INTEGRAL

Science Highlights

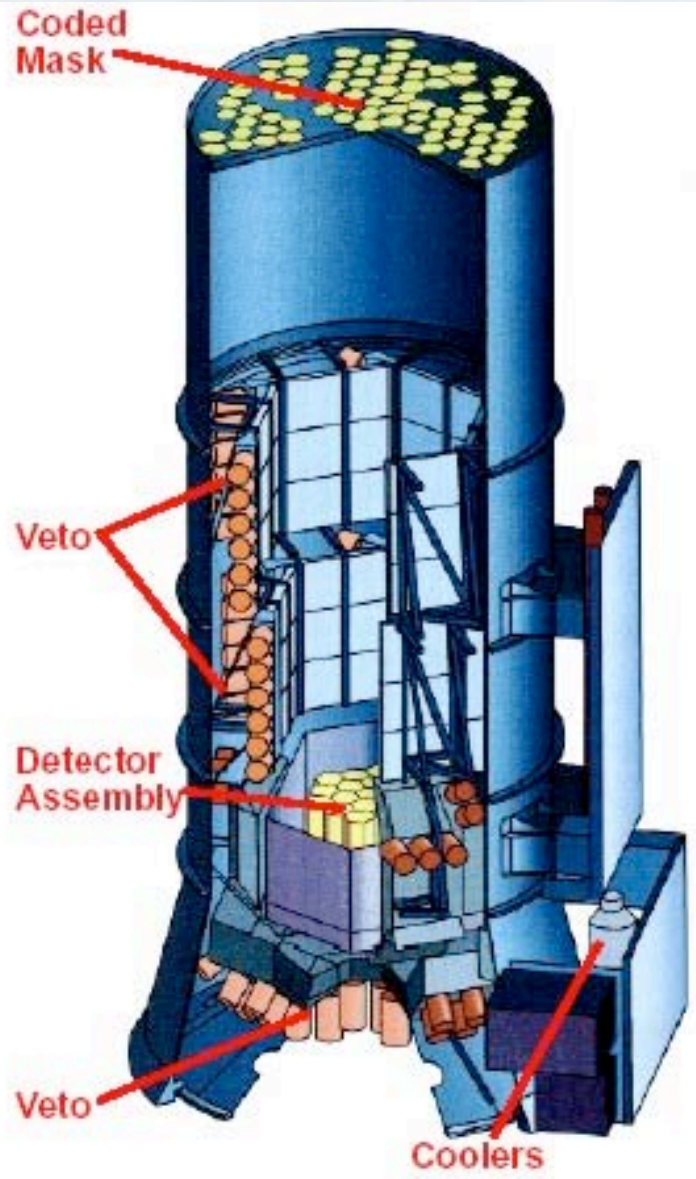
Mission Status

- Spacecraft
  - 3.5 years in orbit
  - Nominal operation
  - > 10 yr of on-board fuel remaining
- Instruments
  - Small degradation of SPI and JEM-X early in mission
  - Stable operation since mid-2004
- Mission Extension
  - Approved by ESA through 2008 with recommendation to continue to 2010.
  - NASA participation beyond FY06 tbd (MO&DA Senior Review)
- Ongoing International GO program
  - NASA supported US participation
  - Administered by NASA INTEGRAL GOF

Observing Program, Data Rights

- *Currently in mission cycle 3*
- *25% of data reserved for Core Program*
  - *Deep Galactic central region exposure*
  - *Norma, Scutum, Sagatarius, spiral arms*
  - *Galactic plane scan*
  - *20% for cycle 4 and beyond, but will institute key projects*
- *All data are proprietary for 1 year*
  - *Lots of discussion about waiving this for cycle 4+ CP, but no policy change as yet*
  - *NASA mirrors public data archive*

Primary Instruments



SPECTROMETER (SPI)

20 keV - 8 MeV

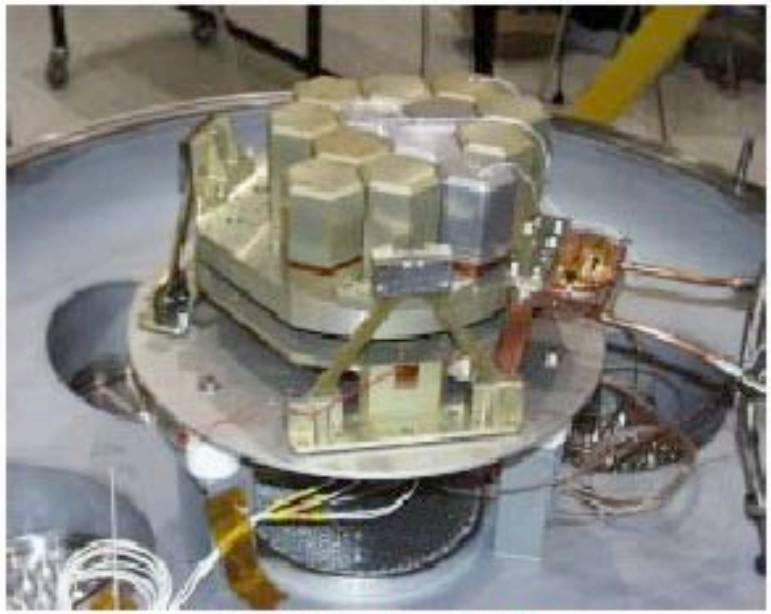
19 Ge detectors (energy resolution: 2 keV @ 1 MeV)

17 16 deg fully coded FOV

Line sensitivity 2×10^{-5} ph cm^{-2} s^{-1} @ 1 MeV, 10^6 s

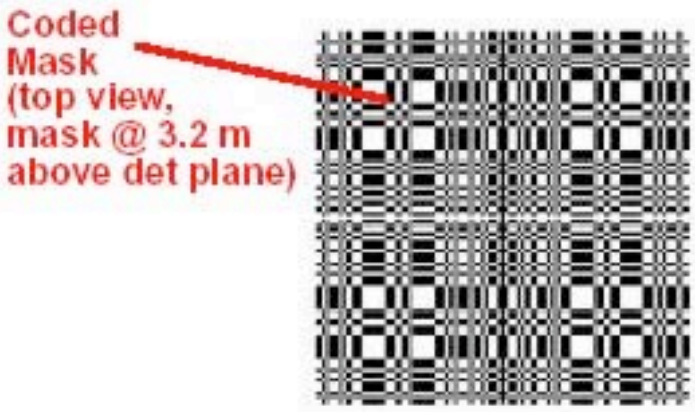
1300 kg, 370 W, 30 kbs

PI institutes: CESR Toulouse (F), MPE Garching (D)



Detector plane (EM)

Primary Instruments



IMAGER (IBIS)

15 keV - 10 MeV

16384 CdTe dets & 4096 CsI dets

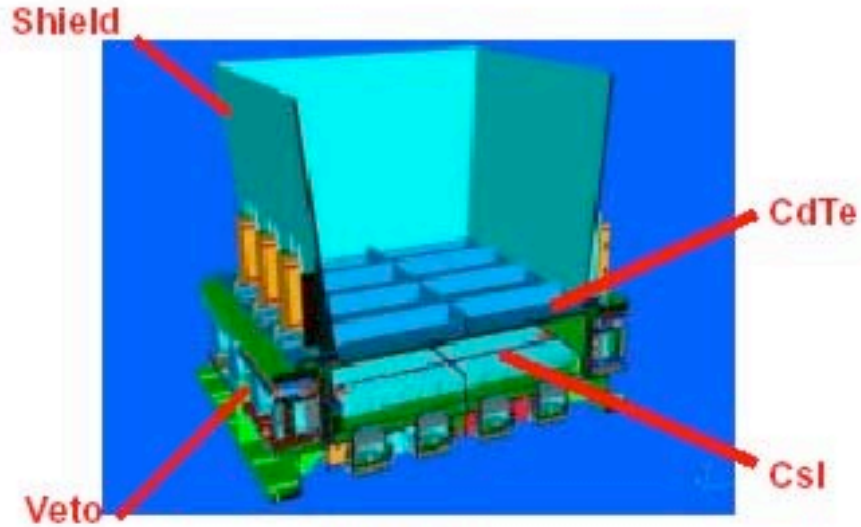
9 x 9 deg fully coded FOV, angular res.: 12 arcmin

Cont sensitivity: ~1 mCrab, 100 ks, 20-100 keV

630 kg, 275 W, 57 kbps

PI institutes: IAS Rome (I), CEA-Saclay (F), ITESRE Bologna (I)

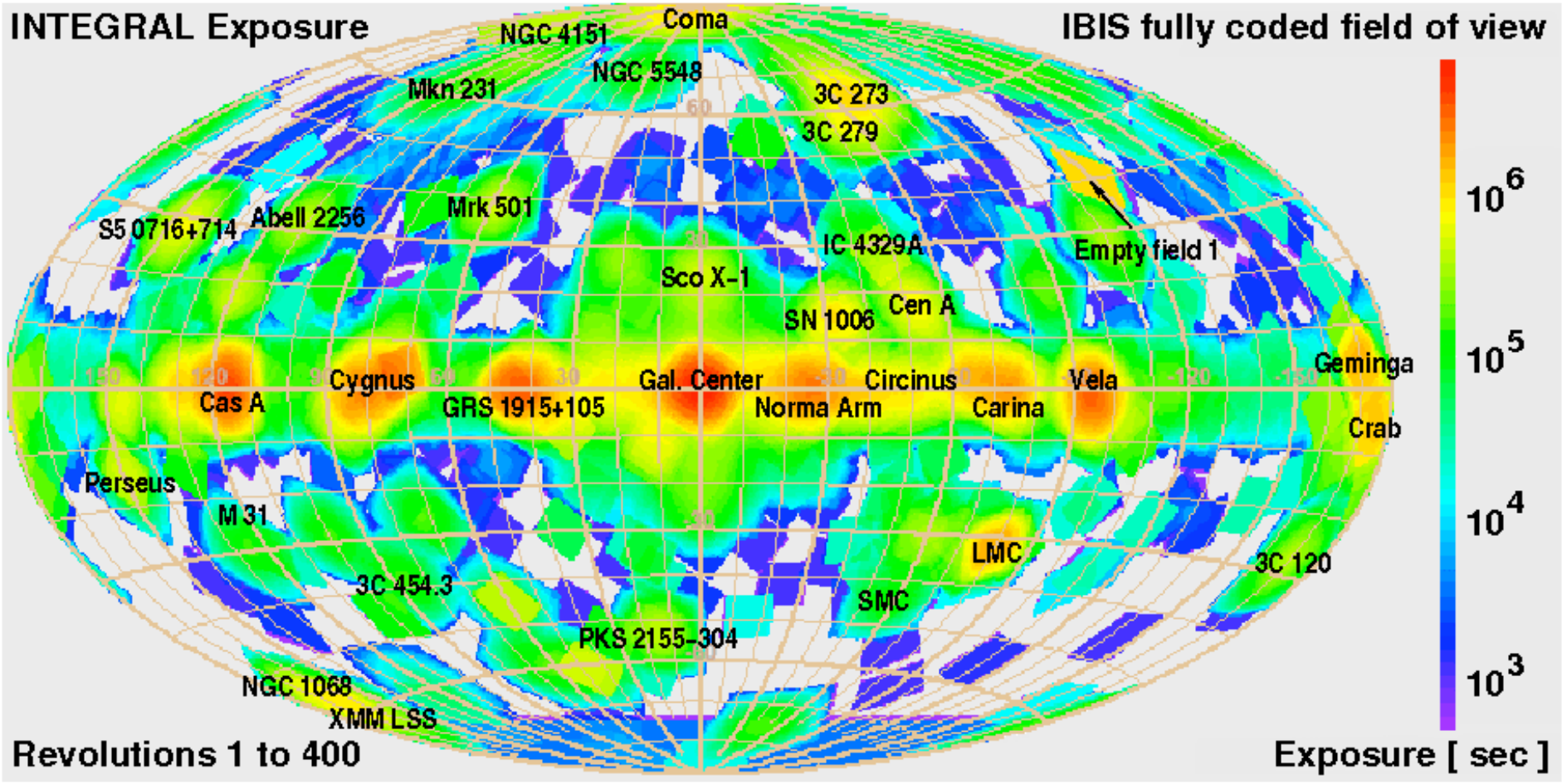
Systematics: achieves statistical limit for ~100 ks



Detector Assembly

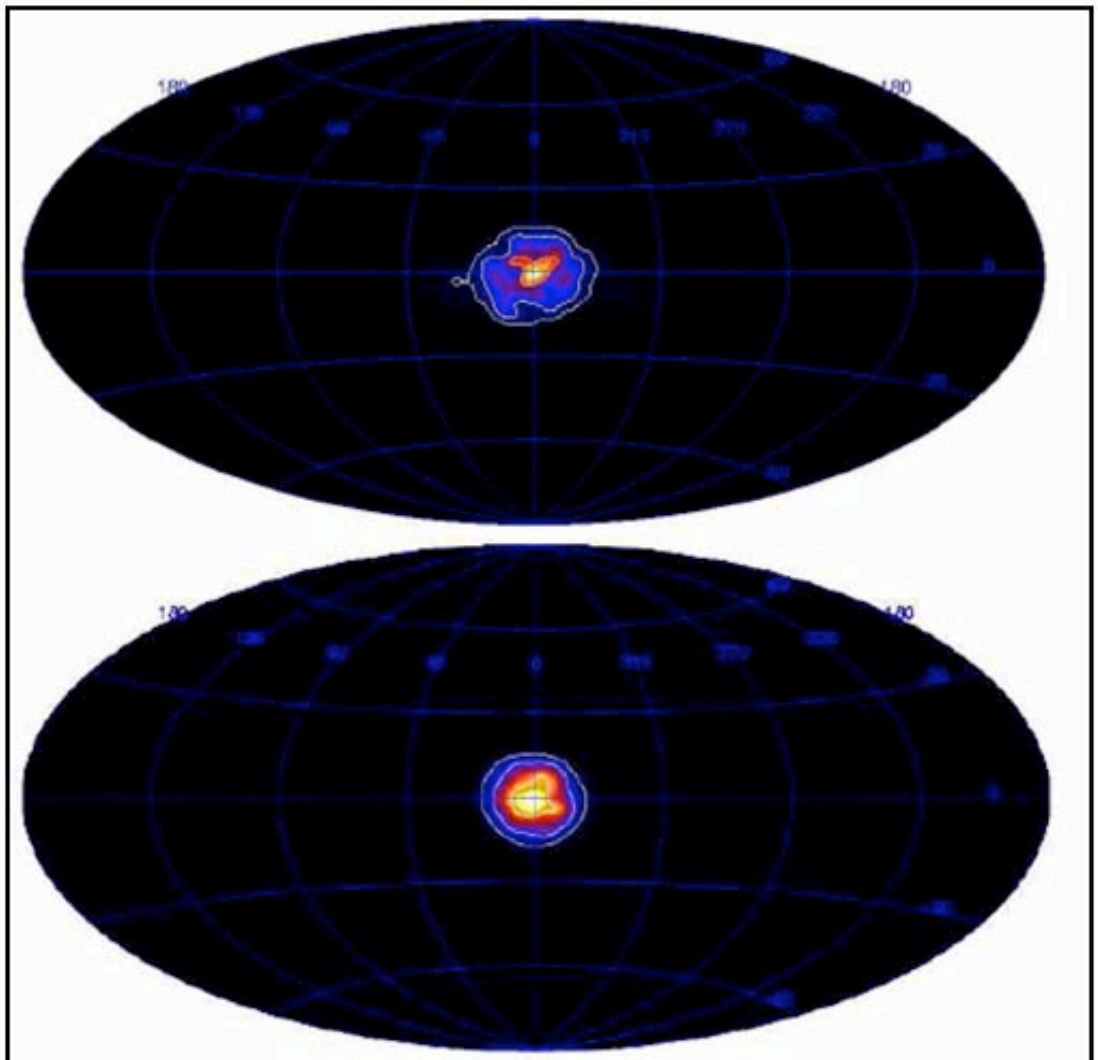
Detector assembly (STM)

Sky Coverage



- *Emphasis on Galactic plane, particularly inner ±40°*

e^+e^- Annihilation Radiation

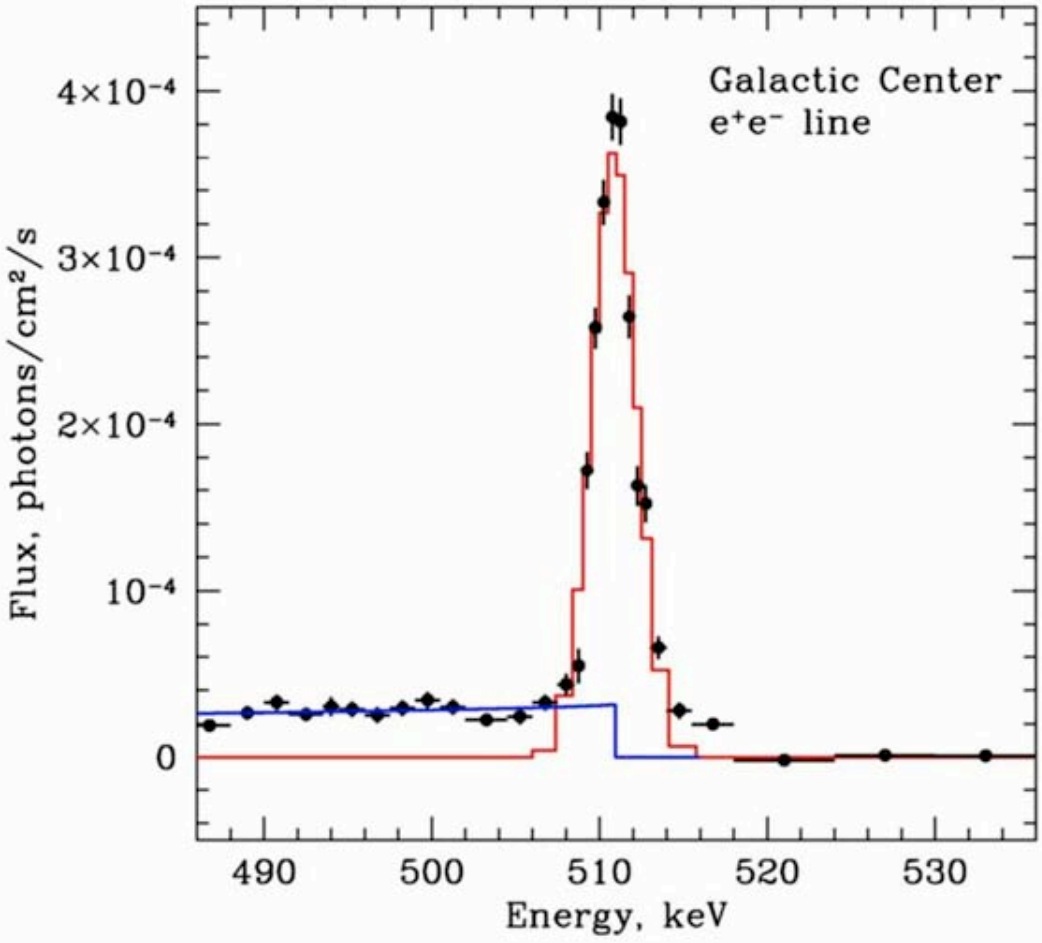


Best fit spatial distribution map of 511 keV line emission (top) and Ps continuum emission. In both cases the emission traces the bulge, with a surprisingly small disk contribution.

- *511 keV line and Ps continuum trace the Bulge, FWHM ~8°*
  - *Hard to reconcile w/known populations?*
  - *No evidence for 511-kev point sources (e.g. Bulge XRBs)*
  - *SN Ia ? (why no disk component)?*
  - *Dark matter?*
- *Surprisingly, small disk component (B:D ~6±3)*
- *No evidence for asymmetry*
- *~10^{-3} cm^{-2}·s^{-1}, =10^{43} annihilations per sec*

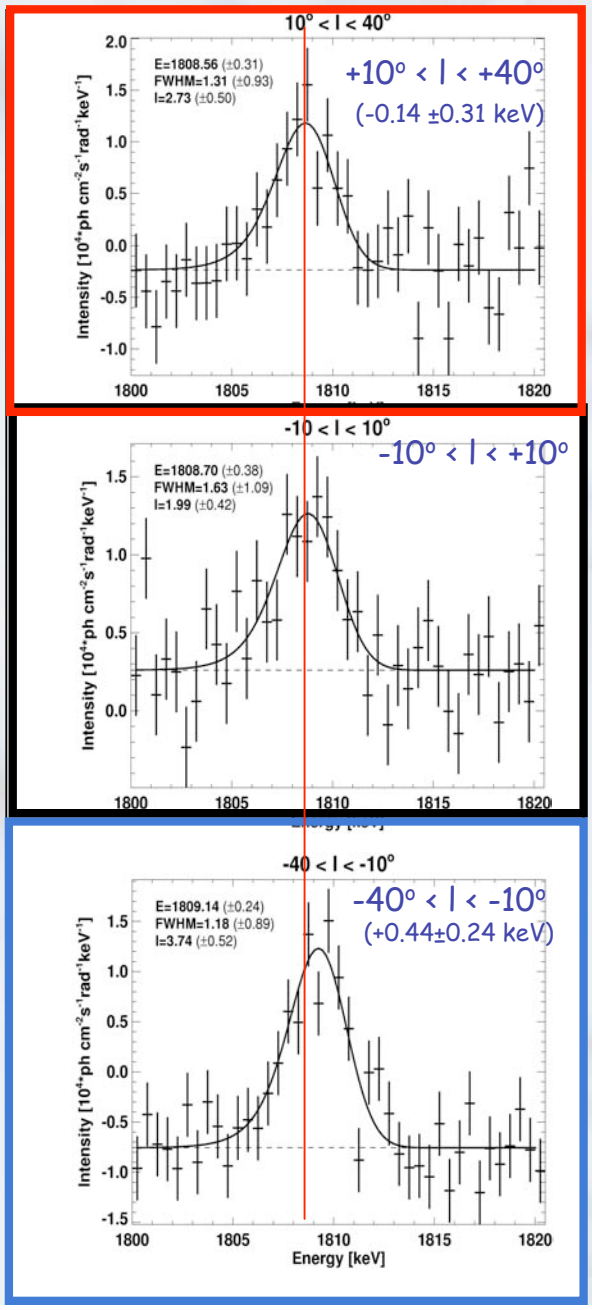
e^+e^- Annihilation Radiation

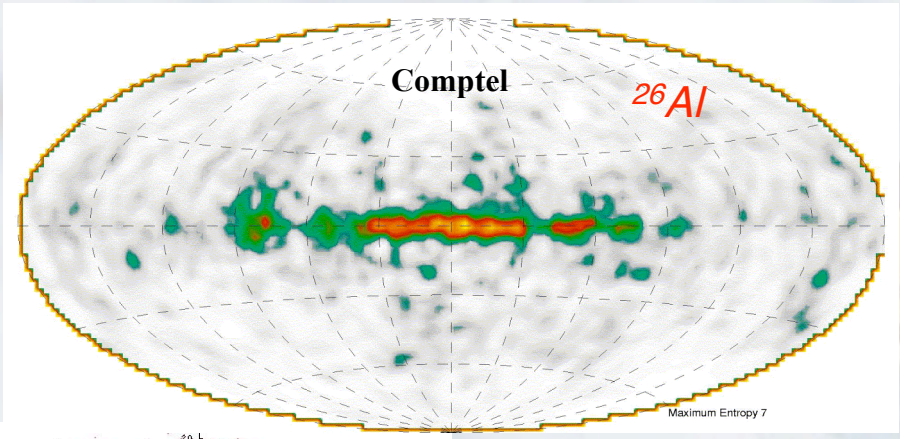
- *Narrow line profile*
  - *Constrains explosive origin scenarios*
  - *Ambient ISM*
  - *Suggests T~8000K, n~0.3 cm^{-3}*
- *Ps fraction ~0.9*
- *No redshift or doppler*
  - *Recall that Nova Mus 91 line was at ~480 keV*
- *Constant intensity*

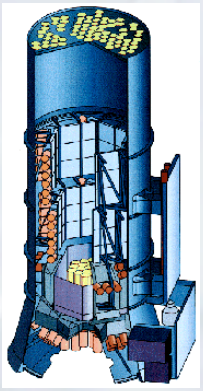


Galactic 511 keV annihilation line profile. The positronium continuum is evident as excess red-wing continuum (blue model curve). The narrow line width constrain models involving explosive injection of positrons into the ISM. The total line flux is about 10^{-3} ph/cm^2/s, and the width is about 3 keV (FWHM).

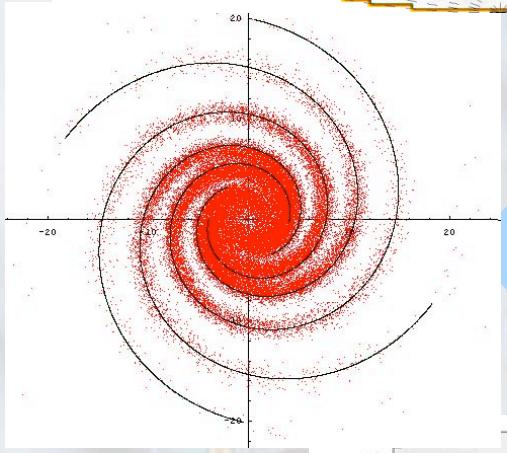
Galactic Nucleosyntheis





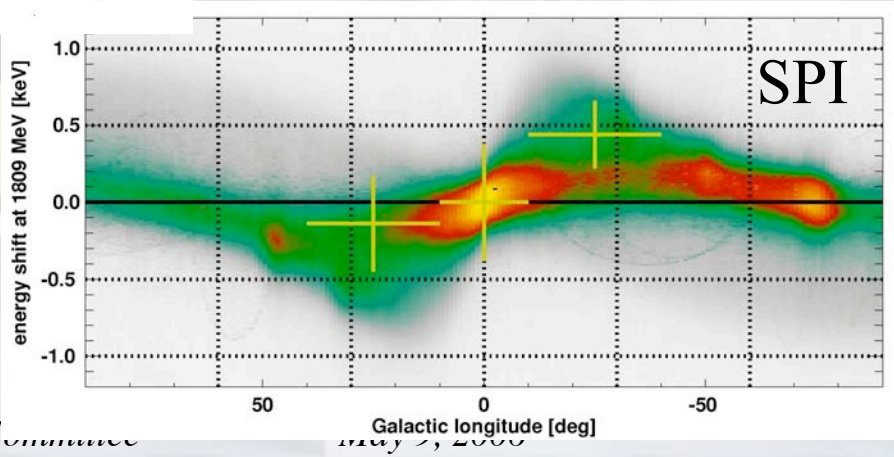


Diehl et al. 2006, Nature, 439, 45



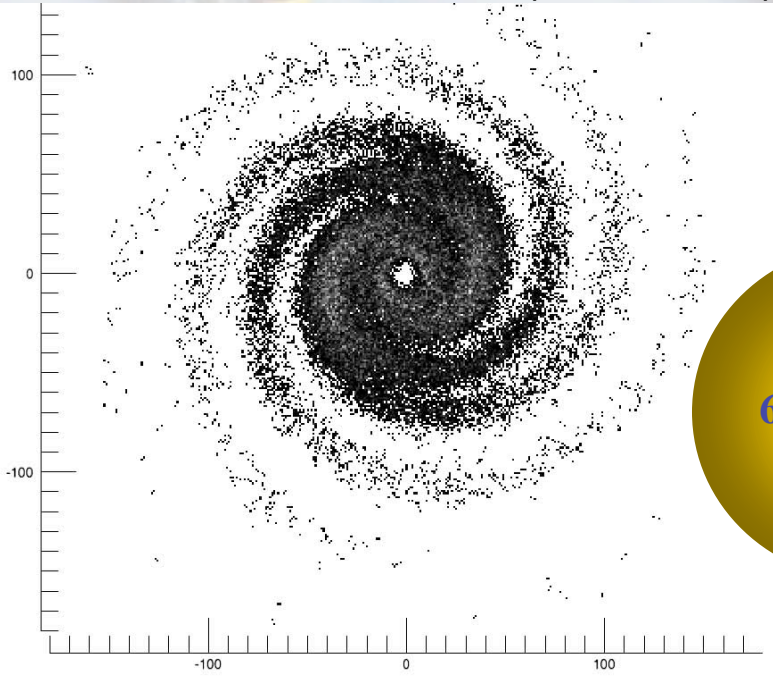
SNR: 1.9 ± 1.1 ctry^{-1}

SFR = 2.8 ± 0.8 M_o yr^{-1}

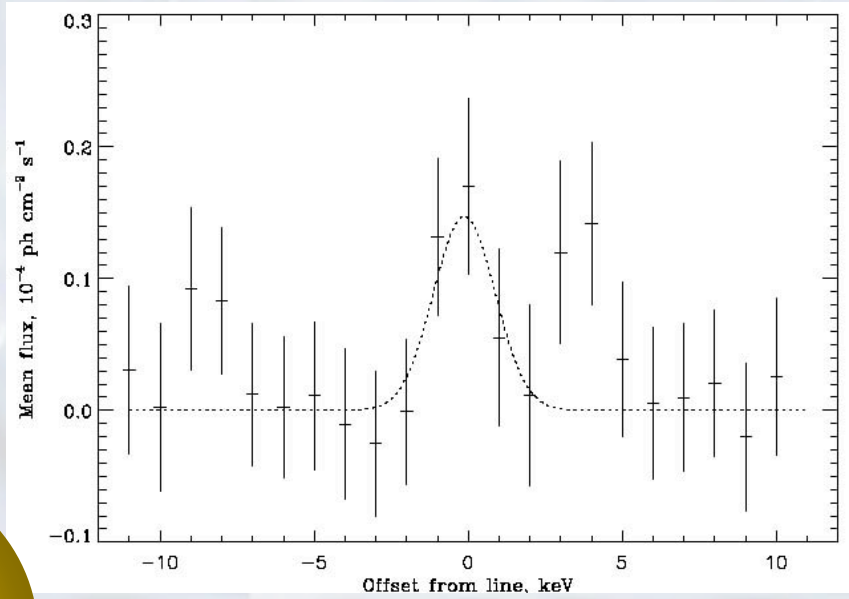


Galactic Nucleosyntheis

26Al: SNII, novae, AGB
60Fe: SNII
Ratio observed (1/9); may need additional W26Al source (WR stars?)

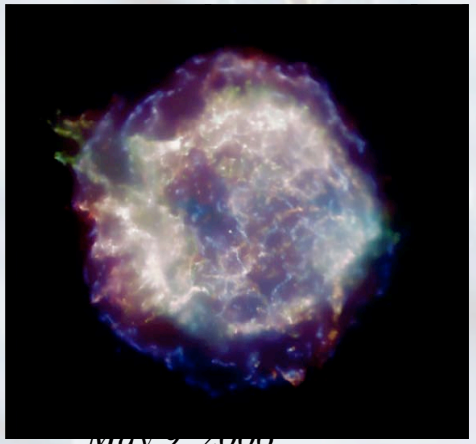


$^{60}F/^{26}Al$



SPI(1.173 MeV &1.333 MeV):
$F = 4\ 10^{-5}\ \gamma\ cm^{-2}\ s^{-1}$ per line

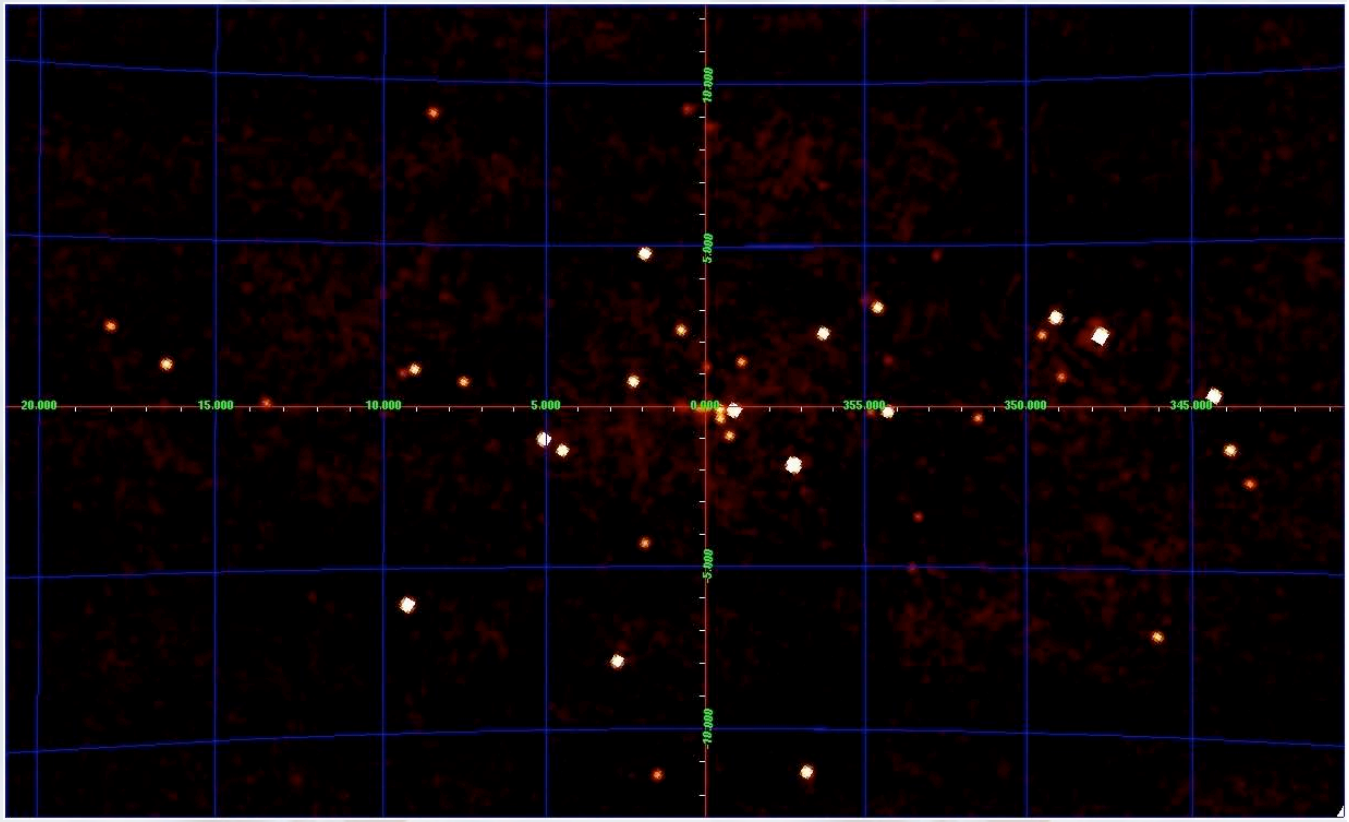
(Harris et al. 2005)



^{44}Ti: Cas A, detected at 68 & 78 keV, but not at 1.1 MeV; Given COMPTEL detection, implies V/ 10^3 km/s

Galactic Plane Monitoring: HMXBs

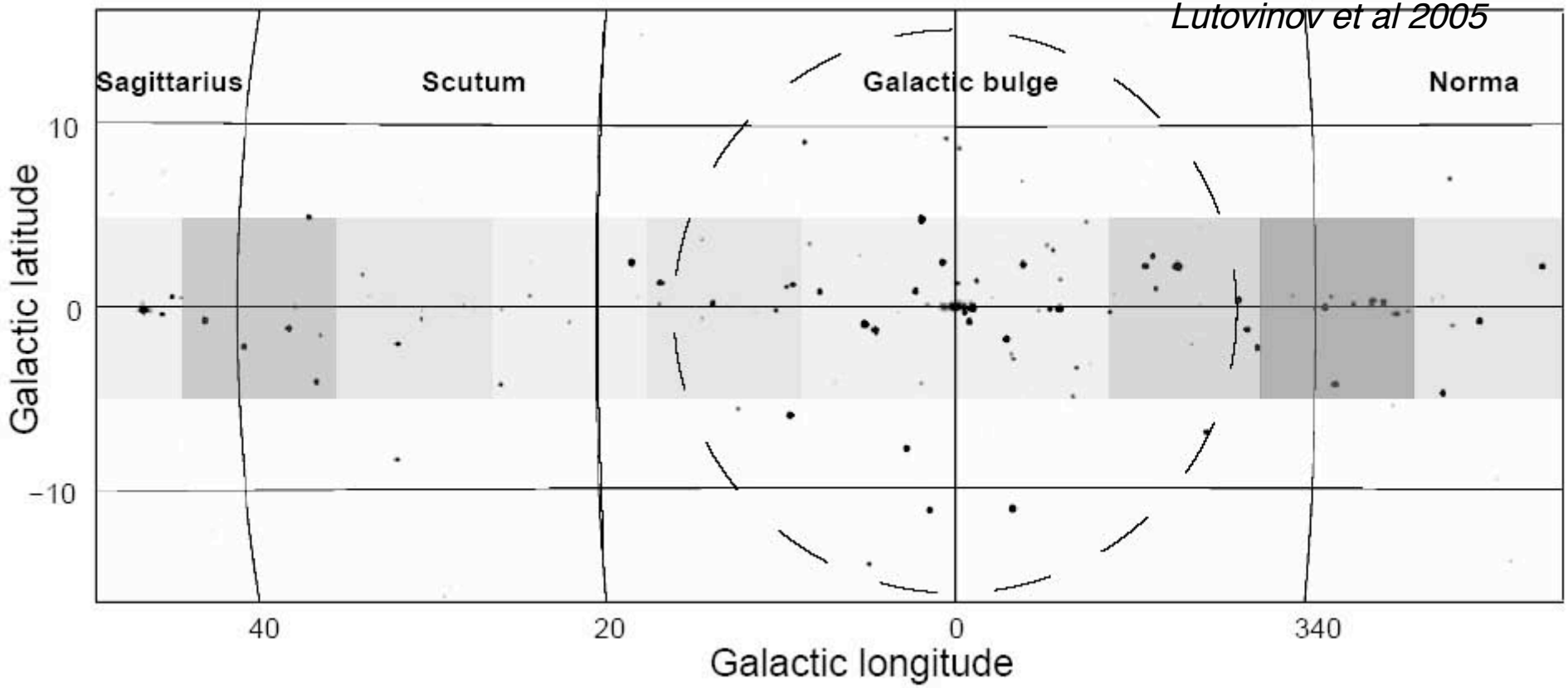
- *Bulge region monitored ~1x per orbit*
- *Deep exposure of GC region in Core Program*
  - *Eventually ~20 Msec near GC*
- *Hard X-ray selected catalog list*
  - *~200+ sources*
  - *~25% "new"*
  - */50% of these highly absorbed*
  - *Slow rotators (100-1000 sec)*



IBIS mosaic: 20-50 keV, 1 Msec, ~40°x20°

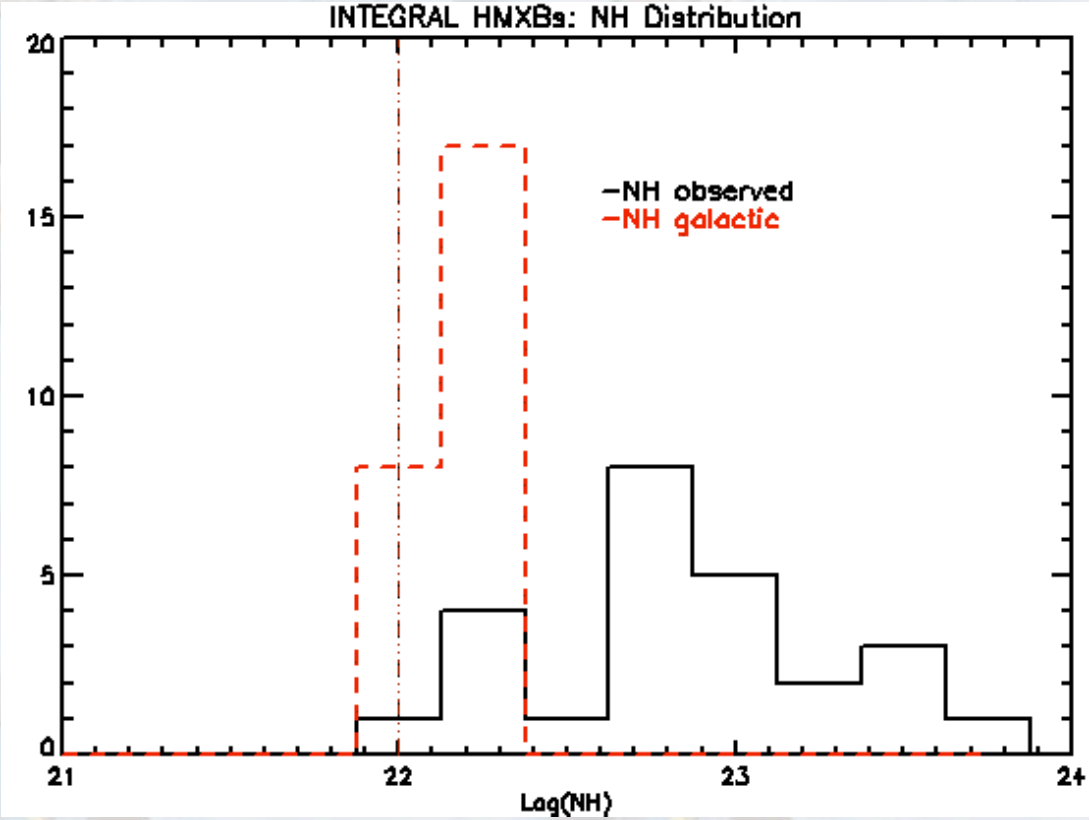
Hidden HMXB Population?

- *Map of INTEGRAL detected Galactic XRBs. Gray scale indicates nominal density of HMXB content.*
- *Highest density is centered on spiral arms, notably Scutum, Norma and Sag. Significant enhancement to overall sample in those regions.*



NH Distribution

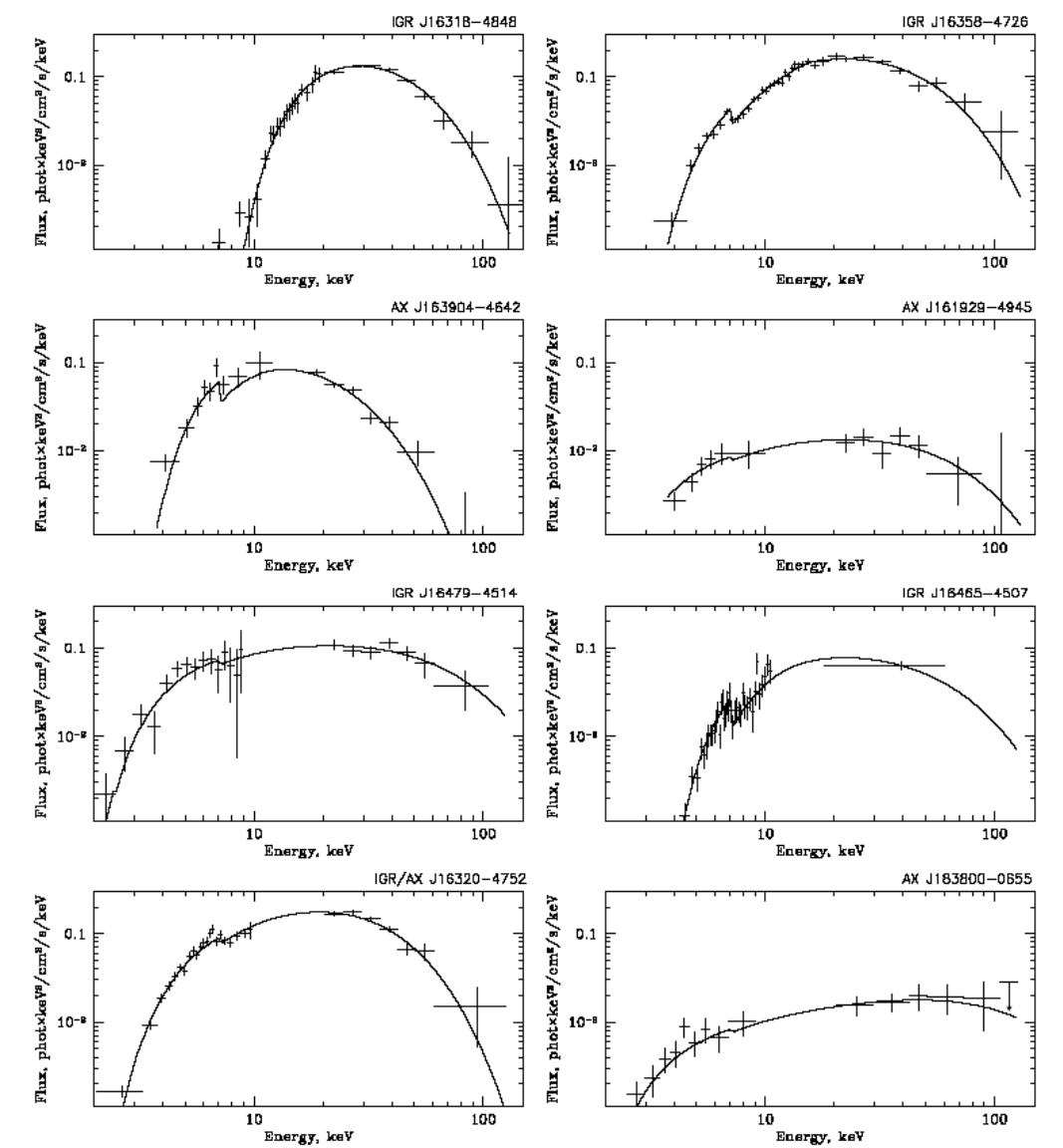
- *Derived, and "cataloged" galactic NH column density towards INTEGRAL HMXB sample*
- *In a number of cases, evidence for local absorption supports this discrepancy*
- *Tendency for high absorption is clear*



Lutovinov, et al 2004; Grebenev et al 2004; Sidoli et al 2004; + few other ATels

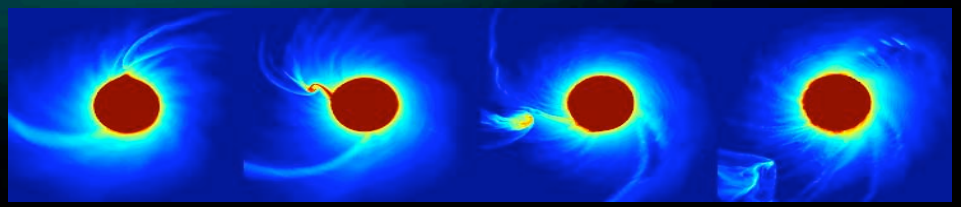
Sample Broad-Band Spectra

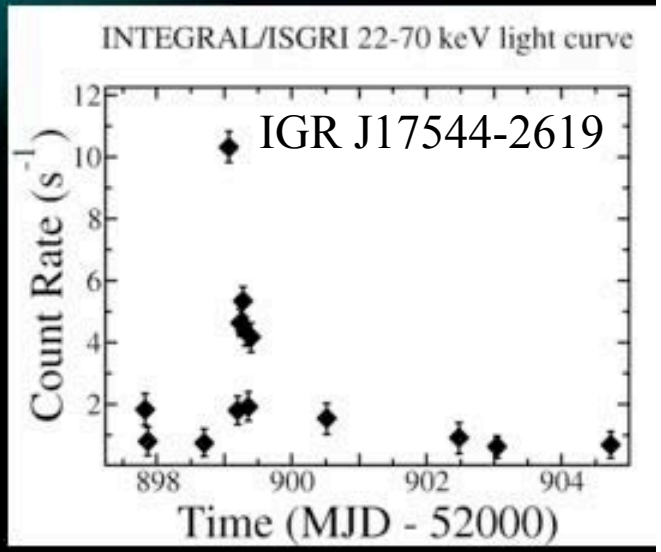
- *Sample spectra from Lutovinov et al 2005 Most objects have characteristic HMXB SED*
  - *AX J183800-0655 BH?*
- *High absorption is evident in low-energy continuum*
  - *Typically little or no flux below ~5 keV*
- *Where high-SN X-ray data is available, spectral features indicative of Compton thick media*



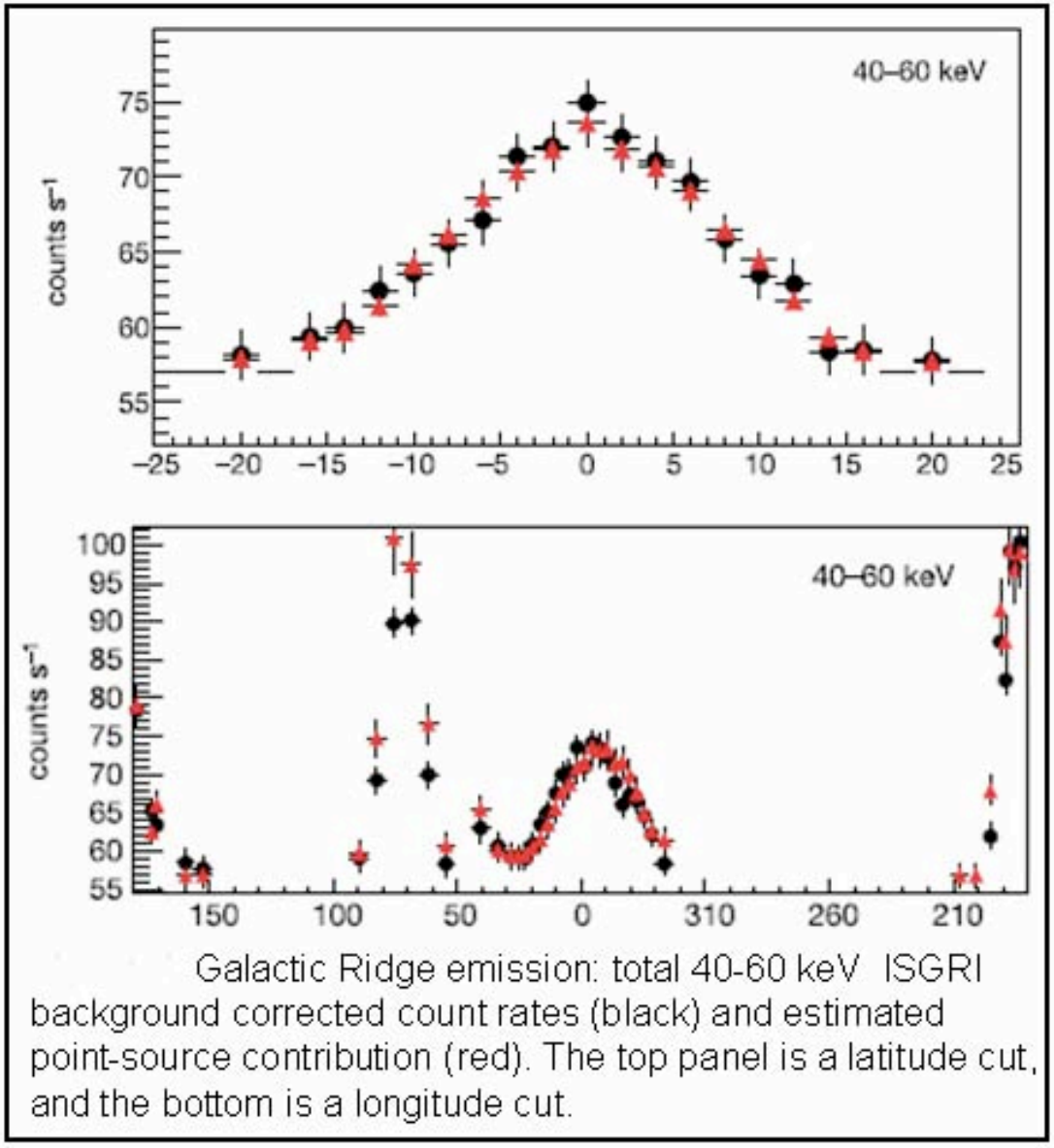
- *"Fast Transients", ~day timescale flares*
- *Hard X-ray selected*
- *~10 now known, 4 w/sg primaries*
- *~2X previously known sg XRBs*

Negueruela, Smith, et al. 2005, (astro-ph/0511088)





Galactic Ridge Emission

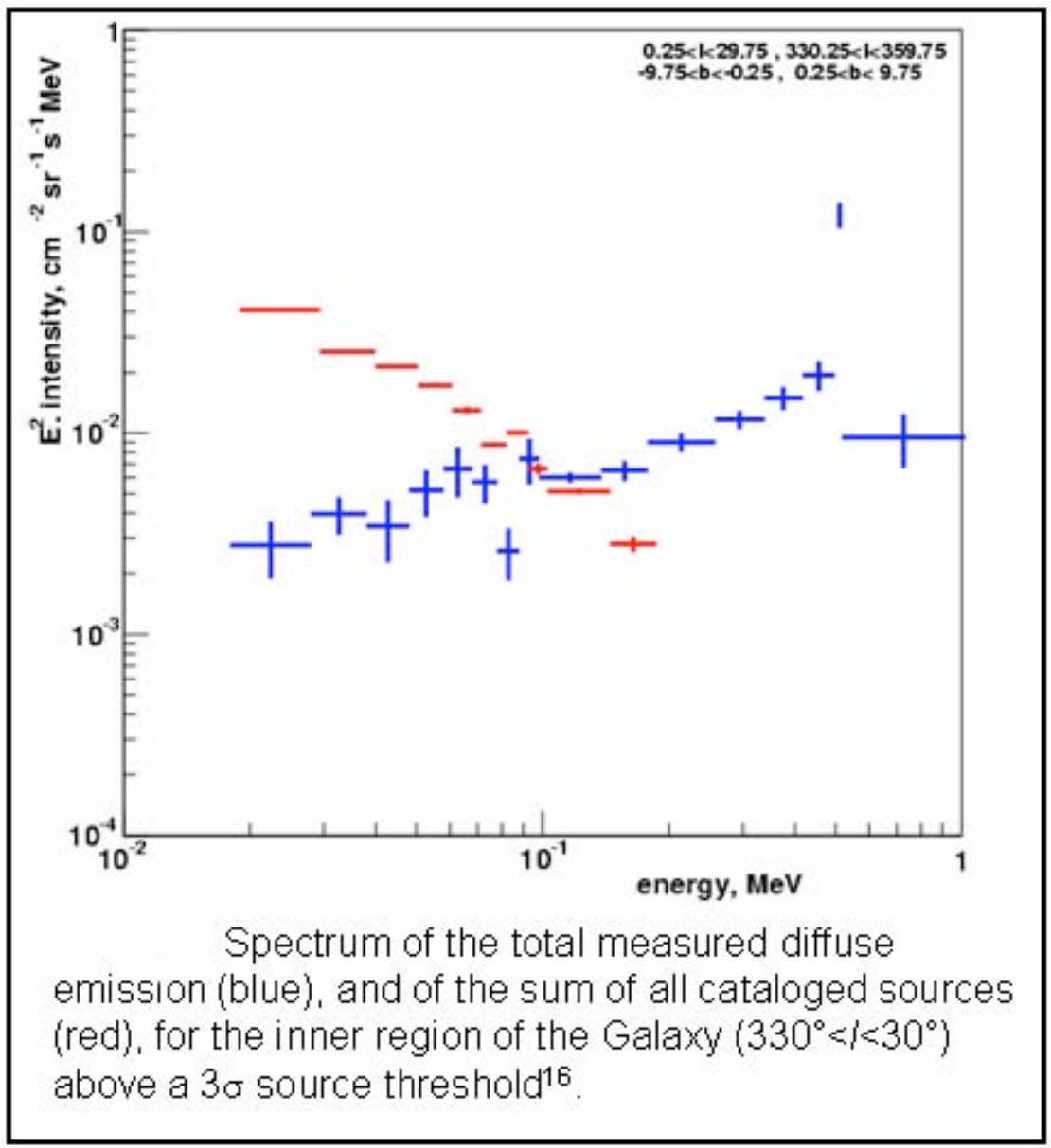


Galactic Ridge emission: total 40-60 keV ISGRI background corrected count rates (black) and estimated point-source contribution (red). The top panel is a latitude cut, and the bottom is a longitude cut.

- *Long standing problem:*
  - *true diffuse, or integrated point sources?*
- *<10 keV X-rays have dominant diffuse component (although see Revnivstev et al 2006)*
- *Diffuse scenarios are problematic:*
  - *Compton scattering?*
    - *Where is the radio emission*
  - *Bremsstrahlung in ISM?*
    - *Ionization balance?*
- *IBIS results indicate that point sources contribute ~90% of inner-Galaxy flux 20-200 keV*

Diffuse Galactic Emission

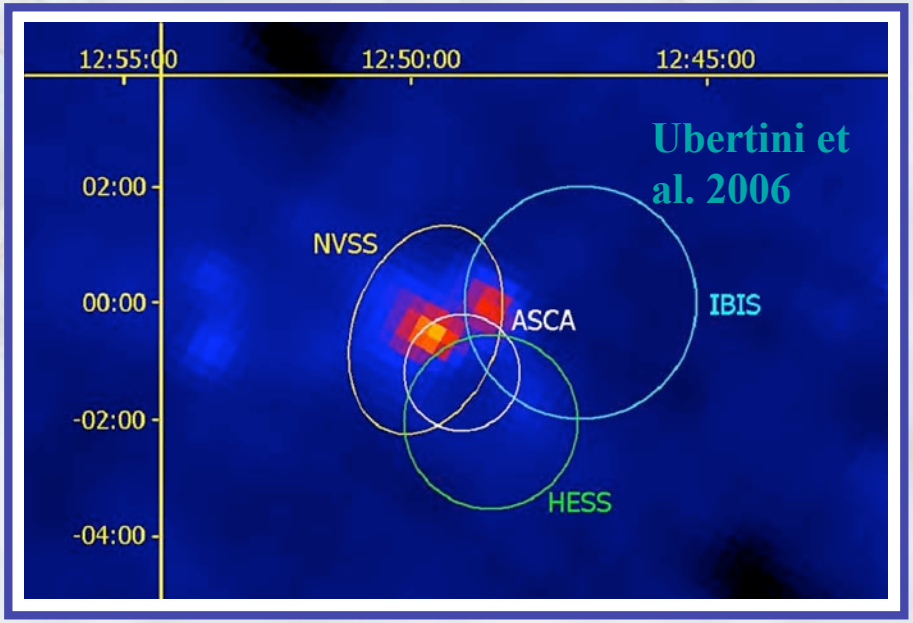
- *SPI has larger FoV, wider energy bandpass than IBIS*
- *Strong et al 2005 find:*
  - *Hard (>200 keV) excess above integrated (known) point-source flux*
  - *Ps continuum evident*
- *Speculation:*
  - *AXP populations*



Spectrum of the total measured diffuse emission (blue), and of the sum of all cataloged sources (red), for the inner region of the Galaxy (330°<*l*<30°) above a 3σ source threshold[16].

INTEGRAL – HESS Associations

- *3 INTEGRAL-HESS associations of interest*
- *PSR 1259-63,Sgr A* region, &IGR18135-1752*

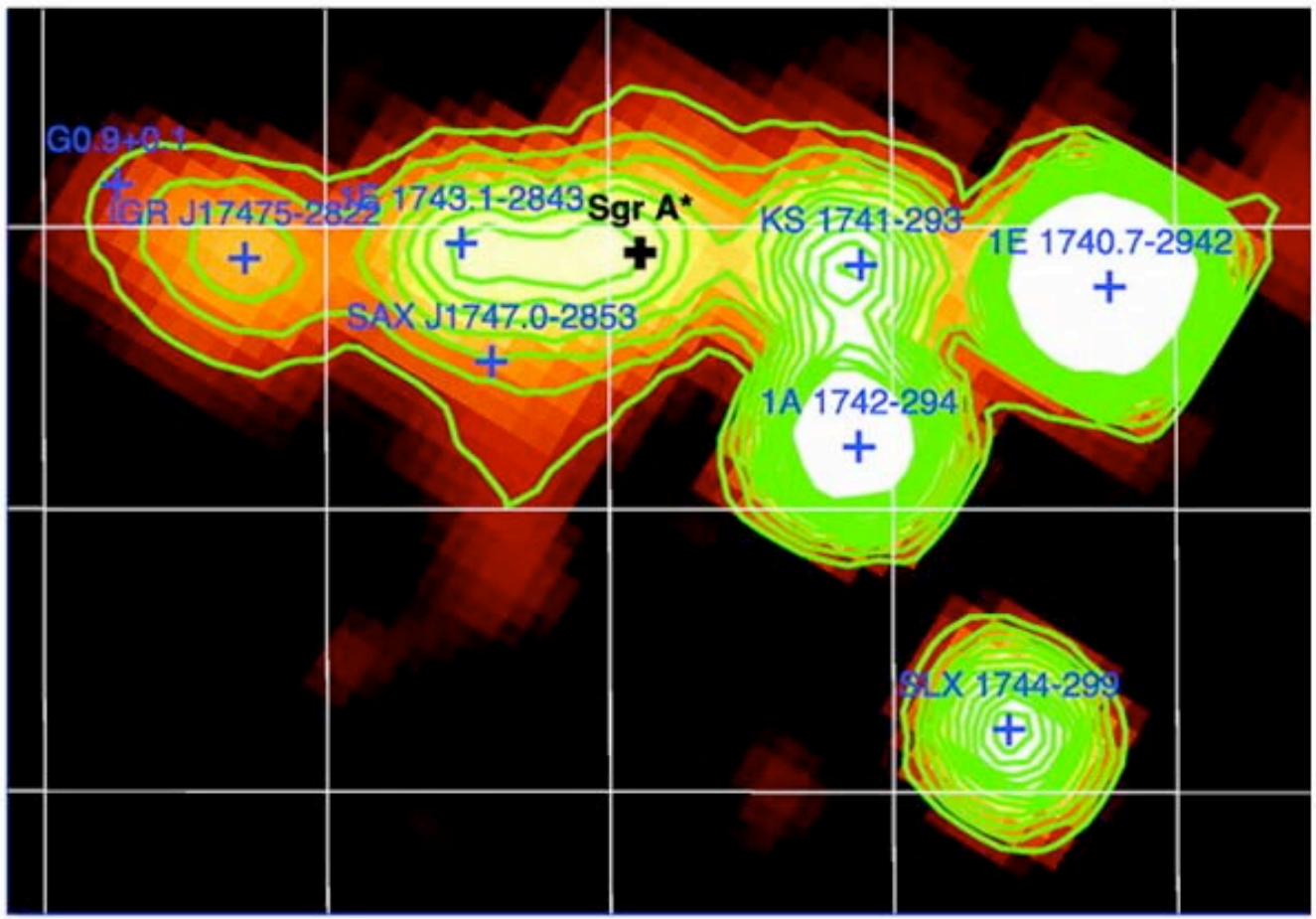


IGR J18135-1751 = HESS J1813-178

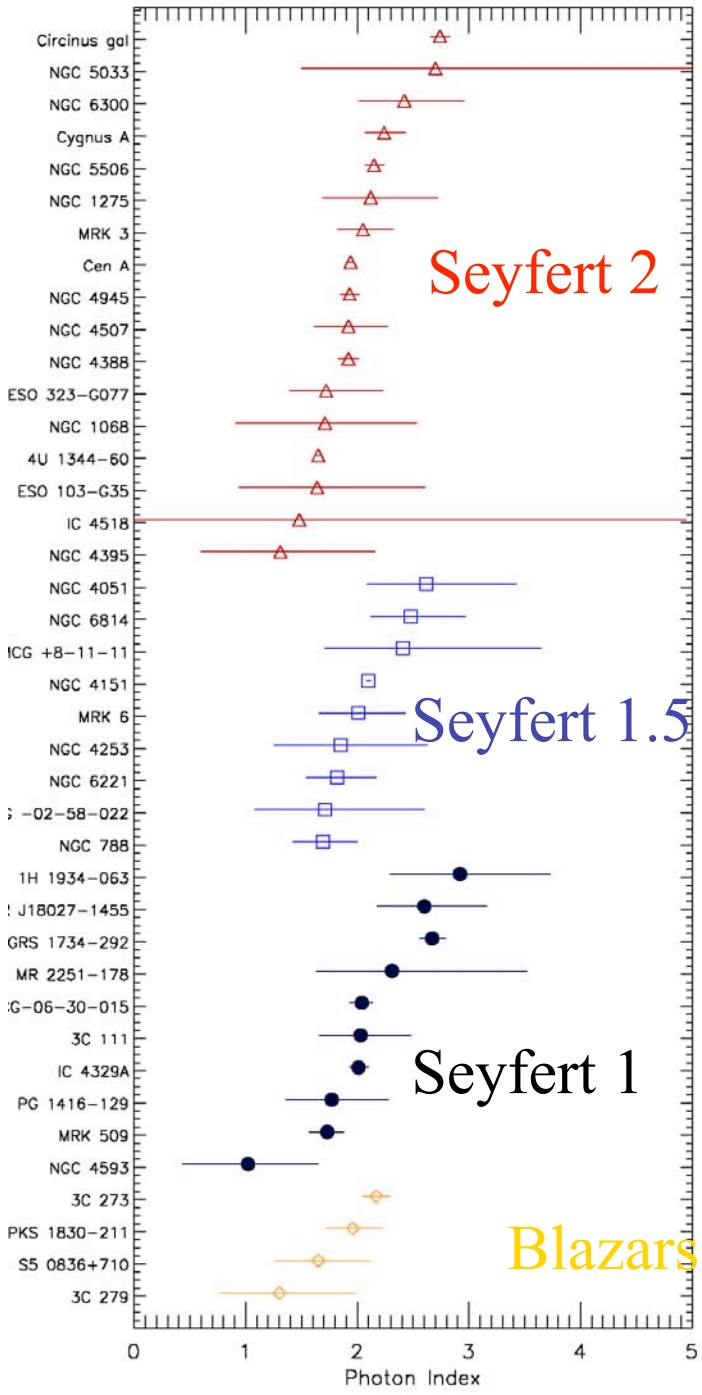
- *PSR 1259-63, (Be star – ms Pulsar Binary)*
- *Sgr A* (extended emission, particle acceleration)*
- *IGR18135-1752 (PWN?)*

Sgr A* - Hard-X-Ray Counterpart?

- *Source coincident w/Sgr A**
- *IBIS resolution ~10' inadequate for unambiguous association*
- *Early reports of contemporaneous flaring now in doubt*
- *Likely that hard-X-rays come from extended emission region ambient to Sgr A**
- *Also the TeV source?*
- *Also, Sgr B2 "Compton Mirror"*
  - *Active period?*



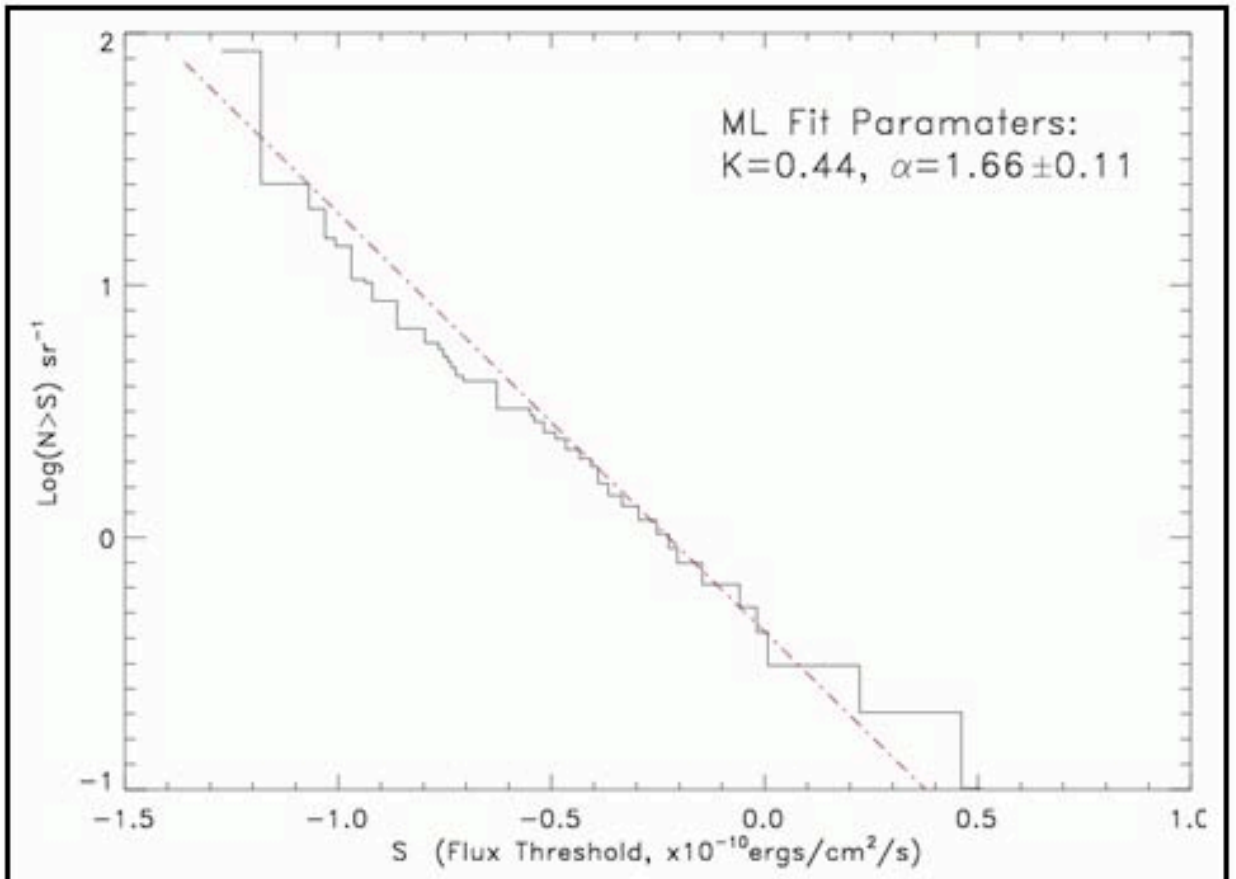
Sgr A* region from Bèlanger et al (2005). ISGRI 20-40 keV significance map constructed from an effective exposure time of 4.7 Ms. Grid spacing is 0.5°. It is now believed that the hard X-ray source IGR J17456-2901, likely associated with Sag A*, is constant in intensity and possibly extended. It may be associated with the HESS TeV source which is also apparently non-varying.



Hard X-ray AGN Survey

- *70 hard X-ray selected AGN, 25,000 sq deg, ~mCrab*
  - *Sub-mCrab on ~7,000 sq deg*
- *~7% "new" sources*
- *Sy-2's harder than Sy-1's*
- *~10% Compton thick ($NH/10^{24}$)*
  - *Less than expected considering DHXRB spectrum*
- *~1% of DHXRB (<Z>=0.22)*
- *Weak absorption-luminosity dependence (higher Lx, less absorbed, consistent /Swift)*

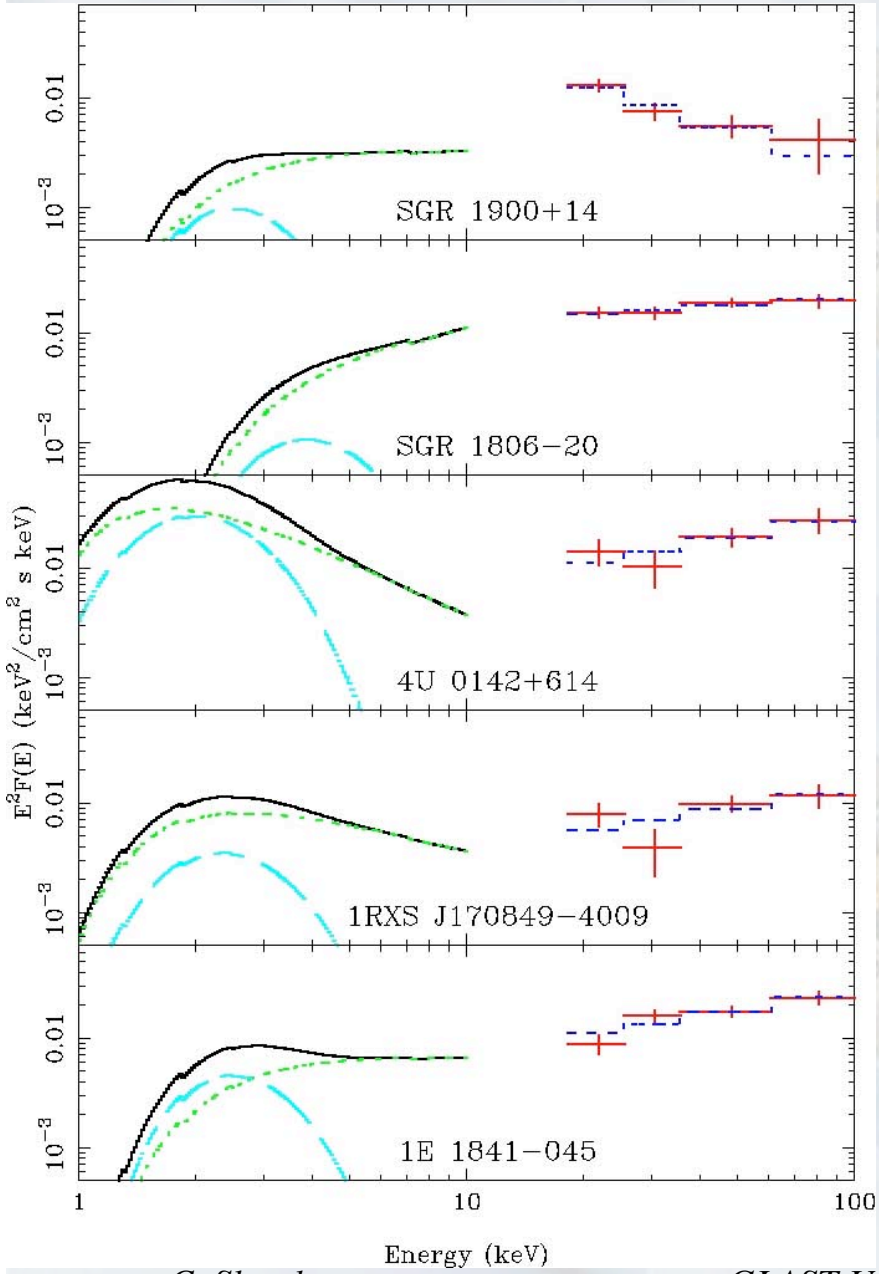
Hard X-ray AGN Survey



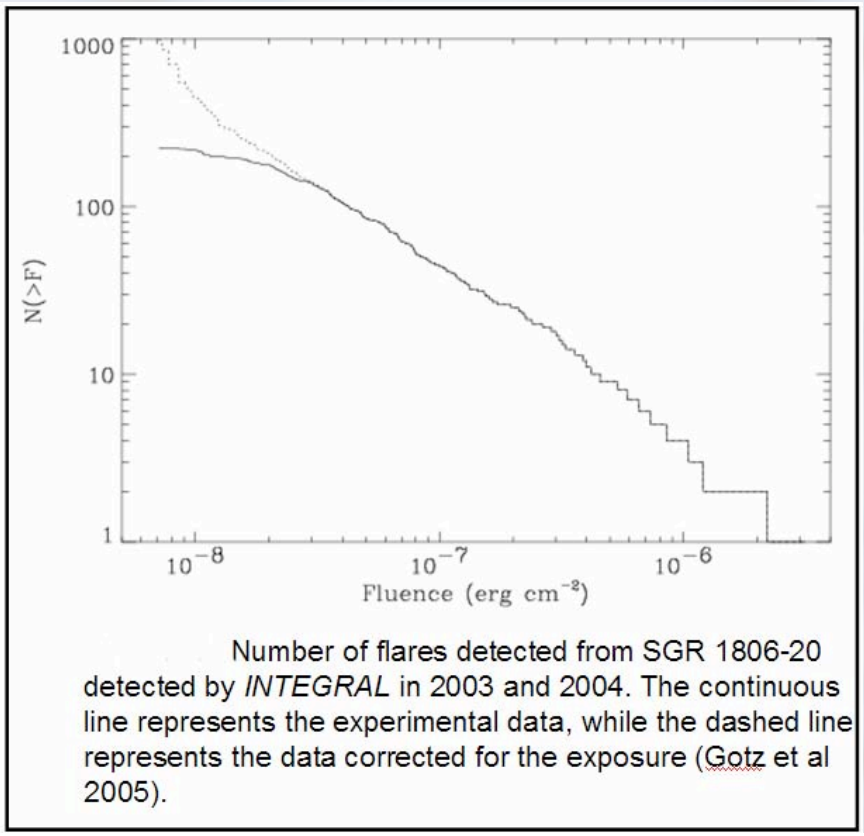
Extragalactic Log(N)-Log(S) distribution derived from 25,000 square degrees of high-latitude sky[63]. It is anticipated that the INTEGRAL-selected AGN sample will expand to ~250 objects, with which issues such as the fraction of absorbed objects, and its implication on the hard-X-ray background spectral decomposition.

- *Log(N) – Log(S) curve for hard-X-ray sample:*
  - *Consistent w/Euclidian space distribution (but low z sample).*
  - *Normalization consistent w/Swift and independent INTEGRAL survey (Krivonos 2005; Tueller private communication)*
  - *~1.2×10^{-2}deg^{-2} @mCrab*
- *With increased high-latitude exposure, expect ~200 AGN*

SGRs, AXPs



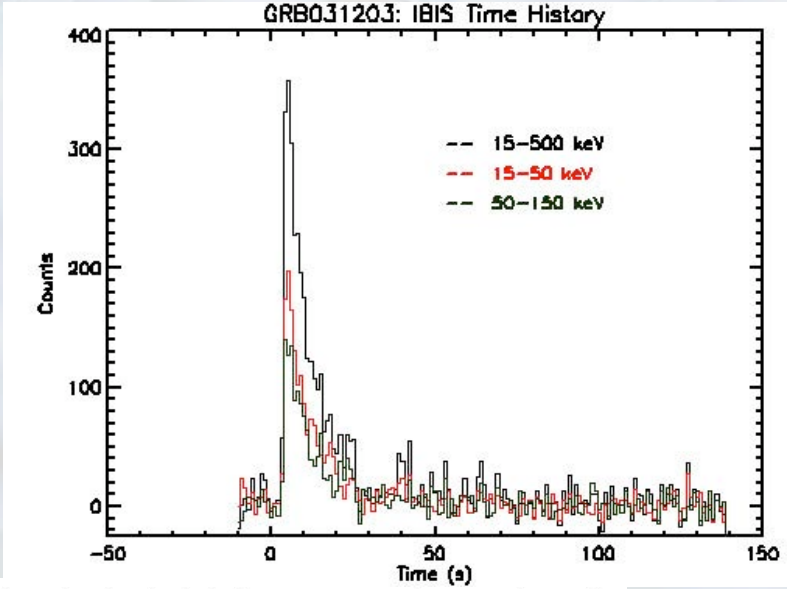
- *AXP 1E 1841-045 showed pulsed emission up to ~150 keV (Kuiper, et al 2004)*
- *Lx exceeds spin-down energy by/10^2*
- *Broad-band spectral differences*
- *SGR 1806-20 and SGR 1900+14 have persistent emission up to 100 keV, with Lx~10^36 erg/s (20-100 keV)*

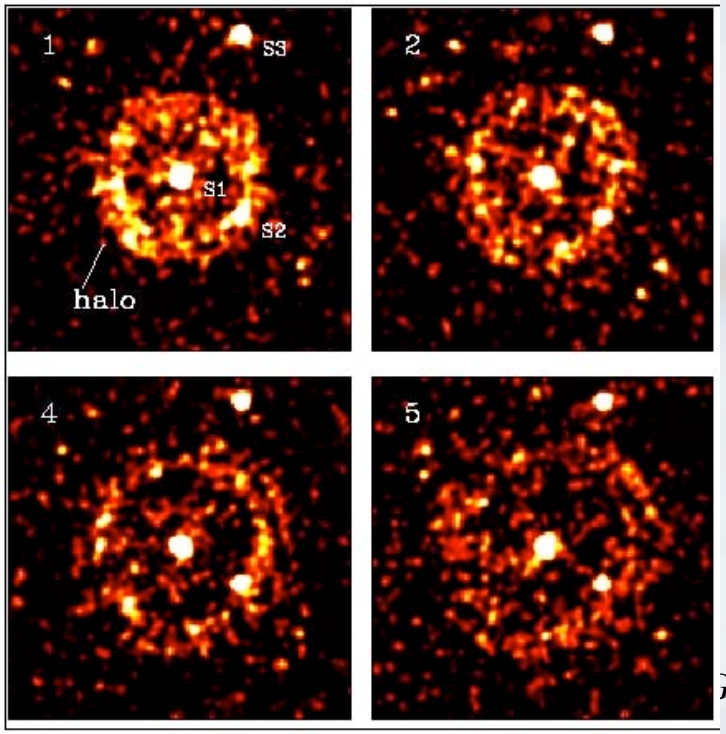


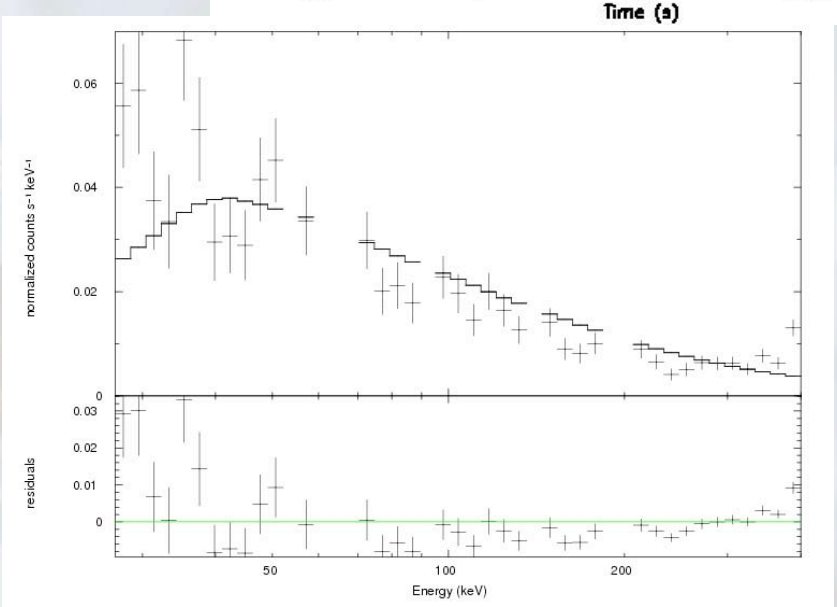
Number of flares detected from SGR 1806-20 detected by *INTEGRAL* in 2003 and 2004. The continuous line represents the experimental data, while the dashed line represents the data corrected for the exposure (Gotz et al 2005).

Gamma-Ray Bursts

- *Prompt, GRB localizations are being disseminated at a rate of about 10 per year.*
- *Notable case: GRB 031203 position distributed 20 seconds after its detection*
- *In addition to the bursts imaged by IBIS, SPI ACS system is component of the IPN.*
  - *Isotropic response, it detects about ~70 bursts/year down to a threshold of 7×10^{-8} erg/cm^2, many localized by triangulation.*

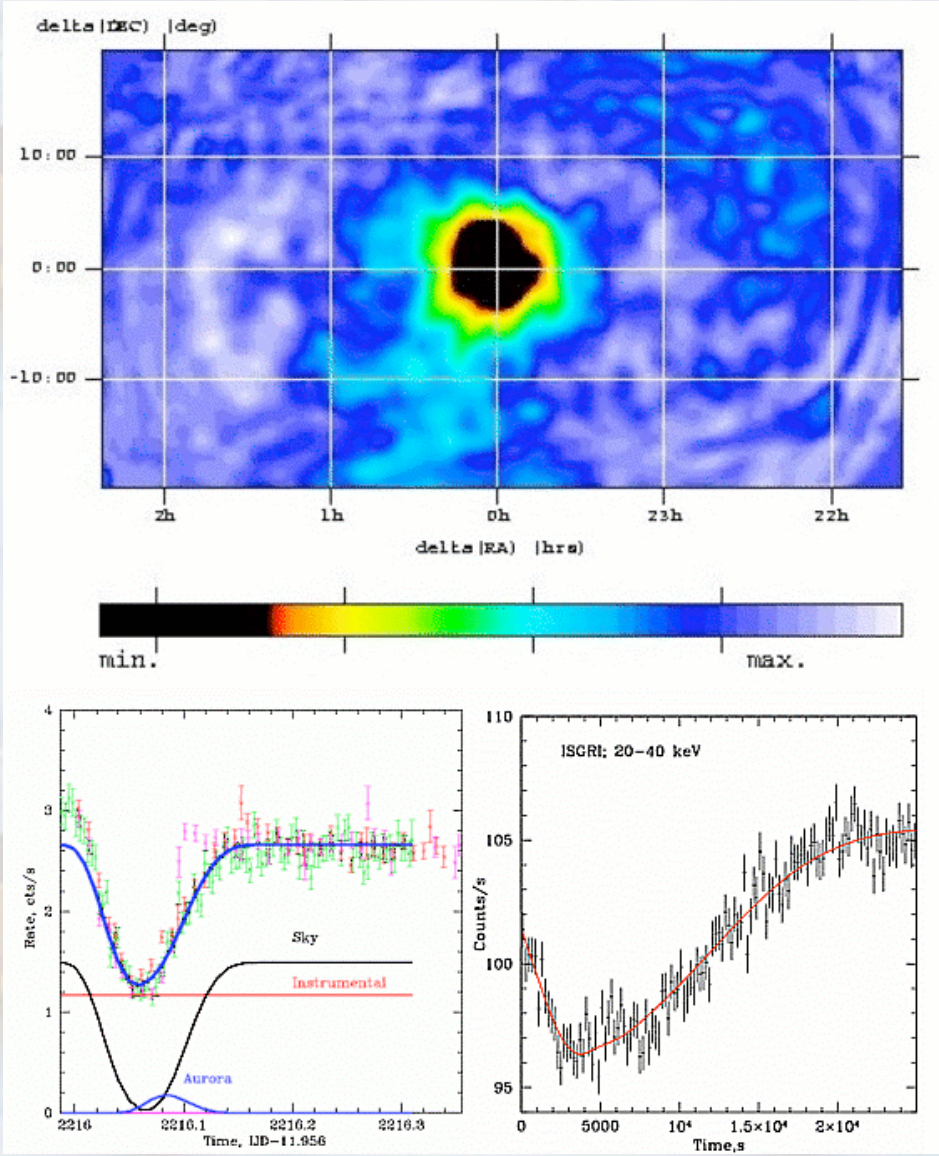






Hard-X-Ray, γ-Ray Background

- *Recent Earth-pointing observation: determine cosmic high energy background by using the Earth as an occulter.*
- *"Point and shoot" observation; blinded star trackers*
- *Complications: reflected emission, cosmic-ray Bremsstrahlung*
- *Ongoing analysis …*



Lessons Learned

- *Don't squeeze ground calibrations out of development schedule*
- *Engage community as extensively and as early on as possible*
  - *INTEGRAL Core Program encompasses too much key science*
  - *Usable SW calibrations & backgrounds by time of first data release*
  - *Liberal data rights policy*
- *Scientists should participate at all levels of development*
  - *Early INTEGRAL SW development "top heavy" w/computer jocks*
- *Retain archive & theory research program*
- *One pre-launch symposium is adequate*
- *Don't have Russians launch it (politics …)*