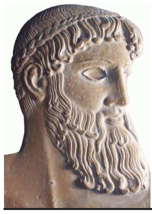

Research interests

My "ten-thousand hours" have been spent learning how to coax solutions out of a computer to the equations of magnetohydrodynamics (MHD) as applied to astrophysical systems[1]. This interest began as an M.Sc. student when, in 1982, my advisor Dick Henriksen showed me a preprint with the first images of what were then considered high-resolution, 2-D, axisymmetric simulations of astrophysical jets. The paper's first author, Mike Norman, was someone whom I had not yet met but who would become one of my most influential mentors.

As a preprint from a well-funded organisation like the Max Planck Institute (where Mike was a post-doc), it contained numerous colour glossy images which never appeared in the journals. Truth be told, it was these images that struck me the most. The possibility that one could present a *visual* solution to such a complex problem and convey in a single image what might otherwise take pages of description and equations was an eye-opener.

For half of my doctoral work and all through my first PDF, I had the privilege of working closely with Mike. It was during those years that we developed one of the first codes capable of multi-dimensional MHD simulations, and the first to bear the *ZEUS* moniker. In 1992, we released *ZEUS-3D* (version 3.2) for public use.

Another extremely influential mentor was Jack Burns who did his best to turn me into a radio astronomer while I was his Ph.D. student. Indeed, we did some rather ambitious multi-frequency, multi-configuration VLA observations of several important extragalactic radio sources, including Centaurus A, 3C 219, and 3C 388. I enjoyed radio astronomy thoroughly, but alas, it did not stick; the last time I was on an NRAO proposal was in the early 1990s.

Instead, I continued developing and supporting the algorithms in *ZEUS*, and released my own public domain version of *ZEUS-3D* in 2007. Most recently, with former Ph.D. student Jon Ramsey and former PDF Sasha Men'shchikov, we have developed the first adaptive mesh refinement (AMR) version of *ZEUS*, called AZEuS[2] (a contraction of AMR and *ZEUS-3D*) which Jon and I first applied to a problem in protostellar jets. This work made up a significant portion of Jon's Ph.D. dissertation.

For an overview on astrophysical jets, see my review paper in *Physics in Canada*. For a quick *visual* introduction to Jon's and my work, click here.

What we've learned from these simulations include the following:

1. Fluxes of mass, momentum, angular momentum, and energy all fall short of observed values until the jet has reached a length of at least 1,000 AU.
2. After 1,000 AU, the jet's advance and rotational speeds are tightly related to the characteristic magnetic field strength near the launching site, B_i: $v_\mathrm{jet} \propto B_\mathrm{i}^{0.44}$; $v_\mathrm{rot} \propto B_\mathrm{i}^{0.66}$. Taken together, $v_\mathrm{rot} \propto v_\mathrm{jet}^{3/2}$.

[1] What the late Queen's professor and radio astronomer Vic Hughes used to dismiss as "doing sums".

[2] Also serves as the acronym: *Adaptive Zone Eulerian Scheme*.

3. For $\beta_{\rm i} = 2p_{\rm i}/B_{\rm i}^2 < 1$, jets are dominated by $B_{\rm pol}$ and are launched primarily by the Blandford & Payne "bead-on-a-wire" mechanism. For $\beta_{\rm i} > 1$, jets are dominated by $B_{\rm tor}$ and are launched by a "coiled spring" mechanism.

4. Within a few AU of the protostellar surface, jet flow is unstable to the simple harmonic generation of knots whose frequency is a strong function of $B_{\rm i}$.

5. And here's the most surprising result: *Regardless of* $B_{\rm i}$, *jets attain a magnetic "nose-"cone" configuration in which* $\beta \rightarrow 1$. Thus, the magnetic field strength in the jet is unrelated to the magnetic field strength near the accretion disc, the region from which the jet's magnetism is ultimately drawn.

AZEuS is in its infancy, and there is plenty to do and learn. From the work Jon and I started, many open questions remain any of which could be addressed in an M.Sc. thesis or Ph.D. dissertation.

1. What is the mechanism by which all magneto-centrifugally launched protostellar jets should attain a $\beta \sim 1$ configuration (where thermal and magnetic energy densities are comparable), regardless of the value of β at the launch site?

2. How can the observed trend $v_{\rm rot} \propto v_{\rm jet}^{3/2}$ be tested observationally and can it be made into a useful observational tool?

3. Even though current observations cannot peer close enough to the disc surface to observe the jet launching site directly, we should anticipate one day soon this may be possible. What might the observer see there (*e.g.*, periodically driven knots), and how can this information be used to measure the local physical conditions?

4. Observed jets are knotty (*e.g.*, HH objects). What must be done to the initial or boundary conditions of this problem to account for such macroscopic features? (*e.g.*, Raga *et al.*, 2011)

5. These simulations use the equations of ideal MHD only. What differences would microphysical processes such as radiation, ambipolar diffusion, even viscosity make?

I am also very interested in studying the process of collapse and, in particular, how a giant molecular cloud gives rise to an open star cluster. This is an enormously complicated problem posing all sorts of physical and numerical challenges, only some of which have been addressed in AZEuS. For those interested, I have listed a few topics for M.Sc. theses and Ph.D. dissertations here, all of which involve contributing to the development of AZEuS, with the goal of releasing it into the public domain much like *ZEUS-3D* has been.

D. Clarke, November 2011; modified 4/13.