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ASTRONOMIE & ASTROPHYSIQUE

Magnetic reconnection at the terrestrial magnetopause:

a simulation approach

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Brussels, October 11th, 2016

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Space weather effects at Earth

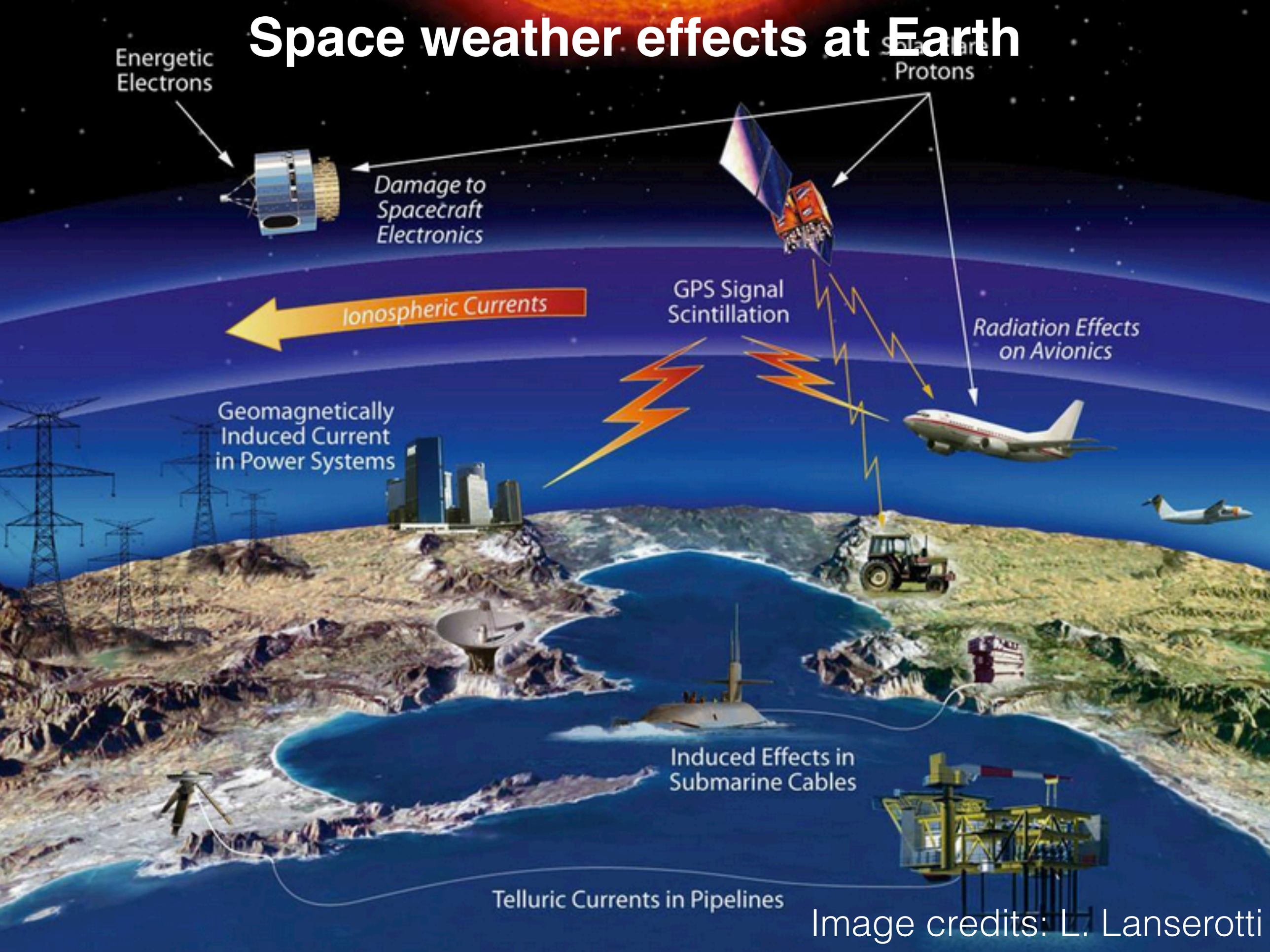

Image credits: L. Lanserotti

The Sun-Earth connection

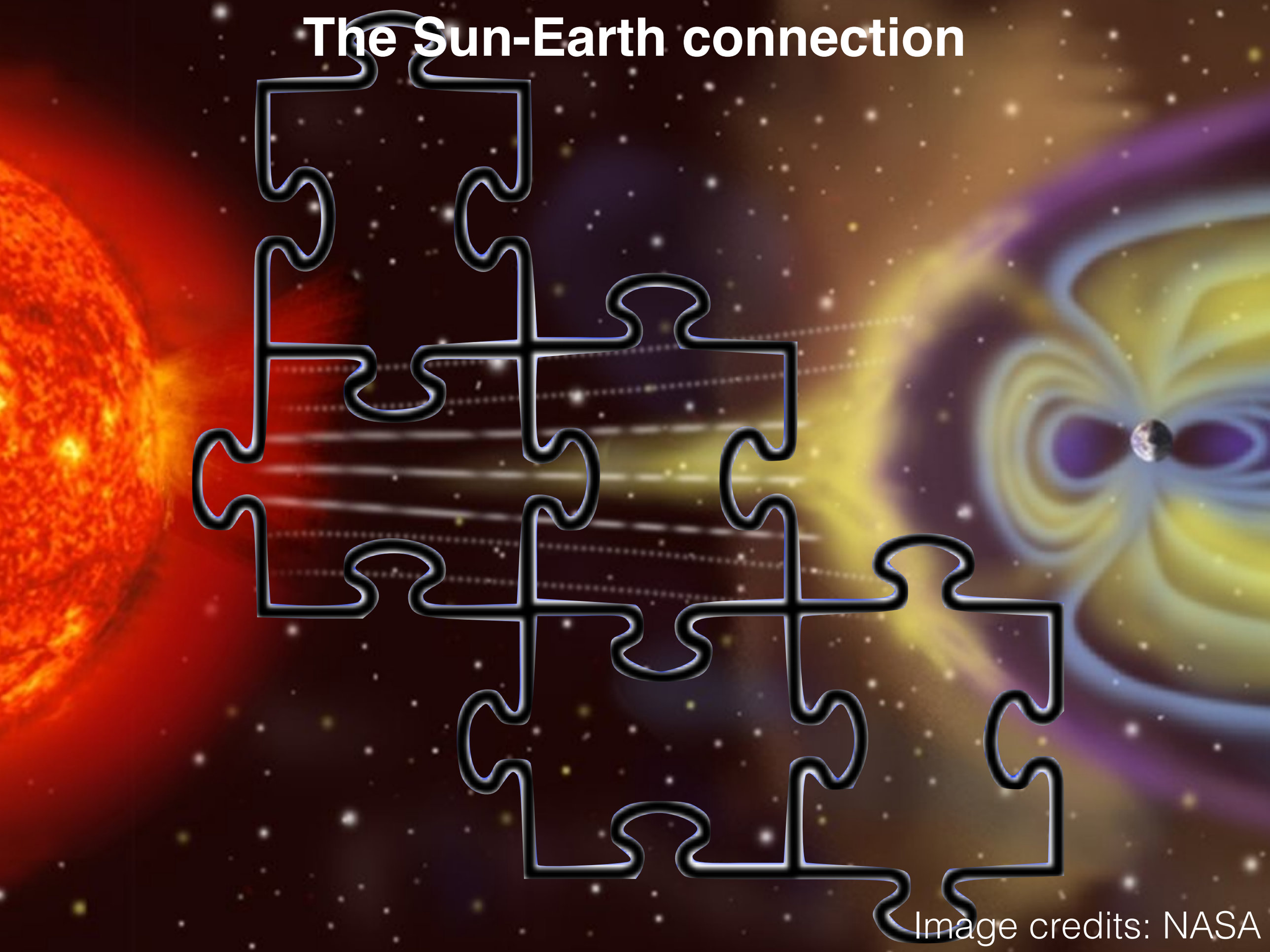

Image credits: NASA

The Sun-Earth connection

Coronal Mass Ejection at the Sun

Image credits: NASA

The Sun-Earth connection

Coronal Mass Ejection at the Sun

propagation in the background solar wind

Image credits: NASA

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reconnection at the terrestrial magnetopause

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Coronal Mass Ejection at the Sun

propagation in the background solar wind

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reconnection at the terrestrial magnetotail

geomagnetic effects at Earth

Image credits: NASA

The Magnetospheric Multiscale Mission (MMS)

- launched on March 13th, 2015
- four spacecrafts flying in formation with variable separation (d_i, d_e separation)
- will skim the magnetopause boundary during the first phase of operation
- aims at understanding the interplay of micro- and macro-scale in magnetopause reconnection

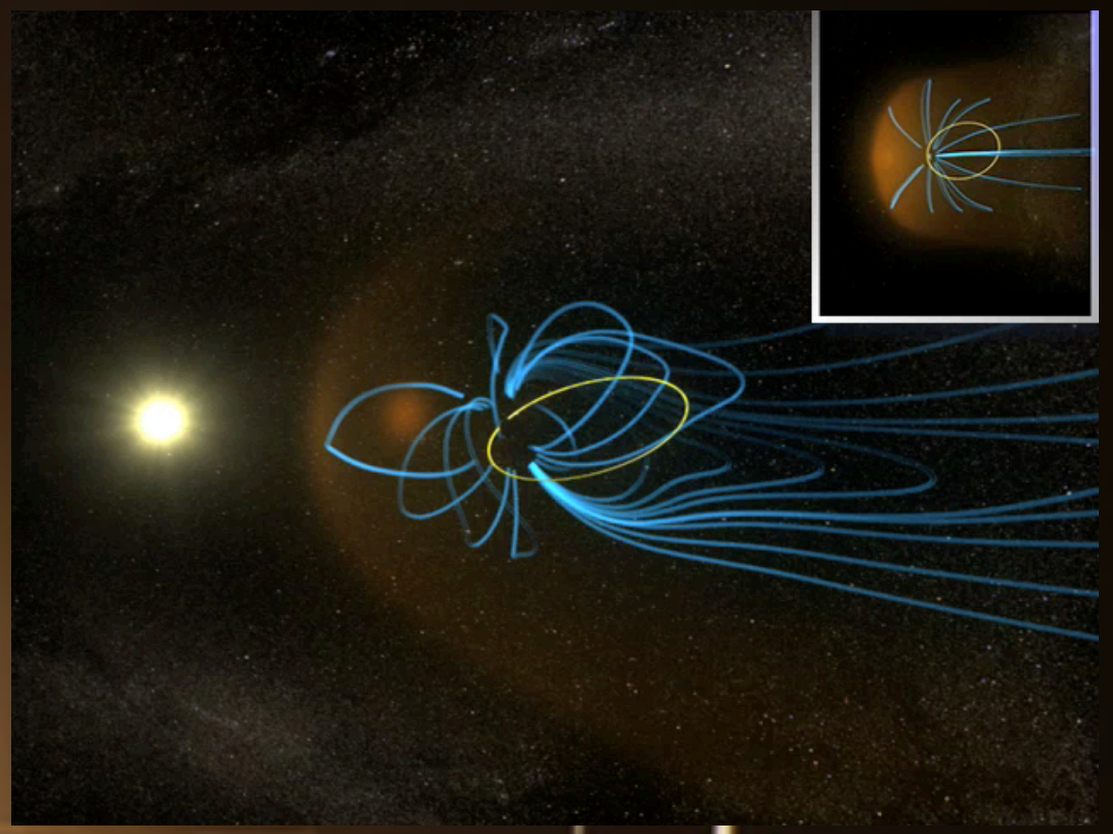
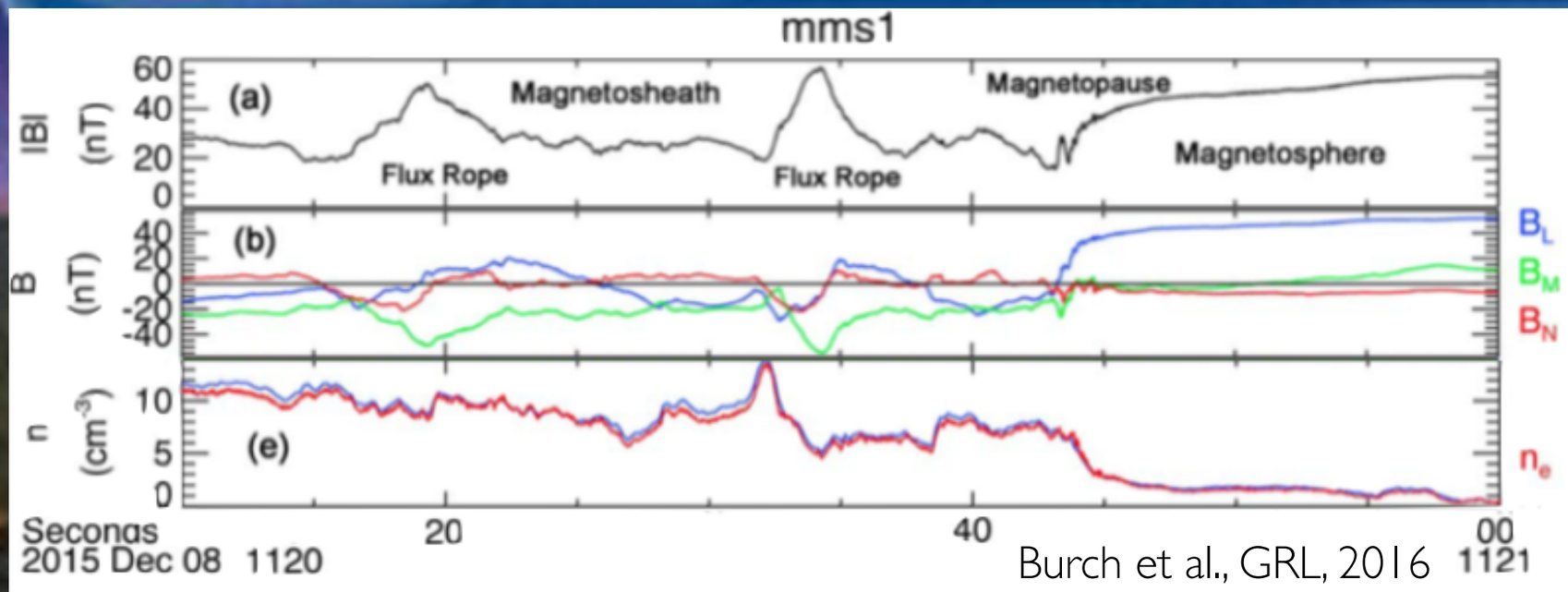


Image credits: NASA

The terrestrial magnetopause

L
N
bow shock
magnetosheath
magnetopause
cusp
trapping region
neutral sheet

Image credits: NASA



Burch et al., GRL, 2016

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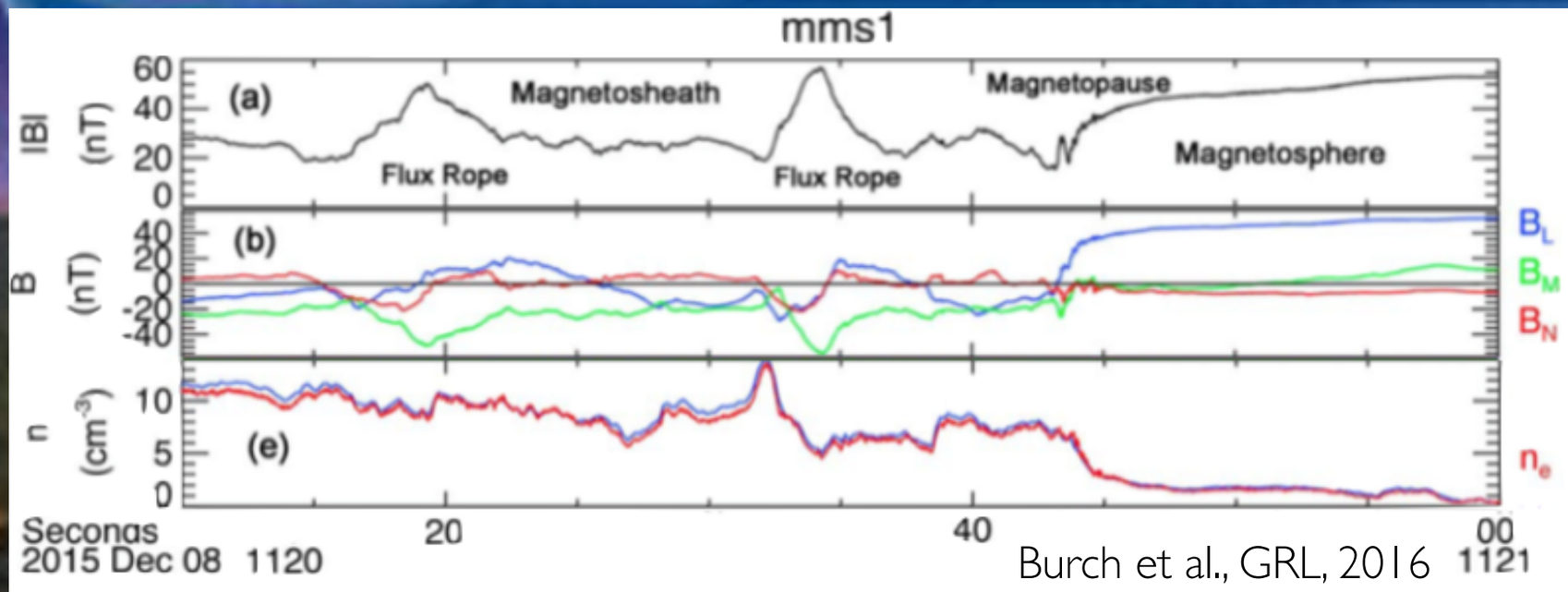

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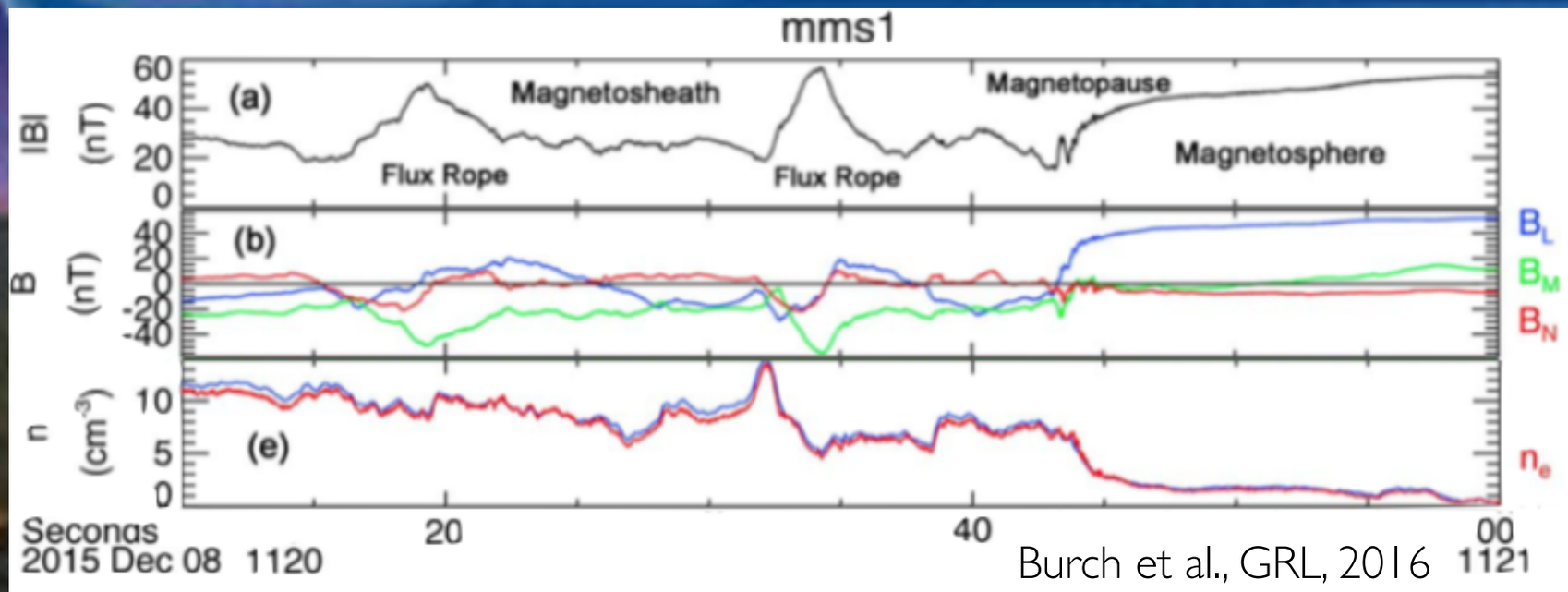

Burch et al., GRL, 2016

The terrestrial magnetopause

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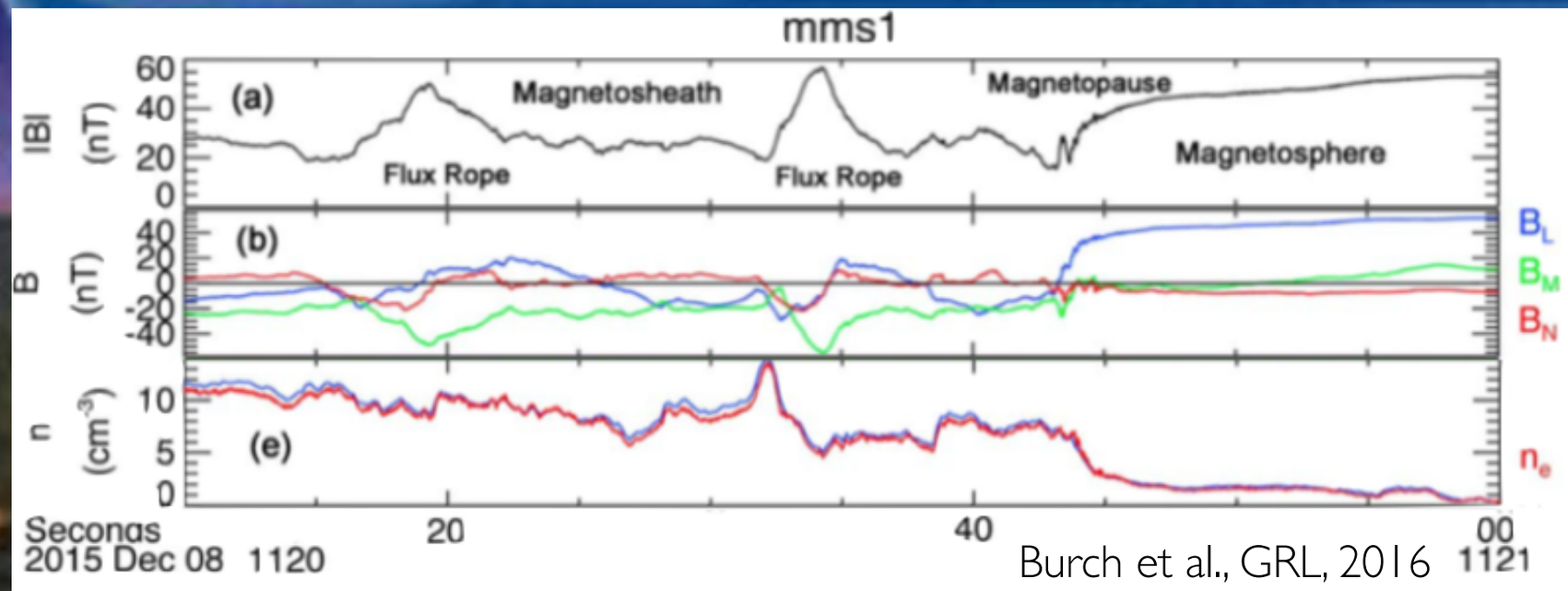
magnetic reconnection
at the magnetopause

cusp

trapping region

neutral sheet



Burch et al., GRL, 2016

Image credits: NASA

The terrestrial magnetopause

L
N

bow shock

magnetosheath

magnetopause

~ 10 R_E ~ 300 d_i ~ 64 000 km

cusp

trapping region

neutral sheet

lobes

Image credits: NASA

Burch et al., GRL, 2016

The terrestrial magnetopause

L

N

bow shock

magnetosheath

magnetopause

~ 10 R_E ~ 300

SPHERE

SHEAT

y/d_i

x/d_i

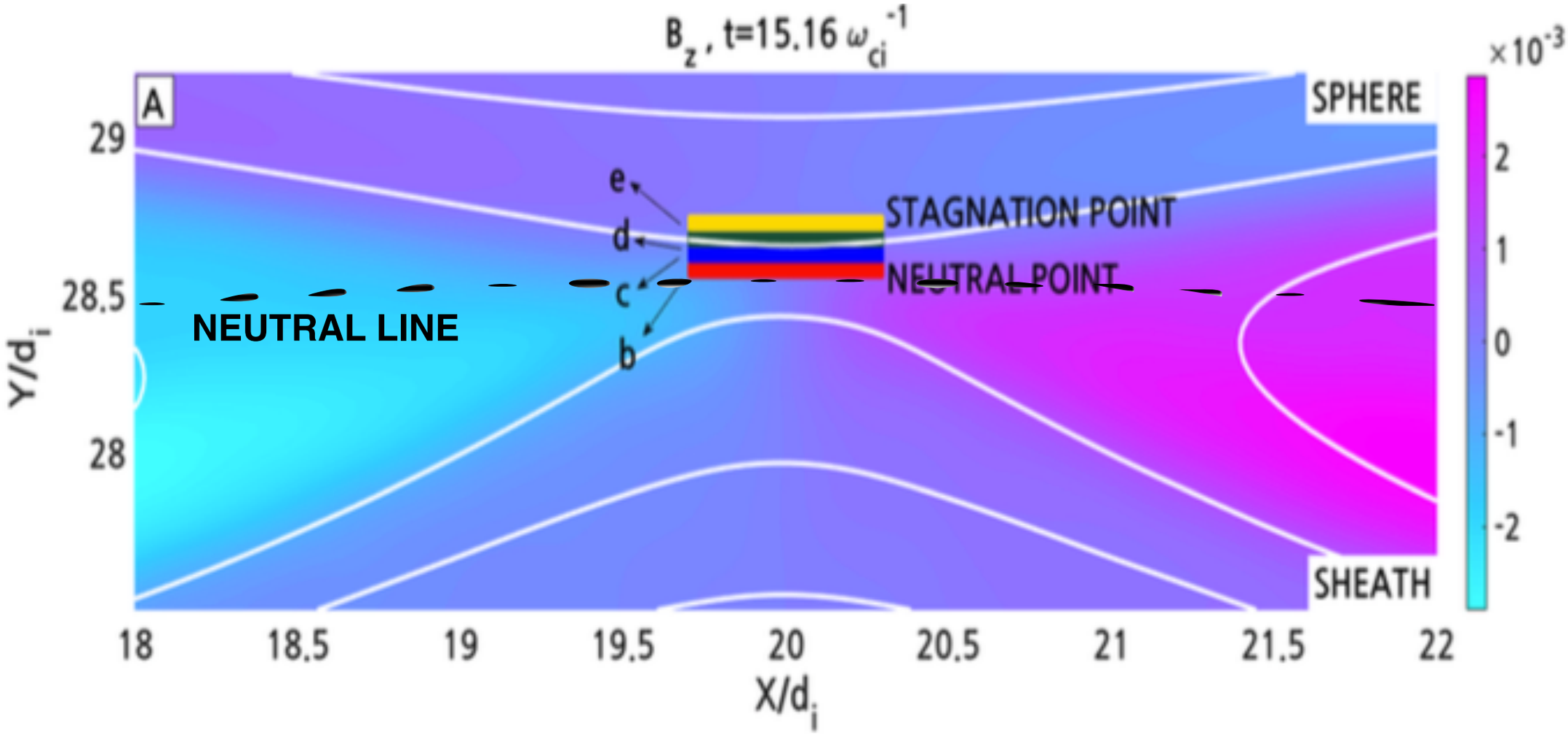
H

$1d_i$ ~ 200 km

Image credits: NASA

Burch et al., GRL, 2016

Focus on the Electron Diffusion Region



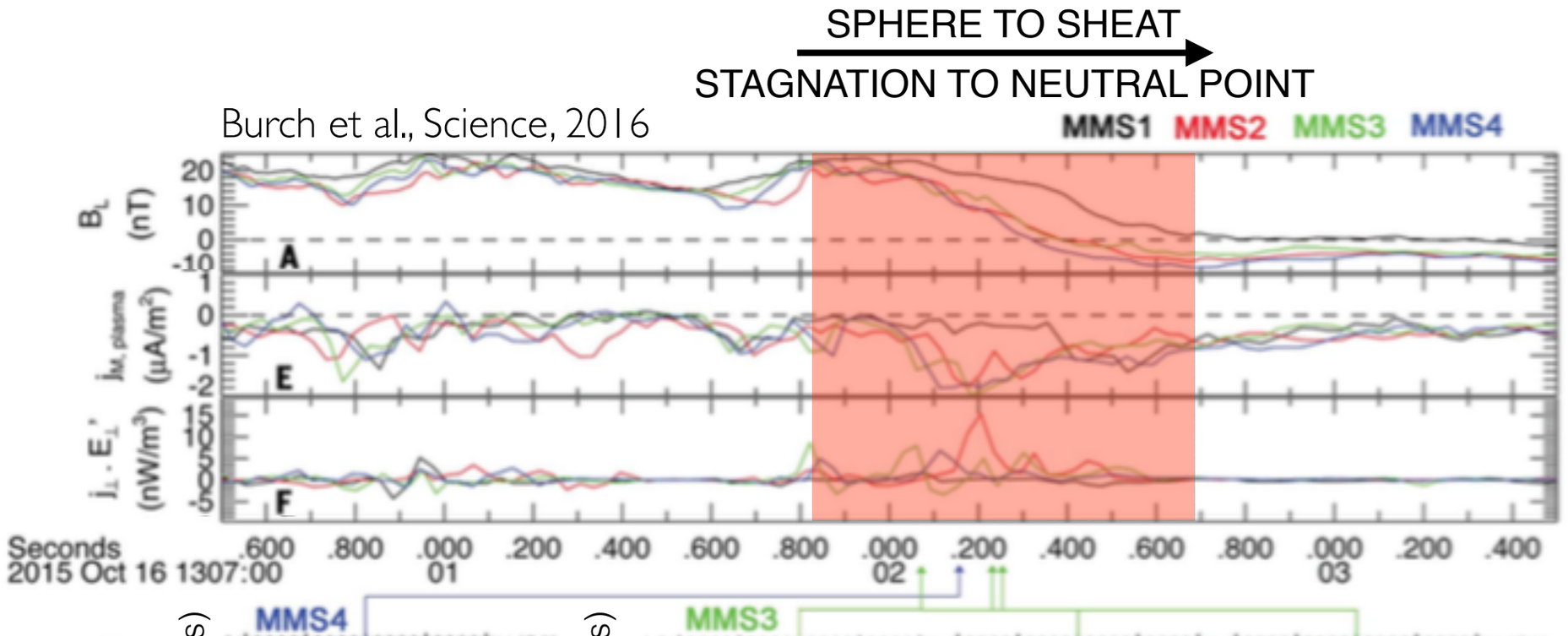
Identifiable by:

- inversion of the longitudinal magnetic field component, B_L (B_x)
- increased out of plane current, J_M (J_z)
- area of increased dissipation, $\mathbf{J}.\mathbf{E} > 0$

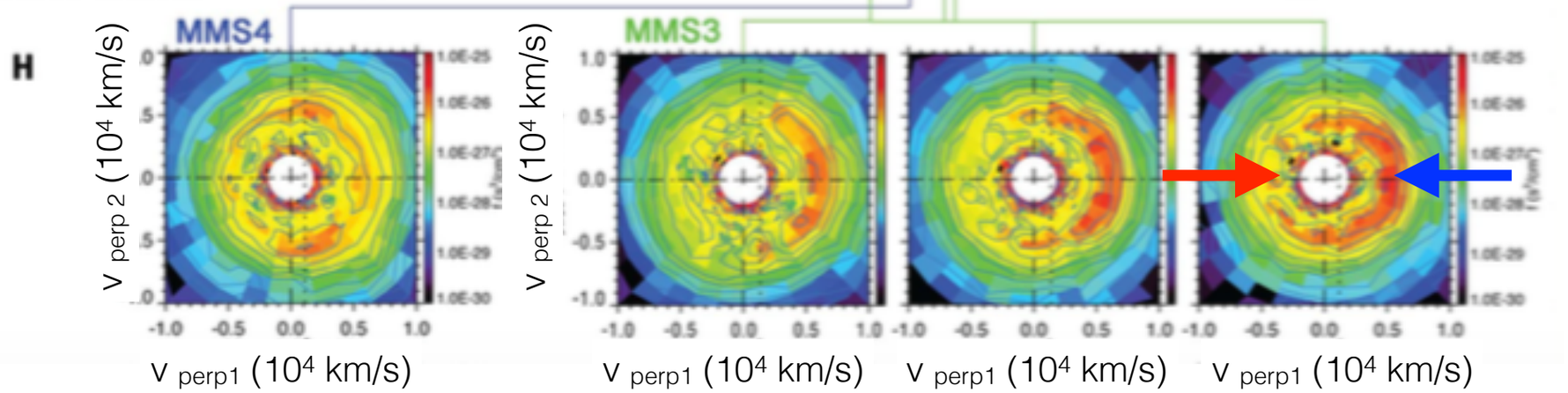
Important because:

- driver of the reconnection process
- preferential channel of entrance for solar wind particles into the magnetospheric system

MMS encounters with Electron Diffusion and observation of the electron crescent



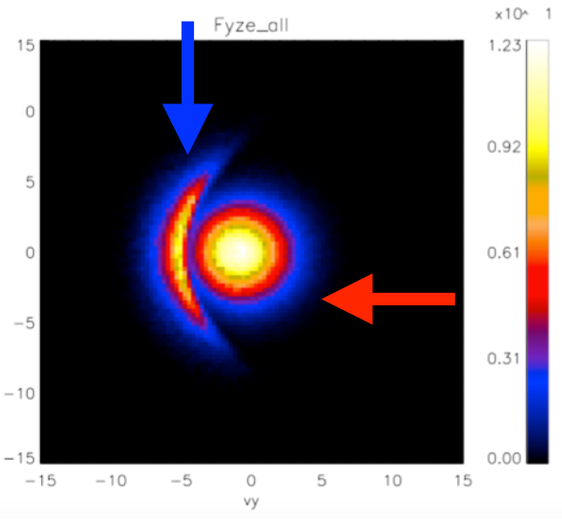
- ☑ inversion of B_L
- ☑ J_M peak
- ☑ J.E peak



observation of a core + crescent structure in the perpendicular velocity space, as expected from Hesse et al, 2014, 16

CORE POPULATION: ANISOTROPIC + GYROTROPIC

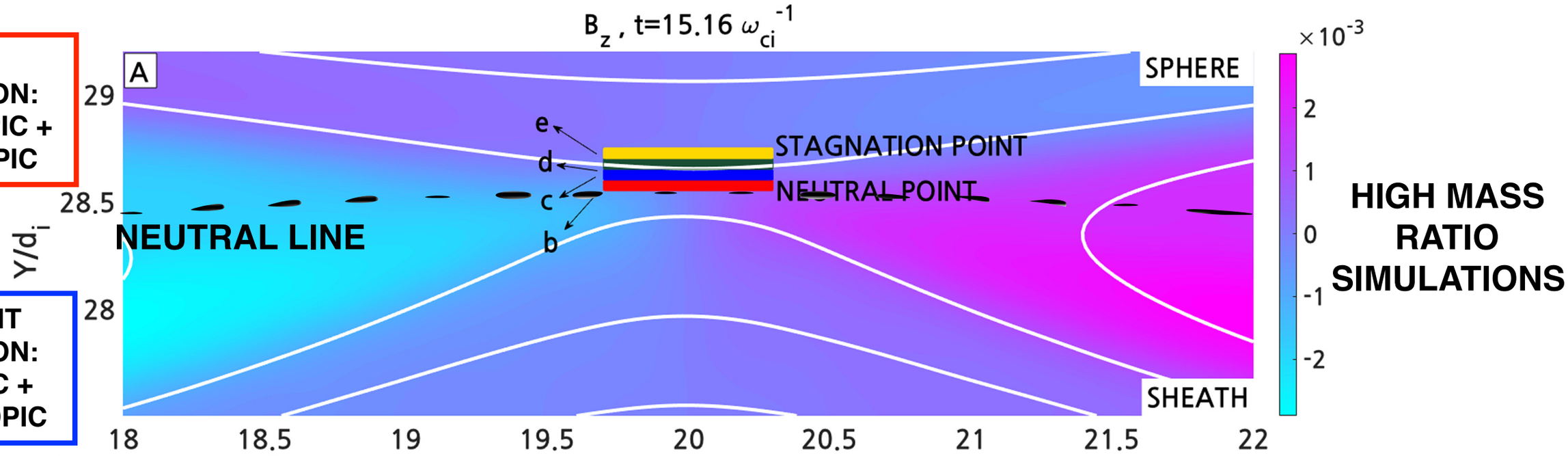
CRESCENT POPULATION: ISOTROPIC + AGYROTROPIC



Fully kinetic simulation of magnetopause reconnection

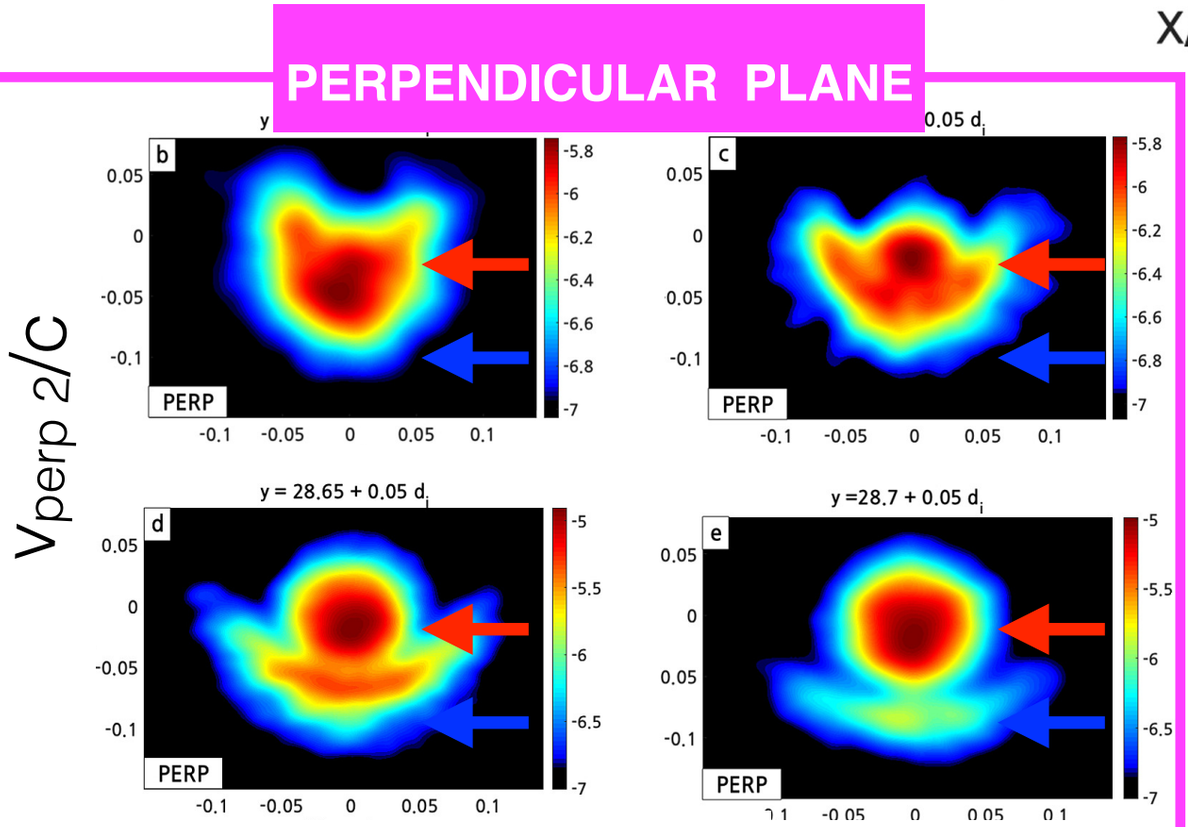
CORE POPULATION: ANISOTROPIC + GYROTROPIC

CRESCENT POPULATION: ISOTROPIC + AGYROTROPIC

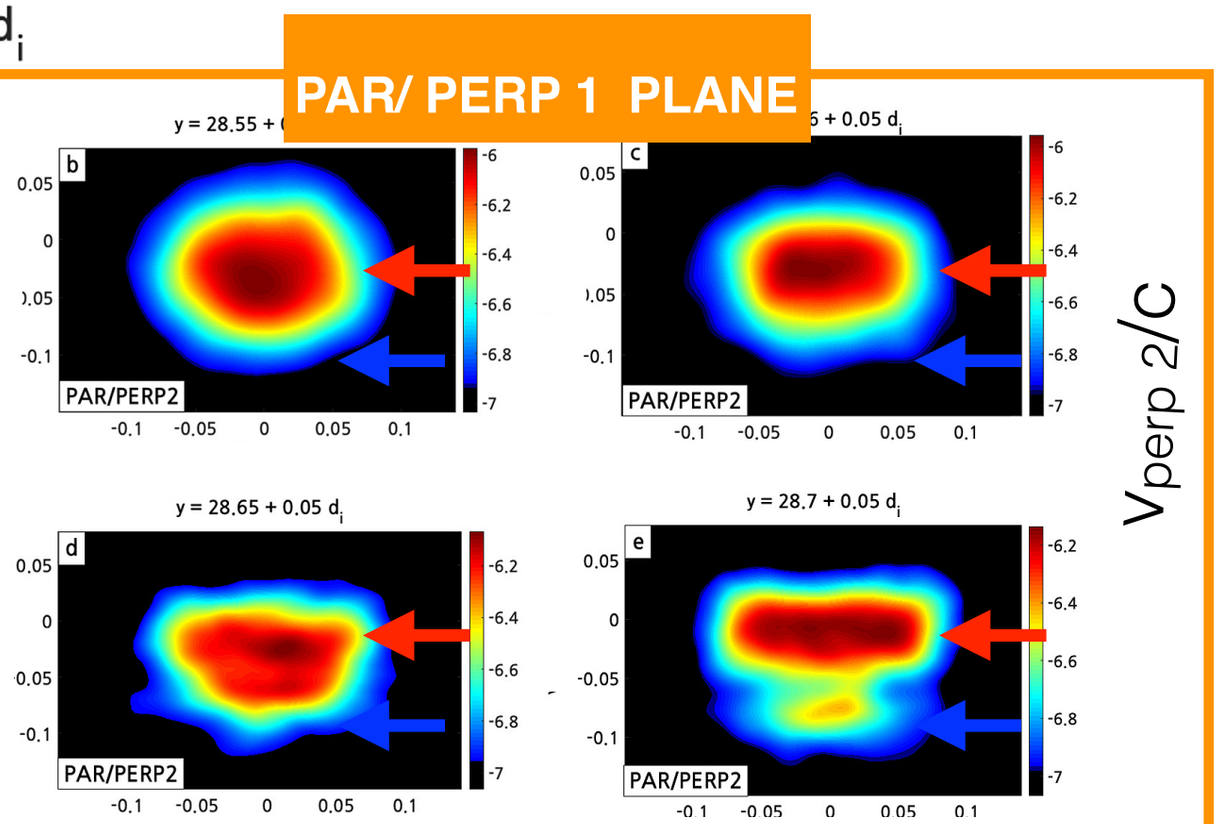


HIGH MASS RATIO SIMULATIONS

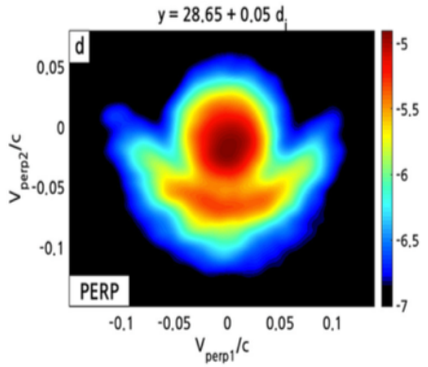
PERPENDICULAR PLANE



PAR/ PERP 1 PLANE



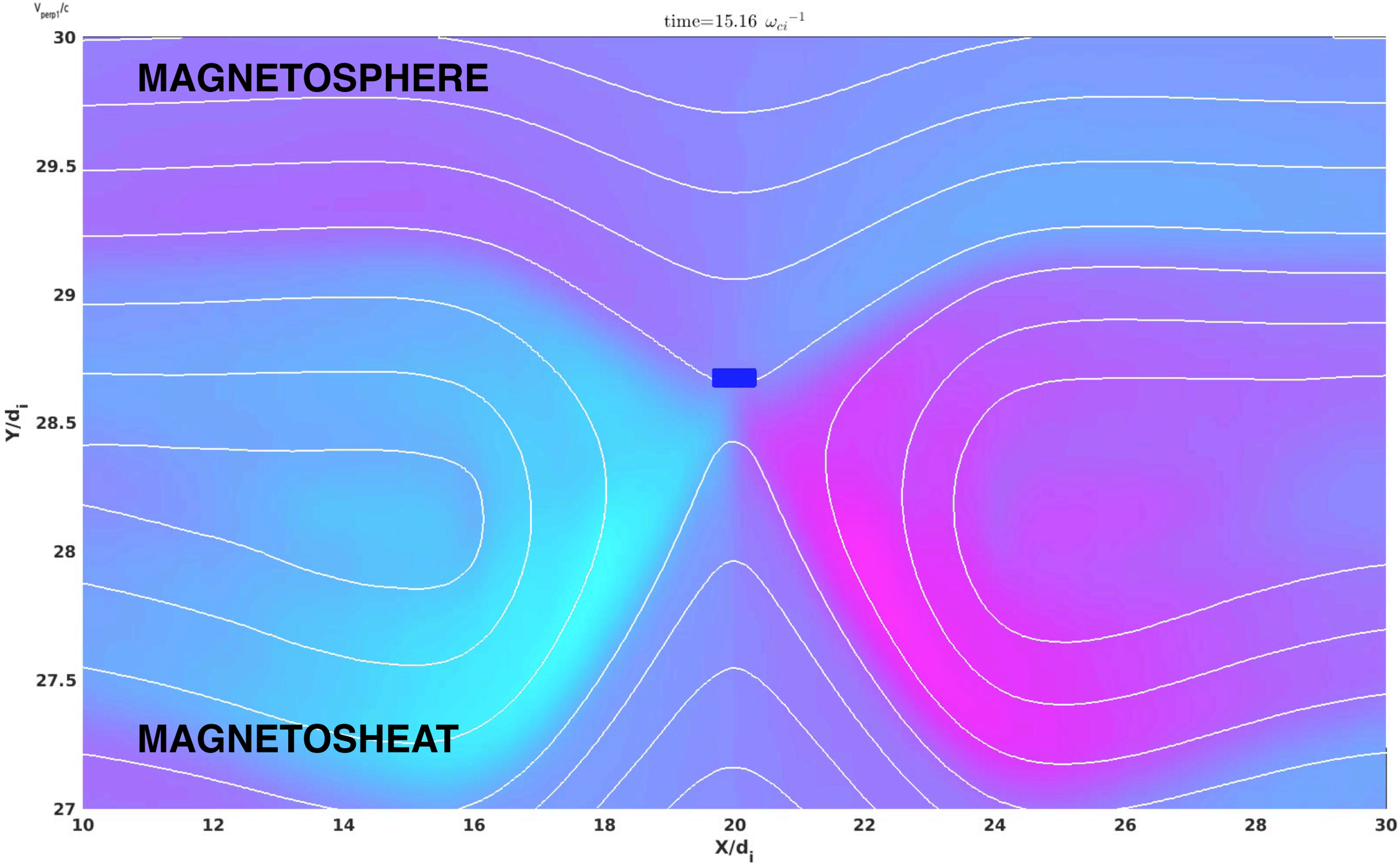
Origin of the core and crescent electron population



CORE POPULATION: ANISOTROPIC + GYROTROPIC

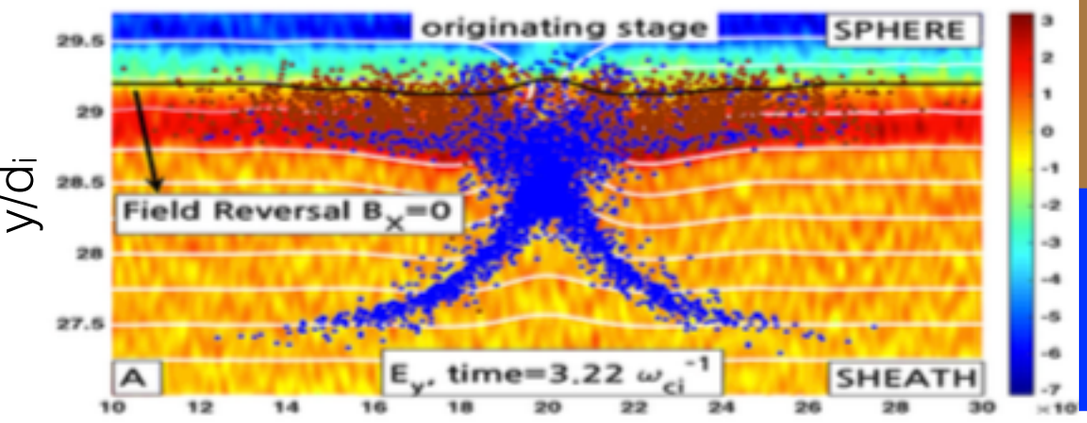
CRESCENT POPULATION: ISOTROPIC + AGYROTROPIC

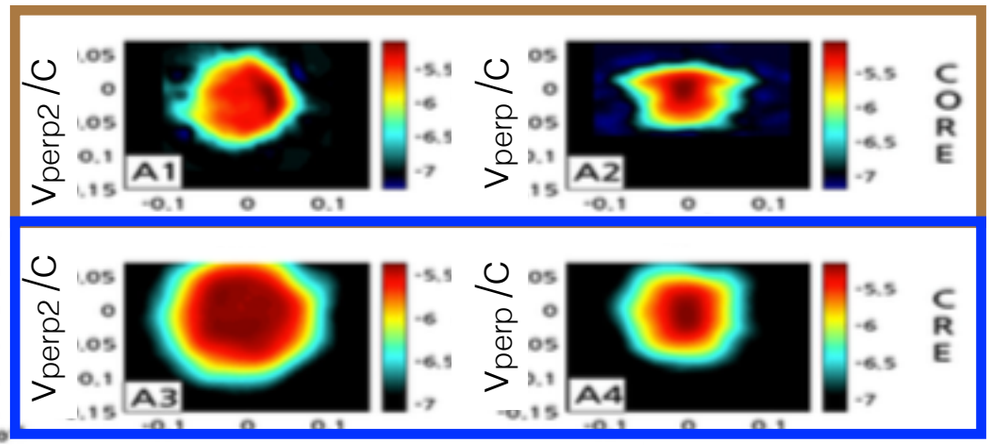
backtracing of core and crescent electrons



Origin of the core and crescent electron population

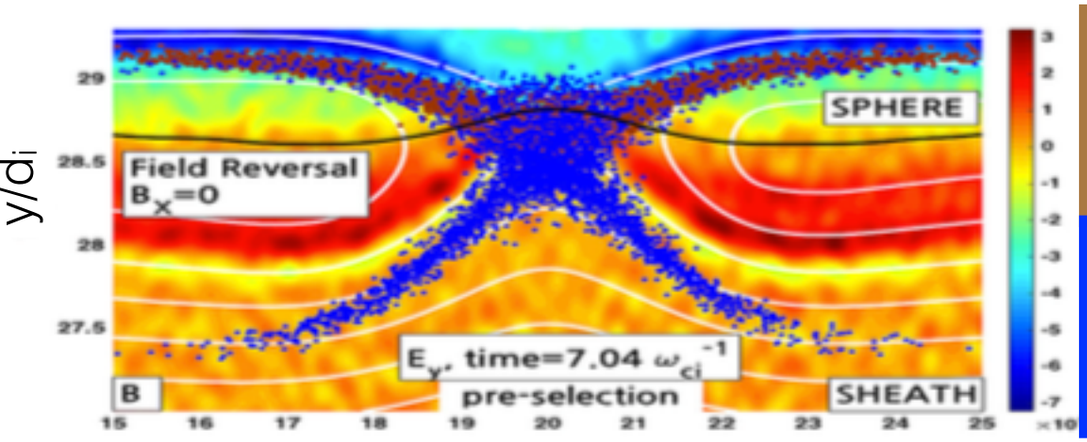
CORE **CRESCENT**

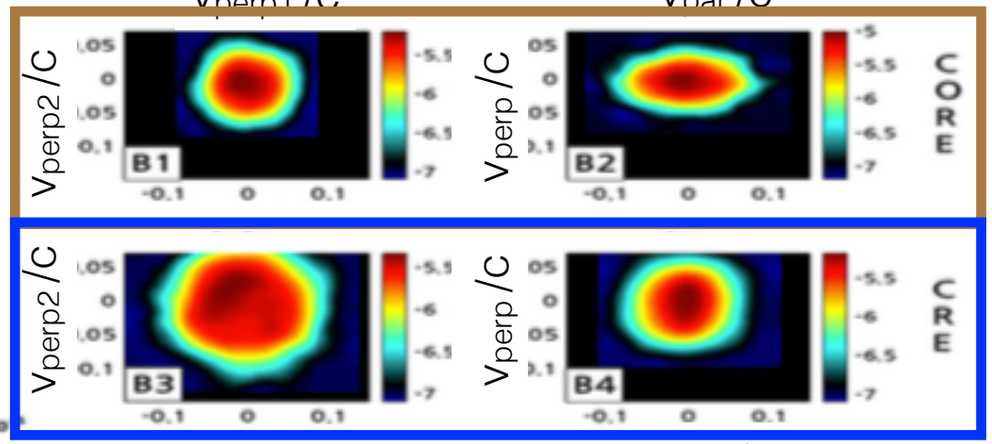




ORIGINATING STAGE

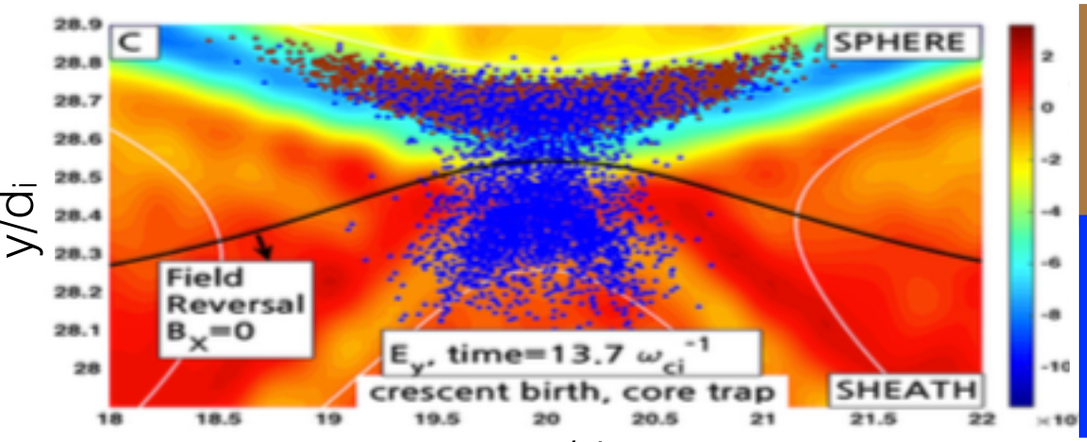
- crescent particles originate from deeper into the magnetosheat
- core particles cross the exhaust from the sheat to the upper separatrix
- crescent particles do not cross the exhaust

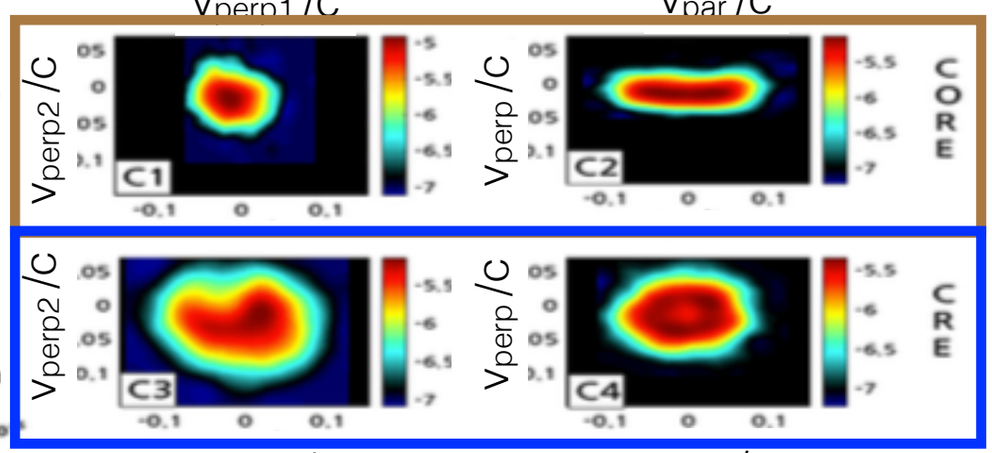




PRESELECTION STAGE

- crescent and core particles are separated in space
- differences in phase space start being evident

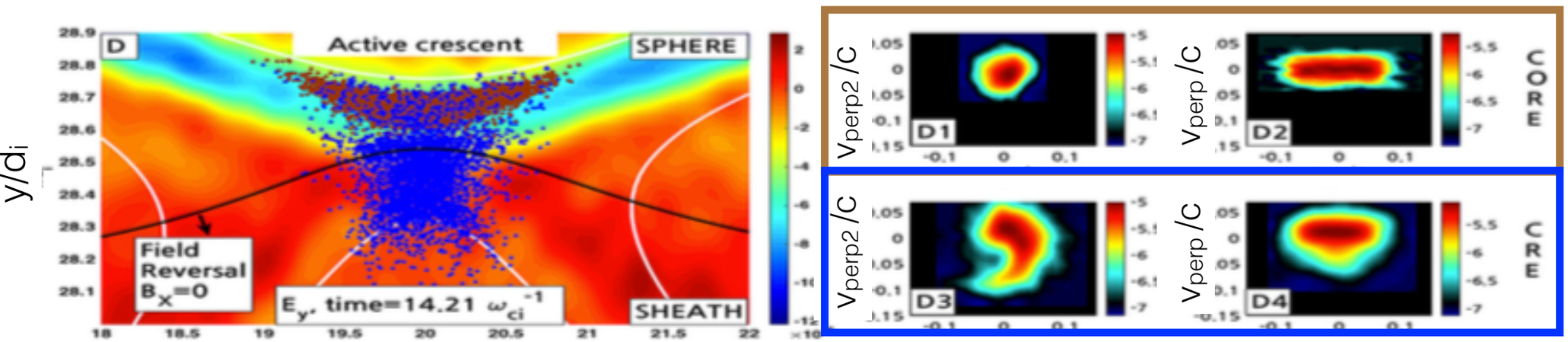




CRESCENT BIRTH & CORE TRAP

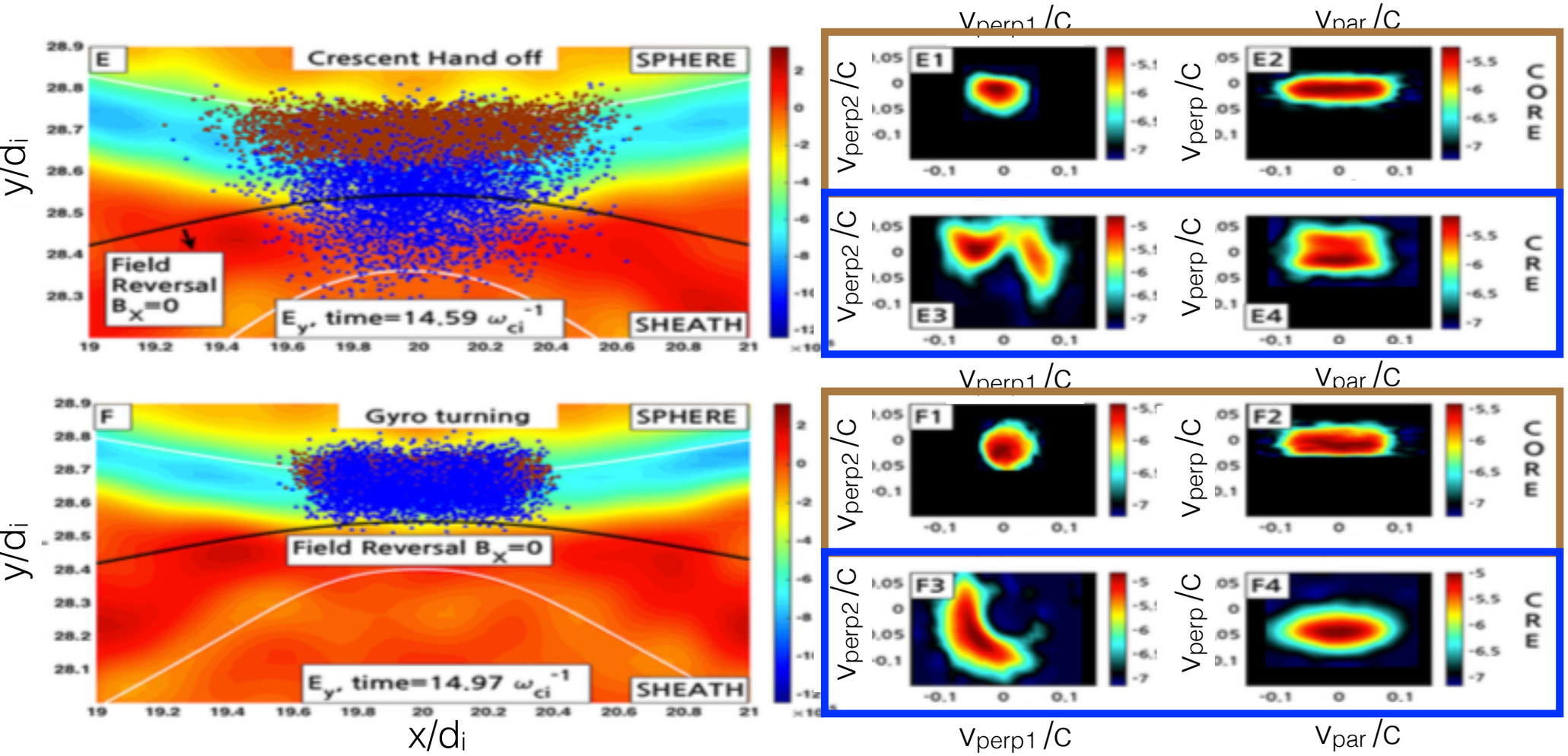
- core particles are segregated at the shoulder of the am bipolar field
  → parallel acceleration
- crescent particles around the EDR
  → preliminary signature of the crescent

Origin of the core and crescent electron population



ACTIVE CRESCENT

- the crescent is formed
- most of the crescent particles are still in the sheat



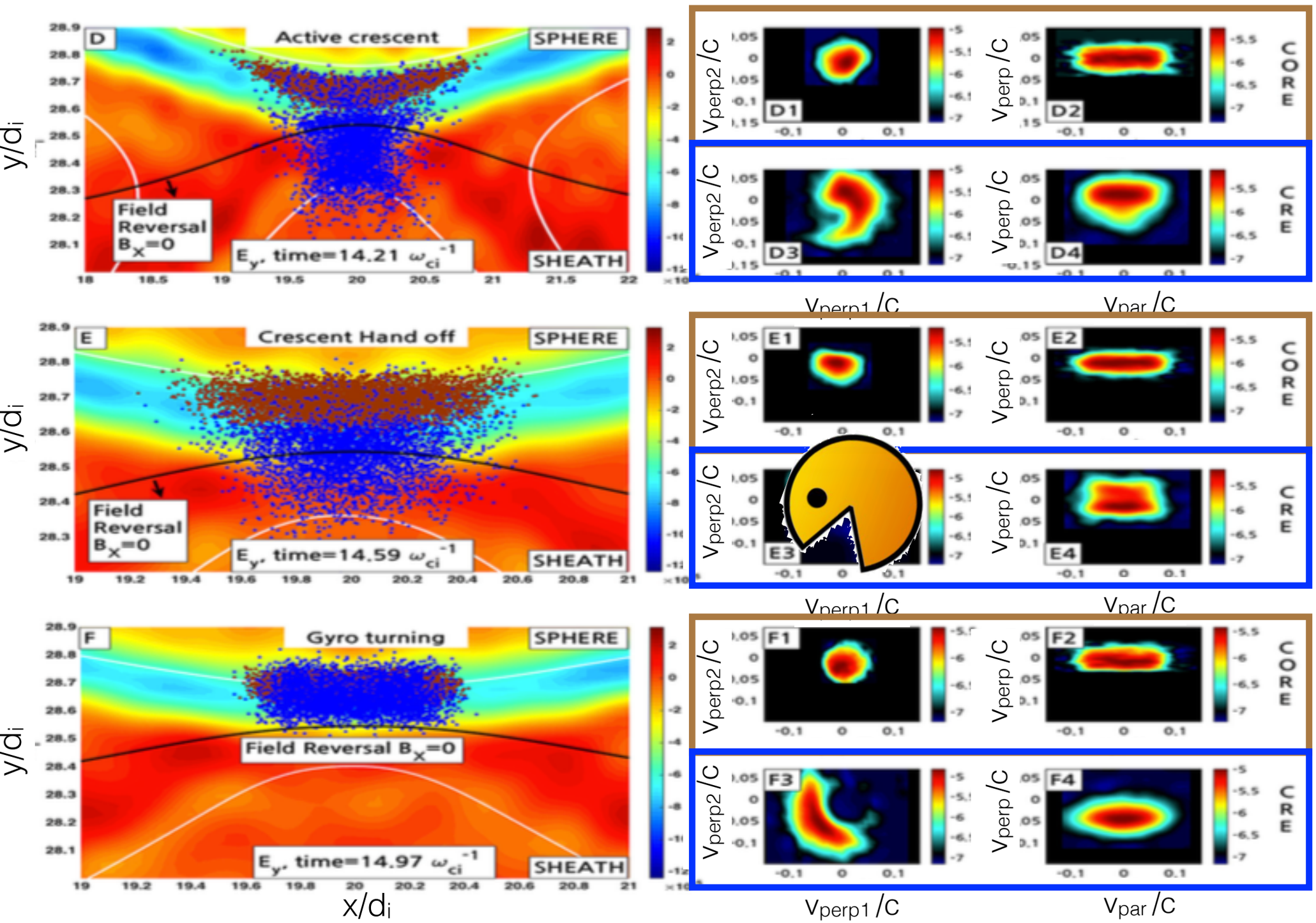
CRESCENT HAND OFF

- approximately half of the electrons are in the sheet (below the inversion line), half in the sphere
- in phase space, “pacman-like” shape → particles gyrating around oppositely-directed magnetic field lines

GYROTURNING

- the crescent particles have finally been completely gyroturned into the sphere

Origin of the core and crescent electron population



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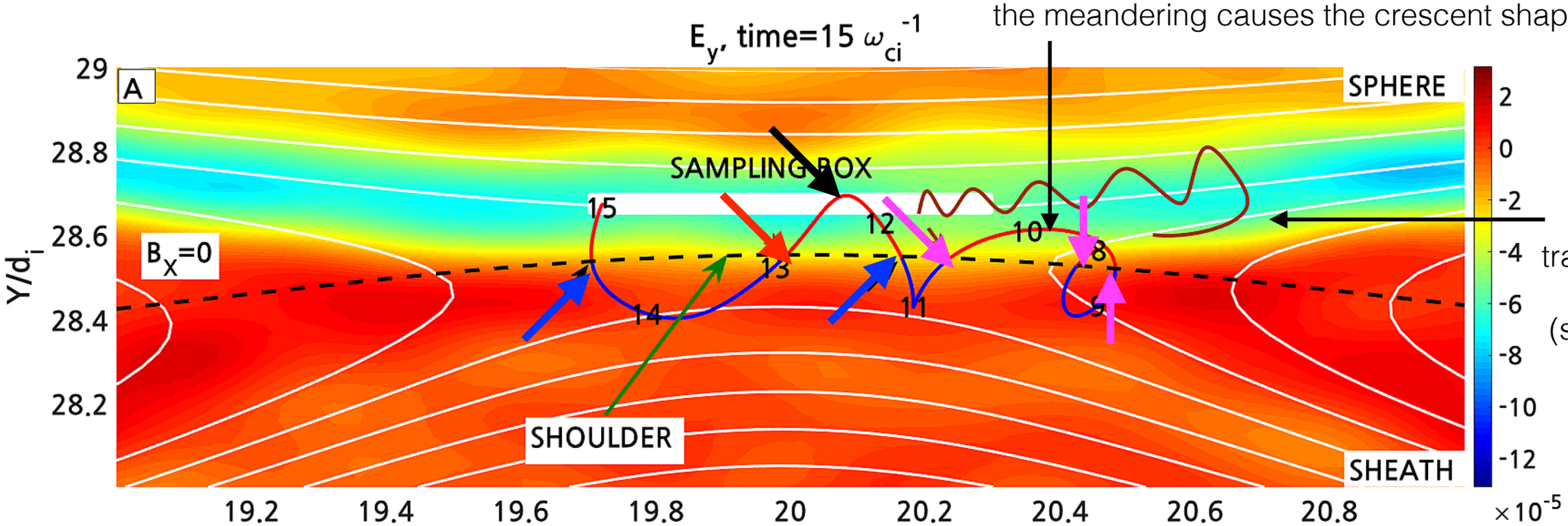
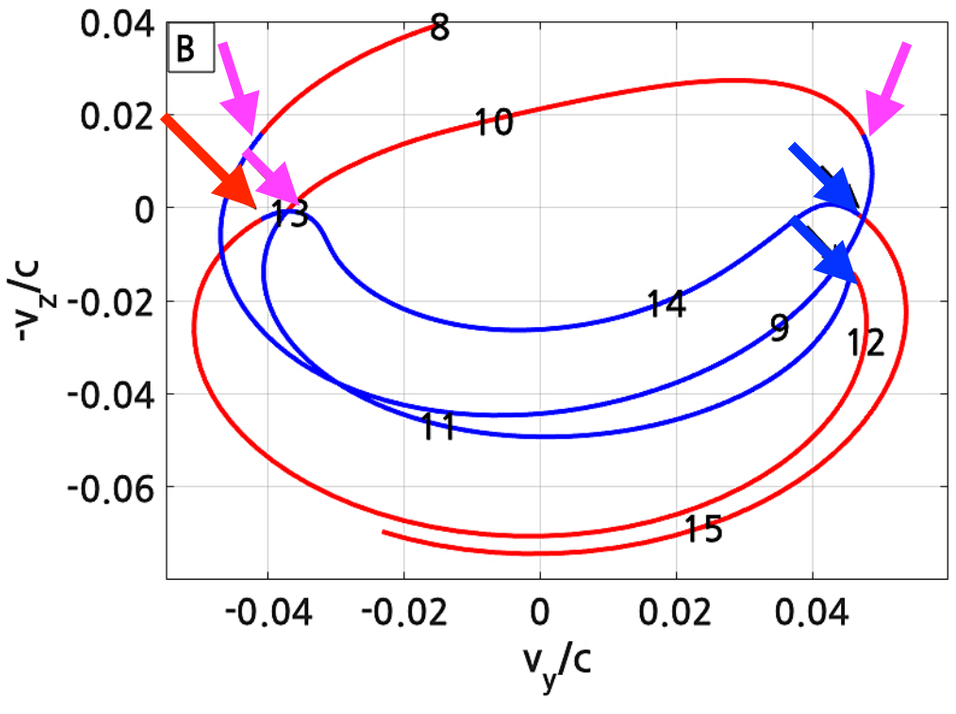
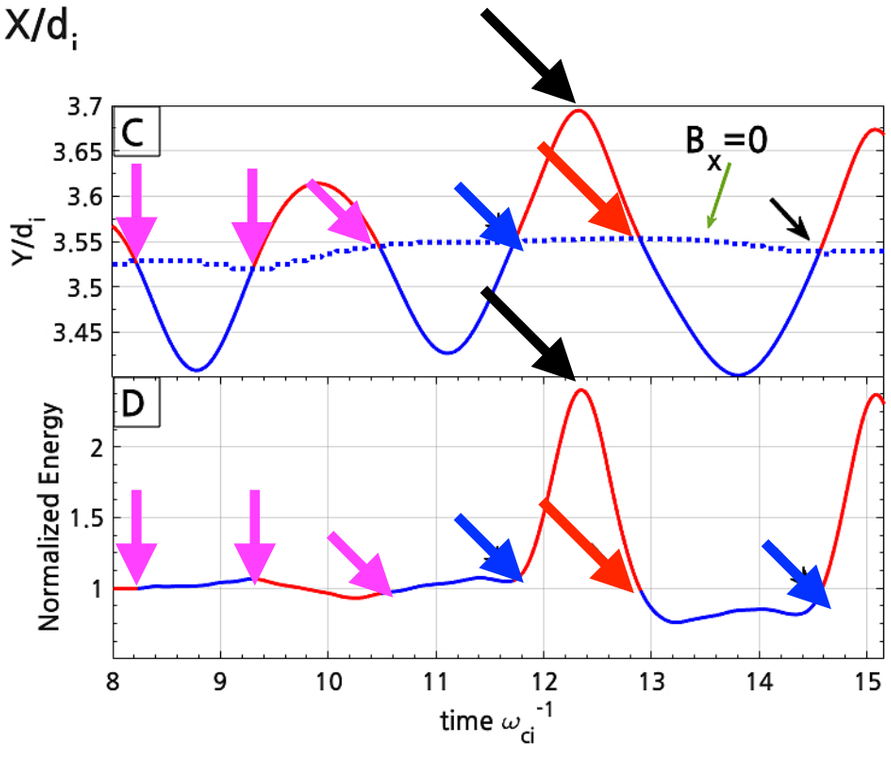
Trace of single electrons

CRESCENT ELECTRON
meanders at the inversion line, crossing back and forth between the sheat and the sphere
the meandering causes the crescent shape in velocity space



CORE ELECTRON
trapped at the ambipolar electric field
(sphere-side separatrix)





CROSSING WHEN MAGNETISED:
no change in energy,
no switch to other energy shell in perp plane

(UNMAGNETISED) CROSSING SHEAT TO SPHERE:
energy increases,
electron switches to higher energy shell

(UNMAGNETISED) CROSSING SPHERETO SHEAT:
after the **energy decrease**,
electron switches to lower energy shell

Conclusions

Reconnection at the terrestrial magnetopause is a fundamental piece of the Sun-Earth connection puzzle

The MMS mission has been recently launched to investigate magnetopause reconnection at the ion and electron scales

The MMS can, for the first time, investigate velocity space with electron-scale resolution
→ observations and simulations are finally on an equal footing as regards electrons

We investigate the origin of the crescent distribution observed in the perpendicular velocity space with fully kinetic simulations

Our ion to electron mass ratio is higher than comparable simulations (mr= 256 vs mr= 25)

We identify different path of access to the Electron Diffusion Region for core and crescent electrons

Core electrons cross the exhaust and are eventually trapped at the sphere-side separatrix, where they get accelerated in the parallel direction by the ambipolar field

Crescent electrons meander back and forth between the sheat and the sphere; crossing the neutral line when unmagnetised translated to switching to an higher (sheat to sphere) or lower (sphere to sheat) energy shell
→ crescent formation

REFERENCE: Arokiaraj, Innocenti, Cazzola, Lapenta, *"On the electron mixing of the crescent and core populations in reconnection at the Earth's magnetopause "*, in preparation

THANK YOU FOR YOUR ATTENTION