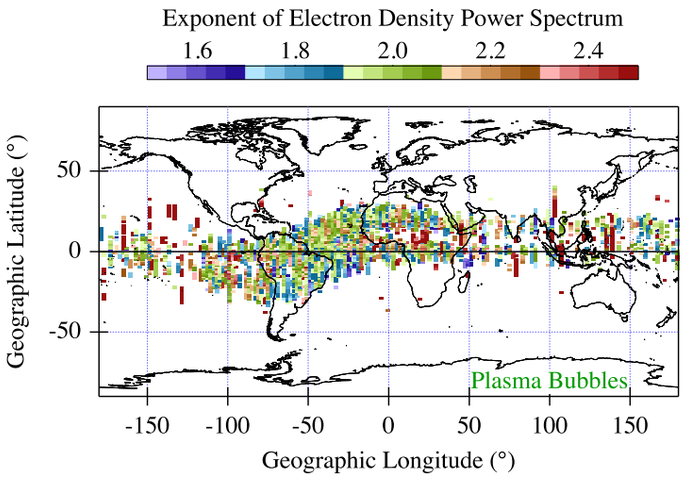
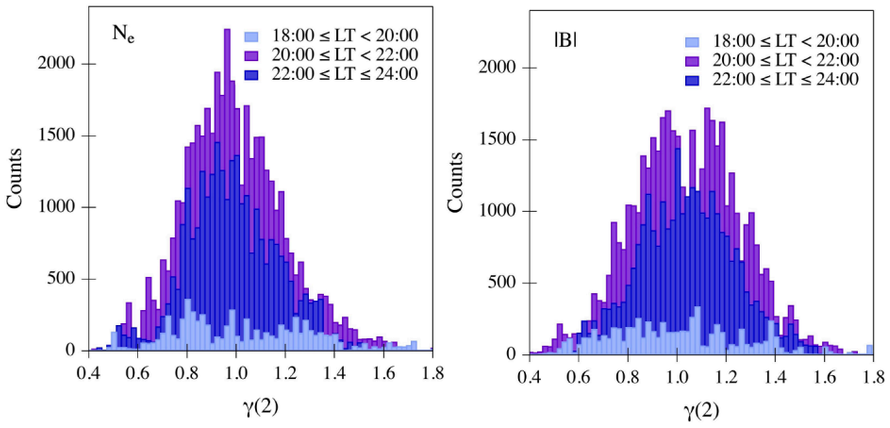
Ionospheric Turbulence and the Equatorial Plasma Density Irregularities: Scaling Features and RODI

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





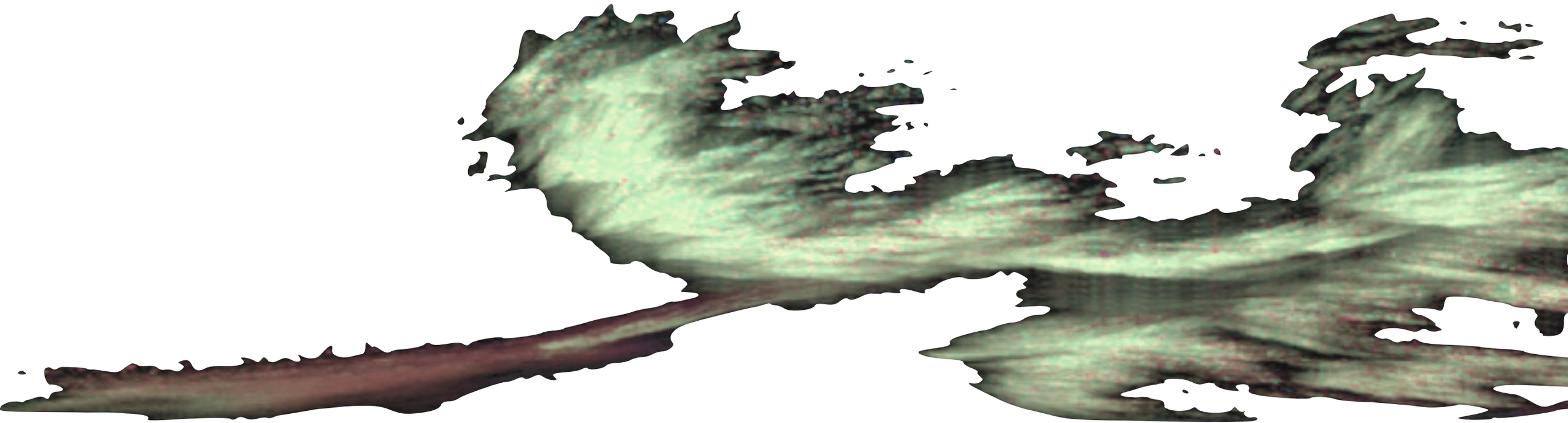
Aim

To investigate the scaling features of electron density and magnetic field fluctuations inside the plasma bubbles.

Results

1. The turbulence character of these structures is supported and the existence of a clear link between the observed scaling properties and the value of RODI is found.

2. The spectral features of plasma irregularities cannot be directly inferred from their magnetic signatures. A relation more complex than the linear one is necessary to properly describe the role played by the evolution of plasma bubbles with local time.



DATA

1 April 2014 - **31 January 2016** (High solar activity)

Kp<3 (low/moderate geomagnetic activity)

18:00-24:00 LT

|Lat| < 40°

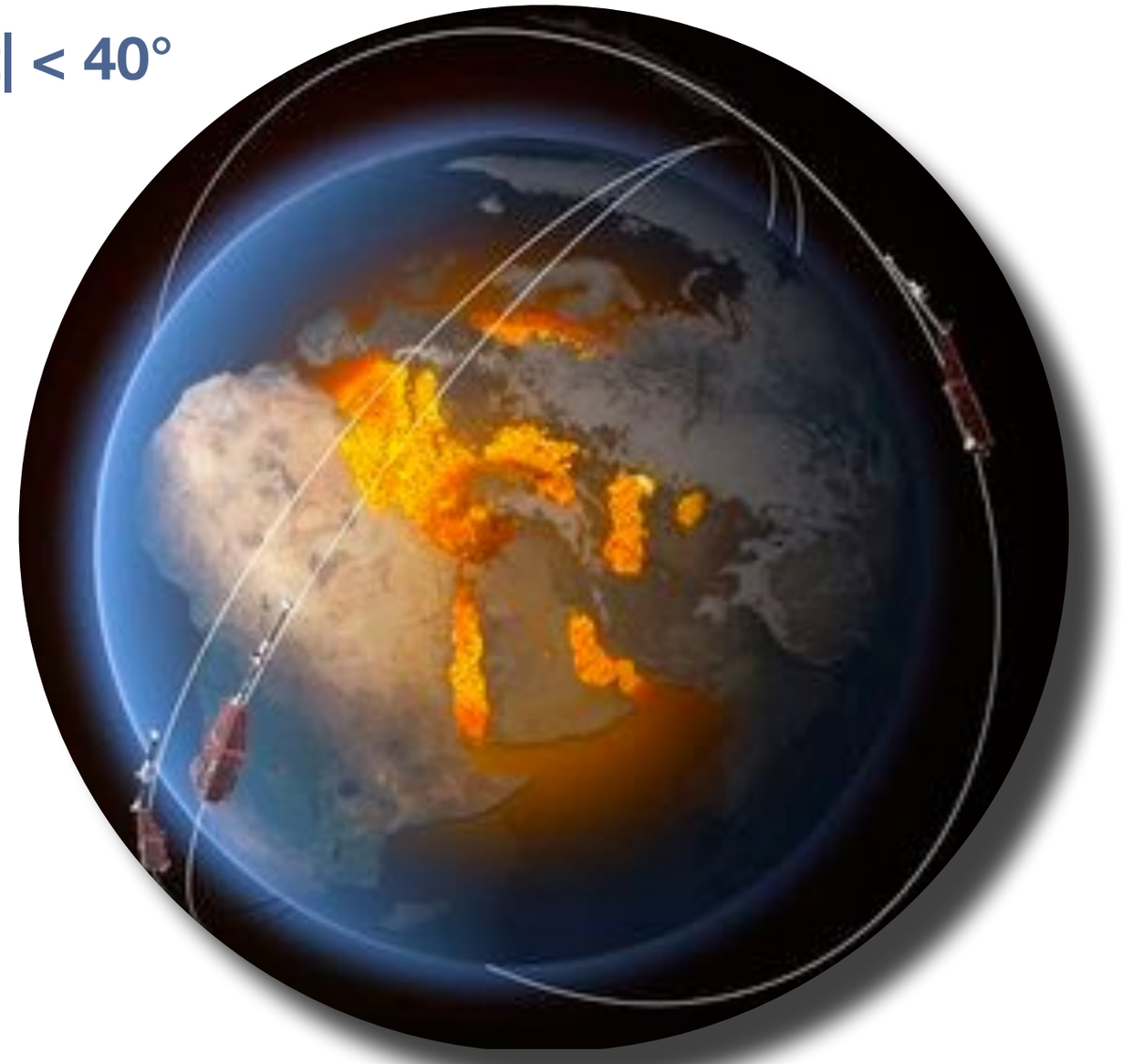
Swarm A

★1Hz **Electron density** time series

★1 Hz **Magnetic field strength** time series.To highlight the magnetic signatures associated with plasma bubbles, we remove from the magnetic field measurements the contribution due to the magnetic field of internal origin, as modeled by CHAOS-6.

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

★Swarm Level-2 Ionospheric Bubble Index (**IBI**) product.



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:

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

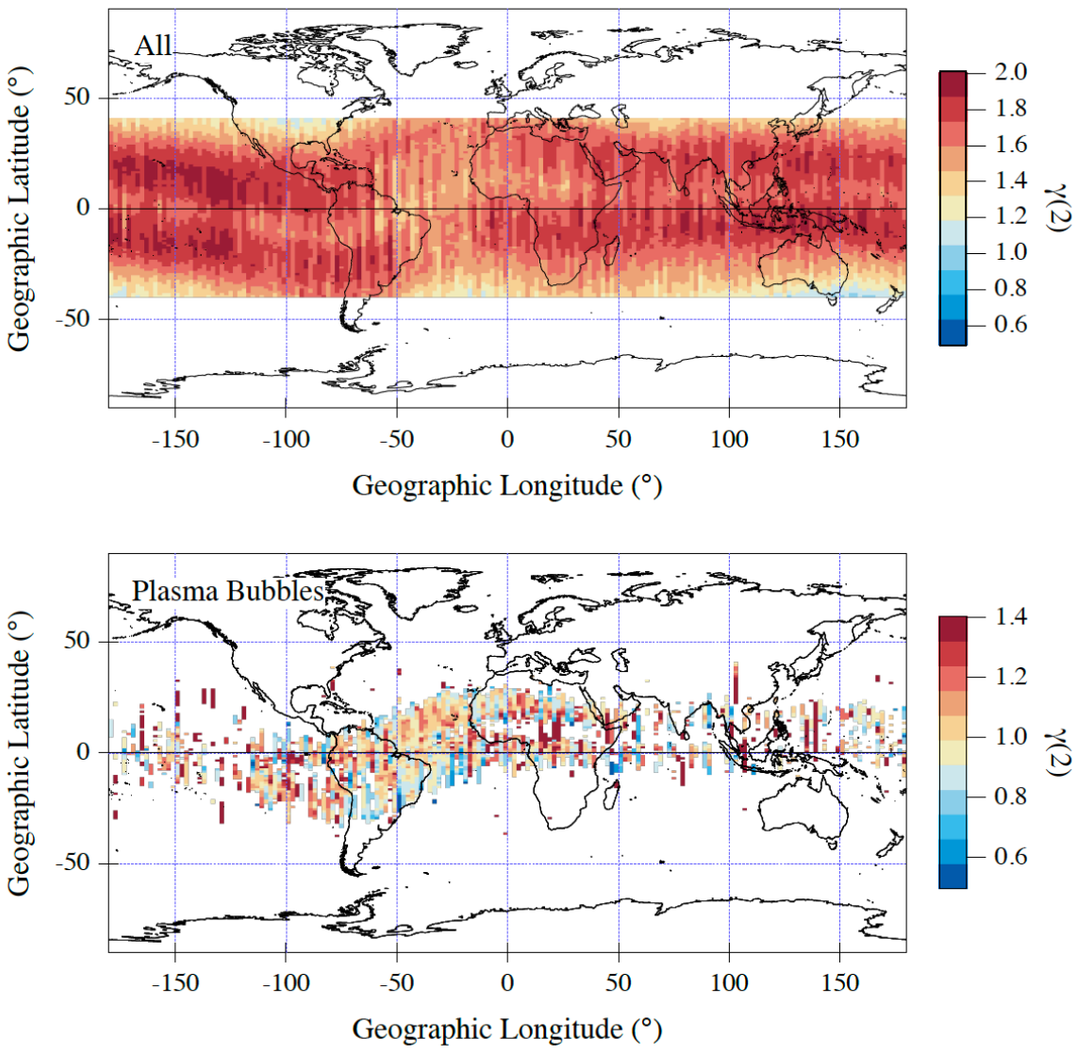
We have estimated:

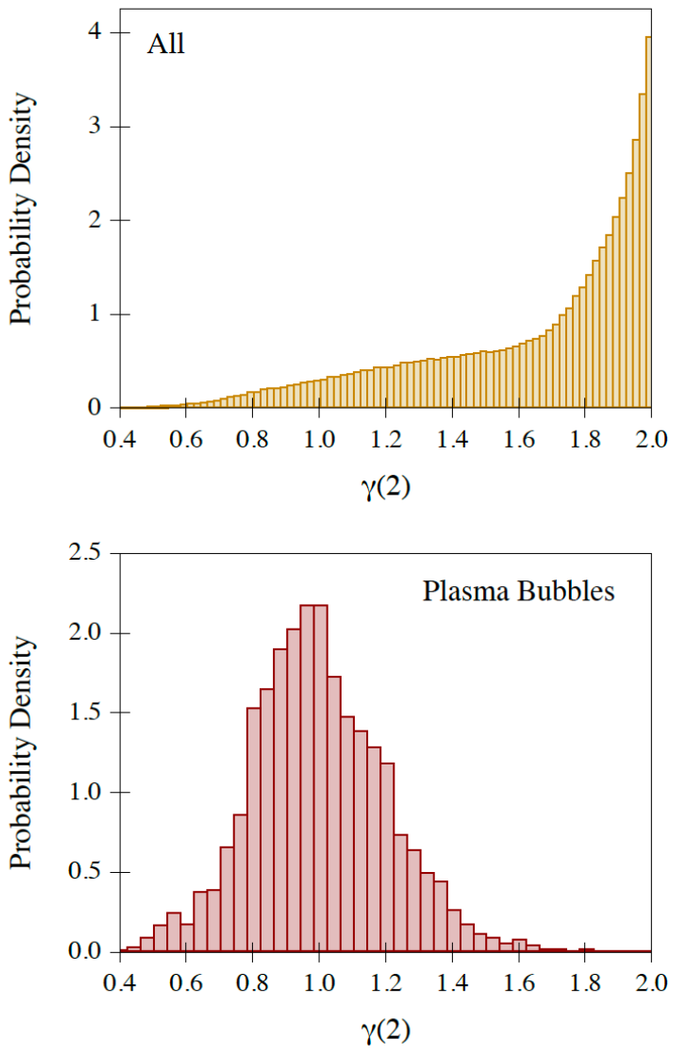
$\gamma(1)$ first-order scaling exponent, known as Hurst exponent

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

Results: Turbulent Character of plasma bubbles

$$S_2(\tau) = < |N_e(t+\tau) - N_e(t)|^2 >_T \sim \tau^{\gamma(2)}$$



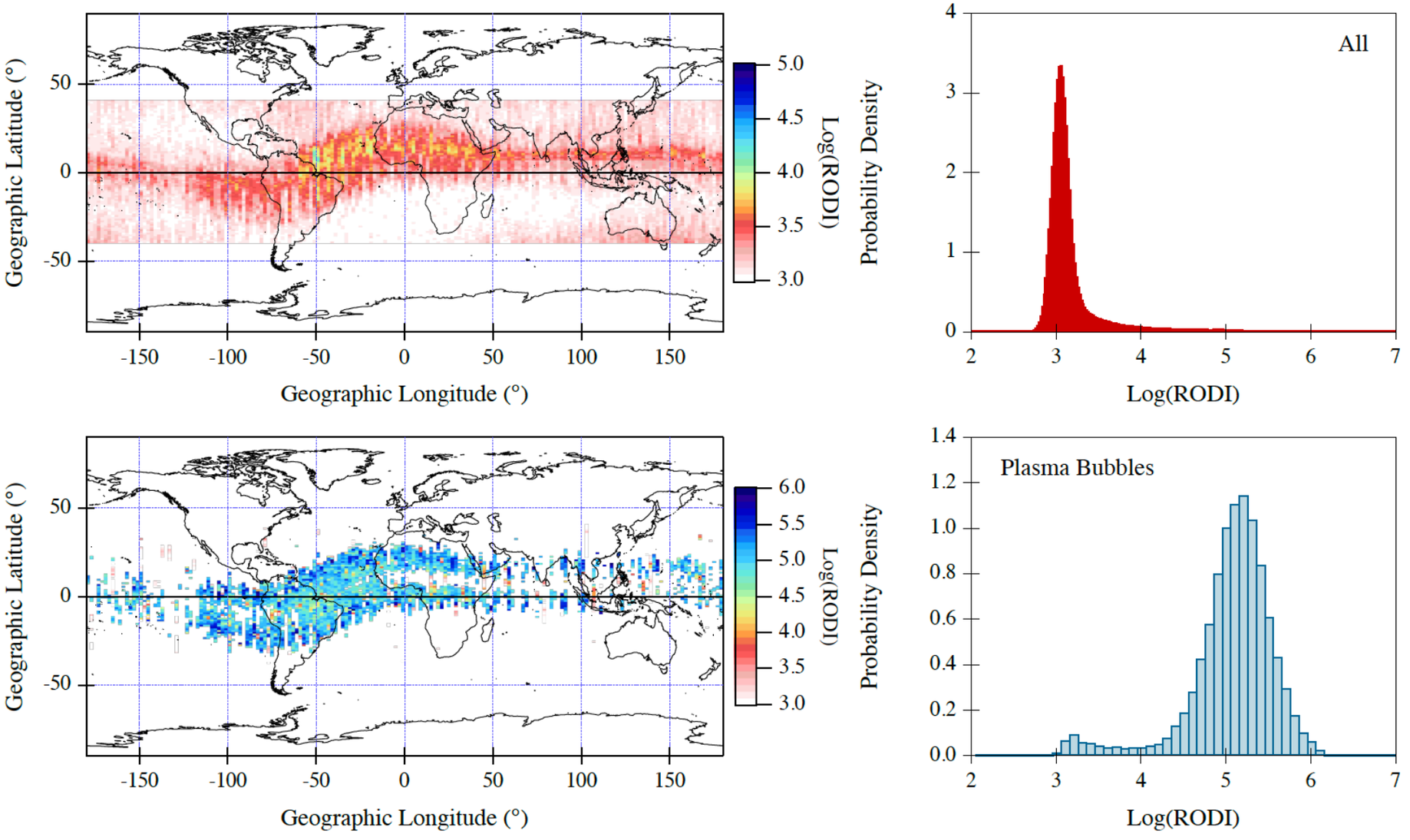


Plasma bubbles exhibit scaling properties, which are completely different from the surrounding environment.

In the case of magnetohydrodynamic turbulence, the observed spectral features could be the result of a 2D intermittent turbulence due to the formation of coherent structures.

From De Michelis et al., Remote Sensing, 13, 759, 2021

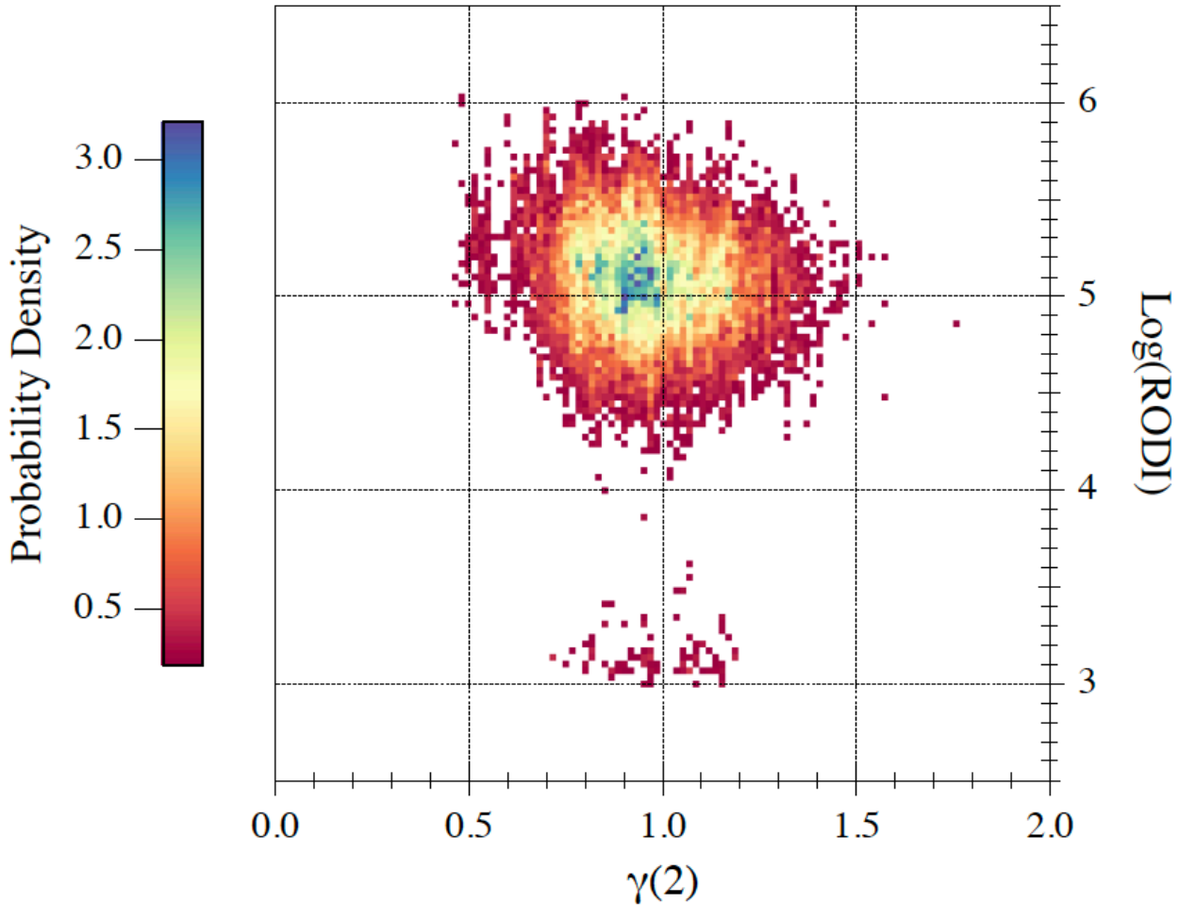
Results



Inside the plasma bubbles RODI reaches high values (>10^4 $cm^{-3}s^{-1}$) which are not observed outside these irregularities where the mean value of RODI is around 10^3 $cm^{-3}s^{-1}$

From De Michelis et al., Remote Sensing, 13, 759, 2021

Results: High RODI values inside plasma bubbles



The joint probability density between RODI and $\gamma(2)$ scaling exponent shows that inside plasma bubbles the *Ne* fluctuations, which seem to be characterized by a turbulent nature, also show large density gradients as highlighted by the associated RODI values.

From De Michelis et al., Remote Sensing, 13, 759, 2021

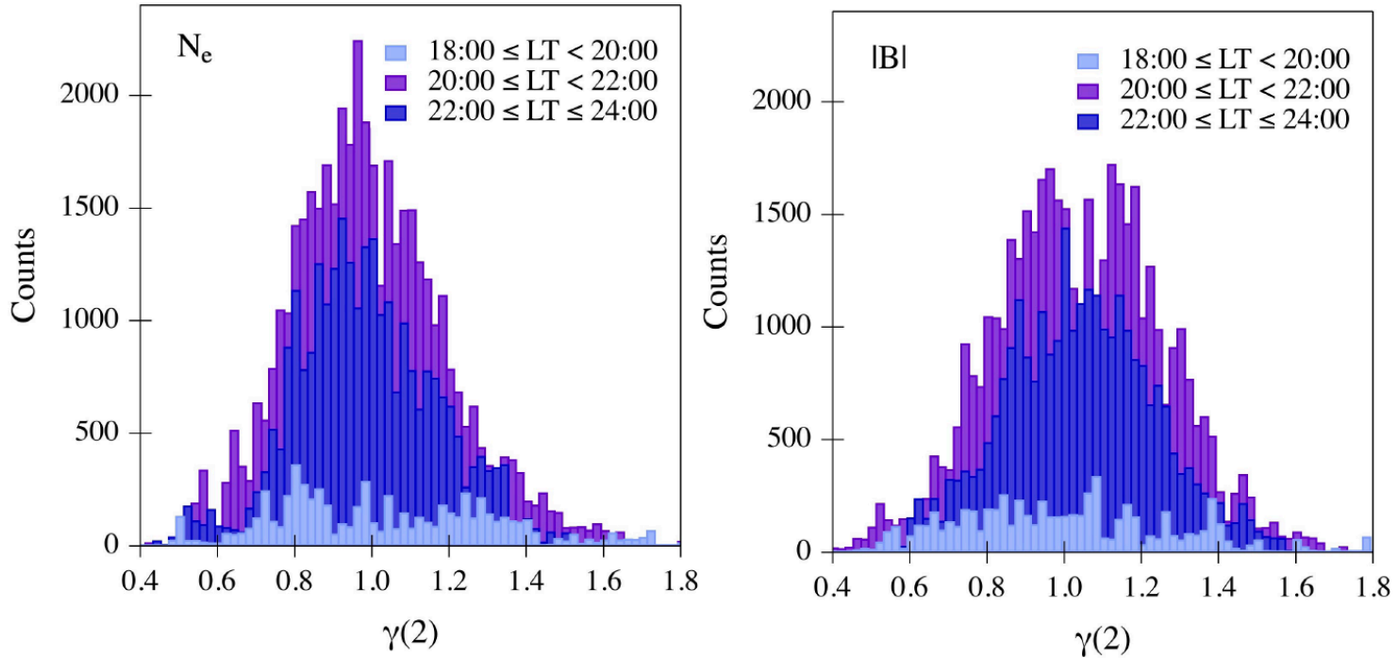
Results: Magnetic field and electron density scaling properties

Plasma density irregularities are associated with magnetic field perturbations
that can be used as a proxy for plasma irregularities. The features obtained using the magnetic signatures of the plasma depletions are consistent with those obtained by directly using the electron density measurements.

$$\Delta B \sim -\frac{\mu_0 k_B}{B}\Delta[N_e(T_e + T_i)]$$

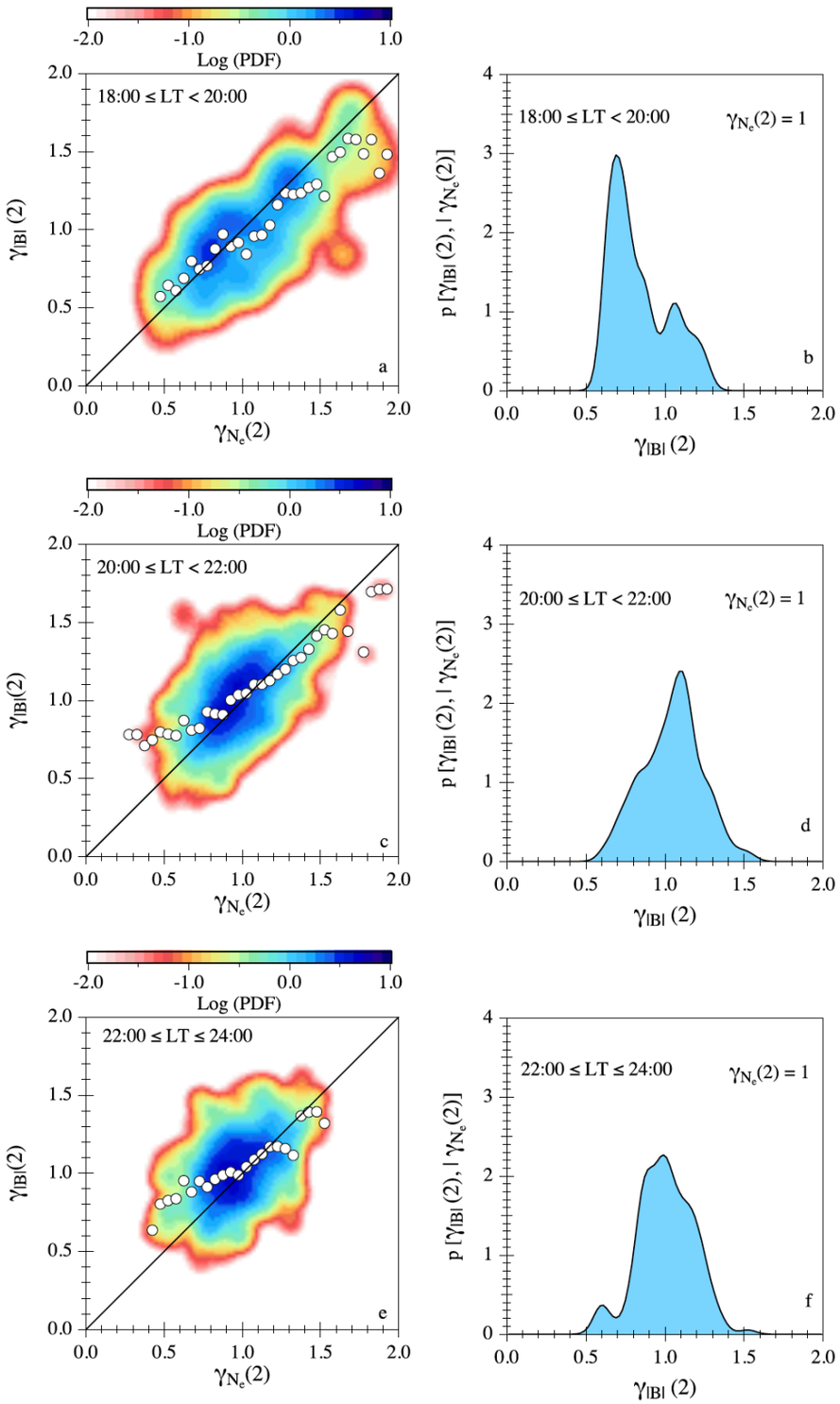
While it is correct to assume that some plasma bubbles features can be inferred using the corresponding magnetic signatures, the assumption that plasma bubbles scaling properties can be inferred using the associated magnetic field scaling properties may be not necessarily correct as well.

! $\Delta B \sim C_0 \Delta N_e \sim \tau^{\gamma(1)}$



From De Michelis et al., Remote Sensing, 14, 918, 2022

Results: Magnetic field and electron density scaling properties



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The joint probability distributions of $\gamma(2)$ values relative to Ne and |B| along with the mean values of $\gamma_{|B|}(2)$ exponent (white circles) for fixed $\gamma_{N_e}(2)$ at the three different selected two-hour time intervals.

- There is a large spreading of the observed distributions with most of the values concentrated around [$\gamma_{N_e}(2)$, $\gamma_{|B|}(2)$] = [1, 1], which indicates that the relation between electron density and magnetic field scaling exponents can be assumed to be linear only in a zero-order approximation.

- Looking at the trend of the mean values of $\gamma_{|B|}(2)$ fixed $\gamma_{N_e}(2)$, we can realize how the relation between the two scaling indices significantly departs from a linear trend for $\gamma_{N_e}(2)$ < 0.9 at LT>20:00.

- The observed distributions are multimodal, thus supporting the hypothesis that a linear relation between magnetic field intensity and plasma density spectral features has to be considered valid only on average being a very crude approximation.

- This result suggests that a more complex relation might exist between plasma density and magnetic field variations.

Papers summarized in the presentation

Open Access Article

Ionospheric Turbulence and the Equatorial Plasma Density Irregularities: Scaling Features and RODI

by Paola De Michelis [1,*], Giuseppe Consolini [2], Roberta Tozzi [1], Alessio Pignalberi [1], Michael Pezzopane [1], Igino Coco [1], Fabio Giannattasio [1] and Maria Federica Marcucci [2]

[1] Istituto Nazionale di Geofisica e Vulcanologia, Via di Vigna Murata 605, 00143 Roma, Italy

[2] INAF—Istituto di Astrofisica e Planetologia Spaziali, Via del Fosso del Cavaliere 100, 00133 Roma, Italy

[*] Author to whom correspondence should be addressed.

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Magnetic Field and Electron Density Scaling Properties in the Equatorial Plasma Bubbles

by Paola De Michelis [1,*], Giuseppe Consolini [2], Tommaso Alberti [2], Roberta Tozzi [1], Fabio Giannattasio [1], Igino Coco [1], Michael Pezzopane [1] and Alessio Pignalberi [1]

[1] Istituto Nazionale di Geofisica e Vulcanologia, Via di Vigna Murata 605, 00143 Roma, Italy

[2] INAF—Istituto di Astrofisica e Planetologia Spaziali, Via del Fosso del Cavaliere 100, 00133 Roma, Italy

[*] Author to whom correspondence should be addressed.

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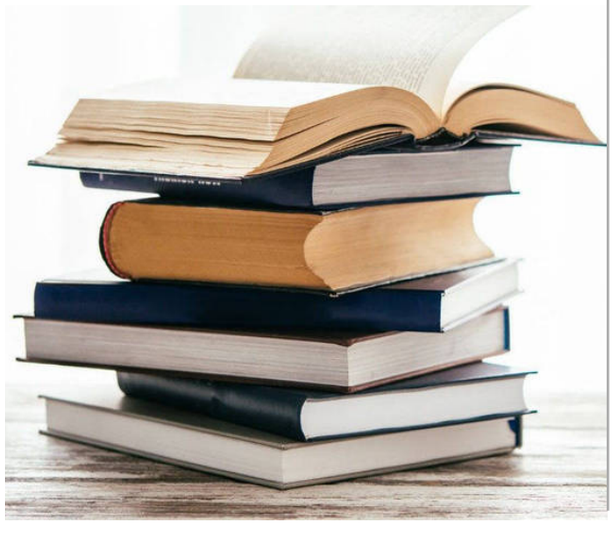

Email: paola.demichelis@ingv.it