Scientific Aspects of Proposed Program

We expect that over its lifetime, TORRE will engage in a number of scientific studies, most of which are yet to be conceived. Observing time with TORRE will be available to the astronomical community at large; however, initially we expect scientific investigations with TORRE to be initiated by scientists affiliated with our collaboration. Briefly, we describe below a number of projects which will be implemented by researchers in our collaboration within the first year TORRE becomes operational.

Projects to be Directed by C. M. Johns-Krull (Rice University)

High Precision Photometric Follow-up of Transiting Extra-Solar Candidates: Observations of planetary transits of stars offer a number of advantages when studying the properties of extra-solar planets. Even rather low quality data still permit a rather precise measure of the relative size of a star and its planet, but the brighter stars provide adequate flux to enable interesting follow-up observations, including observations of atmospheric composition (Charbonneau et al. 2002; Vidal-Madjar et al. 2004), exosphere extent (Vidal-Madjar et al. 2003), and infrared emission (Charbonneau et al. 2005; Deming et al. 2005). Most transiting extra-solar planetary systems, discovered by OGLE (e.g. Bouchy et al. 2005), are too faint (V~15) for such studies. C. Johns-Krull is an extended member of the XO project, which aims to find planets transiting stars sufficiently bright to enable interesting follow up studies (McCullough et al. 2005). The XO project announced its first extra-solar planet discovery, XO-1b, this past year (McCullough et al. 2006).

In addition to atmospheric studies of planets, transits around bright stars also provide the best constraints on planetary interior models, which currently cannot explain the observations (Konacki et al. 2005). They also can provide an empirical determination of stellar limb darkening and the frequency and contrast of star spots (Silva 2003). Transits provide simple 1-dimensional imaging of the stellar photospheres, because an inverted transit light curve represents a 1-dimensional trace through the 2-dimensional convolution of the star’s brightness distribution with a uniform disk equal in radius to the planet. In an analogous manner, eclipses in principle can provide the brightness distribution on the face of the planet as the star acts as a knife edge cutting across the disk of the planet during ingress or egress.

Comparison studies will become increasingly interesting and important as different methods of discovering transiting extra-solar planets produce additional systems. Some radial-velocity surveys (Robinson et al. 2006; da Silva et al. 2006) have a selection bias for high metallicity stars, in order to increase the fraction of observed stars that have hot Jupiters (Valenti & Fischer 2005). Photometric surveys for transits are biased toward large depths of the transits (i.e large planets and/or small stars) and short periods, both of which increase detectability. The XO telescopes themselves identify potential transit candidates by observing large swaths of the sky each night. Promising candidates are then distributed to an extended team of follow-up observers who get precise photometry , which combined with light curve modeling, cull out many false positives and facilitate the science described above. The most promising candidates then are observed spectroscopically to detect the reflex radial velocity motion and confirm the planetary nature of the transiting body. In his role as a member of the XO extended team, Johns-Krull will use TORRE to obtain precise, multicolor photometry of transit candidates discovered by the XO project. The rapid response and extreme scheduling flexibility TORRE will provide will make it a very valuable contributor to the XO mission to discover extra-solar planets.

Stellar Rotation in Young Clusters: The specific angular momentum of molecular clouds, from which stars form, is observed to be orders of magnitude higher than that of main sequence or pre-main sequence (PMS) stars (Tomisaka 2000). During the star formation process, angular momentum must be lost as the molecular cloud collapses to form a protostar, and eventually a T Tauri star (TTS), the penultimate stage of star formation. Edwards et al. (1993) proposed that an interaction between stellar magnetospheres and circumstellar disks (known as ``disk-locking") would cause the spin down of stars during the PMS evolutionary stage. Models for the star-disk interaction (Konigl 1991; Shu et al. 1994; Ostriker & Shu 1995), indicate torques due to the magnetic field transfers angular momentum from the star to the circumstellar disk. Angular momentum in the disk is then lost through disk winds which are driven along open magnetic field lines (Shu et al. 1994). One way to map out the evolution of angular momentum observationally is to determine the rotation periods (and radii) of stars of different masses and ages. Rotation periods of stars are determined from the modulation of their light by stellar spots. The pictured outlined above suggests that stars with disks and signatures of accretion (classical TTSs) should be rotating more slowly than their counterparts without disks (weak-lined or naked TTSs). As disks evolve and stars are ``freed" from their lock, they should spin up.

A number of variability studies have been carried out in the Orion Nebula Cluster (ONC) and its ``flanking fields" (Herbst et al. 2002; Stassun et al. 1999; Rebull 2001) as well as in the open cluster NGC 2264 (Lamm et al. 2005; Makidon et al. 2004) to assess the role of circumstellar disks in establishing and regulating stellar angular momenta. Attridge & Herbst (1992) first reported a bimodal period distribution for the brighter stars in the ONC (age ~1 Myr), which was later confirmed by Herbst et al. (2002) to be the result of higher mass stars (M > 0.25 Msol) being locked to their disks. Herbst et al. (2002) suggest that the locking period for the higher mass stars is about P = 7.5 days, while stars with shorter periods (P = 3.2 days) are presumably not locked to their disks. One question that naturally arises from the Herbst et al. (2002) ONC study is: how does the period distribution evolve with time and when might stars typically decouple from their disks? In an effort to answer this question, Lamm et al. (2005) carried out a variability study of NGC 2264 (age ~3 Myr). A bimodal distribution in rotation periods for higher mass stars (M > 0.25 Msol), was found in this cluster too, with peaks located at about P = 1.9 days and P = 4.7 days. This is regarded as evidence for a spin-up of a significant fraction of stars within 2 Myr, consistent with conservation of angular momentum and shrinking stellar radius (Lamm et al. 2005).

While these studies provide some very interesting results on the two clusters studied, and show some general consistency with one another, there is much work left to be done in order to have a complete picture of rotation in young stars. Natural questions to ask include: do these trends continue to older clusters? Are the rotational properties actually related to disk properties? Some progress has been made on the latter question, but the results are currently ambiguous. Stassun et al. (1999) find no correlation between rotation period and the presence of an infrared (IR) excess indicative of a circumstellar disk in a sample of 254 stars in Orion. On the other hand, Herbst et al. (2002) do find a statistically significant correlation between disk signatures and rotation in their Orion sample. Rebull et al. (2002) do not find this correlation in their sample of stars from the ONC and NGC 2264; however, they point out that the expected relationship is complicated (see also Johns-Krull & Gafford 2002) and that a larger statistical sample combined with more sensitive disk indicators are required to provide a definitive test of disk locking.

Rotation periods for stars in more young clusters are needed. To this end, C. Johns-Krull (in collaboration with C. Hamilton) began a photometric monitoring study of NGC 2362 (~5 Myr). Initial results of our study have been resented at the 14th Cambridge Workshop on Cool Stars, Stellar Systems, and the Sun in November 2006, and a full journal paper in in preparation. This monitoring campaign was conducted with the Tenagra Observatory robotic 32” telescope (with a 15’ FOV) and the McDonald Observatory 30” telescope (with a 43’ FOV). TORRE will be very competitive with these telescopes and will easily be able to carry on similar monitoring. We will initiate monitoring campaigns in order to determine stellar rotation curves in several well placed young clusters including IC 348 (~1 Myr), NGC 6618 (~1 Myr), IC 1590 (~2.5 Myr), NGC 6823 (~6.6 Myr), IC 4996 (~ 8.8 Myr), and NGC 1893 (~10 Myr).

Projects to be Directed by P. Hartigan (Rice University)

Jet Launching in Young Stars: One of the key discoveries in the past two decades in the field of star formation is that highly-collimated supersonic outflowing jets accompany all stars with actively accreting disks. These jets emerge perpendicular to the disk plane, and become visible as a series of bow shocks as the jet propagates away from the disk. Jets accompany accretion disks in other astrophysical objects such as X-ray binaries and black holes, but the process is easiest to study in star formation because the objects are closer and the jets radiate emission lines that can be imaged. Observations from the Hubble Space Telescope reveal clear proper motions of jet knots away from the disk after a time interval of only a year for most objects.

The means by which accretion disks eject jets is one of the major unsolved questions in star formation research. Most modern models invoke magnetic fields to drive jets, but direct evidence for these fields is elusive. In all models, jets play a crucial role in the evolution of both the star and the protoplanetary disk by removing the excess angular momentum that accumulates as material in the disk falls towards the star. On parsec scales, jets deposit energy and momentum back into the natal molecular cloud, completing a feedback loop that connects conditions in the molecular cloud to the onset of star formation.

Surprisingly, a dedicated small telescope can make a substantial impact in the study of jet formation despite the fact that the largest telescopes both on the ground and in space have devoted extensive time to this issue. A major unsolved question is whether or not the knots in the jet are driven by sudden increases in the mass accretion rate in the disk, or by a purely magnetic instability that occurs some distance above the midplane and occurs independently of any variation in the accretion rate.

There is a simple way to test whether or not jets are driven by magnetic instabilites or by accretion events. By monitoring the brightness of a large sample of young stars with jets to detect sudden increases in brightness caused by accretion events, one can obtain a record of the mass accretion rates of these systems over an observing season. If an accretion event occurs (as has been seen sporadically in monitoring programs on timescales of a week or so, e.g. Li et al 2001), then it should be accompanied by a jet knot if accretion is tied directly to outflow. The jet knot can then be observed later with HST once it moves away from the source. By obtaining two exposures with HST, one can measure proper motions in the jet and trace the time of ejection for any observed knot. This ejection time should match with a brightness spike in the photometric record if accretion is tied directly to outflow. Alternatively, the times will be uncorrelated if the jet knots are purely magnetic in nature.

The targets will be stars that have colors dominated by accretion, so that any other photometric variations caused by starspots are negligible. It will be important to distinguish photometric changes caused by reddening variations from those caused by accretion events, and this can be done by monitoring the brightness of the H-alpha emission line relative to the brightness in the R-band, which will increase in an accretion event but be unaffected by reddening. The program will obtain a full suite of colors (UBVRIH□) that will also aid interpretation. The stars are just a bit too faint for large amateur telescopes, and the amount of telescope time needed is prohibitive for anything other than a dedicated facility such as TORRE.

Projects to be Directed by R. J. Dufour (Rice University)

BVRIH(alpha)□ Photometric Monitoring of Cataclysmic Variables: Cataclysmic variable stars have irregular light curves and outbursts over periods of a few to hundreds of days. U Gem stars have periods of 30-500 days with 2-6 mag outbursts of 5-20 days duration. Z Cam stars show more cyclic variations of 2-3 mags over tens of days but have long “standstill” events covering several cycles. SU UMa stars have two distinct types of outbursts: (a) faint, frequent, and short over 1-2 days, and (b) brighter superoutbursts with 10-20 days duration. R CrB “inverse nova” stars with irregular and infrequent drops of several magnitudes from a rather constant level of 10-100 day durations. And the largest group, Z Cam, or symbiotic stars, which are close binary systems usually consisting of a red giant and a hot blue stars. The symbiotic stars are of particular interest to Dufour because of their emission-line spectrum variability. Weekly BVRIH□□ monitoring of symbiotic stars will be useful in characterizing their continuum variability and the extent of Halpha variations compared to the BVRI continuum. This can be accurately done for many symbiotics north of -30 declination given recently published UBVRI photometric sequences for fields around 81 symbiotic stars by Henden and Munari (2006) –which makes accurate photometry possible under non-photometric conditions. Additionally, imagery of these with a transmission grating will permit spectral variations in the stronger emission lines to be compared with the continuum variations, which greatly enhances the astrophysical interpretation of the outburst phenomena.

Supernovae in Dwarf Starburst Galaxies: Many automated supernova searches target massive spiral and elliptical galaxies with ~100 billion stellar populations. In comparison, relatively nearby starbursting dwarf irregulars such as IC 10, IC 1613, NGC 1624 NGC 4214, NGC 4449, NGC 6822, etc. in the 1- 30Mpc distant range are typically not studied. Several of the target galaxies, such as I Zw 18 at 14Mpc are among the most metal-poor star forming systems known. Detection of supernovae (Type II being the more likely candidate objects) in them would not only be exceptional in terms of brightness (V ~ +13 for an unreddened Type II SNe in a 10Mpc distant galaxy) but also from a Population I progenitor of known metallicity (from HII region spectroscopy and the fact that the Irr galaxies have small metallicity gradients and relatively low dust content). Some ~50 good candidate galaxies exist for which weekly observations of ~20+/night in BVRIHa reaching R~16-18 mag is practical. A good summer undergraduate student project would be to develop an algorithm to align and compare images taken at different epochs to search for SNe (or even bright novae in several of the Local Group Irr systems).

Red – Near IR Emission Line Maps and Absolute Fluxes in Planetary Nebulae: During bright moon periods, the broad-band filter wheel could be swapped out with a wheel containing several interference filters (some of which Dufour has already or can purchase) which will image selected Galactic planetary nebulae in the red – nearIR emission lines of Halpha, [N II] 6583A, [S II] 6717+31A, [Ar III] 7136A, and [S III] 9532A (and a few continuum regions between emission lines). These would generally be nearby sizable PNe of several to tens of arc minute diameters for the purpose of making calibrated surface brightness maps of the nebulae in these lines (a first for many in the IR lines) to study their ionization structure. During these observations, if the sky is photometric, spectrophotometric standard stars and a few small PNe with known integrated spectral line fluxes will be observed to calibrate the imagery to an absolute flux scale. If the sky conditions are not photometric, useful science is still possible from the ionization structure maps that can be generated from the imagery (H+, N+, S+, Ar++, and S++) which will enable one to model the ionization structure with a photoionization code such as CLOUDY (Ferland et al., 1998)