Synthetic Observations of Globular Cluster Stellar Streams with the Roman Space Telescope

Aster Winkler [1,2] , Tjitske Starkenburg [2,3]

[1]Brown University, Providence, RI 02912, USA

[2]Center for Interdisciplinary Exploration and Research in Astrophysics (CIERA), Northwestern University, 1800 Sherman Ave, Evanston, IL 60201

[3]The SkAI Institute, 875 N Michigan Ave Suite 4010, Chicago, IL 60611

Summary

Stellar streams can act as probes into galactic evolution, structure, and dark matter distribution. As stellar streams are promising targets for next-generation telescopes, synthetic observations are crucial in predicting the power of and interpreting the data from real observations. This work presents the first detailed synthetic study of two simulated globular cluster stellar streams with realistic stellar populations. We first study the distribution of different stellar types and apparent magnitudes within the Milky Way to better characterize stellar stream structure (part 1). We then simulate an observation of the stellar streams around M31 by the Roman space telescope, showing that Roman will be a powerful observatory in the study of extragalactic stellar streams (part 2).

Globular Clusters and Stellar Streams

Globular clusters (Fig. 1) are massive, dense, old star clusters that orbit galaxies in their stellar halos. Over the course of their orbits, especially near pericenter, the host galaxy may strip the globular cluster of some of its stars. These stars retain a similar orbit to the cluster, and form a long, thin **stellar stream**.

Stellar streams are:

- Direct evidence for hierarchical structure formation
- Fossil records of early star formation and galaxy evolution
- Tracers for dark matter distribution within galaxies and galactic halos

Fig. 1: Globular cluster M13, image taken by author.

A Post-Processing Pipeline for Simulating Stellar Streams

Stellar streams are difficult to model self consistently, given the range of scales involved in their formation and evolution, from galaxies to individual stream stars. Grudić et al. (2023), Rodriguez et al. (2023) and Panithanpaisal et al. (in prep) describe a post-processing method for modeling stellar streams (see Figure 2). We study two stellar streams (7002 and 18573) modeled this way. Both streams came from globular clusters accreted onto the host galaxy.

Grudić et al. (2023) *Maps GMC properties from FIRE-2 simulation onto smaller-scale simulation to model **star cluster** formation*

→ Clusters →

Rodriguez et al. (2023) *Evolves clusters forwards in time, keeping track of **escaped stars***

→ Escaped stars →

Panithanpaisal et al. (in prep) *Evolves escaped stars forwards in time as they form **stellar streams** in the host galaxy*

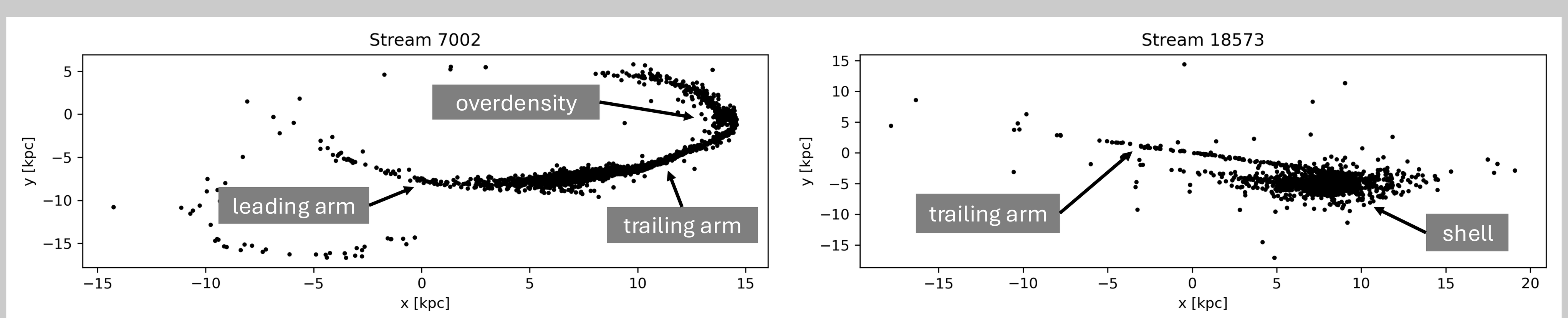

Fig. 2: The stellar streams used in this analysis, stream 7002 (left) and stream 18573 (right). Annotated features from Panithanpaisal et al. (in prep)

Part 1: Stream Structure and Composition

Method:

1. **Compiled a dataset** of every object in each stream, including positions, velocities, ejection times, masses, binary flags, and star types
2. **Generated isochrones** for both streams in Roman bands using the PARSEC isochrones (Girardi 2021) web interface
3. **Found luminosities and absolute magnitudes** in Roman bands for all stream objects, by comparing stream-object masses with isochrone-object masses
4. **Calculated apparent magnitudes**, assuming the streams orbit the Milky Way, shown in Figure 3
5. **Plotted spatial distributions** of interesting star types, shown in Figure 4

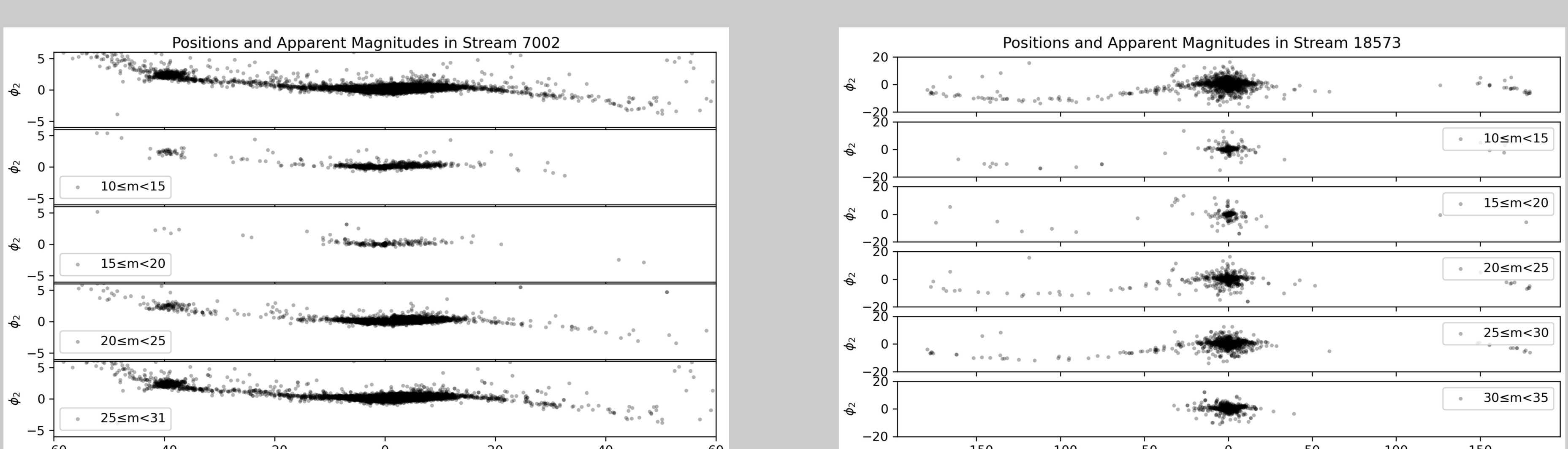

Fig. 3: Apparent magnitude bins in band F062 for stream 7002 (left) and stream 18573 (right) in a stream-aligned coordinate view, assuming both streams are in orbit around the Milky Way. In this view, the globular clusters generating the streams would be located at approximately (0,0). The top panel for both streams shows all stars.

- 7002 displays an overdensity on the left arm. From its absence in the third panel, but presence in all others, it must contain multiple stellar populations.
- 18573's trailing arm is extremely diffuse and dim; in observation, only the shell component would likely be visible.

7002: 47605 objects

- 91% low-mass MS stars
- 3% high-mass MS stars
- 6% white dwarfs
- <1% helium branch stars, compact objects

18573: 20843 objects

- 90% low-mass MS stars
- 5% high-mass MS stars
- 5% white dwarfs
- <1% helium branch stars, compact objects

Most stream stars are too dim to be seen; the brightest region of each stream will be around its globular cluster.

Part 1 cont.: Stellar Distributions

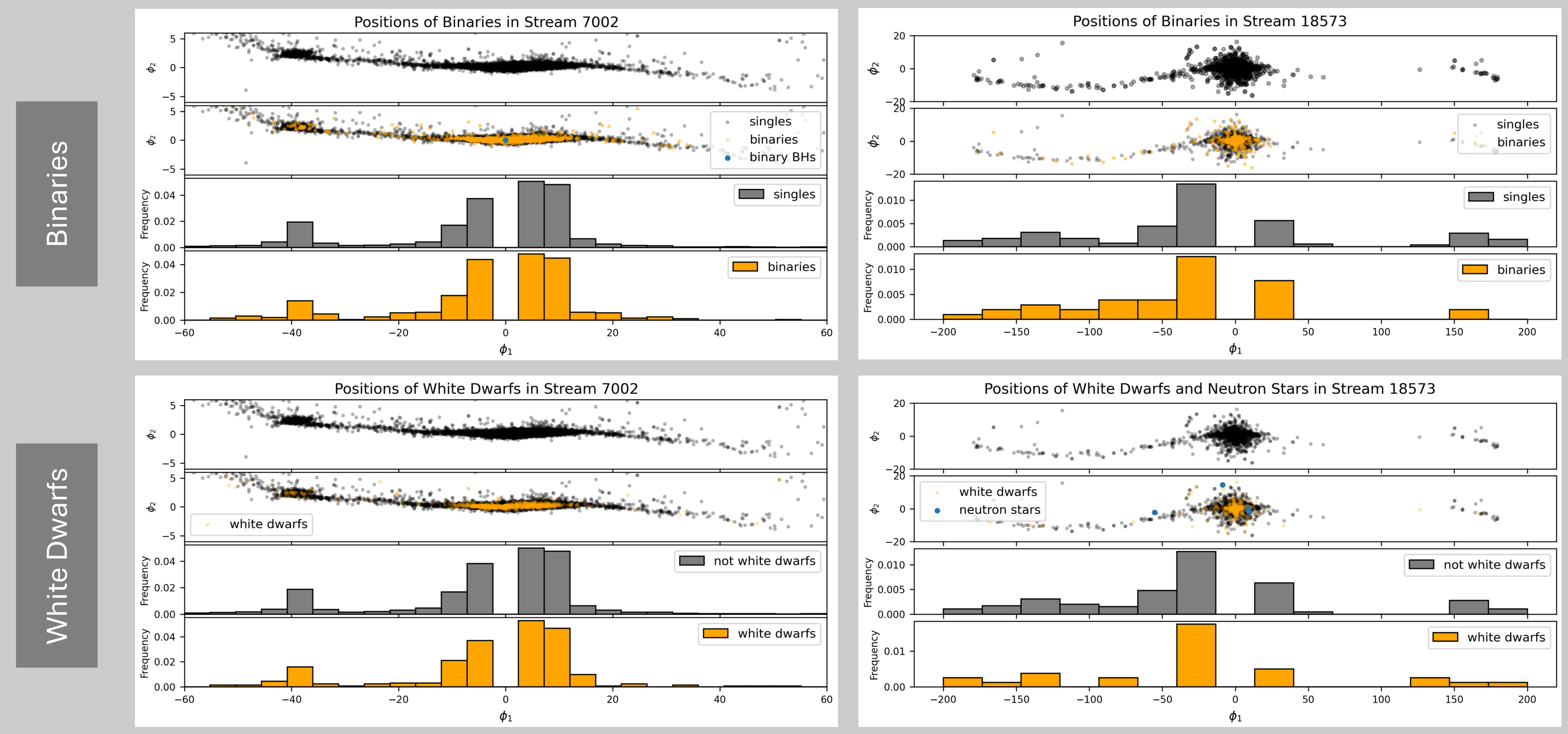

Fig. 4: Distributions of binaries (top row) and white dwarfs (bottom row) in streams 7002 (left column) and 18573 (right column). In the scatter plots, white dwarfs are in yellow while other stars are in black. The binary black holes of 7002 and the neutron stars of 18573 are shown in blue.

- 7002 has a black hole binary pair of 12.3 and 13.4 solar masses at (0,0), which was ejected from the globular cluster late, at 13.1 Gyr. They are the only black holes in either of the streams.
- 18573 has four neutron stars (not in binaries). They are the only neutron stars in either of the streams.
- Surprisingly, we find that all stellar types follow approximately the same distribution in both streams. This could be because both streams primarily experience stripping episodes during their pericenter passages, where the tidal radius is much smaller than at other parts of the orbit.

Part 2: A Synthetic Roman Observation

Method:

1. **Repositioned streams** around the Andromeda Galaxy (M31), ~770 kpc from the Milky Way
2. **Created stellar population models** for foreground structures: the Milky Way thin disk, thick disk, and stellar halo, and the M31 stellar halo, using the methodology of Aganze et al. (2024)
3. **Applied magnitude cuts** to streams and foreground objects for a 1-hour Roman exposure
4. **Generated a synthetic observation** by combining streams with foreground objects in a Roman field of view (Fig. 5)

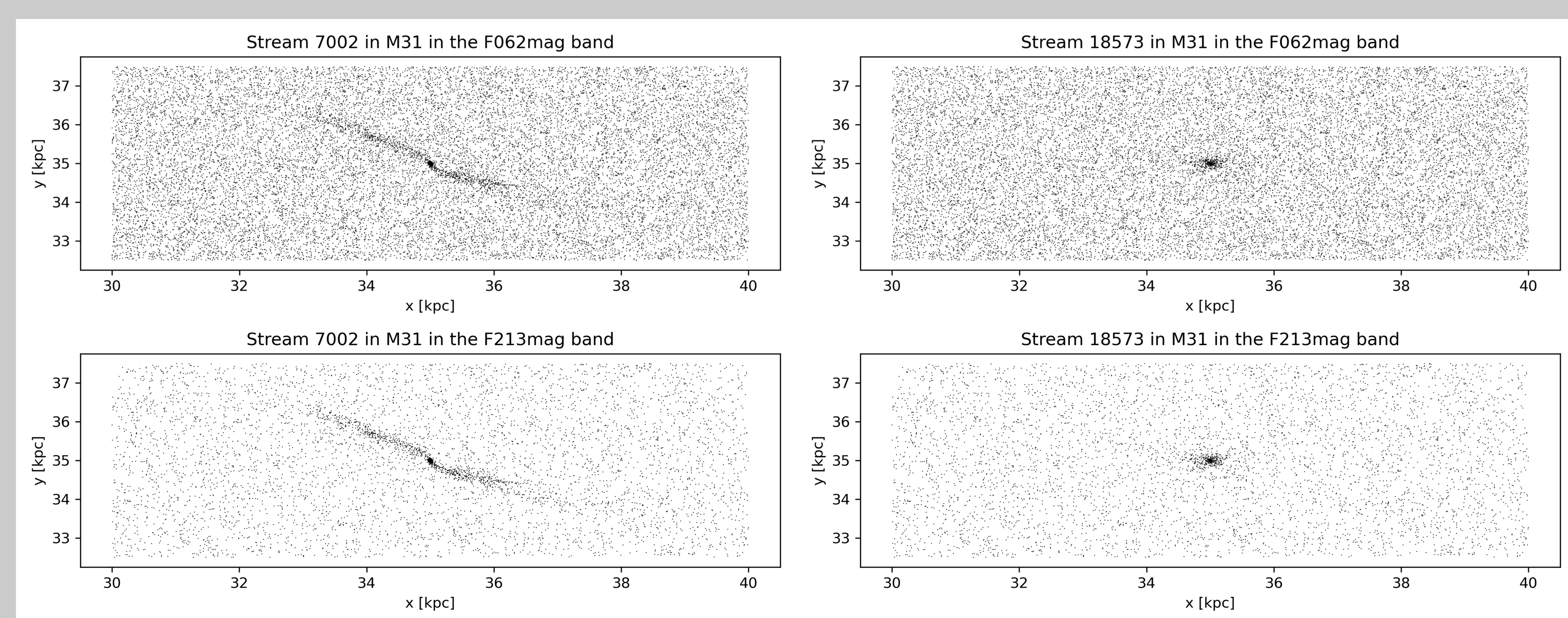

Fig. 5: Stream 7002 (left column) and stream 18573 (right column) orbiting M31, imaged with a Roman field of view for a 1-hour exposure in the F062 (R) band (top row) and the F213 (K) band (bottom row), pictured against foreground stars.

- 7002: The central regions of the stream are visible, with clear presence of the stream's arms.
- 18573: The shell is visible, while the long, diffuse arm is not.
- The F213 band, deeper infrared than F062, displays the streams more prominently.

Stellar streams orbiting M31 are visible to a 1-hour exposure of the Roman space telescope.

Conclusions and Next Steps

The stellar streams studied here are comprised primarily of low-mass, low-luminosity stars. As such, most stream stars are not visible, and diffuse structures in the stream (such as 18573's trailing arm) may be missed by observation. However, the high central densities of stellar streams mean that their central regions and prominent structures (such as 18573's shell) are readily accessible to observation. **Our results suggest that the Roman space telescope is poised to greatly expand the study of extragalactic stellar streams.** Future directions for study include: updating our foreground Milky Way and M31 stars from the FIRE simulated galaxy in which the cluster was evolved, adding background galaxies to mock Roman observations, and studying binaries and compact objects in the streams.

References and Acknowledgments

Aganze, C., Pearson, S., Starkenburg, T., et al. 2024, ApJ, 962, 151; Girardi, L. 2021, CMD 3.8 input form; Grudić, M. Y., Hafen, Z., Rodriguez, C. L., et al. 2023, MNRAS, 519, 1366; STScI 2025, Roman User Documentation: WFI Quick Reference; Panithanpaisal, N., Sanderson, R. E., Rodgriguez, C. L., et al. in prep; Rodriguez, C. L., Hafen, Z., Grudić, M. Y., et al. 2023, MNRAS, 521, 124.

This material is based upon work supported by the National Science Foundation (NSF) under Grant Numbers AST-2149425 and AST-2446392. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the NSF.