Catalogues of galaxy clusters in the era of large X-ray surveys
An illustration with SPIDERS

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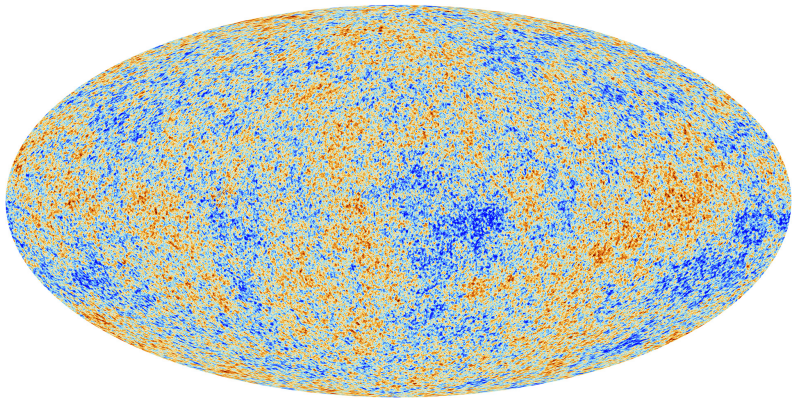
Workshop "Treasures Hidden in High-Energy Catalogues"
IRAP, Toulouse – 24 May 2018

Clusters of galaxies ; large-scale structure

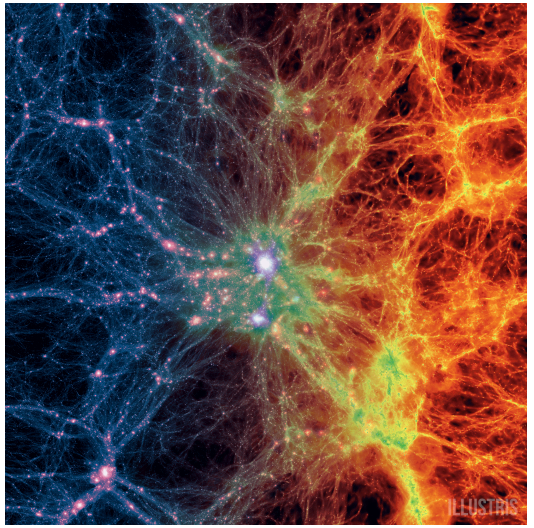
- **Coherent model of structure formation**

- **Primordial fluctuations grow in expanding universe:**
  - Dark matter? Accelerated expansion?
  - Emergence of cosmic web?

- **Clusters of galaxies form last:**
  - Nature, origin of 1st structures?
  - Physical mechanisms entering their formation?

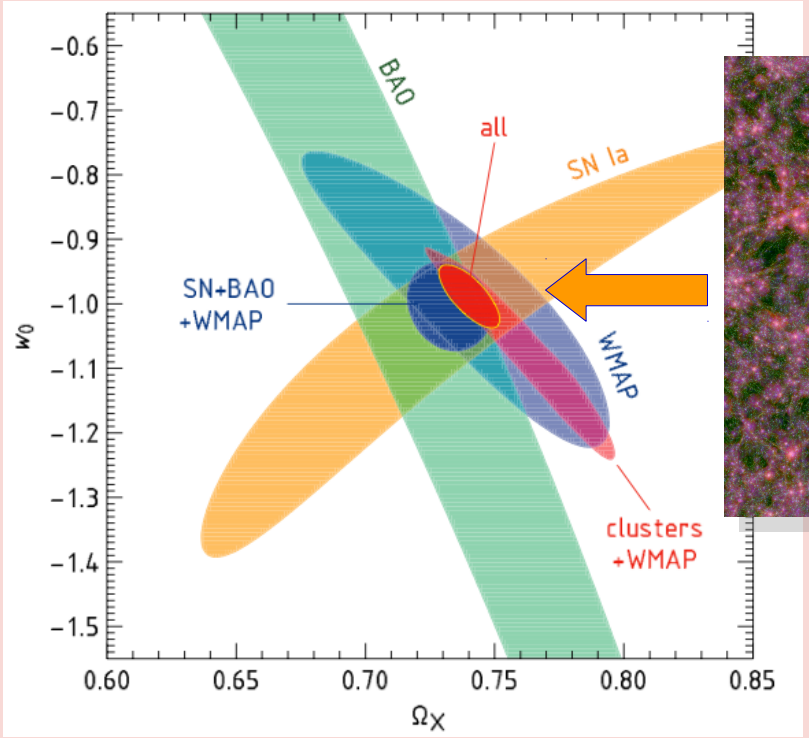


(Planck) CMB = Primordial fluctuations

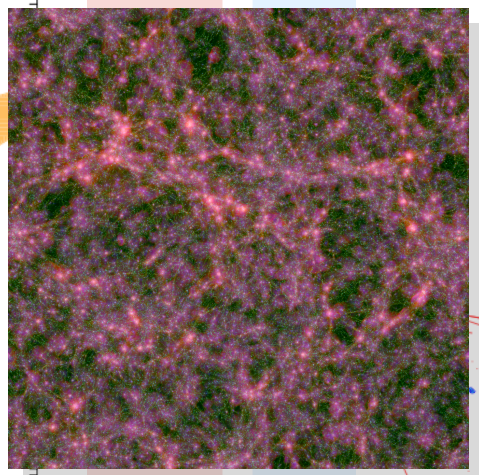


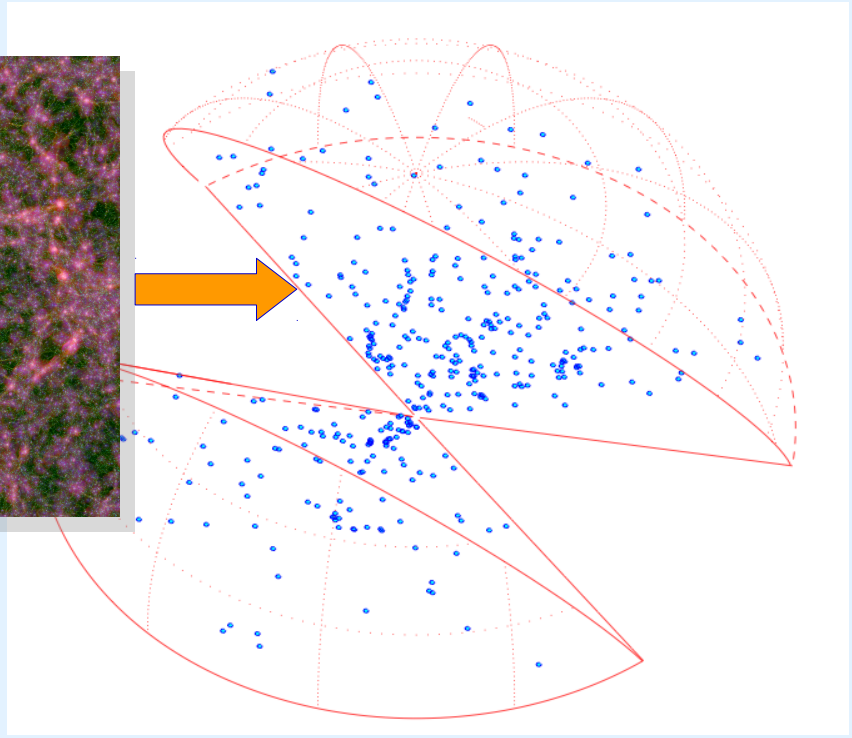
Dark matter ← → Gas density (simulation z=0 "today")

Clusters of galaxies as cosmological probes



Vikhlinin et al. 2009



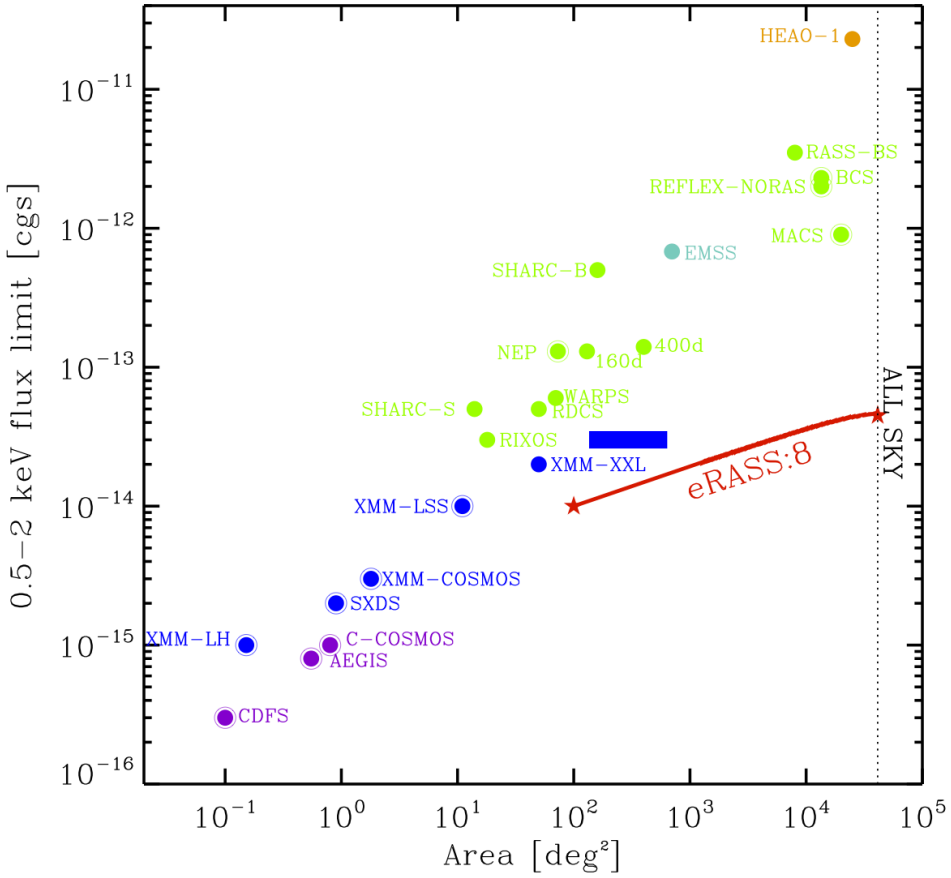


Guzzo et al. 2009

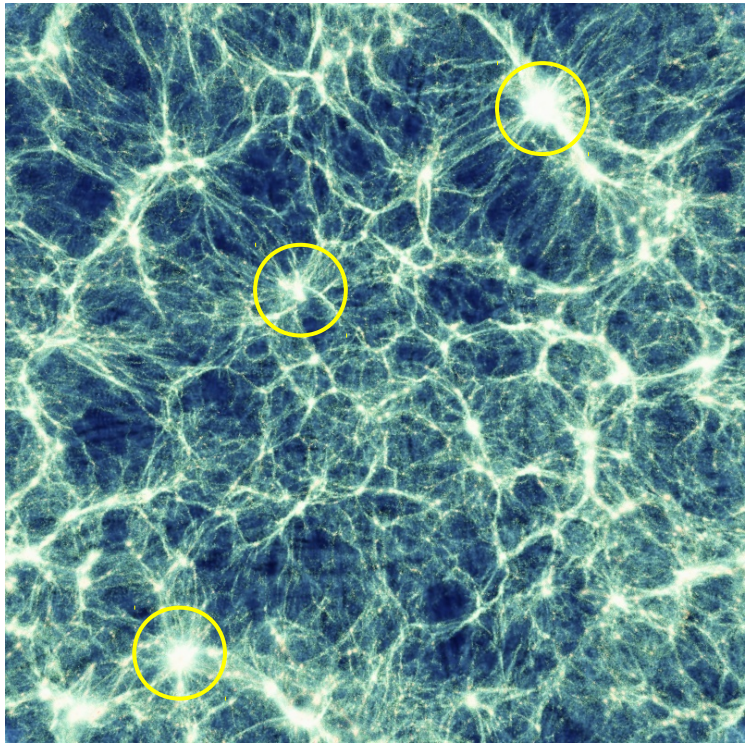
Growth of structures+expansion history
Halo mass function *n(M,z)*
Physics of X-ray emitting intracluster gas

Large-scale structure
ξ(s ; z) and/or P(k ; M, z)
Using clusters as highly biased tracers

Large galaxy cluster surveys (X-rays)

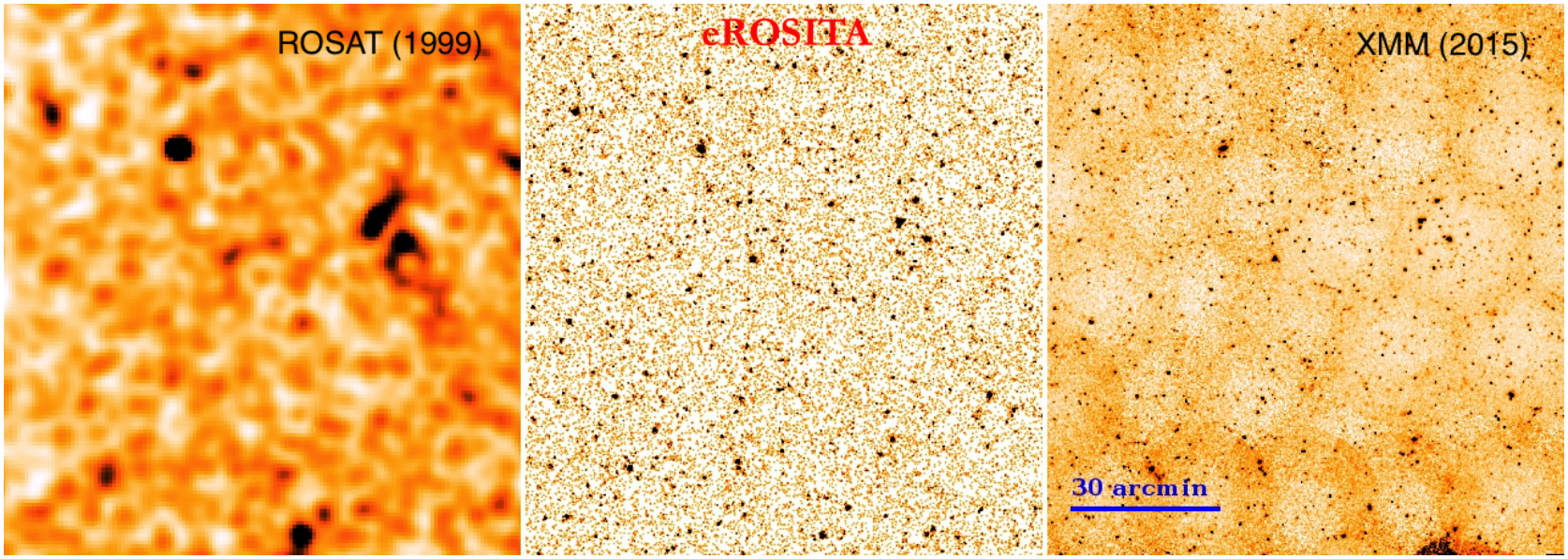


eROSITA science book
(Merloni+12)



Gas density @ z=0
Simulation K. Dolag

The eROSITA all-sky survey



- **Point-source sensitivity: ~ 10^{-14} (0.5-2 keV) and 2 × 10^{-13} (2-10 keV) ergs/s/cm^2**
- **Extended sources sensitivity ~ 3-4 × 10^{-14} ergs/s/cm^2**

- Wide-area census of galaxy clusters (10^5) and active galactic nuclei (3M) in soft+hard X-rays bands

Merloni et al. 2012 – Image credits: MPE, eROSITA_DE, XMM-XXL

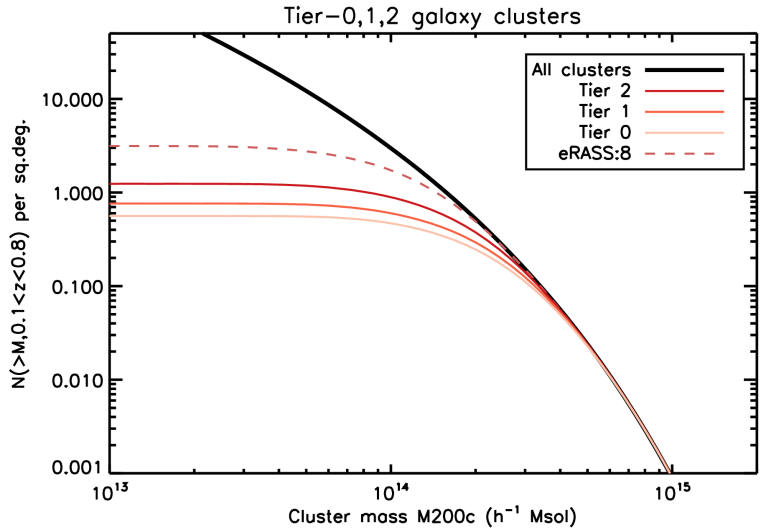
Multi-tiered galaxy cluster optical follow-up

- **Northern hemisphere: SDSS-IV+V**

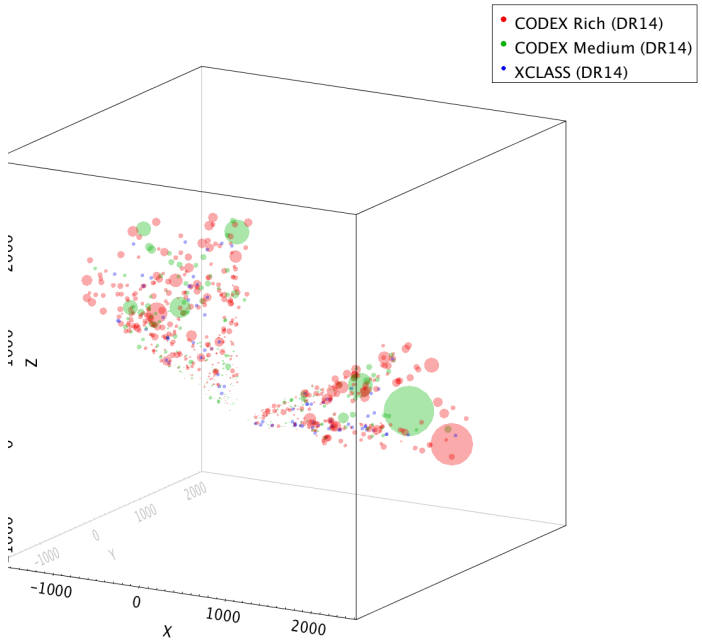
- SPIDERS (PI: A. Merloni, K. Nandra)
- "Tier 0": RASS and XMM sources (mainly AGN and clusters)
- "Tier 1 (& 2)": **e**RASS:1 follow-up (extended and point-sources)

- **Southern hemisphere: ESO/4MOST+SDSS-V**

- 4-m VISTA telescope
- AGN and galaxy cluster surveys
- Operations start 2021

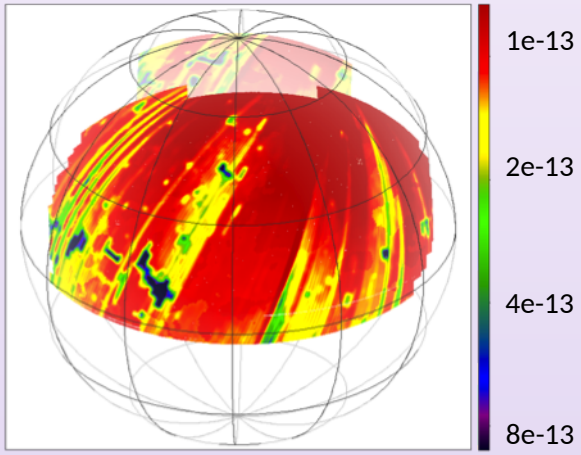


Clerc et al. 2016



Tier 0 (pre-eRosita): CODEX (RASS+RedMapper)

RASS-faint sensitivity ergs/s/cm²



SDSS ugriz+RedMapper

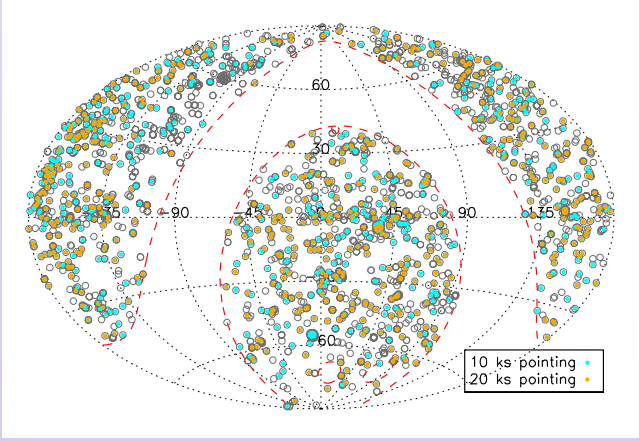
Goal: secure spectroscopic confirmation of 75% CODEX clusters (=4,500) + statistical velocity dispersion for massive subsamples

- Optimal (balanced) target prioritization
- ~10,000 deg²
- $0.1 < z < 0.6$ red-sequences
- Median mass ≈ 4×10^{14} M_{sol}

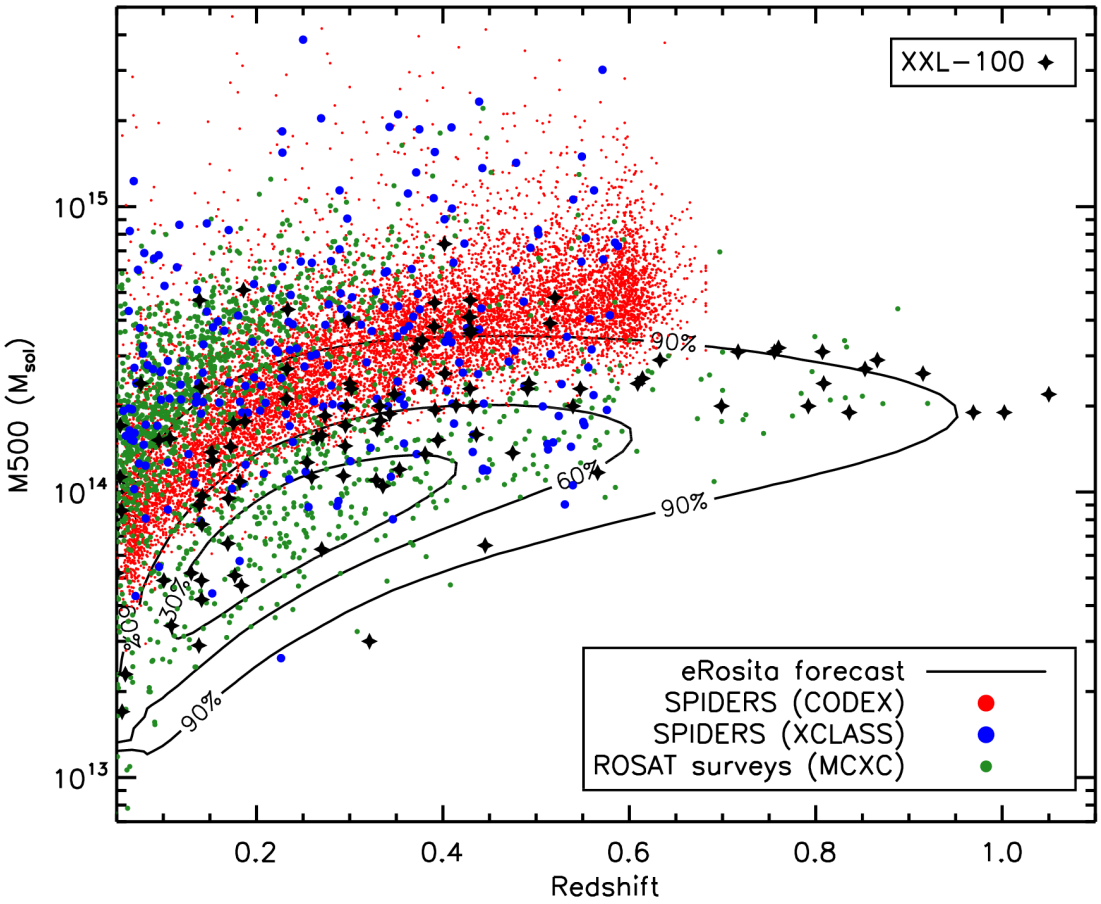
Pre-eRosita: RM-XCLASS (XCLASS+RedMapper)

- XMM archive "C1" clusters correlated to RedMapper catalogue *(Sadibekova+14)*

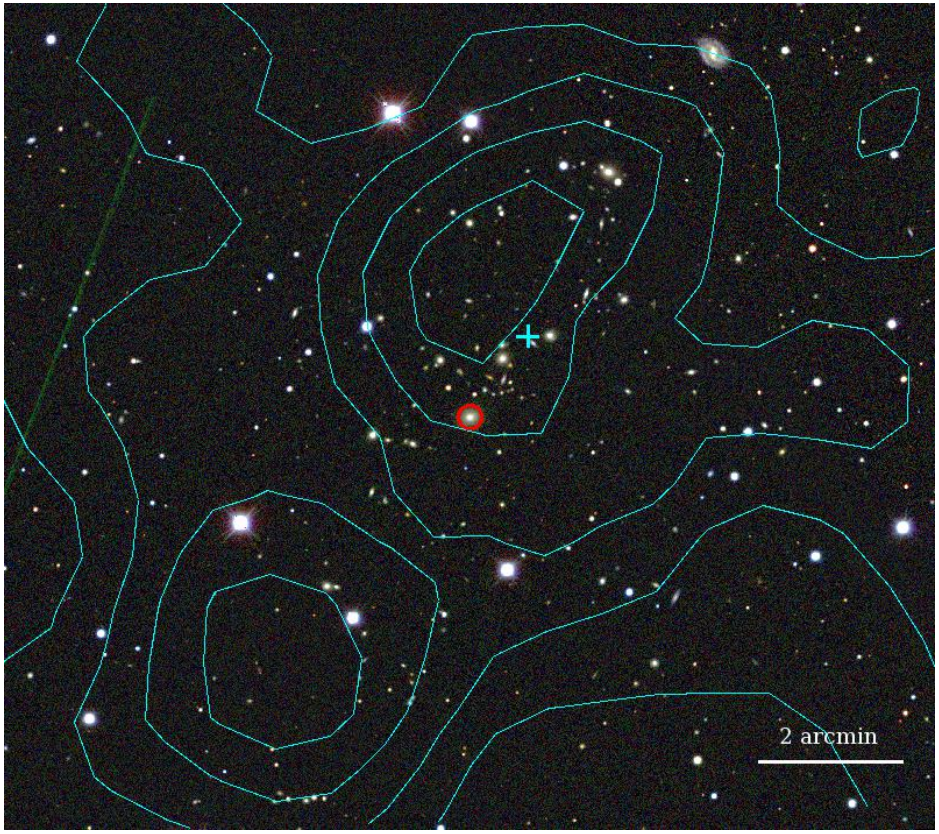
- 278 clusters in footprint (~50-60 deg²)
- XMM-quality characterization
- Lower mass regime (good for scaling relations)
- High target prioritization

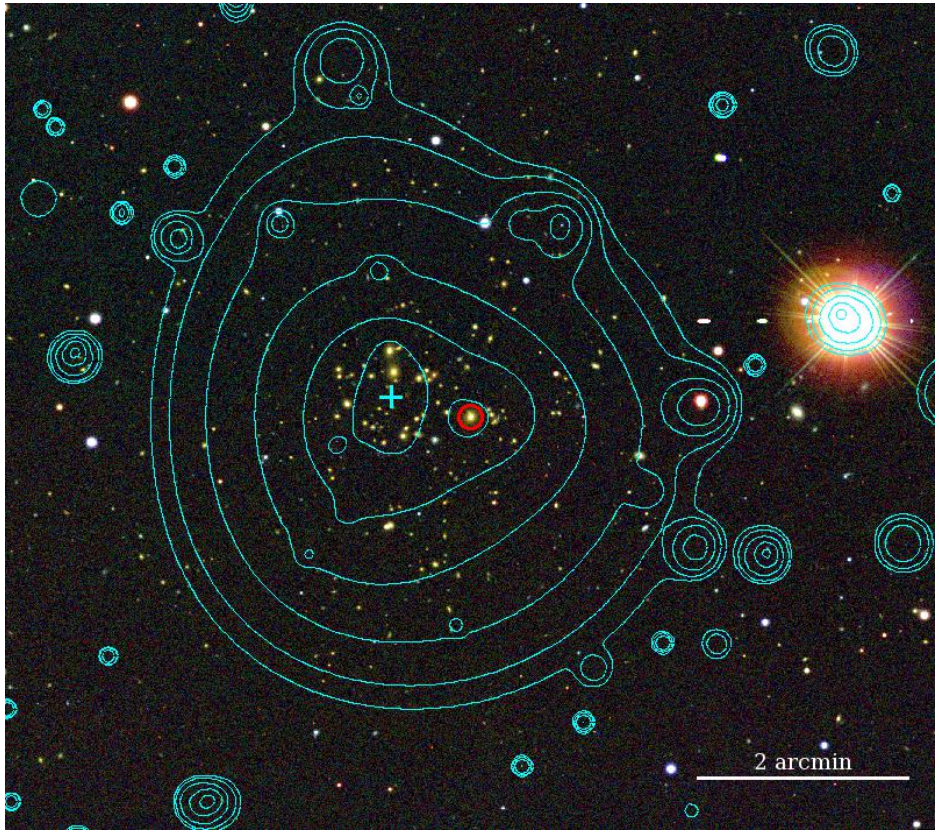


RASS, ROSAT, eRASS, *XMM-XXL*, SPIDERS



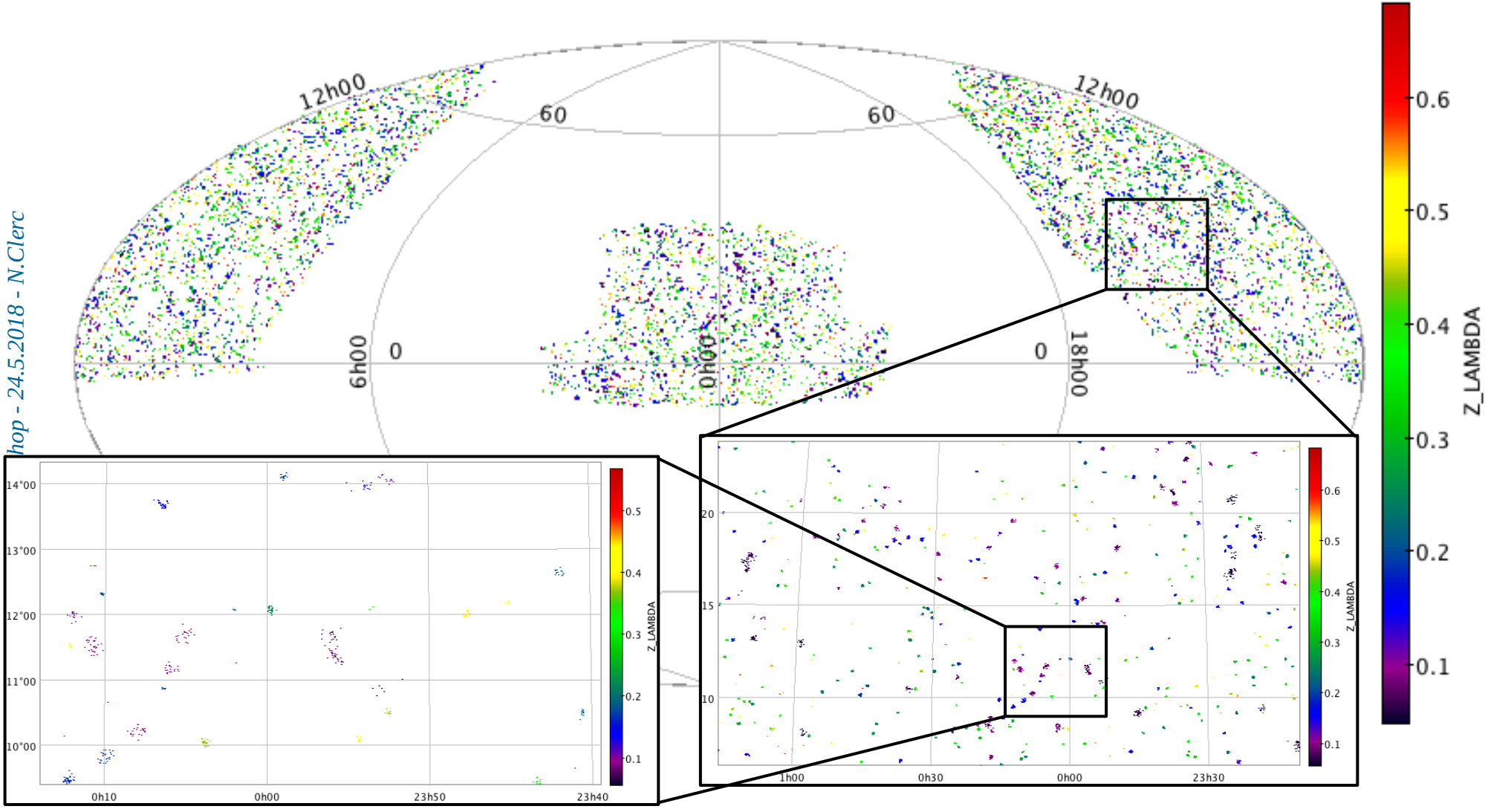
RASS faint sources *vs.* XMM extended





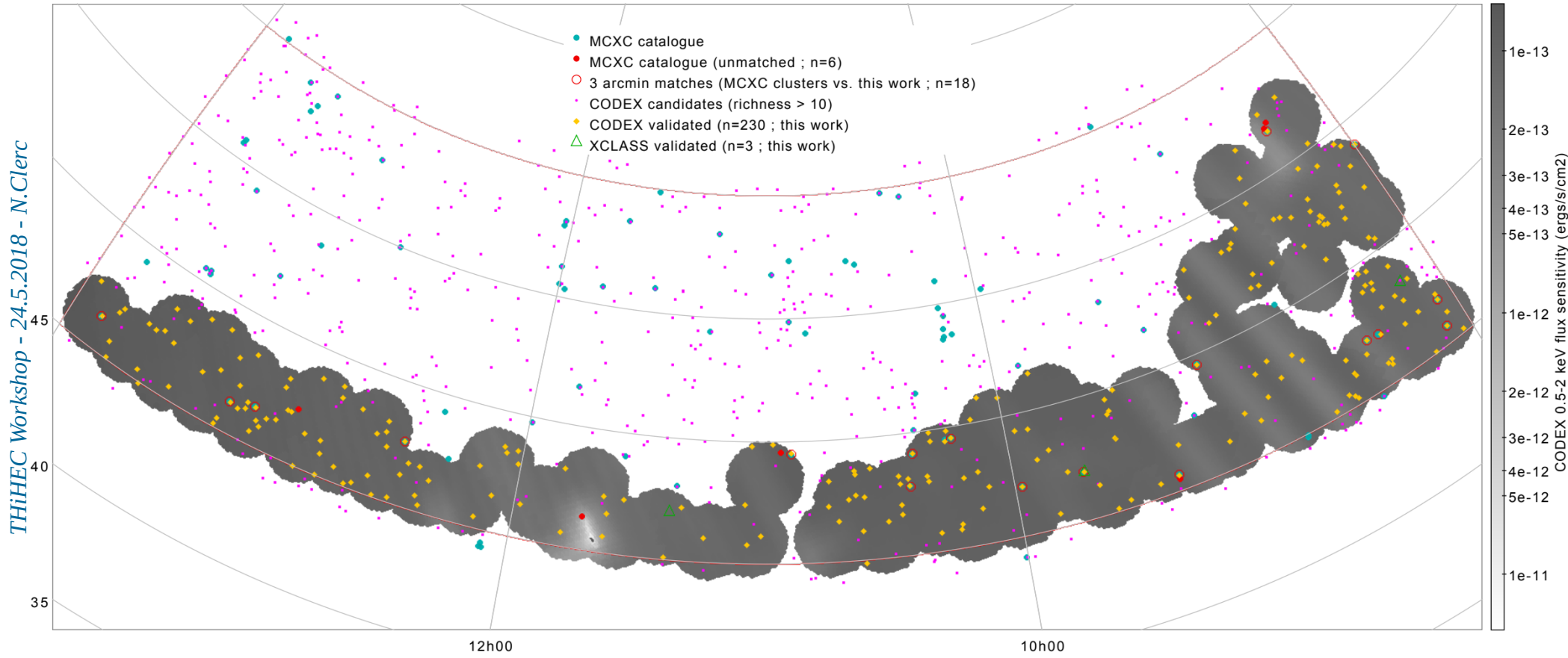
NC et al. 2016

Targeting 50,000 red-sequence galaxies



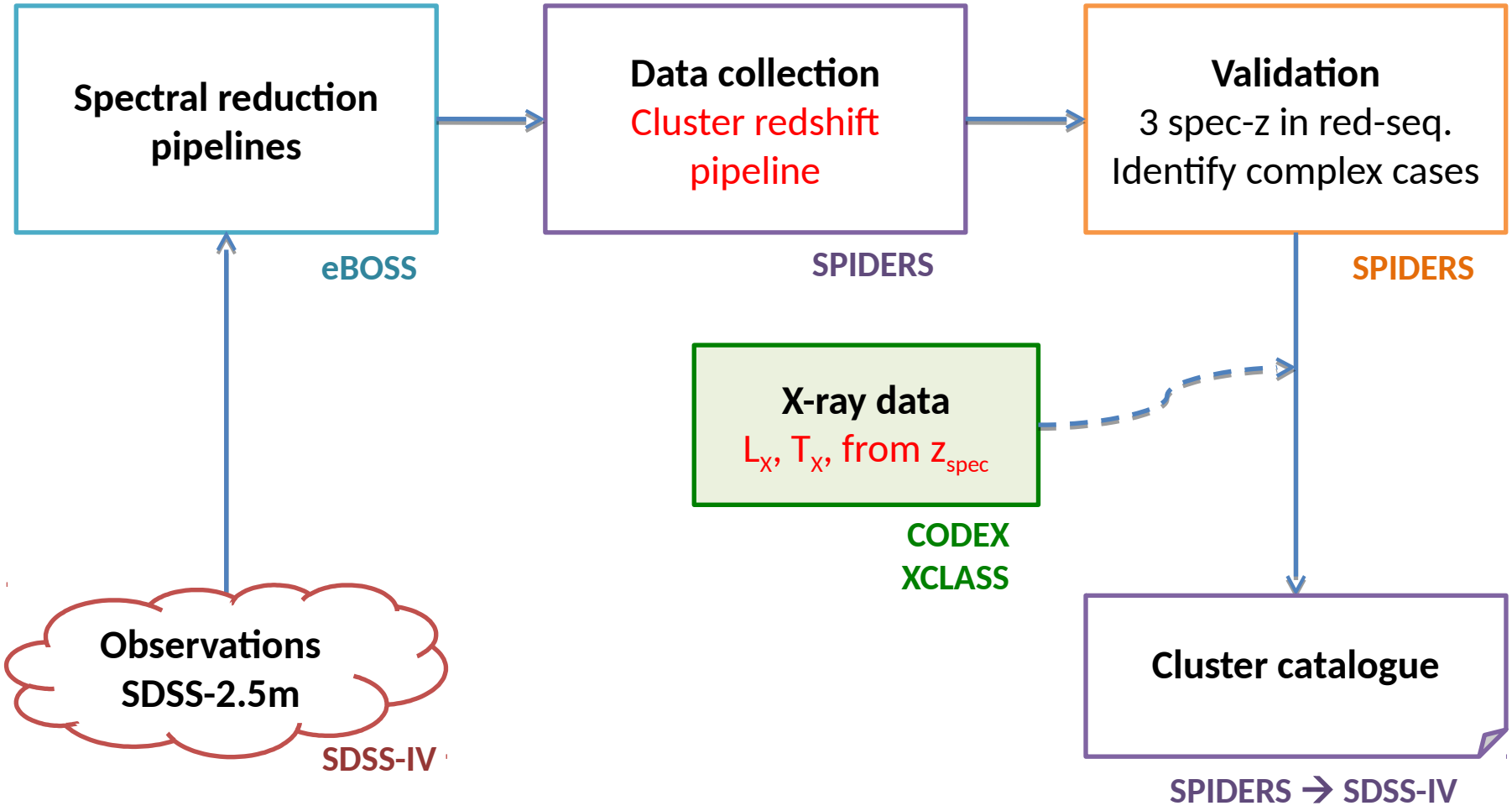
NC et al. 2016

Demonstration sample (300 deg^2)



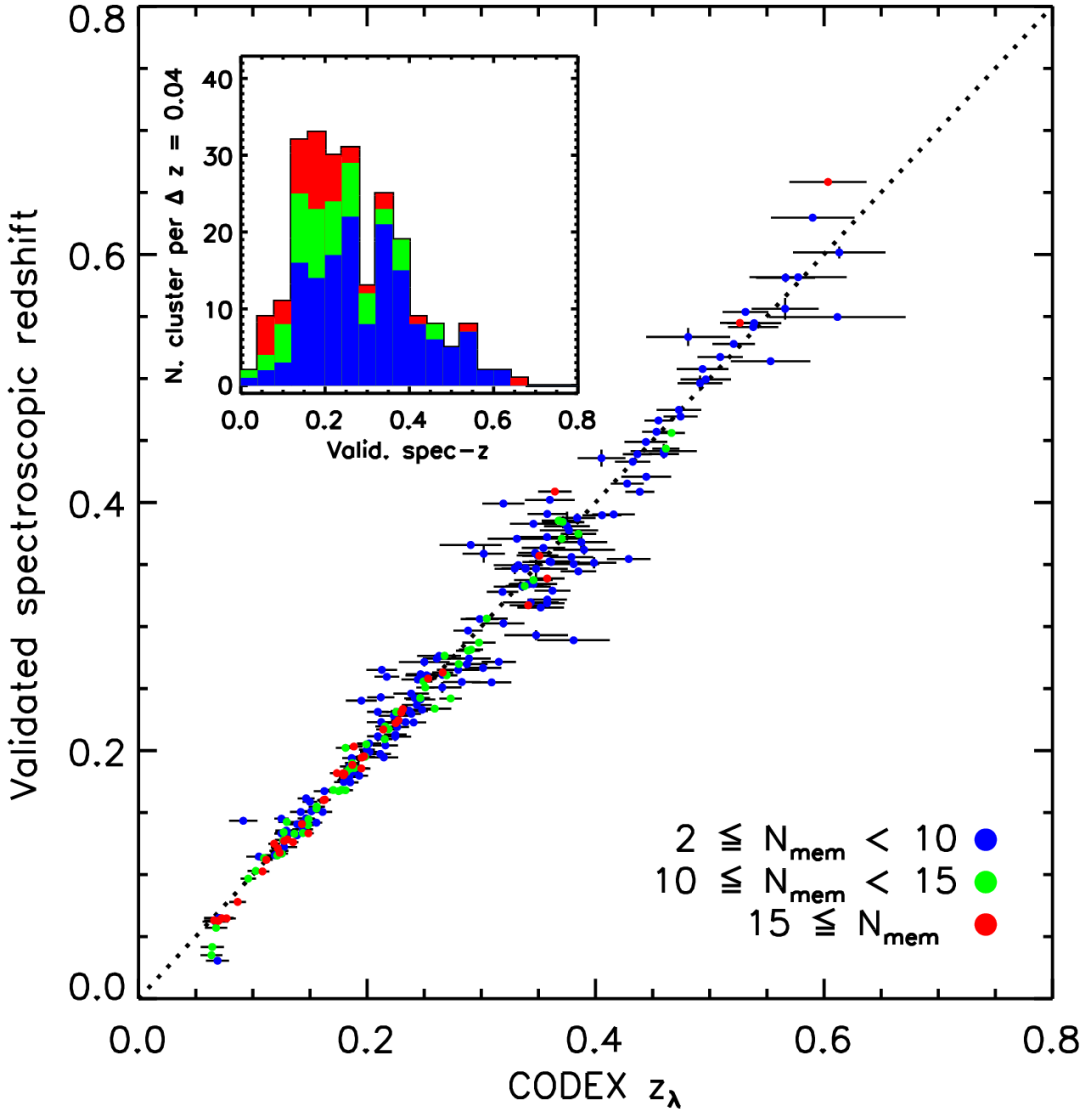
NC et al. 2016

Pipeline



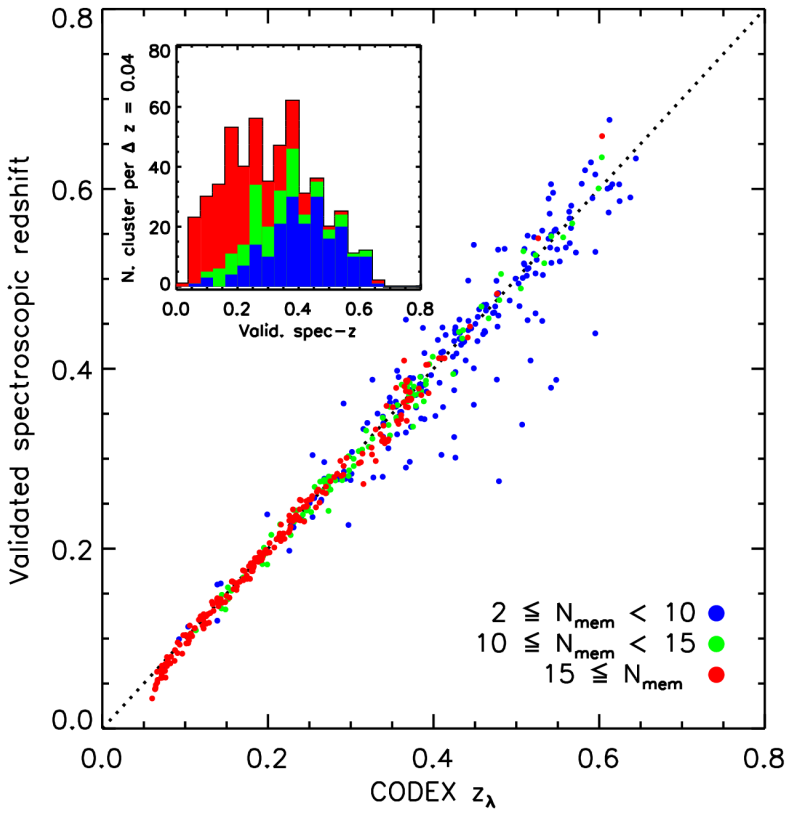
Clerc et al. 2016

Cluster redshift confirmation



NC et al. 2016

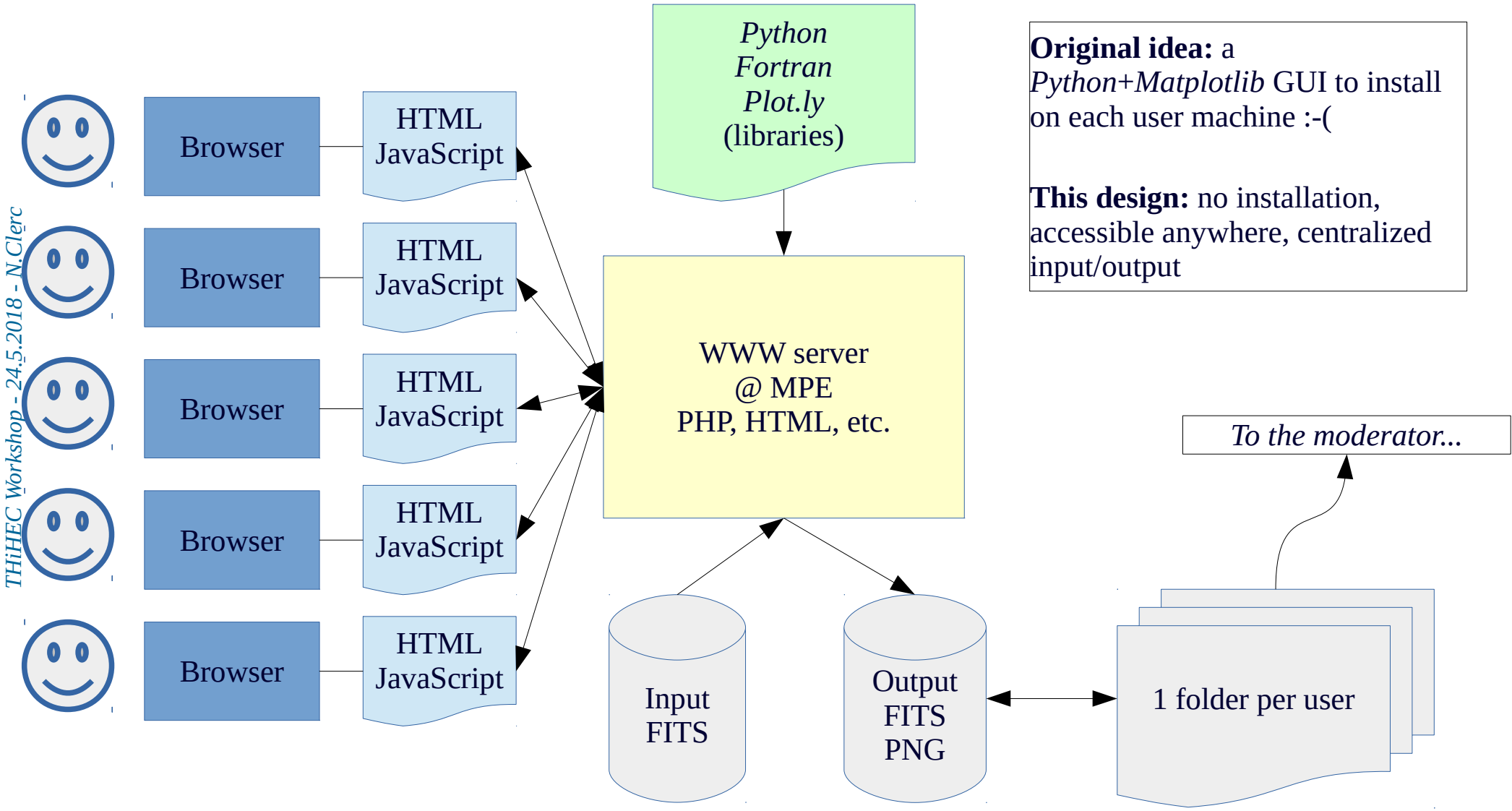
Latest public catalogue online: *SDSS-DR14*



See Value-Added Catalogue description in SDSS Data Release 14 Paper 2018, ApJS 235, 42

- **573 completed fields**
  - Selected upon photometric richness greater than 30
  - Spectroscopic observations processed, <2% suspicious redshifts
- **Visual inspection is crucial**
  - Team of ~10 scientists, double inspections
  - Specific on-line tool for remote/collaborative use
  - A training set for future machine-learning algos.
- **Merged catalogue: 520 objects [sdss.org/dr14]**
  - $\delta z/z \sim 10^{-3}$ (stat.) ; median ~ 13 gal./system
  - Recalculation of distance-dependent quantities
    - L_X, R_{200}, $M_{500}(L_X)$...

Visual inspection



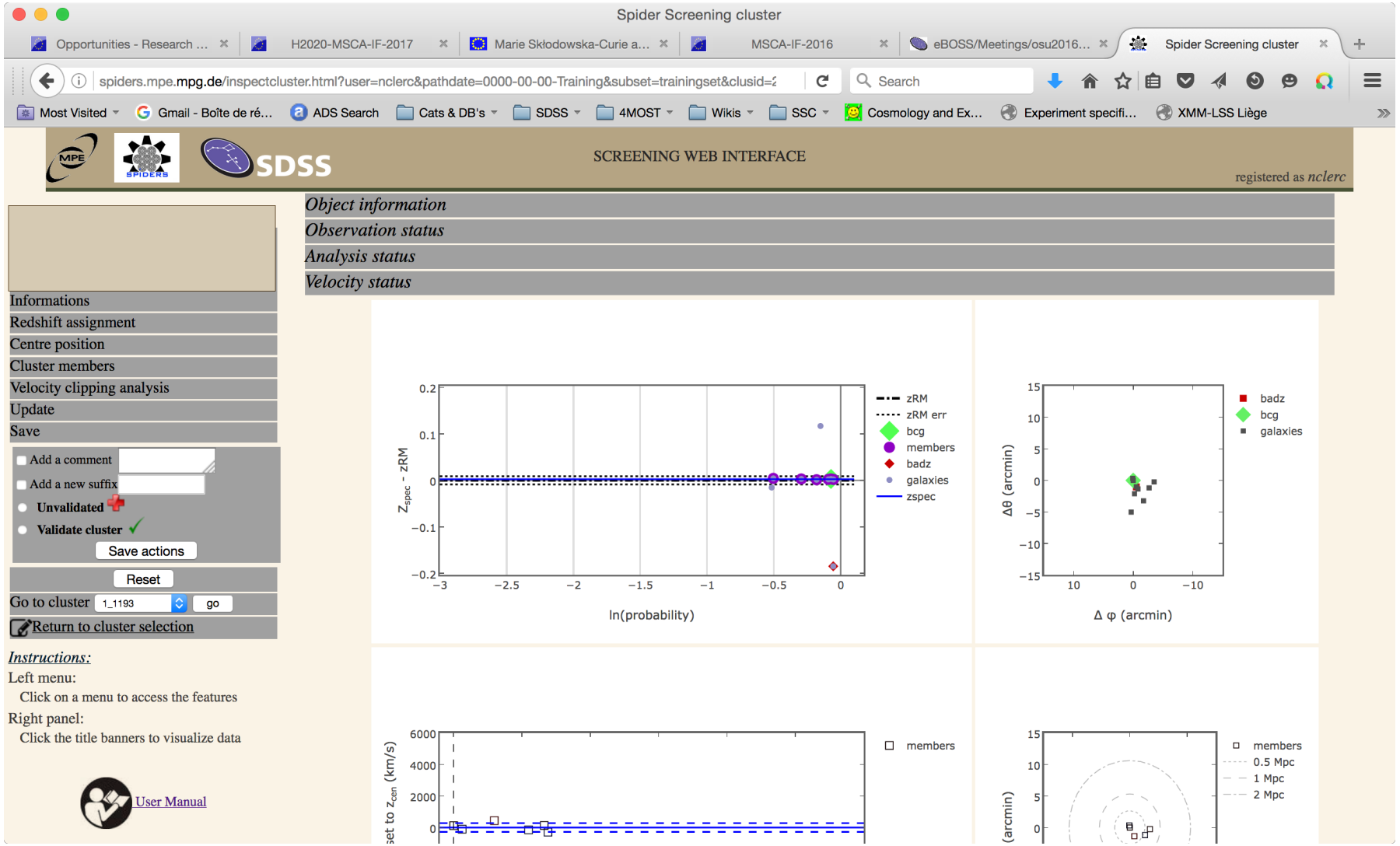
Original idea: a *Python+Matplotlib* GUI to install on each user machine :-(

This design: no installation, accessible anywhere, centralized input/output

Visual inspection

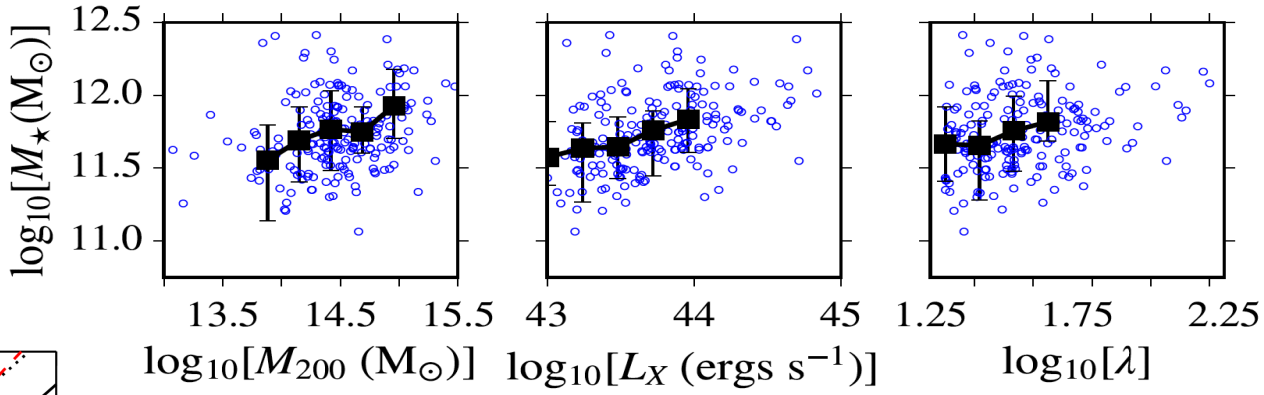
“WebScreening” - online tool for collaborative cluster validation

(A. Gueguen, N. Clerc, V. Prasad - MPE)

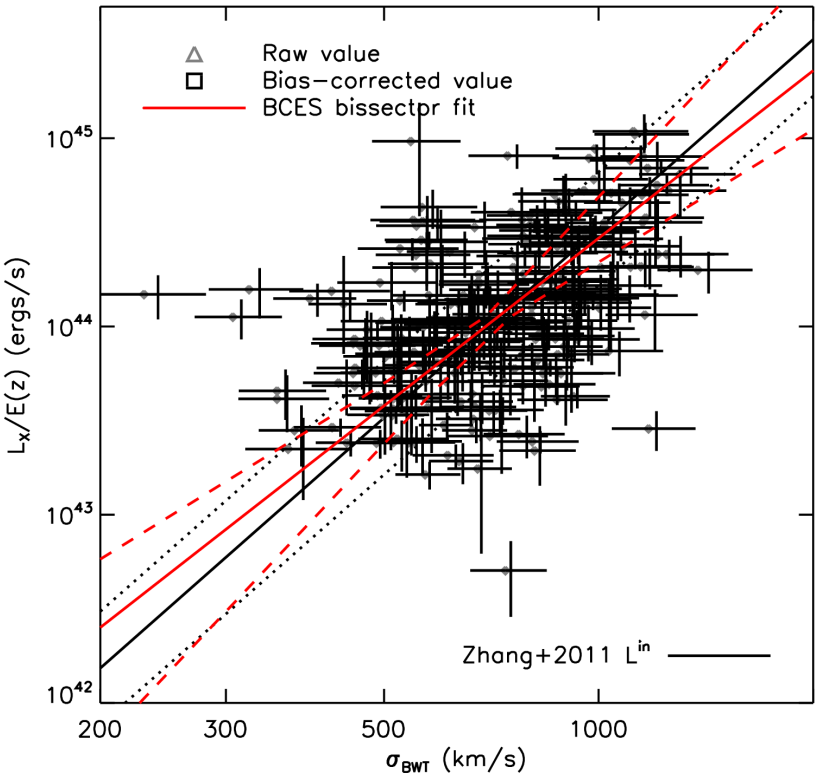


Treasures in the SPIDERS DR14 catalogue

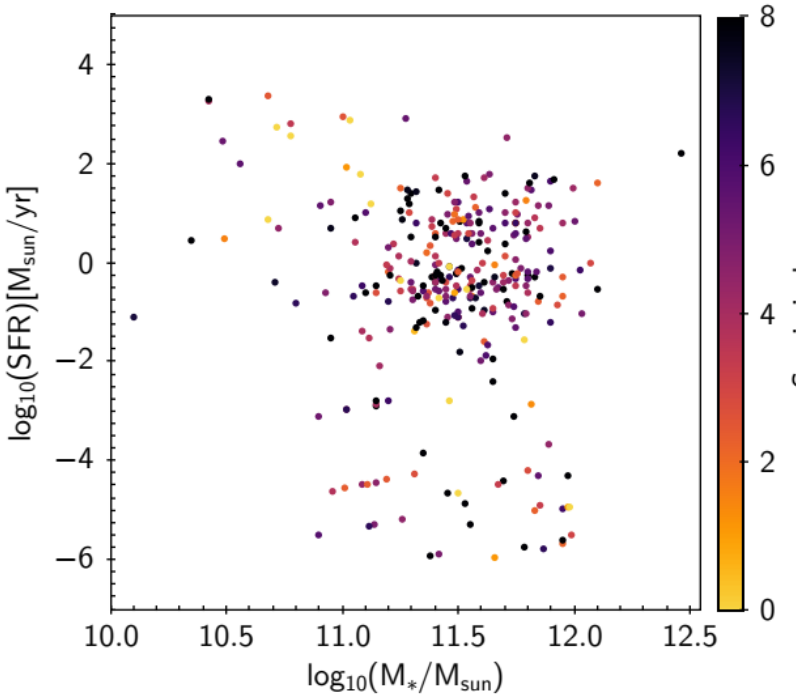
Only systems with > 15 spec-z
Bias correction and uncertainties on v-disp from HIFLUGCS resampling models ↓



↑ adapted from Furnell et al., A&A



Catalogue presented in
SDSS Data Release 14 Paper 2018, ApJS 235, 42

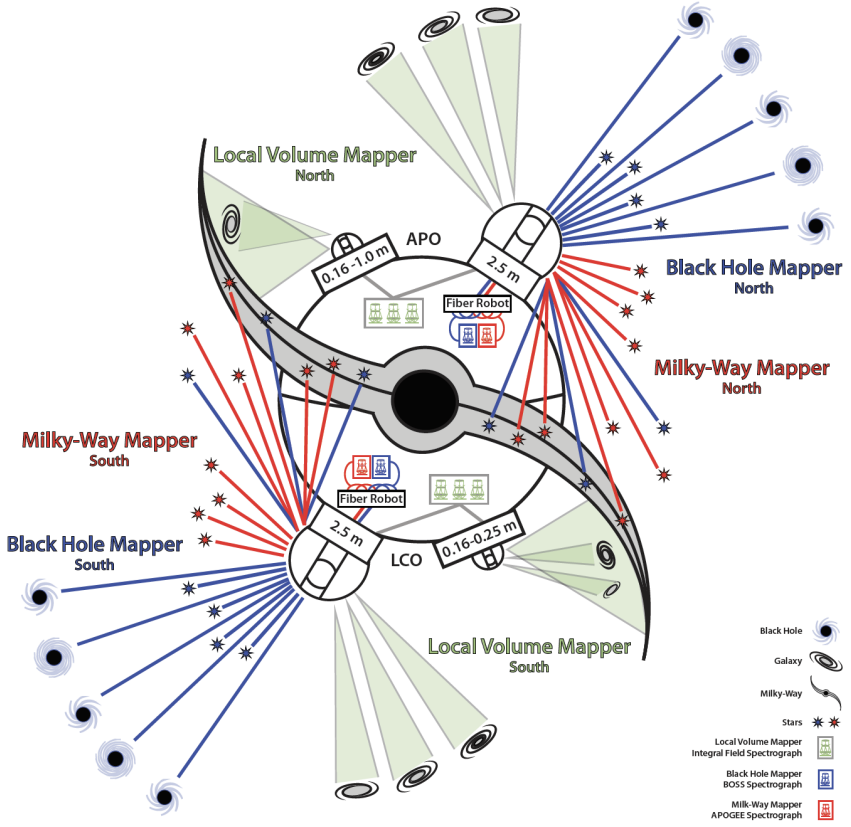


← Online catalogue of BCG properties (Erfanianfar et al. In prep.)

SPIDERS current status

- RASS/XMM targeting until *eROSITA* sources available
- 2016 – SDSS Data Release 13: “demonstration sample”
  - public, 230 clusters, down to low S/N
- 2017 – SDSS Data Release 14: 2,500 deg^2 coverage
  - 520 clusters, richness > 30, median #redshifts/cluster ~ 13
- Next DR in 2019, observations going on.
- *Current studies on:*
  - *Dynamical mass modeling (innovative stacked approaches)*
  - *Clustering of clusters (large volume/statistics)*
  - *High-redshift (z~0.6-0.7) efficiency boost (using deeper photometry)*

SDSS-V: pioneering panoptic spectroscopy



- 5-year program begin mid-2020 in both hemispheres
- 3 science programs
  - *Milky Way Mapper*
  - ***Black Hole Mapper***
  - *Local Volume Mapper*

- SDSS-V is
  - An observing facility
  - A science survey program
  - A consortium & collaboration
  - In particular, 80k spec-z in 10k X-ray clusters

- See A. Merloni's talk
- More info : arXiv 1711.03234 (Kollmeier, et al.)

Conclusions

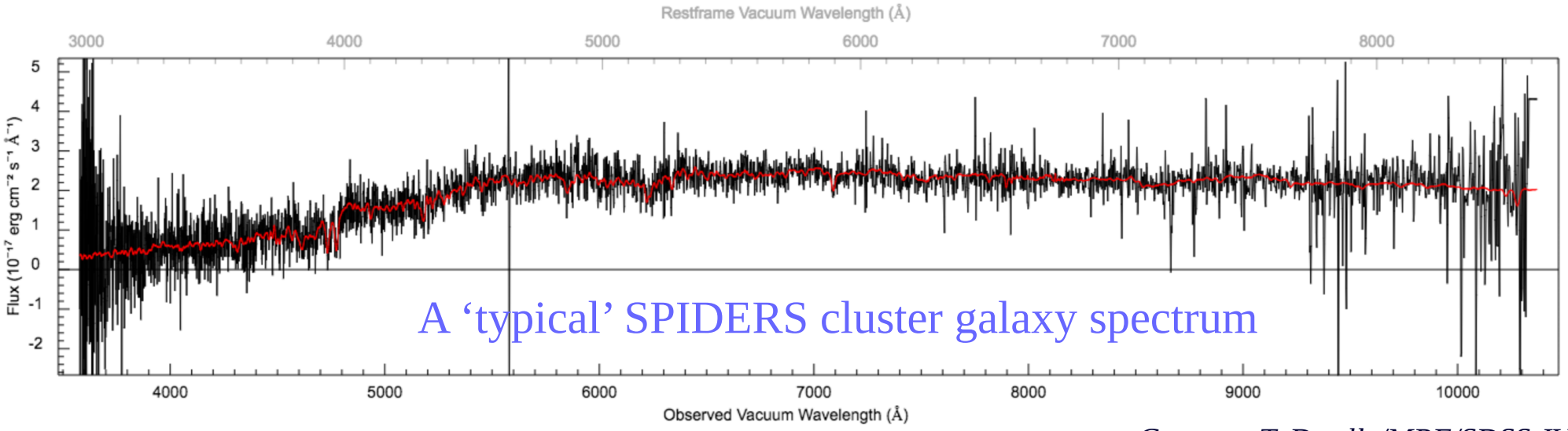
- Current and upcoming studies are changing our approach to cluster surveys:

✔ Statistics – new approach to galaxy cluster samples, drawn from a pool of ~10^5 objects across the entire extra-galactic sky (*eROSITA*)

✔ Precision measurements – accurate redshifts enabling precise positions, masses & mapping of the baryonic cosmic web (SPIDERS)

Thank you!

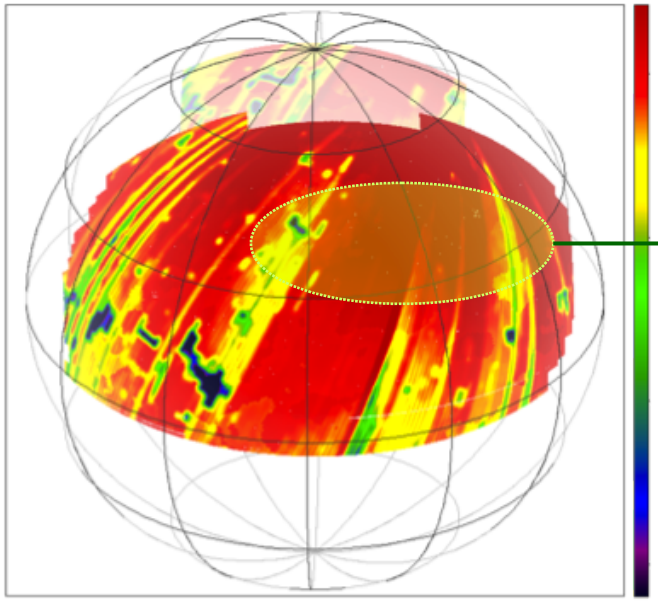
Data quality & reduction



A ‘typical’ SPIDERS cluster galaxy spectrum

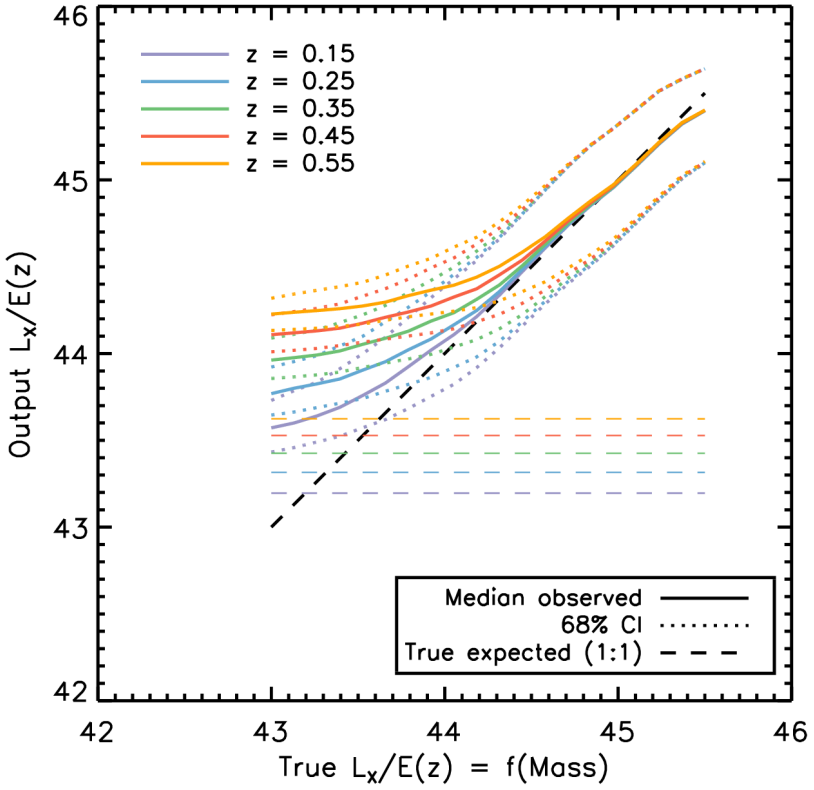
Courtesy T. Dwelly/MPE/SDSS-IV

Modeling the survey



RASS sensitivity (flux units)

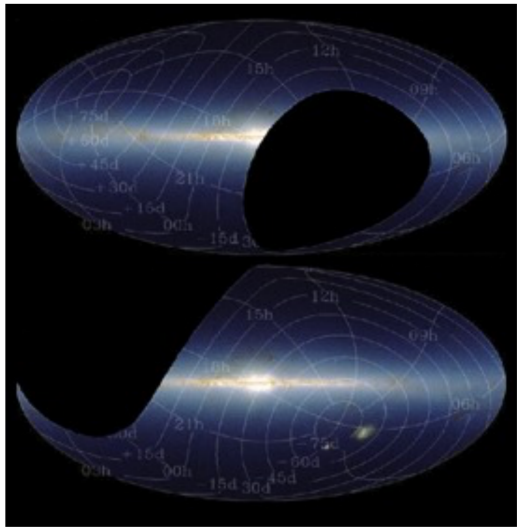
Mass function
+ detection efficiency
+ measurement errors
+ AGN HOD model
(*Allevato+12*)



NC et al. 2016
Finoguenov et al. In prep.

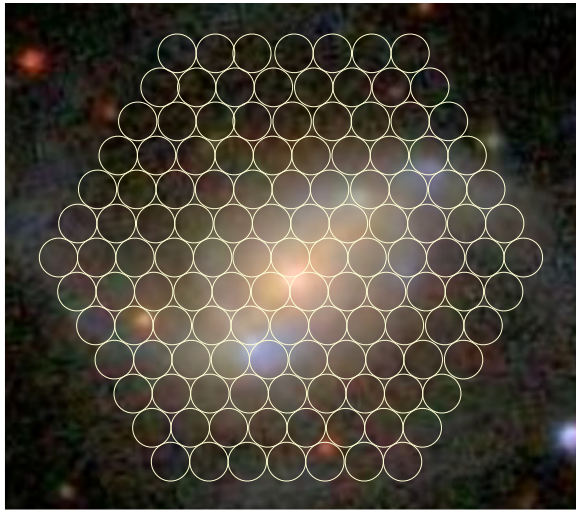
SDSS-IV surveys (2014 through 2020)

APOGEE-2



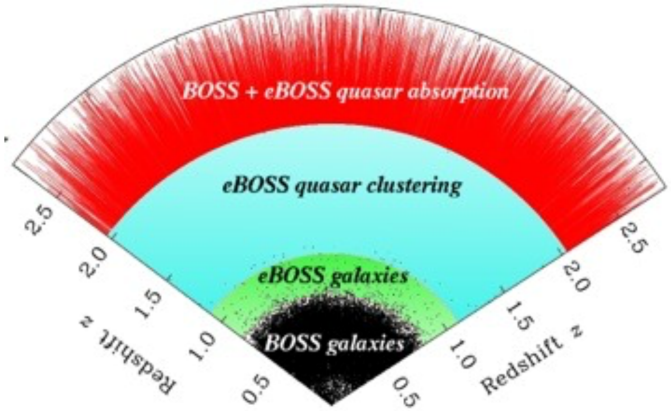
Maps hundreds of thousands of individual stars in the Milky Way.

MaNGA



Maps 10,000 nearby galaxies.

eBOSS, TDSS, SPIDERS



Maps the Universe of galaxies and quasars. Especially quasars.

galaxy evolution & dark matter

dark energy & cosmology