2nd MMT Science Symposium

May 19, 2010

Abstracts

Oral Presentations

(* denotes Presenters)

"Yellow Supergiants in the Andromeda Galaxy (M31): Putting Massive Star Evolutionary Theory to the Test", P. Massey* and M. Drout (Lowell Obs), N. Caldwell and S. Tokarz (CFA), G. Meynet (Geneva University)

The yellow supergiant content of nearby galaxies can provide a critical test of stellar evolution theory, bridging the gap between the hot, massive stars and the cool red supergiants. But, this region of the color-magnitude diagram is dominated by foreground contamination, requiring membership to somehow be determined. Fortunately, the large negative systemic velocity of M31, coupled to its high rotation rate, provides the means for separating the contaminating foreground dwarfs from the bona fide yellow supergiants within M31. Using Hectospec on the mighty MMT, we obtained radial velocities of ~2900 individual targets within the correct color-magnitude range corresponding to masses of 12 solar-masses and higher. A comparison of these velocities to those expected from M31's rotation curve reveals 54 rank-1 (near certain) and 66 rank-2 (probable) yellow supergiant members, indicating a foreground contamination greater or equal to 96%. We expect some modest contamination from Milky Way halo giants among the remainder, particularly for the rank-2 candidates, and indeed follow-up spectroscopy of a small sample eliminates four rank 2's while confirming five others. We find excellent agreement between the location of yellow supergiants in the H-R diagram and that predicted by the latest Geneva evolutionary tracks that include rotation. However, the relative number of yellow supergiants seen as a function of mass varies from that predicted by the models by a factor of greater than 10, in the sense that more high-mass yellow supergiants are predicted than those are actually observed. Comparing the total number (16) of greater than 20 solar-mass yellow supergiants with the estimated number (24,800) of unevolved O stars indicates that the duration of the yellow supergiant phase is ~3000 years. This is consistent with what the 12 solar-mass and 15 solar-mass evolutionary tracks predict, but disagrees with the 20,000-80,000 year timescales predicted by the models for higher masses.

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“Hypervelocity Stars”, W.R. Brown*, M.J. Geller and S.J. Kenyon (SAO)

A massive black hole sits in the heart of the Milky Way. One consequence of the black hole is that it ejects "hypervelocity stars" from the Milky Way at ~1000 km/s speeds. We discovered the first hypervelocity star at the MMT in 2005, and since then our MMT survey has discovered 14 more unbound stars. The distribution of hypervelocity stars, in space and in velocity, is linked to the black hole ejection mechanism, and reveals the history of stars interacting with the black hole. Measuring hypervelocity star trajectories may also place unique constraints on the distribution of dark matter in the Galaxy.

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“Spectroscopic Observations of the Icy Dwarf Planet Eris with the MMT”, S.C. Tegler (NAU), W.M. Grundy (Lowell Obs), F. Vilas* (MMT), D.M. Cornelison (NAU), W. Romanishin (U. Oklahoma), C. Maleszewski (LPL), M. Abernathy (U. Glasgow)

We describe optical spectroscopic observations of the icy dwarf planet Eris taken with the 6.5m MMT and the Red Channel Spectrograph on 2008 October 3 UT. By comparing our MMT spectra of Eris with our laboratory spectra of ice mixtures, we place constraints on the chemical composition across and into the surface of Eris. Such constraints help identify the important processes operating on the surface of Eris. Furthermore, our work provides comparative planetology context for the New Horizons spacecraft flyby of another analogous icy dwarf planet, Pluto.

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“AGN Reverberation Mapping with MMT/Hectospec”, C. Impey (U. Arizona), M. Elvis, B. Kelly, F. Civano, S. Tang (CfA); (J. Trump*, U. Arizona)

I will present results from the first-ever multi-object AGN reverberation mapping study, performed using MMT/Hectospec from February-May 2010. Reverberation mapping measures the time delay between variability in the continuum and the broad emission lines in the optical spectrum of an AGN, allowing for direct measurements of the broad emission line region size and, using the virial theorem, the black hole mass. I will show how MMT/Hectospec can be used for the accurate spectrophotometry required by reverberation mapping. The 37 AGNs targeted by our campaign nearly double the total sample of reverberation-mapped AGNs, and are especially important in understanding AGNs at $z>0.4$ (where only 1 previous AGN has reverberation mapping). I will show how these more accurate masses are especially useful in studying AGN fueling and evolution in the AGN-galaxy relations.

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“Globular Clusters in M31: Velocity Dispersions and Mass-to-Light Ratios”, N. Caldwell (CfA); (J. Strader*)

New MMT/Hectochelle high-resolution spectroscopy of globular clusters in M31 has been used to derive internal velocity dispersions for nearly 200 clusters; this is the largest such data set for any

galaxy. We use these observations to derive mass-to-light ratios for a large sample of objects, and discuss resulting trends with cluster properties such as metallicity.

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"Dust Grain Growth in Coeval, Young Binaries: Which Stars are Forming Planets?", A. Skemer*, L. Close, P. Hinz, W.J. Hoffmann (Steward Obs.)

Dust grain-growth is one of the initial steps to forming core-accretion planets. However, the stellar/disk properties that lead to grain-growth are still unknown, in part, because the effects of stellar age are difficult to disentangle in large samples. Here we remove the uncertainty of stellar age by studying binary stars, which are thought to be coeval. By spatially resolving the stars, and spectrally resolving the 10 micron silicate feature, we can determine which star in each pair is more efficiently growing grains, and forming planets.

Our work is made possible by the MMT's unique, low-emissivity, mid-IR adaptive optics system, and its combination 10 micron imager/spectrograph/nulling interferometer, BLINC-MIRAC4.

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"Discovery of Gravity Waves in Pluto's Sub-microbar Atmosphere", W. B. Hubbard* (LPL), D. W. McCarthy, C. A. Kulesa (U. of Ariz.), S. D. Benecchi (Space Tel. Sci. Inst.), M. J. Person, J. L. Elliot (MIT), A. A. S. Gulbis (SAAO)

An Arizona-MIT team observing at the MMT recorded a grazing occultation of a star by Pluto on 2007 March 18 at an unprecedented signal-to-noise ratio. Data taken simultaneously at 1.6 micrometers (H band) and in the red end of the visible band (about 0.8 micrometers) show large-scale, nearly limb-aligned density fluctuations in Pluto's atmosphere over a pressure range of ~0.1-0.7 microbars (0.01 to 0.07 Pa; radius range of 1500 to 1350 km). The features are fully resolved and, importantly, achromatic. The data are good enough to show a spectral cutoff moving up in wavenumber as altitude decreases in Pluto's atmosphere. After applying scintillation theory to the data, we find that the wavenumber cutoff agrees with predictions for dissipation of gravity waves by diffusion of heat and momentum. Except for much lower characteristic frequencies, Pluto's high atmosphere resembles the Earth's in some respects.

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"The Effect of Environment on Shear in Strong Gravitational Lenses", K.C. Wong* (U. of Arizona), C.R. Keeton (Rutgers Univ.), K.A. Williams (U. of Texas), I.G. Momcheva (OCIW), A.I. Zabludoff (U. of Arizona)

Using new photometric and spectroscopic data in the fields of nine strong gravitational lenses that lie in galaxy groups, we analyze the effects of both the local group environment and line-of-sight structures on the lens potential. We derive the shear directly from measurements of the complex lens environment, independent of the shear obtained from lens modeling. We account for possible tidal stripping of the group galaxies by allowing the fraction of total mass apportioned to the group dark matter halo and the individual group galaxies to be a free parameter. The environment produces an

average shear of \gamma = 0.09 \pm 0.03, significant enough to affect quantities derived from lens observables. However, the direction and magnitude of the shears derived from the environment does not match those obtained via lens modeling in three of the six 4-image systems where we have calculated model shears. The source of this disagreement is not clear, implying that the assumptions inherent in both approaches must be reconsidered. If only the local group environment of the lens is included, the average shear is \gamma = 0.05 \pm 0.03, indicating that line-of-sight contributions to the lens potential are not negligible. We isolate the effects of various theoretical and observational uncertainties on our results. Of those uncertainties, scatter in the Faber-Jackson relation dominates, boosting the scatter in the shear components \gamma_c and \gamma_s by as much as 0.03. The error in the group centroid position also has a large effect on lenses near the centers of their respective groups, resulting in an offset in \gamma_c or \gamma_s of as much as 0.05. Future surveys of lens environments should prioritize spectroscopic sampling of both the local lens environment and objects along the line of sight, particularly those bright (I < 21.5) objects projected within 2' of the lens.

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"Spectroscopy of M81 Globular Clusters", J.B. Nantais* and J.P. Huchra (CfA)

We obtained spectra of 74 globular clusters (GCs) in M81. These GCs had been identified as candidates in an HST ACS I-band survey. Sixty-eight of these 74 clusters lie within 7' of the M81 nucleus. Sixty-two of these clusters are newly spectroscopically confirmed, more than doubling the number of confirmed M81 GCs from 46 to 108. We determined metallicities for our 74 observed clusters using an empirical calibration based on Milky Way GCs. We combined our results with 34 M81 GC velocities and 33 metallicities from the literature and analyzed the kinematics and metallicity of the M81 GC system. The mean of the total sample of 107 metallicities is -1.06 +/- 0.07, higher than either M31 or the Milky Way. We suspect this high mean metallicity is due to an overrepresentation of metal-rich (MR) clusters in our sample created by the spatial limits of the HST I-band survey. The metallicity distribution shows marginal evidence for bimodality, with the mean metallicities of MR and metal-poor (MP) GCs similar to those of M31 and the Milky Way. The GC system as a whole, and the MP GCs alone, show evidence of a radial metallicity gradient. The M81 GC system as a whole shows strong evidence of rotation, with V_r (deprojected) = 108 +/- 22 km/s overall. This result is likely biased toward high rotational velocity due to overrepresentation of MR, inner clusters. The rotation patterns among GC subpopulations are roughly similar to those of the Milky Way: clusters at small projected radii and MR clusters rotate strongly, while clusters at large projected radii and MP clusters show weaker evidence of rotation.

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"10 Micron Nulling Interferometry at MMT", N. Stock*, P. Hinz (Steward Obs), W. Liu (IPAC), K. Su (Steward Obs)

The MMT has been home to the 10 micron nulling interferometer BLINC for much of the past decade, during which time it has been used to study dust in both protostellar and debris disks. In this talk, I will describe the basics and uses of nulling interferometry at a single aperture telescope such as the MMT. I will focus on how the implementation of adaptive optics at the MMT has significantly

improved the quality of the data taken and conclude with some of the recent science being done with this system on debris disks.

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"A Search for Satellites of Asteroid 4 Vesta using Megacam", E.A. Jensen*(MMTO), M.V. Sykes (PSI), M.L.N. Ashby (Harvard/Smithsonian CfA), F. Vilas (MMTO)

Asteroid 4 Vesta suffered a major impact creating the S pole crater, and many spallation fragments of this impact span the distance from the 3:1 Kirkwood Gap to near-Earth space as smaller asteroids and the sources of the Howardite-Eucrite-Diogenite meteorites. To date, however, no satellites of Vesta have been identified. This lack of satellites seems unusual when viewed in the context of the increasing number of satellites found around much smaller asteroids coupled with the obvious source of satellite material. With the arrival of the Dawn space probe at Vesta in July 2011, the questions of whether and where satellites of Vesta exist affect both safety during the spacecraft approach to the asteroid and the science that we can learn from the mission.

The 6.5-m MMT telescope observed the 25 arcminutes of the sky surrounding Vesta on UT 2006 Jan 5-6th using the megacam imager with the r' filter. The CCD chips gaps served as a makeshift occulting mask for the Vesta (m_V=6.2). Analysis of the 100 million pixels shows no detectable satellite around Vesta. The noise was characterized to see if a satellite could be present within the low SNR regime using a local maximum detecting function. Several thousand local maxima were identified, and of these, no apparent point sources were found to be statistically significant. The brightness from scattering photons with distance from Vesta is determined providing the sensitivity limit of the CCD response to potential satellites. For instance, at 50,000 km from Vesta, a satellite requires a visual magnitude around 19.5; closer to Vesta, it must be brighter, and at the edge of the Hill Sphere (around 114,000 km) the m_V must be brighter than 20.5. The sensitivity of this detection method is currently being tested with simulated satellites of varying magnitude.

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"Galactic Metallicity Gradients and their Evolution", L. Stanghellini*, L. Magrini, E. Villaver, D. Galli (NOAO)

Nearby spiral galaxies such as M33 and M81 are ideal laboratories to study the radial metallicity gradients in an assortment of stellar populations. These gradients, together with their evolution, are essential to constrain chemical evolutionary models. We used Hectospec on the MMT to acquire high quality spectra of HII regions and planetary nebulae (PNe) in M33 and M81. For each galaxy, both sets of objects were observed together, making the comparison of their alpha-element abundances free of observational biases. We found mild metallicity gradients in M33 for both the young and old stellar populations; gradients in M81 are steeper, in broad agreement with the situation of the latter galaxy within its group. In both galaxies the observations are compatible with gradients steepening with time since galaxy formation. Oxygen abundances in PNe and HII regions of M81 indicate a general oxygen enrichment in the last 10 Gyr.

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"Short-Period Binary White Dwarfs", W. R. Brown and S. J. Kenyon (SAO); (M. Kilic*)

I will present an overview of recent MMT discoveries of half a dozen short period white dwarf binaries that will merge within a few hundred million years. I will discuss the prior and future evolution of these systems, including the merger products, i.e. SNe Ia, .Ia, RCrB stars, AM CVn, and helium-rich subdwarf stars.

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"Using Hectochelle to Learn about Dwarf Spheroidal Galaxies", E. Olszewski (Steward Obs), M. Walker (IOA, Cambridge), M. Mateo (Michigan)

We will report on new understanding of dwarf spheroidal galaxies gleaned from MMT Hectochelle (and Magellan MMFS) multi-fiber spectroscopy. We will discuss spectra (and MegaCam imaging) that confirm the existence of new low-luminosity dwarfs, the possibility that all dSph galaxies are embedded in identical dark matter halos, and the contentious thought that the dark matter halos of dSph galaxies lie on the same mass/halo-size line as the larger dark matter halos of spiral galaxies.

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"Planet Hunting with the MMTAO system and Clio", P. Hinz* (U. of Arizona)

The MMTAO system has been used with the Clio imager/coronagraph to carry out surveys for wide-period planets around nearby stars, and image known planetary systems. I will present results from these observations, including the characterization of the HR 8799 planetary system in the thermal infrared, the search for "inner" companions in the Fomalhaut system, as well as statistical constraints on wide-period companions. These observations illustrate the benefit of a low thermal background, high spatial resolution capability at the MMT.

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"The Identification and Investigation of Gamma-Ray Burst Progenitors: An MMT Spectropolarmetric Survey of Wolf Rayet Stars in M33", G. G. Williams* (MMTO), P. Smith (Steward Obs), G. Schmidt (NSF), L. Dessart (OAMP)

There is now irrefutable observational evidence that long duration gamma-ray bursts (GRBs) are linked to Type Ic core collapse supernovae (SNe Ic). This association has resulted in a wide acceptance of the collapsar model as an explanation of the origin of GRBs. In the collapsar model, there are three essential requirements: 1.) a massive core, 2.) no hydrogen envelope, and 3.) rapid rotation. These three characteristics are present in a rapidly rotating Wolf-Rayet (WR) star.

We are conducting a spectropolarimetric survey of WR stars in M33 using the CCD imaging/ Spectro- polarimeter (SPOL) at the MMT. The objective of this work is to identify rapidly rotating WR stars and to study them as potential progenitors of long-duration GRBs. The identification is performed using spectropolarimetry to probe asymmetries in the structure of the mass loss envelopes. With rapid

rotators identified, we will to attack the fundamental question: "What characteristic or environmental parameter determines if a massive star progenitor will produce a GRB in addition to the SN Ic?"

We will present results from our previous Galactic survey and provide motivation for this follow-up study of lower metallicity extragalactic WR stars. We will culminate with preliminary results from the current survey and future plans.

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“Binospec and Future MMT Optical Spectroscopy”, D.G. Fabricant* (SAO)

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Abstract Contribution

“SHELS: A Test of Weak Lensing”, M. J. Geller and M. J. Kurtz (SAO), I.P. Dell'Antonio (Brown), D.G. Fabricant and E. Westra (SAO)

Redshift surveys and weak lensing maps are two powerful tools of modern cosmology. SHELS, a deep complete Hectospec redshift survey in the foreground of weak lensing maps covering 6 square degrees of the sky, offers an independent measurement of the dark matter distribution ``imaged'' by the weak lensing map. In a four square field of the Deep Lens Survey (carried out on the KPNO 4-meter) we acquired redshifts for about 10,000 galaxies in a magnitude limited sample with R $\leq$ 20.3. In a two square degree field with a weak lensing map derived from Subaru SuprimeCam data, we carried out a deeper survey of 5000 red galaxies. Among significant weak lensing peaks in both maps with S/N $\geq$ 3.5, only 1/3 correspond to clusters in the redshift survey; the rest are false positives. In both cases the very highest significance peaks (S/N ≥ 5) do correspond to rich clusters in the redshift survey. Furthermore, in the DLS field, the lensing map fails to detect about half of the clusters it should ``see'' including a cluster which is an extended x-ray source. These comparisons of the completeness and efficiency of catalogs of massive clusters of galaxies (halos) derived from weak lensing surveys are the first of their kind and they provide an interesting counterpoint to the simulations.