SCHOOL OF NATURAL SCIENCES AND MATHEMATICS
The University of Texas at Dallas

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Equatorial spread F: A brief introduction with new ground-based observations

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Lightning Talk – 2024 CEDAR Workshop, San Diego, CA.
Acknowledgements: Students, colleagues, Jicamarca staff and NSF.

1. What does equatorial spread F (ESF) mean?

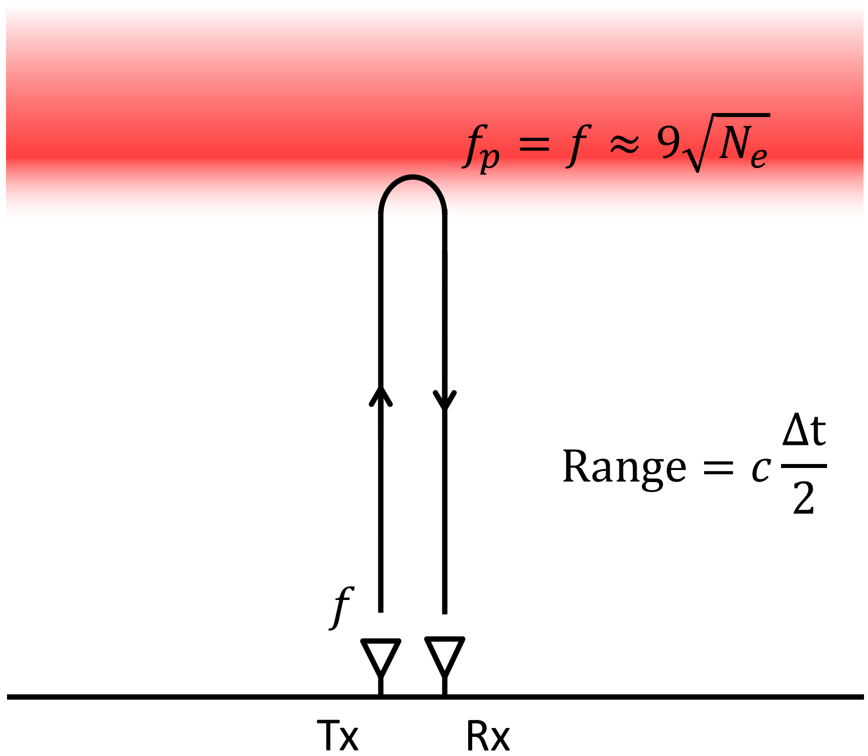
2. What causes ESF?

3. Relevance of ESF beyond fundamental science

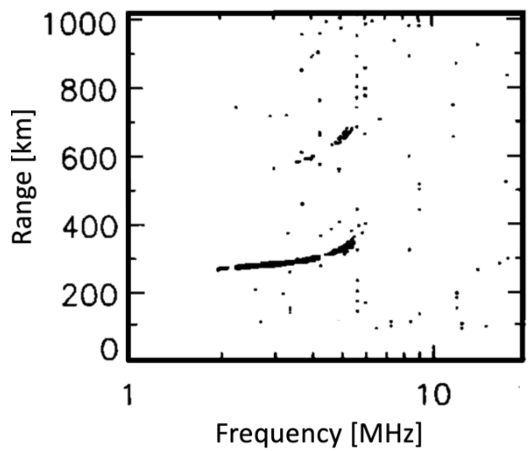
4. Fundamental ESF studies with new ground-based observations

1. ESF

- Vertical radio sounders (ionosondes) create $N_e(h)$ by transmitting signals of varying frequencies and measuring the height at which they match f_P and are reflected.



Prototypical ionogram

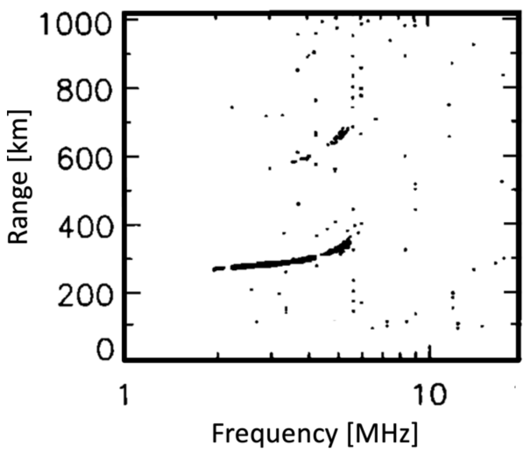


1. ESF

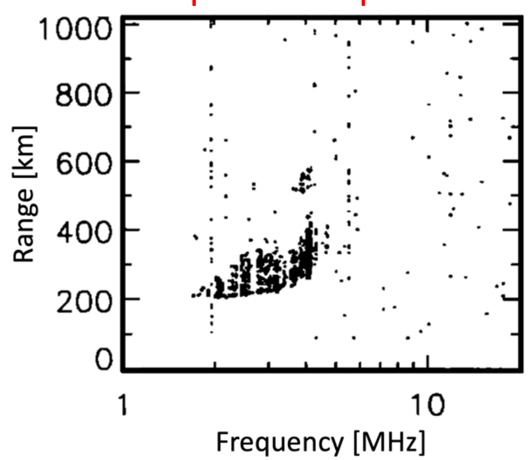
- Vertical radio sounders (ionosondes) create $N_e(h)$ by transmitting signals of varying frequencies and measuring the height at which they match f_P and are reflected.

- Early measurements at the magnetic equator showed diffuse (spread) echoes coming from F-region heights. It was correctly attributed to F-region density irregularities [*Booker and Wells, 1938*].

Prototypical ionogram



Equatorial spread F



2. GRTi

- ESF now refers to the manifestation of a family of interchange plasma instabilities collectively known as Generalized Rayleigh-Taylor instability.

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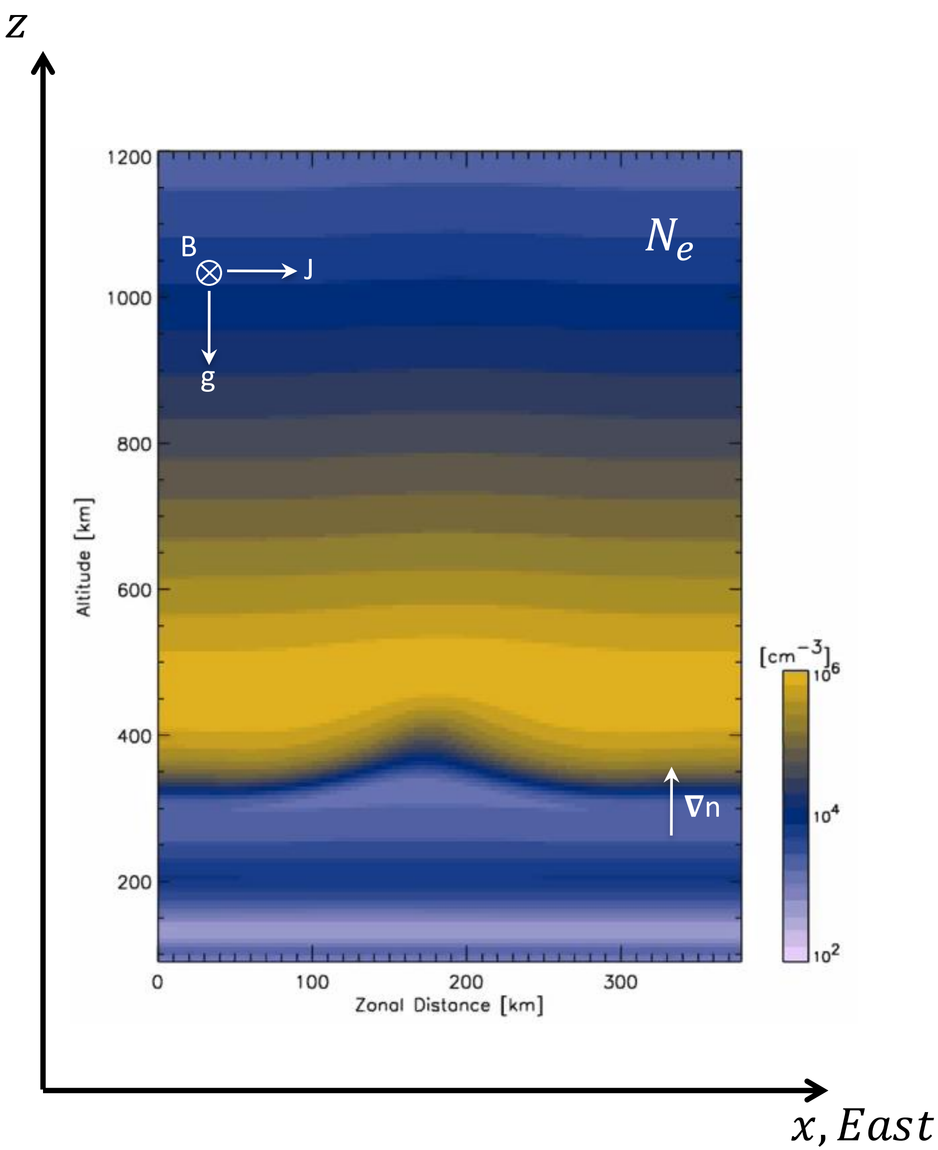

Adapted from Yokoyama et al. (2015)

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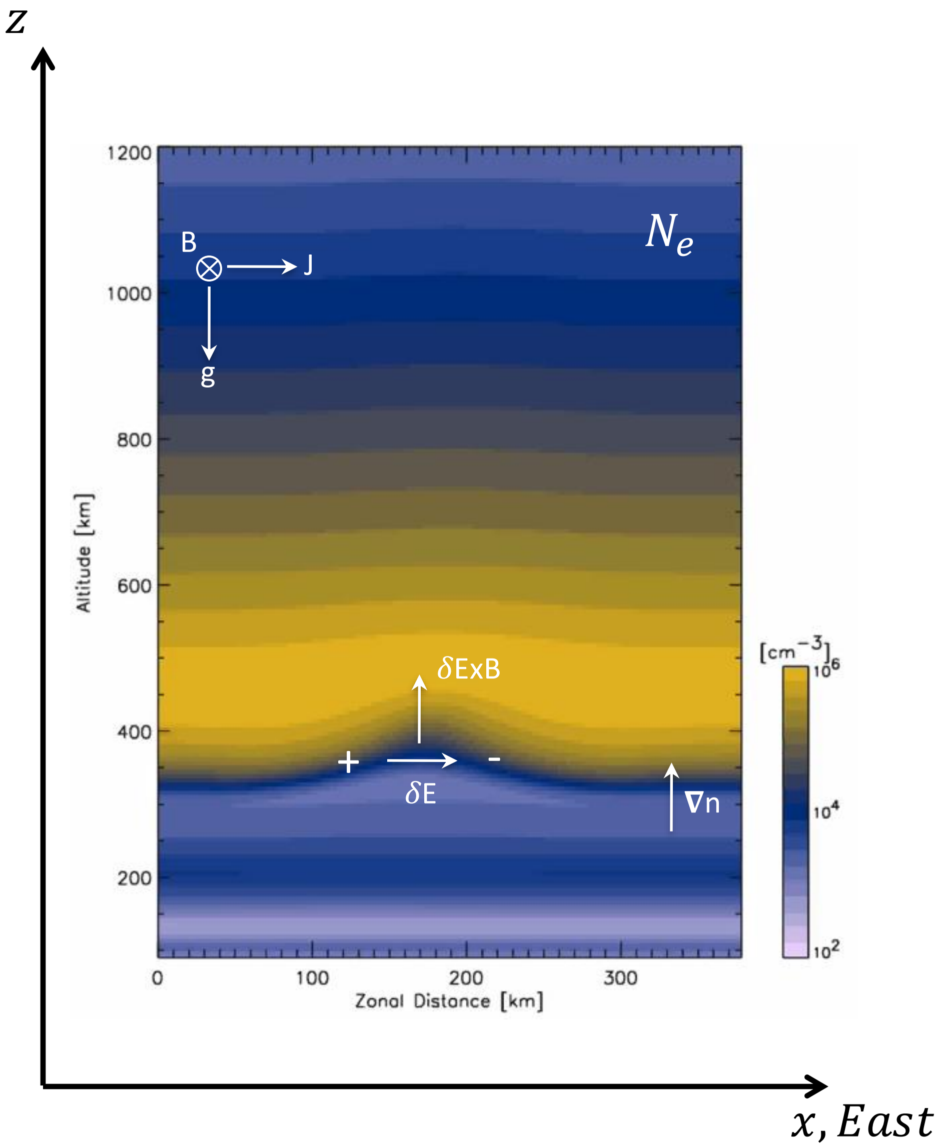


- ESF now refers to the manifestation of a family of interchange plasma instabilities collectively known as Generalized Rayleigh-Taylor instability.

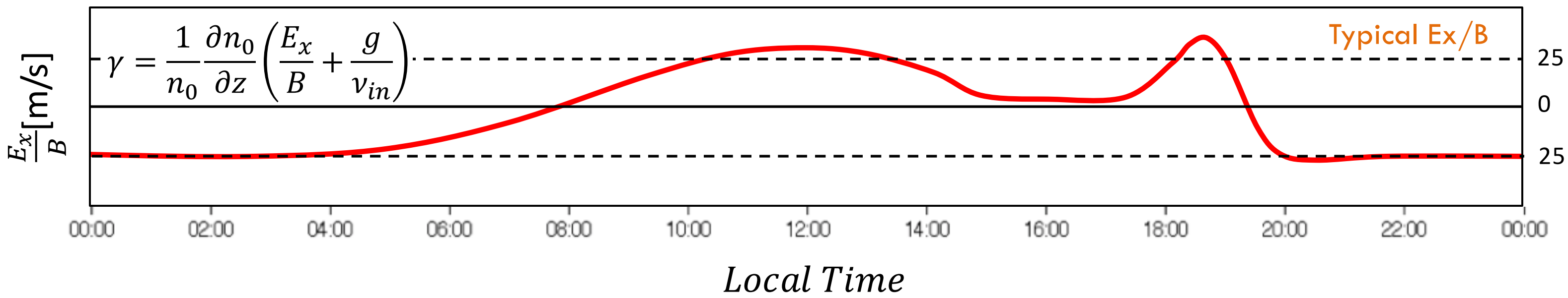
- Local linear stability analyses considering the magnetic equator and currents driven only by gravity and E-fields and a small, gives us the following expression for the growth rate [*B. Basu, 2002*]:

$$\boxed{\gamma = \frac{1}{n_0}\frac{\partial n_0}{\partial z}\left(\frac{E_x}{B} + \frac{g}{\nu_{in}}\right)}$$

Adapted from Yokoyama et al. (2015)

2. GRTi

- One can use ionospheric models (e.g., SAMI2, [*Huba, 2023*]) to evaluate γ



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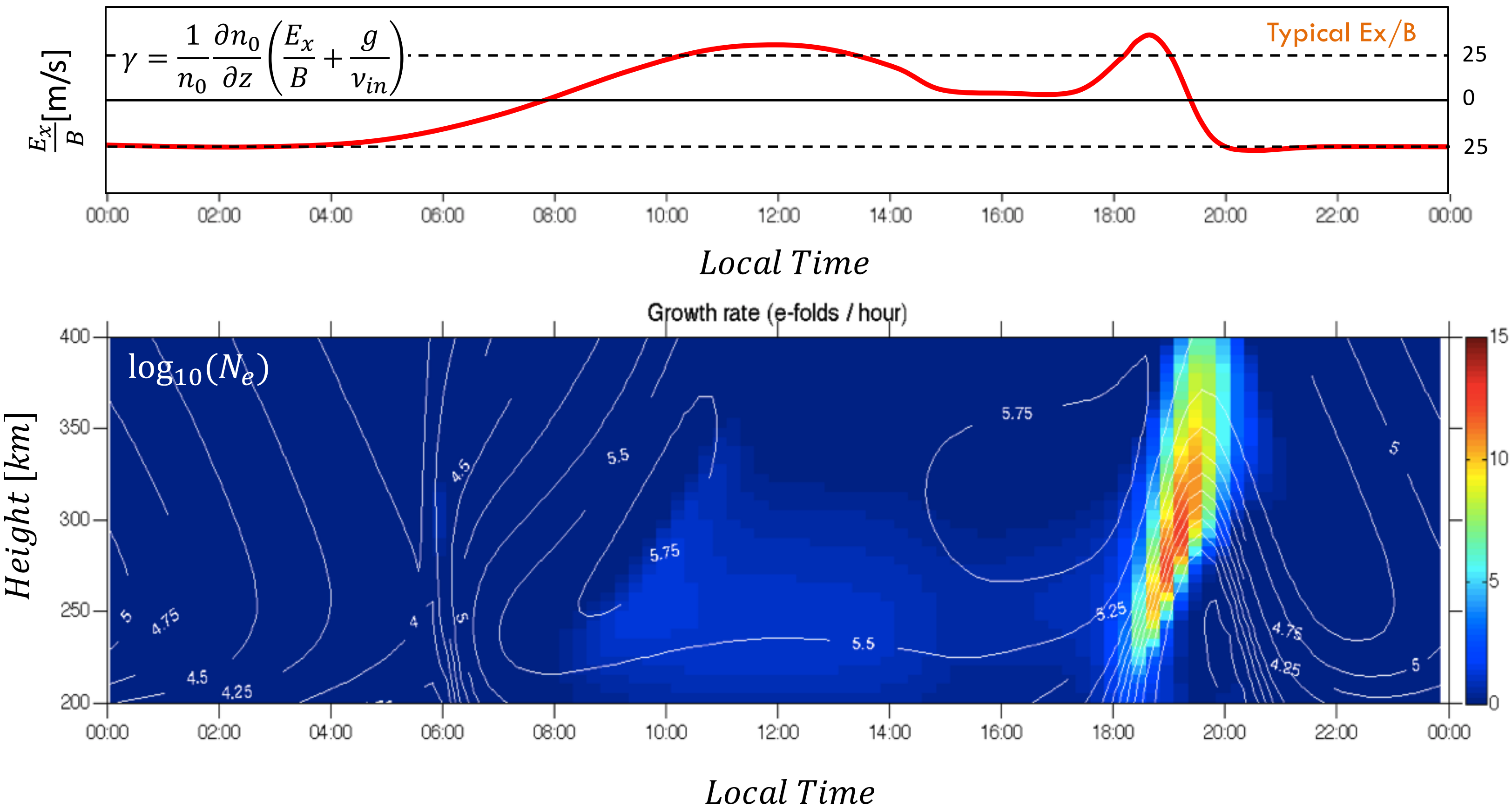
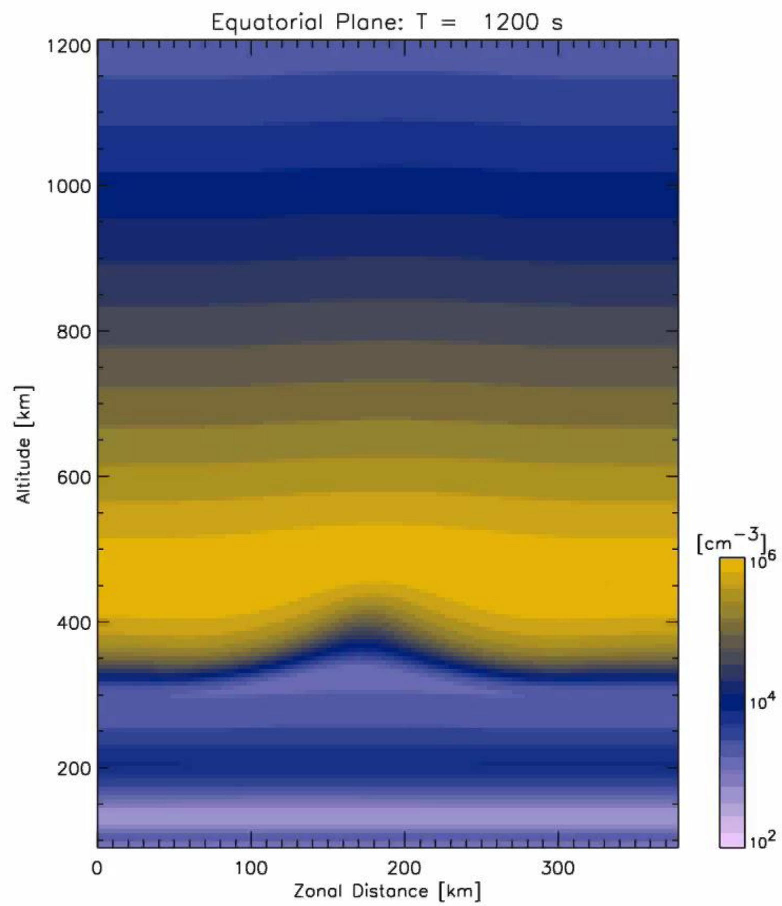


- Simple local growth rate explains main features in ESF
    - Appearance during post-sunset
    - Well-correlated with PRE

2. GRTi



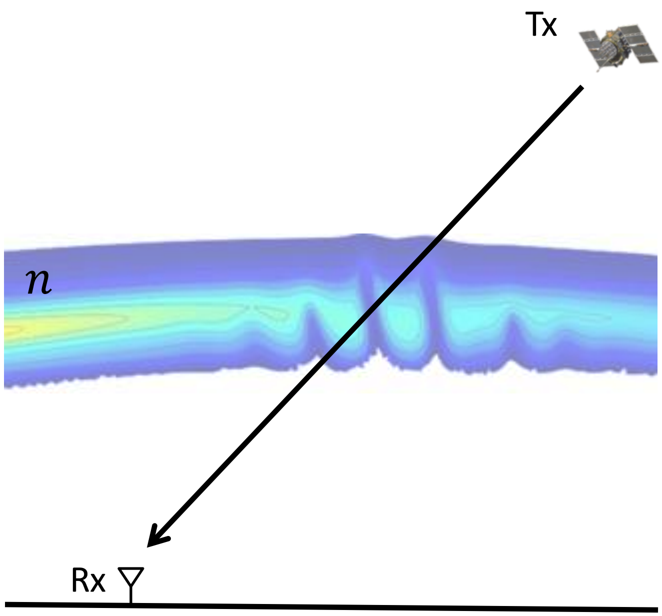
- Advanced numerical models describing the development of ESF have been developed [*Huba et al., 2008; Retterer, 2010; Aveiro and Hysell et al., 2010; Yokoyama et al., 2015*] including some driven by measurements [e.g., Hysell et al., 2014]

- Large-scale (>10s to 100s of km) vertically well-developed ESF irregularities are known as equatorial plasma bubbles (EPBs)

- The development of smaller scale (< 10 km) irregularities can also be seen as EPB grows

Yokoyama et al. (2015)

3. Broader impact



- $n \sim \sqrt{1 - 81\frac{N_e}{f^2}}$

- ESF leads to drastic spatial and temporal variations in the index of refraction (n)

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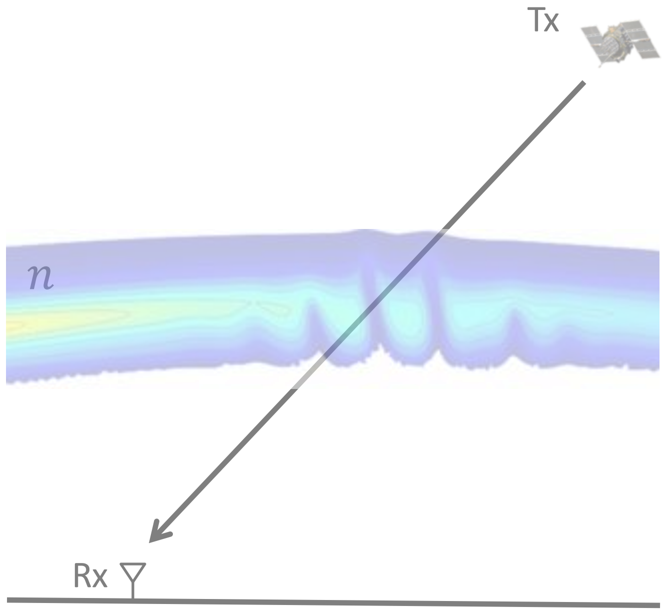
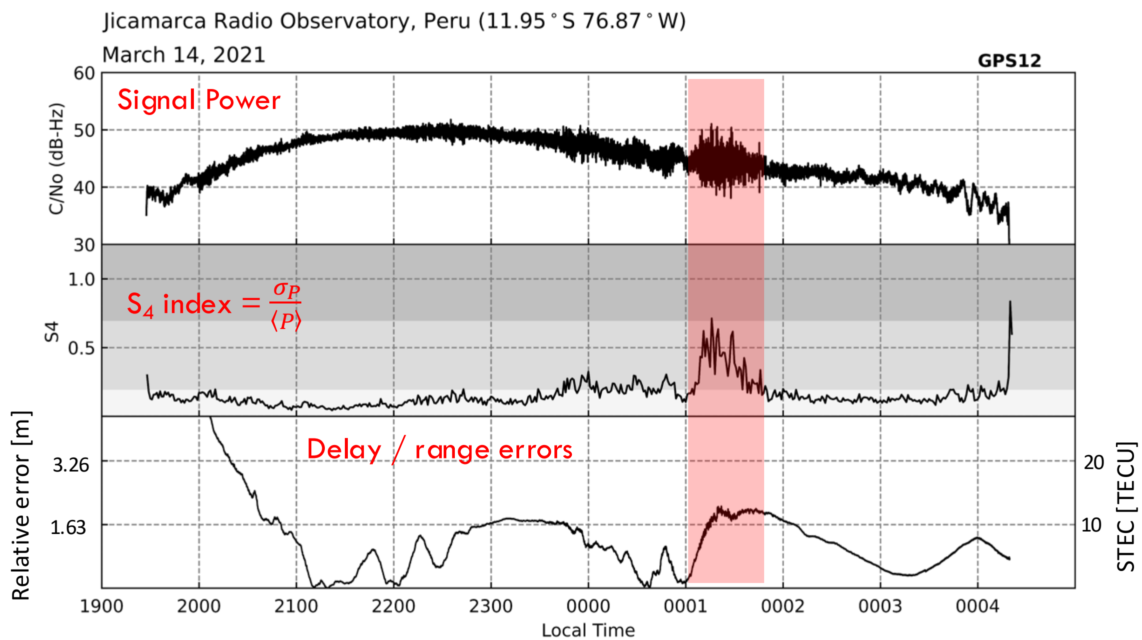


- $n \sim \sqrt{1 - 81\,\frac{N_e}{f^2}}$

- ESF leads to drastic spatial and temporal variations in the index of refraction (n)

- Hard to predict ionospheric fading (scintillation) and delay errors.

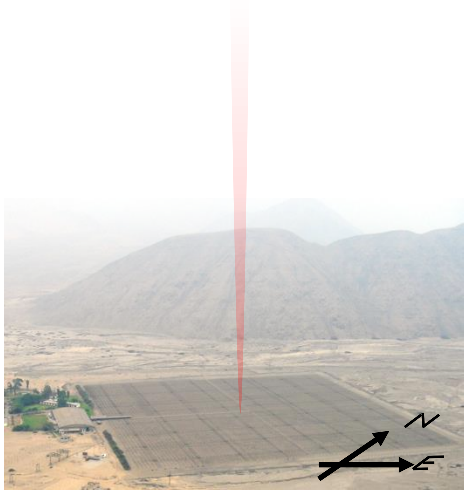
- Complications for signals and systems used for communication, navigation and remote sensing systems [*Basu et al., 1988; Zhang and Morton, 2009; Carrano et al. 2012*].



4.1 New ground-based observations of ESF

Jicamarca Radio Observatory

- Main source of ionospheric radar observations in the equatorial region.
- The Jicamarca radar allows the detection of echoes from thermal waves (e.g., ion acoustic) and from irregularities (e.g., ESF).
- Narrow beam focuses on ESF right above Jicamarca.



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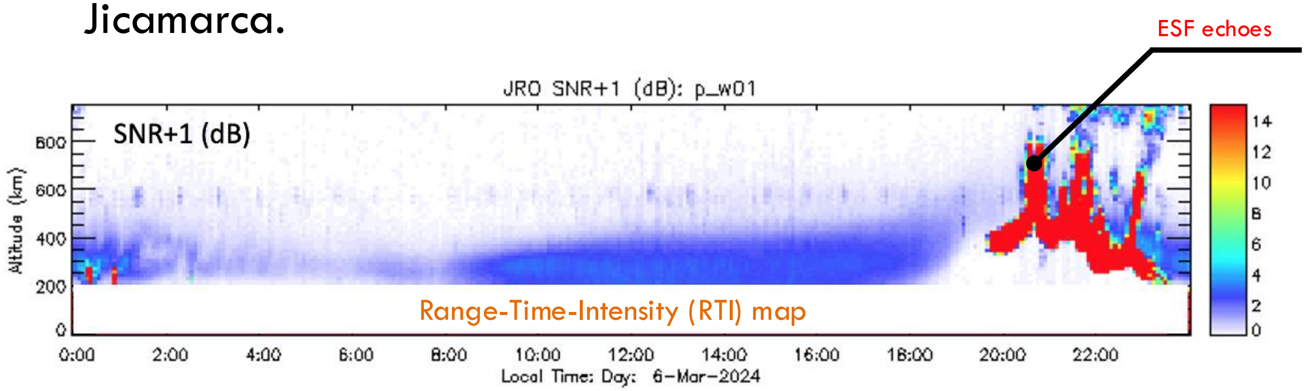
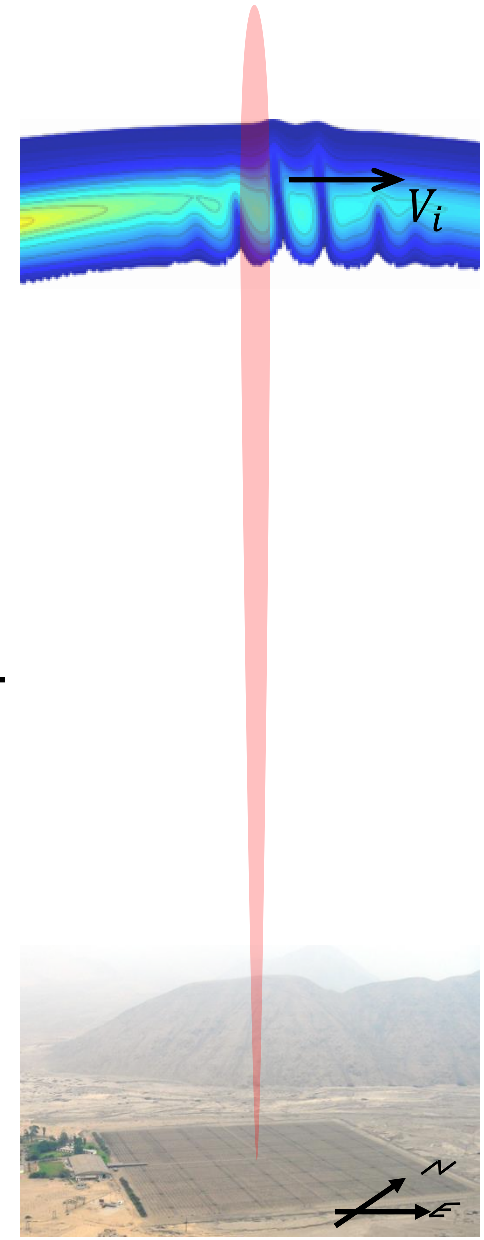


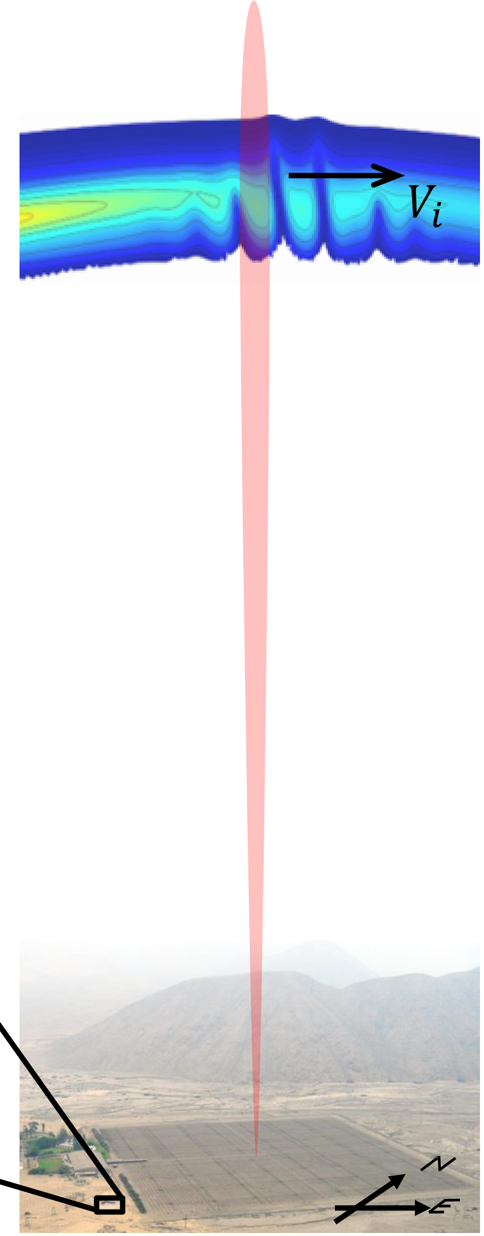


- ESF studies can benefit of observations over a wider FOV.

4.1 New ground-based observations of ESF

New AMISR-14 observations of ESF

- AMISR-14 is a relatively small UHF radar capable of steering the beam electronically.



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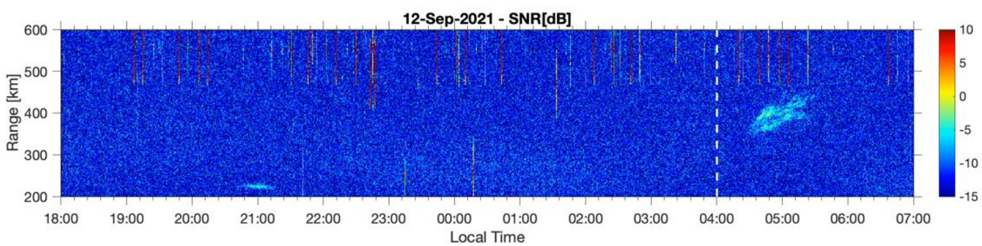
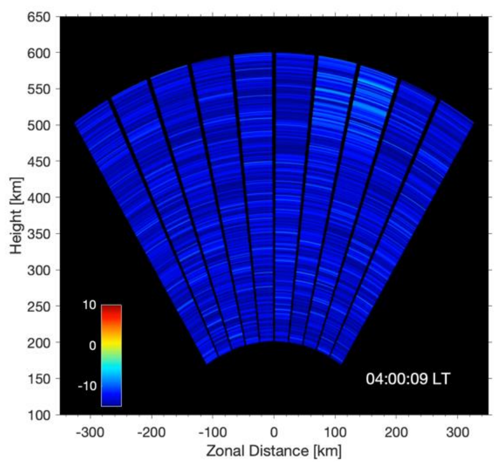
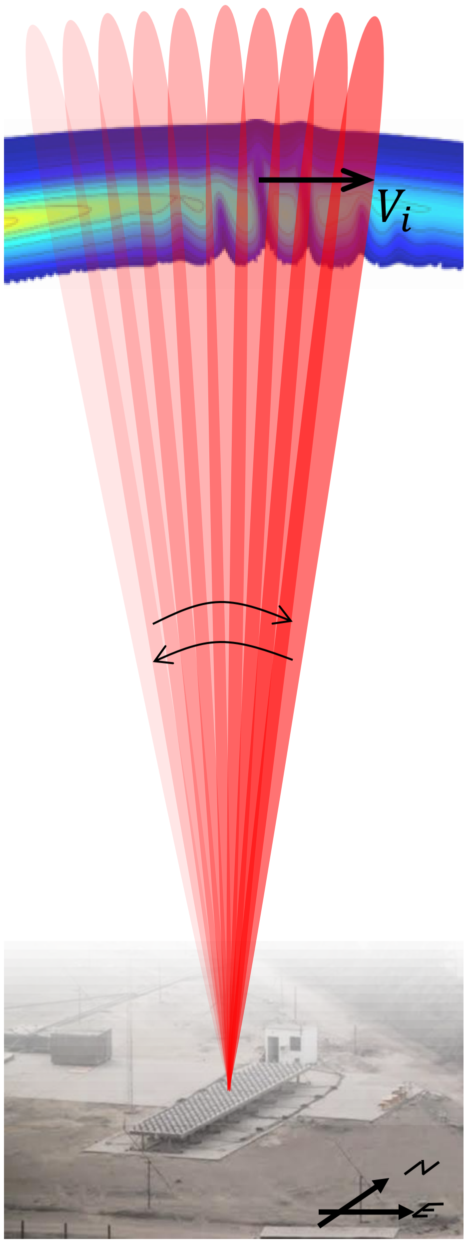
New AMISR-14 observations of ESF

- AMISR-14 is a relatively small UHF radar capable of steering the beam electronically.

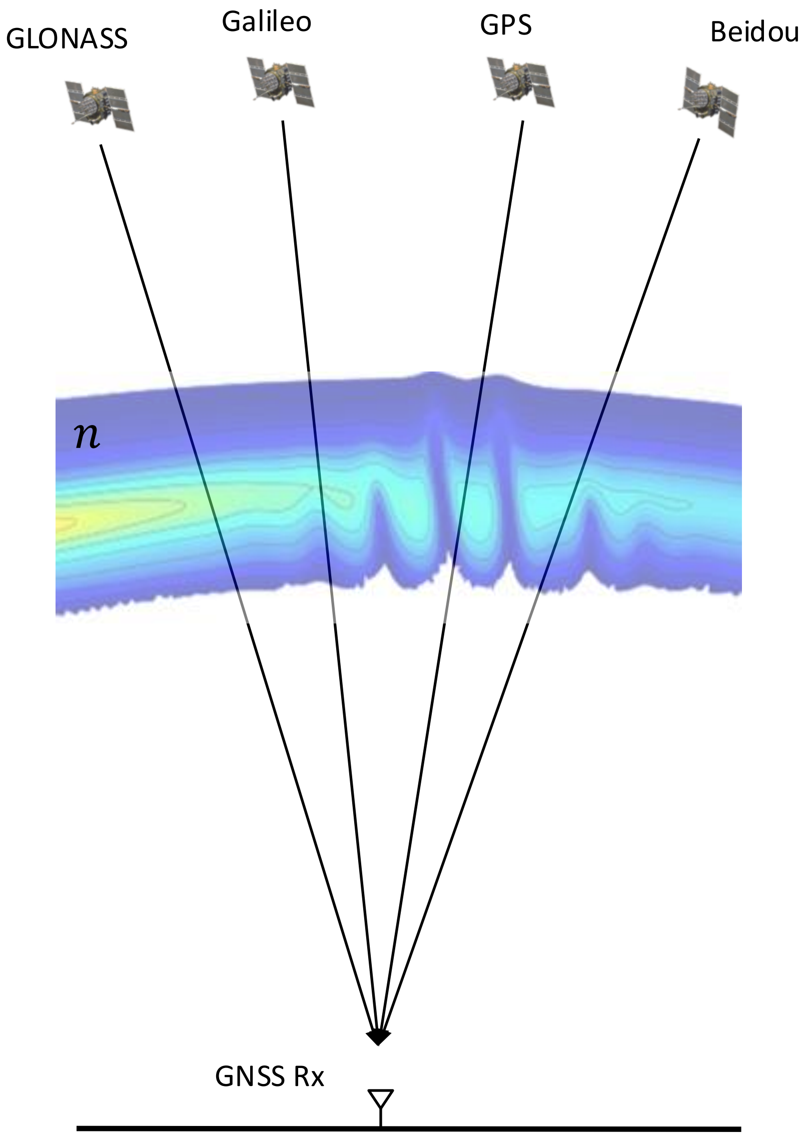
- 2D observations of the spatio-temporal variation of ESF over 400 km zonal distances have been made [*Rodrigues et al., 2023*].



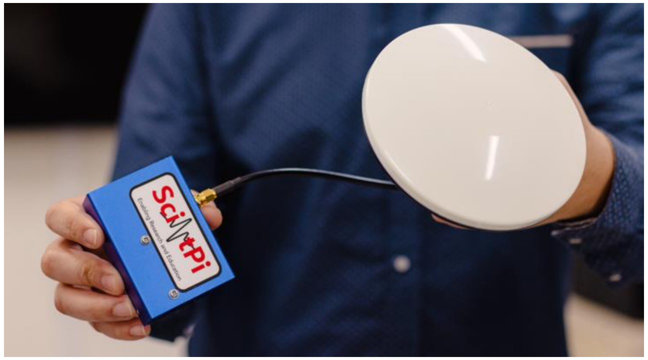




4.2 New ground-based observations of ESF

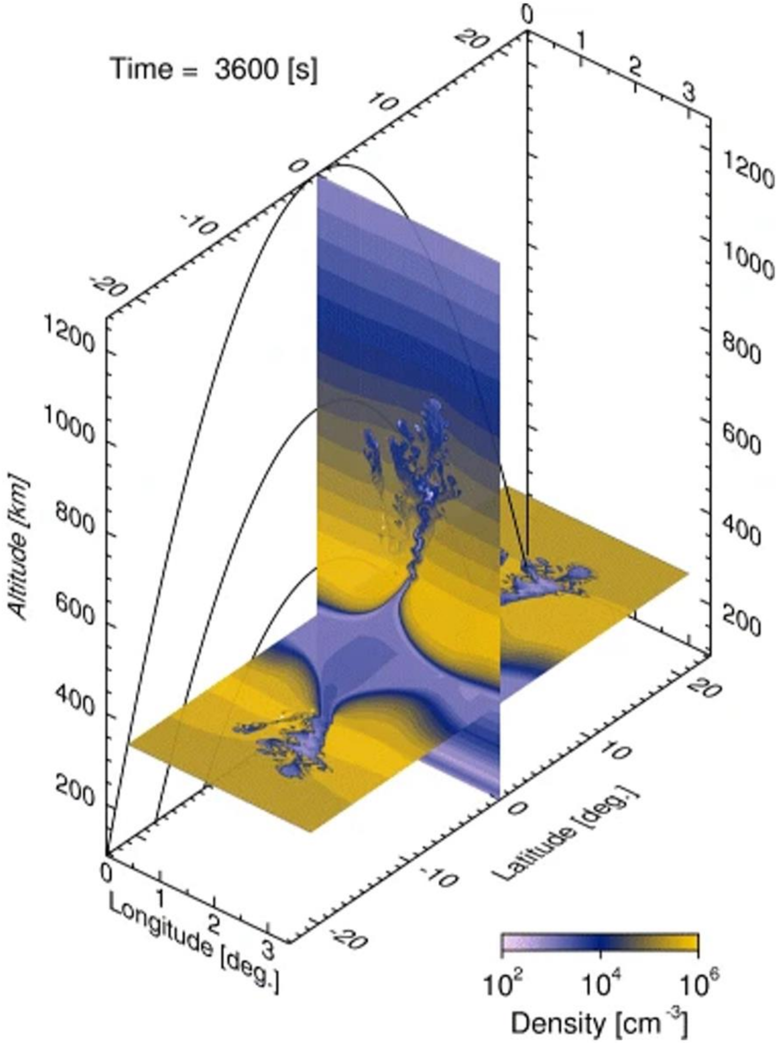


- We saw that ESF irregularities can cause scintillation.
- Signals from Global Navigation Satellite System (GNSS) satellites can be used to monitor and study ESF.
- UTD Students have been developing and deploying low-cost GNSS-based scintillation monitors for distributed studies [*Gomez Socola and Rodrigues, 2022, Wright et al., 2023*].



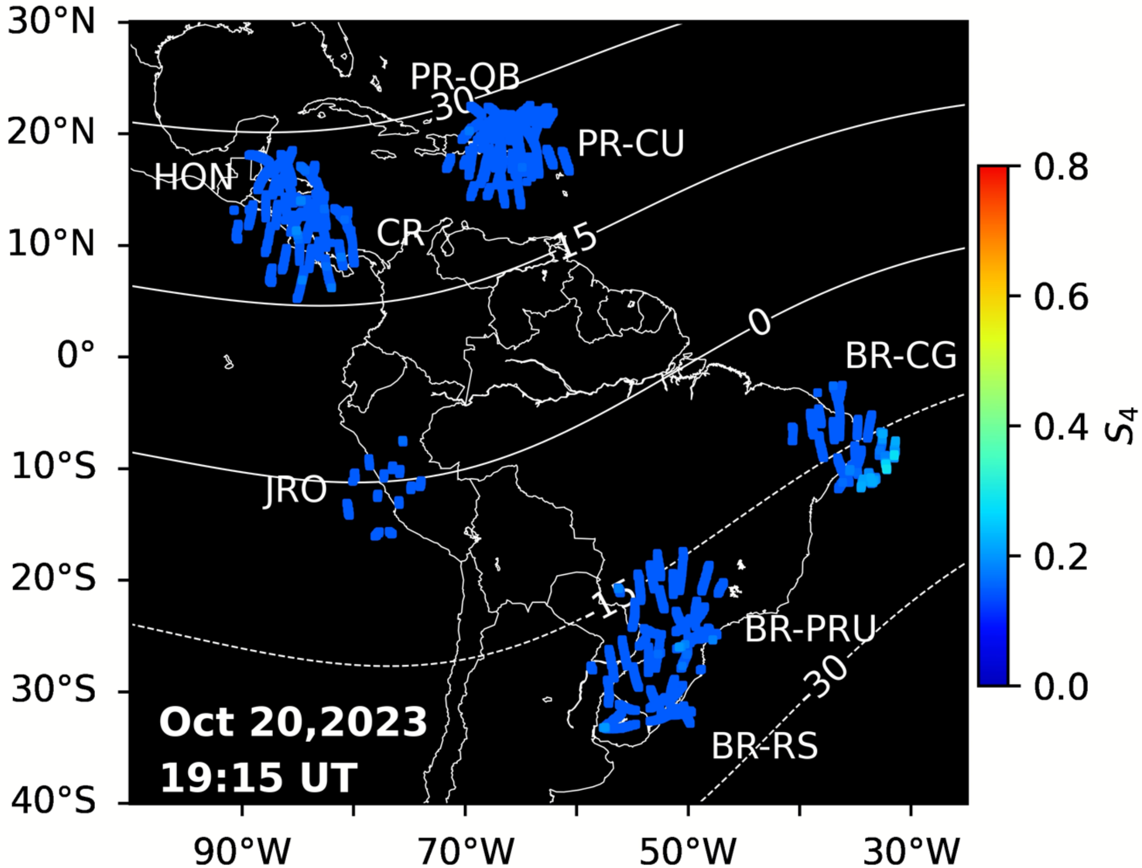
Josemaria G. Socola (ITIT-6, Wed.) and Isaac Wright (EQIT-5, Tue.)

4.2 New ground-based observations of ESF



- As ESF (or EPBs) develop vertically, they map along magnetic field lines and reach low latitudes.
- We seek, for instance, a better understanding of the variability of ESF with respect to longitude and altitude.
- ESF studies can benefit from distributed observations made by small sensors.

4.2 New ground-based observations of ESF



- Results from new ScintPi distributed observations for ESF studies in the American longitude sector.

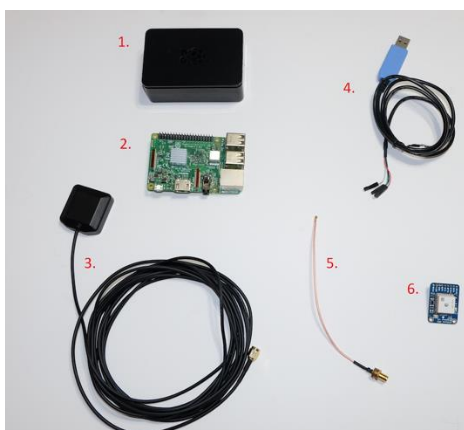
- The S_4 index is a commonly used metric of scintillation severity.

- UFCG, Brazil
- UNESP, Brazil
- Bate papo astronomico, Brazil
- JRO, Peru
- UNAH, Honduras
- TEC, Costa Rica
- UCF, Culebra, PR
- Quebradilla, PR

Final remarks

- Jicamarca International Research Experience Program – JIREP
  - 10-week summer program
  - Applications mid February
  - ESF and many other topics

Sponsored by:



- Build your own GPS scintillation monitor
  - ~$US100.00
  - List of parts
  - Assembly instructions

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Reviews

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