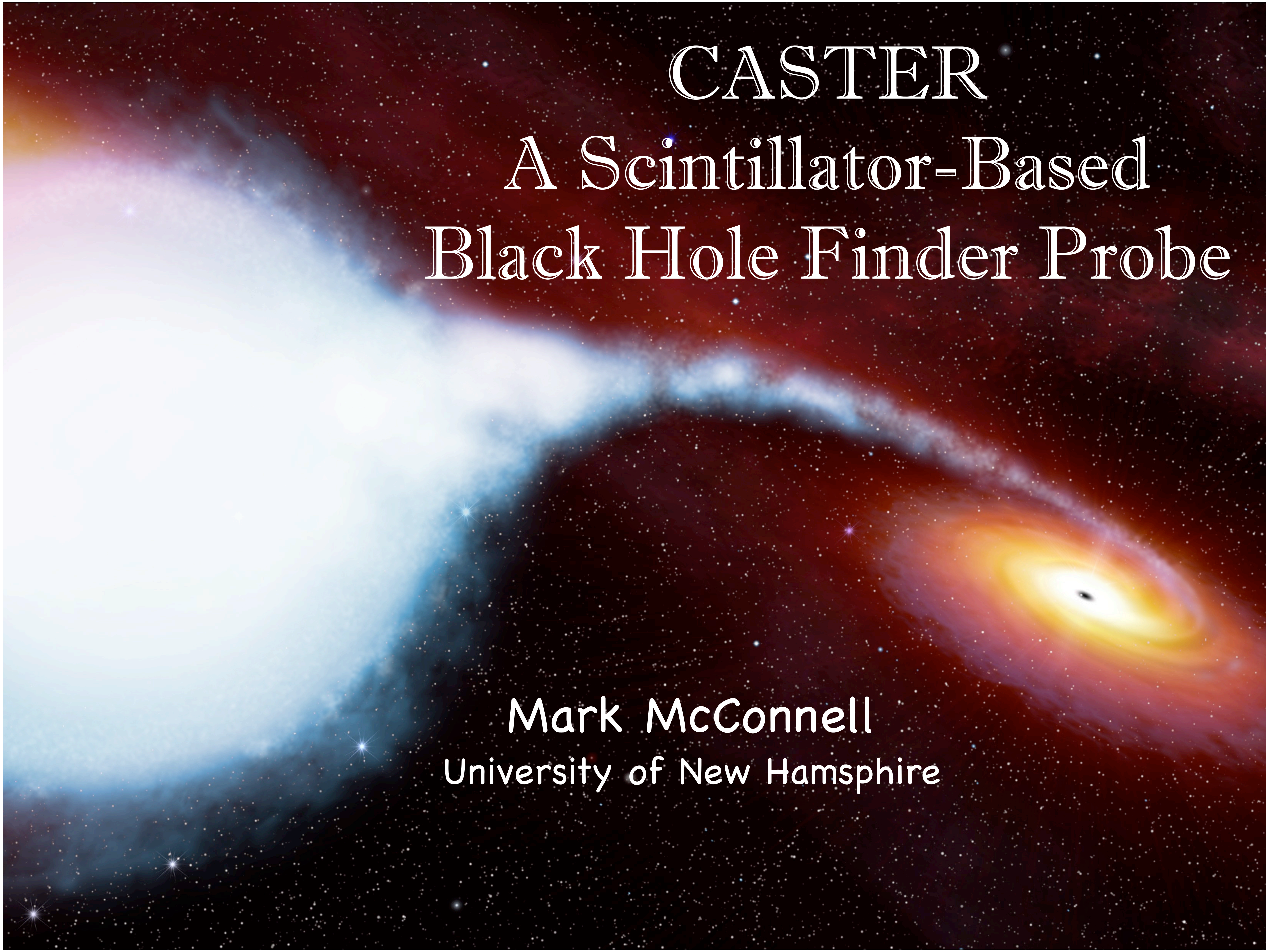

CASTER
A Scintillator-Based Black Hole Finder Probe

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The CASTER Cast

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CASTER

Coded Aperture Survey Telescope for Energetic Radiation

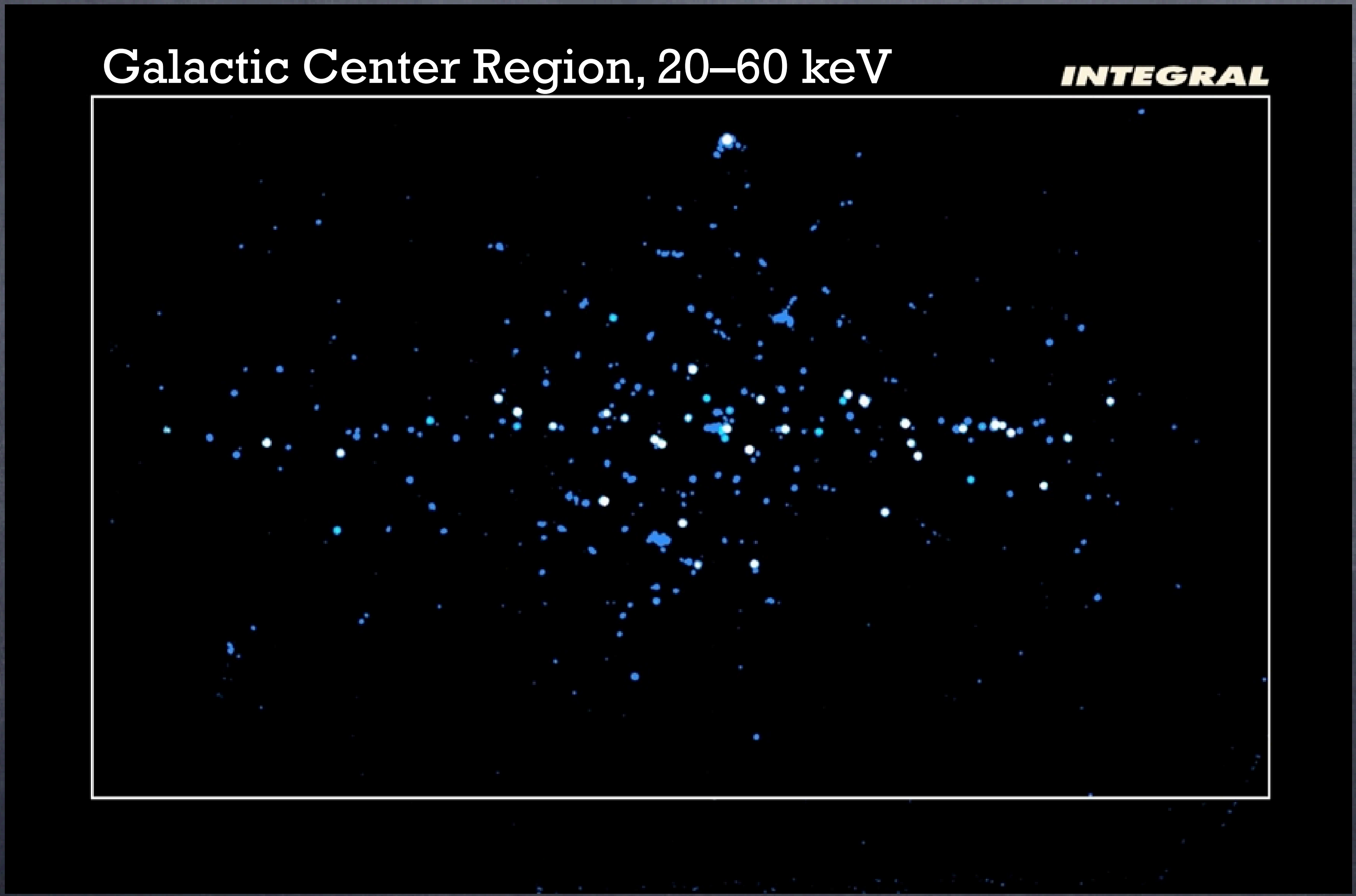
- Proposed as a mission concept for the Black Hole Finder Probe.
- Mission concept closely parallels that of EXIST.
- Coded aperture imaging – 10-600 keV.
- Detectors based on new scintillator technology.
- Implications for mission design?

Motivation for CASTER

- Revisit latest scintillator 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).

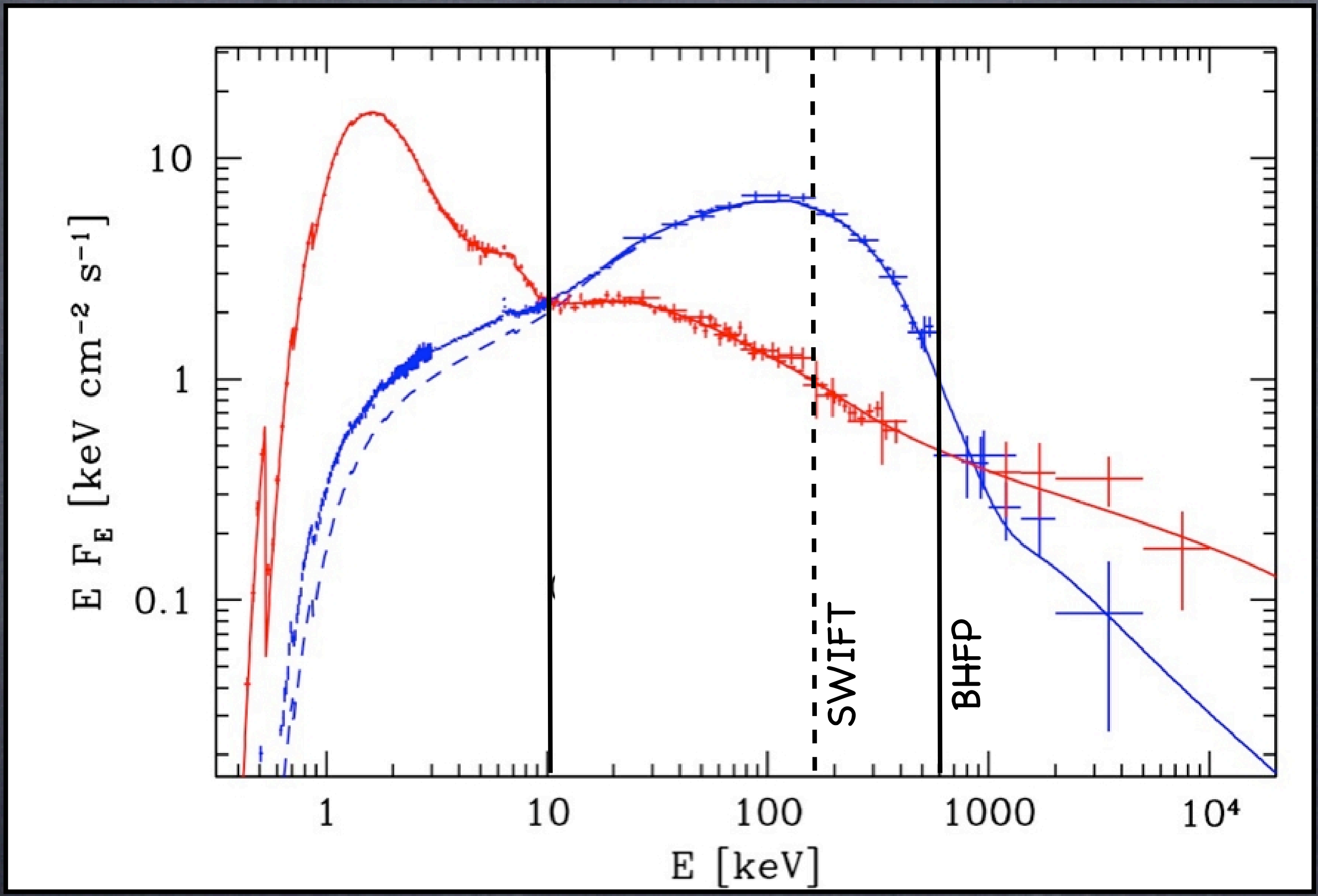
INTEGRAL Sky Map

Bird et al. 2004



91 sources, most probably involve black holes

Cyg X-1 State Comparison

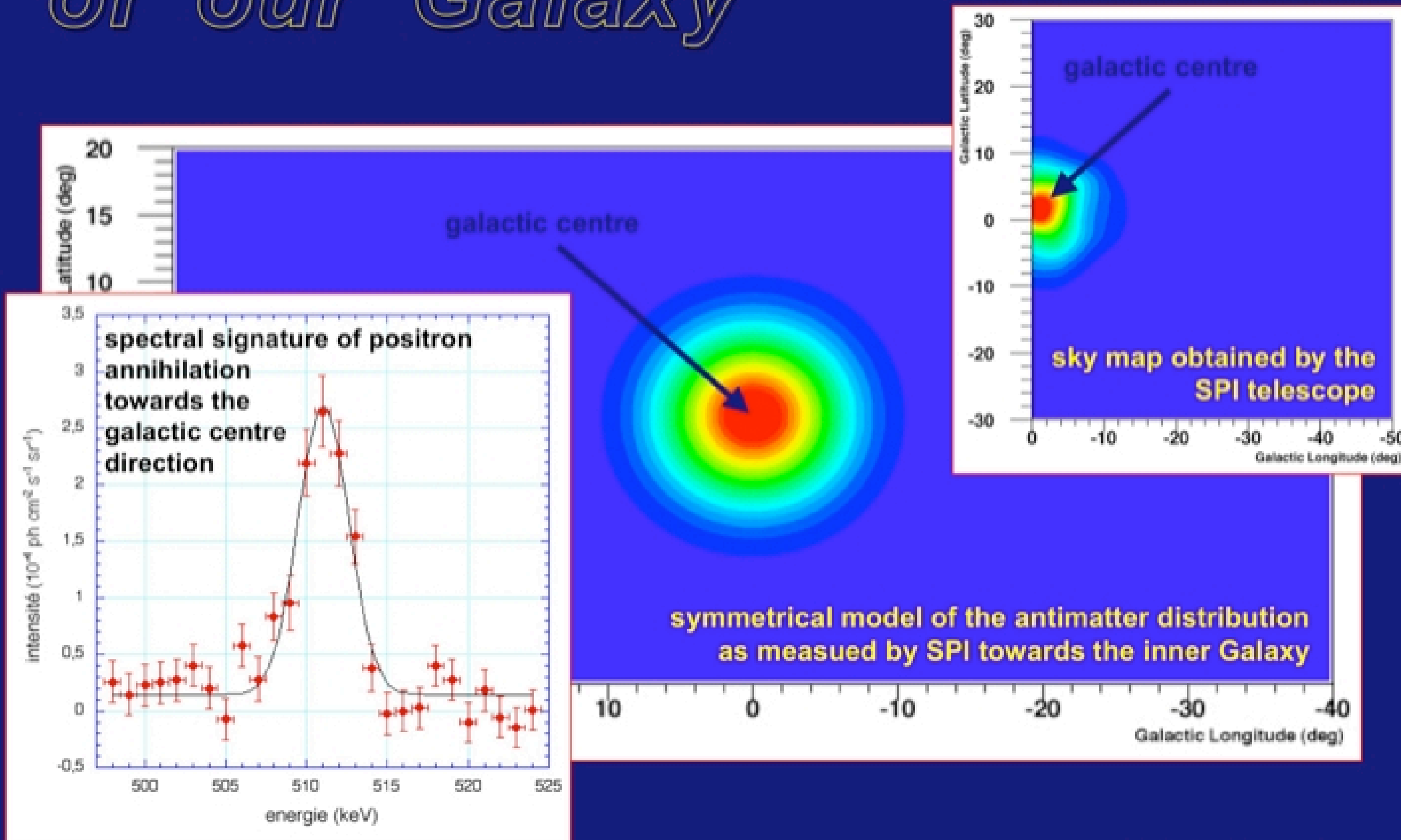


McConnell et al. 2002

Black Hole Spectra

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

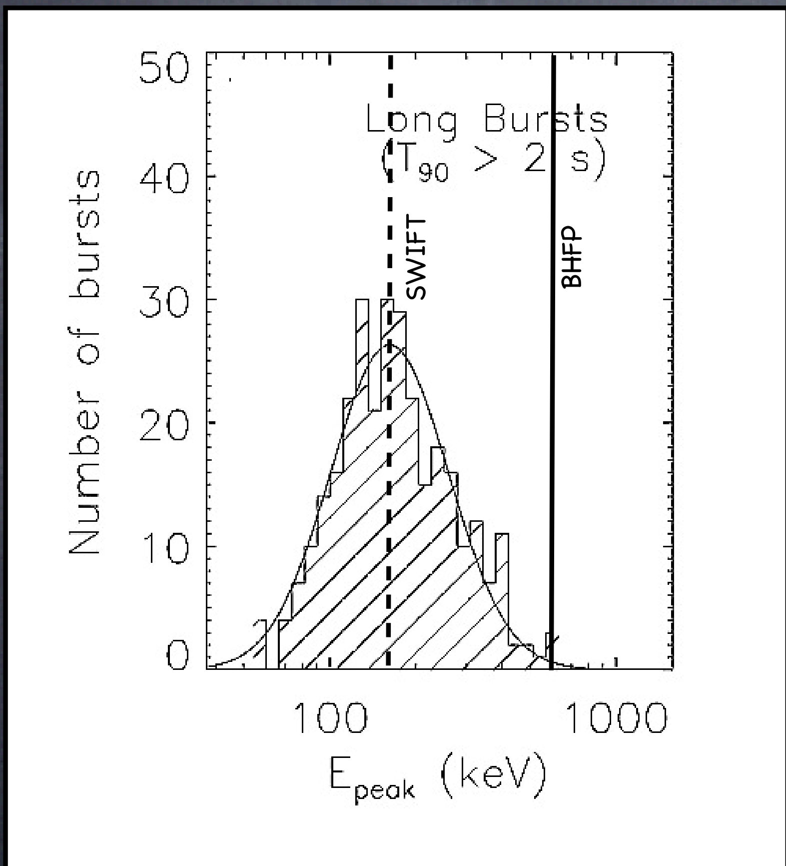
Antimatter in the centre of our Galaxy



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 ($LaBr_3$)
- Lanthanum Chloride ($LaCl_3$)
- 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)

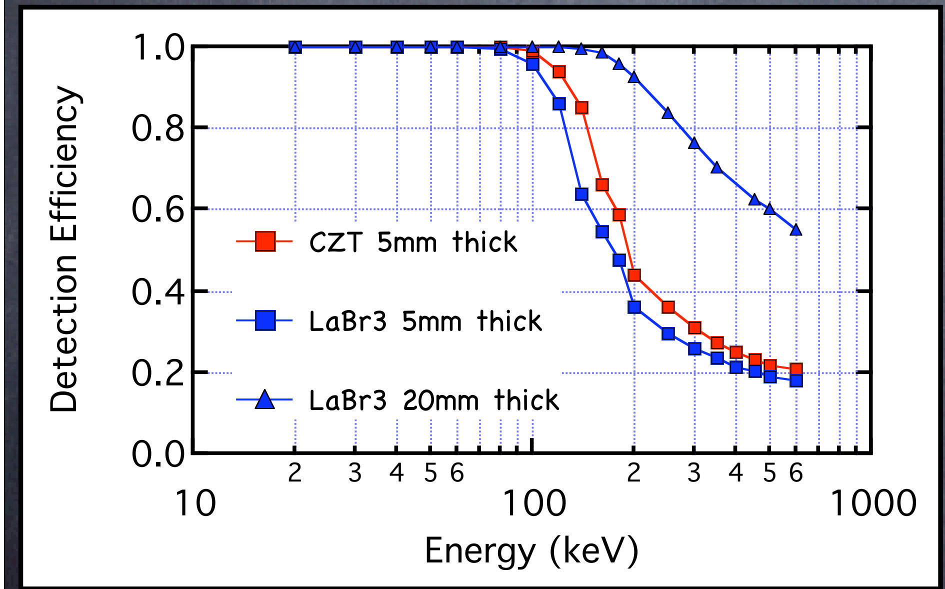
Scintillator Comparison

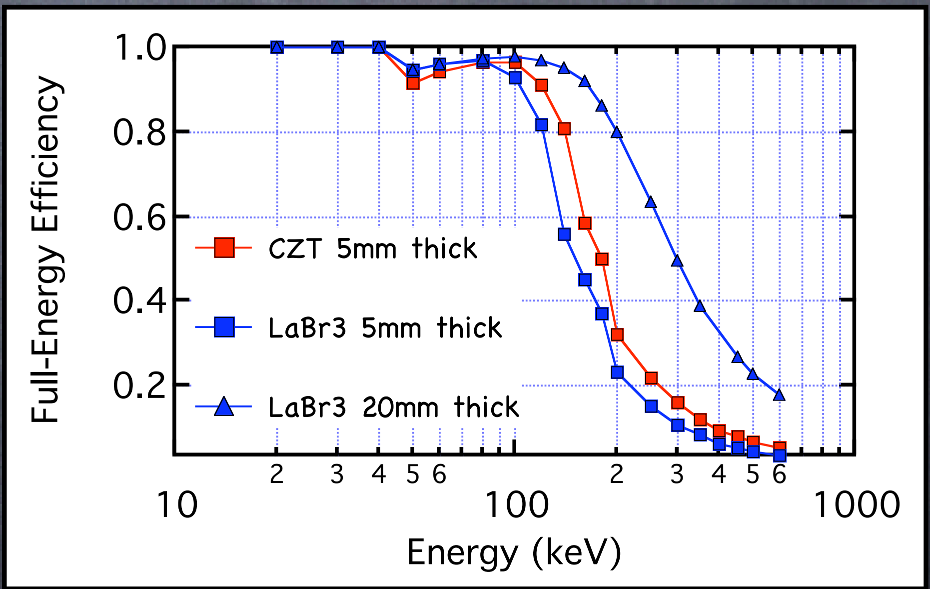
	NaI	$LaCl_3$	$LaBr_3$	BGO	LSO	LPS
Density (g/cm3)	3.67	3.86	5.29	7.13	7.4	6.23
Zeff	51	49.5	46.9	74	66	64.4
Optical Index	1.85	1.9-1.98 ?		2.15	1.82	
Light Output (ph/MeV)	39000	49000	63000	9000	28000	22000
Energy resolution 662 keV	7 %	3.5 %	3 %	> 10%	> 10%	> 10%
Fast Decay (ns)	230	25	35	300	40	30
Peak emission	415	330-352	358-385	480	420	380
Hygroscopy	YES	YES	YES	NO	NO	NO

SAINT-GOBAIN CRYSTALS & DETECTORS

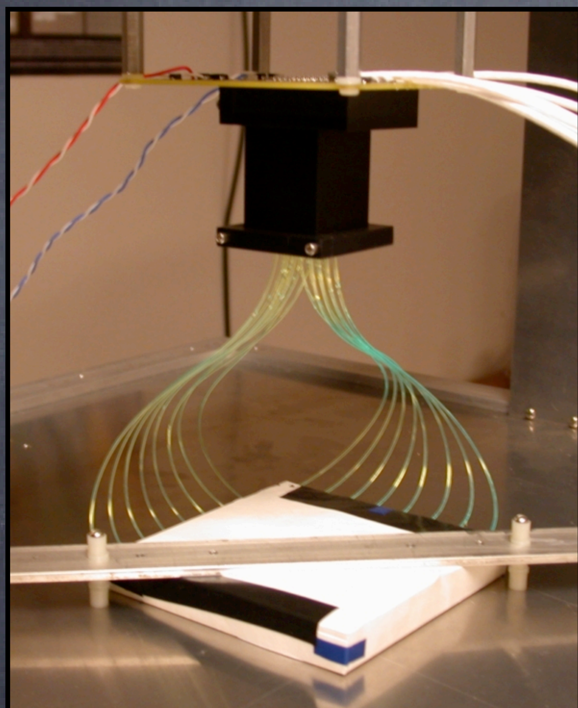
Stopping Power

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





New Readout Technologies



wavelength-shifting
(WLS) fibers

MCP-PMT (Burle)

Flat-Panel PMT (Hamamatsu)

Spatial Resolution
Anger Camera Designs

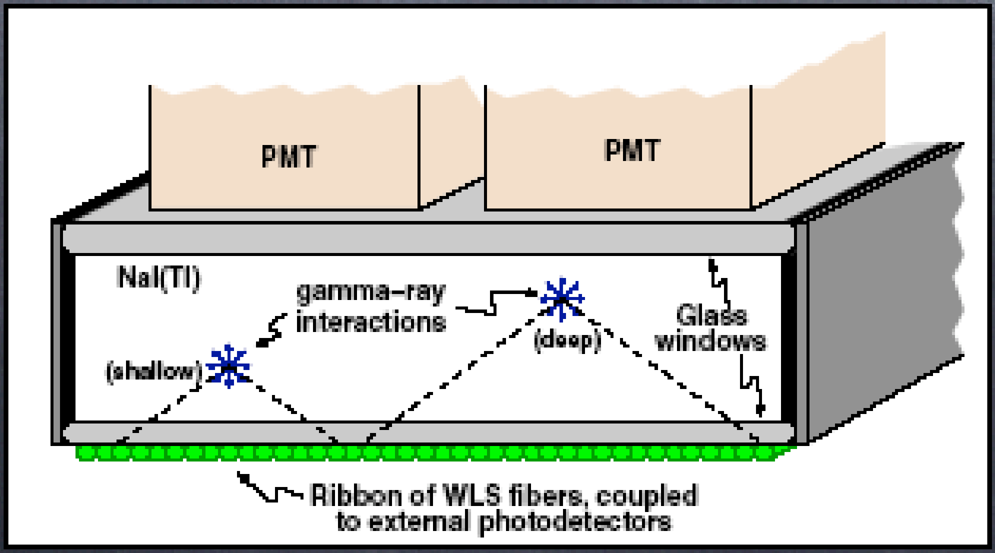
- Performance will depend on several parameters :
  - light output of scintillator
  - thickness
  - energy
- We can estimate the performance based only on increased light output.

Table 3. Anger Camera Examples

	Energy	Thickness	$\sigma_{x,y}$ (avg.)	$\sigma_{x,y}$ (w/$LaBr_3$)
CsI(Tl)/PSPMT (NRL)	60 keV	4 mm	1.0–2.0 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

Modified Camera Designs

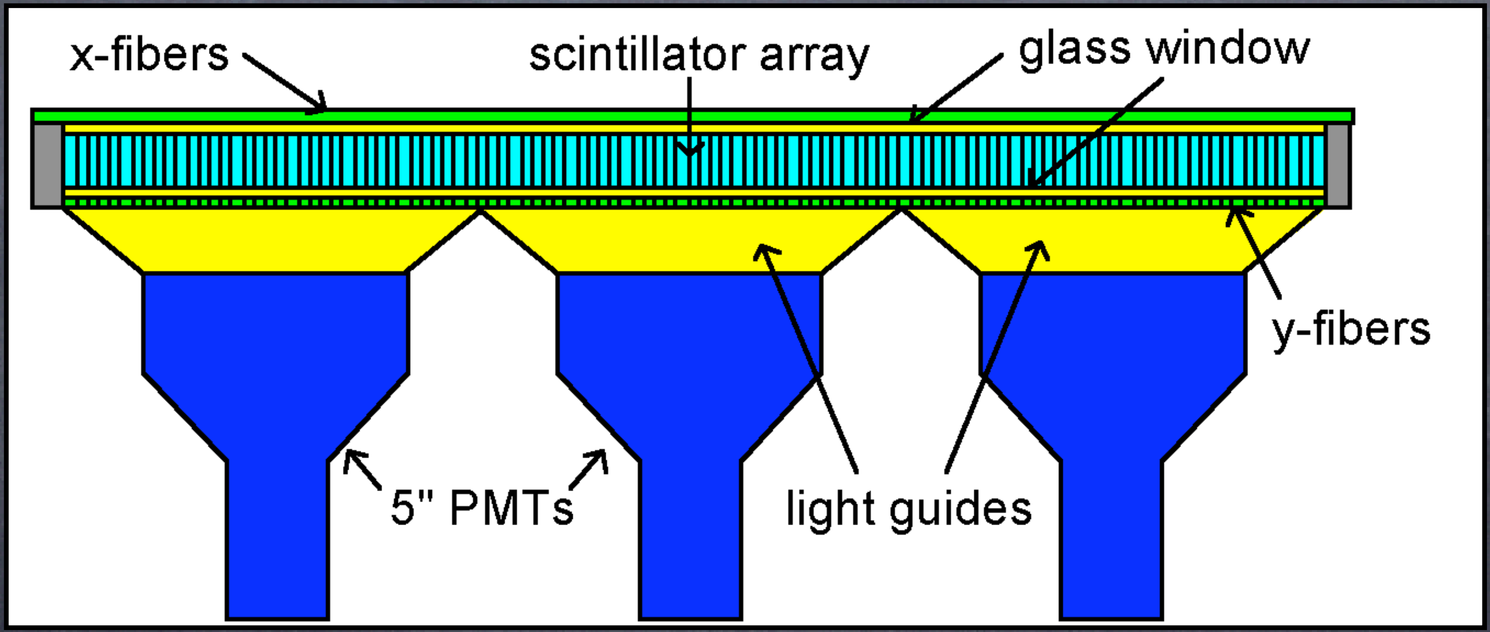
- WLS fiber ribbons can be used to determine depth of interaction (DoI).
- Depth measurement comes from a measure of the light cone projected onto WLS ribbon.
- X-Y (and Z?) location and total energy provided by an array of PMT anodes.



Matthews et al. 2003

Pixellated Scintillator Arrays

Pixellated arrays may be needed to concentrate light at lower energies.

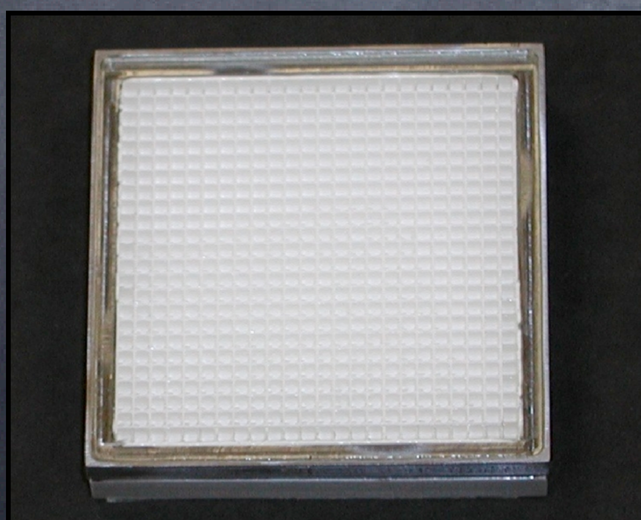


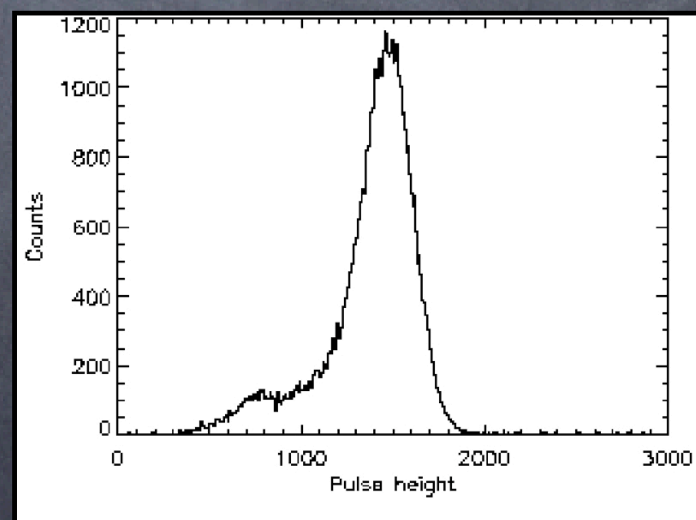
Cherry et al. 2004

At lower energies, depth measurement is not as important, but we need to get X-Y.

Pixellated Scintillator Arrays

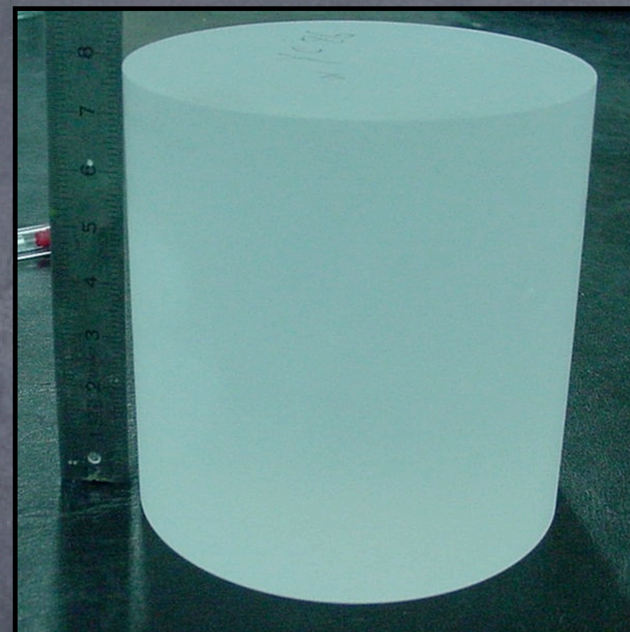
- Segmented CsI array from St. Gobain.
- Individual cells are 2 mm x 2 mm.
- Overall size is 5 cm x 5 cm x 0.6 cm thick.
- Energy resolution comparable to monolithic CsI (19% FWHM @ 60 keV)





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



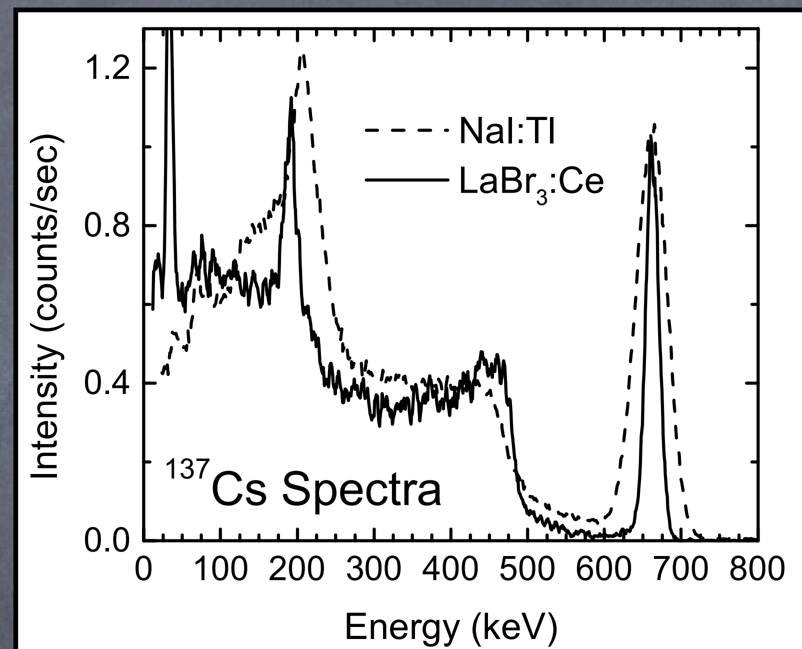
3″ x 3″ $LaCl_3$
(St. Gobain)
$\Delta E/E$ = 4.1%

Cost of Detector Material

- LaX fabrication geometries are expected to be like those of other inorganic scintillators.
- LaX costs are expected to be comparable to that of other inorganic scintillators.
- Cost < \$30 / cm^3.

Energy Resolution

- $LaCl_3$ ≈ 3.5% @ 662 keV
  ≈ 4.1% @ 662 keV
- $LaBr_3$ ≈ 2.7% @ 662 keV
  ≈ 3.8% @ 511 keV
  ≈ 6.8% @ 122 keV



Comparable to off-the-shelf CZT
(eV Products spectrometer grade, CPG detectors).

Comparable to Swift (Hullinger et al. 2004).

Background Issues

- Can be problematic for coded-aperture telescope.
- Fast response of LaX scintillator may make shielding more effective.
- Depth information can also be used to reject some level of background.
  - Thicker detectors do not necessarily imply a larger background.

Environmental Tolerance

- LaX is hygroscopic (like NaI)
- Response to large doses of radiation is unknown
  - induced background (activation)
  - radiation damage
- Beam tests are required (and planned)

Challenges

- Fabrication (availability) of new scintillator material
- Coverage of full energy range from 10 to 600 keV
- 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?

Technology Roadmap

- 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.

Final Thought...