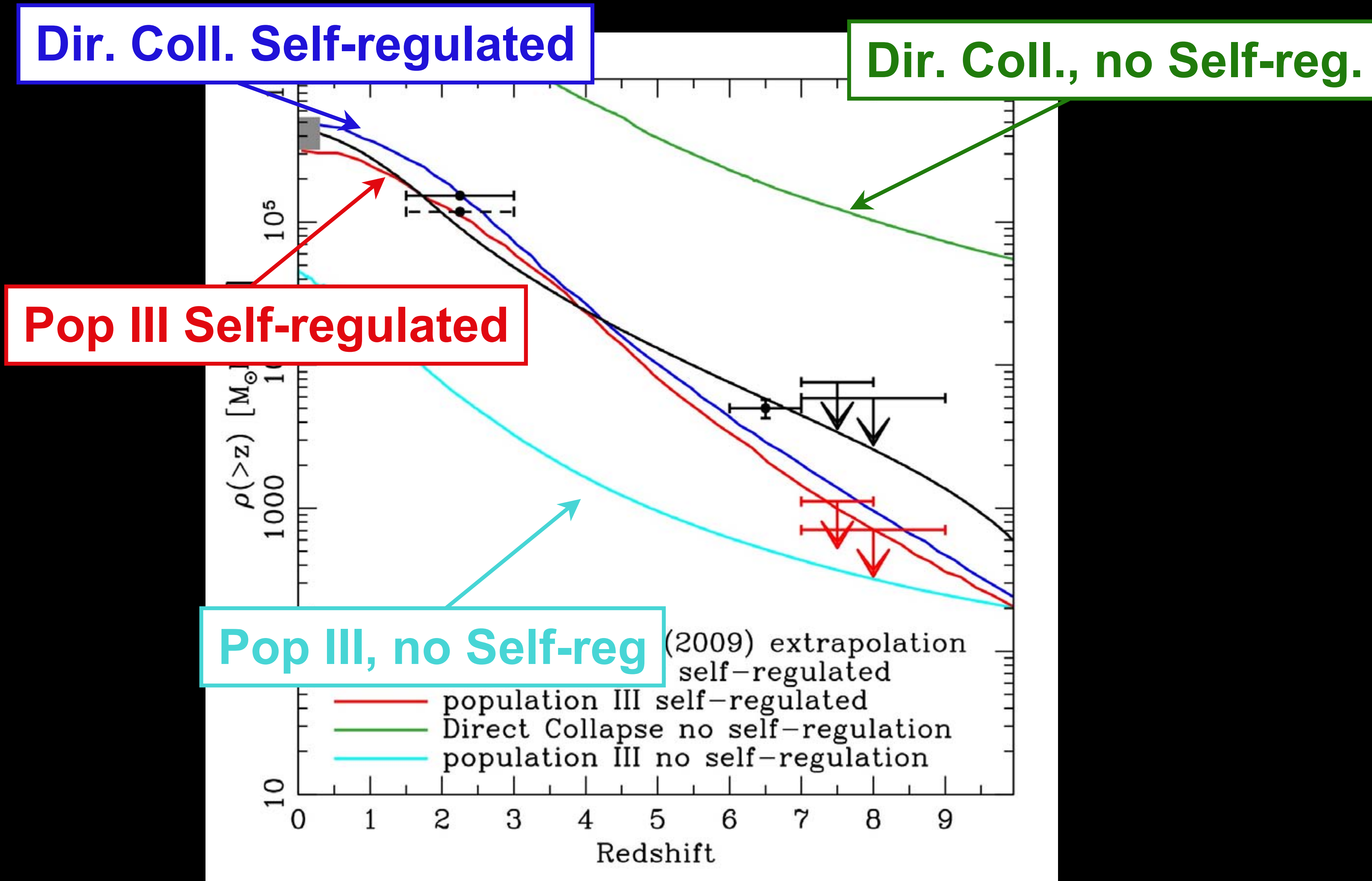
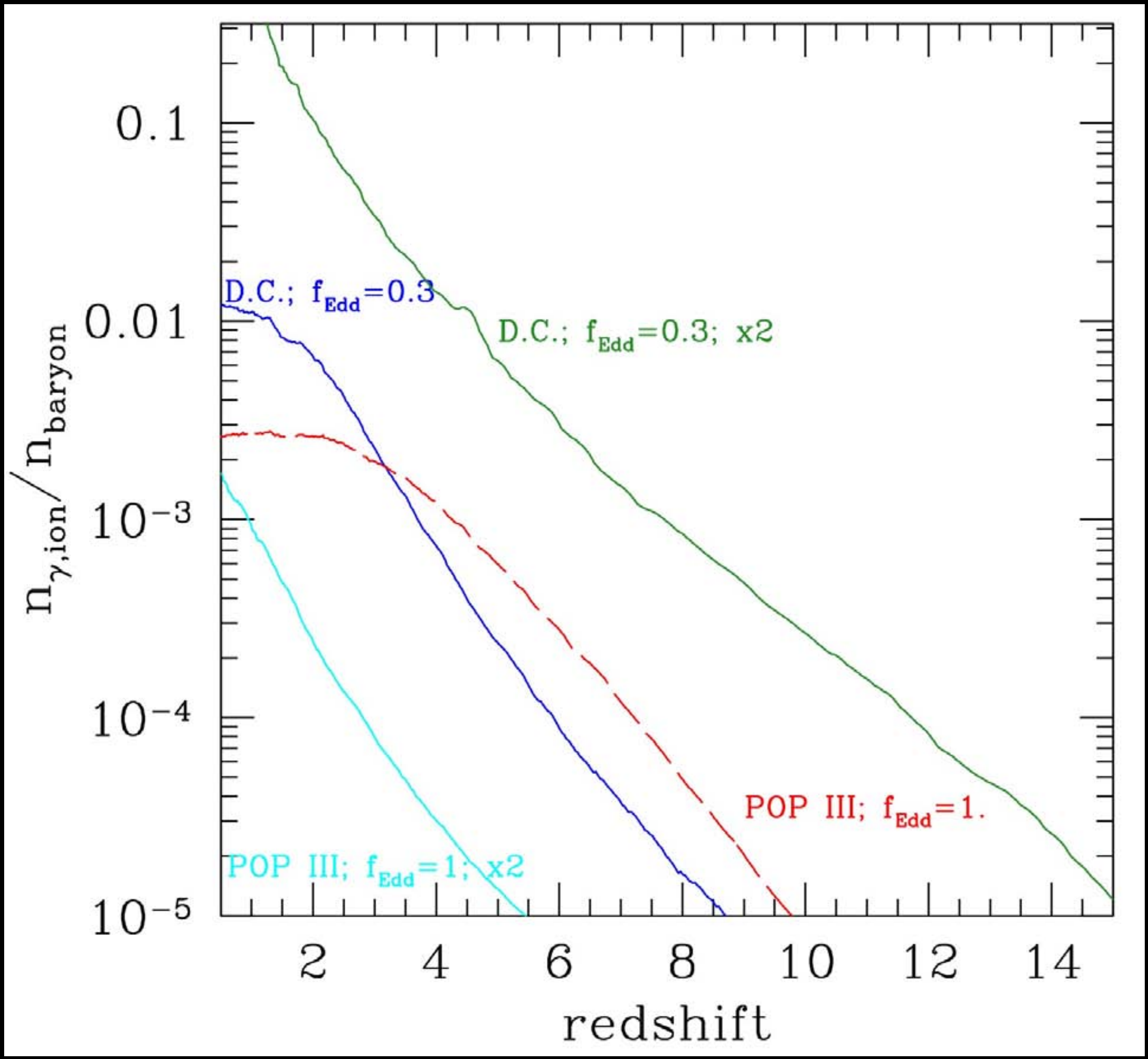


Treister et al. submitted

Hydrogen Re-ionization



AGN cannot re-ionize the Universe at z>6

This is because of heavy obscuration. If unobscured, enough UV photons to re-ionize the Universe

Treister et al. submitted

Summary

- Most BH accretion up to z~3 identified in X-rays, either directly or via stacking.

- Vast majority of accretion, ~70%, is obscured. ~20% of BH accretion is Compton Thick.

- Future X-ray missions (NuSTAR, Astro-H) will be critical to study this population of CT AGN.

- Self-regulation appears to be important for BHs at all redshifts. M-σ relation at all redshifts?

- Stacked detection at z~6 in hard band implies very high obscuration in most sources -> 4π obscuration.

- Due to their high obscuration, these sources do not re-ionize the Universe.