Spectroscopic Observations of a Solar CME event and Simulations and Spectral Synthesis of Stellar CMEs

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Abstract

Coronal mass ejections (CMEs) on the hosting stars are considered to be one of the decisive factors that affect the habitability of its orbiting planets. The propagation direction and true velocity of a CME are among the most decisive factors for its effectiveness. We show that Sun-as-a-star spectroscopic observations, together with imaging observations to derive the true velocity of a solar eruption. Using observations of SDO/EVE (Extreme Ultraviolet Variability Experiment), we found clear blueshifted secondary emission components in extreme-ultraviolet spectral lines during a solar eruption on 2021 Oct. 28.
The stellar CMEs on solar-type stars are studied using simulations. We conducted MHD simulations of stellar CMEs on late-type stars using the Space Weather Modeling Framework (SWMF). We traced the propagation and evolution of CMEs in the 3D outputs. Coronal dimming/brightening are shown on the synthetic EUV images in different passbands. Line profiles of several EUV and soft X-ray lines are synthesized. Doppler shifts or the red-blue wing asymmetry, and their developments are seen during the launch and early propagation of CMEs. Our investigations set constrains on the detectability of stellar CMEs through line asymmetries and provide guidelines for the future search of stellar CMEs.

Observations of a Solar CME

Imaging observations by SDO/AIA and STEREO-A/EUVI

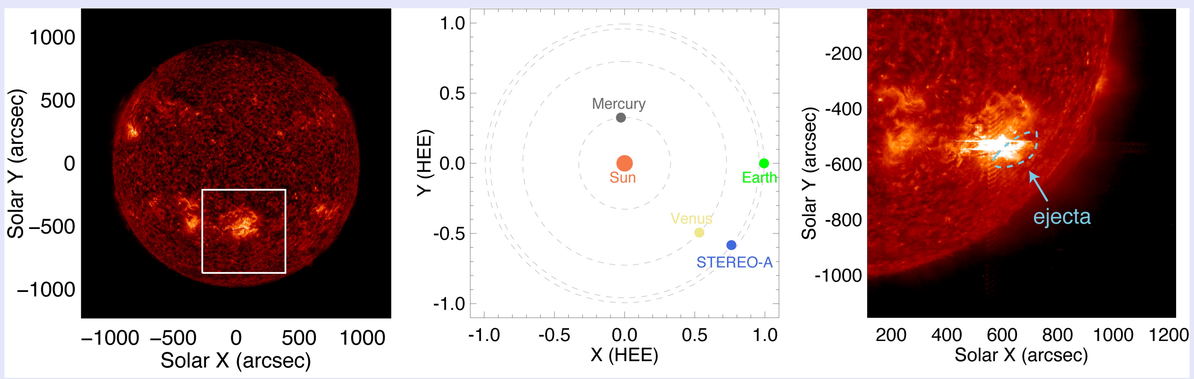

Fig.1: The imaging observations from SDO/AIA (left) as well as STEREO-A/EUVI (right) and the positions of both satellites under HEE system (middle).

Spectra from SDO/EVE

- Spectral lines selected for analysis in EVE MEGS-B dataset

Ion	Rest Wavelength (nm)	log (T/K)
He I	58.4303	4.16
O III	52.5770	4.92
O V	62.9683	5.37
O VI	103.191	5.47
Ne VII	46.5220	5.71
Ne VIII	77.0365	5.81

- Line profile variation: O V 62.96 nm for example

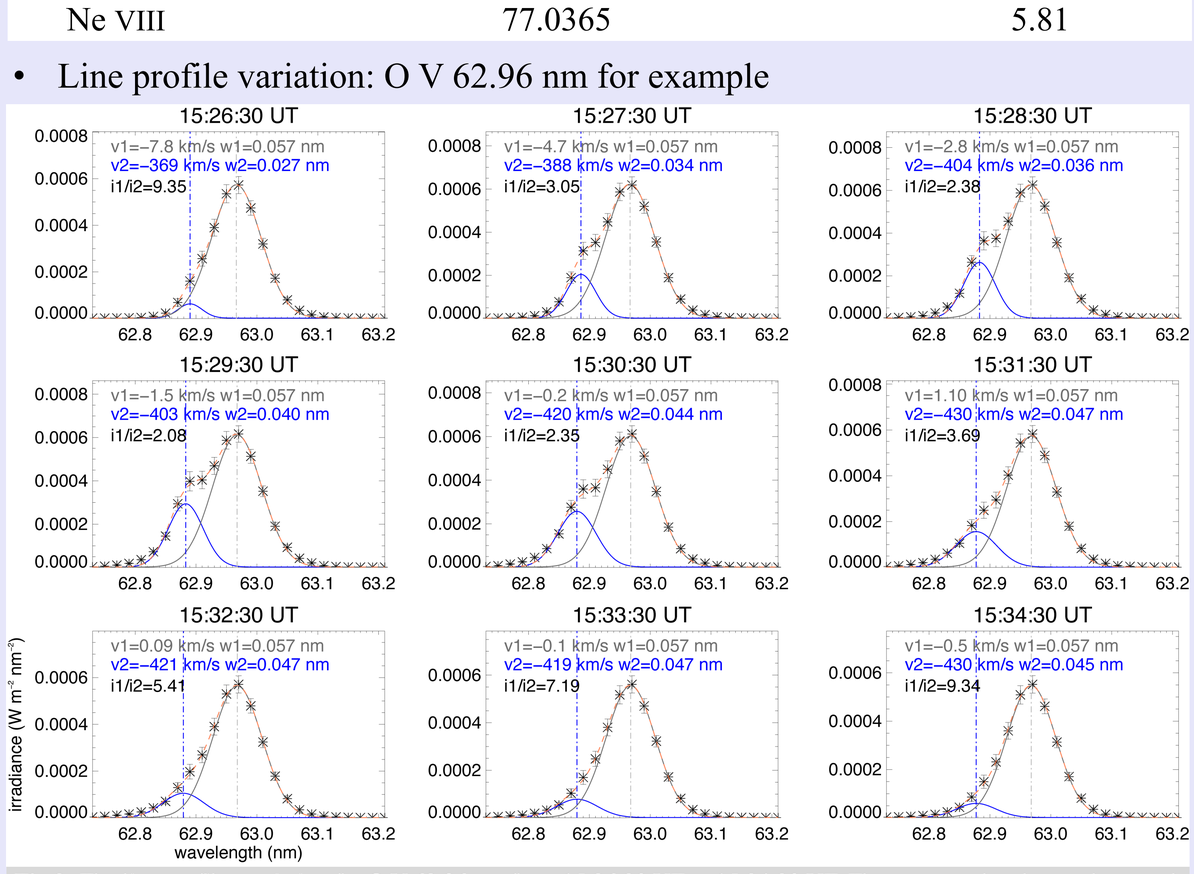

Fig.2: The line profiles variation for O V 62.96 nm from 15:26:30 UT to 15:34:30 UT. The stars are the observed spectral irradiances while the error bars are derived from the measurement precision contained in the EVE observation files.

Full Velocity Calculation

- Combining LOS velocity from spectroscopic analysis and POS velocity from imaging observations

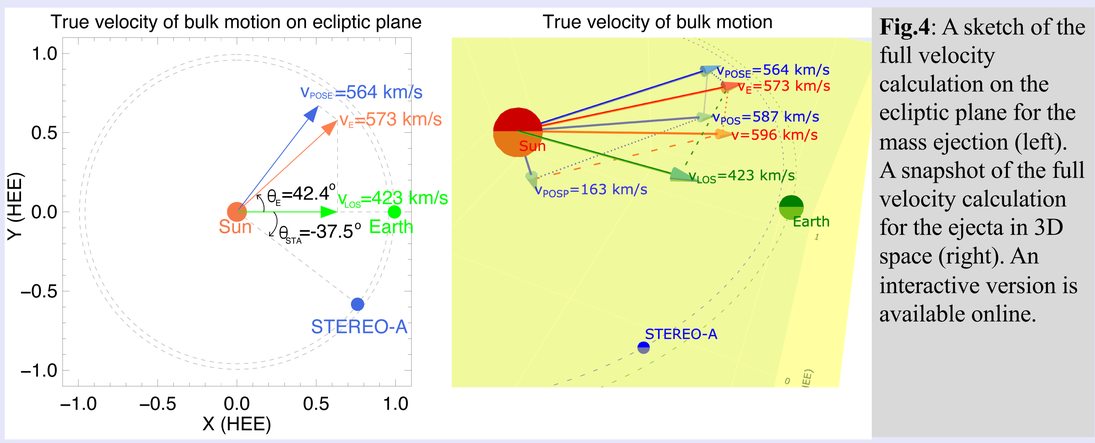

Fig.4: A sketch of the full velocity calculation on the ecliptic plane for the mass ejection (left). A snapshot of the full velocity calculation for the ejecta in 3D space (right). An interactive version is available online.

Simulations of Stellar CMEs

Method

- Target star: , *ι* Horologii, G0V, mass = 1.2 solar mass, radius = 1.16 solar radii, rotation period is around 7.7 days.
- MHD simulation: Using the AWSoM model, we simulated the coronal condition of *ι* Horologii and launched several CMEs. Each CME has a two-hour evolution time.
- Spectral synthesis: We synthesized the line profiles of ten lines, with formation temperature spanning from log T/K = 5.81 to log T/K = 7.06, during the initiation and propagation of the simulated stellar CMEs.

Synthesized EUV images and Line Profiles

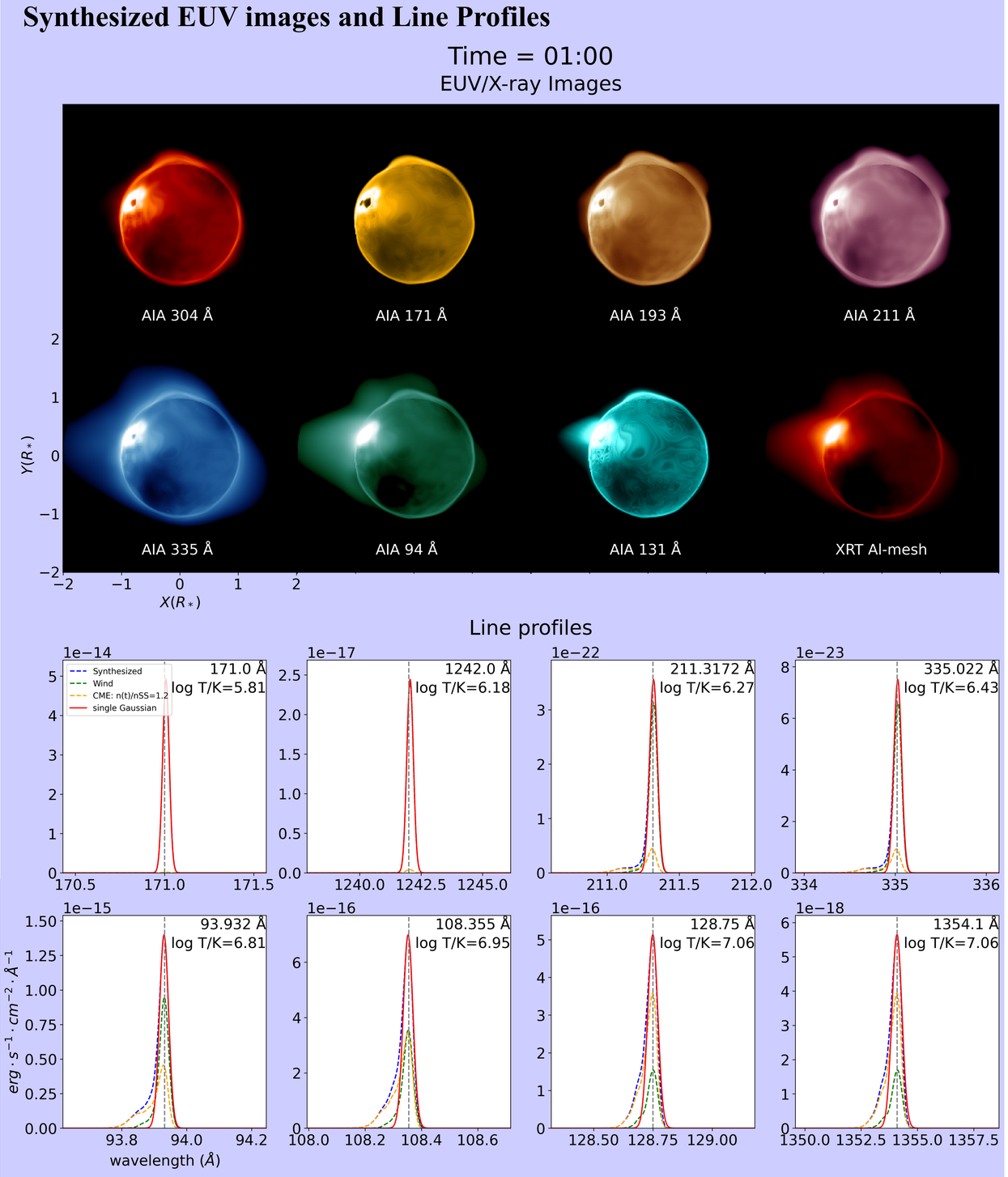

Fig.5: The synthesized EUV images and line profiles of a simulated CME on *ι* Horologii at one hour after the initialization. Top: The synthesized EUV images in SDO/AIA and HINODE/XRT channels. The name of the bands are labeled on each panel. Bottom: The synthesized line profiles assuming the CME travels towards the observer. The name and formation temperature as well as the rest wavelength (from CHIANTI database) are marked in the corresponding panel. The blue dashed lines represent the integrated line profile. The red curve is a single Gaussian fitting result of the primary peak. The green and orange curve show the contributions from the ambient wind and the CME material, respectively. Clear asymmetries are observed.

Ref.: Xu Y, Tian H, Hou Z, et al. Sun-as-a-star Spectroscopic Observations of the Line-of-sight Velocity of a Solar Eruption on 2021 October 28[J]. The Astrophysical Journal, 2022, 931(2): 76.
Xu Y, et al. Simulations of coronal mass ejections on the solar-type star ι Horologii. in prep.