Annual Report 2015

Heliospheric Physics[1] Laboratory for Solar System Physics and Astrophysics
Space Research Centre of the Polish Academy of Science

Studies of the distant heliosphere by remote-sensing observations of Energetic Neutral Atoms

The supersonic, ionized solar wind, emitted by the Sun, carves out a cavity in the interstellar matter called the heliosphere. Its size is determined by a balance between the pressures of the magnetized solar wind and the interstellar gas, which is also magnetized. The heliosphere is bounded by a contact discontinuity layer called the heliopause, which separates the solar wind and interstellar plasmas. While the interstellar plasma is deflected and flows past the heliopause, the neutral component, mainly hydrogen and helium, with small admixtures of other species, like oxygen, neon, and deuterium, penetrates freely into the heliosphere, where it can be directly observed.

The heliospheric structure can be sampled by means of energetic neutral atoms (ENA) that are created by multiple charge exchange reactions between interstellar neutral atoms and protons from the solar wind. One of the important aspects of this interaction is the so-called IBEX ribbon, which is a large, arc-like region of enhanced ENA emission, unexpectedly discovered shortly after the beginning of observations by the NASA space probe Interstellar Boundary Explorer (IBEX). This mission was developed and is led by the Southwest Research Institute in San Antonio, TX under the NASA Small Explorers program. It is managed by the Goddard Space Flight Center for the NASA Science Mission Directorate in Washington, DC. Research is carried out by the IBEX Science Team of researchers from the United States, Poland, Switzerland, Germany, and Russia. The Space Research Centre has participated in the IBEX effort since the planning phase at Co-Investigator level. Another important asset for heliospheric research is the two-spacecraft Voyager flotilla. These spacecraft, launched in the 1970s, are currently the farthest active man-made object from Earth and continue to return a flux of unique data on the surrounding heliospheric and interstellar medium. The data from these spacecraft were analysed and interpreted by Lab members in 2015.

In 2015, an international team of scientists continued to investigate IBEX ribbon, and analyzed its symmetries. They found a strong, spectrally-dependent reflection symmetry throughout the ENA energy range 0.7 – 4.3 keV. The distribution of ENA flux around the ribbon is predominantly unimodal at 0.7 and 1.1 keV, and distinctly bimodal at 2.7 and 4.3 keV. At 1.7 keV, there is a mixture of the two symmetries. The bimodal flux distribution consists of partially opposing bilateral flux lobes, located at the highest and lowest heliographic extents of the ribbon. The vector between the ribbon centre and the heliospheric nose appears to play an organizing role in the spectral dependence of the symmetry axis

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[1] Adapted from *The Space Research Centre PAS Annual Report 2015*; partly based on abstracts of papers authored or co-authored by members and PhD students of the Lab. The full list of papers published in 2015 by members of the Lab is available at http://pfusia.cbk.waw.pl/files/pfusiaPubl.2015.html.

locations as well as asymmetric contributions to the ribbon flux. This suggests an important role of the interstellar magnetic field in organizing the symmetries of the ribbon. The symmetry planes at 2.7 and 4.3 keV, derived by projecting the symmetry axis onto a great circle in the sky, are equivalent to tilting the heliographic equatorial plane with respect to the ribbon centre, suggesting a global heliospheric ordering. The presence and energy dependence of symmetric unilateral and bilateral flux distributions suggest a strong spectral filtration from processes encountered by an ion on its journey from the source plasma to its eventual detection by IBEX. These findings were published in a paper by Funsten et al. in *The Astrophysical Journal* (Vol 799: 68, 2015), by an international team of scientists including M. Bzowski from the Space Research Centre (SRC).

In another study, SRC scientists J. Grygorczuk, A. Czechowski and S. Grzedzielski analysed the plasma flow observed by Voyager 2. In contrast to Voyager 1, Voyager 2 is still inside the heliosphere, penetrating the so called inner heliosheath region, where the solar wind no longer propagates radially anti-sunward. Voyager 2 is able to measure the moments of the distribution function of this plasma and thus can provide the plasma velocity vectors along its trajectory. The SRC scientists noticed that Voyager 2 is very close to the plane defined by the direction towards the IBEX ribbon centre and the direction of inflow of interstellar gas into the heliosphere (see Fig. G1). Since it is likely that the ribbon centre is the direction of the local interstellar magnetic field, the plane defined by the ribbon centre and the inflow velocity vector of interstellar gas is the so-called B-V plane, i.e., one of the fundamental planes in heliospheric physics. If the B-V plane is the exact symmetry plane of the flow, then the plasma velocity should also be restricted to this plane. This is surprising because it was thought that due to the shielding by the heliopause the plasma flow in the inner heliosheath was not linked to the B-V plane, which is determined by factors unrelated to the solar wind. Nevertheless, the SRC team observed that the Voyager 2 (uncorrected) velocity directions do in fact lie in the B-V plane (the black crosses in Figure 1).

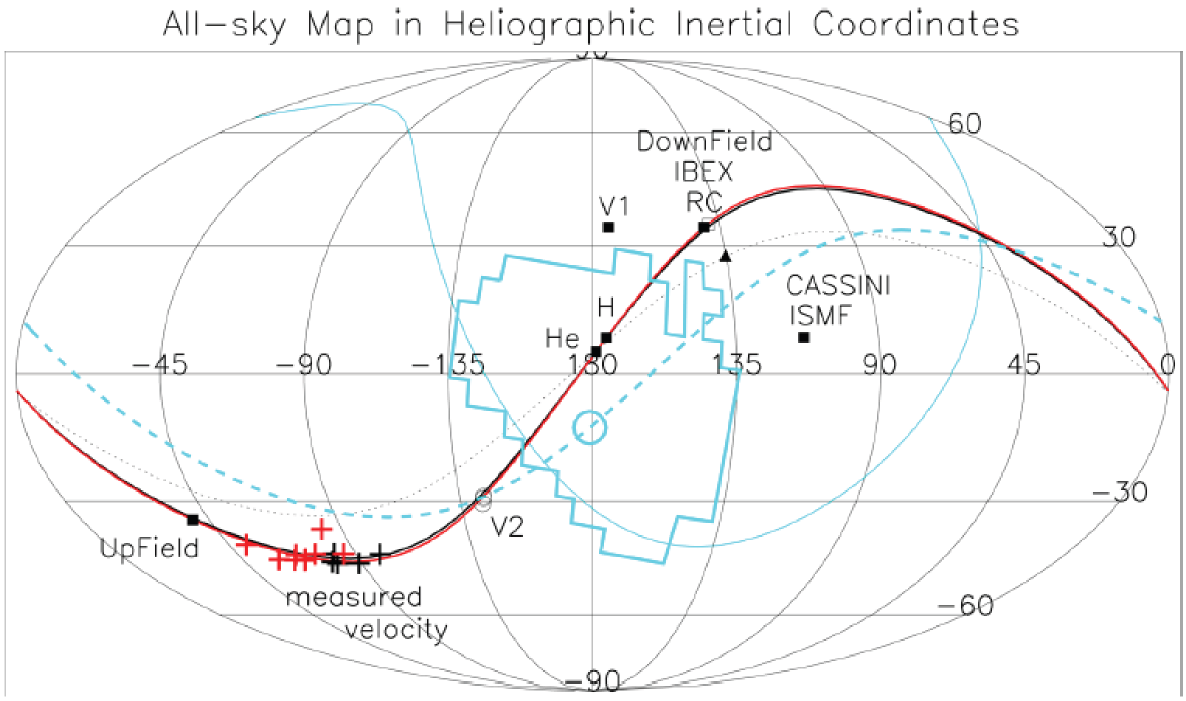

Figure 1 Mollweide projection of the plasma velocity directions observed by Voyager 2 between 2010 and 2014 (crosses), shown in ecliptic coordinates. Adapted from Grygorczuk et al., ***Monthly Notices of Royal Astronomical Society*** **Vol 450, p. L76, 2015.**

In Figure 1, the red line represents the plane defined by the IBEX Ribbon centre (IBEX RC) and the direction of inflow of the interstellar neutral gas (He, H). The Voyager spacecraft (V2) is very close to this plane, which goes through the velocity directions of the inner heliosheath plasma, measured by Voyager.

One of the implications of this finding is that the plasma flow at the heliopause should be approximately parallel to the interstellar plasma flow just outside the heliopause and antiparallel to the interstellar magnetic field. Support for this prediction was provided when SRC researchers noted that the plasma velocity observed by Voyager 2 seems to evolve towards the anti-field direction. These results were published in a paper by Grygorczuk et al. in *Monthly Notices of the Royal Astronomical Society* (Vol 450, p. L76, 2015).

Studies of the interstellar matter in the immediate Galactic neighbourhood of the Sun

Interstellar neutral (ISN) gas is the only population of the interstellar matter surrounding the heliosphere that can be directly sampled from the Earth's orbit. IBEX has been making made such observations since it began its mission in 2009. In 2015, an international team of IBEX scientists achieved an important milestone, resolving the so-called IBEX—Ulysses enigma. Analysis of observations from the first two years of observations, published in a series of papers in 2012, showed that the inflow velocity vector and temperature of ISN He observed by IBEX are tightly correlated and led to the unexpected conclusion that most likely, the flow direction of ISN gas differs (by a few degrees) and is slower (by a few km/s) than previously thought. An alternative explanation for these observations argued that if the velocity vector of ISN gas relative to the Sun is indeed as previously inferred, then its temperature must be substantially higher. The hypothesis of a different velocity vector had a great impact on heliospheric studies and was controversial because if true, the configuration of the heliospheric boundary would be different and the disturbance of interstellar matter in front of the heliosphere would extend substantially farther. This issue became known as the IBEX–Ulysses enigma, since the earlier observations were mostly carried out by the Ulysses space probe.

The experimental and analysis aspects of the early IBEX observations were reviewed in two papers published in *The Astrophysical Journal* by Frisch et al. (with the participation of M. Bzowski and J.M. Sokół from SRC PAS) and in the *Journal of Physics Conference Series* by Möbius et al. (with the participation of M. Bzowski, M.A. Kubiak, and J.M. Sokół). Subsequently, a tentative analysis of IBEX observations of ISN He from the observation seasons 2009 through 2014 were published in 2015 in *The Astrophysical Journal* by McComas et al. and Leonard et al. (with the participation of M. Bzowski, M.A. Kubiak, and J.M. Sokół).

An in-depth analysis of IBEX observations of ISN He was published in October 2015 in a series of fourteen papers in a special issue of *The Astrophysical Journal Supplement Series.* IBEX scientists analysed the observations using three independent models and methods, and verified in greater detail selected aspects of the observations. SRC scientists M. Bzowski, P. Swaczyna, J.M. Sokół, and M.A. Kubiak contributed to ten of these papers and were lead authors in four of them. Within this concerted effort, the SRC scientists, supported by other members of the IBEX team, carried out a full in-depth analysis of ISN He observations.

Swaczyna et al. developed a sophisticated statistical method of analysis of observations. All known uncertainty sources were identified and analysed, and correlations between them were taken into account. The uncertainty system includes the statistical (Poisson) scatter, uncertainty of the spacecraft orientation (significantly improved by Swaczyna et al.), uncertainty of the instrument mounting, uncertainty of the observation background and throughput correction, and uncertainty of the physical interpretation model. Furthermore, the authors developed and applied an advanced method of correcting for data losses due to limited throughput from the instrument to the central electronics unit of the spacecraft (Figure 2). Finally, they performed an extensive analysis of the role of the aforementioned effects and uncertainties in the results of parameter derivation of ISN He observed by IBEX, and found that the most important source of uncertainty is the model of the Warm Breeze.

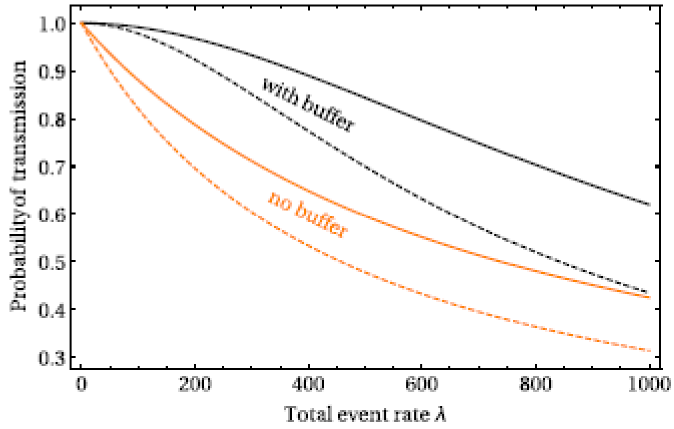

Figure 2 Probabilities of transmission of events registered by the IBEX-Lo instrument to the Central Electronics Unit of the IBEX spacecraft. Adapted from Swaczyna et al., *Astrophysical Journal Supplement Series* Vol 220: 26, 2015.

In addition to neutral atoms, IBEX-Lo registers other events, mostly due to ambient electrons, and all these events must be transmitted to the spacecraft's Central Electronics Unit for further processing. The transmission is carried out through an electronic interface and transmitting an individual event takes a small, but finite amount of time. During this time, the instrument is unable to register new events. To alleviate the potential data loss, a buffer is added, where the incoming events wait to be processed. The buffer has two slots and when both are filled, new incoming events are lost. In a situation when the mean time interval between the incoming events is comparable to the time needed to transmit an event, some data loss is inevitable. Since, however, these losses are well understood, they can be statistically compensated for using a sophisticated analytic method developed and applied to IBEX observations by Swaczyna et al. 2015. Figure 2 presents the data transmission probability as a function of the event rate in an unbuffered measurement system (orange), and with a double (i.e., two-slot) buffer (black), for two event processing times (solid vs broken lines). The figure illustrates that the double buffer used on IBEX-Lo guarantees that only ~10% of valid events are lost because of limited throughput.

The Warm Breeze is another population of interstellar neutral He in the heliosphere. It was discovered by IBEX scientists from SRC in 2014, and its flux must be subtracted from the total observed flux of neutral He atoms observed by IBEX before the parameters of ISN gas can be searched for. However, the parameters of the Warm Breeze (temperature, abundance, and velocity vector) are relatively uncertain and therefore the corresponding model is also uncertain. Based on modelling insights, for some IBEX orbits the Warm Breeze contribution to the total observed signal is comparable to the contribution from ISN He (Figure 3). The contribution from the Warm Breeze was pointed out by Swaczyna et al. as the dominant source of uncertainty of the derived parameters of ISN He. Other sources have a much smaller role, comparable to each other.

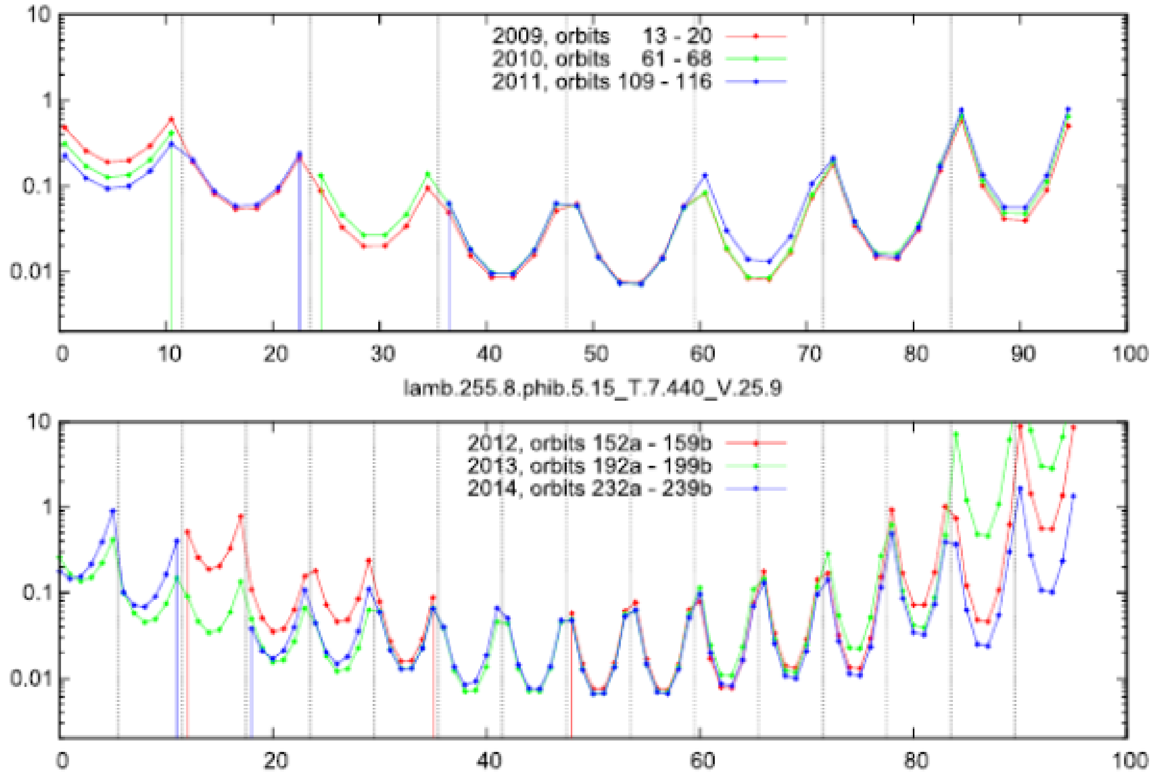

Figure 3 Ratio of the flux of the Warm Breeze to the flux of ISN He observed by IBEX-Lo for the seasons of observations of ISN gas 2009 through 2014. Adapted from Bzowski et al., *The Astrophysical Journal Supplement Series* Vol. 220: 28, 2015.

In Figure 3, different seasons are marked with different colours. The plot helps to identify those orbits and IBEX spin angles for which the contribution of the Warm Breeze to the total flux of neutral He observed by IBEX-Lo is the lowest, and which are hence best suited to searching for ISN He parameters.

Another aspect of the analysis of ISN observations was the refinement of the interpretation model. The interpretation was carried out using the Warsaw Test Particle Model (WTPM), which was originally developed in the 1990s. The present version is described in detail by Sokół et al. The algorithm was refined and a number of important aspects related to the observation process observations were included in the simulation, along with the most up-to-date model of ISN He ionization losses. An overview of the simulation is shown in Figure 4. The model meticulously reproduces the geometry and timing of IBEX observations, the positions and velocities of the Earth with respect to the Sun – and of IBEX with respect to the Earth, together with other details. All of these aspects are analysed to guarantee that no important details are missed (on the one hand), and that unimportant details do not slow down the simulation (on the other hand). The simulation algorithm is described in detail to enable independent implementation.

Another important aspect of IBEX observations is the measurement background and the sensitivity of the IBEX-Lo instrument to neutral atoms with various energies. These aspects were analysed in another paper by Sokół et al. from a modelling perspective, and by Galli et al. from an experimental perspective. In addition to refining the estimate of the ubiquitous background in the data, the latter authors found a finite threshold for the sensitivity of IBEX-Lo to He atoms with low energies of ~20 eV (Figure 4). The magnitude of this threshold was subsequently used in the analysis of ISN He observations, presented by Bzowski et al., 2015.

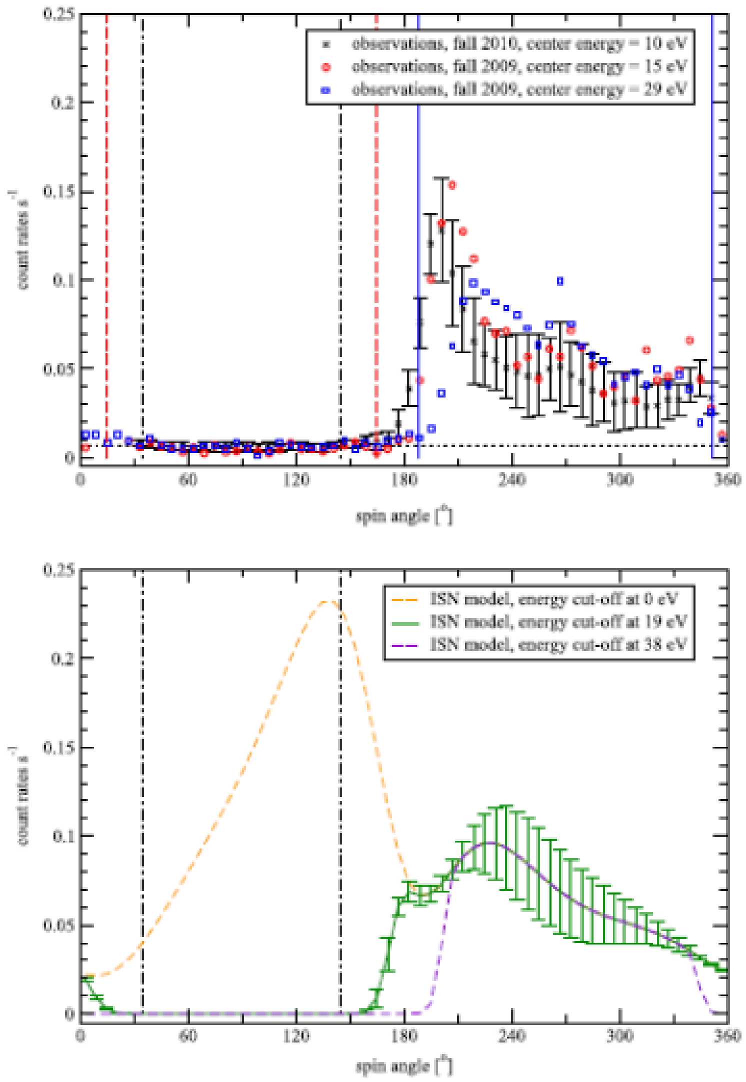

Figure 44 Comparison of ISN He flux simulated for different sensitivity thresholds for selected observation conditions (lower panel) with actual observations (upper panel). Adapted from Galli et al., The Astrophysical Journal Supplement Series Vol. 220:

In Figure 4, the signal is simulated for a several thresholds that are lower than the sensitivity of the instrument to atoms with low energies, and compared to no threshold, as a function of the IBEX spin angle. Note the large difference between the simulated signals for spin angles from 0° to ~200° and the lack of difference for the angles from 200° to 360°. The upper panel presents the actual observations. The existence of the threshold is inferred from the morphological similarity of the simulated and observed signals for an assumed energy cutoff of 19 eV.

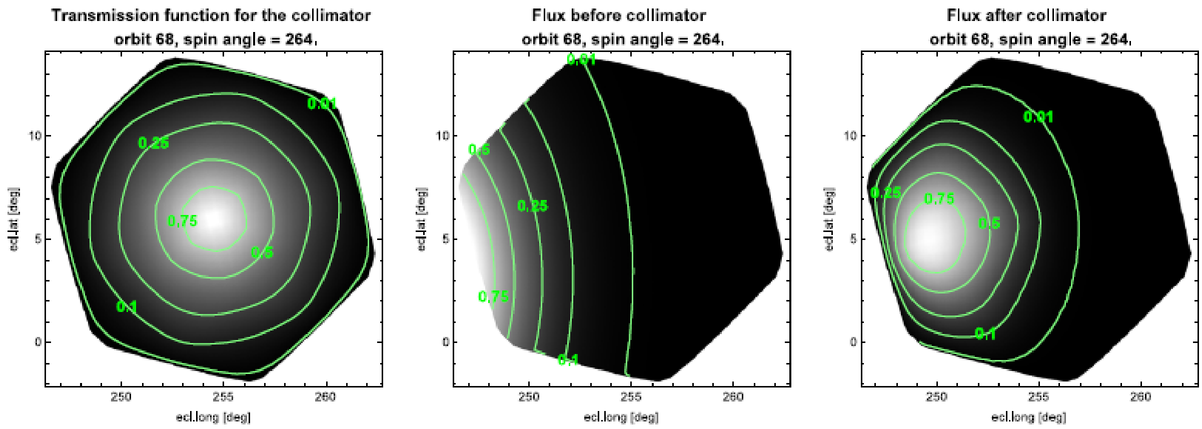

Figure 5 Illustration of simulating the ISN He signal in the Warsaw Test Particle Model. Adapted from Sokół et al., *The Astrophysical Journal Supplement Series* Vol. 220: 27, 2015.

Figure 5 shows that IBEX-Lo has a hexagonal field of view, formed by an aperture fitted with a collimator. The transmission function of the collimator is highly peaked towards the centre of the field of view (the left-hand panel). The maximum intensity of the flux of neutral atoms is typically far off the instrument's line of sight (middle panel). The WTPM convolves the simulated flux distribution on the sky for a given instrument line of sight with the collimator transmission function, returning the collimator-transmitted flux (right-hand panel). This latter flux is subsequently integrated over the collimator field of view and thus an instantaneous signal seen by the instrument is simulated. Finally, the integrated signal is simulated for all line of sight positions for a given IBEX orbit, and binned into spin angle bins corresponding to the actual binning system used in the IBEX data products.

Another important aspect of the analysis of IBEX-Lo observations of ISN He was data selection. As discussed previously, the observed signal is a mixture of unperturbed ISN He and the Warm Breeze. Based on an analysis led by Leonard et al., carried out with the participation of M. Bzowski and M.A. Kubiak from SRC and published in *The Astrophysical Journal*, and other work by Möbius et al. (with M. Bzowski, M.A. Kubiak, J.M. Sokół, and P. Swaczyna), published in the special issue of *The Astrophysical Journal Supplement* Series, the orbits and spin angle ranges with the lowest contribution from the Warm Breeze to the signal were determined. These data were subsequently used in the determination of ISN He parameters, carried out independently by Bzowski et al. on the one hand, and Möbius et al. and Schwadron et al. on the other.

The analysis by Bzowski et al. is based on the method and uncertainty system developed by Swaczyna et al. and uses the WTPM simulation model from Sokół et al. Insights from Galli et al. concerning the background and energy threshold, and Leonard et al. and Möbius et al. concerning data selection are taken into account. Furthermore, the Warm Breeze model, obtained by Kubiak et al. 2014 was used. The analysed data included subsets from the years 2009 to 2014. To date, this is the most comprehensive analysis of ISN He observations from IBEX, using the largest percentage of the data set. Bzowski et al. analysed the entire data set together, and data from individual seasons separately. The results are summarized in Figure 6.

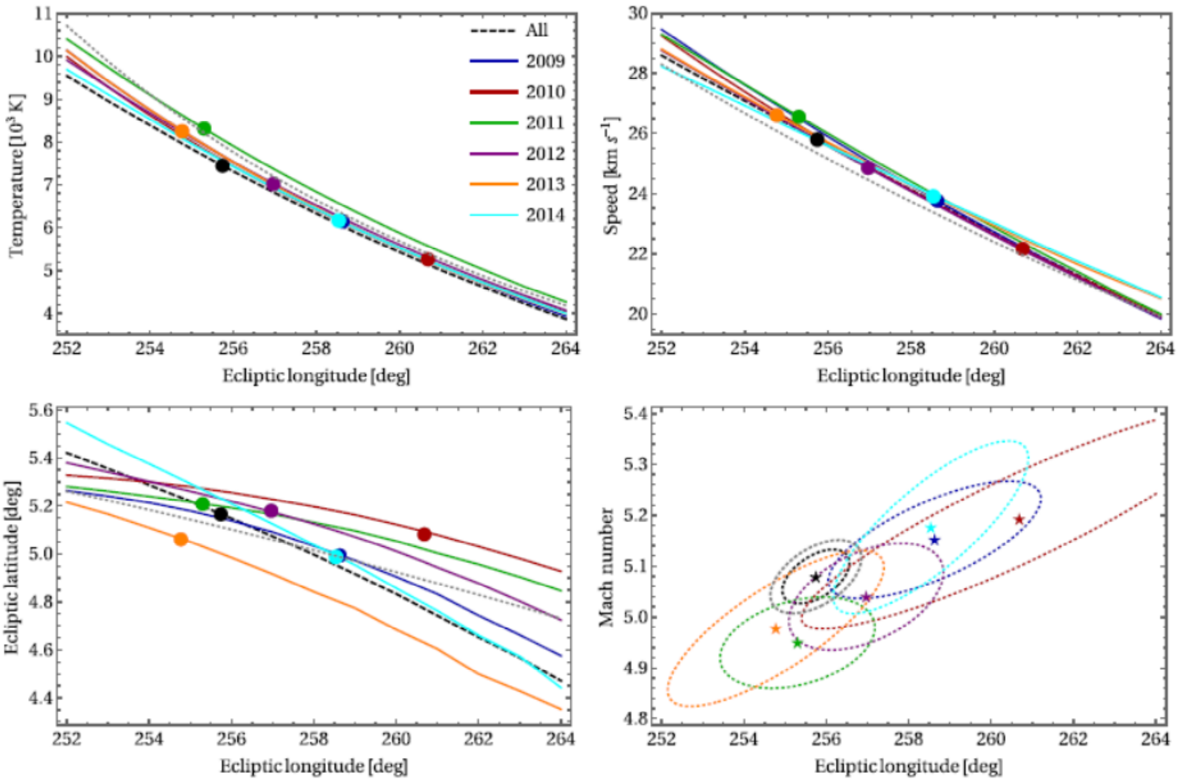

Figure 5 Results of fitting the temperature and inflow velocity vector of ISN He from observations from IBEX-Lo carried out 2009–2014. Source: Bzowski et al., *The Astrophysical Journal Supplement Series* Vol 220: 28, 2015

The parameters are tightly correlated with each other due to the observation geometry: the direction of inflow of ISN He is almost in the plane of motion of the detector. Therefore, observational scatter tends to shift the optimum solution predominantly along the correlation lines. The freedom of motion of the solution across the correlation lines is very tightly constrained. Hence, a fluctuation that displaces the solution obtained for one season of observations in one parameter (e.g., ecliptic longitude of the inflow direction) simultaneously displaces all of the other parameters along the correlation lines. In Figure 6, the upper row and lower-left panels illustrate the projections of the correlation lines from the four-dimensional parameter space on two-dimensional parameter subspaces. In all cases, the inflow longitude is along the horizontal axes. Colours denote individual observation seasons, while black marks the solution obtained for all seasons. Dots indicate optimum solutions for individual seasons and for the entire data set. The lower-right panel presents the contours of the two-sigma uncertainty ellipsoid in the four-dimensional parameter space, projected on the respective two-dimensional parameter subspaces. As Figure 6 shows, although the optimum solution from the entire data set is tightly constrained, global parameters are within the uncertainty ranges of the solutions obtained from the analysis of individual seasons.

The vector of inflow velocity of ISN He on the heliosphere turned out to be in agreement with the earlier estimates obtained from Ulysses (obtained in 2004 by Witte, verified in 2014 by Bzowski et al.), but the temperature obtained from the present analysis of IBEX data, as well as from the reanalysis of Ulysses data by Bzowski et al. 2014 turned out to be substantially higher. Thus, the IBEX-Ulysses enigma has been resolved. This finding was published by Bzowski et al. in *The Astrophysical Journal Supplement Series* Vol 220:28, 2015.

The complementary analysis by Möbius et al. 2015 and Schwadron et al. 2015, carried out with support from M. Bzowski, M.A. Kubiak, P. Swaczyna, and J.M. Sokół from SRC, who used a different interpretation method and model, returned very similar findings. These results were published in the special issue of *The Astrophysical Journal Supplement Series* (Vol 220:24 and 220:25, respectively).

Completing the analysis were studies that excluded specific effects that potentially biased the analysis of either IBEX or Ulysses data. Kucharek et al. (with support from M. Bzowski) analysed the influence of the Earth's gravity on the trajectories of ISN atoms just prior to their detection. The aim was to verify if the expected bending of the trajectories systematically modified the signal, and neglecting the effect would manifest as a systematic modification of the fitted ISN gas parameters. This was not the case: observations showed that the bending of the atom trajectories due to the Earth's gravity is of the order of 0.1°, which is too small to affect the result. A potentially larger deflection could be expected during the autumn observations, but, as shown by Galli et al., ISN He is not observable at this time of the year because of the drop in the sensitivity of the instrument to low-energy He atoms. These findings were published by Kucharek et al. in *The Astrophysical Journal Supplement Series* Vol 220:35, 2015.

Another test study involved verifying that the ISN He temperature derived in 2014 from Ulysses observations was not biased downward as the result of a hypothetical contamination by ISN Ne and O atoms. Although these are much less abundant than ISN He, they were registered by the GAS instrument onboard Ulysses with a much larger efficiency due to their larger impact energy, resulting from their larger specific masses. This study was carried out by Wood et al., supported by M. Bzowski and J.M. Sokół from SRC. Again, the result was negative: ISN Ne and O are very unlikely to modify the Ulysses data to the extent that they are misinterpreted. Hence, the ISN He temperatures inferred from Ulysses observations in 2014 by Bzowski et al., and in 2015 by Wood et al. are valid. Furthermore, they correspond closely to the temperatures obtained by Bzowski et al. in 2015. This analysis was published in a paper in the Special Issue on Interstellar Gas (Wood et al., *The Astrophysical Journal Supplement Series* Vol. 220:31, 2015).

All of this suggests that the temperature and inflow velocity vectors of interstellar matter near to the Sun are known with an unprecedented accuracy and have been confirmed by at least three independent analyses. This makes it possible to go beyond the standard model of ISN gas inflow into the heliosphere, where the parent population outside the heliosphere is given by the Maxwell-Boltzmann distribution function. A step towards the investigation of the hypothetical departure of ISN gas from the equilibrium state is a study by Sokół et al. 2015 (co-authored by M. Bzowski, M.A. Kubiak and P. Swaczyna from SRC among others). This work examined the detectability of hypothetical departures of the distribution function from the perfect thermodynamic equilibrium in the data collected by IBEX. In particular, model maps of the IBEX sky were calculated in two alternative scenarios, namely: (1) when the ISN

He signal observed by IBEX is due to the primary Maxwell-Boltznann population of ISN He and another Maxwell-Boltzmann population of the Warm Breeze; or (2) when the signal is only due to the ISN He population, but with a parent distribution given by the kappa function with a very low value of the kappa parameter, which describes the departure of this distribution from the purely equilibrium Maxwell-Boltzmann state.

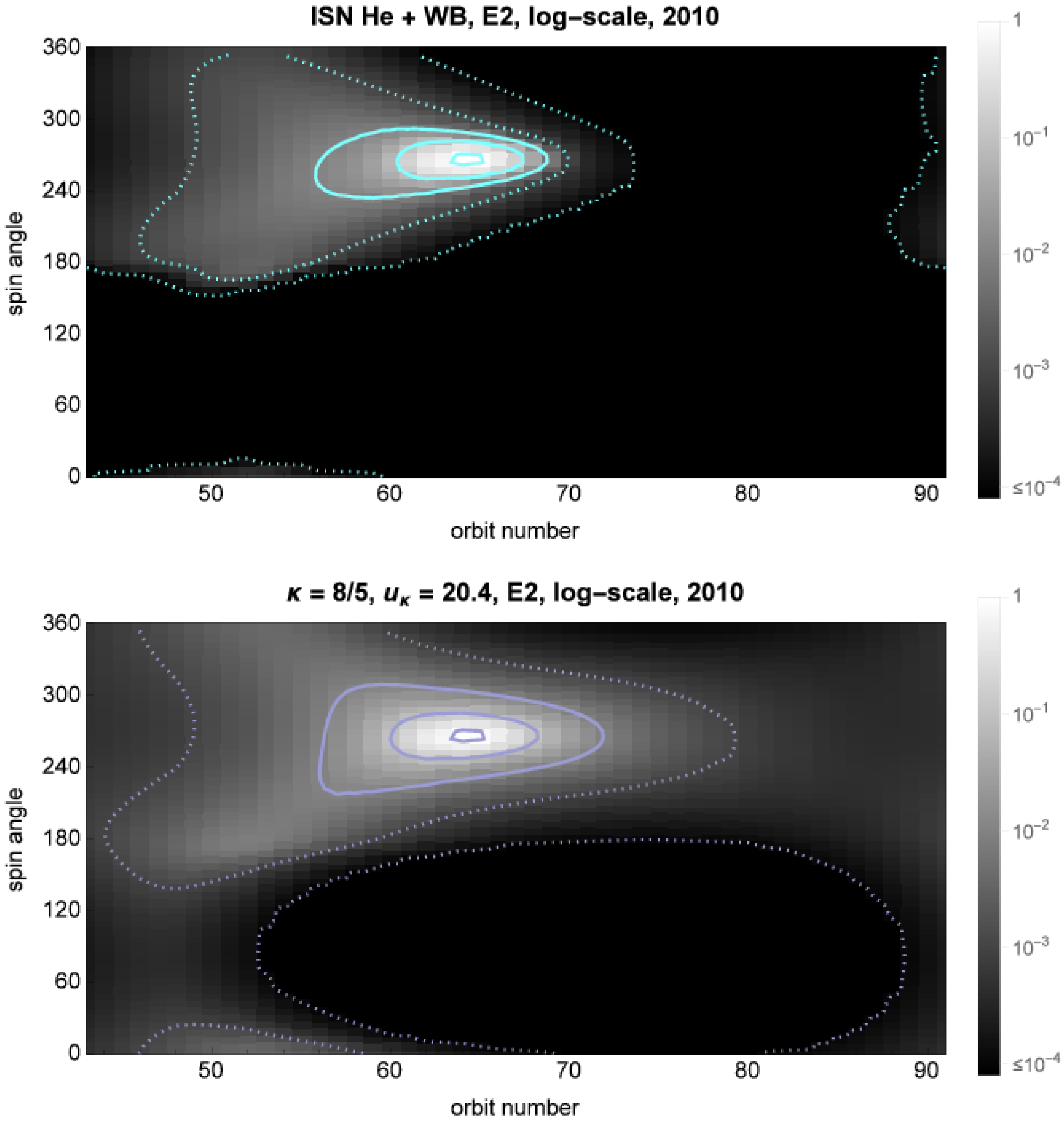

Figure 6 Comparison of simulated full sky maps observed by IBEX-Lo during half a year of measurements in energy channel 2. Adapted from Sokół et al., *The Astrophysical Journal Supplement Series* Vol 220:29, 2015.

Figure 7 is a comparison of simulated full sky maps observed by IBEX-Lo during half-year measurements in energy channel 2, calculated using two alternative hypotheses: (1) that the parent population of the observed flux is a superposition of two Maxwell-Boltzmann functions: ISN He gas with parameters identified by Bzowski et al., 2012, and the Warm

Breeze, with parameters identified by Kubiak et al., 2014 (upper panel); or (2) that the entire signal is due to one population with inflow parameters identical to those of ISN He, but for a parent distribution function given by the kappa function with a low value of the kappa parameter, i.e., strongly departing from the thermodynamic equilibrium. The regions currently open to interpretation (i.e., exceeding the observational background) are marked by the outermost solid contours.

All these findings were summarised by McComas et al. (with the participation of M. Bzowski, M.A. Kubiak, P. Swaczyna and J.M. Sokół from SRC) in a paper published in *The Astrophysical Journal Supplement Series* (Vol 220: 22, 2015). Based on the insights gathered in the context of the project, the IBEX team recommended a temperature of 7500 K, inflow velocity of 25.4 km/s, and ecliptic longitude and latitude of the inflow direction of 255.7° and 5.1° for use in global heliospheric studies.

Studies of the evolution of solar wind structure

In further work on the evolution of the global solar wind structure, PhD students from the SRC (J.M. Sokół and P. Swaczyna supported by M. Bzowski) developed a new method to reconstruct the evolution of heliolatitudinal variation in solar wind speed and density, based on observations of interplanetary scintillation of distant compact radio sources. These observations are available from ground radio observations carried out by the Solar Wind Group, at the Institute for Space-Earth Environmental Research, University of Nagoya, Japan. The group provides solar wind speeds as a function of time and location in the sky. These extremely valuable observations suffer from limited sky coverage and there are gaps in the temporal coverage due to operational reasons. SRC scientists developed a new robust method to filling these gaps in a two-step process. First, gaps in latitudinal coverage are filled for those time intervals where at least partial sky coverage is available (Figure 8); then latitudinal profiles are interpolated that fill the temporal gaps based on a novel method developed by the SRC team (Figure 9). The method description and results of its use to reconstruct solar wind speed and density were published by J.M. Sokół, P. Swaczyna, M. Bzowski, and M. Tokumaru in a paper in *Solar Physics* (Vol. 290, p. 2589, 2015).

Figure 8 is a reconstruction of solar wind speed, based on observations of interplanetary scintillation in from distant compact radio sources. In the first step, full-sky maps of solar wind speed are reconstructed for those Carrington rotation intervals for which the observational coverage is sufficient. Some of those maps are complete and need no reconstruction (the upper-left panel), therefore they are simply approximated by spherical harmonics. Other maps (the lower three panels in the left column) are incomplete and require filling, which is done in the right-hand column.

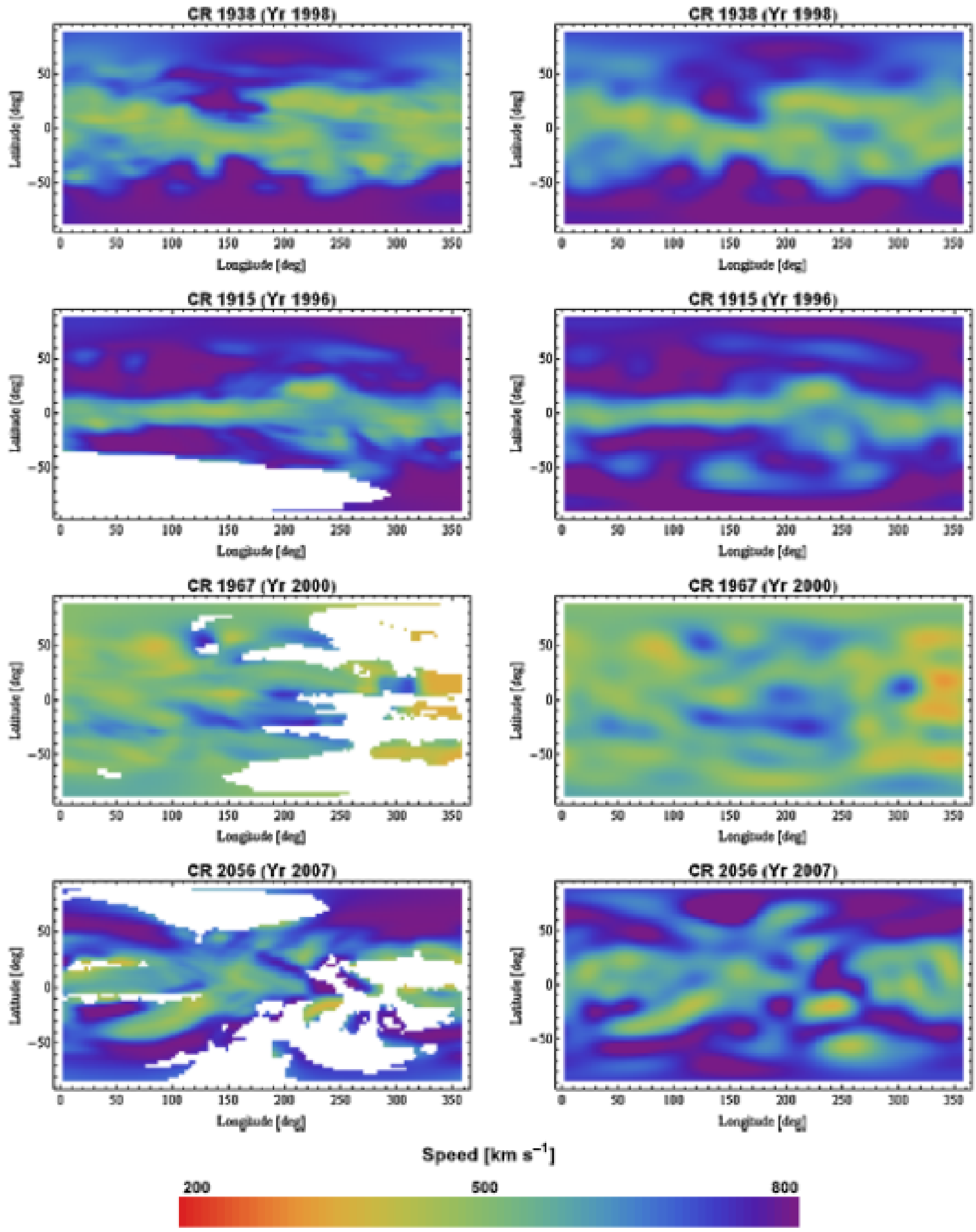

Figure 7 Reconstruction of solar wind speed, based on observations of interplanetary scintillation from distant compact radio sources. Source: Sokół et al., *Solar Physics* Vol 290 p 2589, 2015.

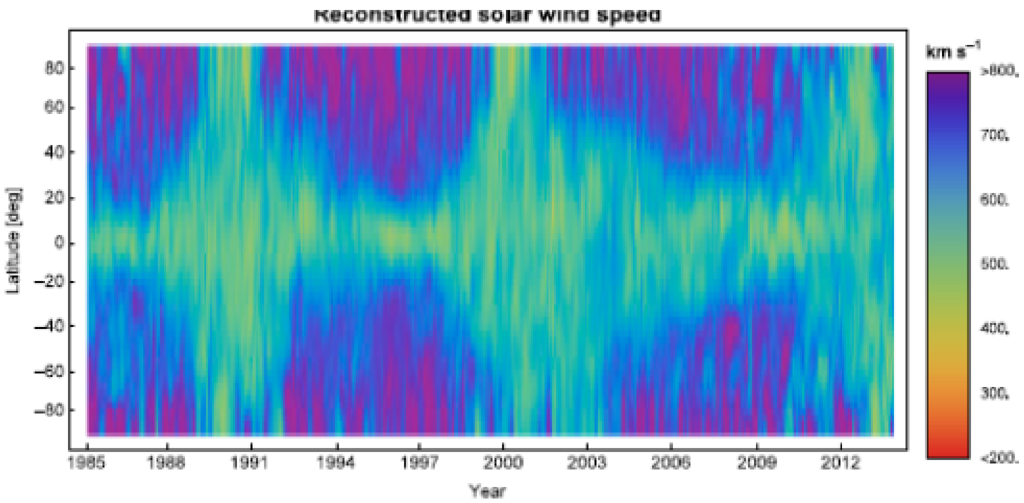

Figure 8 The final effect of the solar wind speed reconstruction. Source: Sokół et al., Solar Physics Vol 290 p 2589, 2015.

Figure 9 shows the final solar wind speed reconstruction. Heliolatitude gaps are filled, and in the next step the heliolatitudinal profile of the solar wind speed is averaged over Carrington rotations. Then the missing Carrington profiles are filled. The final result is a map of Carrington period-averaged profiles of solar wind speed as a function of time and heliolatitude.

Studies of turbulence in space plasma

Turbulence is a complex behaviour in fluids. It is very common in nature, in particular in the solar wind. The mechanism, however, is still not sufficiently clear. SRC scientists (W.M. Macek and A. Wawrzaszek, in collaboration with D.G. Sibeck from NASA GSFC) analysed the intermitted turbulence in magnetospheric and solar wind plasmas using a statistical approach based on experimental data from space missions.

They used data from the quintet of spacecraft from the Time History of Events and Macroscale Interactions during Substorms (THEMIS) mission to investigate the details of the turbulent plasma parameters downstream of collisionless shocks. They investigated both the solar wind and magnetospheric measurements using statistical probability distribution functions of Elsässer variables, which can reveal the intermittent character of turbulence in space plasma. The results suggest that the turbulence downstream of the quasi-perpendicular shock is more intermittent with a larger kurtosis than that downstream of quasi-parallel shocks, which are immersed in a relatively quiet solar wind plasma, confirmed by Wind measurements. It seems that the waves propagating outwards from the Sun underlying the quasi-perpendicular shock are larger than (potentially damped) waves propagating inward. In particular, it is hoped that this difference in the behaviour of fluctuating space plasma parameters downstream of both types of shocks can help to identify complex plasma structures in future space missions. It is also expected that these results will be important for general models of turbulence. These results were published by Macek et al. in the *Journal of Geophysical Research: Space Physics* (Vol. 120, p. 7466, 2915).

Similarly, an international team of scientists led by A. Wawrzaszek and W.M. Macek (SRC) analysed intermittency as the departure of solar wind magnetic turbulence from self-similarity, and investigated its evolution as a function of heliocentric distance and heliolatitude. They analysed data from the Ulysses spacecraft relating to two time intervals near the minima of solar activity (1997—1998 and 2007—2008) and from one interval near the maximum (1999—2001). They modelled a multifractal spectrum of the magnetic field time series, and revealed the intermittent character of turbulence in small-scale fluctuations of the magnetic field embedded in slow and fast solar wind. Generally, a high degree of intermittency (multifractality) was observed at small distances from the Sun in both slow and fast solar wind, which slowly decreases with increasing solar distance and heliolatitude. This suggests that in general, intermittency in the solar wind originates at the Sun. However, it seems that fast and slow streams, shocks, and other nonlinear interactions are also drivers of intermittent turbulence. The analysis suggests that turbulence outside the ecliptic plane evolves too slowly to maintain intermittency with solar distance and heliolatitude. It was confirmed that multifractality and intermittency outside the ecliptic are at a lower level than in the ecliptic plane, and that there is symmetry with respect to this plane. This suggests that similar turbulent properties persist in the northern and southern hemispheres. These findings were published in paper by Wawrzaszek et al. in *The Astrophysical Journal Letters* (Vol 814: 91).