A comet's tale

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Feedback Welcome
research.reading.ac.uk/met-spate/Comets/

Do you observe comets? If so, Sarah Watson and Chris Scott would like to see your images of comets interacting with solar wind structures, in order to test and refine model predictions.

Space within the heliosphere is pervaded by the solar wind, a continuous flow of charged particles and magnetic field that originates from the Sun. The flow is bimodal, with two distinct populations, known as the slow wind (around 400kms^{-1}) and fast wind (greater than 750kms^{-1}). These two winds originate from different regions of the Sun and have distinct differences in density and ion composition. Although these fast and slow streams emerge radially from separate regions, the rotation of the Sun causes them to form spiral structures known as the Parker spiral, after Eugene Parker who first predicted the presence of the solar wind. As they spread through the heliosphere these fast and slow streams can interact where the fast wind 'catches up' with the slow wind. This results in localised intensifications of plasma and magnetic field known as stream interaction regions.

In addition, the heliospheric magnetic field forms regions in which the field polarity is either towards or away from the Sun. These regions of opposing magnetic field are separated by the heliospheric current sheet (HCS). At solar minimum, the HCS is more confined to the ecliptic plane, but during solar maximum, it becomes more complex.

Comets within the heliosphere interact with the solar wind. If a comet crosses the current sheet, or moves between regions of slow and fast solar wind, its tail can be disturbed or even disconnected. Images of these structures will allow us to test and improve a new method predicting how comets respond to heliospheric structures.

The Heliospheric Upwind eXtrapolation with time-dependency (HUXt) model was developed by Matt Owens and Luke Barnard at the University of Reading (Owens *et al.* 2020, Barnard *et al.* 2022). It is an open-source model of the solar wind that uses a reduced physics approach and therefore is computationally quicker than more complex solar wind models that use the full magnetohydrodynamics (MHD) equations. As a result, it can be used to compute many-member ensemble runs of solar wind conditions in a fraction of the time of the full MHD models. It outputs solar wind conditions, including the solar wind speed and the polarity of the IMF throughout the heliosphere, which follows the Parker spiral. The HUXt inner boundary conditions are determined by the output of magnetogram-constrained coronal models.

The accuracy of these types of models can be improved by using data assimilation techniques,

1 *Comet Leonard photographed by Gerald Rhemann in December 2021. The structure within the tail suggests that it was undergoing a tail disconnection event at this time.* (G Rhemann)

in which a combination of model and observations are combined to generate a more accurate reconstruction of the solar wind conditions. The Burger Radial Variational Data Assimilation (BRaVDA) solar wind scheme (Lang et al. 2021) can use data obtained from spacecraft such as the Advanced Composition Explorer (ACE) and the Solar Terrestrial Relations Observatory (STEREO) to improve estimates of the solar wind at the model's sunward boundary, which are then propagated into the modelled heliosphere using the HUXt model. This results in a more accurate forecast of solar wind conditions within the inner heliosphere.

Observing the solar wind

The twin spacecraft of the NASA STEREO mission were launched on 26 October 2006 and are now in heliospheric orbit approximately 1au from the Sun, one travelling ahead of the Earth and the other lagging behind. The mission was designed to make observations of the Sun from two distinct viewing directions in order to provide 3D information about structures in the solar chromosphere and corona. The two spacecraft (named Ahead and Behind, 'A' and 'B', respectively) were moving away from the Earth at around half a million miles per year (the Earth–Sun–spacecraft angle increased by 22.5° per year). Contact with STEREO-B was lost in 2014 but STEREO-A is still operating well and has recently returned to near-Earth space.

The UK provided STEREO with revolutionary wide-field cameras known as Heliospheric Imagers, which are positioned in such a way as to image the solar wind out to distances of 1au (Davis & Bewsher, 2007). Each HI has two cameras, HI-1 and HI-2 that, through a series of precision baffles that remove nearly all scattered sunlight, allow the instrument to detect features that are 10^{14} times fainter than the Sun, even though the Sun is only a few degrees outside the HI-1 field of view. HI-1 has a 20° field of view centred 13.65° from the Sun, while HI-2 has a 70° field of view centred 53.35° from the Sun. As a result, a 90° section of the sky can be imaged, centred along the ecliptic, allowing the solar wind and transient eruptions of solar plasma known as coronal mass ejections (CMEs) to be tracked from the Sun all the way to the orbit of Earth.

While designed to track the evolution of CMEs, the HI cameras have imaged stars, planets, asteroids and comets throughout the STEREO extended mission, including some spectacular observations of the interaction between the solar wind and comet tails.

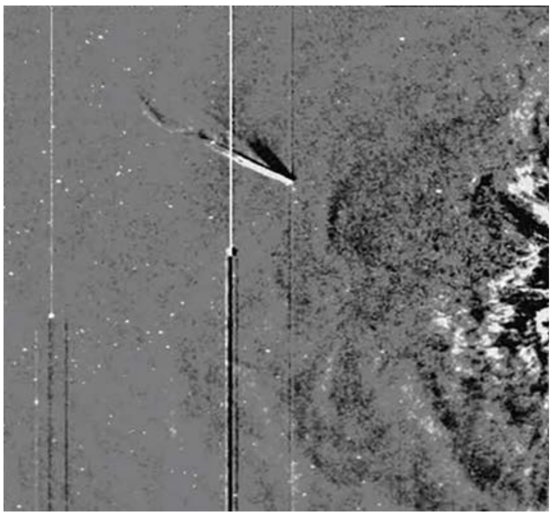
Observing comet tail interactions

Data from STEREO, along with the ability to obtain accurate forecasts of the solar wind conditions in the inner heliosphere from other spacecraft, allow both prediction and observation of the interactions between comets and the solar wind. Since we are now able to model the location of the HCS and the positions of fast solar wind streams more accurately (particularly in the ecliptic), we can explain the cause of turbulence that may occur in a comet's tail as a result. This can vary from a slight wobbling of the tail to more spectacular events such as a complete disconnection. Events such as these can provide stunning images of the comets as they enter the inner heliosphere.

So far, my research has concentrated on analysing comet tail interactions using the STEREO spacecraft. Comets remain within the HI field of view for a few days, and this allows us to observe tail interactions that take place during this period. As an example, HI observations of Comet Nishimura show some striking interactions with the solar wind during its recent path through the HI-camera fields. There is a clear wobble in the tail as the comet encounters differences in solar wind conditions.

However, we can capture comets in the STEREO cameras only if a comet happens to be in the right place at the right time; many pass by unnoticed because they are not within the HI field of view, meaning we miss some of these events. And they can be stunning images, such as the image of Comet Leonard taken by Gerald Rhemann back in December 2021 (figure 1). Having images of these comets as they encounter these solar wind features would also be hugely beneficial to my research.

We have set up a website (research.reading.ac.uk/met-spate/Comets/) containing details of upcoming



2 *Disturbances in the tail of comet Nishimura as seen by STEREO-HI1A in the upper left quadrant of the image. Solar wind flows can be seen emanating from right-hand side of the HI1 image, where the Sun lies just outside the field of view to the right-hand side of the image. The vertical line intersecting the comet tail is due to light reflecting off Venus.* (NASA STEREO)

predictions for comet tail activity for a range of comets. I would be extremely grateful for any images or sketches of each comet before, during and after the predicted time of activity. In this way we will be able to test the accuracy of our solar wind model and understand the cause of cometary activity. We would appreciate all images – good, bad or ugly. We hope that these predictions will not only create the opportunity for some spectacular astrophotography, but it will also benefit our research, by letting us observe comet interactions that we may previously have missed. The forecast on the website will be updated regularly, where solar wind conditions (solar wind speed and the position of the heliospheric current sheet) generated by HUXt will be presented (see figure 3 for an example of a 20-day period in October 2023) along with a list of particular times of interest such as the comet crossing through a significant increase in solar wind speed or a change in the magnetic field polarity. Although some periods may predict no/little activity while a comet is visible from Earth, your comet images would still be useful as they can help us understand the level of solar wind activity needed to cause distortions in the tail.

To kick things off, the website will launch with the anticipated arrival of the comet C/2021 S3 (PANSTARRS) which can be viewed from Earth during the month of February 2024, and will have a visual magnitude of around 7 throughout. During this period, we will be able to predict whether the comet tail will be disturbed and even if there is a chance of a disconnection event around this time. This would be a great opportunity for astronomers to capture some spectacular images throughout this period, and I am particularly interested in images taken around the 6/7/8 February; this is when we anticipate that the comet behaviour will be the most interesting, because it is when we expect the comet to cross the ecliptic where it will encounter the heliospheric current sheet. The orbit of PANSTARRS is shown in figure 5.

Because we are using this website to improve the modelling, the predictions on it are not static. The modelled solar wind conditions are based on solar observations, and as new observations become available, we will rerun the HUXt model and issue updated predictions on the website.

We encourage you to send any comet images, along with the date, time and location of the observer, to be sent to us via the email address on the website (s.r.watson@pgr.reading.ac.uk). All images are welcome! They will help us improve our solar wind model and hopefully will provide a reliable way to forecast the behaviour of these beautiful and dynamic celestial wind socks.

AUTHOR

Sarah Watson (s.r.watson@pgr.reading.ac.uk) is a PhD student at the University of Reading, studying solar wind interactions. Comet Leonard, the first comet she worked on in her PhD, will always hold a special place in her heart; she now has a crochet version on her desk.

Chris Scott is professor in space and atmospheric physics at the University of Reading, interested in using data for space weather forecasts.

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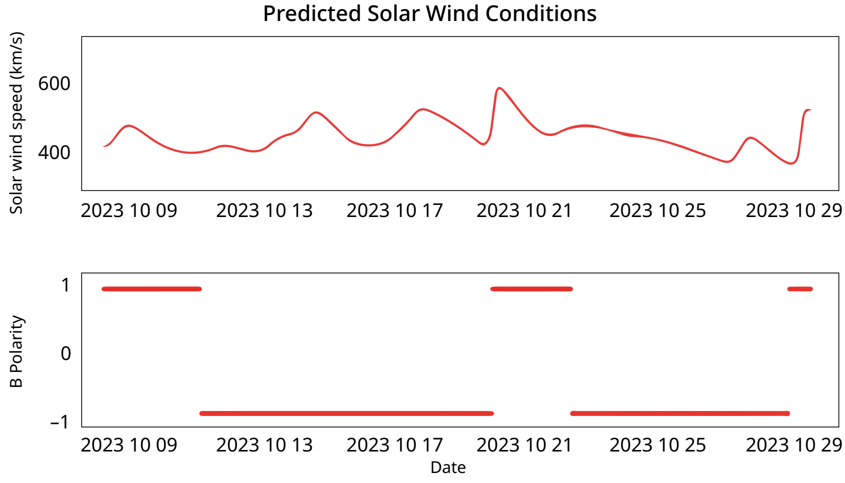
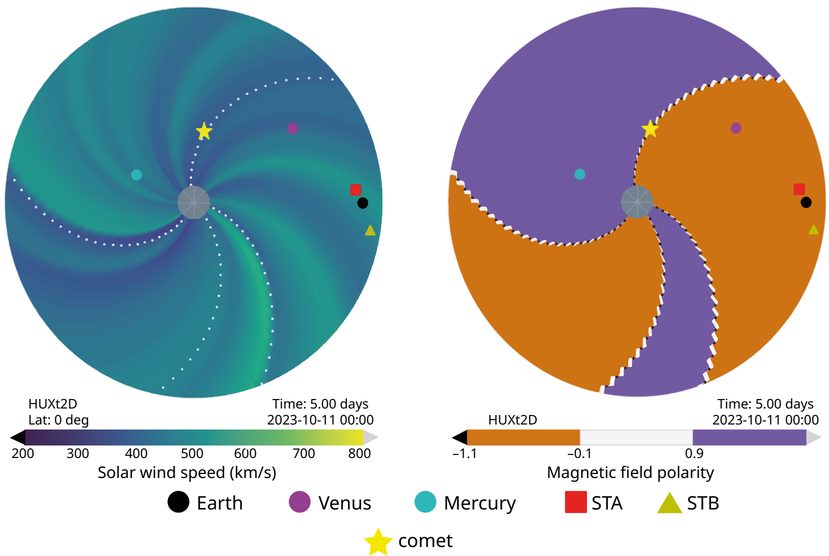
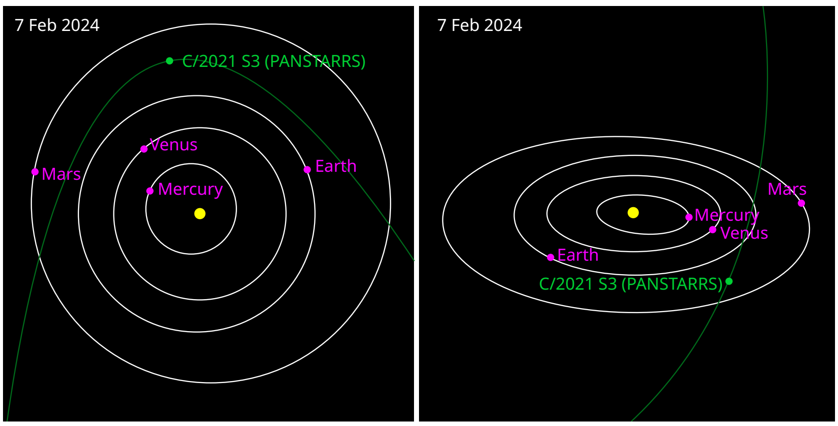


3 *Example of the output from the HUXt model from which solar wind conditions at the location of the comet can be estimated. The top panel shows solar wind speed while the bottom panel shows heliospheric magnetic field polarity. As shown in figure 4, a comet crosses the Heliospheric Current Sheet where the polarity of this field switches from 1 to –1 or vice versa and observations of any changes in response to such interactions will be of great scientific interest.* (S Watson)



4 *A snapshot from a 2D run of the HUXt model. The comet of interest is shown by the yellow star along with the inner planets and STEREO spacecraft. The left panel shows the solar wind speed, with lighter blue regions showing faster solar wind and the white dotted line representing the Heliospheric Current Sheet. The right panel is the same time period but showing the magnetic field polarity.* (S Watson)



5 *The orbit of comet C/2021 S3 (PANSTARRS) viewed from above the ecliptic plane (left panel) and relative to the ecliptic plane (right panel).* (in-the-sky.org)