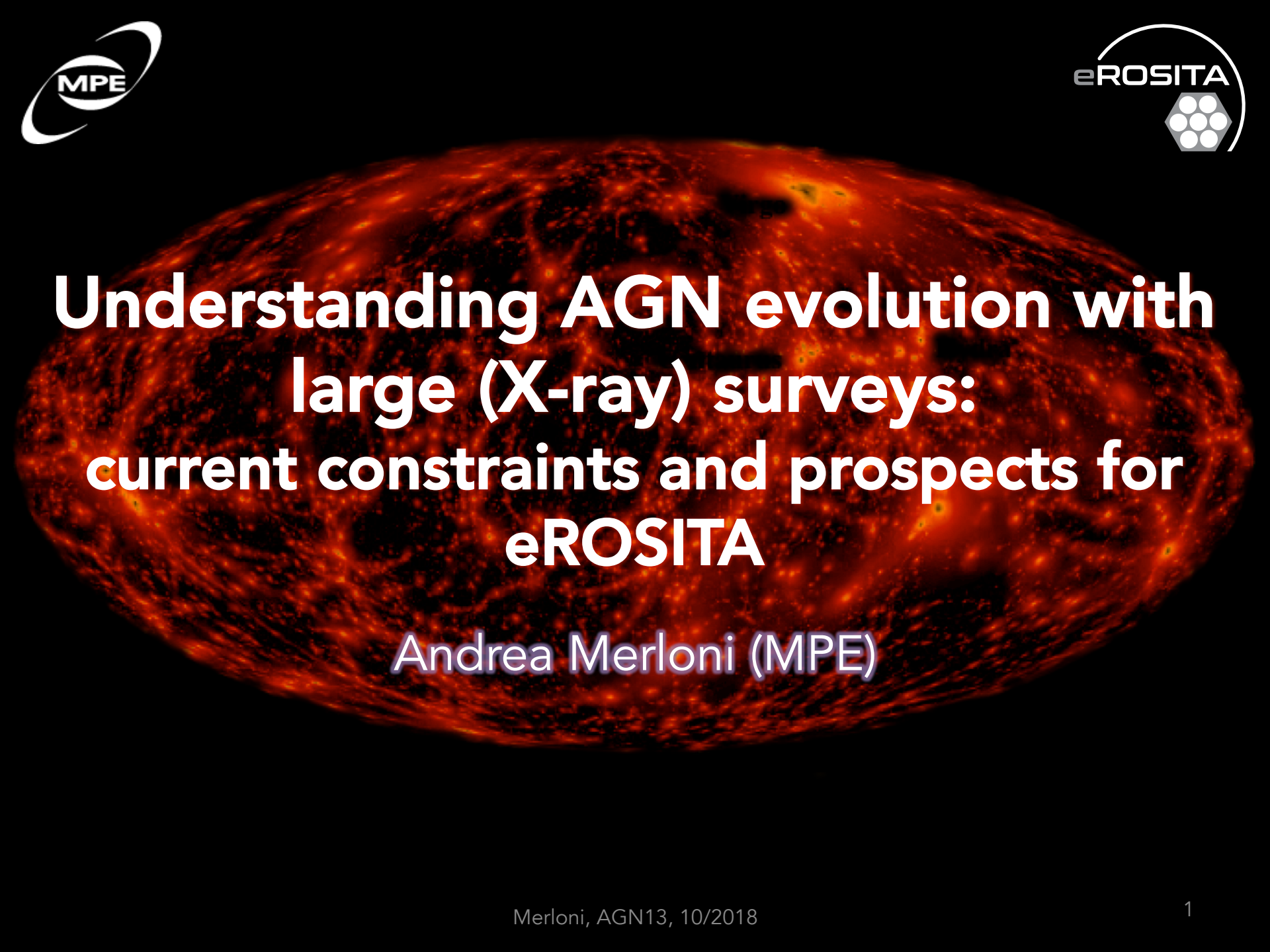
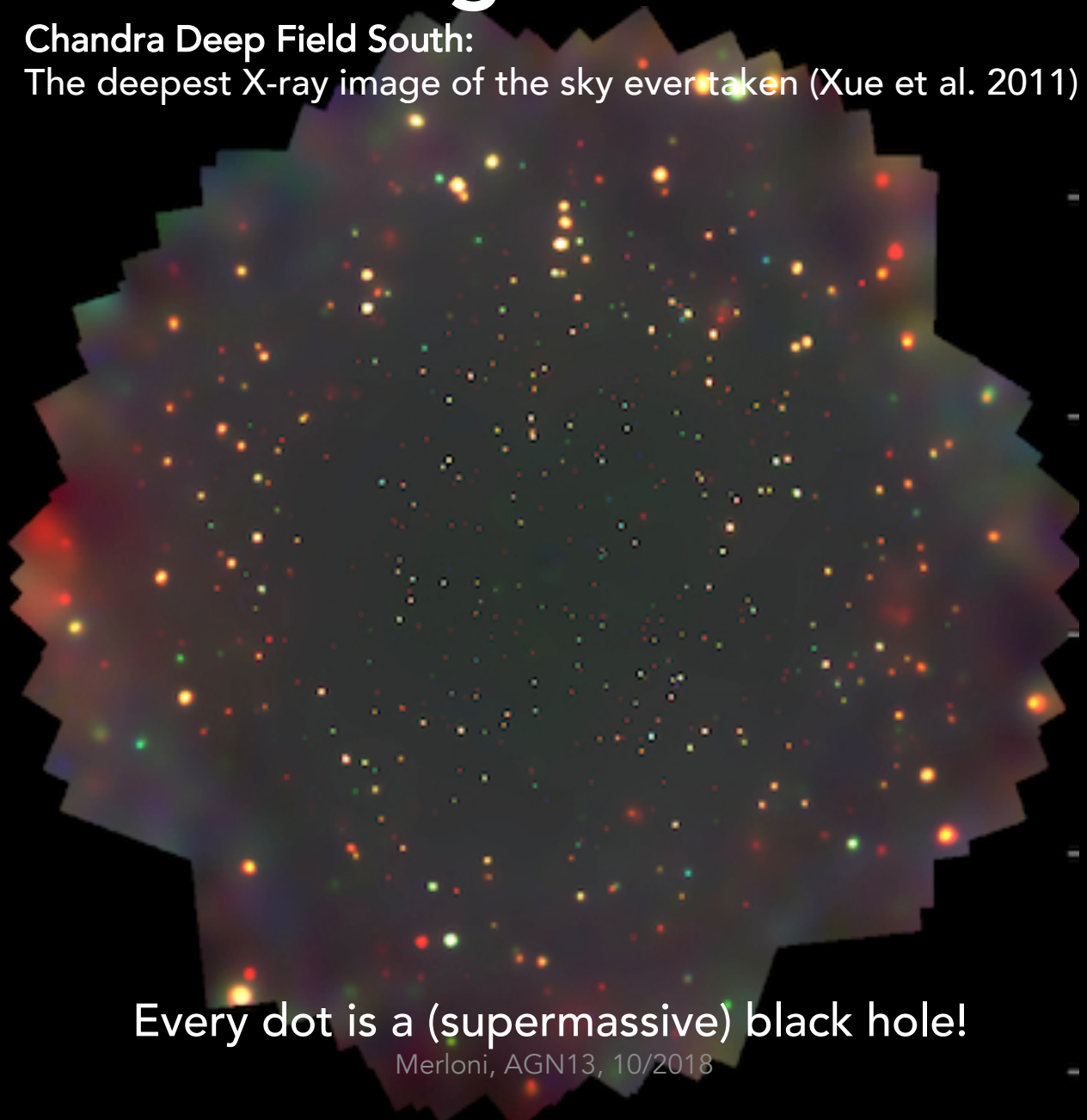


Understanding AGN evolution with large (X-ray) surveys: current constraints and prospects for eROSITA

Andrea Merloni (MPE)

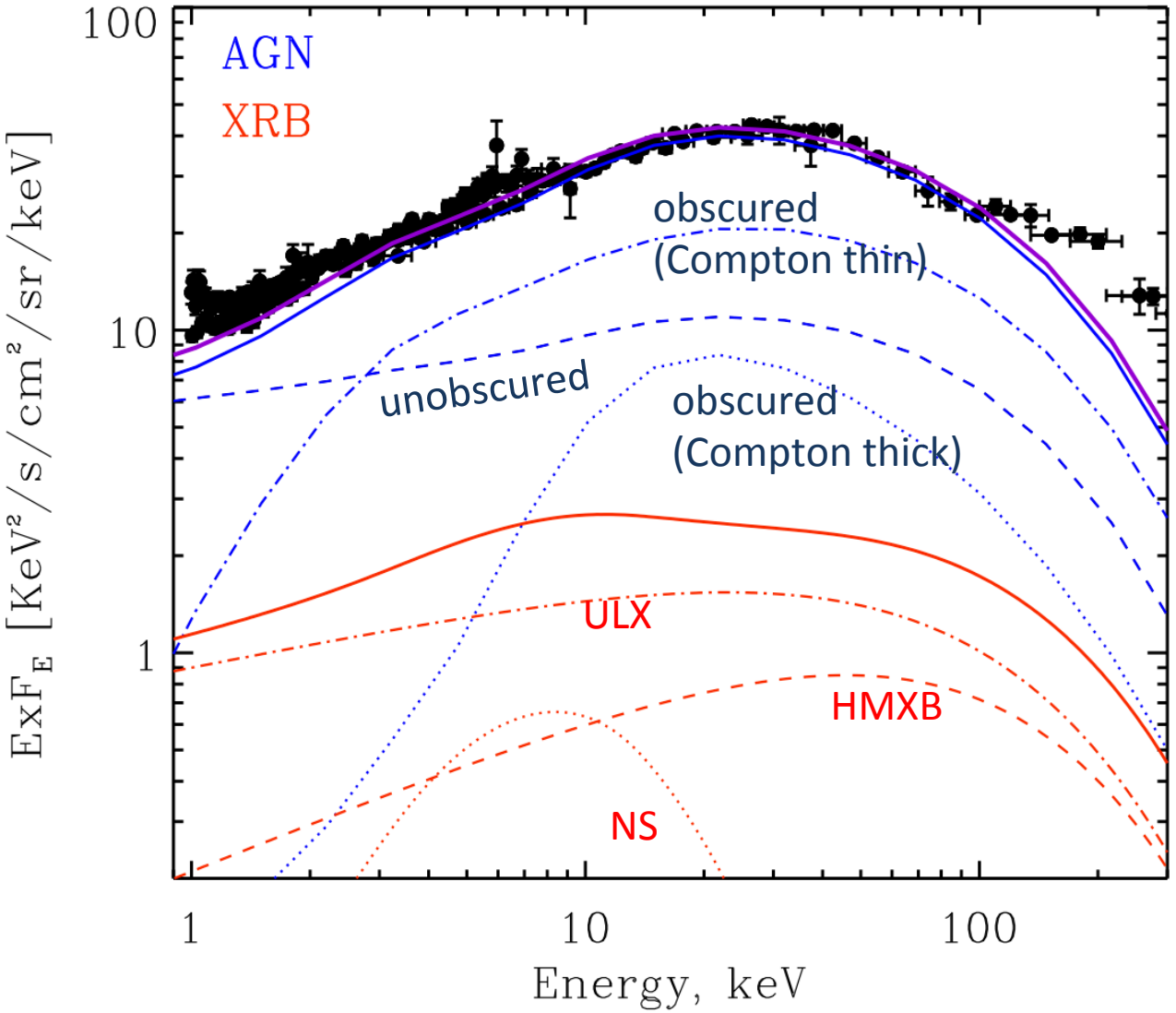
Accreting black holes

Chandra Deep Field South:
The deepest X-ray image of the sky ever taken (Xue et al. 2011)



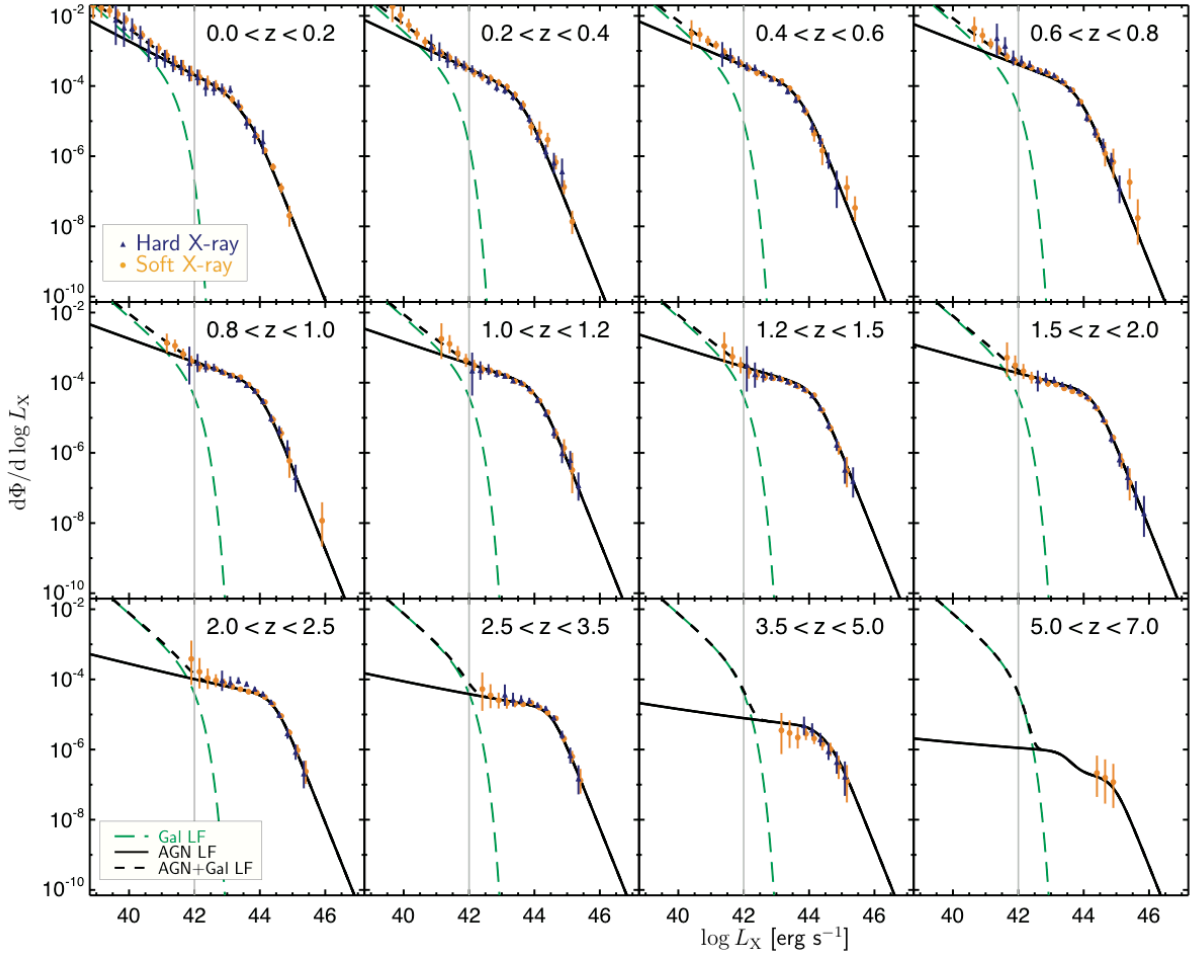
Every dot is a (supermassive) black hole!

X-ray Background resolved



Comastri & Setti 1995; Gilli+2007; Treister+ 2009; Akylas+ 2012; Aird+ 2015

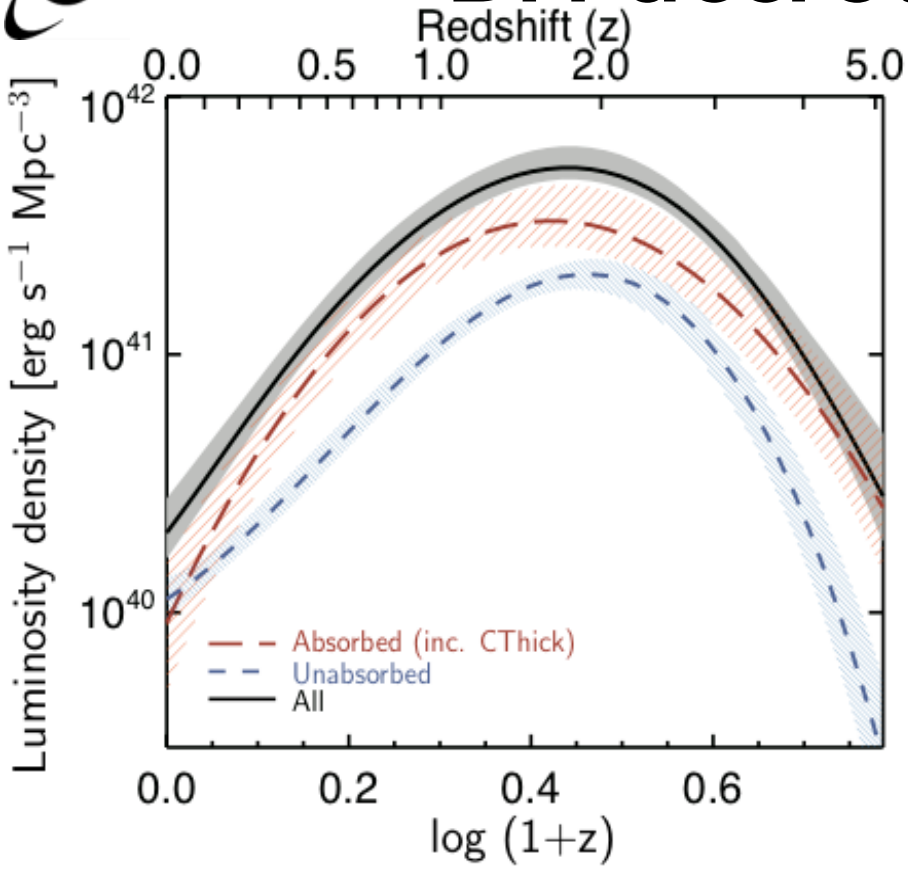
X-ray luminosity function

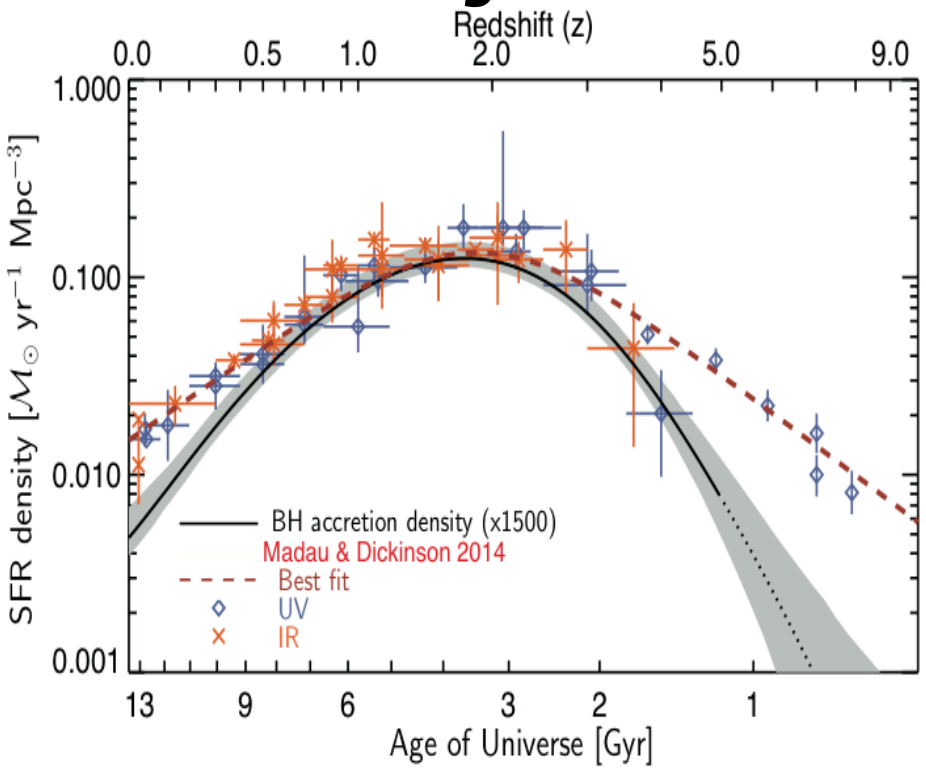


Aird et al. 2015;
See also Ueda et al. 2014; Buchner et al. 2015 Myiaji et al. 2015

- Explore a wide range in Luminosity AND redshift
- Understand **selection function and absorbing column distribution**
- Combine different surveys

BH accretion history



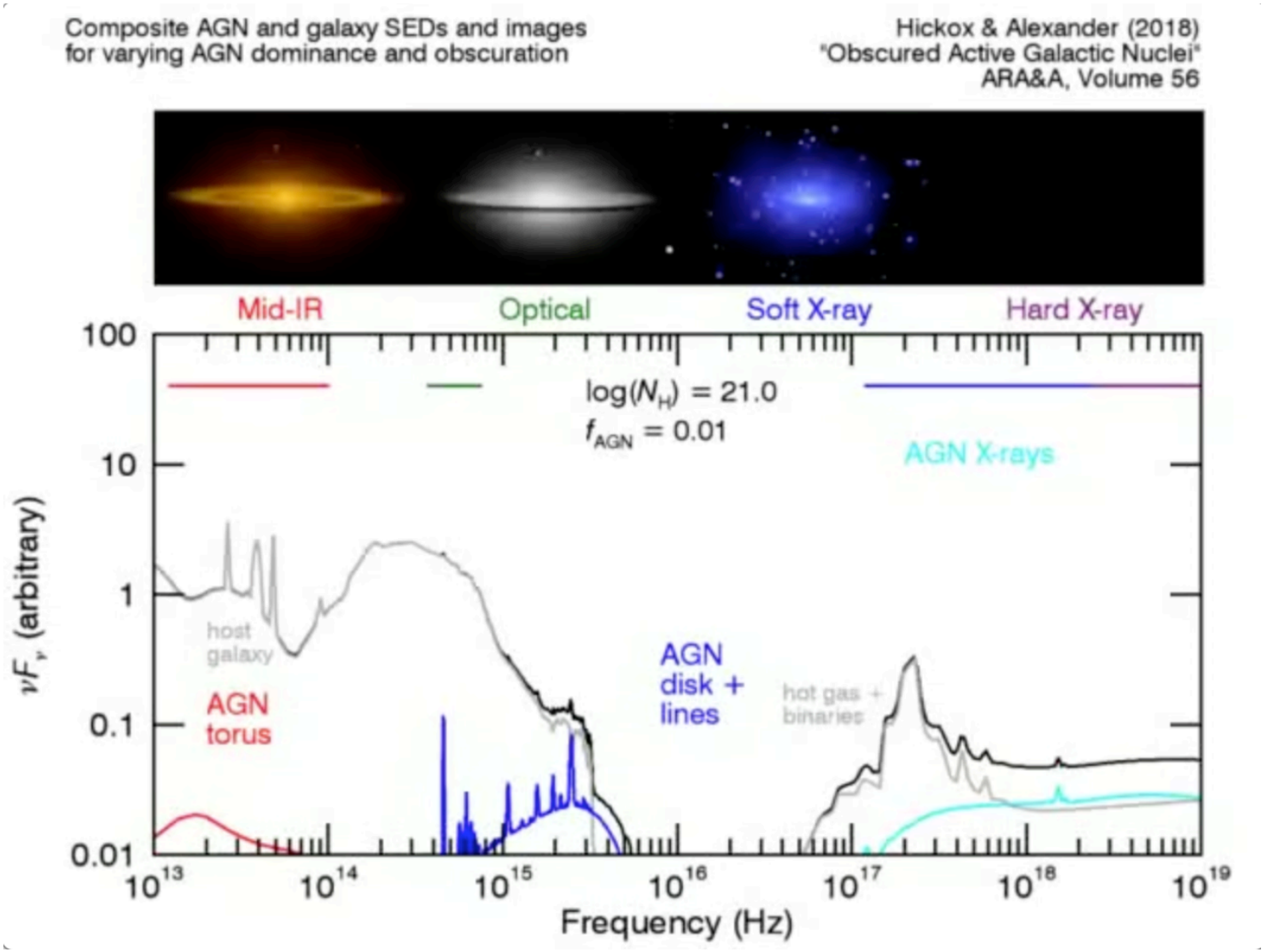


Most SMBH growth in radiatively **efficient** flows (Soltan argument) and behind a veil of obscuration

SMBH growth broadly traces evolution of Star Formation Rate in galaxies

Aird et al 2015; Ueda+ 2003; Marconi+ 2004; Merloni & Heinz 2008; Ueda+ 2014; Delvecchio+ 2014; Buchner+ 2015; Myiaji+ 2015, Merloni 2016, etc.

BH census, matter of contamination



Hickox & Alexander (2018)

AGN selection basics: contrasts

Assume: (1) $M_{BH}/M_* = A_0$; (2) $\log SFR = \alpha(z)(\log M_* - 10.5) + \beta(z)$

(BH-galaxy scaling relation) ("Main sequence" of star formation)

$$\frac{L_{\rm X,AGN}}{L_{\rm X,SF}} \approx 10^5 \lambda\, 10^{-\beta(z)} \left(\frac{f_X}{0.03}\right)\left(\frac{A_0}{0.002}\right)\left(\frac{M_*}{10^{10.5} M_\odot}\right)^{1-\alpha(z)}$$

$$\frac{L_{\rm 1.4GHz,AGN}}{L_{\rm 1.4GHz,SF}} \approx 10^{5.6} \left(\frac{\eta_j}{\epsilon}\lambda\right)^{1.16} 10^{-\beta(z)} \left(\frac{M_*}{10^{10.5} M_\odot}\right)^{1.16-\alpha(z)}$$

$$\frac{L_{\rm IR,AGN}}{L_{\rm IR,SF}} \approx 160 \lambda\, 10^{-\beta(z)} \left(\frac{f_{24}}{0.1}\right)\left(\frac{A_0}{0.002}\right)\left(\frac{M_*}{10^{10.5} M_\odot}\right)^{1-\alpha(z)}$$

$$\frac{L_{\rm B,AGN}}{L_{\rm B,host}} = 39\lambda \left(\frac{f_{\rm B}}{0.1}\right)\left(\frac{A_0}{0.002}\right)\frac{(M_*/L_{\rm B})_{\rm host}}{3(M_\odot/L_\odot)}$$

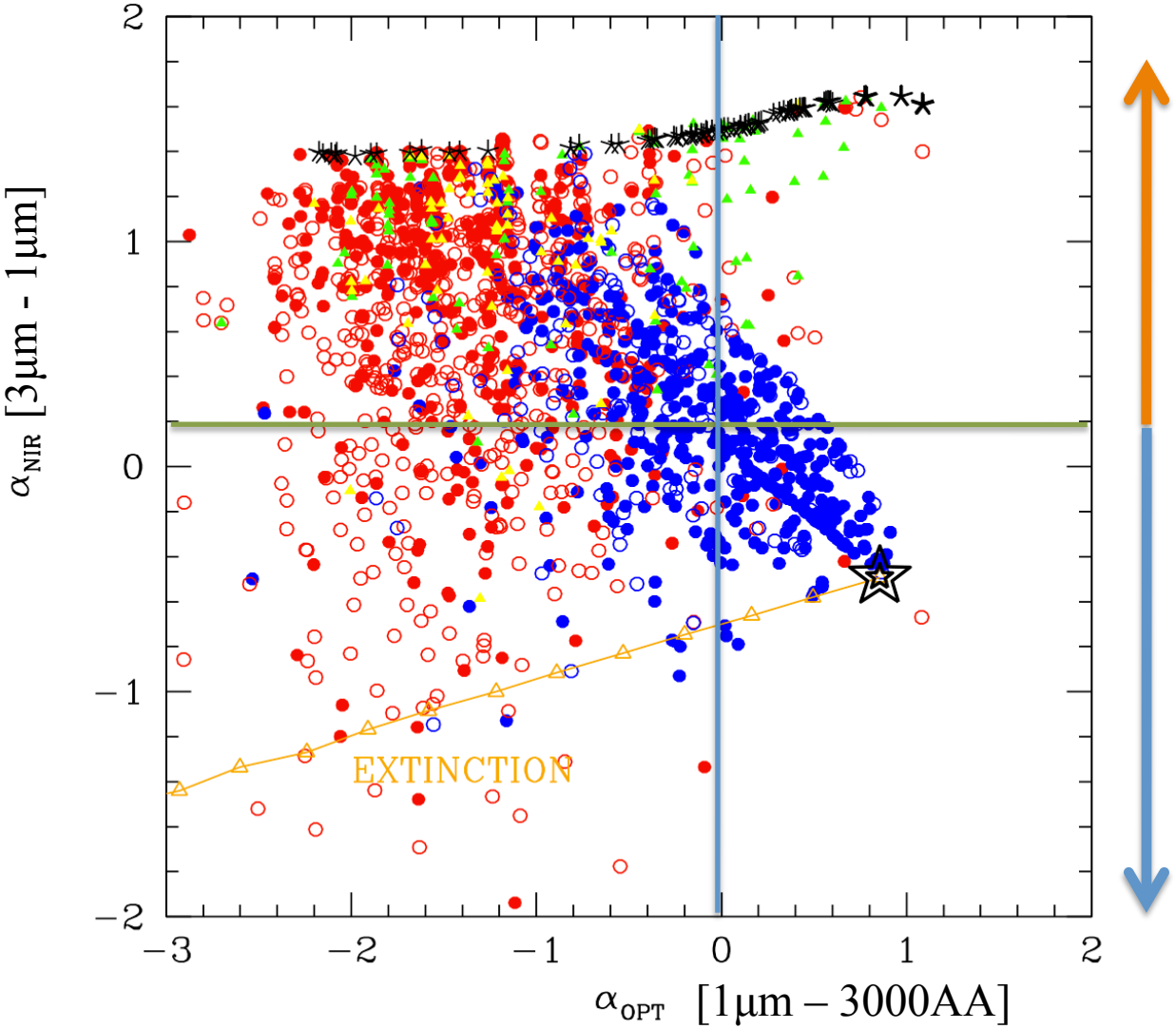
λ = Eddington ratio

Hopkins+ 2009
Merloni (2016)

AGN selection basics: contrasts

	Critical Eddington rate [$M^* = 10^5\ M_{sun}$]		"visible fraction
	z=0	**z=1**	
X-ray	$\approx 2*10^{-5}$	$\approx 2*10^{-4}$	~ 80%
Radio ($\eta_j=\varepsilon$)	$\approx 3*10^{-5}$	$\approx 2*10^{-4}$	ALL? 10%?
MIR	≈ 0.015	≈ 0.13	ALL
Opt/UV	≈ 0.025	≈ 0.2	<50%

Optical/NIR mixing diagram



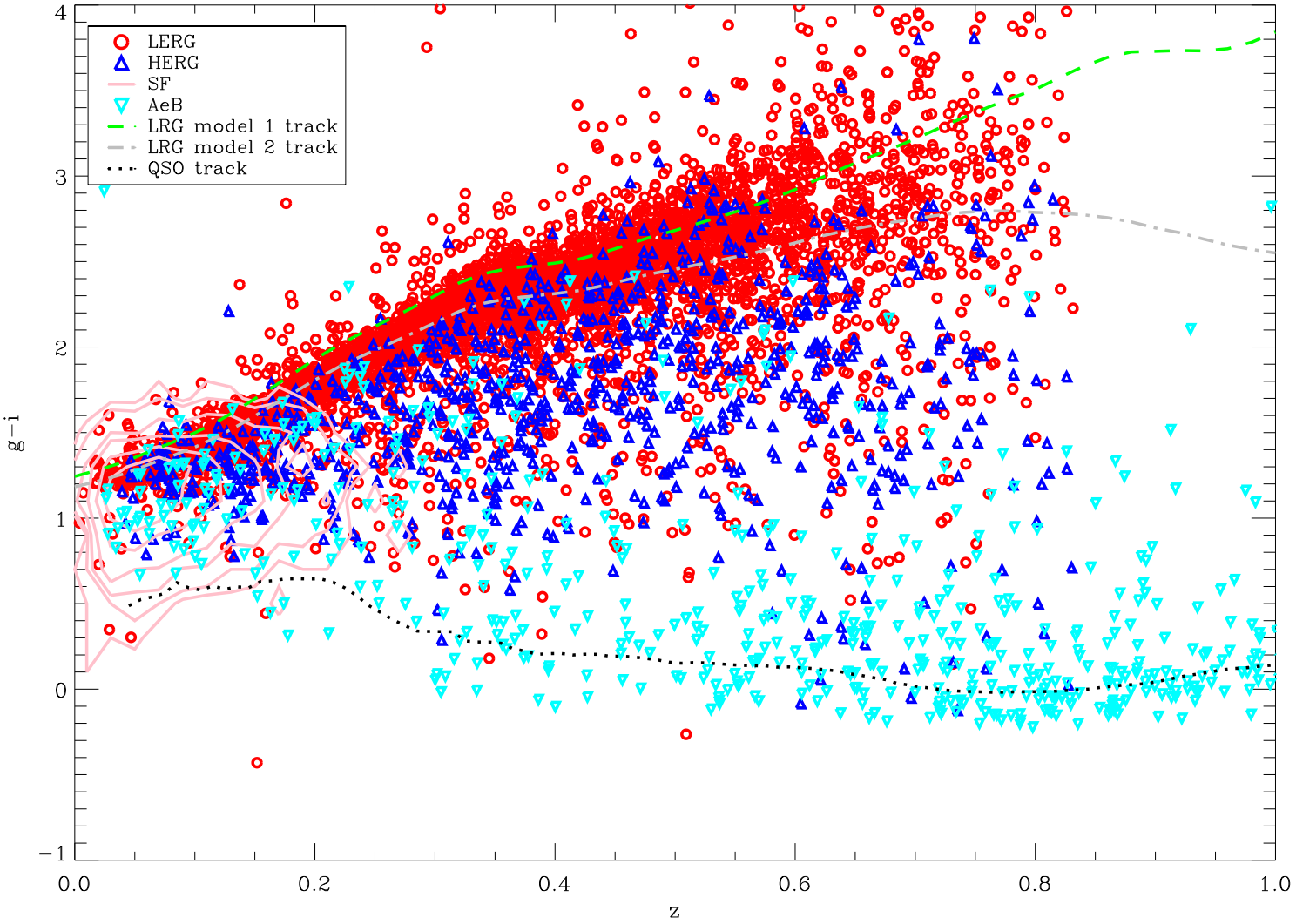
Galaxy dominates

AGN dominates

Hao et al. 2012;
Bongiorno et al. 2012

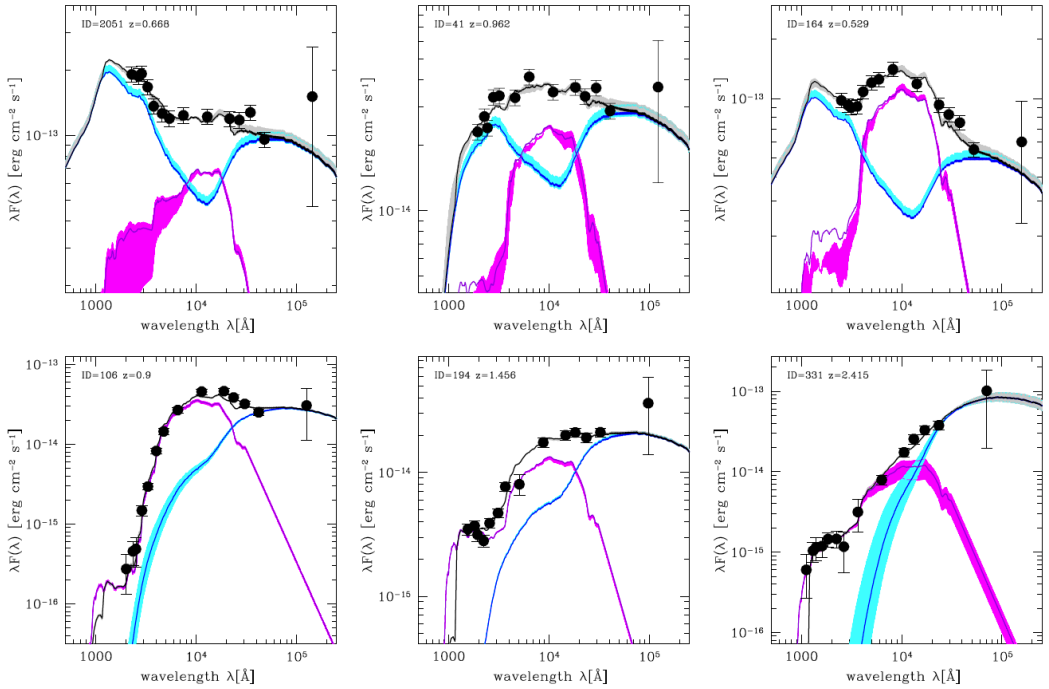
Radio mixing diagram

Ching et al. 2016



XMM-COSMOS AGN

- 1555 X-ray selected AGN (XMM; f_{lim}~ **5×10^{-16}**[0.5-2]; **3×10^{-15}**[2-10])
- **100% redshift complete** (54% specz; 46% photoz)
- 602 Unobscured (71% specz); 953 Obscured (42% specz)
- **Parent sample** ~200k IRAC galaxies (photoz, M_*; Ilbert et al. 2010)

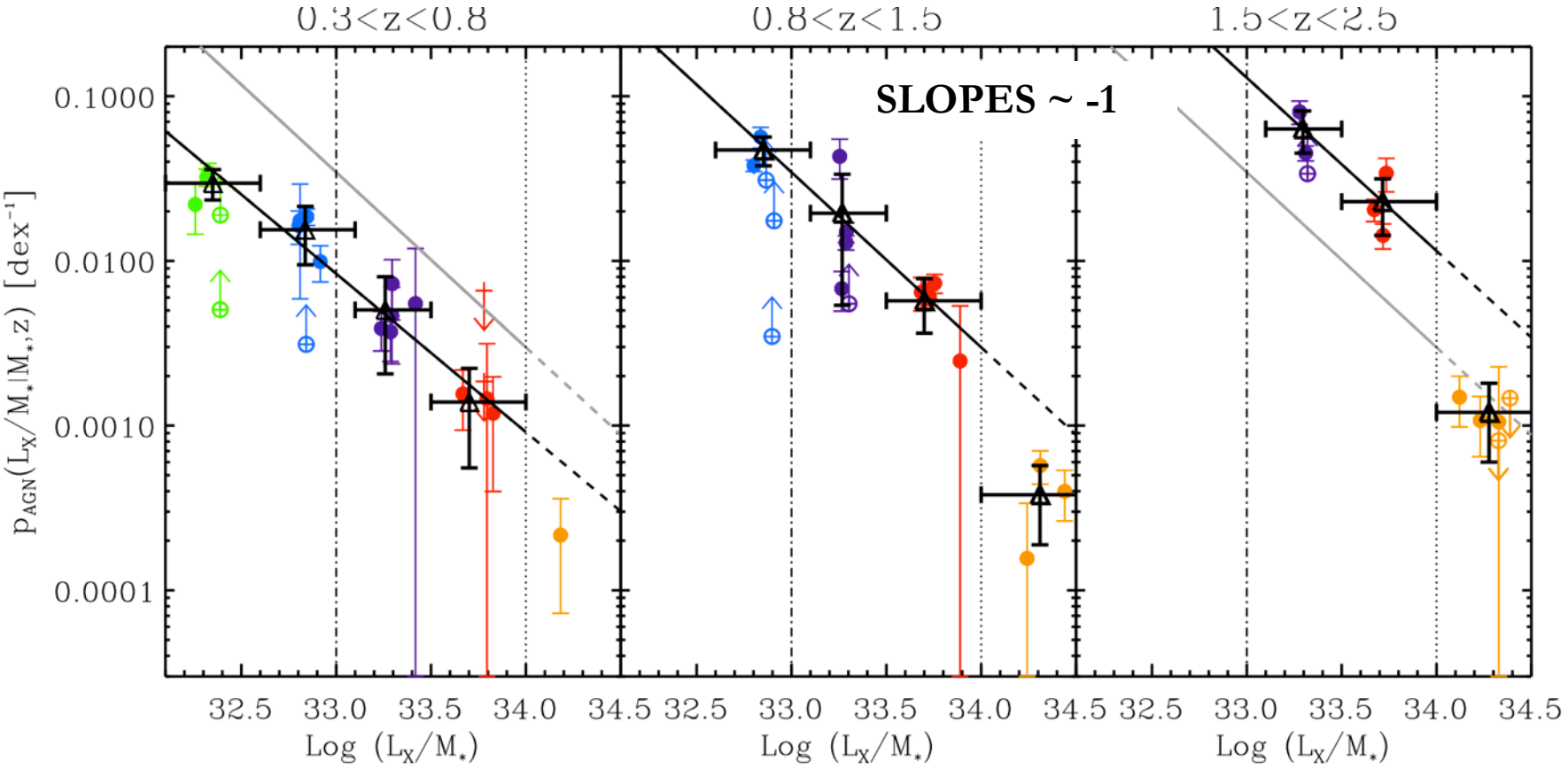


- Uniquely rich multi-wavelength photometry used to **decompose AGN and host galaxy light** in SED fitting

Bongiorno et al. 2012;

Brusa+ 2010; Salvato+ 2009; Lusso+ 2011, 2012; Merloni+ 2014

Specific accretion rate distributions

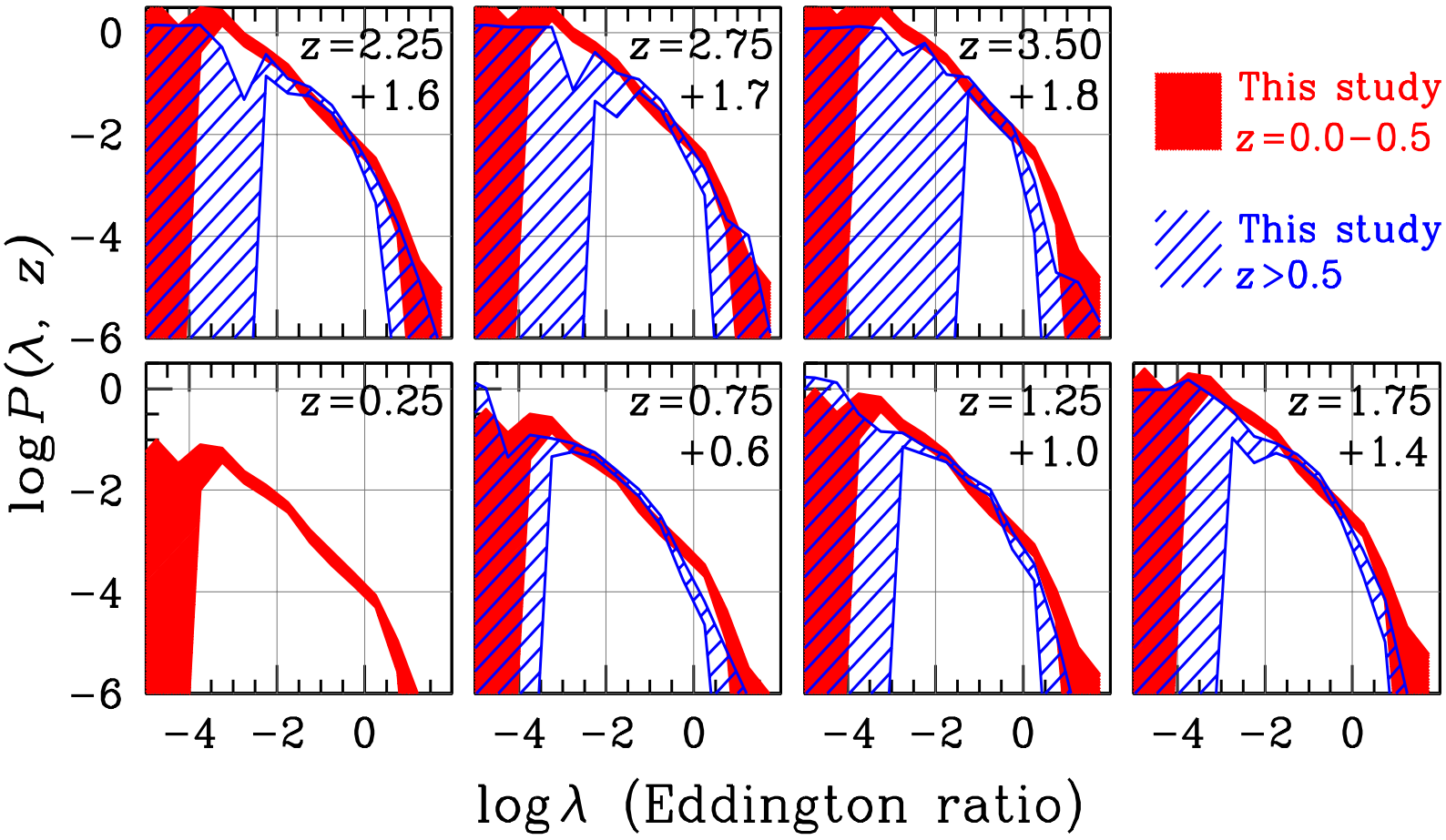


"Specific Accretion rate" (Aird et al. 2012)

Bongiorno et al. 2012

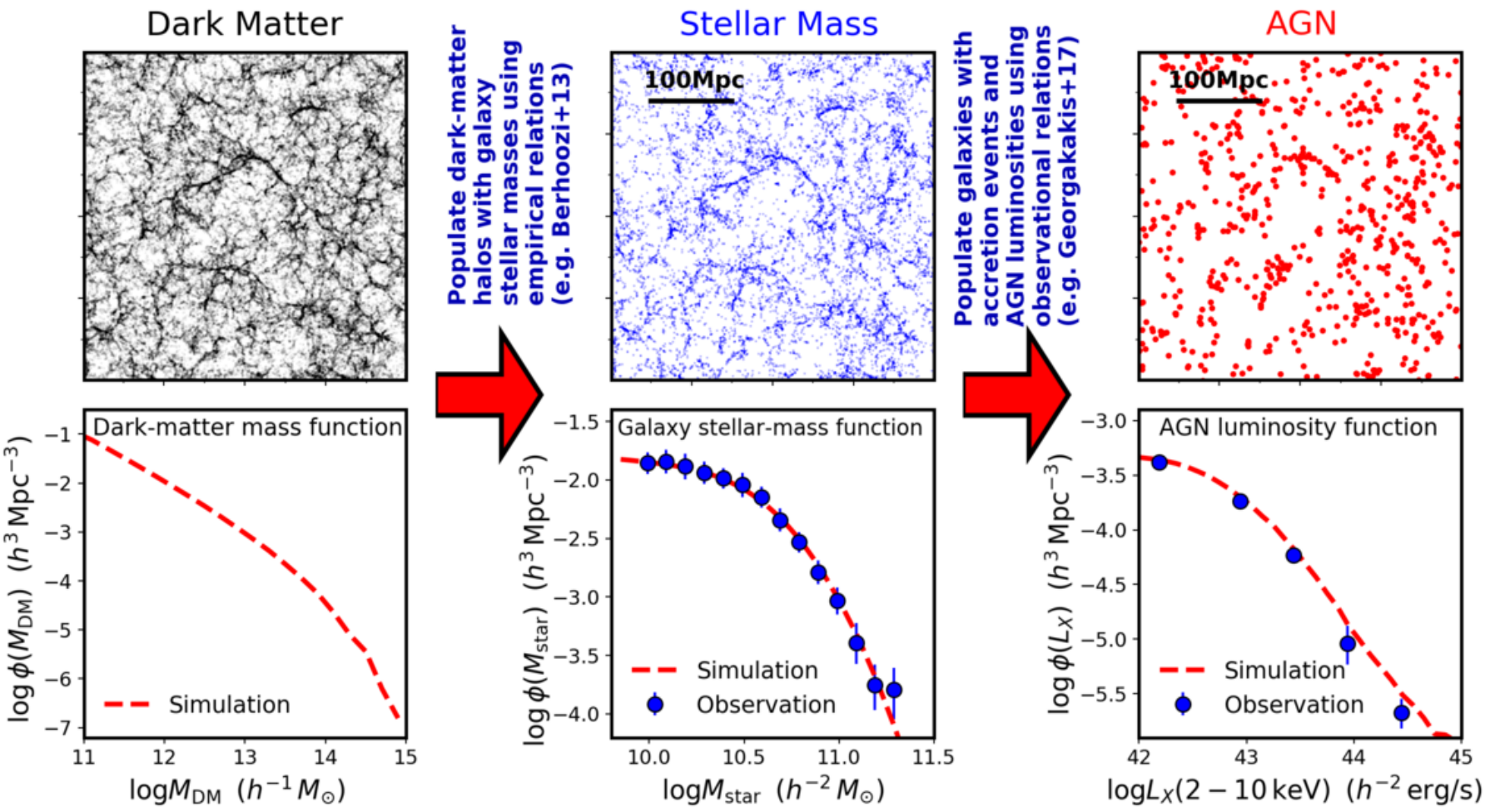
AGN fraction at fixed L_X/M_* ~independent on galaxy mass! Normalization increases as **~(1+z)^4** [cfr. sSFR density]. Break consistent with **~Eddington limit?**

Eddington rate functions



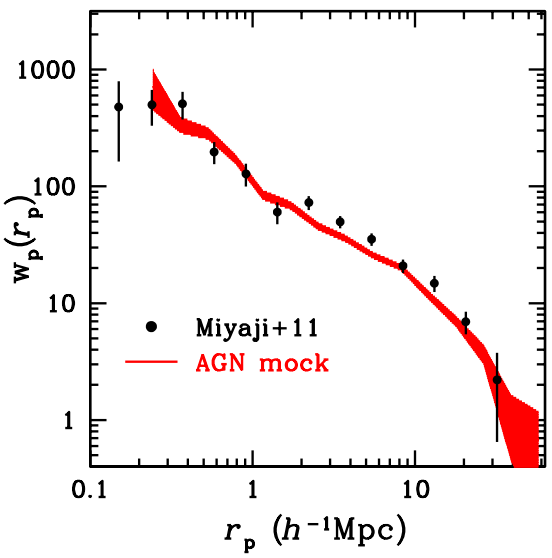
Georgakakis et al. 2017; Aird et al. 2017, see also Bongiorno et al. 2016

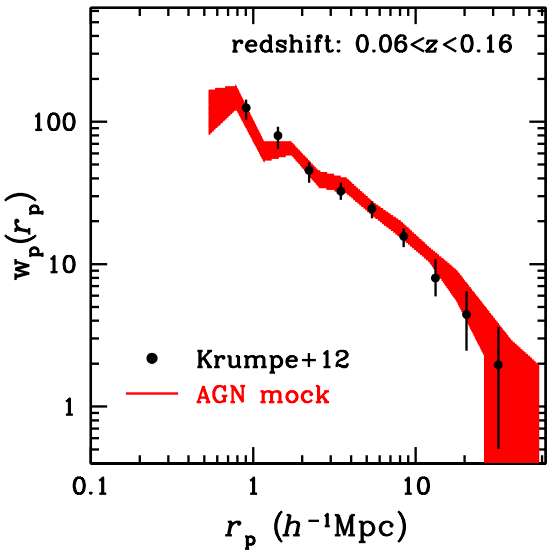
AGN mocks in LSS

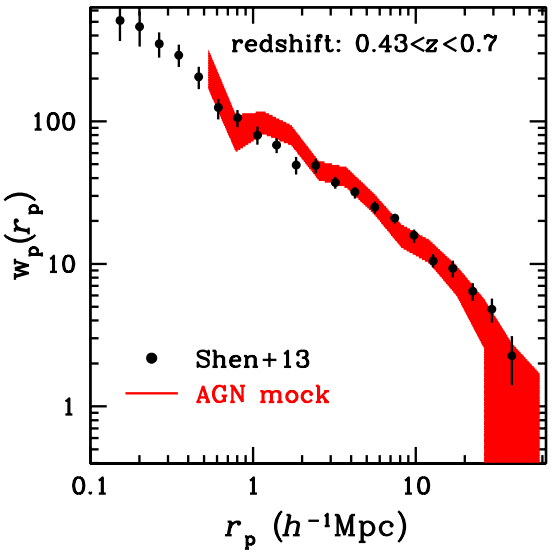


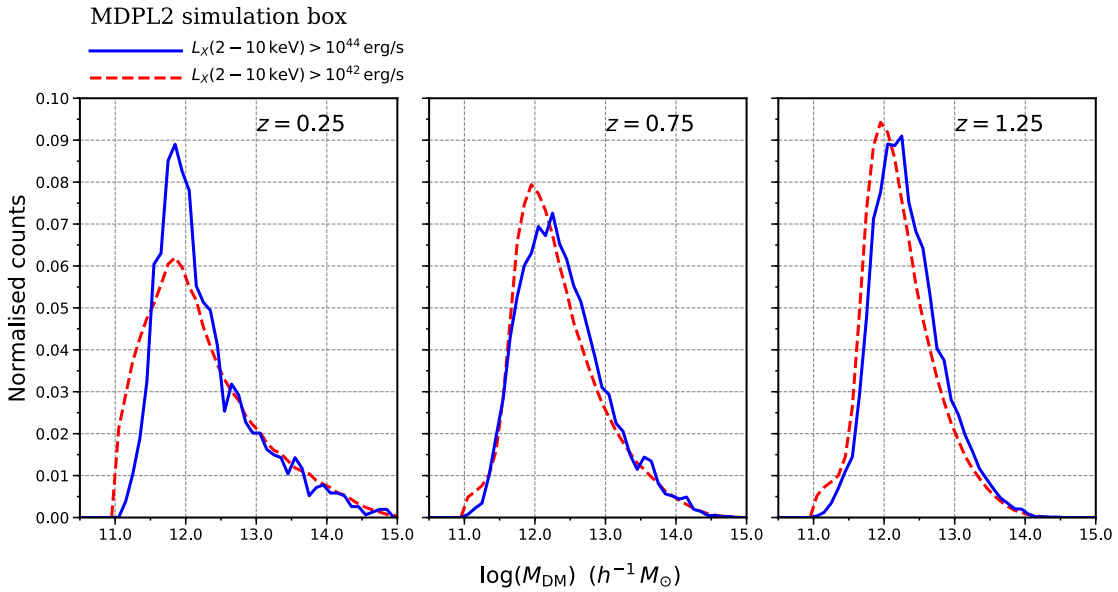
Georgakakis et al. 2018, submitted

AGN mocks and LSS









Georgakakis et al. 2018, submitted

Take home messages #1

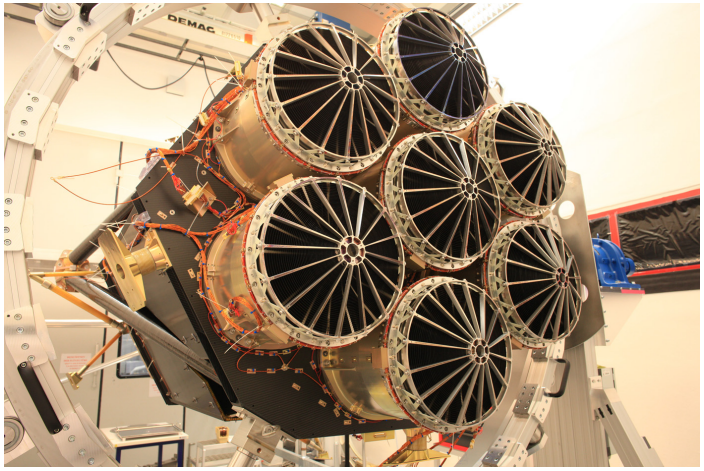
- Accretion rate distributions are key diagnostics of AGN evolution and connection to triggering
- Globally, they can be constrained with state of the art X-ray survey data
- Little evidence of 'typical' AGN being different that overall galaxy population
- A stochastic phenomenon; some particular condition may enhance this probability: mergers, central vs. satellite, etc., but evidence is tantalizing

The need for larger samples

- X-ray surveys provide the least biased view of AGN (against obscuration/ extinction and galaxy dilution)
- We have probed most of the accretion history in the Universe (at least in mass-averaged terms)
- Still, existing X-ray surveys are limited by the sample size (~a few 10^3), mainly because of the limited field of view of sensitive, focusing, X-ray telescopes.
- Larger samples are mandatory to accurately study DISTRIBUTIONS of AGN vs. L, z, λ, N_H, SFR, M* (stochasticity of AGN phenomenon)
- The next step forward will be to bring the study of AGN evolution to the level of statistical significance that galaxy evolution studies enjoyed since the advent of SDSS (-> 10^6)
- WISE has already ushered us in this era, and next generation radio surveys (ASKAP, LOFAR, MeerKAT, APERITF, JVLA) will provide a great step forward

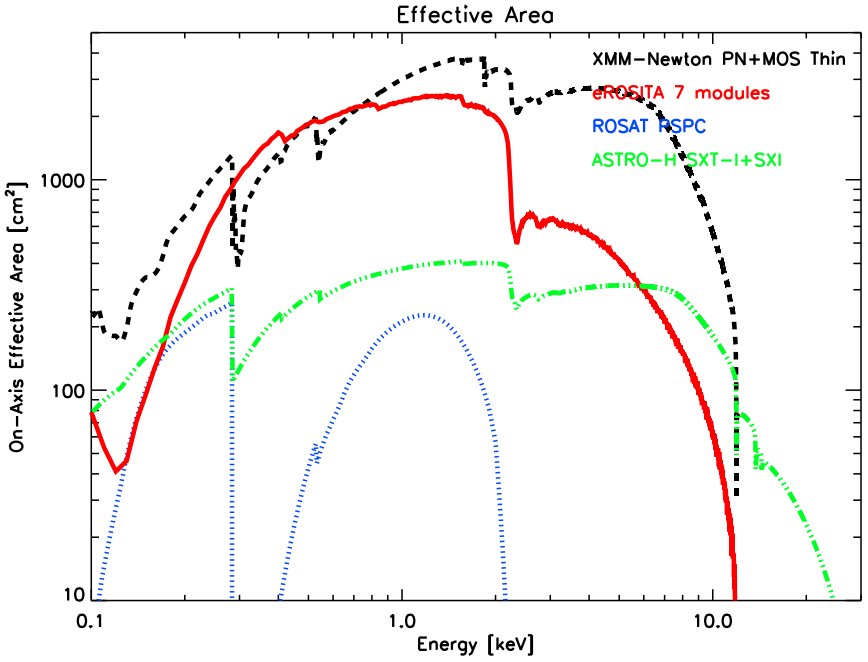
eROSITA

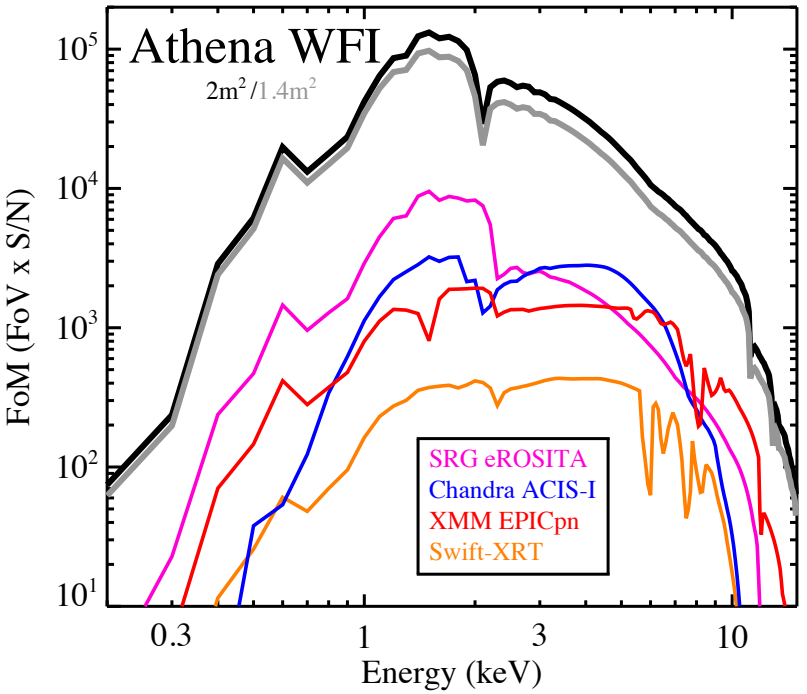
- **eROSITA: Next Generation all-sky X-ray survey**
  - 0.5-2 keV: 30× deeper than ROSAT
  - 2-10 keV: 100× deeper than HEAO-1; 10× XMM Slew
- Large FoV (~1degree), small focal length (1.6 m)
- Image quality, effective area comparable to XMM-Newton, better spectral resolution
- **Driving science**: detect 100,000 clusters (LSS, cosmology)
- Built by consortium led by MPE; **eROSITA is ready**
- All SRG flight H/W ready. Final tests underway; **Launch 04/19**



Effective Area and Grasp

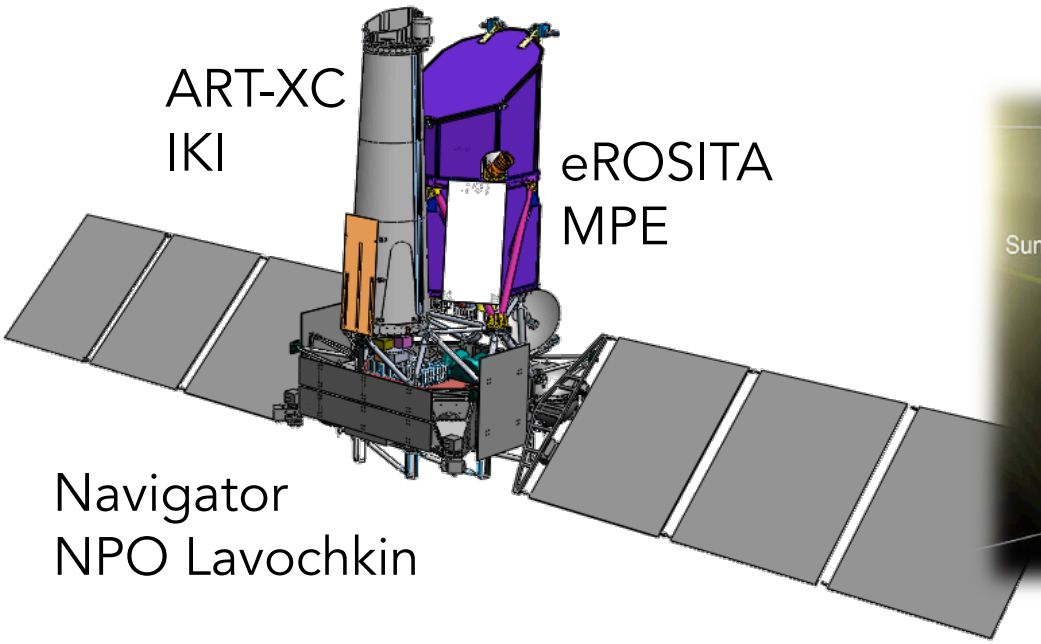
Effective Area: ~1700 cm^2 (FoV avg. @1keV)

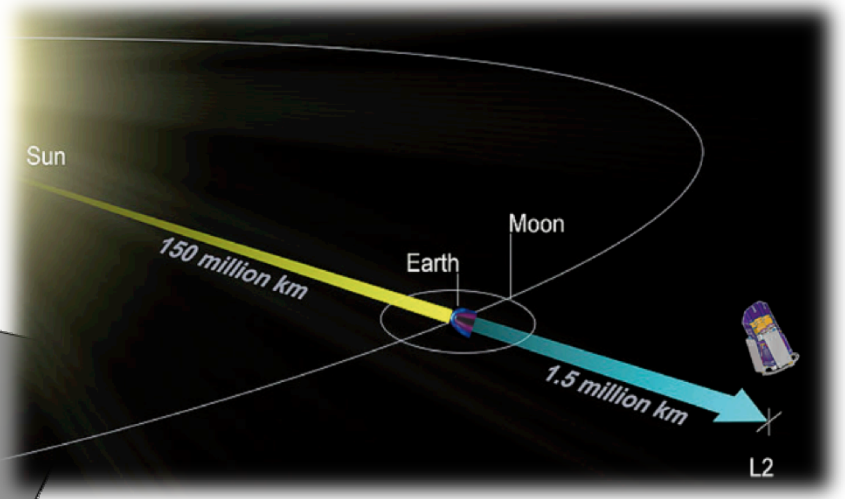




- Effective area at 1keV comparable with XMM-Newton
- Factor ~7-8 larger surveying speed (and 4 years dedicated to all sky survey)
- Survey FoM≈A_{eff}*FoV/(θ*Bkgn) (courtesy of Wik & Horsheimer)

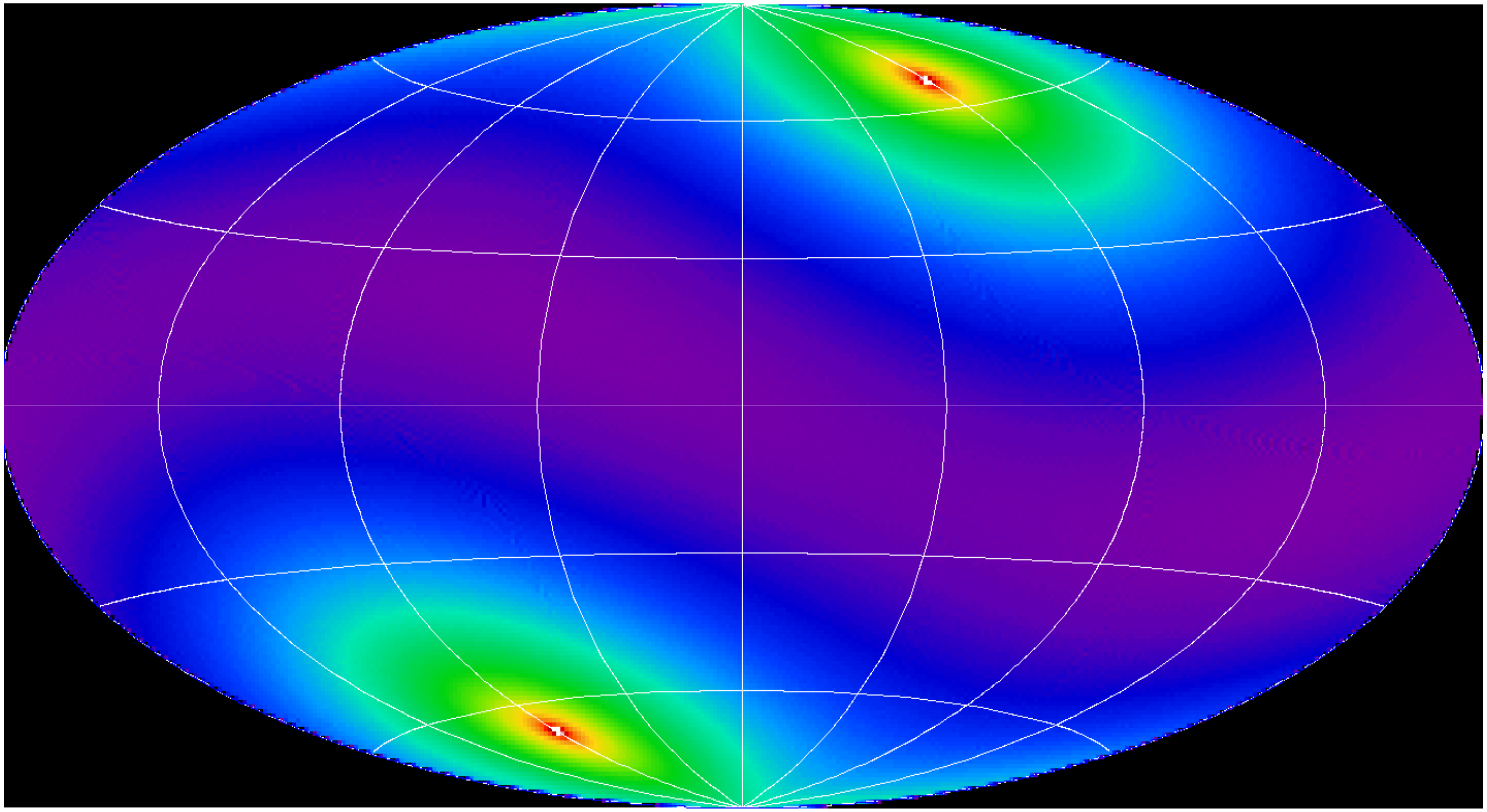
SRG: Mission Profile

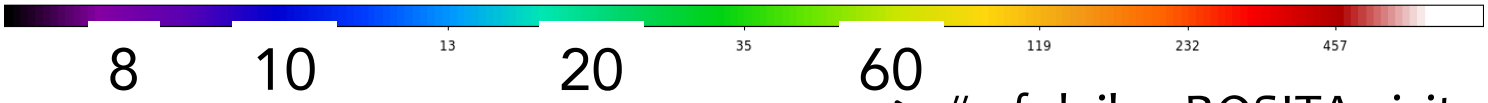




- **Launch**: From Baykonour, Proton–Block-DM
- **3 Months**: flight to L2, PV and calibration phase
- **4 years**: 8 all sky surveys (eRASS:1-8; scanning mode: 6 rotations/day)
- **2.5 years**: pointed observations, including ~20% GTO. 1 AO per year
- **Ground Segment**: 2 x 70m antennas (Bear Lakes and Ussirisk), daily contact (up to ~4 hours); telemetry transfer directly to MPE via Moscow NPOL/IKI Control Center

eROSITA Cadence Map

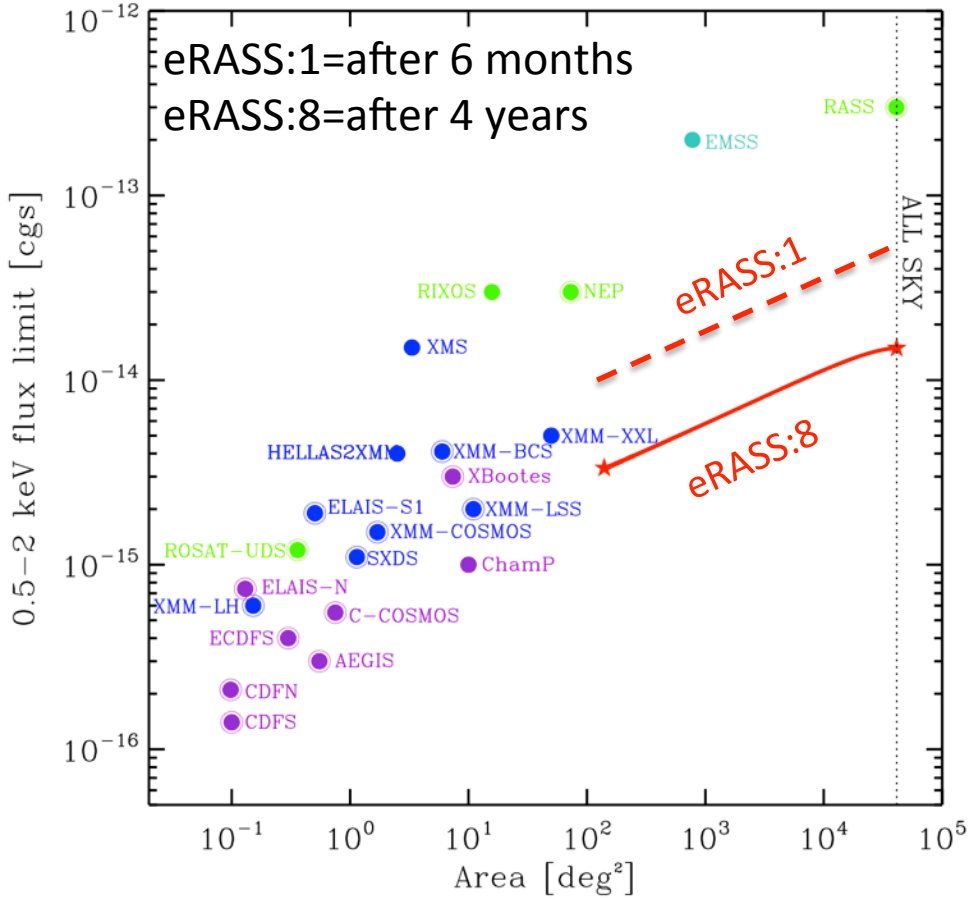




1 daily visit ➔ $F_{0.5\text{-}2} \sim 4\times10^{-14}$ erg/s/cm^2 ➔
$L_X > 10^{43}$ at D<1.5 Gpc (z~0.3); $L_X > 10^{44}$ at D<4.5 Gpc (z~0.7)

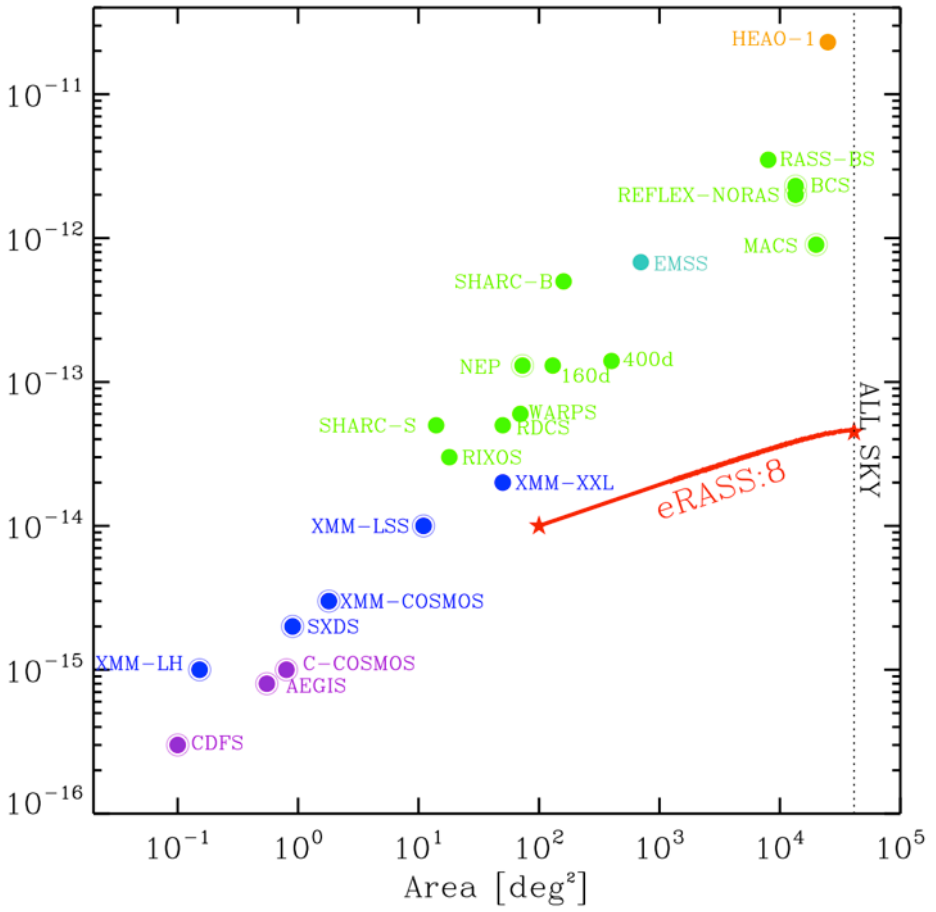
eROSITA surveys in context

Point sources sensitivity



All sky: 10^{-14} (0.5-2 keV)
2×10^{-13} (2-10 keV) [erg/cm²/s]

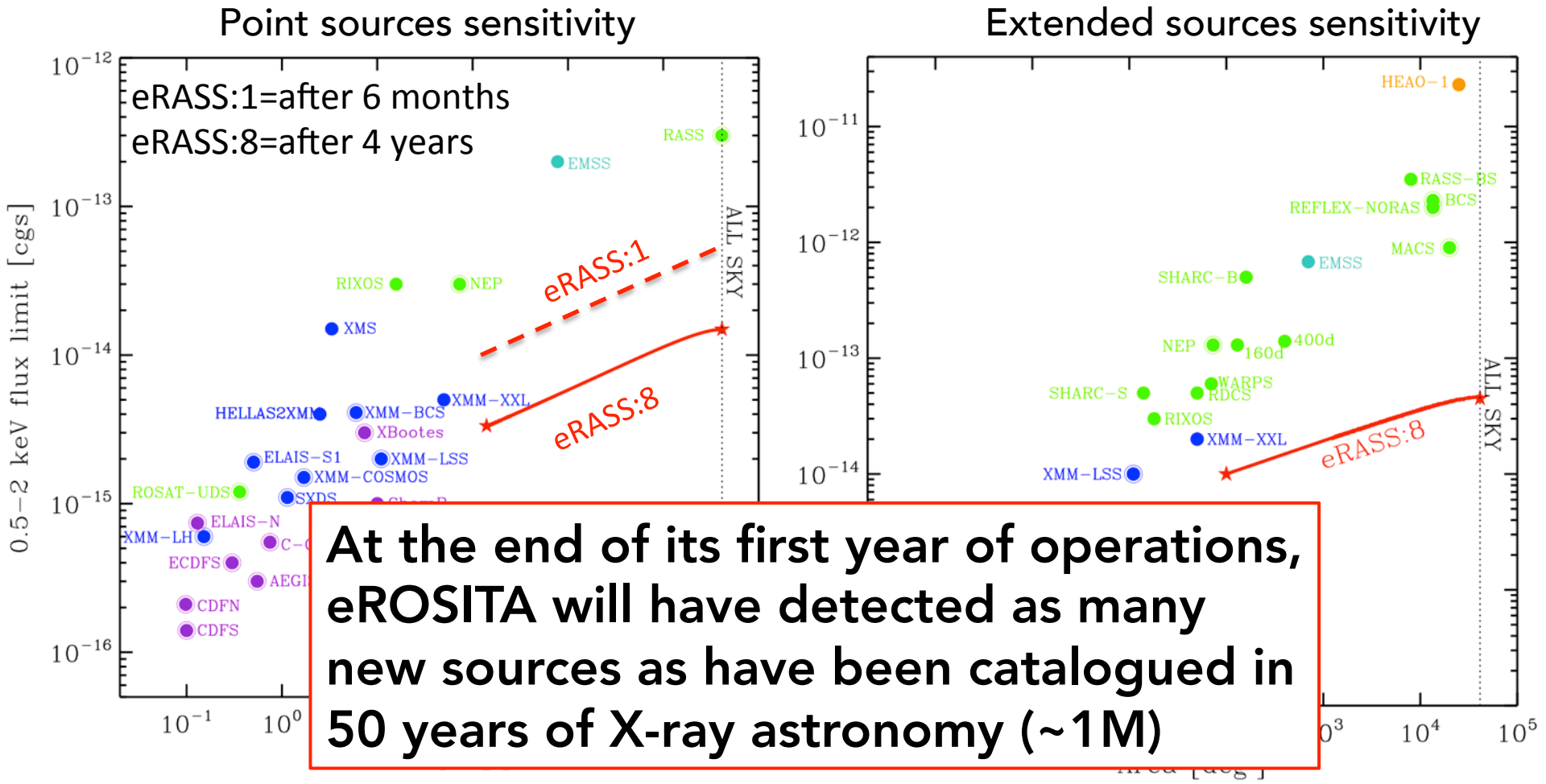
Extended sources sensitivity



All sky: 3.4 x 10^{-14} (0.5-2 keV)

Merloni et al. 2012

eROSITA surveys in context



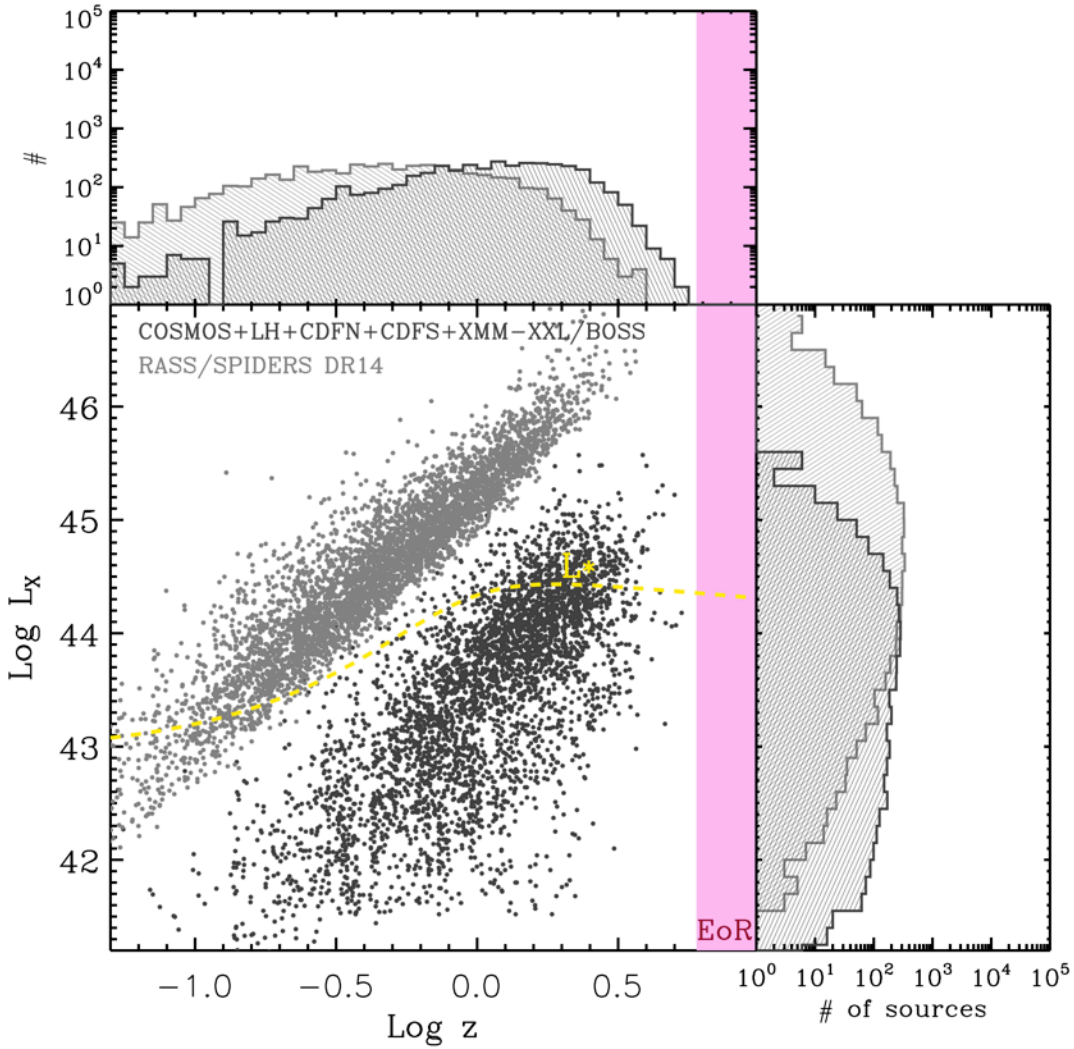
At the end of its first year of operations, eROSITA will have detected as many new sources as have been catalogued in 50 years of X-ray astronomy (~1M)

All sky: 10^{-14} (0.5-2 keV)
2×10^{-13} (2-10 keV) [erg/cm^2/s]

All sky: 3.4×10^{-14} (0.5-2 keV)

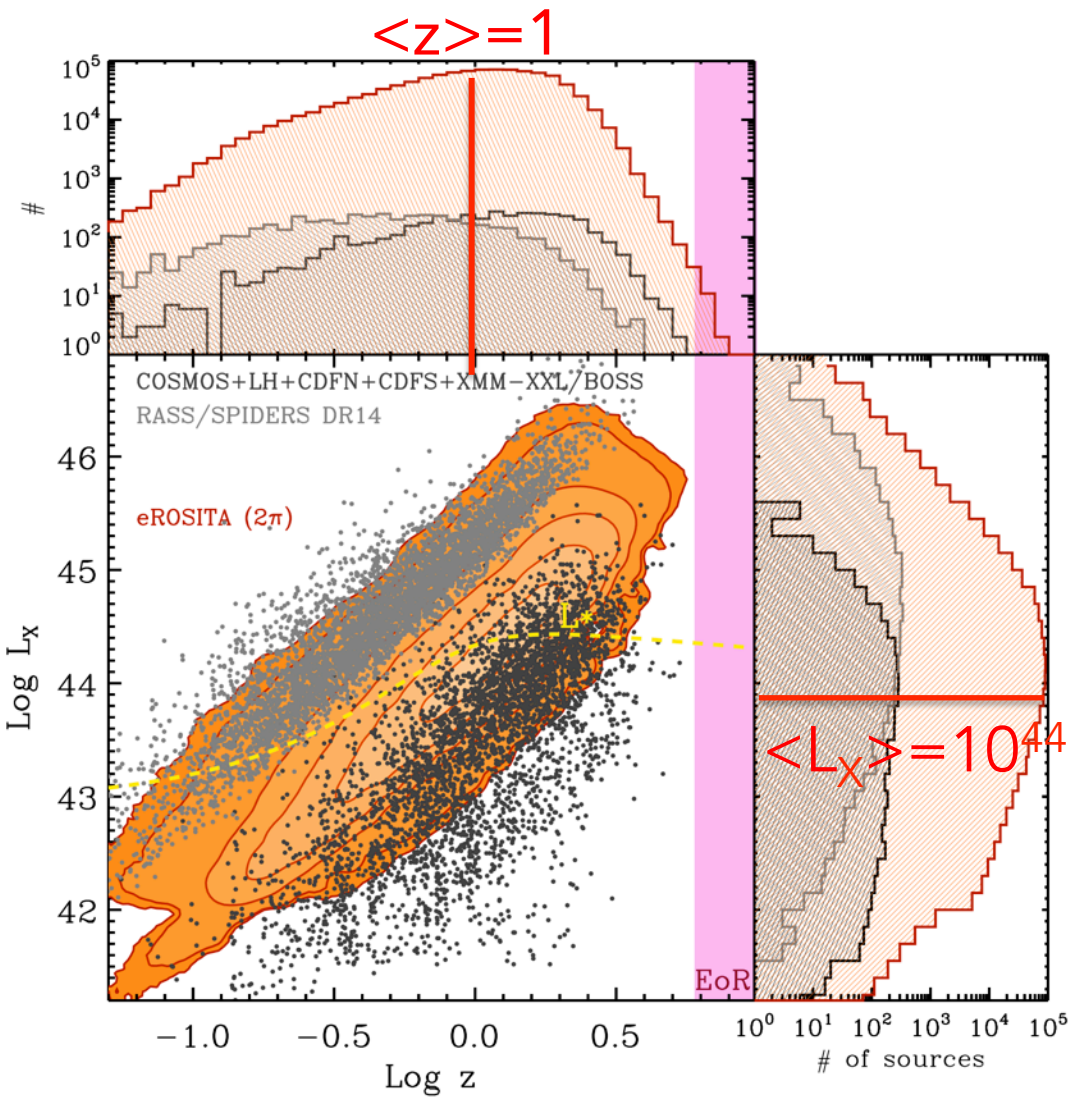
Merloni et al. 2012

3 Million AGN



- The most luminous AGN, tracers of large scale structure: the "quasar" mode of AGN feedback
- (Obscured and Un-obscured) accretion history
- High-z AGN
- SED vs. L, L/L_{EDD}
- All-sky reference
- **>95% identified to i~24** (~80% at i~22)
- High complete spectroscopy with SDSS-V (r~21.5) and 4MOST (r~23)
- All-sky reference for LSS tomography via clustering redshift

3 Million AGN



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eROSITA will tell us…

- Incidence of accreting SMBH (and BH growth rate itself) in:
  - The (z<1) galaxy population overall (Wide area optical/NIR surveys: DES, HSC, LSST, Euclid)
  - Merging galaxies and other morphological freaks (high quality optical/NIR imaging: HSC, LSST, Euclid)
  - Radio galaxies (and jetted AGN of various classes)
  - Voids, filaments, groups, clusters (synergy with SZ surveys, CMB lensing, and X-ray clusters surveys, including eROSITA itself)

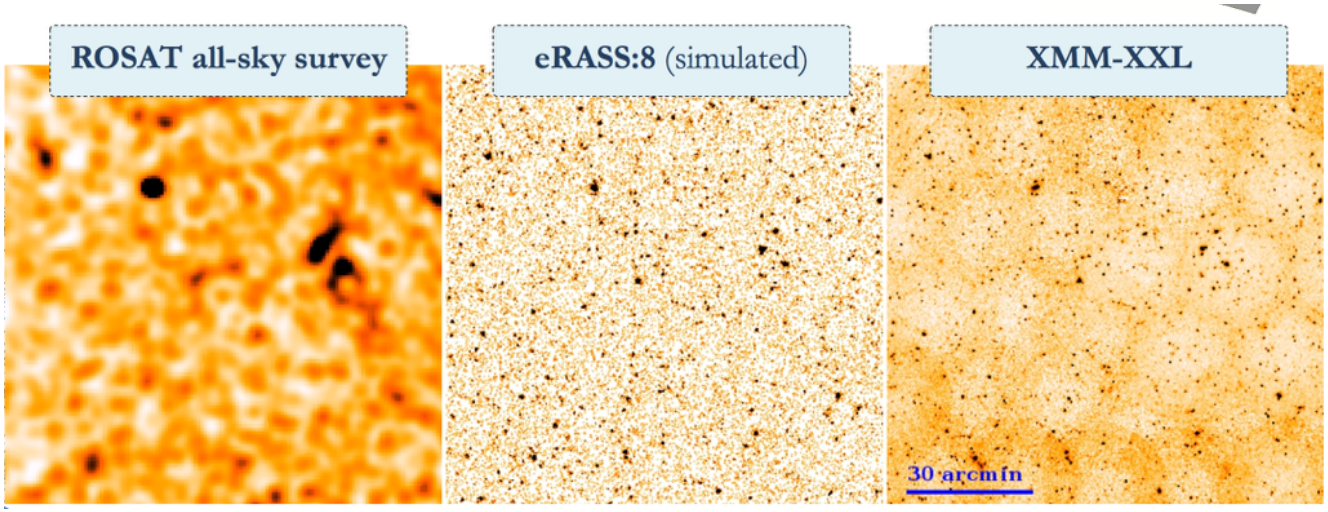

Image credits: MPE, eRosita_DE consortium, XMM-XXL

eROSITA will tell us…

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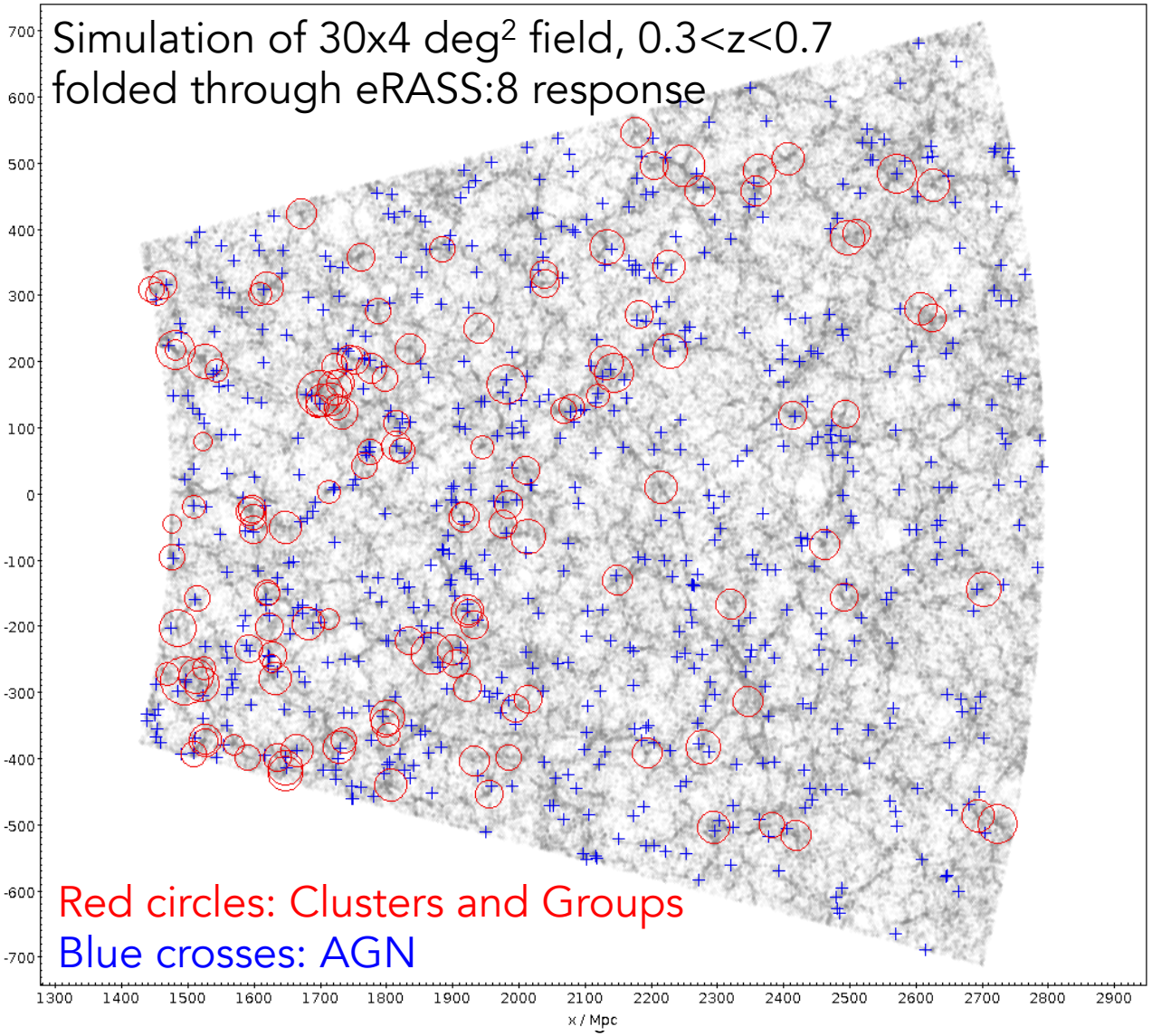


Working with eROSITA

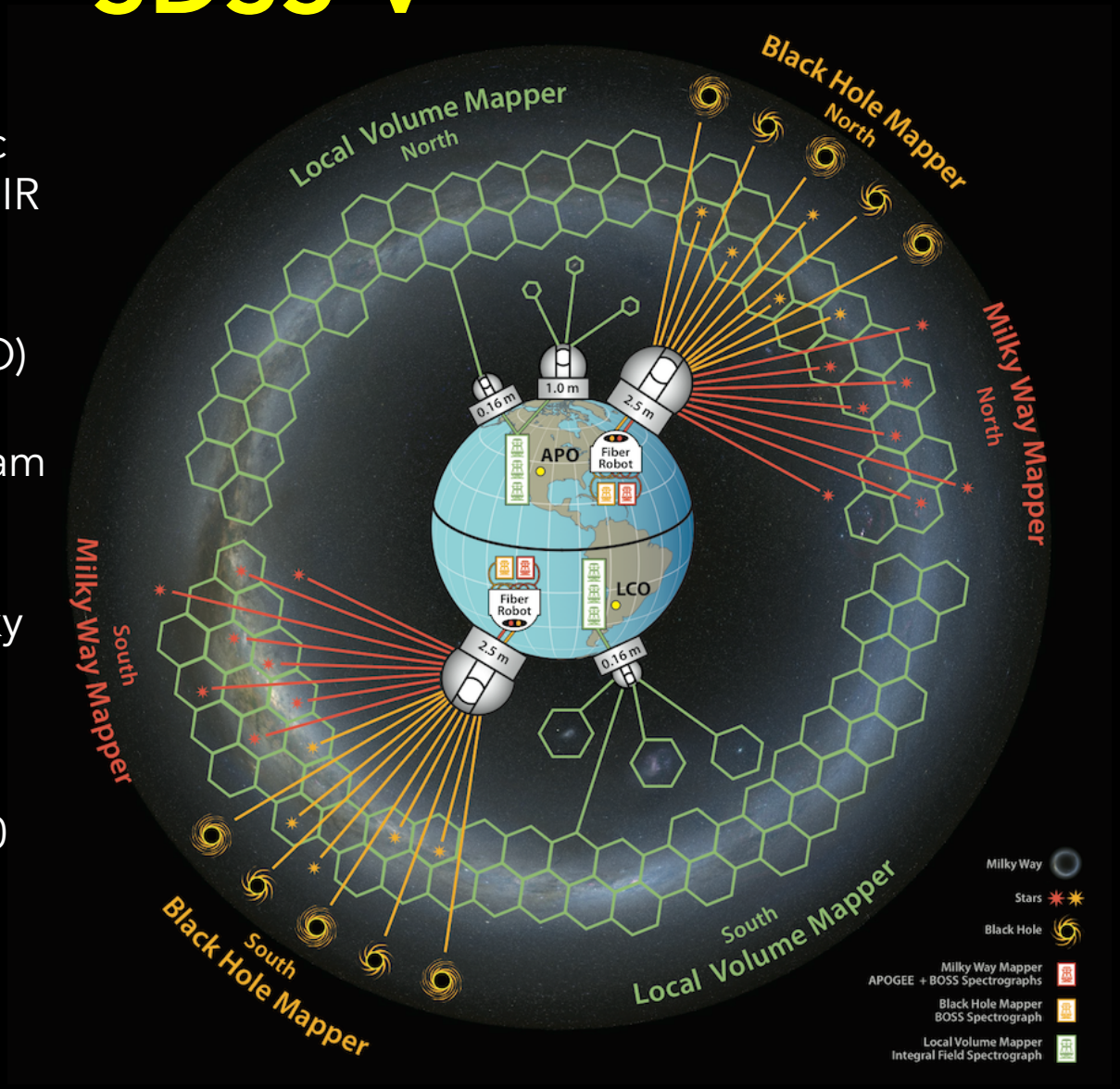
- **eROSITA is a PI instrument**
  - All-sky data reduced and calibrated at MPE with own pipeline
  - Scientific exploitation of data shared between the partners: 50% MPE and 50% IKI, West/East (gal. coord.)
  - German data public after 2 yrs, 3 releases (’21, ’23, ’25; TBC)
  - Proprietary access via eROSITA_DE (/RU) consortium
  - In DE, Projects/papers regulated by working groups. Currently counting about 120 members + 20 EC
- **Working Groups**:
  - Clusters/Cosmology, AGN, Galaxies, Compact objects, Diffuse emission/SNR, Stars, Solar System, Time Domain Astrophysics
- **Collaboration policy (German Consortium):**
  - Individual External Collaborations (proposal to WGs)
  - Group External Collaborations (team-to-team MoUs)
    - CAASTRO->AAL (Australian Community); HSC SSP; SDSS-IV -> SDSS-V; J-PAS; Chilean “DeROSITAS” survey team

Spectroscopic follow-up

- Number density (~100/deg^2) and median optical magnitude of counterparts (r~21.5) is well matched to existing and upcoming multi-object spectroscopic instrument (designed for BAO/LSS/cosmology/GAIA)
- **SDSS-V (2020-2025)** www.sdss.org/future/ - J. Kollmeier (Director)
  - "Black Hole Mapper" S. Anderson (PS), Y. Shen, A. Merloni
  - SDSS + LCO full-sky coverage complete follow-up of early eROSITA survey over ~10,000 deg^2 (300k AGN spectra to r=21.5, 80k galaxies in 10k clusters)
  - Multi-epoch spectroscopy of SDSS QSO (Changing look QSO, etc.)
  - Reverberation Mapping in 5 deep fields
- **VISTA/4MOST (2023-2027)** www.4most.eu - R. De Jong (PI)
  - Complete, systematic follow-up of both Clusters and AGN from eROSITA: reach >90% completeness for eRASS:8 (down to r~22.8)
  - ~800k AGN spectra 0<z<6
  - Both medium- (R~5000) and high-resolution (R~20000) spectra

SDSS-V

- Two ~identical set of robotic positioned Optical (BOSS) +IR (APOGEE) Multi-object spectrographs
- North (APO) and South (LCO) 2.5mt wide-field telescopes
- 5-years All-sky survey program to complement space and ground based programs
- Focus on bright, transient sky
- Short "quanta" of ~15 minutes exposure: visit ~the whole sky in 1 year
- Start operations in mid-2020
- Juna Kollmeier, Director (Carnegie); Hans-Walter Rix Project Scientist (MPIA)



Conclusions

- X-ray (and radio) surveys provide the least biased (and 'cleanest') view of the AGN evolution
- Soltan-like arguments reveal that most BH mass is grown in radiatively efficient discs
- Current samples reveal AGN as stochastic phenomena occurring in all kind of galaxies
- Sample size are still small to unambigously reveal trends with galaxy properties and large scales
- Future of AGN studies with multiwavelength large surveys (WISE, eROSITA, LOFAR, ASKAP, DESI, 4MOST) is bright: larger sample will allow new phenomena to be pinned down

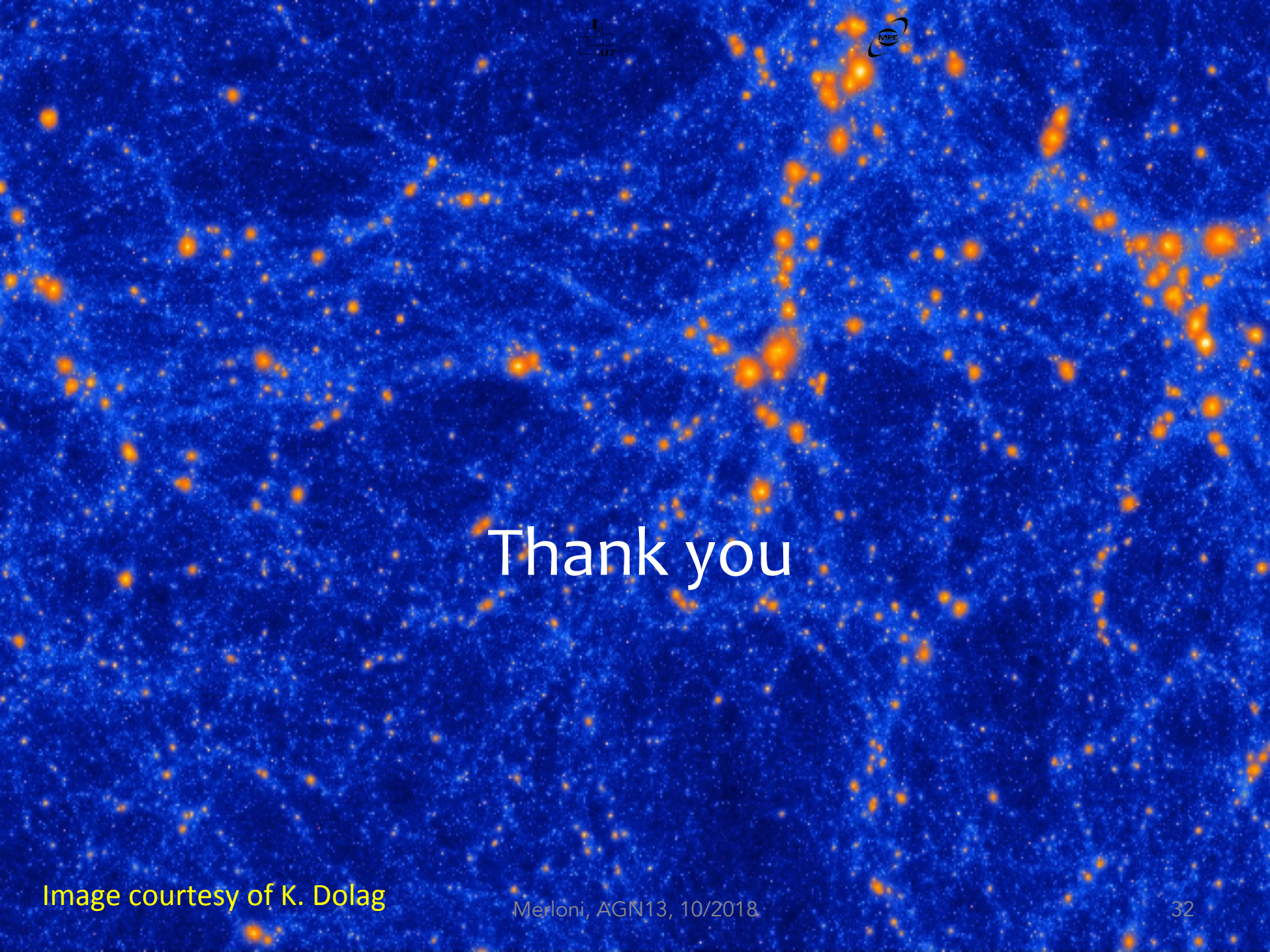


Image courtesy of K. Dolag