EPiGRAM Software for Space Missions

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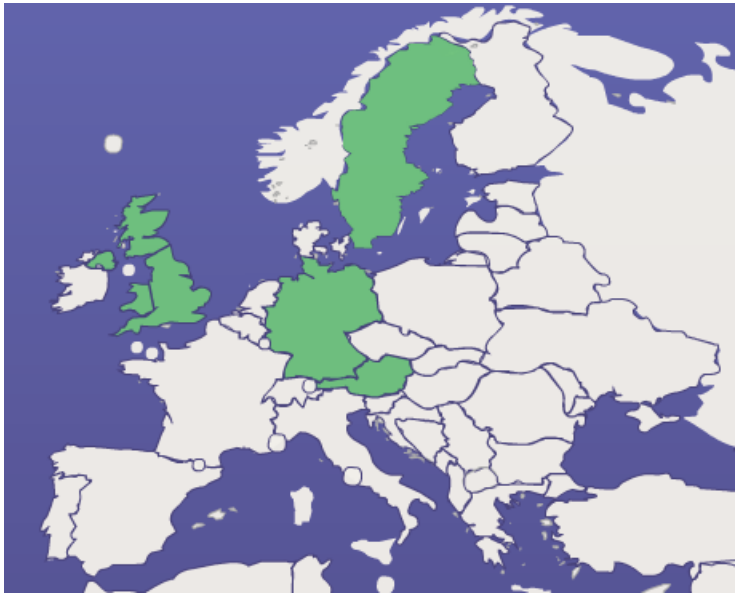
Outline

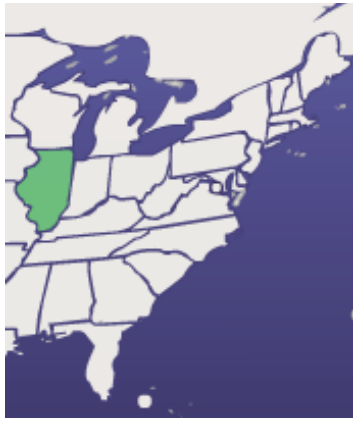
- EPIGRAM project
  - Overview
  - Motivation and Integrated Vision
  - Applications
- EPiGRAM Software for Space Physics
  - Implementation.
  - EPiGRAM-enabled magnetosphere simulations and link to space missions.
  - Current work

EPiGRAM Project

STREP project started in Nov 2013
3 years duration
Total budget: 3 051 679 €
Web site: www.epigram-project.eu
Project partners:

- KTH SE (coordinator)
- TUW AT
- FRAUNHOFER DE
- CRAY UK UK
- UEDIN UK
- UIUC USA





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EPiGRAM = Exascale Programming Models

Focus on preparing Message-Passing and PGAS programming models for exascale:

- **novel concepts and algorithms** in programming models with exascale potential. Prototype implementations in **MPI** and **GPI-2 (PGAS library developed by Fraunhofer)**.
- combine Message-Passing and PGAS for enhanced **interoperability and scalability**.
- follow and support the **standardization** process of MPI and GASPI.

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Motivation - Programming Models for Exascale

- MPI is the dominant programming system in applications at Petascale.
- MPI is at the base of many novel programming and runtime systems for internode communication.
- Some MPI "limitations":
  - Collective bottleneck and not optimized to absorb imbalance.
  - MPI RMA (feature we need to use at exascale) not adopted by application community.
  - MPI RMA high performance might need enhanced synchronization (notified access).
- PGAS and in particular GPI-2 make RMA easy to be used and provide HP RMA synchronization.
- Both MP and PGAS ready to be tuned for exascale that is coming in 2020!

EPiGRAM Integrated Vision

MPI:

- Persistent Collectives
- Neighborhood collectives

GPI-2

- Fast RDMA
- Fault-tolerance

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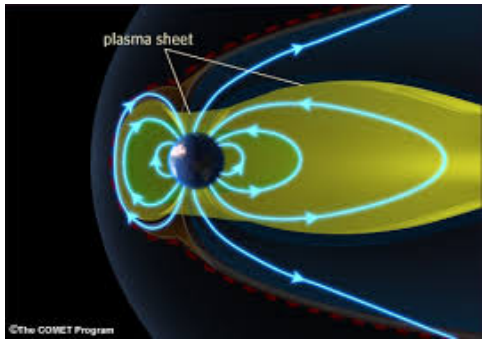
EPiGRAM Applications

- The new concepts and software are tested in the communication kernel of two-real world applications:
  - iPIC3D for space physics, C++ particle-based code, 20,000 LOC
  - Nek5000 CFD code, Fortran77 semi-spectral code, 70,000 LOC
- EPiGRAM application forum: set of 12 applications we present EPiGRAM results to in ad-hoc workshops.

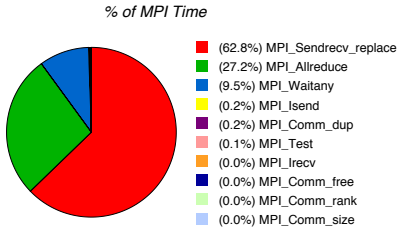
Space Physics

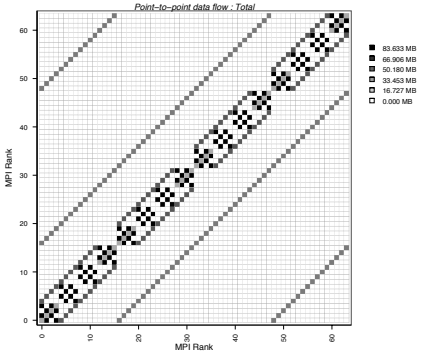
- It studies of the physical phenomena occurring during the interaction of solar wind and Earth magnetosphere.
- Science question:
  - What is the Aristotele's Unmoved Mover that drives plasma flows in space? Magnetic reconnection, turbulence?
- Technological key issue:
  - Can we predict solar storms and violent event in space to protect our satellites and astronauts in space?

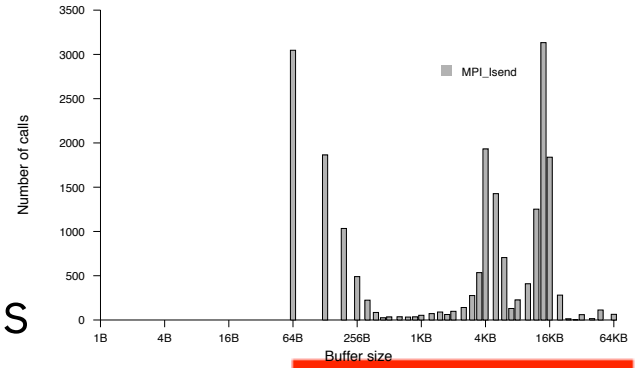


EPiGRAM for Space Physics

- We analyzed the performance of the communication kernel in iPIC3D
- We redeveloped the communication kernel of the iPIC3D code:
  - All non-blocking P2P MPI
  - Use of MPI derived data-types.
  - Use of GPI-2 mixed with MPI.
- We developed parallel I/O based on MPI I/O.
- Overall improvement of performance → EPiGRAM allowed to carry out first realistic large scale particle simulations of magnetospheres.







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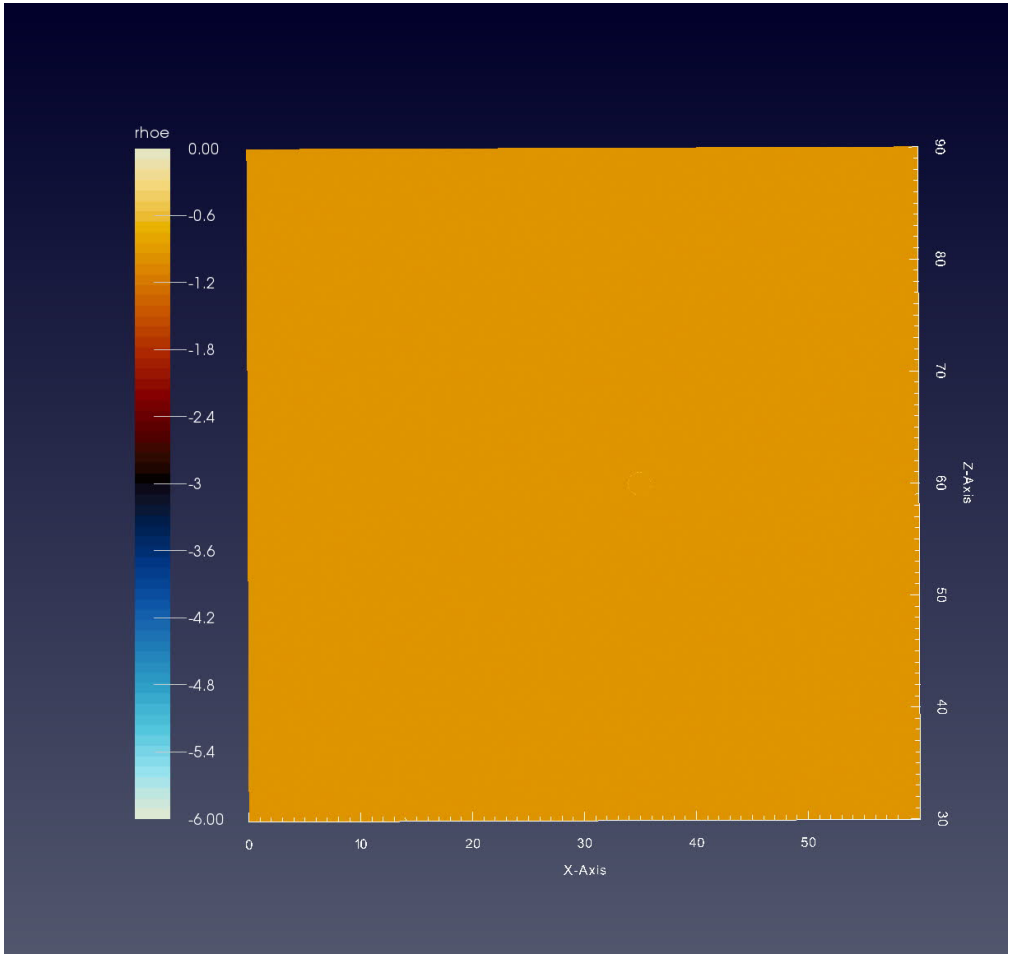
EPiGRAM-enabled Simulations



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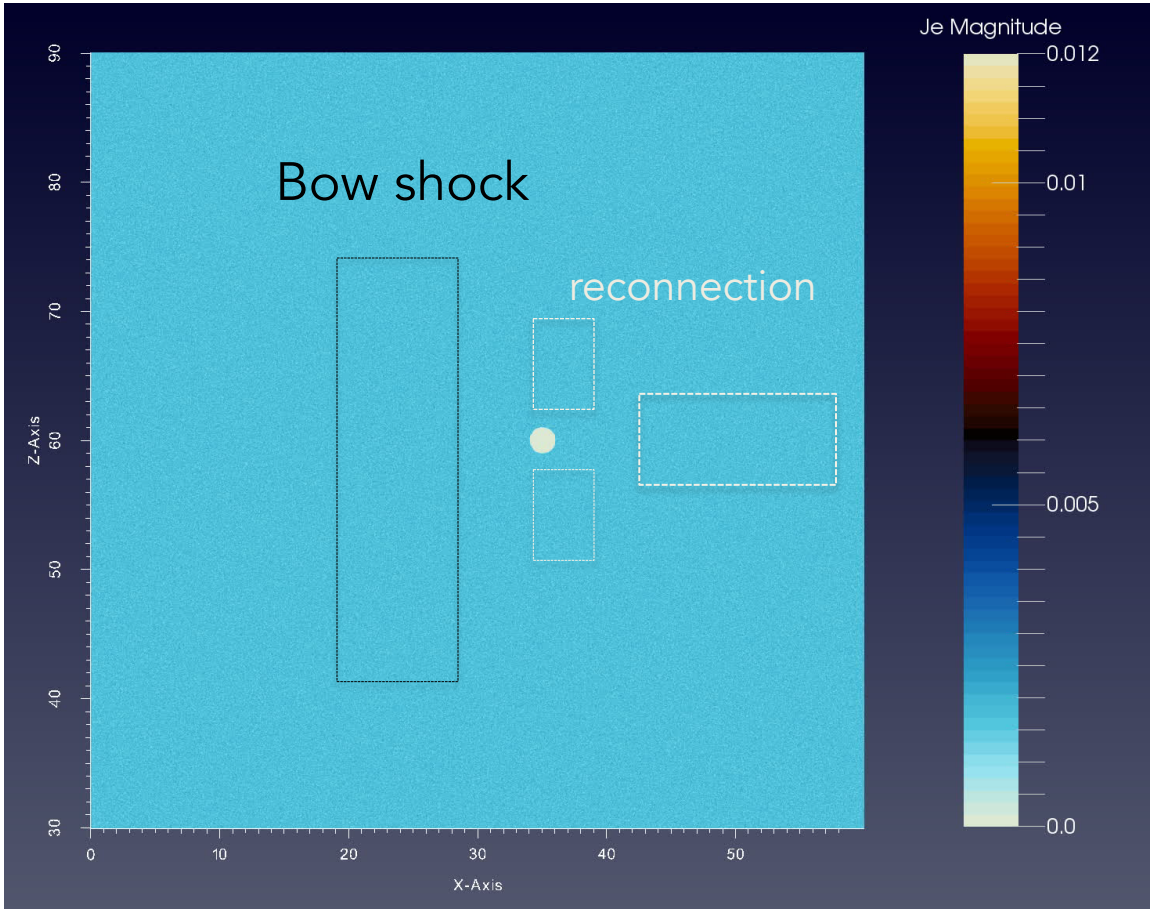
EPiGRAM enabled-simulations



EPIGRAM results are/will be used:

- in preparation of the NASA MMS mission to study magnetic reconnection
- ESA Thor proposed mission to study turbulence close to bow Shock

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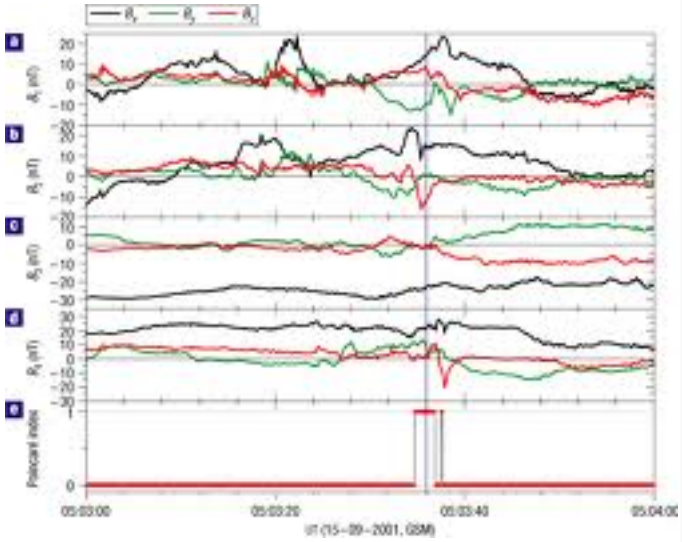
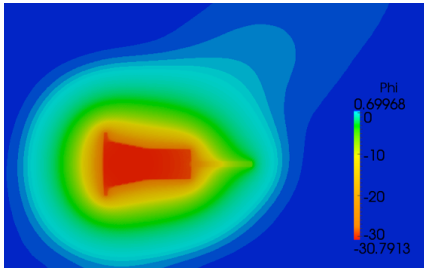
Impact of Simulations on Space Missions

- Simulations are used to have the" big picture" as spacecraft provides only a set of quantities at a given point at a certain time.
- Simulations are used to identify possible signatures of important intermittent phenomena.
- Simulation of spacecraft charging and damage.





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Current Work

- The iPIC3D code has been coupled to other codes within the SWMF framework http://csem.engin.umich.edu/tools/swmf/ to allow for large scale simulation in realistic set-up (coupling with inner magnetosphere/ionosphere).
- Simulation of Earth's magnetosphere requires multi-physics simulations.
- The code coupling is via Message-Passing.
- Studying best strategies for allocating and scheduling resources for the multi-physics framework.

Conclusions

- EPIGRAM focuses on MPI + PGAS for exascale:
  - Improve MP and PGAS.
  - Combine their best features.
  - Prepare a PGAS-based MPI.
- Impact on space physics applications
  - We improved iPIC3D by redesigning its communication kernel and I/O
  - We carried out large-scale simulation to support science of space mission
  - Focus on coupling scheduling for different codes in the same framework by Message Passing.

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