KTH Teknikvetenskap

Gamma-ray activities at KTH

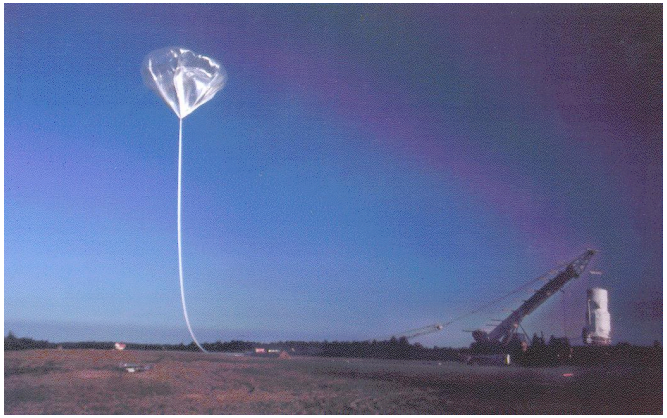
Mark Pearce + Felix Ryde

2012-10-17

The First International Workshop on **H**igh **E**nergy cosmic **R**adiation **D**etection
Center for Particle Astrophysics, Beijing, October 17-18 2012

KTH Teknikvetenskap

Astroparticle physics

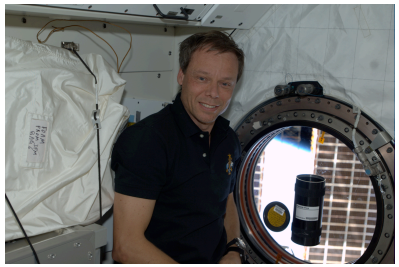


CAPRICE (1990's)
Cosmic antiparticles
Gas-RICH

Fermi (2008 -)
Cosmic gamma-rays + GRBs
CsI(Tl) calorimeter

PoGOLite (now)
Polarised X-rays from point sources
Scintillator Compton polarimeter

PAMELA (2006 -)
Cosmic antiparticles
Anticoincidence shield



PFD / ISS (2009, 2011)
Education

Overview

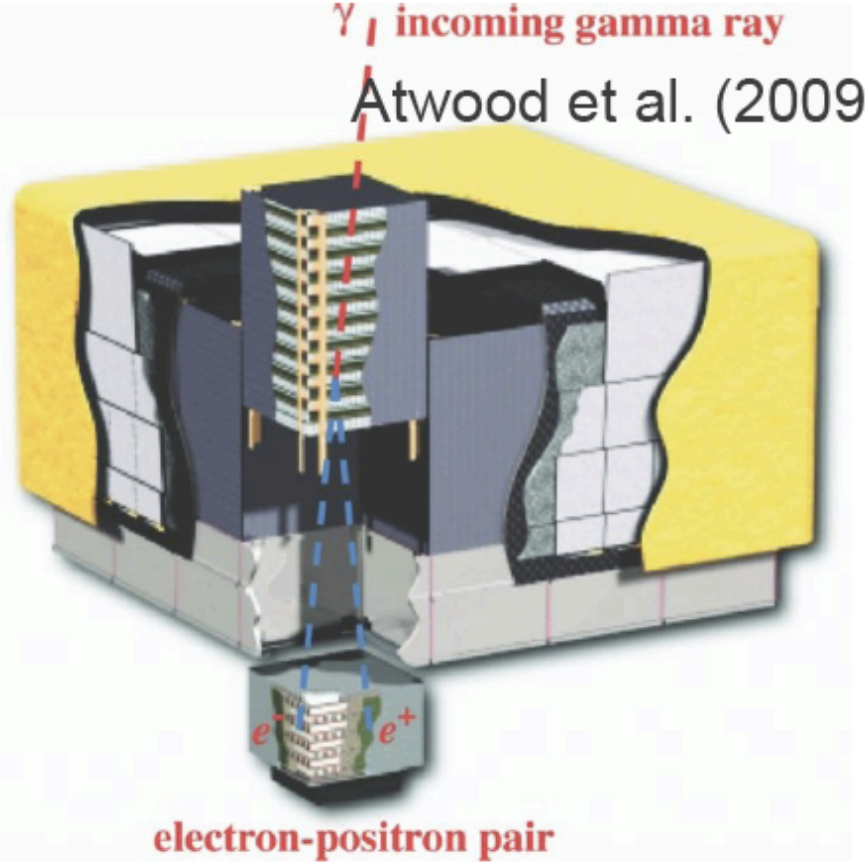
- A secondary HERD science goal: Gamma-ray bursts
  - PoGOLite - a Compton polarimeter for point sources
- Possible contributions to HERD

Gamma-ray bursts with Fermi

Large area telescope (LAT)

- Pair-conversion telescope
- 30 MeV - >300 GeV
- Consists of a precision tracker, calorimeter & anti-coincidence detector
- Scintillation crystals in calorimeter provided by

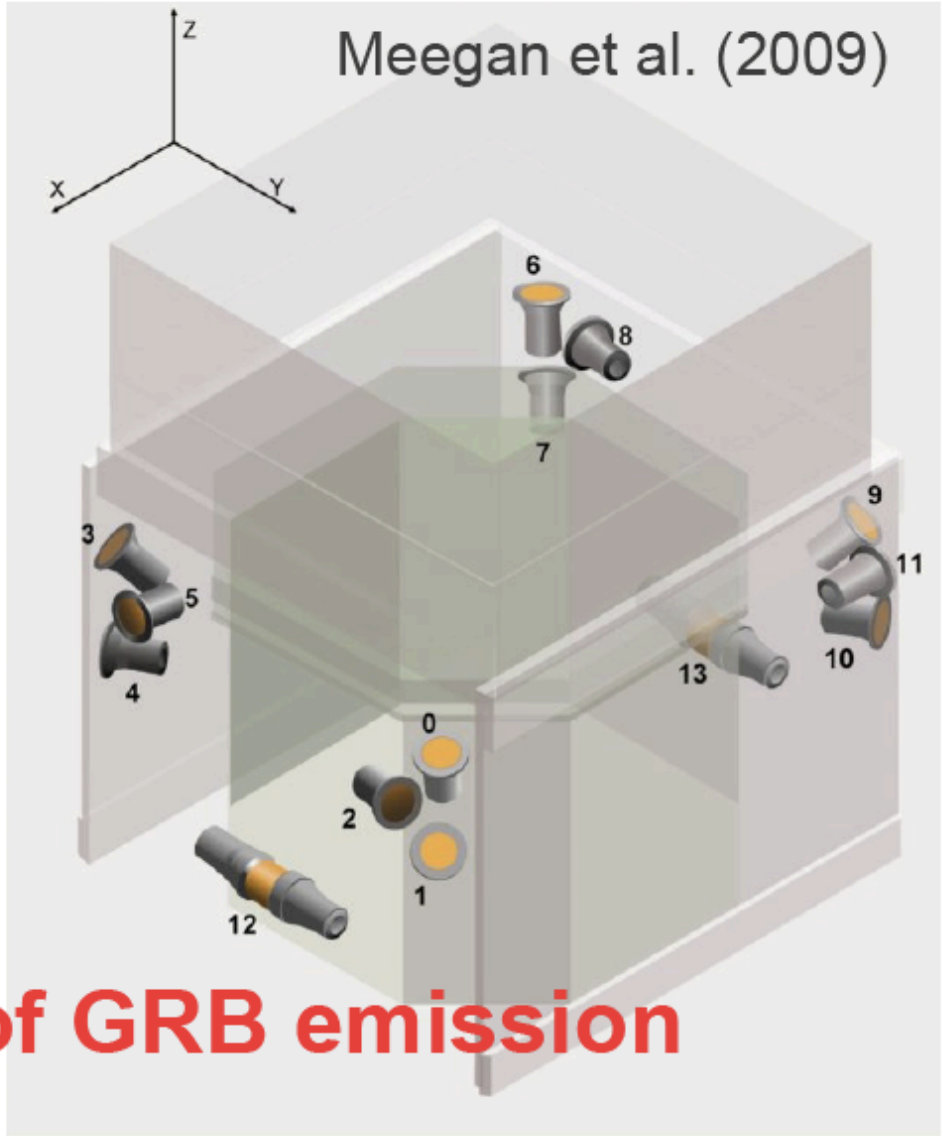
KTH Engineering Sciences



Unprecedented coverage for GRBs at high energies

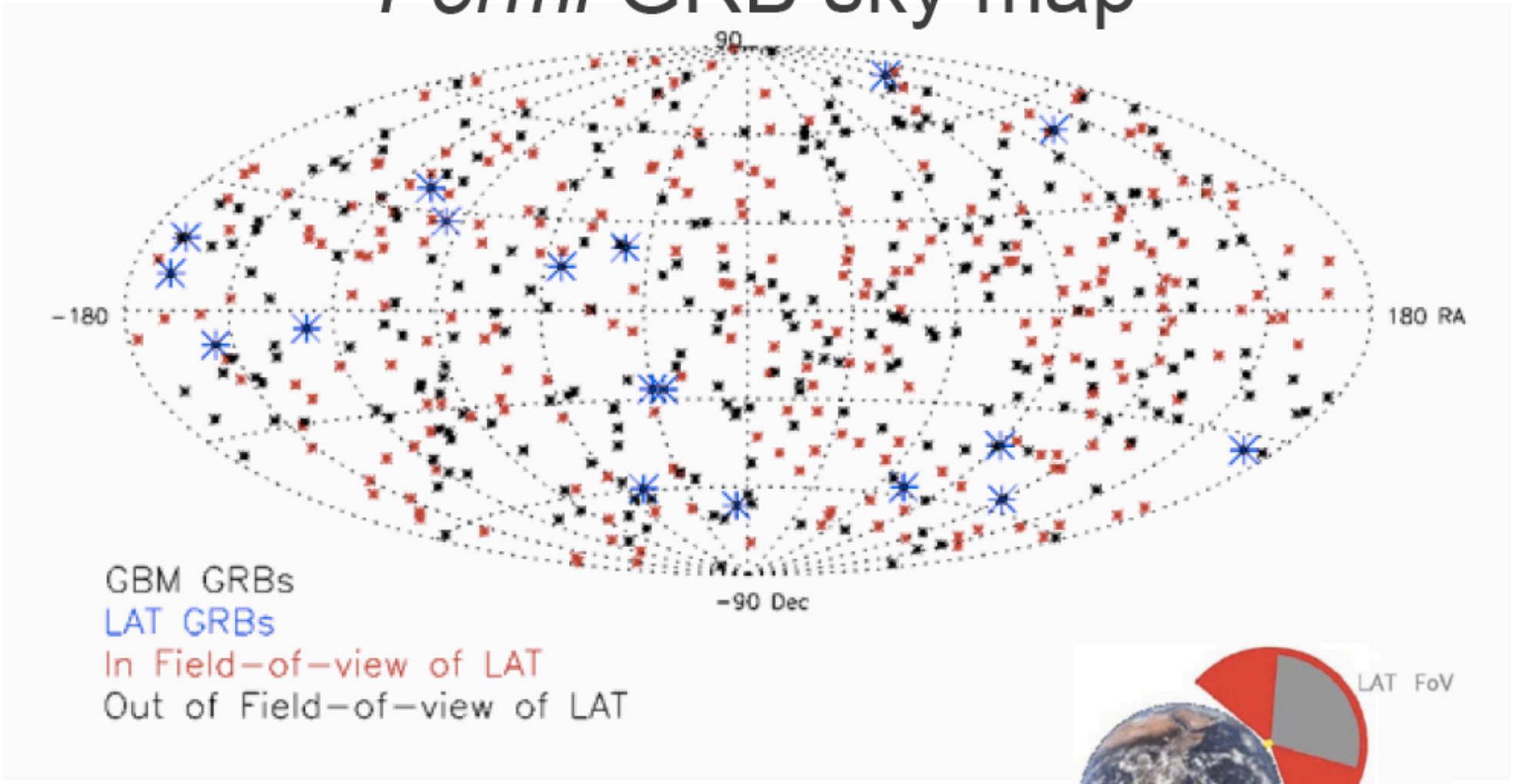
Gamma-ray burst monitor (GBM)

- 12 NaI(Tl) detectors
- 2 BGO detectors
- 8 keV – 40 MeV (combined)
- **Triggers** on GRBs
- **Localizes** GRBs



Covers peak of GRB emission

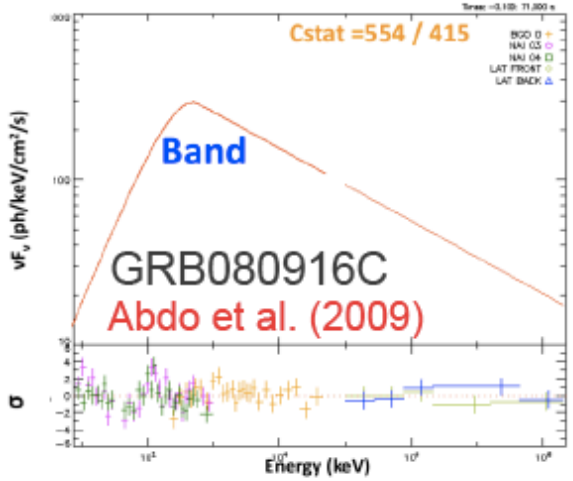
Fermi GRB sky map



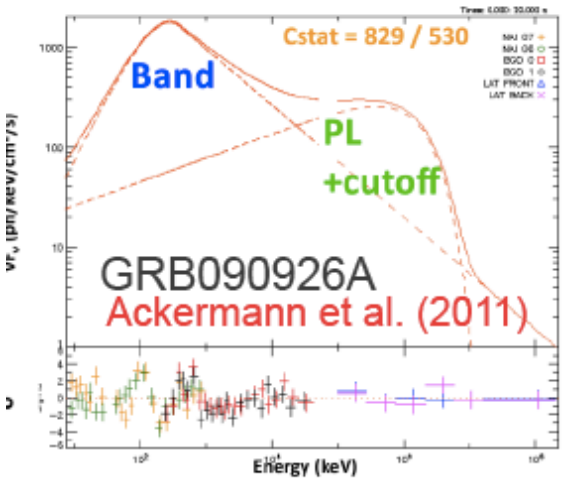
~20 GRBs/month seen by GBM
~1/30 of GBM bursts seen by LAT

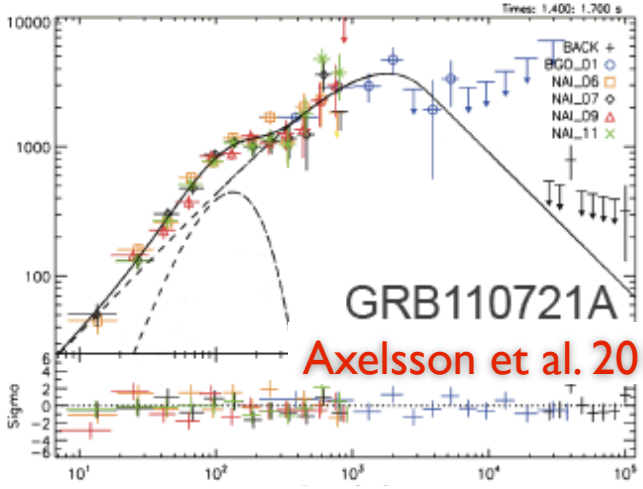
GRB observations by *Fermi*

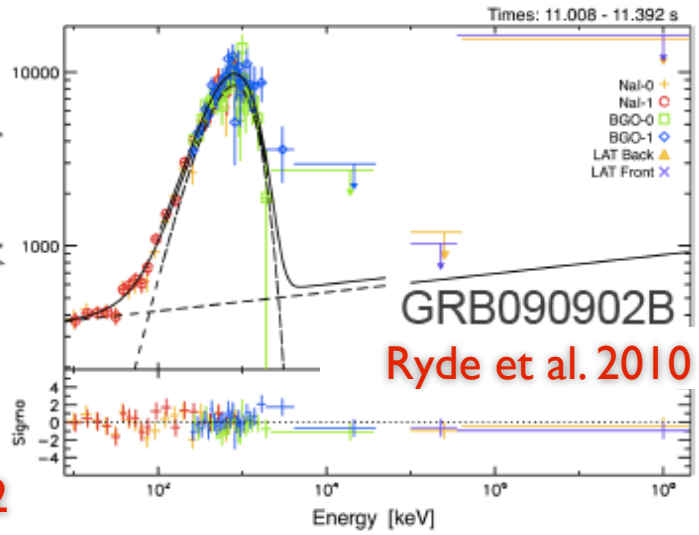
Several spectral shapes observed!



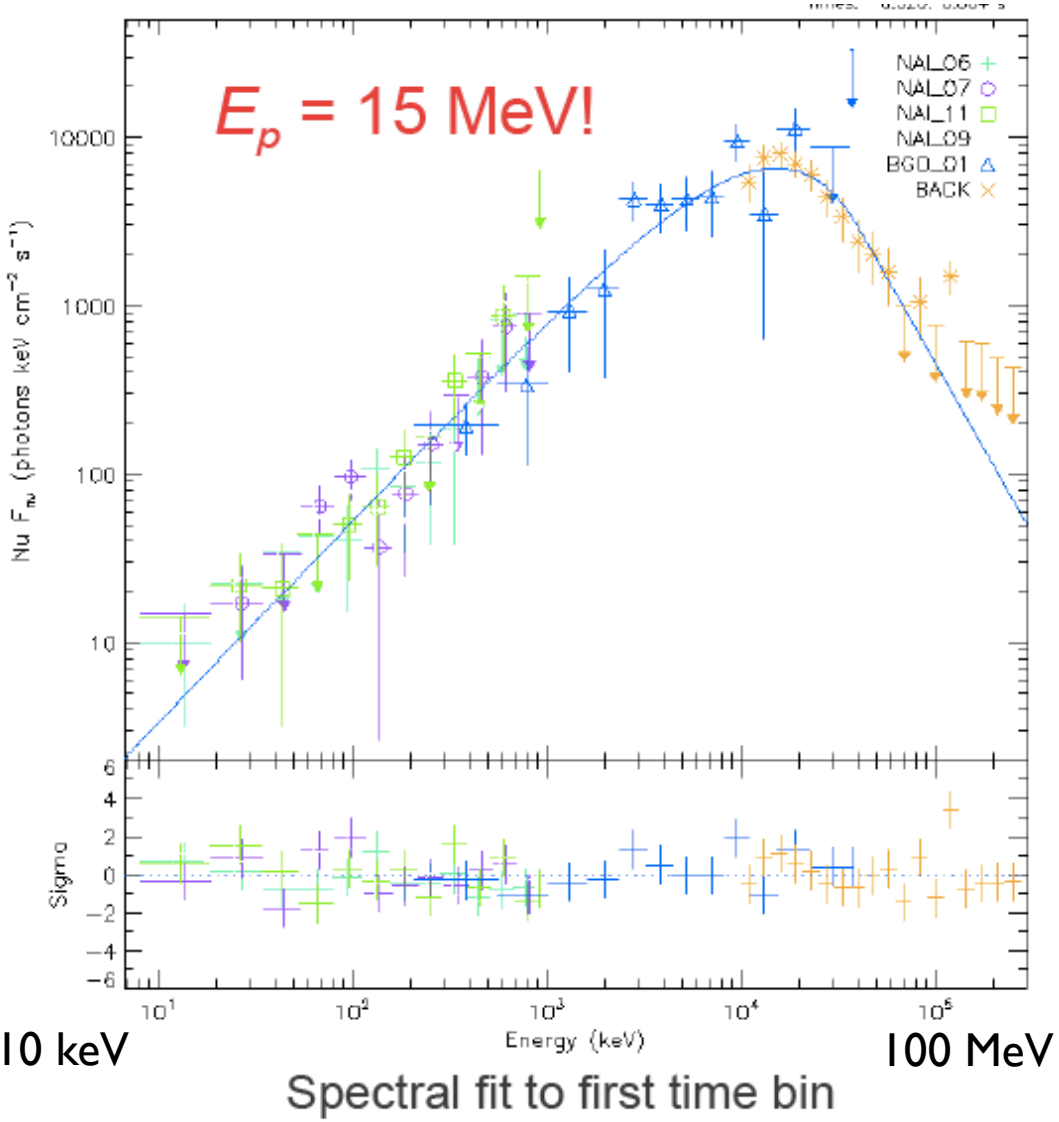
"Band" crisis!







Example GRB110721A Axelsson et al. (Fermi collab.)2012



10 keV 100 MeV

Spectral fit to first time bin

The highest observed peak energy

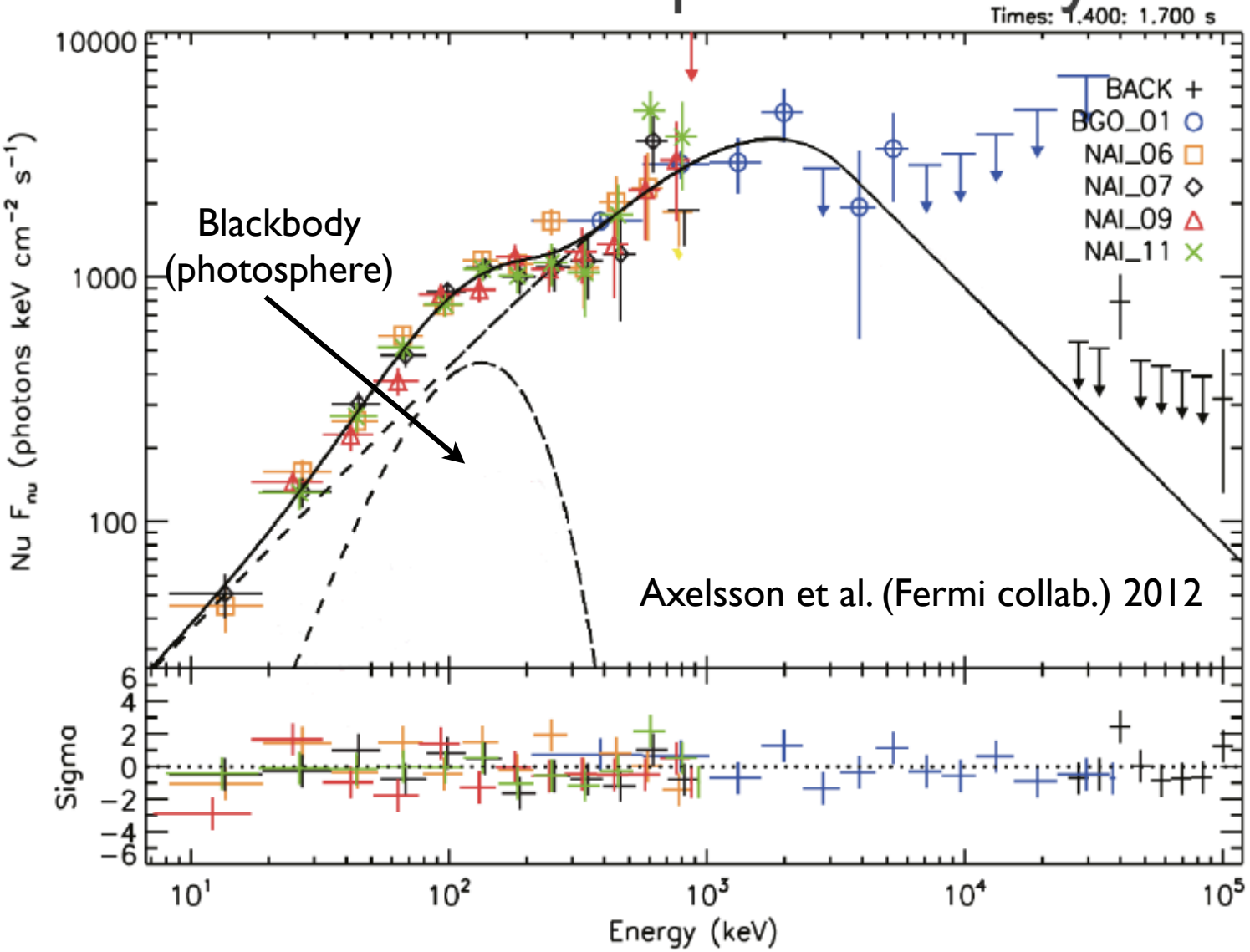
What emission process can produce the observed 'Band spectrum'?

- Synchrotron emission?
  - E_p = 15 MeV puts constraints on the emission radius
  Spectrum requires slow cooling electrons → cooling break above 15 MeV
  → $R < 3 \cdot 10^9 (\Gamma/1000)^3 (\gamma_e/1836)^3 ([1+z]/3)^{-2}$ cm

- Photospheric emission?
  - E_p = 15 MeV implies extremely high temperature at the photosphere
  - IC scattering on hot electrons close to photosphere?

A highly debated issue (see Beloborodov 2012, Zhang et al. 2012, Veres et al. 2012)

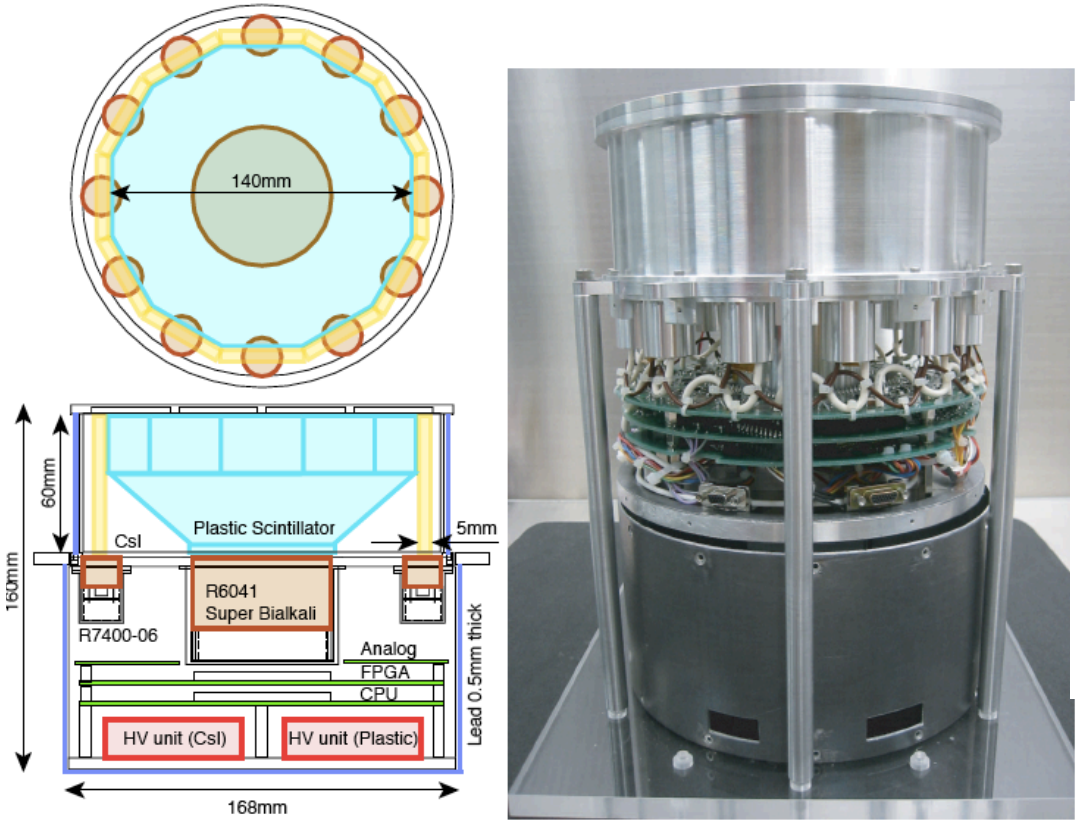
GRB110721A spectral analysis



Two spectral components **statistically required (>5σ)**

Gamma-ray burst polarimeter GAP

(Yonetoku et al. 2006) on board the *IKAROS* solar power sail (Kawaguchi et al. 2008)



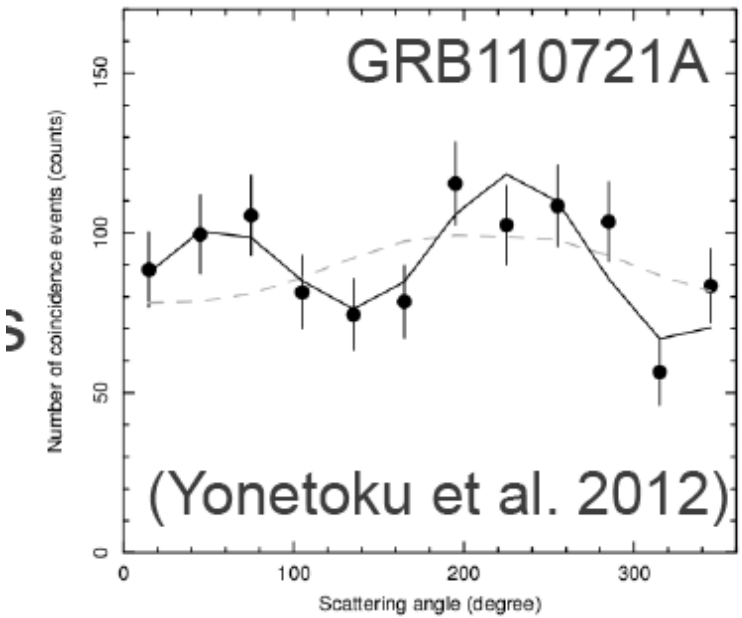
g. 1.2. A schematic view of GAP (left) and a whole integrated system (right).

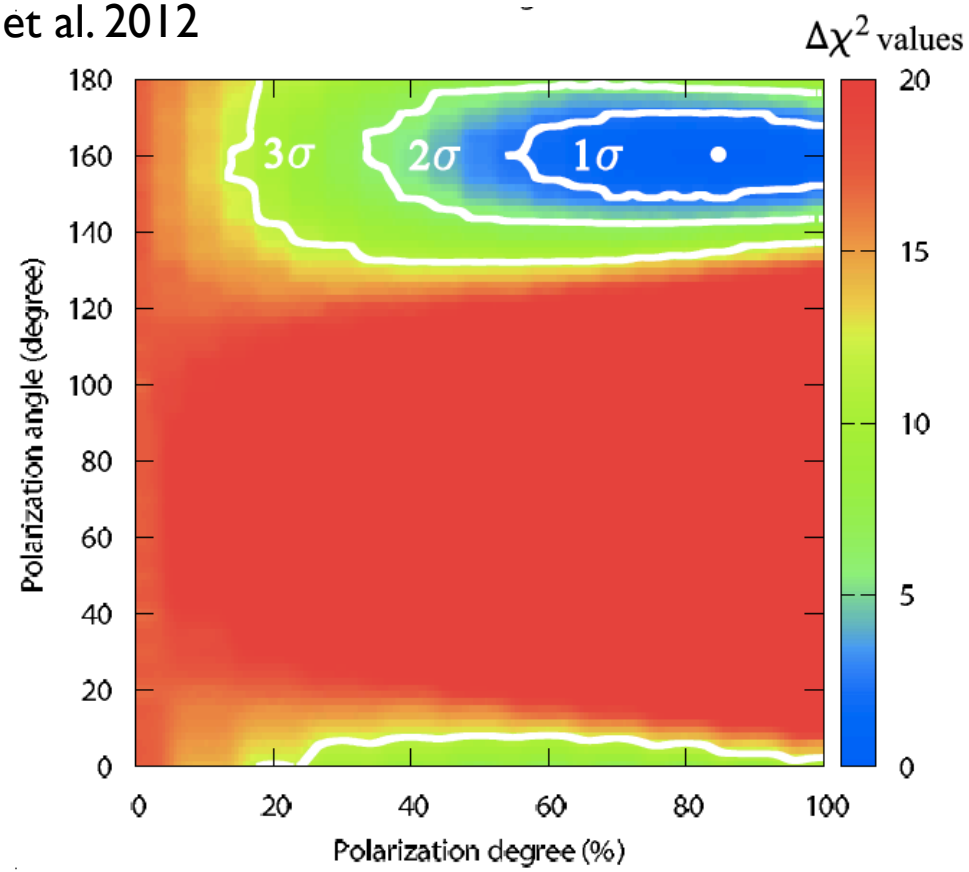
Table 1.1. *GAP characteristics*

Effective Area	geometry	176 cm^2
	polarization	34 cm^2 @ 100 keV
Energy Range	lightcurve	10–300 keV
	spectrum	10–300 keV
	polarization	50–300 keV
Time Resolution	lightcurve	125 msec
	spectrum	—
	polarization	1 sec
Field of View	effective	π str

GAP observations of GRB110721A

Yonetoku et al. 2012





Change in polarisation angle over time?

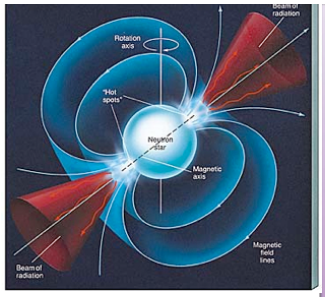
Synchrotron emission from globally ordered magnetic fields?

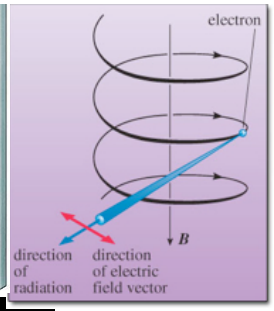
Polarisation from the photosphere?

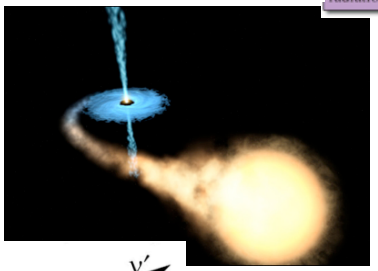
Monitoring of GRBs is a highly interesting science goal

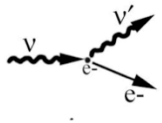
An energy range extending down to ~MeV energies is useful

Polarisation signal in the emission is a strong diagnostic for the emission mechanism and emission site







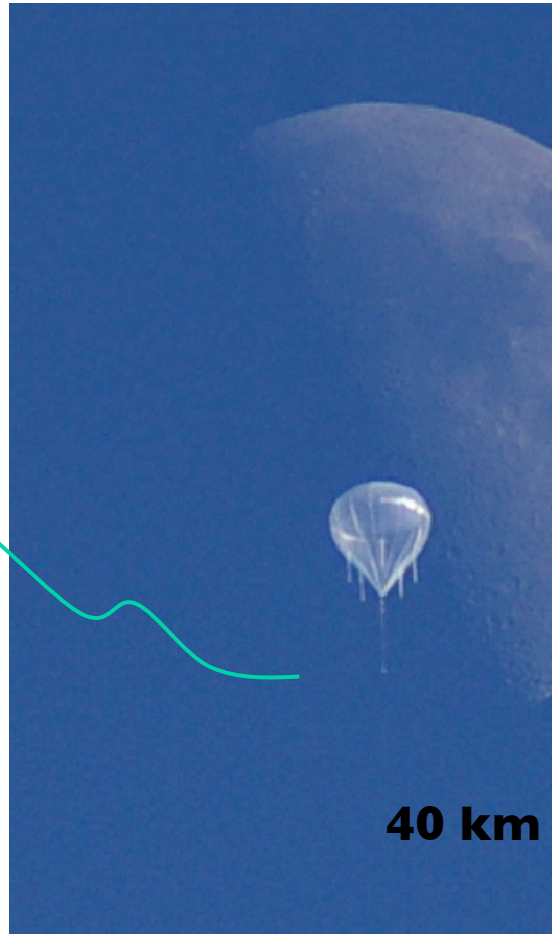


KTH
Stockholm University
DST Control
SSC Esrange

Hiroshima University,
Tokyo Inst. of Tech,
ISAS/JAXA, Waseda Uni.

SLAC - KIPAC
Uni. of Hawaii

γ **25 – ~100 keV**



• **Polarisation** is a **powerful diagnostic** for **source emission** mechanisms. However, essentially **no measurements** in the **X-/gamma-ray** band.

• **PoGOLite** is optimised for **point sources** (e.g. Crab pulsar, Cygnus X-1).

• Measures **10% polarisation** in **200 mCrab sources** in a **6 hour** balloon observation.

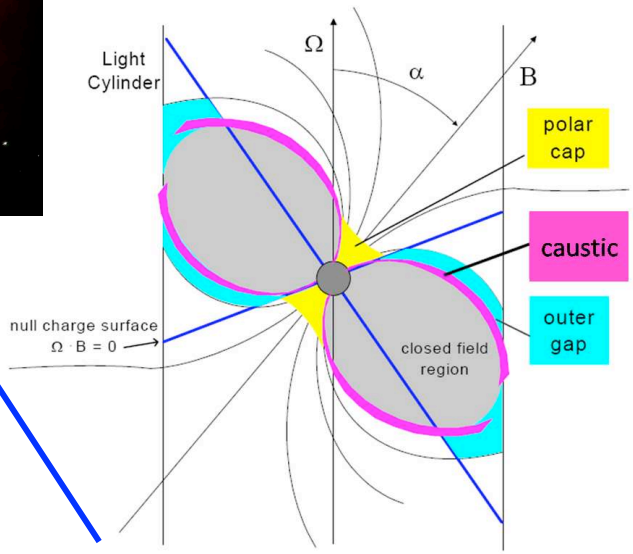
• **Maiden flight** of scaled down (less effective area) **'pathfinder'** took place in **July 2011** from Esrange Space Centre, Sweden. Early termination due to balloon failure.

• Retry summer 2012. No launch attempt due to poor weather.

• Will try again summer 2013...

Crab pulsar emission models

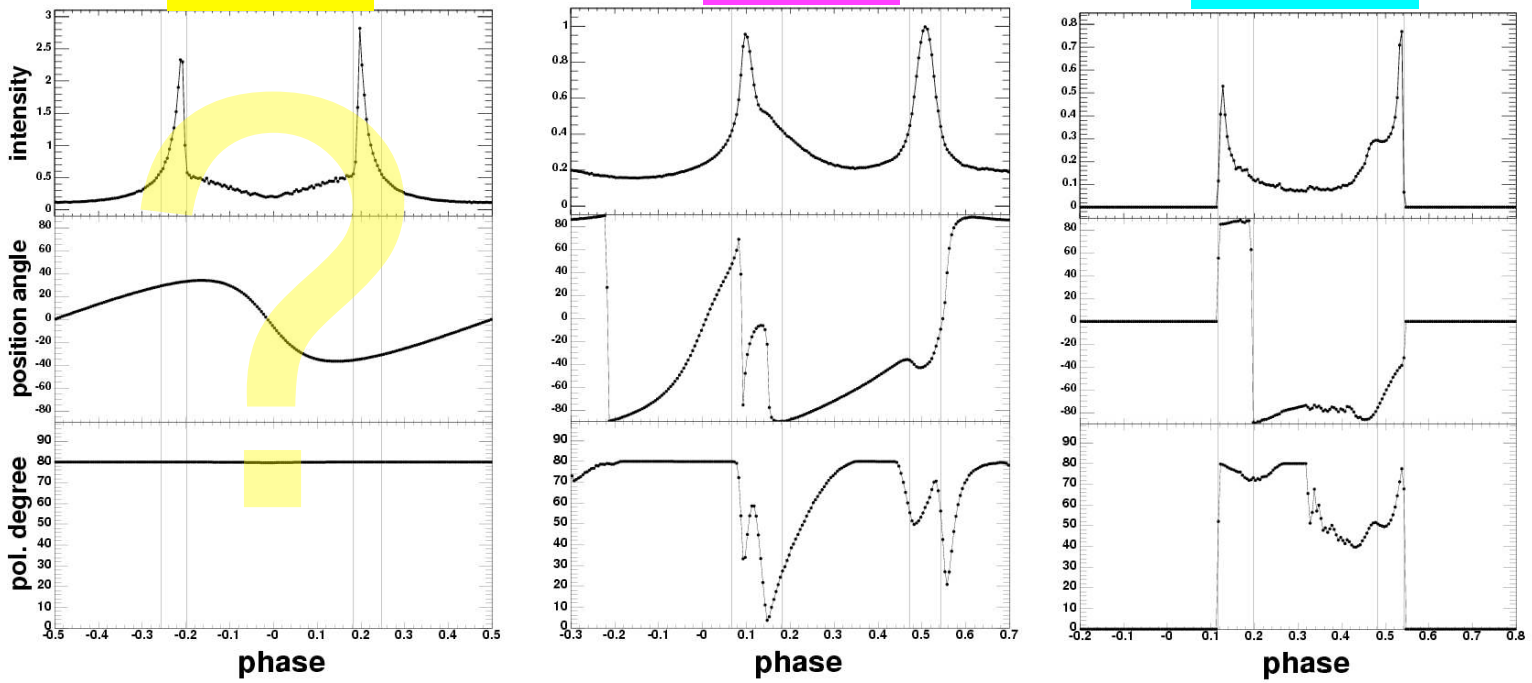
X-rays (Chandra),
optical (HST),
radio (VLA)



Polar cap

Caustic

Outer gap



Intensity

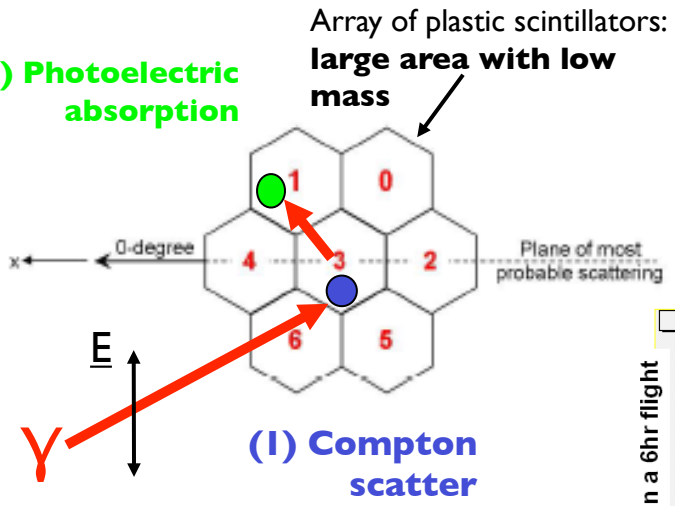
Pol. angle

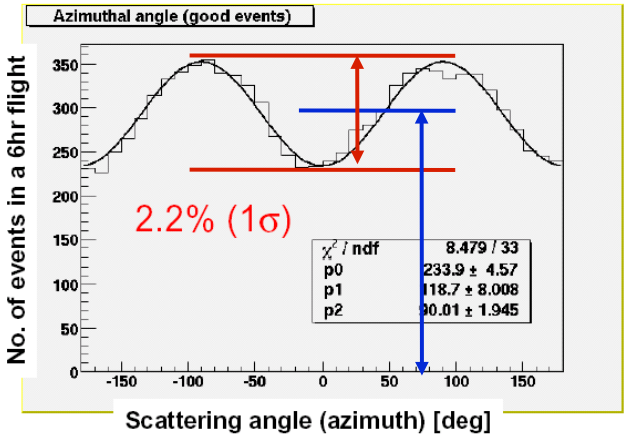
Pol. degree

Numerical data: A. Harding

PoGOLite principle

- γ from a **polarised** source undergo **Compton scattering** in segmented detector material
- Higher probability of being **scattered perpendicular** to the **electric field vector**
- Observed **azimuthal scattering angles** are **modulated by polarisation**





MF=difference/average

- Incident γ deposits little energy at Compton site
- Most deposited at photoelectric absorption site
- Energy difference can be distinguished by simple plastic scintillators (despite intrinsic poor energy resolution)

$$P_{source} = \frac{M_{obs}}{M_{100}}$$

$$MDP_{99\%} = \frac{4.29}{M_{100} R_S} \sqrt{\frac{R_S + R_B}{T}}$$

minimum detectable polarisation

signal rate

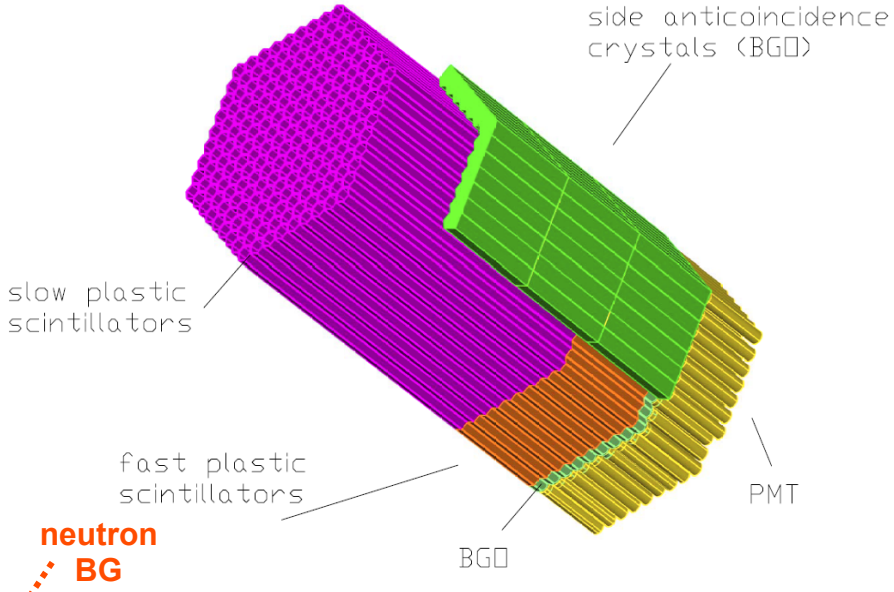
background rate

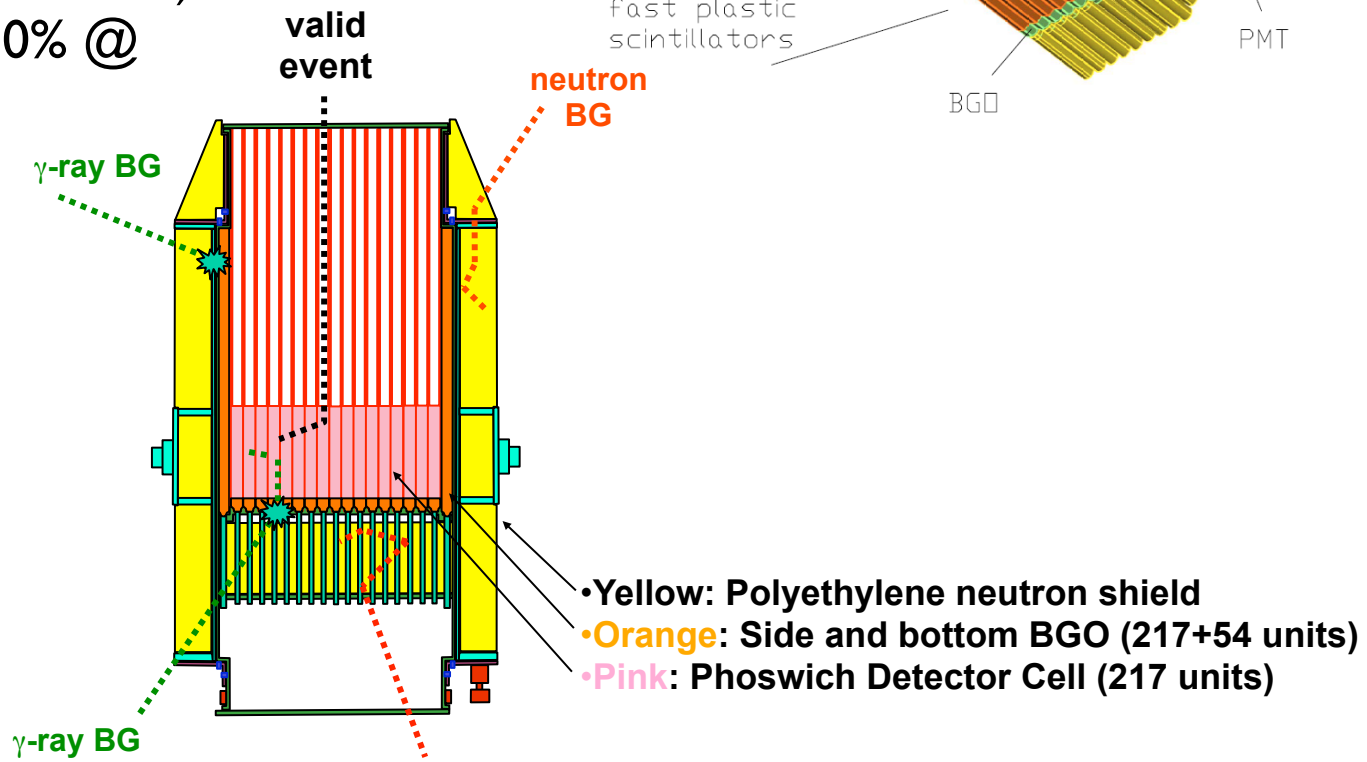
modulation for 100% polarised source

observation time

Implementation

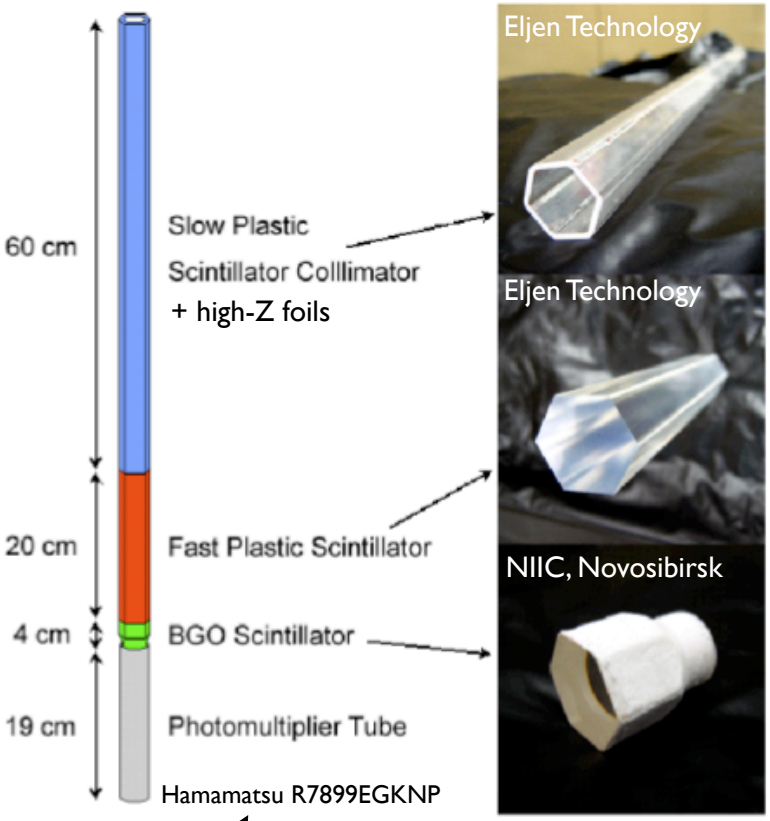
- Slow plastic collimators: **narrow field-of-view** (5 deg^2): **low aperture background**
- Poly-shield + BGO: **low γ + particle backgrounds**
- Plastic scattering scintillators: **large area** (~200 cm^2 @ 50 keV) and **reasonable MF** (~30% @ 50 keV)





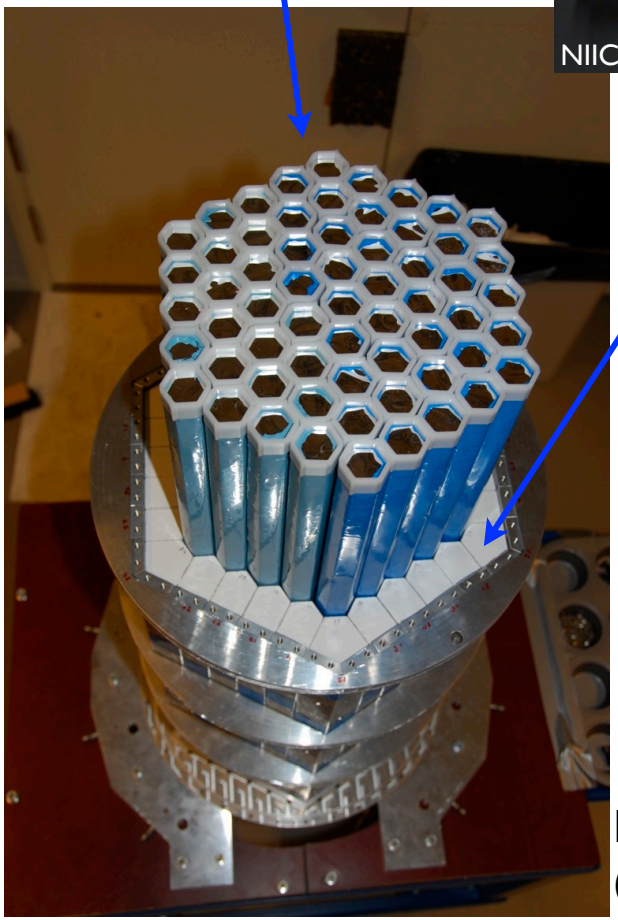
Scintillator array

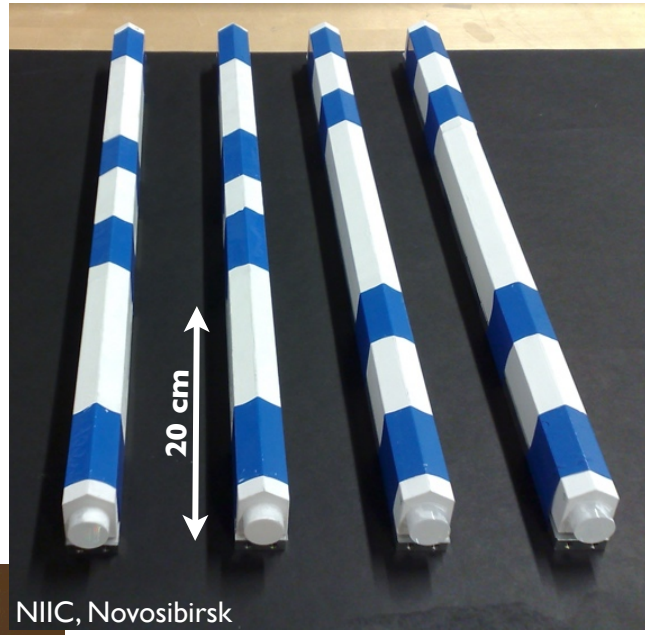
Reflective wrappings:
VM2000 (plastic) / $BaSO_4$ (BGO)



@ 25 keV only 1-3 keV Compton deposited - single p.e. detection
(PMT has 0.05 p.e. ripple @ 10^6 gain)

Phoswich Detector Cells (~30 kg)

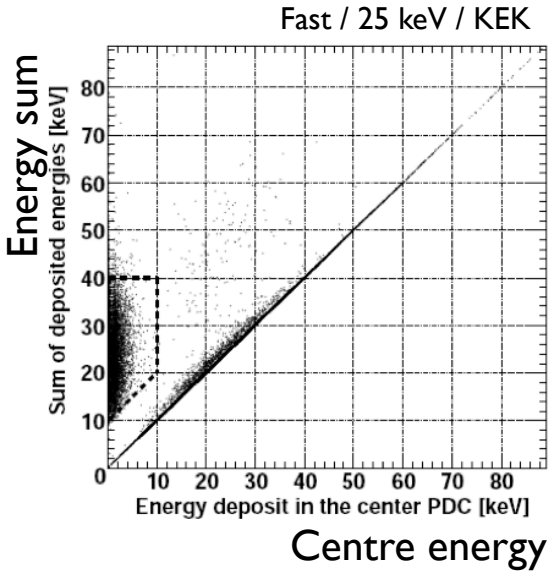




Side anticoincidence, BGO ~150 kg

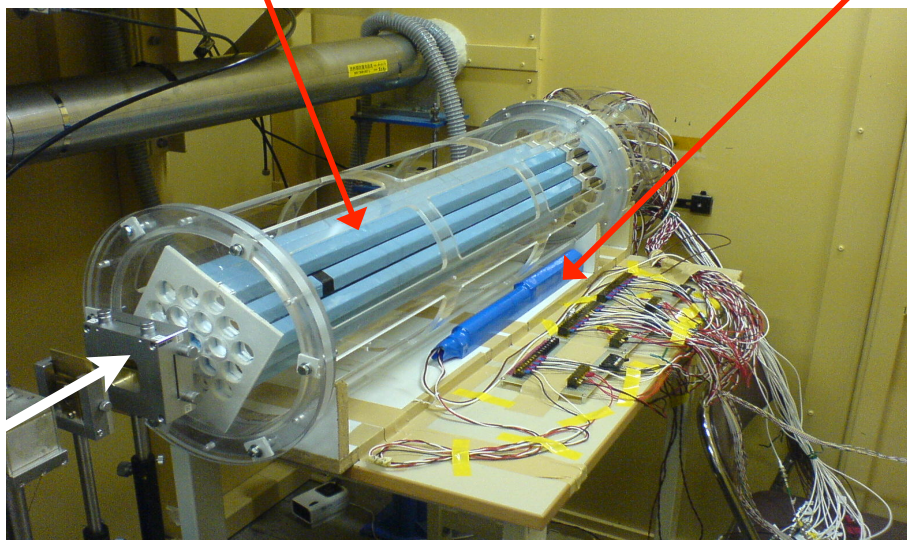
Pathfinder instrument
(61 units)

PoGOLite beam test



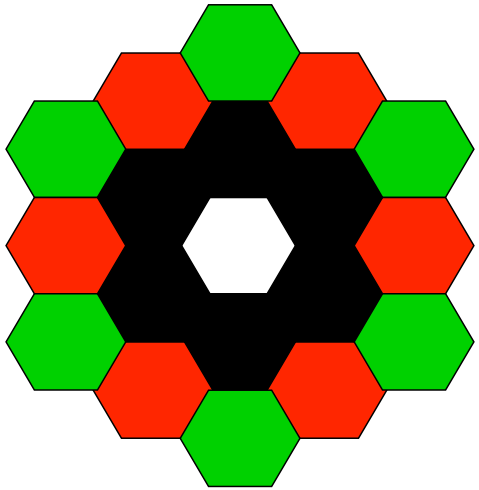
19 phoswich detector cells

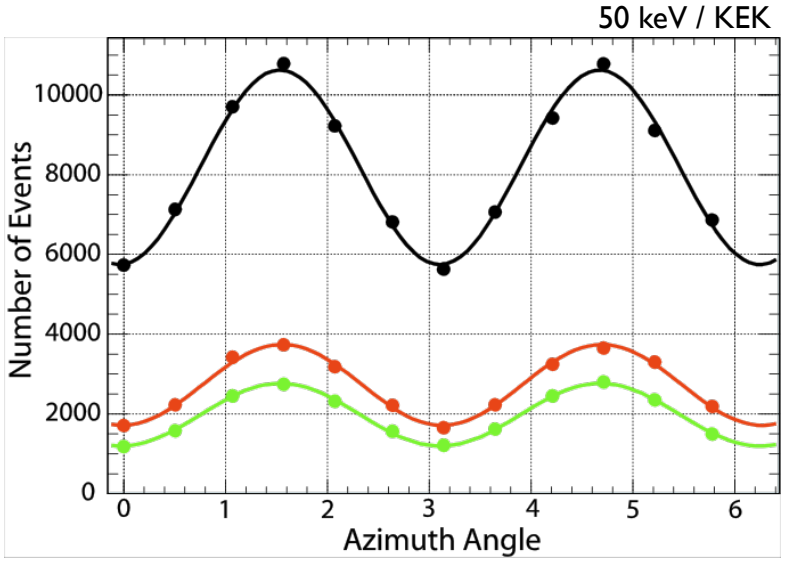
1 segment of the side anticoincidence shield



γ
(90 ± 1)%

19 units





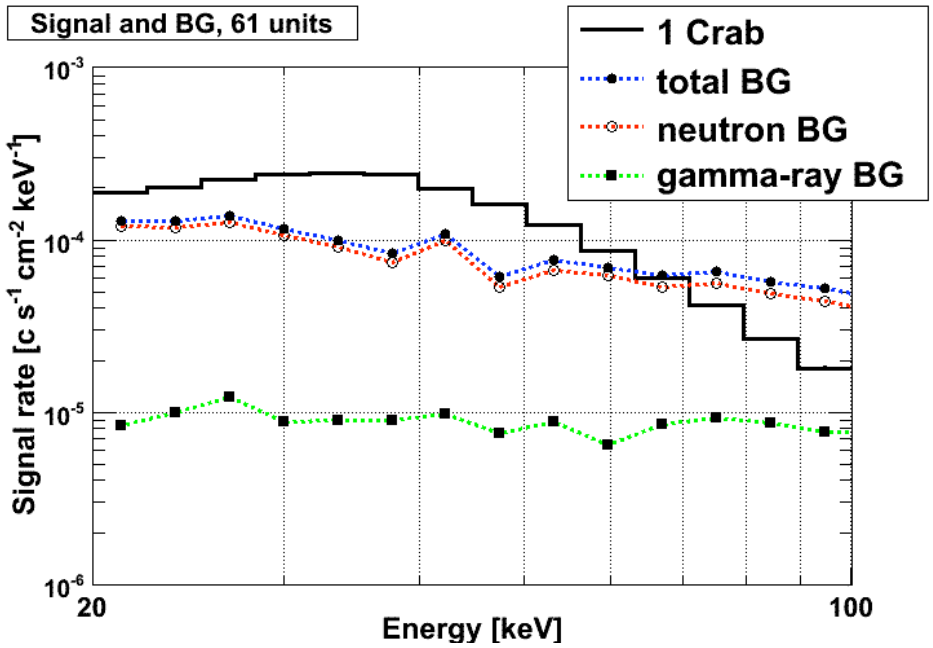
MF

Inner 6 units
(31.3±0.4)%

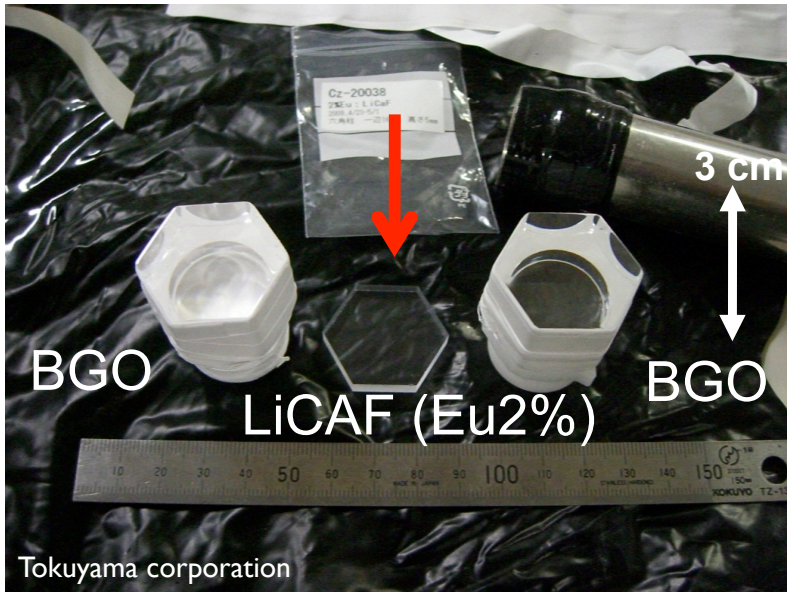
Outer 12 units
(37.9±0.7)%
(40.2±0.8)%

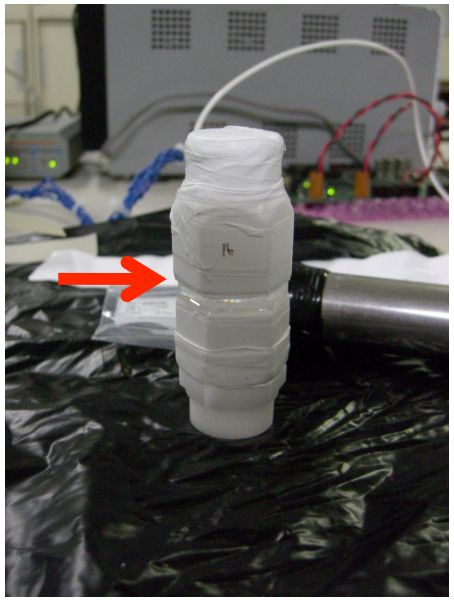
Consistent with Geant-4

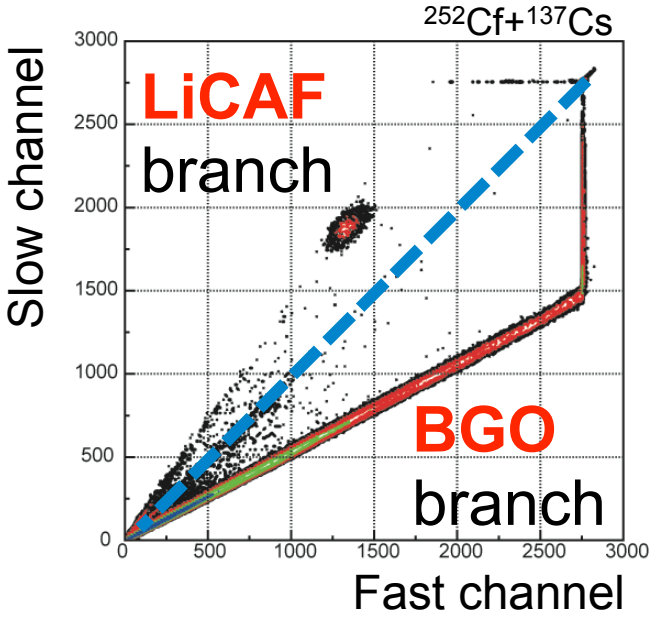
Neutron background



- Neutron background is found to dominate (Geant4 simulations)
- Neutrons are absorbed and thermalised by a thick polyethylene shield
- Neutrons monitored during flight by a novel LiCaAlF6 ('LiCAF') detector in a Phoswich arrangement with BGO
- n+^{6}Li (low Z!)→T+α (MeV line), 9000 γ/n, τ~1.5μs (BGO ~0.3μs)



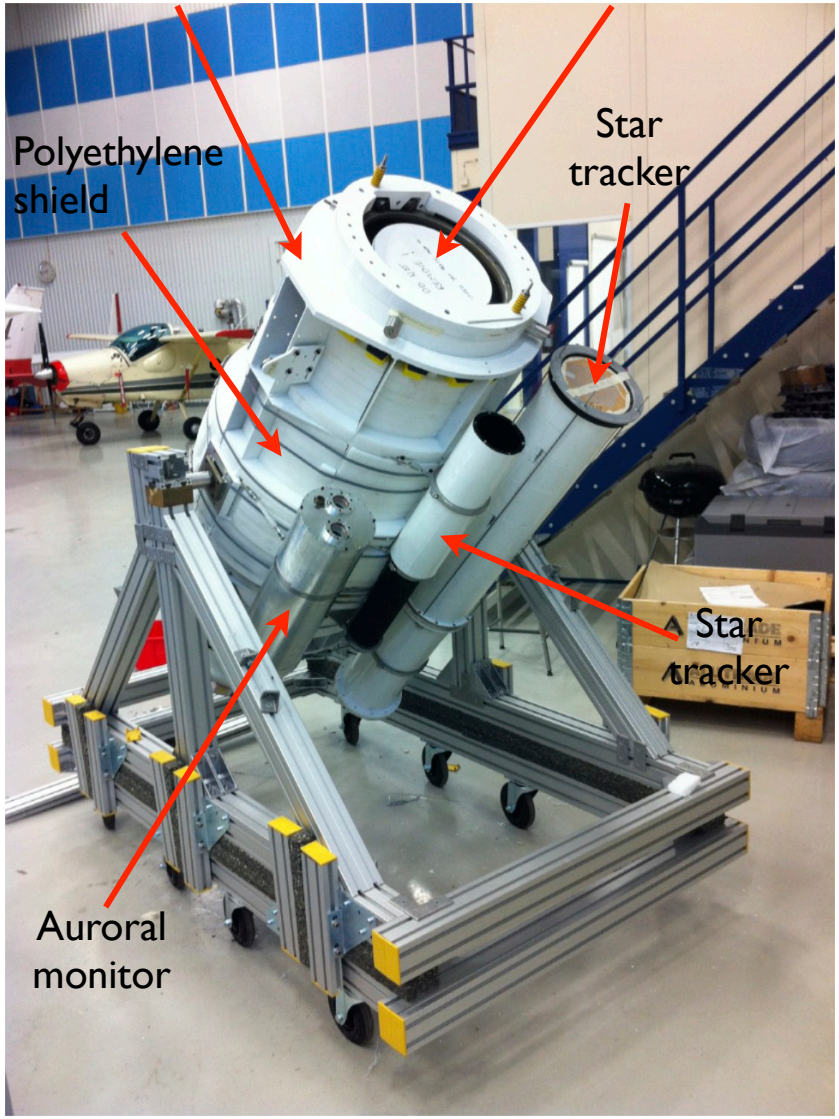




Polarimeter + attitude control

Support frame (stationary)

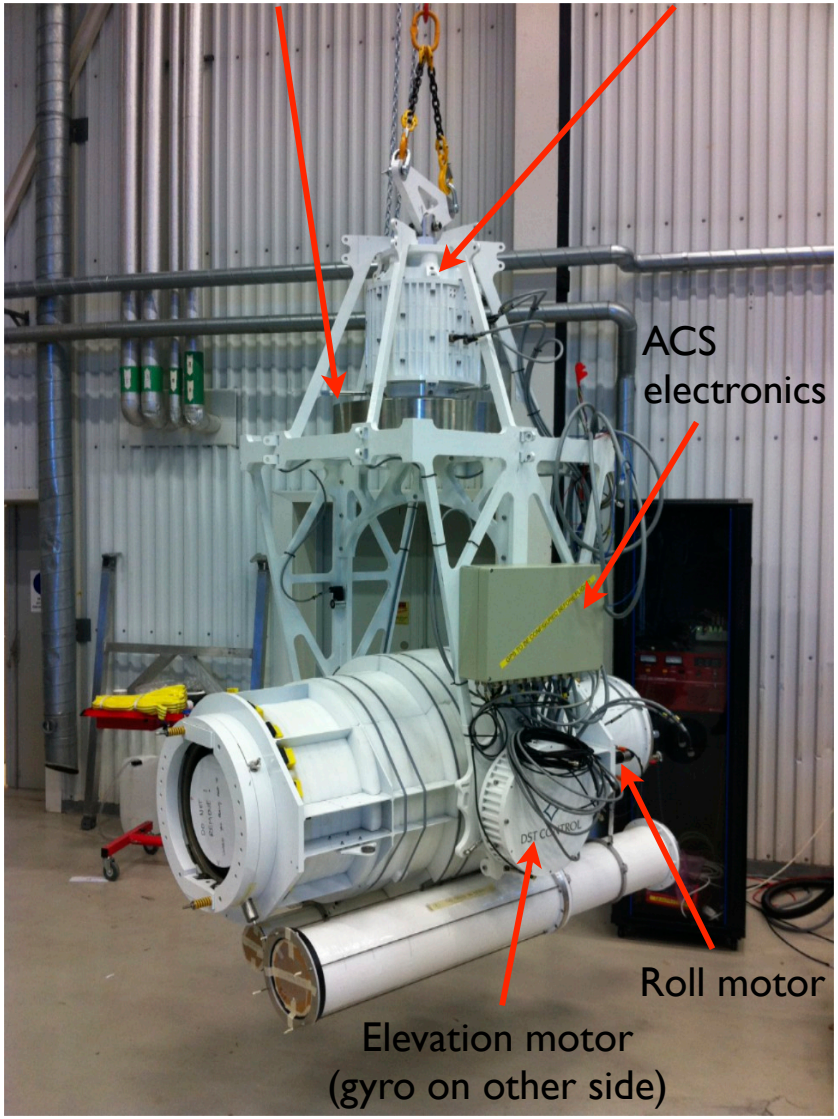
Polarimeter (rotates)



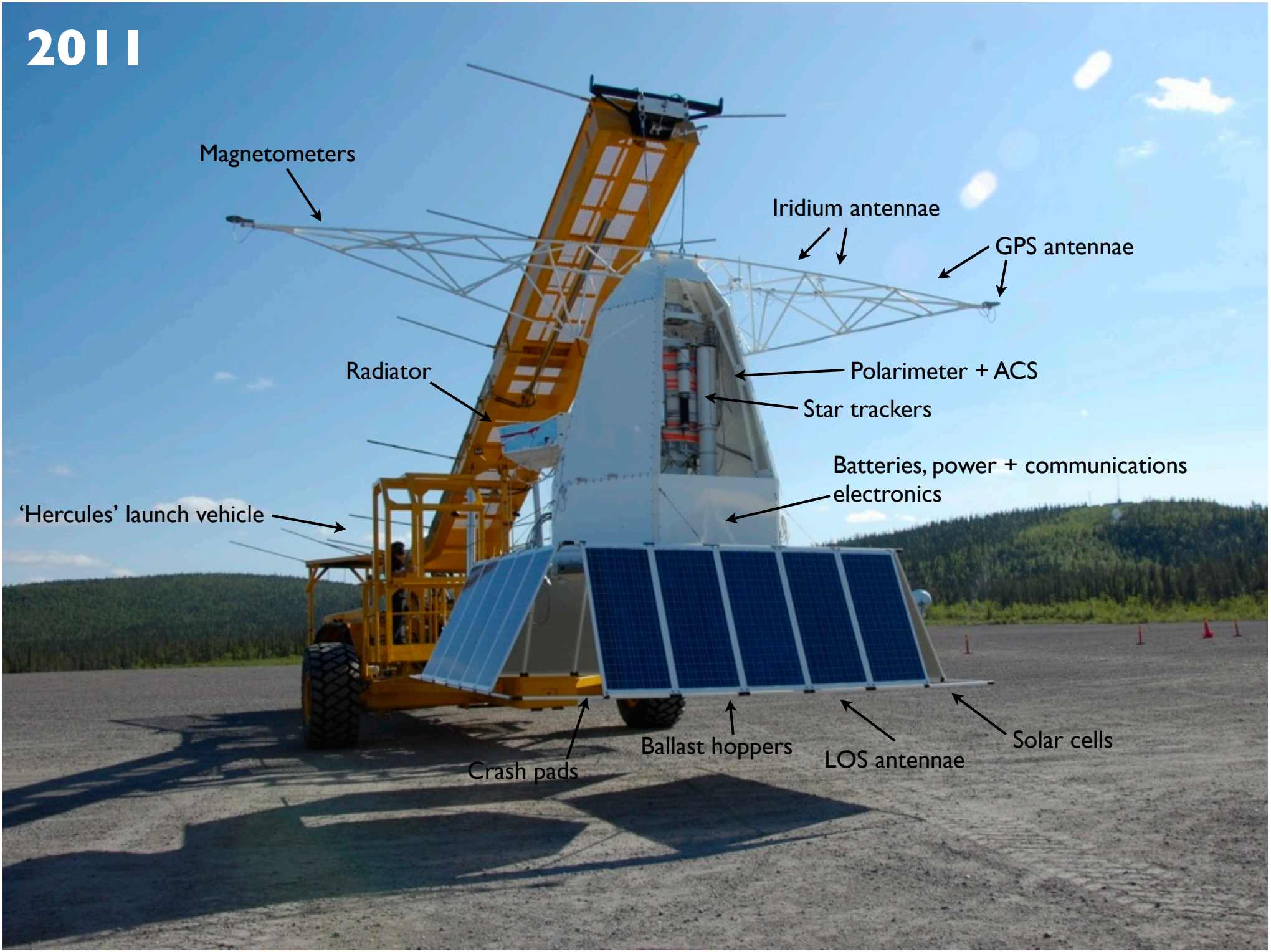
Flywheel

Momentum dump

Aim: pointing to better than 5% of FOV (~0.1°)



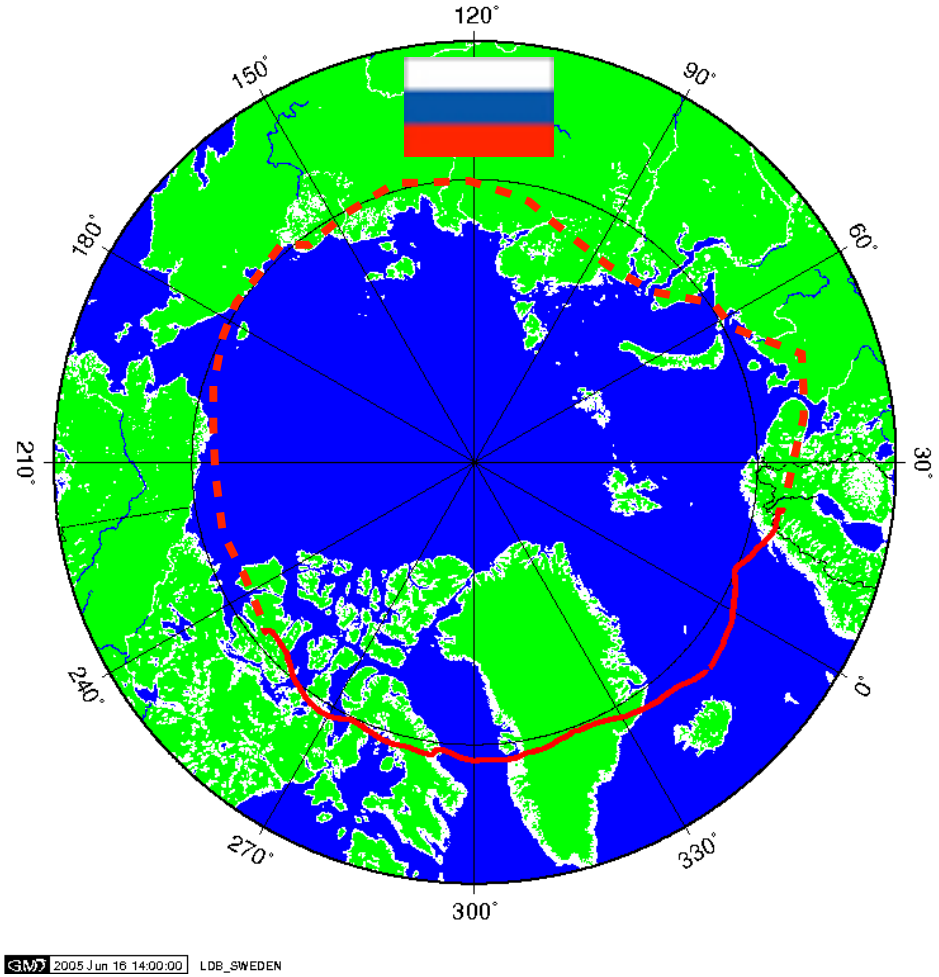
DST CONTROL

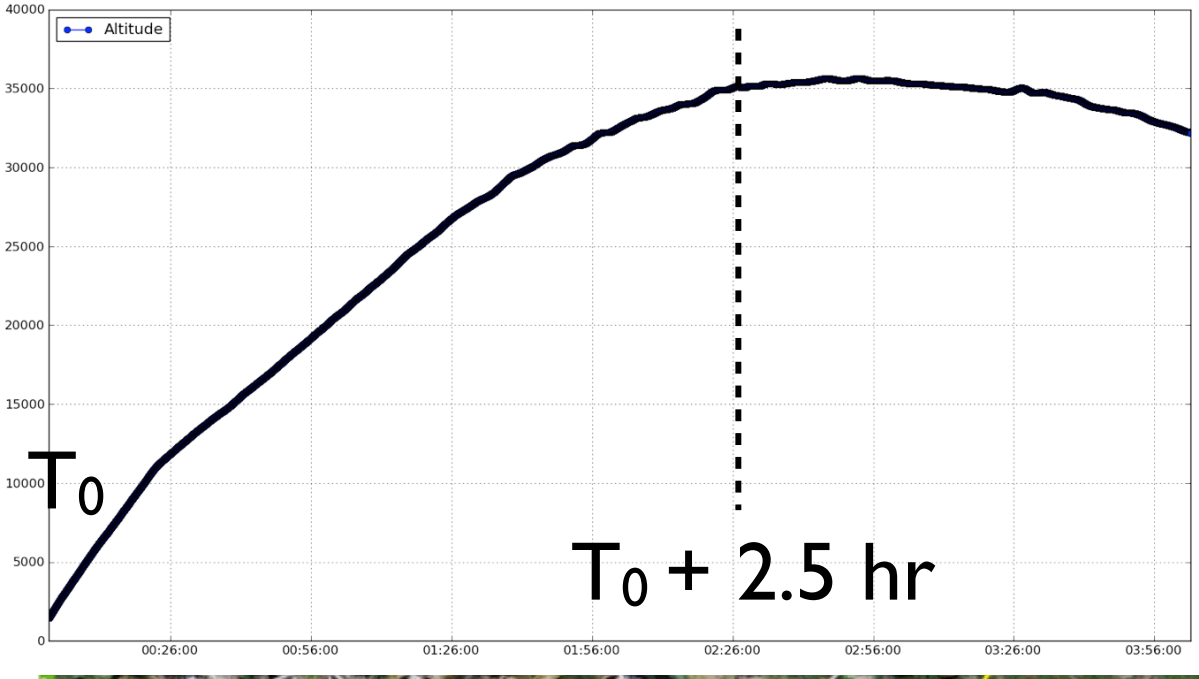

2011
Magnetometers
Iridium antennae
GPS antennae
Radiator
Polarimeter + ACS
Star trackers
Batteries, power + communications electronics
'Hercules' launch vehicle
Crash pads
Ballast hoppers
LOS antennae
Solar cells

2011

2011

- **Goal:** a circumpolar flight.
  - Pioneering! ~15 days aloft.
- **Alternative:** 5 day flight to Victoria Island, Canada.
- Multiple observations of Crab, Cygnus X1 and backgrounds.




Altitude
40000
35000
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25000
20000
15000
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5000
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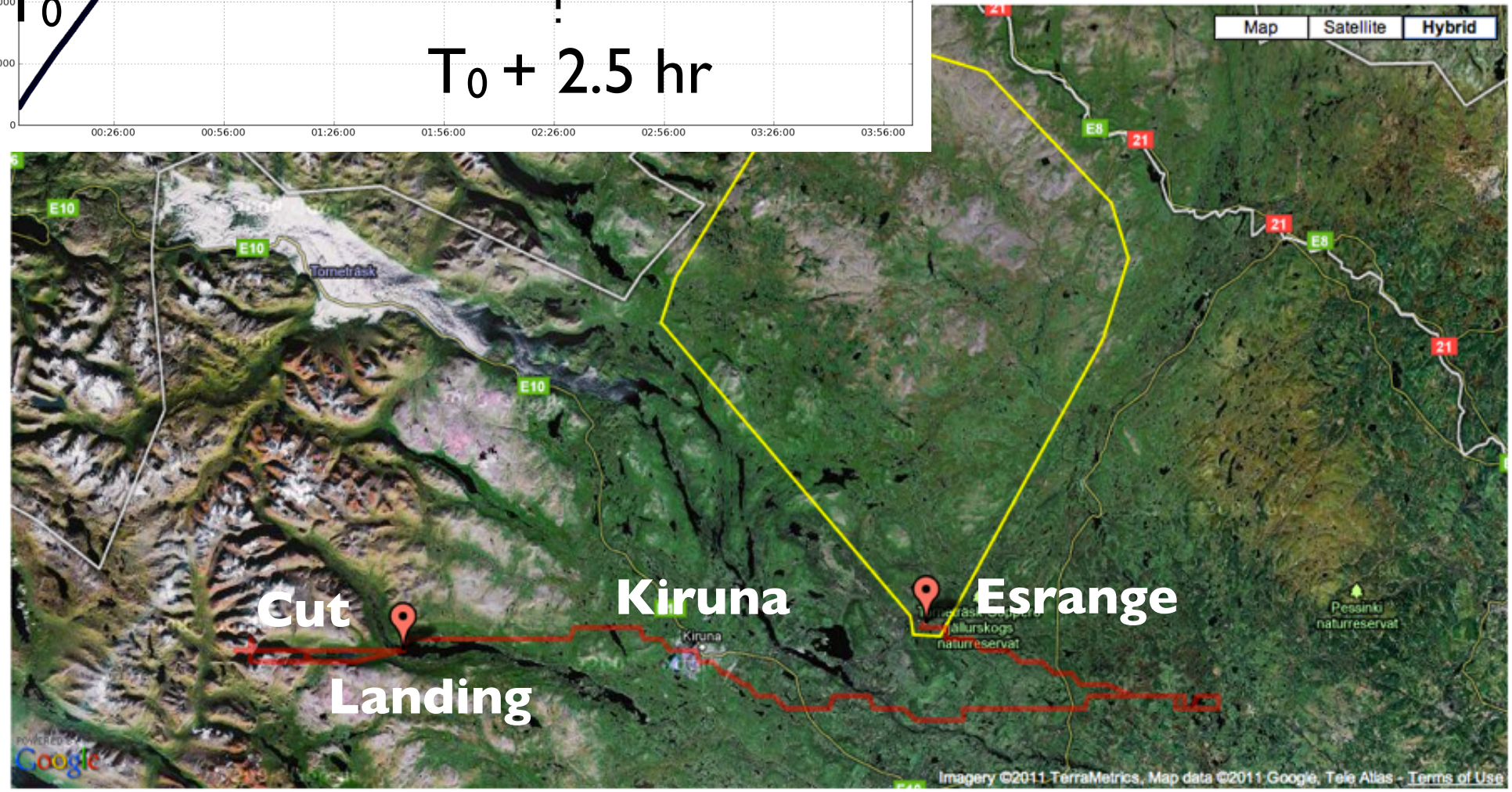
03:26:00
03:56:00
T0
T0 + 2.5 hr


Map
Satellite
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E10
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Torneträsk
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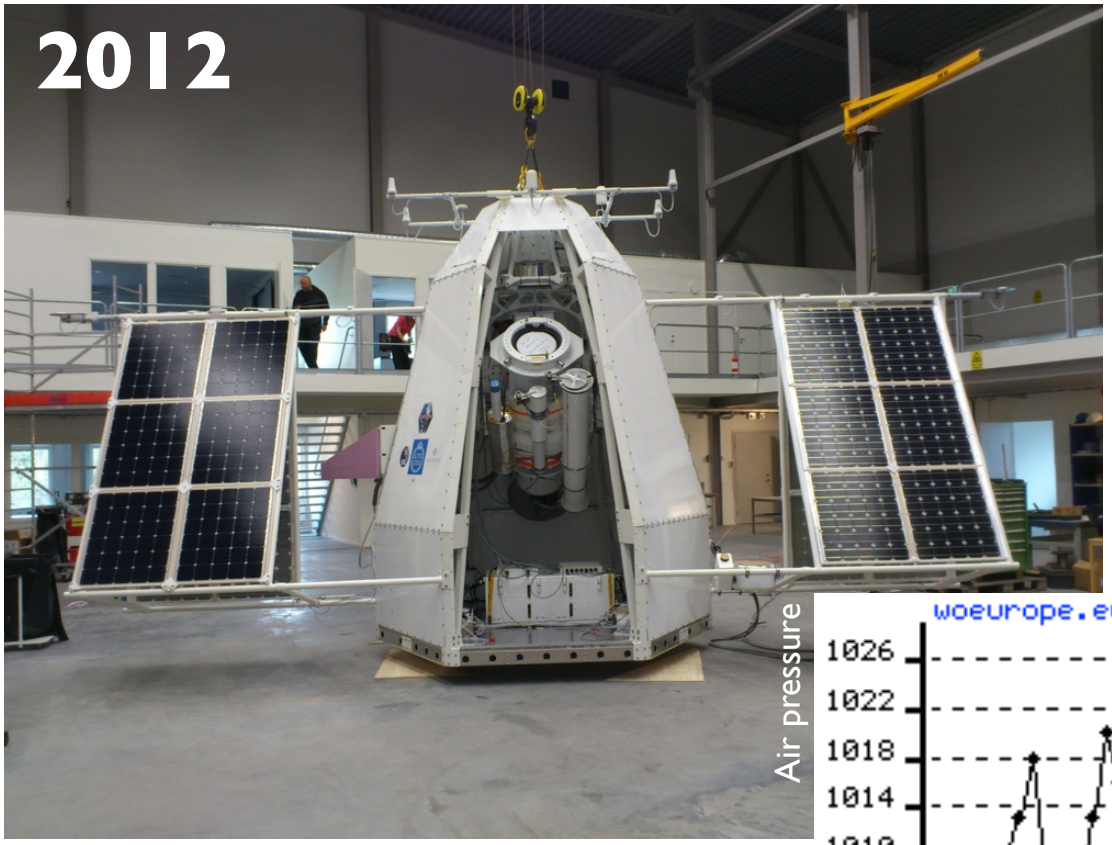
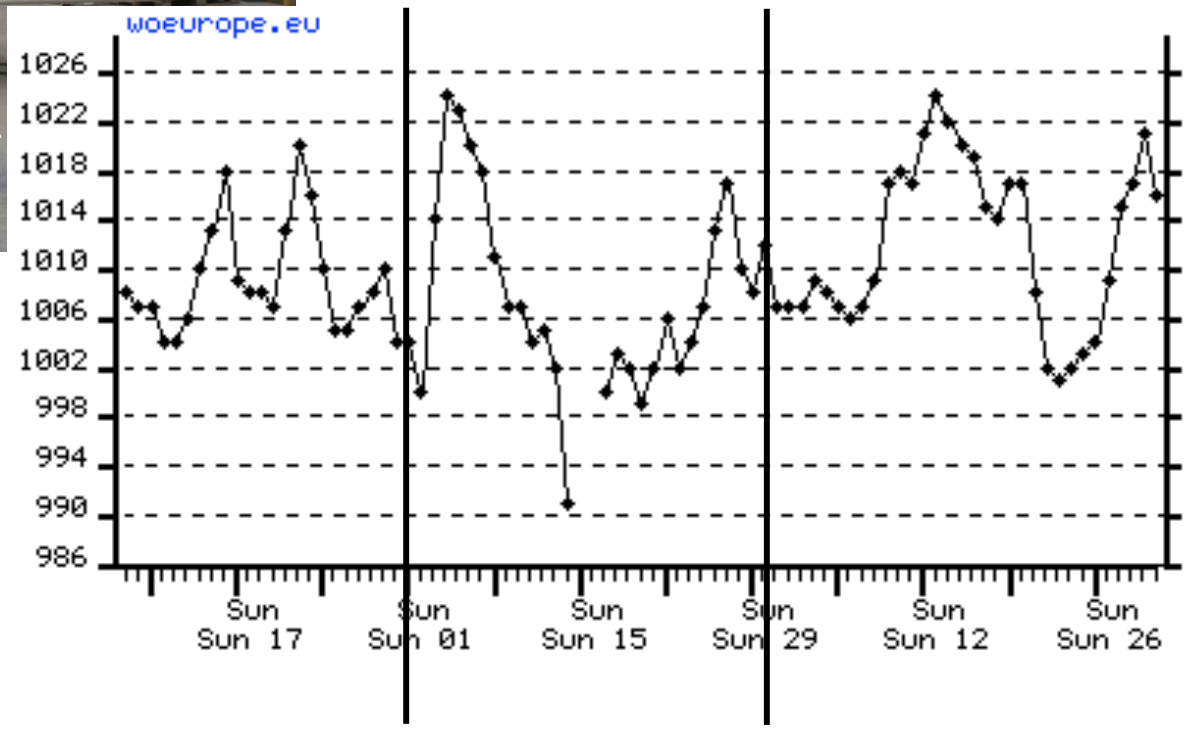
Esrange
Imagery ©2011 TerraMetrics, Map data ©2011 Google, Tele Atlas - Terms of Use





Launch window opens

Launch window closed

Possible contributions to HERD?

- HERD design well matches our experience with scintillator-based detectors.
- Design qualification balloon flight from Esrange Space Centre (a la Fermi/GLAST BFEM)?
- Adding dedicated small lightweight GRB monitors... ideally with polarization capability ... would be very interesting.

- HERD science goals are well aligned to Oskar Klein Centre in Stockholm (e.g. dark matter search).