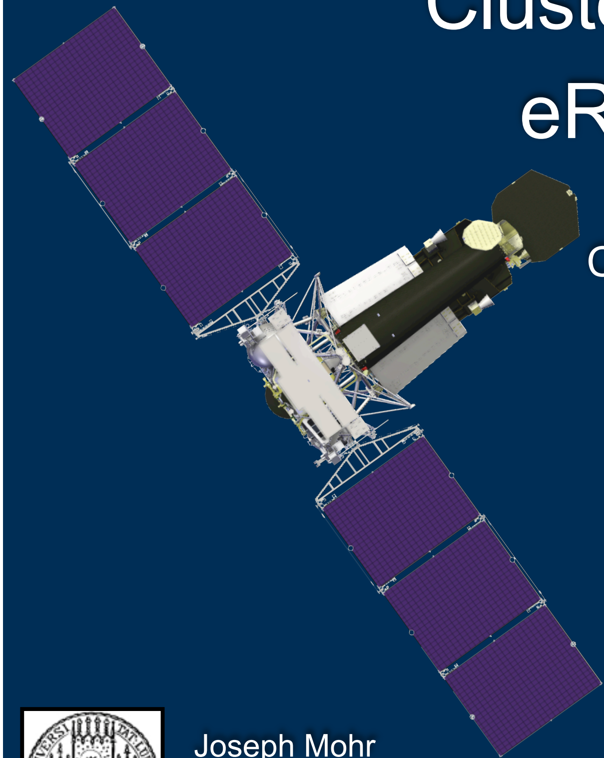
Cluster Cosmology with eROSITA on SRG



Corfu - The Dark Universe

September 18, 2015

Joseph Mohr

Ludwig-Maximilians University Faculty of Physics

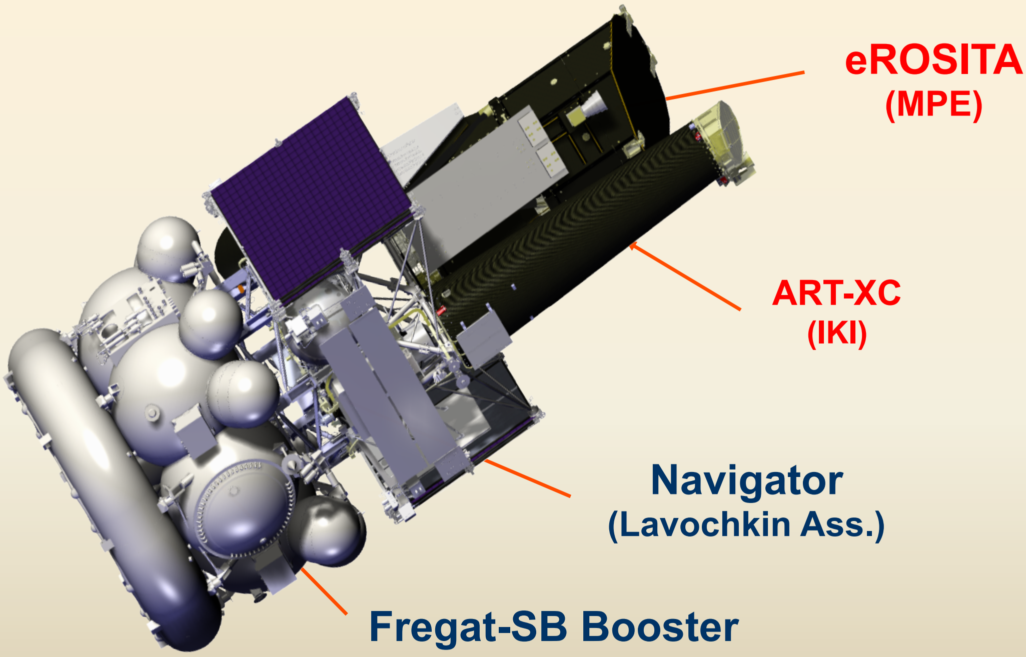
Max Planck Institute for Extraterrestrial Physics

Overview

- SRG Mission Overview
- eROSITA Cluster Cosmology in Context

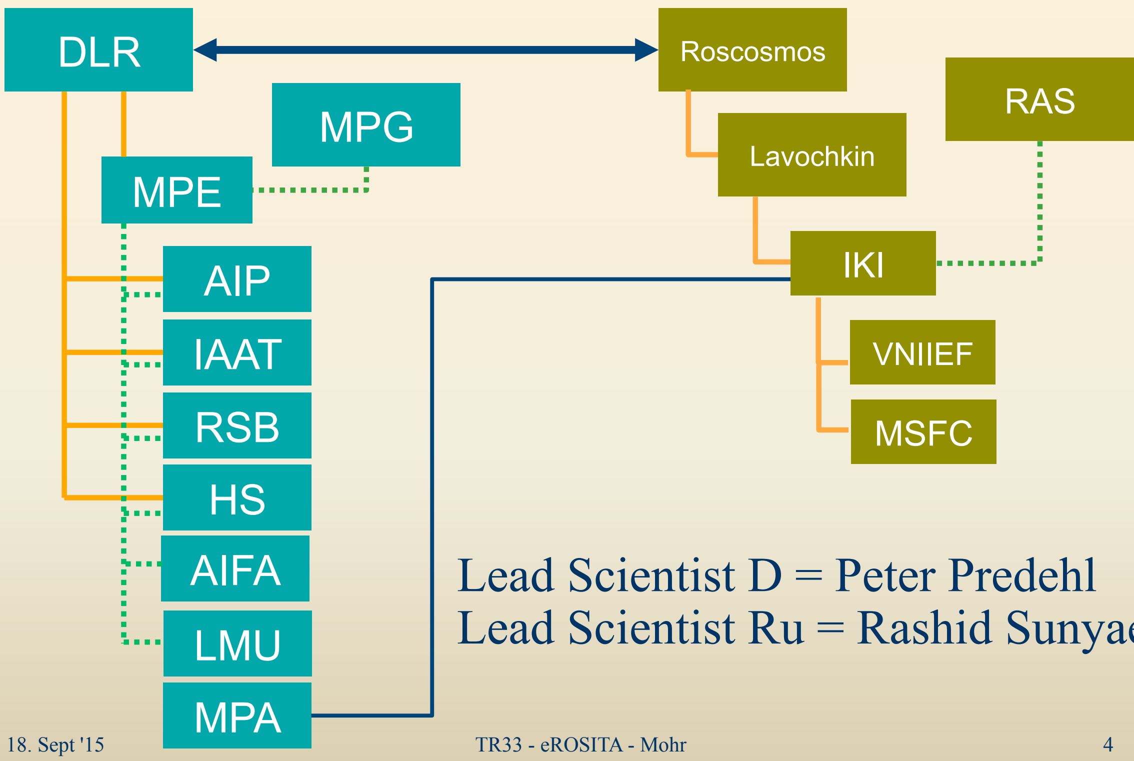
Courtesy: P. Predehl

Spektr-Rentgen-Gamma



Courtesy: P. Predehl

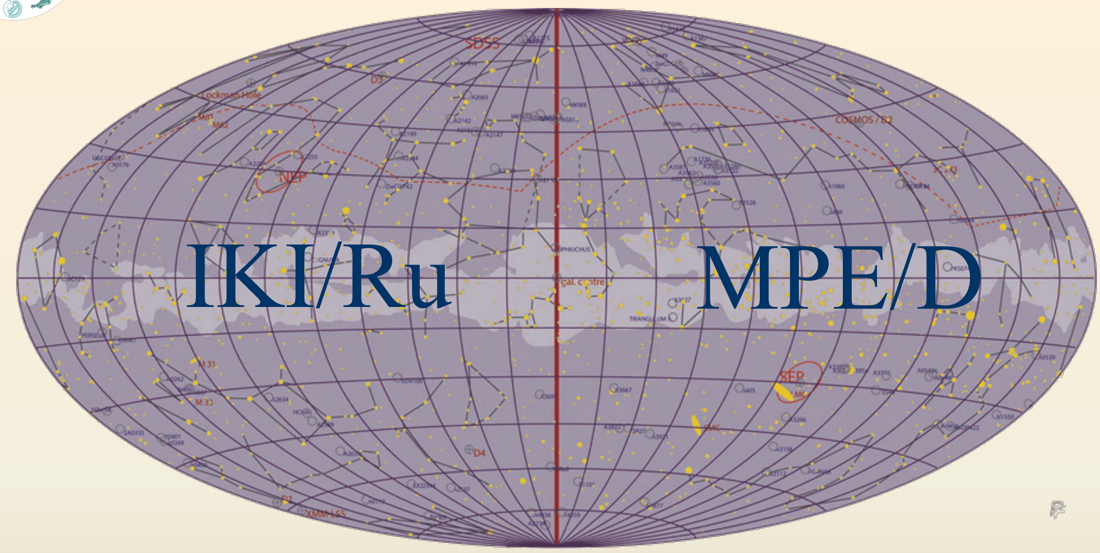
Project Structure



Lead Scientist D = Peter Predehl
Lead Scientist Ru = Rashid Sunyaev

Courtesy: P. Predehl

eROSITA Data Rights



Independent set of science working groups with some coordination expected

eROSITA-D: external collaboration proposals welcomed

eROSITA Science WG Contacts

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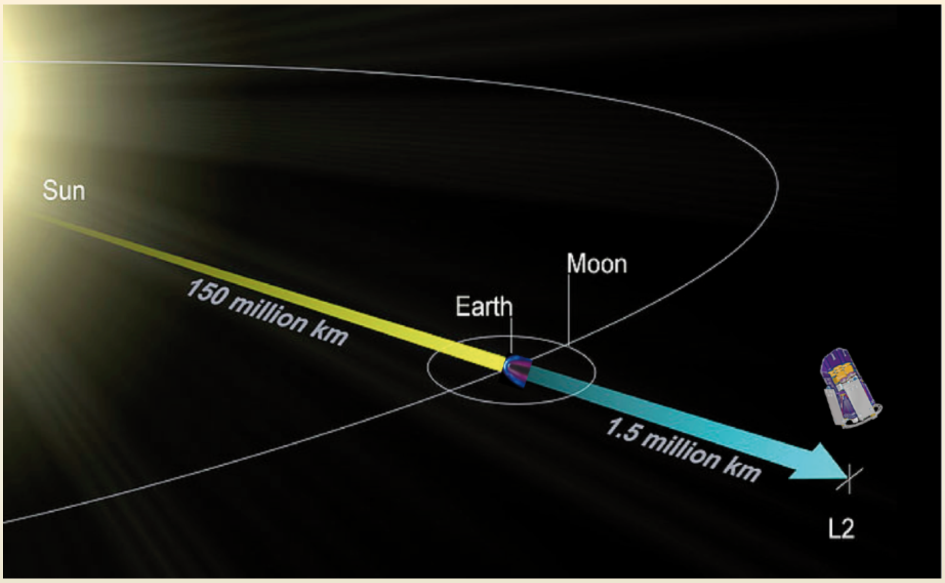
Courtesy: P. Predehl

SRG Mission



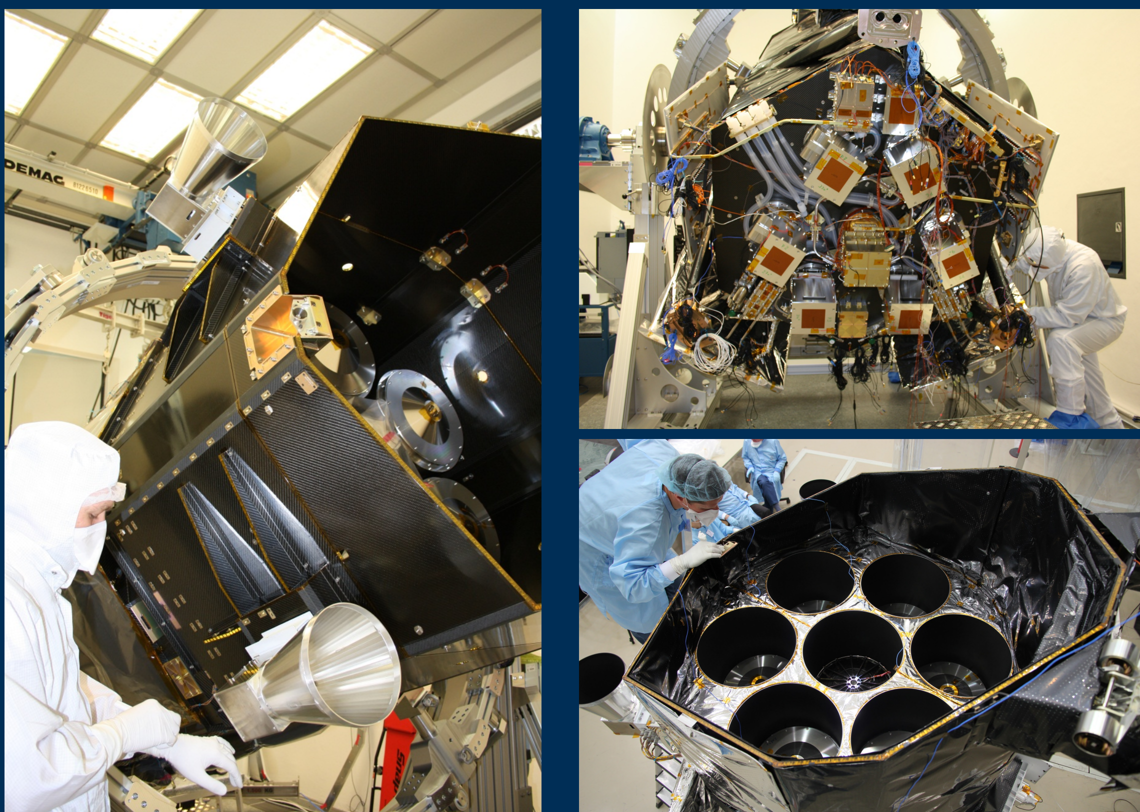
Launch from Baikonur with Zenit-Fregat – March 2017

- 3 months: flight to L2, checkout, verification and calibration phase

- 4 years: 8 all sky surveys (scanning mode: 6 rotations/day, 1 degree advance per day)

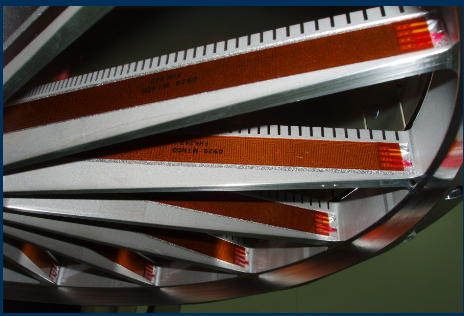
- 3 years: pointed observation phase, including ~20% GTO. 1 AO per year

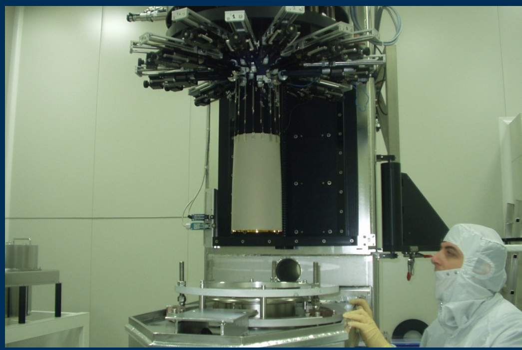
eROSITA



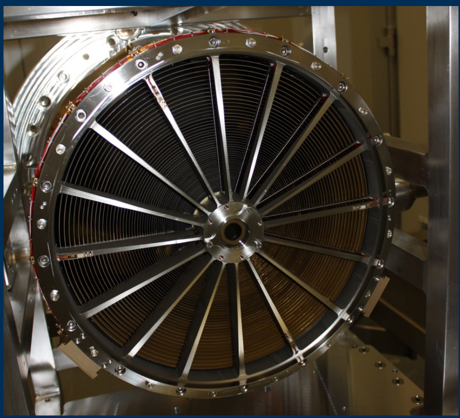
Courtesy: P. Predehl

Mirror System





VOB in action: Integration of a Shell

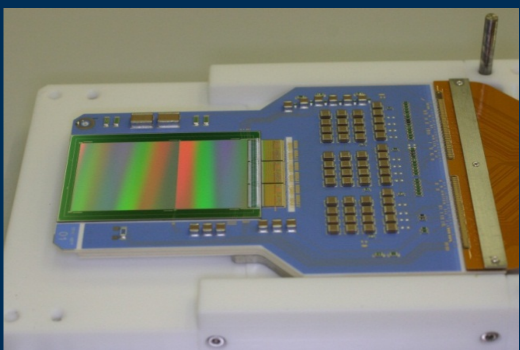


Flight Mirror Module with 54 shells

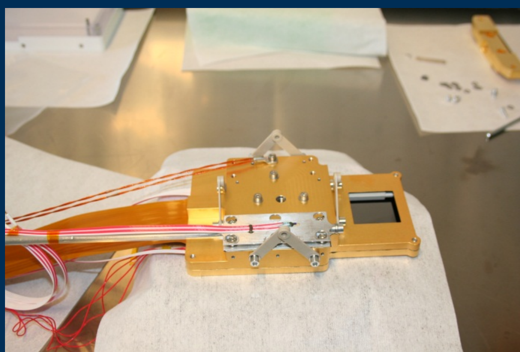
Preparation of PANTER X-ray Tests (FM-3c)

Courtesy: P. Predehl

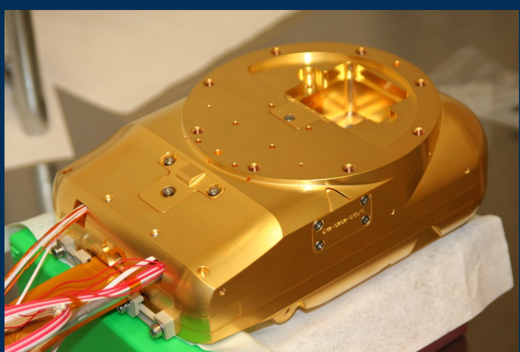
Camera



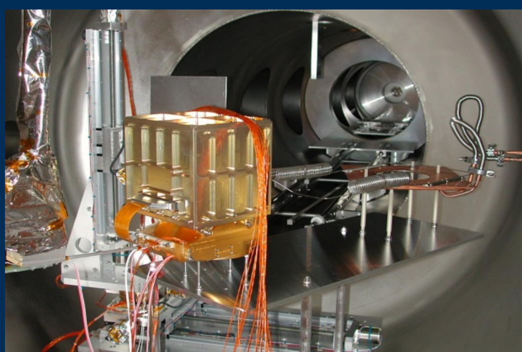
Heart of the Camera: CCD-Module



Cold part of Camera (with test sensors)

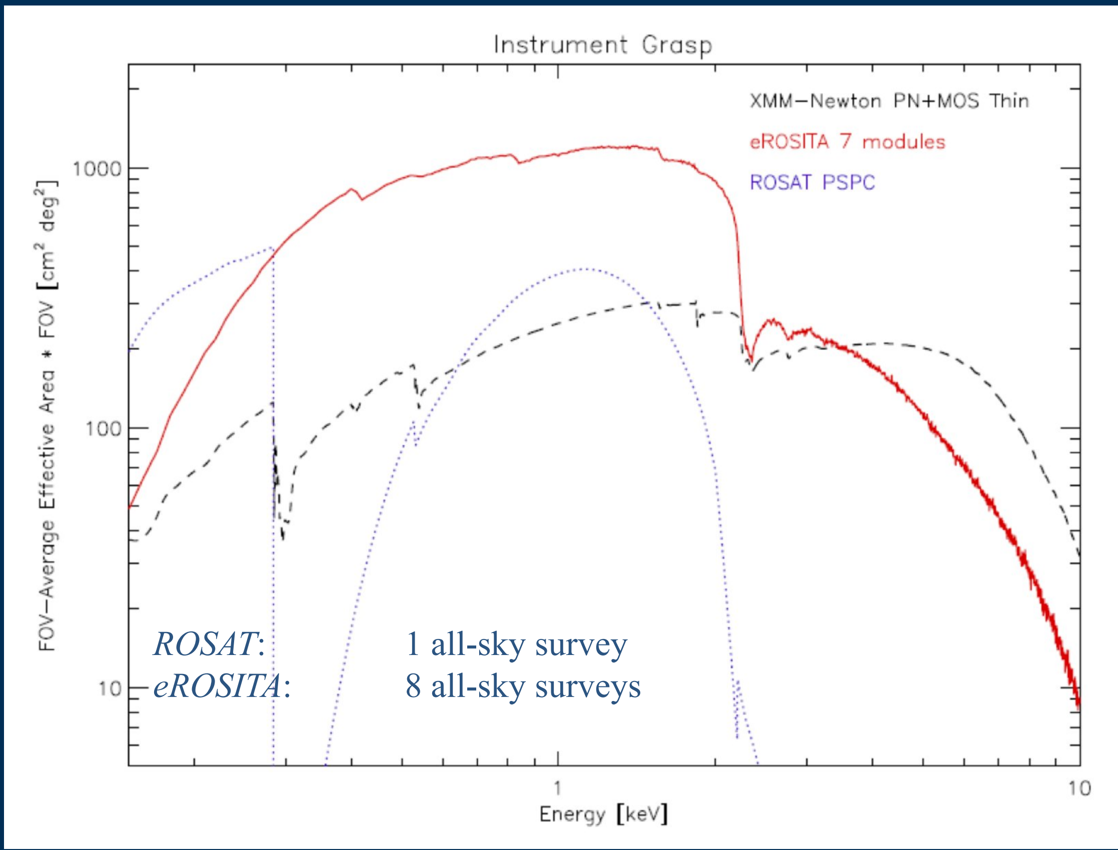


Integrated Camera (with massive Copper Housing)



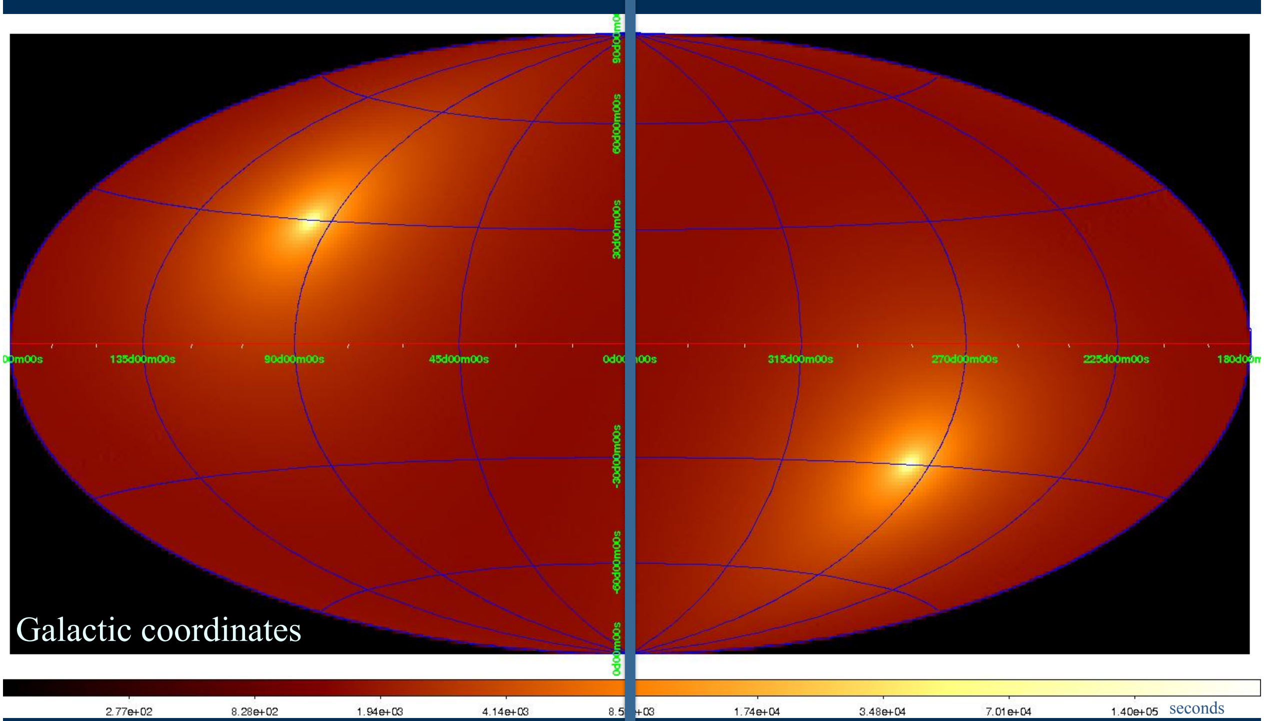
Preparation of Thermal Test

Courtesy: P. Predehl



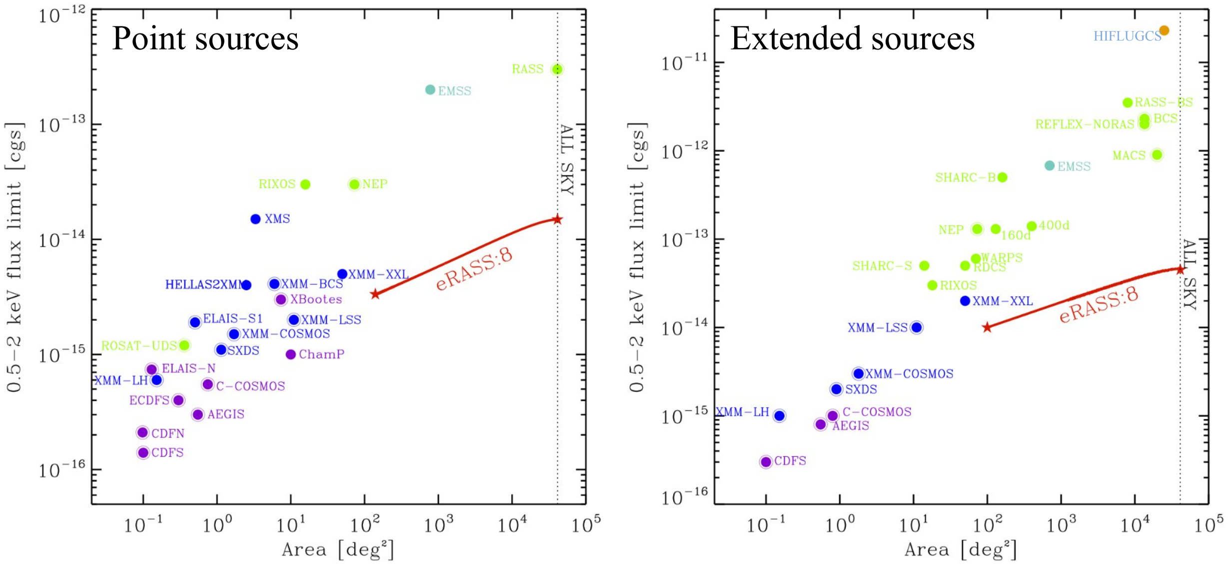
Merloni et al. (arXiv:1209.3114)

Expected *eROSITA* Exposure Map



Provided by J. Robrade

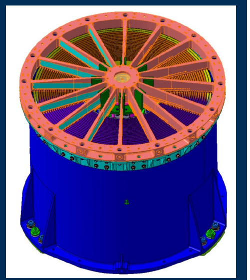
Comparison with other X-ray Surveys



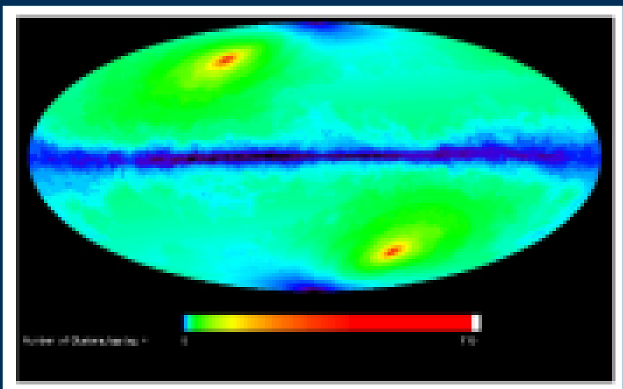
Adapted by Thomas Reiprich from ArXiv:1209.3114

eROSITA Cluster Cosmology in Context

e-ROSITA All Sky X-ray Survey



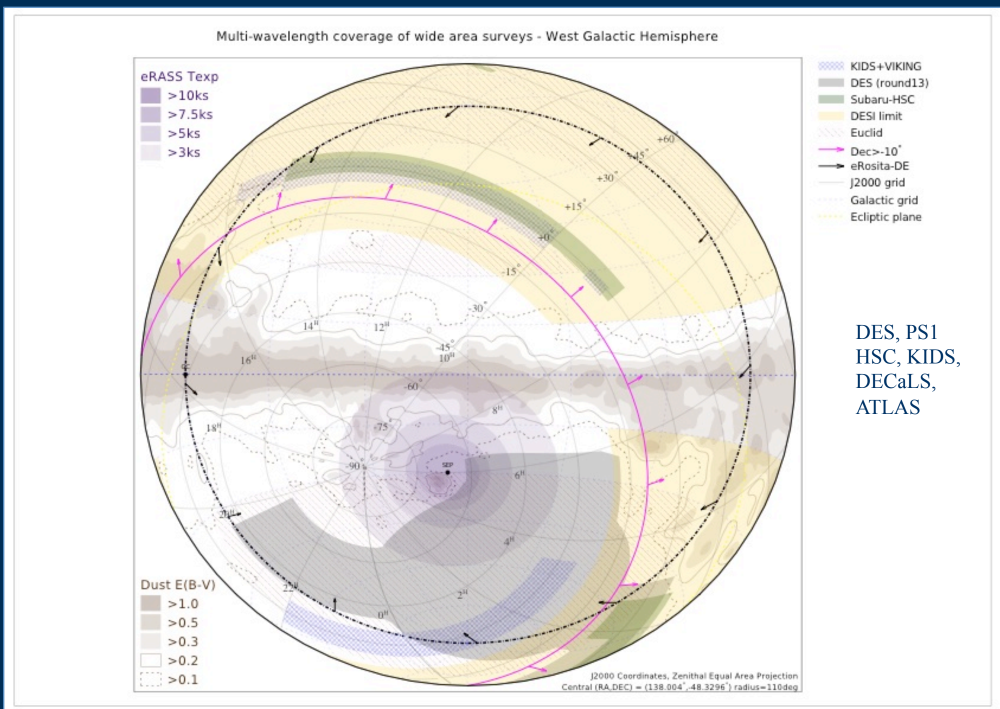
- Good angular resolution –
  - ~16” on axis, 28“ averaged over field (survey mode) (similar to ROSAT PSPC pointed data within inner ring)
- Characteristic flux limit is ~2x10^{-14} erg/s/cm^2 (~30X deeper than ROSAT All Sky Survey w/ CCD spectroscopy)



~10^5 X-ray selected galaxy clusters

Optical Surveys Enable:
  * Cluster confirmation
  * Cluster photo-z’s
  * Weak lensing mass constraints

Optical Surveys - eROSITA-DE



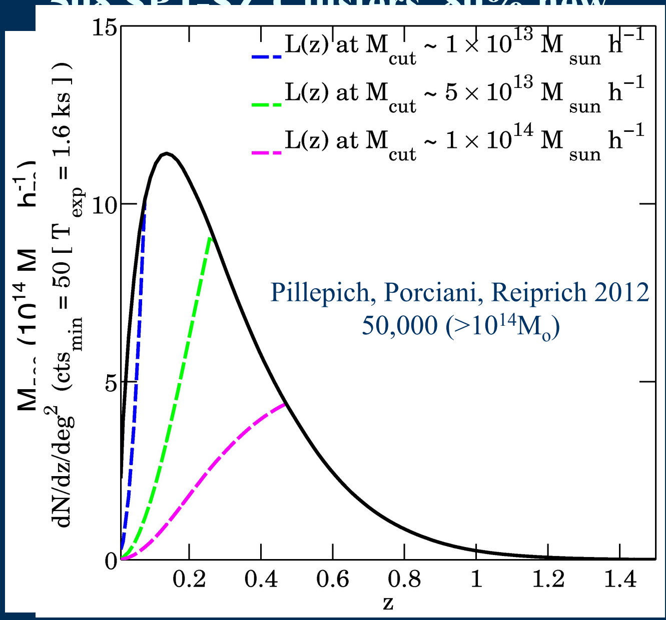
DES, PS1
HSC, KIDS,
DECaLS,
ATLAS

Courtesy: T. Dwelly

Cluster Samples

- X-ray: ~$10^{2\text{-}3}$
  - RASS, XXL, XMM-BCS
- SZE: ~$10^{2\text{-}3}$
  - SPT-SZ, Planck, ACT
- Optical: ~$10^{3\text{-}4}$ (10^5)
  - RCS, SDSS (DES, Euclid, LSST)
- eROSITA: ~50,000

508 SPT-SZ Clusters, 80% new



Cluster Surveys - Cosmological Leverage

Cluster Redshift Distribution

Sensitive to volume-redshift relation and cluster abundance evolution

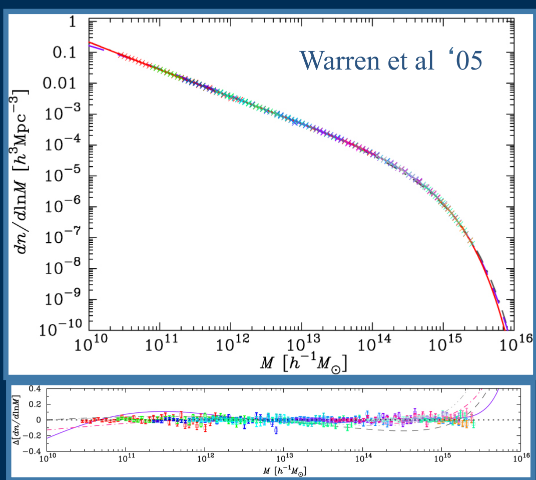
$$\frac{dN(z)}{dz\,d\Omega} = \frac{dV}{dz\,d\Omega}(z)\,n(z)$$

Dark Energy: see Haiman, Mohr, Holder 2001

Cluster Abundance Evolution

Depends on the power spectrum of density fluctuations and growth rate of cosmic structure

Can be studied directly in numerical simulations; simple "cosmology independent" fitting formulae exist



Bottom line: surveys constrain

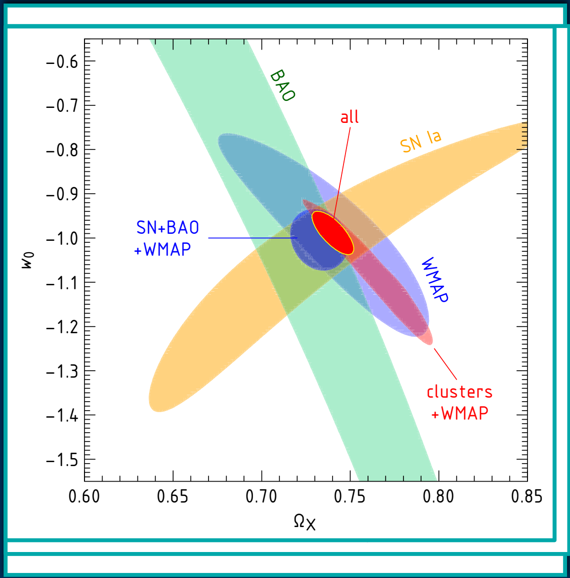
Distances

Characteristics and growth rate of density perturbations

But you must know the mass selection of your survey!

Results: 400 deg² ROSAT Archival Sample
Vikhlinin et al 2009

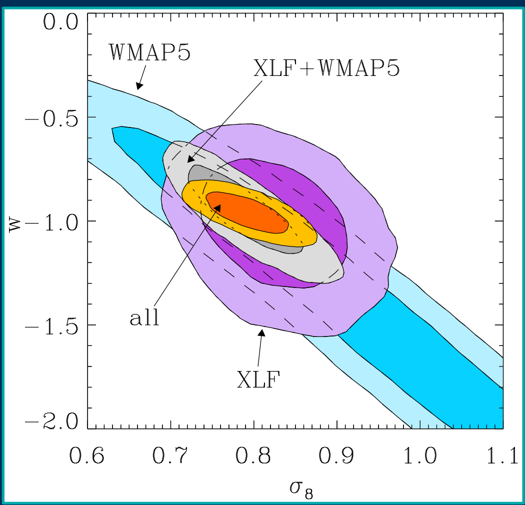
- Analysis:
  - 49 "local" + 37 z>0.35 clusters
  - Mass functions
  - 12 clusters at z>0.55 require DE
  - Independent constraints in good agreement with WMAP+ cosmology
  - w constrained to 0.2(clus)/0.05(all)



Used hydrostatic mass estimates from X-ray

Results: ROSAT All Sky Survey
Mantz et al 2010

- Analysis:
  - Mass function of ~250 clusters
  - Constant f_{ICM} from 42 "relaxed" systems
  - Mass-obs relation normalization freedom allowed and constrained using 6 low z clusters
- Independent constraints
  - σ_8 = 0.82 (0.05)
  - w=-1.01 (0.20)
- Combined constraints
  - WMAP+SNe+BAO+Clusters+f_{ICM}:
    - σ_8 = 0.79 (0.03)
    - w=-0.96 (0.06)

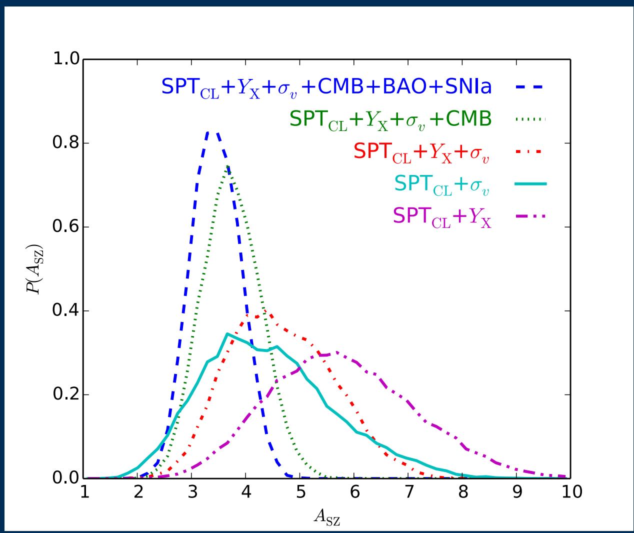


Used hydrostatic mass estimates from X-ray

Progress: Cluster Mass Calibration

Bocquet et al 2015

SZE-Mass Rel'n: $\zeta = A_{SZ}\left(\frac{M_{500}}{3\times10^{14}h^{-1}M_{\odot}}\right)^{B_{SZ}}\left(\frac{E(z)}{E(0.6)}\right)^{C_{SZ}}$

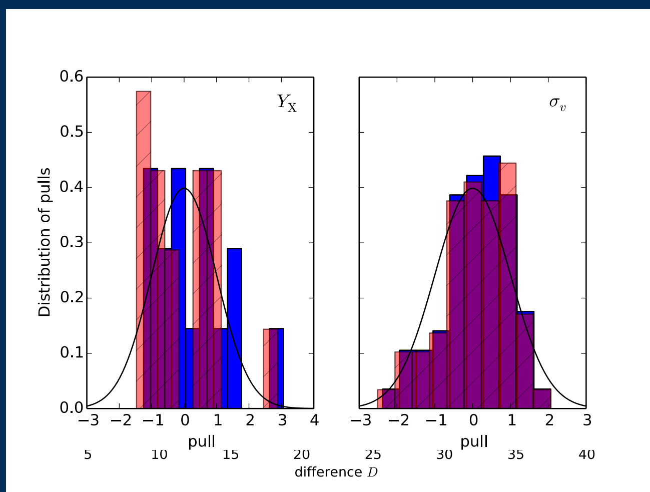


- Mass calibration must be carried out simultaneously with cosmo analysis
- Selection effects must be accounted for (Eddington bias)
- External cosmo constraints act as mass info
- Cluster masses:
  - increase by 21% from X-ray only (purple) to dispersion only (cyan)
  - 25% increase when adding CMB data (green) and additional distance measurements (blue)

Weak lensing mass calibration underway: Applegate, Dietrich, Schrabback, Hoekstra et al

Progress: Consistency Tests

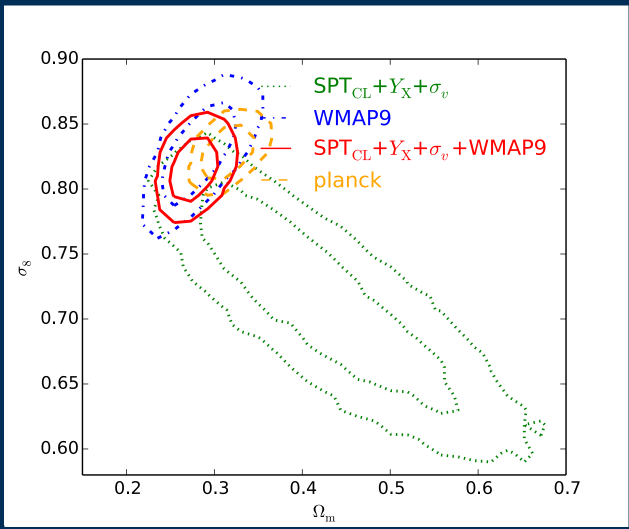
- We probe for consistency between the cluster dataset and the best fit cosmology
- Massfunc(ξ,z) and mass calibration show no significant evidence of tension



Bocquet+15

Results: SPT Cluster Cosmology

Bocquet et al 2015

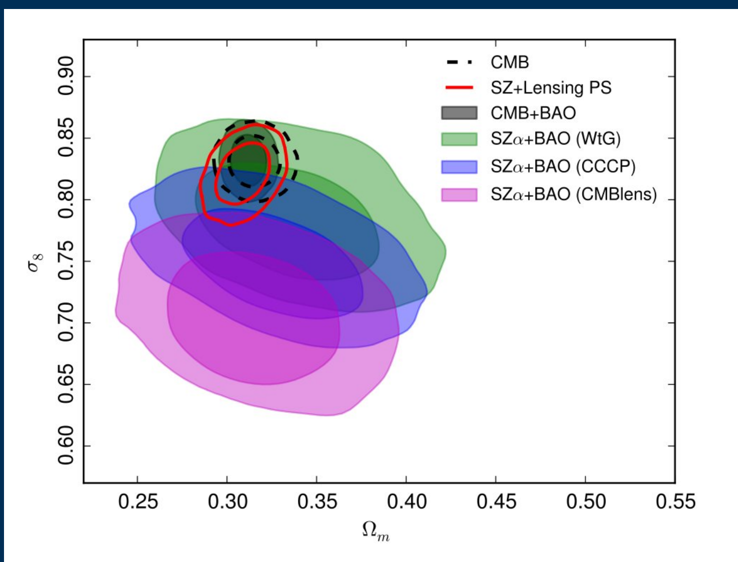


- 94 SPT clusters (720 deg^2)
- Mass calibration
  - 16 X-ray Y_xs
  - 65 velocity dispersions
- PMC algorithm
- 19 parameters
  - 6 cosmological
  - 4 SZ
  - 4 X-ray Y_x
  - 5 velocity dispersion
- Mild tension ~1.1σ-1.5σ

σ_8=0.829+/-0.011 -- w=-0.995+/-0.063 -- Σm_v=(0.148+/-0.081)eV -- γ=0.73+\-0.28

Results: Planck Cluster Cosmology

Planck Collaboration XXIV (2015)



- 439 clusters
- No strong tension with CMB if WL calibrations used
- CMB lensing implies no hydrostatic mass bias, in conflict with simulations

Represents major improvement upon original 2012 cluster cosmology analysis

Summary

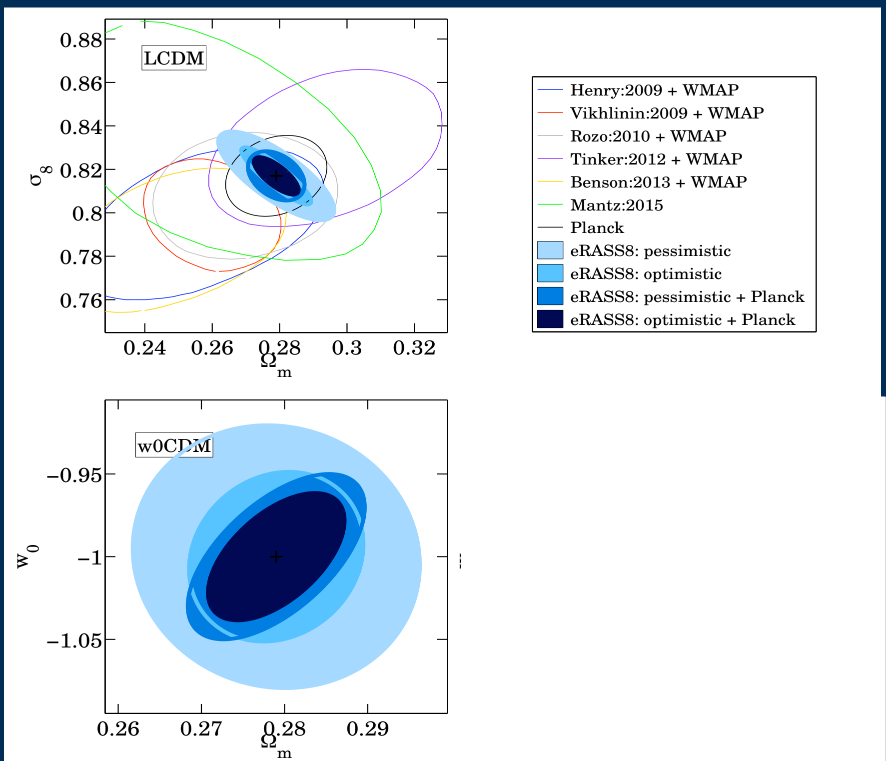
- eROSITA will open new window on the hot Universe
  - Launch in March 2017
  - Eight all sky X-ray surveys over 4 years
  - ~30x deeper than RASS w/ 0.5' PSF and CCD detectors
- Cluster cosmology continues to mature
  - ROSAT samples independently analyzed
    - Cosmology consistent with other probes
  - SZE samples have emerged
    - Cosmology consistent with other probes- better mass calibration == stronger tests
    - SPT has pushed cluster cosmology frontier to z~1.5
  - Algorithms for self-consistent mass calibration improved
  - Systematic WL studies providing first constraints- will continue
  - Theoretical mass function studies continue
  - There is clear path toward analysis of $10^{4\text{-}5}$ eROSITA clusters

Cosmological constraint Forecosts

Pillepich et al 2015

Pessimistic:
+ photo-*z*
+ no groups
+ L_X–M priors from Vikhlinin (2009)

Optimistic:
+ spectro-*z*
+ adding groups
+ 4 times tighter L_X–M priors



Results: Growth Rate of Structure

- One can carry out a consistency test of General Relativity by allowing the growth rate of structure to deviate from the GR expectation

$$\frac{d\ln\delta}{d\ln a} = \Omega_m^\gamma(a)$$

Following Rapetti et al 2010