Introduction: Brian D. Metzger

I am a professor at Columbia and researcher as the Flatiron Institute. I have long standing interests in the central engines of energetic transients: gamma-ray bursts, superluminous supernovae, stellar mergers (both degenerate and non-degenerate), tidal disruption events, and now fast radio bursts. My interest in FRBs started with immediate intrigue in the local-scale environment of FRB 121102, particularly the luminous persistent synchrotron radio source and high rotation measure of the bursts. To me, this immediately suggested that this highly-active FRB engine was embedded in a young nebula energized by the same activity responsible for creating the bursts. As someone deeply familiar with models for gamma-ray bursts and luminous supernovae from newly-born magnetars, I was immediately drawn to magnetars as an FRB source population (though realizing the putative magnetars responsible for repeating FRBs need be far more extreme and active than those in the Galaxy, cautioning against generalizing too much from the Galactic population).

However, despite vindication of this idea coming with the incredible discovery by CHIME/FRB and STARE2 of an FRB from a Galactictic magnetar, I have started to consider alternative FRB engines, in particular accretion-powered jets from stellar-mass compact objects and binary neutron star mergers (work spearheaded by my student Navin Sridhar). While I still believe magnetars are likely (perhaps the most likely) FRB sources, their "stock" now feels a bit overvalued relative to the probability of them being the sole central engine, given new observational hints and the generic nature of the mechanisms ("shocks", "reconnection", "wave decay") likely responsible for generating FRB emission.

I have also done work on FRB emission theory, in collaboration with Lorenzo Sironi and Ben Margalit, on further developing the magnetized shock ("synchrotron maser") mechanism. One of our contributions was to show that a decelerating blastwave (from an arbitrary injection of relativistic energy) which propagates into an external magnetized environment would naturally generate downward drifting frequency structure in the burst as well as an [incoherent] gamma-ray/X-ray synchrotron afterglow in the downstream region of the shock, from the same electron population responsible for the FRB. Incidentally, our predictions for the luminosity and spectrum of this X-ray emission nicely matched that which accompanied FRB 200428 from SGR 1935+2154, when rescaled to the lower energy of this event.

Proposed Talk: X-ray Binary Jets as FRB Sources

I will advance the hypothesis that some FRBs are powered by flares that occur in the evacuated accretion funnels of accreting stellar-mass black holes or neutron stars. Although I could (and we have) delved into possible emission mechanisms of coherent radio emission, my main argument is by a simple analogy: the most developed theoretical models for FRB prompt emission in magnetar magnetosphere or outflows (e.g., relativistic magnetized shocks, magnetic reconnection in a striped magnetar wind, non-linear wave decay) could equally occur in the magnetospheres or outflows of X-ray binary jet. For example, recent GRMHD and particle-in-cell plasma simulations of black hole accretion flows, have uncovered the creation and ejection of plasmoids along the evacuated funnel (the analog of magnetar flares), while there are theoretical reasons to believe accretion-powered jets may possess a radially-alternating magnetic field orientation (the analog of striped pulsar winds). Of course, this does not imply that all X-ray binary jets are necessarily FRB sources: special conditions, such as a particularly powerful jet, or one threaded by a sufficiently high magnetic flux, may be required to produce sufficiently luminous radio emission to detect at large distances, or for the FRB to escape the viscinity of the source without attenuation.

If one accepts X-ray binary jets as putative FRB sources, then a number of consequences follow. For example, periodic arrival windows of the burst (such as the 16 day period observed

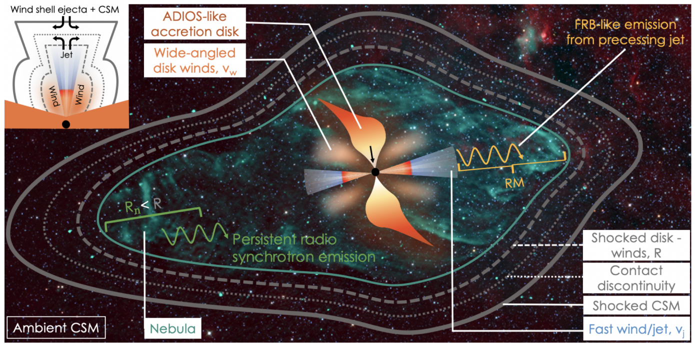

Figure 1: Schematic diagram of the disk wind/jet-inflated nebula. The central black hole or neutron star accretes matter at near or exceeding super-Eddington rate from a companion star undergoing thermal- or dynamical timescale mass transfer. The radiatively inefficient accretion disk is subject to strong outflows in the form of wide-angled disk winds, which feed mass and energy into the large-scale environment, and helps shape the polar accretion funnel and the jet cavity. The wind-fed ejecta shell drives a forward shock (solid grey curve) into the ambient circum-stellar medium (CSM, of density $\rho_{\rm csm}$) that is separated from the ejected shell/shocked disk-jet winds (dashed grey curve; at a distance R given by Eq. 10) by a contact discontinuity (dotted grey curve). The top-left inset shows how the jet 'head' and the disk winds feed matter into their environment and shape-up their surroundings. Yellow wiggles emanating from the jet cavity represents an FRB-like coherent radio pulse beamed along the instantaneous jet axis. The radio pulse travels through a nebula of electrons (green cloud) gyrating around the local magnetic field that imparts a large rotation measure (RM) to the pulse; the electrons cool via various radiative and expansion losses, generating persistent synchrotron radio emission. These electrons are energized and injected into the nebula by the shock formed at the jet - CSM/wind- shell interface. The location of this termination shock determines the boundary of the nebula (with a 'size' R_n). The asymmetric/bipolar shape of the nebula is the result of the higher ram pressure of the jet/disk outflows along the polar accretion axis (with velocities $v_j \gg v_w$) and within the precession cone of the jet (possibly responsible for imparting periodicity in the active FRB phase). The filamentary green structure underlying the schematic is an image of the W50 ('Manatee') nebula surrounding the ULX-like microquasar SS 433.

in FRB 180916) can naturally arise, since - due to relativistic beaming facilitated by geometric beaming - only viewers looking down the barrel of the jet at any given time will observe an FRB. The jets of ultra-luminous X-ray sources are well known to exhibit precession, potentially driven by a number of effects, most notably Lens-Thirring torques, when there exists a misalignment of the disk's angular momentum with respect to the black hole spin. An association between FRB and star-forming galaxies is also expected in luminous X-ray binary models, insofar that both ULX and FRB appear to exhibit a preference for star-forming galaxies (though with spatial offsets between the locations of the most active star-formation, as seen clearly for the ULX population in the Antennae).

A key lesson from the luminous persistent radio emission, and high and time-variable rotation measures, which accompany the environments of several repeating FRBs, is that these FRB sources are embedded in a dense *electron-ion* medium (which basic energetic arguments suggest may be powered by the same activity giving rise to FRBs). While it is uncertain whether pulsar or magnetar outflows contains a substantial ion component, large electron-ion nebulae are directly observed surrounding luminous X-ray binaries, powered by the baryon-rich disk winds which accompany radiatively-inefficient super-Eddington accretion. A famous example is the W50 ("Manatee") nebula surrounding SS433, though the nebula which accompany the most energetic FRB sources may be even more powerful (so-called "ULX Hyper-nebulae"). As I will show, the observed synchrotron properties and high RM values inferred for the persistent source of FRB 121102 are reproduced by a simple model for synchrotron-emitting ULX hyper-nebulae, assuming the progenitor binary to a young ($\lesssim$ decades old) source with an exceptionally high accretion rate $\dot{M} > 10^5 \dot{M}_{\rm Edd}$. These requirements are similar to those which are predicted to immediately precede common envelope events involving a massive star overflowing its Roche Lobe onto a neutron star or black hole companion. A cessation of activity from repeating FRB sources may then be accompanied by a luminous optical/X-ray transient from the common envelope inspiral - at the very least a luminous red nova or dusty infrared transient, or more speculatively a fast luminous optical transient.