# Quo vadis?

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Quo vadis?

Where are you going?

Quo vadis?

Where are you going?

(Where art thou going?)

Quo venimus?

From where are we coming?

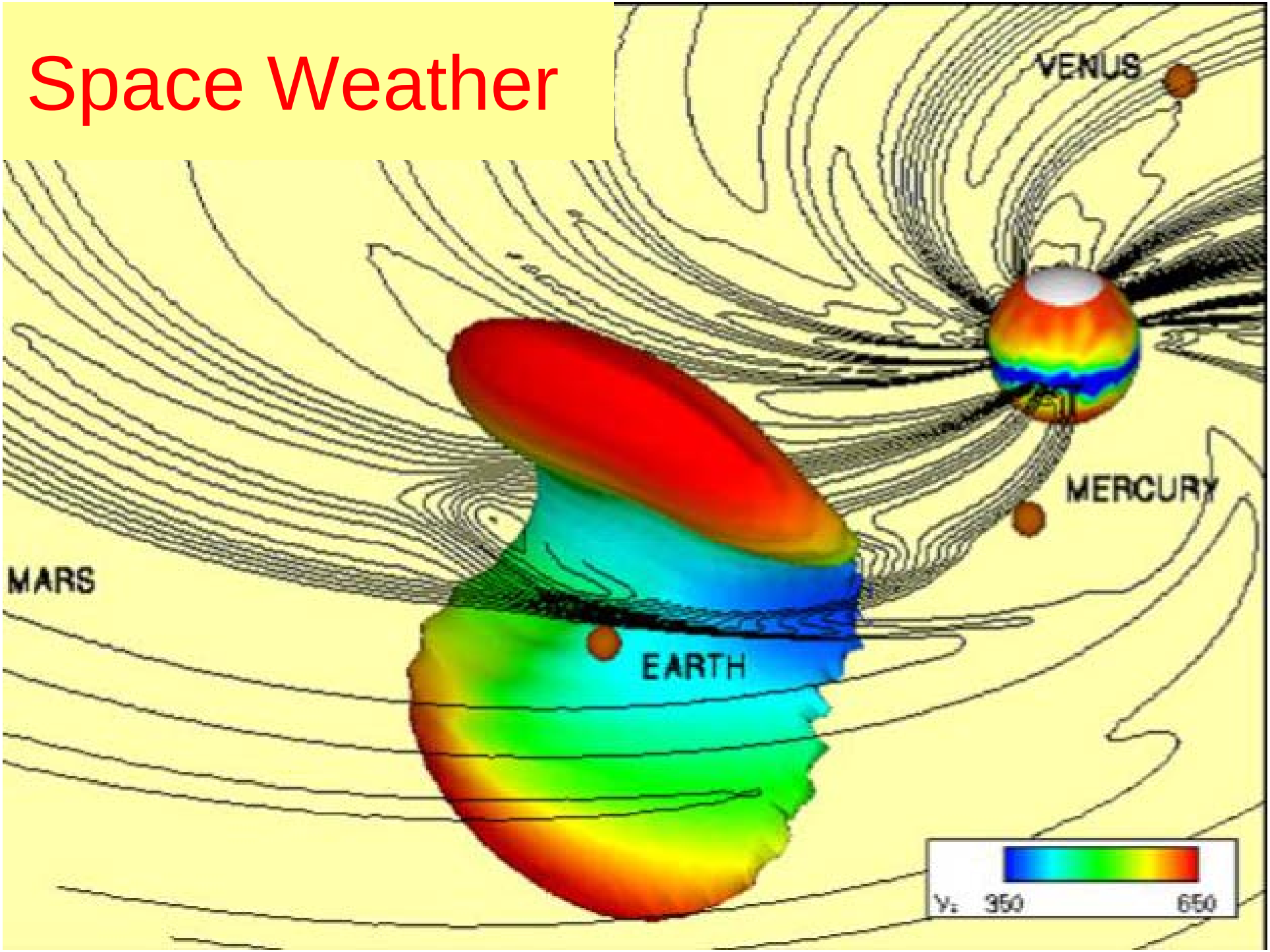
# GEM – Geospace Environment Modeling

- 1987 First planning meeting in Seattle
- 1990 program gets initial funding.
- Goal: To understand how the magnetosphere worked as a global system – how do all the pieces work together.
- Plan: A series of campaigns focusing on problems that needed solving in order to model the magnetosphere globally.

# CISM – Center for Integrated Space Weather Modeling

- 1997 First discussions about how to fund and build a global model.
- 2000 Initial Funding
- 2002 Full Funding
- Goal: The Sun-Earth system must be treated as a system.
- Plan: Create Sun-to-Earth models from existing component models – for both scientific understanding and prediction.

# Space Weather



# Space Weather

- Space weather impacts are well known
  - Navigation (GPS)
  - Power Grids (geomagnetically induced currents)
  - Communications (ionospheric scintillation)
  - Spacecraft (energetic particles)
  - Human’s in space (radiation)
- Applied Science – Science in the service of society

# StarFire Global SBAS is a key enabler

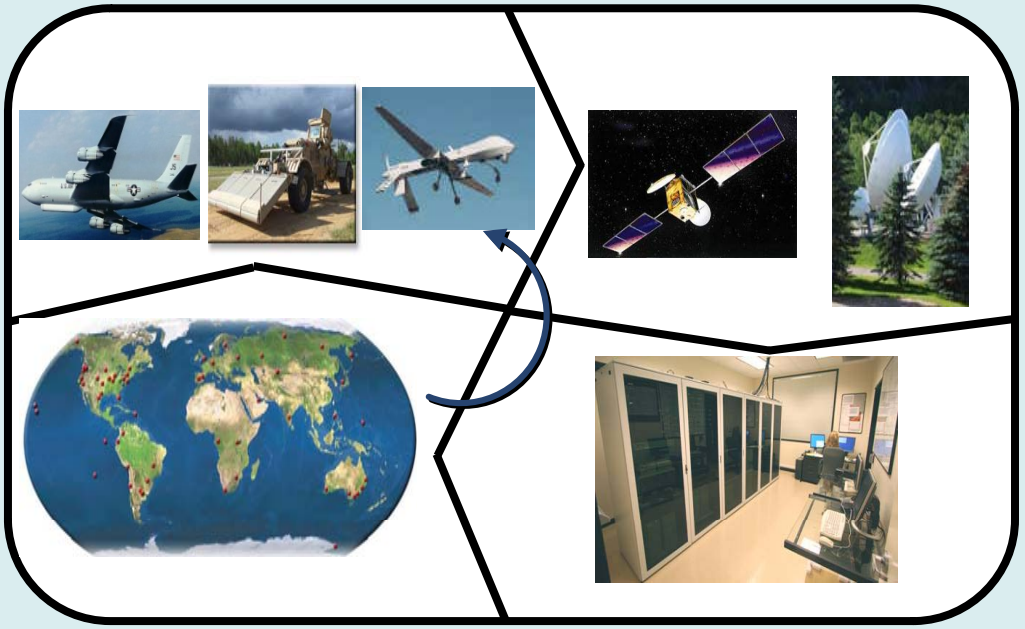
- Deere needed a way to accurately position agricultural equipment in rural areas on a global basis
  - Accurate enough to automatically steer a tractor or a combine
- Solution needed to be simple and not require local infrastructure

Whether your surveying
a 500 mile pipeline or
1000 miles at sea,
you still get 10 cm accuracy

From: Ron Hatch, Space Weather Workshop, April 2010

Deere developed its own commercial system that includes:

- Worldwide network of reference stations
- Processing centers computes orbit & clock corrections
- StarFire channels on GEOs streams corrections to users



## Applications

Precision Farming

- Yield Monitoring
- Automatic Guidance
- Water Management
- Implement Positioning
- Coordinated & Robotic Machines

Other

- Marine Survey
- Land Survey
- Military

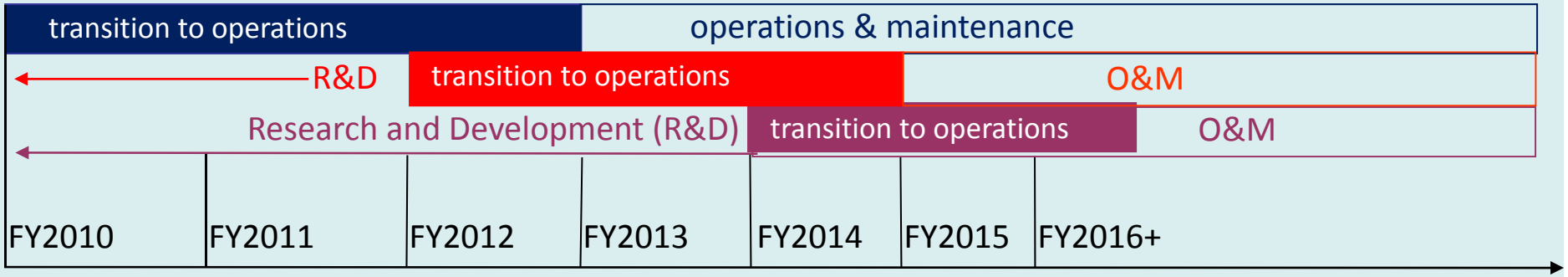
# Space Weather – the science

- Understand the impacts of (primarily) the Sun on the geospace system:
  - Photonic radiation (flares – X rays, EUV)
  - Particle radiation (solar energetic particles – also GCR's)
  - Plasmas and Fields (CME's and CIR's)
- Need to predict the occurrence and the effects of these events

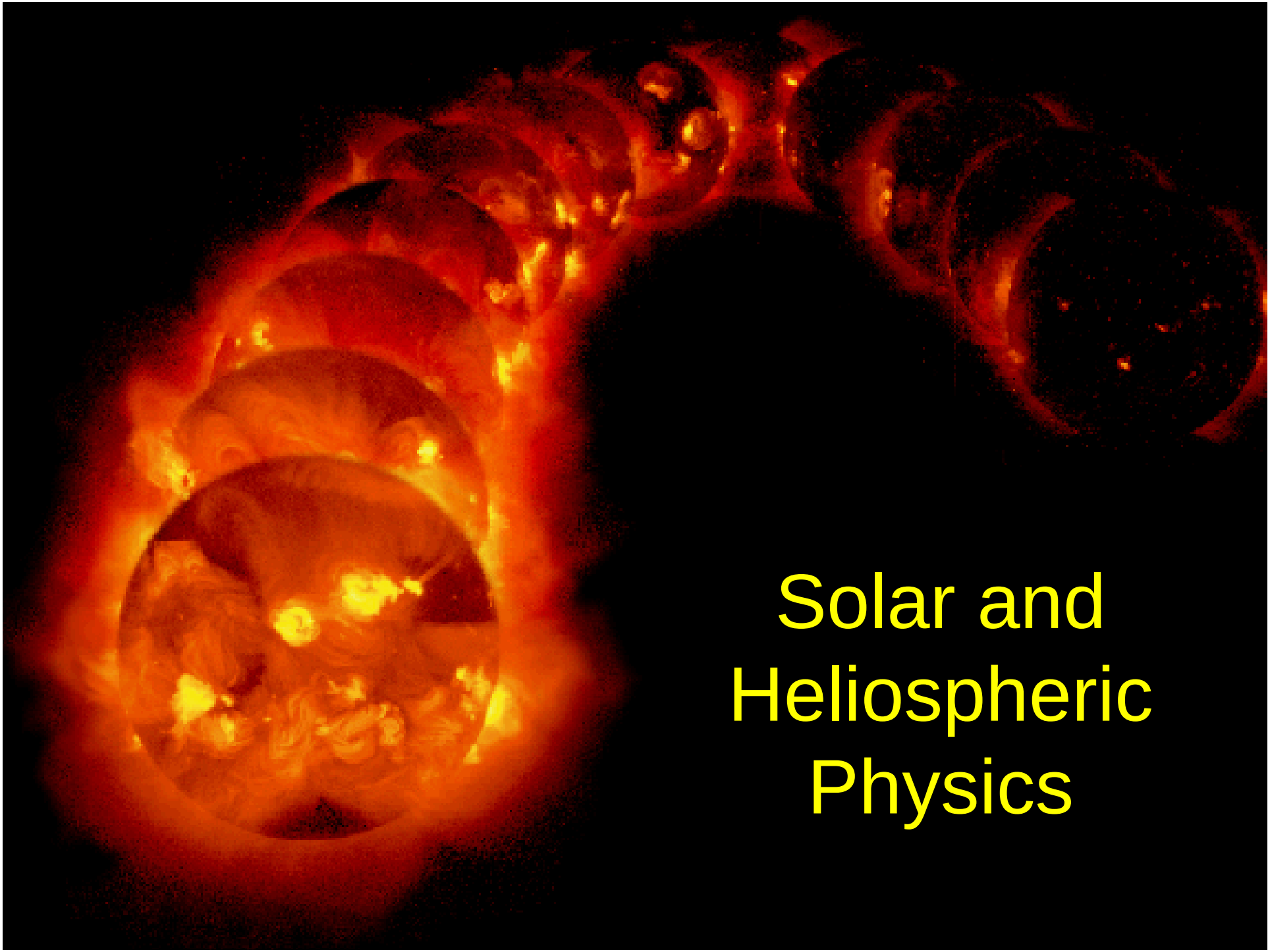
# SWPC plans for model transitions to operations

*The proposed way forward to develop improved space weather models to maximize solar wind and CME data for extended forecast and warnings*

- Solar Wind Disturbance Propagation Model (WSA-Enlil-Cone Model)
  - Geomagnetic storm predictions go from ~1 hour to 18hr - 4 days
    - Geospace Response Model
      - Will replace limited value global predictions with actionable regional forecasts and warnings
        - Energetic Particle Transport Model
          - Model to predict radiation storm peak intensity, timing, and spectrum; no models currently exist!

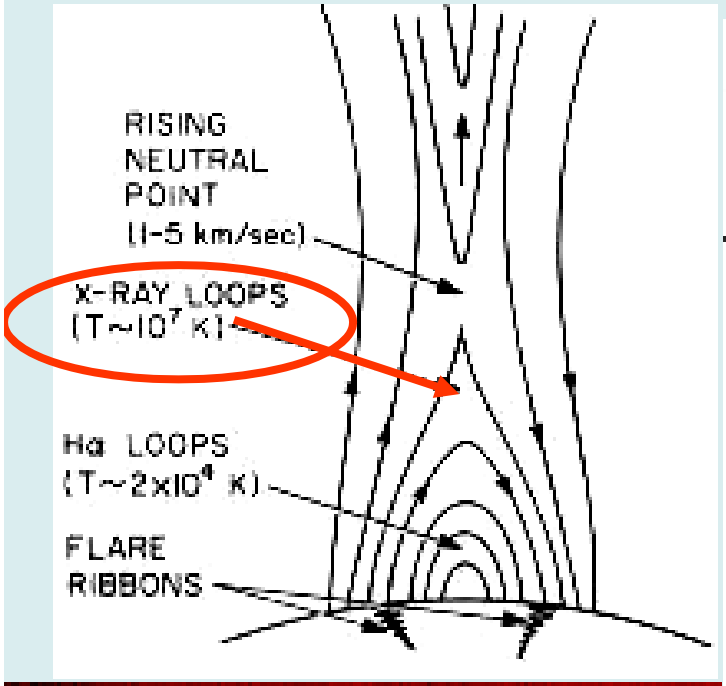


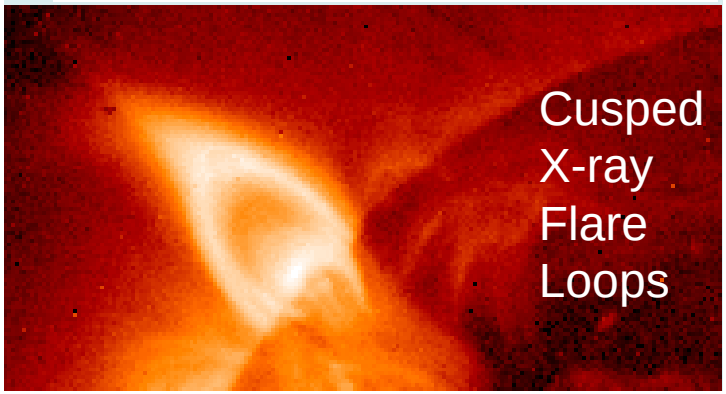

O&M includes Operation to Research (O2R) feedback to continuing R&D


Solar and
Heliospheric
Physics

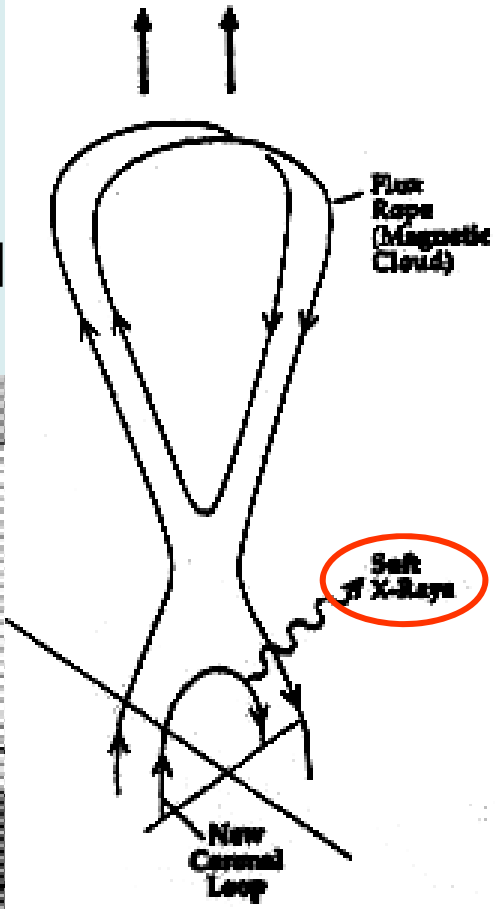
# Solar Flares

- Old flare model [*Pneuman and Kopp*]



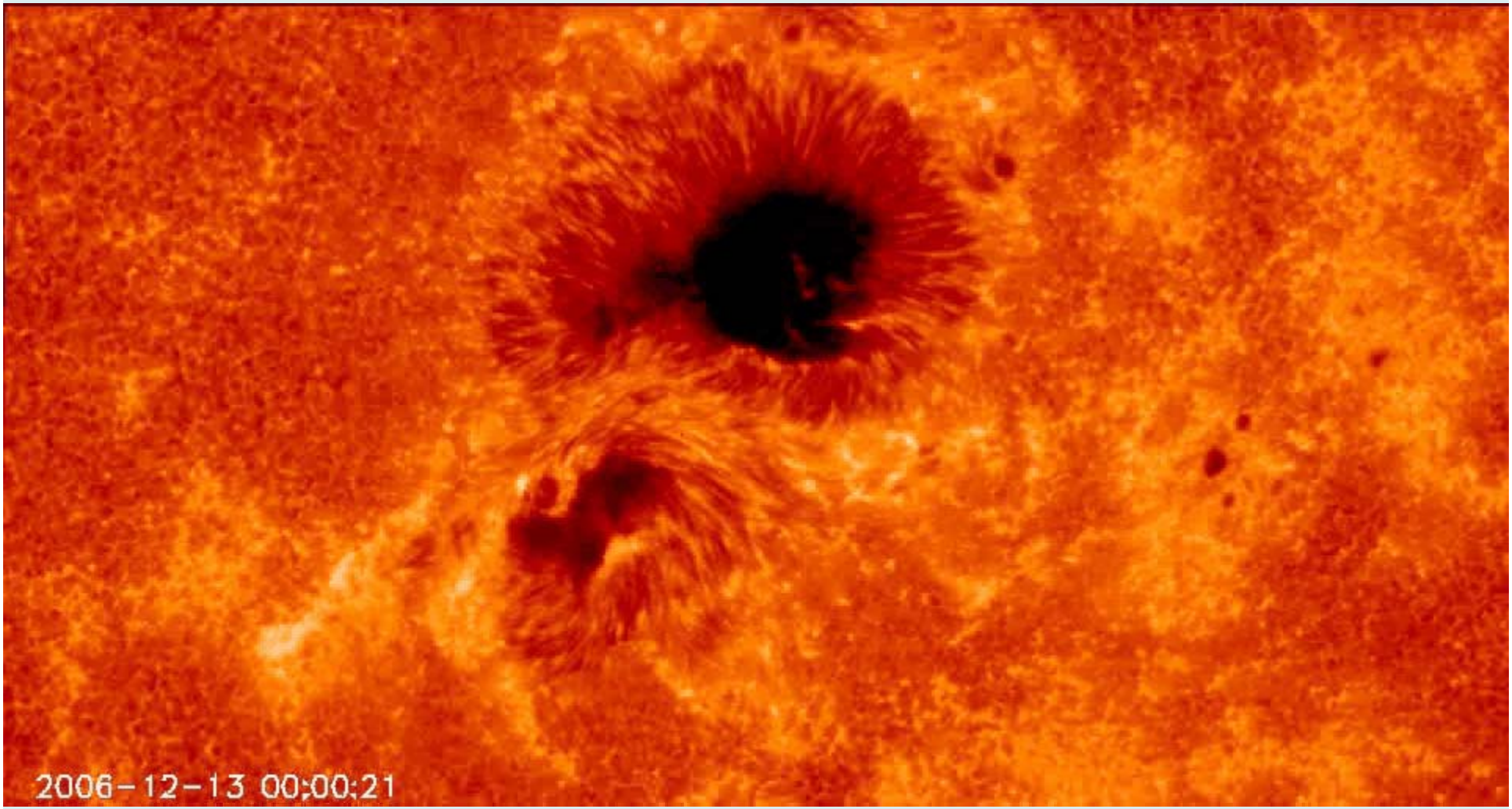

- CME model [*Gosling*]




- CME model [*Forbes*]

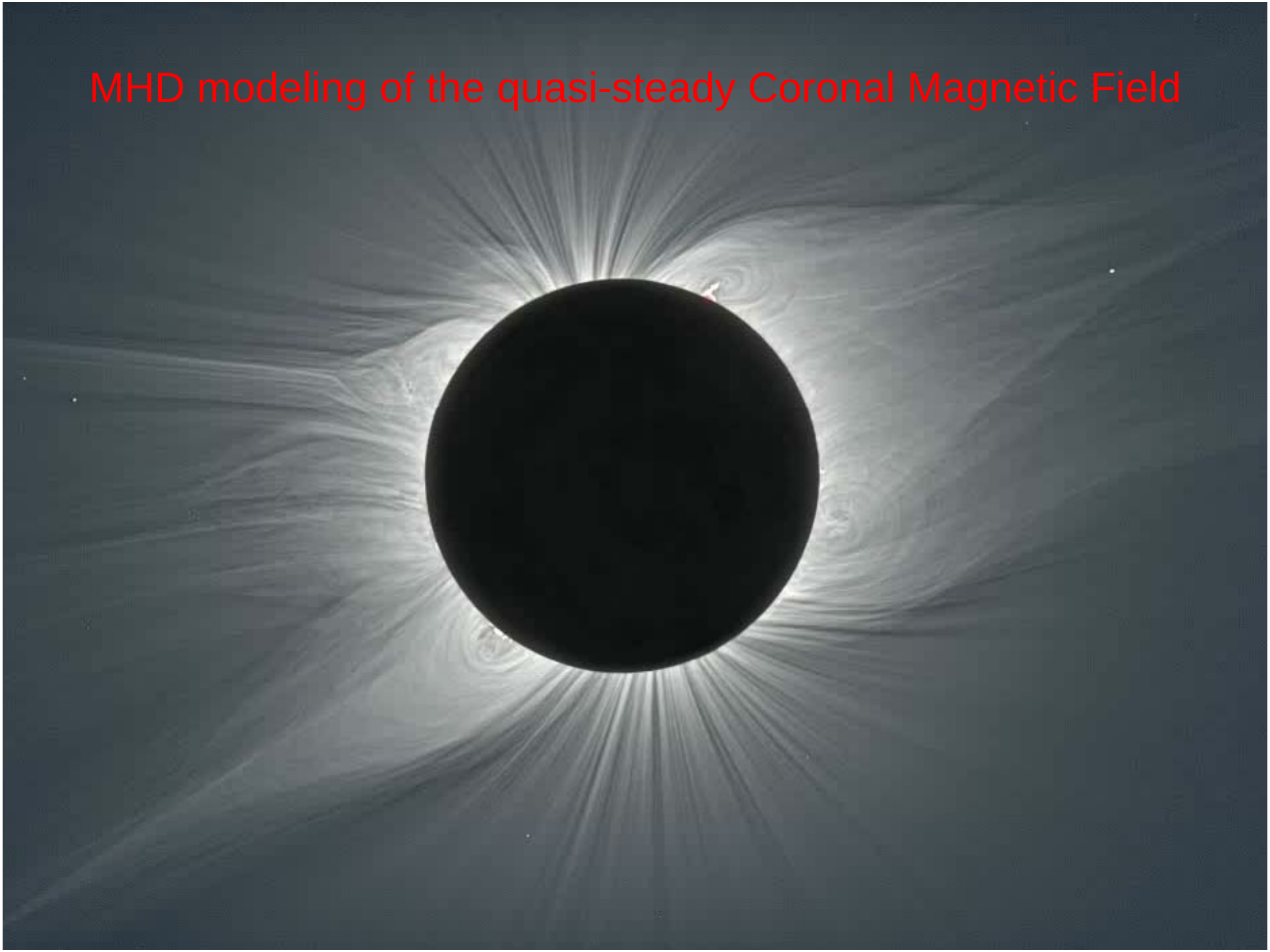

2002-Apr-21
00:43:09

# Flare ribbons above a sunspot

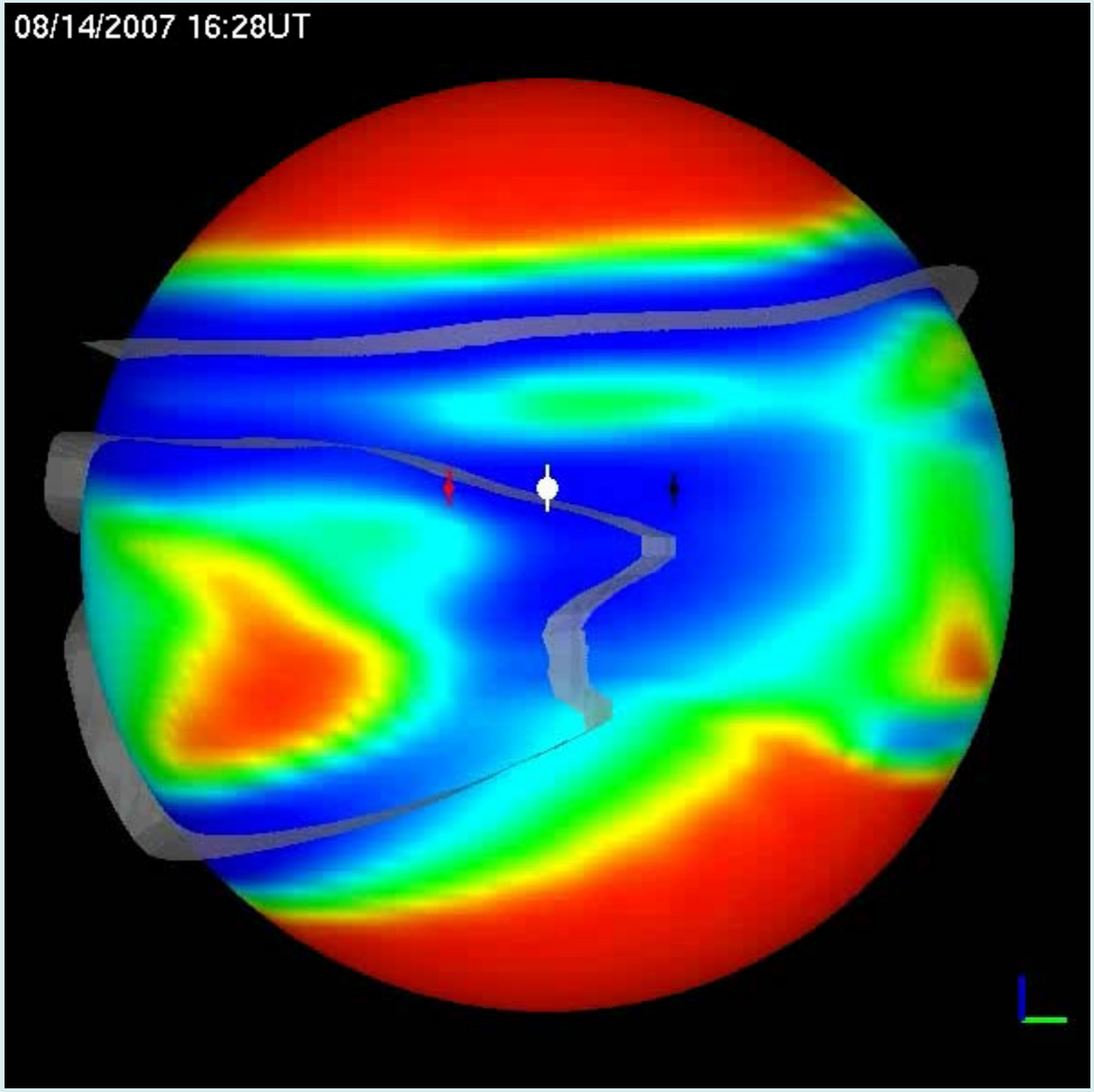



Hinode/SOT high-resolution observations of 12/13/06 flare

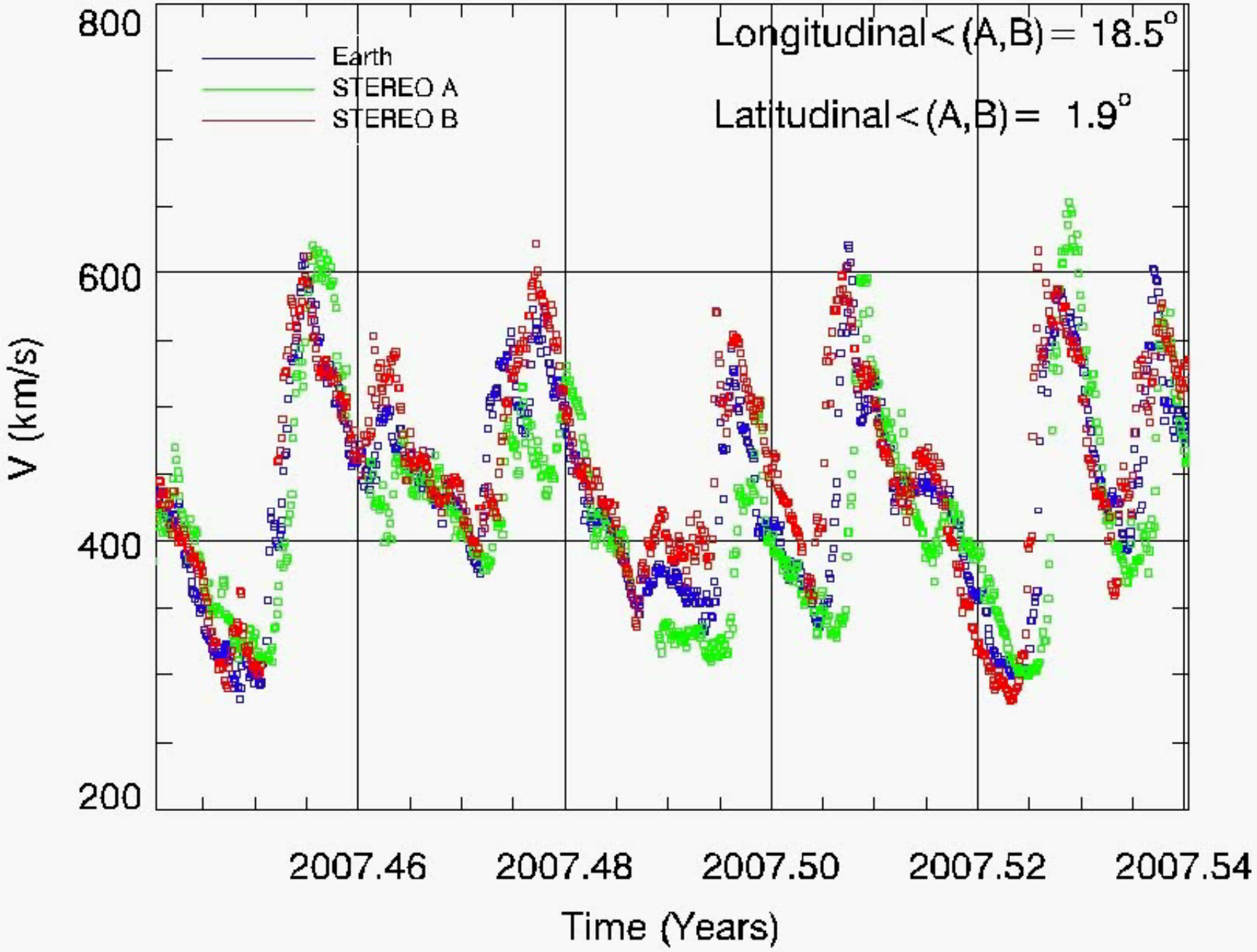
# MHD modeling of the quasi-steady Coronal Magnetic Field



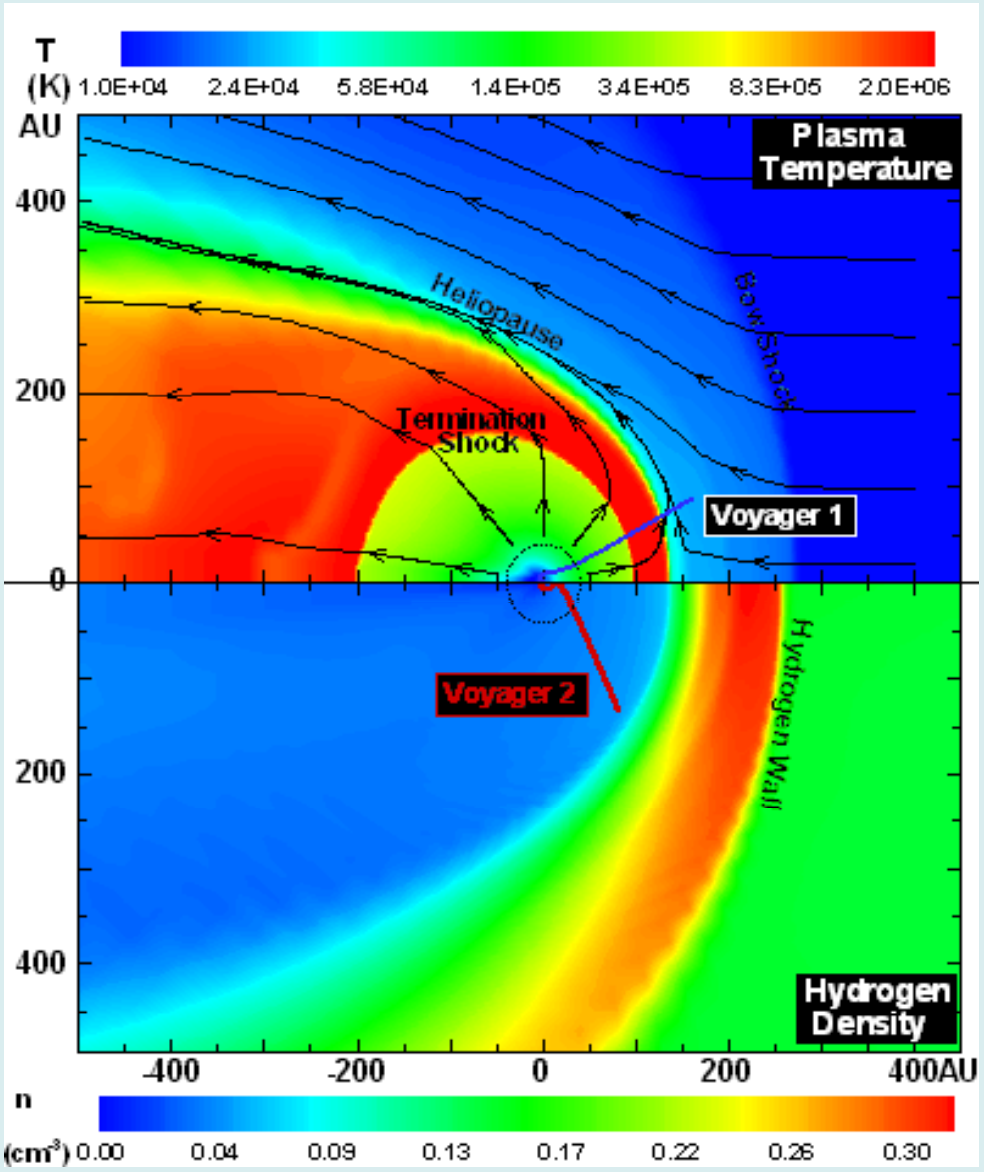
# Solar Wind Predictions – current sheet location and $V_{SW}$ at 1 AU



# Solar Wind Velocity observed at Earth and Stereo A and B



# Where does the solar wind end ? – the interaction of the solar wind and the interstellar medium.



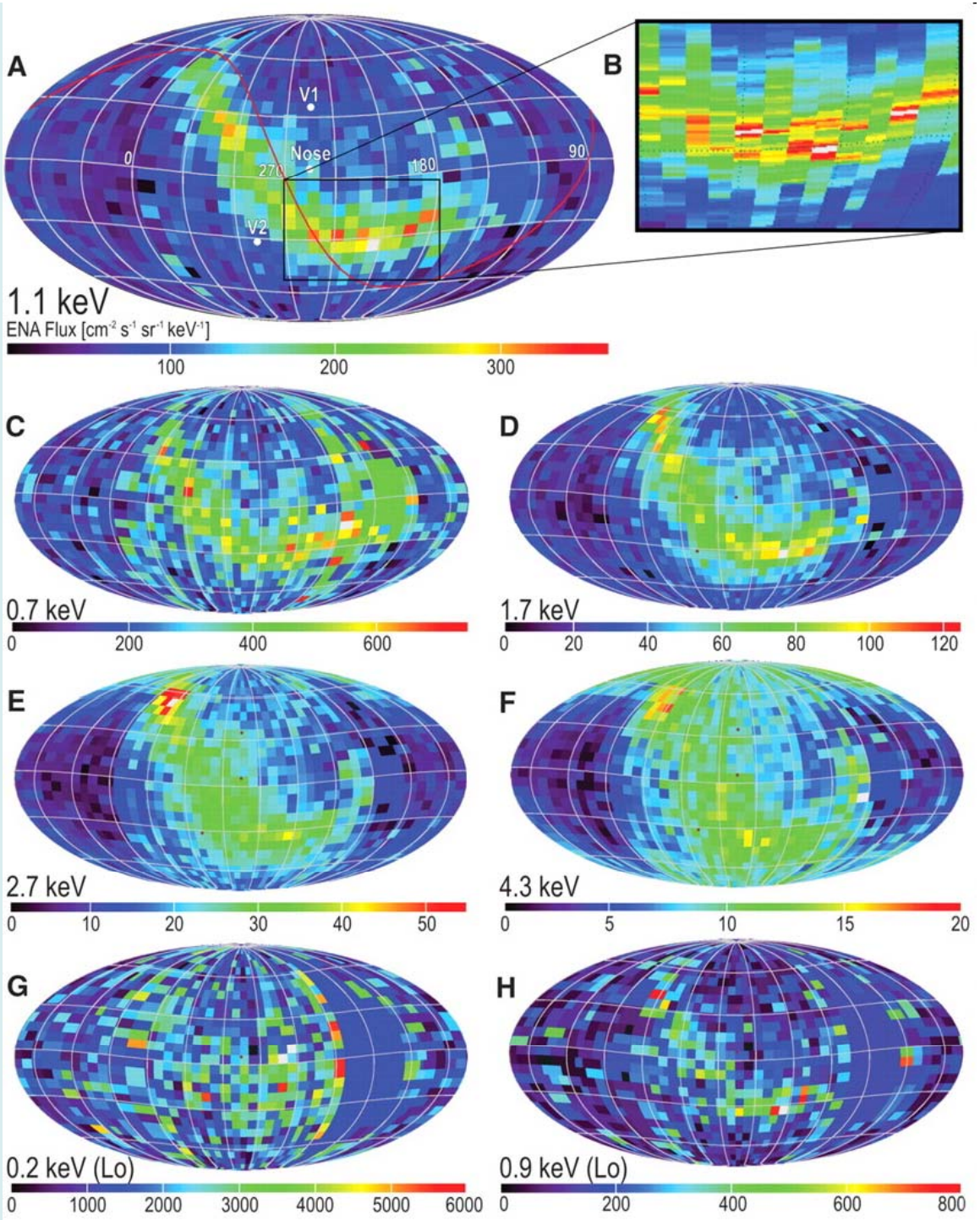

*Plasma temperature and flow lines*

In December 2004 Voyager 1 passed through the termination shock at a distance of 94 AU.

*Plasma density*

Voyager 2 followed in August 2007 at a distance of 84 AU.

Interstellar Boundary Explorer (IBEX) Energetic Neutral Atom Images of the interaction between the Local Interstellar Medium and the Heliosphere



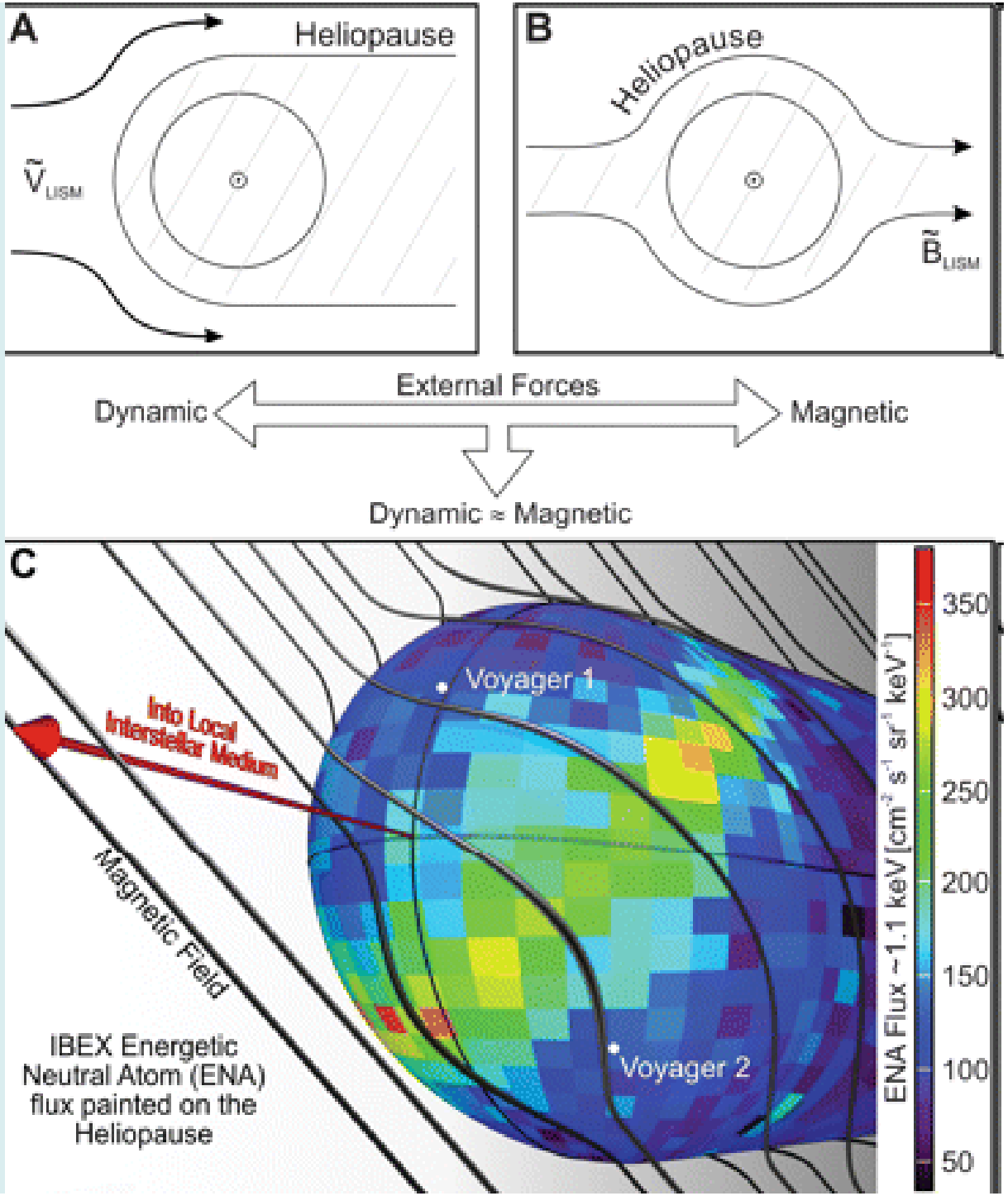

McComas et al., Science, 2009

# The Explanation

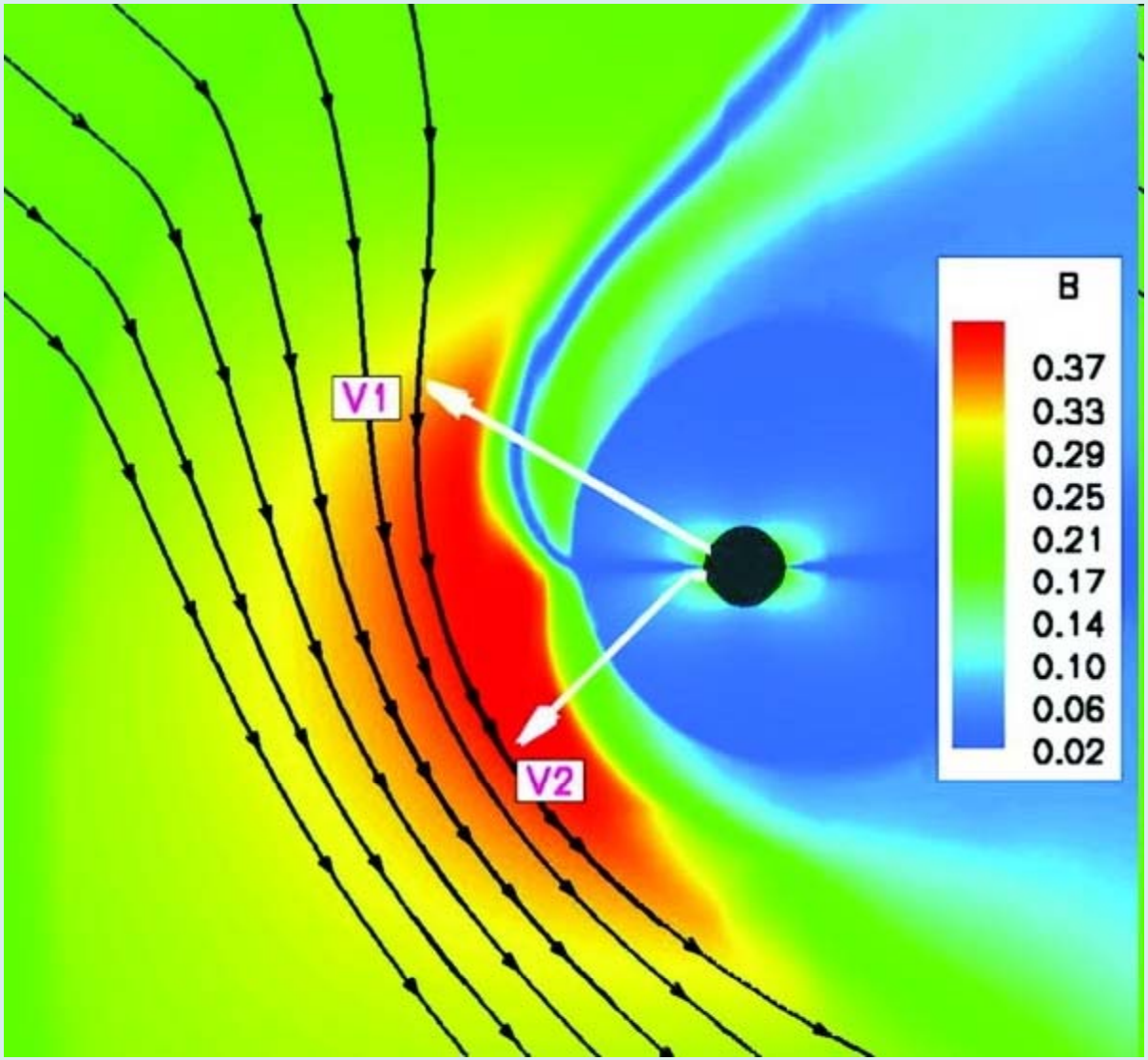
Parker's (1961) sketches of the LISM/Heliosphere interaction for dominant (A) dynamic pressure and (B) magnetic pressure

Visualization of the heliopause showing $B_{LISM}$ and direction of motion

McComas et al., Science, 2009

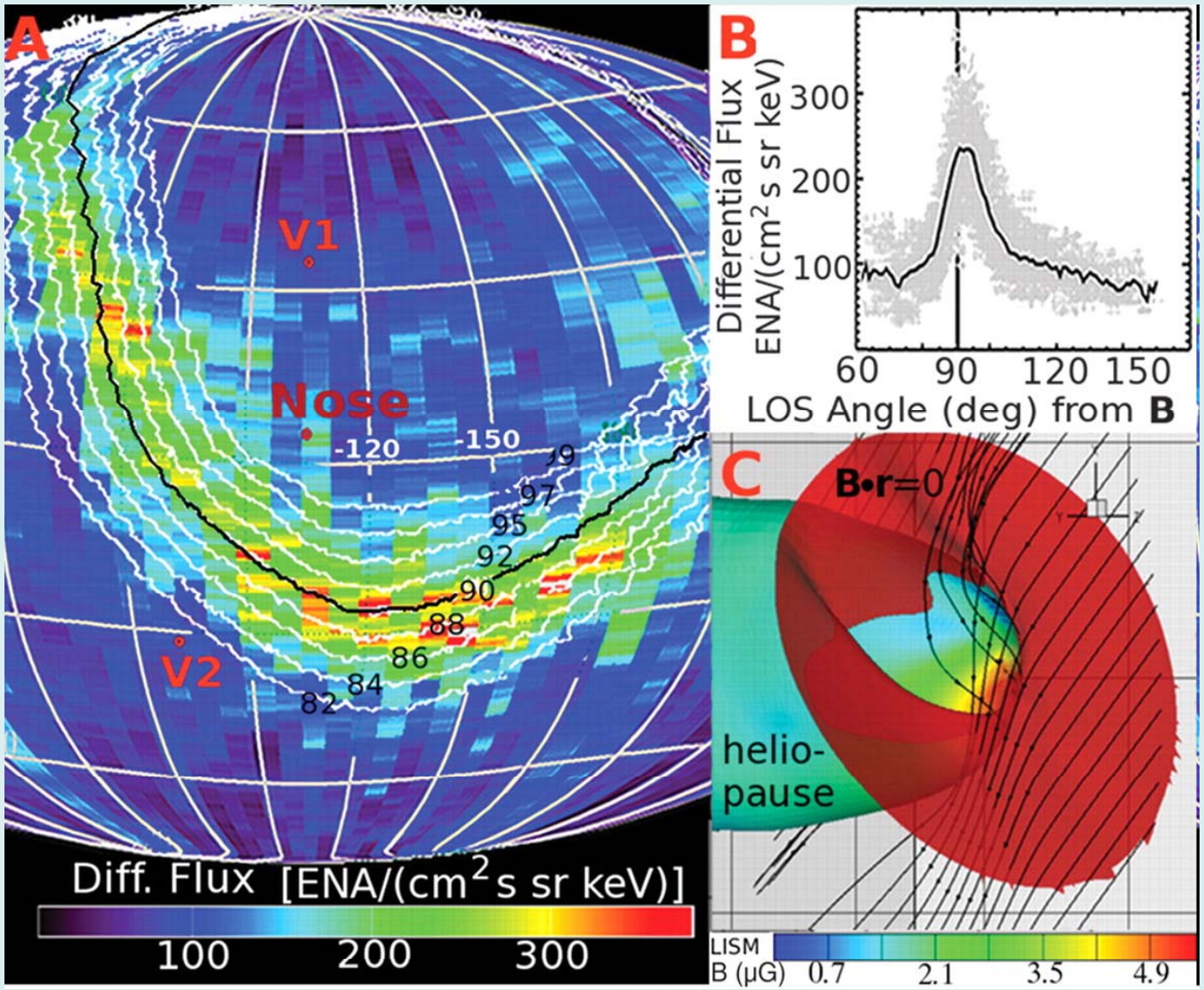


# Local ISM/Heliosphere interaction with a strong $B_{LISM}$




Opher et al.,ApJ, 2006

# Comparison of IBEX image with B.r angle from model




Maximum ENA flux comes from regions where B is orthogonal to line-of-sight.

Schwadron et al., Science, 2009

# The local galactic magnetic field

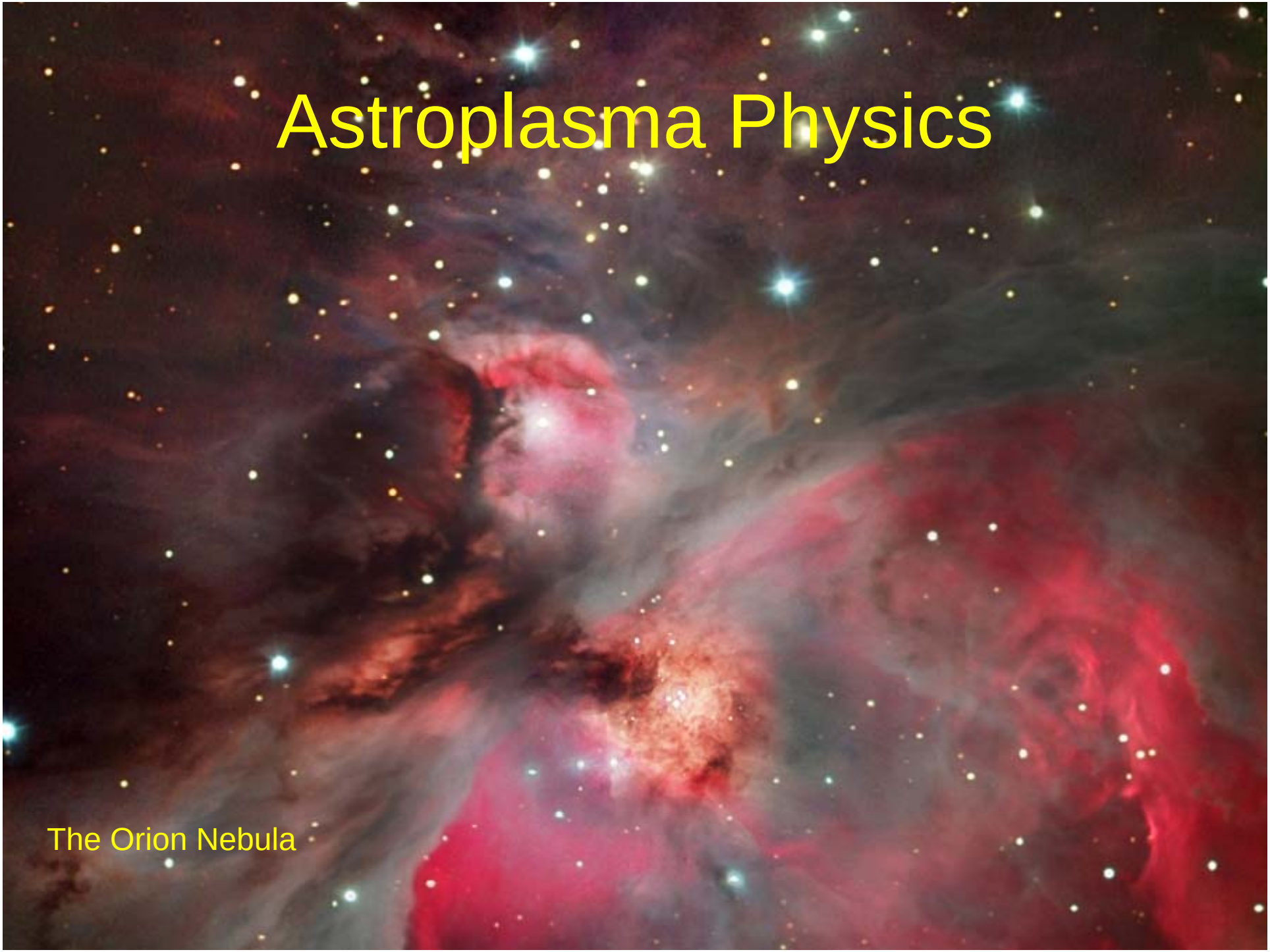
Current best estimate:

$B_{LISM}$ ~ 0.5 nT, at $30^{o}$ to both the galactic plane and the ISM flow direction.

This is several times larger than expected and at an unexpected angle.

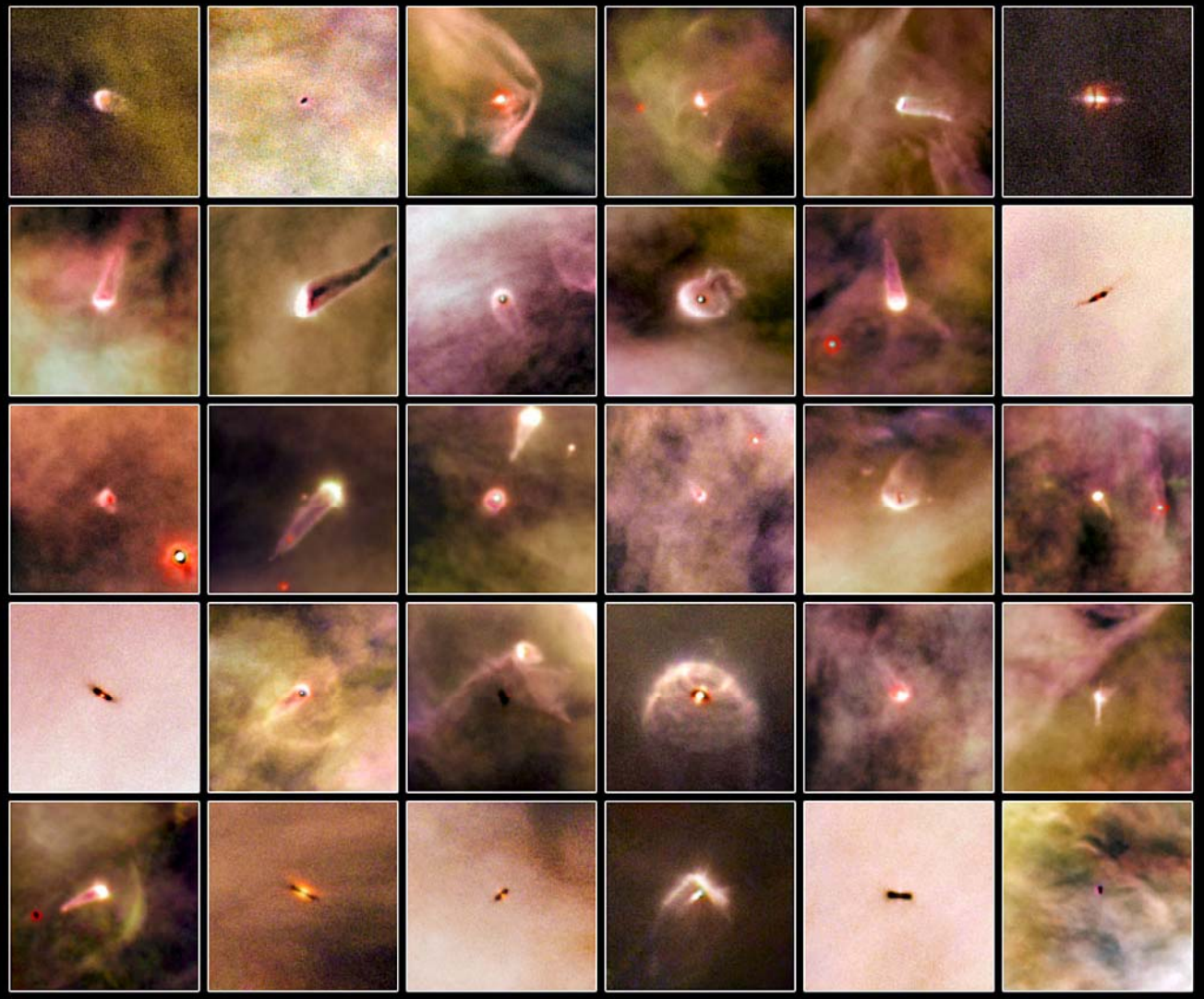
Is the field tilted or turbulent?

# Astroplasma Physics

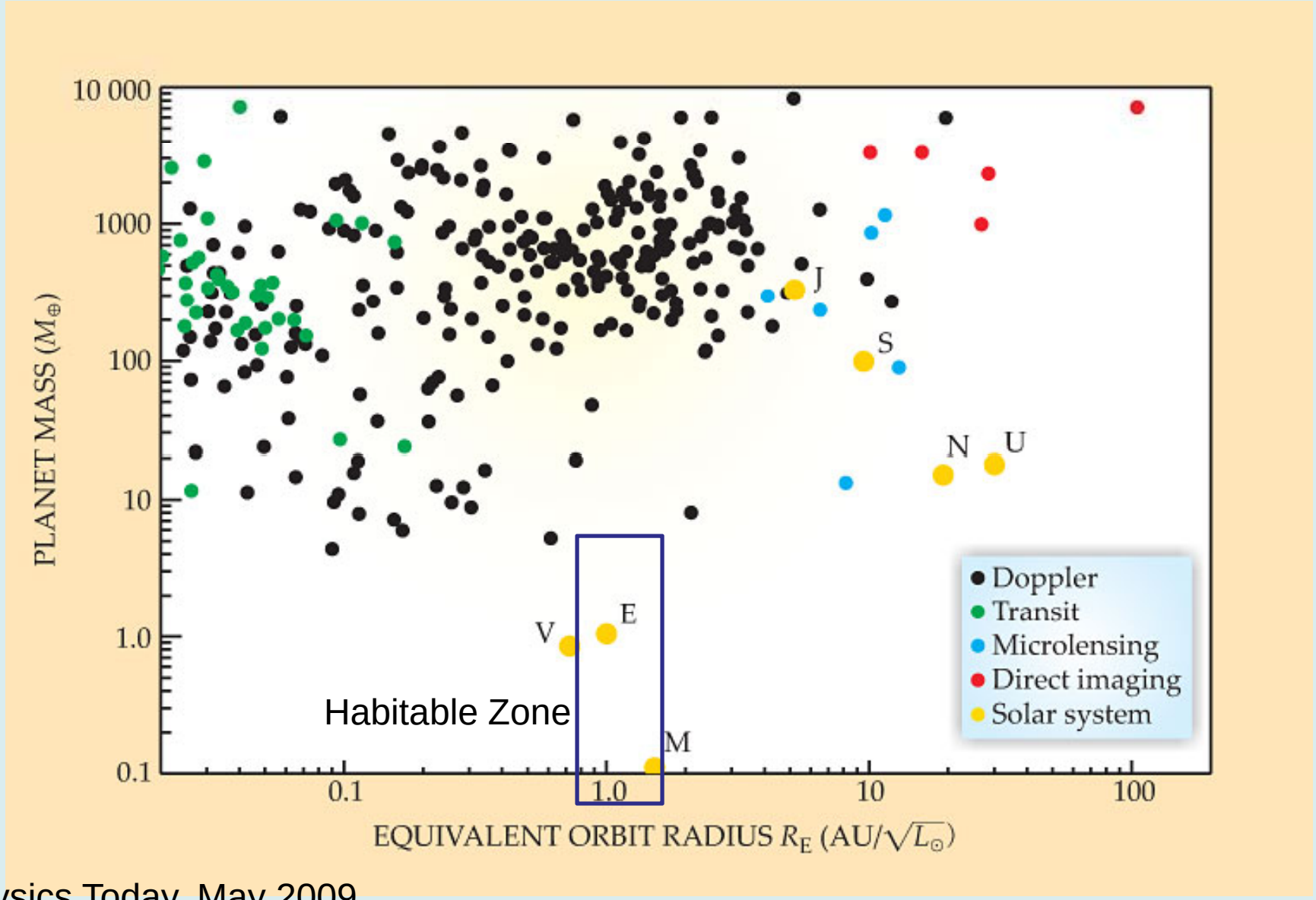


The Orion Nebula

# Bow Shocks and Astrospheres:
## HST Images of 30 Protoplanetary Disks in the Orion Nebula

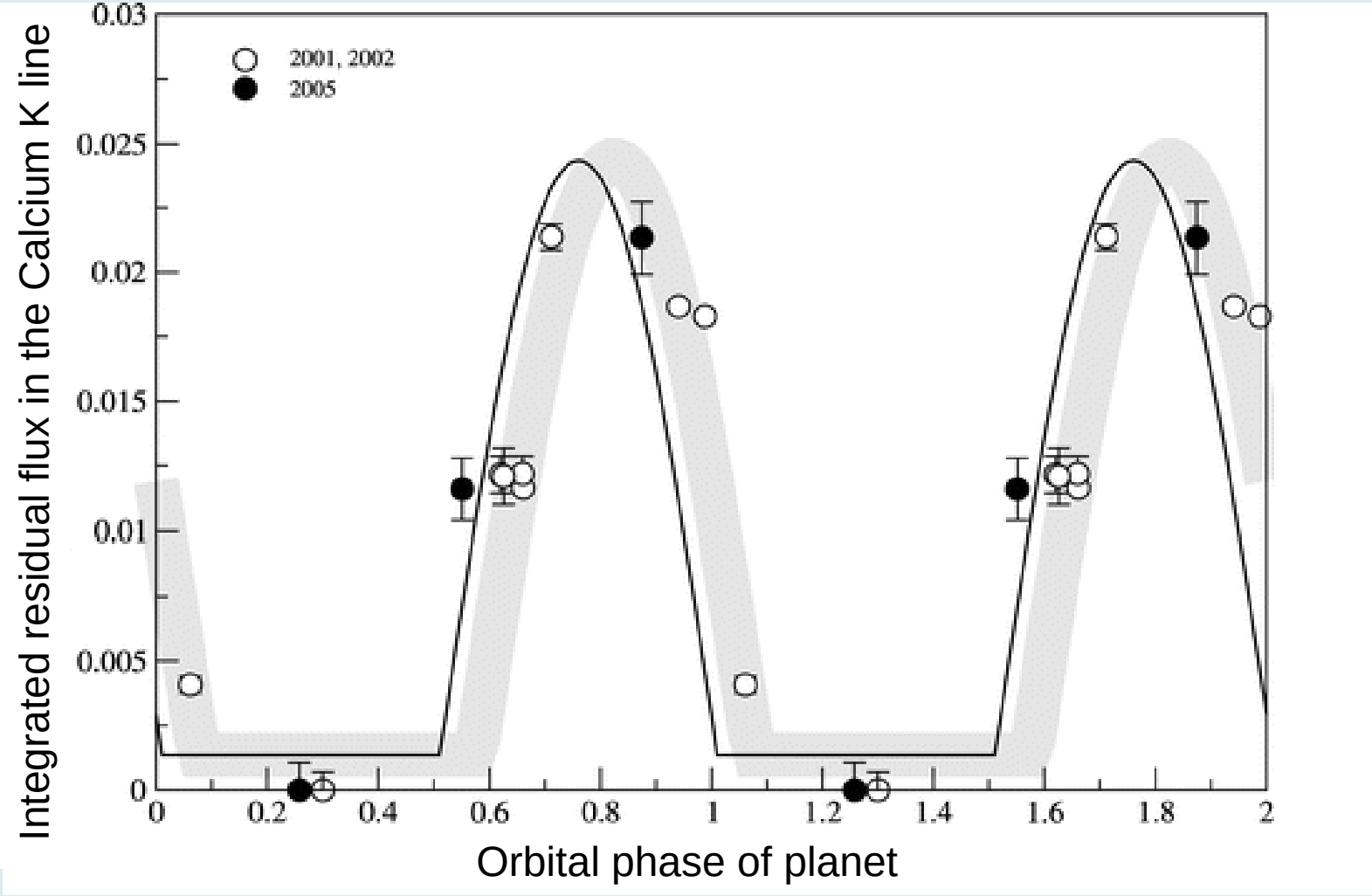


# Mass and normalized distance from star of 300 Exoplanets




Physics Today, May 2009

# Variations in the spectrum of solar-like star HD 179949




The Calcium K line is a chromospheric emission indicative of magnetic active regions. After Shkolnik et al., ApJ, 2008.

# Hot magnetized Jupiter inside its star's Alfven surface magnetically connected to the star