Cross-Scale: Mission Concepts and Constraints

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Step 1: Basic Constraints *(feasability)*

Study of **3 phenomena**: Shocks, Reconnection,Turbulence,
Using a **cross-scale approach**.
Consider: cost issues, lauching capability, mass of instruments
-> **What is feasible ? What is desirable ?**
Conclusion of Marcel's presentation: ***seems possible…***

Step 2: Science Optimisation *(priorites - science traceability matrix)*

Analyze each **priority 5/4 questions** - Identify **key measurements**
Optimize payload and its **distribution over scales**. Propose **trade-off**

Conclusion

Very close to the definition of a mission that provide most of the key mesurements, within a single launch option.

Cost/launch and Orbits

- Cost -> Single Soyouz launch.
- Orbits -> determined by the studied phenomena - ***Shock, Reconnection…***

  Low inclinaison prefered, Apogee ~ **25 Re**, Perigee: **a few Re** (up to 10 Re)
- 'Confortable' payload -> '**medium' size S/C** (m ~ 100 kg)

*Doing **identical S/C** is an **important driver***

Possibilities (see Marcel Van den Berg presentation):

Orbit	Available mass (kg)	Electron scale		Ion scale		Fluid scale		Identical	
		S/C (#)	P/L (kg)	S/C (#)	P/L (kg)	S/C (#)	P/L (kg)	S/C (#)	P/L (kg)
10 Re × 25 Re × 14 °	~965	1	25	4	30	4	5	6	30
4 Re × 25 Re × 14 °	~1235	2	55	4	30	4	5	8	30
~1 Re × 25 Re × 14 °	~1420	4	30	4	30	4	5	9	30
10 Re × 25 Re × 90 °	~765	-	-	4	30	3	5	5	30
4 Re × 25 Re × 90 °	~950	1	30	4	25	4	5	6	30

Mass of instruments

B: Flux Gate, Boom	2.5 kg
Ion (no mass resolution), Electron:	1 kg (1 detector) 1.8 kg (pack of 2 sensors) 7.2 kg (4 packs, full resolution)
Ion (mass-resolved)	3 kg (<40 keV) 5 kg (up to 100 KeV)
High Energy (Electron, Ion)	<1 kg
E-field *(sounder is included)*	3 kg for 1D 5 kg for 2D spin 12 kg full 3D pack (not extended axial boom)
Search Coils	0.5 kg (2 kg if dedicated boom)

These are not 'comfortable' numbers !
-> Margin of 20 % will be considered

Boom issue: is 1 boom possible ?
(add 2 kg if 2 booms needed)

Possible Payloads

❑ **Fully equiped (3D E)**	**3+7.2+7.2+5+2+12**	**37 kg- > 44 kg (20% margin)**
without mas res.	**3+7.2+7.2+2+12**	**32 kg -> 39 kg**
~~**without mas res. and (2D E)**~~	~~**3+7.2+7.2+2+5**~~	~~**30 kg -> 36 kg**~~
❑ **High res. on e- or p+, (3D E)**	**3+7.2+2+2+12**	**27 kg-> 33 kg (20% margin)**
If (2D E)	**3+7.2+2+2+5**	**20 kg -> 24 kg**
❑ ~~**1/4 spin res. e- or p+, (3D E)**~~	~~**3+2+2+2+12**~~	~~**21 kg-> 25 kg (20%**~~ **margin)**
If (2D E)	**3+2+2+2+5**	**14 kg -> 17 kg**
❑ **Minimal (B, e, p)**	**3+1+1**	5kg -> 6 kg **(20% margin)**

A payload of 55 kg is large, but not exagerated if new measurements or very precise and difficult measurements are nedeed.

- **Extended axial boom to get 3D static field, Precise composition instruments**
- **3D energetic distribution functions (cf SCOPE)**

A payload of 30 kg is short if full res. (e- and p+) or 3D E: 35 kg would be better

Constellations

- **Studying 1 scale ->** minimum of **2 points** at the **considered scale**
- **Quantifying 'gradients'** (div., curl.) **-> 4 SC** at the **considered scale**
- **Cross scale analysis ->** Minimum of **3n +1 S/C for n scales**.

If 3 scales are desired -> 3 possibilities are eliminated.
We have no 3 scales/3D possibilities

Orbit	mass (kg)	Electron		Ion		Fluid		Identical	
		S/C (#)	P/L (kg)	S/C (#)	P/L (kg)	S/C (#)	P/L (kg)	S/C (#)	P/L (kg)
10 Re × 25 Re × 14 °	~965	1	25	4	30	4	5	6	30
4 Re × 25 Re × 14 °	~1235	2	55	4	30	4	5	8	30
~1 Re × 25 Re × 14 °	~1420	4	30	4	30	4	5	9	30
10 Re × 25 Re × 90 °	~765	-	-	4	30	3	5	5	30
4 Re × 25 Re × 90 °	~950	1	30	4	25	4	5	6	30

Conclusions

- Nevertheless, possibilities exist and seem attractive:

4x25 RE:	e: 2x55 kg	i: 4x30 kg	f: 4x5 kg	*(250 kg)*
1x25 RE:	e: 4x30 kg	i: 4x30 kg	f: 4x5 kg	*(280 kg)*

Note: 4x25 RE: e: 2x55 kg i: 4x30 kg is nice for inter- agency collaborations
but miss the 3D e,p scales analysis.

However, the full 'space' of possibilities is not explored.

For example: e: 1x55 kg + 3x25 kg i: 3x25 kg f: 3x5 kg *(230 kg)*

The science optimization is needed…

Science Optimisation - Reconnection (1)

1.1.1 What triggers reconnection within a current sheet ?
What is the role of external driving in reconnection onset ?

Problematic: Nature of the local plasma instabilities that trigger magnetic energy dissipation.
Interplay between turbulence and particle dynamics.
Role of current instabilities, how is current diverted, at the different scales.
How are the local processes related to the general structure of current sheet ?

Critical measurements: *(1) Identification of reconnection events*
(2) analysis of wave/turbulence at ion and electron scales
(3) electron and ions dynamics at ion and electron scales
(4) Relation with the macroscopic characteristics of the sheet.

1) 3D E field at electron scale.	***4x3D (2x3D + 2x2D) E at ~ 10 km***
2) 3D Electron distribution at electron scale.	***4x e- at ~10 km (100 hz)***
3) Multi-scale determination of the current	***4xB few 10 –100 -1000 km (in 3D)***
4) Current-sheet characterization	***4 x ions at ~ 1000 km***
5) E.M turbulence at the ion scale	***4x2D E at ~ 1000 km (1x3D ?)***
6) Boundary conditions (macroscopic scale)	***3D fluid parameters (Plasma+B) at f scales***

Science Optimisation - Reconnection (2)

1.3.1 How does the magnetic topology change during the reconnection ?

Problematic: Problem of 'de-freezing' of the magnetic field .
Origin and role of the parallel E field
Characterisation of plasma transport across null points.
Formation of 2D/3D structures ? Regularly or in a patchy way ?

Critical measurements: *1) Measurements of the parallel E field at different scales*
2) identification of 'opening/closing' sequences of B (e measurements)
3) 3D consequences on the magnetic topology, at proton and fluid scales.

1) 3D E field at the electron diffusion scale.	***4x3D E (2x3D + 2x2D) at (10 km)***
2) 3D E field at ion scale.	***2x3D E at (100-1000 km)***
3) 3D Electron/Ions distributions at ion scale	***4x3D e-,p+ at (100-1000 km)***
4) e-,p+ determinations of the current	***4xB at 2 scales 10- 1000 km***
5) Current-sheet characterization	***4 x fluid parameters at 1000 km***

Science Optimisation - Reconnection (3)

1.3.2 How are the ions and the electrons energized as a consequence of reconnection?

Problematic: Acceleration/heating due to conversions of magnetic energy.
Identification of processes leading to: heating of particle populations, formation of energetic tails, jets.
Specific ion dynamics near X point
Turbulence, formation of localized structures (double layers etc…)

Critical measurements: *1) Measurements of 3D E field at different scales*
2) measurements of thermal/energetic electron and ion population at the electron and the ion scales

1) 3D E field at the electron diffusion scale.	***4x3D E (2x3D+2x2D) at (10 km)***
2) 3D E field at I-scale.	***2x3D E at (100-1000 km)***
3) 3D electron distribution at e-scale (10 km).	***4x3D e- at (10 km)***
4) 3D ion distribution at p-scale (100-1000 km).	***4x3D p+ at (100-1000 km)***
5) Energetic particle at p-scale, fluid scale	***4xe- + 4xp+ at 100 -1000 km***

Science Optimisation - Shocks (1)

2.1.1 How are ions reflected and accelerated by the structured shock electric field ?

Problematic**:** Interplay between very fine scale electric field structures and electrons/ion dynamics.

Critical measurements: *1) Turbulence on the front, at electron and ions scale*
2) Characterization of ion dynamic, included high energy

1) 3D E field at the e- scale.	***4x3D (2x3D+2x2D) E at (10 km)***
2) Electron+Ion distributions (2 scales)	***4x3D e-,p+ at 10->1000 km***
3) Energetic electrons, ions	***4xenerg. electrons at >1000 km***
4) Shock characterization	***4 x fluid (Plasma+B) at 1000 km***

2.1.2 How are electron dynamics and electric field fine structure affected by shock reformation and ion dynamics ?

Problematic: 1) Nature of the electron motion (magnetized/unmagnetized) ?
2) Is the electron dynamics dominated by steady field or turbulence ?
3) How is it related to the ion dynamics ?

Critical measurements: *as above + Complete characterization of electron dynamics, included high energy*

As above

Science - Shocks (2)

2.1.3 How do ions thermalize ?

Problematic: Coupling between the ion motion and the macroscale turbulence.

Critical measurements: as above

2.2.1 How do ions generate and scatter from waves in the foreshock ?

Problematic: Wave/ions resonant interactions
Instabilities and non-linear dynamics. Surfing on waves

Critical measurements: *as above*

Science – Turbulence (1)

3.1.1 What is the nature and direction of the energy cascade in homogeneous turbulent collision free plasmas ?

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Problematic: for example: Case of the magnetosheath:
What are the non-linear interaction between mirror modes, ion-cyclotron and whistler modes ? What is the corresponding energy cascade ?
Critical measurements: *Identification of modes at 3 different scales. Basically by k-filtering*

1) E/B field at the electron scale (3D) ***4x2D E/3D B at (10-50 km)***
2) E/B field at the ion scale (3D). ***4x2D E/3D B e- at (100-500 km)***
3) E/B field at the fluid scale (3D). ***4x2D E/3D B e- at (1000-5000 km)***

3.1.2 What is the relation between large and small scales in the case of inhomogeneous plasma ? Is there a particular energy cascade at magnetospheric boundaries ?

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Problematic: Identification of 'structures' (concentration of magnetic helicity)
Coupling between adjacent structures, possible pairing or merging.
Consequences in terms of energy cascade and dissipation at the small scales.
Critical measurements: *Identification of 3D structures. Investigation of their evolution and of their coupling.*

As above + particle measurements at the different scales…

Science – Turbulence (2)

3.1.2 What is the role of turbulence at triggering explosive phenomena, such as the magnetic reconnection?

Problematic: Question related to 'what does trigger the reconnection ?'

Critical measurements: *-*

1) Identification of reconnection events (dissipation of the magnetic energy and increase of plasma energy)

2) Identification of structures and/or waves at the relevant scales.

1) 3D E field at the electron diffusion scale.	***2x3D E at (10 km)***
2) 3D Electron distribution at c/ωpe (10 km)	***4x3D e- at (10 km)***
3) 3D ions distribution at larmor radius (1000 km)	***4x3D p+ at (1000 km)***
4) Small-scale determination of the current	***4xB at (100 km)***
5) E/B field at the electron scale (3D)	*4x2D E/3D B at (10-50 km)*
6) E/B field at the ion scale (3D).	*4x2D E/3D B at (1000 km)*
7) E/B field at the fluid scale (3D).	*4x2D E/3D B at (5000 km)*

Summary (Core group)

(black: turbulence, purple:shocks, blue: reconnexion)

Instrument	Electron scale	P	N	Proton scale	P	N	Fluid scale	P	N
B	dc-100Hz dc-50 Hz dc-1000Hz	5 5 5	4 4 4	dc-100Hz dc-50 Hz dc-1000 Hz	5 5 5	4 4 4	dc-50 Hz dc-50 Hz dc- 100 Hz	5 5 5	4 4 4
Ions No mass	Mom. 100 Hz 3D f(v) 10Hz	5 5	1 1	Mom. 100 Hz 3D f(v) 10Hz 30 keV 10 Hz	5 5 5	4 4 4	Moments spin 3D f(v) 0.5Hz 0.5Hz	5 5 5	4 4 4
Ions Mass-resolved ,	0.5Hz 10Hz 0.5 Hz	5 5 5	1 1 1	Spin 10Hz	5 4	1 2	Spin period 0.5Hz 0.5Hz	5 5	1 2
Electrons (<40 keV)	Mom.100Hz 3D 100 Hz 3D 100 Hz	5 5 5	4 4 4	Mom. 100Hz 3D 100 Hz 3D 100 Hz	5 5 5	4 1 2	Mom.:0.5Hz 3D f(v) 0.5 Hz 0.5 Hz	5 5 5	4 2 2
Energetic Ions	spin 3D f(v) 0.5Hz 3D f(v) 0.5Hz	5 5 3	1 1 1	spin 3D f(v) 0.5Hz 3D f(v) 0.5Hz	5 5 5	4 2 1	spin 3D f(v) 0.5Hz 3D f(v) 0.5Hz	5 5 5	4 2 4
Energetic Electrons	0.5 Hz 0.5Hz 0.5Hz	5 5 3	1 2 1	0.5 Hz 3D f(v) 0.5Hz 3D f(v) 0.5Hz	5 5 5	1 1 4	Spin 0.5Hz 0.5Hz	3 5 5	4 1 4
E-field 3D E-field 3D E-field	4x3D 1x3D 4x3D	5 5 5	4 1 4	4x2D 2x2D 2x2D+2x3D	5 4 5	4 2 4	4x2D 2x2D 4x2D	5 5 5	4 2 4

Conclusions

Consider again:

4x25 RE:	**e: 2x55 kg**	**i: 4x30 kg**	**f: 4x5 kg**	***(250 kg)***
1x25 RE:	**e: 4x30 kg**	**i: 4x30 kg**	**f: 4x5 kg**	***(280 kg)***

And compare with priority table: We are 'short' on the fluid scale (E field and energetic particles miss). We need one additional S/C on e-/p+ scales

An example, with 2 types of S/C: 1 heavy, 9 with 4 slots (Themis Class)

e: 2x3DE, 4xfull res e-, 1 x p+, 1 x energetic particles :
1x55 kg ***(complete)*** **+ 1x28 kg** ***(3+8+12: B+e- (full)+3DE)*** **+ 2x 20kg** ***(3+8+5: B+e-(full)+2DE)***

i: 1x3DE, 1s res. p+, e-, energetic particles :
1x18 kg ***(3+2+2+2+5) (B+e-+p+ (1s)+energetic +2DE)***
1x25 kg ***(3+2+2+2+ 12) (B+e-+p+ (1s)+energetic +3DE)***
1x20 kg ***(3+1+3+2+2+5) (B+e-+p+ (1s)+energetic +2DE+composition)***

fluid: 3x13 kg ***(3+1+1+1+1+5) (B+e-+p+ (spin)+energetic +2DE)***

Total: ***225 kg – 20% payload -> 1125 kg total…***

Conclusions