Automated event identification techniques for magnetic and plasma signatures of reconnection

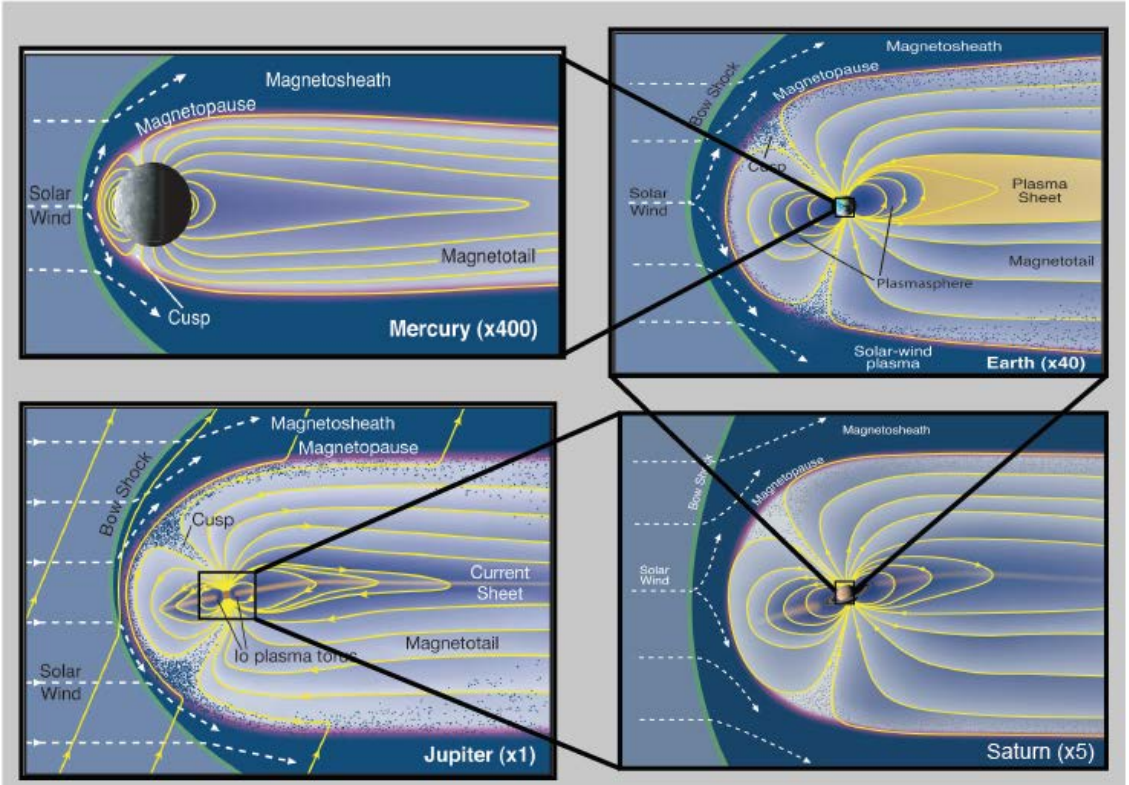


Image Courtesy Fran Bagenal and Steve Bartlett

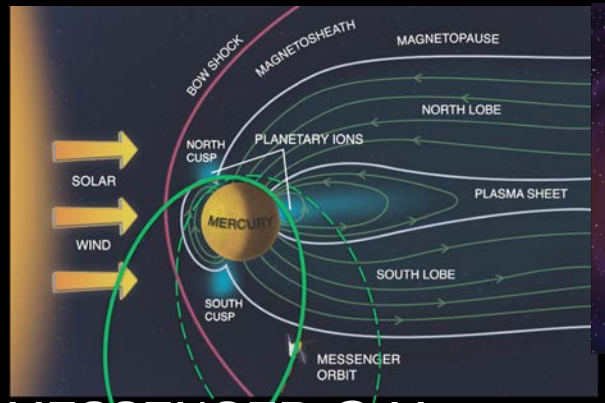
Magnetic reconnection
- Products
- Textbook examples
- Steps to automation
- Current algorithms
- Outstanding problems
- Cassini “challenge”!

Dr. Caitríona Jackman c.jackman@soton.ac.uk

Lorentz Center, September 2017

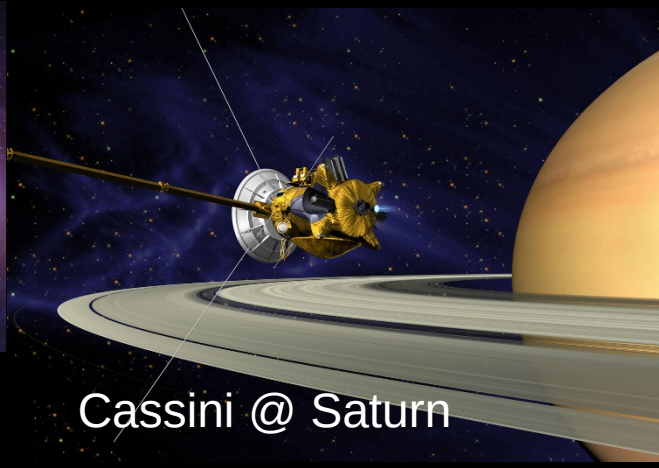
UNIVERSITY OF Southampton

Motivation and Challenges:



MESSENGER @ Mercury

Juno @ Jupiter



Cassini @ Saturn

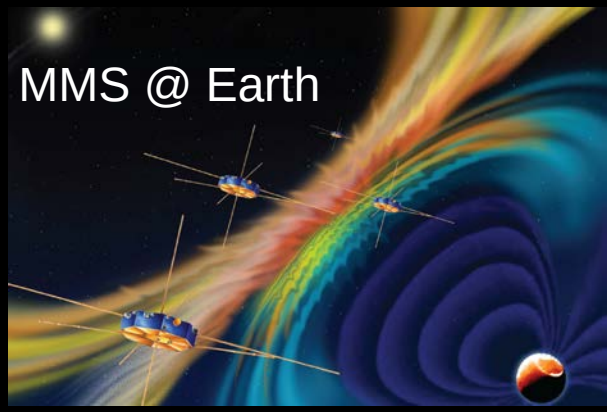
Science gain from large statistical studies

Dataset availability

Mission funding windows

Bridge jargon gap

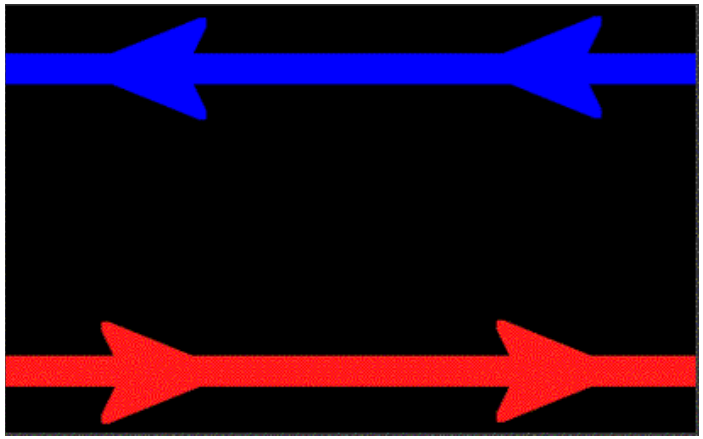
Time investment vs. reward

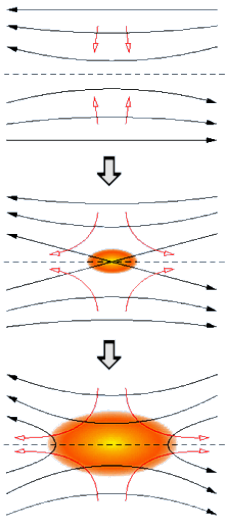


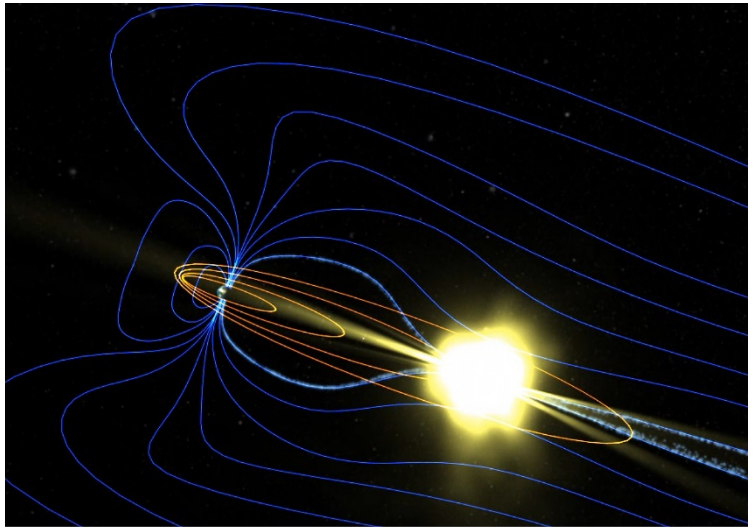
MMS @ Earth

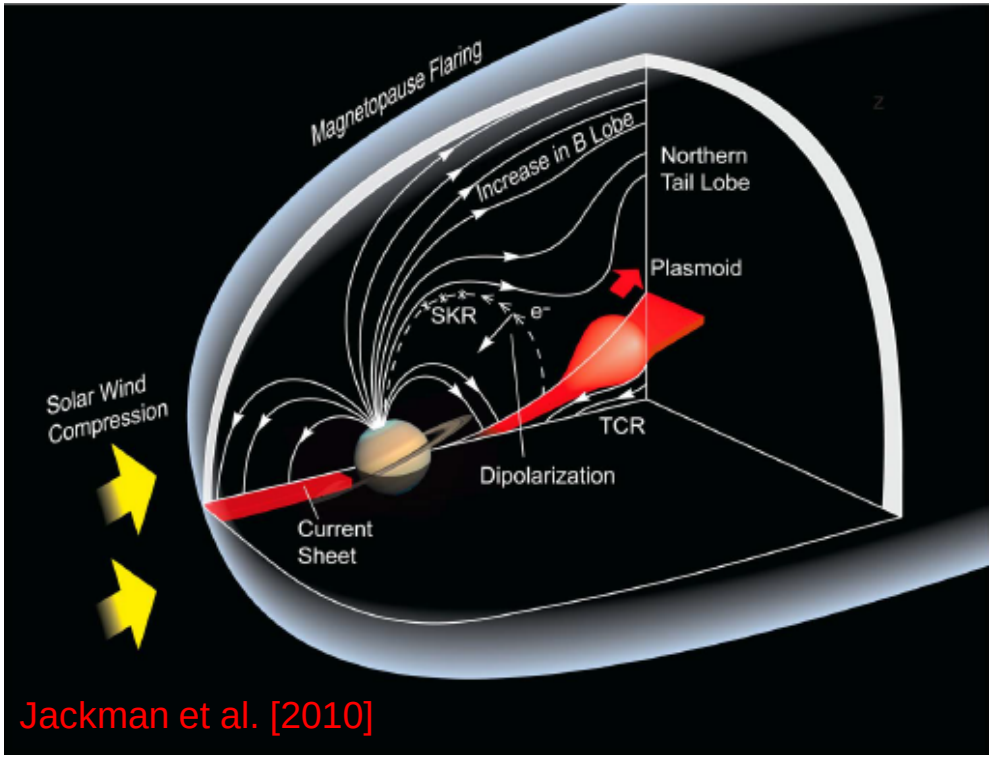
Cluster @ Earth

Magnetic Reconnection









Jackman et al. [2010]

Reconnection involves the explosive release of stored-up energy

Local:

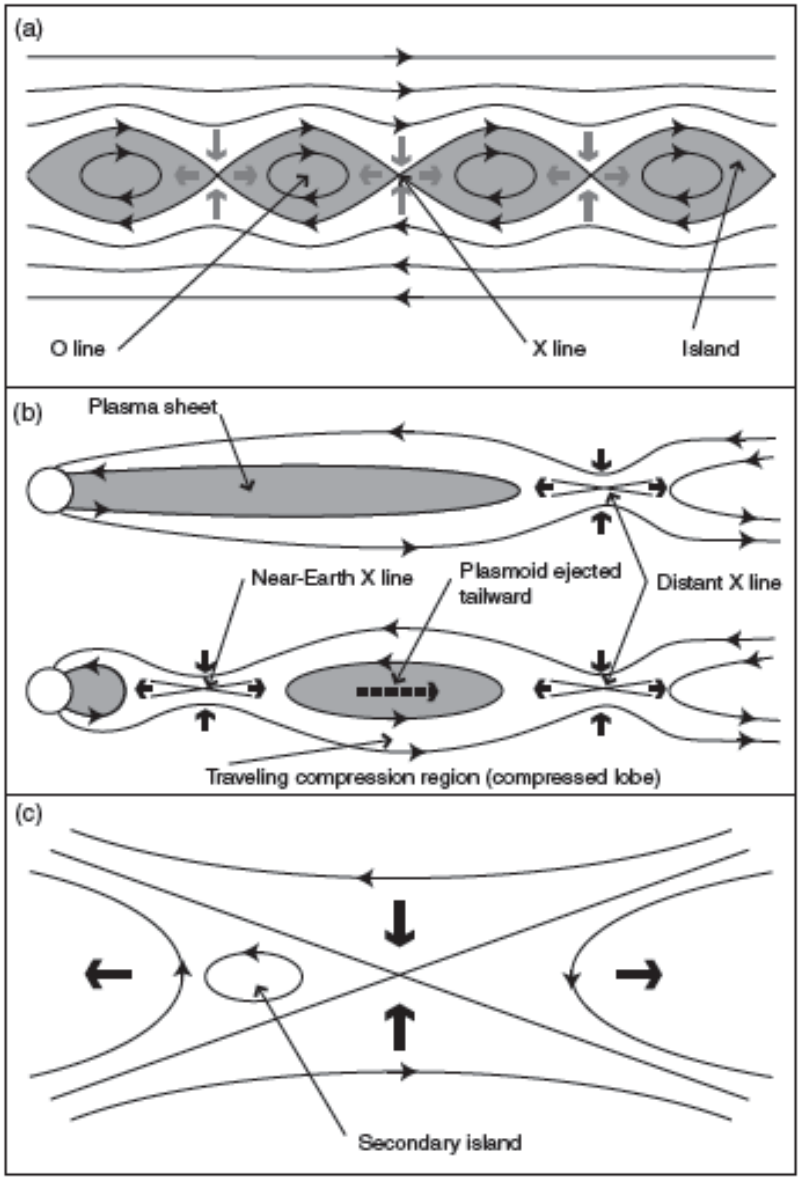
- Reconfiguration of magnetic field: plasmoid release/dipolarization
- Heating of plasma
- Change of plasma flow direction

Global:

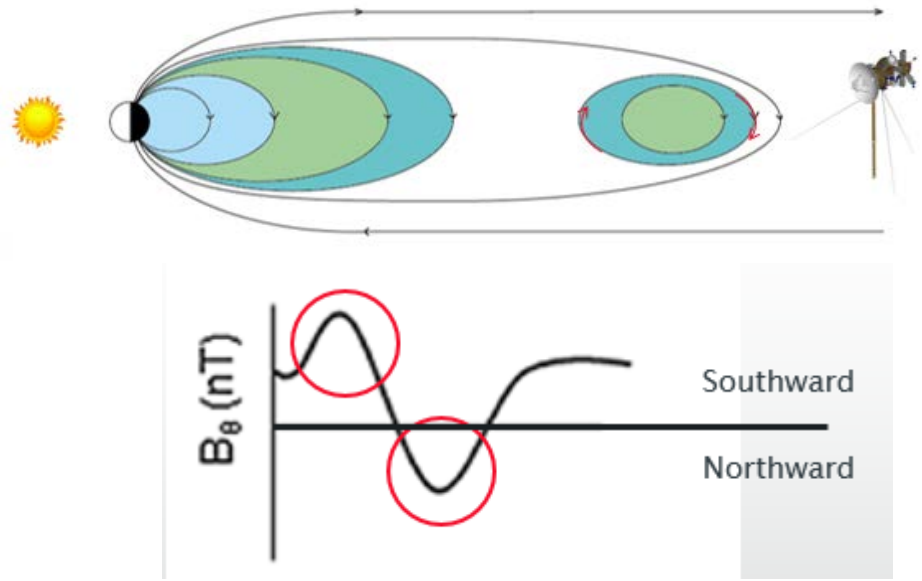
- Auroral precipitation: UV aurora intensity and location change
- Stimulation of radio emissions

In situ signatures of magnetic reconnection

EARTH



JUPITER/SATURN

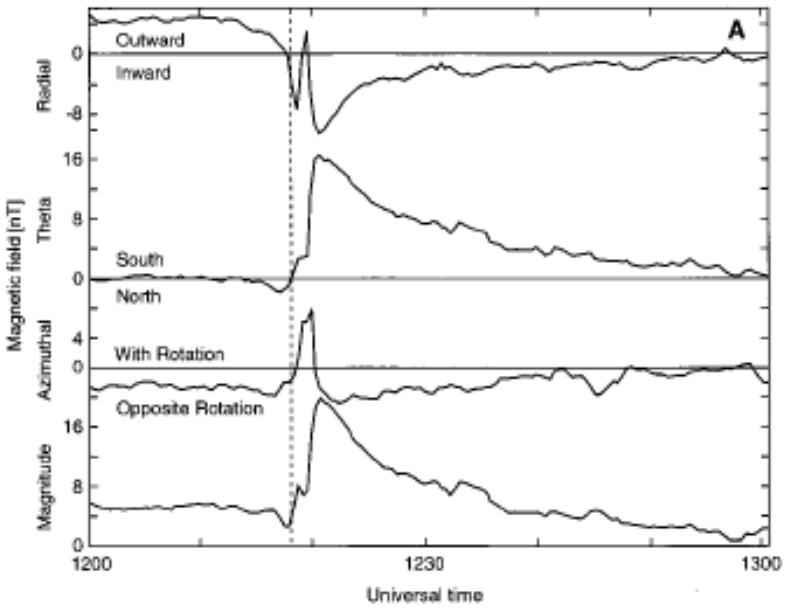


South-north turning of the field can indicate “plasmoid” tailward of the reconnection site

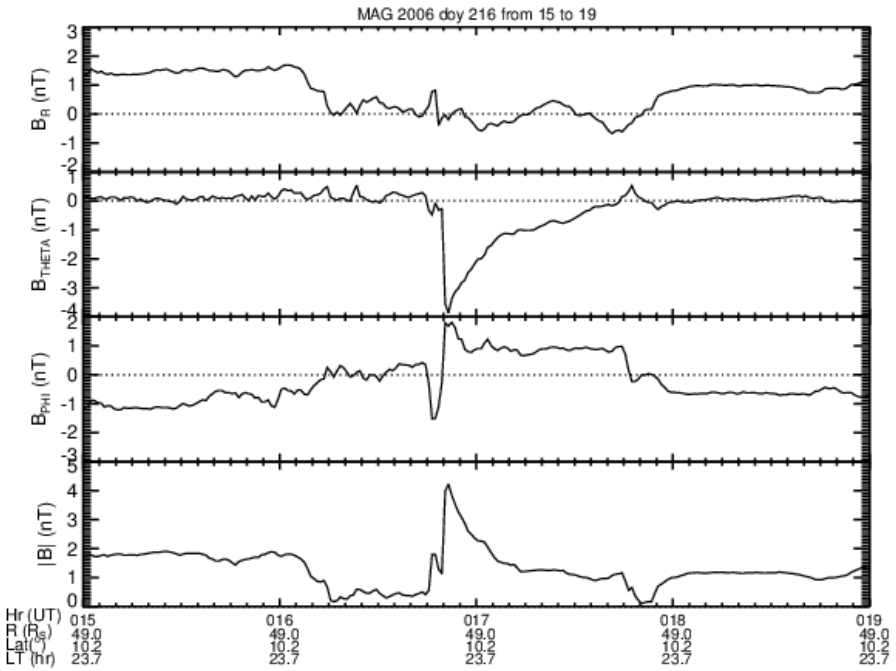
North-south turning of the field can indicate “dipolarization” planetward of the reconnection site

Eastwood and Kiehas [2015]

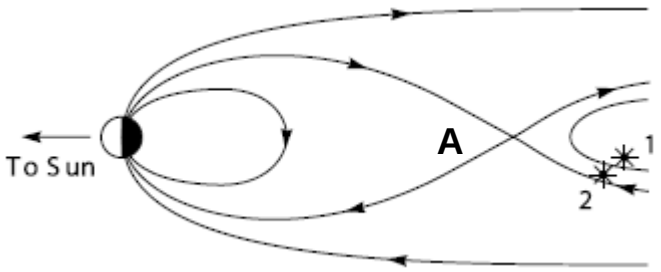
Textbook examples of reconnection products



Jupiter dipolarization:
Russell et al. [Science, 1998]

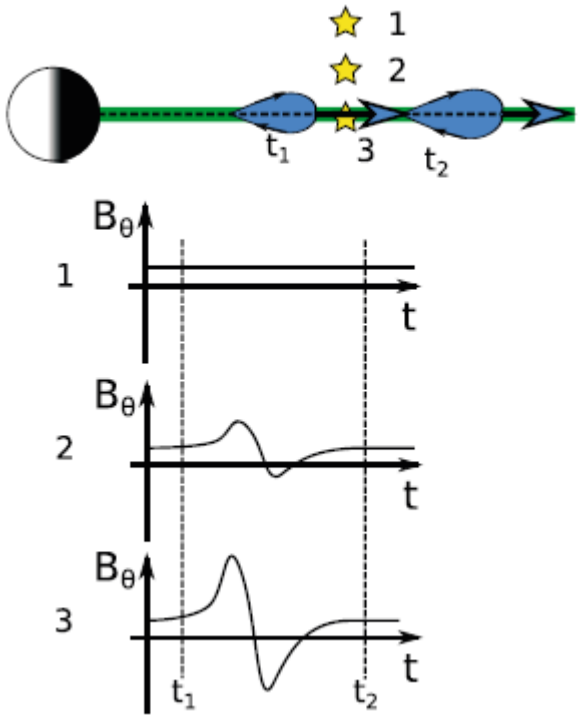


Saturn plasmoid: after
Jackman et al. [GRL, 2007]

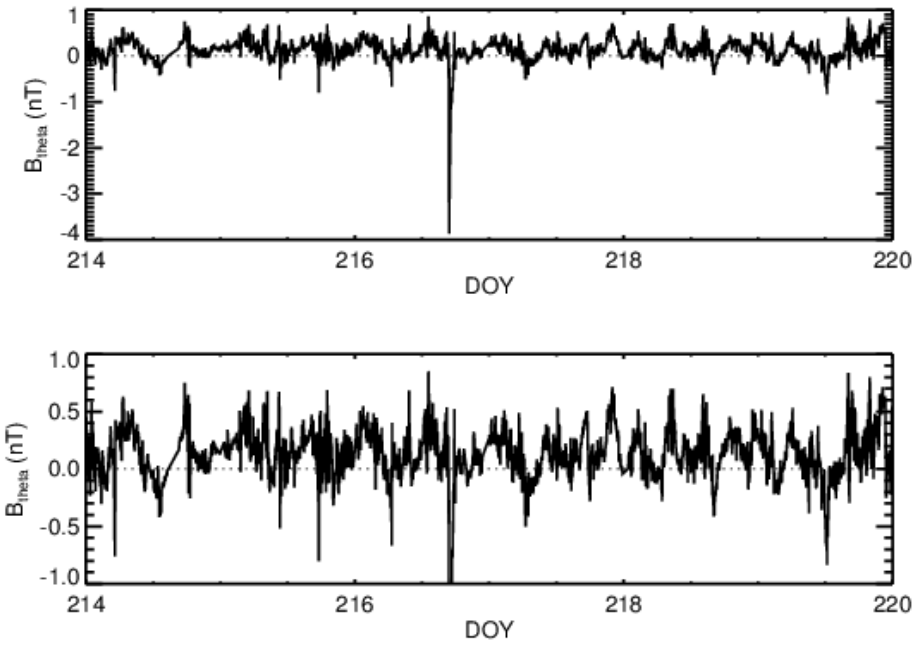


Early observations: “By-eye” selection of large south-north change in B_θ.

Challenge: Sensitivity of signature to viewing geometry



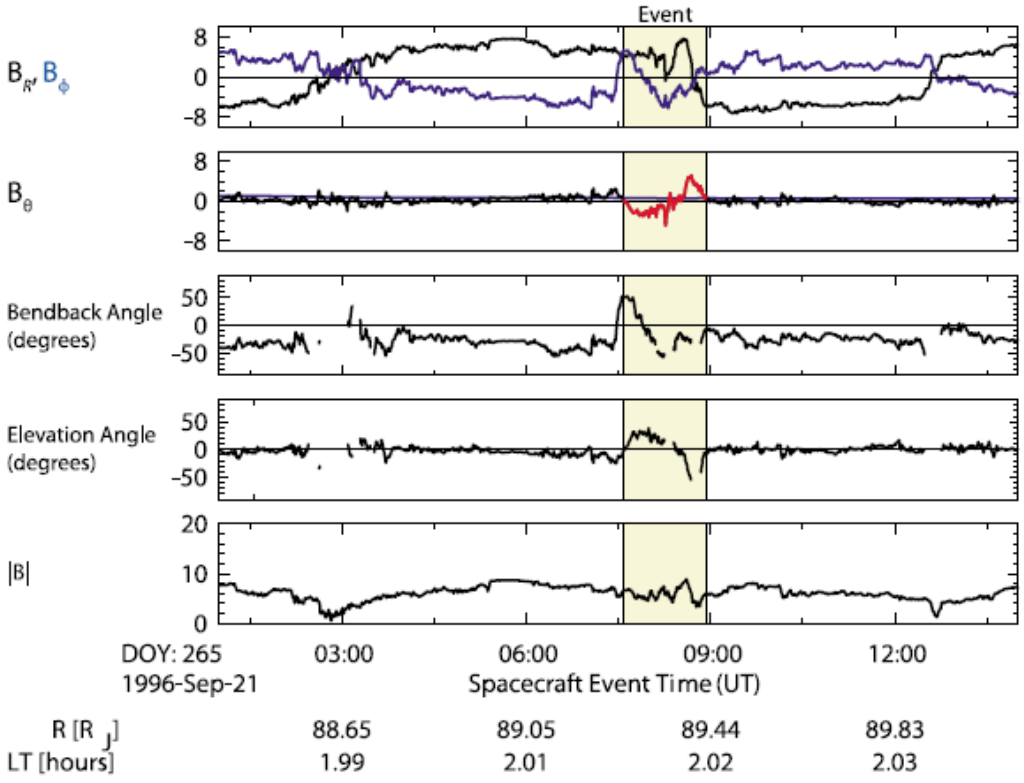
Smith et al. [2016]

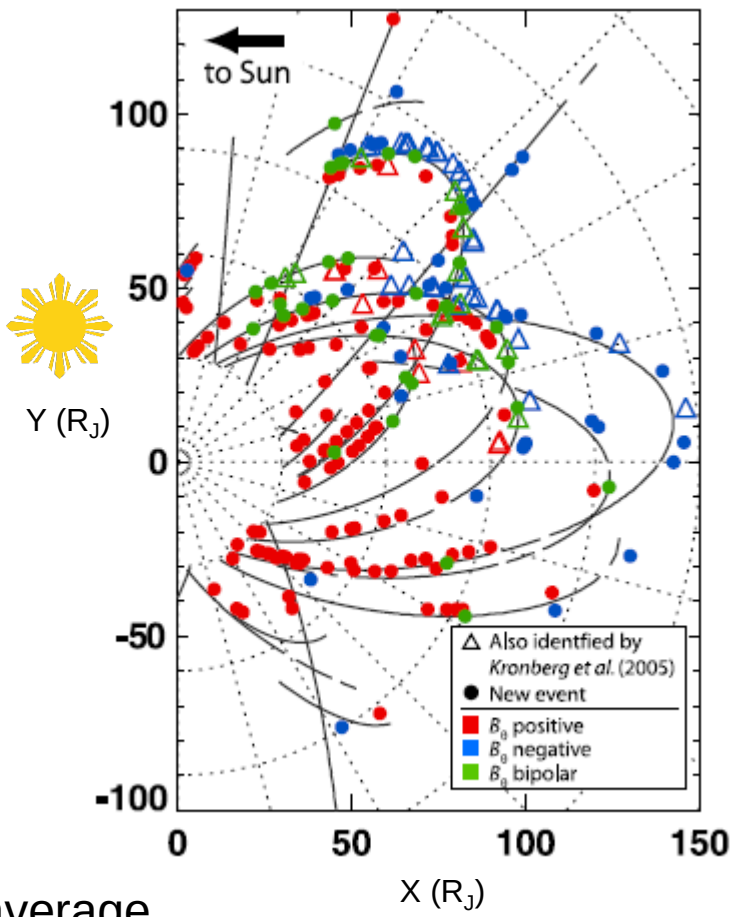


- Spacecraft may observe plasmoid passage from different latitudes
- Different penetration depth into structure
- Same sense but different magnitude of field change

- Plasmoids may also have different sizes
- Early “by-eye” studies found largest examples
- Many other smaller deflections also valid… noise vs. real features?

Early attempts at automated searches: Jupiter





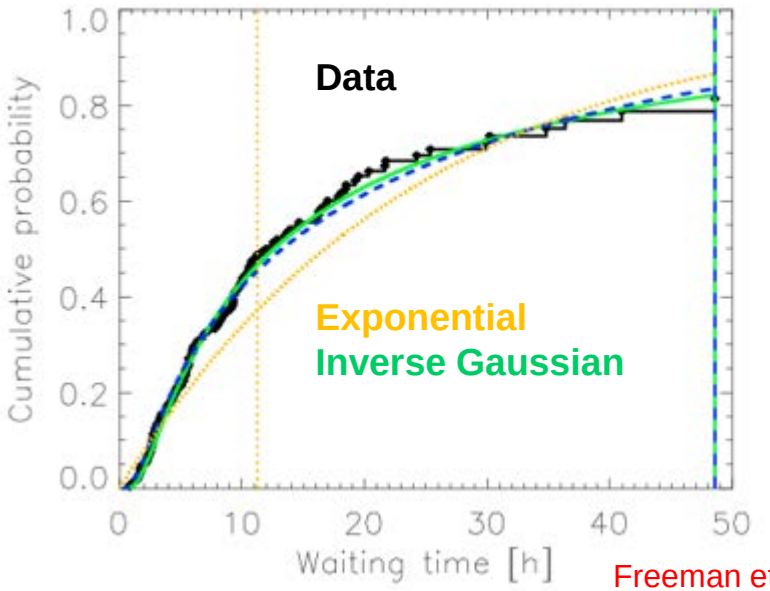
$$\frac{|B_\theta|}{\langle |B_\theta| \rangle} \geq 2,$$

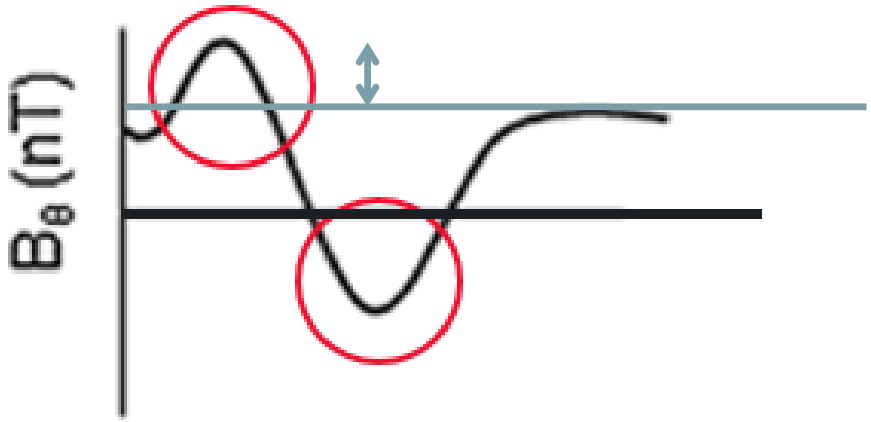
B_θ enhanced above 1-day running average
B_θ enhanced for at least 60 seconds

Vogt et al. [JGR, 2010]

Even basic automation gave an event catalogue of 249 events – ability to conduct statistical analysis

Waiting time distribution of reconnection: Jupiter





Freeman et al. [in prep., 2017]

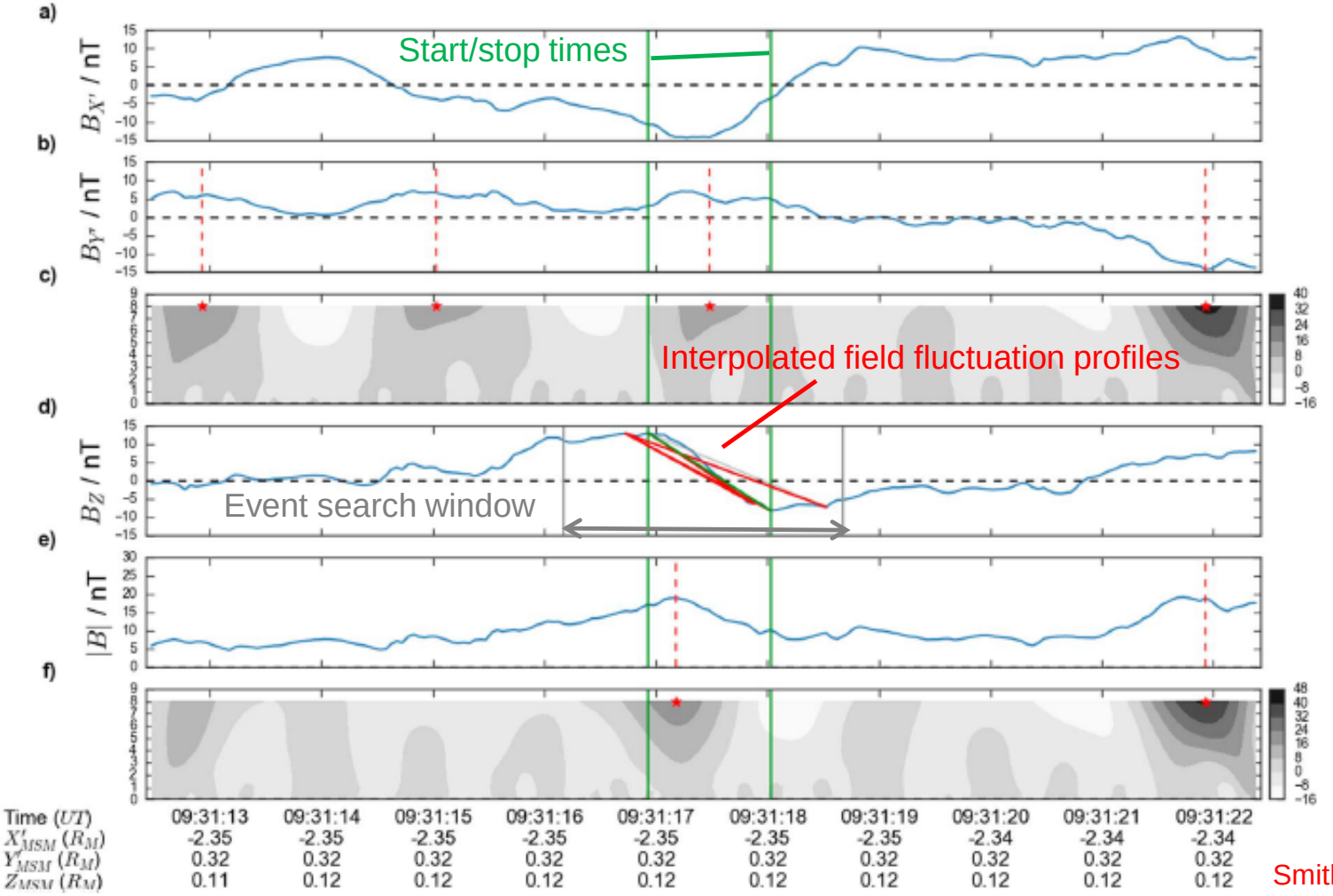
Reconnection event waiting time distribution consistent with Inverse Gaussian… interpret as stochastic integrate-and-fire process.

Explore <u>sensitivity to reconnection event threshold</u>:
$|B_\theta| / \langle|B_\theta|\rangle = A$ $\quad\quad$ $1.5 < A < 4.5$

IG remains a good model over a range of different detection thresholds: Reconnection on multiple scales important to Jupiter's overall mass budget.

Caveat: Are low threshold events still "real"?

Increasing sophistication of automated searches: Mercury

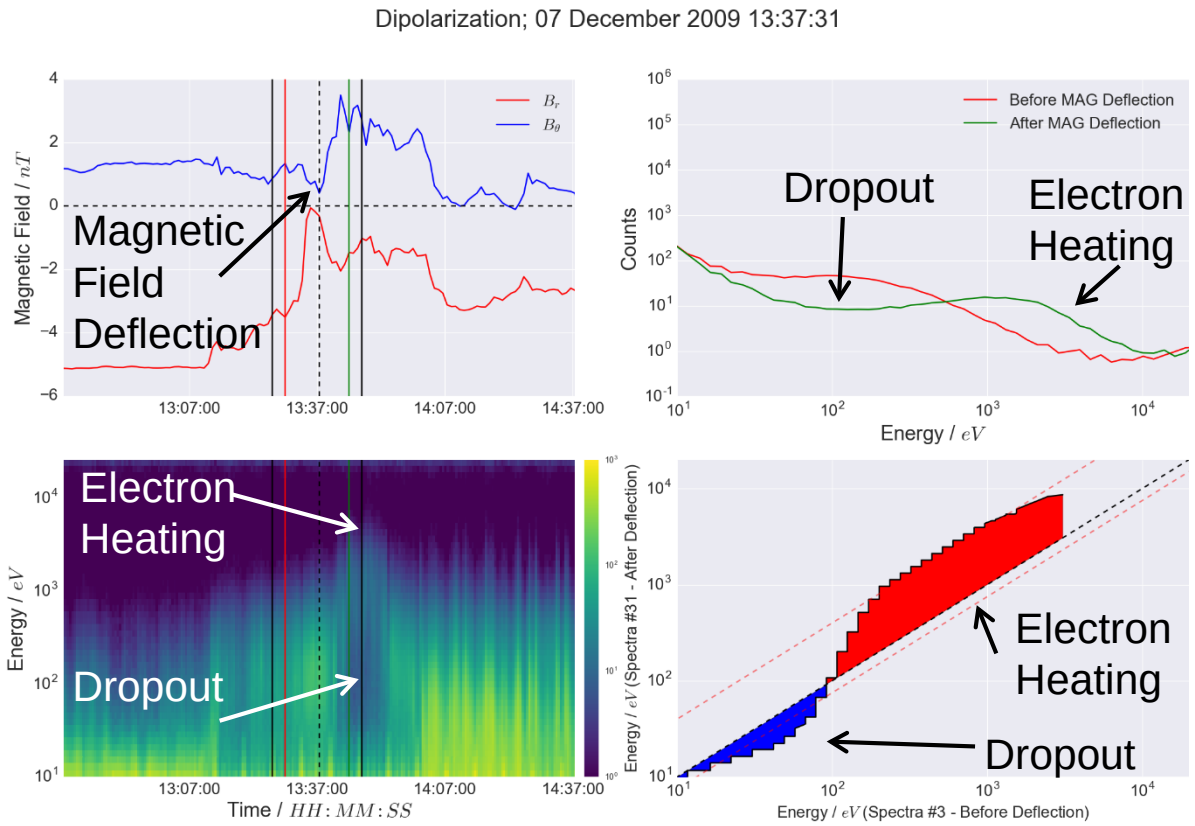


Smith et al. [2017a]

3-stage search for force-free flux ropes:

- Baseline crossing (threshold) & peak detection (continuous wavelet transform)
- Minimum Variance Analysis
- Fitting a force-free flux rope model

Combined search of magnetic field and plasma data



Step 1:
Identify catalogue of magnetic deflections

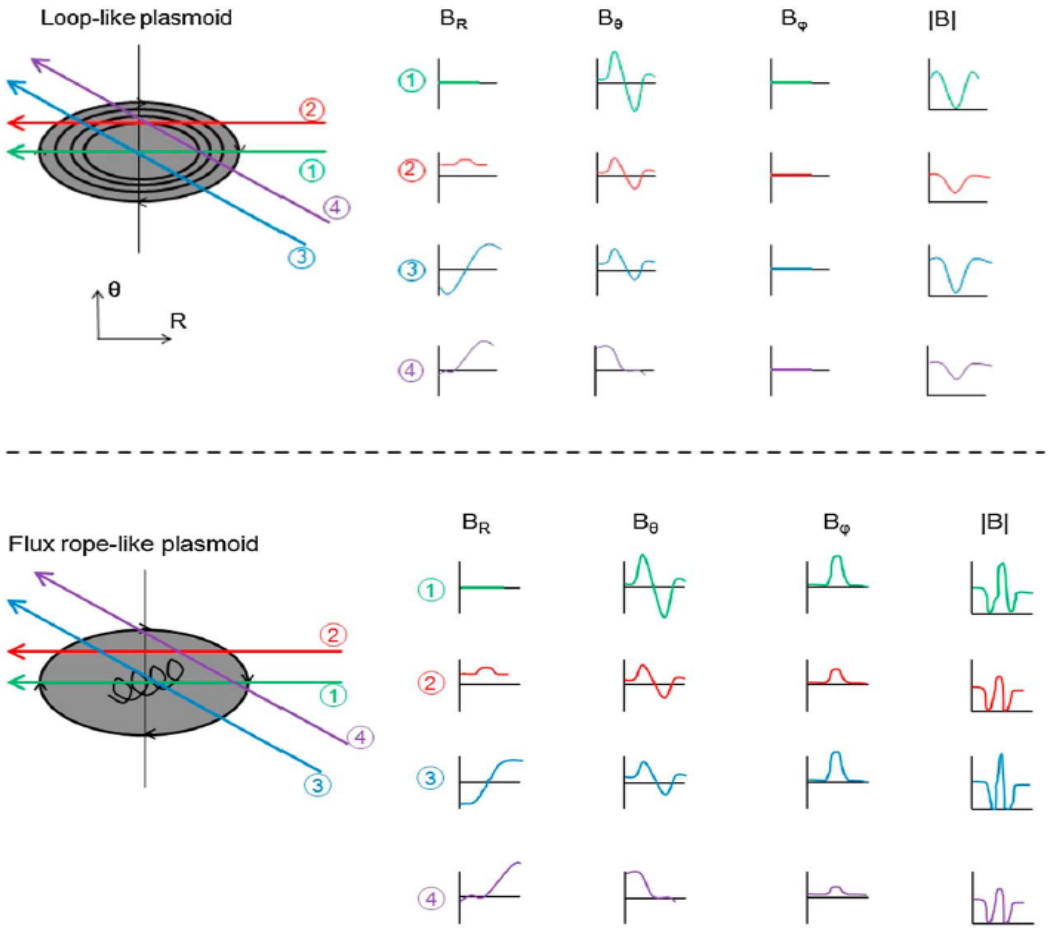
Step 2:
Identify associated characteristic plasma signatures

Q-Q plotting: Gilchrist [2000]; Tindale and Chapman [2016]; Smith et al. [in prep. 2017b]

Automated search for electron heating and dropout:

- Define “initial”/background population
- Search sliding window after reconnection for “energized” population
- Maximise statistical difference using quantile-quantile plotting technique

Further Challenges:



Jackman et al. [2014]

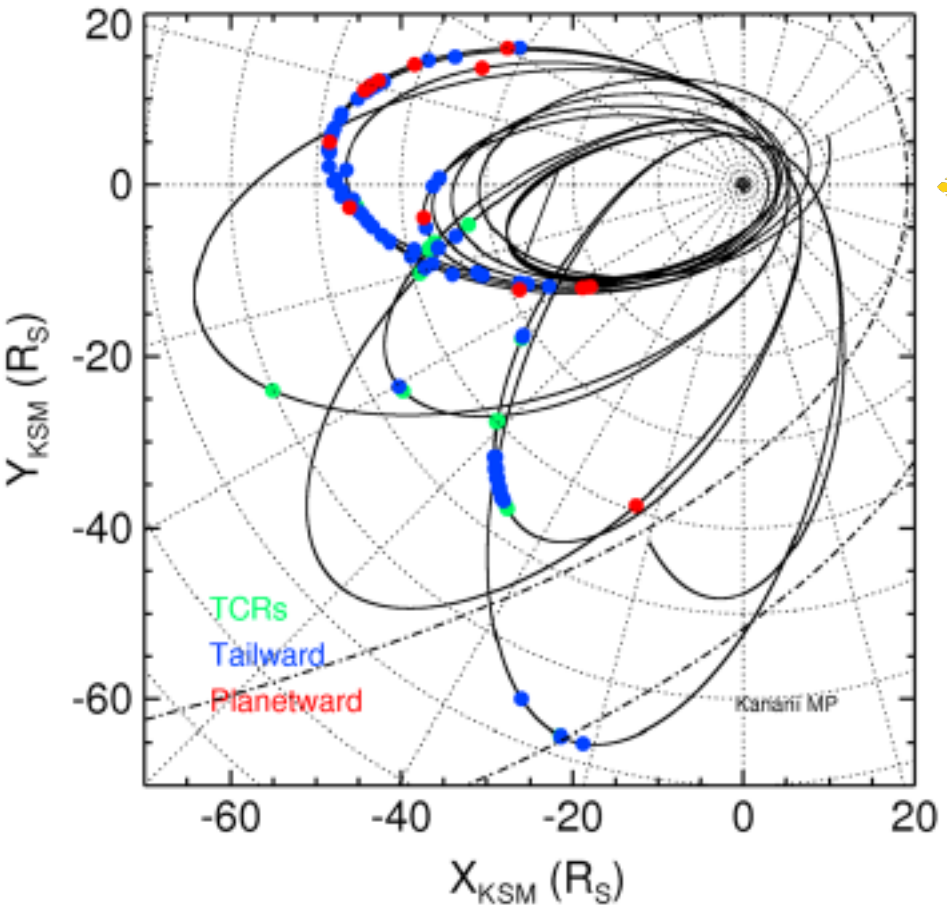
"Zoo" of reconnection signatures depending on:

- Interior structure of plasmoids/flux ropes
- Nature of spacecraft trajectory through the structure
- Nature of the background field and plasma
- Stage of evolution of the structure
- Plasma dataset not as complete as magnetic field

Class imbalance problem!

Cassini data analysis challenge:

- 1 year of Cassini magnetometer data on google drive
- 99 reconnection events labelled
- Can your ML algorithms find the same (or better) events?

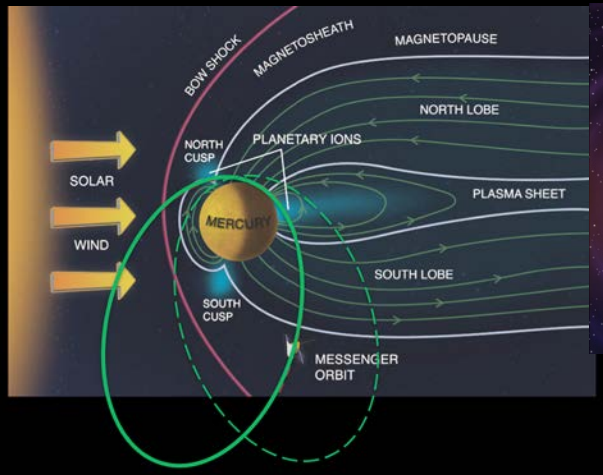


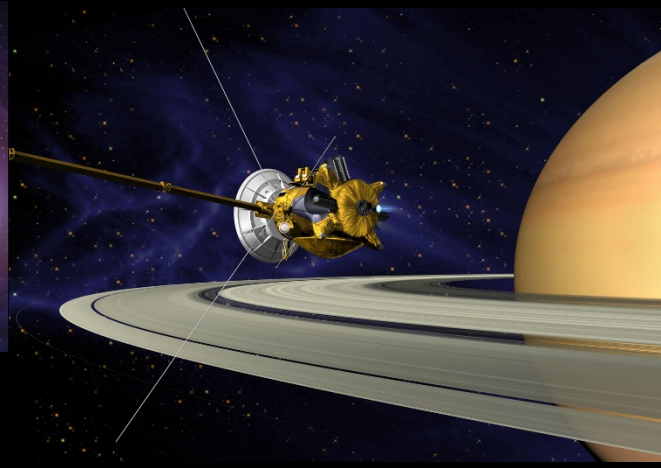
Jackman et al. [2014]

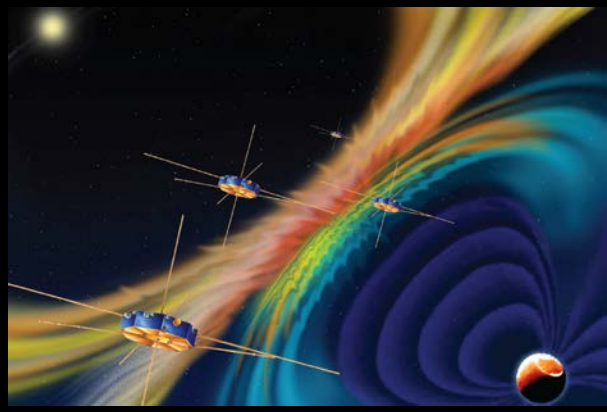
Email me:
c.jackman@soton.ac.uk

For details of data and labelling on google drive

Summary:







Need for ML algorithms to analyse vast amounts of magnetotail data

Viewing constraints and class imbalance problems to consider

Potential for large reward in terms of statistical understanding of influence of reconnection on magnetospheric dynamics.

Cassini challenge? Email c.jackman@soton.ac.uk