Advanced Reproduction of Space Radiation Studies by overdense laser plasma interaction

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The early stages…

VOLUME 43, NUMBER 4 … TTERS 23 JULY 1979

An intense electro… action of the nonlinear pondero… celerated to high energy. Existing glass la… mas of densities 10^{18} cm^{-3} can yield gigaelectronvolt… of acceleration distance. This acceleration … simulation. Applications to accel…

Collective plasma … received …

… becomes … generating the wakes … seen by the following approximate

PHYSICAL REVIEW VOLUME 75, NUMBER 8 APRIL 15, 1949

On the Origin of the Cosmic Radiation

ENRICO FERMI
Institute for Nuclear Studies, University of Chicago, Chicago, Illinois
(Received January 3, 1949)

A theory of the origin of cosmic radiation is proposed according to which and … in the interstellar space of the galaxy … One of the features of the theory is that it yields na… spectral distribution of the cosmic rays. The chief difficult… forward way the heavy nuclei observed in the primar…

PHYSICAL REVIEW VOLUME 79, NUMBER 3 AUGUST 1, 1950

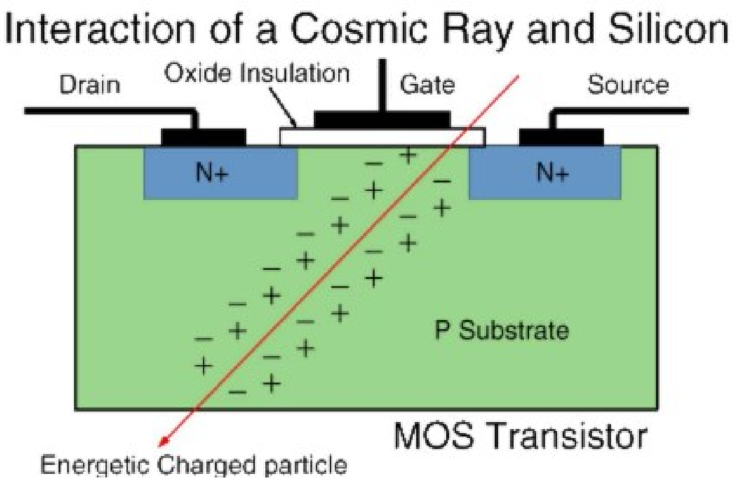
The Origin of Cosmic Rays

EDWIN M. MCMILLAN
Radiation Laboratory, Department of Physics, University of California, Berkeley, California
(Received January 31, 1950)

The original idea of Menzel and Salisbury concerning the origin of cosmic rays has been extended and some of its possible consequences worked out in more detail. It is concluded that … An attempt is made to explain both the "ordinary" cosmic rays and the intensity increases following solar flares in terms of the action of these waves.

Effects of space radiation

- Electronics
  - Ionization / Total Dose Effects
  - Single Event Effects (SEEs)
    - Single Event Upset (SEU)
    - Single Event Latchup (SEL)
  - Displacement damage



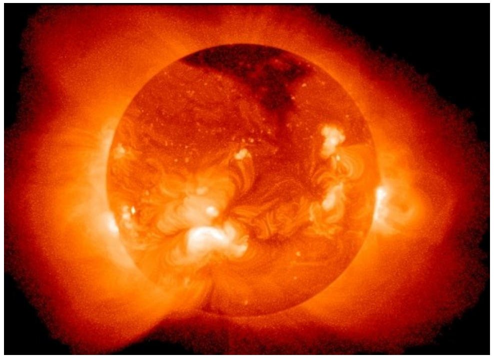
- Biological systems (astronauts)
  - Radiation damage
    - deterministic: immediate damage at sufficiently high dose - acute radiation syndrome
    - stochastic: genetic long-term damages, increased possibility for formation of cancer

Major **showstopper** for space exploration!

Radiation sources in space

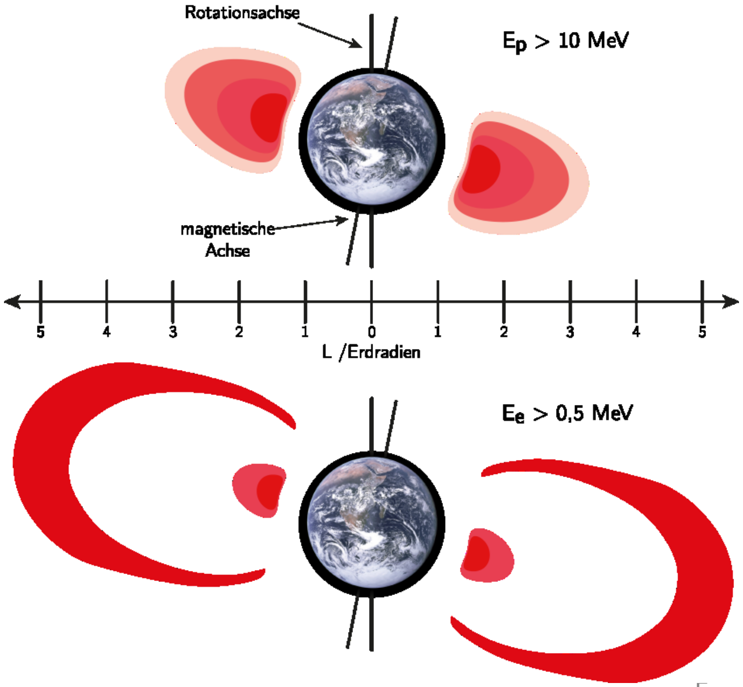
Radiation sources:

- solar wind / CMEs
- galactic cosmic radiation with $E > 10^{20}\mathrm{eV}$
- trapped particles in radiation belts



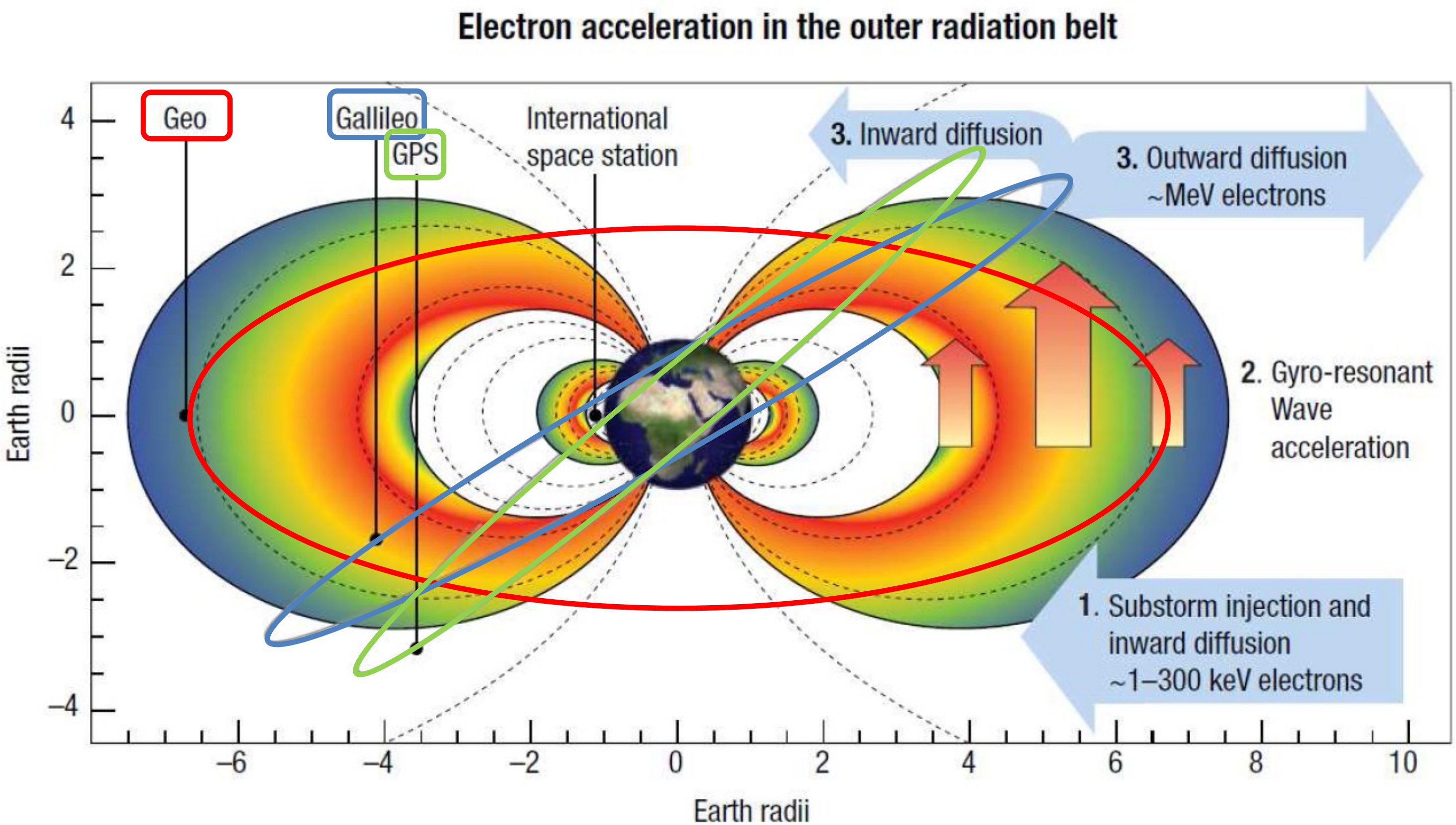
Van Allen radiation belt

- magnetic bottle for protons and electrons
- flux density $1 \cdot 10^{6}\mathrm{cm}^{-2}\mathrm{s}^{-1}$ (for $E_e > 1$ MeV)
- secondary particle showers



Radiation sources in space

R. B. Horne et al., Nature Physics **3**, p.p. 590, 2007



GEO: $r_{\text{orbit}} \approx 42{,}150$ km (meteorological satellites, comsats)

Galileo: $r_{\text{orbit}} \approx 29{,}600$ km (European satellite navigation system)

GPS: $r_{\text{orbit}} \approx 26{,}500$ km (U.S. military satellite navigation system)

Space radiation testing

Novikov, *SINP MSU Preprint* – 2003 – 9/722
Novikov, J. Surface Investigation, **3**, 199-214, 2009

Information on space radiation effects can be obtained by:

- on-board-experiments in space (satellites, ISS)
- ground-based radiation tests
- mathematical modeling

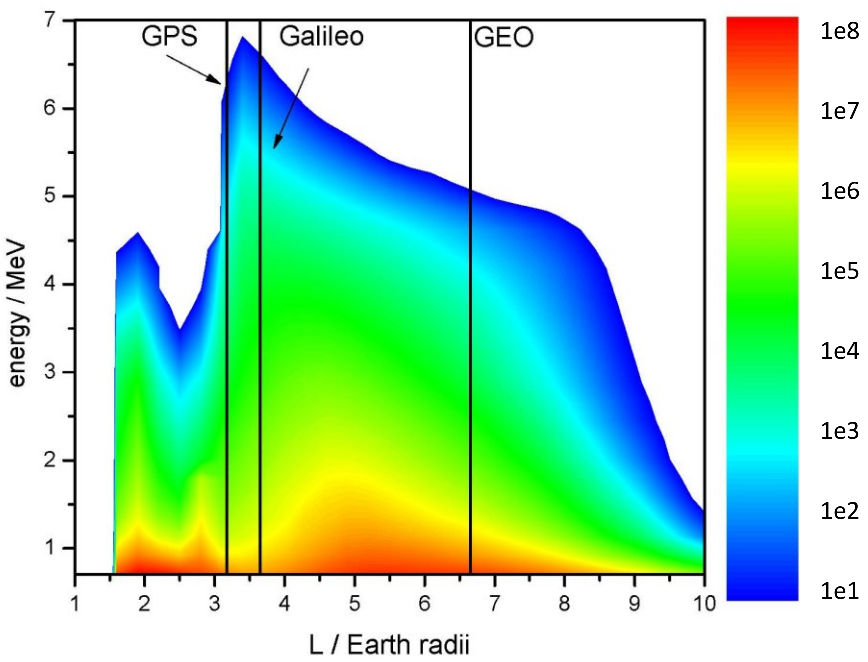
Approaches for radiation tests:

1. Tests under following simplifications:
   - monoenergetic electron and/or ion beams
   - usage of γ-sources (^{60}Co)
   - increase of radiation intensities by a factor of 10^2 - 10^3 for time reduction

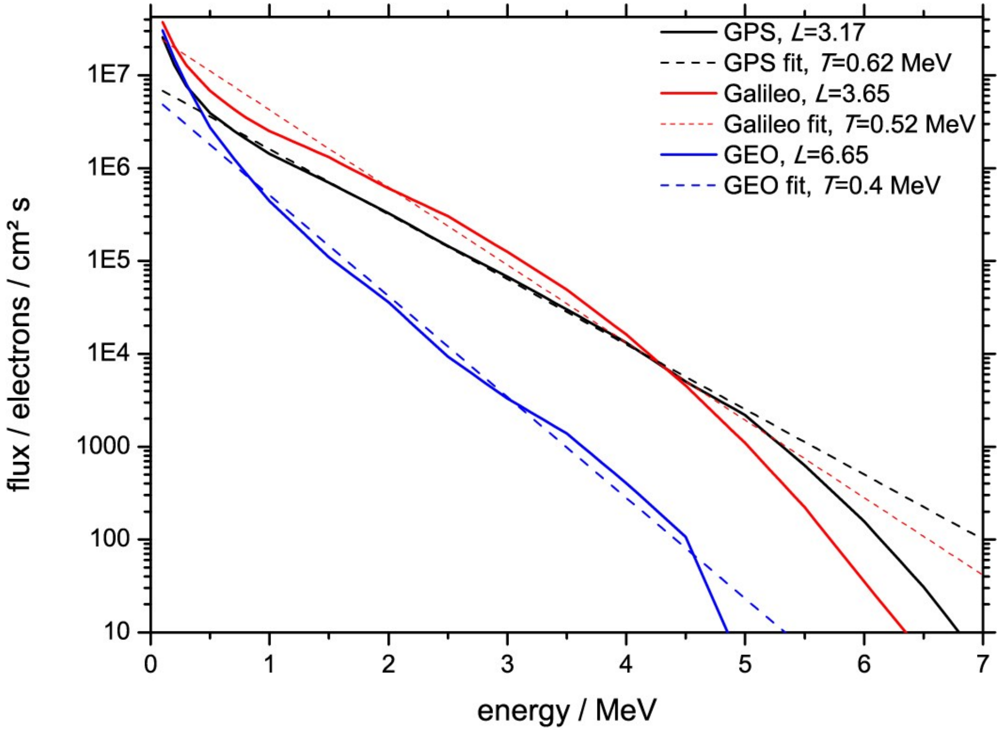
2. Reproduction of space radiation features in ground-based testing means: energy distribution, particle composition, angular distribution, flux, …

Space radiation testing

Van Allen belt electron flux
(NASA's AE8$_{min}$-model)



Boltzmann-distributed electron spectra:
$n(E) = n_0 \cdot \exp\left(-\frac{E}{T}\right)$



Königstein, Karger et al., J. Plasma Physics (2012), vol. 78, part 4, pp. 383-391

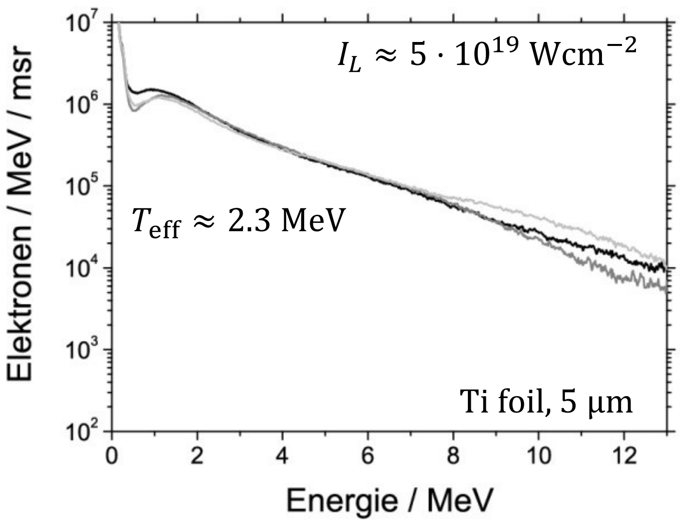
Radiation test with LPAs

Effective electron temperature intensity-dependent scalings:

$T_{\text{eff}} \propto (I\,\lambda^2)^{\zeta}$ with $\zeta = 1/3$ to $1/2$

$T_{\text{eff,Beg}} = 0.1(I_{17}\lambda^2)^{1/3}$ MeV

$$T_{\text{eff,Wilks}} = \left(\sqrt{1 + \frac{I[\text{Wcm}^{-2}]\lambda[\mu\text{m}]^2}{1.37 \cdot 10^{18}}} - 1\right) m_0 c^2$$



Hidding et al., *Rev. Sci. Instrum.* **78**, 083301 (2007)

Königstein, Karger et al., J. Plasma Physics (2012), vol. 78, part 4, pp. 383-391

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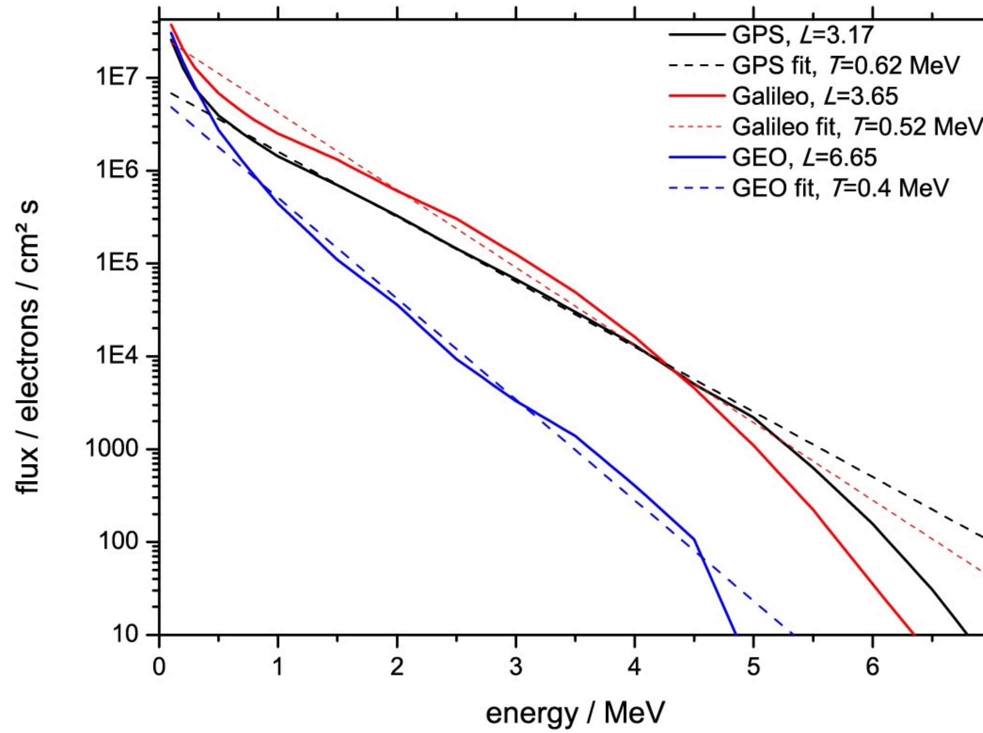

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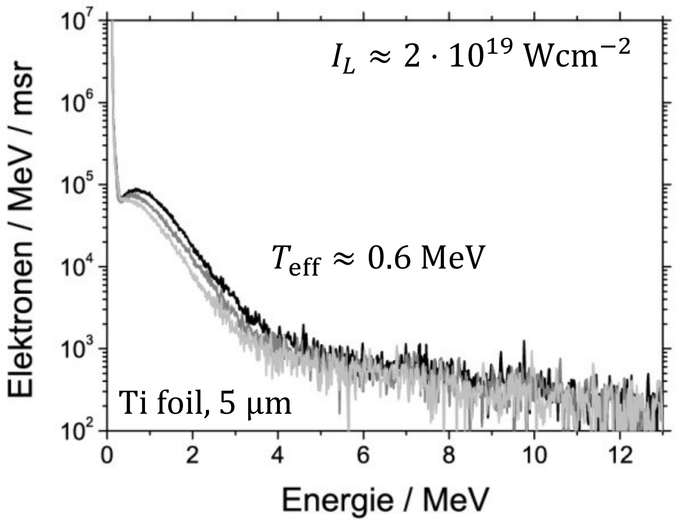

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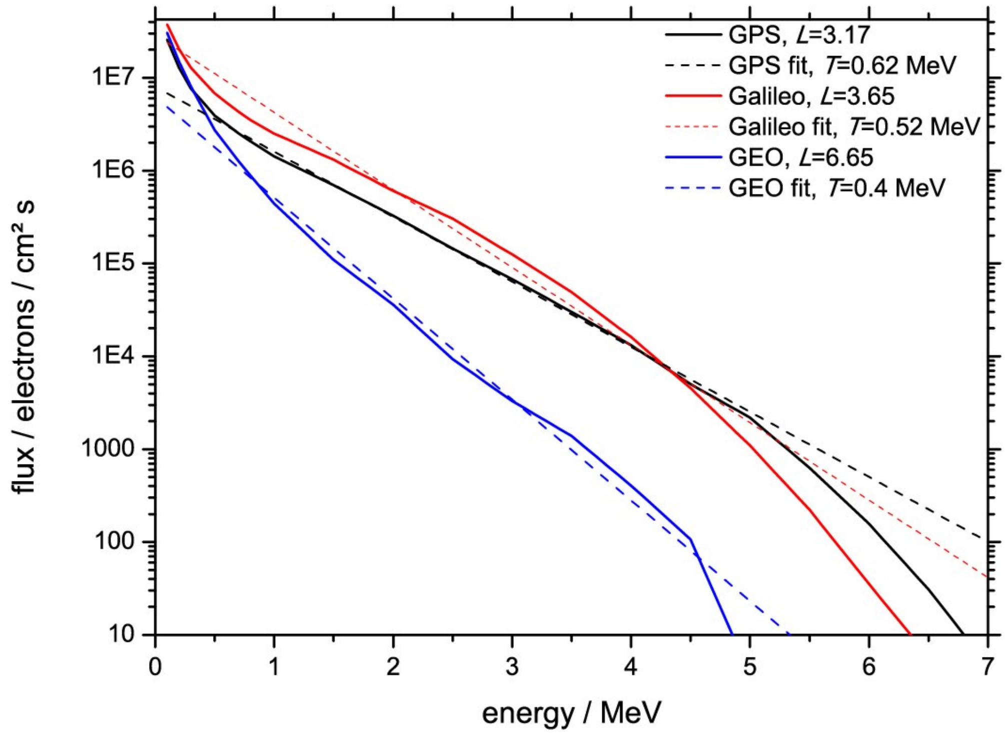
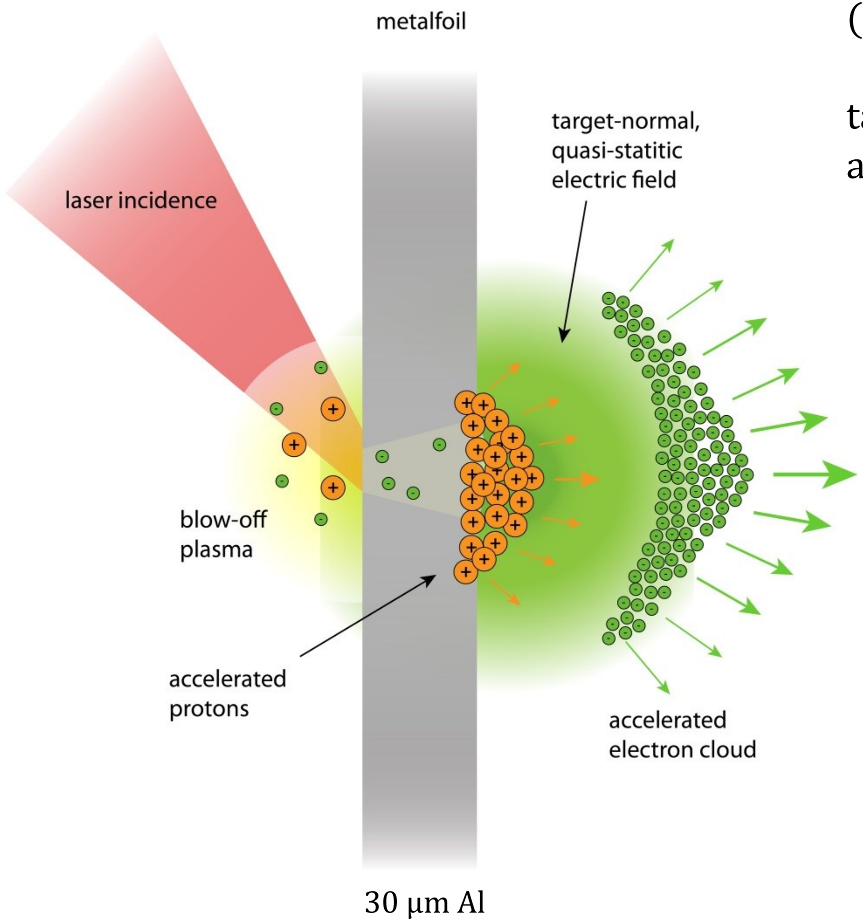


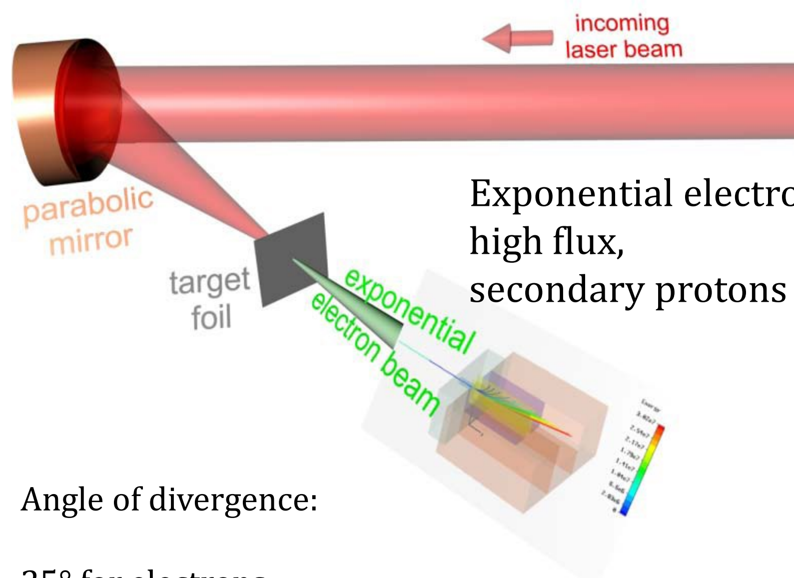
Radiation test with LPAs

TNSA-mechanism



Interaction with foil → laser is reflected at critical density (solid, overdense)

target density: $\sim 10^{24}\mathrm{cm}^{-3}$
accelerating fields: ~ 100 GV/m

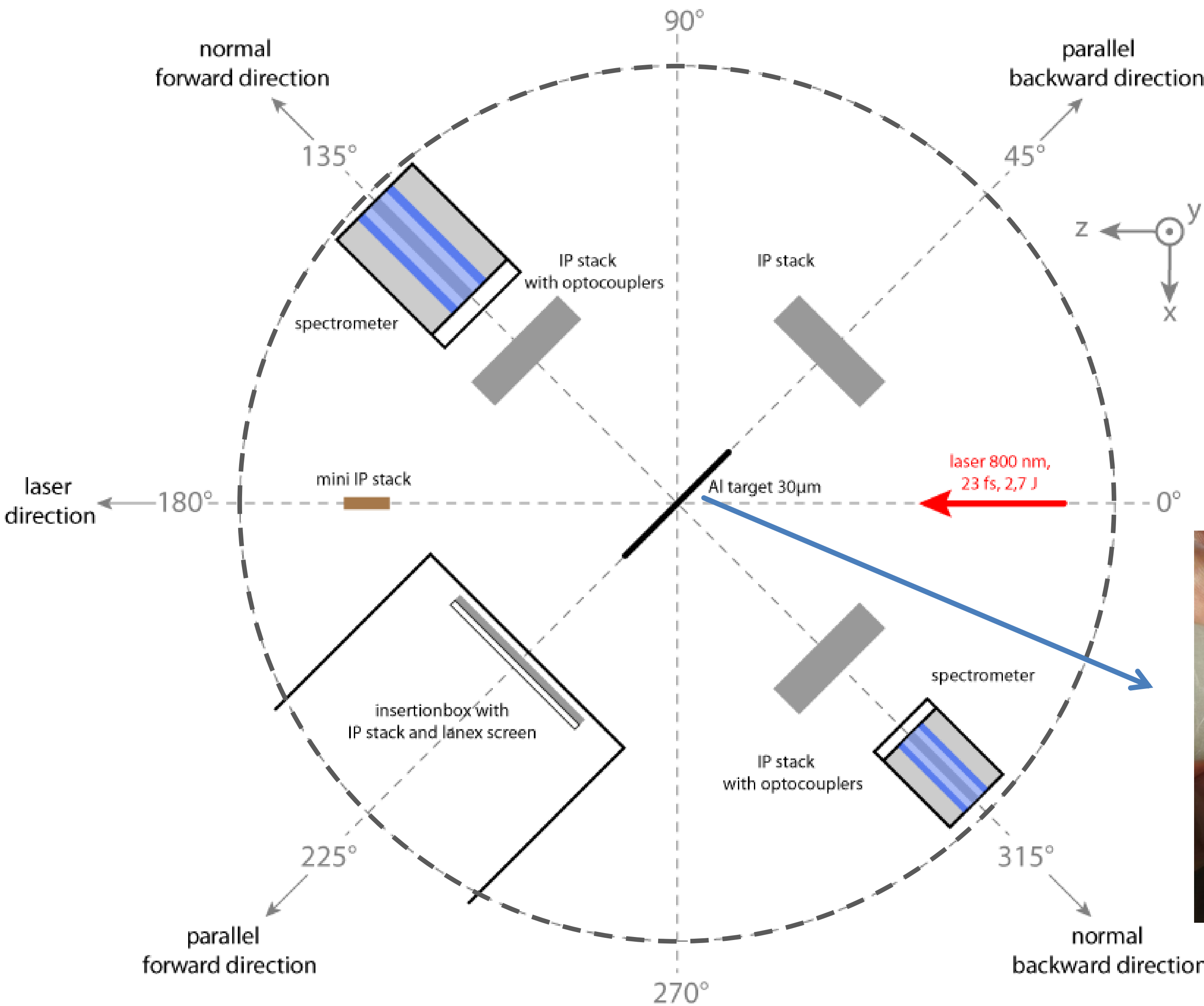


Exponential electron spectra,
high flux,
secondary protons and ions

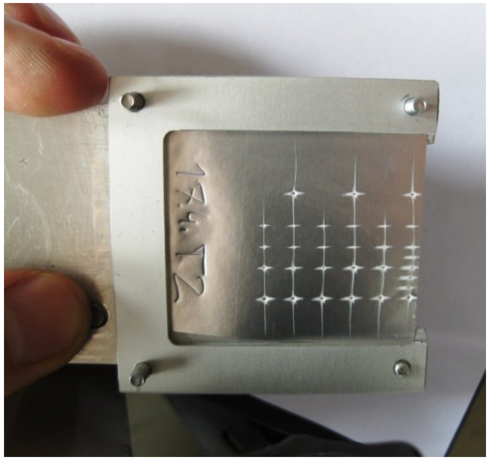
Angle of divergence:

25° for electrons
30° for protons

Proof-of-concept experiment



frame for 30 µm Al foil with $4\times4\text{cm}^2$ target area



Results

- We succeeded to get good results in a proof-of-concept experiment and are preparing a publication. Hence I cannot provide results here.

- Currently we plan to establish a network of laser plasma accelerator facilities to provide beam time to the space industry. If interested in that, feel free to contact me at oliver.karger@uni-hamburg.de

Summary

- space radiation can be a showstopper for space exploration
- various sources of space radiation, especially Van Allen belt
- conventional radiation tests are simplifications and therefore limited

  monoenergetic beams, low flux, long irradiation times
- radiation testing with laser-plasma accelerators are more realistic

  exponential beams possible, higher flux, much shorter irradiations times

  gain advantage to simplify reliability and schedule (1/3 mission cost for testing)
- <u>normal forward direction</u> give a compromise between correct temperature, sufficient number of electrons, and irradiation time
- additional testing method with enormous impact and need for space agencies and related industry

Thank you for your attention

and your patience