Mercury global fully-kinetic plasma simulations in support to BepiColombo

Federico Lavorenti, Pierre Henri,

Francesco Califano, Johannes Benkhoff

Acknowledgement: Jan Deca, Nicolas André, Sae Aizawa, Simon Lindsay

What are the **motivations** behind this work?

1. **BepiColombo** mission cruising to Mercury (arrival 2025)

2. ***In-situ* data** are nice but **hard to interpret** (need a global 3D dynamical view)

3. First **electron observations** at Mercury

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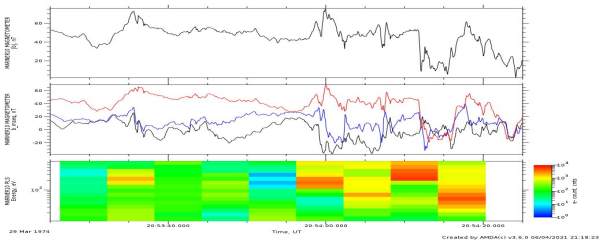

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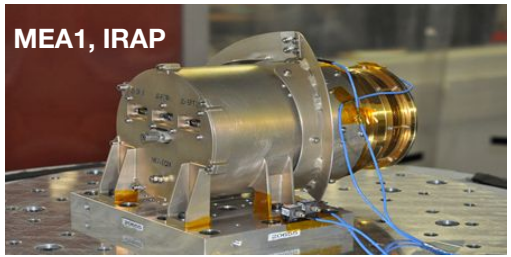
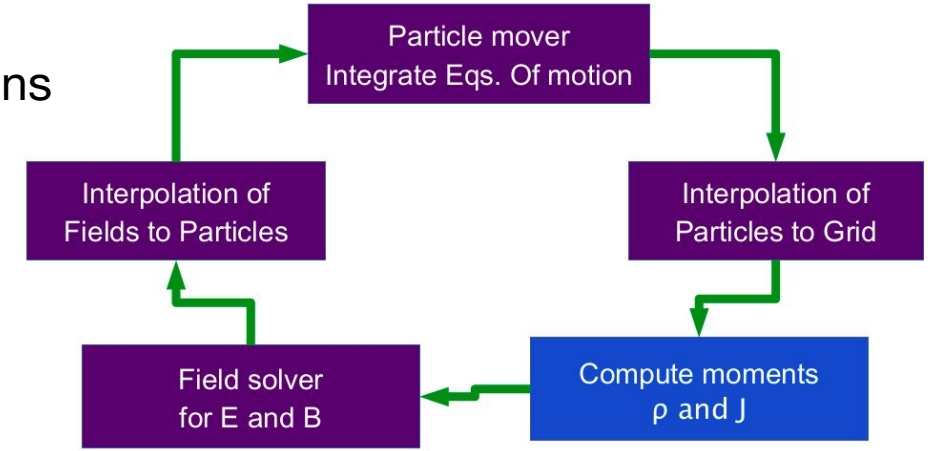
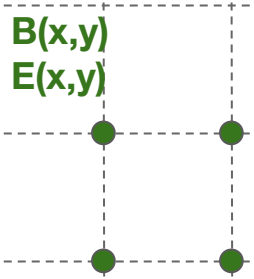


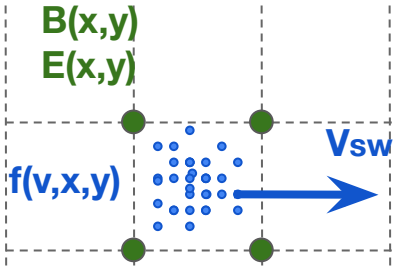
We use the **implicit full-PIC** simulation **code iPIC3D**

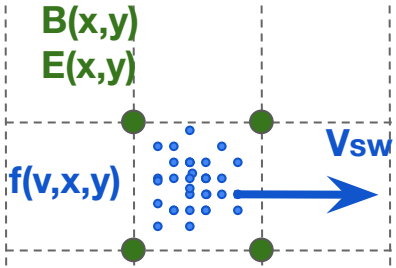
- **particle-in-cell (PIC) algorithm**
  = kinetic physics both ions and electrons
- **semi-implicit integration**
  = reduce computational time
- **highly parallelized MPI**
  = use of large HPC facilities
  (now running @ CEA-TGCC ~ 10 Mc.h./yr)



Lapenta et al. (2006)


B(x,y)
E(x,y)


B(x,y)
E(x,y)
f(v,x,y)
Vsw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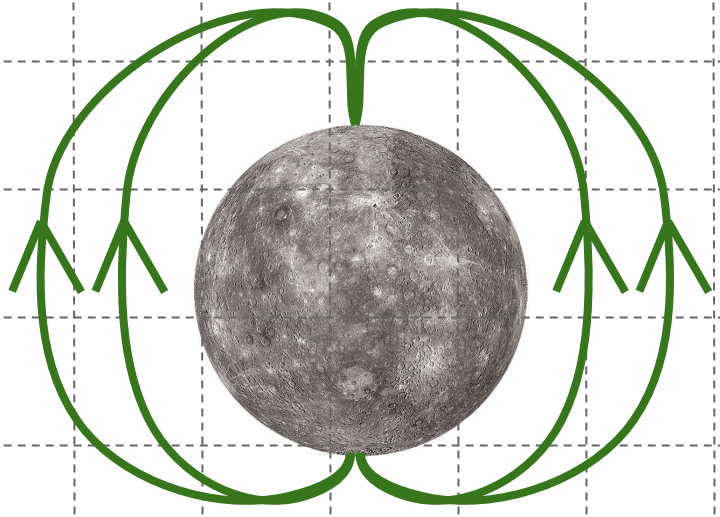

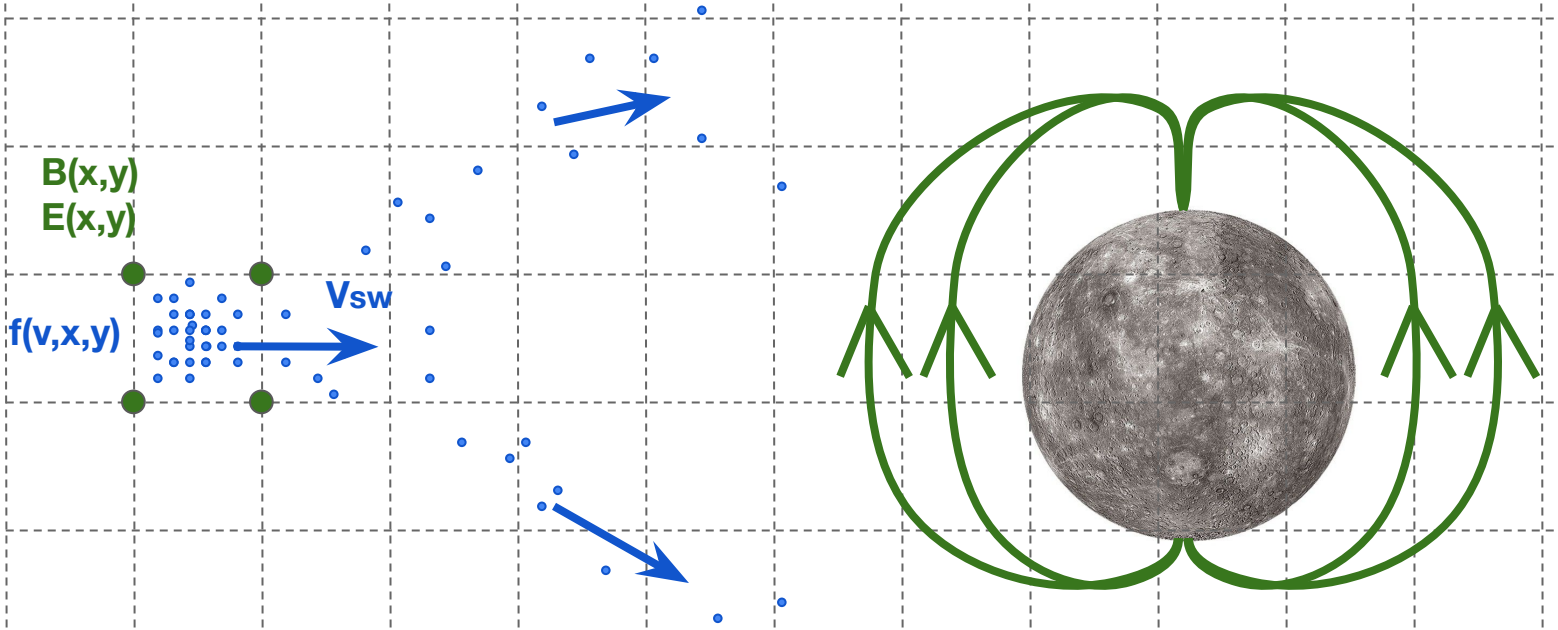
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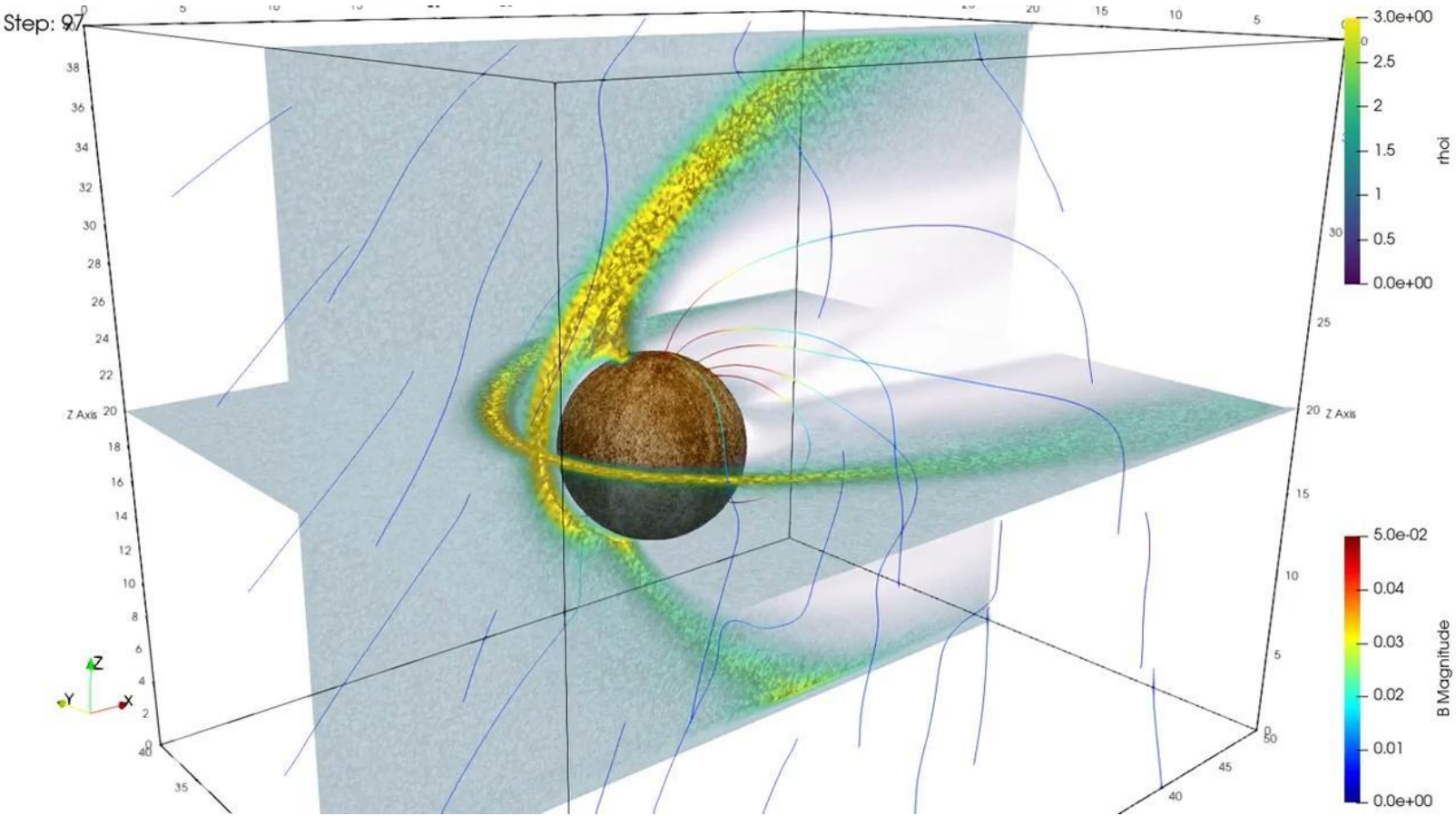
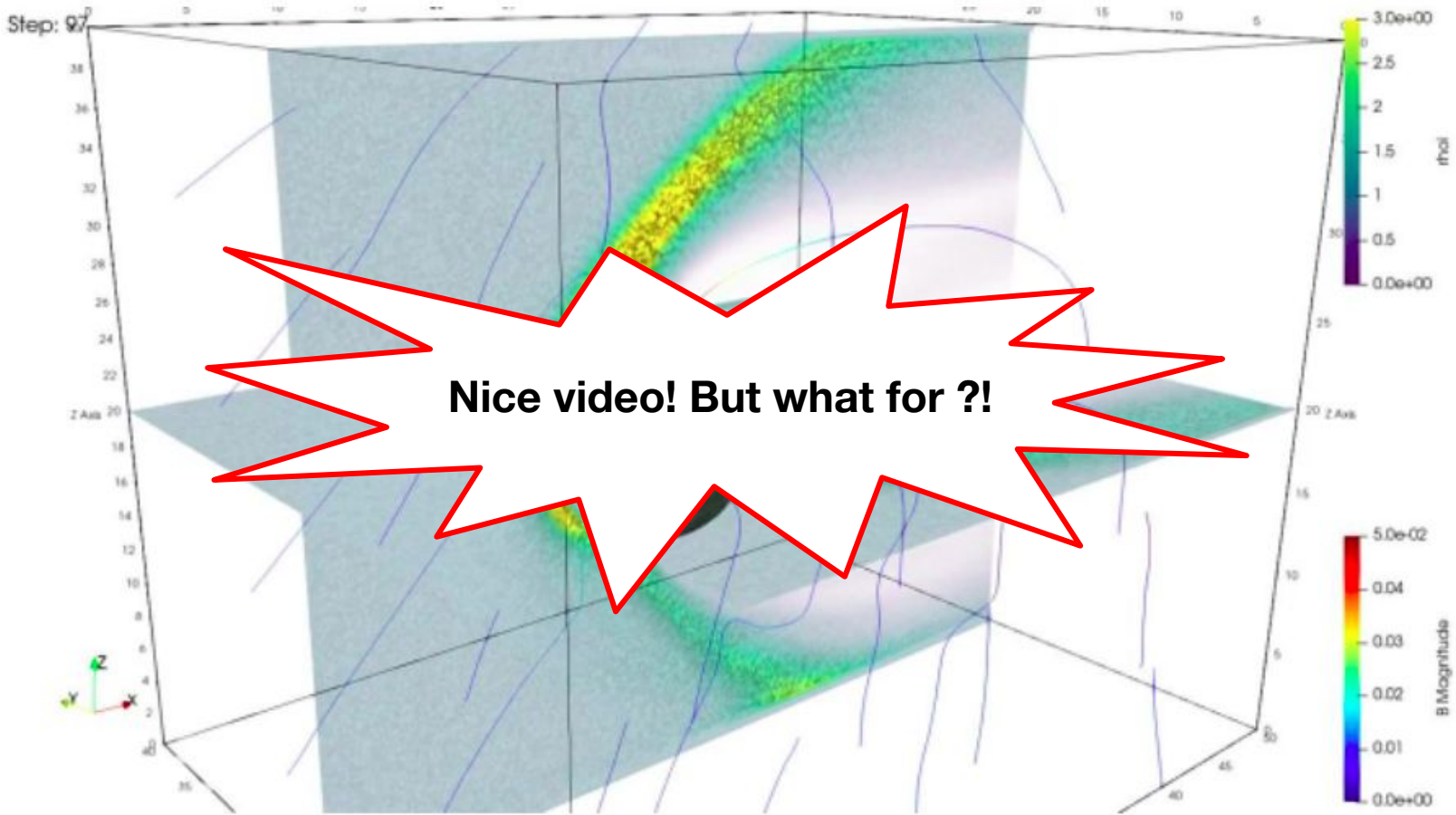
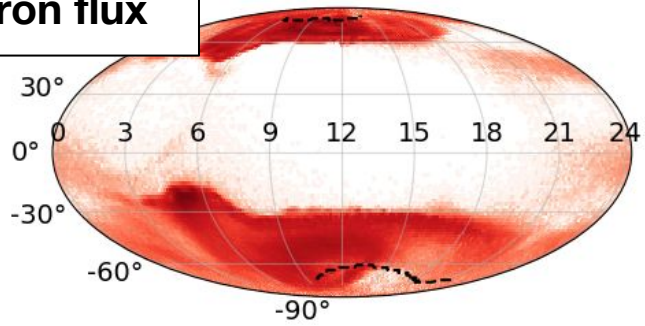
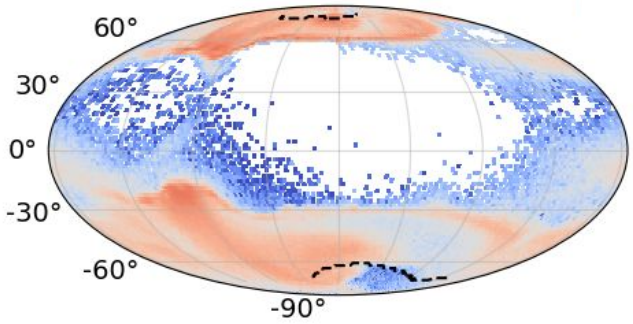

Step: 97
Z Axis
rhoi
3.0e+00
2.5
2
1.5
1
0.5
0.0e+00
B Magnitude
5.0e-02
0.04
0.03
0.02
0.01
0.0e+00
Z
Y
X


Step: 97
Nice video! But what for ?!
rho
B Magnitude
Z Axis

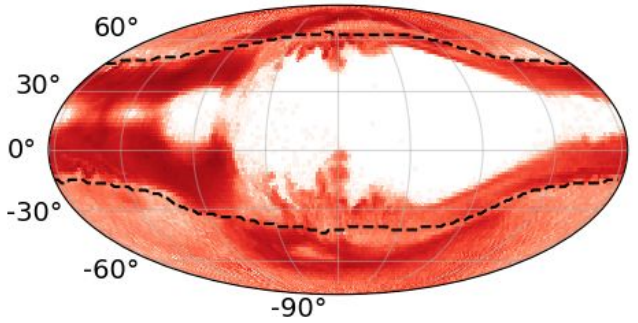
Electron flux

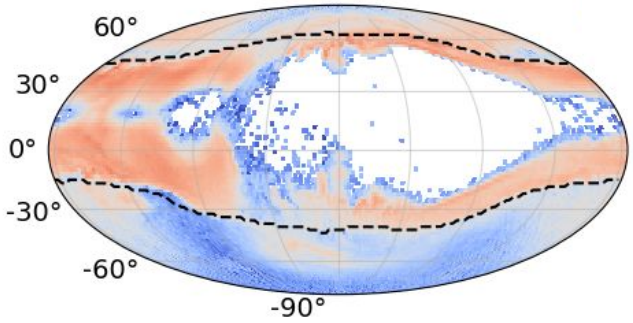
Northward IMF

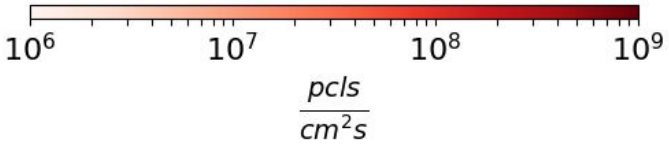


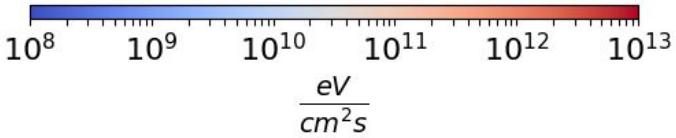


Southward IMF

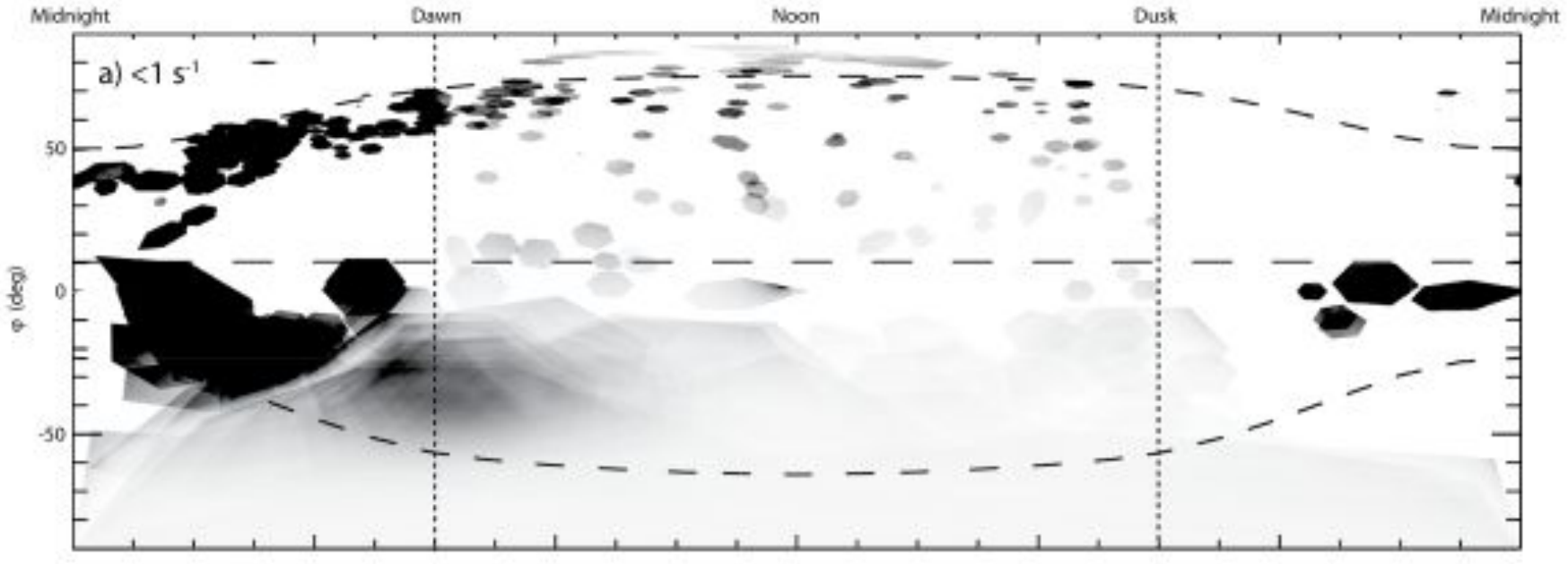








Our simulations explain **X-ray observations** observed by MESSENGER



Lindsay et al. (2022)

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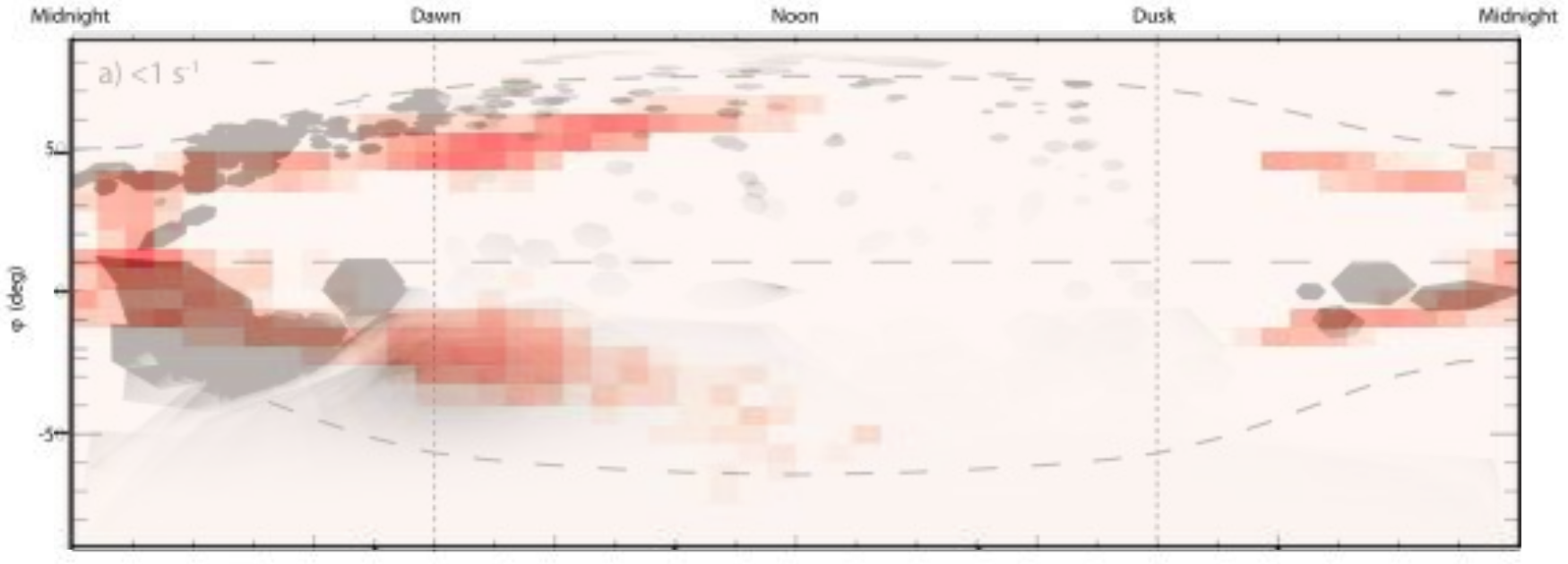

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Conclusions

- **First fully-kinetic** global 3D **simulations** of a “small” planetary magnetosphere

- Model is **representative of Mercury**’s environment
  - validated using mean B-field boundaries

- **First** numerical **evidence of X-ray aurora** at Mercury

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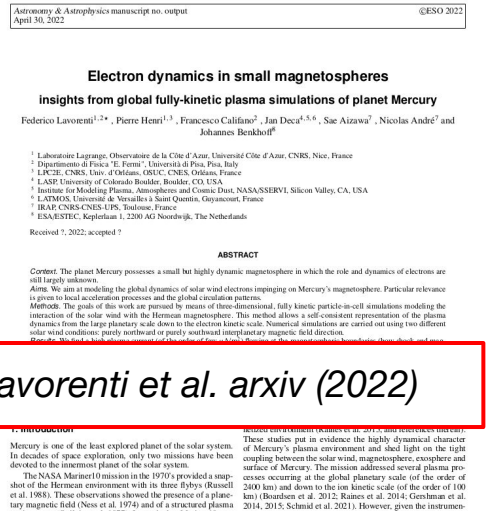

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Electron dynamics in small magnetospheres

insights from global fully-kinetic plasma simulations of planet Mercury

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[2] Dipartimento di Fisica 'E. Fermi', Università di Pisa, Pisa, Italy
[3] LPC2E, CNRS, Univ. d'Orléans, OSUC, CNES, Orléans, France
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[5] Institute for Modeling Plasma, Atmospheres and Cosmic Dust, NASA/SSERVI, Silicon Valley, CA, USA
[6] LATMOS, Université de Versailles à Saint Quentin, Guyancourt, France
[7] IRAP, CNRS-CNES-UPS, Toulouse, France
[8] ESA/ESTEC, Keplerlaan 1, 2200 AG Noordwijk, The Netherlands

Received ?, 2022; accepted ?

ABSTRACT

Context. The planet Mercury possesses a small but highly dynamic magnetosphere in which the role and dynamics of electrons are still largely unknown.
Aims. We aim at modeling the global dynamics of solar wind electrons impinging on Mercury's magnetosphere. Particular relevance is given to local acceleration processes and the global circulation patterns.
Methods. The goals of this work are pursued by means of three-dimensional, fully kinetic particle-in-cell simulations modeling the interaction of the solar wind with the Hermean magnetosphere. This method allows a self-consistent representation of the plasma dynamics from the large planetary scale down to the electron kinetic scale. Numerical simulations are carried out using two different solar wind conditions: purely northward or purely southward interplanetary magnetic field direction.

1. Introduction

Mercury is one of the least explored planet of the solar system. In decades of space exploration, only two missions have been devoted to the innermost planet of the solar system.

The NASA Mariner10 mission in the 1970's provided a snapshot of the Hermean environment with its three flybys (Russell et al. 1988). These observations showed the presence of a planetary magnetic field (Ness et al. 1974) and of a structured plasma

These studies put in evidence the highly dynamical character of Mercury's plasma environment and shed light on the tight coupling between the solar wind, magnetosphere, exosphere and surface of Mercury. The mission addressed several plasma processes occurring at the global planetary scale (of the order of 2400 km) and down to the ion kinetic scale (of the order of 100 km) (Beardsen et al. 2012; Raines et al. 2014; Gershman et al. 2014, 2015; Schmid et al. 2021). However, given the instrumen-

Lavorenti et al. arxiv (2022)

Lavorenti et al. in prep. (2022)

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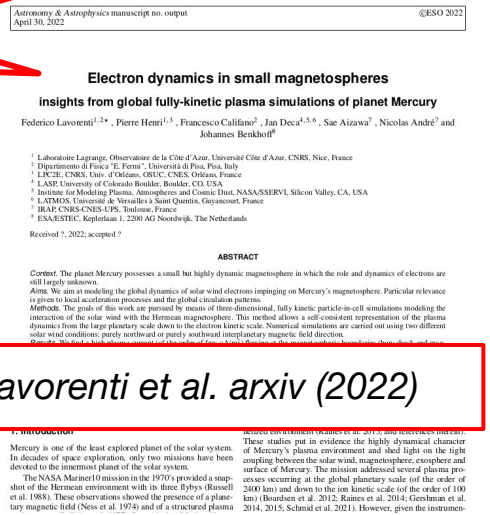

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