Non thermal hard X-ray emission from the radio halo of M87

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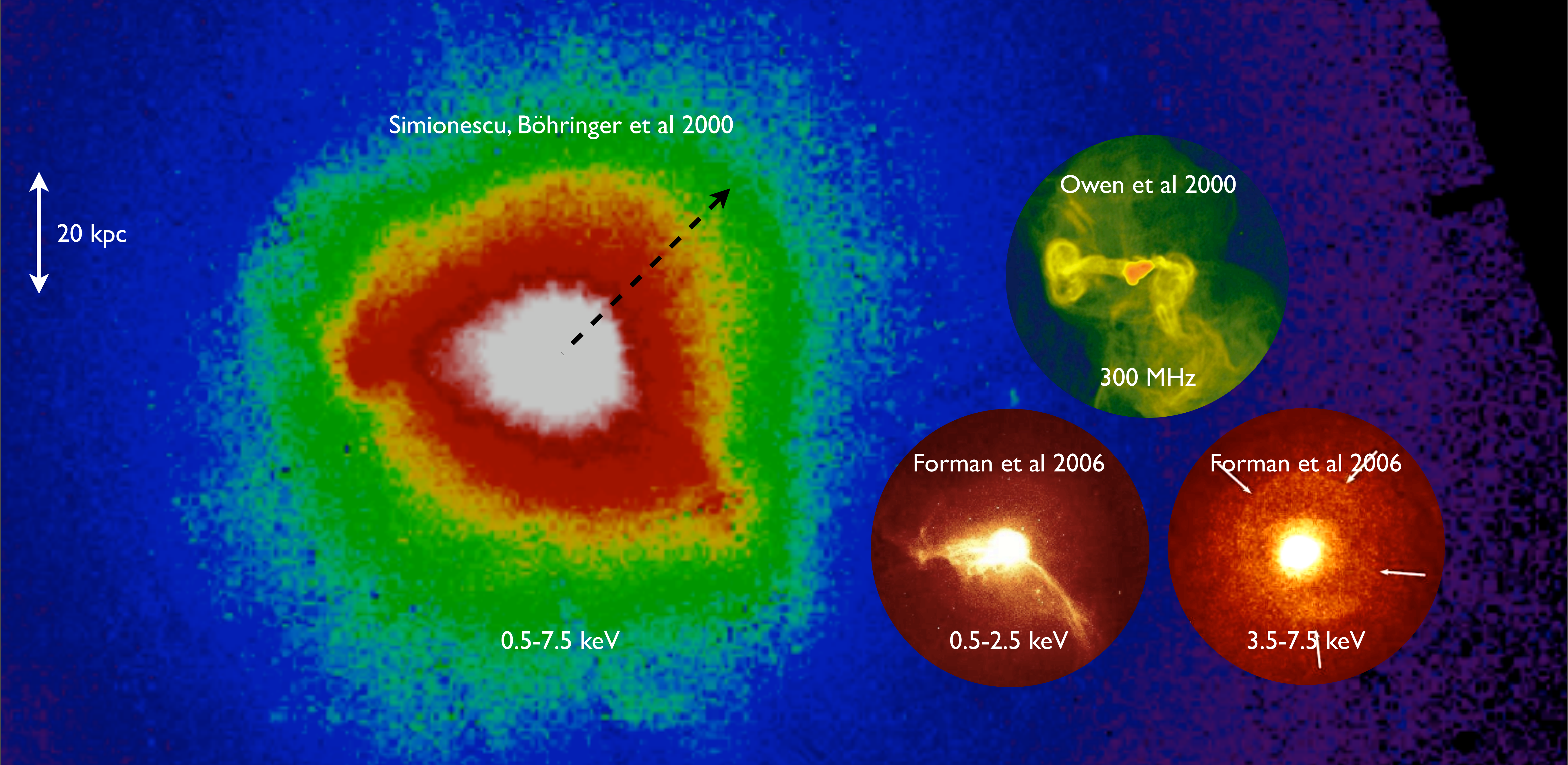
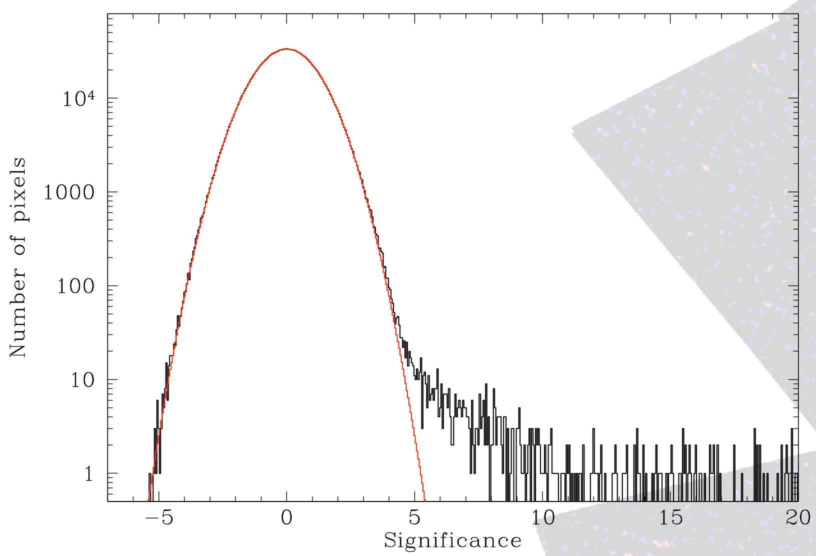
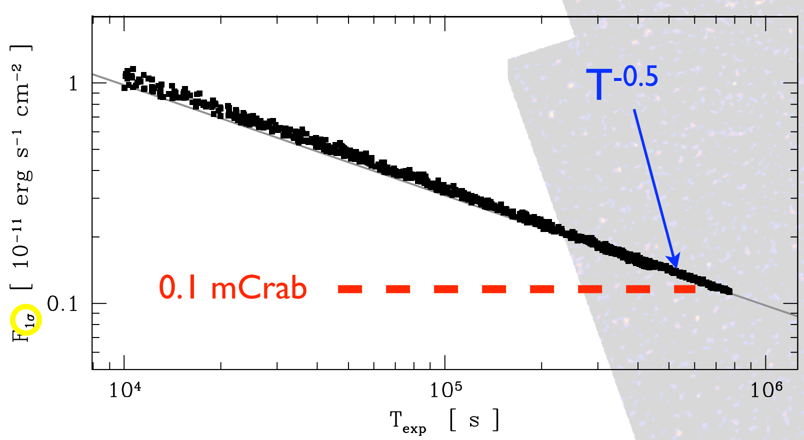


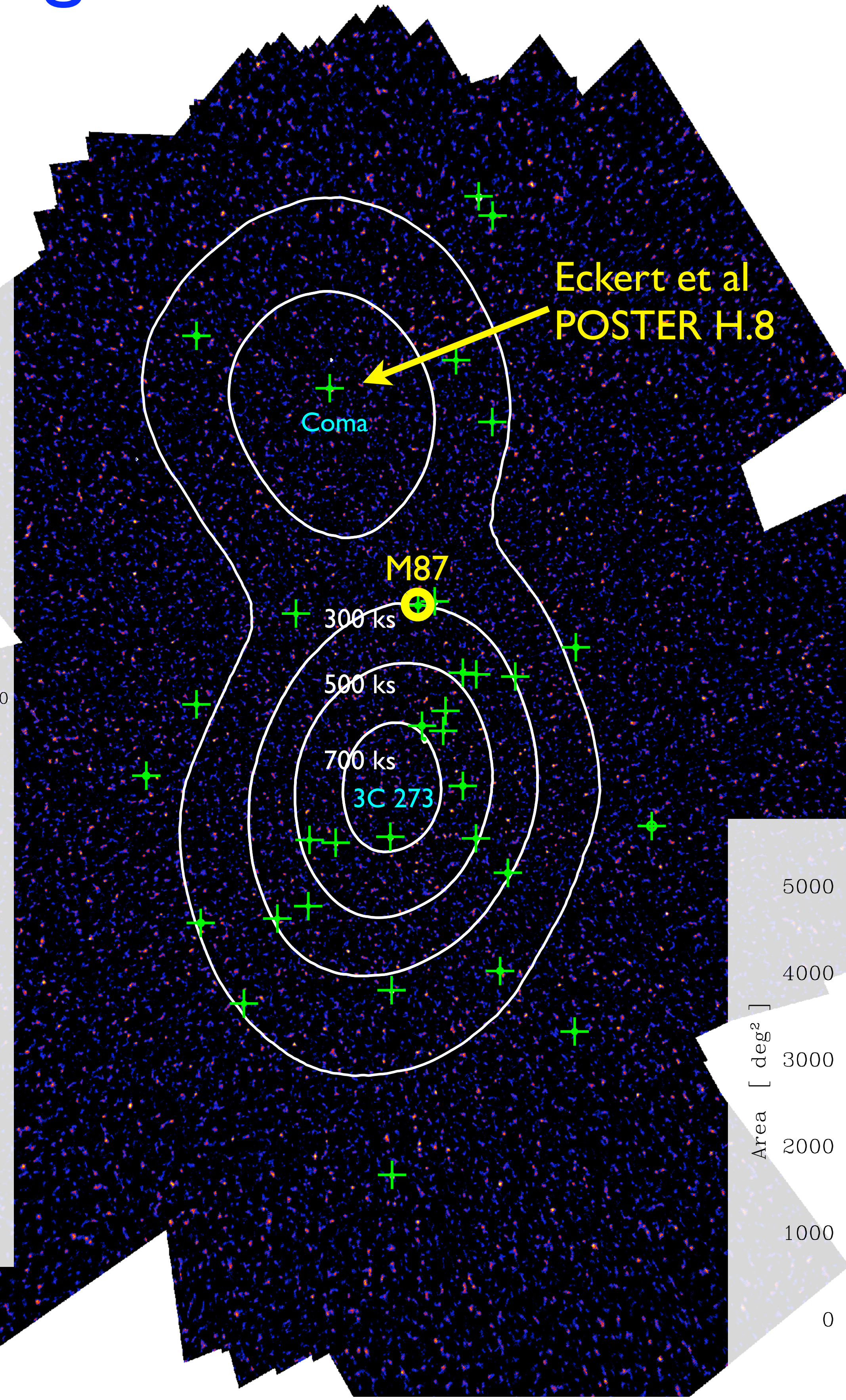
- The radio halo (40kpc) of M87 (Virgo A) was one of the first radio source detected (Bolton & Stanley, 1948)
- The Virgo cooling flow was the first extragalactic X-ray source detected (Byram et al, 1966)
- 3.2×10^{9} Mo SMBH, 16 Mpc
- One sided jet (Owen, 1989) powering radio lobes interacting with X-ray thermal gas
- Low emissivity cooling flow (some Mo/yr), heated by SMBH activity
- Buoyant bubbles lifts 1–10 Mo/yr from the core to the radio halo (Churazov et al, 2001)

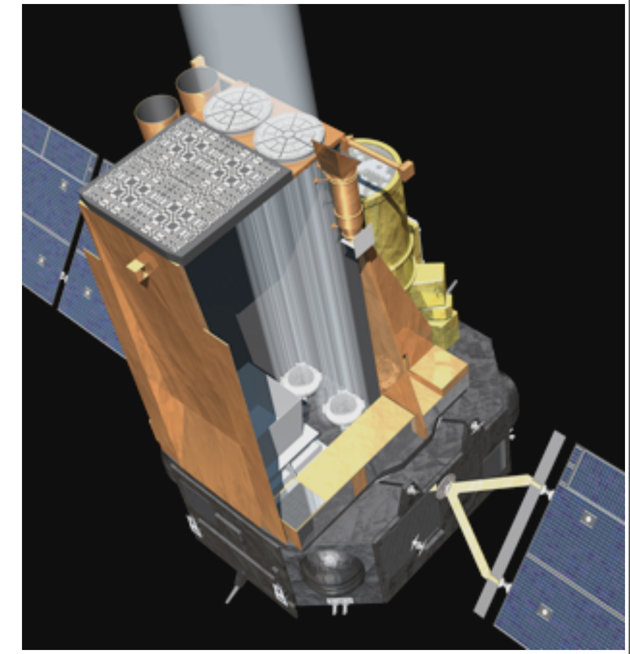
The deepest extragalactic field observed by INTEGRAL

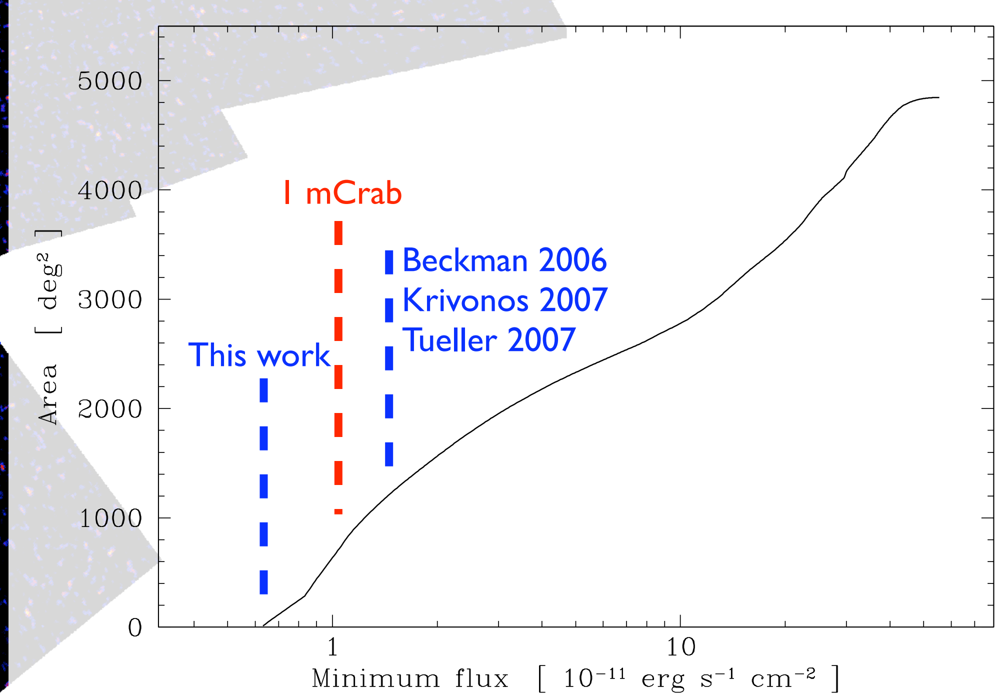
1660 pointings
20-60 kev, to optimize sensitivity
3.9 Ms elapsed time
Maximum effective exposure: ~ 775 ks









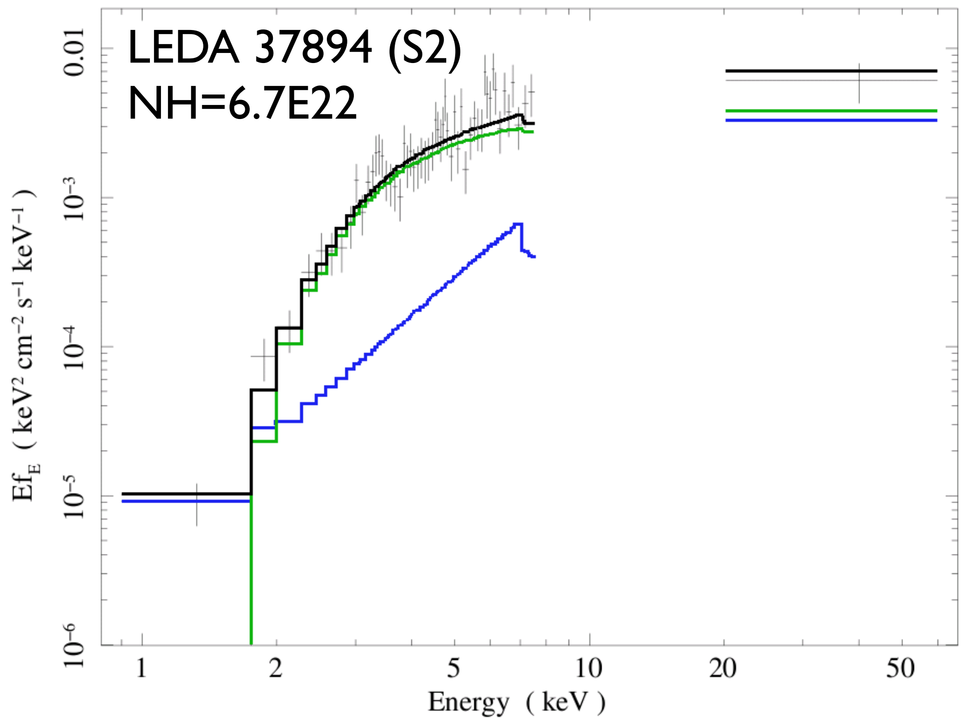


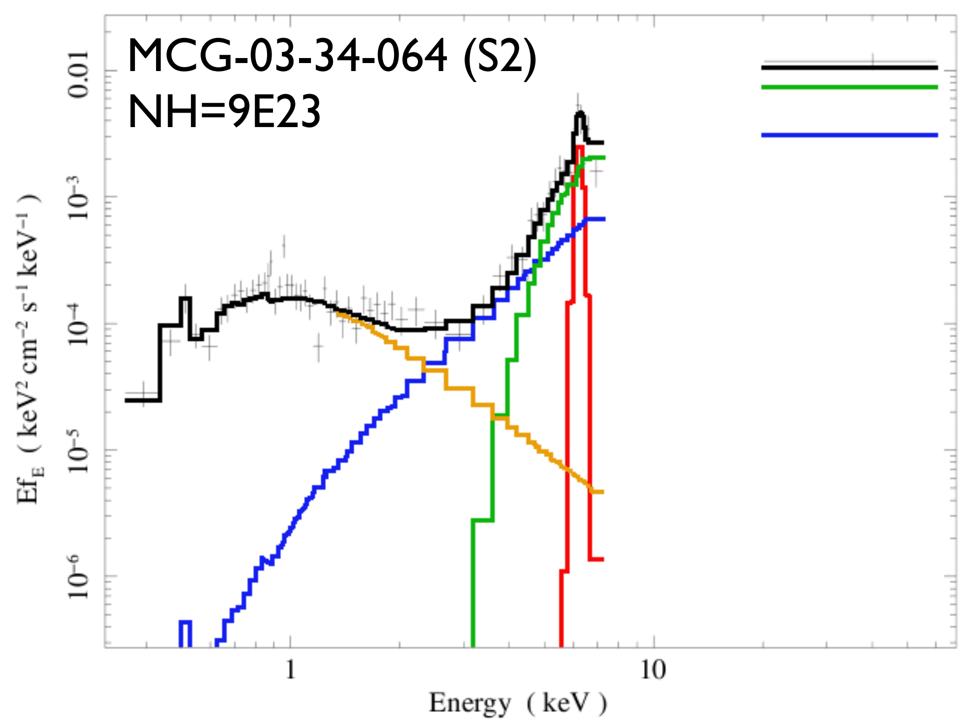
ISGRI allows exposure >100 Msec
i.e. sensitivity < 0.01 mCrab (10^{-13} cgs)
not limited by systematics.

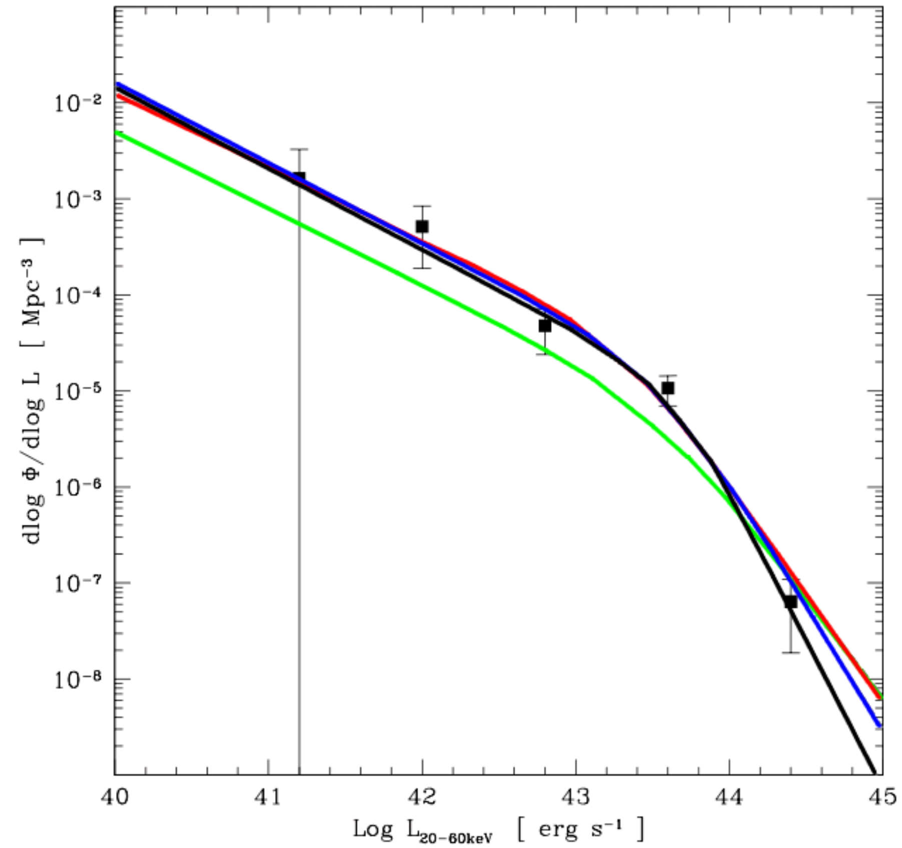
34 sources:

- 5 Seyfert 1
- 4 Seyfert 1.5/1.8
- 8 Seyfert 2
- 4 blazars
- 1 XBONG
- 11 Unidentified (half with ROSAT counterpart)
- 1 Cluster

Newly identified bright AGNs



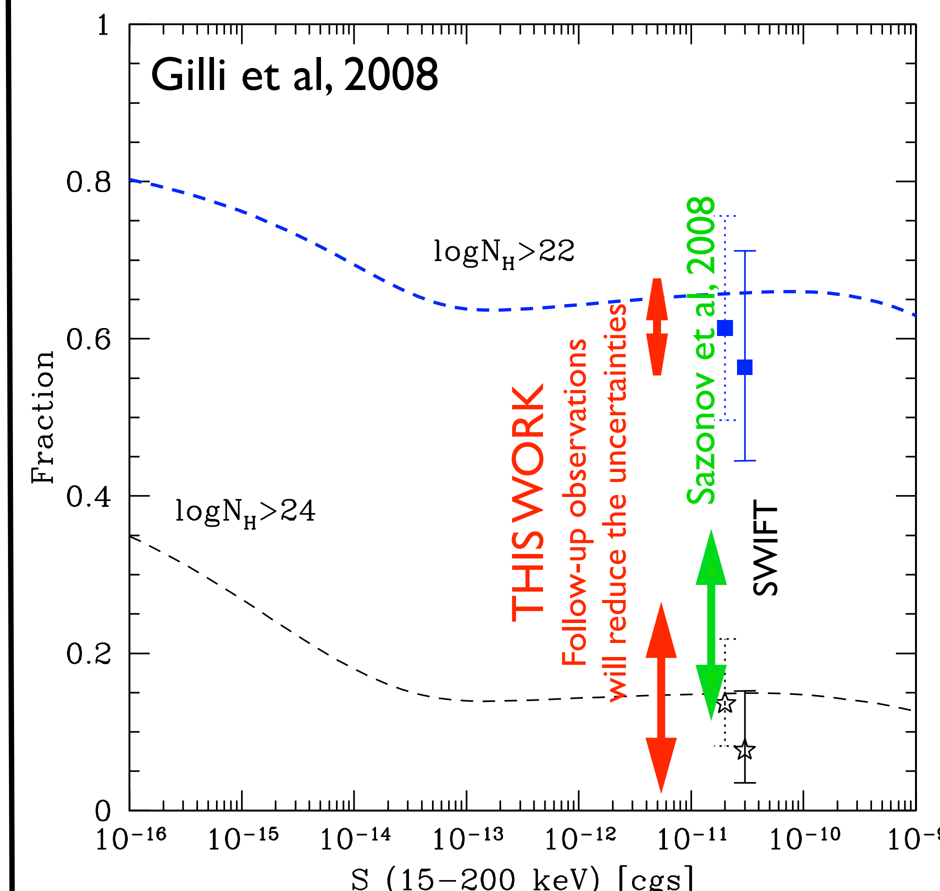




$$\frac{d\Phi(L)}{d\log L} = \frac{\Phi^*}{(L/L^*)^{-\alpha} + (L/L^*)^{-\beta}}$$

$$\log L^* = 43.66^{+0.28}_{-0.60}\ \mathrm{erg\ s^{-1}}$$
$$\alpha = 0.85^{+0.26}_{-0.38}$$
$$\beta = 3.12^{+1.47}_{-1.02}$$
$$\Phi^* = 1.12^{+5.04}_{-0.77}\ 10^{-5}\ \mathrm{Mpc^{-3}}$$

L* smaller than derived at soft X-rays as the soft X-ray AGN population is less absorbed.



There are no bright Compton thick AGN population missed at low energy.

Hard X-ray surveys of local AGNs do constrain synthesis model of the XRB.

Paltani, Walter, McHardy, et al. (2008), A&A in press, astro-ph 0805.0537

M87 at hard X-rays

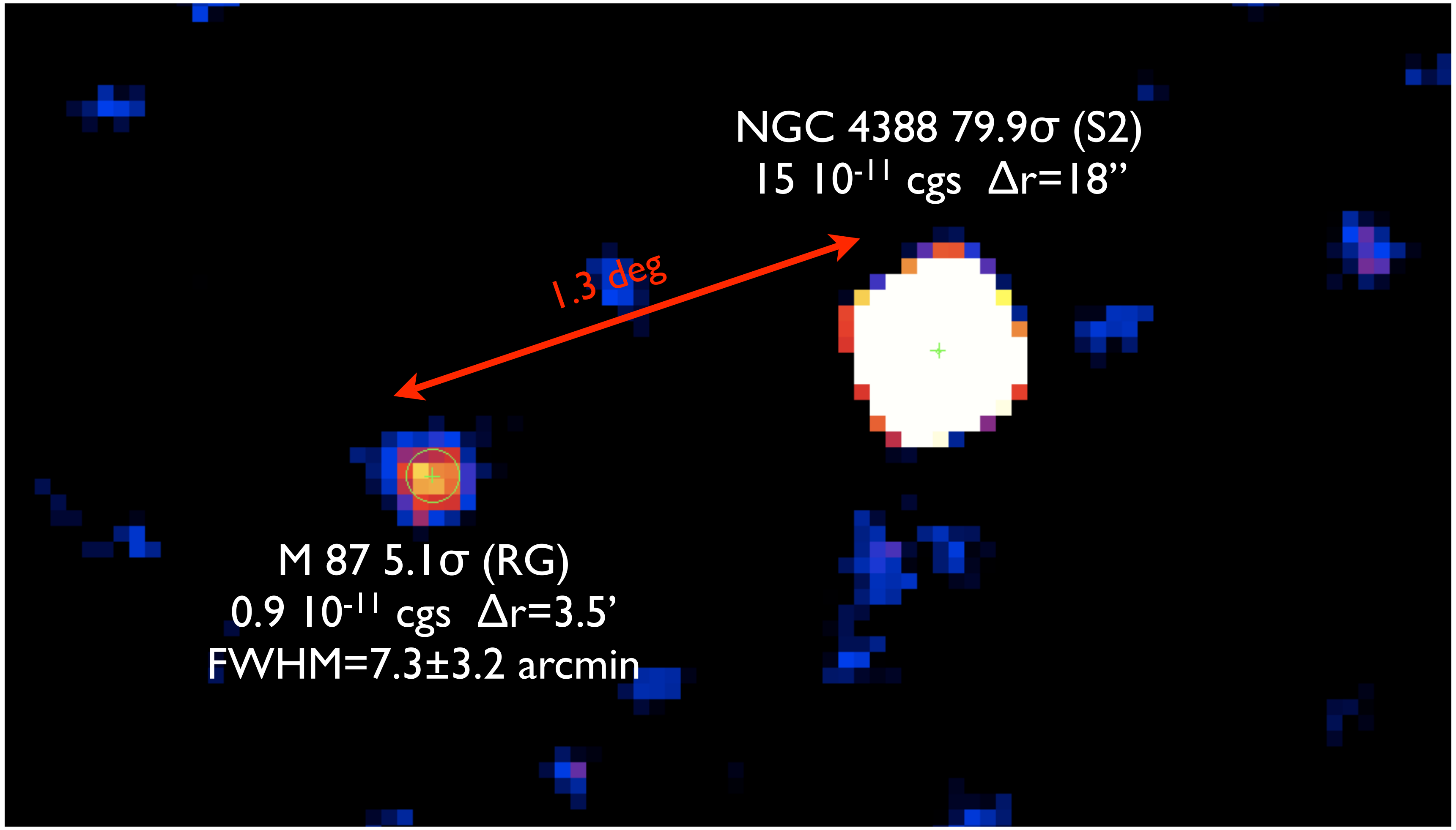
- For many years the hard X-ray emission of M87 appeared displaced by about 1°
- The University of Birmingham coded mask instrument (spacelab 2) provided the first high resolution image and an upper limit of F(20-60) < 1 10^{-11} erg/s/cm^2 (Hanson et al, 1990)
- Ginga scanning data provided a detection with a flux of F(20-60) ~ 4 10^{-11} erg/s/cm^2 (Takano & Koyama, 1991)
- RXTE did not detect any non thermal component with F(20-60) < 3 10^{-12} erg/s/cm^2 (Reynolds et al, 1999)

<u>The INTEGRAL/ISGRI view:</u>

300 ksec eff. exposure
(1 Ms next year)

Consistent with a point source
(psf 6 arcmin)

Position marginally (90%)
consistent with M87.

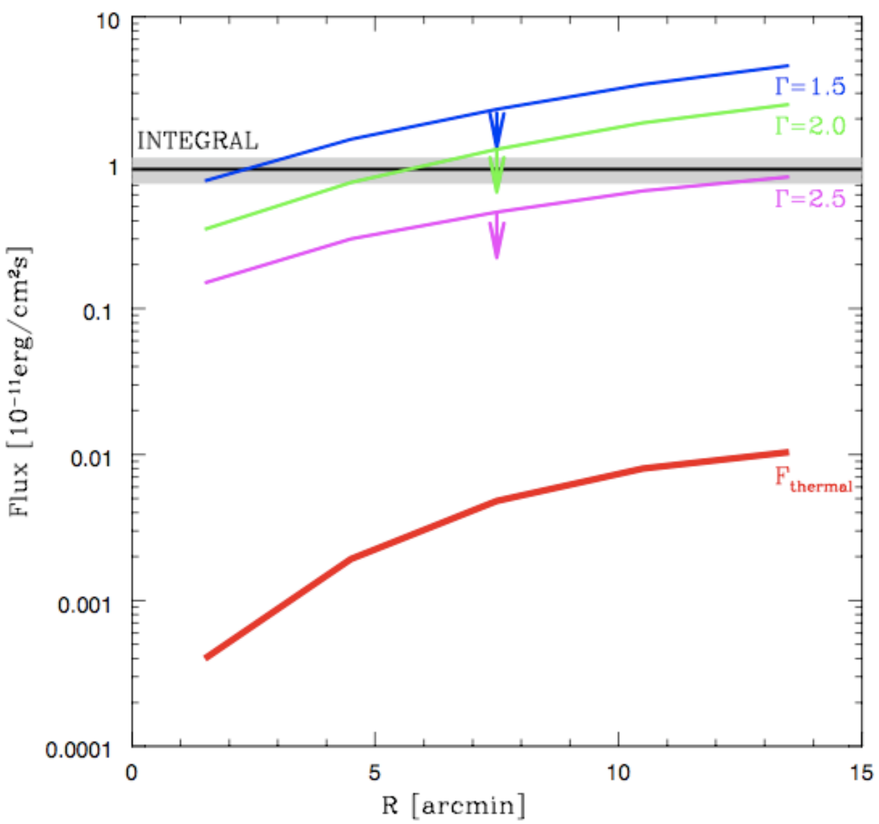


What is it ?

1. Thermal emission from Virgo

- extract XMM spectra from concentric rings
- fit with a thermal spectrum (vmekal, 2T in the inner 6')
- extrapolate between 20-60 keV

→ thermal component is at most few % of the ISGRI detection

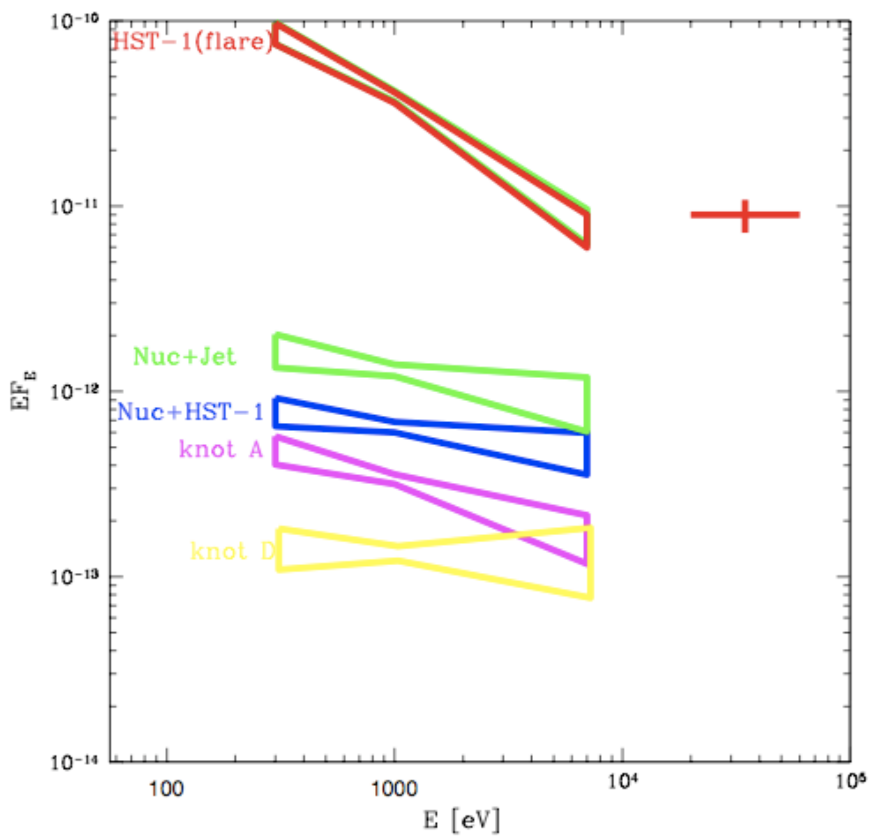


2. Nucleus and kpc jet

Nucleus: F(1-10 keV)~8 10^{-13} erg/s/cm^2; Γ = 2.23
extrapolates to F(20-60 keV)~ (4–6) 10^{-13} erg/s/cm^2

→ nucleus is at most 5 % of ISGRI detection

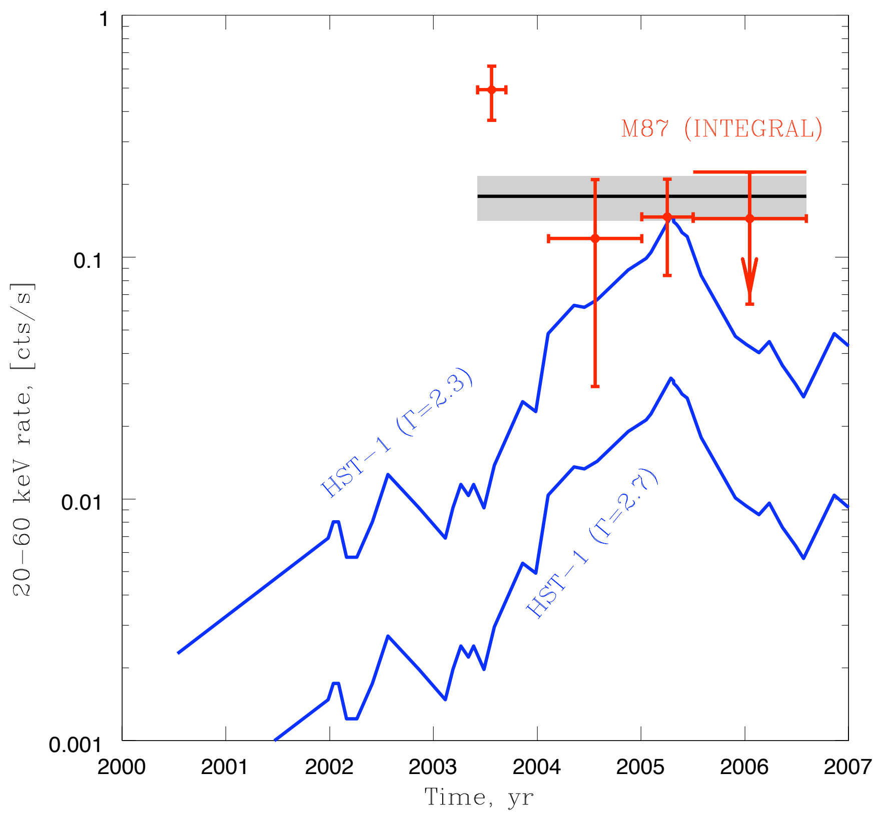
similar argument on the jet knots (excepting HST-1 flare)



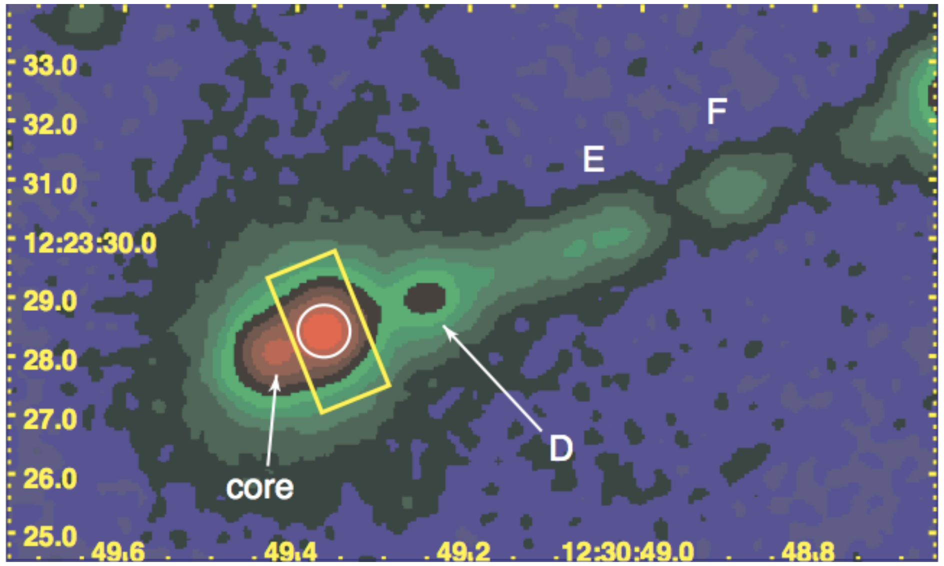
What is it ?

3. HST-1

Since 2001 HST-1 features a huge flare monitored by Chandra
F(0.2-6keV) increasing from 8 10^{-13} to 4 10^{-11} erg/s/cm^2
Spectral shape unclear because of pile-up
Γ_X = 2.4-2.6 has been derived ?
Continuous Clocking mode observation ➙ Γ_X = 2.7



➙ for Γ_X = 2.7 the fluxes do not match
for Γ_X < 2.3 the fluxes could match, however
the expected variability was not observed



Harris et al (2006)

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What is it ?

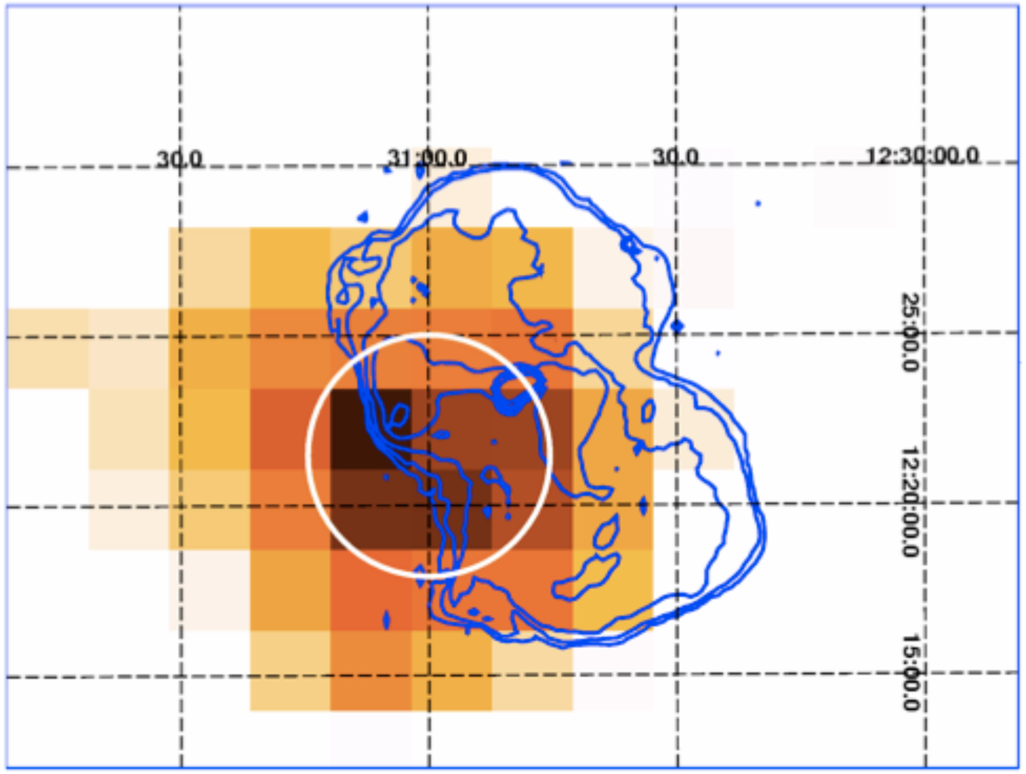
4. Radio halo

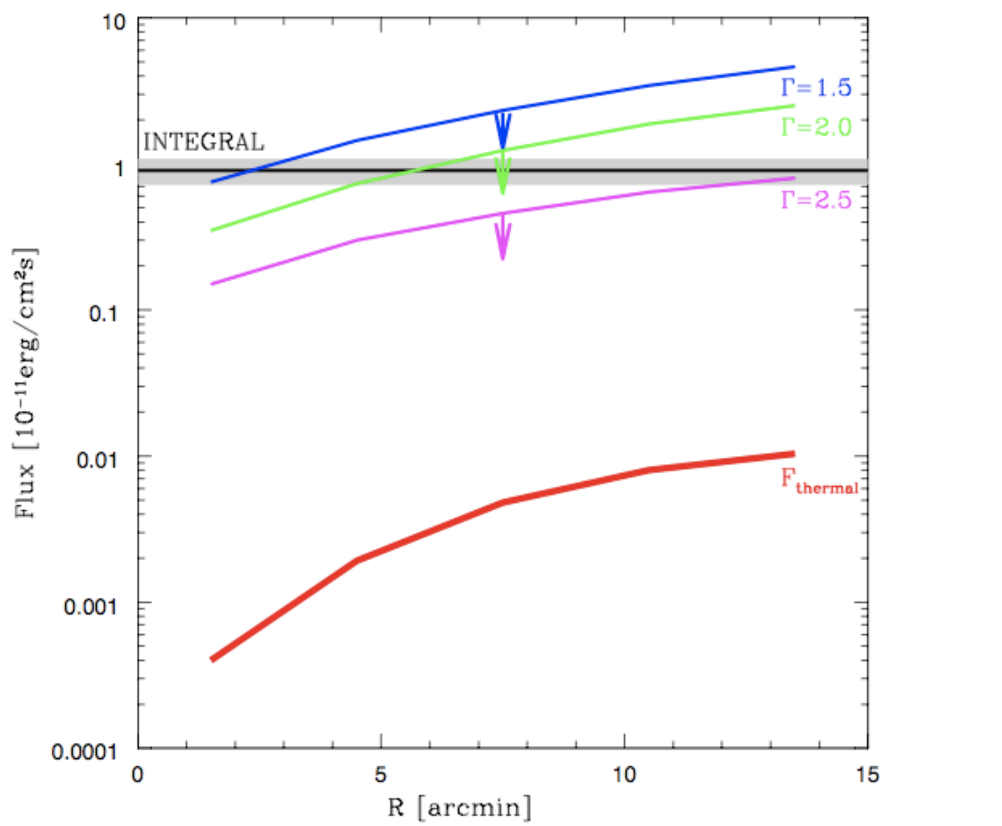
The angular size of the non thermal radio halo (10 armin) is similar to the ISGRI psf

- add a hard X-ray powerlaw to the thermal component
- fit to the integrated XMM spectra extracted from rings
- extrapolate in 20-60 keV band

it works as long as $\Gamma < 2.5$:
 $\Gamma = 1.5$ → inner 3 arcmin
 $\Gamma = 2.0$ → inner 5 arcmin ~ size of radio halo
 $\Gamma = 2.5$ → inner 13 arcmin

→ Could hard X-rays be IC emission ?
→ Do we have a problem with the apparent offset ?





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Physics of the radio halo

Radio emission implies high energy electrons.

The likely seed photons for the IC emission is the IR stellar light:

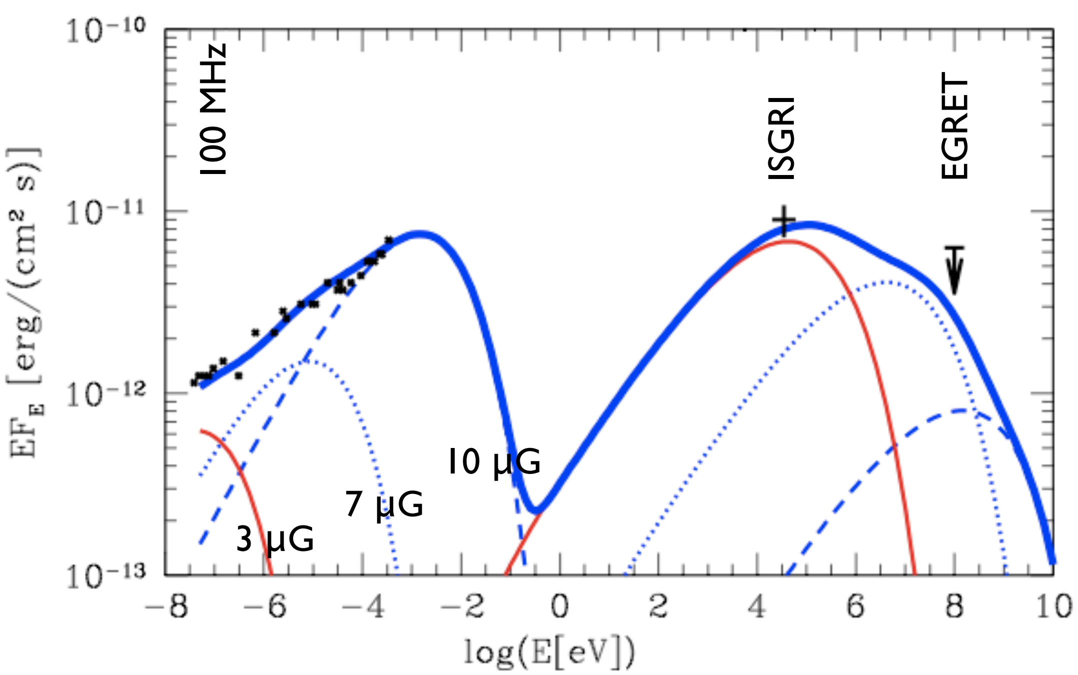
$$U_{\rm bulge} = \frac{L_{\rm bulge}}{4\pi R_{\rm bulge}^2} = 10 \left[\frac{R_{\rm bulge}}{10\ {\rm kpc}}\right]^{-1} {\rm eV/cm^3}$$ (U_{CMB}=0.25 eV/cm^3)

The energy of the electrons IC scattering IR in 20-60 keV band is

$$E_{e,\ \rm IC} \simeq 300 \left[\frac{0.1\ {\rm eV}}{\epsilon_0}\right]^{1/2} \left[\frac{\epsilon}{20\,{\rm keV}}\right]^{1/2} {\rm MeV}$$

These emit synchrotron at $\epsilon_{\rm synch} \simeq 100 \left[\frac{E_{e,\rm IC}}{300{\rm MeV}}\right]^2 \left[\frac{B}{10\ \mu{\rm G}}\right]$ MHz

an we have $\frac{L_{\rm IC}}{L_{\rm S}} = \frac{8\pi U_{\rm rad}}{B^2} \simeq 4 \left[\frac{U_{\rm rad}}{10\ {\rm eV/cm^3}}\right] \left[\frac{B}{10\mu{\rm G}}\right]^{-2}$



The integrated radio flux at 100MHz is ~10^{-12} erg/s/cm^2

→ B ~ 5 μG consistent with other estimates & equipartition.

→ observed hard X-rays at a level which could be expected.

L_X+L_{rad} ~ 10^{42} erg/s ~ 1% mechanical energy

Offset ?

1. First the offset may not be real. We need (and will soon get) more INTEGRAL data.

2. Bulk of emission on the left of the radio halo

3. M87 oscillations:

From XMM pressure/entropy/abundance maps Simionescu et al (2006) have proposed that M87 oscillates at the center of the Virgo cluster.
A similar behavior was proposed by Churazov (2003) for Perseus (see also simulations by Ascasibar & Markevitch 2006).

Dynamical time scale: $D/v_{virial} \sim (20\ \mathrm{kpc})/(500\ \mathrm{km/s}) \sim 0.05\ \mathrm{Gyr}$

IC cooling time scale: $$t_{\rm IC} \simeq 0.1 \left[\frac{U_{\rm rad}}{10\ {\rm eV/cm^3}}\right]^{-1} \left[\frac{E_e}{300\ {\rm MeV}}\right]^{-1}\ {\rm Gyr}$$

The electrons cool slowly, when compared to the path of M87

→ the IC emission may reveal the "foot-print" of M87