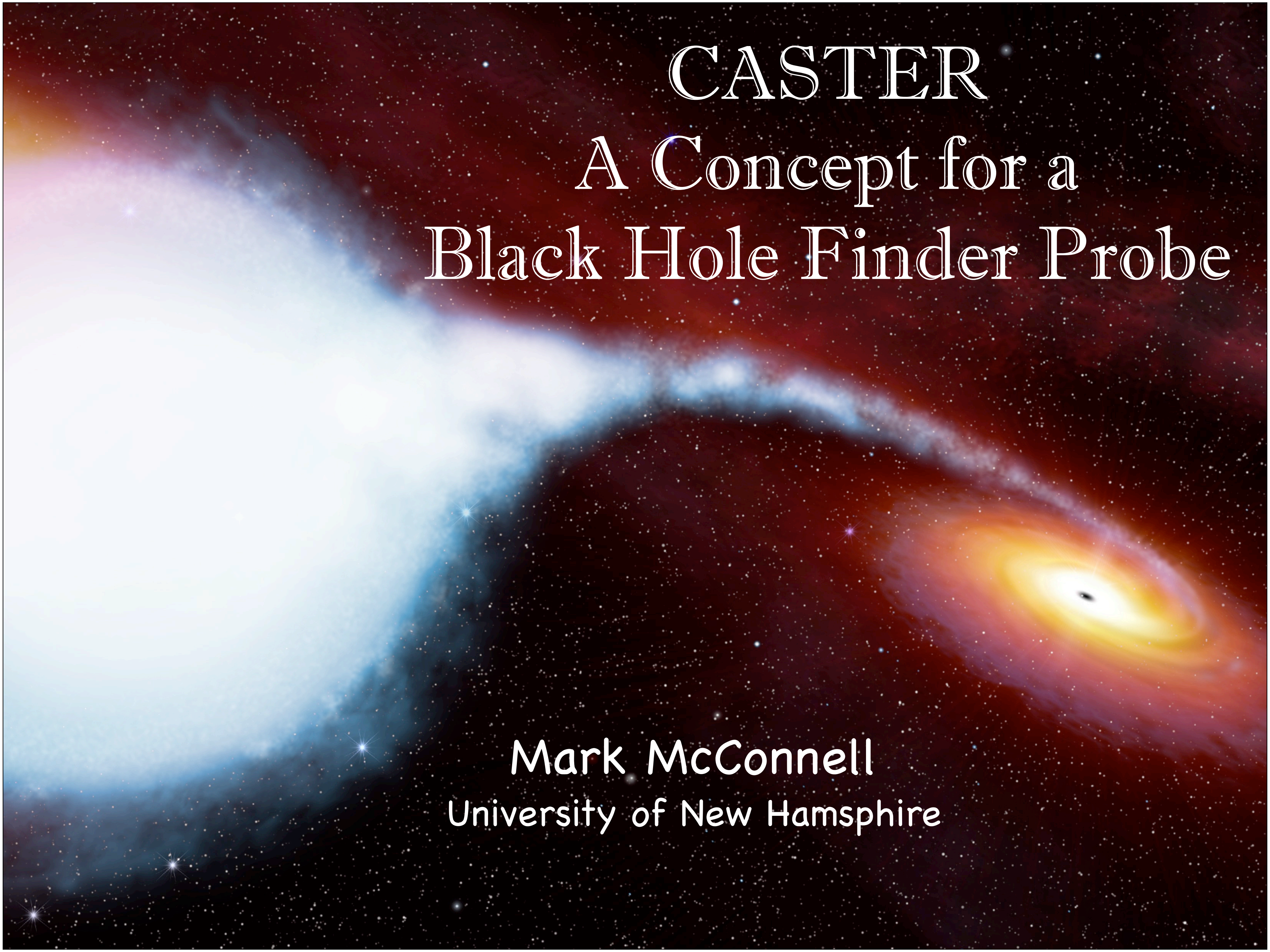

CASTER
A Concept for a Black Hole Finder Probe

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The CASTER Cast

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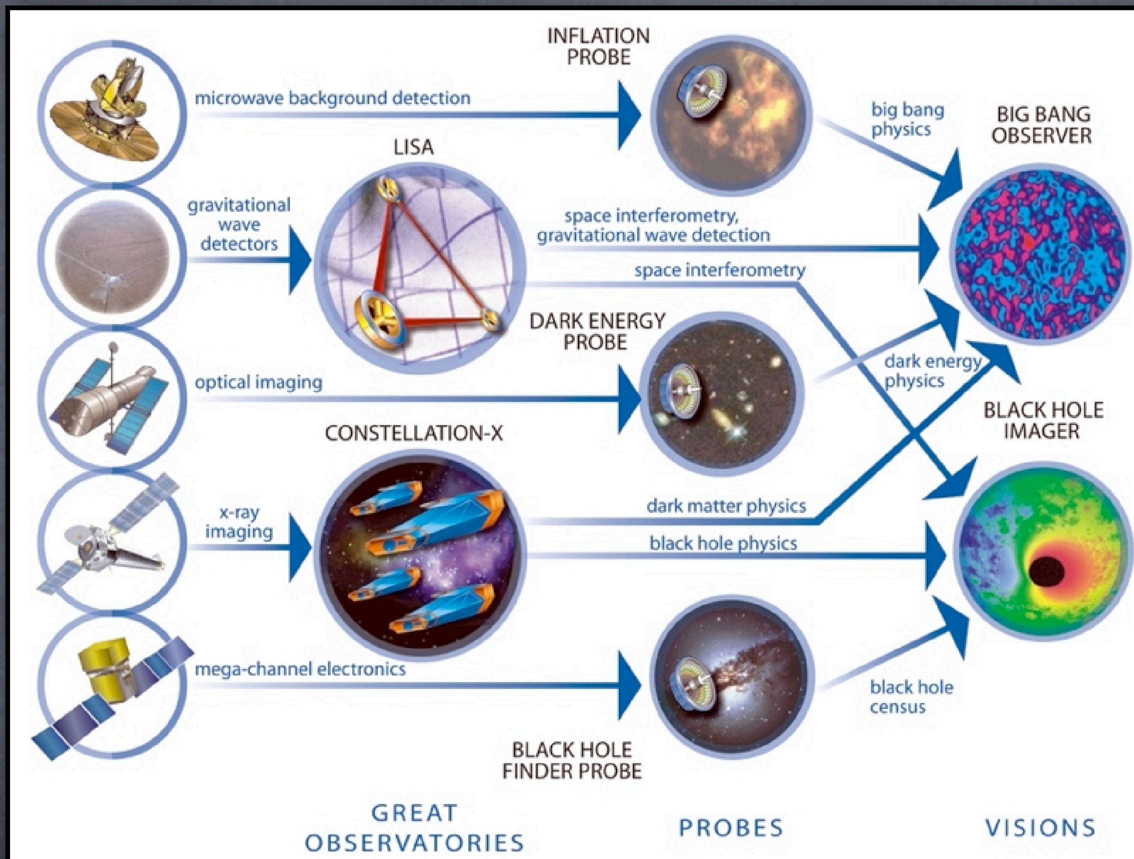
Beyond Einstein Roadmap



- Three Einstein Probes
- Expected launch date : 2012-2020

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

CASTER

Coded Aperture Survey Telescope for Energetic Radiation

- One of two mission concepts proposed for the Black Hole Finder Probe.
- Coded aperture imaging (10-600 keV).
- Detectors based on new scintillator technologies.

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).

The CASTER Payload

- Four High Energy Telescope (HET) modules
  - 50-600 keV
  - detector area (total) ≈ 6.0 m^2
  - $\Delta\theta \approx 10'$
- Two Low Energy Telescope (LET) modules
  - 50-600 keV
  - detector area (total) ≈ 3.0 m^2
  - $\Delta\theta \approx 10'$
- The FoV for each array will be 60° x 120°
- Zenith-pointed mode will scan much of the sky every orbit.

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

Scintillator Materials

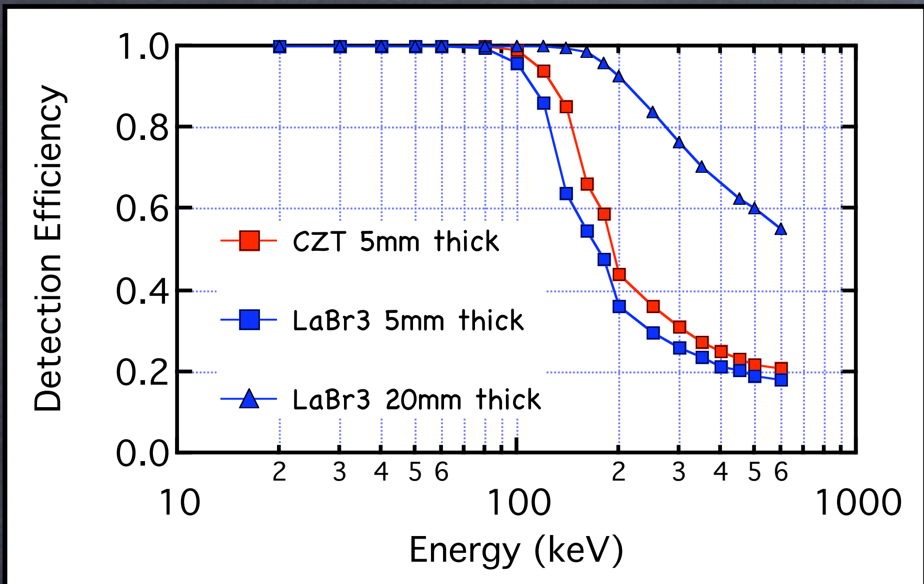
	$LaBr_3$	$LaCl_3$	LuI_2	NaI(Tl)	CsI(Na)	BGO
Density	5.29	3.86	5.6	3.67	4.51	7.13
Light Output photons/MeV	63,000	49,000	>50,000	39,000	39,000	9,000
$\Delta E/E$ @ 662 keV	<3%	4%	10%	7%	7.5%	>10%
Peak λ (nm)	358-385	330-352	475	415	420	480
Fast Decay (ns)	25	25	23	230	630	300

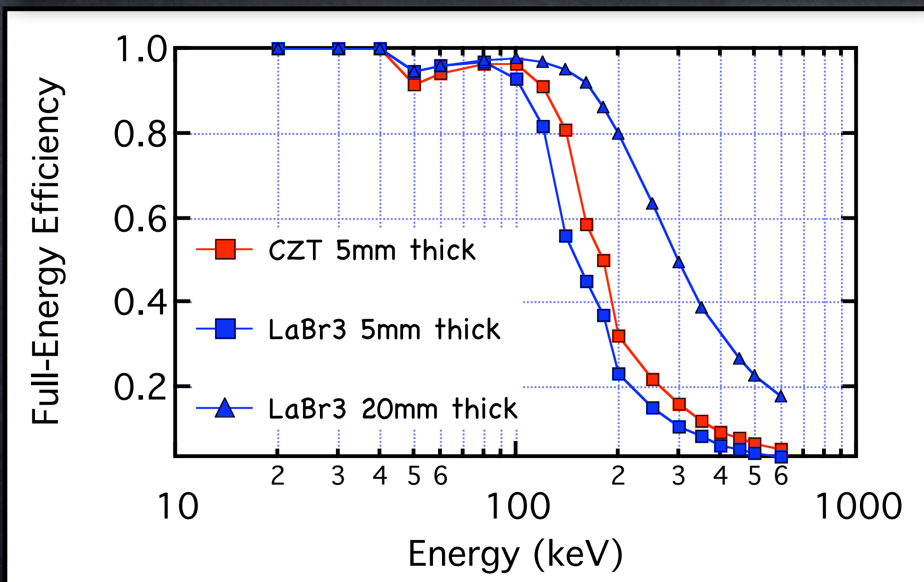
New Scintillator Technology

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)

Stopping Power





- Comparable to CZT.
- Thick scintillators are easier to fabricate.
- At higher energies, scintillators may offer a significant advantage.

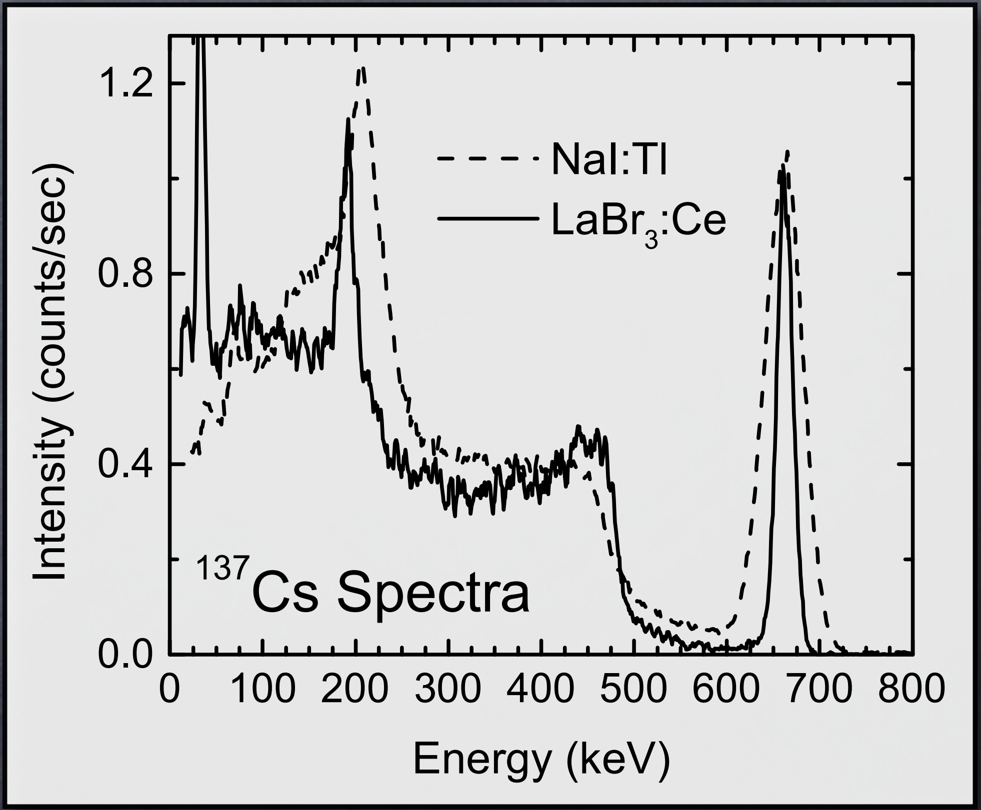
Energy Resolution

Lanthanum Bromide ($LaBr_3$)

≈ 2.7% @ 662 keV
≈ 3.8% @ 511 keV
≈ 6.8% @ 122 keV

Comparable to CZT

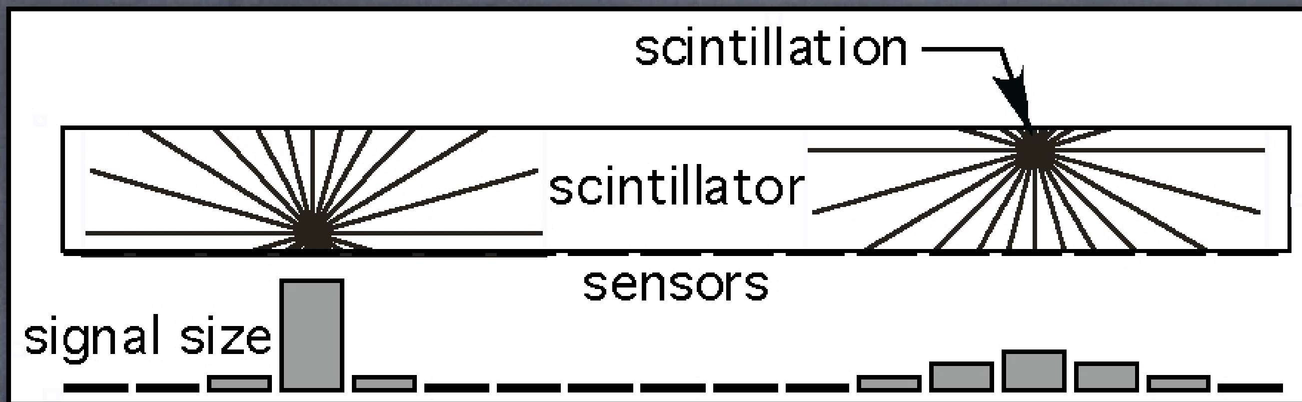
Comparable to Swift
(Hullinger et al. 2004).



Scintillator Imaging

- Goal is to achieve spatial resolution of ≈1-2 mm in all three dimensions (x, y, z).
- Performance will depend on several parameters :
  - light output of scintillator
  - thickness of scintillator
  - energy
- Imaging configurations :
  - Traditional Anger Camera Imaging
  - Depth-Encoding Anger Camera
  - Cross-Fiber Readout

Depth of Interaction



- Depth measurement comes from light cone projected onto sensor array.
- The number of triggered sensors provides a measure of depth.

Anger Camera Imaging

An array of sensors can be used to determine the x-y interaction location.

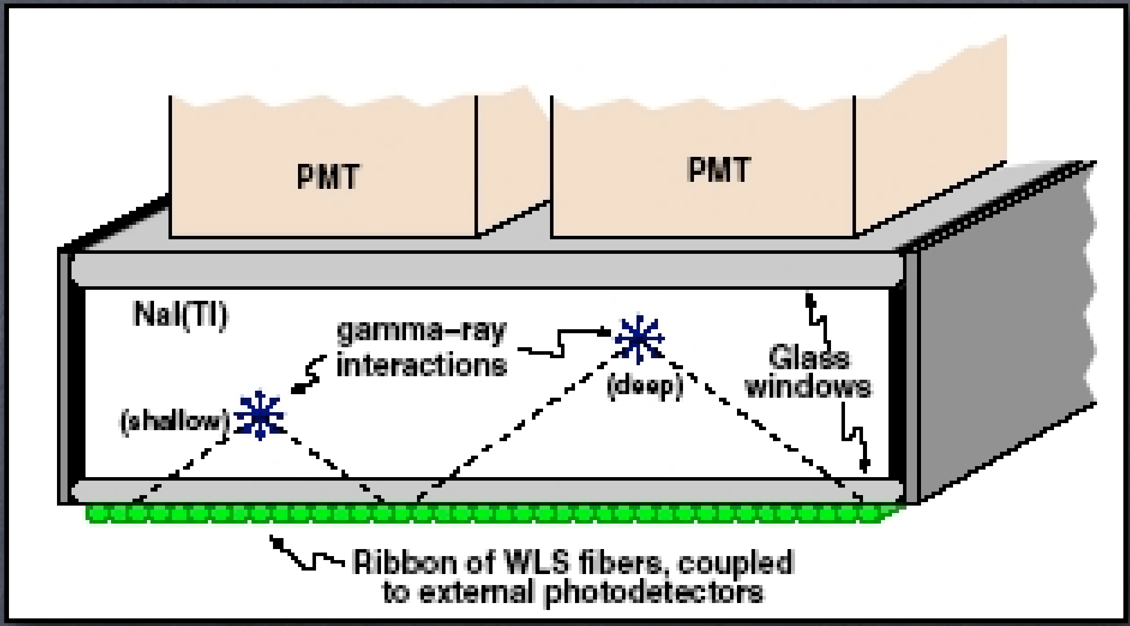
Studies at UAH and UNH will be providing results for $LaBr_3$ and $LaCl_3$ using latest technologies.

Simulation tools are also being developed.

MCP-PMT (Burle)

Flat-Panel PMT (Hamamatsu)

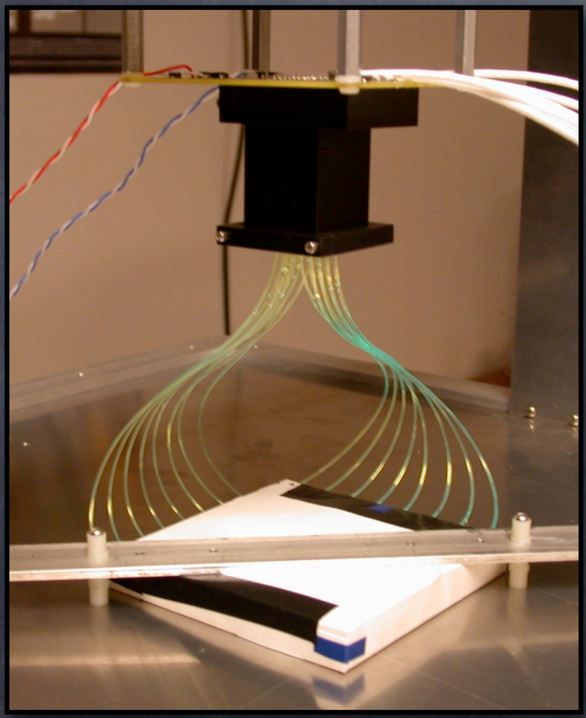
Depth-Encoding Anger Camera



Matthews et al. 2003

- WLS fiber ribbons used to determine depth.
- X-Y location and total energy provided by an array of PMT anodes.

Crossed Fiber Readout

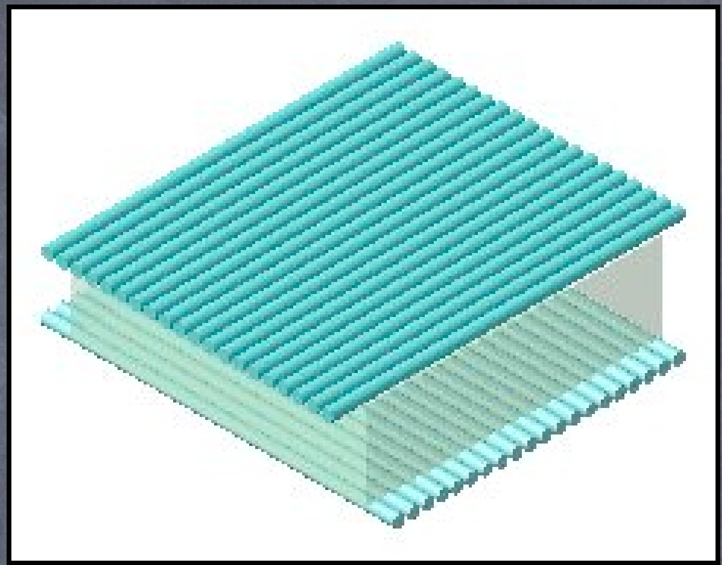


Bravar (2005)
paper 5901-20

- Use of orthogonal WLS fibers for light readout can be used to determine x-y.
- Tests have been made (UNH) using plastic scintillator.
- Same approach could also be used for crystals.

Crossed Fiber Readout

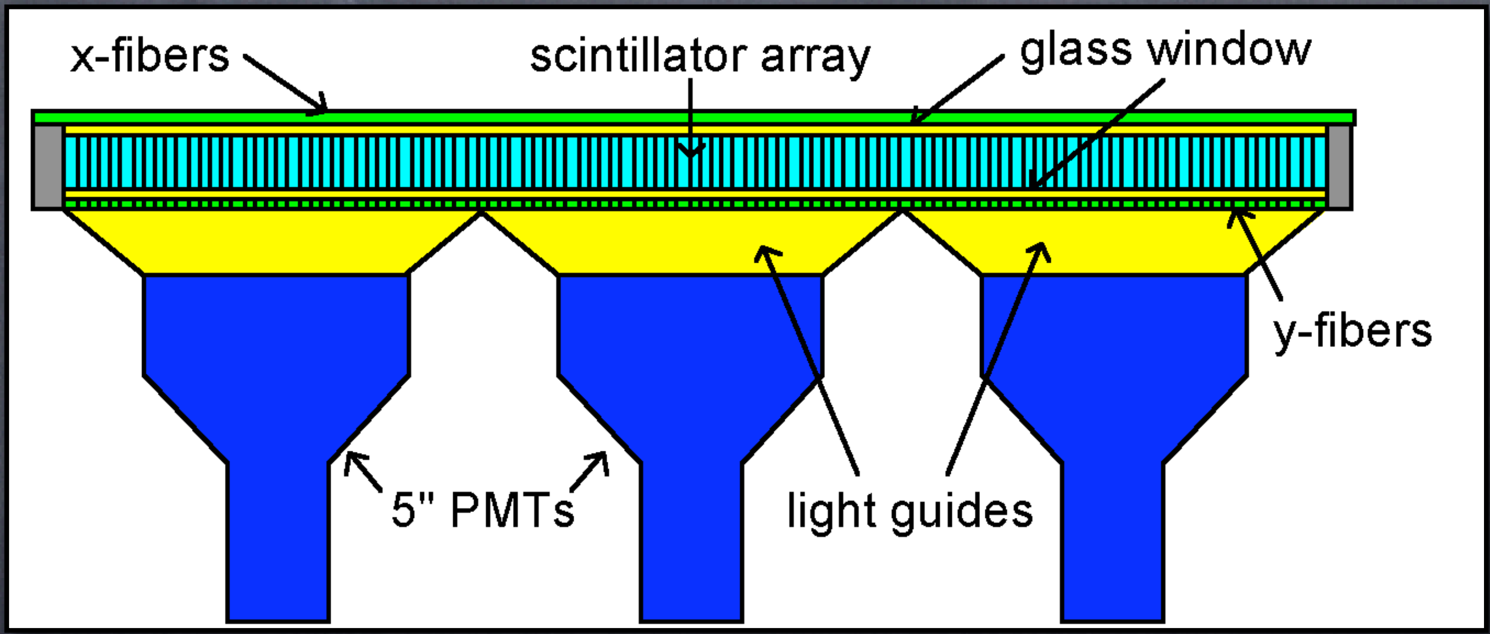
Case et al. (2005) - paper 5898-21



- LSU is developing a coded aperture imager for homeland security.
- HISGRI - High Sensitivity Gamma Ray Imager.
- Initial tests with $LaBr_3$ and $LaCl_3$ are promising.

Pixellated Scintillator Arrays

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



Cherry et al. 2004, Case et al. (2005) - paper 5898-21

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

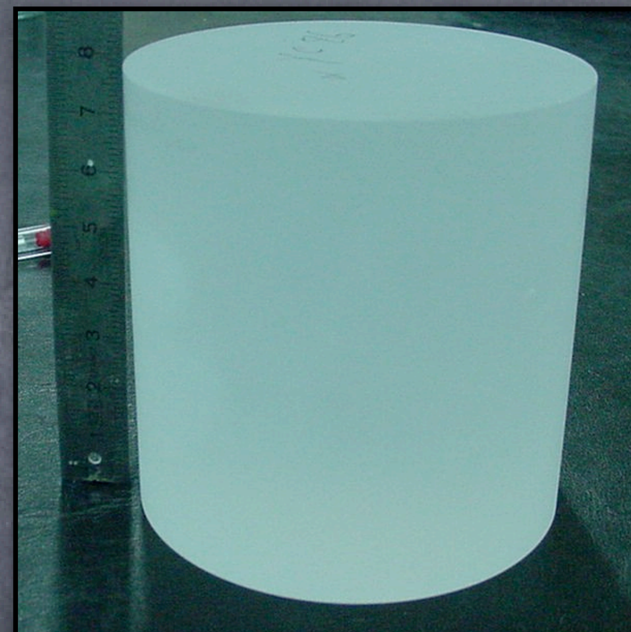
Outstanding Issues

Lanthanum Bromide ($LaBr_3$)

- Availability in large volumes
- Intrinsic background
- Radiation hardness
- Activation
- Background at balloon altitudes
- Background at orbital altitudes

Availability of Detector Material

- Both $LaBr_3$ and $LaCl_3$ still under development (St. Gobain, RMD)
- $LaCl_3$ - BrilLanCe™ 350 (2″)
- $LaBr_3$ - BrilLanCe™ 380 (1.5″)
- No fundamental barriers to larger volumes



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

Ongoing Activities

- **Radiation Beam Tests (UNH) -**
  To evaluate the sensitivity (radiation hardness and activation) of $LaBr_3$ and $LaCl_3$ to various forms of radiation.

- **Balloon Background (UAH, LSU) -**
  Sample crystals will be flown on a balloon flight this fall (2005).

- **Orbital Background Modeling (LANL, UNH) -**
  Estimates of the orbital background will be derived from MMGPOD suite of simulation tools (Weidenspointner et al. 2005).

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 mission concept study will be to consider some of these alternative technologies and their implications for mission design.

Other Challenges

- Spatial resolution of ≈ 1-mm in x, y and z
- 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

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.

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)

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

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)