Ionospheric Turbulence: impact on the Global Navigation Satellite Systems functioning

P. De Michelis, G. Consolini, M. Pezzopane, A. Pignalberi, I. Coco. F. Giannattasio, R. Tozzi and M. F. Marcucci

SWICO
Space Weather Italian Community

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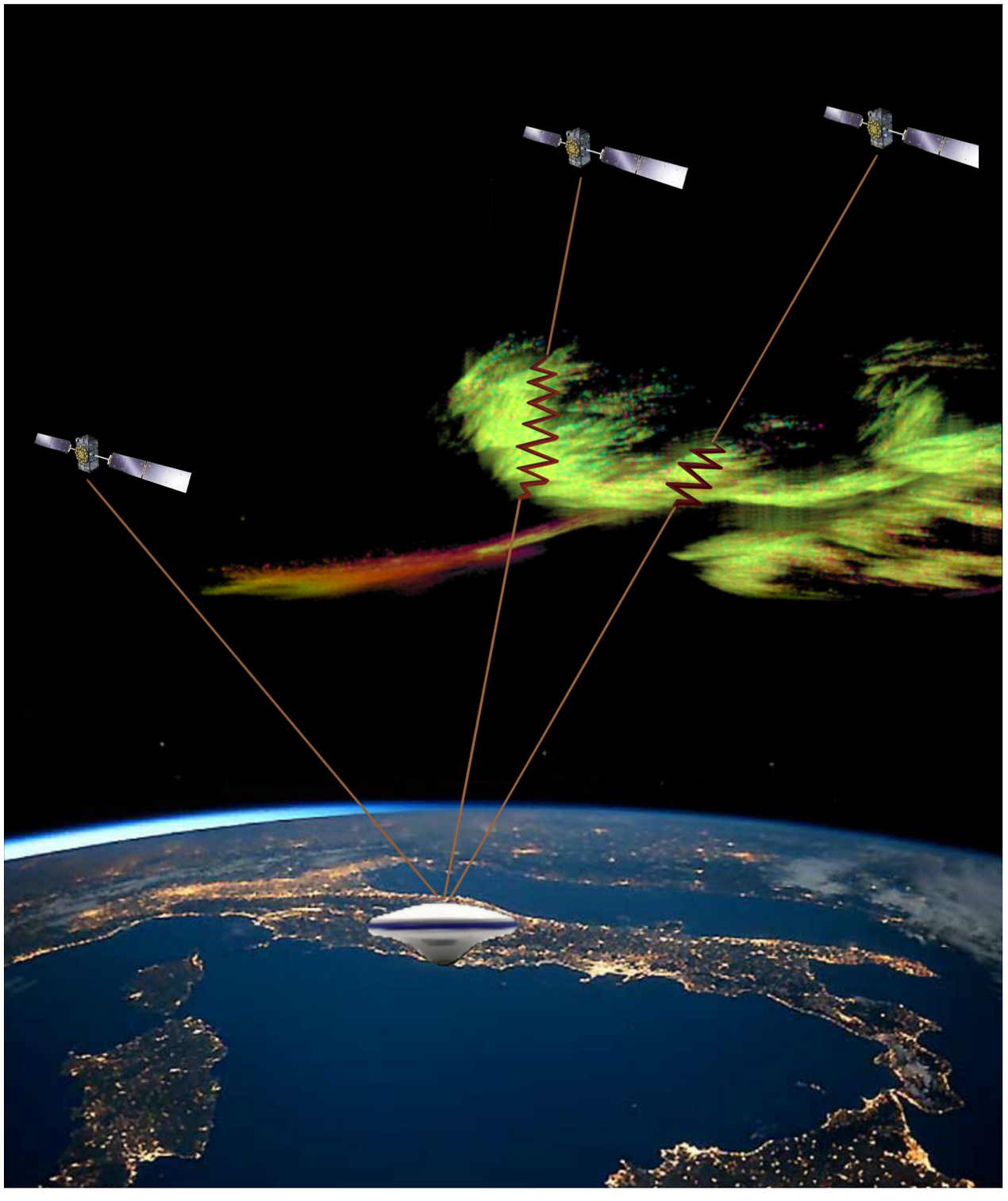
Introduction



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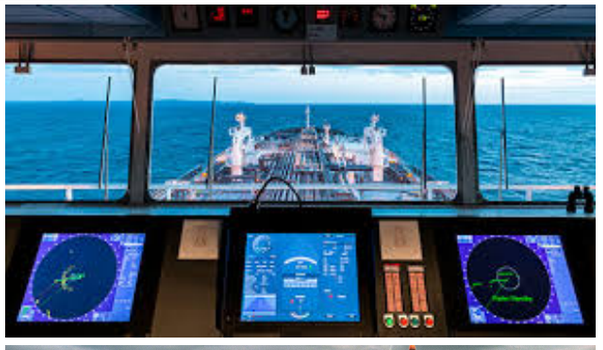

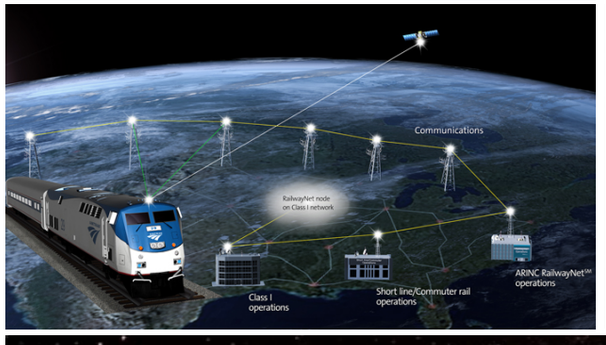

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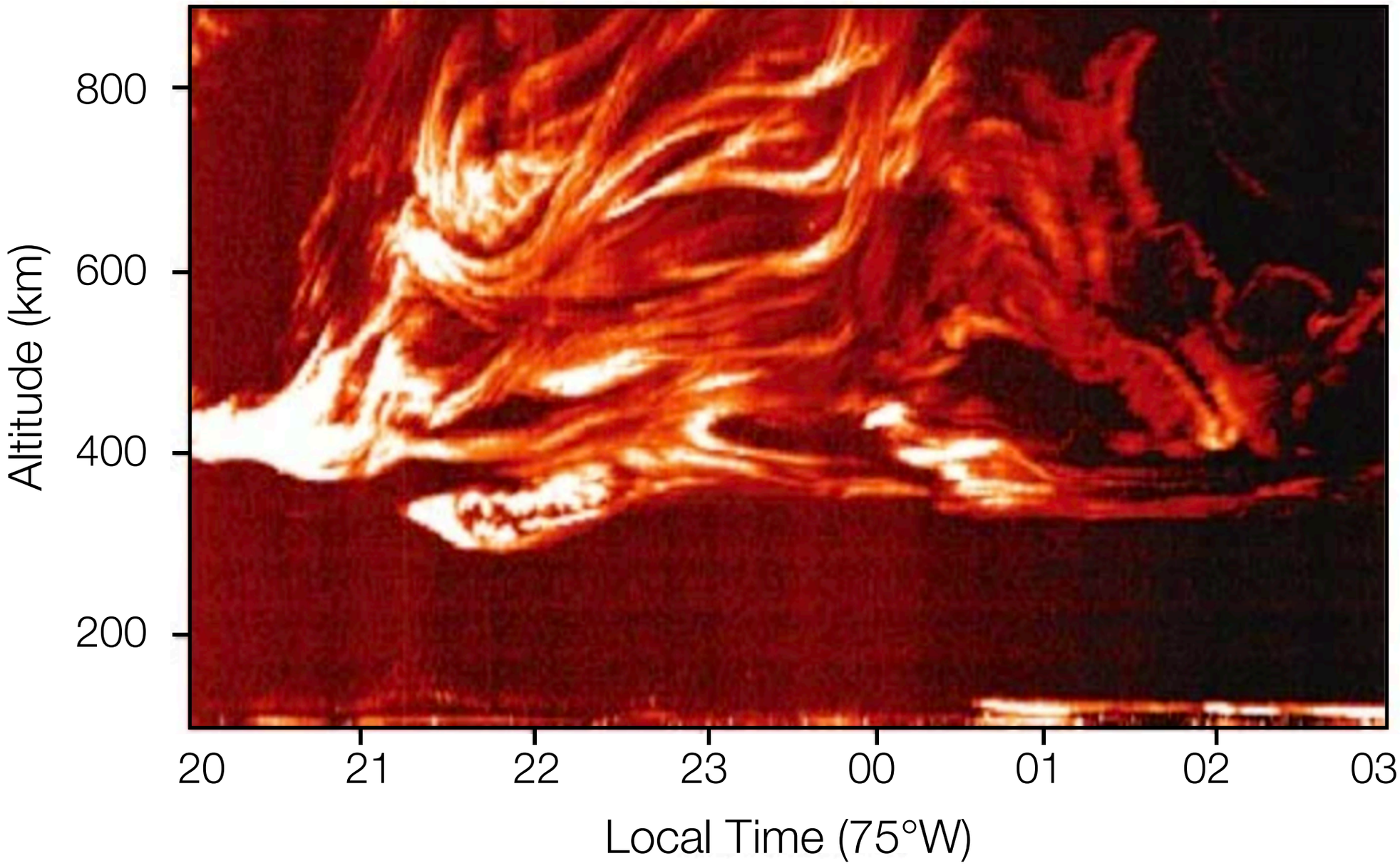


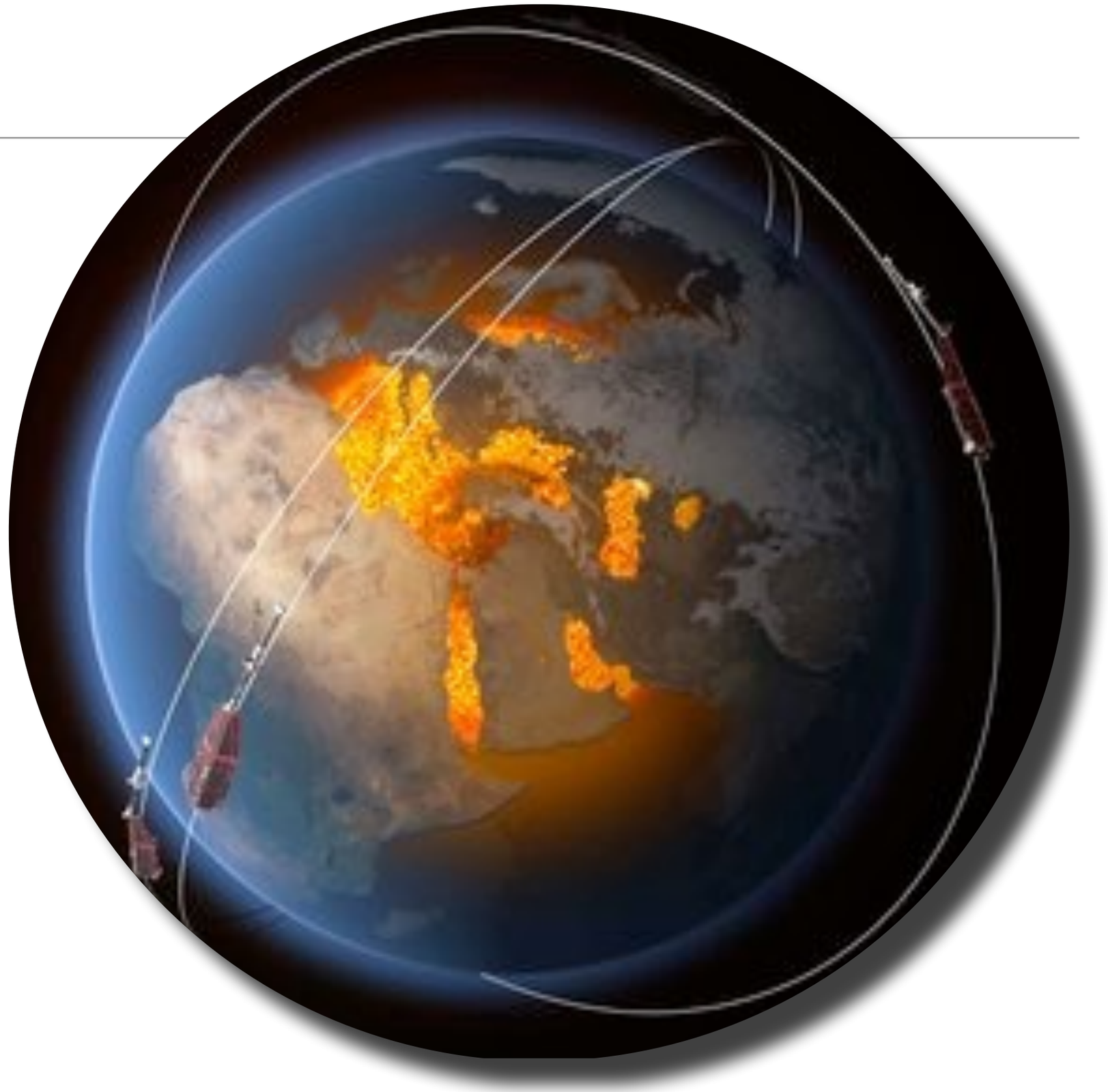
This figure appeared on the cover of *Space Weather quarterly* digest (Vol. 3, Spring 2006).

Data

★ 1Hz Electron density time series measured on board Swarm A in the time interval between April 1st 2014 and March 31st 2018.

★ RODI (Rate of Change of electron density index) with 1s time resolution

★Loss of Lock time series



Method of Analysis: Structure Functions

We consider **qth-order structure function** $S_q(\tau)$, which for a signal $N_e(t)$ defined over an interval T is given by

$$S_q(\tau) =< |N_e(t+\tau) - N_e(t)|^q >_T$$

when we deal with a scale-invariant signal the $S_q(\tau)$ exhibits a power law behavior:

$$S_q(\tau) \sim \tau^{\gamma(q)}$$

We have estimated:

$\gamma(1)$ first-order scaling exponent, known as Hurst exponent

$\gamma(2)$ second-order scaling exponent, which provides the **Fourier power spectral density exponent** β through Wiener-Khinchin theorem ($\beta = \gamma(2) + 1$)

Scaling Exponents in Brief: Meaning

$\gamma(1)$=H

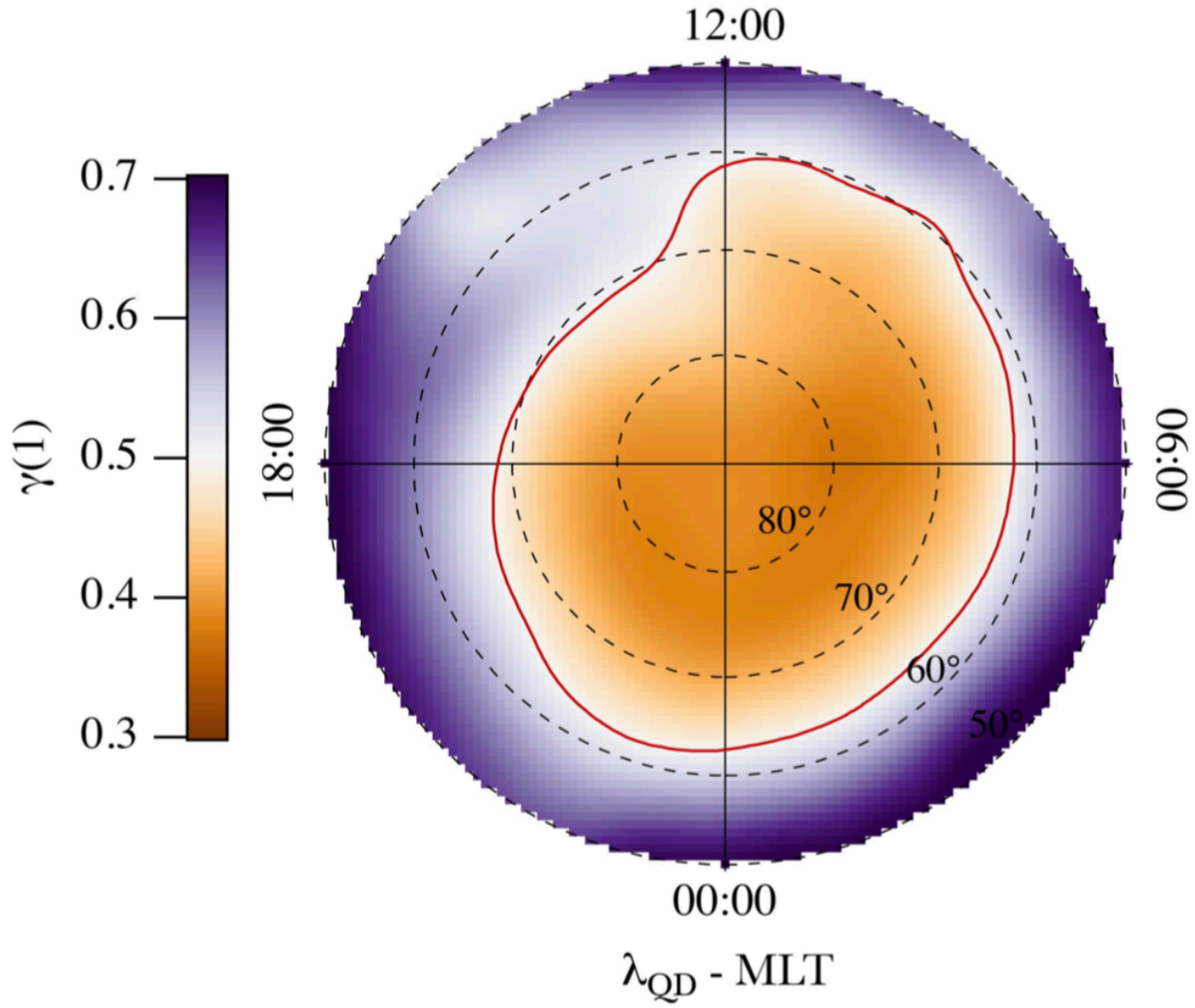
Provides information on the range of correlation of the investigated quantity: values of ***H*<0.5** are the evidence of the **anti-persistent** character of its increments so that we can talk of short correlated signals, values of ***H*>0.5** are the evidence of the **persistent** character of its increments so that we can talk of long-range correlated signals.

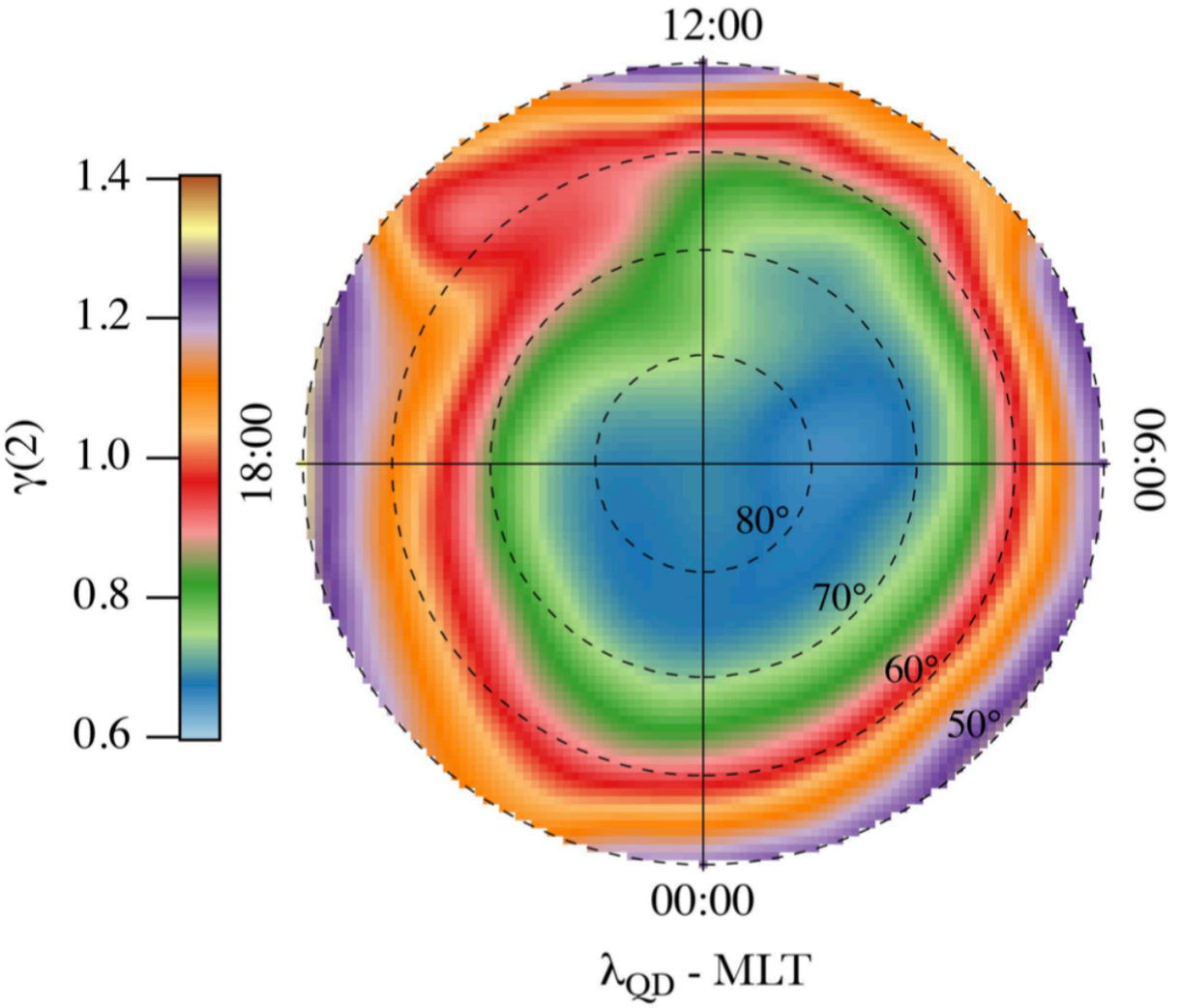
$$\gamma(2) = \beta - 1$$

Through β= γ**(2)+1** provides information on the **spectral features** of the quantity under investigation, representing the slope of a power law PSD can provide information on the presence of turbulence.

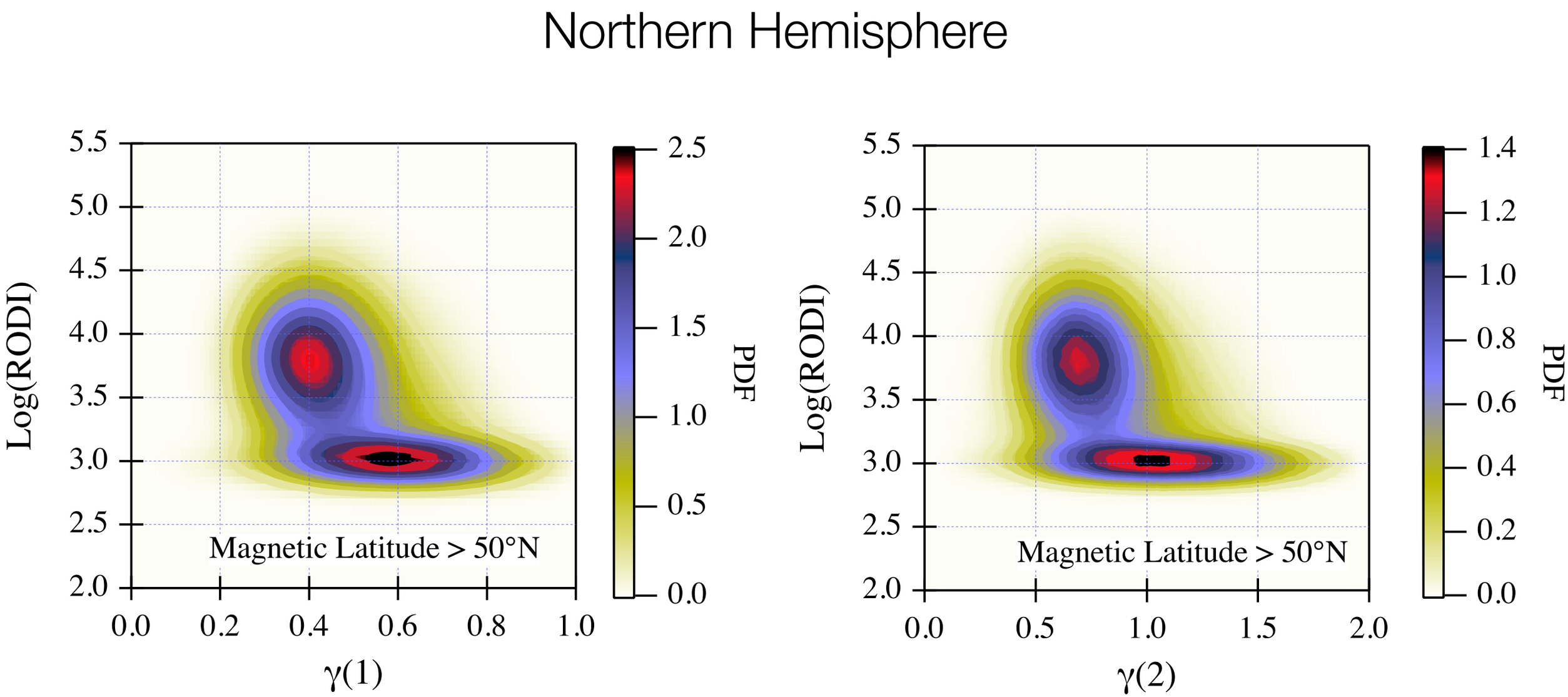
Results: Scaling properties at high latitude

Northern Hemisphere

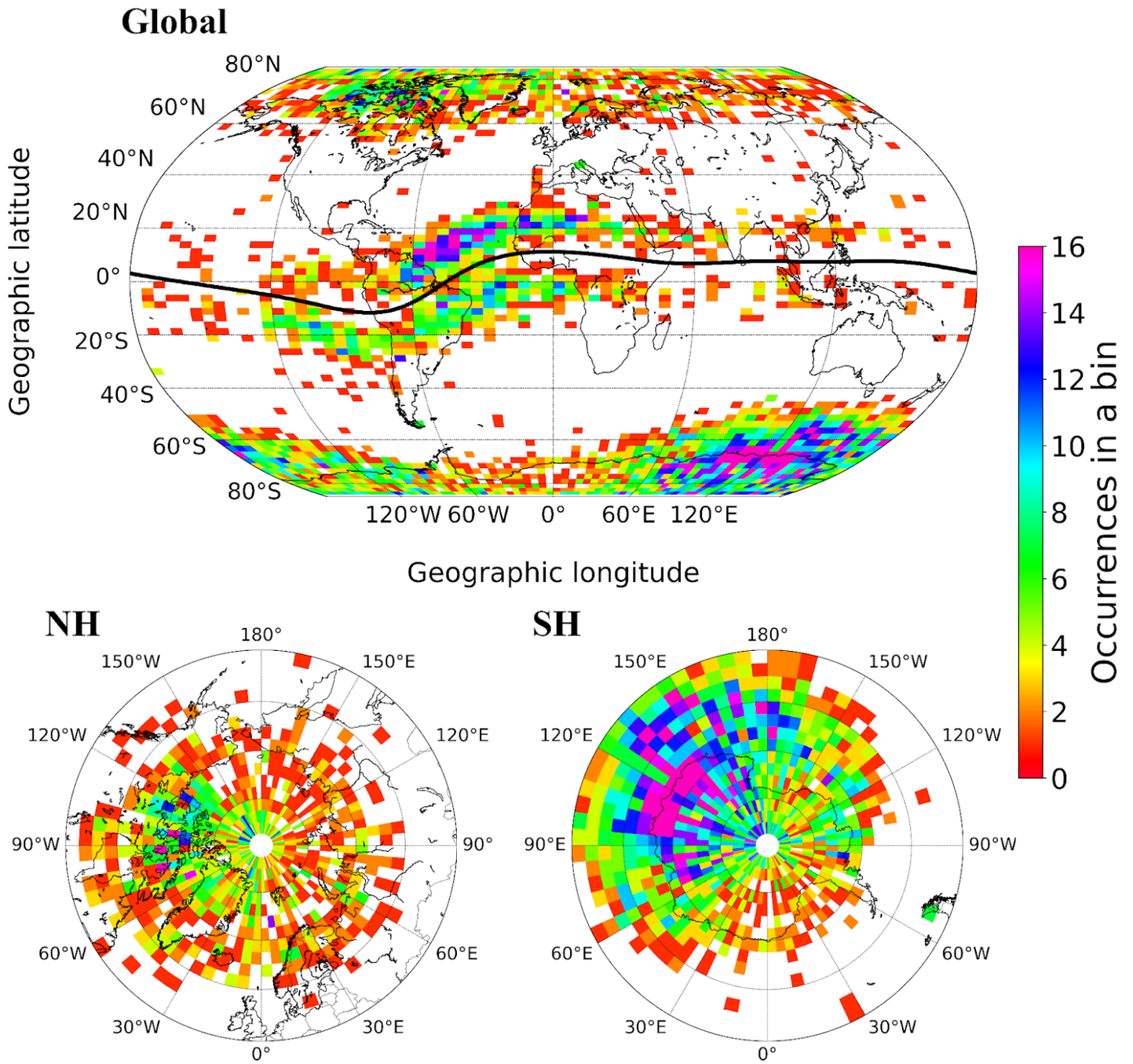




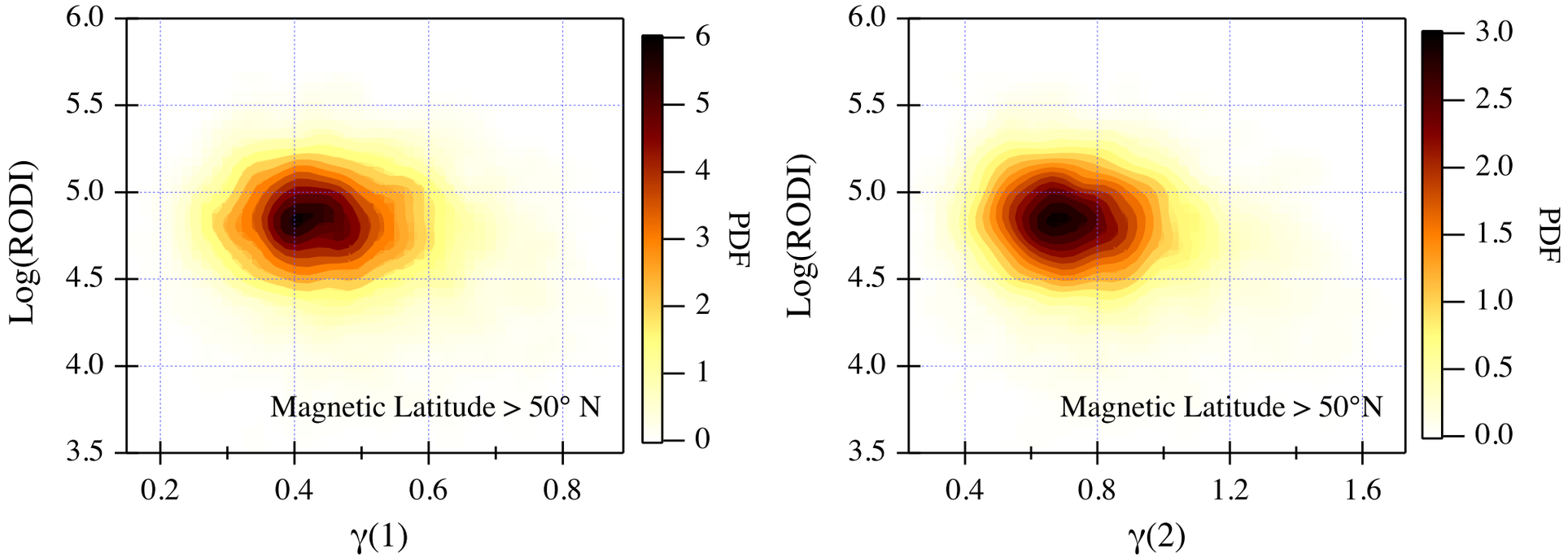
Results: Scaling properties at high latitude



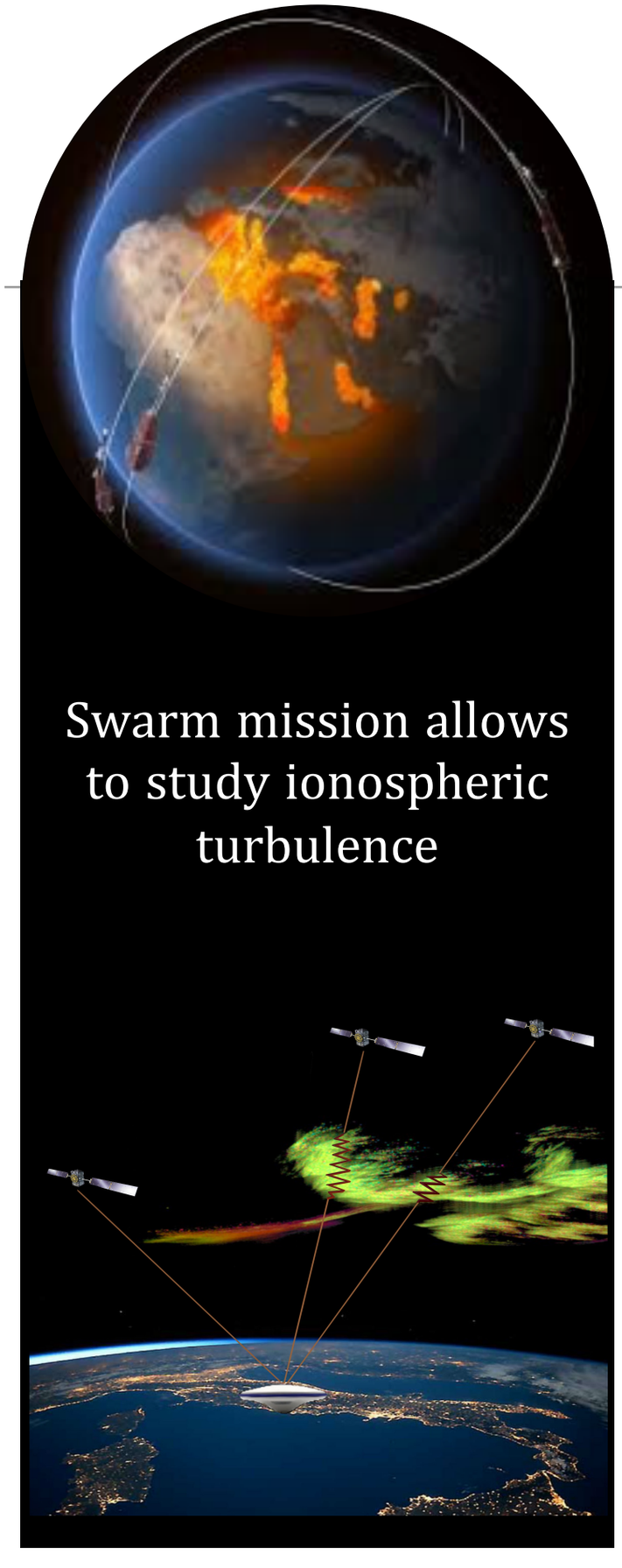
Results: GPS loss of lock



Results: GPS loss of lock and Turbulence



- The occurrence of GPS signal loss is associated with the family characterized by values of the scaling exponents which suggest the existence of turbulence phenomena.
- In addition, within this family an important proxy seems to be the RODI value. Values of Log (RODI) >4 seem to be associated with the occurrence of GPS malfunctions.



Conclusions

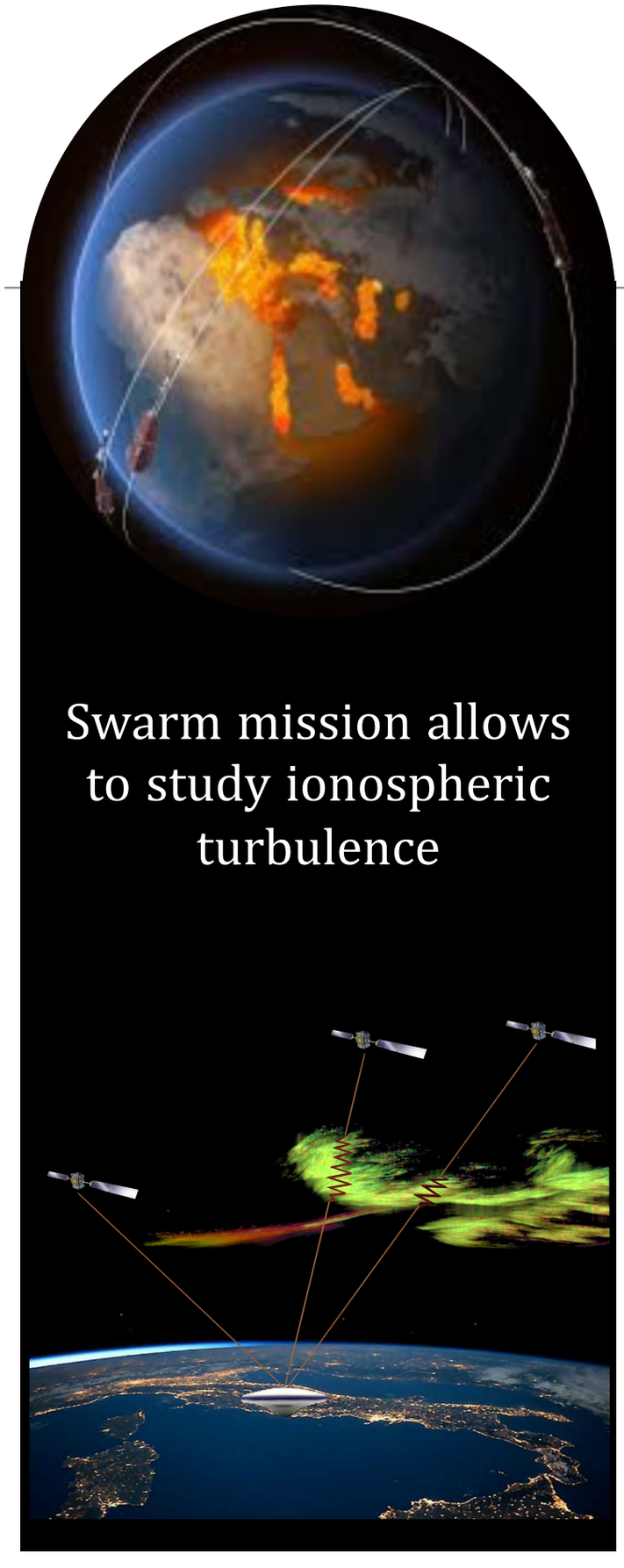
1. We observe **two different families of Ne fluctuations** which are characterized by different mean values of scaling exponents and RODI. This finding suggests that **two main classes of physical phenomena** can be at the origin of the different scaling features;

2. A population is characterized by antipersistency, $\gamma(2) < 1$ and high values of RODI. This family is mainly located inside the auroral oval, where particle precipitation dominates;

3. The other population is characterized by persistency, $\gamma(2) > 1$ and low values of RODI. It is mainly is located at lower latitudes, outside the auroral oval;

4. The **RODI values reasonably capable of capturing the Ne irregularities due to turbulent processes are such that Log(RODI)>3.25** at mid/high latitude, and it is independently on geomagnetic activity level;

Conclusions

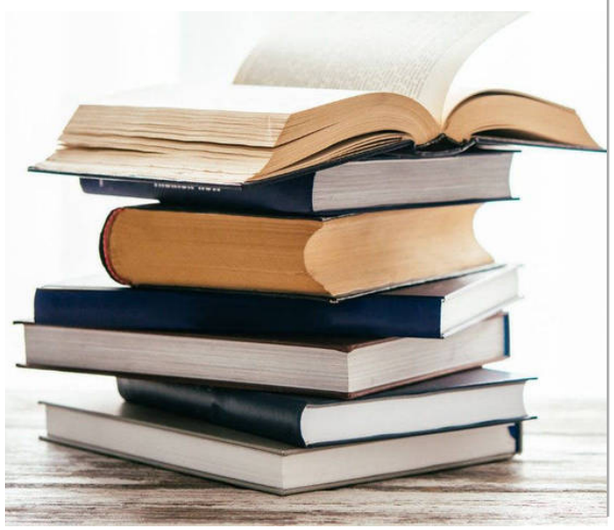


5. Similar results have been obtained at low latitudes.

6. The **GPS loss of lock occurrences are associated with Ne fluctuations generated by a turbulent process and are accompanied by extremely high value of RODI**.

This means that when there is a GPS loss of lock occurrence, the Ne fluctuations are characterized by $\gamma(2) \leq 1$ and extremely high values of RODI $>10^4$ cm^{-3} s^{-1}. This result characterizes the physical conditions that are most likely at the base of the GPS malfunctions.

Papers summarized in the presentation



Paper 1

TITLE: On the 2015 St. Patrick's storm turbulent state of the ionosphere: Hints from the Swarm mission.
AUTHORS: De Michelis P., Pignalberi A., Consolini G., Coco I., Tozzi R., Pezzopane M., Giannattasio F., & Balasis G.
JOURNAL: *Journal of Geophysical Research: Space Physics*, 125, e2020 JA027934. https://doi.org/10.1029/2020JA027934, 2020

Paper 2

TITLE: High-latitude polar pattern of ionospheric electron density: Scaling features and IMF dependence.
AUTHORS: Consolini G., R. Tozzi, P. De Michelis, I. Coco, F. Giannattasio, M. Pezzopane, M.F. Marcucci and G. Balasis.
JOURNAL: *Journal of Atmospheric and Solar-Terrestrial Physics*, 217, https://doi.org/10.1016/j.jastp.2020.105531, 2021

Paper 3

TITLE: Ionospheric turbulence and equatorial plasma density irregularities: scaling features and RODI
AUTHORS: De Michelis P., Consolini G., Tozzi R., Pignalberi A., Pezzopane M., Coco I., Giannattasio F., & Marcucci M. F.
JOURNAL: *Remote Sensing*, 13, 759, https://doi.org/10.3390/rs13040759, 2021

Paper 4

TITLE: Looking for a proxy of the ionospheric turbulence with Swarm data
AUTHORS: De Michelis P., Consolini G., Pignalberi A., Tozzi R., Coco I., Giannattasio F., Pezzopane M., & Balasis G.
JOURNAL: *Scientific Reports*, 11, https://doi.org/10.1038/s41598-021-84985-1, 2021

Paper 5

TITLE: Occurrence of GPS Loss of Lock Based on a Swarm Half-Solar Cycle Dataset and Its Relation to the Background Ionosphere
AUTHORS: Pezzopane M., A. Pignalberi, I. Coco, G. Consolini, **P. De Michelis**, F. Giannattasio, M.F. Marcucci, and R. Tozzi
JOURNAL: *Remote Sensing*, 13, 2209, https://doi.org/10.3390/rs13112209, 2021