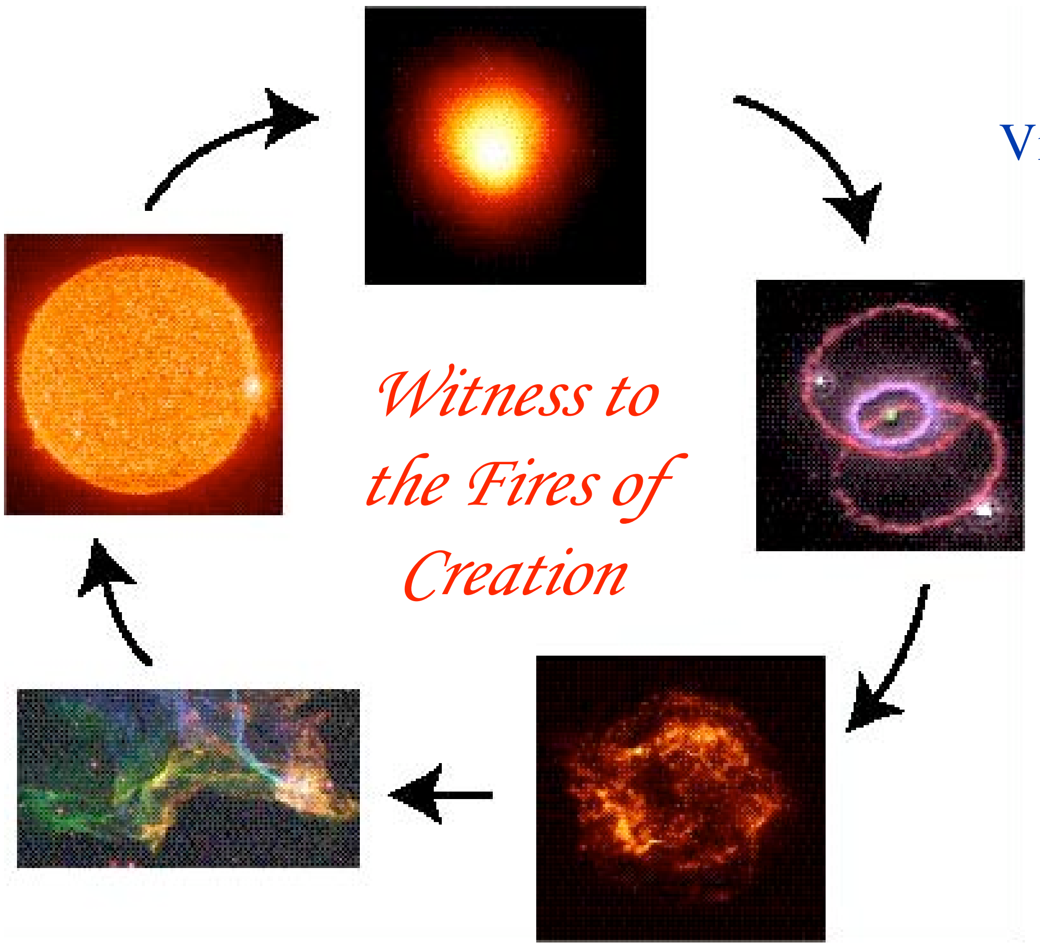
The Advanced Compton Telescope



Vision Mission Concept Study (3/04)

> *"to uncover how supernovae and other stellar explosions work to create the elements"*
>
> -SEU Roadmap 2003

Steve Boggs
for the ACT Team
University of California, Berkeley

GLAST 2007, Stanford University

ACT Overview

Enable high sensitivity γ-ray spectroscopy

Life Cycles of Matter

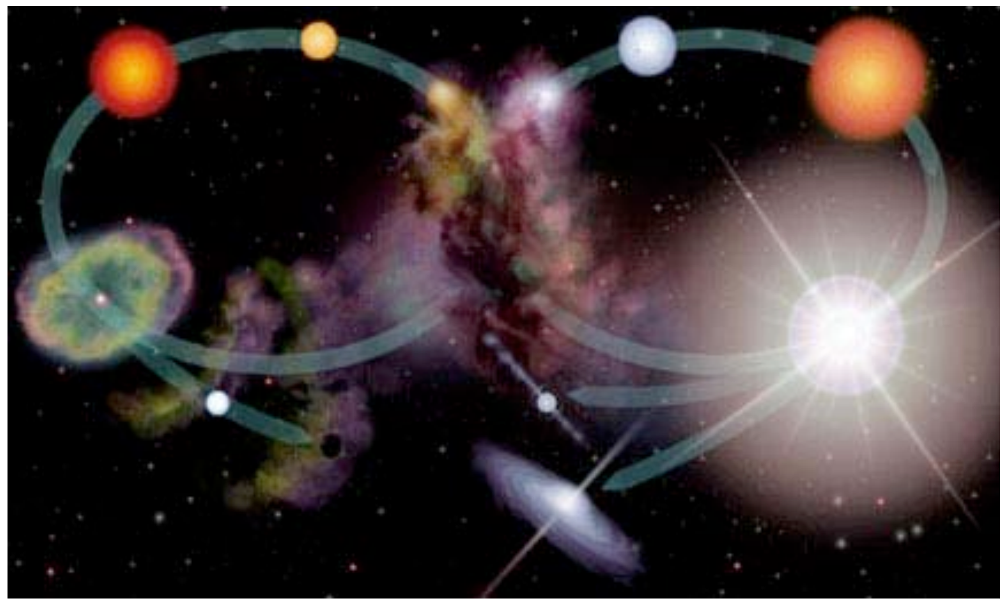
- ✓ Supernovae & nucleosynthesis
- ✓ Supernova remnants & interstellar medium
- ✓ Neutron stars, pulsars, novae

Black Holes

- ✓ Creation & evolution
- ✓ Lepton vs. hadron jets
- ✓ Deeply buried sources

Fundamental Physics & Cosmology

- ✓ Gamma-ray bursts & first stars
- ✓ History of star formation
- ✓ MeV dark matter

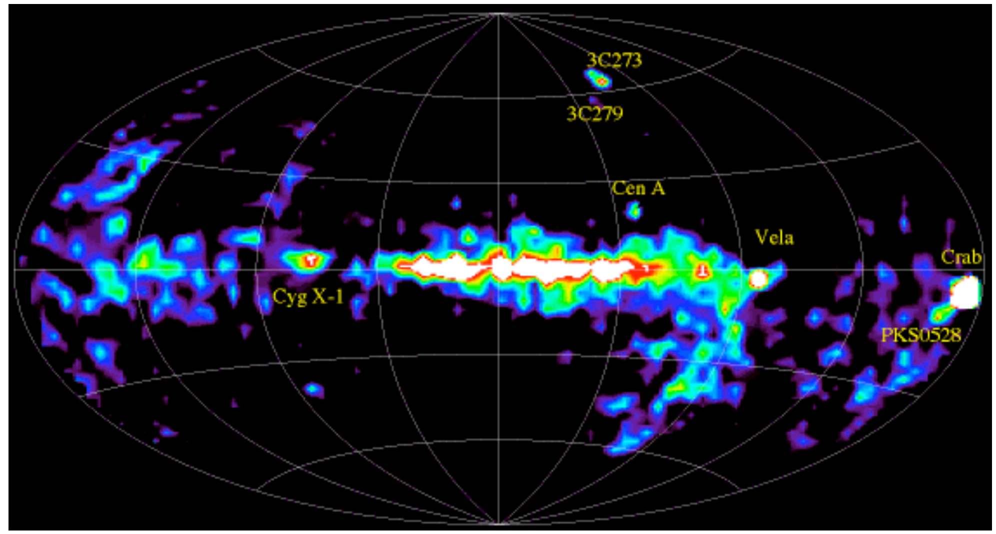


- 100× sensitivity improvement for spectroscopy, imaging & polarization (0.2-10 MeV)
- Advanced 3-D positioning γ-ray spectrometers, 25% sky field-of-view
- LEO equatorial orbit, zenith-pointing survey mode (baseline mission), 80%/orbit

Cosmic High Energy Laboratories

Why MeV gamma-rays?

COMPTEL 1-30 MeV Source Catalog



(Schönfelder et al. 2000)

Unique 0.2-10 MeV Science
- nuclear lines
- e-/e+ mass, annihilation
- peak emission: AGN, BHs, GRBs
- polarization

Sources (5 yr)	COMPTEL	ACT
Supernovae	1	100-200
AGN	15	200-500
Galactic	23	300-500
GRBs	31	1000-1500
Novae	0	25-50

"…to explore the profound mysteries of life, space, time and the workings of the universe."

-NASA Space Science Enterprise Strategy 2003

Type Ia Supernovae

Cosmic Yardsticks, Alchemists

Goal: study ^{56}Ni & ^{56}Co emission from the core of Type Ia supernovae.

1. **Standard candles** -- characterize the ^{56}Ni production, relation to optical
2. **Explosion physics** -- uniquely distinguish explosion physics
3. **SNe Ia rate, local & cosmic** -- direct rates unbiased by extinction

We define the science requirements in terms of the following objective:

ACT must be able to strongly distinguish typical deflagration models from delayed detonation models, even if the supernovae distances are unknown.

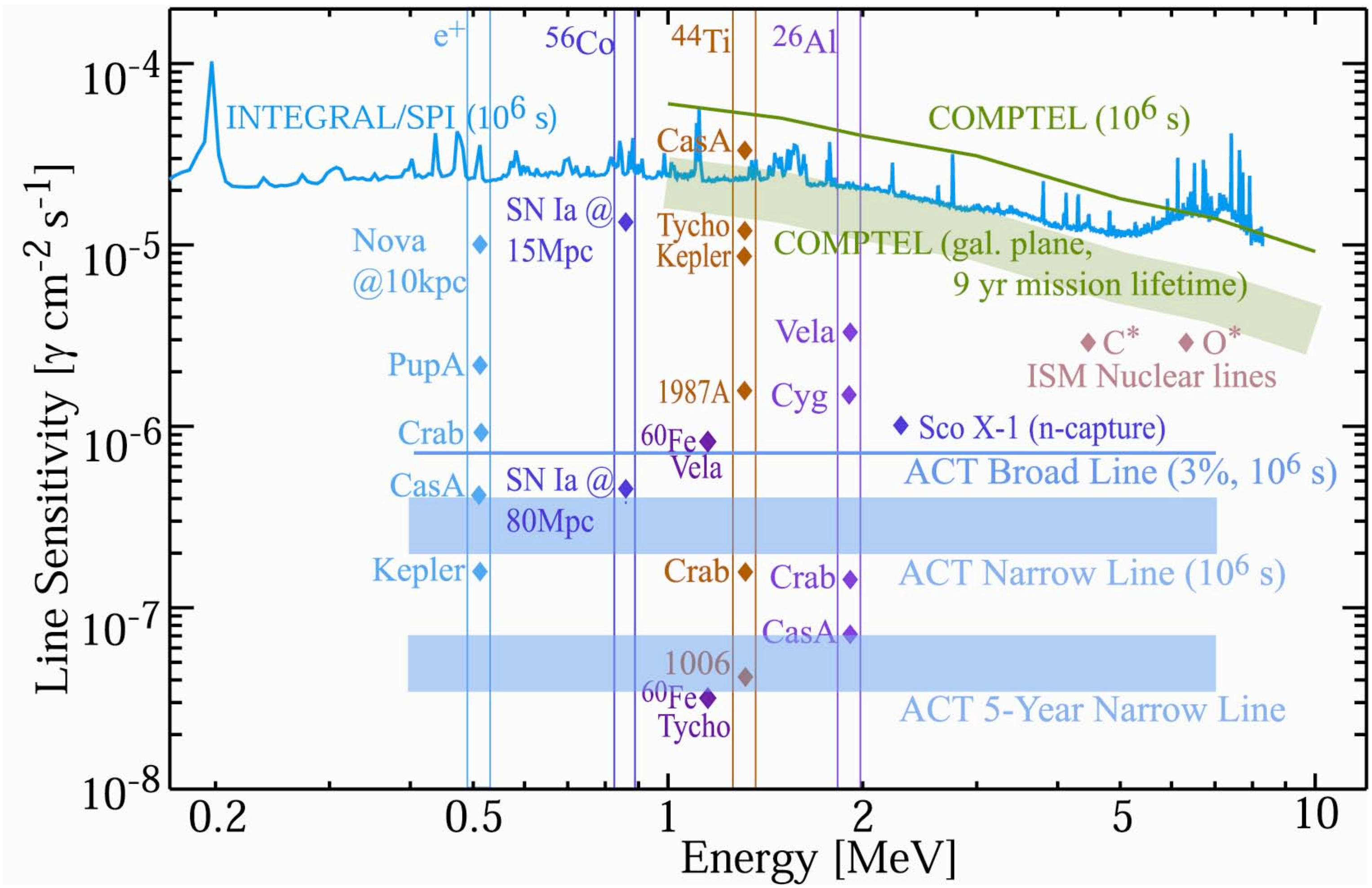
Leading to instrumental requirements:

- broad (3%) line sensitivity at 847 keV: $\sim 7\times 10^{-7}$ ph/cm^2/s
- spectral resolution: $\Delta E/E < 1\%$
- wide field of view: 25% sky

….these lead to 40-50 detections/year (5 @ 15σ)!

Nuclear Line Sensitivity

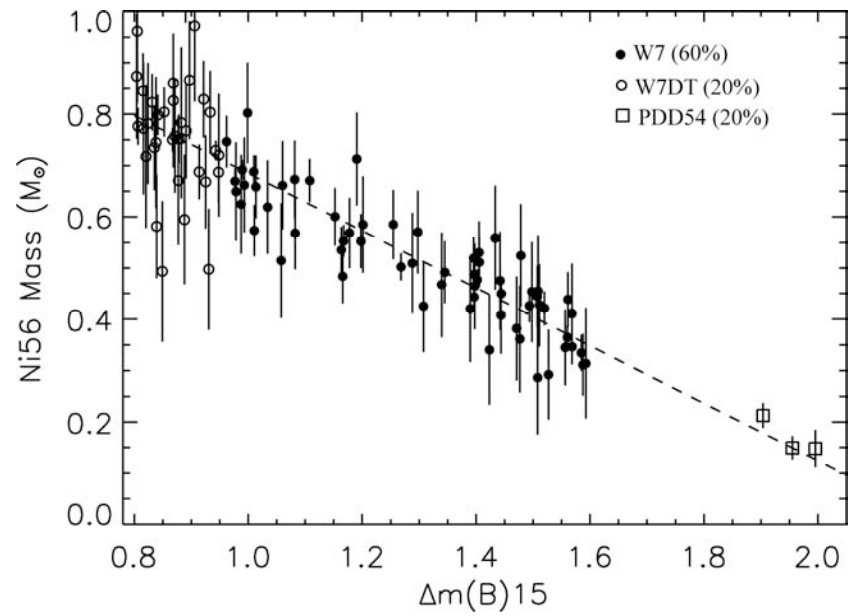
Primary science requirement: systematic study of SNIa spectra, lightcurves to uniquely determine the explosion mechanism, ^{56}Co (0.847 MeV) abundances.

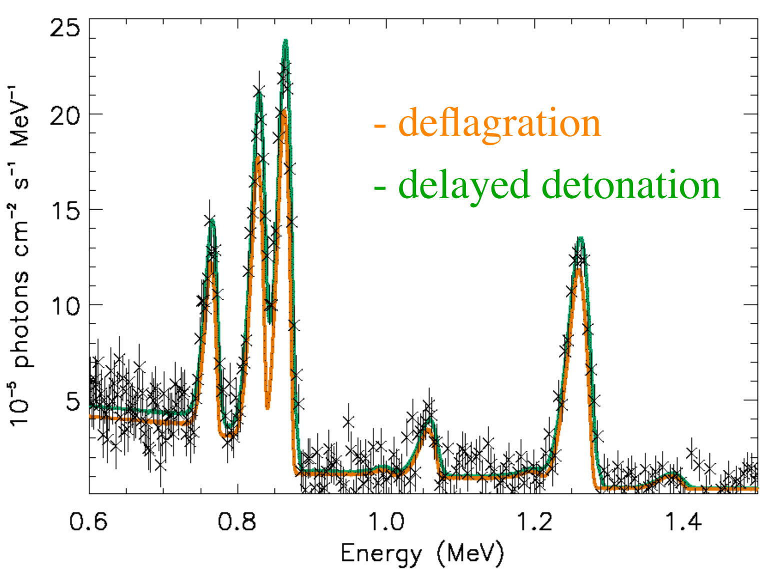


Standard Candle

characterize ^{56}Ni production

Requirements: measurement of ^{56}Ni production in >100 SNe at >5σ levels.

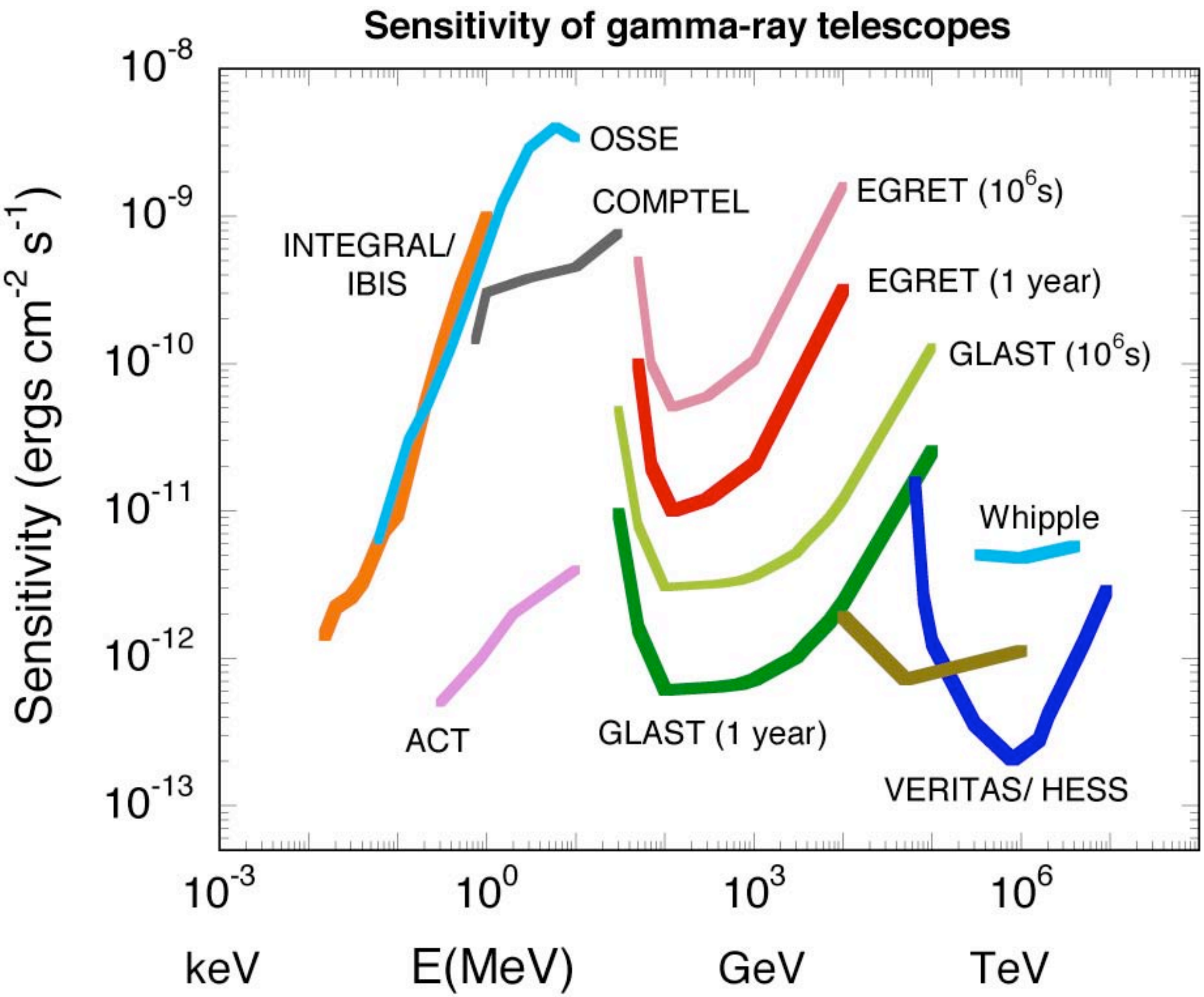




Explosion Physics

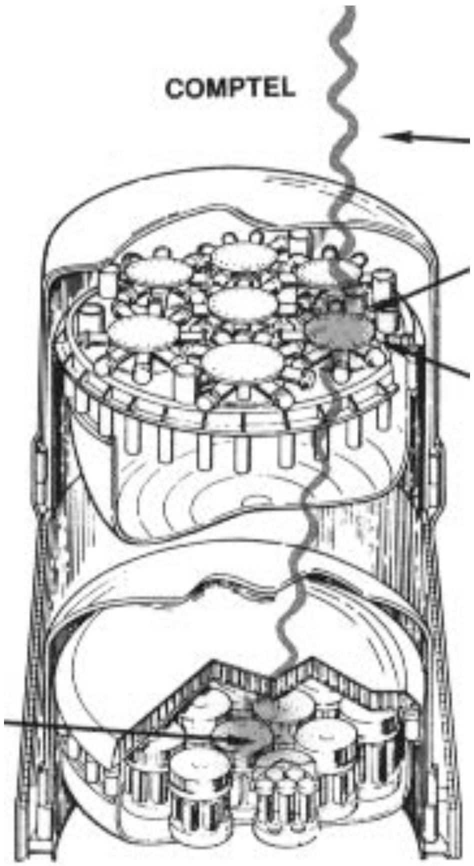
flame propagation, dynamics

Requirements: high sensitivity (>15σ) lightcurves and high-resolution spectra (ΔE/E<1%) of several SNe Ia events of each subclass over the primary 5-year survey.



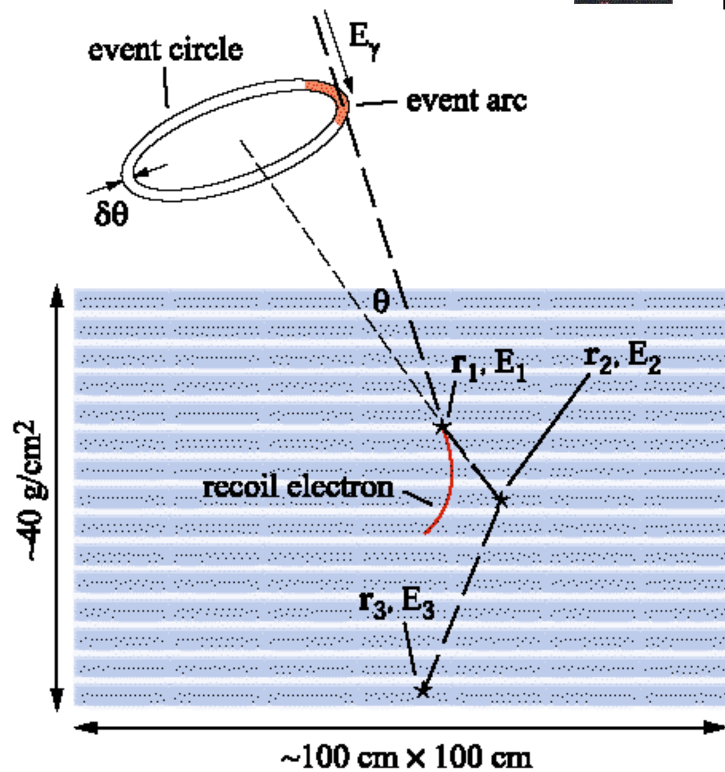
Sensitivity of gamma-ray telescopes
Sensitivity (ergs cm^{-2} s^{-1})
10^{-8}
10^{-9}
10^{-10}
10^{-11}
10^{-12}
10^{-13}
OSSE
COMPTEL
INTEGRAL/
IBIS
EGRET (10^6s)
EGRET (1 year)
GLAST (10^6s)
Whipple
ACT
GLAST (1 year)
VERITAS/ HESS
10^{-3}
10^0
10^3
10^6
keV
E(MeV)
GeV
TeV

Compton Telescopes: Then & Now



CGRO/COMPTEL

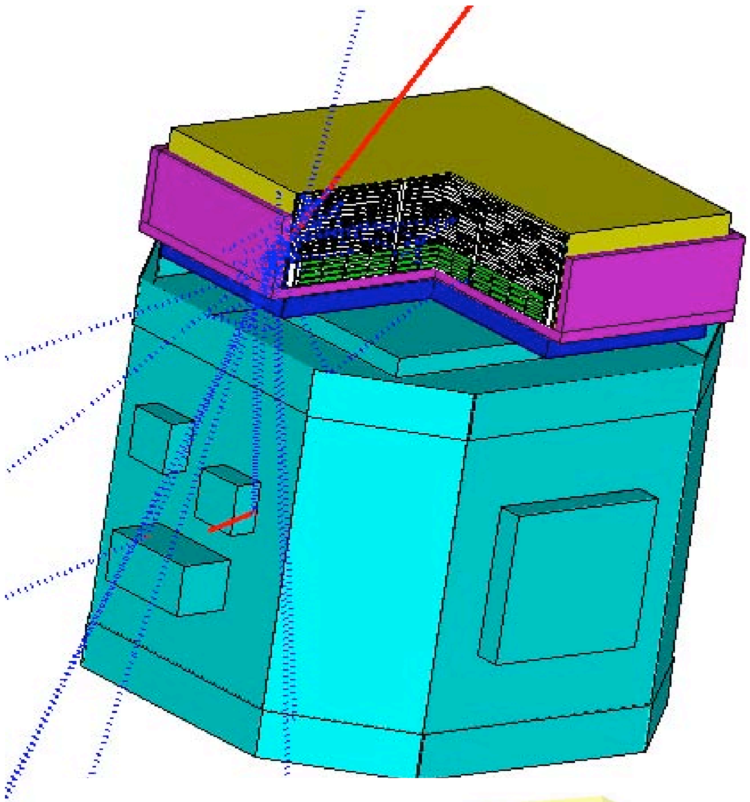
- ~40 cm^3 resolution
- $\Delta E/E \sim 10\%$
- 0.1% efficiency

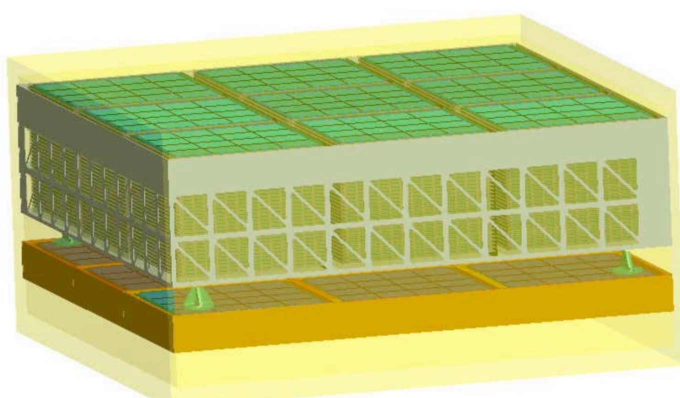


ACT Enabling Detectors

- 1 mm^3 resolution
- $\Delta E/E \sim 0.2\text{-}1\%$
- 10-20% efficiency
- background rejection
- polarization, wide FoV

Baseline ACT Instrument



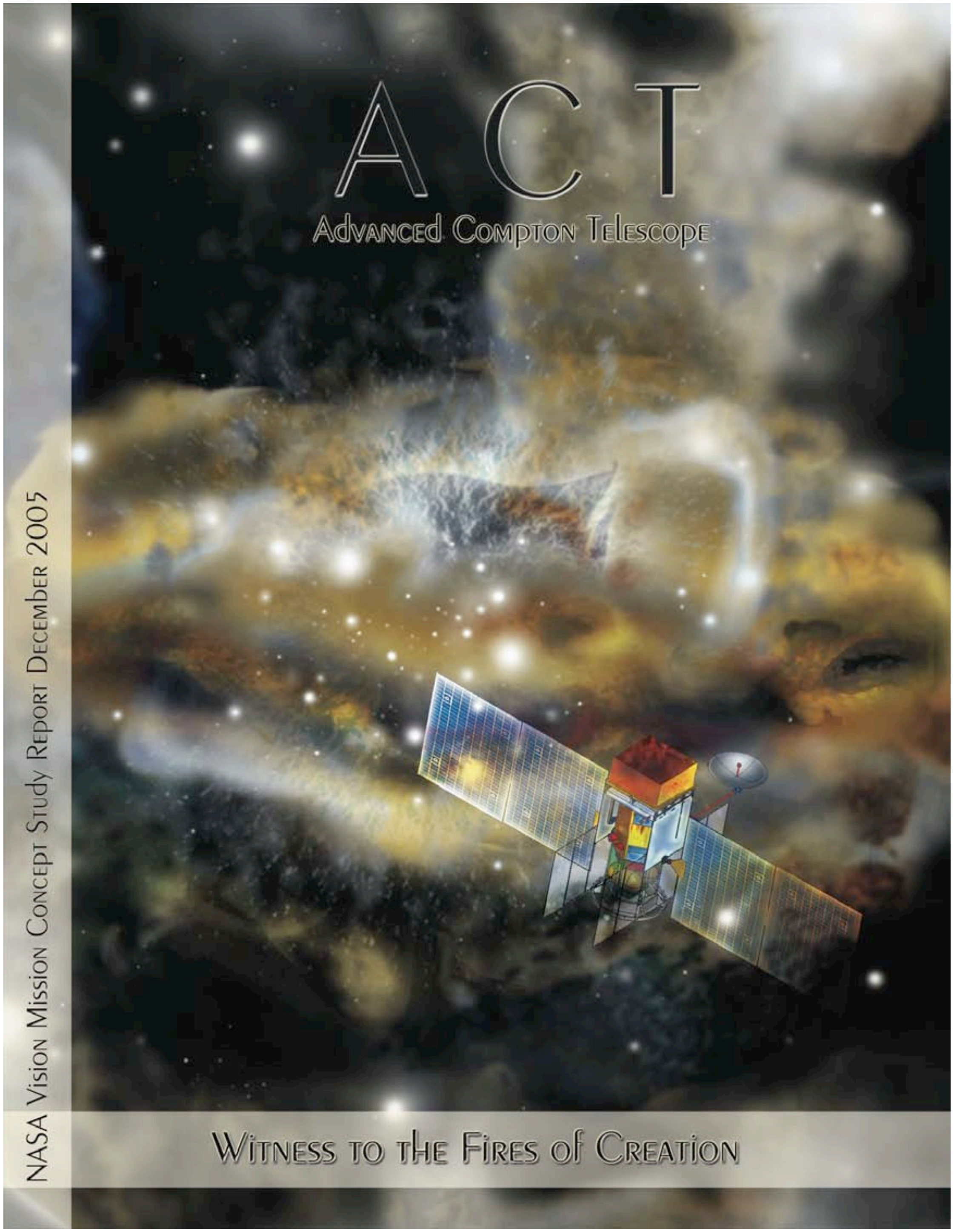


D1: 27 layers 2-mm thick Si
- 10x10 cm2, 64x64 strips
- 3888 det., 248,832 chns
- -30° C, Stirling cycle cooler

D2: 4 layers, 16-mm thick Ge
- 9.2x9.2 cm2, 90x90 strips
- 576 det., 103,680 chns
- 80 K, Turbo-Brayton cooler

BGO: 4-cm thick shield
ACD: plastic scintillator

ACT Apples/Oranges Envelope:
- 1850-kg instrument (w/o margin)
- 2000 W instrument (w/o margin)
- Delta IV shroud (~4m dia.)



astro-ph/608532

- full science goals
- detailed performance
- mission design & readiness
- technology recommedations

ACT Collaboration

Steven Boggs[a], James Kurfess[b], James Ryan[c], Elena Aprile[d], Neil Gehrels[e], Marc Kippen[f], Mark Leising[g], Uwe Oberlack[h], Cornelia Wunderer[a], Allen Zych[i], Peter Bloser[c], Michael Harris[j], Andrew Hoover[f], Alexei Klimenk[f], Dan Kocevski[h], Mark McConnell[3], Peter Milne[k], Elena I. Novikova[b], Bernard Phlips[b], Mark Polsen[i], Steven Sturner[e], Derek Tournear[f], Georg Weidenspointner[j], Eric Wulf[b], Andreas Zoglauer[a], Matthew Baring[h], John Beacom[l], Lars Bildsten[m], Charles Dermer[b], Dieter Hartmann[g], Margarita Hernanz[n], David Smith[o], Sumner Starrfield[p], for the larger ACT collaboration

[a]University of California, Berkeley; [b]Naval Research Laboratory; [c]University of New Hampshire; [d]Columbia University; [e]Goddard Space Flight Center; [f]Los Alamos National Laboratory; [g]Clemson University; [h]Rice University, [i]University of California, Riverside; [j]CESR, France; [k]Arizona State University; [l]Ohio State University; [m]University of California, Santa Barbara; [n]IEEC-CSIC, Spain; [o]University of California, Santa Cruz; [p]University of Arizona, Tucson

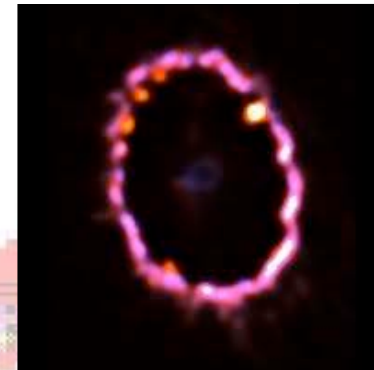
ACT Science Overview

Where do the chemical building blocks of life, planets, stars originate?

How do the chemical elements evolve?

What powers supernovae explosions?

Resolved spectroscopy and flux of nuclear lines from the heart of supernovae



(J. Wilms)

What is the physics at the edge of a black hole?

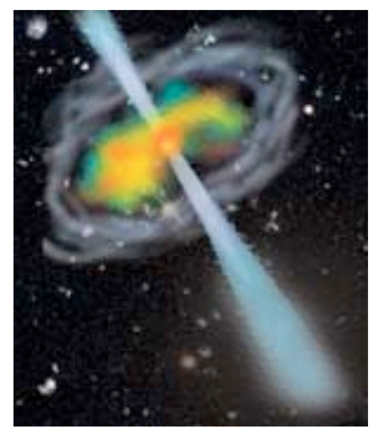
How do matter & antimatter behave in extreme environments?

Spectroscopy, polarization, and timing of photons from black holes, neutron stars, and novae

When did the first stars form?

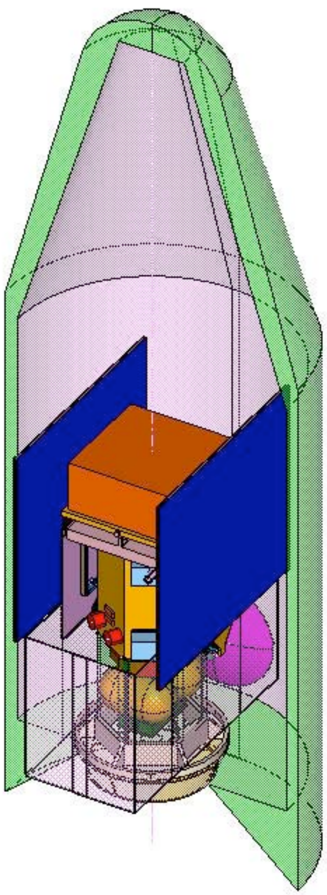
Can gamma-ray bursts measure the geometry of the Universe?

Gamma-ray burst localization, spectroscopy, polarization and timing

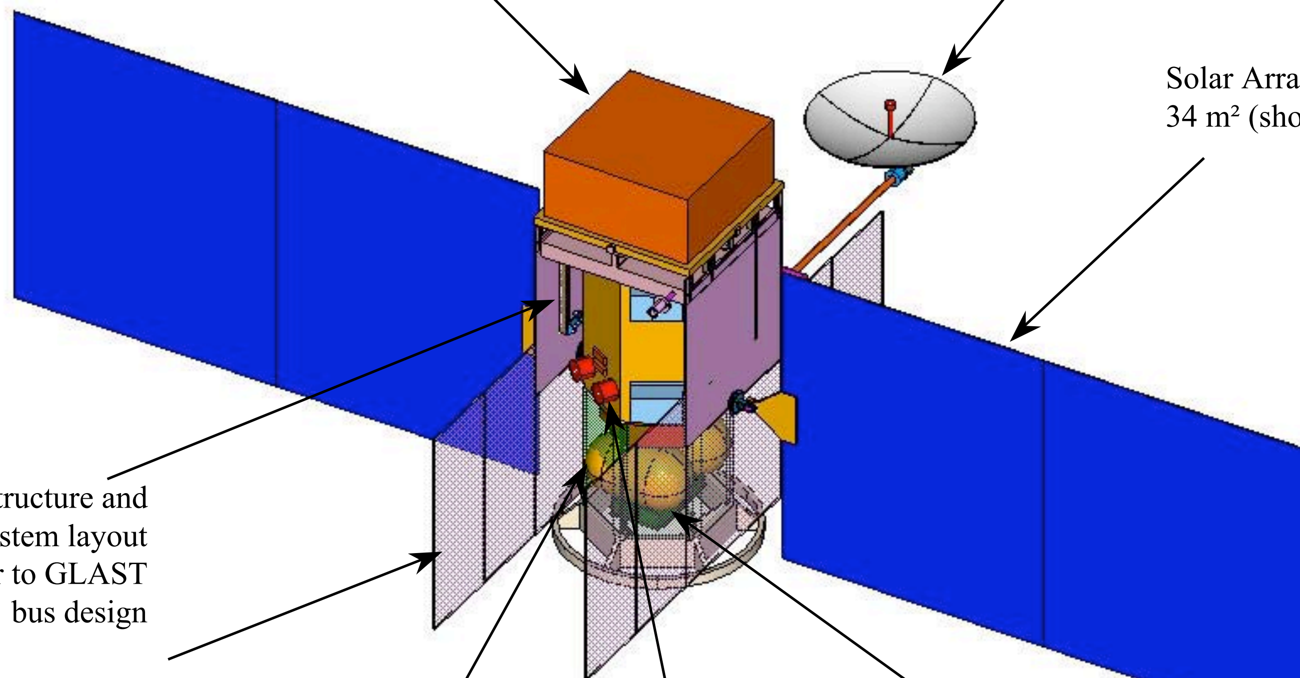


Backup Slides

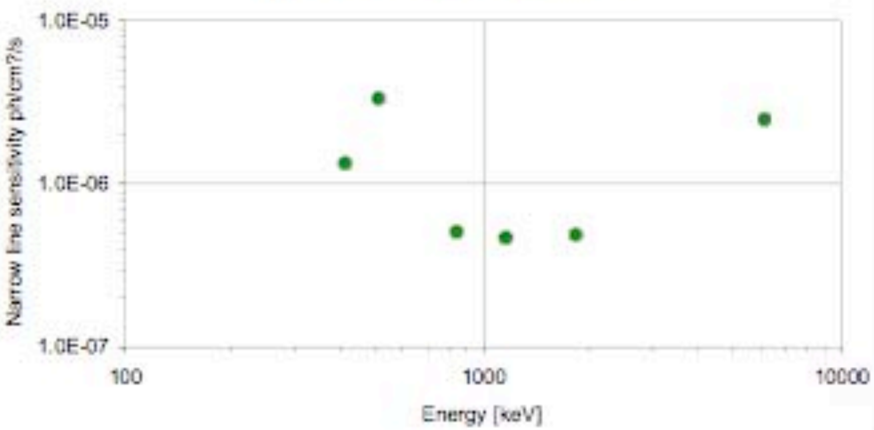
ACT Mission Configuration



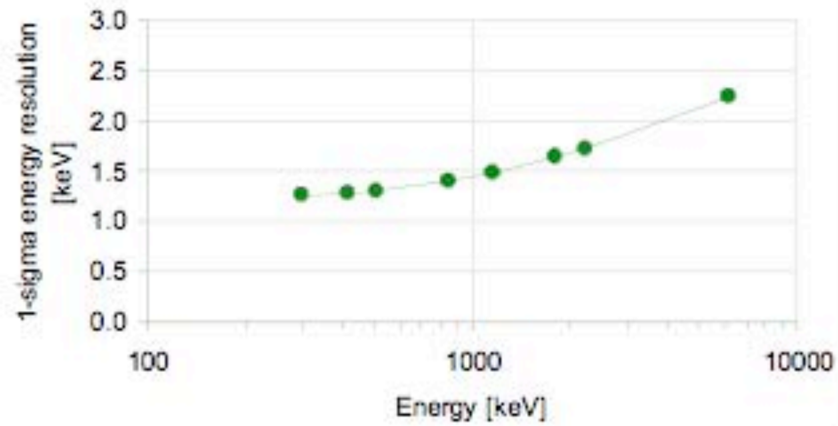
Delta IV 4m fairing



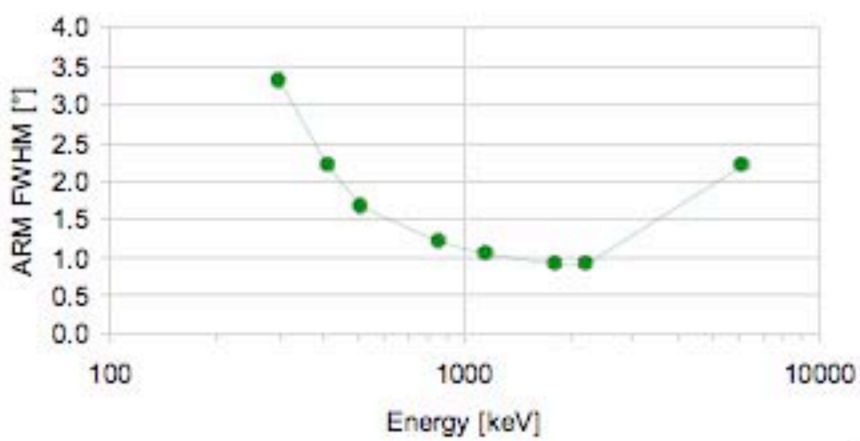
Narrow line sensitivities (3σ, 10^6s)



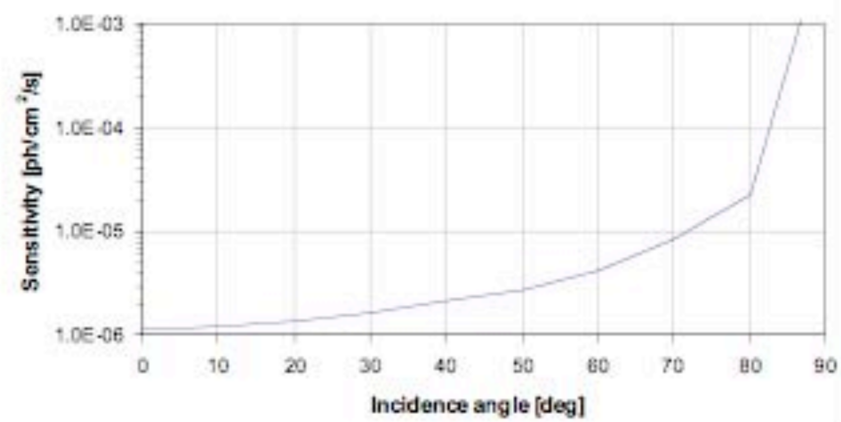
1-sigma Energy resolution



Angular resolution measure



Sensitivity as a function of incidence angle for 847 keV broad line (3σ, 10^6s)



Alternate ACT Designs

Tracking Si/CdZnTe calorimeter (UCR) →e^- tracking, room T
limit: *power (#strips)*

Ge/BGO shield (UCB) → high spectral resolution
limit: *power (cooling), mass (BGO)*

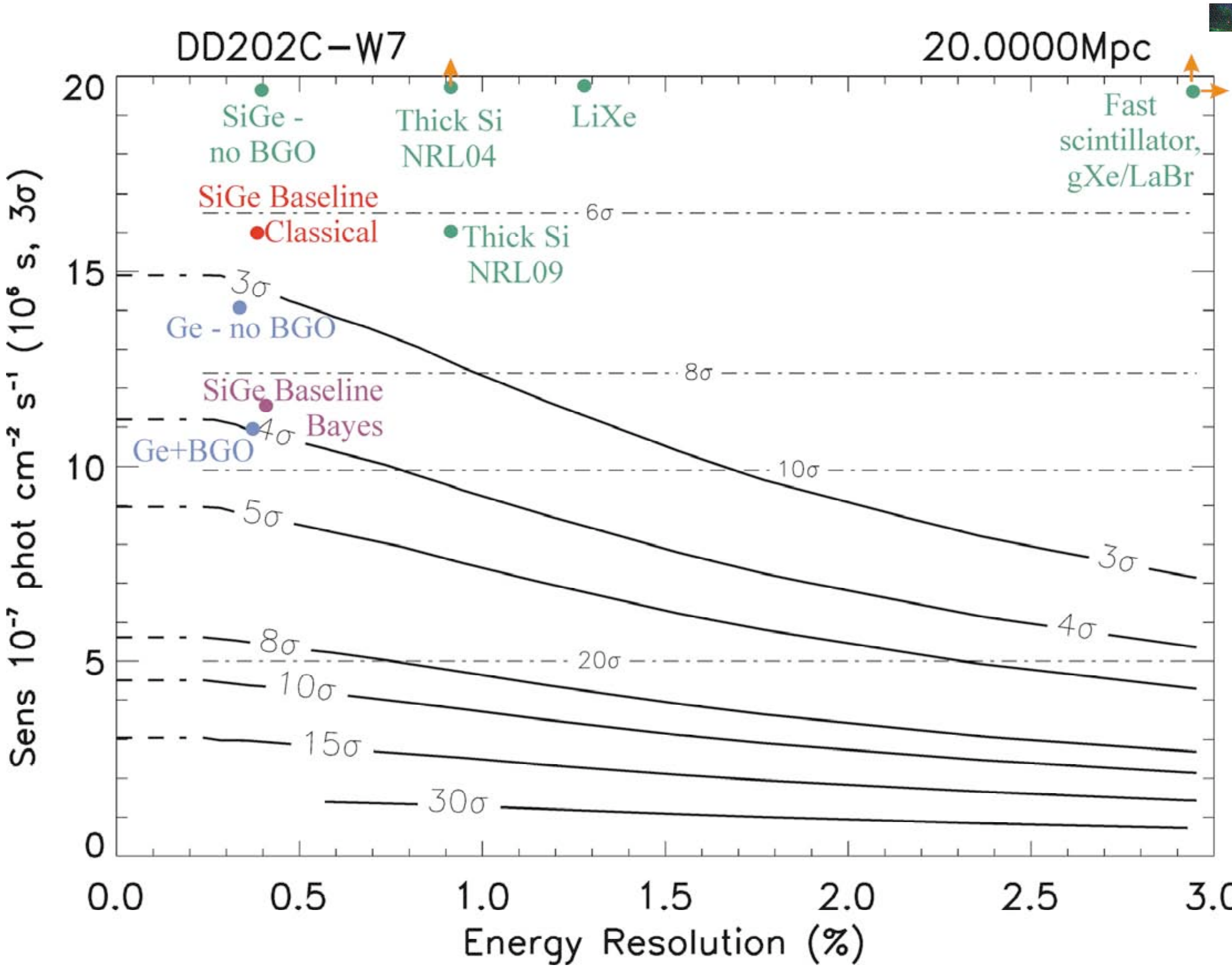
Thick Si (NRL) → reduce Doppler broadening, minimal cooling

LXe (Rice, Columbia) → fast timing, good stopping power
limit: *mass (detector)*

Gaseous Xe/$LaBr_3$ (GSFC/UNH) → e^- tracking
limit: *mass, power (#chns?)*

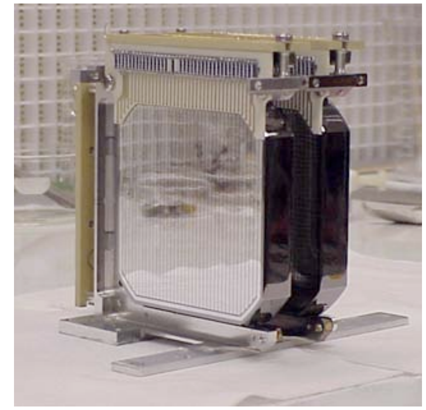
$LaBr_3$ (UNH) → fast timing (modern COMPTEL)
limit: *mass ($LaBr_3$)*

ACT Technology Comparisons



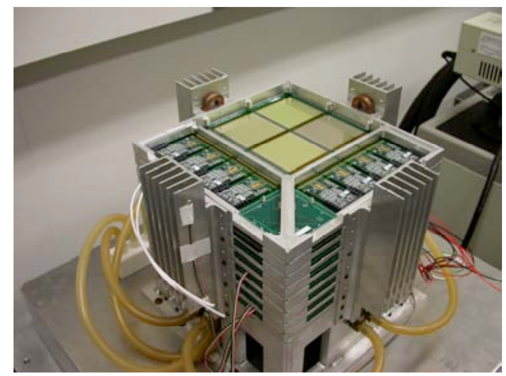
ACT Technology Recommendations

1. Germanium detectors: enabling technology development
• electrode optimization
• environmental testing
• mfg large numbers



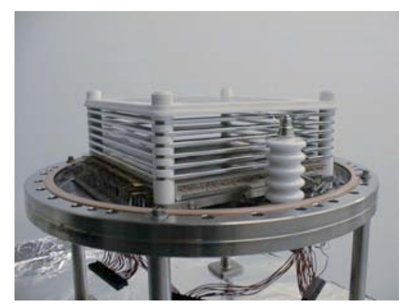
(NCT/UCB)

2. Thick Si detectors: enabling technology development
• basic development for thicker detectors
• mfg large numbers



(NRL)

3. LXe detectors: laboratory demonstration
• optimized spectral performance



(LXeGRIT/Columbia/Rice)

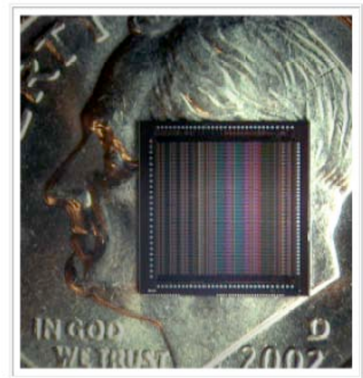
ACT Technology Recommendations (Cont.)

4. Readout electronics: basic development
• ~1 mW/chn readout
• 0.1 mW preamps

5. Cryogenics: study and development
• detailed technical study
• enabling development of scaling

6. Passive materials: study and development
• low-Z structure
• minimal cryostats

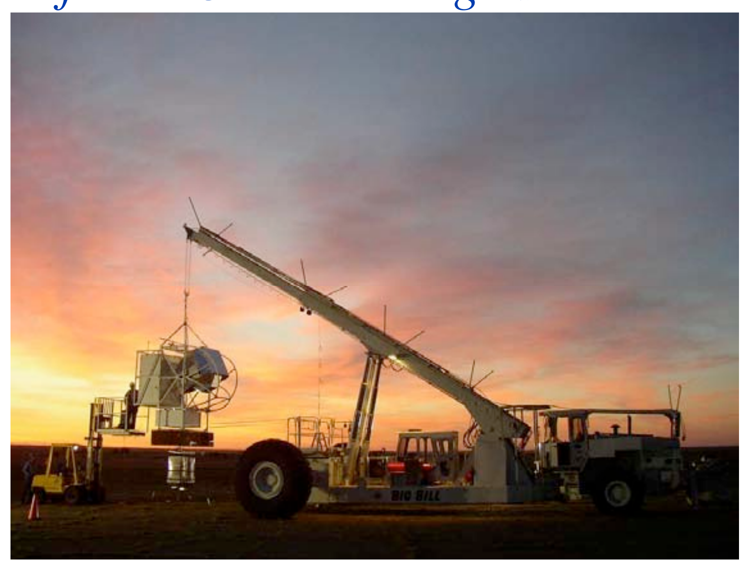
7. Simulation toolset: basic development
• integrated simulation package
• tested environmental inputs
• data and imaging analysis software



(RENA-2/Nova R&D)

(NICMOS/HST)

→ Plus, balloon demonstrations of all ACT technologies.

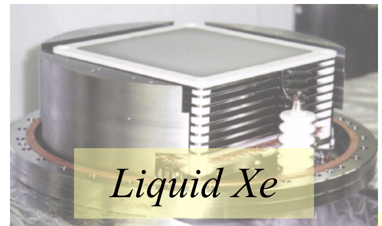


ACT Enabling Technologies

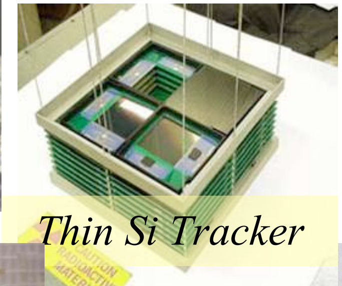
The ACT Vision Mission study identifies the most promising detectors and highest priority technology developments.

Recommendations:

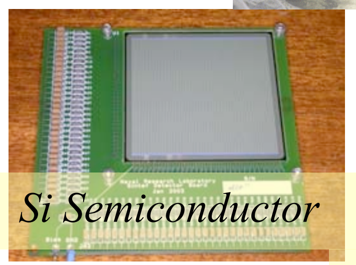
- Ge, thick Si, (LXe)
- low-power readouts
- cryogenics, materials, sims



Liquid Xe

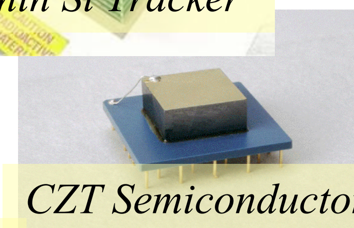


Thin Si Tracker



Si Semiconductor

Ge Semiconductor



CZT Semiconductor

Property	Si Strip	Ge Strip	Liquid Xe	CZT Strip	Xe μWell
$\Delta E/E$ (1 MeV)	0.2-1%	0.2%	3%	1%	1.7%
Spatial Resol.	<1-mm^3	<1-mm^3	<1-mm^3	<1-mm^3	0.2-mm^3
Z density	14 2.3 g/cm^3	32 5.3 g/cm^3	54 3.0 g/cm^3	48 8.3 g/cm^3	54 (3 atm) 0.02 g/cm^3
Volume (achvd.)	60 cm^3	130 cm^3	3000 cm^3	4 cm^3	50 cm^3
Operating T	-30° C	-190° C	-100° C	10° C	20° C

ACT Baseline Science
Instrument Performance

Energy range	0.2-10 MeV
*Spectral resolution	0.2-1%
*Field of View	25% sky (zenith pointer)
Sky coverage	80% per orbit
Angular resolution	~1°
Point source localization	5'
Detector area, depth	~12,000 cm^2, 47 g/cm^2
Effective area	~1000 cm^2
*3% broad line sensitivity (10^6s)	1.2×10^{-6} ph/cm^2/s
Narrow line sensitivity	5×10^{-7} ph/cm^2/s
Continuum sensitivity	$(1/E)\times10^{-5}$ ph/cm^2/s/MeV
GRB fluence sensitivity	3×10^{-8} erg/cm^2
Data mode	Every photon to ground

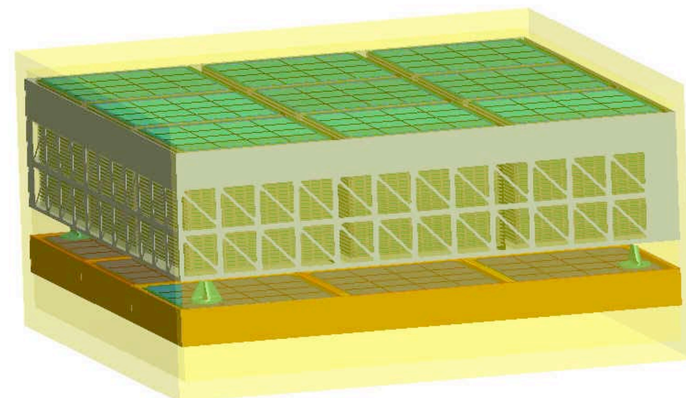
**Primary science requirement driven by Type Ia supernovae.*

ACT Mission Overview

✓ Instrument Synthesis & Analysis Laboratory (ISAL), September 2004

✓ Integrated Mission Design Center (IMDC), November 2004

- launch ~2015, 5-10 year lifetime
- 550 km LEO, <10° inclination, Delta IV (4240)
- 1° attitude, 1’ aspect, zenith pointer
- instrument 2100 kg, S/C 1425 kg, propellant 462 kg
- 3340 W power, 69 Mbps average telemetry
- $760M (FY04)



Systems	Current	Heritage	ACT	ACT TRL
DC Power	2kW	AQUA	3.8 kW	TRL-9
Data Bus (Spacewire)	32Mbps	SWIFT	60Mbps	TRL-7
TDRSS Ku-band	1 Gbps	GLAST	625Mbps	TRL-8/9
Cryocooler (80K)	300W	NICMOS	600W	TRL-9
Cryocooler (-30° C)	100W	RHESSI	300W	TRL-9

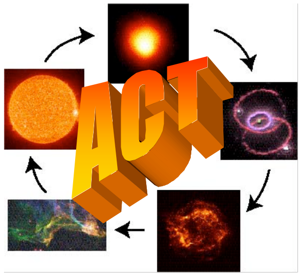
“Baseline ACT” for ISAL & IMDC:

D1: 32 layers SiDs 2-mm thick each

D2: 3 layers, GeDs 16-mm thick each

1.2 m^2 area, 144 detectors/layer

ACT in NASA’s Strategic Plan



✓ Selected in March 2004 for a NASA Vision Mission concept study

✓2005 NASA Universe Strategic Roadmap identifies the Nuclear Astrophysics Compton Telescope as a Pathways to Life Observatory

✓ Space Science strategic objective 5.12 – understand the development of structure and the cycles of matter and energy in the evolving universe (2003)

✓ACT identified in the 2003 SEU Roadmap under *Cycles of Matter and Energy* (“will be undertaken after Beyond Einstein has begun”)

✓Nuclear astrophysics was identified by the Gamma-Ray Astrophysics Working Group (GRAPWG) in 1999 as the ‘highest-priority science goal’, and ACT as the ‘highest priority major gamma-ray mission’