Daniel Kocevski
Statement of Research Interests

Overview: The focus of my research has covered a variety of topics in the field of time-domain astrophysics. My work in recent years has ranged from the gamma-ray and x-ray analysis of the prompt emission from gamma-ray bursts (GRBs), multi-wavelength observations of their long-lived afterglows, demographic studies of SNe and GRB host galaxies, and the use of GRB afterglows as probes of the physical conditions of the early Universe. Now, as a member of the Fermi collaboration at Stanford University, I am leading the development of techniques for the analysis of high-energy transient phenomena and investigating the origins of GeV emission from a variety of transient sources. Below are a few highlights of my ongoing research as well as a discussion of where I would like to focus my attention in the coming years. This work would make use of the observational resources made available through collaborators at UC Berkeley, Caltech, and Stanford University, as well as guest observer programs at national observatories and publicly available data through the Swift and Fermi collaborations. It is expected that NASA will continue to fund the operation of the the Fermi and Swift spacecrafts for at least another 5 years, and upcoming missions like NuSTAR (launch 2012) and ASTRO-H (launch 2014) as well as the next generation of atmospheric Cherenkov telescopes (CTA, HAWC), the IceCube neutrino detector, and the Advance Ligo gravitational wave detector, will provide a wealth of new data that will complement high-energy observations of transient phenomena by Fermi well into the end of the decade.

GRBs as Probes of the Early Universe: The unprecedented ability of NASA's highly successful Swift spacecraft to quickly slew and localize GRB afterglows with its X-ray telescope has facilitated followup observations of hundreds of bursts, resulting in a wealth of new information regarding the nature of these events. It is now well established that long GRBs are associated with the collimated emission from the death of stars at cosmological distances, making them among the most distant and luminous events observed in the Universe. As a NSF Astronomy & Astrophysics Fellow at UC Berkeley, I worked on a series of studies addressing these new observations. This work included investigations into the origin of late-time X-ray flares and their connection to the long-lived activity of a GRB's central engine (Butler & Kocevski 2007a; Kocevski et al. 2007), multi-wavelength observations of afterglow emission with ground-based and space-based observatories to place constraints on afterglow models (Bloom et al. 2009) and to investigate the physical conditions surrounding the burst location (Butler & Kocevski 2007b; Perley et al. 2008). Many of these studies were among the first to capitalize on the broad-band data made possible in the Swift era and contributed to a vigorous period of growth in the GRB community.

We now know that GRB afterglows are so luminous that they serve as potential beacons to the distant Universe and provide absorption columns over a wide range of frequencies with which to study the properties of high redshift galaxies that would otherwise evade detection. The afterglow associated with GRB 080319B[1], which occurred at $z = 0.935$ and reached 5th magnitude in *V* band, would have been easily detected in the *K* band with a meter-class telescope out to $z \sim 17$ (Bloom et al. 2009). This makes them ideal candidates with which to constrain the nature of the first stars, galaxies, and the reionization history of the Universe. I plan to continue my work with collaborators at UCB, Caltech, and UCSC to use the Keck telescopes to examine the properties of high redshift galaxies through absorption line spectroscopy at infrared wavelengths. Such observations will allow for investigations of the metallicity content and ISM properties of LMC-like proto-galaxies in the very early Universe. Since GRB progenitors are thought to be associated with regions of high star formation, observations of these dwarf galaxies at high redshift could further our knowledge of star formation in metal-poor environments as well as how the star formation rate (SFR) density varies in the early Universe. Directly tracing the SFR back to the first stars has become an important goal of observational cosmology and GRB afterglows offer a unique tool at accomplishing this task.

GRB Demographics & Cosmography: Investigations into the intrinsic energy released by GRBs have begun to provide insights into the nature of their progenitors and the mechanisms producing their prompt gamma-ray emission. By using the results of a novel Bayesian fitting technique developed by Nathaniel Butler and myself, we were able to release the first Swift spectral catalog (Butler, Kocevski, et al. 2007) and refute the physical origins of several high-energy correlations that were reported using pre-Swift observations (Butler, Kocevski, & Bloom 2009; Kocevski 2011). These correlations had gained significant attention in preceding years because they provided constraints to theoretical models designed to explain the origin of the prompt gamma-ray emission and held the potential to allow GRBs to be used

[1] http://www.kocevski.com/astro10

as standard candles for cosmological applications. In addition, by using the timing of breaks in afterglow light curves that are thought to reflect the effects of jet collimation, we were able to show that the true, collimation-corrected, energy distribution was far broader than previously believed (Kocevski & Butler 2008). These results conflicted with interpretations of pre-Swift observations which suggested that the collimation-corrected energy may act as a standard candle, challenging the proposed use of GRBs for precision cosmology.

Nonetheless, the recent detection of a GRB at z = 8.2 have rekindled hopes that GRBs could be used to perform cosmography of the early Universe. The extent to which the GRB co-moving rate density is connected to the cosmic SFR, for example, has been an active area of research. I plan to expand my work in this area through the use of a population synthesis code that I originally designed to simulate the GRB detection rate by NASA's Fermi spacecraft. By modeling the GRB luminosity function and varying the underlying co-moving rate density, it will be possible to simulate the GRB population observed by particular spacecraft and compare those models to the observed population. I also plan to use this code to further our investigations into why clear signs of time dilation have never been detected in GRB light curves (Kocevski & Petrosian 2011) and to re-examine the origin of the high-energy correlations observed in the GRB data, in the hopes of determining which are more severely affected by selection effects (Kocevski 2011). Determining the robustness of such correlations is an important step towards potentially using GRBs for cosmological applications at redshifts far exceeding those of SNe Ia. I also plan to continue leading an effort within the Fermi collaboration to use my simulation code to isolate a set of observable parameters that could distinguish high redshift GRBs without the need of spectroscopic determinations. The goal of this effort would be to use such determinations to trigger Swift, Chandra, and eventually NuSTAR and JWST, target-of-opportunity requests with which to perform multi-wavelength followup observations of these high redshift sources.

GRB and SNe Host Galaxies: Investigating the environments in which SNe and GRBs occur has long been an important path to understanding the nature of their progenitors, as different origin models have traditionally predicted distinct GRB and SNe host galaxy populations. While at Berkeley, I participated in optical and infrared followup observations of afterglow positions to study the differences between short and long GRB host properties (Bloom et al. 2007), the nature of "dark GRBs", which are bright in gamma-ray and X-ray emission, yet exhibit little or no visible light (Perley et al. 2009), and to place limits on the optical emission from the decay of radioactive elements released during the merger of two compact objects (Kocevski et al. 2010). Many of these studies utilized the unique capabilities of the Keck telescopes and significantly shaped our early understanding of the nature of the galaxies harboring these events. A growing body of observational evidence now links GRB progenitors to low metallicity environments associated with massive star formation in low mass galaxies. Whether low metallicity environments are required to produce GRB and broad-line SNe progenitors or if they simply occur in these low metallicity, low mass galaxies because they are the most common star forming galaxies in the Universe is currently a vigorous area of debate. In Kocevski, West, and Modjaz (2009) we address this question by modeling the mass distribution for long GRBs host galaxies and found that sub-solar metallicity requirements effectively limit GRBs to the lowest stellar mass spirals and dwarf galaxies, matching observations. In Kocevski & West (2011), we focused on the mass-metallicity (M-Z) relation for long GRB host galaxies, which studies have shown to be systematically offset towards lower metallicities relative to the M-Z relation defined by the general star forming galaxy population sampled by SDSS. We show that such an offset could be partially explained if low-metallicity galaxies produce more stars than their equally massive, high-metallicity counterparts, in which case transient events that closely trace the SFR would be more likely to be found in these low metallicity, low mass, galaxies. Our work has shown that such biases must be taken into account when using host demographics to infer the properties of transient progenitors

Our work on GRB host galaxies highlights the fact that many questions still exist regarding the physical conditions necessary to produce GRBs and broad-lined SNe progenitors. I intend to expand my work in this area in the coming years by examining the differences between galaxies that harbor various classes of transient sources. Our proposed explanation for the offset between the GRB and SDSS defined M-Z relations firmly predicts that such an offset would not be expected of transient events that do not follow as closely the star formation history of their host galaxies, such as short duration GRBs and Ia SNe. By quantifying the M-Z relation for different types of SNe found through untargeted surveys, such as the Palomar Transient Factory, Pan-STARRS, and eventually LSST, we can firmly test this prediction. I also plan to continue our work to assemble data with which to examine how the properties of GRB and SNe host galaxies evolve with redshift. In this way, we can examine the metallicity dependance of their progenitors by testing our prediction that the mass range of galaxies capable of producing a GRB should broaden with increasing redshift. Investigations into the properties of host galaxies such as these will give us broader insights into the nature of the underlying progenitor and the environmental conditions that are necessary for their production, as well as star formation in metal-poor environments and the star formation history of the early Universe.

High-Energy Astrophysics with Fermi: Over the past three years at Stanford University, I have served as a member of the Fermi Gamma-ray Space Telescope collaboration, leading the development of automated analysis techniques for the study of transient phenomena and using the spacecraft's unprecedented spectral coverage to investigate the prompt emission associated with GRBs, solar flares, and other transient sources. Since its launch in June of 2008, Fermi's Gamma-ray Burst Monitor (GBM) has already surpassed the number of GRBs detected by Swift, and has detected dozens of these bursts at GeV energies with its Large Area Telescope (LAT). These GeV detections have revealed that the prompt GRB spectra are far more complex than previously understood. Through a series of collaboration papers (Abdo et al. 2009a, 2009b; Ackerman 2010), we have shown that LAT detected GRBs do not show clear evidence for the prompt inverse-Compton components at high energies that many theorists had expected. Instead, Fermi observations have revealed previously undetected thermal signatures as well as delayed and long-lived GeV emission. The interpretation of both of these new components has proven to be a source for vigorous debate within the high-energy community. Nonetheless, the detection of GeV photons from such highly variable sources has allowed us to place constraints on the physical conditions of the emitting region, suggesting that the ejecta responsible for this emission must be traveling at nearly the speed of light to avoid attenuation due to pair production. Conversely, we have also shown that LAT "dark" bursts must suffer significant attenuation above 100 MeV in order to have gone undetected (Abdo et al. 2011). The near simultaneous detection of keV and GeV emission from the short duration GRB 090510[2] has also allowed us to place stringent limits on the frequency dependent variation of the speed of light predicted by some quantum gravity models (Abdo et al. 2009c).

Observations of unexpected flares associated with the Crab nebula and the detection of X class solar flares from the Sun serve to prove that Fermi continues to detect unique high-energy transient phenomena that we are only beginning to explore. I intend to continue my leading participation in the investigation of these new discoveries as they emerge. The nature of the delayed high-energy emission from GRBs, for example, has yet to be fully understood and I plan to continue our work towards developing a model to explain this emission. Likewise, I plan to continue our investigations into the origin of the thermal spectral component that Fermi has detected in the spectra of some GRBs. As Fermi gathers more data on such bursts, we plan to address whether the source-frame temperature of the underlying blackbody is narrowly distributed, which could finally shed light on the properties of the emitting region's photosphere as well as give us a method to determine the distance to a burst from the gamma-ray data alone. Such queries into how the temporal and spectral features of these newly detected emission components relate to other source frame properties may also finally give us insight into whether the composition of the emitting region are magnetic or particle dominated and whether the GeV emission arises from shocks internal or external to the GRB outflow.

Multi-messenger Astrophysics: The Fermi spacecraft also stands to compliment upcoming non-electromagnetic observations of transient phenomena. Advanced LIGO is expected to detect gravitational wave signals of coalescing binary systems, and Fermi is likely of providing the first electromagnetic confirmation of such an event. Such a detection will be a breakthrough in astrophysics and would advance our understanding of transient gamma-ray progenitors. Likewise, the detection of a neutrino signal by the IceCube and/or ANTARES neutrino telescopes during a GRB or active galactic nuclei (AGN) flare would provide definitive evidence of hadronic interactions in their respective jet outflows. All-sky gamma-ray observations with Fermi are well suited for comparisons with transient multi-messenger observatories, making coordinated observations a powerful research tool in the coming years.