Studies of ionospheric radio wave scintillation by using LOFAR observations

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Motivation

The radio wave scintillation mechanism

LOFAR scintillation observations

Examples

Conclusions

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Ionospheric irregularities and their effects on radio waves

- Irregularities forming in the ionosphere due to instability mechanisms
- Temporal fluctuations on received phase and intensity
- Outages in systems (e.g., satellite navigation)
- Use of LOFAR to detect ionospheric irregularities forming over various spatial scales and their effects on radio-wave propagation
- Increase understanding of the ionosphere

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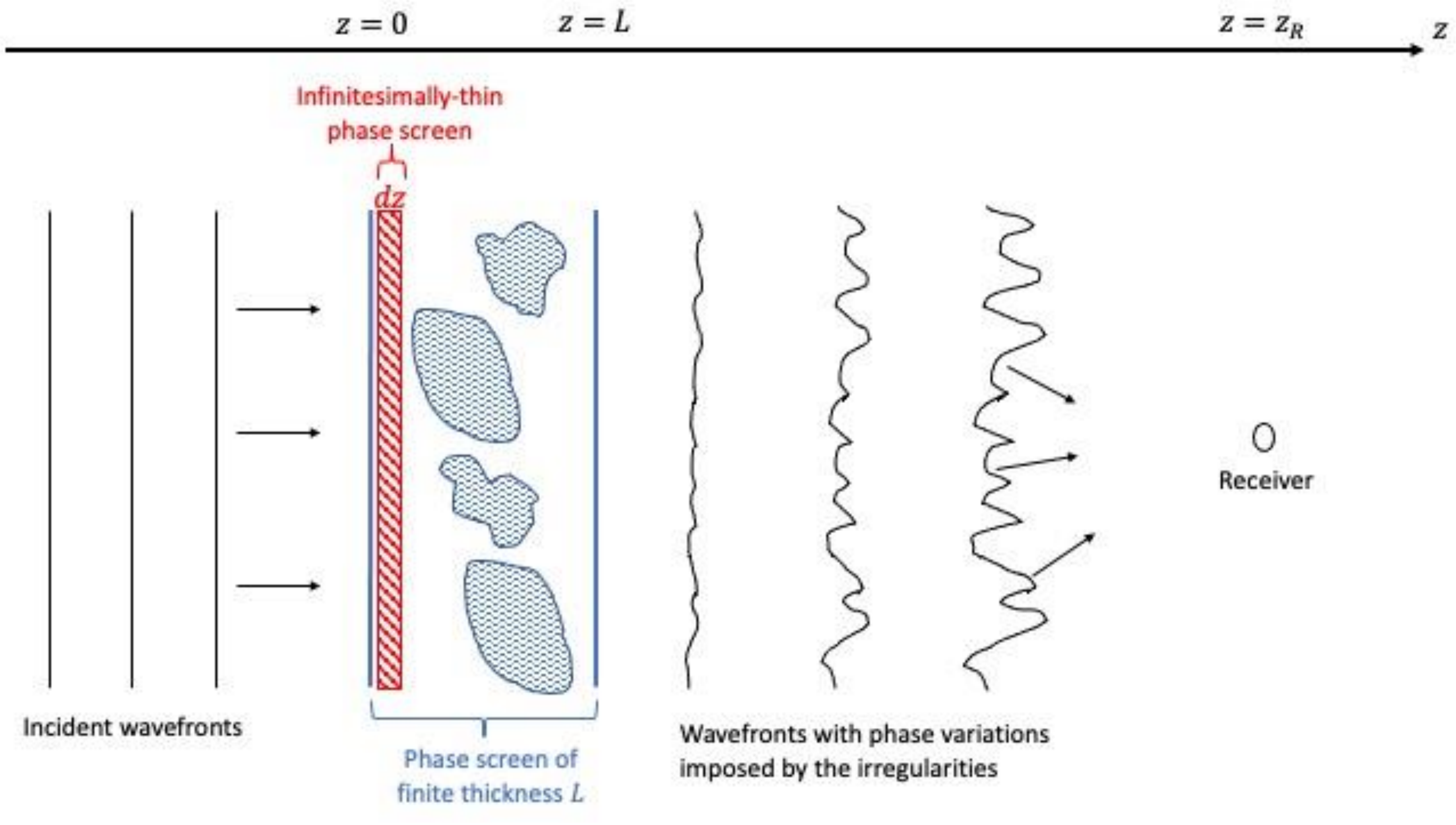
The propagation problem

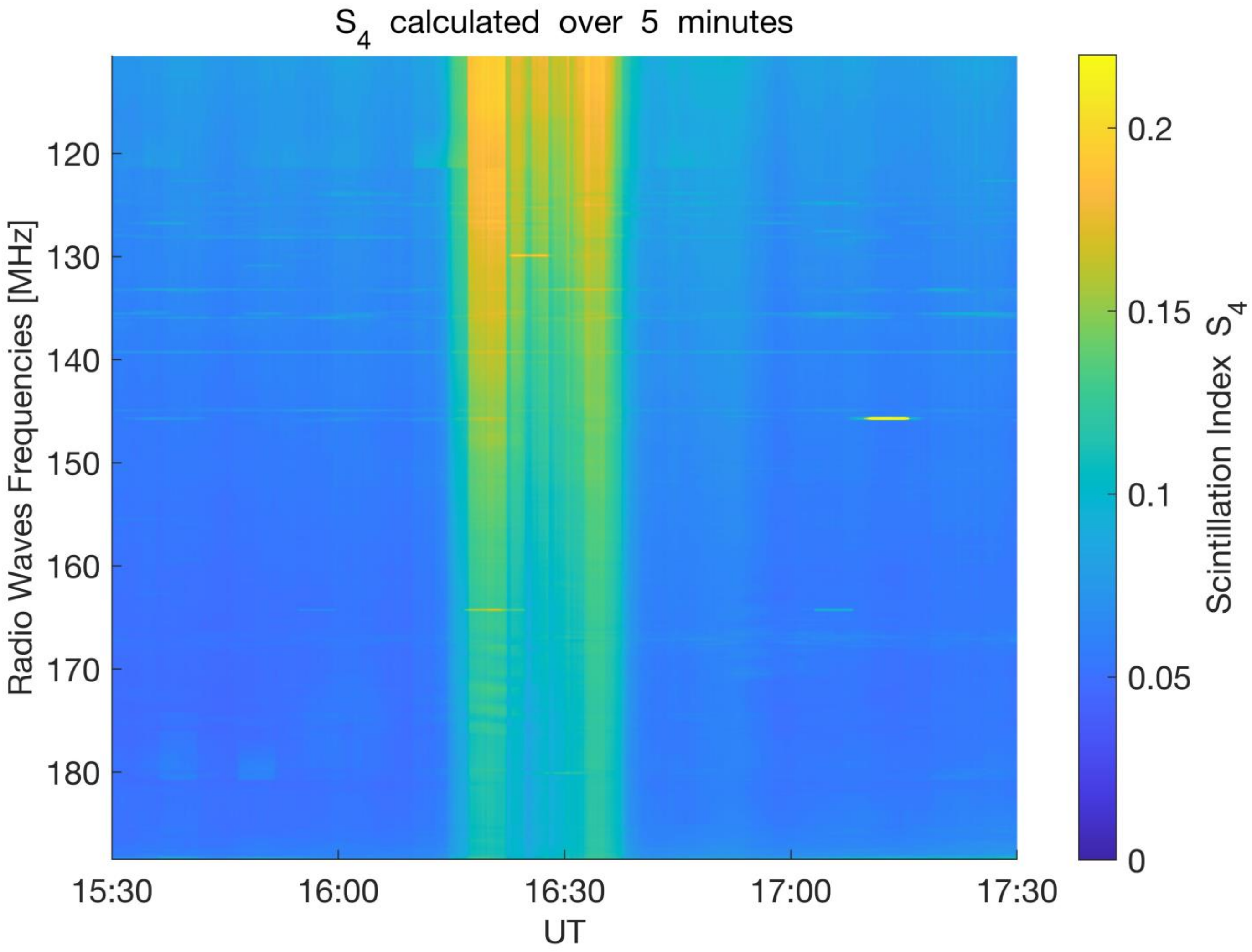


Credit: Forte et al., ApJS, 2022

Radio wave scintillation observed through LOFAR radio telescopes

Scintillation from plasma tail of Comet Neowise (3C196 utilised as a source)

16 July 2020



Credit: Fallows et al., A&A, 2022

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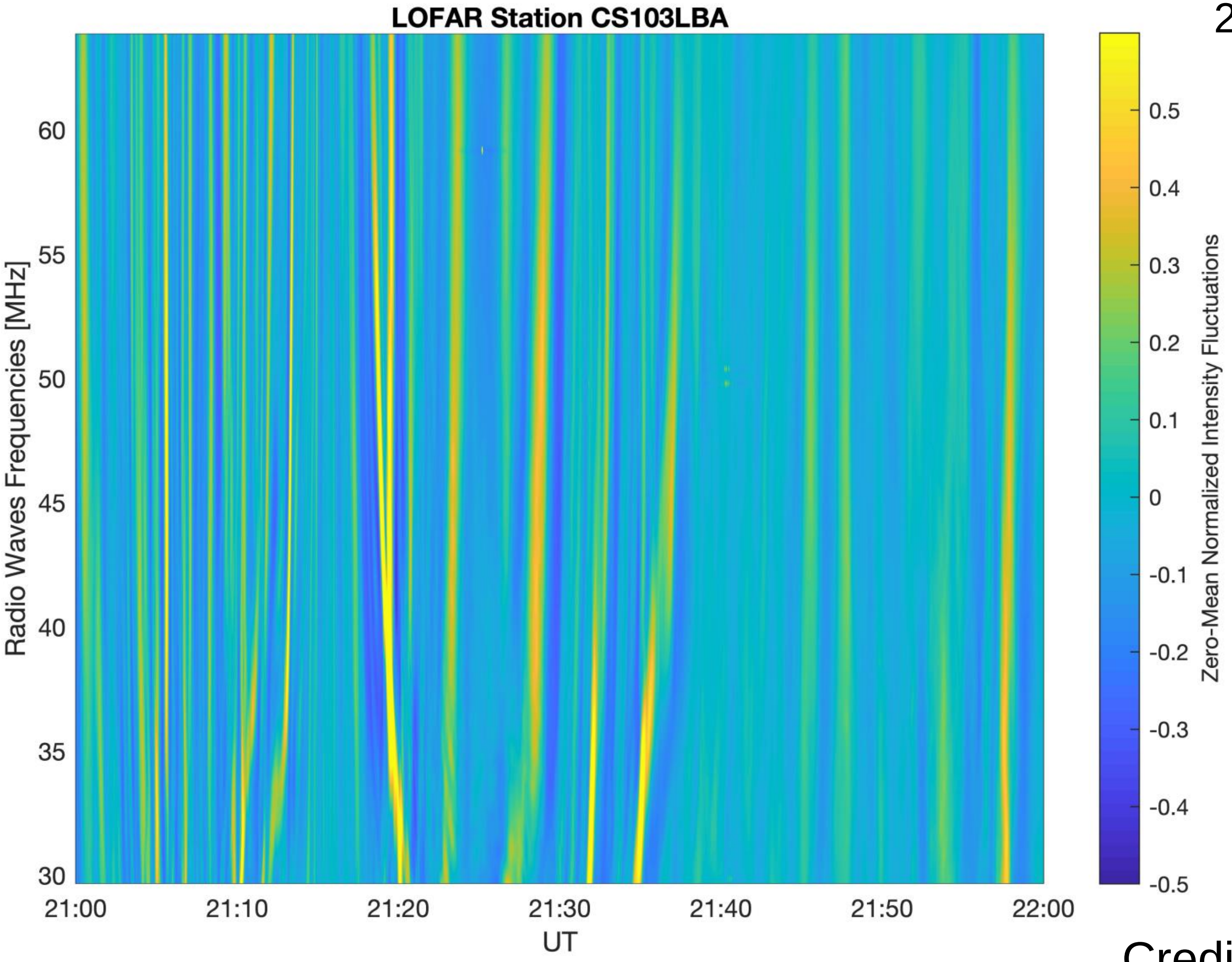
Radio wave scintillation observed through LOFAR radio telescopes

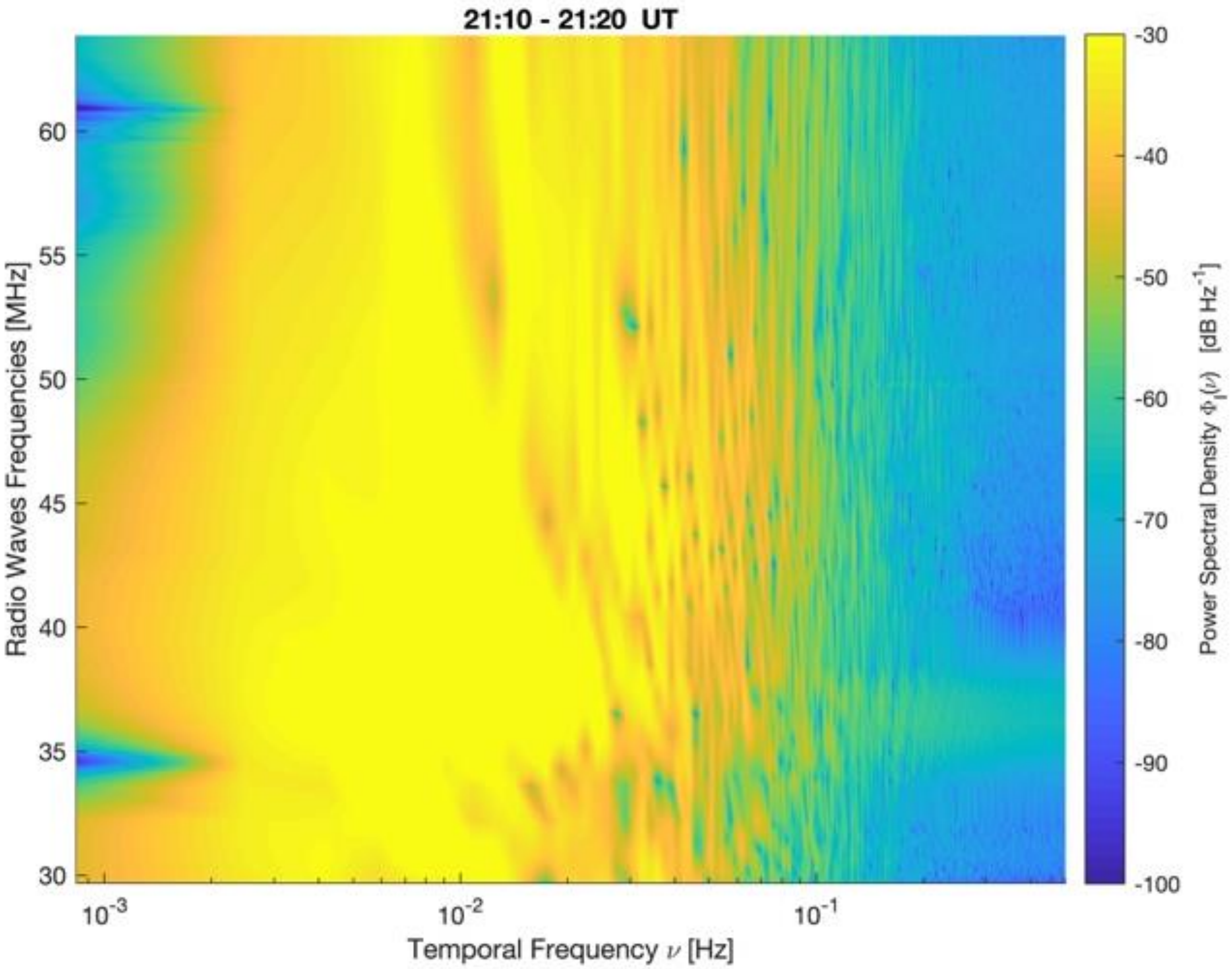
23 September 2018 17:01 UT -
24 September 2018 05:46 UT

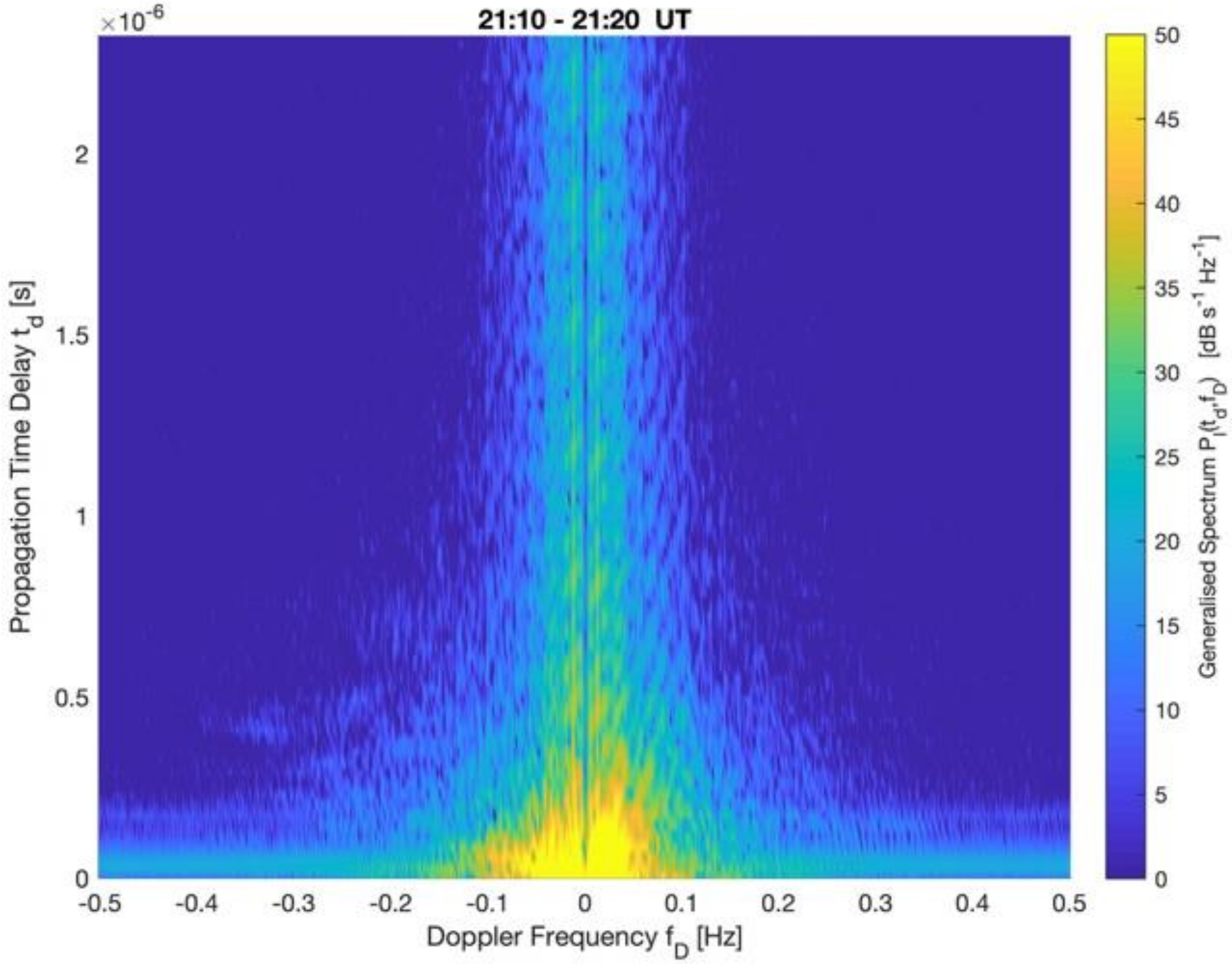
Source: CasA



Credit: Forte et al., ApJS, 2022

Methods of analysis





Credit: Forte et al., ApJS, 2022

LOFAR VHF Zero-Mean Normalised Intensity Fluctuations

- Different time intervals are sensitive to different spatial scales.
- In the weak scattering approximation, the Fresnel scale of the irregularities is of the order of approximately 1800-3200 m.
- The relative drift velocity of irregularities implies averaging over different spatial scales.
- The intensity fluctuations are not ergodic.

Credit: Flisek et al., under review

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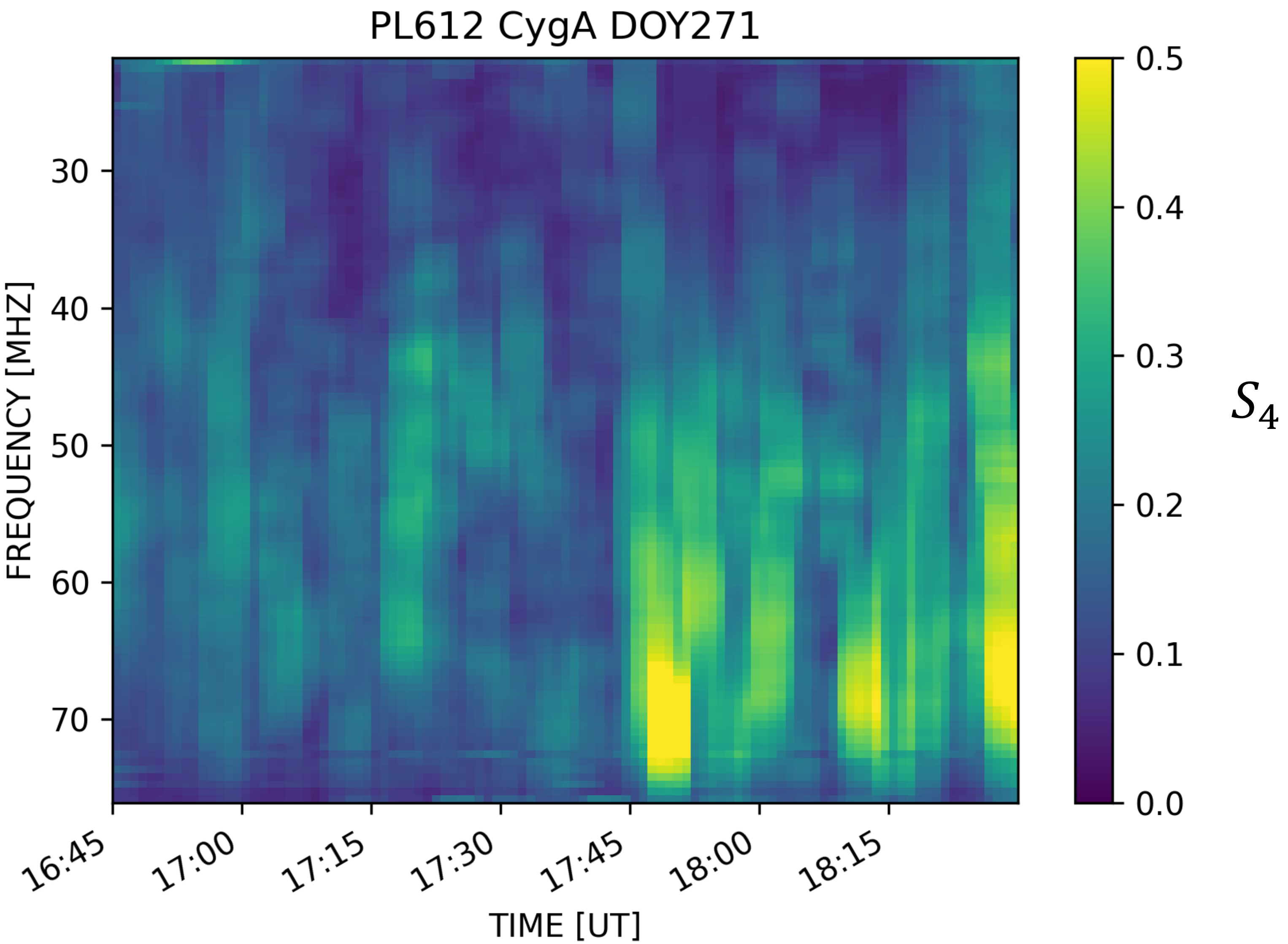
Example: DOY271 2017

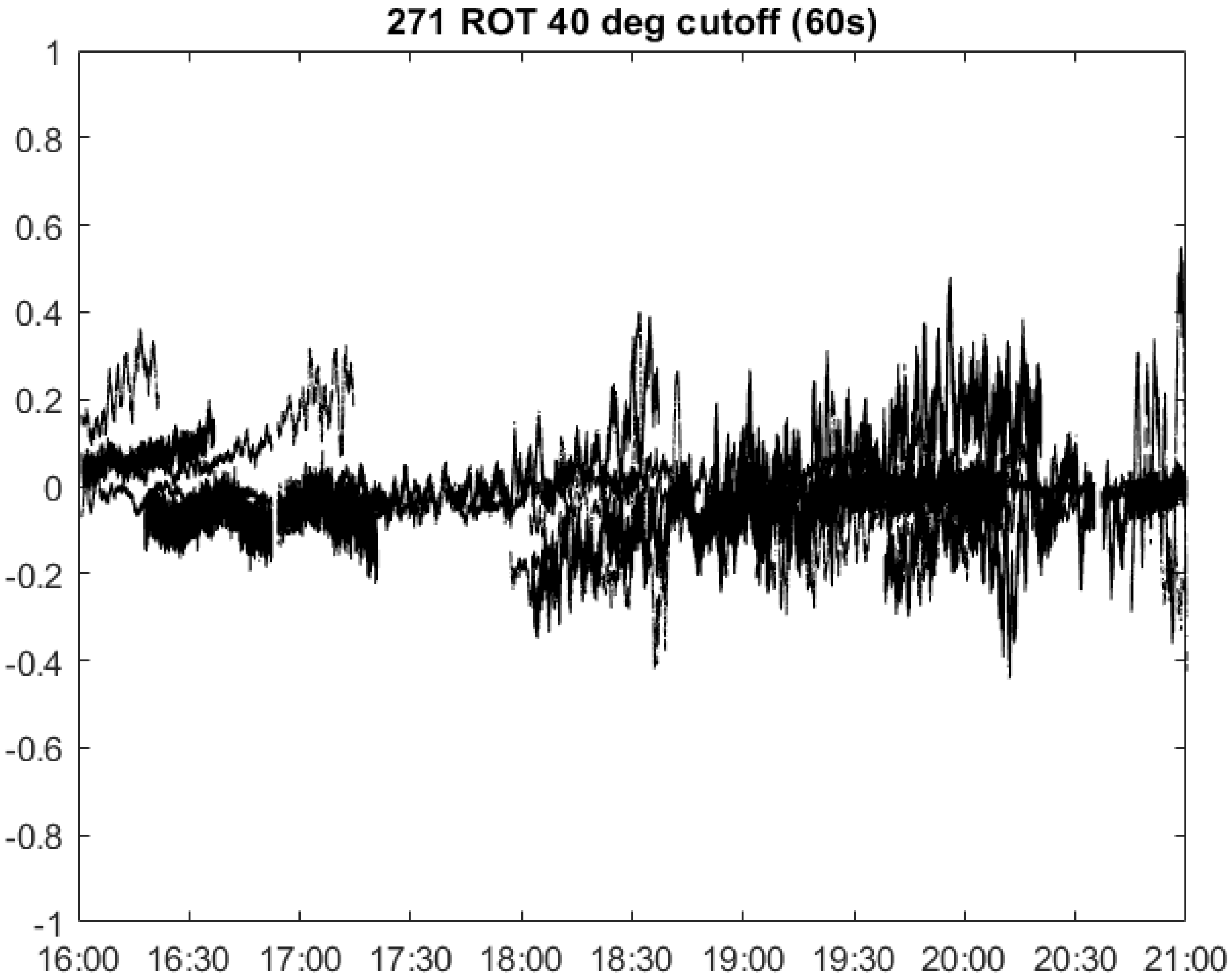
LOFAR S_4 scintillation index estimated over various VHF radio-wave frequencies



Credit: Flisek et al., under review

Example: DOY271 2017

ROT
[TECU/min]

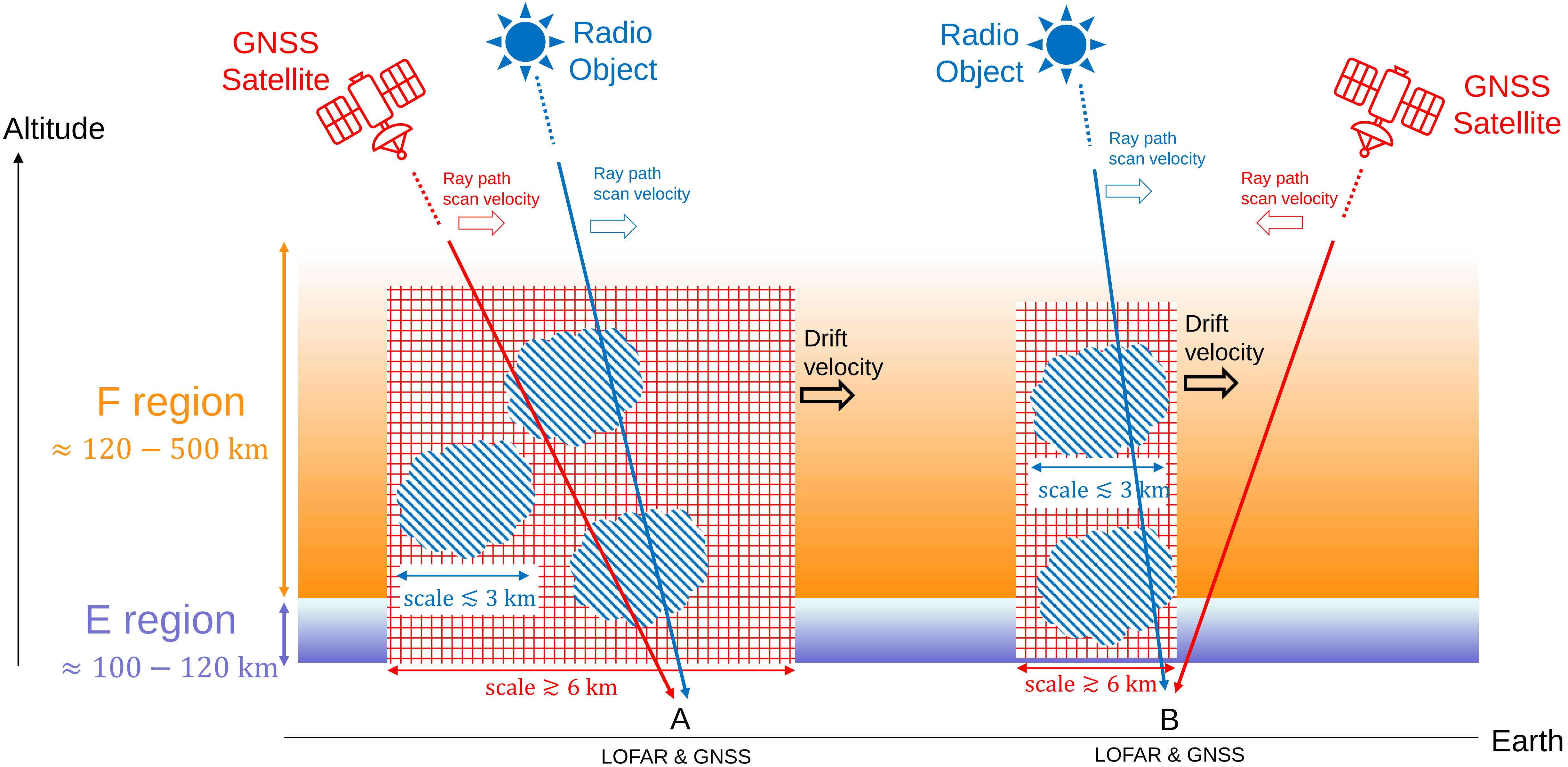


UT

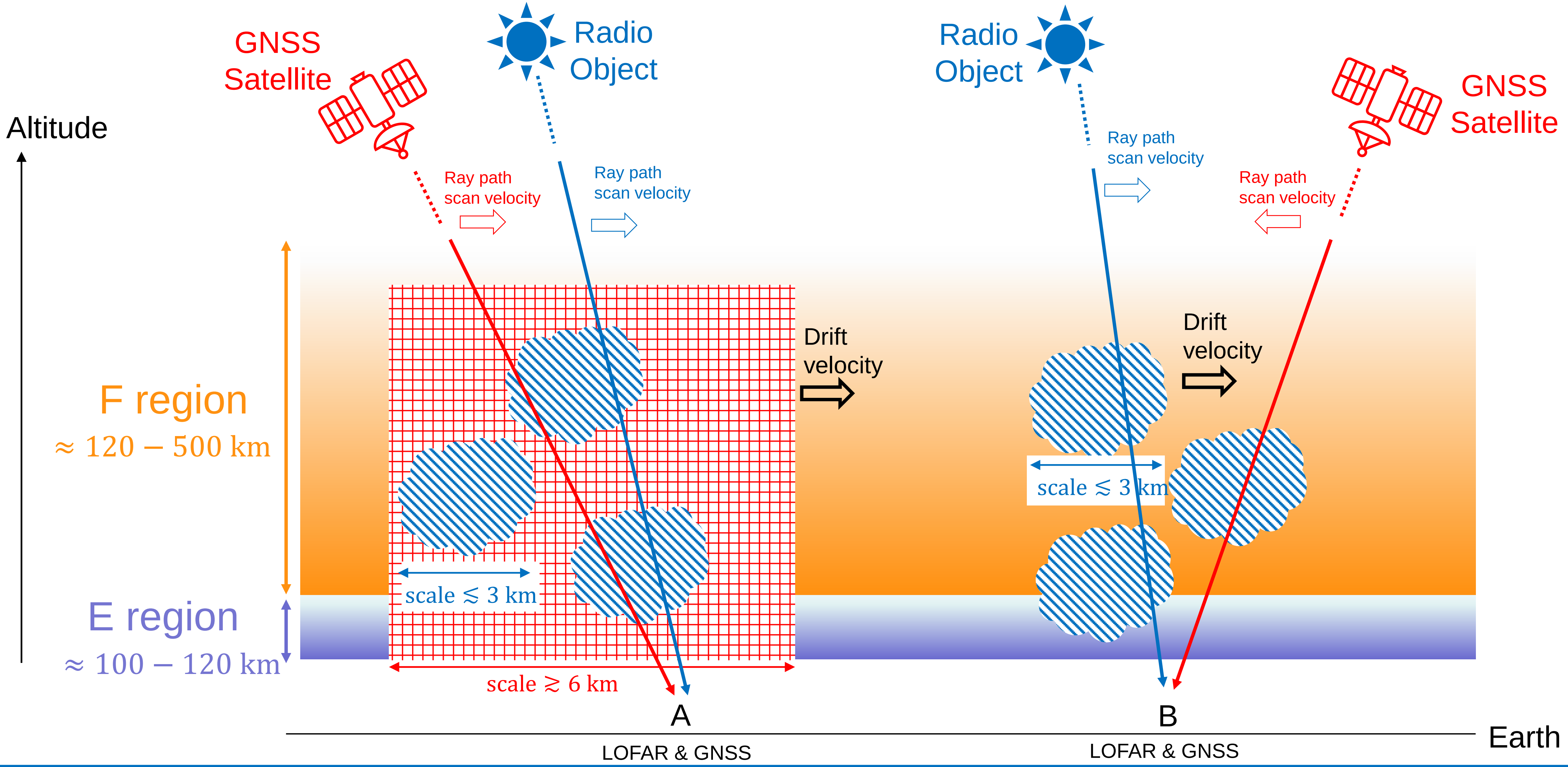
GNSS Rate of Change of Total Electron Content (ROT) over 60 s (or 1 minute) temporal intervals

Credit: Flisek et al., under review

A: Enhancement in LOFAR VHF scintillation and in GNSS ROT
B: Enhancement in LOFAR VHF scintillation and not in GNSS ROT



A: Enhancement in LOFAR VHF scintillation and in GNSS ROT
B: Enhancement in LOFAR VHF scintillation and not in GNSS ROT



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- LOFAR enables the observation of different gradients in the ionosphere.
- For example, LOFAR can detect different gradients in the ionosphere which are not necessarily detected through GNSS.
- Radio wave scintillation can be utilised to estimate spatial scales of irregularities originating scintillation on LOFAR measurements.
- These measurements have the potential to advance the understanding of ionospheric mechanisms.

Credit: Flisek et al., under review

Acknowledgments

Data obtained with the International LOFAR Telescope (ILT) under project codes LC7 001 and LC8 001. LOFAR (van Haarlem et al., 2013) is the Low Frequency Array designed and constructed by ASTRON. It has observing, data processing, and data storage facilities in several countries, that are owned by various parties (each with their own funding sources), and that are collectively operated by the ILT foundation under a joint scientific policy. The ILT resources have benefitted from the following recent major funding sources: CNRS-INSU, Observatoire de Paris and Universite d'Orleans, France; BMBF, MIWF-NRW, MPG, Germany; Science Foundation Ireland (SFI), Department of Business, Enterprise and Innovation (DBEI), Ireland; NWO, The Netherlands; The Science and Technology Facilities Council, UK; Ministry of Science and Higher Education, Poland.

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References

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- Flisek P. et al.,Towards the possibility to combine LOFAR and GNSS measurements to sense ionospheric irregularities, under review at Journal of Space Weather and Space Climate.

Thank you for the attention.

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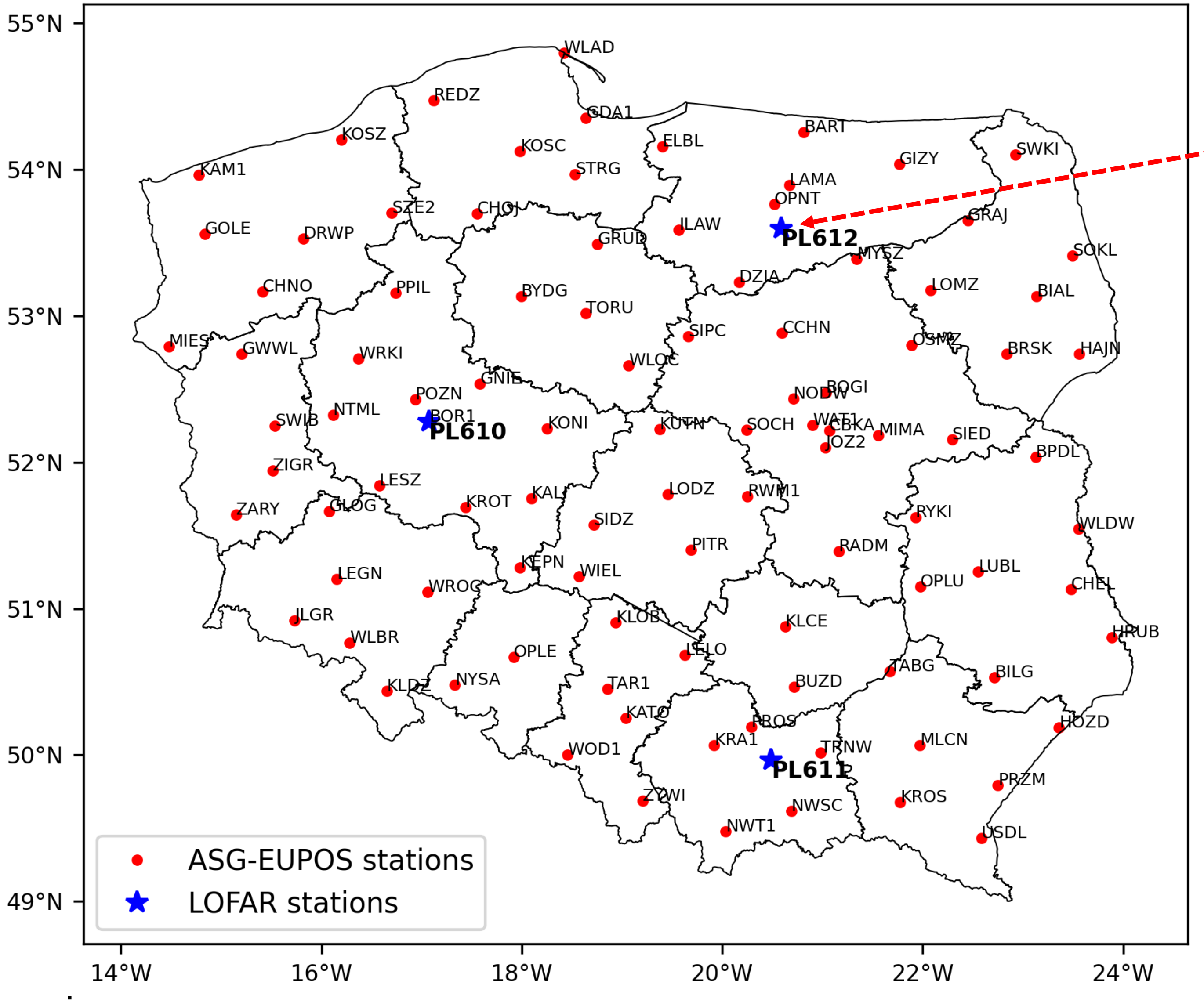
The experimental datasets

Dense network of GNSS geodetic stations

Three LOFAR stations



One GNSS Ionospheric station

Credit: Flisek et al., under review

Example: DOY271 2017

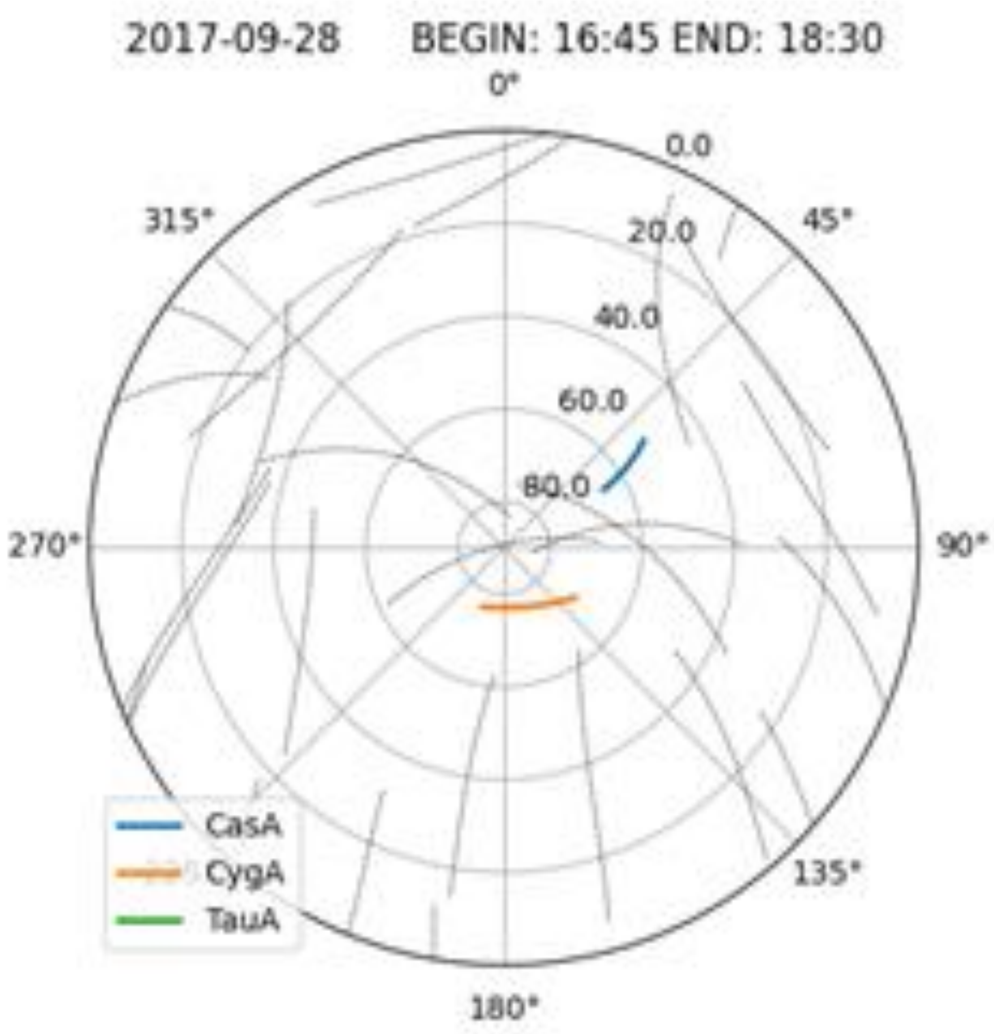
GNSS satellites

LOFAR:

Cassiopeia A

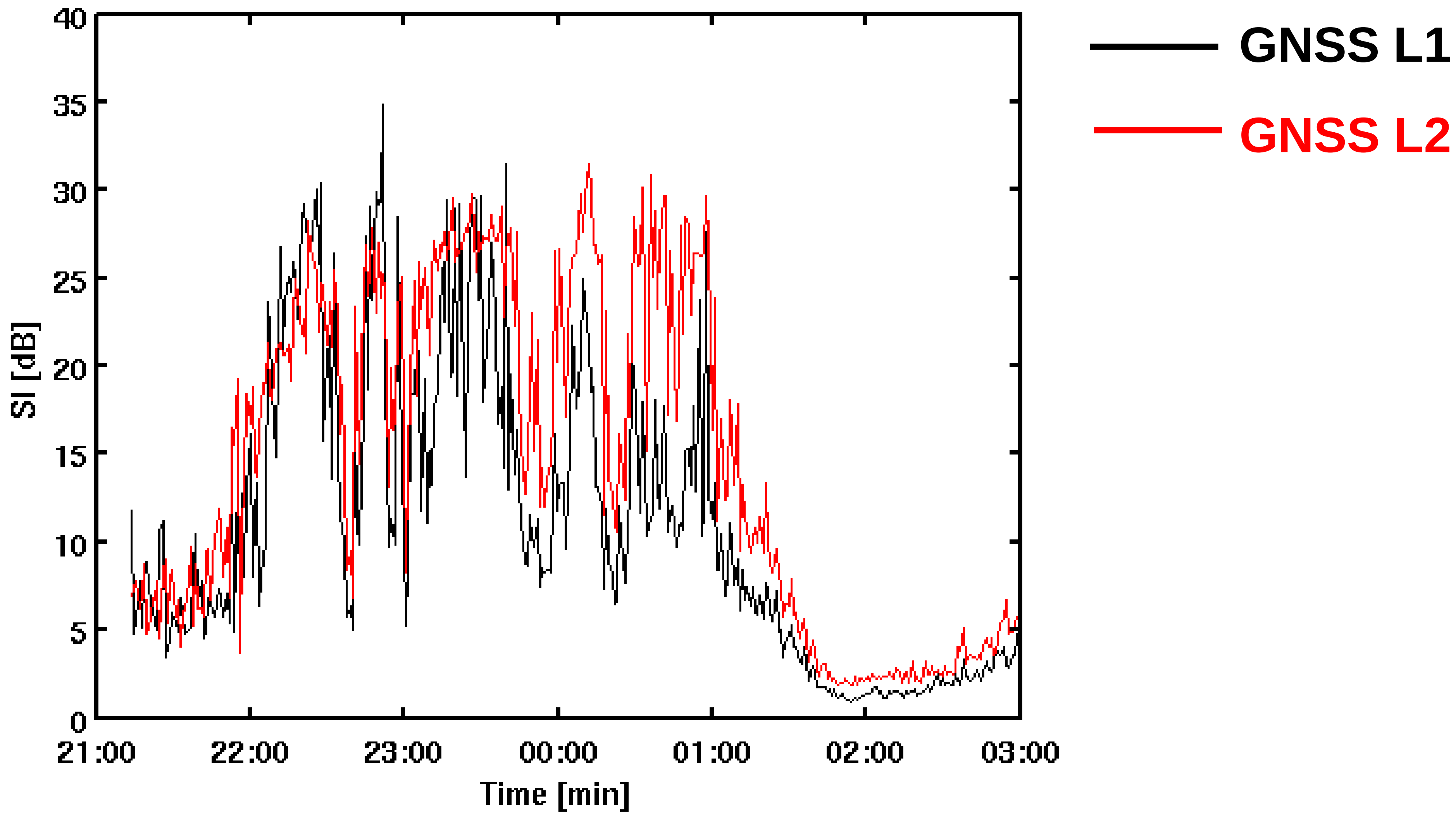
Cygnus A

Taurus A



Credit: Flisek et al., under review

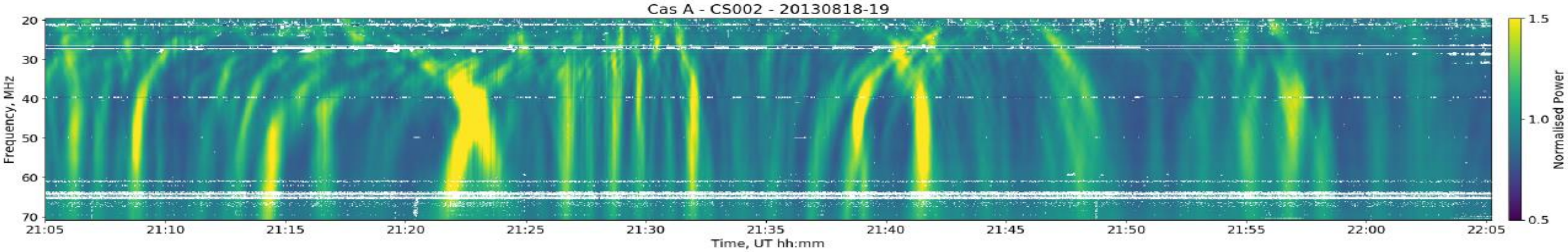
Fading caused by ionospheric scintillation

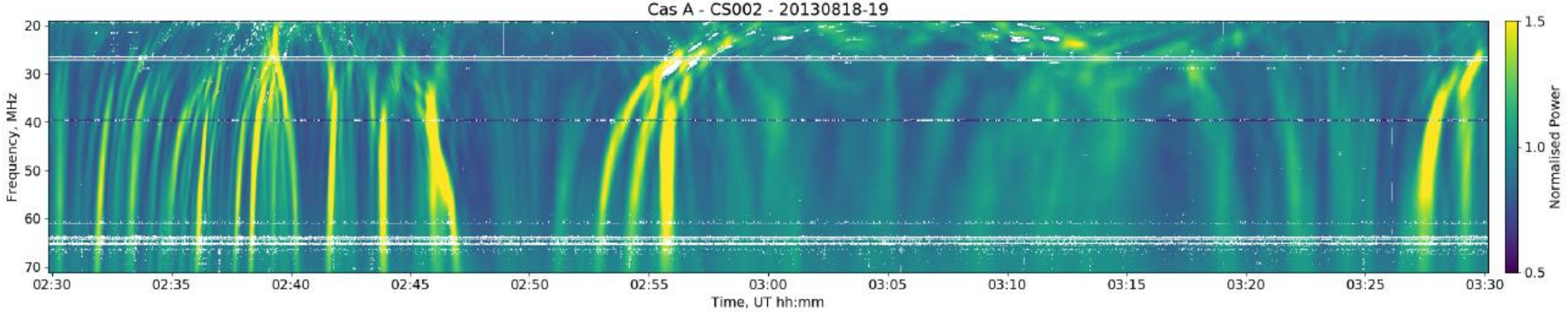


10 March 2012
PRN31

Credit: Forte et al., in preparation

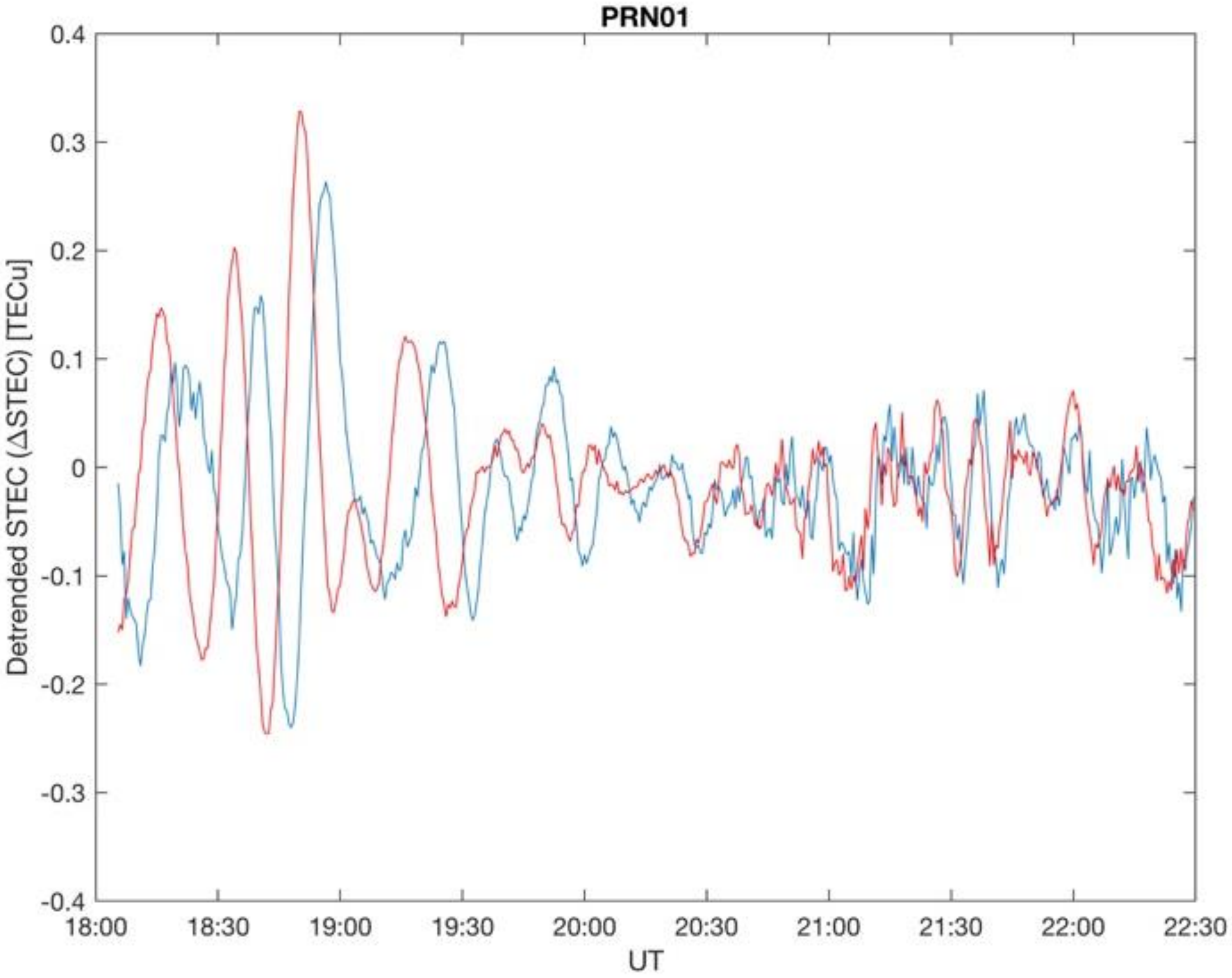
Example: irregularities related to TID





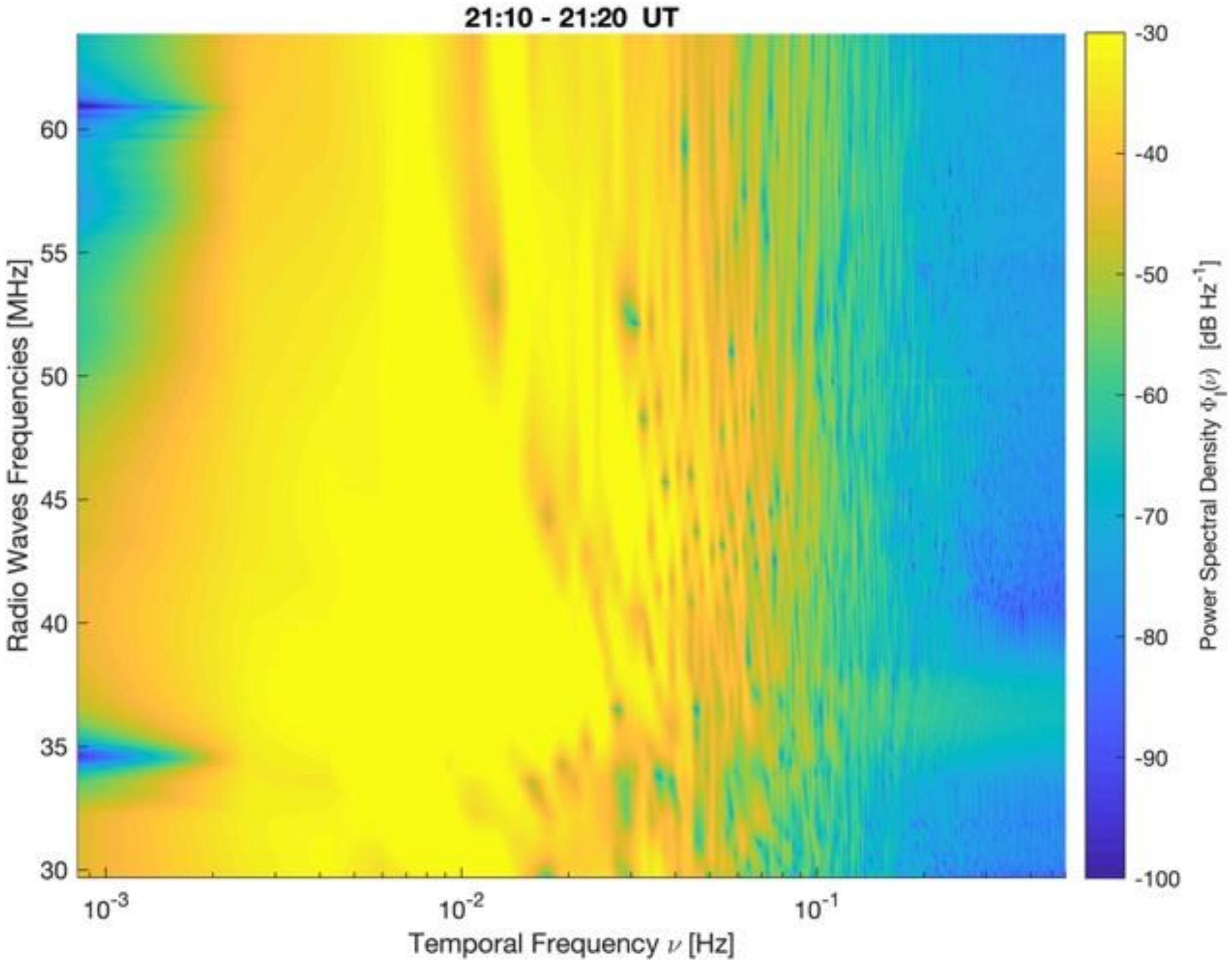
Credit: Fallows et al., JSWC, 2022

Example: irregularities related to TID



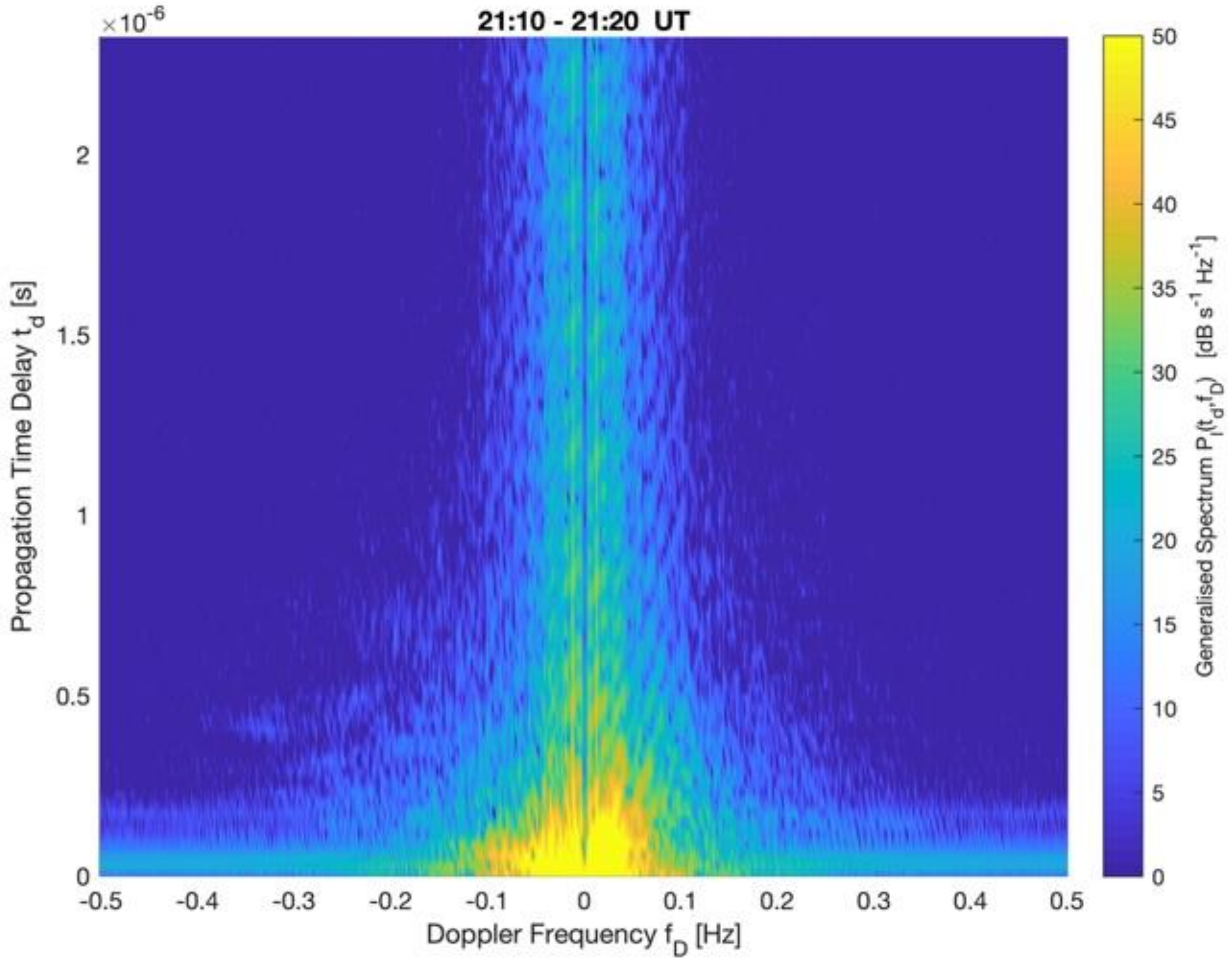
Credit: Fallows et al., JSWC, 2022

Methods of analysis



Credit: Forte et al., ApJS, 2022

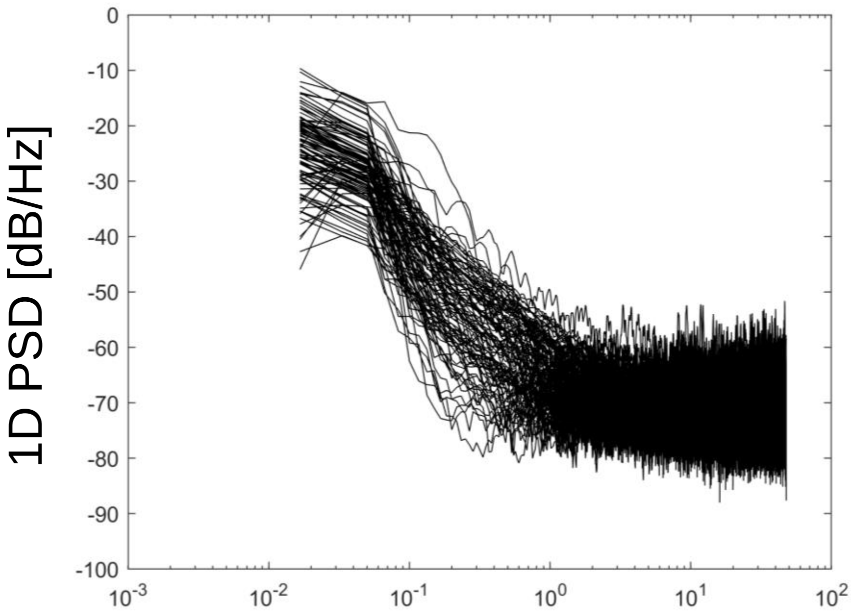
Methods of analysis



Credit: Forte et al., ApJS, 2022

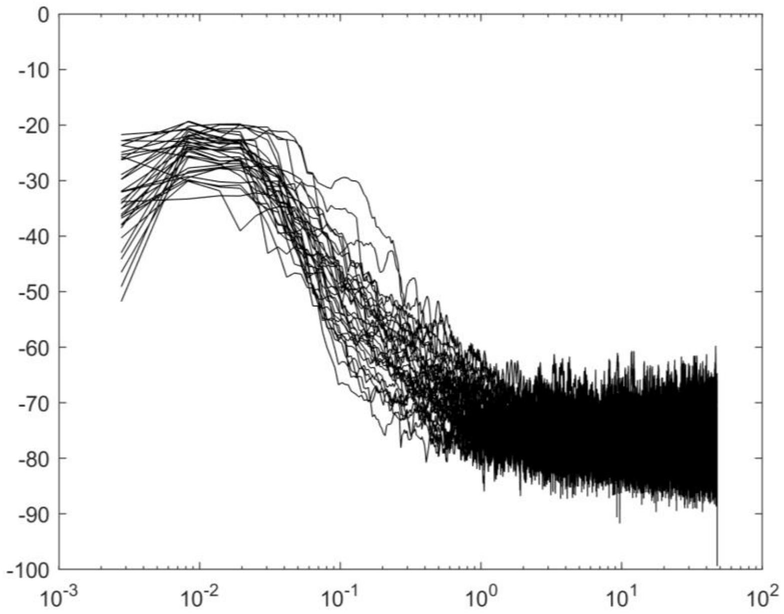
LOFAR VHF Zero-Mean Normalised Intensity Fluctuations

1 minute



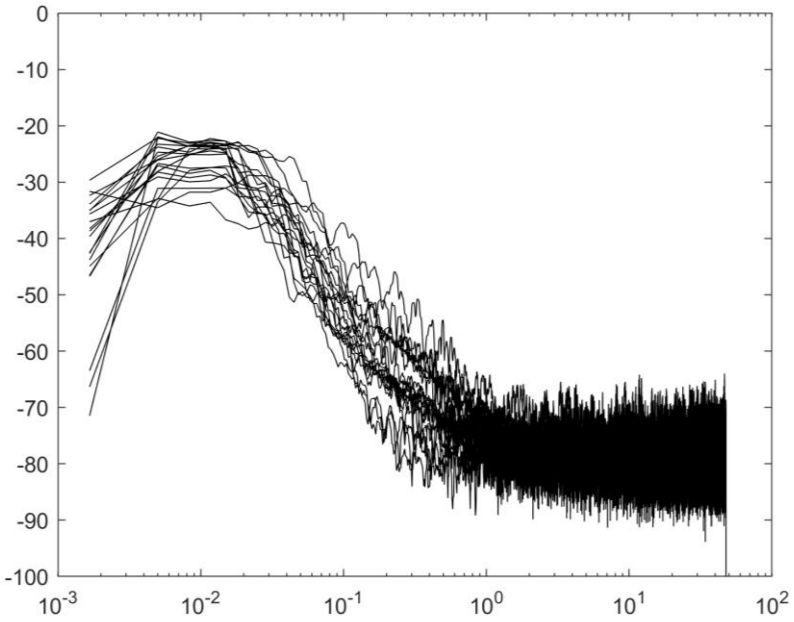
Temporal Frequency [Hz]

3 minutes



Temporal Frequency [Hz]

5 minutes



Temporal Frequency [Hz]

PL612 - DOY271 2017, 16:45-18:30 UT

Credit: Flisek et al., under review