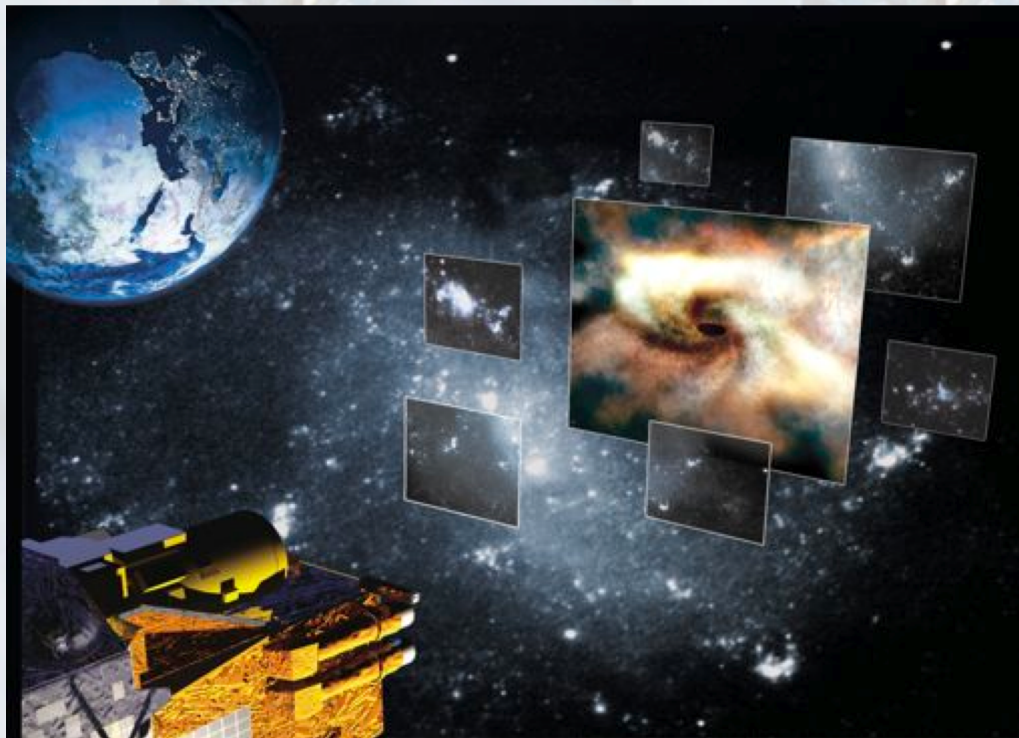




# ***INTEGRAL***



Neil Gehrels  
NASA/GSFC  
INTEGRAL US Project Scientist

Mark Leising  
Clemson University  
INTEGRAL US User's Group Chair

Steve Sturmer  
GSFC/CRESST  
INTEGRAL US GOF Lead Scientist



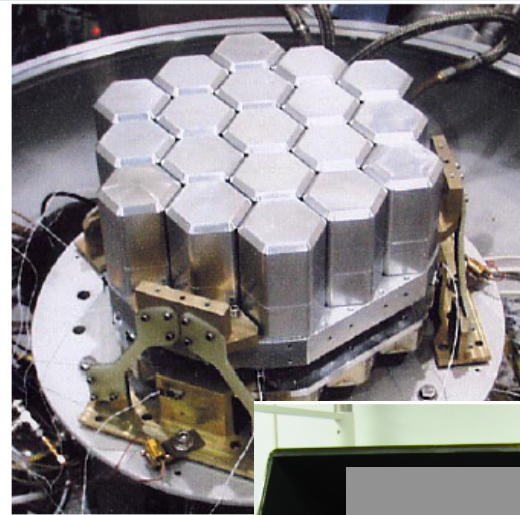
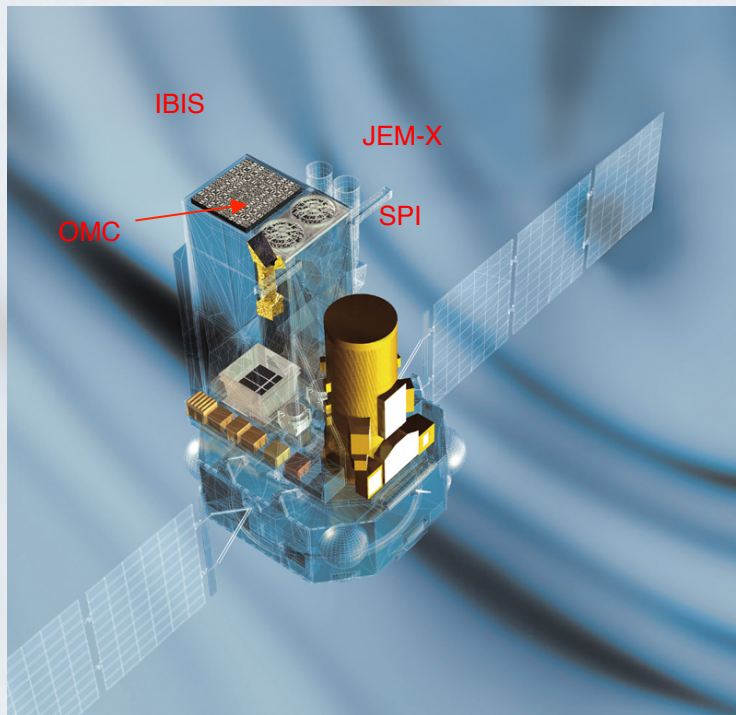
# ***Mission Summary***

## ❖ ESA Mission with significant US and Russian Participation

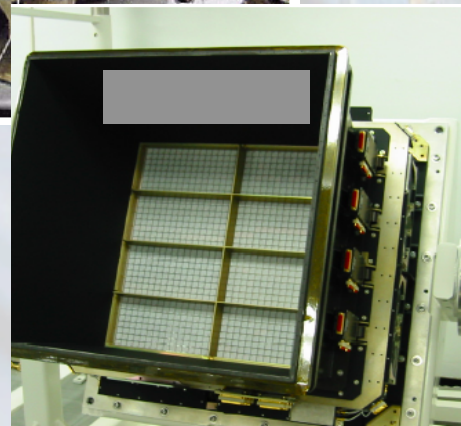
- Launch October 17, 2002

## ❖ Science

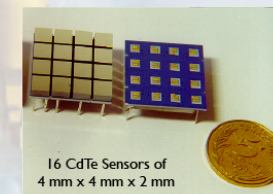
- Gamma-ray astronomy (20 keV – 10 MeV)
- 2 Main gamma-ray instruments – SPI (spectrometer) & IBIS (imager)
- INTEGRAL is the only operating or planned mission providing imaging and spectrometry in the MeV energy band



SPI Ge Detectors



IBIS CdTe Detectors



16 CdTe Sensors of  
4 mm x 4 mm x 2 mm

# ***Mission Summary***

## ❖ Status

- ESA has approved operation of *INTEGRAL* through 2012
- The spacecraft is functioning flawlessly
- >10 years of hydrazine fuel remaining
- There has been a ~8% degradation in SPI's sensitivity

## ❖ NASA Contributions

- Background reduction electronics
- Detector response generation
- Data analysis software
- Goldstone telemetry and tracking support
- US INTEGRAL Guest Observer Facility at NASA/GSFC
- US funded GI program
- Mirror to the INTEGRAL Public Data Archive at the HEASARC

## ❖ The cost of the US program is <5% of the other partners (ESA, European countries, Russia)



# **INTEGRAL's Unique Science Capabilities**

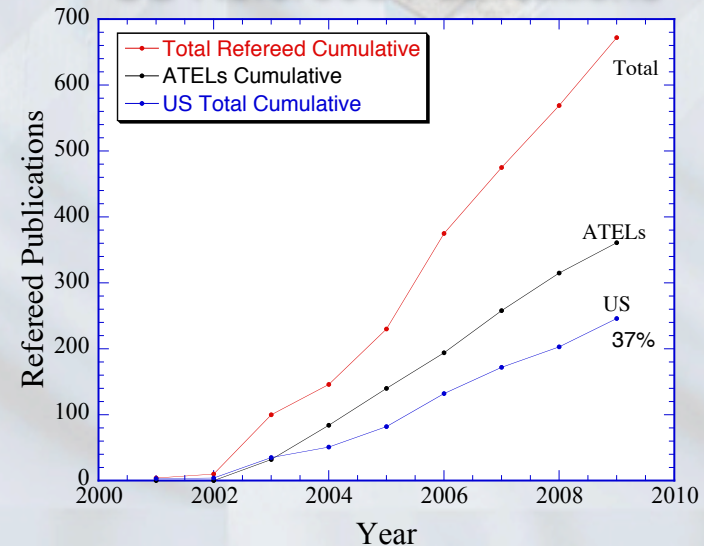
- *Energy Coverage (keV - MeV)*  
*bridges Chandra/Fermi*  
*penetrating radiation*  
*reveals transrelativistic electrons and  $T \sim 10^9$*
- *Nuclear Line Spectroscopy*  
*stellar and supernova nucleosynthesis and galactic structure*  
*positron production in compact objects and dark matter?*  
*no successor planned*
- *Hard X-ray Angular Resolution*  
*discover sources for extensive multi- $\lambda$  follow-up*  
*help identify Fermi sources*
- *Gamma-ray Polarimetry*  
*bright sources, pulsars & GRB's*
- *Long-Term, Wide-Field Monitoring*  
*extensive observations of Galaxy - diffuse and point source*  
*requirements benefit each other*  
*the volatile high-energy sky demands this*



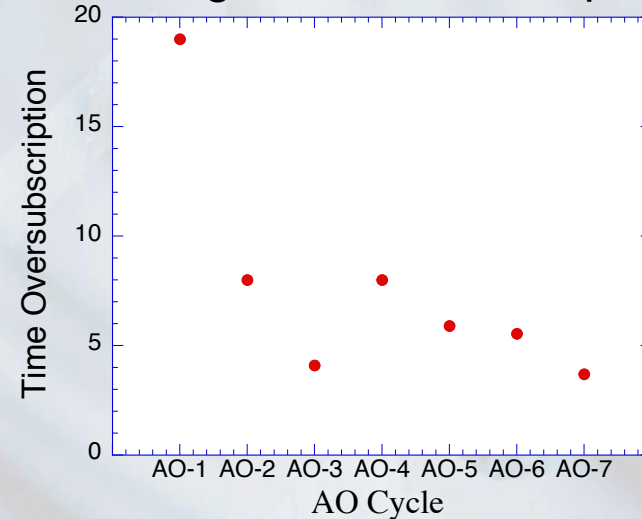
# US Scientist Participation in Mission

- 137 winning GI proposals with US PIs in AO-1 to 7 (18.5% of total)
- 55% of AO-6 and AO-7 proposals have US participation
- ~35 proposals from ~15 institutions funded per year
- 83 US first author publications (12% of total)
- 246 US author publications (37% of total)
- 368 ATELS containing either INTEGRAL direct or follow-up observations
  - 16% of all ATELS 2003-present

## US Refereed Publications



## GI Program Oversubscription



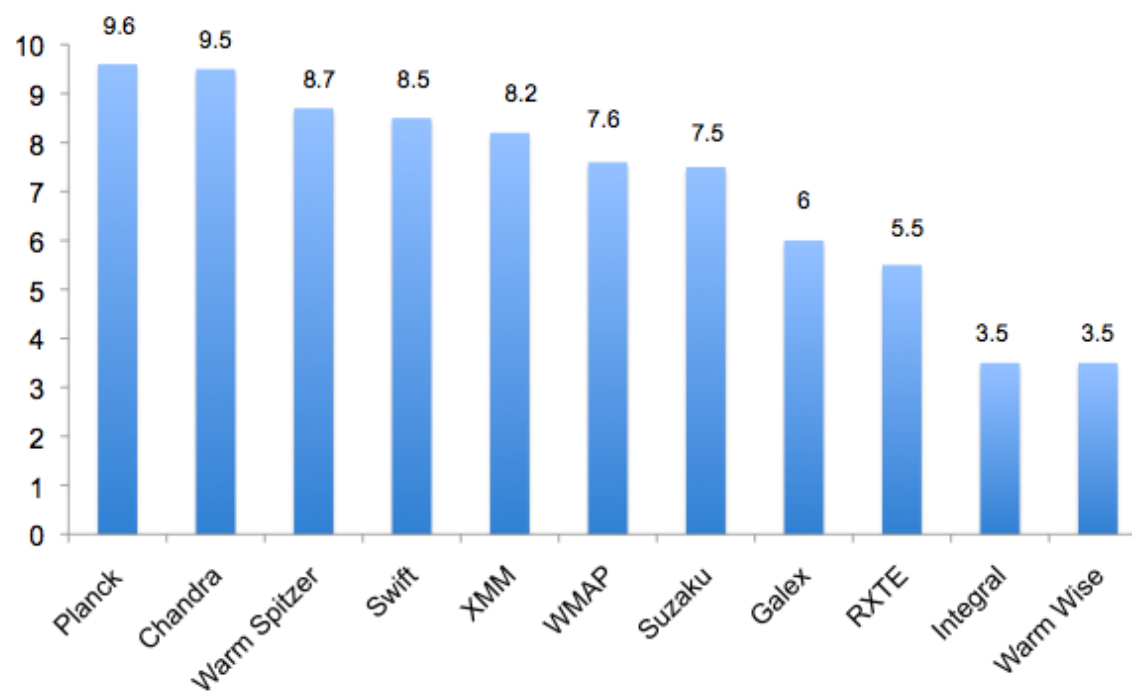
# ***Proposed Budget***

	FY10	FY11	FY12	FY13	FY14
In-Guideline	\$641k	\$0k	\$0k	\$0k	\$0k
Satellite Comm	\$53k	\$54k	\$56k	\$58k	\$59k
GO Program	\$300k	\$300k	\$300k	\$300k	\$300k
GOF Staff	\$288k	\$298k	\$308k	\$318k	\$328k
<b>TOTAL Proposed</b>	<b>\$641k</b>	<b>\$652k</b>	<b>\$664k</b>	<b>\$676k</b>	<b>\$688k</b>

- Not included for SMD is \$1.8M per year for Goldstone tracking



### Astrophysics Division Senior Review 2010 Ranking



## **Science strengths:**

- *The major strength of INTEGRAL is in gamma-ray line studies, especially  $^{26}\text{Al}$  and the 0.511 MeV annihilation line, a capability unique among current operating missions. INTEGRAL employed this capability to reveal clues to the nature of ongoing nucleosynthesis. The  $^{26}\text{Al}$  and  $^{60}\text{Fe}$  mapping provides information for massive star inventories in nearby star-forming complexes.*
- *INTEGRAL gave confirmation of disk asymmetry for the  $e^+/e^-$  annihilation line.*
- *INTEGRAL also carried out population studies of HMXBs and SFXTs.*
- *The recently developed gamma-ray polarization capability is unique among current missions and potentially important. The polarized emission from GRBs and pulsars has been measured.*
- *INTEGRAL would contribute substantially to our understanding of novae or Type Ia supernovae by observing gamma-ray lines if such events were to occur locally during the next two years, but the probability is low. Other studies include those of black hole binary accretion, cyclotron line sources, magnetars, cataclysmic variables, and AGN.*



## ***Proposal weaknesses:***

- The proposal did not make a strong case that this mission has not reached a point of diminishing return.*
- The proposal did not list the number of GOs that need to be funded per year or the oversubscription rate. The SRC estimates that only about 20 proposals a year are submitted and accepted.*
- The proposal did not, therefore, make a case that there is strong community interest in the new results that will come from continued US participation.*
- The archival data is lightly used. The community does not find the INTEGRAL archive to be as important a resource as the archives of other missions.*





# ***High Return on a Small Investment***

- Provides a unique observational capability in the 20 keV- 10 MeV band crucial to connecting Chandra, Swift, and Suzaku in the x-ray band to Fermi and AGILE at much higher energies.
- Many areas of INTEGRAL science take years of exposure, e.g. nucleosynthesis. Hence INTEGRAL is now reaching discovery phase in these areas.
- NASA provides critical DSN telemetry via an international agreement through FY11 at a cost of \$1.8M per year.
- US scientists play a key role in INTEGRAL science that depends on NASA funding.
- Many of the key INTEGRAL results have significant US participation:
  - Galactic 511 keV annihilation radiation (Skinner, Rothschild, Higdon, Lingenfelter)
  - Galactic sources (Tomsick, Pottschmidt, Rothschild)
  - Galactic nucleosynthesis (Leising, Hartmann)
  - Gamma-ray bursts/Polarization Studies (Hurley, Kouvoiliotou, Boggs, Finger, Baring)
- US scientists are involved in 37% of all papers and 55% of AO-6 and AO-7 proposals (13% as PI)
- ~\$650k will enable continued US scientific discovery with INTEGRAL

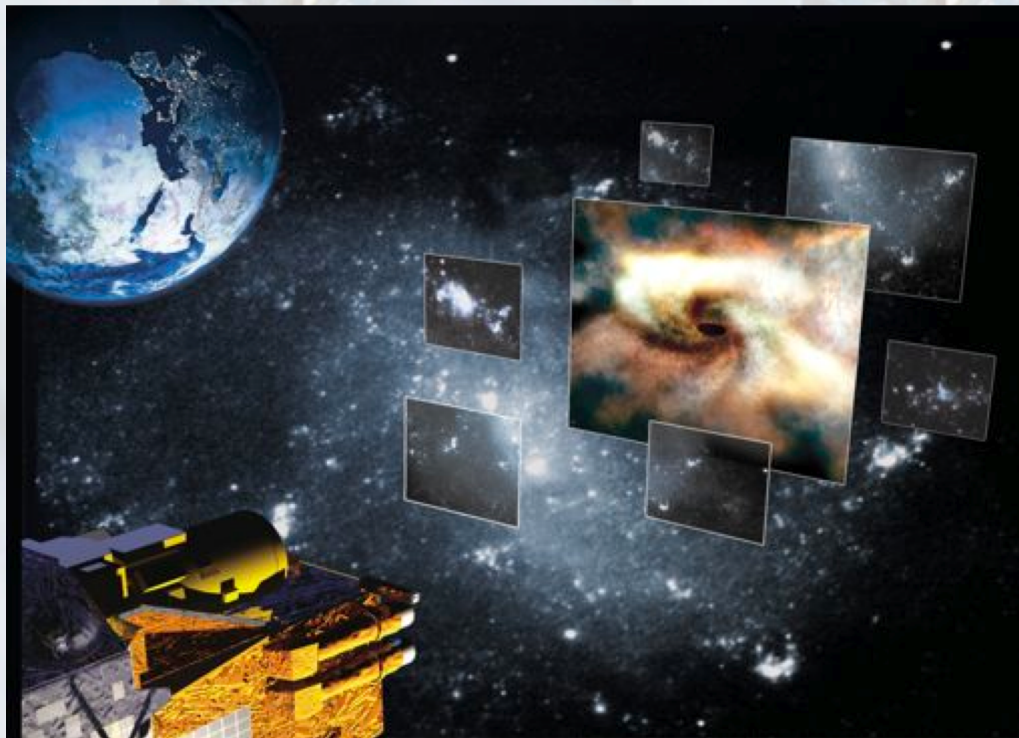
# Progress Since SR2008

SR 2008	Progress since SR 2008	SR 2010
Mapping $^{26}\text{Al}$ 1.809 MeV emission to produce detailed rotation curves	Significant progress is being made in doing detailed spectroscopy of star forming regions and a Galactic rotation curve (ref. Figure 12 of proposal)	Progressing to performing detailed studies of $^{26}\text{Al}$ and $^{60}\text{Fe}$ emission from individual star forming regions
Mapping $^{60}\text{Fe}$ in the Galaxy	Work in progress	
Confirm the asymmetry of the Galactic 511 keV emission	Results with additional data confirm asymmetry (7 <sup>th</sup> INTEGRAL Workshop)	New ping-pong observations have been recently completed and analysis is underway
Detect Type Ia SN or nearby classical nova	No suitable target	Awaiting closer events
Population studies of absorbed HMXBs	12 publications in the last 2 years on observations and follow-ups of these sources	INTEGRAL continues to discover HMXBs in both classes; Distinguish between alternative SFXT models;
Establish the taxonomy of SFXTs	Have almost doubled number of confirmed SFXTs and have determined the orbital periods for a subset of 4 of them	
	First measurements of polarization in gamma rays – Crab, GRBs	Polarization studies for other sources





# ***INTEGRAL Science***



Neil Gehrels  
NASA/GSFC  
INTEGRAL US Project Scientist

**Mark Leising**  
**Clemson University**  
**INTEGRAL US User's Group Chair**

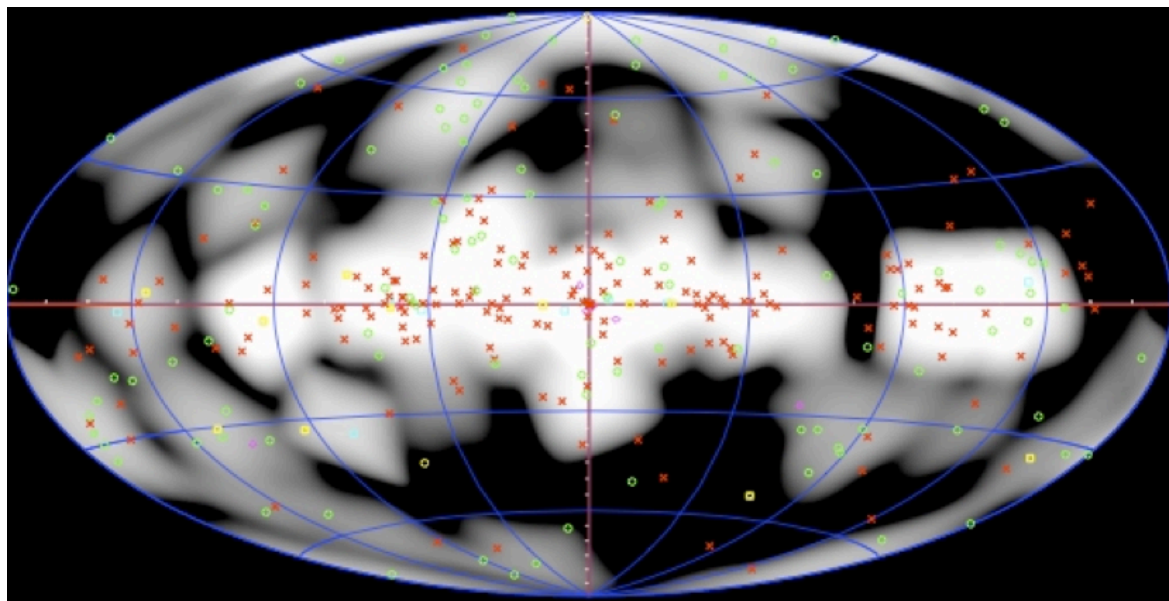
Steve Sturmer  
GSFC/CRESST  
INTEGRAL US GOF Lead Scientist

# ***INTEGRAL's Unique Science Capabilities***

- *Energy Coverage (keV - MeV)*  
*bridges Chandra/Fermi*  
*penetrating radiation*  
*reveals transrelativistic electrons and  $T \sim 10^9$*
- *Nuclear Line Spectroscopy*  
*stellar and supernova nucleosynthesis and galactic structure*  
*positron production in compact objects and dark matter?*  
*no successor planned*
- *Hard X-ray Angular Resolution*  
*discover sources for extensive multi- $\lambda$  follow-up*  
*help identify Fermi sources*
- *Gamma-ray Polarimetry*  
*bright sources, pulsars & GRB's*
- *Long-Term, Wide-Field Monitoring*  
*extensive observations of Galaxy - diffuse and point source*  
*requirements benefit each other*  
*the volatile high-energy sky demands this*

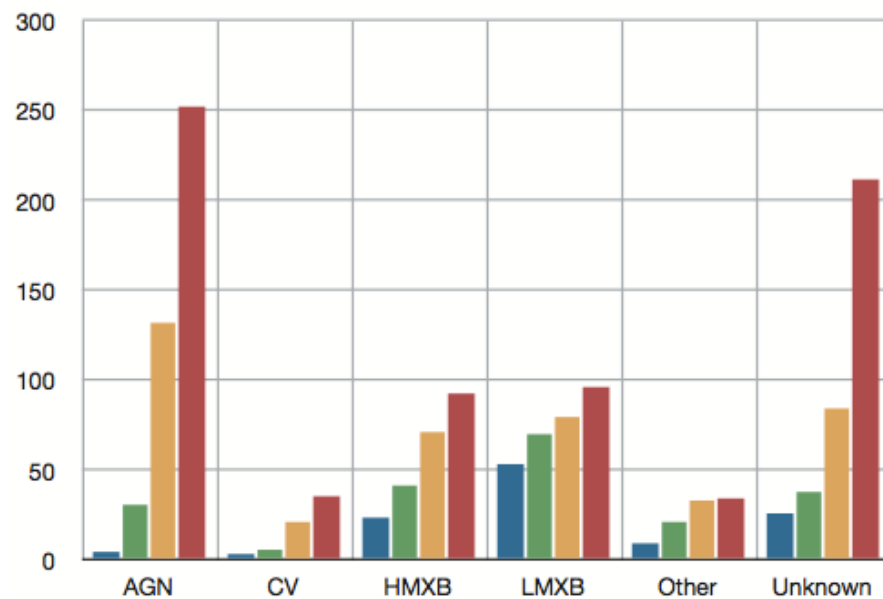


## *INTEGRAL Continues to Discover Sources at a High Rate*

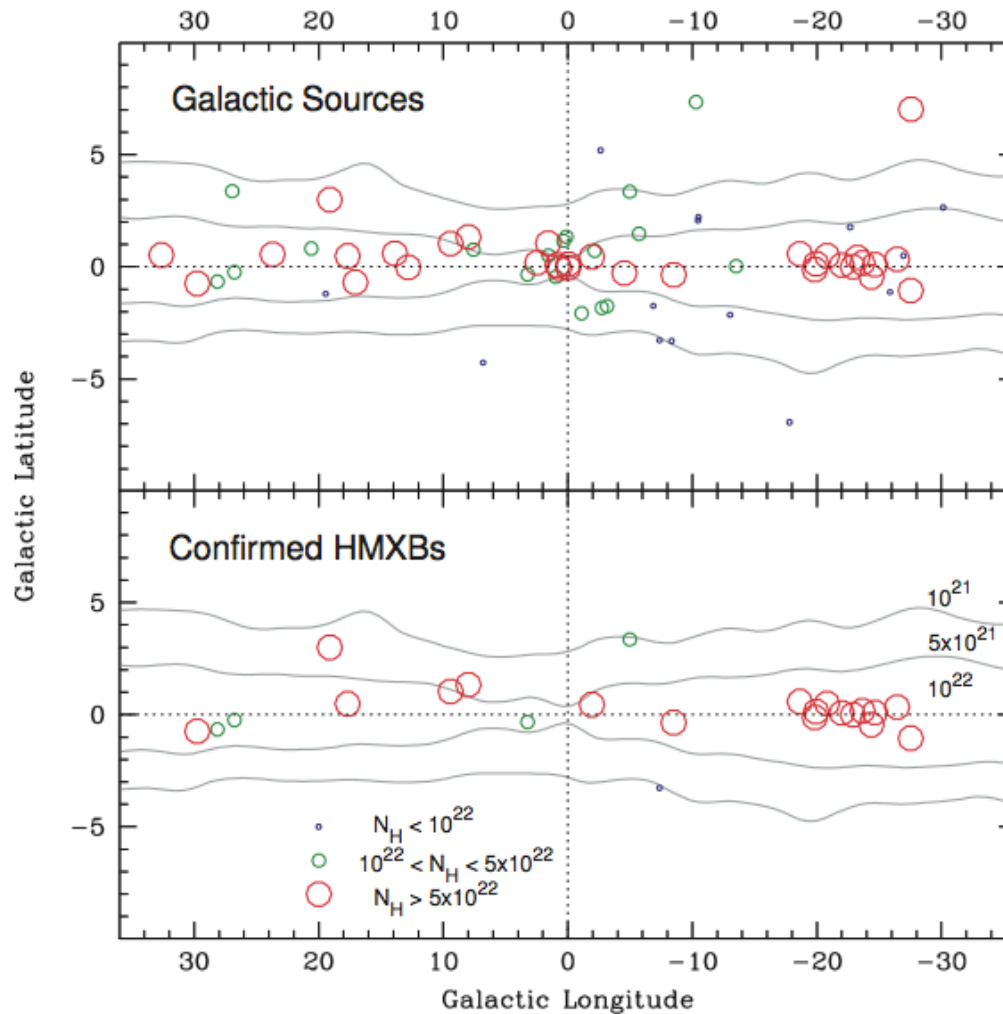


*New sources and added  
exposure in 4<sup>th</sup> ISGRI  
Catalog;  
-- 2 years --  
(Bird et al. 2010)*

*Number of  
new sources  
by class in*



# High Mass X-ray Binaries



*INTEGRAL* discoveries:

- **obscured sources** (column densities greatly exceed ISM values; self-embedded)
- **supergiant fast transients** (bright flares over hours -- from wind accretors?)

*INTEGRAL* facilitates extensive broad-band campaigns, and will discover more to permit class studies; determine orbital periods; clarify mechanisms of each type and relationship to each other; constrain binary population synthesis models.

*Future: expect ~20 new HMXB's in coming two years*



# Black Hole Transients – recent results

*Spectra of externally triggered targets of opportunity:*

*GX 339-4 (Caballero et al. 2009) and 1E 1740.7-2942 (Bouchet et al. 2009)*

*Both require 2 high energy spectral components (only INTEGRAL)*

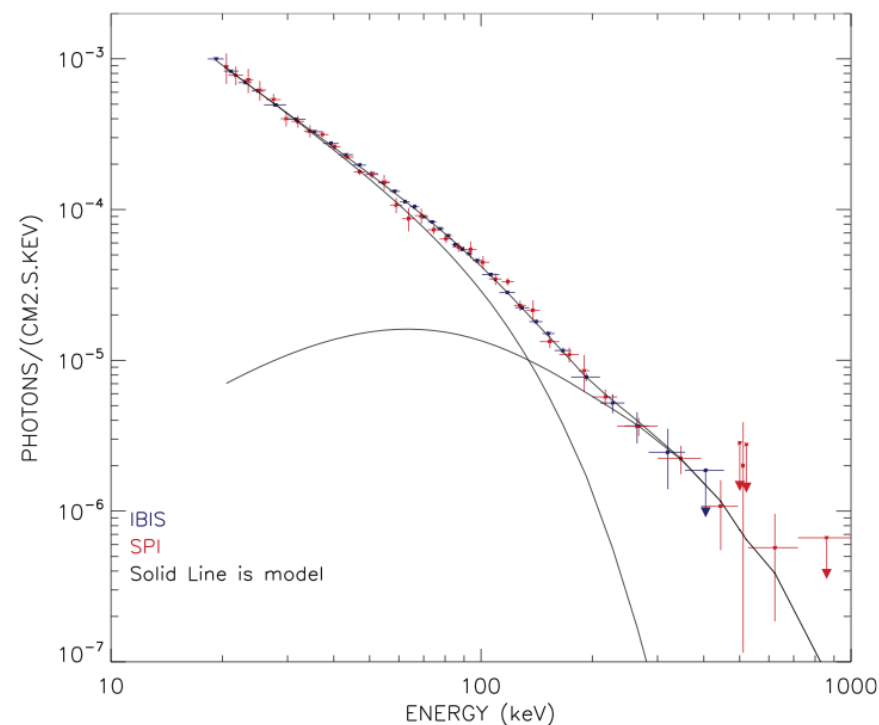
*Serendipitous ISGRI detection of outburst of H1743-322 triggered many observations, including INTEGRAL following it through decline*

*INTEGRAL detection triggered radio observations of H1743-322 on MJD 54744 leading to detection of jet*

*GX 339-4 Spectrum*

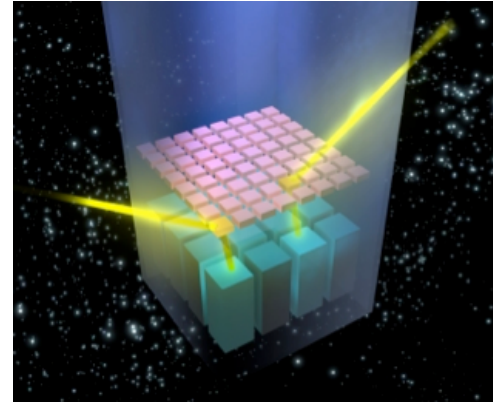
*SPI & IBIS data*

*two thermal components*



*Future: expect improved understanding of emission processes from INTEGRAL/Fermi studies of, e.g., Cyg X-3*

## *INTEGRAL Polarimetry*



### *Crab Nebula*

- *SPI* (0.1 – 1 MeV) *Dean et al. 2008*
- *IBIS* (200 – 800 keV) *Forot et al. 2008*

### *GRB 041219a*

- *SPI* (100 – 350 keV) *Kalemci et al. 2007*
- *SPI* (0.1 – 1 MeV) *McGlynn et al. 2007*
- *IBIS* (200 – 800 keV) *Götz et al. (2009)*

### *GRB 061122*

- *SPI* (0.1 – 1 MeV) *McGlynn et al. 2009*



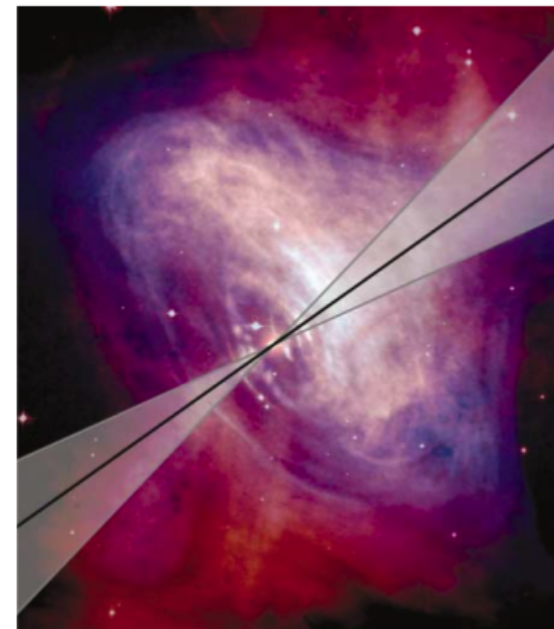
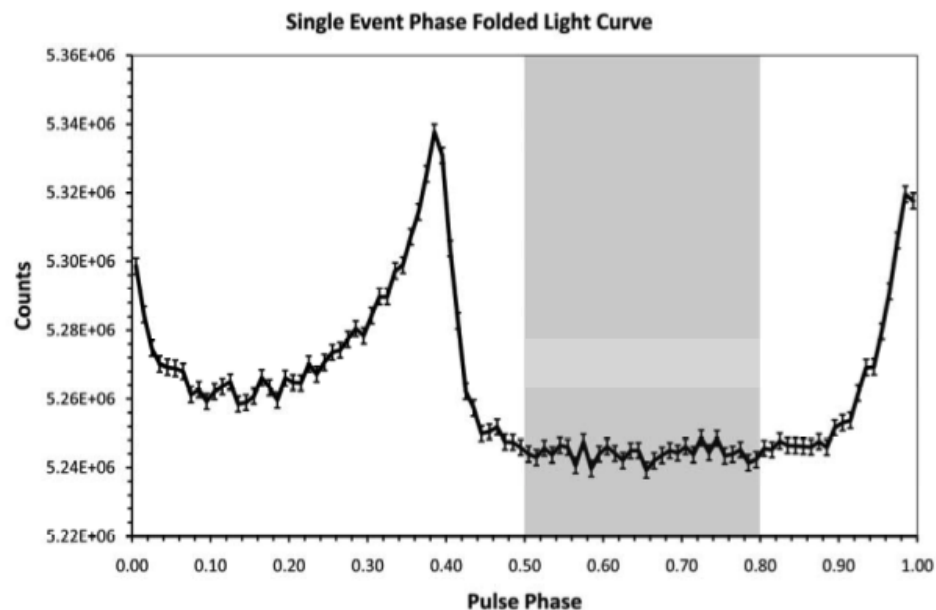
# *INTEGRAL / SPI Polarization of the Crab Nebula*

*Dean et al. Science 2008*

*0.1 – 1 MeV data, 2003 – 2006, unpulsed emission*

*$\pi = 46 \pm 10 \%$*

*$\Psi = 123^\circ \pm 10^\circ \rightarrow$  aligned with pulsar spin axis*



*Future: improved understanding of instruments should yield better results and measurements of, e.g., Vela pulsar and new (bright) GRB(s).*

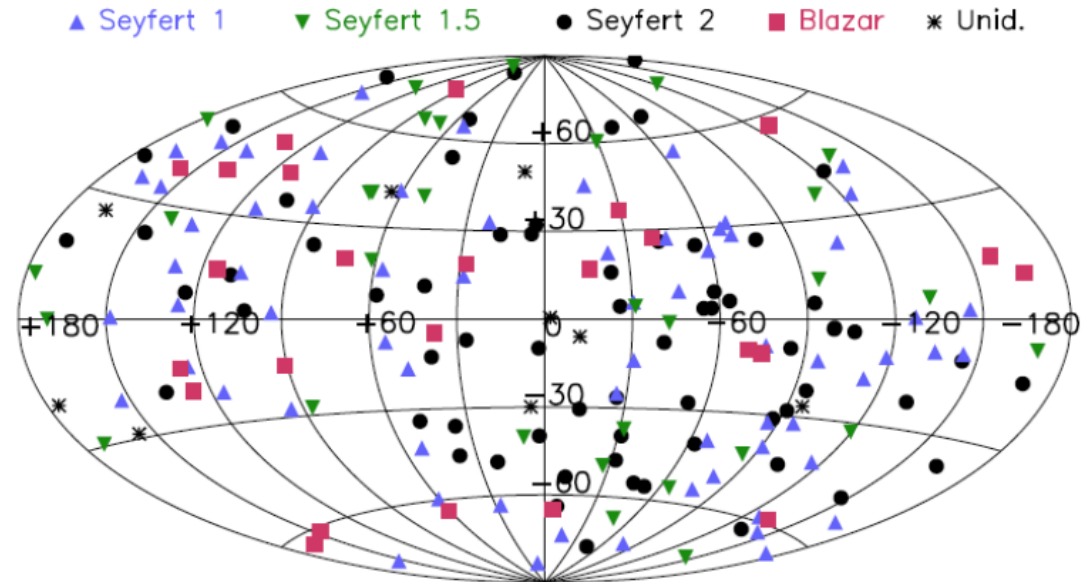
# INTEGRAL AGN

*2<sup>nd</sup> INTEGRAL AGN*

*Catalog – 199 sources*

*Beckmann et al. 2009*

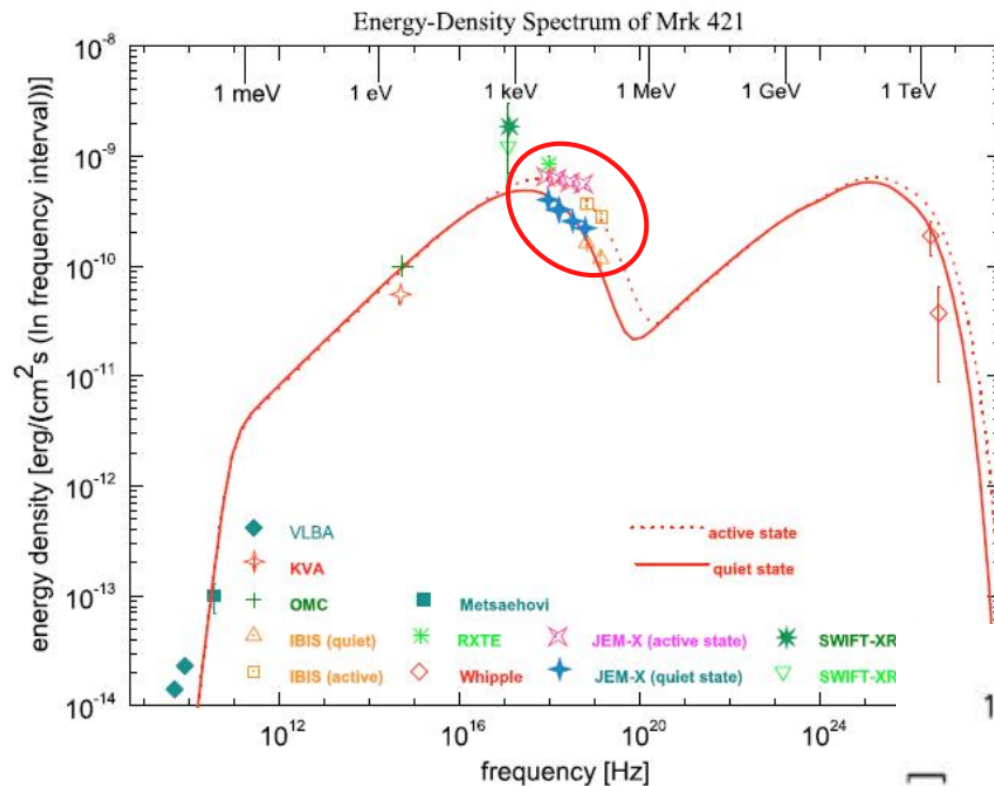
*148 unparallelled spectra*



## Seyfert Galaxies

- *INTEGRAL detects obscured sources, including Compton thick AGN ( $N_H > 10^{24} \text{ cm}^{-2}$ )*
- *Fraction of these among all Seyfert galaxies is smaller than expected*
- *Compton thick sources fall short of hard X-ray background ( $\sim 9\%$ )*

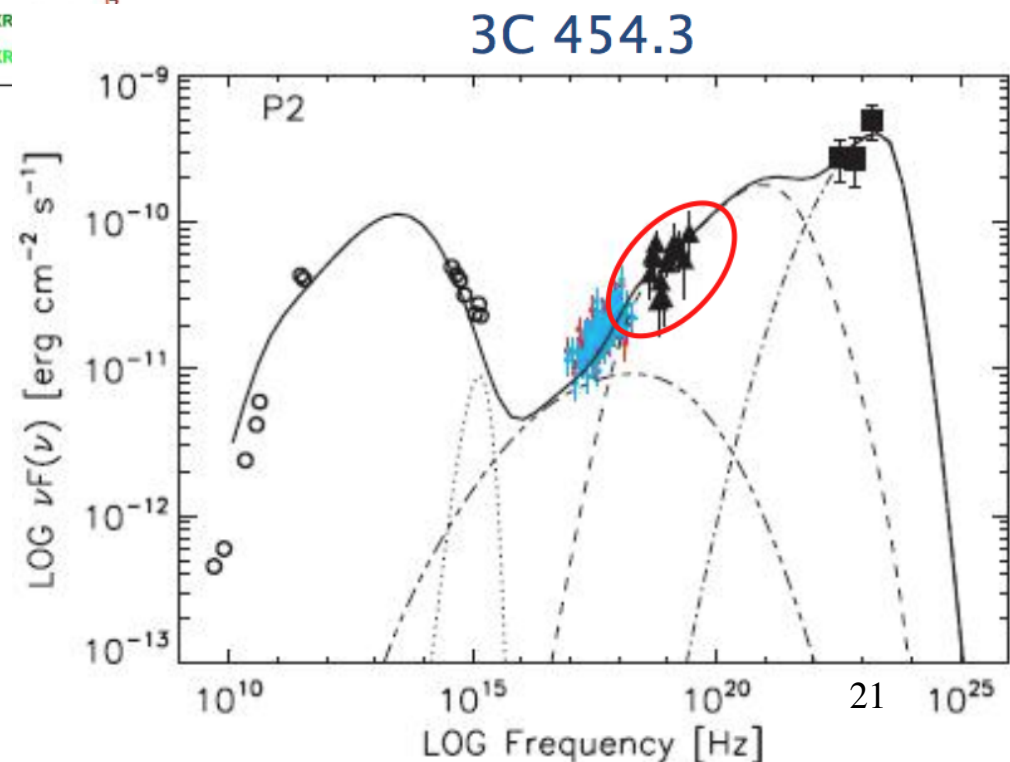




*Future: more detailed constraints on SED's with Fermi and TeV measurements of inverse-Compton component.*

## INTEGRAL Blazars

*INTEGRAL energy range is essential to constrain synchrotron emission (high-frequency BL Lacs) or inverse Compton emission (low-frequency BL Lacs and FSRQ)*

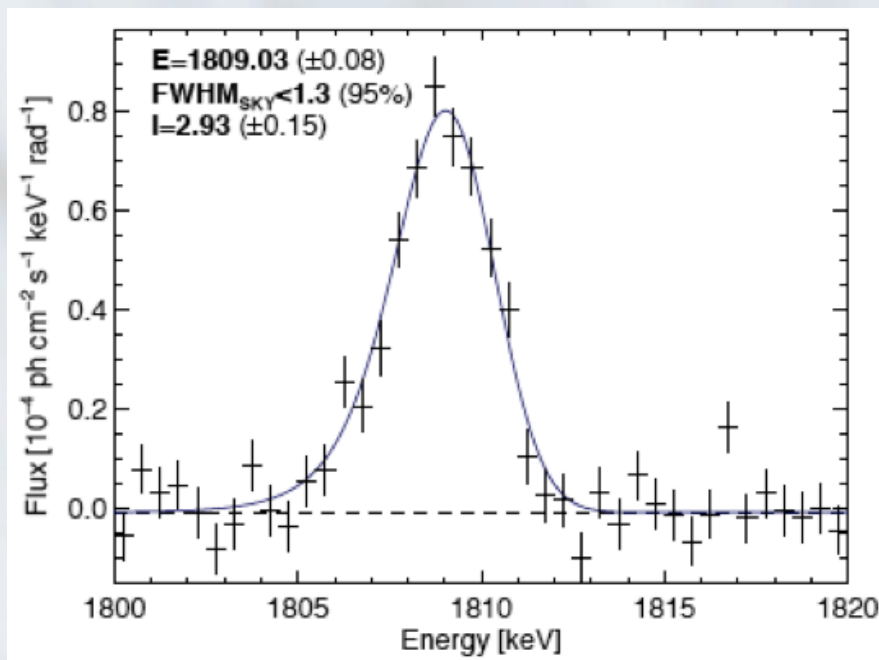


# INTEGRAL / SPI Radioactive Decay Nuclear Lines

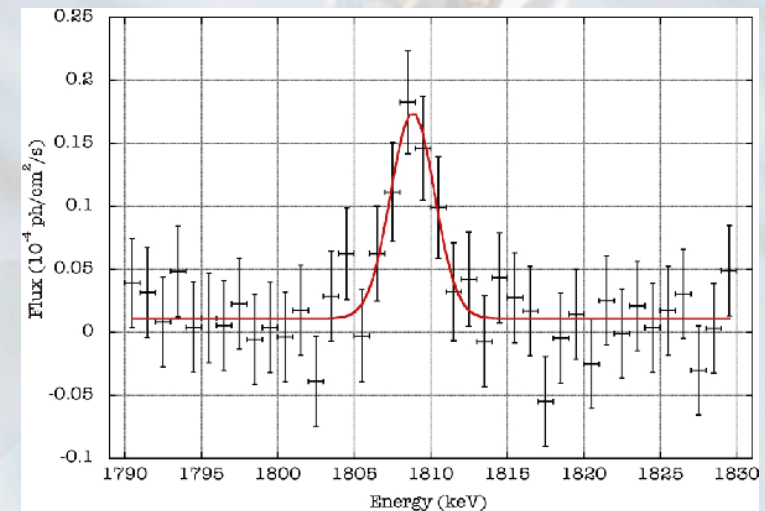
$^{26}\text{Al}$  -- Records  $\sim 1$  My snapshot of massive star and SN II nucleosynthesis throughout the galaxy and (now) in individual star forming regions.

$^{60}\text{Fe}$  --  $\sim 2$  My of supernova nucleosynthesis

*Cygnus OB Association:  
Martin et al. 2009*

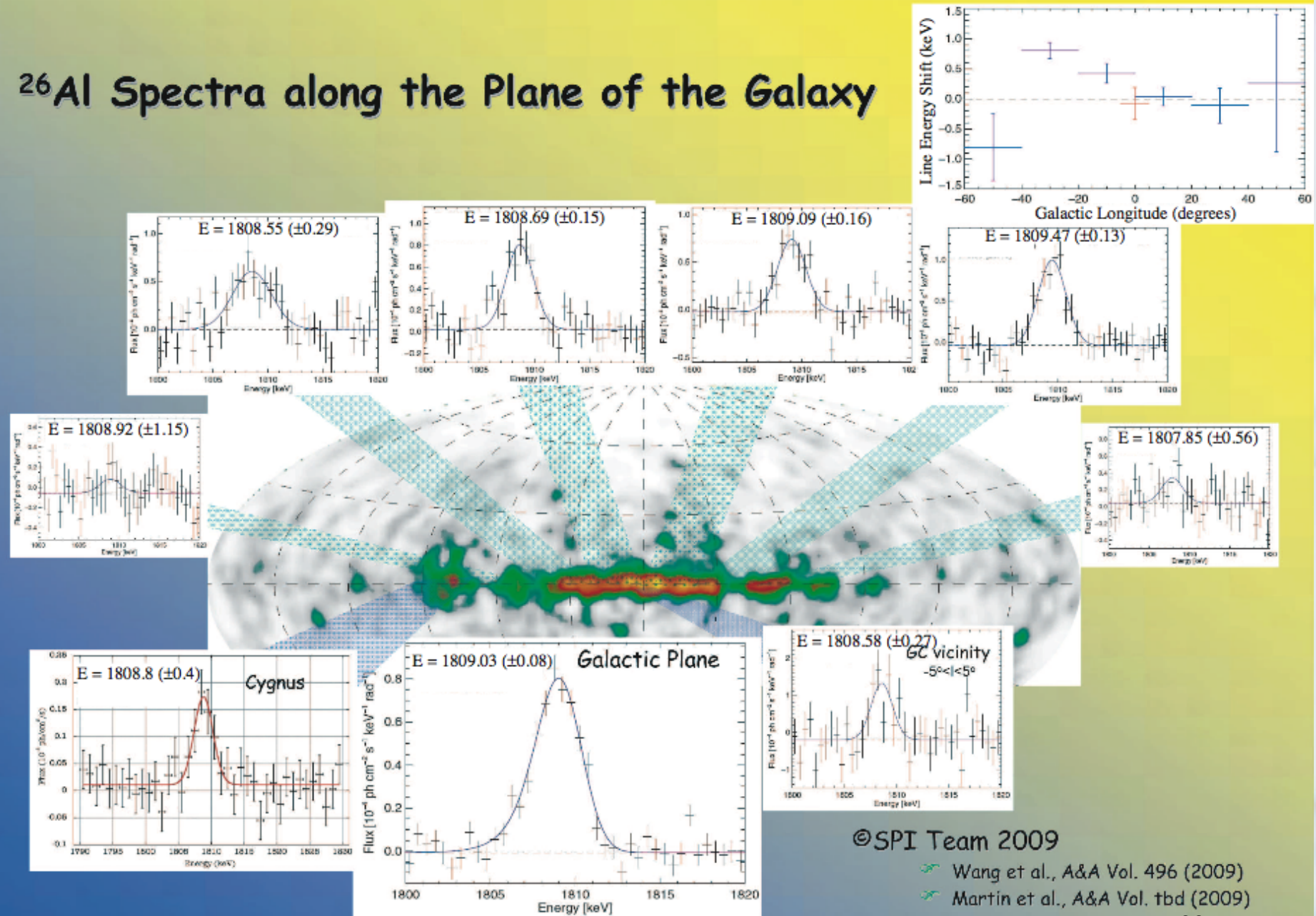


*Wang et al. 2009  
Central Milky Way*



*INTEGRAL nuclear spectroscopy is  
completely unique*

## $^{26}\text{Al}$ Spectra along the Plane of the Galaxy





# **$^{60}\text{Fe}$ relative to $^{26}\text{Al}$**

Mass production ratio (SPI only):

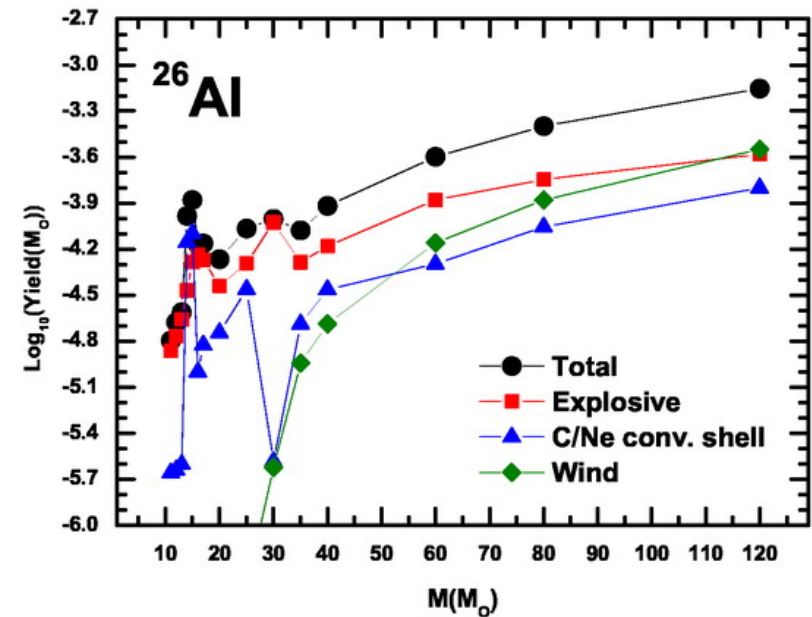
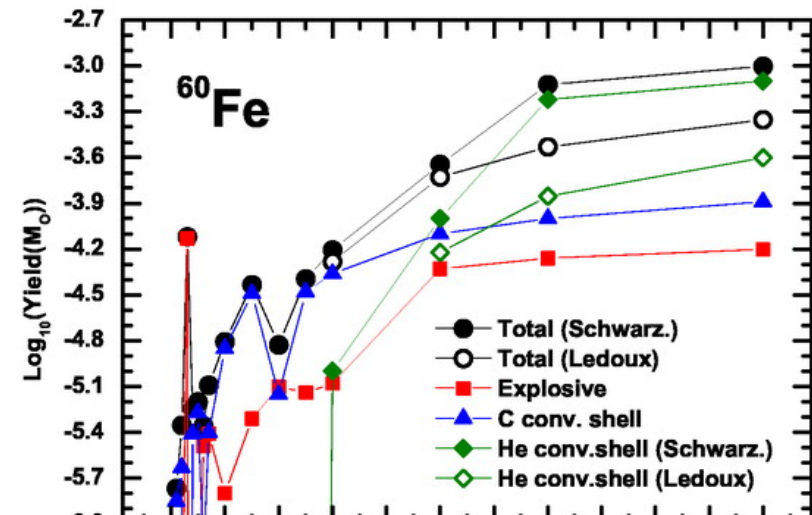
$$P(60)/P(26) = 0.25 \pm 0.09$$

Globally, for inner galaxy

Constrains details of massive stars,  
including convective mixing, and  
initial mass function

Combined with, e.g., total UV power  
and star counts, constrains age  
and history of associations  
Voss et al. 2009

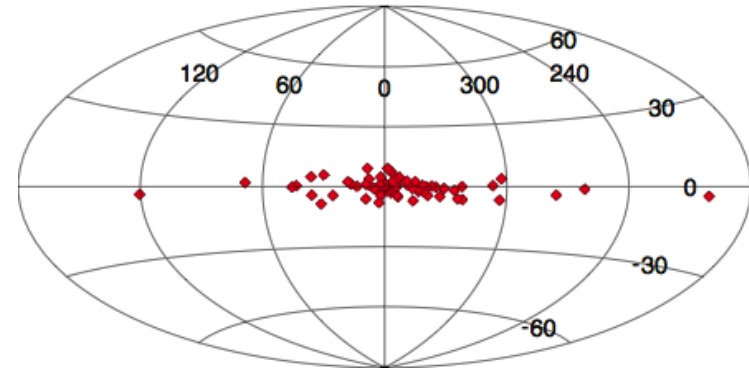
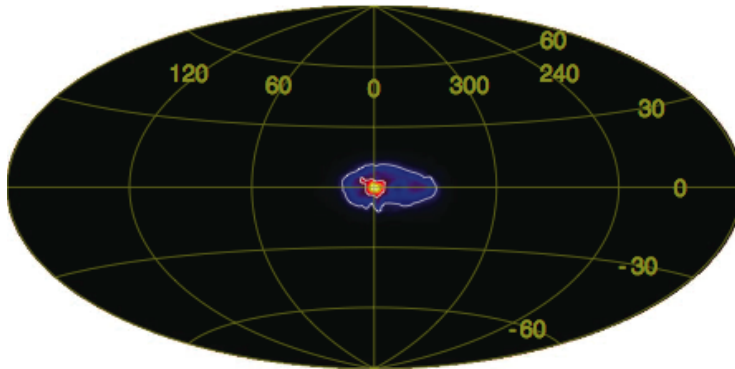
Future: improved S/N  $^{60}\text{Fe}$   
measurements ( $\sim 3 \rightarrow 7$  years);  $^{26}\text{Al}$   
from other regions (Orion) and  
improved spectroscopy.



Limongi & Chieffi

# Electron-Positron Annihilation

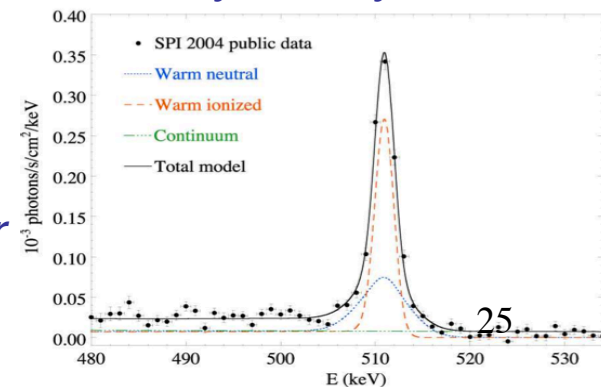
- Galactic Annihilation Radiation (511 keV  $e^-e^+$ ) presents a unique view of our Milky Way: A correlation between the disc asymmetry (left) and Hard Low-Mass X-ray Binaries (right)?



- Theoretical studies (Higdon et al. 2009, Jean et al. 2009) suggest positron transport over large distances divorces annihilation from production sites
- Still, the *origin of the bright positron 'bulge' is unknown*
- Now: Key Project data on either side of bulge to characterize asymmetry

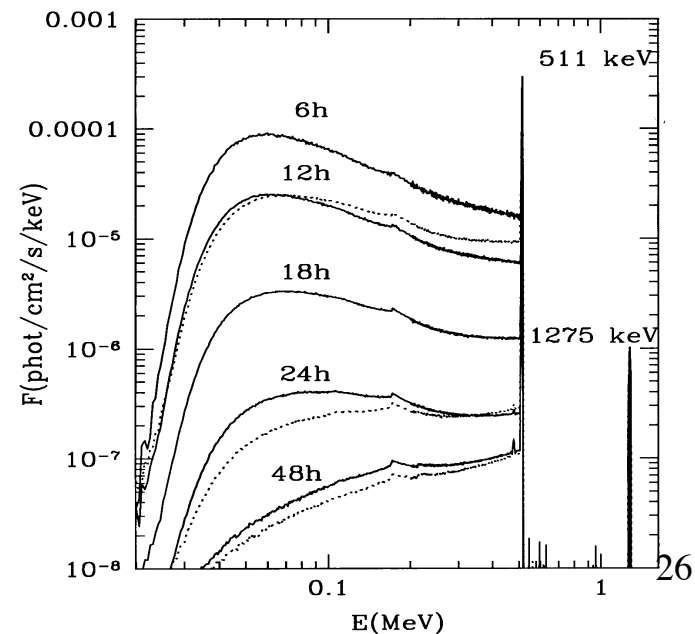
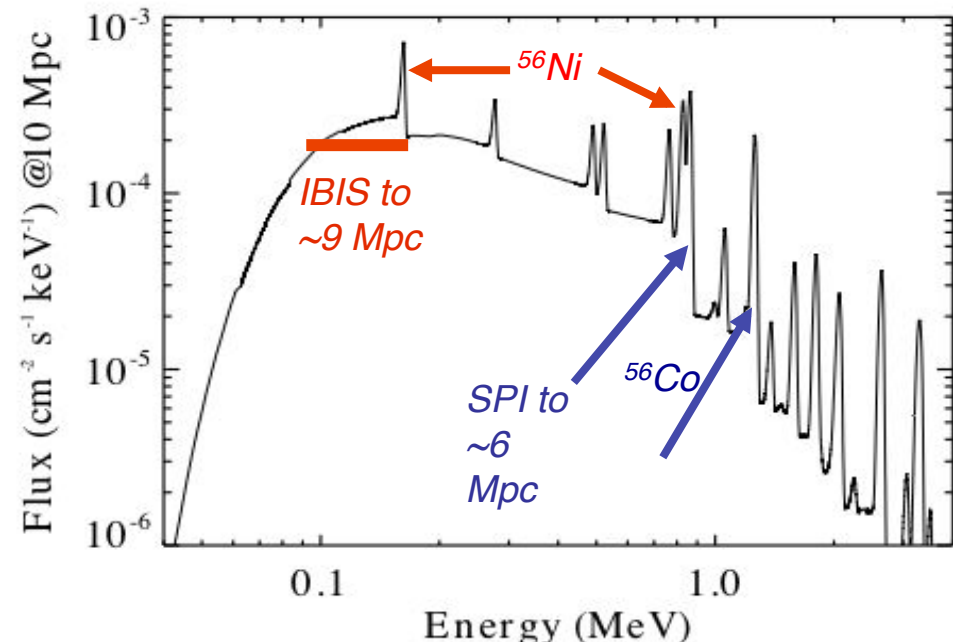
*Future: better constraints on disk asymmetry; disk flux; spatially-resolved spectroscopy of annihilation processes*

*Total inner galaxy spectrum*



# The Unpredictable

- *Thermonuclear SN*  
*understand the nuclear*  
*flame and empirical*  
*brightness calibration*
- *Classical Novae*  
*understand convective*  
*mixing/burning*
- *Bright X-ray Novae*  
*precision study of black*  
*hole accretion, pair*  
*production?*



All likely at 1 per 5 year level;  
Ready for once-in-a-lifetime event?

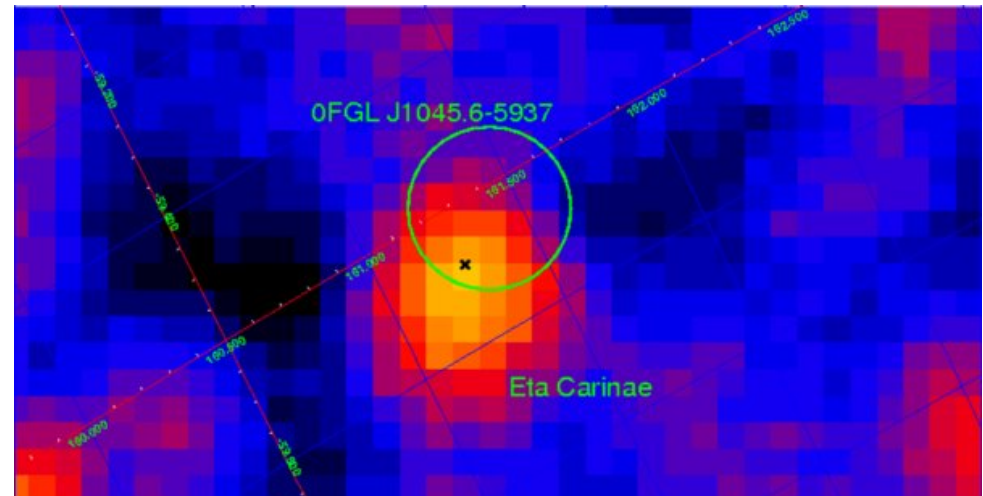


# ***INTEGRAL and Fermi/AGILE***

## *INTEGRAL*

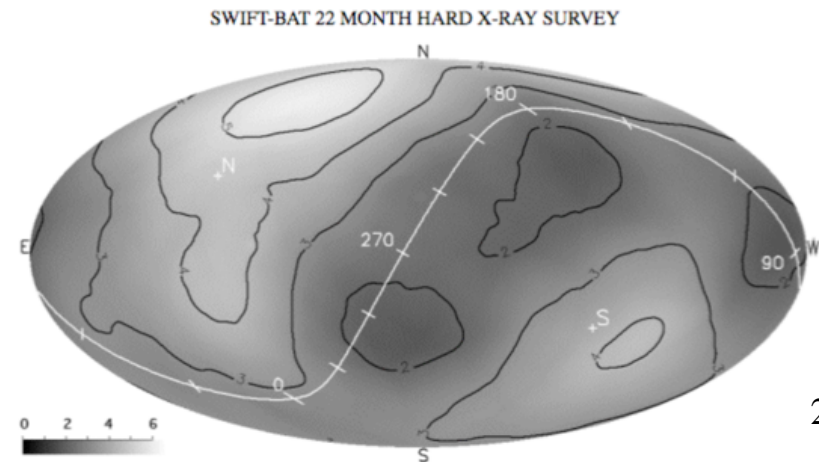
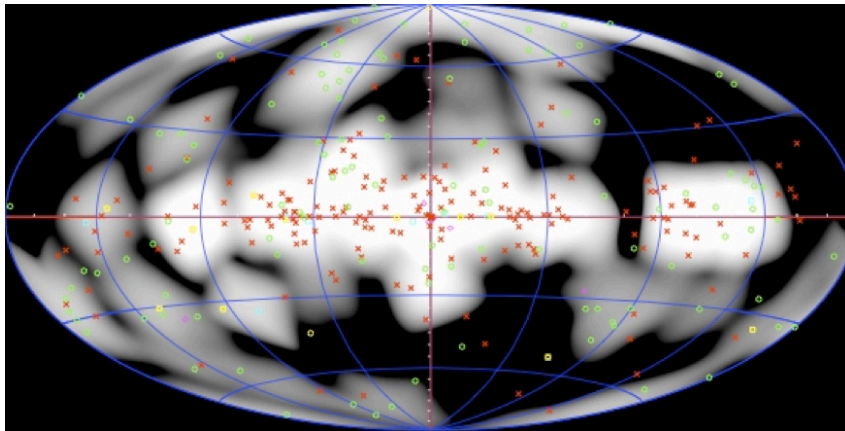
- *Identifies hard X-ray sources in LAT error circles*
- *Contributes over two energy decades to broad-band SED's (blazars, pulsars, PWN, X-ray binaries)*
- *XRB Variability*
  - *Phase dependency of X-ray, GeV, TeV (LSI +61303, LS 5039)*
  - *Correlations of variability in X-rays,  $\gamma$ -rays in Cyg X-3*
- *Provides complementary constraints on cosmic ray propagation models*

*IBIS 18—60 keV  
significance (colors) with  
Fermi error circle (green)  
and  $\eta$ -Car (black)  
Ubertini et al. 2009*



# ***INTEGRAL and SWIFT***

- Continue strong and excellent collaboration on GRB's, SGR's, AGNs and follow-ups of new IGR/SWIFT sources
- *Swift and INTEGRAL have complementary capabilities*
- **INTEGRAL**
  - concentrates on galactic plane
  - broad gamma-ray energy coverage
  - fine spectroscopy
  - deep hard X-ray observations over limited regions
- **Swift**
  - all-sky coverage with high duty cycle
  - sensitive UV/optical and X-ray telescopes
  - rapid response



## Concluding remarks

*INTEGRAL provides several **unique capabilities** (some are unique now, and **for the foreseeable future**) to do science otherwise inaccessible.*

*INTEGRAL has a high degree of **synergism with other missions** and observatories, serving as the discoverer of some objects enabling many other follow-up observations, and as the sensitive follow-up observer for others.*

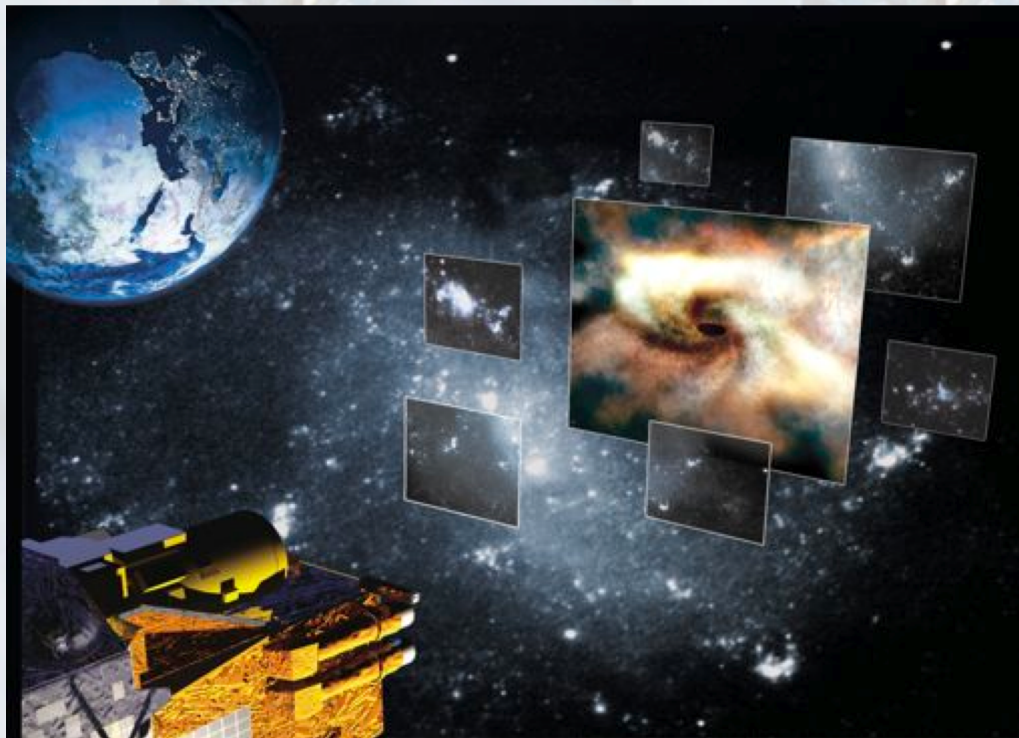
*Significant exposure needed to complete studies of diffuse line emission continues to accrue, dominating upcoming plans, while still **improving analysis methods** promise new and better science.*

*While it is hard to promise the serendipitous and unpredictable, extrapolation of current INTEGRAL activity suggests many **exciting science results in the coming two years**.*





# ***INTEGRAL Budget***



**Neil Gehrels**  
**NASA/GSFC**  
**INTEGRAL US Project Scientist**

Mark Leising  
Clemson University  
INTEGRAL US User's Group Chair

Steve Sturmer  
GSFC/CRESST  
INTEGRAL US GOF Lead Scientist

# ***Proposed Budget***

	FY10	FY11	FY12	FY13	FY14
In-Guideline	\$641k	\$0k	\$0k	\$0k	\$0k
Satellite Comm	\$53k	\$54k	\$56k	\$58k	\$59k
GO Program	\$300k	\$300k	\$300k	\$300k	\$300k
GOF Staff	\$288k	\$298k	\$308k	\$318k	\$328k
<b>TOTAL Proposed</b>	<b>\$641k</b>	<b>\$652k</b>	<b>\$664k</b>	<b>\$676k</b>	<b>\$688k</b>

- Not included for SMD is \$1.8M per year for Goldstone tracking

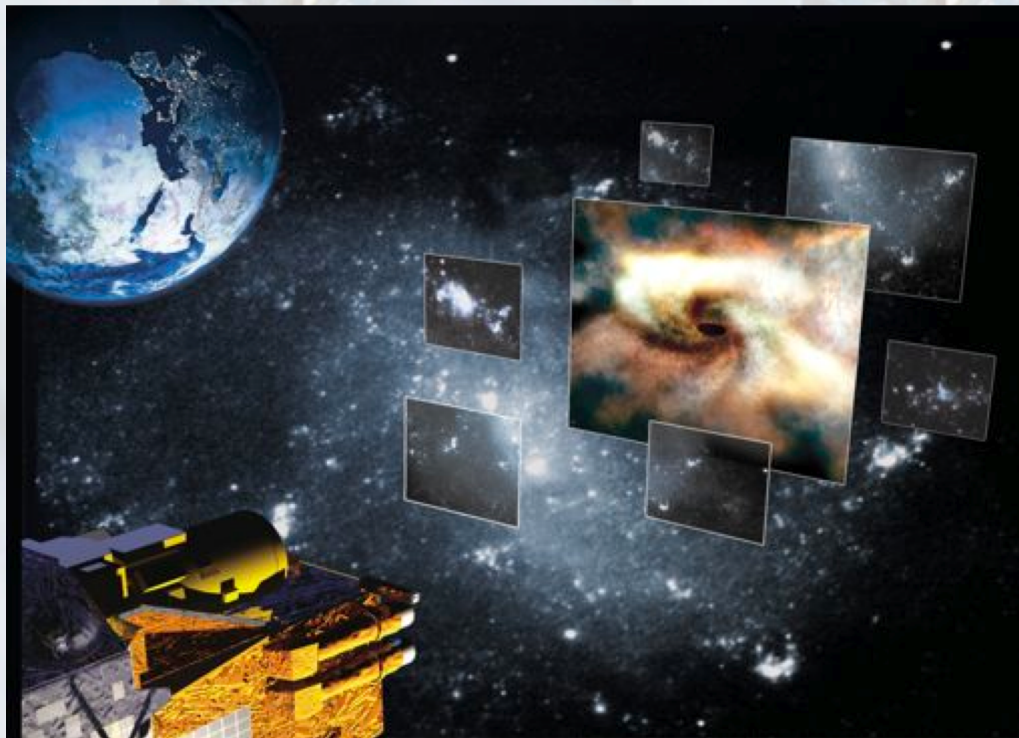


# ***Proposed Budget***

- We propose a minimal over-guide budget of ~\$650k per year.
- This budget contains ~\$50k for Goldstone support to SMD with the remainder roughly evenly split between GOF activities and the GI program.
- This budget maximizes the level of US PI grant support. We expect to enable 10-15 US PI investigations per year supported at the \$20k - \$30k level.
- This will ensure US participation in the INTEGRAL AO process and support the advancement and health of the US gamma-ray community.
- GOF functions include:
  - Managing and promoting the US GI program
  - Assisting US scientists with their data downloads and data analysis
  - Managing the US mirror to the INTEGRAL public data archive – essential due to slow data transfer rates from Europe
  - Updating the SPI instrument response matrices
  - Organizing meetings of the US INTEGRAL User's Group
  - Maintaining the INTEGRAL GOF website
- This is a high return on a small investment.



# ***INTEGRAL – Reference Material***



**Neil Gehrels**  
**NASA/GSFC**  
**INTEGRAL US Project Scientist**

**Mark Leising**  
**Clemson University**  
**INTEGRAL US User's Group Chair**

**Steve Sturmer**  
**GSFC/CRESST**  
**INTEGRAL US GOF Lead Scientist**

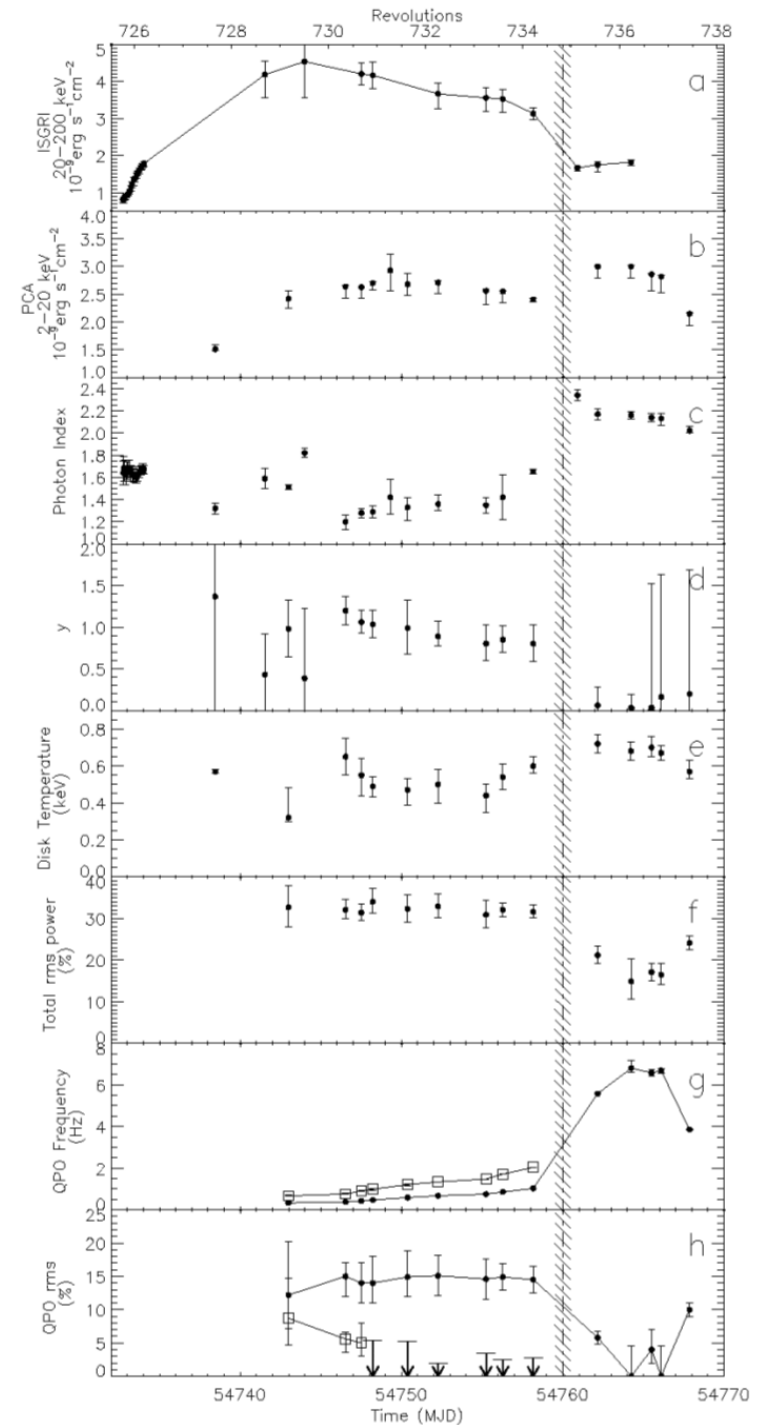
## *HMXB Papers*

From list of publications (2008-2009):

- Tomsick et al., **Chandra cycle 8** (US first author)
- Tomsick et al., **Chandra cycle 9** (US first author)
- Rodriguez et al., **Swift paper #1** (US co-author)
- Rodriguez et al., **Swift paper #2** (US co-author)
- Butler et al., **optical follow-up** (US first author)
- Chaty et al., **optical/IR follow-up** (US co-author)
- Masetti et al., **optical follow-up** (US co-authors)
- Masetti et al., **optical/IR follow-up** (US co-authors)
- Cuadra et al., stellar winds in the Gal. Center region (US first author)
- Morris et al., Suzaku follow-up (US first author)
- Reig et al., 4U 2206+54 (US co-author)
- Tomsick et al., IGR J16207-5129 (US first author) ..

## Black Hole Transient H1743-322

- Early detection by INTEGRAL allowed for a detailed study of spectral and timing properties during the rise.
- Fairly usual evolution from the Hard State to the Intermediate State, but such detailed studies are more often possible during outburst decay.
- Also, INTEGRAL triggered a radio observation on MJD 54744, and radio emission was detected at 2 mJy (jet).





## *Black Hole Transients Papers*

### From list of publications:

- Caballero-Garcia et al., **GX 339-4** (US co-authors)
- Del Santo et al., **GX 339-4** (US co-authors)
- Motta et al., **GX 339-4** (US co-author)
- Prat et al., **H 1743-322** (US co-author)
- Capitanio et al., IGR J17091-3624 and IGR J17098-3628 (US co-author)
- Hjalmarsdotter et al., Cyg X-3 (US co-author)
- Malzac et al., Cyg X-1 (US co-author?)
- BHs for other papers: GRS 1915+105, SS 433, XTE J1818-245, 1E 1740.7-2942

# INTEGRAL / IBIS Polarization Measurement

## GRB 041219a

GRB 041219a - Götz et al., ApJ, 695, L208 (2009)

200-800 keV

Evidence for variable levels of polarization.

