Hidden growing black holes: What is the nature of obscuration in AGN?

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(he/him)

DARTMOUTH

Astronomy 511: Topics in Observational Extra-galactic Astronomy

Images and videos courtesy of NASA/*Chandra/HST* unless otherwise noted

ANNUAL REVIEWS

Annual Review of Astronomy and Astrophysics

Obscured Active Galactic Nuclei

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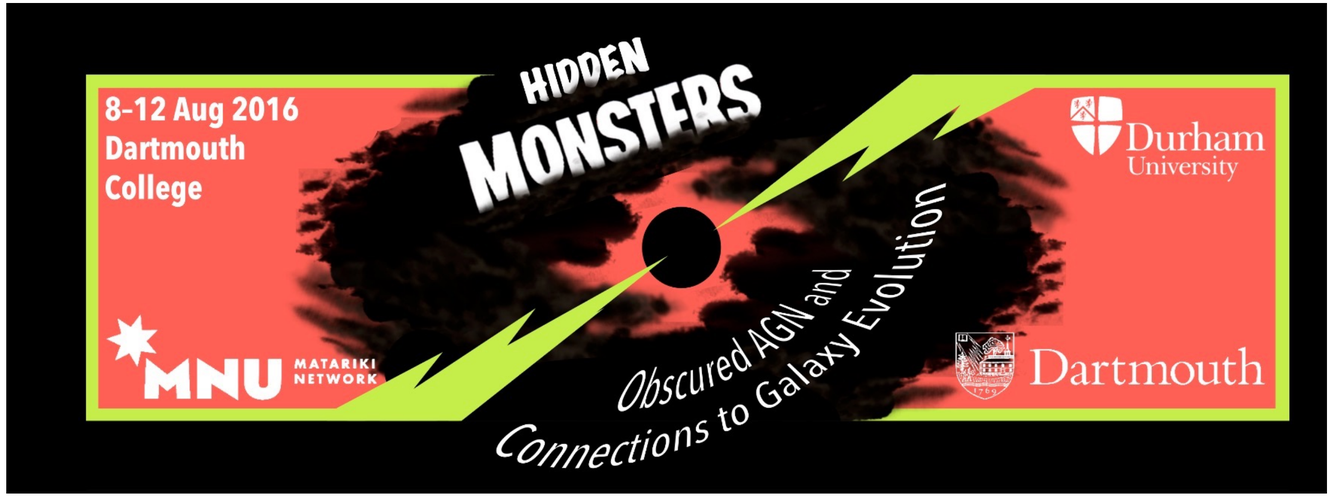
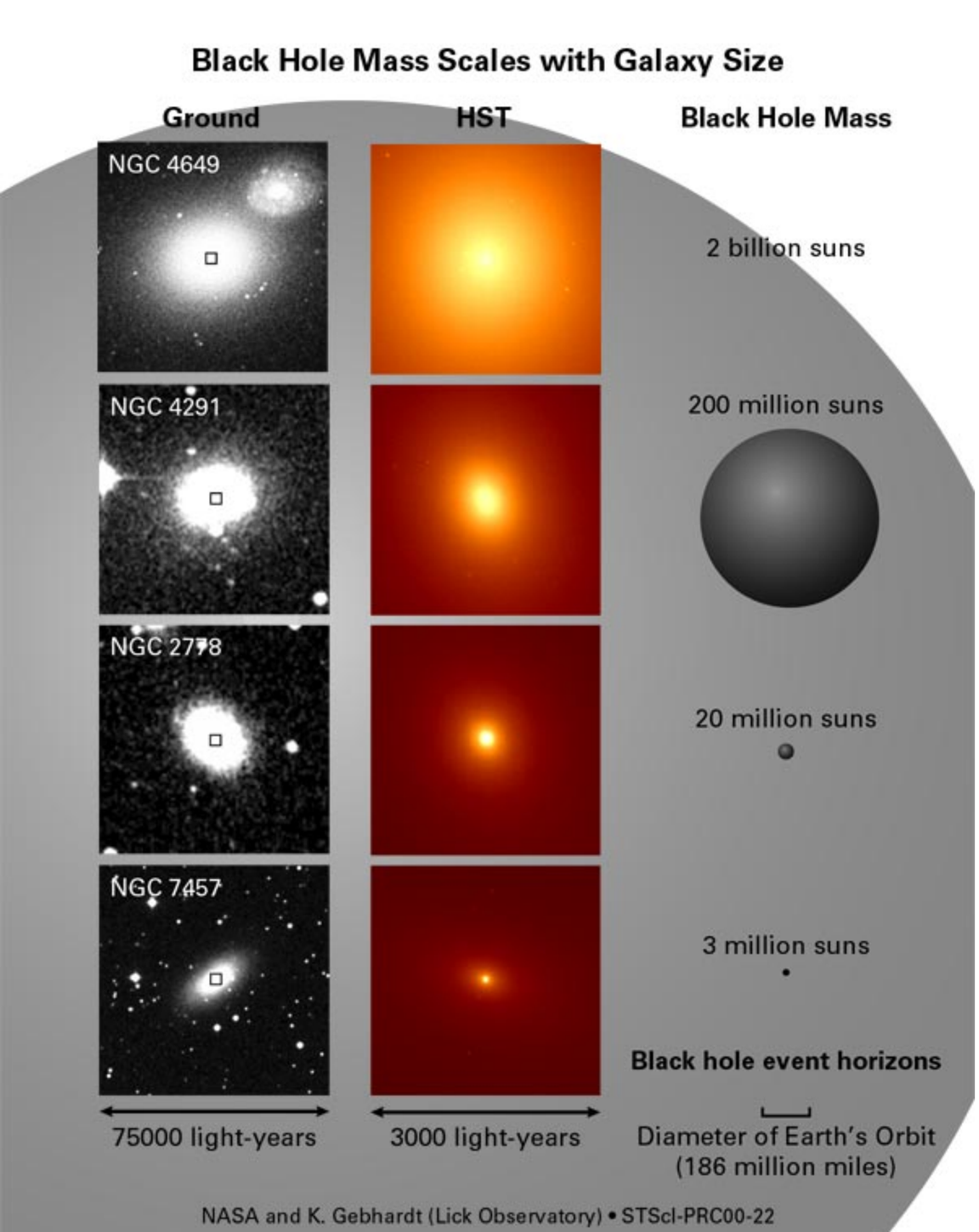
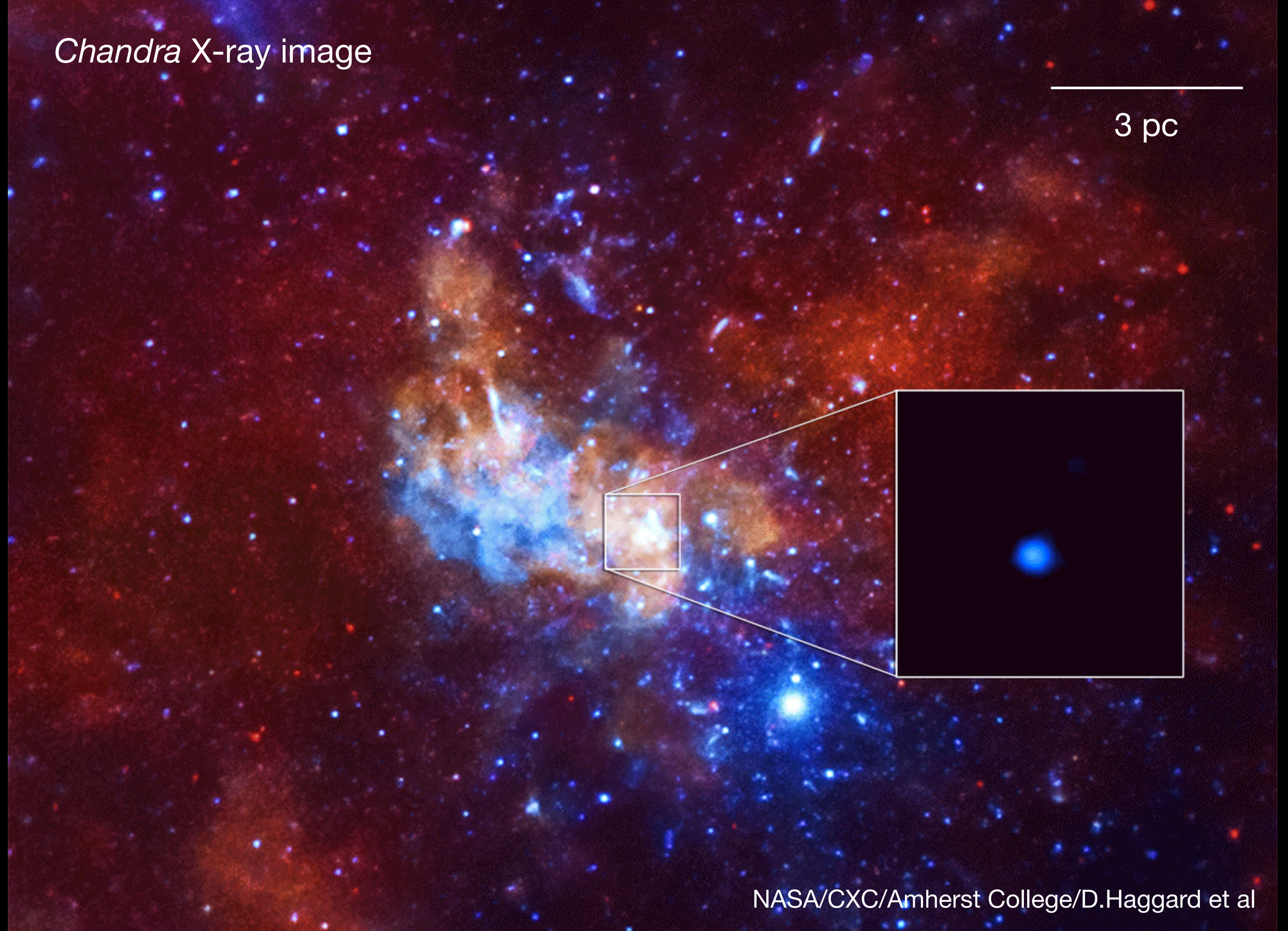


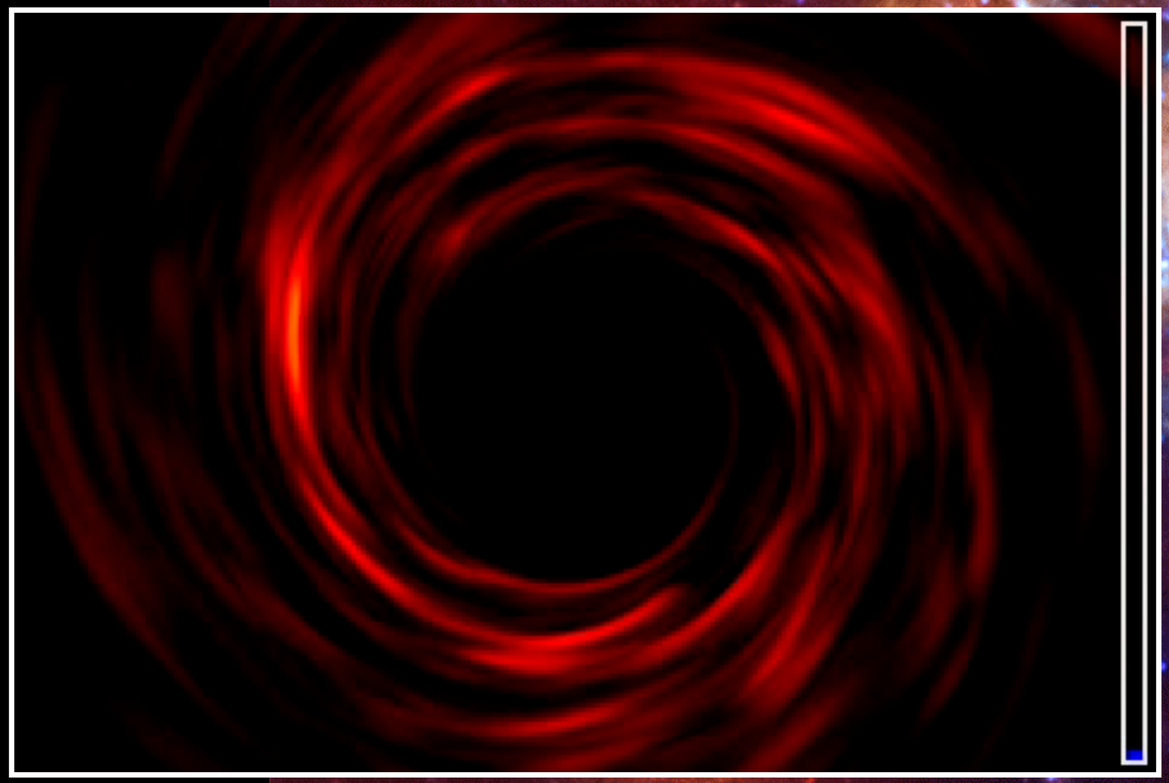
Video credit ESO



The big question:

What is the origin of supermassive black holes?


Chandra X-ray image
3 pc
NASA/CXC/Amherst College/D.Haggard et al



3 pc

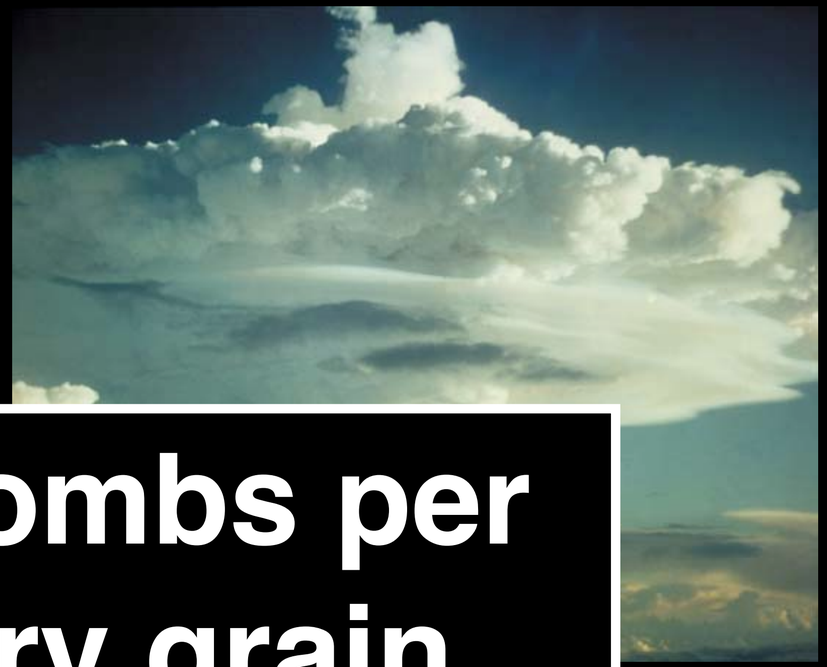
Armitage & Reynolds (2003)

NASA/CXC/Amherst College/D.Haggard et al

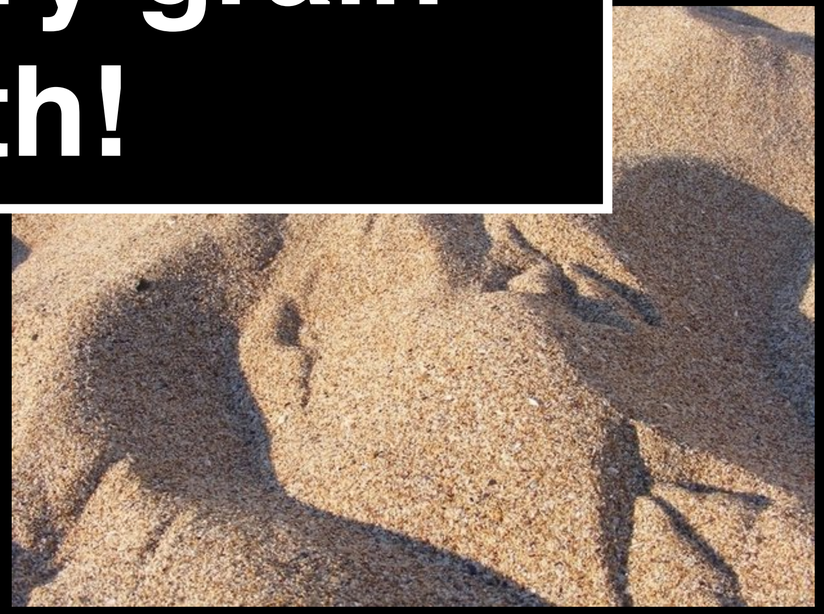

Credit: ESO


A galaxy


A quasar



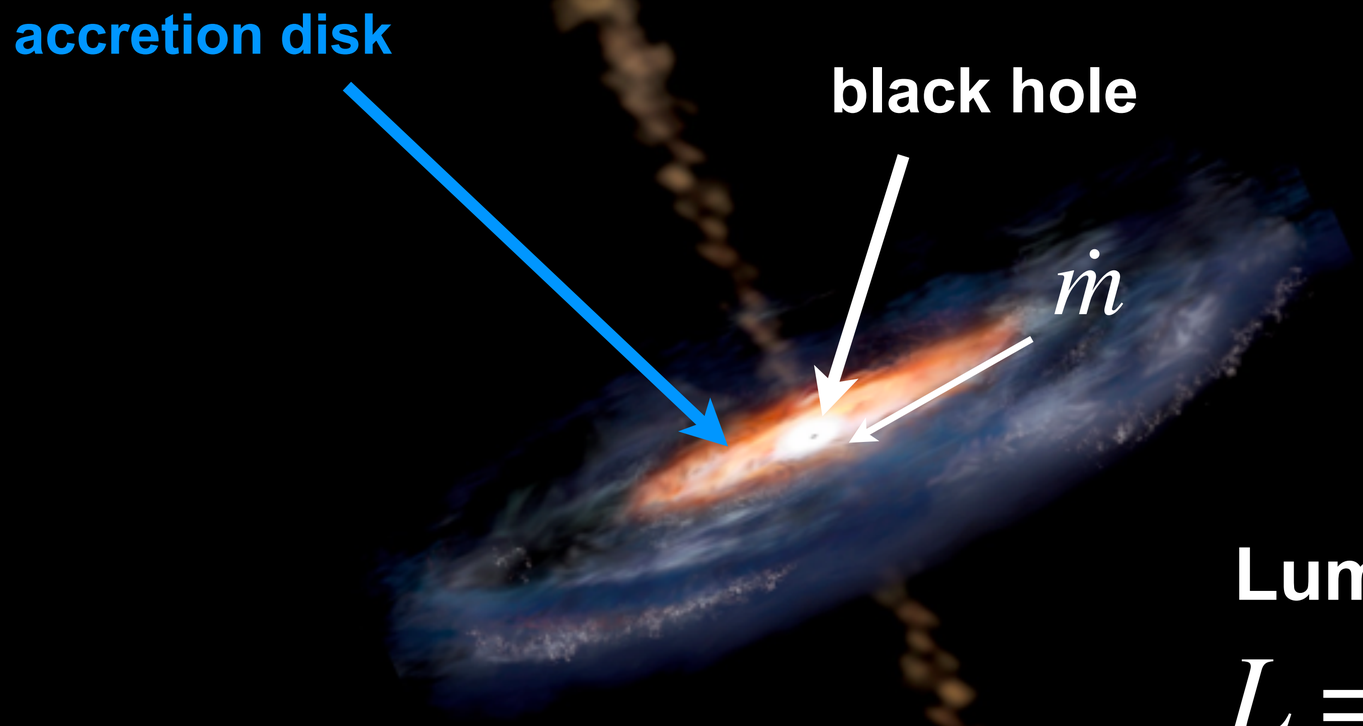
10 hydrogen bombs per second for every grain of sand on Earth!



A hydrogen bomb produces 10^{24} erg of energy

There are 10^{22} grains of sand on Earth

active galactic nucleus (AGN or quasar)



Luminosity:

$$L = \eta \, \dot{m} \, c^2$$

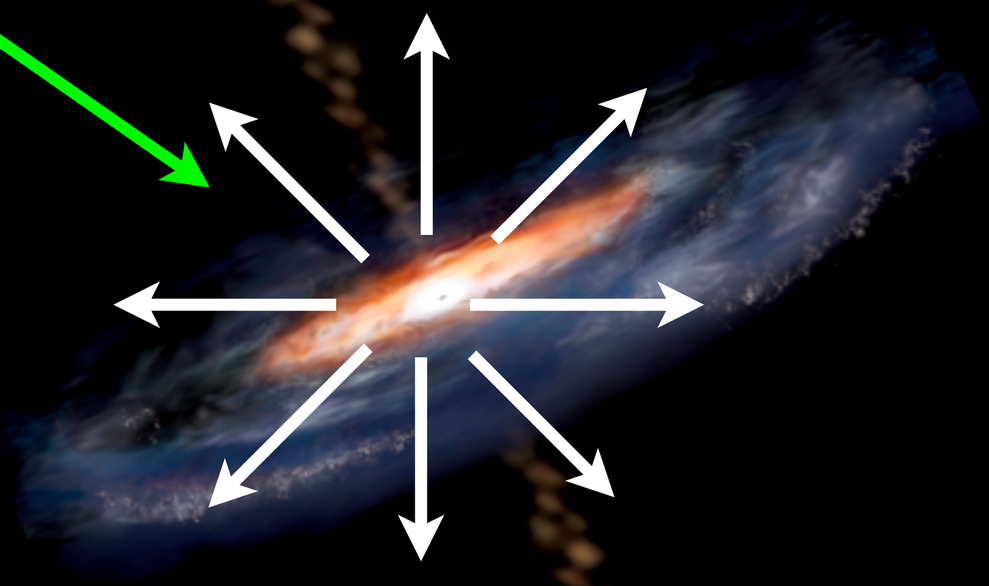
$$\eta \sim 0.1$$

(0.007 for fusion in stars)

The Eddington limit

Gravity

Radiation pressure



There is a limit to how fast black holes can grow, where radiation pressure equals gravity

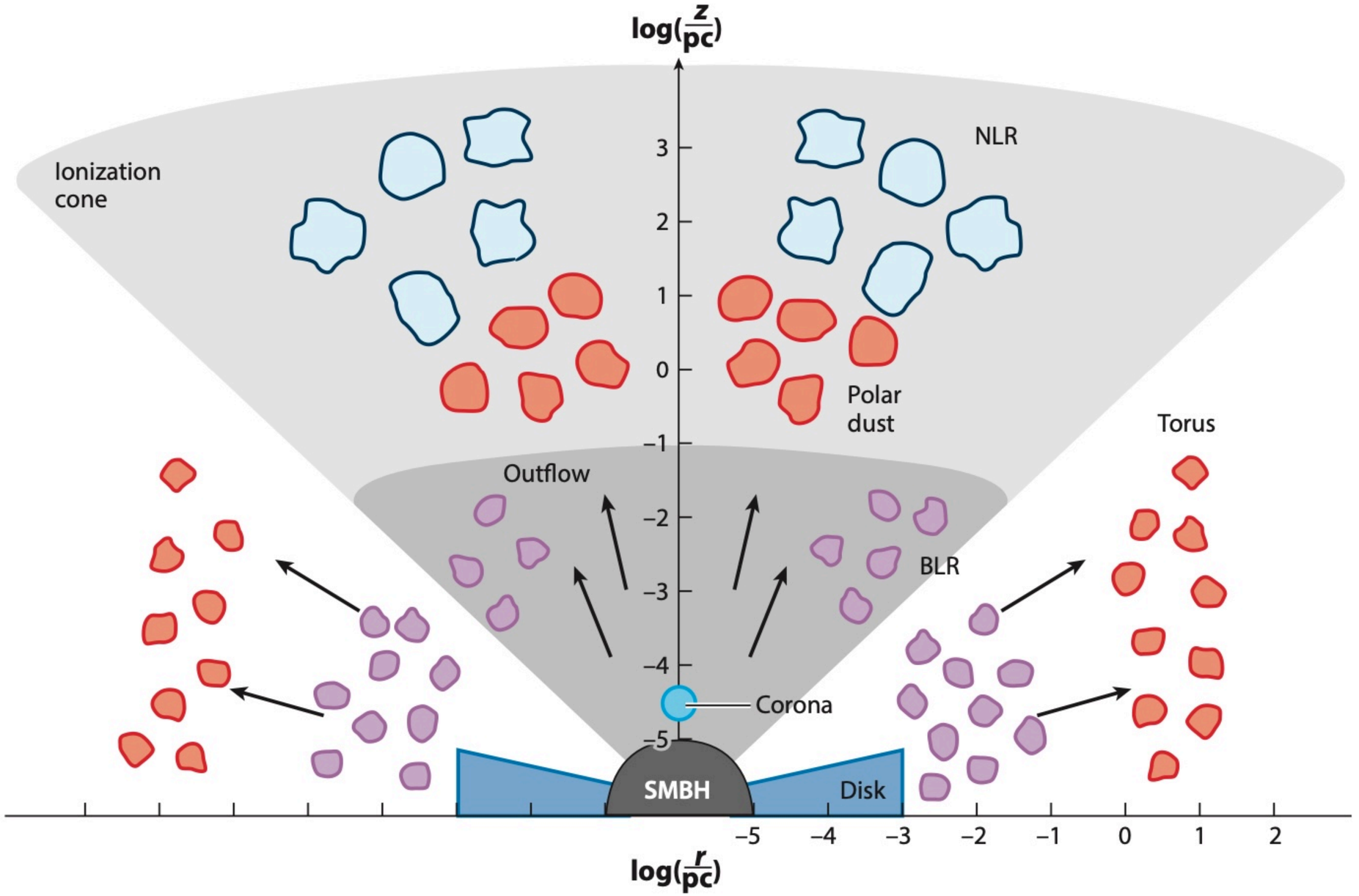
The Eddington ratio

$$\lambda = L/L_{Edd}$$

$$L_{\mathrm{Edd}} = \frac{4\pi G M_{\mathrm{BH}} m_{\mathrm{p}} c}{\sigma_{\mathrm{T}}}$$

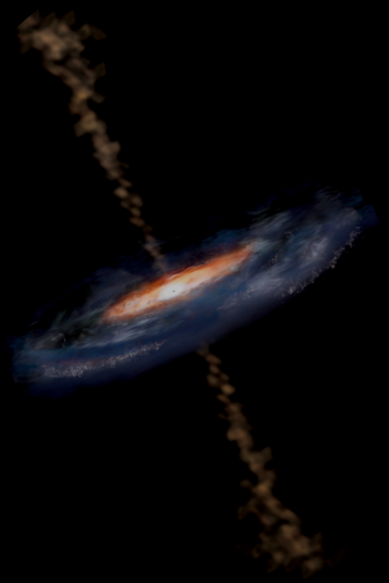
$$L_{\mathrm{Edd}} \approx 10^{38}\ \mathrm{erg\ s^{-1}}\ M_{\mathrm{BH}}\,(M_{\odot})$$

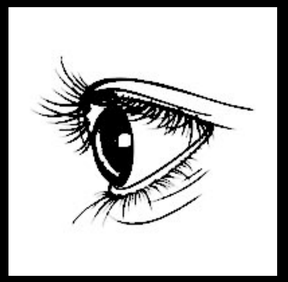
AGN structure



Adapted from Ramos Almeida & Ricci (2017)

How do we identify AGN?





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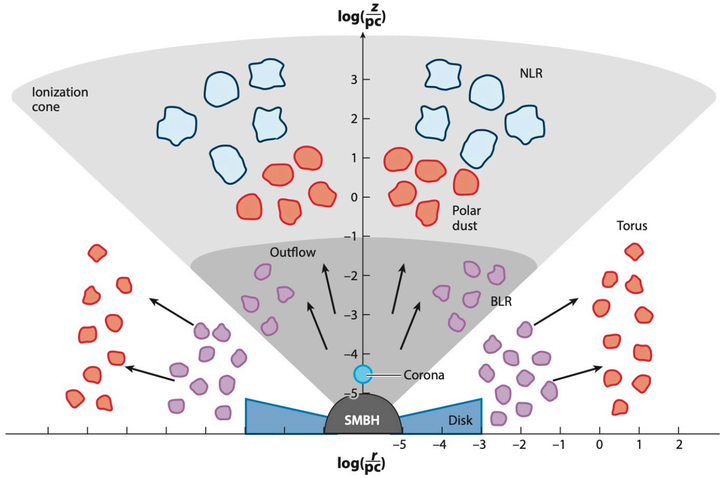
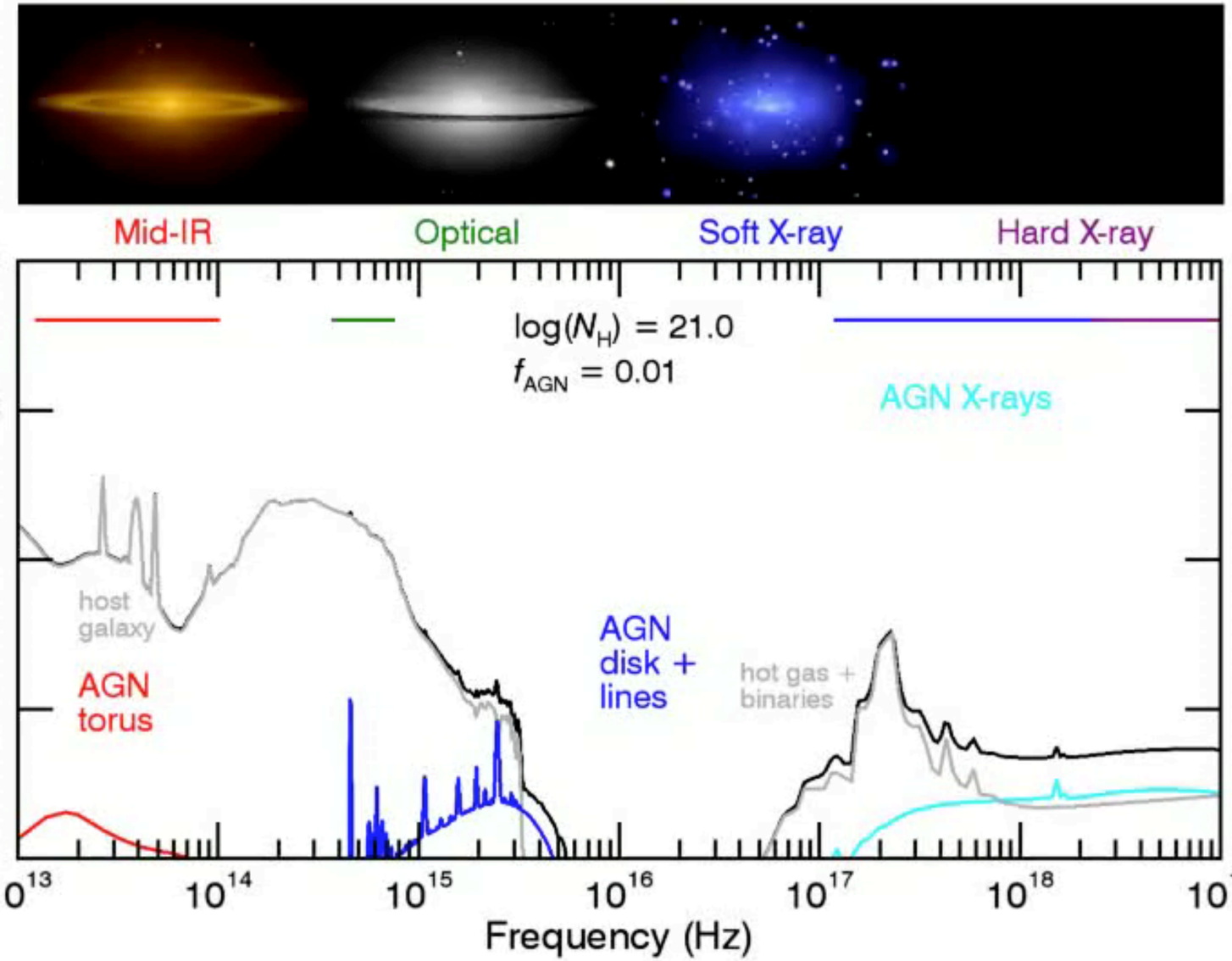


Composite AGN and galaxy SEDs and images for varying AGN dominance and obscuration

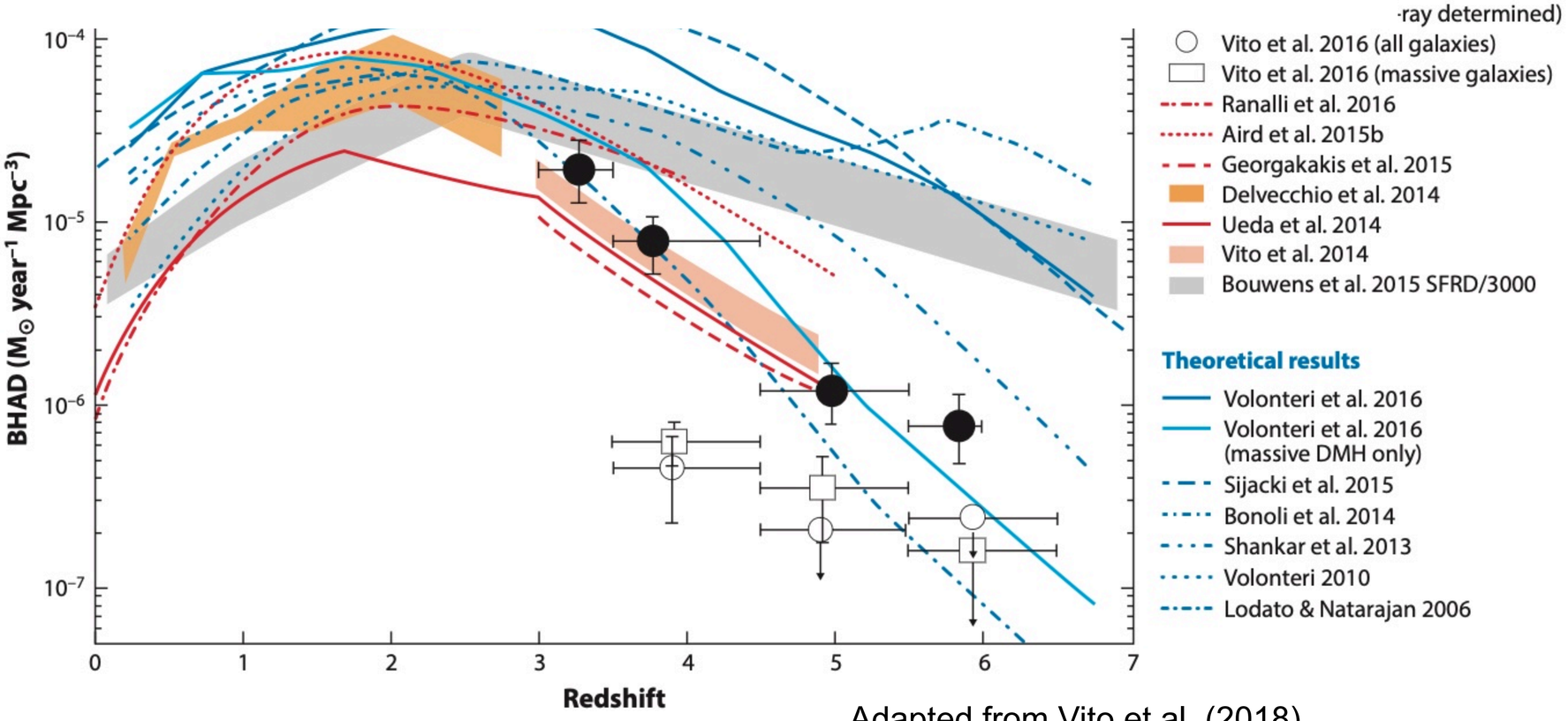
Hickox & Alexander (2018)
"Obscured Active Galactic Nuclei"
ARA&A, Volume 56



We can use AGN to trace the **black hole growth history** of the Universe

$$\rho(z) = \rho(z_S) + \int_z^{z_S} \int_{L_{min}}^{L_{max}} \frac{(1-\eta)\,L}{\eta\,c^2} \Phi(L,z) d\log L \frac{dt}{dz} dz.$$

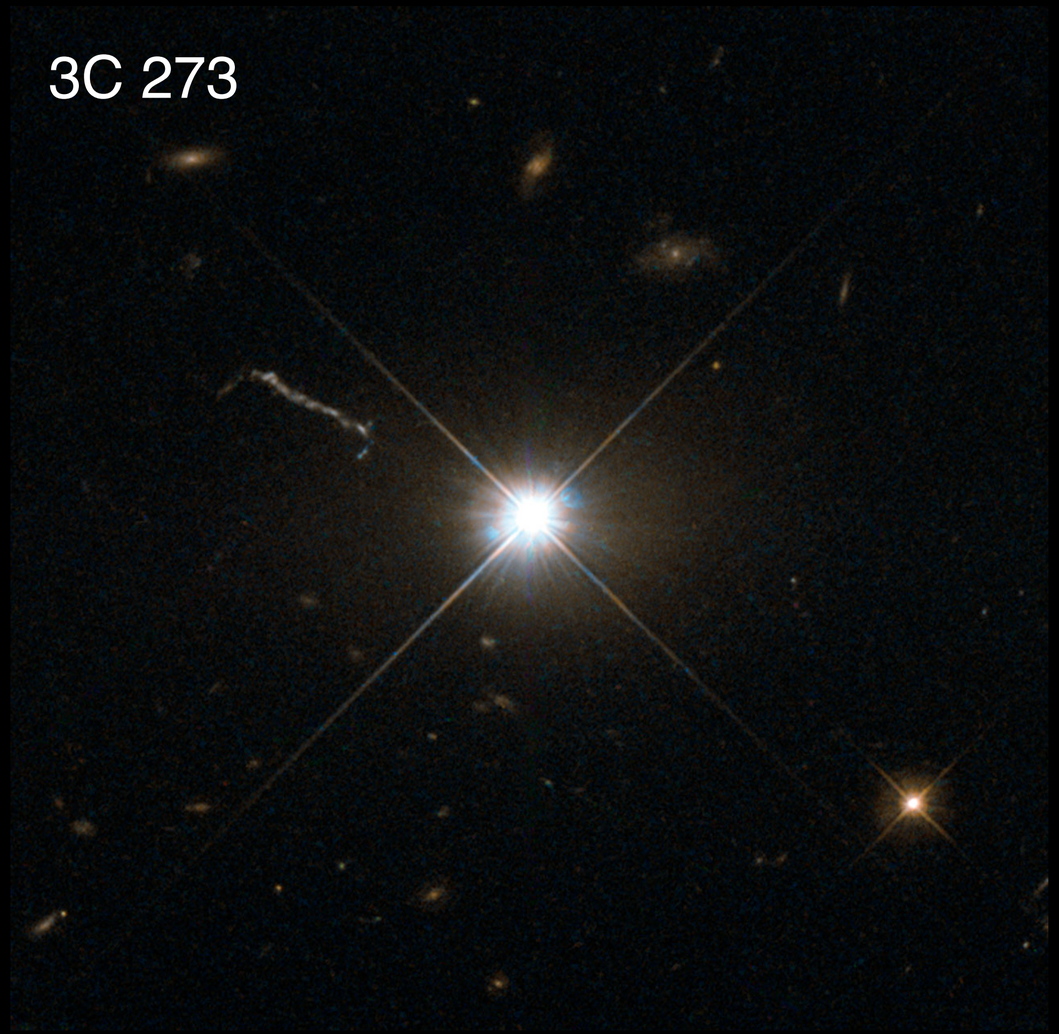
Annana et al. (2019)



Adapted from Vito et al. (2018)

However, most AGN are **“hidden” by gas and dust**

(e.g. Hickox et al. 2007, Treister et al. 2010, Merloni et al. 2014, Assef et al. 2015, Mateos et al. 2017)



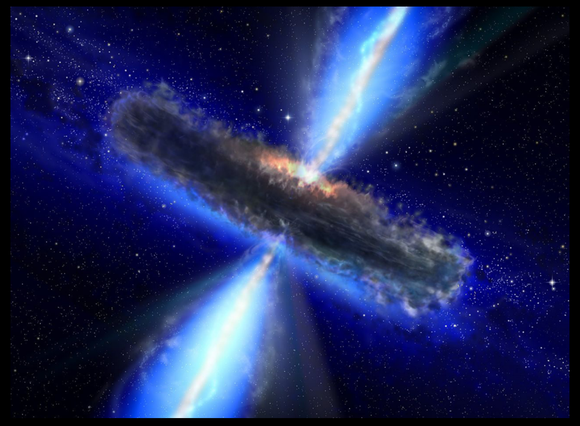
Schawinski et al. (2012)

Need to understand obscured AGN to:

1. Obtain a **complete census** of black hole growth in the Universe

2. Determine black hole **accretion physics** (such as the global radiative efficiency) and the origin of the **cosmic X-ray background**

3. Understand the mechanisms of **black hole fueling** and **galaxy-black hole co-evolution**



Three key questions about obscured AGN

1. How do we **identify obscured AGN?**

2. **How heavily buried** and **widespread** are obscured AGN?

3. What is the **physical nature** of the obscuring material?

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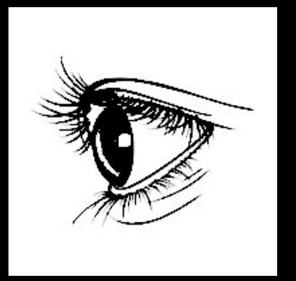
How do we identify **obscured** AGN?

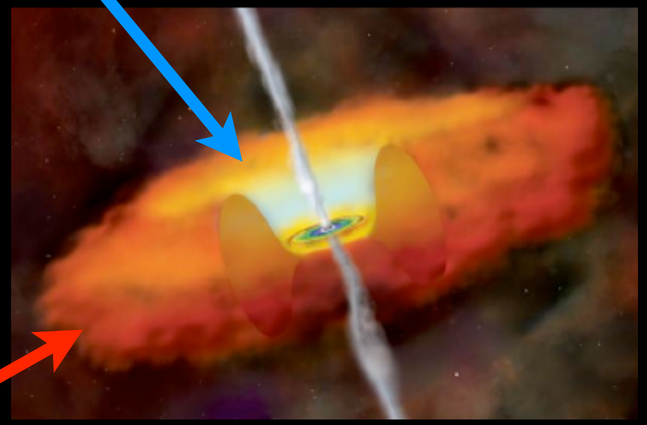


Defining obscured AGN

$$N_{\rm H} > 10^{22}\ {\rm cm}^{-2}$$

$$A_V > 3$$

Unobscured



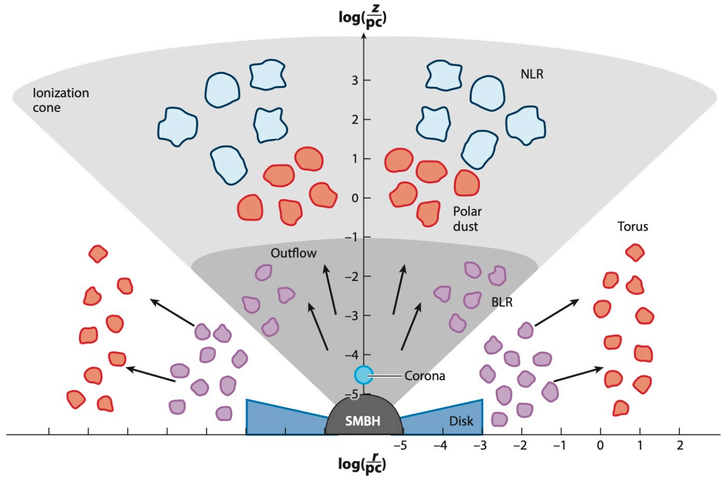
$$N_{\rm H} = 10^{24}\ {\rm cm}^{-2}$$

Compton thick

Obscured

(e.g., Hickox et al. 2007, Treister et al. 2010, Merloni et al. 2014, Assef et al. 2015)

How do we identify **obscured** AGN?



Composite AGN and galaxy SEDs and images for varying AGN dominance and obscuration

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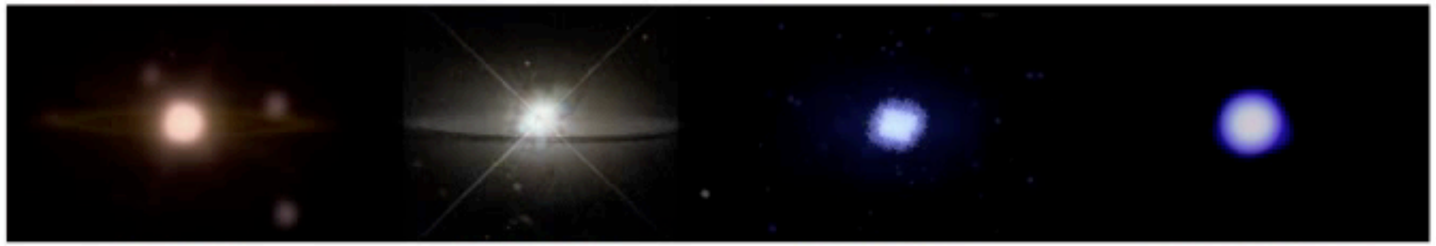
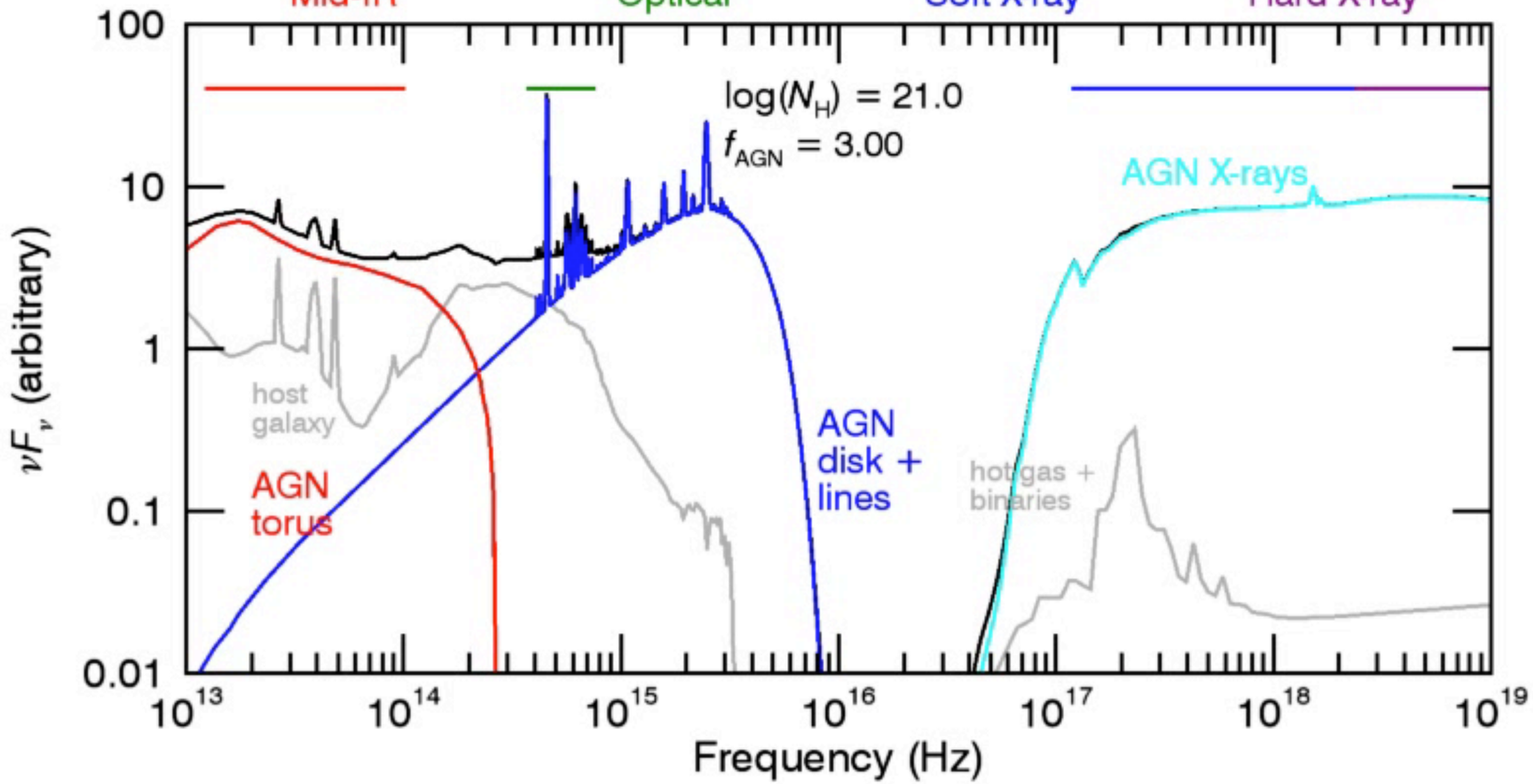
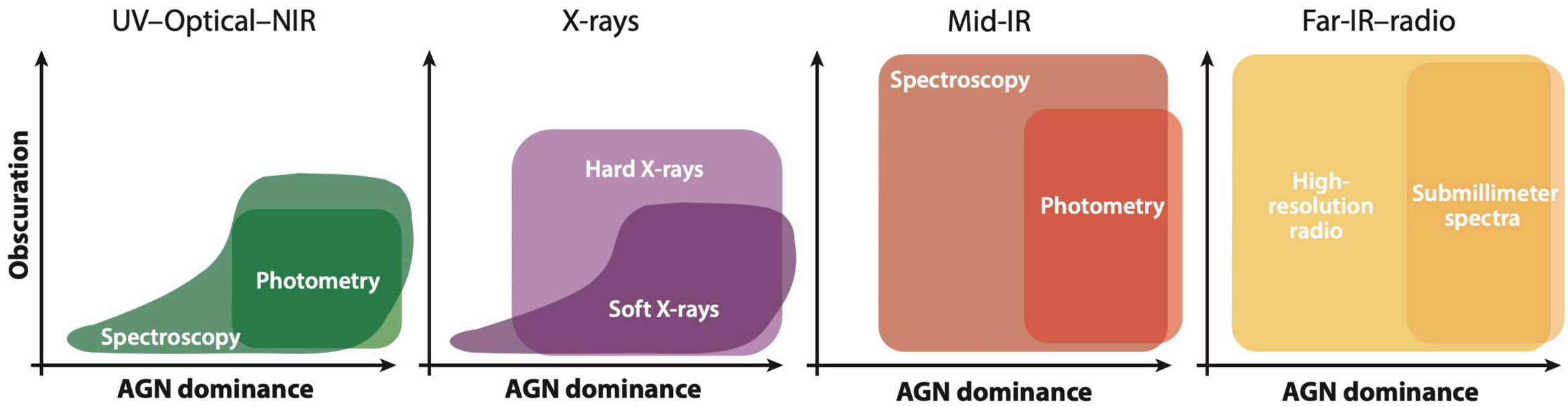




How do we identify **obscured** AGN?



Hickox & Alexander (2018)

1. How do we **identify obscured AGN?**

Obscured AGN show signatures across a **range of wavelengths**, each of which has different strengths and weaknesses. Much recent work has focused on **mid-IR and X-ray studies**

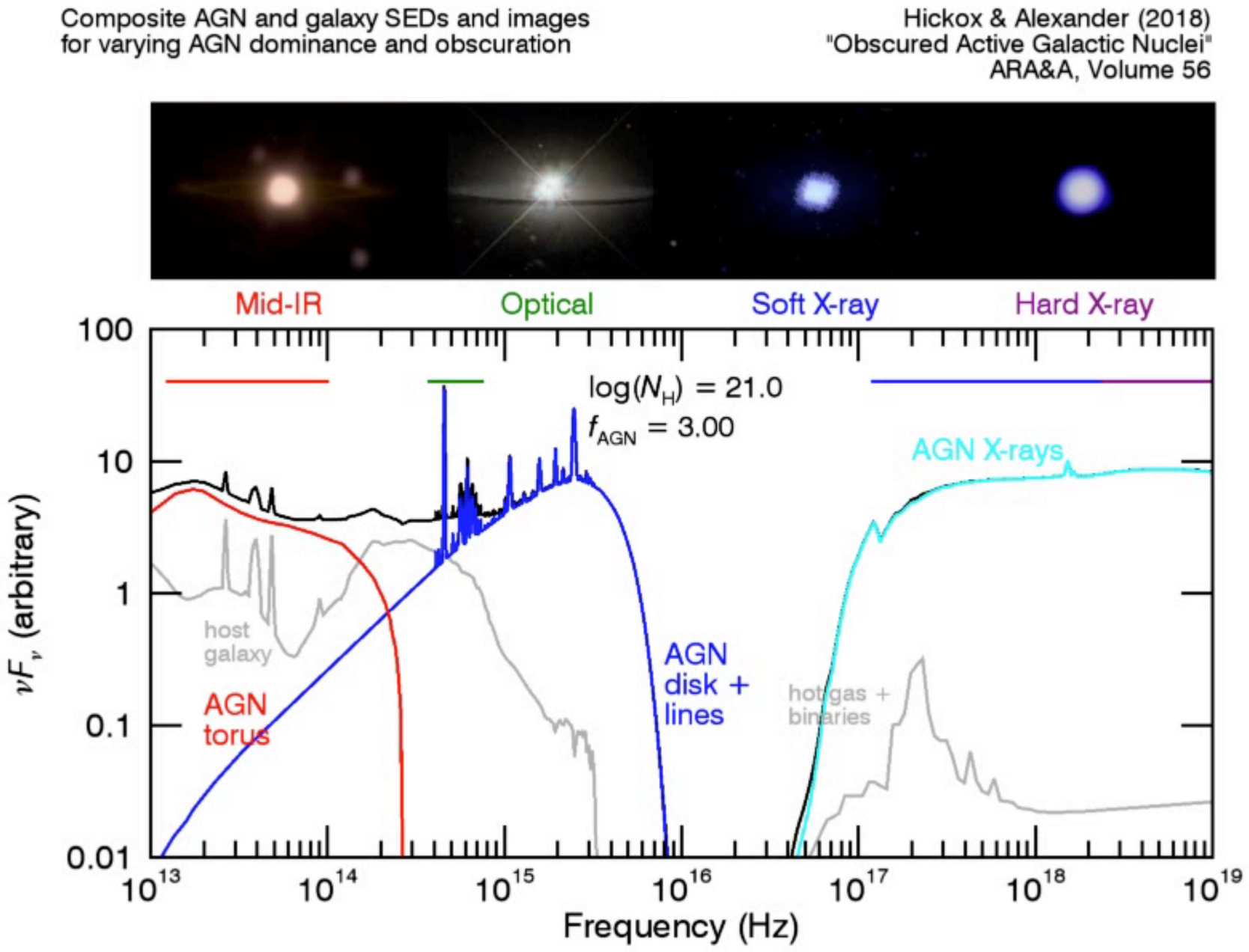
Three key questions about obscured AGN

1. How do we **identify obscured AGN?**

2. **How heavily buried** and **widespread** are obscured AGN?

3. What is the **physical nature** of the obscuring material?

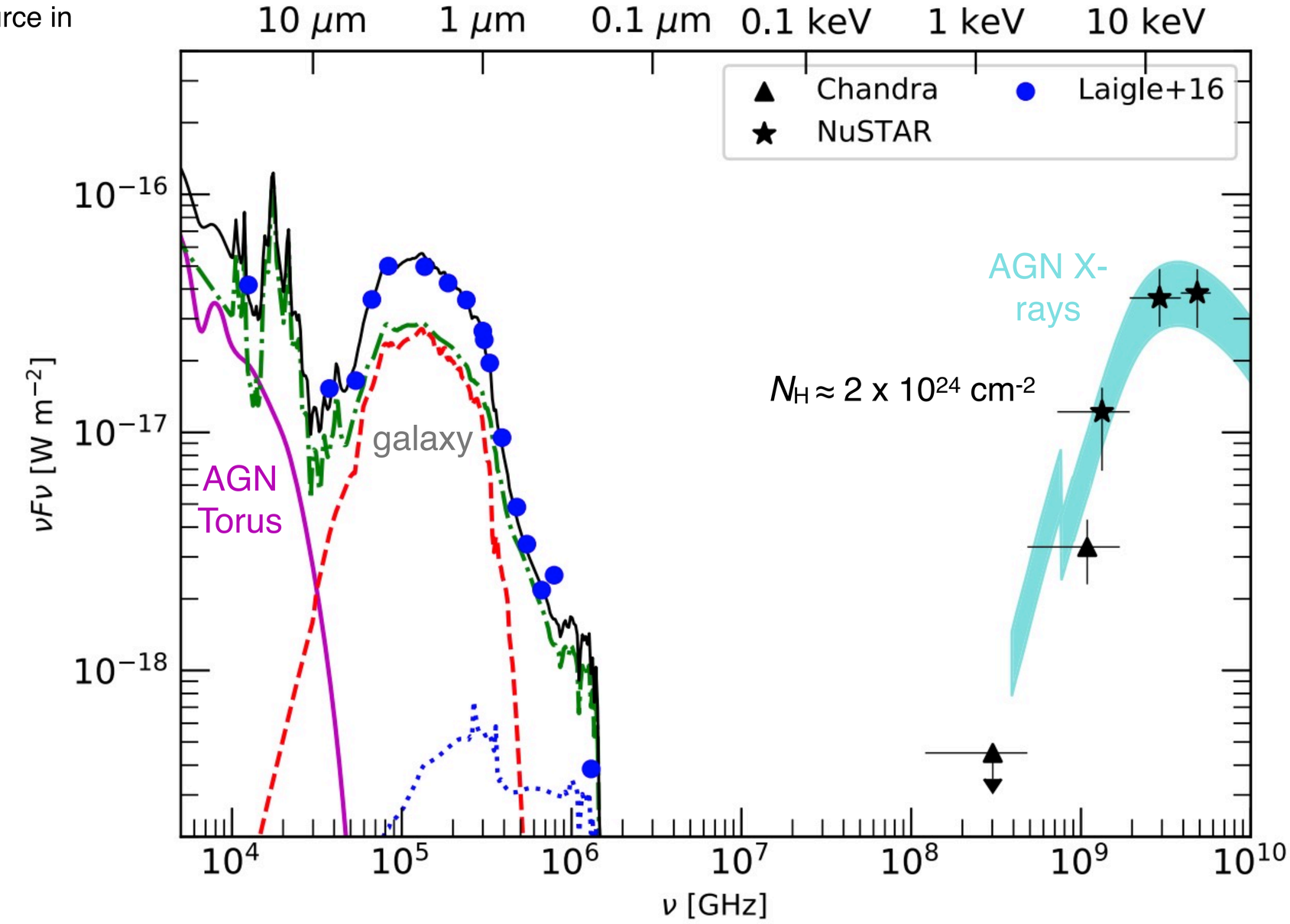
How **heavily buried** are obscured AGN?



How **heavily buried** are obscured AGN: SED and X-ray spectral fitting

NuSTAR detected hard X-ray source in COSMOS field

Masini et al. (2018)



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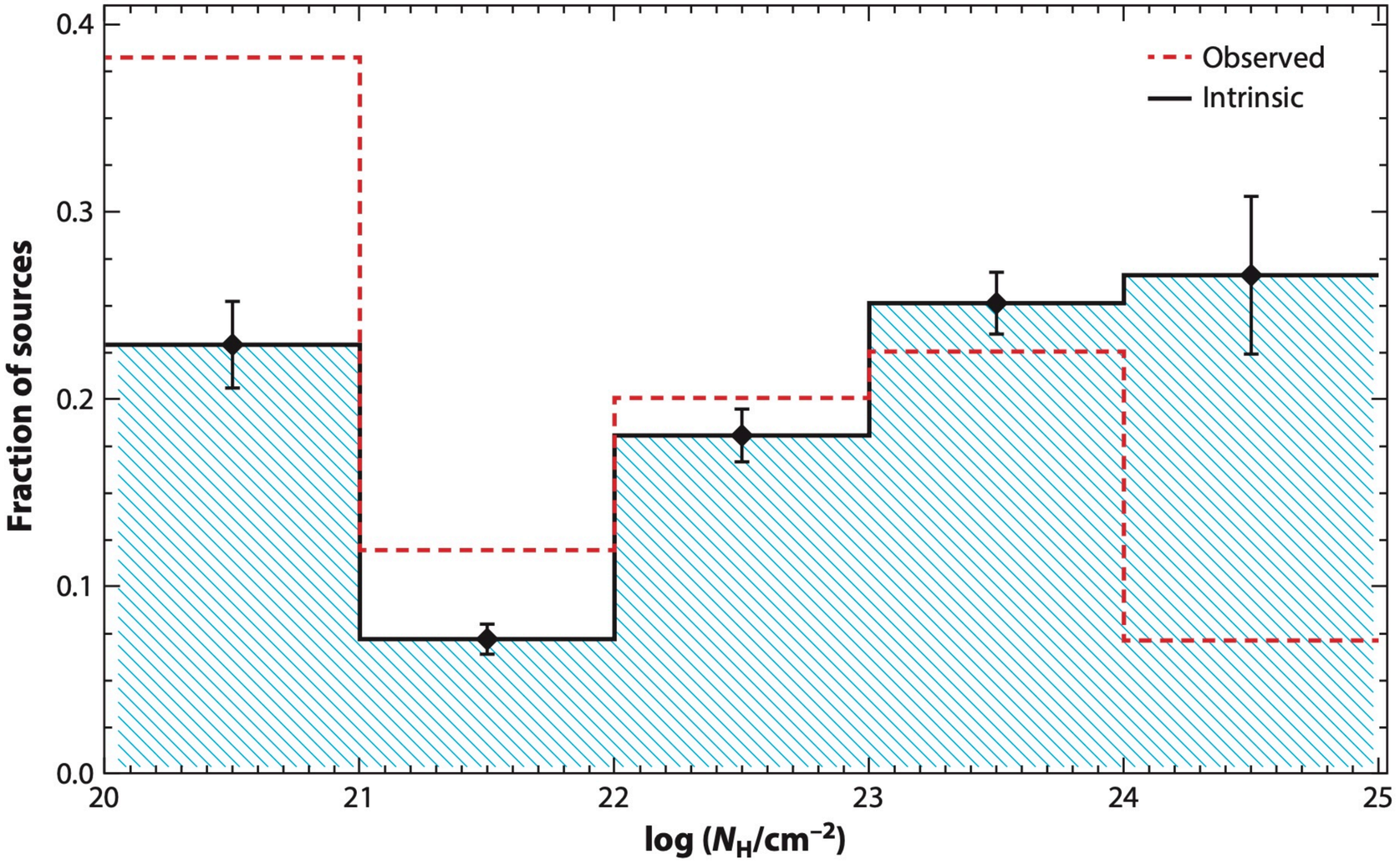
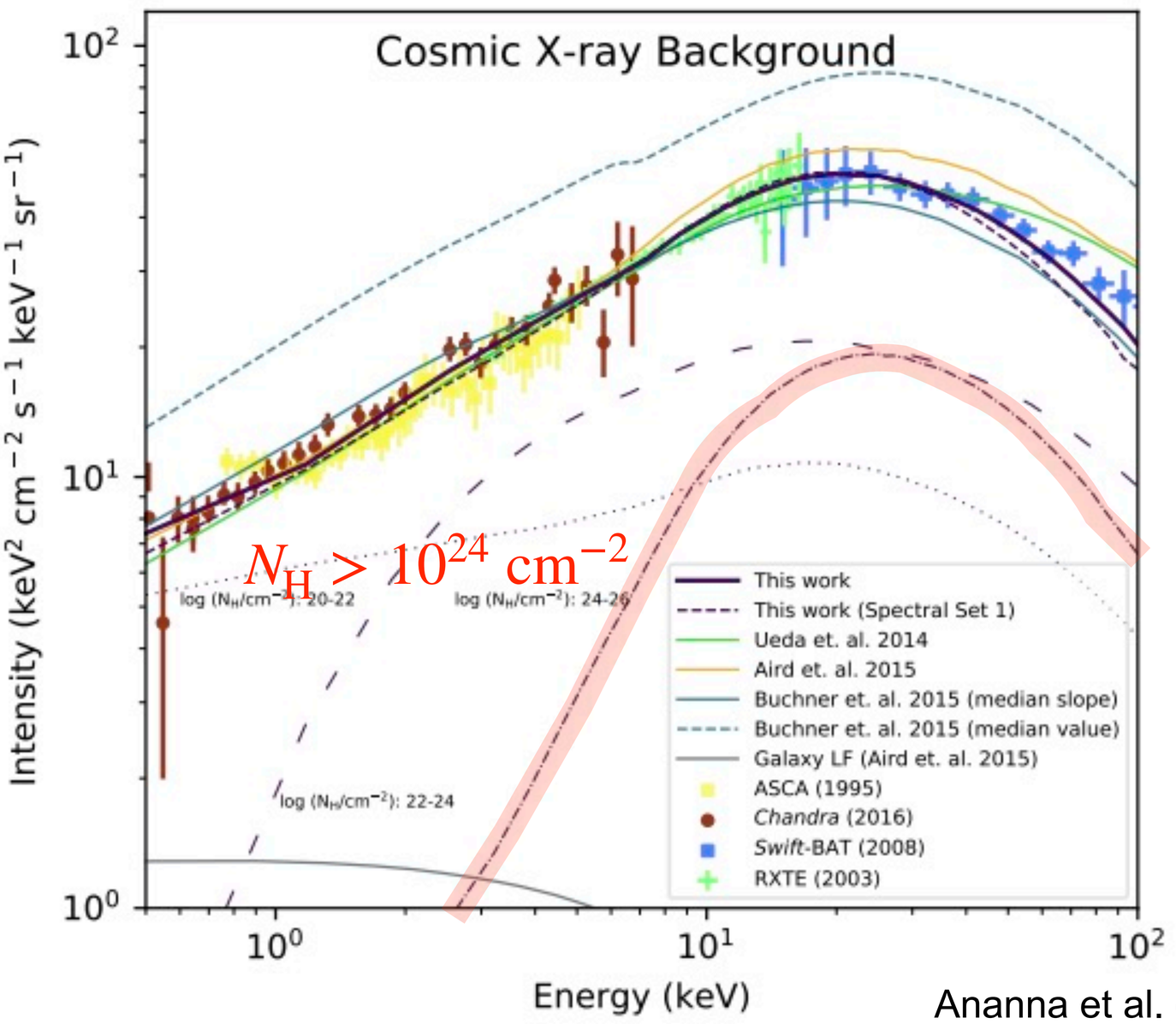


Adapted from Ricci et al. (2017)

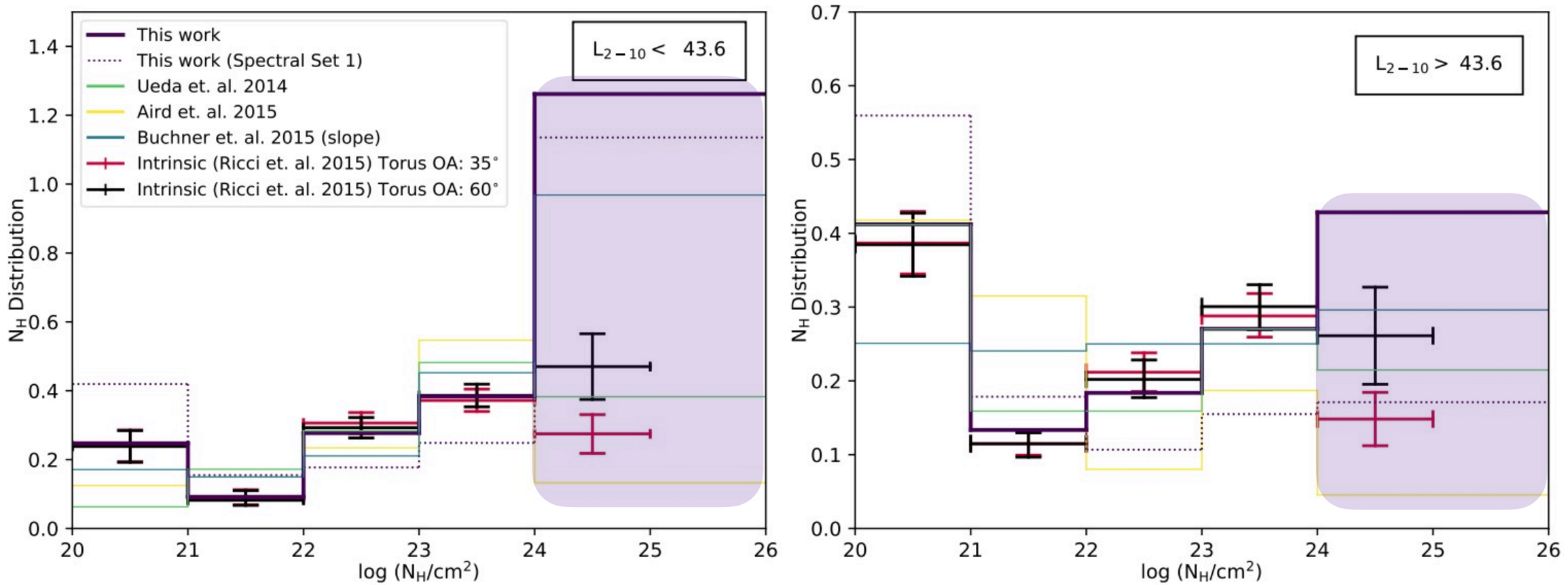
How **heavily buried** are obscured AGN?: Cosmic X-ray background

Synthesis model of the **cosmic X-ray background**



Ananna et al. (2019)

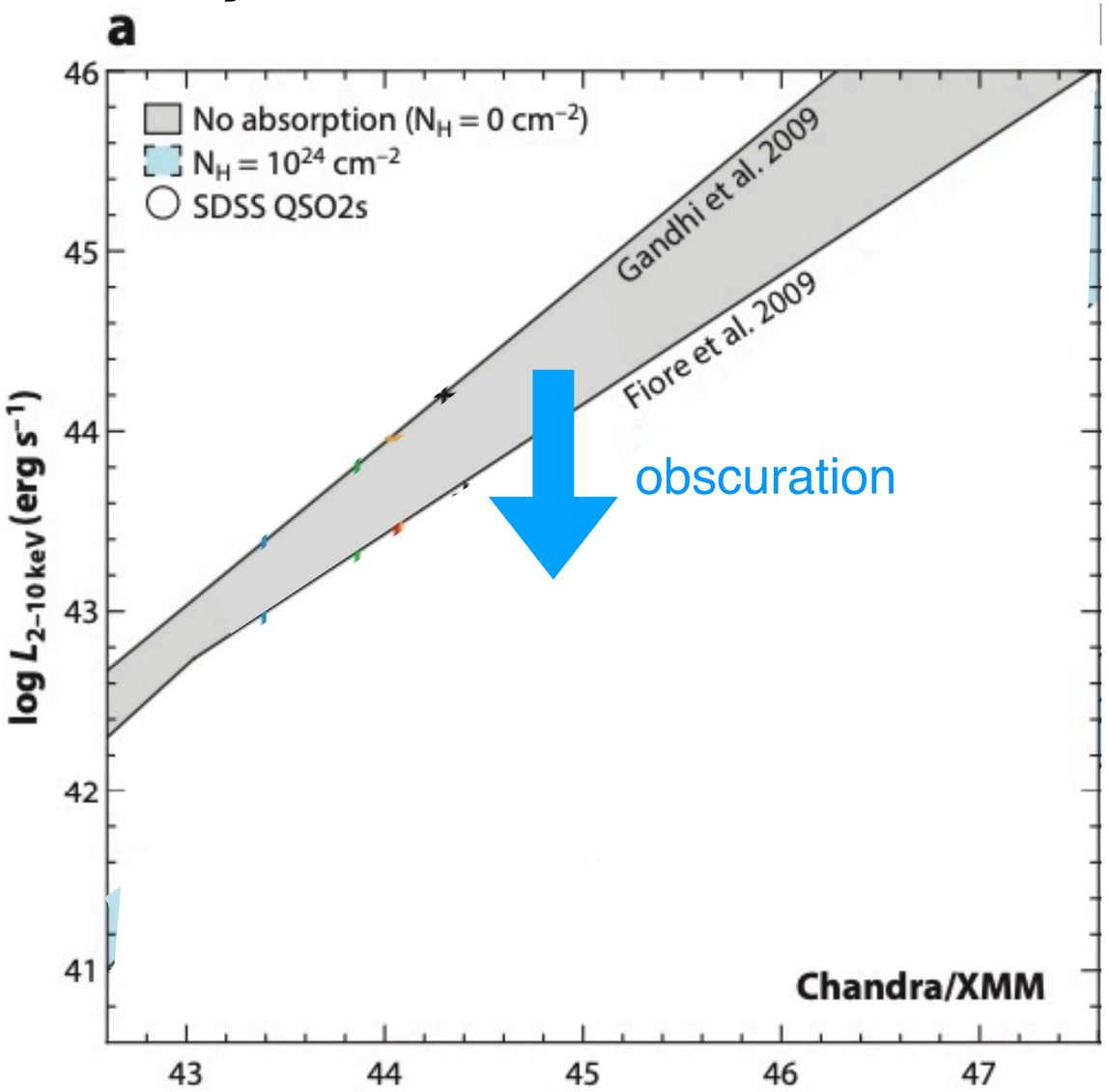
How **heavily buried** are obscured AGN?: Cosmic X-ray background



"This new population synthesis model suggests that, intrinsically, **50% ± 9% (56% ± 7%) of all AGNs within *z* = 0.1 (1.0) are Compton-thick.**"

Ananna et al. (2019)

How **heavily buried** are obscured AGN?: X-ray and mid-IR luminosity

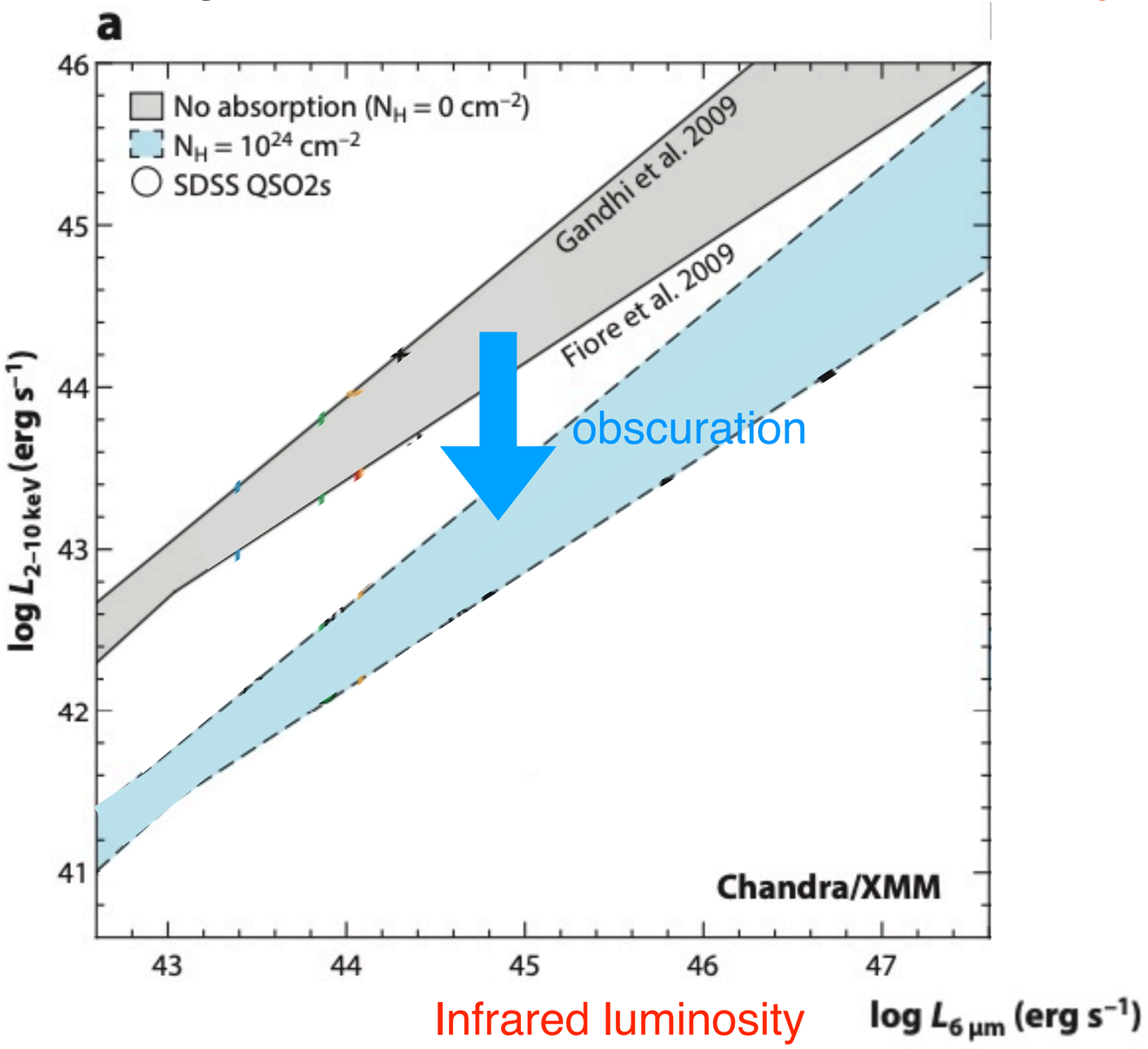


X-ray luminosity

Infrared luminosity

Adapted from Lansbury et al. (2015)

How **heavily buried** are obscured AGN?: X-ray and mid-IR luminosity



X-ray luminosity

Infrared luminosity

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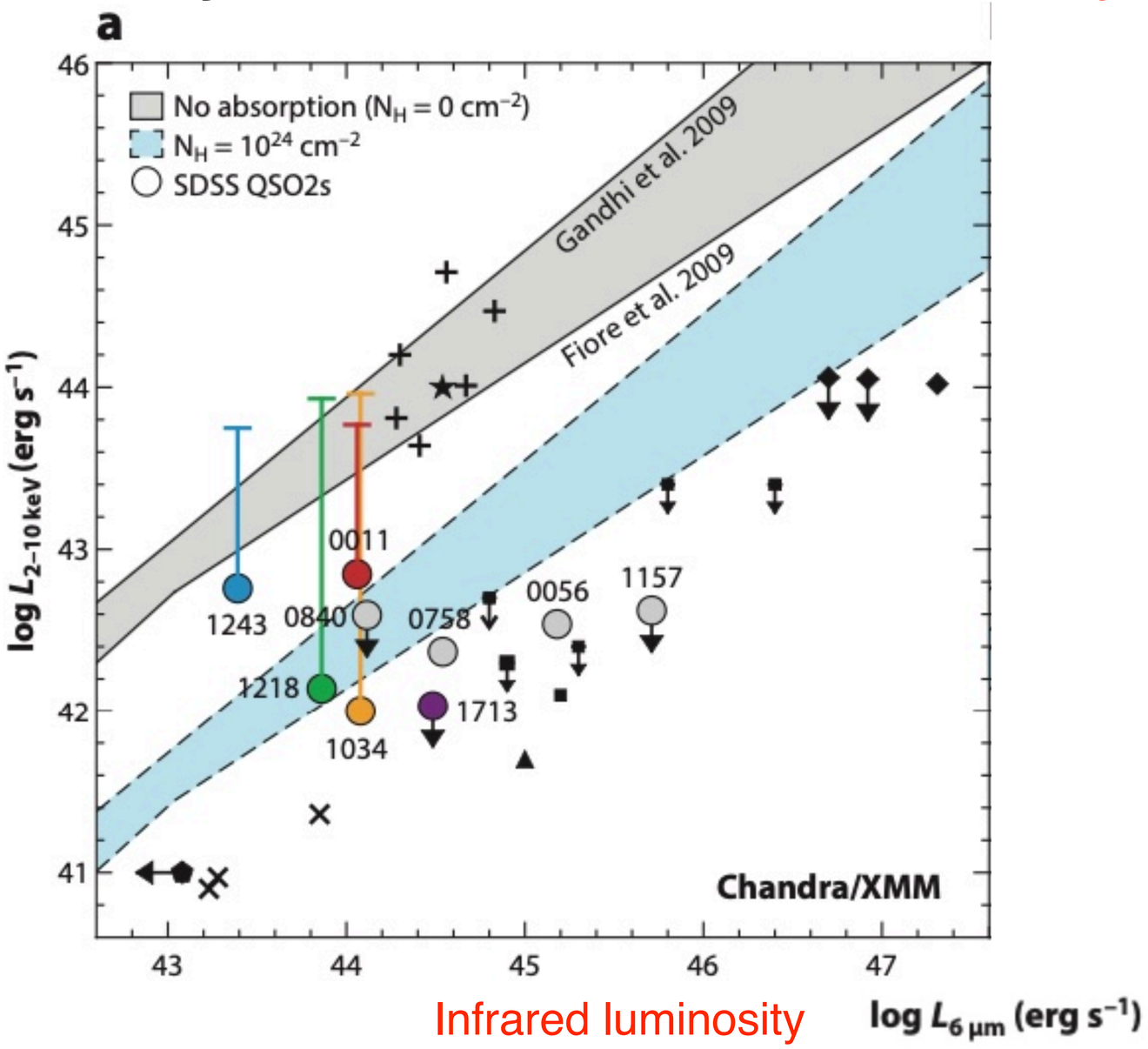

X-ray luminosity

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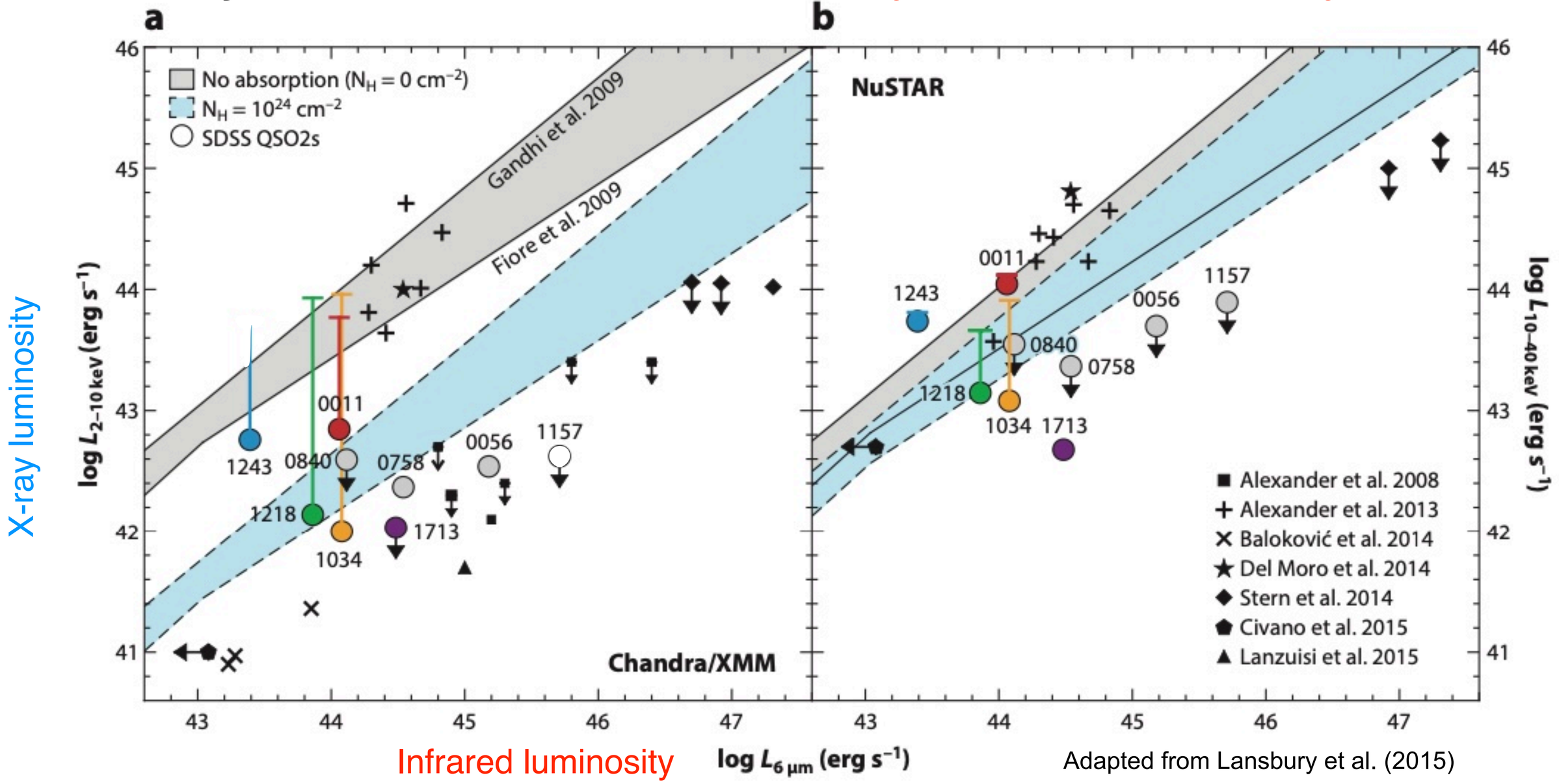
How **heavily buried** are obscured AGN?: X-ray and mid-IR luminosity

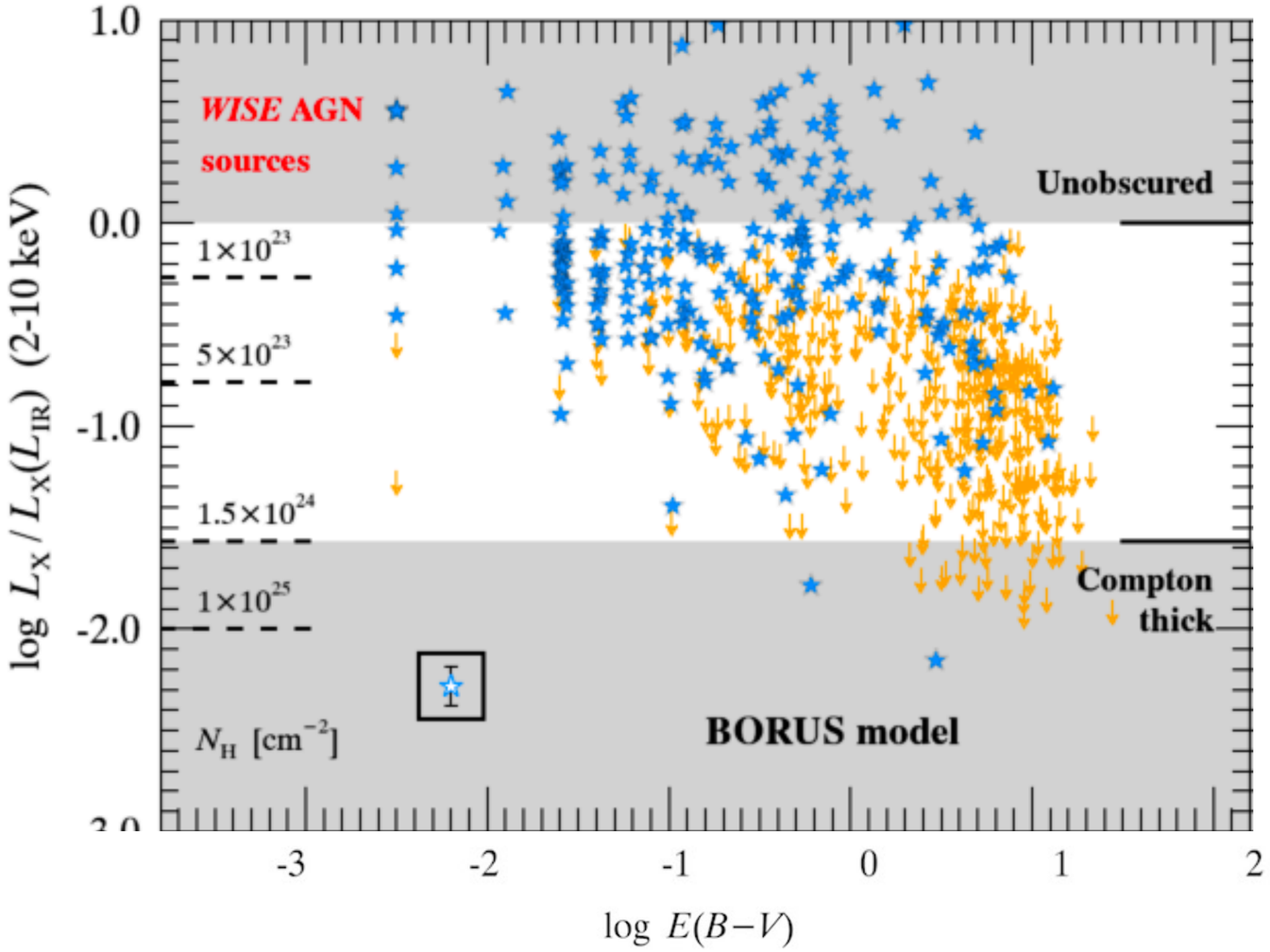


Adapted from Lansbury et al. (2015)

How **widespread** are heavily obscured AGN?: X-ray and mid-IR luminosity

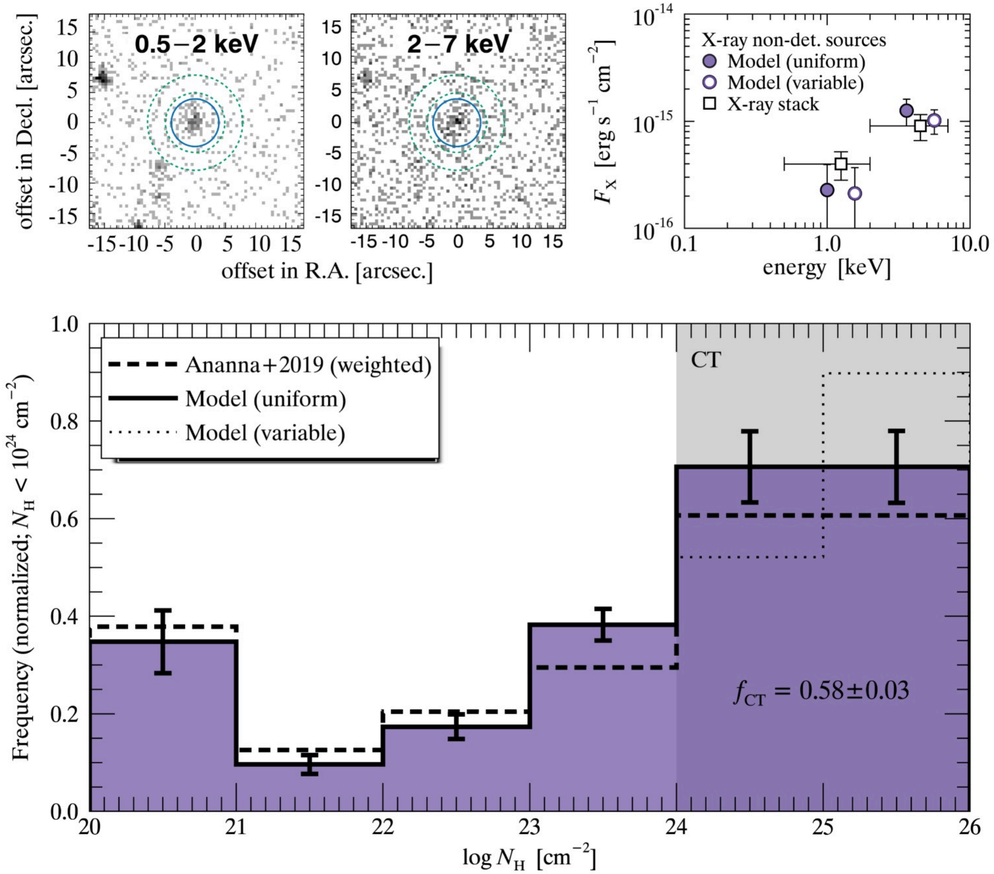
Select AGN across much of the sky! (*WISE,* SDSS, UKIDSS)

← Suppression of L_X



Dust obscuration →

X-ray non-detections!



Carroll et al. (2021, 2023)

2. **How heavily buried** and **widespread** are obscured AGN?

Obscured AGN can be **extremely heavily buried** and **make up the majority** of growing black holes. They **may be missed** in most studies (for example with X-rays) of the AGN population

Three key questions about obscured AGN

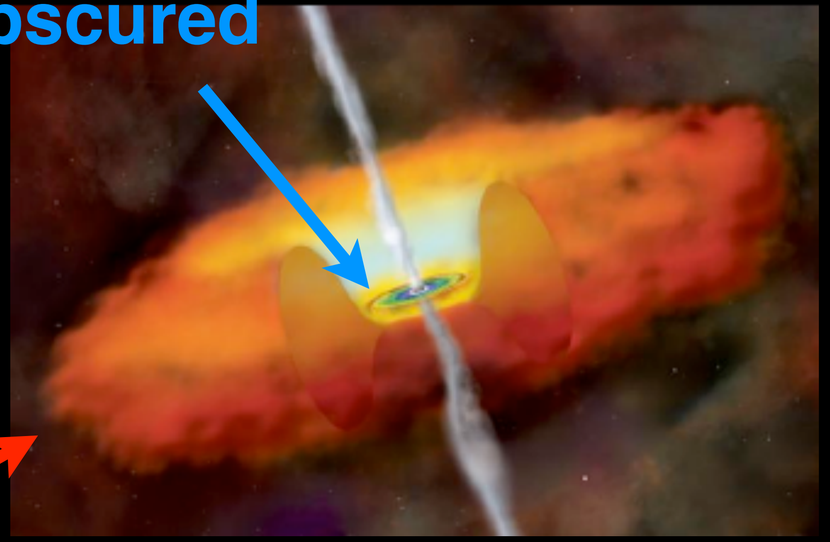
1. How do we **identify obscured AGN?**

2. **How heavily buried** and **widespread** are obscured AGN?

3. What is the **physical nature** of the obscuring material?

Does obscuration happen on small or large scales?

Unobscured

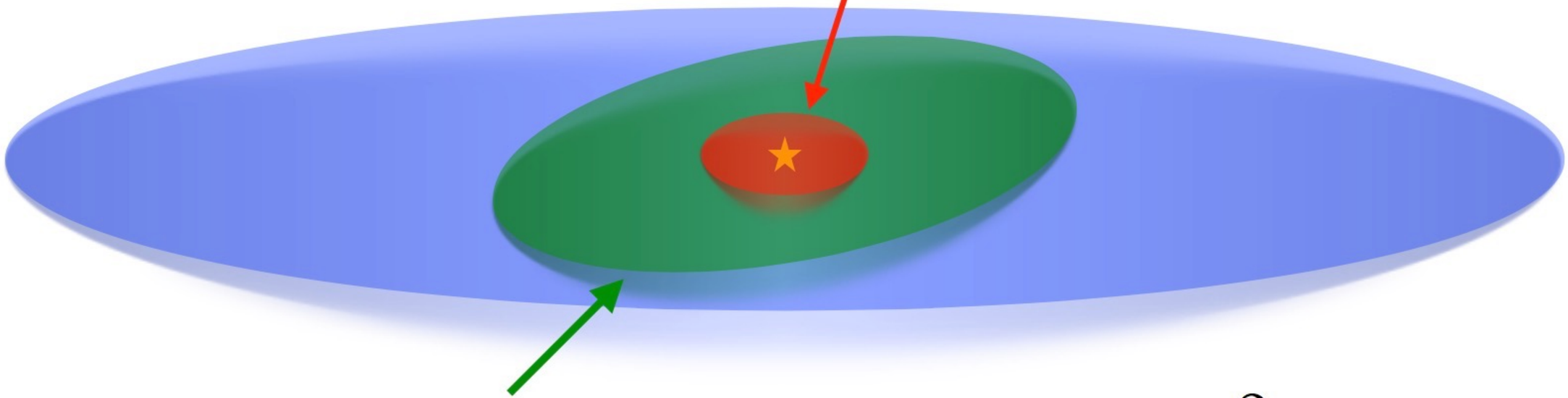


~10 pc

Obscured

~10 kpc

Level of obscuration depends on scale



Host galaxy
($R > 1$ kpc, $M_H < 10^{10}\ M_\odot$)
$N_H < 10^{23}$ cm^{-2}

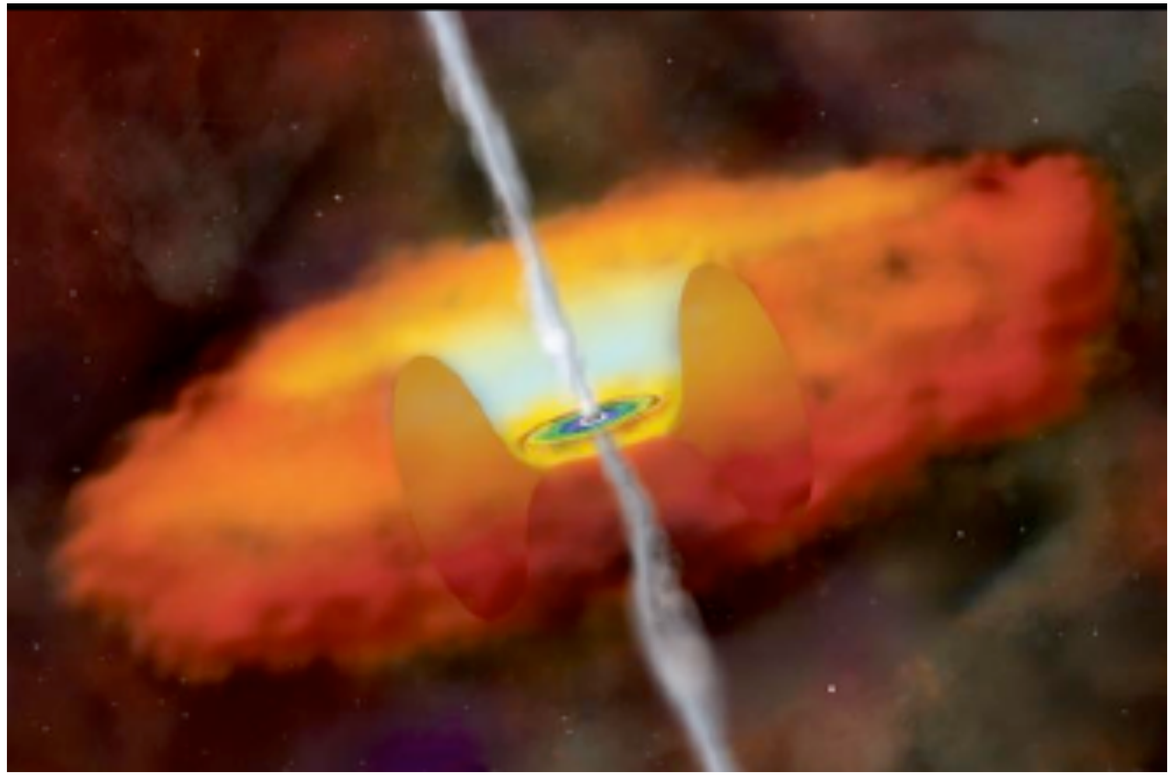
Nuclear torus
($R < 10$ pc, $M_H < 10^{8}\ M_\odot$)
$N_H < 10^{25}$ cm^{-2}

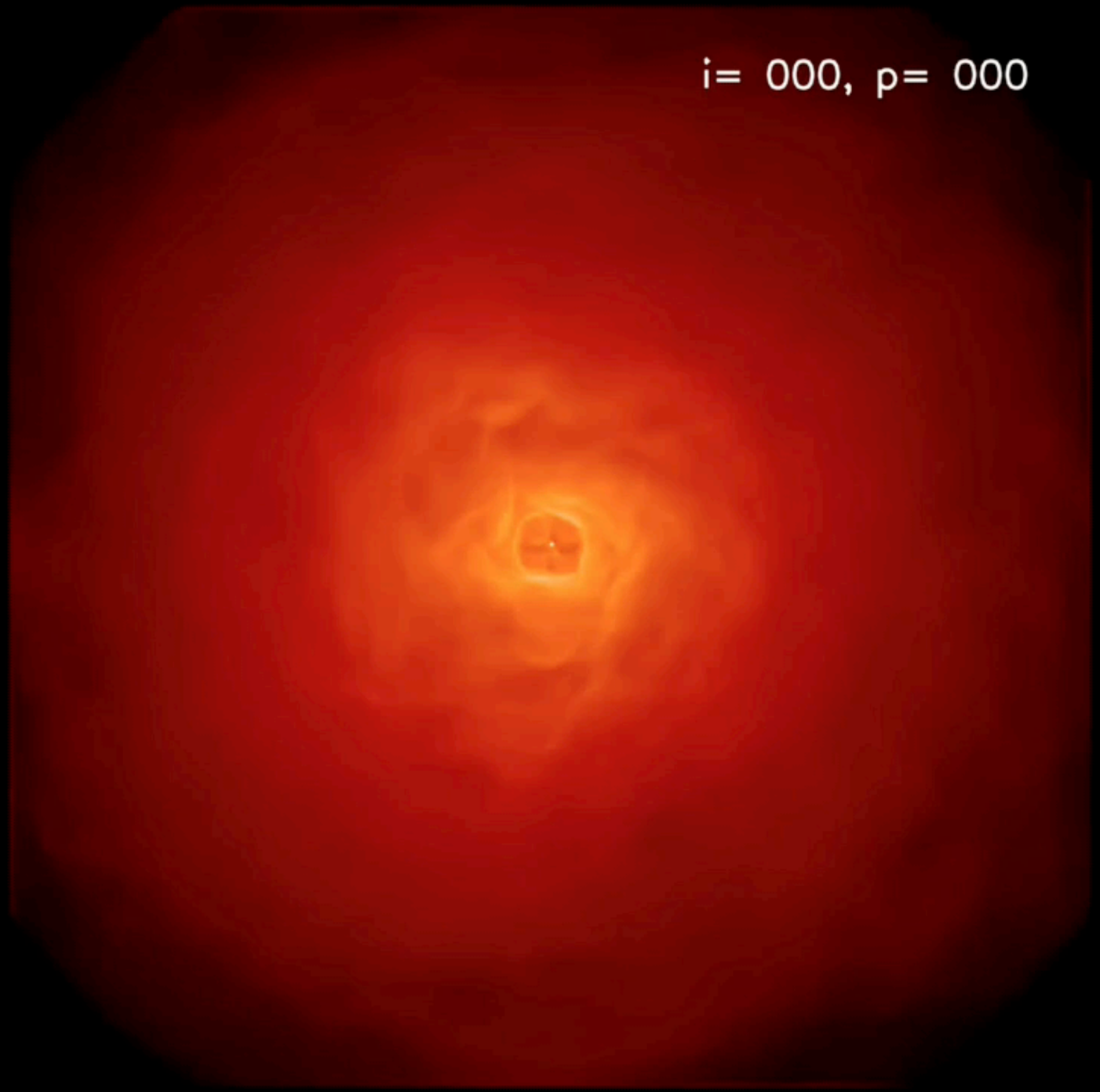
Circumnuclear starburst
(R ~10—100 pc, $M_H < 10^{9}\ M_\odot$)
$N_H < 10^{24}$ cm^{-2}

$$M_{\rm H} \propto R^2 N_{\rm H}$$

Hickox & Alexander, ARA&A (2018)

Evidence for “torus" obscuration



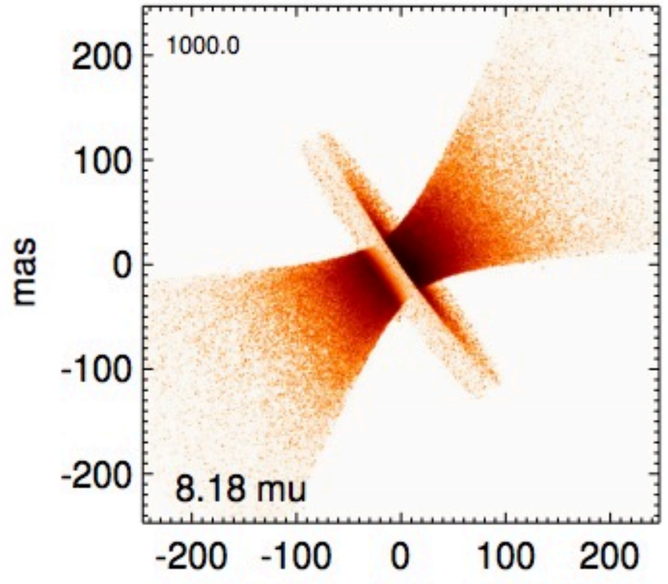


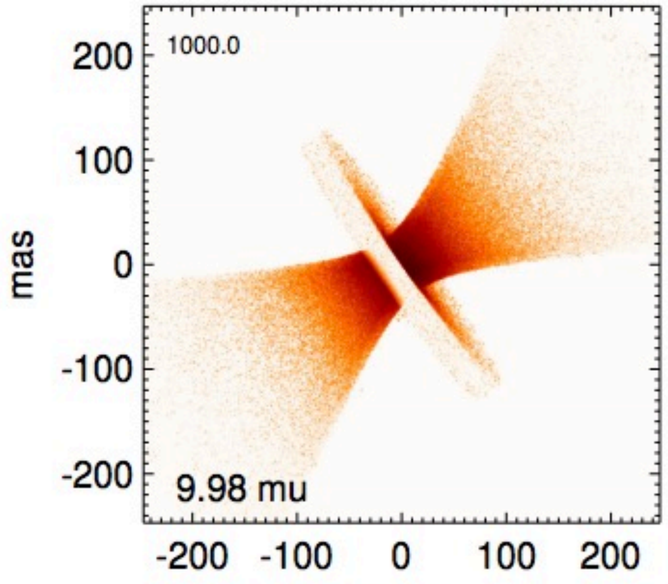
Simulation by Wada,
Schartmann & Meijerink (2016)

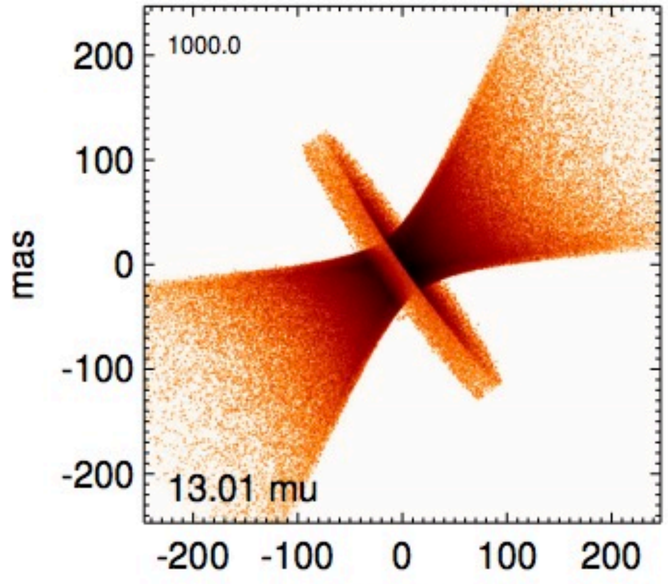
The Circinus Galaxy with VLTI/MIDI

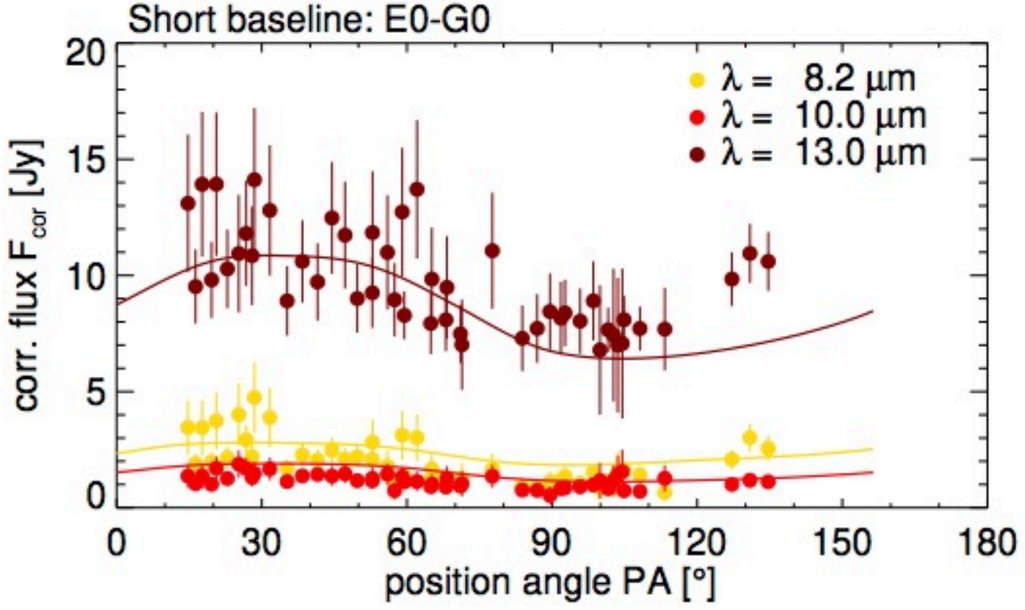
The Circinus Galaxy with VLTI/MIDI

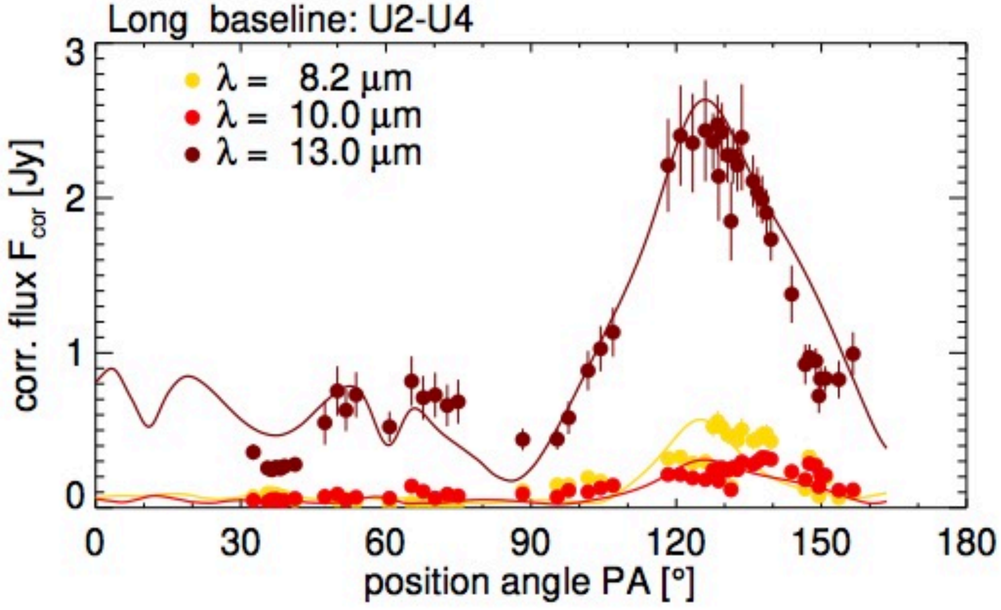
Stalevski, Tristram & Asmus (2019)







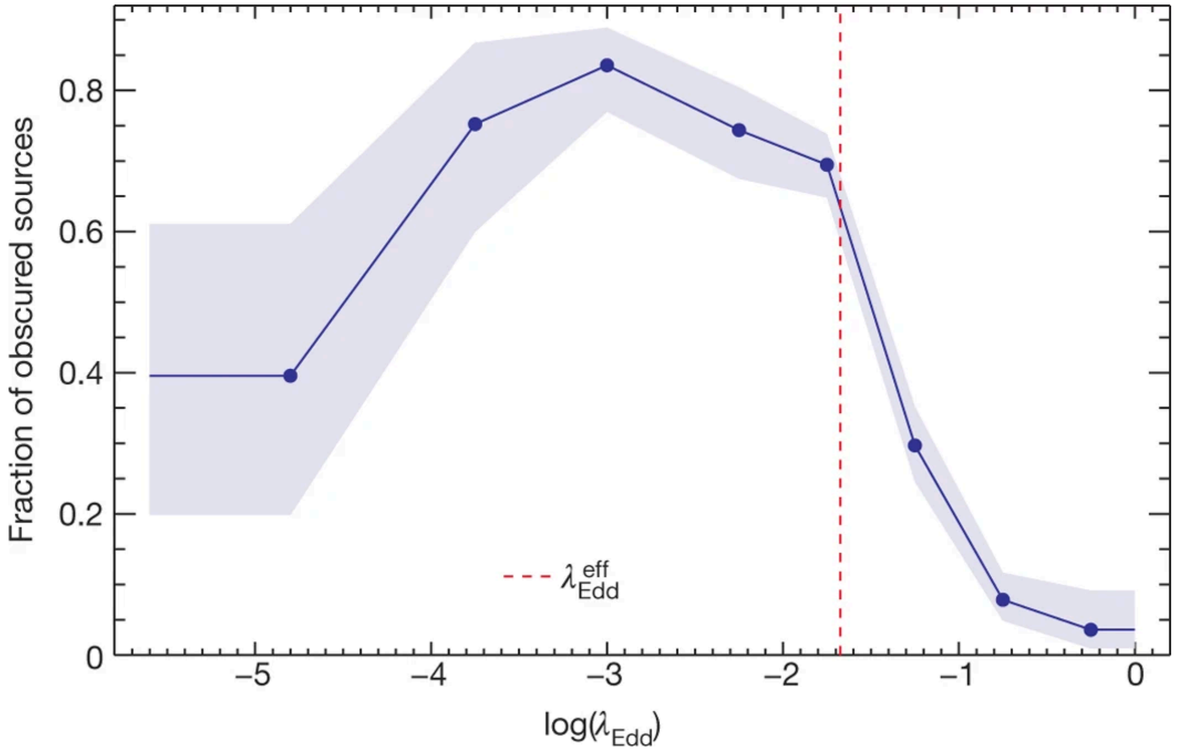


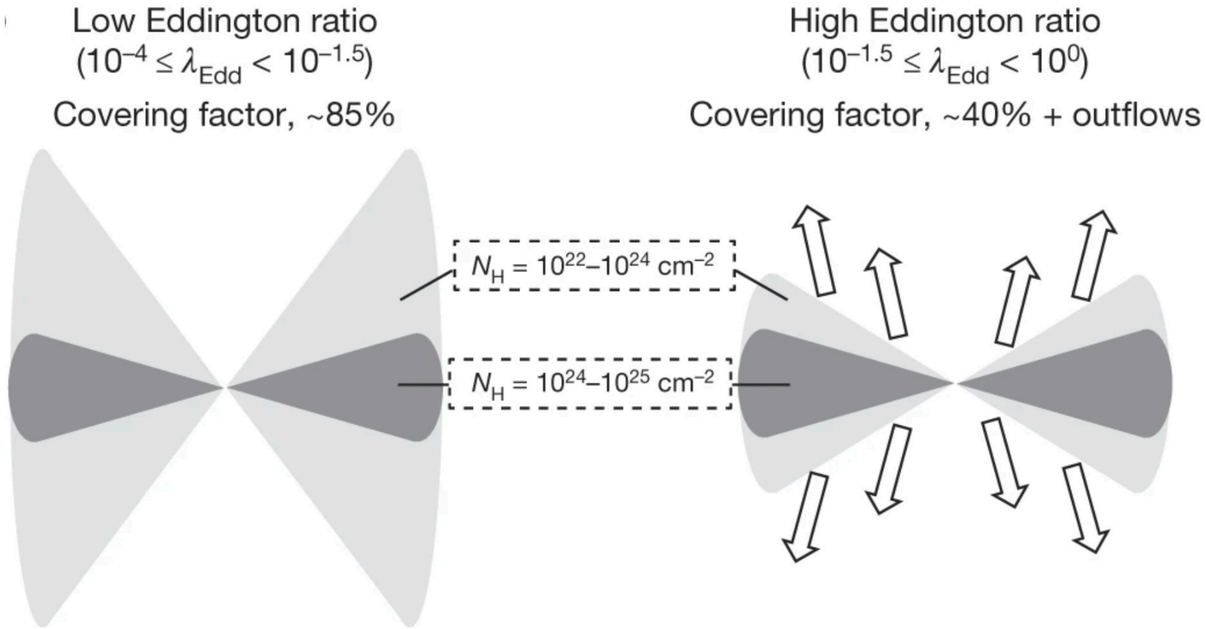


The “torus”: Radiation regulation of obscuration

Ricci et al. (2017)

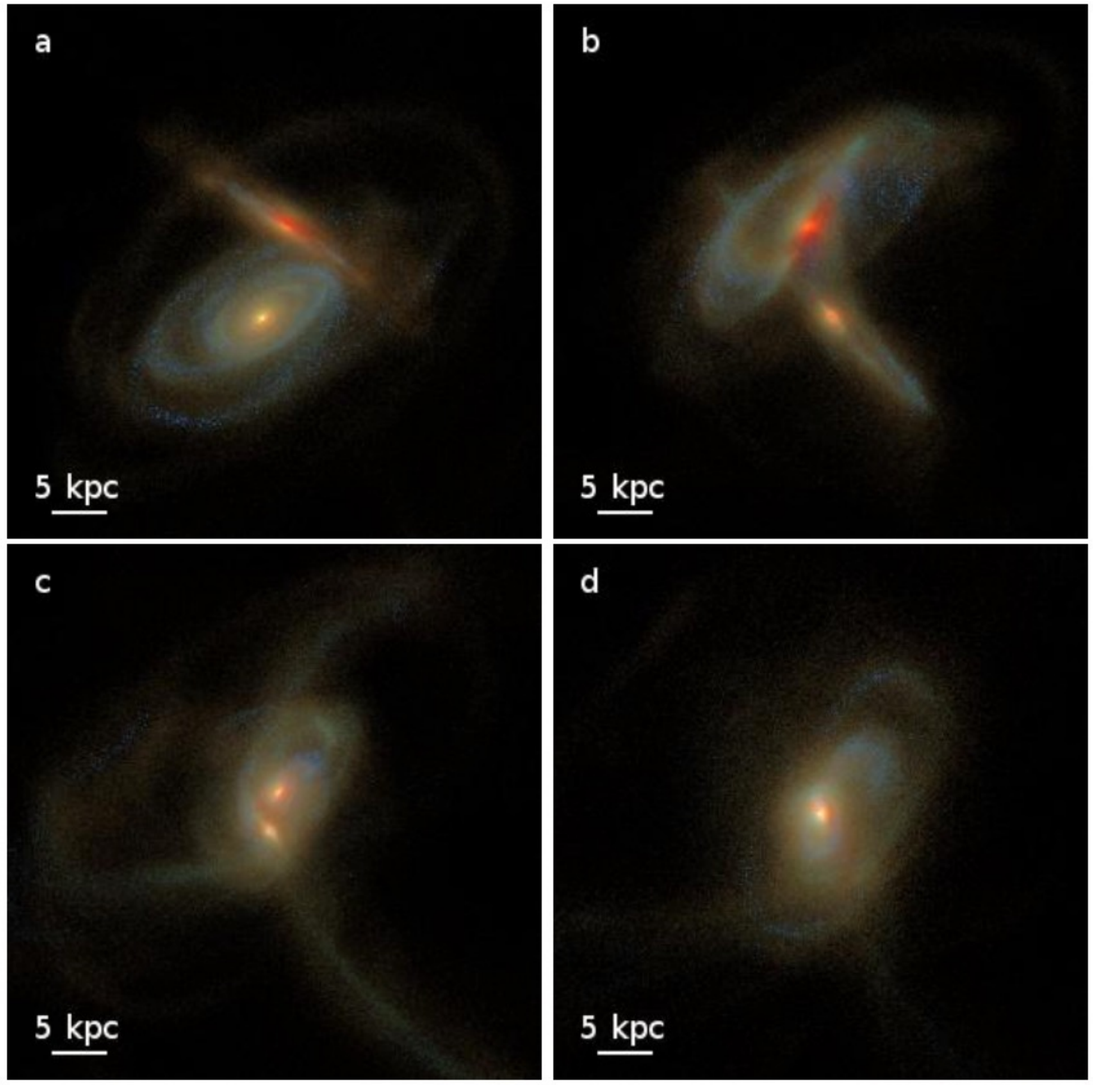
Local hard X-ray selected AGN - **higher Eddington ratio systems are less obscured**

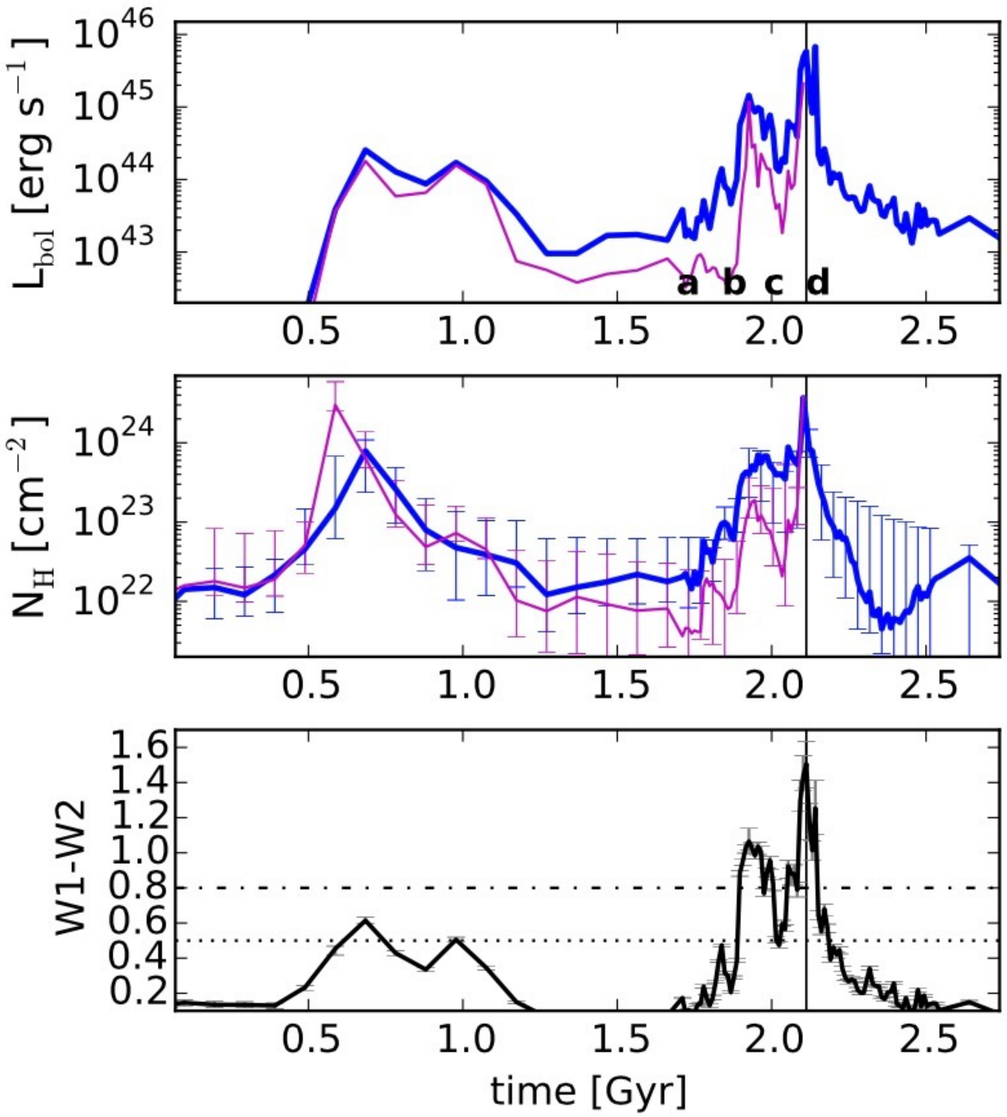




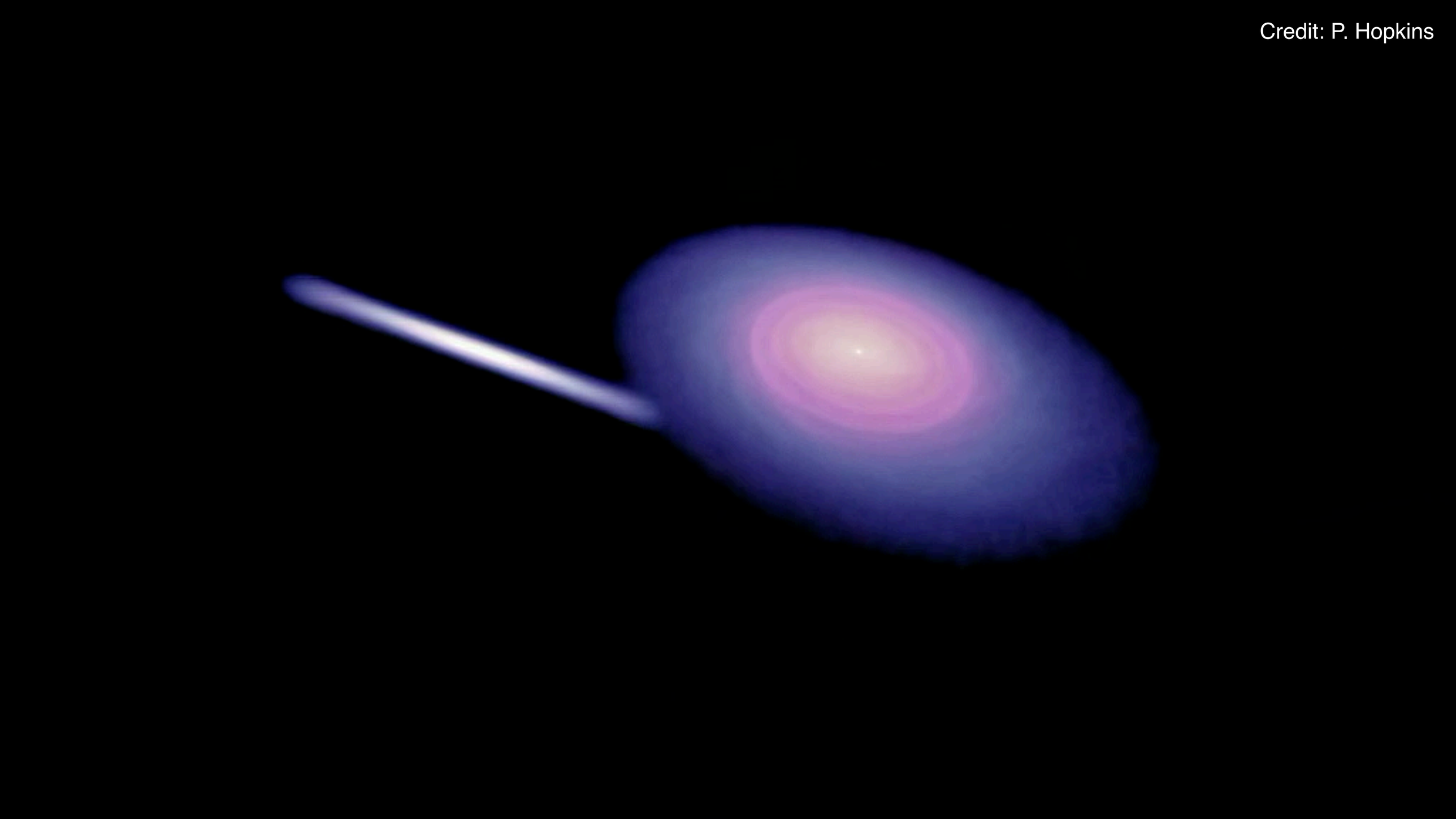
Evidence for host galaxy obscuration

Simulations: Obscuration in **galaxy mergers**

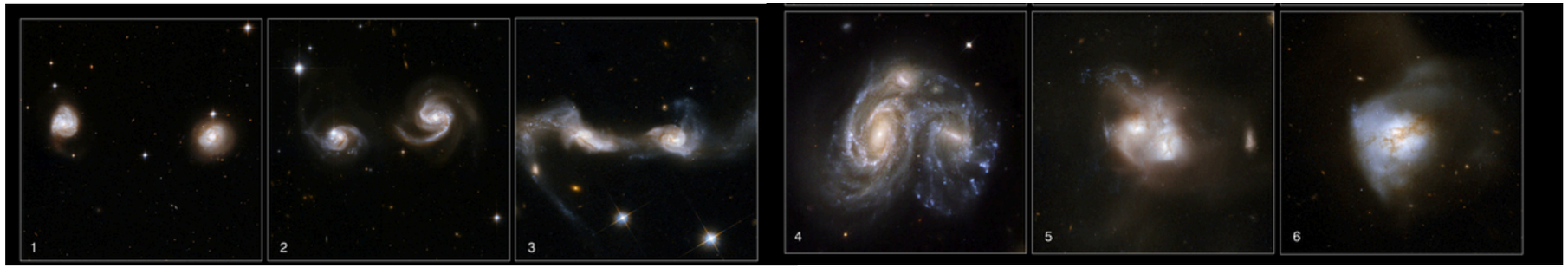




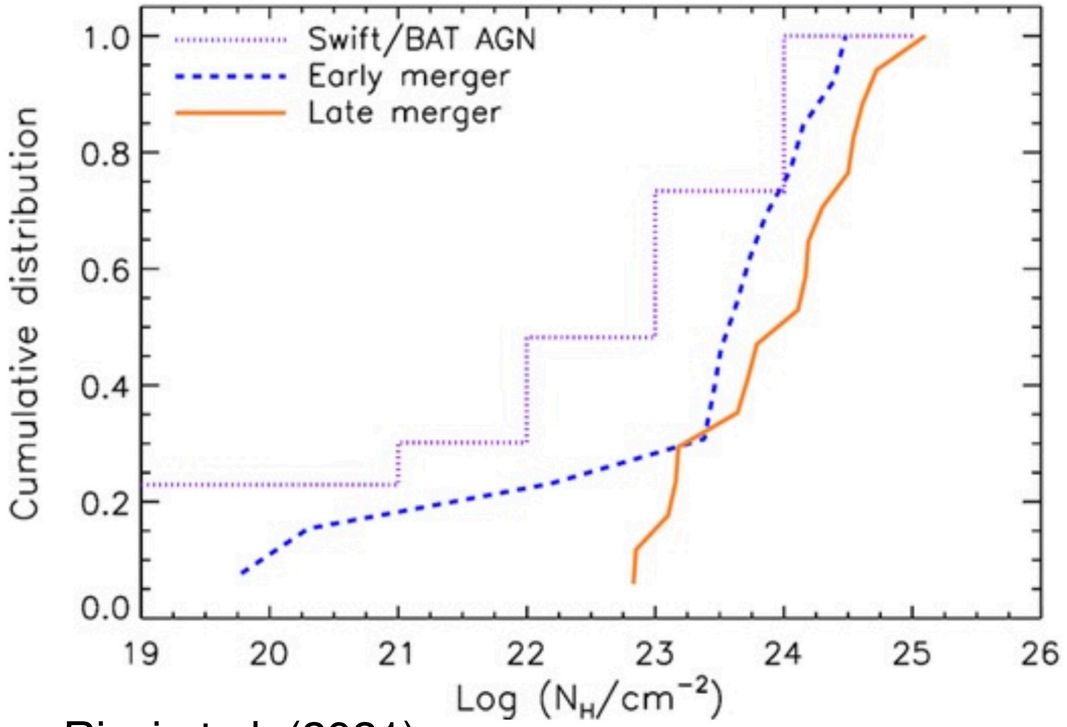
Blecha et al. (2018)


Credit: P. Hopkins

Observations: Obscuration along the **merger sequence**

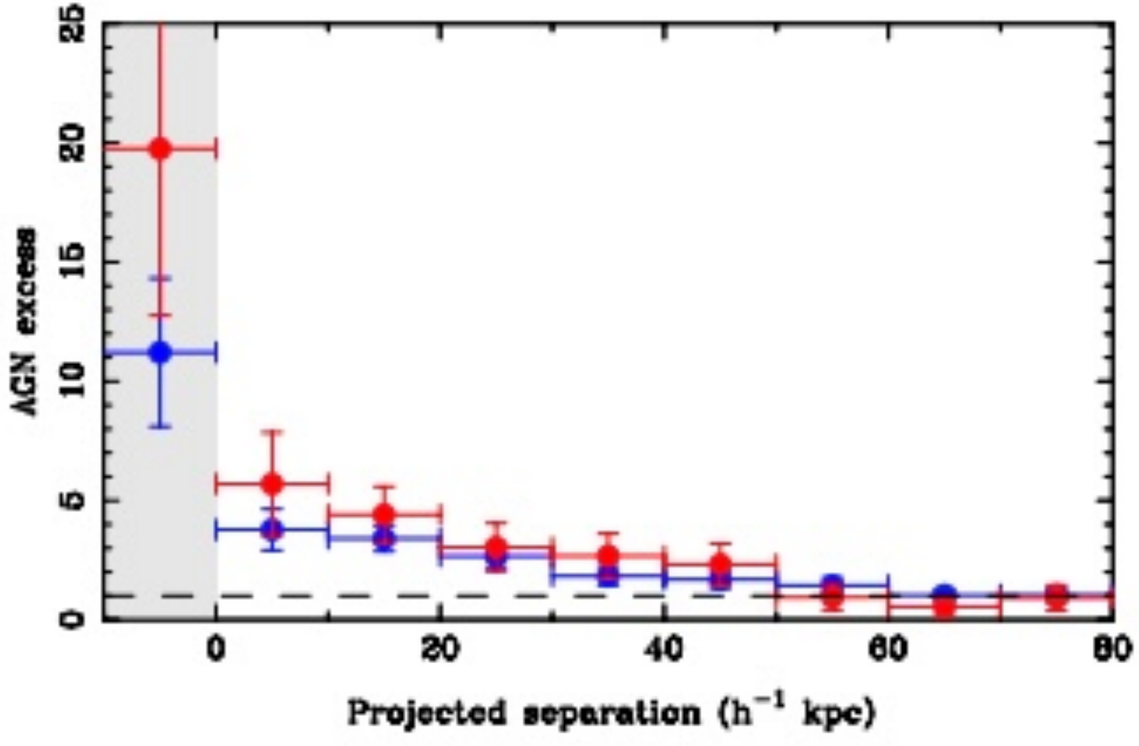


X-ray AGN



Ricci et al. (2021)

WISE IR AGN

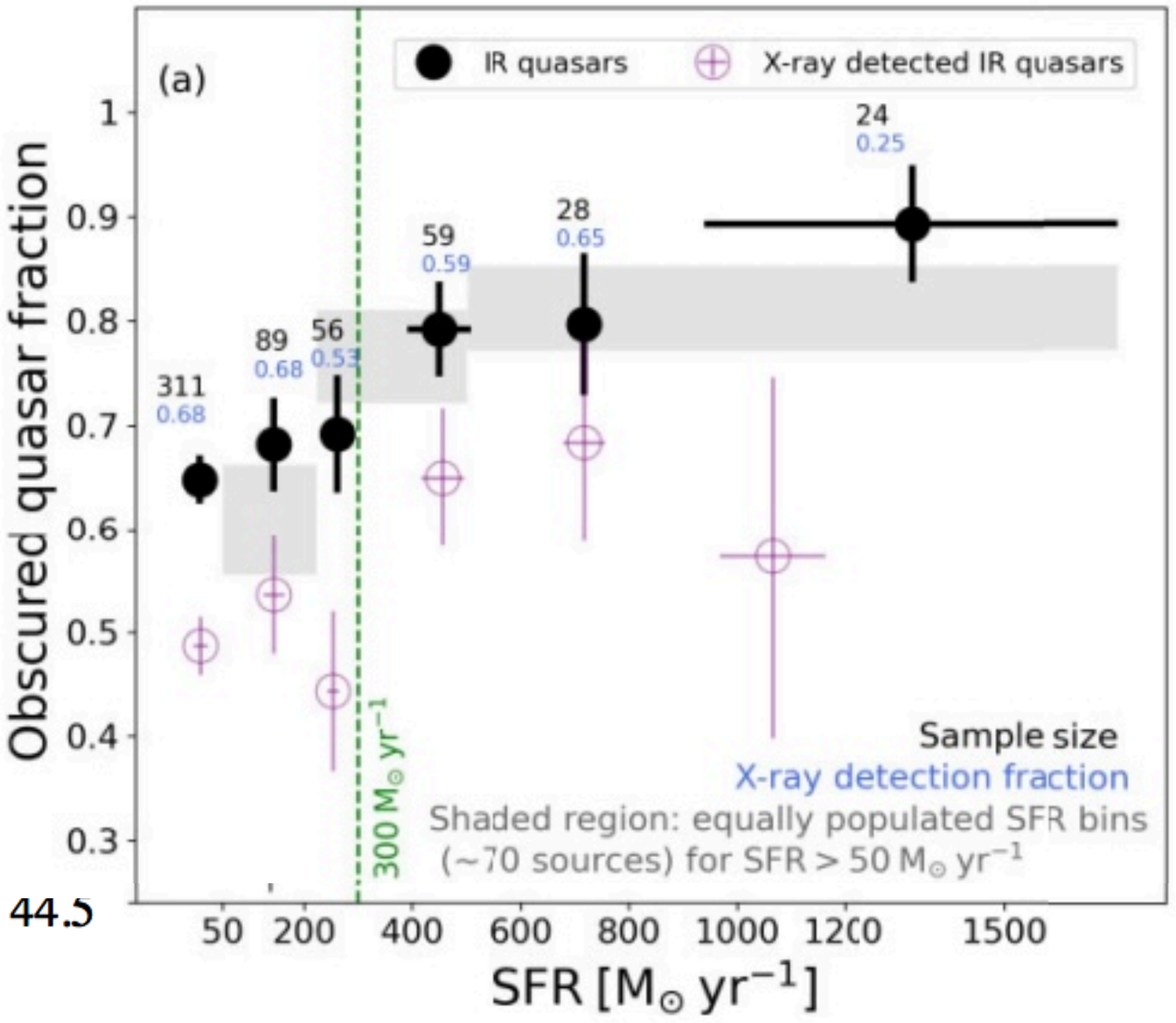


Satyapal, Ellison, et al. (2014)

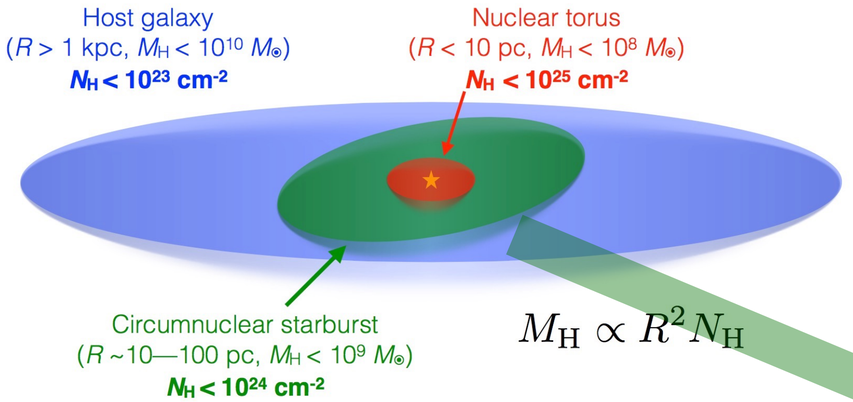
Highly star-forming quasars are **more obscured!**

Chen et al. (2015)

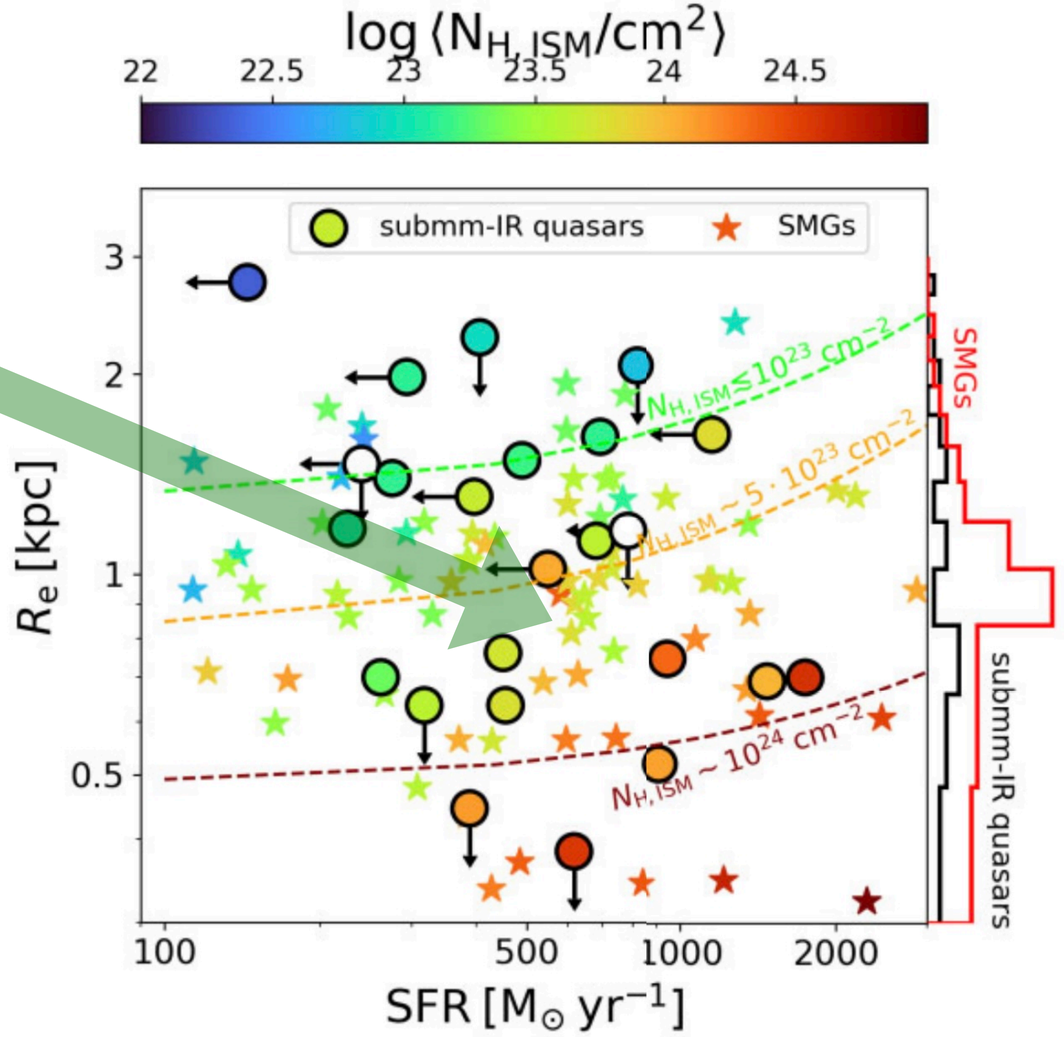
See also Andonie et al. (2022, 2023)



Star-forming gas can reach **Compton-thick** obscuration!



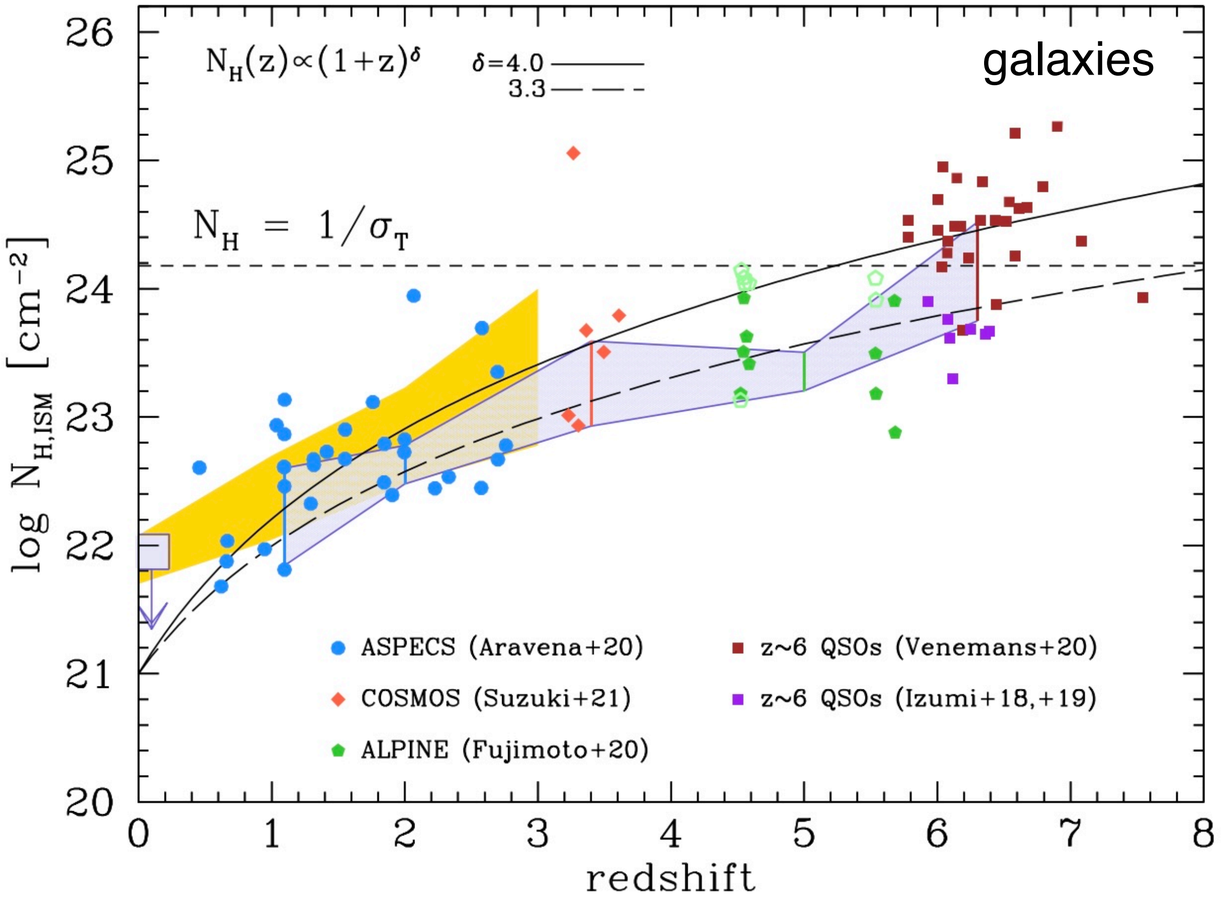
$$M_{\rm H} \propto R^2 N_{\rm H}$$

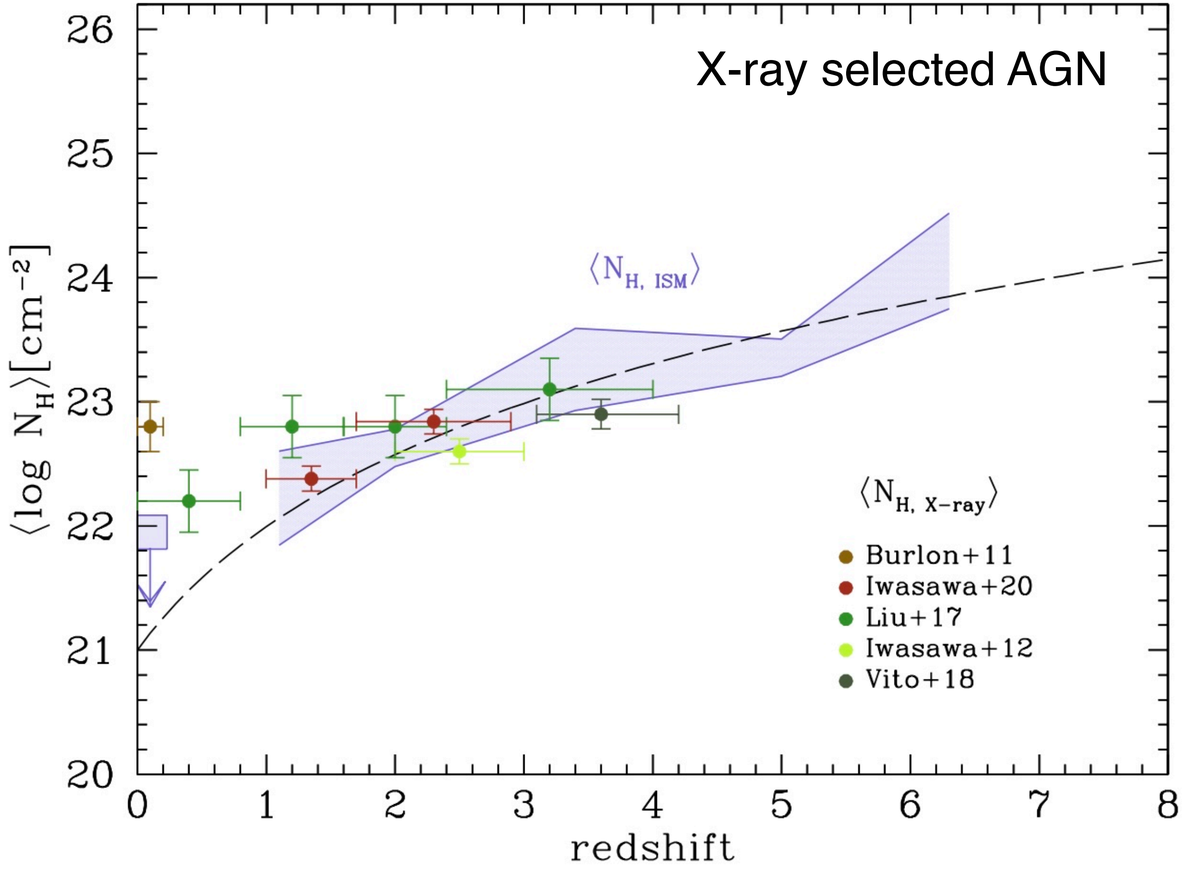


Andonie et al. (2023)

Host galaxy obscuration is expected to **increase with redshift**

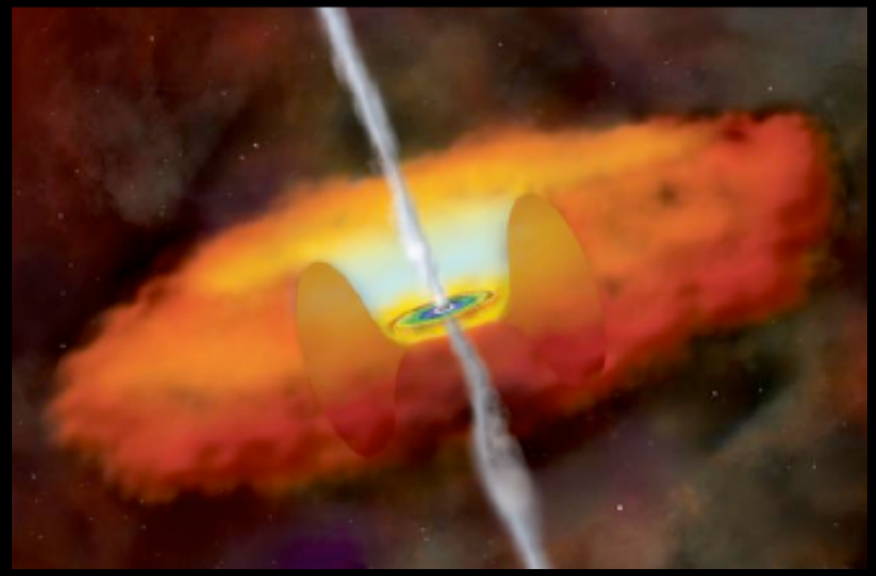
See also e.g., Buchner & Bauer (2017), Circosta et al. (2019)





Gilli et al. (2022)

What are the **dark matter halos** that host obscured AGN?

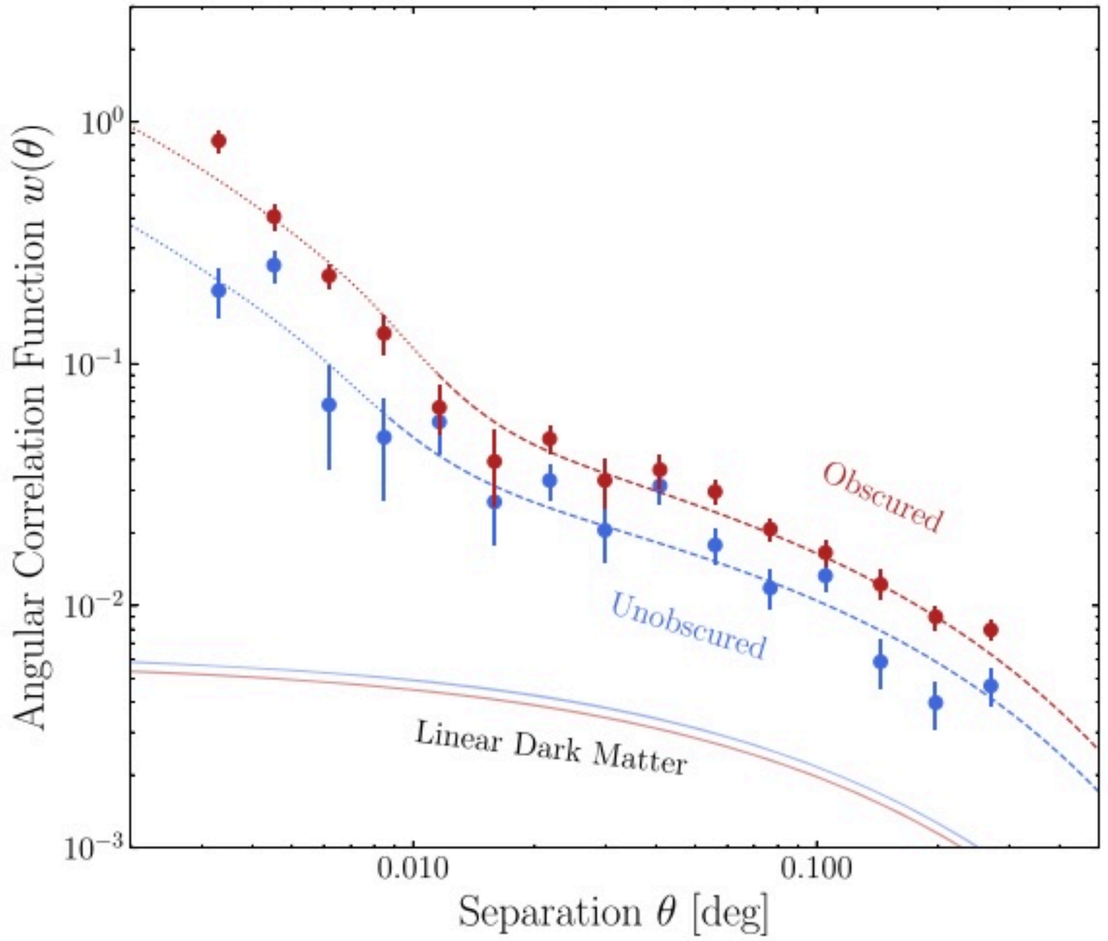


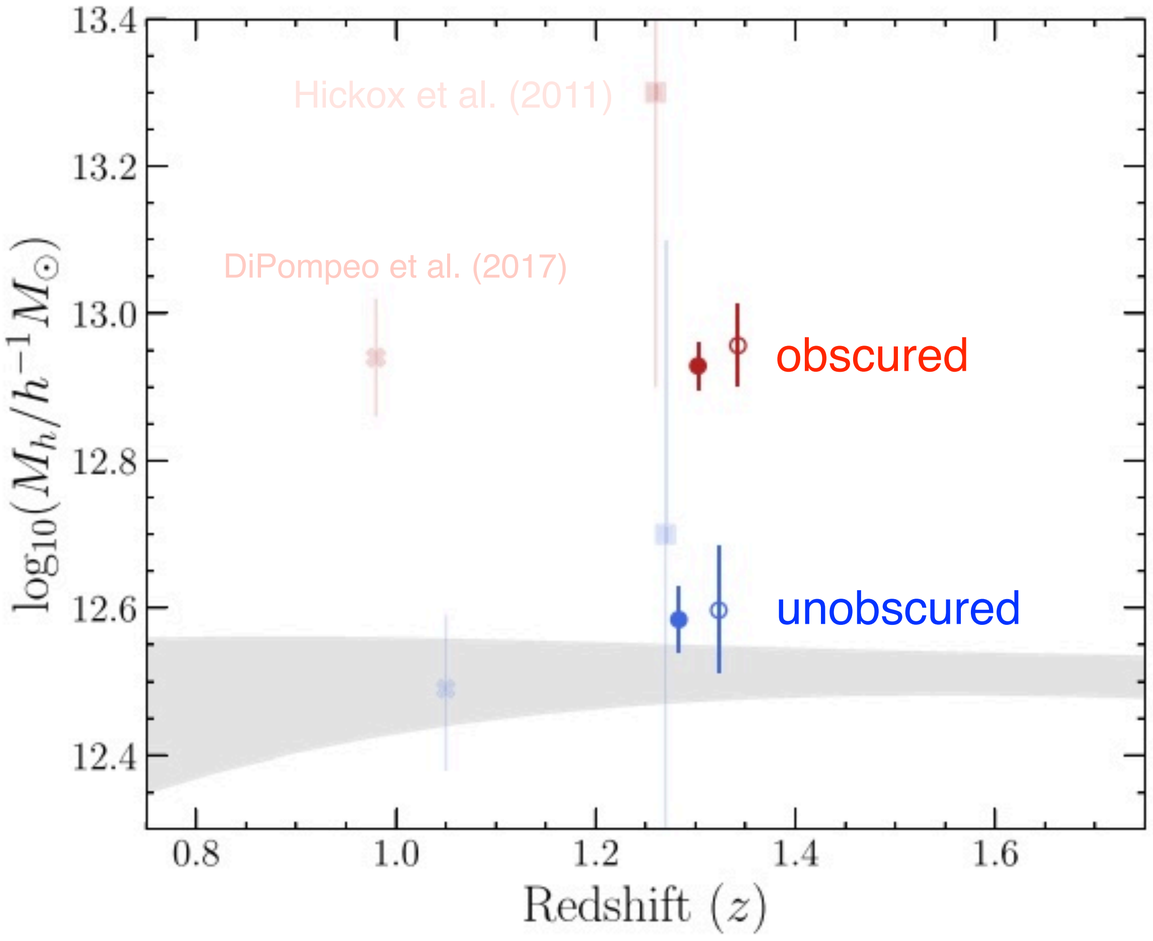
unified model “torus”:
no difference in clustering

galaxy-scale structures and interactions: **possible difference in clustering**

Measuring halo masses with **clustering** and **CMB lensing**

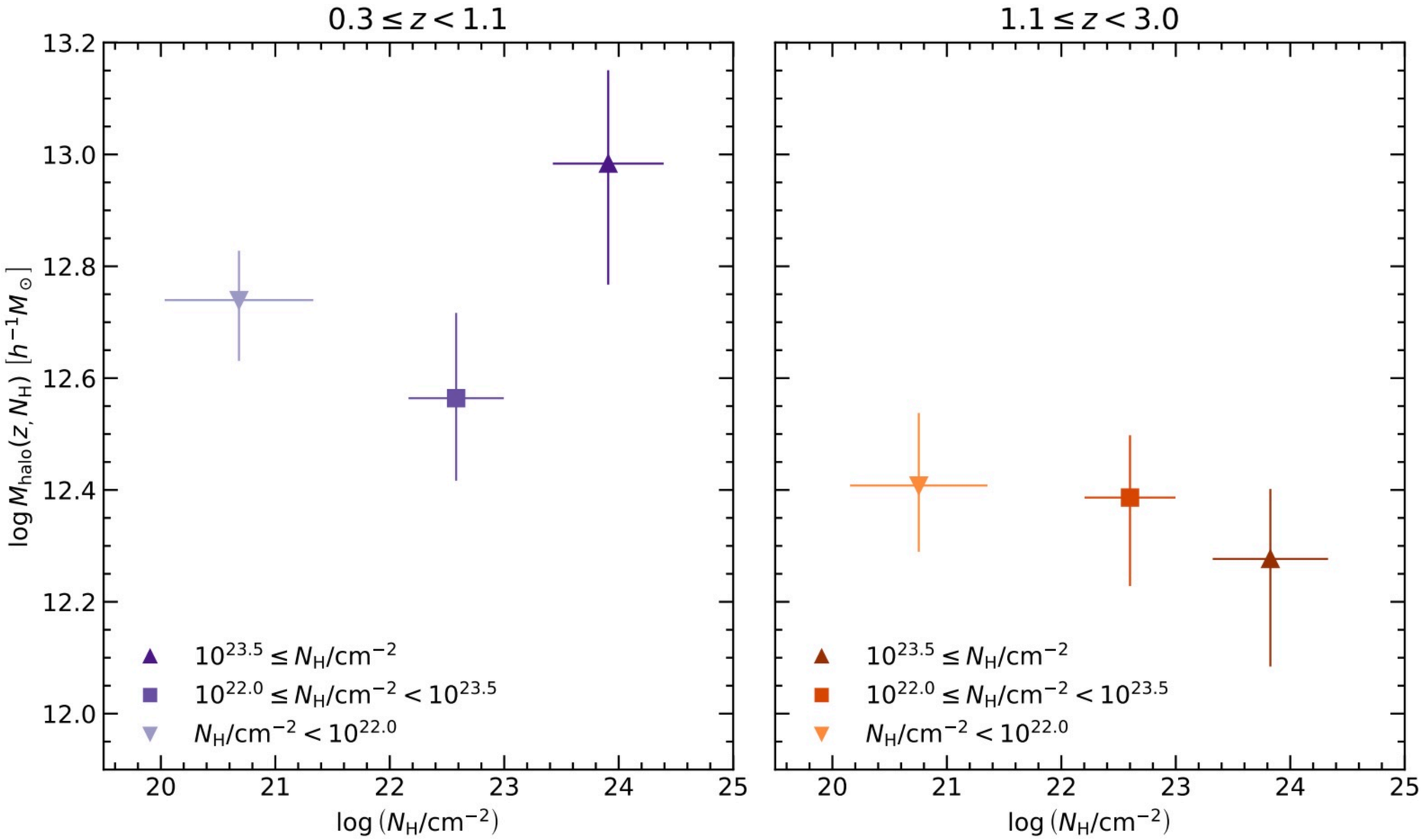
Stronger clustering means **higher halo mass** for mid-IR selected obscured AGN





Petter et al. (2023)

But **not seen** in **X-ray** selected samples! **A puzzle…**



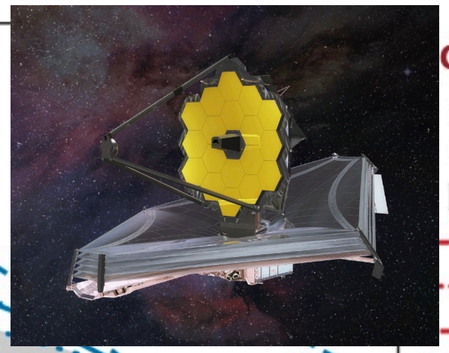
Viitanen et al. (2023)

3. What is the **physical nature** of the obscuring material?

The **nuclear torus is a key component** of obscuration, but some must come from material on the scale of the host galaxy that is associated with **galaxy evolution processes** and is increasingly important at **high redshift**

Looking forward: the **high-redshift** frontier

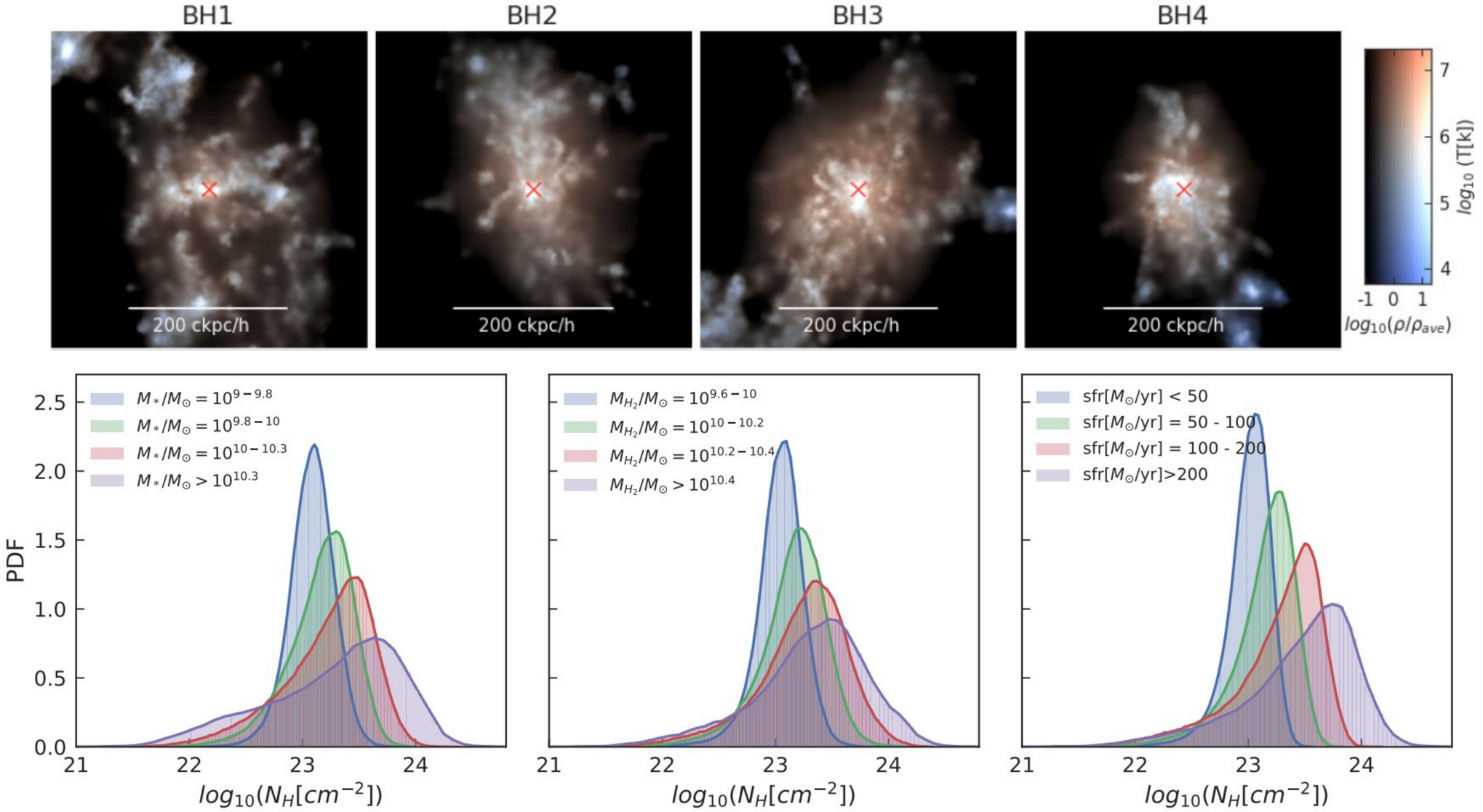
JWST! (e.g., Yang et al. 2023, Juodžbalis et al. 2023, Goulding et al. 2023 and many more!)



adapted from Vito et al. (2018)

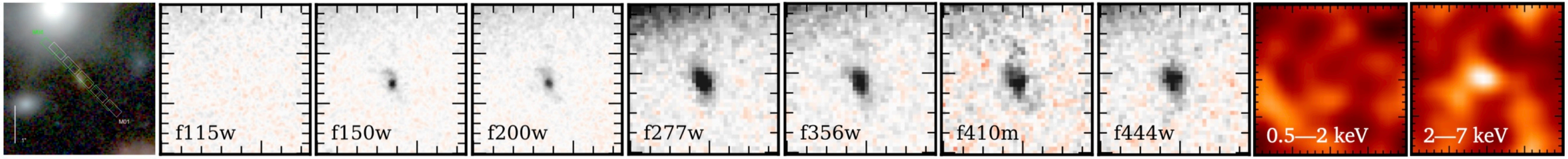
Looking forward: the **high-redshift** frontier

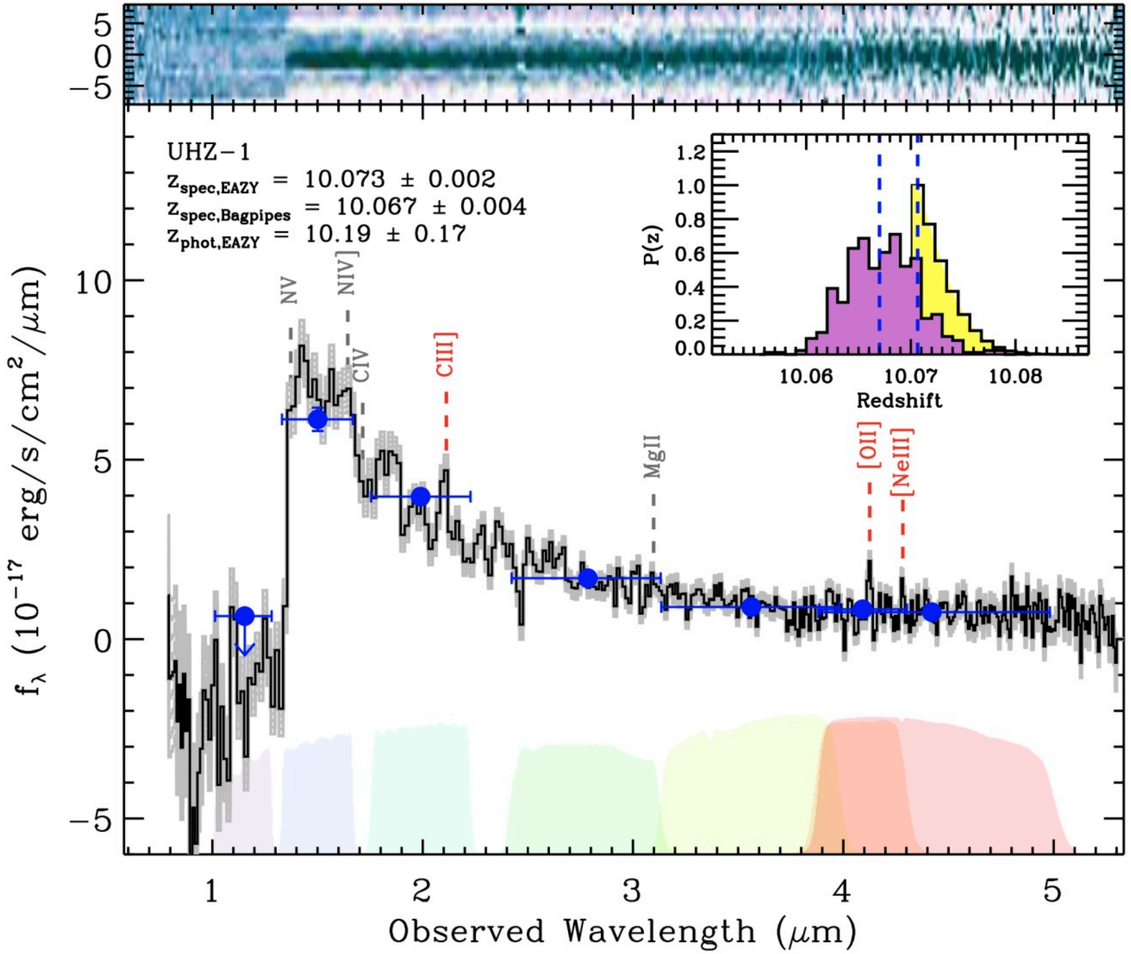
AGN obscuration in the **BlueTides simulation**



Ni et al. (2020)

Looking forward: the **high-redshift** frontier

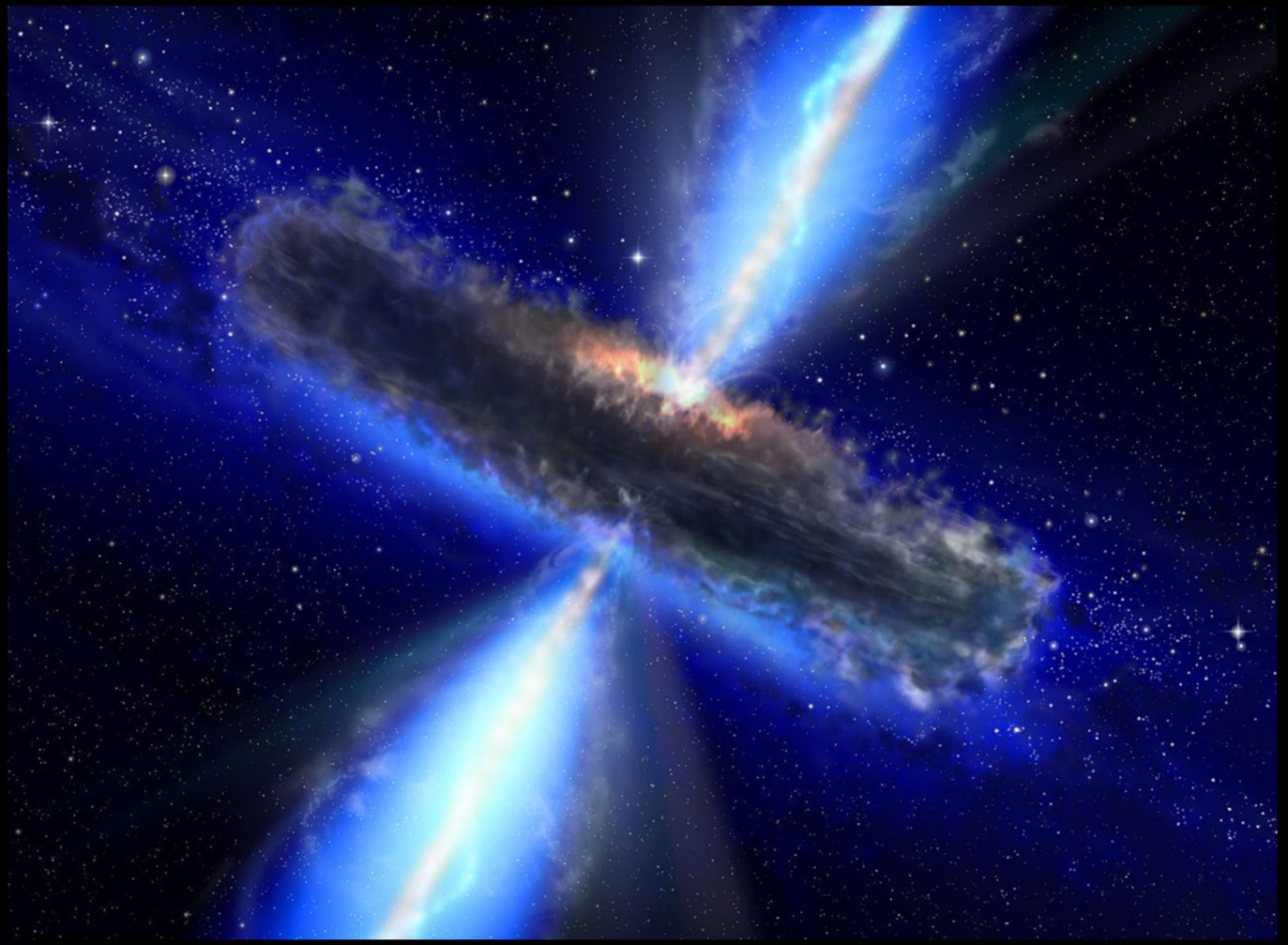




X-ray detected obscured AGN at ***z*=10!**

Goulding et al. (2023)

Obscured AGN are a critical component to the evolution of supermassive black holes and galaxies - with lots of discovery for the future!



Thanks to NASA, the NSF, and ultimately taxpayers for enabling these remarkable discoveries

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