Exoplanet Modulations of Stellar Coronal Radio Emissions

O. Cohen[1], S. Moschou[2], A. Glocer[3], I. Sokolov[4], T. Mazeh[5], J. Drake[2], C. Garraffo[2], J. Alvarado-Gomez[2]
1 - U. of Massachusetts Lowell; 2 - Smithsonian Astrophysical Observatory; 3 - NASA GSFC; 4 - U. of Michigan; 5 - Tel-Aviv University

What Do we do?

- Using an MHD model for the corona of a Sun-like star, we create synthetic radio images of the free-free Bremsstrahlung stellar coronae radiation for a range of radio frequencies.
- We impose a planet in the simulation domain and place it at different semi-major axes, and with a different dipole field strength.
- For each case, we calculate the ratio of the coronal radio emissions with and without the planet.
- We estimate the modulation of the coronal radio emissions from four viewing angles – pre-transit, transit, post-transit, and planet eclipse.

Methodology

- We use the AWSoM (BATS-R-US) MHD model to self-consistently simulate the stellar corona and stellar wind of a Sun-like star with a dipole magnetic field of 10 G.
- The planet is implemented in the simulation as an additional boundary condition. We use planetary field of 0.3 G (Earth-like) and 1 G (Jupiter-like).

Synthetic Radio Images

1. The intensity of each pixel, *I*, for a given frequency, ν, is the integral over the emissivity along the ray: $$I_\nu = \int B_\nu(T)\kappa_\nu ds.$$
2. For Bremsstrahlung emission, where *h*ν << kT, the Planckian spectral black body intensity is: $$B_\nu(T) = \frac{2k_B T_e \nu^2}{c^2}$$
3. The absorption coefficient, κν, is: $$\kappa_\nu = \frac{n_e^2 e^6}{\nu^2 (k_B T_e)^{3/2} m_e^{3/2} c} < g_{ff} >$$

and the index of refraction is related to the dielectric permittivity: $$n^2 = \epsilon = 1 - \frac{\omega_p^2}{\omega^2} = 1 - \frac{\rho}{\rho_c}$$

with $\omega_p^2 = 4\pi e^2 n_e / m_e \qquad \rho_c = m_p m_e \omega^2 / 4\pi e^2$

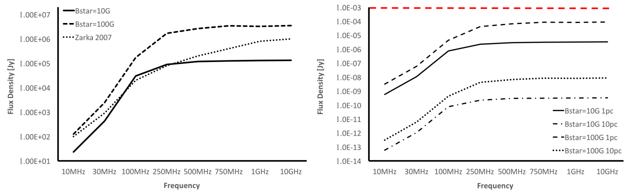

Figure 1 *- Left: Simulated radio spectrum for the case without a planet using stellar dipole field of 10 and 100 G as seen from the Earth. Dotted line shows the observed solar spectrum (Taken from Zarka 2007). Right, the same radio flux spectrum as seen from 1 and 10 pc.*

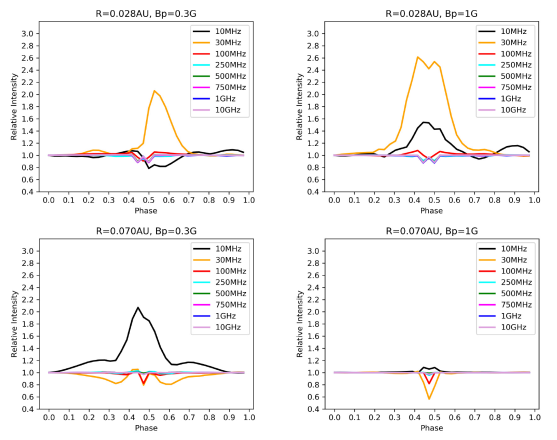

Figure 5 *– Synthetic light-curves for varies radio frequencies as a function of the planetary orbital phase as observed from the transit location (transit occurs at phase of 0.5). Light-curves are for two specific cases showing the relative radio flux modulation. These modulations are significant for some frequencies and may be observable.*

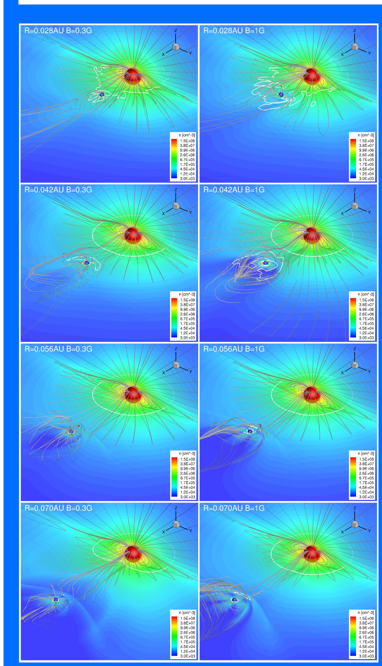

Figure 2 *- Three-dimensional display of the results for planetary field of 0.3 G (left) and 1G (right), for the different orbital separations (top to bottom). Each plot shows the star and planet as red and blue spheres, respectively, color contours of the number density, and selected field lines. The white solid line marks the Alfv'en surface of the star and the planet.*

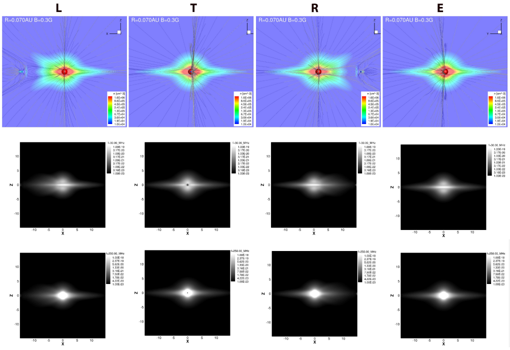

Figure 3 *- Top - similar display as in Figure 2 shown from different viewing angles on the results for the planet located at 6 stellar radii (0.028 AU). The other two rows show the synthetic radio images for 30 MHz (middle) and 250 MHz (bottom) for the corresponding viewing angle. The radio flux is in units of W s^{-1} m^2.*

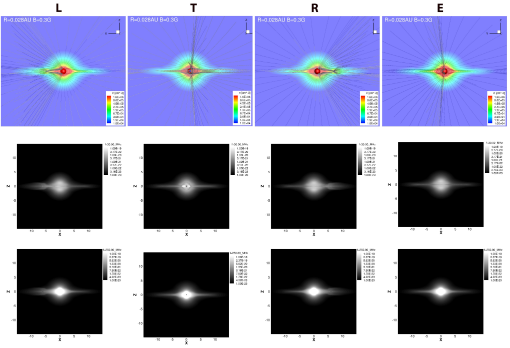

Figure 4 *- Similar plots to Figure 3 but for the planet located at 15 stellar radii (0.028 AU).*

Main Findings

- We find that the source of the modulations is the modification of the radio wave refraction pattern as a result of the change in the ambient plasma density by the planet.
- We find that the absolute magnitude of the modulation is significant, above 10% in the 10-100MHz bands and between 2-10% in the frequencies above 250 MHz.
- We find that the planetary magnetic field strength does not have a strong impact on the radio flux modulations, while the polarity of the planetary field can play a role when the planet is very close to the star.
- We also find that the strength of the stellar field affects the modulations due to the increase in coronal density for a stronger stellar field.

We plan to apply the new radio tool to specific planetary system in order to provide predictions for radio observations of exoplanets.

For more information: ofer_cohen@uml.edu

Reference: Cohen et. al, Exo- planet Modulation of Stellar Coronal Radio Emission. Astronomical. J., 156:202, November 2018.