National Aeronautics and Space Administration

A SEARCH FOR FLICKERING TO PROBE ACCRETION ACTIVITY AND BINARITY IN DYING STARS USING TESS DATA

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Program: Innovative Spontaneous Concepts

Introduction

•Major astrophysical accomplishment of the 20th century -- success of models of the structure and evolution of single stars of all masses.
•The challenges for the 21st century are stellar birth, stellar death, and the impact of binary interactions on stellar evolution.
•Binary interactions dominate a substantial fraction of stellar phenomenology (e.g., Cataclysmic variables, Type Ia Supernovae, mergers & Gravitational Wave sources)
(a) Believed to underlie the formation of the overwhelming majority of Planetary Nebulae (PNe), the bright end-stage of most stars in the Universe (that evolve in a Hubble time).
(b) Strong binary interaction during the RGB phase can cut short/eliminate the AGB red giant phase
(c) Post-AGB evolution can be prolonged due to mass-transfer back onto the primary from a circumbinary disk

•However, observational evidence for widespread binarity in dying stars has been lacking
•We developed a new technique of using UV observations (with GALEX) to search for the presence of binarity and associated accretion in these objects (Sahai et al. 2008, ApJ, 689, 1274; Sahai et al. 2011, ApJ, 740, L39; Sahai et al. 2015, ApJ, 810, 77; Sahai et al. 2016, J. Phys. Conf.Ser. 728, 042003; Sahai et al. 2018, ApJ, 860, 105 [Setal18])
•Follow-up pilot studies of X-ray observations with XMM-Newton and Chandra support our hypothesis that dying stars with a high value of the GALEX FUV/NUV flux ratio, R>0.17 (fuvAGB stars), are binaries with accretion-activity (Fig. 1)
•UV observations (HST/STI)S of our prime fuvAGB star, Y Gem, shows flickering on <20 sec timescales, telltale signature of an active accretion disk (Setal18). These data also show evidence of infall and outflow motions at high-velocities (~500 km/s) -- the infall is likely due to material captured gravitationally by the companion from the Roche-lobe of the primary star (Roche-lobe overflow), and the outlow is likely driven by the accretion disk (Fig. 2).

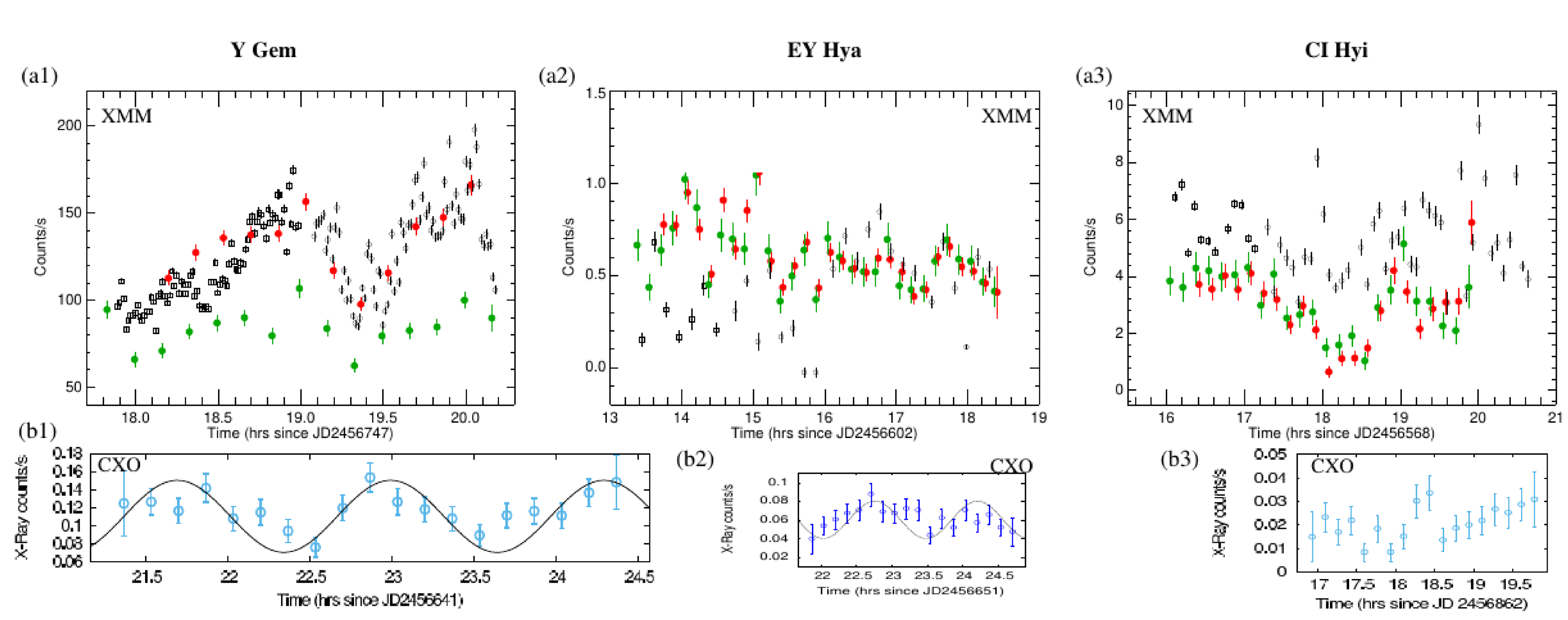

Figure 1. X-ray & UV light-curves: (a) XMM (EPIC=pn+MOS1+MOS2: red, MOS=MOS1+MOS2: green, UVM2: black squares, UVW2: black circles), and (b) CXO (ACIS-S). The EPIC, MOS and UVW2 data have been re-scaled Sinusoidal fits with periods, P=1.35 and 1.45 hr are shown for Y Gem & EY Hya, respectively (from Sahai et al 2015)

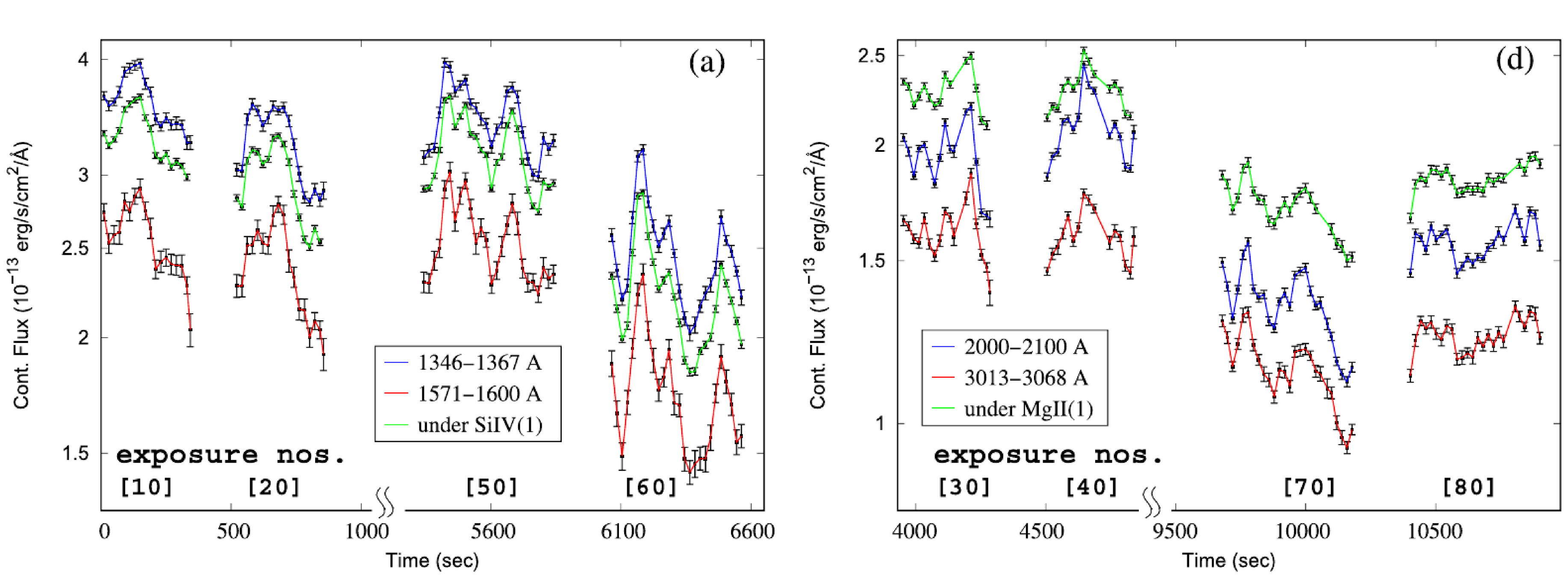

Figure 2. UV flickering in Y Gem, the brightest fuvAGB star, observed with HST/STIS (adapted from Sahai et al. 2018)

Benefits to NASA and JPL (or significance of results):

•Our study, with its innovative approach to the statistical study of binarity+accretion in dying stars, has made significant progress in the study of the life-cycles of stars, which is an important component of NASA's Destiny, Structure & Evolution of the Universe Science.
•It raises JPL's scientific competitiveness in future proposals with TESS, HST, Chandra, XMM-Newton, SOFIA, and the ROSES/ADAP program.
•It has provided scientific support for NASA's SmallSat initiative (concept paper to NASA RFI NNH172DA010L), and the science case for the ngVLA

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Program Objectives

•Use TESS to search for flickering in a statistical sample of UV-emitting AGB stars: obtain and characterize the 2-min cadence light-curves of a sample of about 30 dying stars with UV emission, in order to distinguish between extrinsic (binarity) and intrinsic (coronal) mechanisms for UV.
•A subsample of our target list was scheduled for observations (Cycle 1). These light-curves are expected to show the presence of flickering if accretion activity is ongoing, as we found in the UV, but the fractional amplitude of variations is expected to be much smaller: TESS $\Delta m<\sim 0.005$, compared to FUV $\Delta m\sim 0.25$-0.45.
•TESS's superb photometric accuracy (1σ noise sensitivity of 690 ppm in a 2-min intgeration time for faintest objects in our sample) can enable detection of optical flickering in AGB stars.

Approach and Results

TESS pipeline light curves

•The TESS pipeline provides two main products for the light curves: SAP_FLUX and PDCSAP_FLUX. The SAP_FLUX has many (but not all) instrumental artifacts removed, and PDCSAP_FLUX, is a detrended version of SAP_FLUX, in which overall smooth changes are removed to optimize detection of sharp-edged dips that are characteristic of transiting planets. As an example, we show these curves for the star AG Cet in Fig. 3.
•Obvious artifacts: spikes, very noisy regions in the SAP curve at the beginning and ends of the observational window,
•Subtle artifacts: small bumps in the PDCSAP curve at time>$\sim$1400 days that are due to momentum dumps that occur during this period.
•Long-term smooth variation in the SAP flux may or may not be an artifact -- requires comparison with the light curves of several nearby stars to see if they display similar long-term trends in their SAP flux as AG Cet.

Flickering Analysis & Results

•Custom (python) program to search for flickering in our available Cycle-1 targets. Using the SAP_FLUX light curves, we first identified "good" regions of data for the SAP_FLUX light curve of each target, i.e., those not affected by spikes or other artifacts and divided these up into sub-intervals of 200 to 1000 seconds. We de-trended each of these regions to remove any smooth variations, and then computed the observed rms noise (sigma_obs) in each subinterval. We then determined the ratio of sigma_obs to the expected noise, sigma_exp. This ratio, which we call the flicker_ratio, was tabulated for each of these regions for each target.
•Our results suggest that we can detect the presence of excess noise due to flickering – the flicker_ratio for the fuvAGB stars with the highest values of the FUV/NUV ratio, are significantly higher (factor $\sim$ 2) than for the nuvAGB stars (Fig. 4). The flicker-ratio varies during the ~20 day observation period for each target.
•More careful analysis necessary
(a) We also find a high flicker-ratio for the red supergiant α Orionis, which is known to show chromospheric emission, but is not a known binary. Since α Orionis is very bright and covers a large number of pixels, it is possible that the pipeline aperture is not adequately large, and additional photometric noise has been introduced into its light curve as a result of small movements of the target within the aperture. Thus, very bright stars may require custom photometry.
(b) An additional test would be to extract the light curves of a sample of field stars within the vicinity of each target, and determine the median flicker ratio for this sample -- these stars should generally have low flicker ratios (unless of course, by coincidence of them is a binary undergoing accretion).

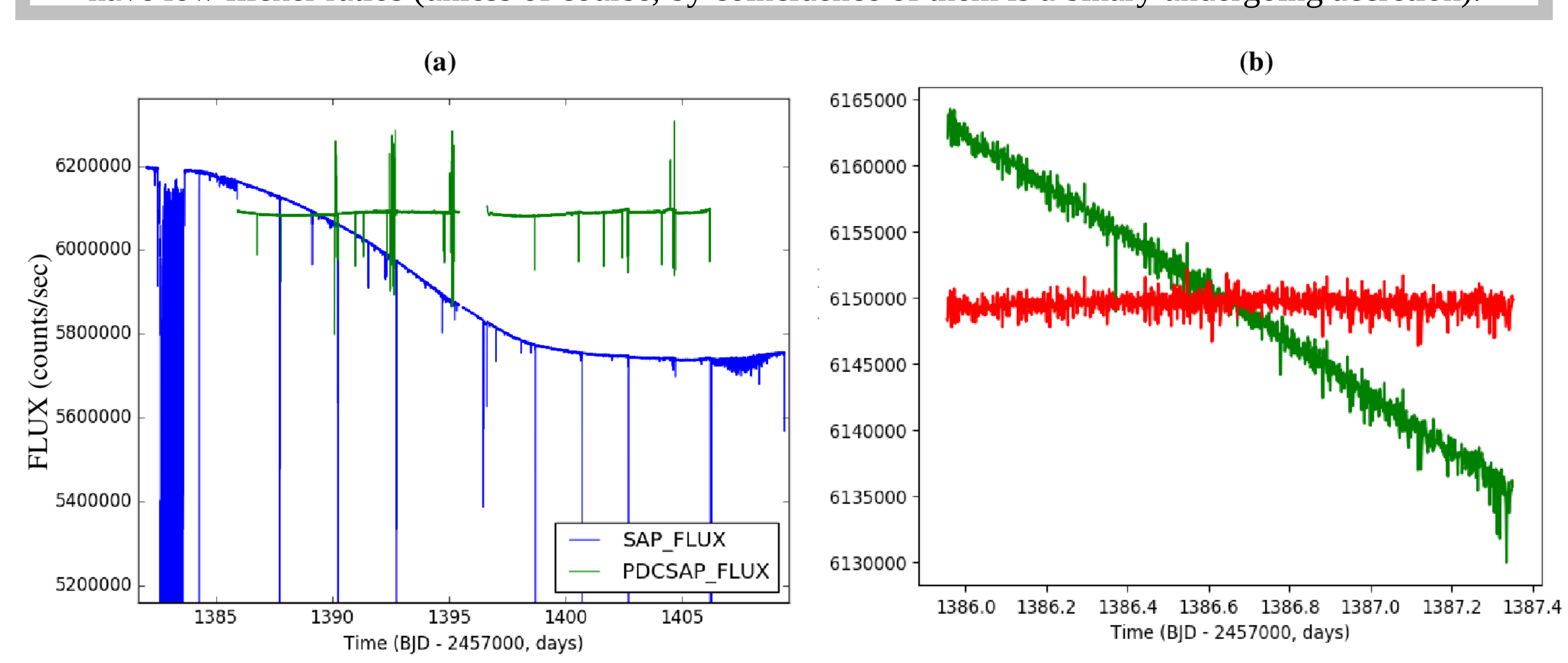

Figure 3. (a) Pipeline TESS light curves (2-min cadence) of AG Cet -- both the SAP (raw) flux and the PDCSAP (de-trended) flux curves are shown, (b) The SAP and de-trended light curve in a 1000 sec sub-interval for determining the flicker-ratio

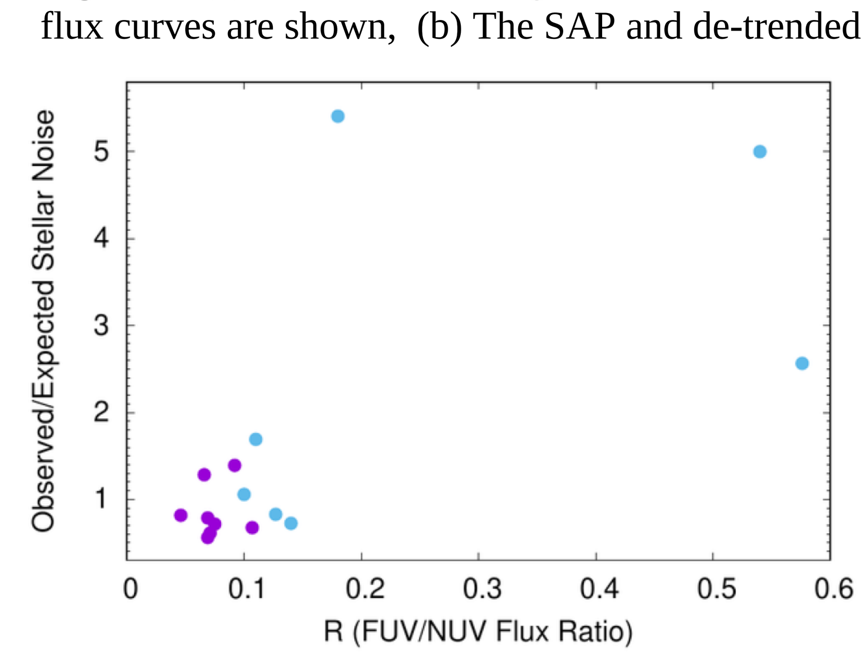

Figure 4. The flicker-ratio (observed to expected noise) for stars with UV-emission. Stars with high FUV/NUV show stronger Flicker-ratios (i.e. high observed to expected noise).

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