THOR – ESA M4 candidate mission

To explore turbulent energy dissipation and particle energization in space plasma

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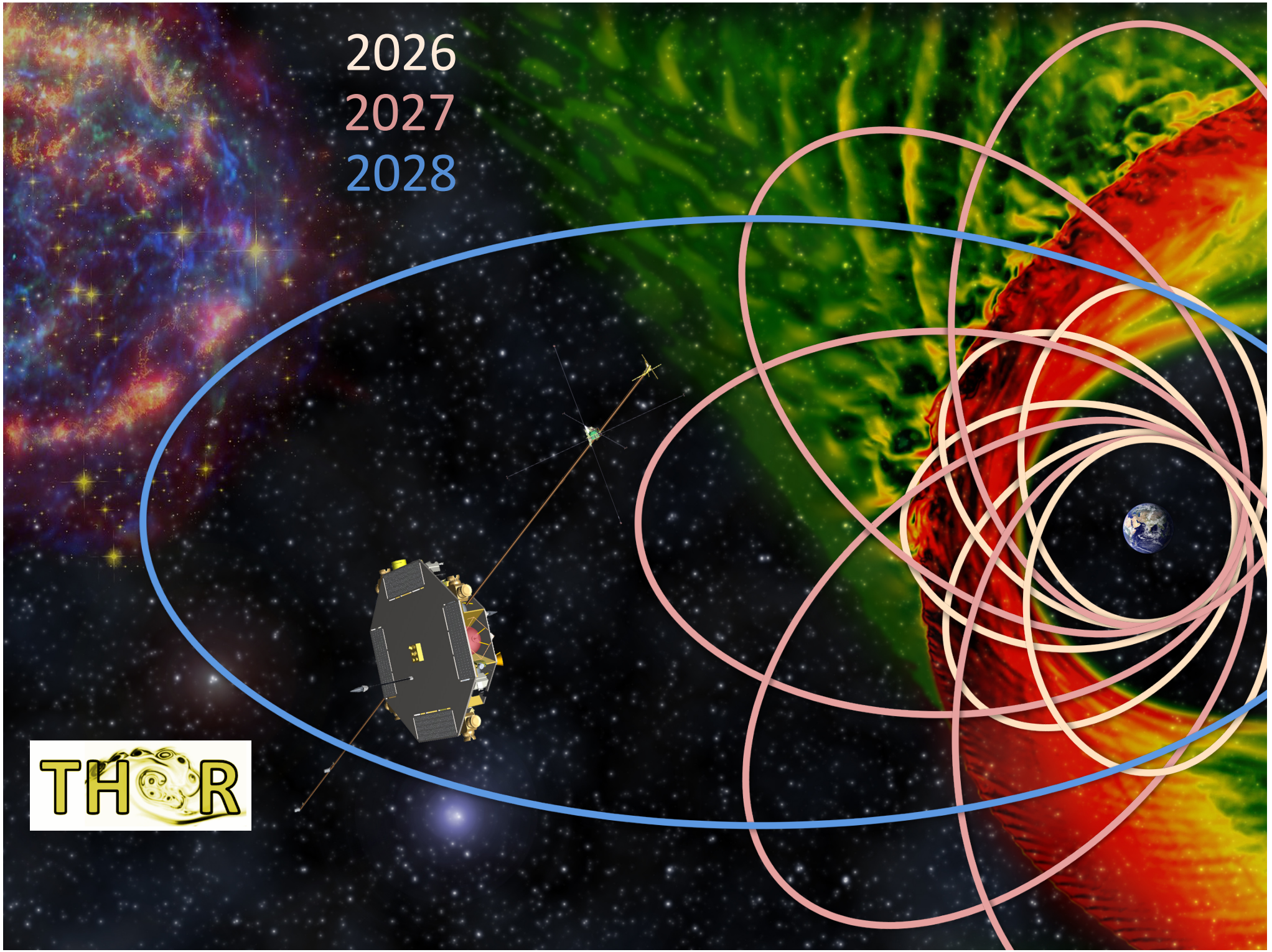
THOR team

http://thor.irfu.se/thor-team

Vlasovia 2016

THORsday


2026
2027
2028
THOR

Science

Exploring plasma energization in space turbulence

- ✓ How is plasma heated and particles accelerated?
  - *Coherent structures & wave identification*
  - *Their effects on plasma*
- ✓ How is the dissipated energy partitioned?
  - *Electrons vs protons vs heavier ions*
  - *Heating vs. particle acceleration*
- ✓ How does dissipation operate in different regimes of turbulence?
  - *Pristine solar wind*
  - *Flow interaction regions*
  - *Shocks and sheath regions behind shocks*

THOR - first dedicated mission!

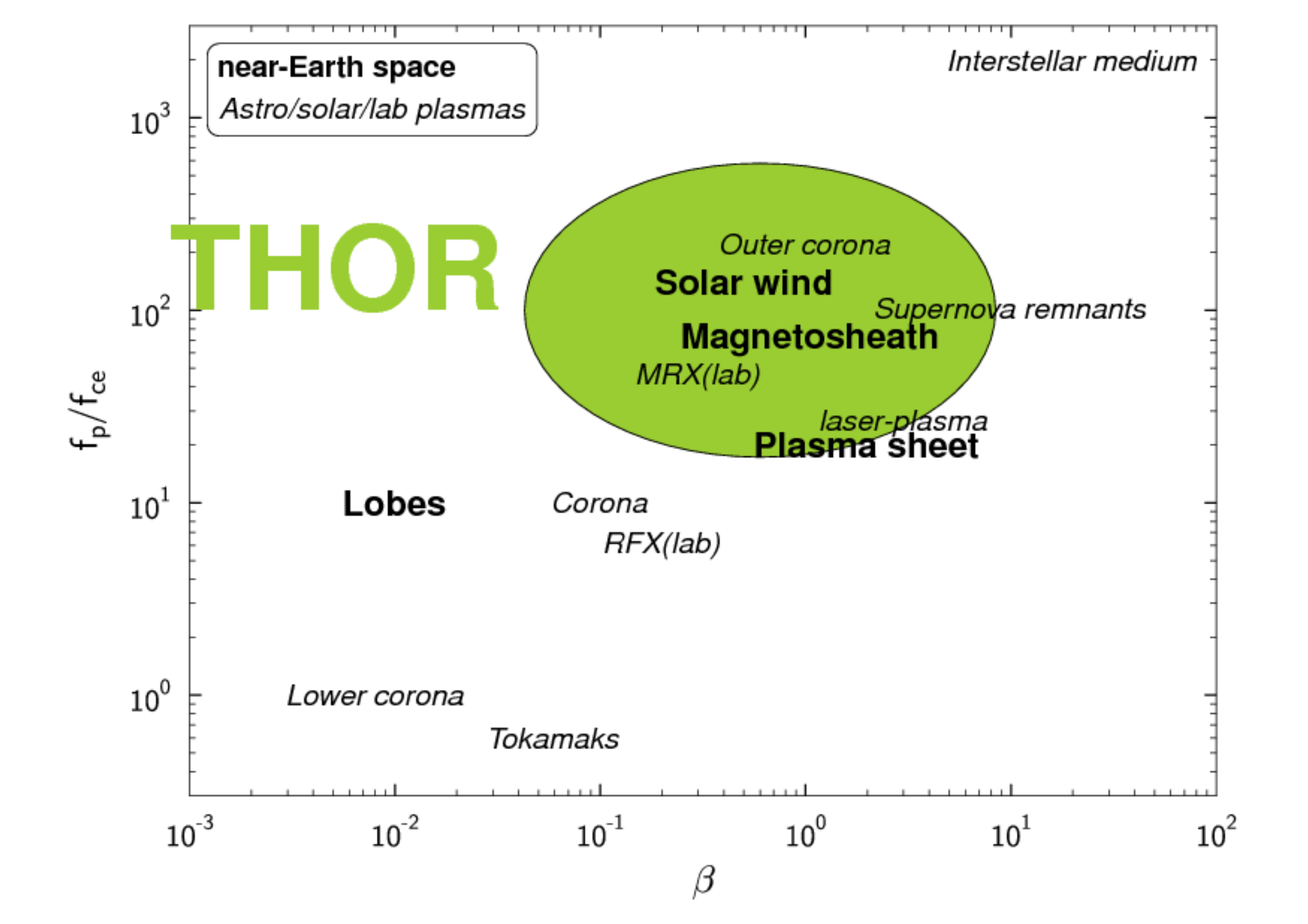
THOR team

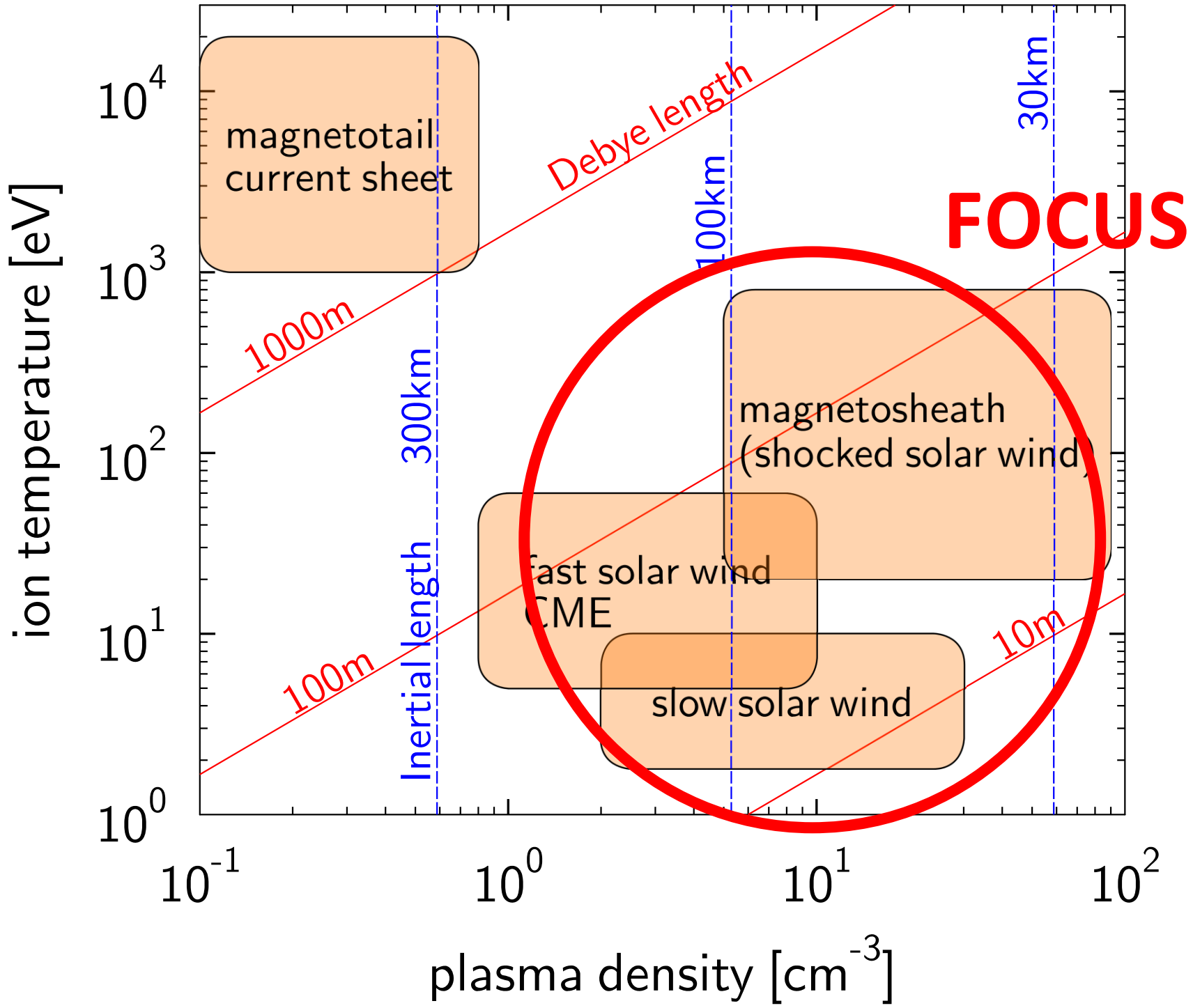
- ✓ Science team 230+ scientists supporting
  New members welcome!
- ✓ 10 instrument teams (50+ engineers)
- ✓ Industry: two competing studies
- ✓ THOR Science Study Team
  11 scientists + ~10 ESA

THOR timeline

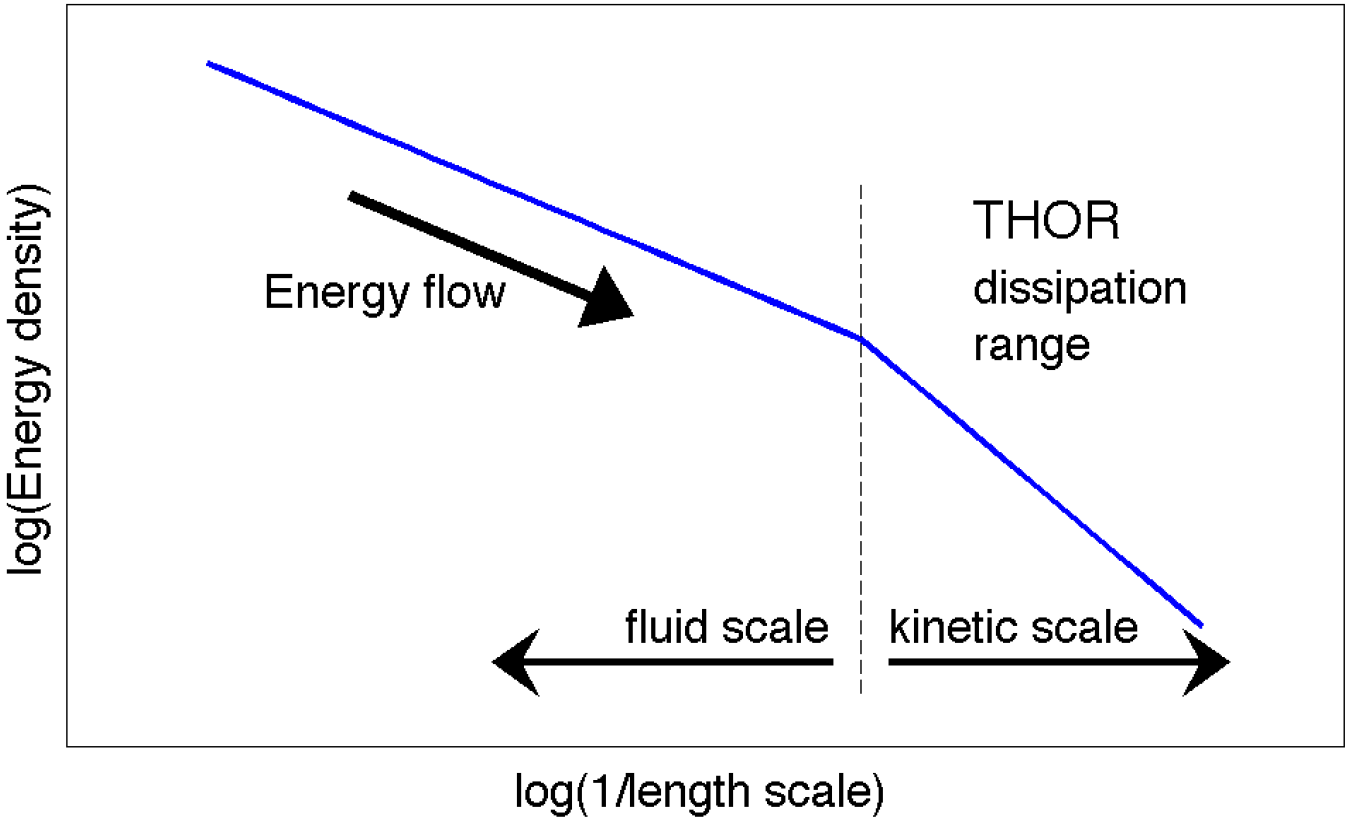
✓ 2010	~~EIDOSCOPE~~ ESA MoO (~100M€)
✓ 2012	~~Tor~~ SNSB (4M€)
✓ 2012	~~Tor~~ ESA S1 (40M€)
✓ 2015	THOR ESA M4 (450M€)
✓ 2015-06-04	THOR selected for study phase
✓ 2016-2017	1 year study phase
✓ 2016-07-27..29	THOR #2 workshop @Barcelona
✓ 2017 Jun	ESA final M4 down-selection
✓ *2026*	*Launch*

THOR is currently in study phase!
All inputs (science, mission, payload, support)
are important and welcome!


near-Earth space
Astro/solar/lab plasmas
Interstellar medium
THOR
Outer corona
Solar wind
Supernova remnants
Magnetosheath
MRX(lab)
laser-plasma
Plasma sheet
Lobes
Corona
RFX(lab)
Lower corona
Tokamaks
10^3
10^2
10^1
10^0
f_p/f_{ce}
10^{-3}
10^{-2}
10^{-1}
10^0
10^1
10^2
β


magnetotail
current sheet
Debye length
1000m
100m
10m
30km
100km
300km
Inertial length
FOCUS
magnetosheath
(shocked solar wind)
fast solar wind
CME
slow solar wind
ion temperature [eV]
plasma density [cm^{-3}]
10^0
10^1
10^2
10^3
10^4
10^{-1}
10^0
10^1
10^2

Kinetic scales

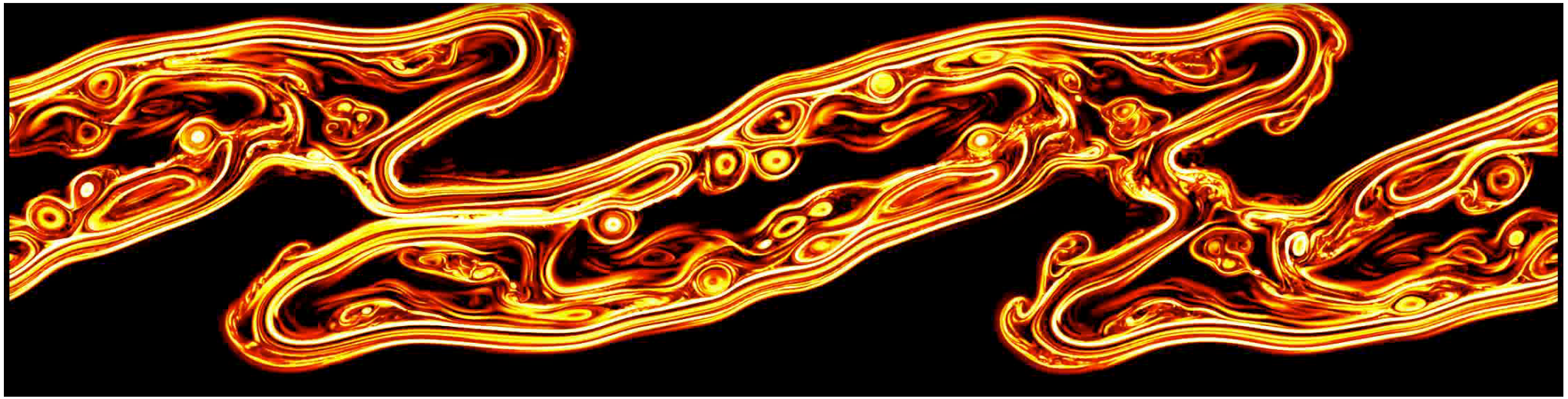


Required measurements!

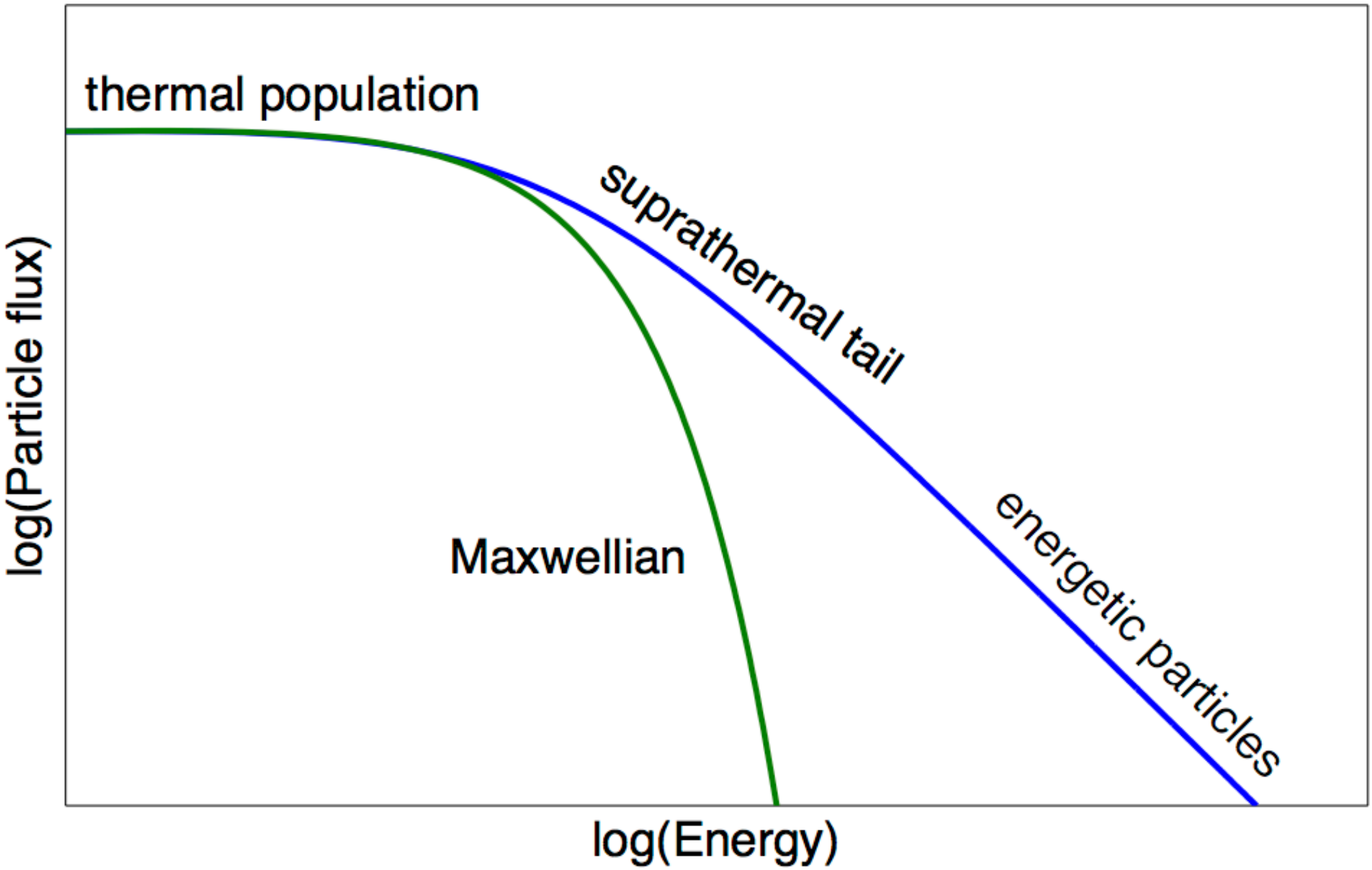
Fields:
E, **B**

Fluid:
n_i,$\mathbf{v}_i$,$\mathbf{T}_i$,…

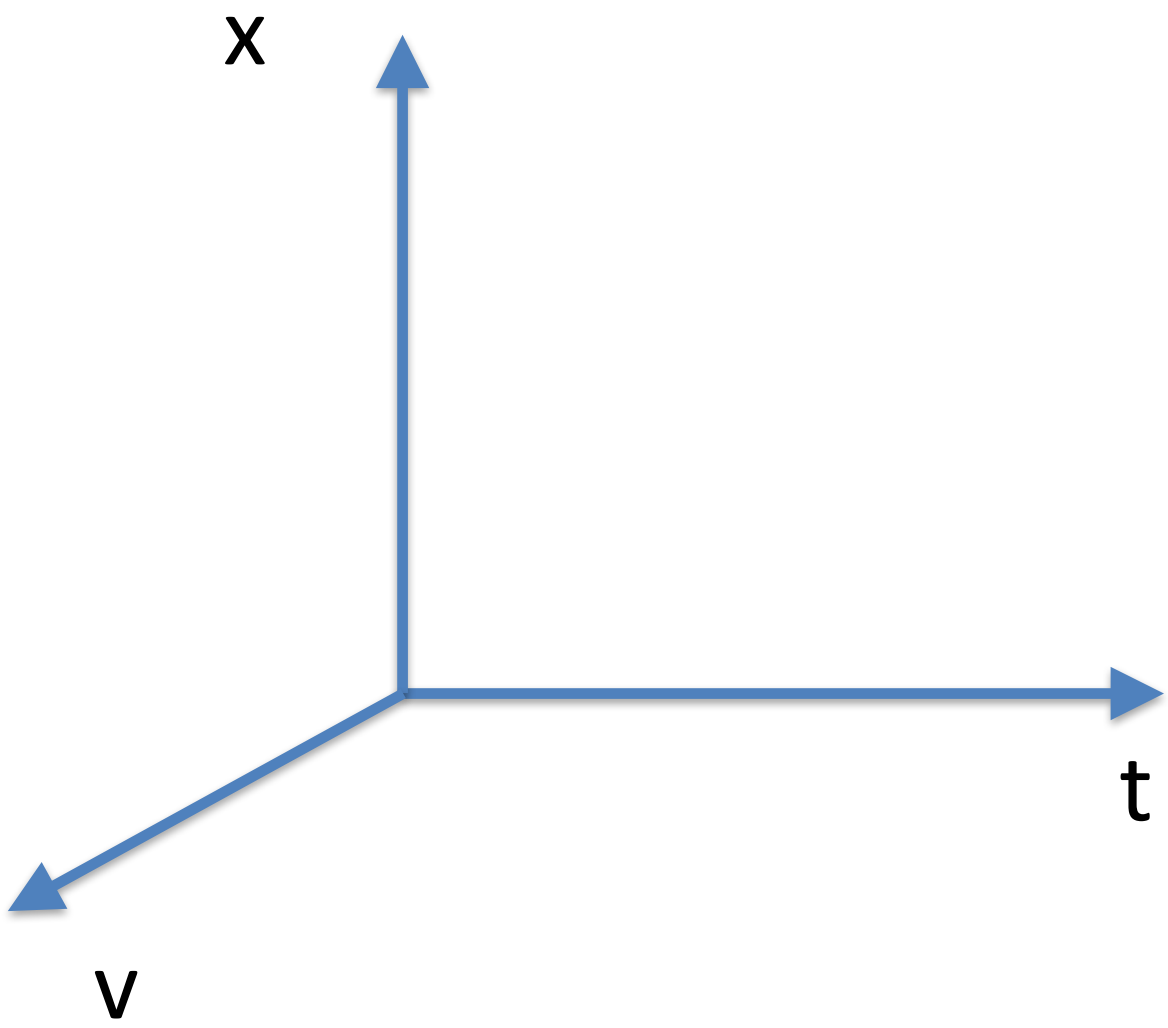
Kinetic:
$f_i(\mathbf{v})$
tails, beams,..



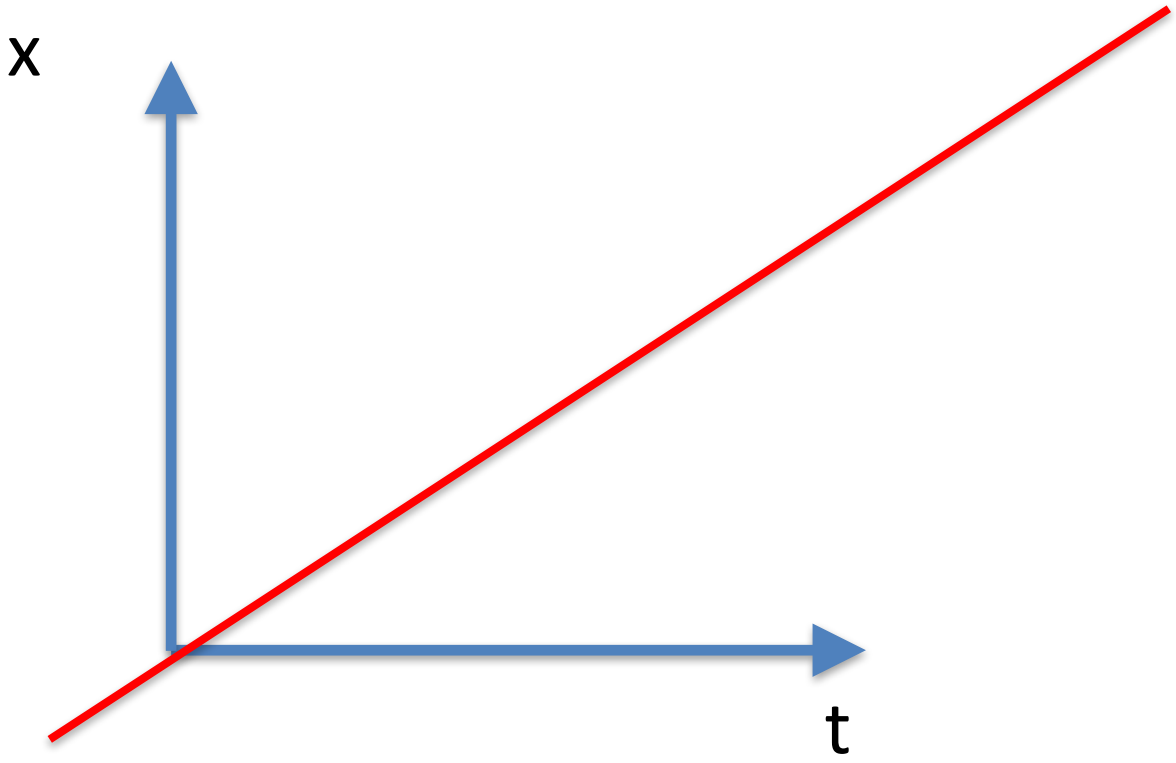
Particle energization



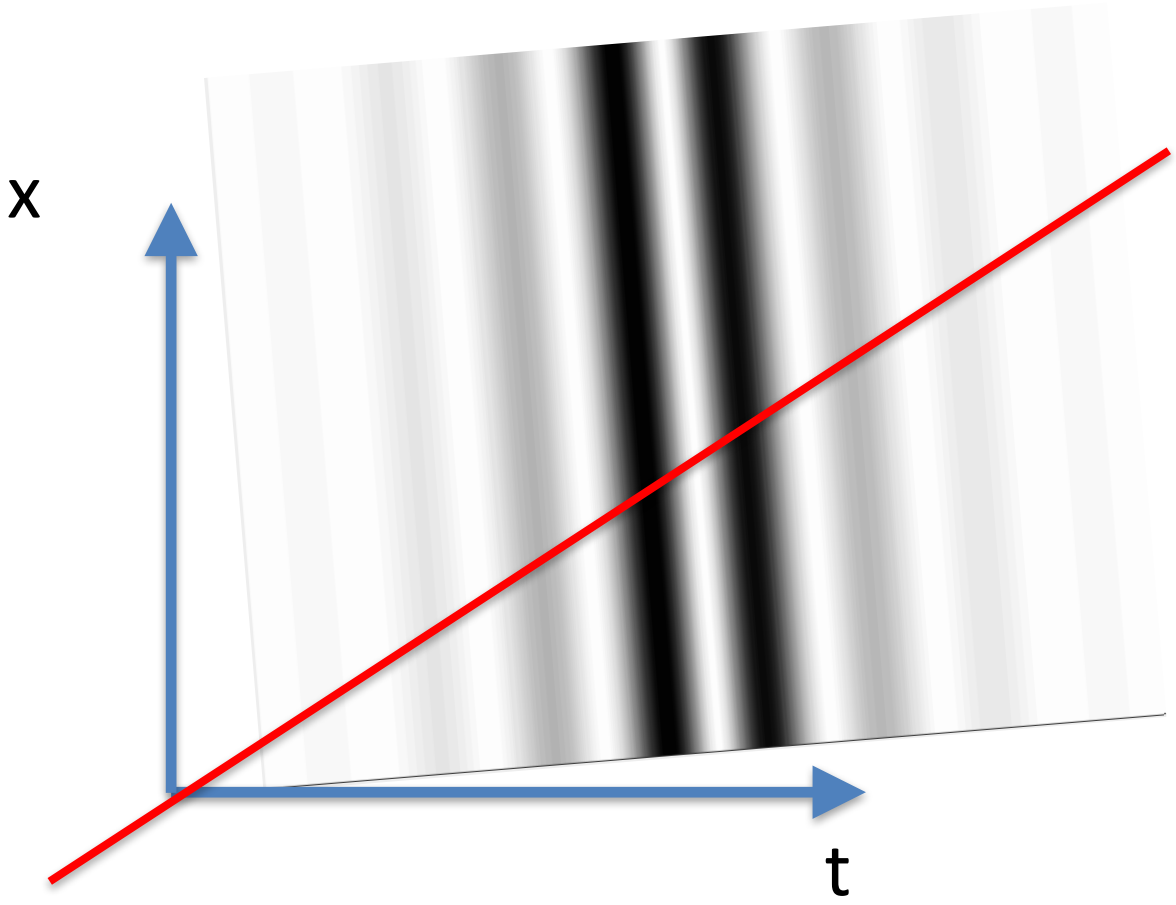
$f(\mathbf{r},\mathbf{v},t)$



$f(\mathbf{r},\mathbf{v},t)$



Plasma velocity >> s/c velocity

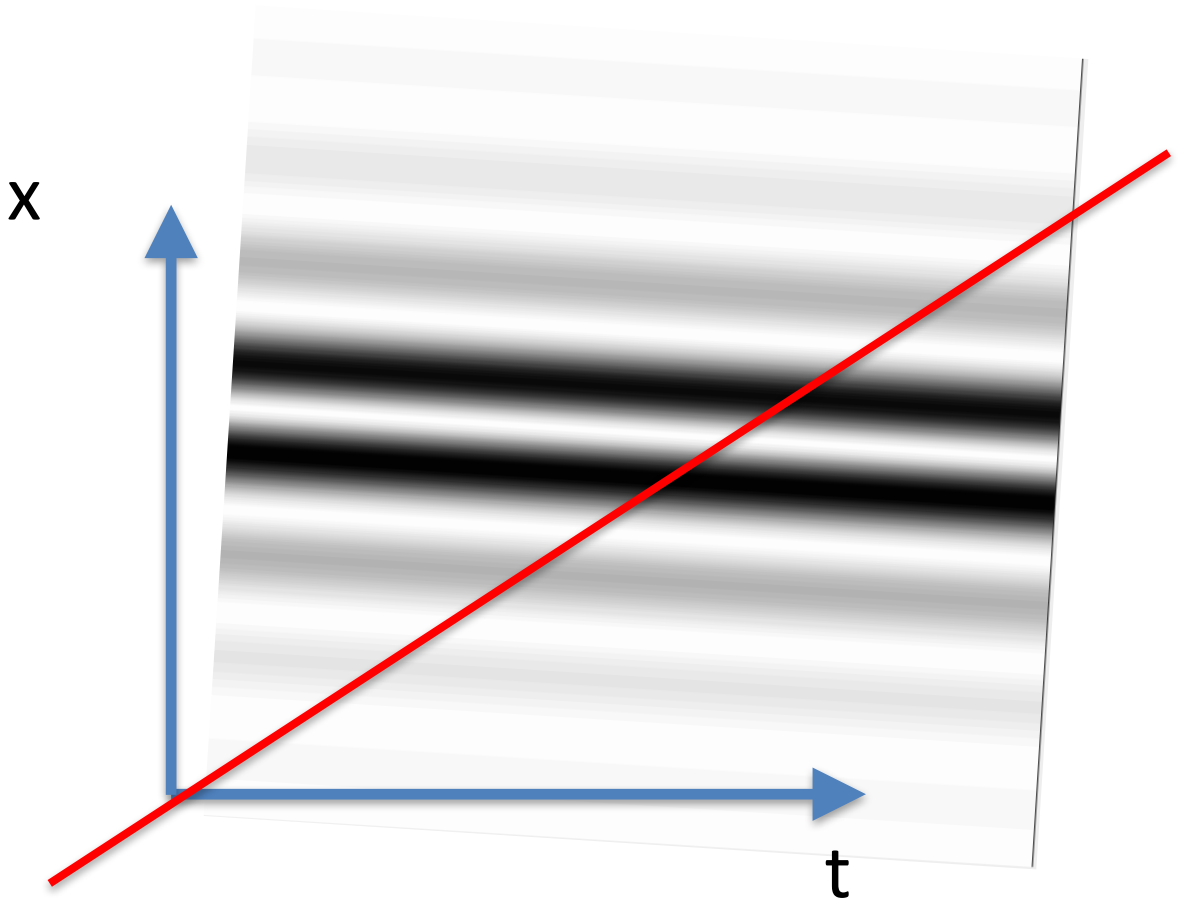


$f(\mathbf{r},\mathbf{v},t)$

spacecraft

Plasma velocity >> s/c velocity

REQUIRED: sufficient temporal resolution (ion/e- gyrofr.)



$f(\mathbf{r},\mathbf{v},t)$

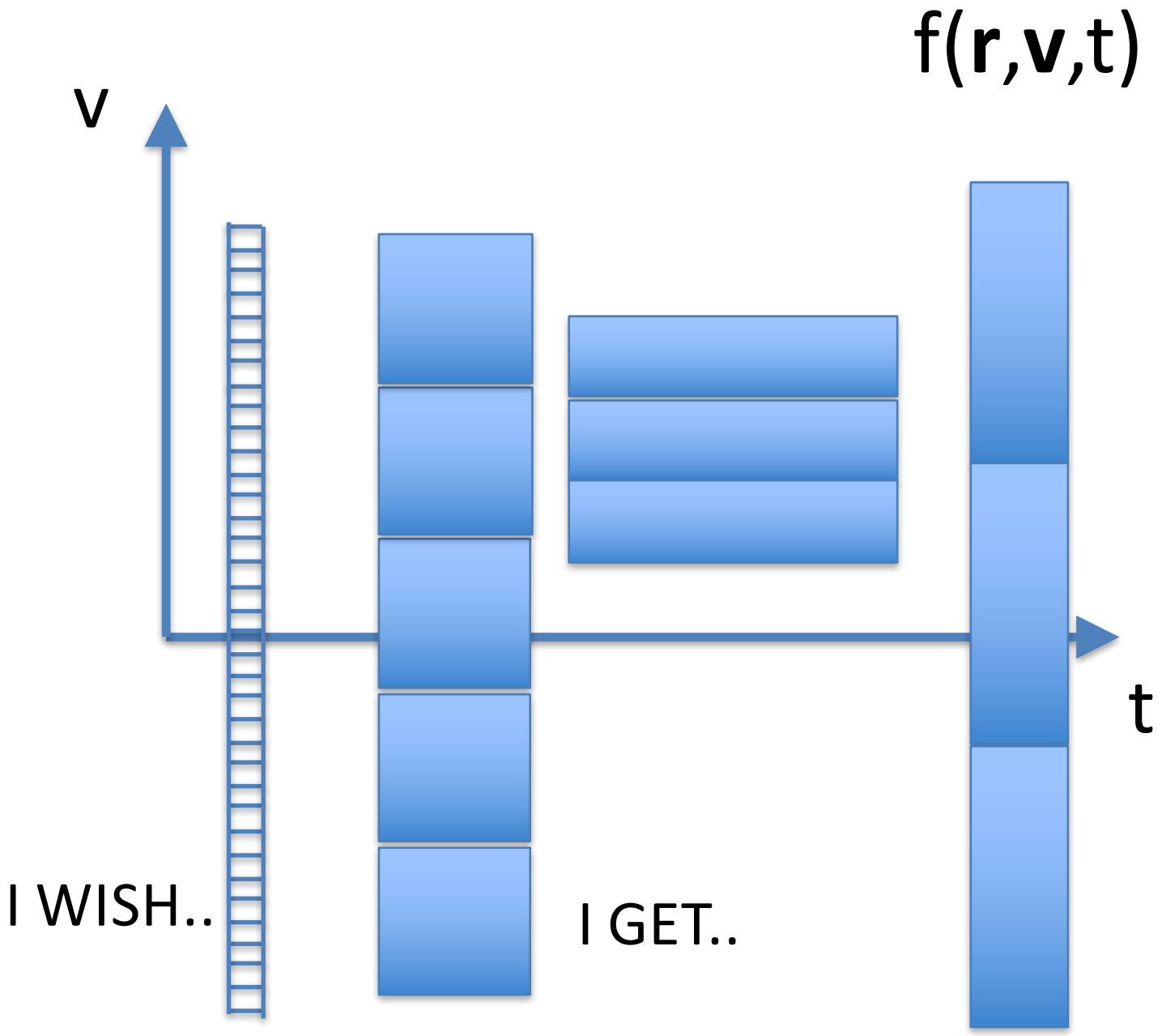
spacecraft

Plasma velocity >> s/c velocity

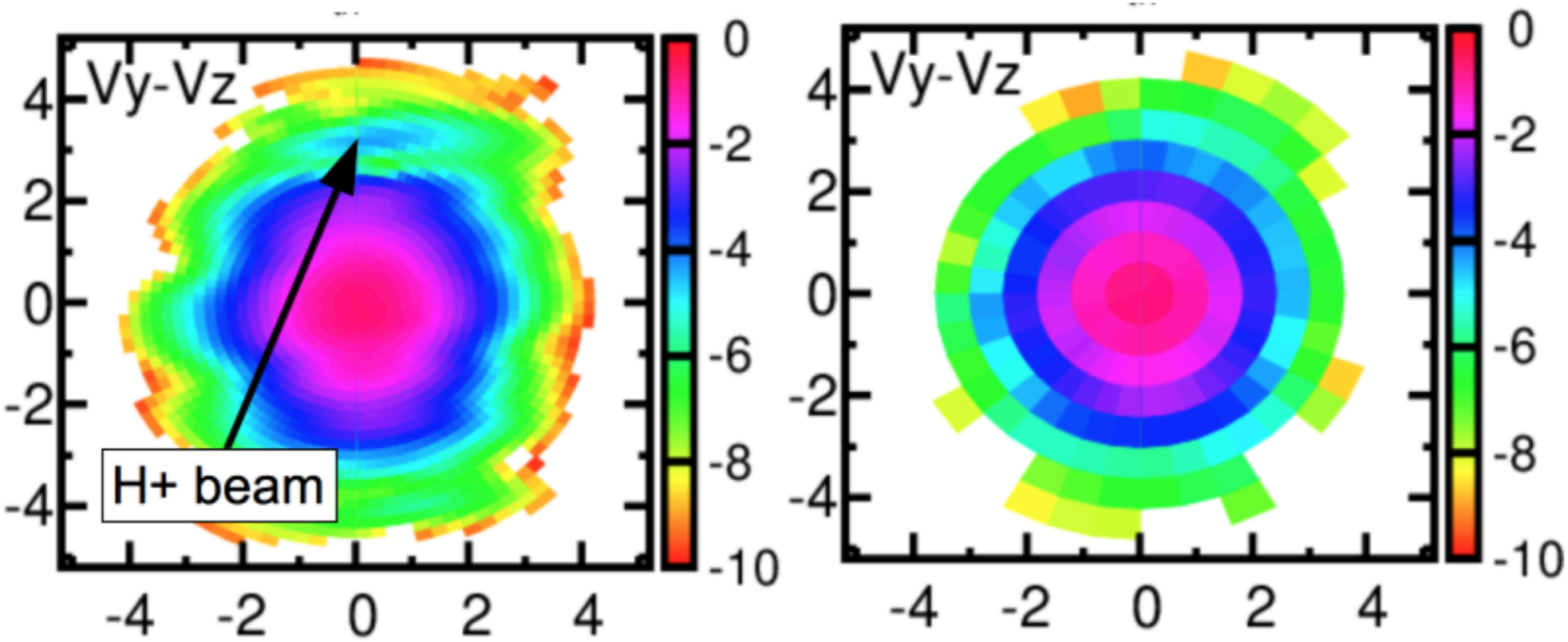
REQUIRED: sufficient temporal resolution (ion/e- gyrofr.)

REQUIRED: spatial resolution (ion/e- kinetic scales)

temporal resolution of Doppler shifted spatial scale


f(r,v,t)
v
t
I WISH..
I GET..

f(**r**,**v**,t)



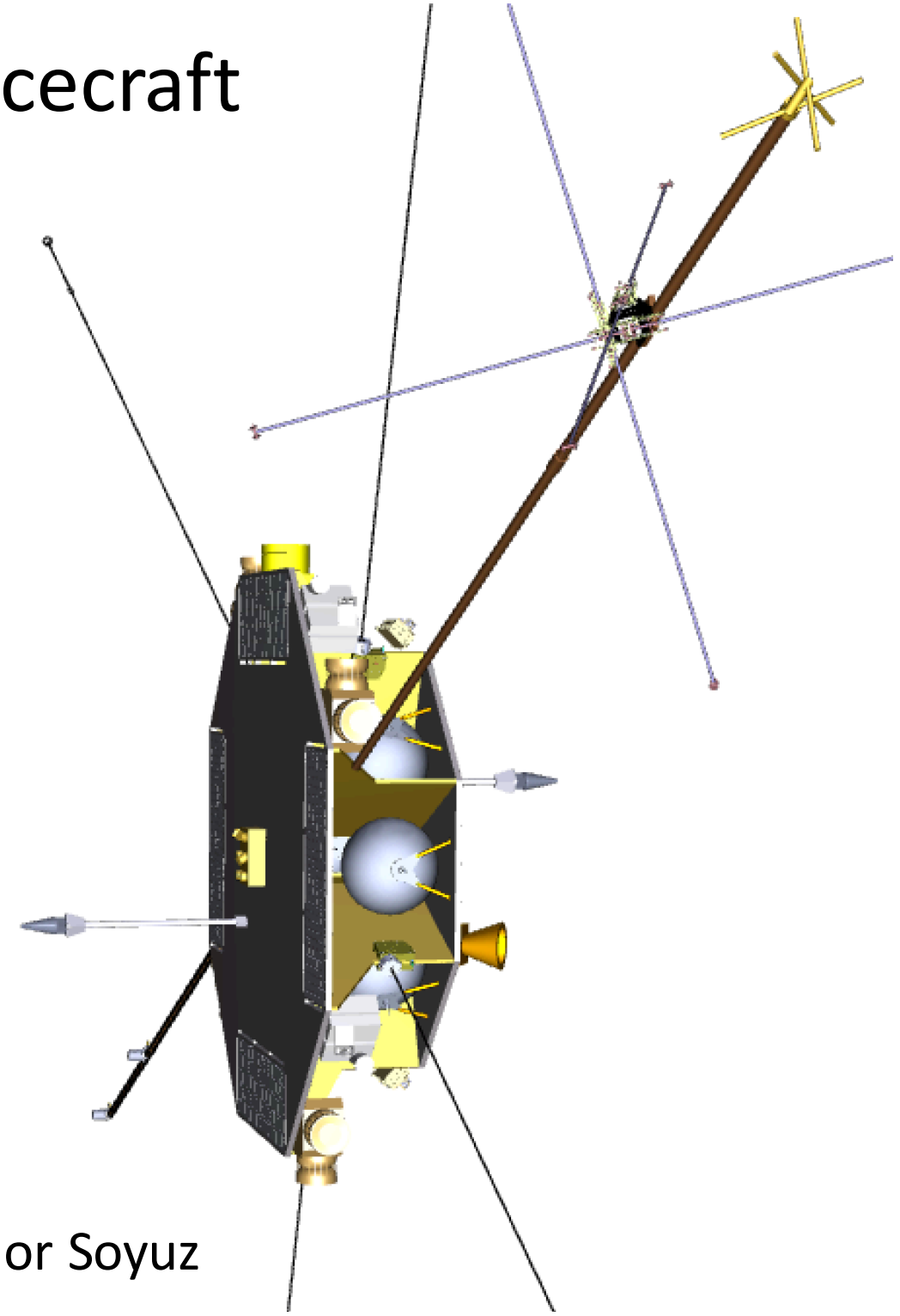
REQUIRED: sufficiently high resolution in velocity space

Thorbulence **H**eating **O**bserve**R**

Norse mythology: Thor is a hammer-wielding god associated with thunder and lightning, storms and strength, as well as the protection of mankind. Thor brings **order out of chaos**.

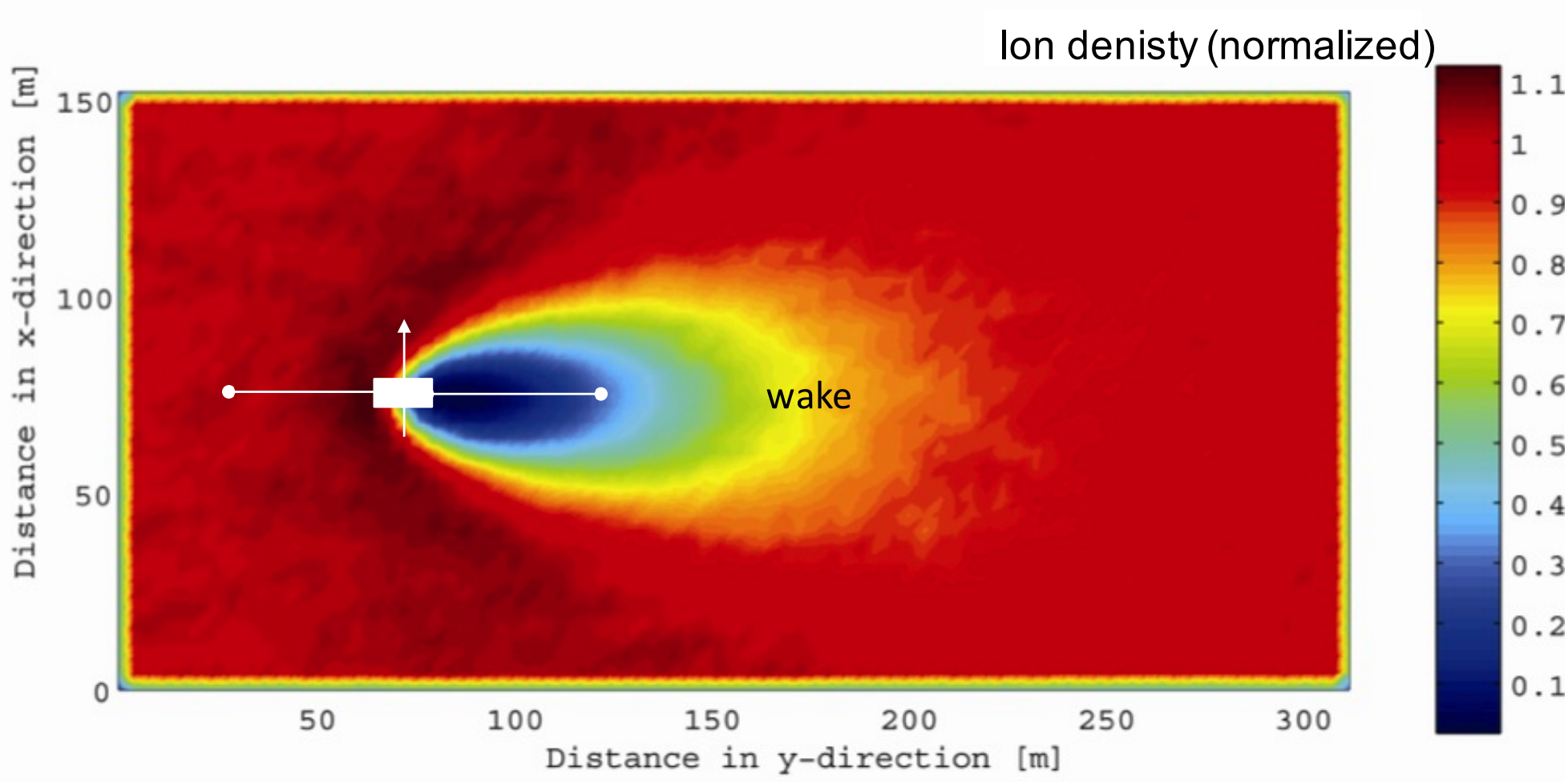
Spacecraft

- ✓Payload 160+kg
- ✓Wet mass 900+kg
- ✓Sun-pointer
- ✓Slow spinner (2 rpm)
- ✓Long (>6m) booms for magnetometers
- ✓Active potential control
- ✓10+ Tbit data storage
- ✓~10GB/day downlinked



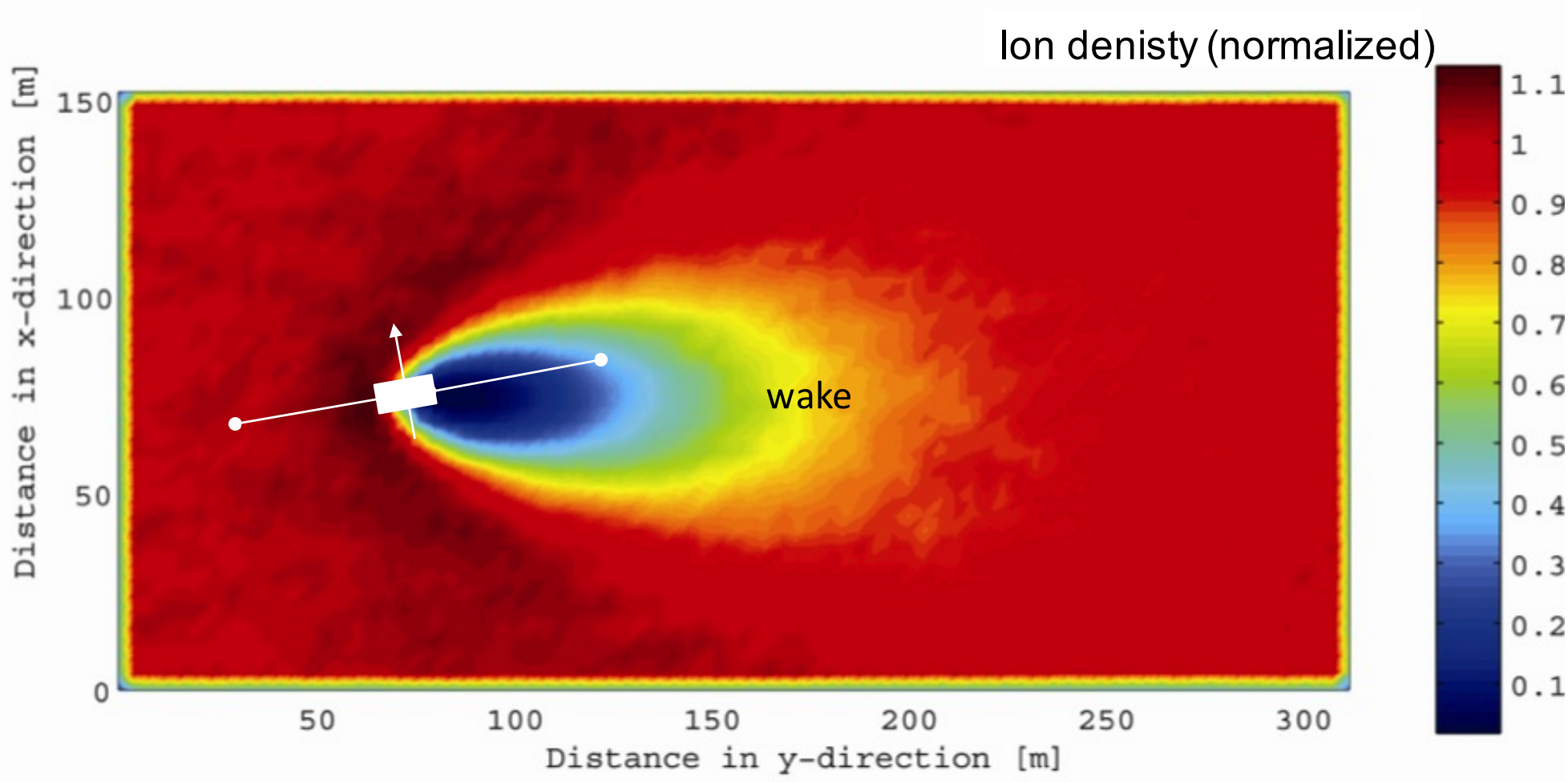
Launcher: Ariane-6 or Soyuz

Electric field measurement



Spin plane close to ecliptic

Electric field measurement



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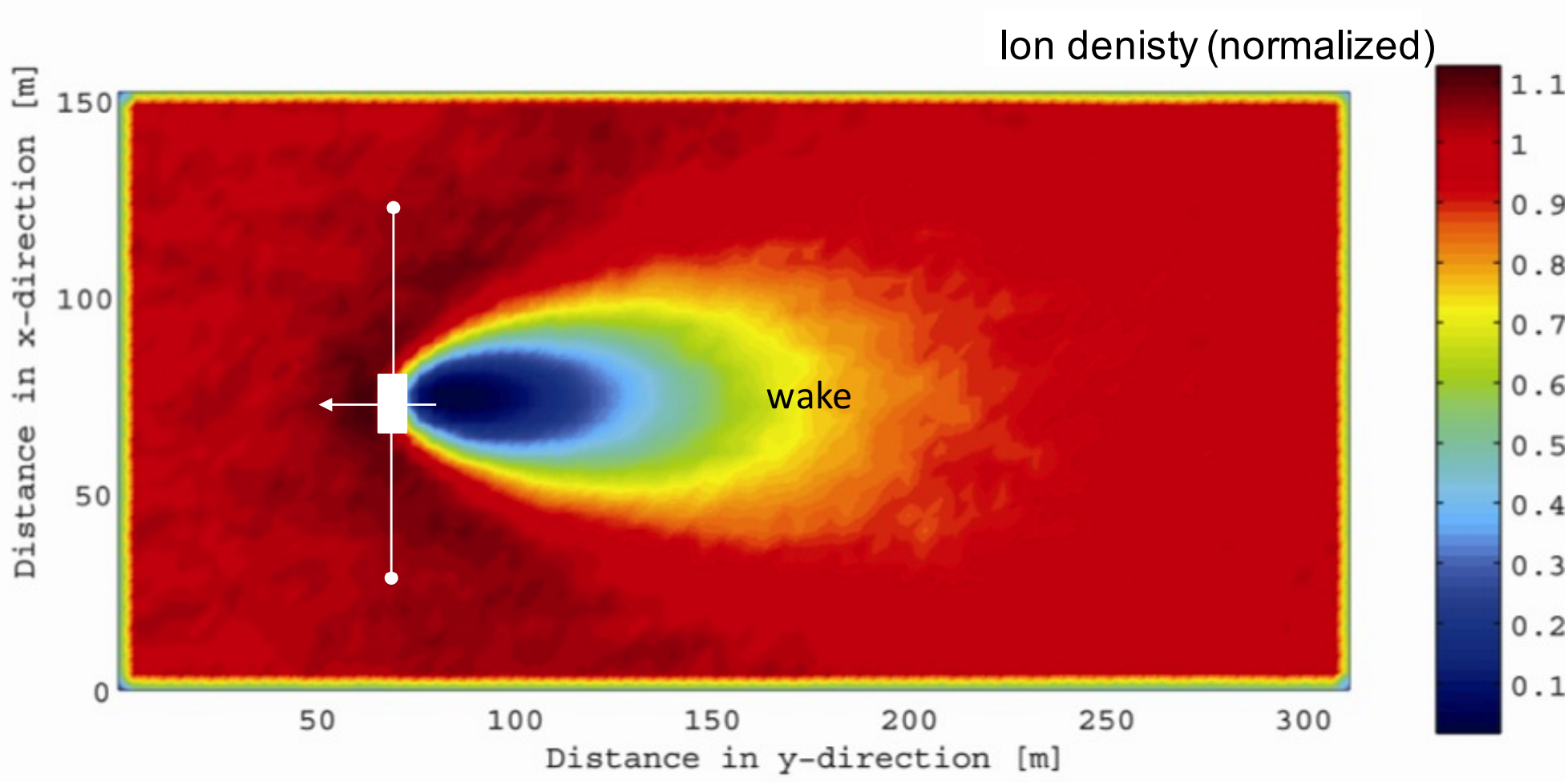
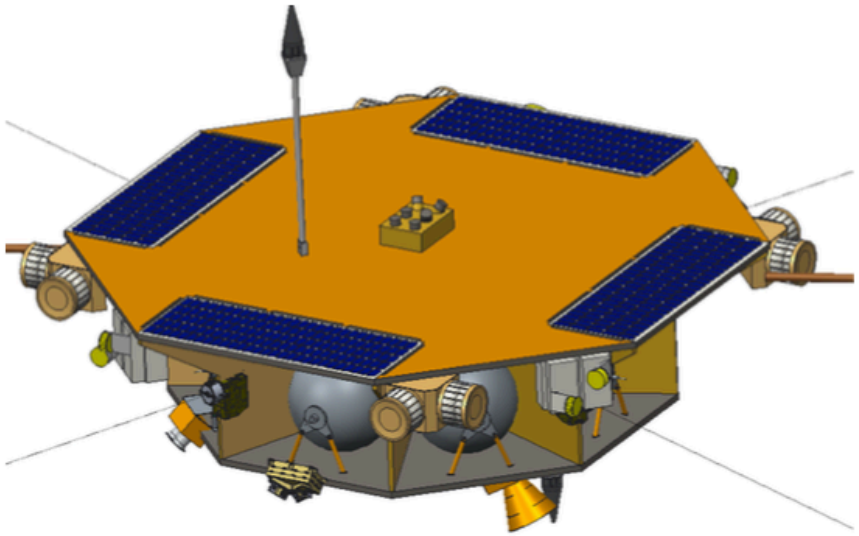
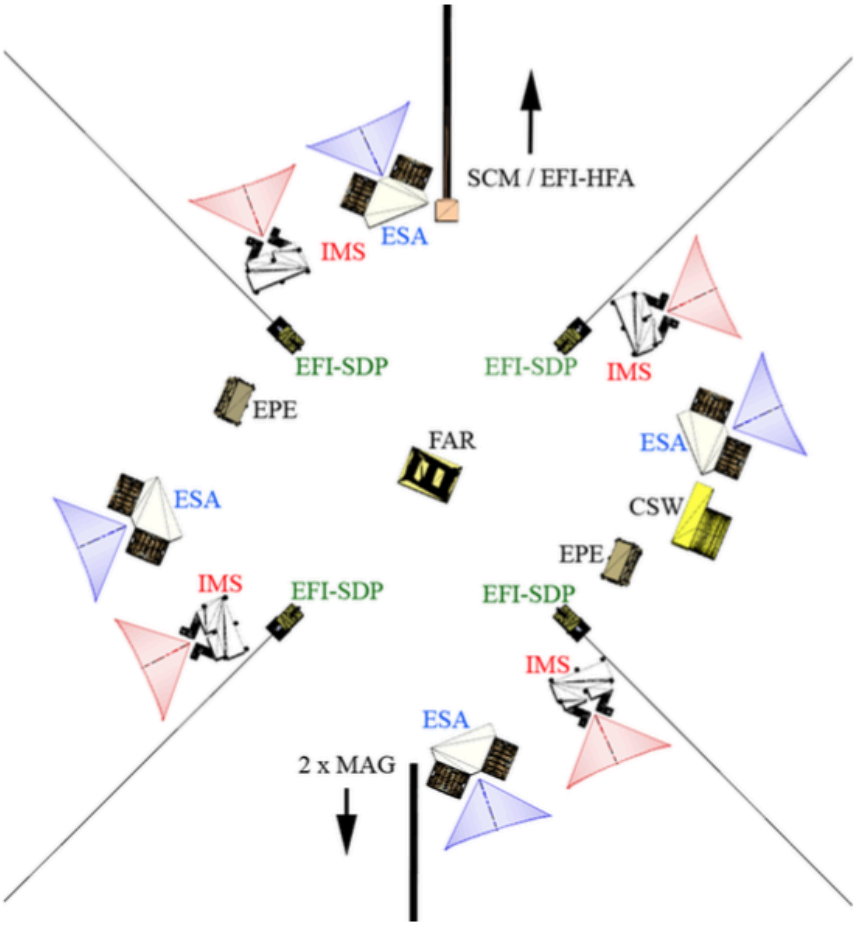


Sunward spin-axis significantly increases the accuracy of the **E** field and satellite potential mesurement.

Payload





Full 3D distribution function measurement of electrons and mass resolved ions independent of spin!

Payload

	Instrument	Measurement	Teams (PI, Co-PI, *Lead-CoI*)
FIELDS	**MAG**	B field DC	IWF(AU), ICL(UK)
	SCM	B field AC	LPP(FR), LPC2E(FR)
	EFI	E field DC/AC	IRF(SE), SSL(US), *SRC-PAS(PL), KTH(SE)*
	FWP	E&B data products	IAP(CZ), SRC-PAS(PL), *U.Sheffield(UK), LESIA(FR)*
PARTICLES	**ESA**	e^- spectrometer	MSSL(UK), NASA/GSFC(US)
	CSW	Cold solar wind ions	IRAP(FR), BIRA-ISAB(BE)
	IMS	H^+, He^{++}, He^+ ,O^+	LPP(FR), UNH(USA), *ISA/JAXA(JP), MPS(DE)*
	PPU	Particle data products	INAF-IAPS(IT)
	FAR	Faraday cup	MFF(CZ)
	EPE	Energetic particles	IEAP(DE), U.Turku(FI)

Single s/c with highest resolution field and particle measurements ever, to satisfy the THOR science requirements!

Payload

Key improvements in comparison to earlier/upcoming missions:

- ✓ accuracy/sensitivity/resolution of **E** and **B** field measurements,
- ✓ temporal resolution of mass resolved ions (H+, He++),
- ✓ temporal/angular/energy resolution of electrons.

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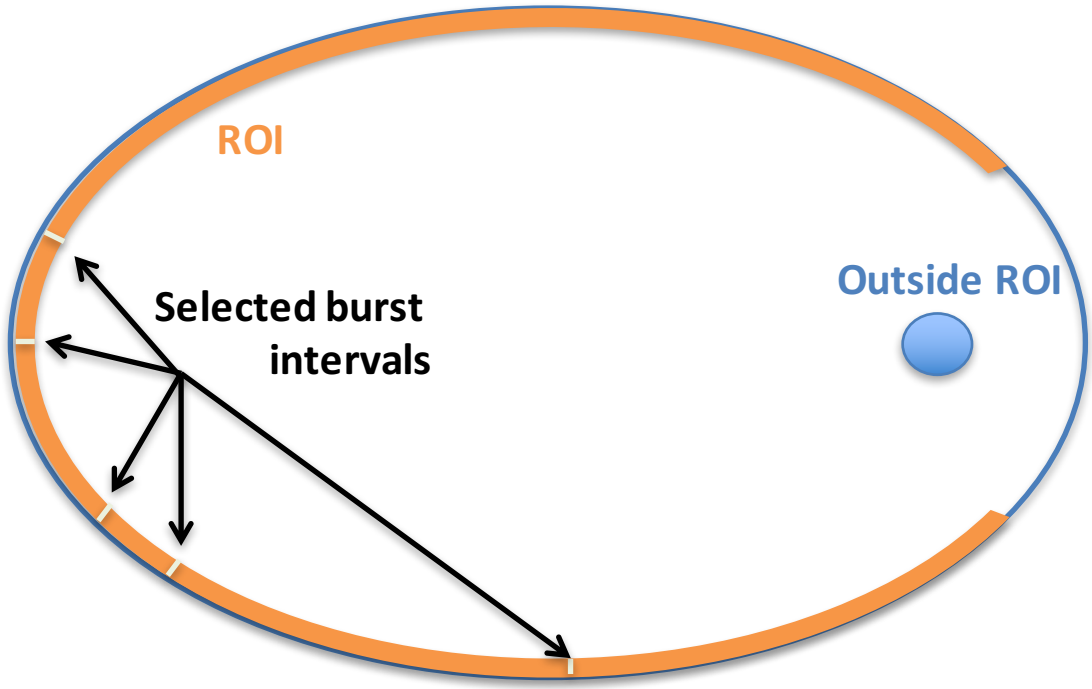
Operations



ROI

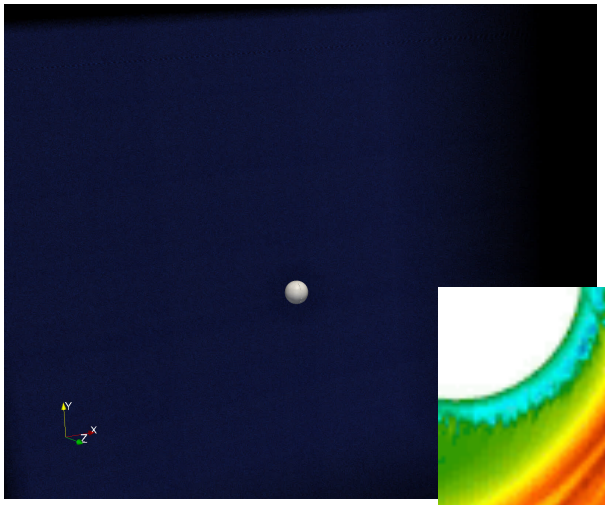
- ✓ **all instruments** are in **SCIENCE** mode
- ✓ Instrument performance requirements apply here

Outside ROI

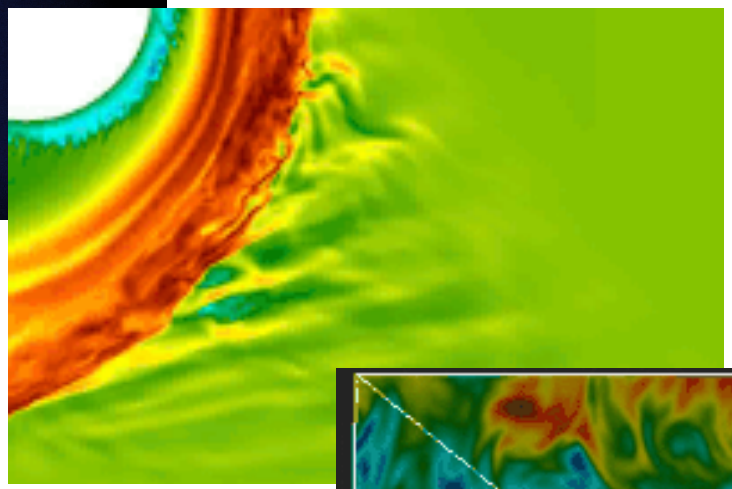
- ✓ Instruments in any mode, including SCIENCE, burst selection is not possible
- ✓ Some instruments can be OFF (TEA, CSW, etc)
- ✓ Instrument performance requirements do not apply here

- ✓ All the data saved on-board (~10TB).
- ✓ Survey data from the whole orbit are transmitted to ground.
- ✓ Selective downlink (Scientist In The Loop) used to select Burst data for downlink.
- ✓ Burst data include continuous time series, snapshots and spectra.

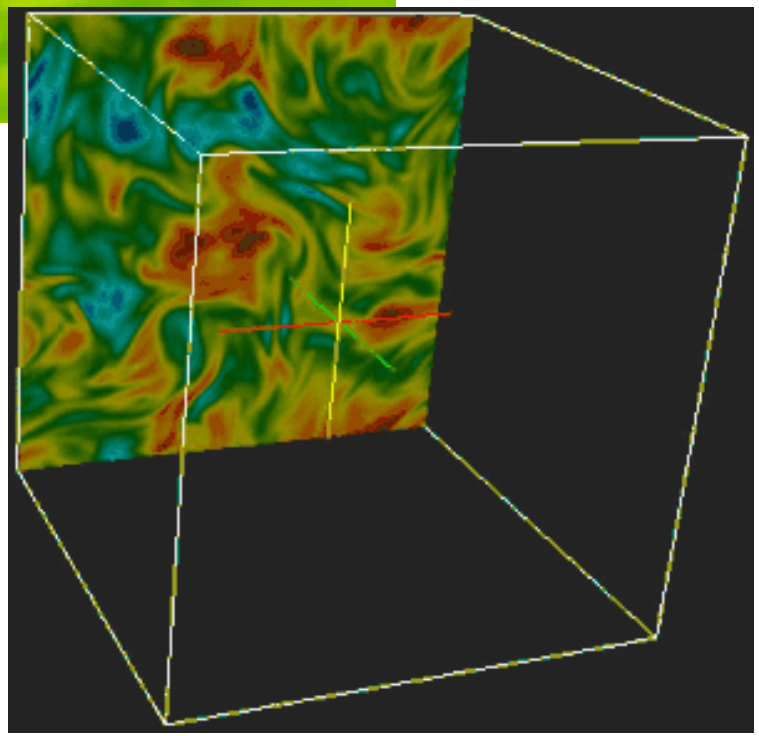
Numerical simulations in support of THOR



Global 3D



Global 2D



Kinetic 3D

HVM3D3V

iPIC3D

AstroGK

GENE

P3D

TFPC

Vlasiator

vpic-H3D

dHybrid

Vlem2D3V

Exploring plasma energization in space turbulence

Thank you!