Research Interests

My primary research interest is in using multiwavelength data to characterize the endpoints of stellar evolution as well as low-mass main-sequence stars ($M < M_\odot$). My senior thesis was on radio observations of pulsars, and I have maintained an active interest in neutron stars since. I am now working to place constraints on the neutron star equation of state, an area where observational astronomy intersects with theoretical physics. One major effort I am leading is to use catalog-level matching and follow-up observations to identify new candidate isolated neutron stars. These blackbody X-ray emitters may present the best opportunity to measure neutron star masses and radii under normal conditions (i.e., in the absence of significant accretion or strong magnetic fields); unfortunately only seven such objects are known.

I have also conducted multiwavelength observations of low-mass white dwarfs discovered in the Sloan Digital Sky Survey (SDSS). Such white dwarfs are thought to be the products of binary evolution and are very likely to be paired with another compact object. However, there is no sign of companions to these white dwarfs in the SDSS data. My observations are intended to uncover these hidden companions; radial velocity monitoring in particular may allow us to measure the companion masses—an exciting prospect if these unseen companions are in fact neutron stars.

In addition, I have assembled several samples of X-ray bright stars with which to examine the connection between activity and e.g., stellar age or metallicity. Main-sequence stars, and especially those less massive than the Sun, have active magnetic fields that are responsible for strong chromospheric and coronal emission. However, the mechanisms underlying this emission—and their relationship to fundamental stellar properties—are not well understood. This is especially true in stars with $M < \sim 0.3 \, M_\odot$, which are fully convective and therefore lack the radiative/convective zone boundary needed to generate $\alpha-\Omega$ dynamos such as that seen in the Sun.

I am now proposing to extend our understanding of the relationship between X-ray luminosity and age in particular by obtaining Chandra observations of the intermediate-age open cluster M37. I am also working on modeling the distribution of X-ray sources in the Milky Way and will test this model with our various samples of X-ray emitting stars. Ultimately, this work will allow us to infer the spatial distribution of stellar ages within the Galaxy, which is essential to understanding our Galaxy’s formation and evolution.

Finally, I am working on a sample of morphologically diverse nearby galaxies with nuclear star clusters (NCs). These are concentrated collections of stars found in the centers of many galaxies whose relationship to the massive black holes (BHs) that are also frequent inhabitants of galactic centers is poorly understood. With my collaborators, I determined that galaxies of all Hubble types and with a wide range of masses host nuclear clusters and active galactic nuclei (AGN), which are proxies for the presence of black holes. I am now leading an effort to combine archival and new X-ray observations to improve our black hole mass estimates and examine $M_{\text{BH}}/M_{\text{NC}}$ and its implications for compact massive object formation in detail.

Missing Objects: Isolated Neutron Stars and Companions to Low-Mass White Dwarfs

While neutron stars have been widely studied for four decades, only seven X-ray bright isolated neutron stars (INSs) are known, far short of the number expected to be detected by the ROSAT All-Sky Survey (RASS; Voges et al. 1999). This is particularly unfortunate because the spectral energy distributions of these thermal emitters may provide the best opportunity for empirically constraining the neutron star mass-radius relation and hence the equation of state (EOS) of neutron degenerate matter. Furthermore, follow-up X-ray spectra may, for example, constrain the physics of neutron star atmospheres.

The current sample of known INSs has proved too small and too diverse in detail to address definitively questions such as the nature of the neutron star EOS. I therefore correlated the SDSS Data Release 4 (DR4; Adelman-McCarthy et al. 2004) with the RASS to select a dozen new INS candidates (Agüeros et al. 2006). Among these was the especially interesting source 1RXS J140654.5+525316, which survived my rigorous selection process—including Chandra follow-up imaging—and for which I used XMM-Newton to obtain
an X–ray spectrum. I also obtained an hour of Gemini time to image the field more deeply in the optical, and in a paper in preparation I present these data and discuss the implications for future INS searches.

While my work on SDSS low–mass white dwarfs (LMWDs) may seem unrelated, it was sparked by the realization that most LMWDs are known as companions to millisecond pulsars (MSPs), meaning that they are in effect discovered as by–products of radio searches for neutron stars. By contrast, the SDSS LMWDs are optically selected, and the SDSS data show no spectroscopic or photometric evidence for any companions. This is surprising, as studies of large samples of WDs have found that in the majority of cases, WDs with $M \lesssim 0.4 \, M_\odot$ have degenerate stellar companions (Liebert et al. 2005). The companion can be another WD (e.g., Marsh et al. 1995) or a neutron star. In the latter case, the less massive progenitor evolves into a LMWD in a near–circular orbit around the NS “reborn” as an MSP.

Because of the tantalizing connections between LMWDs and MSPs, I searched for radio pulsations from putative pulsar companions to 15 spectroscopically confirmed SDSS LMWDs using the Green Bank Telescope (GBT). No convincing pulsar signal is detected in the data. This is consistent with the findings of van Leeuwen et al. (2007), who conducted a search for radio pulsations at 340 MHz from unseen companions to five SDSS LMWDs. My non–detections place stronger constraints on the probability that the companion to a given LMWD is a radio pulsar: $P < 10^{-14}\%$ (Agüeros et al. 2009b).

While these non–detections may not be surprising given the relative birth rate of MSPs (thought to be $\sim 3 \times 10^{-6} \, \text{yr}^{-1}$ in the Galactic disk; Lorimer 2008) and of LMWDs (difficult to estimate, but naively, $\sim 2 \times 10^{-4} \, \text{yr}^{-1}$ in the DR4 volume), the question of whether or not these LMWDs have companions, and of the companions’ nature, remains unanswered. With Craig Heinke (University of Alberta), I am exploring whether we can detect these companions in the X–ray (i.e., whether the companions are neutron stars but not radio pulsars). In a recently submitted paper, we reported on GBT and XMM–Newton observations of SDSS J091709.55+463821.8 that failed to uncover a neutron star companion to this, the lowest–mass SDSS WD known ($M \sim 0.17 \, M_\odot$). We conclude that J0917+4638’s more massive companion (known from radial velocity monitoring to have $M \geq 0.28 \, M_\odot$) is almost certainly another WD (Agüeros et al. 2009c).

I have also obtained radial velocity data with Gemini for three SDSS LMWDs, and with Mukremin Kilic (Harvard Smithsonian Center for Astrophysics) I received time on the 6.5–m telescope at the MMT Observatory, AZ, to monitor several more of these objects. We recently published our results for LP400–22, for which we found a mass ratio $\leq 0.46$ (Kilic et al. 2009). Interestingly, for the roughly ten WD/WD systems for which both WD masses have been measured, the mass ratios $\approx 1$, which is contrary to what is expected from standard population synthesis models (Nelemans & Tout 2005). Given that both LP400–22 and J0917+4638 are in systems with mass ratios $\ll 1$, determining the mass ratios of the other LMWD systems for which the nature of the companion is currently unknown will be important in understanding the role of energy versus momentum balance in reconstructing common envelop evolution.

Stellar X–ray Sources: Samples, Questions, and Galactic Distribution

I have worked on two separate projects using SDSS data and follow–up spectroscopy to characterize large samples of X–ray emitting stars. I constructed a sample of 709 stellar X–ray emitters cataloged in the RASS and falling within the footprint of the SDSS Data Release 1 (Abazajian et al. 2003). The final catalog contains optical, infrared, and X–ray data, along with spectral information for these stars (Agüeros et al. 2009a). Separately, I helped produce a catalog of 348 serendipitously detected X–ray stars in the Chandra Multiwavelength Project (ChaMP; Covey et al. 2008). Together, these two samples help us fill out the X–ray luminosity vs. distance plane for nearby stars.

One intriguing result made possible by these catalogs came from a sample of 36 newly identified X–ray emitting M stars for which we used H$\alpha$ equivalent widths to estimate $L_{\text{H}\alpha}$ and $(g – K_s)$ colors to estimate bolometric luminosities. When we examined the relationship between $L_{\text{H}\alpha}/L_{\text{bol}}$ and $L_X/L_{\text{bol}}$, we found that they are linearly related below $L_X/L_{\text{bol}} \sim 3 \times 10^{-4}$, while $L_{\text{H}\alpha}/L_{\text{bol}}$ appears to turn over at larger $L_X/L_{\text{bol}}$ values. The steepening of the $L_X/L_{\text{bol}}$ vs. $L_{\text{H}\alpha}/L_{\text{bol}}$ relation when high $L_X/L_{\text{bol}}$ sources are
excluded, and the turnover in $L_{\text{H}\alpha}/L_{\text{bol}}$ at large $L_X/L_{\text{bol}}$, reveal that stars with very active coronae can possess very pedestrian chromospheres, at least when viewed at distinct epochs.

There are at least two plausible explanations for this seeming disconnect between the chromospheric and coronal properties of the stars with the most active coronae: either intense coronal X–rays disrupt the chromospheric emission mechanism responsible for Hα emission, or the most luminous X–ray sources were undergoing flare events that were not captured in the non–simultaneous optical observations. The relatively weak coronae implied by the $L_X/L_{\text{H}\alpha}$ relationship measured from the low–activity portion of our sample and the apparent breakdown of this relationship at high activity levels present intriguing clues to the temporal behavior of coronal activity over timescales characteristic of both the non–simultaneity effects ($t < 10$ yr) and population effects ($t > 1$ Gyr) discussed above. A larger spectroscopic sample is needed to test these ideas, and I am currently discussing how best to acquire such a sample with Kevin Covey (Center for Astrophysics) and Andrew West (MIT).

Furthermore, in order to deepen our understanding of how $L_X$ varies with stellar age, I have proposed a 185 ks Chandra observation of the intermediate–age open cluster M37. M37’s rich membership, good match to Chandra’s field–of–view, and large number of newly measured stellar periods ($\gtrsim 600$) make it a promising new testbed for examining the evolution of coronal X–ray emission.

Finally, I am working with Kevin Covey and Paul Green (Center for Astrophysics) to develop a new model for the spatial distribution of X–ray sources in our Galaxy. By applying a statistical model of the age/activity relation to this dataset, we will infer the spatial distribution of stellar ages within the Galaxy. This distribution can then be used to test and inform models of Galactic formation and evolution.

**Nuclear Star Clusters: The Other Inhabitants of Galactic Centers**

Recently, my collaborators and I selected 176 galaxies with known nuclear clusters to determine whether the presence of such a cluster precludes the presence of a central black hole. Using optical spectroscopy and archival radio and X–ray data, we found galaxies of all Hubble types and with a wide range of masses ($10^9 - 10^{11} M_\odot$) hosting both AGN and NCs. From the optical spectra, we classified 10% of the galaxies as AGN and an additional 15% as composite, indicating a mix of AGN and star formation spectra. Given that AGN are proxies for the presence of central BHs, we concluded that galaxies with NCs and BHs are relatively common. We also found that variations of the AGN fraction with Hubble type in our sample suggest that NCs may not play a significant role in promoting or suppressing the formation of, or at least activity of, massive BHs (Seth et al. 2008).

Our study of the demographics of galaxies hosting NCs and BHs and of the relationship between these two types of objects would benefit from having a larger number of galaxies for which we have confirmed the presence of BHs through measurements of $L_X$. I recently proposed a 47 ks Chandra survey of eight galaxies to complement the ten galaxies in our sample with archival high–resolution X–ray data. These data will allow us to improve our BH mass estimates and examine $M_{\text{BH}}/M_{\text{NC}}$ and its implications for central massive object formation in greater detail. Furthermore, they will significantly increase the available sample of BHs with lower mass limits, and with Anil Seth (Center for Astrophysics) I plan to obtain high–resolution optical spectra with Magellan to estimate upper mass limits for the BHs currently lacking them.

**References**


Lorimer, D. R. 2008, Living Reviews in Relativity, 11, 8