ULTRAVIOLET ASTRONOMY IN THE XXI CENTURY

e-Workshop 2020 – October 27-29

JcUVA+

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ABSTRACT:
PolStar is a FUV spectropolarimeter Explorer-class mission that is the first to combine the spectropolarimetric capabilities previously achieved in UL and HST with the polarimetric capabilities of a true successor to WUPPE. PolStar will provide access to the suite of resonance lines in the FUV to map the photospheric structure of massive stars in 3D and gain insight into the effects that these structures have on the mass loss and stellar evolution of the stars themselves. The mission will also address science related to how massive binary pairs interact with each other, and provide access to the interstellar reddening law via Fe II (250 nm) and >200 nm to map the winds and magnetospheric structure of massive stars. The first 3D tomographic models of the stellar magnetospheres and their known magnetic structures on the stellar surfaces will obtain the first complete picture of the stellar environment. PolStar is the first non-solar-mission optimized for stellar high resolution UV spectral polarimetry, delivering a spectral resolving power of R ~ 30,000, while also measuring all 4 Stokes parameters simultaneously in one observation for a timely and scientifically compelling mission. Recent advances in detector technology makes this mission possible now and delivers more than an order of magnitude improvement in sensitivity and spectral resolution over its predecessors.

MISSION MOTIVATION:

• Massive stars are the most important contributors to galactic cosmic evolution. They provide the raw materials and heavy elements for the interstellar medium, planets and all living matter, and the UV light to illuminate them and catalyze chemistry. Their rapid evolution, extreme luminosity, fundamental dynamical and chemical interactions with their environments will be revealed by PolStar.

• PolStar is a FUV (Far Ultraviolet) spectropolarimeter mission designed to target massive stars and their environments. PolStar will take advantage of resonance lines only available in the FUV to measure for the first time the magnetic and wind environment around massive stars to constrain models of rotation and mass loss that affect the star’s evolution and end-state. We will deliver the first 3D tomographic models of the stellar magnetospheres and tie them to known magnetic structures on the stellar surfaces to obtain the first complete picture of the stellar environment.

• PolStar is the first non-solar-mission optimized for stellar high resolution UV spectral polarimetry, delivering a spectral resolving power of R ~ 30,000, while also measuring all 4 Stokes parameters simultaneously in one observation for a timely and scientifically compelling mission. Recent advances in detector technology makes this mission possible now and delivers more than an order of magnitude improvement in sensitivity and spectral resolution over its predecessors.

SPECTROPOLARIMETRIC DIAGNOSTICS:

• Polarization data are referenced in terms of the Stokes vector.
• Q and U are measures of linear polarization, providing both amplitude and position angle (or orientation) information; metrics are relative intensities of pQ=Q/I and pU=U/I.
• V is circular polarization, which for astrophysics is typically associated with sensitivity to magnetism; metric is pV=V/I.
• Crucial for PolStar will be the combination of polarization data with monitoring for time-variable measures.

• Continuum PolStar - Thomson scattering of free electrons produces linearly polarized scattered light and is the dominant polarizing (and depolarizing) opacity in the continuum of massive stars (see left).
• Line PolStar - one key effect is doppler shift - the rapid rotation of the star, disk rotation, fast winds, coronal magnetospheres all represent supersonic motions that lead to changes in the linear polarization - both amplitude and position angle - across a resolved spectral line (see left).
• A second key effect on line polarization is the polarographic response of lines to magnetism. Key for PolStar is the well-known Zeeman effect that produces circular polarization for studying stellar magnetic fields. PolStar is well matched in scope for a closely associated Hanle effect, a weak Zeeman effect leading to alteration of the linear polarization (as opposed to circular) across a resonance scattering line that has long been used in the Solar community.

PHYSICS, STRUCTURE, AND VARIABILITY OF RADIATIVELY-DRIVEN WINDS

A key defining characteristic of massive stars is their strong winds. Because of their high luminosities, a large number of photons can be absorbed or scattered through spectral lines in the outer layers of massive stars, leading to a radiative acceleration that is strong enough to generate an outflow: the radiatively driven stellar wind. Since (UV) spectral lines are sensitive to both velocity and density structures in the stellar wind, they permit the study of two key effects:

• Small-scale structures: Clumps and Blobs - to understand the spatio-temporal structure of clumping and its evolutionary dependence, high-cadence (hours), high signal-to-noise ratio (>100) spectroscopic time series of O stars are required, focused on wind-sensitive resonance lines that are only present in the far UV

• Large-scale structures: Co-rotating Interaction Regions (CIRs) - to test the relationship between photometric and wind evolution, long-cadence (months), high signal-to-noise ratio (>100) UV spectroscopic time series of O stars are required. As many photometric and wind lines as possible would be monitored simultaneously in order to sample the transition region between the stellar surface and the wind-dominated atmosphere.

ORIGIN AND EVOLUTION OF BE STAR DISKS

Be stars are a common class of variable, rapidly rotating, near-massive (mass range 1.5 - 9 M⊙), hot supergiants (spectral-type B0 - B2 stars). In addition to their Balmer emission, Be stars have an infrared excess from free-free emission, and they are intrinsically polarized. We know from optical and IR interferometry that the hydrogen emission lines, IR excess, and polarization are due to the line-driven stellar wind. Color scales range from log(I) = 1 for lowest density (blue) to log(I) = -1 for highest density (red), with yellow (log(I) = 0) representing density equal to the interstellar steady-state. The vertical variation extends from the subsonic wind base at the left to the sonic wind base at the right. The display shows the density at a height of one stellar radius (R). The 3 panels show time series at t = 300, 350, and 450 ks, long after the initial condensation of dust developed into a statistically already turbulent state. From Owocki & Sundqvist (2018).

WIND/MAGNETIC FIELD INTERACTION AND MAGNETOSPHERIC PHYSICS

In hot stars, fossil magnetic fields with surface strength from 100 G to a few tens of kG, usually dominated by oblique dipole, have formed and frozen into their radiation envelopes long before the PMS stage (e.g., Alecian et al. 2013). Such fields may contain the imprint of magnetic hydromagnetic activity occurring during early phases of star formation, before the star is visible. Moreover, they have important consequences for later formation phases, especially in their role as intermediaries in accretion and mass-loss processes. During main sequence (MS) and post-main sequence (post-MS) evolution, fossil magnetic fields have been shown to couple strongly to stellar winds, enhancing the shedding of rotational angular momentum through magnetic braking (Townsend et al. 2010).

Simultaneously, the presence of the field impedes mass loss, redirecting outflowing wind back toward the stellar surface. As rotation and mass loss are key determinants of the evolution of hot stars, magnetic fields potentially have an enormous impact (e.g. Petit et al. 2017; Georgy et al. 2018, Kenzevethy et al. 2019).

An illustration of the approach of building 3D tomographs of the magnetic field and associated structures around a star based on a detailed evolution of emission line profiles, and their polarimetric properties as a function of wavelength. The source rotates under our line of sight, which will use this approach to map the winds and magnetospheric fields of massive stars. The strong resonance lines in the FUV that map the large diameter of disk structures. From Owocki et al. (2018) and Owocki et al. (2019).

Sophisticated tomographic mapping of stellar surface structures and magnetic fields is now possible. However, due to the current reliance on visible wavelength tomography, such mapping is effectively confined to the stellar photosphere. The range of stellar and circumstellar diagnostics provided by PolStar thanks to its UV wavelength coverage, when coupled with the high-cadence, long-term continuous monitoring from space, will allow the extension of indirect mapping methods into the discs and winds of hot stars, providing the first truly 3D views of these magnetospheres and immediate environments.

Therefore the unique capabilities of PolStar, namely spaceborne UV high-resolution spectropolarimetry, will allow us for the first time, to fully characterise the direct relation of stellar magnetic fields with circumstellar activity. The Sun is currently the only star for which a reliable map of its 3D environment exists. PolStar will provide such maps for a set of well-chosen, high hot stars.

The key diagnostics required for this science case are simultaneous, multi-epoch spectropolarimetry of photospheric lines, wind-sensitive resonance lines, and the (polarized) continuum at high spectral resolving power and high signal-to-noise ratio (100-1000+).