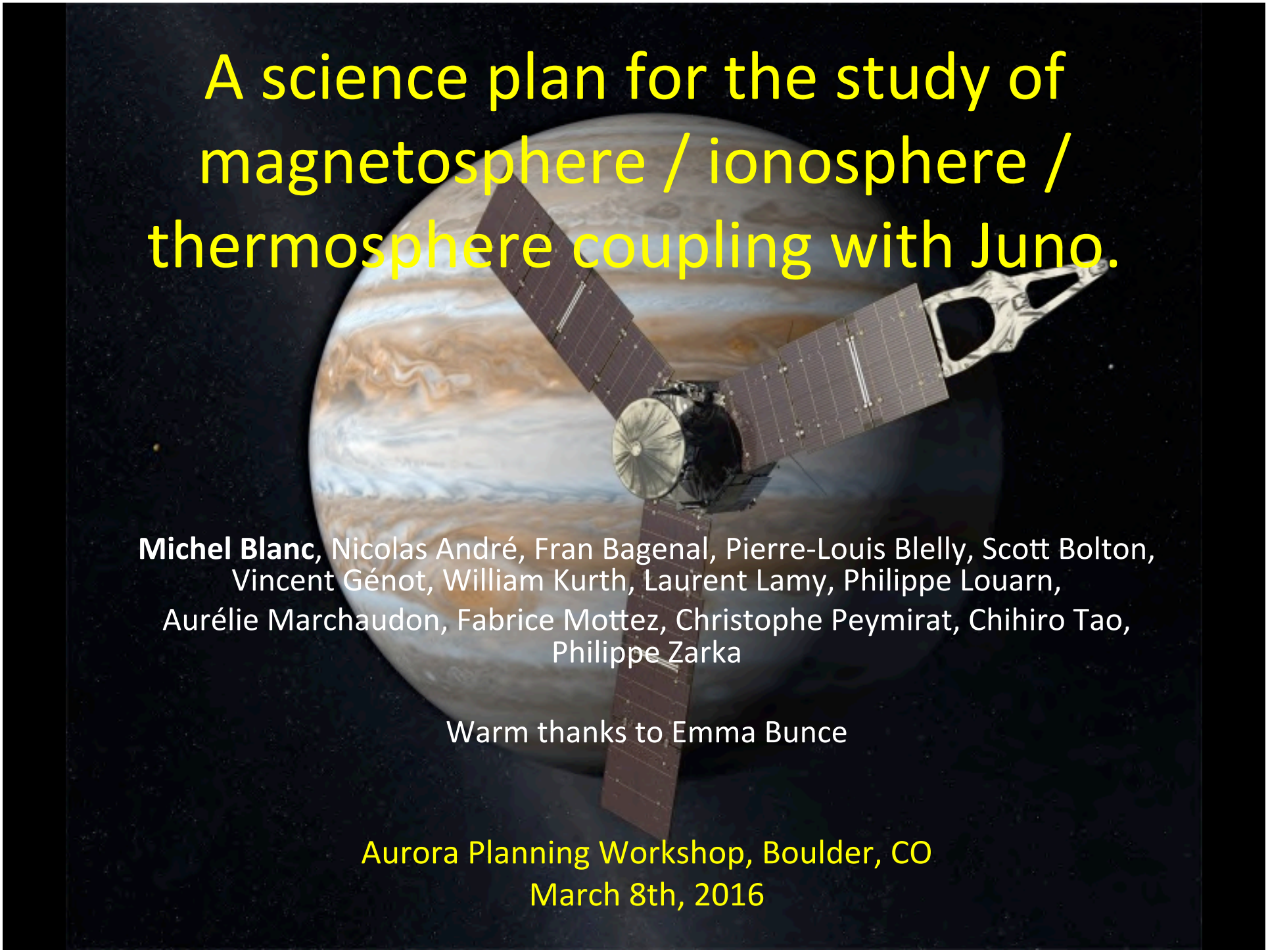
A science plan for the study of magnetosphere / ionosphere / thermosphere coupling with Juno.



Michel Blanc, Nicolas André, Fran Bagenal, Pierre-Louis Blelly, Scott Bolton, Vincent Génot, William Kurth, Laurent Lamy, Philippe Louarn, Aurélie Marchaudon, Fabrice Mottez, Christophe Peymirat, Chihiro Tao, Philippe Zarka

Warm thanks to Emma Bunce

Aurora Planning Workshop, Boulder, CO
March 8th, 2016

PROBLEMS OF ASTROPHYSICAL INTEREST

ANGULAR MOMENTUM TRANSFER

- How is angular momentum transferred between a central magnetized fast-rotating object and its surrounding plasma disk?

LINEAR MOMENTUM TRANSFER

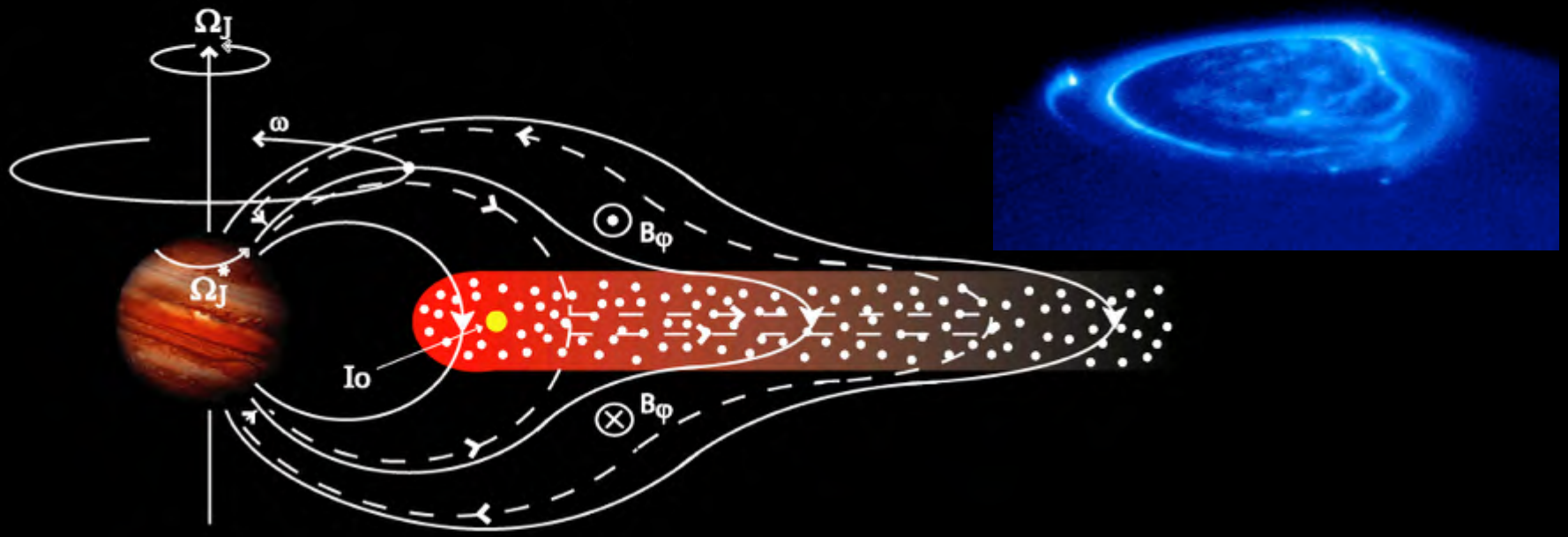
- How is momentum transferred between a central magnetized object and a surrounding plasma flow?

POWERING A RADIO SOURCE

- By which processes does this coupling between the central object and its environment power strong radio emissions and turn the central object into a radio source ?

M-I-T ELECTRODYNAMIC COUPLING PLAYS A KEY ROLE

Field distortion and related electric current system associated with imperfect rotational coupling



Bunce & Cowley (2001b), Cowley and Bunce, 2001
After Hill (1979) and Vasyliunas (1983)

The magnetic field distortion is associated with an electric current system which has

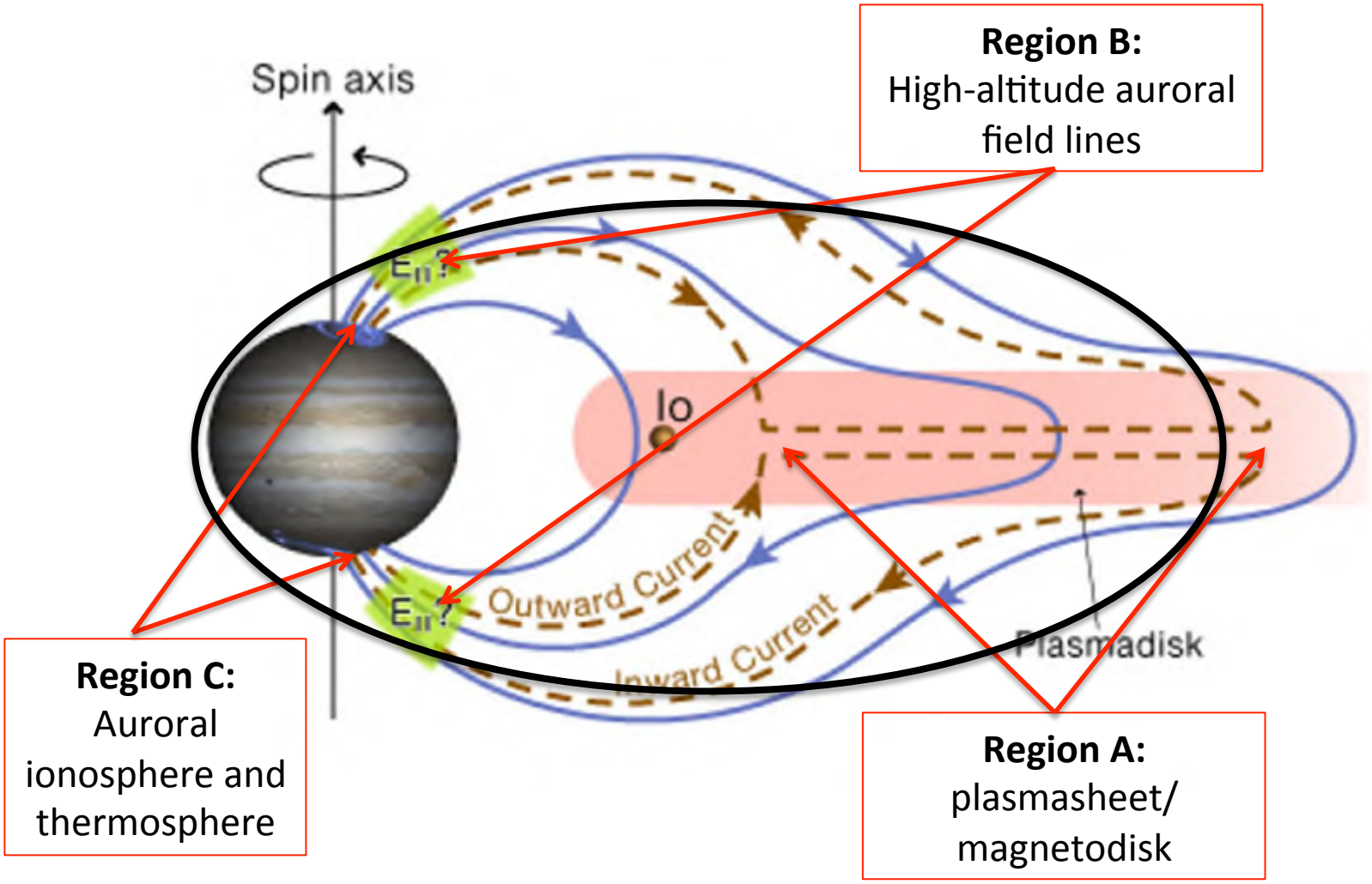
→ Opposite Bϕ on either side of equator

→ Radial current in the equatorial plane associated with **j**x**B** force

→ Equatorward Pedersen currents in the ionosphere

→ Up and down directed field-aligned currents which join and close these currents

PROPOSED APPROACH:
FOCUS ON 3 REGIONS ALONG THIS CURRENT LOOP
USING JUNO



Region B:
High-altitude auroral field lines

Region C:
Auroral ionosphere and thermosphere

Region A:
plasmasheet/ magnetodisk

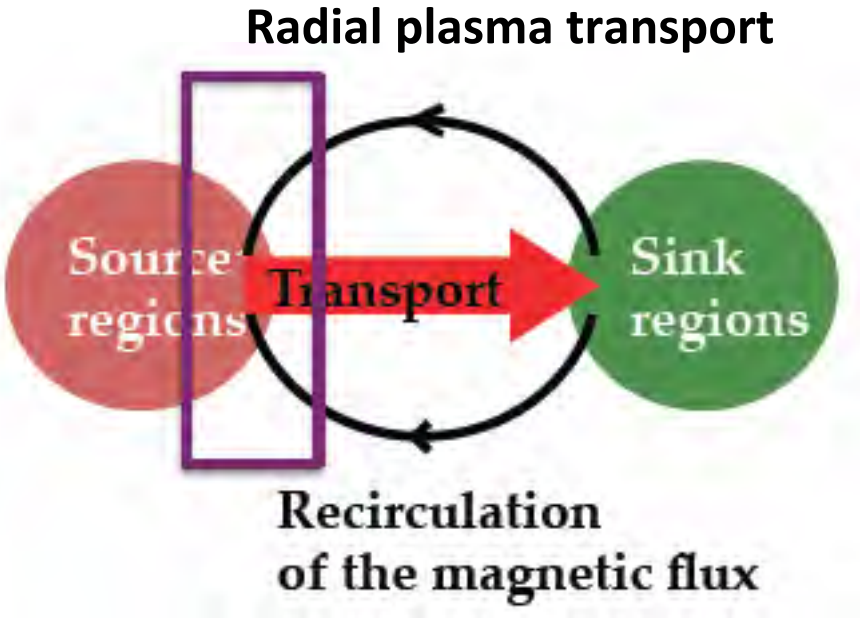
(from Cowley and Bunce, 2001)

REGION A: THE MAGNETODISC

- OBJECTIVE: determine the radial current in the disk, and the radial transport of mass and angular momentum.

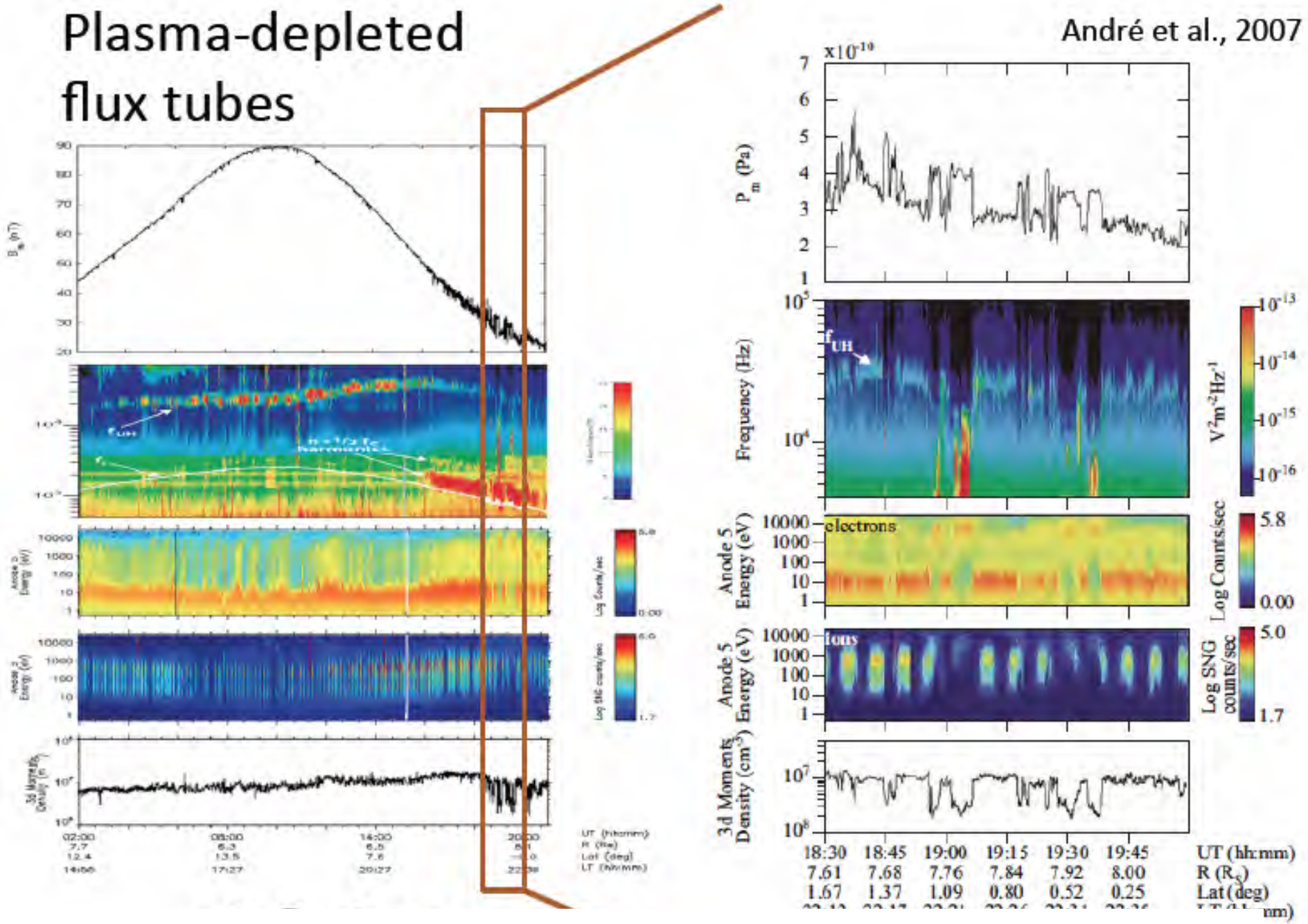
- MEASUREMENT GOAL: Characterize the net radial transport of matter, and the magnetic torque, at all scales.
  - **Small scales: interchange instability (1)**
  - **Large scale: global instabilities of the magnetodisk (2)**
  - Other?

- MEANS:
  - Synoptic multi-instrument studies (fields, waves, particles)
  - Models of the processes at different scales



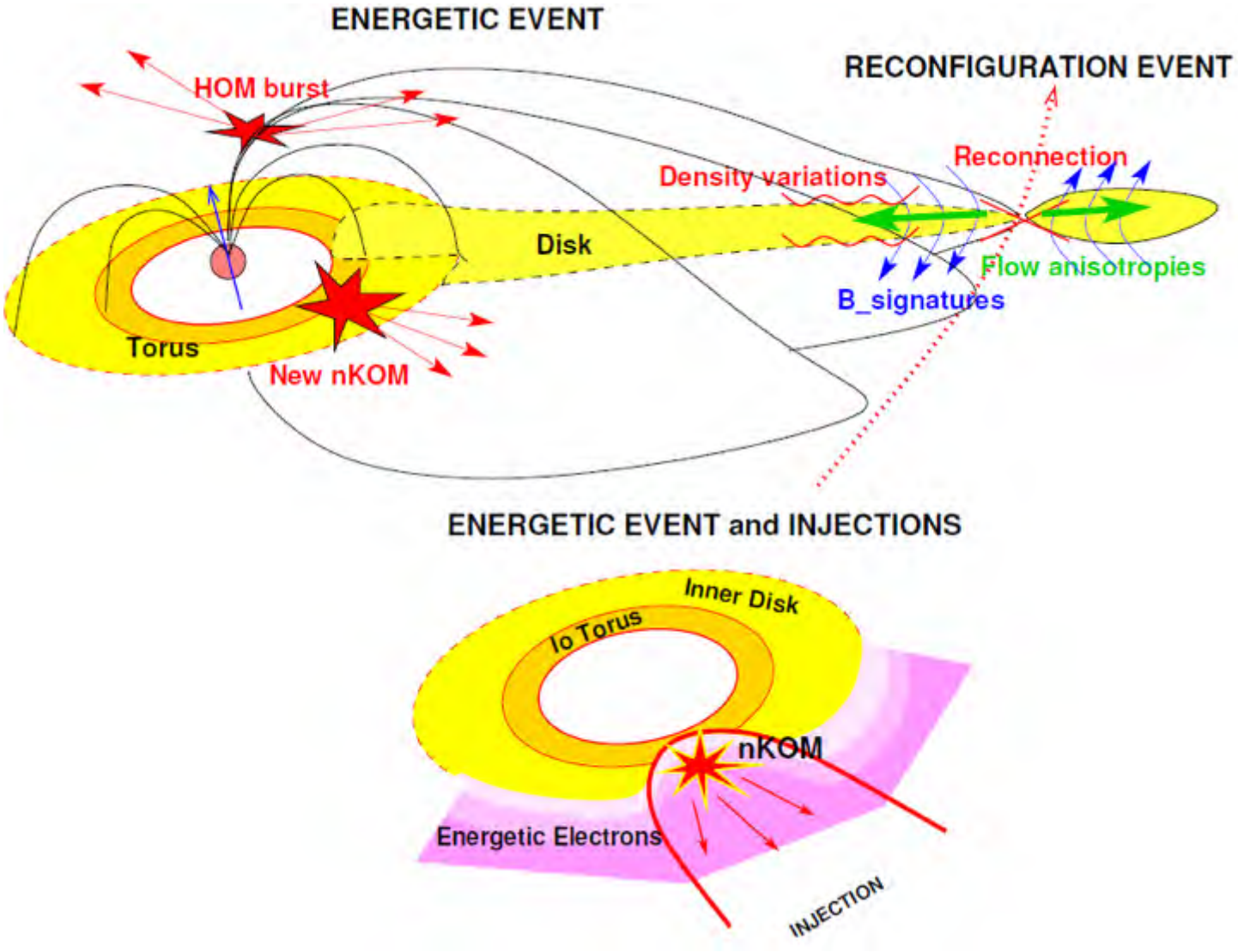
Plasma-depleted flux tubes

André et al., 2007



(1) Study of the Interchange instability at Saturn with CASSINI

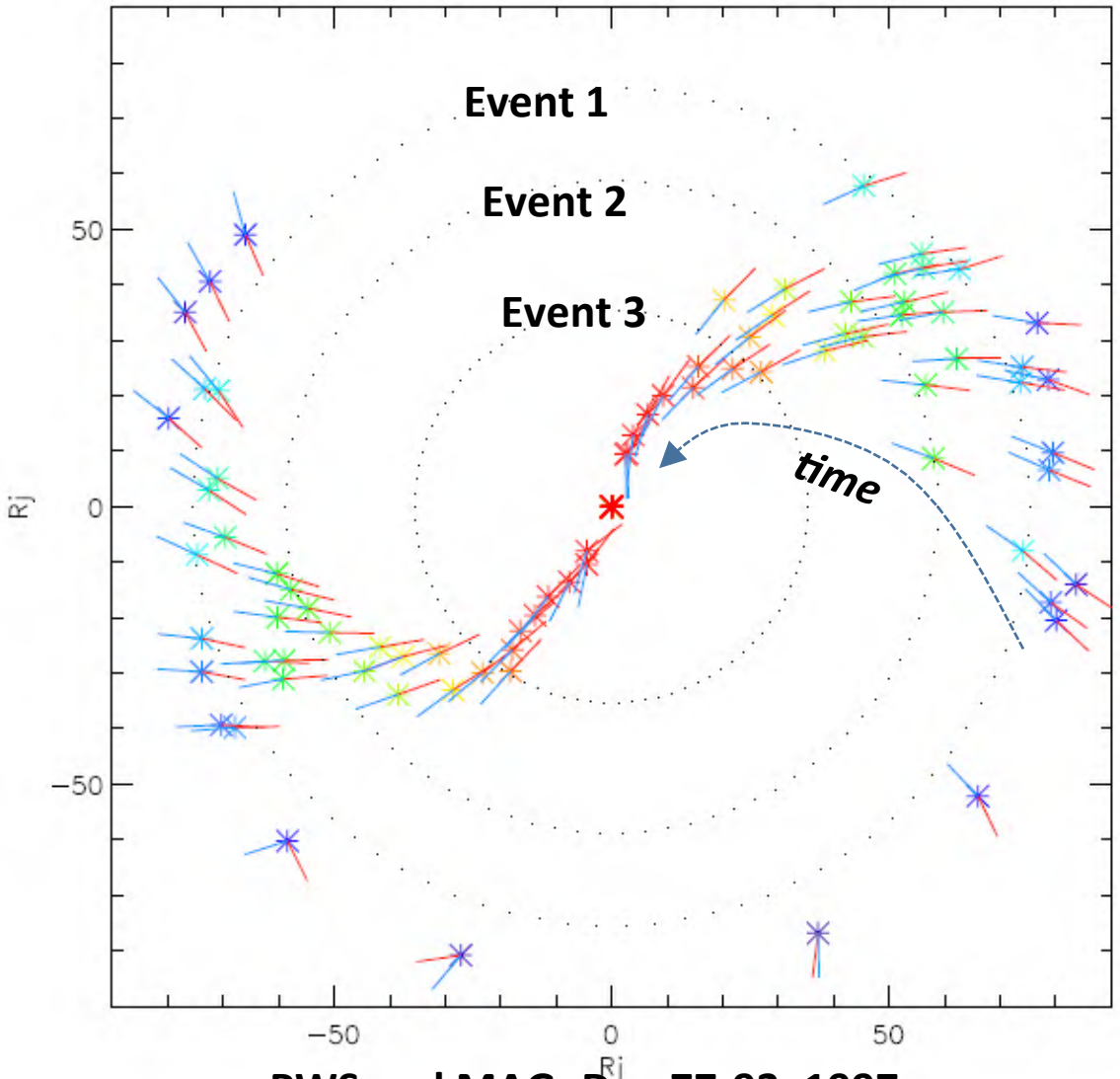
(2) A sketch of the large-scale plasmadisk disruption process



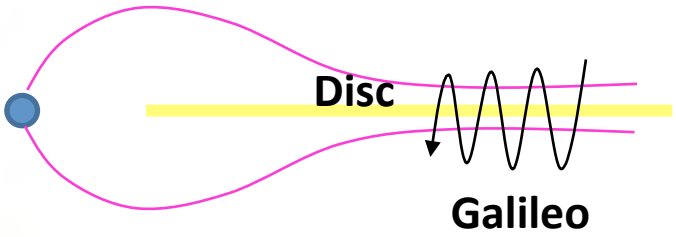
Louarn et al., JGR blue, 119, 6, pp. 4495-4511 (June 2014)

Magnetic signature of angular momentum transfer to the disk on magnetodisk crossings

~ intersection of the magneto-disc neutral plane with the ecliptic plane.



PWS and MAG- Doy 77-93, 1997

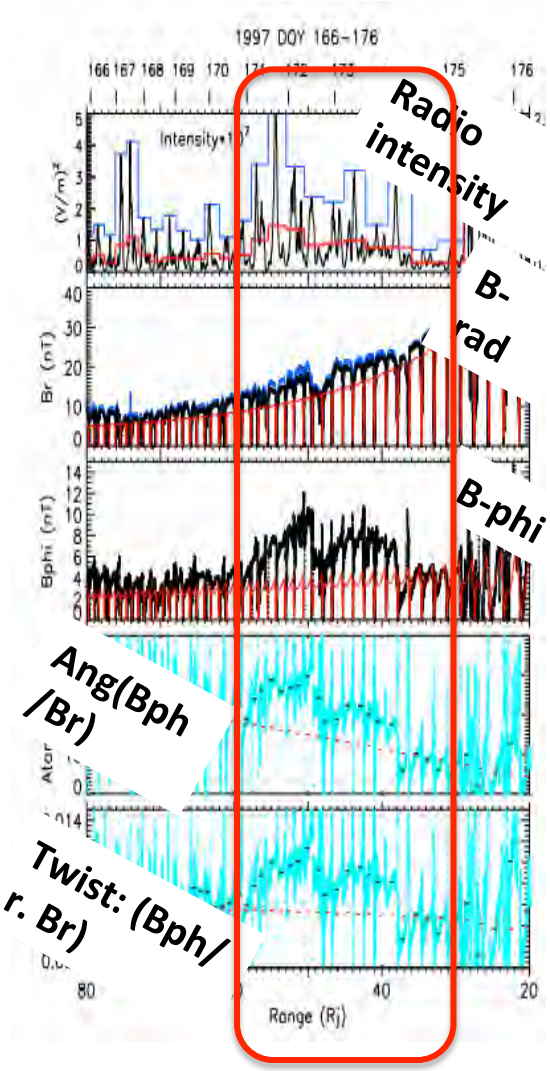


Spiral-like pattern with distorsions corresponding to the events

Louarn et al., 2014

Linking the disc magnetic twist and the radio flux

PWS and MAG- Doy 166-176, 1997



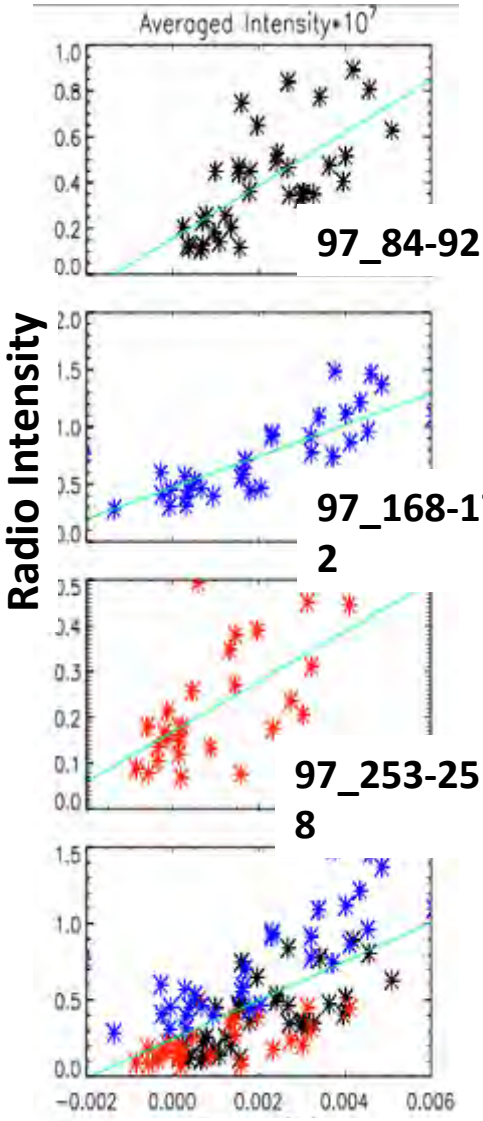
Example of radio/twist correlation

Intense radio flux = more twisted disc

Obvious link with M-I coupling.

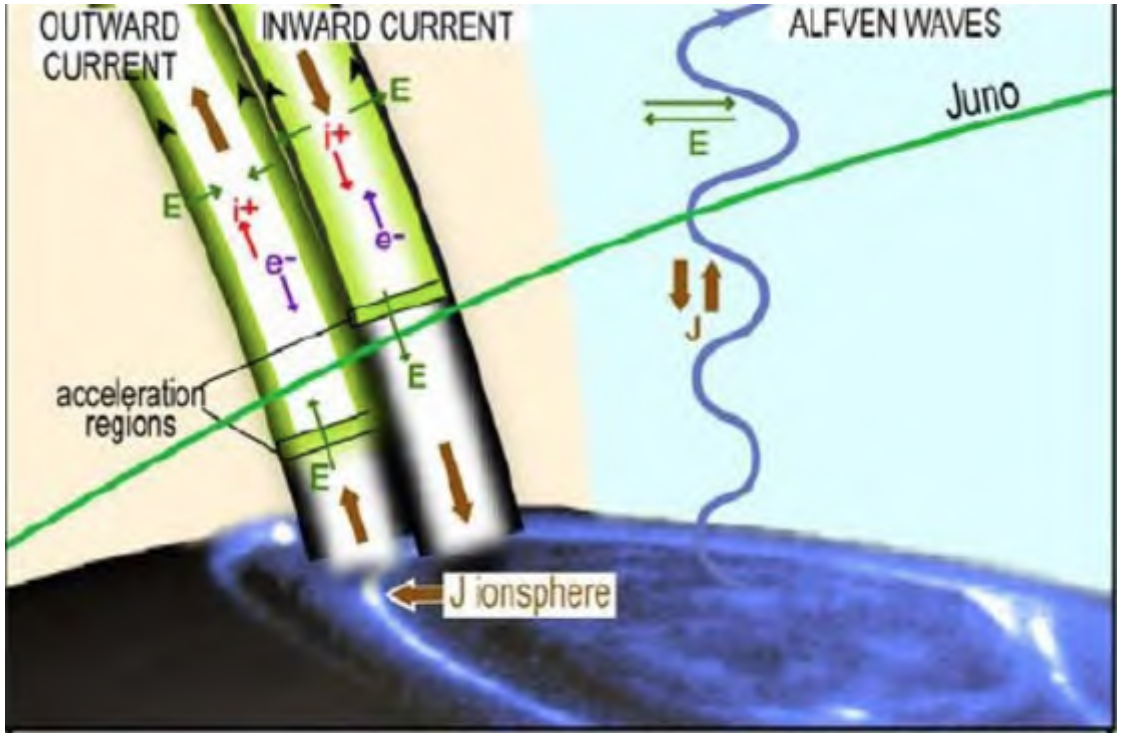
Twist -> J_rad -> J//

Hill's model: Would be connected to long term variations of dM/dt



Louarn et al., 2016

REGION B: AURORAL FIELD LINES



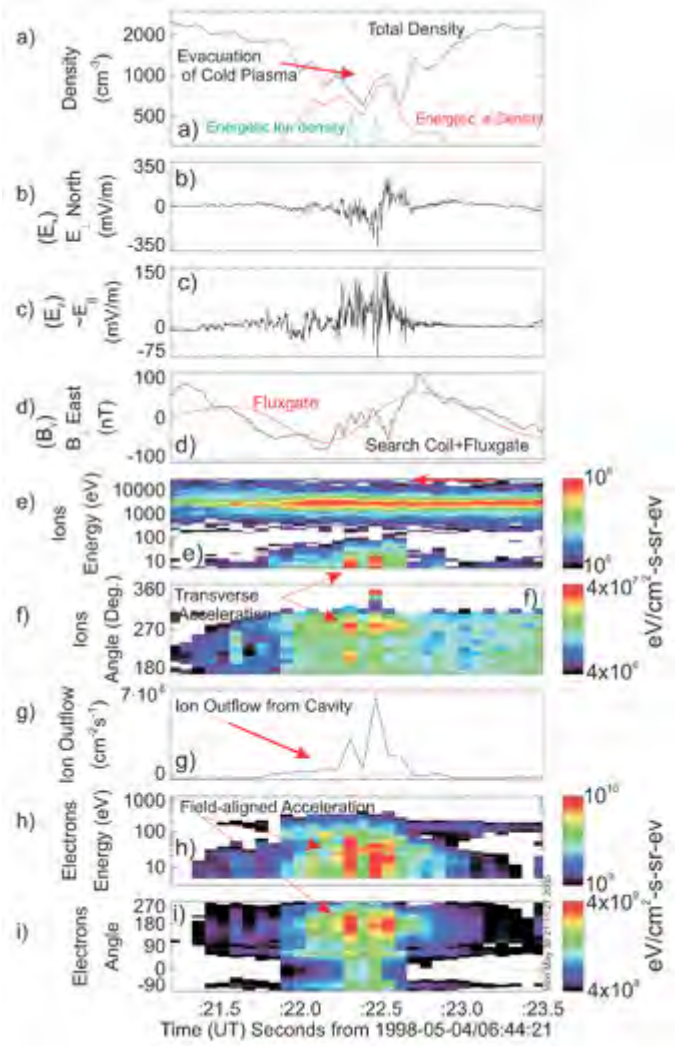
OBJECTIVES:

- Characterize the auroral acceleration regions at all scales, and the net field-aligned current flow
- Integrate across all scales to find the effective current-voltage characteristics
- Identify the sources of free energy which power radio emissions

MEANS:

- Synoptic multi-instrument studies
- Detailed study of the exact conjugacy between acceleration regions and auroral forms

CHARACTERIZING AURORAL FIELD LINES EXAMPLE OF EARTH CAVITIES



A topside ionospheric cavity observed by FAST (Chaston et al., 2006) on Earth orbit

Density cavity

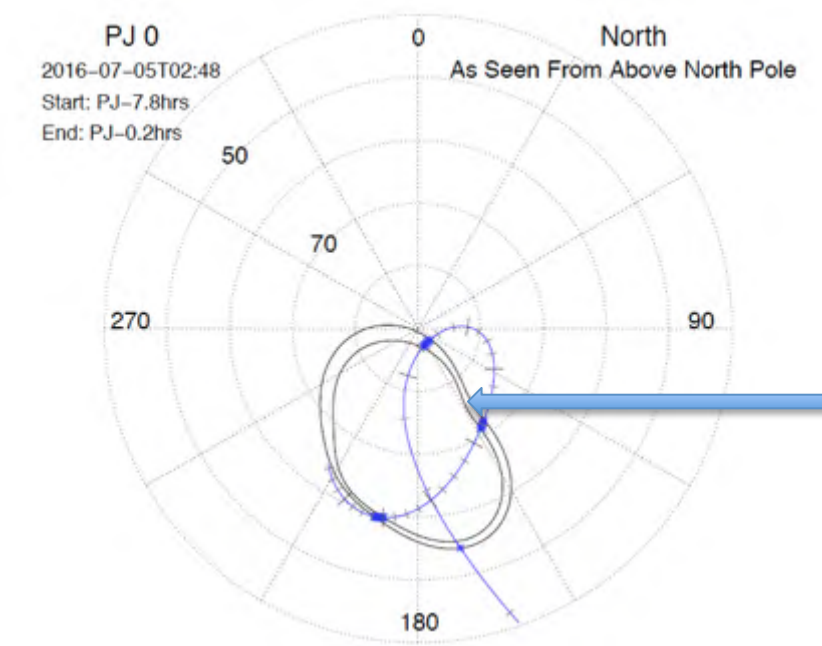
Electric field

Jpar from Delta B

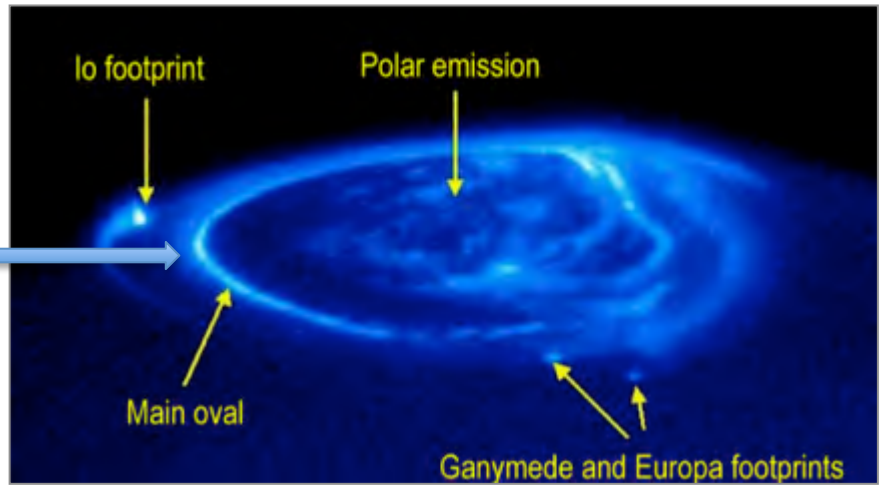
Ion acceleration

Electron acceleration

REGION C: AURORAL IONOSPHERE AND THERMOSPHERE



TWO COMPLEMENTARY TOOLS



2-D MAPPING OF KEY QUANTITIES:

- Field-aligned currents
- Particle precipitation fluxes
- Associated energy deposition

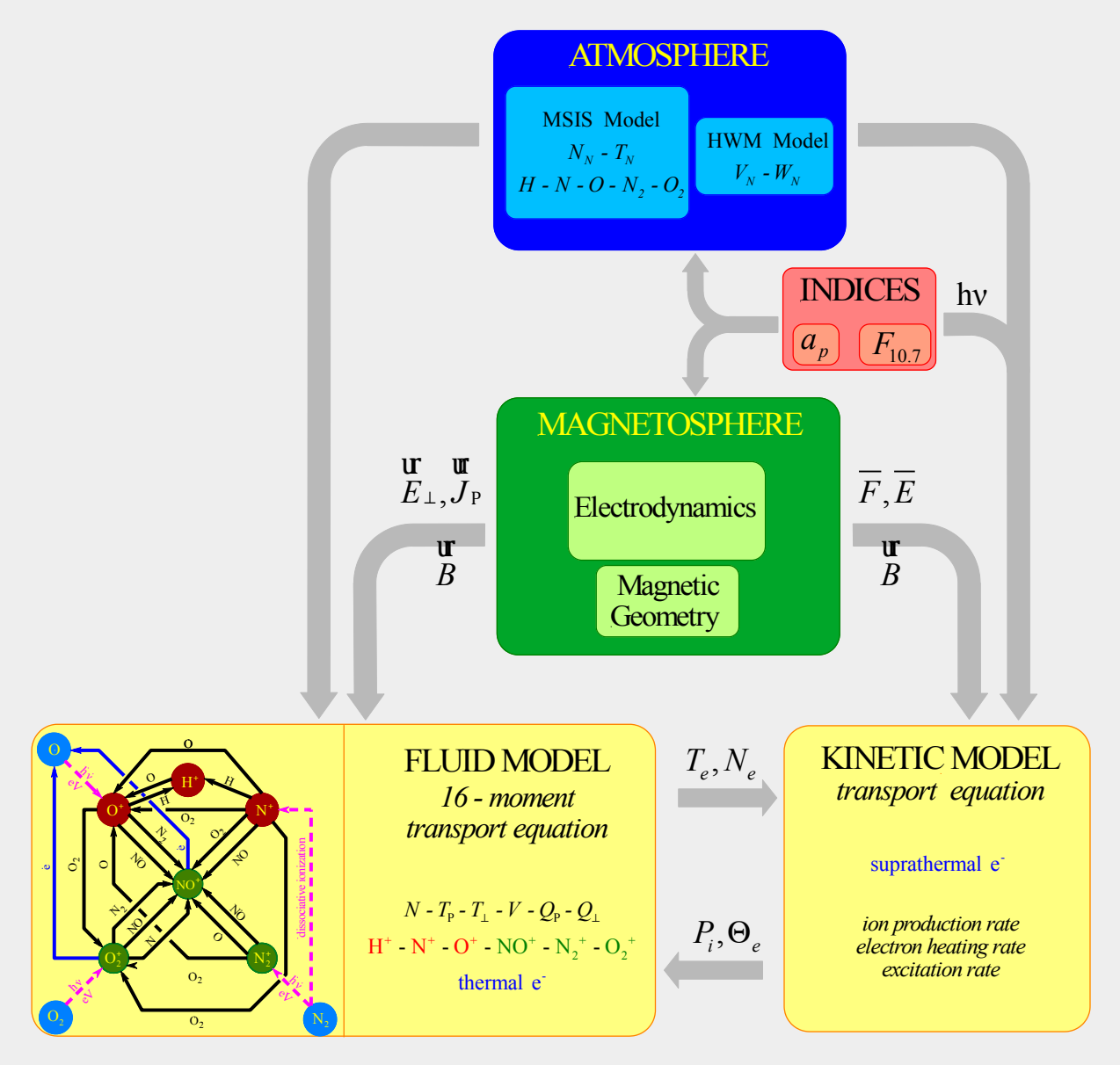
3-D MODELING:

- **Ionosphere model (IPIM)**
- **M-I-T coupling model (TIEGCM)**
- Providing such outputs as:

Ionospheric conductivities, winds, Joule heating and angular momentum budget of thermosphere

3-D IPIM-Jupiter Ionosphere model

(Blelly and Marchaudon)



2-D M-I-T coupling model (C. Tao)

⇒ calculate (i) thermosphere/Ionosphere model and (ii) torque equation of the out-flowing magnetospheric plasma, interactively

(i) Thermosphere/Ionosphere 2D
(3 components in latitude & altitude)

(ii) Magnetospheric plasma 1D
(azimuthal component in radial)

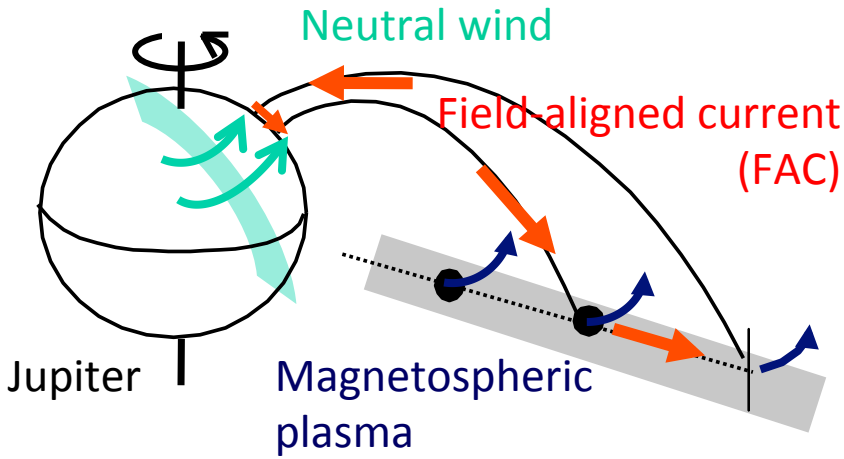


Fig. Model Region

Assumption:

- Rotation axisymmetric
- Ignoring the Alfven transit time | Static condition
- Magnetic field
  dipole on ionosphere
  empirical model at magnetospheric equator [Nichols and Cowley, 2004]

Coupling Current & Thermosphere

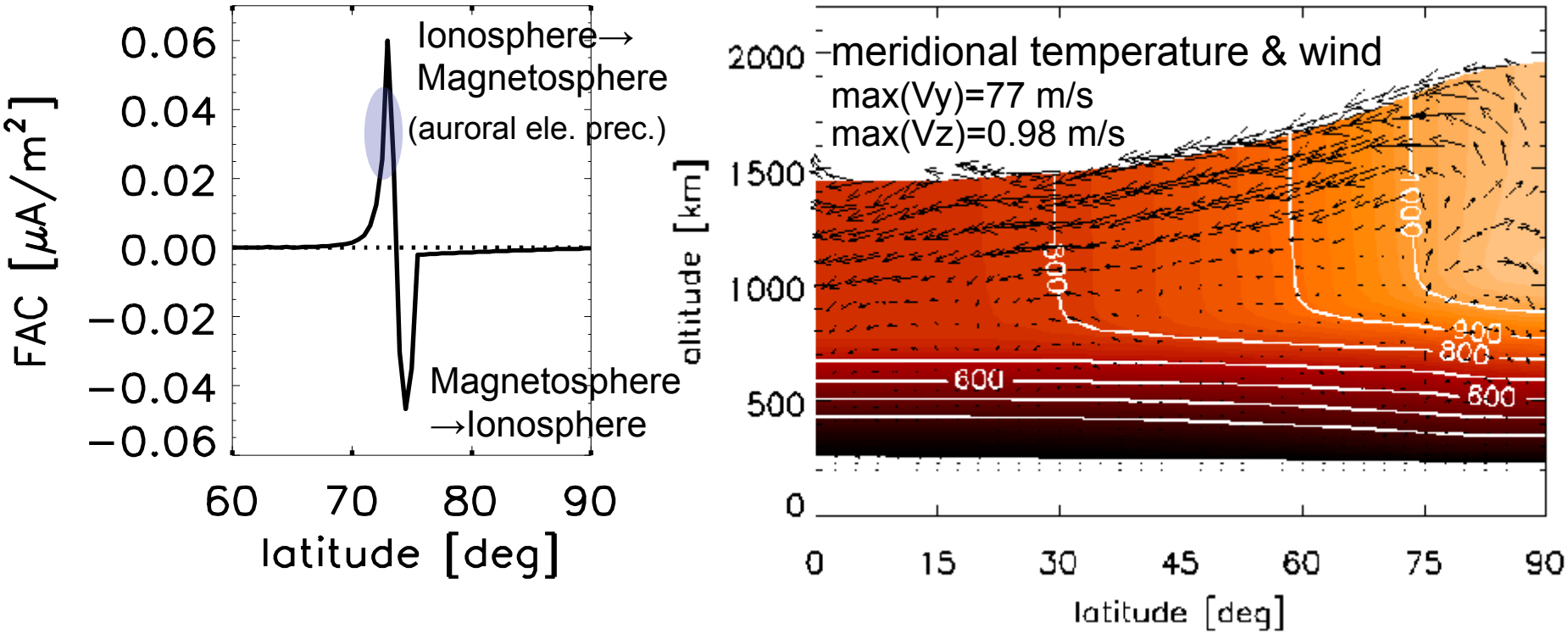


Fig. Latitudinal distribution of FAC (left) and meridional temperature and wind fields (right).

FAC is formed
⇔Obs. 0.04-0.4 μA/m²
[Gustin et al., 2004]

Temperature: Joule heating in high latitudes

Meridional circulation : heating in the high latitudes

Energy budget: where does Jupiter rotational energy go? Magnetodisk rotation, atmosphere heating?

How to feed the model with Juno observations ?

Step-1: Relate model parameters with observable parameters

Field-aligned current ⇔ UV + MAG

Ionosphere H_3^+ density + temperature ⇔ IR

Step-2: Constrain parameters by observation and comparison

magnetic field + UV → field-aligned current

particle obs. → auroral electron spectrum, mag. plasma velocity (?)

IR obs. → temperature

IR high-spectral obs. (ground-based) → wind field

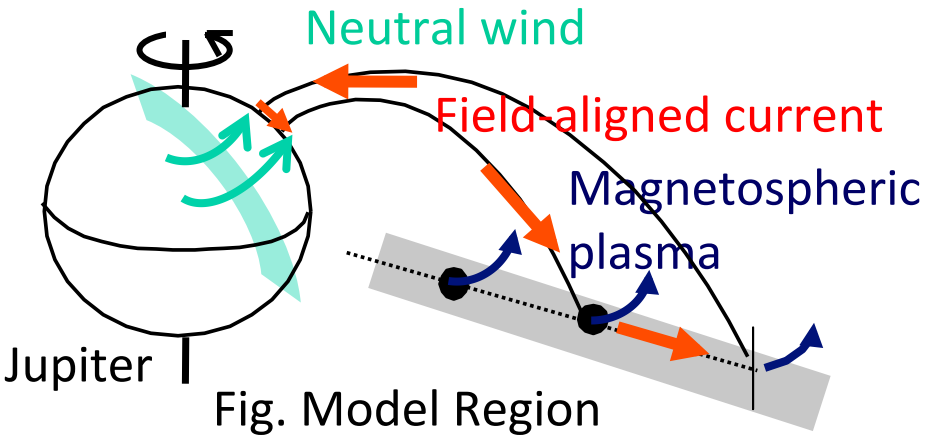


Fig. Model Region

*Link these observed parameters in a model to evaluate energy transfer in the system

*Constrain how much "additional" heating is required.

Or other ideas/suggestions ?

3-D M-I-T COUPLING MODEL FOR JUPITER

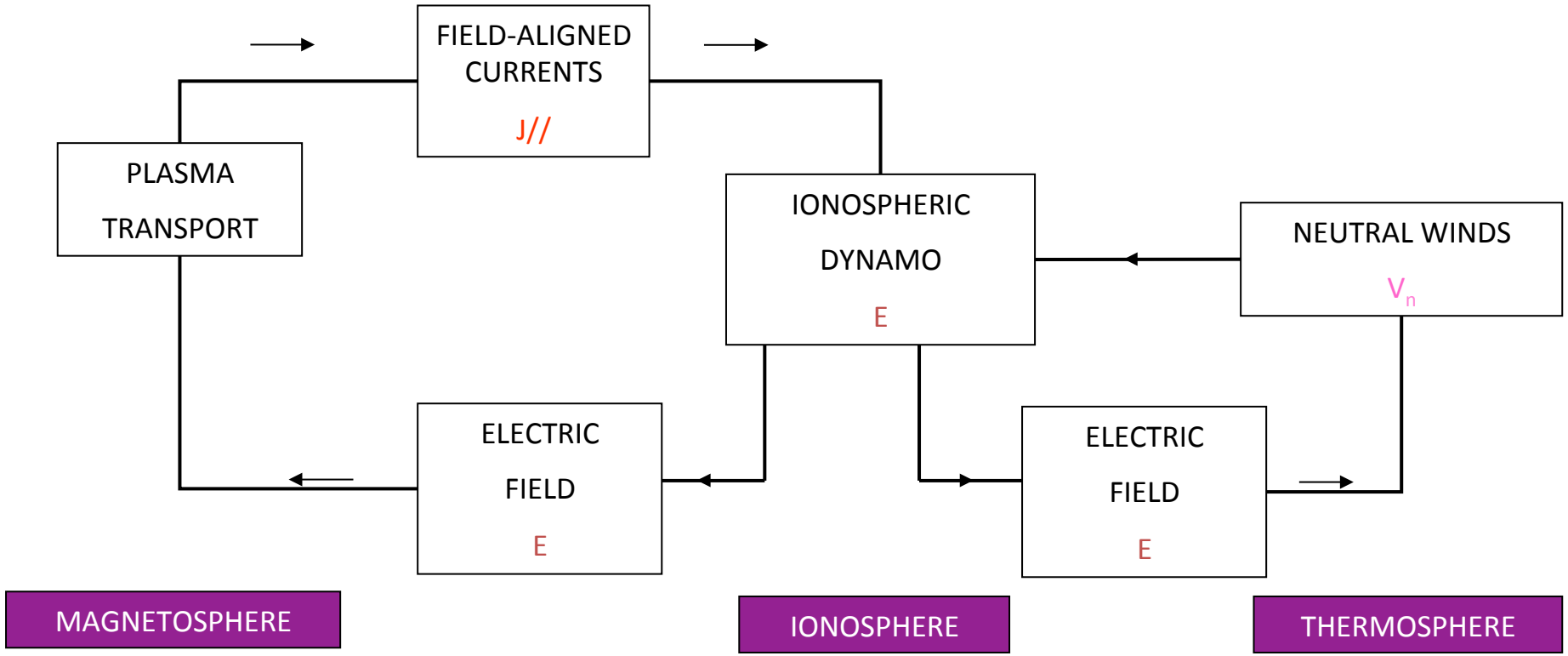
(C. Peymirat, work in progress)

➔ Non dipole magnetic fleid model ==> Euler potentials

➔ Sources of the plasma ==> rings and satellites

➔ Transport of magnetospheric plasma ==> centrifugal force, corotation electric fields, ionospheric dynamo

➔ Field-aligned currents ==> generated by satellite and tori motions



CONCLUSIONS

- Understanding momentum transfer through the diversity of magnetospheres is a problem of major astrophysical interest

- Juno offers a unique opportunity to study it in the reference fast rotating magnetosphere.

- Addressing this major science objective requires:
  - A focus on the three « key regions »
  - appropriately planned observations,
  - efficient tools for multi-instrument studies,
  - modelling tools

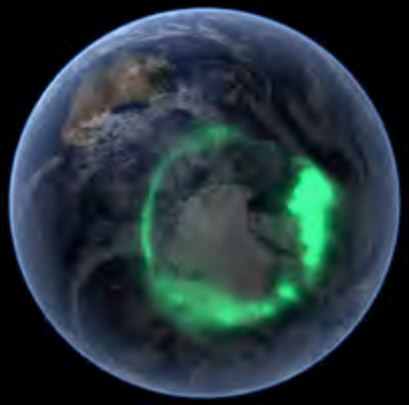
  - ALL INTERESTED COILLEAGUES AND TEAMS ARE INVITED TO JOIN THIS TEAM EFFORT

Thank you very much for your attention!

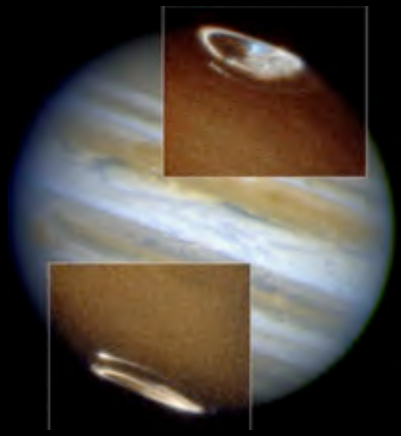
This talk partially reflects the outcome of a seminar
organized by IRAP and LESIA in Toulouse on oct. 13 and 14, 2015.

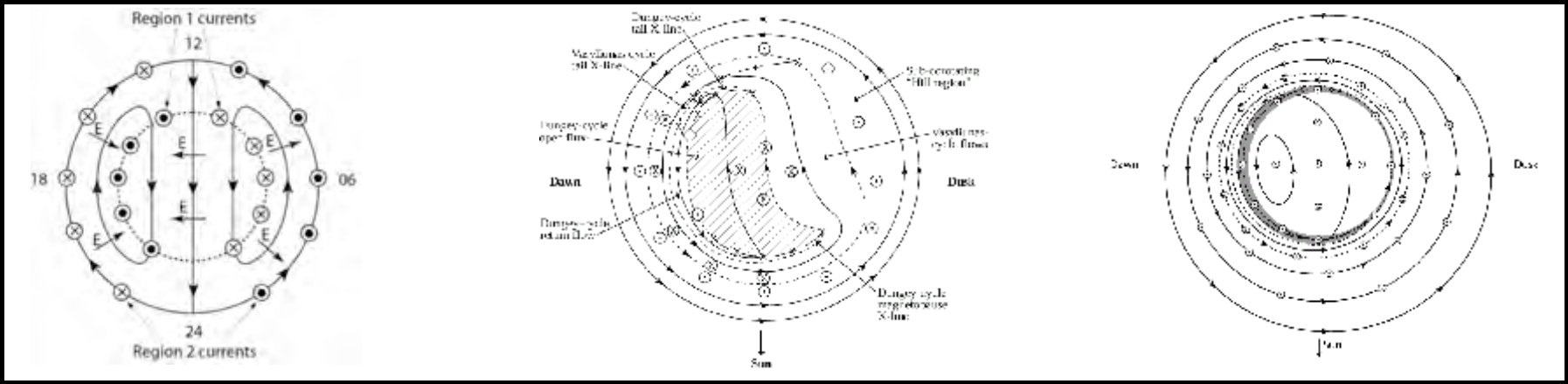
All presentatlons are available at:
http://cdpp.eu/workshops/Jupiter_MIT_coupling/

Pioneering work by the Leicester group, following Tom Hill's initial works, visited via an analytic approach the diversity of coupling currents and plasma flows :



Ionospheric Flows and Currents





Taken from Cowley [2001]

Taken from Cowley et al [2003]

Taken from Cowley et al [2004]

The field-aligned currents that flow between the ionosphere/thermosphere and magnetosphere in planetary plasma systems are fundamental to the processes that transfer stress between these regions via the planetary magnetic field (see, e.g., the review by Cowley [2000]).