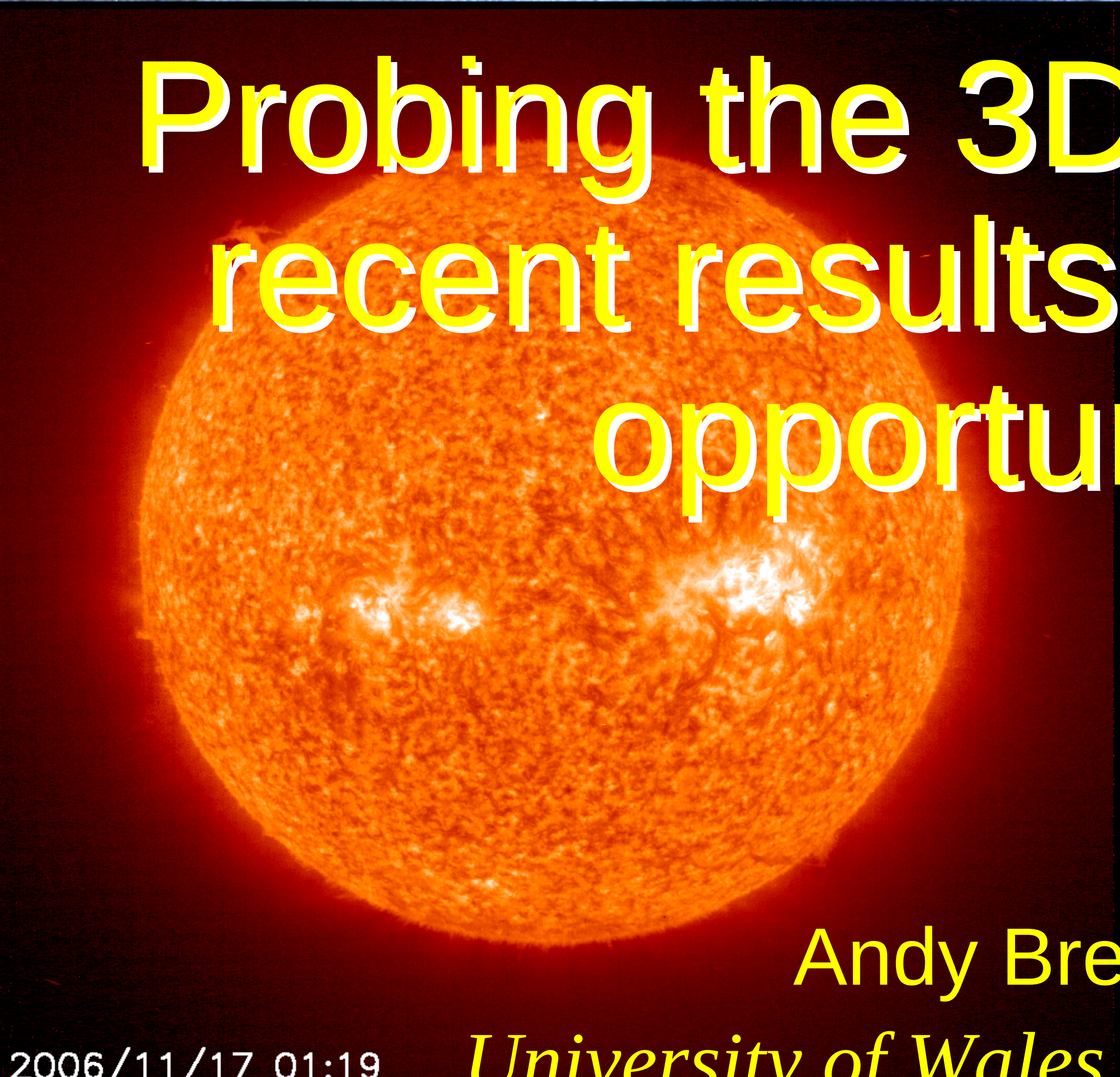
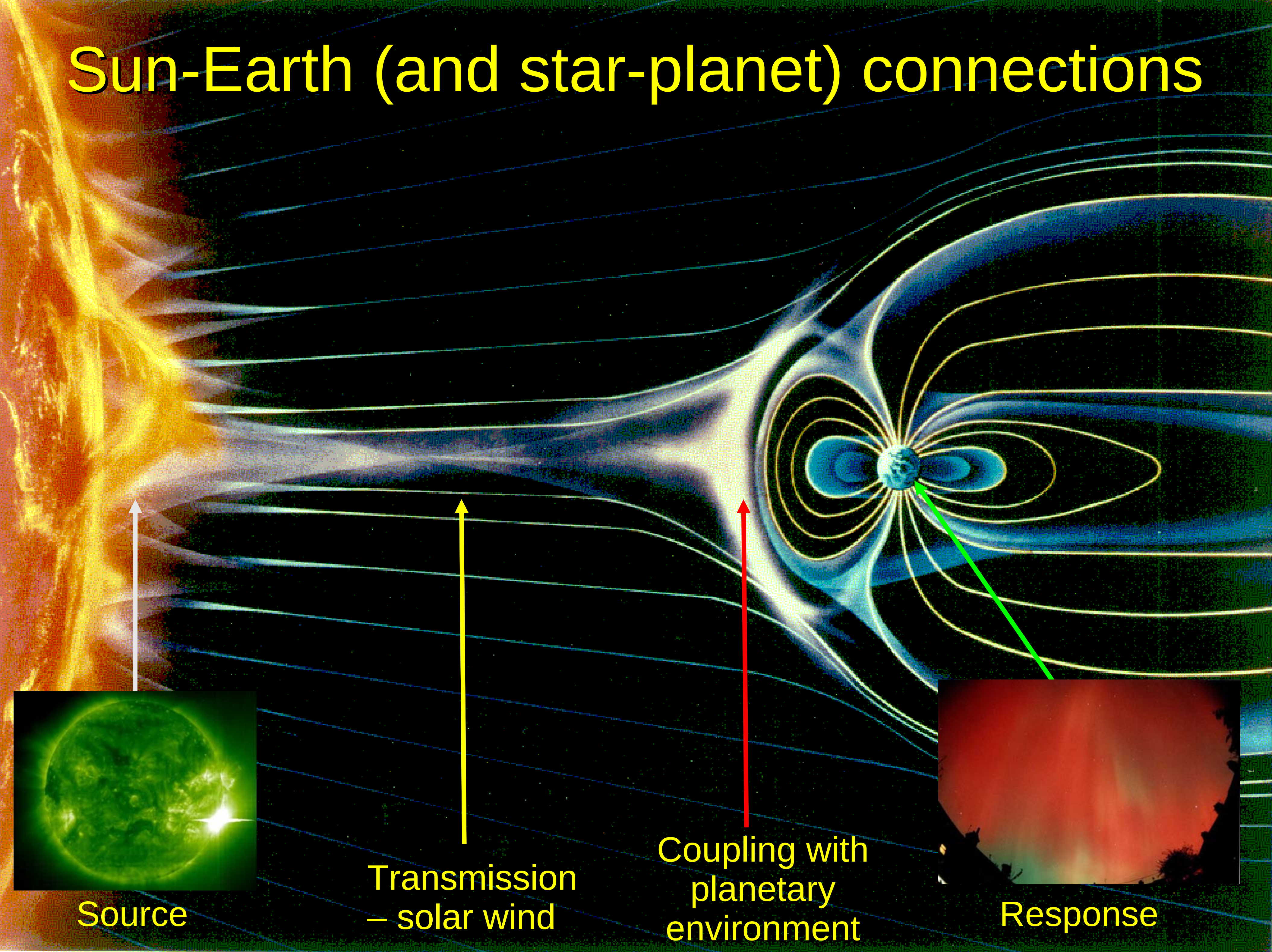
Prifysgol Cymru
Aberystwyth
The University of Wales

Probing the 3D solar wind: recent results and future opportunities



Andy Breen
University of Wales, Aberystwyth

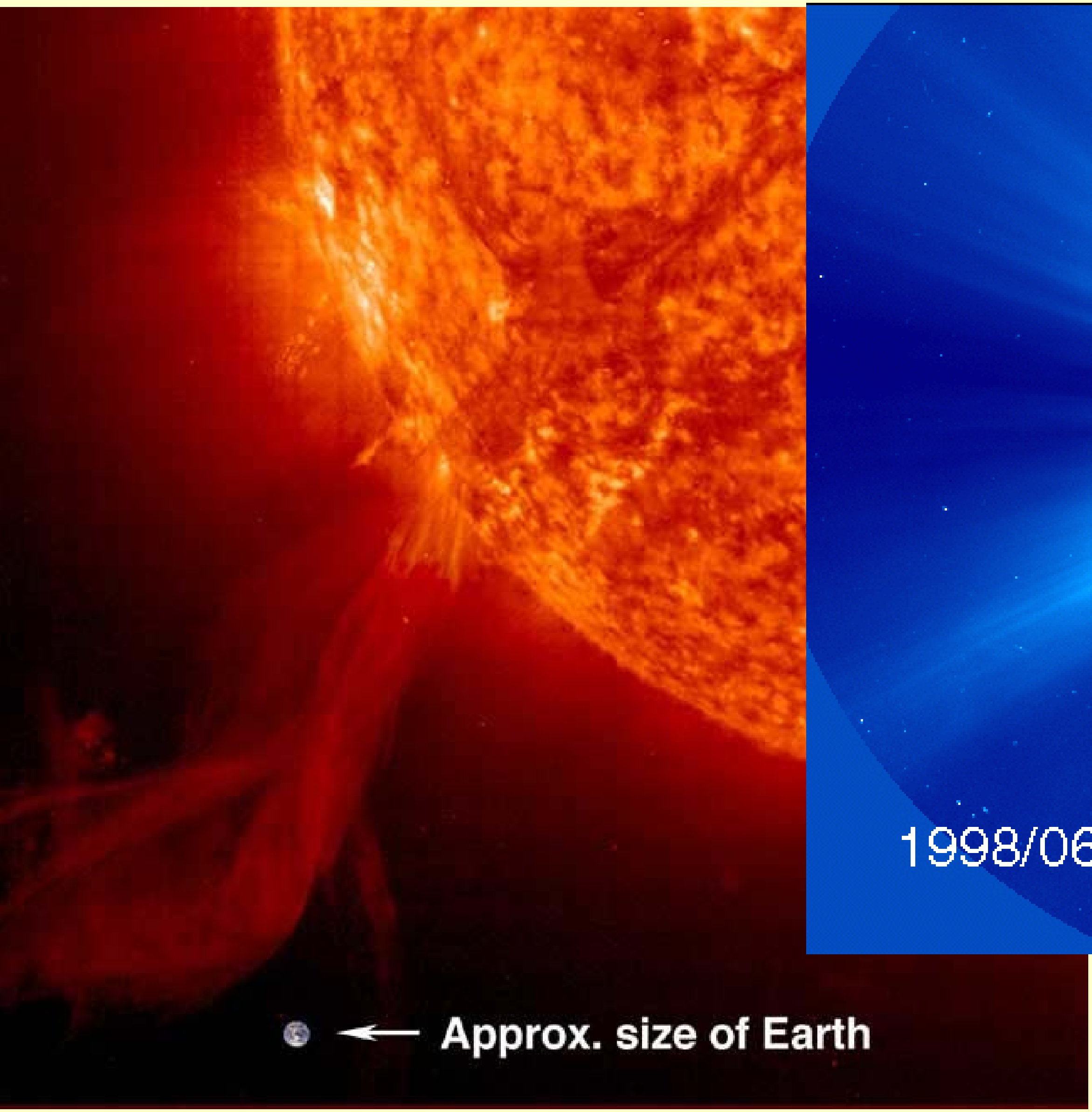

Sun-Earth (and star-planet) connections
Source
Transmission
– solar wind
Coupling with
planetary
environment
Response

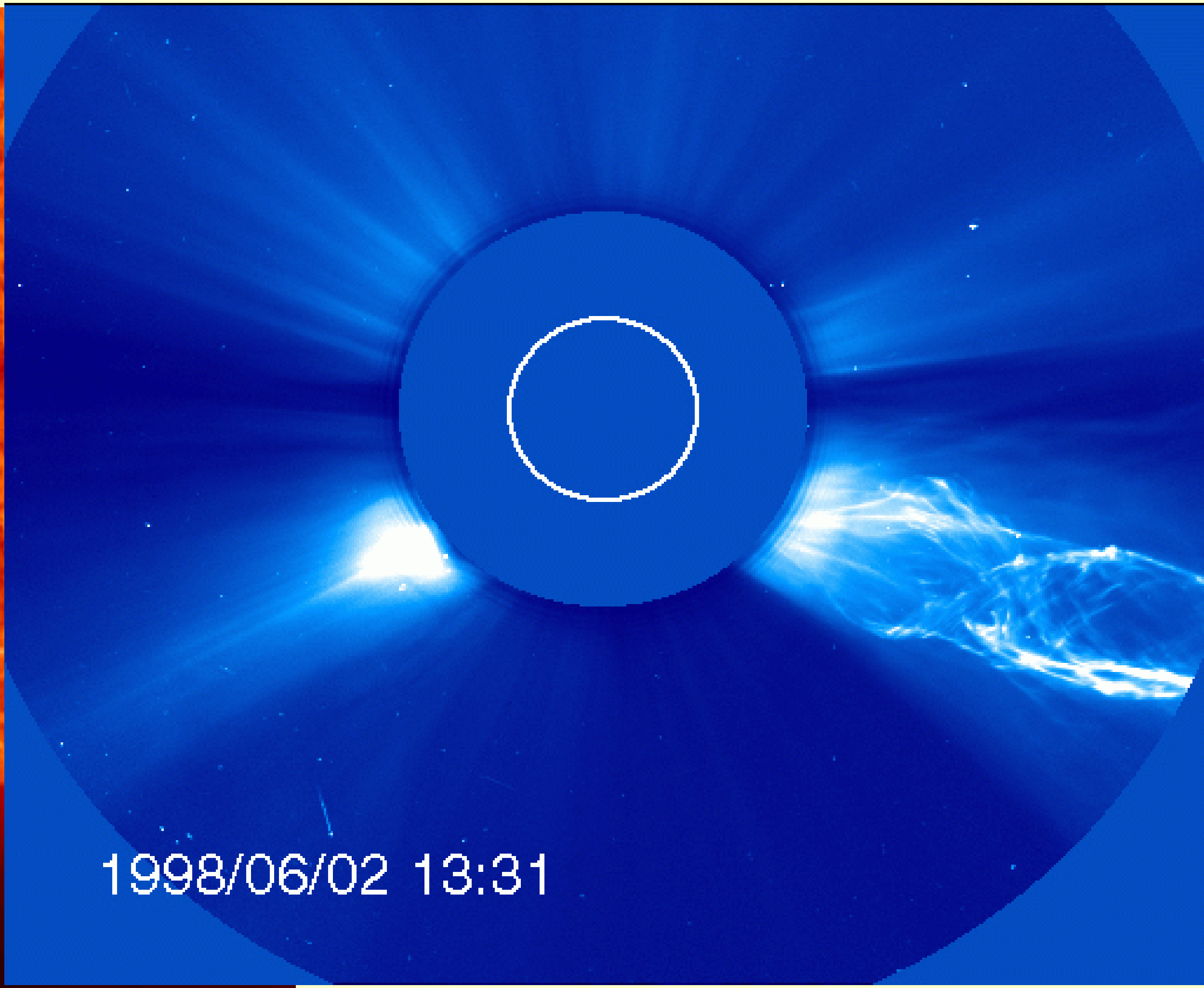
Transmission – the Solar Wind

Continuous, supersonic outflow from Sun, carrying magnetic field with it:

- Carries effects of solar eruptions out to the planets
- Structure changes significantly from emergence from corona to planetary distances
- Interaction between transients (mass ejections) and background wind is important
- Role of off-radial flow likely to be important

Solar storms





Solar wind observations

White-light measurements

- Intensity of scattered light   N
- Track large-scale features to estimate wind speed

Radio bursts

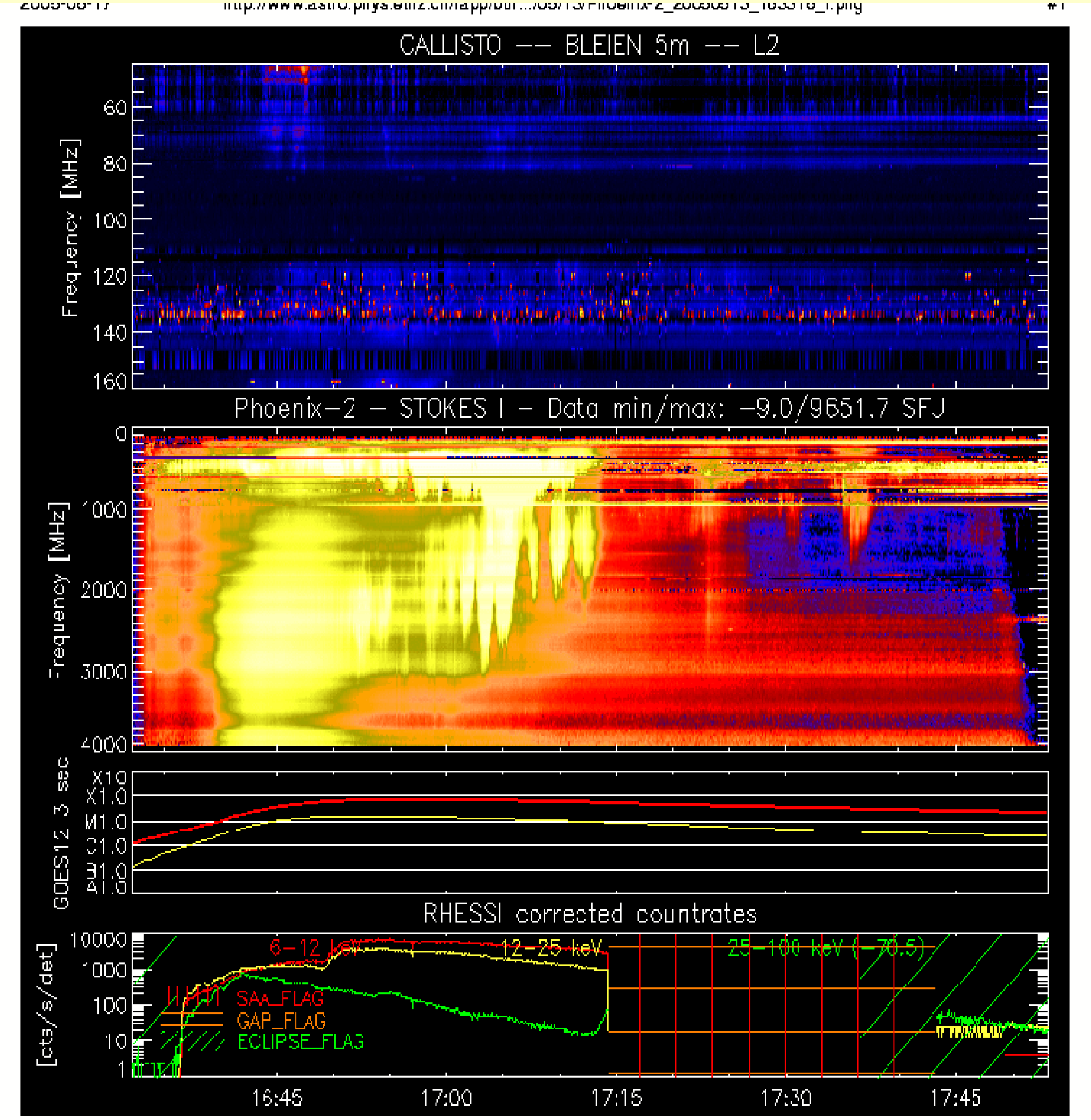
- Radio emission from particles accelerated on shock fronts
- Track shocks on stream interfaces
- Track shocks in CME/solar wind interaction

Interplanetary Scintillation (IPS)

- Variation in apparent intensity of distant radio source N^2
- Track (or cross-correlate) drift of scattering pattern to estimate wind speed

Radio bursts

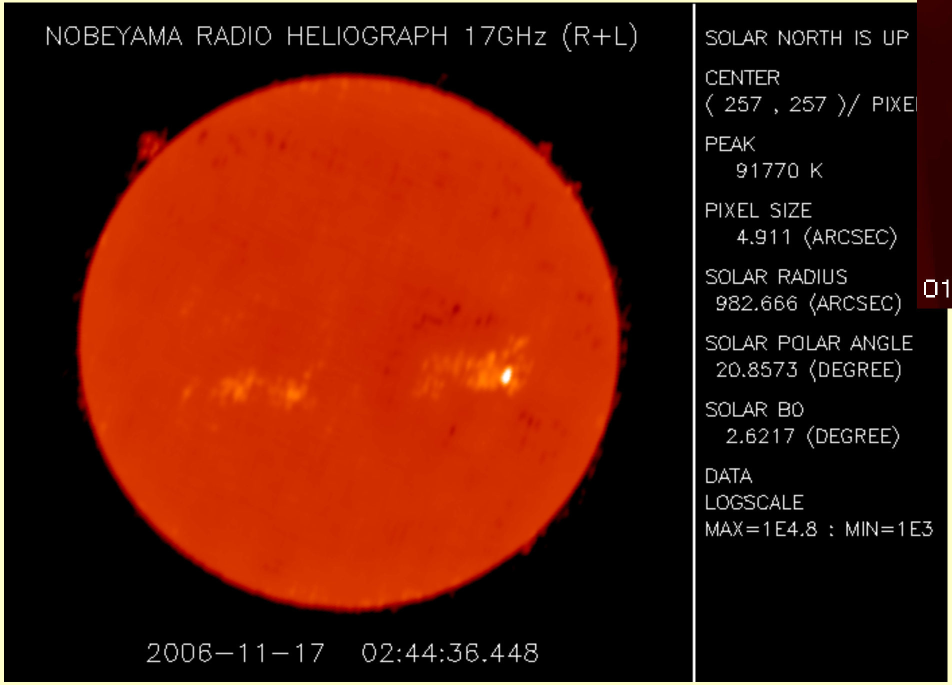
- Non-thermal radio bursts – driven by energetic electrons from the Sun
- Frequency of emission closely related to plasma frequency – so drops away with increasing distance from the Sun as electron density falls away
- Metric-wavelength emission close to Sun
- Kilometric emission by 1 AU
- Frequency/time plots of radio bursts provide information on velocity of source region
- Complex interplanetary type III bursts arise from electrons accelerated on CME-driven shocks



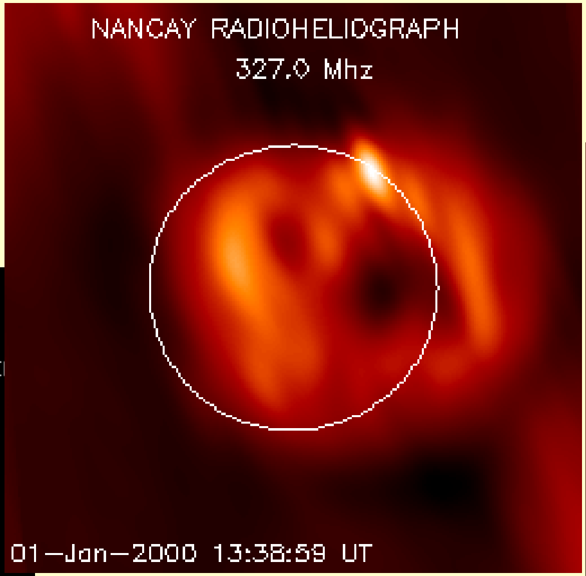
ETH Phoenix-2 radiospectrogram, 2005/05/12

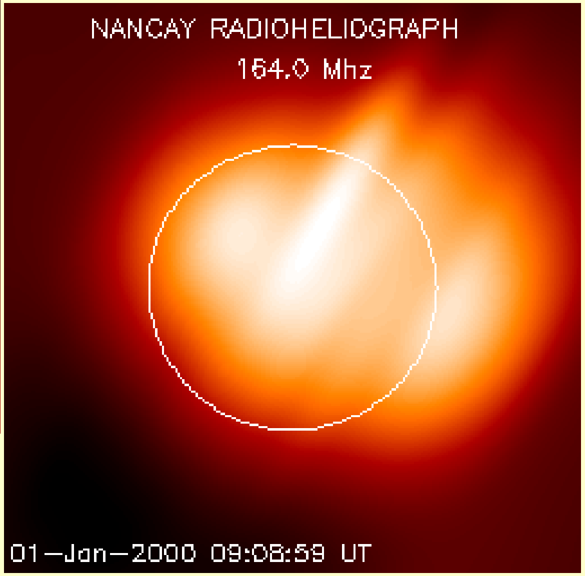
Imaging radio bursts

Given a sufficiently large telescope, can image structure of radio bursts

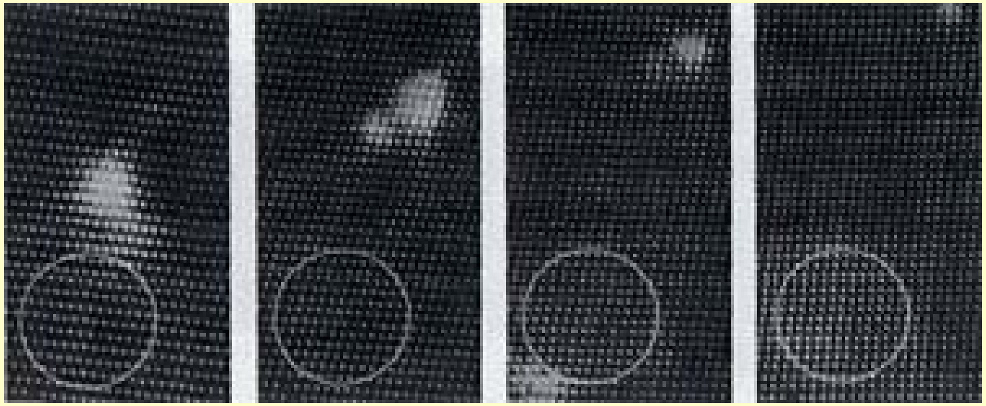


17 GHz radio emisson close to the Sun, Nobeyama radioheliograph





327 and 164 MHz radio images from the Nancay radioheliograph



Radio burst at 80 MHz, Culgoora radioheliograph

Ionospheric effects

- Upper atmosphere of Earth (above ~60 km) partially ionised by solar EUV

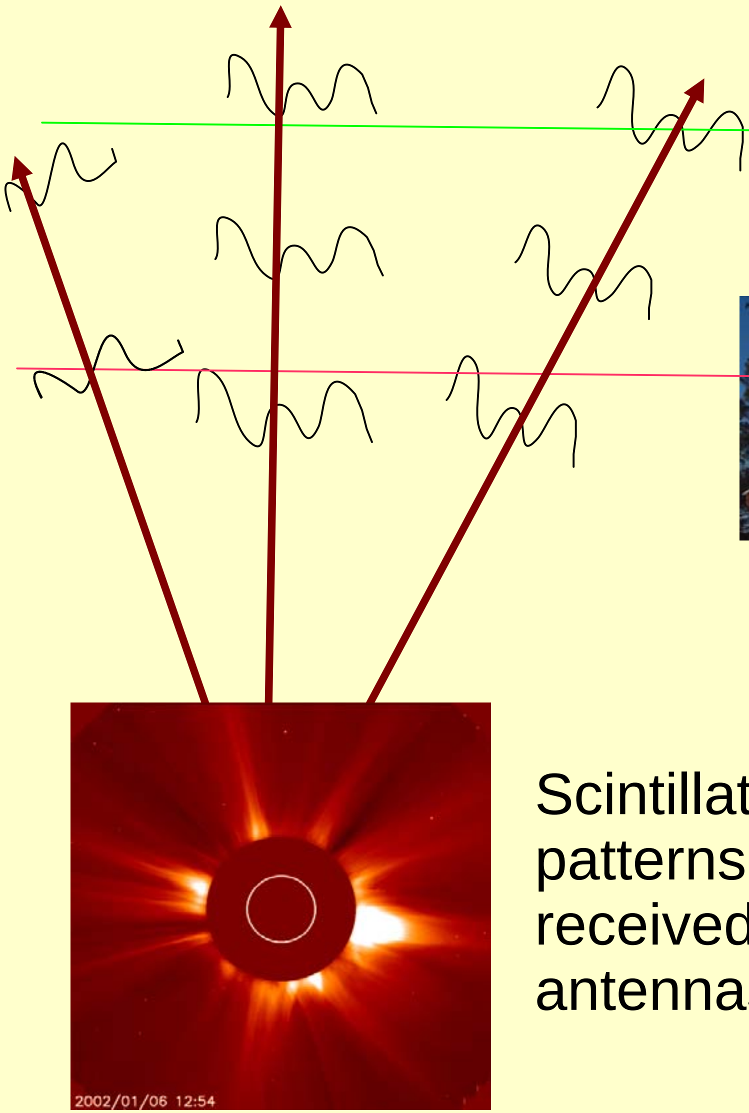
- Peak in ionospheric electron density at ~ 300-400 km
- At F2 peak, electron density ~ 10^{11} – 10^{12} m^{-3}
- => plasma frequency at F2 peak ~ 3-10 MHz

- Can't observe bursts with frequencies of less than a few MHz from the Earth
- Ground-based telescopes can only observe coronal radio bursts out to ~3 R_{Sun}

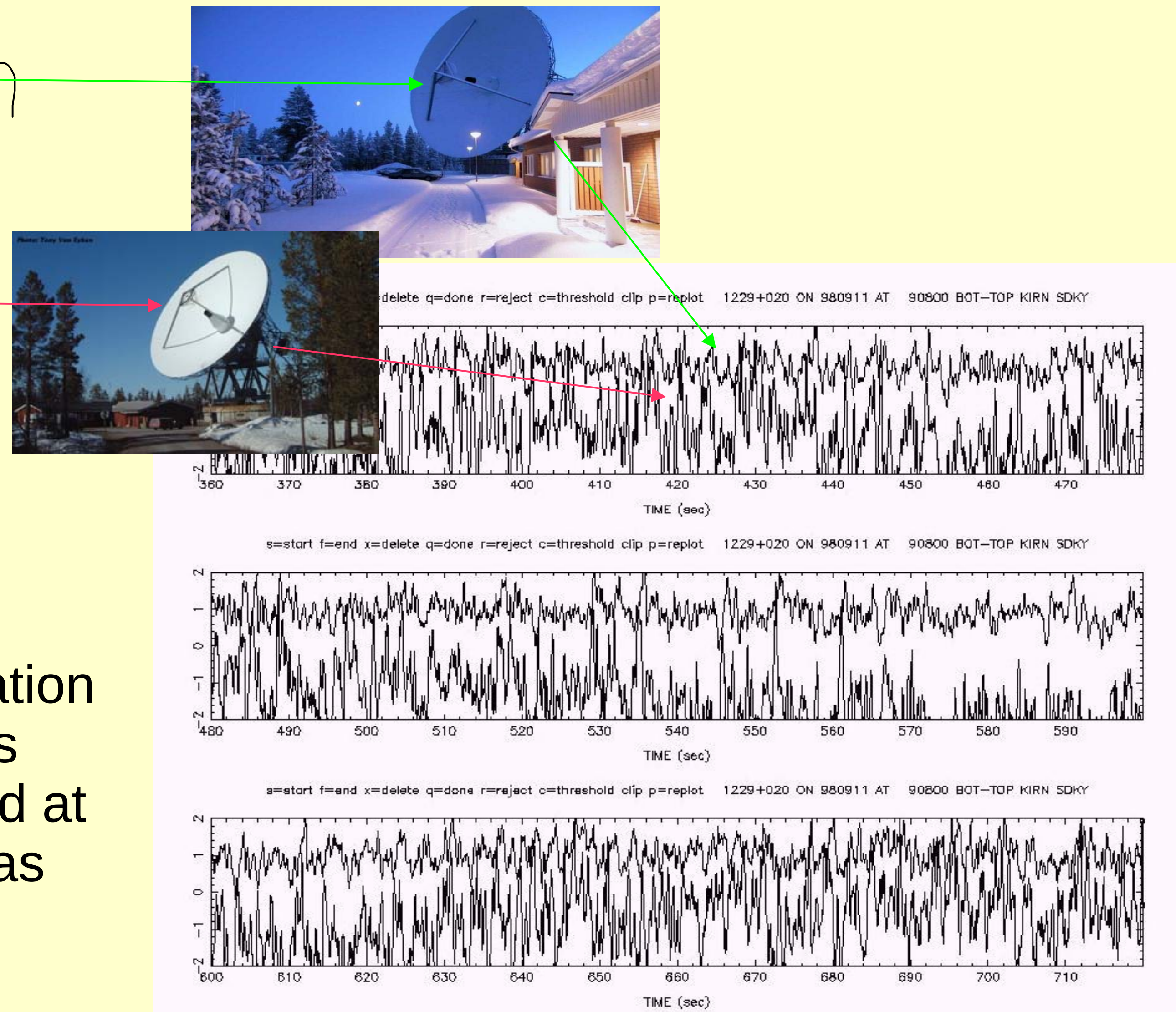
- Space-based instruments can track motion of bursts, but aren't large enough to image them

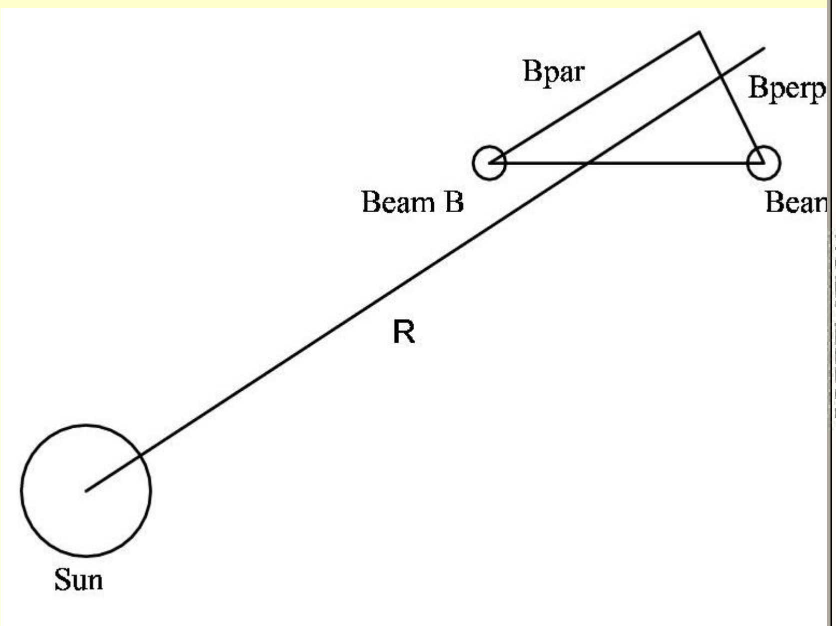
If we want to image interplanetary radio bursts, we must put a large telescope above the Earth's ionosphere

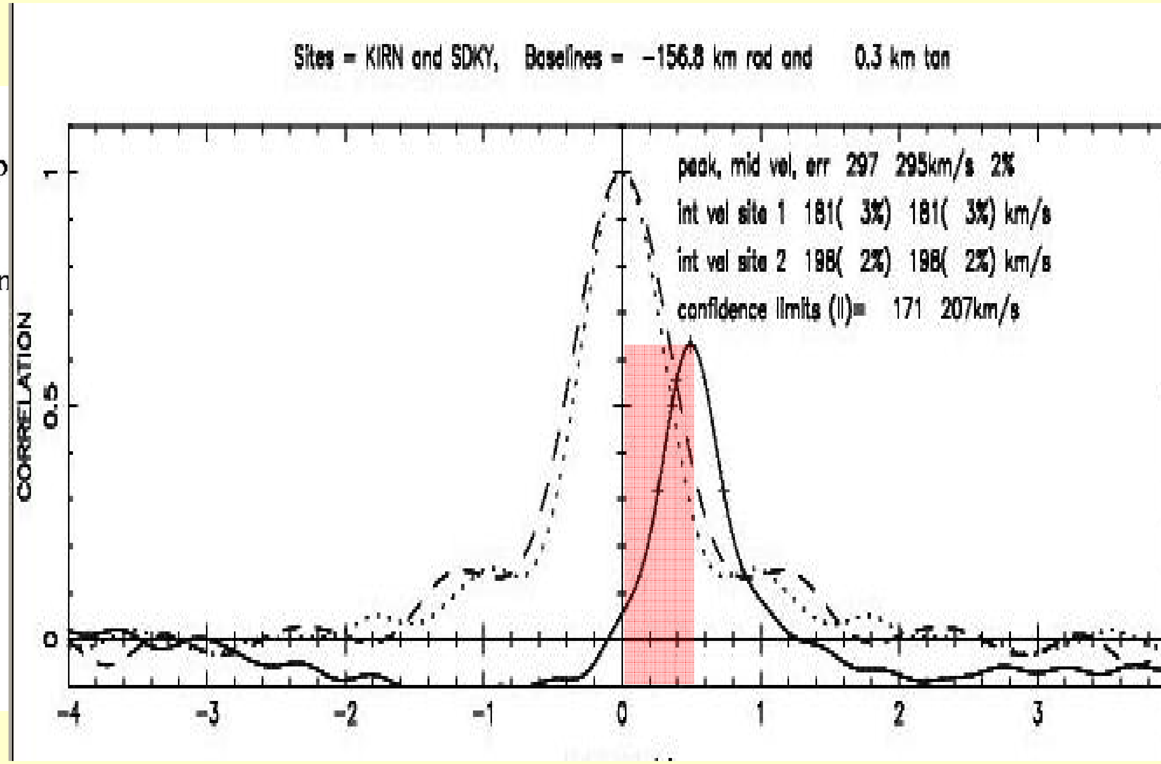
Interplanetary scintillation



Scintillation patterns received at antennas

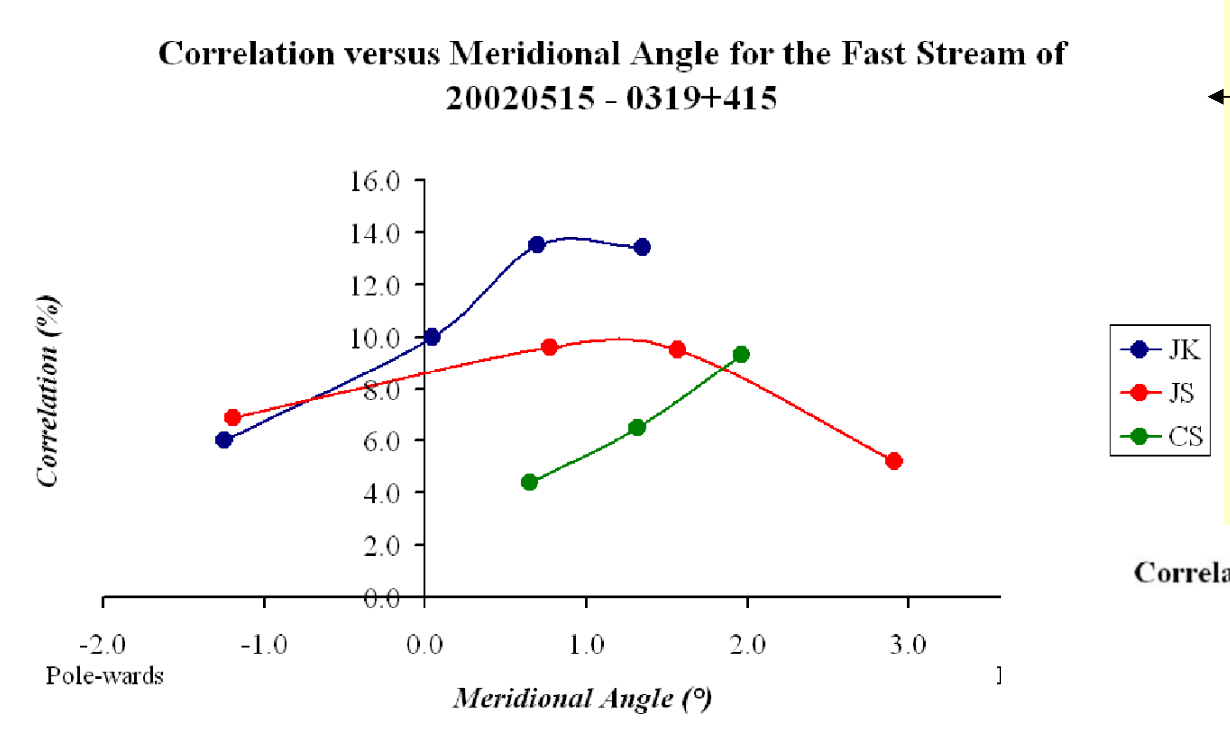






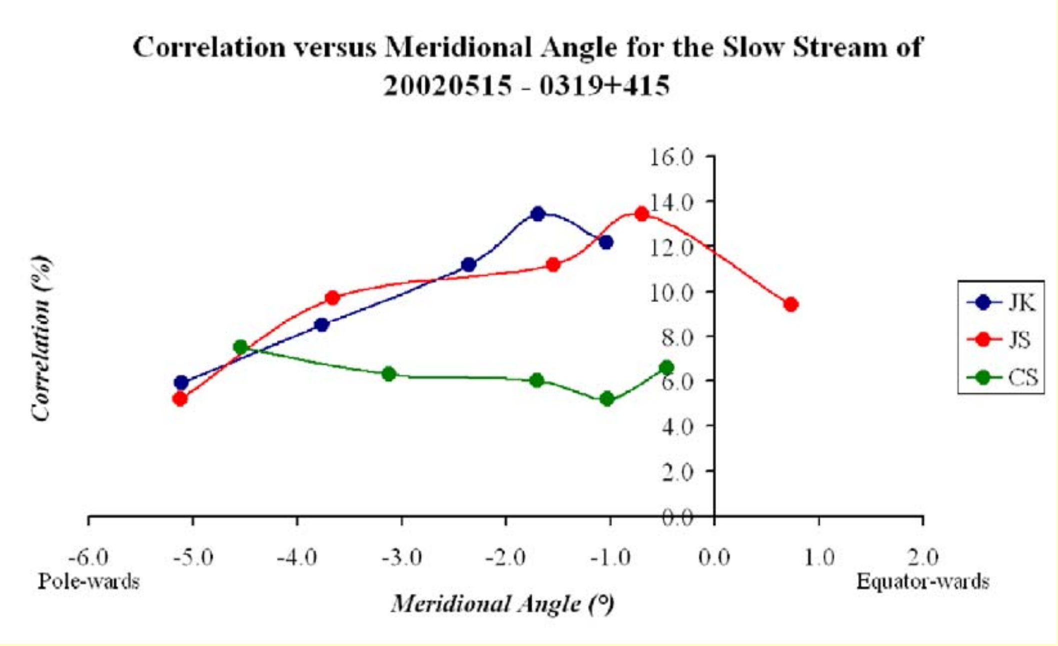
- Observe when separation of beams in plane of sky is close to radial direction – time-lag for maximum cross-correlation provides an estimate of solar wind outflow speed
- Maximum correlation occurs when separation of beams in plane of sky is parallel to projection of solar wind outflow in plane of sky

Fast and Slow Stream Directions

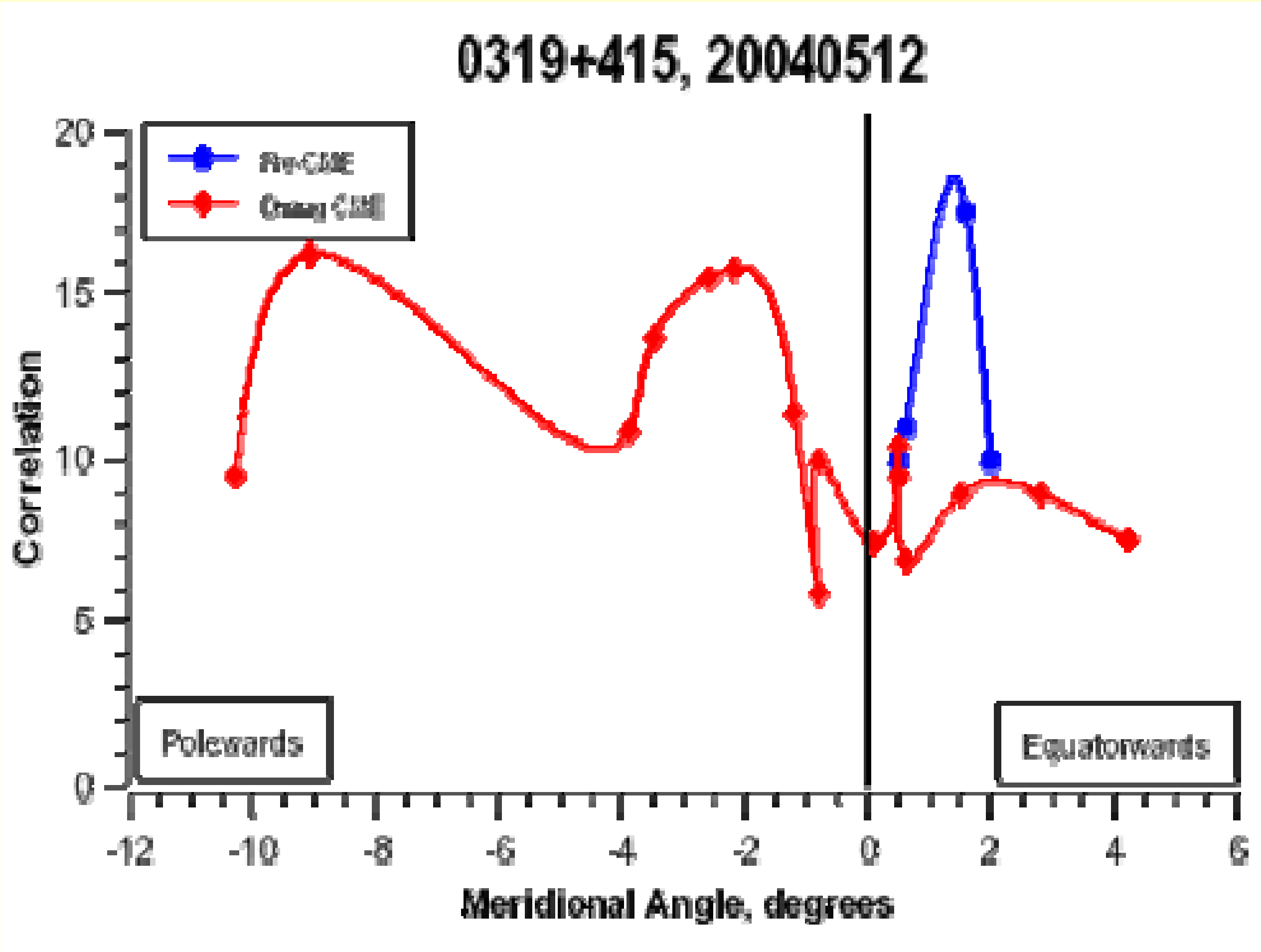


← Over-expansion of the fast wind

Effects of stream interaction or genuine expansion (resulting in a 'convergence layer' between fast and slow streams)? →



Dynamics of solar mass ejections



CME observations

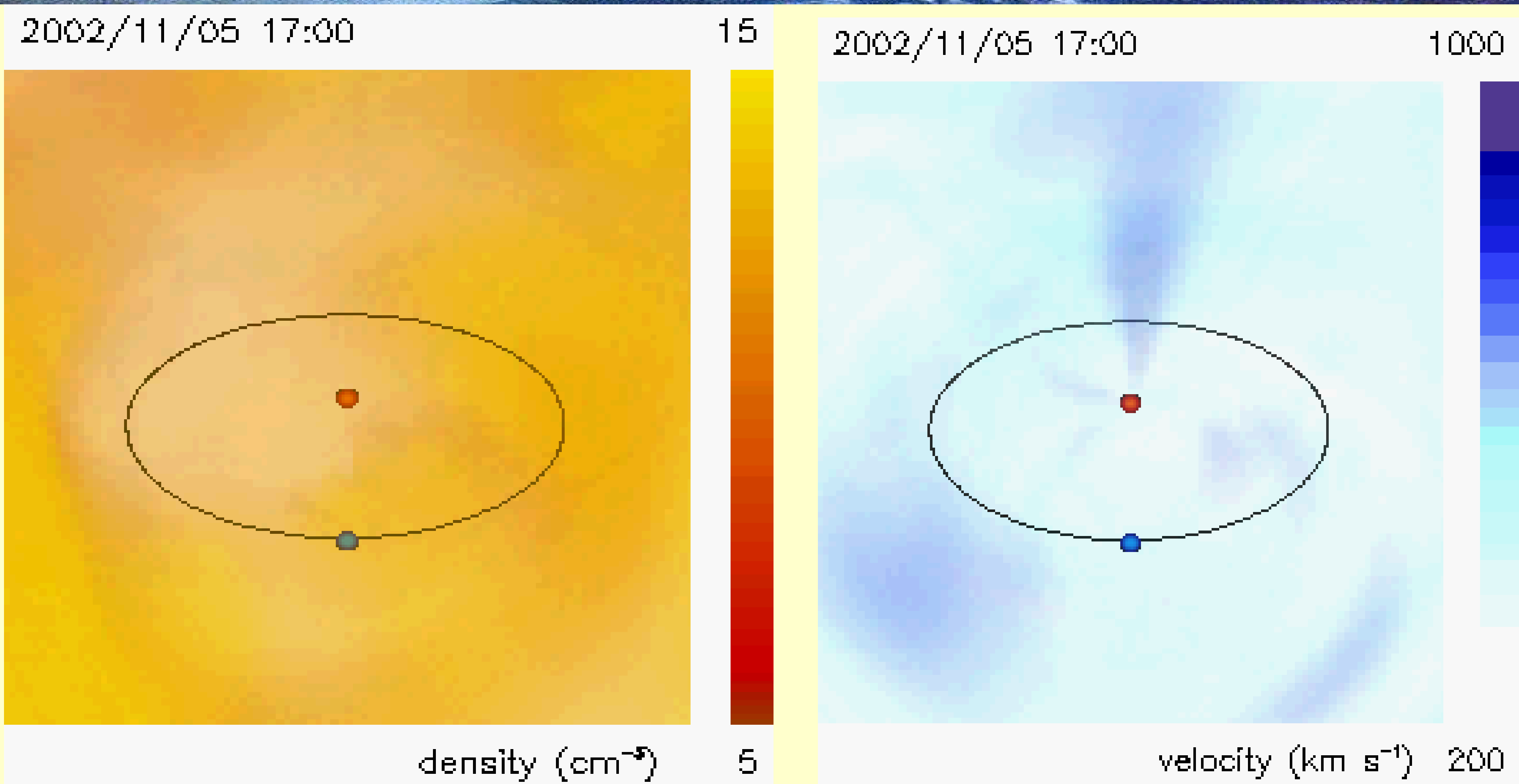
CMEs converge on speed of solar wind ahead of event

Features within CMEs interact (“self-cannibalise”)

Clear evidence of flow rotation in solar wind during CME passage

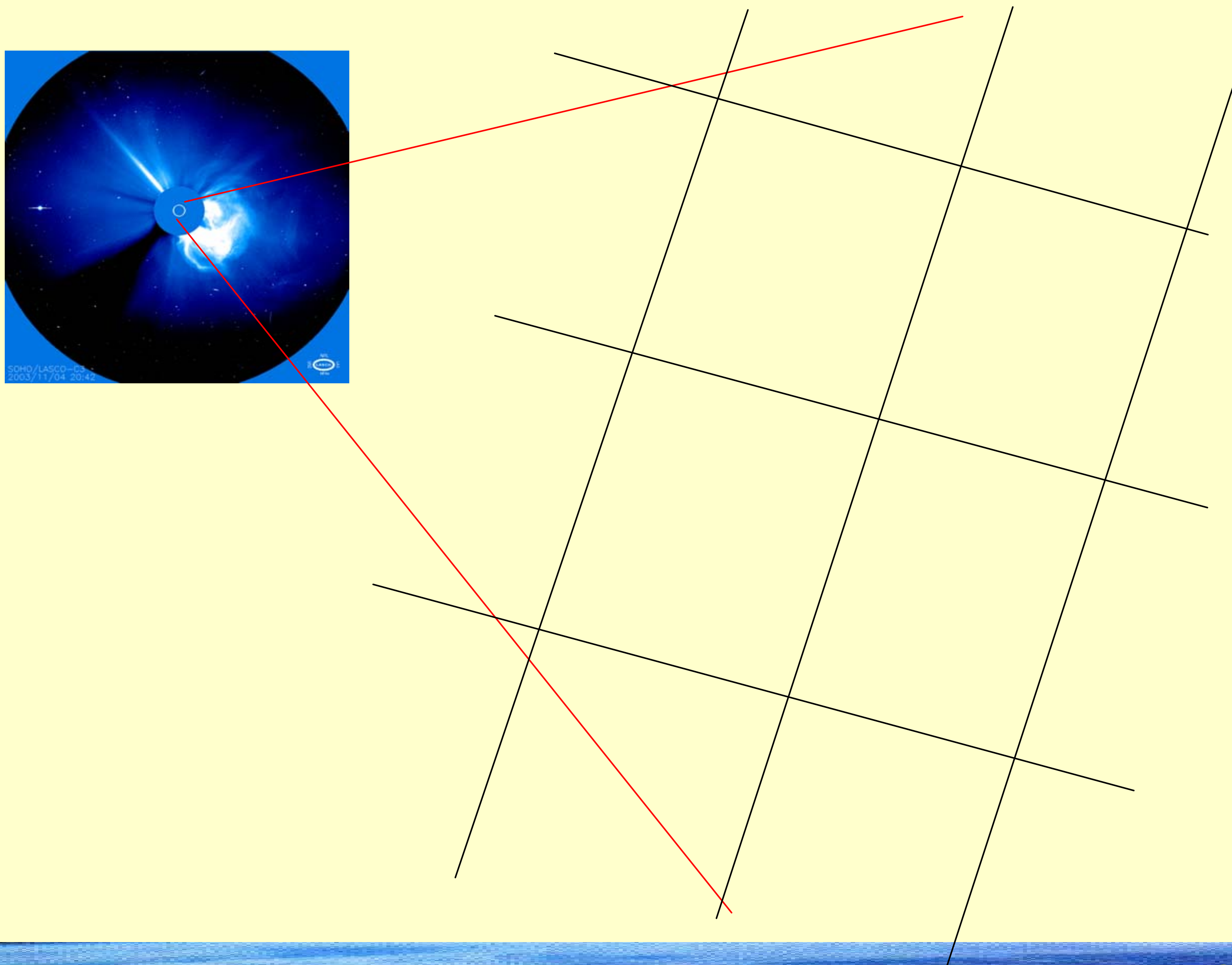
Bisi et al,, Proc. Solar Wind 11, 2005
Jones et al., JGR, 2006 (in press)
Breen et al., in prep. for GRL, 2006

Solar wind imaging



Solar wind density and velocity structure in November 2002, reconstructed by B.V. Jackson (San Diego) using U. Nagoya IPS data (M. Kojima and M. Tokumaru)

Imaging CME evolution



Need to be able to observe a large number of radio sources to image internal structure *(minimum of 4 across extent of CME to detect leading arcs, void/ejecta and asymmetries – more for details)*

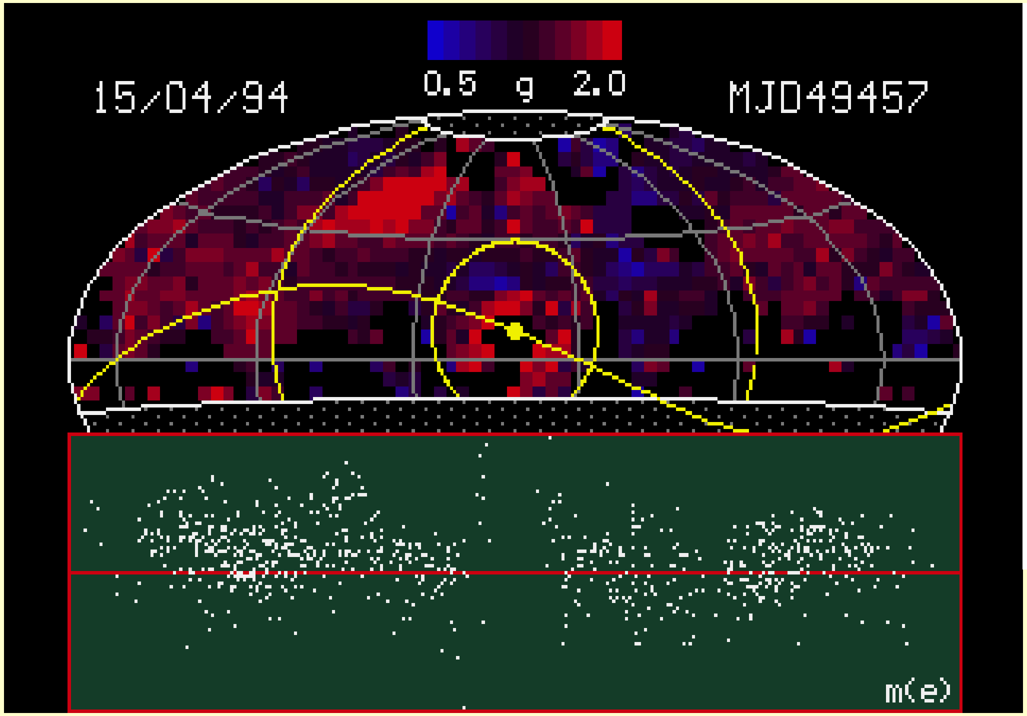
Need to use weak sources: LoFAR should be capable of this

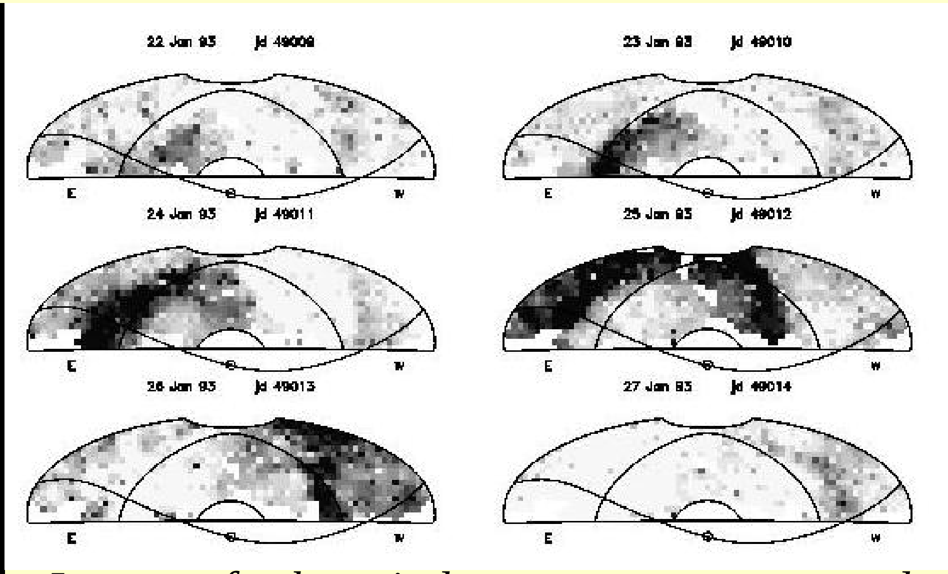
Imaging IPS - constraints

To image structure of solar wind – and CMEs – need to observe as many radio sources as possible

Most compact radio sources are brighter at lower frequencies

For “best” imaging, use a low-frequency system





Images of solar wind structure reconstructed from Cambridge 81.5 MHz IPS data by Graham Woan (Glasgow)

http://radio.astro.gla.ac.uk/ips/ips.htm

Ionospheric effects (again)

For IPS imaging, want to observe at lower frequencies

The ionosphere also contains irregularities which produce scintillation

- Effects of ionospheric scintillation are only noticeable under very disturbed conditions at ~ 1 GHz
- Severe ionospheric effects at < 100 MHz

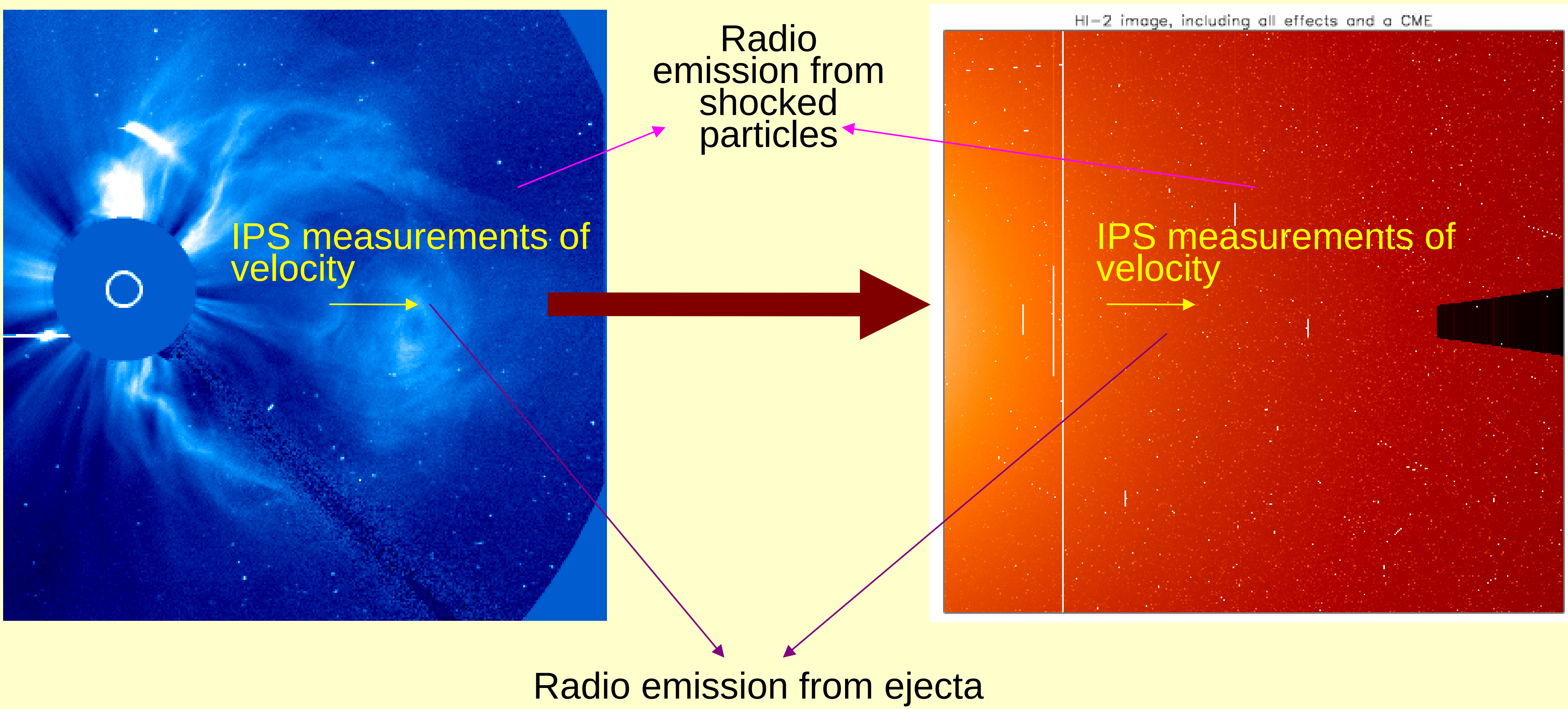
Very hard to compensate for ionospheric scintillation

Ideally, would like to observe from above the ionosphere

But

IPS requires large antennas which cannot be carried on spacecraft

Combined measurements



Combine white-light, radio burst and IPS images to compare motions of bulk density changes, shocks and plasma/waves

To the Moon...

- Ample space for large antennas
- Low radio noise
- No ionosphere
- Can observe radio bursts far from Sun
- IPS doesn't suffer from ionospheric scintillation
- Solar-terrestrial (and solar-planetary) studies would benefit strongly from a lunar observatory