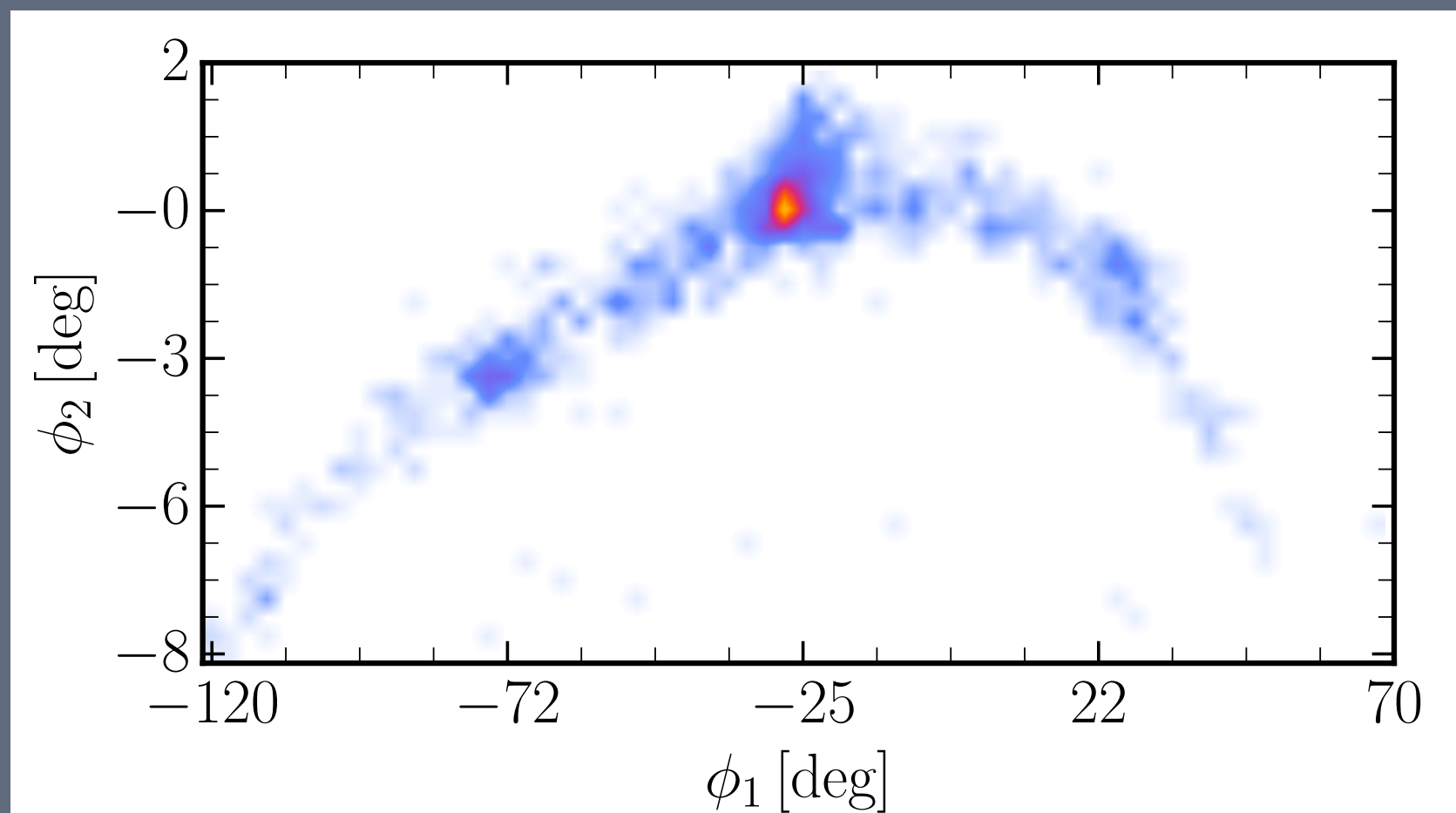




KICC WORKSHOP | 2ND JUNE 2023

SIMULATION BASED INFERENCE FOR STELLAR STREAMS

BASED ON 2304.02032

COLLABORATORS AT UVA



**Uddipta
Bhardwaj**



**Mathis
Gerdes**



**Christoph
Weniger**



**Samaya
Nissanke**



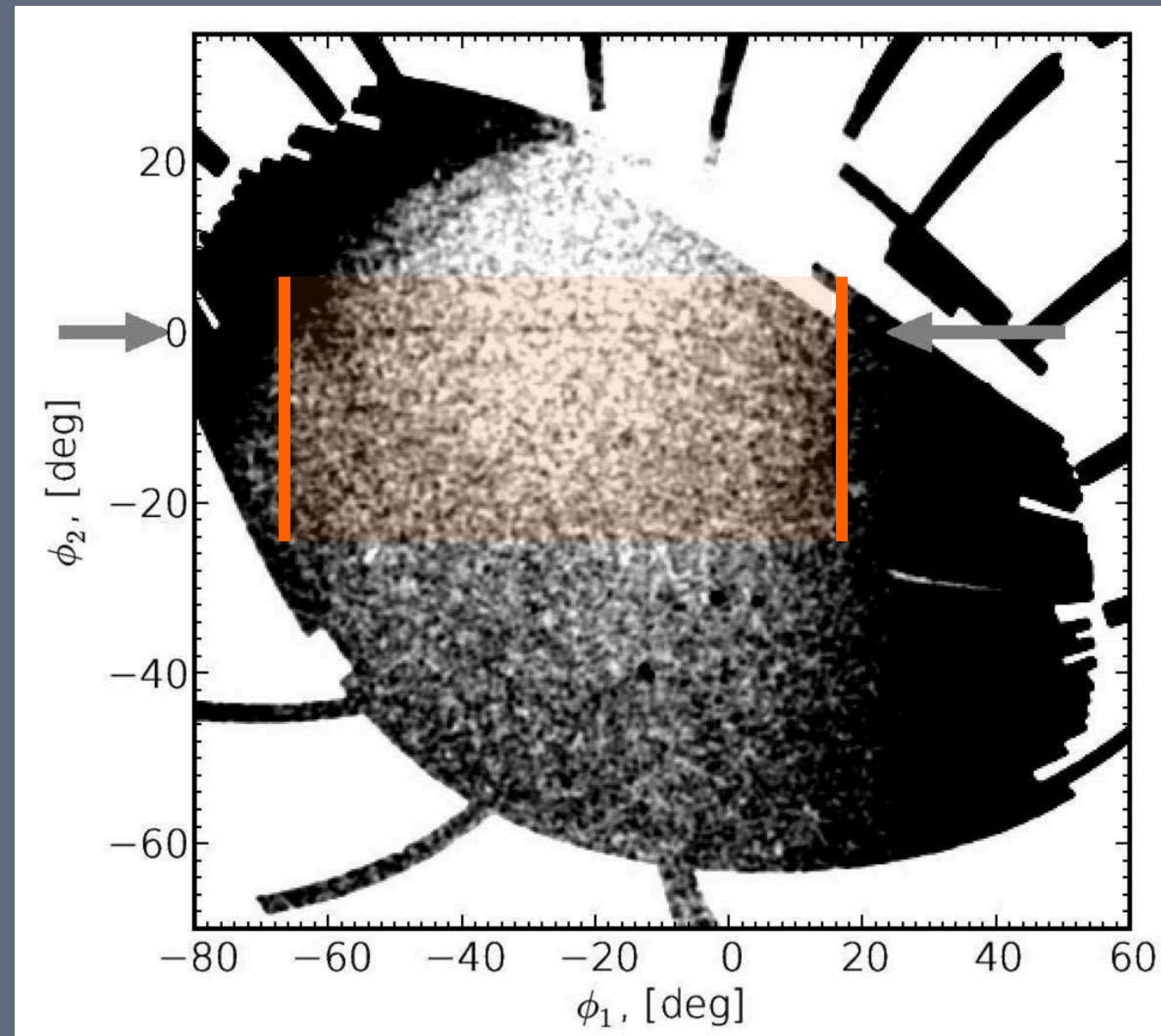
**Ben
Miller**

James Alvey
University of Amsterdam
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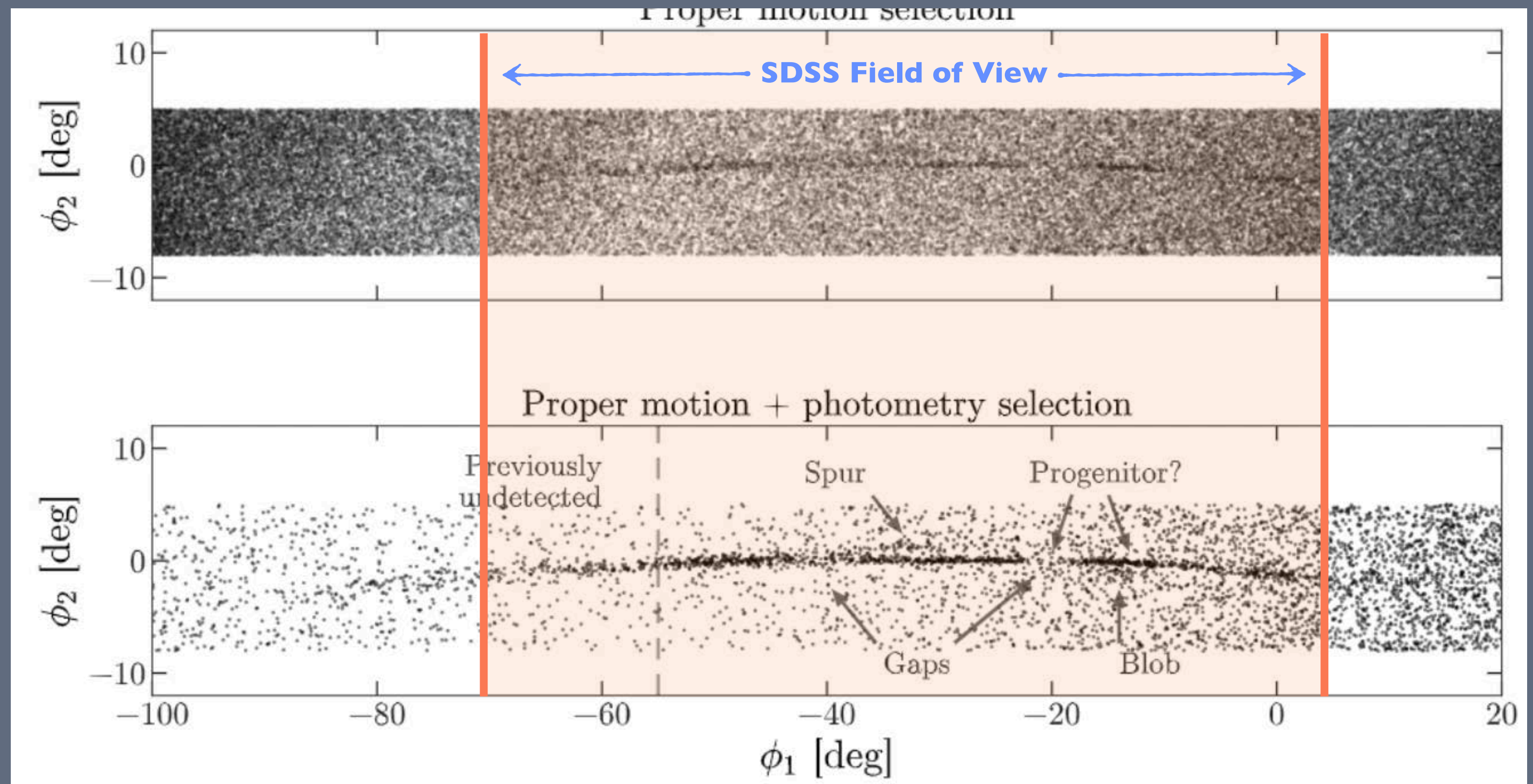
Key Question: Can we do Bayesian inference on any forward/simulation-based model?

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)

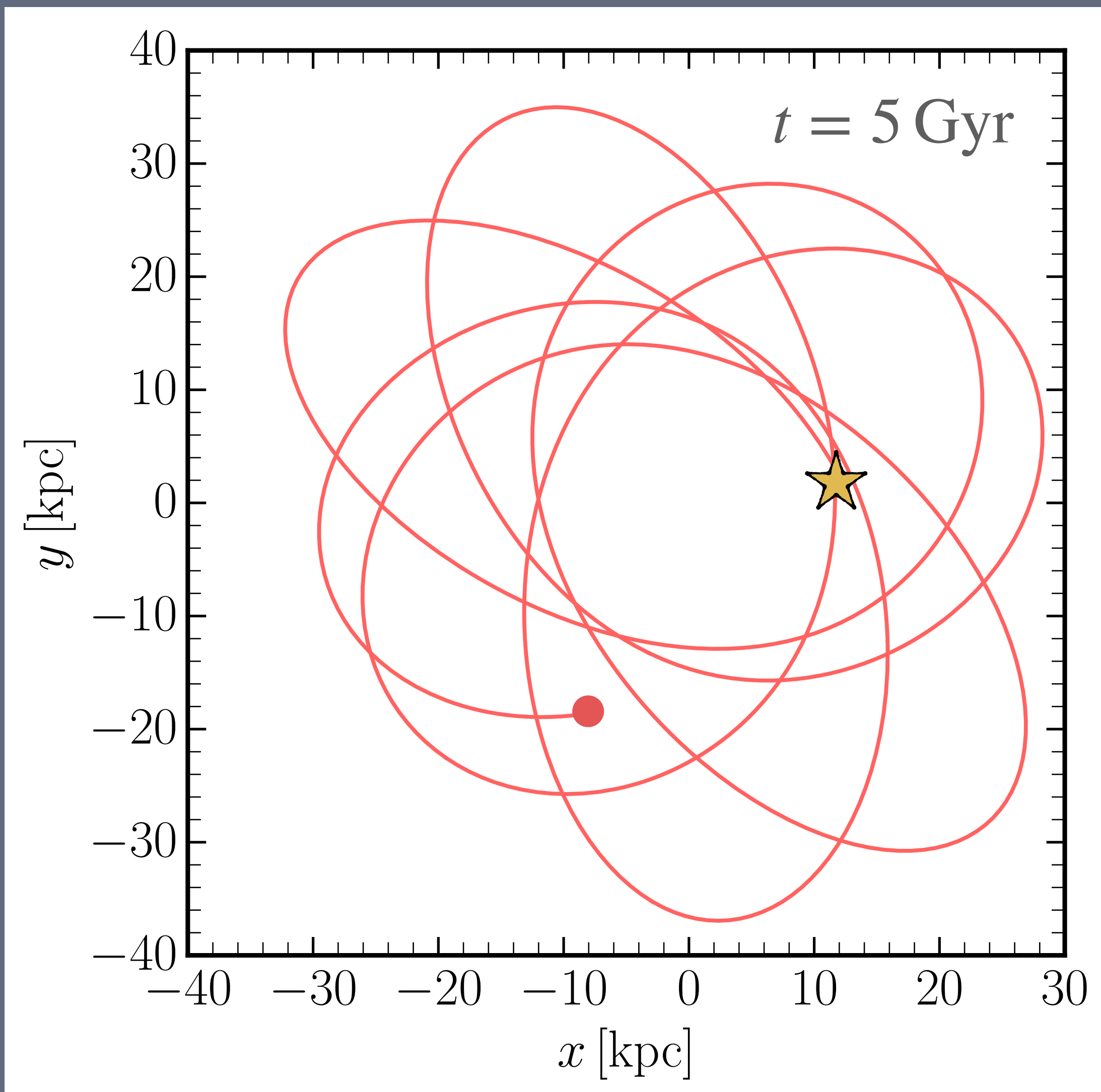
Credit: Banik et al. (2019)

Constraints on the subhalo
mass function

Credit: Bonaca et al. (2019)

Detections of low mass subhalos?

STEP I: TRACE OUT THE CLUSTER TRAJECTORY



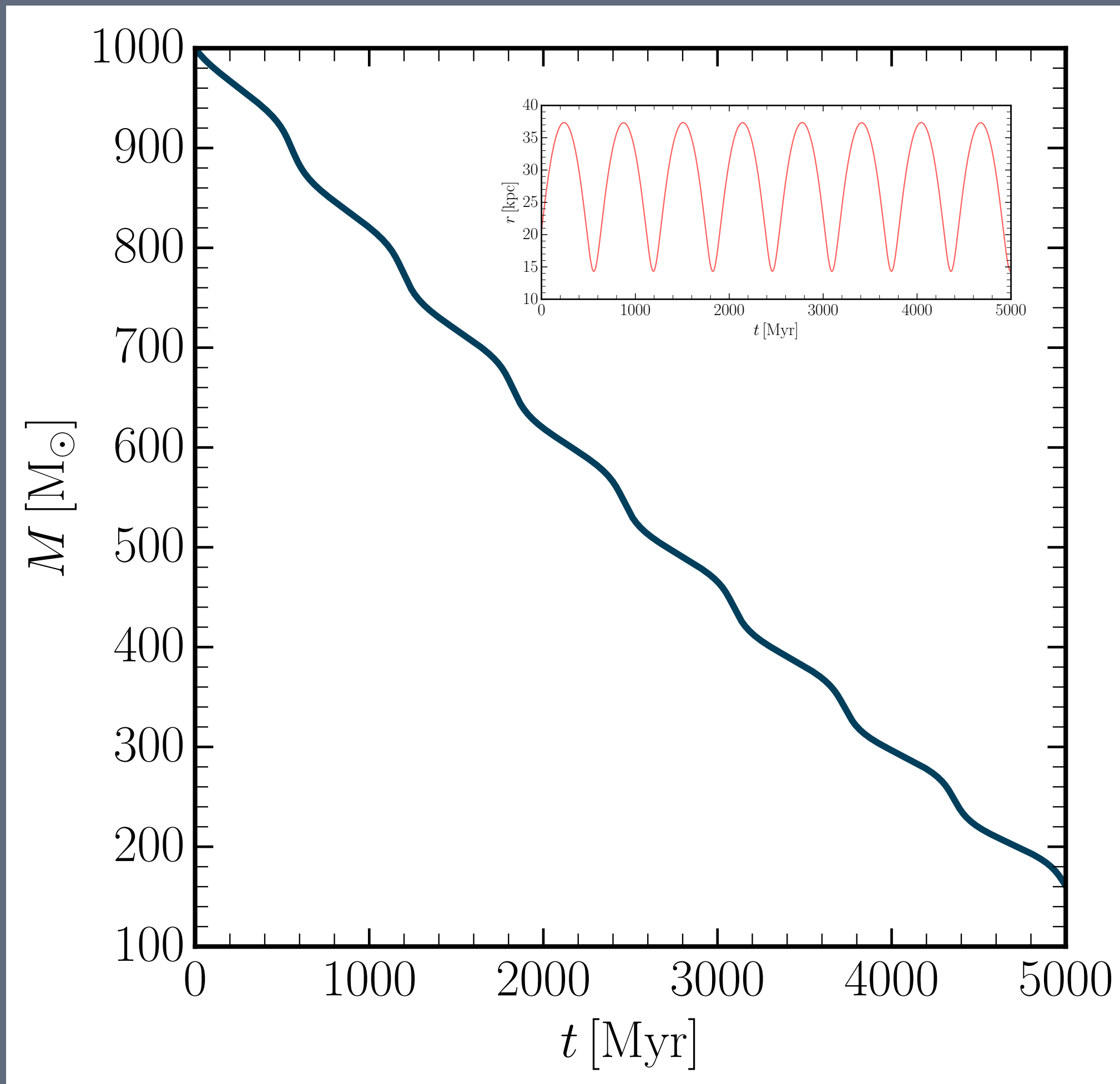
PARAMS

$$(x_c, y_c, z_c)$$

$$(v_{x_c}, v_{y_c}, v_{z_c})$$

$$t_{\text{age}}$$

STEP II: MASS LOSS OF THE CLUSTER BY TIDAL STRIPPING



PARAMS
 $\mathbf{X}_c(t)$
 $(M_0, \xi_0, \alpha, r_h, \bar{m})$

STEP III: STOCHASTICALLY SAMPLE STRIPPING TIMES FOR STARS

PARAMS

$\mathbf{M}_c(t)$

$\bar{m}$

STEP IV: RELEASE STARS FROM THESE STRIPPING TIMES

PARAMS

$\vec{t}_{\text{strip}}$

$(\sigma_v, \lambda_{\text{rel}}, \lambda_{\text{match}}, p_{\text{near}})$

STEP V: EVOLVE THE STARS FORWARDS TO GENERATE STREAM

PARAMS

$\vec{t}_{\text{strip}}$

$\vec{X}_{\text{stars}}^0$

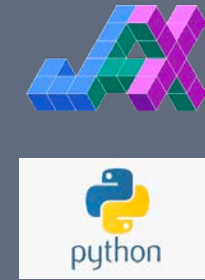
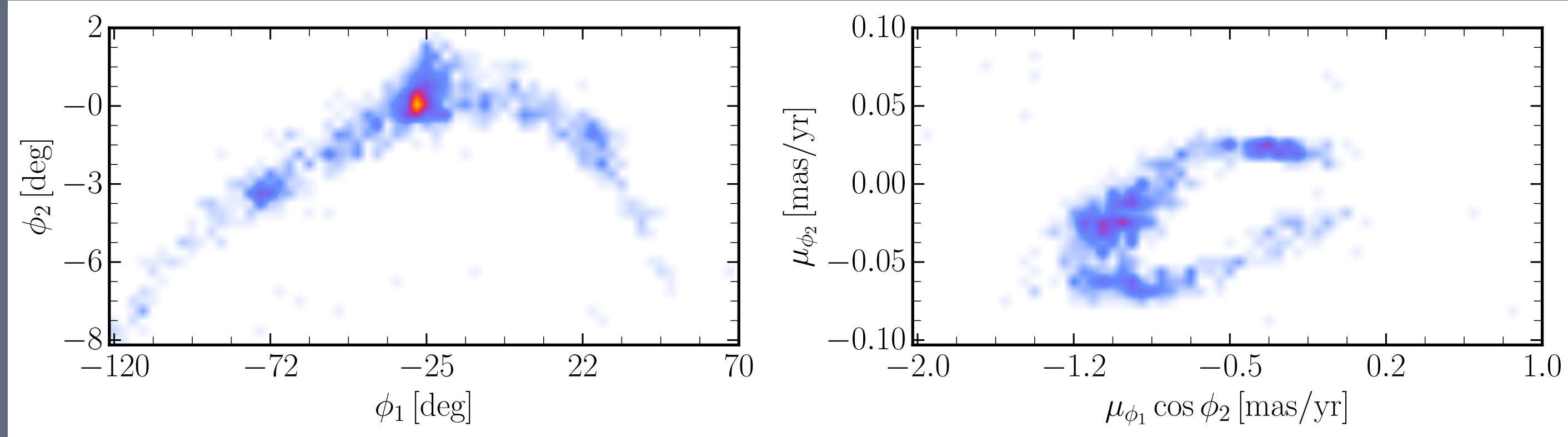
STEP VI: REMEMBER THE DATA - NOISE MODELS ETC.

PARAMS

$$\delta_{\phi_1}, \delta_{\phi_2}, \delta_{\mu_{\phi_1} \cos \phi_2}, \delta_{\mu_{\phi_2}}, \delta_r, \delta_{v_r}$$

We don't actually observe the stream directly, we need to make observations with e.g. Gaia, which comes with certain complications e.g. membership probabilities, measurement errors

STATISTICAL MODEL: LIKELIHOOD PROBLEMS



$$\begin{aligned}
 p(\text{stream} \mid \vec{\theta}) = & p(\text{stream} \mid \vec{X}_{\text{stars}}^f, \delta_{\phi_1}, \delta_{\phi_2}, \delta_{\mu_{\phi_1} \cos \phi_2}, \delta_{\mu_{\phi_2}}, \delta_r, \delta_{v_r}, N_{\text{background}}, p_{\text{background}}, p_{\text{selection}}) && \text{DETECTION} \\
 & \times p(\vec{X}_{\text{stars}}^f \mid \vec{t}_{\text{strip}}, \vec{X}_{\text{stars}}^0) && \text{STAR EVOLUTION} \\
 & \times p(\vec{X}_{\text{stars}}^0 \mid \vec{t}_{\text{strip}}, M_c(t), \mathbf{X}_c(t), \sigma_v, \lambda_{\text{rel}}, \lambda_{\text{match}}) && \text{STAR INITIAL CONDITIONS} \\
 & \times p(\vec{t}_{\text{strip}} \mid M_c(t), \bar{m}) && \text{STRIPPING TIMES} \\
 & \times p(M(t) \mid \mathbf{X}_c(t), M_0, \xi_0, \alpha, r_h, \bar{m}) && \text{MASS EVOLUTION} \\
 & \times p(\mathbf{X}_c(t) \mid x_c, y_c, z_c, v_{x,c}, v_{y,c}, v_{z,c}, t_{\text{age}}) && \text{CLUSTER EVOLUTION}
 \end{aligned}$$

$$\vec{\theta} = [x_c, y_c, z_c, v_{x,c}, v_{y,c}, v_{z,c}, t_{\text{age}}, M_0, \xi_0, \alpha, r_h, \bar{m}, \sigma_v, \lambda_{\text{rel}}, \lambda_{\text{match}}, p_{\text{near}}, \delta_{\phi_1}, \delta_{\phi_2}, \delta_{\mu_{\phi_1} \cos \phi_2}, \delta_{\mu_{\phi_2}}, \delta_r, \delta_{v_r}, N_{\text{background}}, p_{\text{background}}, p_{\text{selection}}]$$

SBI FOR STREAMS: RESULTS ON MOCK DATA

SBI FOR STREAMS: RESULTS ON MOCK DATA

THREE THINGS THAT WORRY ME* (A WISH LIST)

SBI FOR STREAMS: PROS AND CONS + OUTLOOK