Resolving CME Characteristics with Polarized White Light Data

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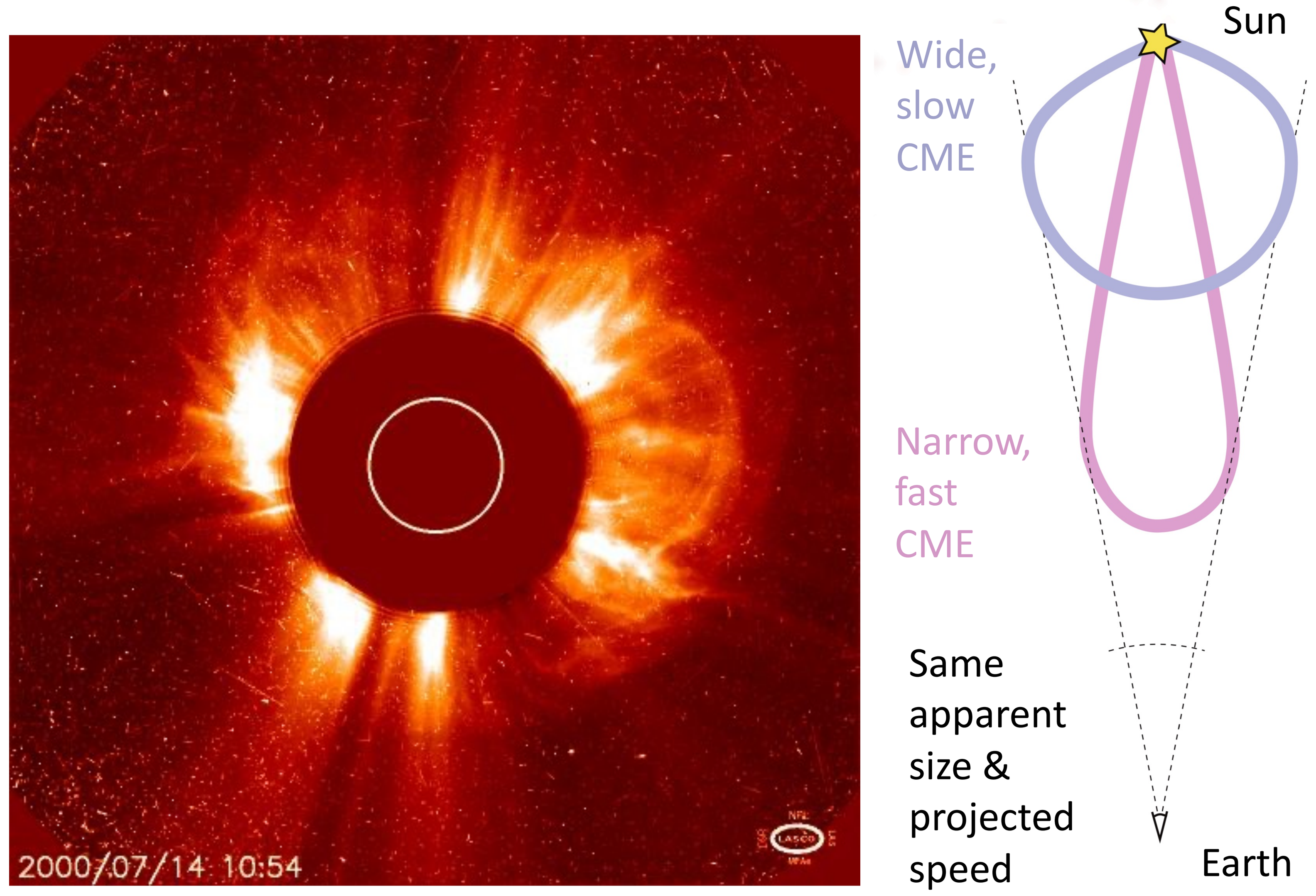
Forecasting CME arrival times is hard - but doesn't have to be!

Resolving the positional ambiguity in Earth-directed eruptions (Halo & partial halo CMEs) is a critical problem in forecasting CME arrival times that polarized light observations can resolve.

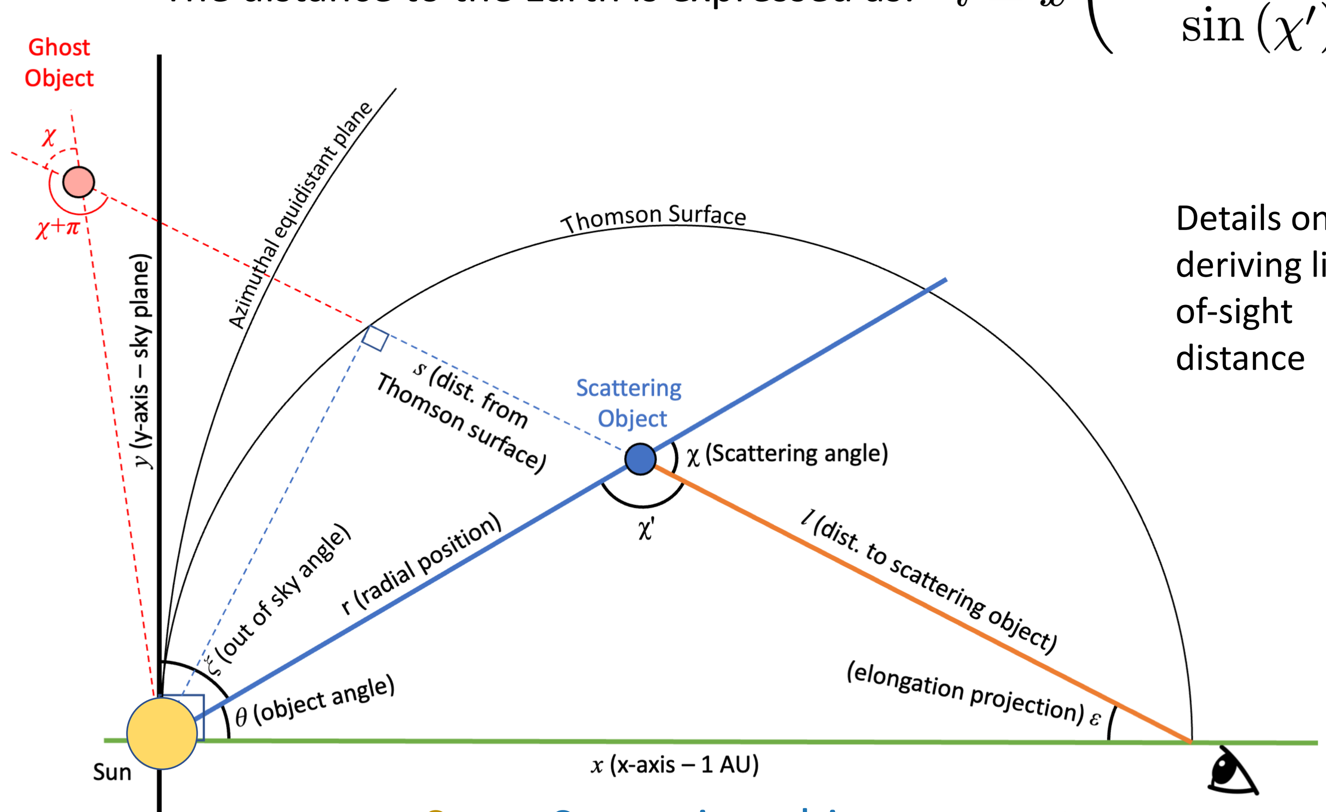


The *new* PUNCH coronal and heliospheric imagers measure polarized visible light, which reveals the 3D location of features in the corona and solar wind for improved forecasting.

Polarization reveals 3D structure via scattering angle

Polarization reveals the position of features that scatter light (l; orange line) along the line of sight. Projecting the feature onto the sky plane (y) at small angles, and the azimuthal-equidistant plane further out. The ratio of polarized (pB) and total brightness (B) in map projections, $p = pB/B$, and the *polarization ratio*, $PR = (1-p)/(1+p)$, directly yield the scattering angle of a feature via a simple expression: $\chi = \cos^{-1}(\pm\sqrt{PR})$. From here, it's possible to compute the 3D position of features using the geometry and expression below.

The distance to the Earth is expressed as: $l = x\left(\frac{\sin(\pi/2 - \xi)}{\sin(\chi')}\right)$



Sun – Scattering object geometry.

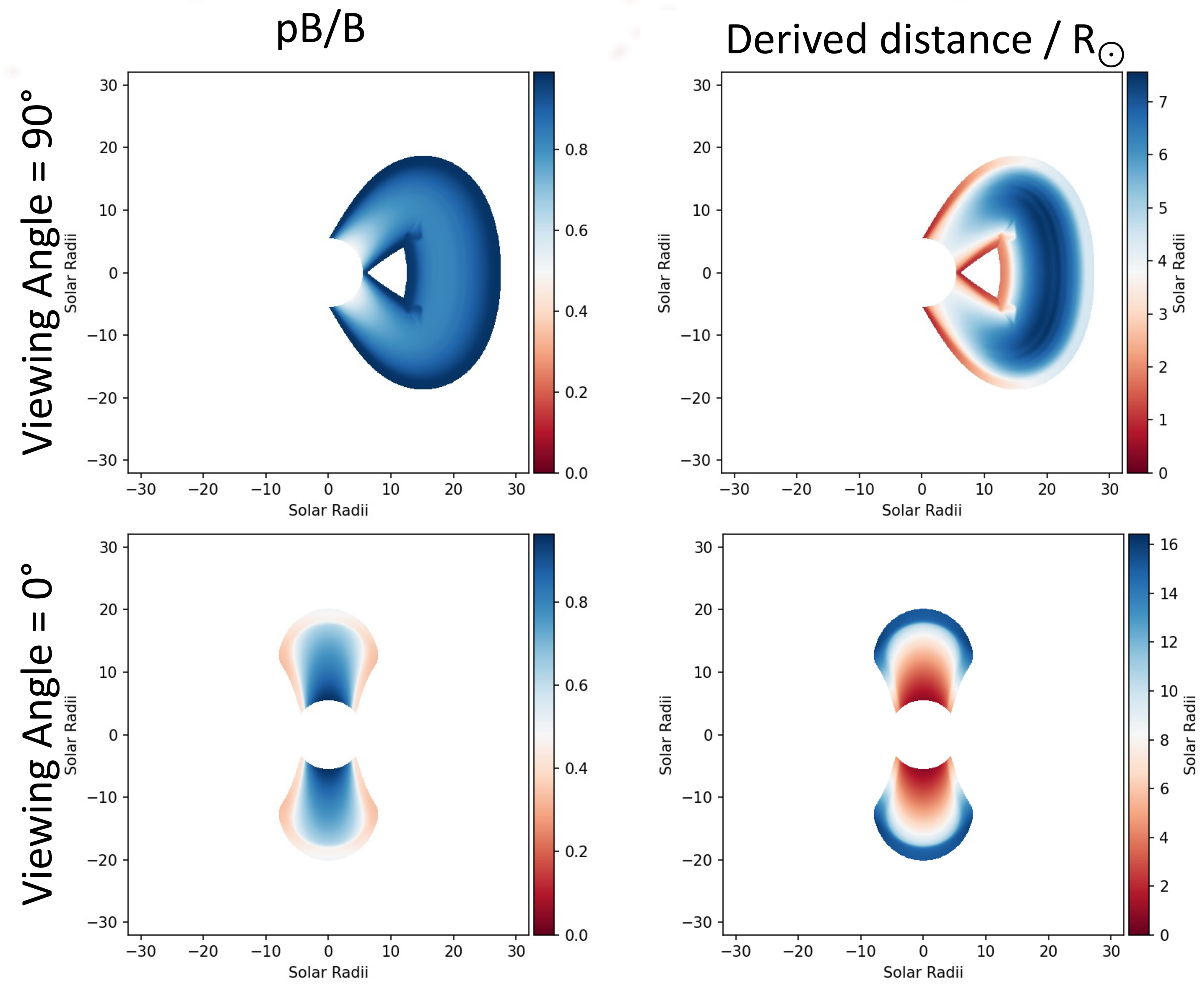
Details on deriving line-of-sight distance

PUNCH leverages ***solpolpy***, a new Python package for analysis of heliophysics polarization observations. The package resolves degree of polarization and includes tools for 3D analysis. ***solpolpy*** is publicly available via github

Details on solpolpy

Forward modeling demonstrates the technique

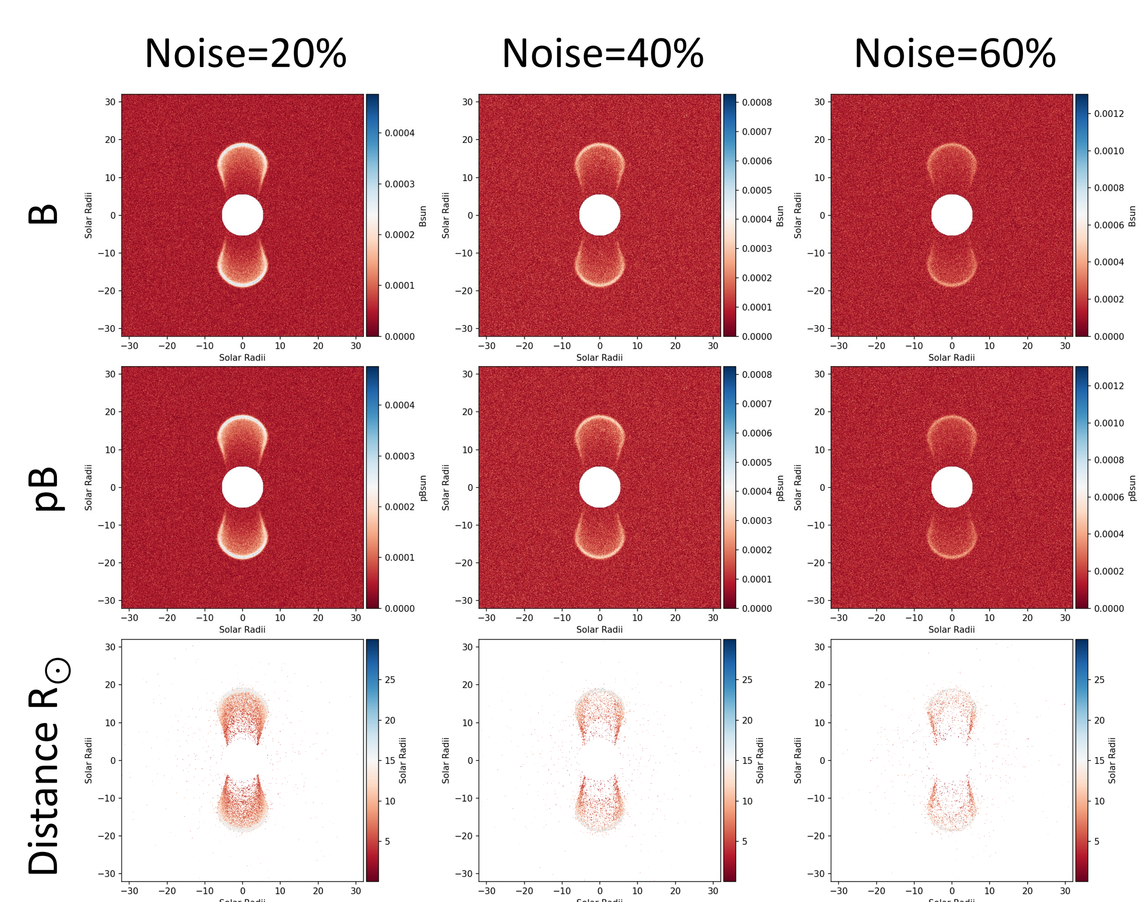
Simulated brightness (B) and polarized brightness (pB) using the ***FORWARD*** code and a croissant model CME, with a leading edge at 20 $R_\odot$, yield accurate line-of-sight positions for the CME. The **top row** shows the CME in the plane-of-the-sky; the **bottom row** along the line-of-sight (traveling towards the observer). The calculation gives the line-of-sight average distance; due to the concentration of mass in the CME legs, the derived distance near the Sun is lower than the leading edge (**bottom right**).

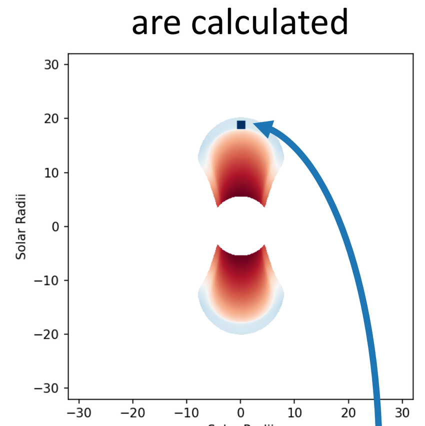


Details on FORWARD

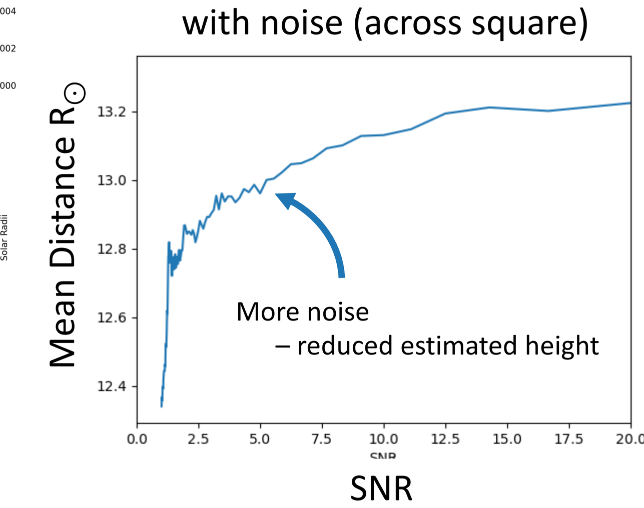
Successful reconstructions with noisy data

Realistic signal noise is not a barrier to accurate distance measurements. We reduce the the signal-to-noise ratio (**top two rows, left**) and repeat the distance determination calculation **(bottom row, left).** Distance determinations yield accurate results even for very poor SNR ratio **(bottom row, right)** proving the technique will work even for the faintest events.



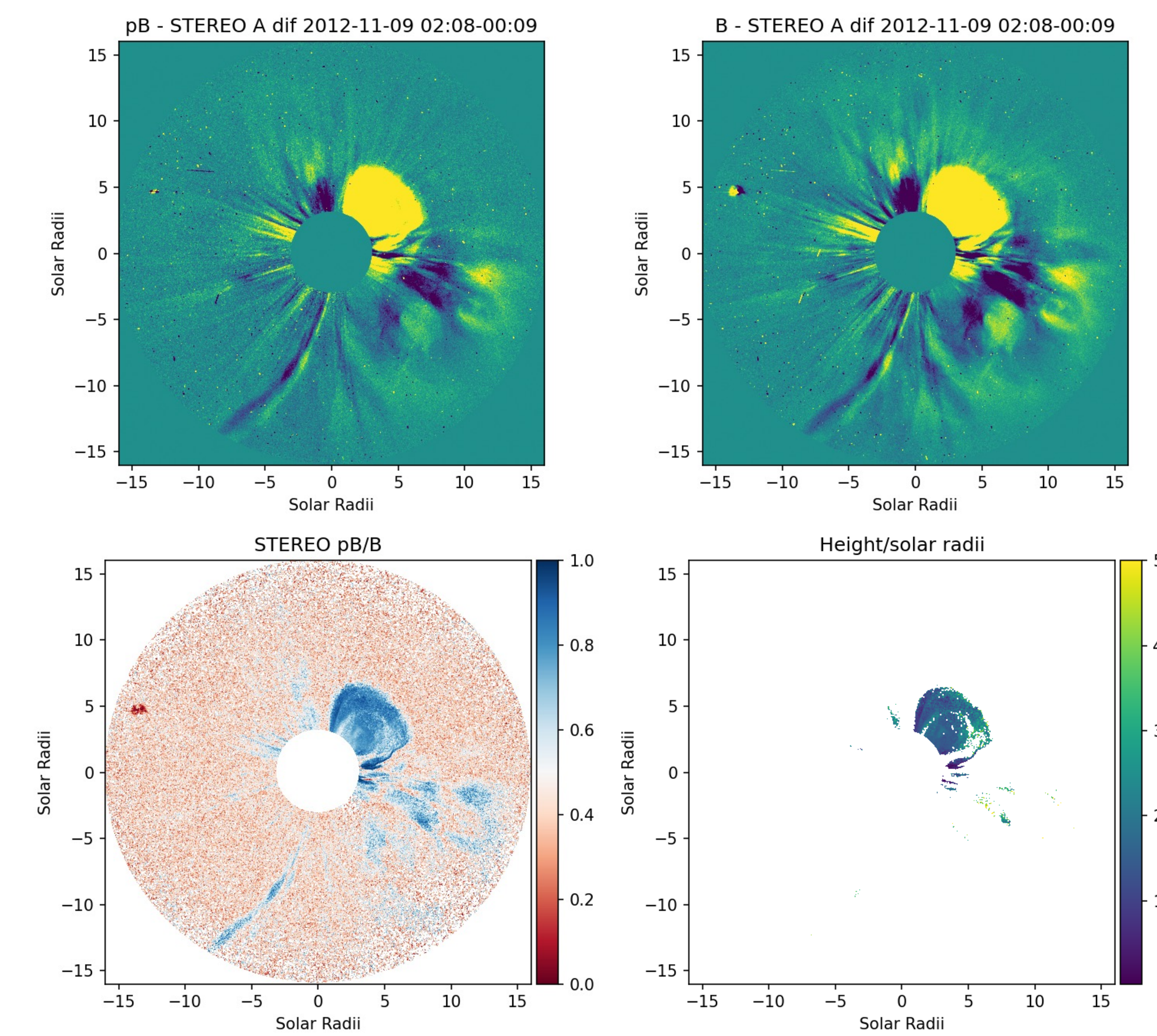


Details on the noise

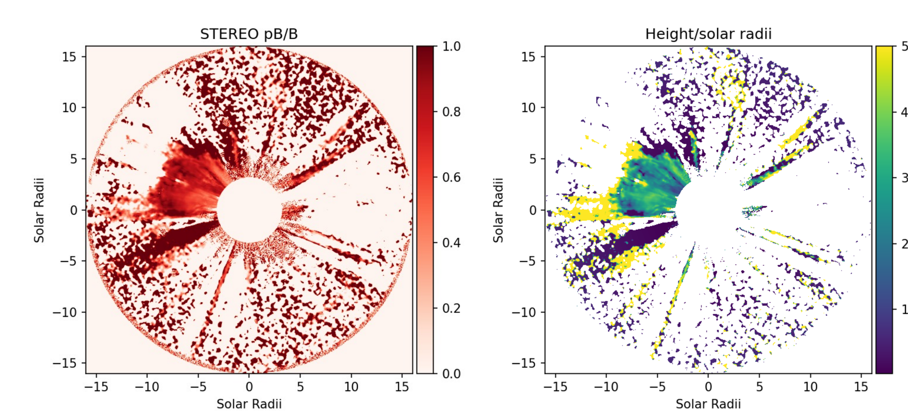


Real-world demonstrations using STEREO data

A real-world demonstration of ***solpolpy*** and the distance mapping tool used STEREO polarized brightness observations from 2012-Nov-09: The STEREO polarized brightness triplet is resolved into pB (**top left**) and B (**top right**) using ***solpolpy***, The ratio (**bottom left**) yields a derived height map (**bottom right**) with distances appropriately ranging between 2 and 5 $R_\odot$.



Details on CME chirality derivation



A second test using high SNR data from 2010-Apr-03: DeForest et al. (2017) demonstrated how these observations can be used to determine the chirality of the structure, using a similar approach to the distance-determination described here.

PUNCH will provide near-real-time line-of-sight CME kinematic measurements

The ***solpolpy*** polarization analysis toolkit will provide everything required to compute distances of solar and heliospheric features in real and synthetic polarization observations. The resolver accurately reconstructs line-of-sight distances of structures, resolving important ambiguities to improve CME model fits and arrival-time forecasts.

Using successive measurements will provide accurate estimates of line-of-sight velocities; **when used with PUNCH observables, the resolver will provide a powerful, real-time, eruption arrival diagnostic.** Advanced processing with similar techniques also reveals the chirality of CMEs. For future instrument concepts and further details on the technique see Poster: *SwSCOR: Space Weather Solar Coronagraph* by DeForest et al.

Image noise has a limited impact the reconstruction. PUNCH's high-SNR observations, coupled with powerful techniques like noise gating, will yield high-fidelity distance measurements.

Details on PUNCH