Simultaneous imaging of recurrent plasma injection signatures in Saturn's auroras and energetic neutral atom flux

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Joe Kinrade[1] j.kinrade@lancaster.ac.uk

Sarah Badman[1] Chris Paranicas[2] Don Mitchell[2] Becky Gray[1] Chris Arridge[1]
Alex Bader[1] Carley Martin[1] Stan Cowley[3] Gabby Provan[3]

1 Introduction

Recent studies have revealed that large-scale injections of plasma into Saturn's magnetosphere are significant in driving morning-sector auroral emissions in its ionosphere (Bader+ 2019). Such injection signatures are readily observed as rotating enhancements in Energetic Neutral Atom (ENA) flux, when incoming hot ions charge exchange with the neutral cloud. Several multi-instrument studies have shown a general local time relationship between auroral and ENA injection signatures (Mitchell+ 2009, Lamy+ 2013, Nichols+ 2014), suggesting a transient current system which links the outer-middle magnetosphere to the ionosphere.

Here we report high latitude observations taken by Cassini's imagers on 9 April 2014, the UVIS and INCA, providing simultaneous global views of the southern ultraviolet auroras and magnetospheric ion dynamics. We attempt to track the location and extents of these injection signatures in order to test if the auroral and ENA signatures are always counterpart.

2 Tracking auroral patches

- We systematically identify rotating auroral patches in the UVIS imagery and track them in time.
- Consider all pixels within 30° latitude of the pole, apply some smoothing, and contour areas above the 97% intensity threshold for each image. This isn't perfect at replicating what the eye sees, but it's simple, adaptable and repeatable.
- Each patch has a position centroid, contour outlines, and extents in latitude and local time. Brightness within each patch area is also recorded, the maximum intensity being a close proxy for emitted power.

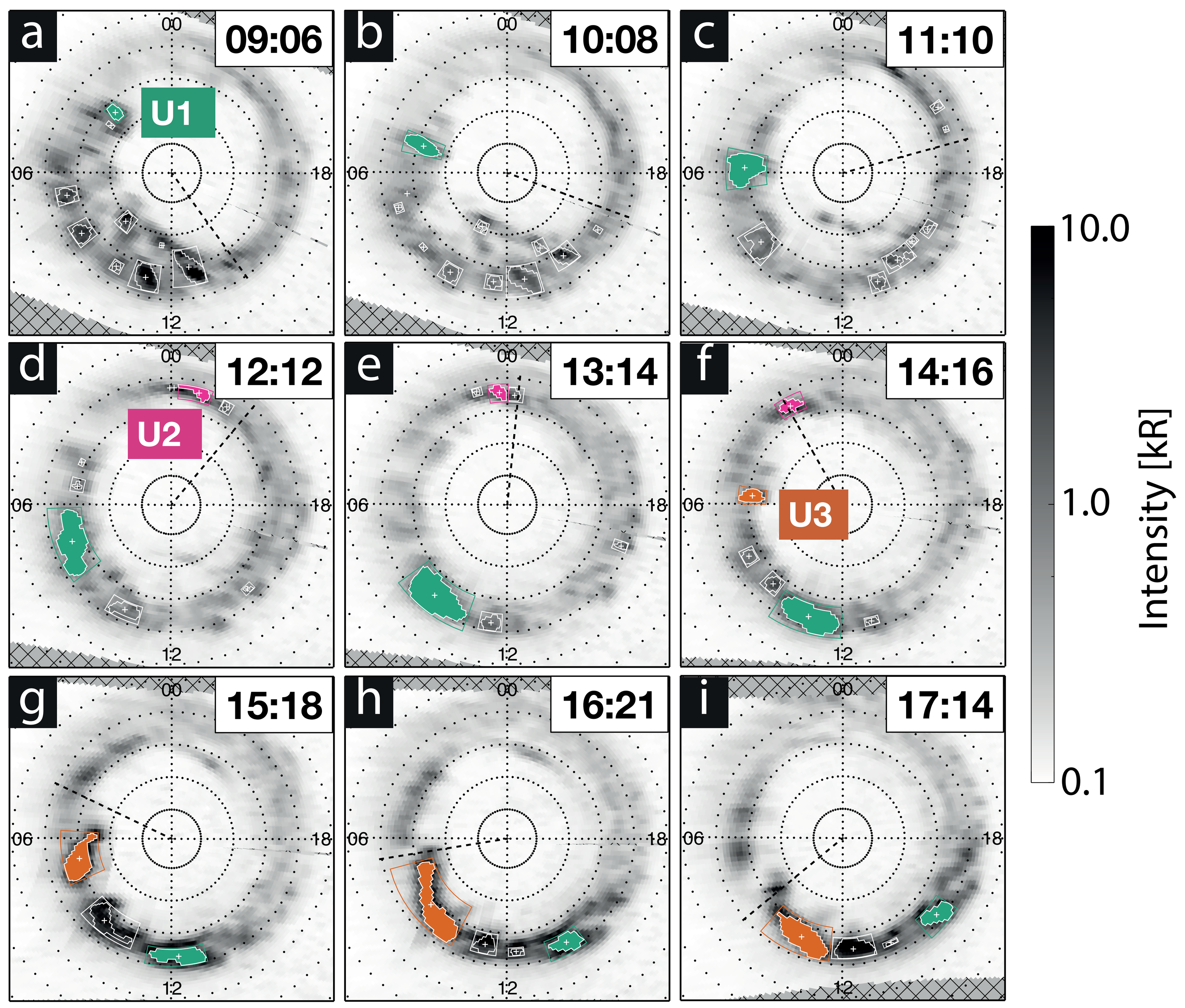

Figure A. A sequence of composite UVIS images from 9 April 2014 revealing the auroral morphology in Saturn's southern hemisphere over ~ 9 h (mid-exposure times shown). Each image is made up of ~2 swath scans, with an effective exposure time of ~ 1 h. Radial dashed lines show the local time position of peak upward current associated with the rotating planetary period oscillation (PPO) magnetic field in the south (e.g. Provan+ 2016).

3 Tracking ENA patches

- INCA captures line-of-sight integral ENA flux remotely as an image.
- If Cassini was on an inclined orbit, the image may be projected into the magnetospheric equatorial plane.
- Assumes that most neutral density is confined to a thin disk acting as an ENA-emitter when impacted by injected ions.
- Azimuthal ENA gradients (e.g. injection signatures) can be tracked using keograms.

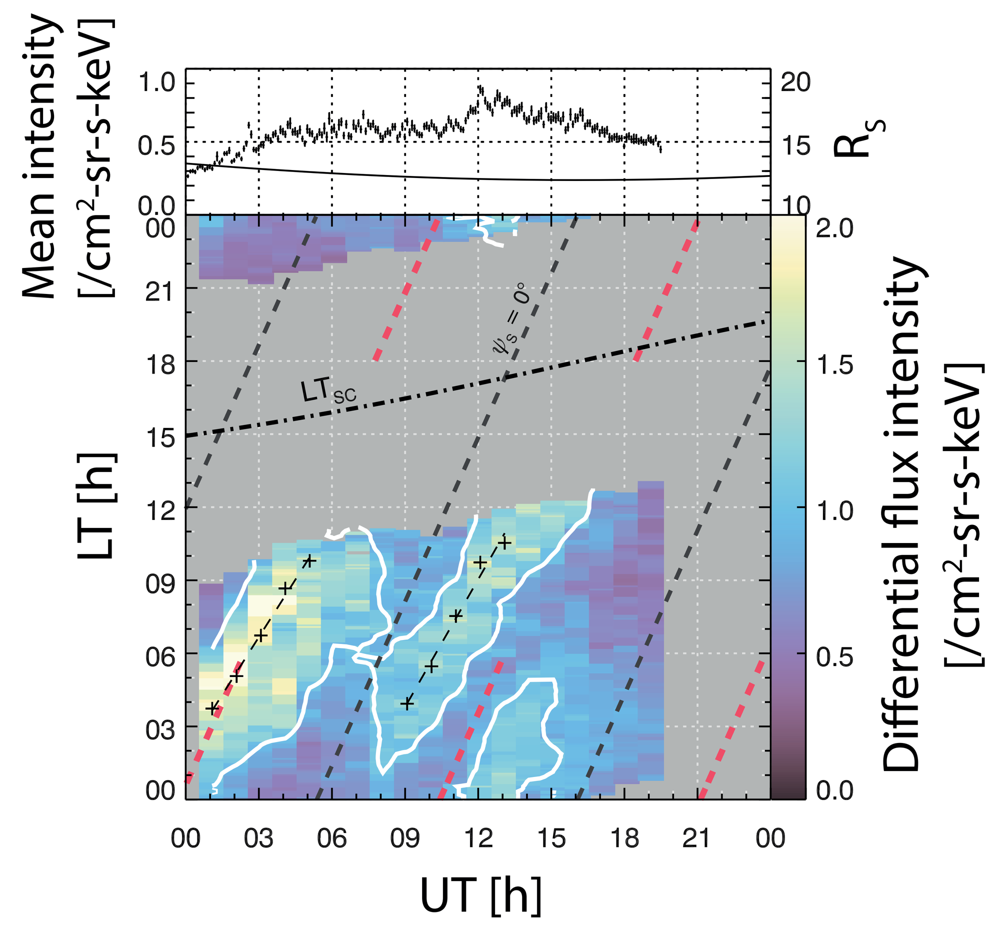

Figure B. Keogram showing ENA flux intensity variation in local time. Median values between 1-20 R_S, out to the orbit of Titan, are shown. Diagonal features here are ENA signatures of injected plasma, rotating in the same direction as the planet. Their azimuthal speed is ~70% of rigid co-rotation. Dashed lines show the southern PPO dipole direction (**black**) and expected thinning of the plasma sheet in the tail (red) (Bradley+ 2018).

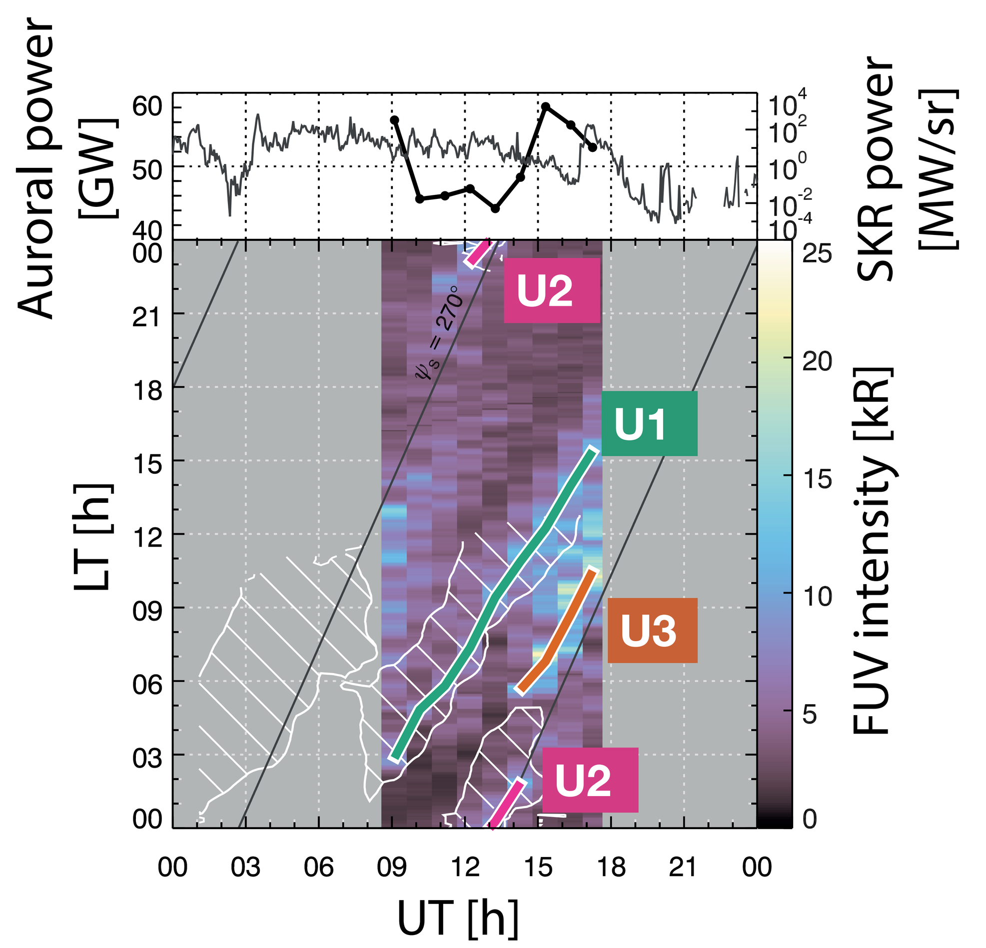

Figure C. Keogram showing auroral intensity variation in local time. Coloured tracks follow the centroid position of the patches identified in Figure A. ENA patch outlines based on Figure B (white) show that auroral patches **U1** and **U2** are probably injection signatures. **U3** however, although clearly a similar injection signature, has no counterpart in the ENA imagery. Solid **black** lines show the expected location of the peak upward current associated with the southern PPO system.

Are the injection signatures rotation modulated?

- An older injection signature in the auroral intensity, **U2**, brightens as it moves through local midnight, coincident with a region of expected PPO upward current rotating past it.
- May be evidence of auroral modulation by the same recurrent energization process observed statistically in ENA imagery, or could be direct modulation by PPO current.

Do ENA injection signatures have auroral counterparts?

- Evidence here suggests so, and they can track closely in local time.
- Two injection signatures observed successively as rotating patches in the auroras and ENA flux.
- Auroral patch **U1** forms pre-dawn and tracks an ENA signature in local time for ~ 9 hours.
- Patch **U2** is an older signature, but still has a clear ENA match.
- ***But*** we also observe a clear auroral injection signature without any ENA flux, **U3** . The source region driving this auroral patch may have an energy distribution not imaged in the 24-55 keV ENAs, or may have been located outside of the INCA projection.

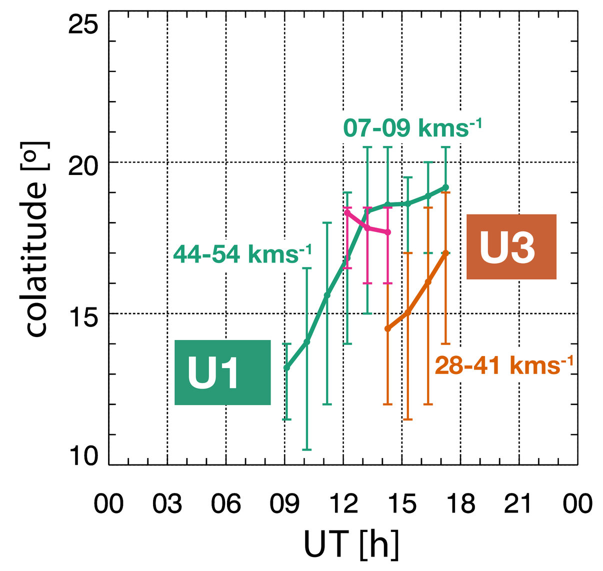

Figure Di. Auroral patch colatitudes & magnetospheric mapping speeds

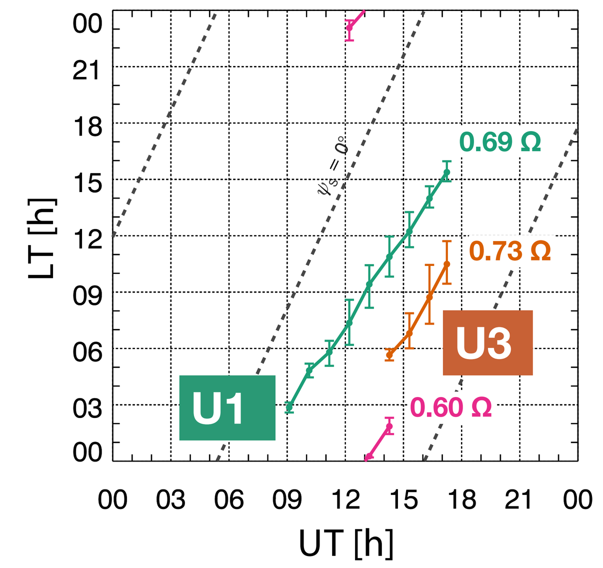

Figure Dii. Auroral patch azimuthal speeds as a fraction of rigid corotation, Ω

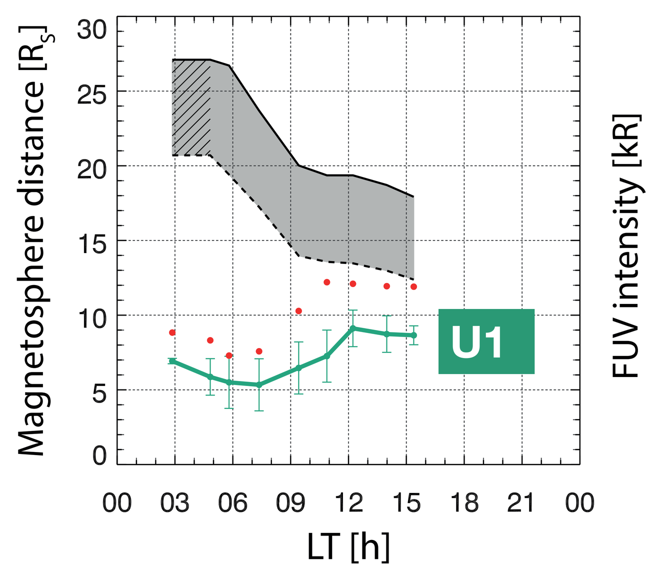

Figure Diii. Auroral patch **U1** mapping distance estimates from the UCL magnetodisk model (Sorba+2018) (grey shaded region) & intensity (maximum values shown by red dots) versus local time

4 Kilometric Radio Signatures

Auroral acceleration processes are closely related to a kilometric radio emission at Saturn (SKR), peaking at ~100-400kHz. SKR is a useful indicator of magnetospheric dynamics (Reed+ 2018):

- Magnetic reconnection events are associated with intensification & extension of the spectral range at lower frequencies (*LFEs*) as the acceleration region reaches higher altitudes (Jackman+ 2009).
- Narrowband SKR (nKSR) at ~10-40 kHz is thought to be emitted in regions of strong plasma density gradients (Ye+ 2009), and is visible only from high-latitude satellite passes.

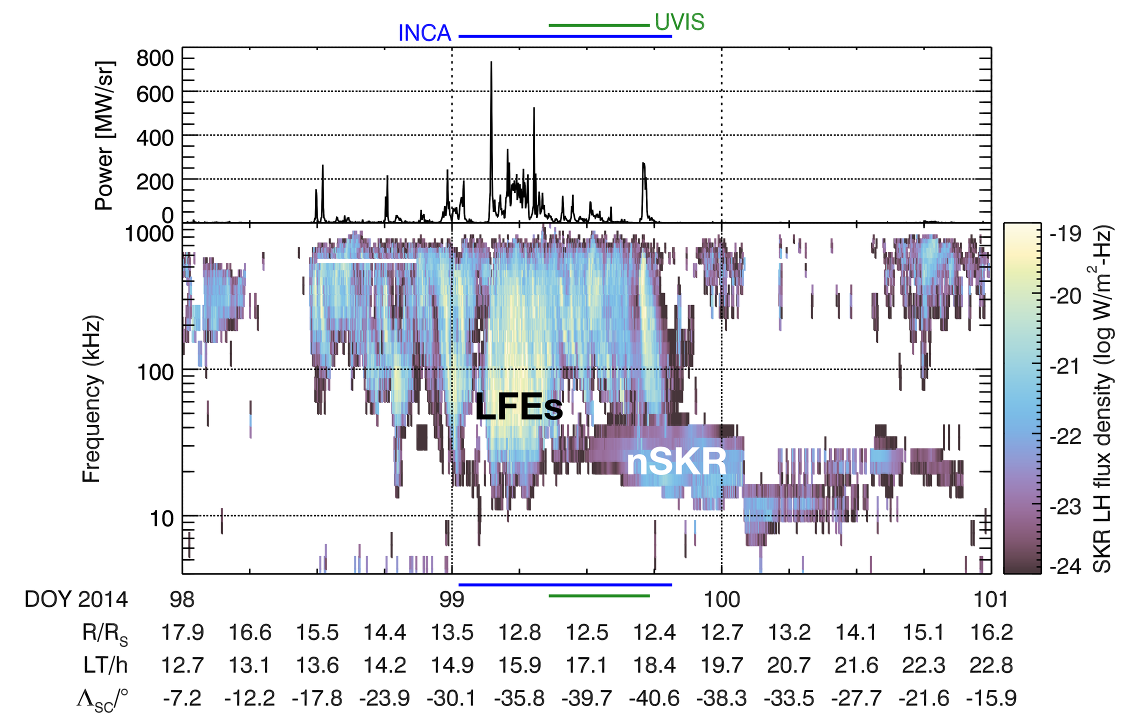

Figure E. A radio power spectrogram showing both LFE and nSKR presence during the INCA and UVIS imaging windows.

Do we detect a radial boundary or plasmapause?

- Patch **U1** slowed down as it moved equatorward around the dawn flank, implying a radial 'braking' of the injected source region in the magnetosphere as it moved inwards. Mapped radial speed estimates slow from ~44-54 kms^{-1} to ~7-9 kms^{-1}.
- Latter speed estimate consistent with inward interchange flows (e.g. Paranicas+ 2016).
- Braking could indicate entropy or dipolar boundary being reached.
- Patch intensity also increased as the source region slowed down.
- nSKR power increased for > 12 hours, symptomatic of enhanced plasma pressure gradients in the inner magnetosphere.

5 What have we learned?

- Case study reported when INCA and UVIS were imaging simultaneously from high latitude orbit position, providing views of the southern auroral morphology and global plasma dynamics at the same time.
- **Clear LT-matching signatures** show that large-scale ENA injections can map to auroral latitudes, not necessarily equatorward as indicated by the Carbary+ (2008) statistical study. The mapping in reality is more complex than the LT-symmetric model.
- This apparent 1:1 mapping, spread across a local time range of ~3-6 hours, indicates **a region of possible current flow linking the two enhancements**, which is not fully resolved by the instruments.
- **There are not always matching signatures in the ENA flux and auroras.**

References

*submitted

Mitchell+ 2009
Carbary+ 2008
Sorba+ 2018
Bader+ 2019*
Lamy+ 2013
Ye+ 2009
Nichols+ 2014
Bradley+ 2018
Jackman+ 2009
Reed+ 2018
Paranicas+ 2016
Provan+ 2016

Affiliations

[1]Lancaster University
[2]JHU APL
[3]University of Leicester

Data Sources

SKR data:
http://http://amda.cdpp.eu
UCL magnetodisk model:
Arianna Sorba & Nick Achilleos