2009 SAO Summer Intern Project Abstracts

A Spitzer View of Star Formation in Cygnus-X North

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We present new images and photometry from the massive star forming complex, Cygnus-X North, obtained with the Infrared Array Camera (IRAC) and the Multiband Imaging Photometer for Spitzer (MIPS) on board the Spitzer Space Telescope. A combination of IRAC, MIPS, UKIDSS, and 2MASS photometry are used to classify young stellar objects (YSOs) by their IR spectral energy distributions. Of the $8,231$ sources detected exhibiting infrared excess, 670 are classified as Class I and $7,249$ are classified as Class II. Using optical spectra from 272 sources in the Cygnus-X North complex, we identify 20 B type stars. We find that YSOs tend to be clustered in H II regions around massive stars. We present a minimal spanning tree analysis of YSO clusters in Cygnus-X North. The fraction of infrared excess sources that belong to clusters with > 10 members is found to be $\sim 50-70\%$. Most Class II objects lie in dense clusters within H II region cavities, while Class I sources tend to reside in more filamentary structures along the bright-rimmed clouds, indicating possible triggered star formation. This work is supported in part by the NSF REU and DOD ASSURE programs under NSF grant no. 0754568 and by the Smithsonian Institution.

Truncated Disks in TW Hya Association Multiple Star Systems

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We present high angular resolution (0.3" = 13 AU) SubMillimeter Array (SMA) observations of the 880 micron thermal continuum emission from circumstellar disks in the nearby HD 98800 and Hen 3-600 multiple-star systems. In both cases, the dust emission is localized around a single stellar component (HD 98800 B and Hen 3-600 A) with no evidence for circum-system material. We use two-dimensional Monte Carlo radiative transfer calculations to compare the SMA visibilities and broadband spectral energy distributions with truncated disk models, and use the results to estimate disk size. The inferred outer radii of $10-15$ AU for HD 98800 B and $15-25$ AU for Hen 3-600 A are in good agreement with theoretical predictions for disk truncation through tidal interactions with the stellar companions. This work is supported in part by the NSF REU and DOD ASSURE programs under NSF grant no. 0754568 and by the Smithsonian Institution.

The First Uniform and Statistical Sample of Type Ibc Supernovae Light-Curves

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Through our dedicated Palomar 60-inch monitoring campaign, we obtained detailed optical observations for ~ 36 local ($d < 150$ Mpc) SNe Ibc between 2004 and 2007. Here we present a preliminary analysis of the light-curves and peak absolute magnitudes, representing the first uniform and statistical data set. We find significant dispersion in both the width and decay rates of the light-curves, and, through a comparison with the small, well-studied, set of SNe Ibc in the literature, find that a significant fraction of SNe Ibc are heavily extincted ($A_V > 0.5$ mag). After correcting our light-curves for local extinction, we construct M_V peak histograms for our SNe Ib and Ic. The resulting distributions are found to be statistically indistinguishable, and, therefore, not inconsistent with a single progenitor model. A comparison of SNe Ibc peak magnitudes to the inferred values from nearby ($z < 0.7$) GRB-SNe shows significant overlap between the two samples, although a K-S test reveals that SNe Ibc are, on average, less luminous than GRB-SNe. This result may suggest that the Nickel production mechanism of GRB-SNe is distinct from that of ordinary SNe Ibc, however, it is also likely that this result stems from the many biases plaguing existing GRB-SNe studies.

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Interesting Things We Can Learn About Galaxies From the Deepest IRAC Image Ever Taken

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We construct deep infrared source counts in the deepest infrared image ever taken using the IRAC instrument aboard the Spitzer Space Telescope. We also use the integrated flux from these sources to estimate the contribution from extragalactic sources to the Cosmic Infrared Background (CIRB). Finally, we use the deep infrared photometry mosaic along with observations in the zÂt' band taken with the MMT and F814W band image taken with HST to identify candidate Lyman-Break Galaxies. We find ~ 30 candidate galaxies at redshifts ~ 6 and 7 within the compared field size of 220 arcminutes^2. This work is supported in part by the NSF REU and DOD ASSURE programs under NSF grant no. 0754568 and by the Smithsonian Institution.

Observations of Cepheids with Spitzer

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Classical Cepheid variable stars have remained important indicators of extragalactic distance and Galactic evolution since the discovery of the Leavitt Law in 1908. The *Spitzer* Space Telescope has opened the possibility of extending the study of Cepheids into the infrared, where interstellar extinction is reduced. We have obtained photometry from images of a sample of Galactic Cepheids with the IRAC instrument on *Spitzer*. Here we present mid-infrared period-luminosity relations for Classical Cepheids in the Galaxy. We find a significant period - color relation for the $[3.6]-[8.0]$ IRAC color. Other mid- infrared colors for Cepheids are strongly affected by variable molecular spectral features, in particular deep CO absorption bands. We discuss the extended emission around RS Pup, 1 Car, δ Cep, RT Aur, S Mus and T Mon and whether it might be associated with stellar mass loss. This work is supported in part by the NSF REU and DOD ASSURE programs under NSF grant no. 0754568 and by the Smithsonian Institution.

SUZAKU X-RAY SPECTRA AND PULSE PROFILE VARIATIONS DURING THE SUPERORBITAL CYCLE OF LMC X-4

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We present results from spectral and temporal analyses of *Suzaku* observations of the high mass X-ray binary LMC X-4 at different phases in its superorbital cycle, which is due to the precession of a warped accretion disk. Using the full 13 years of available RXTE/ASM data, we apply the ANOVA and Lomb Normalized Periodogram methods to obtain an improved superorbital period measurement of 30.32 ± 0.04 days, which accurately determines superorbital phases of *Suzaku* observations. The phase averaged X-ray spectra from *Suzaku* observations during the high state of the superorbital period can be modeled as the combination of emission lines, a power-law with $\Gamma \sim 0.67$, and a blackbody with $kT_{\rm BB} \sim 0.17$ keV, which most likely originates from reprocessing of the hard X-rays by the inner accretion disk. We calculate the source luminosity and the blackbody radius, assuming the distance to the source is 50 kpc. The energy resolved profiles show single peaked soft pulses but a more complex pattern of hard pulses; cross-correlation of the hard with the soft pulses shows a phase shift between the two. As with the similar systems SMC X-1 and Her X-1, the variation of this phase shift throughout the superorbital period in LMC X-4 is broadly consistent with the picture in which a precessing disk reprocesses the hard X-rays and produces the observed soft spectral component at different orientations. This work is supported in part by the NSF REU and DOD ASSURE programs under NSF grant no. 0754568 and by the Smithsonian Institution.

The abundance distribution in M31 from optical spectroscopy of HII regions and planetary nebulae

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We present the largest available full-wavelength optical spectroscopic sample of HII regions and planetary nebulae in Andromeda. We have collected spectra with the Hectospec multi-fiber spectrograph of the 6.5m MMT. We use strong line ratios to determine the radial oxygen abundance gradient in the galaxy. Such gradients are useful in constraining models of the chemical evolution of spiral galaxies; particularly the radial variation in gas infall and star formation constraining models of the chemical evolution of spiral galaxies; particularly the radial variation in gas infall and star formation rate. The resulting HII region abundance estimates cover the range from about 4 to 20 kpc in radius in the disk, with a sample size more than twice as large as any previous study. A linear fit to the gradient indicates roughly solar abundances at 20 kpc and twice solar in the inner region, in good agreement with past observations. The planetary nebulae sample extends from 0 to about 25 kpc, with limited coverage at larger distances; a range much larger than any previous study and a sample size several times more numerous. We report trends in the extinction of both the HII regions and planetary nebulae and estimate oxygen abundances for several planetary nebulae in the dwarf satellite NGC205.

Accretion Signatures in TW Hya

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High resolution optical spectra of the nearby accreting T Tauri star TW Hya were taken during three nights in February 2007 using the MIKE spectrograph on the Magellan/Clay telescope. These optical spectra were used to evaluate the presence of "optical veiling", an optical continuum thought to be produced by the accretion process. Contemporaneously, a long observation of the X-ray spectrum of TW Hya was obtained by the CHANDRA satellite. We find a correlation between the amount of veiling and the coronal X-ray emission in which the X-rays are delayed by +0.11 day, suggesting that the accretion process can feed the stellar corona. In addition, we have made temperature measurements of the veiling continuum produced by the hotspot in the photosphere of TW Hya, with results ranging from 8500 K – 12000 K. These results will help to identify the contributions of both accretion and coronal activity to the X-ray emission, and determine the characteristics of the accretion process.

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Submillimeter Variability and the Gamma-ray Connection in Fermi Blazars

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Observations with the Fermi Large Area Telescope have provided a wealth of new information on blazar behavior. To place the high-energy inverse-Compton component in context, we explore correlations between the gamma-ray properties of these objects and submillimeter observations of their parsec-scale jets using data from the Submillimeter Array (SMA). We report on the submillimeter properties of a sample of 171 blazars, 43 of which were detected by Fermi during the first three months of observations. Subclass is determined using the Candidate Gamma-Ray Blazar Survey (Healey et al. 2008), resulting in 35 BL Lac objects and 136 flat-spectrum radio quasars (FSRQs) in our total sample. The submillimeter blazar light curves are modeled as continuous first-order autoregressive processes using a routine from Kelly et al. (2009), from which we derive characteristic timescales. The amplitude of variability is parameterized using the variability index from Hovatta et al. (2008). We calculate energy spectral indices using contemporaneous observations in the 1 mm and 850 micron bands and taking the average over August-October 2008. Our blazar sample exhibits no differences in submillimeter variability amplitude or characteristic timescale based on subclass or luminosity. Submillimeter and gamma-ray energy spectral indices place constraints on the peak frequencies of the two spectral components, but do not necessarily support the spectral sequence interpretation of blazar SEDs (Fossati et al. 1998). All of the light curves are consistent with being produced by a single process that accounts for both low and high states. There is some evidence that objects may be transitioning between BL Lac- and FSRQ-like states during flaring epochs.

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A Spectroscopic Study of Stars in the Open Cluster M67

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We present a spectroscopic study of the properties of 201 stars in the open star cluster M67. We use echelle spectra (R 40,000) obtained with the Hectochelle multi-object spectrograph on the MMT telescope. The 150A-wide spectra are centered on 5225 A and include a rich array of narrow absorption lines and the MgIb triplet. We describe the data reduction process and our method for determination of the stellar effective temperature, surface gravity, metallicity, projected rotation velocity, and radial velocity from cross-correlation of the observed spectra with a library of synthetic spectra. From our analysis of the 201 M67 members, we present values for the cluster age and metallicity. his work is supported in part by the NSF REU and DOD ASSURE programs under NSF grant no. 0754568 and by the Smithsonian Institution.