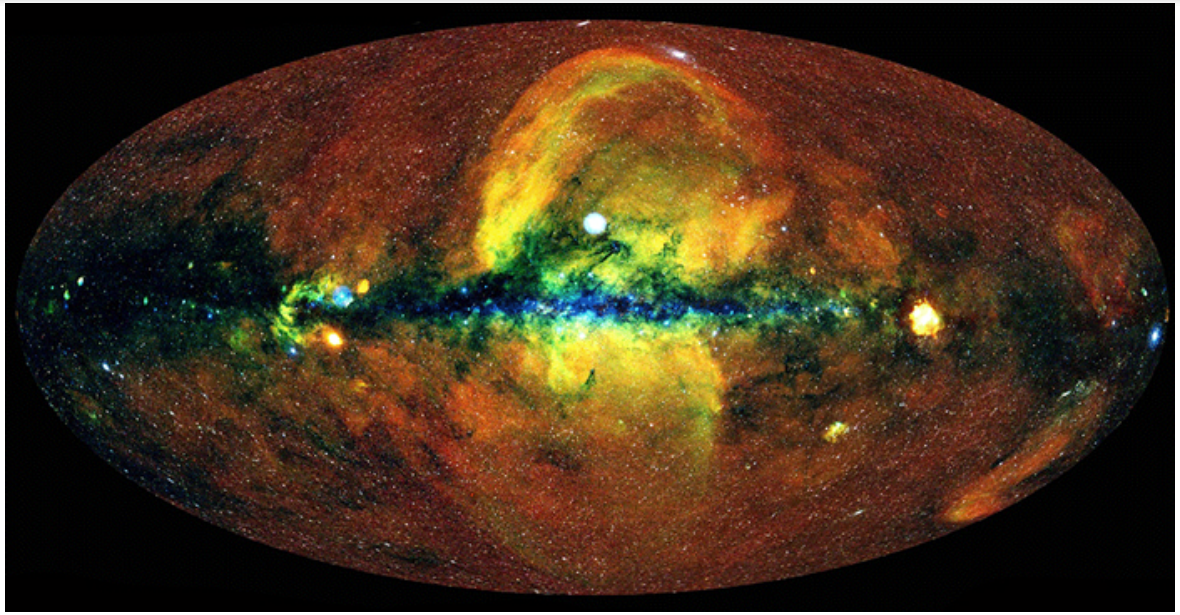
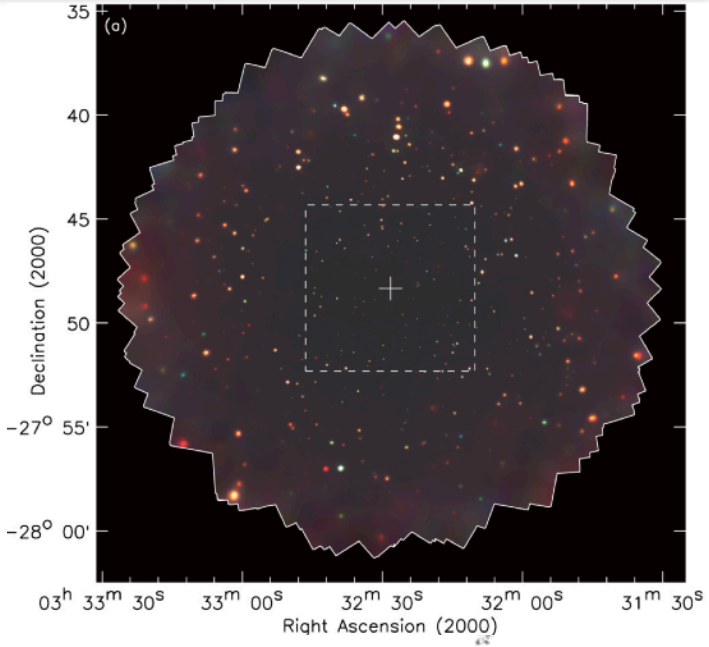
AGN X-ray / Multi-wavelength Surveys Review





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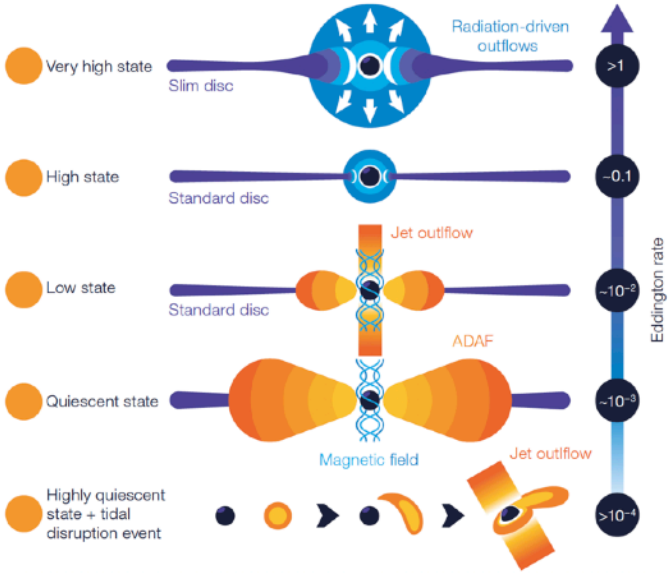
CATA
CENTRO DE ASTROFÍSICA Y TECNOLOGÍAS AFINES

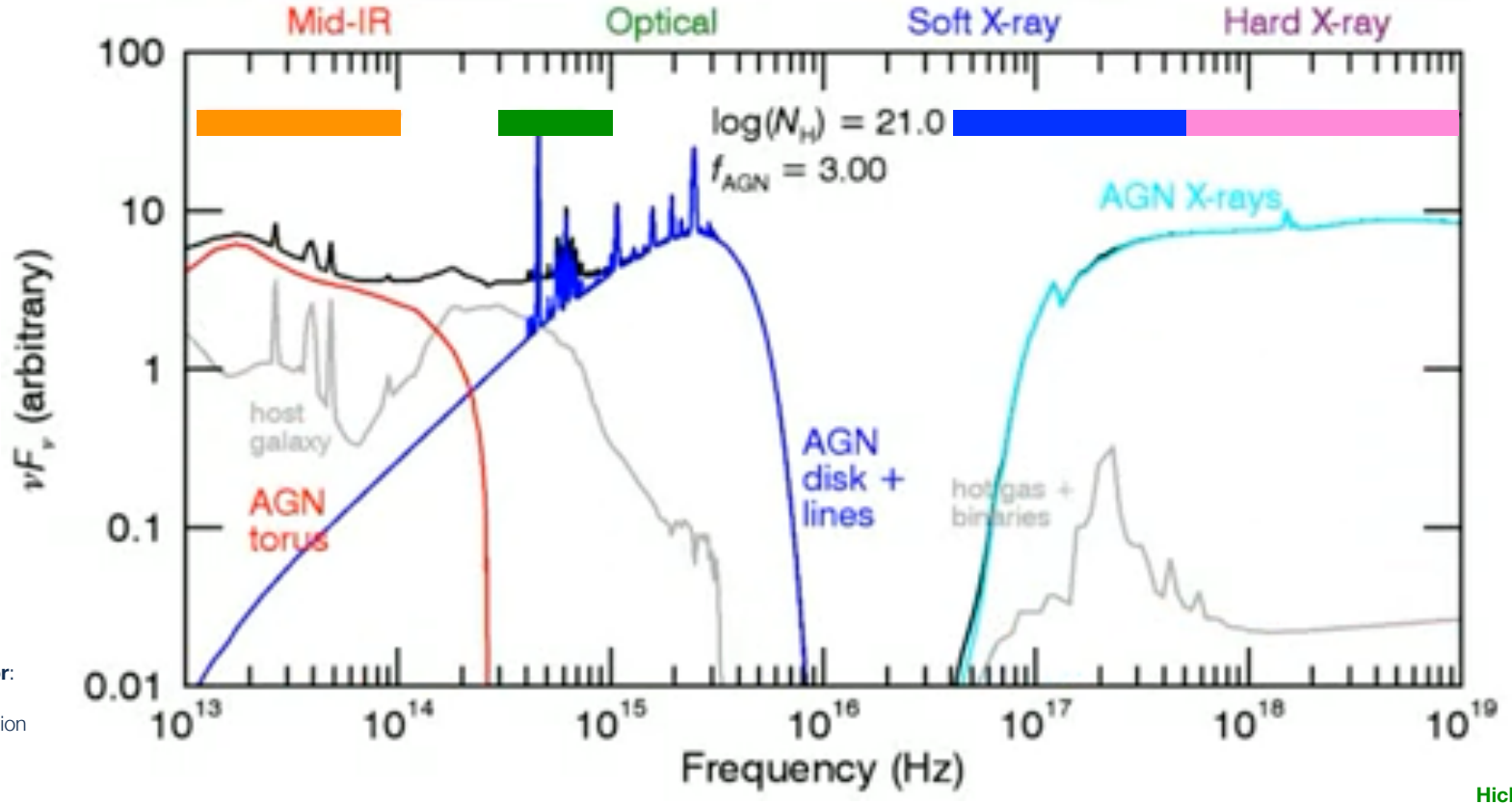
INSTITUTO MILENIO DE ASTROFÍSICA

Motivations for (X-ray) surveys of AGN

- **Central engine structure and physics**
  - ➡ SMBH => accretion (UV/opt) + b-fields => corona, jet (X-rays/radio)
  - ➡ => ionization (BLR, NLR) + winds (BAL) + dust reprocessing (MIR)
- **BH Demographics + Unification**
  - ➡ Domesticate the AGN zoo (orientation, M_{BH}, L/L_{Edd}, RL-ness, …)
  - ➡ Establish distributions of M_{BH}, L/L_{Edd}, RL-ness, θ_{open}, hosts, …
  - ➡ Quantify cosmic accretion (and star formation) history
- **Co-evolution of SMBH and host**
  - ➡ Pin down BH (and host) formation scenarios
  - ➡ Elucidate SMBH+host relations + feedback mechanisms/efficiency
- **Tools**
  - ➡ Use as probe of space-time, cosmology, physical constants, large-scale structure, line-of-sight gas, …

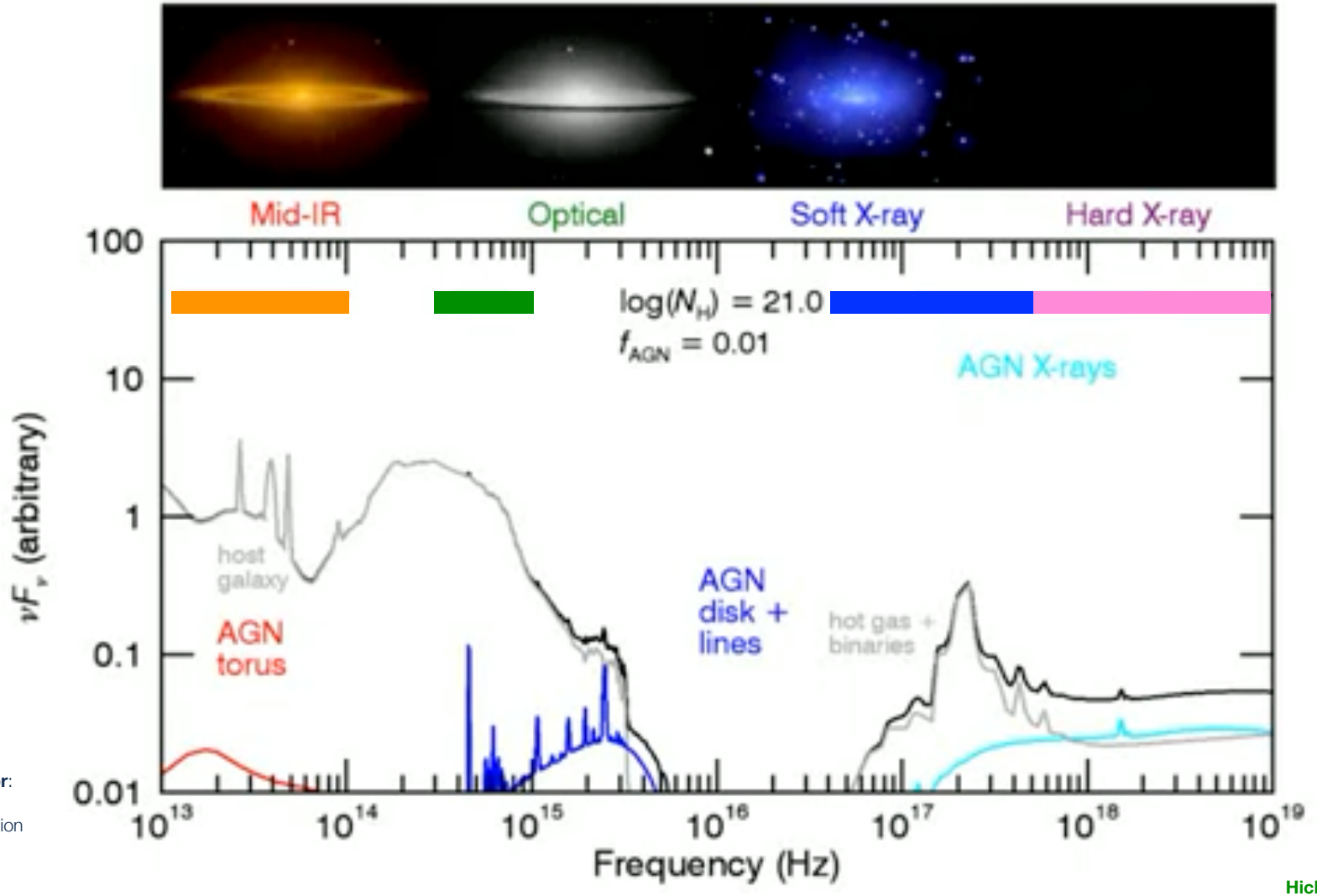


Bauer+23



Caveat emptor: early type host shown. separation for starbursting galaxies harder.

Hickox+Alexander18



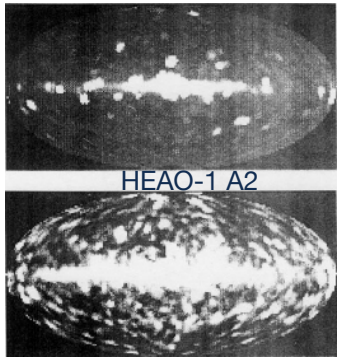
Caveat emptor: early type host shown. separation for starbursting galaxies harder.

Hickox+Alexander18

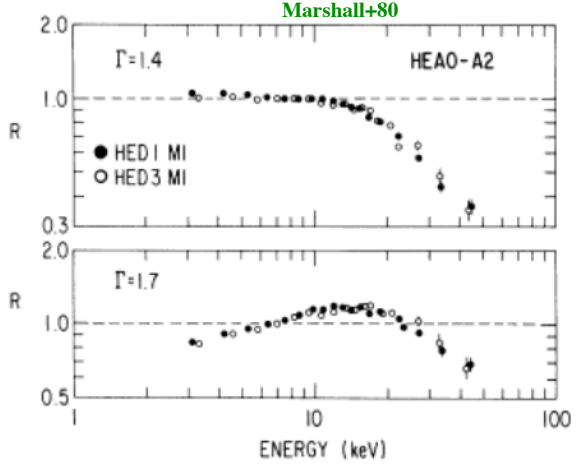
Historical advancement

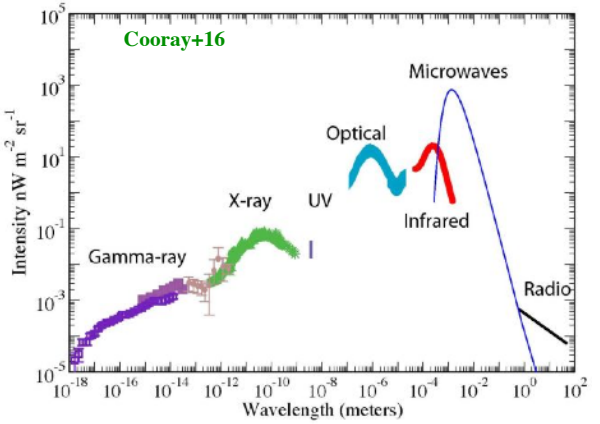
- **CXRB and first AGNs in X-rays**
  - ➡ First galactic X-ray source, Sco X-1, and diffuse cosmic X-ray background (CXRB) first background discovered (Giacconi+62).
- **First samples (1970s-1980s)**
  - ➡ UHURU (Forman+78), ARIEL-V (Warwick+81), HEAO-1 (Marshall+82, Wood+84), Einstein HRI+IPC (Giacconi+79, Harris+94, Moran+96)
  - ➡ Einstein objects accounted for ~40% of XRB.
  - ➡ **substantial difficulties to constrain optical counterparts (hence true energetics)**

Fabian+Bacons+92

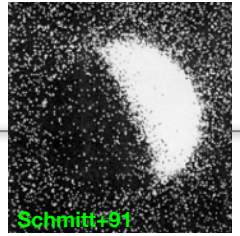


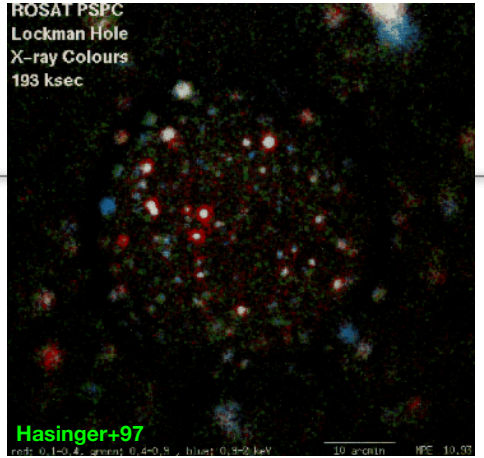
Marshall+80



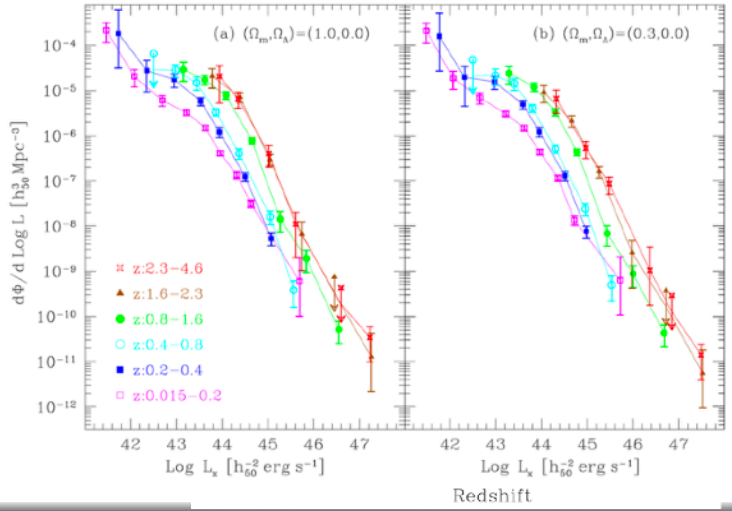


Historical advancement

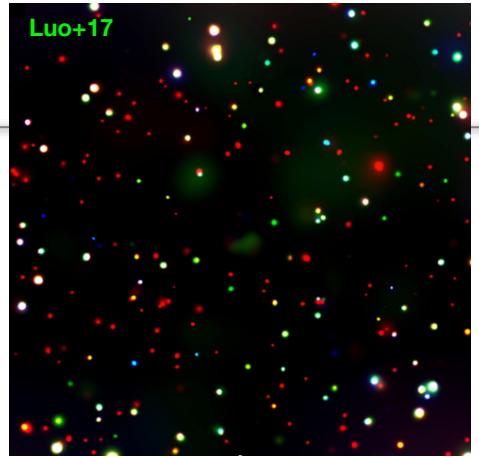




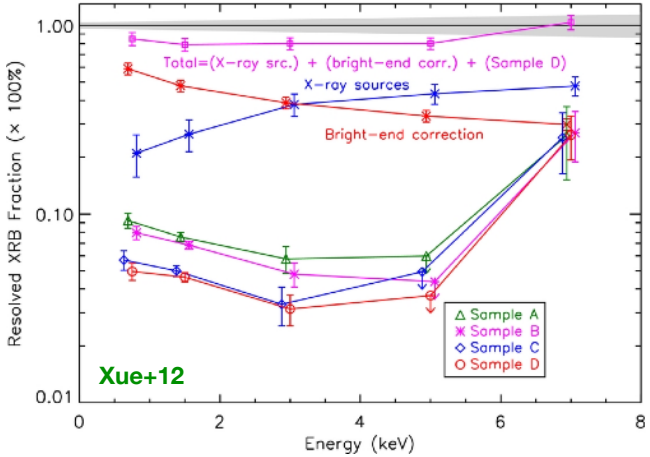
- **ROSAT (0.1-2.4 keV; 1990-1999)**
  - ➡ PSPC 2-deg FOV => all-sky survey during ~1.5 yr; pointed PSPC + HRI obs. thereafter
    - ➡ 1RXS = 18.8k bright (Voges+96), 105k faint (Voges+00)
    - ➡ 2RXS = 135k srcs (Boller+16)
  - ➡ 60%–90% EEF ~ **100–200" PSF**
    - ➡ issues with counterpart IDs + follow-up (e.g.,Laurent-Muehleisen+97, Bade+98, Bauer+00, Zickgraf+03, …)
  - ➡ XLF => Luminosity dependent density evolution
  - ➡ **obscured AGN completely missed, ambiguity in spectra constraints**

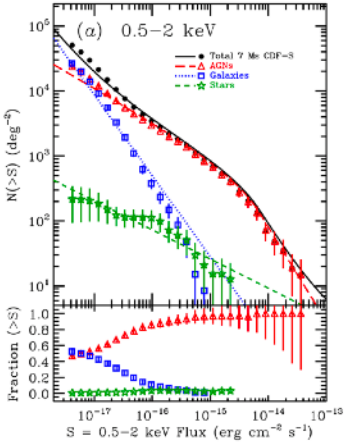


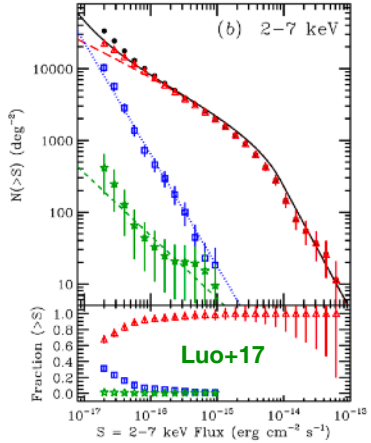
Historical advancement



- **Chandra + XMM + Swift/XRT era (0.5-8 keV; 1999+)**
  - ➡ 0.5-5” PSFs => **relatively unambiguous counterpart identification**
  - ➡ 20’-30’ FOVs => **<3-5% sky coverage to date**
  - ➡ “arms race” in deep fields => **~90% of XRB accounted for.**
  - ➡ MOS spectra => **higher fraction of objects can be identified**





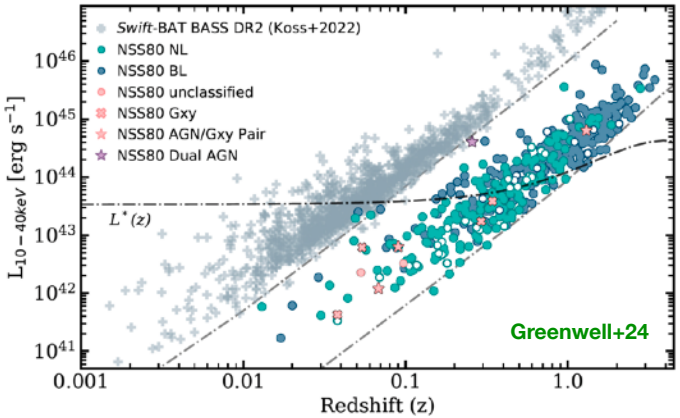


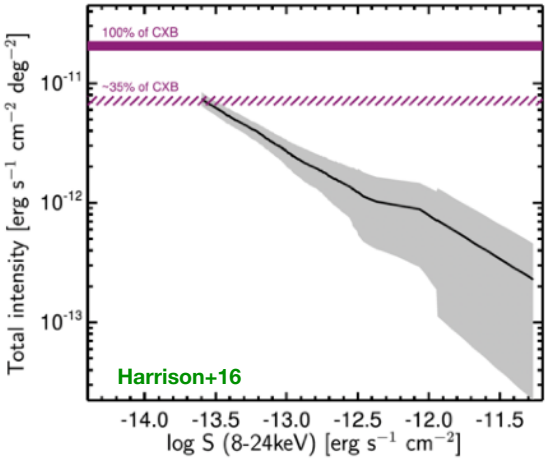
Historical advancement

> 10 keV missions can produce less-biased (by N_H) AGN samples

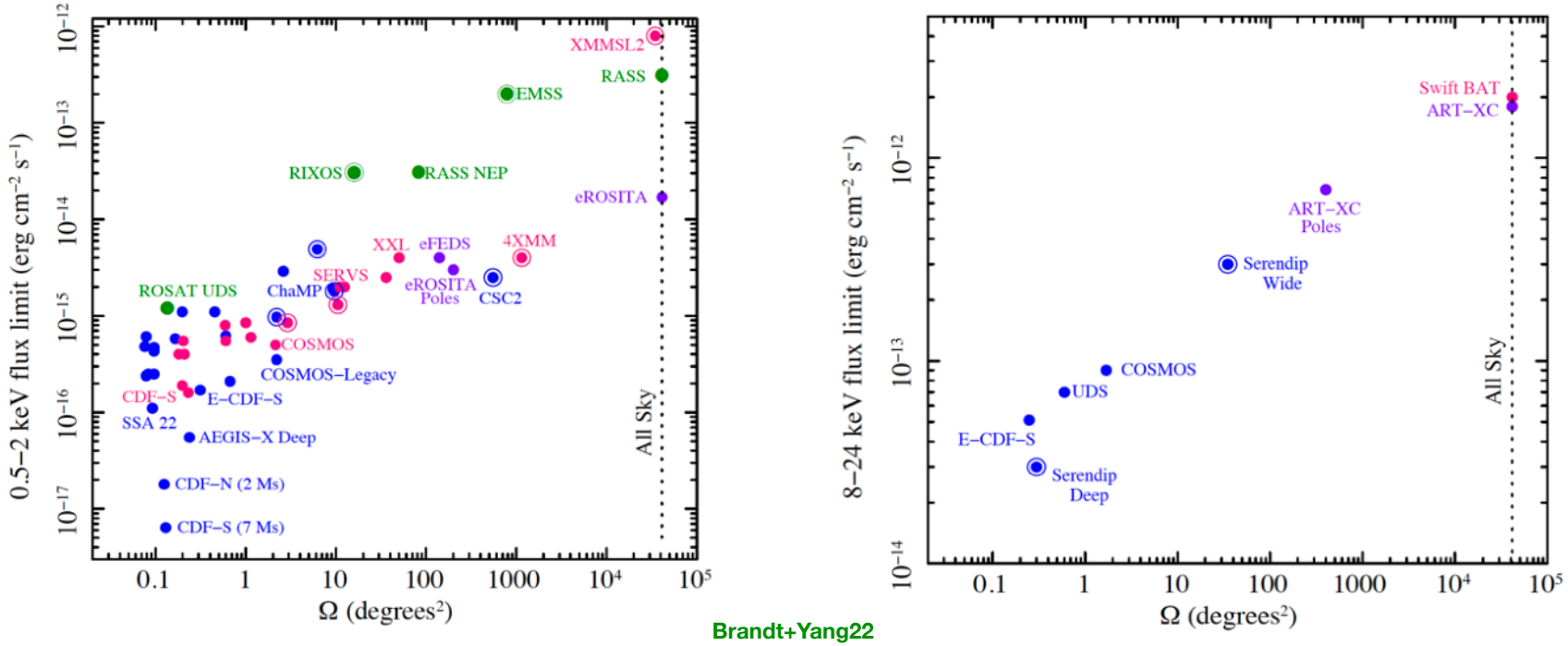
- **Swift BAT (14-195keV, 2004+)**
  - ➡ all-sky survey (157mo = 1800+ srcs)
  - ➡ ~100% w/ IDs via XRT + spectra => legacy sample (Koss+22)
  - ➡ <1% of XRB resolved near peak (Burlon+11)

- **NuSTAR (3-79keV, 2012+)**
  - ➡ NuSTAR 18” PSF => **decent counterpart identification**
  - ➡ 12’x12’ FOV => **<0.1% sky coverage to date**
  - ➡ ~35% of XRB near peak resolved
  - ➡ 76% w/ <10 keV detection in Chandra, XMM-Newton,Swift-XRT





Historical advancement



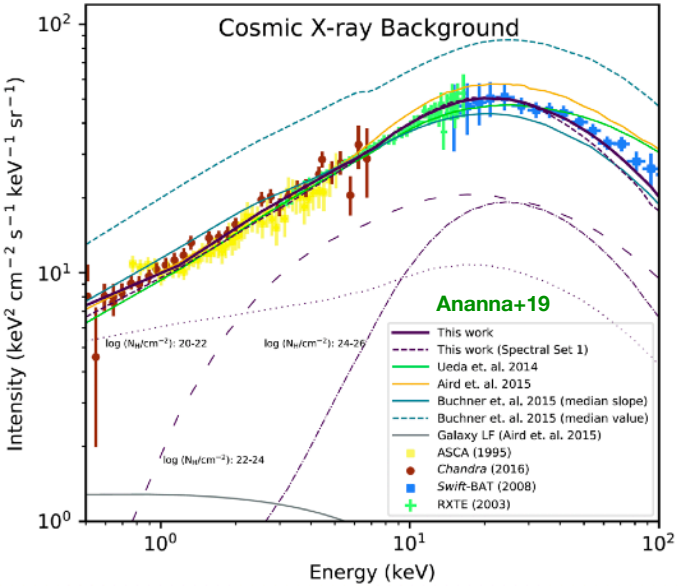
Brandt+Yang22

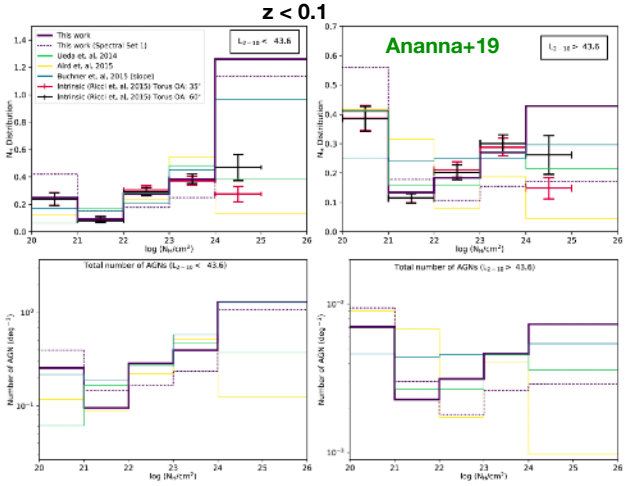
Historical advancement (other wavelengths)

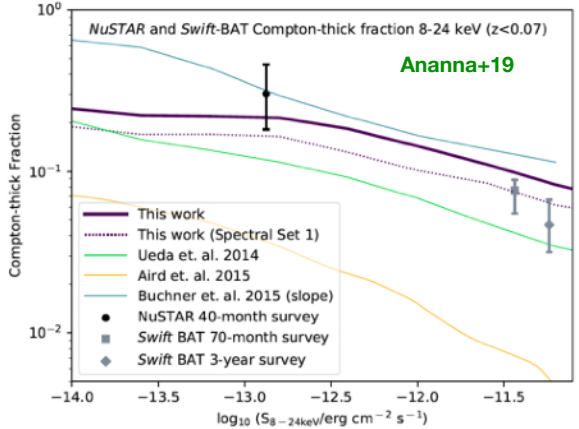
- **3C (59+), GB (86+), FIRST+NVSS (97+,98+), SUMMS (99+)** => radio-loud AGN
- **Palomar-Green QSO sample (83+)** => type 1 AGN
- **IRAS (83), Spitzer (03-20), WISE (09-24)** => obscured AGN + torus
- **HST (1990+)** => all types of AGN (COSMOS, GOODS, CANDELS), M_σ
- **AAO+SDSS+LAMOST+DESI (97+)** => QSOs + type1+2 AGN => **Juna, Julien**
- **Gaia (13+)** => QSOs
- **JWST (21+)** => MIR + hi-z AGN => **Julien**
- …

Key results: Background synthesis models

- Can successfully reproduce XRB (e.g., Gilli+07, Ueda+14; Aird+15; Buchner+15; Ananna+19)
- ~50% of accretion is CT, **not tracked by X-rays**
- Strong assumptions remain for several key factors ($N_H > 10^{24}$ cm^{-2}, X-ray spectral shapes)

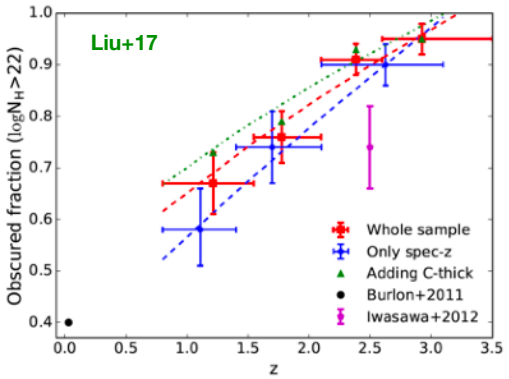


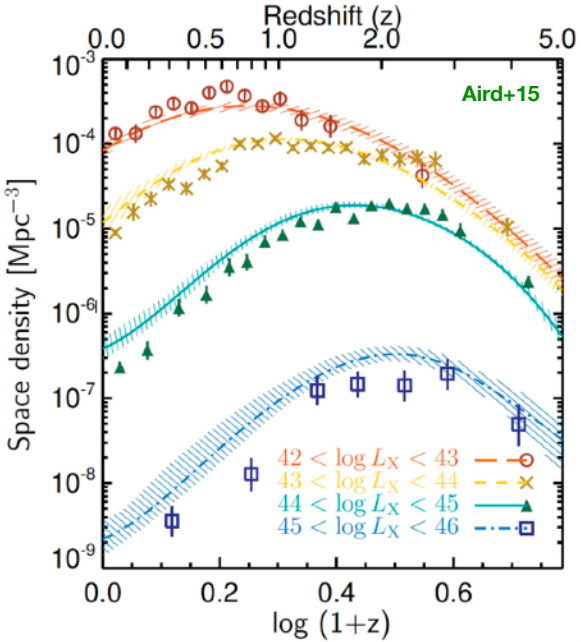


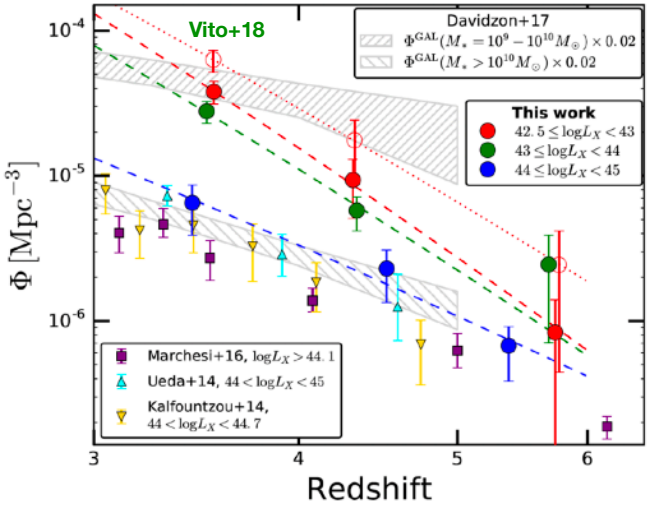


Key results:
AGN Downsizing

- ~complete AGN samples over wide L_X, z, and N_H ranges allow detailed characterization of AGN XLF.
- "AGN downsizing" => higher L_X AGNs peaks at higher z (e.g., Cowie+03; Ueda+14; Aird+15).
- Evolution of obscuration
- Uncertainties for CT and low-L_X, and hi-z regimes
- Including JWST results critical.

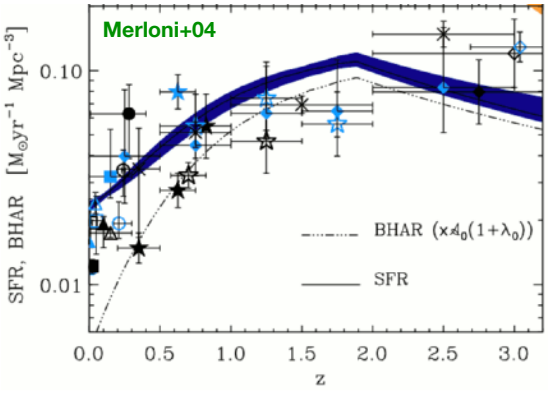


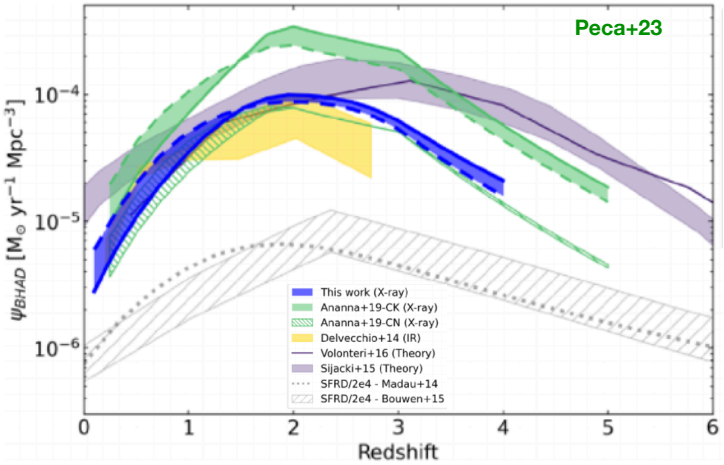


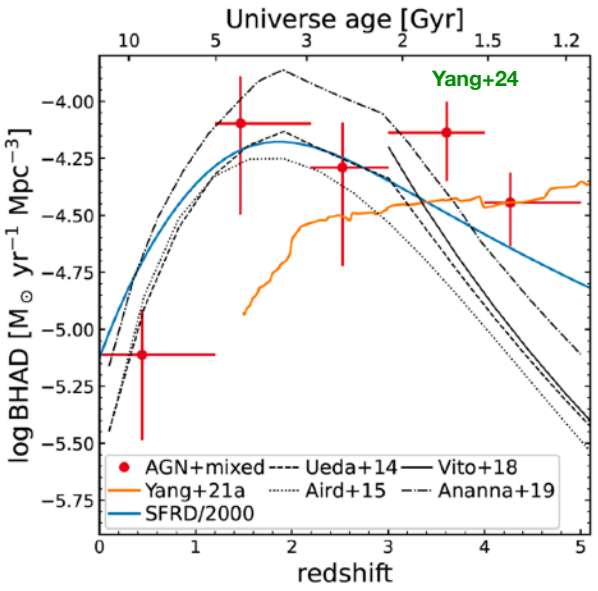


Key results:
Cosmic Black Holes Accretion Rate/Density (BHAD)

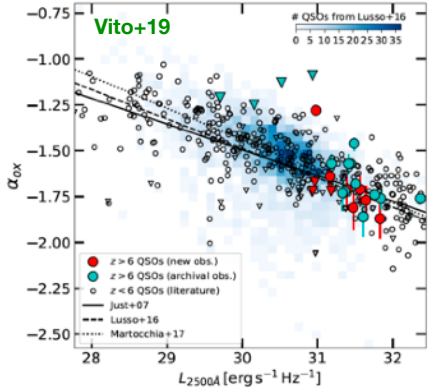
- Fairly good reckoning of where and how strongly non-CT SMBHs grow now.
- MIRI-based BHAD becomes significantly higher than the X-ray-based BHAD by ~0.5 dex at z > 3, implying MIRI is detecting new heavily obscured/CT AGN.



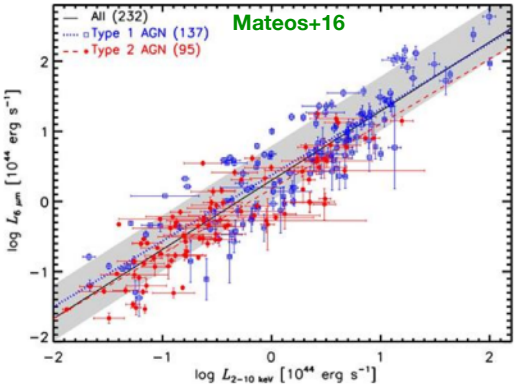


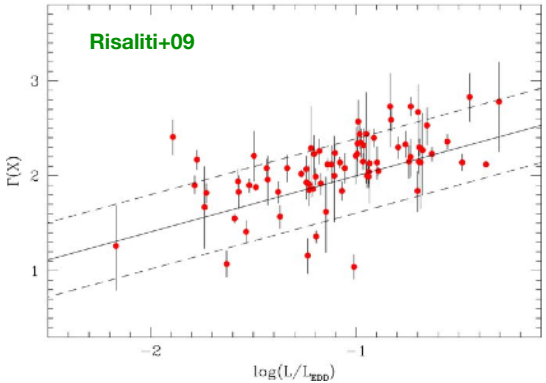


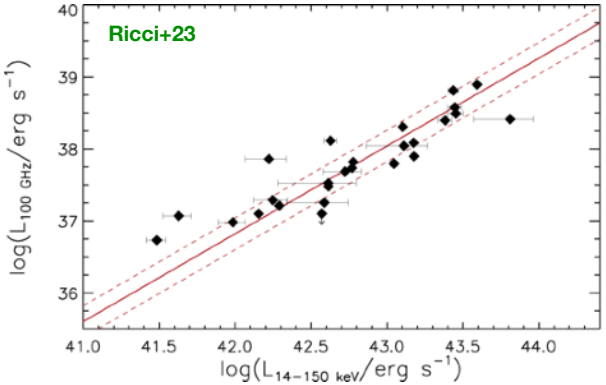
Key results: AGN Physics

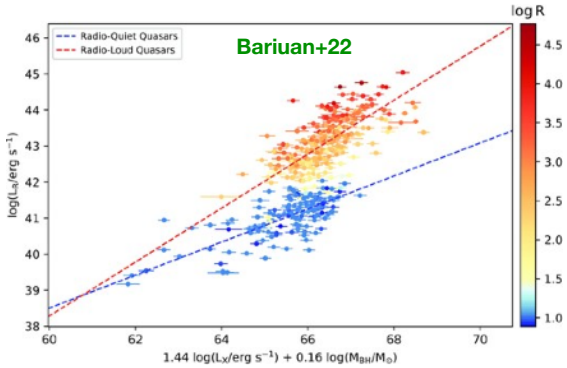


- Refine relations b/t different AGN components to probe physics and structure:
  - ➡ α_{ox} and Γ => disk+corona
  - ➡ X-ray-6um disk/corona+torus
  - ➡ mm/X-ray => corona/jet launching region?
  - ➡ radio/X-ray/MBH => jet upper bound?



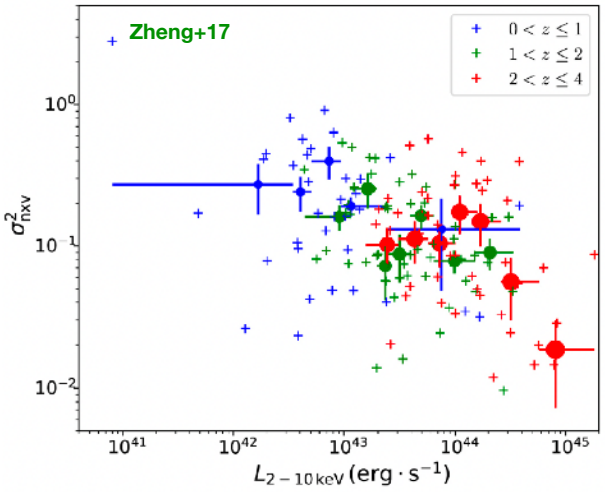


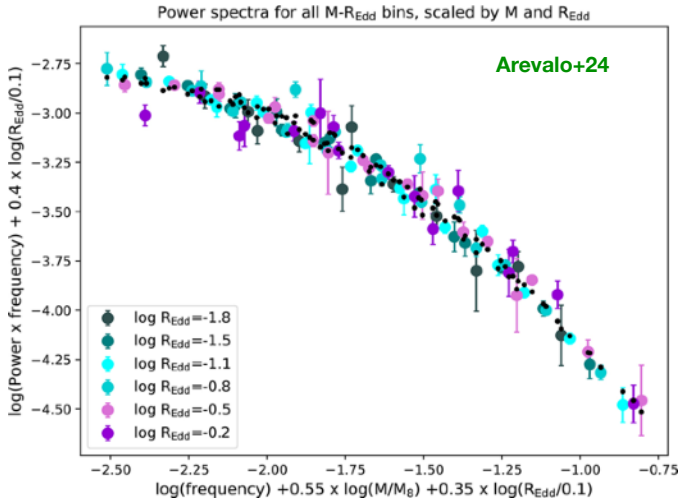


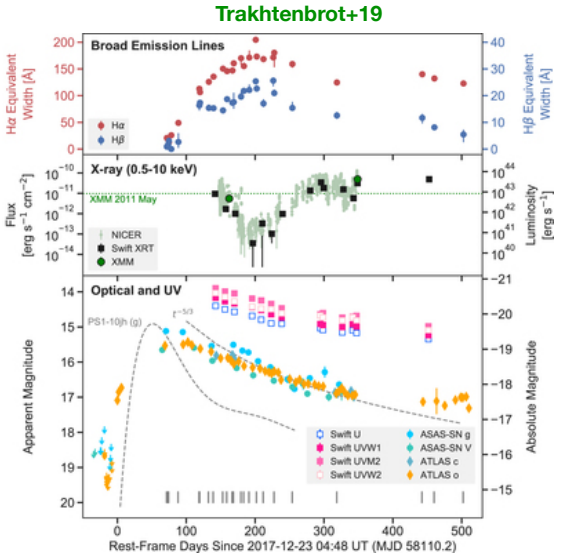


Key results:
AGN Physics

- Assess variability of disk and corona, probe how and why they relate to SMBH properties
- Find and track transient events, which can provide powerful constraints on models.



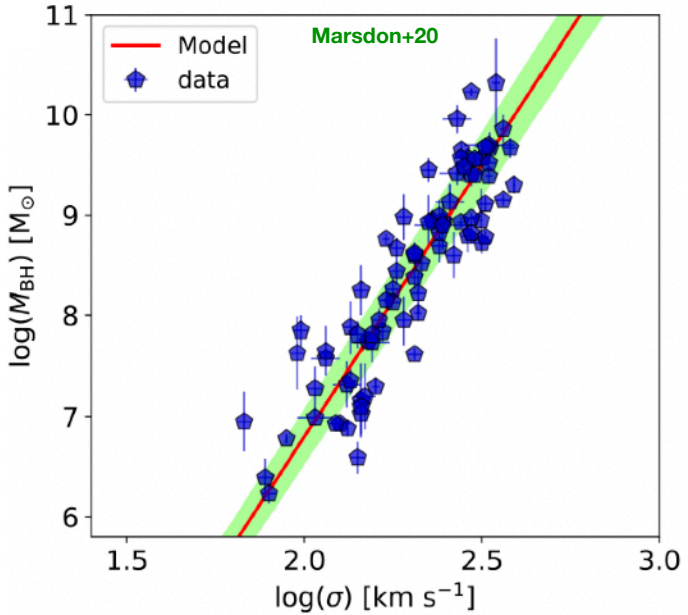


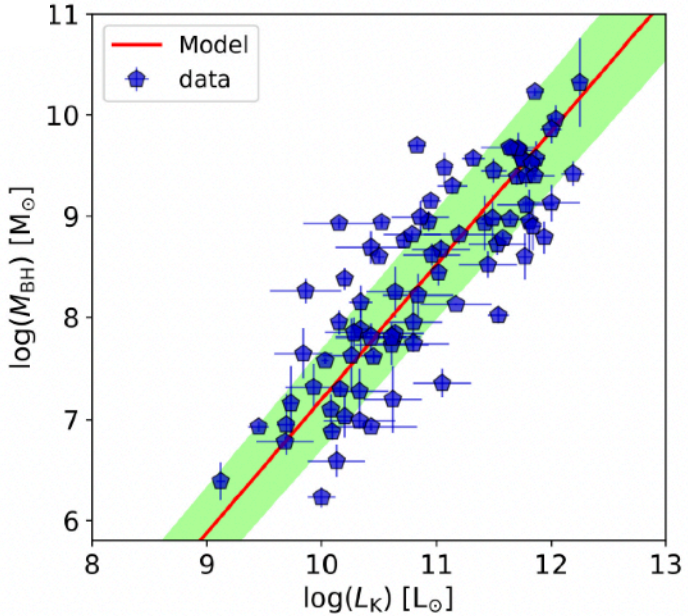


Key results: AGN + Host

James

- Fundamental relation between the SMBH mass and spheroid mass (also total stellar and halo)
- Important to understand how BHAR related to gas supply, host, feedback





Current + Future…

- **eROSITA!!!** => uniform sample ~3 million AGNs, probing AGN evolution, large-scale structure, and variability.
- **JWST + Euclid** => pushing hi-z AGN evolution.
- **Einstein Probe + SVOM** => Pushing boundaries on X-ray transient and variability behavior
- **LSST + Roman** => Pushing boundaries on optical transient and variability behavior
- **Athena, AXIS?, HEX-P?, Lynx? …**

- **Open questions:**
  - SMBH seeds => How did the first SMBHs form so quickly in the early universe?
  - SMBH physics (better models, CSAGN)
  - SMBH demographics => What is the full extent of the obscured AGN population?
  - SMBH+host => How exactly do AGNs regulate star formation in their host galaxies?
  - Continued use of SMBH as probes