Triggering and Regulation of Extragalactic Star Formation - J1023+1952 as a unique laboratory

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Introduction

The tidal dwarf galaxy J1023+1952 sits at the intersection of two tidal streams in the merger system Arp 94, and is believed to have formed from tidal debris stripped from the spiral galaxy NGC 3227 (Lisenfeld et al. 2008).

The southern half of J1023+1952 contains massive on-going star formation, while the northern half is inactive. However, column densities in HI and H_2 are fairly uniform across its full extent; each half contains a high density ridge with $N_H \sim 2.8 \times 10^{21}$ cm^{-2} (Mundell et al. 2004). The regions with on-going SF have lower velocity dispersions in the CO (FWHM = 30-70 kms^{-1}) compared to the rest of the dwarf (FWHM = 80-120 kms^{-1})(Lisenfeld et al. 2008).

A dynamical trigger is required to explain the SF in J1023+1952. We present a comparison of the cluster luminosity functions (CLFs) in different environments across the system, specifically between those in J1023+1952,and in the spiral arms and bar of NGC 3227 with the goal of determining the triggering mechanism.

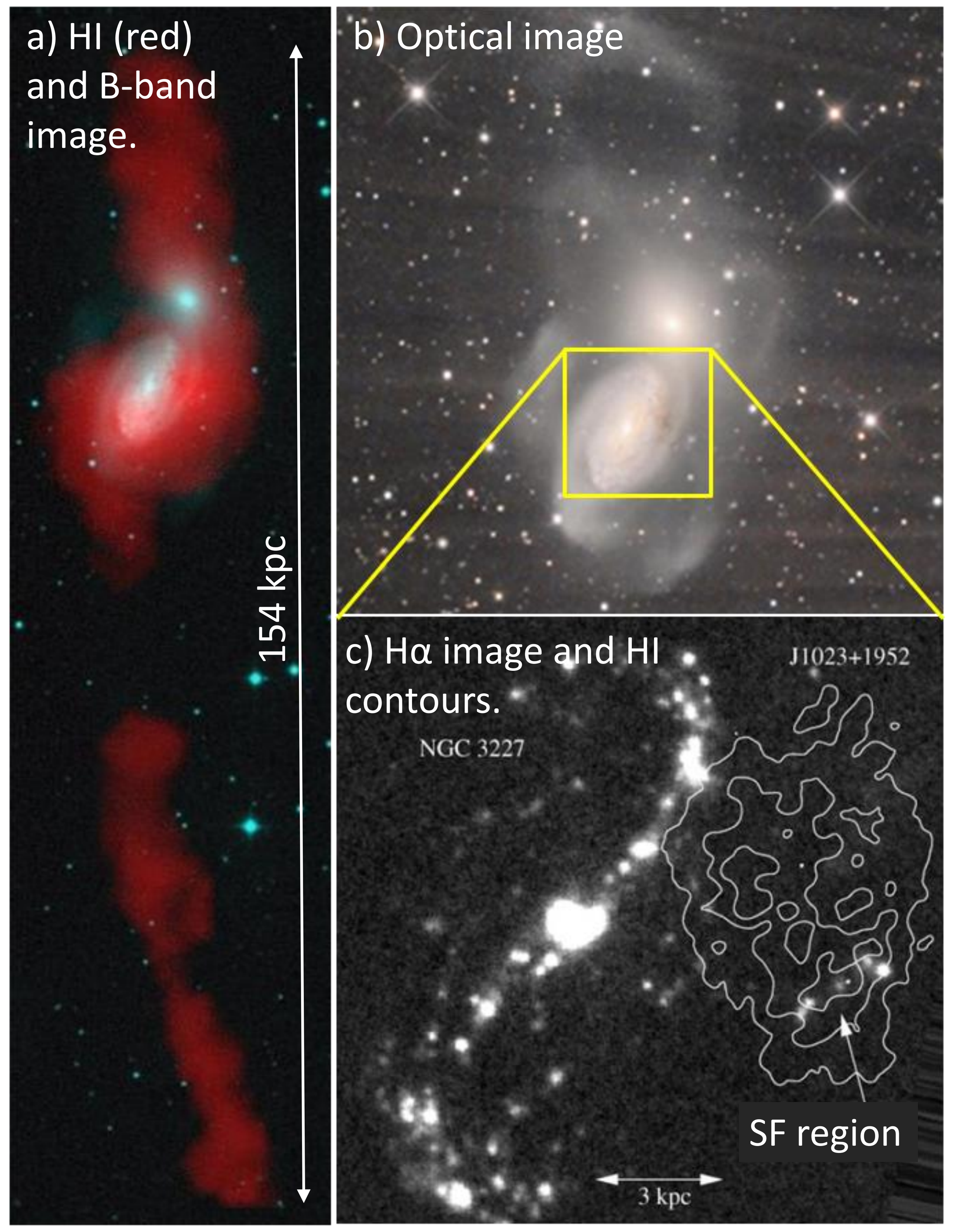

Figure 1: a) VLA D-configuration HI (red; Mundell et al. 1995) on an optical DSS B-band image of Arp 94 showing the full extent of the tidal tails, b) optical image showing loops of tidal debris and c) Hα image of NGC 3227 with HI contours of J1023+1952 superimposed (Mundell et al. 2004). The contours correspond to column densities of 0.4, 1.6, 3.2 and 3.9 x 10^{21} cm^{-2}.

J1023+1952

- Tidal dwarf galaxy formed out of debris stripped from NGC 3227 – evidence suggests it is not a pre-existing dwarf galaxy:
  - Kinematically distinct from NGC 3227.
  - Lacks IR emission → no detectable old stellar population.
  - Recycled gas - metal rich with [12 + log(O/H) = 8.6 ± 0.2].
- Dynamical mass ~ 3.6 x 10^9 $M_\odot$.
- Mass in HI ~ 3.8 x 10^8 $M_\odot$.
- Distance = 20.4 Mpc.
- HI column densities in the range 4 x 10^{20} cm^{-2} < N_H< 4 x 10^{21} cm^{-2}.
- On-going massive SF occurs only in the south.
- Optical and IR SEDs suggest SF is recent (<10 Myr).
- Hα flux ~ 2.55 x 10^{-14} ergs s^{-1} cm^{-2} corresponding to a star formation rate SFR(Hα) ~ 10.6 x 10^{-3} $M_\odot$ yr^{-1}.

Aperture Photometry

- B, R and I band imaging carried out using the 2.54 m Isaac Newton Telescope (INT).
- Color-magnitude and color-color diagrams of optical knots within J1023+1952 were compared with sources within the spiral arms and bar of NGC 3227.
- The INT lacks the resolution to resolve clusters, and errors on diffuse emission are large.
- Additional uncertainty in extinction in the disk of NGC 3227.
- It is unclear whether any environmental distinction between cluster populations is present.

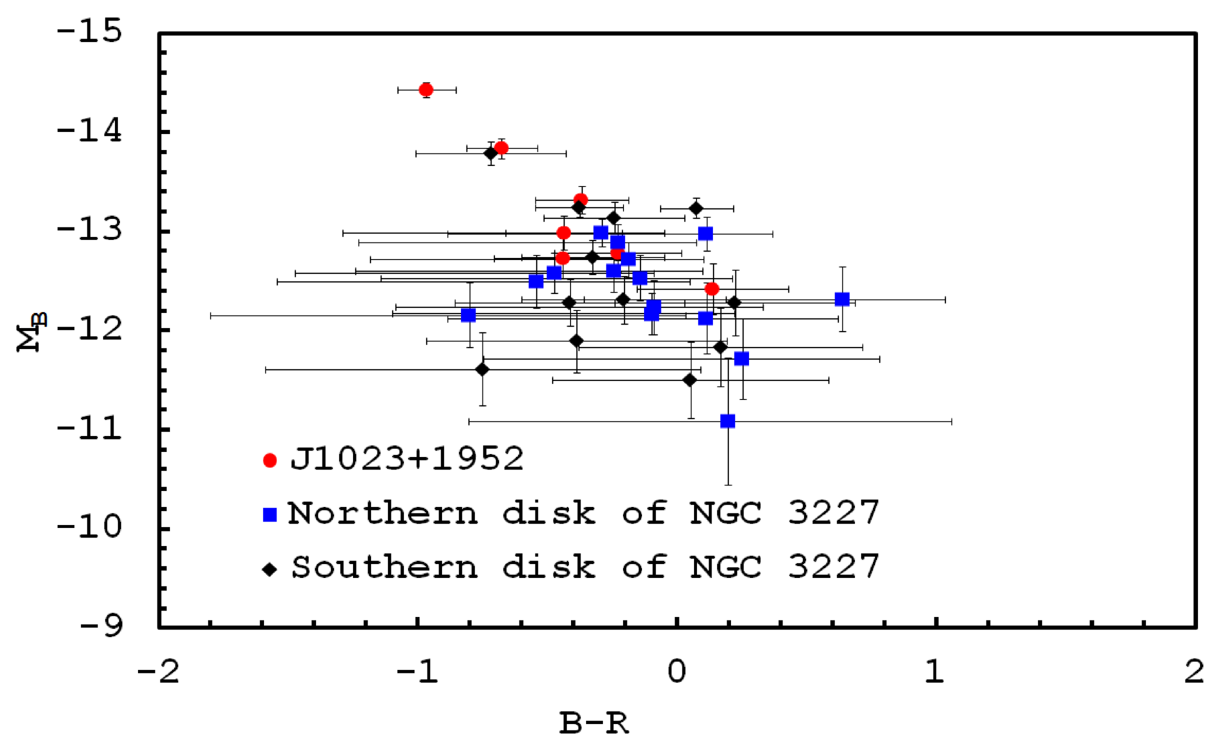

Figure 2: Color-magnitude diagram for optical knots in the system.

Cluster luminosity and mass functions

- Hubble Space Telescope imaging using WFC3 in F547M.
- Automated object detection using SExtractor.
- Measuring the CLF for young stellar clusters may give clues about local conditions and any environmental differences.
- The CLF is approximately a power law: $N \propto L^{\alpha}$.
- Cluster age and mass distributions are independent, and so the index of the LF is the same as the index for the cluster mass function (CMF) which is also a power law (Fall, 2006).
- CMFs differ due to varying amounts of disruption over the various environments (Bastian et al. 2011).

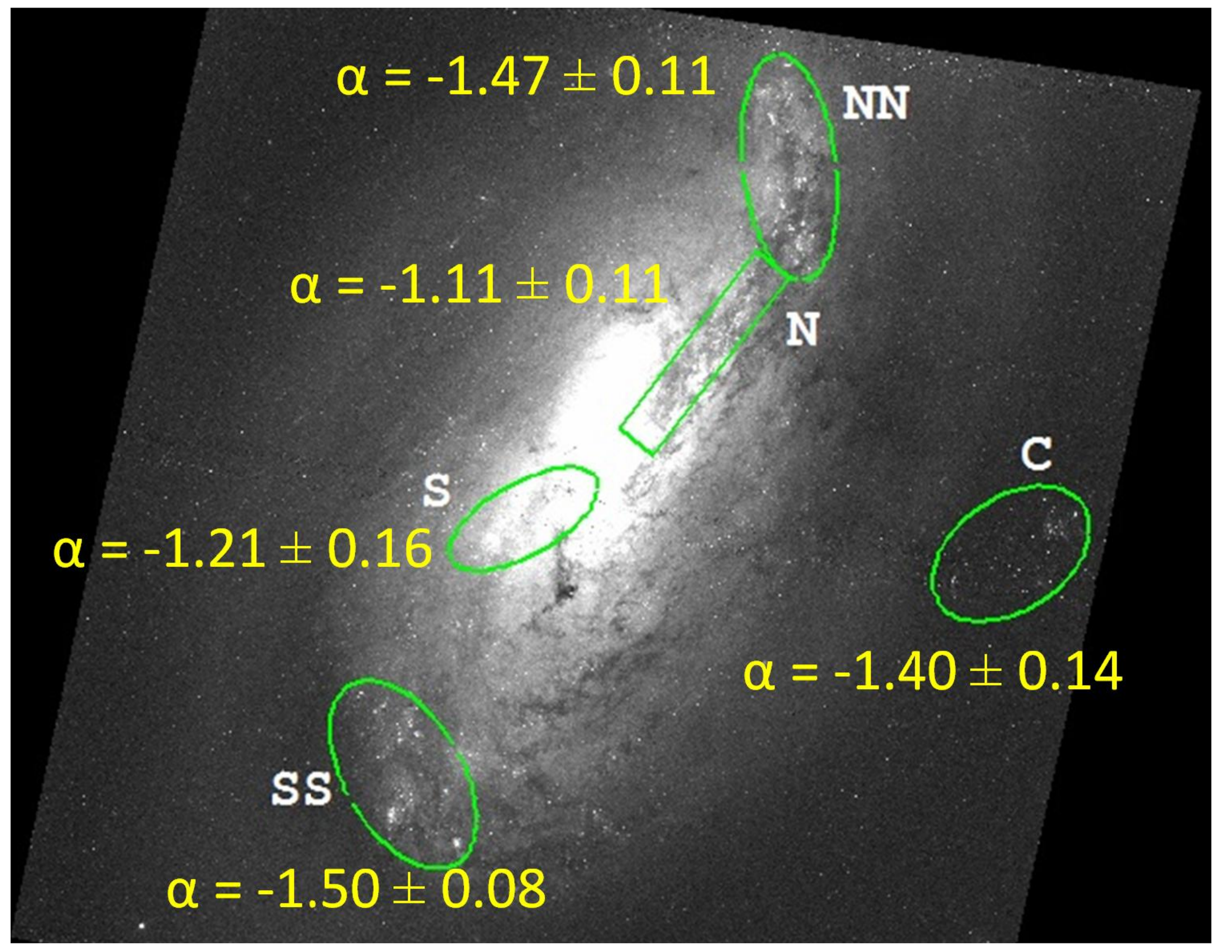

Figure 3: Regions for which the CLF index was calculated.

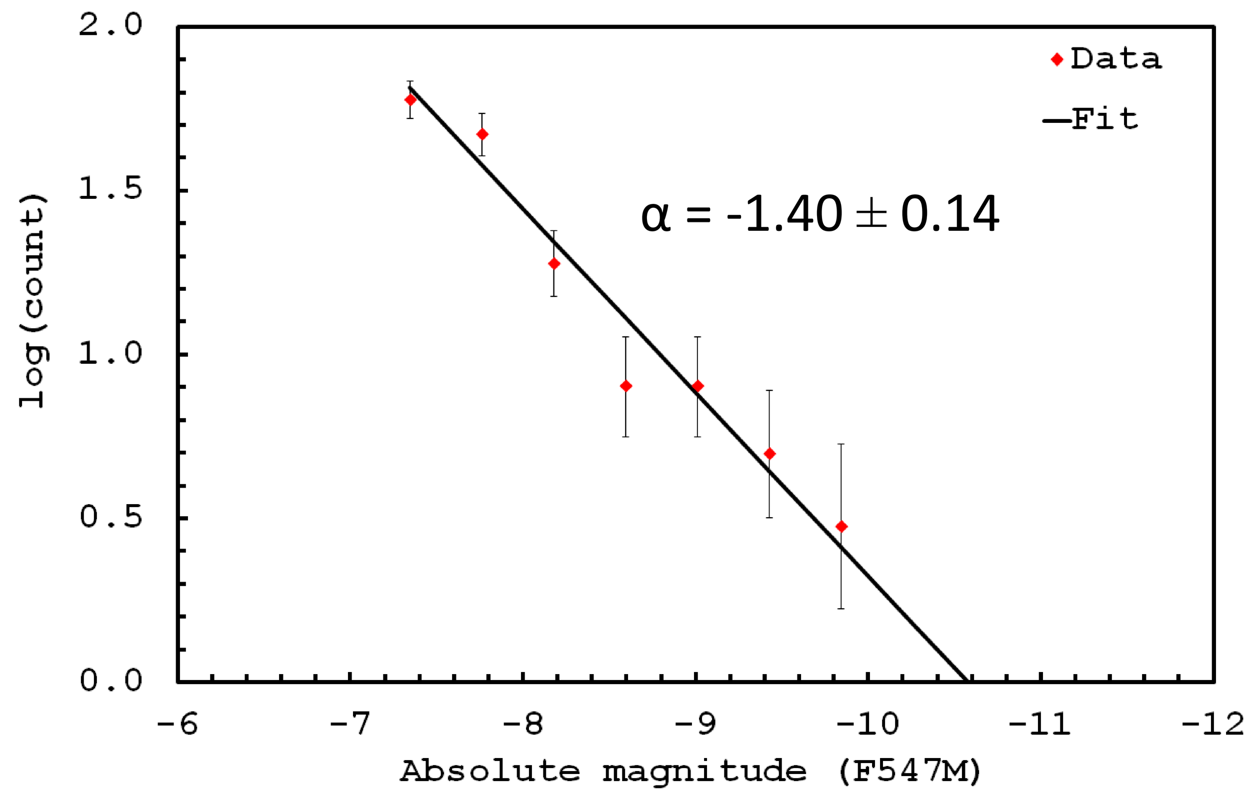

Figure 4: (above) the CLF for clusters in J1023+1952, or region C in Figure 3.

Conclusions

- The indices of the CLFs and CMFs vary across different environments, suggesting varying levels of cluster disruption.
- The level of disruption in the dwarf appears to be comparable to the SF regions in the outer spiral arms of NGC 3227. This might suggest that the conditions in these regions are similar.
- It is not clear whether differences in the bar are real; NGC 3227 hosts an AGN, and infalling gas in the bar may present a different SF environment.
- Further high-resolution multi-band imaging could allow cluster populations to be studied further in color-magnitude and color-color diagrams.
- Determination of the SF efficiency at each site might yield further clues into environmental differences.

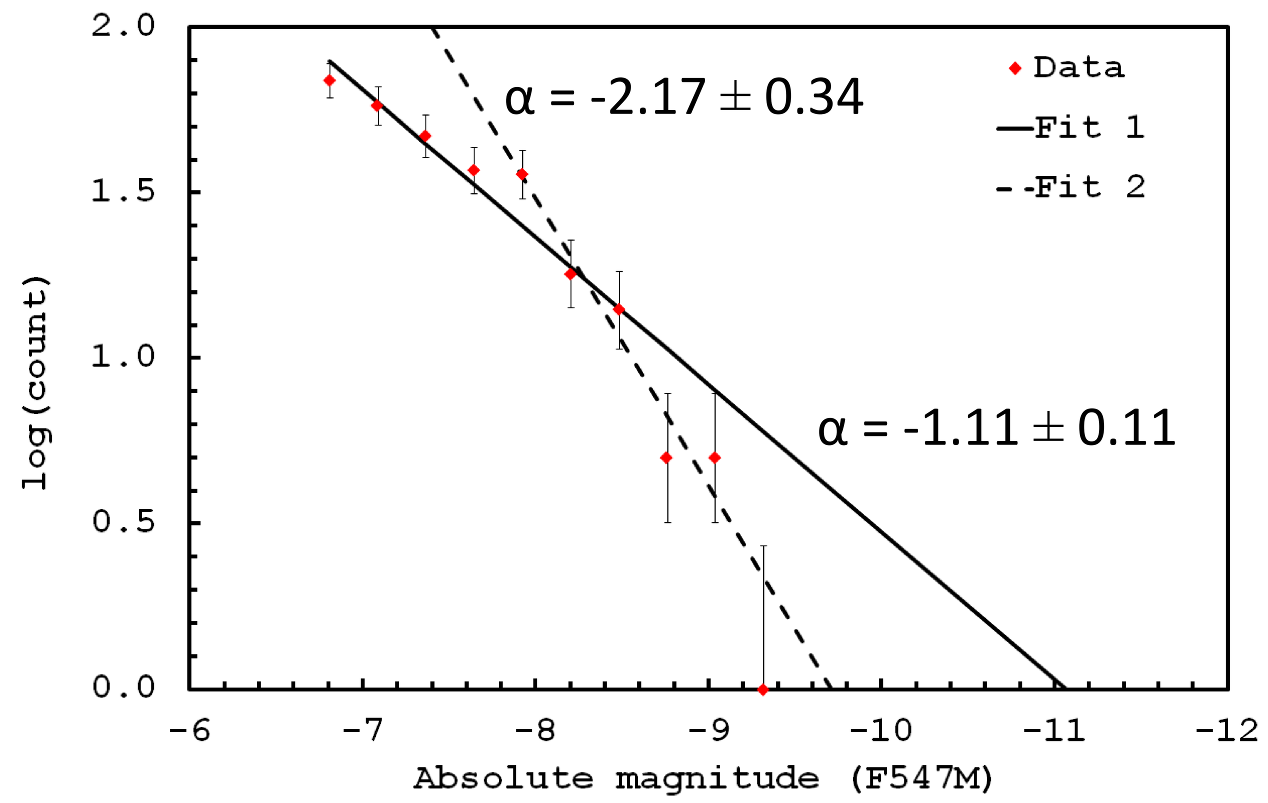

Figure 5: (right) the CLF for clusters in the northern bar of NGC 3227, or region N in Figure 2. If the completeness limit in this region is taken at a slightly higher value, a drastically different result is found. It is unclear if lower values of the LF indices in the bar regions are real, or due to difficulties in detection.

References
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