AWARE: an algorithm for the automated characterization of EUV waves in the solar atmosphere

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Introduction

Extreme ultraviolet (EUV) waves are large-scale propagating disturbances observed in the solar corona, frequently associated with coronal mass ejections and flares (Thompson et al., 1999, Thompson & Myers 2009). They appear as faint, extended structures propagating from a source region across the structured solar corona, making them difficult to isolate and measure. To further the understanding of EUV waves, we have constructed the Automated Wave Analysis and REduction (AWARE) algorithm for the measurement of EUV waves (Ireland et al, submitted). AWARE is implemented using the *persistence transform*, simple *image processing operations* and the *RANSAC algorithm.*

Algorithm

Stage 1: image processing

An input datacube (a time-ordered stack of 2d images) is transformed first by applying the **persistence transform** $P(t)$ (Figure 1); then the running difference is calculated to find the RDP images. An RDP image efficiently isolates propagating features that brighten successive pixels along the direction of travel (Thompson & Young 2016). Figure 2 shows RDP images compared to running difference (RD, used in NEMO, Podladchikova & Berghmans 2005), percentage base difference (PBD, used in CorPITA, Long et al. 2014) and percentage running difference (PRD, used in Solar Demon, Kraaikamp & Verbeeck 2015) images for three different EUV waves seen in AIA 211Å data.

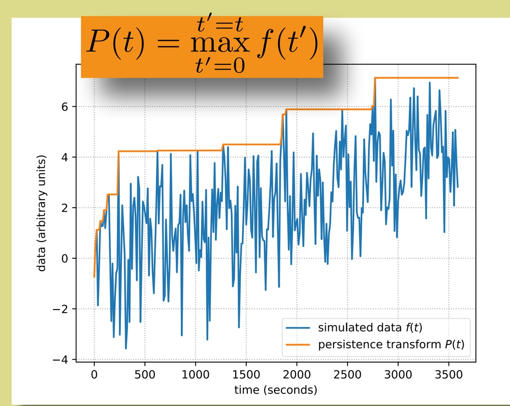


Figure 1: demonstration of the persistence transform

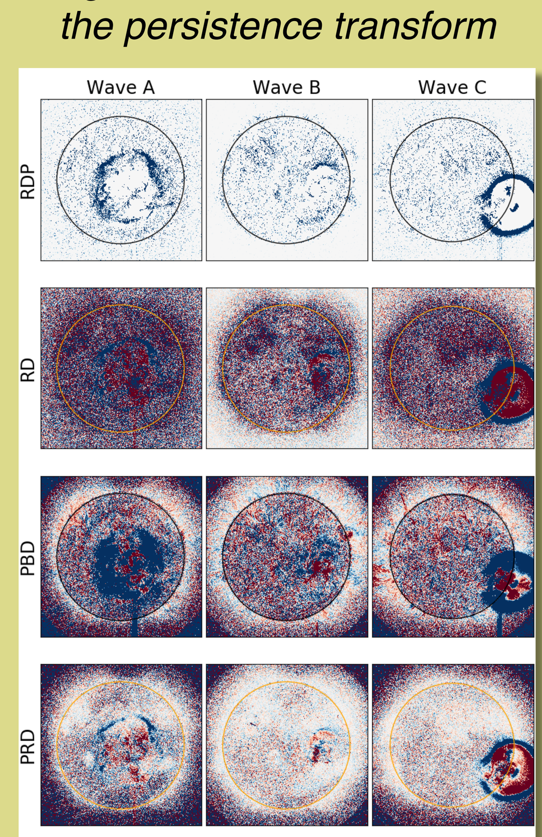


Figure 2: comparison of differencing schemes for AIA 211Å data for three different EUV waves.

The resulting RDP images are then cleaned using a **median filter** (to remove noise) and a **morphological closing** (to fill in small gaps in the wavefront) isolating the location of the EUV wave - see Figure 3.

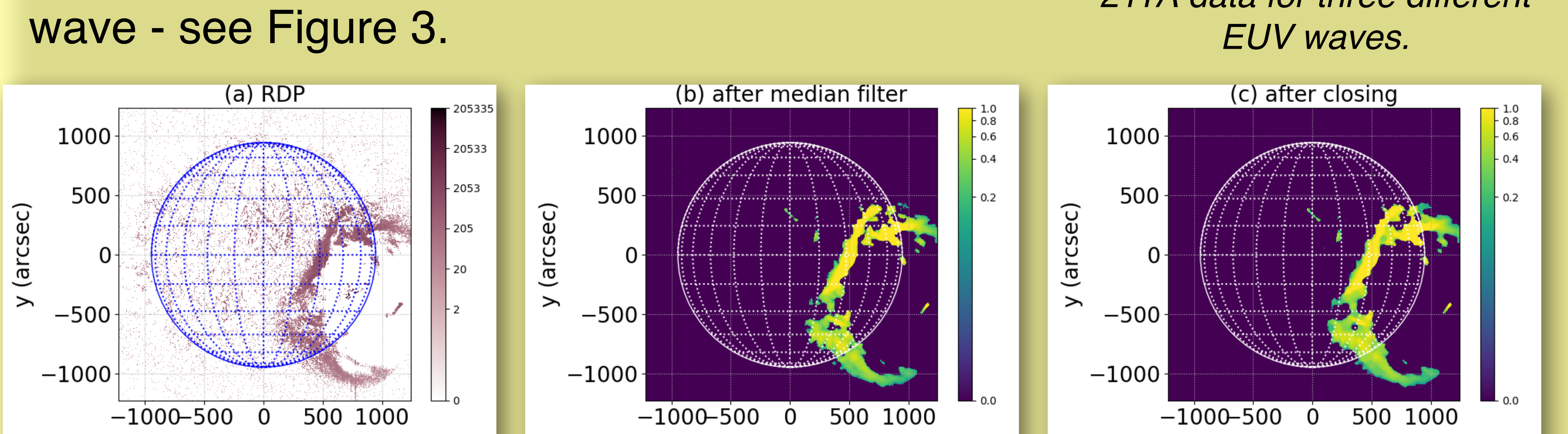


Figure 3: (a) raw RDP image, (b) image after median filter, (c) image after morphological closing operation. The median filter and closing operator have the same size.

Stage 2: dynamics

1. Binary masks are created from the isolated wavefronts (Fig. 3c) and applied to RDP images to find emission due to EUV wave at all times (Fig. 4a).
2. Great arcs are drawn from wave initiation point and wave position and error along great arc measured.
3. **RANSAC** algorithm is used to determine which positions are fit (Fig 4b, g) with the wave progress model $\text{wave progress}(t) = s_0 + v_{fit}t + a_{fit}t^2/2$.
4. Fit model to measured wave positions (via χ^2 minimization) to find a velocity v_{fit} and acceleration a_{fit} for each arc (Fig. 4e, f, 5).

Example: 7 June 2011

All AIA 211Å data in the hour following the flare initiation time 06:16 UT were downloaded and summed in space (8x8) and time (x2) and then fed in to AWARE. Figure 4 summarizes the results. A modified CorPITA score (Figure 4c, 5b, c; Long et al. 2014) is used to assess fit quality.

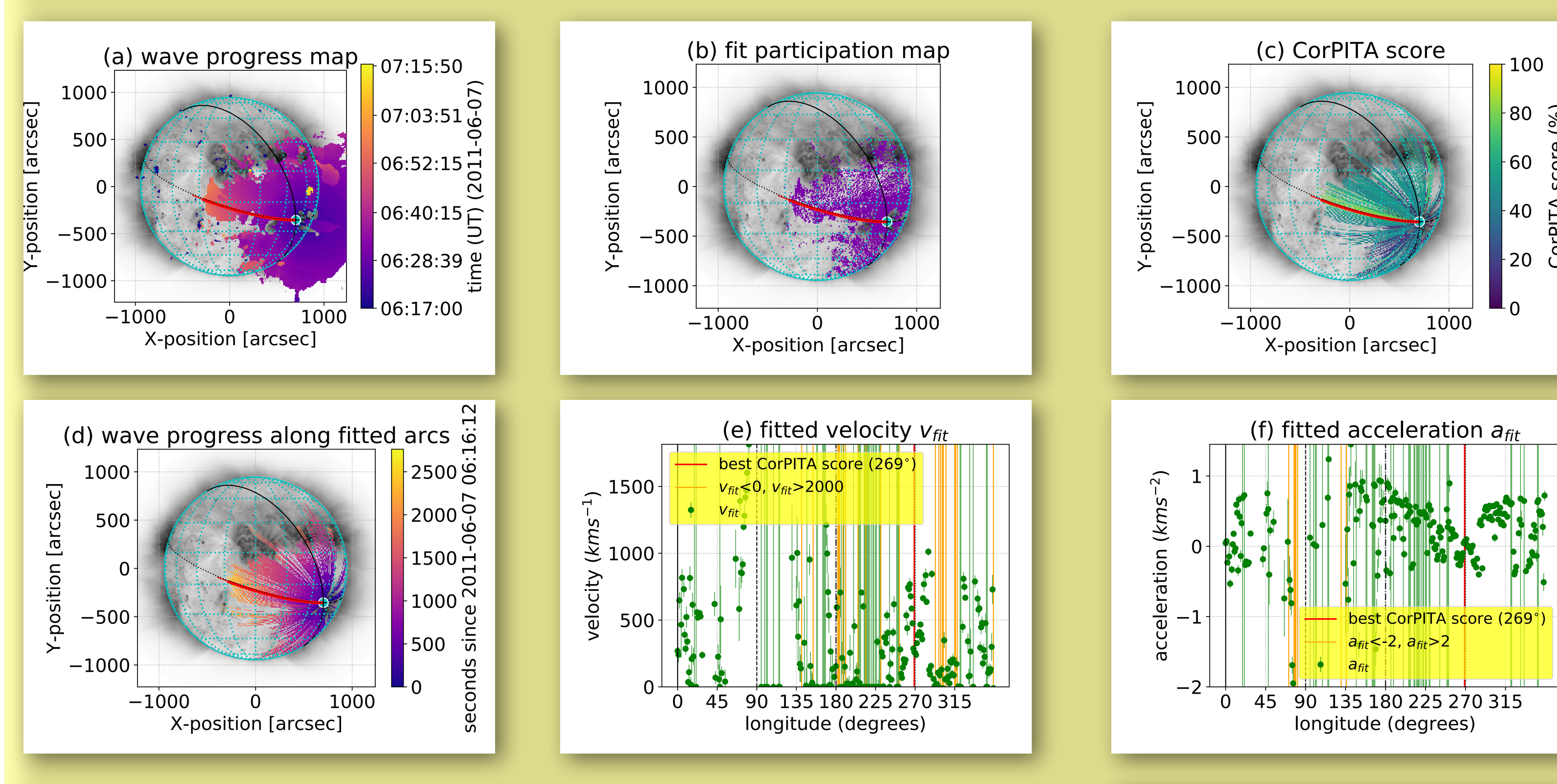
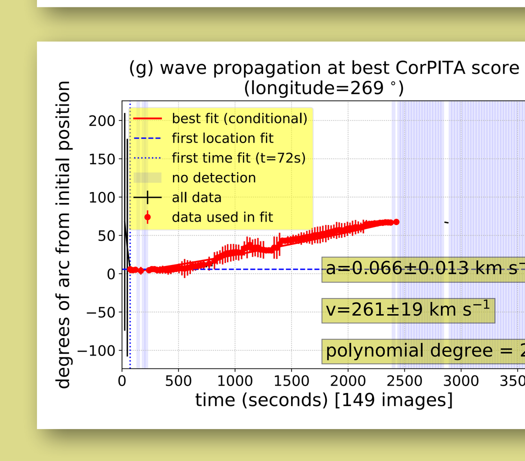
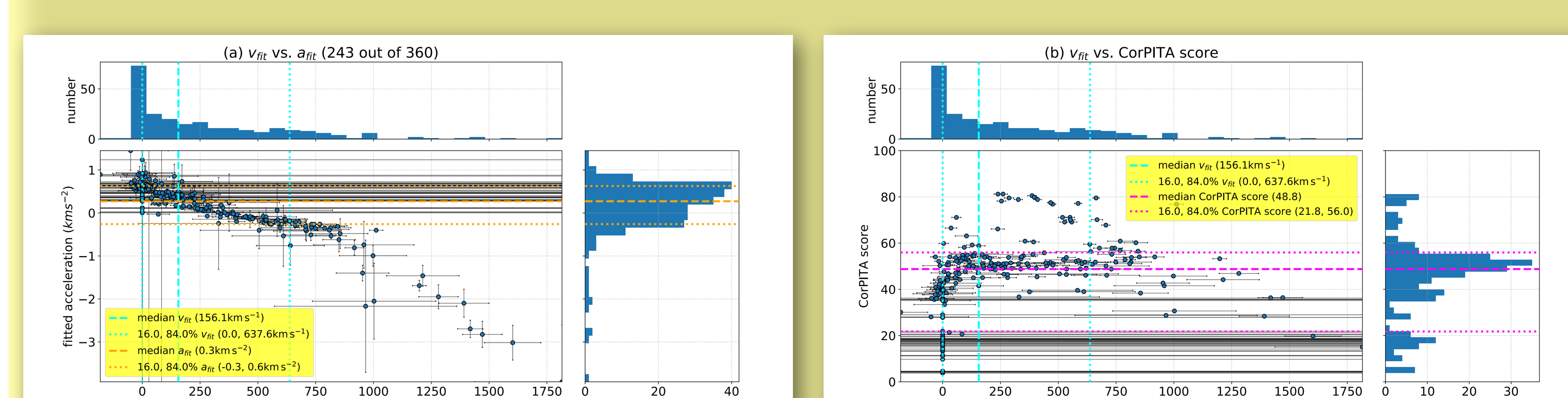


Figure 4: summaries of the detection and the dynamics: (a) wave progress map, (b) pixels used in fitting, (c) CorPITA score along each arc, (d) wave progress as fit, (e) initial velocity found v_{fit}, (f) fitted acceleration a_{fit}, (g) detail of wave propagation along the arc with the highest CorPITA score. The red line in plots (a-d) indicate the location of the arc with the best CorPITA score.



Further detail of the dynamics and fit quality are given below in Figure 5. Plot (a) demonstrates a v_{fit} - a_{fit} correlation that can be explained by the minimization used to fit the data.



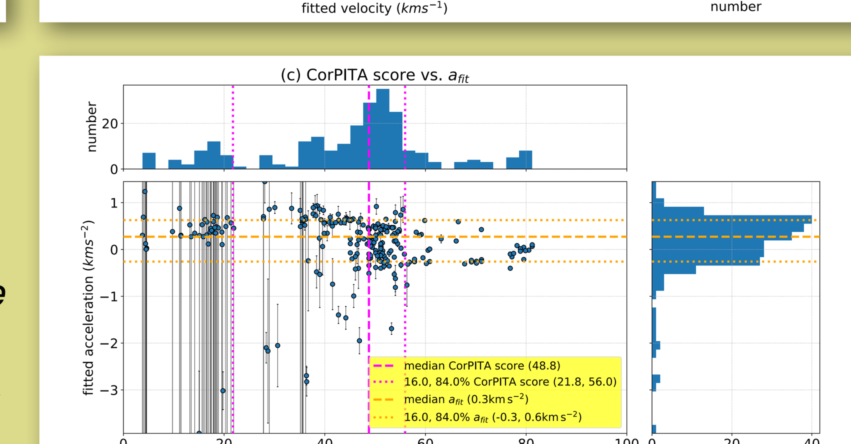


Figure 5: plot (a) shows v_{fit} versus a_{fit} for all the arcs fit with standard error bars; of the 360 arcs for which a fit was attempted 243 successful fits were obtained. Also shown are histograms of the values of each quantity. Plots (b) and (c) show the distribution of v_{fit} and a_{fit} with CorPITA score.

Conclusions

The persistence transform isolates propagating features that brighten successive pixels. The separation of the algorithm in to two distinct stages permits the further development of each independently. Use of the RANSAC algorithm automates the means of finding the duration of the wavefront along each arc given sufficient data. A fully automatic EUV wave detection and characterization facility (similar to part of the operational Solar Demon) is possible using large flare events as initiation points and times.

Ireland et al., submitted to Solar Physics
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