

Interdisciplinary Application of Electron Tracking Compton Camera (ETCC) and Planning for a Circum-Polar Stratospheric Flight of the Balloon-borne ETCC

Sachiko Arvelius¹, Toru Tanimori², Esa Turunen³

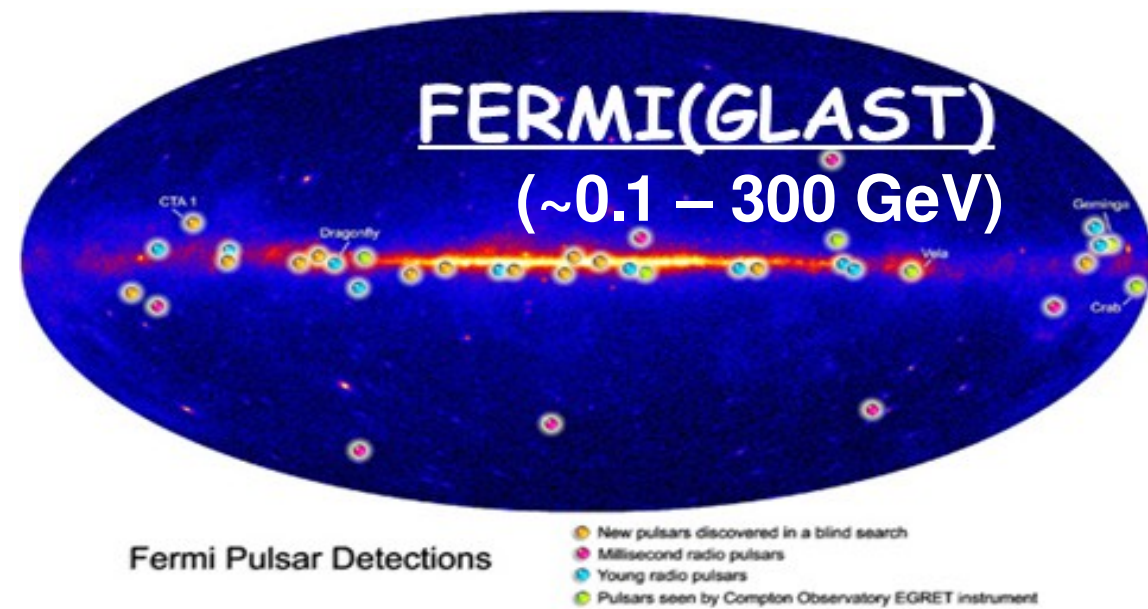
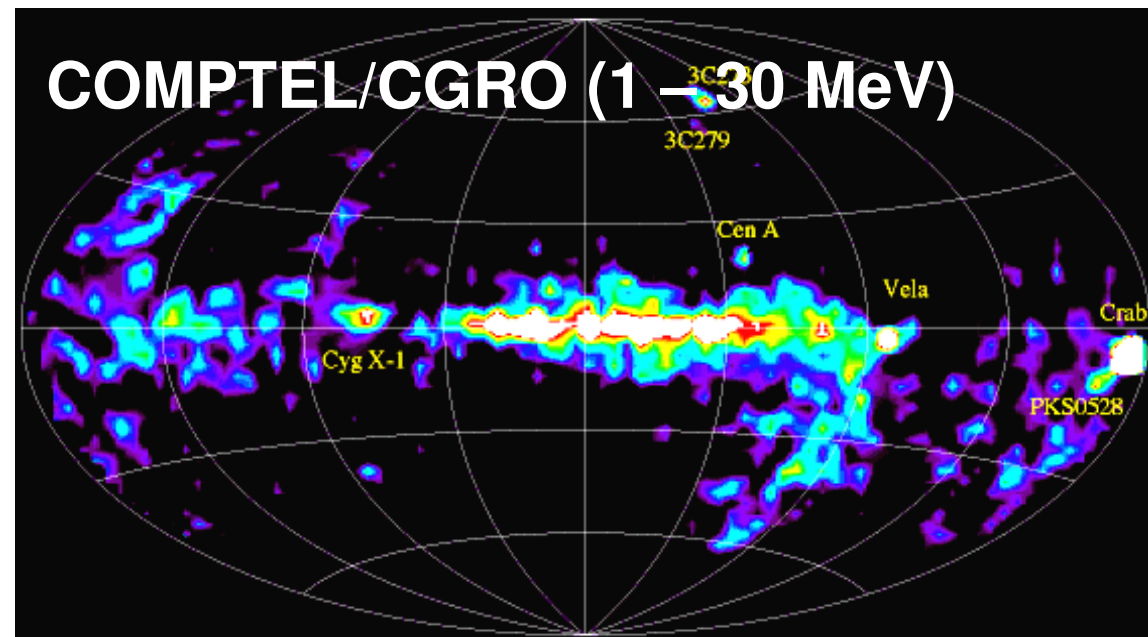
1: Div. of Space Technology (Kiruna), Dept. of Computer Science, Electrical- and Space Engineering, Luleå University of Technology, Sweden

2: Cosmic Ray Group, Dept. of Physics, Graduate School of Science, Kyoto University, Japan

3: EISCAT, Headquarters (Kiruna), Sweden

Corresponding E-mail: sachiko.arvelius@ltu.se

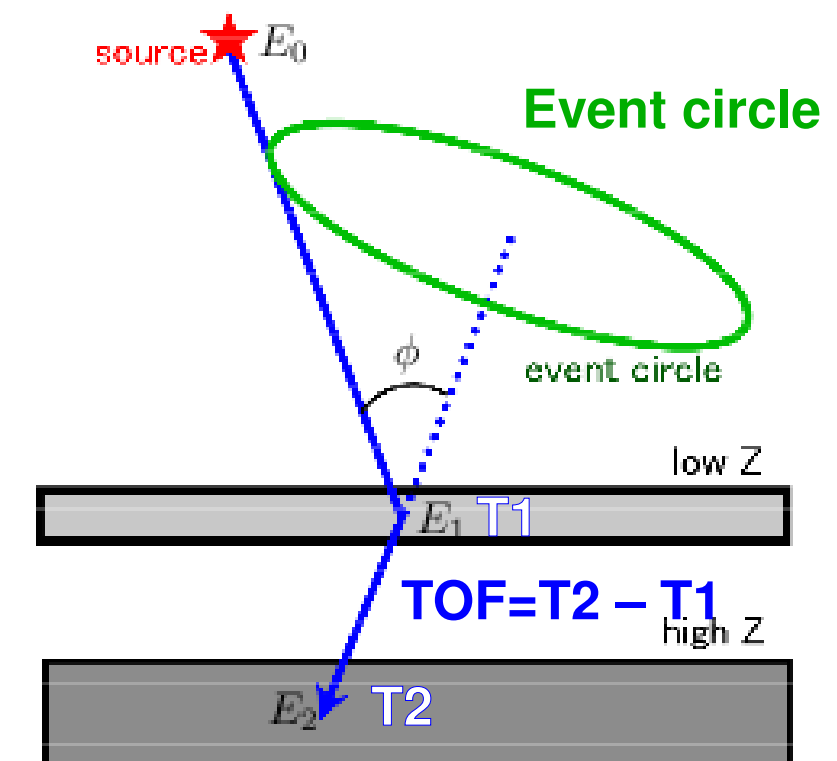




1. Astronomical Motivation

Left figures: **COMPTEL** (The Imaging Compton Telescope) on-board CGRO (Compton Gamma Ray Observatory) detected **~30 gamma-ray sources for 9 years** [Schönfelder et al., 2000], while **Fermi** (former, Gamma-ray Large Area Space Telescope, GLAST) detected **1451 gamma-ray sources during the first 11-month observation** [Abdo et al., 2010].

Gamma-ray source



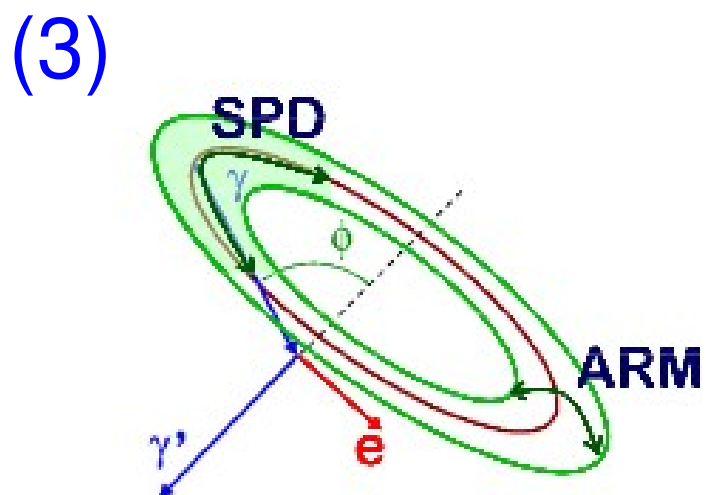
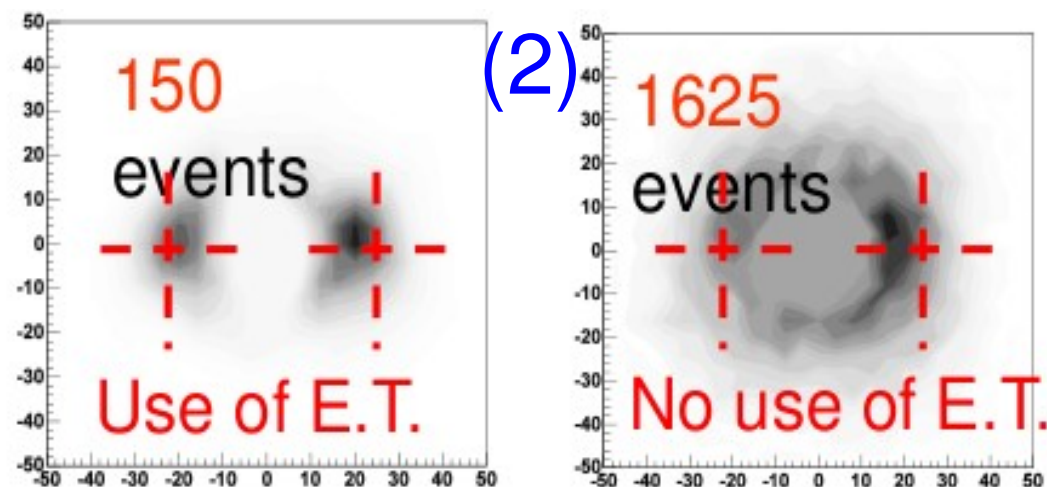
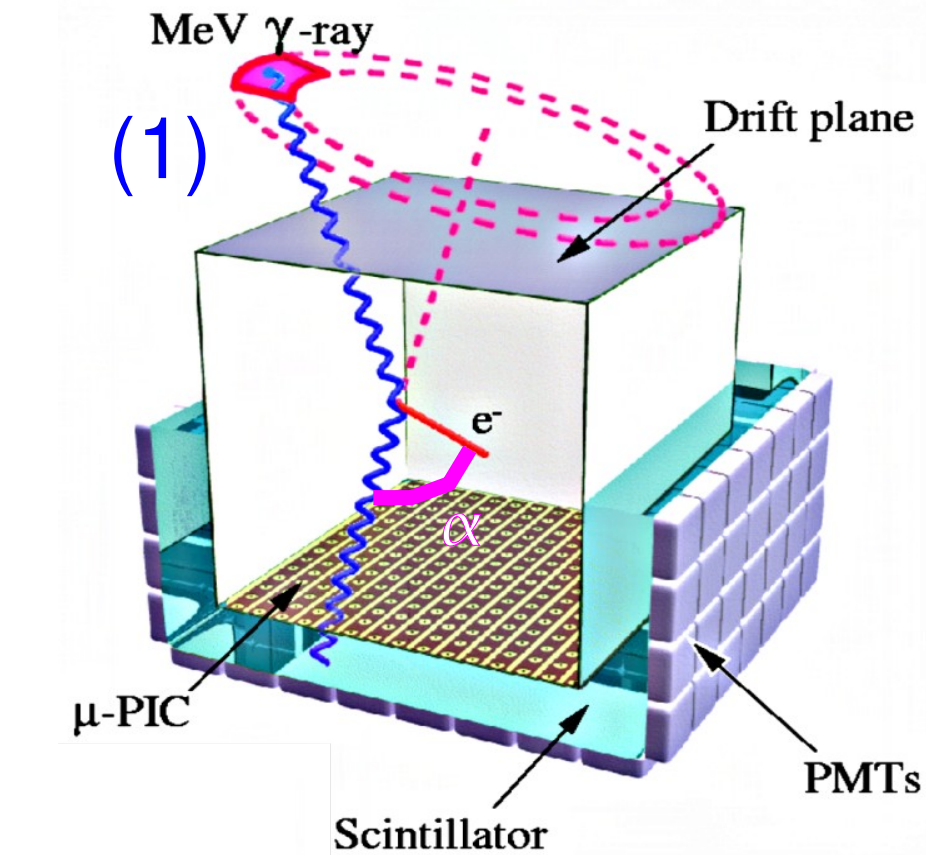
Right figure: **COMPTEL** could reconstruct (Compton) **event circles** and has adopted **Time-Of-Flight (TOF) between 2 detectors** to determine the timing of scattered gamma-rays. These detection methods could not reject **backgrounds** sufficiently [Weidenspointner et al., 2001].

2. Principles of ETCC

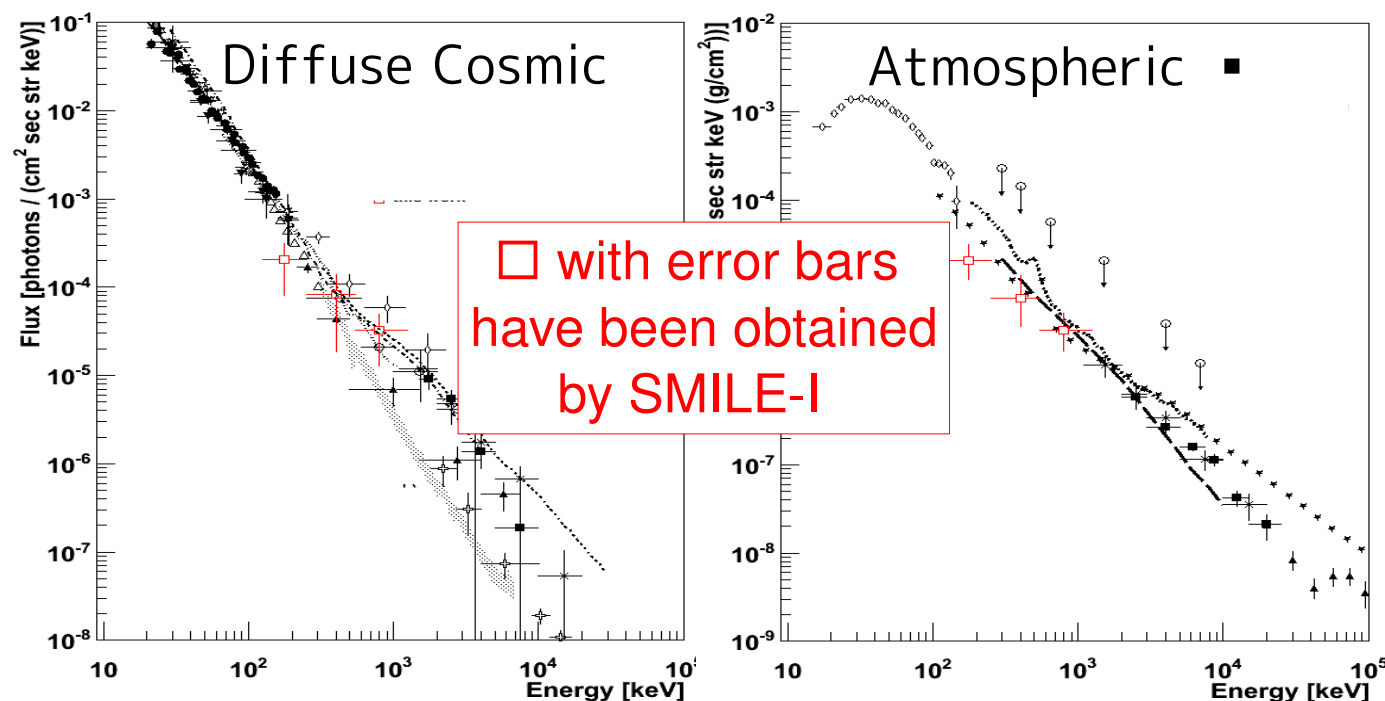
Figure (1): **ETCC** consists of a **gaseous tracker** (Time Projection Chamber, **TPC**, with micro-Pixel Chamber, **μ -PIC**) that detects **Compton-recoil electrons**, and an **absorber** (Pixel Scintillator Arrays, **PSAs**, with Multi-anode Photo-multipliers) that detects **Compton-scattered gamma-rays**. The angle α (in the figure, Electron Tracking technique, **E.T.**) makes us identify **Compton scattering**.

Figure (2): The angle α can be obtained by both **kinematics** and **geometry**, but **independently**, which means that the **Compton method with E.T. technique (ETCC)** gives almost **10 times better efficiency** in detection.

Figure (3): The angular resolutions (**ARM** and **SPD** in the figure) are due to **Doppler broadening** (of targeted parent gas atoms or molecules) and **multi-scatters** (of electrons), respectively.



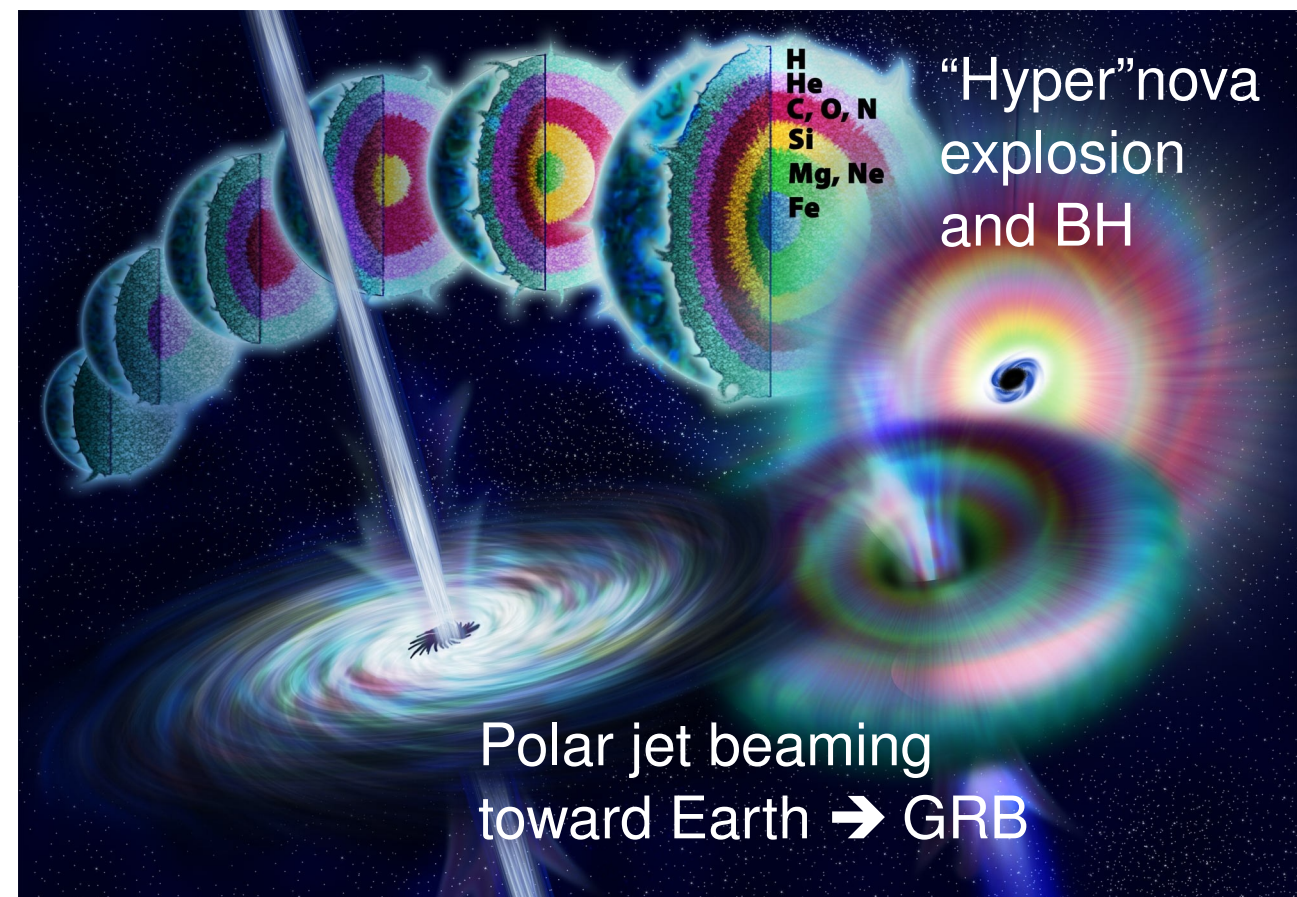
3a. MeV Gamma-ray Astronomy/Astrophysics



Performance Test of Balloon-borne 10x10x10cm³ ETCC

SMILE-I (2006 in Japan) has been succeeded in detecting and differing **diffuse cosmic gamma-rays** and **atmospheric gamma-rays**, both of who range from **~100 keV to ~1 MeV in energy** [Takada et al., 2011].

Gamma-Ray Burst (GRB) and **Gamma-ray Imaging** by balloon-borne ETCC (for future **satellite-borne ETCC**).



Picture above: Press Release 05-156 by NSF.

Line γ : $^{26}\text{Al}(\beta^+, \gamma)$, $^{60}\text{Fe}(\beta^-, \gamma)$, 511 keV, and etc.

— **Nucleosynthesis** in **SNR** and **Galactic plane**

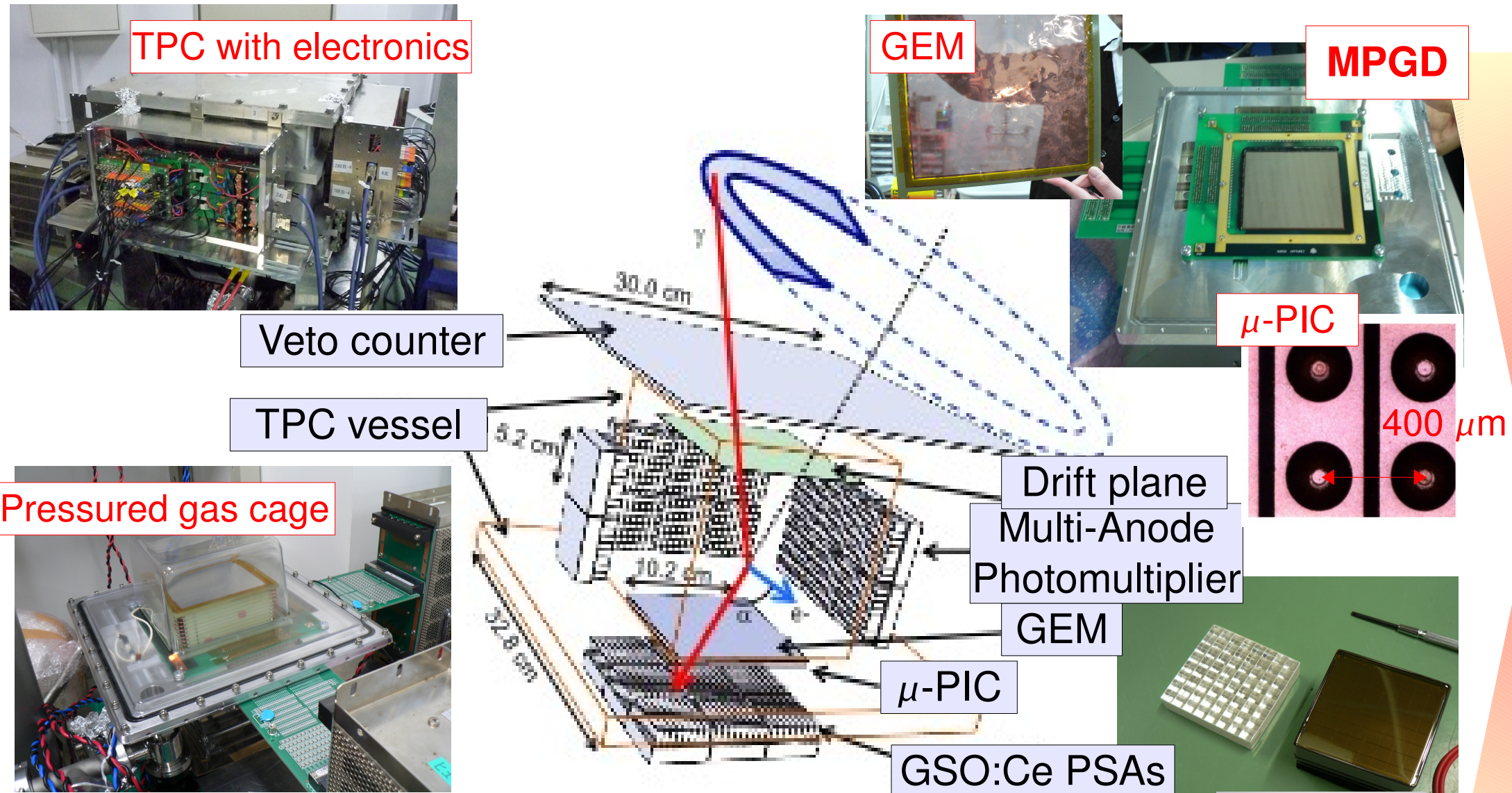
Continuum γ :

— **Strong Gravitational Potential (BH), Cosmic ray Acceleration**

3. SMILE (Sub-MeV gamma-ray Imaging Loaded-on-balloon Experiment) -II Project

MeV Gamma-ray Imaging

3a.



TPC/SMILE-II is scaled to 30x30x30 cm³ in volume.

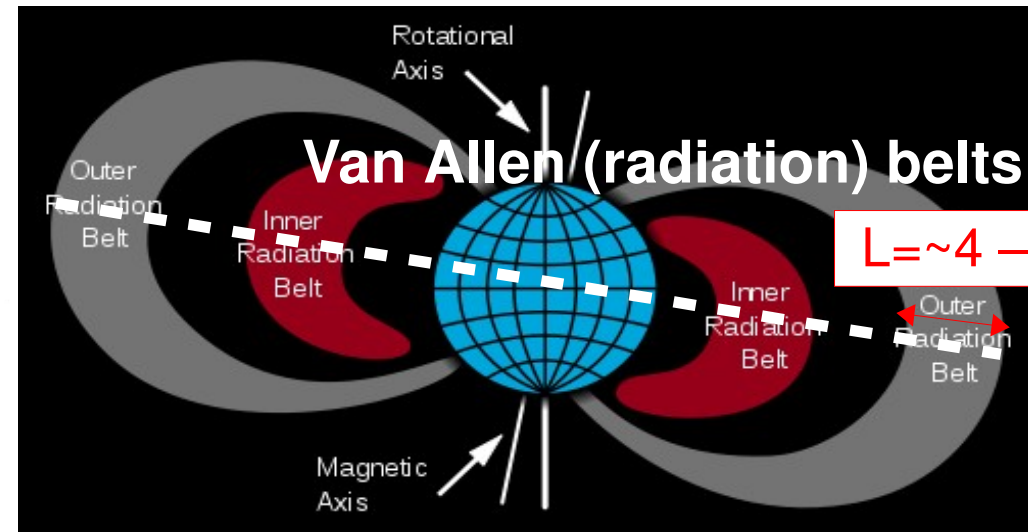
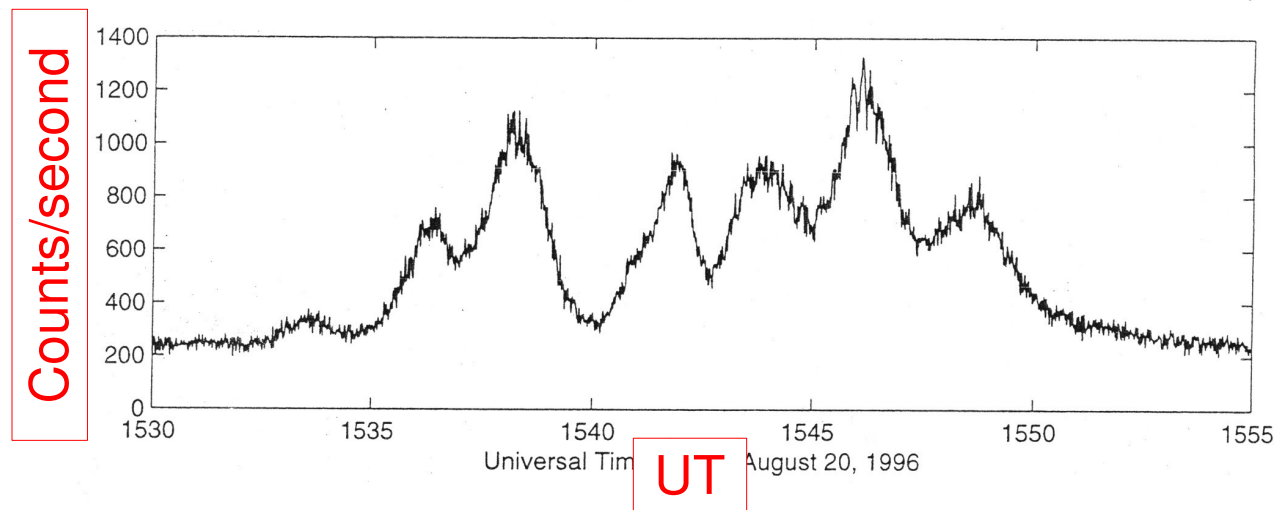
3b.

Terrestrial MeV Spectroscopy
Solar Neutron Imaging

3c.

Ground-based Observation
Data Exploitation

3b. Terrestrial MeV Space Physics

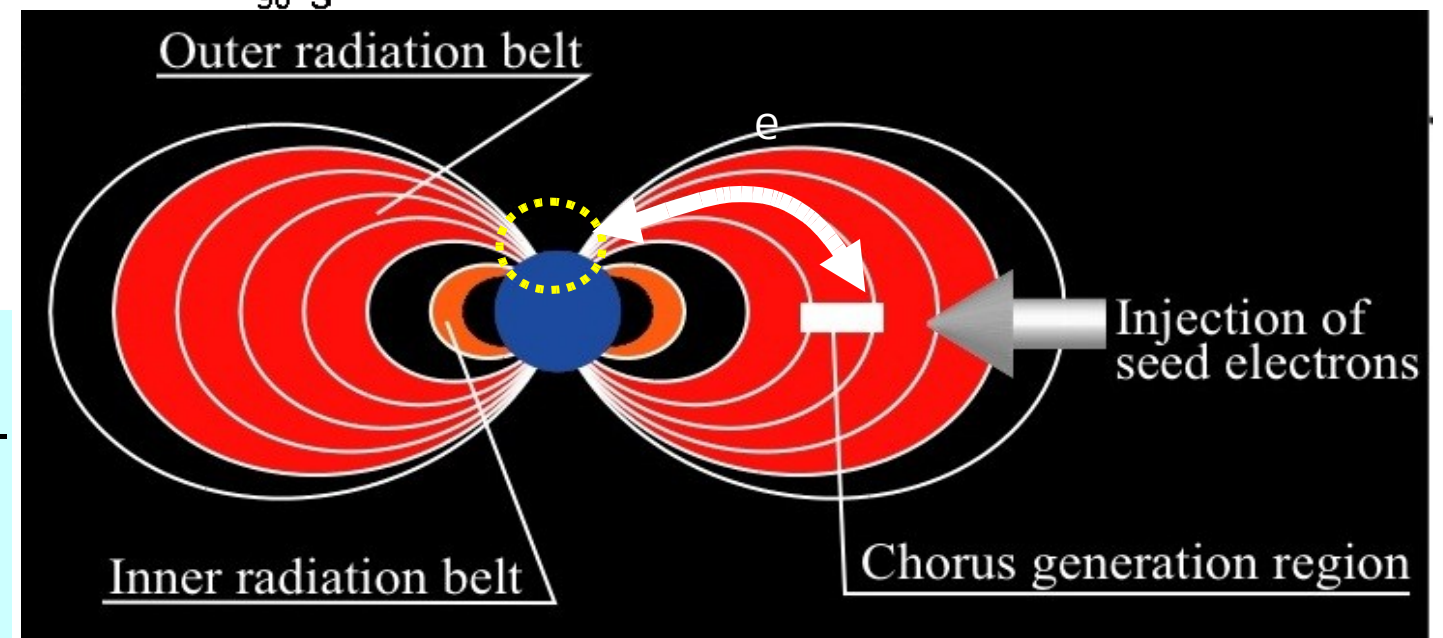
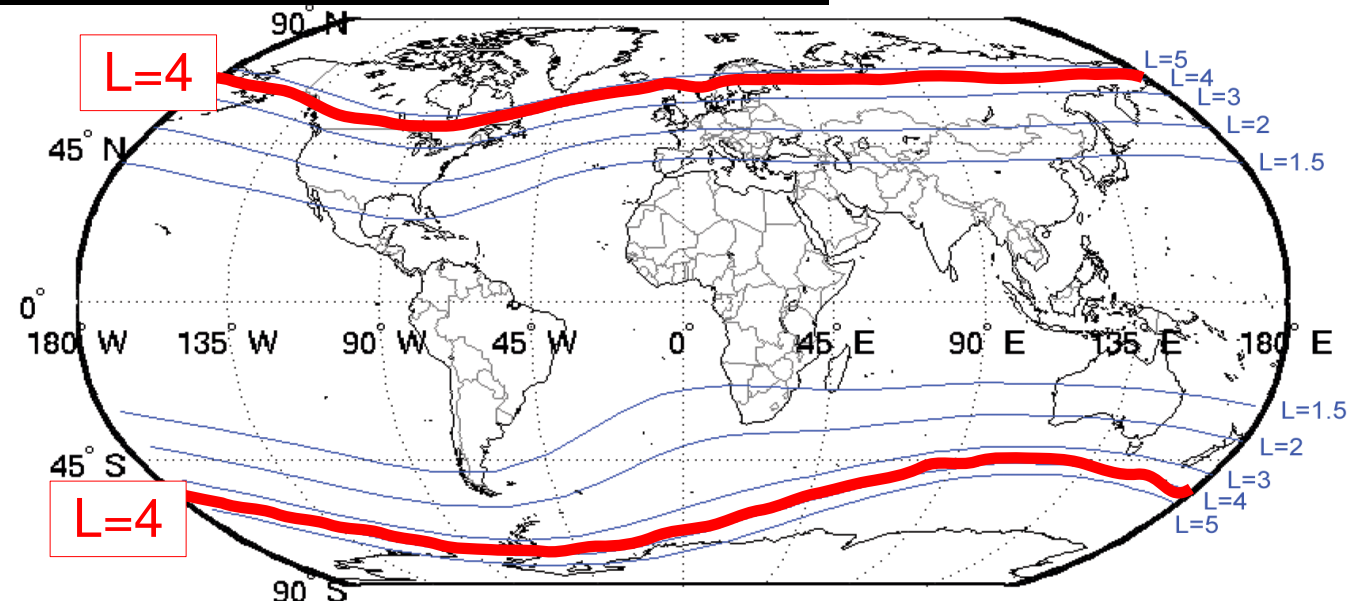


Figures from Wikipedia and the *L*-value on the flat map is generated by the *IGRF* model.

Energetic particle precipitation in the polar atmosphere

Hard X-rays (>100 keV) produced by **Bremsstrahlung** of **relativistic electron precipitations (REP)** from the (outer) **radiation belt** could be detected. However, **there was no other quantities on REP**, such as spatial/temporal distributions and variation, and spectrum [Lorentzen et al., 2000].

REP is the electrons with the energy of \sim MeV, and drifted in the **loss cone** and finally lost in the atmosphere. The drift may be caused by **wave-particle interaction**. Above all, **The mechanism of MeV acceleration of electrons is still unclear.**

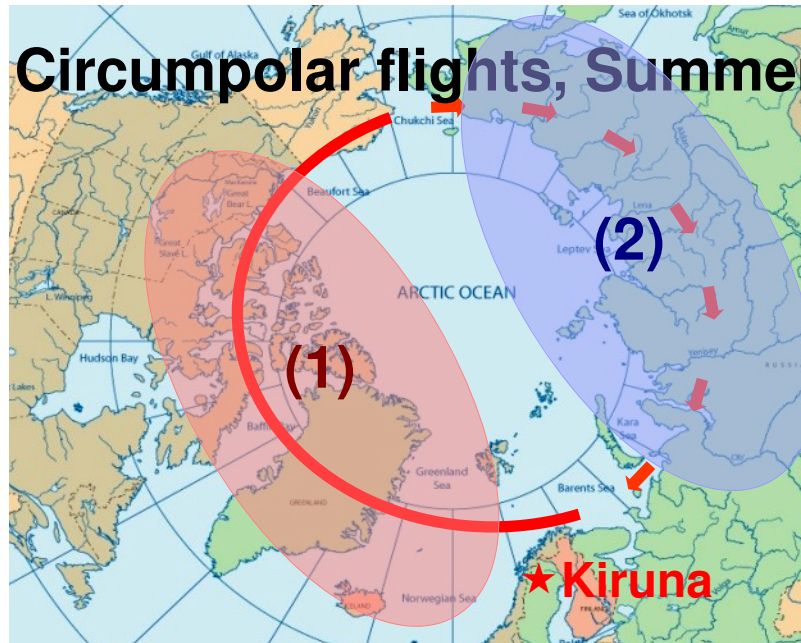


From Tanimori's presentation (2011)

Circum-Polar Balloon Flight



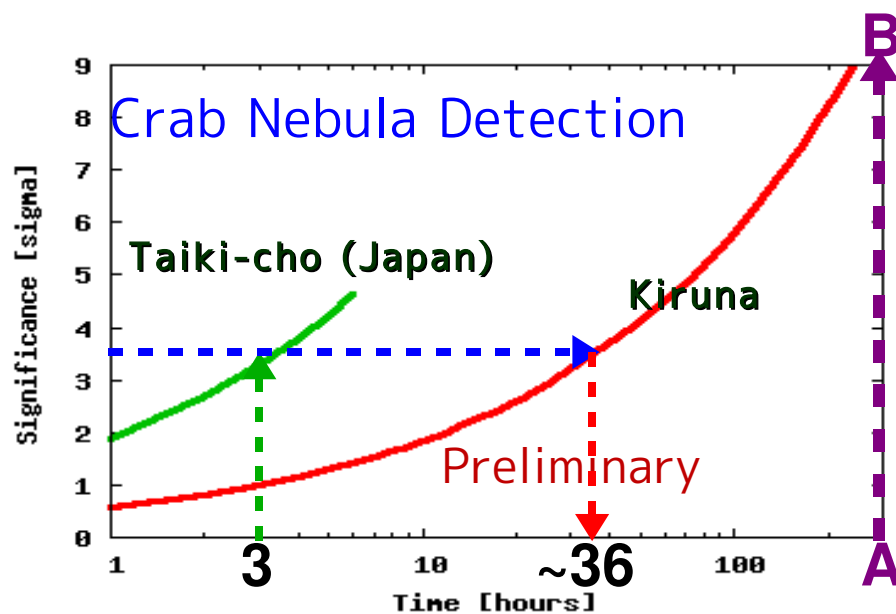
Balloon launch yard at Esrange/SSC, Kiruna, Sweden



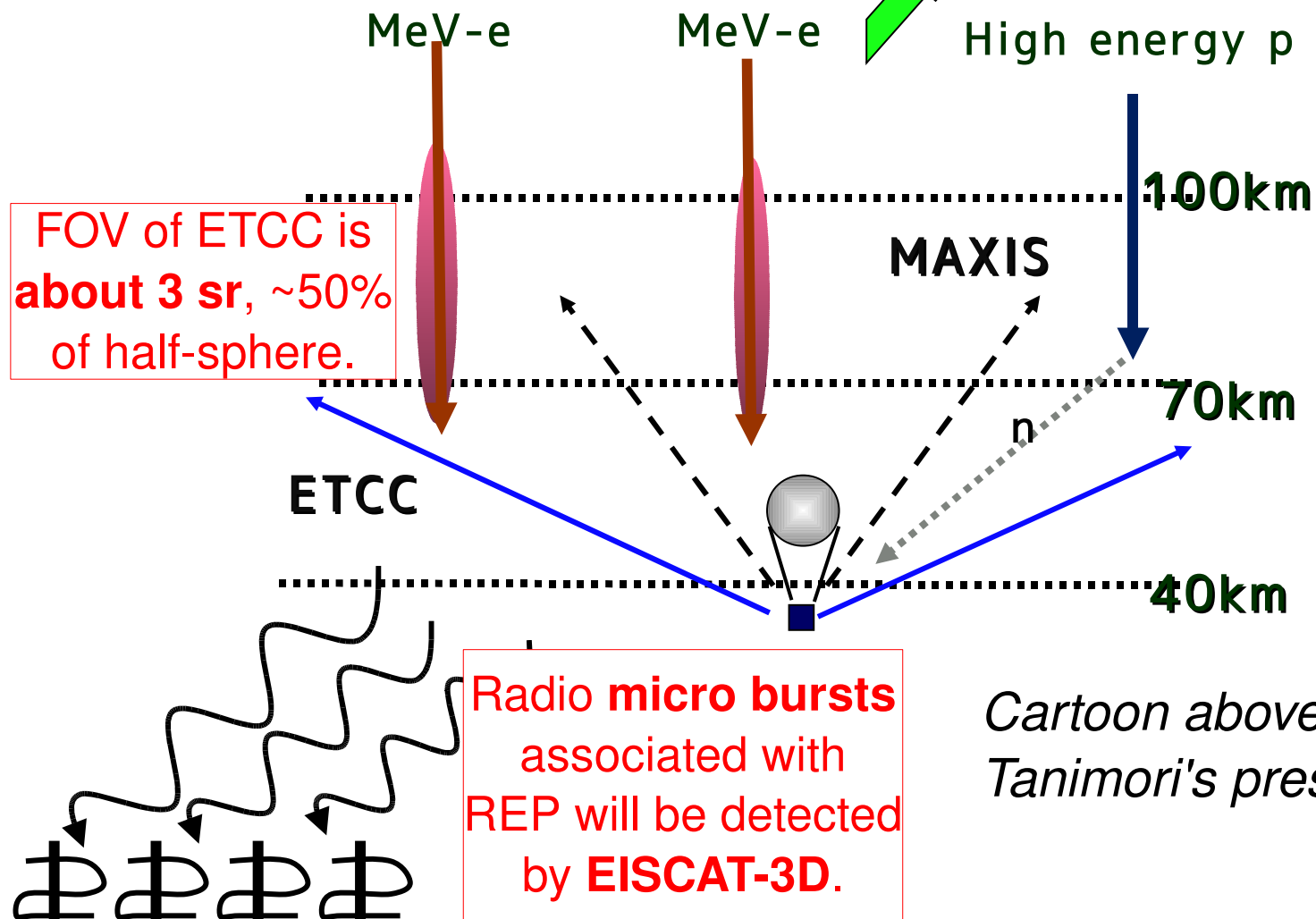
Circumpolar flights, Summer

CN(Crab Nebula)/GRB mode will be prioritised in the region (1) because L is too large (except **Solar Proton Event, SPE**), whereas **REP mode** will be the main mode in the region (2).

Japanese **ERG mission** will join in 2014.

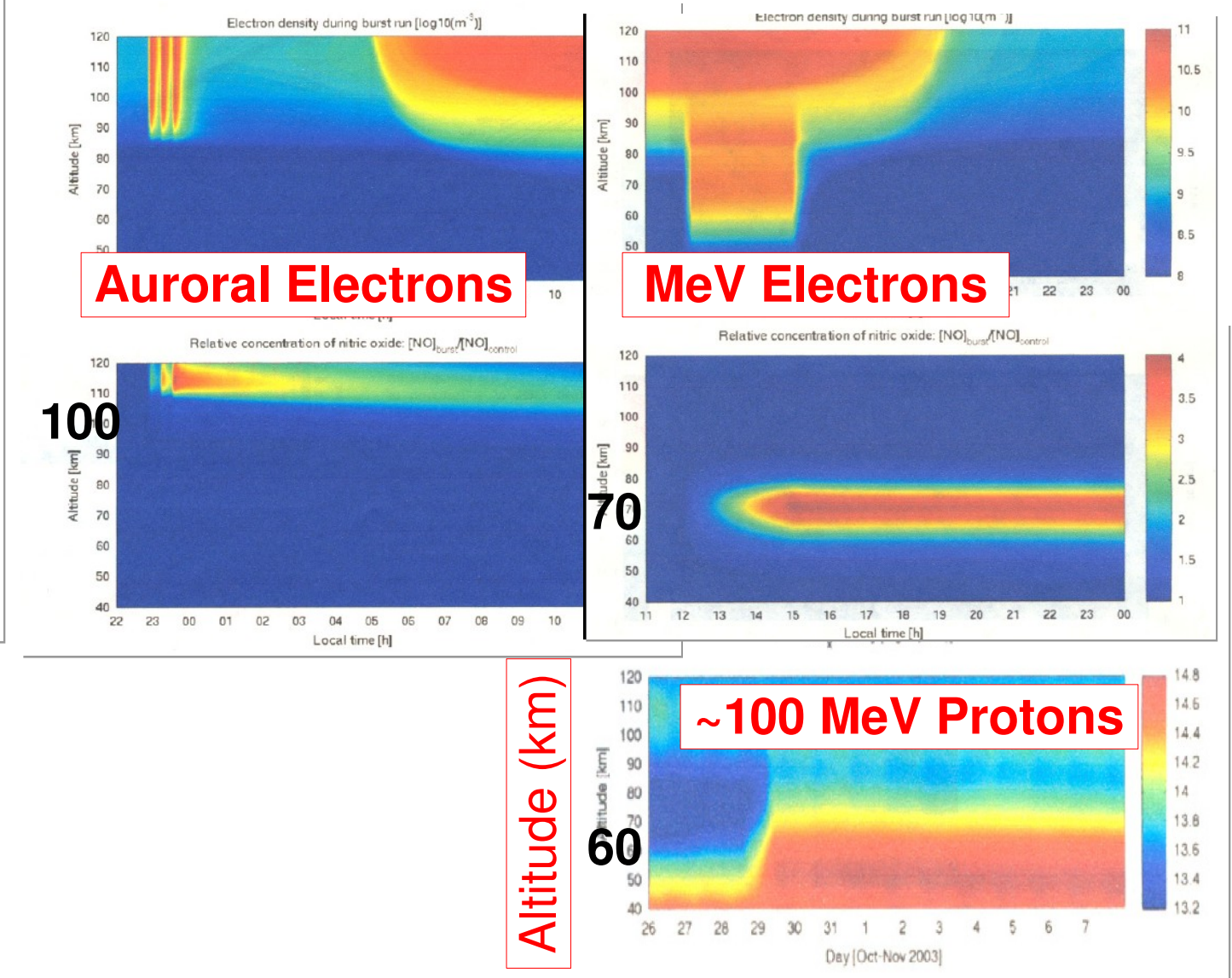
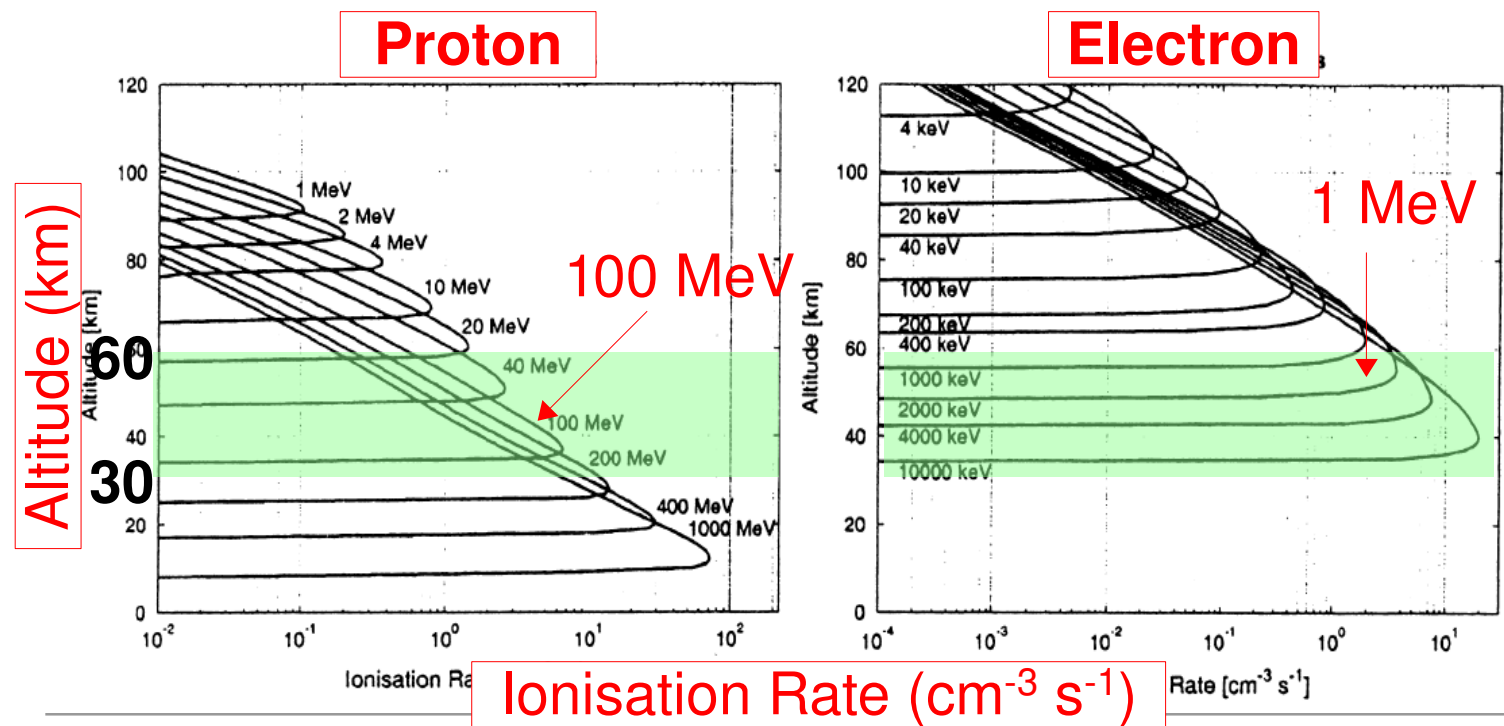


A corresponds to the duration of CPBF, and **B** does to the significance (σ) which will be **more than 9σ** !



Cartoon above from Tanimori's presentation.

3c. Polar Atmospheric Science



Energetic Particle Precipitations and their Impact onto the Polar Atmosphere

Energetic particles, such as **REP** and **Solar Proton Events (SPE)**, are nowadays believed to affect on the **chemical processes** in the polar upper atmosphere (**mesosphere** and **stratosphere**) in terms of creation and transport of **NOx** and **HOx**.

Above all, we **do NOT know** about energetic particles' **rate**, **position**, **time**, **flux**, and **spatial spread** at all.

Figures above: **Effects** of different particle precipitation **in time line** (e.g. continuation) by means of **1D Sodankylä Ion Chemistry (SIC)** simulation [Turunen et al., 2009].

Idea for the contents here from Tanimori's presentation

References:

- Abdo et al., *ApJS*, **188**, 405, 2010
 - Lorentzen et al., *JGR*, **105**, 5381, 2000
 - Schönfelder et al., *A&AS*, **143**, 145, 2000
 - Takada et al., *ApJ*, **733**, 13, 2011
 - Turunen et al., *JA&STP*, **71**, 1176, 2009
 - Weidenspointner et al., *A&A*, **368**, 347, 2001,
- and
- Tanimori, Turunen, and Arvelius, presentation by Prof. Tanimori at *The 15th EISCAT International Workshop* (www.leme.ac.cn/the_15th_eiscat_international_workshop.html).

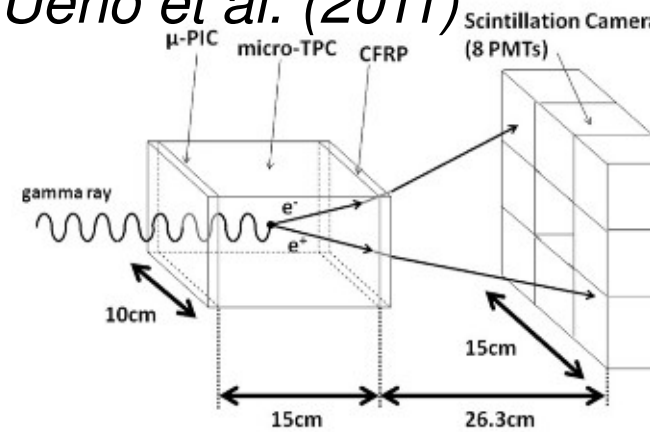
Acknowledgement:

This work (and individually, S. Arvelius) is supported by the planning grant awarded from *VINNOVA/VINNMER Marie Curie international qualification* in Sweden (www.vinnova.se).

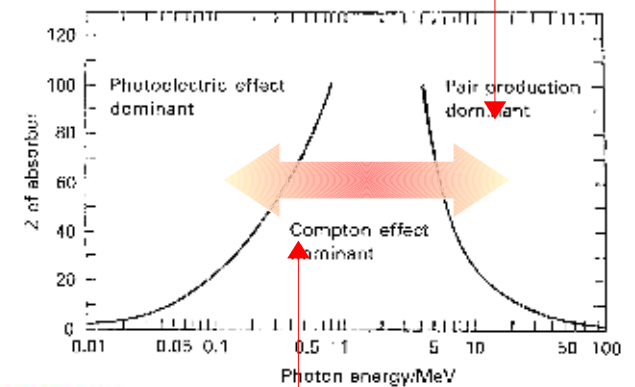
Multiple Applications of ETCC

- EXTRA -

Ueno et al. (2011)

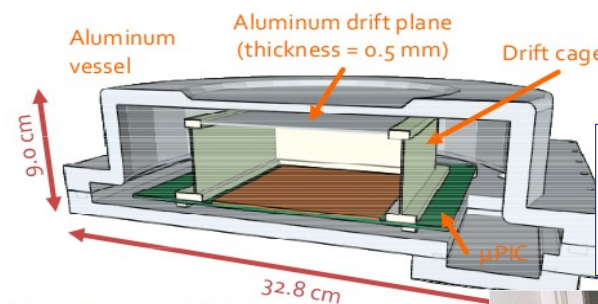
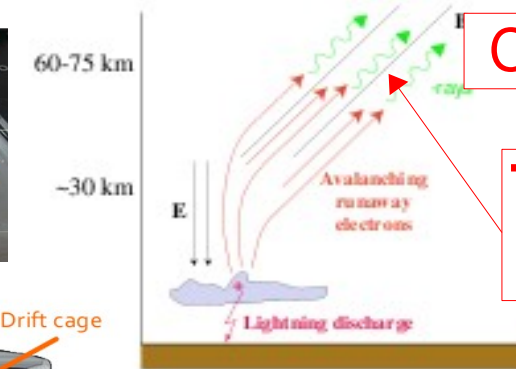
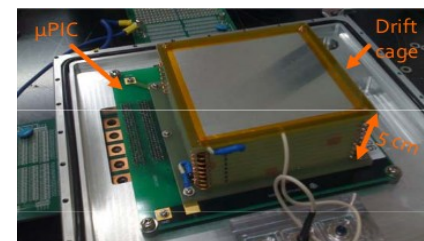


Pair Creation



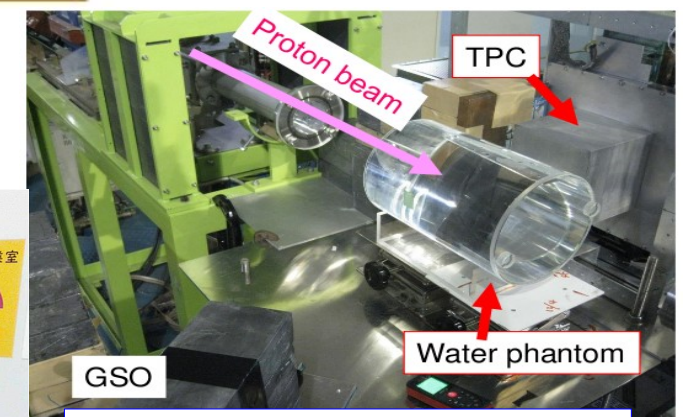
Compton Effect

Terrestrial Gamma-ray Flash, TGF

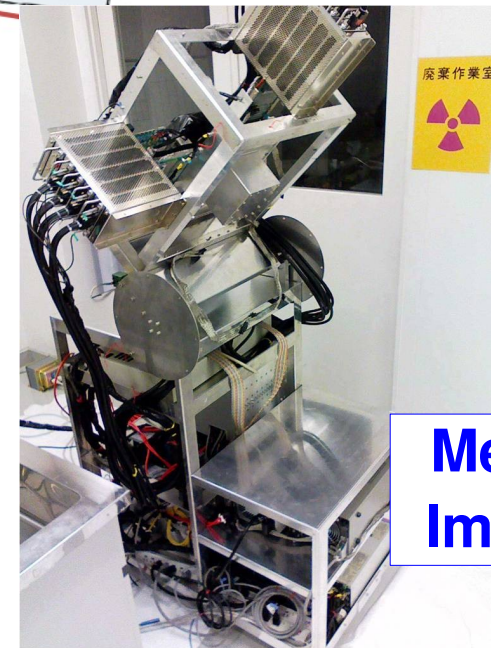


Neutron Imaging

TPC measures 3D track of proton-triton pair.



Radiation (Proton) Therapy



Medical Imaging