FRAM: Introduction & data analysis

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FRAM =

Fotometrický Robotický Atmosférický Monitor

Photometric Robotic Atmospheric Monitor

Fram, Fridtjof Nansen's pollar vessel (“forward” in Norwegian)

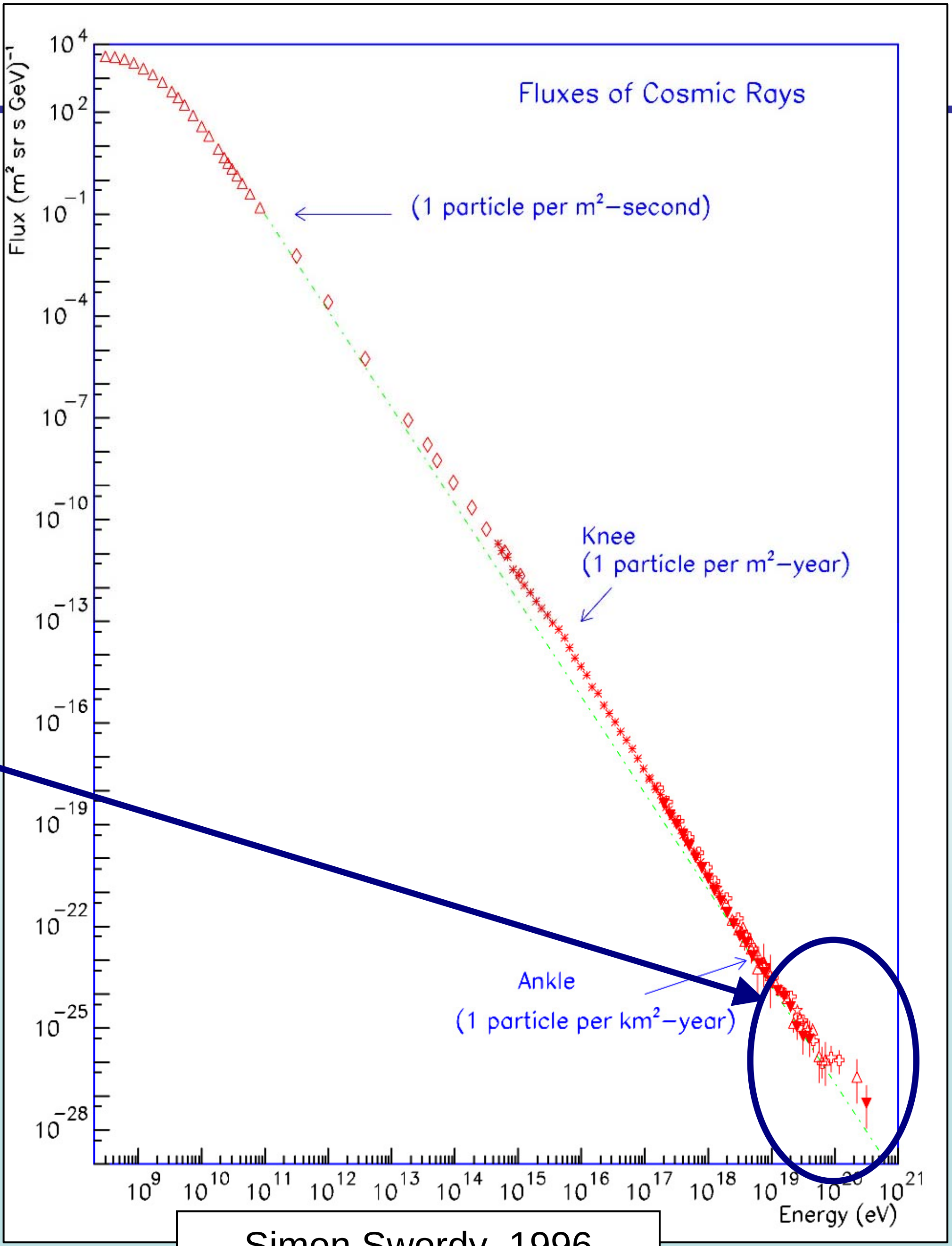
“Astrophysics in the 21st century will mainly concentrate on two fundamental problems.
The first problem is something
we would like to see, but we don‘t see.
This something is dark matter.
And the second problem is something
we don‘t want to see,
but we unfortunately observe.
In this second case I mean
ultra-high energy cosmic rays.”

David N. Schramm

What are ultra-high energy cosmic rays (UHECRs)?

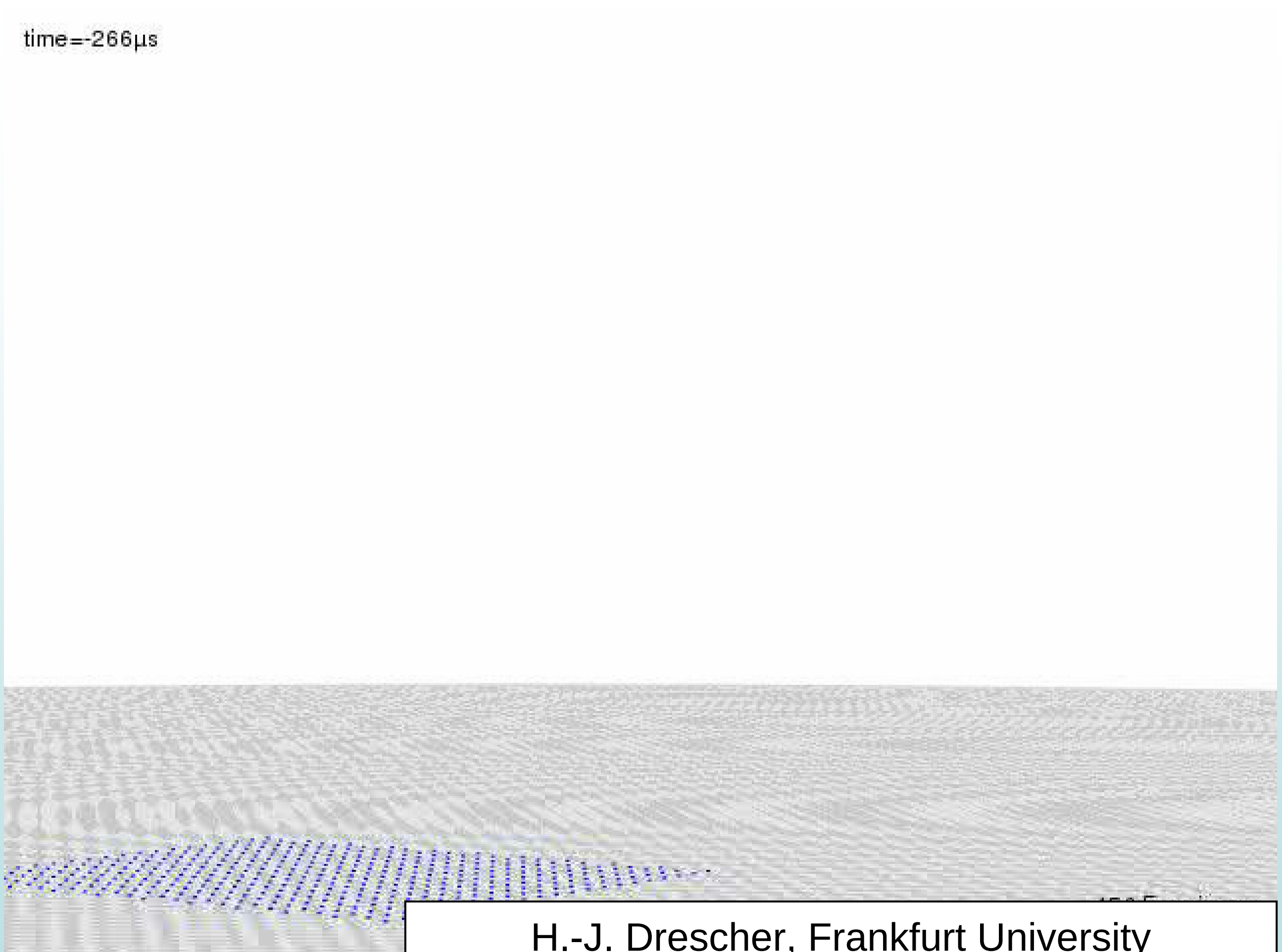
UHECRs are particles with energy above "ankle", say, above 3 x 10^{18} eV.

The most energetic event:
Detector Fly's Eye, Utah, USA, October 15th 1991
3 x 10^{20} eV ≈ 50 J



Simon Swordy, 1996

Extensive air showers



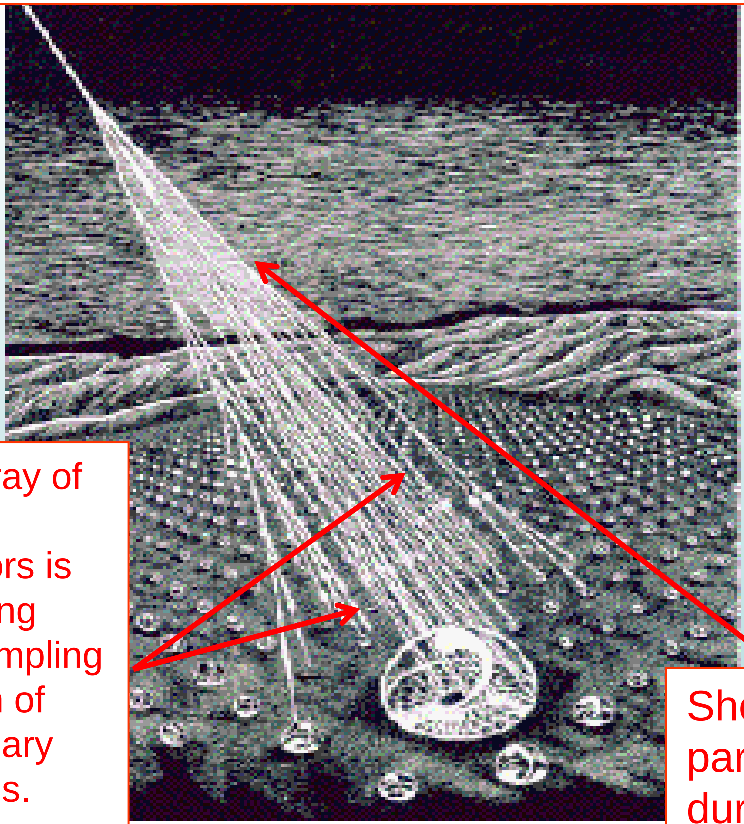
H.-J. Drescher, Frankfurt University

- Primary particle interacts with atmosphere
- Number of secondary particles is created
- Secondaries interact again, and again, ...
- Typical shower 10^{20} eV: 10^{10} particles at ground
- Animation color code:

blue: electrons/positrons
cyan: photons
orange: protons
red: neutrons
gray: mesons
green: muons

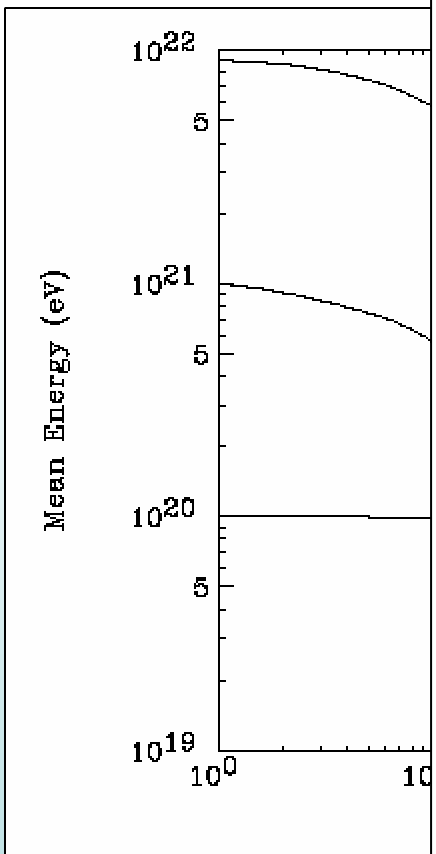
(10^{-6} thinning)

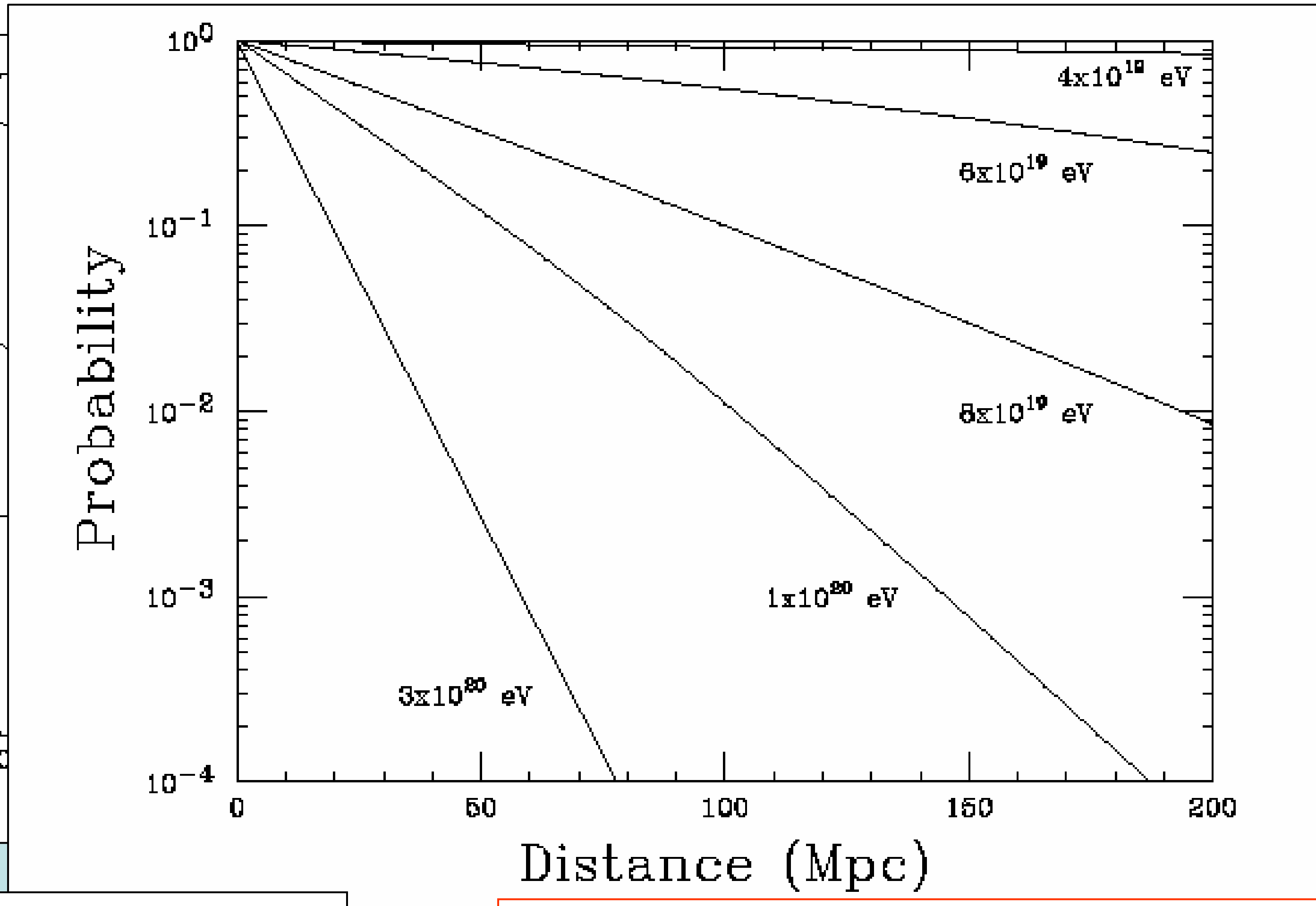
How to detect UHECRs?



- The number of secondary particles is proportional to energy of primary particle
- Relative time of detection of individual secondary particles carries information about incident direction of primary particle
- Types of detectors: ground arrays and fluorescence telescopes

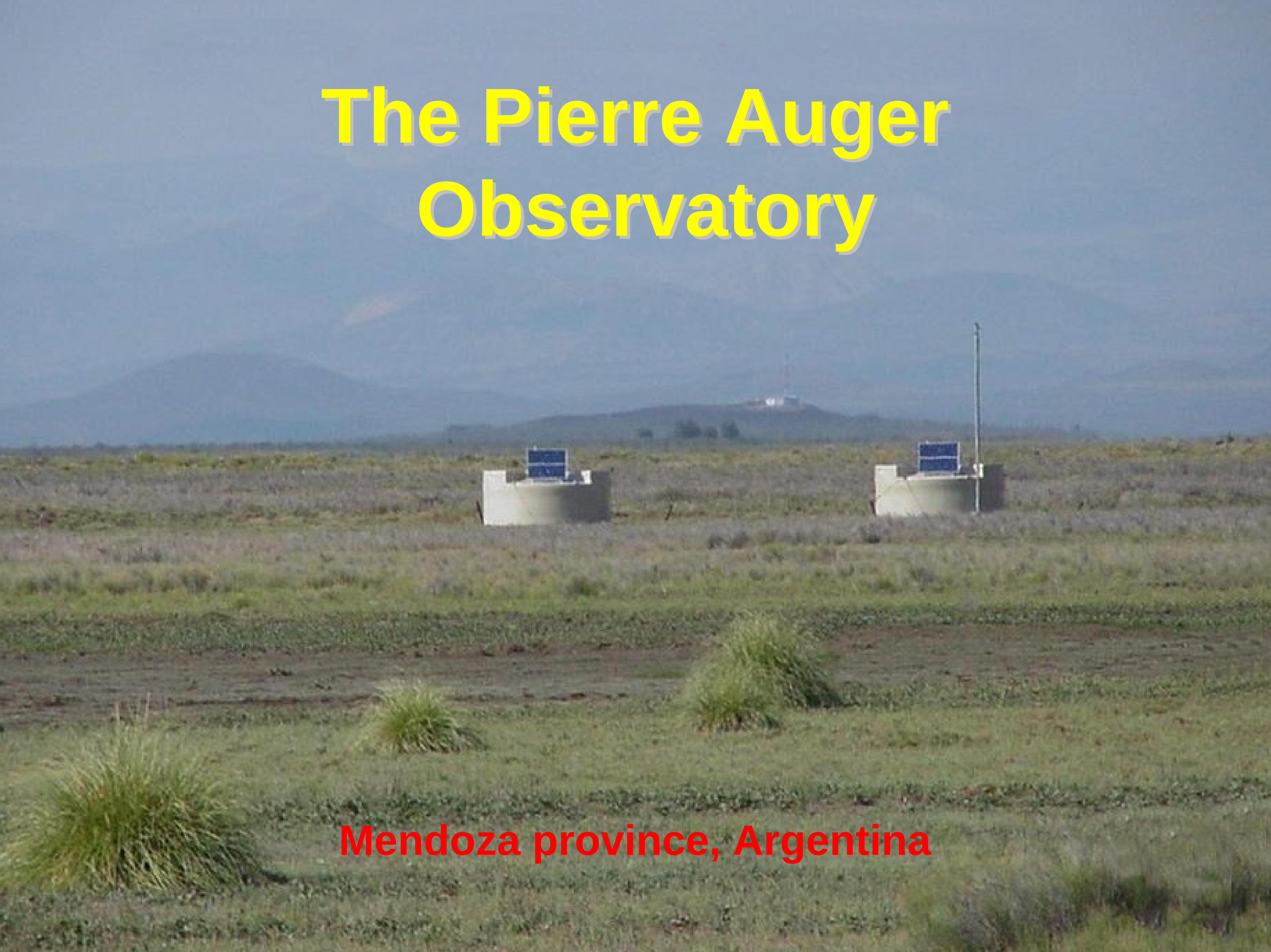
GZK suppression





Paul Sommers, 2003

Sources of particles with E > 10^{20} eV have to be within “GZK-sphere” (100 Mpc)

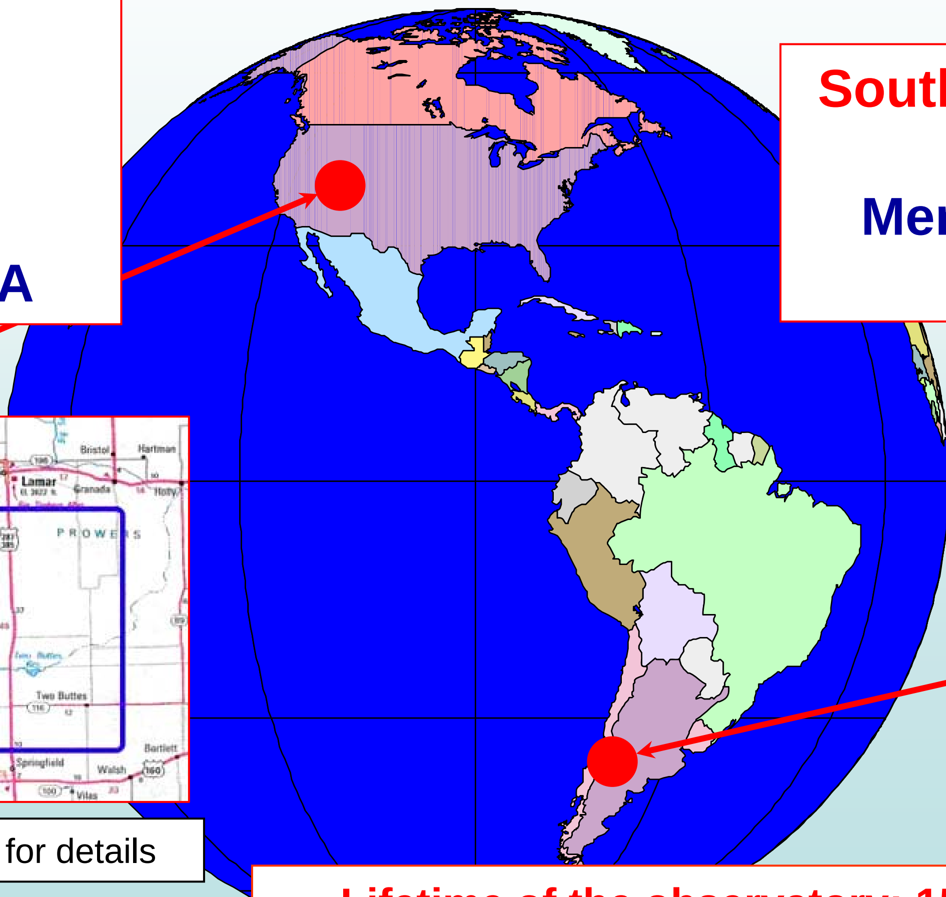

The Pierre Auger Observatory
Mendoza province, Argentina

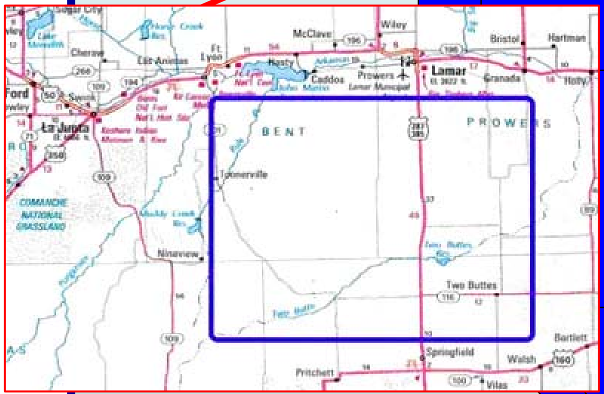
Pierre Auger Observatory

The southern site in Argentina is currently almost finished (inauguration Nov 2008).

Northern hemisphere (planned):
Lamar, Colorado, USA

Southern hemisphere:
Malargüe, Mendoza province, Argentina





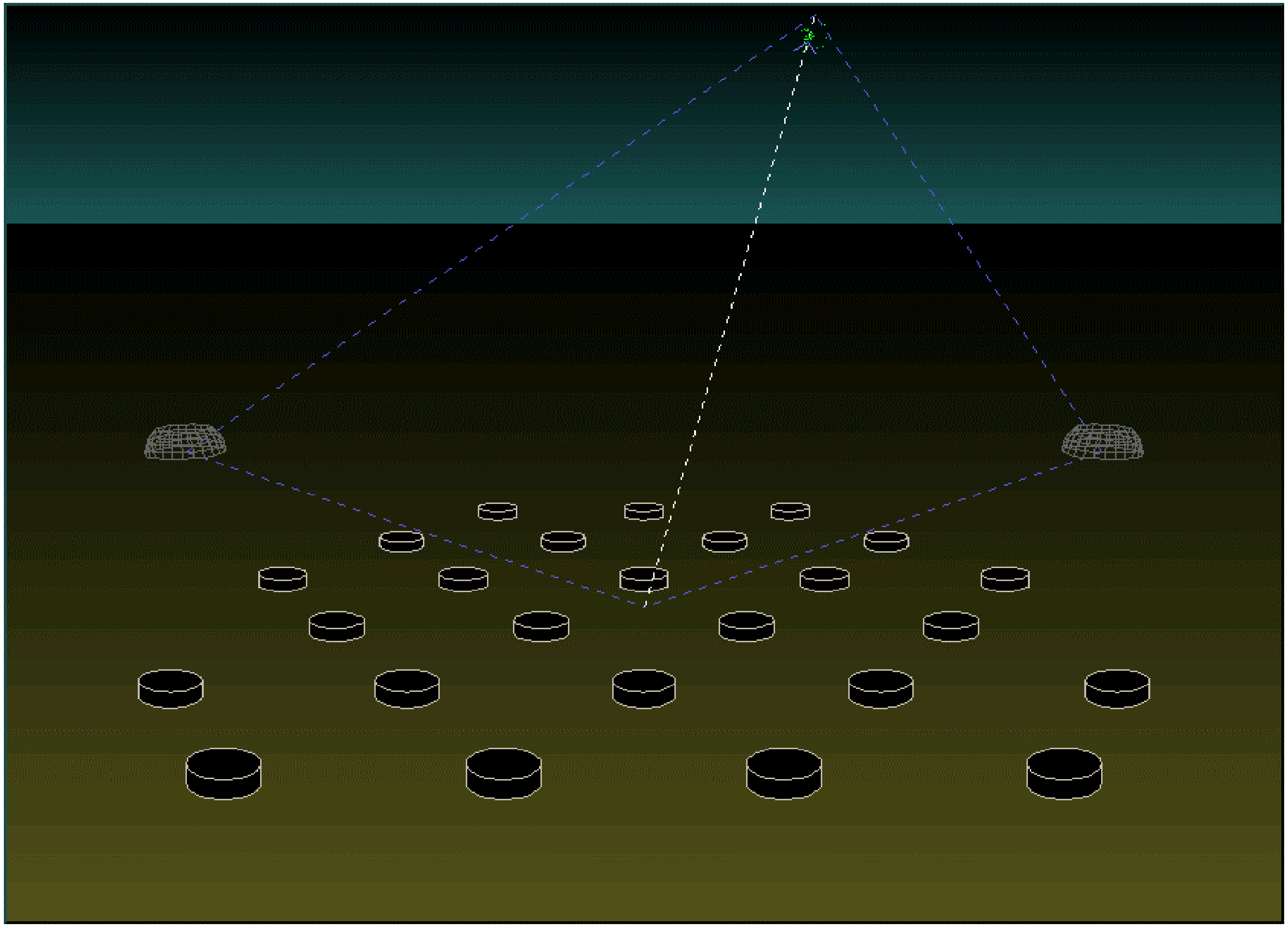
See www.augernorth.org for details

Lifetime of the observatory: 15 - 20 yrs

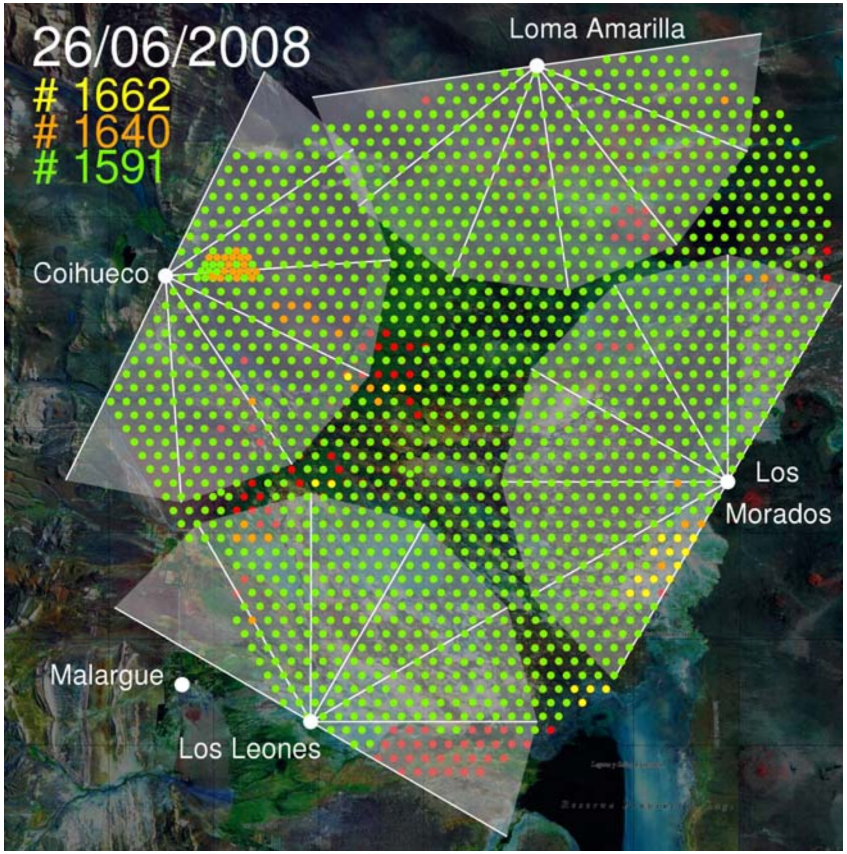
The Pierre Auger Observatory = hybrid detector of cosmic rays

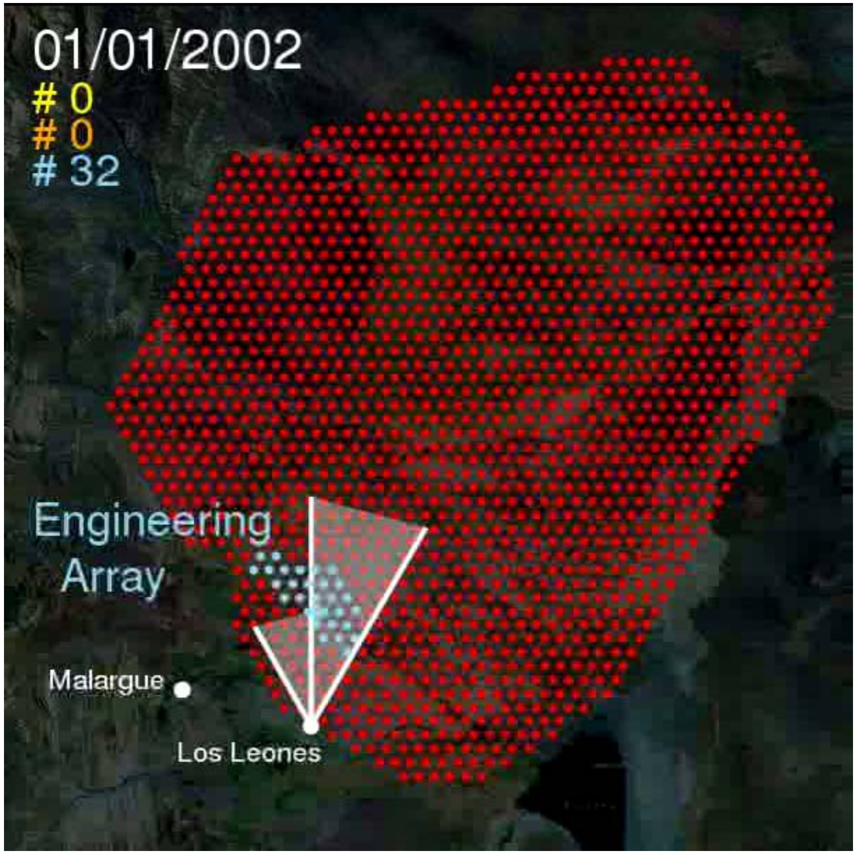
• The array of surface Cherenkovov detectors will be accompanied with system of fluorescence telescopes, which will observe faint UV/visible light during clear nights. This fluorescence light origins as by-product during the interactions of shower particles with the atmosphere.

Scheme of hybrid detector function

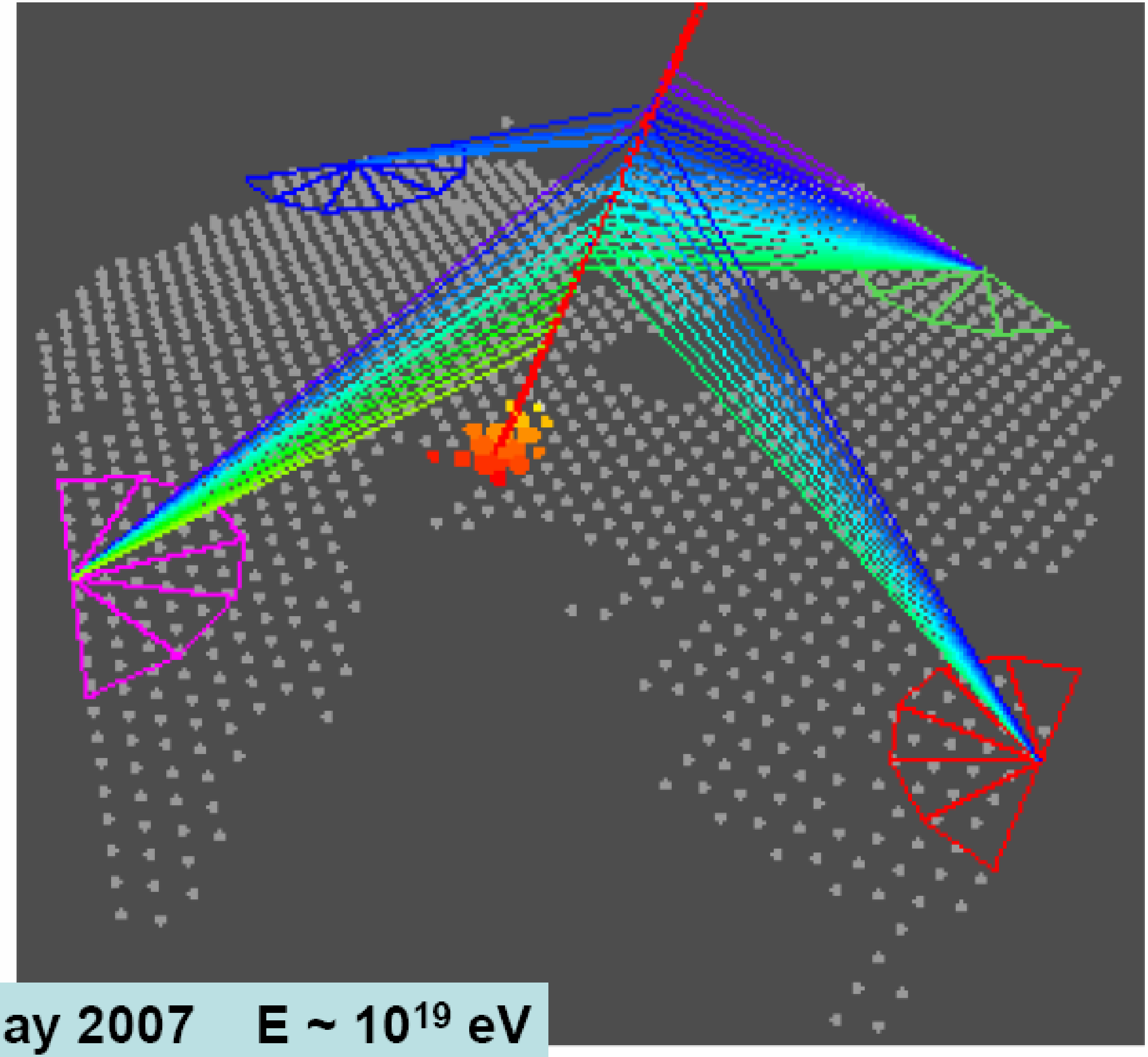


Evolution of the *hybrid detector*



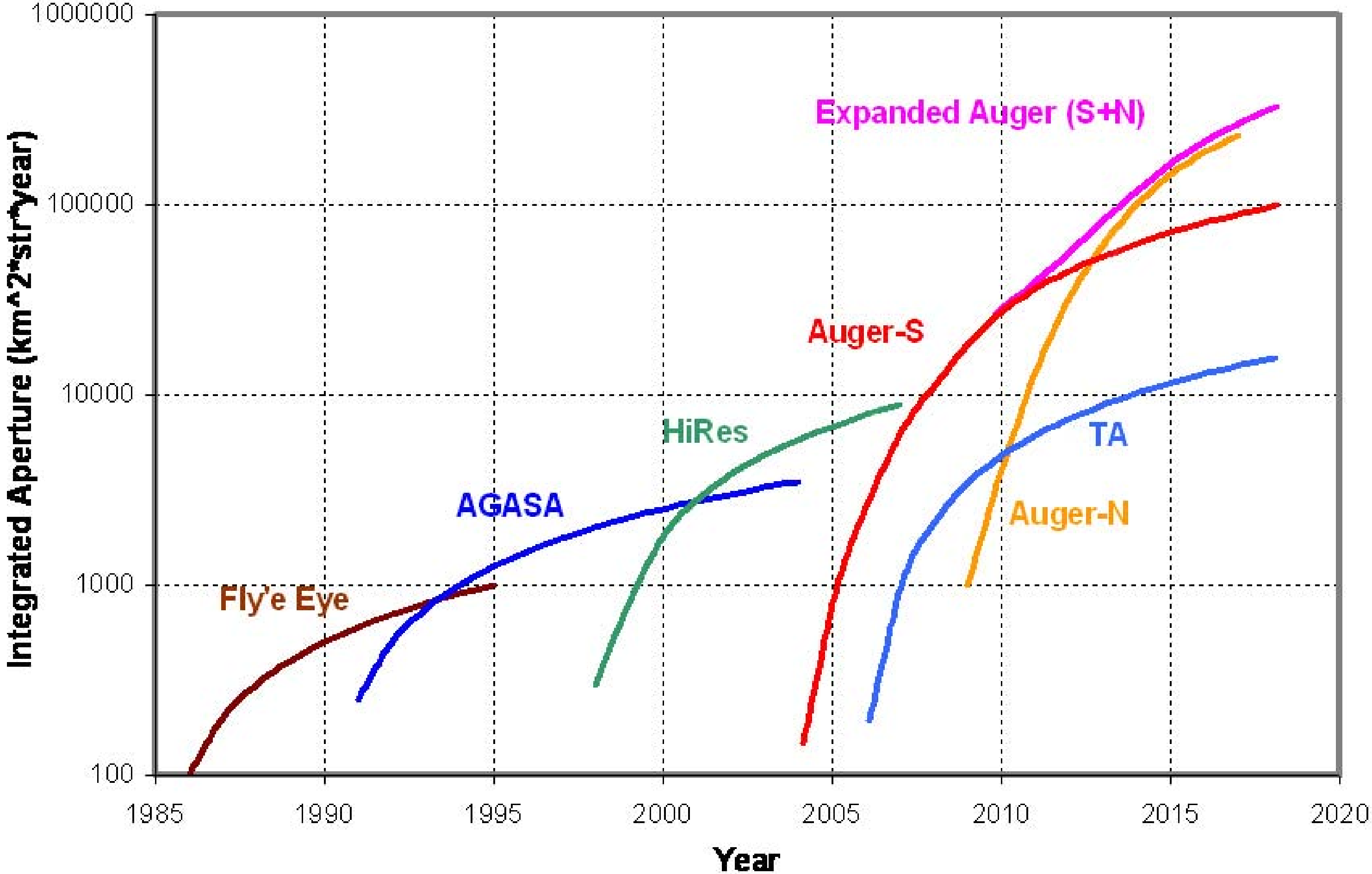


Production of scientific data since late 2003.



20 May 2007 E ~ 10^{19} eV

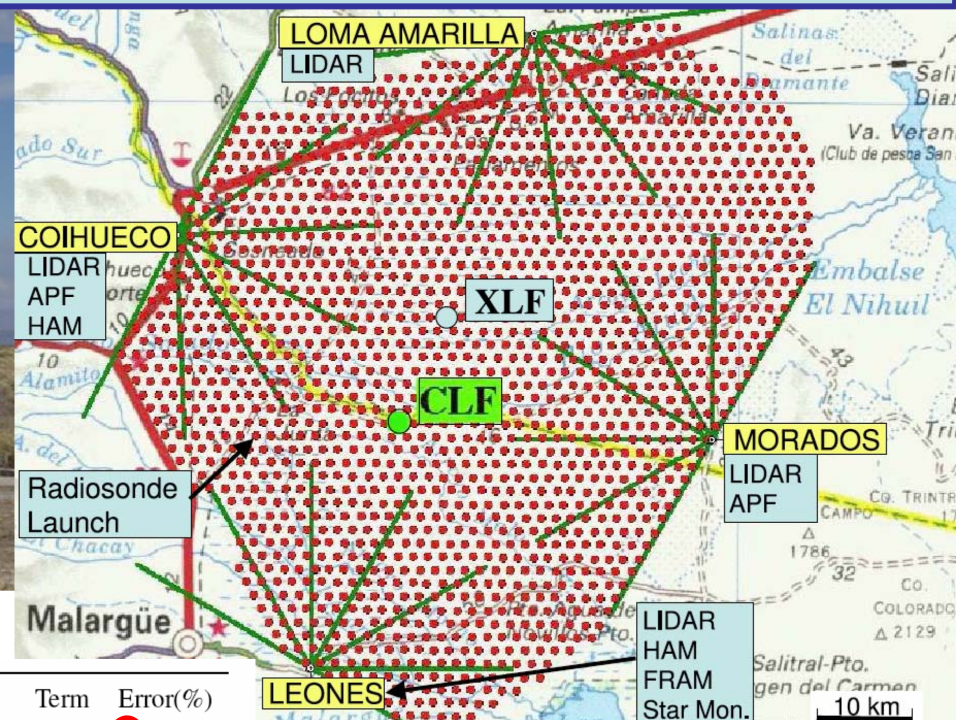
Comparison of integrated aperture



Currently (Aug 2008) ~ 7 x AGASA

Energy estimation, atmospheric monitoring

Central Laser Facility



Term	Error(%)	Term	Error(%)
Light collection	5	Atmosphere (aerosols)	10
Detector photometric calibration	12	Atmosphere (clouds)	5
Geometric reconstruction	2	Atmosphere (density profile)	2
Correction for Missing Energy	3	Fluorescence yield	15
	Quadrature Sum = 23		

Current estimates of systematic errors of the FD energy measurement

LIDAR

Transmission, extinction, optical depth

Transmission = exp (- optical depth) = exp (- integral of extinction)

$$T(h) = \exp\left[-\tau(h)/\sin\varphi\right] = \exp\left[-\int_{h_{\rm gnd}}^{h} \alpha_{\rm tot}(h')dh'/\sin\varphi\right]$$

Total extinction = aerosol extinction + molecular extinction

$$\alpha_{\rm tot}(h,\lambda) = \alpha_{\rm abs}(h,\lambda) + \beta(h,\lambda)$$

Molecular (Rayleigh) extinction can be obtained analytically (next slide) and it is dependent on the pressure and temperature:

$$\beta(h,\lambda) = \beta_s(\lambda)\frac{p(h)}{p_s}\frac{T_s}{T(h)}$$

For the aerosol optical depth τ_a, dependence on the wavelength is usually parametrized using Ångstrom coefficient γ:

$$\tau_a(\lambda) = \tau_0 \cdot \left(\frac{\lambda_0}{\lambda}\right)^{\gamma}$$

What is FRAM?

Precise photometry of bright standard (not-variable) stars

Non-invasive method (producing no light).

Independent, continuously measuring fast system at least with high relative precision.

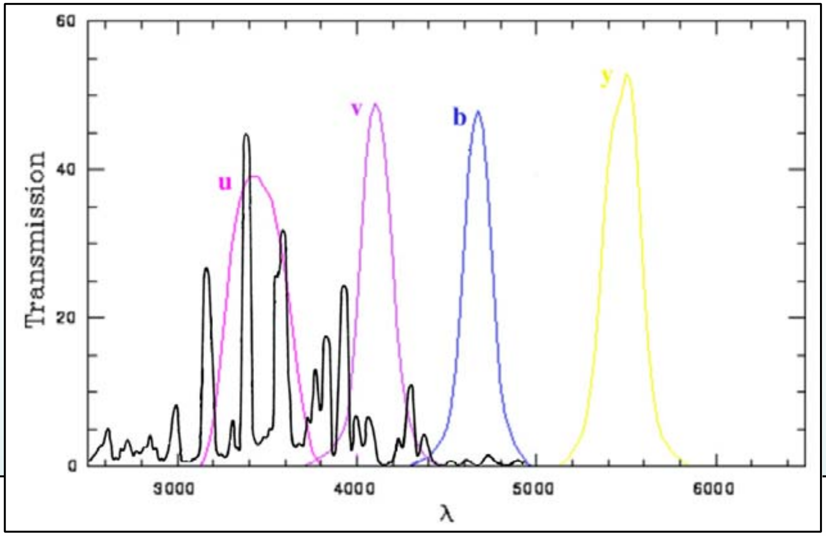
Fully robotic, small photometric telescope driven by specially developed Linux RTS2 system. (Based upon the experience with follow-up robotic telescopes for observations of GRB optical transients.)

Cross-check measurements with HAM, CLF, LIDARs…

Main disadvantage:

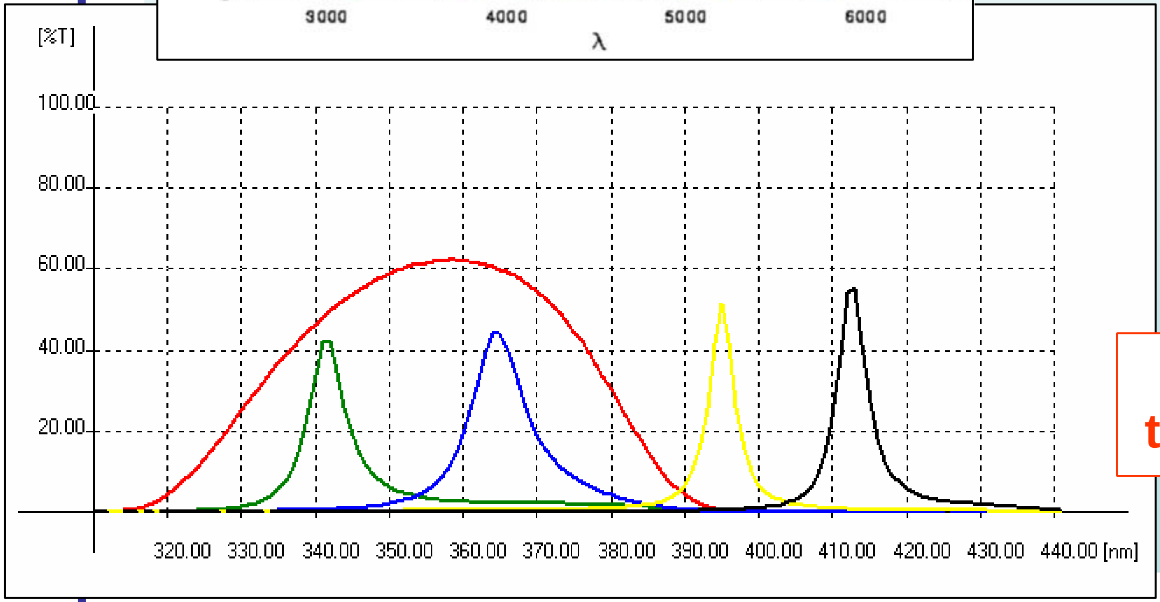
We know only integral extinction from observer to the star (outside of the atmosphere) & for precise evaluation of optical depth τ we need to add information about $\rho(r)$ dependence.

Set of FRAM filters (10 filters)



Use of Strömgren uvby filters advantages:

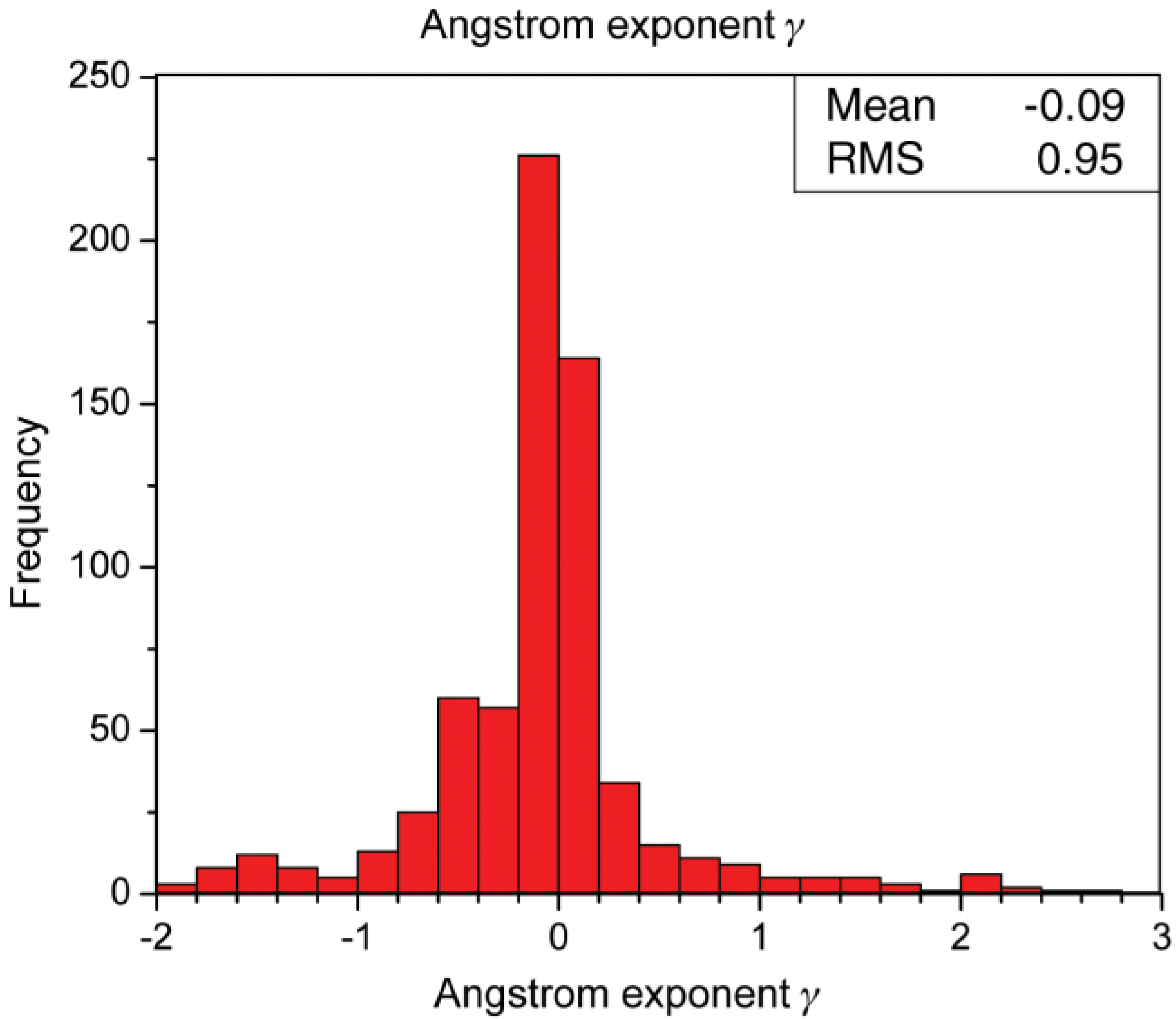
- **four point measurements (better fit of dependence on wavelength (γ))**
- **better and more precise measurements of standard stars**



Narrowband filters transmission curves

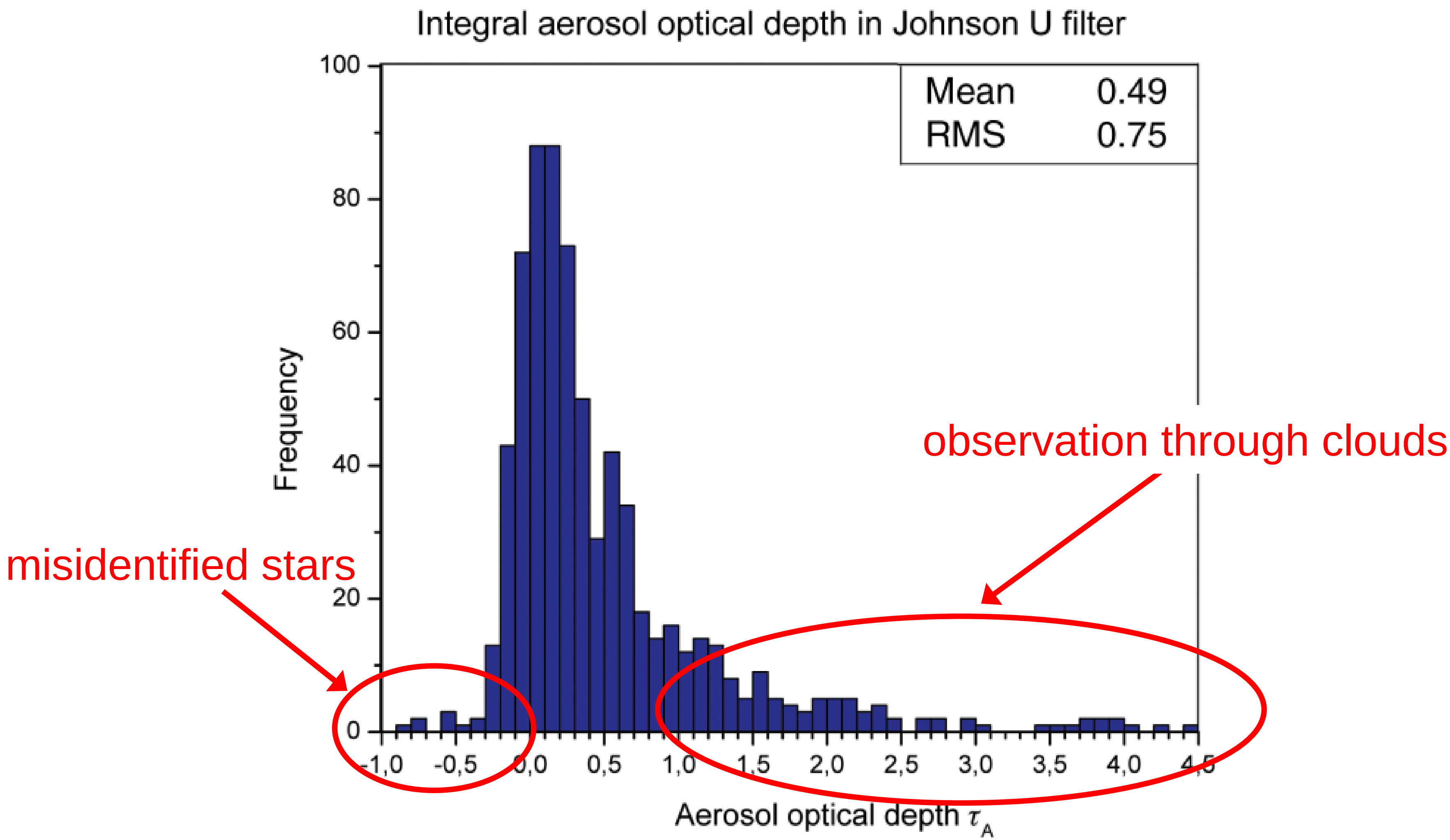
Preliminary FRAM results - gamma

- Results for the **Angstrom coefficient** values presented at the International Cosmic Ray Conference, Merida, Mexico, July 2007



Preliminary results – Aerosol Optical Depth

- **only the hardware quality cuts were applied**, consequently some reconstruction artifacts are still apparent (negative values are misidentified stars, right tail is due to observation through clouds)



Advanced analysis

Use of the WF camera data to check the conditions:
(WF camera is used for main telescope/photometer pointing)

- automatic analysis of the WF images done

- for each image we have limiting magnitude, number of detected stars and zeropoint (magnitude equivalent to unit signal)

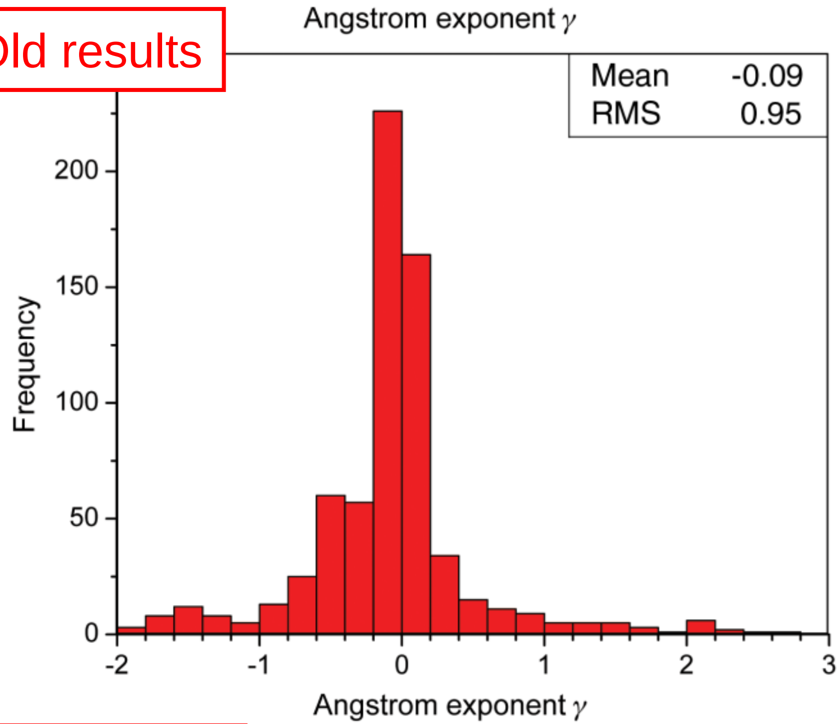
- we usually have 3 or 4 exposures (5-sec length) taken during the photometer readout

- limiting magnitude should be > 12 mag
(otherwise too cloudy, should be around 13.5 in good conditions)

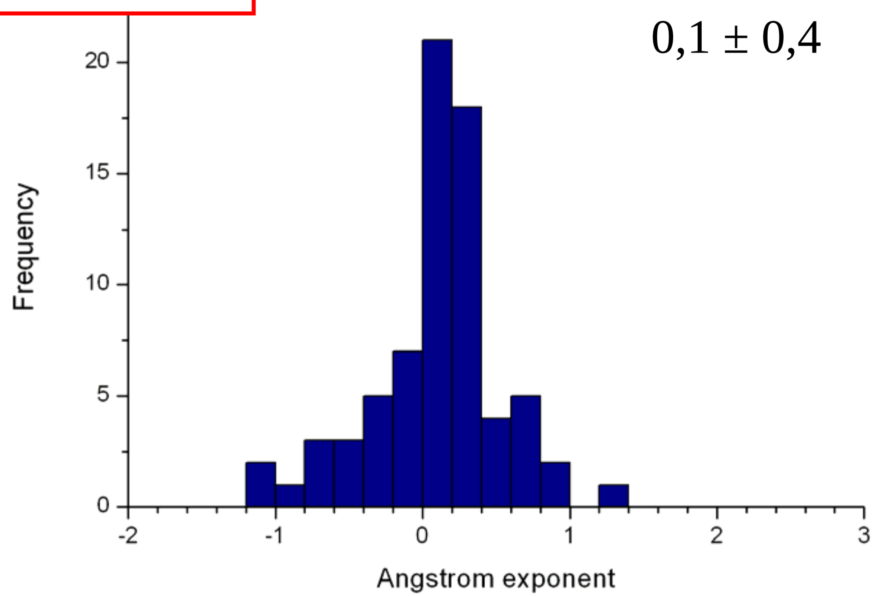
  - number of stars should not vary by more than 30%
  (stable conditions, no patched clouds)

Advanced analysis results

Old results



New results



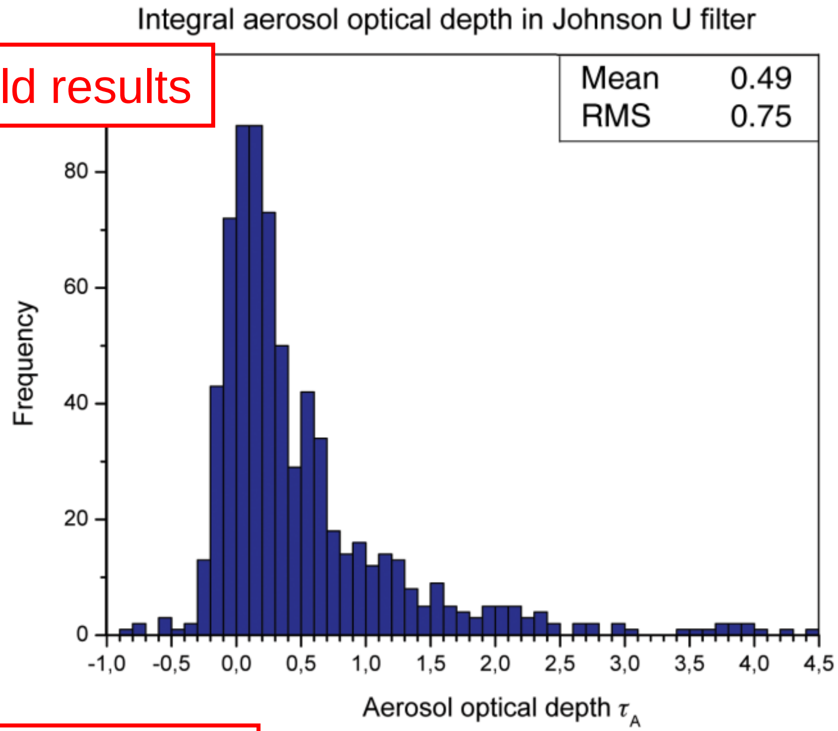
(tested on two months of data, Dec 06 – Jan 07)

Angstrom exponent is rather stable, the influence is not that prominent.

Mean value grew little (now closer to the HAM result: 0.7 +/- 0.6) and RMS is much smaller.

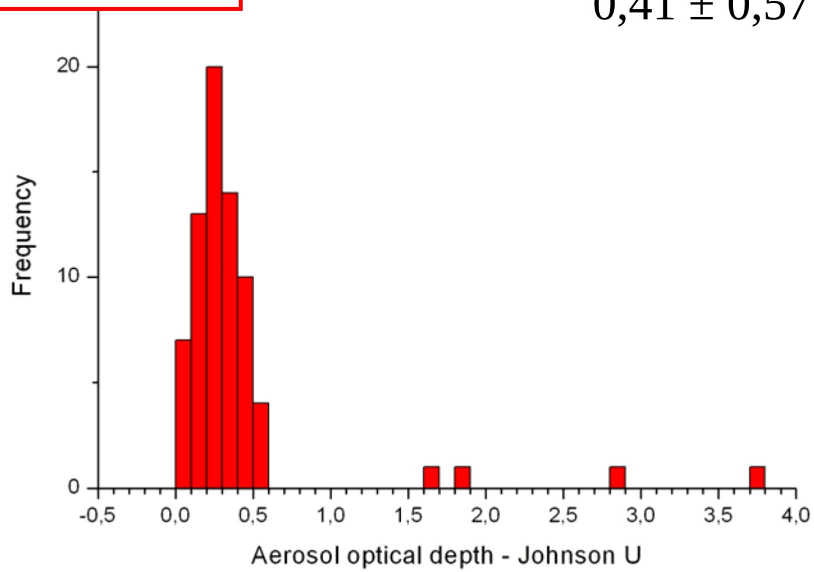
Advanced analysis results II

Old results



New results

$0{,}41 \pm 0{,}57$



Aerosol optical depth distribution is much narrower.

However, some outlayers are still present, even at very high values (although sky should be clear and stable according to WF camera).

These persisting high values found for different target stars, we are now trying to identify, what is causing this.

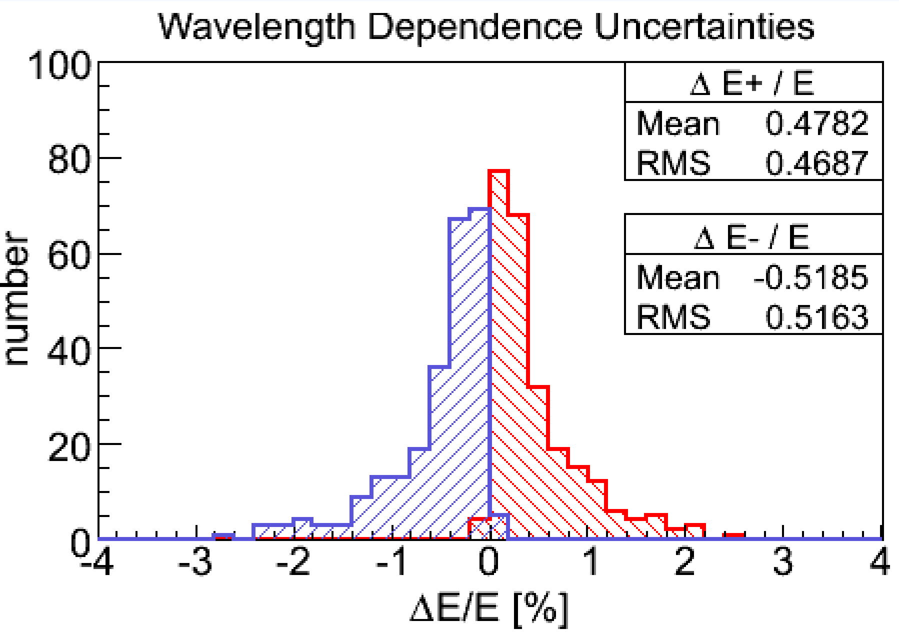
Mean value for AOD is still very high, but even median is about twice higher than expected from CLF/LIDAR measurements (0.2 vs. <0.1).

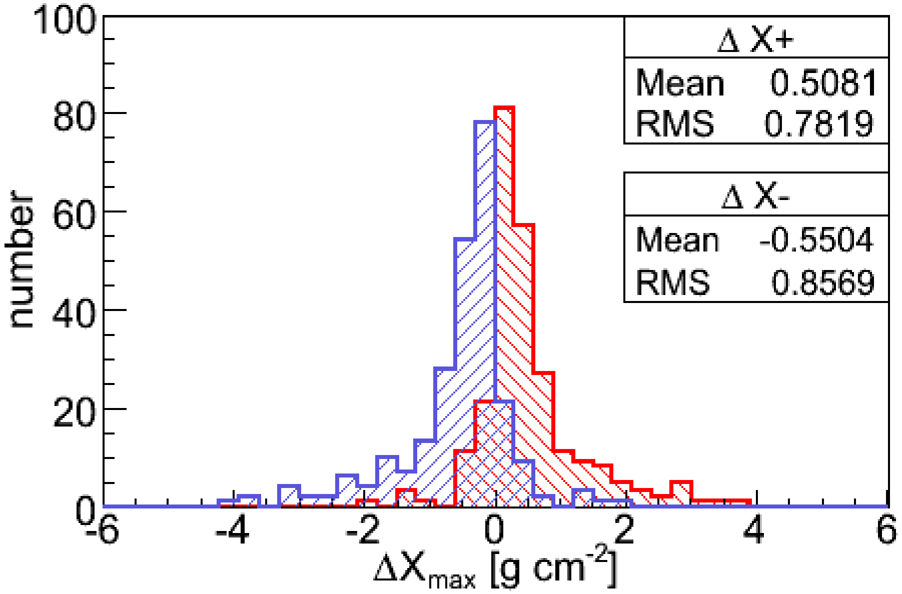
We observe through the whole atmosphere, but some systematic effect can be still hidden in it.

Uncertainty in aerosol scattering wavelength dependence

$\Delta E / E = 1\ \%$

$\Delta X_{max} = 1\ g\ cm^{-2}$





Measured by Horizontal Attenuation Monitor and FRAM:

- aerosol optical depth is measured using artificial ground-based light source or stars in multiple narrowband filters
- typical range: $\gamma \in [0, 1]$

Analysis: To do & What can be done more?

Complete "new style" analysis that is using WF camera information (process all available data)

Improve the molecular optical depth subtraction (currently just the naïve sinusoidal annual variations of temperature; much better to use real data)

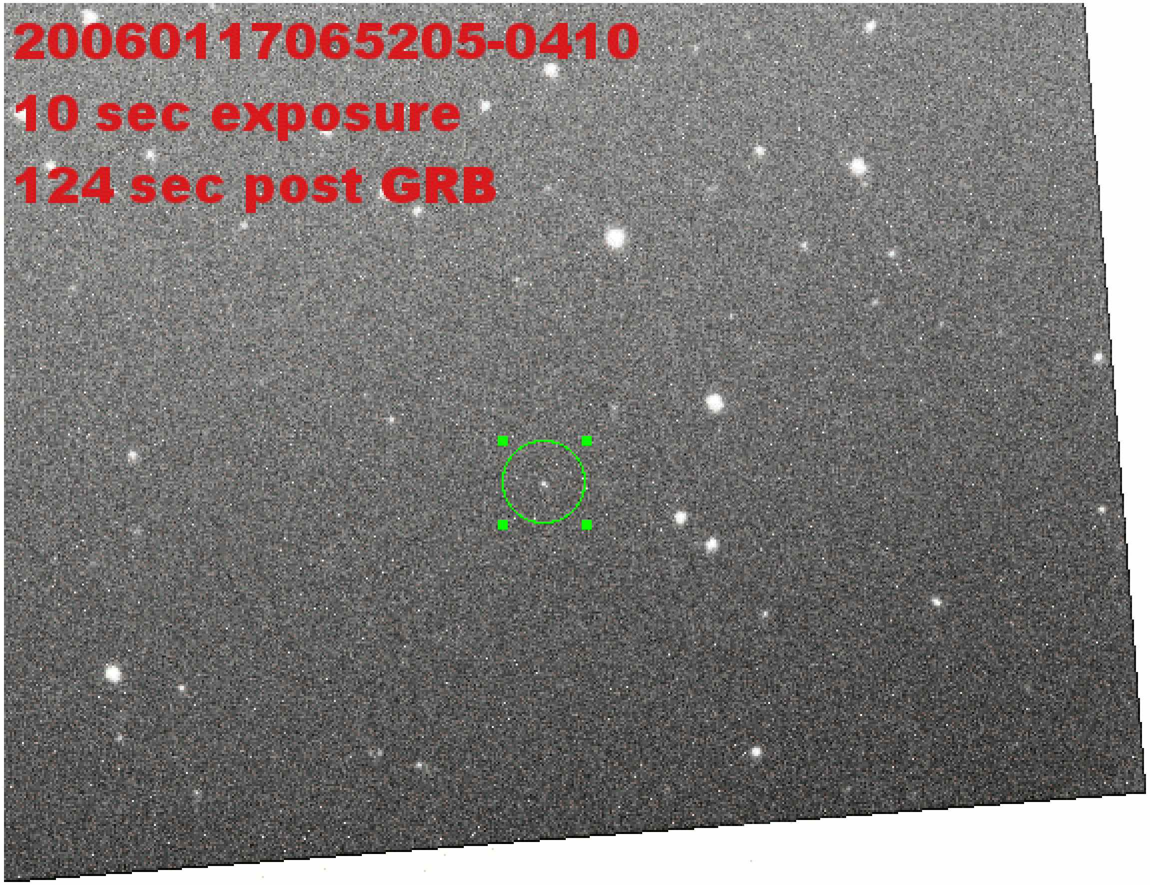
Compare data to HAM on day-to-day basis (problematic, since HAM is not operational since Nov'07)

Analyze annual variations (still needs more data; is anything like monthly model of γ possible? Changes of γ during bush-fire seasons?)

Make the Shoot-the-Shower at FRAM useful (algorithm ready for some time; initial tests successful, but nobody ever analyzed any data)

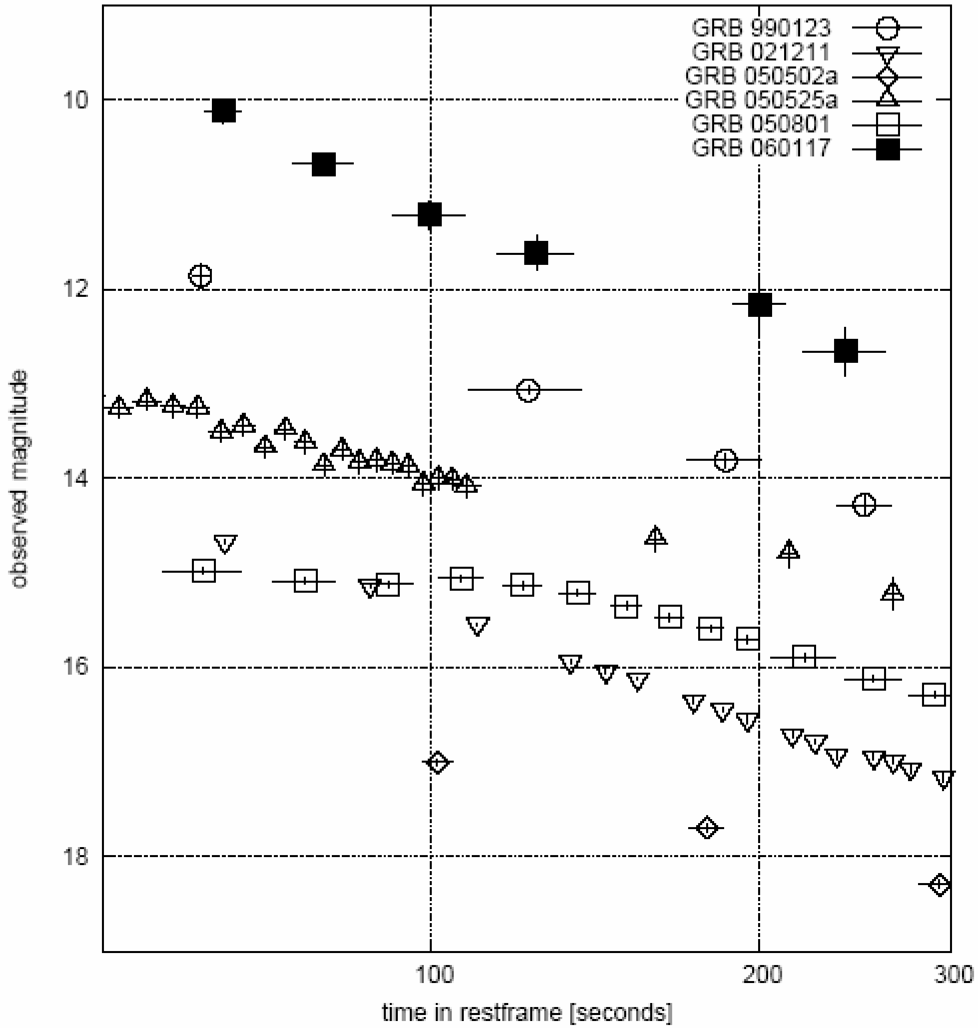
Astronomical Observations

Possible GRB OT detection? GRB 060117



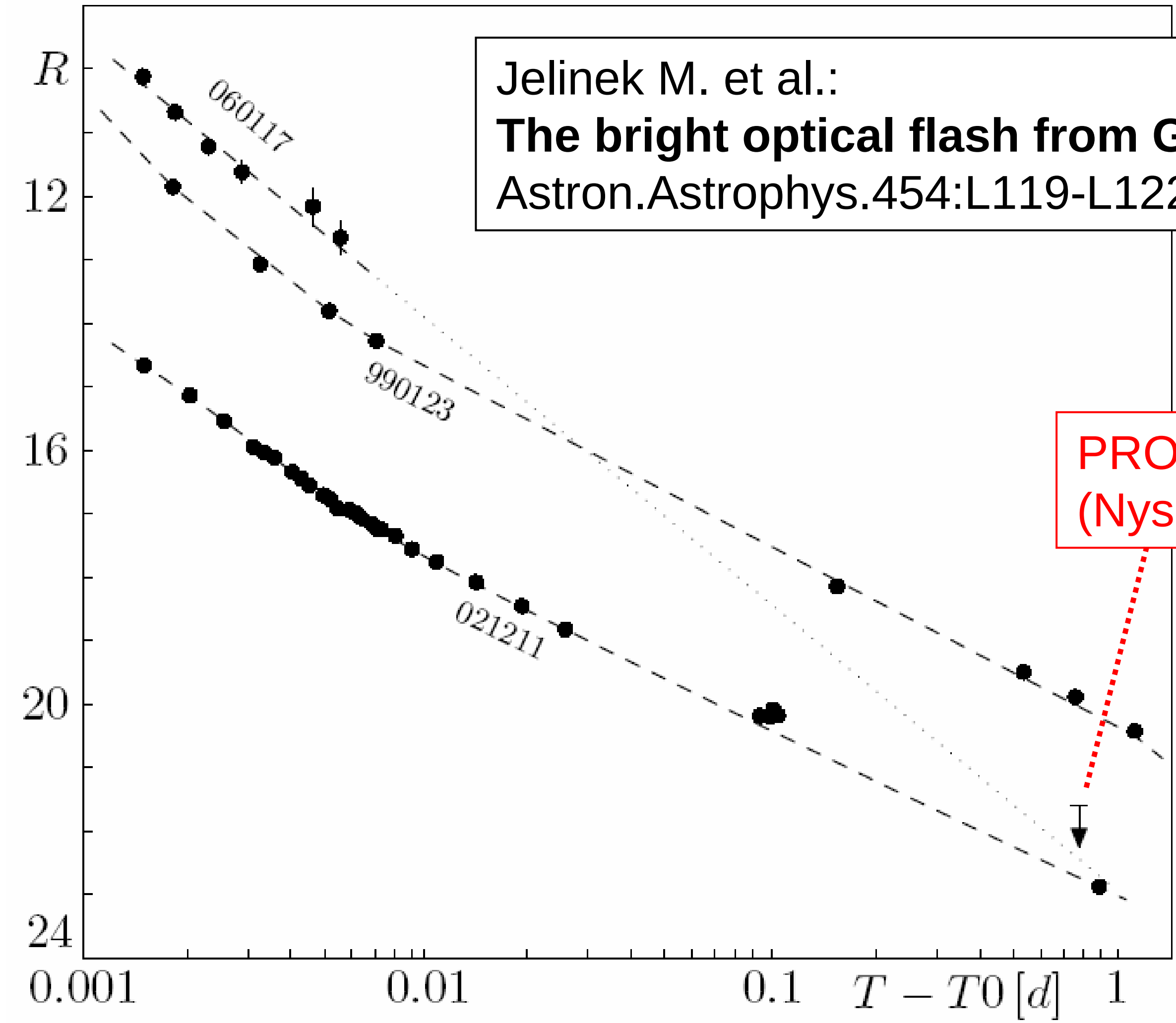
On Jan 17, 2006 FRAM detected a very bright optical counterpart of GRB 060117.

GRB 060117



Lightcurve of GRB OT and comparison to other bright counterparts

GRB 060117



Jelinek M. et al.:
The bright optical flash from GRB 060117,
Astron.Astrophys.454:L119-L122, 2006

PROMPT limit
(Nysewander et al.)

Surprising decay of GRB 060117 OT