2019 SAO Summer Intern AAS Abstracts, given at the January 2020 Meeting in Honolulu

Note: this summary contains a “bonus abstract,” Jonathan’s poster describing the history of our REU site extending all the way back to 1994:

The SAO Astronomy REU Summer Program: The First 26 Years
McDowell, J.\(^1\); Ashby, M.\(^1\); Jones, C.\(^1\)

\(^1\)Center for Astrophysics \mid Harvard \& Smithsonian )

Over 250 undergraduates have now gone through the NSF-funded SAO Astro Research Experience for Undergraduates summer program. The program emphasises preparing undergraduates for graduate school both through research and professional development training. In this poster we will give a brief review of the program and discuss how it has evolved over the past quarter century.

Triggered Star Formation In IC1396A
Adams, J. I.\(^1\); Barlach-Christensen, I.\(^2\); Patel, N.\(^3\)

\(^1\)Physics and Astronomy, Amherst College, Amherst, MA, \(^2\)Department of Astronomy and Theoretical Physics, Lund University, Lund, Sweden, \(^3\)Center for Astrophysics \mid Harvard \& Smithsonian )

Bright-rimmed globules are often found at the interfaces between molecular clouds and HII regions. IC1396A is a well known such globule in the Cepheus OB association region, with evidence of star-formation in the eastern edge of the globule, possibly indicative of radiative implosion (Sicilia-Aguilar et al., 2018). By identifying and studying in more detail the embedded protostars in this globule, we aim to prove definitively whether star-formation in this region is due to triggered or spontaneous processes. We have analyzed Submillimeter Array archival observations at 230 GHz, of the southern rim of IC1396A globule, which includes another proto-stellar source \(\gamma\). We detected dust continuum emission associated with a source \(\gamma_b\), located directly North of \(\gamma\), separated by 5.8\(^\prime\)\(^\prime\). Continuum emission is unresolved in our 8\(^\prime\) beam. Several molecular lines were also detected in our SMA observations, including CO, \(^{12}\)CO, \(^{18}\)O, H\(_2\)CO, and SO lines. H\(_2\)CO and CO emission appear to trace an outflow. We estimate the mass of the dust and gas envelope around \(\gamma_b\) to be 7-8.5 M\(_\odot\), assuming optically thin dust emission, which is significantly greater than previous estimates (Reach et al. 2014). A column density of 4\times10^{12} \text{cm}^{-2} and excitation temperature of 43 K was derived from observations of three H\(_2\)CO lines. Our detection of the SO molecule, which commonly indicates shocked material, is consistent with characteristics of triggering or outflow activity. The close proximity of this source (0.08 pc in projected distance) to the bright rim in globule IC1396A is also indicative of compression of gas by triggering processes. Future higher angular resolution observations of this region are needed to investigate the multiplicity of star-formation, to study the outflow properties, and to probe the physical conditions in shocked regions in order to check the importance of triggering via radiatively driven implosion in this globule.
Rotationally Modulated Magnetic Variability in Praesepe K and M Dwarfs
Ash, A.¹; Douglas, S. T.²; Núñez, A.³; Morris, B.⁴; Agüeros, M.³

¹University of North Georgia, Dahlonega, GA, ²Center for Astrophysics | Harvard & Smithsonian, ³Columbia University, New York, NY, ⁴University of Bern, Bern, Switzerland

The magnetic field of K and M dwarfs is known to vary on many timescales, from minutes to years. The mechanism causing this variability is not well known, however there is marginal evidence indicating that observed variability in Hα emission is caused by magnetically active regions rotating into and out of the field of view. We investigate whether chromospheric activity varies on timescales of stellar rotation in K and M dwarfs by correlating the equivalent width of the Hα line to flux in the K2 bandpass. Photometric variability is driven by dark starspots or bright plages rotating into and out of view. A correlation between Hα emission and flux would indicate that starspots and plages are a primary source of observed variability. We observed thirty-three K and M dwarfs with the OSMOS spectrograph at MDM observatory, and two K dwarfs with the ARCES spectrograph at APO observatory. We compare the equivalent widths measured from these spectra with simultaneous photometric measurements from K2 Campaign 16. We see an increase in activity strength with later spectral types, and decreasing variability with increasing magnetic field strength. We find significant variability in eleven of our targets, with nine targets also showing a correlation between the Hα equivalent width and flux in the Kepler bandpass. One additional target appeared to be significantly variable, however the variability was driven by a flare event. We find six stars which get darker as Hα activity increases, suggesting starspot-dominated magnetic variability. Two targets get brighter as Hα activity increases, suggesting plage-driven magnetic variability. Targets with spot driven magnetic variability tend to be rapid rotators, whereas stars with plage-driven variability tend to be slow rotators. The SAO REU program is funded in part by the National Science Foundation REU and Department of Defense ASSURE programs under NSF Grant no. AST-1852268, and by the Smithsonian Institution.

Classifying X-ray Binaries Using Machine Learning
de Beurs, Z. L.¹; Islam, N.²; Gopalan, G.³; Vrtilek, S.²

¹Department of Astronomy, University of Texas at Austin, Austin, TX, ²Center for Astrophysics, Harvard-Smithsonian, Cambridge, MA, ³Faculty of Physical Sciences, University of Iceland, Reykjavik, Iceland

Consisting of a compact object that accretes material from an orbiting secondary star, X-ray binaries have been observed for more than half a century. However, there is still no straightforward means to determine the nature of the compact object: a neutron star or a black hole. We compare three classification machine learning methods (Bayesian Gaussian Processes, K-Nearest Neighbors, and Support vector Machines) to develop a tool for classifying the compact objects in X-ray

The SAO REU program is funded in part by the National Science Foundation REU and Department of Defense ASSURE programs under NSF Grant no. AST-1852268, and by the Smithsonian Institution.
Each machine learning method uses spatial patterns which exist between systems of the same type in 3D Color-Color-Intensity diagrams. We tested a Bayesian Gaussian Process model that has been used to classify sources observed with the RXTE/ASM with data from the more sensitive MAXI/GSC. Using the MAXI/GSC data, we reproduce the result that the model can accurately classify well-known X-ray binaries. However, we find that the model often misclassifies non-pulsing neutron star systems containing "bursters" as black holes when they are close to the boundary between black holes and neutron stars. We find that K-Nearest Neighbors and Support Vector Machines on average predict the correct classification with greater probability and speed than the Bayesian Gaussian Process, with exceptions for specific systems. Overall, all three methods have a high predictive accuracy, indicating a feasible method to classify X-ray binaries into black holes, non-pulsing neutron stars, or pulsars; nonetheless, all three methods have a relatively high error rate for classifying burster systems. This research has made use of MAXI data provided by RIKEN, JAXA and the MAXI team. The SAO REU program is funded in part by the National Science Foundation REU and Department of Defense ASSURE programs under NSF Grant no. AST-1852268, and by the Smithsonian Institution.

Photometric Classification of Transients from the Pan-STARRS1 Medium-Deep Survey

Dauphin, F.\textsuperscript{1}; Hosseinzadeh, G.\textsuperscript{2}; Villar, V.\textsuperscript{2}; Berger, E.\textsuperscript{2}; Gomez, S.\textsuperscript{2}

(\textsuperscript{1}Carnegie Mellon University, Pittsburgh, PA, \textsuperscript{2}Center for Astrophysics \ Harvard & Smithsonian)

Traditionally, supernovae are classified via spectroscopy, but those classification methods are too expensive to keep up with the discovery rates of upcoming surveys like LSST. Here, we present the photometric classification of 2350 transients discovered with the Pan-STARRS Medium Deep Survey, with an eye towards future machine learning classification methods. We propose a parametric light curve model, which we then fit to the full sample of supernovae using a Markov chain Monte Carlo routine. Then, using principal component analysis on the model light curves, SMOTE re-sampling, and random forests, we train a classification pipeline on 500 spectroscopically classified supernovae. Applying it to the 2350 previously unclassified transients, we find 1798 Type Ia, 82 Type Ibc, 347 Type II, 68 Type IIn, and 53 superluminous supernovae. Our pipeline results in 87\% accuracy, 64\% precision, and 61\% recall. Finally, we compare our newly classified sample to previous large samples from the literature and discuss applications of such data sets in understanding the physics of supernovae. The SAO REU program is funded in part by the National Science Foundation REU and Department of Defense ASSURE programs under NSF Grant no. AST-1852268 and by the Smithsonian Institution.

Constraining the Star Formation Rate and AGN Fraction in IR-Luminous Merging Galaxies using SED Fitting

Della Costa, J., III\textsuperscript{1}; Frigo, A.\textsuperscript{2}; Smith, H.\textsuperscript{3}; Ashby, M.\textsuperscript{3}

(\textsuperscript{1}Astronomy, University of Florida, Gainesville, Gainesville, FL, \textsuperscript{2}Physics, Stony Brook University, Stony Brook, NY \textsuperscript{3}Center for Astrophysics \ Harvard & Smithsonian, Cambridge)
Ultra Luminous Infrared Galaxies (ULIRGs), galaxies with infrared (IR) luminosities $\geq 10^{12} \, \text{L}_\odot$, are thought to arise from galaxy mergers in the local universe. The extreme IR luminosities originate from both star formation (SF) and merger-triggered accretion onto supermassive black holes, when large amounts of dust absorb and re-emit ultraviolet and optical photons from these phenomena. However, it is difficult to determine which phenomenon contributes most to the IR luminosity in ULIRGs. In this study, we seek to disentangle the light emitted from SF and active galactic nuclei (AGNs) in order to estimate the contributions from each, and to better understand the star formation rates (SFRs) in merging ULIRGs, and also to understand the effect of merger stage on them.

We use the Code Investigating GALaxy Emission (CIGALE) to fit the Spectral Energy Distributions (SEDs) of the galaxies used in this study. We focus mainly on constraining the far-infrared peak and turnover (FIRPT), as this feature is arguably the best indicator of the specific source of the IR luminosity. We show that supplementing Herschel PACS Photometric measurements with PACS Spectrophotometry sufficiently constrains estimates of the SF and AGN contributions to the FIRPT in ULIRGS to within 10%. We combine the results of our SED analysis for 49 galaxies with a previous sample of 189 merging ULIRGs having little to no PACS PHOT data. We find that the PACS Spec data alone can be used to determine the SF and AGN contributions to the FIRPT again to within 10%. Additionally, we find that merger stage does not significantly impact the physical characteristics derived from the best fit SED models of the galaxy fluxes. This work will aid future studies in quantifying the various physical processes occurring within merging ULIRGs and help separate the different contributions from their high SFRs and/or AGNs. The SAO REU program is funded in part by the National Science Foundation REU and Department of Defense ASSURE programs under NSF Grant no. AST-1852268, and by the Smithsonian Institution.

Modeling WL 17: An Unusual and Complex Protostellar Disk

Gulick, H.\(^1\); Sadavoy, S.\(^2\); Matrà, L.\(^2\)

\(^1\)University of Iowa, Iowa City, IA, \(^2\)Center for Astrophysics \& Harvard & Smithsonian, Cambridge, MA

WL 17 is a protostar located in the Ophiuchus L1688 molecular cloud complex and has a known disk with a diameter of order 50 AU. We fit three models, a Gaussian disk with a cavity, an asymmetric disk with a cavity, and a Nuker profile to the observed disk visibilities in 0.25" resolution ALMA data of WL 17 at 1.3 mm or 233 GHz. A Gaussian disk with cavity function is the best constrained model. We recover the central cavity with a diameter of 0.2" and identify previously undetected substructures within the disk. We also fit archival WL 17 data at 100 GHz and measure the spectral index for the best-fit model at 100 GHz and 233 GHz, and determine that the WL 17 observations are consistent with optically thick dust emission with a spectral index of $\sim$2.0. The SAO REU program is funded in part by the National Science Foundation REU and Department of Defense ASSURE programs under NSF Grant no. AST-1852268, and by the Smithsonian Institution.
New Insights into the Escaping Atmospheres of HAT-P-11b and WASP-69b: Simulated 10830 Å Helium Line Transmission Spectra

Harada, C.¹; Oklopčić, A.²

(¹University of Maryland, College Park, MD, ²Center for Astrophysics | Harvard & Smithsonian)

Hydrodynamic escape from exoplanet atmospheres may be an important evolutionary process for many irradiated gas-rich planets, and could help explain trends in the observed exoplanet population. Observational evidence for atmospheric escape has usually come from observations of excess hydrogen Ly-α absorption in exoplanet transit spectra. However, because the Ly-α line core can be heavily affected by interstellar absorption and geocoronal emission, recent studies (both observational and theoretical) have turned to the 10830 Å line of metastable helium as an alternative probe of escaping exoplanet atmospheres. The primary advantages of this line over the Ly-α are its resilience to interstellar contamination and its accessibility from high-resolution ground-based spectrographs. In this work, we present simulated high-resolution transmission spectra at the 10830 helium line for two exoplanets: HAT-P-11b, a warm Neptune-mass planet, and WASP-69b, a hot Jupiter. Using a 1D atmospheric model of hydrogen and helium, we simulate possible outflow conditions for the two planets, then couple our model outputs to a new radiative transfer solver to predict spectra. We then compare our results to recent observations of HAT-P-11b and WASP-69b to place constraints on their outflow temperatures and mass loss rates. We find that a range of hydrodynamic models can reasonably reproduce the observations, with our most-likely model of HAT-P-11b having an isothermal outflow temperature of $T_0 = 7300$ K and a total mass loss rate of $\dot{M} = 3.16 \times 10^{10}$ g s$^{-1}$, and our most-likely WASP-69b model having $T_0 = 10000$ K and $\dot{M} = 5.01 \times 10^{11}$ g s$^{-1}$. We attribute the degeneracy between $T_0$ and $\dot{M}$ to the quality of the observations and suggest that higher precision measurements and resolved time-series spectra may help to mitigate the degeneracy in future efforts. The SAO REU program is funded in part by the National Science Foundation REU and Department of Defense ASSURE programs under NSF Grant no. AST-1852268, and by the Smithsonian Institution.

The Extended, Asymmetric Hot Gaseous Halos of Early-Type Galaxies

Lin, K.¹; Kim, D.²; Islam, N.²; Mossman, A.²

(¹University of Massachusetts Amherst, Amherst, MA, ²Center for Astrophysics | Harvard & Smithsonian)

The hot interstellar medium (ISM) in early-type galaxies (ETGs) is important for understanding galaxy formation and evolution. Here, we present two-dimensional maps and radial profiles of the hot gas properties (temperature, density, metallicity, pressure, entropy, and mass) for two nearby giant ellipticals, NGC 1550 and NGC 4636, produced from XMM-Newton archival data to uniquely examine the extended hot gaseous halos in a wide radius range and the effect of the metal abundance variation. We show evidence for asymmetric distributions in 2D surface brightness, temperature, and for the first time, Fe abundance maps. We further compute the cooling-time and the ratios between the cooling and freefall time of the hot gas. Based on our results, we address the possible effects of AGN feedback on the multiphase ISM. This work was supported by the 2017 Smithsonian Scholarly Study Program. The SAO REU program is funded in part by the National Science Foundation REU and Department of Defense ASSURE programs under NSF Grant no. AST-1852268, and by the Smithsonian Institution.
Spectroscopic Variability of Changing-Look Quasar Candidates

Moseley, S.¹; MacLeod, C.²; Green, P.²; Anderson, S.³; Ruan, J.¹; Runnoe, J.⁵; Eracleous, M.⁶; Dodd, S.³

(¹Carleton College, Northfield, MN, ²Center for Astrophysics | Harvard & Smithsonian, ³University of Washington, Seattle, WA, ⁴McGill University, Montreal, QC, Canada, ⁵Vanderbilt University, Nashville, TN, ⁶Pennsylvania State University, University Park, PA)

The Time Domain Spectroscopic Survey (TDSS) is accumulating multiple spectra for over 10,000 quasars over the SDSS survey area. We present an analysis of a small fraction of these sources that were discovered by TDSS to be extremely variable. We use photometry from SDSS, Pan-STARRS, PTF, and CRTS to constrain the timescales, and spectroscopy from TDSS to measure the continuum and Balmer line variability that may be linked to state changes in quasars. The SAO REU program is funded in part by the National Science Foundation REU and Department of Defense ASSURE programs under NSF Grant no. AST-1852268, and by the Smithsonian Institution.

Measuring the Timeline of Cosmic Reionization with Galaxies

Whitler, L.¹; Mason, C.²; Ren, K.³; Conroy, C.²

(¹Arizona State University, Tempe, AZ, ²Center for Astrophysics | Harvard & Smithsonian, Cambridge, MA, ³University of Melbourne, Melbourne, Australia)

Reionization of hydrogen is closely linked to the first structures in the universe, so understanding the timeline of reionization promises to shed light on the nature of these early objects. In particular, transmission of Ly-α from galaxies through the intergalactic medium (IGM) is sensitive to neutral hydrogen in the IGM, so can be used to probe the timeline of reionization. In this work, we implement an improved model of the relation between galaxy UV luminosity and dark matter halo mass to infer the volume-averaged fraction of neutral hydrogen in the IGM from observations of Ly-α. Many models assume that UV-bright galaxies are hosted by massive dark matter halos in overdense regions of the IGM, and thus reside in relatively large ionized regions. However, observations and N-body simulations indicate that scatter in the UV luminosity to halo mass relation is expected. We now model the relation with scatter to assess the impact on Ly-α visibility during reionization. We show that scatter in the UV luminosity-halo mass relation tends to reduce Ly-α visibility compared to models without scatter, and that this is most significant for UV-bright galaxies. We use our new models to infer the neutral fraction at $z \approx 7$, updating the inference without scatter, and place our results in the context of other constraints on the reionization timeline. The SAO REU program is funded in part by the National Science Foundation REU and Department of Defense ASSURE programs under NSF Grant no. AST-1852268, and by the Smithsonian Institution.