Tracking travelling ionospheric disturbances in the mid-latitude ionosphere from Poland to the North Sea with LOFAR.

G. Dorrian[1], D. R. Themens[1], T. Renkwitz[2], G. Nykiel[3], A. Wood[1], B. Boyde[1], R. A. Fallows[4], M. Mevius[5], H. Trigg[1]

[1]University of Birmingham,[2]Leibniz Institute of Atmospheric Physics,[3]Gdansk University of Technology,[4]RAL Space,[5]ASTRON

Travelling Ionospheric Disturbances

Travelling ionospheric disturbances (TIDs) are wave-like perturbations to the Earth's ionosphere which are the ionospheric manifestations of atmospheric gravity waves. They can propagate over large distances (>10^3 km) and may have wavelengths ranging from a few 10s of km to over 1000 km. As they pass through the line-of-sight from a radio source to a LOFAR antenna they can appear as a series of rapid changes in received signal power from the radio source, caused by plasma sub-structures within the TID (Dorrian et al., 2023).

Quasi-Periodic Scintillations

Quasi-periodic scintillations (QPS) are recurrent, steady variations in received signal power caused by the passage of small-scale (<20 km) ionospheric plasma blobs crossing the line-of-sight from an exo-atmospheric radio source to a ground based receiver, such as a LOFAR station. QPS are typically characterised as a rapid drop in signal power as a function of time, which may be bounded on one or both sides by a 'ringing pattern' caused by Fresnel diffraction of the radio signal as it passes through steep plasma gradients on the leading and/or trailing edges of the plasma blob.

LOFAR observations

In the early morning of 17th. December 2018, during ionospheric scintillation observations using Cassiopeia-A & Cygnus-A, LOFAR stations across Europe detected the passage of a TID all the way from Poland, across Northern Europe, to the North Sea. The TID appeared in LOFAR dynamic spectra as a series of signal intensity variations, which exhibited the characteristics of asymmetric QPS. Large signal enhancements were consistently followed by a ringing pattern-like series of features which decreased in intensity with time. In some instances, particularly during observations of the TID by German stations DE603 & DE604, as many as 7 intensity fringes were observed. As the TID travelled over Europe, the signal patterns were observed consistently and time-sequentially in data from LOFAR stations along the line of travel. Co-temporal data from an ionosonde and a radar at Juliusruh demonstrated that the TID was propagating in a sporadic-E layer at 110 km altitude. This represents the first observations of asymmetric QPS, nested within a TID, travelling over 1200 km from the position of its first detection by Polish LOFAR stations to the North Sea. Considerable variation in TID characteristics, such as number of QPS, and intensity of ringing irregularity patterns. Figure 1 shows the TID appearance in several LOFAR stations across Europe. Figure 2 shows a zoomed-in view of the TID from several LOFAR stations, showing the asymmetric QPS, with large signal enhancements, followed by the ringing pattern.

Figure 1

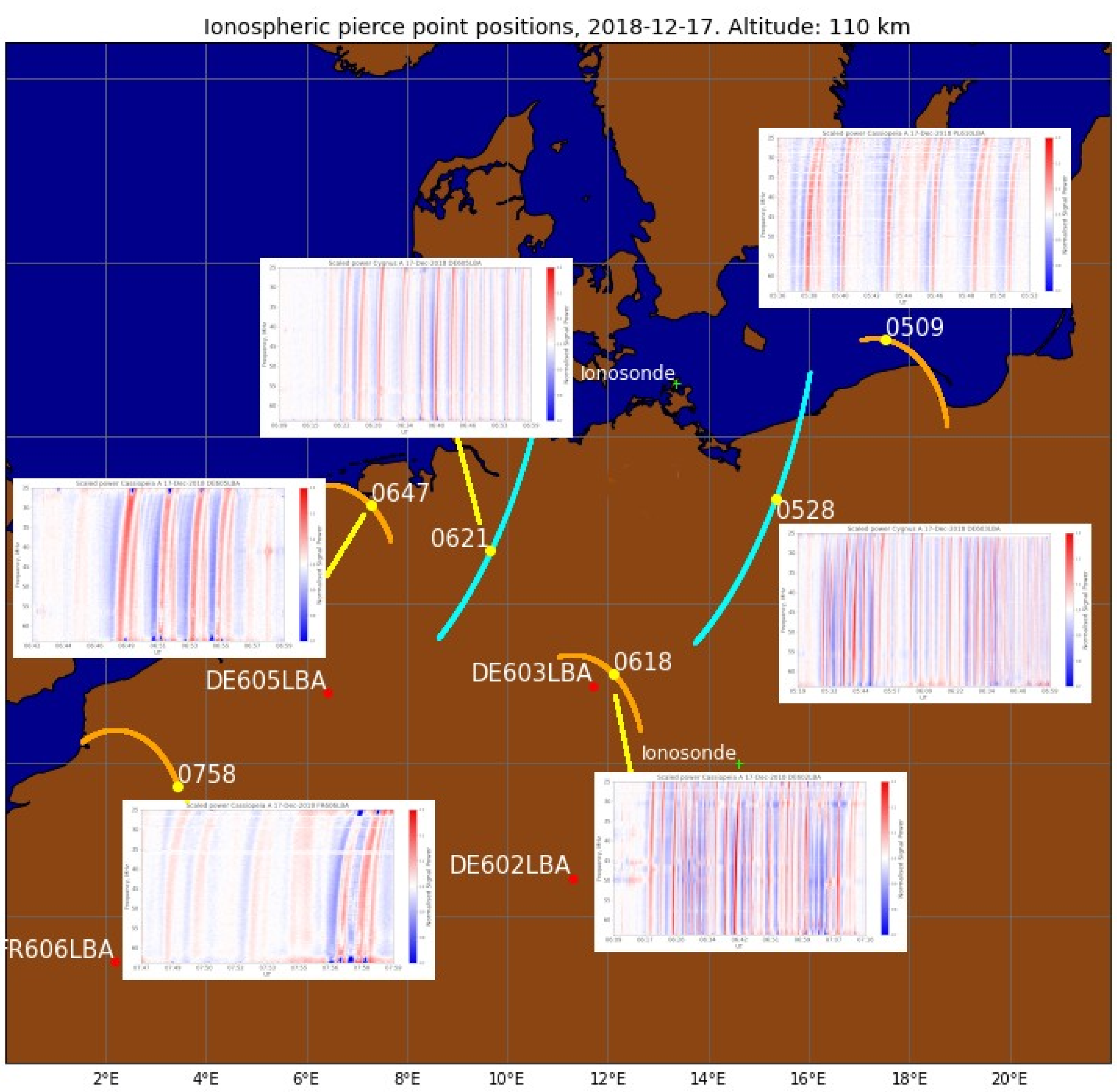


Figure 2

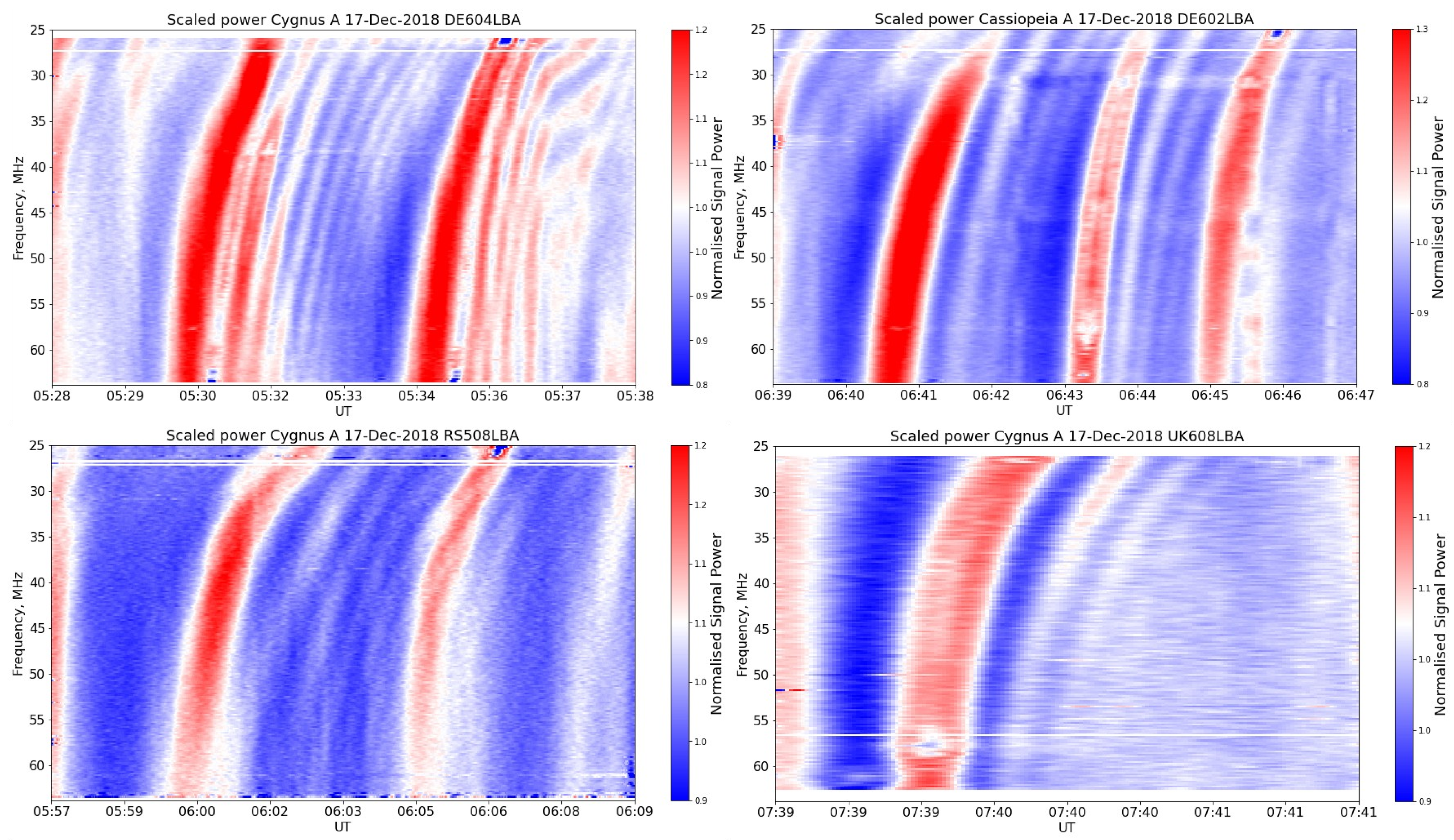
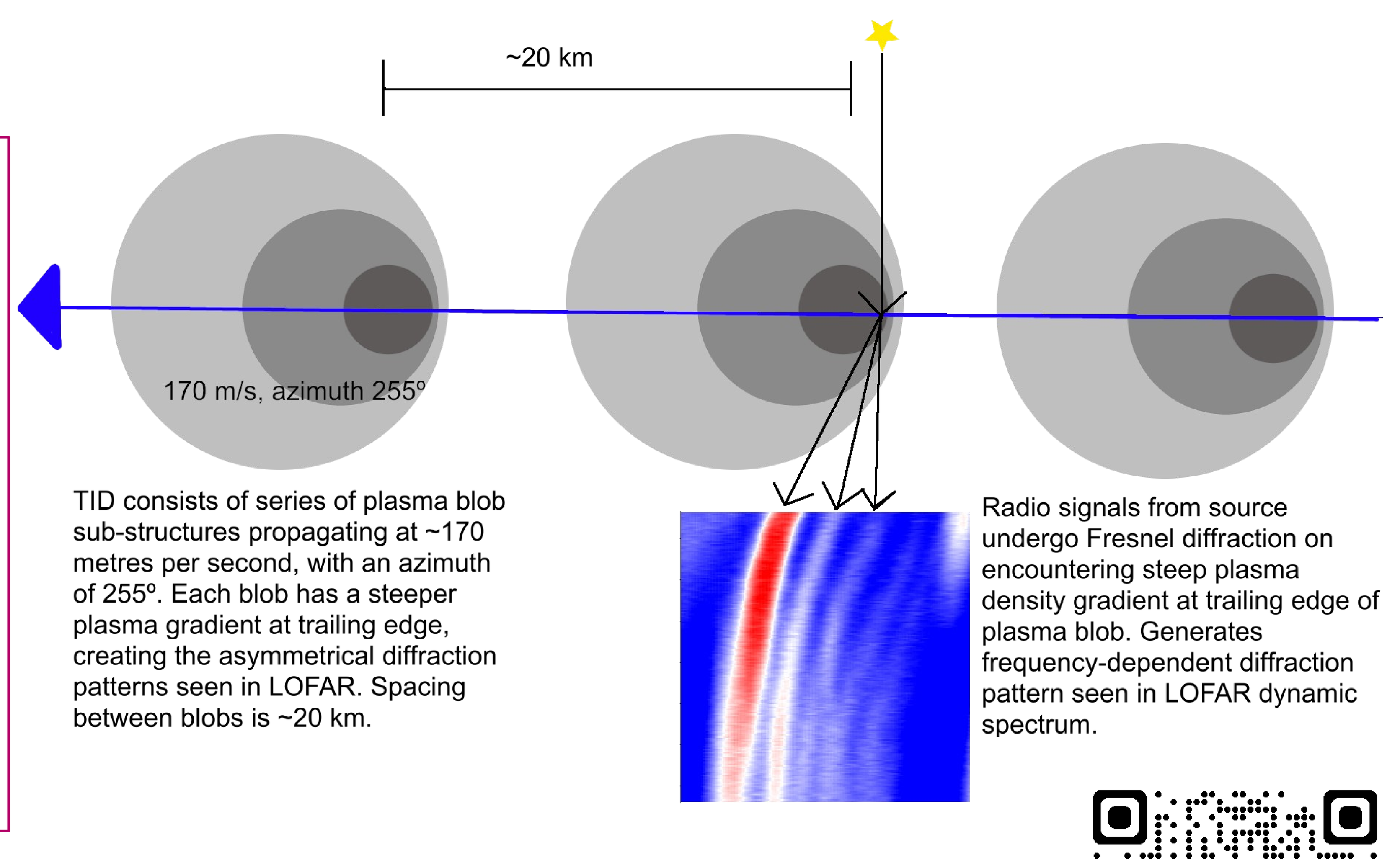


Figure 1 shows the time-sequential detection of the TID in numerous LOFAR stations across Europe. The arcs are the *ionospheric pierce points* (IPP) for the lines of sight from each LOFAR station to Cassiopeia A (orange arcs) and Cygnus A (blue arcs) projected to an altitude of 110 km. Several examples of asymmetric QPS are shown in Figure 2 from different LOFAR stations & radio sources. Frequency dependent behaviour is clearly seen with the QPS being curvi-linear on the vertical axes. At least 7 intensity fringes can be seen in DE604 observations (top left).

Discussion

Figure 3 shows a simple schematic of the phenomena. The TID consists of a series of sub-structures (plasma blobs – grey circles). Using co-temporal radar and ionosonde data the altitude of the TID was established at 110 km. Using the positions of the LOFAR IPPs and the onset timings of the TID in sequential LOFAR stations, the TID was modelled as having a velocity of 170ms^{-1} travelling on an azimuth of 255°. Each plasma blob has an asymmetric plasma density distribution (grey shading), with steep plasma gradient on trailing edge. As radio signals from the source pass through this region they undergo Fresnel diffraction which LOFAR observes in many different frequencies simultaneously, giving the curvi-linear 'ringing' pattern visible in the dynamic spectrum. The asymmetry of the plasma density distribution is responsible for the asymmetry in the diffraction pattern. Full results are discussed in (https://arxiv.org/abs/2401.16932) and an accompanying work examining symmetrical QPS observations by LOFAR is also in development and can be found here (https://arxiv.org/abs/2312.04387).

Figure 3



For further information please contact Dr Gareth Dorrian (g.dorrian@bham.ac.uk)