



Aurora on Mars

Plasma Acceleration above Martian Magnetic Anomalies

R. Lundin¹, D. Winningham², S. Barabash¹, R. Frahm², M. Holmström¹, J.-A. Sauvaud³, A. Fedorov³, K. Asamura⁴, A. J. Coates⁵, Y. Soobiah⁵, K.C. Hsieh⁶, M. Grande⁷, H. Koskinen^{8*}, E. Kallio⁸, J. Kozyra⁹, J. Woch¹⁰, M. Fraenz¹⁰, D. Brain¹¹, J. Luhmann¹¹, S. McKenna-Lawler¹², R. S. Orsini¹³, P. Brandt¹⁴, P. Wurz¹⁵

1 Swedish Institute of Space Physics, Box 812, S-98 128, Kiruna, Sweden

2 Southwest Research Institute, San Antonio, TX 7228-0510, USA

3 Centre d'Etude Spatiale des Rayonnements, BP-4346, F-31028 Toulouse, France

4 Institute of Space and Astronautical Science, 3-1-1 Yoshinodai, Sagamichara, Japan

5 Mullard Space Science Laboratory, University College London, Surrey RH5 6NT, UK

6 University of Arizona, Tucson, AZ 85721, USA

7 Rutherford Appleton Laboratory, Chilton, Didcot, Oxfordshire OX11 0QX, UK

8 Finnish Meteorological Institute, Box 503 FIN-00101 Helsinki, Finland

9 Space Physics Research Laboratory, University of Michigan, Ann Arbor, MI 48109-2143, USA

10 Max-Planck-Institut für Sonnensystemforschung, D-37191 Katlenburg-Lindau, Germany

11 Space Science Laboratory, University of California in Berkeley, Berkeley, CA 94720-7450, USA

12 Space Technology Ltd., National University of Ireland, Maynooth, Co. Kildare, Ireland

13 Istituto di Fisica dello Spazio Interplanetari, I-00133 Rome, Italy

14 Applied Physics Laboratory, Johns Hopkins University, Laurel, MD 20723-6099, USA

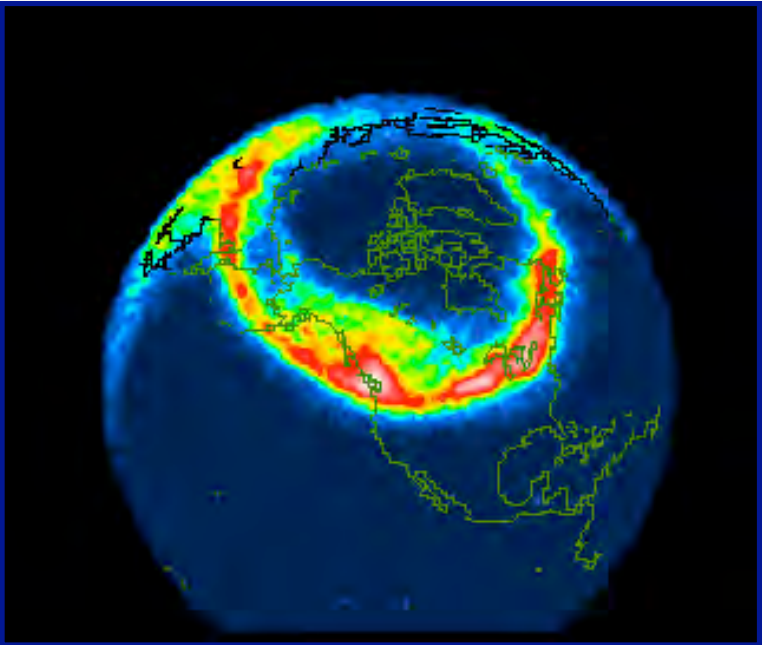
15 University of Bern, Physikalisches Institut, CH-3012 Bern Switzerland



Aurora on Mars

- Aurorae: Caused by accelerated charged particles precipitating along magnetic field lines into a planetary atmosphere - the auroral brightness is roughly proportional to the precipitating particle energy flux.
- The Analyzer of Space Plasma and Energetic Atoms (ASPERA-3) experiment on the Mars Express spacecraft has made a detailed study of acceleration processes on the nightside of Mars.
- We observe accelerated electrons and ions in the deep nightside high altitude region of Mars that map geographically to interface/cleft regions associated with Martian crustal magnetization regions.

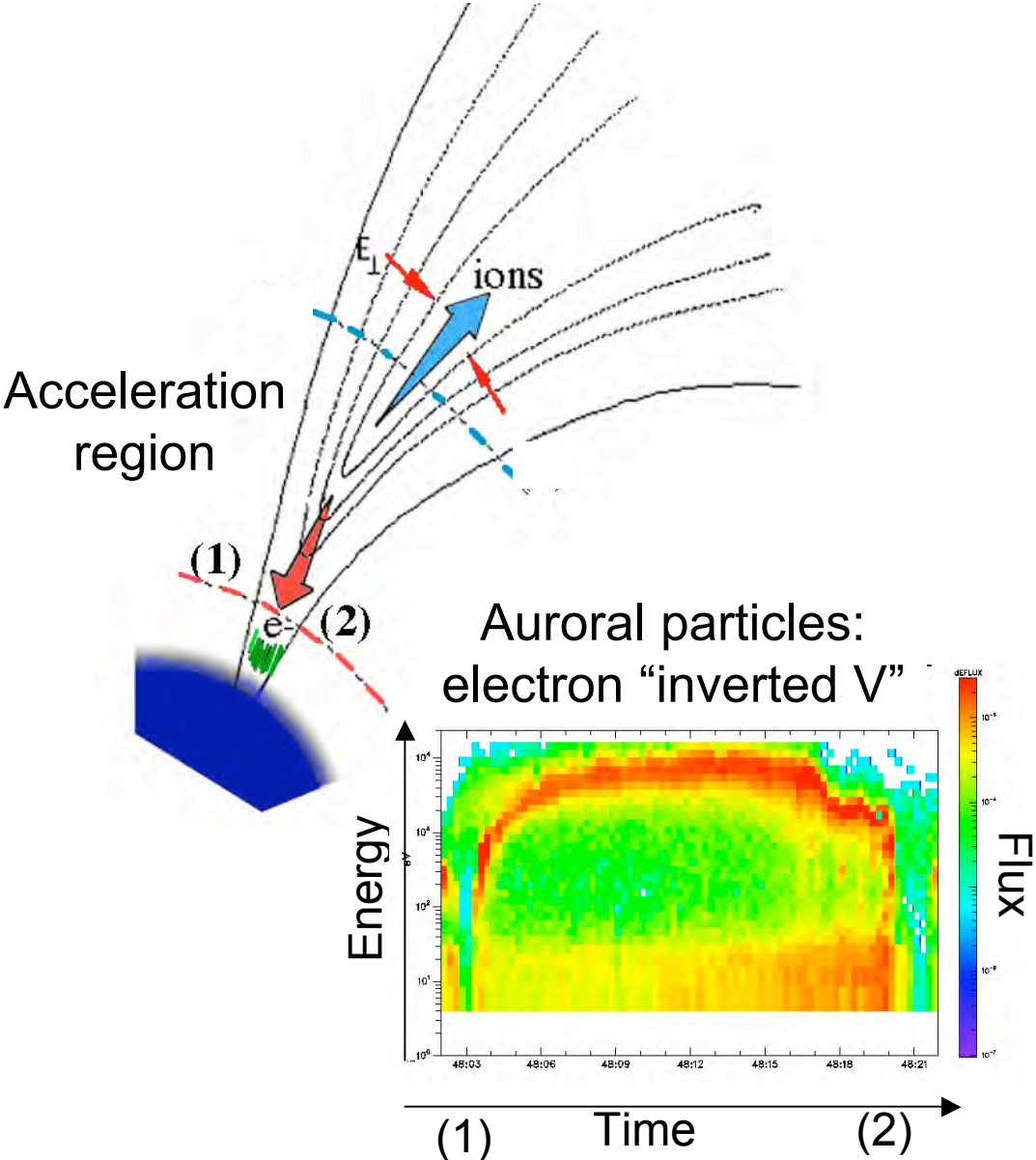
Aurora over the Earth produced by energetic electrons



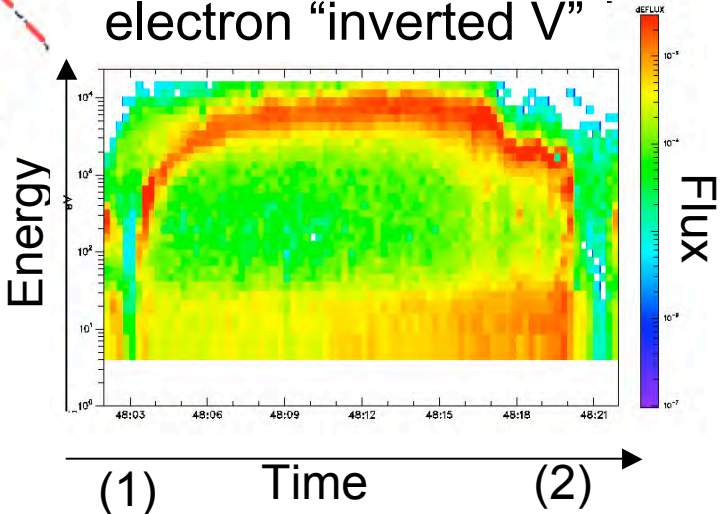
Aurora imaged by the NASA/Polar satellite
(VIS camera, U of Iowa, USA)



Aurora over Kiruna (photo M. Yamauchi, 2005)

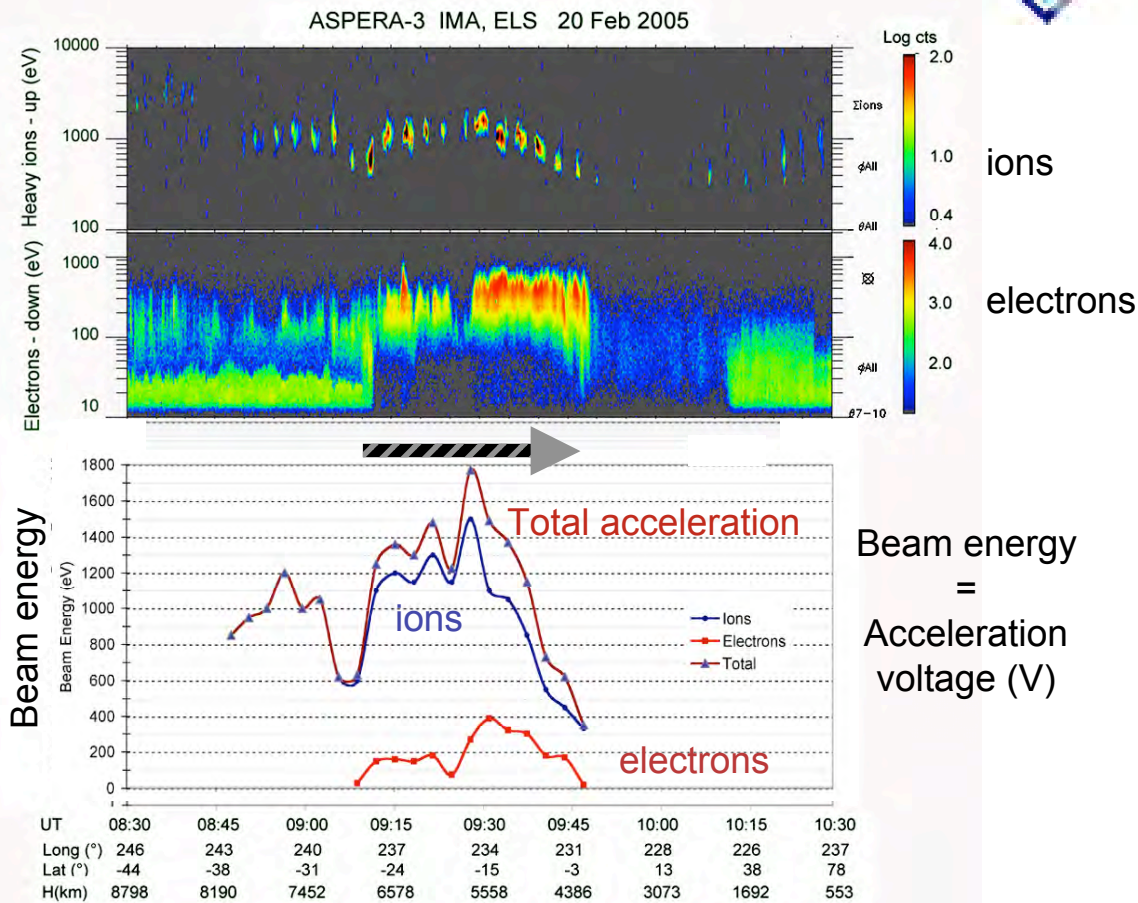
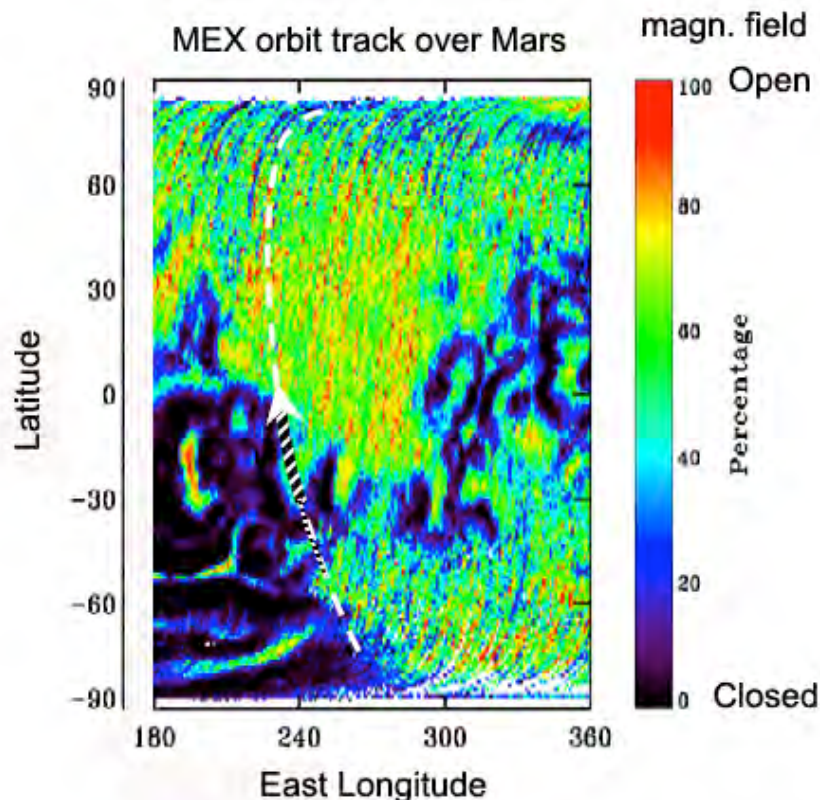


Auroral particles:
electron "inverted V"





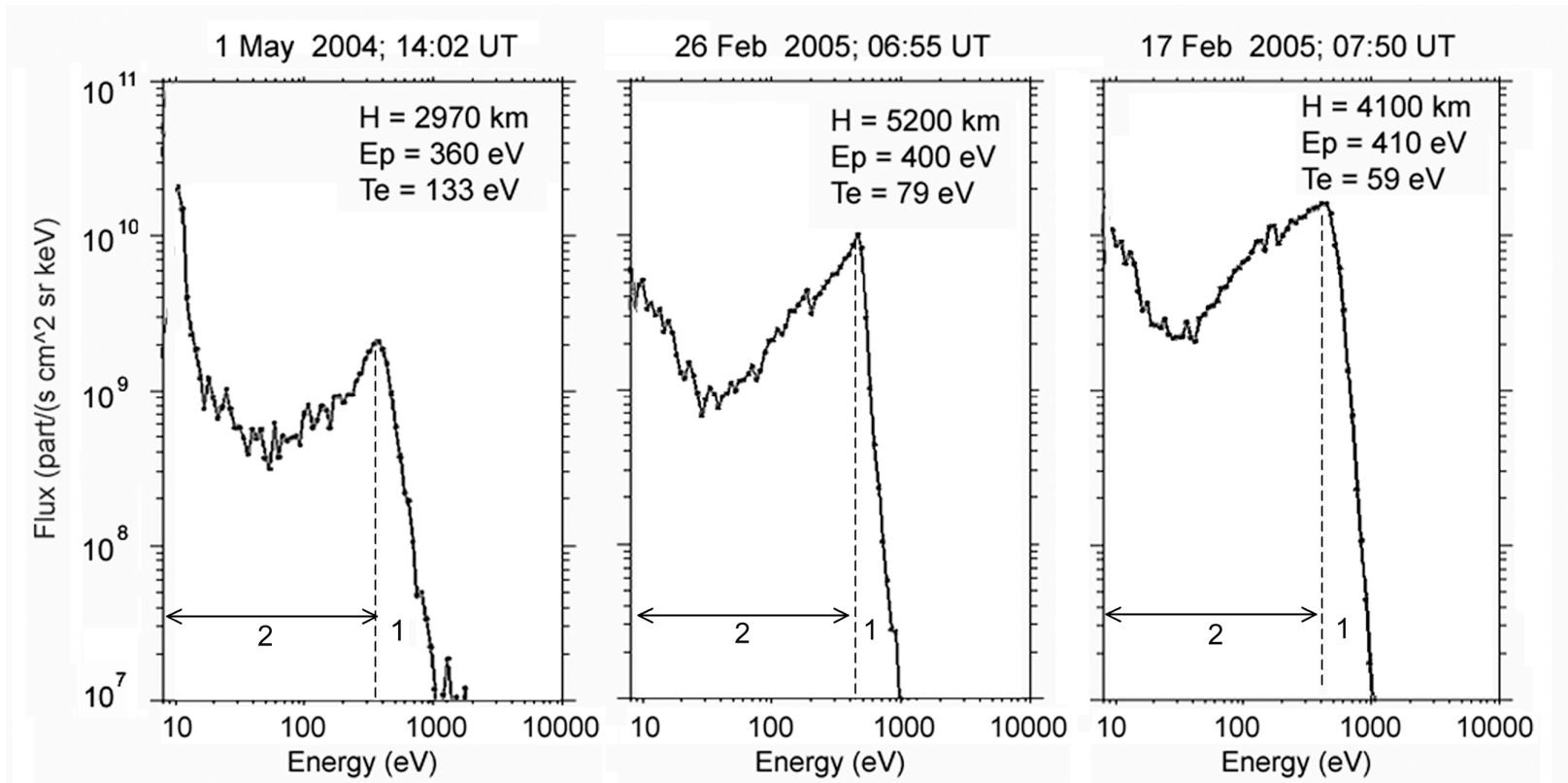
Energized electrons precipitating into the midnight atmosphere of Mars



- (Left) : Orbit track of spacecraft in latitude and east longitude coordinates showing the traversal of an “inverted V” event (dashed line) adjacent to a crustal magnetic field anomaly (dark region).
- (Right) : Energy-time spectrogram for ions and electrons during an “Inverted V” event in the nightside. Third panel shows acceleration energy (energy peaks).



Energy spectra of electrons with characteristics typical of field-aligned acceleration

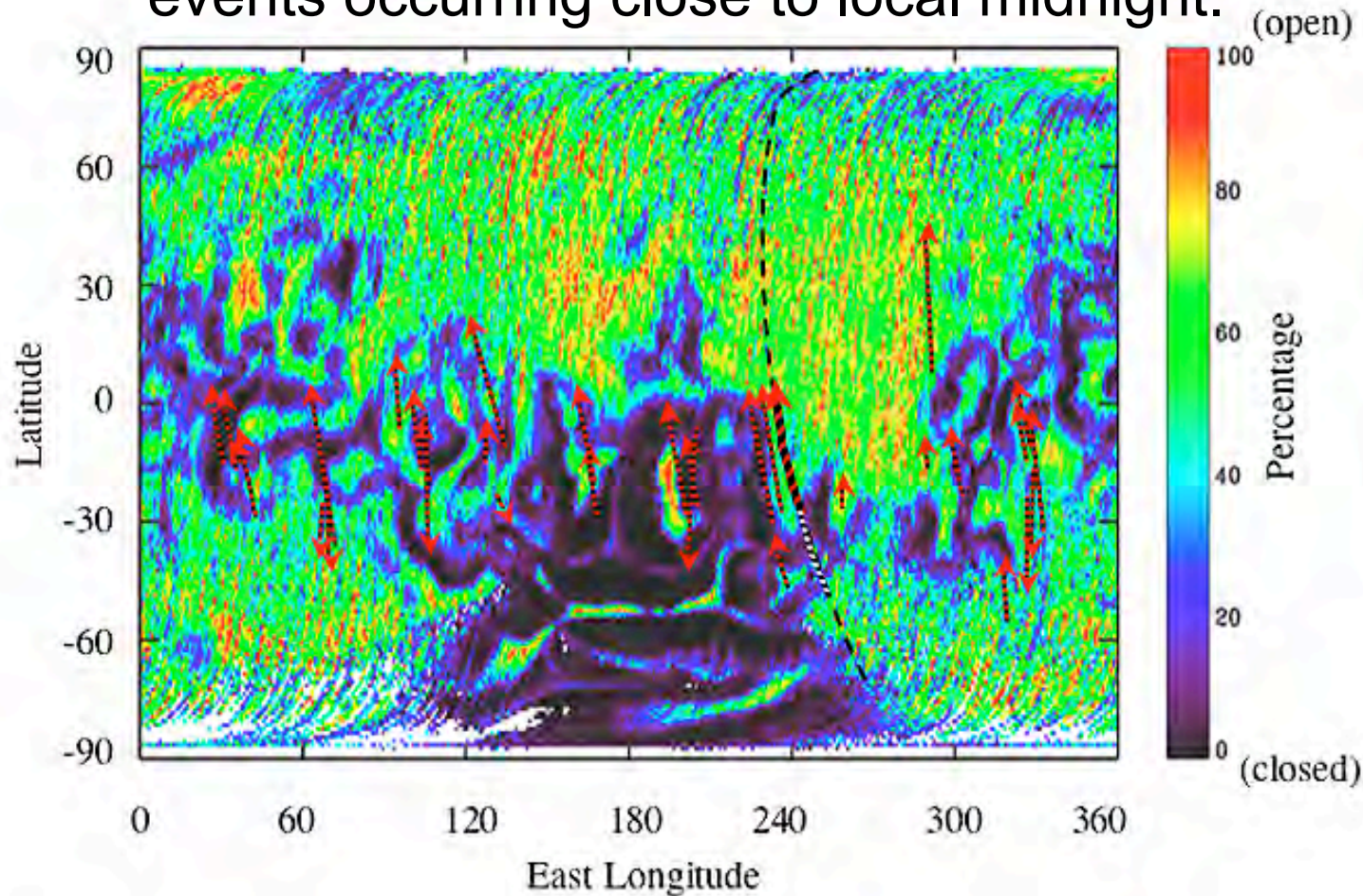


Acceleration through a potential drop eV_0 ($E_p = eV_0$). Energy regimes correspond to accelerated primaries (1), backscattered + secondary electrons (2)

(D. Evans, J. Geophys. Res., 1974)



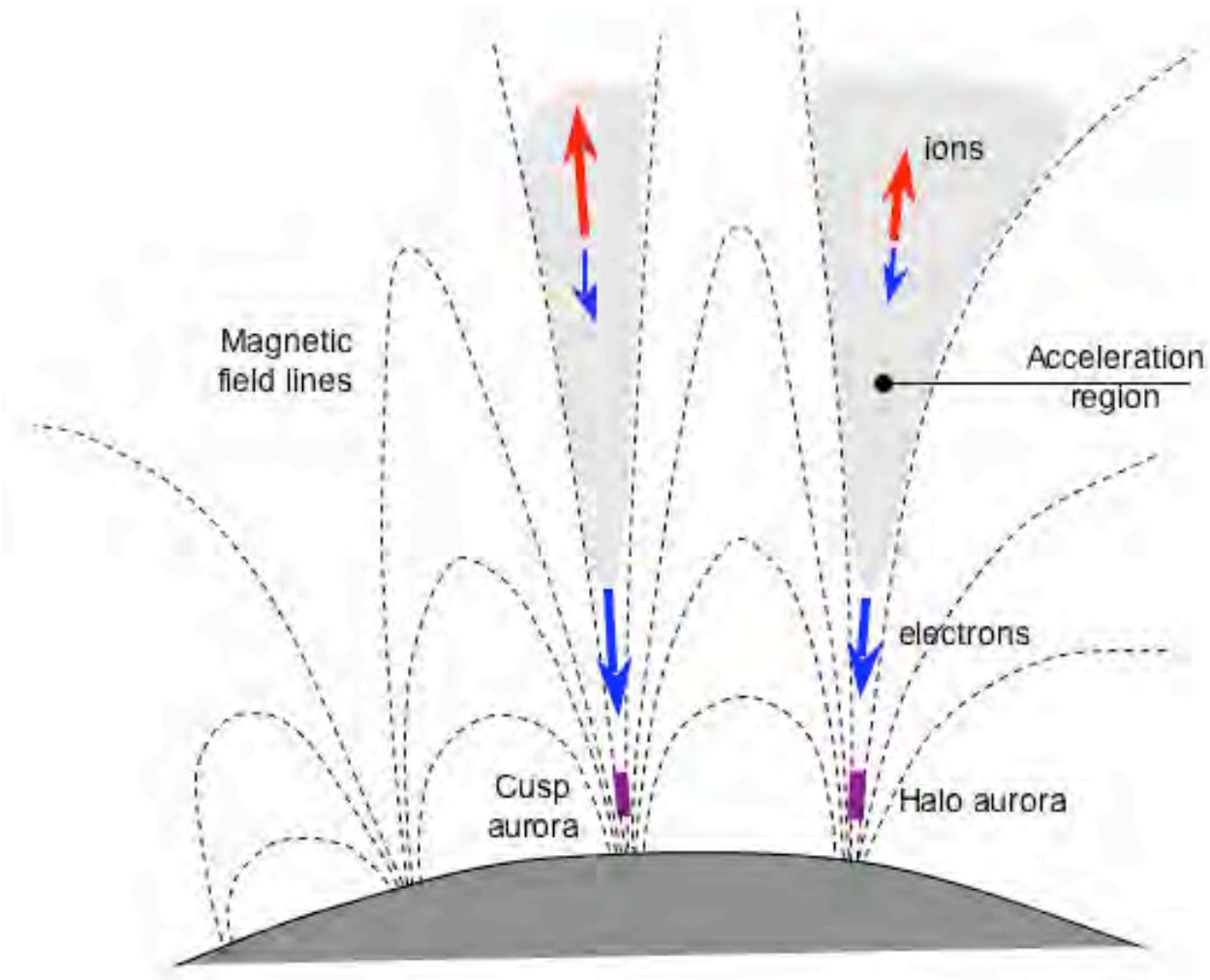
Map of crustal magnetic field at 400 km marking ion and electron acceleration (“inverted V”) events. All events occurring close to local midnight.



The scale indicates the percentage of open magnetic field lines at MGS altitudes, red indicating 100% open and black fully closed magnetic flux tubes. The satellite ground track are indicated by dashed lines, the arrow marking exit of “inverted V”.



Acceleration and guidance of ions and electrons along crustal magnetic field lines at Mars



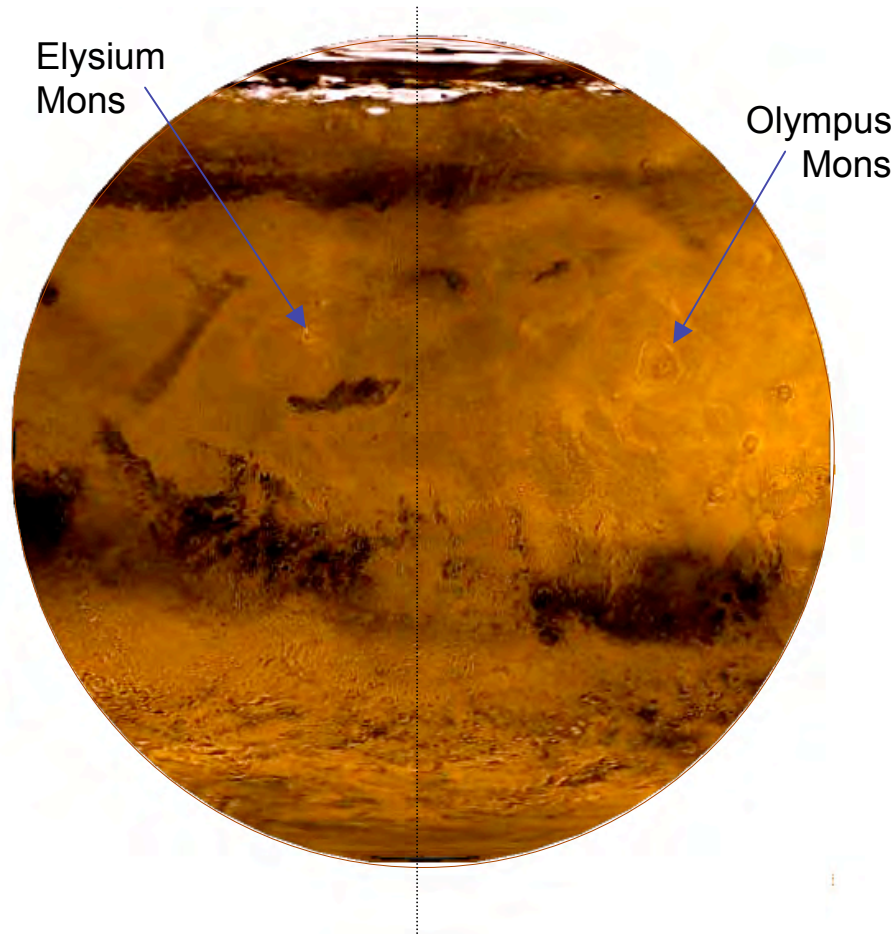
Cusp/cleft aurora is expected to occur between adjacent anomalies and halo aurora circumscribing the large-scale region of crustal magnetization.



Daytime and nighttime - map of Mars

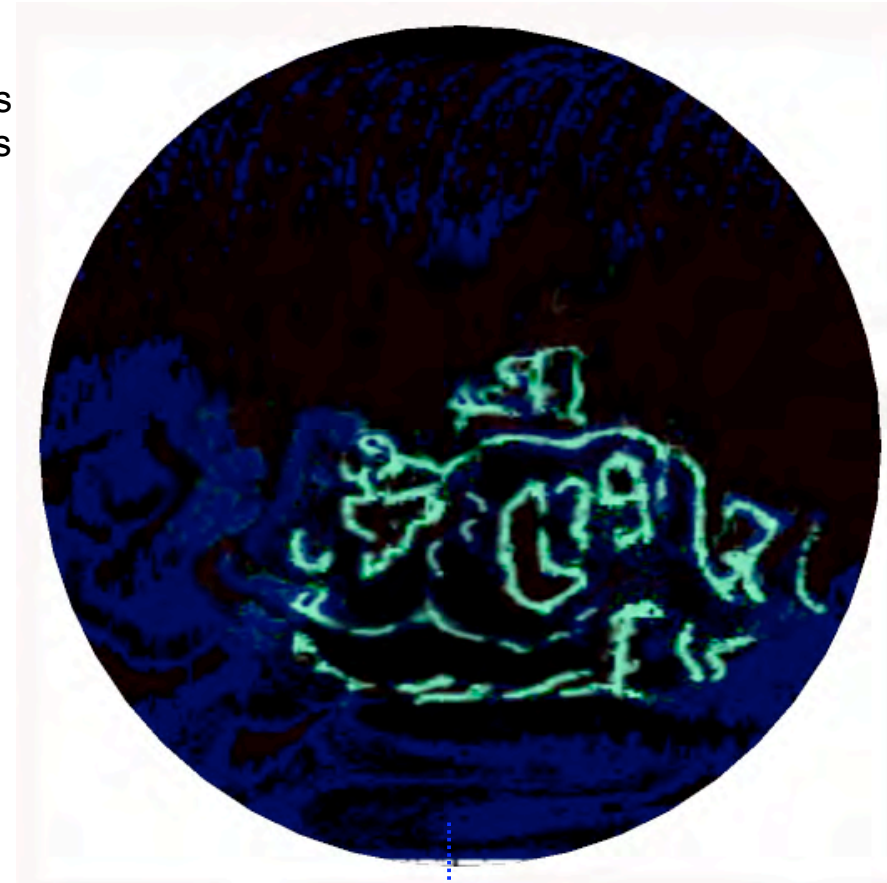


Noon: No aurora



180° East longitude

Midnight: Aurora inferred from crustal magnetizations and electron precipitation



180° East longitude



Conclusions

Auroral particle acceleration over Mars

- Upward accelerated ions and downward accelerated electrons are observed near local midnight, on flux tubes connecting to strong crustal magnetizations. Strong similarities with auroral plasma acceleration near the Earth
 - ⇒ Discrete aurorae likely in boundaries interfacing crustal magnetization regions at Mars.
- Aurora on Mars should form complex patterns over the nightside southern hemisphere, near the equator (compare with polar aurora over the Earth).
 - ⇒ Aurora on Mars cannot be observed from the Earth (like polar aurora on e.g. Jupiter and Saturn)