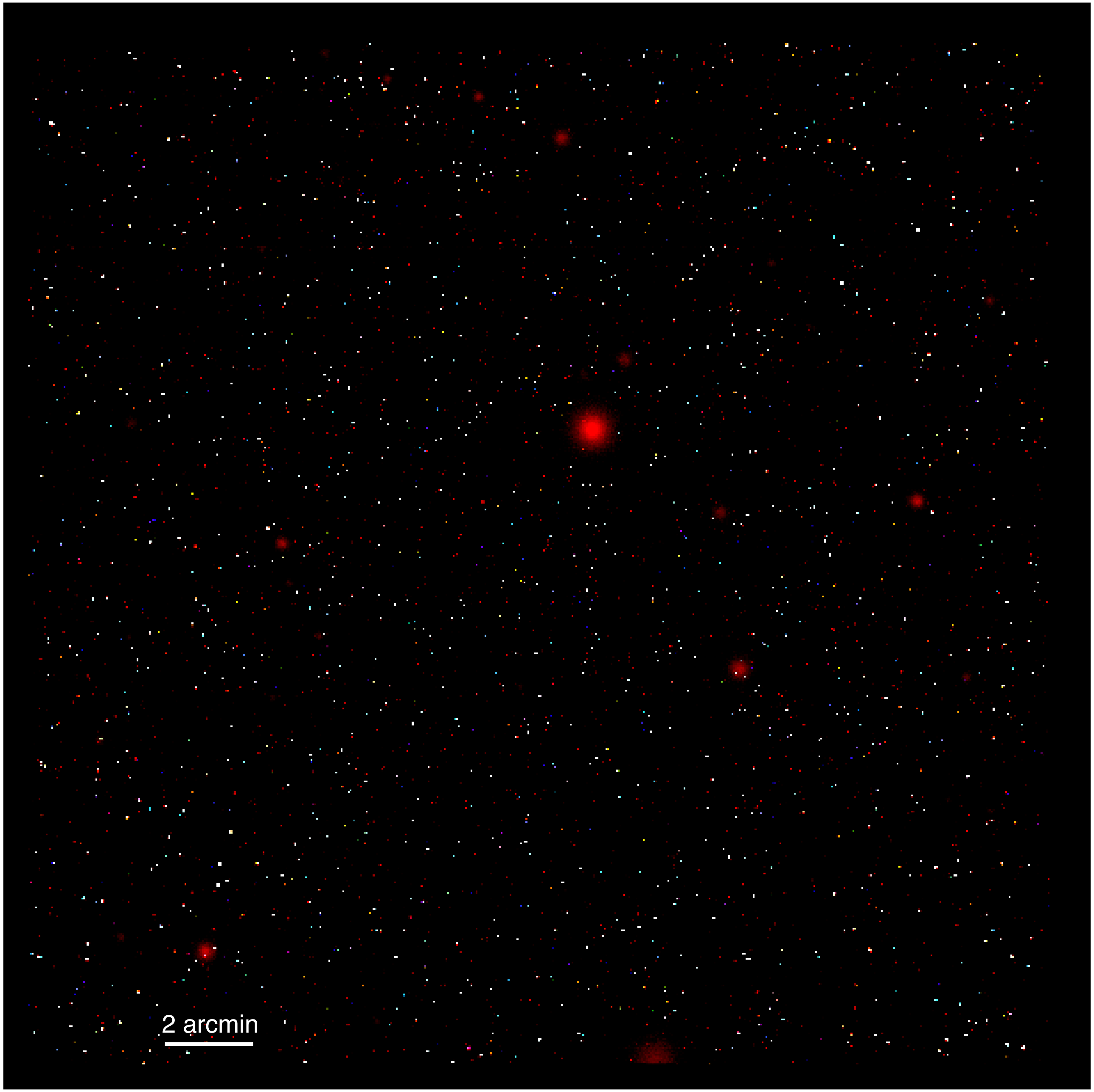
Understanding the AGN population: X-ray surveys



X-rays as a strategic tool in AGN analysis

X-ray emission contributes only to <10% to AGN bolometric luminosity. However, X-ray emission offers an unique point of view in the AGN analysis. In fact, X-ray offer the…

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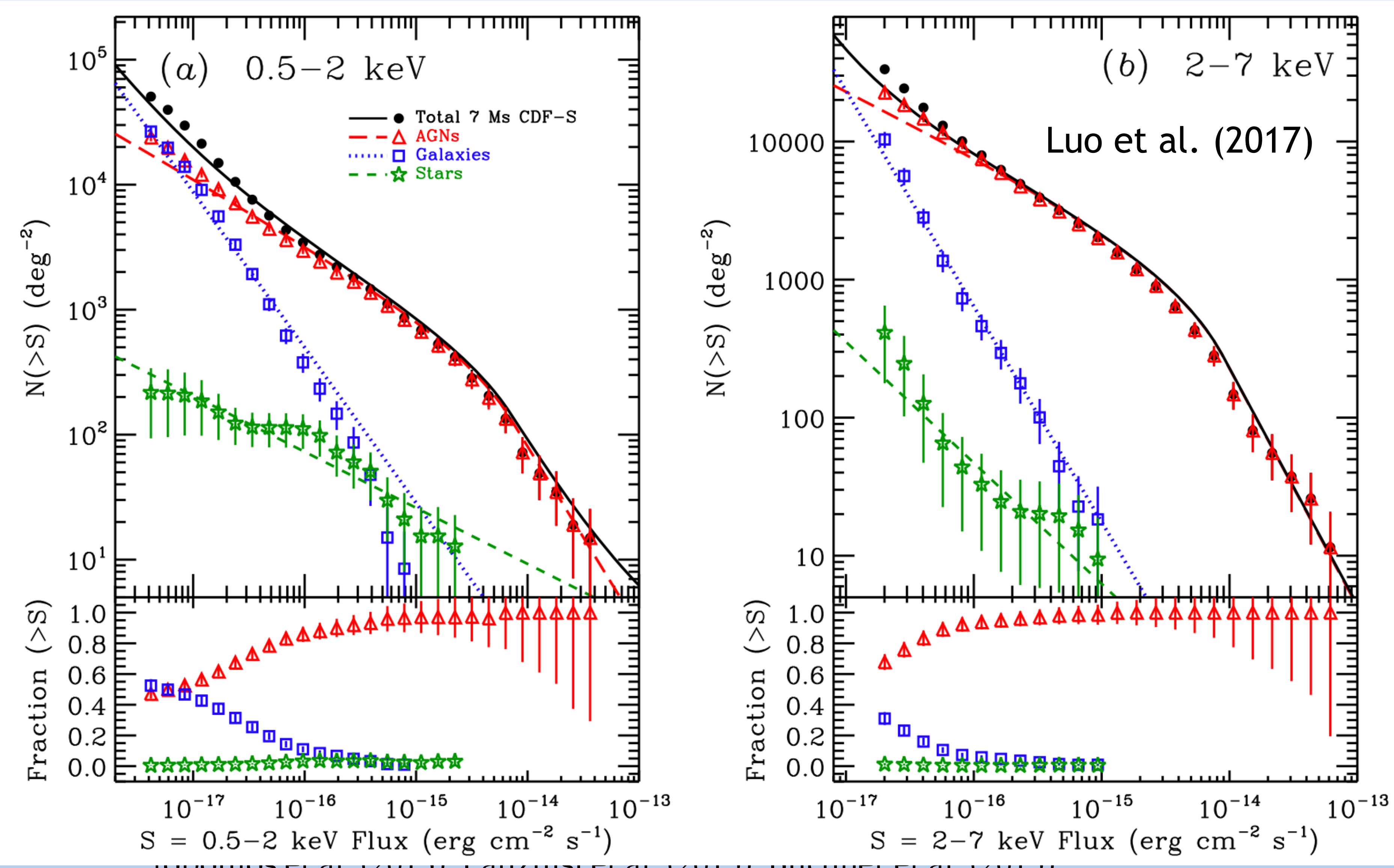

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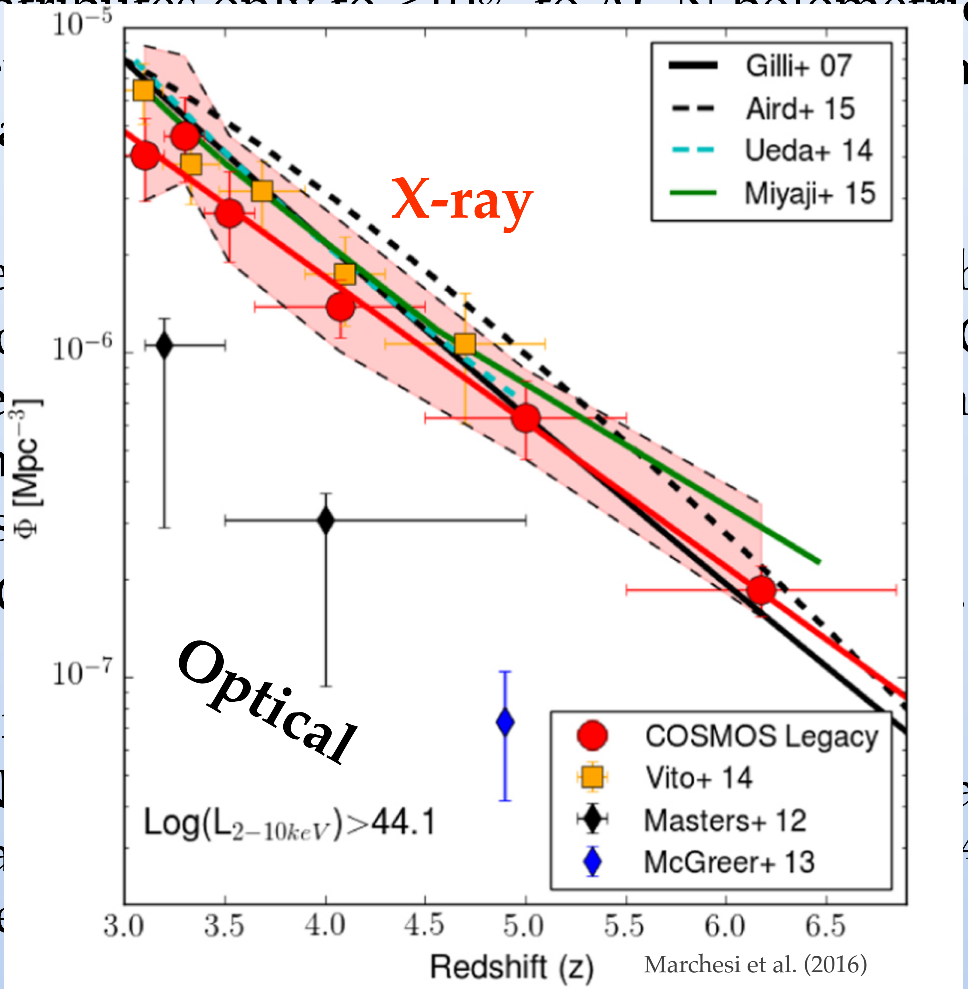

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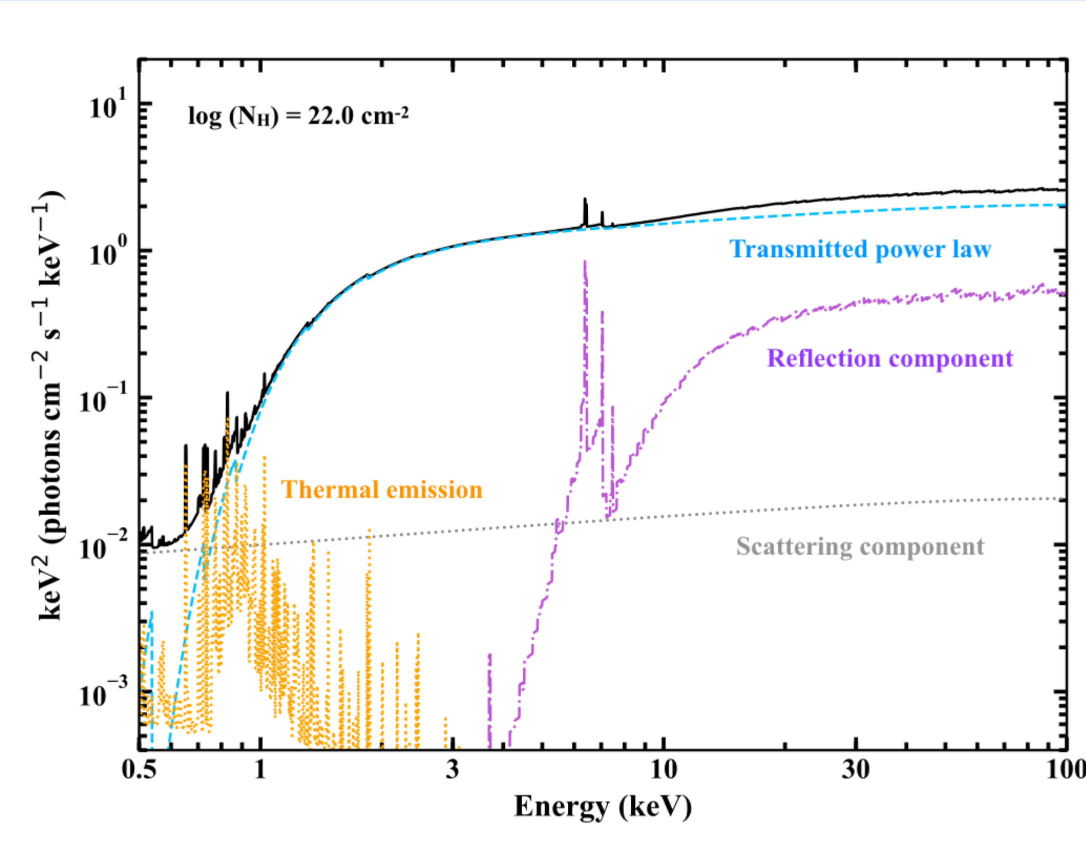
AGN obscuration: the X-ray spectral prospective

- AGN emission from accretion disk and the corona, surrounded by a dense torus of gas and dust.
- Depending on our viewing angle with respect to the central engine, part of the emission can be suppressed (absorption by metals).



Courtesy of X. Zhao

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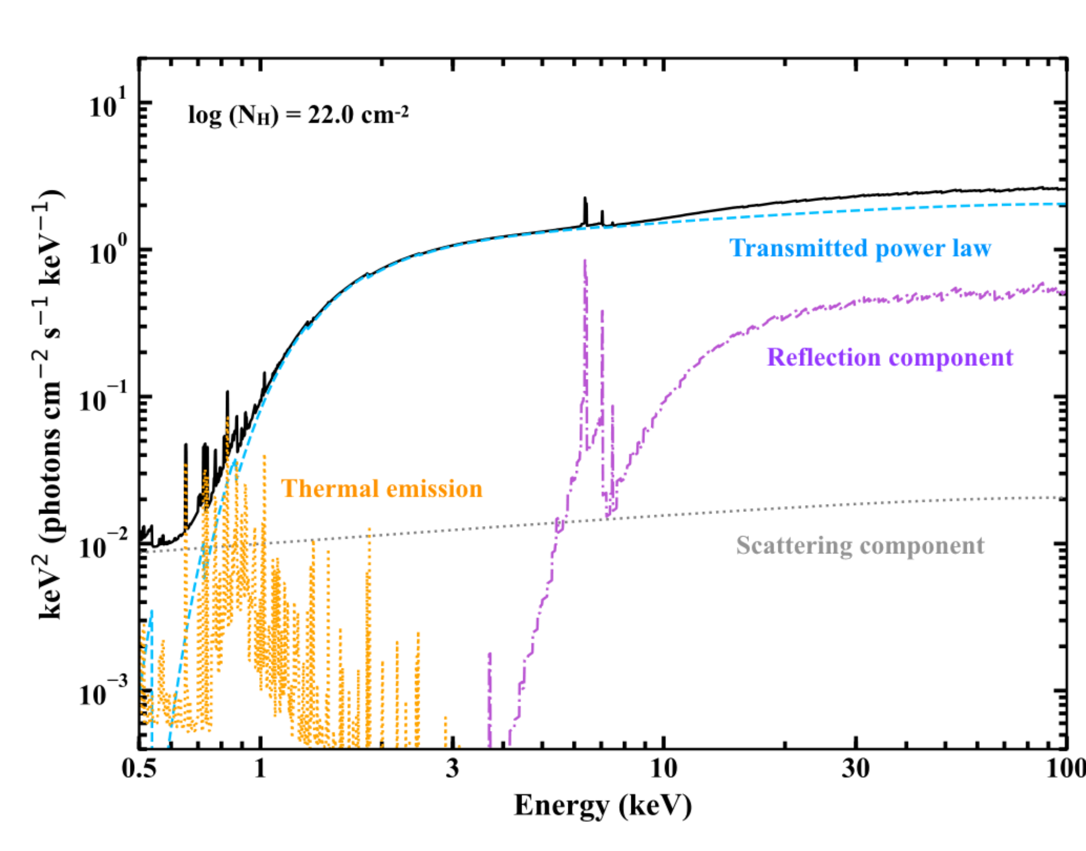

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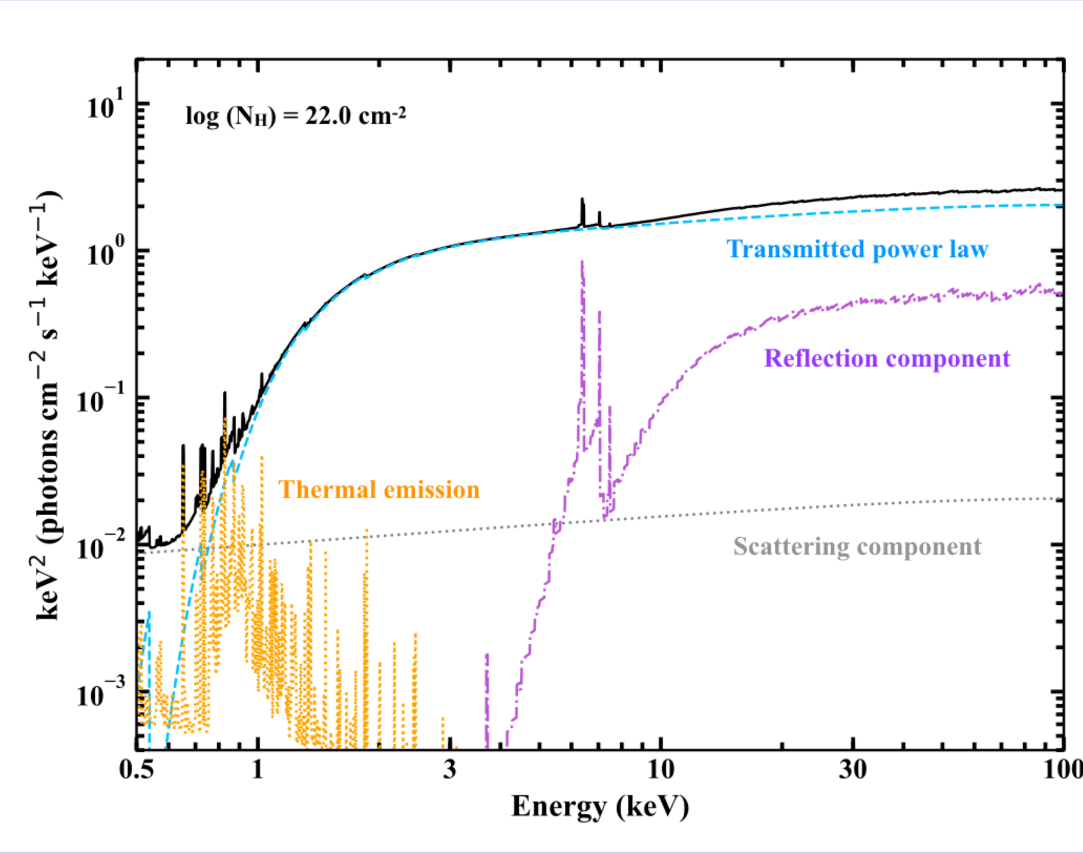

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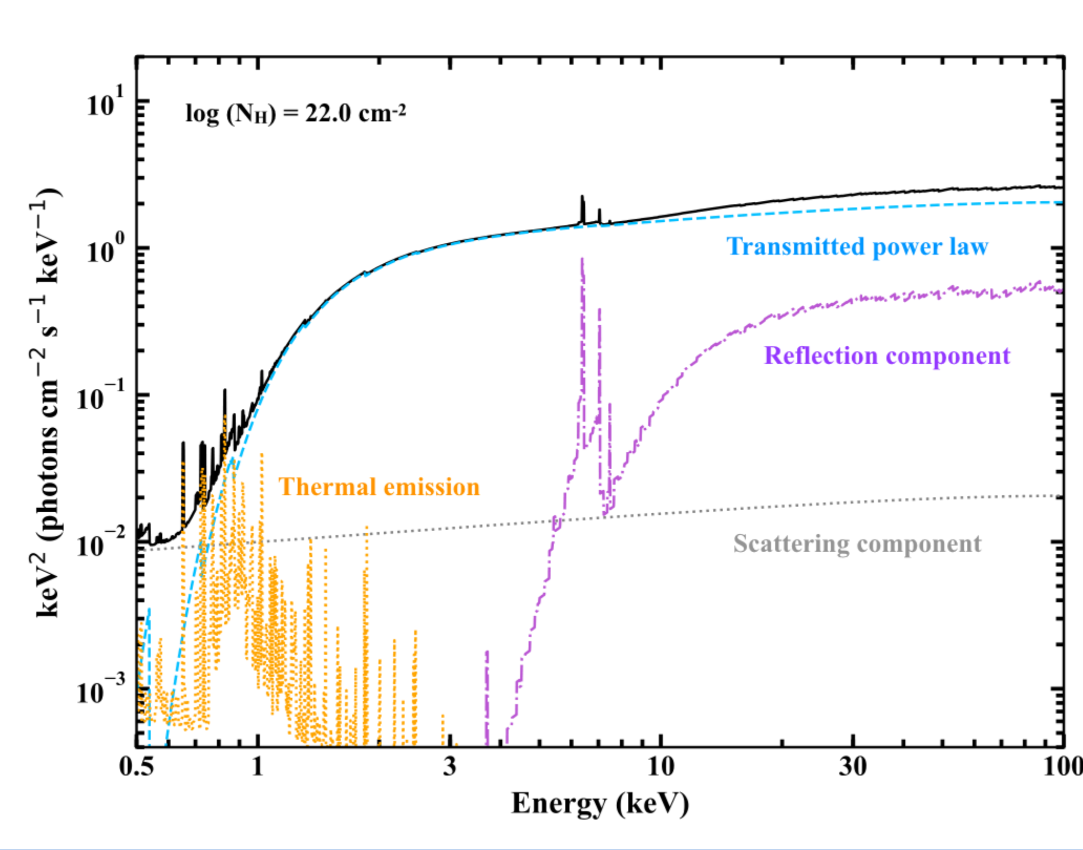
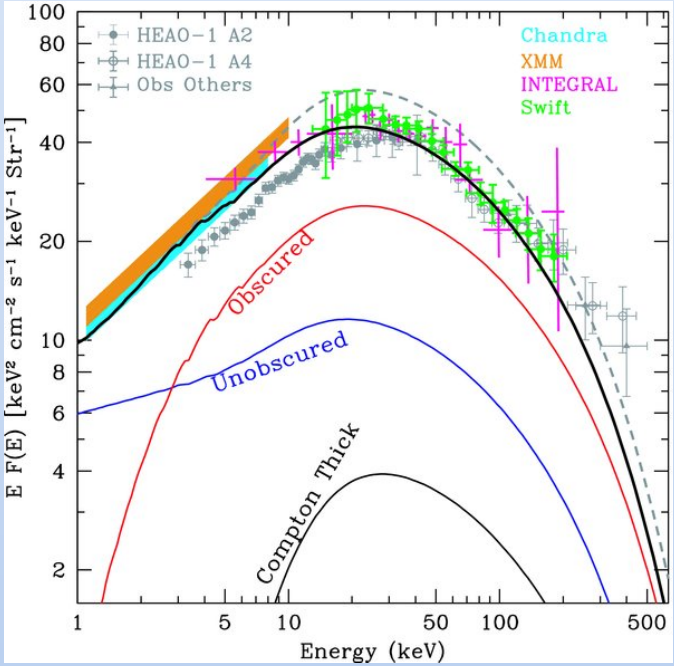
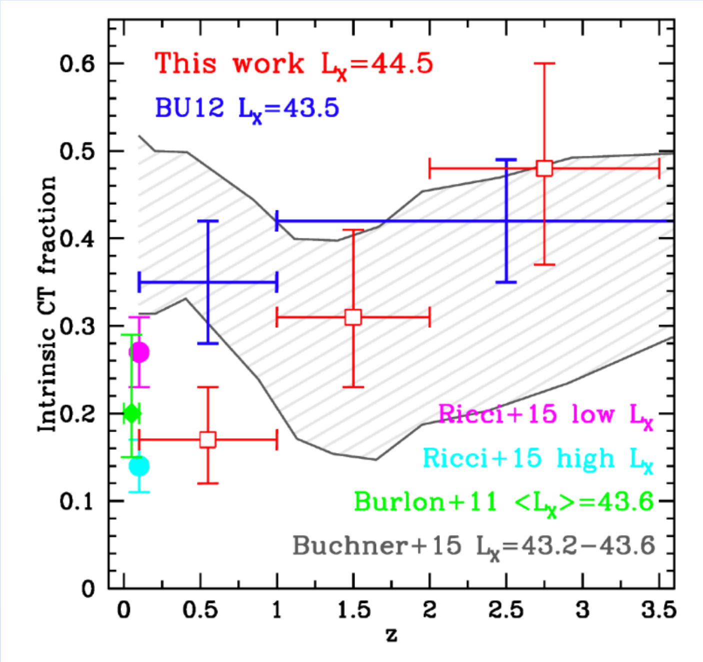


Courtesy of X. Zhao

The difficult hunt for heavily obscured AGN

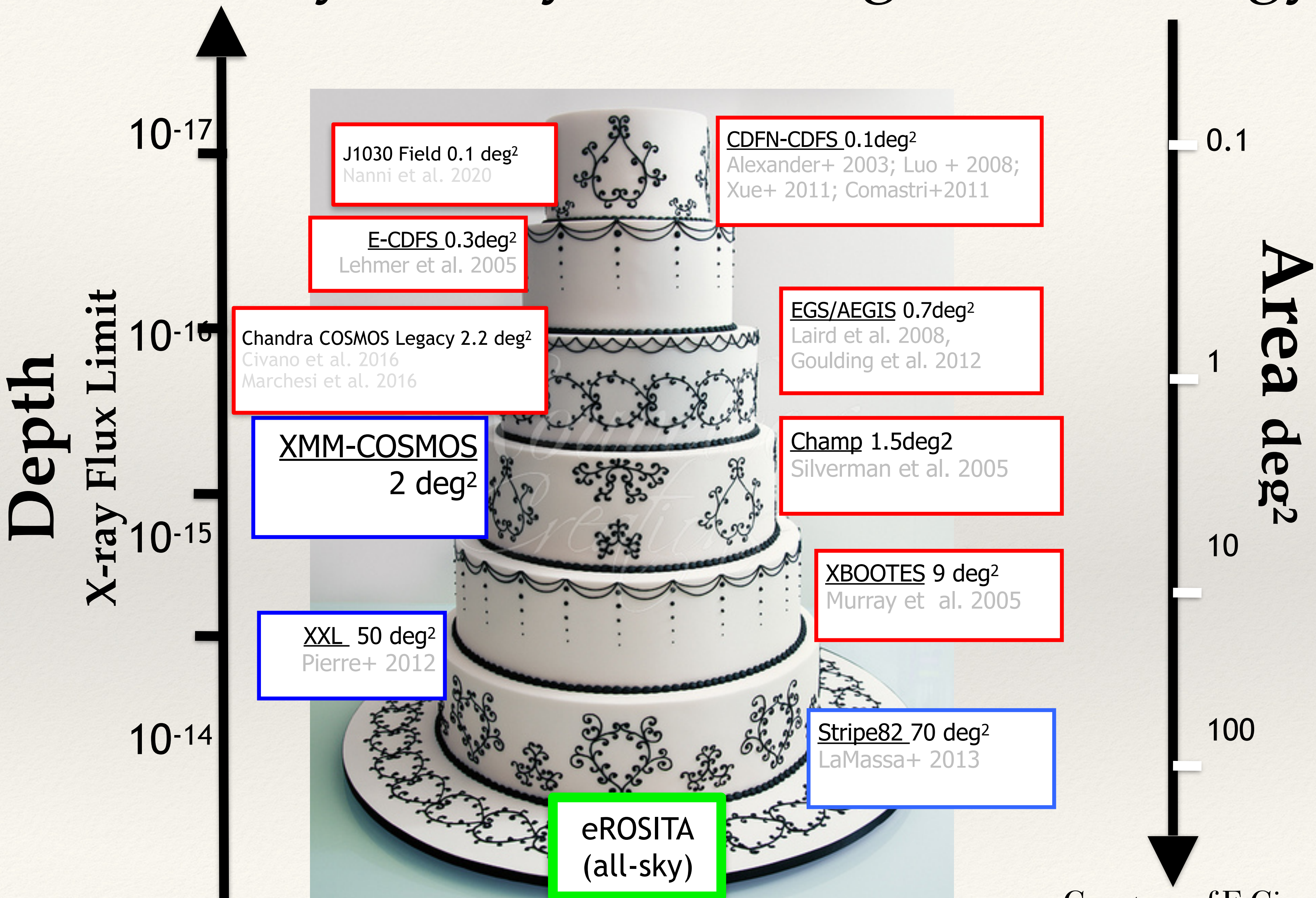
- Heavily obscured, and particularly Compton thick AGN (τ>1; NH>10^{24} cm^{-2}) should be numerous (~20-50% of whole AGN X-ray population at CXB peak) based on CXB models: surveys are the most efficient way to detect the largest number of them.
- Evidence of increasing fraction of obscured AGN at higher redshifts: evidence of a denser environment?





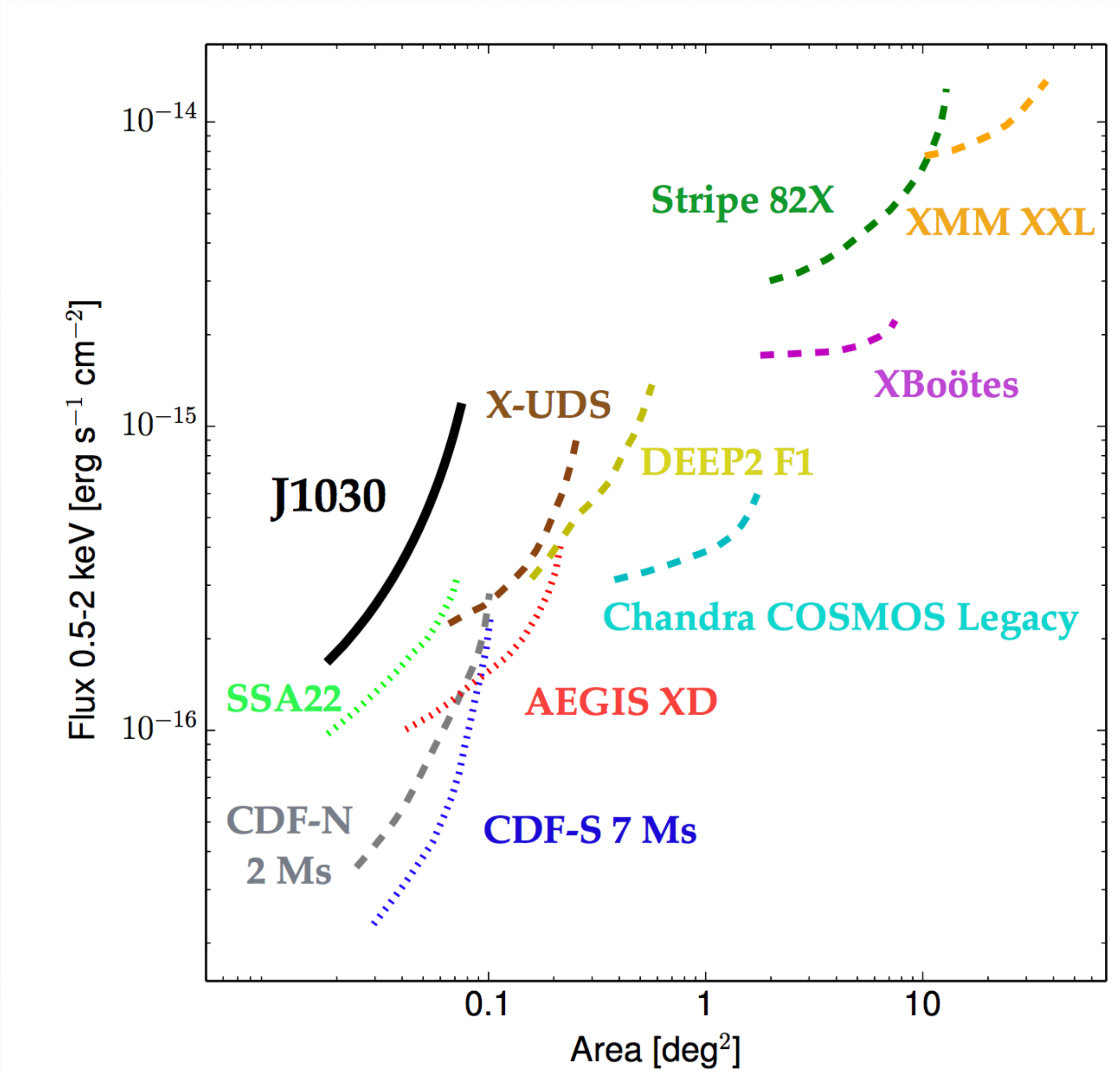
See Gilli+07, Ajello+08, Treister+09, Burlon+11, Brightman & Nandra 11, Vasudevan+13, Vignali+13, Balokovic+14, Lanzuisi+15, Ricci+16, Lanzuisi+18, Tasnim Ananna+19

The X-ray surveys wedding-cake strategy



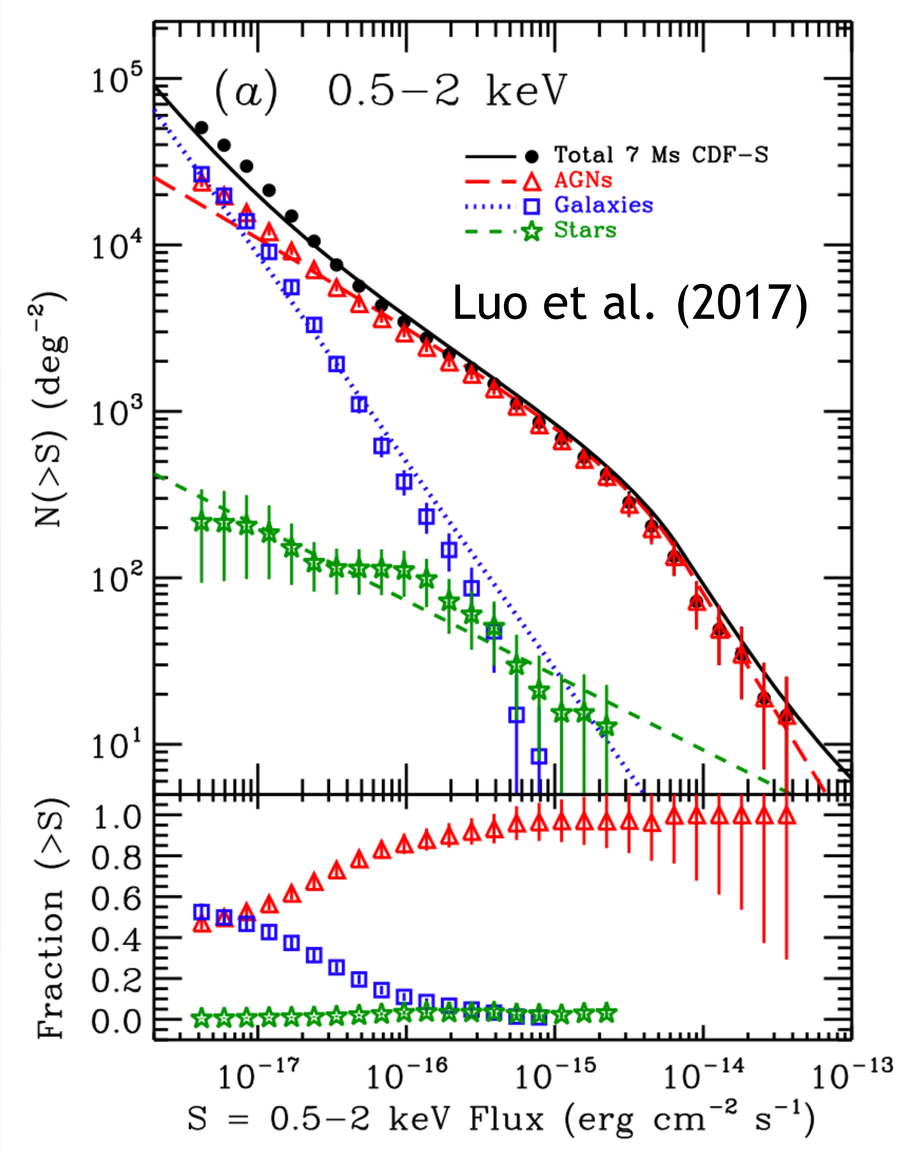
Courtesy of F.Civano

The landscape of current X-ray surveys



Nanni et al. 2020

Different surveys for different science



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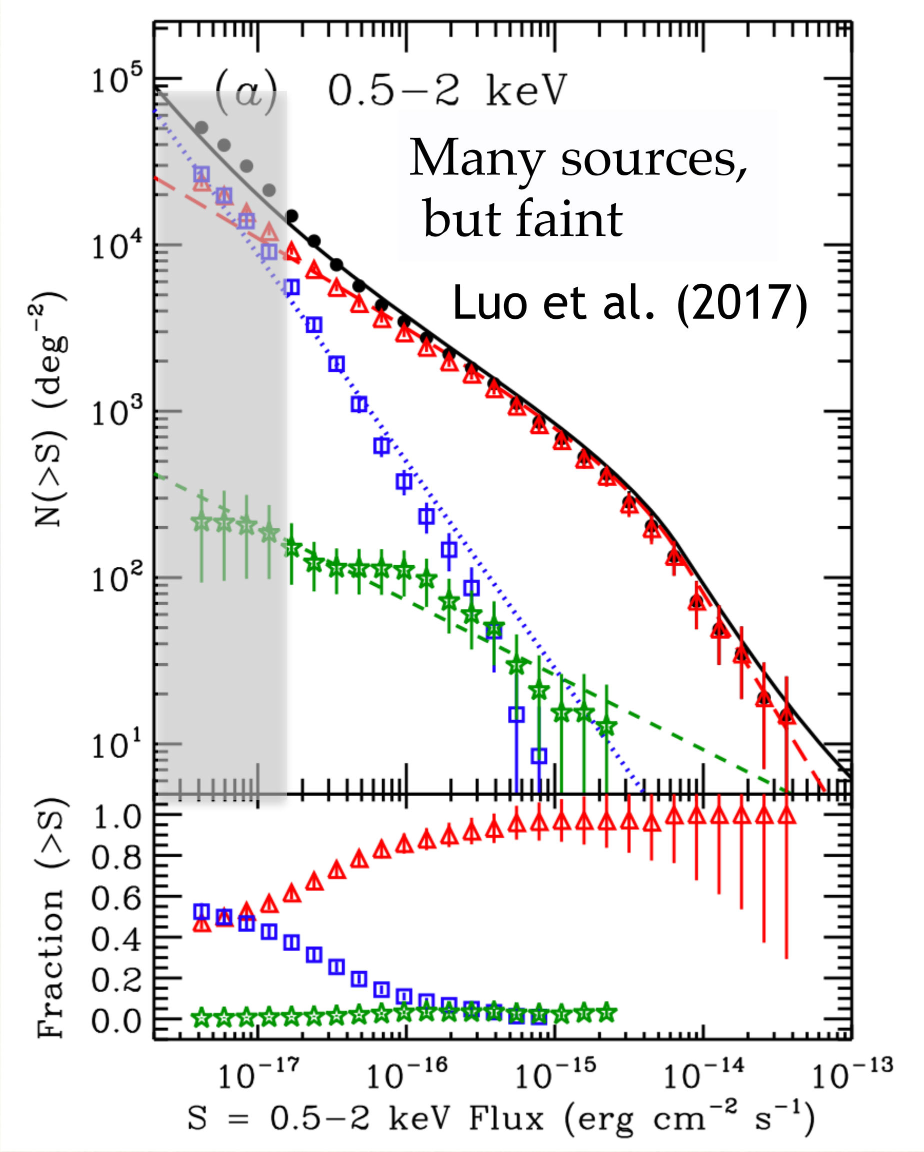

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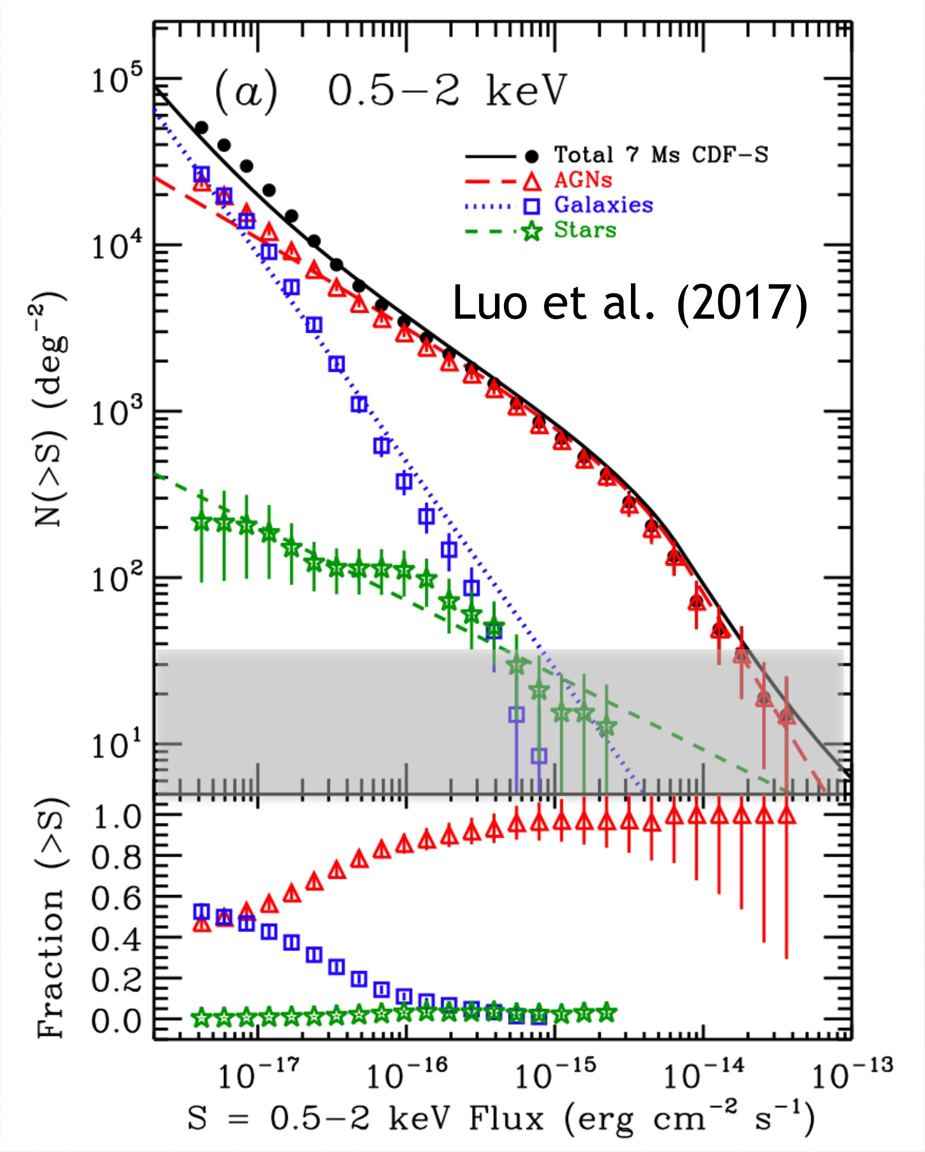
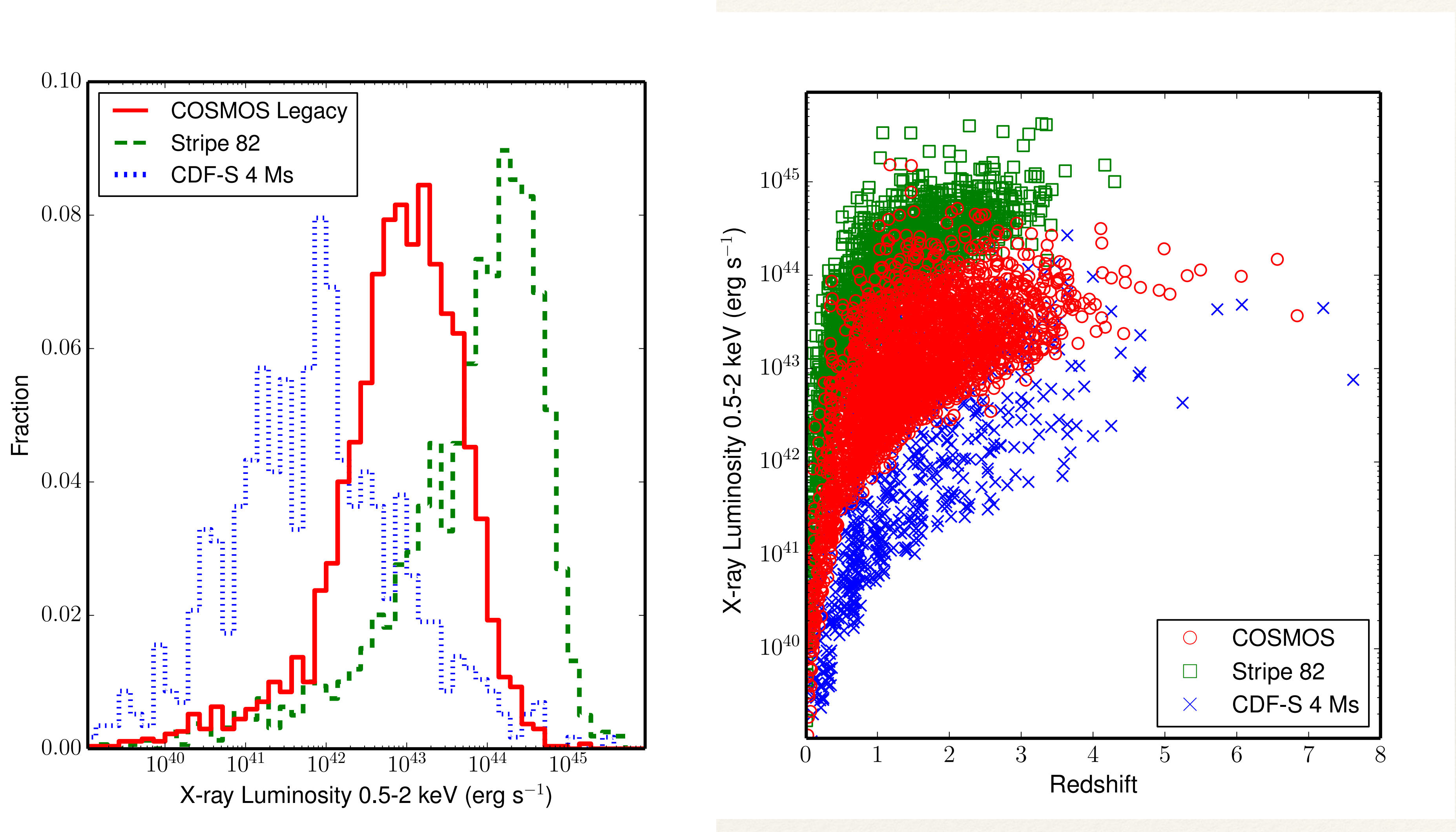


Extremely bright, but rare

Different surveys for different science

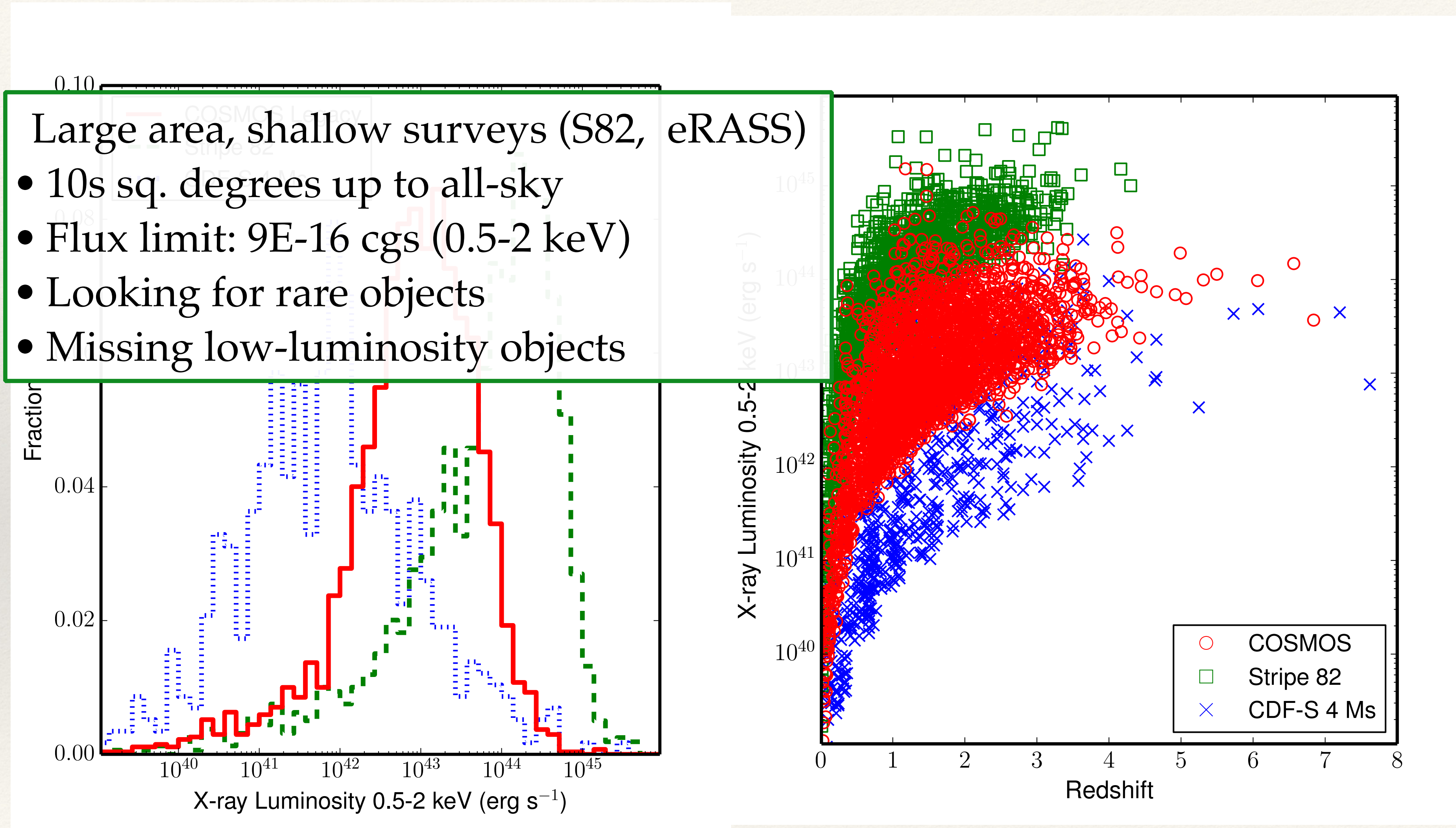


Marchesi et al. 2016

Different surveys for different science

Large area, shallow surveys (S82, eRASS)

- 10s sq. degrees up to all-sky
- Flux limit: 9E-16 cgs (0.5-2 keV)
- Looking for rare objects
- Missing low-luminosity objects



Marchesi et al. 2016

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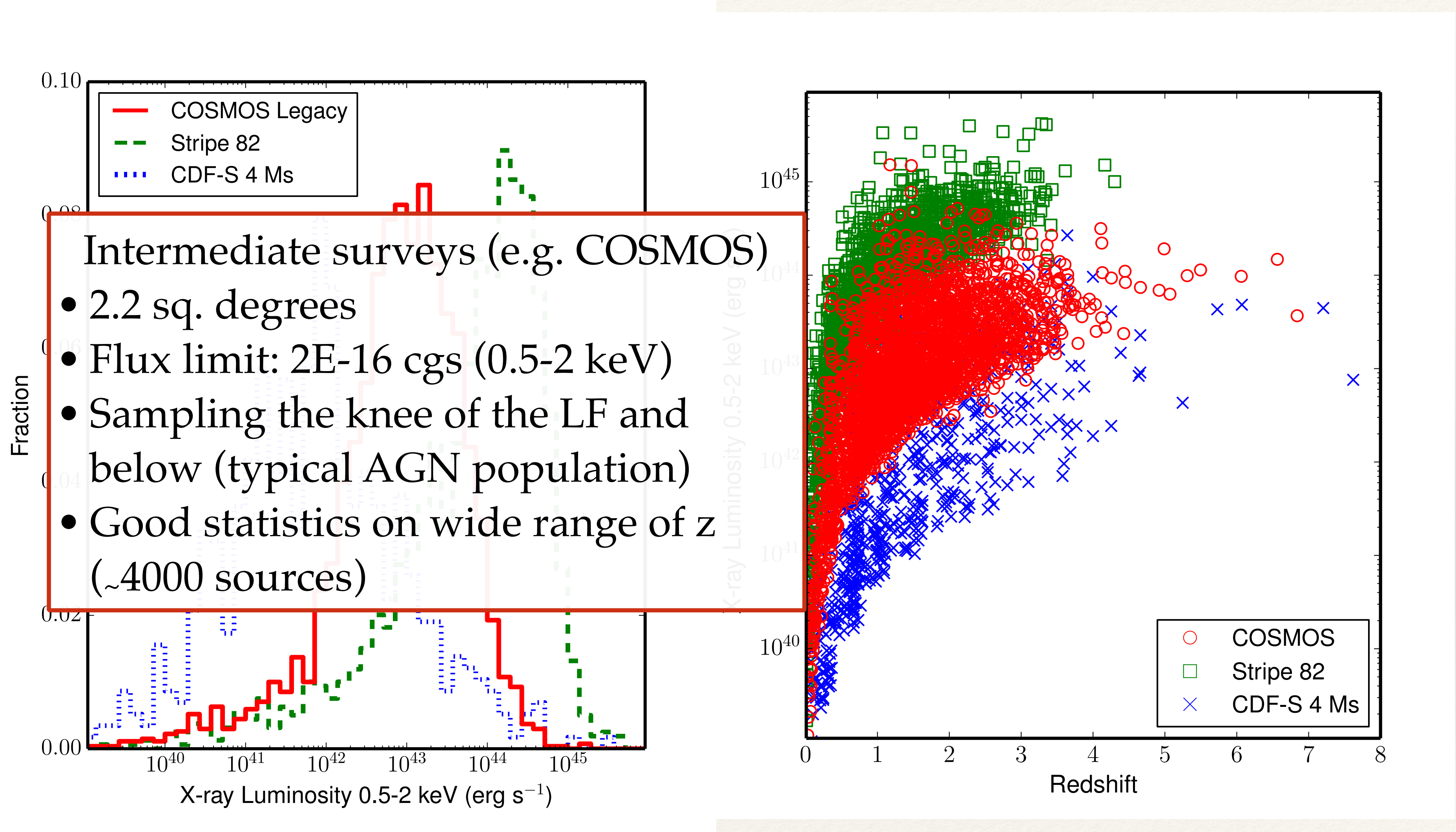
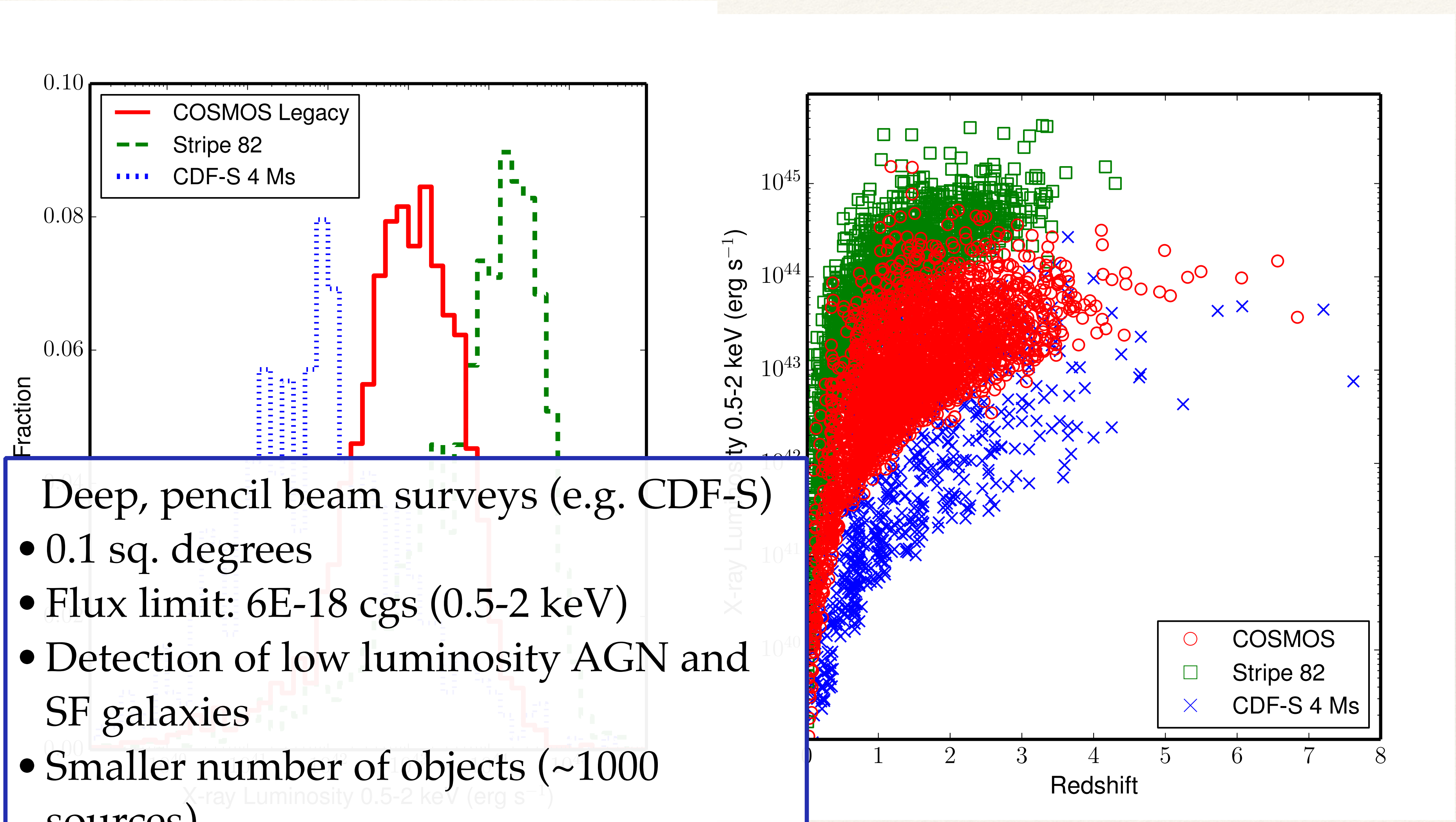


Intermediate surveys (e.g. COSMOS)

- 2.2 sq. degrees
- Flux limit: 2E-16 cgs (0.5-2 keV)
- Sampling the knee of the LF and below (typical AGN population)
- Good statistics on wide range of z (~4000 sources)

Marchesi et al. 2016

Different surveys for different science



Deep, pencil beam surveys (e.g. CDF-S)

- 0.1 sq. degrees
- Flux limit: 6E-18 cgs (0.5-2 keV)
- Detection of low luminosity AGN and SF galaxies
- Smaller number of objects (~1000 sources)

Marchesi et al. 2016

Chandra Deep Field-South (CDF-S)

≈7Ms *Chandra* exposure (last obs. at March 2016)

≈3Ms XMM-*Newton* exposure

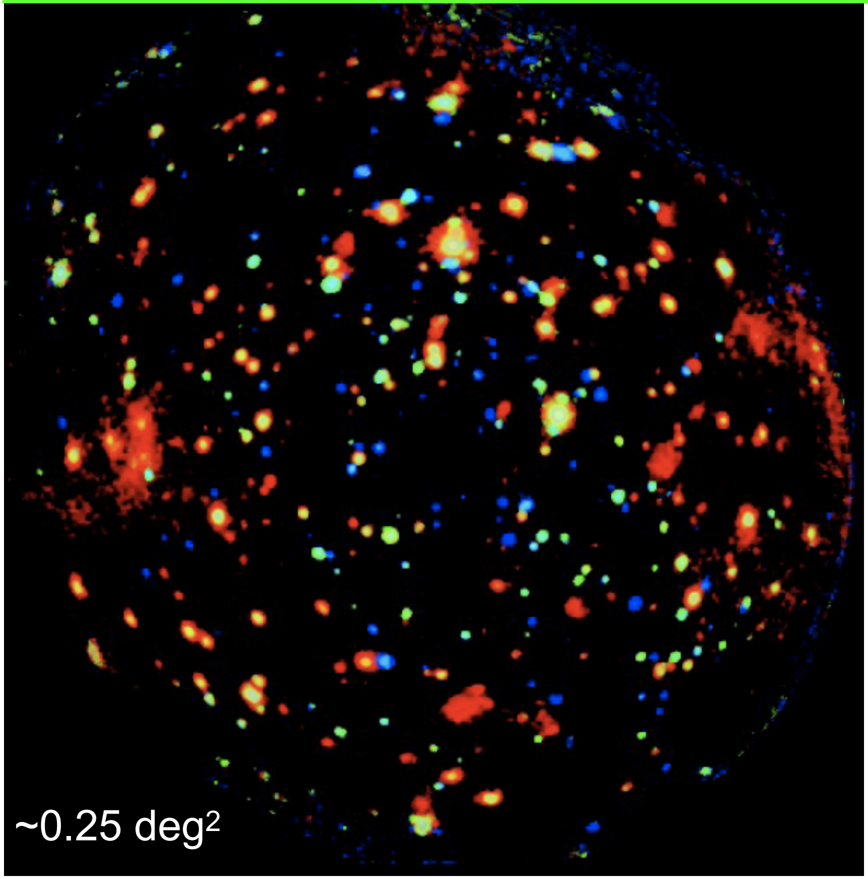
Deep multi-wavelength coverage

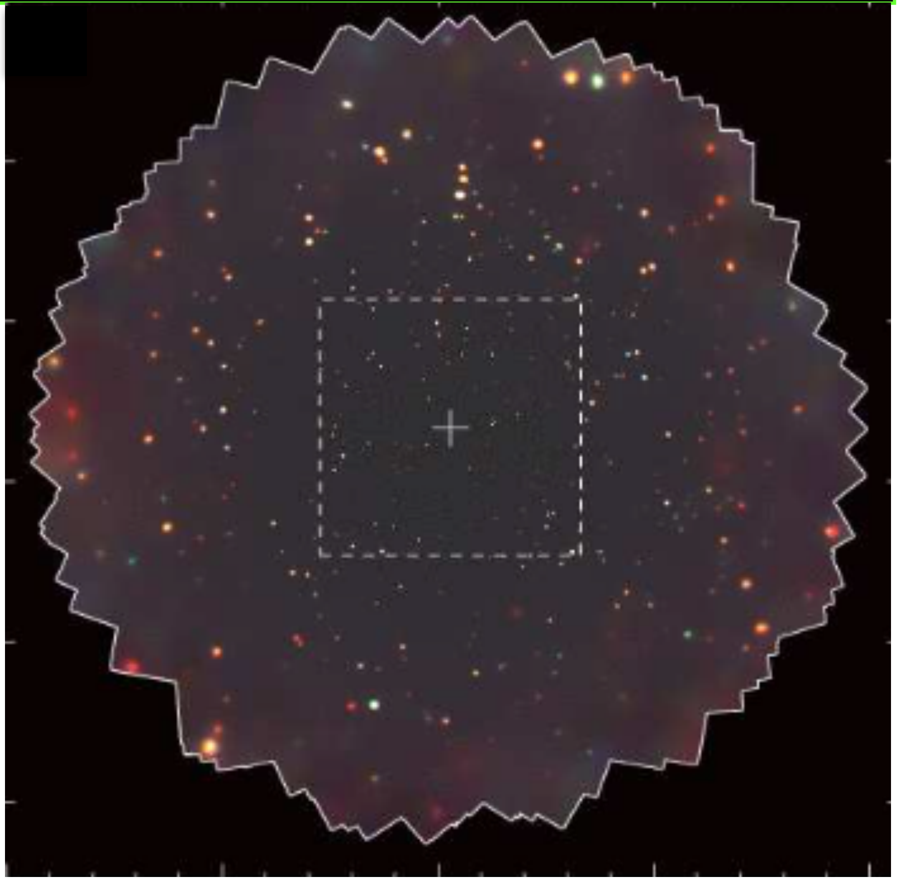
One of the legacy fields (no deeper field for the next 20 yrs)

Chandra: good on-axis PSF (i.e., excellent angular resolution) and low background
➔ Sensitive to faint and distant AGN

XMM-*Newton*: larger effective area (hence photon statistics), but much worse angular resolution and higher background
➔ Better for X-ray spectroscopy of relatively bright AGN

The deepest X-ray field: CDF-S





XMM-CDFS 3 Ms survey
(PI: A. Comastri; Ranalli+13)

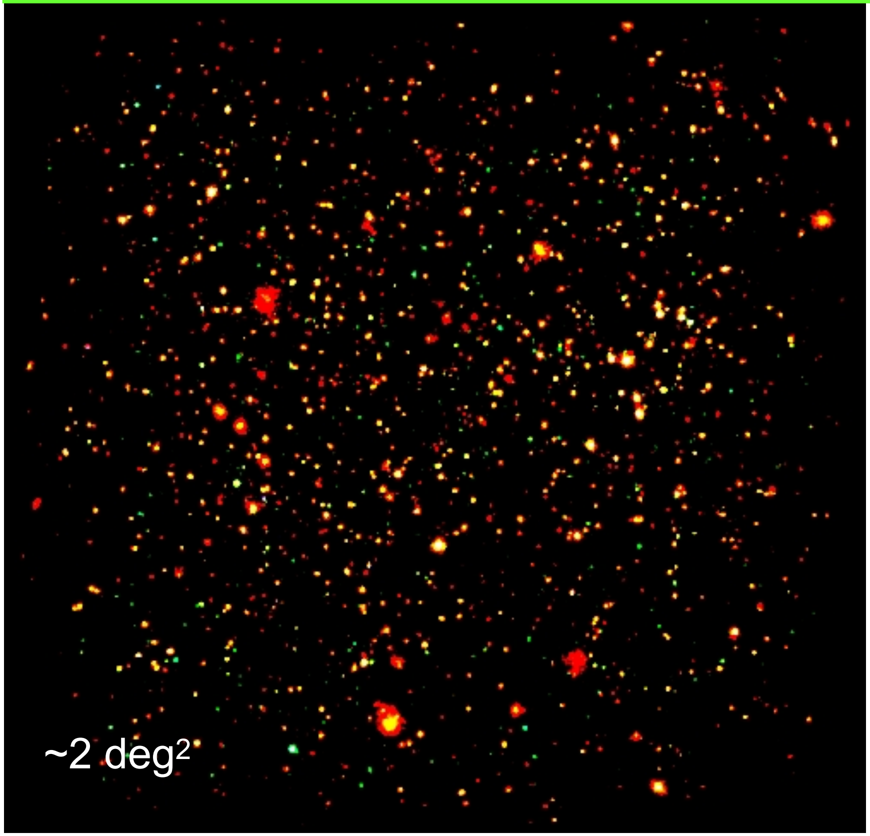
Chandra-CDFS 7 Ms survey
(PI: R. Giacconi, W.N Brandt; Xue+11, Luo+17)

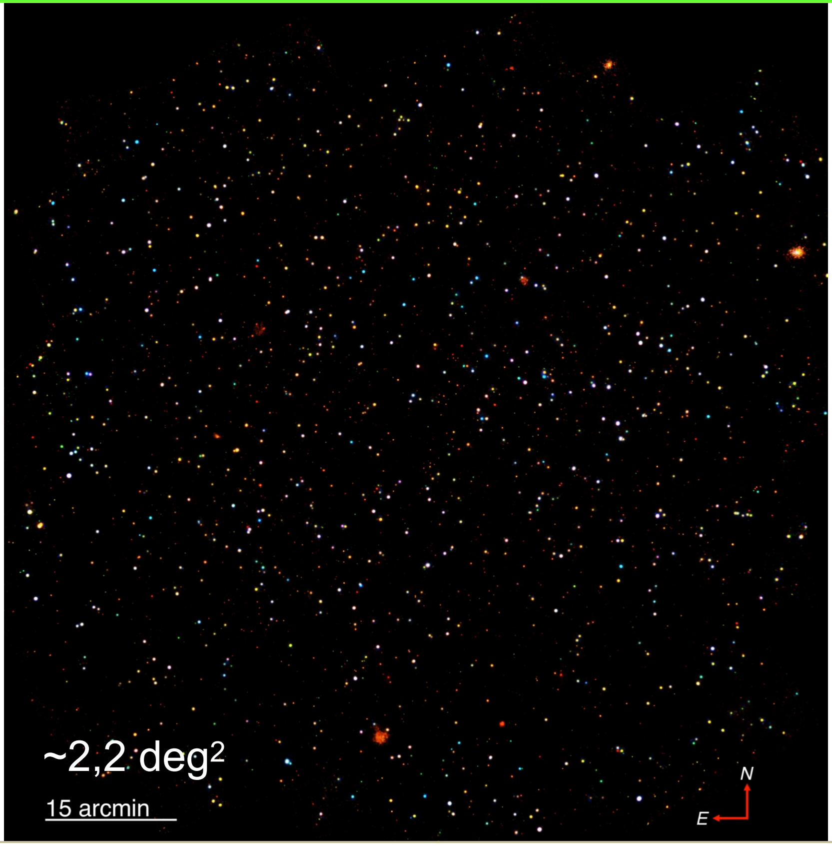
F(2-10keV)≈6.6×10^{-16} erg/cm^2/s

F(0.5-2keV)≈6.4^{-18} erg/cm^2/s

Capable of probing the high-z Universe with some photon statistics

Relatively large-area X-ray field: COSMOS





XMM-COSMOS 1.5 Ms survey
(PI: G. Hasinger; Cappelluti+09)

F(2-10keV)≈9.3×10^{-15} erg/cm^2/s

Chandra-COSMOS 4.6 Ms survey
(PI: M. Elvis, F. Civano; Elvis+09, Civano+16)

F(0.5-2keV)≈1.9×10^{-16} erg/cm^2/s

Sampling the typical AGN population

Exploring the whole sky: eROSITA

- eROSITA: launched in 2020, excellent combination of effective area (i.e., number of photons collected in a given amount of time) and field of view (portion of sky covered in a single pointing) -> All-sky survey
- Main goal: survey of galaxy clusters (up to 100,000) to study cosmological parameters up to z~1.
- However, up to 1 million AGNs will be detected in the process.

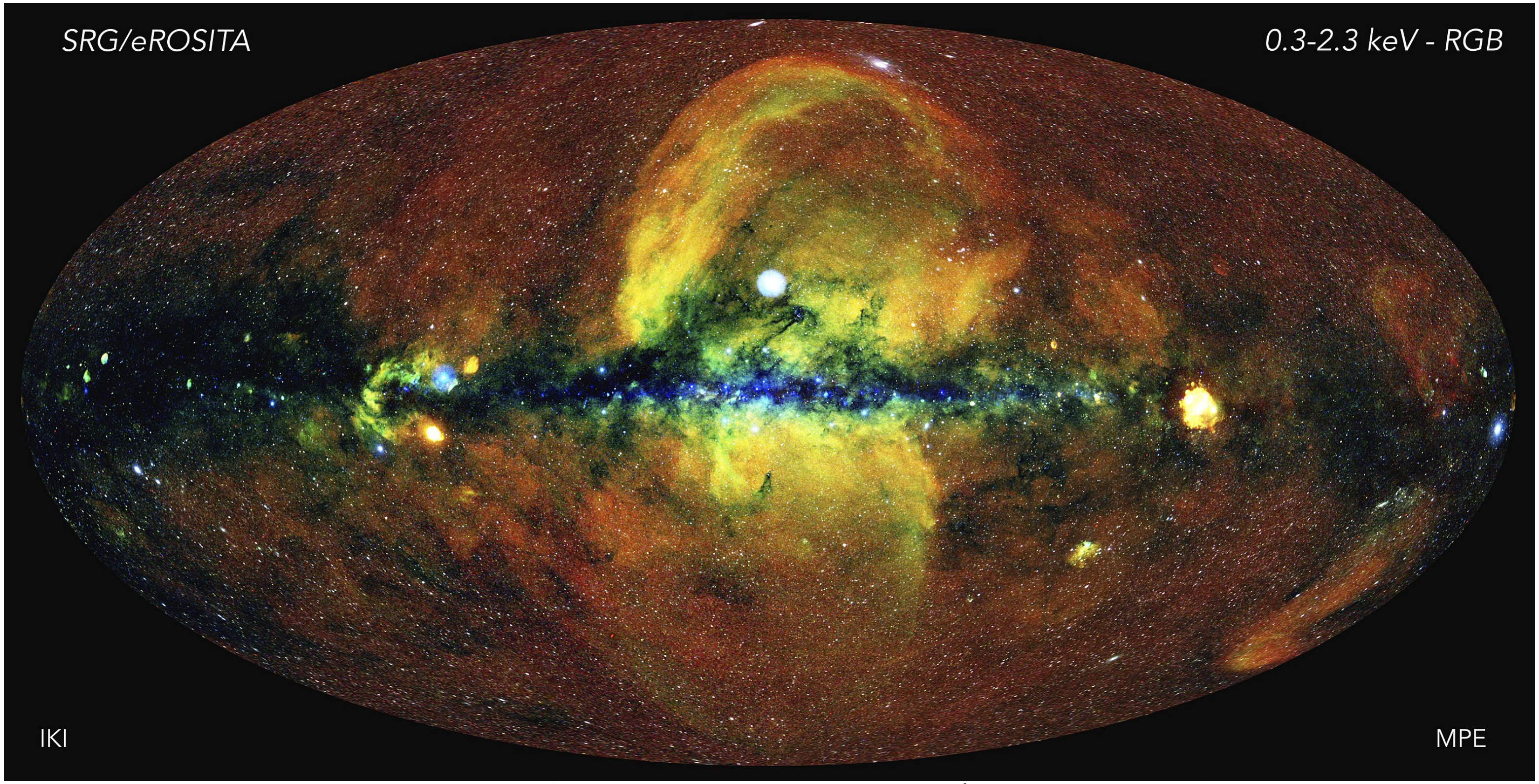
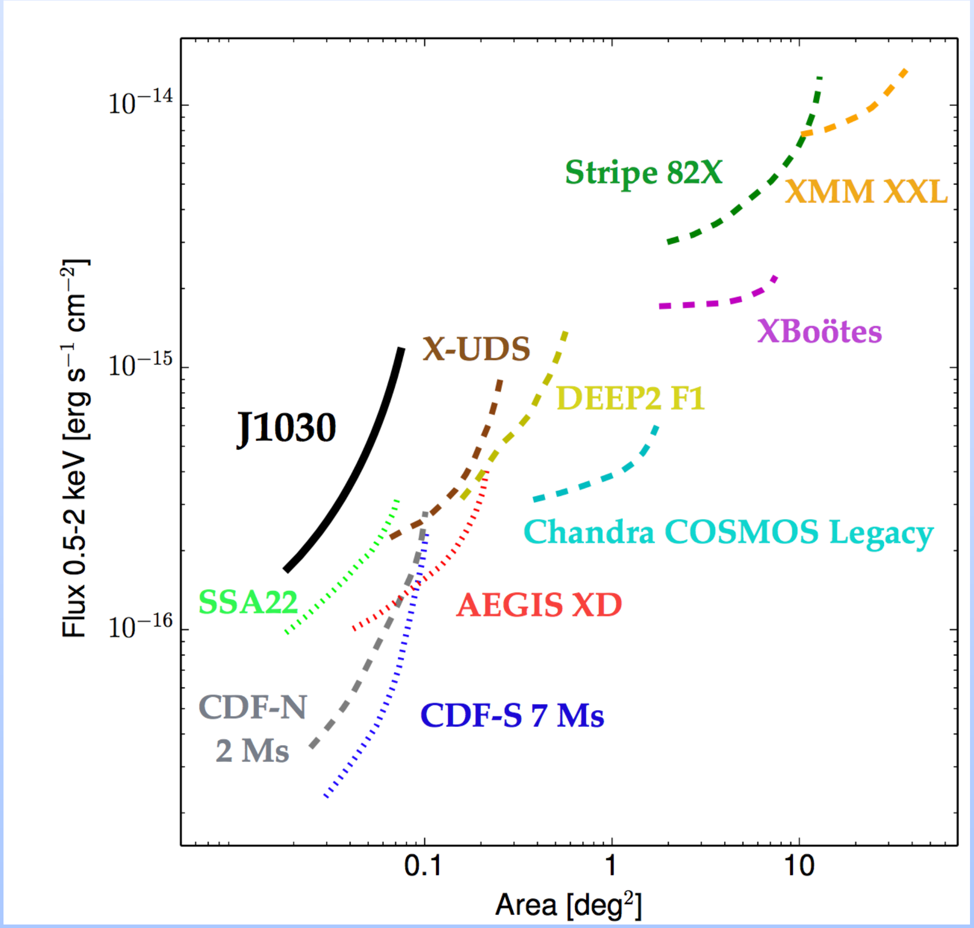


Image: J. Buchner

Capable of probing rare (e.g., luminous and/or peculiar) objects

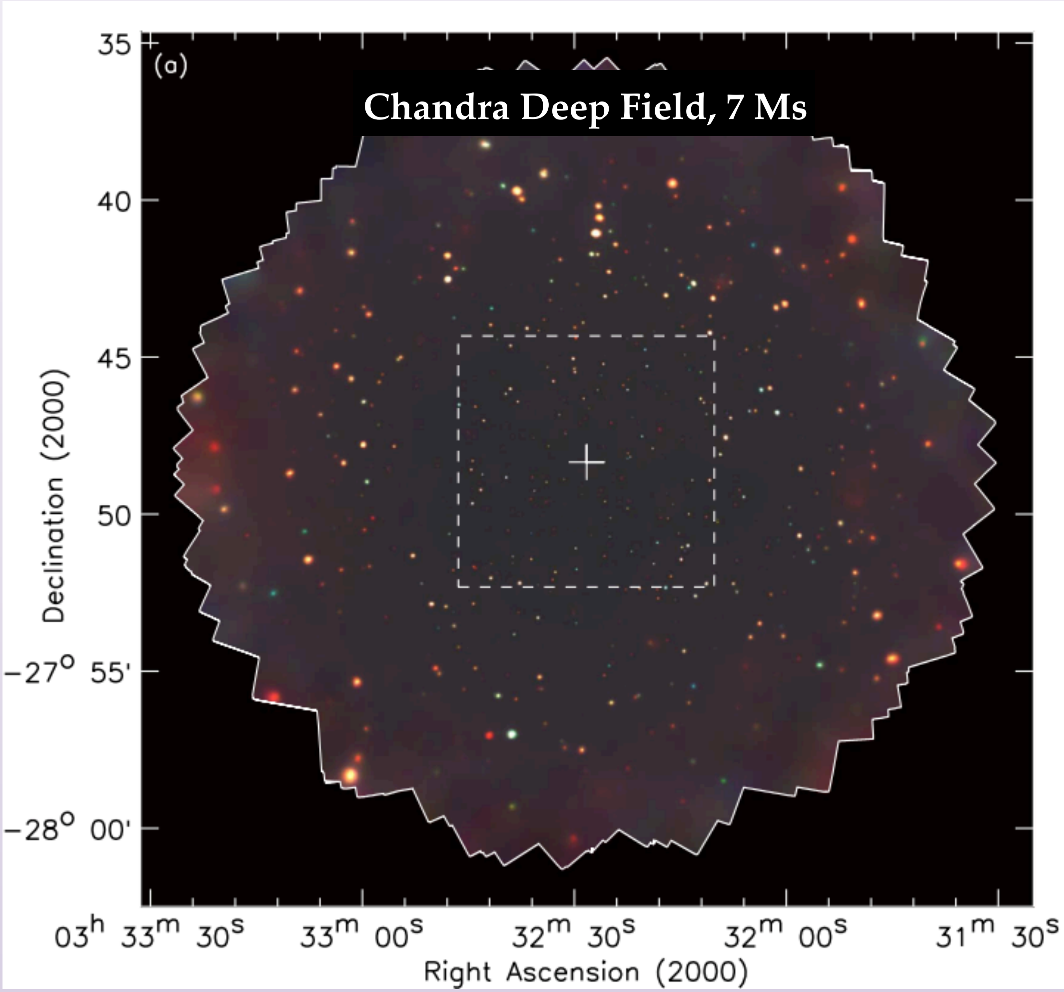
Summary: current landscape

- X-ray surveys are best instrument to study the whole AGN population in a statistically meaningful way
- Wedding cake approach: given a certain amount of time, we can spend it on a small portion of sky (finding intrinsically faint sources) or on tens of sq. degrees (finding rare objects).
- Each approach has pros and cons: this is why we need all type of surveys
- Instruments: Chandra (best angular resolution), XMM-Newton (large effective area).
- Chandra to reach faintest fluxes, XMM to collect more photons.
- But Chandra and XMM-Newton are 23 years old…



The need for new X-ray facilities

- Optical/NIR surveys are biased against obscured AGN at high-z.
- A complete census of accreting supermassive black holes (including obscured and/or intrinsically faint) requires X-ray facilities, and deep surveys.



Luo et al. (2017)

The need for new X-ray facilities

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- However, the two most powerful X-ray telescopes currently available (*Chandra* and XMM-*Newton*) are both 21 years old.
- In particular *Chandra* (only sub-arcsecond X-ray instrument) has seen a significant worsening in effective area below 1 keV, which strongly limits its efficiency as a survey instrument.

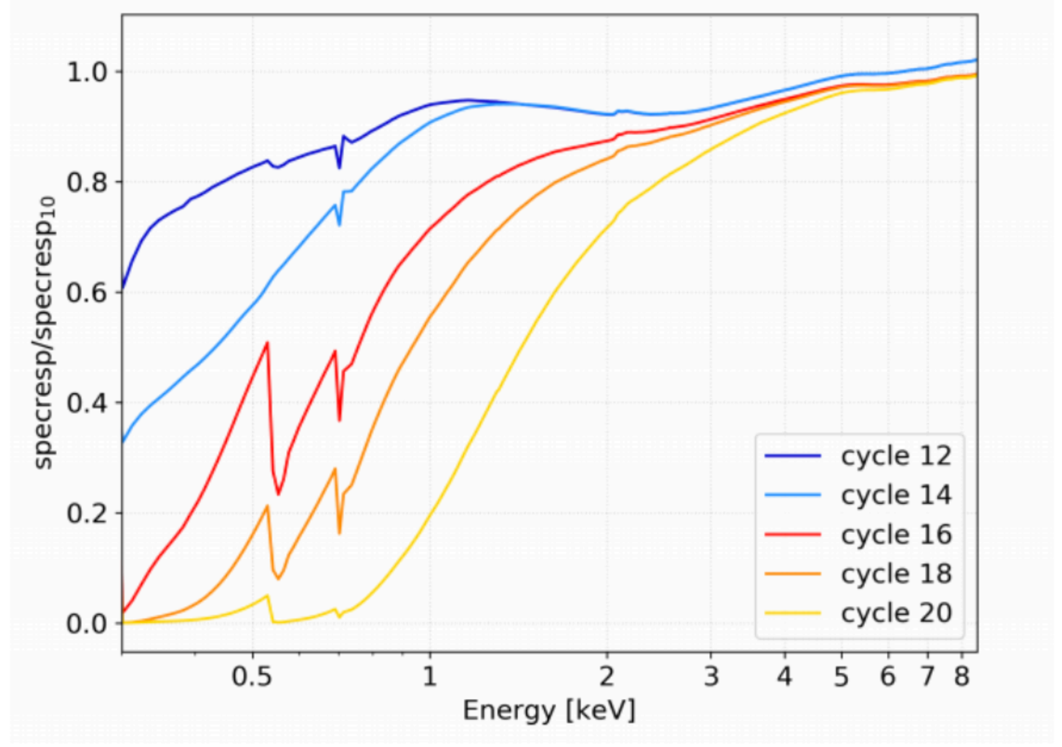

Figure 15. ACIS-I effective area degradation through years. We show the ARF ratios between cycles 12 (blue), 14 (light blue), 16 (red), 18 (orange), 20 (yellow) and the cycle 10.

Peca et al. (2021)

The need for new X-ray facilities

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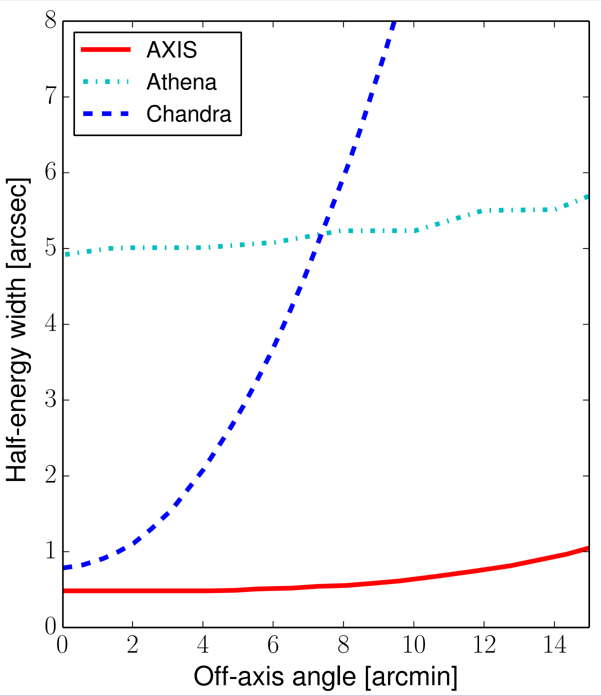
- An "XMM-*Newton* 2.0" is being developed (*Athena*), but no X-ray instrument with *Chandra*-like spatial resolution has been cleared for development.

AXIS and *Athena*: a possible bright X-ray future

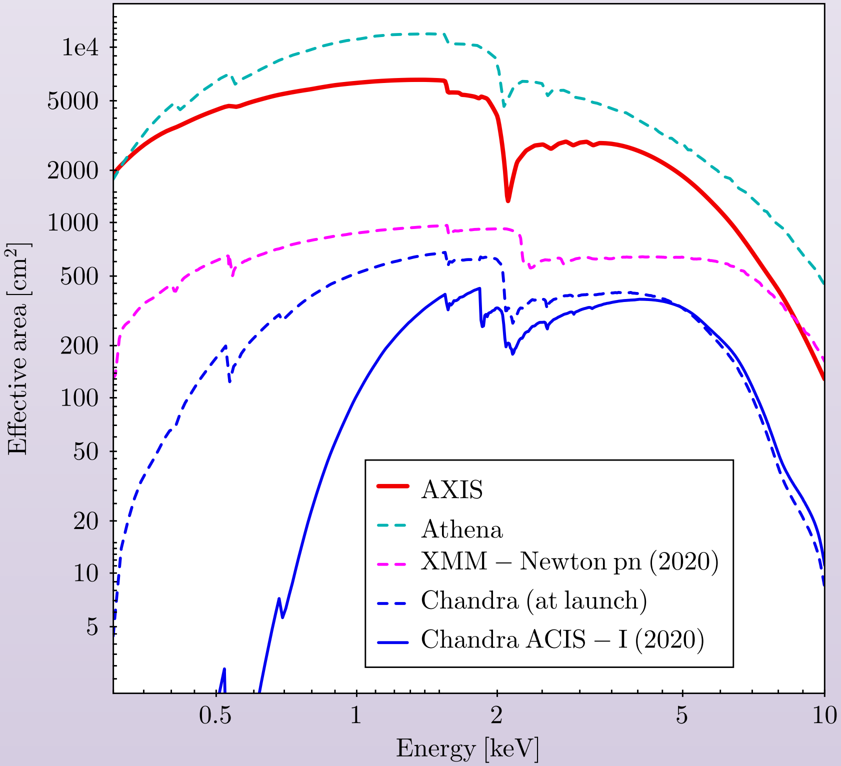
AXIS

- Probe mission (cost <1 B$)
- Feasibility study funded by NASA.
- White paper (https://ui.adsabs.harvard.edu/abs/2019BAAS...51g.107M/abstract) submitted to NASA 2020 Decadal Survey.
- Subarcsecond resolution over wide (24′x24′) field of view.
- Large effective area.

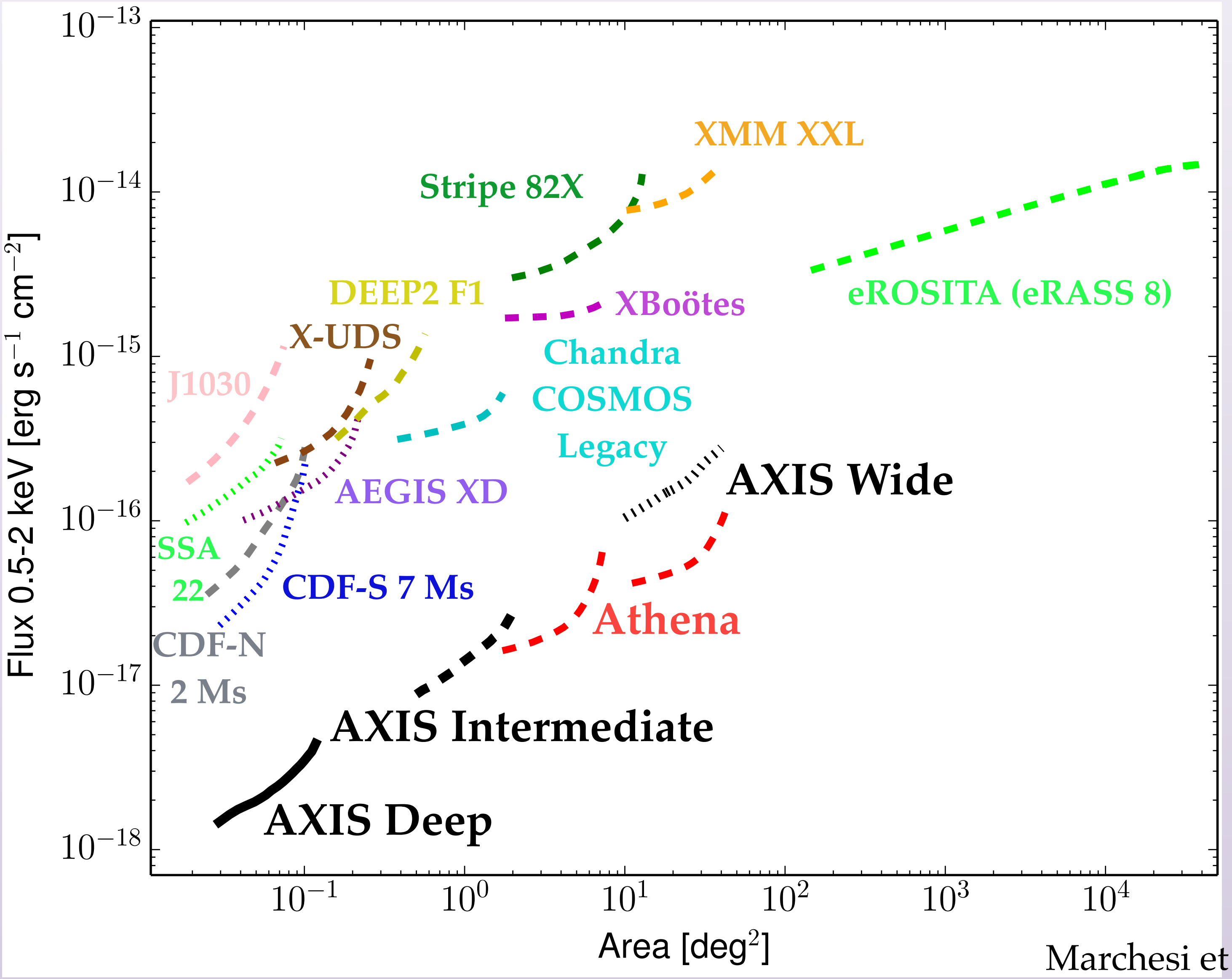


Athena

- *Athena*: next ESA X-ray observatory.
- Expected launch: early 2030s.
- Survey instrument: Wide Field Imager
- Excellent effective area and field of view (40′ radius): ideal for surveys.
- Good PSF (5-10″), stable even at large off-axis angles.



The landscape of current and future X-ray surveys



Marchesi et al. (2020)

AXIS and Athena X-ray surveys
A whole new X-ray AGN population

Survey	Area	Tile exposure	Total exposure	Flux limit (0.5–2 keV)	Number of detections	
	deg^2	ks	Ms	$erg\ s^{-1}\ cm^{-2}$	AGN	Galaxies
Deep	0.147	5000	5	5×10^{-19}	3496	5387
Intermediate	2.5	300	5	3×10^{-18}	32655	22071
Wide	50	15	5	4×10^{-17}	190149	21840

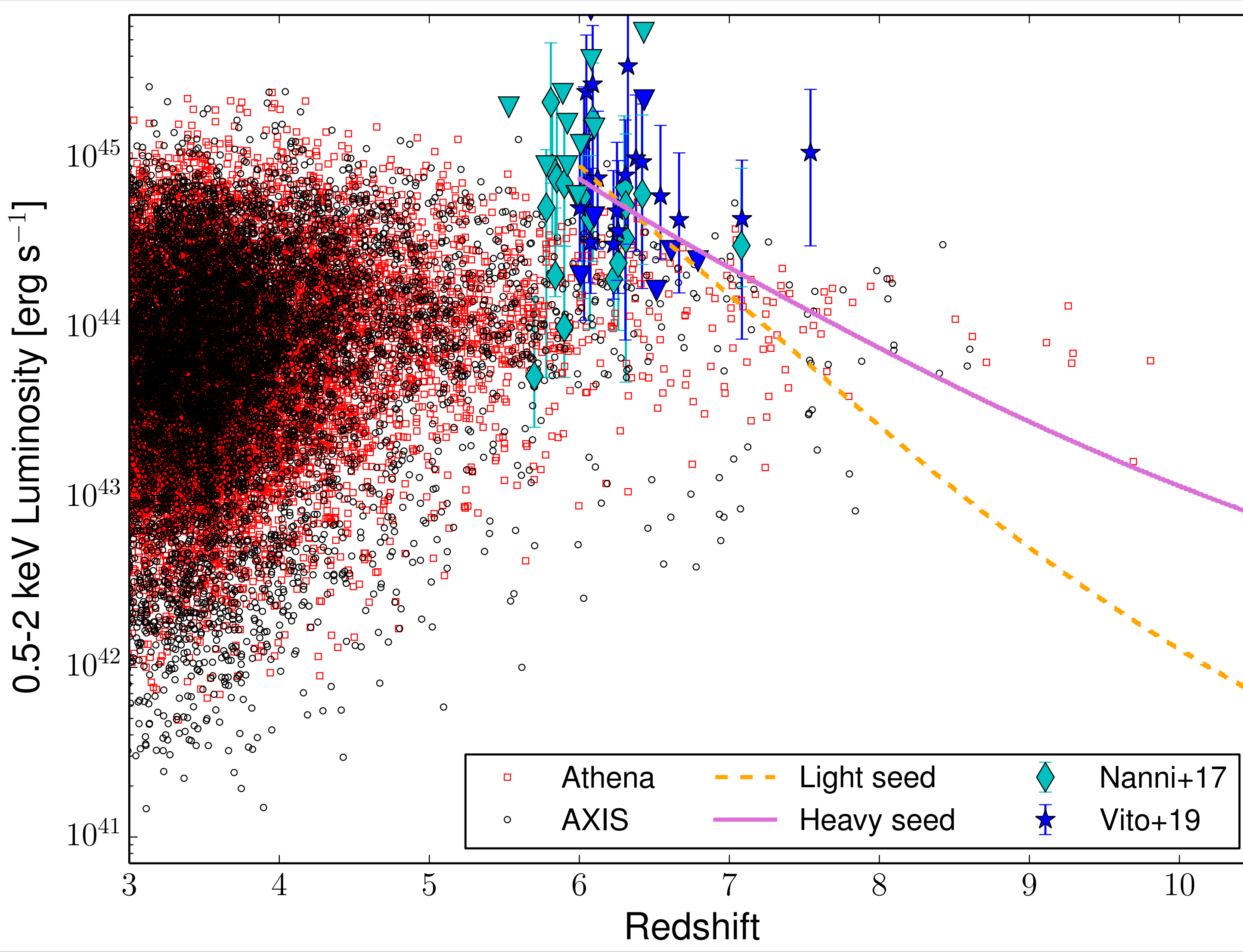
Survey Athena	Area deg^2	Tile exposure ks	Total exposure Ms	Flux limit (0.5-2 keV) $erg\ s^{-1}\ cm^{-2}$	Number of AGN
Deep	7.6	1000/1400	15.25	$1x10^{-17}$	48,000
Wide	63.2	90	9.3	$3x10^{-17}$	230,000

- Overall, AXIS and Athena will detect ~500,000 AGN (assuming no overlap).
- >90% of these objects will be detected for the first time in the X-rays.
- The AXIS Deep field will be the first X-ray survey where non-active galaxies dominate the overall population (60%).
- Counterpart identification and redshift measurement: a challenge for new optical/NIR missions (LSST; Roman Space Telescope; see Comparat+19; Hemmati+19).
- Complementarity with JWST: identification of heavily obscured AGN.

Marchesi et al. (2020)

Science with AXIS and *Athena*: the high-*z* Universe

- Up to 20,000 $z>3$ AGN (<500 in current X-ray surveys combined!)



Marchesi et al. (2020)

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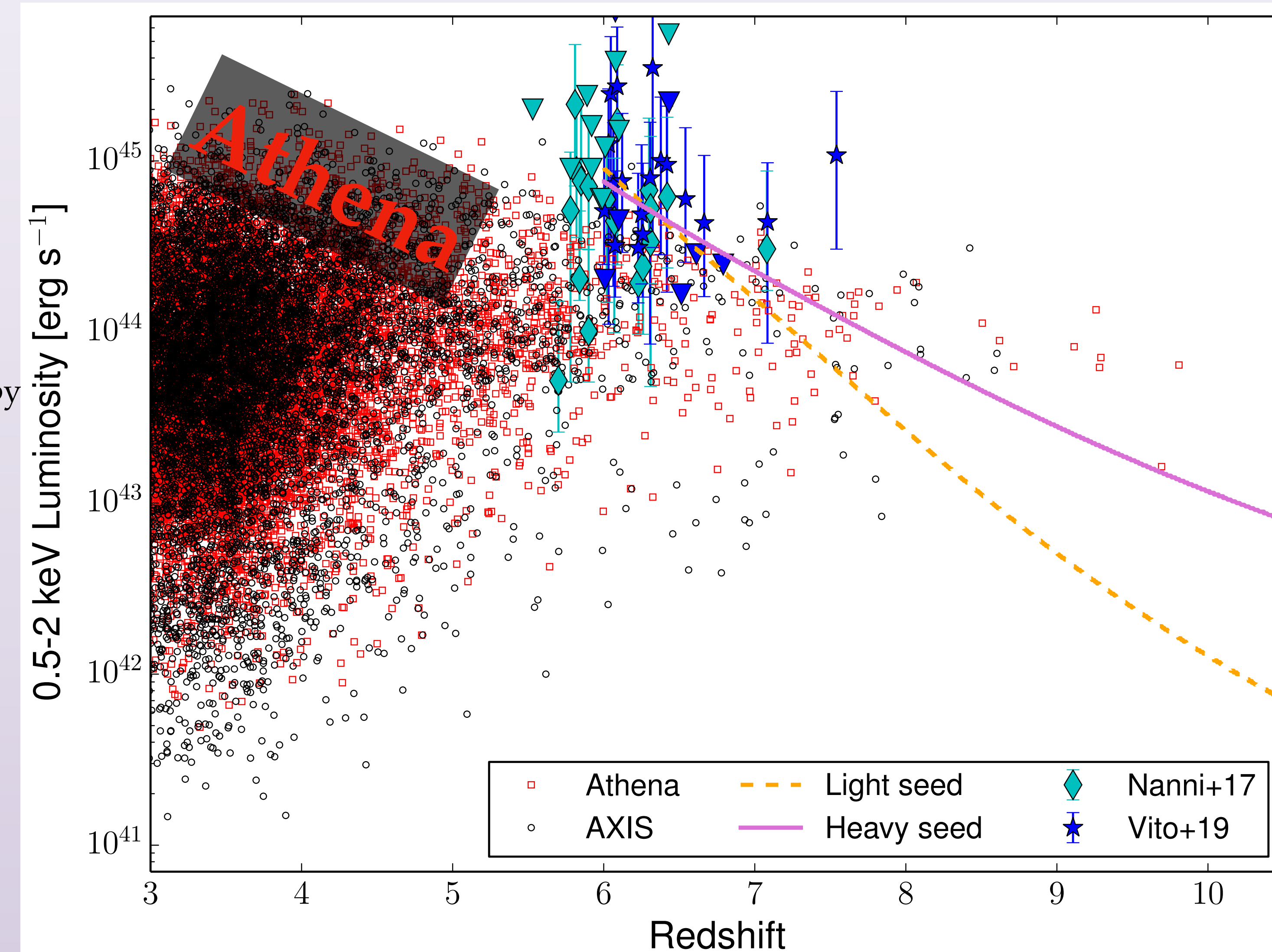
- Excellent complementarity: more sources (and generally more counts) detected by Athena



Marchesi et al. (2020)

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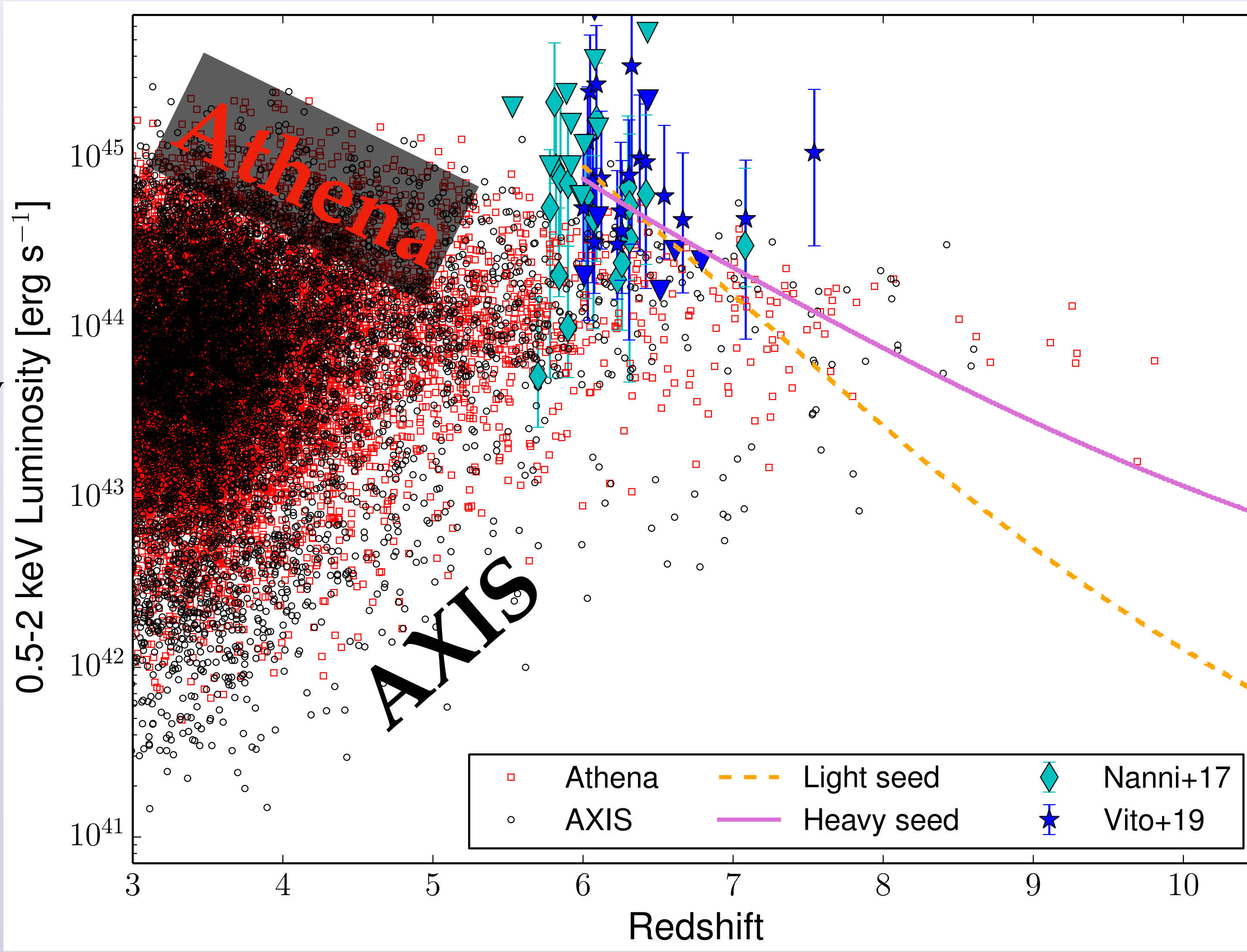
- Less luminous objects detected by AXIS.



Marchesi et al. (2020)

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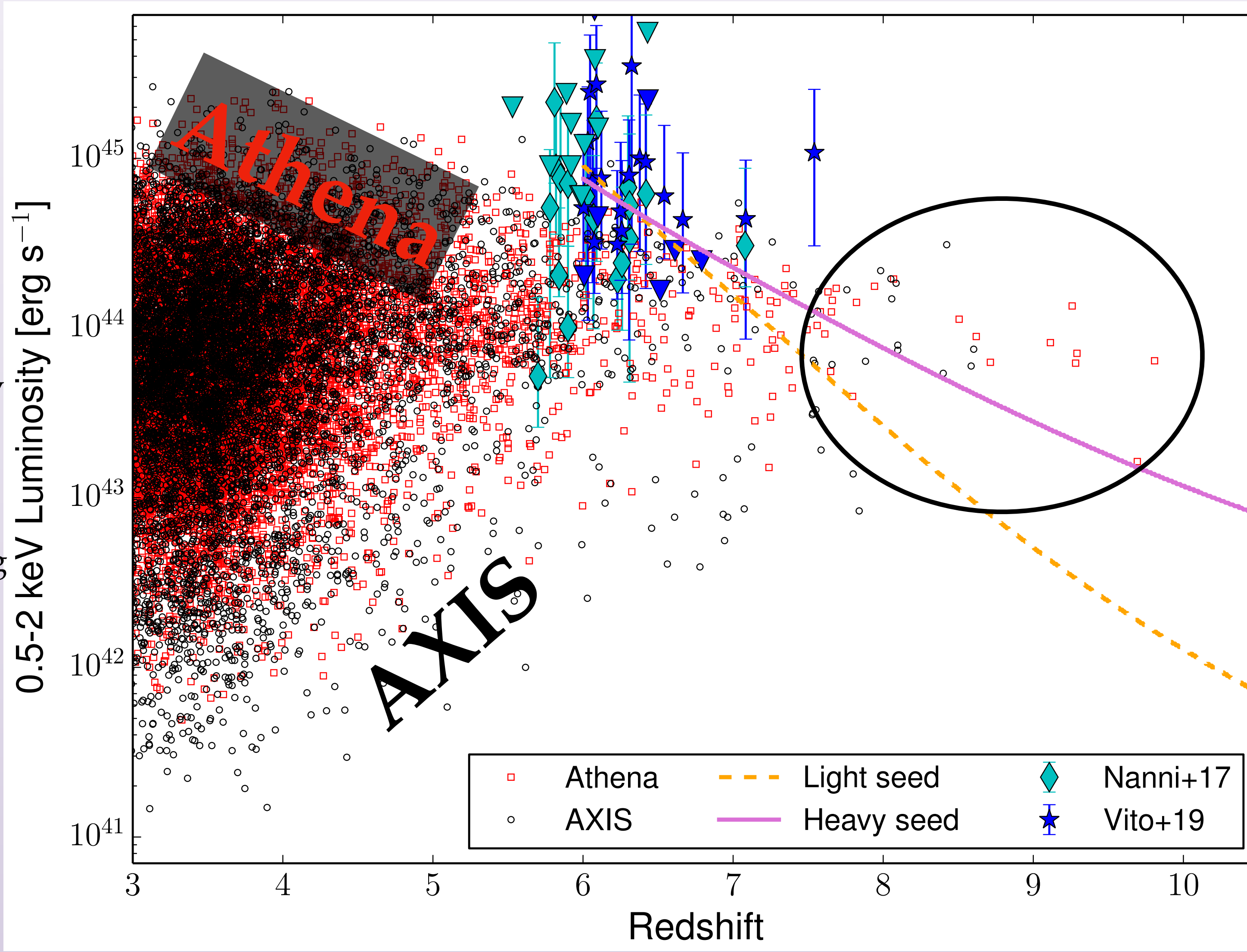
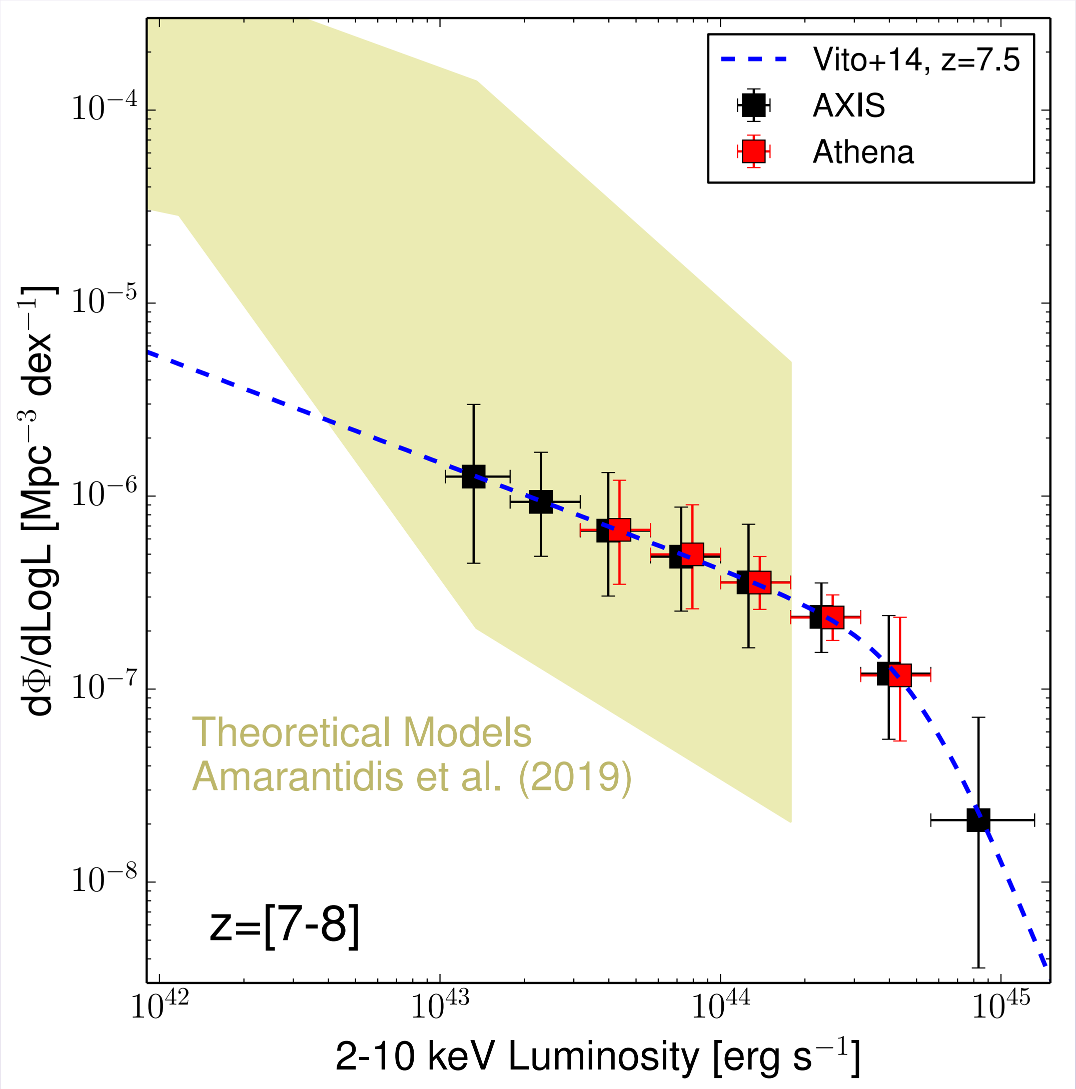
- Excellent complementarity: more sources (and generally more counts) detected by Athena
- Less luminous objects detected by AXIS.
- Tracking of first accreting BH seeds up to z~8-9: a whole new science.



Marchesi et al. (2020)

Science with AXIS and *Athena*: high-z XLF

- AXIS and *Athena* will also detect enough objects at z>7 (>80 sources) to constrain XLF with <50% uncertainties up to z~8 and $L_{05-2}=10^{43}$ erg/s.
- Unprecedented tuning of theoretical models, and exclusion of many combinations of parameters.

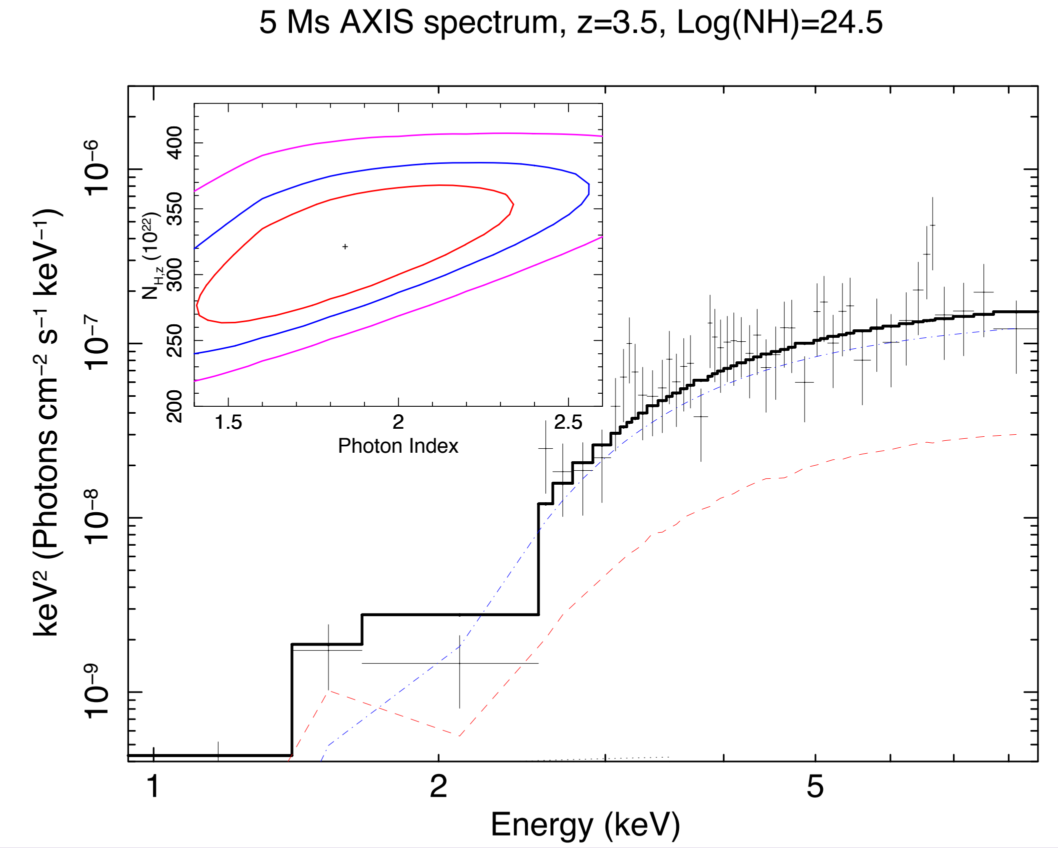


See Amarantidis et al. (2019); Ni et al. (2020)

Marchesi et al. (2020)

Science with AXIS and *Athena*: high-*z*, heavily obscured AGN

- Before the peak of AGN activity (i.e., at z>3), SMBHs are expected to accrete in a heavily obscured phase.
- Current facilities cannot detect significant number of high-z, heavily obscured AGN.
- AXIS and *Athena* will detect ~1000 Compton thick AGN (i.e., with column density >10^{24} cm^{-2}) at z>3
- 200 of these objects will be detected with >100 net counts —> Unprecedented high-quality spectral analysis at high redshift.



Marchesi et al. (2020)