Searching for New Stellar Streams in the DESI Milky Way Survey: Characterization of the Cocytos Stream

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CONTEXT & SUMMARY: TESTING GALAXY FORMATION MODELS WITH STELLAR STREAMS IN THE MILKY WAY

Galaxy formation models predict that the Milky Way's halo was built up by accreting dwarf galaxy progenitors. Stellar streams are remnants of tidally disrupted galaxies and globular clusters orbiting the Milky Way. The discovery, census, and characterization of stellar streams in the Milky Way help complete this picture by constraining the number of visible Milky Way dwarf galaxies and the number of invisible dark subhalos by their gravitational interactions with streams and the formation of Globular clusters. The DESI Milky Way survey covers a **14,000 sq. deg footprin**t with a depth of **r=19 mag**. With these capabilities, it provides the largest sample of distant (>10 kpc) metal-poor stars compared to previous optical fiber-fed spectroscopic surveys. We present a characterization of the Cocytos stream. The Cocytos stream was first photometrically discovered by Grillmair et al., 2009. We re-discovered by doing a clustering analysis with a catalog of distant DESI giants in the DESI Year 1 data. We supplemented these data with additional Gaia astrometry and Magellan/MagE spectroscopy. Our analysis reveals a metal-rich (**[Fe/H]=-1.3)**, thick stream (width=1.7 deg), at a **distance of ~26 kpc,** with low internal velocity dispersion **(~10km/s)**. Combining these measurements, the orbital parameters of the stream, and previous kinematic associations with the Virgo Overdensities***, we speculate that the Cocytos stream is a result of a disrupted globular cluster that came in with the Gaia-Enceladus merger***. This work showcases the need for spectroscopic follow-up of photometrically-discovered streams in the LSST era.

THE DESI MILKY WAY SURVEY

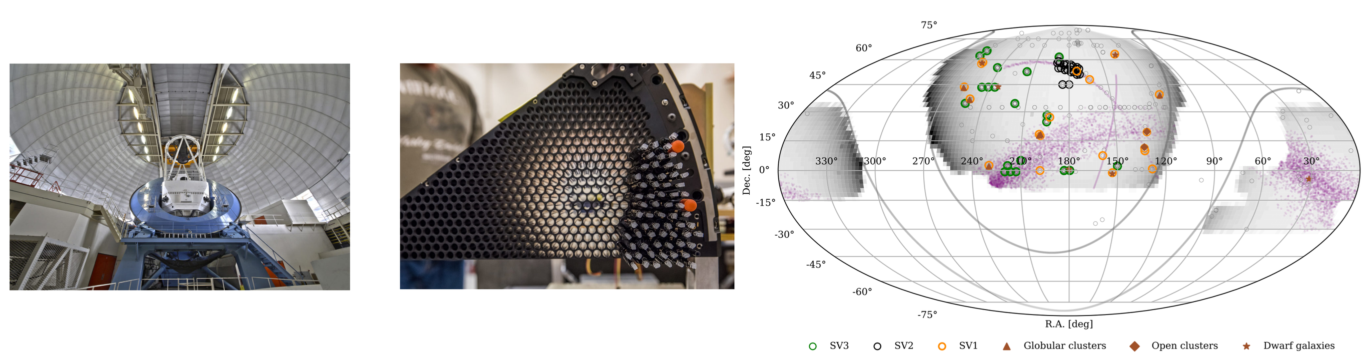
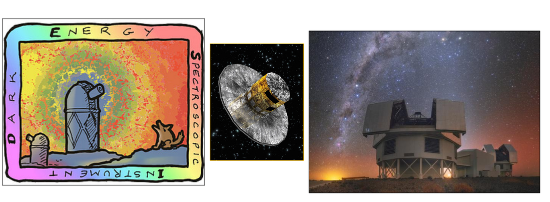


Figure 1: Image of the DESI instrument mounted on the 4-m Mayall Telescope in Arizona, fibers for the DESI spectrograph and sky distribution of the DESI footprint (Cooper et al. 2023)

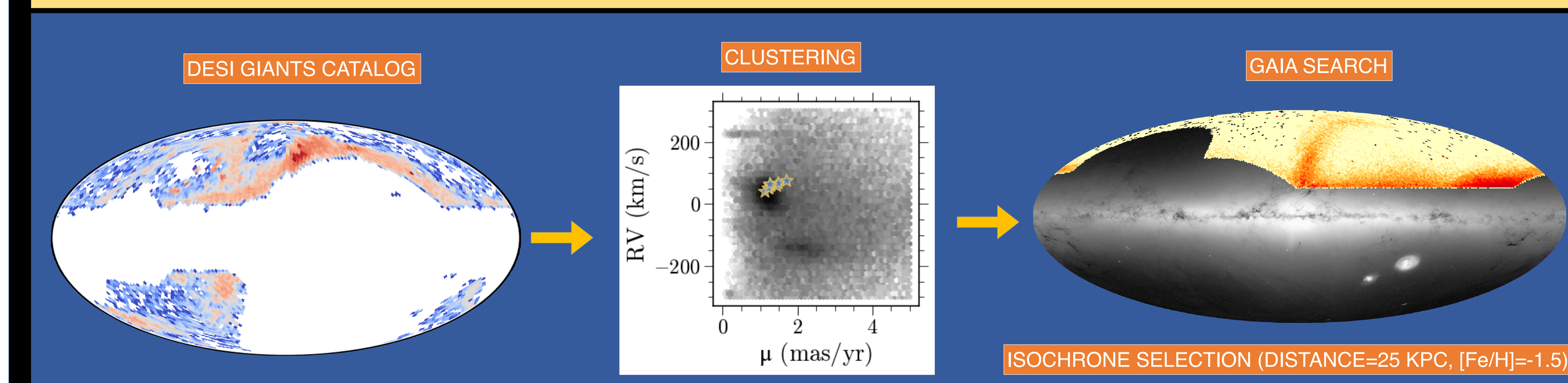
The Dark Energy Survey Instrument (DESI) is a low-resolution (R~2500-5000) fiber-fed spectrograph installed on the **4-meter** Mayall telescope at Kitt Peak in Arizona. The Milky Way survey uses this instrument to obtain spectra of **~7 million stars** and measure their radial motion to a precision of **1-10 km/s** and their composition ([Fe/H]) (Cooper et al. 2023) . These stars were selected to have precise 5-dimensional positions and velocities, enabled by the European **Gaia satellite**, generating the largest map of distant stars in the Galaxy.

FACILITIES AND REFERENCES



Cooper et al. 2023 ApJ, 947, 37; Grillmair 2009, ApJ, 693, 1118; Cargile et al. 2020, ApJ, 900, 28; Li et al. 2022, ApJ, 928, 30; Roediger et al. 2014, ApJS, 210; Vivas et al. 2016, ApJ, 831, 165

THE DISCOVERY OF THE COCYTOS STREAM IN THE DESI MW SURVEY DATA



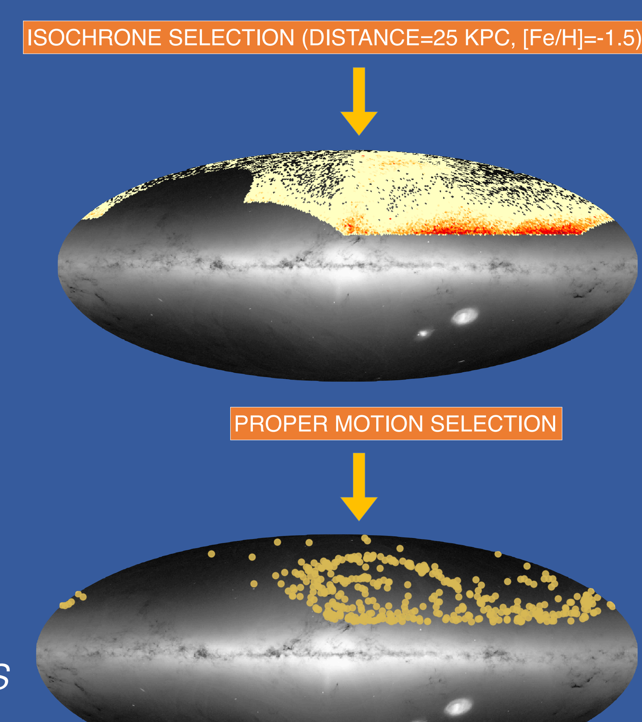


Figure 2: Illustration of the search for new streams in DESI and Gaia. Starting with a catalog of distant (> ten kpc) giant stars, we searched for clusters using an unsupervised clustering algorithm. Once a cluster has been detected, we further searched for additional members (mostly giant stars) by carefully filtering out co-moving stars (i.e., stars with the same motion in the sky) at a distance similar to the original cluster& with similar composition as the original cluster. Here, we show an application of this search in Gaia DR3 to a cluster of 7 giants that align with the Cocytos stream.

MEASURING THE RADIAL MOTION AND COMPOSITION OF THE STREAM WITH FOLLOW-UP SPECTROSCOPY

σ_V: 10±1 km/s	Mv: -5±0.4	Distance: ~25 kpc
[Fe/H]: -1.3 (DESI) -1.5 (MagE)	Stellar Mass: 5±0.1x 10^3 Msun	Apocenter:120 kpc
$\sigma_{[Fe/H]}$: ~0.1	Width: 0.7±0.2 kpc	Pericenter: 23 kpc
		Eccentricity:0.6

We conducted follow-up spectroscopy of Gaia members with the MagE spectrograph mounted on Magellan. With these data, we can confirm the membership of our Gaia-selected giant stars based on their full 6-D motion and chemical composition. We are also able to isolate the stream from other nearby structures in the same region of the Galaxy.

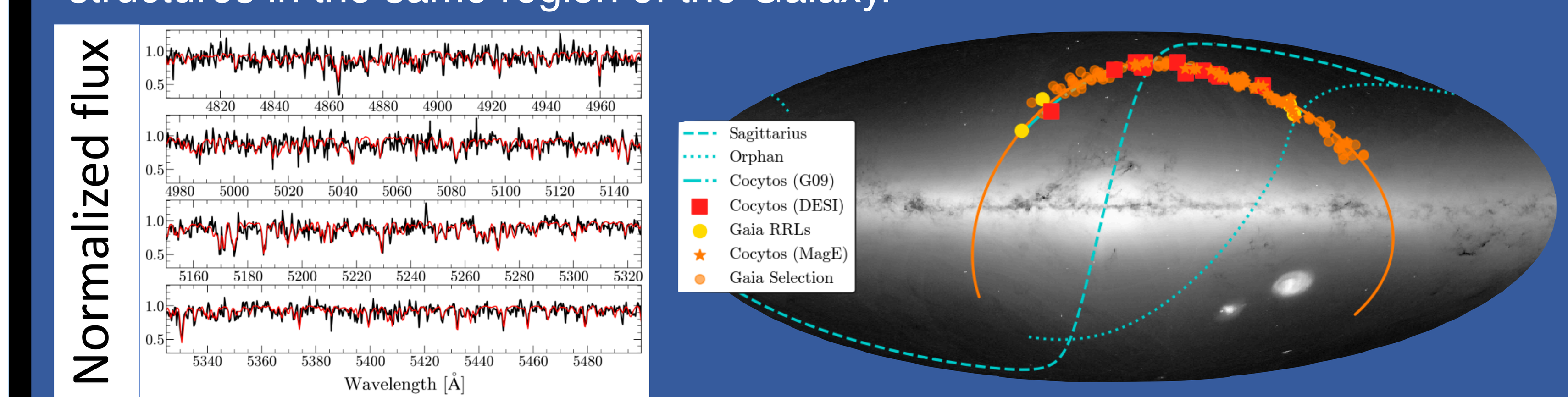


Figure 3: Left: example of a spectrum of a giant star fitted to a model used to estimate the Cocytos's metallicity and radial velocity. Stellar models & fitting used the MineSweeper pipeline (Cargile et al. 2020). Right: Kinematically selected final members of the Cocytos stream were compared, with their orbit shown in orange. We show the tracks of two other prominent streams: Orphan & Sagittarius and the original track of Cocytos by Grillmair et al. 2009.

INSIGHTS FROM CHEMISTRY & KINEMATICS: IS COCYTOS ASSOCIATED WITH GAIA-ENCELADUS?

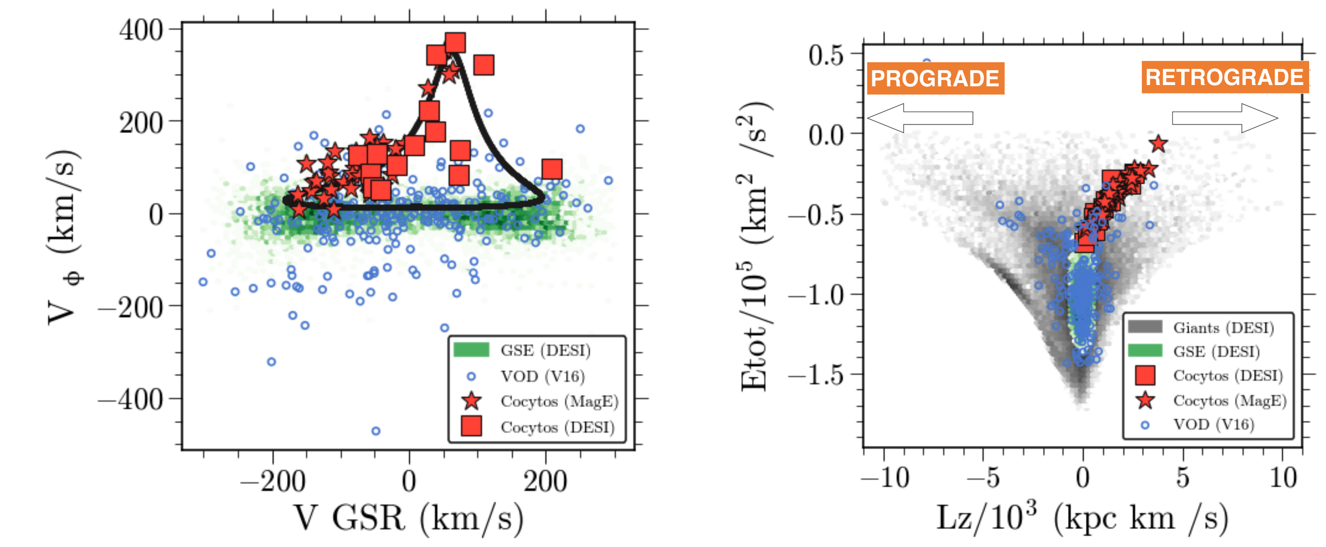


Figure 4: Cocytos stream members obtained by DESI & MagE (red) compared to DESI GSE members (green, Carrillo et al. in prep.) and a sample of RRLs in the VOD (blue) by Vivas et al. 2016. Left: Galactocentric radial and azimuthal velocities show an overlap in orbit. Right: Energy-Lz distribution showing the overlap between Cocytos, the VOD and GSE. Distant DESI giants are shown in black.

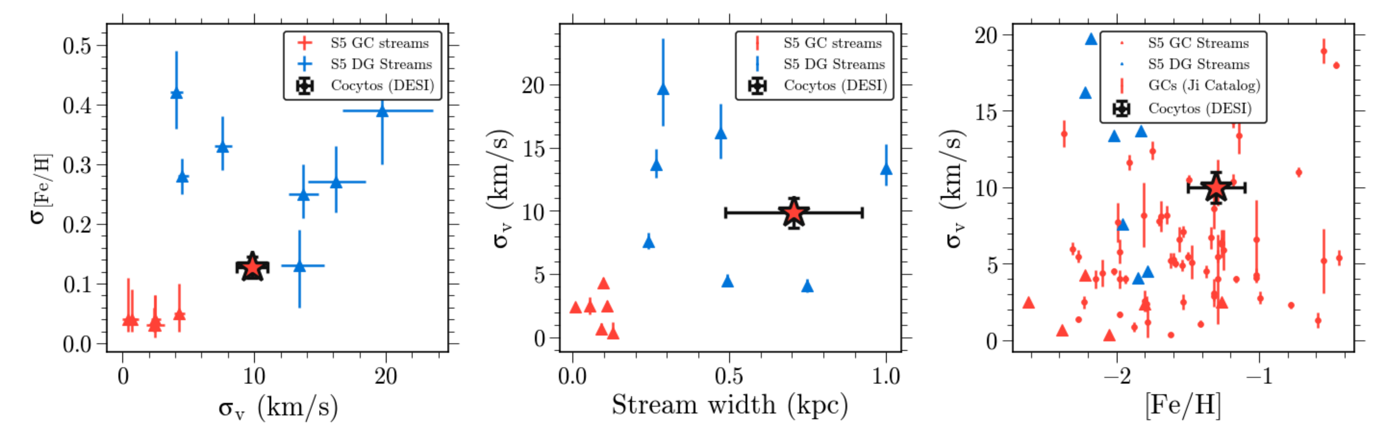
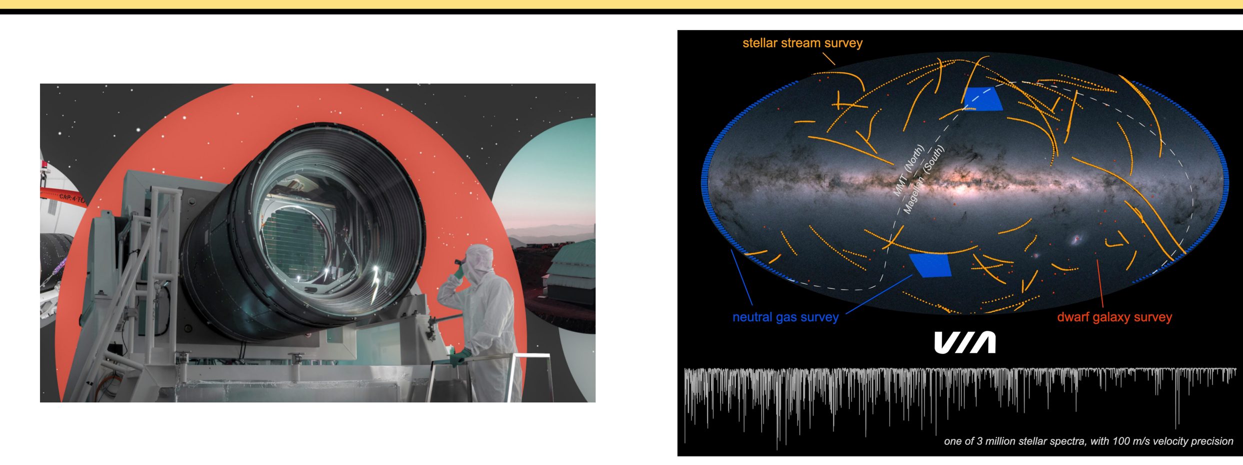


Figure 5: Velocity dispersion, metallicity and width compared to streams in the S5 survey classified separated into globular cluster progenitors or dwarf galaxy progenitors (Li et al. 2022). Left: velocity dispersions and metallicity dispersion. Center: physical width and velocity dispersion. Right: metallicities velocity dispersions. Globular clusters by Roediger et al. 2014 are shown as red points.

STREAMS IN THE RUBIN AND THE VIA ERA



We plan to complete the validation and follow-up of all the structures in DESI MWS. The Rubin Observatory will start operations in 2024 and will uncover a relatively large sample of streams in the Milky Way. Spectroscopic follow-up of new and existing streams will be needed to map their orbits in the Galaxy, measure their chemical composition and compare this distribution to predictions by galaxy formation models. The VIA project (2027) will obtain RVs for most of these streams down to G=24 at a precision of 100 m/s.