Institut für theoretische Physik

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Electrodynamics of the Martian Dynamo Region

The M^4 Approach

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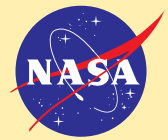

March 31, 2014

MUAN Workshop, Köln, Germany

Outline

Introduction

Mars' Multifluid MHD Model

Results for Magnetic Cusp and Arcades

Conclusions

Mars' Dynamo Region (I)

- Definition: A **dynamo current** is generated by differential motions of positive and negative species.
- Mars' case:
  - ↳ positive ions → governed by collision with atmospheric wind-driven neutral particles (demagnetized)
  - ↳ electrons → governed by gyromotion (magnetized)

Demagnetized ions Demagnetized electrons	⇒ No differential current

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Demagnetized ions Magnetized electrons	⇒ Ionospheric current
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Mars' Dynamo Region (II)

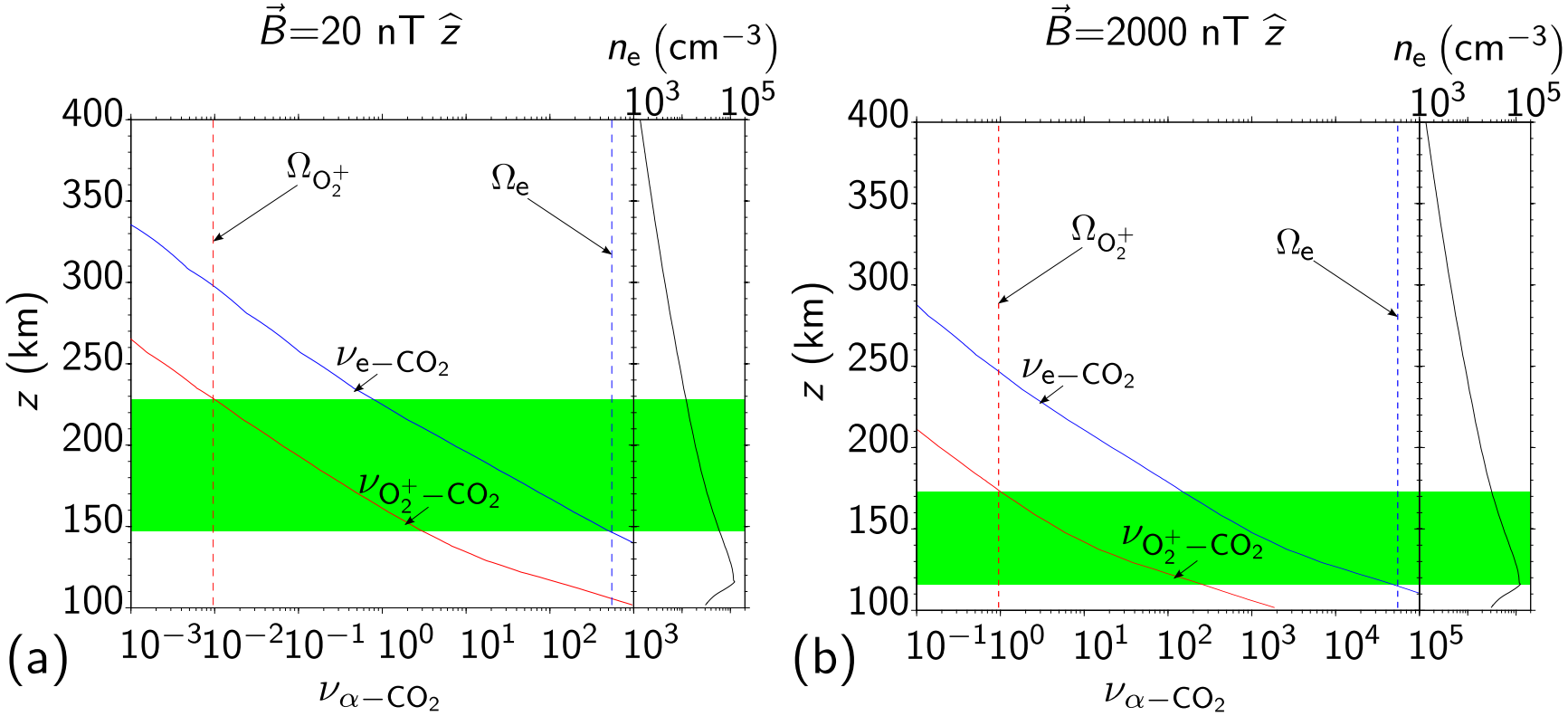


Figure : Expected locations of nighttime ionospheric currents (a) $\vec{B}$=20 nT $\hat{z}$ (typical); (b) $\vec{B}$=2000 nT $\hat{z}$ (near n_e peak).

Objectives of the Study

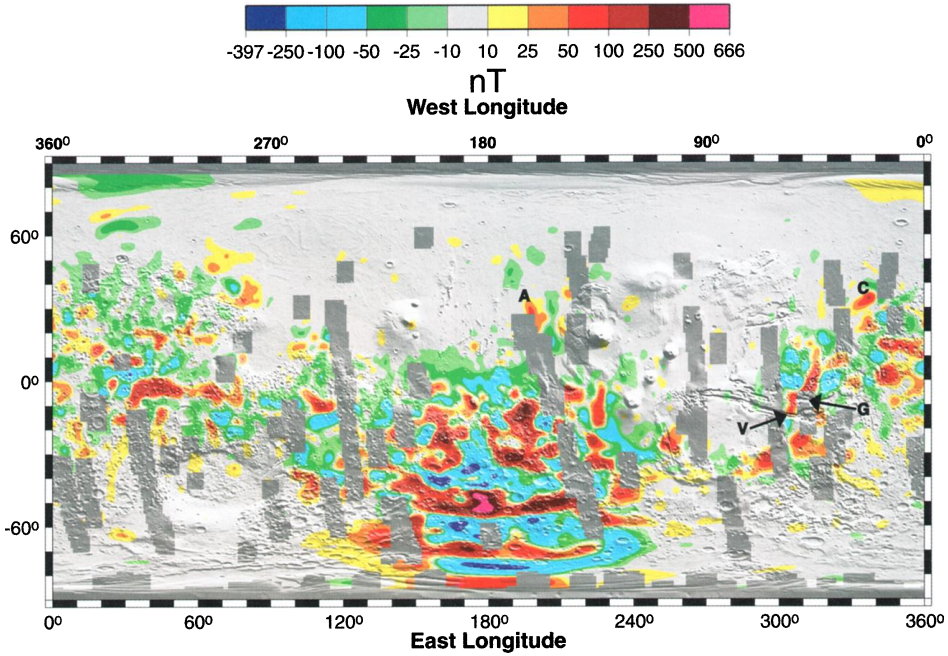


Figure : Radial magnetic field (B_r) computed at 200 km altitude in color, overlain on gray-shaded topographic gradient map of Mars (MOLA data). The dark grey bands show regions of inadequate data coverage [Purucker et al., 2000, Plate 1].

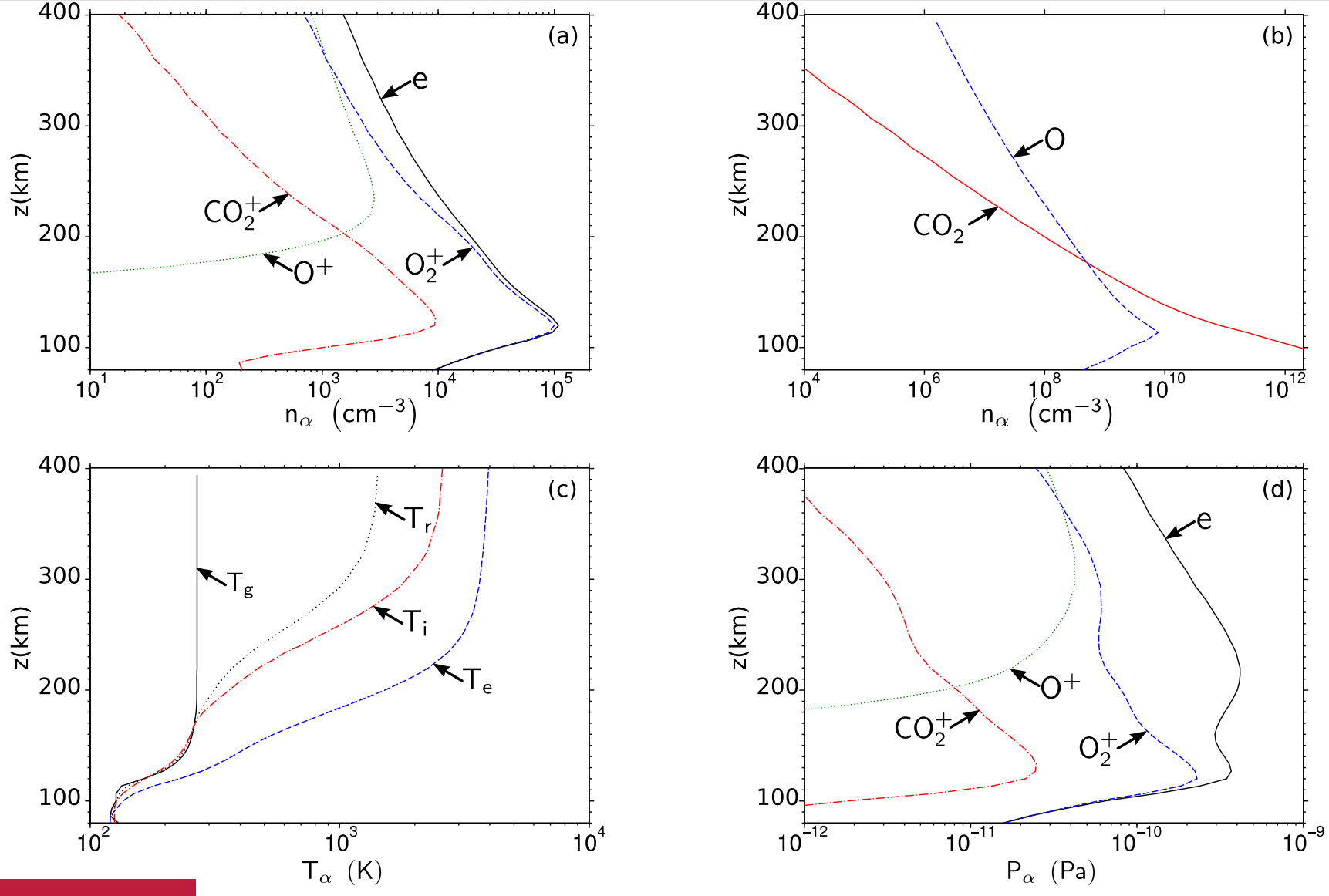
The M^4 approach [Riousset et al., 2013]:

- **M**ars (CO_2, & O)
- **M**ultifluid (O_2^+, CO_2^+, O^+, & e)
- **M**agnetoHydroDynamic (MHD)
- **M**odel

Two case studies [Riousset et al., 2014]:

- Cusp: case of the isolated buried magnetic dipole
- Arcades: striped magnetic topology

Initial Conditions

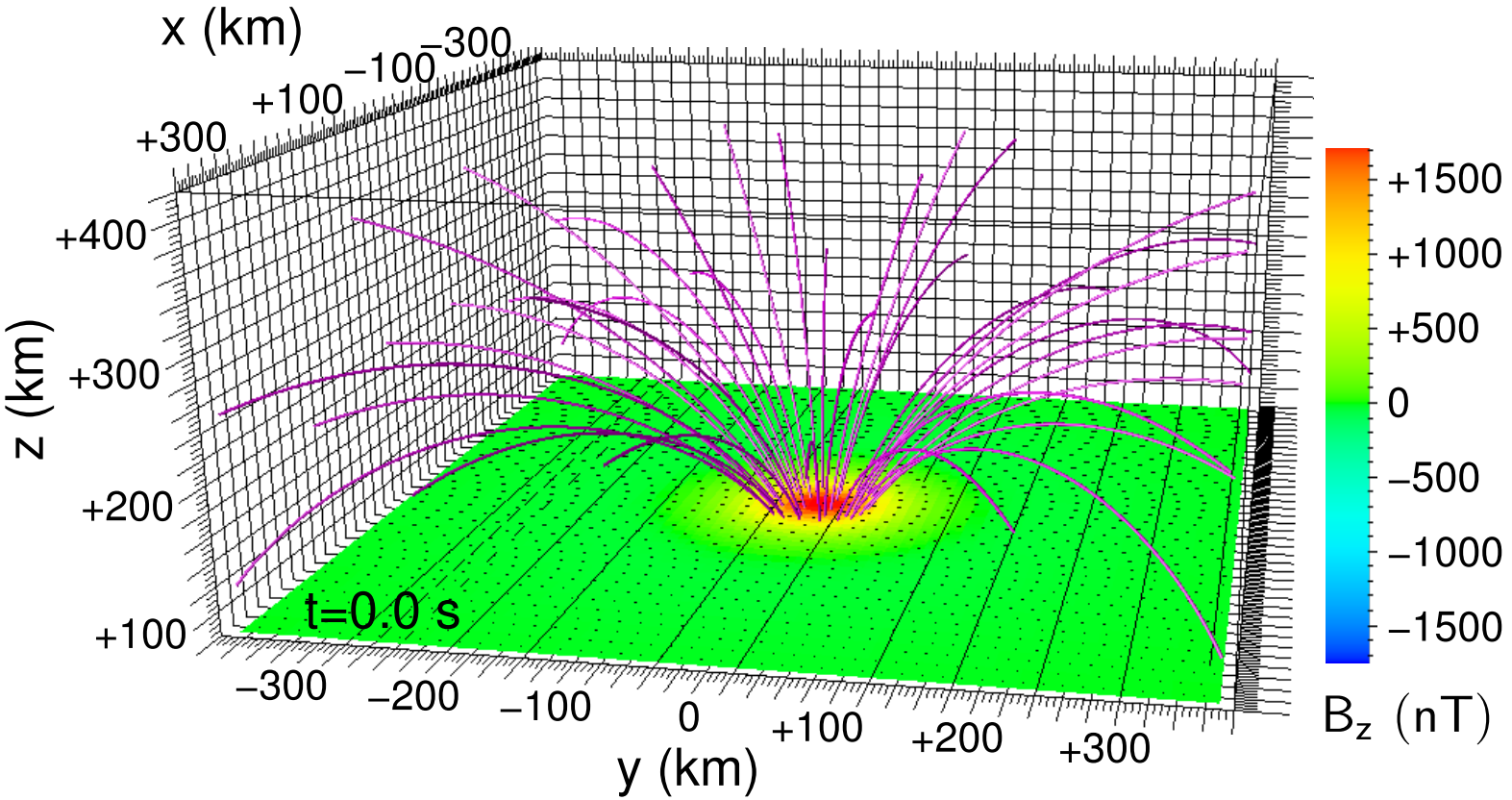


Multifluid Model Formulation

Based on Paty and Winglee [2006] for Ganymede published in [Riousset et al., 2013]

- Conservation of matter (O_2^+, CO_2^+, & O^+)
- Plasma approximation (e)
- Equation of state (O_2^+, CO_2^+, O^+, & e)
- Conservation of momentum (O_2^+, CO_2^+, & O^+)
- Plasma current definition (e)
- Maxwell–Faraday equation ($\vec{B}$)
- Maxwell–Ampère equation ($\vec{J}$)
- Generalized Ohm's law ($\vec{E}$)

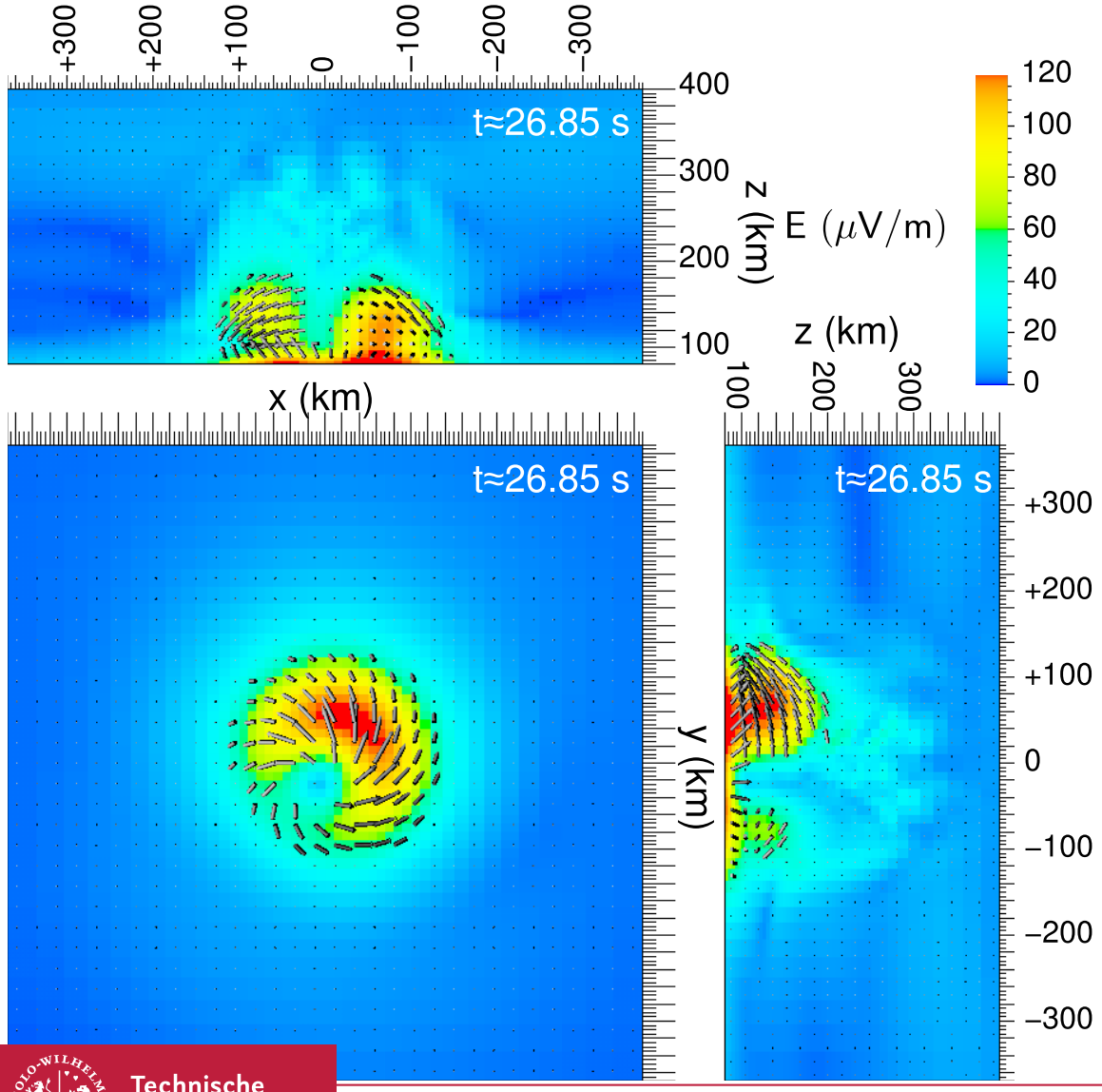
Magnetic Field



- Isolated dipole
- Vertical, upward, buried at –20 km
- Magnetic moment: $\vec{\mu}$=10^{16} A·m^2 $\hat{z}$

- Analog to cusp (e.g., at (15°N;15°E) and (10°S;110°E))
- Building block for complex structure (loop, arcades)

Electric Field



Generalized Ohm's law:

$$\vec{E} = \vec{E}_1 + \vec{E}_2 + \vec{E}_3 + \vec{E}_4$$

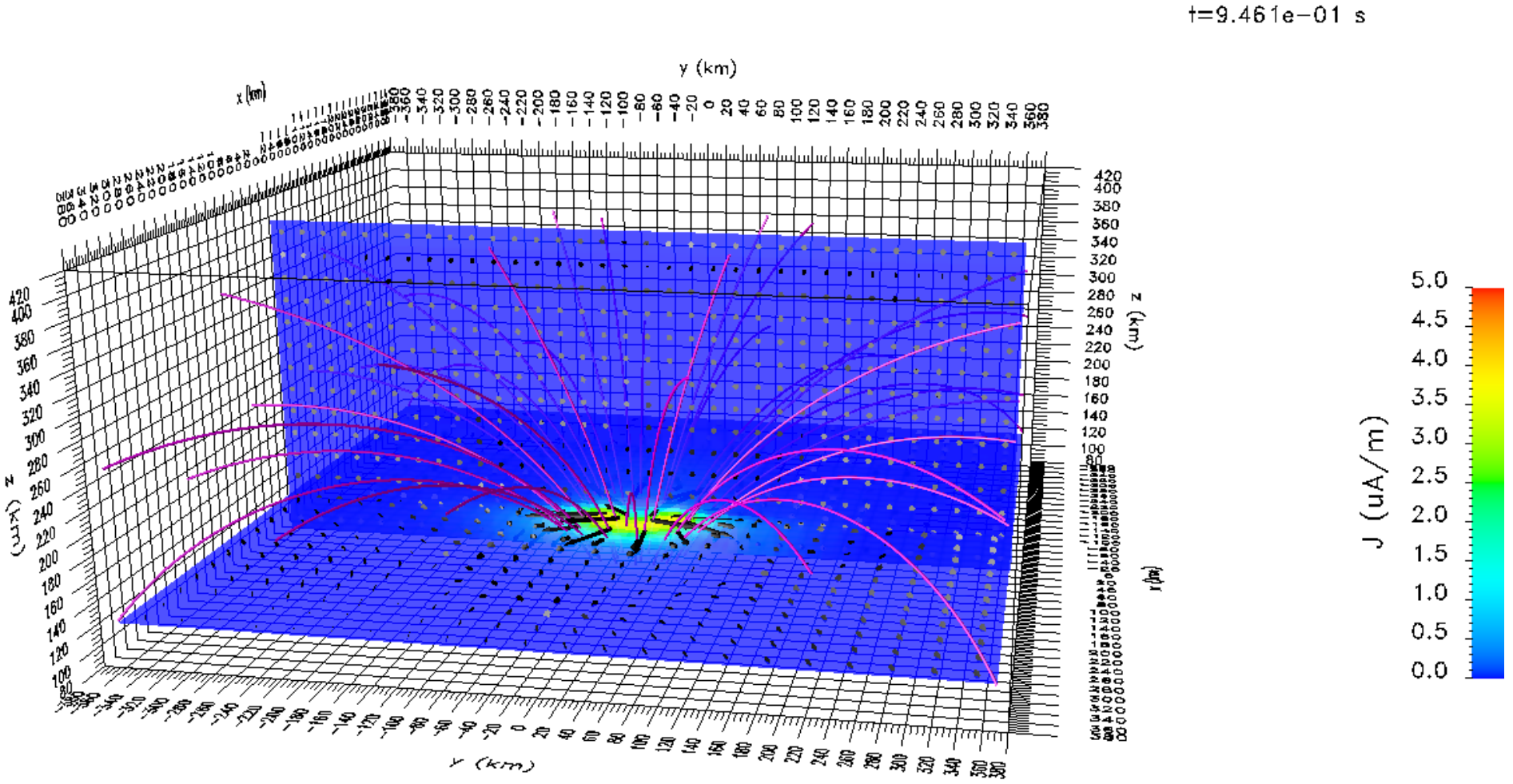
$$\vec{E}_1 = \frac{\vec{J} \times \vec{B}}{e n_e}$$

$$\vec{E}_2 = -\sum_i \frac{n_i \vec{V}_i \times \vec{B}}{n_e}$$

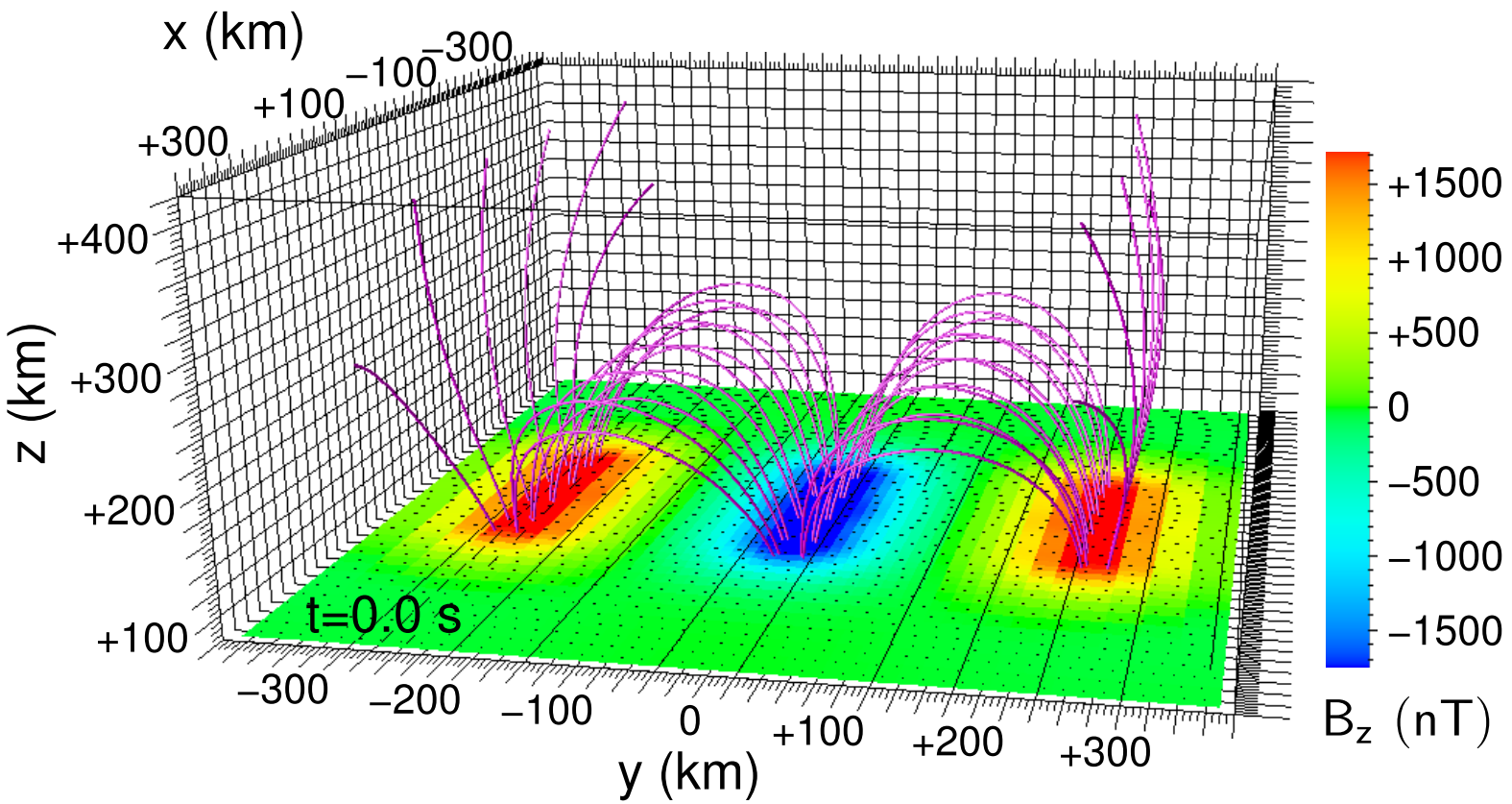
$$\vec{E}_3 = -\frac{\vec{\nabla} P_e}{e n_e}$$

$$\vec{E}_4 = \frac{m_e}{e} \sum_{t=i,n} \nu_{te} \left(\vec{V}_t - \vec{V}_e \right)$$

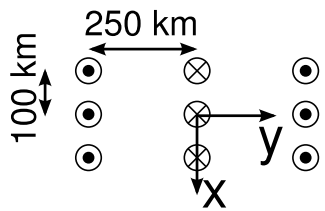
Dynamo Current



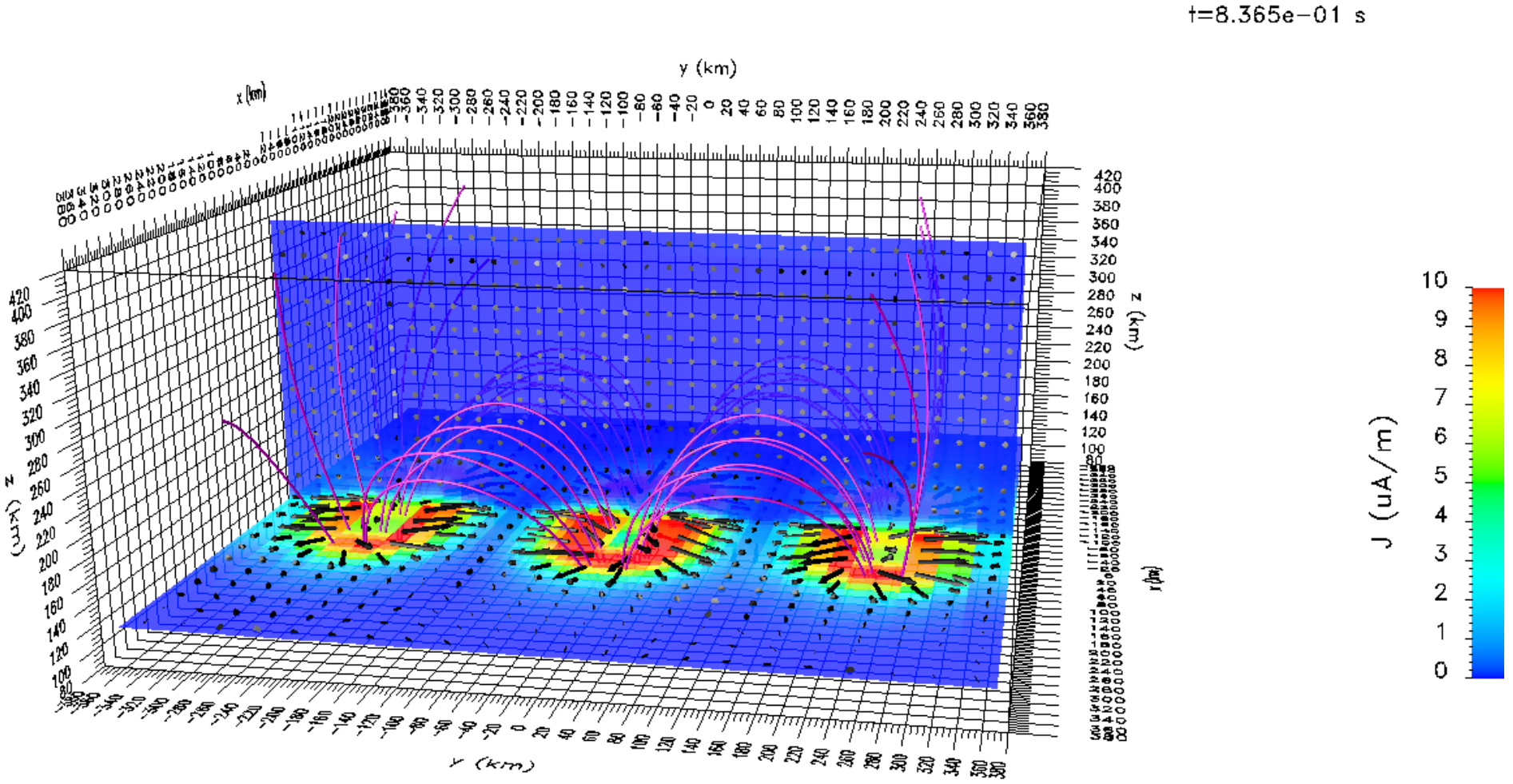
Magnetic Field



- 9 dipoles
- Vertical, upward and downward, buried at –20 km
- Magnetic moment: $\vec{\mu}=\pm 10^{16}$ A·m^2 $\hat{z}$



Dynamo Current



Principal Contributions

The principal results and contributions following from this work can be summarized as follows:

1. The dynamo current forms in a torus shape around the base of an isolated magnetic cusp due to the $\vec{E}\times\vec{B}$-drift of electrons;
2. The asymmetry in the horizontal component of the electric field is explained by the dependence of $\vec{E}$ on the collision-driven ion dynamics;
3. The organized pattern of the dynamo current produced by a striped magnetic field topology can be straightforwardly explained using the results from isolated vertically oriented, upward and downward magnetic dipoles, and the principle of superposition;
4. Strongly magnetized regions of Mars (e.g., Terra Sirenum) are likely to shield the local atmosphere and alter the motion of charged particles from the lower to the upper atmosphere.

Acknowledgments

Thank You For Your Attention
Questions?

This work is available online at:
`http://www.jeremy.riousset.com/`

- J. A. Riousset, C. S. Paty, R. J. Lillis, M. O. Fillingim, S. L. England, P. G. Withers, and J. P. M. Hale. Three-dimensional multifluid modeling of atmospheric electrodynamics in Mars' dynamo region. *J. Geophys. Res.*, 118(6):3647--3659, 2013. doi: 10.1002/jgra.50328
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This work was supported by the National Aeronautics and Space Administration under grant NNX10AM88G-MFRP to the Georgia Institute of Technology.

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