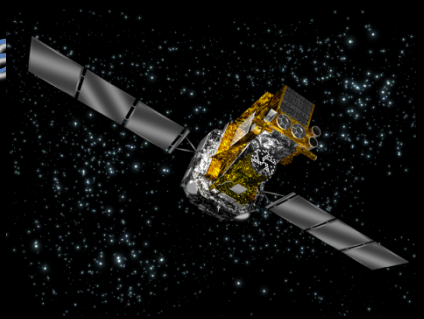
Review AO-9 programme versus legacy:
the extra-galactic INTEGRAL sky:

- What we have already accomplished
- What we will do by 2014
- What INTEGRAL can do in the next 4years (2014 on)
- ..and what we cannot do, even if….
- How to structure the next document (IUG priority)

Pietro Ubertini

on behalf of the IBIS survey/AGN tea

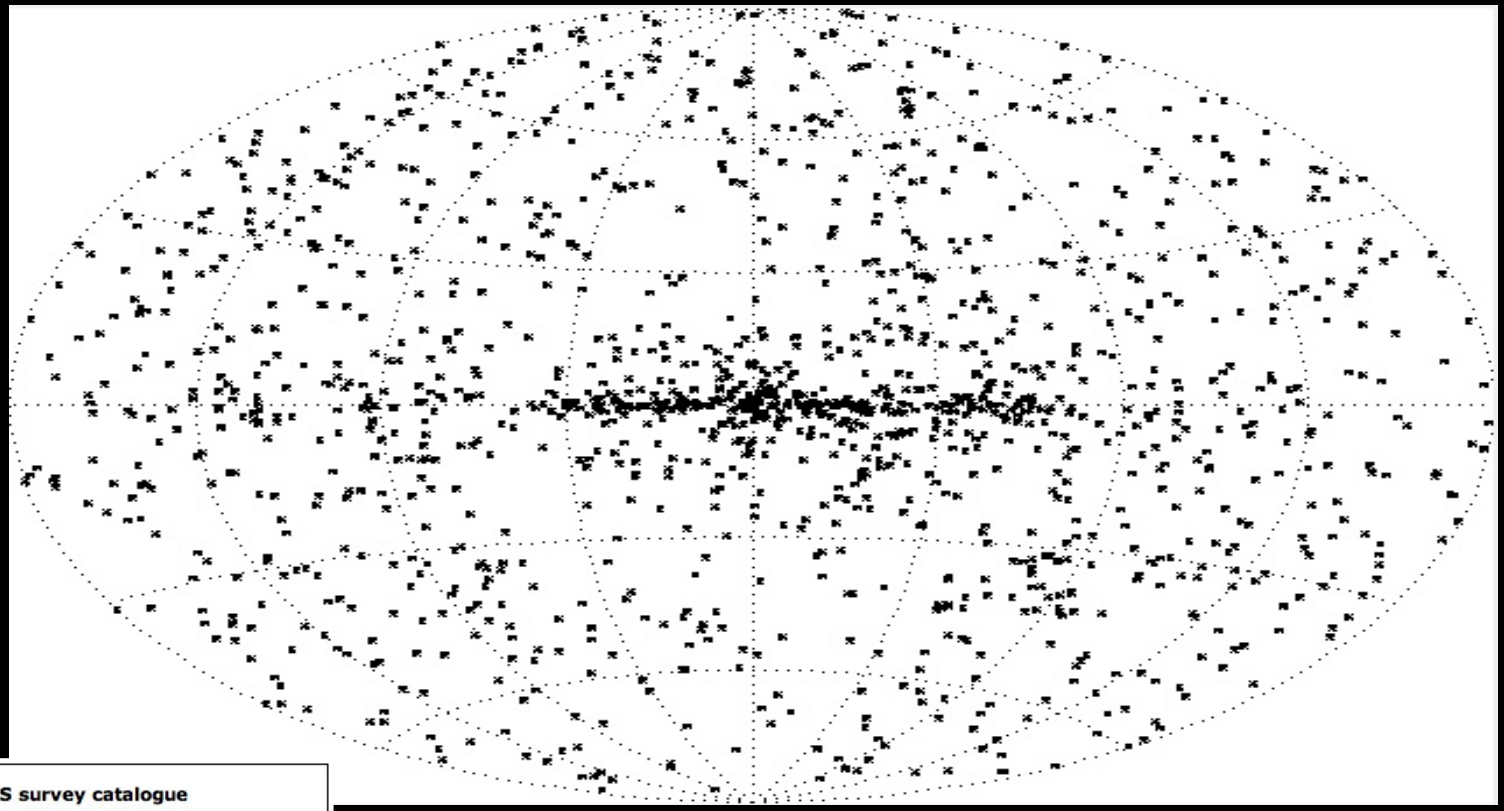


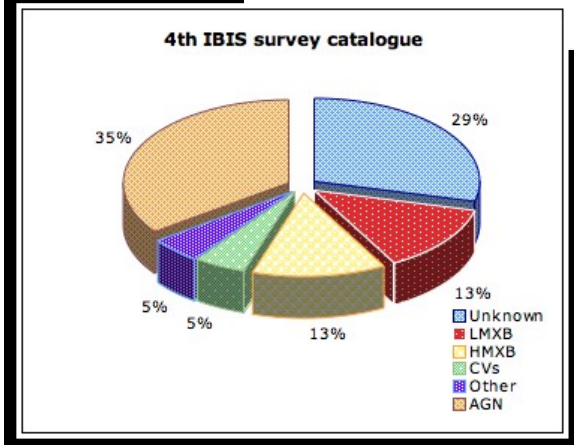
INTEGRAL USER GROUP
18-19 January 2012

Istituto di Astrofisica Spaziale e Fisica Cosmica - Roma

INAF

A golden age for hard X-ray studies





ADAPTED FROM SWIFT-BAT/ INTEGRAL-IBIS SURVEYS

(CUSUMANO ET AL. 2010, BIRD ET AL. 2010, TUELLER ET AL. 2009, KRIVONOS ET AL. 2007)

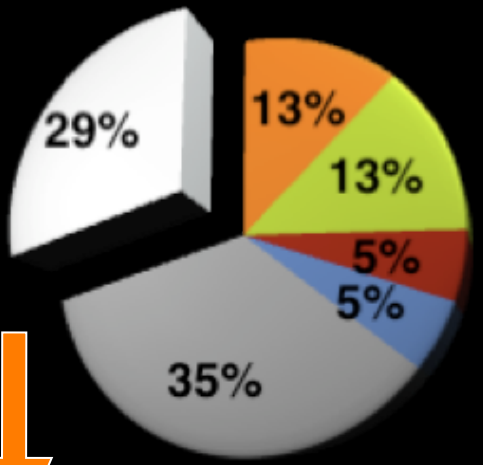
Around 1500 (a few 1000s?) sources detected so far

most are Active Nuclei, even on the Galactic plane

Extensive optical follow-up and identification

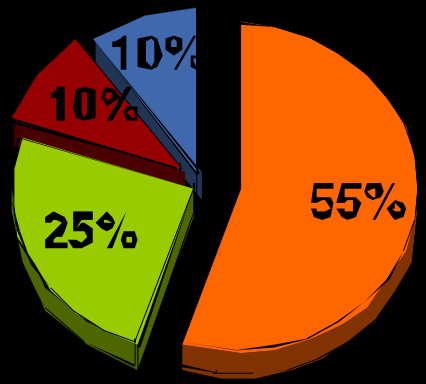
(Masetti et al. 2004-2011)

4th IBIS catalogue



LMXBs
HMXBs
CVs
Other
AGNs
Unknown

Identified sources



- More and more AGN represent the dominating INTEGRAL source population

-> as predicted in the extension document!

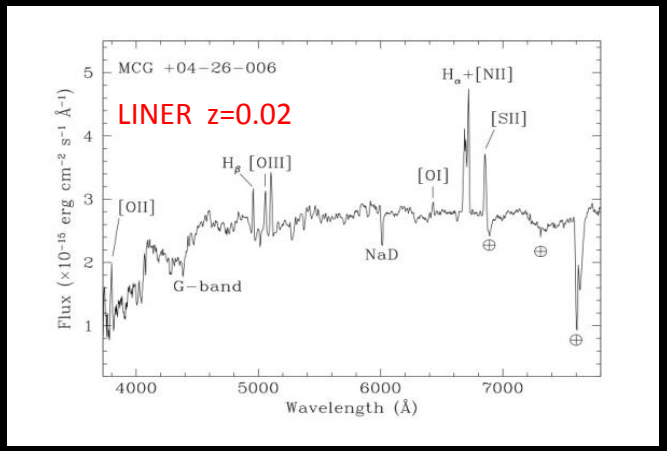
- Average < z > = 0.576 (with new high redshift QSO identification, see Masetti et al. 2011) compared to < z > = 0.135 from Bird 4th catalogue (see also Krivonos et al. 2010)

-> we go deeply in the Universe as predicted in the extension document!

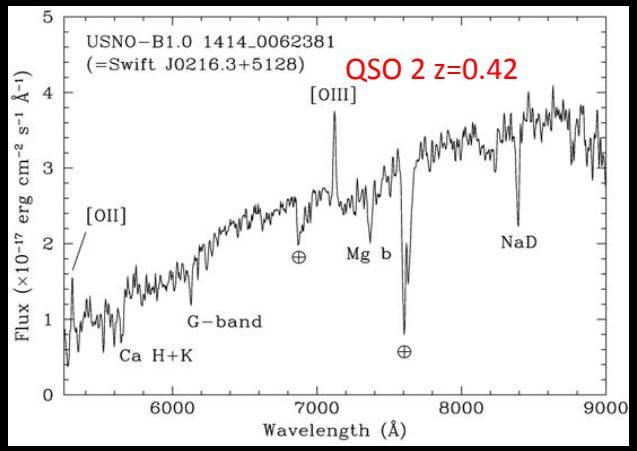
AGNs CVs HMXBs Other

The high energy AGN population: NOT ONLY SEYFERT GALAXIES BUT…

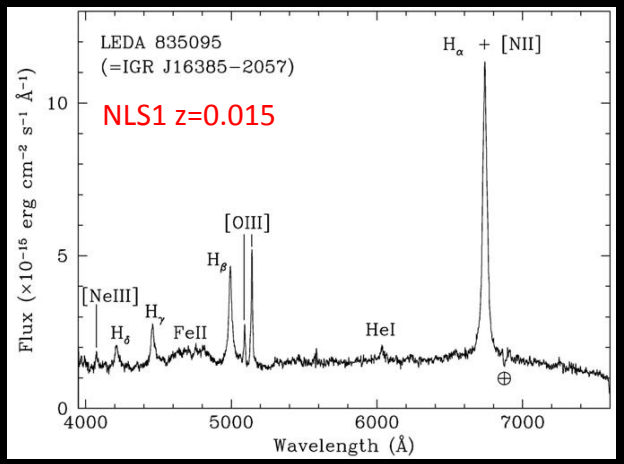
(as predicted in the 2010 document!)



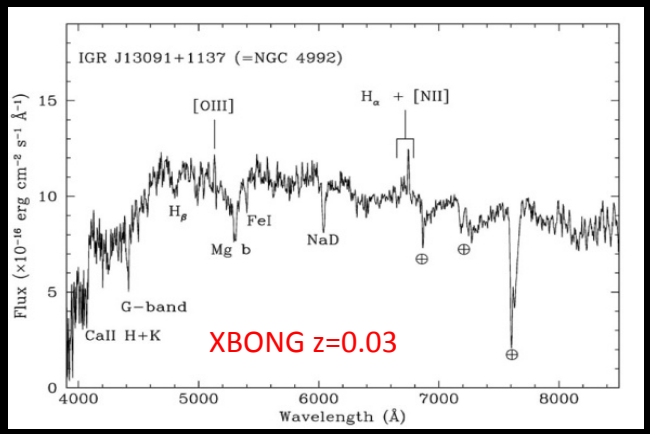
A few LINERs all with $N_H \geq 22$
none CT



Also a few type 2 QSO $22.2 \leq N_H \leq 23.4$



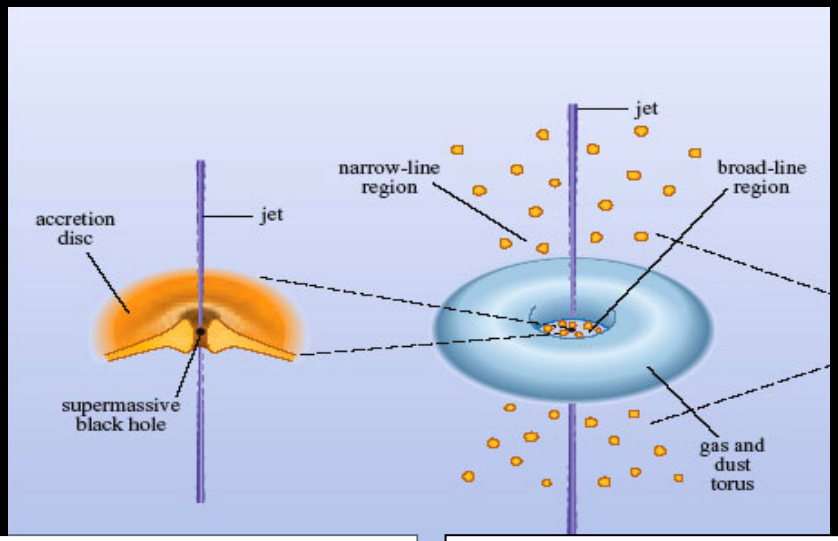
14 Narrow Line Syfert Galaxies



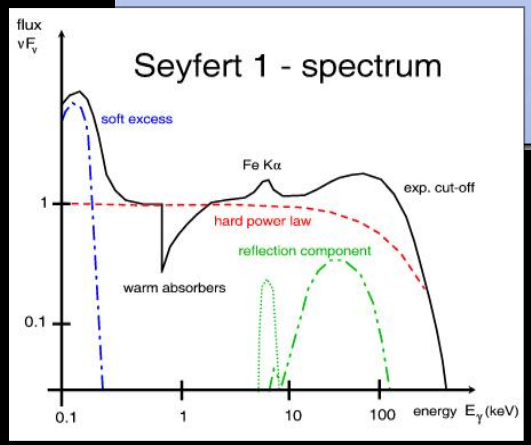
4 X-ray Bright Optically Normal Galaxies (XBONG)
$0.01 \leq z \leq 0.1$ $N_H \geq 23$

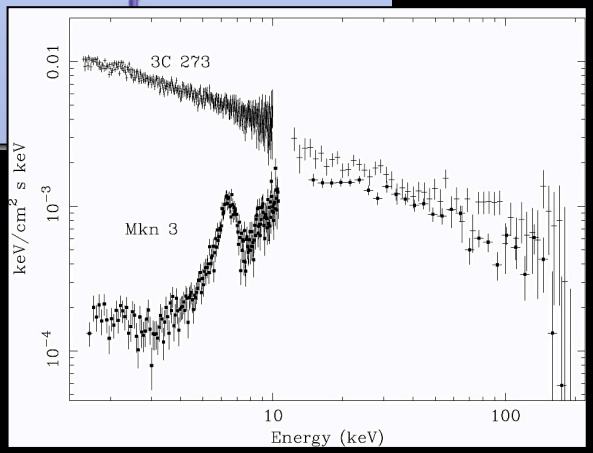
INTEGRAL studies of AGN: a powerful tool for the extragalactic science

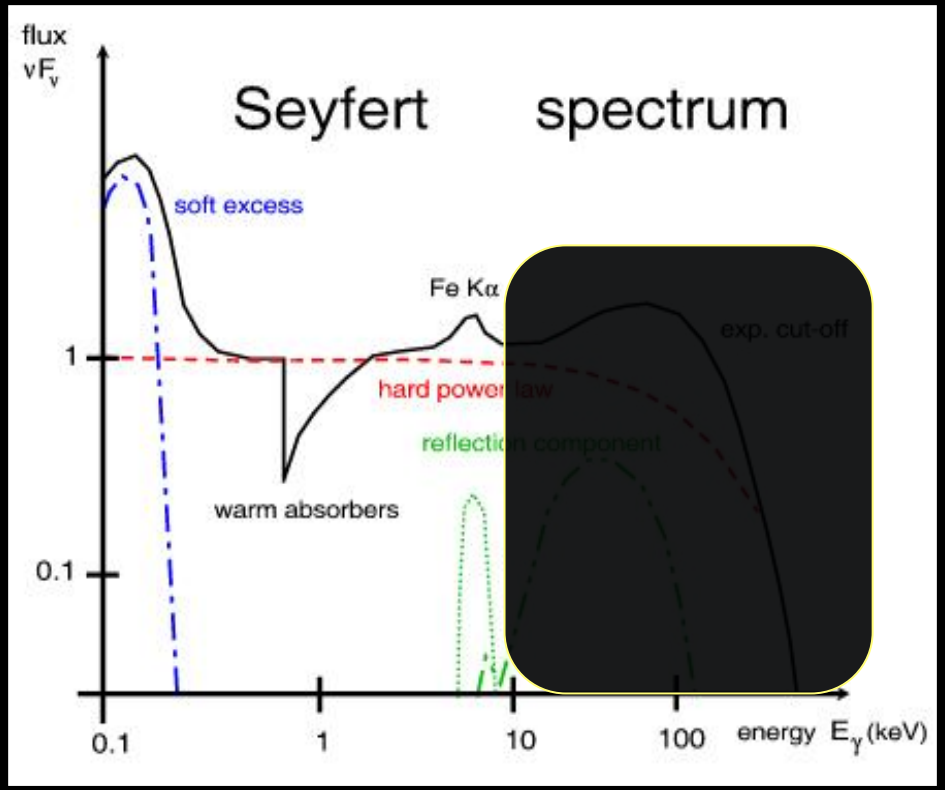
Hard X-rays together with X-rays can:



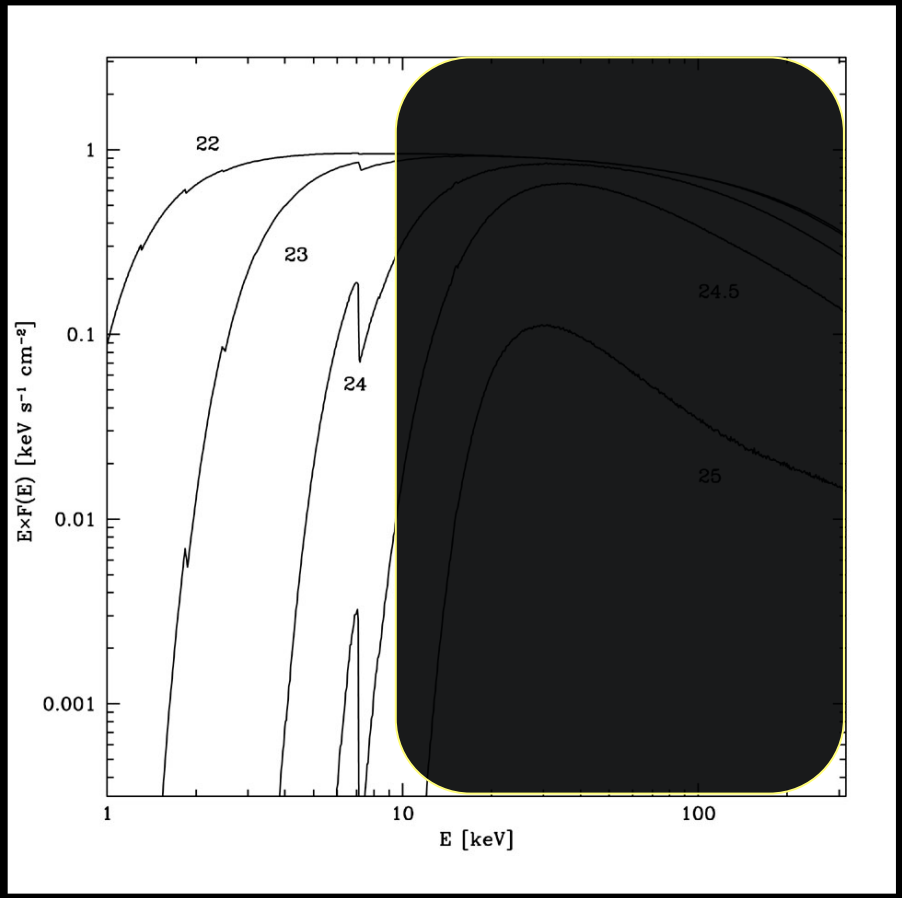
- **Probe the accretion physics of the disk/corona/jet(?) system**
  - **Broad-band spectral parameters**
  - **Hard X-ray variability**
- **Probe the distribution and physics of the surrounding material**
  - **Broad-band spectral parameters**
  - **Seyfert statistics**







The added value of the hard-X coverage

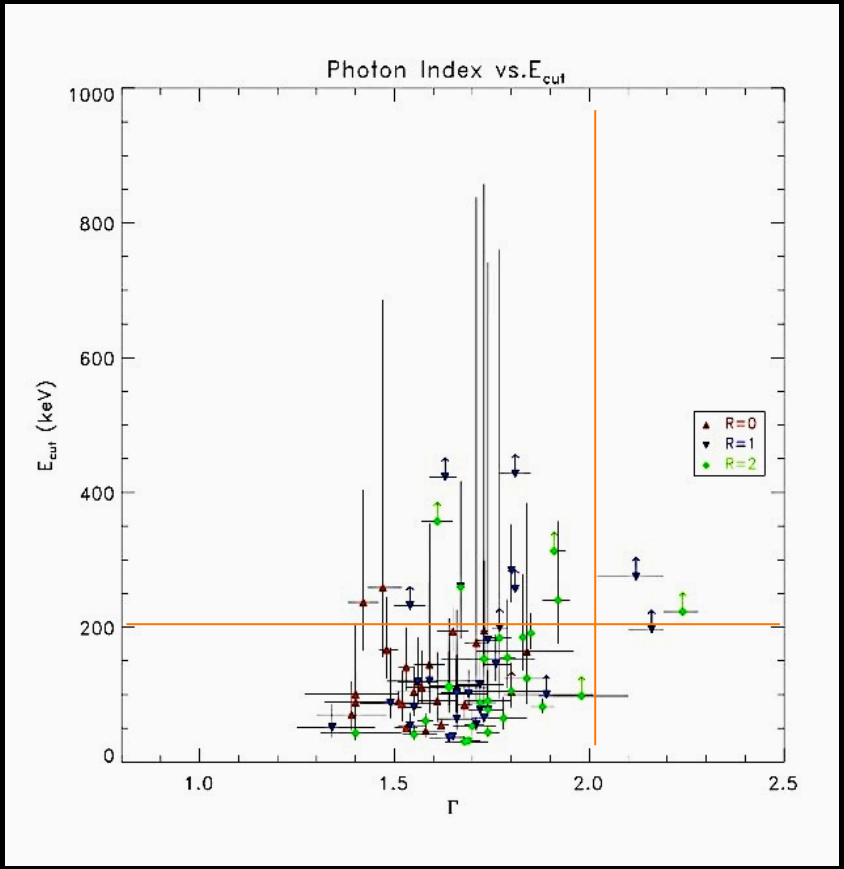


- AGN modelling & physics
- Unified theory, torus studies, etc
- X-ray Background (XRB) studies

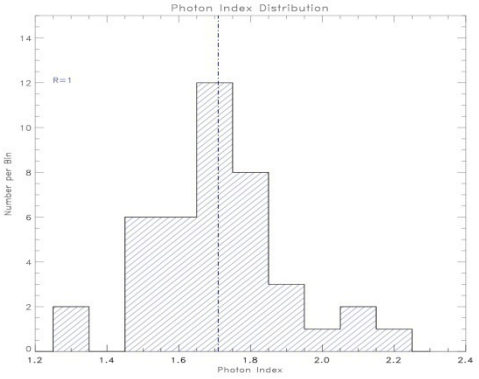
Probe the accretion physics of the disk/corona/jet(?) system 1

Broad-band Spectra of type 1 Seyferts

(Molina et al. in preparation, Ricci et al. 2011)



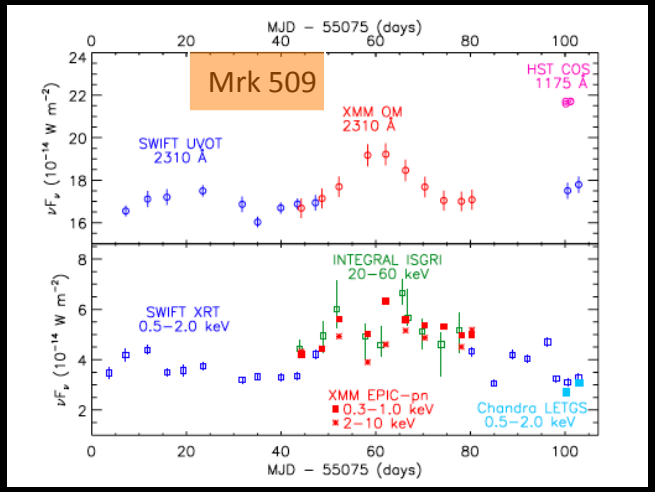
For R=1



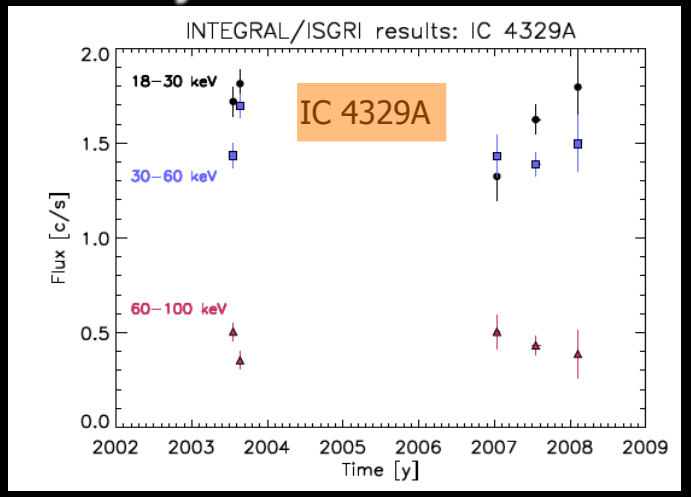
The majority of type 1 AGN have photon index flatter than 1.9 and E_c below 200 keV, independently from R

Probe the accretion physics of the disk/corona/jet(?) system 2

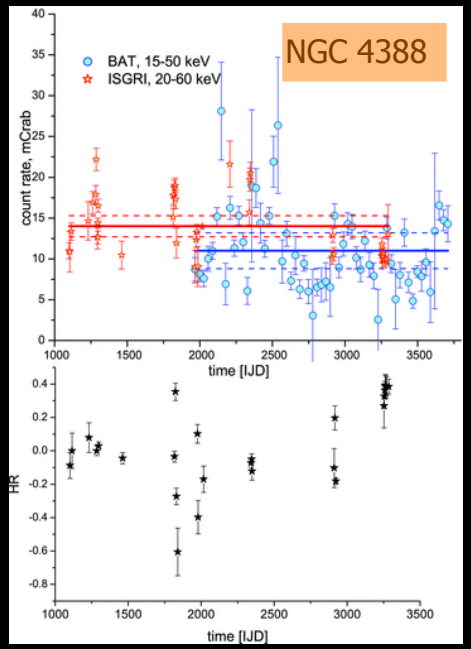
Hard X-ray variability



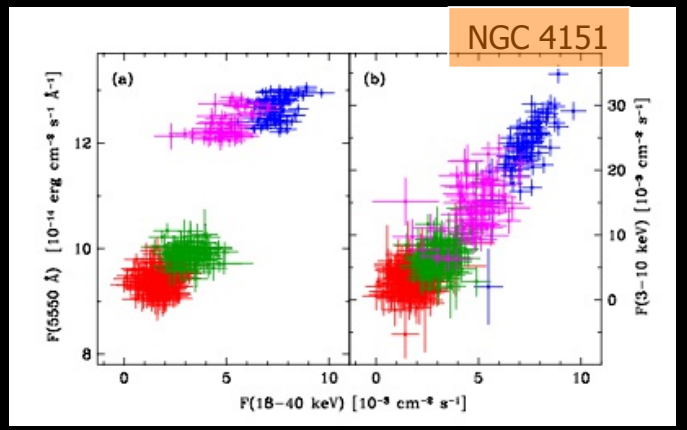
Kaastra et al. 2011: XMM+INTEGRAL



Soldi et al. 2010: evidence of cut-off variation



Fedorova et al. 2011: complex variability behaviour, i.e. the spectral shape and the 20–60 keV flux vary independently



Lubinski et al. 2010: strong linear correlation between Optical/X-rays (3-10 keV) and hard X-rays >20 keV) and almost the same spectral slope!

INTEGRAL AO9 800 ksec: t*his long term monitoring of the brightest Seyfert galaxy will be a true legacy for the INTEGRAL mission, providing the best spectral timing data at hard X-rays for years to come* → ***a mission legacy?...NuStar to arrive soon!!***

Probe the distribution and physics of the surrounding material

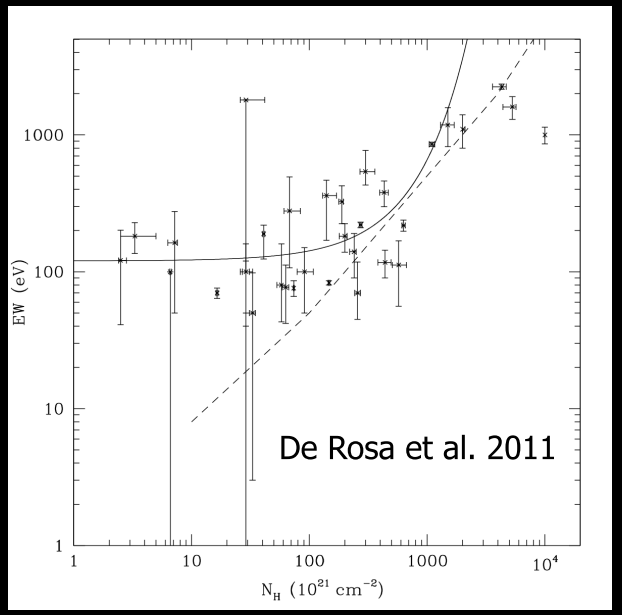
High energy spectral parameters of type 2 Seyferts

(De Rosa et al. 2011, Ricci et al. 2011)

- High energy cut-off is ubiquitous in the X-ray spectra of type 2 AGN

--> **this evidence puts strong constraints on XRB synthesis model**

- **In heavily obscured Seyferts (N_H above $10^{23.5-24}$ cm^{-2}) the Fe line is produced in a torus also responsible for the absorption**
- **In Compton thin sources (N_H above $10^{23.5-24}$ cm^{-2}), as well as for type 1 AGN, a high fraction of the Fe K line has to be produced in a gas located closer to the black hole than to the torus --> likely the BLR**



Constrain the reflection features (i.e., reflection fraction, equivalent width of the Fe line)

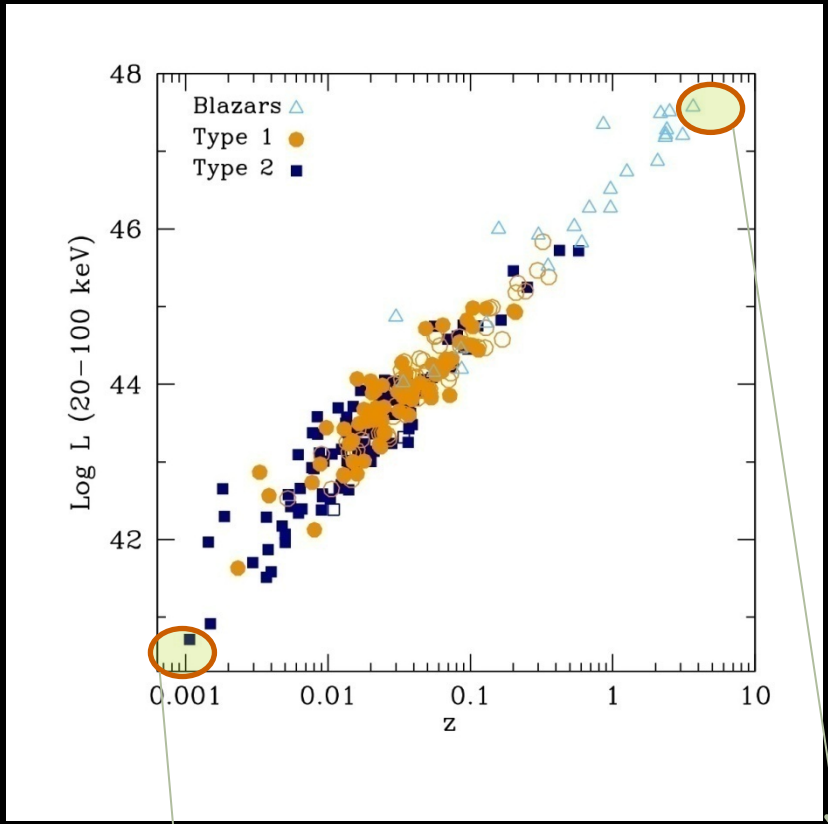
--> COMMON LEGACY INTEGRAL - XMM-Newton

NEXT STEP:

Broadband time-resolved variability study to directly observe the N*H,* Fe EW and R variations. These observational campaigns have been performed in a limited energy band, so far, in just few sources like NGC1365, NGC7582, i.e. the so called “Changing look”

-> Good candidate for INTEGRAL KP →we need to keep going to solve the XRB issue!

The INTEGRAL AGN catalogue



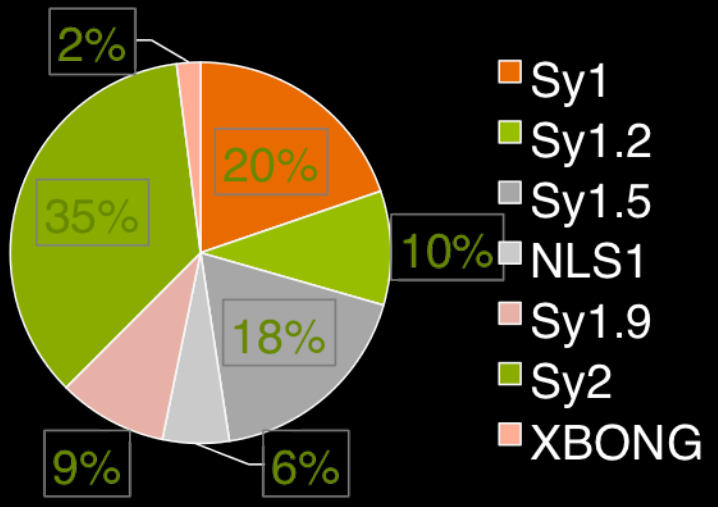
IGR J22517+2218 z=3.7
Log L=47.7, M 10^9 M_0

NGC4395 z=0.001
Log L=40.7, M~ 4×10^5 M_0

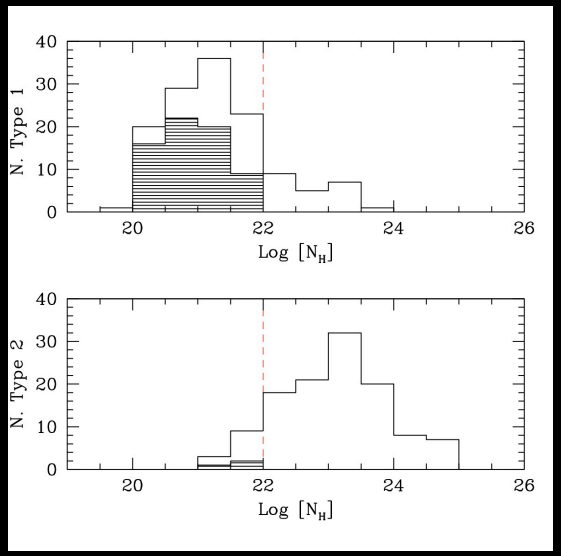
272 AGN

the most comprehensive one !
(Malizia et al. 2011)

4th IBIS catalogue
(Bird et al. 2010)
+
All-Sky Hard X-ray Survey
(Krivonos et al. 2010 +updates)



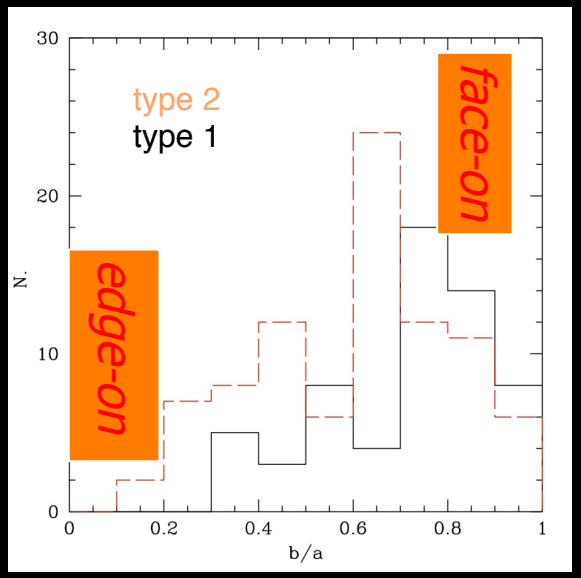
INTEGRAL absorption studies for the Unified Theory verification



1. X-ray absorption versus Optical classification

There is a number of AGN for which the expected optical and X-ray characteristics are not the same and thus apparently not in agreement with the unified scheme. Using the last INTEGRAL AGN catalogue Malizia et al. 2012a (in prepation) find that AGN unification holds for most sources with only 5-6% outside the scheme, absorbed broad line Sey can be explained with obscuration unrelated to the torus and unabsorbed narrow line Sey need deeper X-ray observations.

2. X-ray absorption versus host galaxy axial ratio



The inclination of the host galaxy (axial ratio) can play a role in relation to the X-ray absorption:

a) if absorber/torus aligned with galaxy:
Sy1 face-on and Sy2 edge-on

b) if not, no correlation between
Sy type and axial ratio expected

neither works :

Sy 2 uncorrelated with a/b
Sy 1 correlated with a/b

→ need for dual absorbers

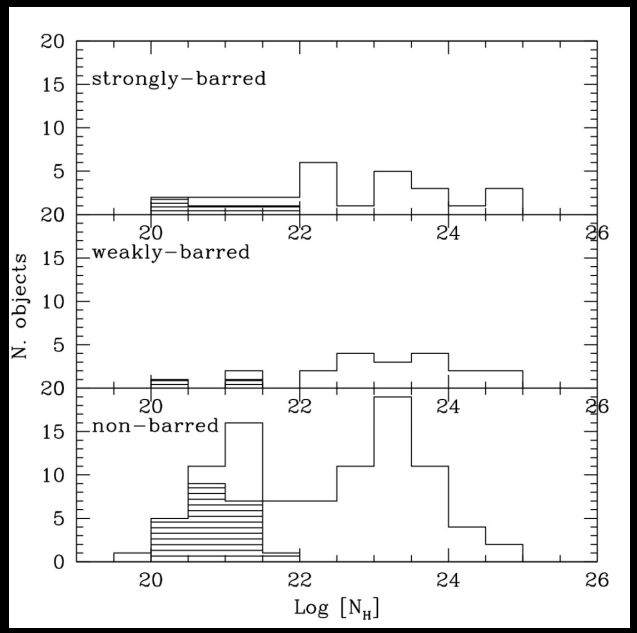
Malizia et al. 2012b (in prepation)

INTEGRAL absorption studies for the Unified Theory verification *(continued)*

3. X-ray absorption versus galactic structures and interactions

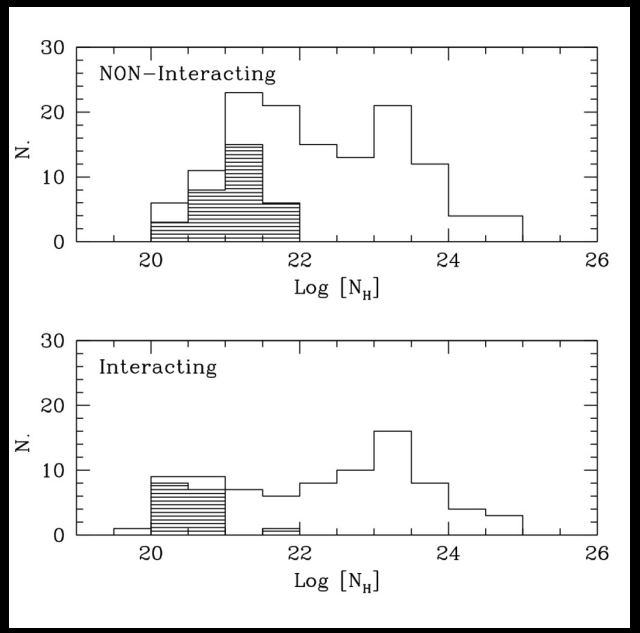
Possible connection between the X-ray absorption and the large scale structures could be represented by the presence of large gravitational torques such as in barred and interacting galaxies. Using the last INTEGRAL AGN sample Malizia et al. 2012c (in preparation) find any correlation between absorption and presence of bars and/or interactions.

INTEGRAL AGN sample



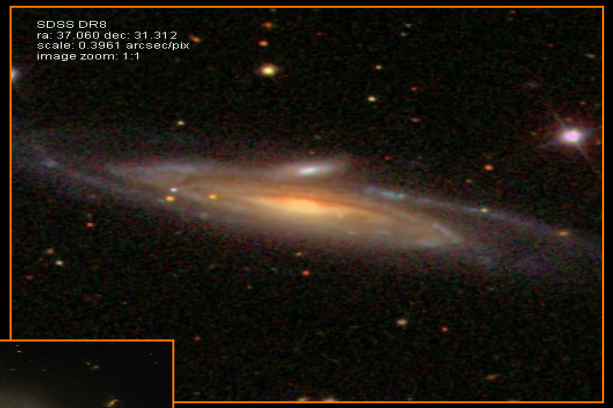
40% strongly barred

38% interacting



Galaxy interaction & merging:
a few examples from the INTEGRAL AGN catalogue

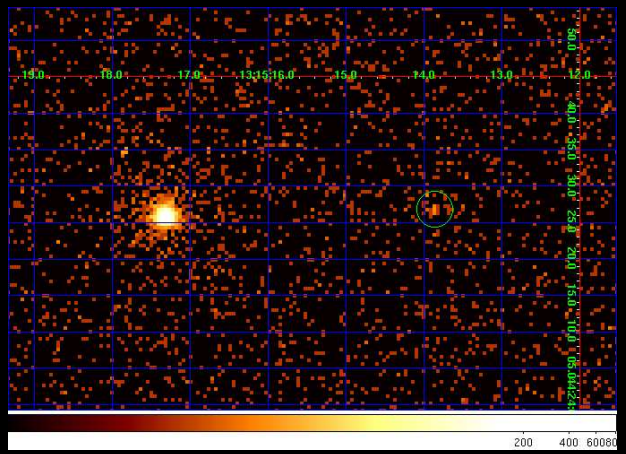
NGC 2992



Mrk 1040

NGC 7469

UGC08327



--> not all of them have double active nucleus

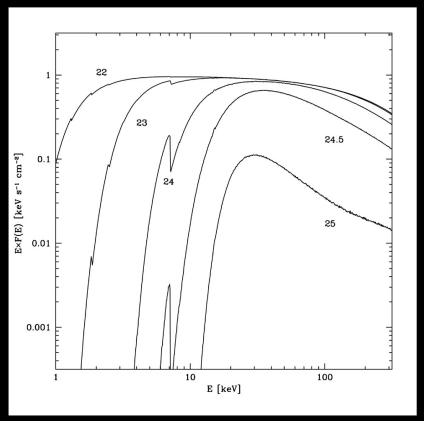
The revised fraction of Absorbed and Compton thick AGN: a key study by INTEGRAL

Results from the INTEGRAL/IBIS complete sample of AGN (Malizia et al. 2009)

Reduction of hard X-ray flux as a function of column density.

Loss of about 15 objects above Log(NH) = 24

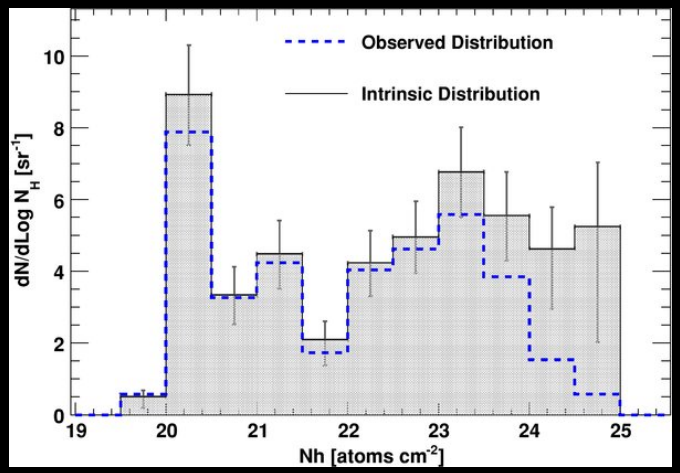
Abs. AGN 43% → 51%
CT AGN 7% → 21%



Range NH (Log)	Flux Reduction	Number missed‡
24-24.5	8%	0.5
24.5-25	25%	3
25-25.5	64%	12

‡ Assuming Euclidean LogN-LogS

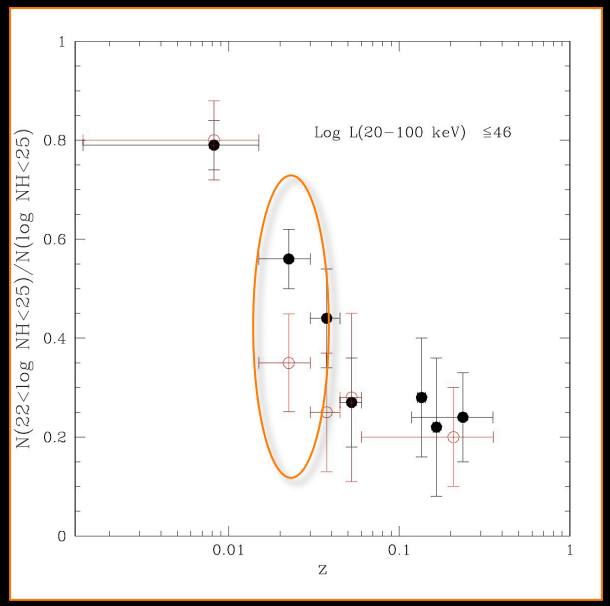
INTEGRAL results have been confirmed by Swift/BAT



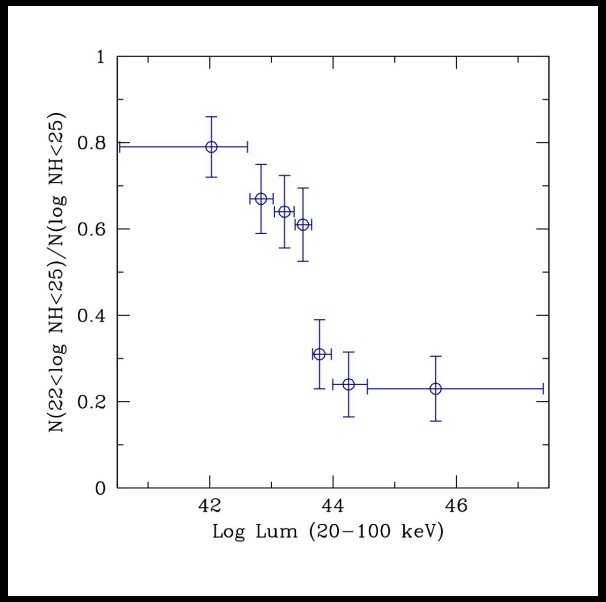
Adopting a similar correction, also Burlon et al. (2011) found a fraction of CT AGN~ 20% using a BAT sample of AGN!!

Work in progress

The fraction of absorbed sources as a function of redshift



red points: cat3 Complete Sample
black points: cat4 extended AGN sample of 272 objects ➡ as expected going deeper the fraction of absorbed AGN increases in the second bin while is unchanged in the first (z<0.015)



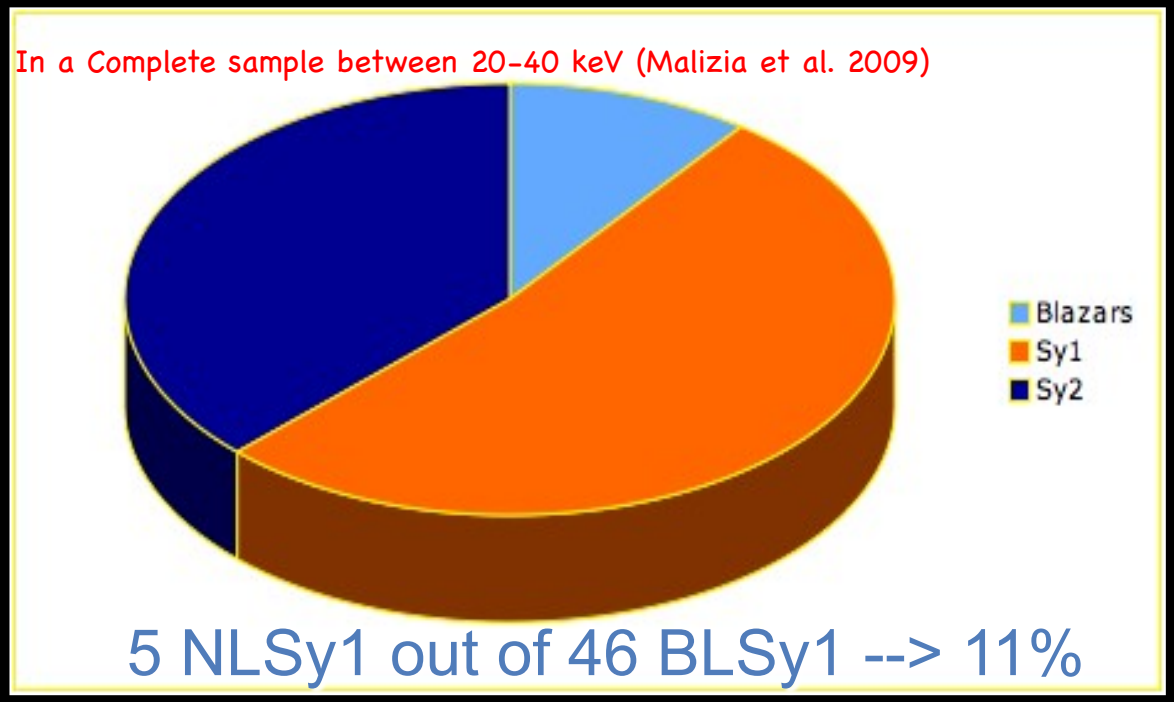
INTEGRAL confirms the decrease of the fraction of absorbed AGN with Luminosity

FUTURE WORK: HXLF TAKING INTO ACCOUNT THE N_H DISTRIBUTION

Hard X-ray selected INTEGRAL NLSy1

(Panessa et al. 2011, Ricci et al. 2011)

NLSy1 are characterized by extreme X-RAY spectral complexity

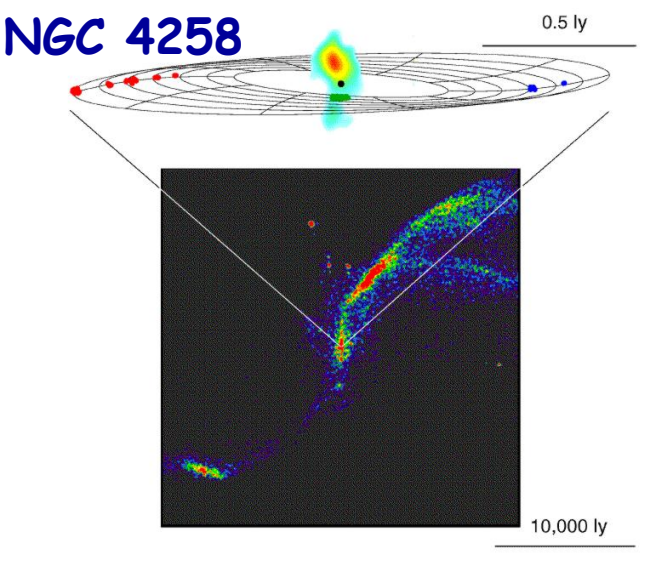


- ✓ 5-15 % of NLSy1 in the hard X-ray sky

- ✓ ROSAT: 46 % (BLSy1, Grupe et al. 2004)
  1 % (AGN in deep field, Hasinger et al. 2000)
- ✓ OPTICAL: 15% (vs. BLSy1, Zhou et al. 2006, Williams et al. 2002)

INTEGRAL AGN multi-wavelength follow-up

22 GHz water masers

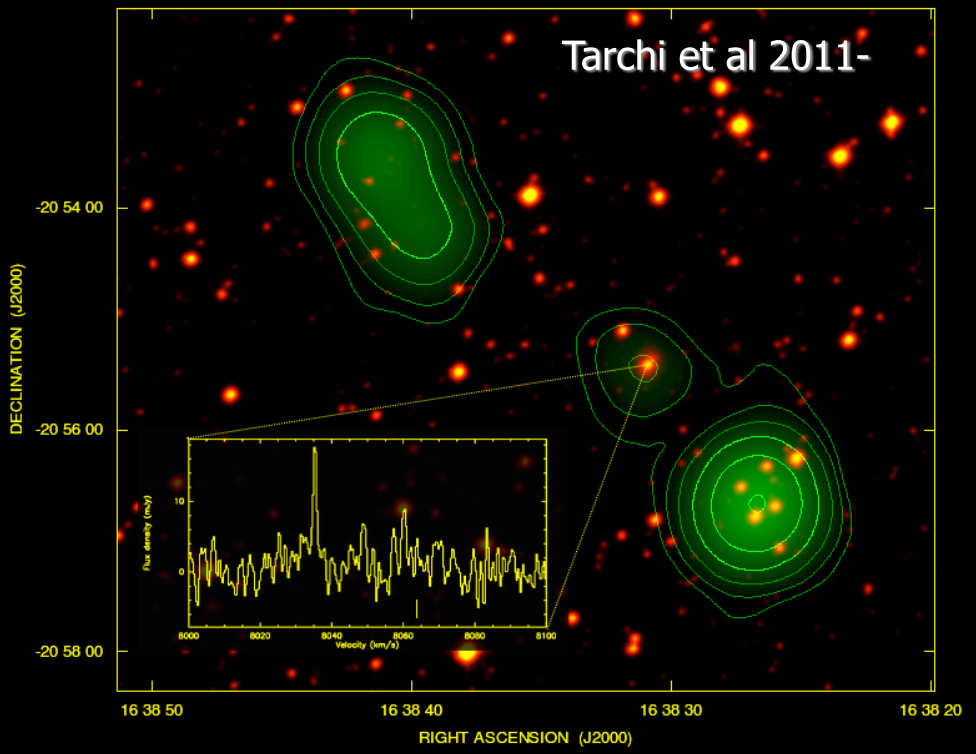


✓ Water maser emission traces a disk, a jet or outflow

The discovery of a water mega-maser in IGR J16385-2057:

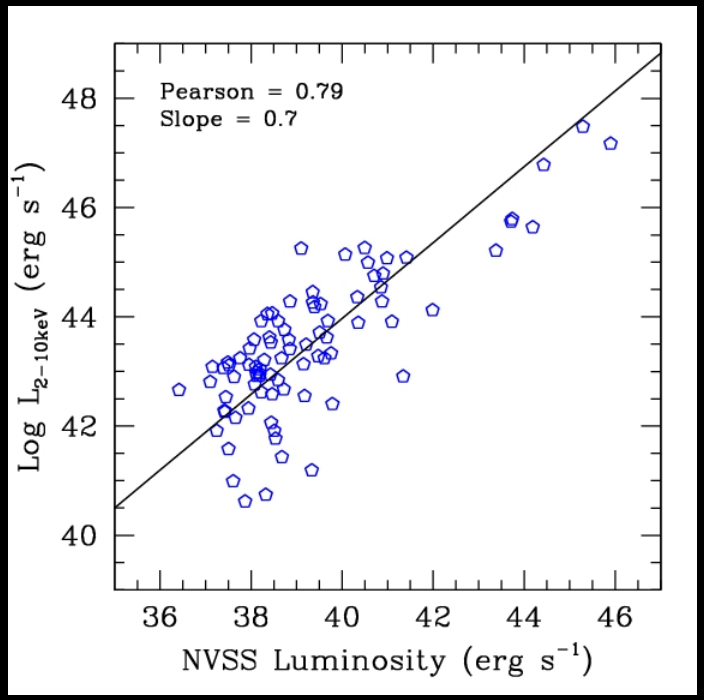
- it is a NLSy1 (masers are tipically found in obscured AGN)
- it resides in an elliptical galaxy (masers are rare in ellipticals)

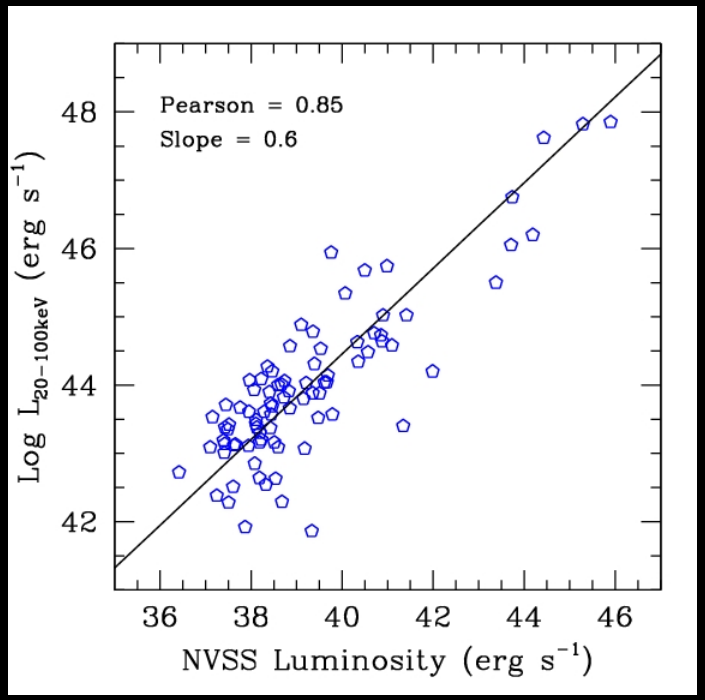
INTEGRAL POM December 2011



✓ FUTURE: 22 GHz survey of INTEGRAL AGN --> Castangia et al. in preparation

Hard-X and radio connection: Hard X-ray versus radio correlations





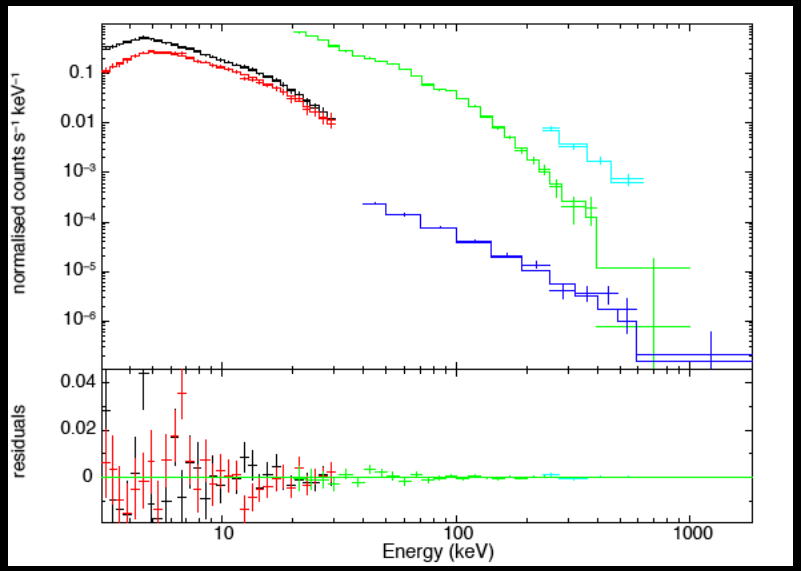
✓ Correlation between 2-10 keV, 20-100 keV vs radio luminosity

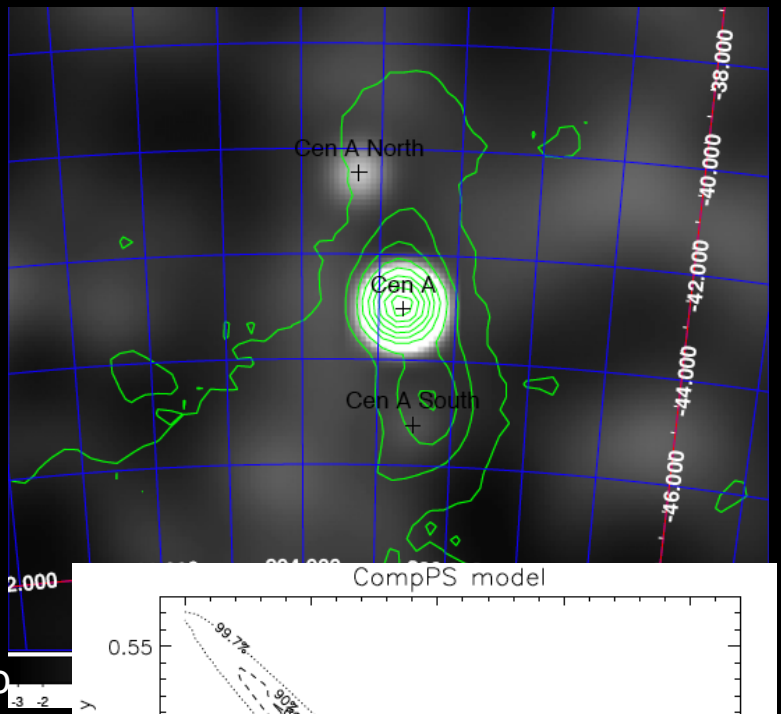
--> **DISK / JET Connection in high luminosity RADIO - QUIET AGN**

Maiorano et al. in preparation

Hard-X and radio connection: Broad-band emission from BLRGs

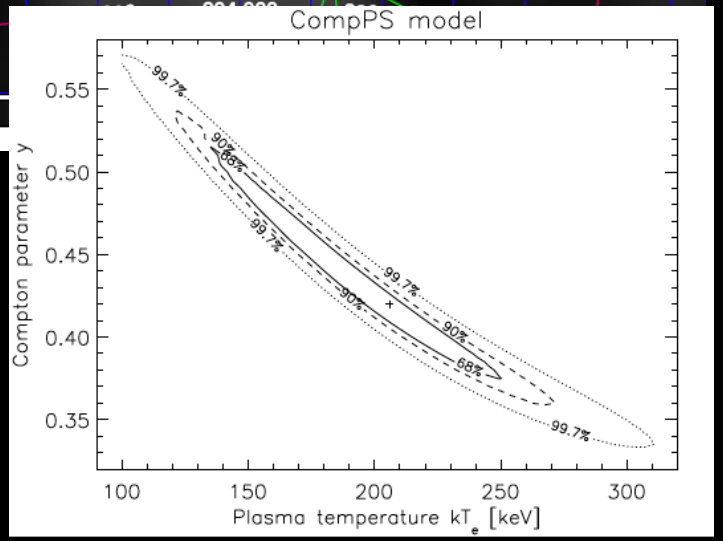
(Beckmann et al. 2011)





The radio galaxy Cen A has been detected all the way up to the TeV energy range.

While gamma-rays, as detected by CGRO and Fermi, are caused by non-thermal (jet) processes, the main process in the hard X-ray emission of Cen A is still not unambiguously determined, since it is either dominated by thermal inverse Compton emission or by non-thermal emission from the base of the jet



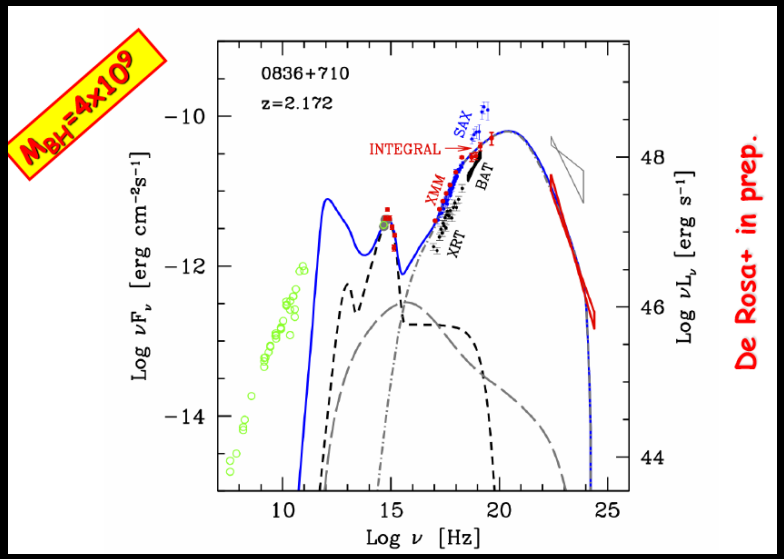
Hard-X and radio connection: Blazars

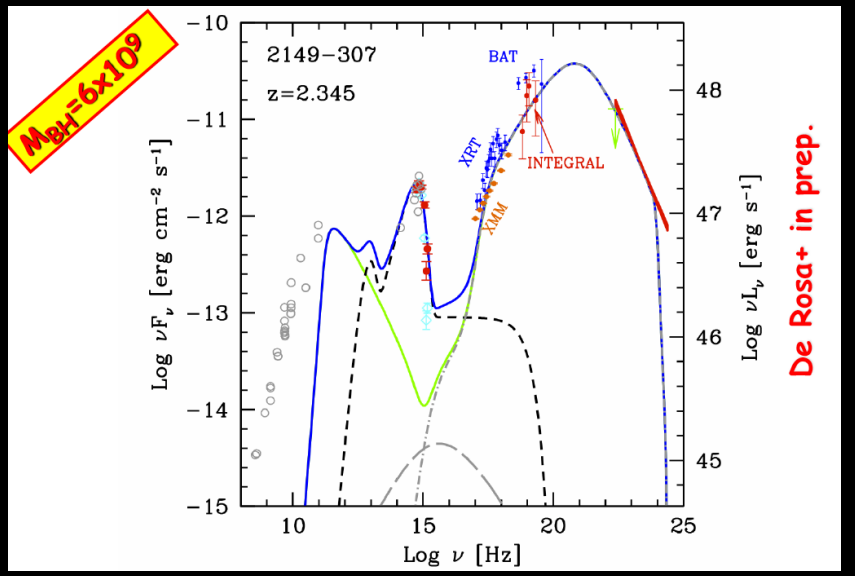
(De Rosa et al in preparation, Ghisellini et al. 2011)

Search for EARLY and HEAVY black holes → blazars

In very powerful FSRQs the hard X–ray flux is close to the emission peak

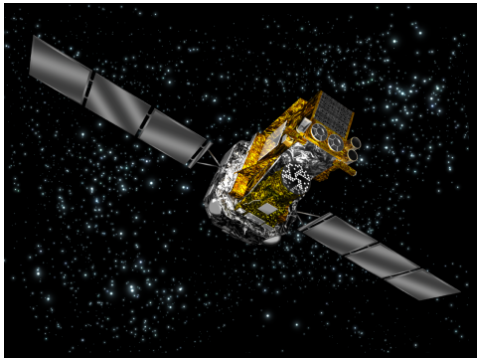
--> hard X–rays carry a very significant fraction of the jet luminosity, making them visible and detectable at very high redshift





Most powerful jets!

→ as predicted in the 2010 extension document we have started to detect the heavier-primordial structure in the Universe…we neeed to keep going!!



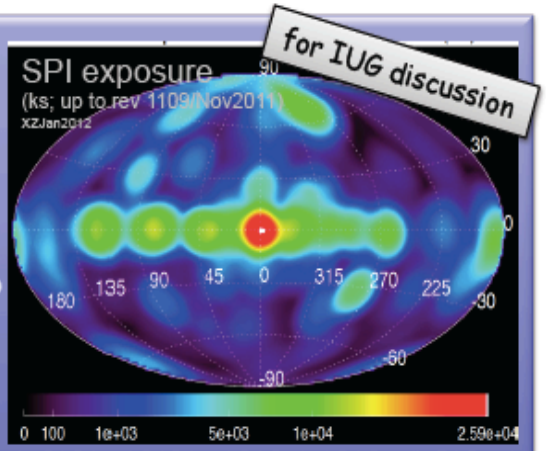
Accomplishments and ..

- "Ultra-deep observations during the next 4 years will verify the evolution of the AGN luminosity function with redshift, vs brightness/distance effects" (Winkler, 26 October 2010):
  - AO8 --> 5.8 Ms (3C 273, NGC 4151, M81)
  - AO9 --> 4.3 Ms on the same targets

- **Nustar will be a key plaier… ASTRO-H + INTEGRAL will be a unique opportunity for AGN studies in the next decade**

Requirements to Establish the Legacy

- Which INTEGRAL data will remain unique?
  - Line Spectroscopy
  - MW-Galaxy Survey at >100 keV → few MeV
  - All-Sky AGN Survey
- Which Science Issues make up the Legacy?
  - Transients Monitoring
  - Polarization
  - Line Spectroscopy >100 keV



- Estimate the needs versus INTEGRAL's potential
  - How much exposure in mid latitudes would be needed to change any of the 511 bulge extent results significantly (DM origin/SMBH)?
  - How much GPlane exposure is needed to get the 511 brightness of the disk sufficiently well? (what is the requirement?)
  - How much inhomogeneity in the GPlane exposure can be tolerated without harming the astrophysics conclusions, eg on search for ^{44}Ti sources?
  - How much Orion exposure is be needed to obtain a meaningful lines result?
  - How much LMC exposure is needed to consolidate the SN1987A ^{44}Ti result?