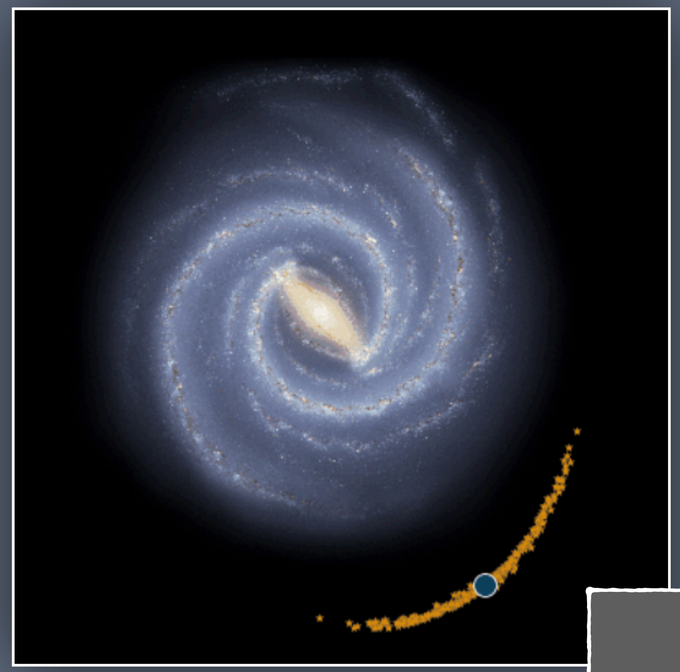

14th International Conference on Identification of Dark Matter

18-22 July 2022
Vienna, Austria

CAN STELLAR STREAMS SEE DARK MATTER SUBSTRUCTURE?

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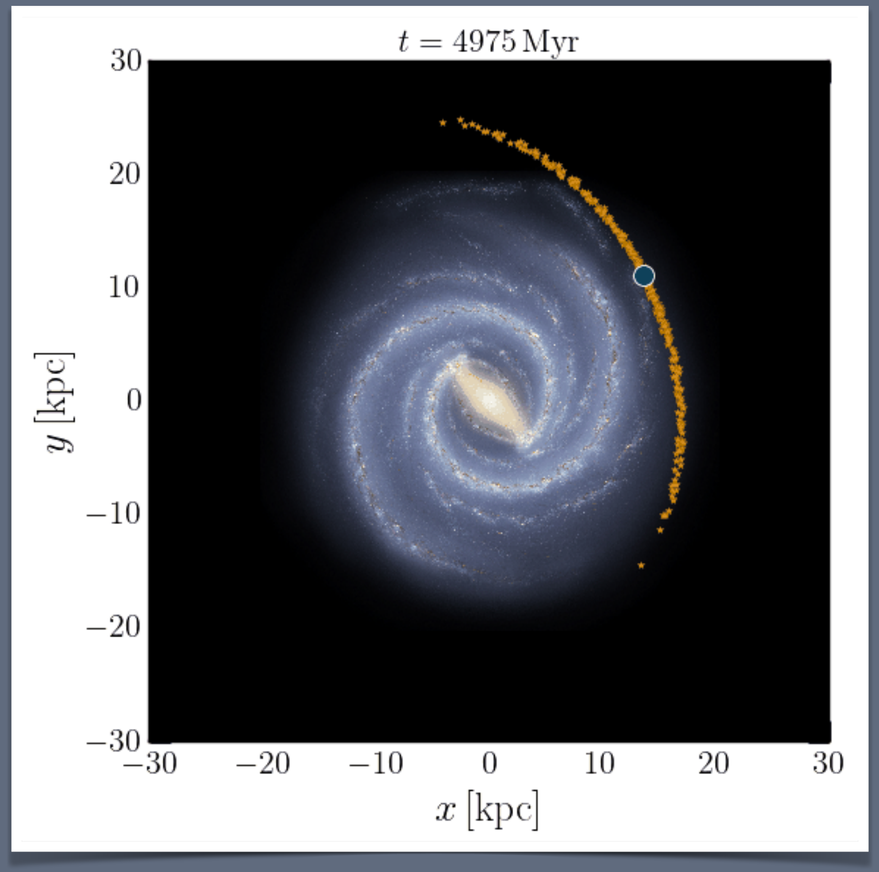
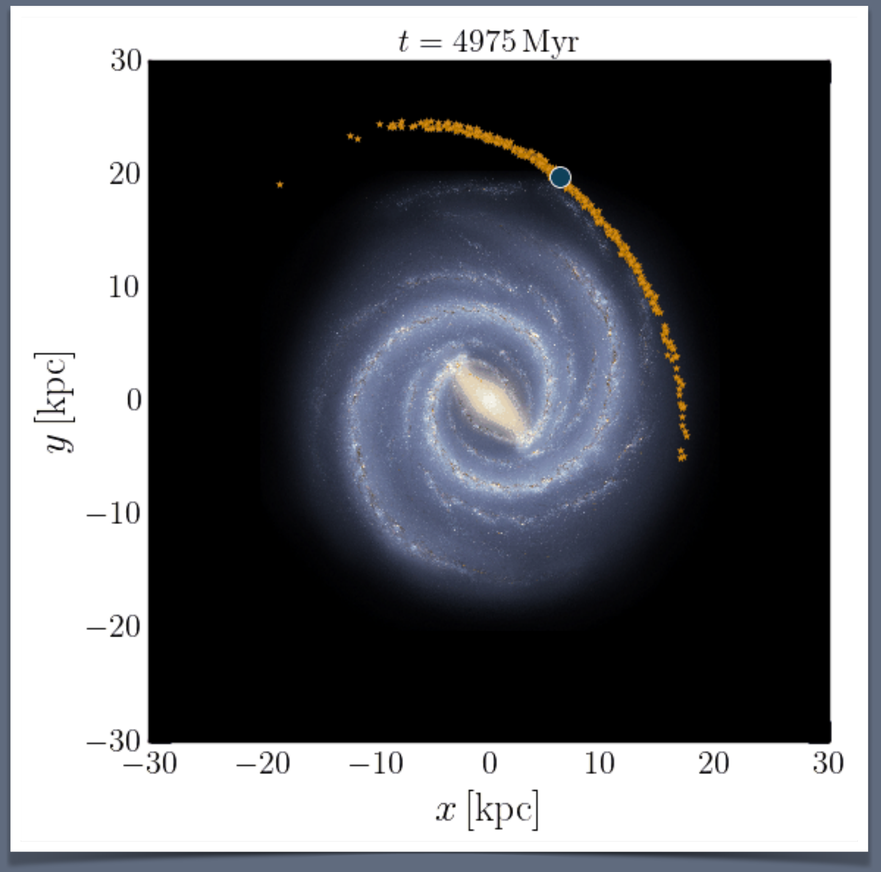
Collaborators

Mathis Gerdes

Christoph Weniger

Warmup Question: **Which of these streams was generated in the presence of a CDM-like sub halo population?**





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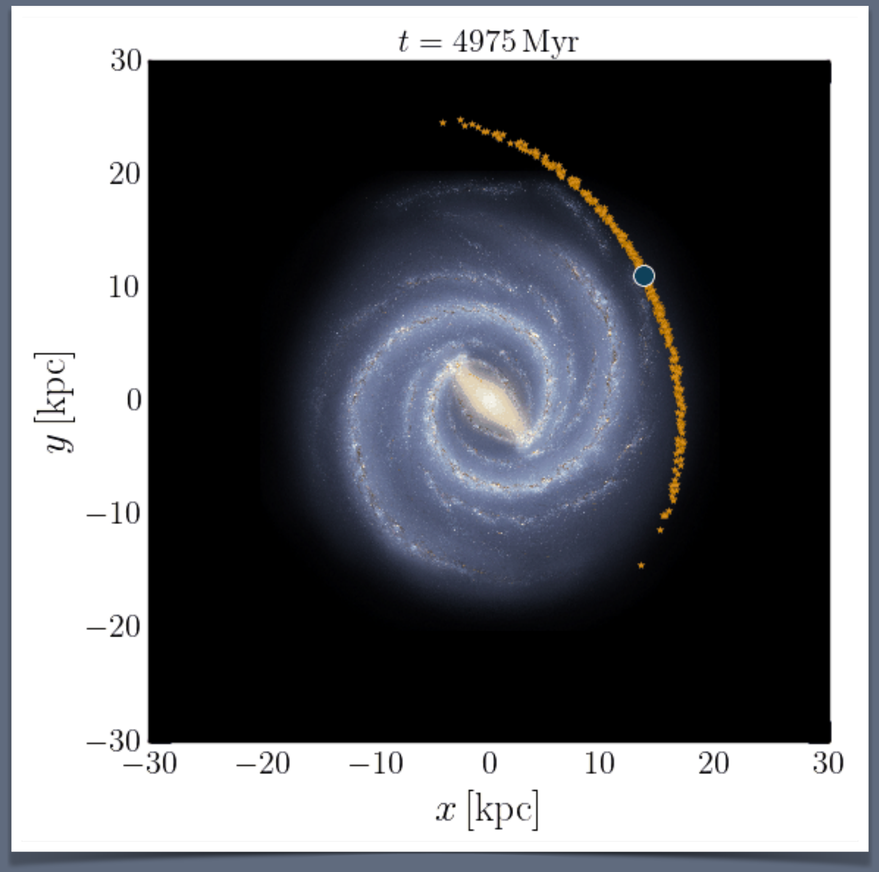
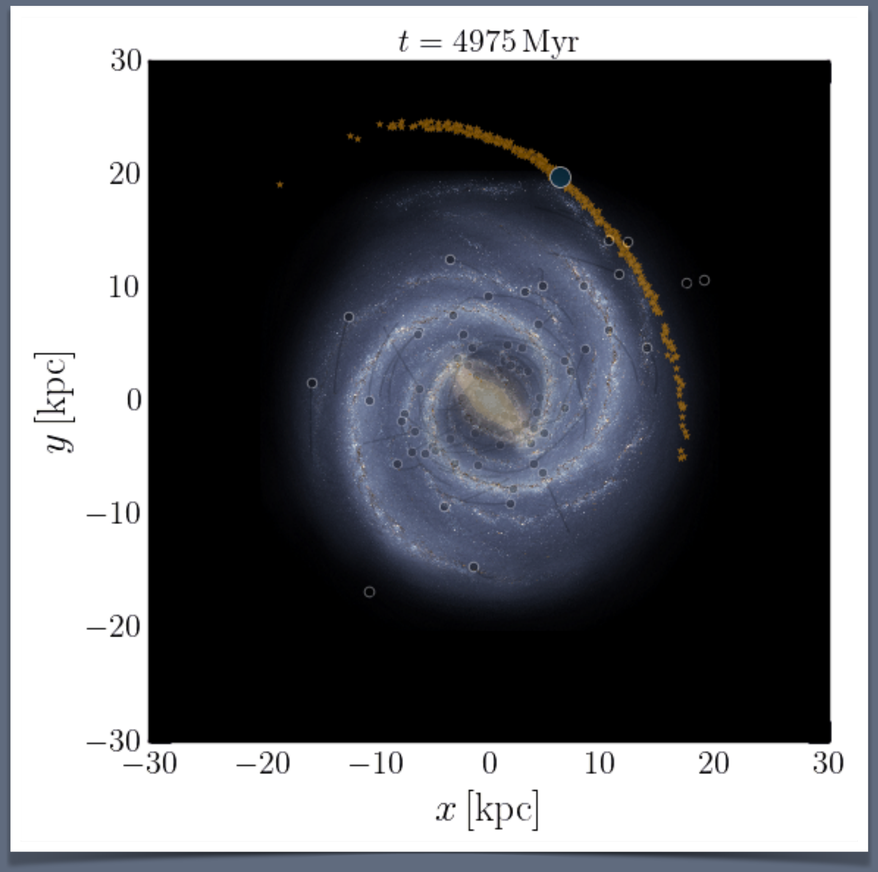
Warmup Question: **Which of these streams was generated in the presence of a CDM-like sub halo population?**





Rest of the talk: **How do we quantify this?**

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OUTLINE: **USING STELLAR STREAMS TO PROBE DARK MATTER**

PART #1 **Motivation:** Dark Matter and Data

PART #2 **Inference:** Simulation Based Inference

PART #3 **Modelling:** Stellar Stream Simulator

PART #4 **Application:** Detecting a Subhalo Population

PART #5 **Outlook:** Questions to Ask and Future Data

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Question: Why are stellar streams a promising probe of dark matter?

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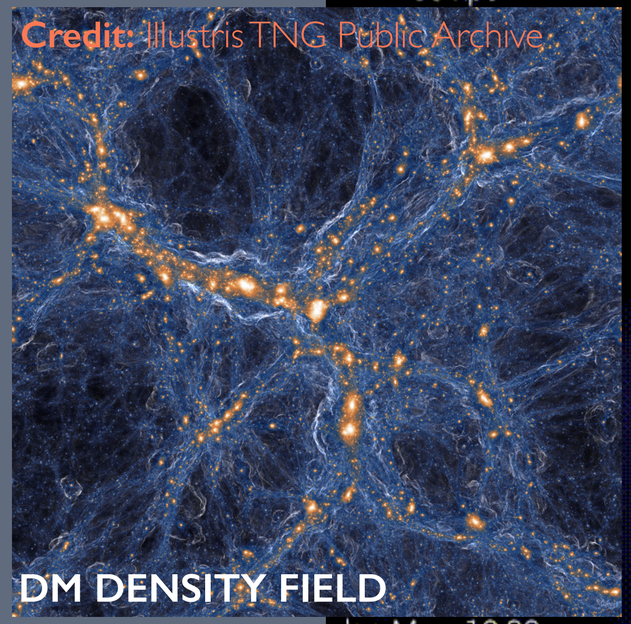
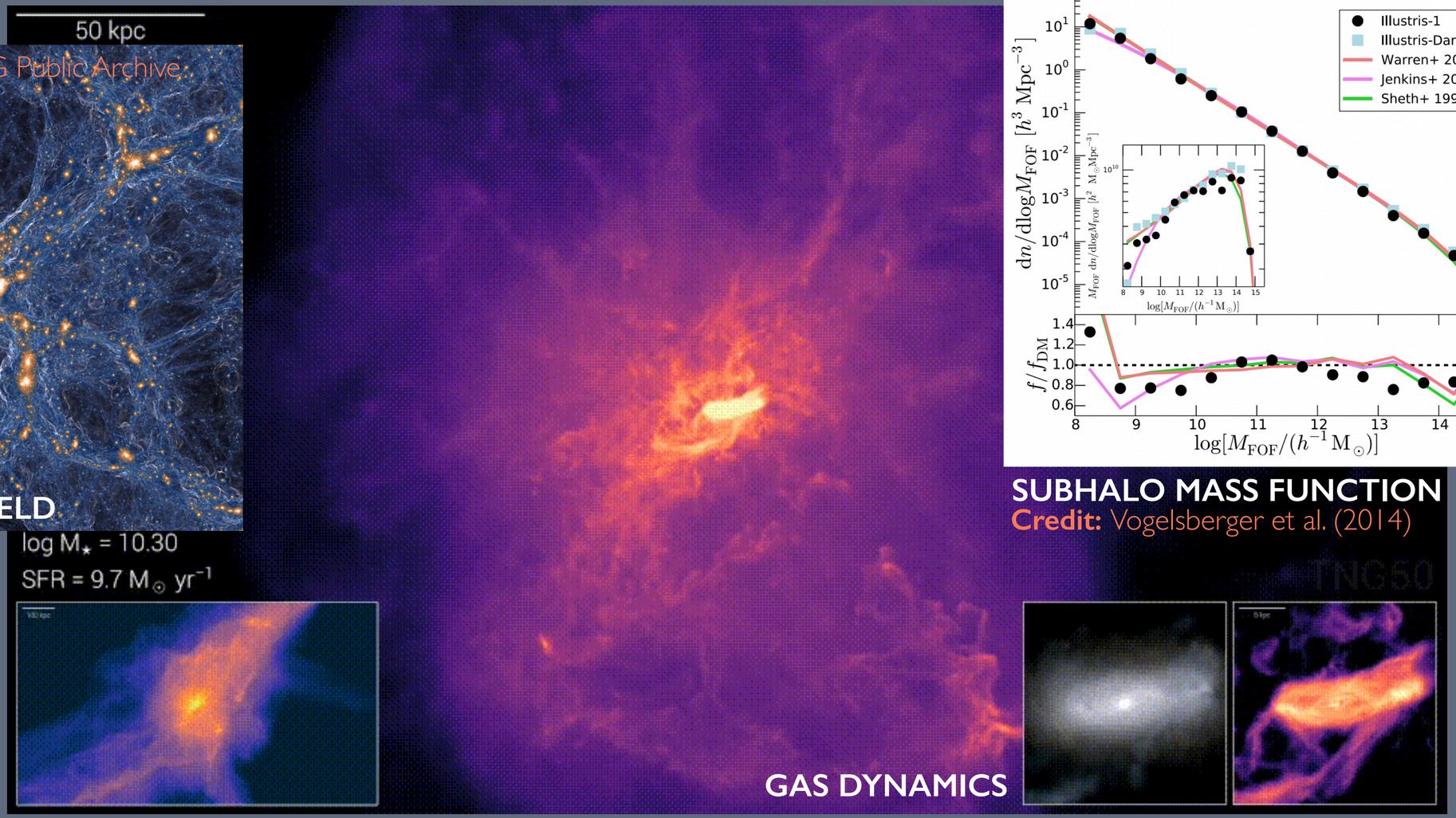
STRUCTURE FORMATION: **INCREASINGLY DETAILED PICTURE OF HOW DARK MATTER CLUSTERS AND GALAXIES FORM**





SUBHALO MASS FUNCTION
Credit: Vogelsberger et al. (2014)

Credit: Illustris TNG Public Archive

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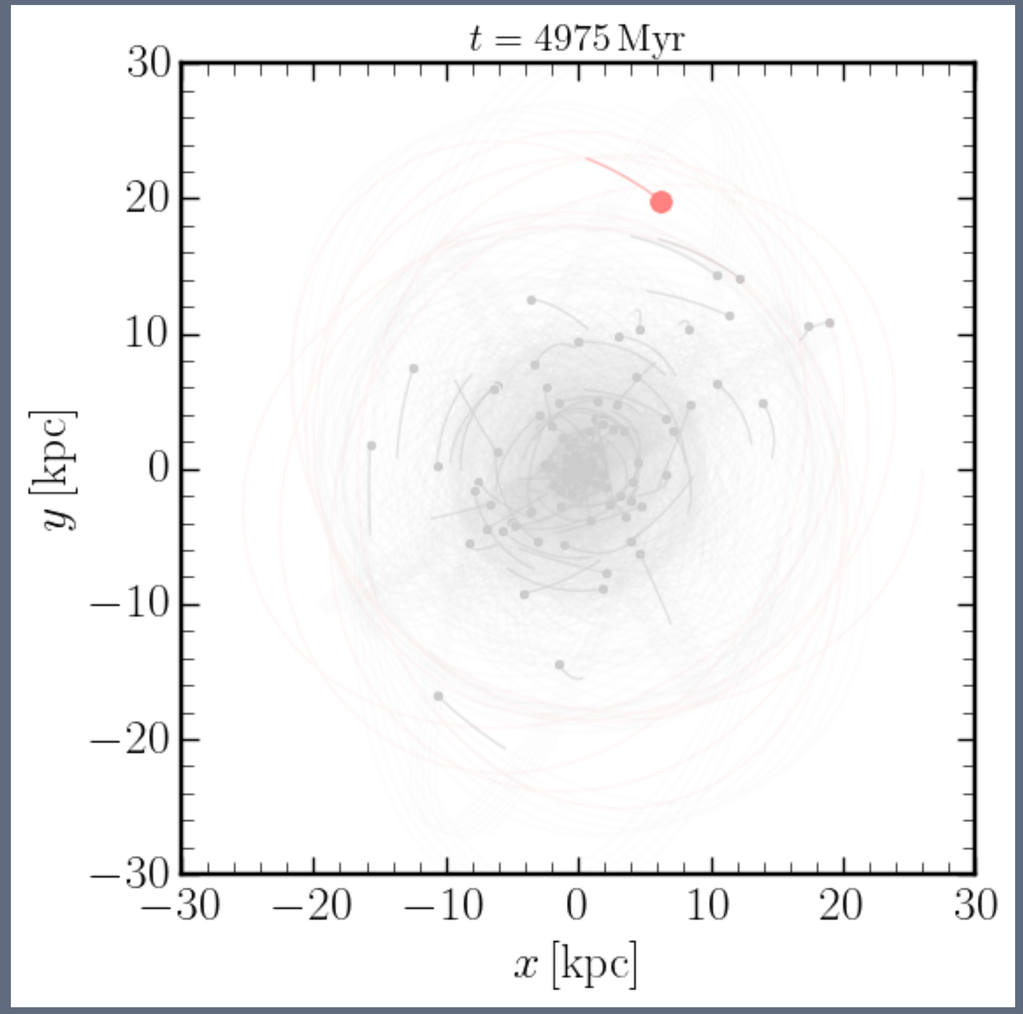
STELLAR STREAM DYNAMICS: **OLD DYNAMICAL OBJECTS THAT TRACE OUT THE MILKY WAY POTENTIAL (INCLUDING SUBHALOS!)**



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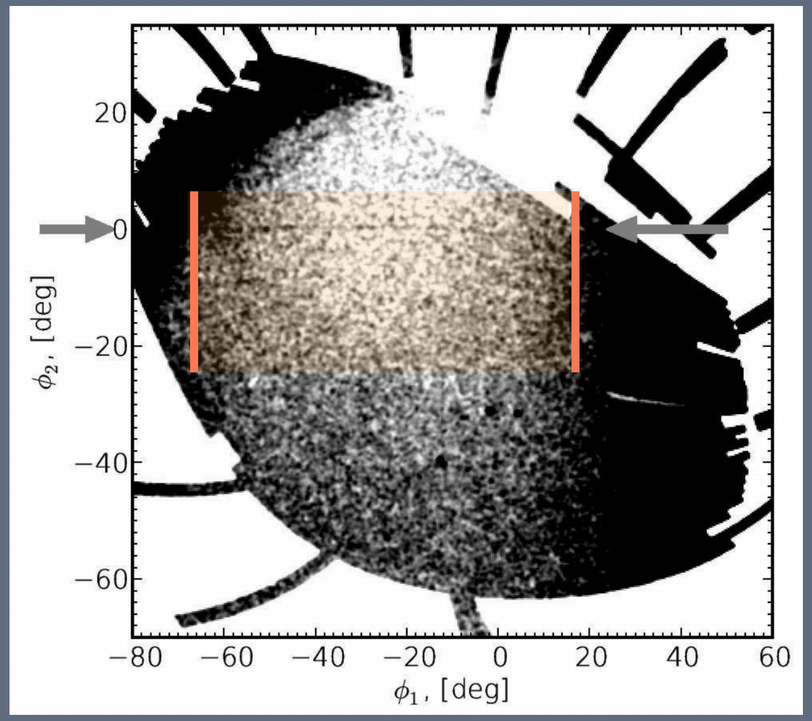
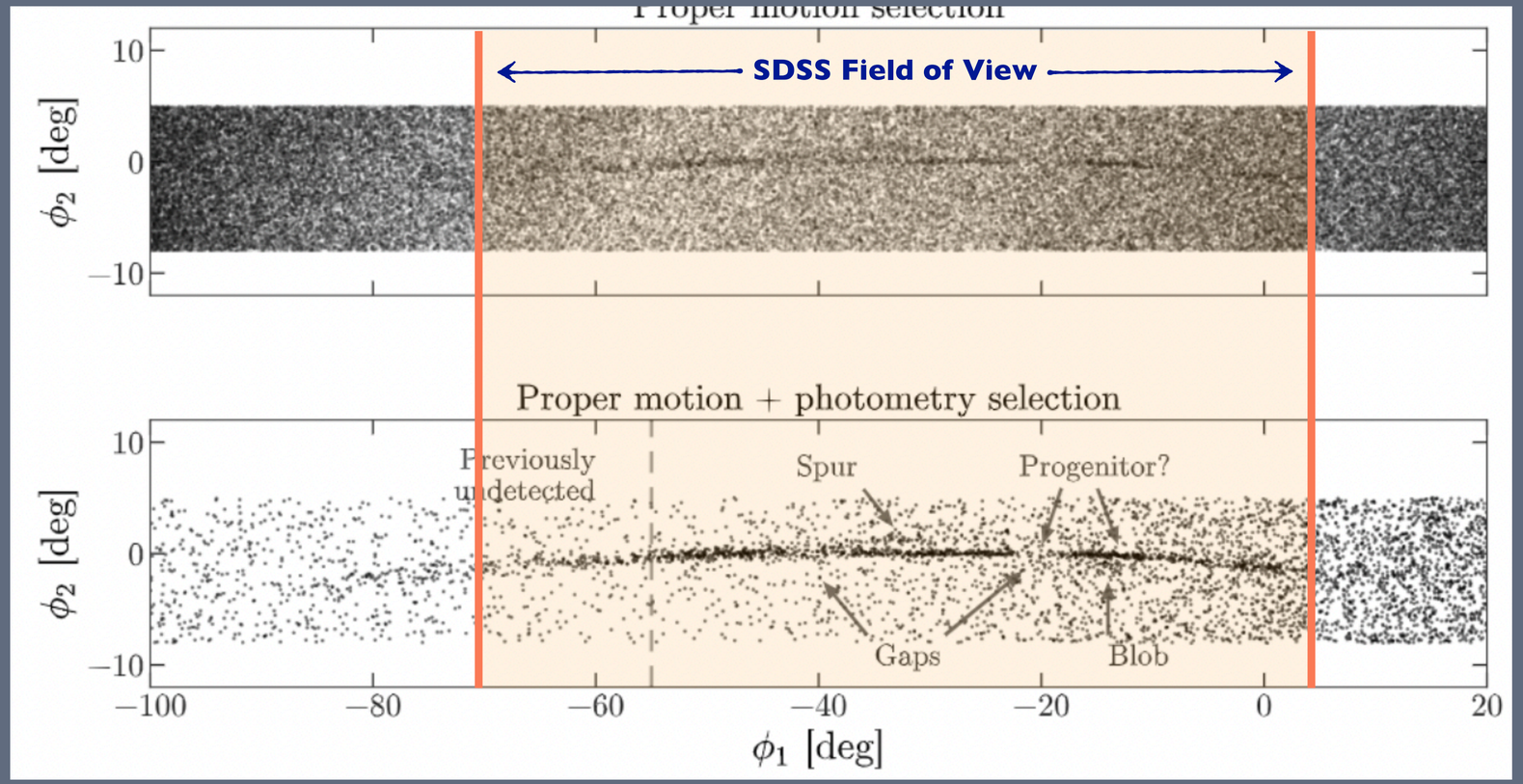
MILKY WAY OBSERVATIONS: MORE AND MORE PHOTOMETRIC AND SPECTROSCOPIC DATA AVAILABLE



Credit: Koposov et al. (2010)

From SDSS…



Credit: Price-Whelan et al. (2018)

…to GAIA (and beyond)

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Question: How do we do parameter estimation with really complex models?

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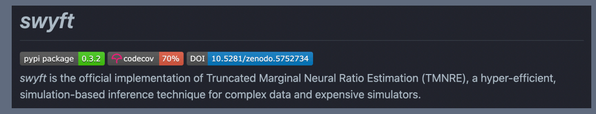
SIMULATION BASED INFERENCE: **KEY FEATURES**

See also these talks!

Christoph Weniger
Thursday @ 10am

Noemi Anau Montel
…in about 1 hour!

#1 **Implementation:** swyft (TMNRE)



https://github.com/undark-lab/swyft

#2 **Bayesian:** A fully bayesian framework for parameter estimation

#3 **SBI:** Example of an "implicit likelihood method" (there are more!)

#4 **Approach:** Automatically construct an optimal summary statistic

…to distinguish between joint and marginal samples

ask me how/why this works!

#5 **Marginal:** Directly estimates the params of interest

…so very simulation efficient!

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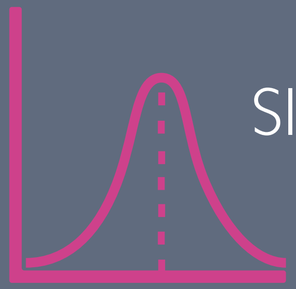
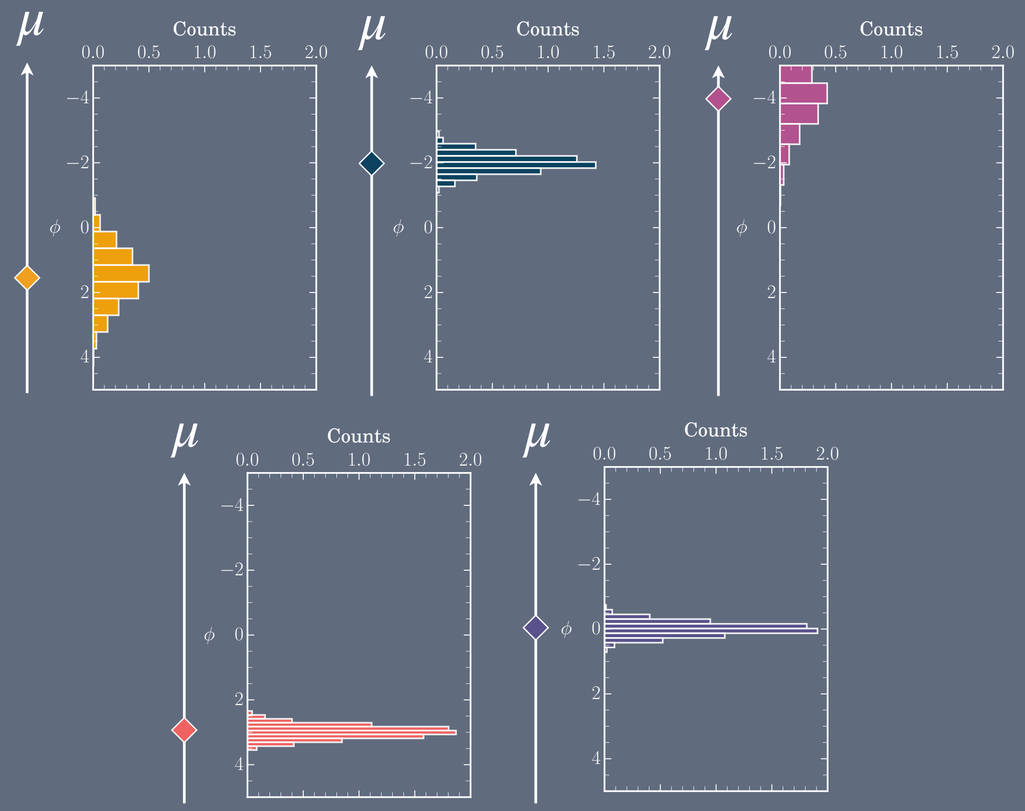


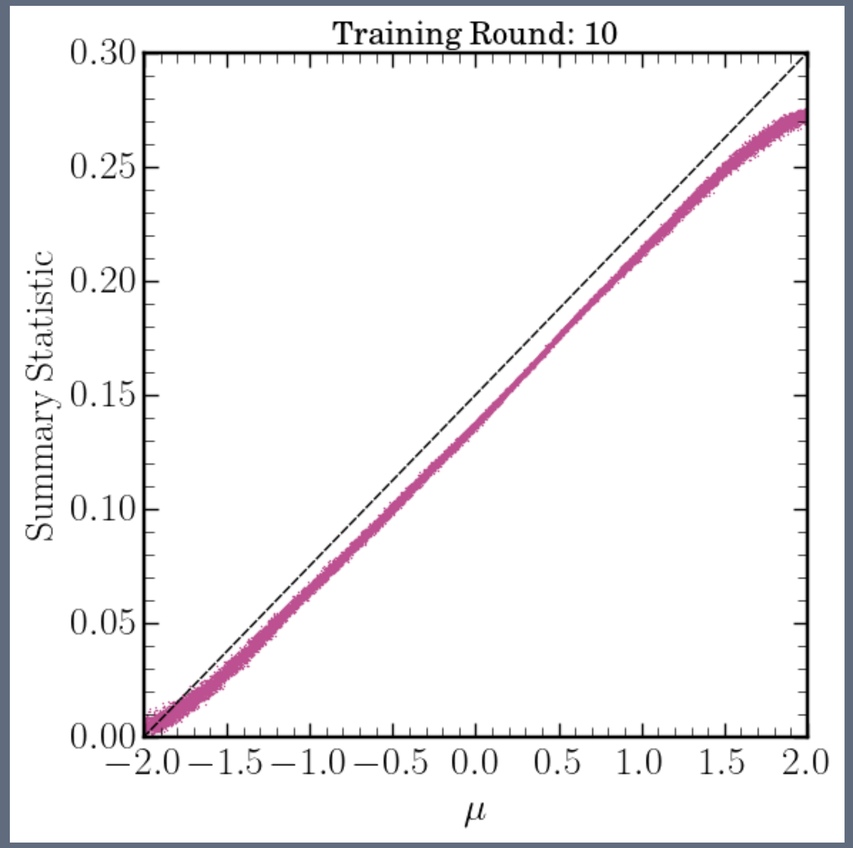
SIMULATION BASED INFERENCE: **EXAMPLE**

MEANINGFUL SUMMARY STATISTICS



MODEL

$$x \sim \mathcal{N}(\mu, 1)$$



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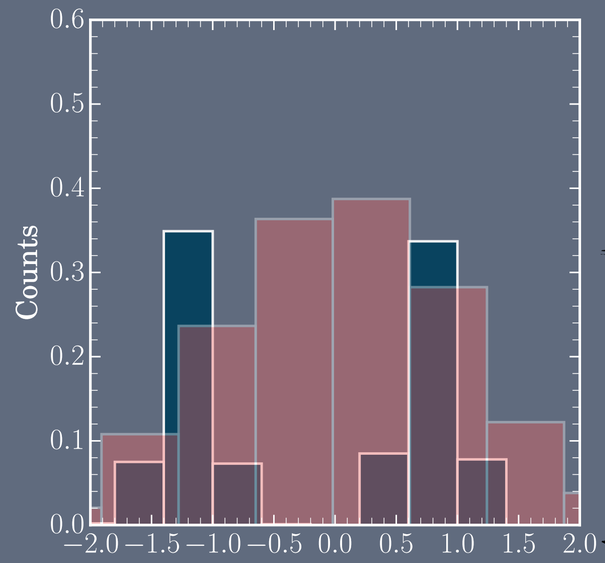
SIMULATION BASED INFERENCE: **EXAMPLE**

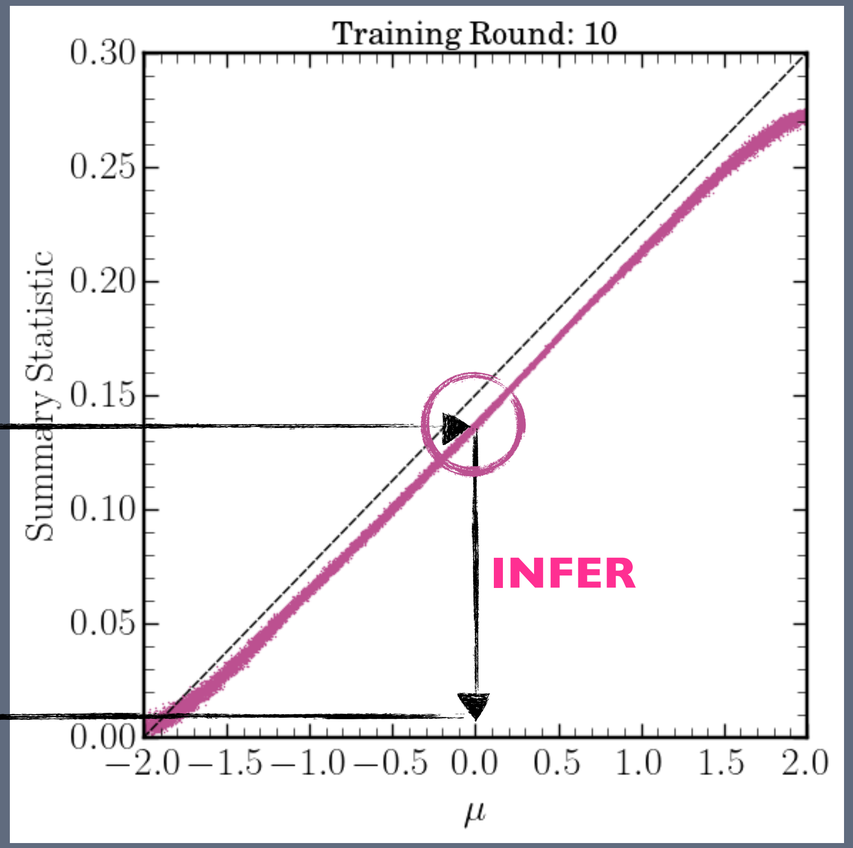
MEANINGFUL SUMMARY STATISTICS

WARNING: What happens if we do inference on this example?



SUMMARISE

REMODEL



…in other words, we have to be very sure that we can generate the features in our data using the simulator

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Question: What physics do we resolve in our stellar stream model, and why?

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MODELLING A STELLAR STREAM: **CHALLENGES**

#1 **Gravitational Potential:** Milky Way stars + DM, subhalos, dSphs, GMCs…

#2 **Progenitor Evolution:** Orbit dynamics, stellar composition

#3 **Subhalo Properties:** Subhalo mass function, radial distribution, density profile

#4 **Stream Formation:** Tidal stripping of progenitor, interaction with subhalos

#5 **Data:** Realistic comparison to Gaia data for e.g. GD-1

+ others we haven't thought of yet!

Coming soon (~Sep.): **a fully self-consistent code to generate streams**

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Question: Can we use simulation based inference to reliably infer properties of stellar stream?

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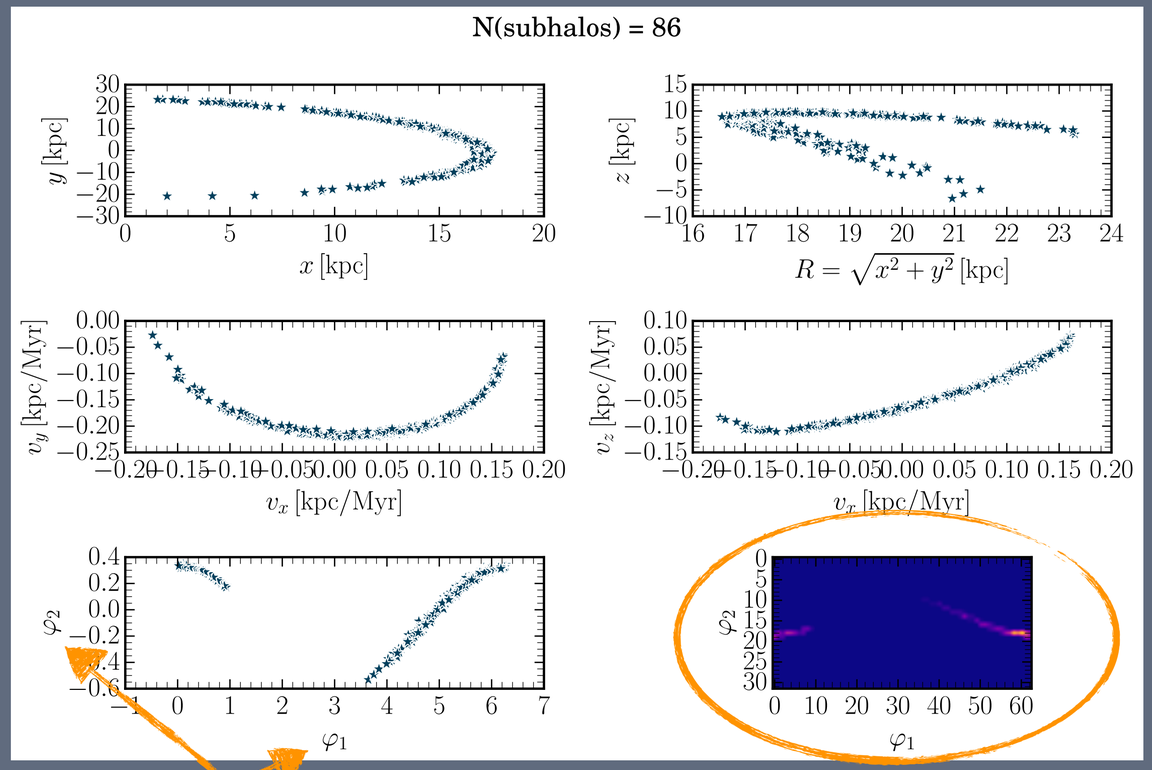
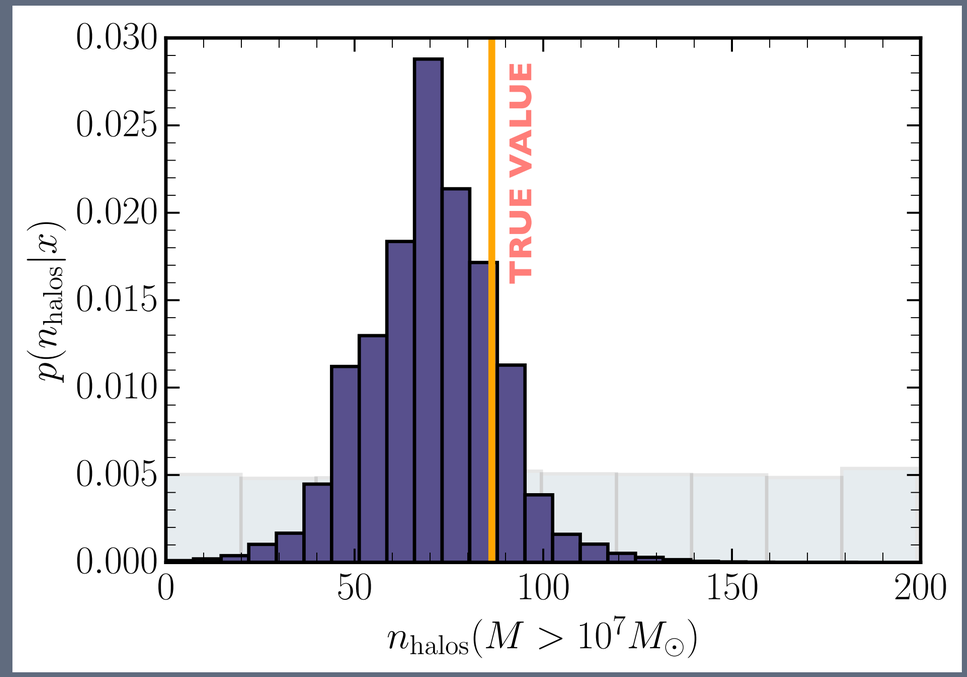
TRAILER: DETECTING A SUBHALO POPULATION



GD-1 centric co-ordinates

Shown to swyft

swyft



CAVEATS TO THIS RESULT

1. Calibrated on the simulator only, not GD-1 data
2. Only varying the number of subhalos, not all parameters
3. Evolves halos with $M > 10^7 M_\odot$ with CDM-like distribution

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Question: What sort of physics questions can we ask (and answer!) with this approach?

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SUMMARY: CAN STELLAR STREAMS SEE DARK MATTER SUBSTRUCTURE?

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ask me

Future Directions:

- Coupling with N-body simulations
- Simultaneous analysis of multiple streams (c.f. LSST)
- Development of globular cluster evolution models
- Mapping onto DM production models

Thank you for your attention
(…and keep an eye out on arxiv/Github)!

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