TIDAL STREAMS &
the Potential of the Milky Way

adrian price-whelan

kathryn johnston
david hogg
Tidal Streams

Distances 10–100 kpc
Tidal Streams

Distances 10–100 kpc

~20 known around Milky Way

(100 total?)
Tidal Streams

Distances 10–100 kpc

~20 known around Milky Way

(100 total?)

Sgr, Orphan, GD1, Pal 5 most prominent

(Many other short streams, many w/ no progenitors)
Tidal Streams

Dynamically cold
(small spreads in orbital properties)

Stream morphology set by progenitor orbit
(and internal dynamics...
Tidal Streams

Dynamically cold
(small spreads in orbital properties)

Stream morphology set by progenitor orbit
(and internal dynamics...)

Can measure host galaxy potential
With near-future surveys we can measure 6D kinematics

\((l, b, D, \mu_l, \mu_b, v_{\text{los}})\)
RR Lyrae
as dynamical tracers
RR Lyrae

as dynamical tracers

Bright, $M_V \sim 0.5$
RR Lyrae
as dynamical tracers

Bright, $M_V \sim 0.5$

Found in many streams
(some may only have a few...)
RR Lyrae
as dynamical tracers

Bright, $M_V \sim 0.5$

Found in many streams
(some may only have a few...)

Easy to identify from light curve
RR Lyrae
as dynamical tracers

Bright, $M_V \sim 0.5$

Found in many streams
(some may only have a few...)

Easy to identify from light curve

Period-Luminosity relation for precise distances
(2% uncertainty in relative distances)
“Orphan stream”
(no uncertainty)
M giants
(15-20%)
BHB stars

(10%)
RR Lyrae

with PL (2%)
RR Lyrae in Gaia

Transverse velocity error

\[ \sigma_{\mu} \quad d_{\odot} \]

G [mag]

100 km/s

10 km/s

1 km/s

1 kpc

10 kpc

100 kpc

post-launch estimates
RR Lyrae in Gaia

15 km/s at 30 kpc

$G [\text{mag}]$

$\sigma_\mu \ d_\odot$

$\sigma_\mu \ d_\odot$

post-launch estimates
“Orphan stream”
(no uncertainty)
Gaia
(~ 0.03 mas/yr)
How do we use these data?
How do we use these data?

We need fast generative models
How do we use these data?

We need fast generative models

N-body
Rewinder
Stream formation

potential center
Stream formation

L2

L1

potential center
Rewinder

$t = 0$

Price-Whelan et al. (2014)
Rewinder

$t = 0$

Price-Whelan et al. (2014)
Rewinder

evaluate likelihood

$t = -1$

Price-Whelan et al. (2014)
Rewinder

$t = -2$

Price-Whelan et al. (2014)
Rewinder

evaluate likelihood

\[ t = -2 \]

Price-Whelan et al. (2014)
\( t = -3 \)

*Price-Whelan et al. (2014)*
Rewinder

\[
\begin{align*}
\text{per star} & \quad \tau_{\text{ub}} \quad \text{unbinding time} \\
K & \quad \text{leading/trailing tail} \\
(l, b, d, \mu_l, \mu_b, v_r) & \\
\text{progenitor} & \quad M(t) \quad \text{mass vs. time} \\
(l, b, d, \mu_l, \mu_b, v_r) & \\
\text{potential} & \quad \Phi \quad \text{any parametrization}
\end{align*}
\]

*Price-Whelan et al. (2014)*
**Rewinder**

- **per star**
  - $\tau_{\text{ub}}$ unbinding time
  - $K$ leading/trailing tail
  - $(l, b, d, \mu_l, \mu_b, v_r)$

- **progenitor**
  - $M(t)$ mass vs. time
  - $(l, b, d, \mu_l, \mu_b, v_r)$

- **potential**
  - $\Phi$ any parametrization

*Price-Whelan et al. (2014)*
Rewinder

\[ \tau_{ub} \] unbinding time

\[ K \] leading/trailing tail

\[ (l, b, d, \mu_l, \mu_b, v_r) \]

\[ M(t) \] mass vs. time

\[ (l, b, d, \mu_l, \mu_b, v_r) \]

\[ \Phi \] any parametrization

Price-Whelan et al. (2014)
8 “RR Lyrae” stars
Gaia velocity errors
2% distance errors
+ progenitor

Price-Whelan et al. (2014)
8 RR Lyrae stars

Gaia velocity errors

2% distance error

Price-Whelan et al. (2014)
This is fine as a test, but we are all liars.
We must move away from static, analytic potentials!

With restrictive models, we will make uninterpretable, biased measurements.
For example,

**Basis Function Expansions**

\[
\rho_{nlm} = \tilde{\rho}_{nl}(r) Y_{lm}(\theta, \phi)
\]

\[
\Phi_{nlm} = \tilde{\Phi}_{nl}(r) Y_{lm}(\theta, \phi)
\]
Current stream models can recover true parameters of true potential
(from “observed” simulations)
Current stream models can recover true parameters of true potential (from “observed” simulations)

Moving to more general potential models & real obs. uncertainties is going to hurt (but we have to do it)
Current stream models can recover true parameters of true potential
(from “observed” simulations)

Moving to more general potential models & real obs. uncertainties is going to hurt
(but we have to do it)

Rewinder can do this, but more work to be done!