The Black Hole Mapper in SDSS-V

(Scott Anderson, BHM Program Head, Univ. of Washington)

Black Hole Mapper (BHM) in SDSS-V
Overview

*Many involved (dozens), but principal BHM formal leads so far also include:

* **Andrea Merloni** (MPE)--Survey Scientist--especially leading on BHM eROSITA (SPIDERS-II) aspects [also Kirpal Nandra (MPE) on SC]

* **Yue Shen** (UIUC)--Survey Scientist--especially leading on BHM time-domain (ReSpeQ) quasar aspects

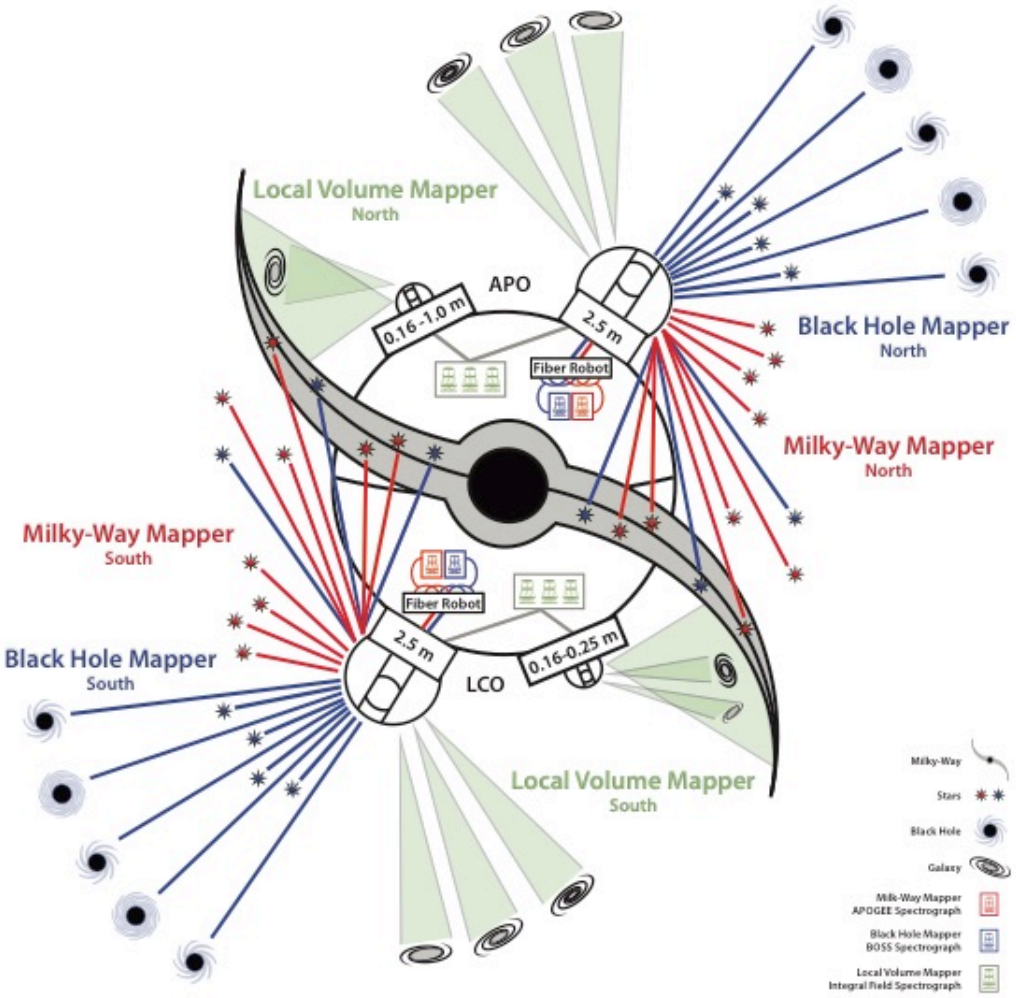
* Nicolas Clerc (Toulouse)—Galaxy clusters WG chair
Mike Eracleous (Penn State)—Accretion astrophysics WG co-chair
Keith Horne (St. Andrews)—Reverberation mapping WG co-chair
Axel Schwope (AIP/Postdam)--X-ray stars WG chair

+other WGs and also chairs/co-chairs TBD

MANY THANKS for inviting BHM/SDSS-V to your webinar series!

SDSS-V Basics (esp. for Multi-Object Spectroscopy)

- Dual hemisphere, including 2.5m's North (APO) and South (LCO)
- Robotic fiber positioner, which is rapidly reconfigurable.
- Wide-field, with multi-object spectroscopy (MOS) over bulk of sky – often also multi-epoch (2020-2025).
- Low-res optical (BOSS) MOS spectra for Black Hole Mapper (BHM), *and* high-res IR spectra esp. for MWM, of distinct targets in same fields. (+ LVM w/IFU).
- Juna Kollmeier, Director (Carnegie); Hans-Walter Rix Project Scientist (MPIA).

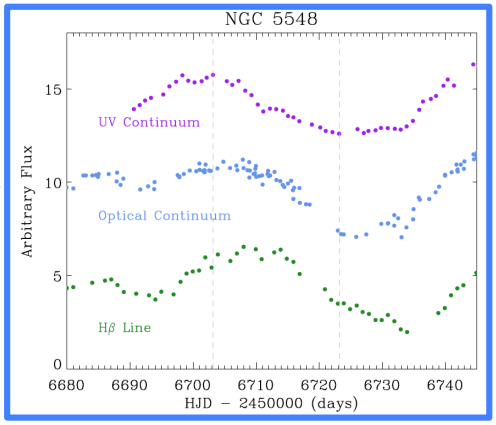


Black Hole Mapper (BHM) in SDSS-V

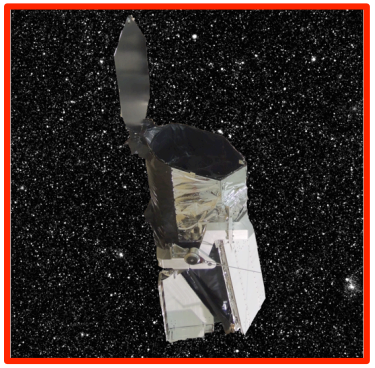
- Quasar/AGN emphasis, as among Universe's most luminous objects, powered by accretion onto SMBHs (co-evolving via feedback with the host galaxies in which they reside).
- BHM exploits – with order(s) of magnitude advances -- two hallmark characteristics of quasars: marked variability on a range of timescales, and prodigious luminosity extending to X-rays.
- *Repeat time-domain (TD) optical spectra of ~$10^{4.5}$ known (SDSS) quasars over broad range of timespans from days to decades, sampling changes on light-travel, dynamical, etc. timescales, to measure BH masses, BLR dynamics, astrophysics of quasar accretion & outflows, etc. (spatially unresolved size scales, probed via TD).*
- Optical follow-up spectra of *eROSITA* X-ray sources: IDs & redshifts, demographics, evolution, & astrophysical studies of ~$10^{5.5}$ X-ray source counterparts—esp. quasars, but also galaxy clusters,+ XRBs, CVs, flaring stars, etc.—from first 1.5 years of *eROSITA* repeat scans.

BHM provides obscuration-unbiased demographics of BH growth/evolution from *eROSITA* optical spectroscopic IDs, and TD optical spectra of known quasars, time-resolving the innermost regions around SMBHs, from reverberation masses, to BLR dynamics, to accretion and outflow astrophysics.

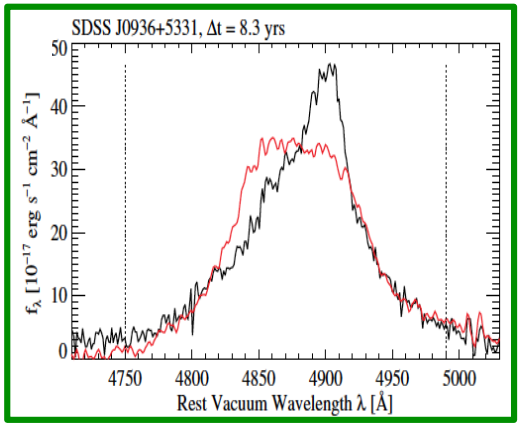
Pei et al. 2017



Reverberation Mapping
Measuring BLR sizes and BH masses

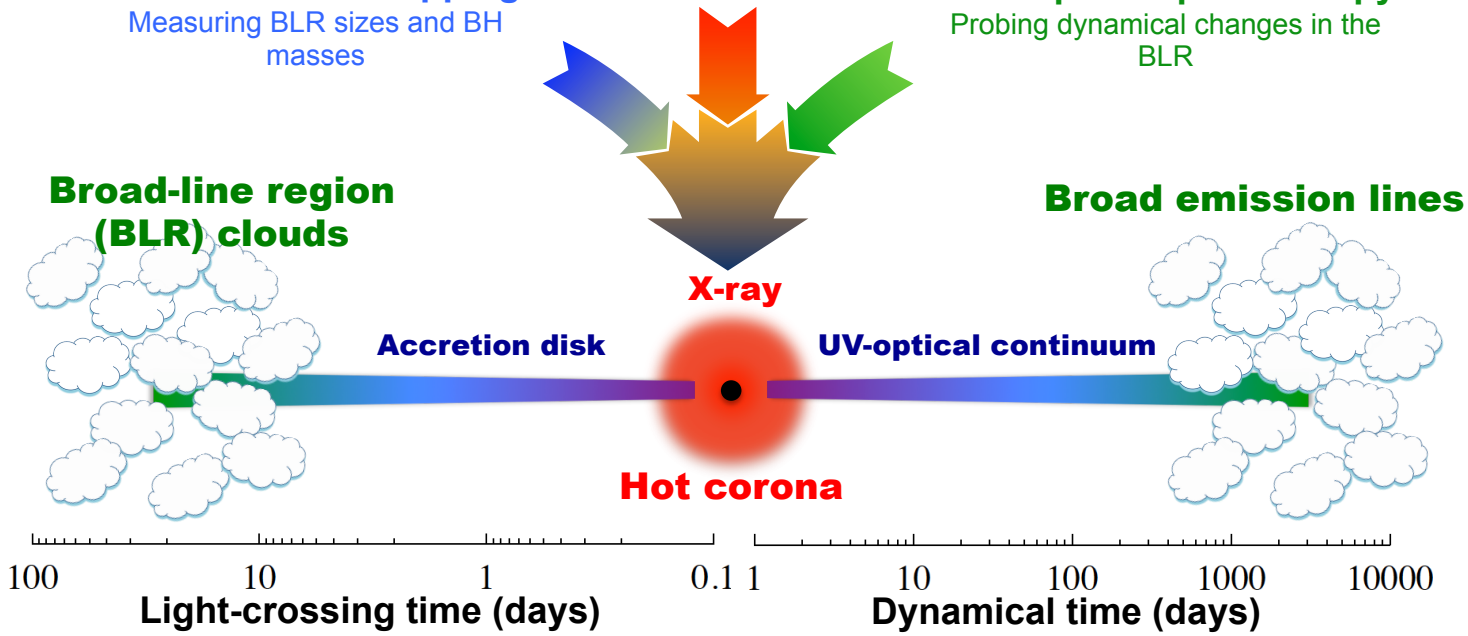


eROSITA
Probing the hot X-ray corona



Multi-epoch Spectroscopy
Probing dynamical changes in the BLR

Liu et al. 2014



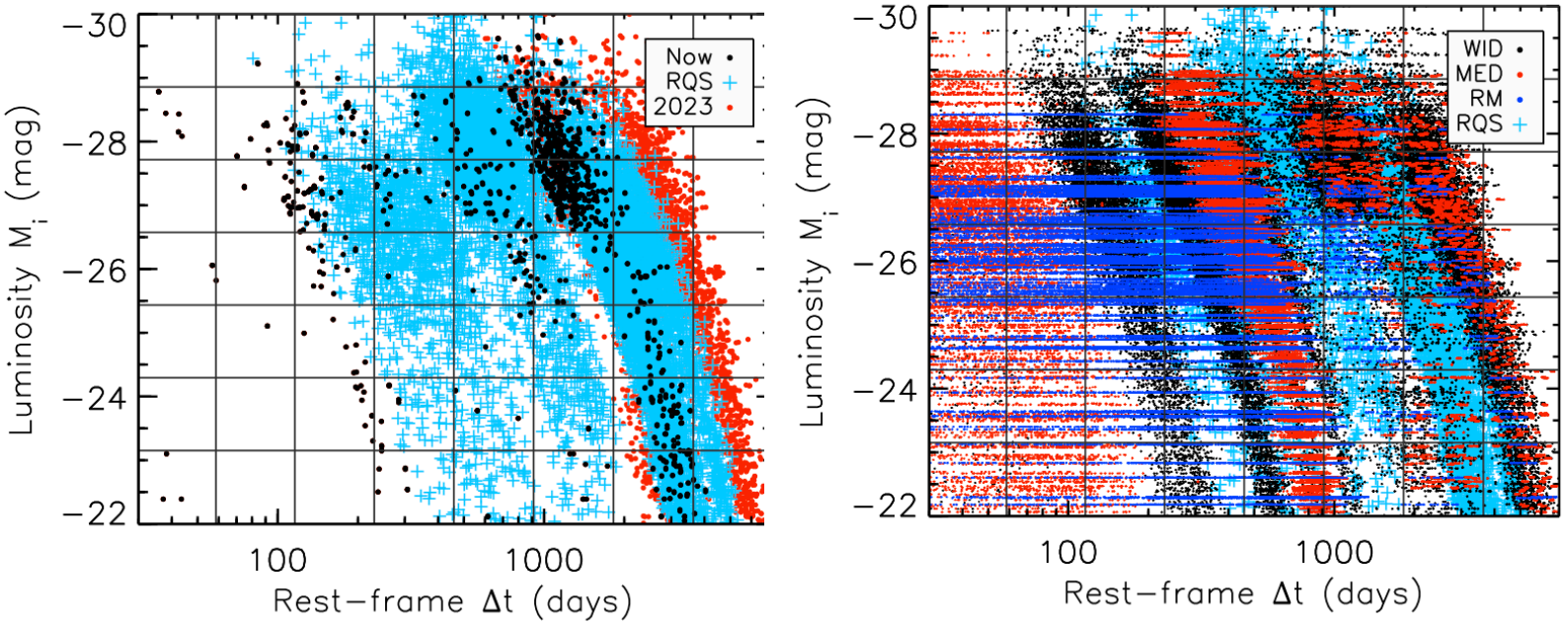
BHM Time-Domain Survey Outline (ReSpeQ heritage)

Spectral time-domain astrophysics of quasars: BH masses, binarity, accretion and events, BLR dynamics, outflows, etc. Broad range of time-sampling/cadence, days to decades.

- For >20,000 quasars, ~2-3 epochs during SDSS-V plus earlier-epoch SDSS spectra, sampling ~1-10 year timescales, e.g., transition times of changing look quasars, BAL disappearance and emergence, etc. *(wide area, but low-cadence tier; >~3000 deg^2).*
- For >2000 quasars, ~12 epochs (maybe in concentrated ~2 yrs), probing down to ~1-month to 1-year timescales, adding unfolding BLR structural and dynamical changes *(medium tier; >~300 deg^2)*.
- Reverberation mapping (RM) for >1000 quasars in 5 fields, >10^2 epochs, sampling down to days to weeks; lags between continuum and BLR emission yield BH masses; premier RM sample at high L, z. (small area, but high-cadence tier; >~30 deg^2).

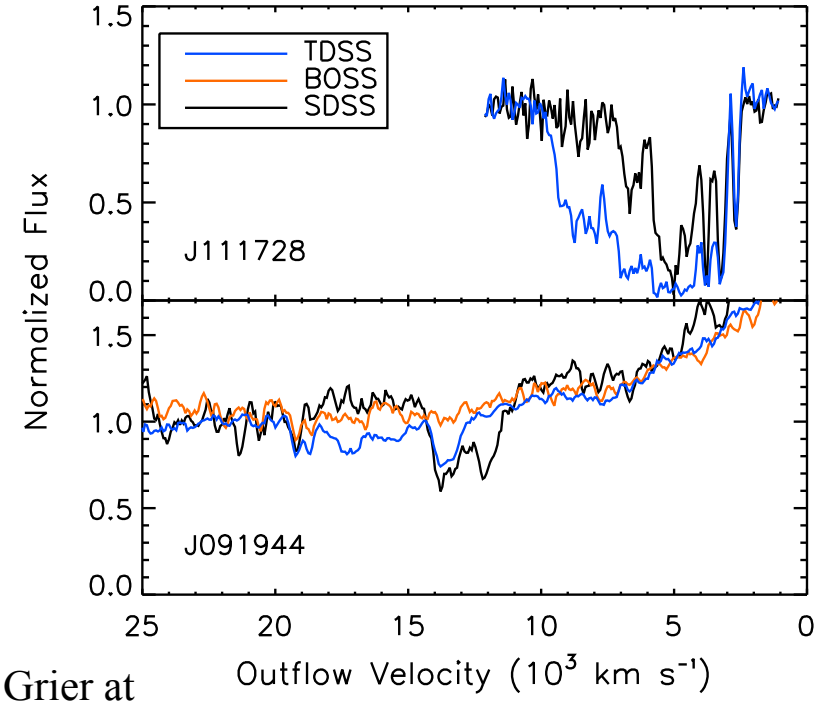
BHM TD Samples Quasars Across M_i - Δt Plane

(med/low cadence tiers yield~60K fiber-epochs, w/ good sampling across plane; C. MacLeod and P. Green et al.)

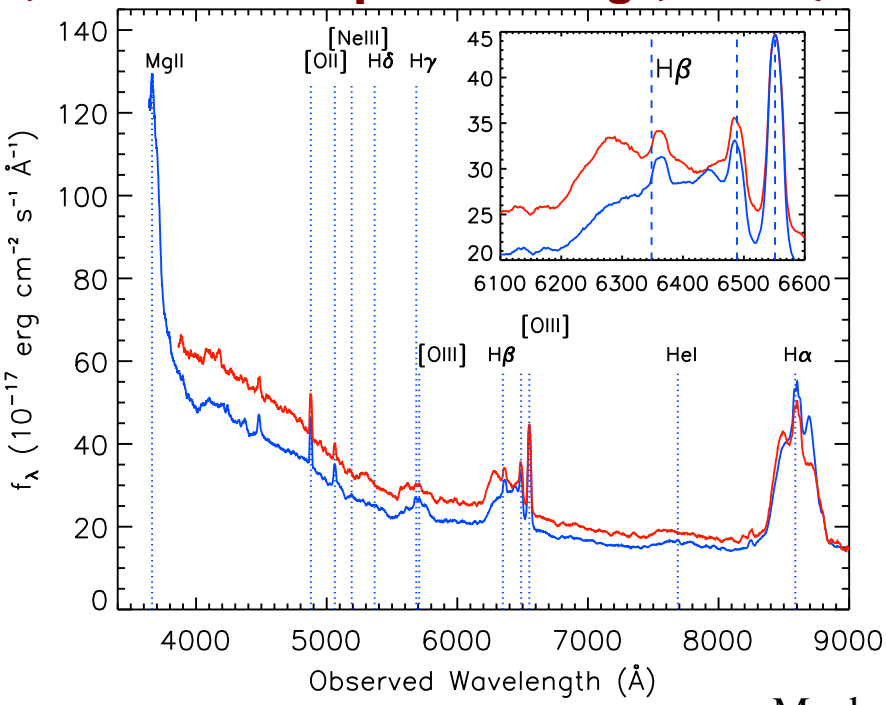


For i<19, TD current/future expectations from example 200deg^2 sky region. *Left:* black shows current coverage of M_i-Δt plane in repeat quasar spectra; cyan adds RQS (MacLeod et al. 2018) upcoming in TDSS; red adds solitary SDSS-V epoch. *Right:* shows full SDSS-V expectation, with BHM wide/low-cadence tier (>20,000 quasars in 3000deg^2 w/several added epochs; black), plus BHM medium tier with ~12 epochs (>2000 quasars; red), which fill the plane. RM will also contributes (dark blue).

BHM/TD preview examples (from TDSS) corresponding to BHM low- and medium-cadence tiers: variable BAL, emission line-profile change, & CLQ

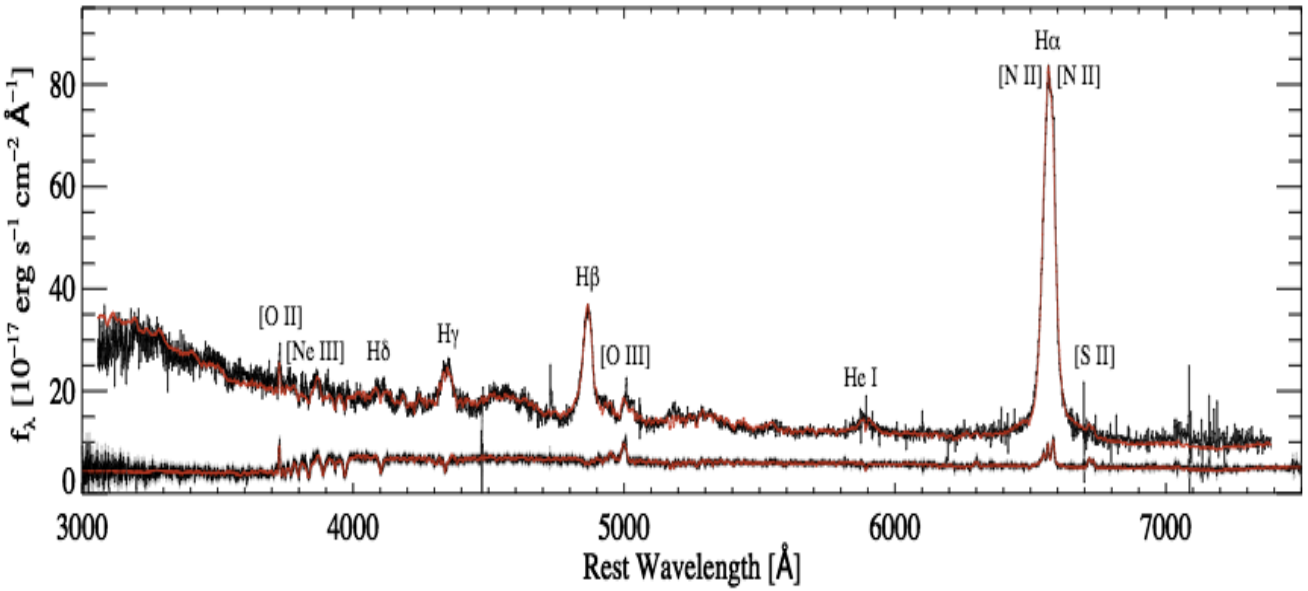


Grier at al. 2016; McGraw et al. 2017



Macleod et al. 2018

Runnoe et al. 2016



Limitations of the current RM AGN sample

~60 AGN with RM lag measurements

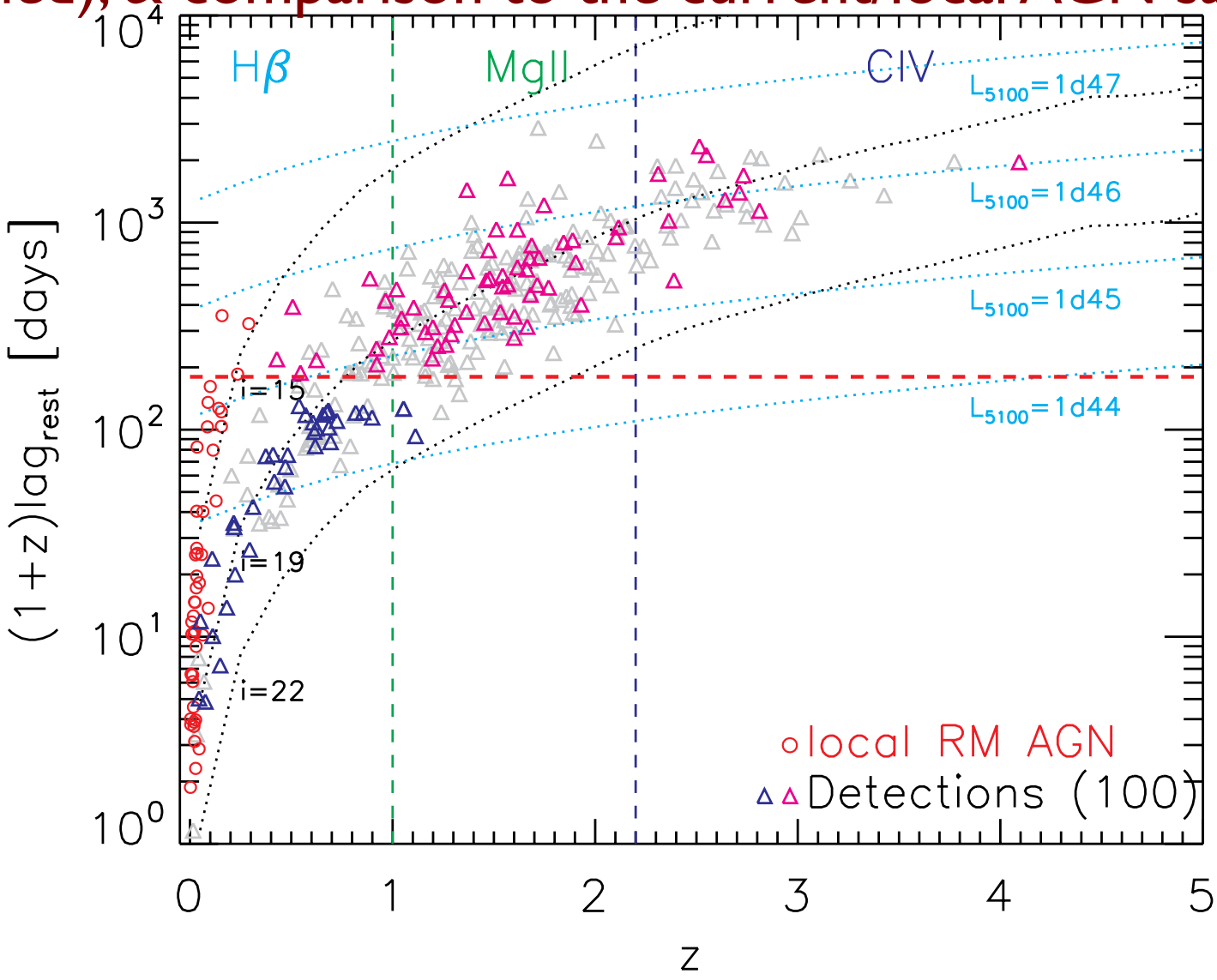
- ❑ almost exclusively at z<0.3
- ❑ Most are Hbeta lags with some CIV lags and few/no MgII lags
- ❑ Sample heterogeneous, and does not uniformly sample the AGN parameter space (luminosity, Eddington ratios, emission line properties)

→ Two decades of effort !!

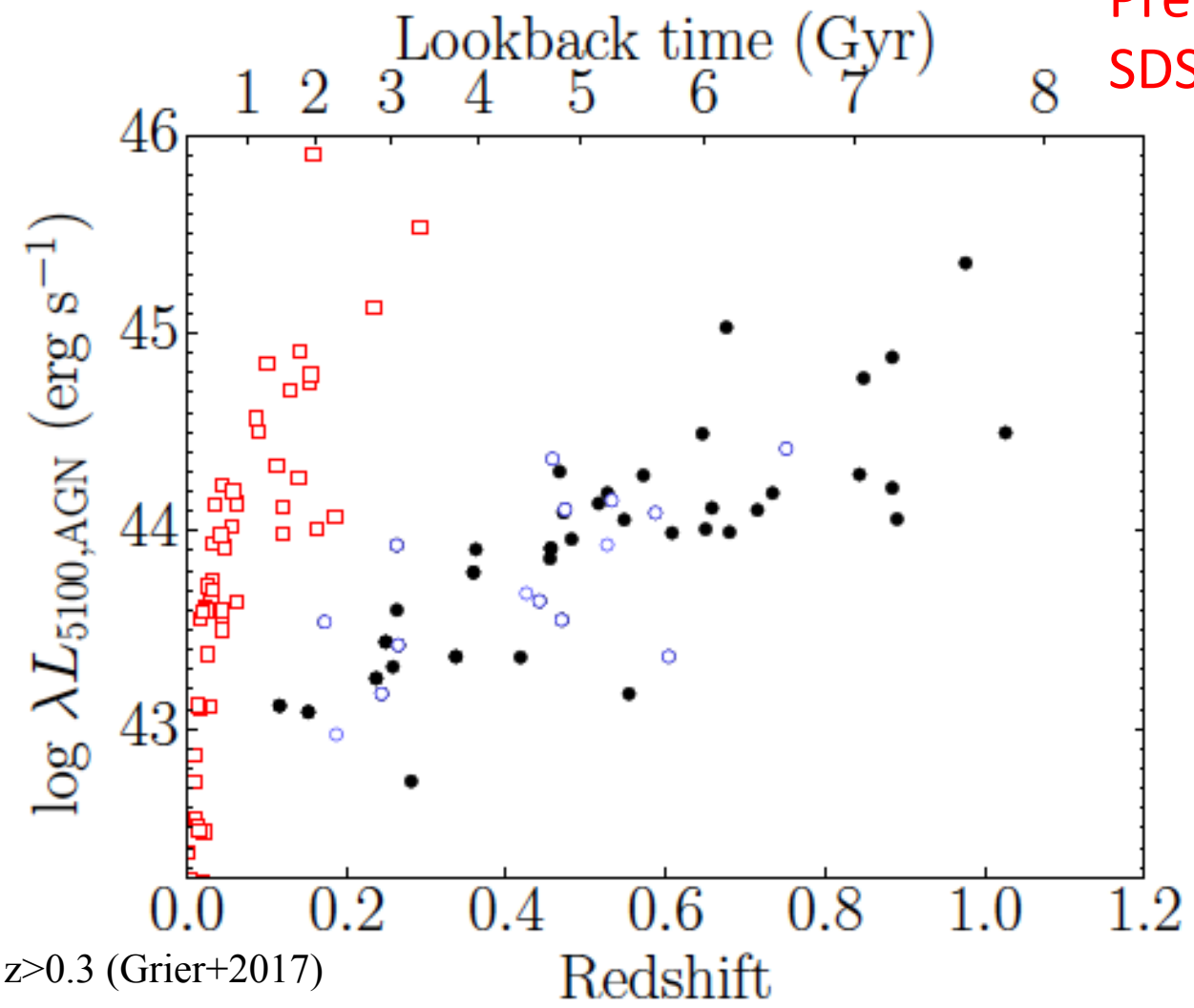
The limitations of the current RM sample severely impact the reliability of the single-epoch BH mass estimators at high-redshift.

Need to substantially improve the RM sample, in a more efficient way.

Forecast for a single BHM RM field in SDSS-V (5 fields planned), & comparison to the current/local AGN sample

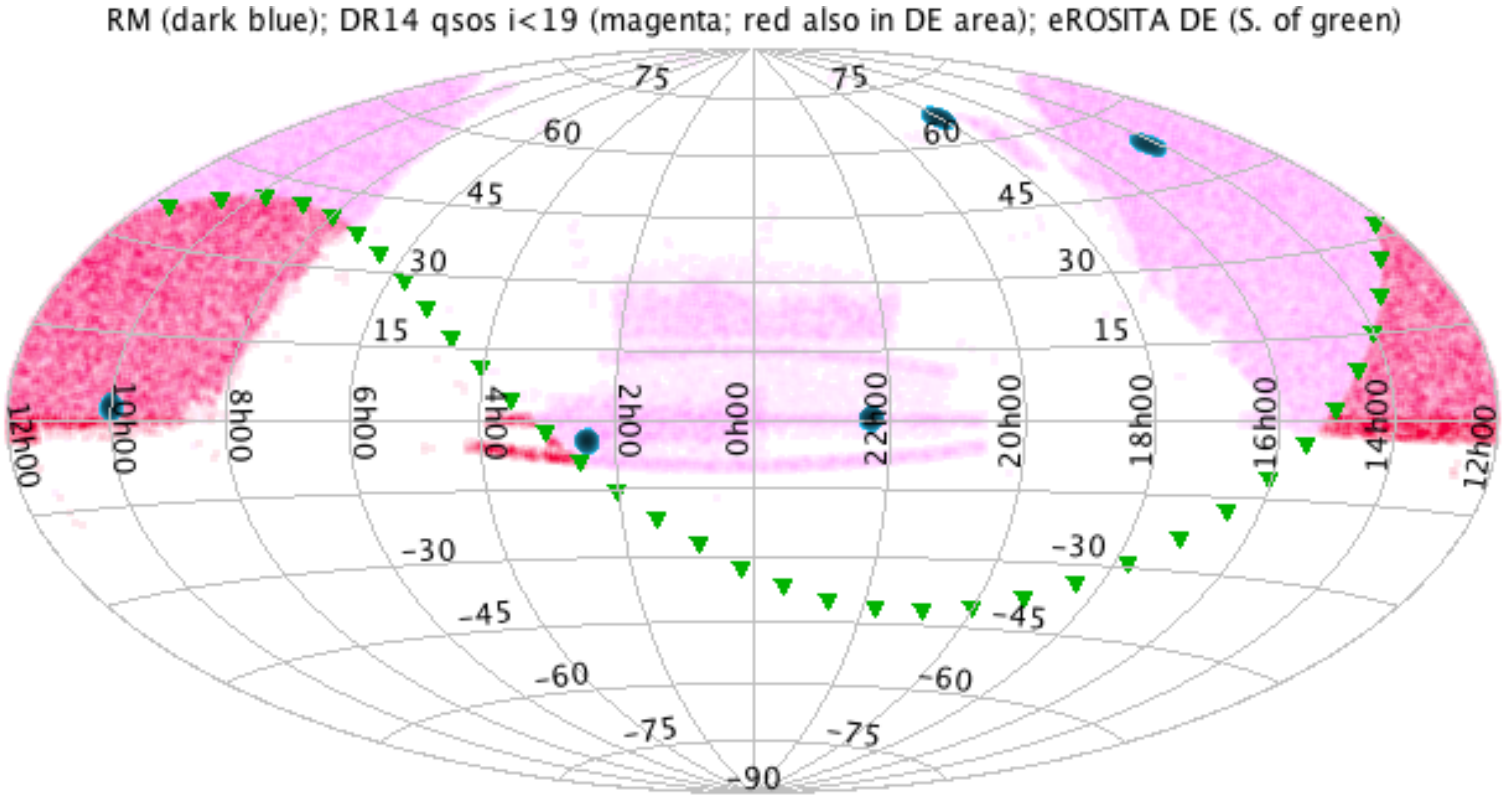


Preview from SDSSIV-RM



RM lags at z>0.3 (Grier+2017)

Main BHM Targeting Areas (TD, mainly North)



BHM /TD quasar targets fall mainly in North. Red and dark blue show, respectively, likely target areas for wide-area/low-cadence TD, and high-cadence RM fields. Specific area for medium tier TBD, but magenta+red depicts DR14 area coverage from which known Sloan quasars may be selected. The red region is prime for low-cadence TD tier, as it also overlaps the *eROSITA*-DE North area; in this ~3000 deg^2 area both BHM TD quasars, and *eROSITA* X-ray sources get SDSS-V optical spectra.

BHM eROSITA (SPIDERSII heritage) Survey Outline

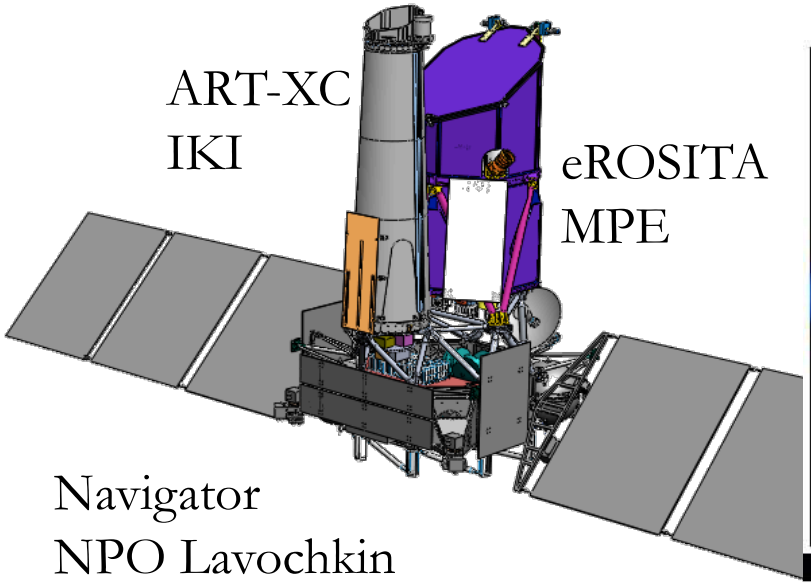
Optical spectra of *eROSITA* X-ray sources in DE half of sky, mainly first ~1.5 years of *eROSITA (*later, 4MOST). Largest X-ray/optical survey yet.

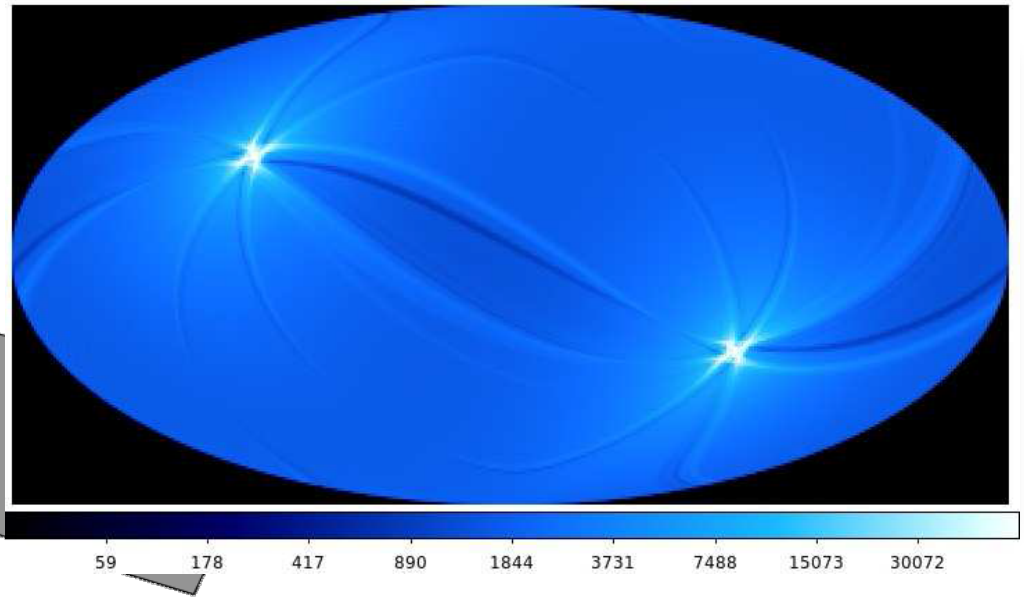
- BHM optical spectroscopic IDs/redshifts, evolution, & astrophysics of >300,000 X-ray source counterparts, especially AGN.
- X-rays escape relatively unaltered from inner regions near SMBHs, enabling obscuration-unbiased AGN samples vs. optical-only.
- Plus optical spectra of ~10^4 X-ray emitting clusters of galaxies, for cluster astrophysics and cosmology studies.
- Also X-ray emitting CVs & other compact binaries, flaring stars, transients etc. in Milky Way and nearby galaxies.
- In some ways, extension of SDSS-IV SPIDERS plans, adjusted due to launch delay…but markedly expanded in SDSS-V/BHM via LCO access to South hemisphere, accessing the bulk of *eROSITA*-DE area.

eROSITA is ready!

- End to end, qualification tests completed in 12/2016
- Shipped to Moscow in 01/2017, integration/tests ongoing
- Launch in early-mid 2019
- Mirrors: Focal length: 1.6 m, Field of view: 1 degree (diameter)
- On-axis **HEW**~16”; FoV avg. ~25” (~5”-10” spatial resolution)
- Effective area ~XMM at 1keV
- **Cameras Spectral resolution** at all measured energies within specs (R~20 @1.5keV)

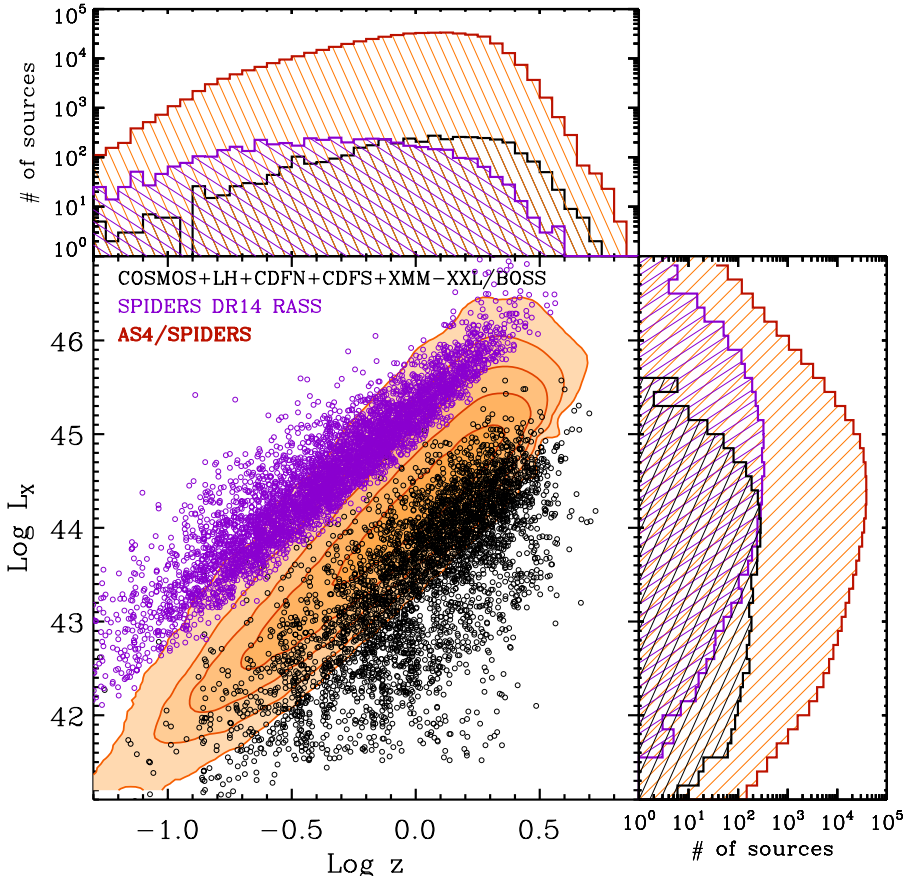
SRG: Mission timeline



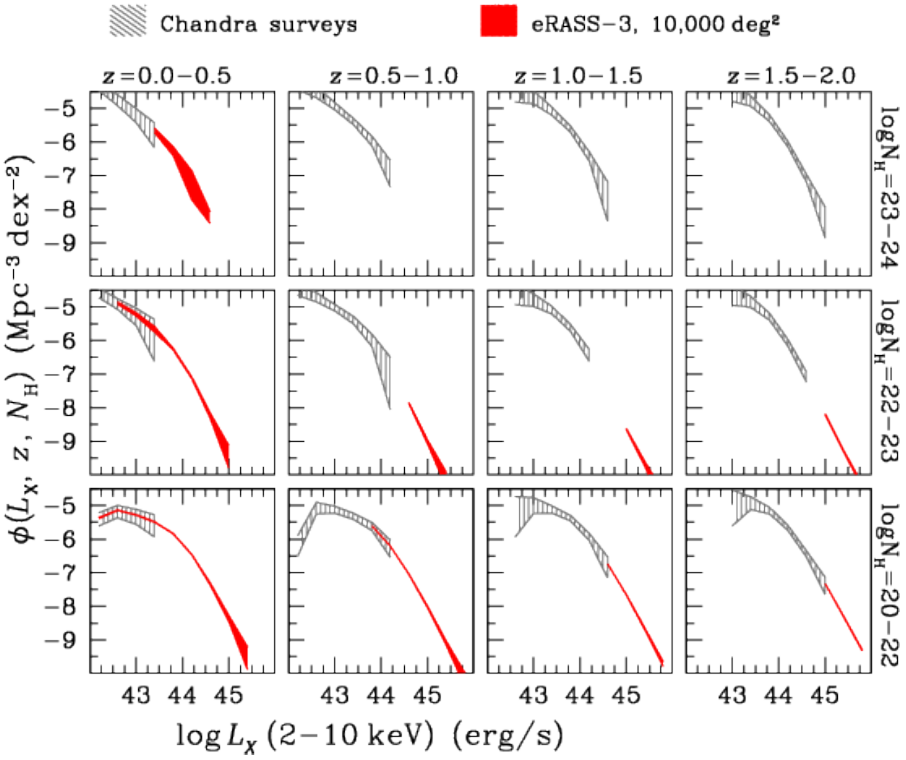


- **eROSITA delivered to Russia**: January 20, 2017
- **T0= Launch estimate*:** Spring '19 from Baykonour
- **3 Months:** flight to L2, PV and calibration phase (mini-survey, possible targets for SDSS-IV)
- **4 years**: 8 all sky surveys eRASS:1-8 (scanning mode: 6 rotations/day)
  - eRASS:1 catalog ready as early as T0+10 months
  - eRASS:3 catalog ready as early as T0+22 months
- **Data releases (TBC):** [2021, eRASS:1]; [2022, eRASS:3]?

Anticipated BHM/*eROSITA* AGN LF Constraints



L_x vs z plane anticipated for AGN from SDSS-V/BHM + *eROSITA*. Note ~100X advance in sample size.



Significant improvement in the constraints on the bright-end of the X-ray LF

SPIDERS pilot in XMM-XXL field

Fig. 1

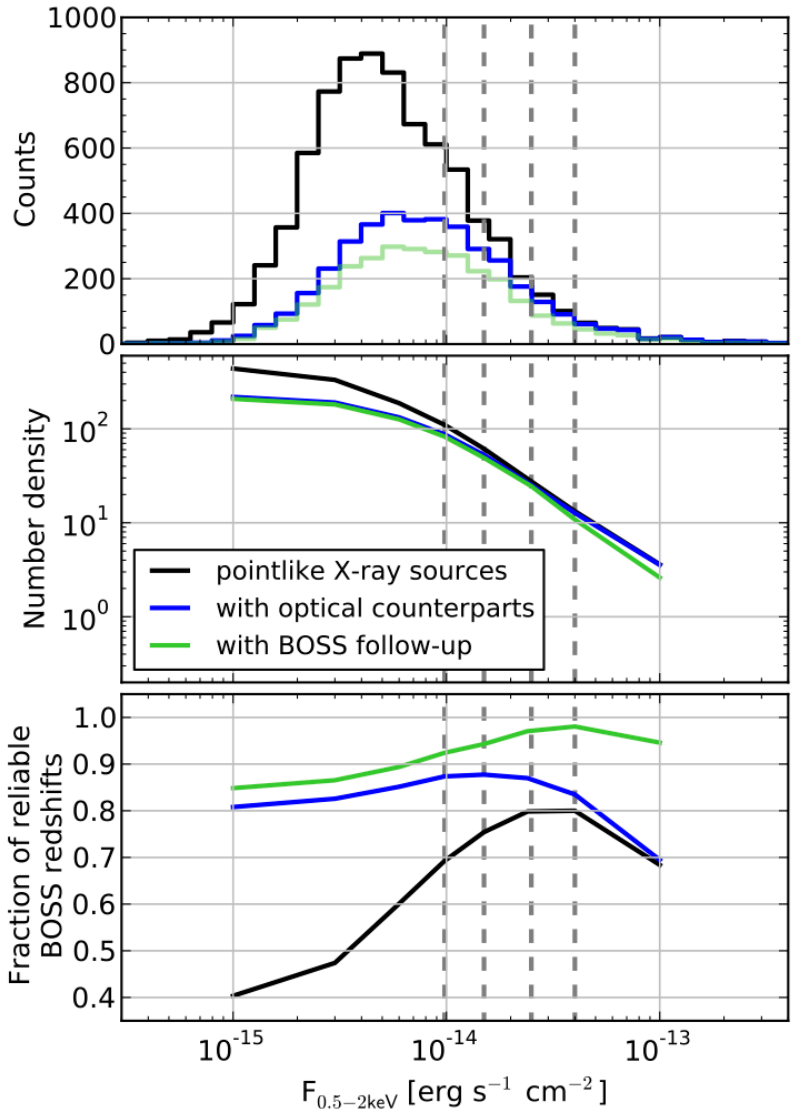


Fig. 2

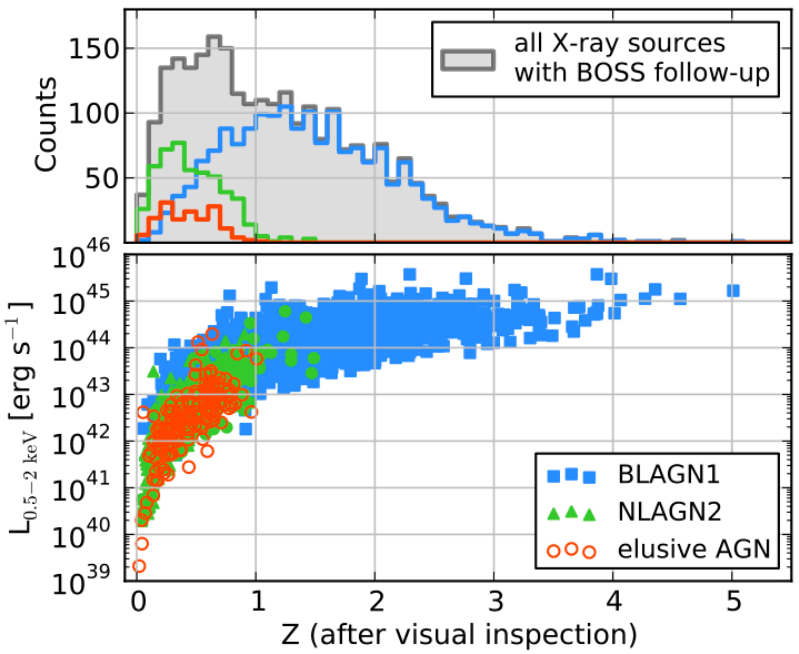
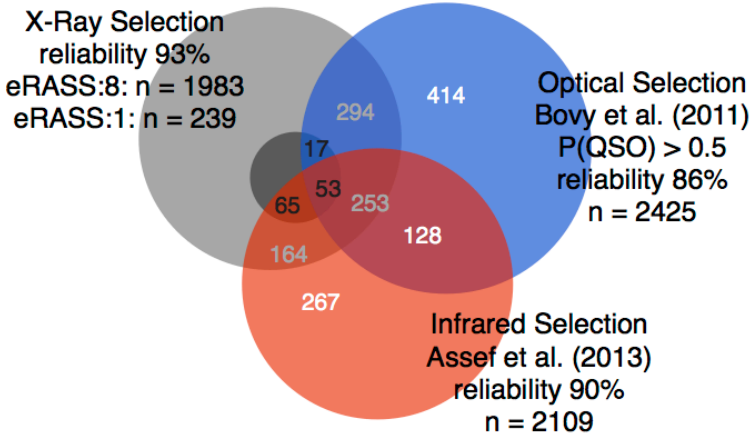
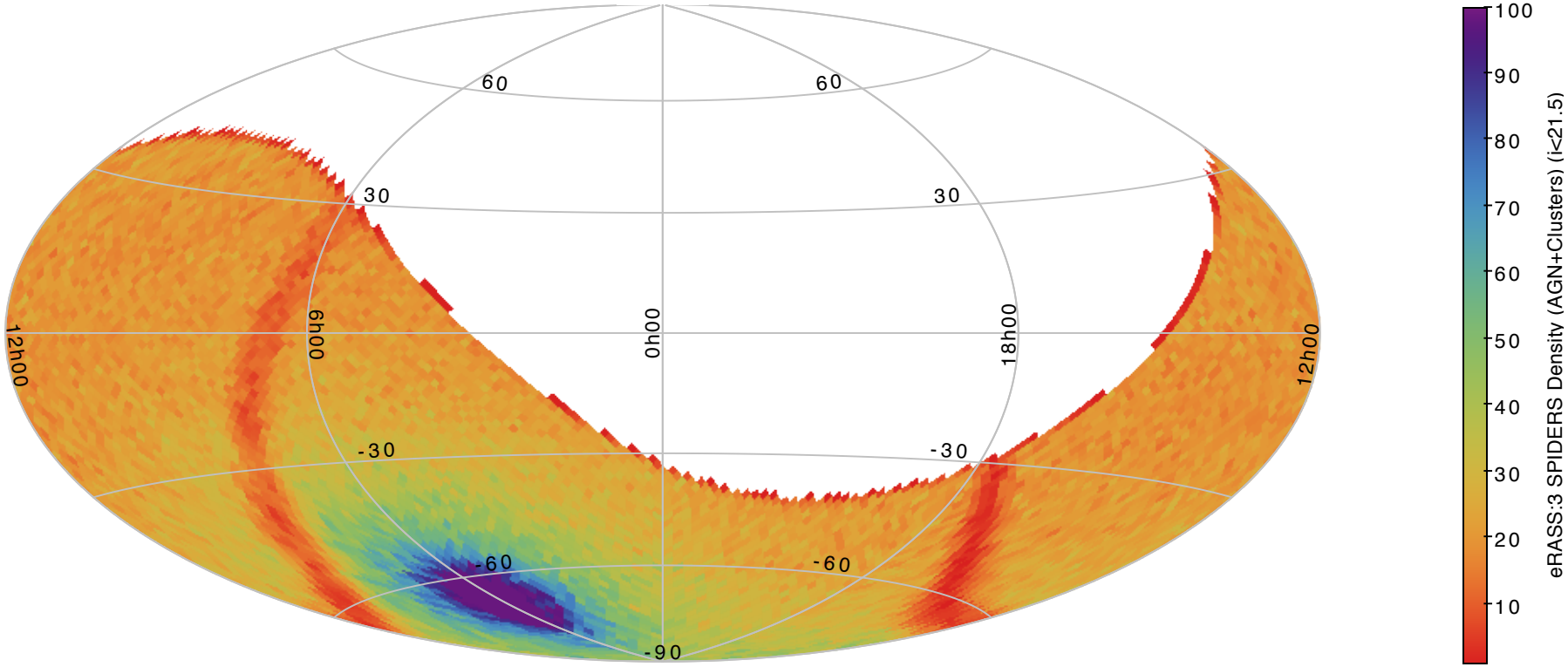


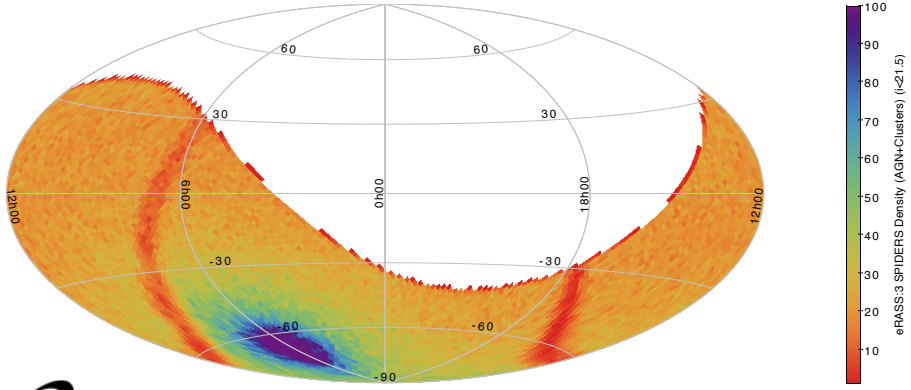
Fig. 3

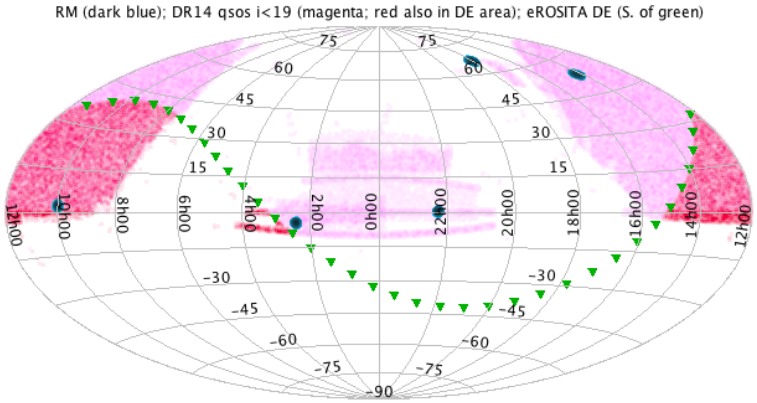


eRASS:3 source density



BHM Areas: *eROSITA*-DE mainly S., Time-Domain mainly N., but…





Estimated eRASS:3 source density in DE half of sky, after 3 *eROSITA* all-sky scans completed about 1.5 years into mission.

Total BHM program takes about ½ of the dark fiber-hours, North and South, approx evenly split between *eROSITA* and TD.

Although BHM/*eROSITA*-DE targets are South of green triangles, note 3000 deg^2 of *eROSITA*-DE coverage in North overlaps with prime area for BHM time-domain wide/low-cadence tier. In this ~3000 deg^2 North area, both TD quasars & *eROSITA* X-ray sources will be spectroscopic targets in SDSS-V/ BHM.

.

Black Hole Mapper in SDSS-V

Table 1: BHM multi-epoch and sub-exposures (current/approximate) plans

TD Tiers[1]	no. of ∼15 min. sub-exposures per time-resolved spectrum (flux limits)	number of time-resolved epochs	approximate number of fields[2]	total no. of science targets [thousands]
Wide	4 (i <19)	≥ 2	>600 (N)	> 20
Medium	4 (i <19)	≥ 12	>60 (N)	> 2
RM, Deep	8 (i <20)	~ 178	>5 (N?)[3]	> 1
eROSITA Tiers[4]	no. of ∼15 min. sub-exposures per time-resolved spectrum (flux limits)[5]	number of time-resolved epochs	approximate number of fields[2,6,7]	total no. of science targets [thousands]
Hemisphere	3-4 ($f_X > 2.5$; i <21.8)	$1 \leq n \leq 4$	∼600(N) + ∼2800(S)	>250
Deep/CVZ	6-8 ($f_X > 1$; i <22.4)	$1 \leq n \leq 8$	∼80 (TBC; CVZ S)	> 30 (TBC)

BHM in SDSS-V Summary

Combining X-ray and optical variability surveys across the sky, SDSS-V in 2020-2025 will provide order(s) of magnitude advances in quasar/SMBH and related studies, such as:

- Repeat spectra of >20,000 quasars sampling timescales from months to decades that will reveal the astrophysics of SMBH accretion disk properties and accretion state transitions, dynamical changes in broad line regions, binary black hole signatures, and variability constraints on quasar outflows.
- RM black hole mass measures using higher cadence SDSS-V spectra (extending down to weeks or days) for about a thousand quasars of diverse redshift and luminosity (vs. the current/historical RM sample that relies on only ~60 nearby & lower-luminosity AGN).
- Redshifts and spectral identifications for >300,000 obscured & unobscured *eROSITA* X-ray emitting AGN, providing highly unbiased measures/mappings of quasar clustering, demographics, and growth and evolution of SMBHs over cosmic time.
- A closely related spectral survey of >10,000 X-ray emitting clusters from the *eROSITA* survey to understand cluster physics & constrain the cosmological model. Plus X-ray stars in Milky Way and nearby galaxies.

(Re)Engaging with BHM

Obviously lots of work and science ahead, and we hope you may be interested in (re)joining and planning for BHM as we move forward, e.g., you might consider:

- attending this webinar (thanks!), and/or otherwise contacting Andrea Merloni, Yue Shen, or Scott Anderson (or others in BHM/SDSS-V) directly;

- joining BHM email distribution lists, which include bhm-xray@sdss.org, bhm-qsotd@sdss.org, bhm@sdss.org

- joining general BHM telecons that we started recently (we keep teams and other interested folks alerted to these, including via above email lists);

- consulting some other general background materials on SDSS-V linked from

  http://www.sdss.org/future/

  e.g., includes link to white paper (Kollmeier et al. 2017) on SDSS-V
  https://arxiv.org/abs/1711.03234

Thanks, and QUESTIONS?