# HIGHER-ORDER STATISTICS IN COMPRESSIVE SOLAR WIND PLASMA TURBULENCE: HIGH-RESOLUTION DENSITY OBSERVATIONS FROM MMS

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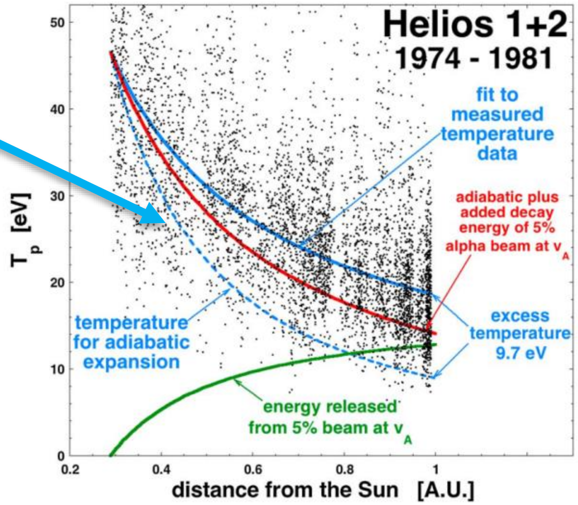
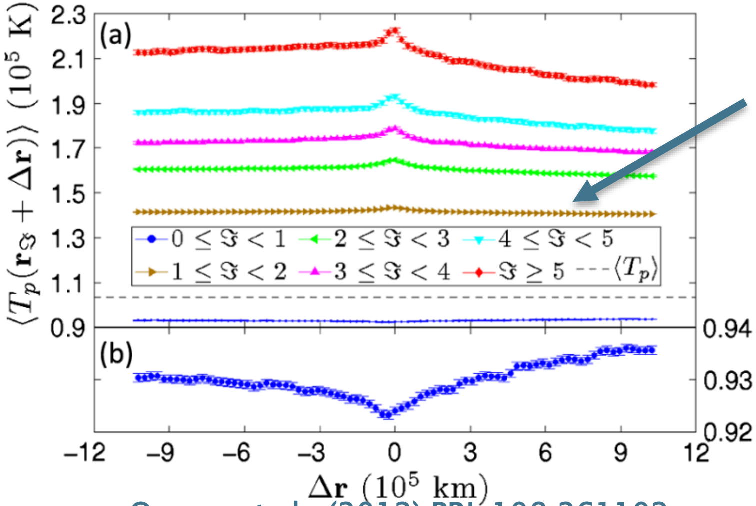
- Introduction
- The solar wind is a turbulent plasma that cools much slower than expected for an adiabatically expanding gas.
- Heating is often concentrated near intermittently distributed strong gradients in measurements (e.g. magnetic fields/density/velocity)
- Understanding the statistics of fluctuations will help us in understanding the heating in the solar wind and in turbulent plasmas in general (i.e. the solar corona, fusion plasmas, accretion disks).
- We investigate intermittent density fluctuations in the solar wind with the Magnetospheric Multiscale mission (MMS).



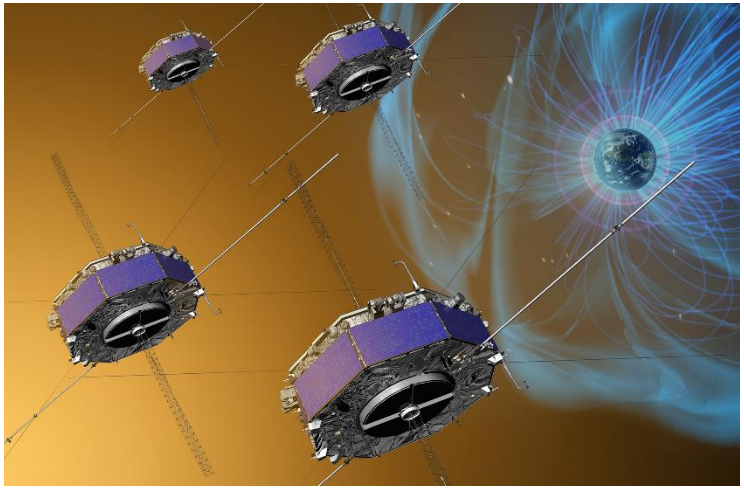
Borovsky et al,. (2014) JGR 119 5210-5219

Temperature



$\Im$ denotes the strength of the gradient (partial variance of increments e.g. Greco et al 2008 GRL)

Osman et al,. (2012) PRL 108.261102



The four MMS spacecraft. Original Image: *NASA/Goddard Space Flight Center*

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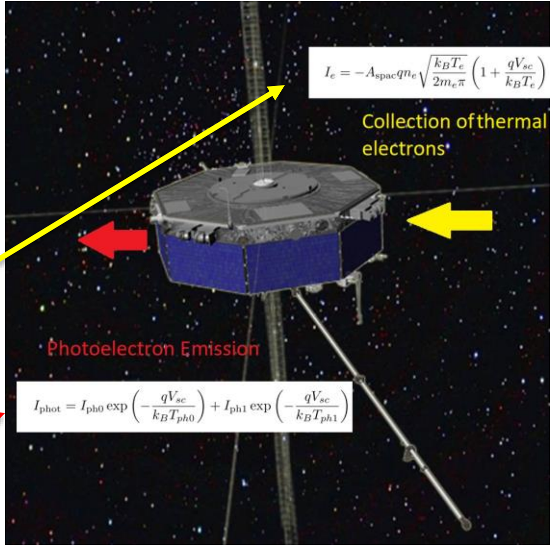
# USING SPACECRAFT POTENTIAL TO INFER THE PLASMA DENSITY

- Using the spacecraft potential allows the density to be derived with very high time resolutions 8kHz for MMS as opposed to 33Hz with the direct plasma measurement. This allows us to study density fluctuations at faster timescales than proton gyration scales in the solar wind
- The potential of a spacecraft with respect to the plasma is governed by the currents to and from the spacecraft
- In the solar wind the two dominant sources of current are photoelectrons emitted by the spacecraft (from the sunlit surfaces) and thermal electrons which are collected by the spacecraft.
- The size of the thermal electron current (Ie) is proportional to the ambient electron density and the square root of the electron temperature
- Photoelectron parameters (Iph0,Tph0, Iph1,Tph1) are obtained by calibrating fitting the thermal current Ie (which is measured using lower time resolution plasma data) to the spacecraft potential assuming that Ie~Iph
- These two currents can be equated and solved for the electron density (this also assumes an electron temperature where the mean can be used).
- The MMS mission consist of four spacecraft in a tetrahedral configuration. This allows fluctuations of variables to be calculated between different times on a single spacecraft and between spacecraft.
- The time lags allow a lot of different scales to be surveyed by varying τ, it is however limited to a single direction; the bulk velocity direction. Spatial lags have the advantage that multiple directions can be surveyed, but only a single scale i.e. the spacecraft separation size.

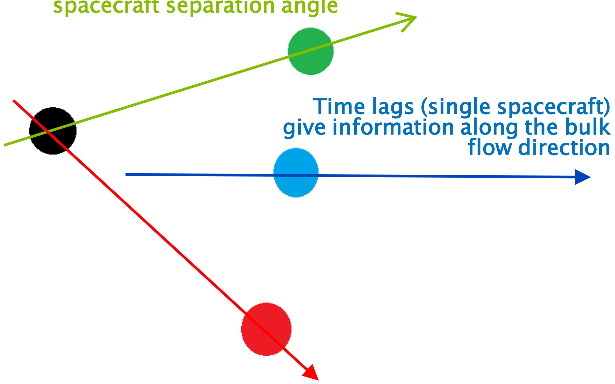
Original Image *NASA/Goddard Space Flight Center*



$$I_e = -A_{\text{spac}} q n_e \sqrt{\frac{k_B T_e}{2 m_e \pi}} \left(1 + \frac{q V_{sc}}{k_B T_e}\right)$$

$$I_{\text{phot}} = I_{\text{ph0}} \exp\left(-\frac{q V_{sc}}{k_B T_{ph0}}\right) + I_{\text{ph1}} \exp\left(-\frac{q V_{sc}}{k_B T_{ph1}}\right)$$

$$n_{e,SC} = \frac{1}{q A_{\text{spac}}} \sqrt{\left(\frac{2\pi m_e}{k_B T_e}\right)} \left(1 + \frac{q V_{sc}}{k_B T_e}\right)^{-1} \left(I_{ph0} \exp\left(\frac{-q V_{sc}}{k_B T_{ph0}}\right) + I_{ph1} \exp\left(\frac{-q V_{sc}}{k_B T_{ph1}}\right)\right)$$



Lags between spacecraft give information along the spacecraft separation angle

Time lags (single spacecraft) give information along the bulk flow direction

$$\delta n_e(t, \tau) = n_e(t + \tau) - n_e(t),$$

$$\delta n_e(\vec{\lambda_{1,2}}) = n_e(\vec{\lambda_1}) - n_e(\vec{\lambda_2}).$$

**Time lag**

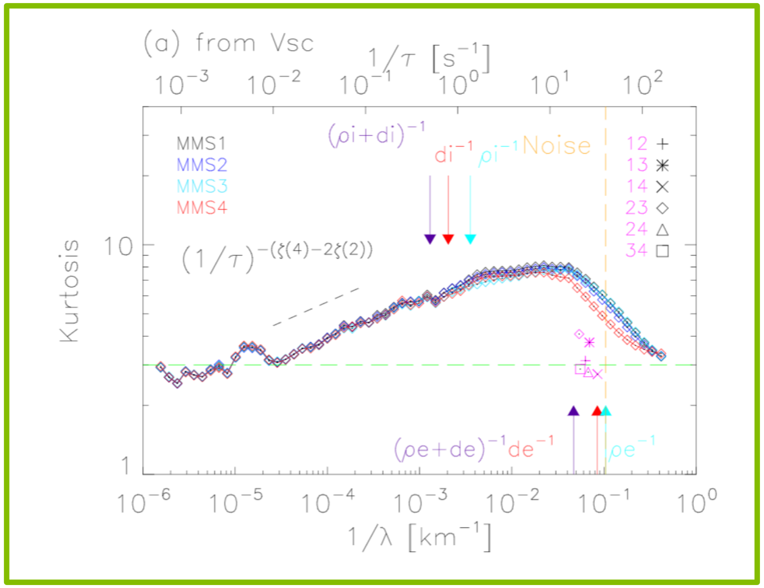
**Spatial lag**

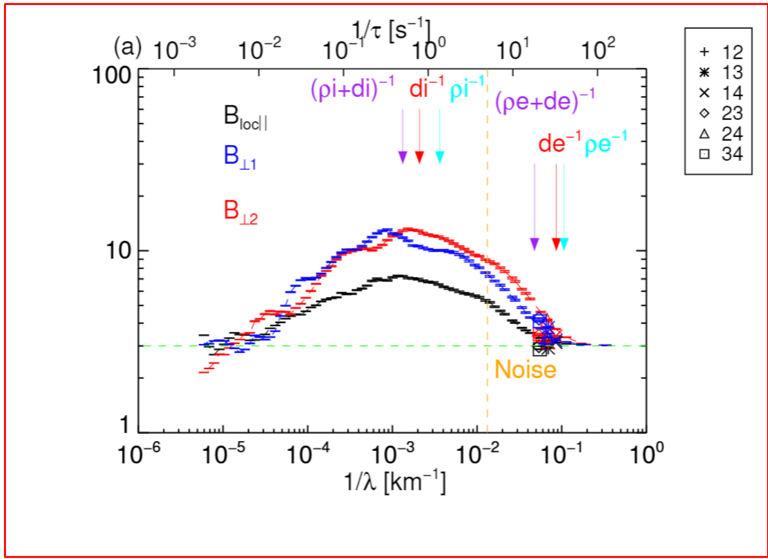
# QUANTIFYING INTERMITTENCY-I SCALE DEPENDENT KURTOSIS

- To quantify intermittency in the density fluctuations we calculate the kurtosis (fourth order moment) of the fluctuations between time lags (lines) and spatial lags (points).

$$\kappa = \frac{\langle \delta n_e^4 \rangle}{\langle \delta n_e^2 \rangle^2},$$

  - The time lagged values show an increase at large scales which is consistent with a power law (black dotted line).
  - When we arrive near the proton gyration scales (inverted arrows) there is a plateau and the intermittency does not increase further.
- There is also disagreement between time lags and spatial lags. This may be due to;
  1. Fluctuations evolving faster than the advection time over the spacecraft (breakdown of Taylor's hypothesis)
  2. Wave activity that reduces the kurtosis in certain directions
  3. Differences in the directions
  4. Structures are larger than the spacecraft separation sizes (all spacecraft see the same)
  5. A sampling effect with respect to the bulk flow direction
  - To understand this result multi spacecraft observations with the baseline along the bulk flow direction will need to be made. Comparisons with numerical simulations would also be beneficial.
  - The peak at ion scales is similar wo what is seen in the magnetic fields however instrumental noise means we cannot compare the time and spatial lags



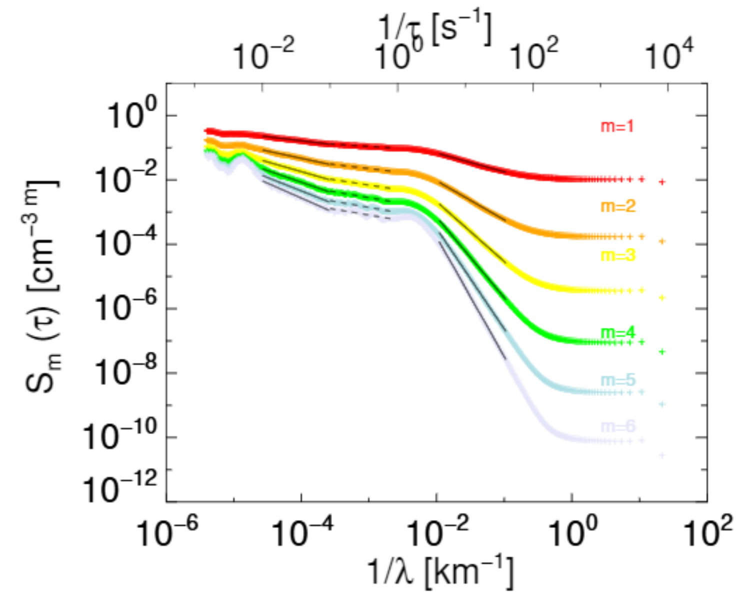


# QUANTIFYING INTERMITTENCY-II AND CONCLUSIONS

- For an additional measurement of the intermittency we calculate the scaling exponents ζ(m) (gradient of Sm) from the m–th order structure functions Sm.

$$S_m(\tau) = \langle |\delta n_e(t,\tau)|^m \rangle_t$$

- The structure functions show two distinct ranges at large (inertial scales) and small (sub ion scales).
- There is a possible third transition range in between the two ranges but it is too short to fit
- The scaling exponents are obtained from the fits to the structure functions (black lines)
- For a (non–intermittent) monofractal process a linear dependency is expected between the order m and the exponent
- For an (intermittent) multifractal process there is a nonlinear dependency between ζ and m.
- The strong curvature in the inertial range (a) is suggestive of intermittency. This juxtaposes strongly with the Sub–ion range (b) which is monofractal.



- Conclusions

1. The spacecraft potential gives an excellent high time resolution method to study sun ion scale turbulence
2. The scale dependent kurtosis of density and magnetic field fluctuations suggests a plateau in kurtosis at ion scales. The scaling exponents also suggest this region is not intermittent.
3. Time lags give good scale coverage but poor directional coverage. Spatial lags give good directional coverage but poor scale coverage. Future mission concepts should strive to have good directional and scale coverage
4. There is a difference between time lags and spatial lags which we have several hypotheses to explain (breakdown of Taylor, structure sizes, sampling effect, waves, directional differences)