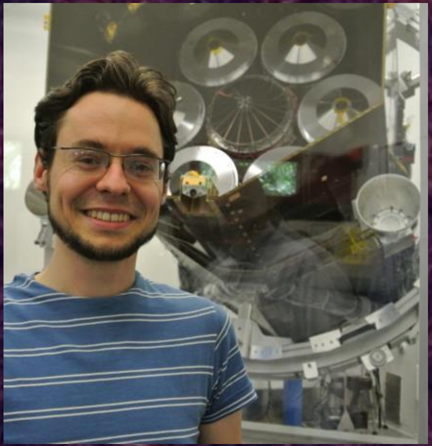
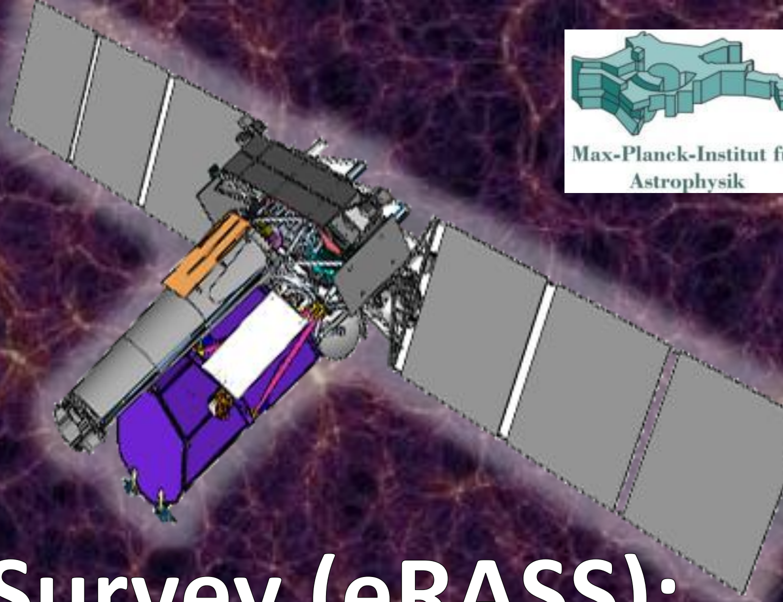




Max-Planck-Institut für Astrophysik

eROSITA/SRG All-Sky Survey (eRASS):

New era of large-scale structure studies with (X-ray selected) AGN

By	Alex Kolodzig (MPA)
Collaborators	Marat Gilfanov (MPA,IKI), Gert Hütsi (MPA), Rashid Sunyaev (MPA,IKI)
Publications	Kolodzig et al. 2013b, A&A, 558, 90 (ArXiv : 1305.0819) Hüsti et al. 2014, submitted (ArXiv: 1403.5555)
At	Clustering Measurements of AGN, ESO, Garching, Germany, 14.-18.06.2014

Background Picture: Millennium Simulation (MPA); Spectrum-Roentgen-Gamma satellite (P. Predehl 2011)

X-ray surveys of the last ~2 decades

Max-Planck-Institut für Astrophysik

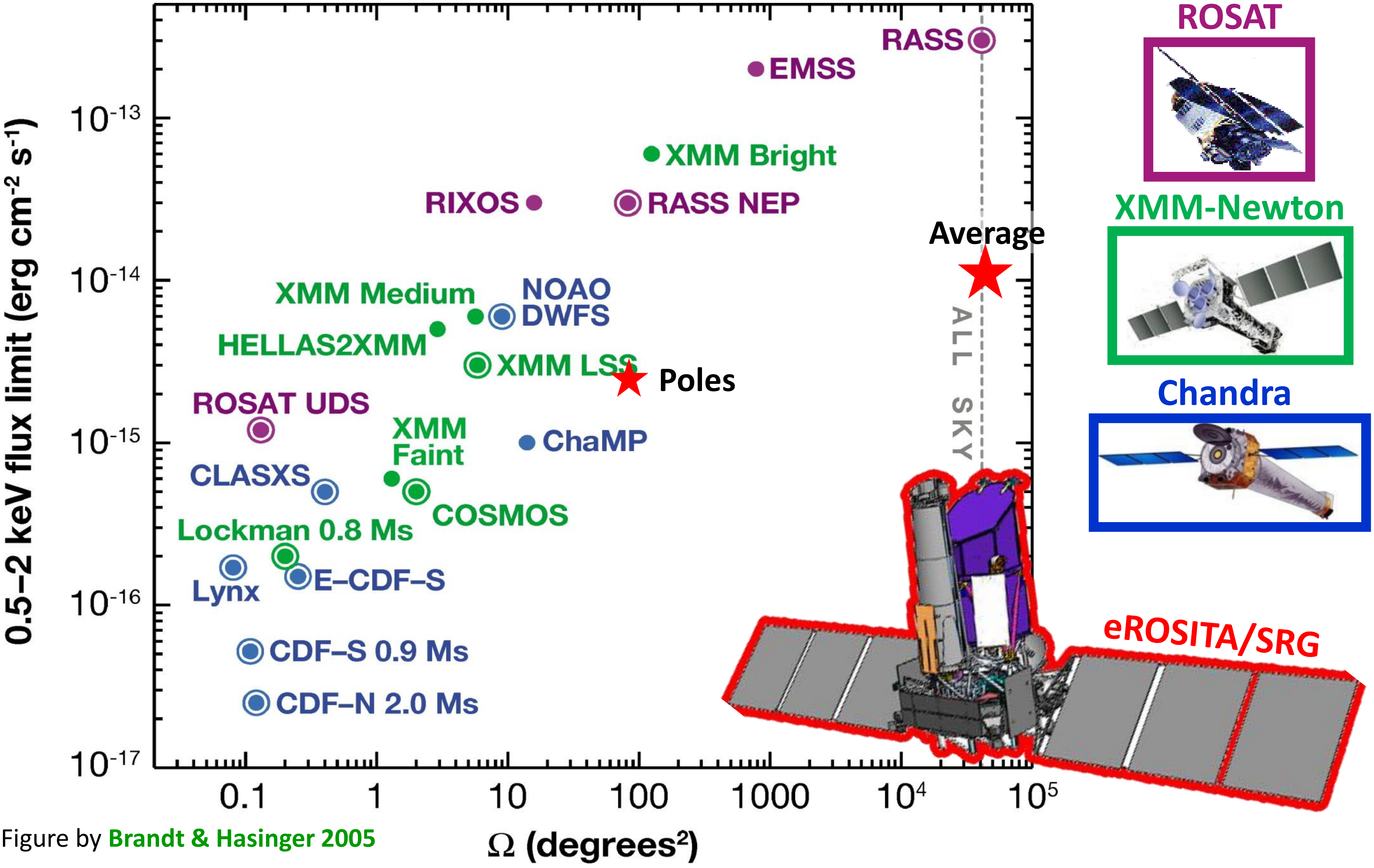
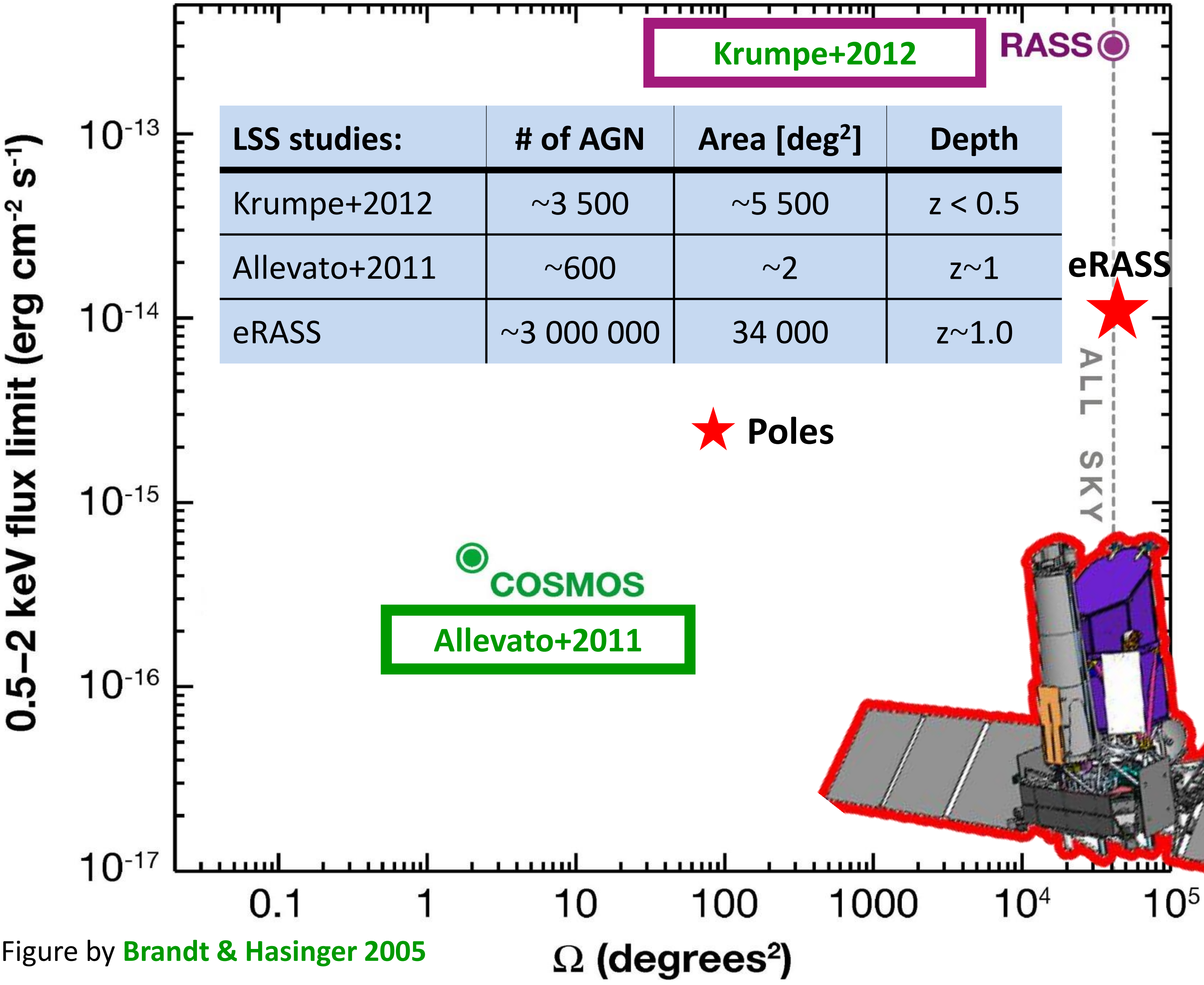


Figure by **Brandt & Hasinger 2005**

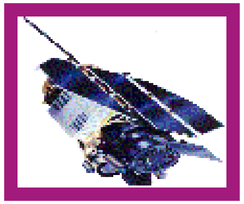
Large-scale structure studies in X-rays

Max-Planck-Institut für Astrophysik



LSS studies:	# of AGN	Area [deg^2]	Depth
Krumpe+2012	~3 500	~5 500	z < 0.5
Allevato+2011	~600	~2	z~1
eRASS	~3 000 000	34 000	z~1.0

ROSAT



XMM-Newton

Chandra

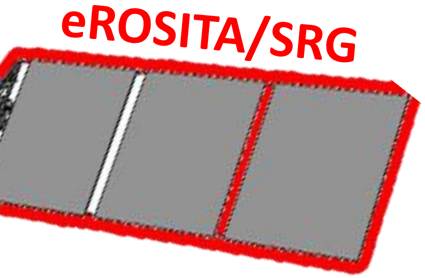
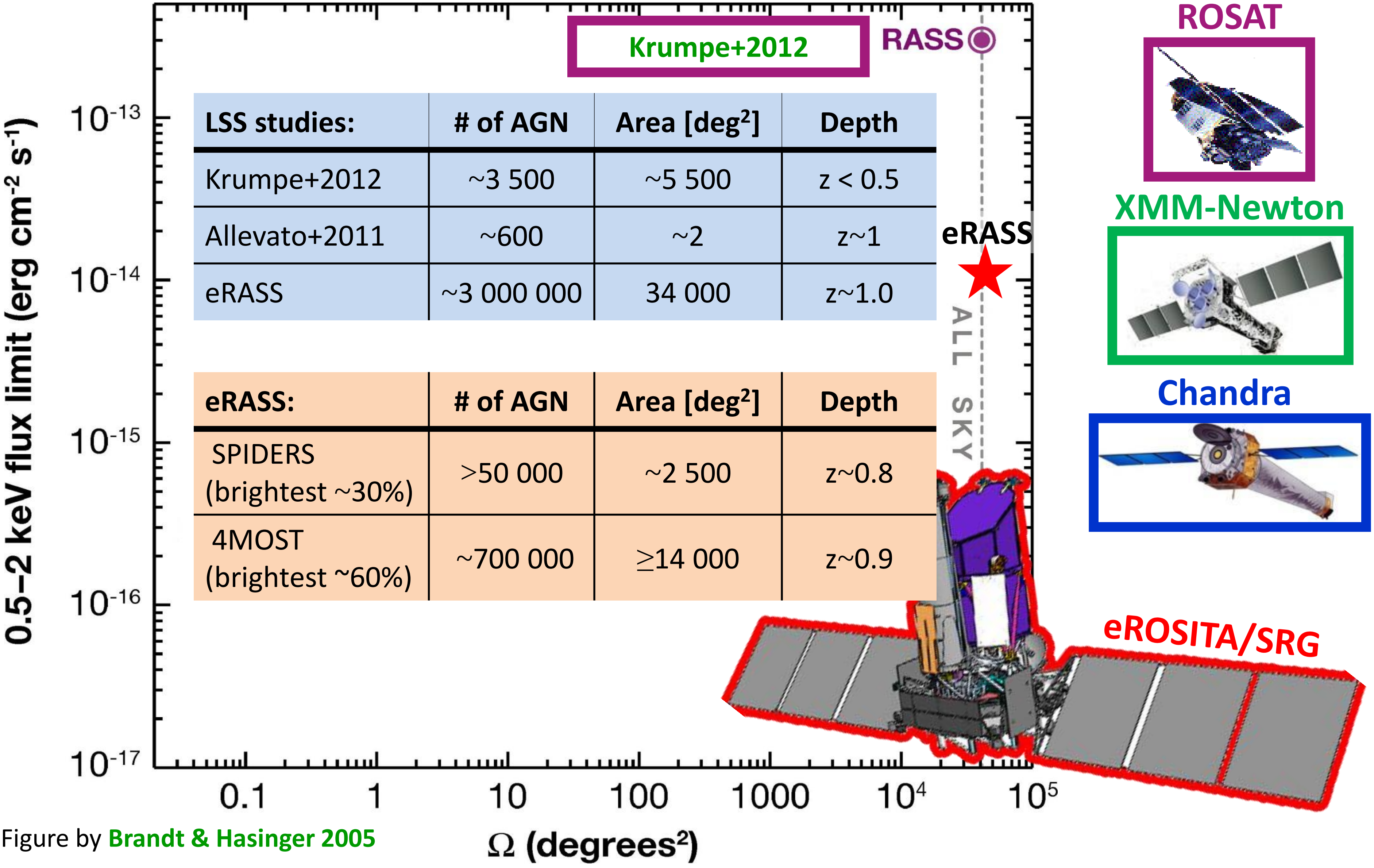


Figure by **Brandt & Hasinger 2005**

Large-scale structure studies in X-rays

Max-Planck-Institut für Astrophysik

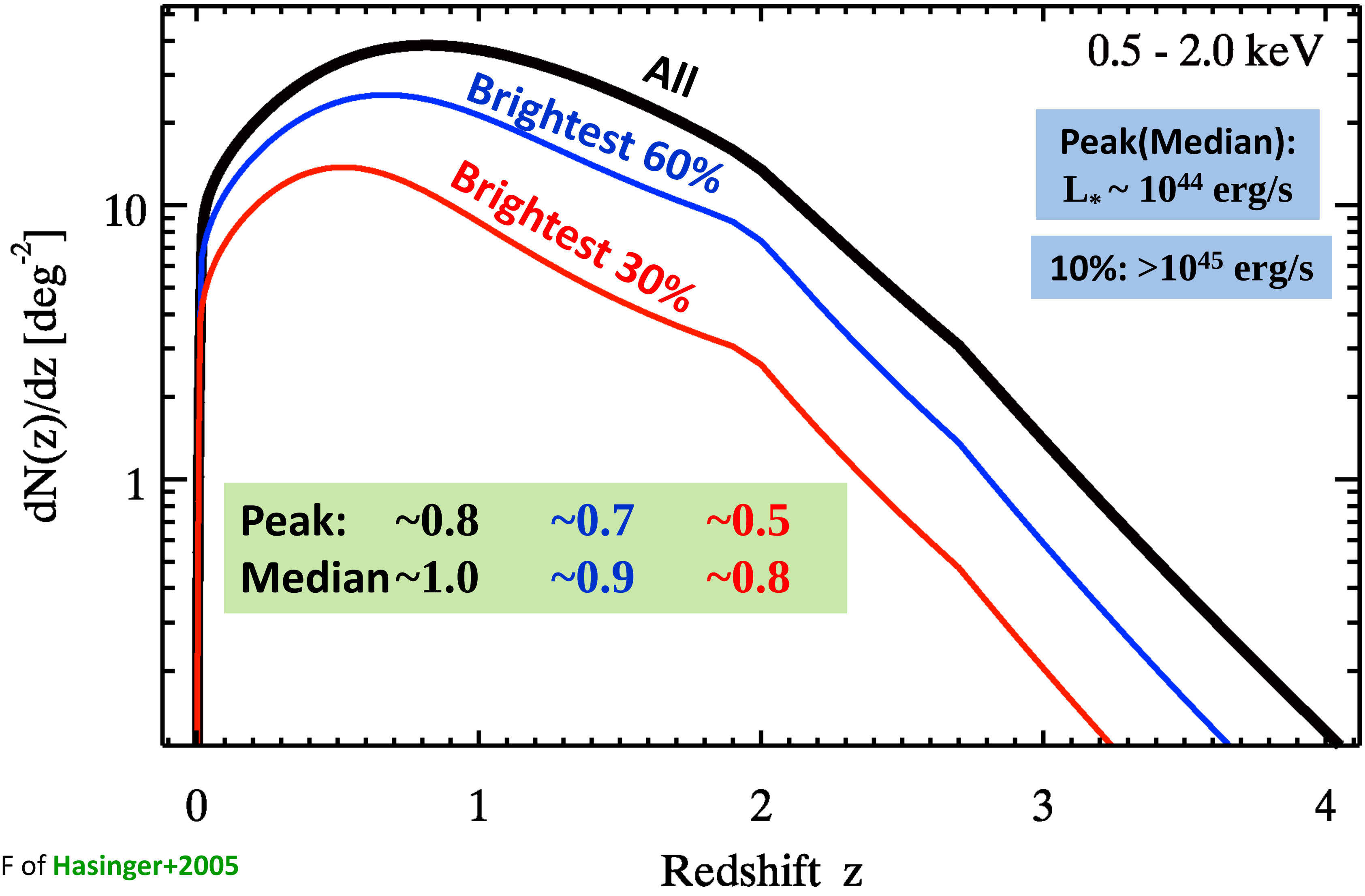


LSS studies:	# of AGN	Area [deg²]	Depth
Krumpe+2012	~3 500	~5 500	z < 0.5
Allevato+2011	~600	~2	z~1
eRASS	~3 000 000	34 000	z~1.0

eRASS:	# of AGN	Area [deg²]	Depth
SPIDERS (brightest ~30%)	>50 000	~2 500	z~0.8
4MOST (brightest ~60%)	~700 000	≥14 000	z~0.9

Figure by **Brandt & Hasinger 2005**

eRASS: predicted redshift distribution



Peak(Median):
$L_* \sim 10^{44}$ erg/s

10%: $>10^{45}$ erg/s

Peak:	~0.8	~0.7	~0.5
Median	~1.0	~0.9	~0.8

XLF of **Hasinger+2005**

Tools of eRASS for LSS studies

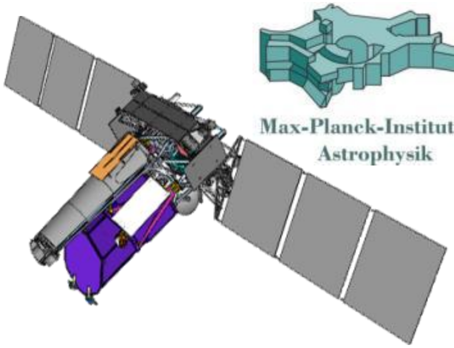
Max-Planck-Institut für Astrophysik

- AGN as phase of galaxy evolution:
  - **X-ray Luminosity Function** (see **Kolodzig et al. 2013a**)**:**
    - AGN evolution
    - accretion history of SMBHs
  - **Clustering strength (linear bias factor)**:
    - AGN environment
    - AGN triggering mechanism
    - SMBH co-evolution with dark matter halo

- AGN as cosmological probe:
  - **Baryonic acoustic oscillations** (BAOs)
    - independent constrains on cosmological parameters

Clustering Model

Our Clustering Model



Max-Planck-Institut für Astrophysik

- Based on **Hütsi, Gilfanov & Sunyaev 2012**:
  - Angular Power Spectrum: $C_\ell = \frac{2}{\pi}\int P_{\rm DM}^{\rm lin}(k)\,W_\ell^2(k,z)\,k\,{\rm d}k$

$$W_\ell(k,z) = \int j_\ell\left(k\,r(z)\right)\, \underset{\downarrow}{g(z)}\; b(z)\; \phi(z)\; {\rm d}z$$

growth factor

Assumptions:

- Mass of dark matter halo (DMH) of AGN hosts:

  (e.g. **Allevato et al. 2011**, **Krumpe et al. 2012**, **Mountrichas et al. 2013**)

  $M_{\rm DMH,eff} = 2\times10^{13}\,M_\odot/{\rm h}$ -> bias $b(z, M_{\rm DMH,eff})$

- X-ray Luminosity Function of **Hasinger et al. 2005** (0.5 - 2.0 keV) for flux-cut and redshift-evolution -> selection function $\phi(z)$

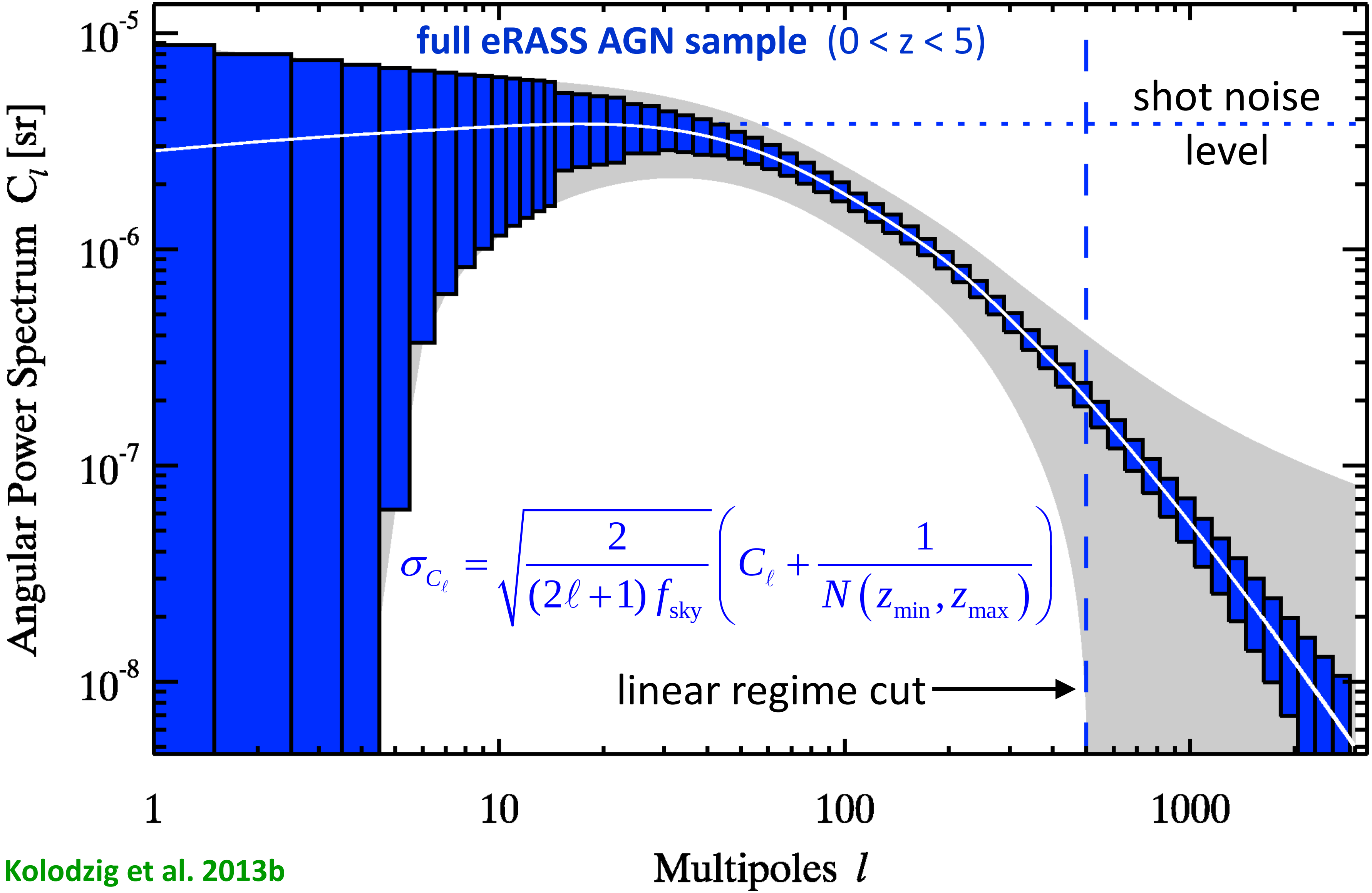
  (LDDE model, with redshift cutoff of **Brusa et al. 2009** at z>2.7)

- Cosmology: flat ΛCDM, $\Omega_\Lambda = 0.7$, $\Omega_{\rm m} = 0.3$, $\Omega_{\rm b} = 0.05$, ${\rm h} = 0.7$, $\sigma_8 = 0.8$

- Assume: redshifts are known!

predicted angular power spectrum - C_l

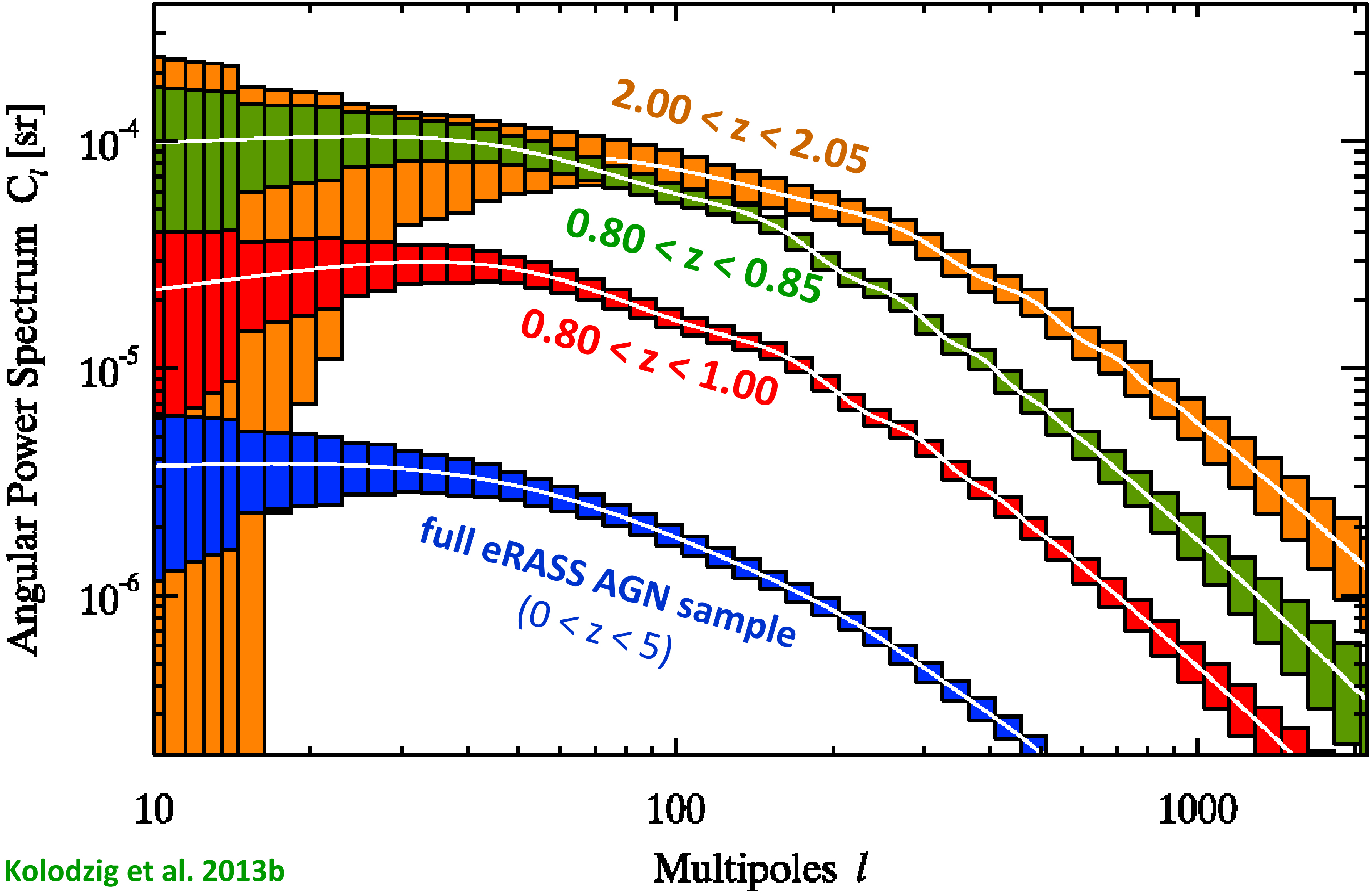
Max-Planck-Institut für Astrophysik



$$\sigma_{C_\ell} = \sqrt{\frac{2}{(2\ell+1)\, f_{\mathrm{sky}}}} \left(C_\ell + \frac{1}{N(z_{\mathrm{min}}, z_{\mathrm{max}})} \right)$$

Kolodzig et al. 2013b

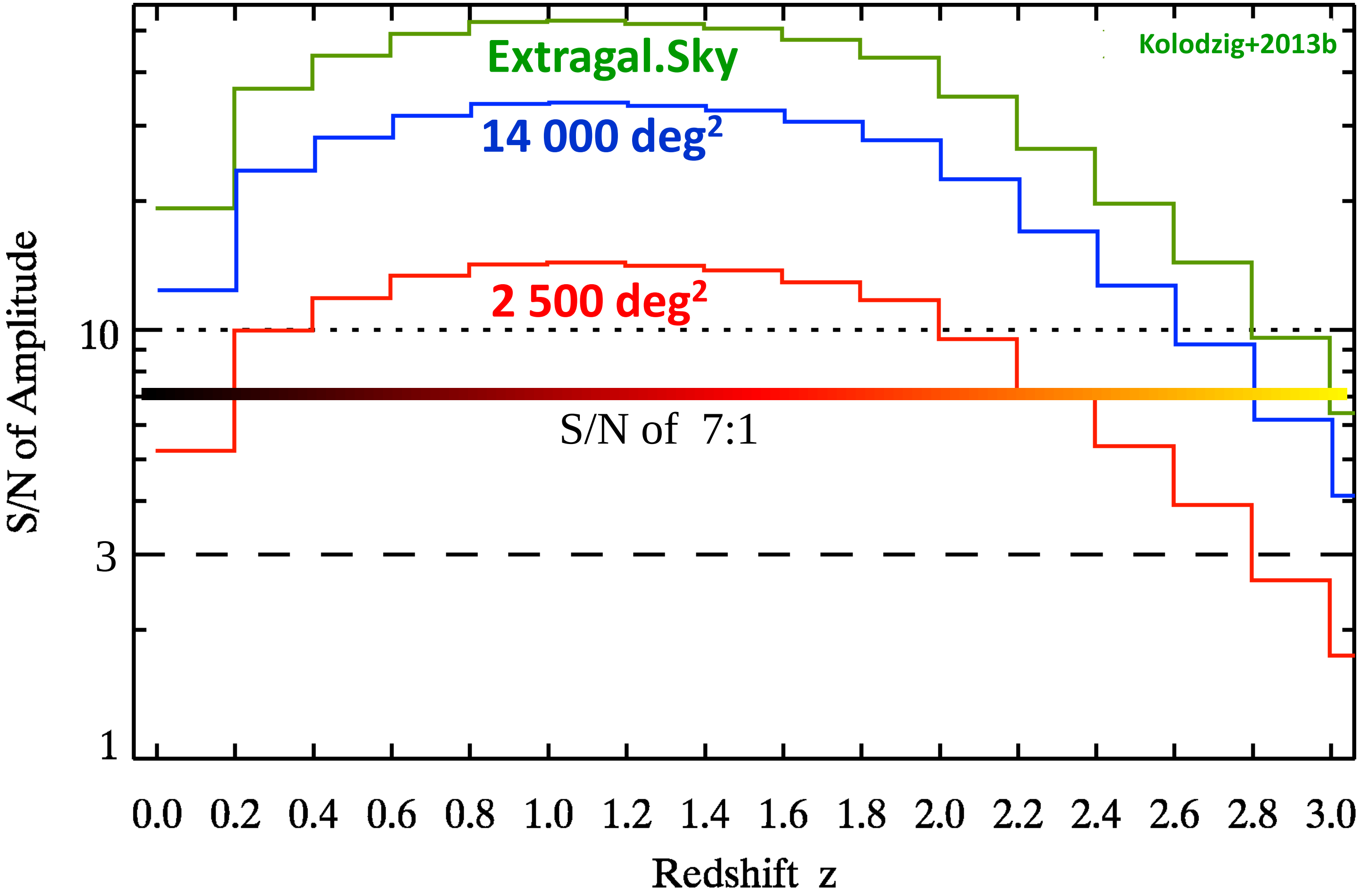
predicted angular power spectrum - C_l



Kolodzig et al. 2013b

Clustering Strength
(Linear Bias Factor)

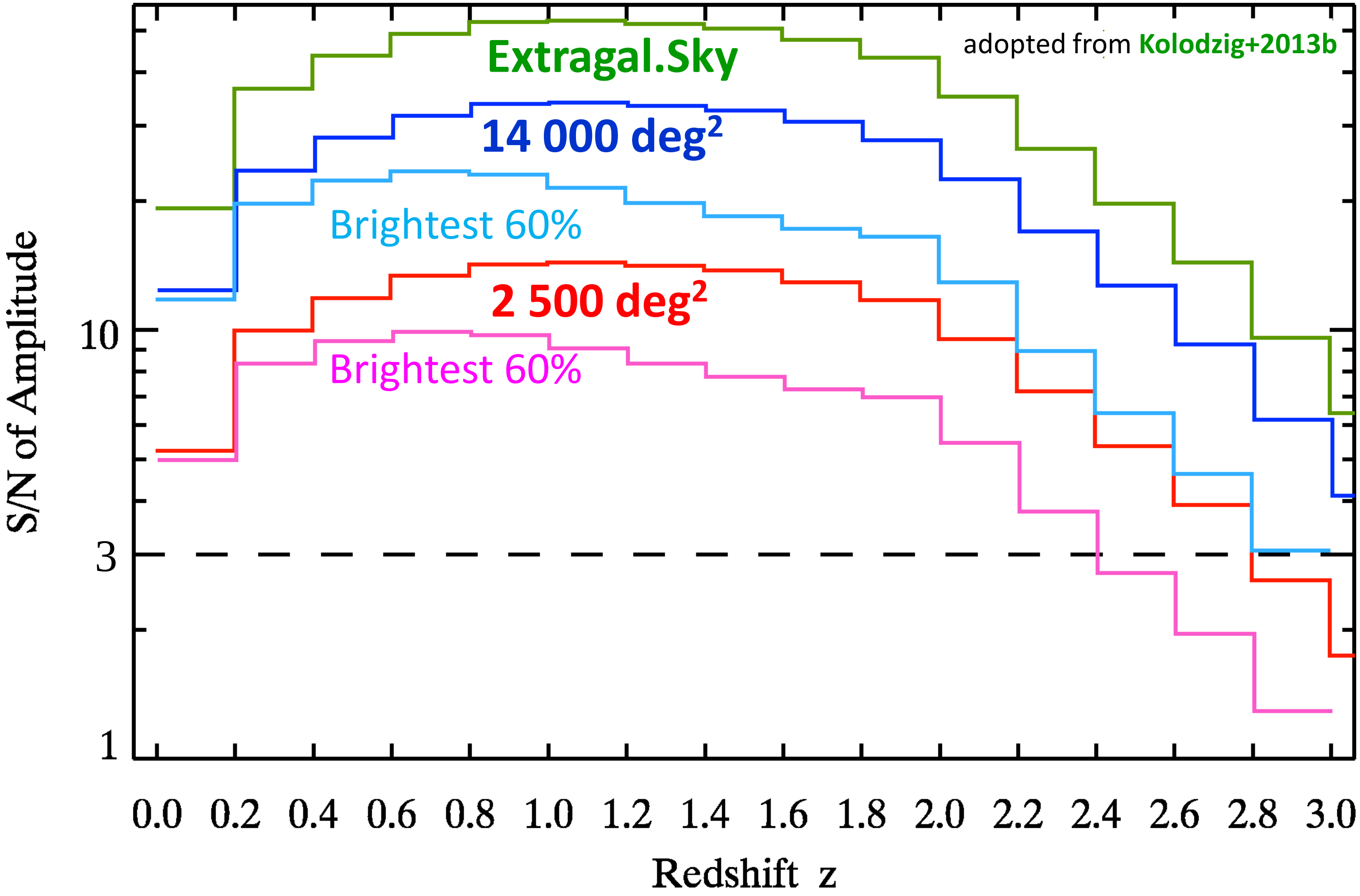
Clustering Strength vs. redshift



- high S/N (>10) for wide z-range and "small" sky fraction

Clustering Strength vs. redshift

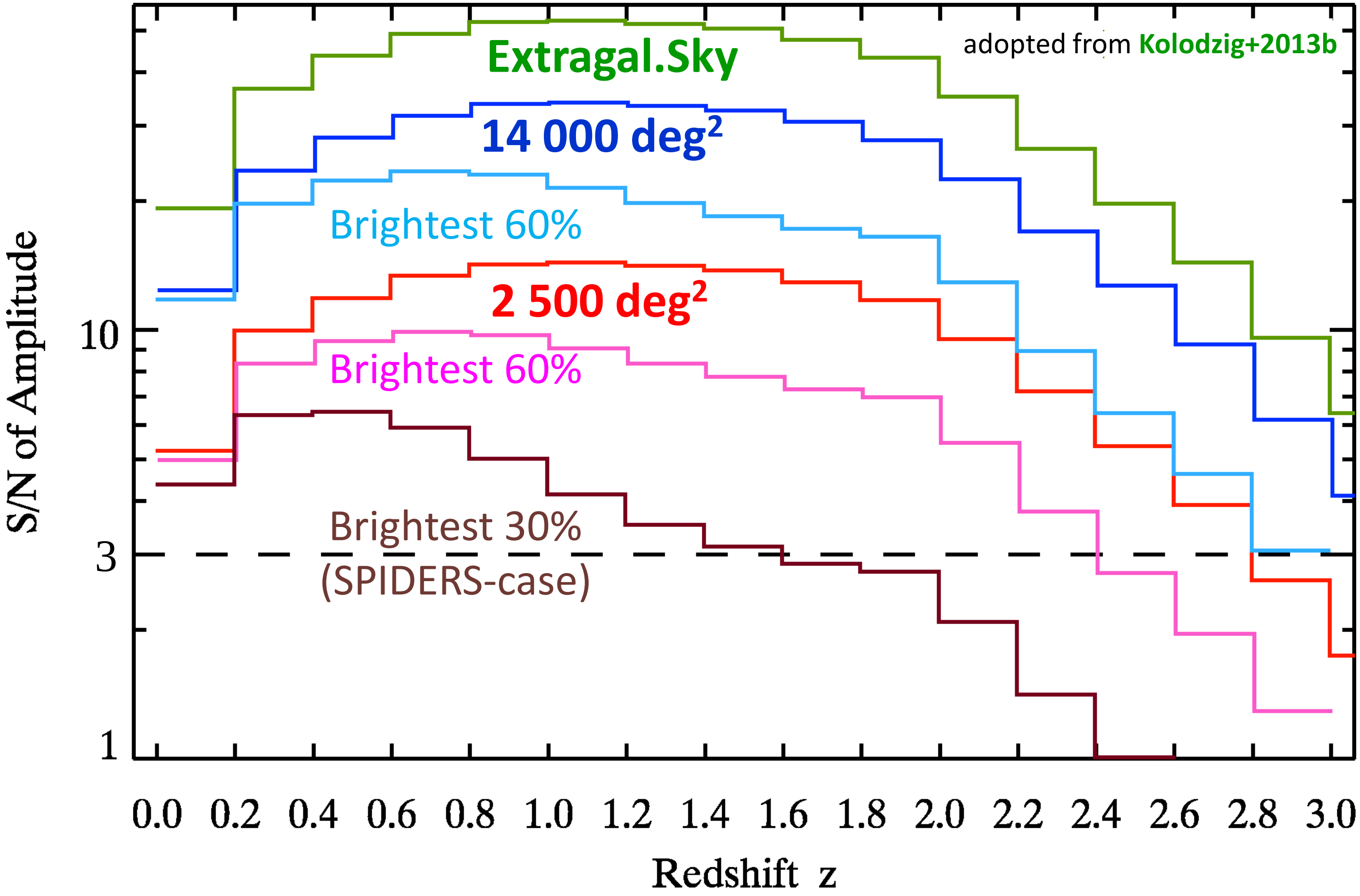
Max-Planck-Institut für Astrophysik



- brightest 60% (4MOST-case) and 2 500 deg^2:
  - good S/N (≥ 3) up to z~2.5

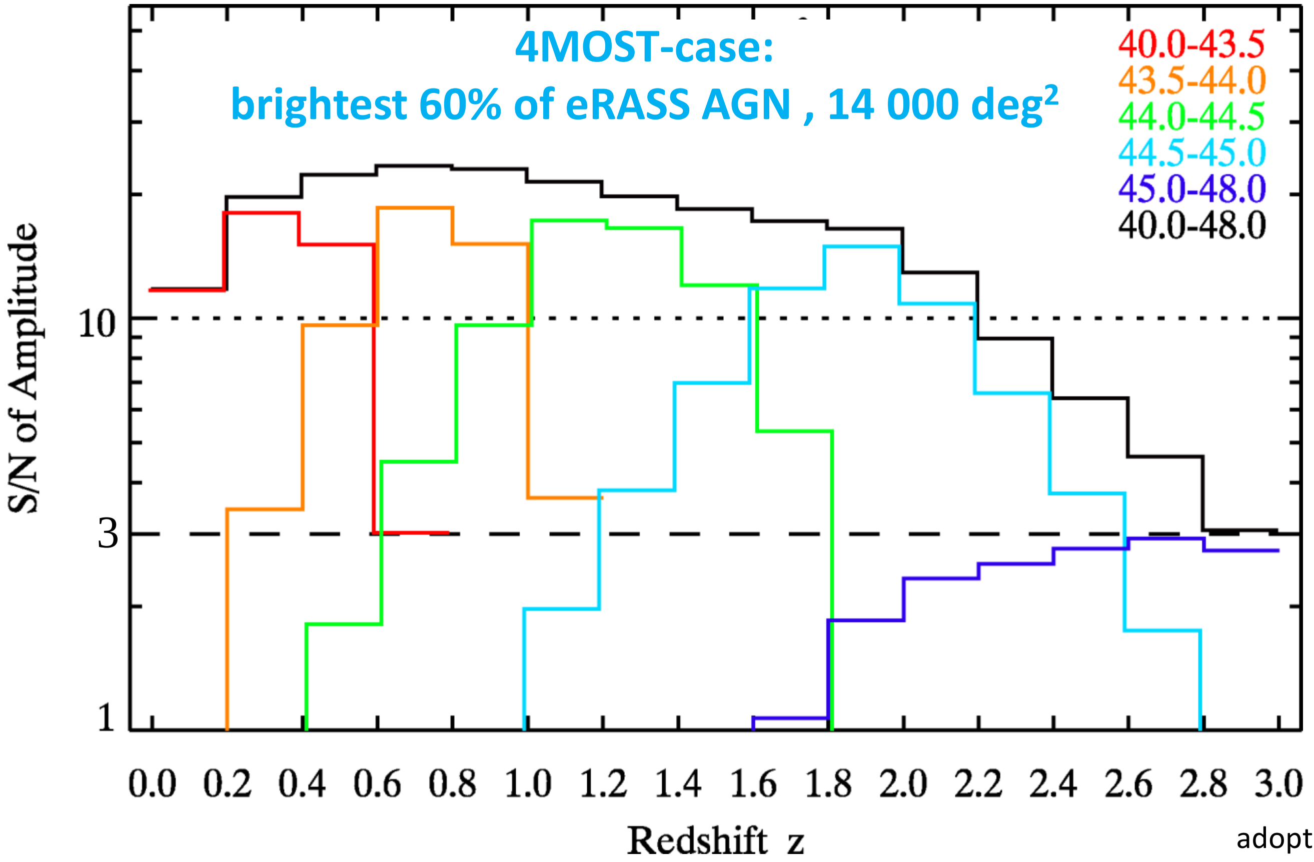
Clustering Strength vs. redshift

Max-Planck-Institut für Astrophysik



- brightest 30% (SPIDERS-case) and 2 500 deg^2:
  - good S/N (≥ 3) up to $z\sim2.0$

Clustering Strength vs. redshift

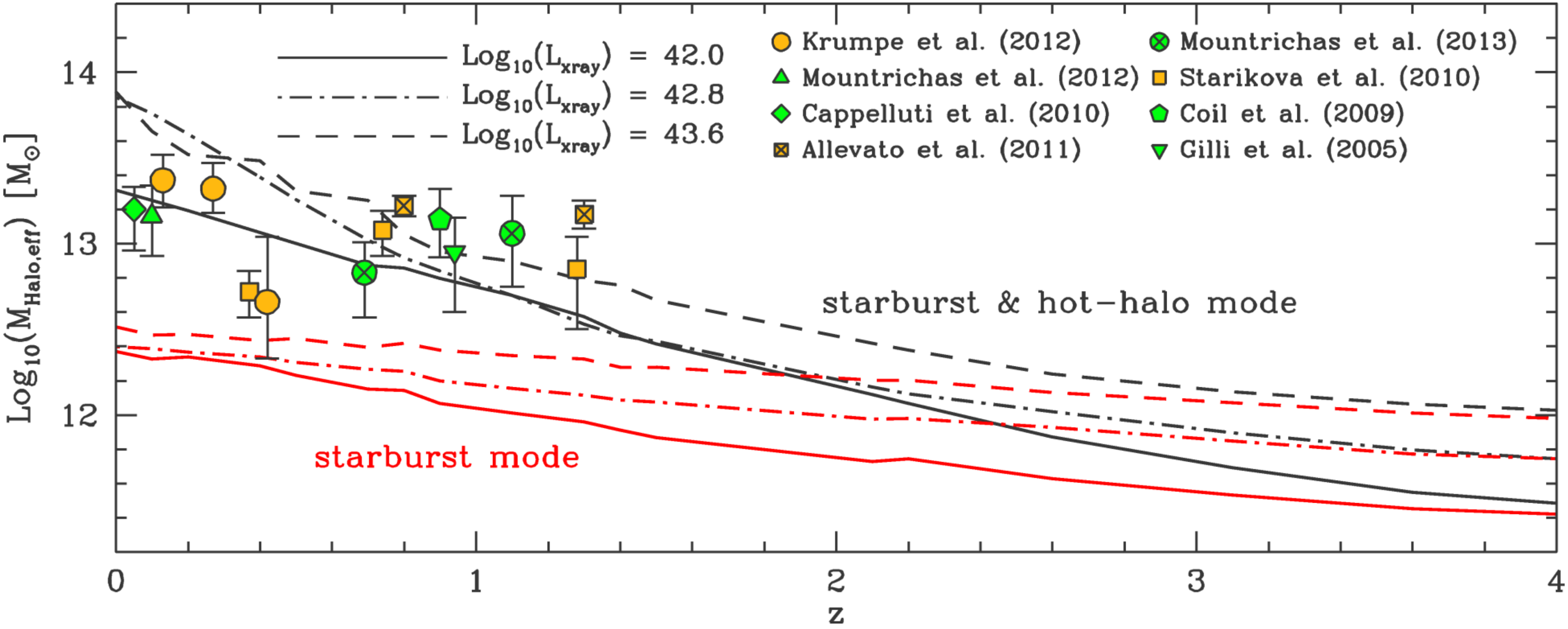


adopted from **Kolodzig+2013b**

- 1st time: accurate luminosity and redshift resolved studies
  → studies of dark-matter-halo mass of AGN to unprecedented detail
- 1st time: statistically meaningful sample of AGN with $L_X > 10^{44}$ erg/s
  → comparison with optical quasar-studies possible

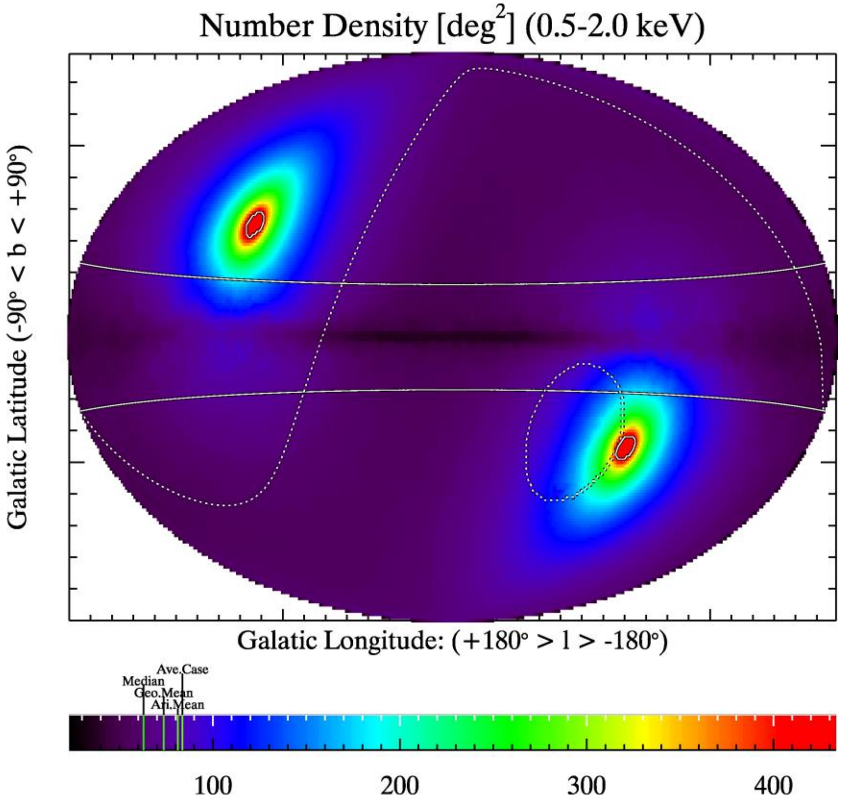
Clustering Strength Measurements - state of the art

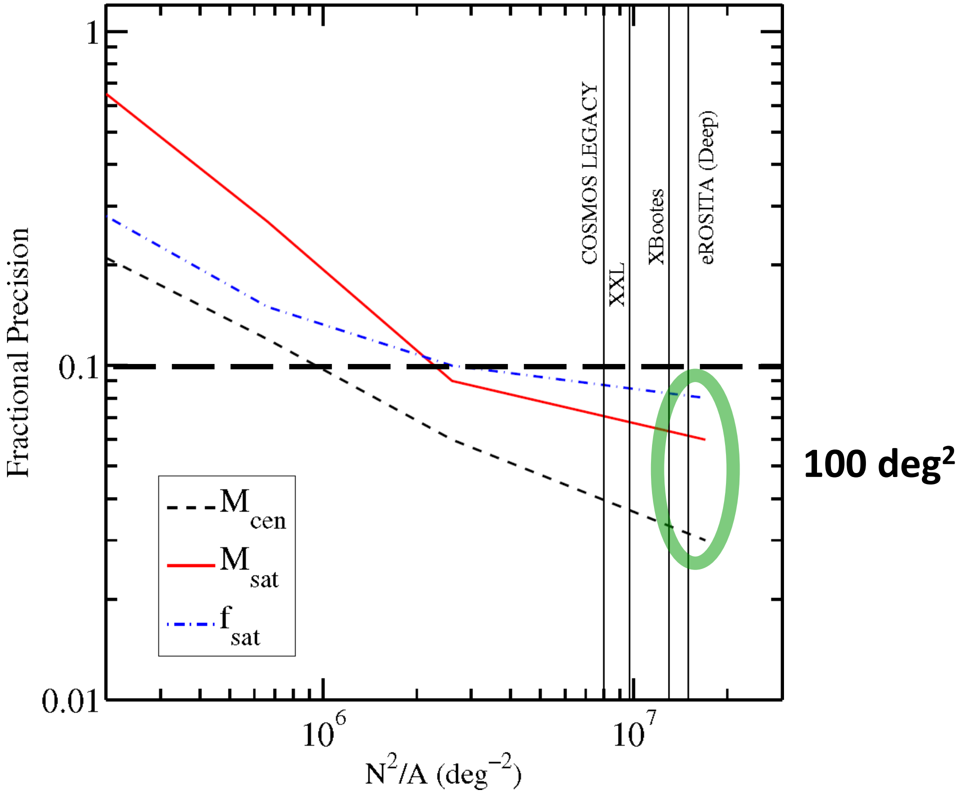
Max-Planck-Institut für Astrophysik



Fanidakis et al. 2013

Small scales: HOD modeling possible





Richardson et al. 2013

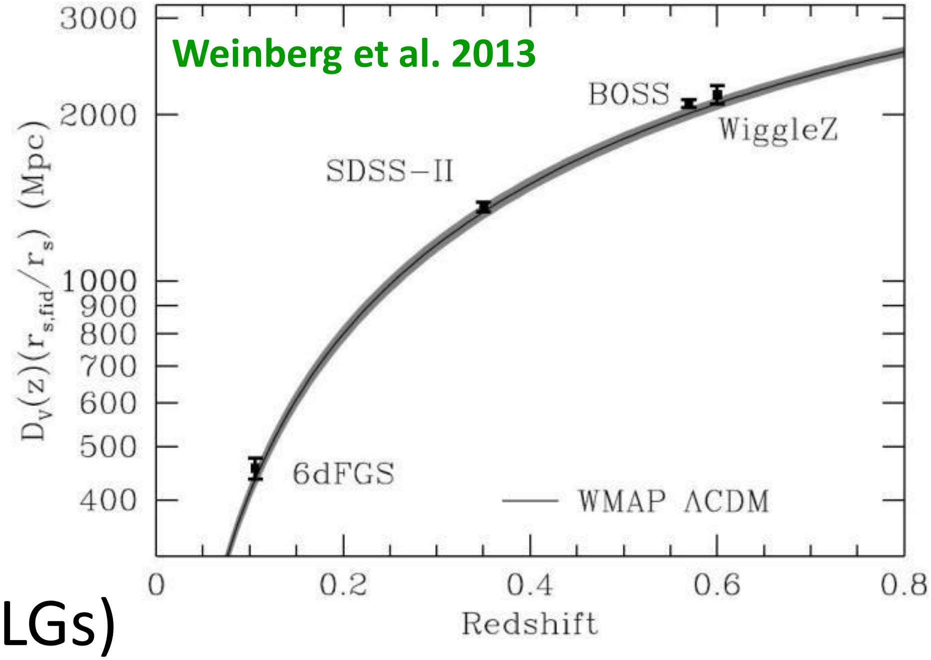
Extragal.Sky Average: ~80 AGN/deg^2

Ecliptic Poles: >400 AGN/deg^2

Baryonic Acoustic Oscillations (BAOs)

BAOs beyond z>0.8

- Redshift-Range:
  $0.8 < z < 2.0$
  - so far no detection
  - best tracers:
    AGN, QSOs and
    emission line galaxies (ELGs)

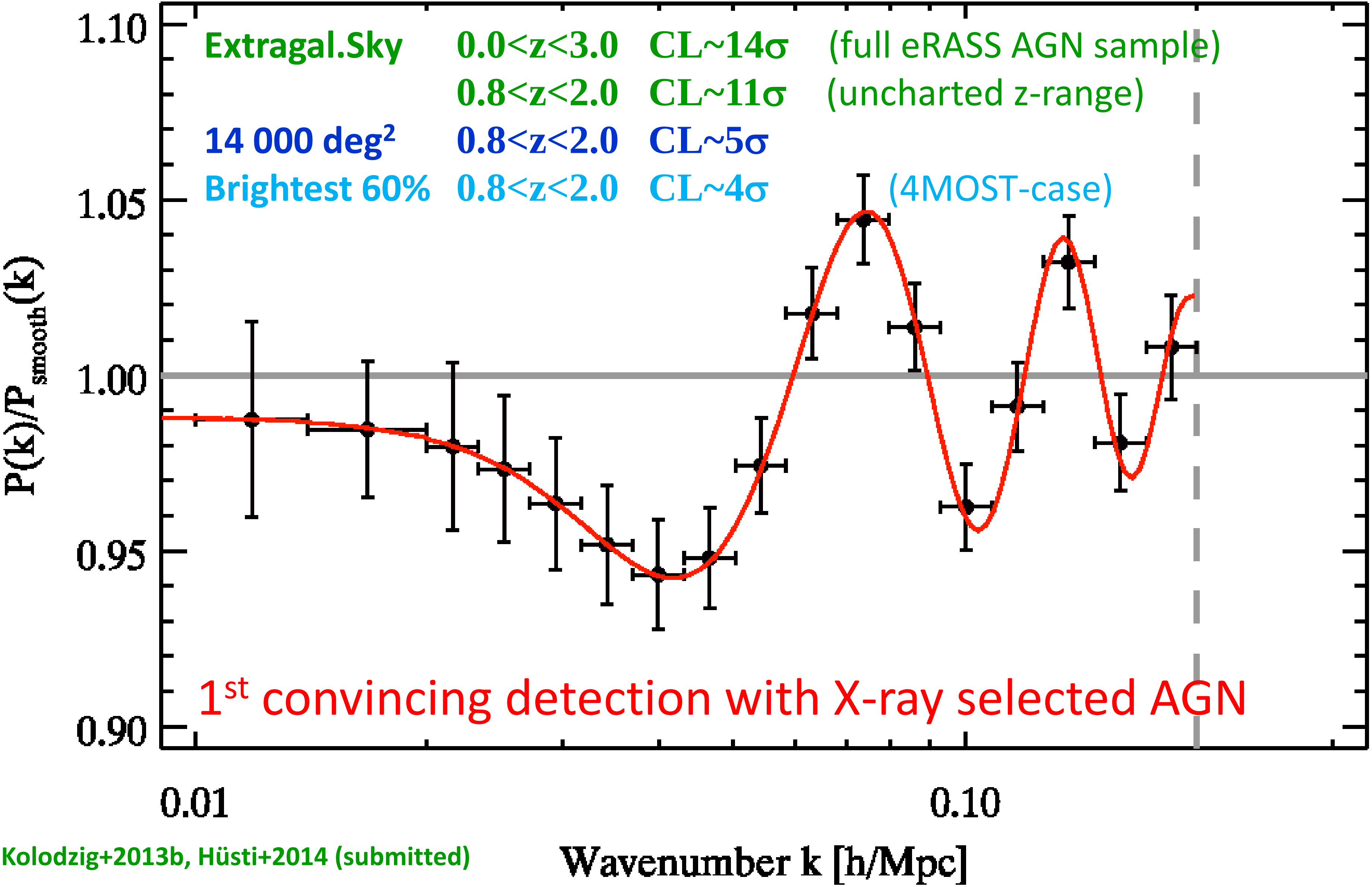


  - planned galaxy surveys:
    - **eRASS** (2014-2019): AGN ~34 kdeg^2 (4MOST: ≥14 kdeg^2)

    Dedicated optical BAO surveys:
    - **eBOSS** (2014-2020): ELGs ~1.5 kdeg^2, QSOs ~7.5 kdeg^2
    - **DESI (BigBOSS)** (>2020): ELGs ~14 kdeg^2

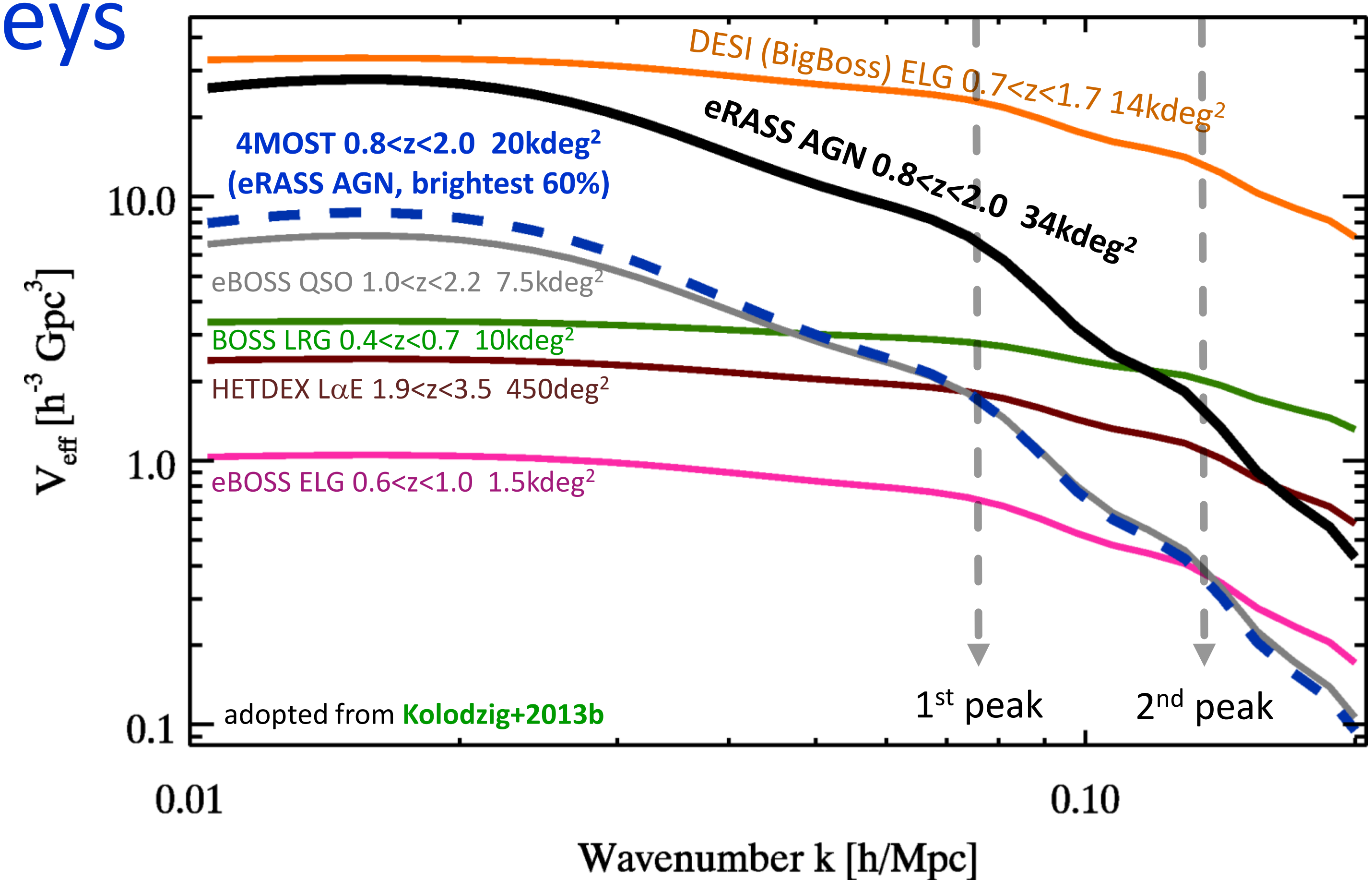
BAOs with eRASS AGN sample

Max-Planck-Institut für Astrophysik



Kolodzig+2013b, Hüsti+2014 (submitted)

Comparison with dedicated BAO surveys



- comparable with dedicated BAO surveys due to large sky coverage of eRASS (spec-z for Extragal.Sky)

We need redshifts!

Max-Planck-Institut für Astrophysik

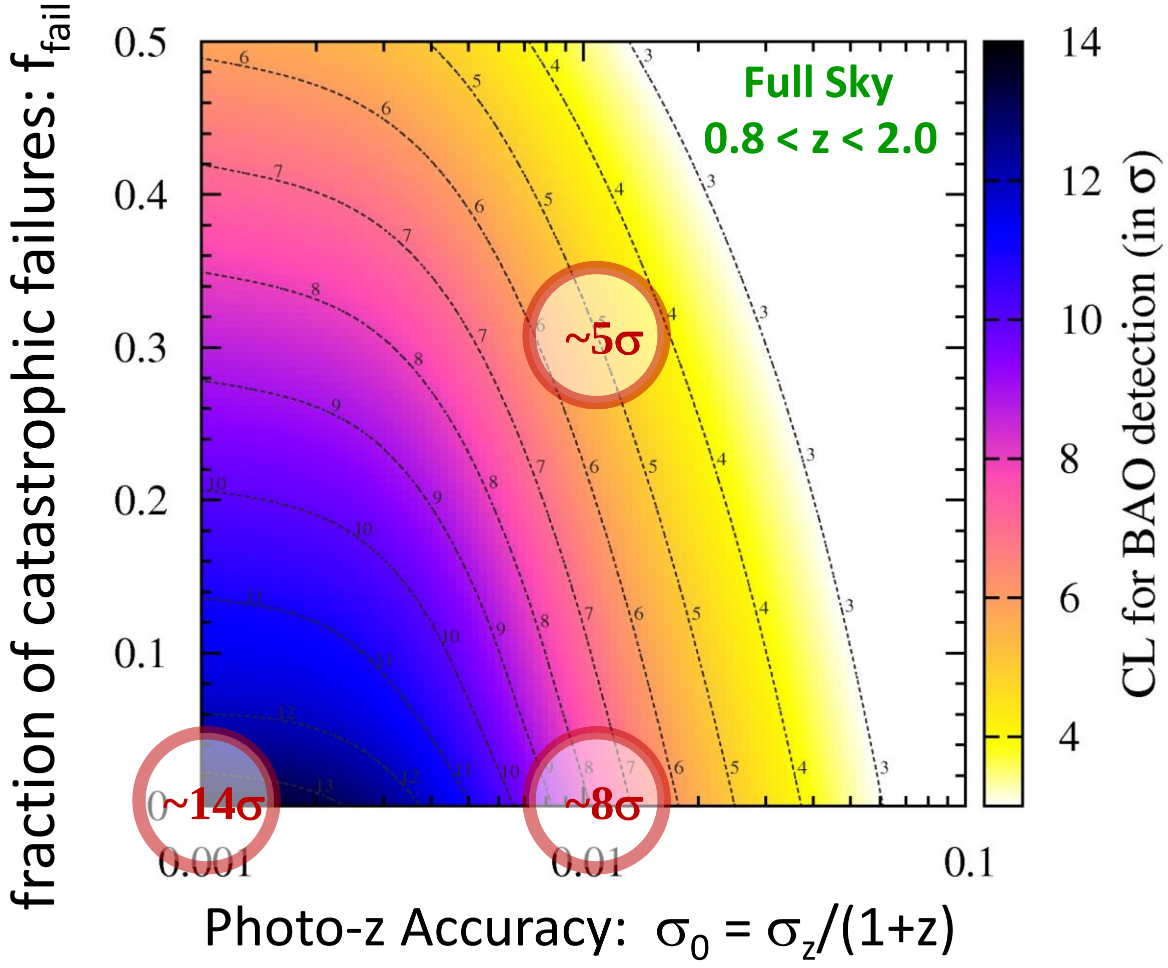
- For clustering strength & XLF:
  - Required Accuracy: $\delta z \sim 0.10$ at $z{\sim}1$ → photo-z sufficient
  - Required photometry:
    - ugrizYJHK-Bands or more (**Salvato et al. 2011**)
    - Or narrow bands as for J-PAS
  - Optimal photo-z suppliers:
    - J-PAS (2015-2021): ~8.5 kdeg^2, $\sim 7\times10^5$ counterparts ($I_{AB} = 22.5$ mag)
  - Current/future photo-z suppliers:
    - SDSS: ~14 kdeg^2, $\sim 10^6$ counterparts ($I_{AB} = 21.3$ mag), ugriz-Bands
    - Pan-STARRS PS1: ~30 kdeg^2, $>2\times10^6$ counterparts, griz-Bands
    - Euclid (2020-2026): ~15 kdeg^2 ($|b|>30°$), YJH-Bands
    - LSST (>2019): ~20 kdeg^2, ugrizy-Bands
    - …

    →Problems with reliability of photo-z (**Salvato et al. 2011**)
  - Spec-z suppliers:
    - SPIDERS: ~2.5 kdeg^2, ~50 000 spectra
    - 4MOST (>2020): ~14 kdeg^2, ~700 000 spectra

We need redshifts!

Accuracy requirements for BAO detection

Max-Planck-Institut für Astrophysik



Hüsti et al. 2014, submitted, ArXiv: 1403.5555 → see for other X-ray survey strategies

We need redshifts!

- For $\geq 3\sigma$ detection of BAOs with eRASS AGN:
  - Required Accuracy (Extragal.Sky): $\sigma_0 \leq 0.01$
  - Required Size (for spec-z): $\geq 10\,000$ deg^2
  - Potential suppliers:
    - J-PAS (2015-2021): ~8.5 kdeg^2, ~700 000 counterparts → ~3σ with $\sigma_0 \sim 0.01$ ($f_{fail} = 0.0$)
    - 4MOST (>2020): ~14 kdeg^2, ~700 000 spectra → ~4σ

Summary

- AGN sample of eROSITA/SRG All-Sky Survey:

  "New era of large-scale structure studies with AGN"

  - Clustering strength:
    - $>10\%$ accuracy for wide z-range for $\geq 2\ 500\ \mathrm{deg}^2$; → SPIDERS: $>30\%$ up to $z{\sim}2$
    - 1st time: Luminosity & redshift resolved studies of dark-matter-halo mass of AGN up to $z{\sim}3$
    - 1st time: comparison with optical quasar studies (for $L_X > 10^{44}$ erg/s)
  - Baryonic Acoustic Oscillations:
    - 1st time: convincing detection with X-ray selected AGN
    - possible $\sim 11\sigma$ for extragalactic sky & uncharted region: $0.8<z<2.0$; → 4MOST $\sim 4\sigma$
    - Comparable with dedicated optical surveys

- Remarks:
  - We rely on large & deep photometric & spectroscopic follow-up surveys
  - Cross-correlation with other galaxy types (e.g. ELGs) might have even better statistics

- For details see:

  Kolodzig et al. 2013b, A&A 558, 90 (ArXiv: 1305.0819)

  Hüsti et al. 2014, submitted (ArXiv: 1403.5555)

alex@mpa-garching.mpg.de