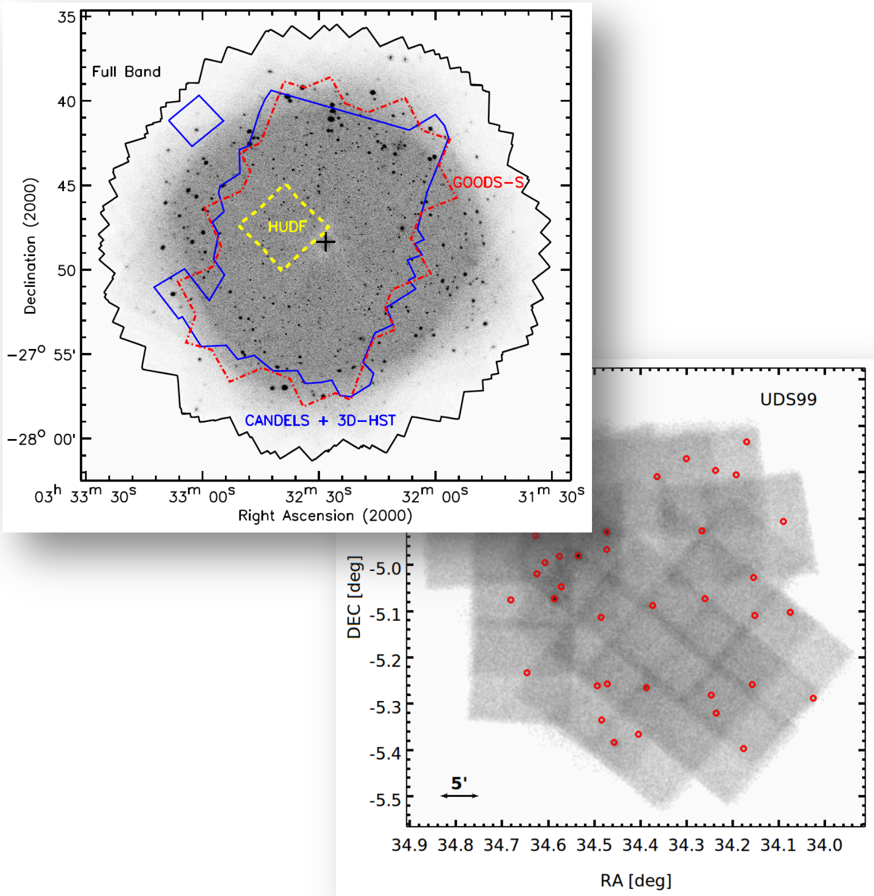
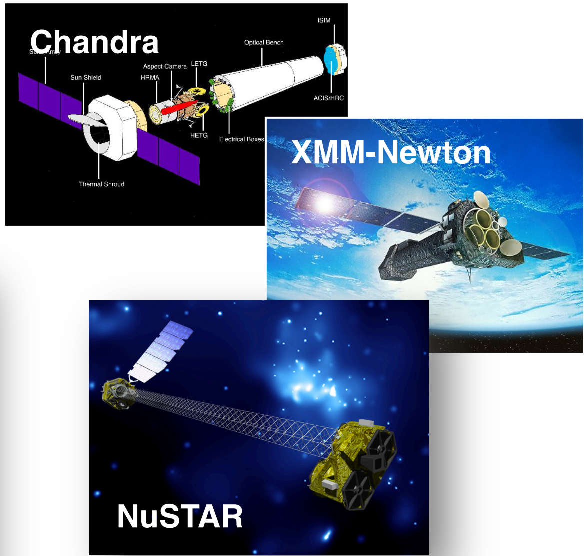
Cosmic X-ray surveys of Active Galactic Nuclei

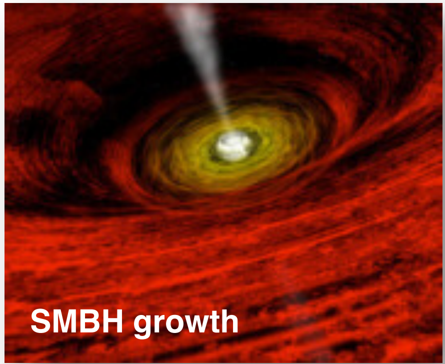


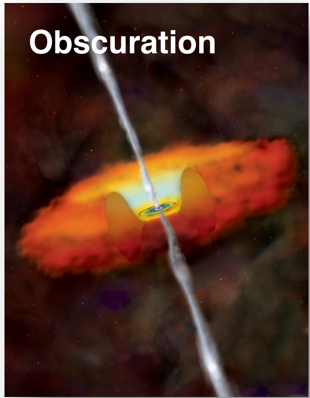


David M Alexander (Durham)

Broad scientific motivation

(1) Cosmic census of AGN activity: how, when, and where do SMBHs grow, and how is this growth related to obscuration?

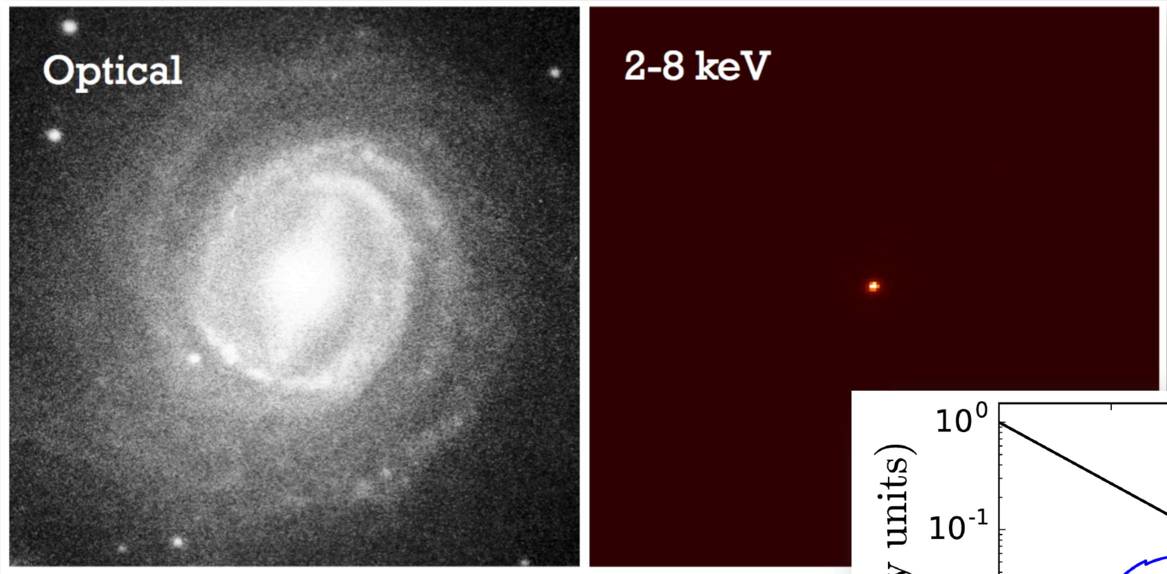




(2) Impact of AGN on galaxies: where are AGN found in the galaxy population and what impact do they have on the growth of the galaxy?

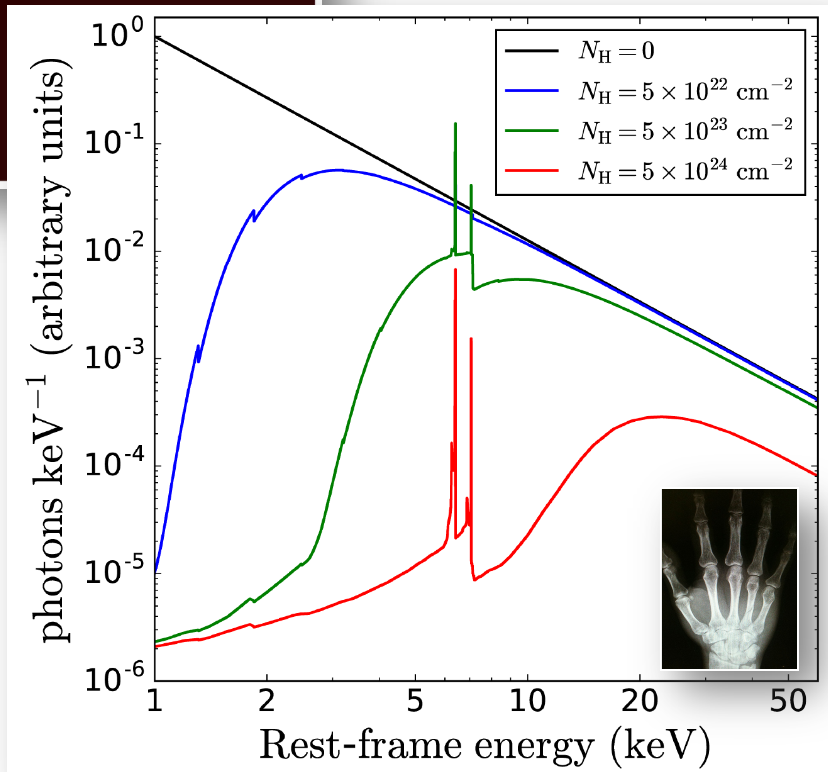
Effectiveness of X-rays for AGN selection

(1) Host galaxy is typically weak in X-rays, efficiently isolating the AGN



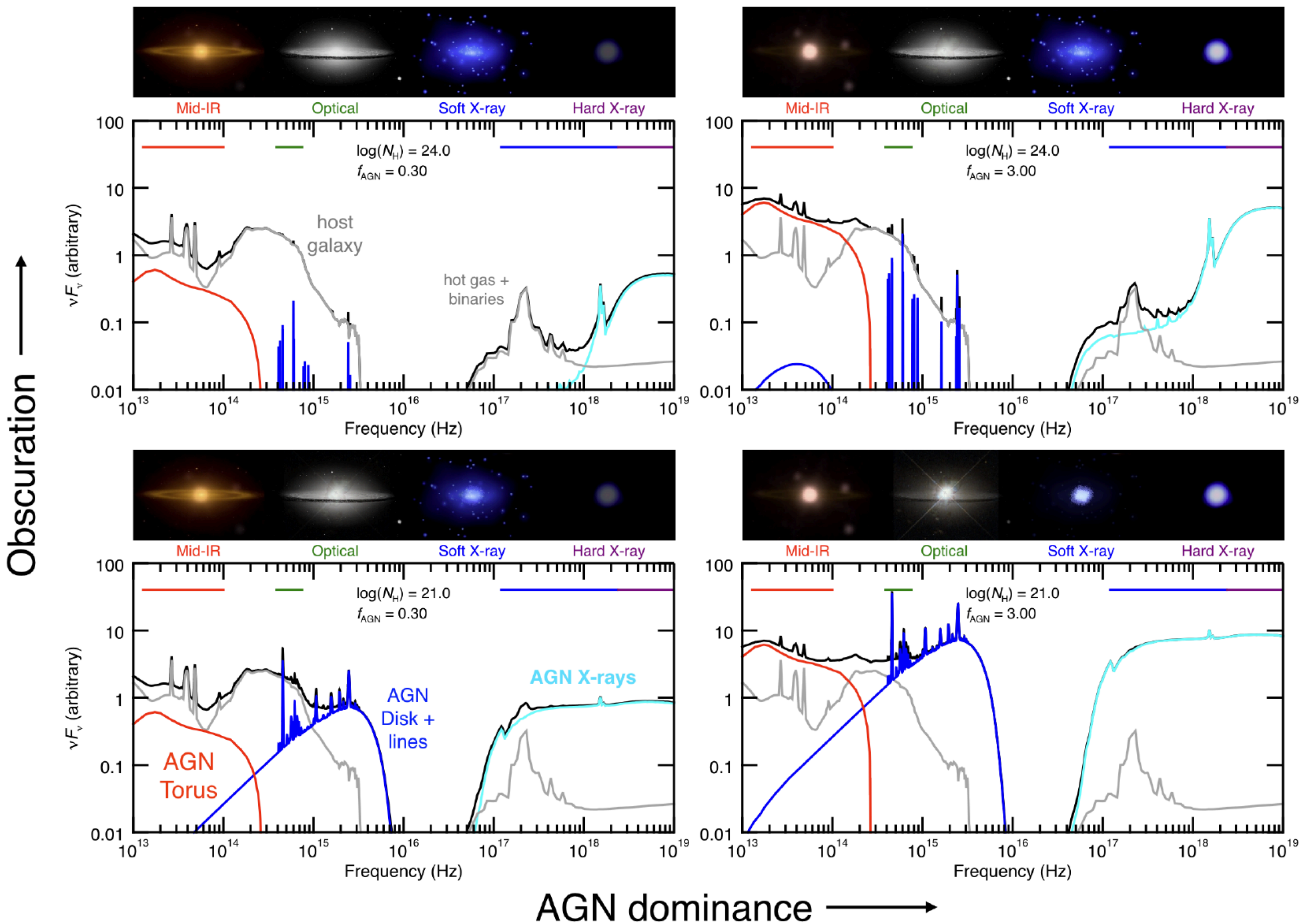
Brandt & Alexander (2015) review

Xue (2017) review



(2) X-ray photons highly penetrating, particularly at high energies – even heavily obscured AGN can be identified (but C-thick challenging)

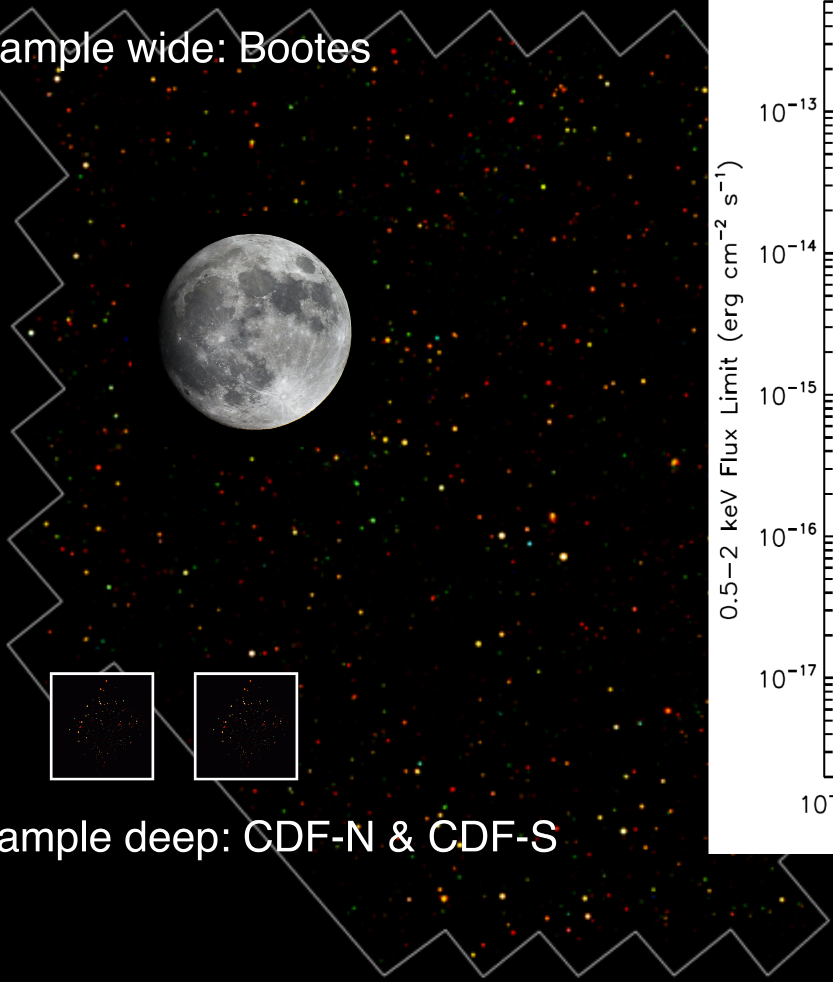
X-ray band is also rich in diagnostics on the environment in the vicinity of the black hole



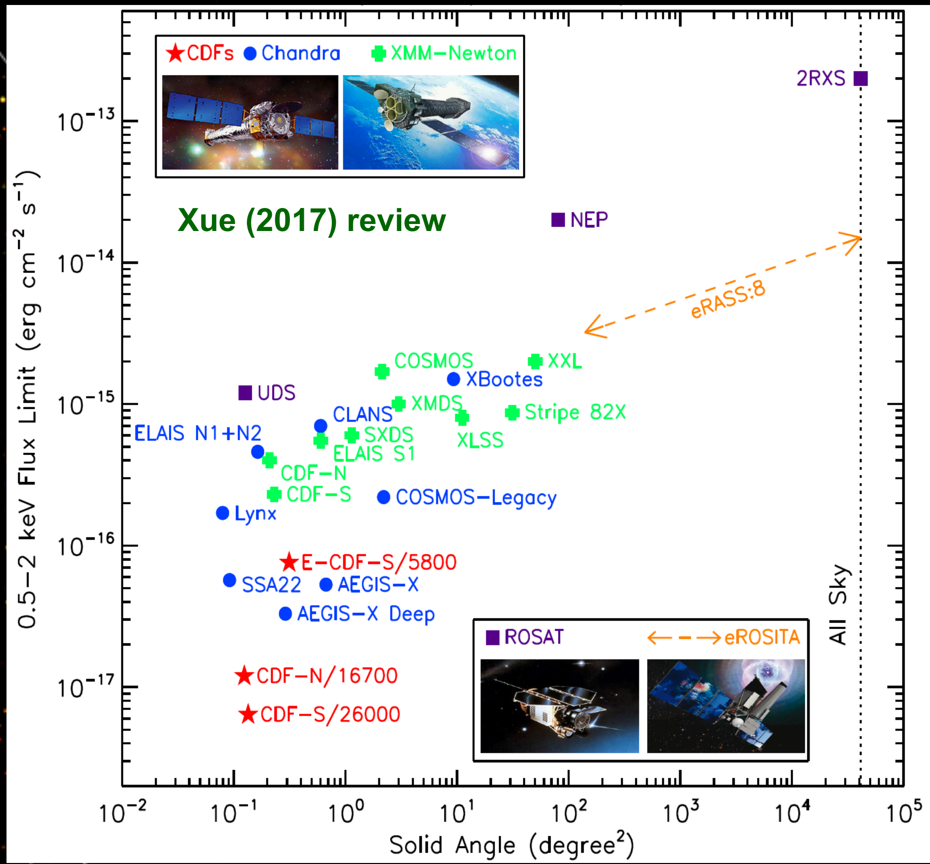
X-ray observations are (currently) the most efficient and effective way to identify the majority of the AGN population

X-ray surveys flux-area: softer X-rays (<10 keV)

Example wide: Bootes



Example deep: CDF-N & CDF-S

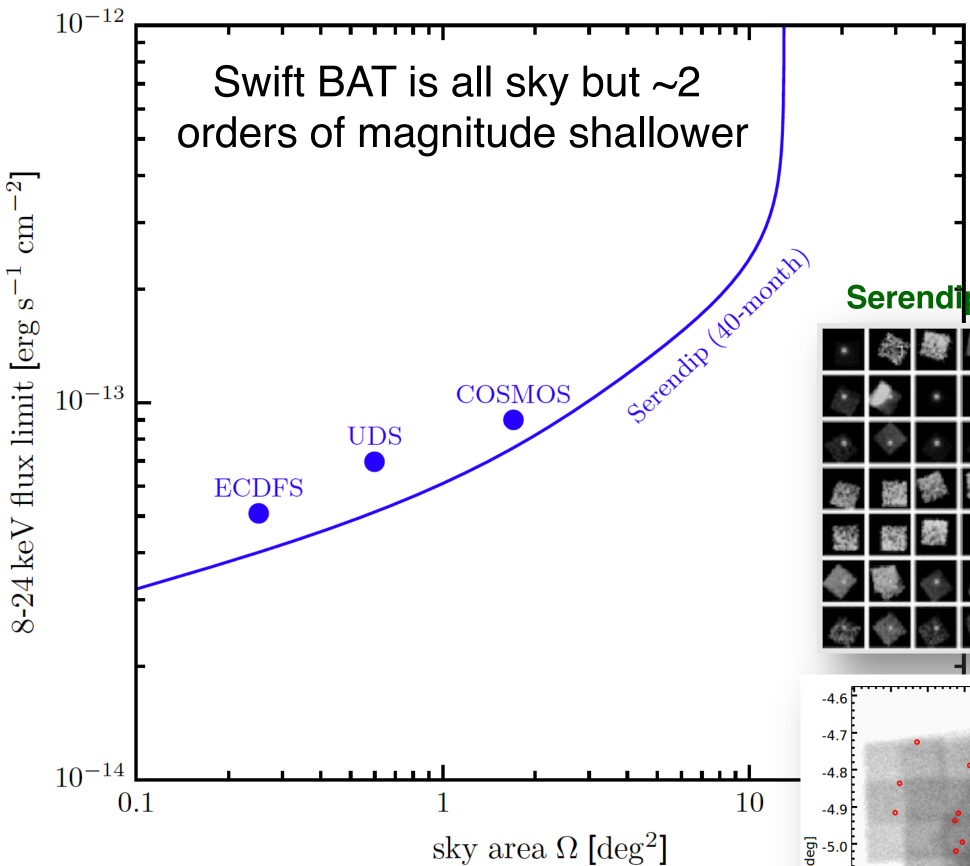


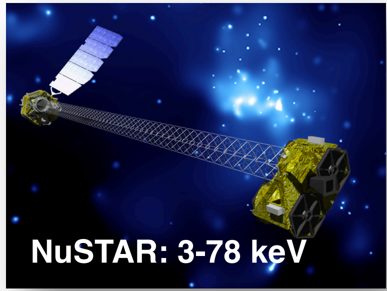
>500,000 X-ray sources from Chandra+XMM-Newton surveys

Some of the main Chandra/XMM surveys:

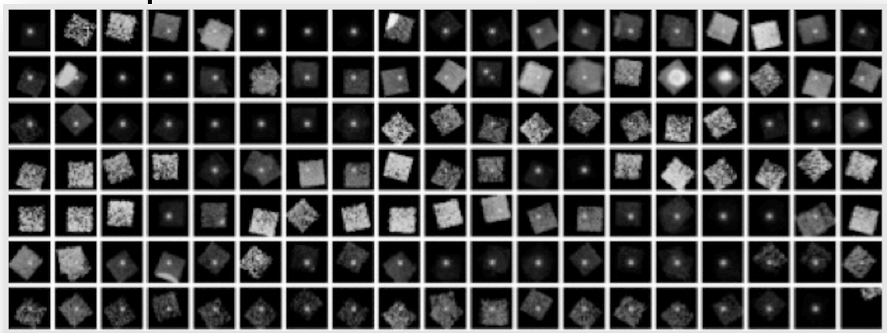
- **CDFs: Alexander et al. (2003); Ranalli et al. (2013); Xue et al. (2011, 2016); Luo et al. (2017)**
- **COSMOS: Cappelluti et al. (2009); Elvis et al. (2009); Civano et al. (2016)**
- **Bootes: Kenter et al. (2005); Murray et al. (2005)**
- **Serendipitous surveys: Watson et al. (2001, 2009); Rosen et al. (2016); Traulsen et al. (2019)**

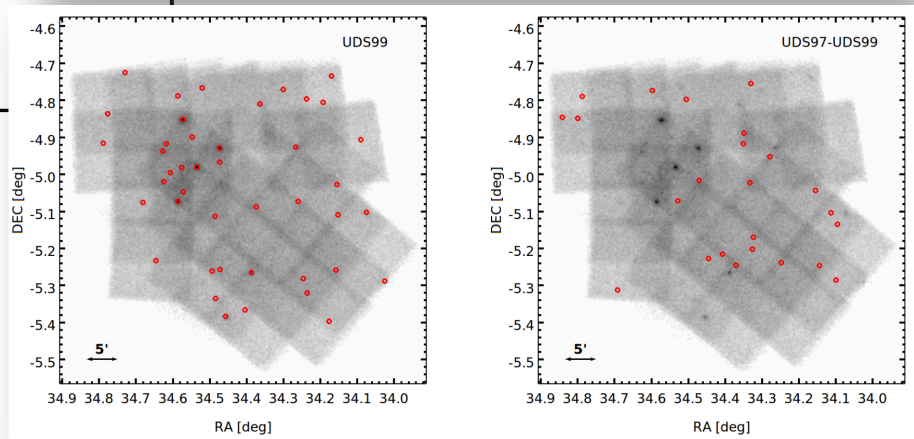
X-ray surveys flux area: harder X-rays (>10 keV)





Serendip: Lansbury et al. (2017; Klindt et al. (in prep)





UDS: Masini et al. (2018)

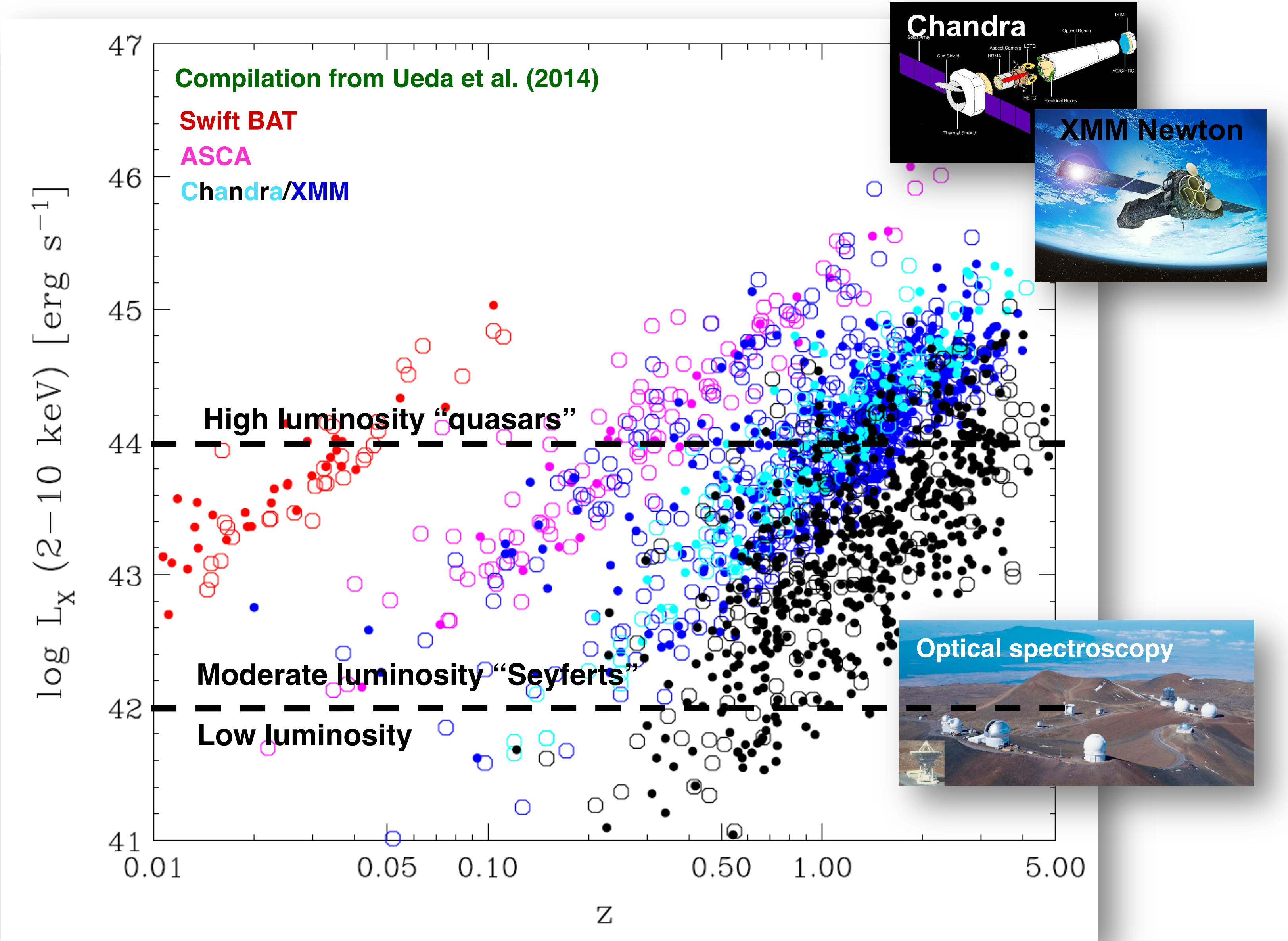
~1,000 sources from NuSTAR surveys but unique energy-depth coverage

The main NuSTAR surveys:

- **ECDF: Mullaney et al. (2015)**
- **COSMOS: Civano et al. (2015)**
- **UDS: Masini et al. (2018)**
- **Serendipitous survey: Alexander et al. (2013); Lansbury et al. (2017); Klindt et al. (in prep)**

Properties of the X-ray detected AGN, their evolution and obscuration

Cosmic X-ray surveys of distant AGNs: softer X-rays



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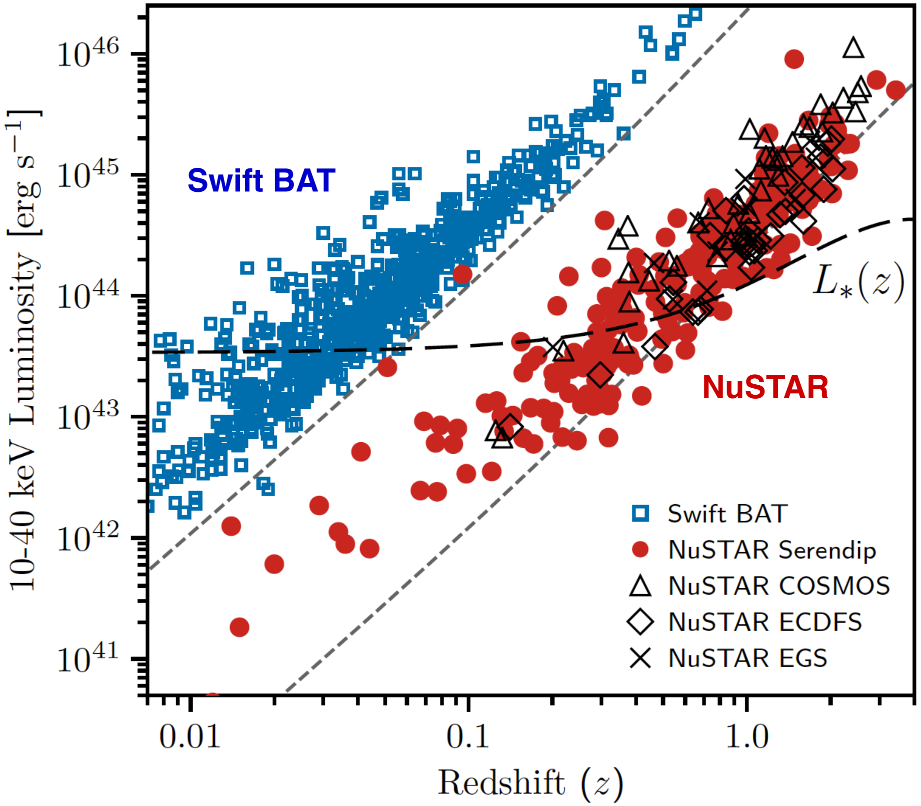
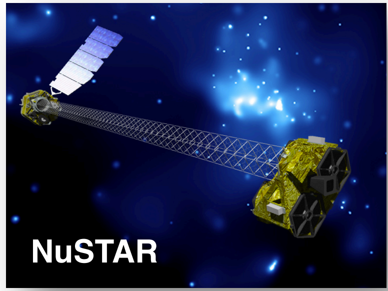
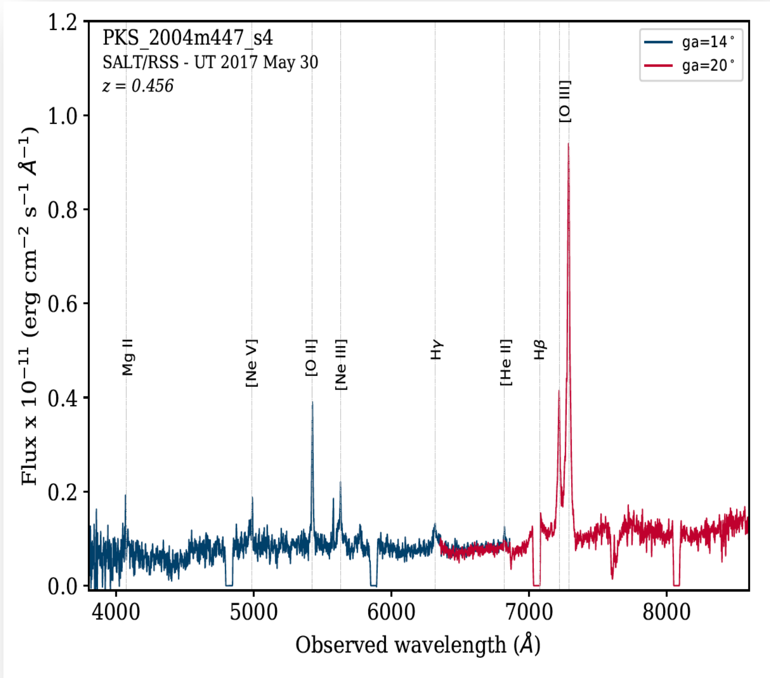


Lansbury et al. (2017); Klindt et al. (in prep)

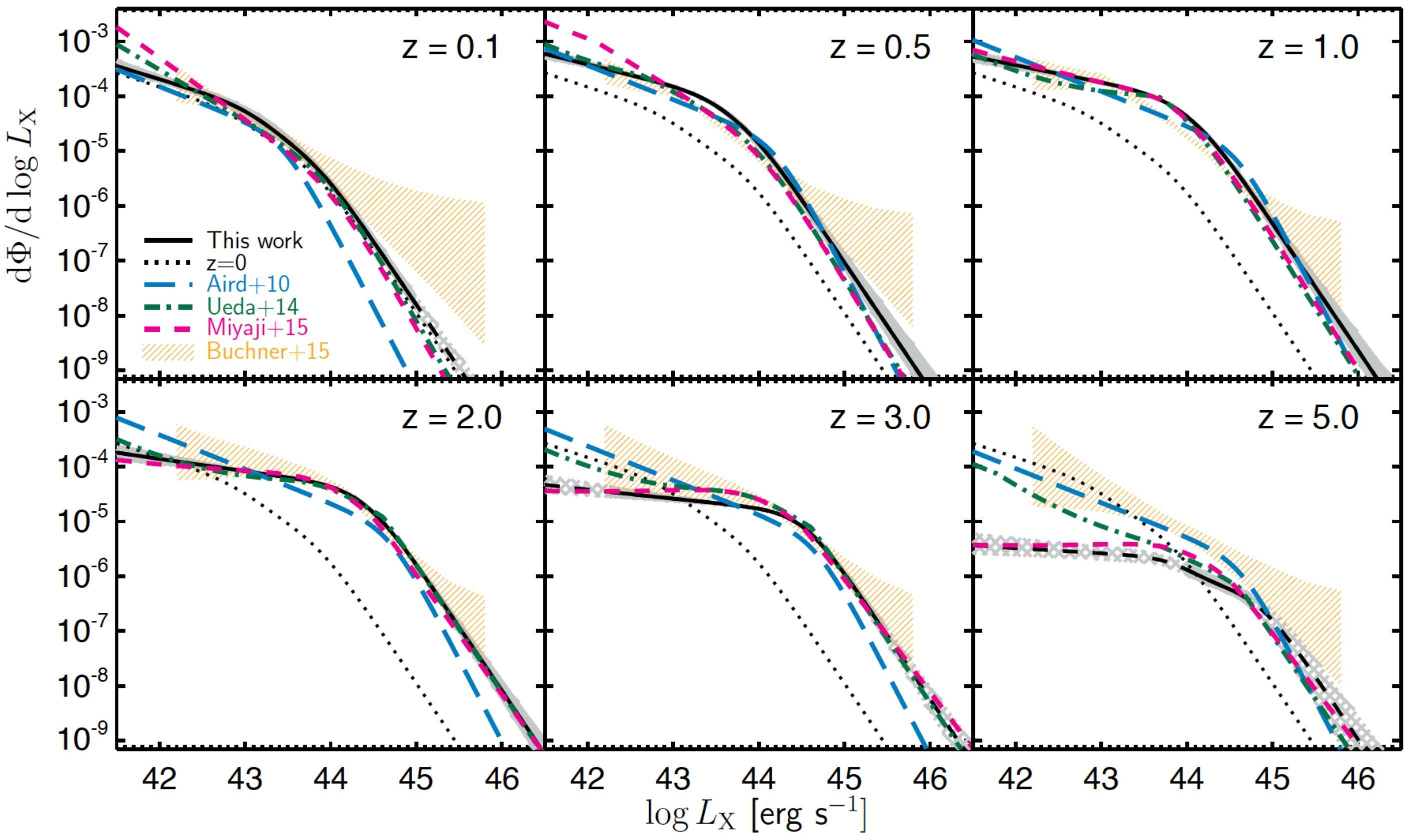




Lower source stats and narrower L_X-z plane but NuSTAR complements Swift-BAT and extends energy coverage over Chandra and XMM-Newton

Evolution of AGN: X-ray luminosity functions

Redshift-dependent X-ray luminosity functions for Compton-thin AGN ($N_H < 10^{24}$ cm^{-2})



Aird et al. (2015) compared to other studies

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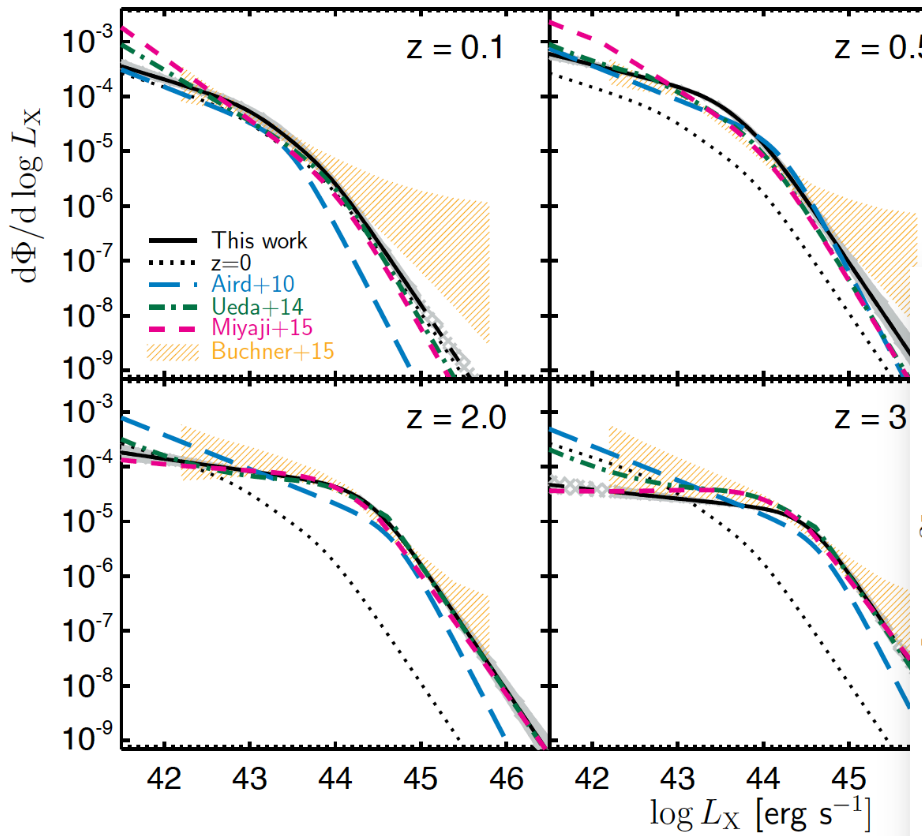

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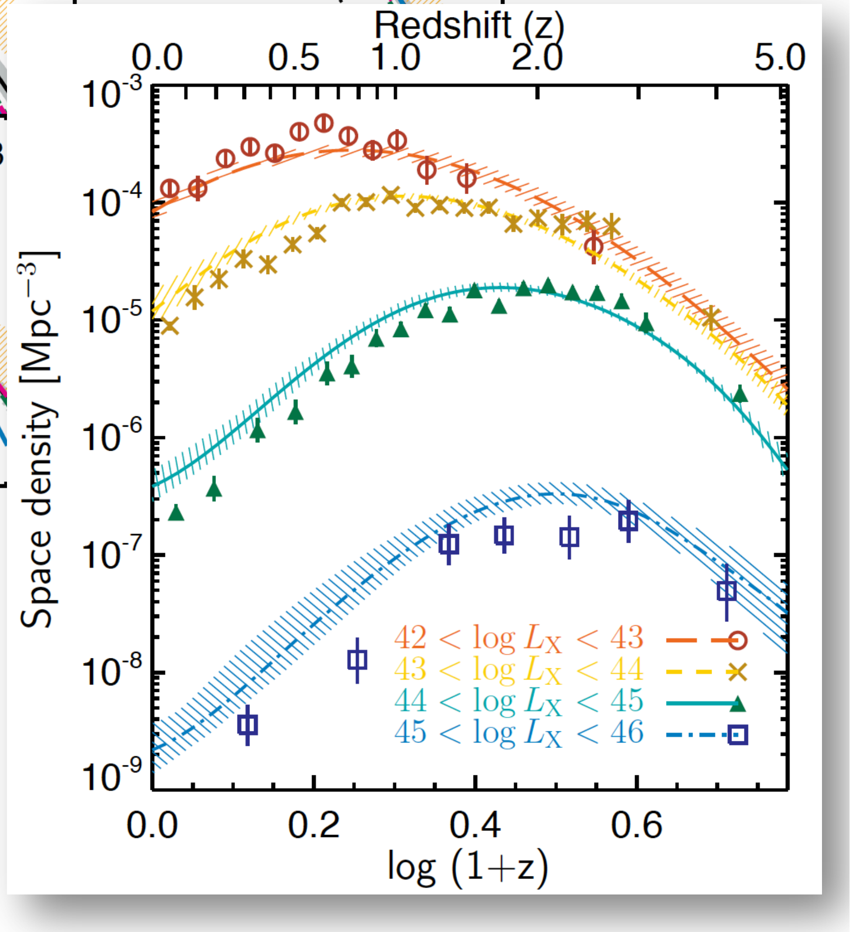
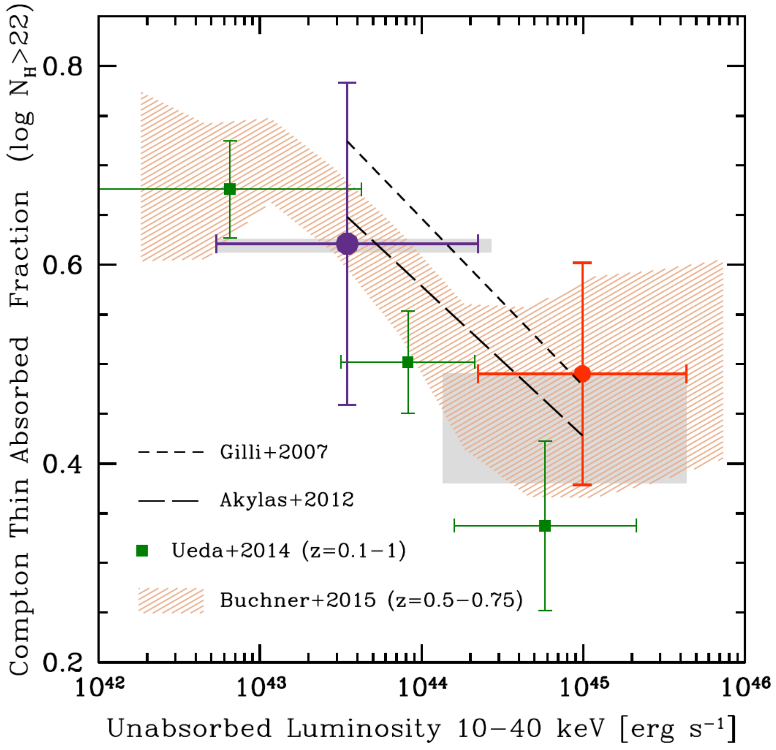


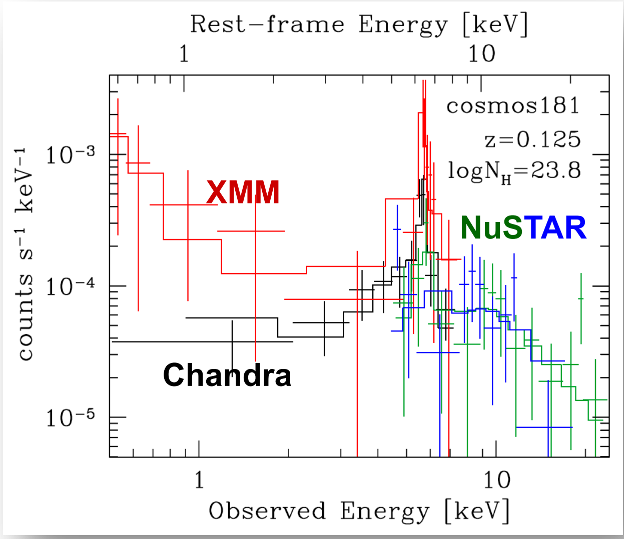
Broad conclusion: luminosity dependent redshift evolution; i.e., higher-luminosity AGN common at higher-z, lower luminosity at lower-z

Absorption: luminosity and redshift dependencies



Absorbed AGN fraction (C-thin) dependent on X-ray luminosity: Chandra/XMM+NuSTAR data

Zappacosta et al. (2018); also see C Ricci talk



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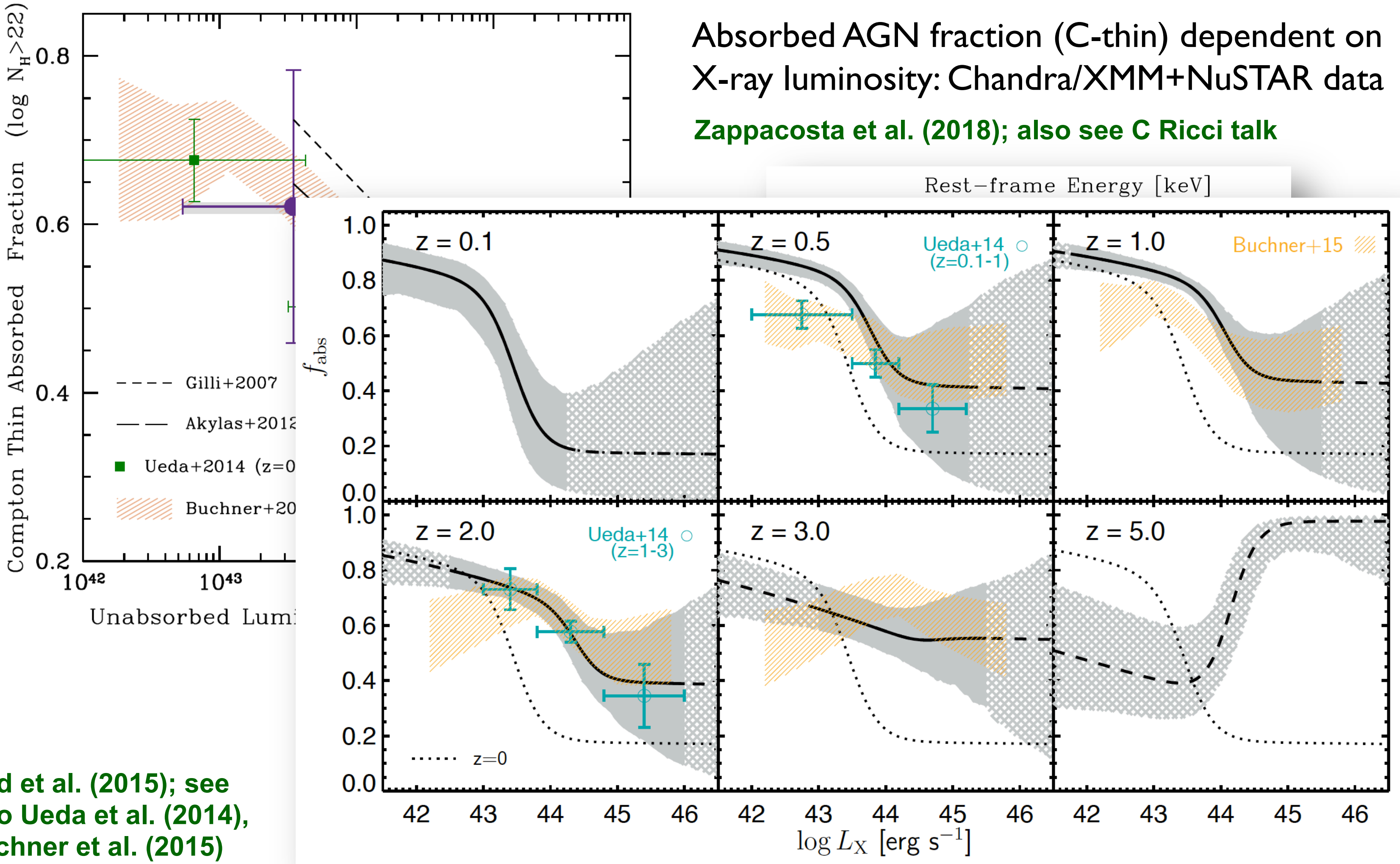


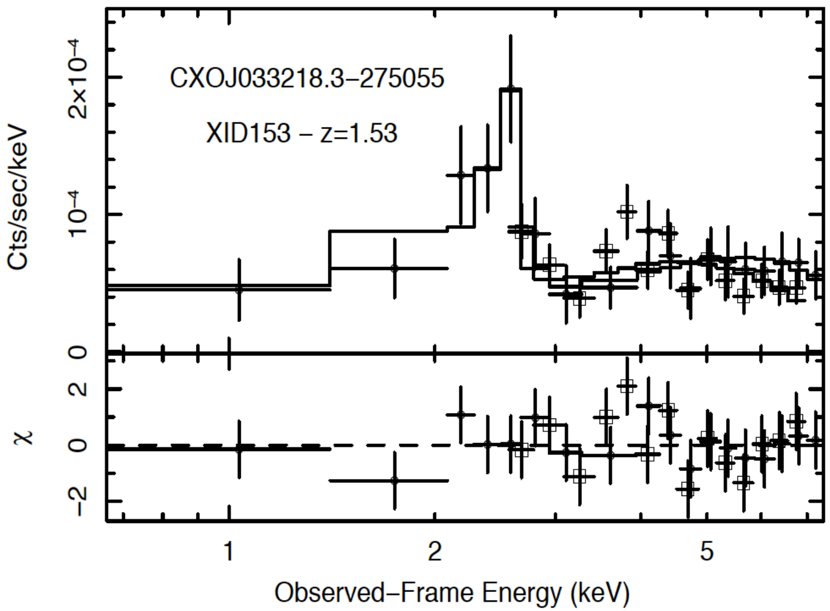
Aird et al. (2015); see also Ueda et al. (2014), Buchner et al. (2015)

Redshift dependent absorption evolution? This is likely driven by the luminosity dependent absorbed fraction combined with the luminosity-dependent evolution of AGN

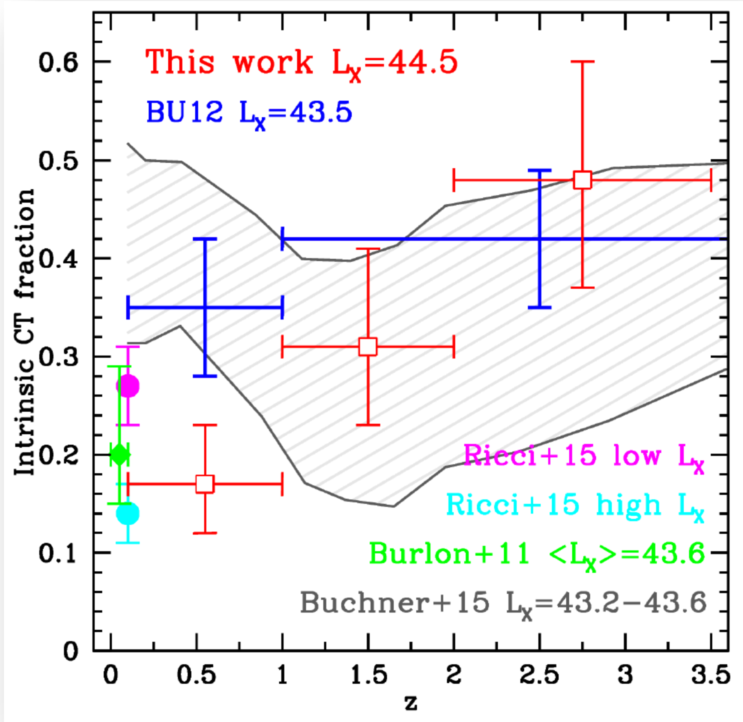
Limited constraints on Compton-thick AGN

However, C-thick AGN are challenging to robustly identify so we are limited by small samples

High-quality X-ray data: a clear C-thick AGN but rare



Comastri et al. (2011); Marcesi et al. (2018)



Lanzuisi et al. (2017)

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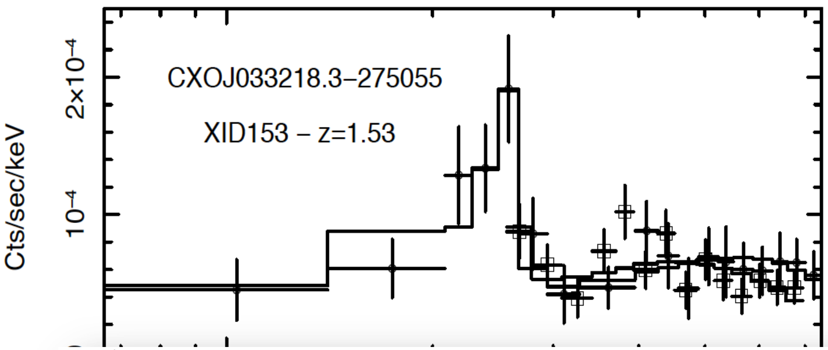

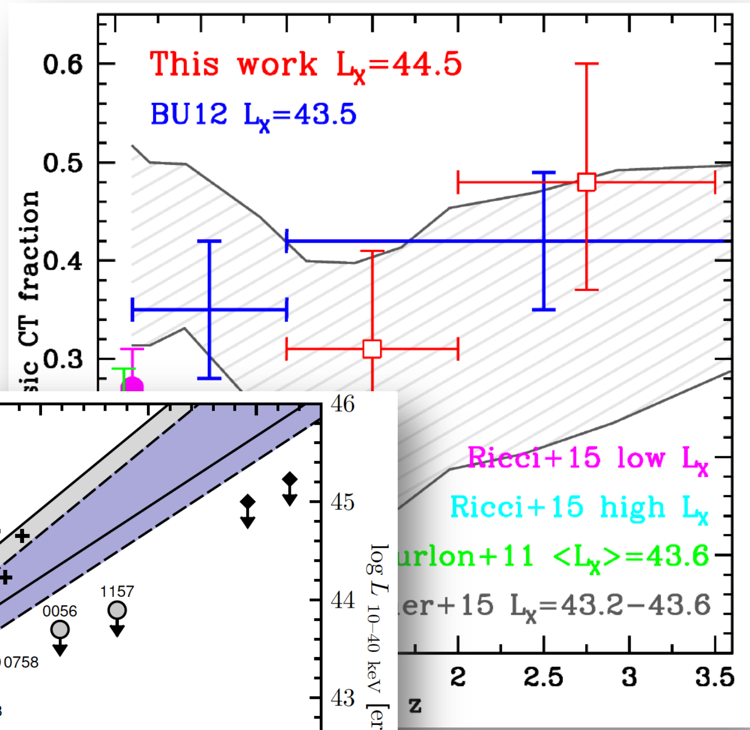

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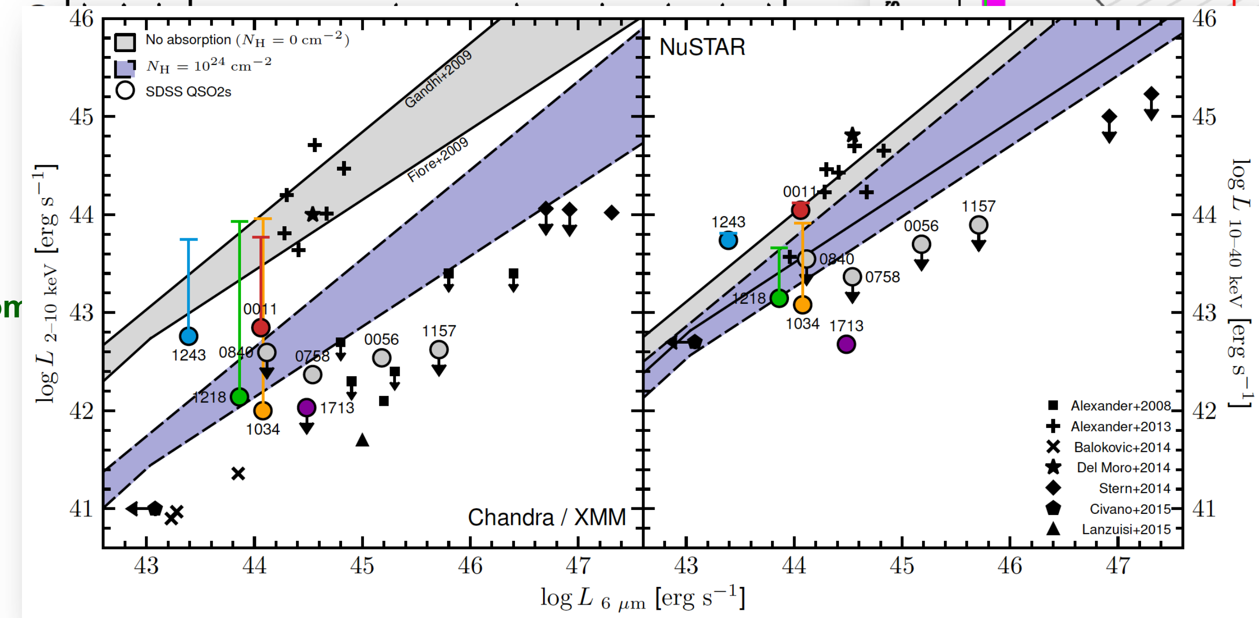
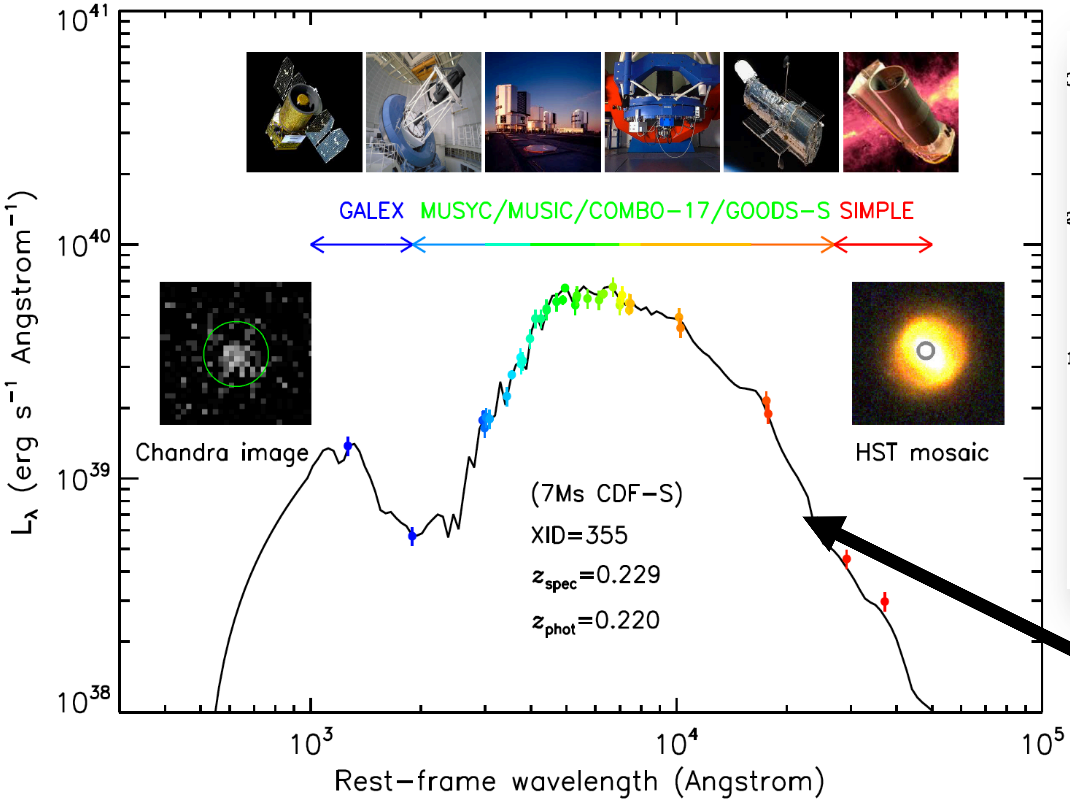


Lansbury et al. (2017)

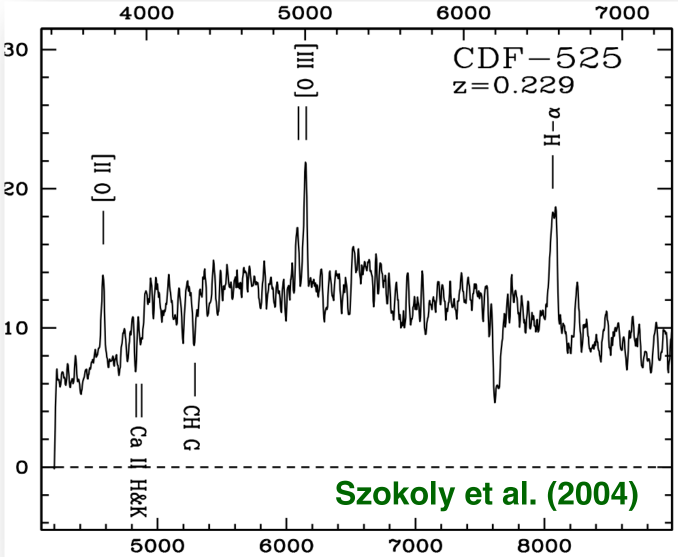
Fainter systems can be indirectly identified using absorption-independent measurements (e.g., rest-frame 6um) compared to the observed X-ray luminosity but are less robust

X-ray AGN within the galaxy population

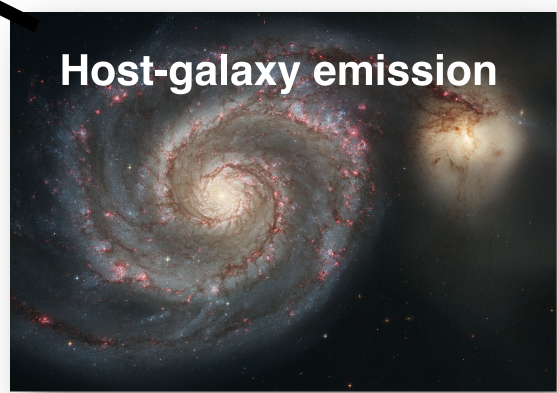
Multi-wavelength SEDs: measuring host properties



Xue (2017) review



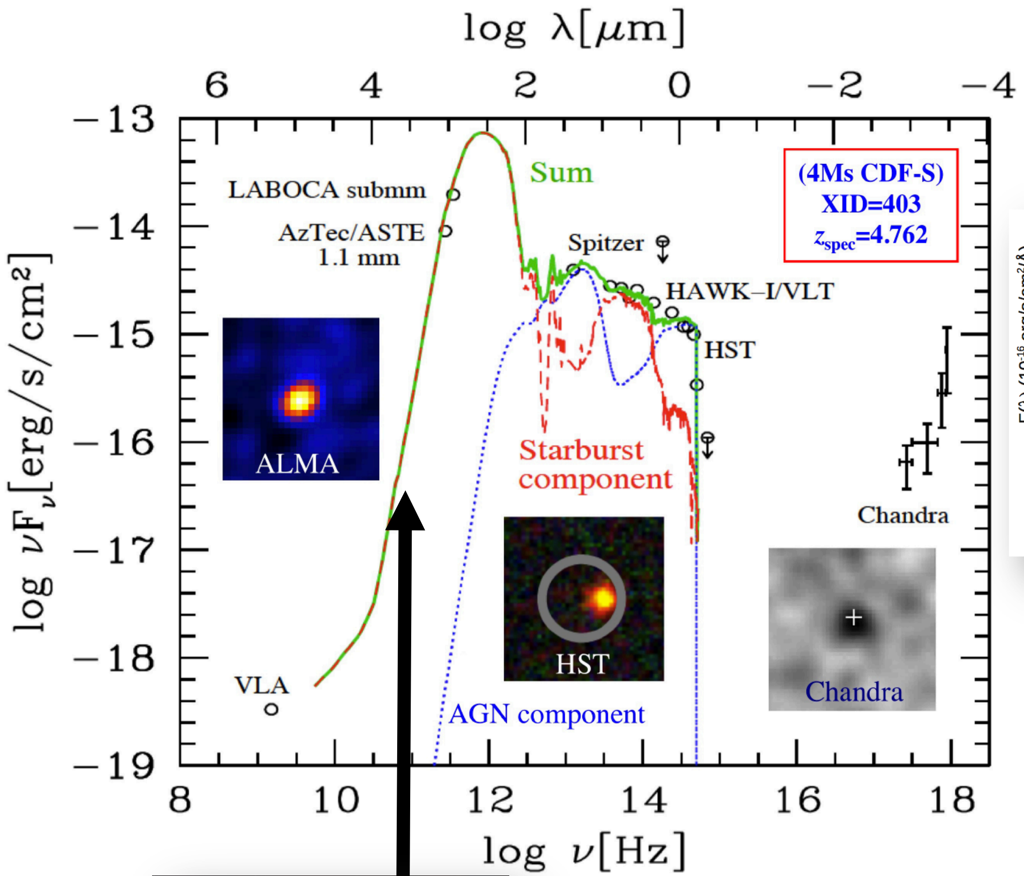
Szokoly et al. (2004)



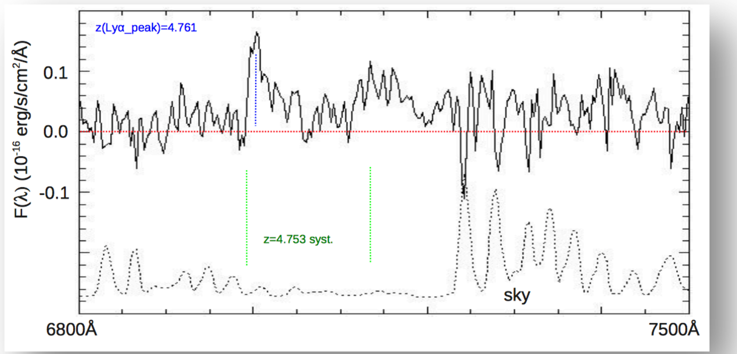
Most X-ray AGNs are obscured: the optical-near-IR emission is dominated by the host galaxy - great for determining the host-galaxy properties

But care is required to isolate the host galaxy when the AGN is luminous and unobscured

Multi-wavelength SEDs: star-formation rates



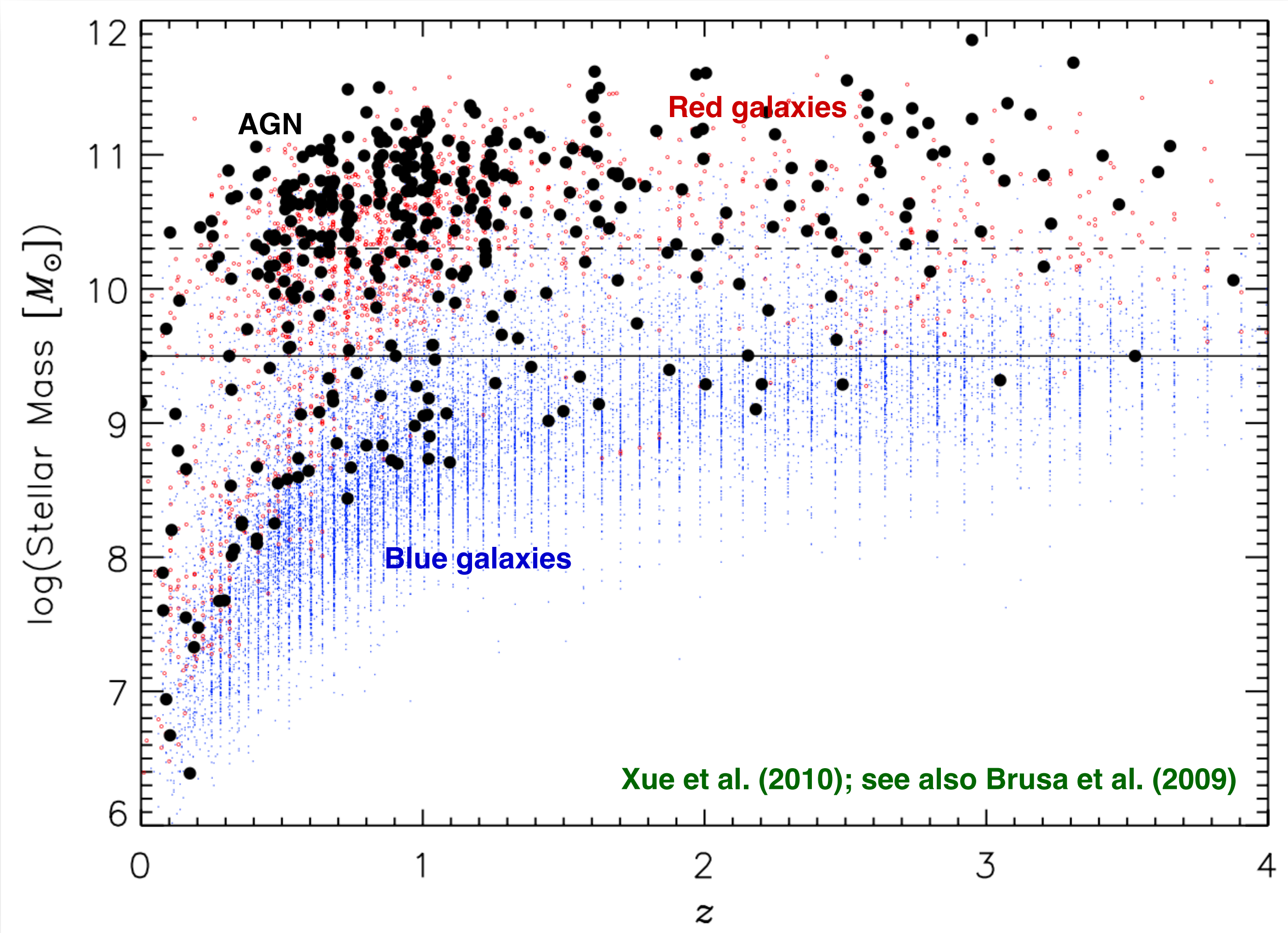
Gilli et al. (2011, 2014)



An optically faint z~4.8 heavily obscured AGN

High sensitivity in far-IR-mm waveband required for star-formation rates: Herschel is okay, ALMA is ideal

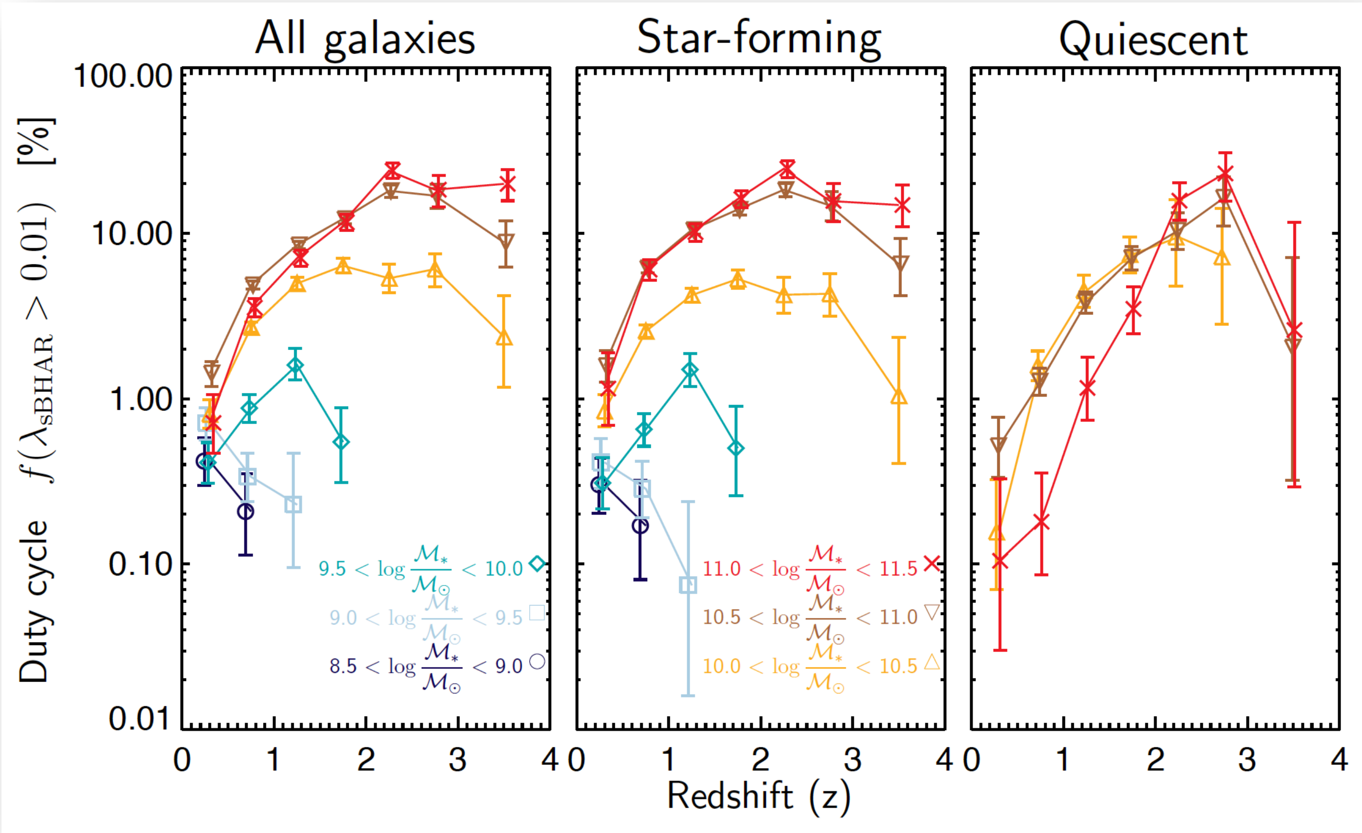
AGN host galaxies: masses



Majority of X-ray AGNs found in massive galaxies but X-ray sensitivity effects are critical; i.e., at a fixed L_X you can detect a lower Edd-ratio system in high-mass galaxy than a low-mass galaxy

Incidence of AGN in the galaxy population

Fraction of galaxies hosting AGN depends on the X-ray luminosity limit and, more physically, the Eddington ratio limit – AGN fraction below is for an estimated Eddington ratio>0.01

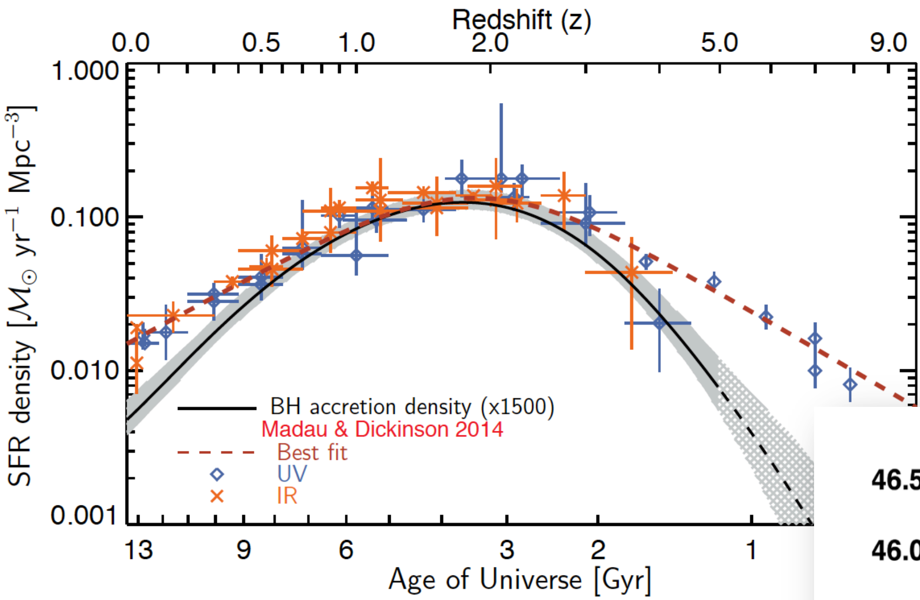


Aird et al. (2015); see also Bongiorno et al. (2012) and M. Jones talk

An increase in duty cycle of AGN seen with redshift. High-mass galaxies have higher AGN fraction than lower mass, for the majority of hosts; but no clear mass dependence in quiescent galaxies

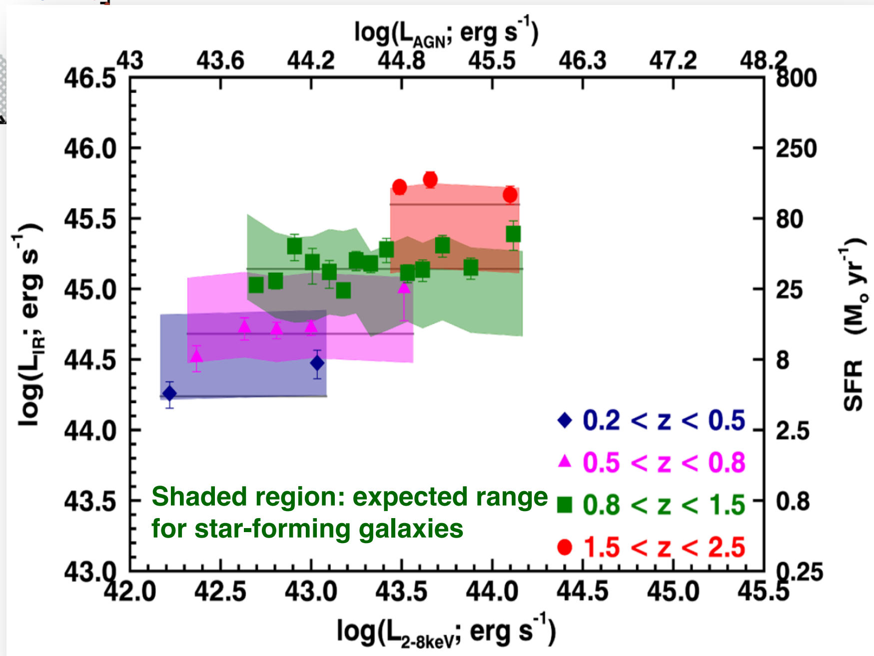
Connection between AGN and star formation?

Globally AGN emission tracks the star-formation emission, as we may expect given the local SMBH-galaxy scaling relationships



Aird et al. (2015)

Stanley et al. (2015); see also Rosario et al. (2012), Santini et al. (2012)

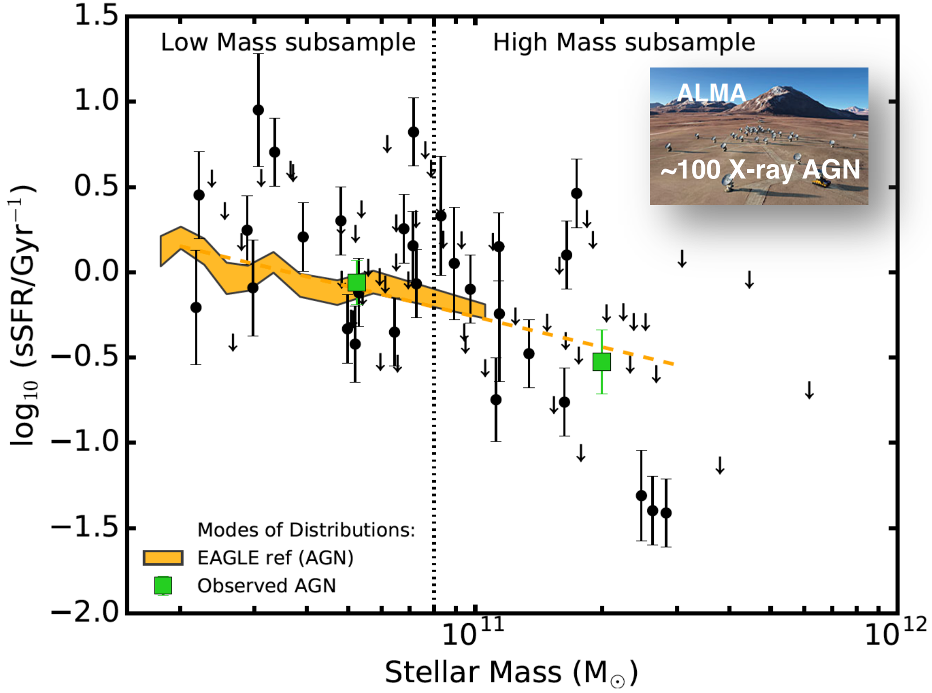


Average star-formation luminosity as a function of AGN luminosity: on average AGN reside in typical star-forming galaxies

So AGN do not have any impact on the galaxy wide SF in the host galaxy?

Impact of AGN on galaxy wide star formation?

Average SFRs are limited in identifying impact of AGN on SF: we need SFR distributions – this requires ALMA for high-z AGN



Scholtz et al. (2018); see also Mullaney et al. (2015)

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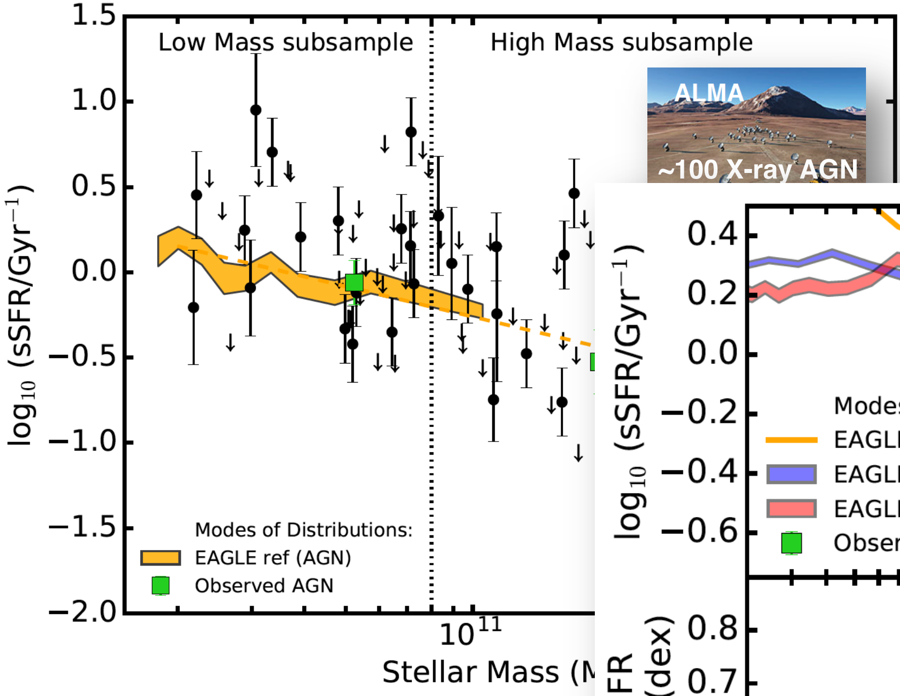

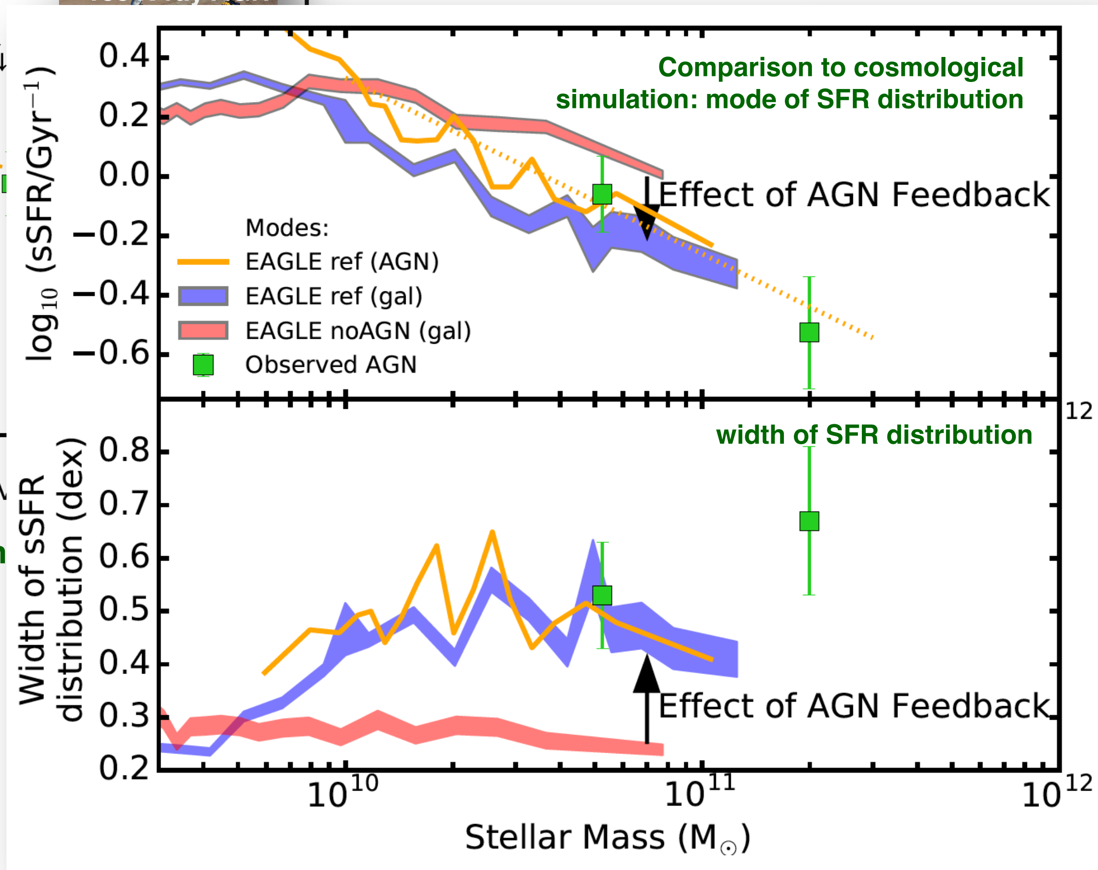

Scholtz et al. (2018); see also Mullan

Impact of AGN is seen but is likely slow on galaxy scales (>AGN duration) – localised impact may be more rapid

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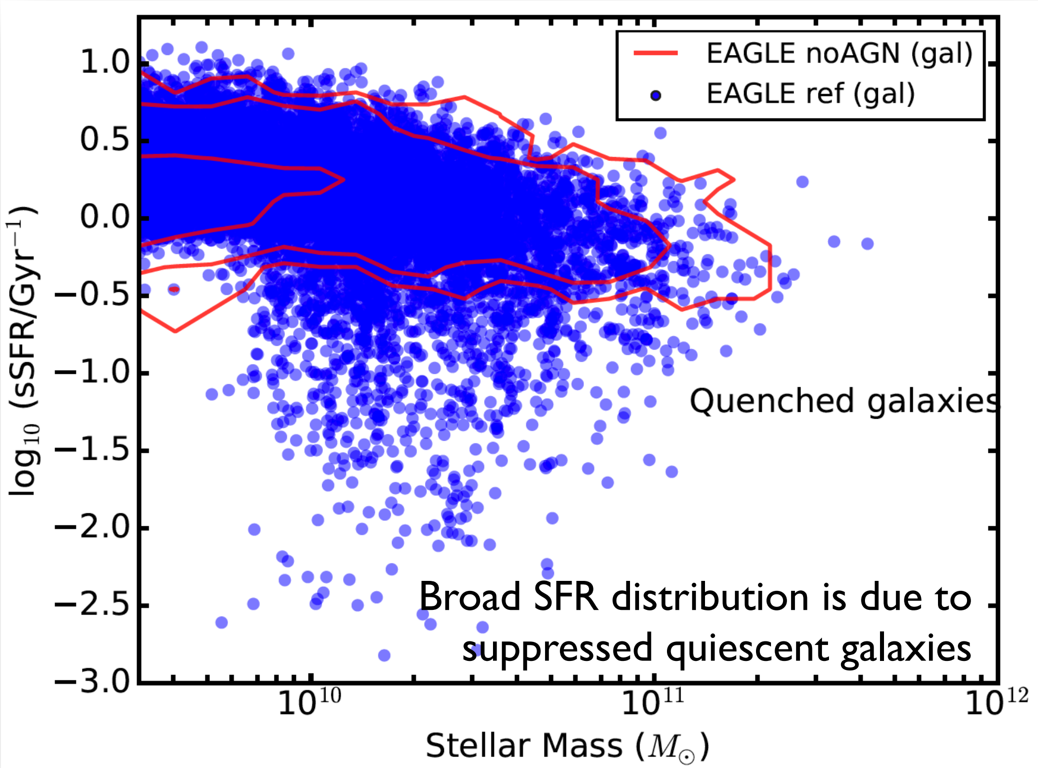

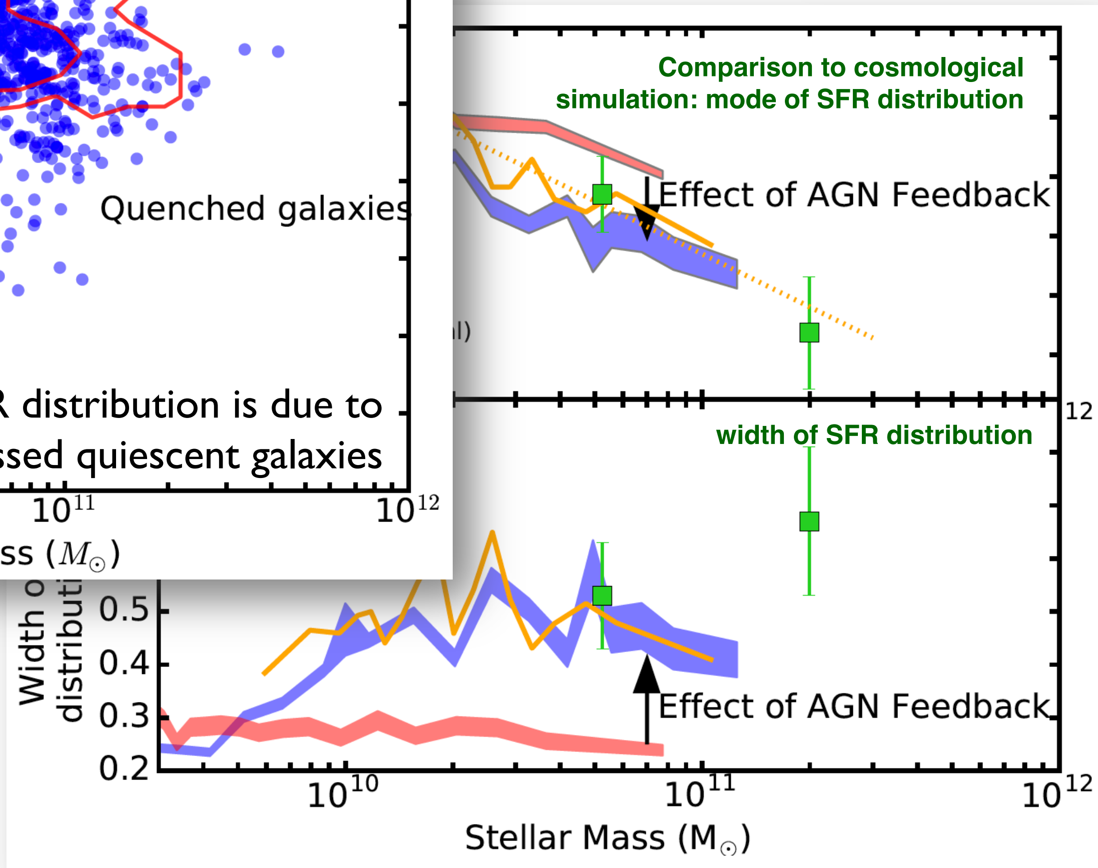

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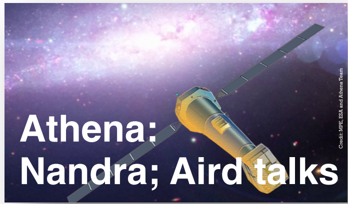
Summary and future directions

With cosmic X-ray surveys we have made good progress on the evolution of AGN (at least out to z~3), their obscuration properties (at least for C-thin), ubiquity of AGN in the galaxy population, their star-formation properties, and their global impact on SF

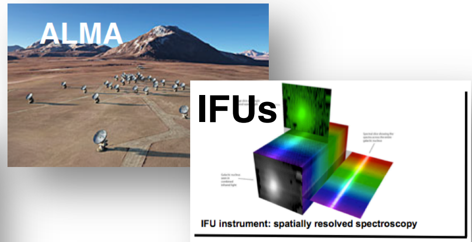
Some areas where there is the potential for great future progress:

- Space density and properties of C-thick AGN:
  requires high sensitivity and count rates to robustly identify



- Space density of highest-redshift (and most luminous) AGN:
  requires very large areal coverage (or large area and deep)

- More detailed understanding of the impact of AGN on star formation:
  requires more detailed multi-wavelength observations
  (KASHz: Harrison et al. 2016; SUPER; Circosta et al. 2018)



- Impact of large-scale structure on AGN:
  requires deep large-area surveys
  (X-SERVS PI Brandt; Chandra Wide-Deep PI Hickox)