BRIGHT: An Exploration of the Environments of Short Gamma-ray Bursts and their Connection to Neutron Star Mergers

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Gemini Science Meeting 2022

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Abstract

Short gamma-ray bursts (GRBs; z~0.1-2), originate from neutron star binaries, thus are directly connected to the local population of gravitational wave mergers. However, neither of these events alone can be used to fully determine the formation and evolution of these systems. Instead, we can use the host galaxies of short GRBs to determine their environments, merger timescales, kick velocities, and evolution with cosmic time. Here, I discuss building the largest, public catalog of short GRB host galaxies (BRIGHT), which takes advantage of 15 years' worth of large telescope observations, including current and archival Gemini observations. I apply spectral energy distribution (SED) modeling to the hosts using these observations to determine their stellar population properties, such as mass, age, metallicity, and star formation rate. I also showcase our new results in the context of the field galaxy population to understand how neutron star mergers depend on their environments. Finally, I note how this research will have important implications for stellar evolutionary fates and follow-up of gravitational wave events.

Short GRBs and their Host Galaxies

- **Short GRBs** are massive explosions that likely originate from neutron star mergers (e.g. GW170817)
- **Host galaxy studies** of these events are necessary to:
  - Understand their **environments** and **formation channels**,
  - Uncover the **merger timescales** (delay-times) and redshift distributions,
  - And determine binary properties, such as **kick velocities**.

The Host Breakdown

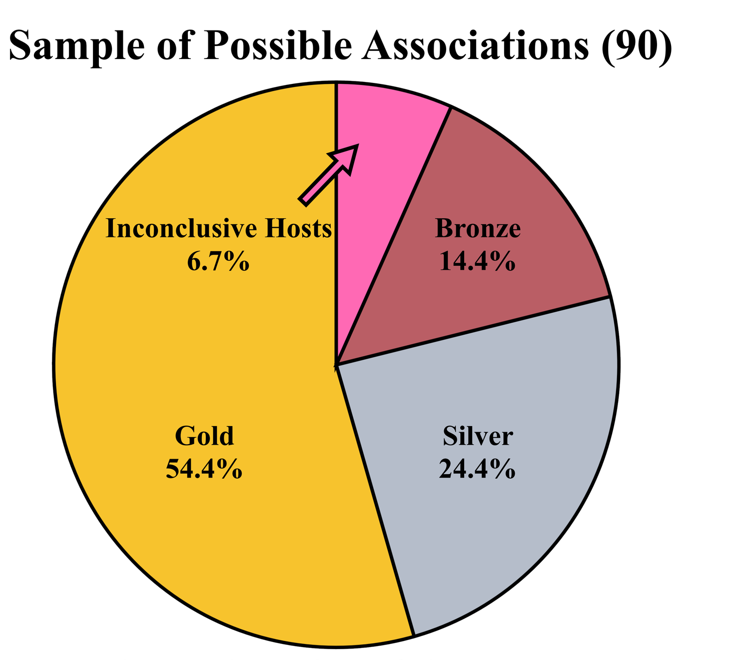


Figure 3: The total number of short GRBs not in observing constraint regions: Gold, Silver, and Bronze samples represent the host associated sample, with Gold having the lowest probability of chance coincidence (best host association) and Bronze having the highest. Inconclusive host associations are also shown. *From Fong, Nugent, Dong et al. 2022.*

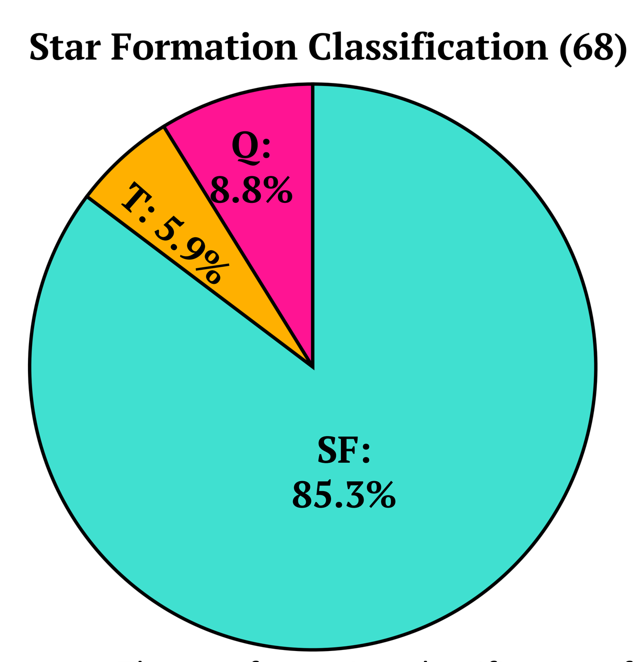


Figure 4: The star formation classifications for the full sample. SF represents star-forming (blue), T denotes hosts transitioning from star forming to quiescent (yellow), and Q refers to quiescent hosts (pink). The star forming fraction is consistent across Gold, Silver, and Bronze samples. *From Nugent et al. 2022.*

- 84 total host associations: largest short GRB host sample to date
  - Best associations = Gold Sample
- 68 hosts have enough data to determine their stellar population properties with SED modeling code *Prospector*
  - With star-formation rate (SFR), stellar mass, and redshift we can determine star formation classification

Redshift and Ages

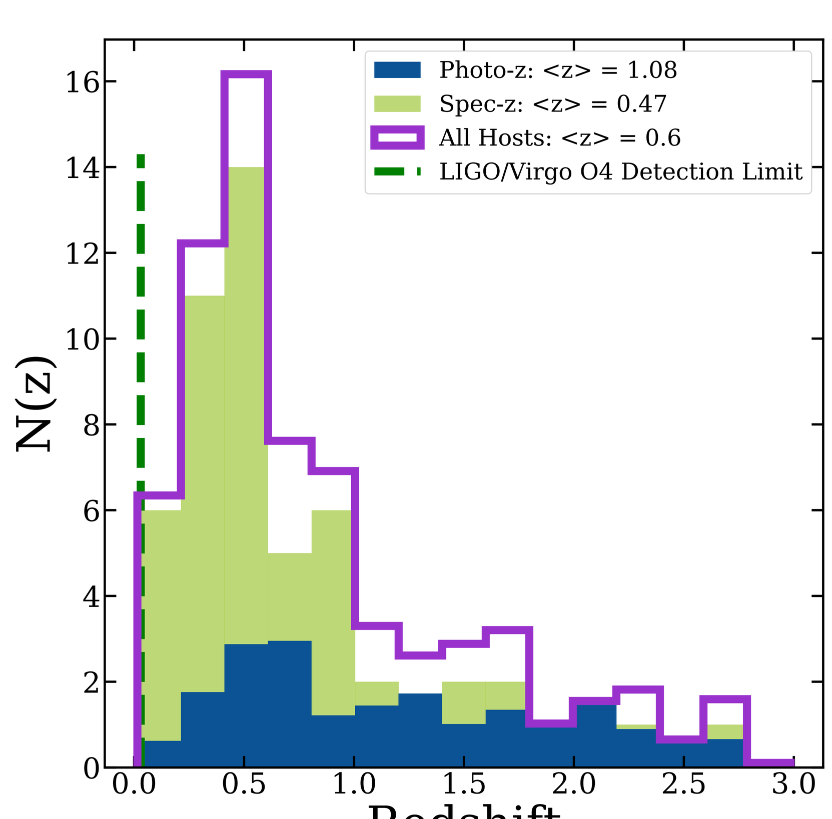


Figure 5: The short GRB host redshift distribution, with the full sample outlined in purple, the spectroscopic redshift in green, and the photometric redshift sample in blue. We show the LIGO/Virgo O4 detection limits for neutron star mergers with the dashed green line. *From Nugent et al. 2022.*

- The z > 1.0 short GRB sample is much larger than known before
  - The high-redshift sample is important for understanding the complete delay time distribution (see *Zevin, Nugent, et al. 2022*)
- We find significant evidence for a decreased short GRB progenitor formation efficiency since z = 2.0

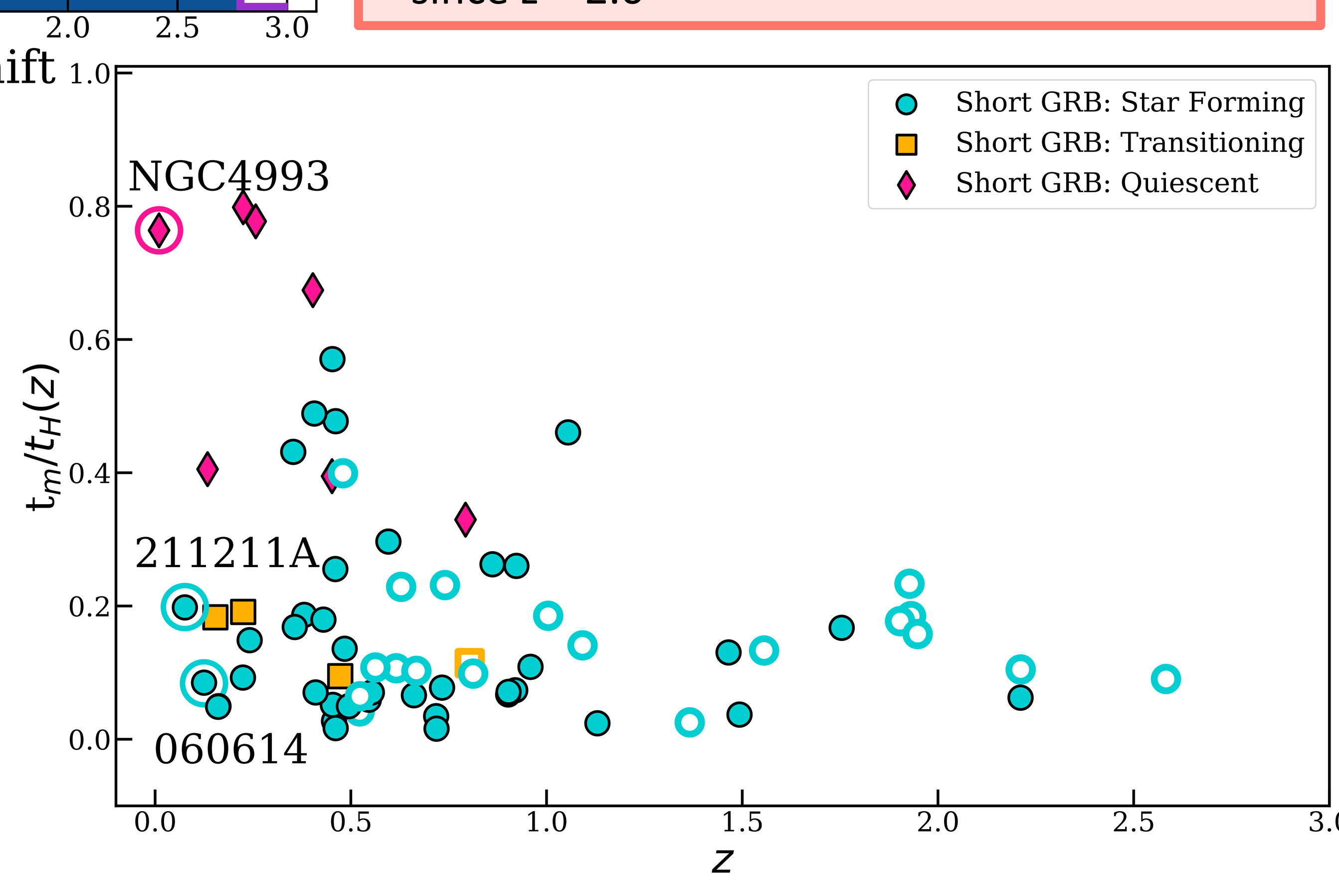


Figure 6: The stellar population age of the short GRB hosts, normalized by the age of the universe at their redshift, versus their spectroscopic (color-filled circles) or photometric (white-filled) redshifts. Pink diamonds represent quiescent hosts, yellow squares are transitioning hosts, and blue circles are star-forming hosts. *From Nugent et al. 2022.*

The Gemini Contribution

- ~10% of our photometry and ~26% of our spectra are from Gemini
  - From both our program and archival data from 2005-2021
  - Faintest host detected with Gemini is g≈26 mag AB
  - Highest redshift host detected by Gemini is at z = 1.754

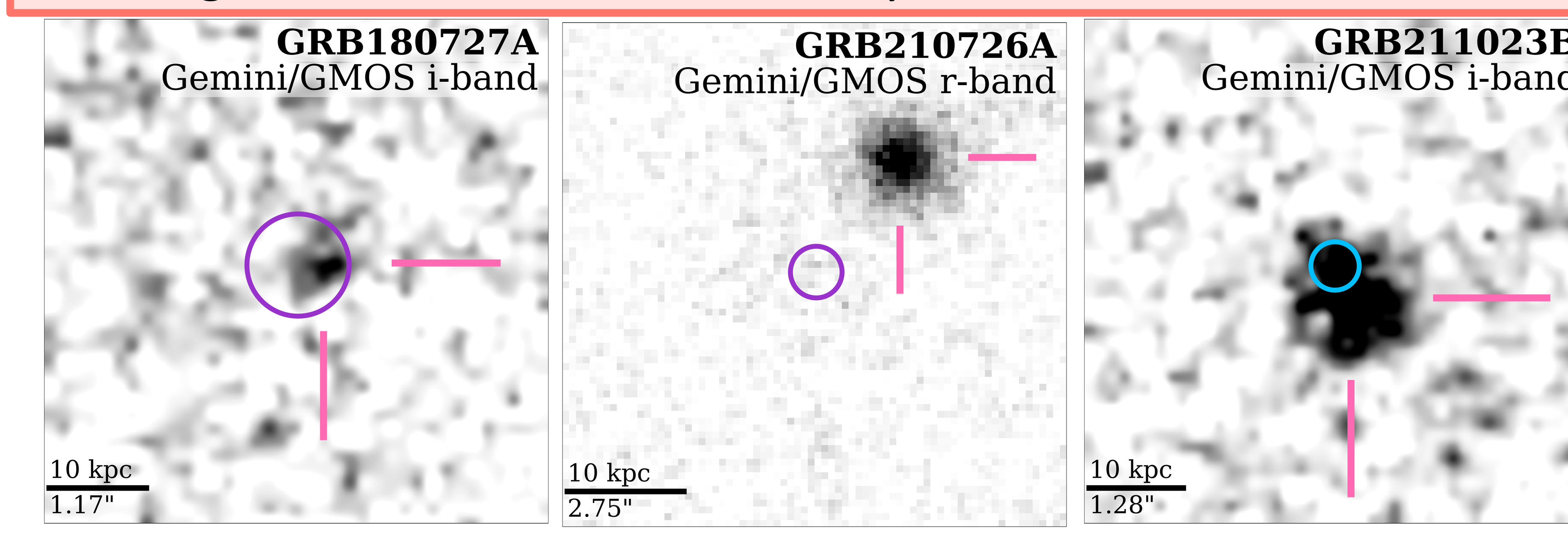


Figure 1: A selection of short GRB host photometry taken with Gemini/GMOS imaging. The pink crosshairs denote the location of the host, the purple circles represent the X-ray afterglow positions of the short GRBs, and the blue circle shows the optical afterglow position. *From Fong, Nugent, Dong et al. 2022.*

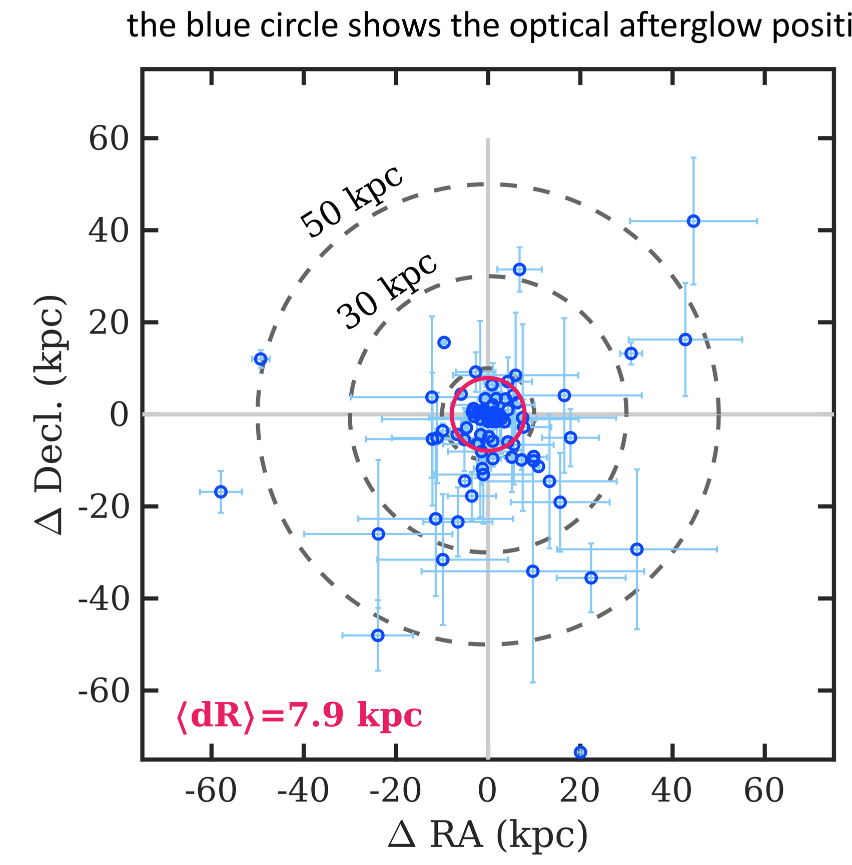


Figure 2: The physical offsets of short GRBs from the center of their host galaxies (determined from their most precise afterglow positions) and their 1-sigma uncertainties.

- We use our Gemini Rapid-ToO program to follow-up on short GRB afterglows to determine their hosts
- With our new sample, we are now detecting higher offsets for short GRBs than known before

Star formation Rates and Masses

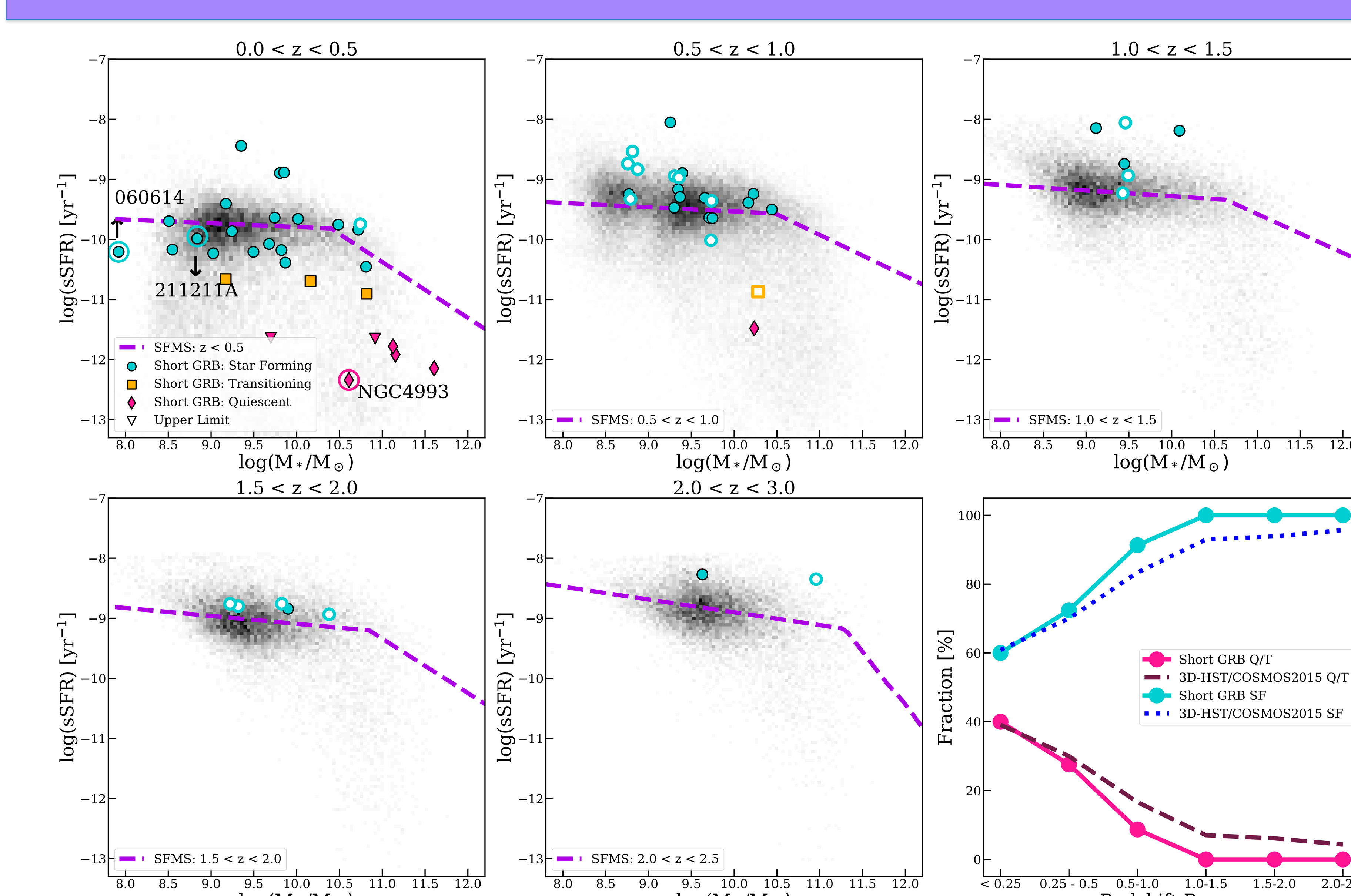
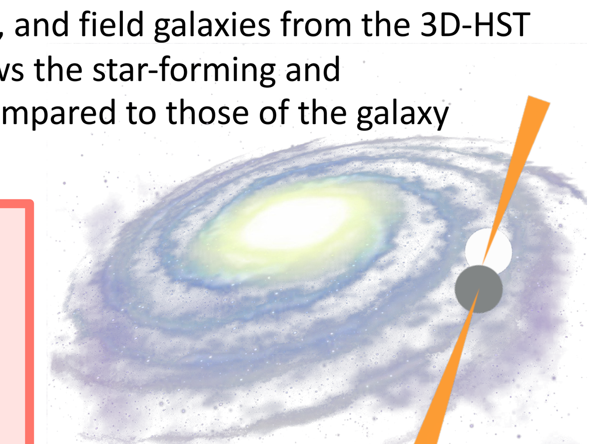


Figure 7: Short GRB SFRs and masses (star-forming: blue circles, transitioning: yellow squares, quiescent: pink diamonds) compared to the star-forming main sequence (SFMS; purple line), and field galaxies from the 3D-HST and COSMOS2015 surveys (grey histogram). The bottom rightmost plot shows the star-forming and transitioning/quiescent galaxy fractions at various redshifts of short GRBs compared to those of the galaxy surveys. *From Nugent et al. 2022.*



- Short GRBs and their neutron star mergers progenitors are expected to occur in hosts that:
  - Trace the properties of the field galaxy population at their respective redshifts
  - Are not typically the most massive or quiescent galaxy in the field
- Local universe events GW/GRB 170817 and GRB 211211A occurred in hosts with starkly contrasting stellar masses and SFR's
  - May have unique implications for neutron star merger host-based follow-up searches in LIGO/Virgo O4

All data products are available on the Broad-band Repository for Investigating Gamma-ray burst Host Traits at bright.ciera.northwestern.edu!

The Fong Group acknowledges support from the National Science Foundation under AAG and CAREER grants.