Using Global Simulations of Earth's Magnetosphere to Model X-Ray Imaging

Joachim Raeder

Space Science Center, University of New Hampshire, Durham, NH 03824, USA

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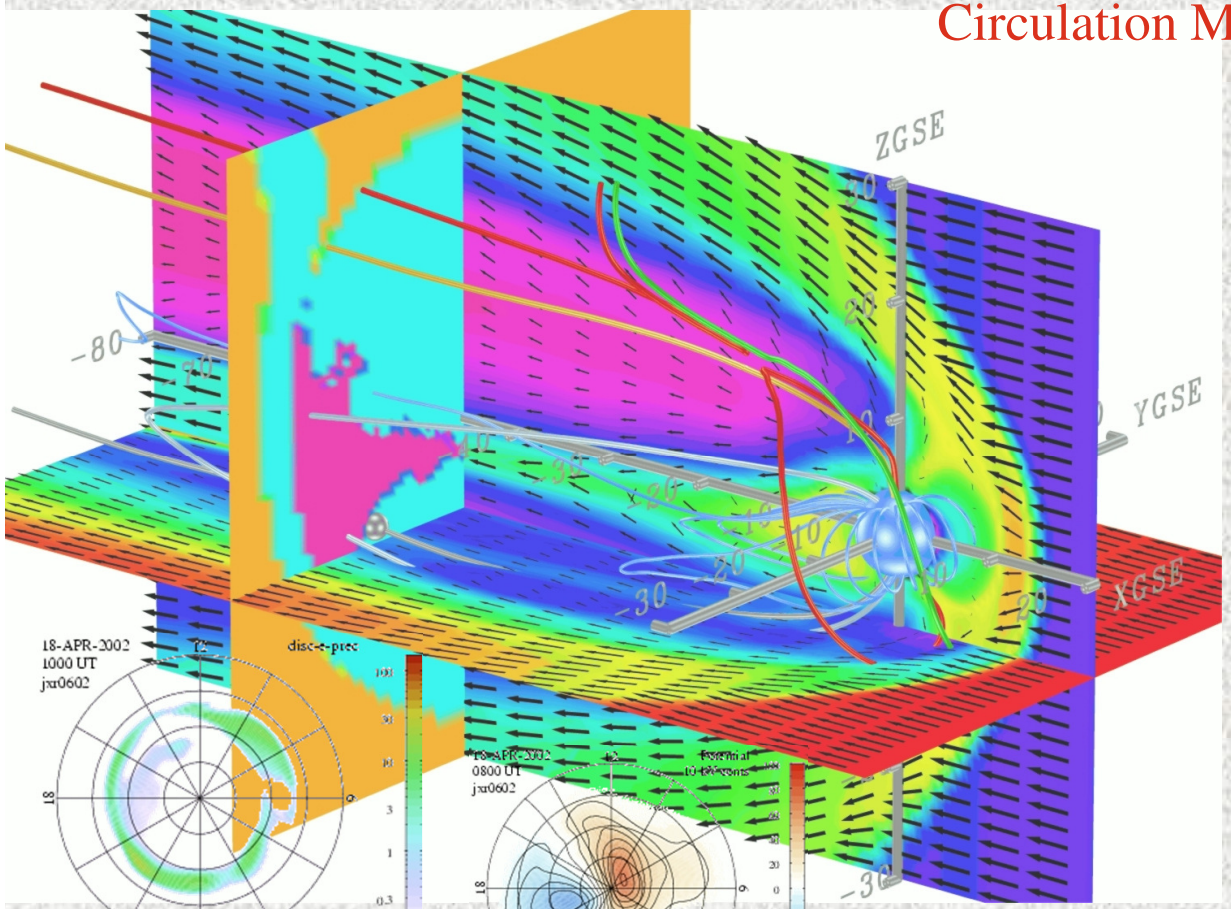
Ideally, we would like to “see” the plasma of the magnetosphere. There are different ways to produce such images:

- Statistical maps. Such maps gloss over most dynamical behavior. Useful for some quantities (BS, MP position, for example).
- Remote imaging. Unfortunately there are few “emissions” from the collisionless magnetosphere plasma. So far mostly ENA images of hot ions and EUV of the plasmasphere. Often lack spatial and/or temporal resolution.
- Numerical models. They can provide very detailed views, but need verification.
- Data assimilative numerical models. They take into account nearly all available information. Widely used in meteorology. The more data the better.

OpenGGCM: Global Magnetosphere Modeling

The Open Geospace General Circulation Model:



Aurora

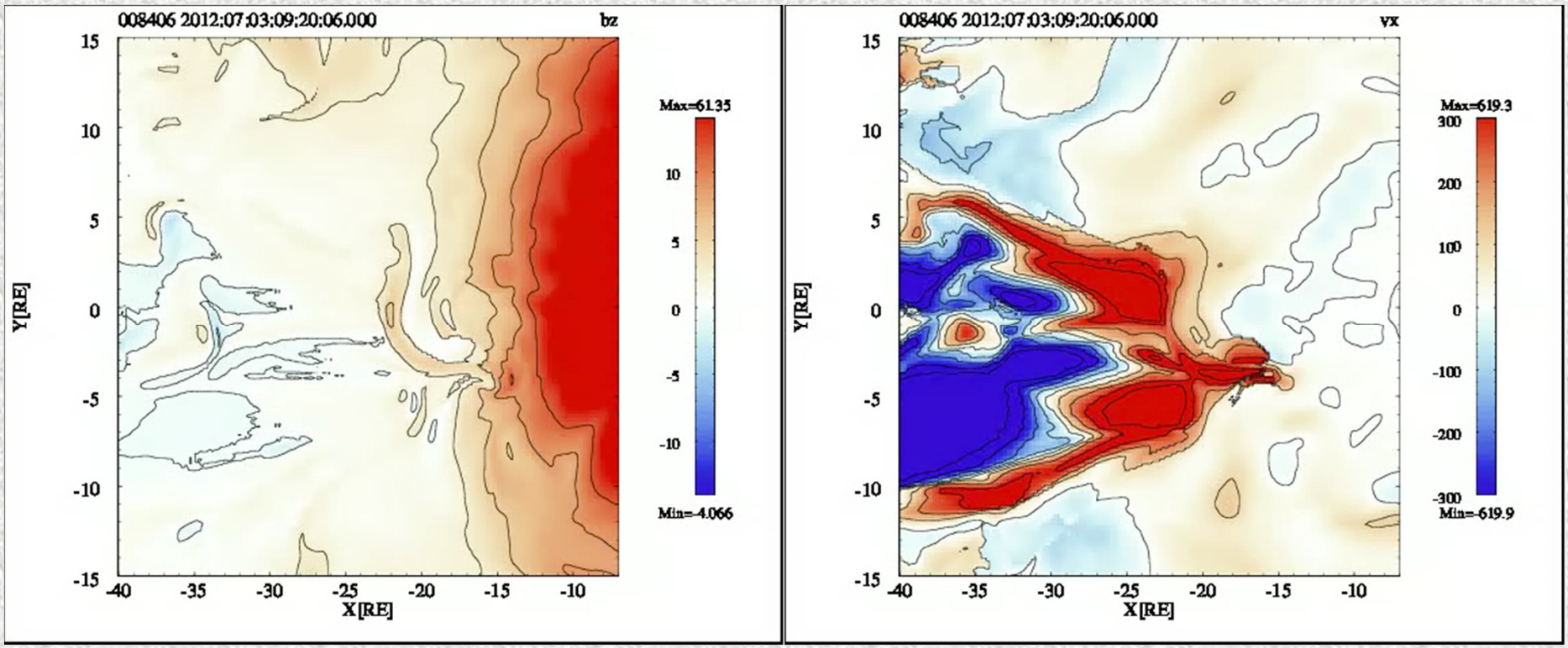
Ionosphere Potential

- Coupled global magnetosphere - ionosphere - thermosphere model.
- 3d Magnetohydrodynamic magnetosphere model.
- Coupled with NOAA/SEC 3d dynamic/chemistry ionosphere - thermosphere model (CTIM).
- Coupled with inner magnetosphere / ring current models: Rice U. RCM, NASA/GSFC CRCM.
- Model runs on demand (>300 so far) provided at the Community Coordinated Modeling Center (CCMC at NASA/GSFC).
  http://ccmc.gsfc.nasa.gov/
- Fully parallelized code, real-time capable. Runs on IBM/datastar, IA32/I64 based clusters, PS3 clusters, and other hardware.
- Used for basic research, numerical experiments, hypothesis testing, data analysis support, NASA/THEMIS mission support, mission planning, space weather studies, and Numerical Space Weather Forecasting in the future.
- Funding from NASA/LWS, NASA/TR&T, NSF/GEM, NSF/ITR, NSF/PetaApps, AF/MURI programs.

Personnel: J. Raeder, M. Gilson, W. Li, A. Liwei Lin, K. Germaschewski, Y. Ge,, (UNH), T. Fuller-Rowell, N. Muriyama (NOAA/SEC), F. Toffoletto, A. Chan, B. Hu (Rice U.), M.-C. Fok, A. Glocer (GSFC), A. Richmond, A. Maute (NCAR)

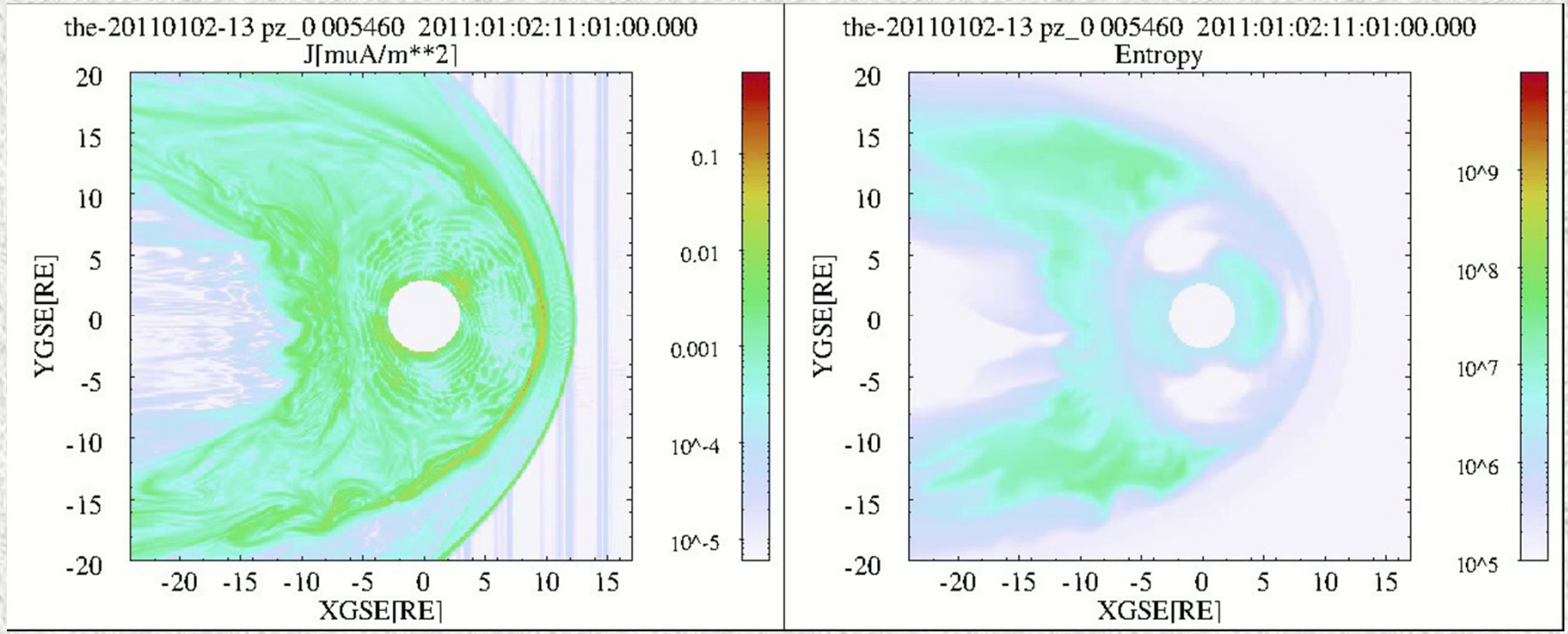
Typical dynamics of the magnetosphere: magnetotail

- Strong flows, associated with magnetic structures.
- Time scale of minutes, spatial scale of ~1 RE.
- Not good candidates for X-ray imaging because density is low (<1/cc).

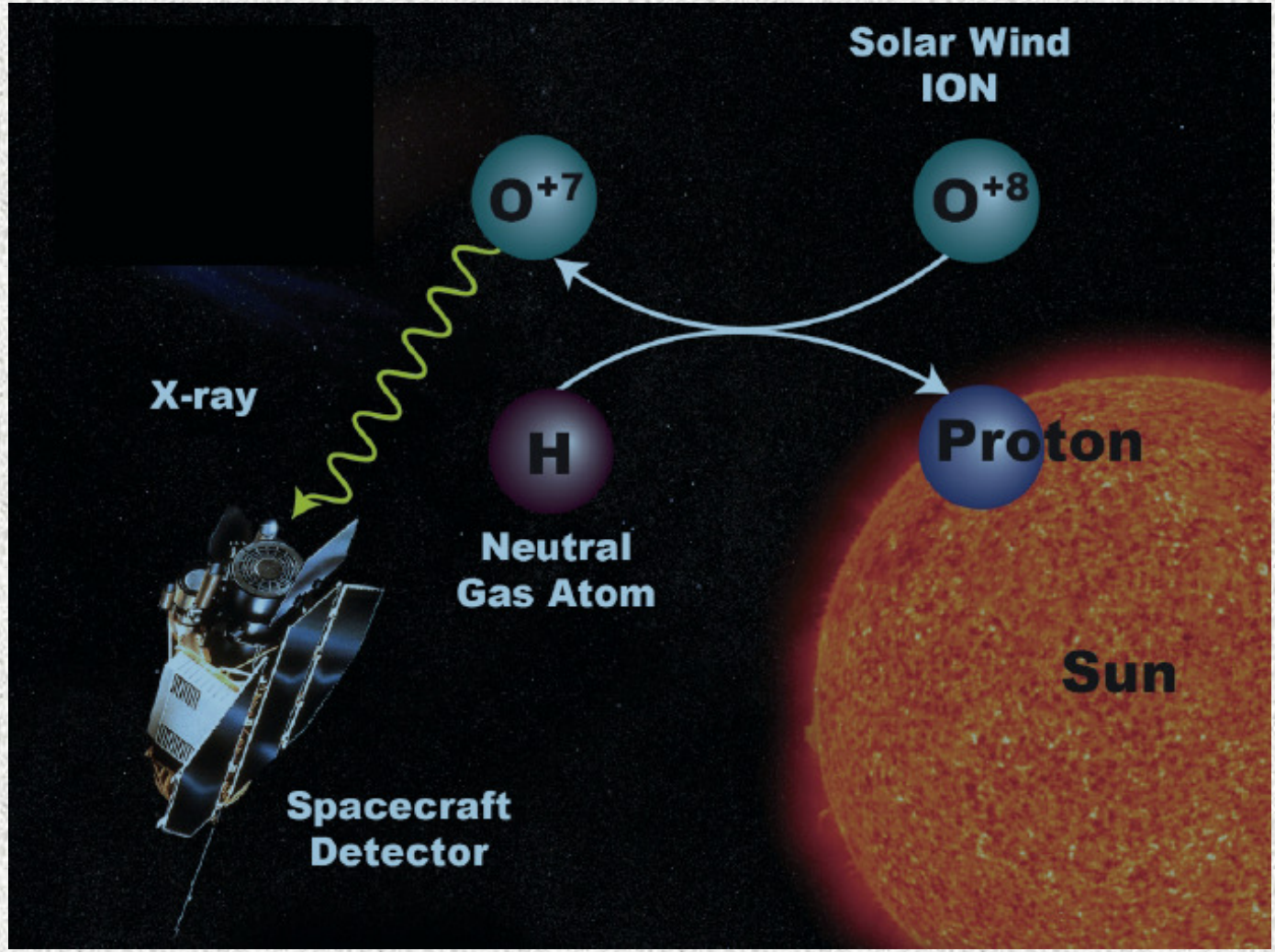


Typical dynamics of the magnetosphere: magnetopause

- Magnetopause has also very dynamic structures, for example Flux Transfer Events and Kelvin-Helmholtz waves.
- These are important for plasma entry, but not well mapped and understood.
- Since magnetosheath density is high (10-100/cc), opportunity for x-ray imaging is much better.



X-Ray Imaging: Charge exchange between highly charged SW ions and exosphere.

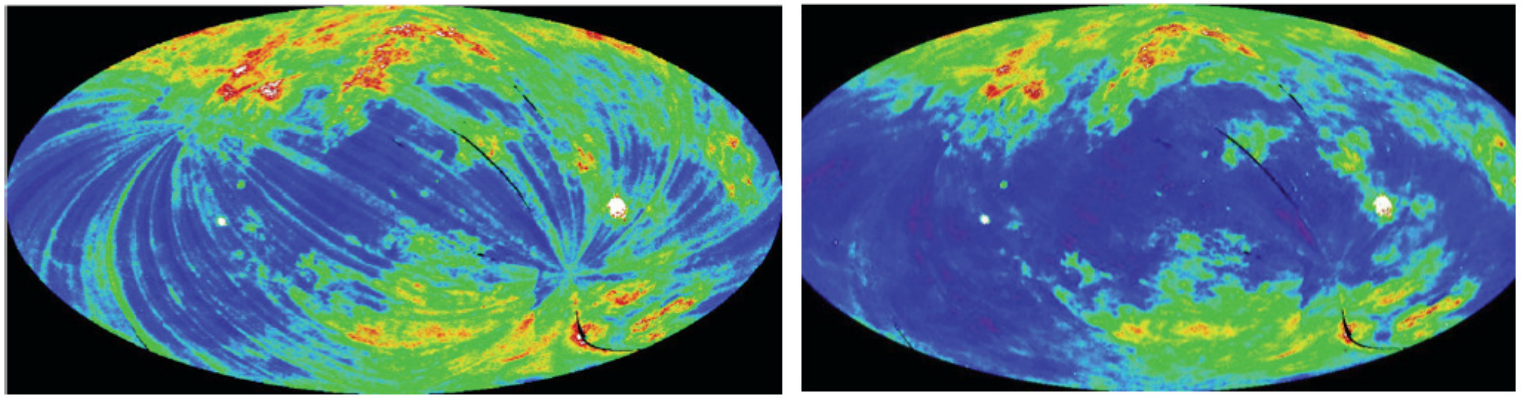


From D. Sibeck, NASA/GSFC

X-Ray Imaging: Astronomers' noise is our signal.

ROSAT Soft (¼ keV) X-Ray All Sky Images

(Looking Out Through the Terminator Magnetosheath)



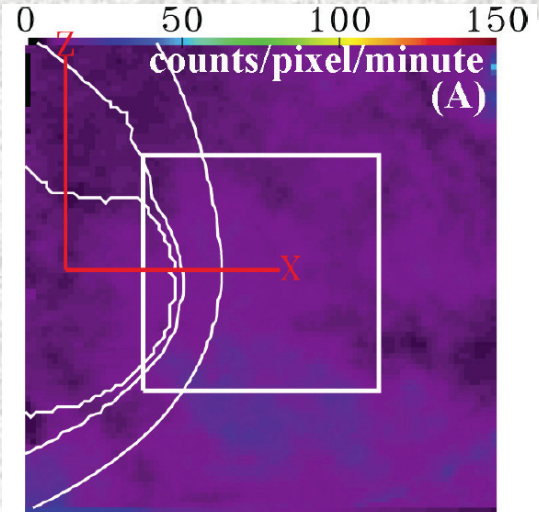
As observed

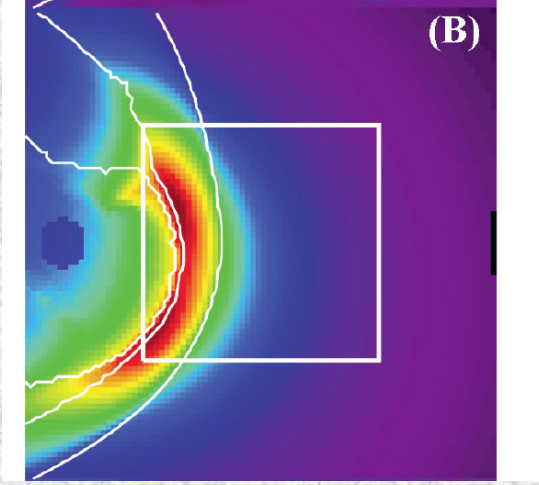
With Earth's foreground (magnetosheath) 'Contamination' Removed

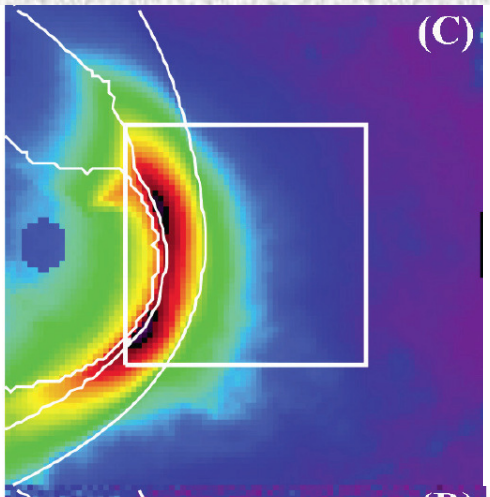
Snowden et al. [1997]

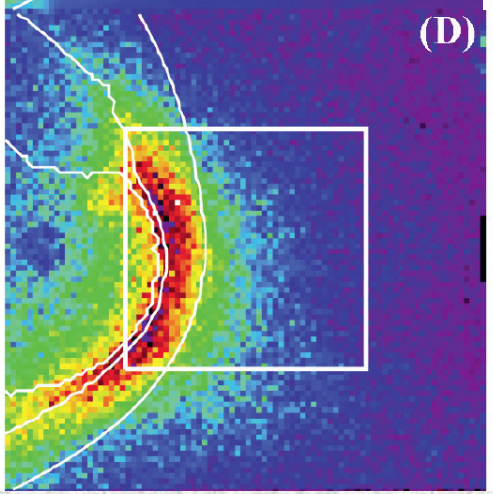
Simulating the Instrument Response is Critical

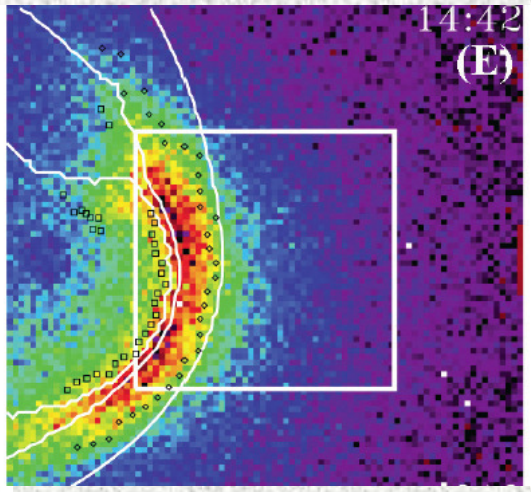
- So far, simulations have addressed stationary situations.









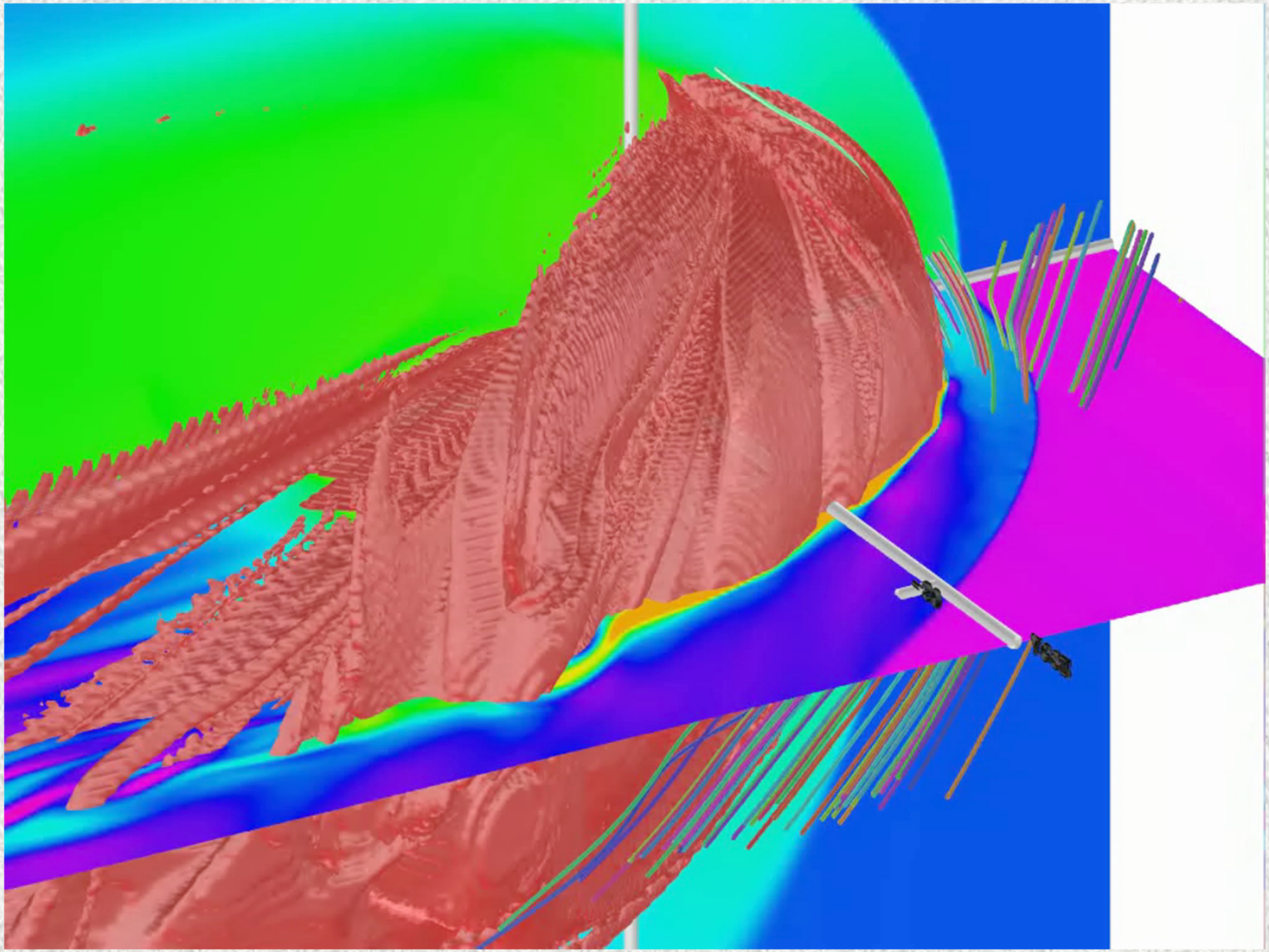


A. Background.
B. LOS emissions.
C. Sum of A+B.
D. Added noise.
E. Expected image D - A

From Sibeck et al. AGU 2012

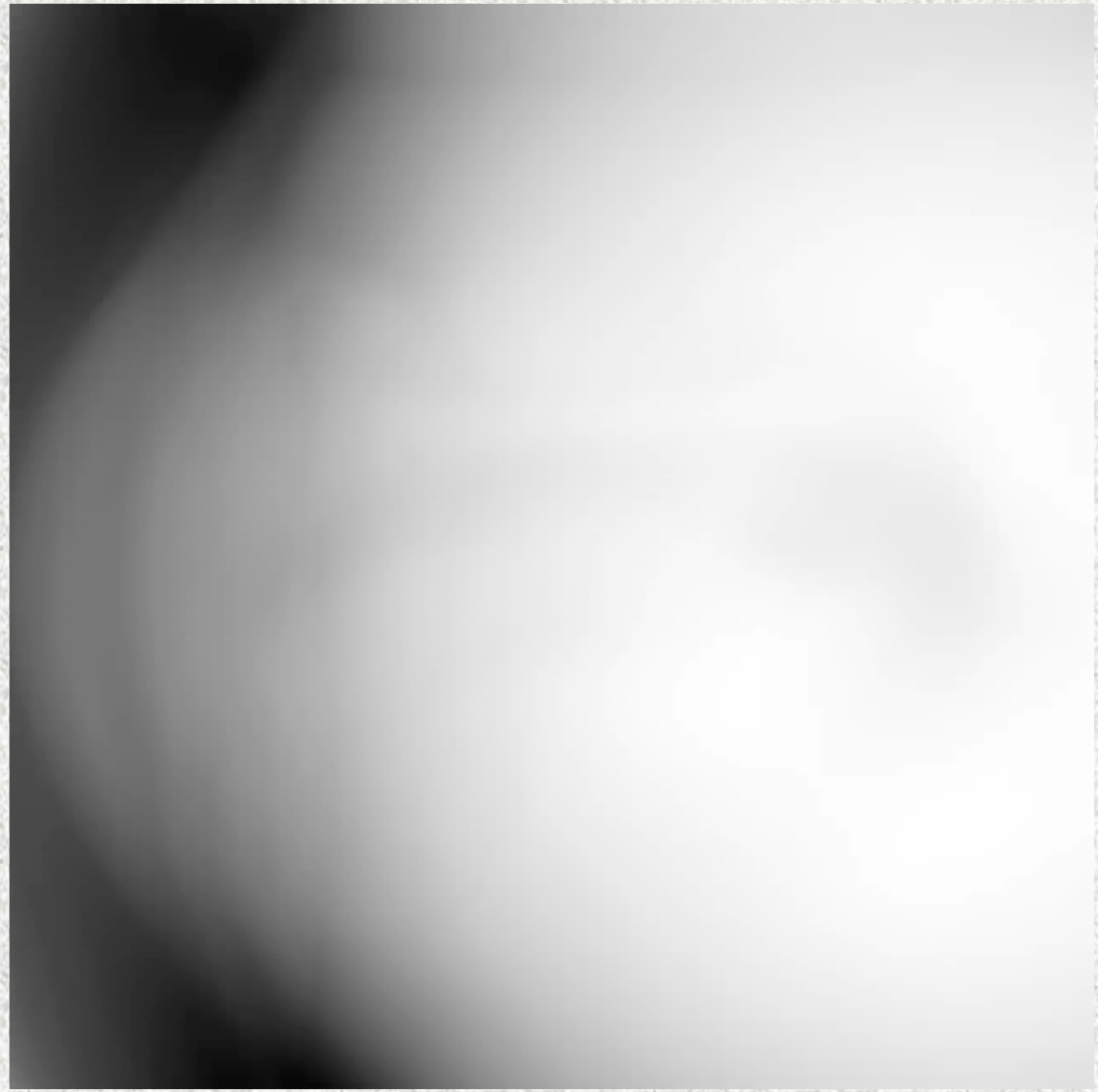
But the Most Interesting Processes are Dynamic

Flux Transfer Events (FTEs), Kelvin-Helmholtz (KH) waves, and possibly both together. This is what we would like to see with x-ray vision!



First Attempt at LOS Simulation

- Very primitive emission function: f(N_SW,N_EX,v_rel,…)=N_SW.
- Traced from (30,15,5) GSE.
- Still, we get a faint image of the waves, which are just barely discernible.



Goal: How can we tease information out of such movies, simulated or real?

- Since we want to know phase speed, wavelength, etc., we can integrate in z along an equatorial band (stacking).
- The orbits should be optimized to get optimal pixel counts.
- Instead of viewing onto the magnetopause it may be better to view tangential to the magnetopause.
- Using spatial derivatives / gradients may reveal more information.
- Temporal derivatives should also show propagating structures like FTEs and KH.
- Ultimately, data-assimilative models should be used to obtain an optimal solution of the state of the magnetosphere.

Summary

- The magnetosphere has still many poorly known dynamical processes that a x-ray imager could help solve.
- Global simulations and modeling the LOS images are critical to demonstrate the usefulness of such a mission and to optimize mission parameters.
- Work is underway. Come and see next year!

Two more announcements:

1. "Trillian", a CRAY X6m-E with 4096 cores of fun.

2. Post-doc / researcher position available at UNH:
Requirements: Fortran/C/MPI in Linux/Unix environment, MHD/fluid numerics, plasma/magnetosphere background.
If interested, send resume to j.raeder@unh.edu.
(Sorry, position was just filled).