Compton-thick AGN

The hidden population at cosmic noon revealed by Chandra

featuring: Antonis Georgakakis, Kirpal Nandra, Li-Ting Hsu, C. Rangel, Murray Brightman, Andrea Merloni, Mara Salvato, J. Donley, Dale Kocevski, James Aird, Nic Ross, Zhu Liu, Marie-Luise Menzel, Charlotte Simmonds, Franz Bauer, Robert Nikutta, Ezekiel Treister, Tonima T. Ananna, Keiichi Wada, Mislav Baloković, Peter Boorman

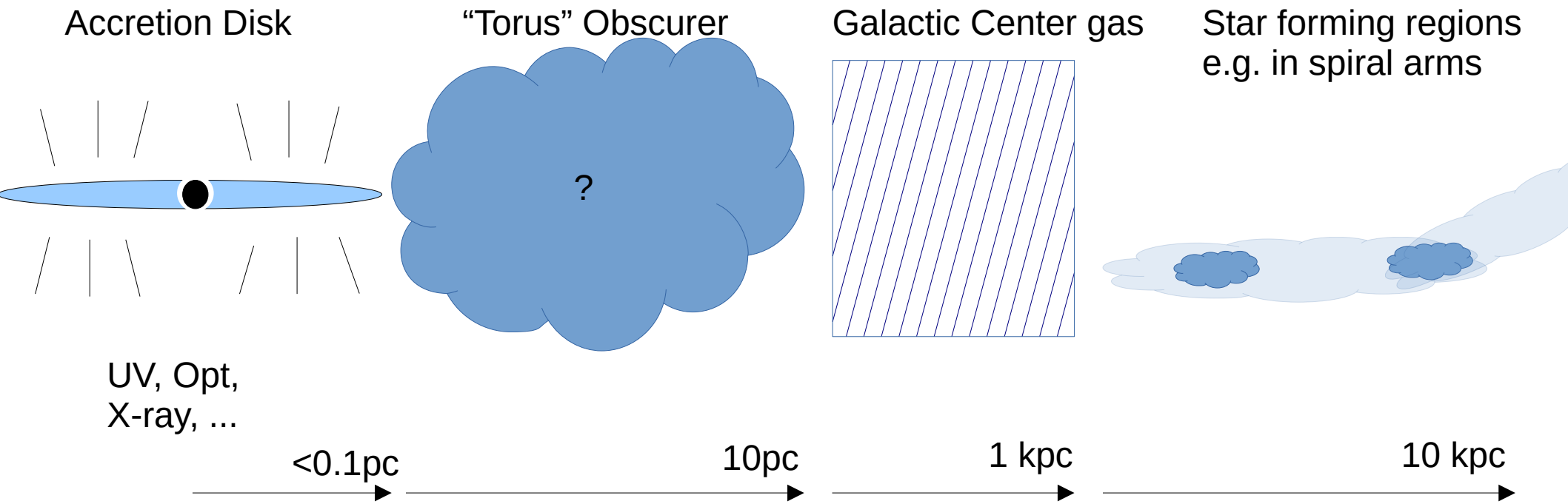
Johannes Buchner

http://astrost.at/istics/

25y of Chandra Science, Dec 3-6 2024

Active Galactic Nuclei

... embedded in galactic centers



Nuclear obscuration

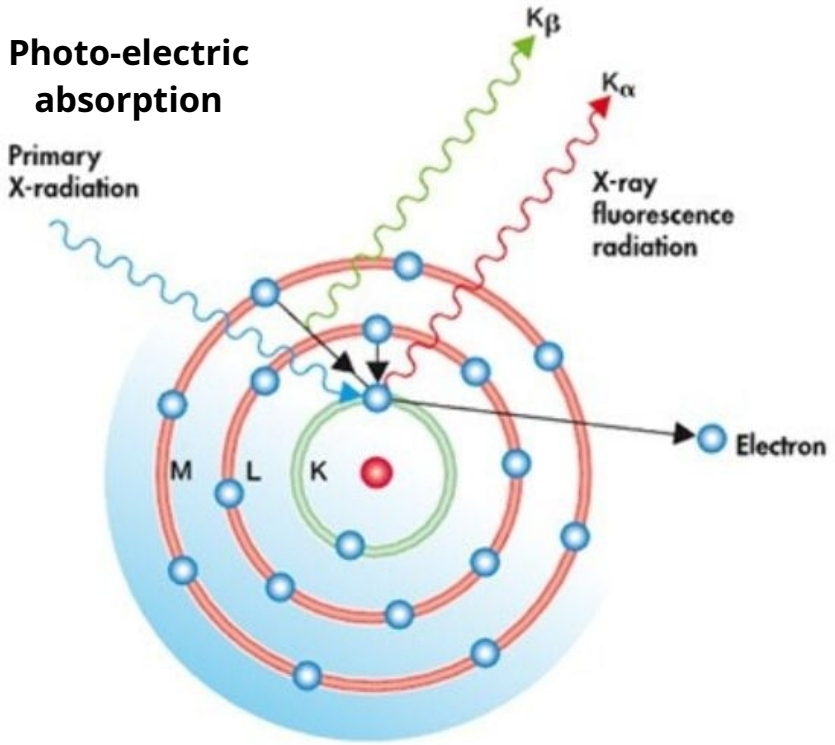
Galaxy-scale obscuration

Milky Way: $10^{20}/cm^2$ (polar) $10^{22\text{-}23}/cm^2$ (eq)

Gamma-ray bursts also (Buchner+19a)

X-ray obscuration: physical processes

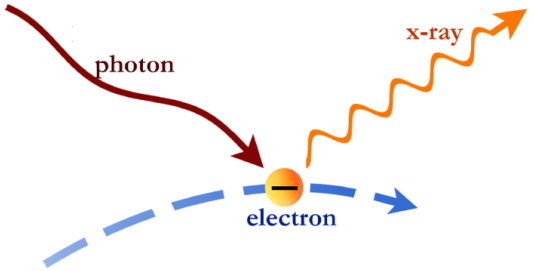
Photo-electric absorption

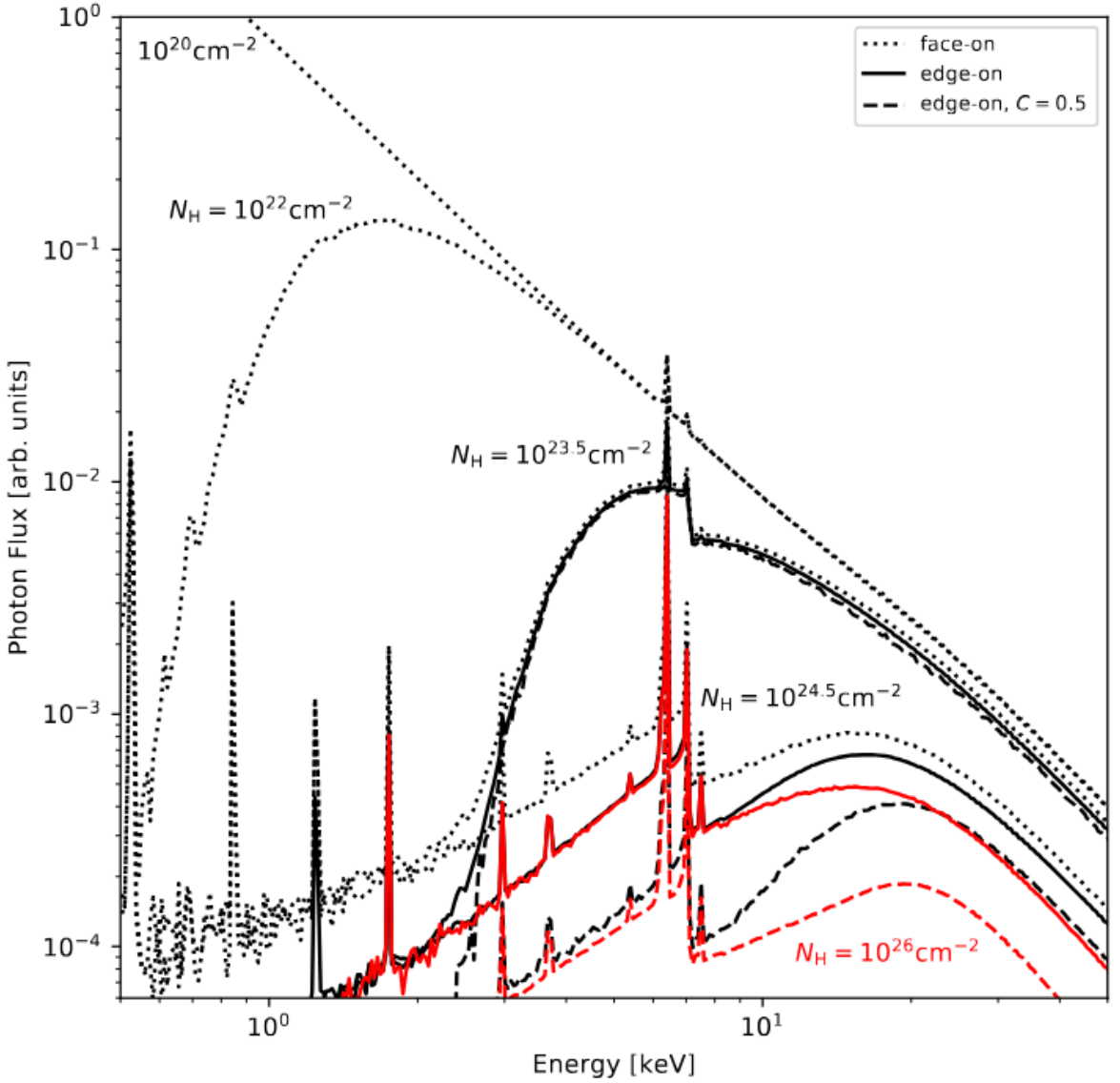


Cross-section: $\sigma \approx 10^{22}/\mathrm{cm}^2\ (E_{keV})^{-3}$

Mostly: H, He, O, Fe (Wilms+2000)

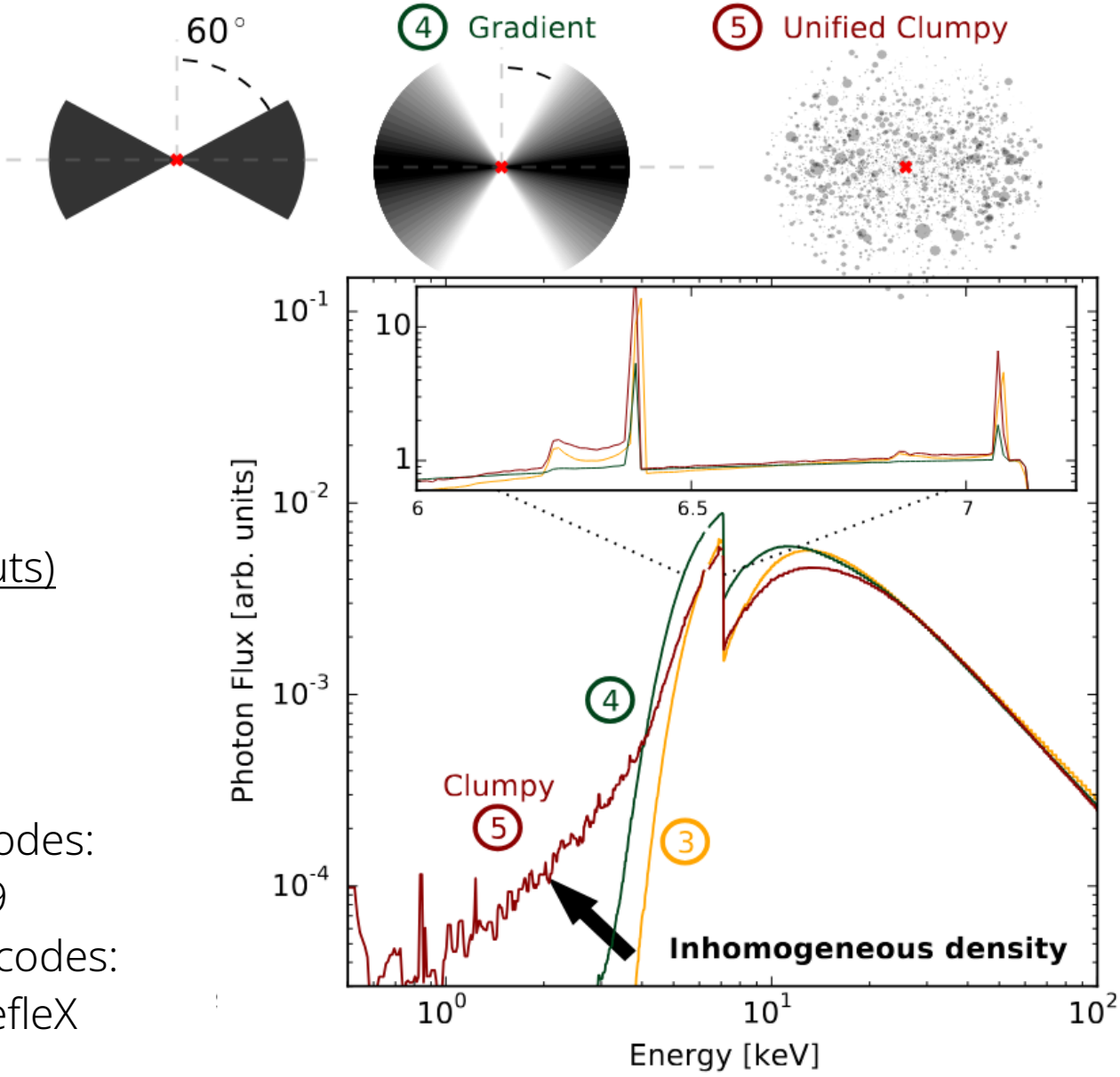
3) Compton scattering





Compton reflection spectroscopy

Geometry leaves imprints in Compton-thick spectra



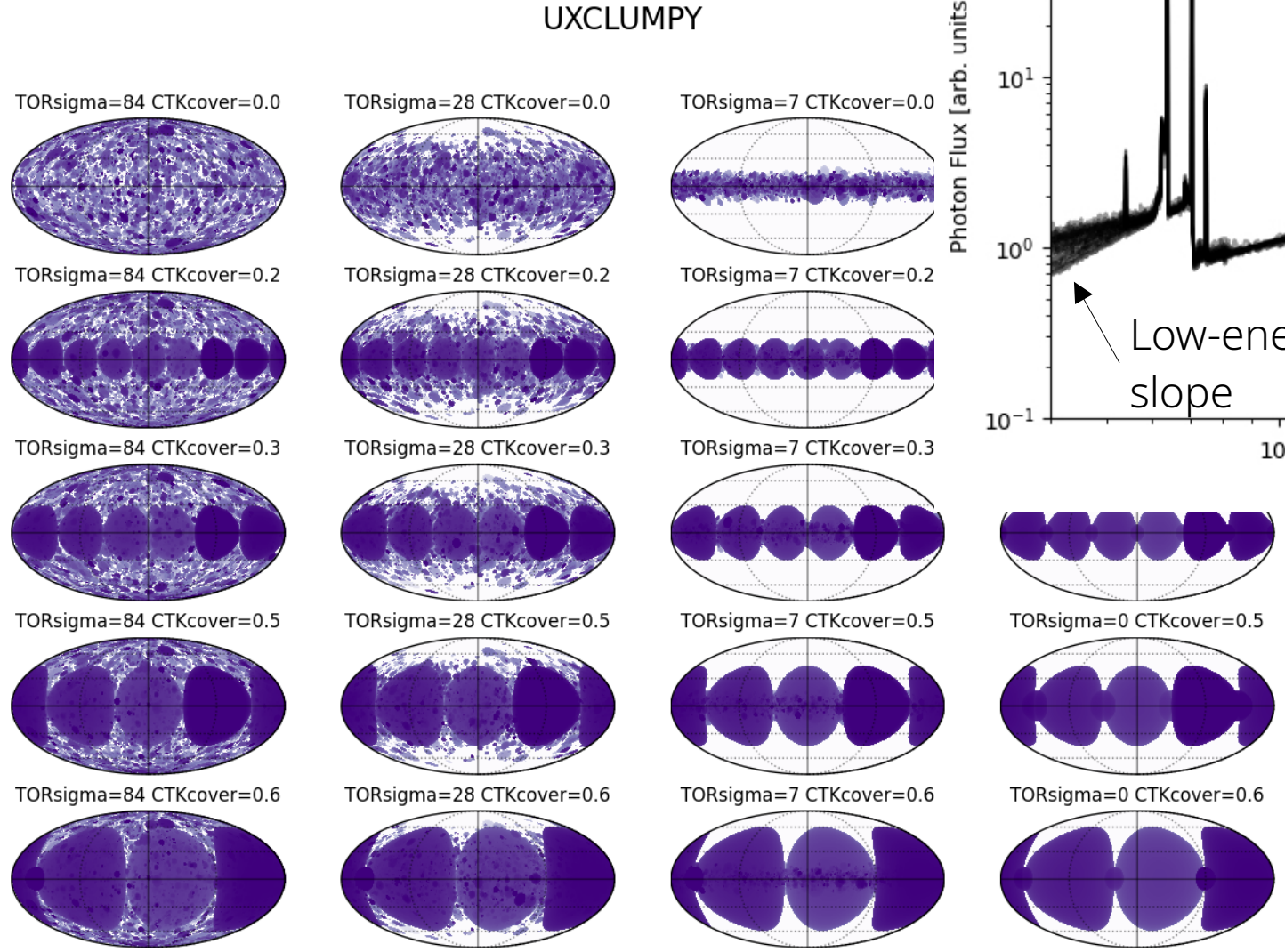
<u>Ad-hoc models (disks, clumps & donuts)</u>

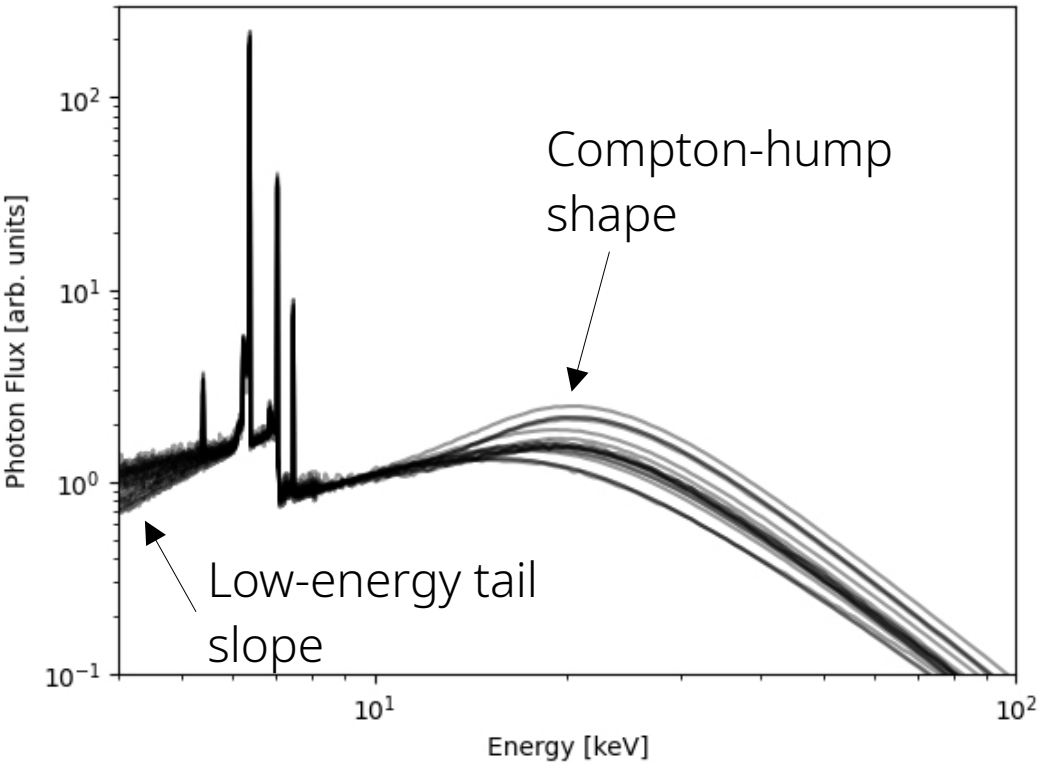
Matt+99
Murphy&Yaqoob09
Brightman&Nandra11
Balokovic+14
Furui+16
Paltani&Ricci17
Tanimoto+19
Vander Meulen+24

Open source codes:
XARS, SKIRT9
Closed source codes:
MONACO, RefleX

Diversity of spectral shapes

Geometry leaves imprints in Compton-thick spectra





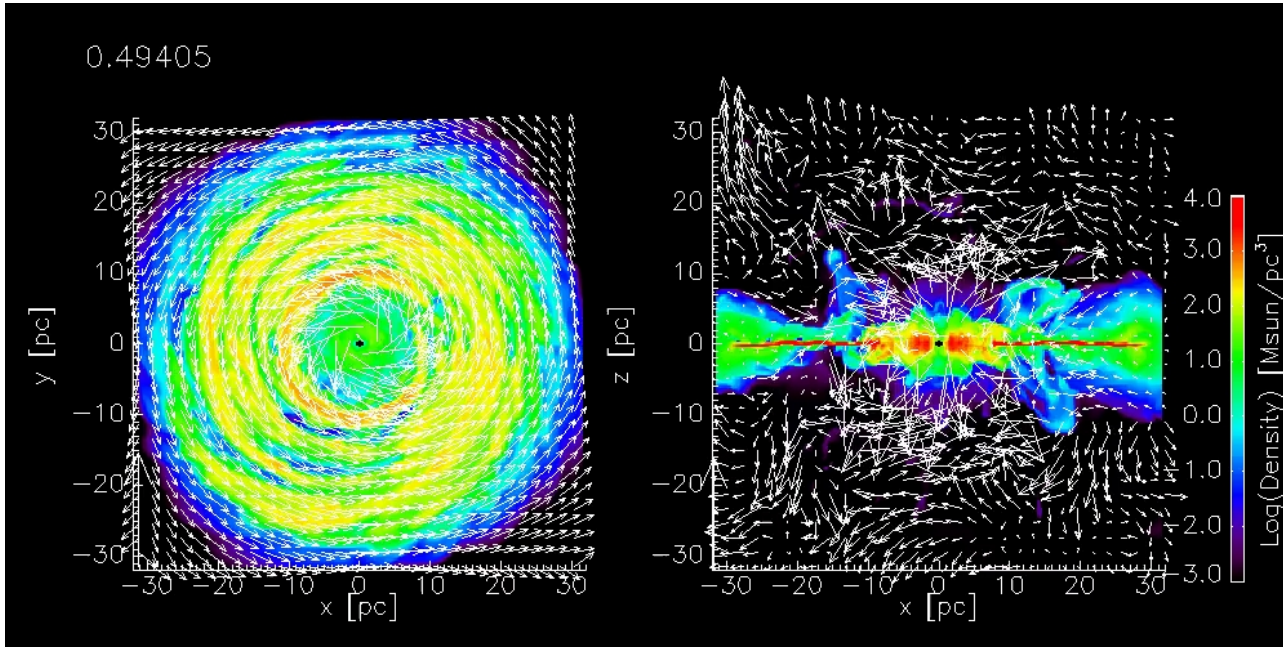
Degenerate with photon index and line-of-sight column density

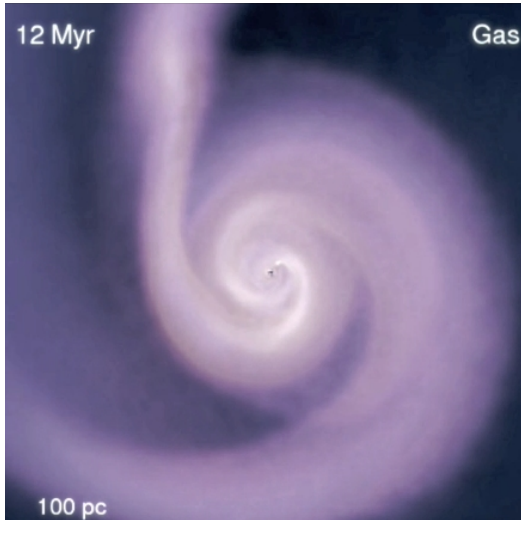
→ need to fully explore degeneracies

Physical torus models

Definition:
mechanism to create/maintain geometry

- Radiative fountain
  e.g. Wada+12,+18
- failed outflow
  e.g. Dorodnitsyn+17
- Warped disks
  e.g. Pringle97
- Clumpy torus
  e.g. Bannikova+12, Chen+16
- Large-scale inflows
  e.g. Hopkins+12, Gaspari+15

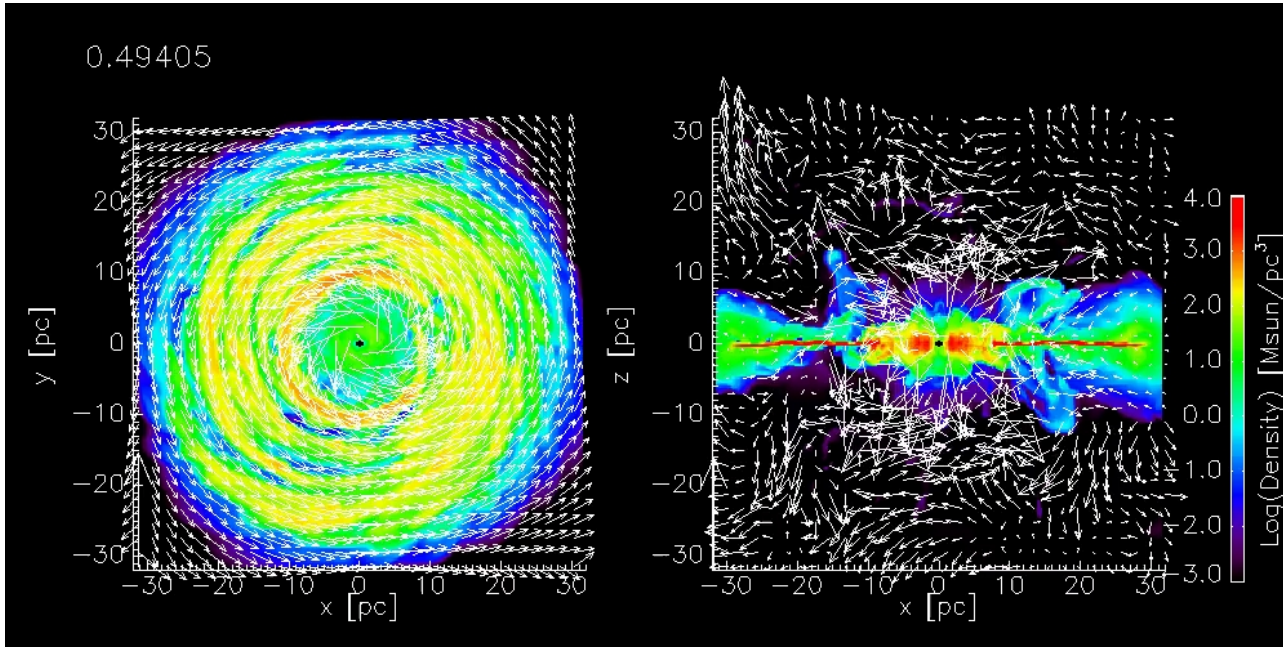




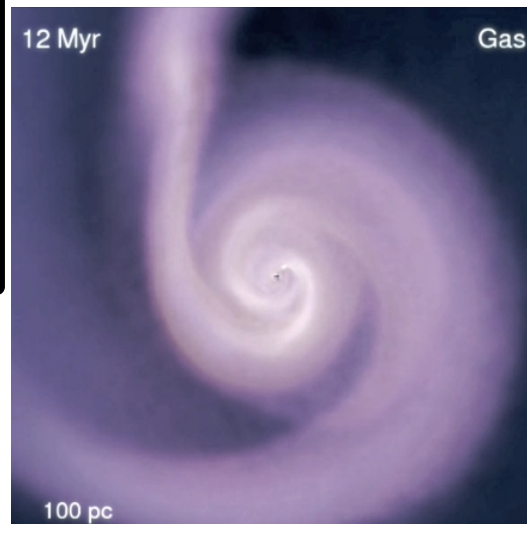
Physical torus models

Definition:
mechanism to create/maintain geometry

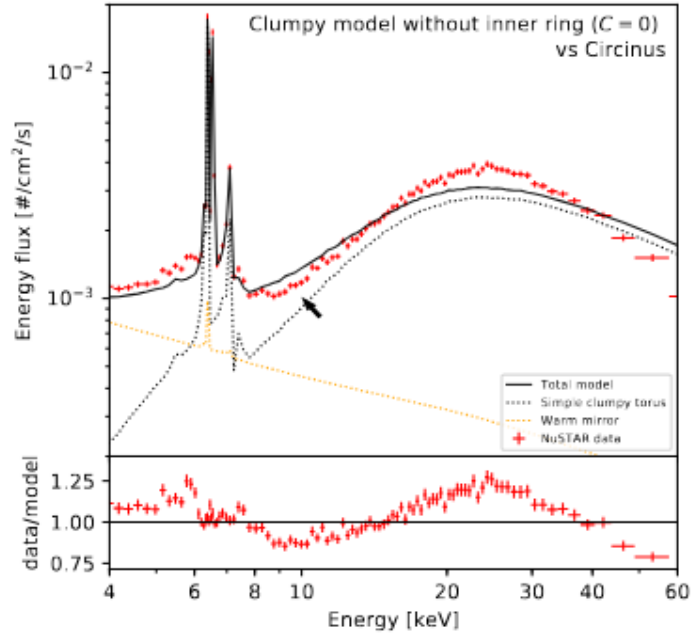
- Radiative fountain
  e.g. Wada+12,+18
- failed outflow
  e.g. Dorodnitsyn+17
- Warped disks
  e.g. Pringle97
- Clumpy torus
  e.g. Bannikova+12, Chen+16
- Large-scale inflows
  e.g. Hopkins+12, Gaspari+15

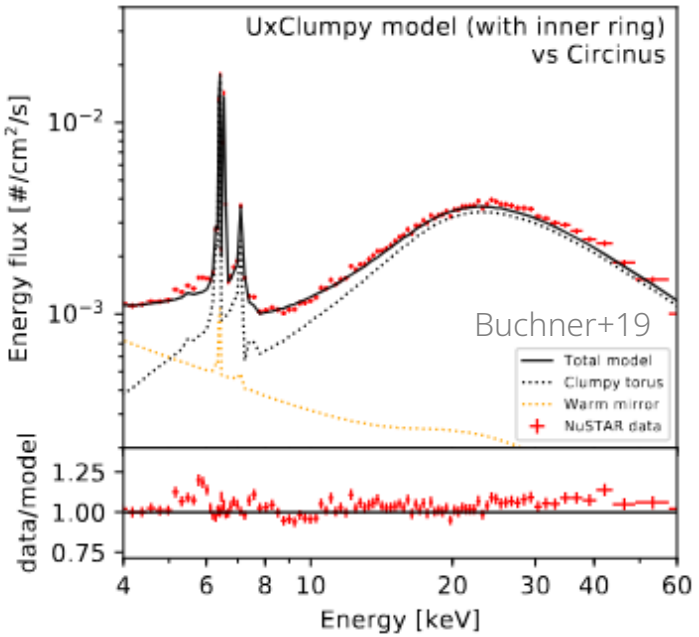


X-ray spectral template available
Warped Disk
Radiative Fountain
Buchner+21
atable download: https://github.com/JohannesBuchner/xars/



Local AGN with NuSTAR





Circinus, NGC1068, …

<u>But</u>

Chandra at z~1-3: 1-32 keV

Questions on Compton-thick AGN

What are covering factors of individual sources & samples?

What is the prevalence of Compton-thick accretion in the universe?

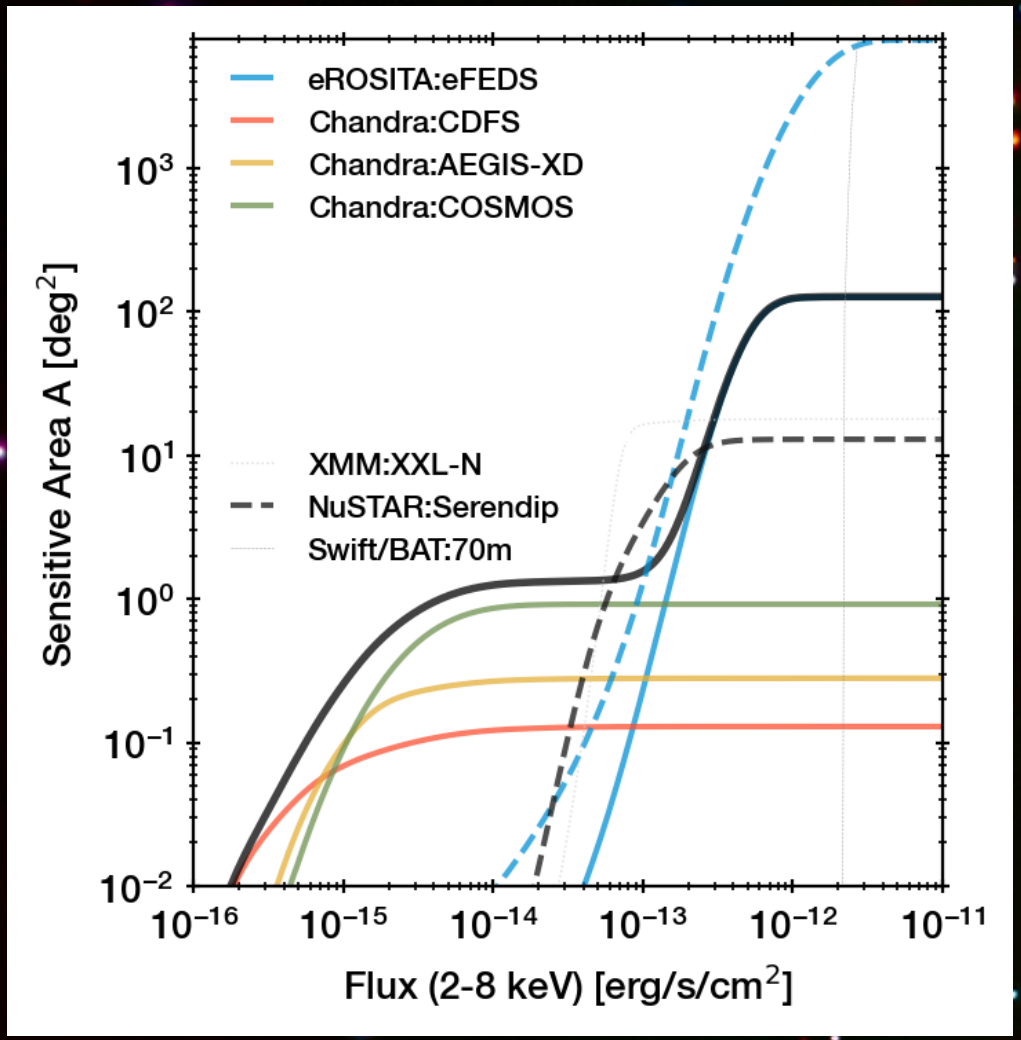
Chandra deep fields

CDF-S: Giacconi, Brandt, Tananbaum
COSMOS: Civano, Elvis, Puccetti
AEGIS-XD: Nandra

~100 CTK in deep fields (e.g. Brightman+15)

66 in local Universe (DoCTA, Boorman+24)

Reviews: Brandt&Hasinger05, Brandt&Alexander15
Counterpart association & redshifts (Brusa, Marchesi, Hsu, Luo, Xue, Salvato ...)



X-ray: NASA/CXC/Penn State/B.Luo et al.

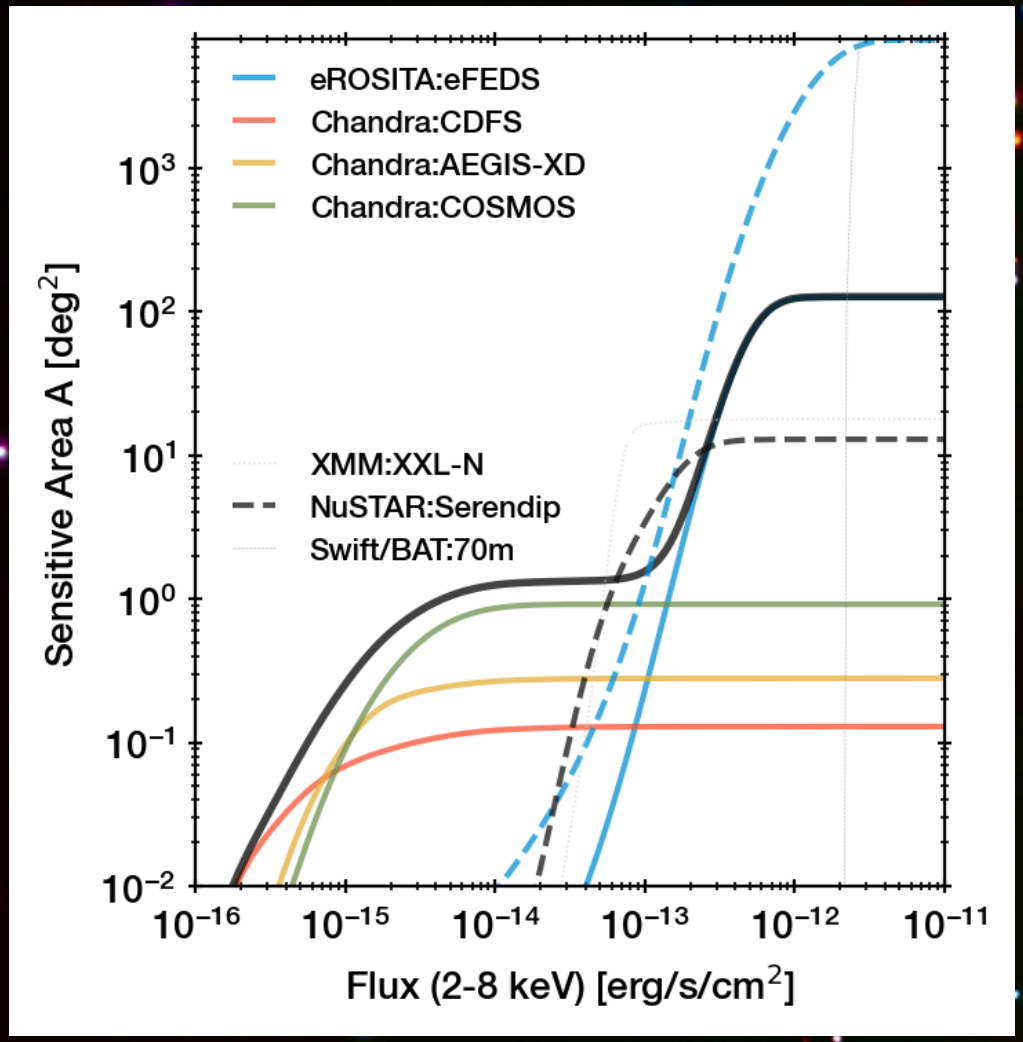
Chandra deep fields

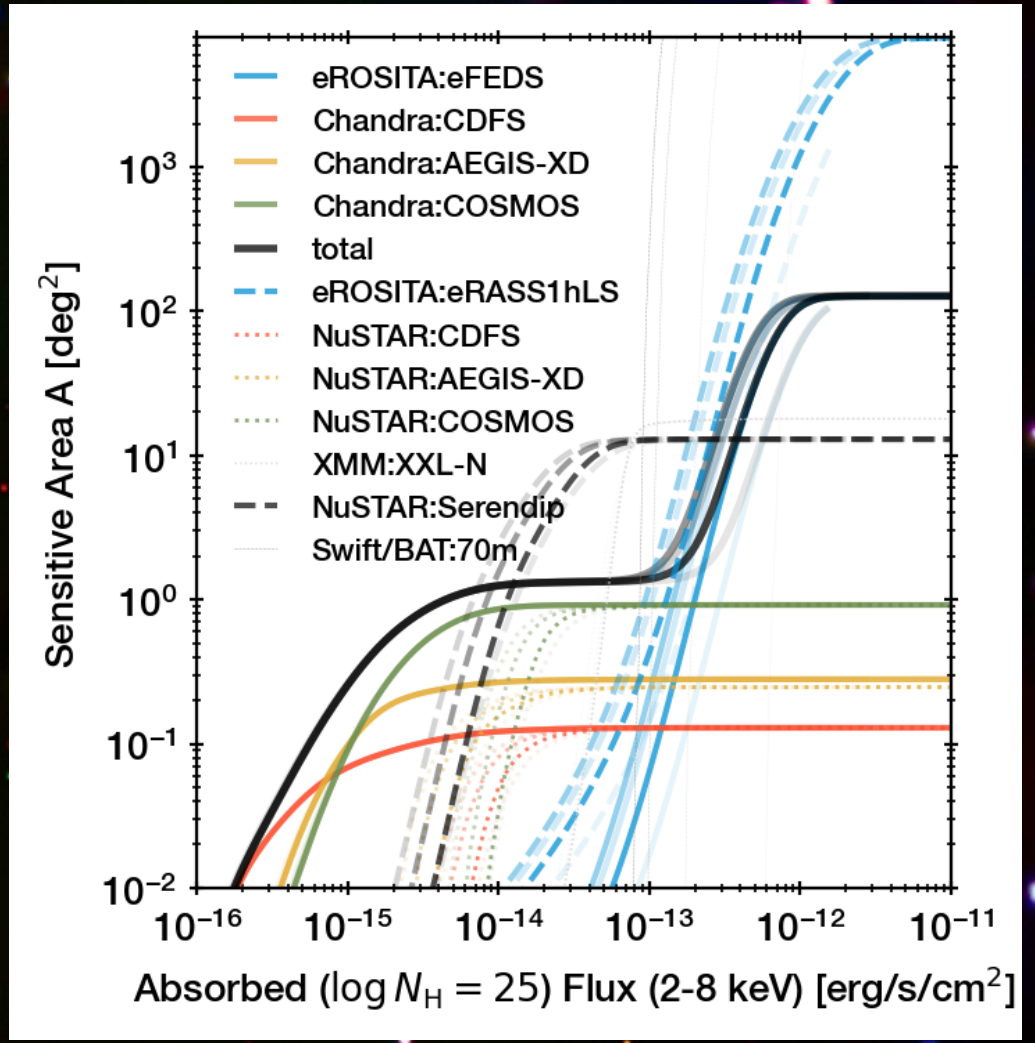
CDF-S: Giacconi, Brandt, Tananbaum
COSMOS: Civano, Elvis, Puccetti
AEGIS-XD: Nandra

~100 CTK in deep fields (e.g. Brightman+15)

66 in local Universe (DoCTA, Boorman+24)

Reviews: Brandt&Hasinger05, Brandt&Alexander15
Counterpart association & redshifts (Brusa, Marchesi, Hsu, Luo, Xue, Salvato ...)

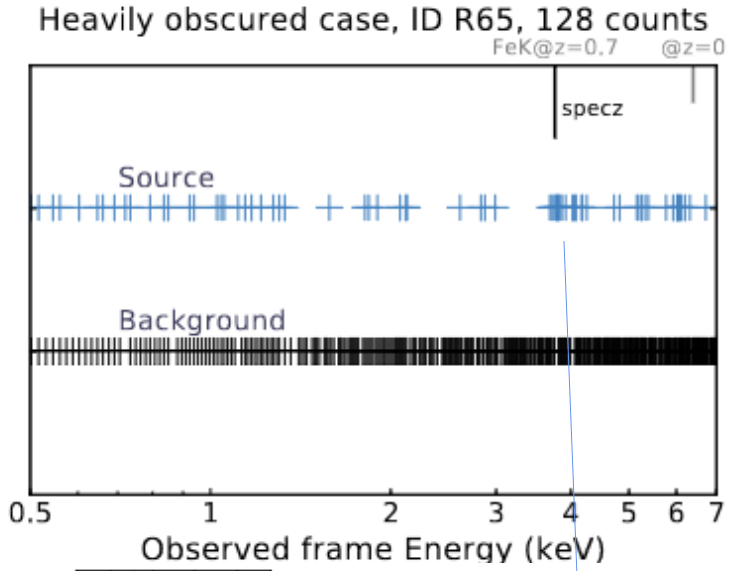


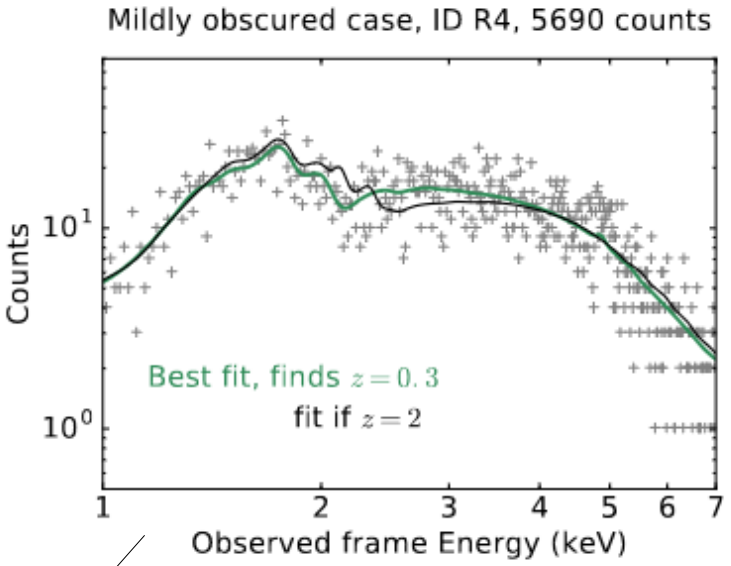


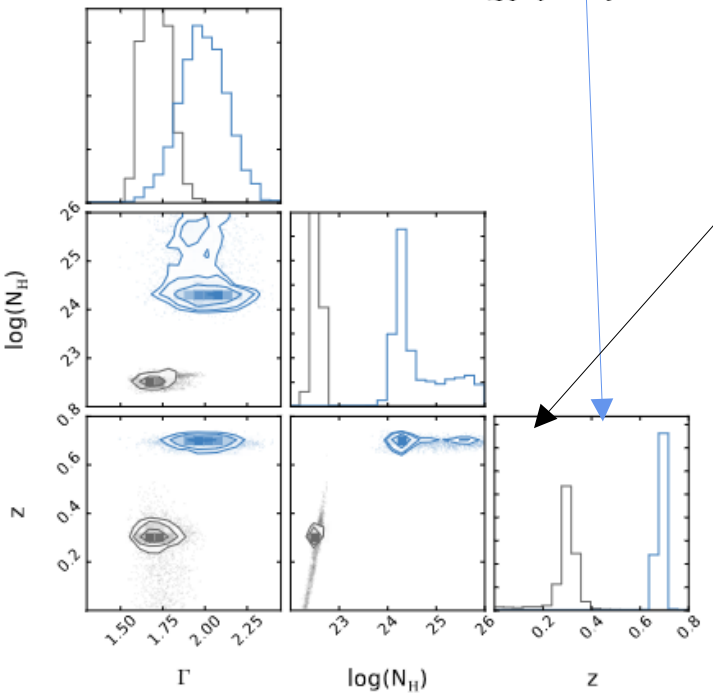
X-ray: NASA/CXC/Penn State/B.Luo et al.

ACIS X-ray spectroscopic redshifts (XZ)

Simmonds, JB+18; Sicilian+22



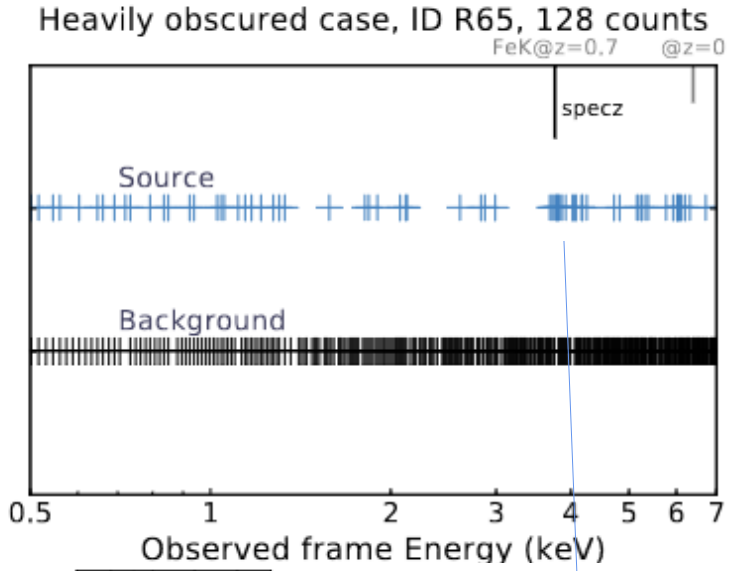


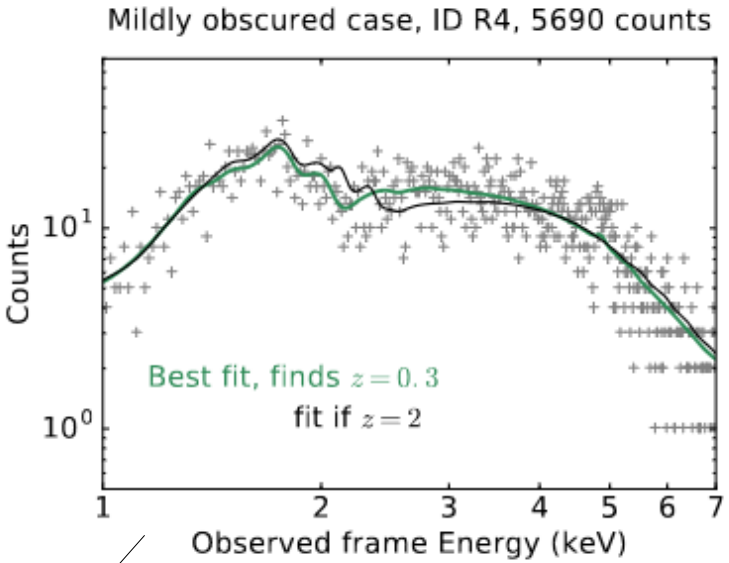


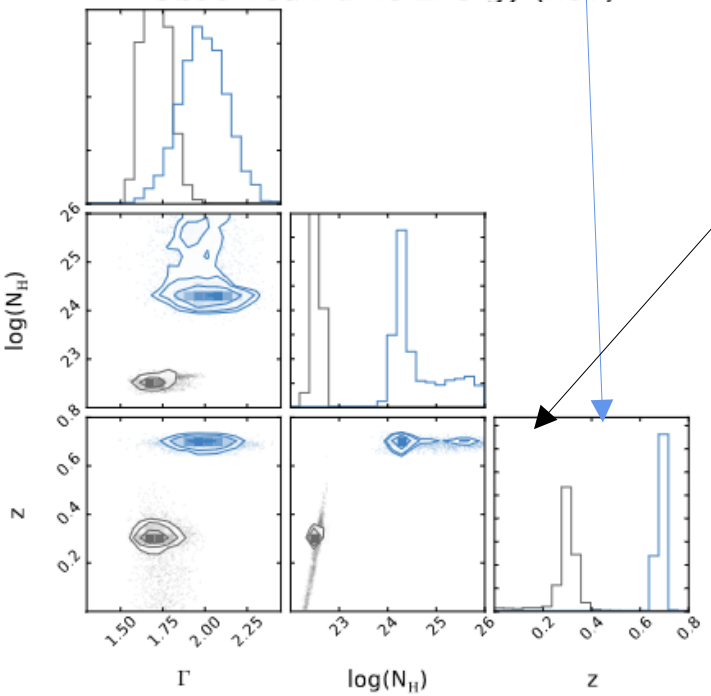
Can infer redshift from 100-1000 counts from absorption edges & lines

ACIS X-ray spectroscopic redshifts (XZ)

Simmonds, JB+18; Sicilian+22







Astrostatistical methods enrich archival analysis for decades

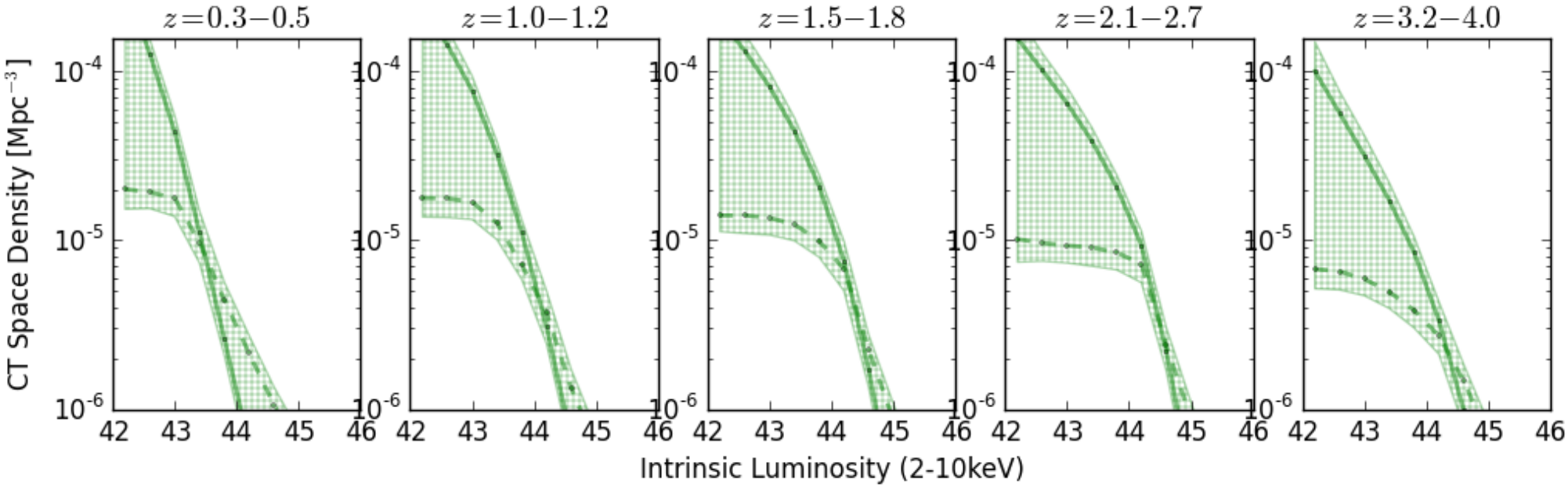
Can infer redshift from 100-1000 counts from absorption edges & lines

BXA: pyxspec/sherpa with nested sampling for robust parameter inference and model comparison

https://johannesbuchner.github.io/BXA/

Luminosity function of CTK AGN

$\Phi(L, N_{\rm H}, z)$ Buchner+15: space densities available on vizier



Robust, non-parametric, Bayesian methodology

rigid parametric: Ueda+03,+14

flexible:

Buchner+15 (GP, spectra),
Aird+15 (GMM, photometry)
Ananna+21 (NN, summary statistics)

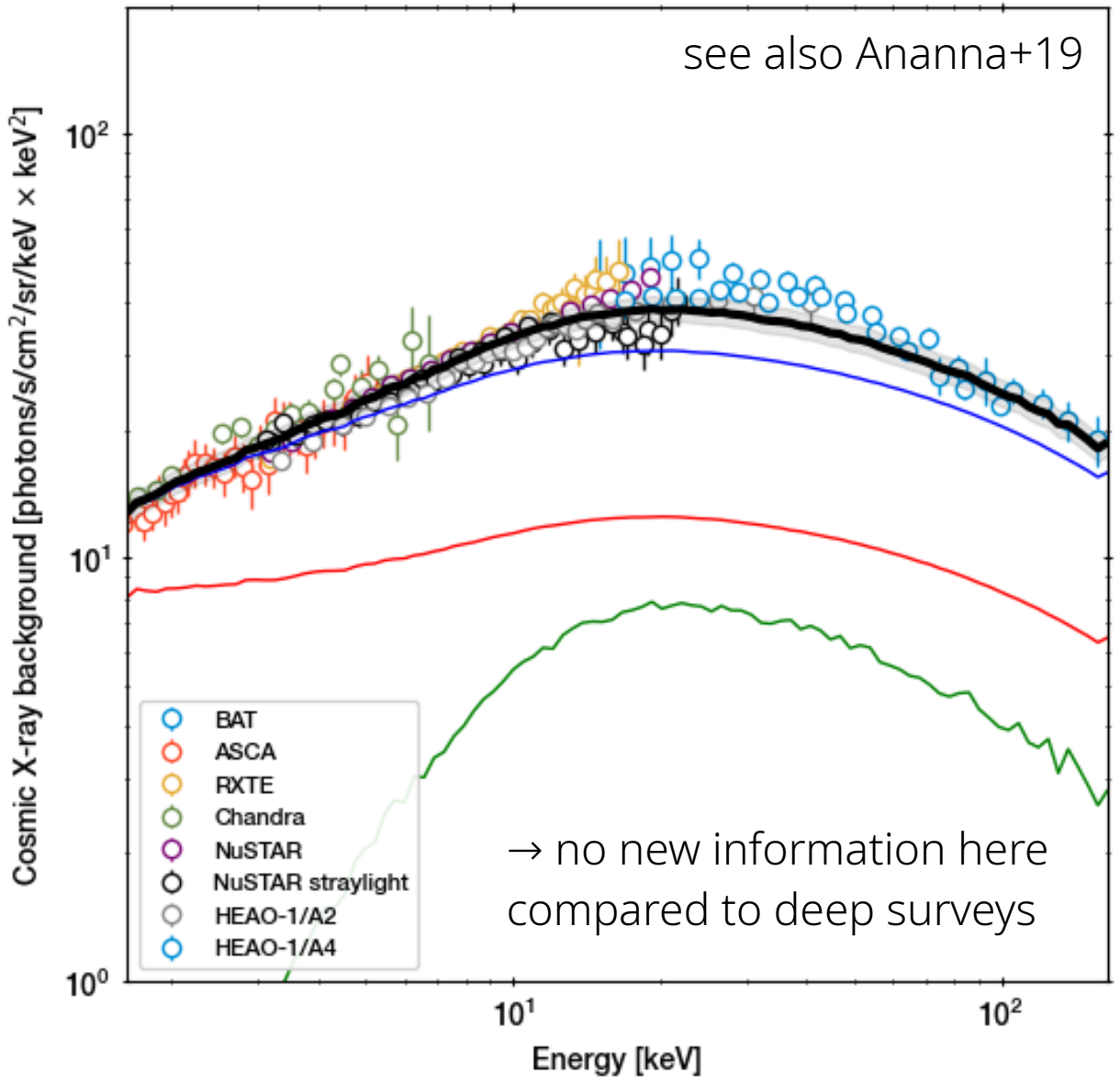
CTK fraction ~38% (in number & luminosity)

L-dependence? Evolution? unclear, but both likely mild
→ Athena

(surprising given the Iwasawa-Taniguchi effect)

Cosmic X-ray Background

Prediction of the extragalactic background light

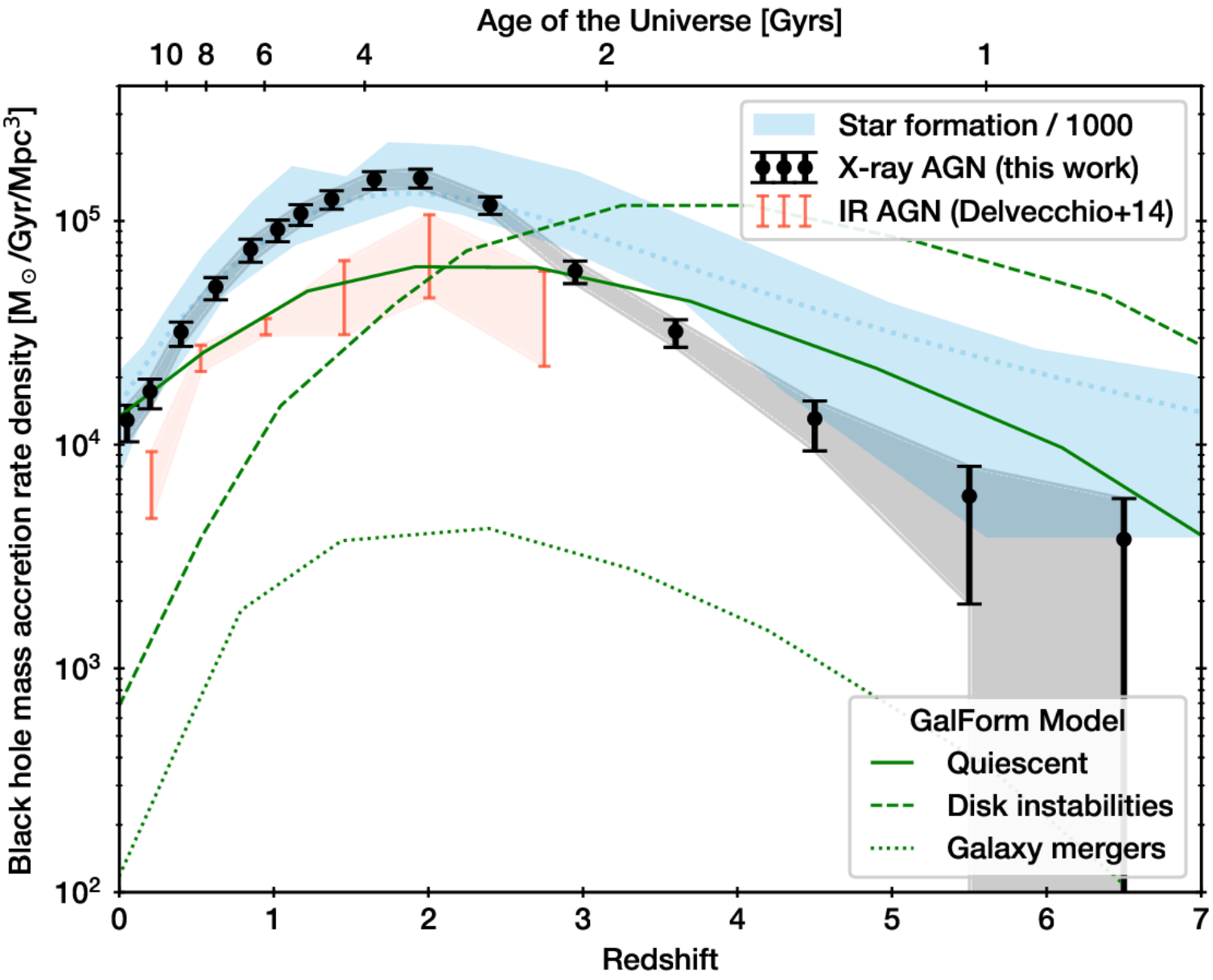


Prediction of unseen surveys

	Swift/BAT	Nu*Serendip
# AGN	733-798	149-165
obs	1302-3328	149-301
# CTK	50-293	14-68
obs:	40-128	1-26

Black Hole accretion history

Buchner+15, Merloni15

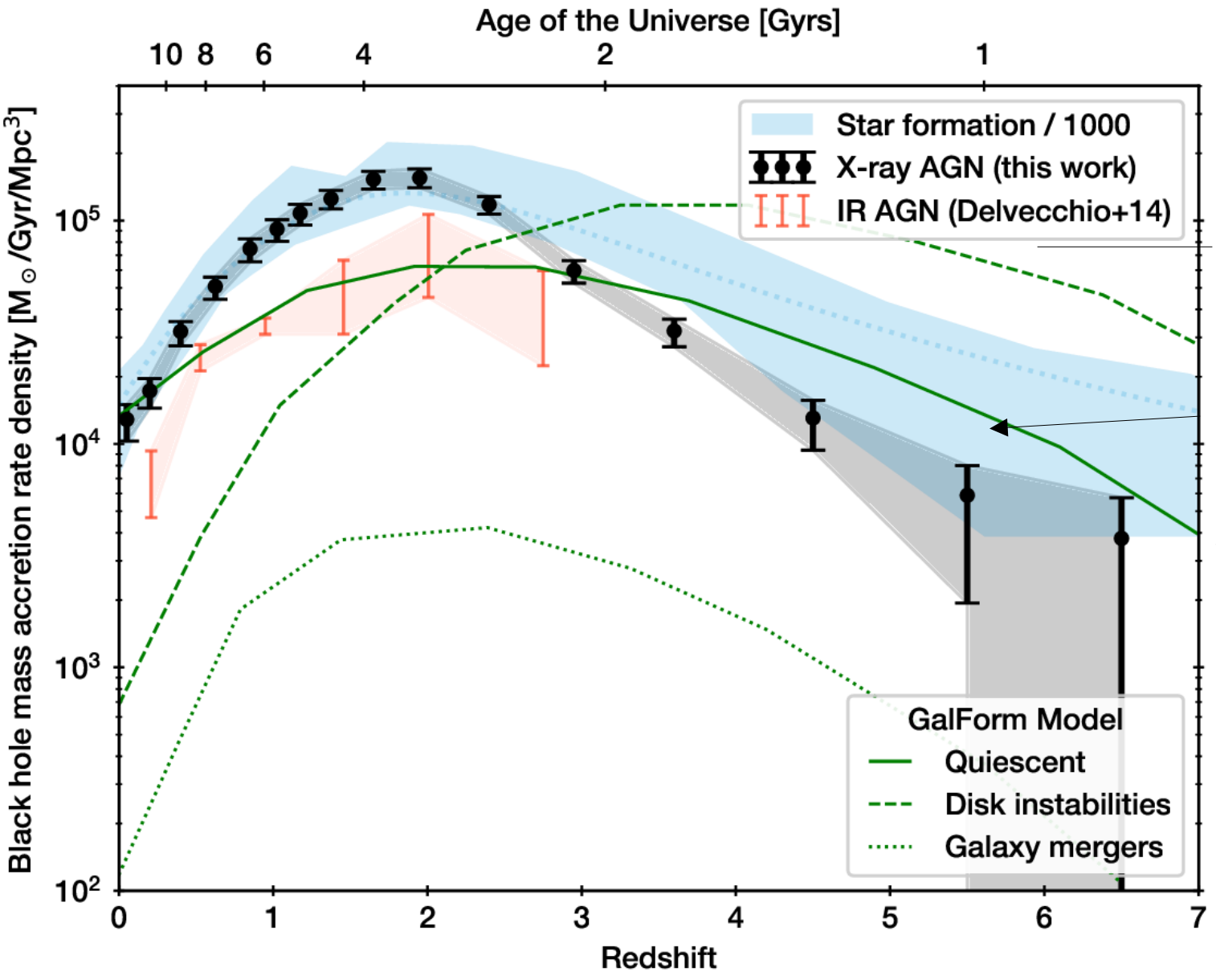


see also Madau&Dickinson14, Aird+15, Ananna+, Ueda+, etc

Black Hole accretion history

Buchner+15, Merloni15

see also Madau&Dickinson14, Aird+15, Ananna+, Ueda+, etc



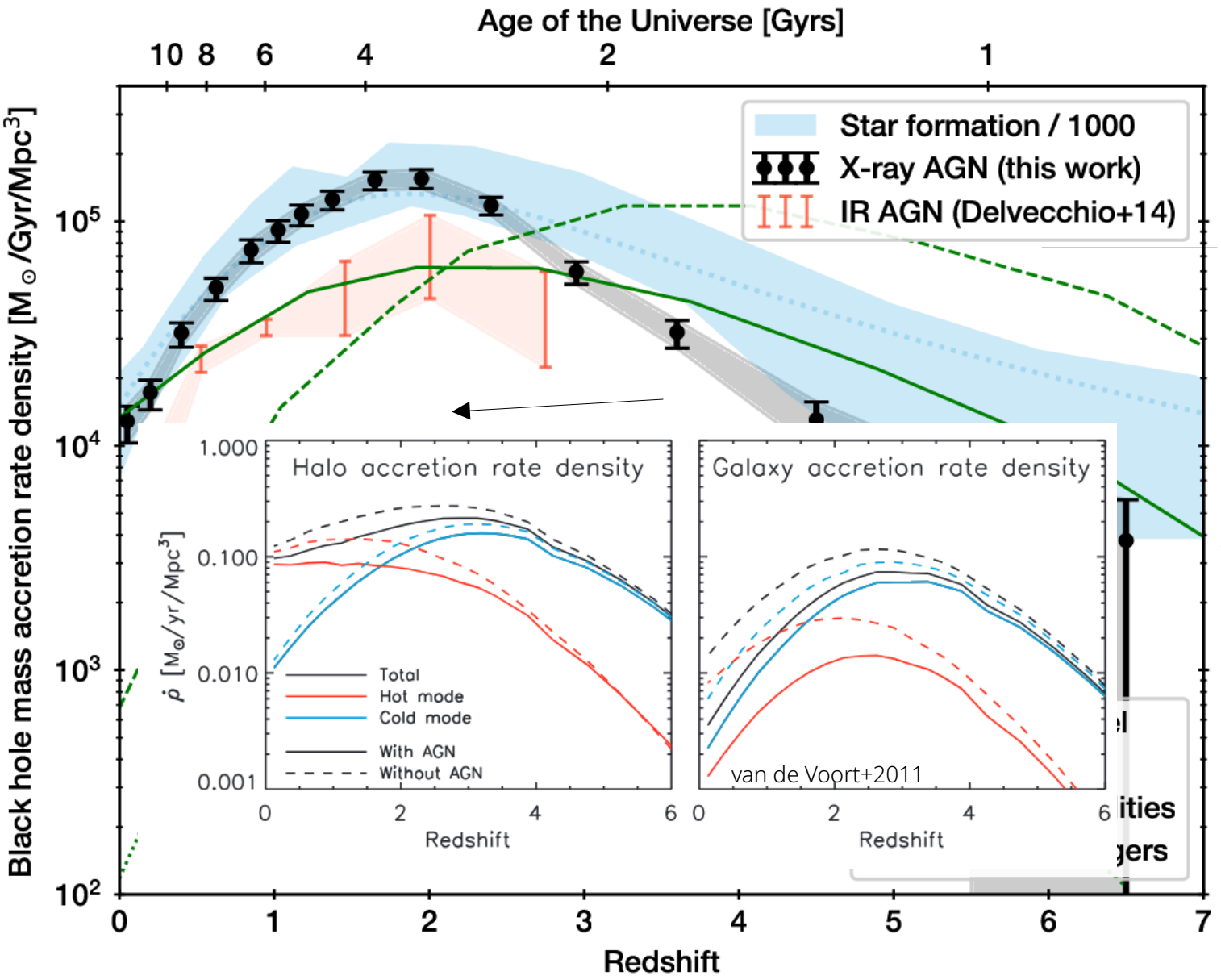
LRD if AGN

Confirmed by detection of z=6 quasars in 140deg^2 eROSITA field (J. Wolf+21)
(0.5-2.3keV → 2-16keV)

Black Hole accretion history

Buchner+15, Merloni15

see also Madau&Dickinson14, Aird+15, Ananna+, Ueda+, etc

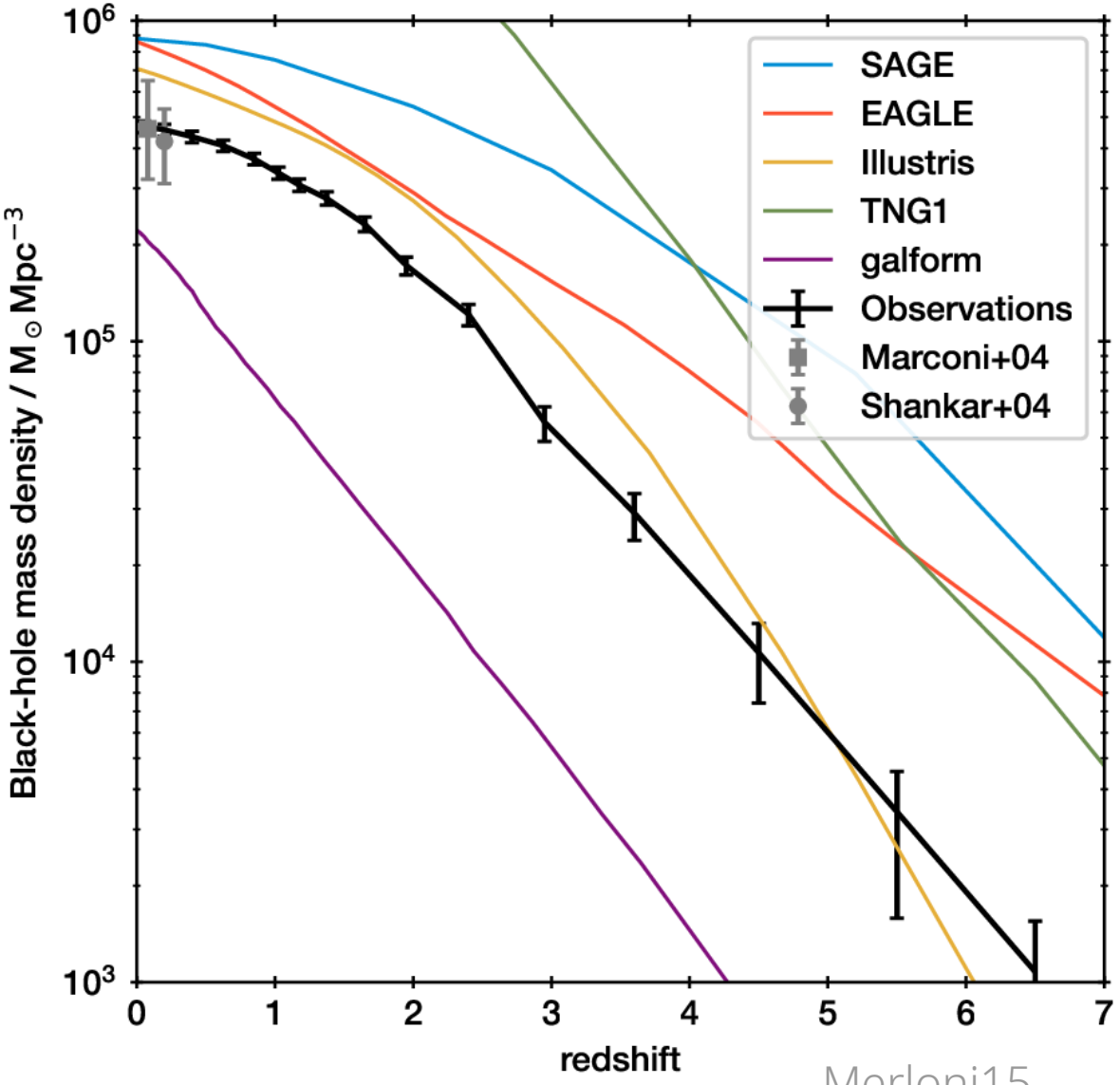


LRD if AGN

Confirmed by detection of z=6 quasars in 140deg² eROSITA field (J. Wolf+21)
(0.5-2.3keV → 2-16keV)

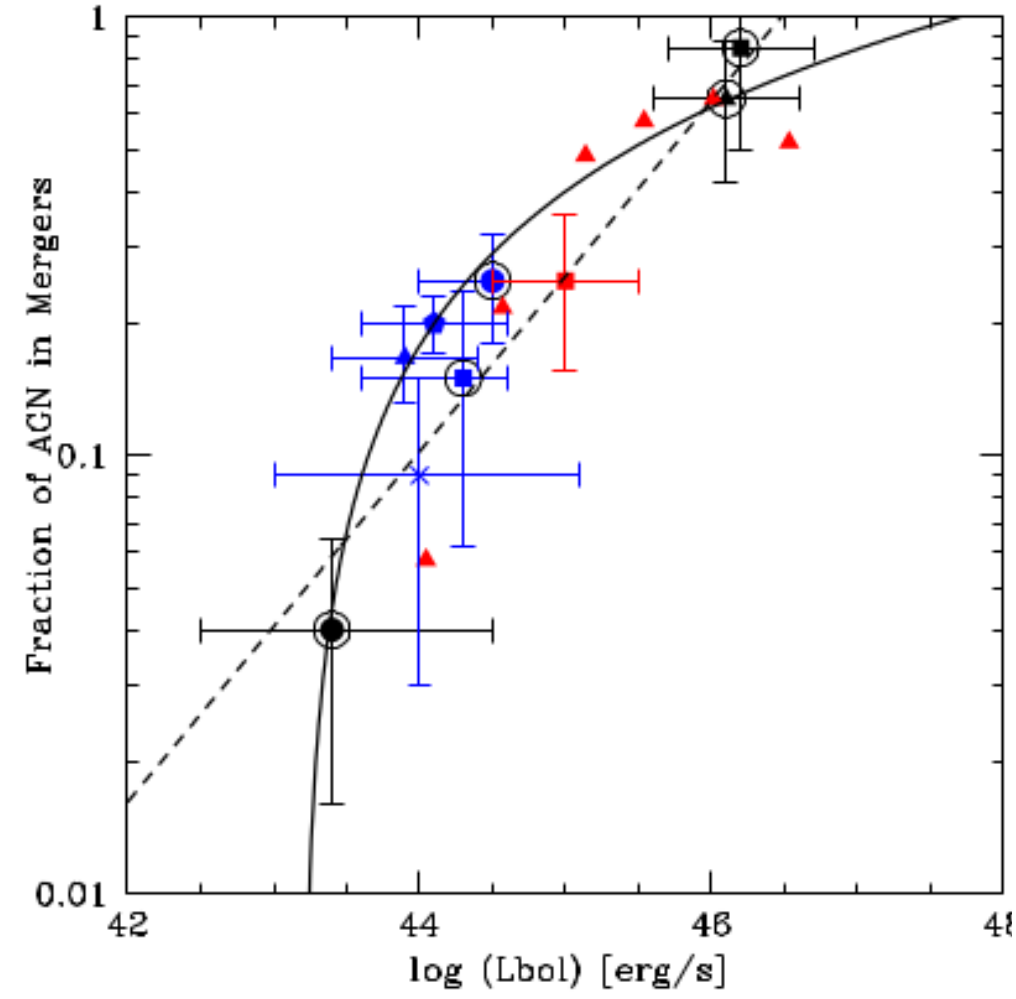
<8" mirrors (Athena & AXIS)
→ obscured AGN population

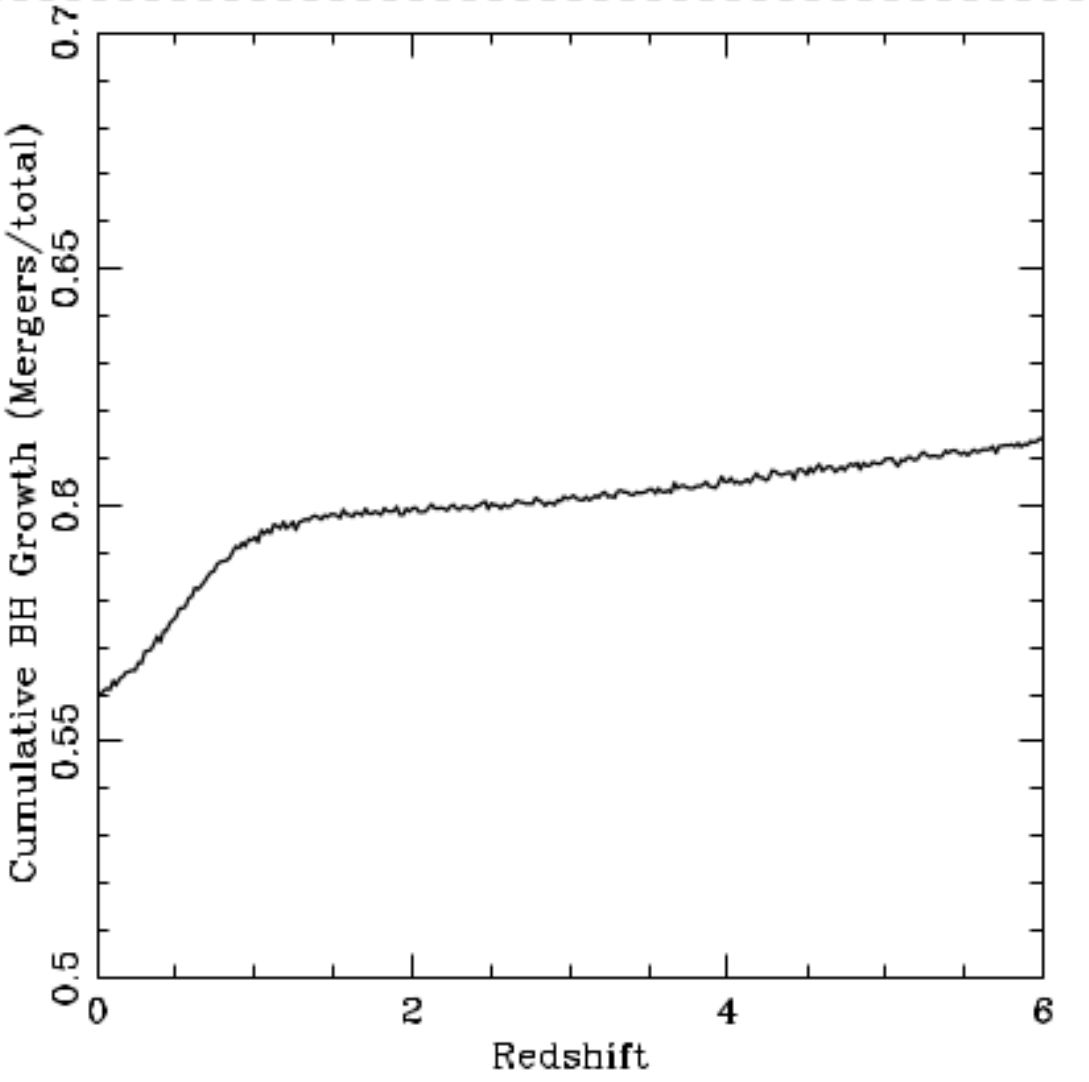
Luminosity-weighted: black hole mass



Merloni15

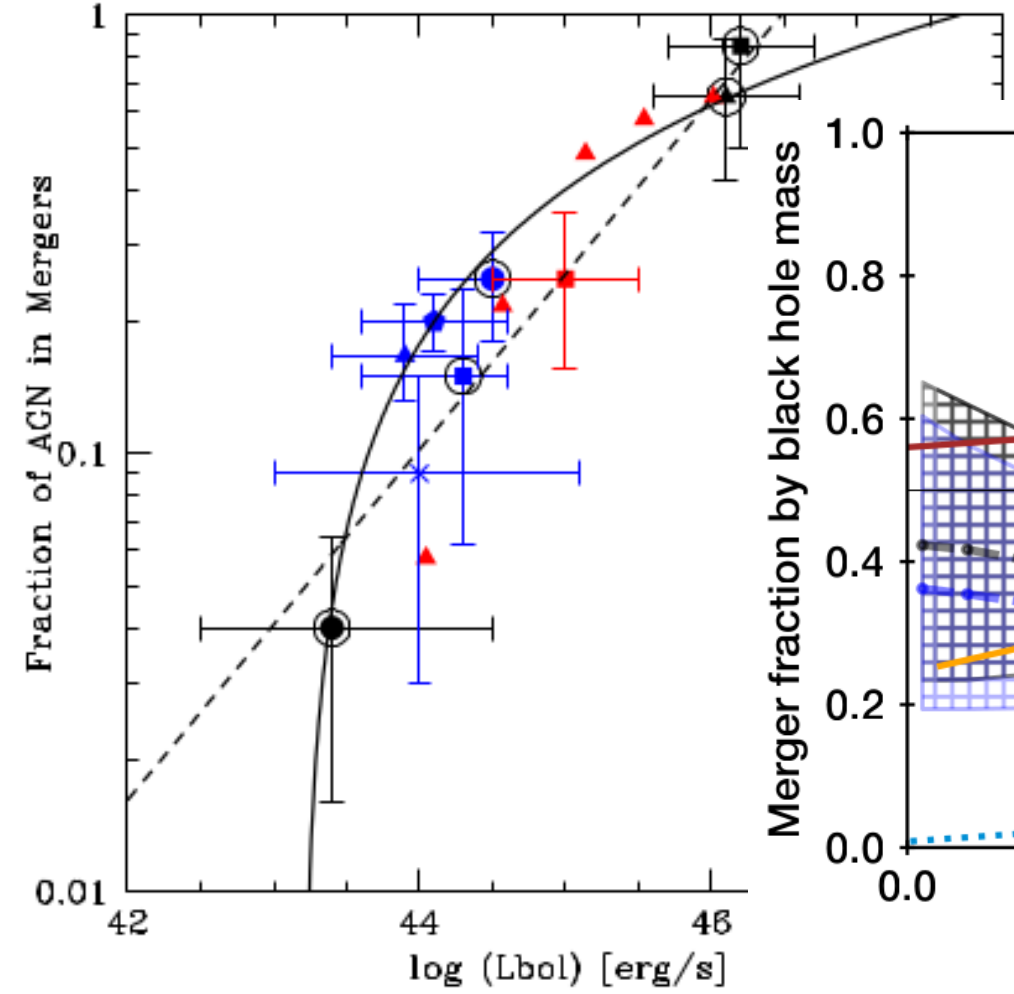
Luminosity-weighted: mergers



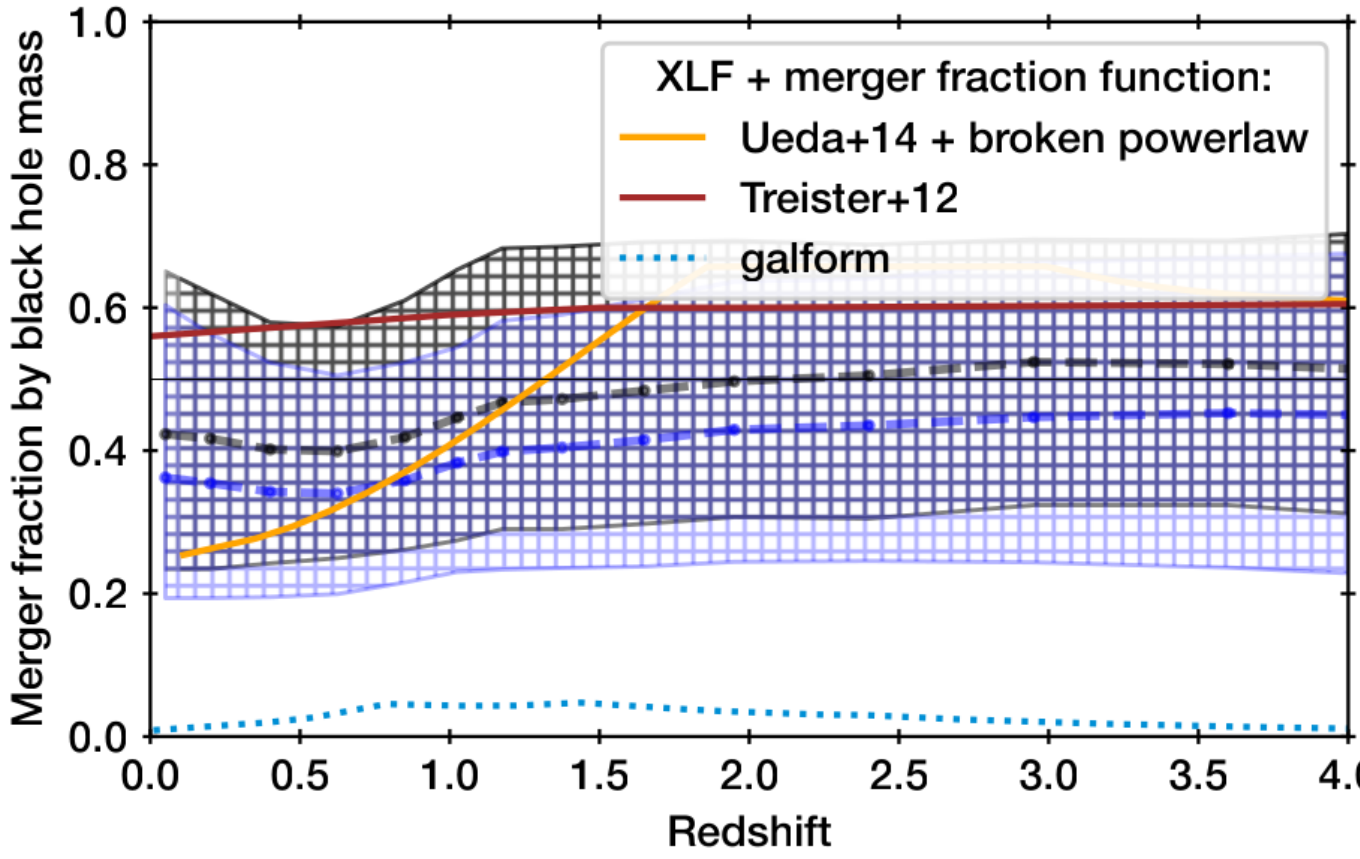


Treister+12

Black hole mass built in mergers



Treister+12



Uncertainties remain at bright end

→ large-area, hard response instrument (Athena)

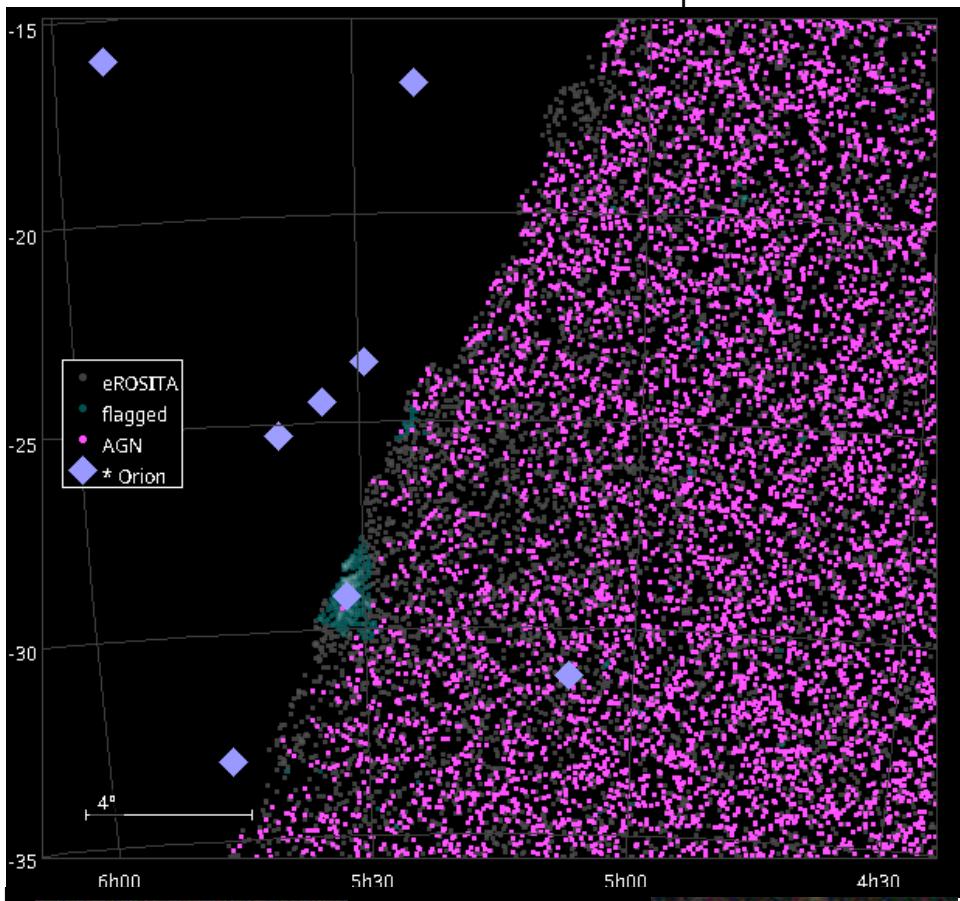
Compton-thick AGN

- Chandra sheds light on heavily obscured AGN!
- Discovery machine at cosmic noon
- Future: Athena/WFI

  with NWAY, BXA astrostatistics tools

  ~~HEX-P?~~ AXIS? XRISM?

Galaxies in luminous AGN phase



Multi-wavelength characterisation is key: Buchner+24