# Science Planning Software @ ESAC

SOLab/eFinder and MAPPS/EPS

# Solar Orbiter science operations planning

Planning process for Solar Orbiter is complicated due to, a.o:

- **Orbital evolution:** science goals linked to opportunity windows
- RS payload only operational during 3x10days/orbit
- Highly **variable downlink** with long periods of very poor communications
  ⇒ Long latencies on science data
- Limited **memory space** onboard
- Variable **power** restrictions & EMC requirements

Long Term challenges

- Highly variable **thermal** environment
  ⇒ in-flight calibration sometimes needs quick turn-around
- High-resolution science requires fine-pointing to target which cannot be pre-planned
  ⇒ need for Very-Short-Term Planning **(VSTP) cycle for fine-pointing**

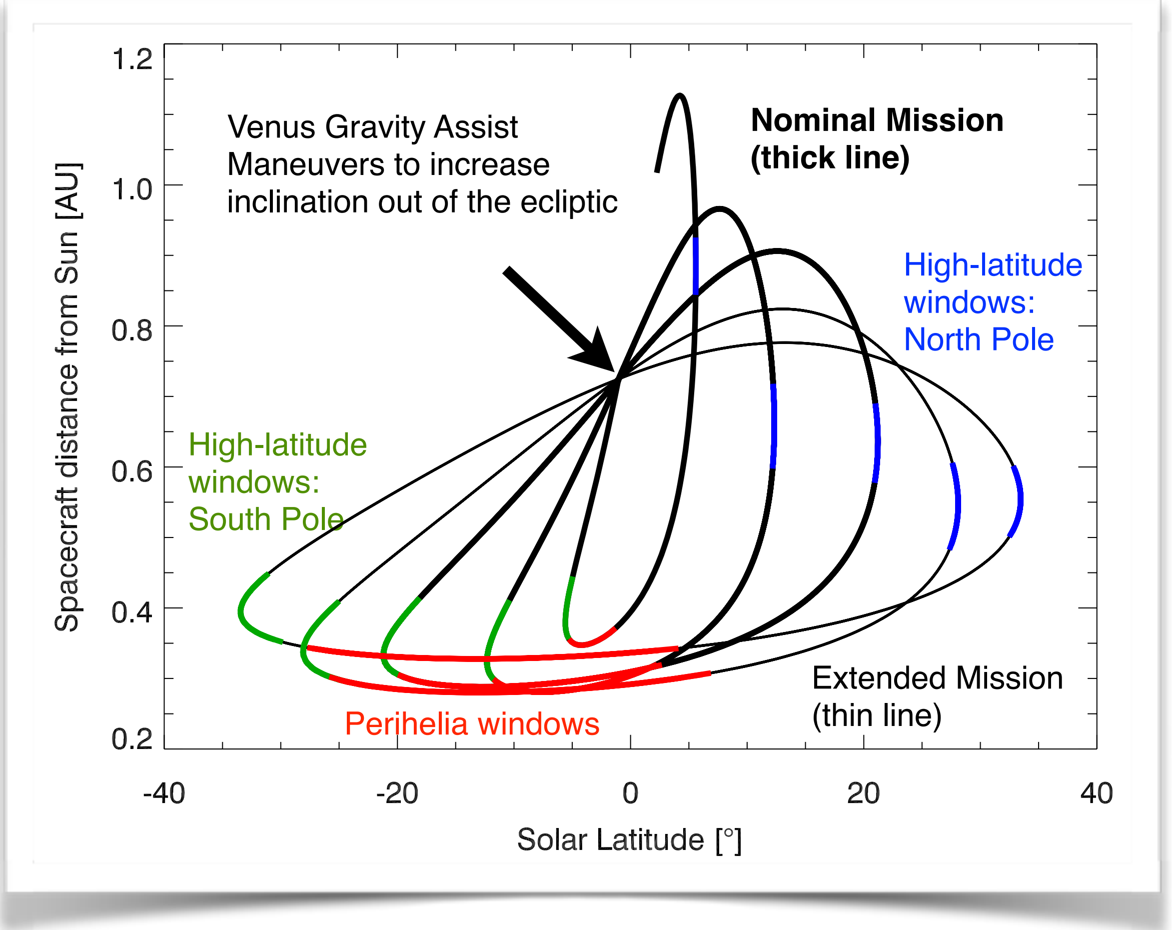
Short Term challenges

- Mission science outcome depends on **coordinated observations of unpredictable solar activity**

# Long Term planning challenges

Long-Term Planning important for:

- Orbital evolution: science opportunity windows
- Highly variable downlink & limited memory space
- Science goals depend on coordinated observations
- Observation time restrictions (RSW) & EMC requirements




⇒ very restricted data generation & long latencies

⇒ orbits cannot be planned in isolation

⇒ TM generation must be under control to not break future plans

⇒ also instrument operations cannot be planned in isolation

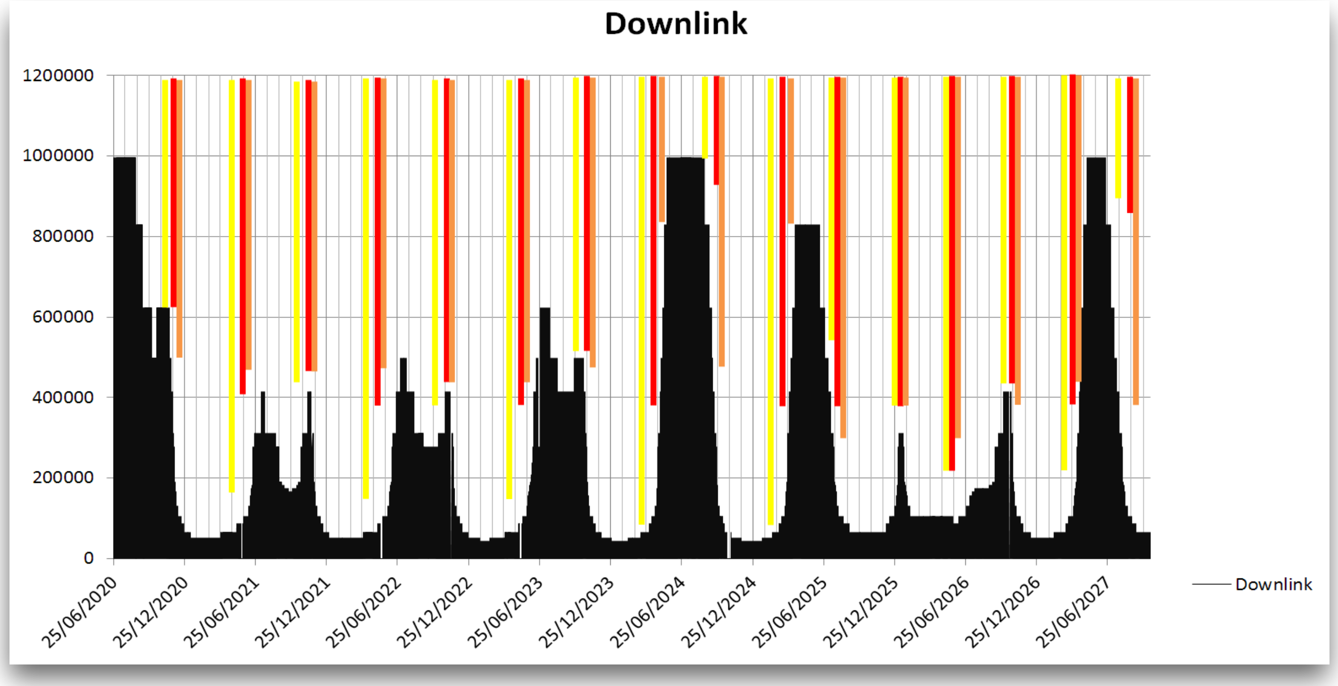
**Solar Orbiter needs Mission Level planning cycle & constraint checking at all planning levels**

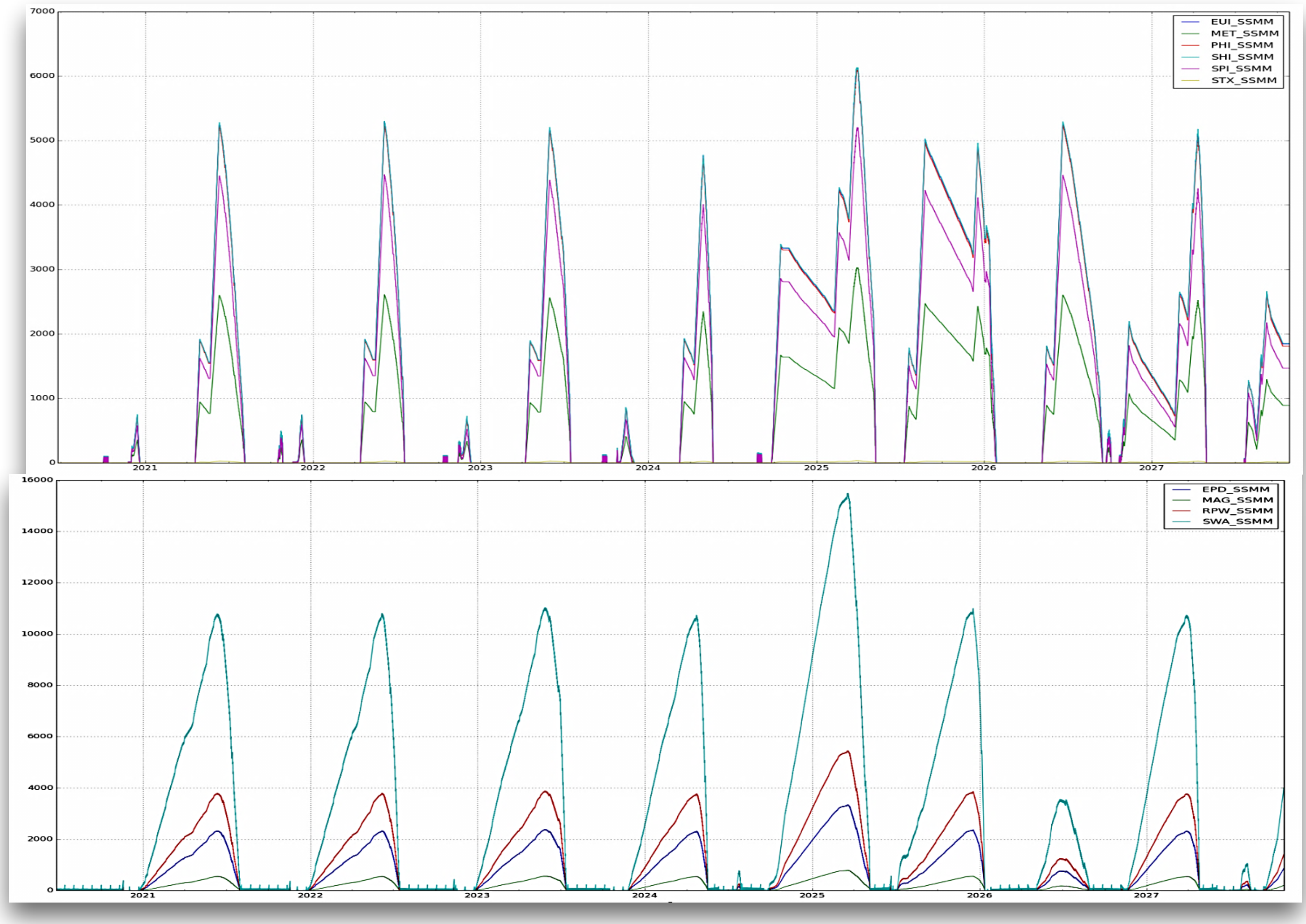
# Past simulations

- Past mission simulations limited to TM return analysis
- 'Flat' data generation based on instruments' TM allocations
- Need to move towards simulation of actual science operations

➡ Simulation of draft Science Activity Plans

➡ Mission Level Planning

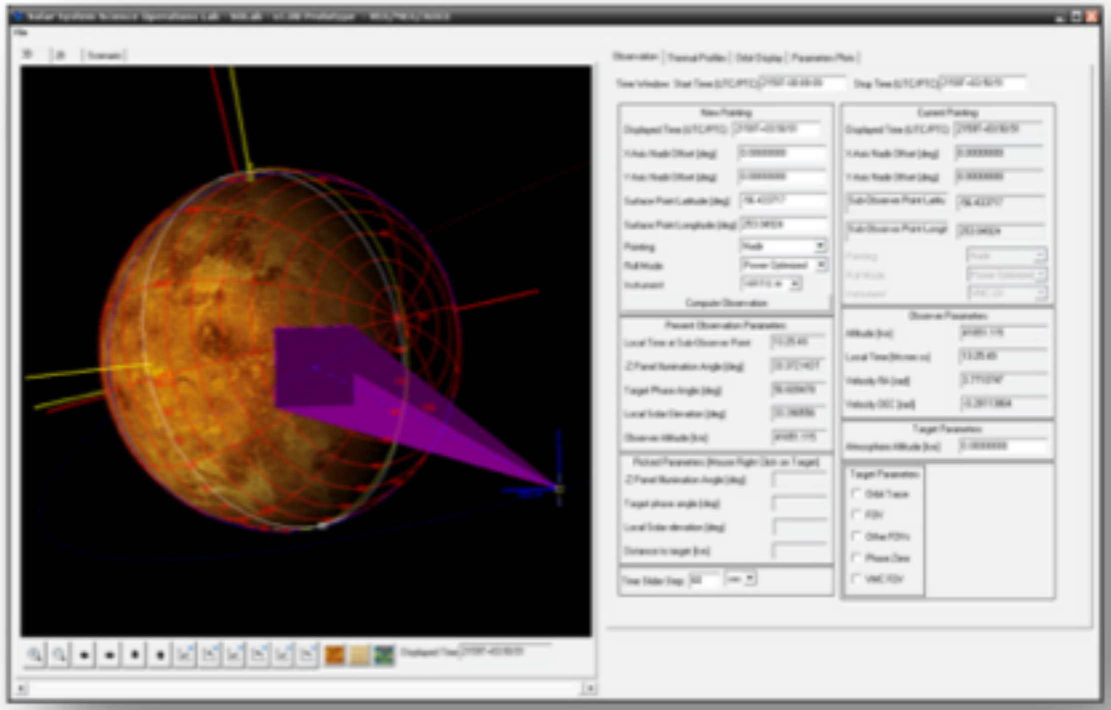


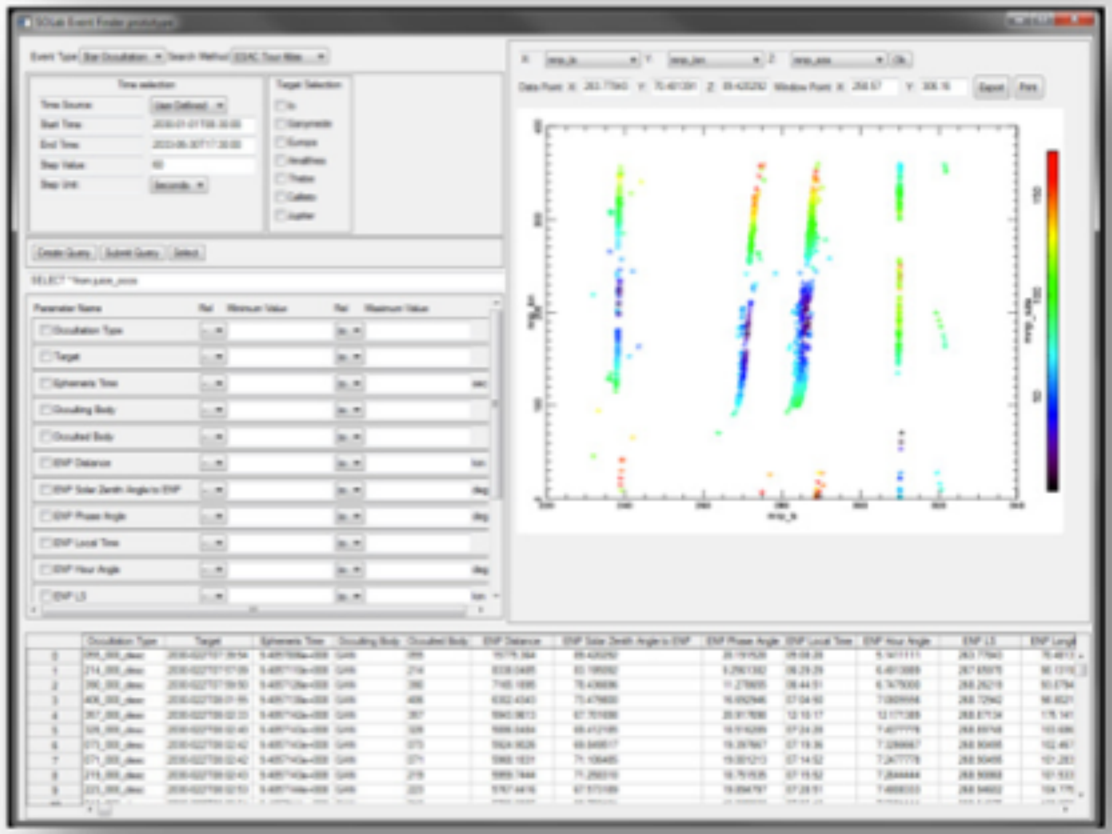



# Tools to support mission level planning: **SOLab**

## Solar System Science Operations Laboratory (SOLab):

- Research project for geometry computation and 3D visualization
- Quick analysis and visualization of observation scenarios
- Support to Medium and Long Term science operations planning
- Interactive pointing and attitude simulation
- Science opportunity analysis





**Geometry-scientific observation opportunities** analysis and **visualisation** originally designed for planetary missions

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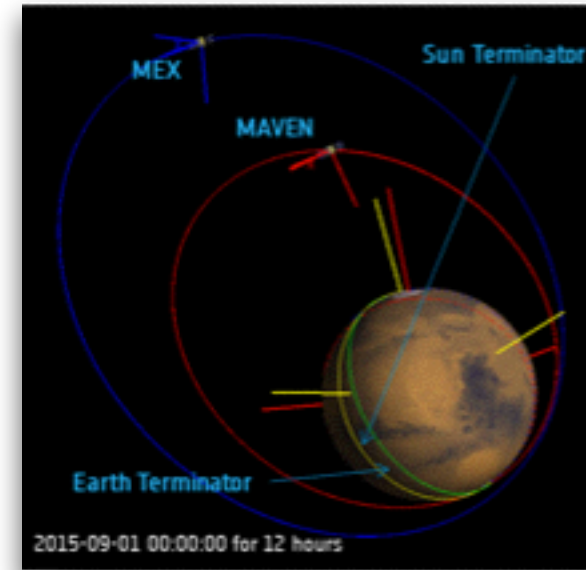


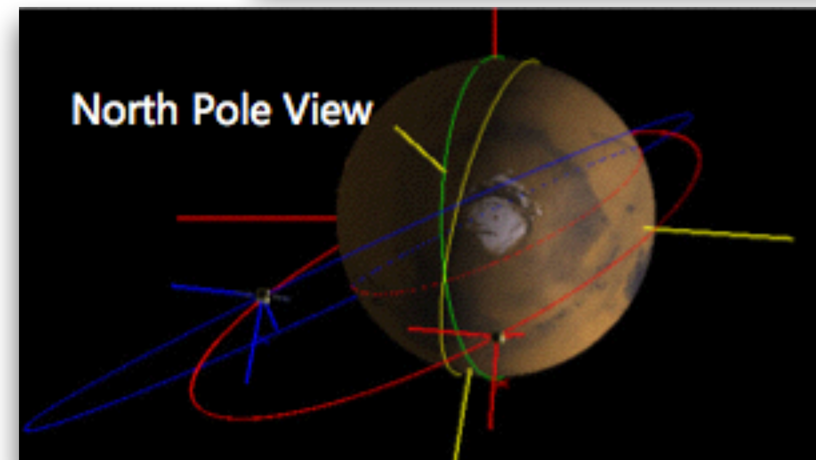


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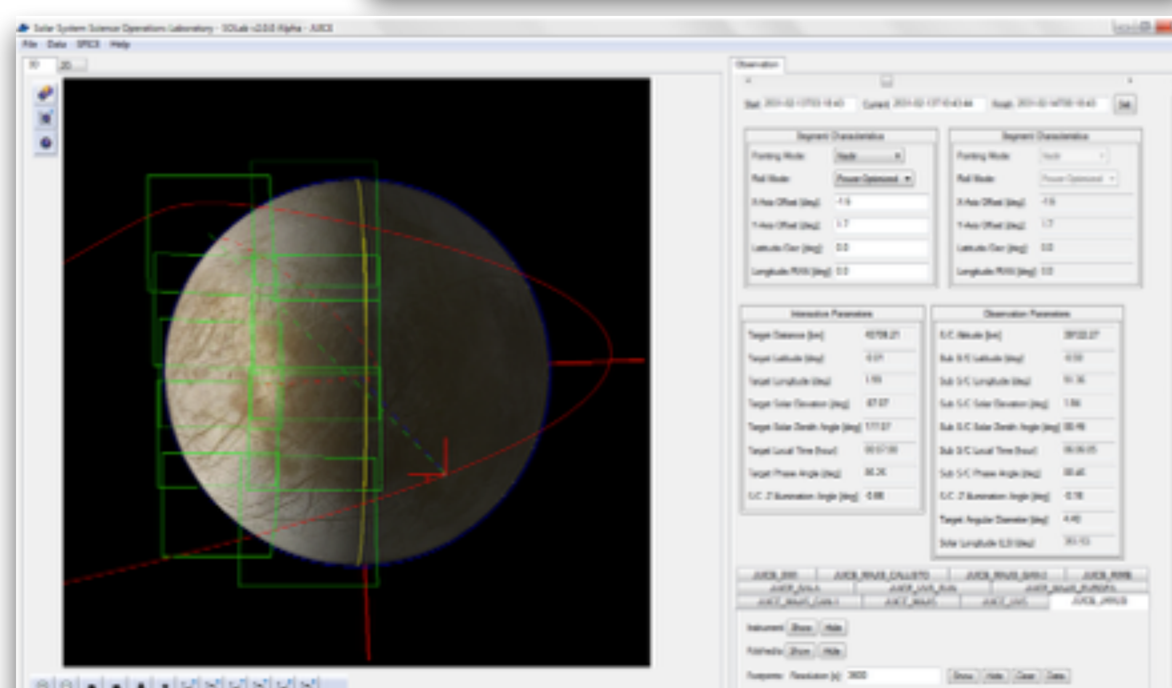


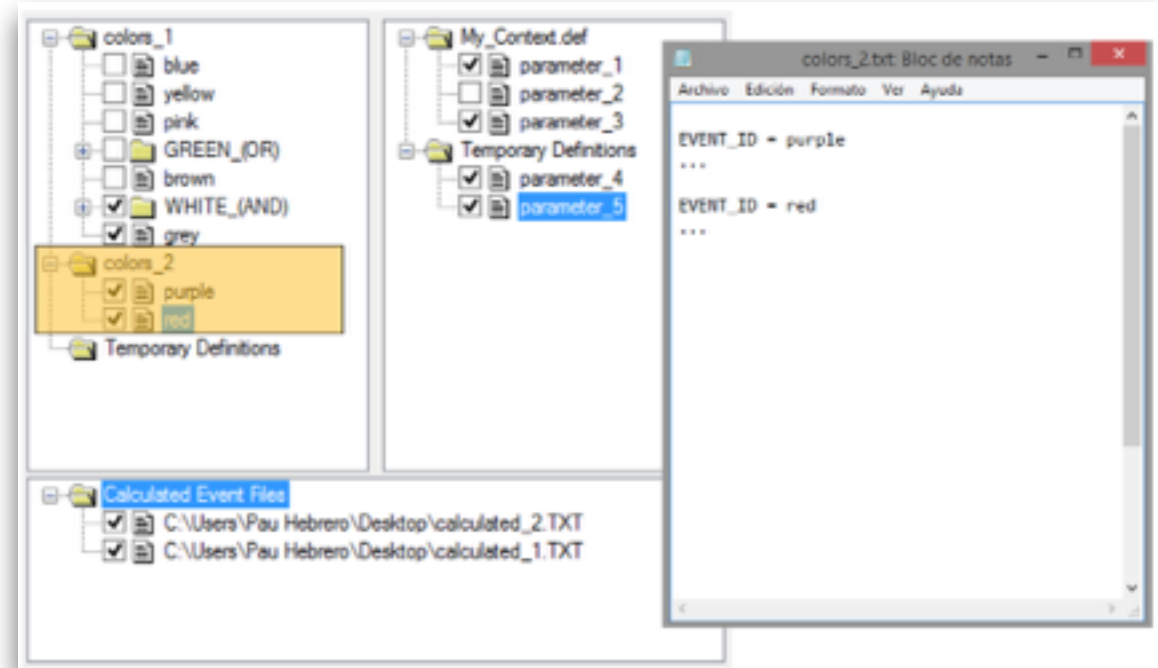
**Geometry-scientific observation opportunities** analysis and **visualisation** originally designed for planetary missions

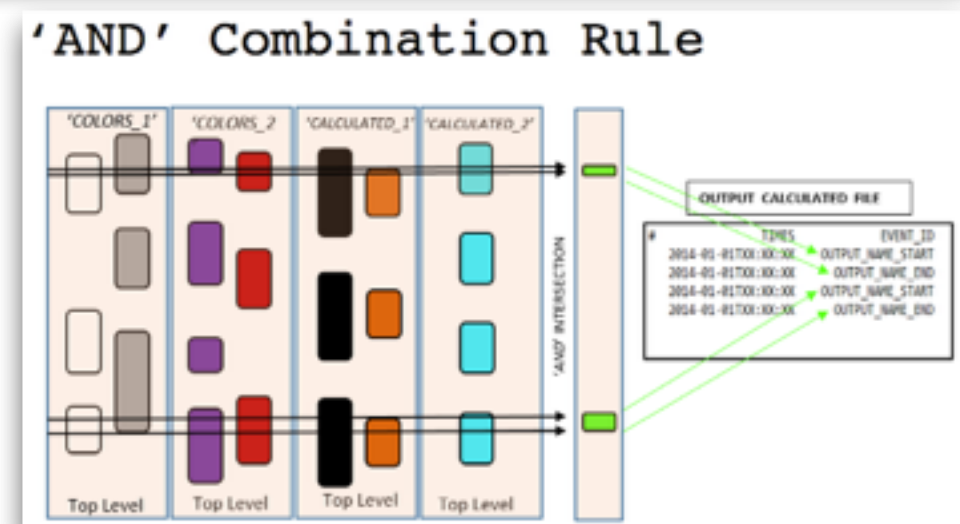
# Tools to support mission level planning: **eFinder**

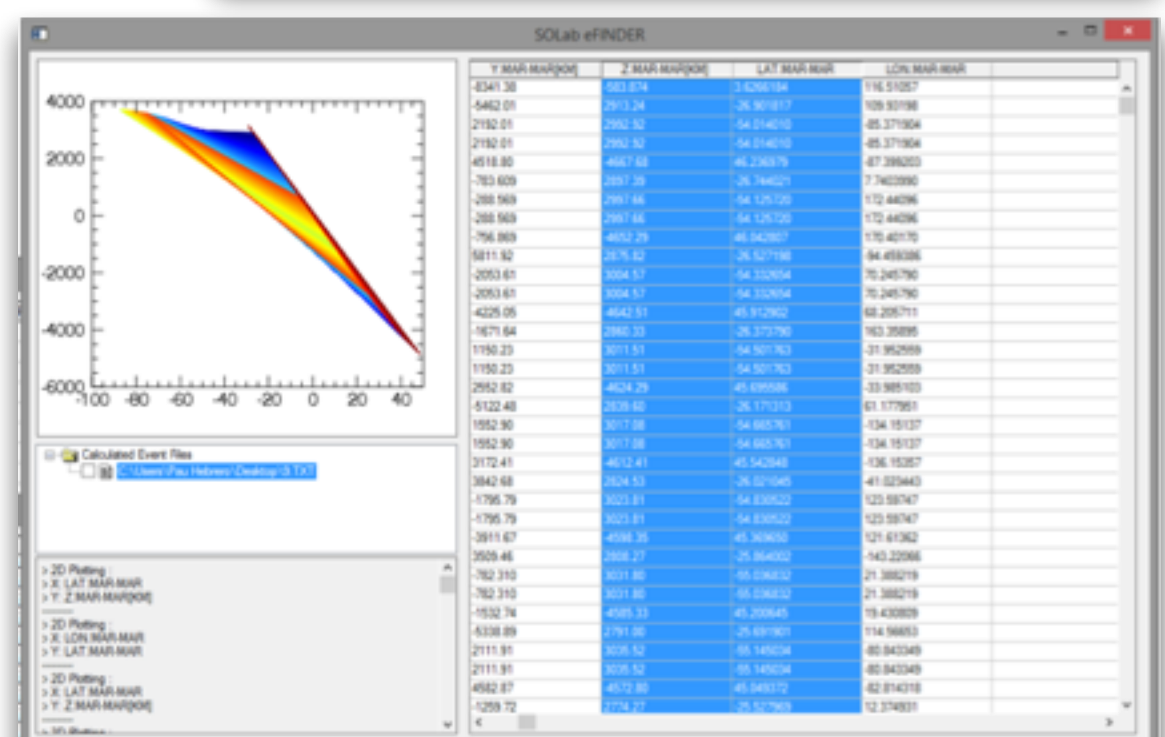
**eFinder = plug-in module for SOLab**

- IDL code linked to SPICE kernels
- Calculating any geometrical space event: ‘Event Finder’
- Finding any context parameter for those events: ‘Context Finder’
- Visualizing calculated events: ‘Event Handler’ (if not plugged in SOLab)

**Not (yet) operationally stable.**
**eFinder not yet plugged into SOLab.**



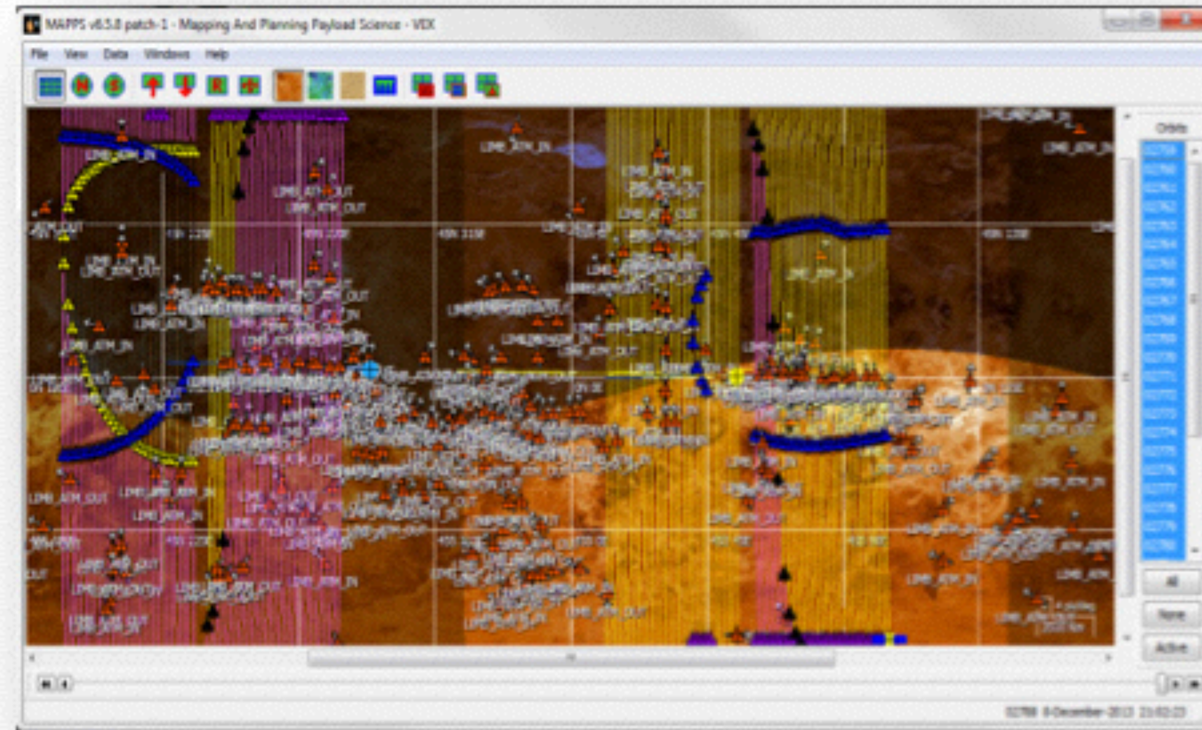
# Tools to support mission level planning: **MAPPS/EPS**

## Mission Analysis and Payload Planning System (MAPPS):

- Geometry computation for Spacecrafts, Instruments and Targets
- Visualization of multiple parameters and overlays in 2D
- Simulation of events and operational timelines

## Experiment Planning System (EPS):

- Payload and spacecraft resources, sequences and transitions.
- Generation of command level sequences
- Payload planning files



**Operational tools**, simulation, visualisation linked to actual **operations timelines processing**

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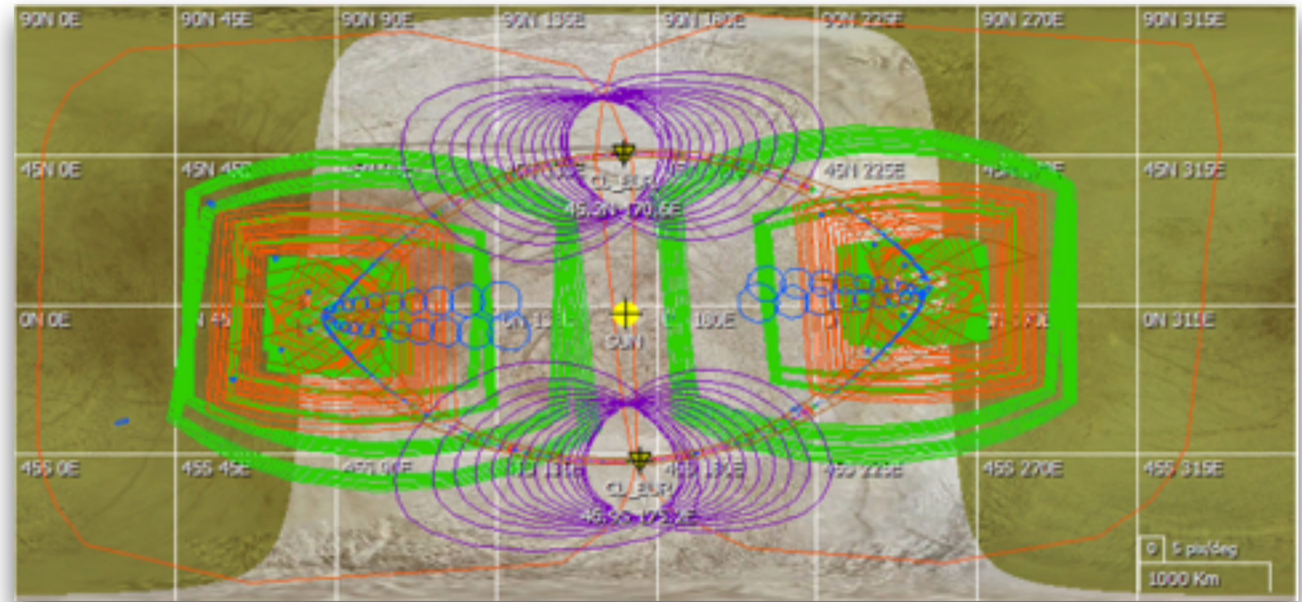
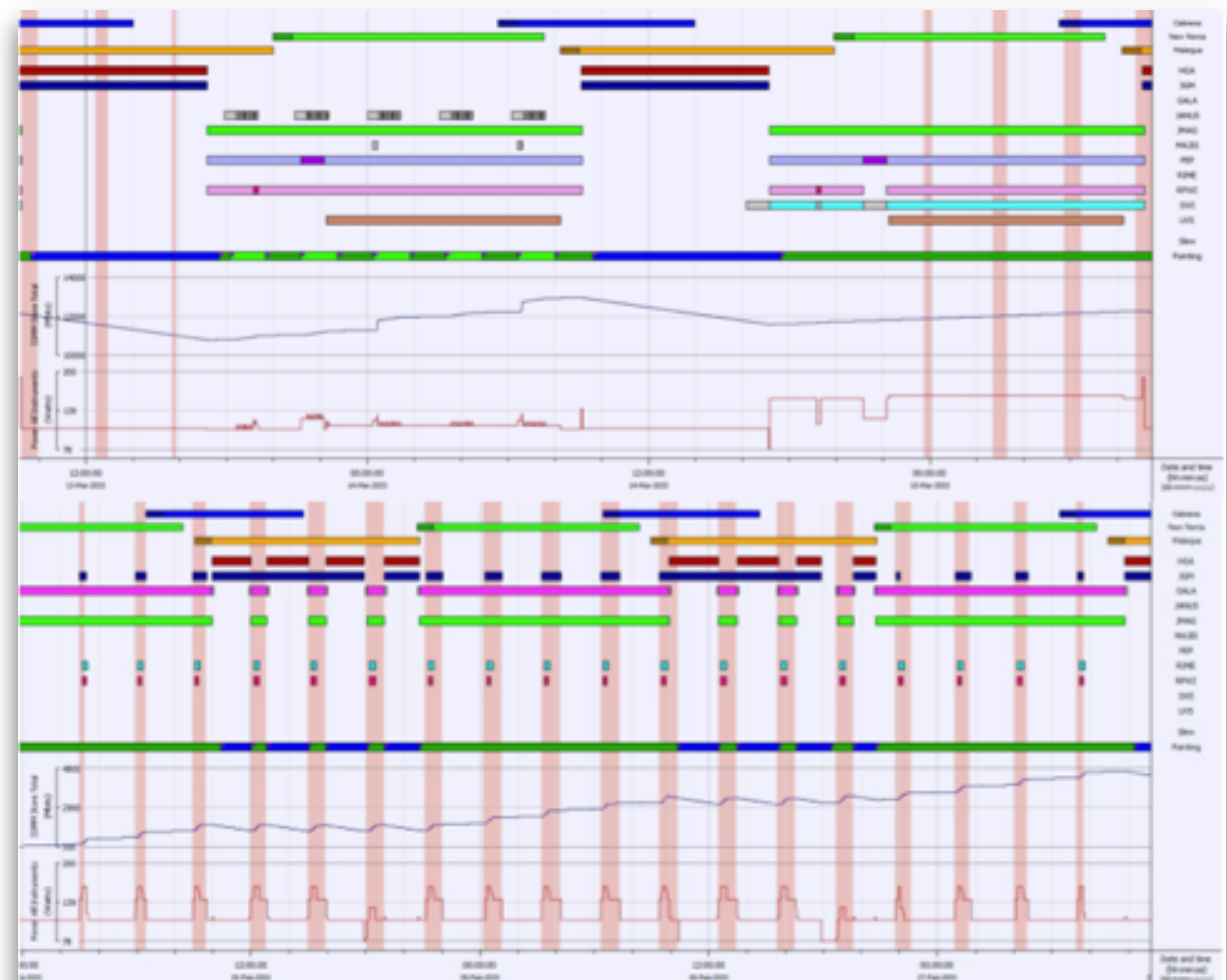


**Operational tools**, simulation, visualisation linked to actual **operations timelines processing**

# Summary SOLab/eFinder

**Advantages of SOLab/eFinder (once linked):**

- Detailed pointing geometry analysis *(SOLab)*
- Sophisticated, IDL & SPICE-based event finding algorithm, can combine different event types *(eFinder)*
- Easy insertion of new bodies and SCs *(eFinder)*
- Sophisticated 3D visualisation + context information *(SOLab)*
- Tool designed for support during mission analysis phase and SAP planning *(SOLab)*

**Disadvantages of SOLab/eFinder:**

- Prototypes, non-operational tools and both tools not yet linked
- ESAC-only usage due to constraints in point 1
- Maintenance support not clear and not guaranteed over mission timeline
- Cannot simulate operational details like power, comms, TM, SSMM usage, …
- Mainly interesting during mission analysis and LTP phase, less useful in later phases.
- Several design choices are planetary-specific, not relevant for Solar Orbiter (surface coverage, illumination, ...)

# Summary MAPPS/EPS

**Advantages of MAPPS/EPS:**

- Operational tool, that can be distributed to instrument teams if needed
- Combination of geometry computations, simulation of events and operational timelines
- Direct link to instrument and operational constraints modelling (in EPS) -> Operational feasibility analysis
- Visualisation of operational timelines & geometry/pointing on 2D surface of the Sun (3D being implemented)
- Timelines of high-level science activities can be expanded into low level command sequence timelines
- Tools can support mission at all planning levels

**Disadvantages of MAPPS/EPS:**

- Less sophisticated visualisation (3D being implemented)
- Might need SolO-specific updates or add-ons (TBC)
- SW relies on TEC (ESTEC) support and other missions' needs.
- MAPPS/EPS setup and configuration not straightforward.

# Low Latency Data Visualisation

Andrew Walsh
Solar Orbiter SOC

SOWG #5, ESAC, 8-10 July 2014

# Reminder: Uses of LL Data

Low Latency Data are low volume science data, downlinked with the highest science priority. They have the following functions:

- To allow assessment of instrument health and performance.
- A means of choosing selective data for downlink.
- Support S/C pointing planning when tracking solar features (VSTP only): compensating feature’s proper motion and/or re-targeting.

- We aim to provide a browsing and visualisation tool that will be needed to fulfil the first two functions.
- Pointing updates at VSTP will be handled by a dedicated tool within SOC.
- We do not aim to provide a full (or half!) featured data analysis tool.

# Current Concept

1. LL Data are generated at the SOC with instrument team provided pipelines.
2. Pipelines take the form of virtual machines that take science TM packets as input and output data products that allow visual representation.
3. Pipelines are simple and static.
    - Static calibrations only
    - Only run on near real-time data (no reprocessing)
4. Output from each pipeline is combined as needed and sent to:
    - **LL Data Display Tool**
    - PTR Generation Tool
    - Science (& planning) archive

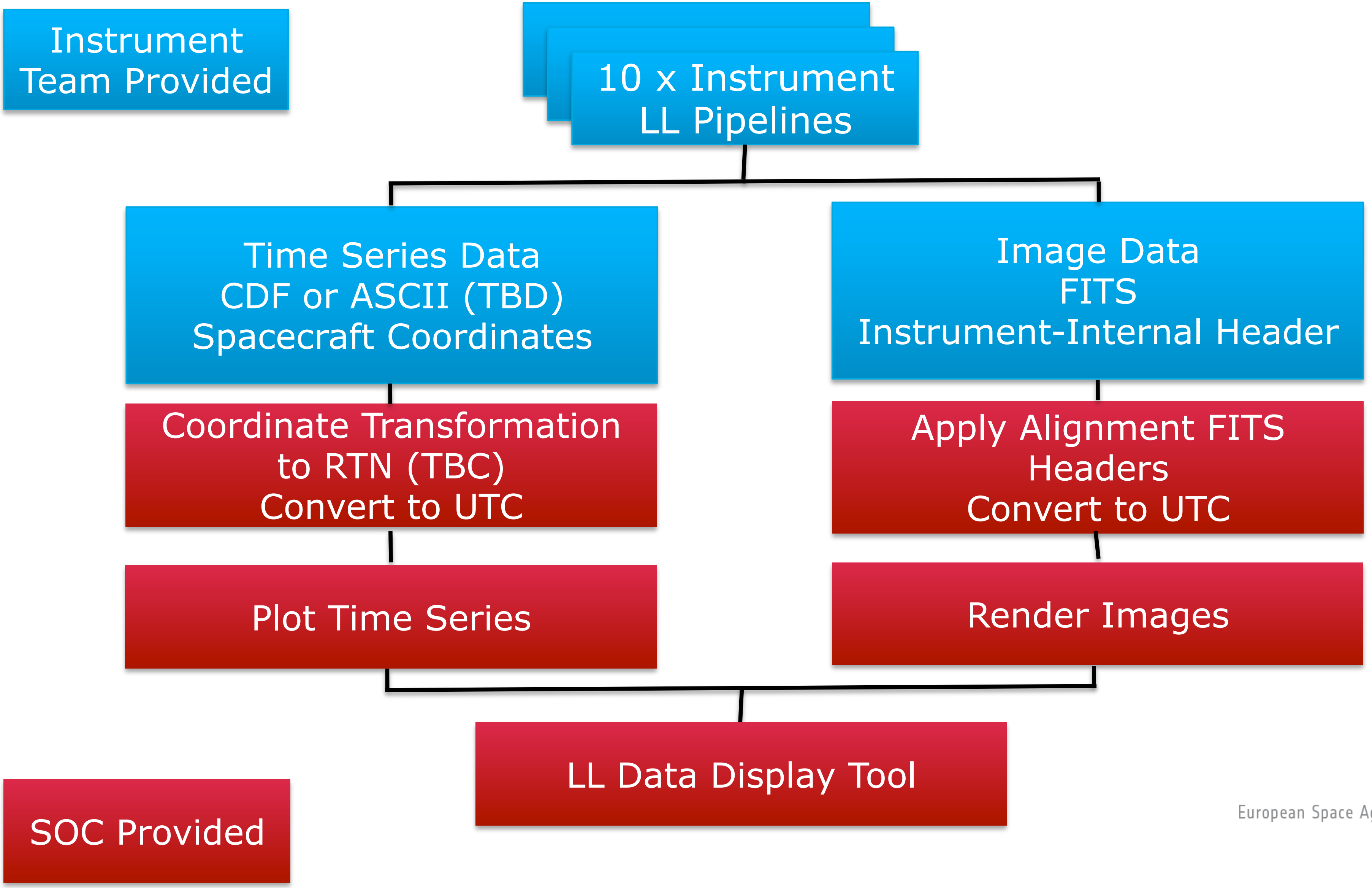
# Proposed Tool

- Our proposal is to provide a simple web-based tool that:
    1. Is fast.
    2. Has no requirements on the client side apart from a browser.
    3. Will allow side-by-side visualisation of multiple in situ and remote sensing data, and provide a (very) rudimentary assessment of linkage between the two.
- This implies:
    1. A minimum of on-the-fly calculations.
    2. Serving pre-generated plots.
    3. LL Pipelines producing data files, not plots.

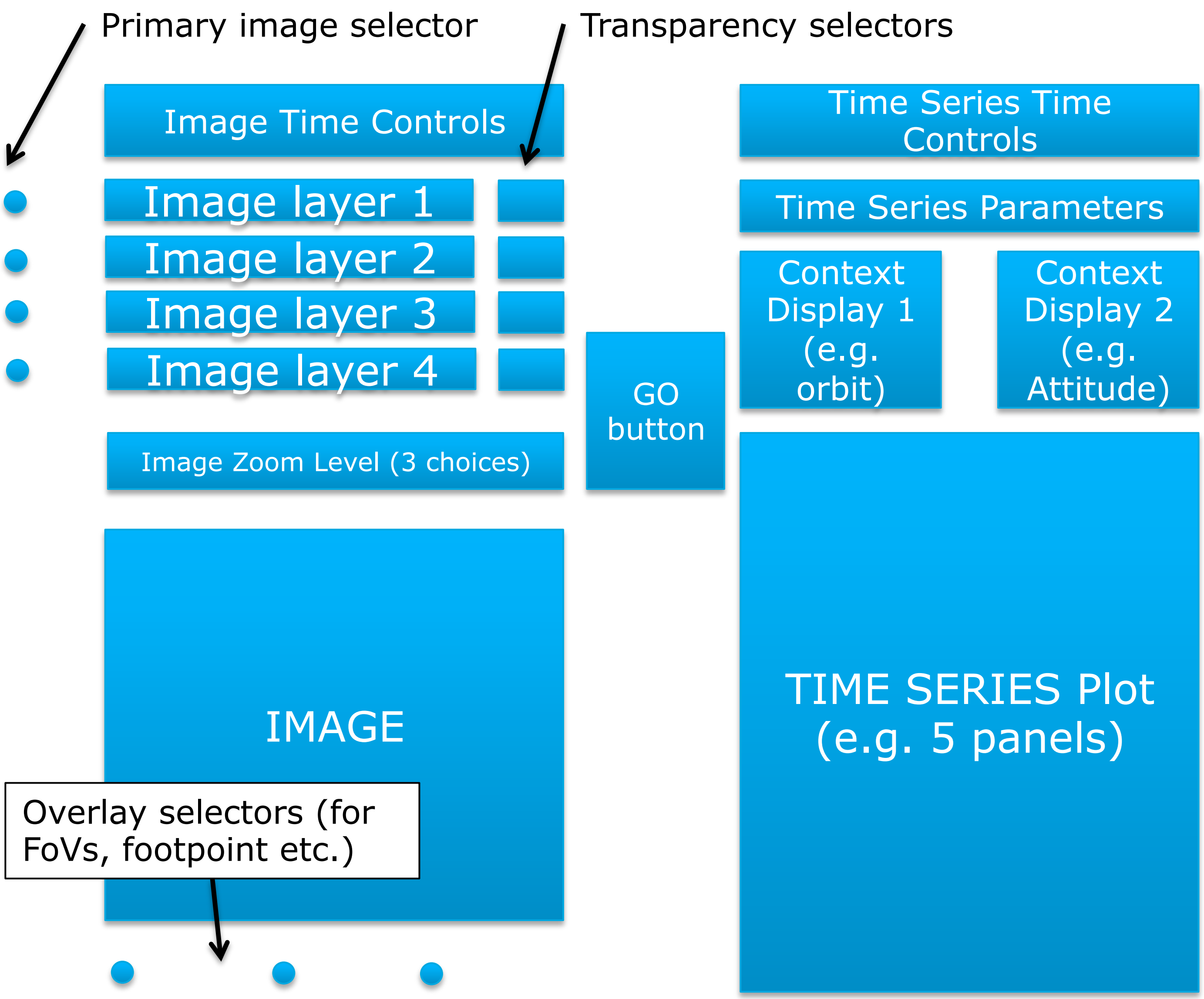
# SOC Post Processing

- Our proposal is that any postprocessing common to multiple instruments' LL data that can be centralised will be centralised.
- Instrument pipelines will provide:
  - FITS format for images, only containing instrument headers (i.e. aligned to instrument boresights).
  - CDF or ASCII for Time Series (including SPICE & STIX spectra / light curves?), vector quantities in spacecraft coordinates.
- SOC will apply any coordinate transformations and metadata that require platform information:
  - SOC will augment instrument-provided FITS headers with static misalignment information & WCS.
  - SOC will transform time series data into a more scientifically useful coordinate system (probably spacecraft-centric RTN).
  - SOC will convert from onboard time to UTC.

# Proposed Tool



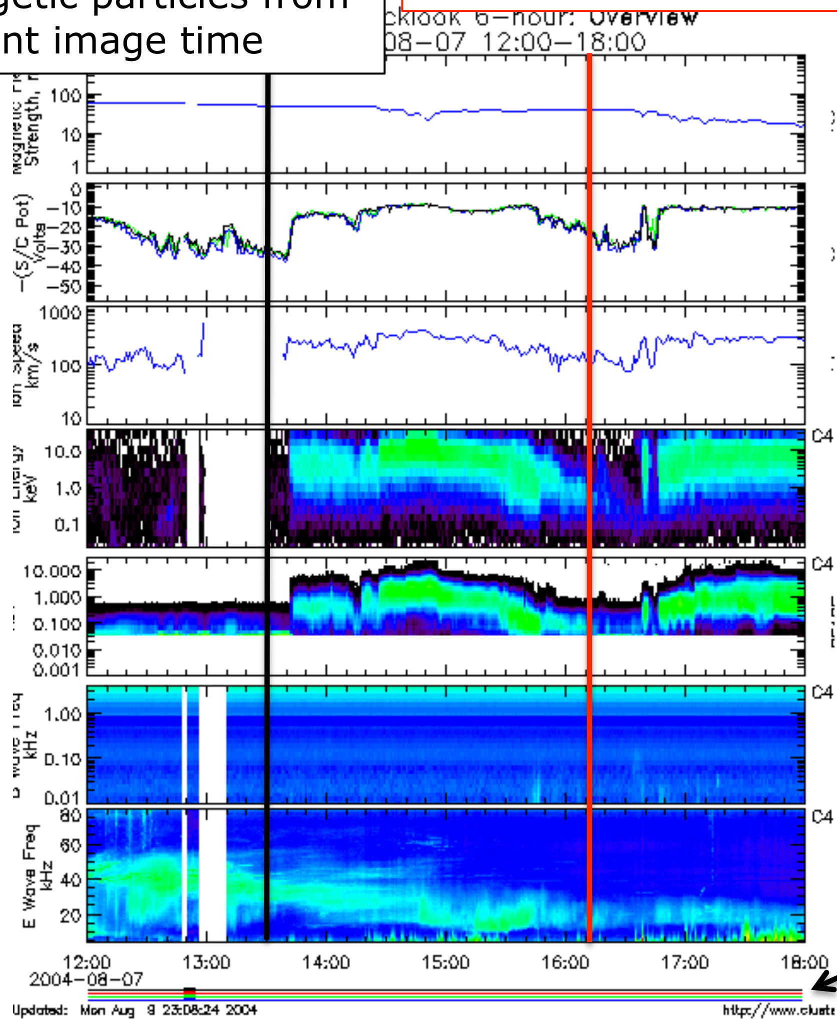
# Example Layout



# Example: Time Series Plot

ETA of (fastest?) energetic particles from current image time

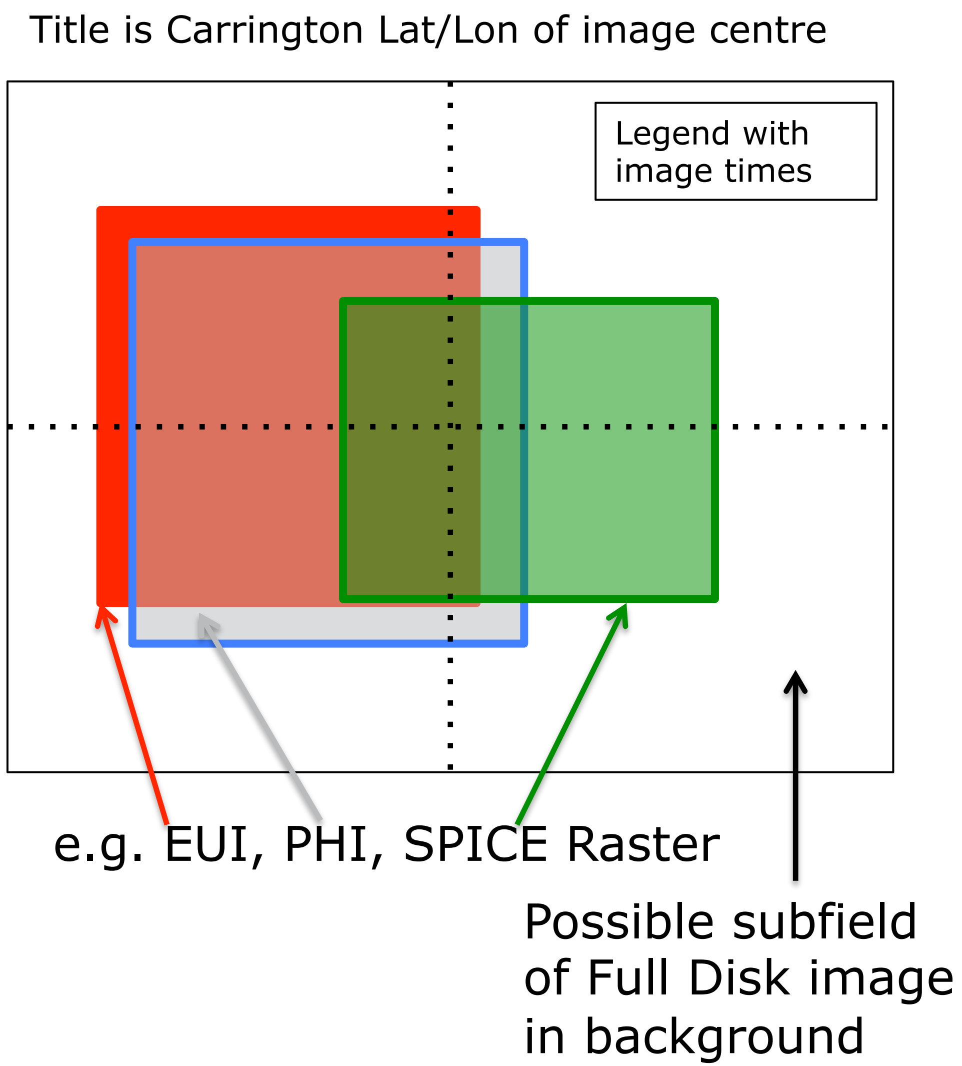
ETA of Solar Wind from current image time




- Choice of several (~6) predefined combinations of parameters e.g.
  - Overview
  - Linkage
  - Waves
  - Particles
- Choice of several predefined durations e.g. 6hrs, 1day, 3days
- STIX Lightcurves and SPICE spectral intensities could be plotted as time series here.

Simple way of showing in situ science plan: Thick line = burst mode, each colour represents a different instrument

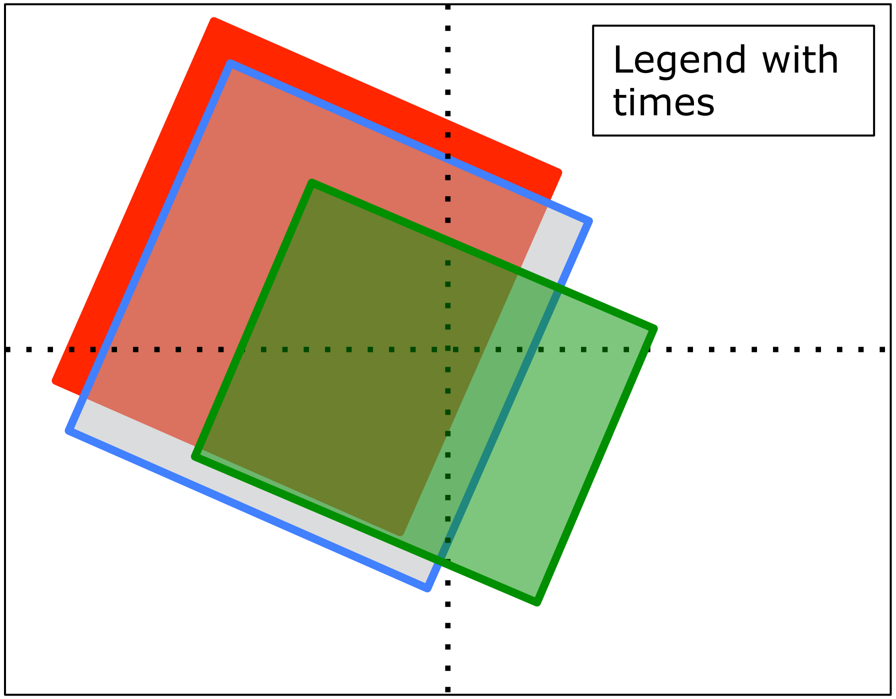
# Example: Small FoV Images




- Centred on Spacecraft boresight we use for pointing.
- FoV Large enough to cover all small FoV instruments.
- Based on static coalignment numbers, not dynamic.
- In a rolled state, keep overall FoV the same, move images.
- Adjustable transparency
- Overlaid FoVs instead / as well as data

# Example: Small FoV Images

Title is Carrington Lat/Lon of image centre




- Centred on Spacecraft boresight we use for pointing.
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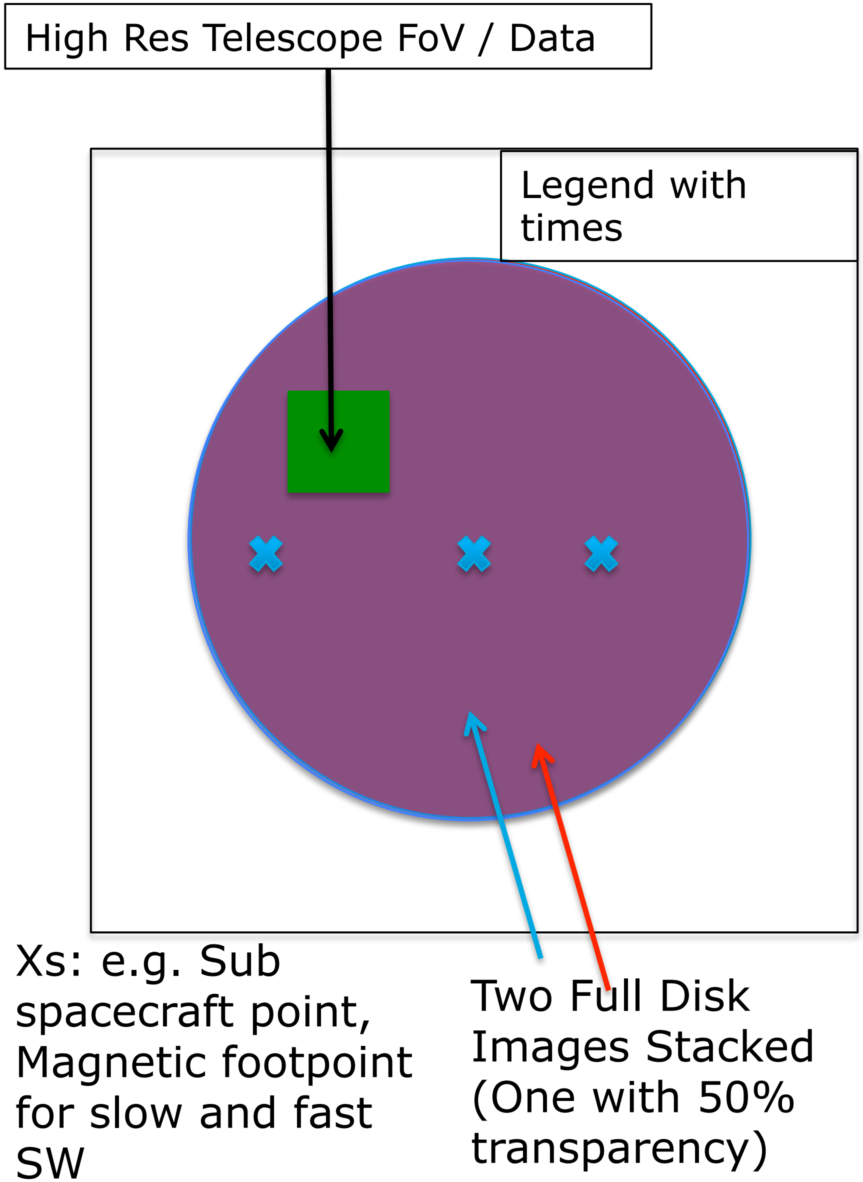
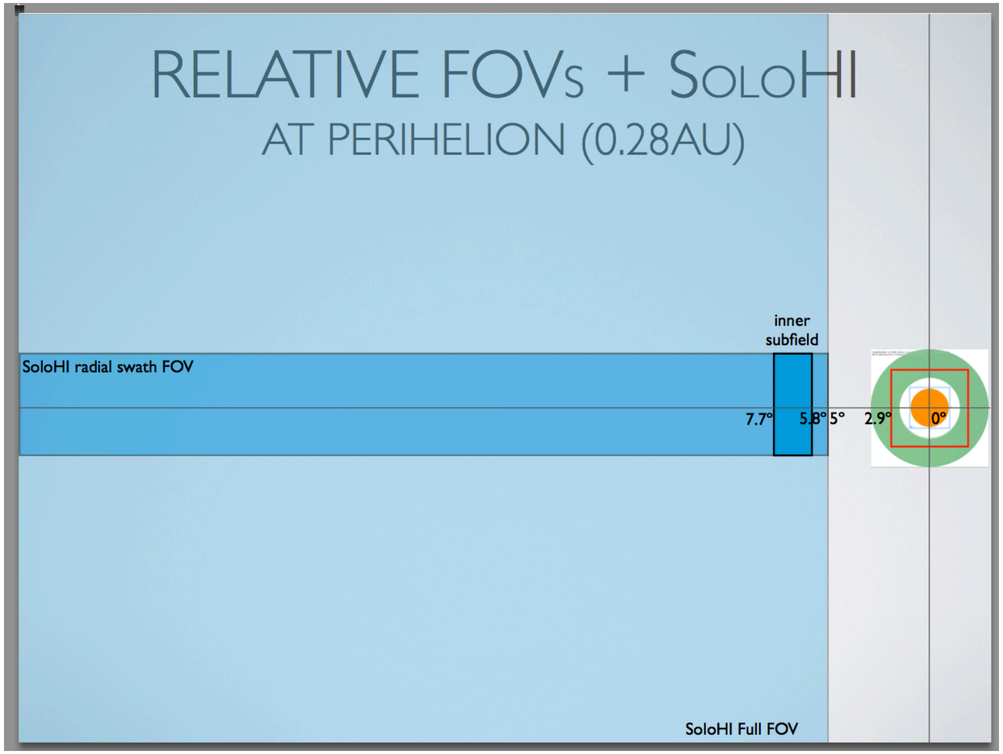
# Example: Full Disk Images



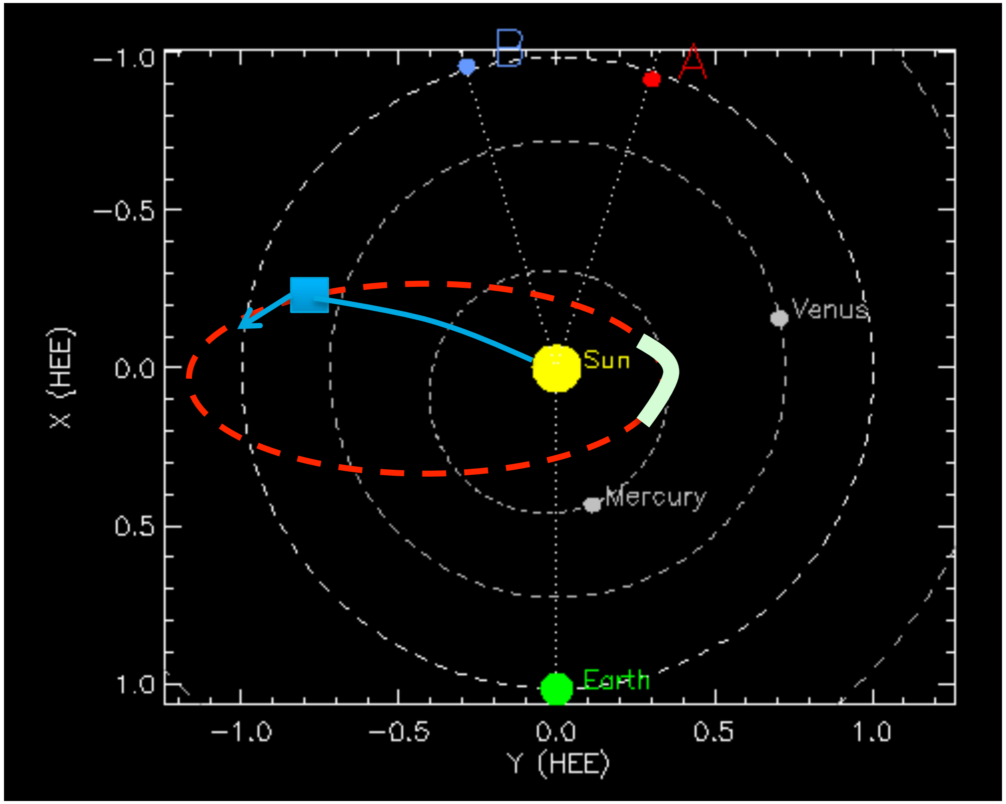

- Solar North always 'up'
- Spacecraft boresight always in the centre
- North/South solar pole and equator marked on high inclination images.
- Optional grid overlay
- Magnetic footpoints calculated with modal slow and fast SW velocities, not directly from SWA data.

# Example: 'Coronal' Field of View




1. Full Disk+METIS+SOLO-HI
2. Also version with just Full Disk+ METIS?
3. Note: SOLO-HI has multiple possible FoV sizes, so less obvious what to do here.

# Example: Simple Ephemeris

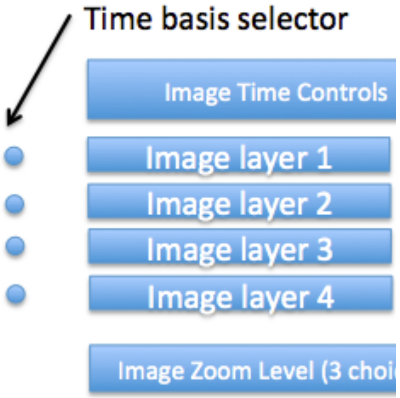


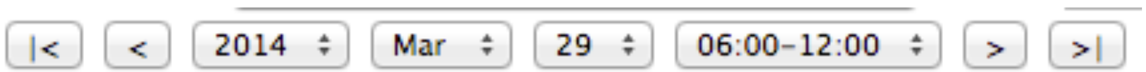

1. Simple 2D orbit projection
2. Position of spacecraft on orbit.
3. RSWs highlighted.
4. Model Parker Spiral field line.
5. Earth and other assets (SPP)

# Limited HK & Planning Display

- Static display of top level planning information.
  - Planned instrument modes.
  - 1 chart per day – simple display of an image outside main window.
- Limited HK and events information.
  - Actual Instrument modes
  - Times of trigger issuing / receipt
  - Subset of platform activities that have a science impact (Rolls, HGA pointings, wheel offloadings).
- We don’t intend this to be an HK Browser.
  - HK will be distributed separately.

# Time Handling




- Choose a time, it plots the closest images to that time.
- If the image time is TBD minutes away from requested time, tool warns user.
- 'Study' based instruments should have a validity time for each study and a valid study would be plotted rather than the closest image.
- Since different instruments have different cadences the forward and back buttons cycle through at the cadence of the layer selected as the time basis (primary layer).
- Time series side is easy given plots will have fixed durations.
- Possibility to set one side as primary or have a simple, static propagation system – the in situ side automatically displays the energetic particle ETA period for the current image for example?

# Access (Details TBD)

- Because Low Latency Data Display Tool will be needed operationally, we envisage two instances:
    1. An operational instance with access limited to Instrument Team Institutions and ESA establishments.
    2. An open instance accessible by the wider scientific community and general public.
- Technical details TBD.

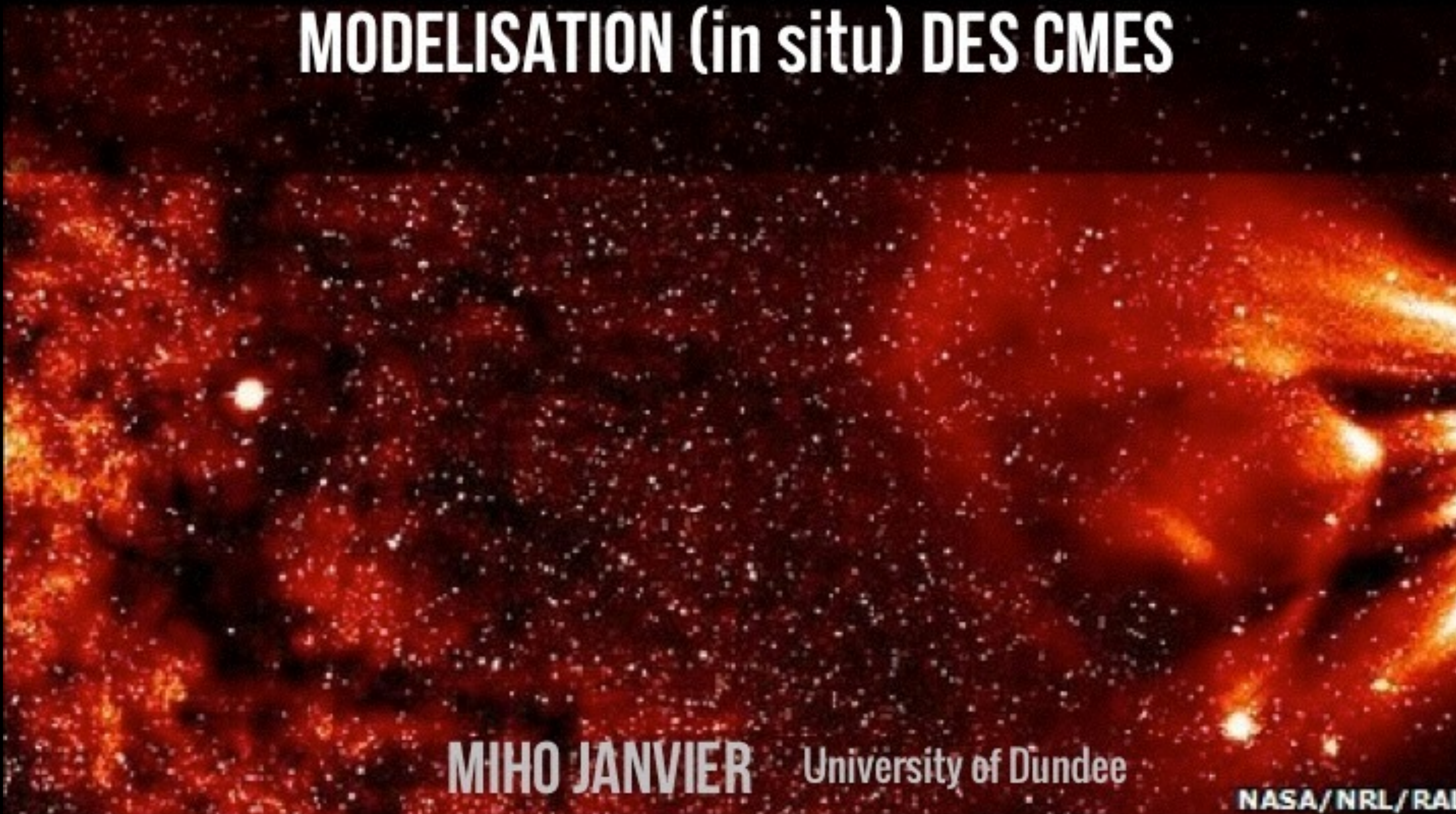
# Summary & Questions for Working Groups:

- We aim to provide a web-based tool, serving pre-generated plots in various combinations.
- Speed and simplicity are key.
- Separate tool will handle PTR generation.
- We believe this will address the 3 defined uses of LL data.

Bearing in mind we're not providing a science analysis tool and we will also make available all LL Data files to Instrument teams:

- Have we missed anything?
- Which combinations of Time Series Parameters would be the most useful?

# MODELISATION (in situ) DES CMES




MIHO JANVIER University of Dundee

Collaboration: Pascal Démoulin, Sergio Dasso, Noé Lugaz

Observatoire de Paris UBA (Argentine) Univ. New Hampshire (US)

# MODELISATION (in situ) DES CMES

CMEs vs ICMEs

Les sous-structures des ICMEs

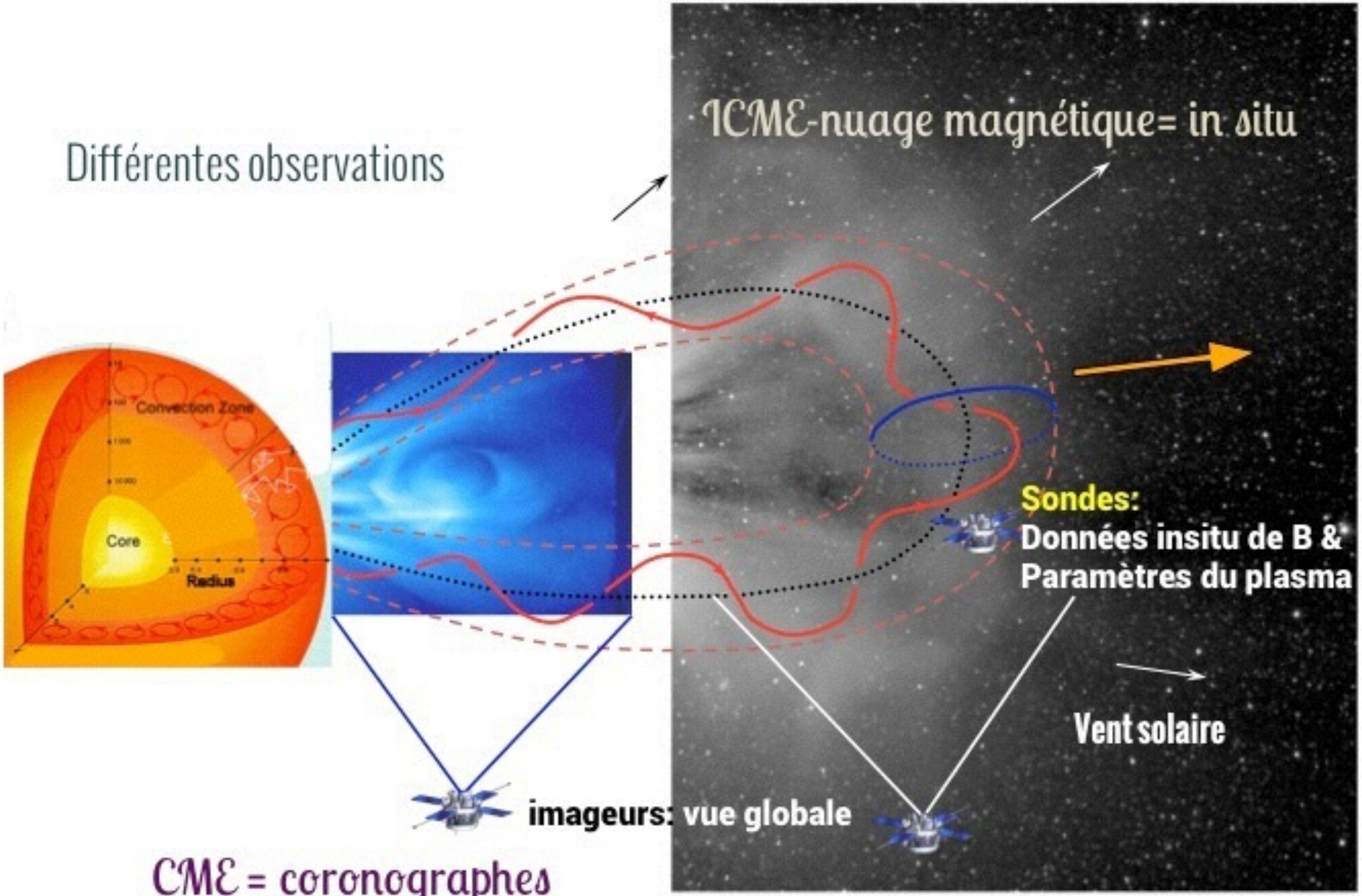
Liens mesures in situ – remote sensing

Etudes statistiques: forme générique des ICMEs


Limitations des catalogues: objectif Solar orbiter

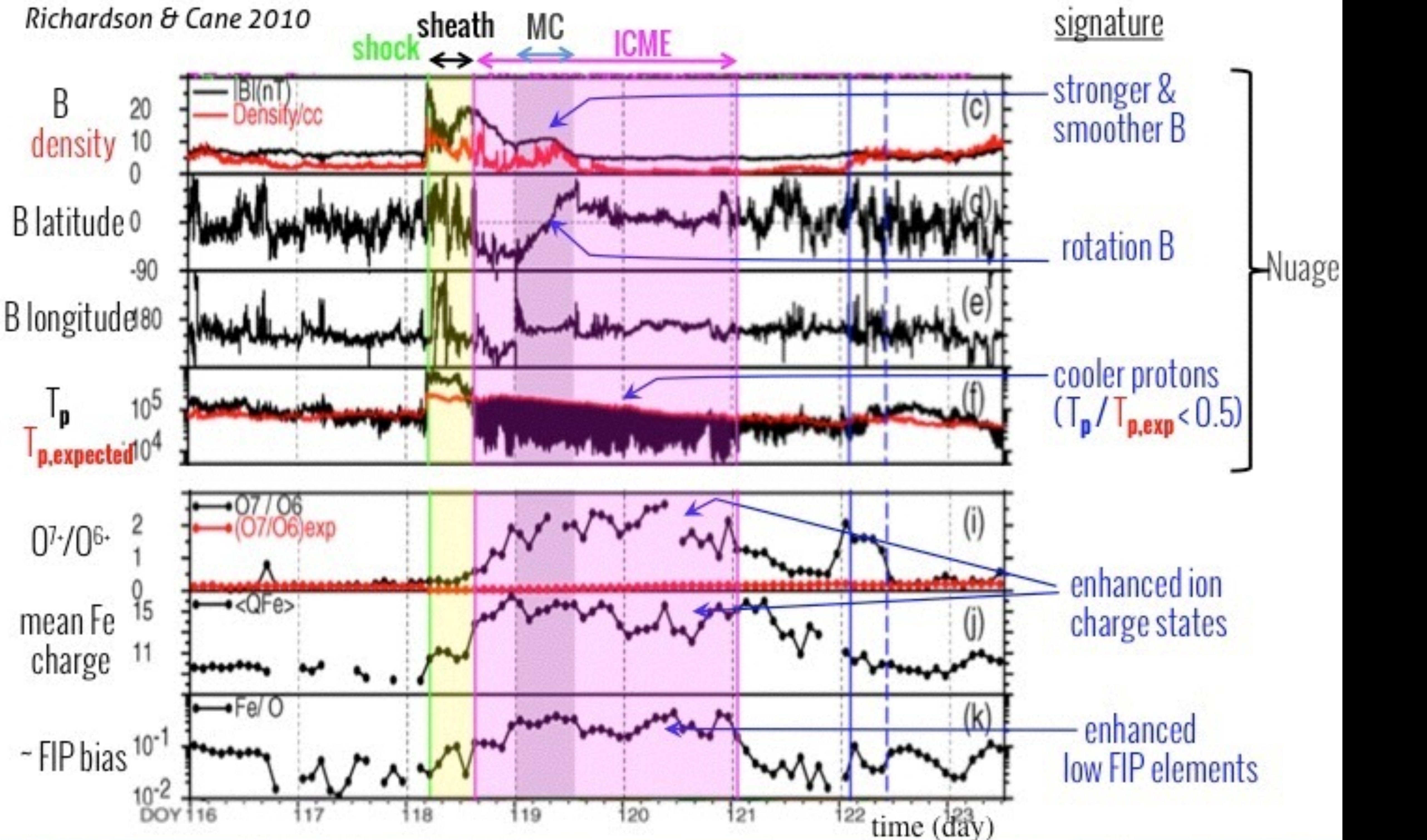
# CMES, ICMES ET SOUS-STRUCTURES

Différentes observations



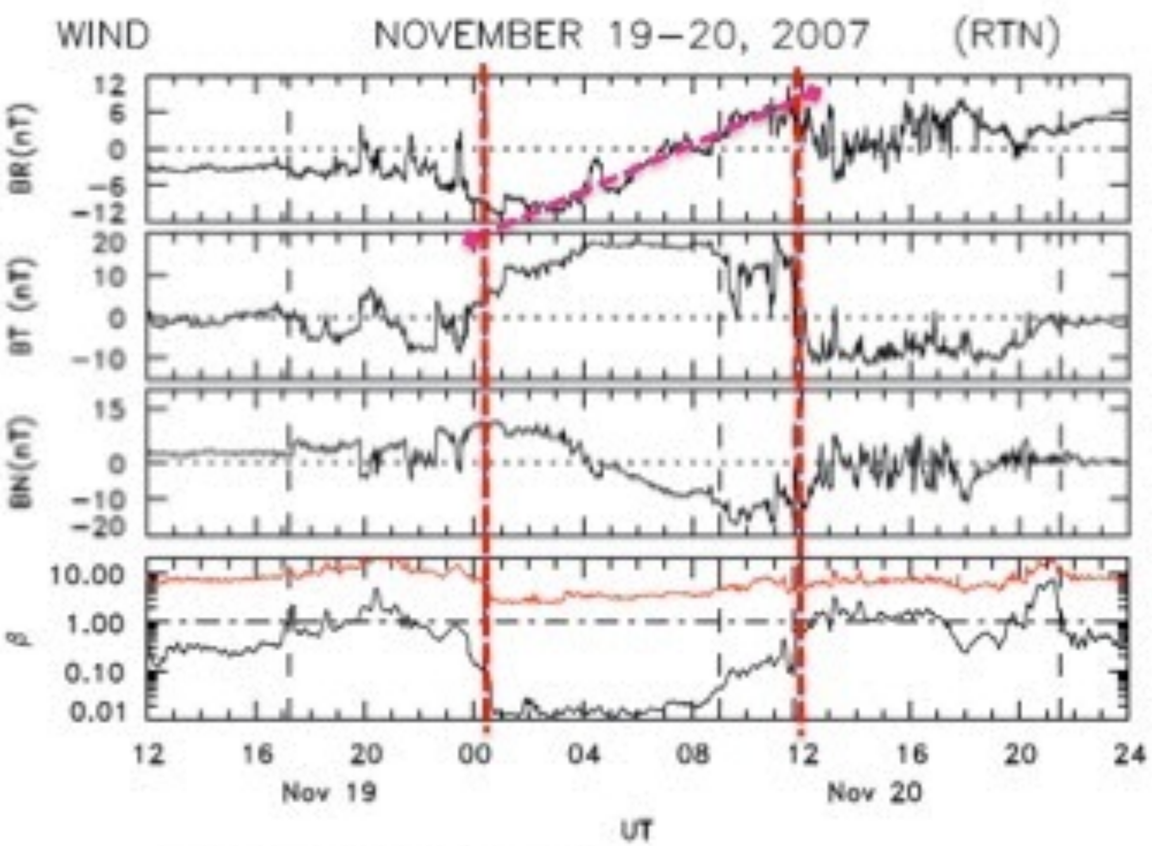

CME = coronographes

# EXAMPLE DE DÉTECTION IN SITU D'UNE ICME + NUAGE MAGN.

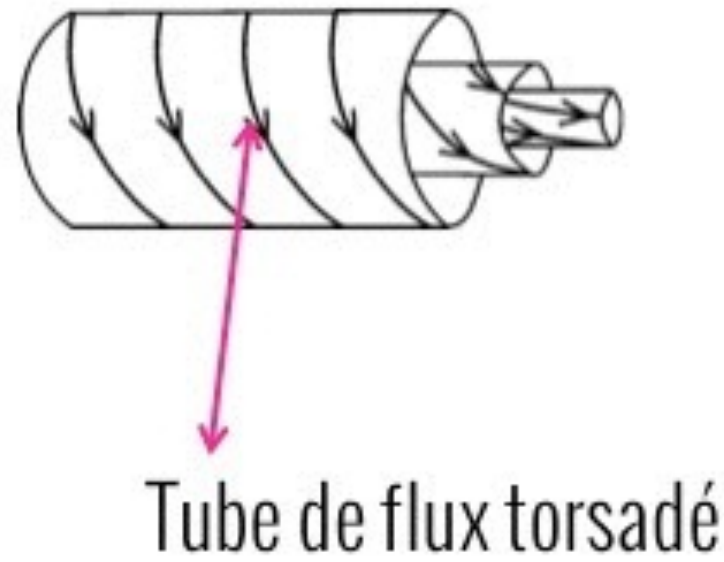


# LIEN NUAGE MAGNÉTIQUE – TUBE DE FLUX TORSADÉ

**Rotation** large et lisse

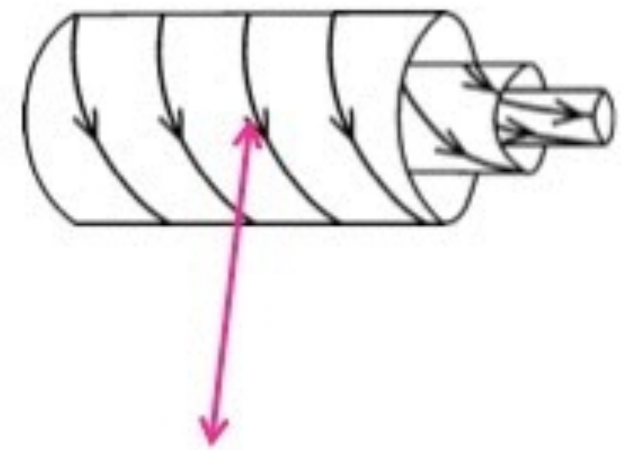



*Farrugia et al. (2011)*



# LIEN NUAGE MAGNÉTIQUE – TUBE DE FLUX TORSADÉ

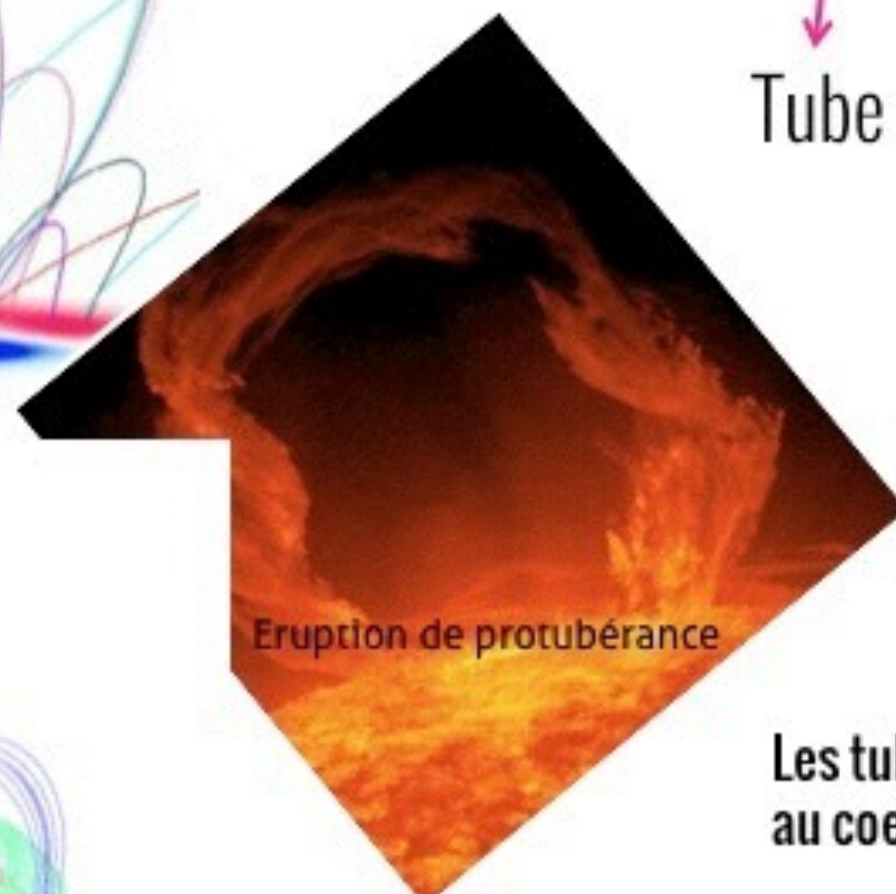
## Tubes de flux torsadés dans la couronne solaire

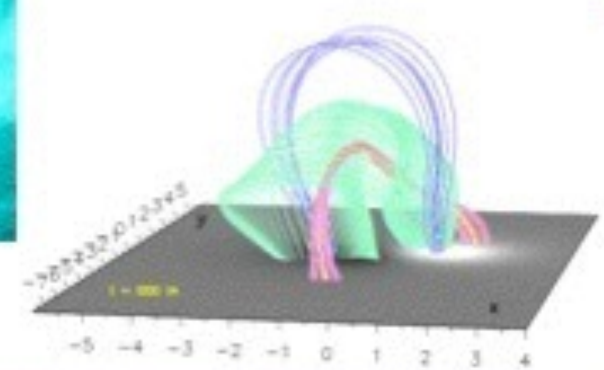


Tube de flux torsadé



Instabilité du tube de flux

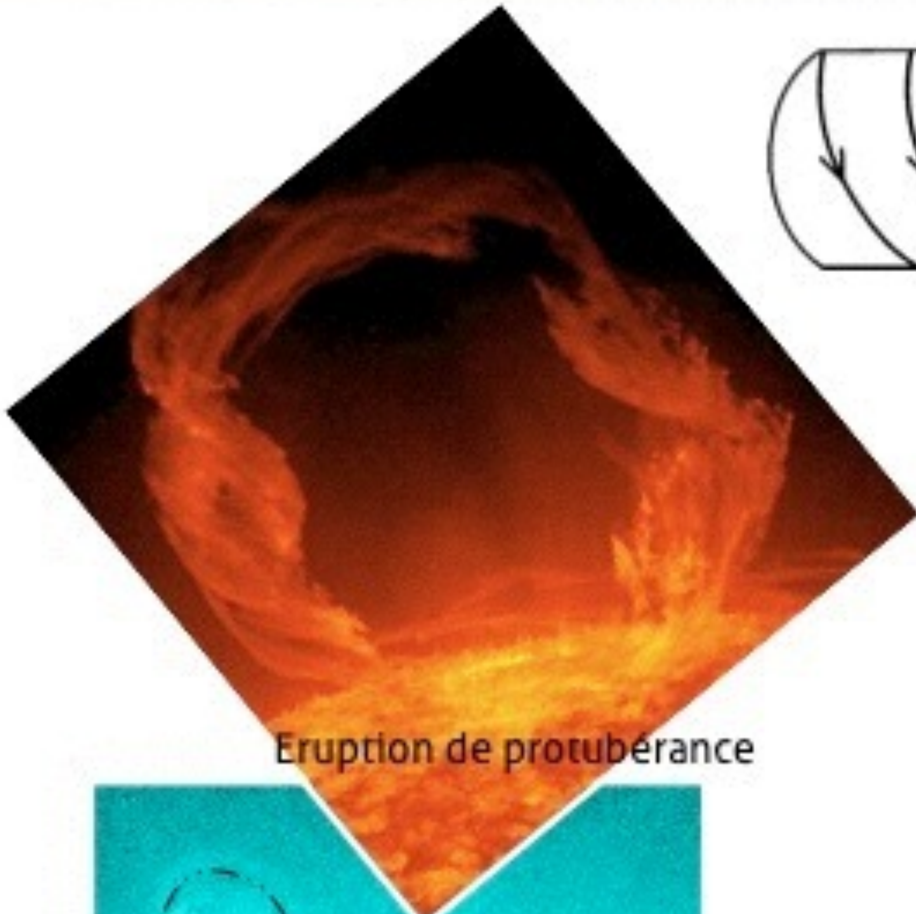


**Simulation MHD OHM**

**Les tubes de flux torsadés sont au coeur des éruptions solaires**

# PHASE PRE-/ERUPTIVE – PROPAGATION



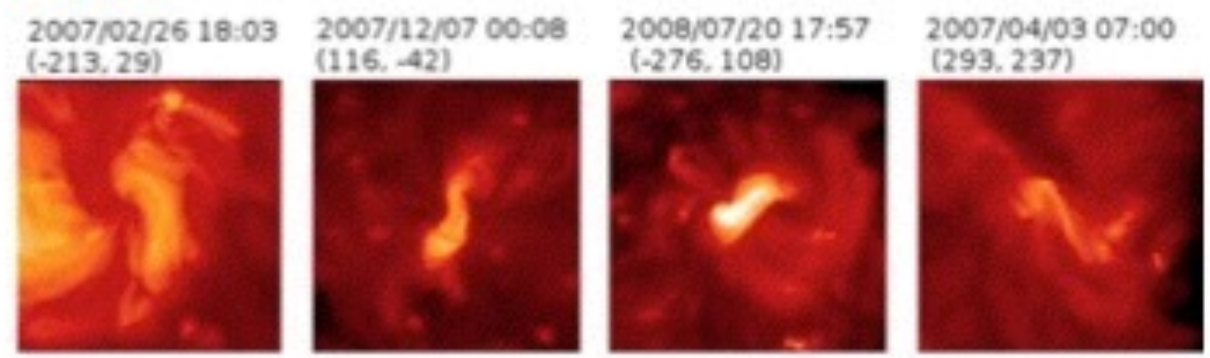


Instabilité du tube de flux

## Etudes de cas

-Etude des sigmoids/protubérances/filaments

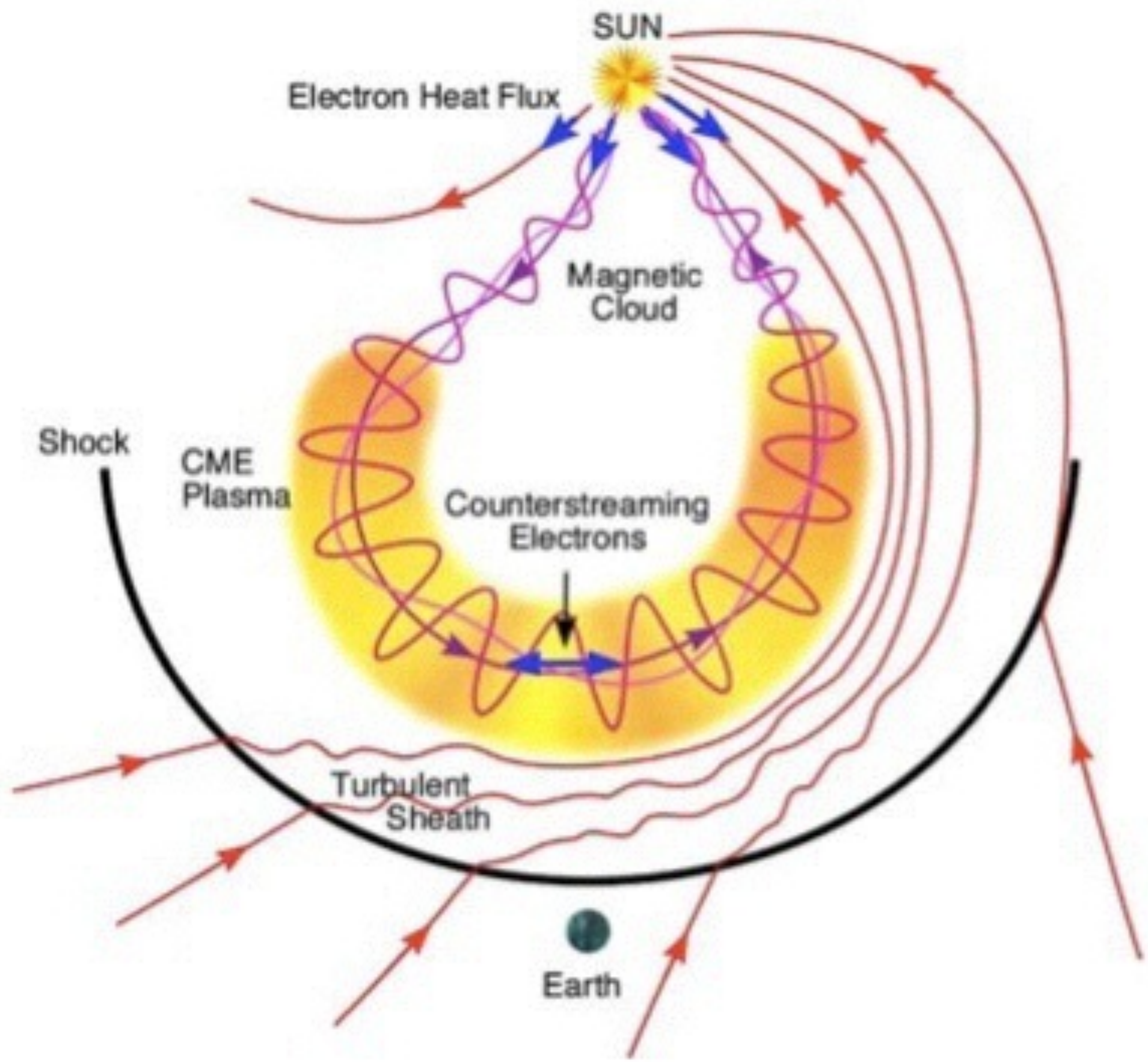
**EUI: morphologie (reconnaissance de filaments)**
**PHI: reconstruction magnétique (PFSS? Fromage? (XTRAPOL - XTRAPOLS) NLFFF?)**
**SPICE: FIPs, abondances**




-Propagation des CMEs dans l'héliosphère interne

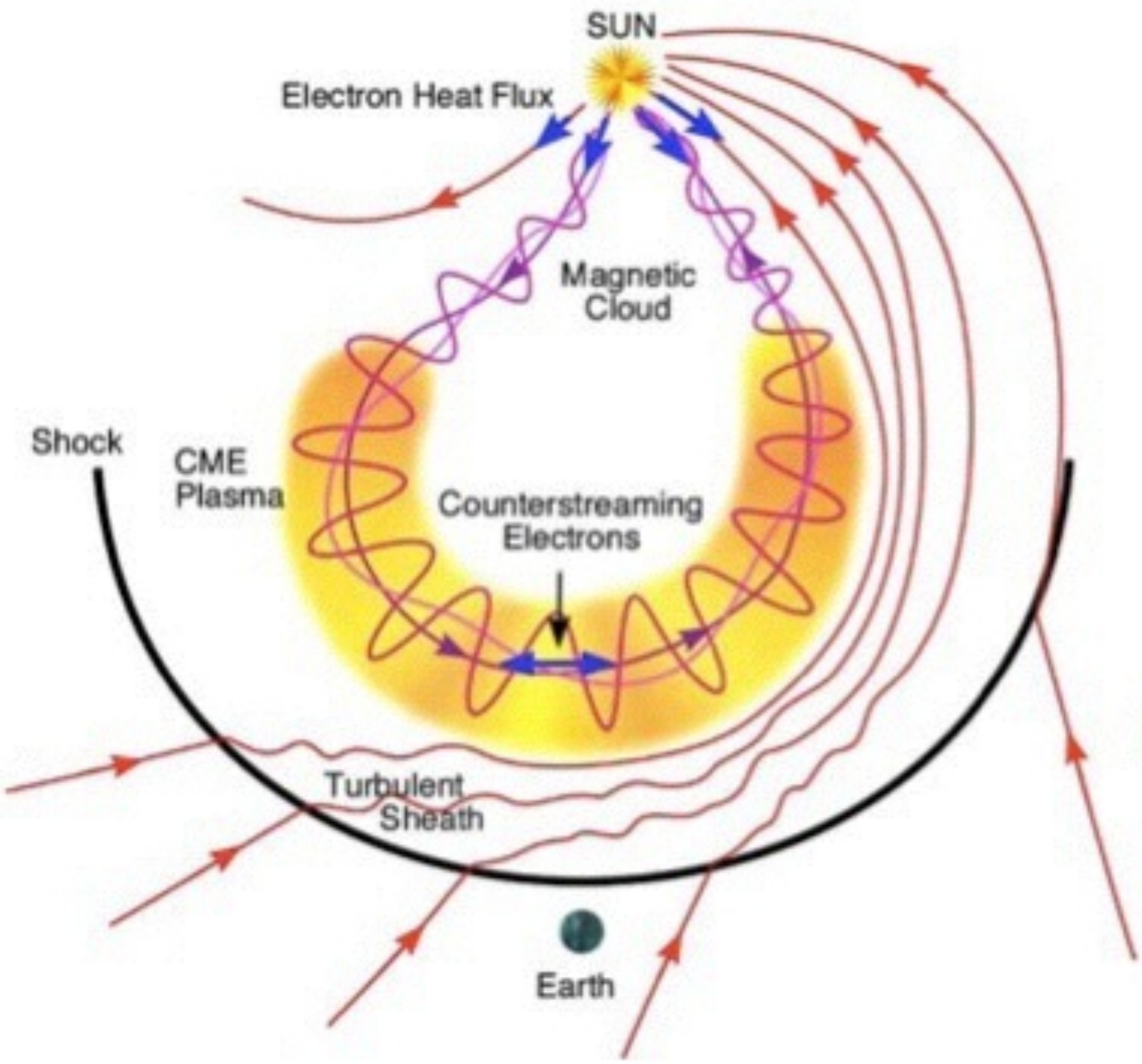
**(effets d'interaction avec le vent solaire sont moindres)**
**MAG: mesure du champ magnétique**
**SWA: mesure plasma**
**...**

# STRUCTURE GÉNÉRALE D'UNE ICME




*( Zurbuchen & Richardson 2006 )*

# STRUCTURE GÉNÉRALE D'UNE ICME




( Zurbuchen & Richardson 2006 )

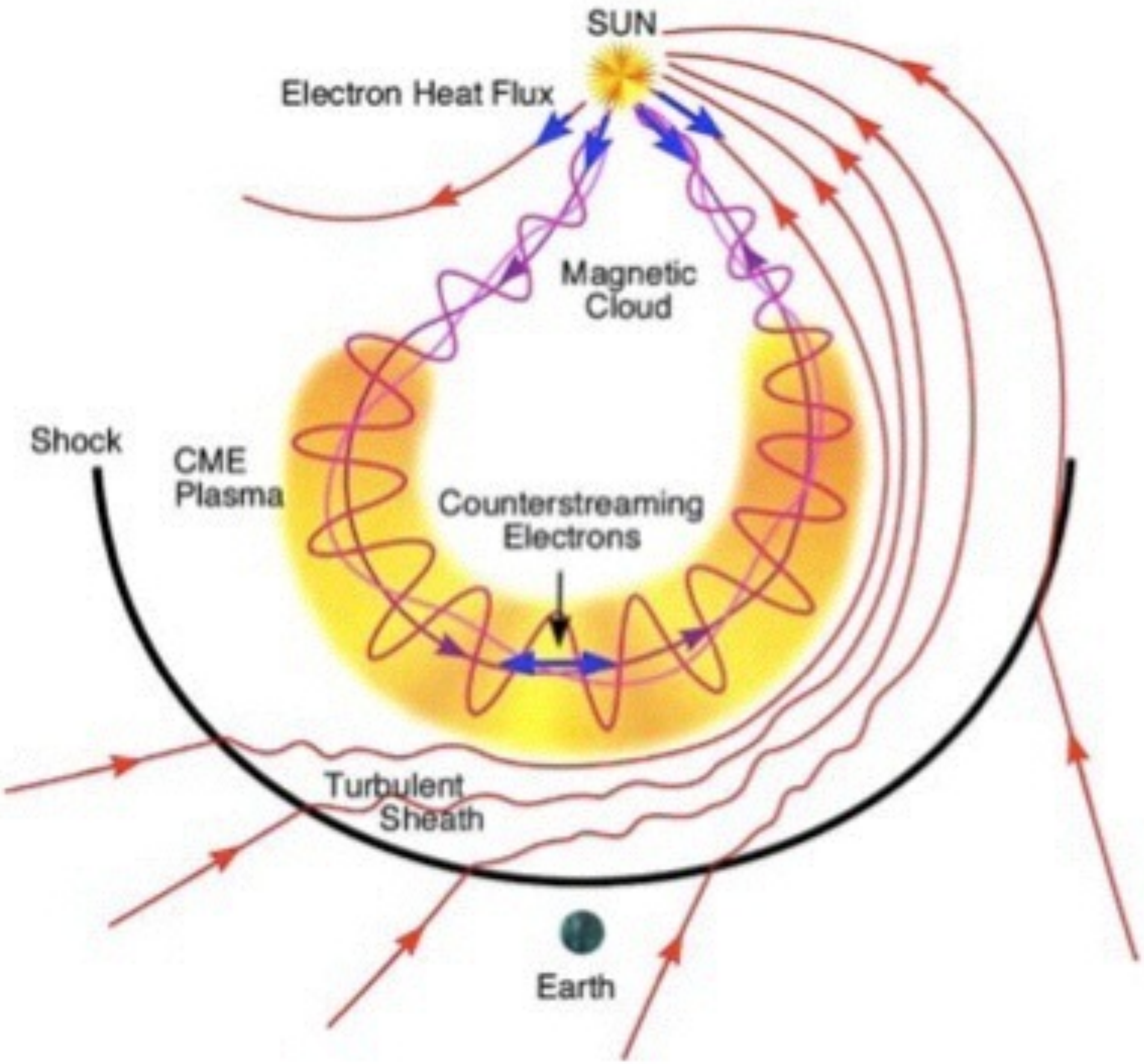
Quelle est la forme (générique) 3D des ICMEs?

Forme générique du choc?

Forme de l'axe du nuage magnétique?

**Epaisseur de la gaine?**

# STRUCTURE GÉNÉRALE D'UNE ICME

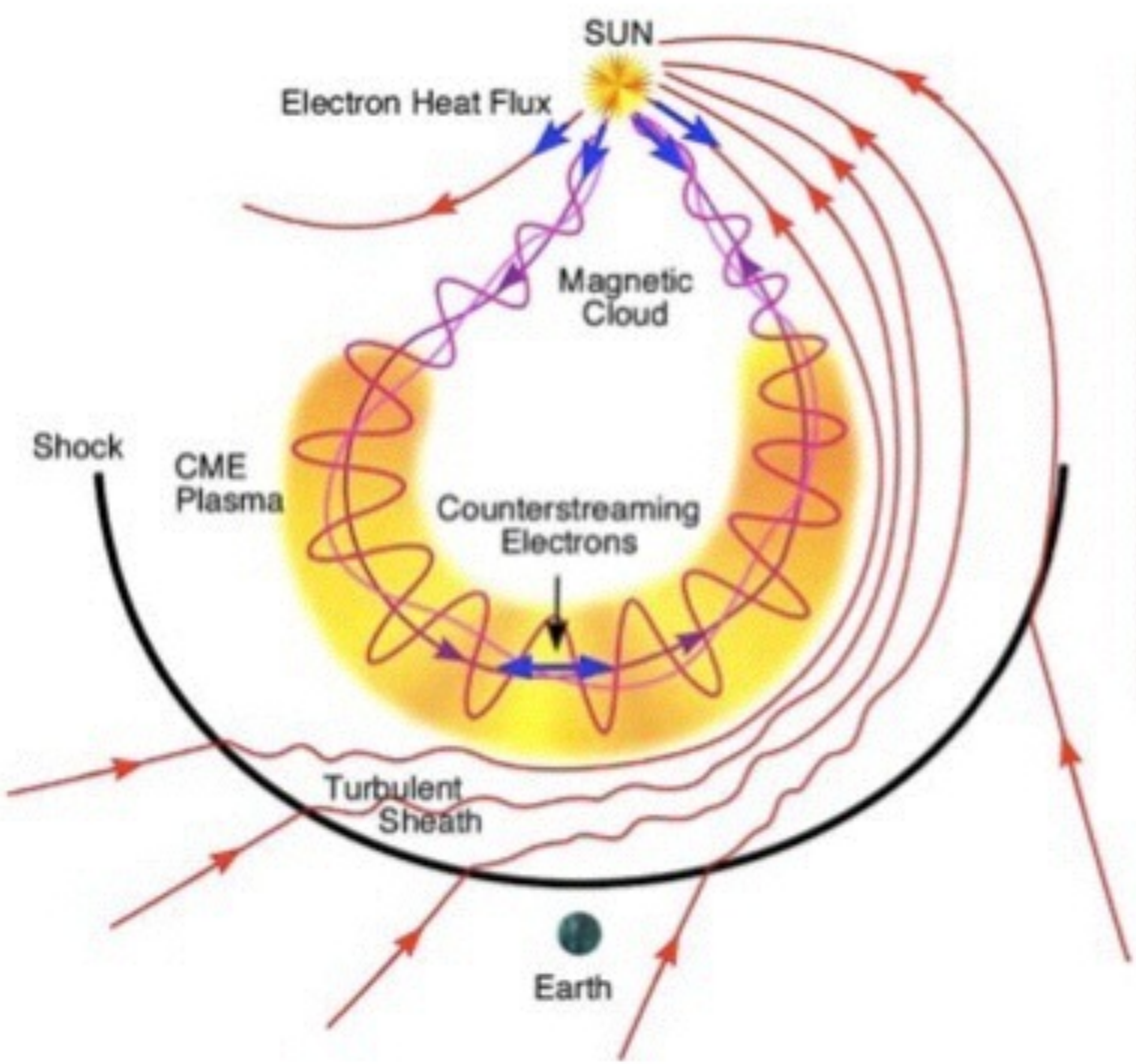



*( Zurbuchen & Richardson 2006 )*

**Connaître la forme du nuage magnétique a des implications pour:**

- Longueur des lignes de champ magnétique →**retard à la detection des particules énergétiques**
[Larson et al. 1997, Masson et al. 2012]
- **Lien avec la configuration 3D** de la source solaire
[Nakwacki et al. 2011]
- Utile pour le **budget de l'hélicité/énergie/flux magnétique**
[Démoulin et al. 2002, Dasso et al. 2005]

# STRUCTURE GÉNÉRALE D'UNE ICME



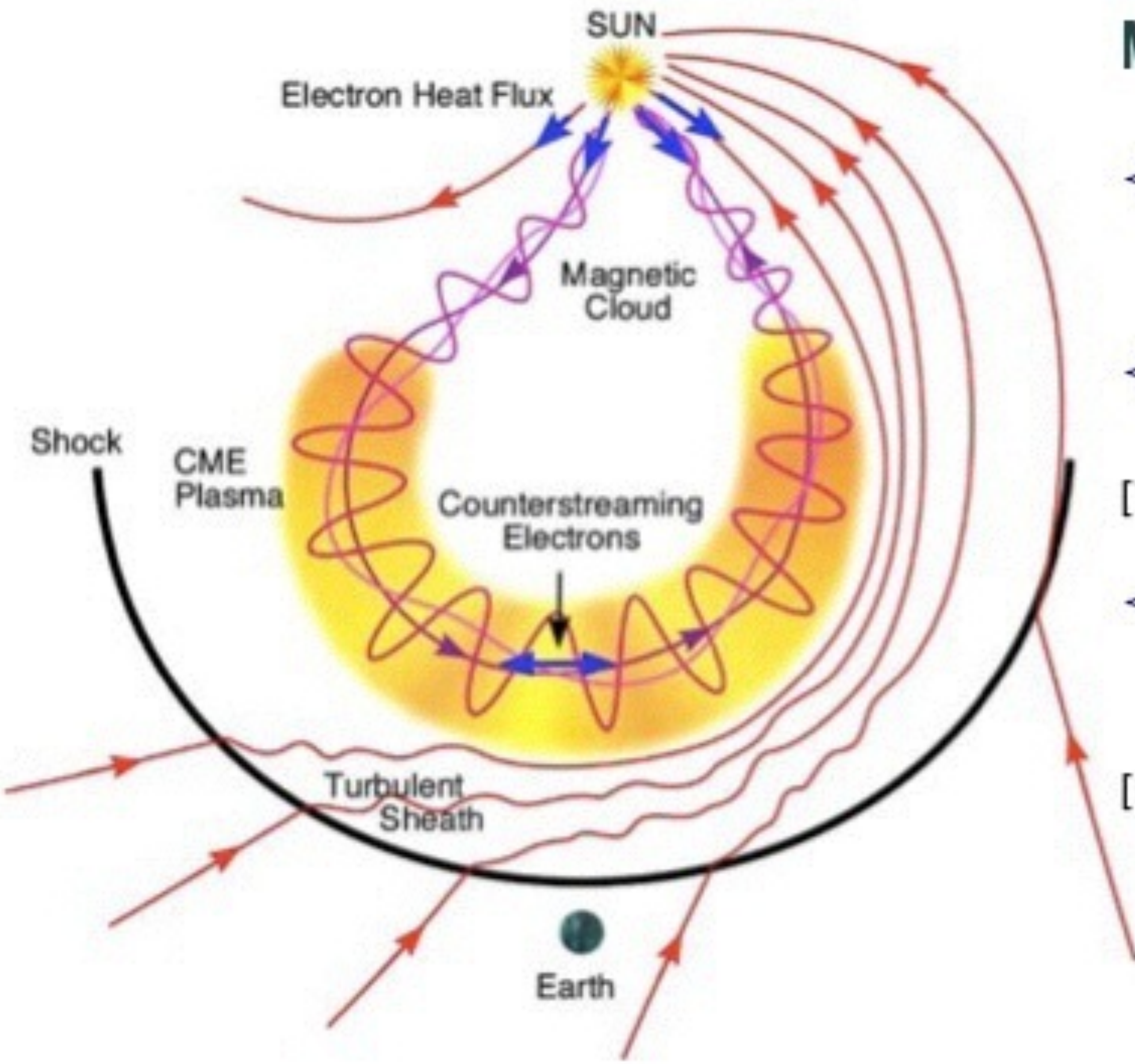

*( Zurbuchen & Richardson 2006 )*

**Connaître la forme du choc a des implications pour:**

- Prédiction de l'interaction avec l'environnement terrestre
  (Mostl & Davies 2013)
- Décroissance du flux de particules énergétiques (effet Forbush)

(Cane 2000, Pierre Auger Collaboration 2011]

# STRUCTURE GÉNÉRALE D'UNE ICME




*( Zurbuchen & Richardson 2006 )*

**MAIS** difficultés pour obtenir la forme 3D:

- ✧ Détection seulement dans une direction (trajectoire de la sonde)
- ✧ Fit de modèles aux données: seulement une vue locale

[Vandas & Romashets 2003, Sonnerup et al. 2006]

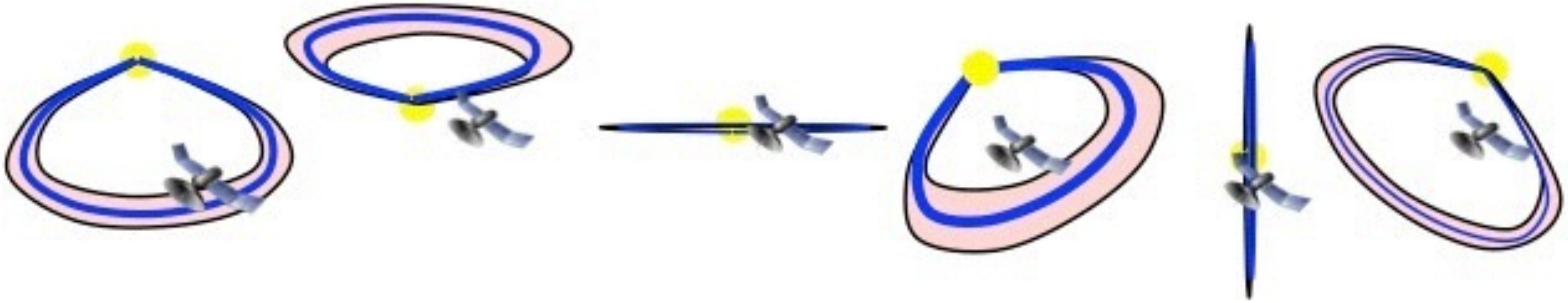
- ✧ Détections simultanées par sondes ou à différentes distances (évolution →1AU) :
  Phénomène rare

[Du et al. 2007, Ruffenach et al. 2012]

# ETUDES STATISTIQUES DES STRUCTURES INTERPLANÉTAIRES

## Solution: ETUDE STATISTIQUE DES NUAGES/CHOCS

- Idée: étudier les probabilités de distribution de paramètres d'orientation sur un catalogue d'évènements



**Liste d'évènements avec leurs paramètres physiques**

| Start | | | | | End | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Yr | Mon | Day | DOY | Hr | Mon | Day | DOY | Hr | $\Delta T$ [a] (Hr) | $\phi_A$ [b] (°) | $\theta_A$ [b] (°) | V [c] km/s | 2Ro [d] (AU) | $B_*$ [e] (nT) |
| 95 | 02 | 8 | 039 | 5.8 | 02 | 9 | 040 | 0.8 | 19.0 | 100 | 18 | 410 | 0.216 | 15.2 |
| 95 | 03 | 4 | 063 | 10.8 | 03 | 5 | 064 | 3.8 | 17.0 | 205 | −76 | 443 | 0.165 | 14.9 |
| 95 | 04 | 3 | 093 | 7.8 | 04 | 4 | 094 | 10.8 | 27.0 | 96 | −22 | 301 | 0.303 | 13.3 |
| 95 | 04 | 6 | 096 | 7.3 | 04 | 6 | 096 | 17.8 | 10.5 | 149 | 58 | 334 | 0.083 | 14.8 |

Orientation de l'axe du nuage

*Janvier, Démoulin & Dasso 2013 → nuages magnétiques*
*Janvier, Démoulin & Dasso 2014 → chocs*
*Janvier, Dasso, Démoulin, Lugaz in prep. → ICMEs*

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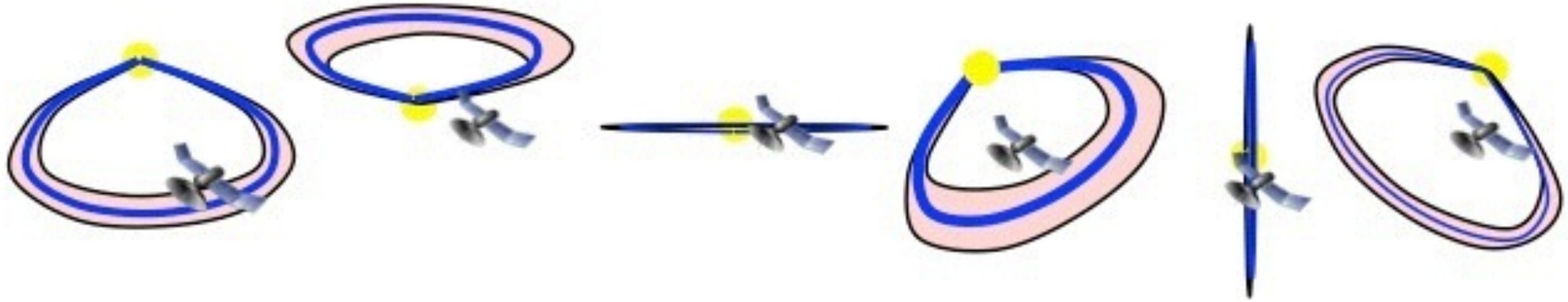
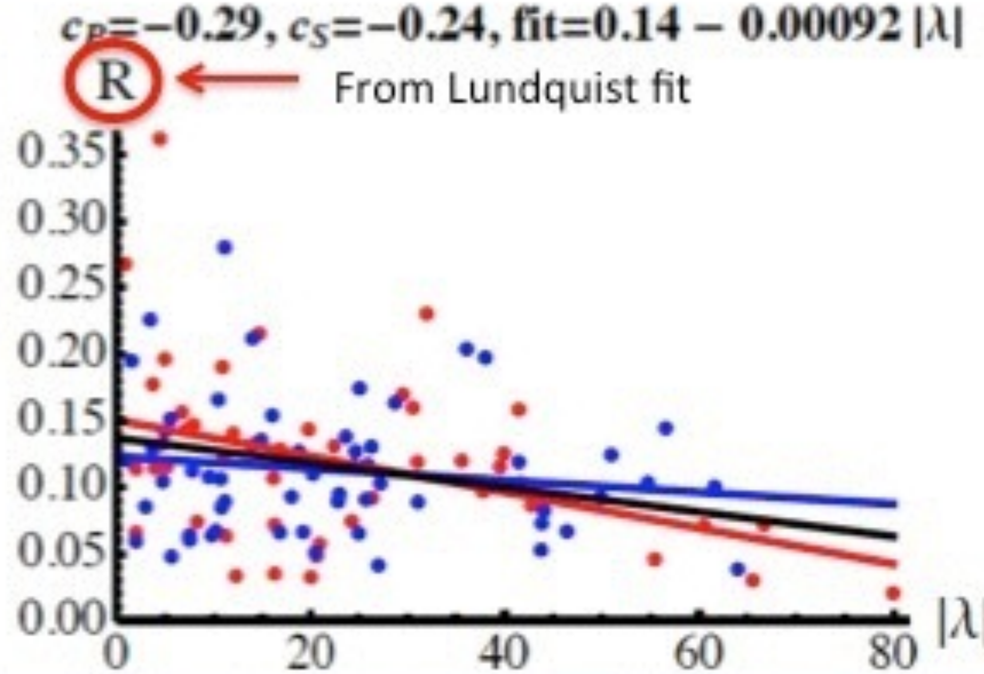


**Liste d'évènements avec leurs paramètres physiques**

**Etude des corrélations entre paramètres**




*Janvier, Démoulin & Dasso 2013 → nuages magnétiques*
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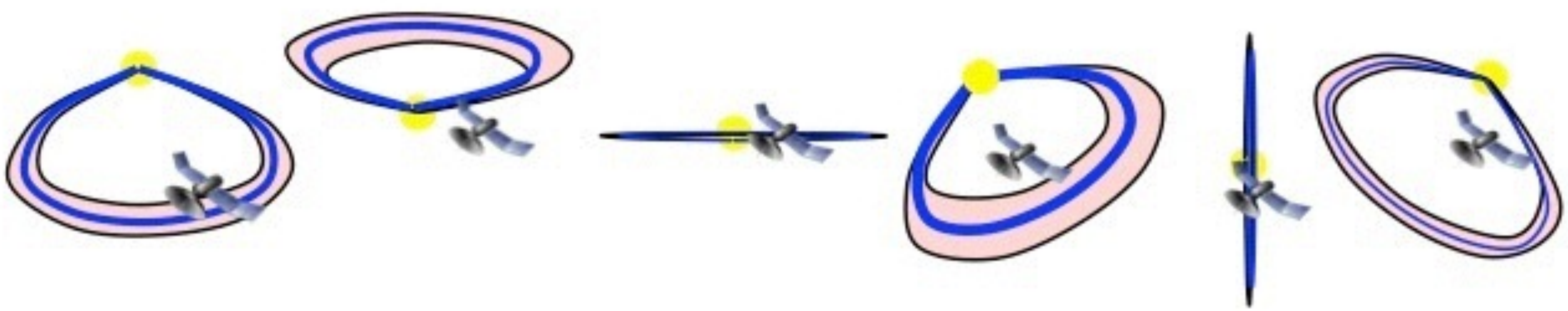


Liste d'évènements avec leurs paramètres physiques

Etude des corrélations entre paramètres

Comparaison des distributions des paramètres locaux avec des modèles synthétiques

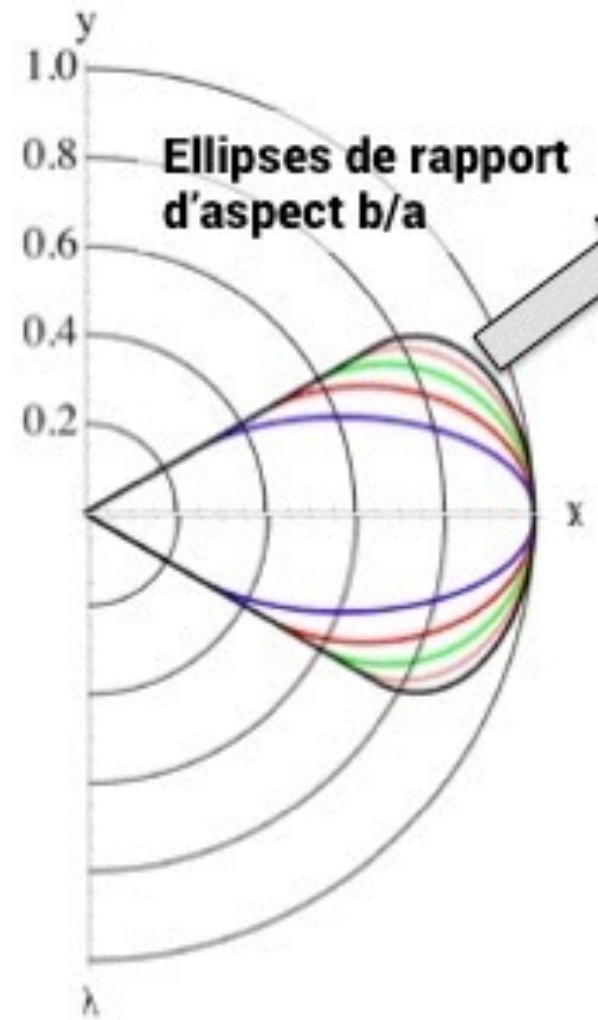
Intégration directe des distributions observées

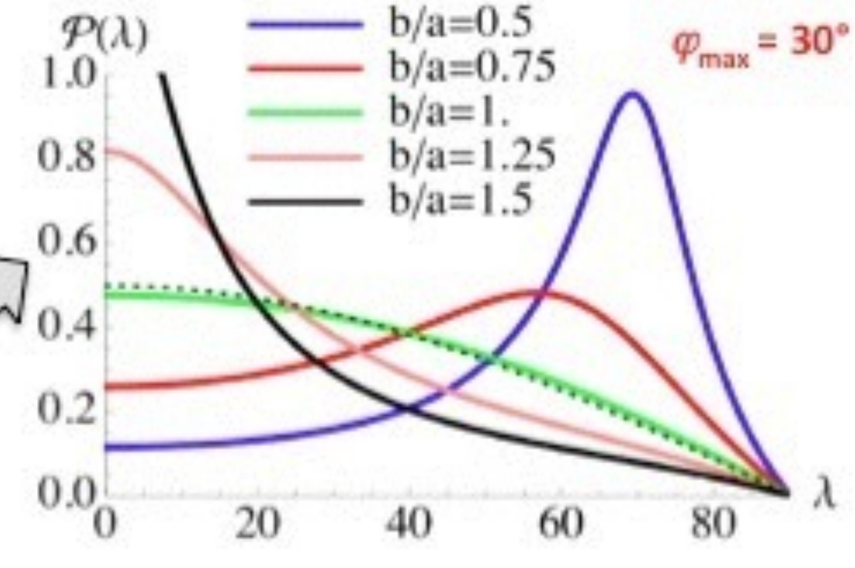
*Janvier, Démoulin & Dasso 2013 → nuages magnétiques*
*Janvier, Démoulin & Dasso 2014 → chocs*
*Janvier, Dasso, Démoulin, Lugaz in prep. → ICMEs*

# ETUDES STATISTIQUES DES STRUCTURES INTERPLANÉTAIRES

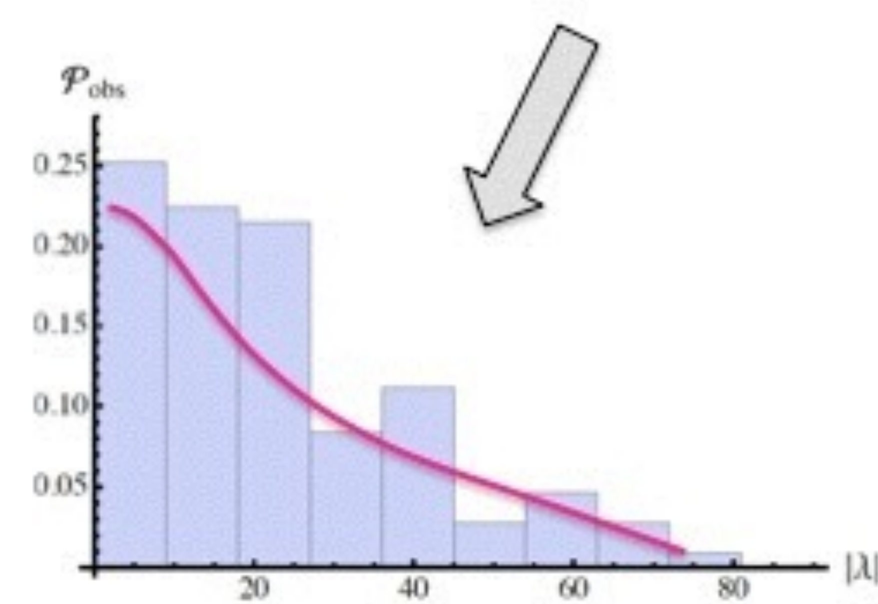
## Solution: ETUDE STATISTIQUE DES NUAGES/CHOCS

**Comparaison** de la distribution du paramètre de localisation le long de l'axe avec un **modèle synthétique**




Distributions synthétiques




Distributions observées

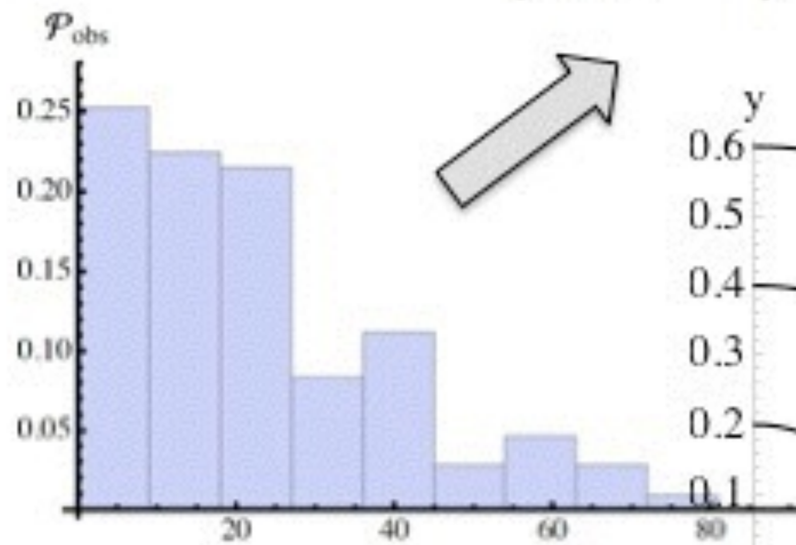
*Janvier, Démoulin & Dasso 2013 → nuages magnétiques*
*Janvier, Démoulin & Dasso 2014 → chocs*
*Janvier, Dasso, Démoulin, Lugaz in prep. → ICMEs*

# ETUDES STATISTIQUES DES STRUCTURES INTERPLANÉTAIRES

## Solution: ETUDE STATISTIQUE DES NUAGES/CHOCS

**Comparaison** de la distribution du paramètre de localisation le long de l'axe avec un **modèle synthétique**

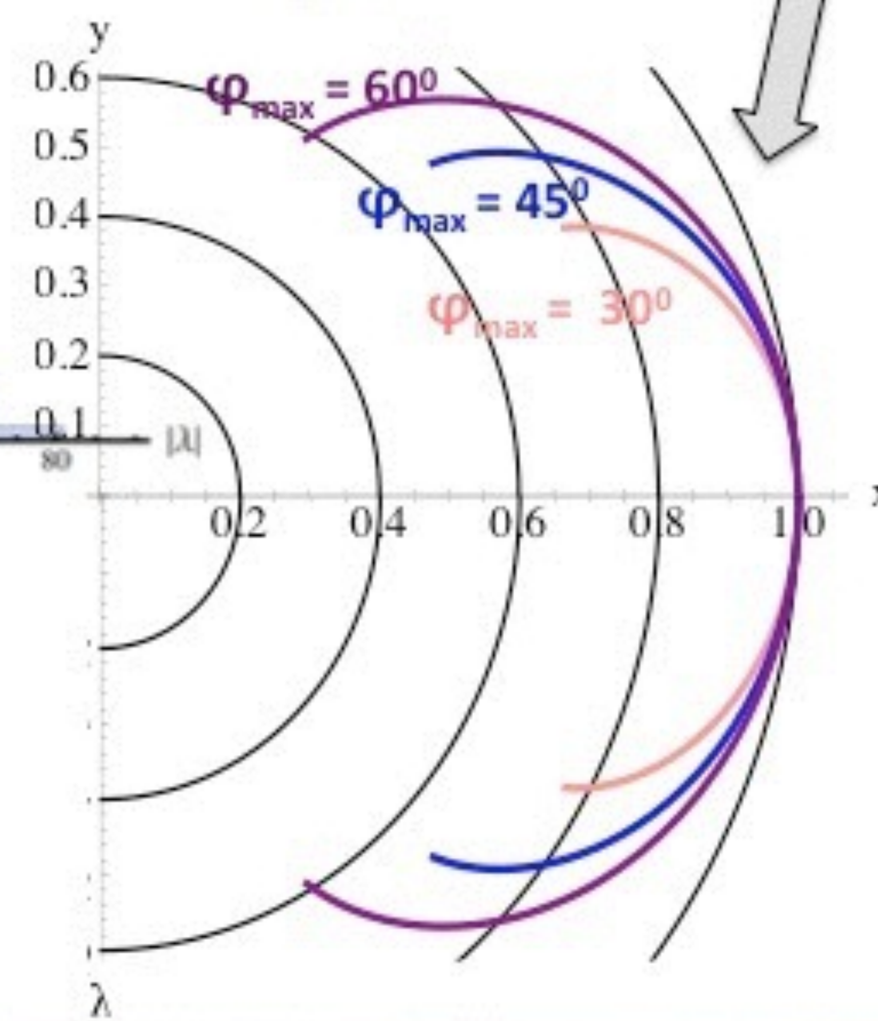
**Intégration directe** des distributions observées




Distributions observées

**Distribution intégrée**

$$\varphi(\lambda) = \varphi_{\max} \int_0^{\lambda} \mathcal{P}_{\text{obs}}(|\lambda'|)\mathrm{d}\lambda'$$




*Janvier, Démoulin & Dasso 2013 → nuages magnétiques*
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*Janvier, Dasso, Démoulin, Lugaz in prep. → ICMEs*

# LIMITATIONS DES CATALOGUES

## Les méthodes et leurs limites

Nuages magnétiques: **Fit des données in situ**

- Force-free field + axe du nuage "droit" (cas simple)
( Burlaga et al. 1981, Lepping et al. 1990, Farrugia et al. 1999, ...)
- Magneto-hydrostatic (Hu & Sonnerup 2001, Hidalgo et al.2002 ...)
- Self-similar expansion (géométrie toroidale)
( Marubashi 1997, Vandas & Romashets 2003, ...)

- **Analyse de la variance minimum**

( Sonnerup & Cahill 1967, Bothmer & Schwenn 1998 )

- **Contraintes physics**

-conservation du flux azimuthal
(important pour les nuages érodés)
( Dasso et al. 2006, Ruffenachet al. 2012 )

Chocs:

- Méthode de la variance minimum (Sonnerup & Cahill. 1967...)
- Analyse de la variance coplanaire (Scudder 2005...)
- Rankine-Hugoniot (Lin et al. 2006...)

**Pb: les résultats dépendent de la méthode et de l'intervalle sélectionné pour les données**

# LIMITATIONS DES CATALOGUES

## Catalogues publiques

Nuages magnétiques:
- Lepping & Wu 2010
- Lynch et al. 2005
- Feng, Wu & Chao 2007 (certains ne sont pas des nuages)

Petits tubes de flux:
- Feng, Wu & Chao 2007
- Feng et al. 2008

ICMEs:
- Richardson & Cane 2010

Chocs:
- Wang et al. 2010
- Feng et al. 2010
- "Kasper's list" : http://www.cfa.harvard.edu/shocks/

**NÉCESSITÉ D'UNE BASE COHÉRENTE + COMPARAISON DIFFÉRENTES MÉTHODES**

# EXAMPLE: CATALOGUES DE CHOCS

"Kasper's list"

CfA Home | HCO Home | SAO Home

HARVARD-SMITHSONIAN CENTER FOR ASTROPHYSICS

About · Research · Education & Outreach · Facilities · Opportunities · Events · News

Back to Shock Database home

Back to spacecraft home

1995 · 1996 · 1997 · 1998 · 1999 · 2000 · 2001 · 2002 · 2003 · 2004 · 2005 · 2006 · 2007 · 2008 · 2009 · 2010 · 2011 · 2012 · 2013 · 2014

## CfA Interplanetary Shock Database - Yearly Summary

| Year | Month | Day | DOY | UT | X | Y | Z | Type | URL | Updated |
|---|---|---|---|---|---|---|---|---|---|---|
| 2014 | 01 | 07 | 7.607552 | 1434 | 195.21 | -27.77 | -13.98 | FF | link | Wed Jun 11 02:40:09 2014 |
| 2014 | 01 | 13 | 13.950816 | 2249 | 193.99 | -4.40 | -15.96 | SF | link | Wed Jun 11 02:44:16 2014 |
| 2014 | 01 | 14 | 14.318837 | 0739 | 193.98 | -3.05 | -16.06 | FR | link | Wed Jun 11 02:46:17 2014 |
| 2014 | 02 | 07 | 38.677795 | 1616 | 200.90 | 77.85 | -12.25 | FF | link | Wed Jun 11 02:50:19 2014 |
| 2014 | 02 | 13 | 44.371858 | 0855 | 204.45 | 88.64 | -9.42 | FF | link | Wed Jun 11 02:54:42 2014 |
| 2014 | 02 | 15 | 46.532344 | 1246 | 206.31 | 91.60 | -8.21 | FF | link | Wed Jun 11 02:56:58 2014 |
| 2014 | 02 | 17 | 48.232517 | 0534 | 206.99 | 93.85 | -7.11 | FR | link | Wed Jun 11 02:59:35 2014 |
| 2014 | 02 | 19 | 50.131684 | 0309 | 208.94 | 95.67 | -5.95 | FF | link | Wed Jun 11 03:03:40 2014 |
| 2014 | 02 | 27 | 58.659878 | 1550 | 219.17 | 99.62 | -0.54 | FF | link | Wed Jun 11 03:05:49 2014 |
| 2014 | 03 | 25 | 84.798698 | 1910 | 252.17 | 57.18 | 14.35 | FF | link | Wed Jun 11 03:07:54 2014 |
| 2014 | 04 | 19 | 109.741927 | 1748 | 259.96 | -24.58 | 20.33 | FF | link | Wed Jun 11 03:12:13 2014 |
| 2014 | 04 | 20 | 110.430955 | 1020 | 259.83 | -26.93 | 20.34 | FF | link | Wed Jun 11 03:14:26 2014 |

sitemeter 22,196

Page updated Fri Jun 13 11:06:02 2014
Michael L Stevens (mstevens@cfa.harvard.edu)

# EXAMPLE: CATALOGUES DE CHOCS

## "Kasper's list"

CfA Interplanetary Shock Database - Individual Event Detail

Database: Wind Shock Analysis
Event ID: 20140071434
Observation time: 01/07/2014 7.60755 1434 [UT]

| Site | Data tables |
| --- | --- |
| Previous event<br>Next event<br>Yearly list<br>Main page<br>Help | General information<br>Asymptotic parameters<br>Shock front normals<br>Key parameters<br>Wave speed and Mach number |

General Information (About, Top)

| |
| --- |
| Year |
| Fractional day of year |
| Arrival time of shock [seconds of day] |
| Shock type |
| Electron data availability |
| X GSE location of spacecraft [Re] |
| Y GSE location of spacecraft [Re] |
| Z GSE location of spacecraft [Re] |
| Upstream plasma points selected for analysis |
| Upstream field points selected for analysis |
| Downstream plasma points selected for analysis |
| Downstream field points selected for analysis |
| Minimum chisq/dof for RH8,RH9,RH10 |
| Event added to database |
| Event last processed |
| Method selected |

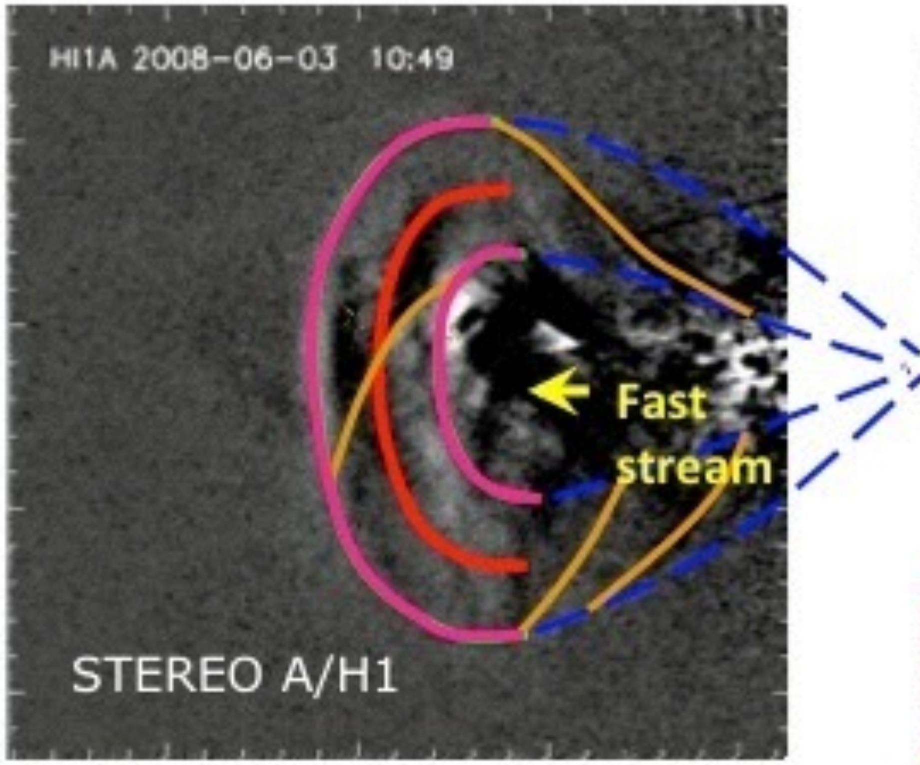
Best values of shock front normal for each method (About, Top)

| Method | Nx | Ny | Nz | Theta [degrees] | Phi [degrees] |
| --- | --- | --- | --- | --- | --- |
| MC | -0.677 ± 0.581 | -0.734 ± 0.536 | 0.056 ± 0.056 | 3.20 ± 18.61 | 227.32 ± 45.34 |
| VC | -0.741 ± 0.047 | -0.417 ± 0.061 | 0.526 ± 0.471 | 31.74 ± 4.15 | 209.35 ± 4.51 |
| MX1 | -0.781 ± 0.063 | -0.426 ± 0.072 | 0.456 ± 0.421 | 27.13 ± 7.31 | 208.62 ± 4.86 |
| MX2 | -0.782 ± 0.057 | -0.422 ± 0.065 | 0.459 ± 0.423 | 27.30 ± 6.61 | 208.33 ± 4.41 |
| MX3 | -0.783 ± 0.055 | -0.419 ± 0.067 | 0.459 ± 0.424 | 27.35 ± 6.17 | 208.15 ± 4.58 |
| RH08 | -0.804 ± 0.006 | -0.385 ± 0.008 | 0.453 ± 0.419 | 26.91 ± 0.64 | 205.57 ± 0.55 |
| RH09 | -0.126 ± 0.064 | -0.989 ± 0.009 | -0.073 ± 0.072 | -4.16 ± 3.62 | 262.73 ± 3.71 |
| RH10 | -0.004 ± 0.070 | -0.989 ± 0.011 | -0.151 ± 0.150 | -8.68 ± 4.03 | 269.75 ± 4.07 |
| Average | -0.587 | -0.598 | 0.273 | 16.349 | 224.977 |
| Median | -0.741 | -0.422 | 0.456 | 27.135 | 209.351 |
| Deviation | 0.326 | 0.266 | 0.279 | 16.586 | 26.415 |

Key shock parameters (About, Top)

| Method | ThetaBn | Shock Speed | Compression |
| --- | --- | --- | --- |
| MC | 48.1 ± 6.6 | 361.5 ± 1.2 | 2.05 ± 0.17 |
| VC | 72.3 ± 7.9 | 410.6 ± 1.3 | 2.05 ± 0.17 |
| MX1 | 67.7 ± 8.0 | 422.7 ± 1.3 | 2.05 ± 0.17 |
| MX2 | 67.9 ± 8.0 | 423.1 ± 1.3 | 2.05 ± 0.17 |
| MX3 | 67.9 ± 8.0 | 423.4 ± 1.3 | 2.05 ± 0.17 |
| RH08 | 67.5 ± 8.2 | 430.1 ± 1.3 | 2.05 ± 0.17 |
| RH09 | 62.1 ± 8.0 | 120.3 ± 1.0 | 2.05 ± 0.17 |
| RH10 | 64.1 ± 8.8 | 58.3 ± 6.9 | 2.05 ± 0.17 |
| Average | 64.7 | 331.2 | 2.05 |
| Median | 67.7 | 422.7 | 2.05 |
| Deviation | 7.3 | 151.8 | 0.00 |

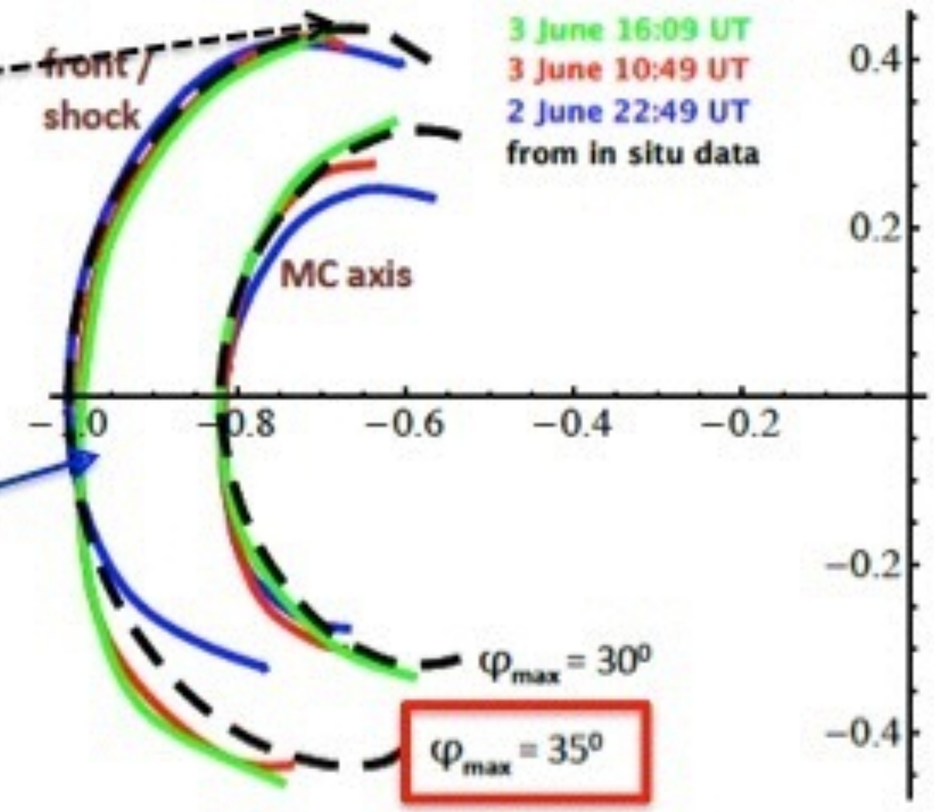
# LIEN AVEC CORONOGRAPHES/IMAGEURS HÉLIOSPHÉRIQUES

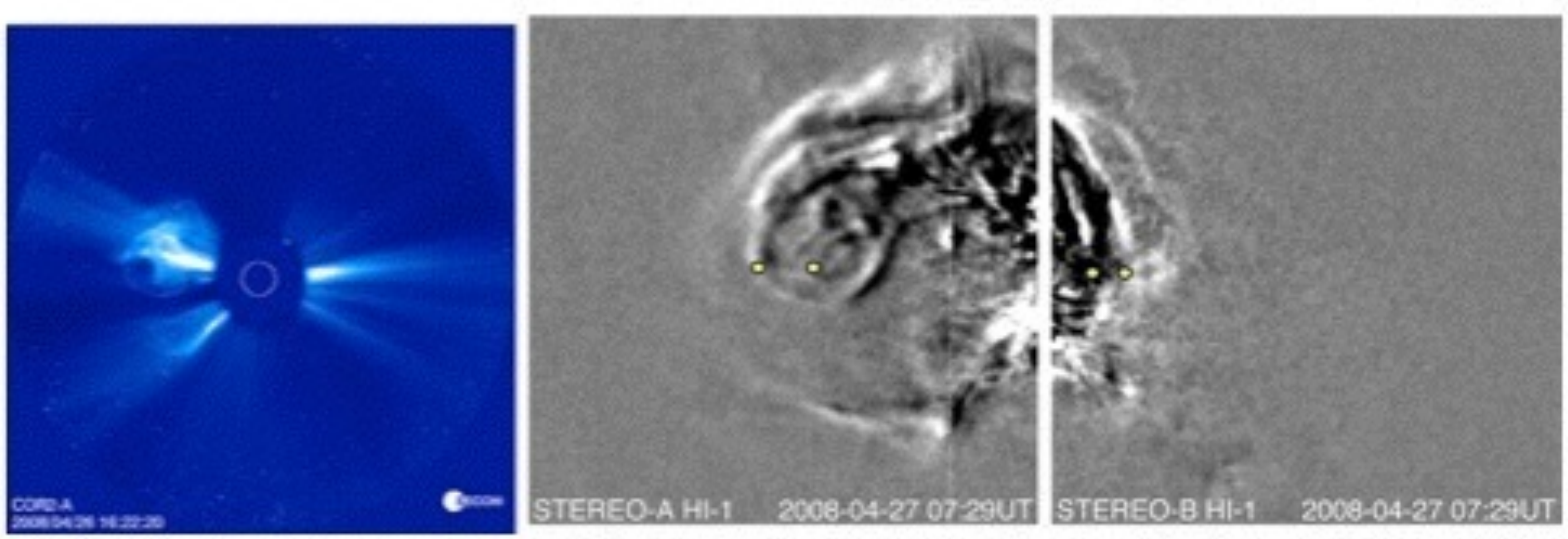



[Möstl et al. 2009]

Méthode statistique (noir-pointillé)

Imageurs (vert,rouge,bleu)




Stéréoscopie?

Reconnaissance de formes?

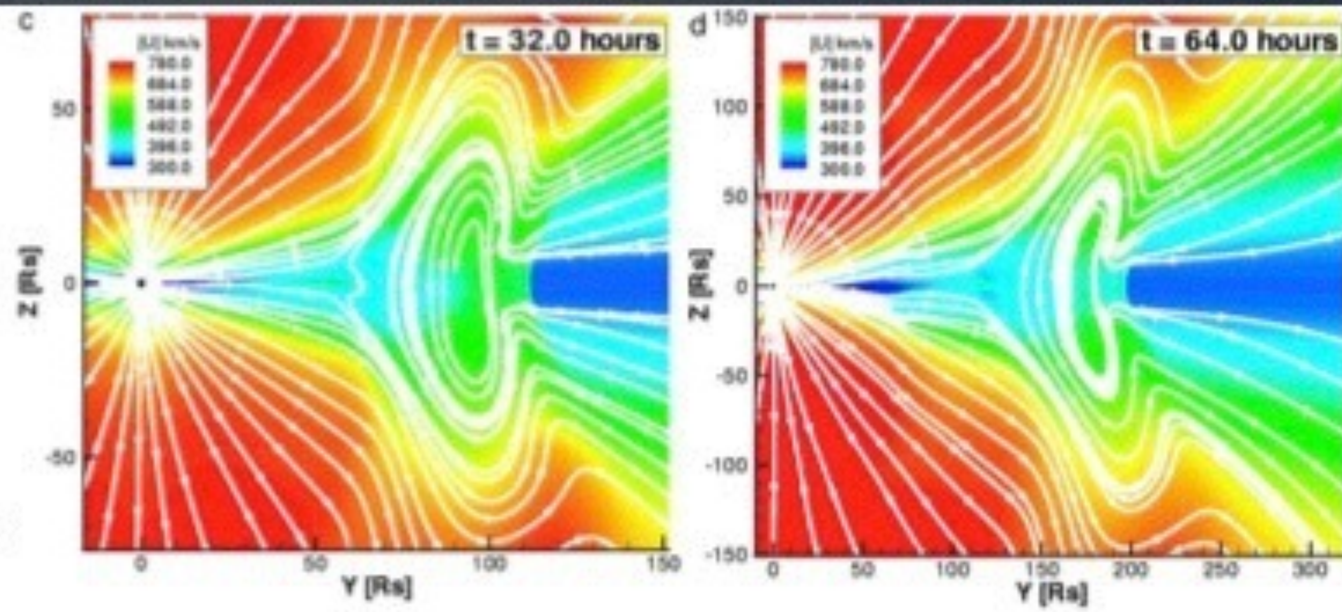
e.g. Lugaz 2010, Mostl 2012

# LIEN AVEC MODÈLES NUMÉRIQUES

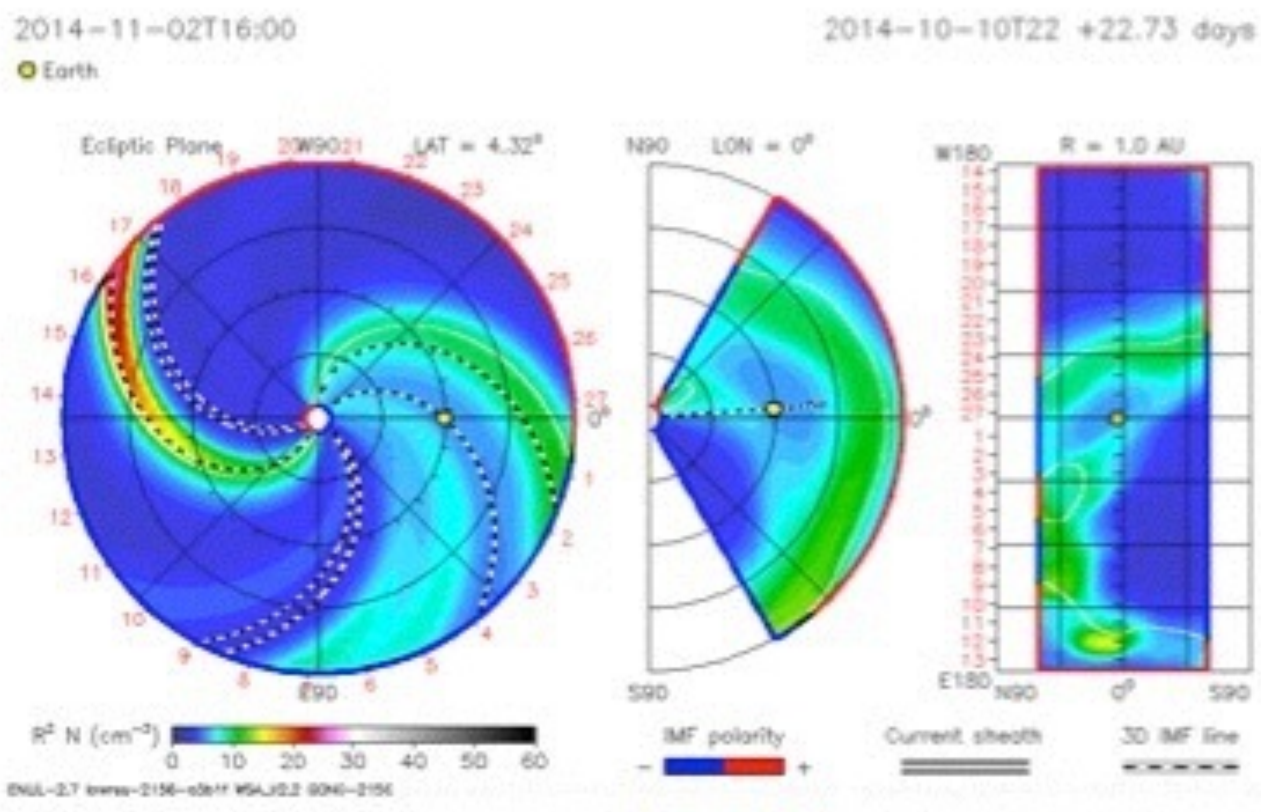
Formes des ICMEs?

- Axe du tube de flux torsadé?
- Taille de la gaine?
- Forme du choc?

e.g. Manchester et al., 2004; Riley et al., 2003; Lugaz and Roussev, 2011




Par ex. : « bean shape » des simulations de Manchester en désaccord avec données in situ…




Et simulations « simples » utilisées par MET office (UK) ou NOAAA (US).

Gros travail sur outils de prédiction! (Propagation des structures doit être confrontée aux imageurs/in situ)

# CONCLUSION: OBJECTIF SOLAR ORBITER

## Lien avec activité coronale (filament/protu, flares)

→ Observations + simulations 3D donnent mécanismes de création/éruption

Données in situ de Solar Orbiter: -lien avec télémetrie
→ monitoring des filaments + lien direct avec données in situ (si éruption)

**Bilans flux/énergie/hélicité magnétique/plasma**

## Forme générique des ICMES à différentes distances

→ Etudes statistiques donnent une bonne idée de la forme générique des ICMEs

Données in situ de Solar Orbiter: -catalogues d'évènements à différentes UA
→ Catalogues « publiques » + fits automatisés pour nuages & chocs

**Développement générique des ICMEs, couronne → Terre**

# Connect_SolO: wind model

Rui PINTO, Alexis ROUILLARD
IRAP

Solar Orbiter Tools Workshop
Toulouse, Nov 2014

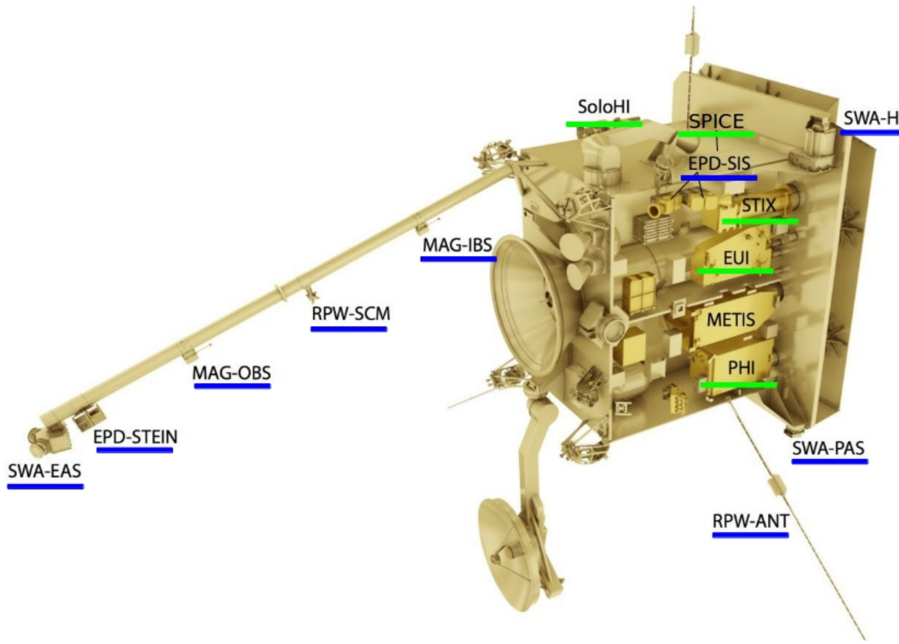
# Goals

- **Surface – heliosphere connections**

- Data:
 **relate in-situ data ↔ remote sensing**

- **Improve Propagation Tool:**
  low corona = critical layer

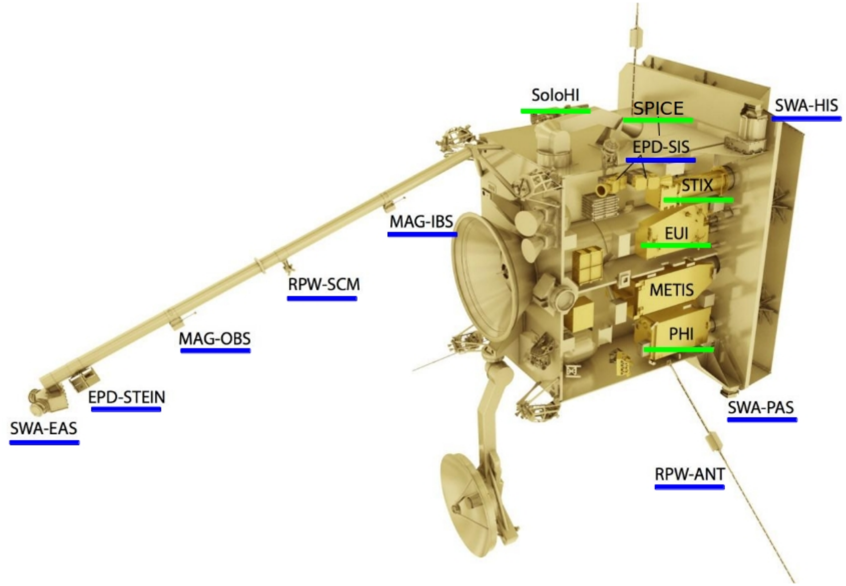
  **Magnetic field geometry**
  **Segregation between fast and slow wind**




- Simple, fast, yet robust models

- Determine:
  wind speed, density, temperature,
  phase speeds
- along any open magnetic flux-tube

# Modelling chain




Remote sensing data

In-situ data

Coronal **B**-field reconstruction
(cf. talk S. Regnier)

**or**

Coronal models

Connect_SolO

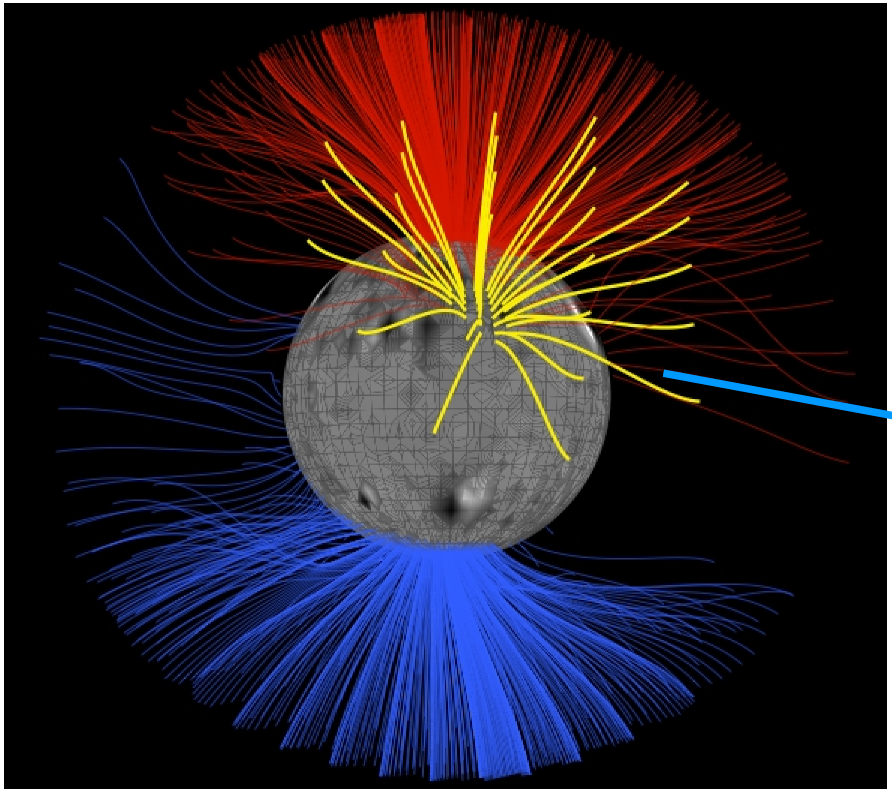
Heliospheric propagation models
(cf. talk C. Tao)

**Possible applications:** wind acceleration, waves, shock, CME propagations, SEP

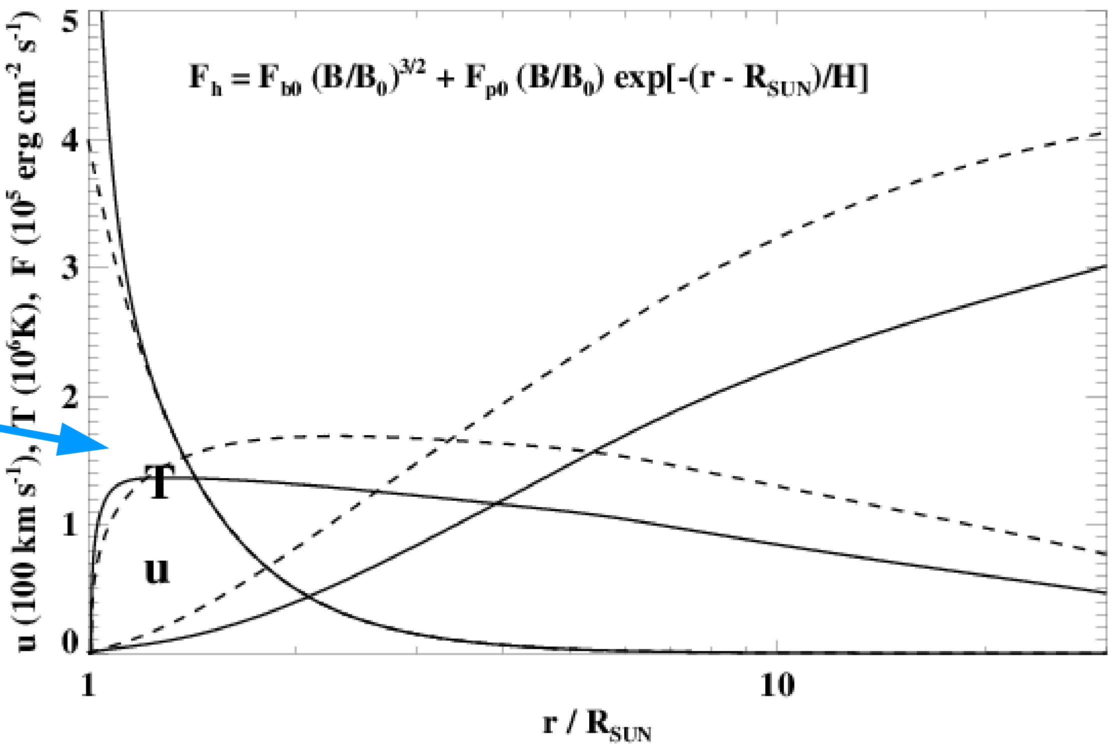
# Connect_SolO

**1) Retrieve the coronal magnetic field;** select a sample of open flux-tubes

**2) compute solar wind profiles along flux-tubes** (flow speed, temperature, phase speeds)



e.g: HMI + PFSS extrapolation



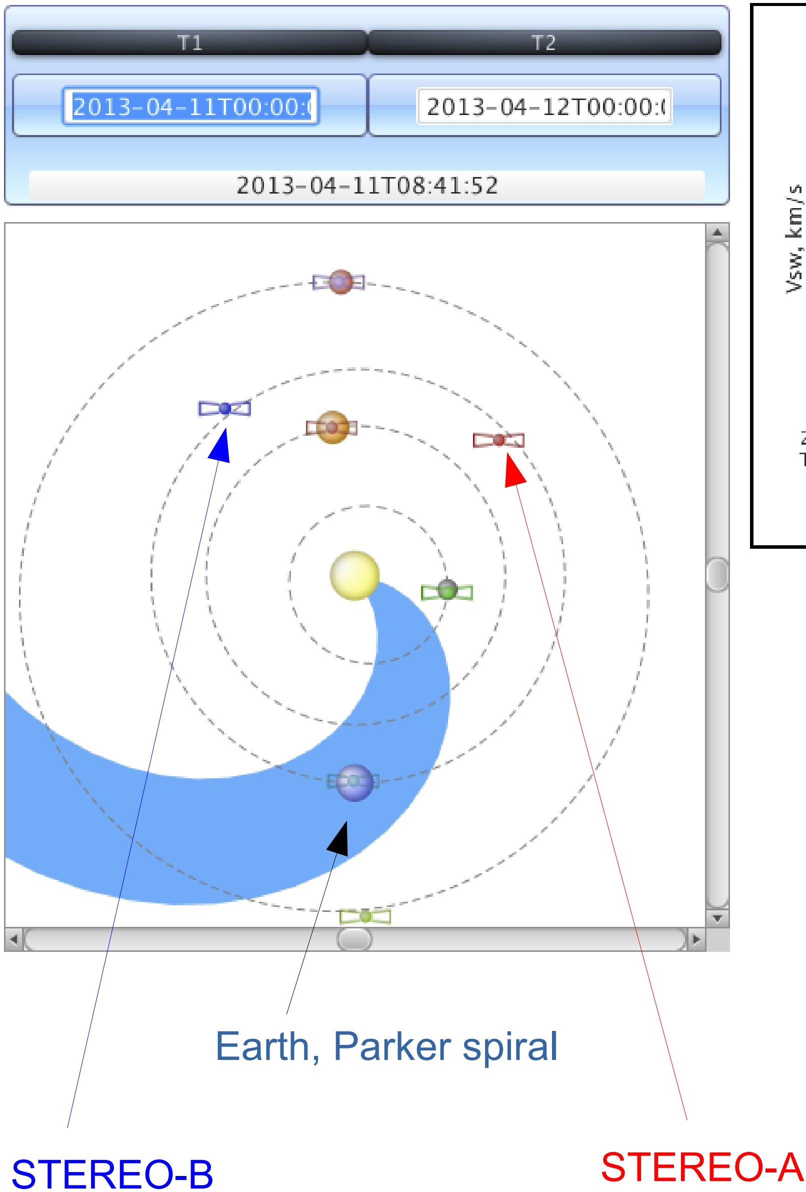

(Pinto, et al, 2009)

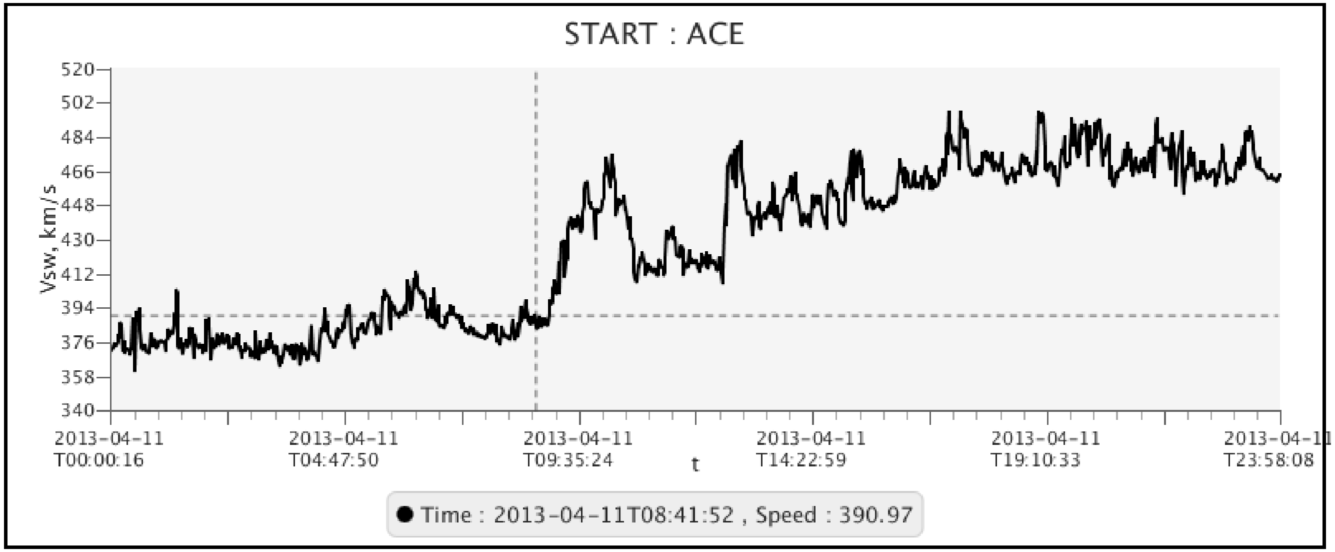
**3) Feed into heliospheric models, select/compare to in-situ data**

. provide alternative to WSA prediction for wind speed
. predict also: temperature, density, phase speeds

# Case study

**Selected event: 2013-04-11**



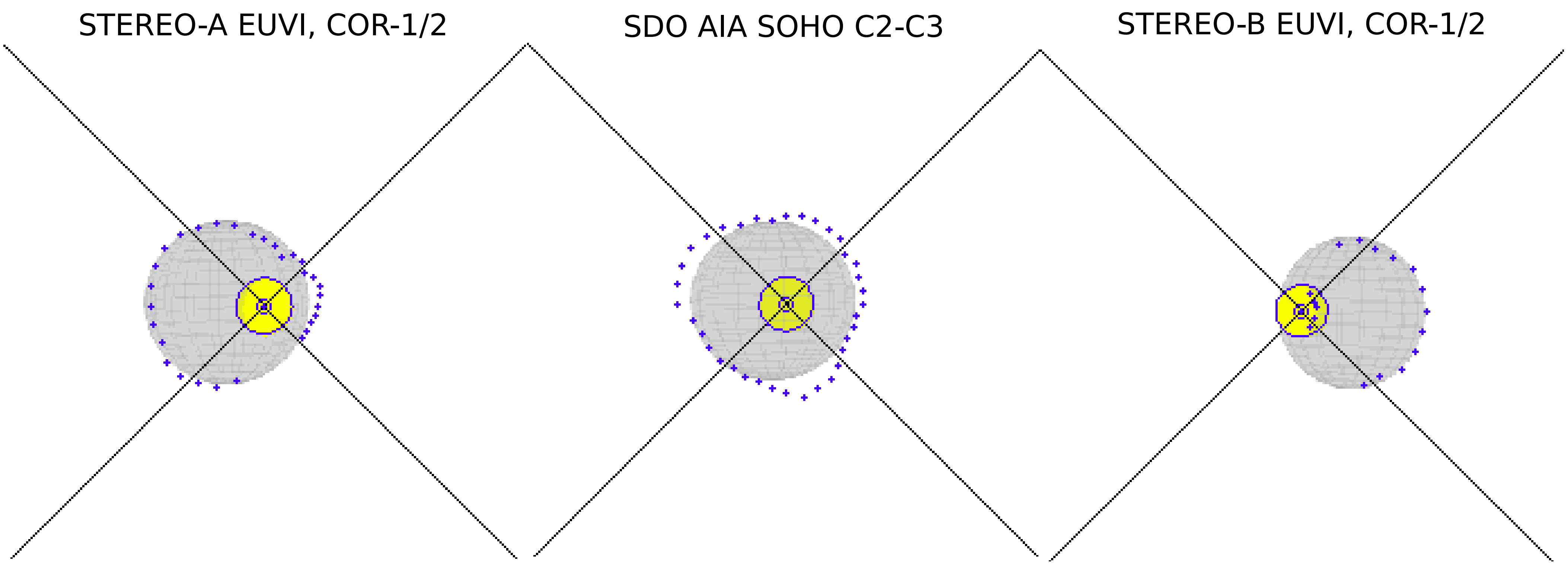




ACE, wind speed ~ 391 km/s (slow wind)

**Multiple s/c data available** (SOHO, STEREO-A/B, SDO).
**ACE wind speed** (to be used as a calibrator).
**SEP event** (at L1) gives reference time.

# Case study

## Tracking the evolution of a pressure wave




- **Ultraviolet images and coronagraph images**
  9 cameras from SDO (AIA), SOHO (C2/C3) and STEREO-A/B (EUVI, COR1/2).
- Extract for each position angle the elongation of the disturbance when it is off the solar disk.
- Interpolate the elongation variation for each position angle over a regular time grid.
- Fit geometrical forms (spheres, ellipsoids) that match best the extent of the disturbance.

# Case study

**Once each ellipsoid is computed:**

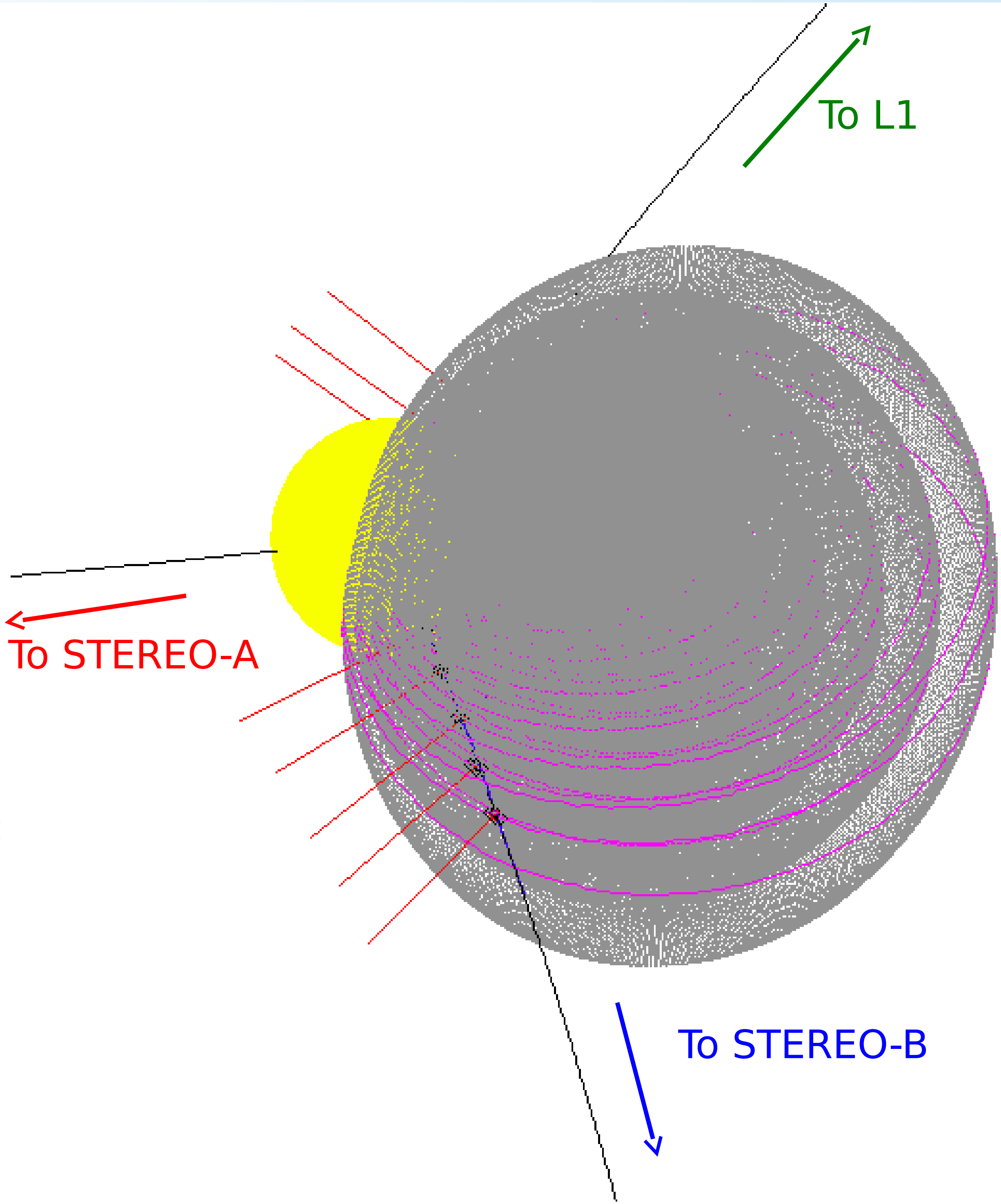
• Trace the magnetic field lines connected to in-situ measurements.

• Trace the spiral down to 2.5 Rsun (depends on the measured solar wind speed at the particle onset time).

• Connect to PFFS field-line.

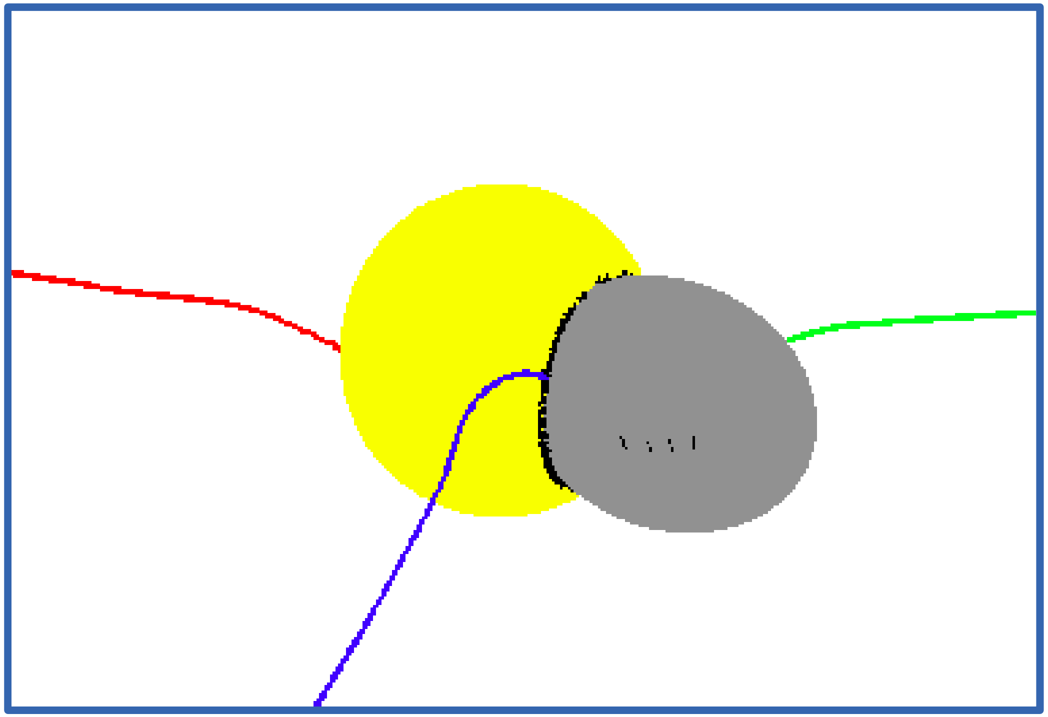
• Determine the intersection of this spiral with the ellipsoid at each timestep.

• Compute at the intersection point, at each time step:
 3-D vector normal to the surface (shock normal), shock geometry,
 3-D shock velocity.

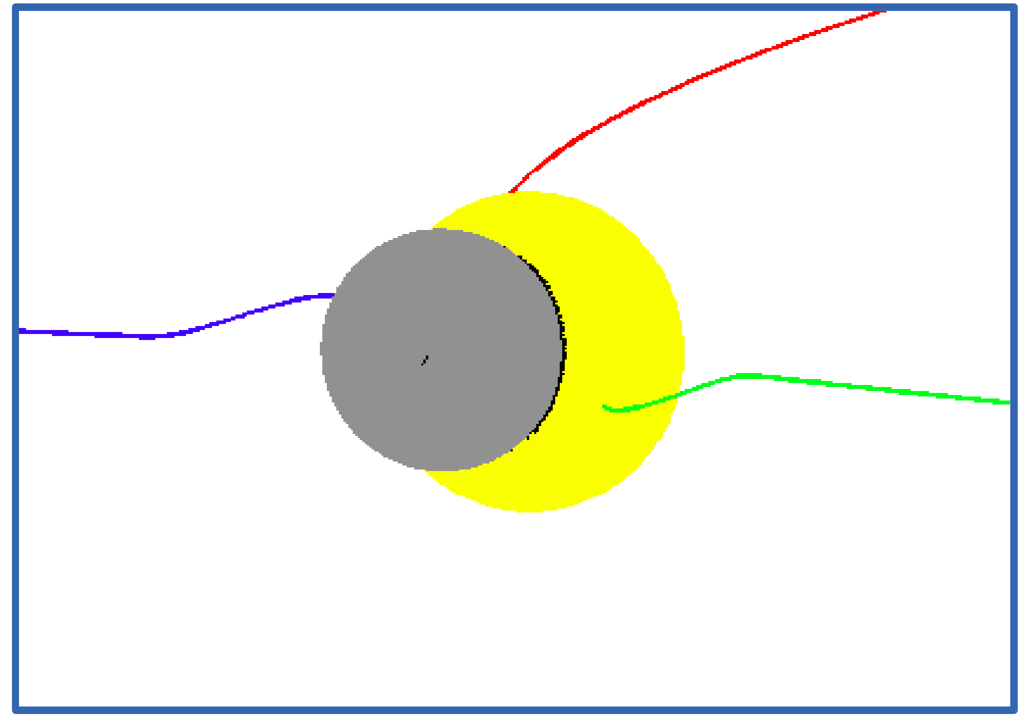


# Case study

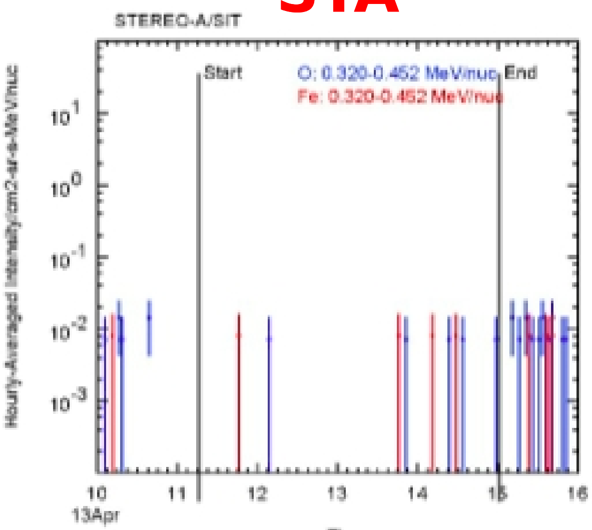
View 1



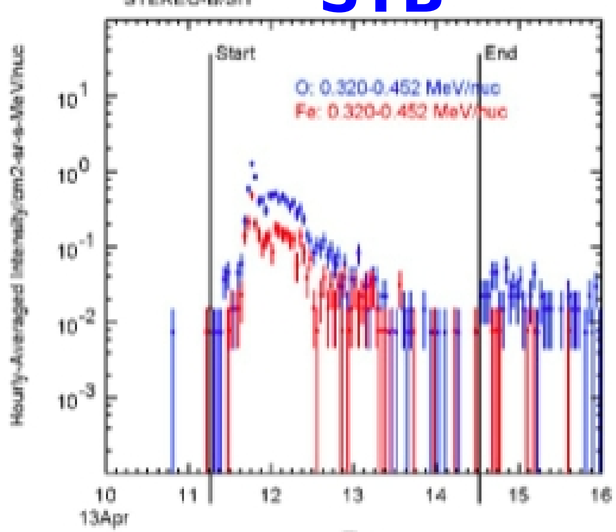
View 2



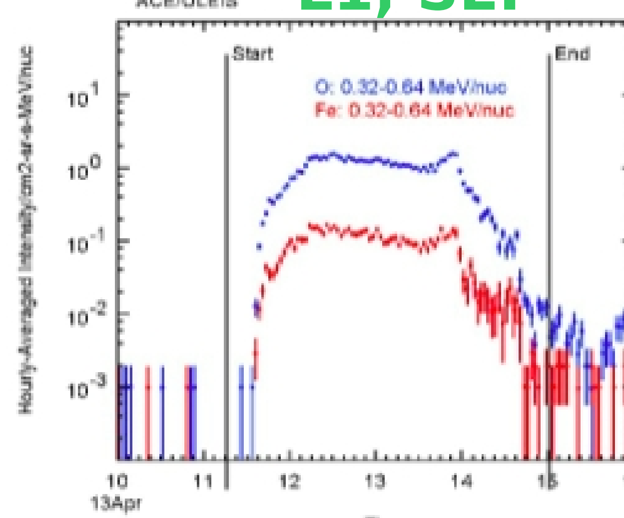
STA



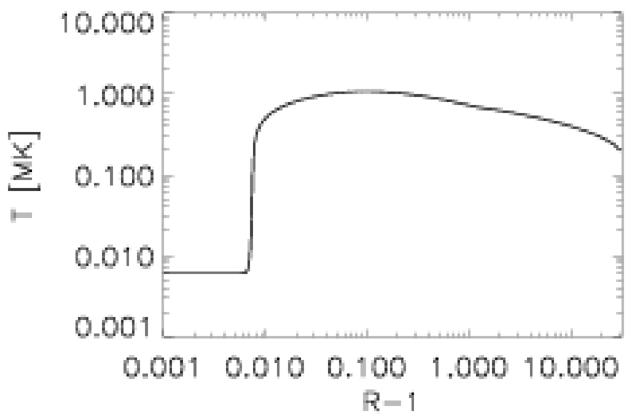

STB

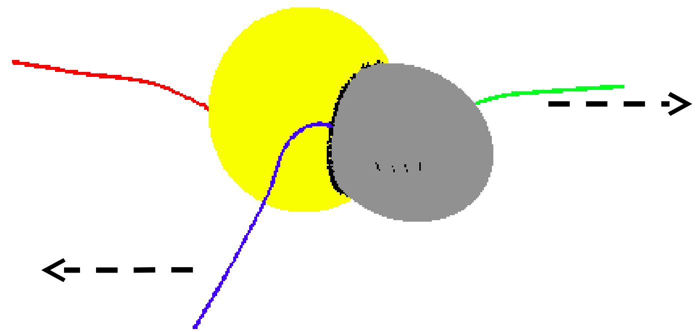


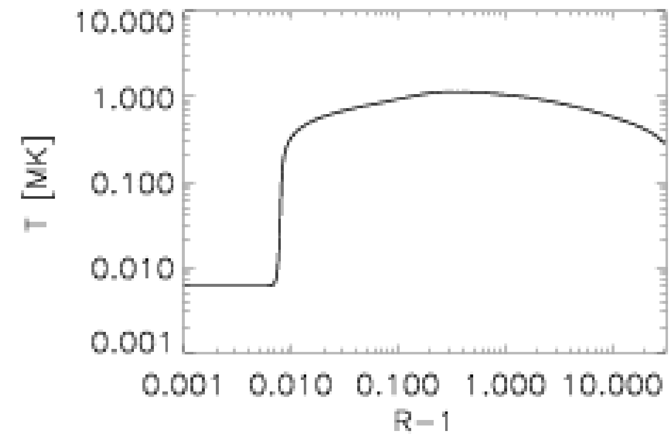

L1, SEP

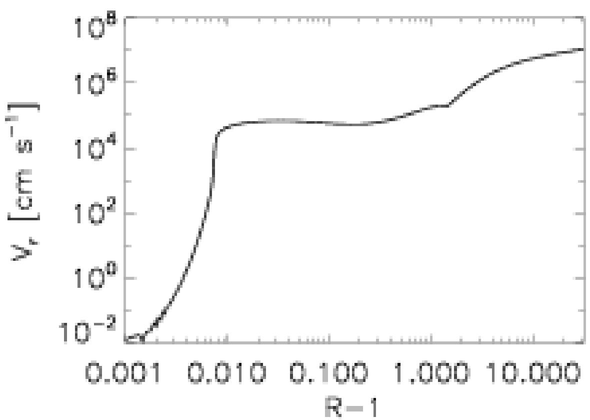


# Case study



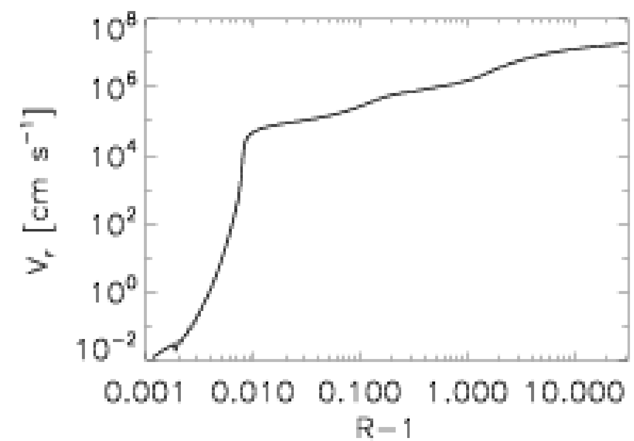



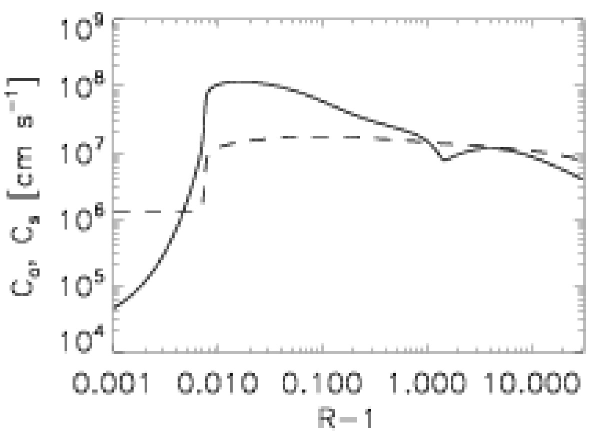


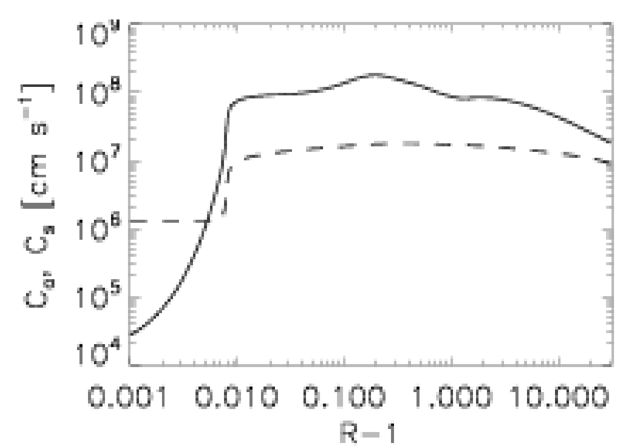




**1-D corona and wind code:**

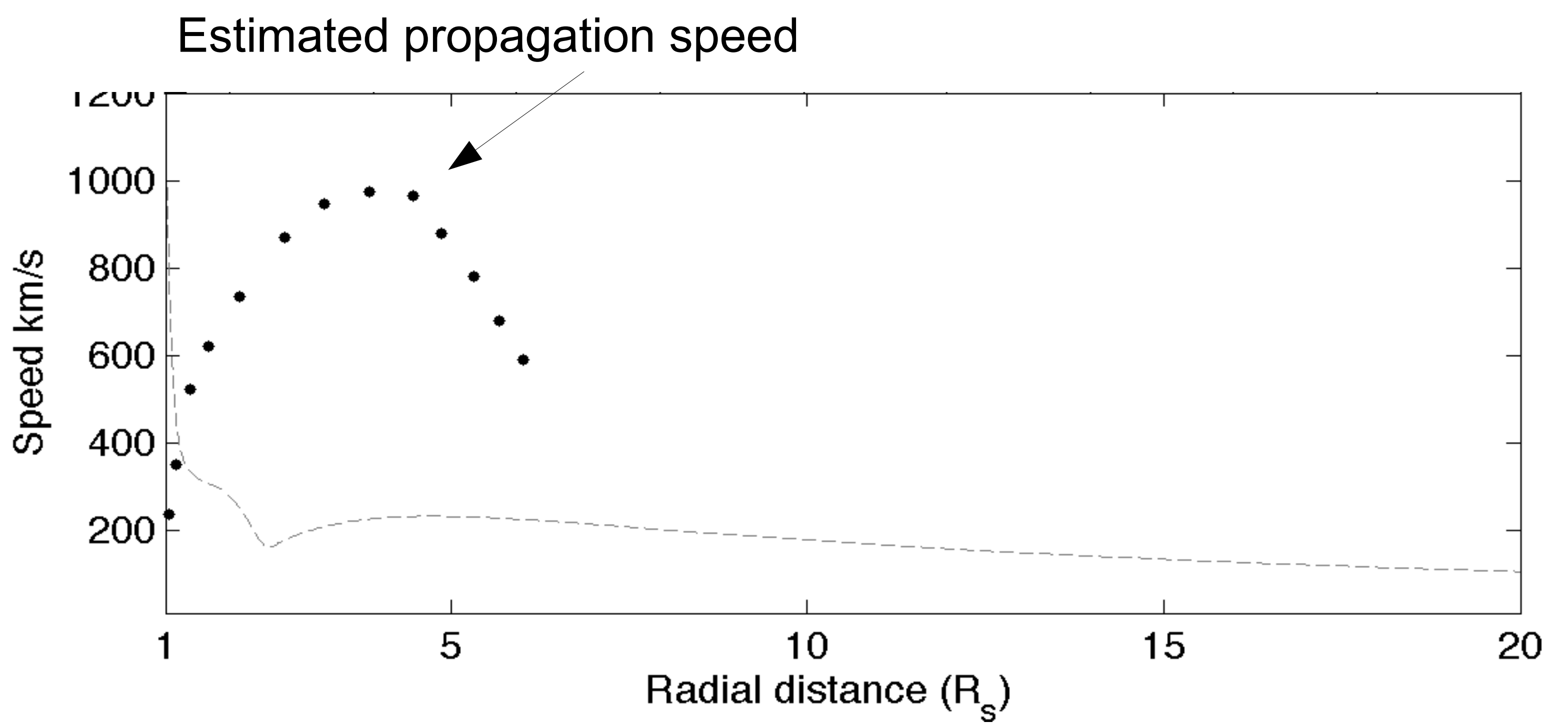
- Based on VP code (Grappin, et al 2010; Pinto et al 2009)
- wind speed, temperature, density, phase speeds
- Chromosphere and corona (up to ~30 Rsun).
- Parametrised heating, radiative/conductive cooling



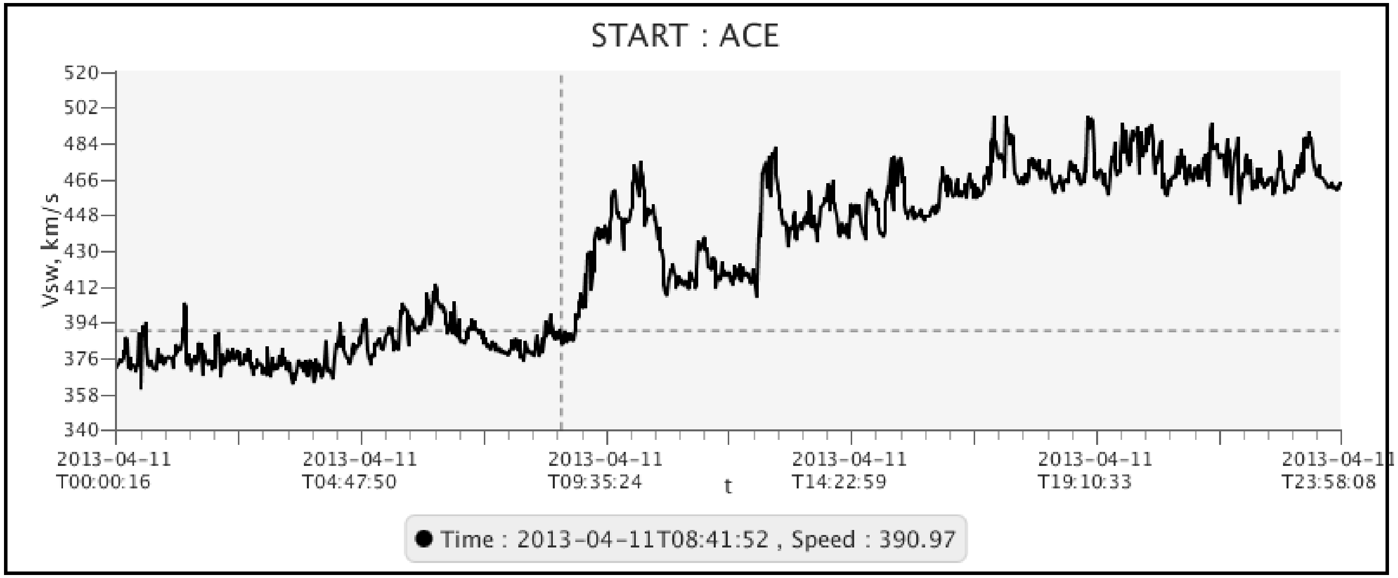
# Case study




Predicted wind speed
@ 30 Rsun = 220 km/s

ACE measurements
@ 1 AU = 391 km/s

Note:
wind not yet at assymptotic value at 30 Rsun!



# Conclusions

## Connect_SolO

Strengths:

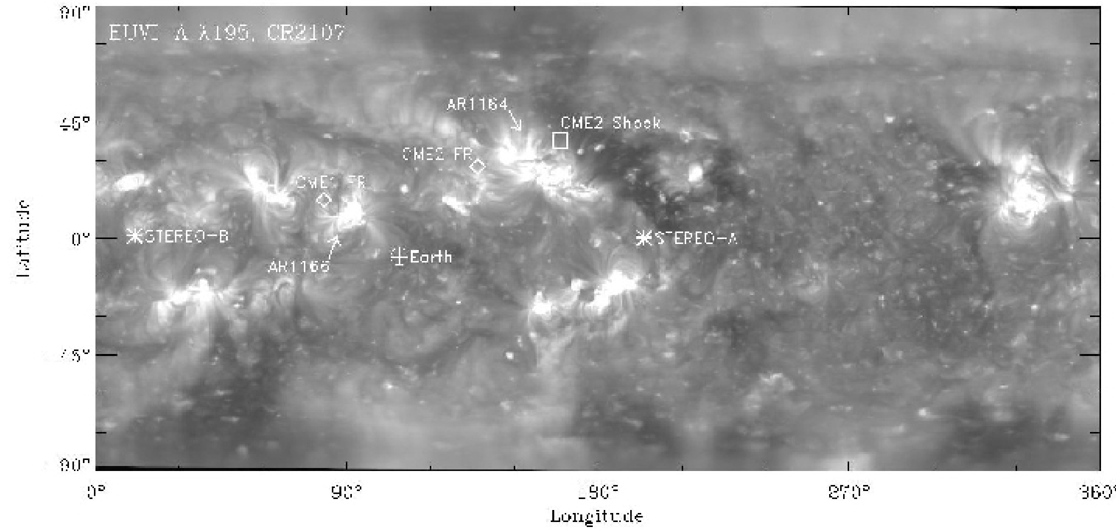
- quick and robust
- good thermodynamics
 (much better than current multi-D models)
- Slow / fast wind ok.
- predicts wind speeds **AND**
  temperature, density, phase speeds

Limitations:

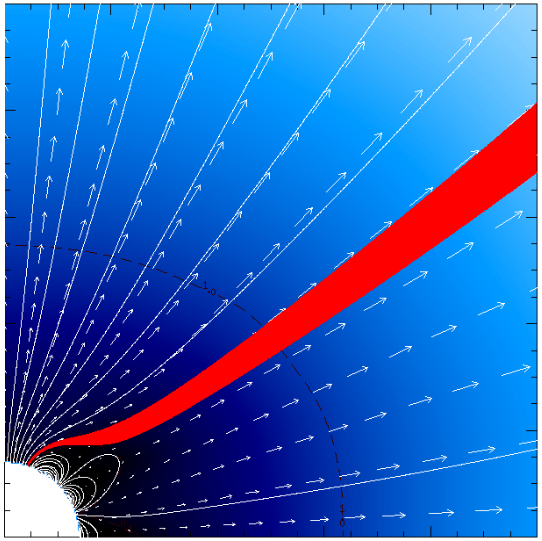
- 1D (even if multi 1D flux-tubes)
- Flux-tube geometry only a good as
  coronal field reconstruction allows

Case study and calibration
(multi spacecraft data)

## Future directions




Sample full Carrington maps



2D coronal field models
(meridional or equatorial)

(Pinto, et al 2011,2013)

# Appendix

Advantages:

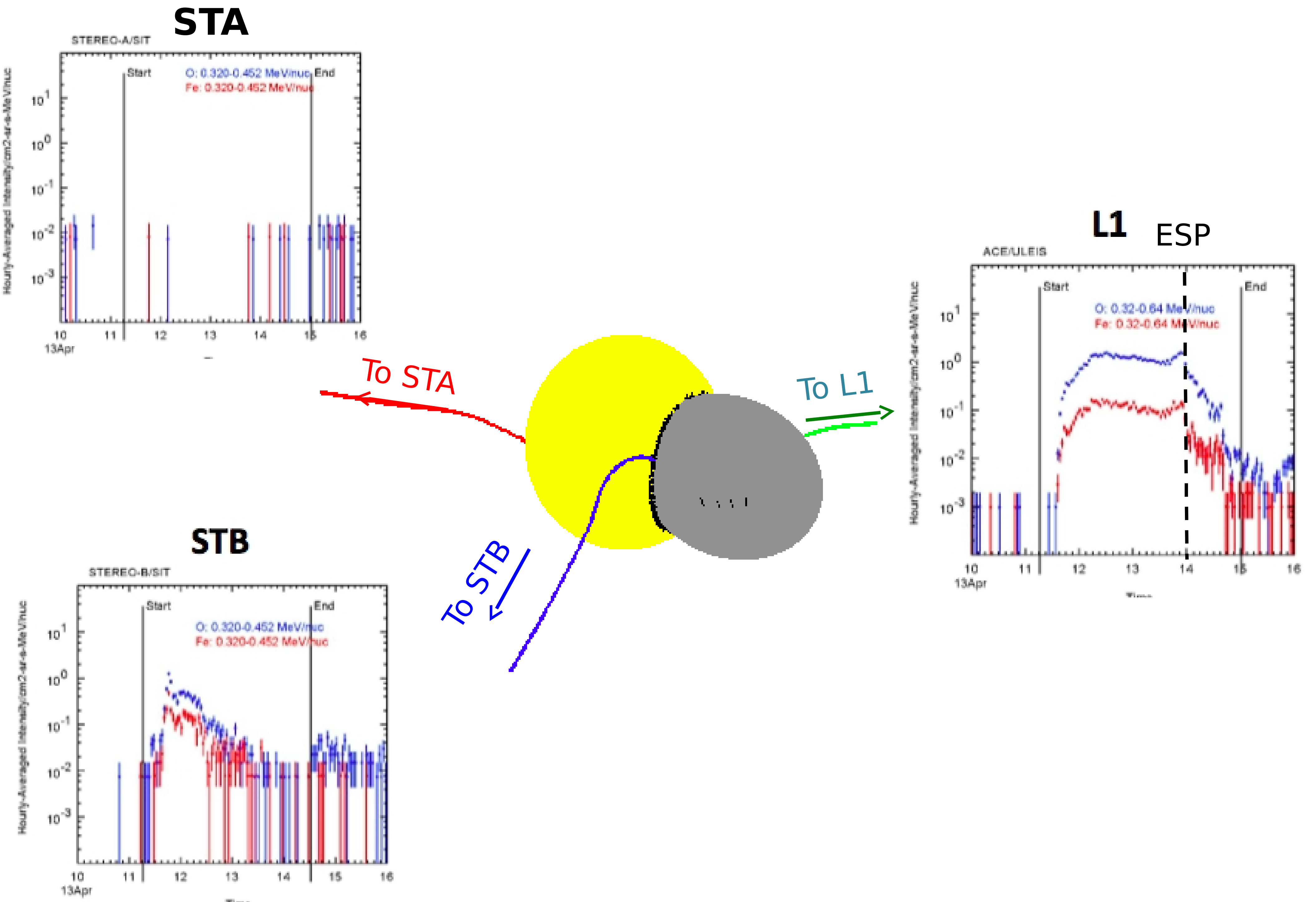
Disadvantages:

The wind code

Based on VP code,
simplified setup (for performance and robustness)
(Grappin et al, ??; Pinto et al, 2009)

Properties:

# Case study


STA
STEREO-A/SIT
Start
End
O: 0.320-0.452 MeV/nuc
Fe: 0.320-0.452 MeV/nuc
Hourly-Averaged Intensity/cm2-sr-s-MeV/nuc
10
13Apr
11
12
13
14
15
16
To STA
To L1
To STB
L1
ESP
ACE/ULEIS
Start
End
O: 0.32-0.64 MeV/nuc
Fe: 0.32-0.64 MeV/nuc
Hourly-Averaged Intensity/cm2-sr-s-MeV/nuc
STB
STEREO-B/SIT
Start
End
O: 0.320-0.452 MeV/nuc
Fe: 0.320-0.452 MeV/nuc
Hourly-Averaged Intensity/cm2-sr-s-MeV/nuc

# *Community-driven Sun-Heliosphere modeling efforts for science planning*

Susanna Parenti

Royal Observatory of Belgium

with inputs from F. Auchère, G. Aulanier,
D. Berghmans, T. Dudok de Wit, L. Harra, L. Klein
B. Lavraud, D. Mackay, L. Rodriguez, A. Zhukov

# Solar Orbiter Science goals

1. How and where do the solar wind plasma and magnetic field originate in the corona?
2. How do solar transients drive heliospheric variability?
3. How do solar eruptions produce energetic particle radiation that fills the heliosphere?
4. How does the solar dynamo work and drive connections between the Sun and the heliosphere?

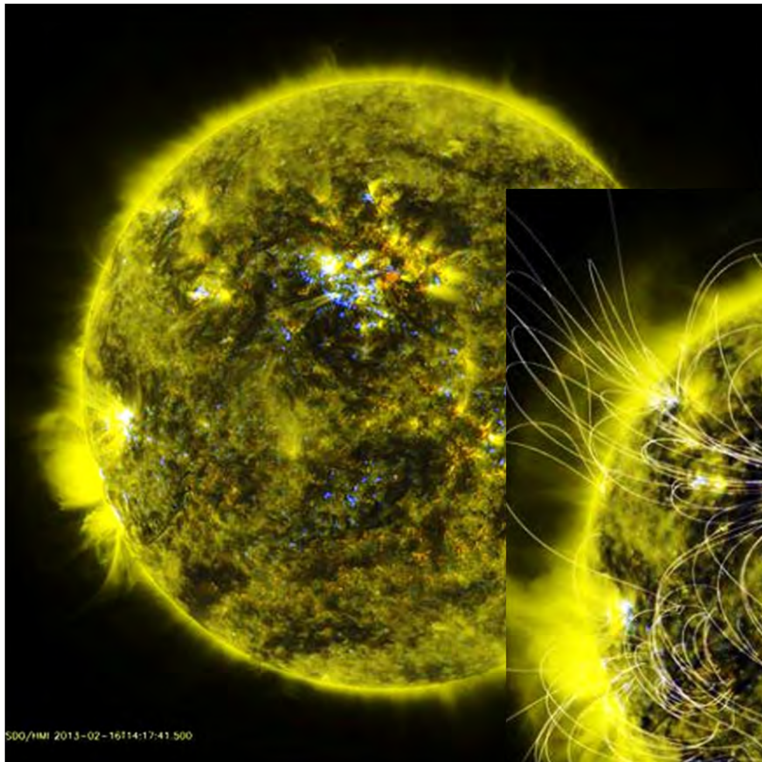
| Orbit 1 science goals: $N_i$ | Orbit 2 science goals: $N_j$ | Orbit 3 science goals: $N_z$ | … |
|---|---|---|---|

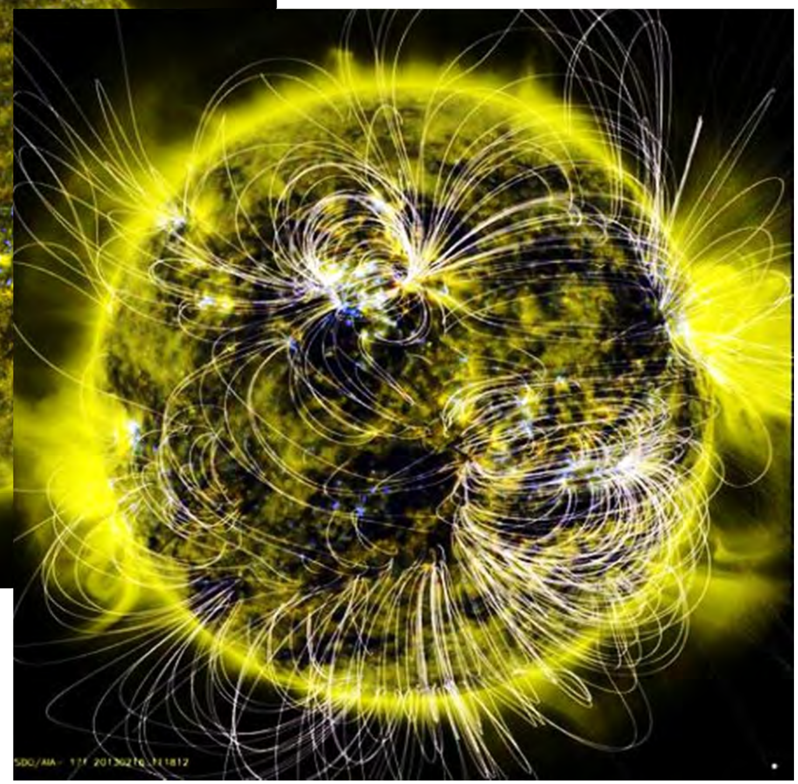
# To achieve Orbiter science goals

- **First step**: to have consistent data from *in-situ* and RS.
- **How**: choice of targets with connectivity to the *in-situ* instruments:
  1. Sources of open/closed magnetic field in quiescent regions
  2. Sources of eruptions/transients
- **Tools used to validate the connectivity of a target**
  – Check what we need
  – Check what we have
  – Implementation of the missing needs

# Planning for the first orbit: an example

**STEP A:**
RS precursor observations

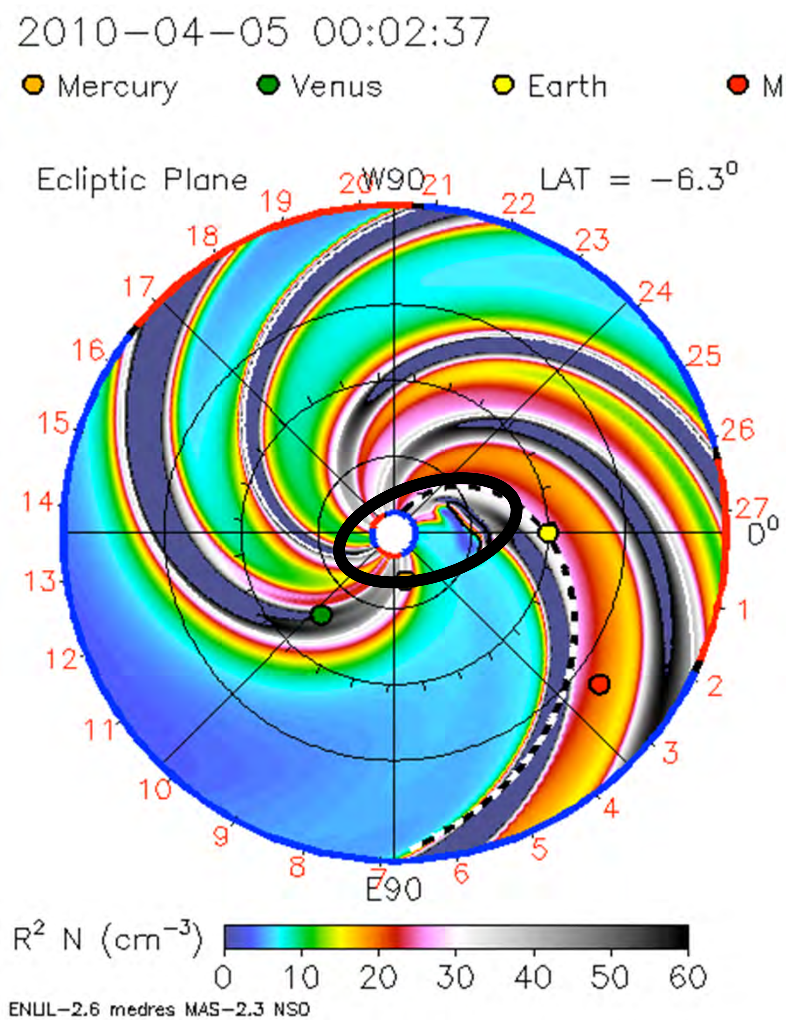


**STEP B:**

- Extrapolation of photospheric magnetic field (~ 2 Rsun)
- Use theory/modeling for B and wind paths

# Planning for the first orbit: cont’s




**STEP C:**

- Use theory/modeling for B and wind paths
- Lower boundary condition given by STEP B
- MHD heliospheric model (ex ENLIL)

**STEP D:**

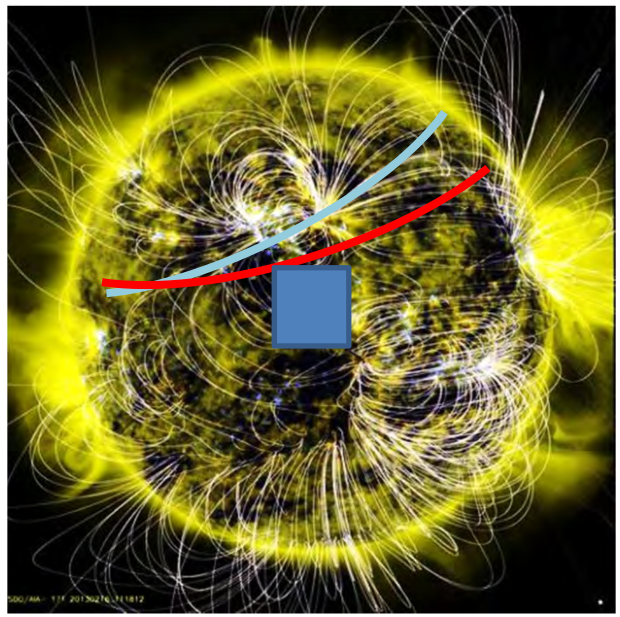
- Identify the spasecraft orbit within the large scale magnetic/wind structure.

# Planning for the first orbit: cont's

**STEP E:**

Identify the paths on the Sun with connectivity with the S/C

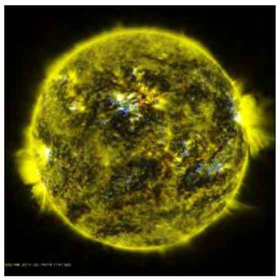
Prediction of connectivity for wind



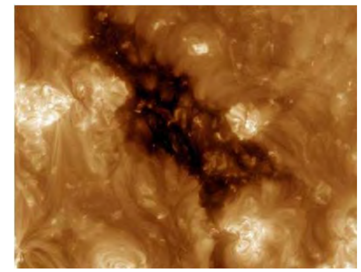
Prediction of possible connectivity for SEP/CMEs

RS high resolution FOV for the 1st orbit → We can miss the connectivity!

# STEP F:
# Decision making for the targets



Pre-science windows observations



Target

**turn-around time of < 3 days**

INPUTS:

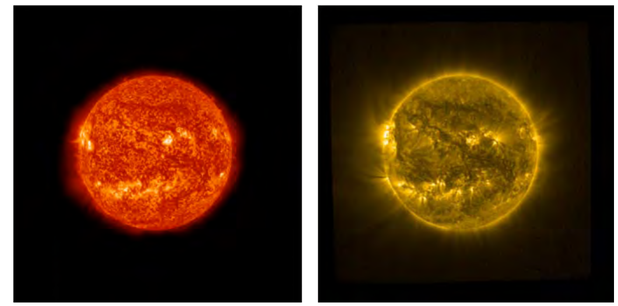
- Paths of connectivity for wind/particles and B
- Forecast activity

Criteria for the TARGET choice:

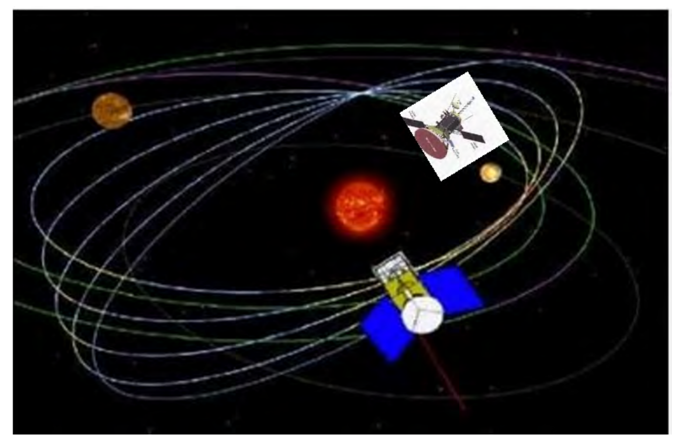
- Science goal assigned to the orbit
- Quality of the predictions
- Quality of the source regions
- Presence of potential erupting targets

# Step A
# What we need: observations

- FSI Thumbnails (compression > $10^3$)
- PHI full disk B maps
- METIS WL corona
- *In-situ ?*
- ….



Small data volume to be downlink within 1 single pass.



- Multi-instrument observations:
  - SDO, Probe+, Stereo (?)
  - On ground/space Earth based data

# Steps B/C/D/E
# Theory and modeling supports : needs

- Compute quantities such as: **B**, wind paths and velocity…
- With boundary conditions given by:
  - magnetograms, full disk EUV images, *in-situ* **B, v,** n, **…**
- With temporal uncertainties of :
  - TBD.
- With spatial uncertainties of:
  - On disk should be < 1/3 of the high resolution FOV of remote sensing instruments
- To be fast as: < 2 days (fine repointing turn-around time as defined by Daniel’s doc)

# Steps B/C/D/E
# What we have: modeling/theory

- What kind of models exist
  - Which physics/complexity they have
    - e.g. time dependence; PFSS vs NLFFF
  - Which quantities they predict
    - e.g. B and/or v
  - With which precision
    - Global models  miss small scales
    - Errors on the hypotheses/boundary conditions
  - How fast they are:
    - extrapolation vs. iterative model (NLFFF)
    - rapidity vs. resolution

# Steps B/C/D/E
# Models of the corona and heliosphere

- Coronal models
  - Potential field source surface (PFSS) model (e.g. Wang & Sheeley, DeRosa & Schrijver,..)
  - CORHEL/MAS model (Linker et al.)
  - Nonlinear force-free field (NLFFF) model (Yeates & MacKay)

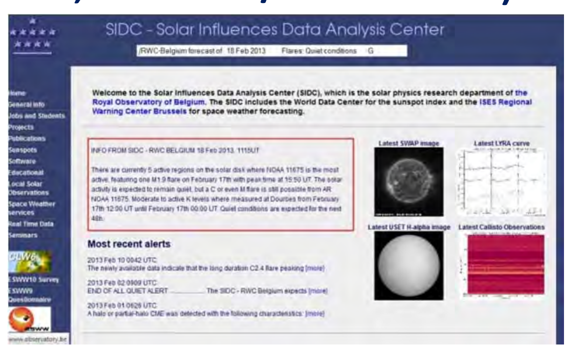
- Solar wind models (taking a coronal model as a lower boundary condition)
  - Wang-Sheeley-Arge (WSA) model
  - ENLIL model (Odstrcil et al.)
  - SWMF model (Gombosi et al.)
  - ...

# Steps E/F
# Empirical models/rules

Existing results from observations: empirical rules

- latitude of AR and prominence crown
- critical heights of prominences
- links between sunspot group/AR types and flare probabilities
- …..

We should use the extensive experience of space weather community (e.g. SIDC; NOAA/SWPC….)

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# STEP F
# Putting it all together

- 3D Visualization Tool(s)
  - RS & *in-situ* data
  - Models (and results of) for wind/B (e.g. WSA-ENLIL)
  - Models for CMEs expansion giving inputs to large scale modeling
  - multi-instrument/mission positions

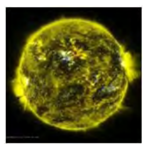
Evolutions of e.g.:

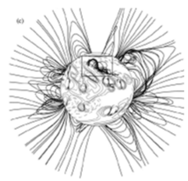
JHelioviewer, HELIO, FESTIVAL, AMDA, 3DView Multimission

- ESA quicklook
- Link with SODAWG activity

# How to implement the missing needs?

- A good coordination is needed to assure the fast and efficient work of the chain





prediction

- Use the expertise of the instruments team members and external experts (new Co-Is?)

➔ Build a team/WG to address the modeling/forecasting support.

- Inputs from SOWG, SWT, SODAWG instruments' teams and report to SOWG

# Solar Orbiter Operation Plans: SOOPs

- To optimize the scientific return we need to have consistent observing programs from all the instruments.

- SOOP: a unique document assembling the programs of each instrument for a given science case/orbit


- RSWG exercise on first orbit: pointing Sun-Center

# Extrapolations de champ magnétique

*Mise à jour,  et défis pour Solar Orbiter*

**Stephane REGNIER**

*Northumbria University, Newcastle Upon Tyne*

# Extrapolations de champ magnétique: un succès

A un instant donné, la couronne solaire est en équilibre

Idéalement:

Equilibre magnétohydrostatique (mhs)

$$-\vec{\nabla}p + \rho\vec{g} + \vec{j} \wedge \vec{B} = \vec{0}$$

Actuellement, les extrapolations magnétiques utilisées sont des extrapolations force-free

Equilibre force-free

$$\vec{j} \wedge \vec{B} = \vec{0}$$

$$\vec{j} = \vec{0}$$

Potential Field

$$\vec{j} = \frac{\vec{\nabla} \wedge \vec{B}}{\mu_0} = \alpha\vec{B}$$

Linear Force-free Field

$$\vec{j} = \alpha(\vec{r})\vec{B}$$

Nonlinear Force-free Field (nlff)

## Extrapolations de champ magnétique: besoins

**Champ potentiel :**

- composante verticale du champ magnétique (type MDI, HMI, Hinode/SOT/NFI) en coordonnées Cartésiennes;

- composante radiale du champ magnétique pour modele PFSS: observations de la face visible + modele d'évolution du champ ; cf modele de Schrijver et Derosa

**Champ nlff :**

Carte vectorielle du champ magnétique (3 composantes du champ sur la surface photosphérique) pour coordonnées Cartésiennes et sphériques; type SOLIS, HMI, Hinode

# Extrapolations de champ magnétique: un succès

Energie magnétique

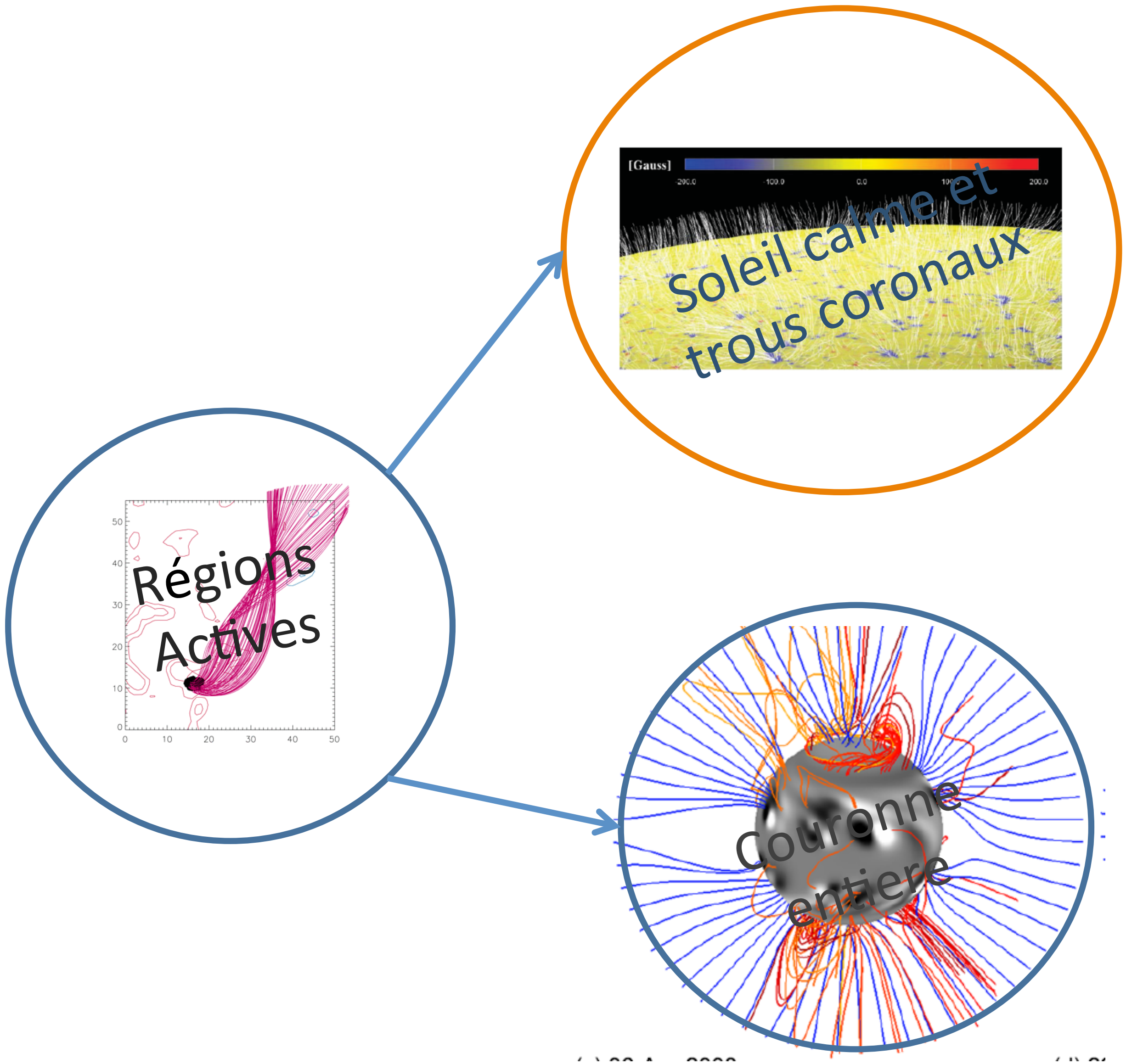
Helicite magnétique

Géométrie de B

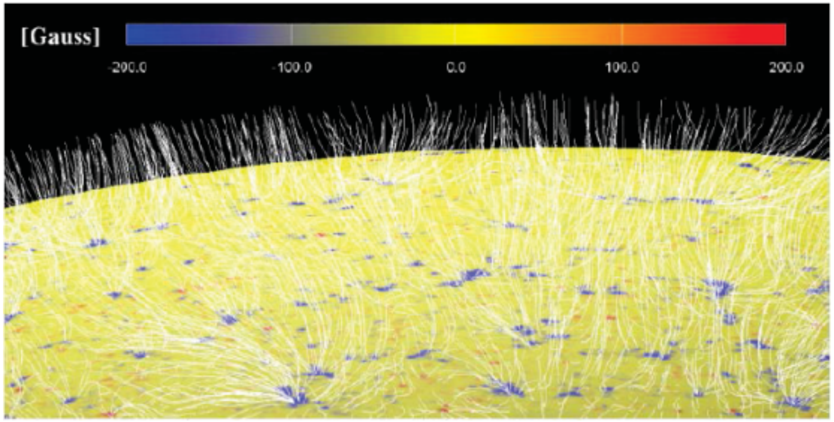
Topologie de B

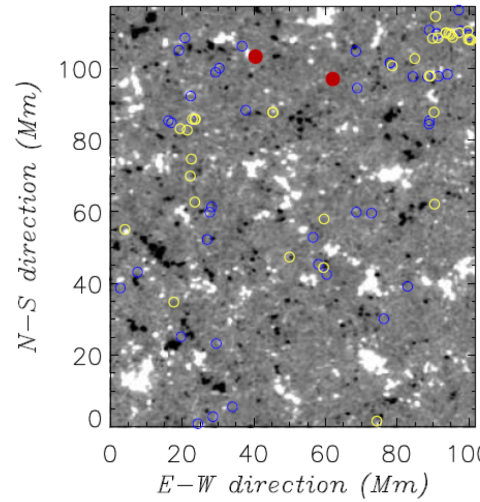
Liens X-ray-UV-B

Liens radio-B



# Champ magnétique polaire




Actuellement

- Champ potentiel
- Pas de courant électrique
- Pas d’étude de l’évolution

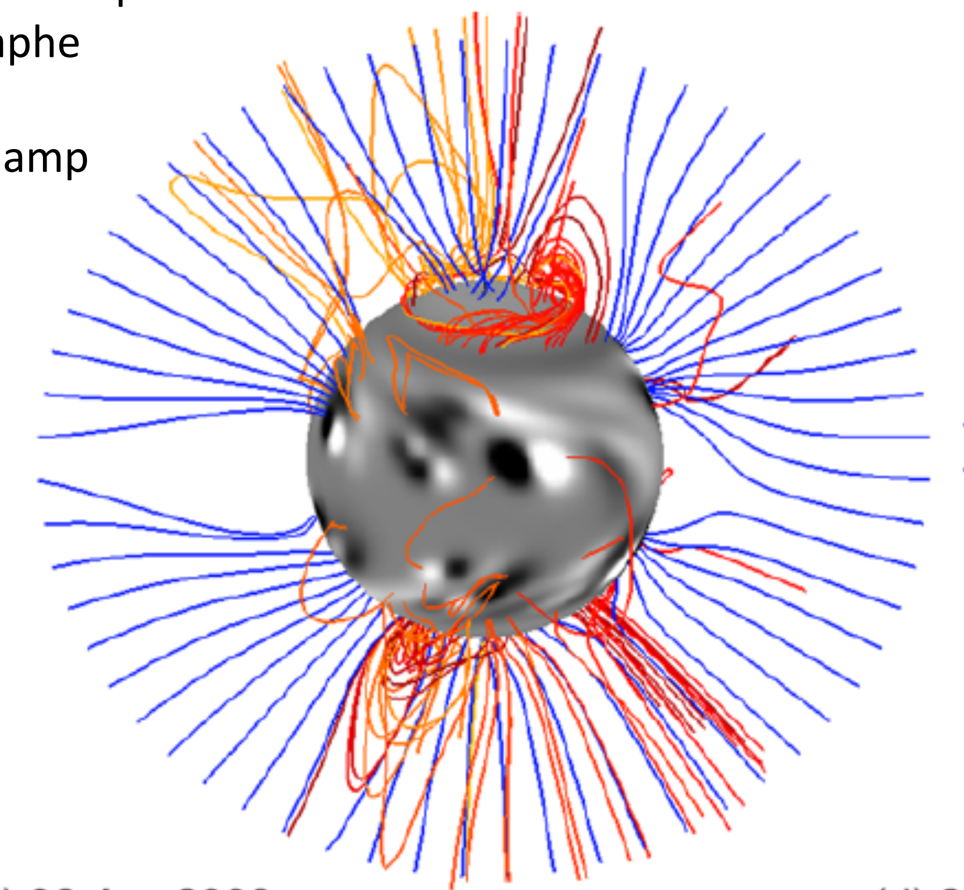
SO/PHI

- Mesure du champ aux poles (réduction des effets de projection)
- Filling facteur
- Mesure des courants
- Modeles nlff ou mhs

# Origines magnétiques des particules énergétiques

Actuellement

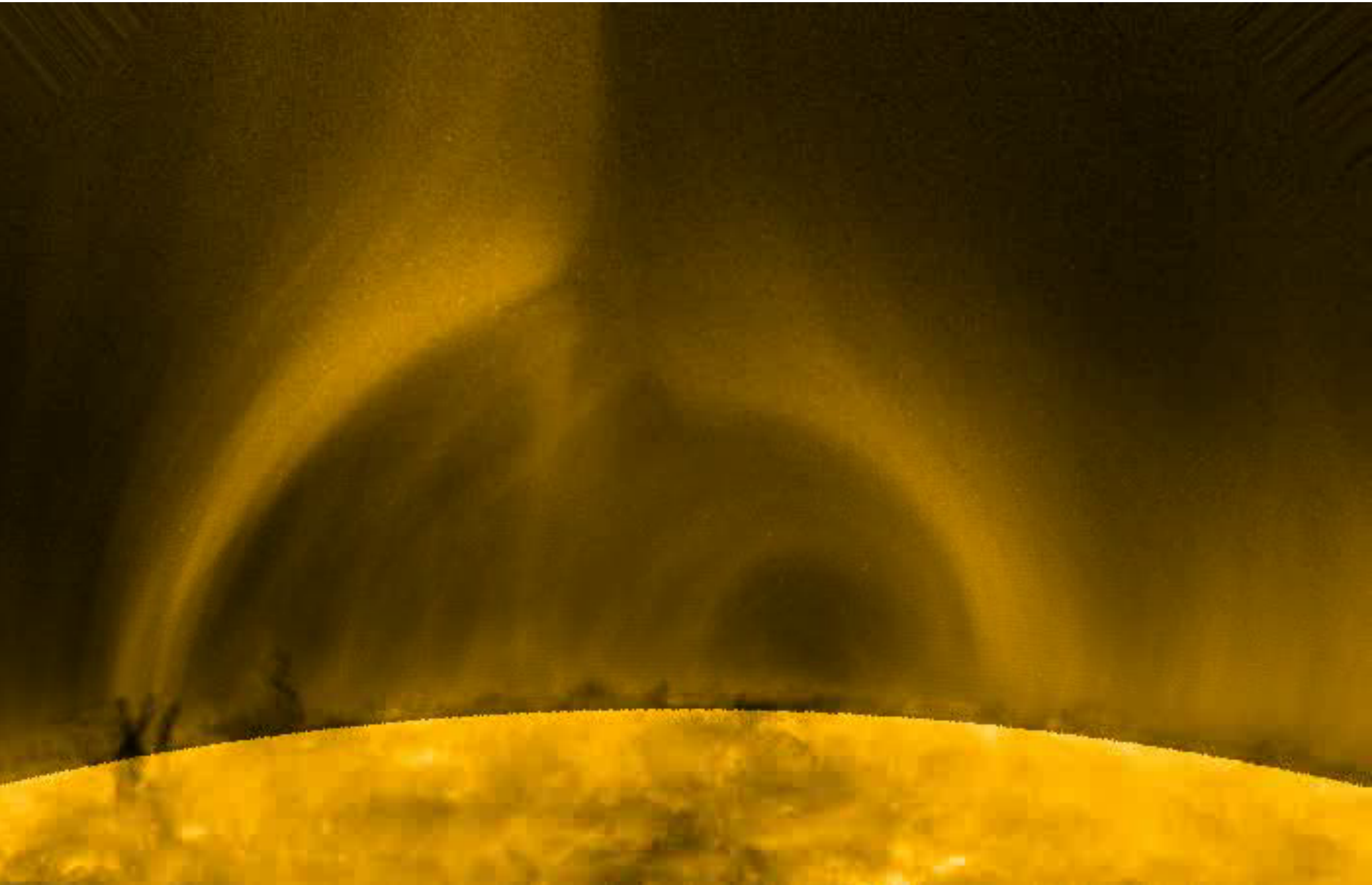
- Sparkles ou EUV bright dots: corrélation entre “nanoflares” et lignes de champ
  -> Imageur EUV et Magnétographe
- Corrélation entre évacuation du plasma et champ “ouvert”
  -> Spectrométres et Magnétographe
- Corrélation entre source radio coronale et champ ouvert
  -> Instruments radio et Magnétographe
- Mesure de l’altitude des “EIT waves”
- Tentatives d’identification des lignes de champ transportant les particules énergétiques



Solar Orbiter

- Identification des lignes de champ
- Modeles PFSS ou nlff pour supporter les observations EUV et X-ray

# Sources magnétiques du vent solaire lent



# Evolution du champ magnétique

- **Série temporelle de champ magnétique extrapolé**

  Injection d'énergie, d'hélicité, changement de topologie, … (voir Sun et al.)

- **Série temporelle de champ magnétique extrapolé + modélisation MHD entre deux cartes de champ magnétique**

  Nécessite le champ de vitesse; extrapolation utilisée pour ajuster la modélisation MHD (Cheung and Derosa)

- **Série temporelle de champ magnétique extrapolé + modélisation MHD lorsque les ingrédients nécessaires sont présents**

  Estimation du temps de déclenchement, de l'énergie magnétique (Amari et al.)