Image credit: Seth Shostak

Searching for nanosecond-scale lunar pulses

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Lunaska collaboration:
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Searching for nanosecond-scale lunar pulses

Image credit: Seth Shostak

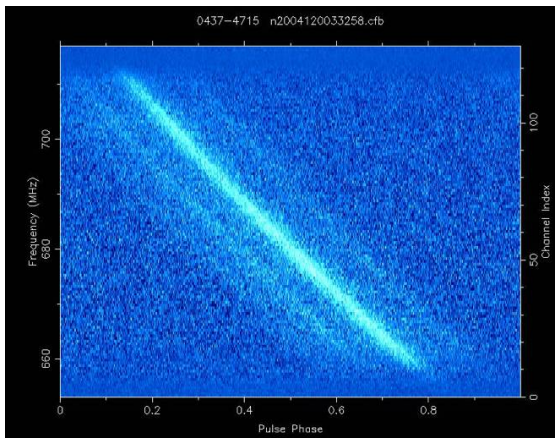
1. How to make a nanosecond-scale pulse
2. Why they're important
3. How to find one

Requirements for nanosecond-scale pulses

Broad-band:

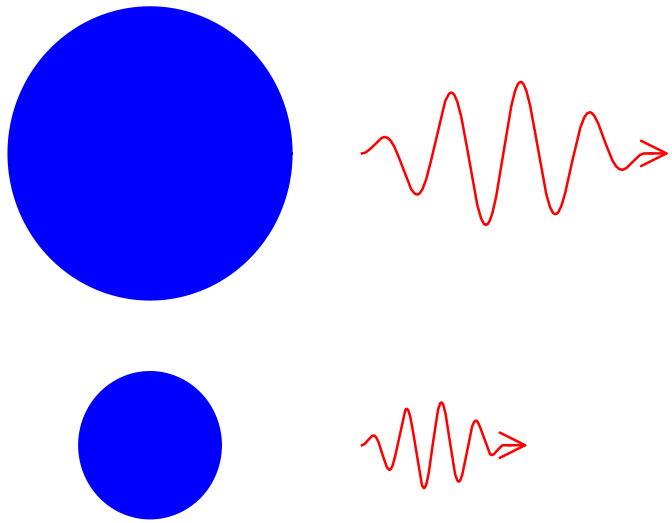
$\Delta t \sim \mathrm{ns} \implies \Delta\nu \sim \mathrm{GHz}$

Interstellar dispersion:



In solar system: no dispersion

Emission region:

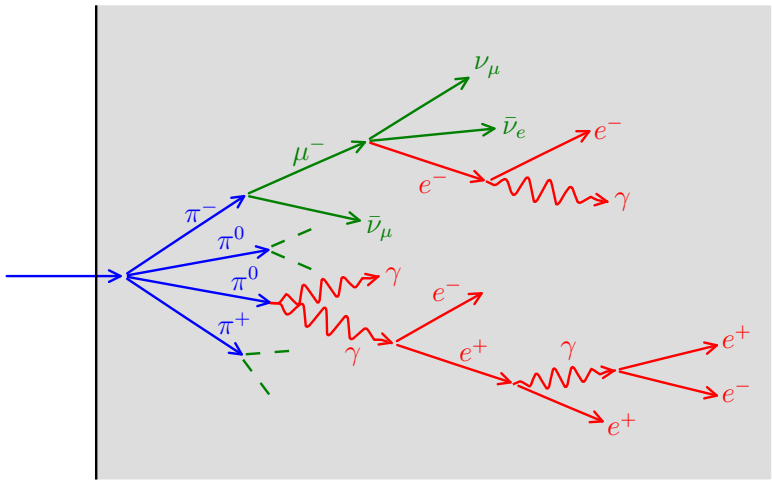


Size $\sim 30\mathrm{cm}$

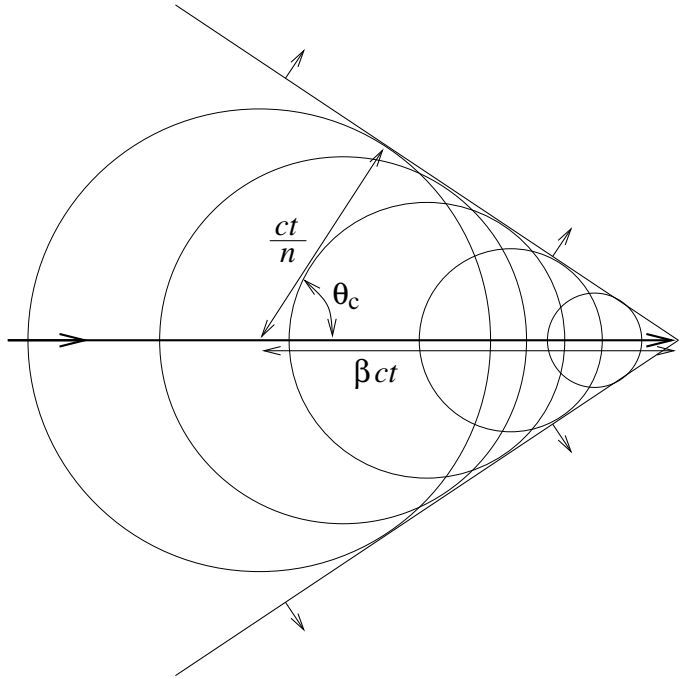
Both wrong! (sort of)

Particle cascades

Cascades in dense media



Cherenkov angle θ_c



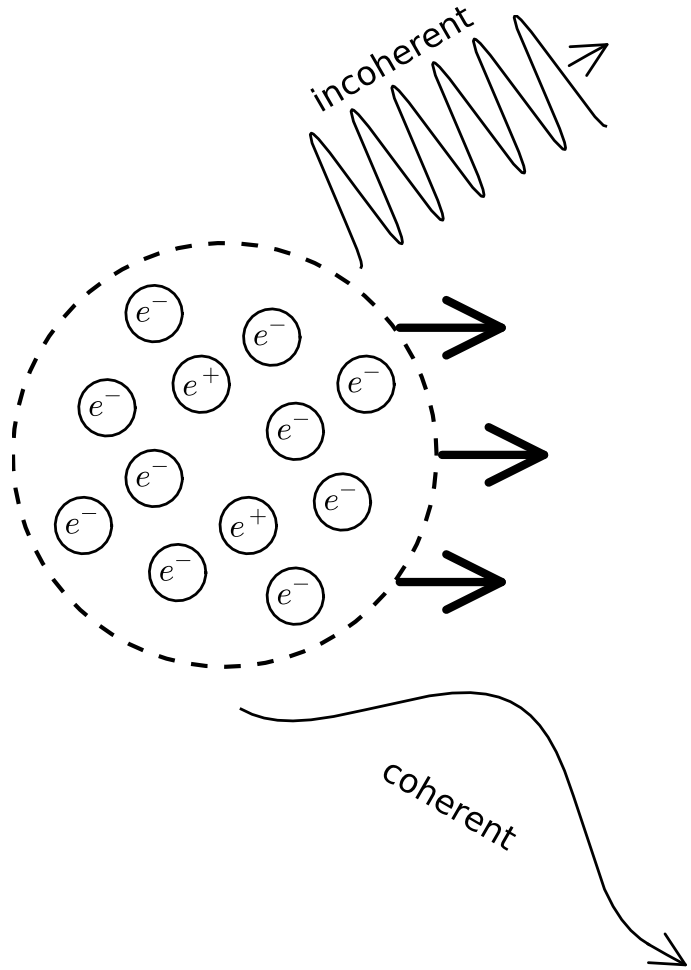
Askaryan effect

Charge excess:

$$\gamma + e_m^- \rightarrow \gamma + e^-$$
$$e^- + e_m^- \rightarrow e^- + e^-$$
$$e^+ + e_m^- \rightarrow e^+ + e^-$$
$$e^+ + e_m^- \rightarrow \gamma + \gamma$$

Scaling laws:

Single particle:	$I \propto q^2$
Incoherent:	$I \propto nq^2$
Coherent:	$I \propto (nq)^2$



Askaryan effect

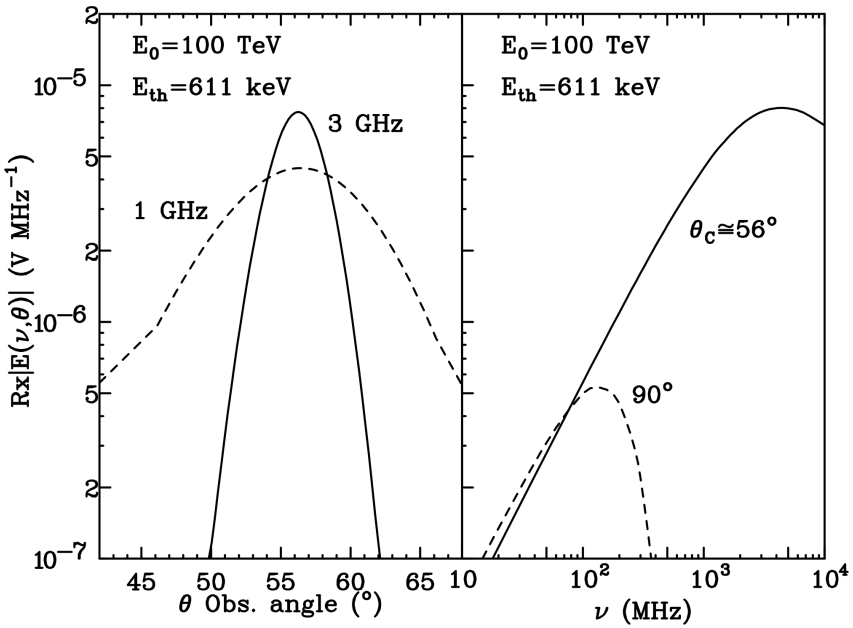
Charge excess:

$$\gamma + e^-_m \rightarrow \gamma + e^-$$
$$e^- + e^-_m \rightarrow e^- + e^-$$
$$e^+ + e^-_m \rightarrow e^+ + e^-$$
$$e^+ + e^-_m \rightarrow \gamma + \gamma$$

Scaling laws:

Single particle:	$I \propto q^2$
Incoherent:	$I \propto nq^2$
Coherent:	$I \propto (nq)^2$

Emission vs angle and frequency

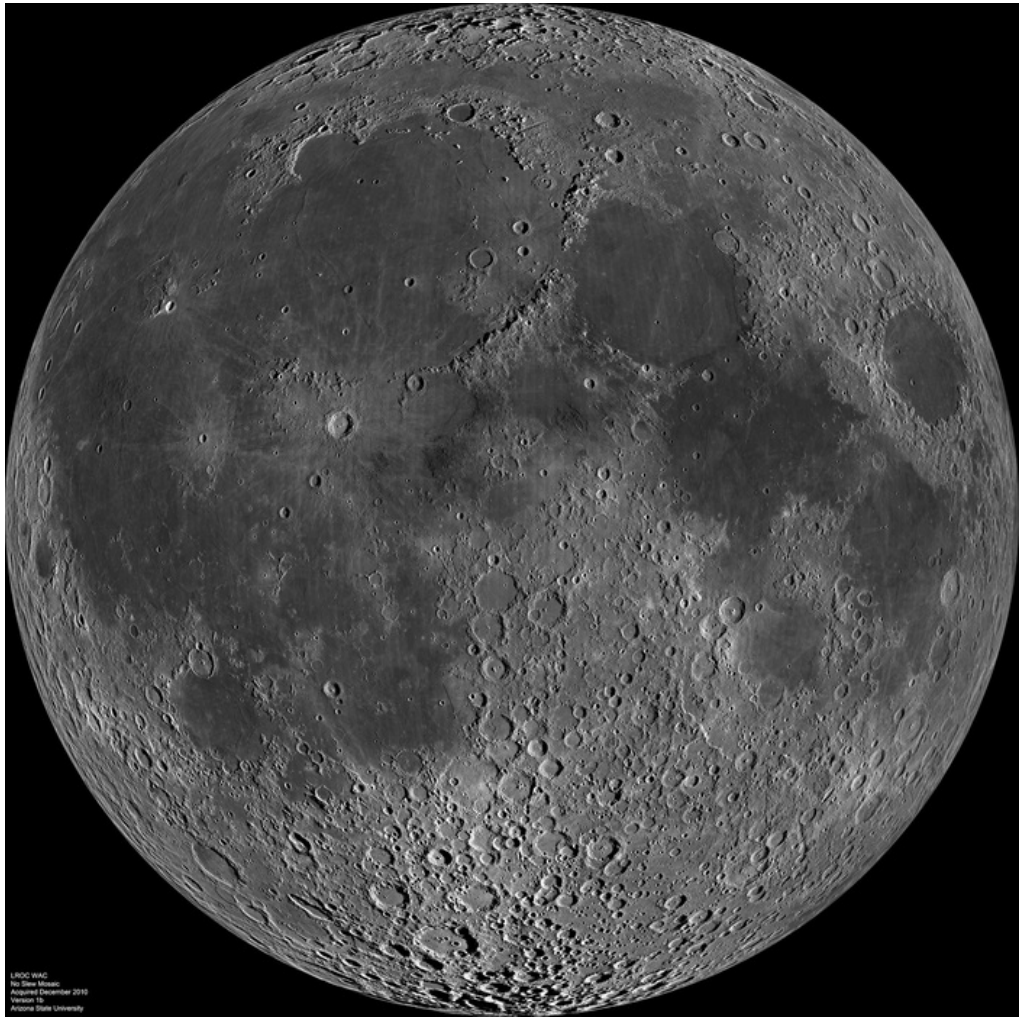


Alvarez-Muñiz & Zas, AIP Proc. (2001)

Experimentally verified at SLAC (Saltzberg et al., 2001).

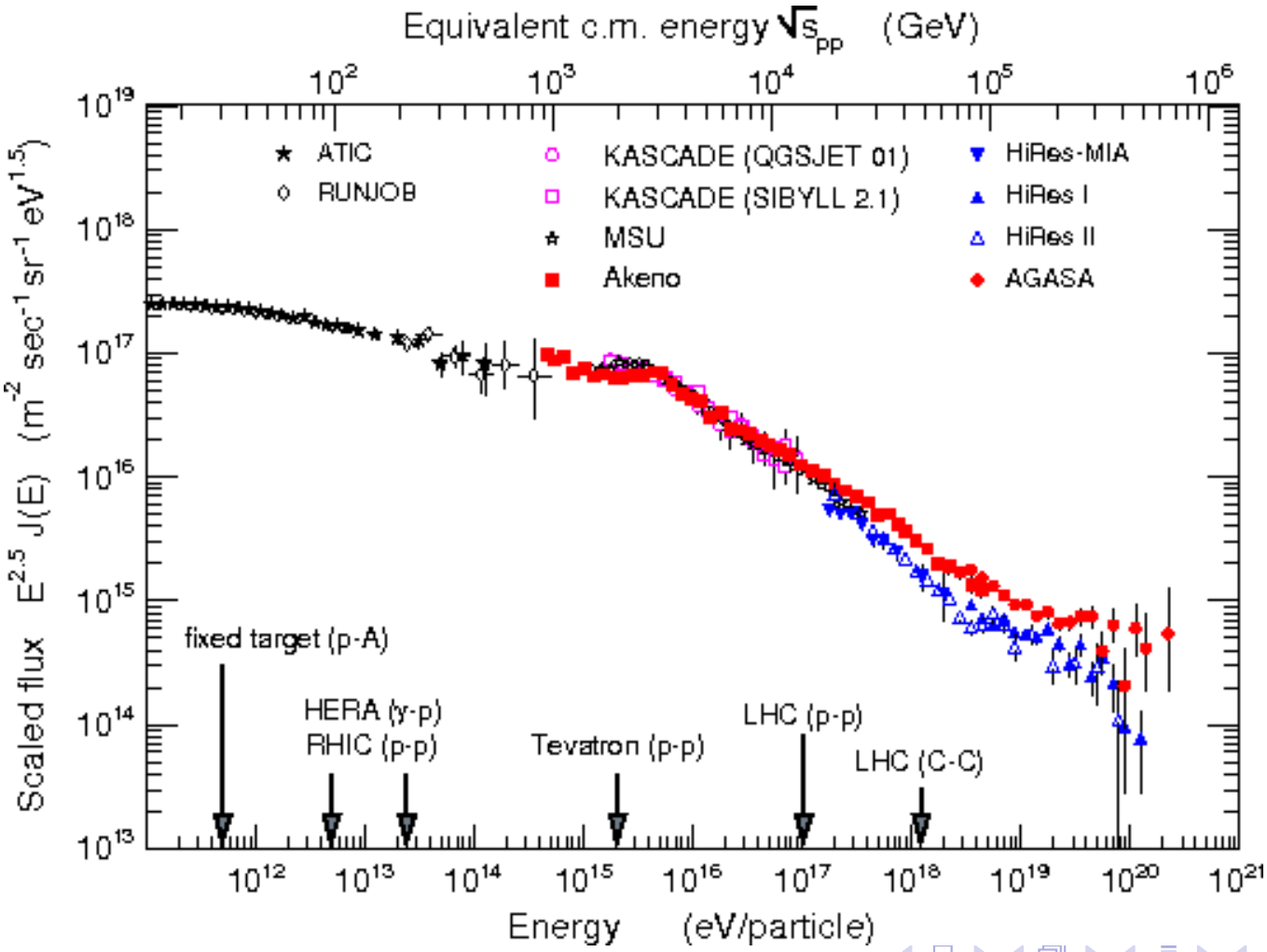
A suitable target

- Dense
- Radio-transparent (somewhat)
- Big
- Nearby



Cosmic rays

Cosmic ray spectrum



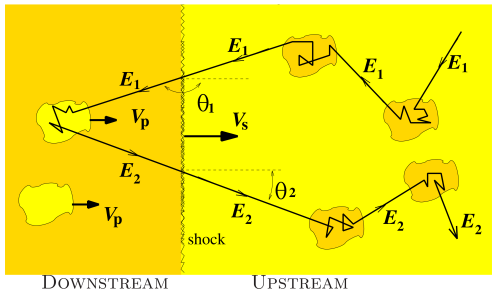
Cosmic ray production

Top-down

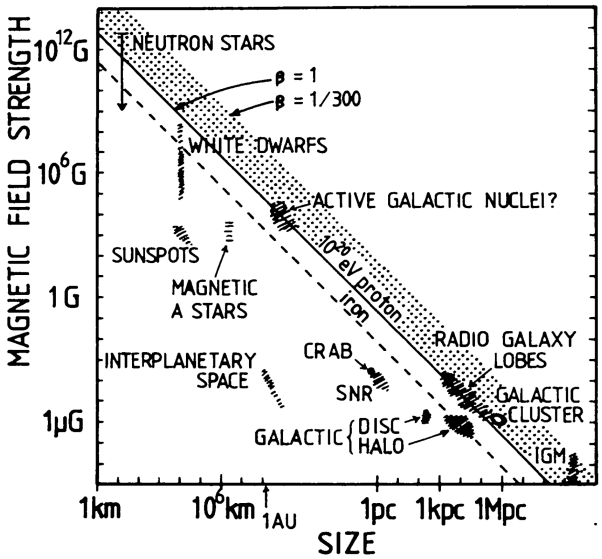
- Topological defects
- Dark matter

Bottom-up

- Shock acceleration

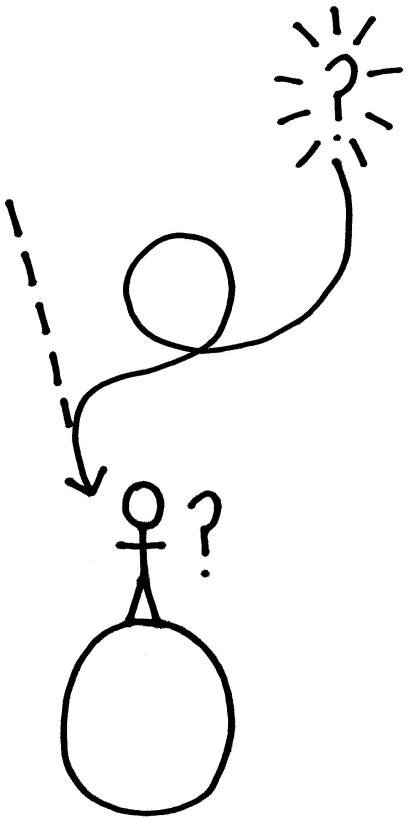


Constraints on cosmic ray sources

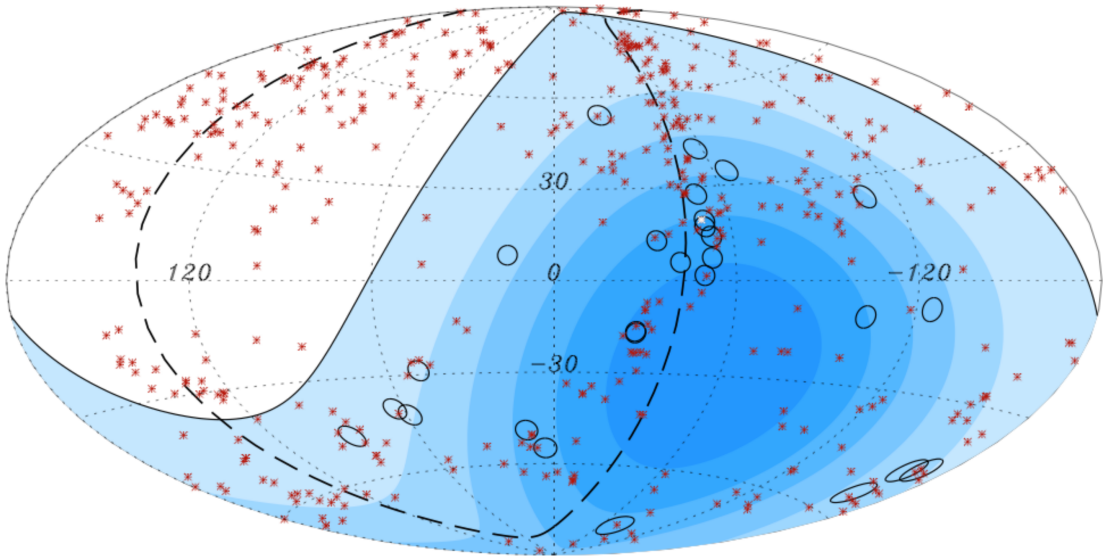


Hillas, ARA&A (1984)

Cosmic ray arrival directions

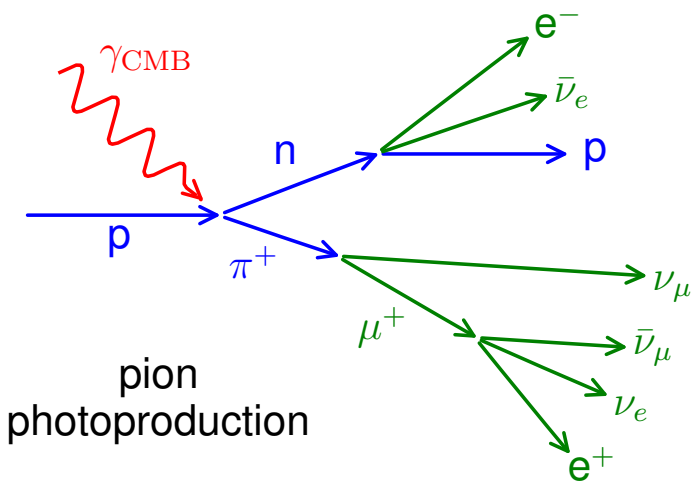


Cosmic ray arrival directions

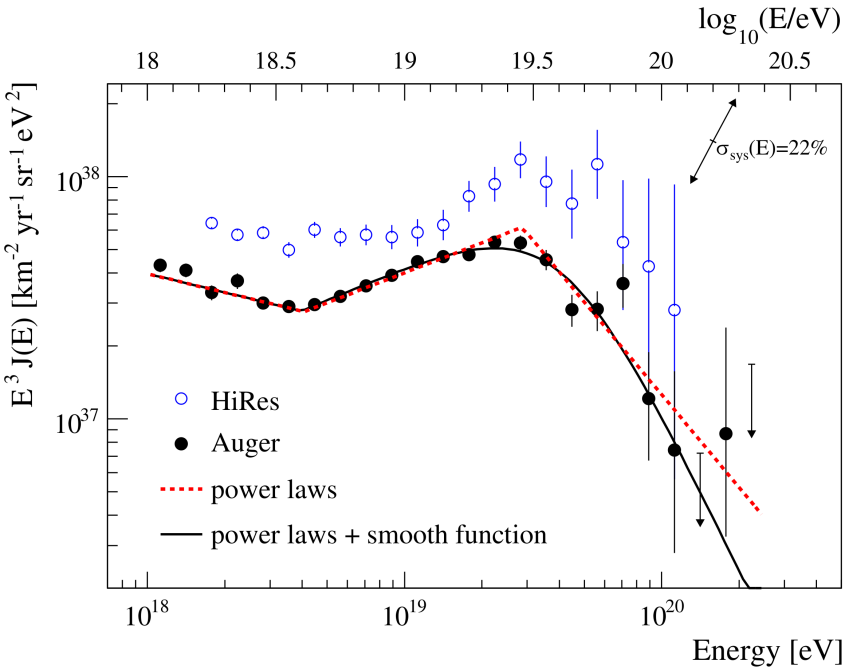


Pierre Auger Collaboration, Astropart. Phys. (2008)

GZK interactions



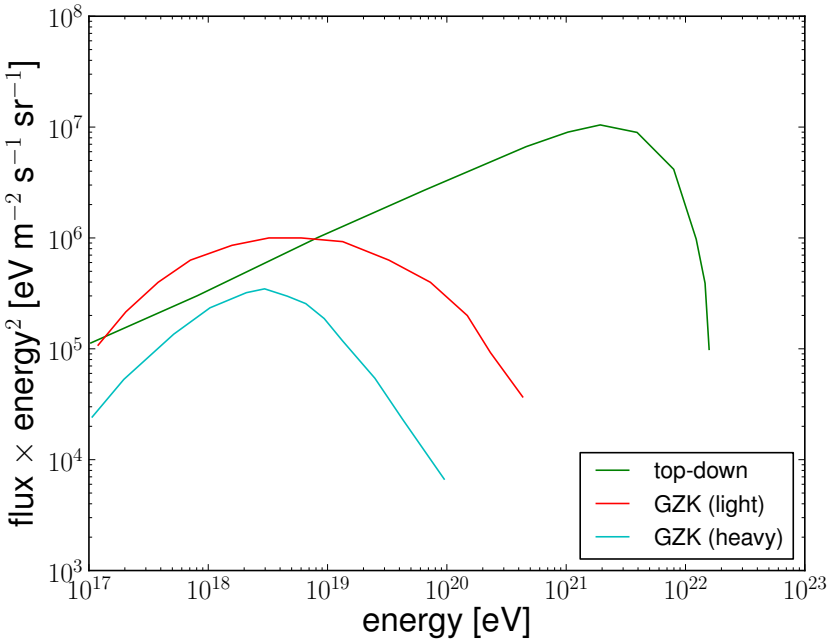
Cosmic ray spectrum



Pierre Auger Collaboration, Phys. Lett. B (2010)

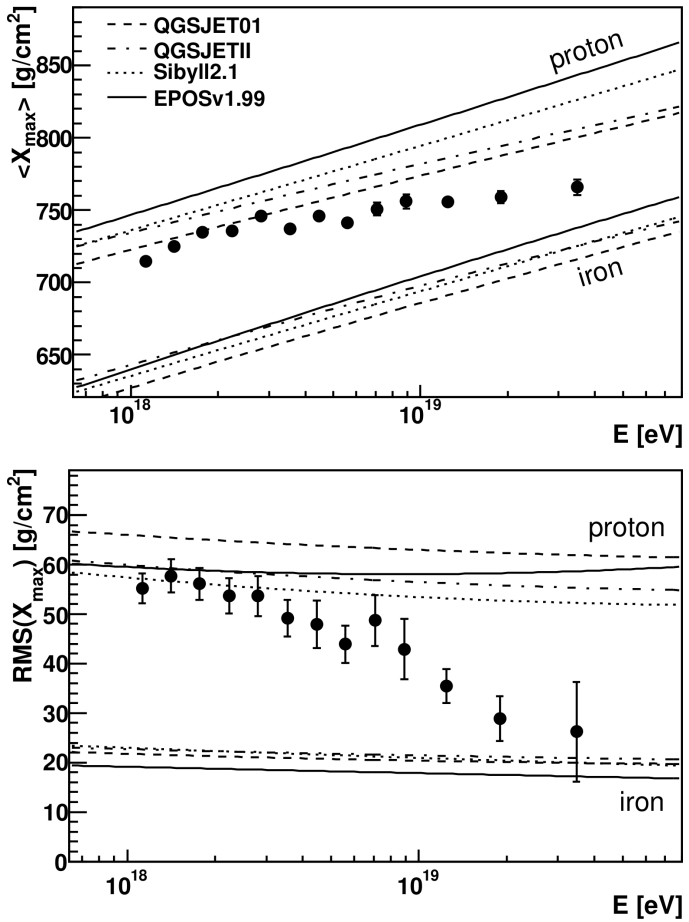
Neutrino flux

Neutrino flux predictions



top-down: Protheroe & Stanev
GZK (light): Engel et al.
GZK (heavy): Allard et al.

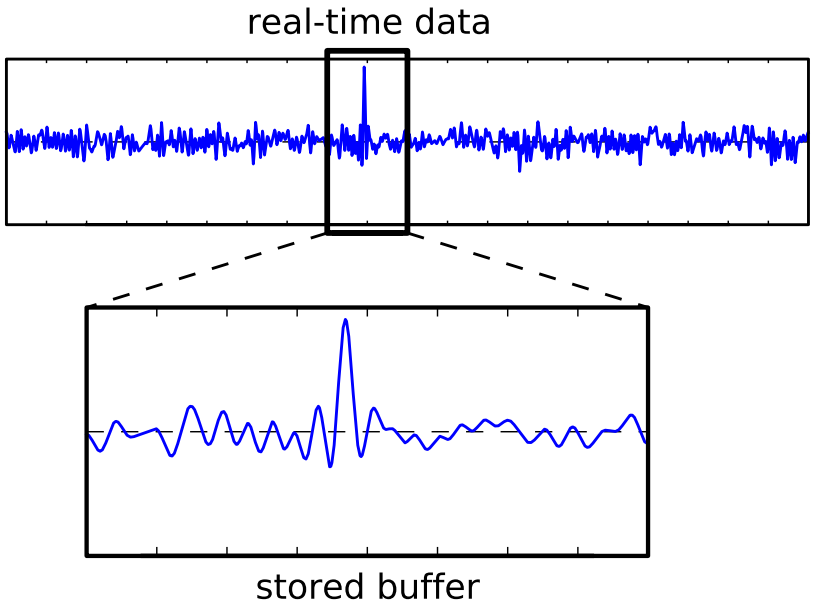
Depth of cosmic ray showers

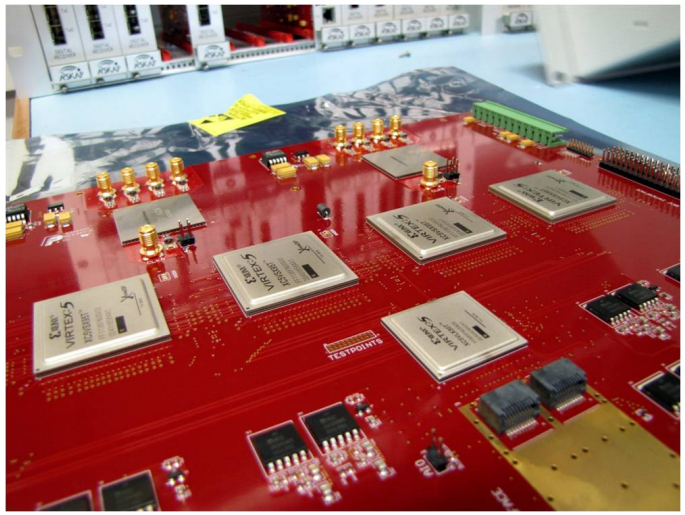


Pierre Auger Collaboration, Phys. Rev. Lett. (2010)

Triggering

Detect pulse...
$\rightarrow$ store buffer.

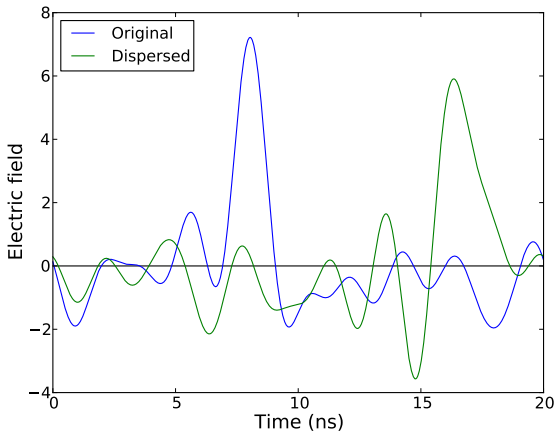


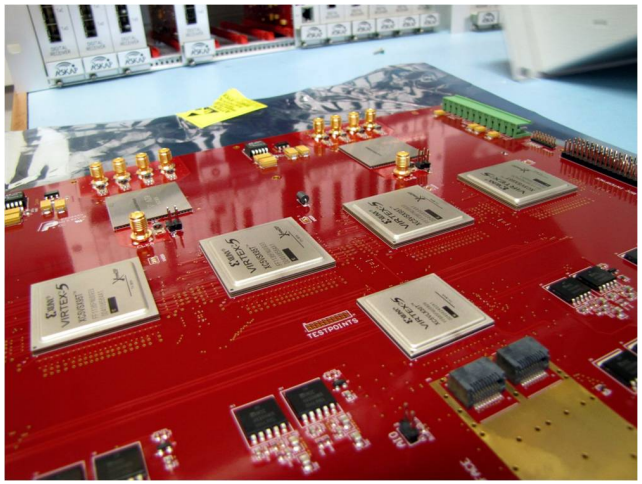


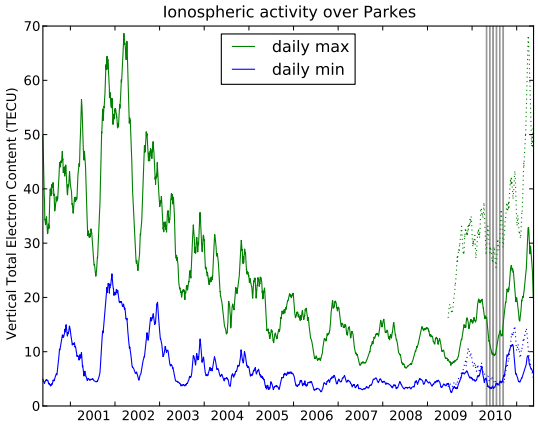
"Bedlam" Parkes backend

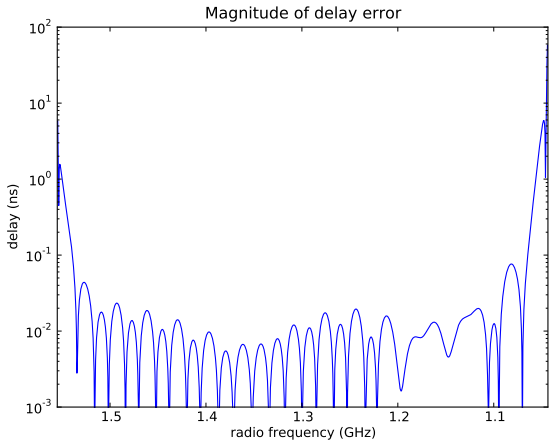
8 μs buffers
$\times$ 4 beams $\times$ 2 pols

Ionospheric dispersion





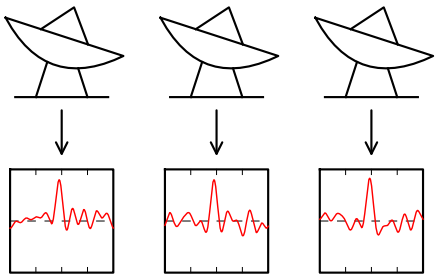


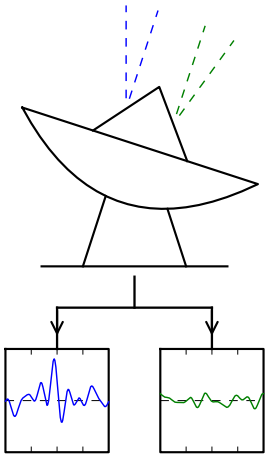


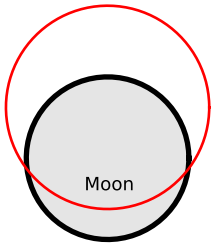
1 TECU $\simeq 3 \times 10^{-7}$ pc cm^{-3}

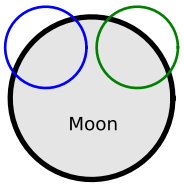
Incoherent versus Coherent

Incoherent

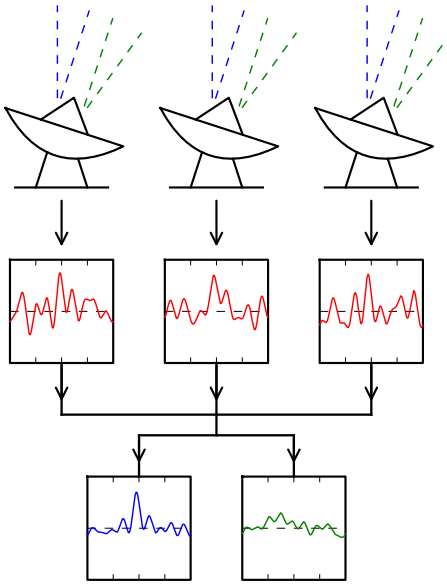


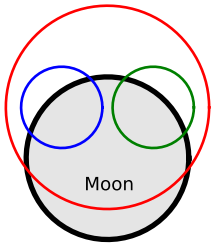






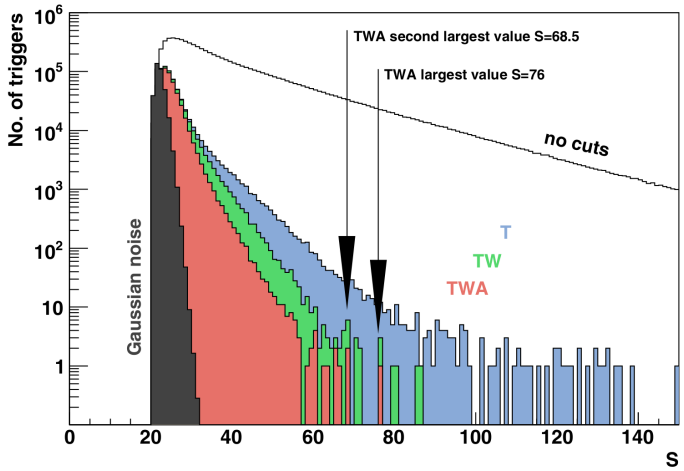
Coherent





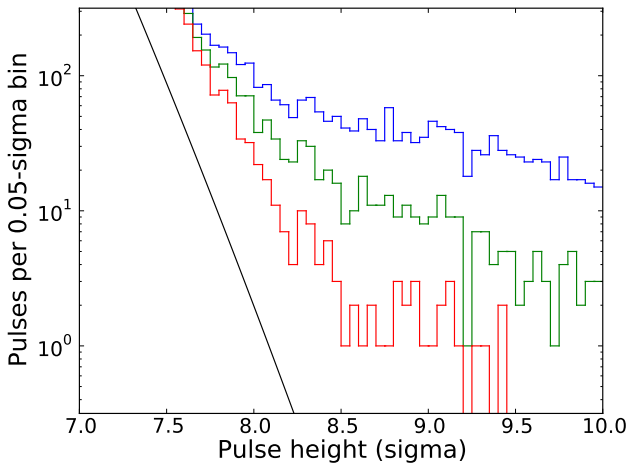
RFI rejection

Westerbork (2007/08)

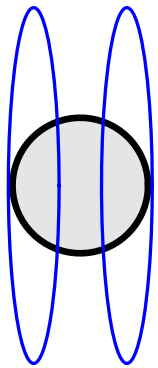


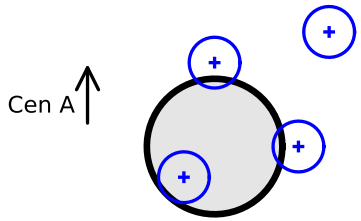
Buitink et al., A&A (2010)

Parkes (2010)

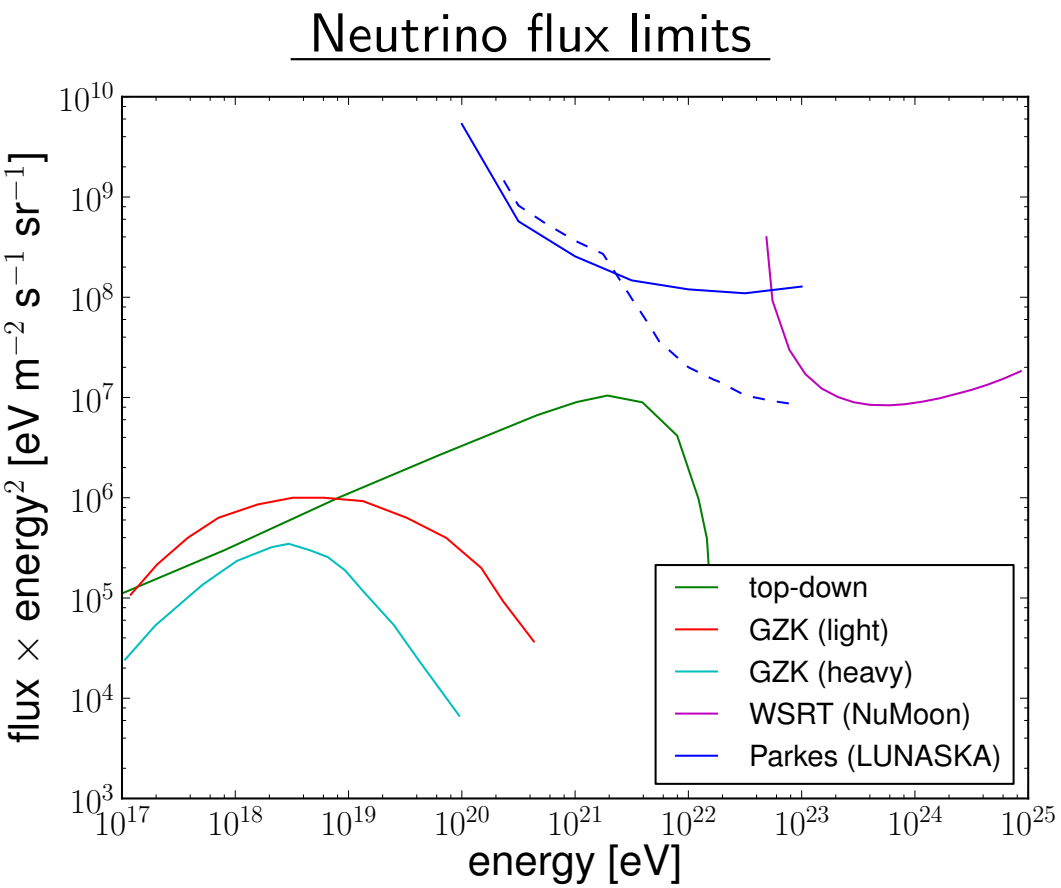


Bray et al. (in prep.)





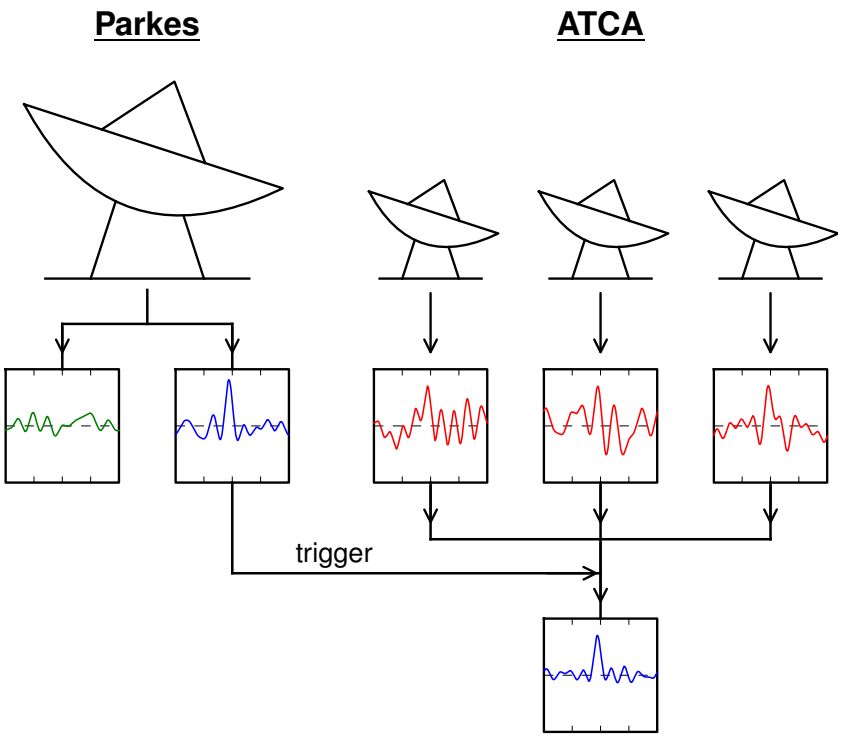
Neutrino flux limits

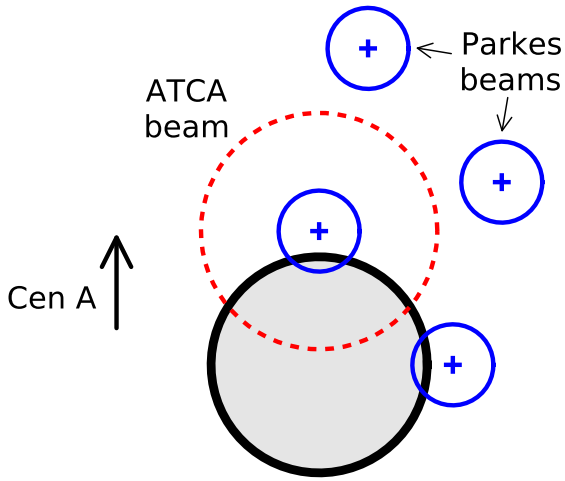


Big uncertainties!

- surface roughness
- ν cross-section

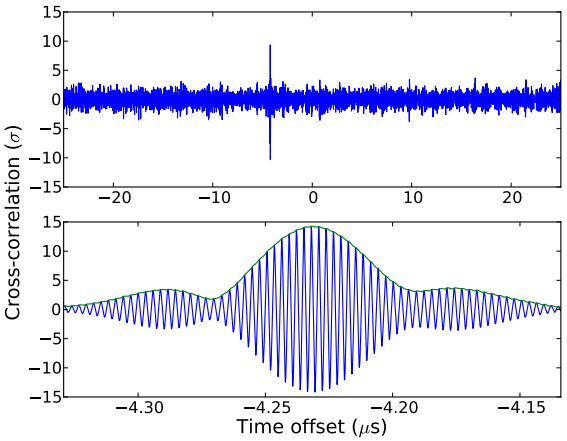
Parkes-ATCA experiment





Timing calibration

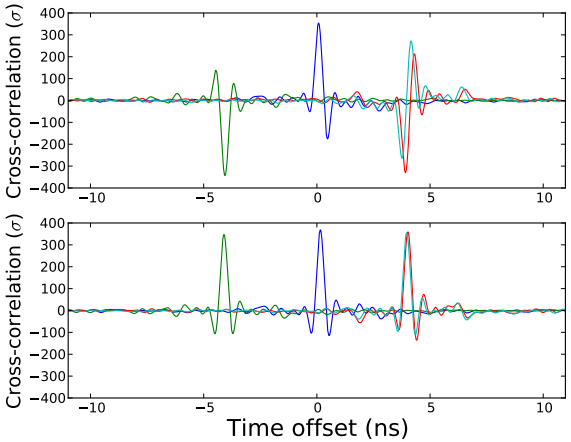
Parkes-ATCA



Standard VLBI problem, except:

- smaller buffers
- lower precision required

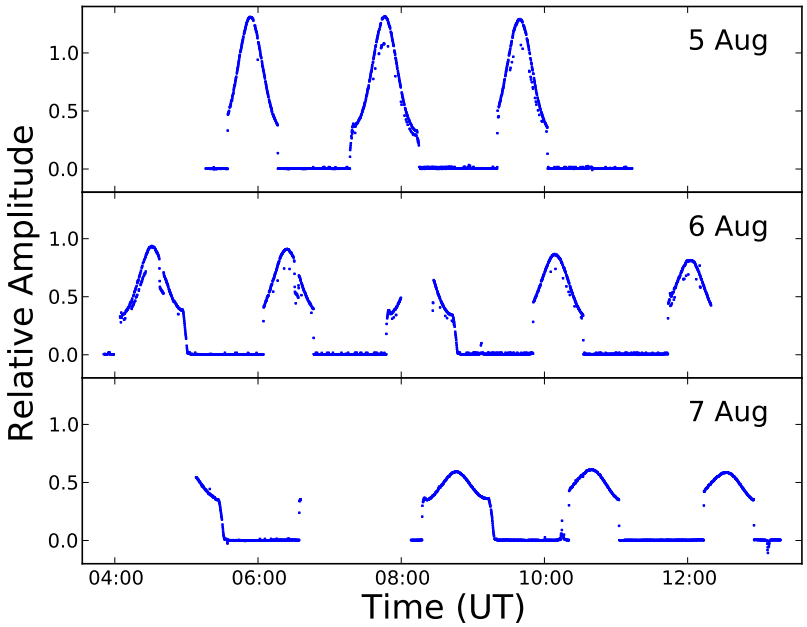
ATCA



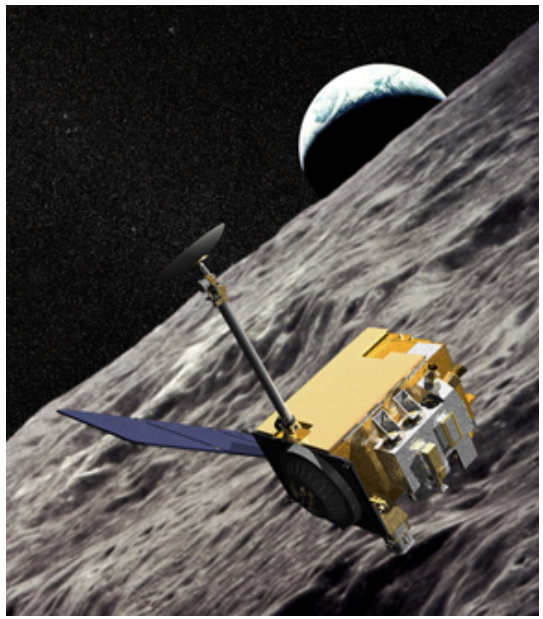
Standard ATCA calibration, except:

- different

Lunar orbiter



Modulated CW signal



NASA Lunar Reconnaissance Orbiter

Frequency matches (2.27 GHz).
Period matches (113 mins).

- Problem?

Summary

- Nanosecond-scale pulses can come from particle cascades.
- Detecting them would tell us a lot about cosmic rays.
- We're working on it.