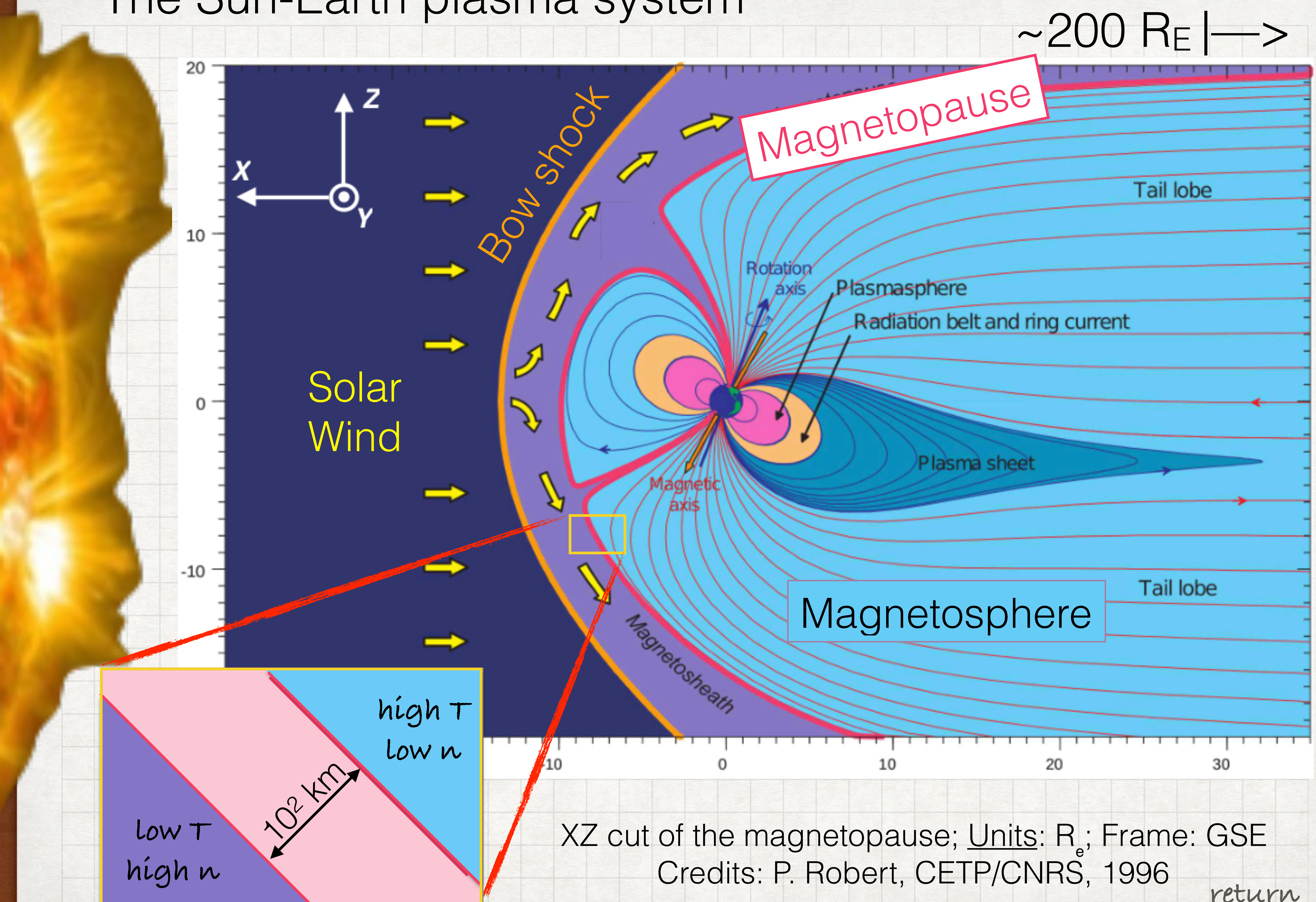
First year seminary @ UniPi

09/10/2017

- Speaker: Roberto Manuzzo
- Working @(with): UPMC, Ecole Polytechnique (L.Rezeau, G.Belmont), UniPi (F.Califano)
- Target: Unequal temperature plasmas mixing across the Magnetopause

The Sun-Earth plasma system



XZ cut of the magnetopause; Units: R_e; Frame: GSE
Credits: P. Robert, CETP/CNRS, 1996

return

Sun not in scale

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From Vlasov to single fluid... and after?

* $f = f(\overline{r}(t), \overline{v}(t), t)$

$$\partial_t f + \overline{v} \cdot \overline{\nabla} f + \frac{\overline{F}}{m} \cdot \overline{\nabla} f = (\partial_t f))_{coll}$$

$$\prec \xi \succ (\mathbf{r}, t) = \frac{\int \xi(\mathbf{r}, \mathbf{v}, t)\, f(\mathbf{r}, \mathbf{v}, t) d\mathbf{v}}{\int f(\mathbf{r}, \mathbf{v}, t) d\mathbf{v}}$$

for a single fluid collisionless plasma:

$\xi = m\mathbf{v}^0$
$$\frac{\partial n}{\partial t} + \overline{\nabla} \cdot (n\mathbf{U}) = 0$$

$\xi = m\mathbf{v}^1$
$$\frac{\partial (mn\mathbf{U})}{\partial t} + \overline{\nabla} \cdot (mn\mathbf{U}\mathbf{U}) - mn < \overline{F} >= 0$$

$\xi = \frac{1}{2} m\mathbf{v}^2$
$$\frac{\partial (n\frac{1}{2}mU^2)}{\partial t} + \overline{\nabla} \cdot (n\frac{1}{2}mU^2\mathbf{U}) - n < \overline{F} \cdot \mathbf{U} >= 0$$

Problem: only one fluid! No energy exchanges are even defined...

Solution: find the way to perform a self-consistent evolution of 2 plasma fluids involving energy exchanges between hot and cold ions and electrons...

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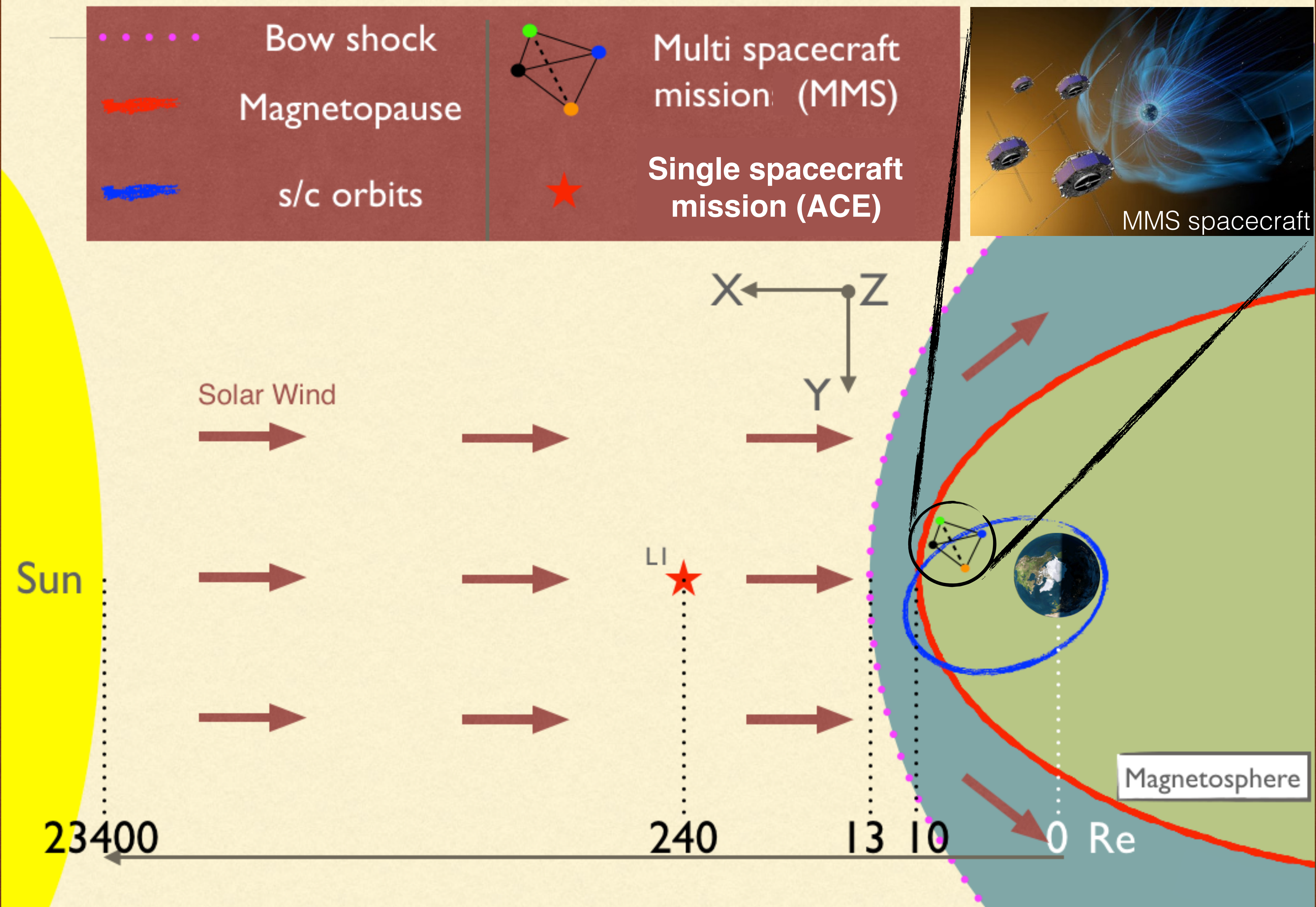
1. Data analysis on Magnetospheric MultiScale spacecraft data

How do we probe the magnetopause?



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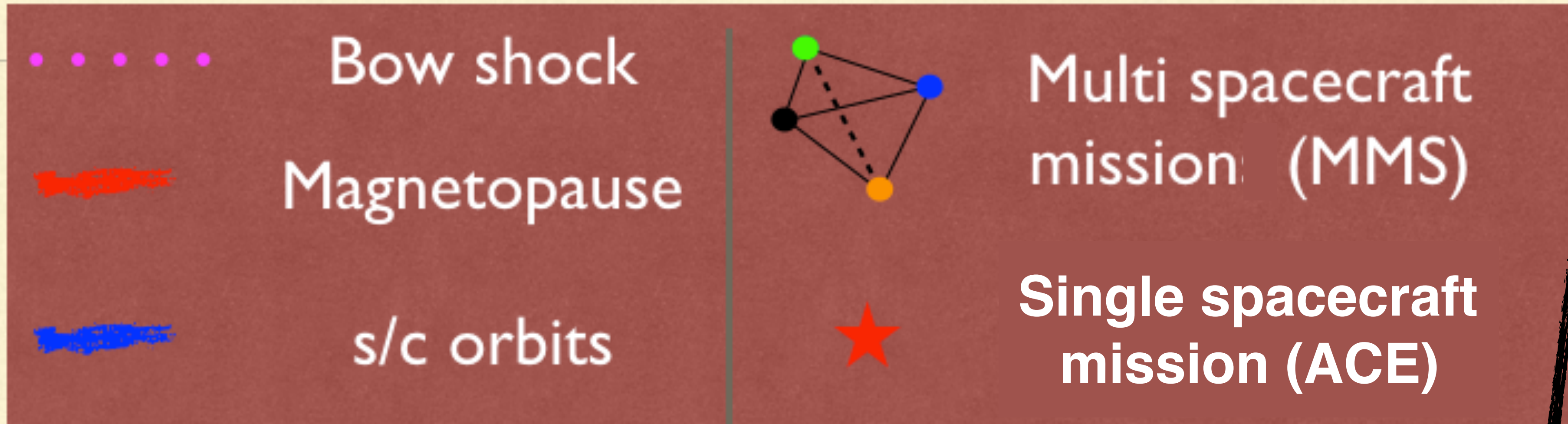
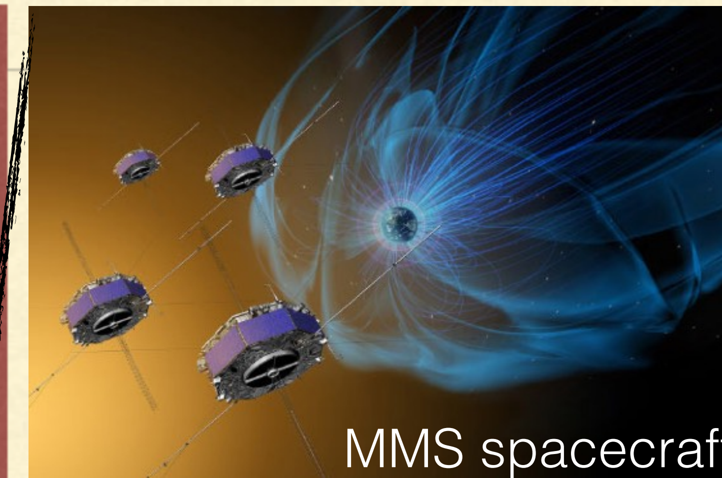




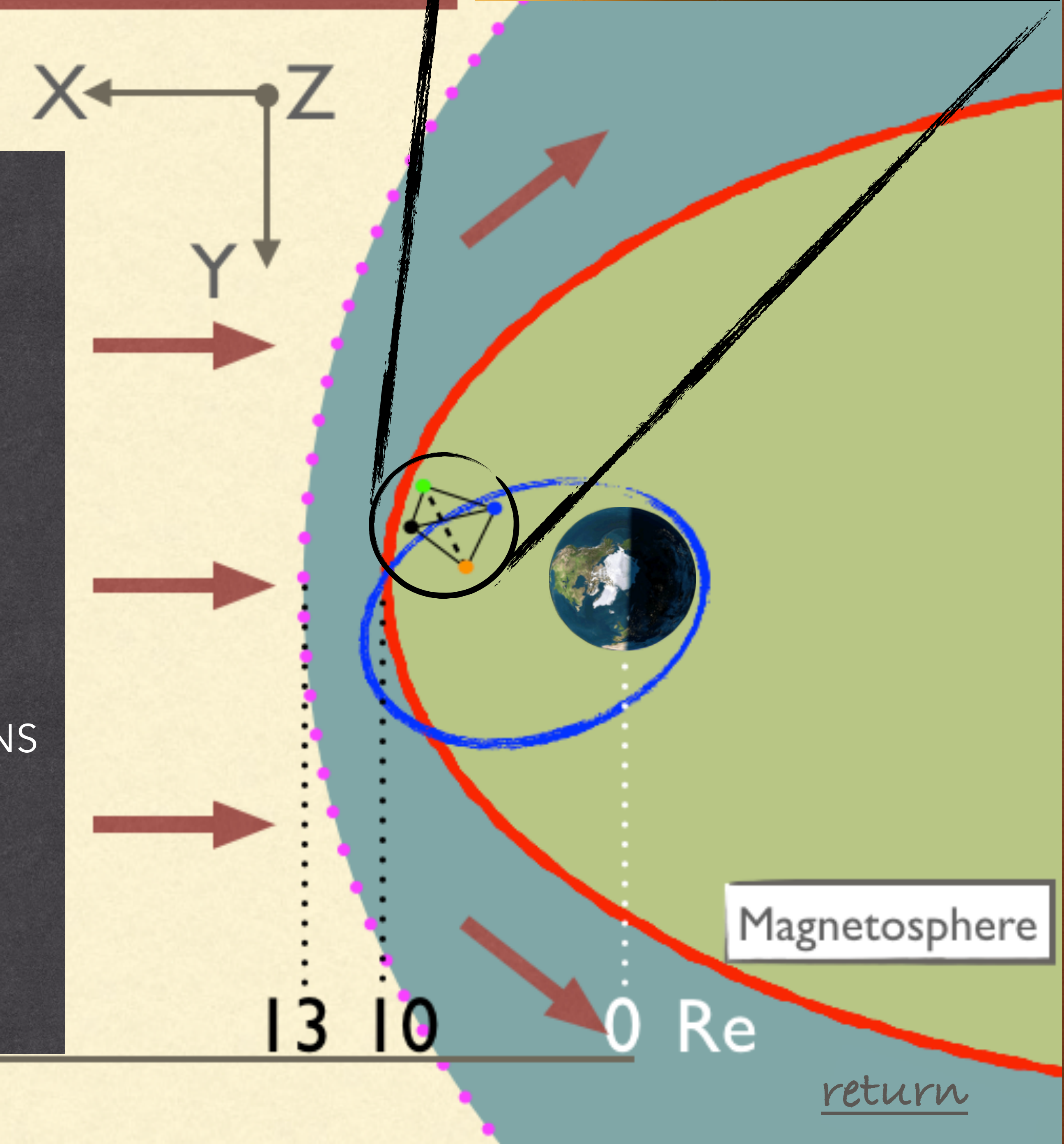
✻ WHAT MMS MEASURES (AND HOW)?

- FIELDS

	E	B
Survey	DC, ~S/s	16 S/s
Burst	100 kS/s	128 S/s

- PARTICLES 3D3V DISTRIBUTION FUNCTIONS

  - Ions => 150 S/s
  - Electrons => 30 S/s



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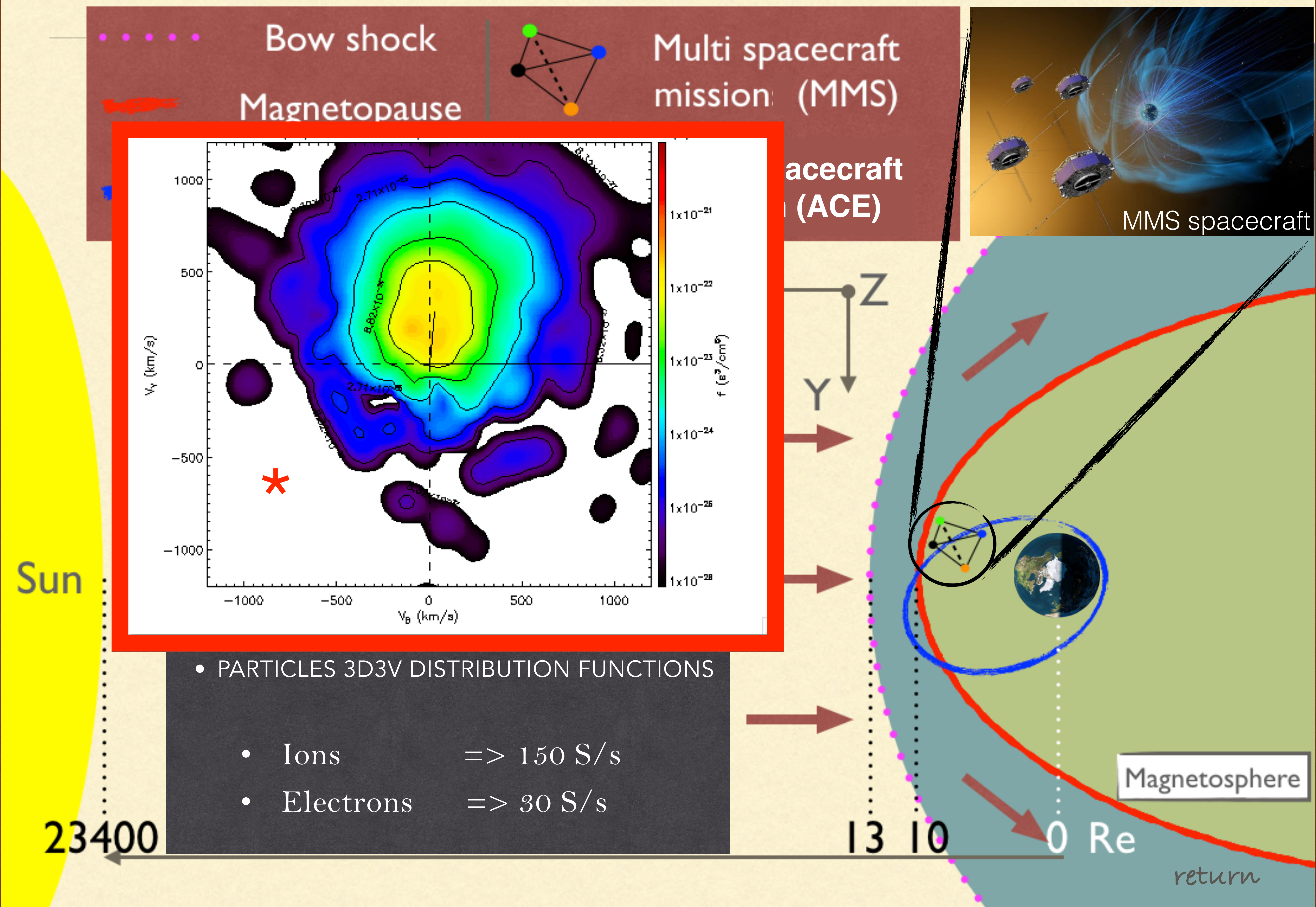

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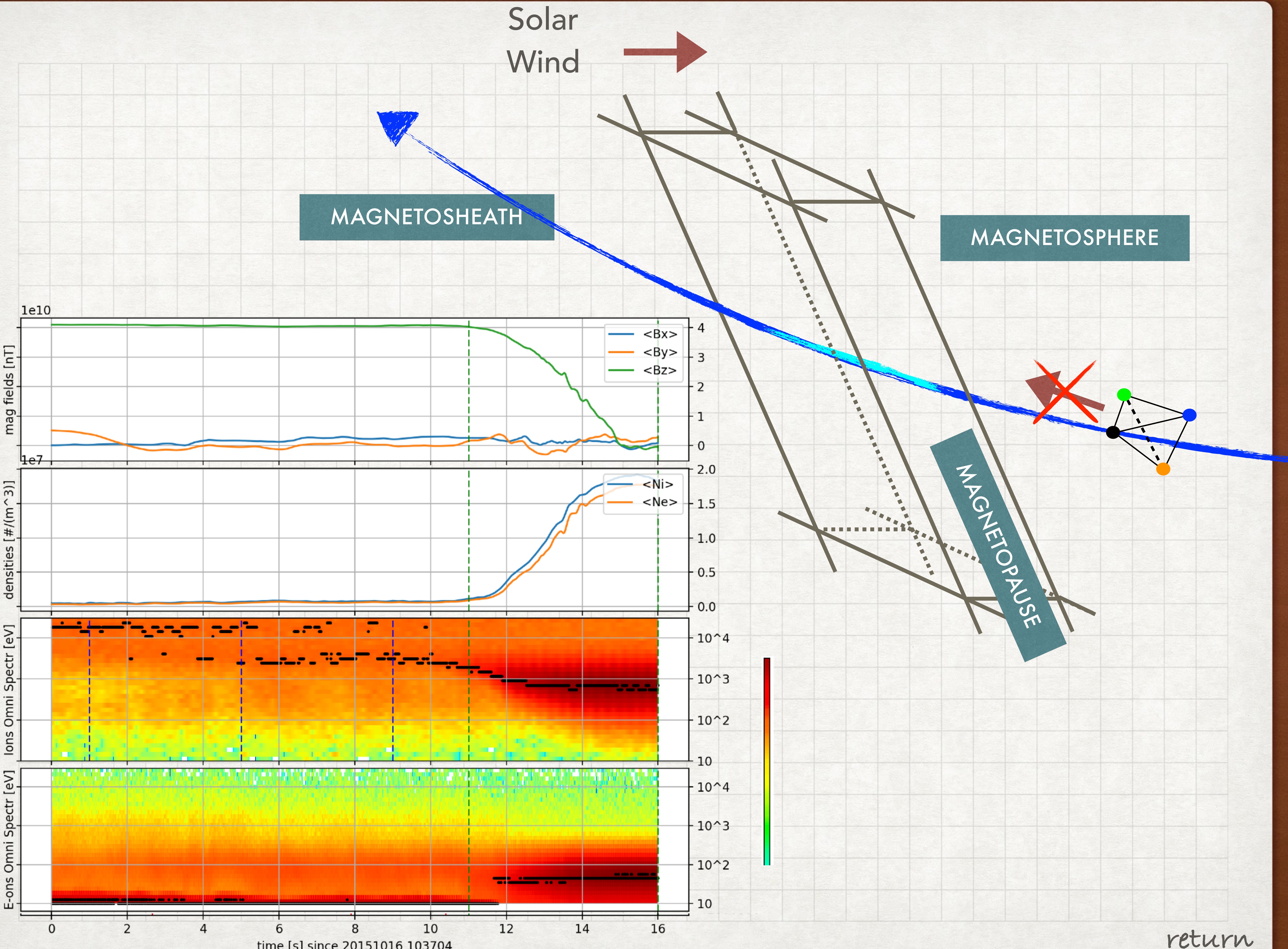

Solar Wind
MAGNETOSHEATH
MAGNETOSPHERE
MAGNETOPAUSE
1e10
mag fields [nT]
<Bx>
<By>
<Bz>
1e7
densities [#/(m^3)]
<Ni>
<Ne>
Ions Omni Spectr [eV]
E-ons Omni Spectr [eV]
time [s] since 20151016 103704

return

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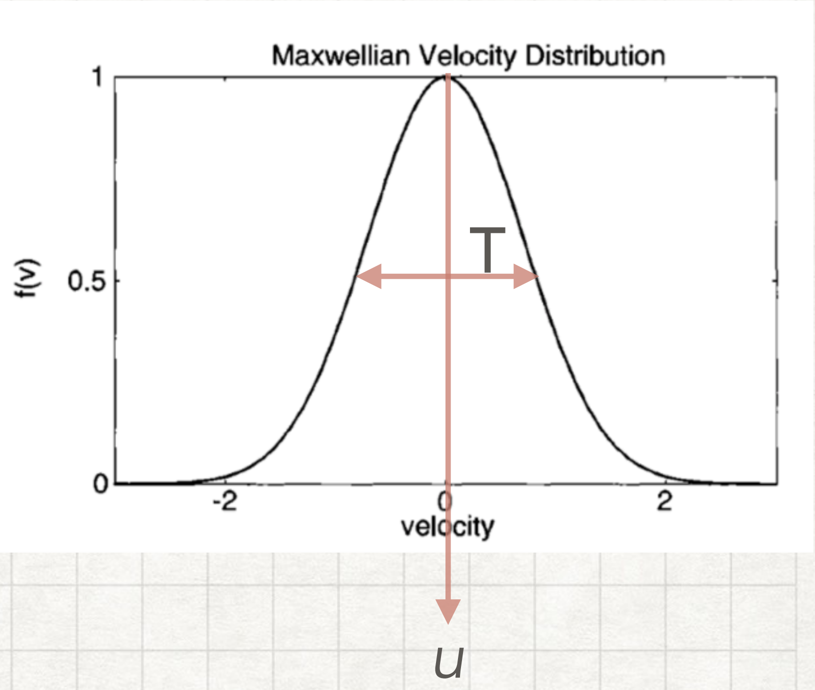
    - Hermite analysis of 3V distribution function

How to discover several species in one distribution function?

-) Reminder: the physical meaning of a distribution function in a 1V phase space:

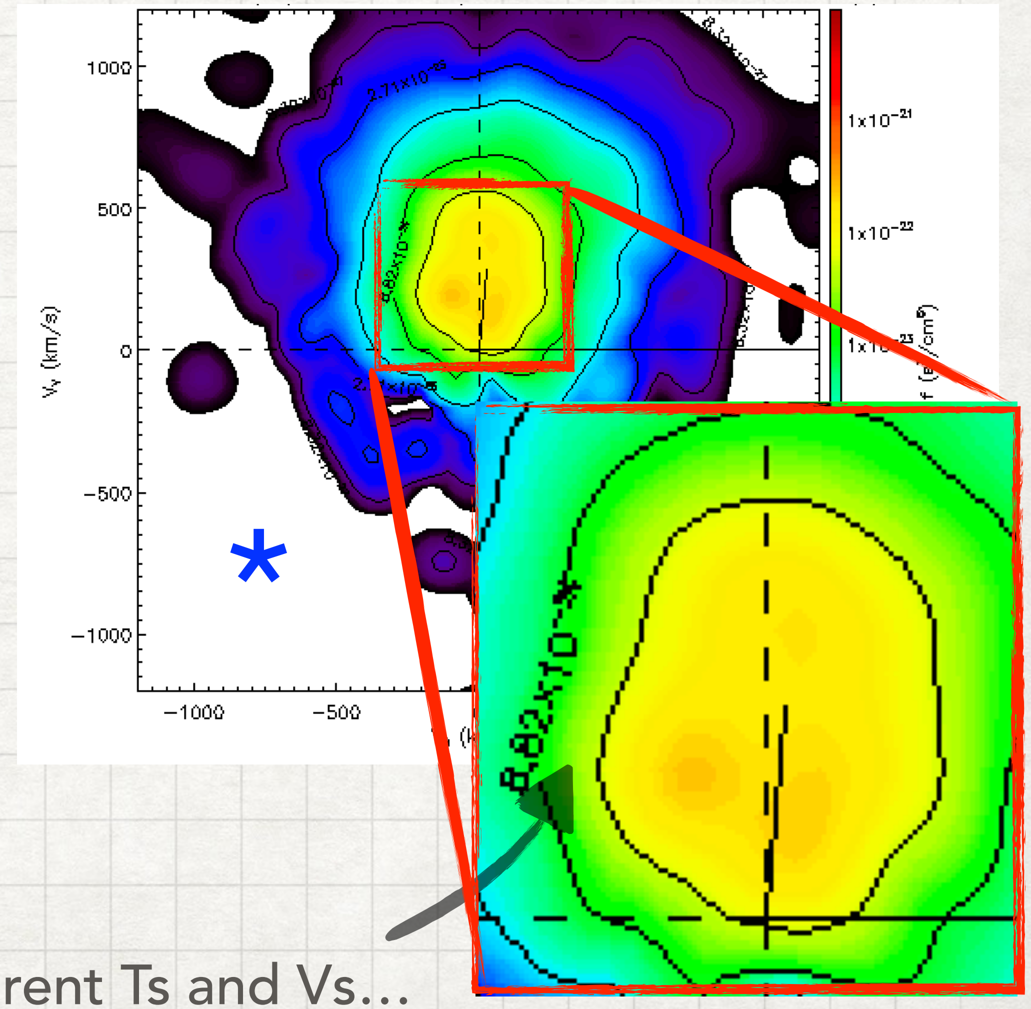


$$* \quad f_{MB}(v) = n\left(\frac{m}{2\pi kT}\right)^{3/2} Exp\left(-\frac{m(v-u)^2}{2kT}\right)$$

-) 1V Hermite transform representation[Servidio[2017]]:

$$\begin{cases} f_{\mathbf{v}} = \sum_m f_m \psi_m(\mathbf{v}) \\ \int_{\infty}^{\infty} \psi_m \psi_l = \delta_{ml} \\ \psi_m(v) = \dfrac{H\left(\frac{v-u}{v_{th}}\right)}{\sqrt{2^m m! \sqrt{\pi} v_{th}}} exp\left(-\dfrac{m(v-u)^2}{2v_{th}^2}\right) \\ H_m(v) = (-1)^m e^{v^2} \dfrac{d^m}{dv^m} e^{-v^2} \end{cases}$$

$$N.B.: \ \psi_{m=0}(v) \propto F_{MB}$$



-) idea: apply the HTR to the 3V distr. func.:

$$\psi_m(\mathbf{v}) = \psi(m_x, v_x)\psi(m_y, v_y)\psi(m_z, v_z)$$

allowing for the presence of different species having different Ts and Vs...

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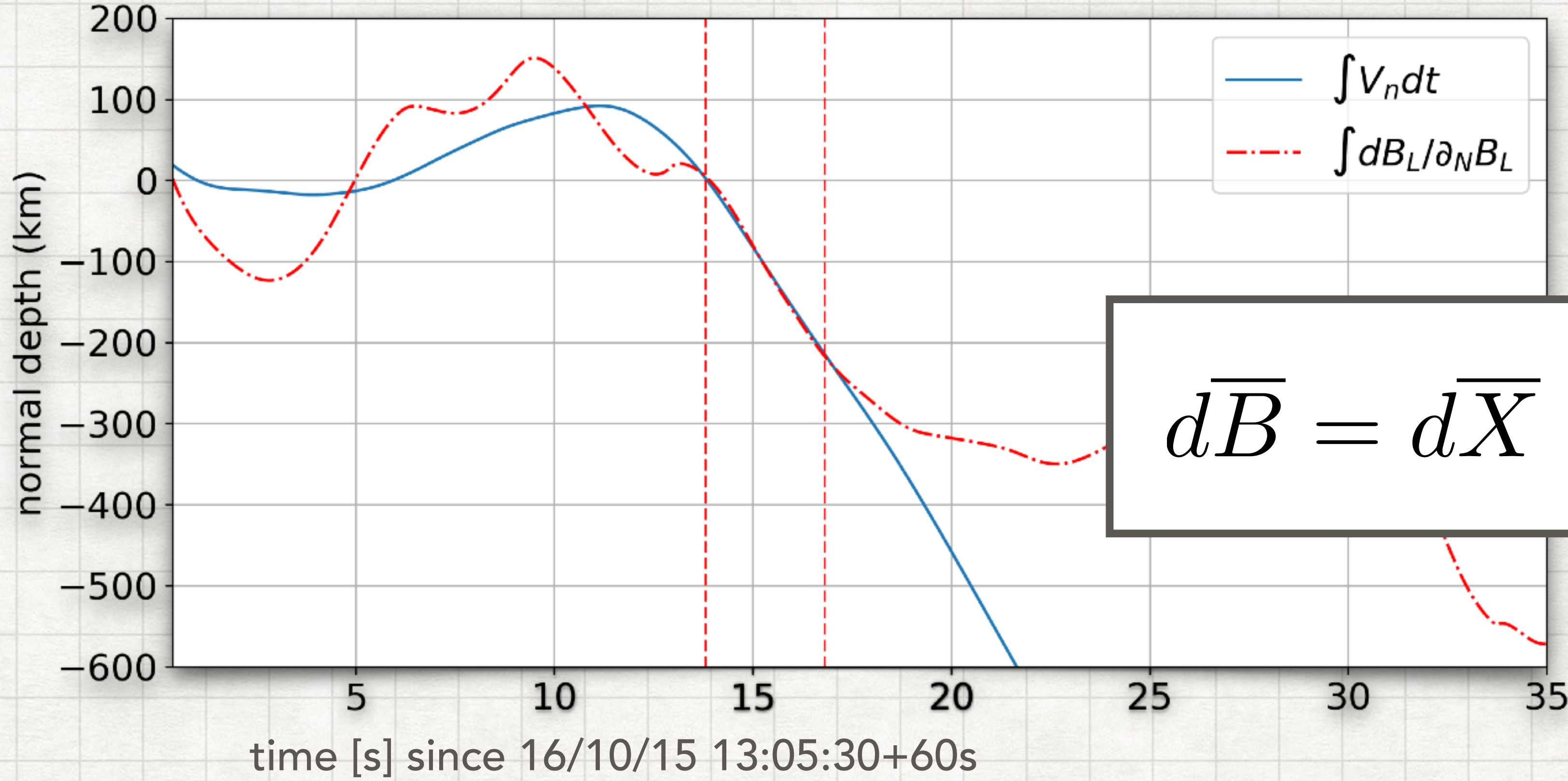
A more precise determination of the magnetopause thickness…

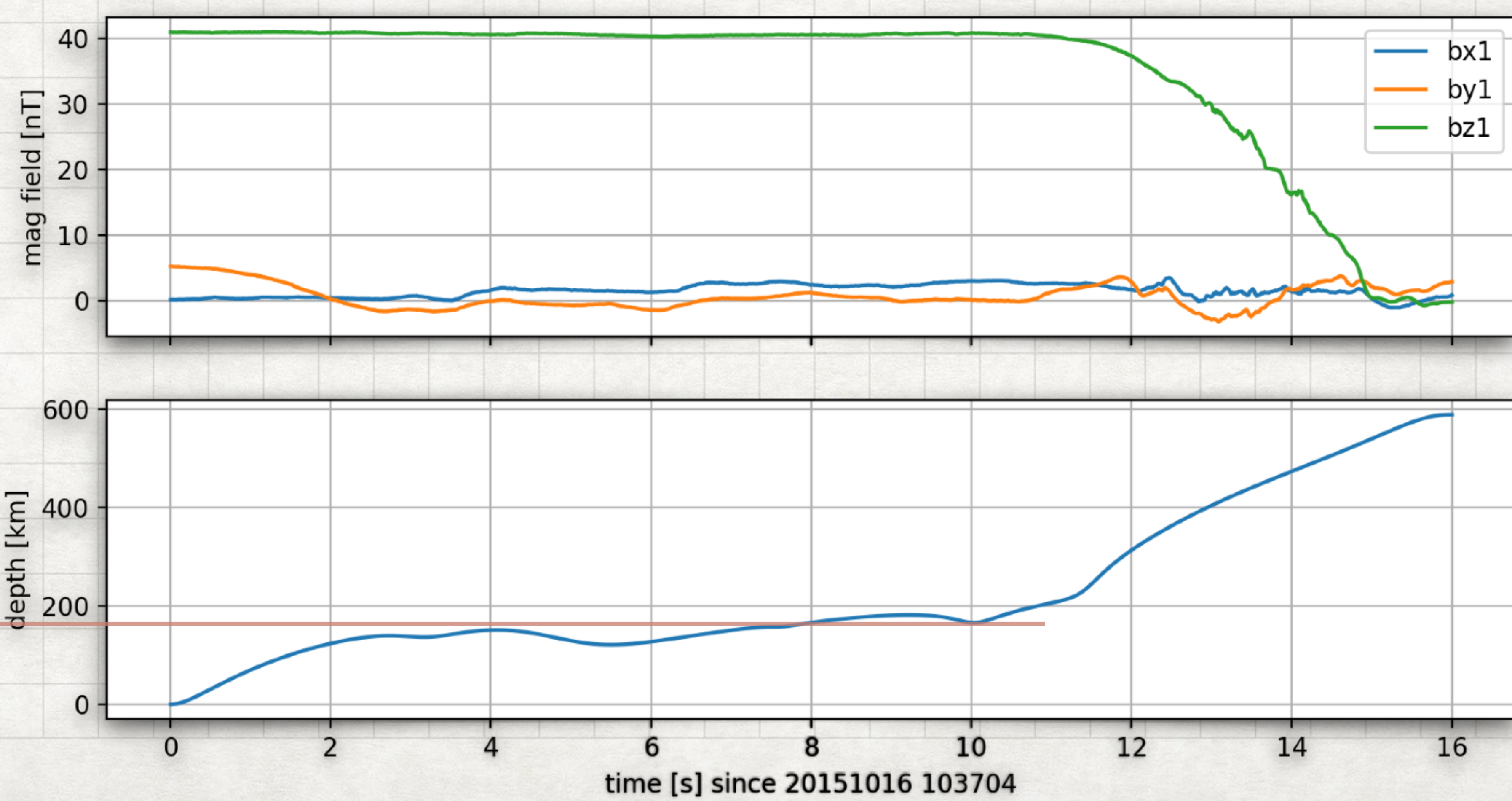


$$d\overline{B} = d\overline{X} \cdot \overline{\nabla}\,\overline{B} + a + o(d\overline{X}^2)$$

Rezeau [2017]

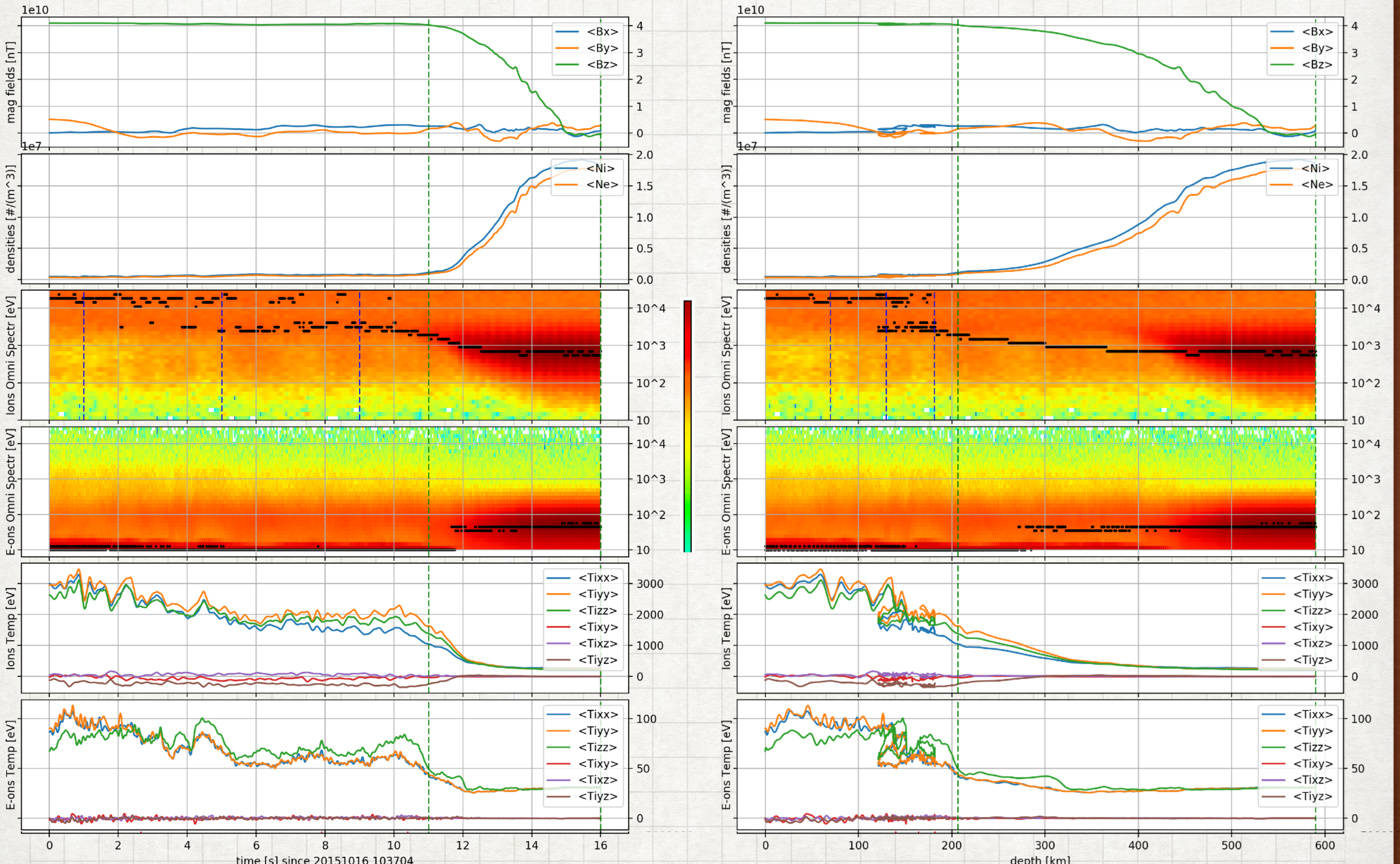
+ next study

~6 di



Berchem [1982]

...which allows for the projection of data into space:



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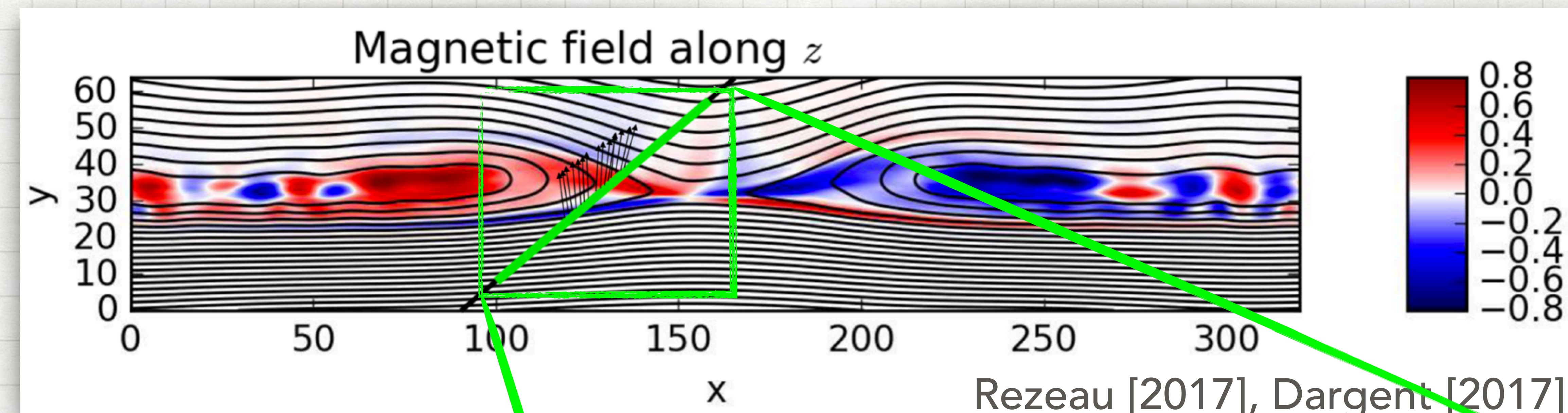
A more precise determination of the normal to the magnetopause

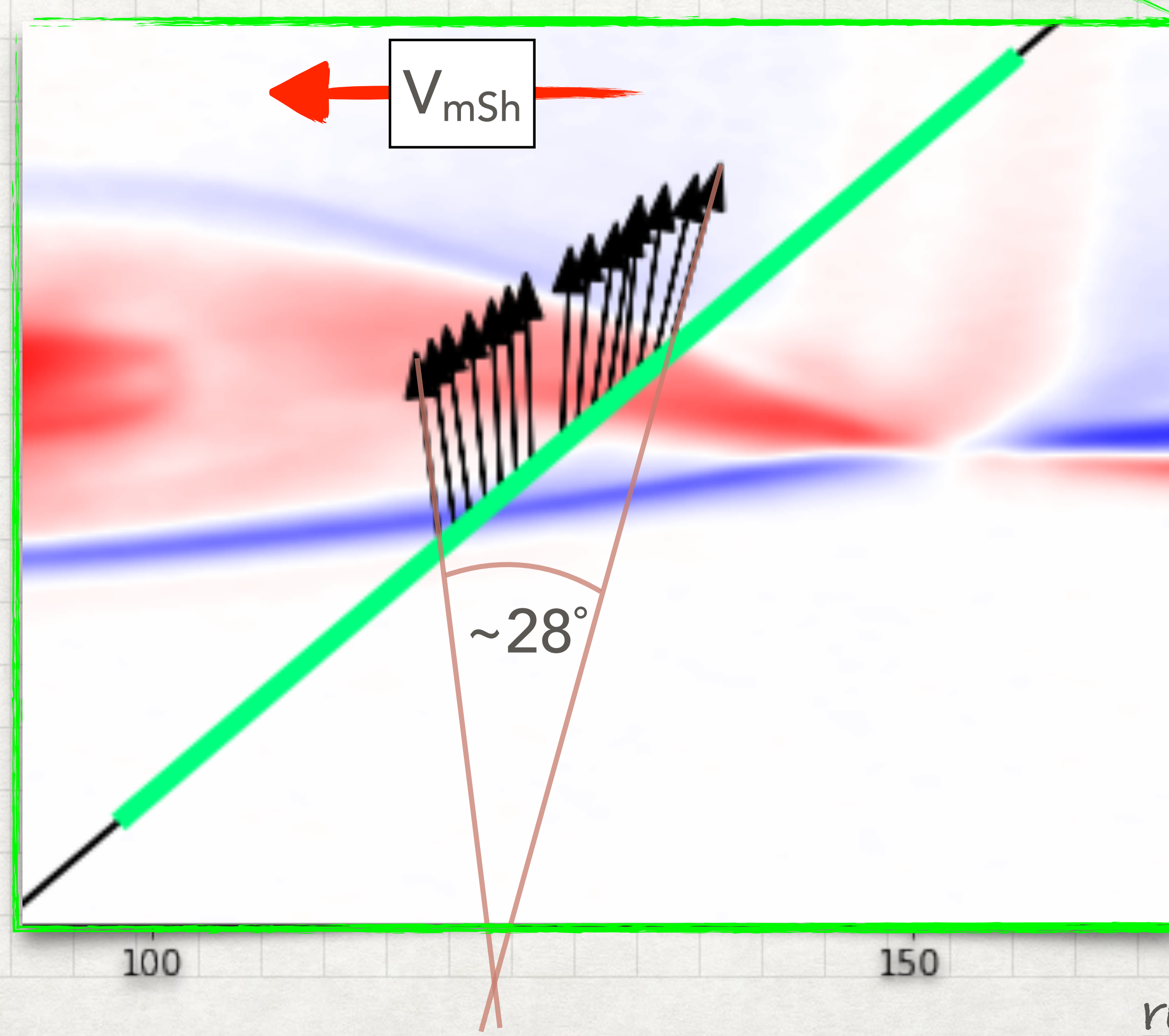


Global method are senseless in these cases!

V_{mSh}~300 km/s

x Sin(20°) ~ 80 km/s

different from ~ 0 km/s !



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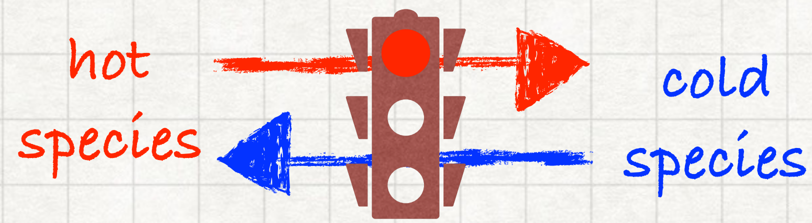
2. Simulations
    - 2->4-fluid code
        - 4-Fluid code (i&e,low_T ⊕ i&e,high_T), large scale structure without en. evo constr.

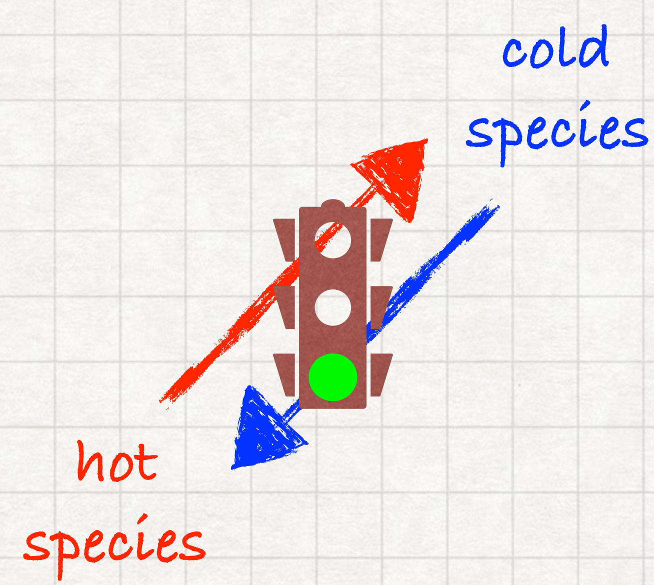
From the 2-fluid to the 4-fluid

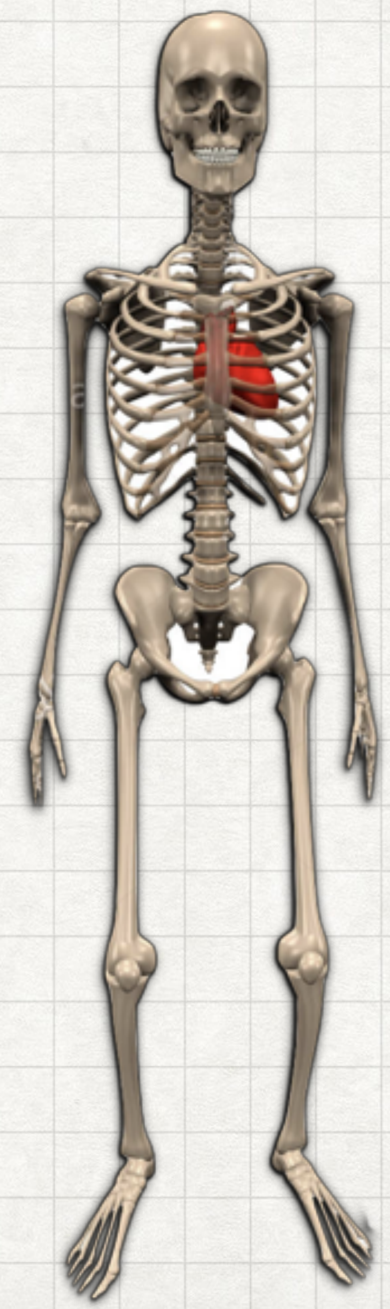
=> Advance the highest order terms, T_α, by means of a polytropic closure where the entropy is conserved because heat sources/fluxes and viscous stresses are neglected.

$$\begin{cases} t & \frac{\partial S_\alpha}{\partial t} + \overline{\nabla}\cdot(S_\alpha \mathbf{U}_\alpha) \propto -\overline{\nabla}\cdot\bar{q}_\alpha - \Pi_{IJ\alpha}\frac{\partial U_{I\alpha}}{\partial_J} + Q_\alpha \\ t+1 & P_\alpha = S_\alpha n^{\gamma-1} \\ t+2 & T_\alpha = P_\alpha/n \end{cases}$$

$$with\ \alpha = i \wedge e$$







Solution: compute the T_α as function of lower order terms without invoking constraints on the energy exchanges

$$T_\alpha = T_\alpha(n_\alpha, n_\beta, \mathbf{U}_\alpha, \mathbf{U}_\beta)$$

$$with\ \alpha = i \vee e \vee i \vee e\ \wedge\ \beta = \{i, e, i, e\} \setminus \alpha$$

return

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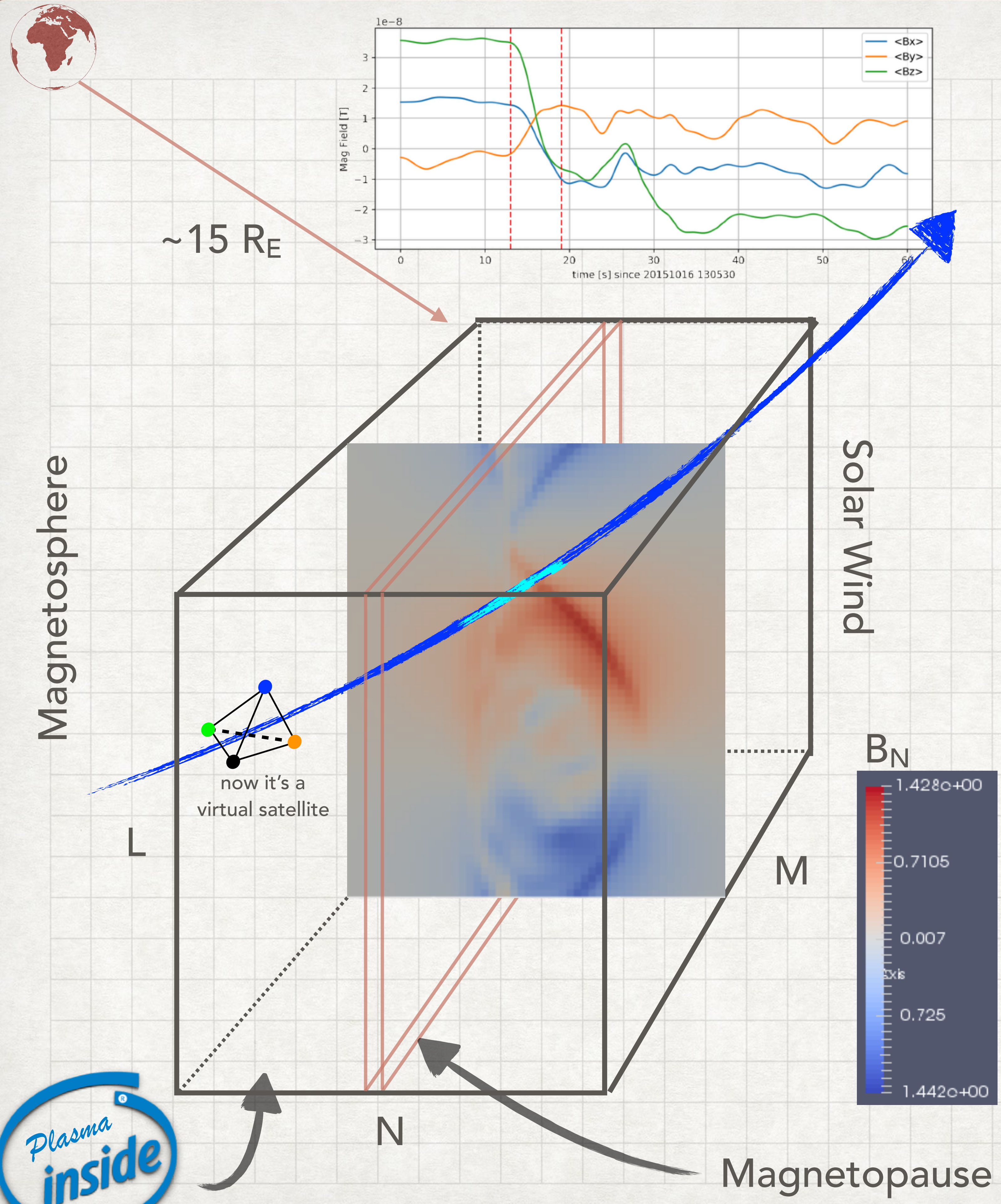

Quantity	Function
$\lvert B\rvert$	$a_{\lvert B\rvert} + b_{\lvert B\rvert}\ (tanh(\frac{x-c_{\lvert B\rvert}}{d_{\lvert B\rvert}}) + b'_{\lvert B\rvert} tanh(\frac{x-c'_{\lvert B\rvert}}{d_{\lvert B\rvert}}))$
$B_M \angle B_T$	$a_\alpha + b_\alpha\ tanh(\frac{x-c_\alpha}{d_\alpha}) + a'_\alpha$
B_M	$a_m + b_m\ tanh(\frac{x-c_m}{d_m})$
B_L	$a_l + b_l\ tanh(\frac{x-c_l}{d_l})$
N_i	$a_n + b_n\ tanh(\frac{x-c_n}{d_n})$
U_i	$a_u\,(1 +\ tanh(\frac{x-c_u}{d_u}))$
P_i	$a_{Pi} + b_{Pi}\ tanh(\frac{x-c_{Pi}}{d_{Pi}})$
P_e	$a_{Pe} + b_{Pe}\ tanh(\frac{x-c_{Pe}}{d_{Pe}})$

return

THANKS

References

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- *Berchem & al., “The thickness of the magnetopause current layer: ISEE 1 and 2 observations”, J.* Geophys. Res.87-A4, 2108, (1982)

- Rezeau, Belmont, Manuzzo et al., “Analyzing the magnetopause internal structure: new possibilities offered by MMS tested in a case study”, submitted to JGR, (2017)

- Shi et al., “Dimensional analysis of observed structures using multipoint magnetic field measurements: Application to Cluster”, GRL, vol.32, L12105, (2005)

APPENDICES

The Minimum Directional Derivative method (MDD, Shi [2005])...

$$\overline{\overline{G}} = \nabla \overline{B} \qquad \overline{n} \cdot \overline{\overline{G}} = \overline{D} = \frac{\partial \overline{B}}{\partial \overline{n}}$$

If **n** = **N** was the invariant direction along which all the parameters remain constant => $D^2 = 0$

$$diagonalization(\overline{\overline{G}}\,\overline{\overline{G}}^T) \begin{cases} \lambda_1 & \overline{v}_1 & \text{maximum} \\ \lambda_2 & \overline{v}_2 & \text{intermediate} \\ \lambda_3 & \overline{v}_3 & \text{minimum} \end{cases} \Bigg\} \text{ of } \mathbf{D}$$

$\lambda_1 \gg \lambda_2 \wedge \lambda_3$ => 1D str.

$\lambda_1 \sim \lambda_2 \gg \lambda_3$ => 2D str.

$\lambda_1 \sim \lambda_2 \sim \lambda_3$ => 3D str.

... our Local Normal Aanlysis method (LNA, Rezeau [2017])

Hp.: stationarity and 1D

$$\overline{J} = \overline{N} \times \partial_N \overline{B} \perp \partial_N \overline{B} = -V_N \cdot \partial_N \overline{B}$$

return

Methods used to find the normal to the magnetopause

Common Hypotheses: magnetopause =1D and stationary layer ⇒ $\mathbf{B}_n \neq \mathbf{B}_n(N,t)$

Single spacecraft | Multi spacecraft

Minimum Variance Analysis method

1) Find **N** in order to minimize:

$$\sum_i \left\| (\mathbf{B}_i - \bar{\mathbf{B}}) \cdot \mathbf{N} \right\|^2$$

2) How to? Diagonalize

$$\begin{cases} M_{\mu\nu} = \langle B_\mu B_\nu \rangle - \langle B_\mu \rangle \langle B_\nu \rangle \\ \mu, \nu = x, y, z \end{cases}$$

3) Results:
- -) eigenvalues: λ_1, λ_2, λ_3
- -) eigenvectors: **L**, **M**, **N**

Pro: simple hypotheses
Vs: bad determination if not 1D

BV method

1) Other hypotheses needed:
- -) no flow through the magnetopause
- -) **B** behaves like:

$$\begin{cases} B_L = B_{0L} cos(\alpha) \\ B_N = B_{0N} \\ B_M = B_{0M} sin(\alpha) \end{cases}$$

where:

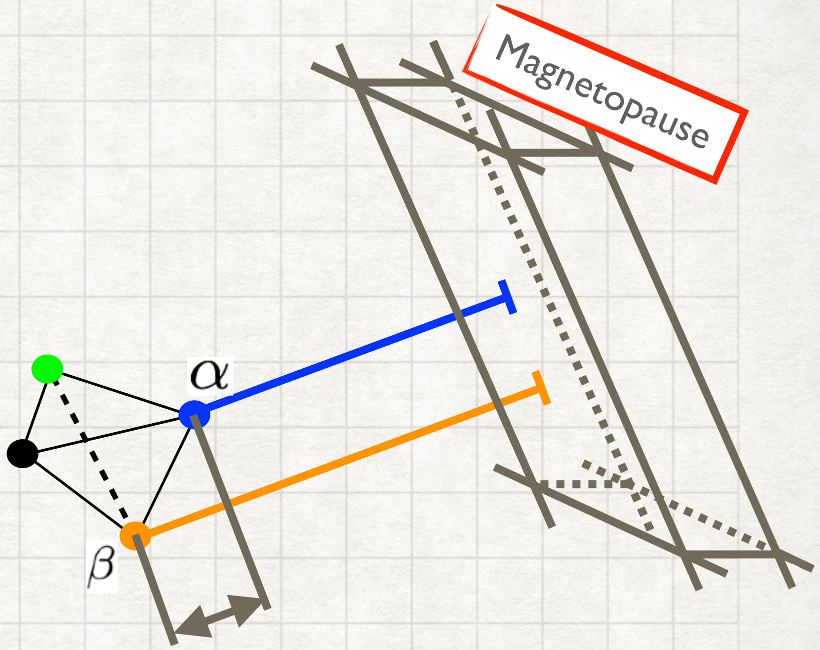
$$\alpha = \alpha_1 + (\alpha_2 - \alpha_1)\frac{N}{y_{max}}$$

and

$$N = \int_{crossing} \mathbf{V}_{BF}(t) \cdot \mathbf{N}\, dt$$

Pro: particle data involved too
Vs: Hypotheses

Constant Velocity Approach method



$\triangle t_{\alpha\beta}$

$\mathbf{r}_{\alpha\beta}$

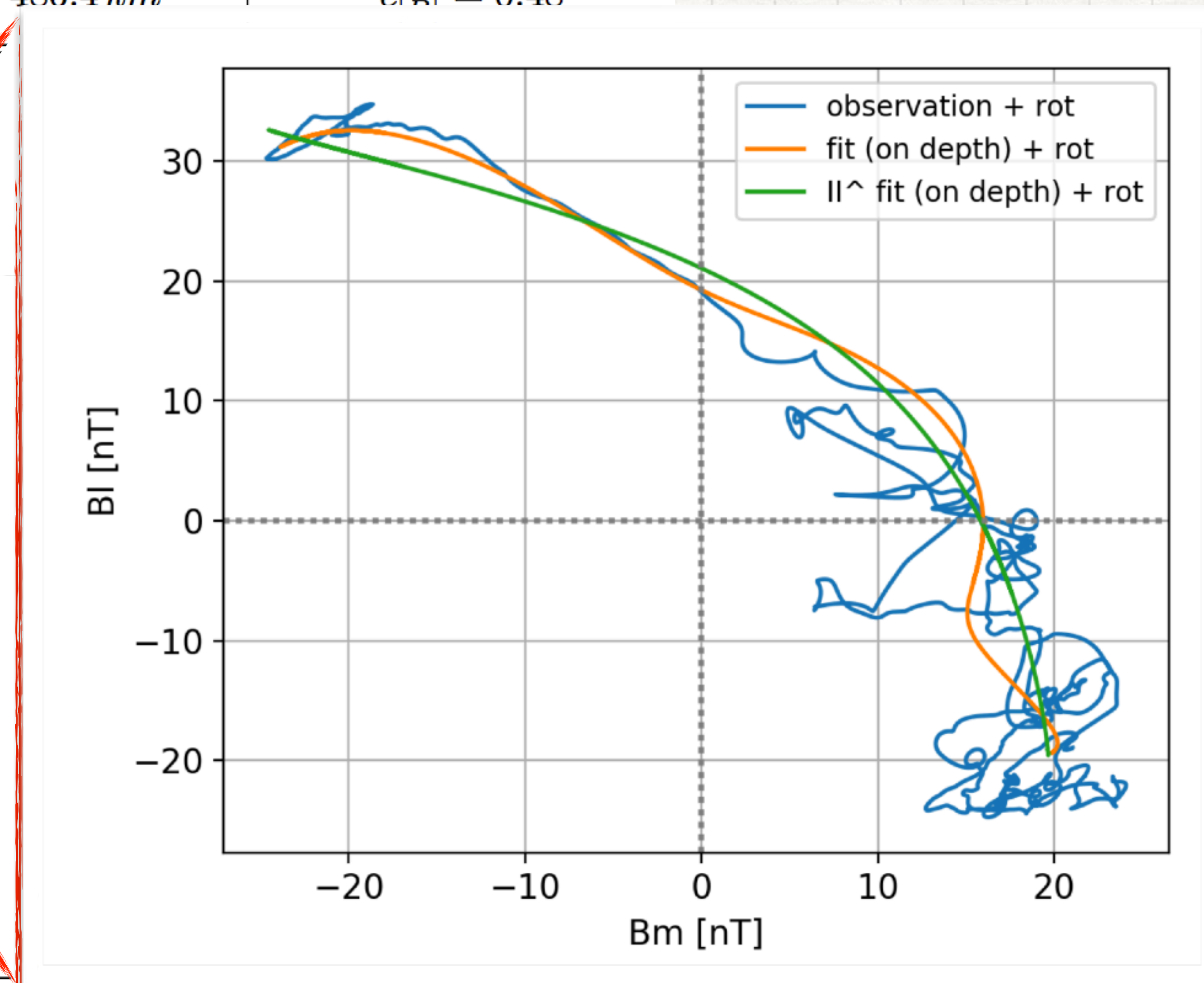
$$(\mathbf{V}\triangle t_{\alpha\beta}) \cdot \mathbf{N} = \mathbf{r}_{\alpha\beta} \cdot \mathbf{N}$$

Pro: Less hypoth, Simple, Mean
Vs: Problem with MMS data

return

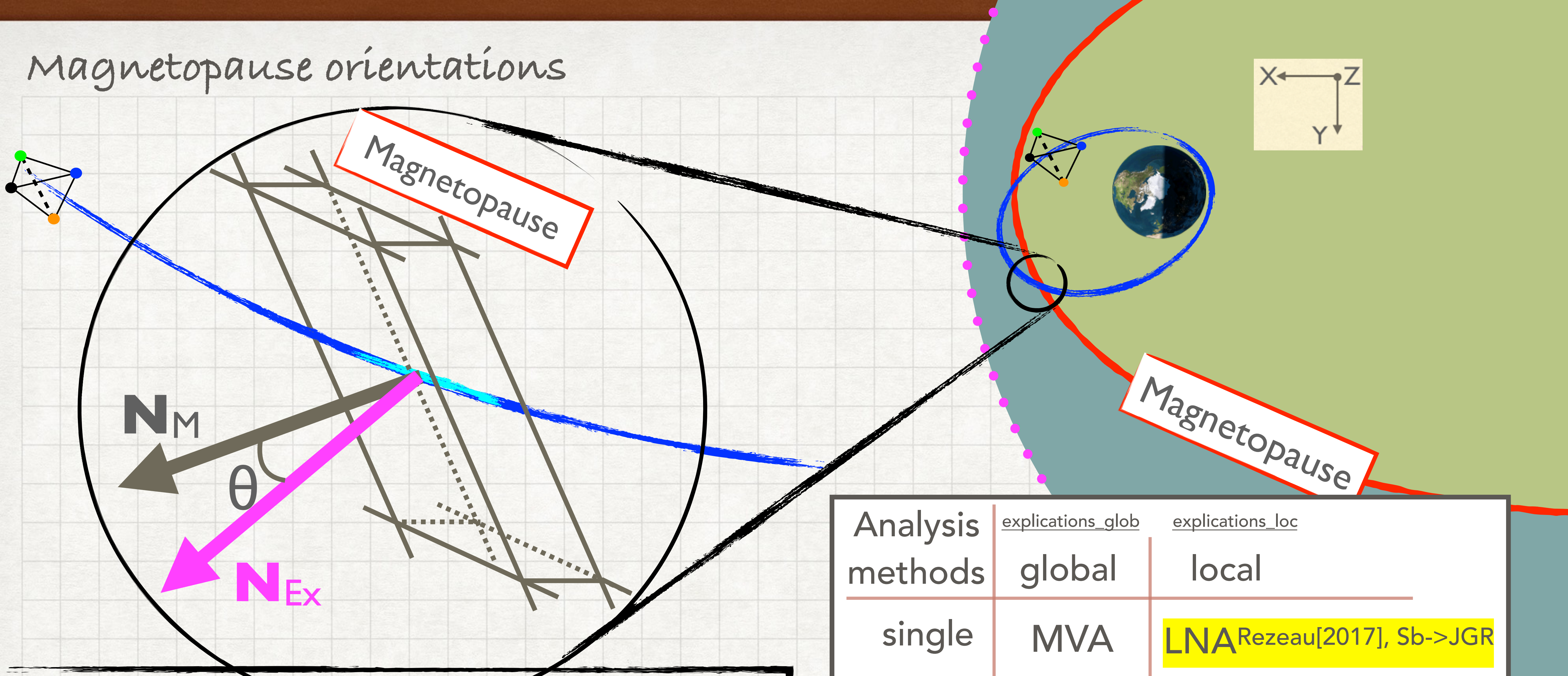
First 2-fluid simulations

Quantity	Function	Parameters	Normalized Parameters
$\lvert B\rvert$	$a_{\lvert B\rvert} + b_{\lvert B\rvert}\ (tanh(\frac{x-c_{\lvert B\rvert}}{d_{\lvert B\rvert}}) + b'_{\lvert B\rvert} tanh(\frac{x-c'_{\lvert B\rvert}}{d_{\lvert B\rvert}}))$	$a_{\lvert B\rvert} = 33.5\,nT$ $b_{\lvert B\rvert} = -11.7\,nT$ $b'_{\lvert B\rvert} = -0.5$ $c_{\lvert B\rvert} = 151.9\,km$ $c'_{\lvert B\rvert} = 486.4\,km$ $d_{\lvert B\rvert} =$ [illegible]	$\tilde{a}_{\lvert B\rvert} = 1.21$ $\tilde{b}_{\lvert B\rvert} = -0.42$ $\tilde{b}'_{\lvert B\rvert} = -0.5$ $\tilde{c}_{\lvert B\rvert} = -0.30$ $\tilde{c}'_{\lvert B\rvert} = 0.48$
$B_M \angle B_T$	$a_\alpha + b_\alpha\ tanh(\frac{x-c_\alpha}{d_\alpha}) + a'_\alpha$	a_α [illegible]	[illegible]
B_M	$a_m + b_m\ tanh(\frac{x-c_m}{d_m})$	[illegible]	[illegible]
B_L	$a_l + b_l\ tanh(\frac{x-c_l}{d_l})$	[illegible]	[illegible]
N_i	$a_n + b_n\ tanh(\frac{x-c_n}{d_n})$	[illegible]	[illegible]
U_i	$a_u\,(1 + \ tanh(\frac{x-c_u}{d_u}))$	a_u [illegible] $c_u =$ [illegible] $d_u =$ [illegible]	[illegible]
P_i	$a_{Pi} + b_{Pi}\ tanh(\frac{x-c_{Pi}}{d_{Pi}})$	$a_{Pi} = 2133\,eV/cm^3$ $b_{Pi} = 933\,eV/cm^3$ $c_{Pi} = 57.6\,km$ $d_{Pi} = 55.8\,km$	$\tilde{a}_{Pi} = 0.558$ $\tilde{b}_{Pi} = 0.244$ $\tilde{c}_{Pi} = -0.52$ $\tilde{d}_{Pi} = 0.13$
P_e	$a_{Pe} + b_{Pe}\ tanh(\frac{x-c_{Pe}}{d_{Pe}})$	$a_{Pe} = 136.8\,eV/cm^3$ $b_{Pe} = 98.5\,eV/cm^3$ $c_{Pe} = 140.6\,km$ $d_{Pe} = 74.7\,km$	$\tilde{a}_{Pe} = 0.036$ $\tilde{b}_{Pe} = 0.026$ $\tilde{c}_{Pe} = -0.33$ $\tilde{d}_{Pe} = 0.17$



return

Magnetopause orientations



Analysis methods	global	local
	explications_glob	explications_loc
single	MVA	LNA Rezeau[2017], Sb->JGR
multi	CVA	MDD Shi[2005]

16/10/2015		13:05:30+60s		13:05:44+5s	
		mean	std	mean	std
MDD vs LNA_max	:	2.04E+01	1.89E+01	7.71E+00	5.79E+00
MDD vs MVAB	:	1.38E+01	1.02E+01	2.44E+01	4.49E+00
LNA_max vs MVAB	:	3.52E+01	2.12E+01	3.21E+01	2.94E+00
MDD vs Shue	:	1.[illegible]	[illegible]	[illegible]	[illegible]
MDD vs LNA_fpi	:	2.[illegible]	[illegible]	[illegible]	[illegible]
LNA_fpi vs Shue	:	3.[illegible]	[illegible]	[illegible]	[illegible]
LNA_fpi vs MVAB	:	3[illegible]	[illegible]	[illegible]	[illegible]
LNA_max vs Shue	:	4[illegible]	[illegible]	[illegible]	[illegible]
LNA_fpi vs LNA_max	:	1[illegible]	[illegible]	[illegible]	[illegible]

16/10/2015		10:37:01+35s		10:37:15+3s	
		mean	std	mean	std
MDD vs LNA_max	:	7.63E+00	8.66E+00	1.55E+00	2.38E-01
MDD vs MVAB	:	1.47E+01	1.18E+01	1.43E+01	1.76E+00
LNA_max vs MVAB	:	1.79E+01	1.08E+01	1.26E+01	1.40E+00
MDD vs Shue	:	2.70E+01	1.54E+01	3.52E+01	1.71E+00
MDD vs LNA_fpi	:	1.52E+01	4.27E+00	1.27E+01	4.61E-01
LNA_fpi vs Shue	:	2.52E+01	6.23E+00	2.25E+01	1.22E+00
LNA_fpi vs MVAB	:	7.62E+00	6.39E+00	3.31E+00	1.99E+00
LNA_max vs Shue	:	3.85E+01	1.08E+01	3.35E+01	1.35E+00
LNA_fpi vs LNA_max	:	1.47E+01	7.29E+00	1.14E+01	7.05E-01

[illegible]		[illegible]:23+70s		12:05:39+5s	
		[illegible]	std	mean	std
[illegible]		[illegible]	2.38E+01	9.36E+00	4.68E+00
[illegible]		[illegible]	1.23E+01	3.68E+01	1.99E+01
[illegible]		[illegible]	2.25E+01	4.01E+01	2.30E+01
[illegible]		[illegible]	1.09E+01	3.15E+01	1.64E+01
[illegible]		[illegible]	2.07E+01	9.32E+00	4.97E+00
[illegible]		[illegible]	2.06E+01	3.40E+01	1.64E+01
LNA_fpi vs MVAB	:	4.09E+01	2.19E+01	3.86E+01	2.20E+01
LNA_max vs Shue	:	3.59E+01	2.12E+01	3.58E+01	1.71E+01
LNA_fpi vs LNA_max	:	8.95E+00	2.32E+01	2.54E+00	1.10E+00