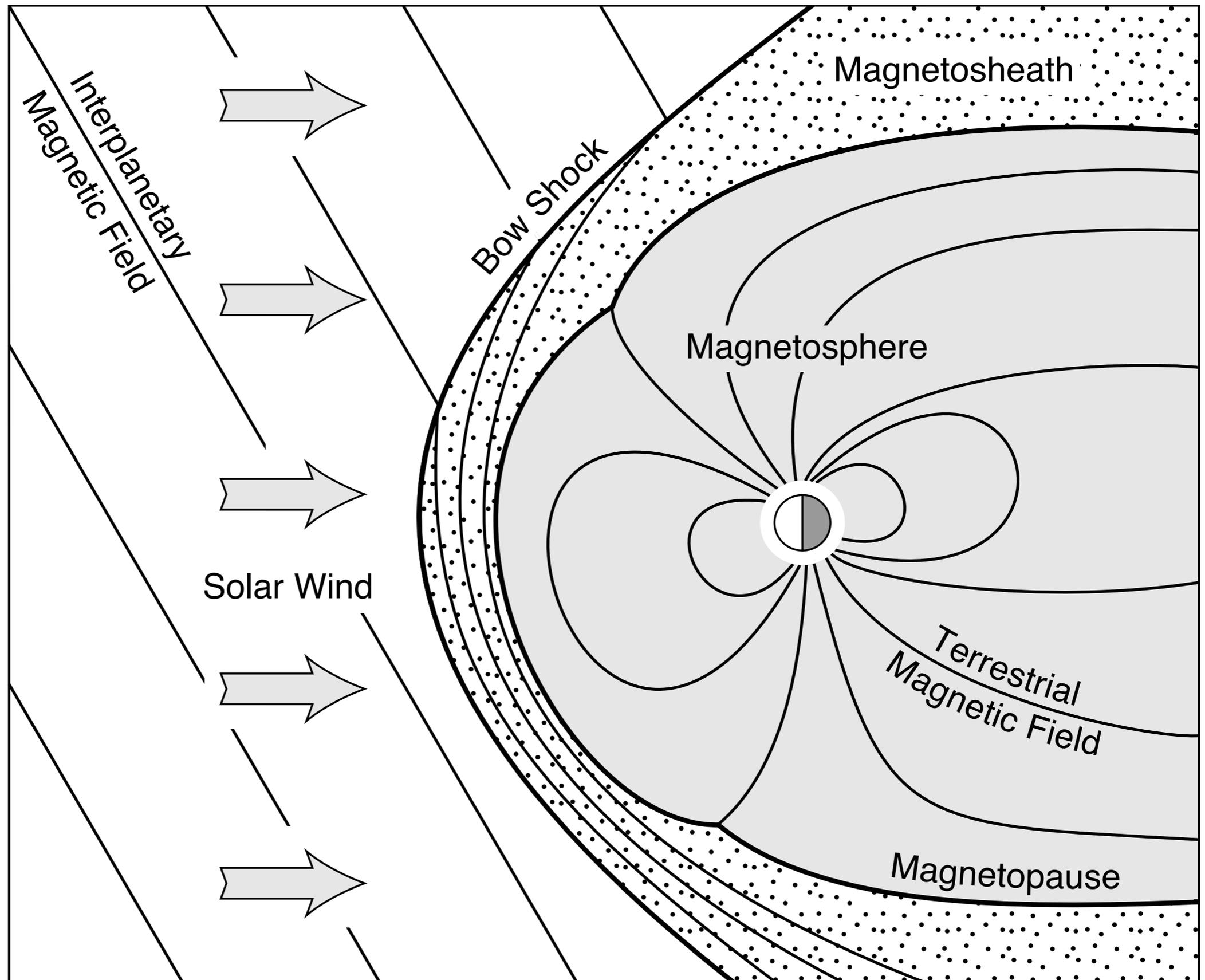
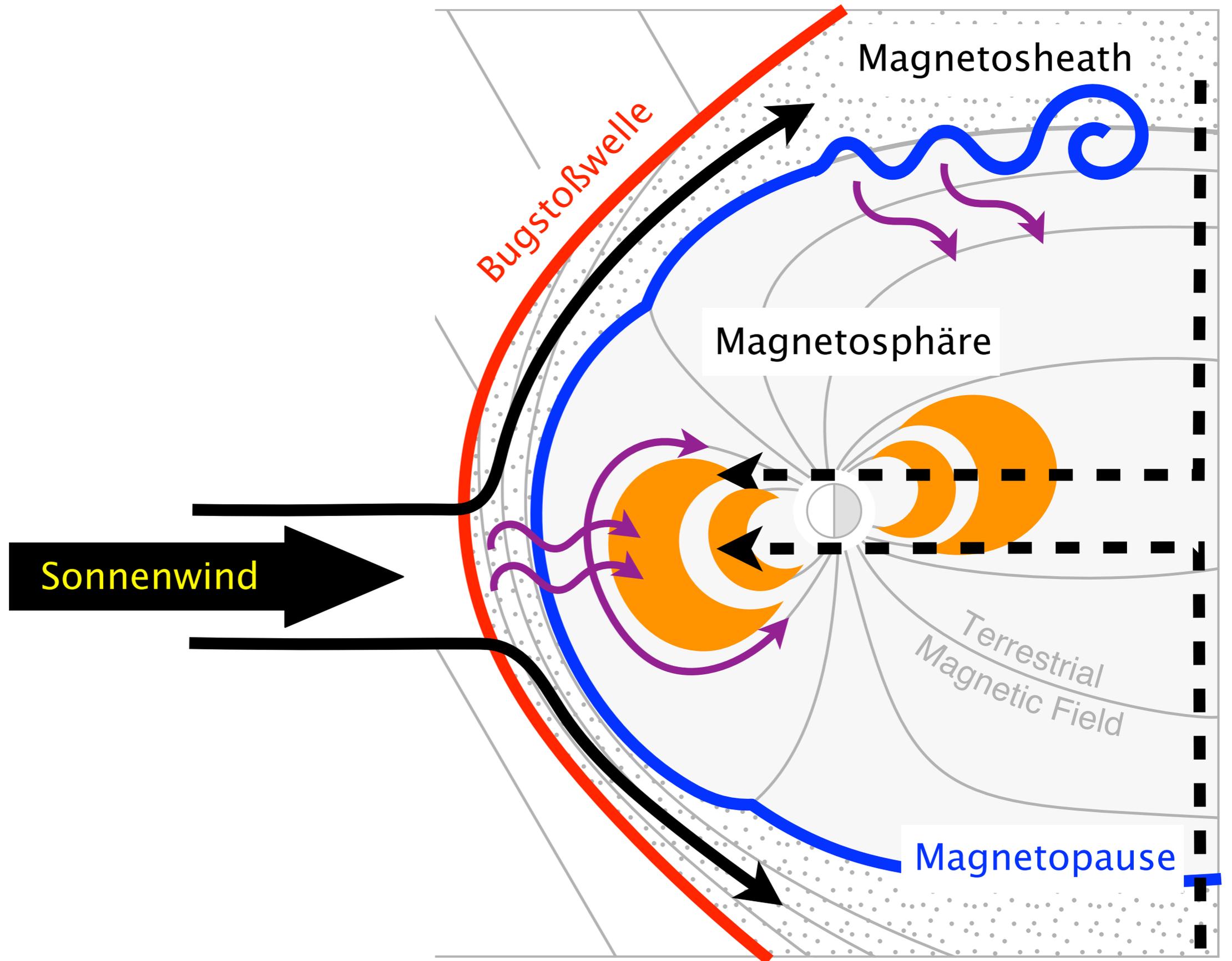


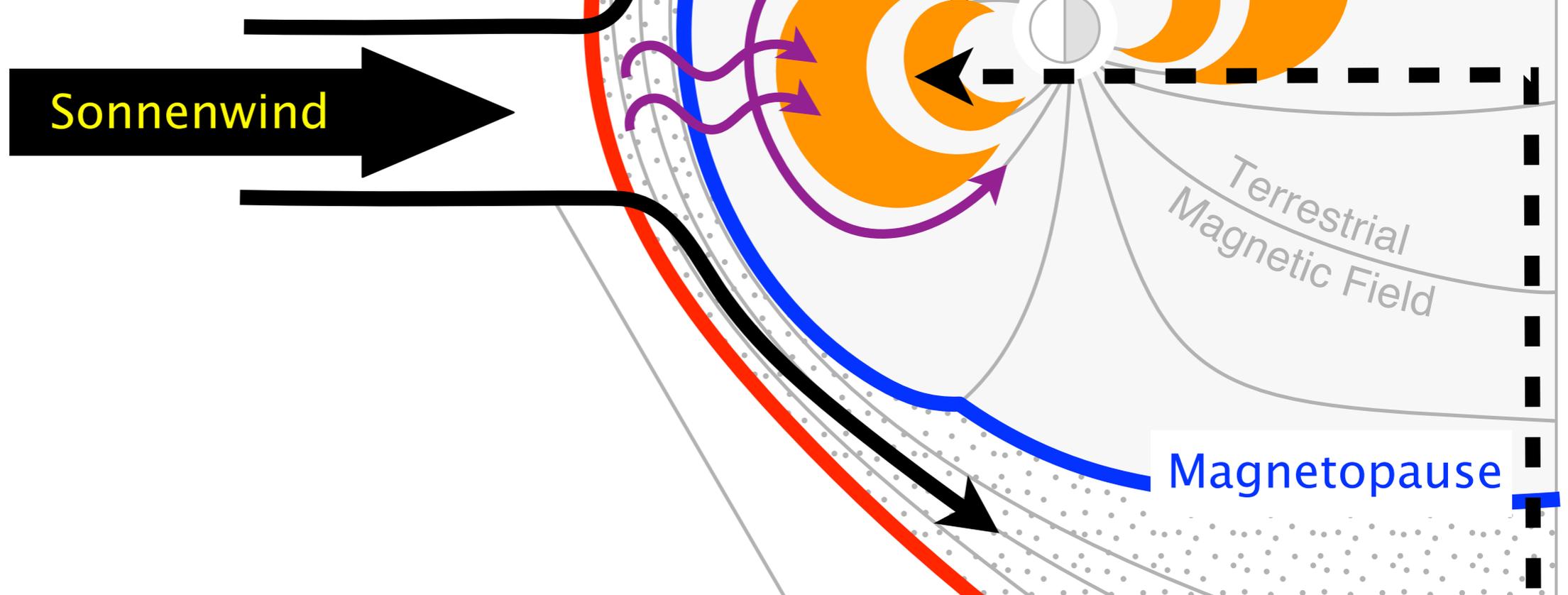
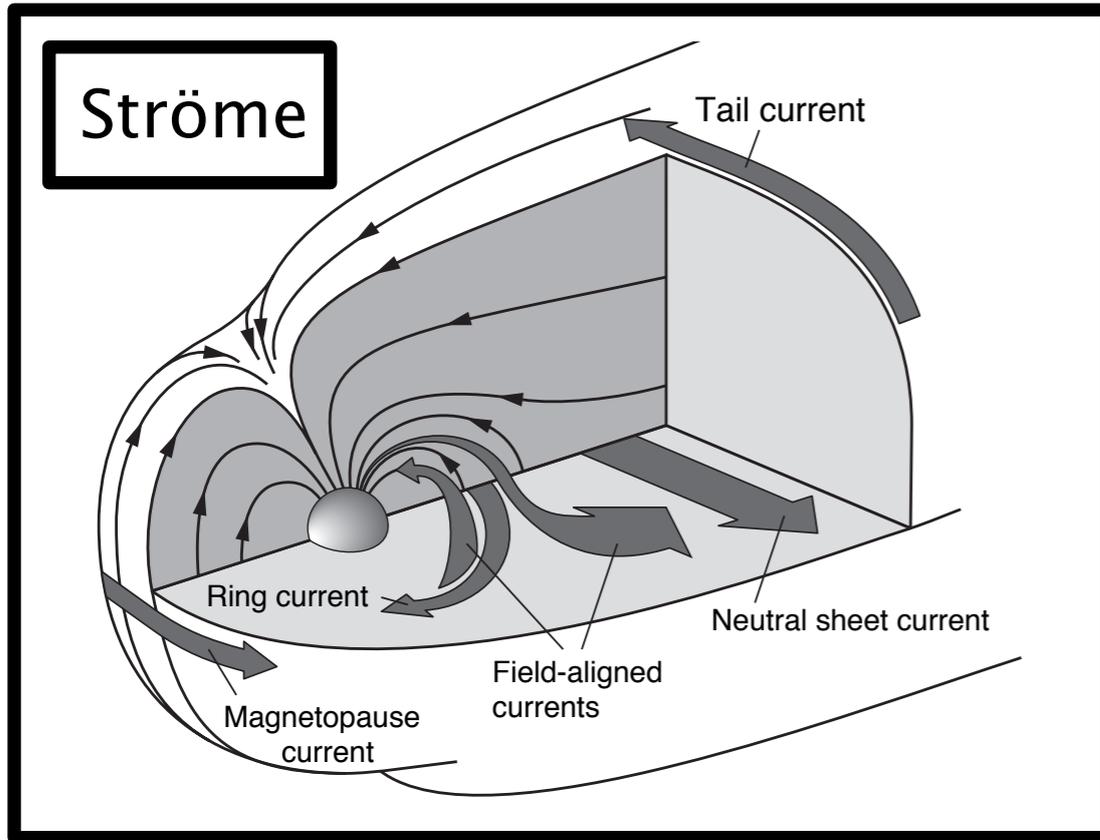
# Viele Punkte ergeben ein Bild: Weltraumbeobachtungen mit mehreren Satelliten

Ferdinand Plaschke

Institut für Weltraumforschung, Graz  
Österreichische Akademie der Wissenschaften

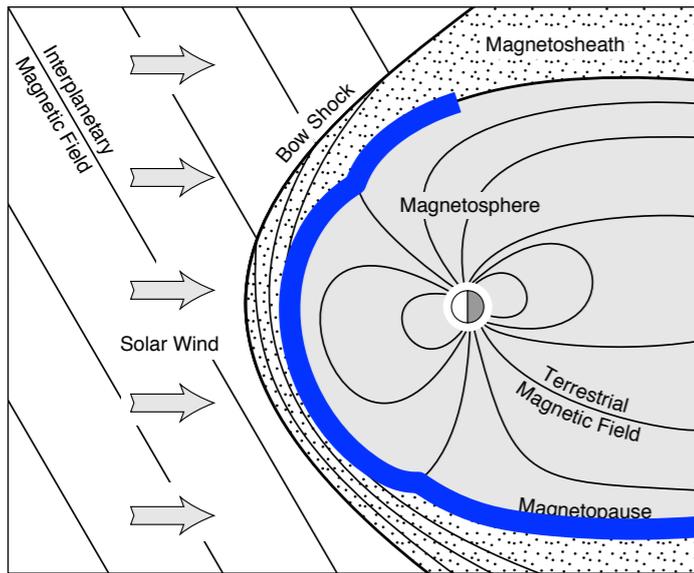




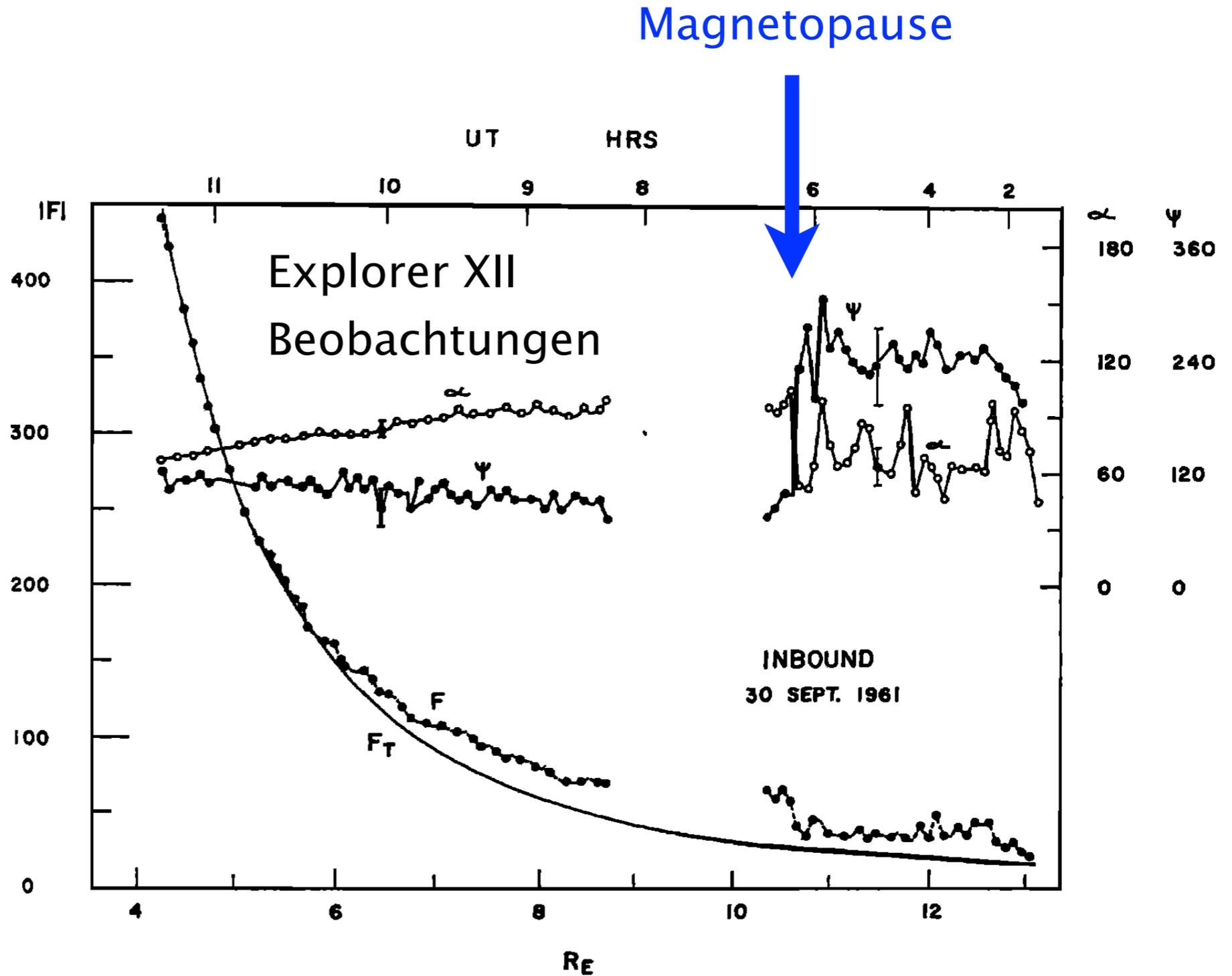


- Die Magnetosphäre besteht aus eine Vielzahl von Regionen mit unterschiedlichen Eigenschaften.
- Wechselwirkungen vermittelt durch:  
Teilchen, Ströme, Felder, Wellen

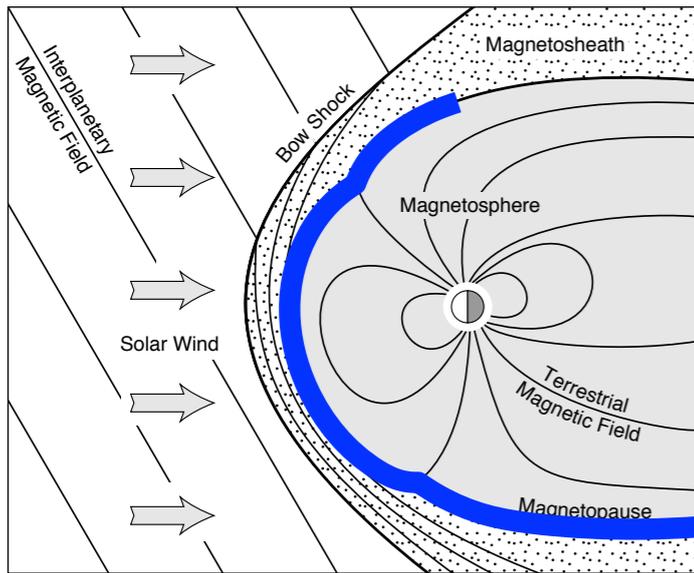
- Unser Ziel ist die Untersuchung dieser Wechselwirkungen.  
Reichen dafür Messungen mit einzelnen Satelliten?



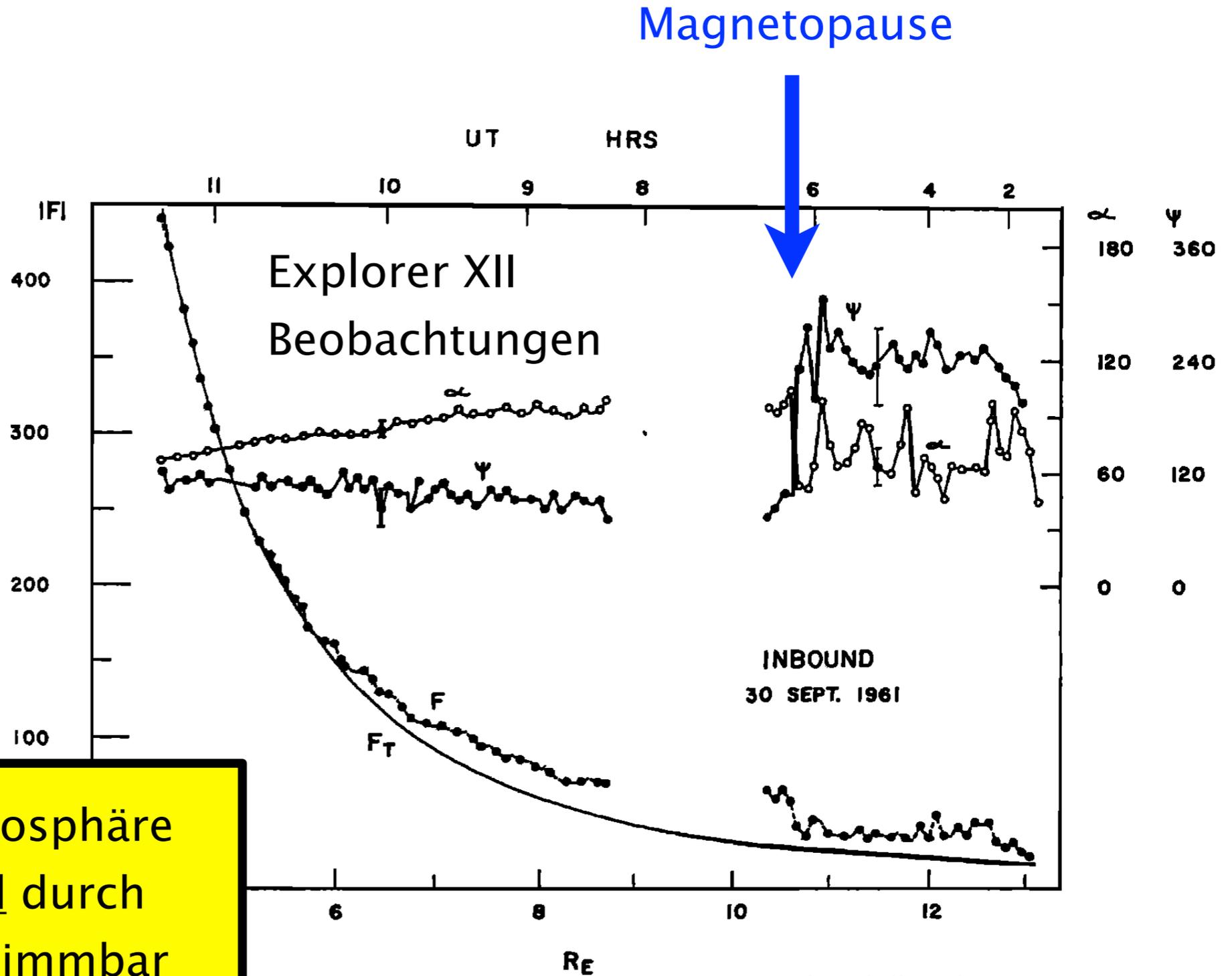
nach Baumjohann und Treumann, 1996



nach Cahill und Amazeen, 1963



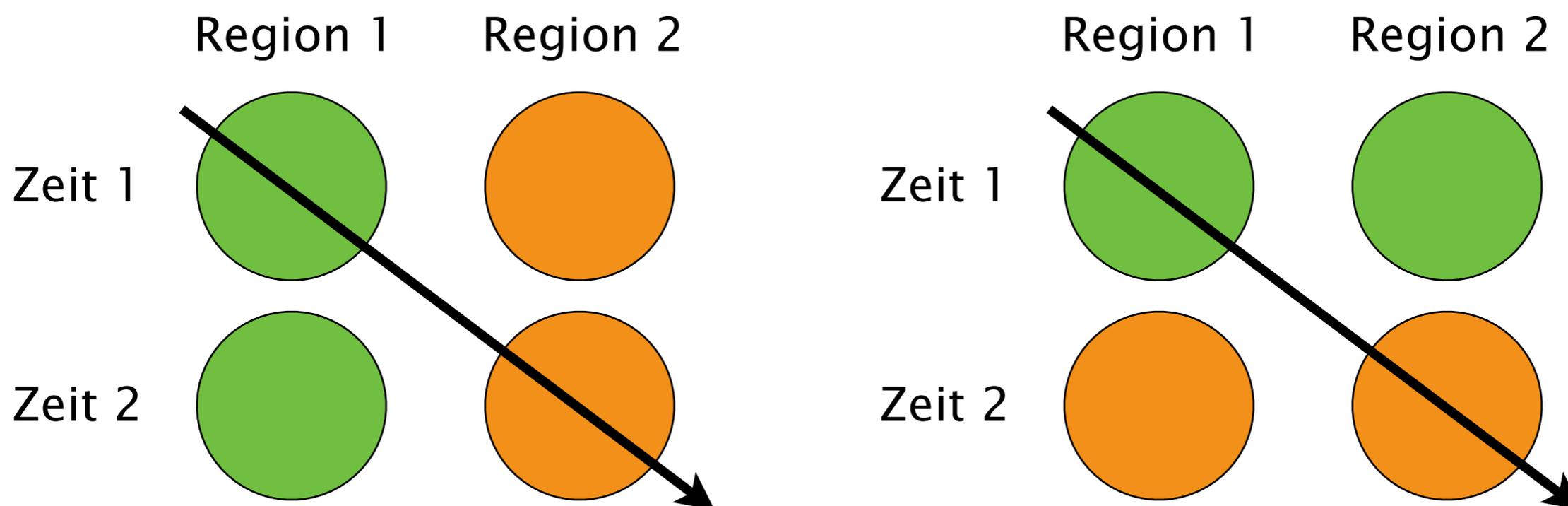
nach Baumjohann und Treumann, 1996



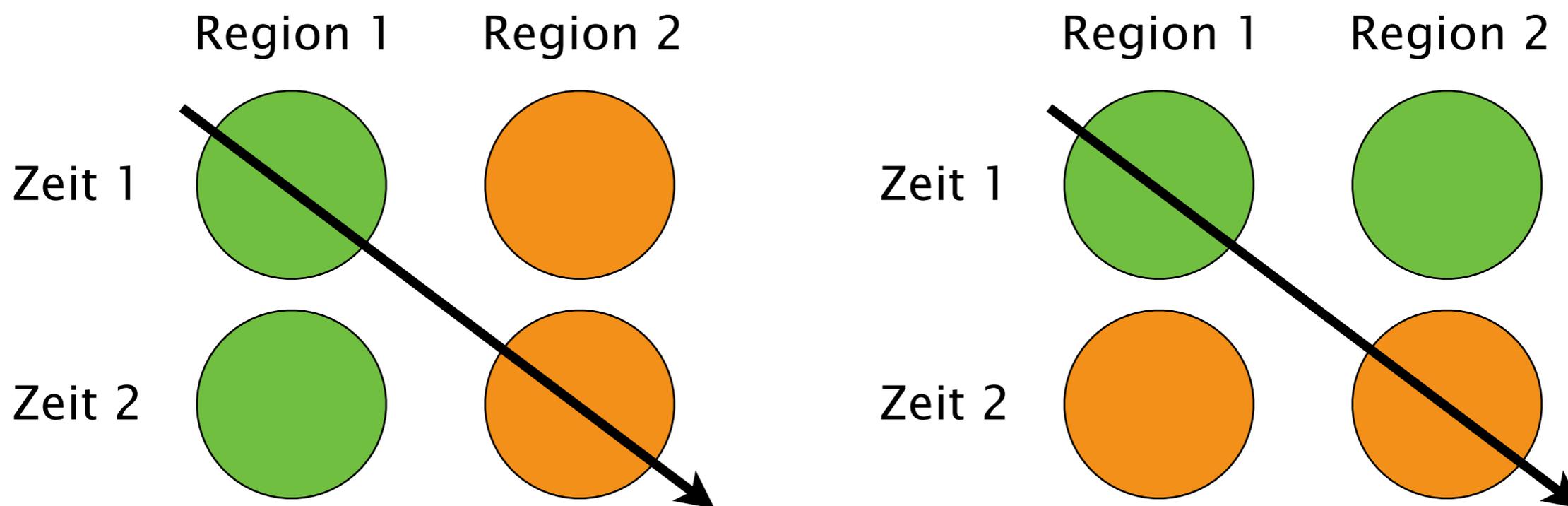
nach Cahill und Amazeen, 1963

Struktur der Magnetosphäre  
im zeitlichen Mittel durch  
Einzelsatelliten bestimmbar

Zeitliche Veränderungen in Messdaten können unterschiedlich interpretiert werden:

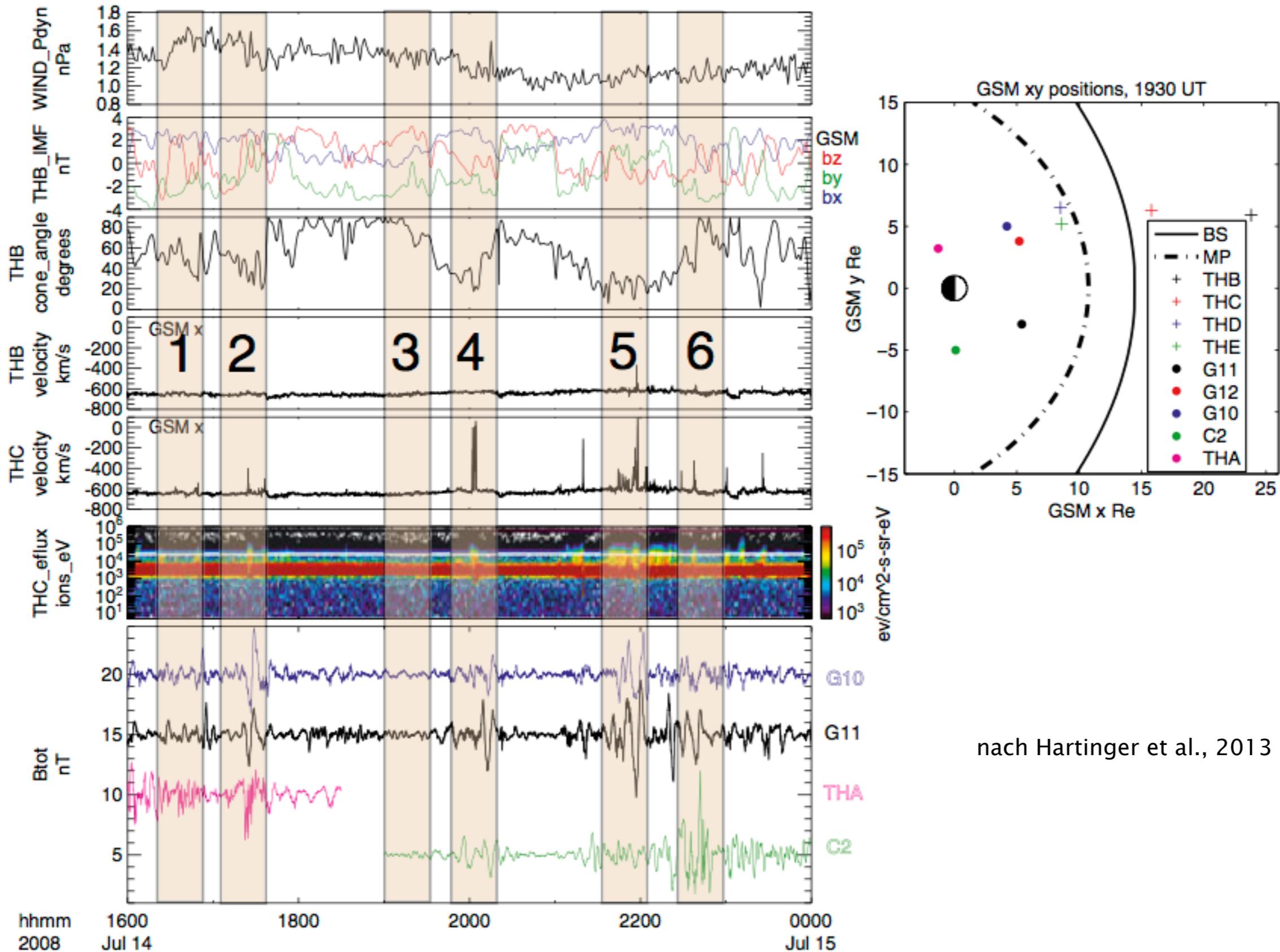


Zeitliche Veränderungen in Messdaten können unterschiedlich interpretiert werden:

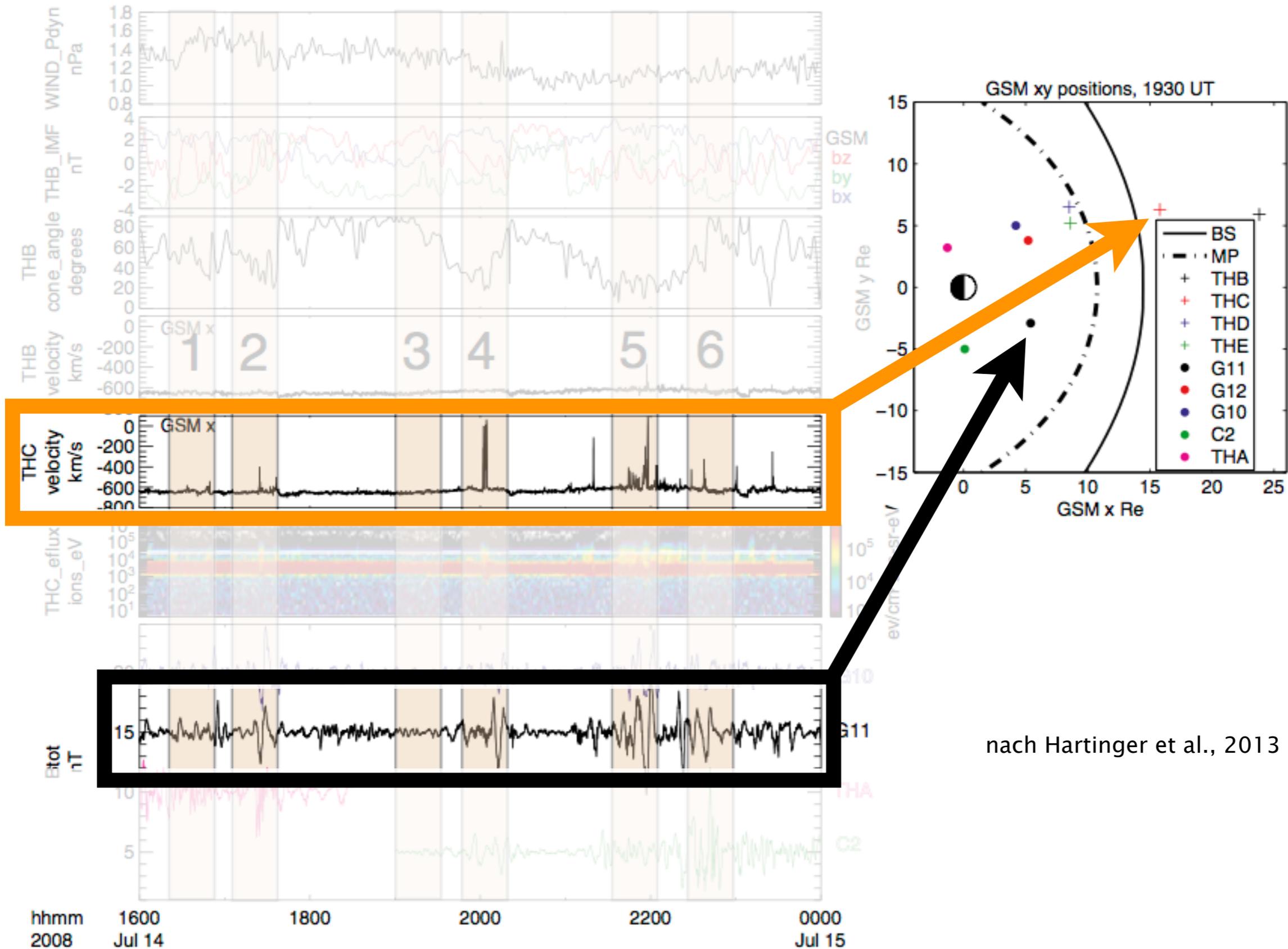


Zeitliche Veränderungen können von räumlichen Veränderungen mit Einzelsatelliten-Messungen nicht unterschieden werden.

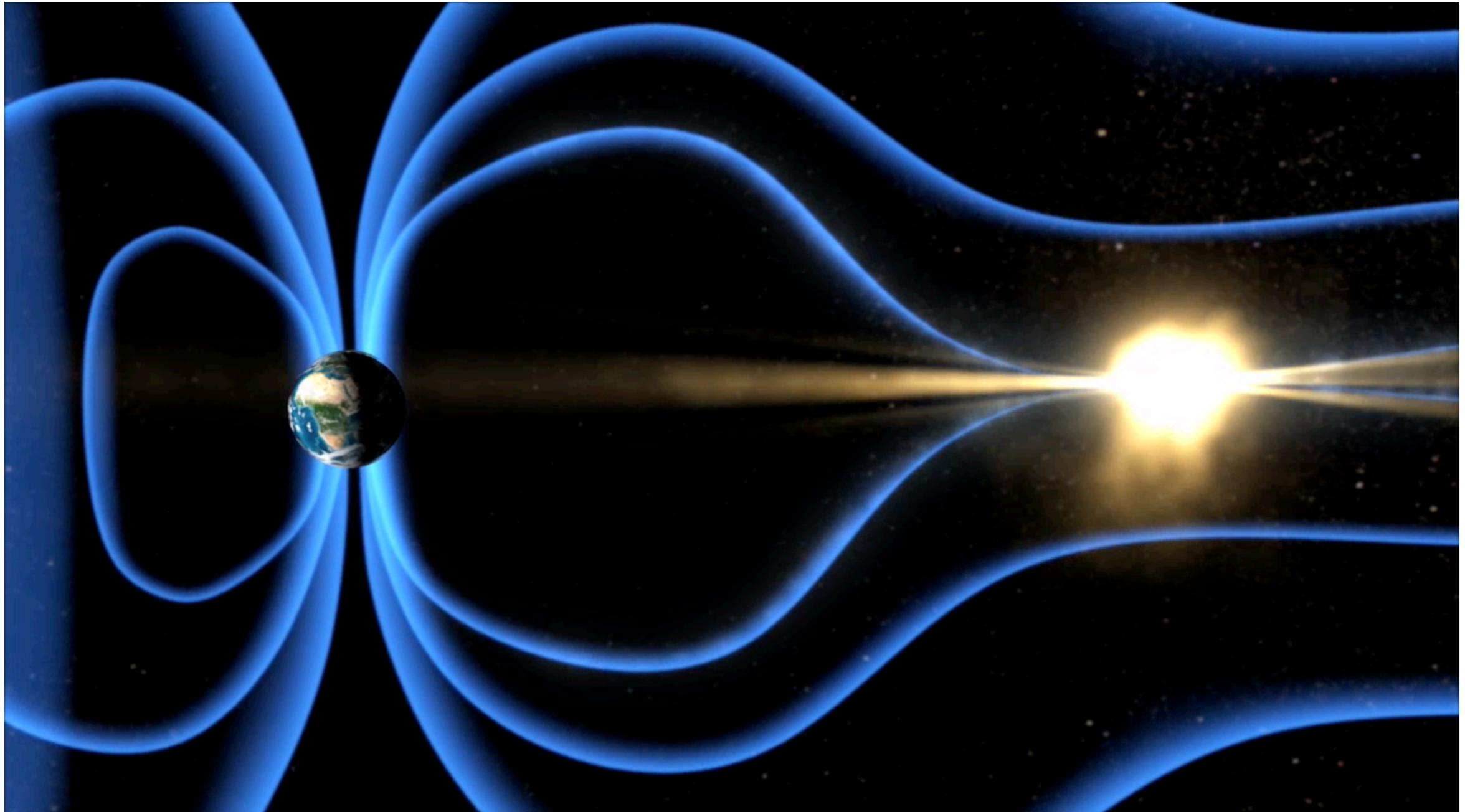
- Einordnung globaler Zusammenhänge
- Bewegung von Grenzflächen,  
Ausbreitung von Wellen
- Messung von Strömen



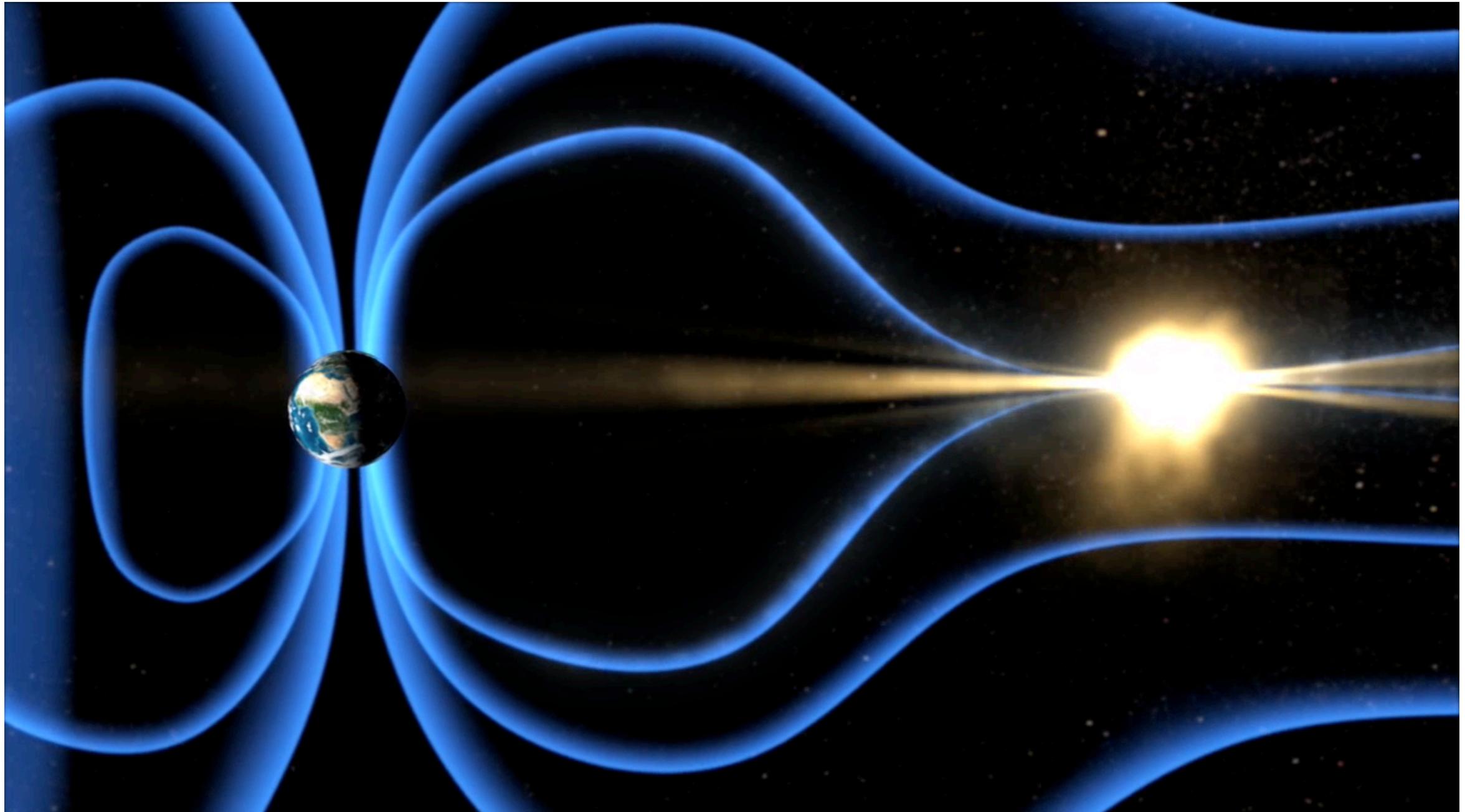
nach Hartinger et al., 2013



nach Hartinger et al., 2013

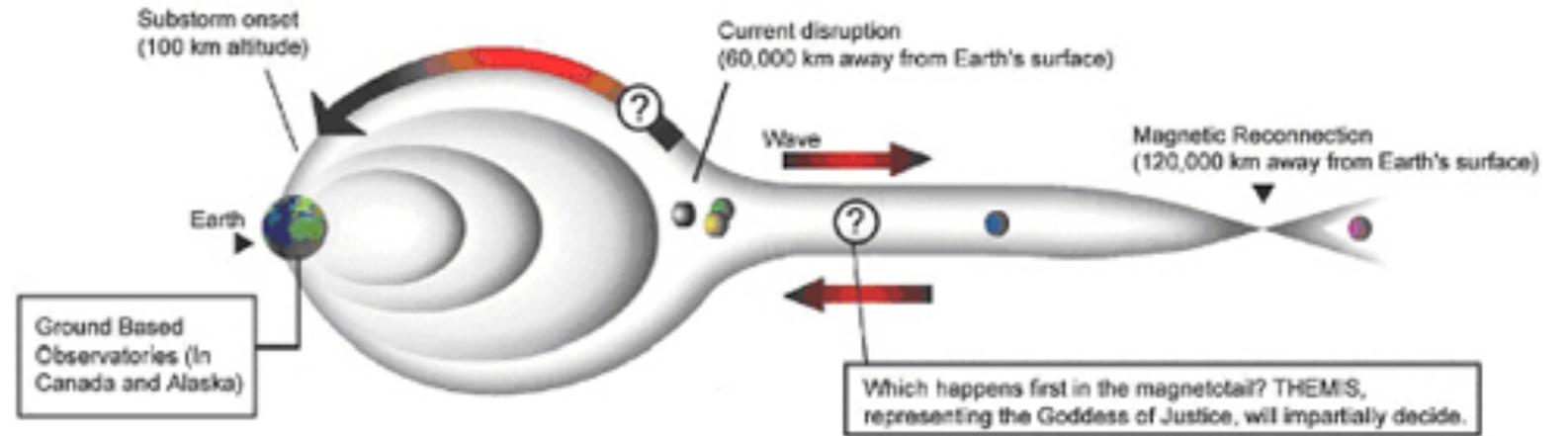


[http://www.nasa.gov/mission\\_pages/themis/multimedia/index.html](http://www.nasa.gov/mission_pages/themis/multimedia/index.html)

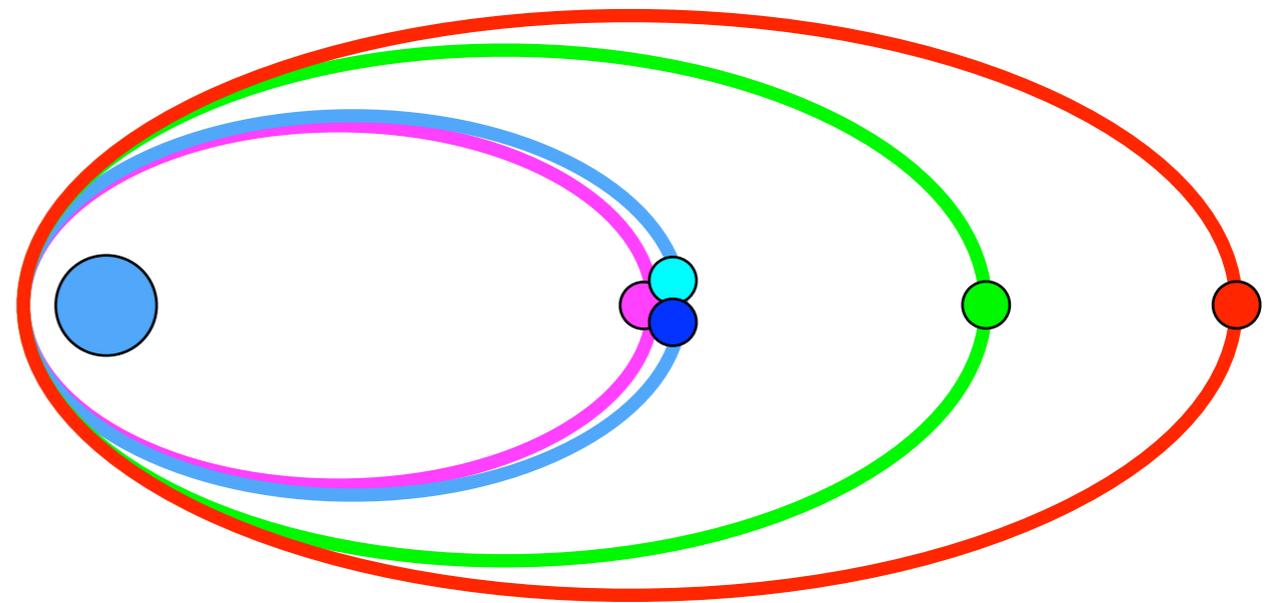


[http://www.nasa.gov/mission\\_pages/themis/multimedia/index.html](http://www.nasa.gov/mission_pages/themis/multimedia/index.html)

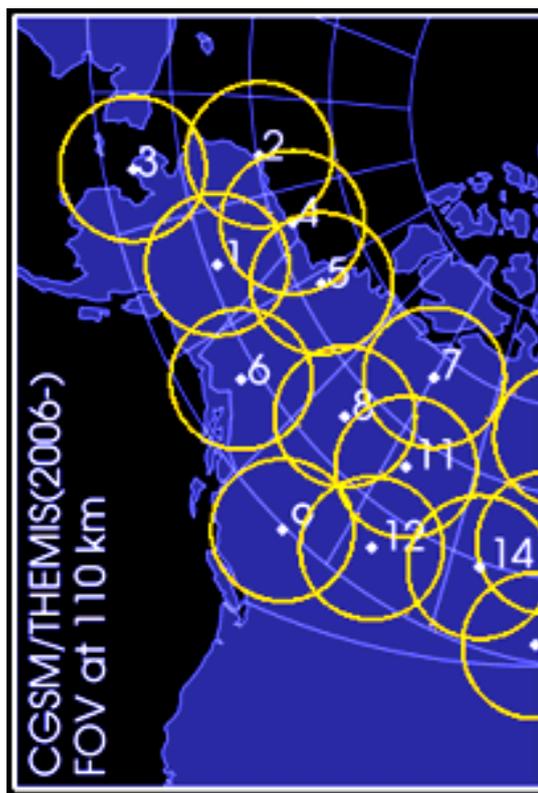
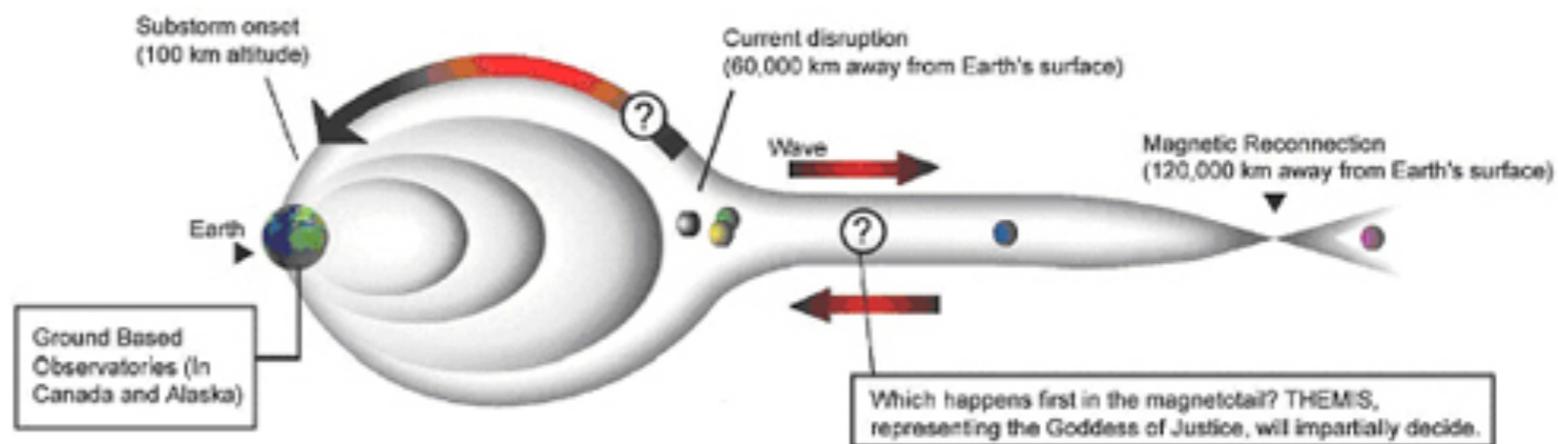
## THEMIS: Time History of Events and Macroscale Interactions during Substorms



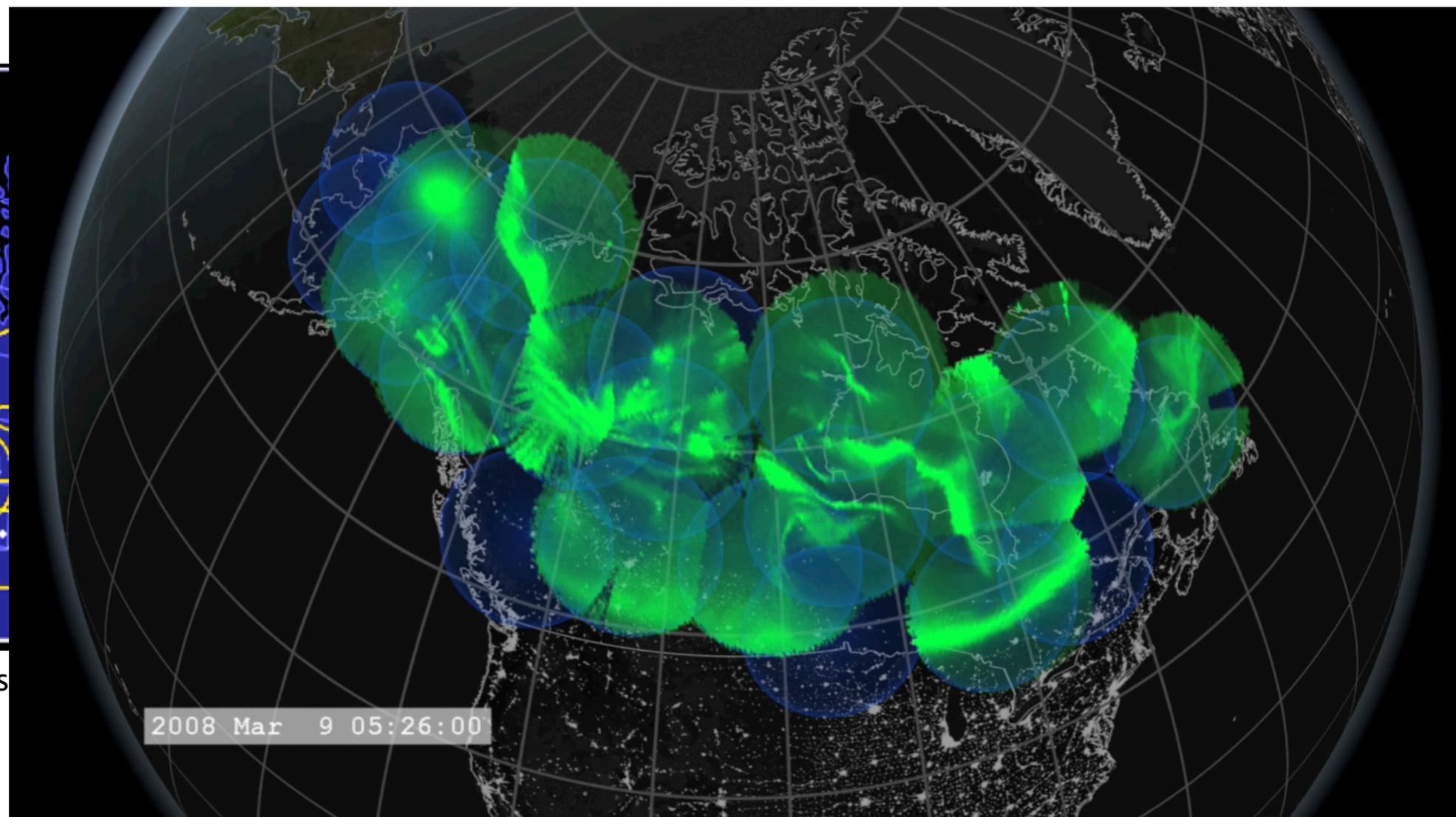
<http://themis.ssl.berkeley.edu>



## THEMIS: Time History of Events and Macroscale Interactions during Substorms

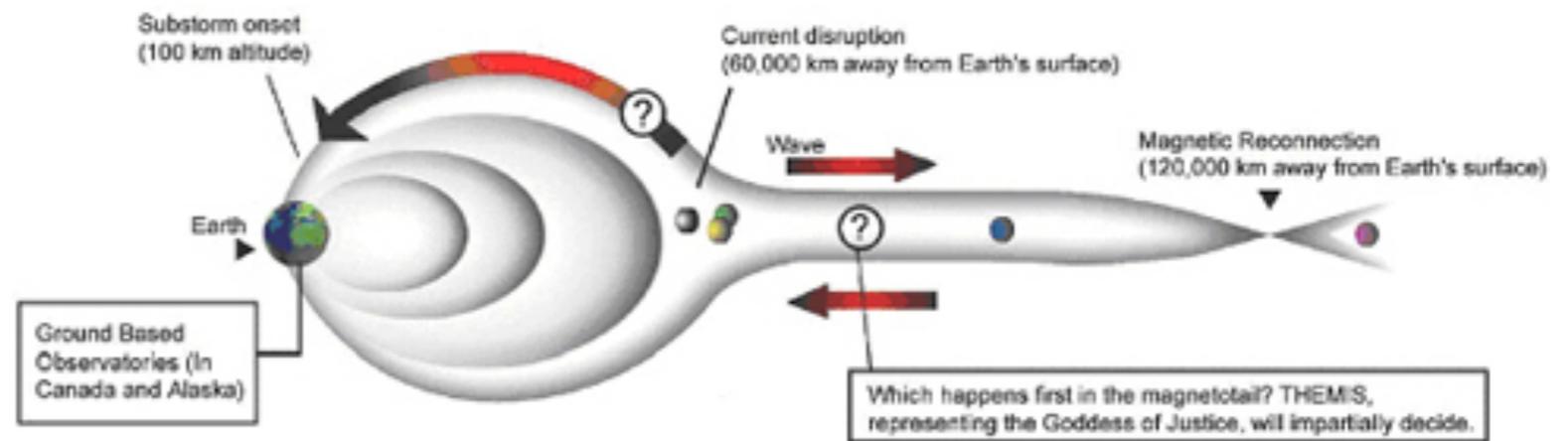


<http://themis.s>



<http://cse.ssl.berkeley.edu/artemis/videos/>

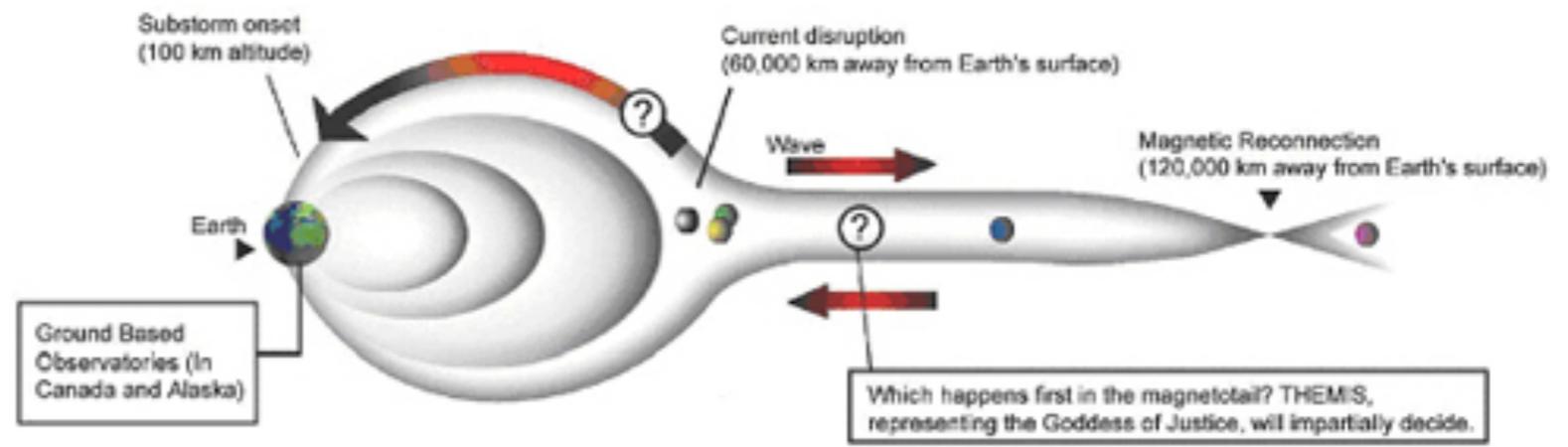
## THEMIS: Time History of Events and Macroscale Interactions during Substorms



Event	Observed time (UT)	Inferred delay (seconds since 04:50:03 UT)
Reconnection onset	04:50:03 (inferred)	$T_{Rx} = 0$
Reconnection effects at P1	04:50:28	25
Reconnection effects at P2	04:50:38	35
Auroral intensification	04:51:39	$T_{AI} = 96$
High-latitude Pi2 onset	04:52:00	117
Substorm expansion onset	04:52:21	$T_{EX} = 138$
Earthward flow onset at P3	04:52:27	144
Mid-latitude Pi2 onset	04:53:05	182
Dipolarization at P3	04:53:05	$T_{CD} = 182$
Auroral electrojet increase	04:54:00	237

aus Angelopoulos et al., 2008

## THEMIS: Time History of Events and Macroscale Interactions during Substorms



Event

Observed time (UT)

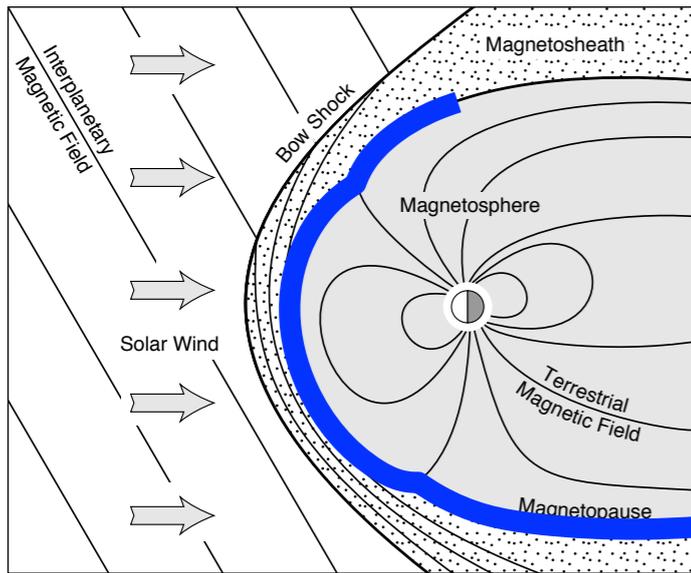
Inferred delay (seconds since 04:50:03 UT)

Reconnection onset  
 Reconnection effects at P1  
 Reconnection effects at P2  
 Auroral intensification  
 High-latitude Pi2 onset  
 Substorm expansion onset  
 Earthward flow onset at P3  
 Mid-latitude Pi2 onset  
 Dipolarization at P3  
 Auroral electrojet increase

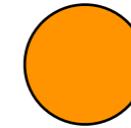
04:50:03 (inferred)  
 04:50:28  
 04:50:38  
 04:51:39  
 04:52:00  
 04:52:21  
 04:52:27  
 04:53:05  
 04:53:05  
 04:54:00

$T_{Rx} = 0$   
 25  
 35  
 $T_{AI} = 96$   
 117  
 $T_{EX} = 138$   
 144  
 182  
 $T_{CD} = 182$   
 237

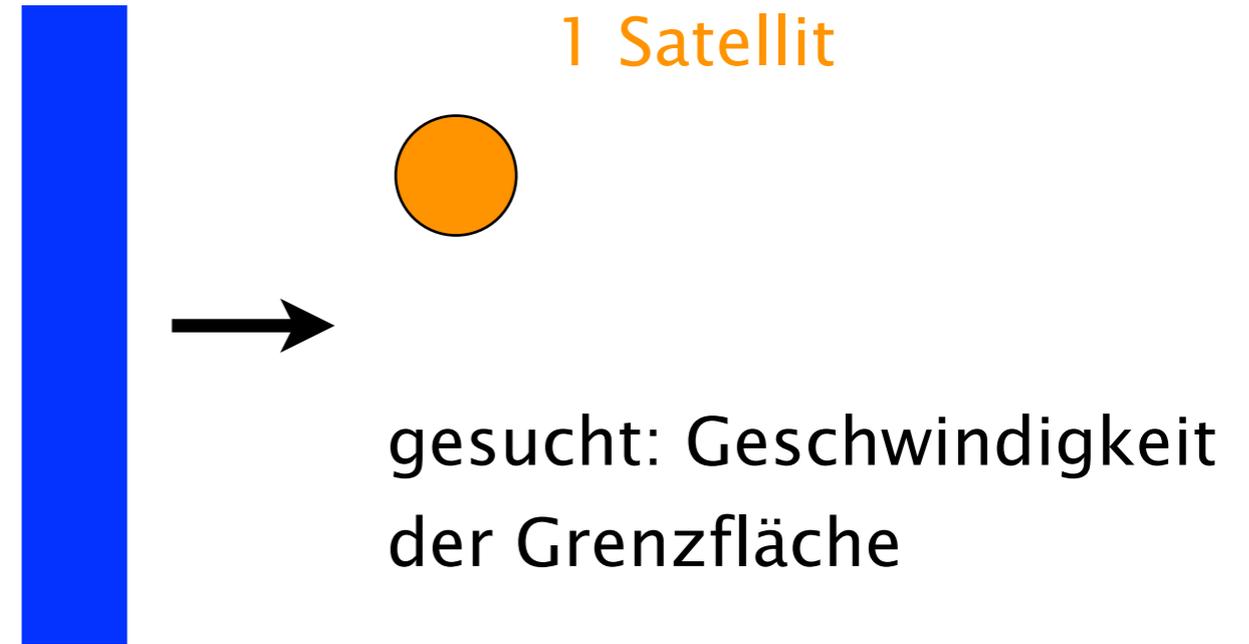
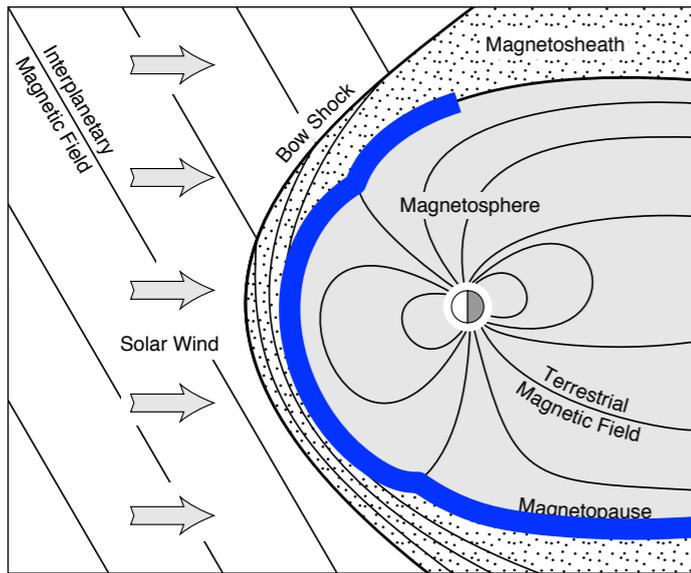
aus Angelopoulos et al., 2008



1 Satellit



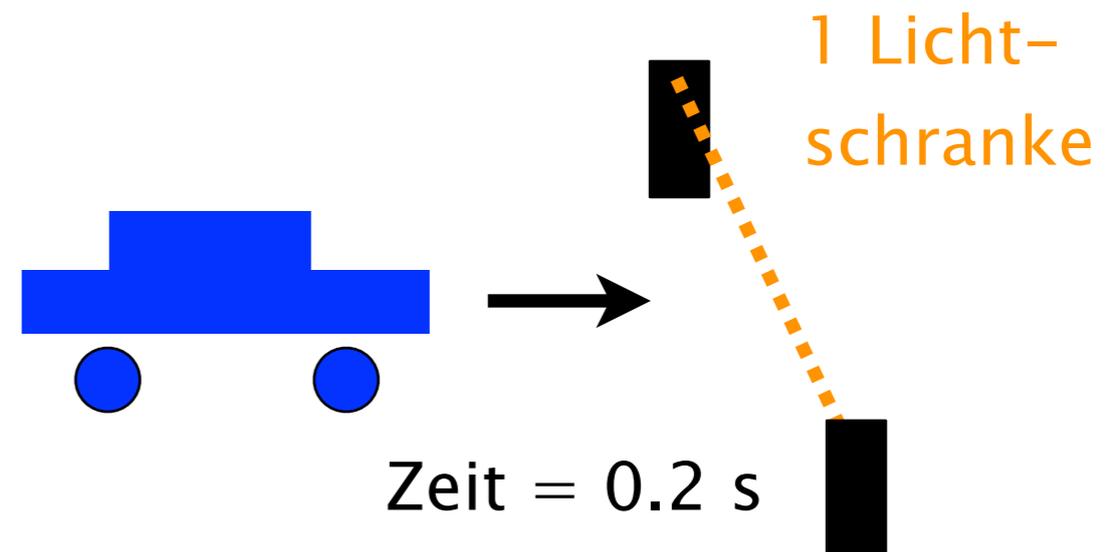
gesucht: Geschwindigkeit  
der Grenzfläche

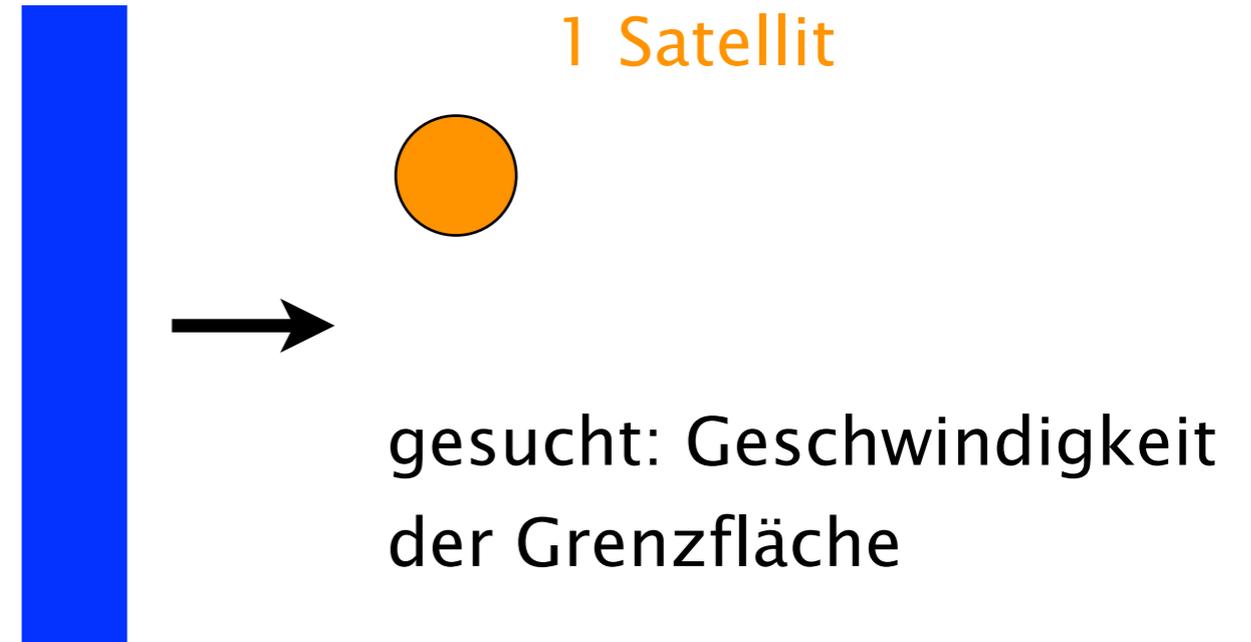
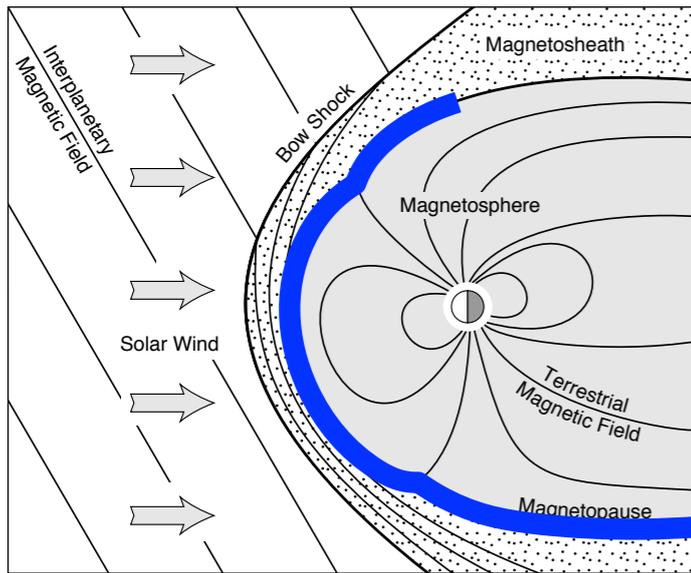


Kann man die Geschwindigkeit eines Autos mit nur einer Lichtschranke bestimmen?

NEIN

JA





Kann man die Geschwindigkeit eines Autos mit nur einer Lichtschranke bestimmen?

Im Prinzip

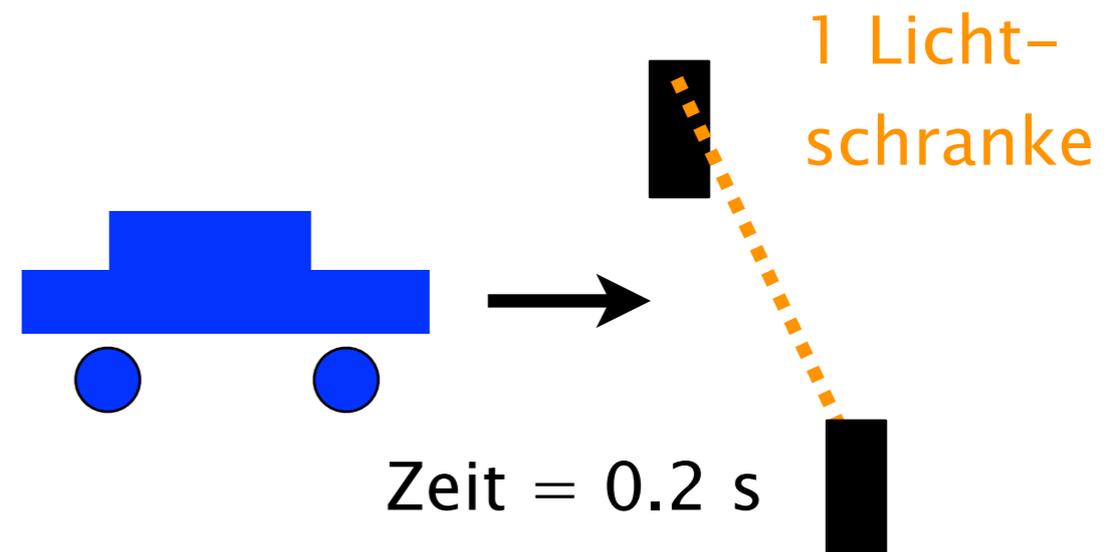
**NEIN**

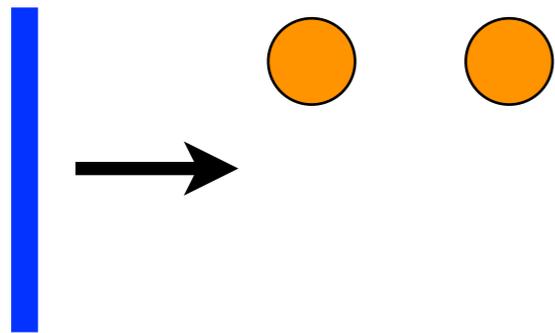
wenn nötig

**JA**

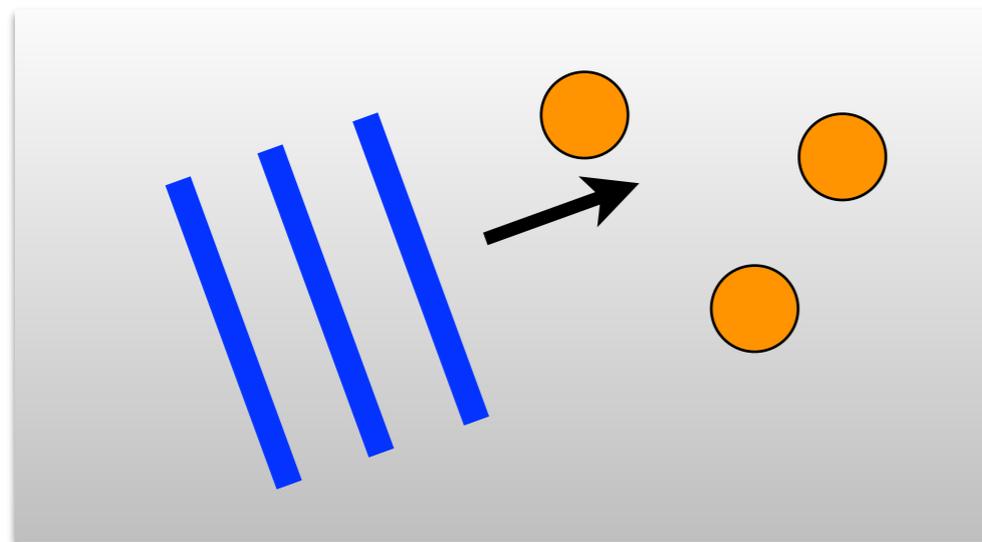
mittlere PKW Länge: 4.5 m

$V = \text{Länge} / \text{Zeit} = 81 \text{ km/h}$

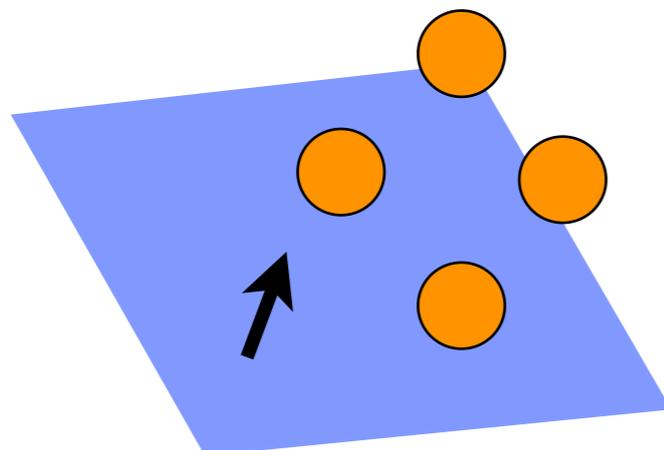




1D Bewegung, Normalenrichtung bekannt,  
2 Satelliten

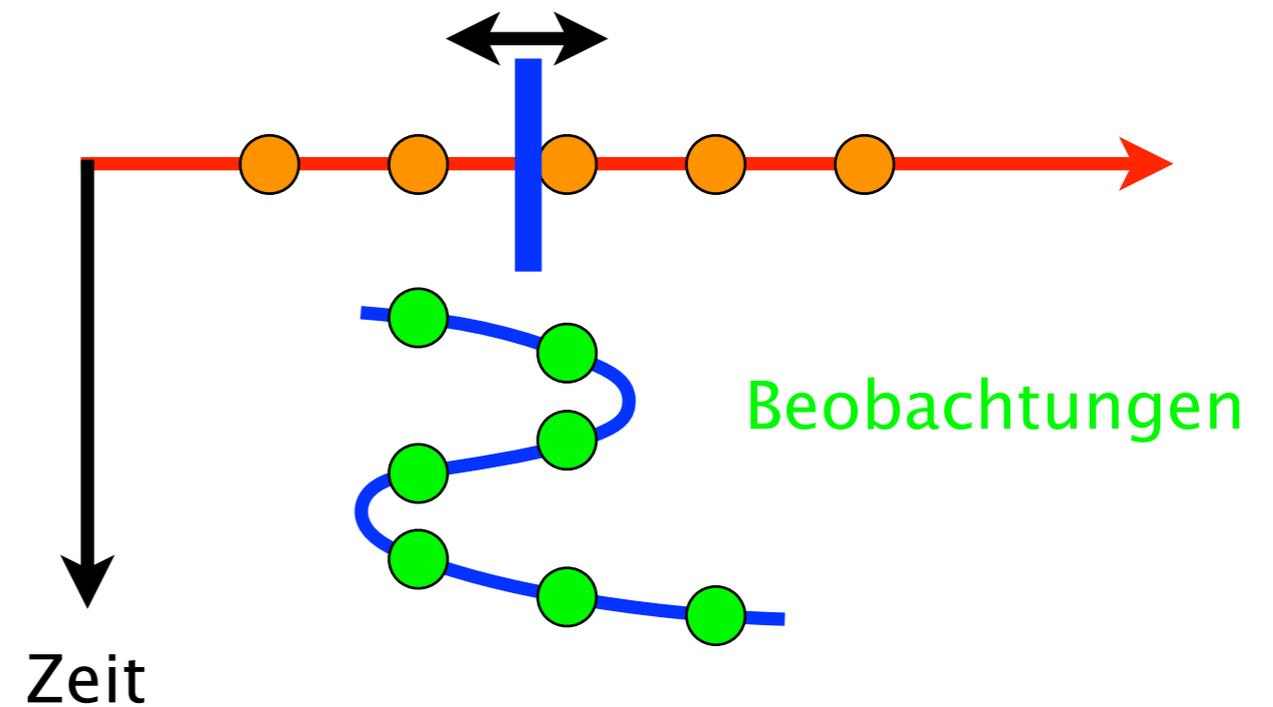
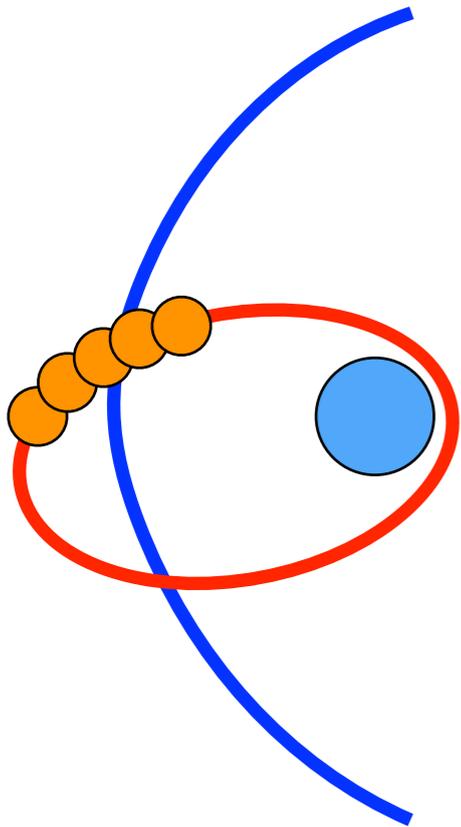


2D Bewegung, Fläche bekannt,  
3 Satelliten

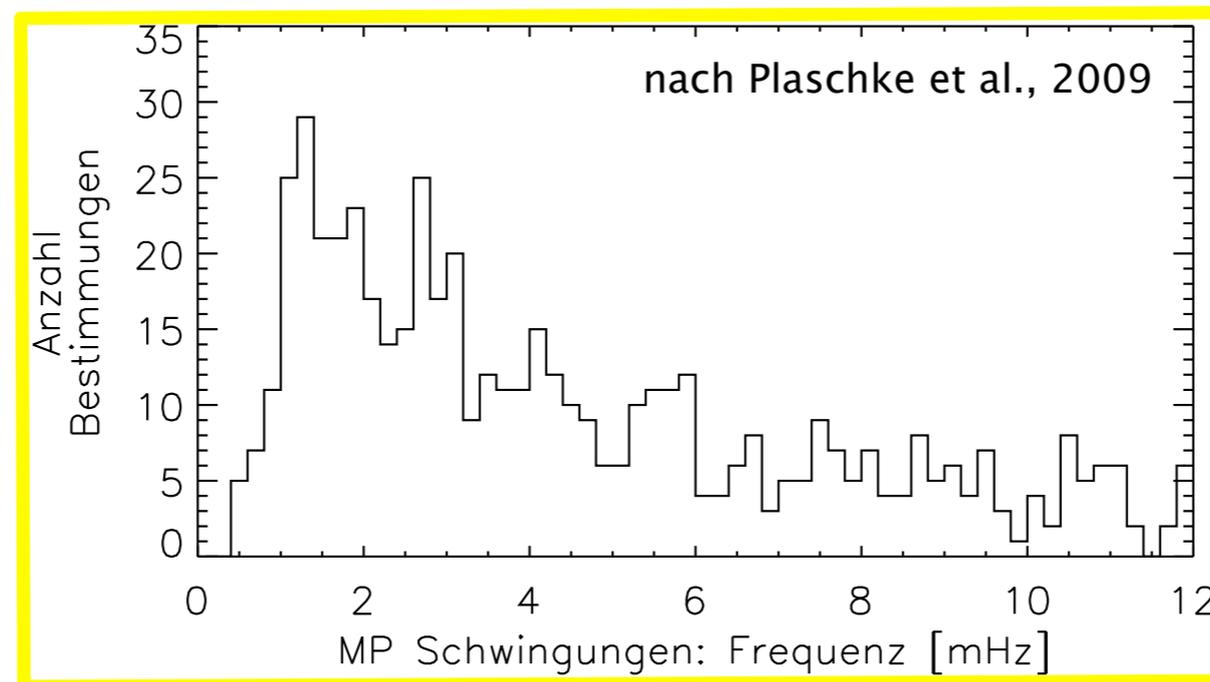
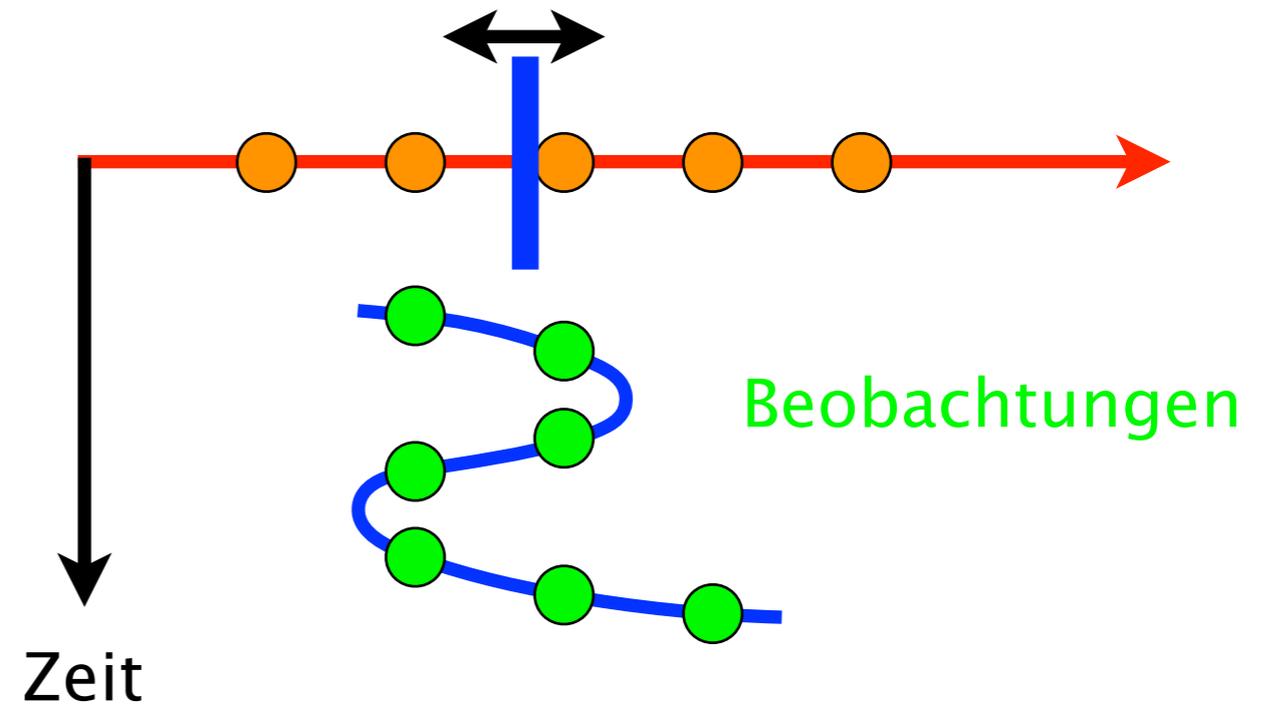
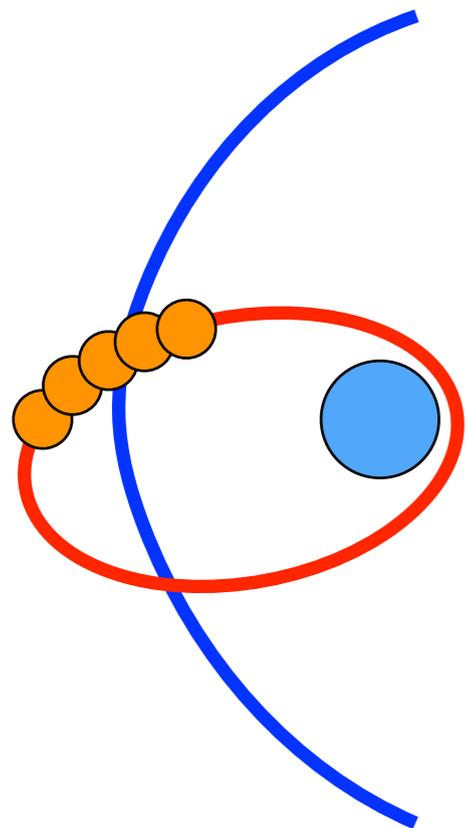


3D Bewegung,  
4 Satelliten

THEMIS Satelliten nach dem Start:  
aufgereiht entlang ihres  
gemeinsamen Orbits  
(Perlenketten-Konfiguration)

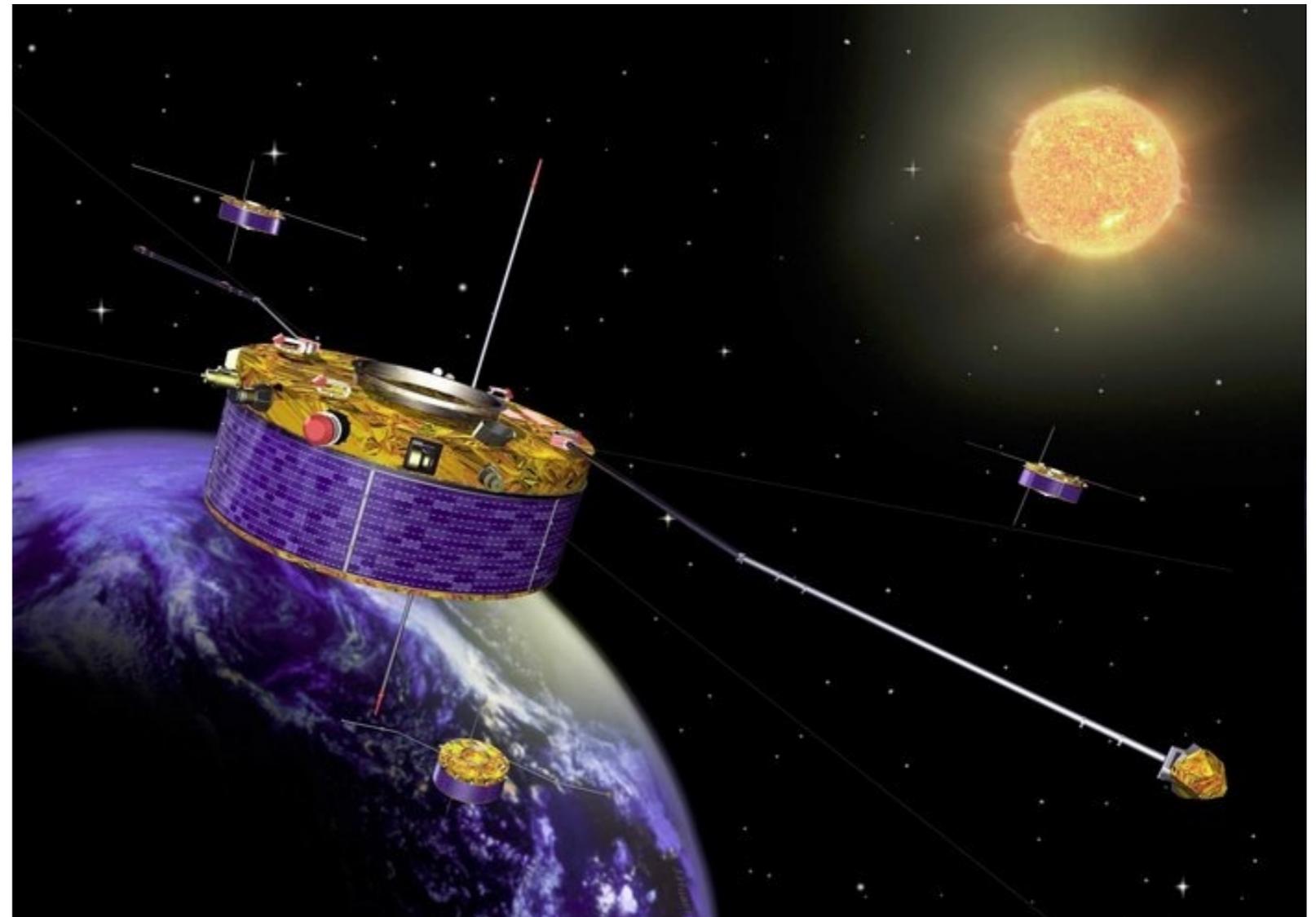
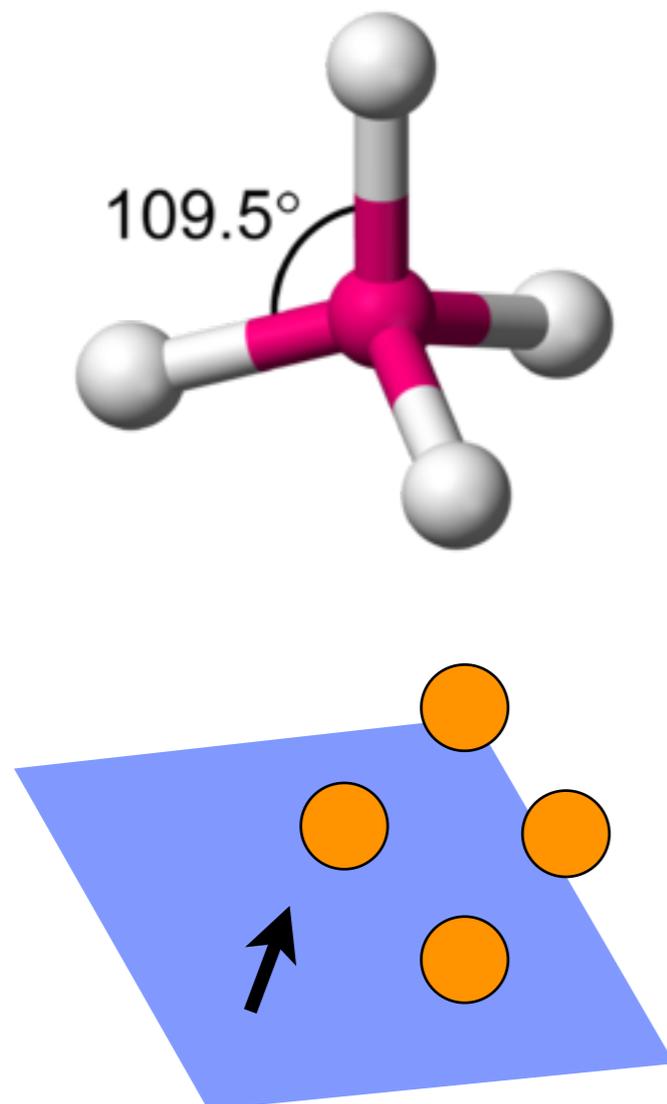


THEMIS Satelliten nach dem Start:  
aufgereiht entlang ihres  
gemeinsamen Orbits  
(Perlenketten-Konfiguration)



Verteilungen der:  
Geschwindigkeit  
Amplitude  
**Frequenz**

## ESA Mission 4 Satelliten in Tetraeder-Konfiguration



[http://www.esa.int/spaceimages/Images/2002/08/The\\_Cluster\\_constellation](http://www.esa.int/spaceimages/Images/2002/08/The_Cluster_constellation)

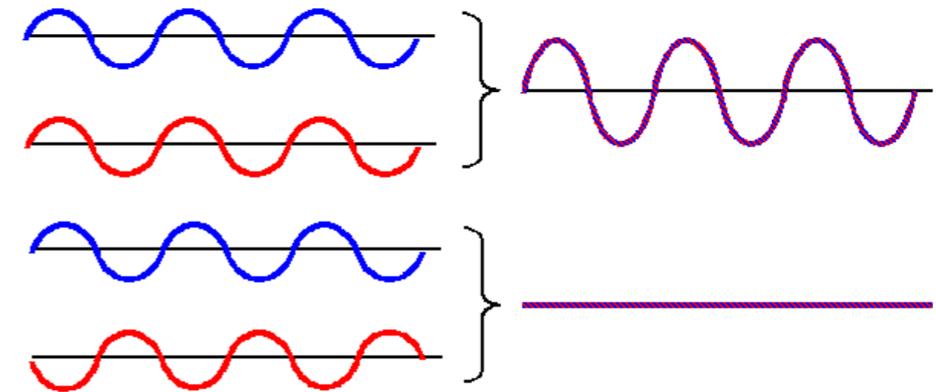
<http://de.wikipedia.org/wiki/Tetraeder>

## Cluster als Wellenteleskop, phasengesteuerte Gruppenantenne



Autor: Spliced,  
[http://de.wikipedia.org/wiki/RAF\\_Fylingdales](http://de.wikipedia.org/wiki/RAF_Fylingdales)

[http://www.tf.uni-kiel.de/matwis/amat/mw1\\_ge/kap\\_2/basics/b2\\_1\\_6.html](http://www.tf.uni-kiel.de/matwis/amat/mw1_ge/kap_2/basics/b2_1_6.html)

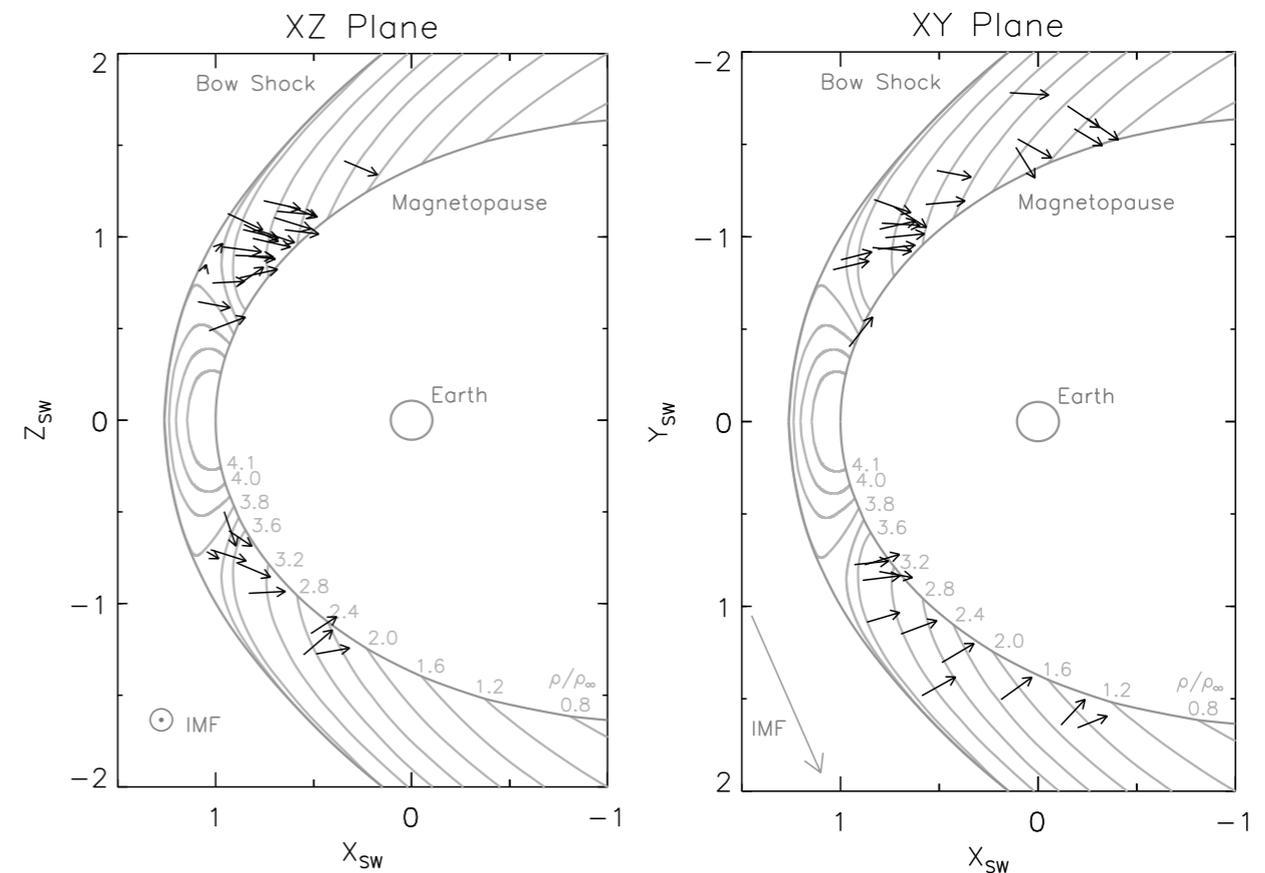
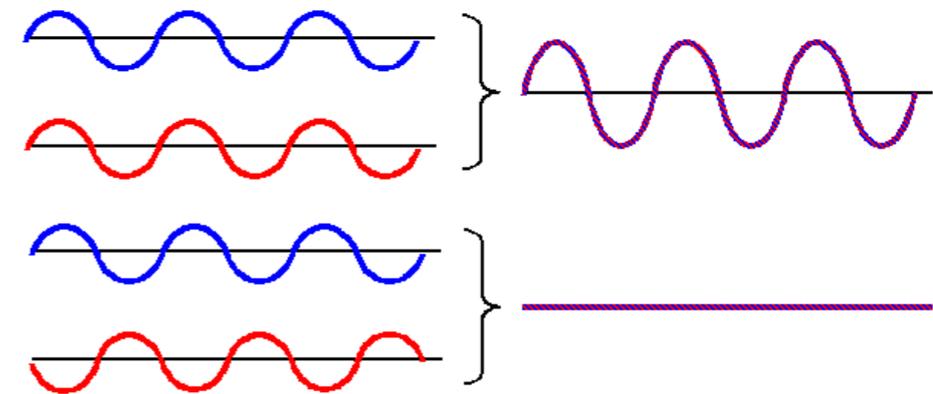


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[http://de.wikipedia.org/wiki/RAF\\_Fylingdales](http://de.wikipedia.org/wiki/RAF_Fylingdales)

[http://www.tf.uni-kiel.de/matwis/amat/mw1\\_ge/kap\\_2/basics/b2\\_1\\_6.html](http://www.tf.uni-kiel.de/matwis/amat/mw1_ge/kap_2/basics/b2_1_6.html)

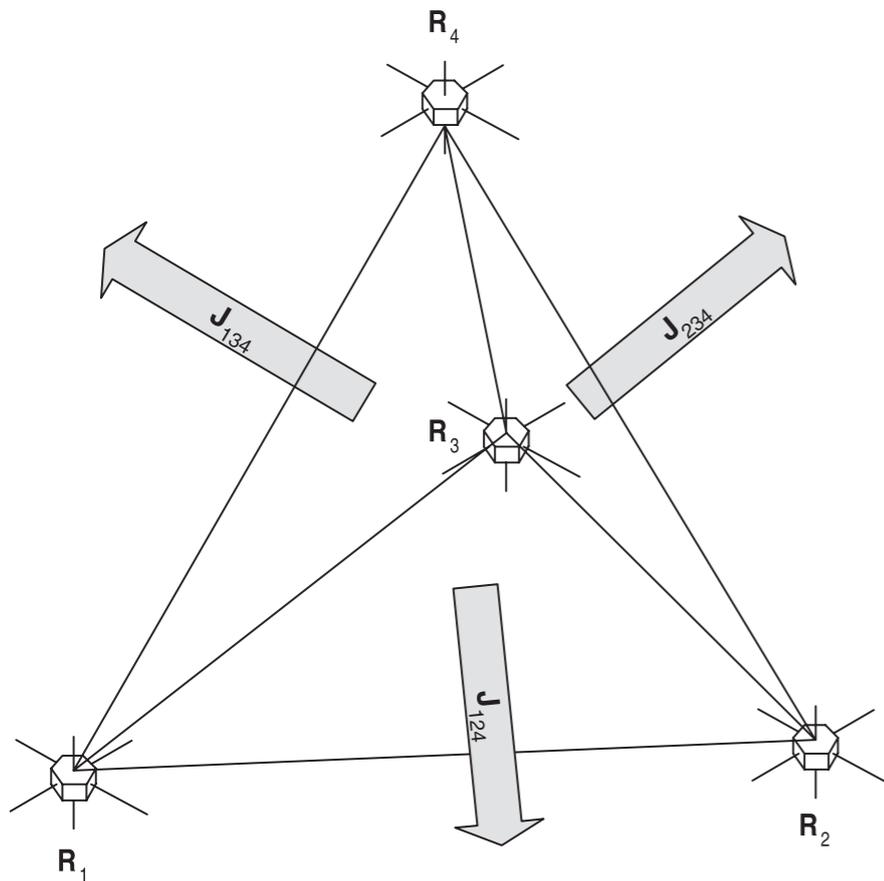


nach Narita und Glassmeier, 2006

Ampèresches Gesetz:

$$\mu_0 \vec{j} = \text{rot} \vec{B}$$

$$\mu_0 \int_A \vec{j} \cdot d\vec{A} = \int_{(A)} \vec{B} \cdot d\vec{S}$$

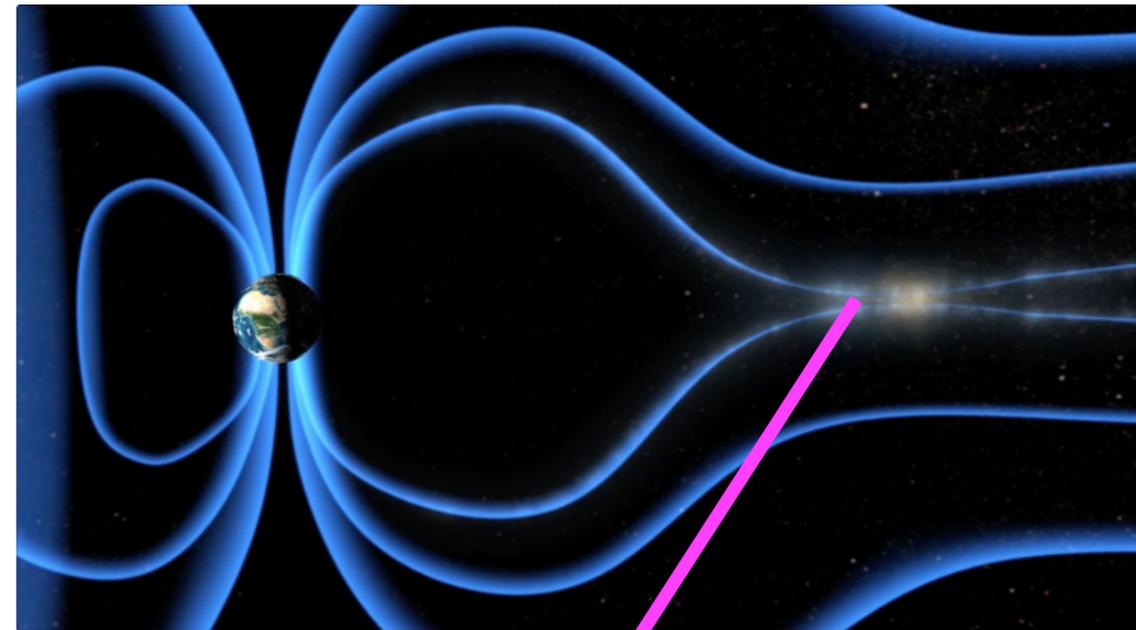


nach Dunlop et al., 2002

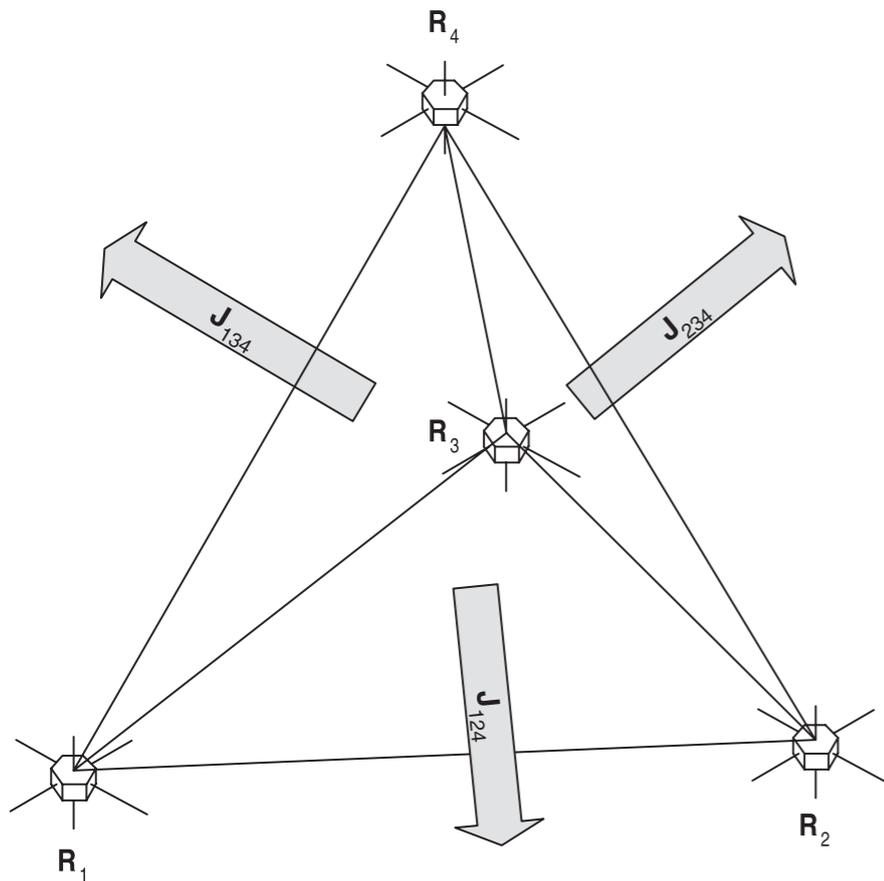
Ampèresches Gesetz:

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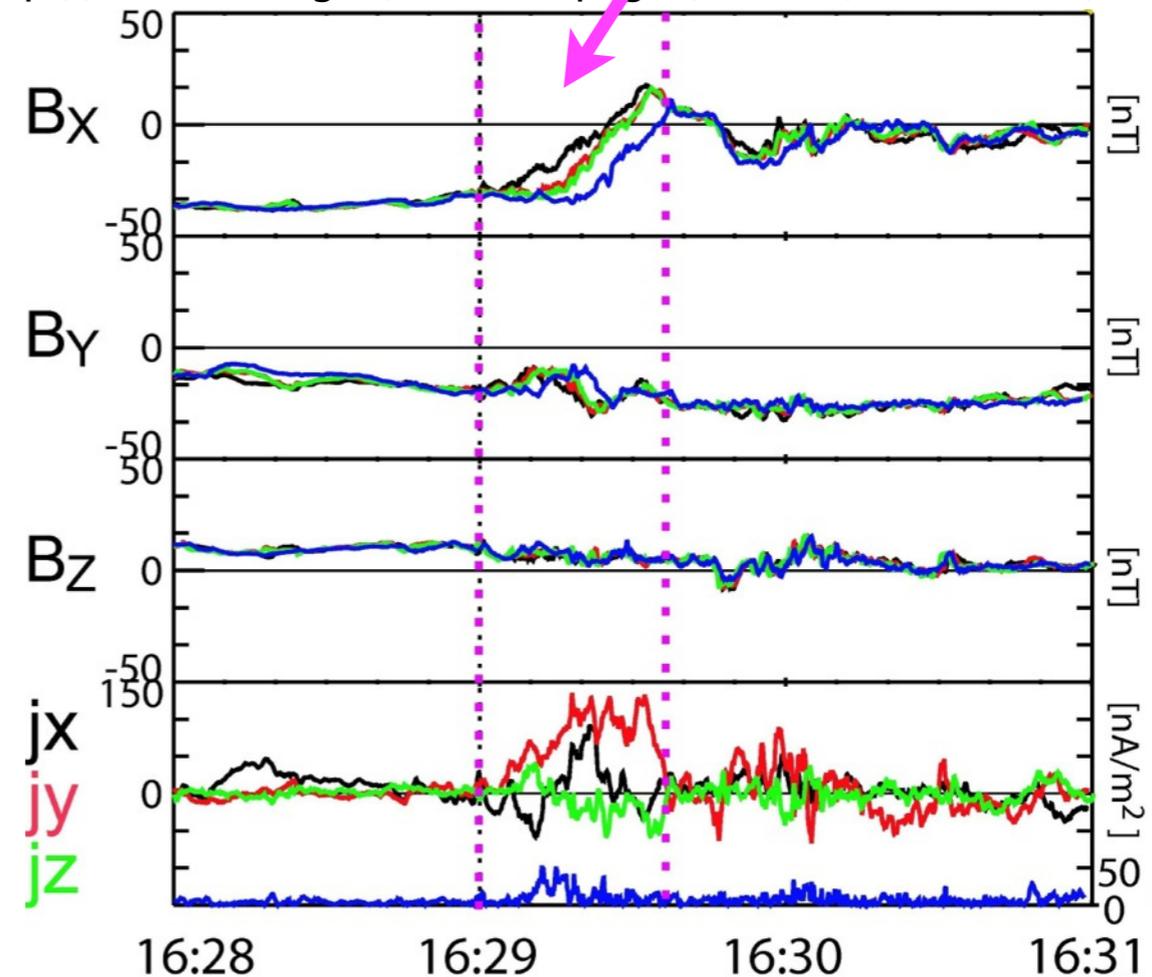
$$\mu_0 \int_A \vec{j} \cdot d\vec{A} = \int_{(A)} \vec{B} \cdot d\vec{S}$$



[http://www.nasa.gov/mission\\_pages/themis/multimedia/index.html](http://www.nasa.gov/mission_pages/themis/multimedia/index.html)



nach Dunlop et al., 2002



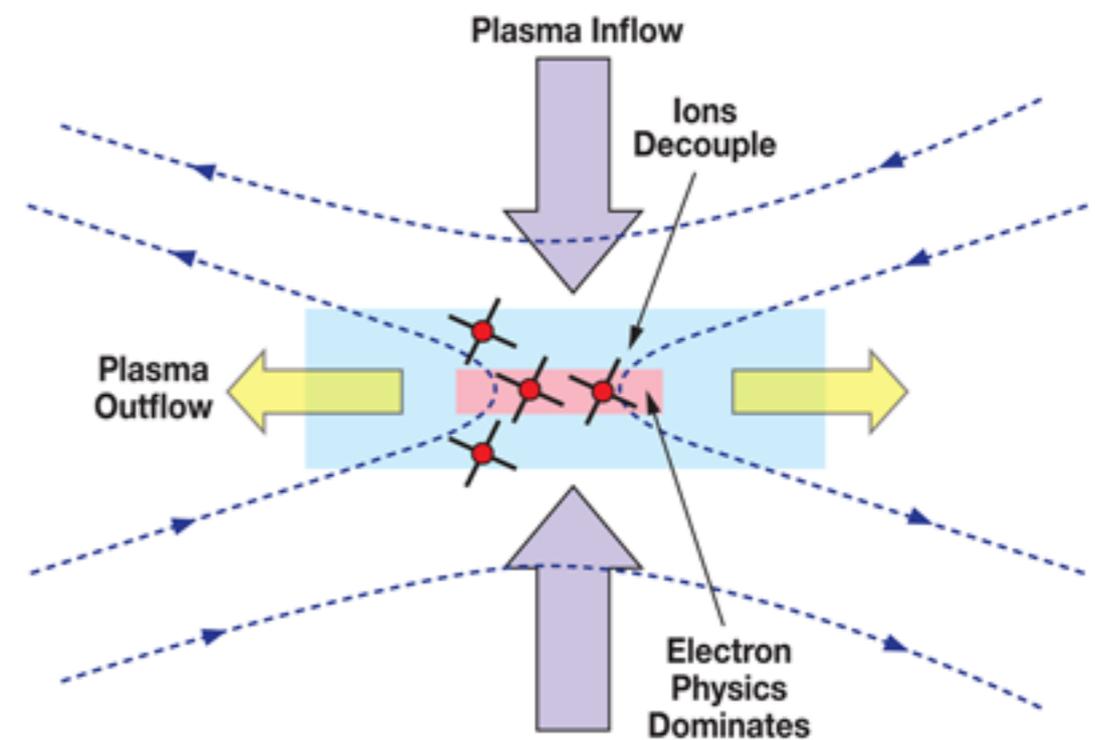
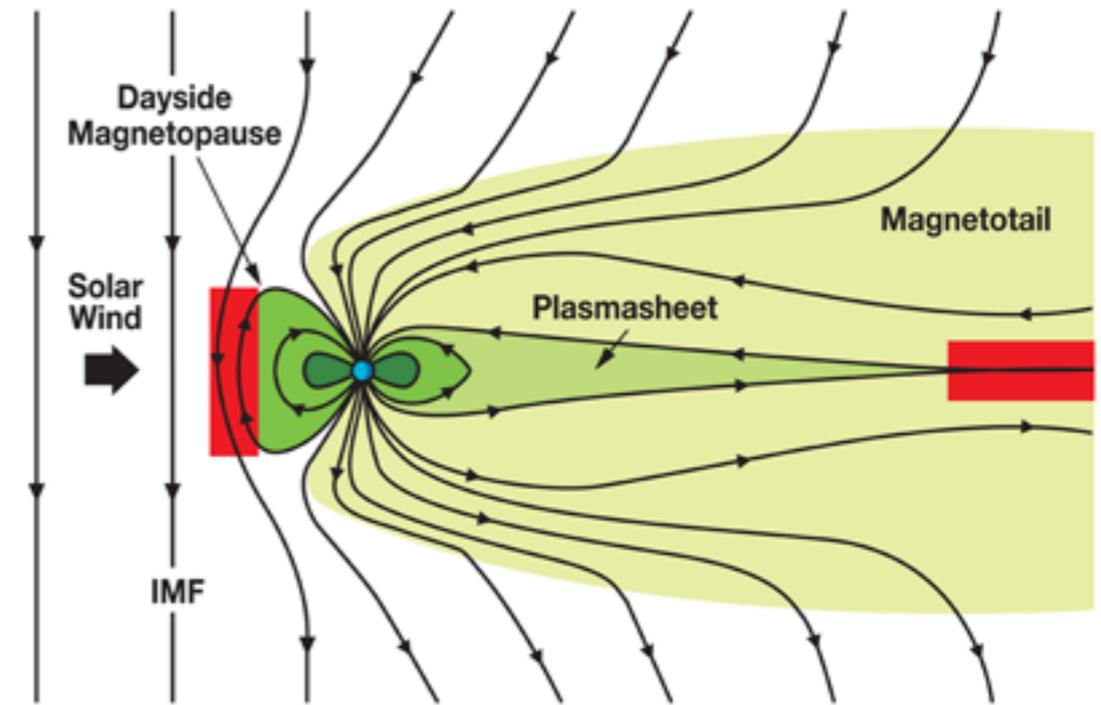
<http://sci.esa.int/jump.cfm?oid=34856>

<http://mms.gsfc.nasa.gov>



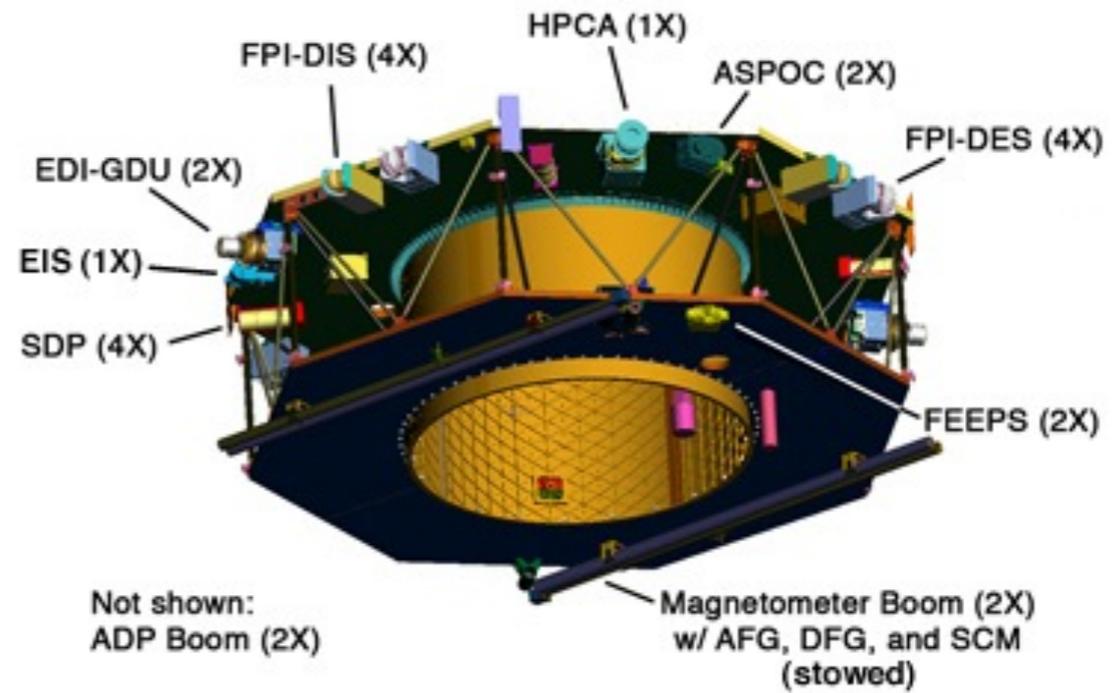
- NASA Mission, 4 Satelliten
- Abstände von ~10 km
- Start: März 2015

■ Wie funktioniert Rekonnexion?





<http://mms.space.swri.edu/instruments.html>

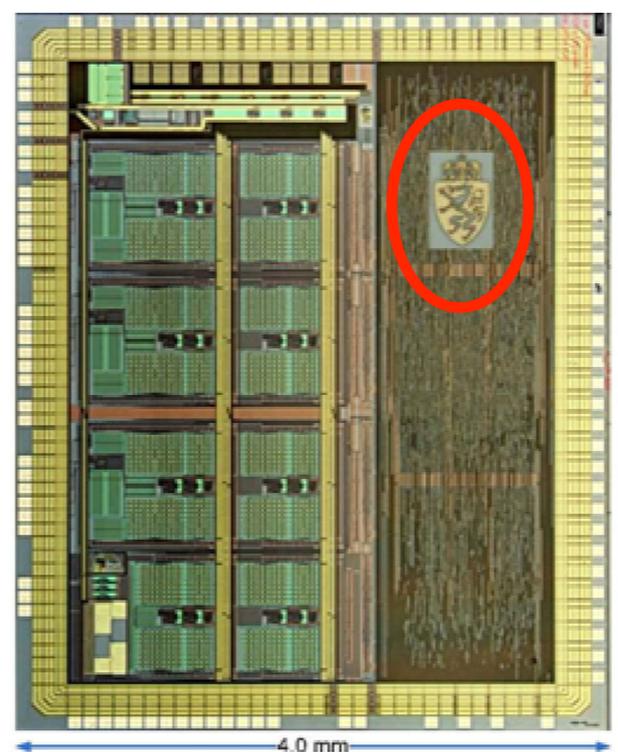
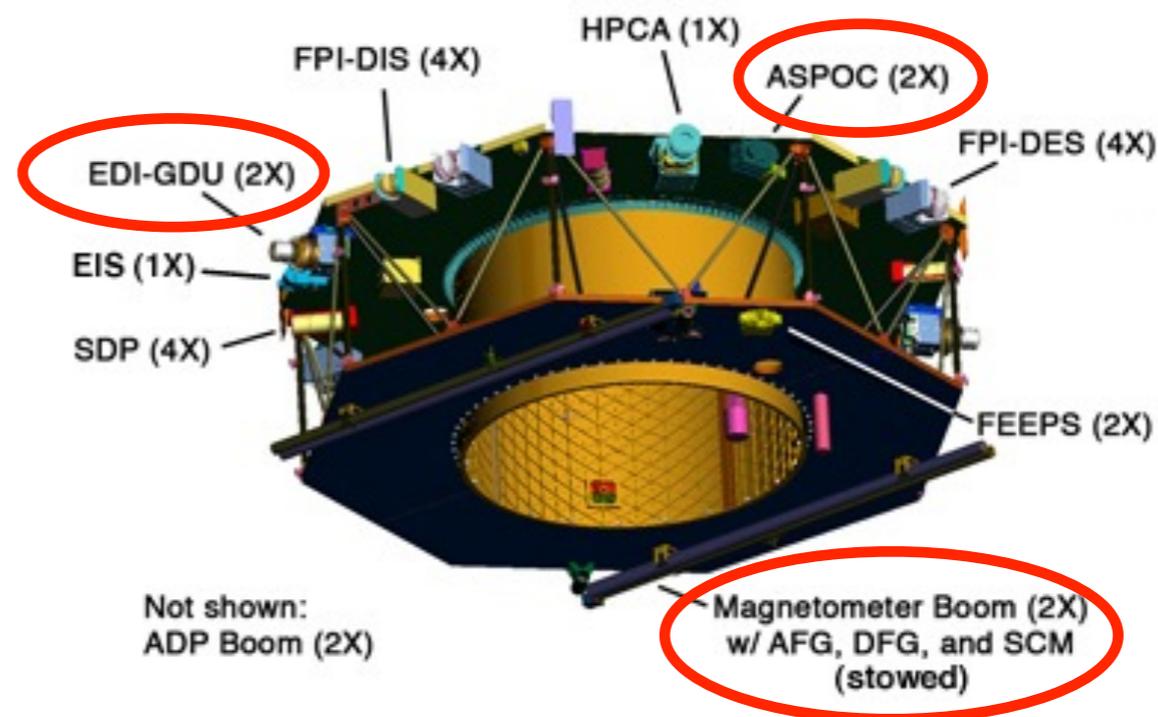


[http://mms.gsfc.nasa.gov/mms\\_spacecraft](http://mms.gsfc.nasa.gov/mms_spacecraft)



[http://mms.gsfc.nasa.gov/mms\\_spacecraft](http://mms.gsfc.nasa.gov/mms_spacecraft)

<http://mms.space.swri.edu/instruments.html>



nach Russell et al., 2014

- FPI = Fast Plasma Instrument
- DIS = Dual Ion Sensors
- DES = Dual Electron Sensors
- HPCA = Hot Plasma Composition Analyzer
- ASPOC = Active Spacecraft Potential Control Device
- FEEPS = Fly's Eye Energetic Particle Sensor
- EIS = Energetic Ion Spectrometer
- EDI = Electron Drift Instrument
- GDU = Gun Detector Unit
- SDP = Spin-plane Double Probe
- ADP = Axial Double Probe
- AFG = Analog Fluxgate Magnetometer
- DFG = Digital Fluxgate Magnetometer
- SCM = Search Coil Magnetometer





