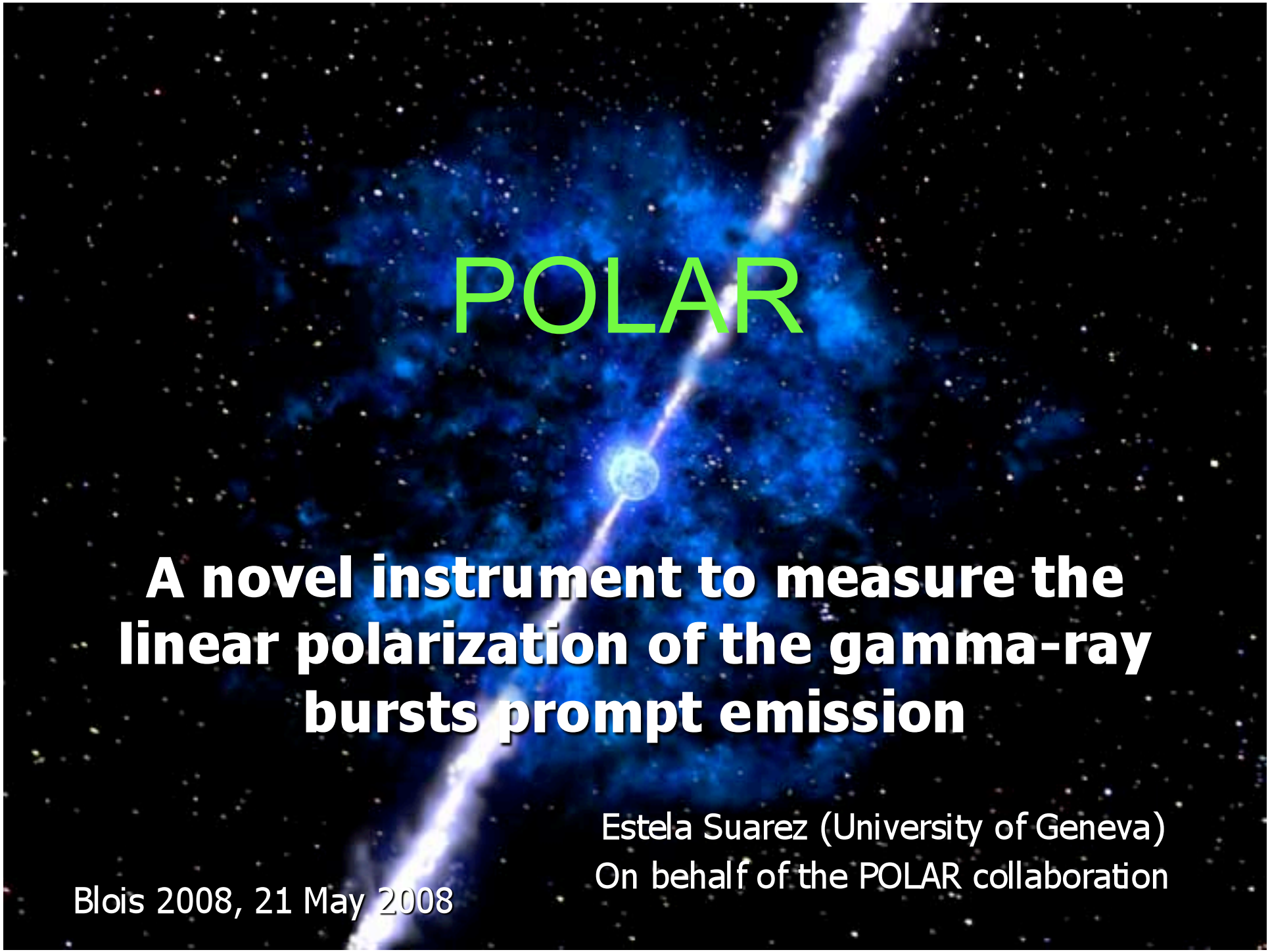
POLAR
A novel instrument to measure the linear polarization of the gamma-ray bursts prompt emission
Estela Suarez (University of Geneva)
On behalf of the POLAR collaboration
Blois 2008, 21 May 2008

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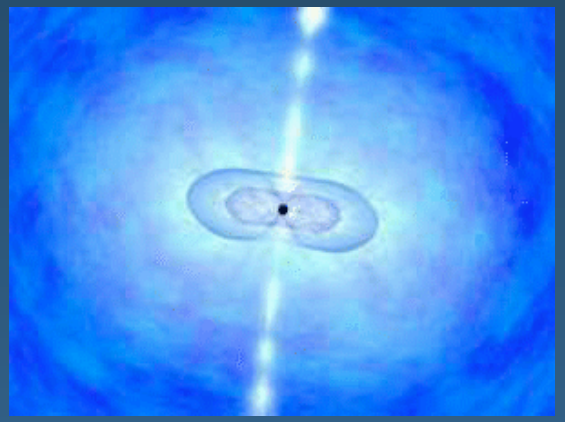
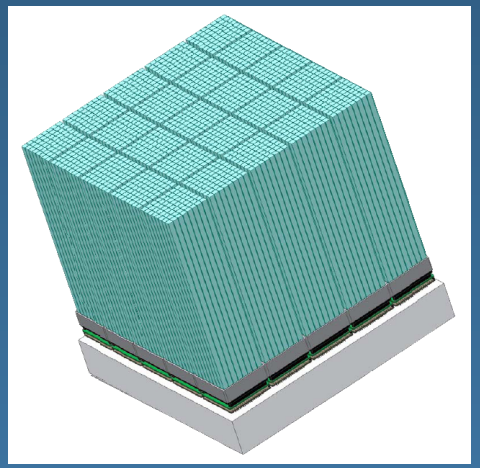
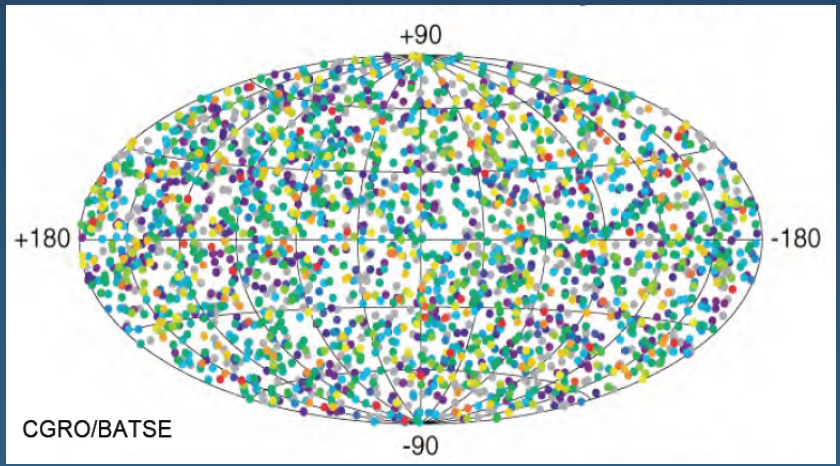
- Gamma Ray Bursts (GRB)
- POLAR
  - Concept
  - Present status
    - Monte Carlo simulations
    - Laboratory results
- Summary



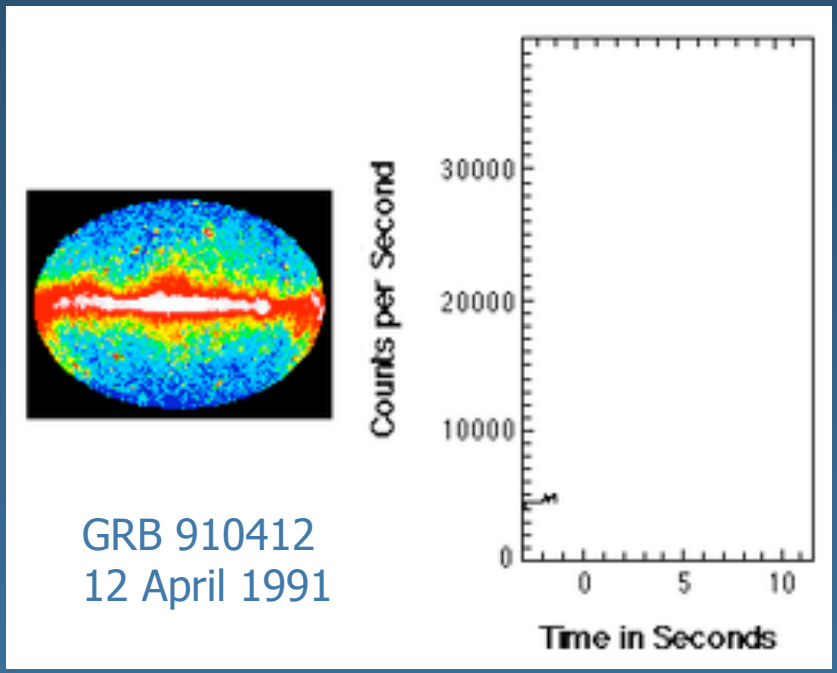


GAMMA RAY BURSTS (GRB)



- GRBs are flashes of gamma rays, at random places in the sky and at random times.
- Currently about 2 to 3 GRB are detected per week

- They are the brightest events in the universe.



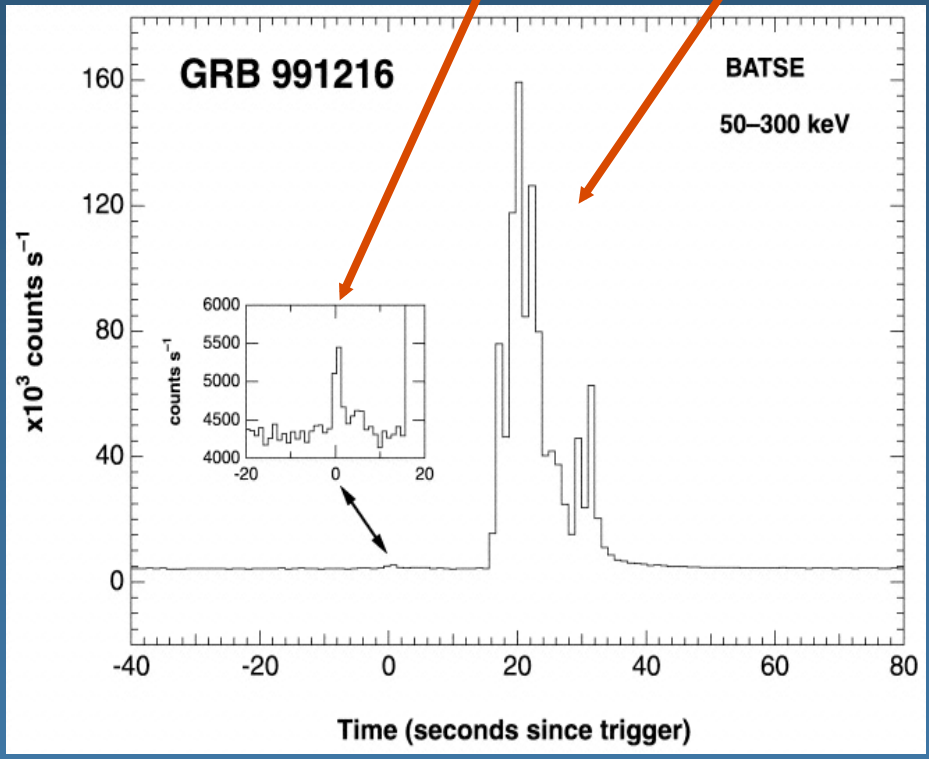
- Nature of their progenitor is unknown.

GAMMA RAY BURSTS (GRB)

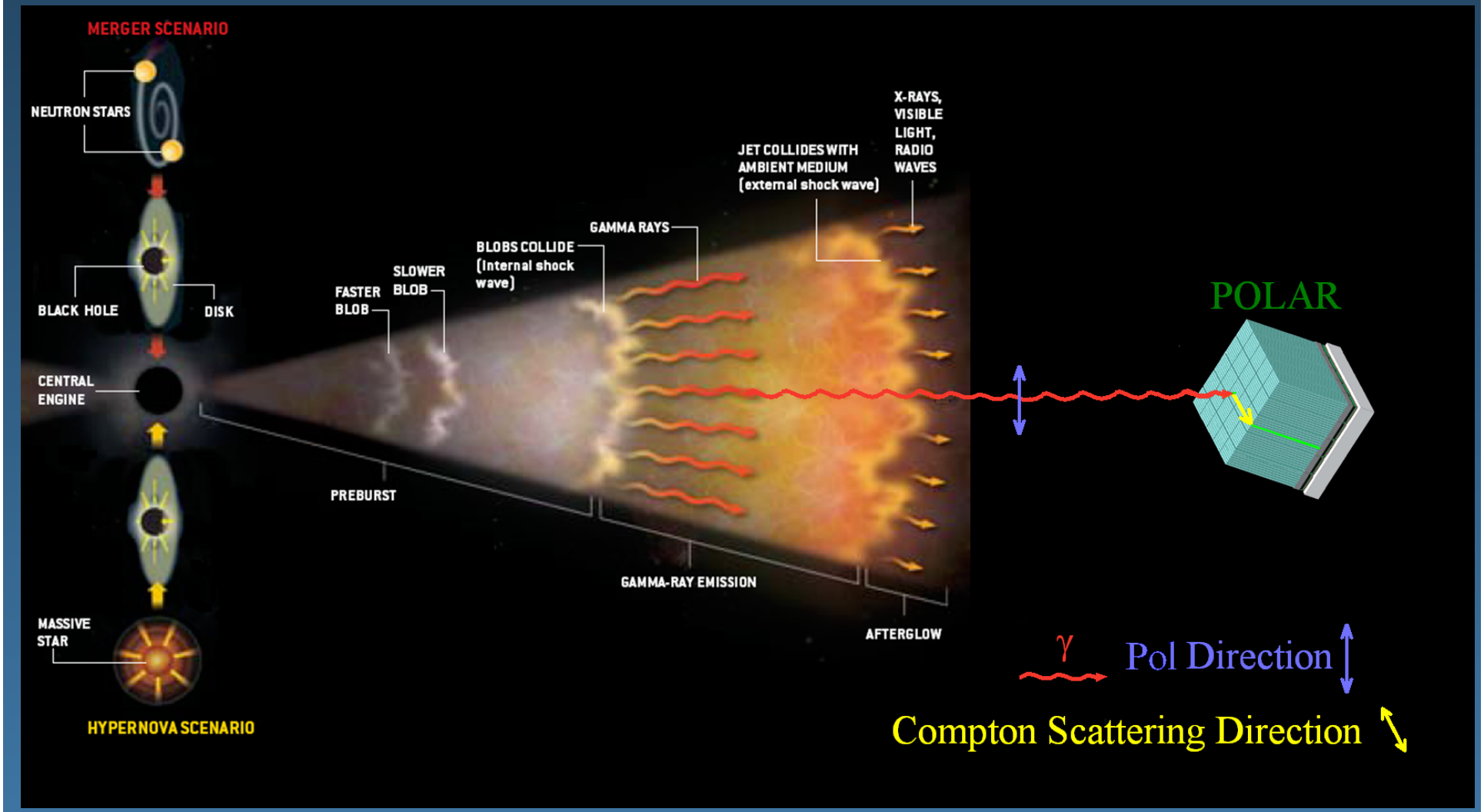
- Spectrum: similar to a broken power law

- Light-curves, although very different from GRB to GRB, show three parts:
  - Pre-burst
  - Prompt emission
  - Afterglow

Typical light-curve

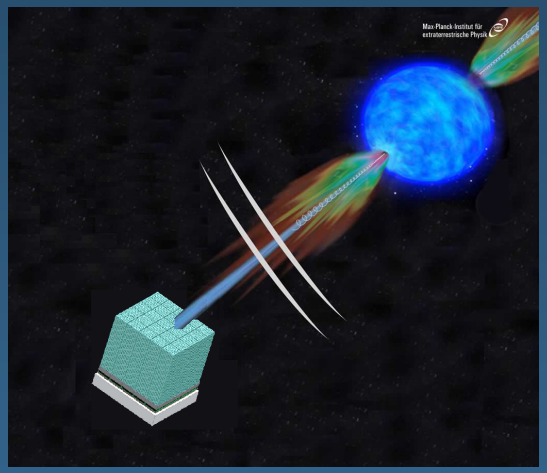


ORIGIN OF GRB



POLARIZATION IN GRB

- Polarization can be produced by:
  - Synchrotron radiation
  - Cyclotron Emission
  - Bremsstrahlung
  - Compton Scattering
  - Magnetic photon splitting

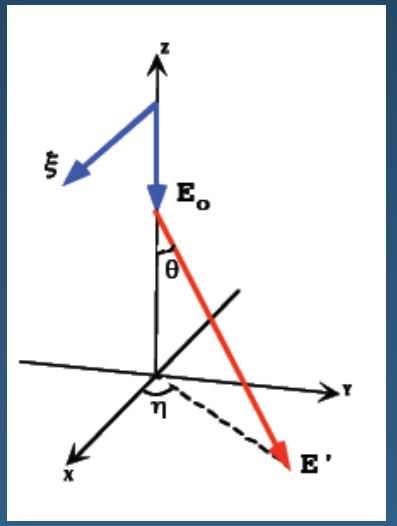


- The three most accepted models of GRBs predict different levels of linear polarization:
  - Fireball Model: $P_{lin} \sim 10\text{-}20\ \%$
  - Cannonball Model: $P_{lin} = 0 - 100\%$
  - Electromagnetic Model: $P_{lin} \sim 50\ \%$

Polarization can indicate which model is the correct one

HIGH ENERGY POLARIMETRY

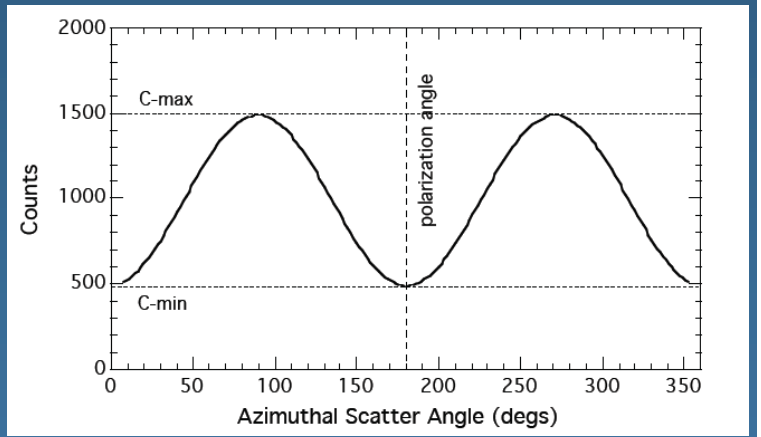
- Measured using Compton Scattering:
  - photons tend to scatter at right angles respect to the initial polarization vector:
    - η - Azimuthal Scatter Angle !
    - θ - Compton Scatter Angle



Klein - Nishina

$$d\sigma = \frac{r_o^2}{2} d\Omega \left(\frac{E'}{E_o}\right)^2 \left(\frac{E_o}{E'} + \frac{E'}{E_o} - 2\sin^2\theta\cos^2\eta\right)$$

- Distribution in azimuth scattering angles:
  - Modulation curve



from M. McConnell,2002

- Level of polarization

$$P = \frac{\mu_p}{\mu_{100}} = \frac{1}{\mu_{100}}\left(\frac{C_{\max} - C_{\min}}{C_{\max} + C_{\min}}\right)$$

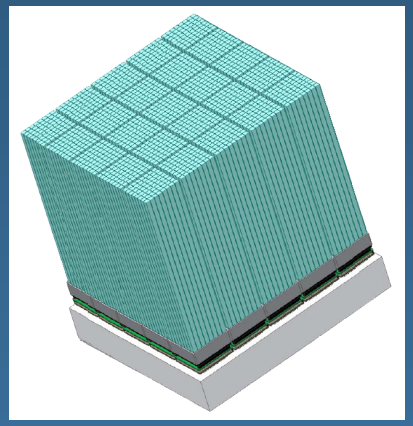
POLAR

REQUIREMENTS

- Compton polarimeter
- Simple, compact instrument:
  - Relies on given burst position and spectrum
- Dedicated for GRB observations only:
  - Large effective area
  - Large modulation factor
  - Large field of view
- Energy range for incoming photons:
  - 50keV – 500keV

DESIGN

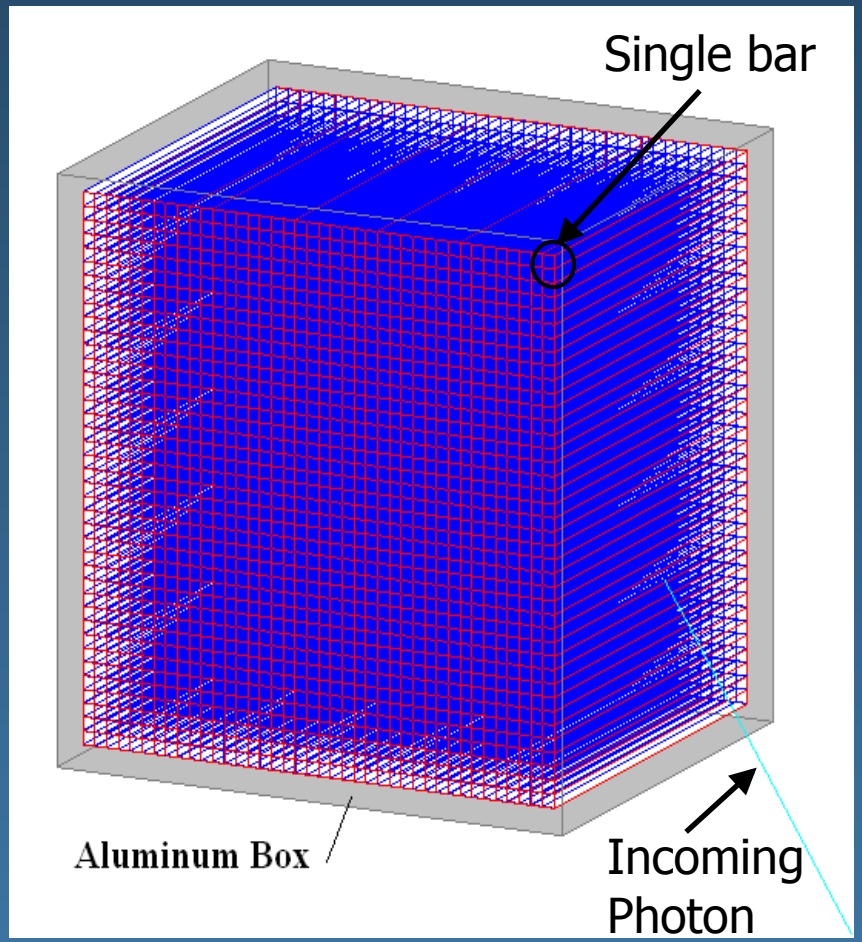
- 40x40 uniform scintillator array
  - Light, fast, and low-Z plastic
  - Scintillator size: 6x6x200mm^3
  - Matching novel MAPM H8500



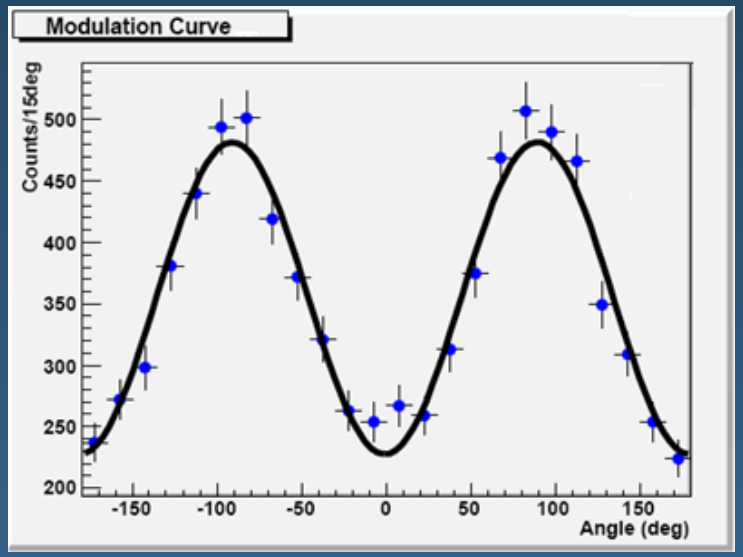
  - $A_{eff} \approx 400$ cm^2
  - $\mu_{100} \approx 35\%$
  - FoV $\approx$ ⅓ of the sky

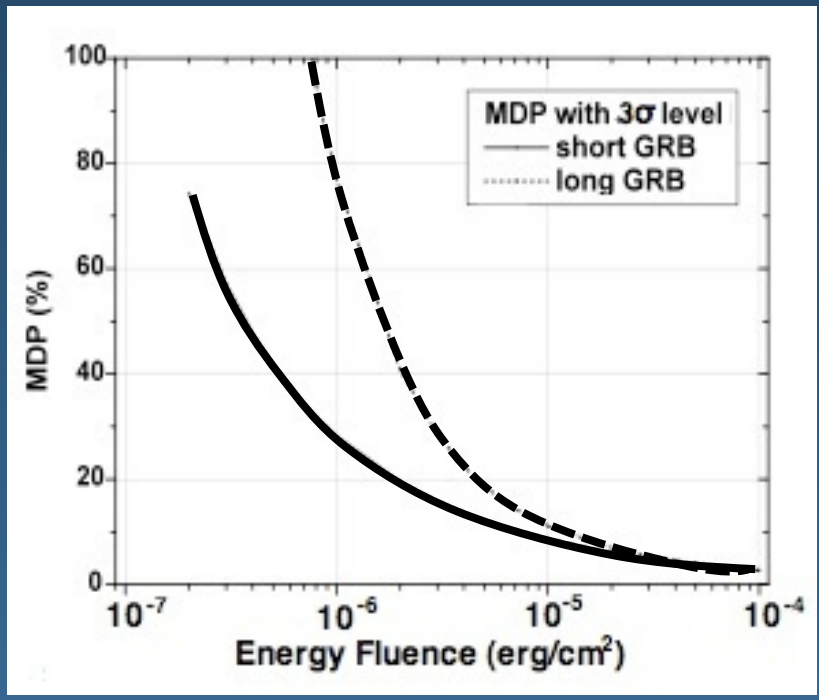
MC SIMULATIONS

- GEANT4 package (CERN)
- Size 240x240x200 mm^3
- 6x6x200mm^3 single plastic bars, wrapped with aluminum foil
- Aluminum wall 1mm thick
- Photon directions and polarization defined by user
- Any given energy spectrum
- Software analysis in ROOT



SOME RESULTS FROM SIMULATIONS





- Compton effect dominates
- Most photons deposit energy in several bars
- Trigger activation: at least 2 channels
- Selection of two highest E depositions
- Reacting pixels define geometry
- MC predicts clear modulation signal

- Minimum Detectable Polarization:

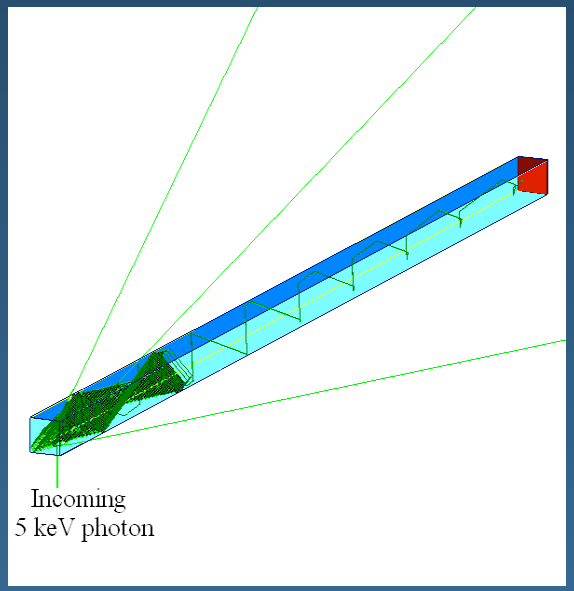
  $E=10^{-5}$ erg/cm^2 $\rightarrow$ $MDP_{3\sigma} \approx 10\%$

Several measurements per year!

LIGHT COLLECTION STUDIES

- Simulations predict:

1. Around 45% of the optical photons reach PM
2. Differences for incoming gammas at top or bottom: 10-20 %
3. Polishing of the scintillator surface is very important



- Experimental measurements are finished for 2 and 3 and they agree with the simulations.

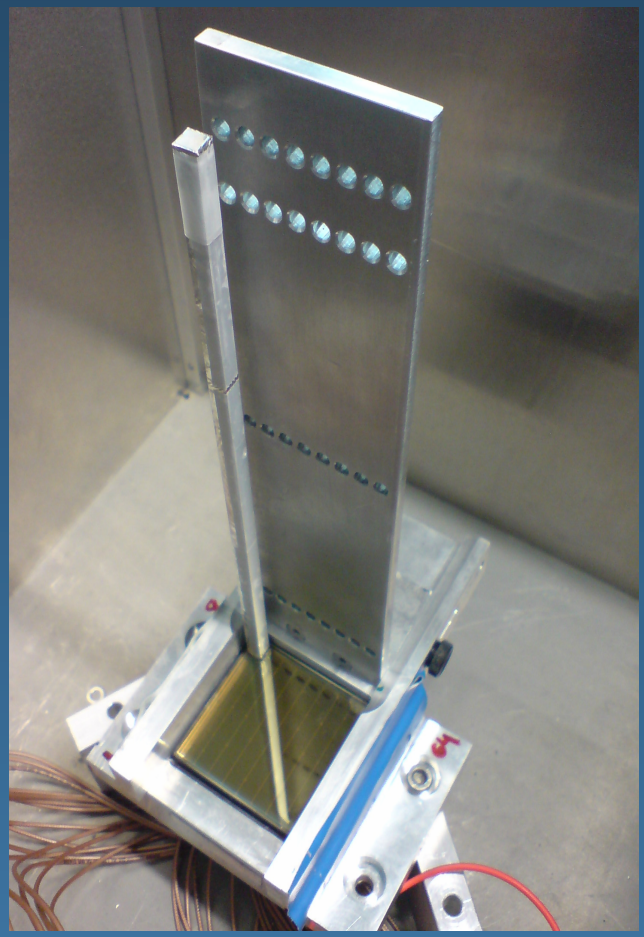
LABORATORY RESULTS

LIGHT COLLECTION

- Goal: optimize light output linearity
- Sources: ^{241}Am, ^{137}Cs, ^{90}Sr
- Wrapping: No coating, Al, Teflon, 3M® Foil

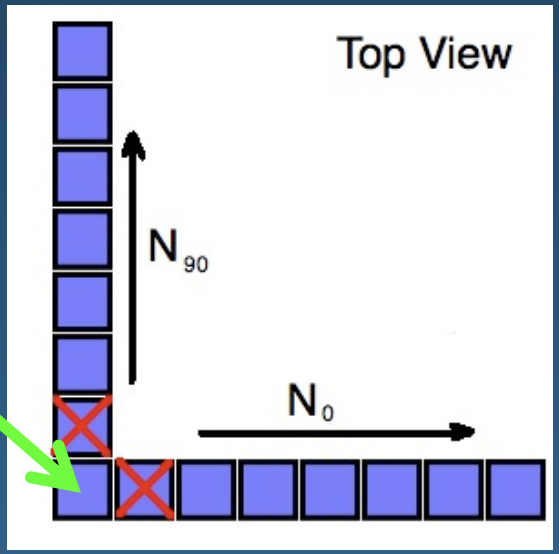
- Results:
  - Amplitude changes between bar ends less than 10%-15%
  - 3M® wrapping clearly makes light output highest and should be used

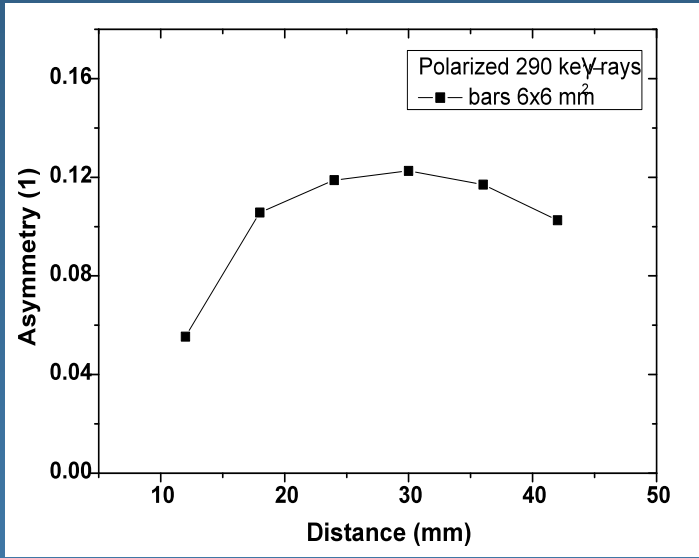
- Results are consistent with MC simulations



ASYMMETRY TESTS with 15 BARS

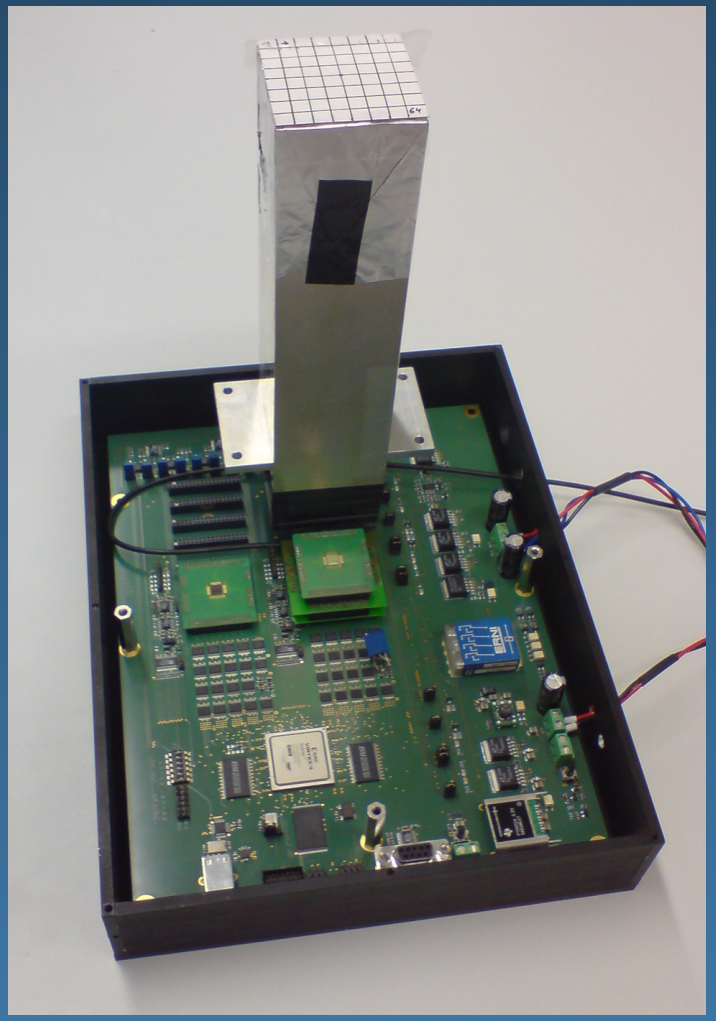
- Tests with 60% polarized photons from radioactive source (Cs^{137}, 290 keV)
- Scintillator bars on MAPMT
- $$Asymmetry = \frac{N_{90} - N_0}{N_{90} + N_0}$$
- Asymmetry up to 12% depending on distance between plastics; draft data





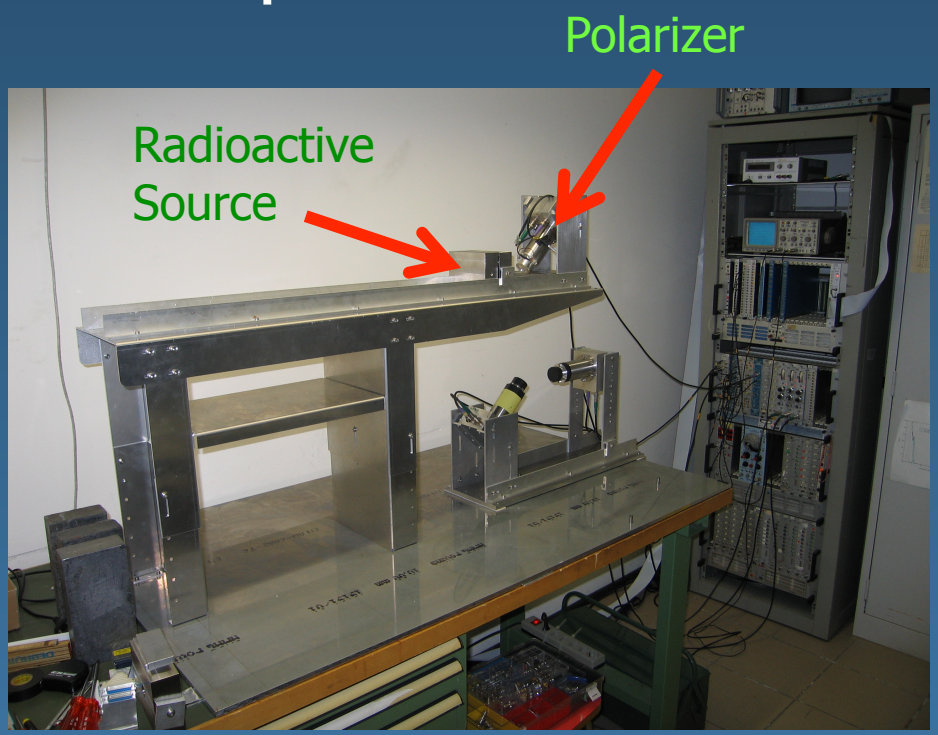
DEMO-MODEL TESTS

- DEMO = 2 out of 25 modules:
  - 2 x 64 BC400 bars (6x6x200 mm^3 each)
  - 2 x H8500 MAPM
- Readout: specially designed electronic board
- Tests:
  - Polarized γ-rays from Cs^{137}
  - 100% polarized γ-rays from synchrotron (SLS @ PSI)

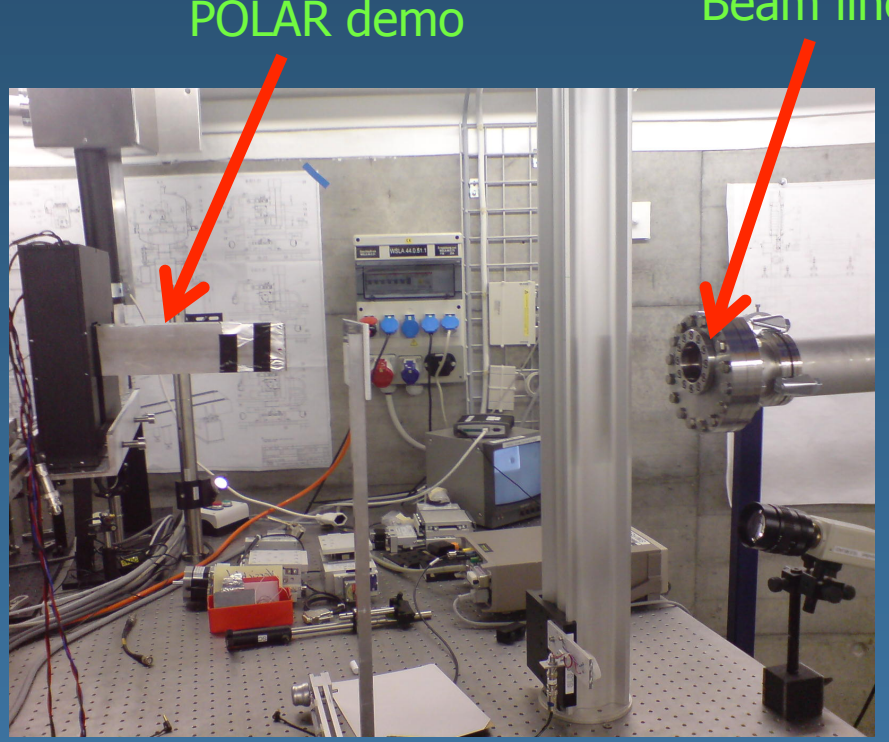


DEMO-MODEL SETUP

- Radioactive source setup:



- Synchrotron (SLS):



SUMMARY

- POLAR – Compton hard X-ray GRB polarimeter using low Z scintillators and MAPMT
- Compact 40x40 homogeneous array of 6x6x200 mm^3 plastics
- $MDP_{3\sigma} \approx 10\%$ for GRB total energy of 10^{-5} erg/cm^2; tens of detections/year
- First asymmetry results obtained demonstrating polarimetric capability. Demo-model measurements being performed at present.
- Engineering-Qualification Model will be ready in 2010.

- Accurate measurements of GRB polarization will:
  - Constrain theoretical models
  - Give crucial information for determining the nature of GRB central engine

POLAR COLLABORATION

1. Centre de Physique des Particules de Marseille (CPPM, France)

- Ch. Tao

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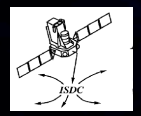
- B. Wu, S. Xiang, S.N. Zhang



4. INTEGRAL Science Data Centre (ISDC, Switzerland)

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- W. Hajdas, A. Mtchedlishvili

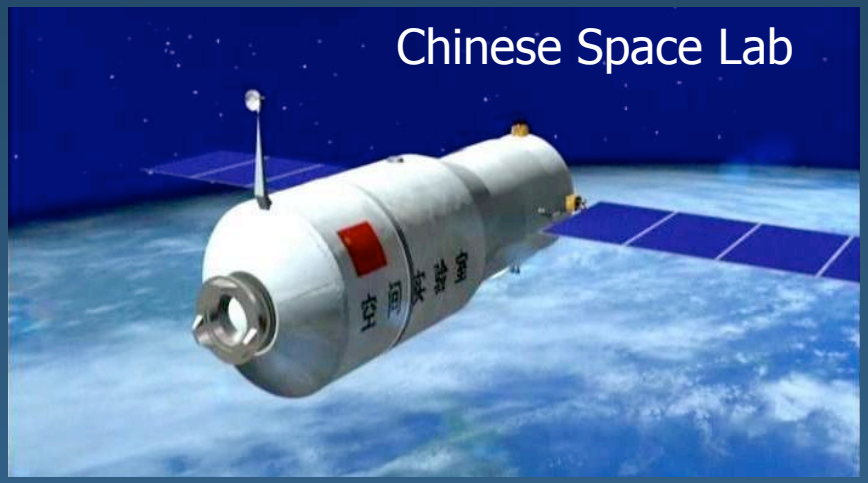
7. The Andrzej Soltan Institute for Nuclear Studies (IPJ, Poland)

- M. Gierlik, R. Marcinkowski, G. Wrochna

Thank you

LAUNCHING POSSIBILITIES

- Chinese Space Lab, ~2012



- International Space Station (ISS)