The Cosmological potential of distant clusters with Athena/WFI

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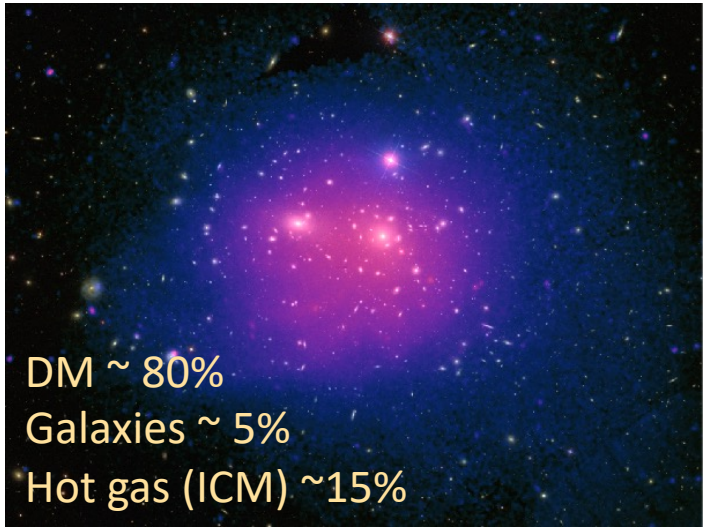
Supervised by M.Pierre

Clusters of galaxies

- Form in the highest peaks of density fluctuations – largest gravitationally bounded structure in the Universe

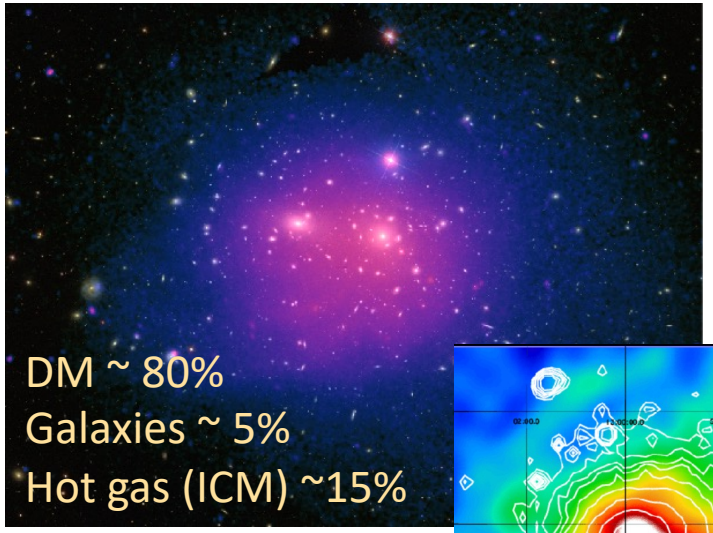


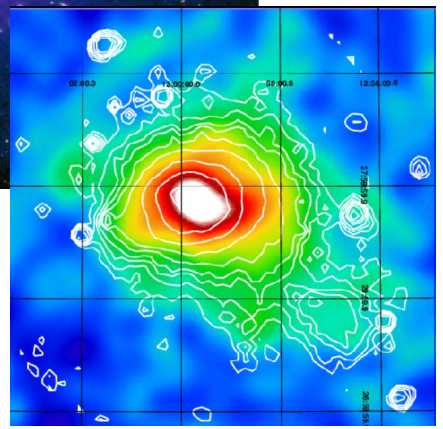
Clusters of galaxies

- Form in the highest peaks of density fluctuations – largest gravitationally bounded structure in the Universe

Optical : Galaxies
Richness λ

WL : Dark Matter
Mass M_{WL}





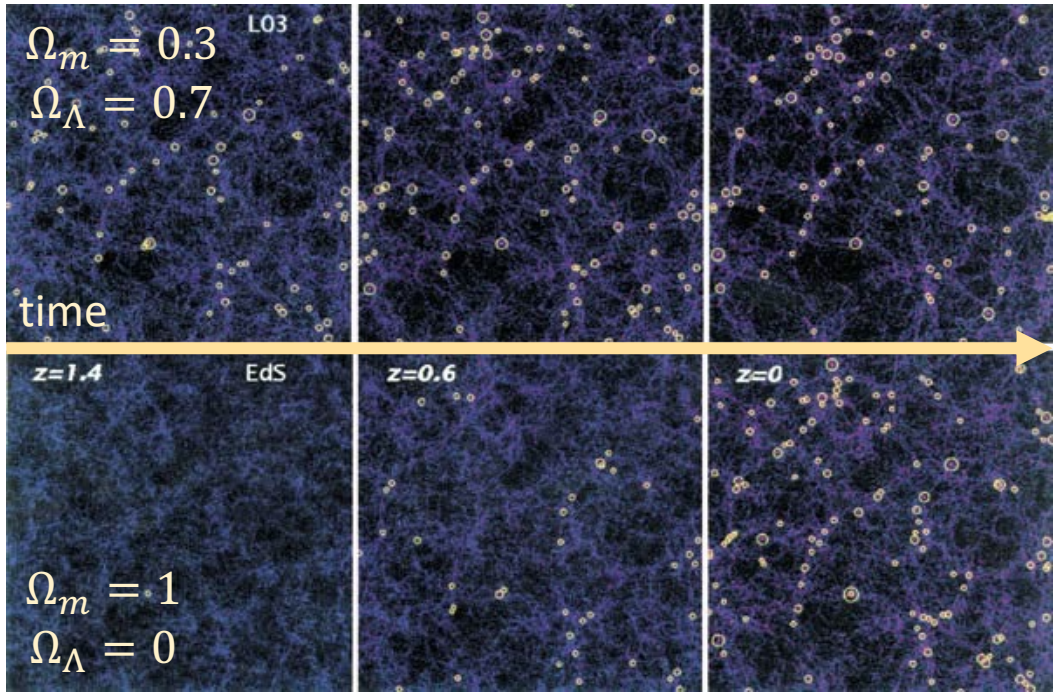
Xrays : ICM
Luminosity, Temperature,
Gas mass

Be careful with projection effects, mergers, cool cores…

Microwave : Sunayev-Zeldovich effect
tSZ, kSZ, Yx

Clusters as Cosmological probes

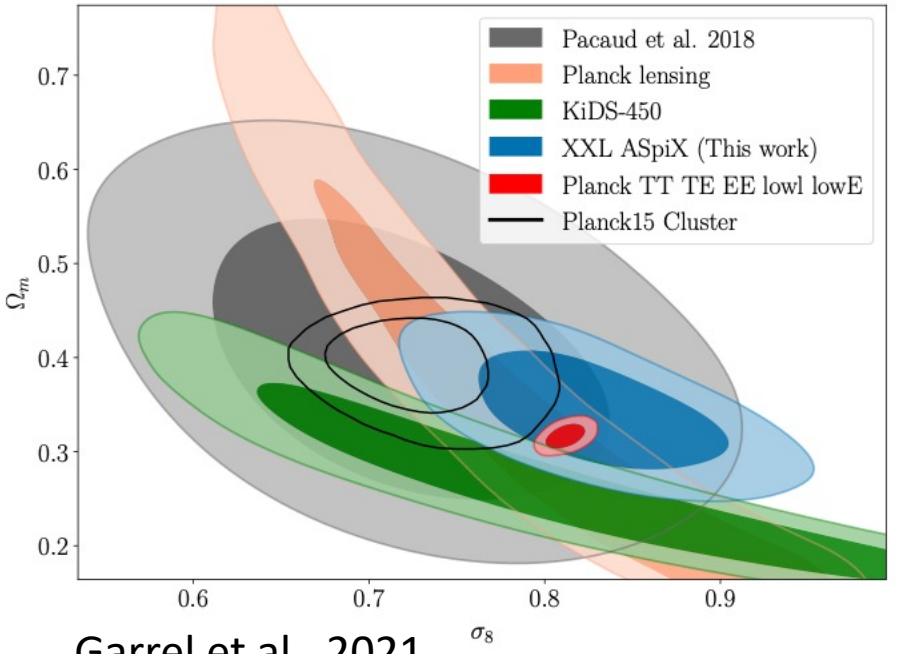
Borgani & Guzzo (2000)



- Cosmological probe for :
  - *Growth of structures*
  - *Expansion*
- Good sensitivity to Ω_m et σ_8

$$\frac{dn}{dMdz}$$

- Xray : XXL, eROSITA
- Optical : DES



Garrel et al., 2021

The (new)Athena mission

- Advanced Telescope for High-Energy Astrophysics

  Cosmic vision L2 Mission - Scheduled late 2030s

  Spectroscopy : X-IFU

  Imaging : WFI

  Aeff = 1.4 m^2 @1keV

  HEW = 5'' (requirement), 8'' (proven)

  FoV : 40' x 40'

  … in danger after ESA budget cuts !

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Which Clusters will Athena detect ?
Down to which mass ? Up to which redshift ?
... and what could it bring to Cosmology in late 2030s ?

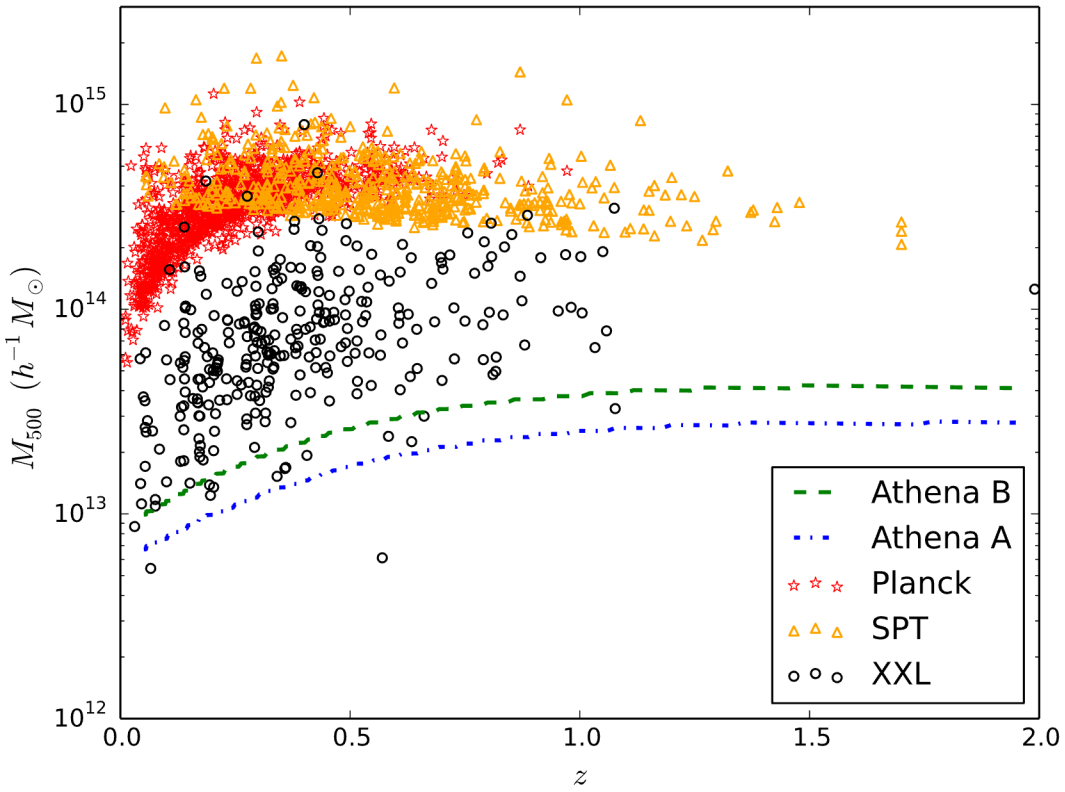
Cluster detection with Athena/WFI (I)

Work Hypothesis

- Sensitivity: **WFI = 5 × XMM**
- Background: 4.33e-6 cts/s/arcsec^2
- Fiducial Cosmology : Planck 2018
- Scaling relations from XXL:
  - *M-T from Lieu et al, 2016*
  - *L-T from Adami et al, 2018*
  - *rc-R_{500} as in Pacaud et al, 2018*

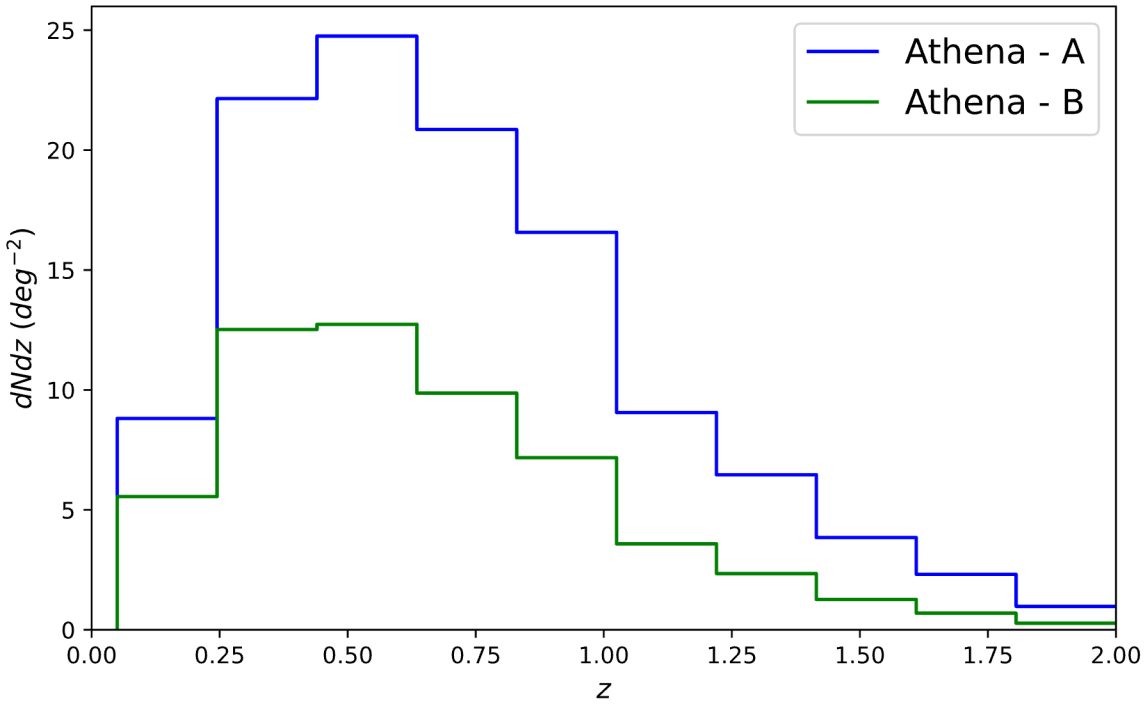
Survey A	Survey B
Depth 80ks Area 50 deg^2	Depth 20ks Area 200 deg^2

Detection limit as a function of M and z



Cluster detection with Athena/WFI (II)

- Number counts



	0<z<2	**1.5<z<2**
Survey A 80ks 50deg2	5800	260
Survey B 20ks 200deg2	11000	**300**
eRosita 1.6 ks all sky	**100000**	30

Cluster detection with Athena/WFI (II)

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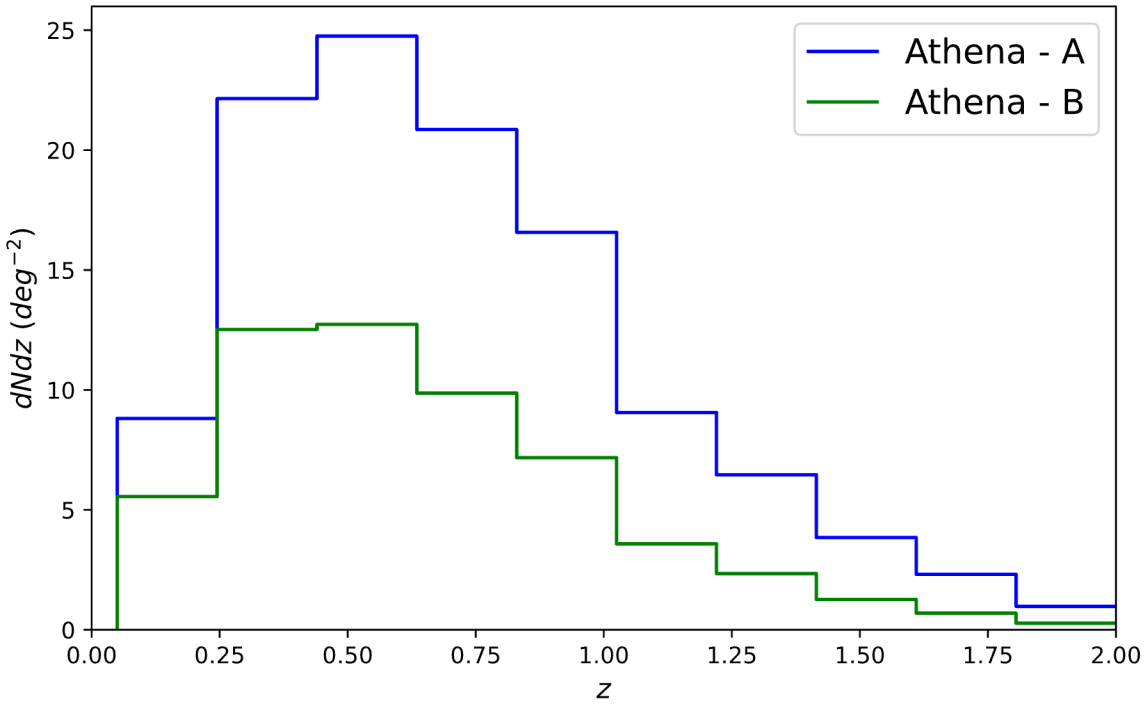

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Interest for cosmology ?

Cosmological analysis - method

- Key idea : do not infer cluster masses !

Forward modelling

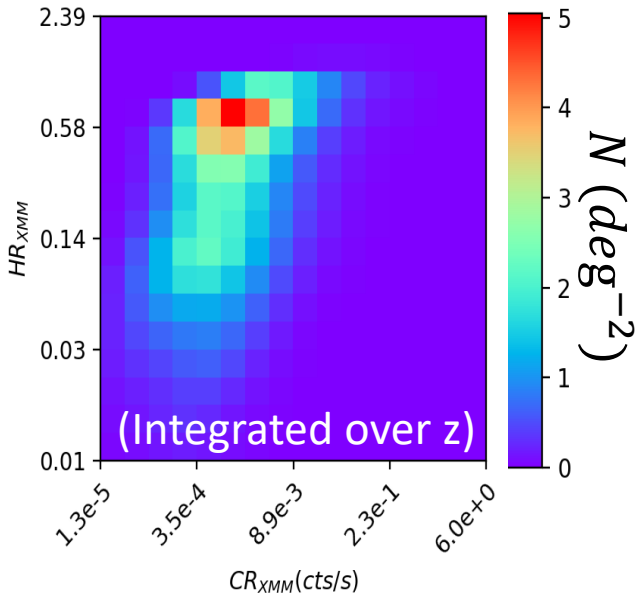
- Cosmology

$$\frac{dn}{dMdz}$$

- Scaling laws
- Instrumental effects
- Selection function

$$\frac{dn}{dzdCRdHR}$$

Xray Observable Diagrams



Fisher Analysis

- Compute derivatives wrt each parameter

$$F_{\mu\nu} = \sum_i \frac{1}{\lambda_i} \frac{\partial \lambda_i}{\partial \theta_\mu} \frac{\partial \lambda_i}{\partial \theta_\nu}$$

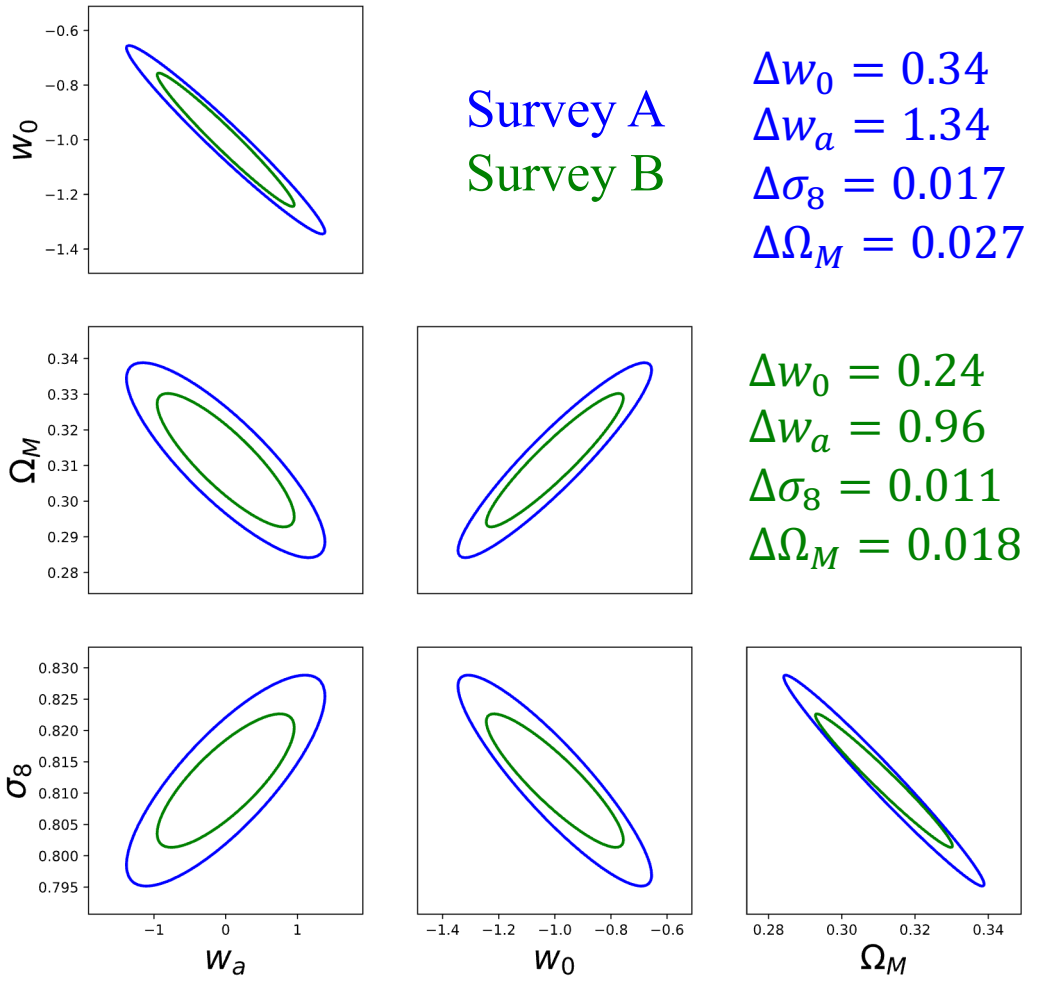
- Add gaussian priors

$$F_{p_i} = \frac{1}{\sigma_{p_i}^2}$$

- Inverse F and extract uncertainties

Cosmological analysis – Results (I)

- Free parameters:
  Cosmology: $\boldsymbol{w_0}, \boldsymbol{w_a}, \Omega_m, \sigma_8, h, \Omega_b, n_s$
  Scaling Laws: $L_0, \alpha_{LT}, \gamma_{LT}, M_0, \alpha_{MT}, \gamma_{MT}$
- Priors: Planck priors on h, Ω_b, n_s
  XXL priors: $L_0, \alpha_{LT}, M_0, \alpha_{MT}$
- XODs resolution: 10x16x16, 0<z<2
- (!) measurement errors not included
- Priors needed to break degenerascies
- Higher nb of clusters in survey B is beneficial for constraining parameters



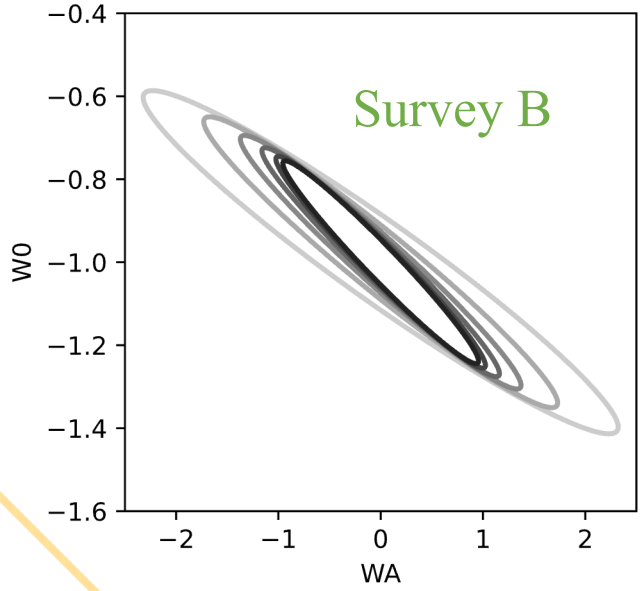
Survey A
Survey B

$\Delta w_0 = 0.34$
$\Delta w_a = 1.34$
$\Delta \sigma_8 = 0.017$
$\Delta \Omega_M = 0.027$

$\Delta w_0 = 0.24$
$\Delta w_a = 0.96$
$\Delta \sigma_8 = 0.011$
$\Delta \Omega_M = 0.018$

Cosmological analysis – Results (II)

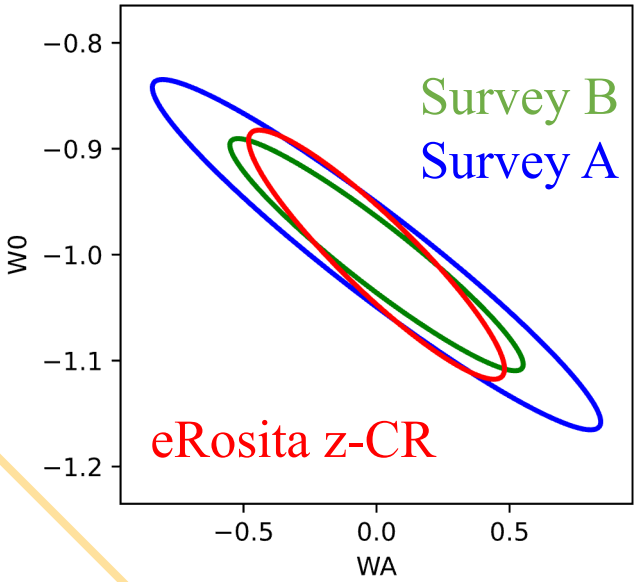
- **Detecting clusters at z>1 is critical for DE EoS parameters**



0<z<2.0 + priors
0<z<1.8 + priors
0<z<1.6 + priors
0<z<1.4 + priors
0<z<1.2 + priors
0<z<1.0 + priors

- **Comparison with eRosita**

Reproducing the method of Pillepich+18
Setup is different than previously (!)



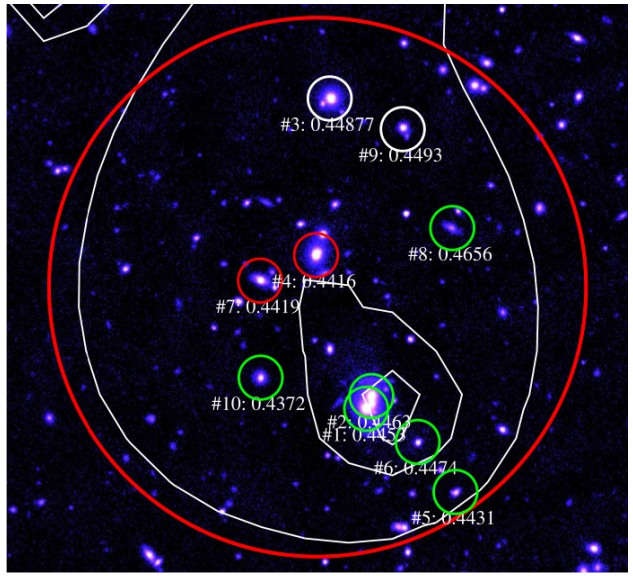
- M-T fixed
- Tight priors on L-T
- ~10 times less clusters in Survey B than in eRASS:8
- Still z-CR-HR for Athena

Conclusion

- Cluster are independent cosmological probes
- Clusters in the $1<z<2$ range have a great potential for cosmology : need to be detected !
- Could provide competitive constraints on DE EoS
- newAthena in phase 0 … We need a flagship mission in Xrays !
- Work in progress: investigate non Gaussianities

Clusters of galaxies (old slide !)

- Can get complicated – Mergers, Cool cores, projection effects, Mass estimation



XLSSC 110, triple merger
Adami et al. 2018

$$\frac{dn}{dMdz}$$

Sensible to selection effects !

Indirect measures through proxies :
Richness – Mass
Xray Lum – Mass
Yx - Mass