On the arcmin structure of the X-ray Universe

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Introduction

- The vast majority of serendipitous X-ray sources detected by *XMM-Newton* are Active Galactic Nuclei (AGN)
- X-ray emission is a common feature of AGN activity: X-ray surveys are very effective to compile comprehensive complete AGN samples
- AGN are known to cluster strongly (e.g. Mullis+04, Gilli+05, Yang+06, Carrera+07, Gilli+09)
- Previous works have reported clustering (or its absence) with variable significance due to small-number statistics

Introduction

- If AGN belong to a large-scale cosmic structure they will tend to appear closer in the sky with respect to a random distribution of sources
- This can be measured by a two-point angular correlation function
- The ideal sample must achieve both width (to prevent single structure biases) and depth (high angular density of sources)

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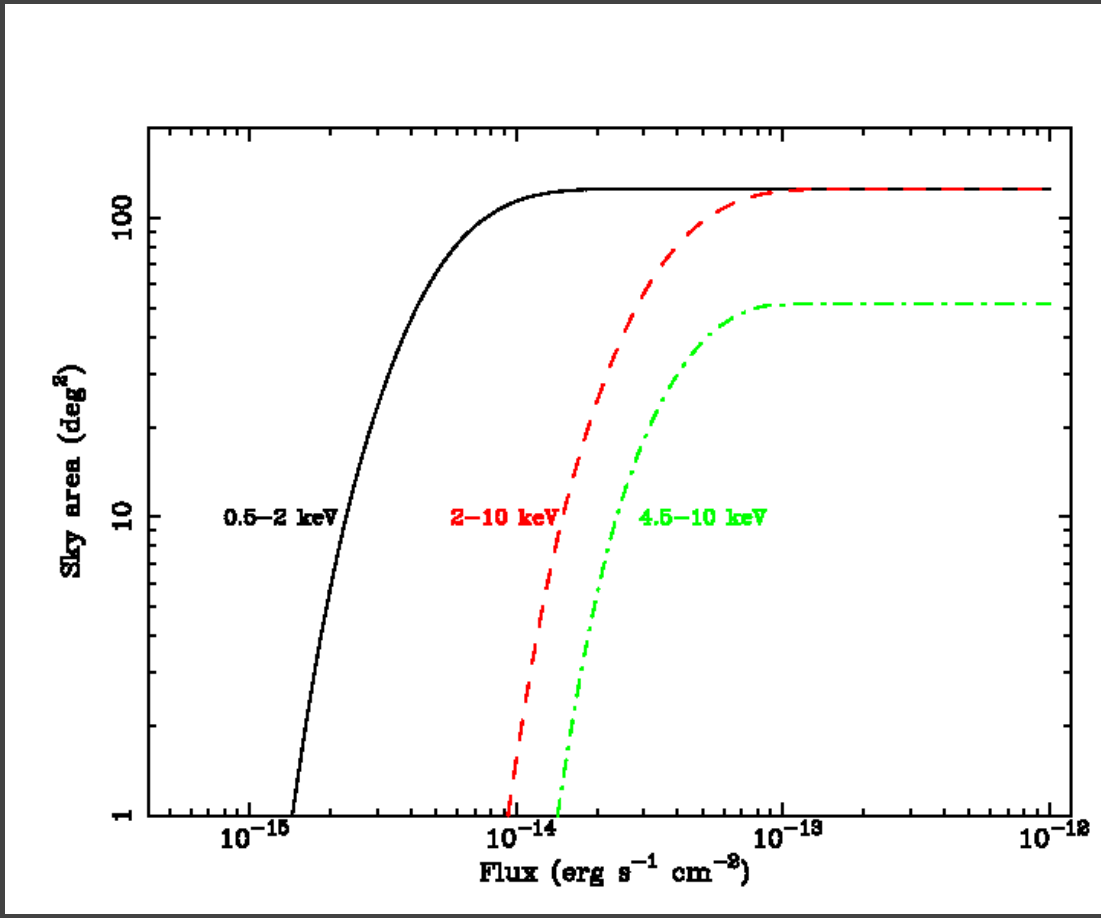
The sample (Mateos et al. 2008)

- Detection bands:
  - Soft: 0.5 – 2 keV (~31000 sources)
  - Hard: 2-10 keV (~9000 sources)
  - Ultrahard: 4.5-10 keV (~1200 sources)

- 1063 *XMM-Newton*/EPIC-pn observations (~125 deg^2)
  - High galactic latitudes
  - > 5 ks clean exposure time (>20 ks in the UH band)
  - No bright or extended X-ray sources



Angular correlation function: method

- We used the estimator proposed by Landy & Szalay (1993):

$$w(\theta_i) = \frac{DD - 2DR + RR}{RR},$$

DD: #pairs data-data sample
DR: #pairs data-random sample
RR: #pairs random-random sample

- Random sample extracted using a bootstrap method (Carrera et al. 07)
  - Randomize the azimuthal angle around the optical axis
  - Accounts for the off-axis sentivity decline
  - CR > CR(x_{new}, y_{new}) until $N_{random} = N_{real}$
  - 100 simulations
- Fit to an analytical model
  - χ^2 technique
  - Takes into account correlations in the errors in different angular bins (Miyaji et al., 2007)

$$w_{model}(\theta) = \left(\frac{\theta}{\theta_0}\right)^{1-\gamma},$$

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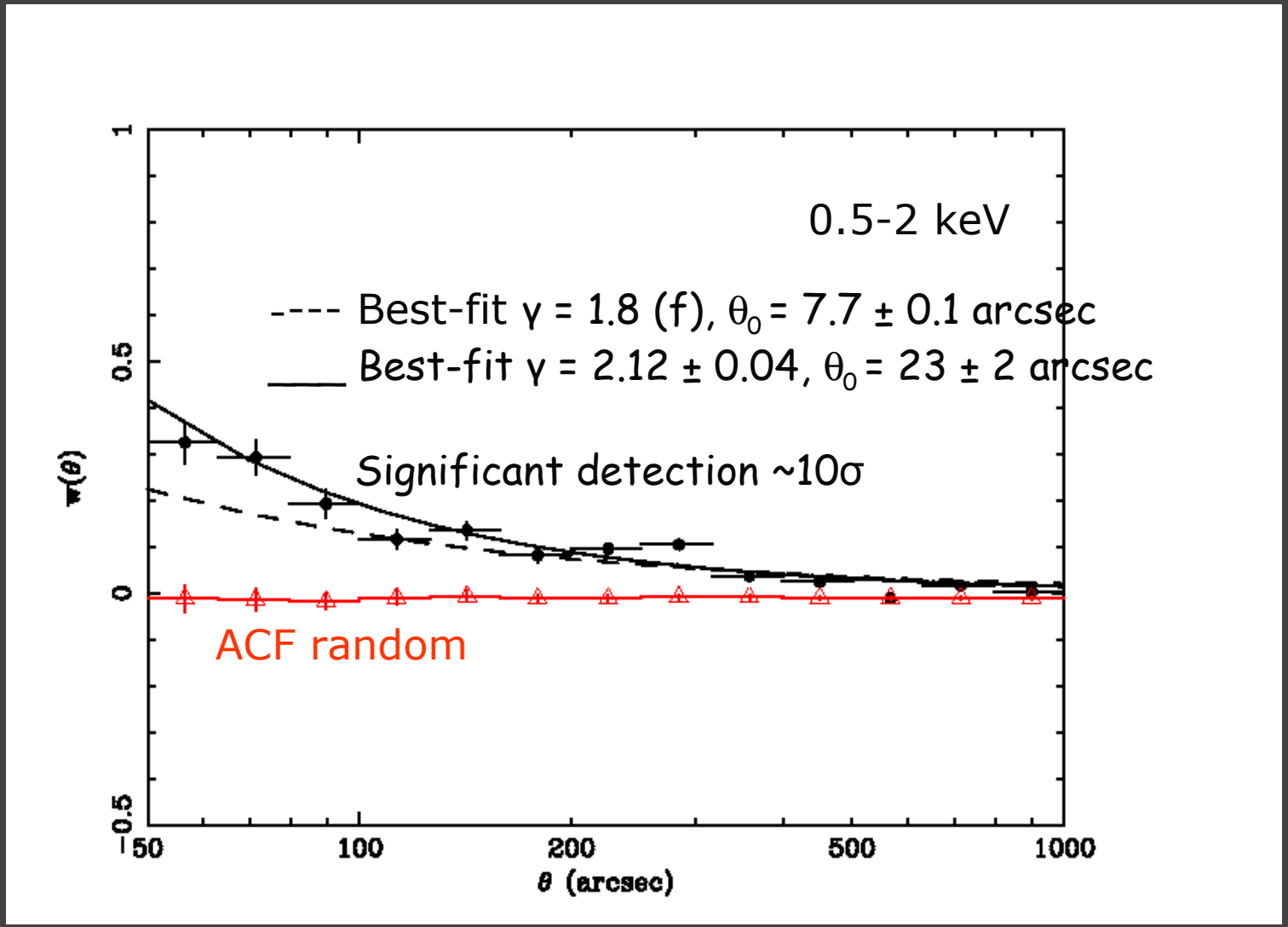
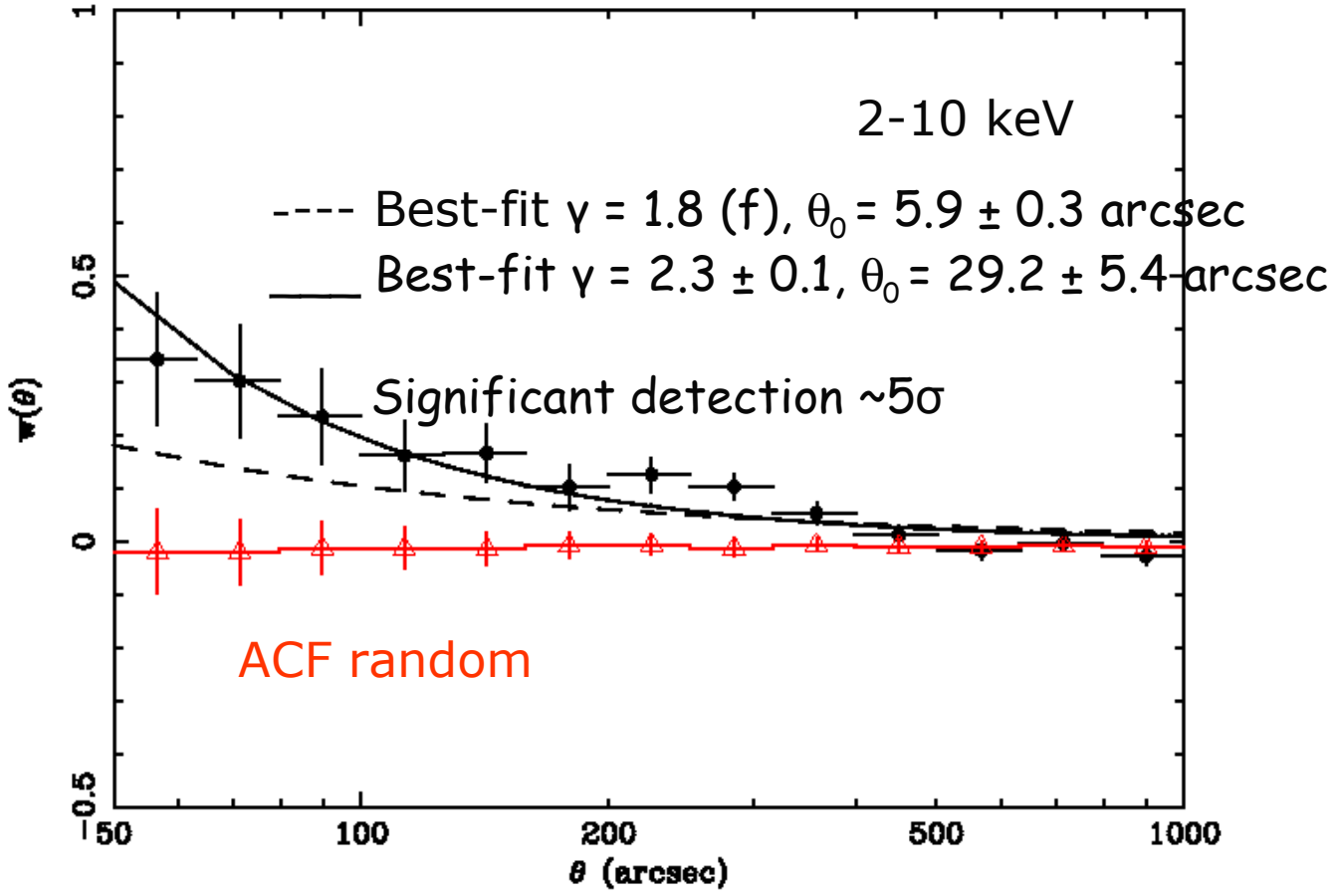
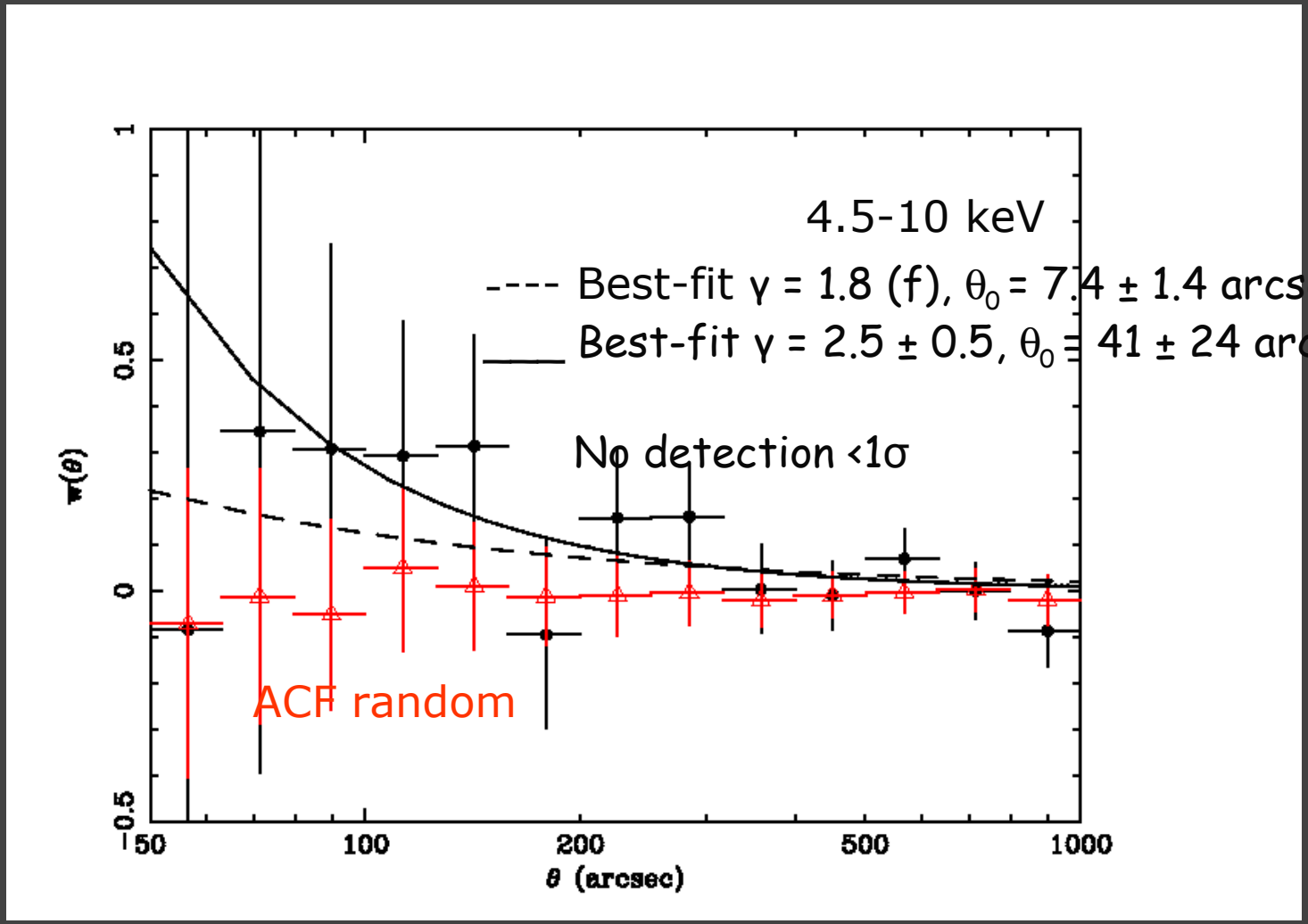
Angular correlation function: results



Angular correlation function: results

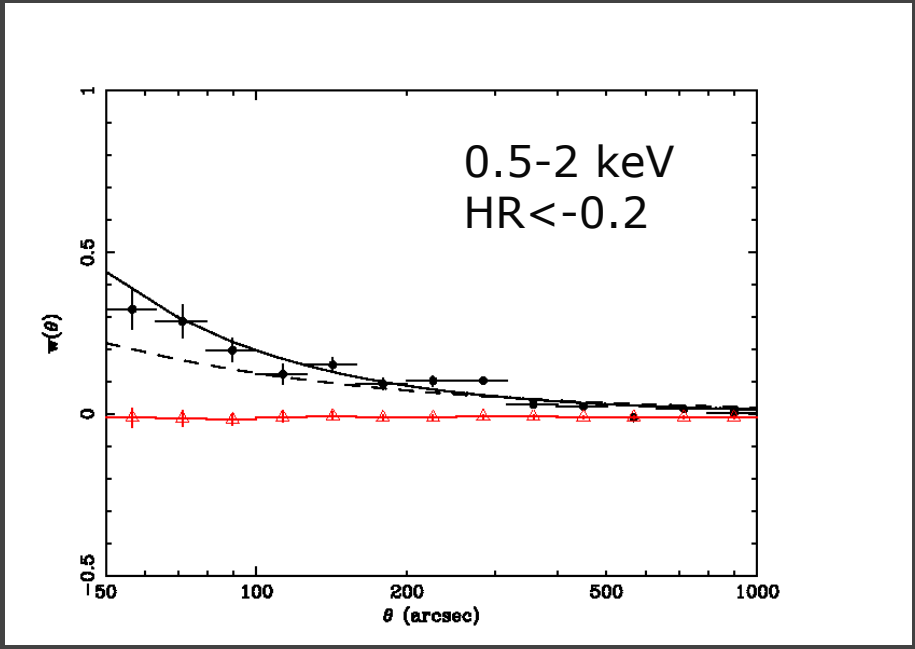


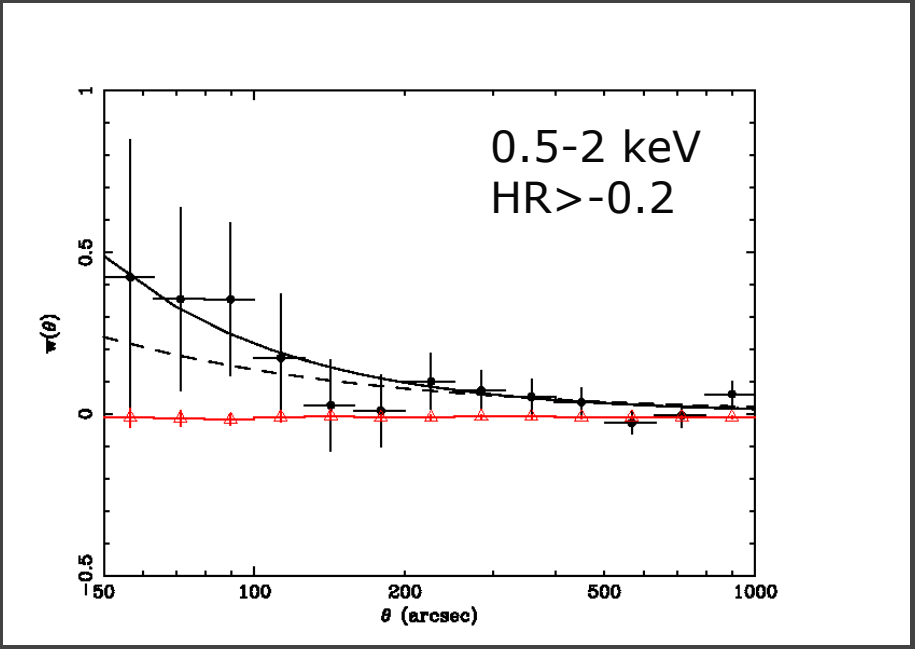
Angular correlation function: results



Do obscured AGN cluster differently?

- Sample splitted in HR<-0.2 and HR>-0.2 subsamples
- Slopes and θ_0 are consistent within 1σ in both the soft and hard bands





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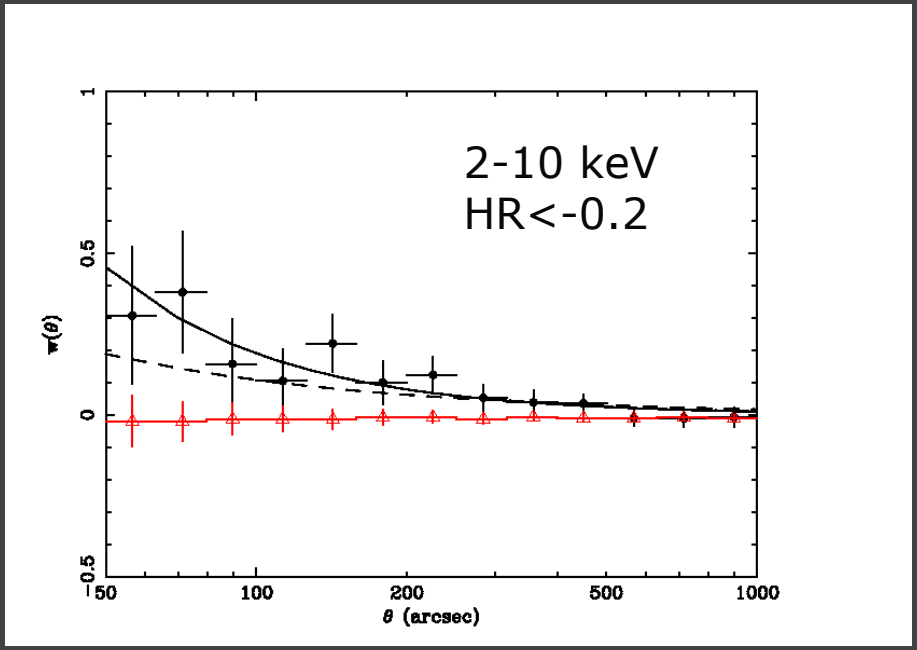

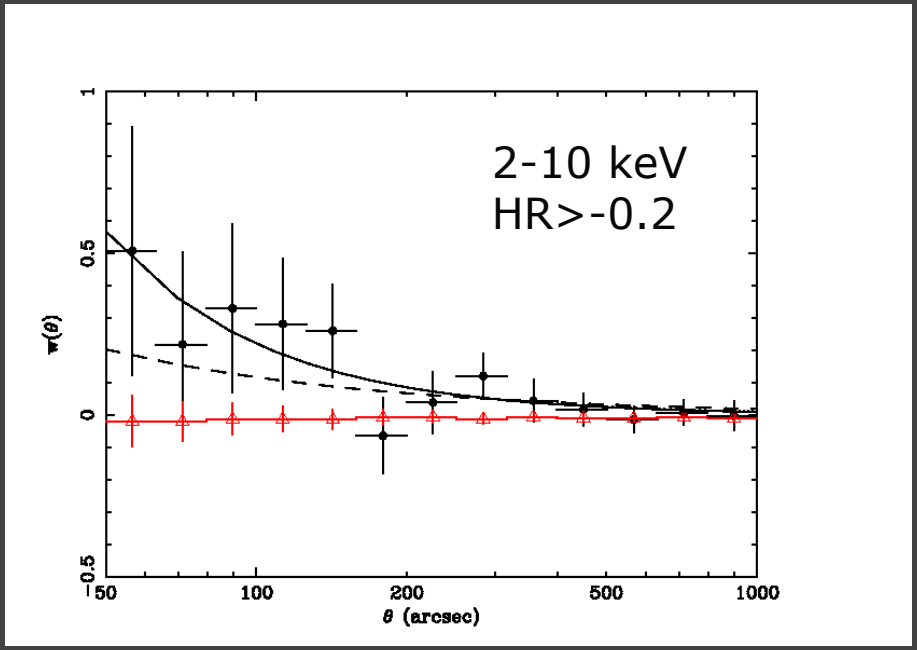

HR>-0.2 sources do not have different clustering properties

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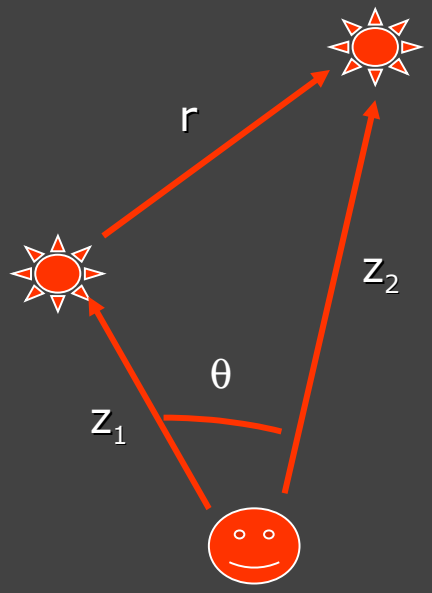
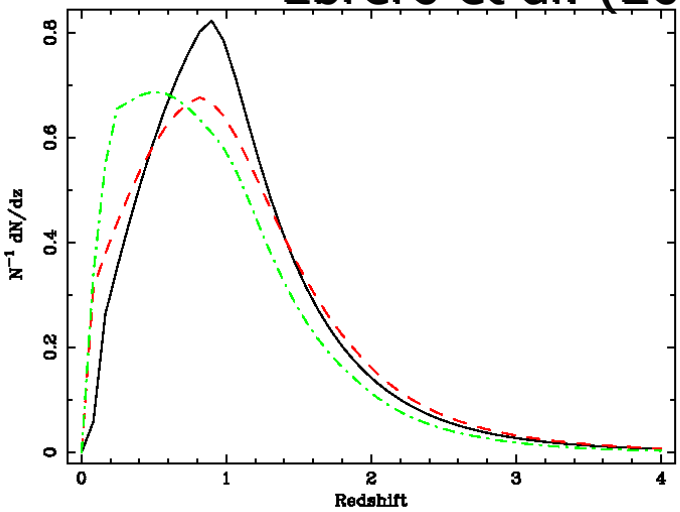
Moving along the third dimension



$$\xi(r,z) = \left(\frac{r}{r_0}\right)^{-\gamma} (1+z)^{-(3+\epsilon)},$$

Spatial correlation function
De Zotti et al. (1990)

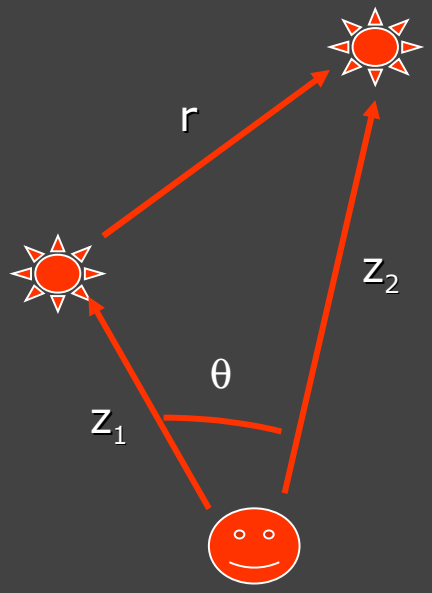
Ebrero et al. (2009b)



$$\theta_0^{\gamma-1} = H_\gamma \left(\frac{r_0^\gamma H_0}{c}\right) \int_0^\infty \left(\frac{1}{N}\frac{dN}{dz}\right)^2 \frac{E(z)(1+z)^{-3-\epsilon+\gamma}}{D_c^{\gamma-1}(z)} dz,$$

Limber's equation

Moving along the third dimension



$$\xi(r,z) = \left(\frac{r}{r_0}\right)^{-\gamma} (1+z)^{-(3+\epsilon)}$$

Spatial correlation function
De Zotti et al. (1990)

X-ray selected AGN

Soft: ε = γ-3 -> r_0 = 12.3 ± 0.1 h^{-1} Mpc
ε = -3 -> r_0 = 6.55 ± 0.05 h^{-1} Mpc

Hard: ε = γ-3 -> r_0 = 9.9 ± 2.2 h^{-1} Mpc
ε = -3 -> r_0 = 5.7 ± 1.4 h^{-1} Mpc

Optically selected AGN

$$\theta_0^{\gamma-1} = H_\gamma \left(\frac{r_0^\gamma H_0}{c}\right) \int_0^\infty \left(\frac{1}{N}\frac{dN}{dz}\right)^2 \frac{E(z)(1+z)^{-3-\epsilon+\gamma}}{D_c^{\gamma-1}(z)} dz,$$

Limber's equation

DMH and the lifetime of AGN

- The bias parameter connects AGN and dark matter haloes

- Large-scale bias relation as a function of halo mass b(M,z) (Sheth et al. 2001)

Estimated from Limber´s equation

$$b^2(z) = \frac{\xi_{\rm AGN}(8,z)}{\xi_{\rm DMH}(8,z)},$$

Derived from the cosmology (Λ-CDM)

Typical log M_{DMH}~12.7±0.3 h^{-1} $M_{\odot}$ at z ~ 1

• Relation between the comoving density of AGN and DMH and their lifetime (Martini & Weinberg 2001):

$$t_{AGN}/t_{DMH} = \Phi_{AGN}/\Phi_{DMH}$$

AGN lifetime: t_{AGN} ~ 3 - 5 x 10^8 yr

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Conclusions

- We have determined with unprecedented accuracy the angular clustering of a very large serendipitous X-ray sample
- Very significant positive clustering signal in both soft and hard X-rays
- Sources with HR > -0.2 do not cluster differently
- Deprojection of ACF via Limber´s equation provide results consistent with SCF results from highly identified AGN samples
- ACF analysis are useful tools to estimate cosmological parameters (bias, mass of DMH, lifetime of AGN)

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