Cluster, MMS and Themis observations from the upstream magnetopause relevant for soft X-ray emissions and SMILE

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Annales Geophysicae

Four-spacecraft determination of magnetopause orientation, motion and thickness: comparison with results from single-spacecraft methods

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GEOPHYSICAL RESEARCH LETTERS, VOL. 29, NO. 9, 1347, 10.1029/2001GL014265,

Three-dimensional energetic ion sounding of the magnetopause using Cluster/RAPID

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[1] We present new results using energetic particles to remotely [*Williams*, 1979; *Williams et al.*, 1979] to

Journal of Geophysical Research: Space Physics

RESEARCH ARTICLE
10.1002/2014JA020539

Characteristics of the flank magnetopause: Cluster observations

Key Points:
- The magnetopause posesses a dawn-dusk asymmetry
- The flank magnetopause is thicker than the dayside magnetopause

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:H ARTICLE
'JA025121

Large-Scale Survey of the Structure of the Dayside Magnetopause by MMS

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G. Paschmann[1], S. E. Haaland[2,3], T. D. Phan[4], B. U. Ö. Sonnerup[5], J. L. Burch[6], R. B. Torbert[7], D. J. Gershman[8,9], J. C. Dorelli[8], B. L. Giles[8], C. Pollock[10], Y. Saito[11], B. Lavraud[12], C. T. Russell[13], R. J. Strangeway[13], W. Baumjohann[14], and S. A. Fuselier[6,15]

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Space Physics

CH ARTICLE
9JA026459

Characteristics of the Flank Magnetopause: THEMIS Observations

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R Space Physics

ARCH ARTICLE
/2019JA027623

Characteristics of the Flank Magnetopause: MMS Results

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S. Haaland[1,2], G. Paschmann[3], M. Øieroset[4], T. Phan[4], H. Hasegawa[5], S. A. Fuselier[6,7], V. Constantinescu[8], S. Eriksson[9], K. J. Trattner[9], S. Fadanelli[10,11], P. Tenfjord[12], B. Lavraud[10], C. Norgren[12], J. P. Eastwood[13], H. Hietala[13], and J. Burch[6]

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JGR Space Physics

REVIEW ARTICLE
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20 Years of Cluster Observations: The Magnetopause

Special Section:
Cluster 20th anniversary: results from the first 3D mission

Key Points:

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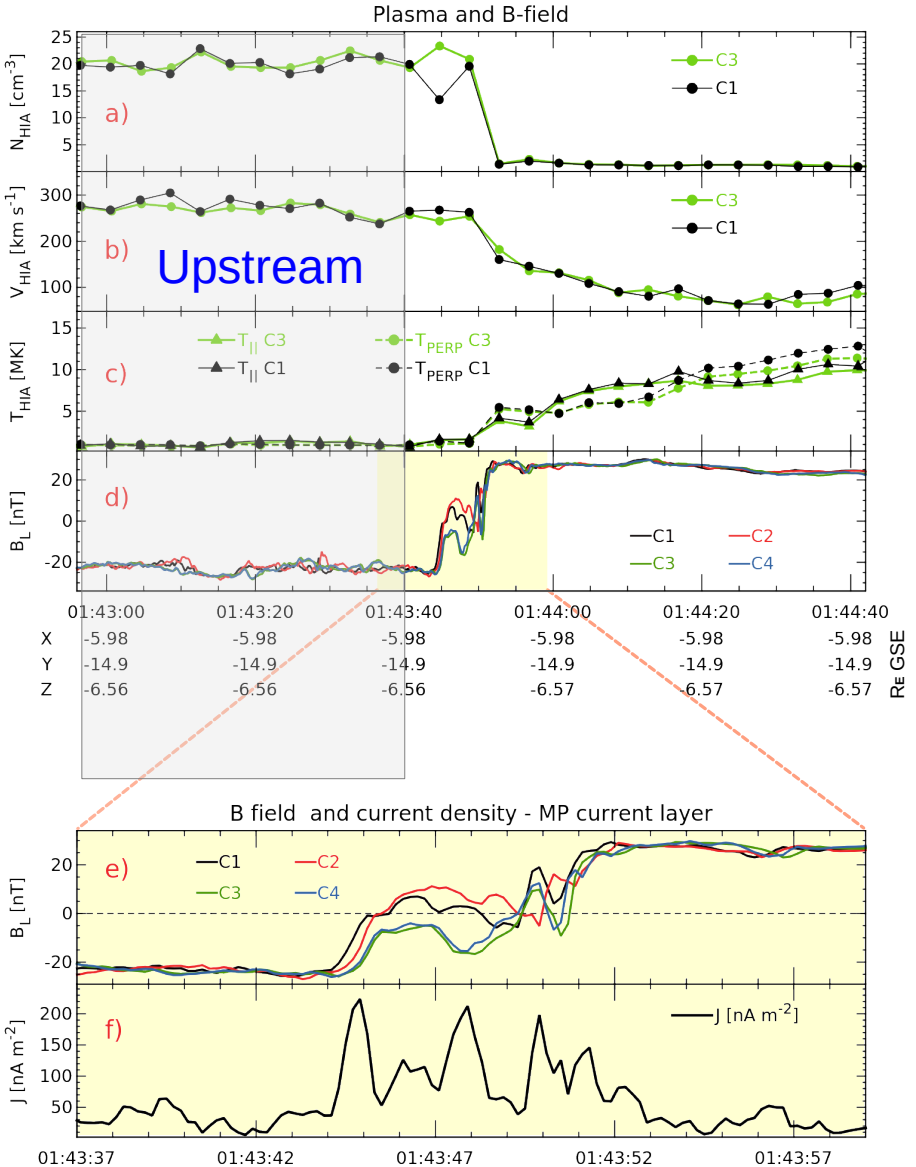
- Magnetopause = current sheet
- Characteristic **observations**
  - Abrupt change in plasma and field parameters
    - Rotation in B
    - Jump in N, T, V
    - Composition and charge state change
    - .. though reconnection causes mixing of plasma regimes
- Observations available from Cluster, MMS, Themis (ISEE, Hawkeye,….)
  - .. and we have catalogs of 1000s of such crossings, incl upstream/downstream regions



Soft X-ray emissions:

- Charge exchange upstream
  - primarily solar wind $O^{7+,6+}$ with H
- MMS and Cluster provide (*) composition information
- All SC can provide upstream parameters (n, T, V, B..)
- Useful for parametrization of models
- .. charge exchange downstream?

(*).. with some caveats..

Solar Wind Charge Exchange

$$H + O^{7+} \rightarrow H^{+} + O^{6+} + \gamma$$

Volume emission rate

$$I_{\gamma} = n_n \cdot n_{sw} \cdot v_{rel} \cdot \langle\sigma\rangle \cdot f \cdot b$$

Parameters involved

γ = soft X-ray photon

n_n = neutral density

n_{sw} = solar wind density

v_{rel} = relative solar wind velocity

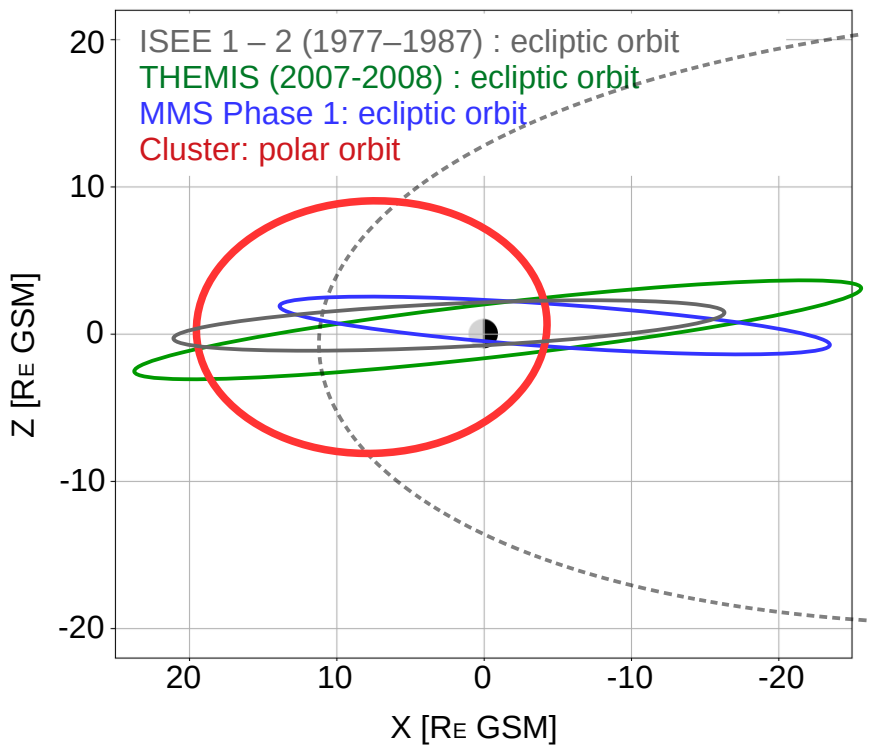
$\langle\sigma\rangle$ = average cross-section

f = solar wind heavy ion ratio

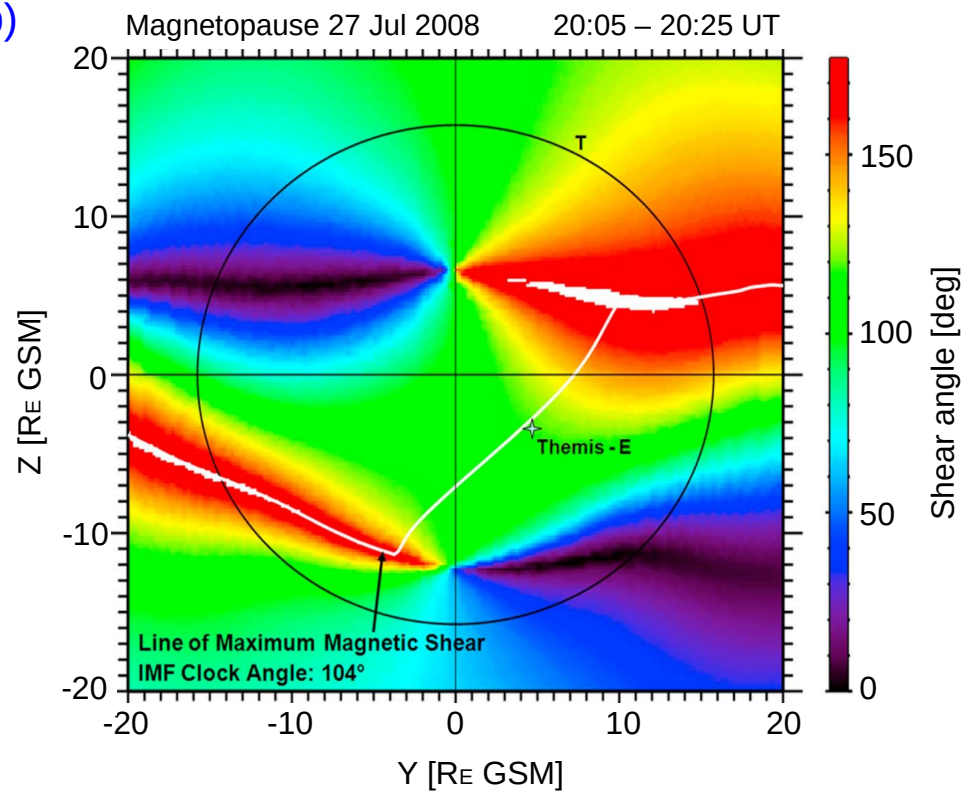
b = photon emission rate

Coverage / Spacecraft orbits

a)



b)



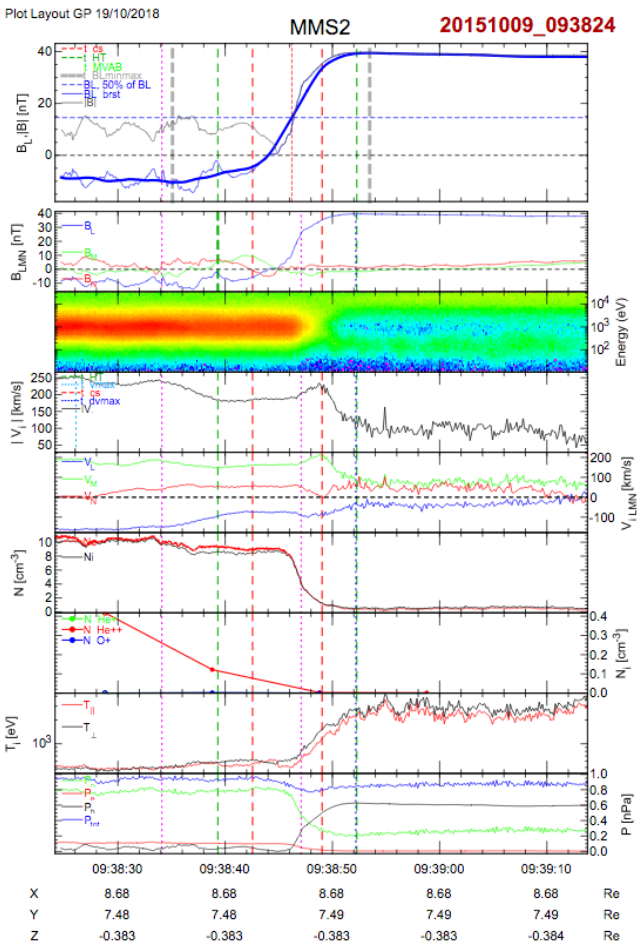
Characterization of the magnetopause

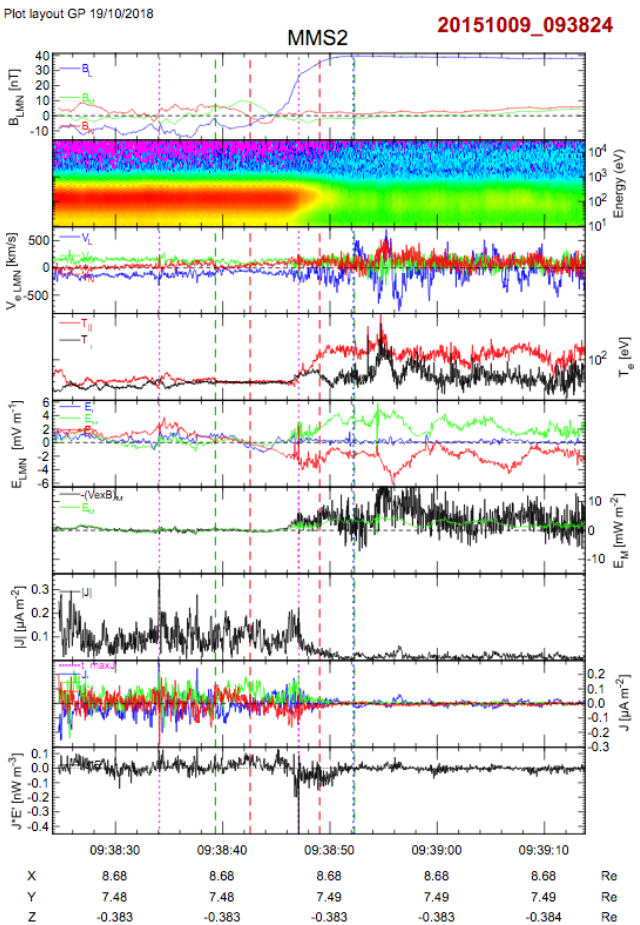
- We have Cluster, THEMIS and MMS databases of
  - Crossing times (season) and SC positons
  - Macroscopic parameters: **L,M,N**, Vn, d, J
  - Upstream/downstream parameters (V, B, E, n, T, β)
  - SW and IMF at BS (OMNI) + geoactivity (AE, Dst)
  - Composition (Cluster RAPID/CODIF, MMS HPCA) (*)
  - Visually inspected !

- ..but our datasets are not the only ….

Example + plot for MMS

(see also www.quackairlines.net)





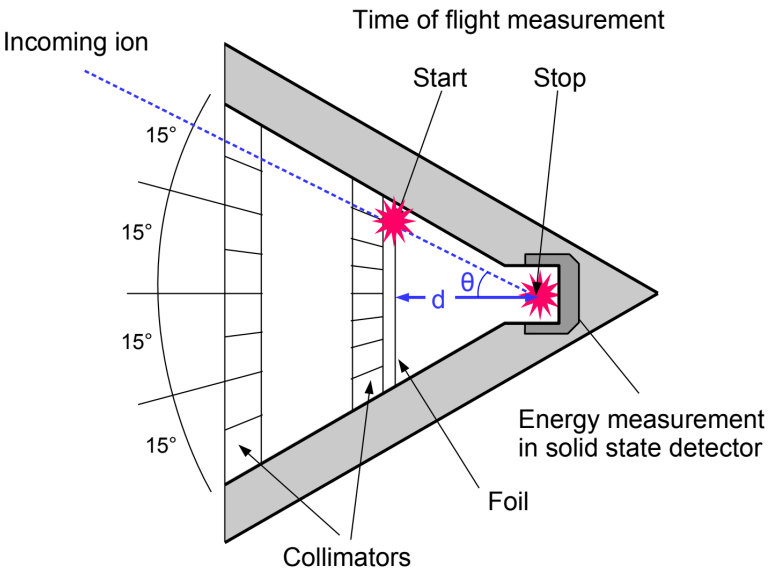

```
:
 Event ID          : 20151009_093824
 FlagStr           : mp,i,mon,gf,s,harri,keep
 GSEpos [Re]       : [ 8.68, 7.48, -0.38 ]
                   :
 LMN coords        :
    L              : [  0.233, -0.140,  0.962 ]
    M              : [ -0.383,  0.896,  0.223 ]
    N              : [  0.894,  0.421, -0.155 ]
                   :
  Times            : (as indicated by red, green lines in plots)
    t_0            : 09:38:46  (red dotted line)
    t_MVAB1        : 09:38:39  (leftmost green line)
    t_MVAB2        : 09:38:52  (rightmost green line)
                   :
|Bmin|, |Vmax|     :
    Bmin           : 0.88 [nT]  at 09:38:44
    Vmax_tht       : 234.14 [km/s]  at 09:38:52
    Vmax_tburst    : 253.81 [km/s]  at 09:38:26
                   :
 Normals           :
    N MVAB         : [  0.708, -0.550, -0.444 ]   (L2/L1 = 1.35)
    N MVAB0        : [  0.947,  0.174, -0.271 ]   (L3/L2 = 6.14)
    N MFR          : [  0.670,  0.742, -0.015 ]   (L2/L1 = 3.96)
                   :
 Durations [s]     : (between red, resp green lines)
    T_CS           : 6.48
    T_MFR/HT       : 12.96
                   :
 Velocity [km/s]   : (based on FPI ion data)
    VnMFR          : 90.2
    VHT.Nmvab      : 98.6  (HTcc = 0.951)
    VHT.Nmvab0     : 3.7
                   :
 CS thickness [km]: (D=T_CS * Vs from above)
    D1=TCS*Vnmfr   : 584
    D2=TCS*VHTn    : 639
    D3=TCS*VHTn0   : 24
                   :
 Currents [uA/m2]  :
    Jave_CS        : 0.065
    Jmax_THT       : 0.221  at 09:38:47
    Jmax_brst      : 0.367  at 09:38:34
                   :
 HPCA mom [1/cm3]  :   Min    -  Max     (  Ave    )  within full brst int
    H+             :   0.397 - 13.722   ( 13.722 )
    He+            :   0.000 -  0.002   (  0.000 )
    He++           :   0.002 -  0.418   (  0.418 )
    O+             :   0.000 -  0.003   (  0.000 )
                   :
 SEH date          : 2019-11-29 08:41:18
                   :
```

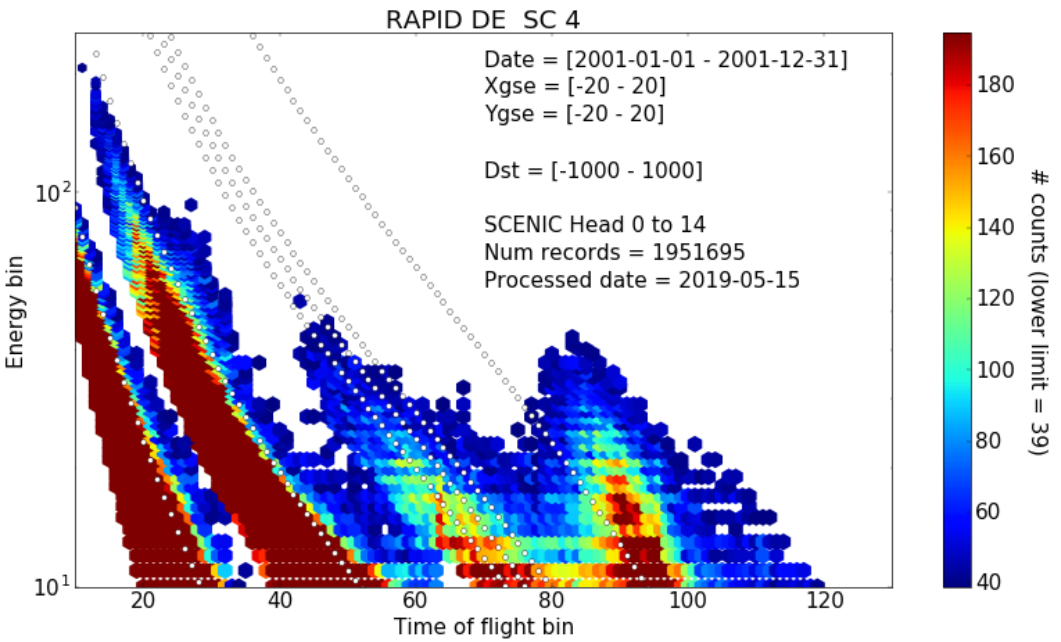
Organization of data - access

- SQL databases
  - Query for times, positions, classifications..
  - Derive statistical moments e.g.:
    - “what is the mean/median.. upstream [n,V,T..] for ..”
    - “what is the position (shape) of … for .. conditions..”
- Coverage:
  - Cluster (2001-2019): ~5800 (flank MPs) + 1109 (mid/high latitudes)
  - MMS (2015-2018): 16793 intervals (whereof ~8670 classified as MP)
  - THEMIS B, C (2007-2009): 1297 MP

Extension possibilities : composition

(Cluster HiLat MP database: already contains RAPID CNO MTRX)

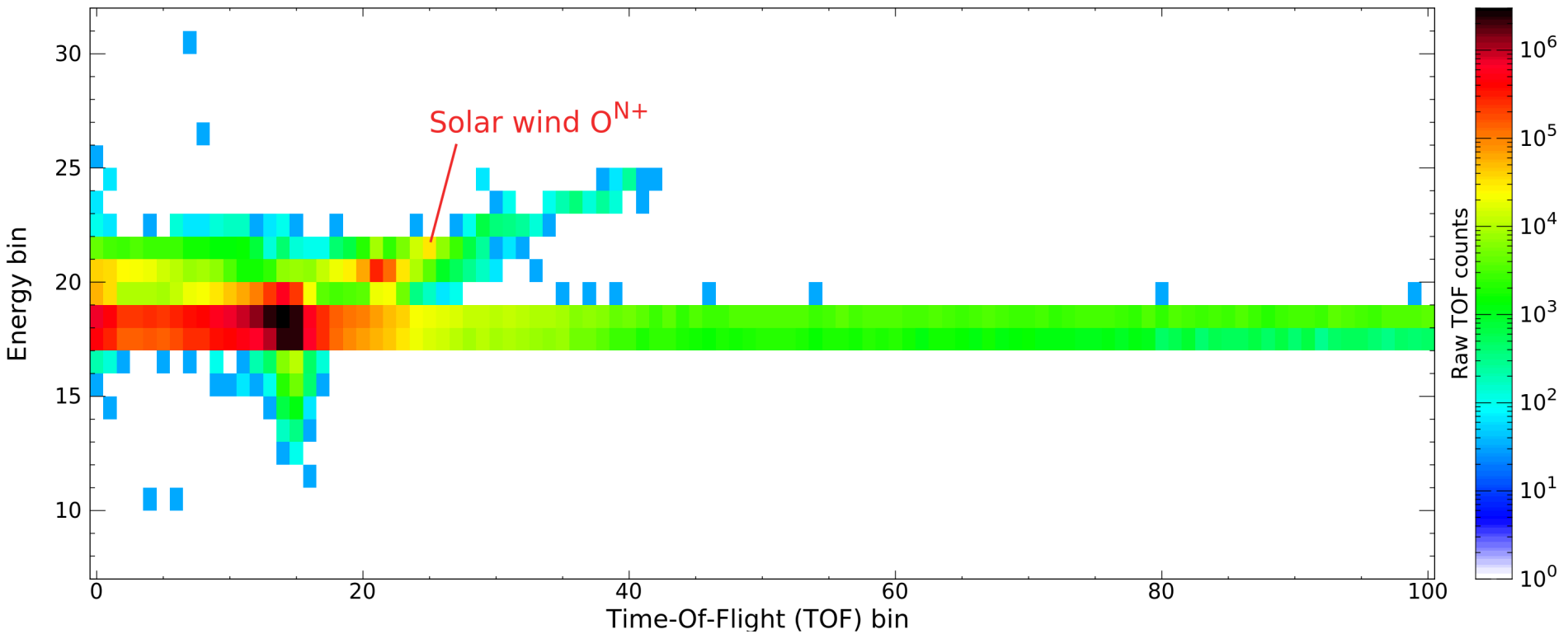




Cluster RAPID:

Oxygen E > 240 keV → most likely solar wind → high charge state

Extension possibilities: composition



MMS HPCA:

E-TOF, E < 40 keV but only O^+ moments in current DB)

More info/ links (dois):

Cluster: Haaland et al. 2021

MMS: Haaland et al, 2020

THEMIS: Haaland et al, 2019

MMS: Paschmann et al, 2018

Cluster: Haaland et al, 2014

… + many many more from other authors…

- More info