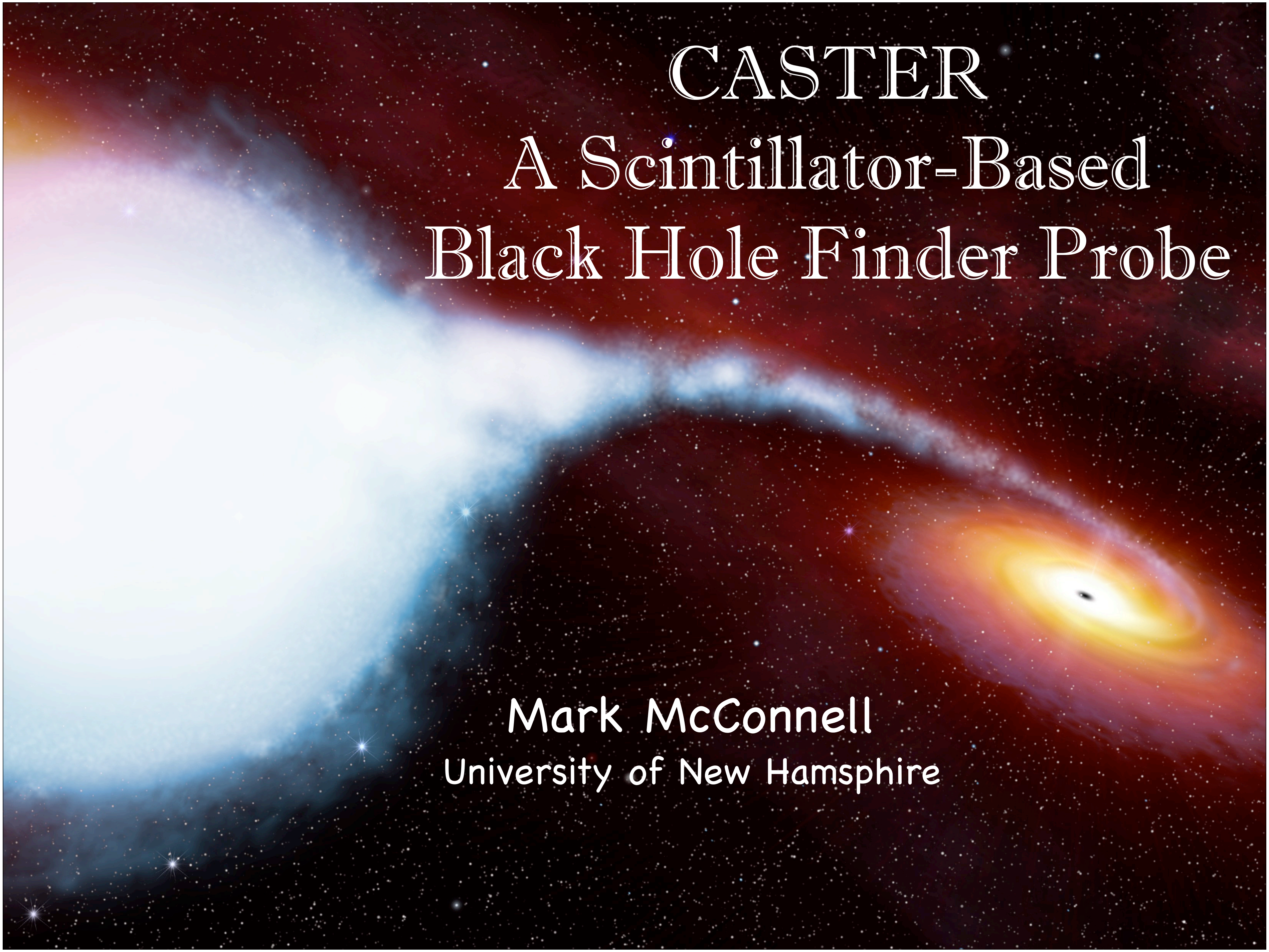


CASTER
A Scintillator-Based Black Hole Finder Probe

Mark McConnell
University of New Hampshire

The CASTER Cast

Mark McConnell, Jim Ryan, John Macri
University of New Hampshire

Mike Cherry, T. Greg Guzik, Brad Schaefer,
J. Greg Stacy, John Wefel
Louisiana State University

R. Marc Kippen, W. Tom Vestrand
Los Alamos National Laboratory

Bill Paciesas, Rich Miller
University of Alabama - Huntsville

Jim Cravens
Southwest Research Institute

Black Hole Finder Probe

- All-sky black hole census
- Total energy range : 10 - 600 keV
- Sensitivity goal ≈0.02 mCrab in 20–100 keV
  - ≈1000x more sensitive than HEAO A-4
  - 1–20x more sensitive than Swift
  - ≈20x more sensitive than BATSE for GRBs
- Angular resolution of 3-5 arcmin will be required to avoid source confusion.

CASTER

Coded Aperture Survey Telescope for Energetic Radiation

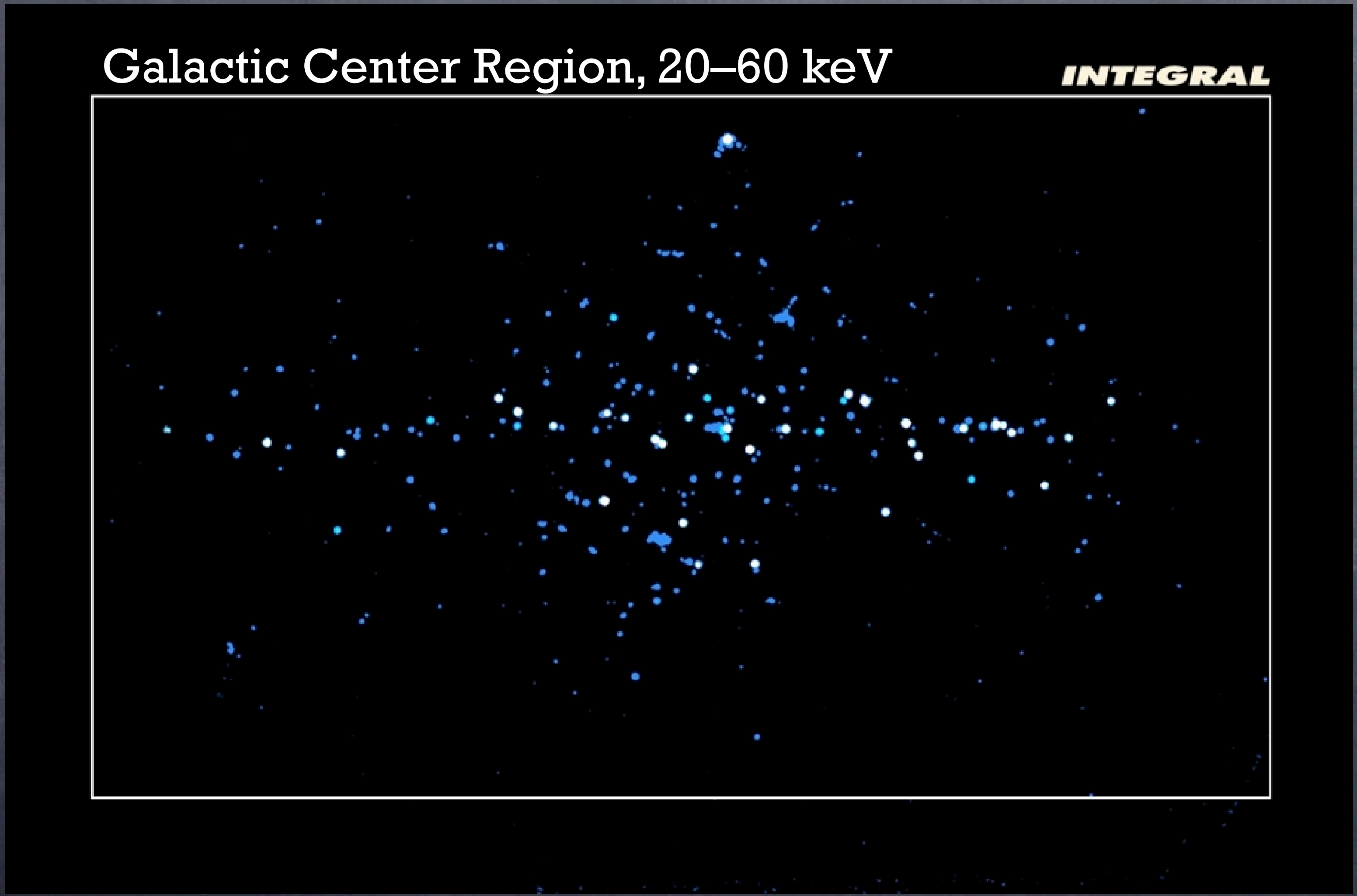
- Proposed as a mission concept for the Black Hole Finder Probe.
- Mission concept closely parallels that of EXIST.
- Coded aperture imaging (10-600 keV).
- Detectors based on new scintillator technologies.
- Implications for mission design?

Motivation for CASTER

- New scintillator and readout technologies.
- New scintillator with high light output :
  - Improved energy resolution
  - Improved spatial resolution
- Traditional technology simplifies implementation.
- Potential for low cost detector technology.
- Emphasize the importance (uniqueness) of observations at higher energies (up to ≈600 keV).

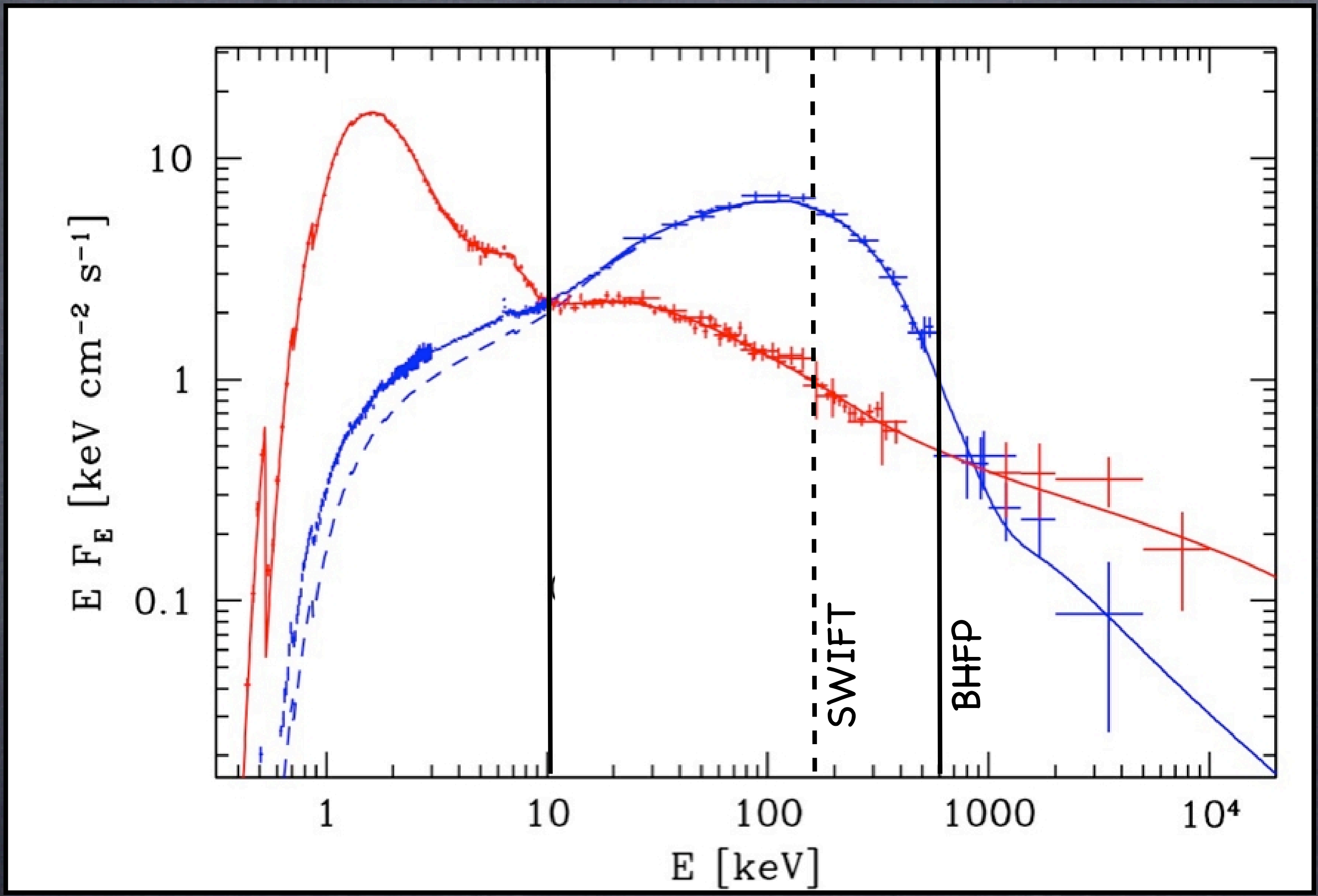
INTEGRAL Sky Map

Bird et al. 2004



91 sources, many involve black holes

Cyg X-1 State Comparison

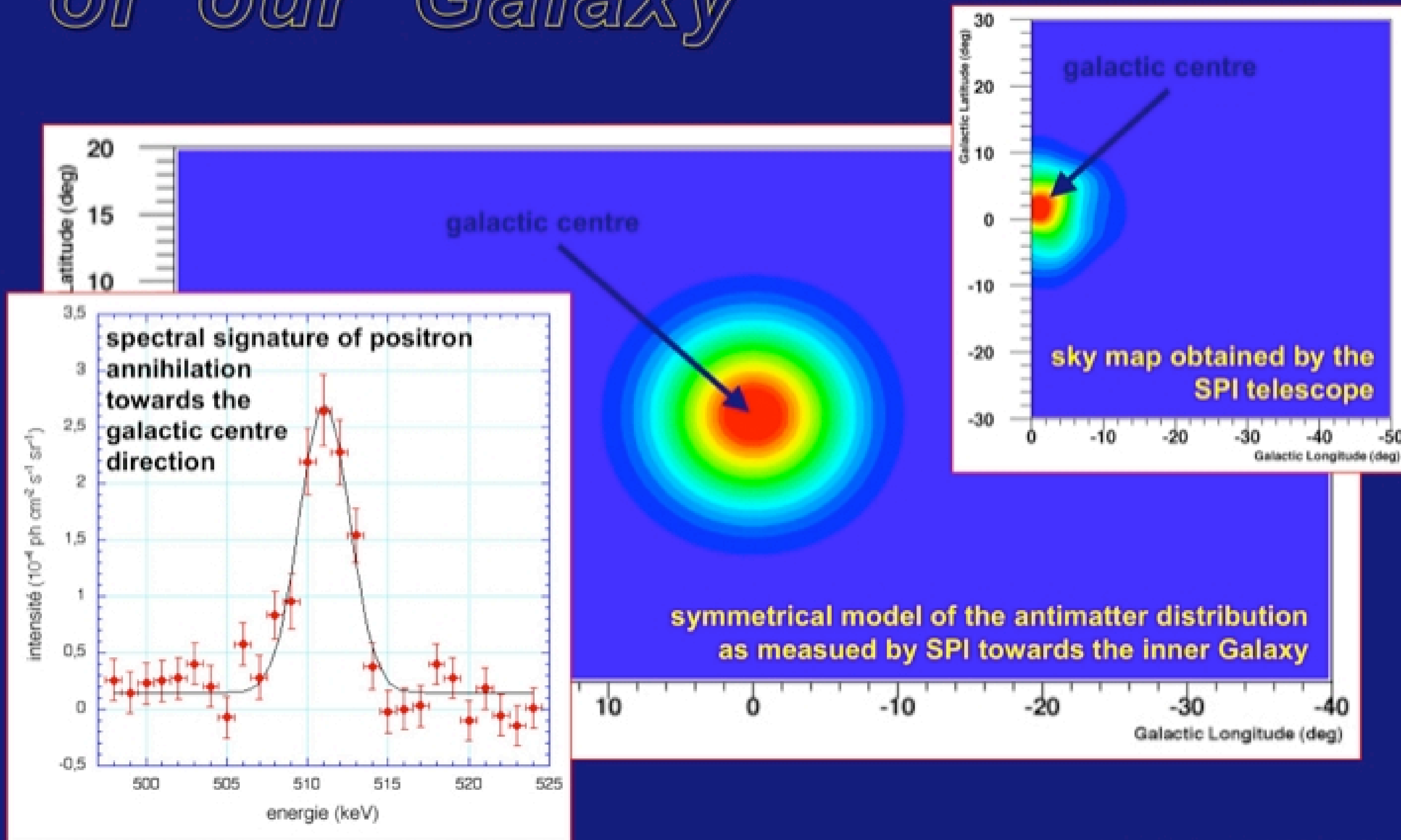


McConnell et al. 2002

Black Hole Spectra

- Observations up to 600 keV explore the range of thermal / non-thermal transitions.
- Cyg X-1 spectrum requires non-thermal component.
- What other sources exhibit similar behavior?
- What is link between galactic black holes and AGN?
- Role of pairs in accretion disk spectra?

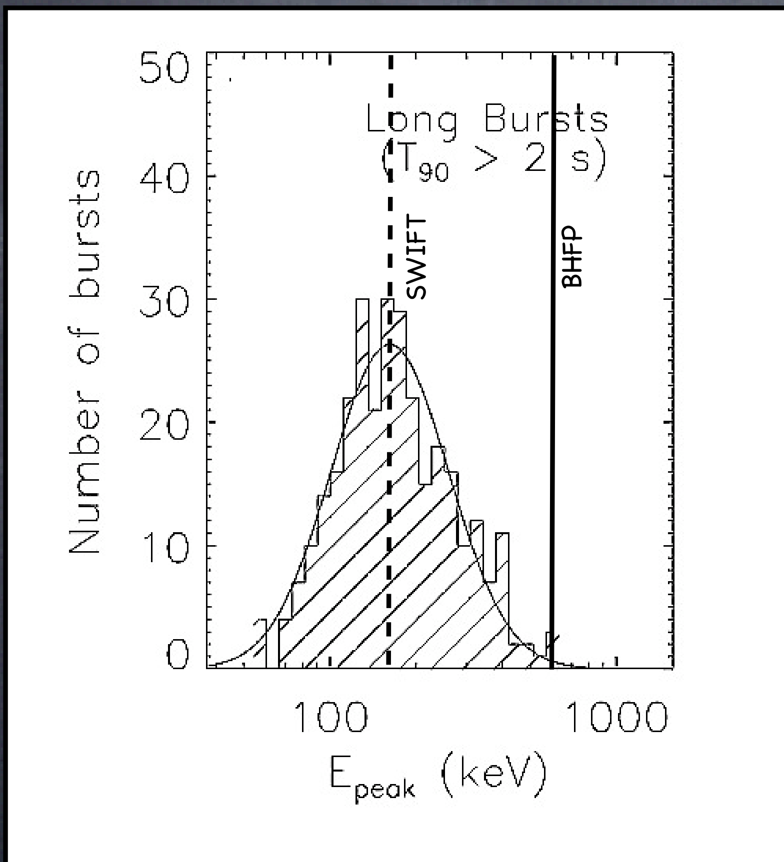
Antimatter in the centre of our Galaxy



Annihilation Radiation

- Origin of 511 keV diffuse emission (OSSE, SPI).
  - Contribution of point sources?
  - Supernovae Ia?
  - Hypernovae? (Casssé et al. 2004)
  - Light Dark Matter (LDM)? (Casssé et al. 2004)

GRB E_{peak} Distribution



- GRB spectra - smoothly broken power-law.
- Observed break energies up to several hundred keV.
- Spectral measurements require data both above and below the break energy.

Detector Requirements

- Energy range ≈ 10-600 keV
- Good stopping power for energies up to ≈600 keV
- Spatial resolution ≈ 1-2 mm in x, y, and z
- Availability in large areas and at low cost
- Energy resolution << NaI
- Environmental tolerance
- Good timing resolution

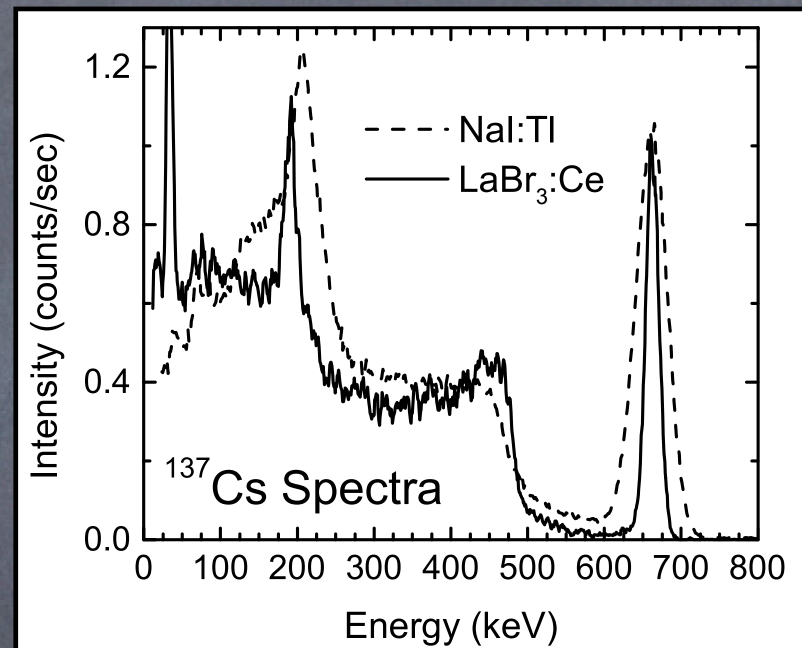
New Scintillator Technology

Lanthanum Bromide ($LaBr_3$)

- High Z material (comparable to NaI)
- High density (higher than that of NaI)
- Higher light output (60% more than NaI)
- Significantly improved linearity (E vs. light output)
- Significantly better energy resolution (<3% vs. 7%)
- Significantly faster decay (35 ns vs. 230 ns)

Energy Resolution

- $LaBr_3 \approx 2.7\%$ @ 662 keV
  $\approx 3.8\%$ @ 511 keV
  $\approx 6.8\%$ @ 122 keV



Comparable to CZT
(eV Products spectrometer grade, CPG detectors)

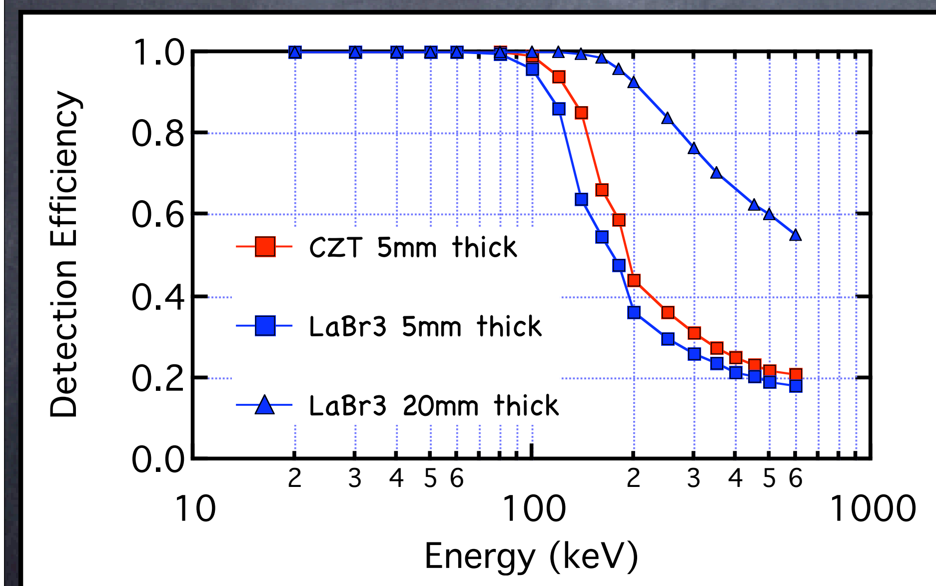
Comparable to Swift (Hullinger et al. 2004).

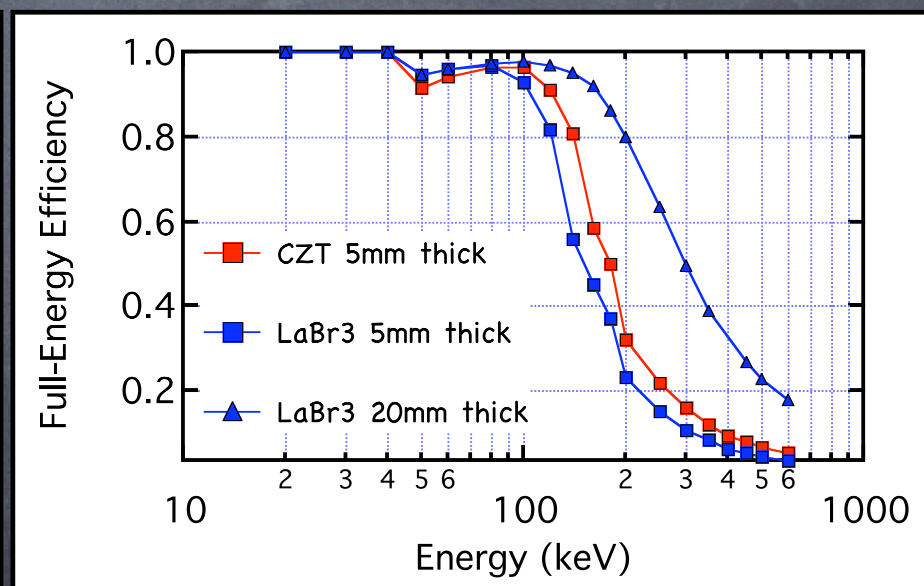
Detector Materials

	$LaBr_3$	$LaCl_3$	NaI(Tl)	CsI(Na)	BGO	CZT	Ge
Density	5.29	3.86	3.67	4.51	7.13	5.78	5.33
Light Output	63,000	49,000	39,000	39,000	9,000	N/A	N/A
ΔE/E (FWHM) @ 662 keV	<3%	4%	7%	7.5%	>10%	<3%	0.3%
Peak λ	358 -385	330 -352	415	420	480	N/A	N/A
Fast Decay	25	25	230	630	300	N/A	N/A

Stopping Power

- Thick scintillators are easier to fabricate.
- This gives a potential advantage at high energies.





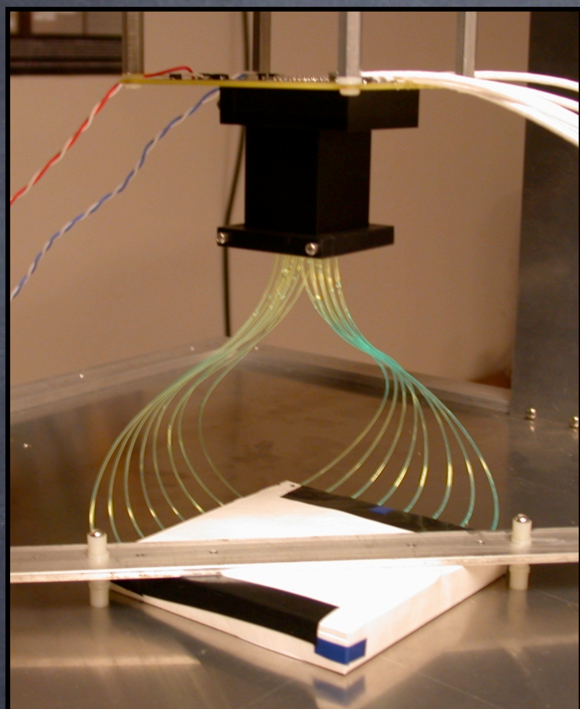
Spatial Resolution
Anger Camera Designs

- Performance will depend on several parameters :
  - light output of scintillator
  - thickness
  - energy

- Estimated resolution based on <u>increased light output</u>.

	Energy	Thickness	σ_{xy}	σ_{xy}
CsI(Tl) (NRL)	60 keV	4 mm	1-2 mm	0.8-1.6 mm
NaI(Tl) (Medical)	141 keV	9.5 mm	1.5 mm	1.2 mm
NaI(Tl) (SIGMA)	30 keV - 1 MeV	12.5 mm	2.5-5.0 mm	2.0-4.0 mm
NaI(Tl) (GRIP)	662 keV	5 cm	3.0 mm	2.4 mm

New Readout Technologies

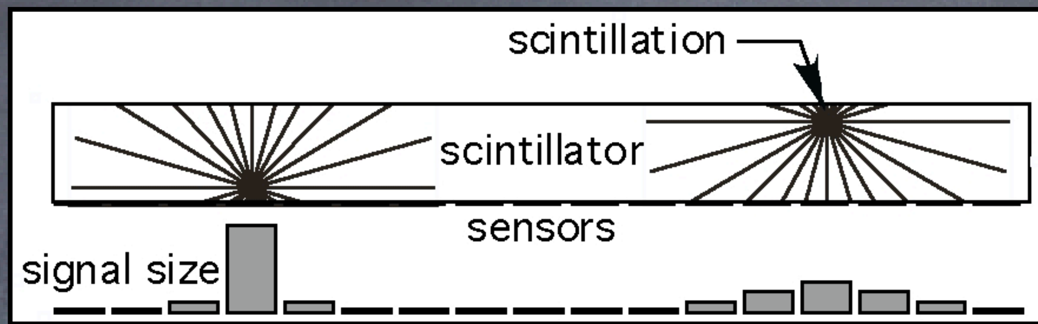


wavelength-shifting (WLS) fibers

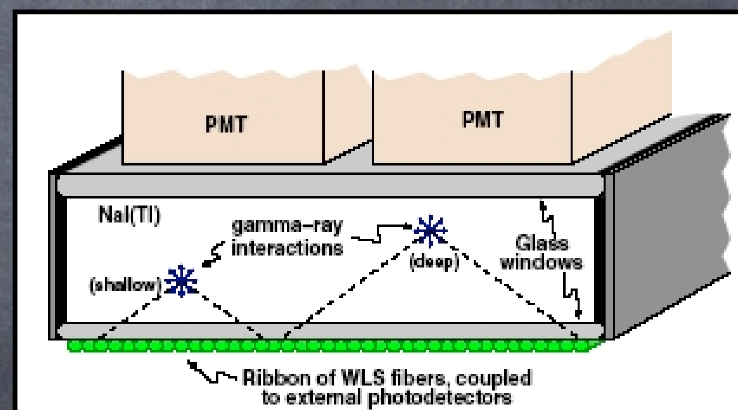
MCP-PMT (Burle)

Flat-Panel PMT (Hamamatsu)

Depth of Interaction



- WLS fiber ribbons can be used to determine depth of interaction (DoI).
- Depth measurement comes from light cone projected onto WLS ribbon.
- X-Y (and Z?) location and total energy provided by an array of PMT anodes.



Matthews et al. 2003

Availability of Detector Material

- Both $LaBr_3$ and $LaCl_3$ still under development
- A lot of interest (incl. medical)
- Development of $LaCl_3$ leads $LaBr_3$
- $LaCl_3$ is available commercially
- Largest $LaBr_3$ to date ≈ 2.3 cm^3
- Cost eventually < \$30 / cm^3

3″ x 3″ $LaCl_3$
(St. Gobain)
$\Delta E/E = 4.1\%$

Challenges

- Fabrication (availability) of new scintillator material
- Spatial resolution of ≈ 1-mm in x, y and z
- On-orbit background of LaX?
- Radiation effects on LaX?
- Handling of multiple interaction sites?
- Ability to do polarimetry?

Implications for Mission Design

- Thicker material ==> greater weight, background?
- Thicker mask ==> greater weight, background?
- Thicker detector/mask ==> restricted FoV?
- Separate low-energy and high-energy imagers?
- Daily sky coverage?

CASTER Mission Concept Study

- Continued Development of $LaBr_3$
- Detector Design Studies (various scintillators)
- Imager Design Studies
- Background Studies (beam tests, MGGPOD)
- Sensor Ruggedization
- Data Handling
- Spacecraft Design
- Mission Design

Summary

- Coded aperture imaging is an attractive way of doing a hard X-ray survey (10-600 keV).
- Alternative detector technologies are worth considering.
- The goal of the CASTER study will be to consider some of these alternative technologies and their implications for mission design.