MNRAS **000**, 000–000 (0000) Preprint 15 October 2016 Compiled using MNRAS LaTeX style file v3.0

Progress Report for TG-AST120060 "Magnetic Towers and Binary-Formed Disks"

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15 October 2016

1 SUMMARY OF SCIENTIFIC DISCOVERIES

Our renewal allocations of TG-AST120060 was 643501.0 SUs on Stampede of TACC. The allocations ended on December 31, 2014. As of December 31, 2014, we used 100% of our allocation to do high resolution simulations on disks and 3D Pulsed jets. We found significant new results related to the formation of disks in binaries (Huarte-Espinosa et al. 2013b; Chen et al. 2016a) and understanding the full 3D emission properties of radiative MHD jets (Huarte-Espinosa et al. 2013a; Hansen et al. 2015a,b). In summary, our principle scientific discoveries are as follows

• We determined that the BHL accretion solution has to be modified for its application to accretion from the primary wind onto an orbiting secondary. This is because the wake that develops in this environment is not aimed towards the instantaneous position of the companion as in the "normal" BHL accretion. Instead, the captured material is accelerated towards a position between the companion's original and current positions.
• We have characterized the accretion process via the "impact parameter"

$$b = \frac{v_s^3 (2Gm/v_w)^2}{2r_s(v_s^2 + v_w^2)^{3/2}} \quad (1)$$

where v_s, m, r_s and v_w are the orbital speed of the secondary star, the mass of the secondary star, the distance between the binary center of mass and the secondary and, finally, the AGB stellar wind speed.
• We found that the formation of disks in 3-D simulations strongly depends on the proper resolution of the impact parameter b. We were also able to resolve, for the first time, bow shocks formed by the interaction of stable disks and the AGB wind.
• We studied the evolution of outflows in both 2 and 3-D simulations and for MHD and pure hydro cases. Such outflows are expected to be a consequence of disk formation in a variety of settings. In particular we explored the consequences of spatial heterogenity in the jet flows in terms of bow shock dynamics and morphologies. Our studies articulated explicitly where mach stems are expected to form and the nature of instabilities in "clumpy flows" tying them directly to Hubble Space Telescope observations of jets.

2 ACCOMPLISHMENTS OF COMPUTATIONAL PLAN

In Huarte-Espinosa et al. 2013b We studied the formation, evolution and physical properties of accretion disks formed via wind capture in binary systems. We first derived a resolution criteria, based on considerations of Bondi-Hoyle flows, that must be met in order to properly resolve the formation of accretion disks around the secondary. We then compare simulations of binaries with three different orbital radii (10, 15, 20 AU). Disks are formed in all three cases, however the size of the disk and, most importantly, its accretion rate decreases with orbital radii. In addition, the shape of the orbital motions of material within the disk becomes increasingly elliptical with increasing binary separation. The flow is mildly unsteady with "fluttering" around the bow shock observed. The disks are generally well aligned with the orbital plane after a few binary orbits. We do not observe the presence of any large scale, violent instabilities (such as the flip-flop mode). For the first time, moreover, it is observed that the wind component that is accreted towards the secondary has a vortex tube-like structure, rather than a column-like one as it was previously thought. In the context of AGB binary systems that might be precursors to Pre-Planetary and Planetary Nebula, we find that the wind accretion rates at the chosen orbital separations are generally too small to produce the most powerful outflows observed in these systems if the companions are main sequence stars but marginally capable if the companions are white dwarfs. It is likely that many of the more powerful PPN and PN involve closer binaries than the ones considered here. The results also demonstrate principles of broad relevance to all wind-capture binary systems.

In Huarte-Espinosa et al. 2013a we studied the jets from active galaxies propagate from the central black hole out to the radio lobes and the interaction between the jets and stellar winds. We presented 3D MHD numerical simulations to model the evolution of the jet-wind interaction and its observational consequences. We explored the relative mechanical luminosity of the radio jets and the stellar winds, the impact parameter between the jets' axis and the stellar orbital path and the relative magnetic field strength of the jets and the stellar winds.

In Hansen et al. 2015b, we explored the dynamics of radiative axisymmetric magnetohydrodynamic (MHD) jets at high resolution using adaptive mesh refinement methods. Such outflows are expected to be a consequence of disk formation in a variety of settings. The goal of the study was to determine both the dynamics and emission properties of such jets. To that end, we implemented microphysics enabling us to produce synthetic maps of H_α and [SII]. The jets were pulsed either sinusoidally or randomly via a time-dependent ejection velocity which leads to a complicated structure of internal shocks and rarefactions as has been seen in previous simulations. The high resolution of our simulations allowed us to explore in great detail the effect of pinch forces (due to the jet's toroidal magnetic field) within the "working surfaces" where pulses interact. We mapped the strong H_α emission marking shock fronts and the strong [S II] emission inside cooling regions behind shocks as observed with high-resolution images of jets. We find that pinch forces in the stronger field cases produce additional emission regions along the axis as compared with purely hydrodynamic runs. These simulations are a first step to understanding the full three-dimensional emission properties of radiative MHD jets. In addition we explored the consequences of spatial heterogenity in the jet flows in terms of bow shock dynamics and morphologies. Our studies articulated explicitly where mach stems are expected to form and the nature of instabilities in "clumpy flows" tying them directly to Hubble Space Telescope observations of jets.

3 PUBLICATIONS AND REPORTS THAT RESULT FROM XSEDE SUPPORT

Publications related to this project are Huarte-Espinosa et al. 2013b; Hansen et al. 2015a,b; Chen et al. 2016a,b; Hartigan et al. 2016

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