PRIMAL: A particle-by-particle M2M Algorithm

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Hunt & Kawata (2013), MNRAS, 430, 1928
Hunt, Kawata & Martel (2013), MNRAS, 432, 3062
Hunt & Kawata (2014), MNRAS, 433, 2112

The Goals

- Milky Way Structure & Dynamics unknown;
  - R_0=8.35 ± 0.35 kpc
  - M_d=6.43 ± 0.63 x 10^{10} $M_\odot$
  - $R_{d,thin}$=2.6 ± 0.52 kpc
  - $R_{d,thick}$=3.6 ± 0.72 kpc
  - $V_{rot,\odot}$=239 ± 5 kms^{-1}
- Hard to know global picture due to position and extinction.

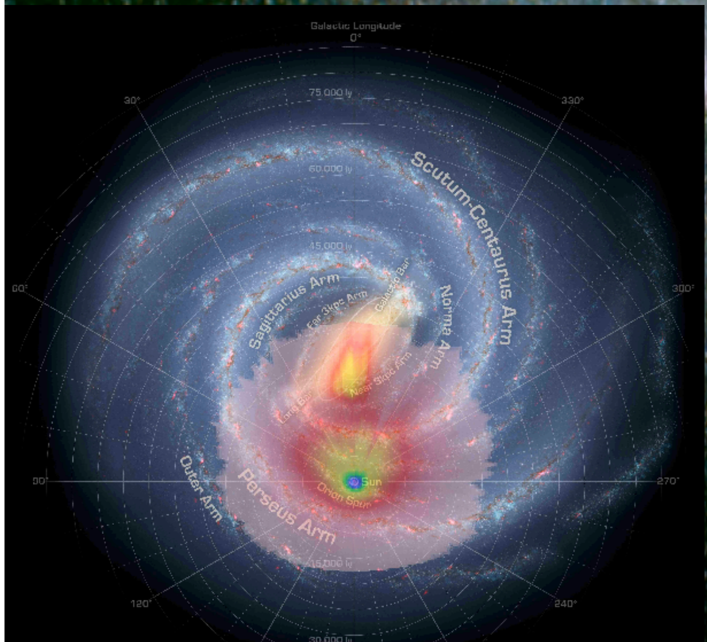
e.g. from McMillan (2011)

Credit: http://mwmw.gsfc.nasa.gov/mmw_sci.html

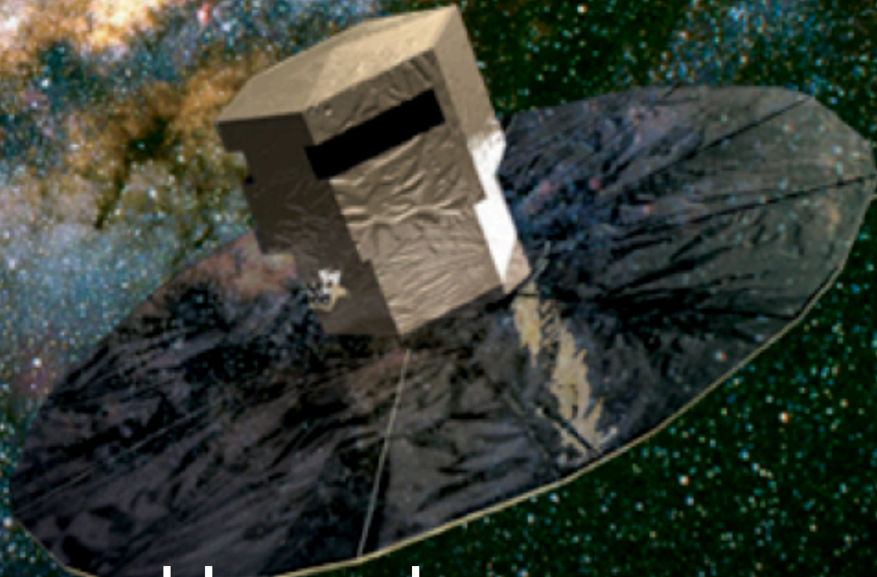
Thus we need good surveys and good models!

Gaia

Gaia (Launched 19th December 2013)
ESA corner-stone mission
Mapping a billion stars in the Milky Way



Credit: X. Luri & DPAC-CU2



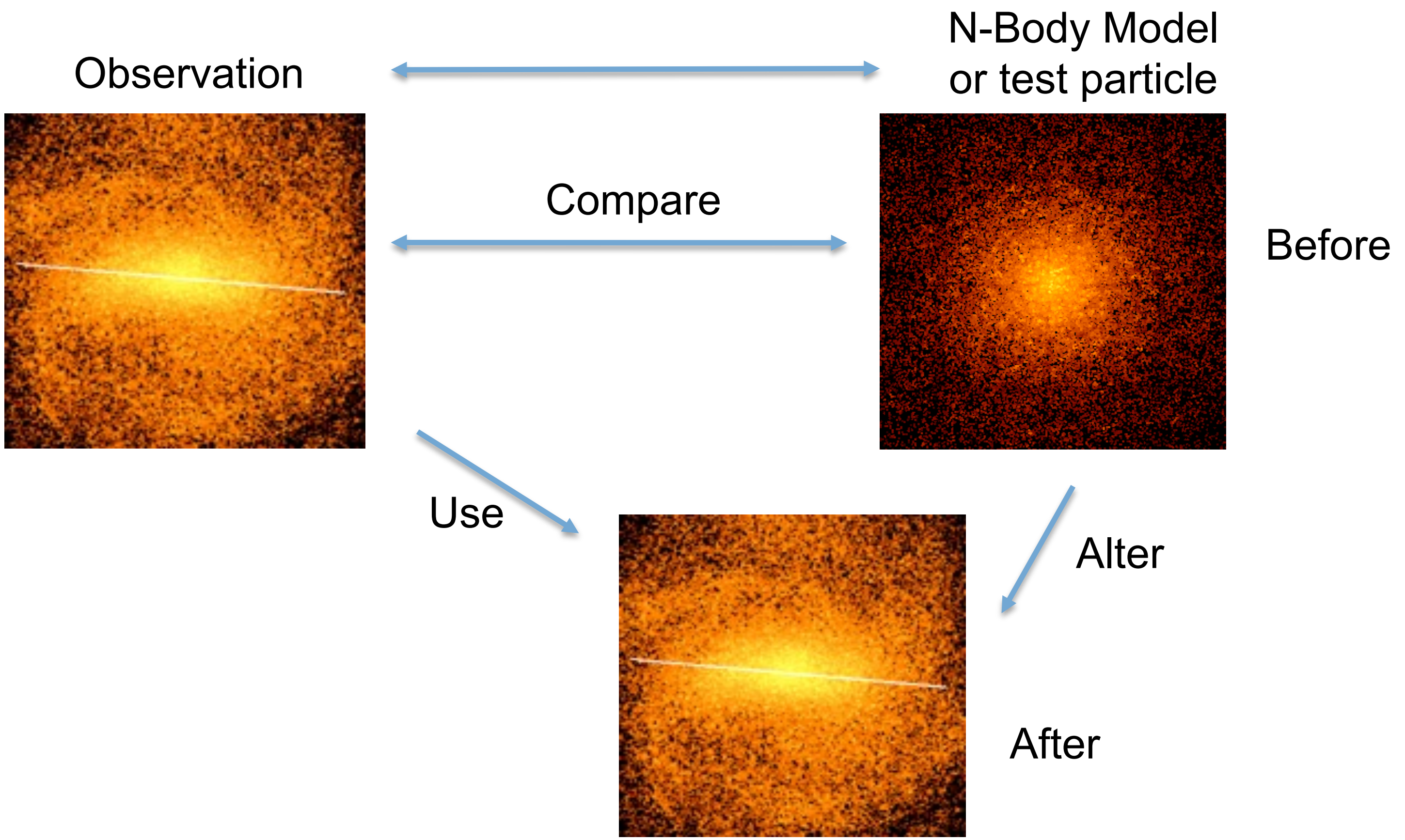
- Also ground based surveys, e.g. Gaia-ESO (VLT)

Modelling with Gaia data

We are developing a new Made-to-Measure dynamical model of the Milky Way.

The vast majority of observed stars will be from the Disc, so we focus on the disc.

The Basic M2M Concept



The Basic M2M Formula

Model

Difference

$$\Delta_j = \frac{y_j(t) - Y_j}{Y_j}.$$

Target

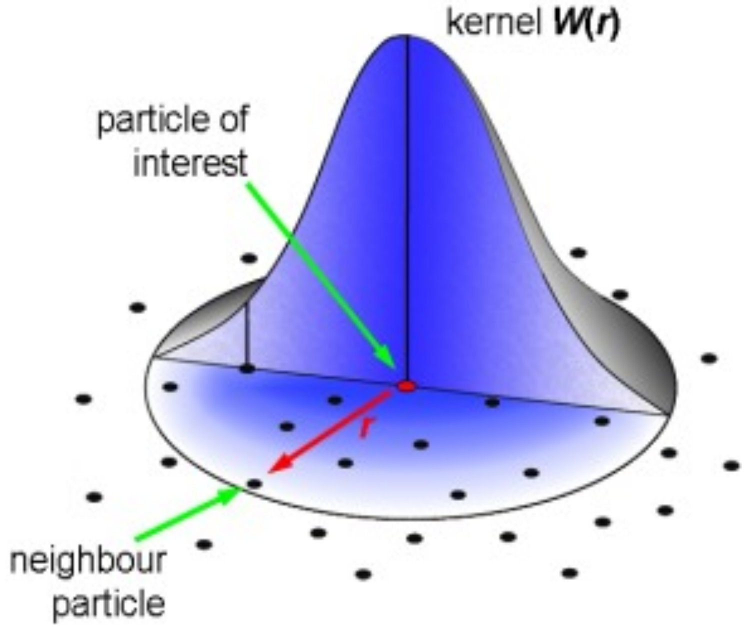
For example, with density:

- If $\Delta\rho > 0$ then m_p decreases
- If $\Delta\rho < 0$ then m_p increases

e.g. Syer & Tremaine (1996), De Lorenzi et. al. (2007), Dehnen (2009), Long & Mao (2010)

Our adaptation: PRIMAL

- Compares target and model observables at target particle positions.
- Uses SPH Kernel to calculate contribution to observable.

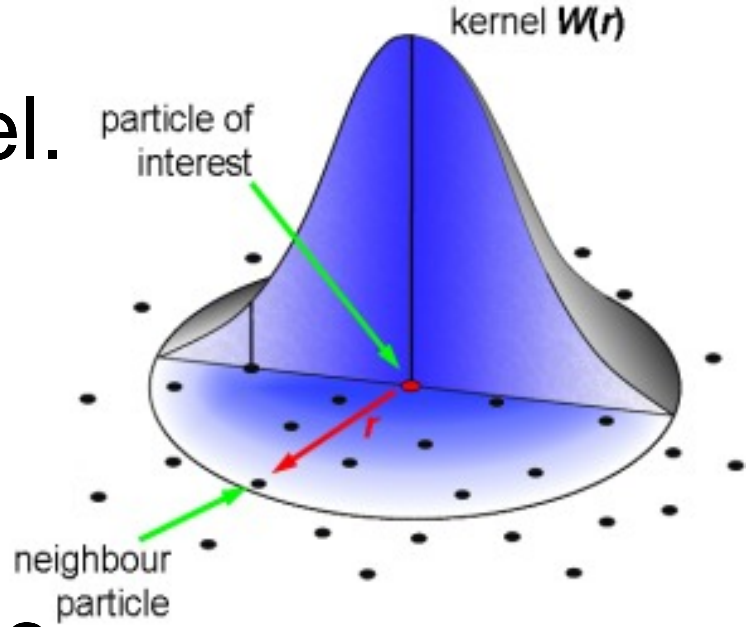


- Use of self-gravity leads to structure and dynamics.

Our adaptation: PRIMAL

- $\mu_{\alpha,\delta}$ & v_r use likelihood equation with SPH Kernel.
- Allows individual errors.

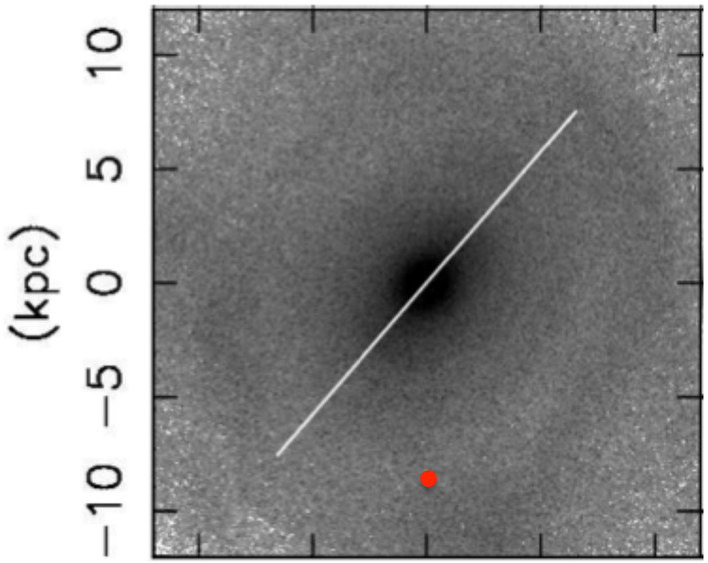
$$\hat{\mathcal{L}}_j = \frac{1}{\sqrt{2\pi}} \sum_i W_{ij} m_i \mathrm{e}^{-(v_j - v_i)^2 / 2\sigma_j^2}$$

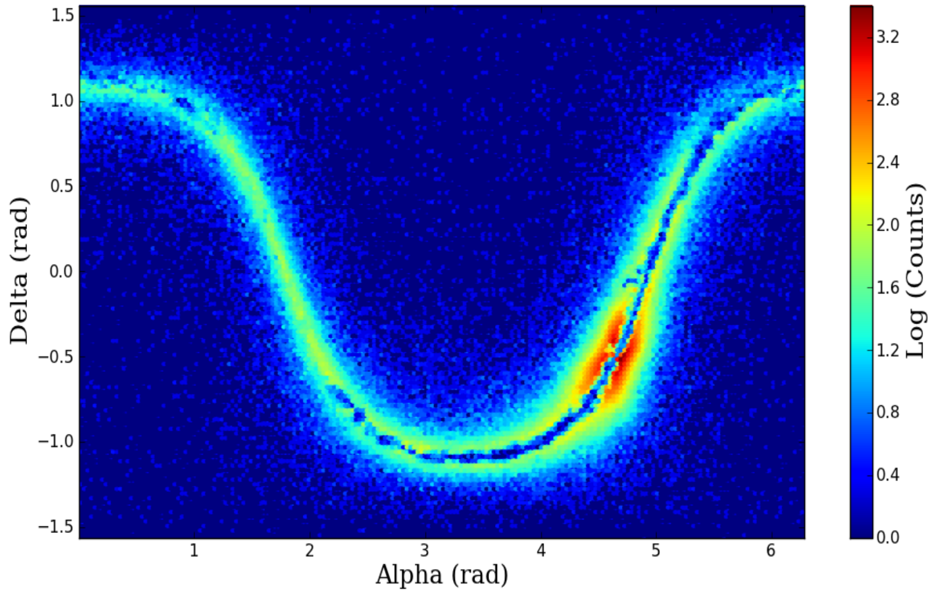


- Resample model particles when their mass is too large or too small.

Making target Gaia data

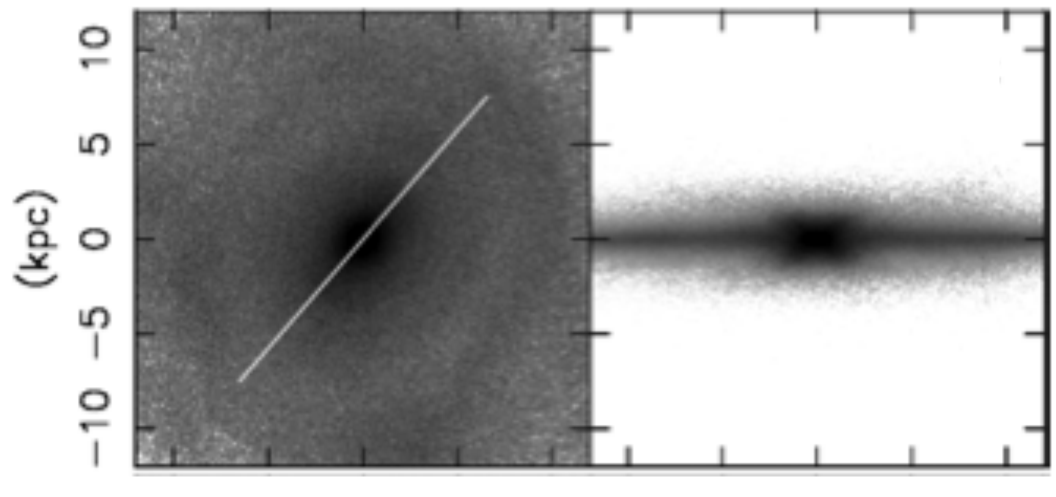
- Gaia astrometry data release expected 2016.
- Need mock Gaia catalogues to test.
- Can ‘observe’ an *N*-body model to get mock data.





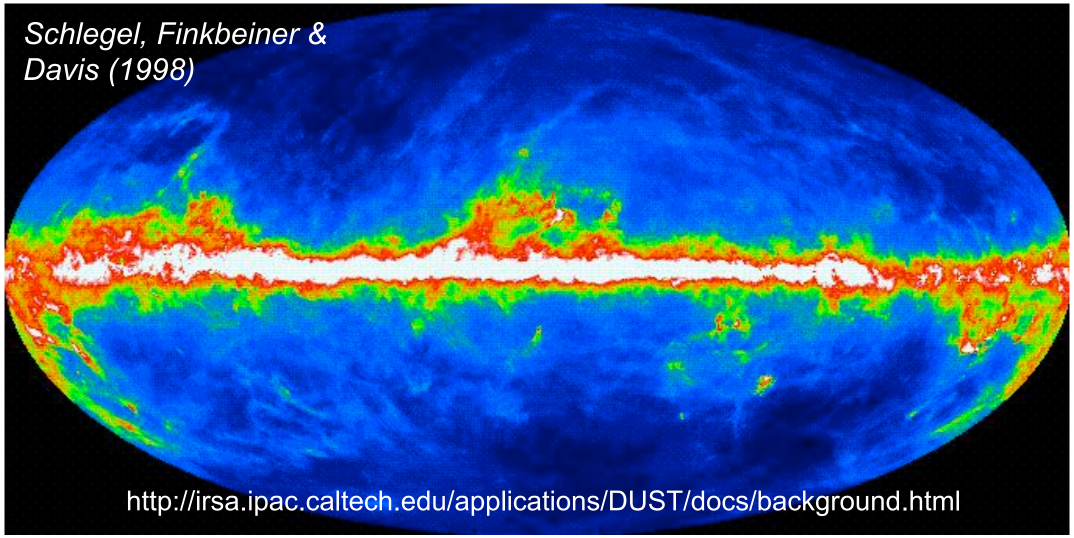
The Target Galaxy

- N-body simulation with GCD+ (Kawata & Gibson (2003), 10^6 particles, 2 Gyr old.
- R_d=3.0 kpc, z_0=0.3 kpc, M_d=5.0x10^{10} $M_\odot$.
- Fixed dark matter halo, M_h=1.75x10^{12} $M_\odot$.



Adding Extinction

- Assume (for now) particles are M0III tracers, with one star = one particle.
- Use 3D extinction maps from Galaxia (Sharma et. al 2011).
- Calculate extinction values for each tracer.

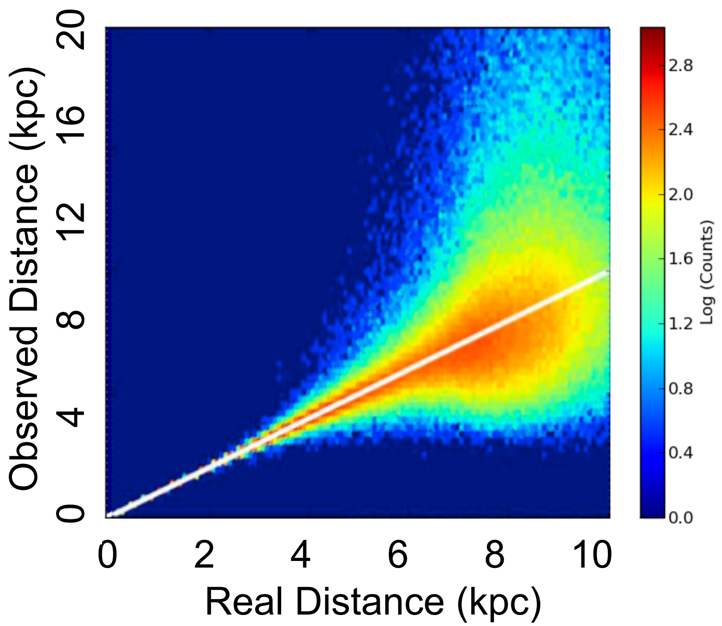


Adding Error

- Use Gaia performance estimates (pre launch).

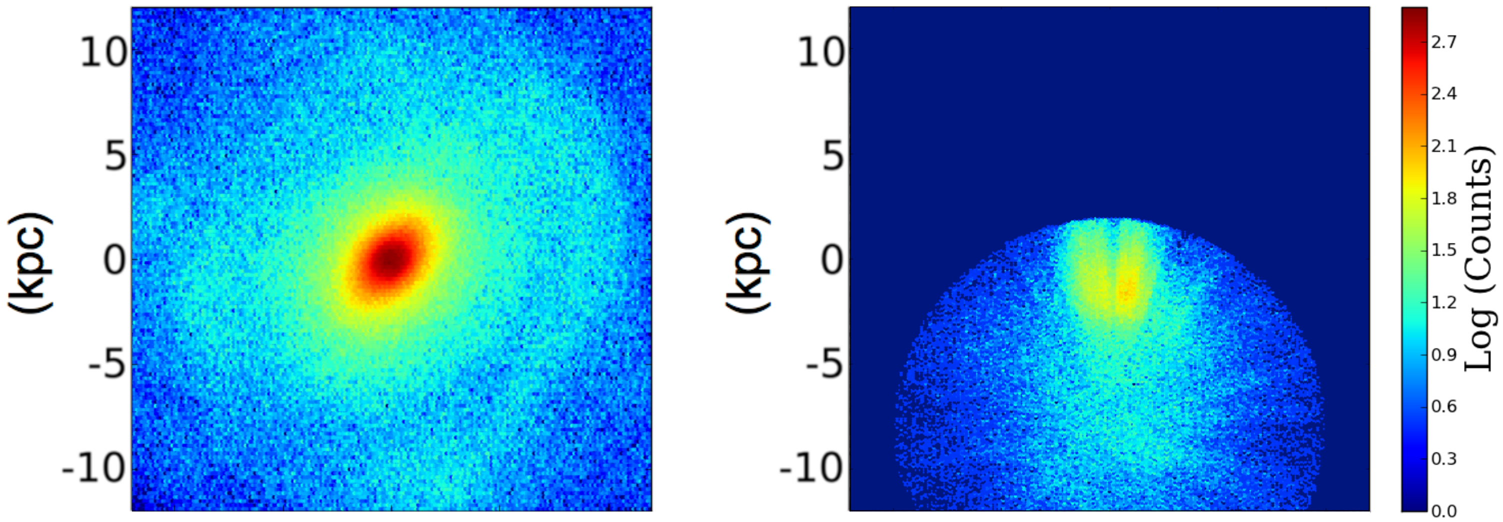
(www.cosmos.esa.int/web/gaia/science-performance)

- Calculate errors for each tracer (M0III).



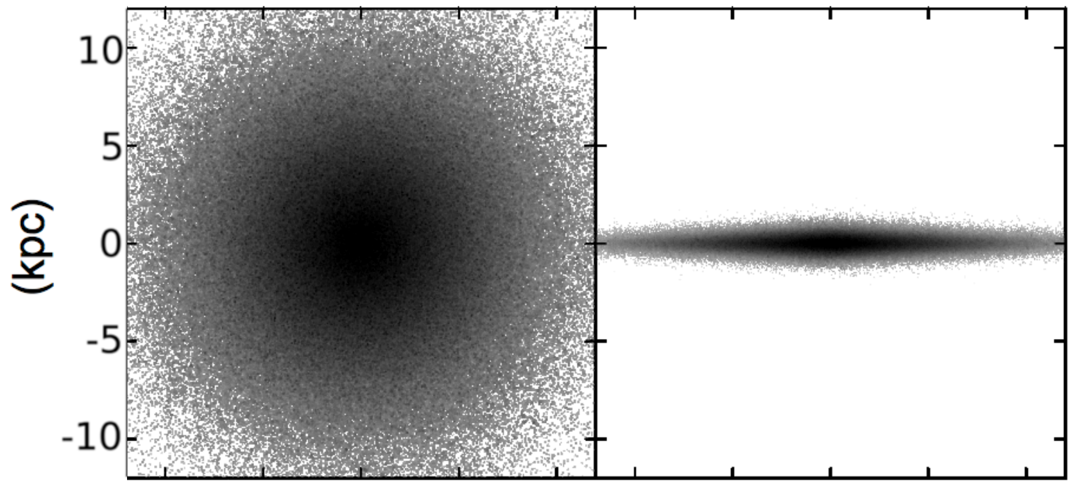
Selecting Observed Range

- Observed data limited to selected range of 10 kpc and 16.5 mag (for M0III).
- For M0III, 173,821 of 1,000,000 selected.



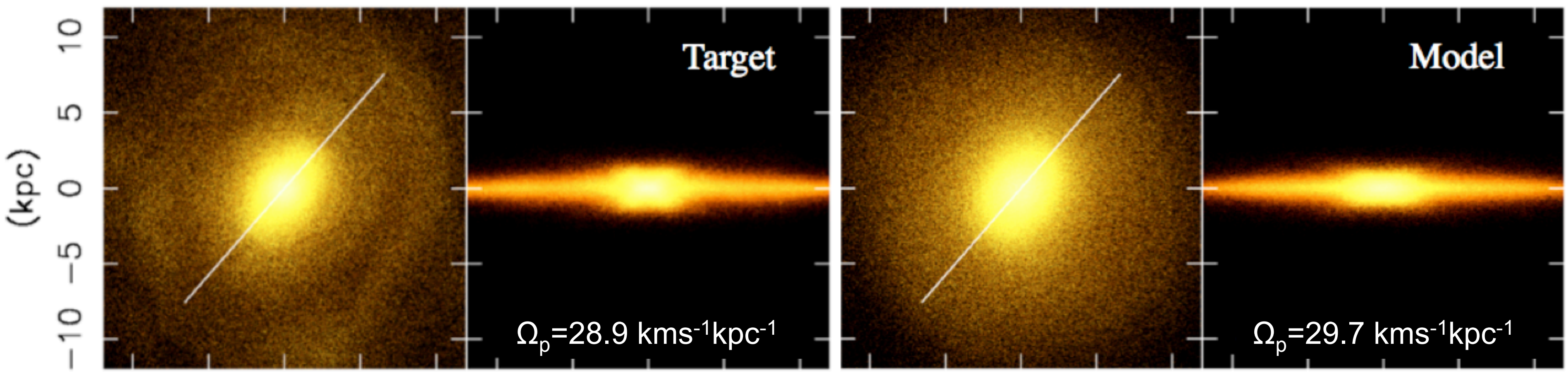
Initial Model Conditions

- Same properties as target except lower scale length ($R_{d,m}$=2.0 kpc, $R_{d,t}$=3.0 kpc).
- Smooth, 10^6 particle, $m_p=5.0\times10^4\ M_\odot$
- Assumed known dark matter halo.

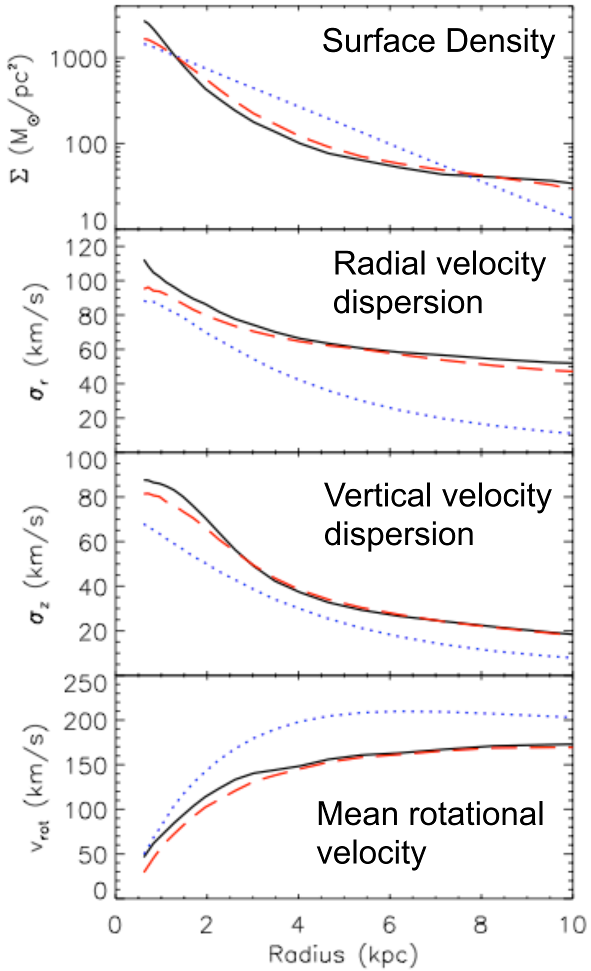


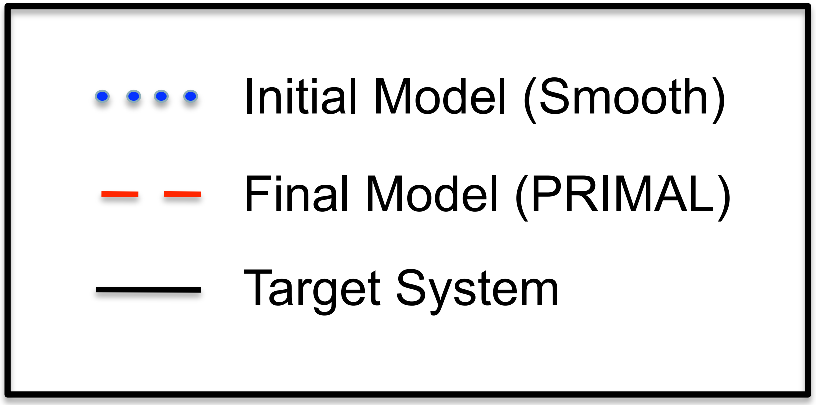
Applying PRIMAL to data

- Morphology recovered well, but missing arm and thinner box.
- Pattern speed recovered excellently.



Radial profiles reproduced

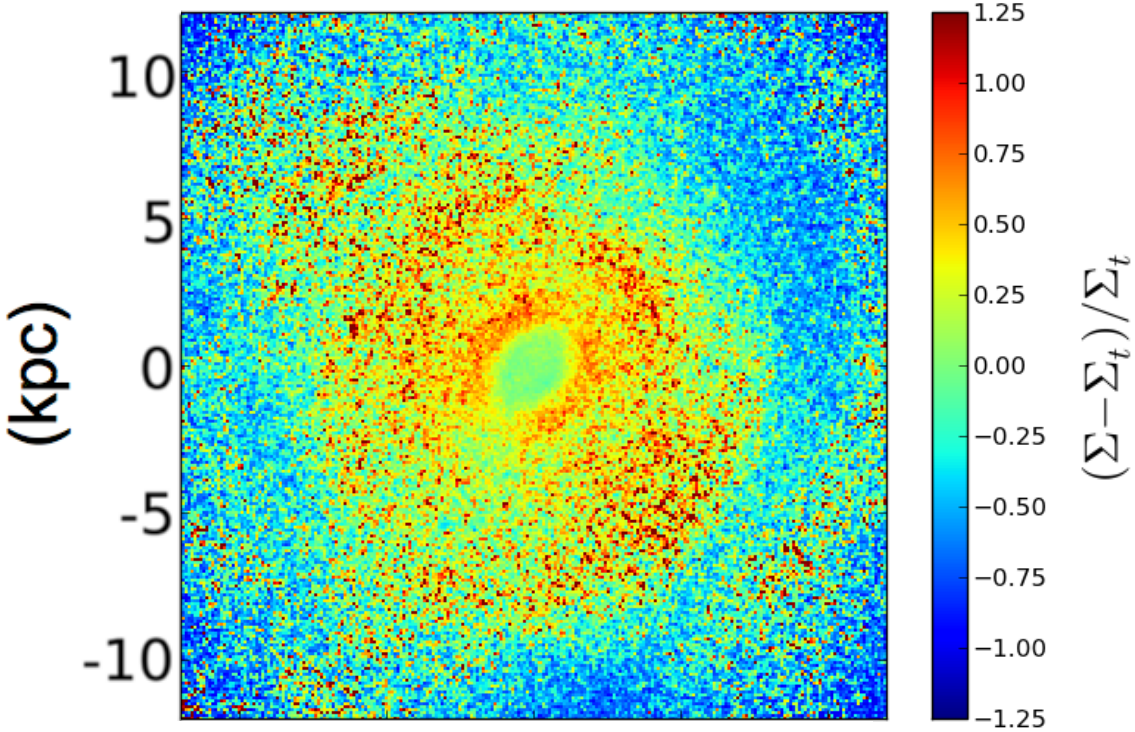




- Not directly constrained.
- Density and velocity radial profiles recovered well.

Surface Density

- Fractional difference in surface density
- Excellent bar recovery.
- Missing arm.
- Over-dense patches.



The next step

- Fit multiple populations with PRIMAL. (In Progress)

- Use SNAPDRAGONS mock data (our Gaia based population synthesis code)

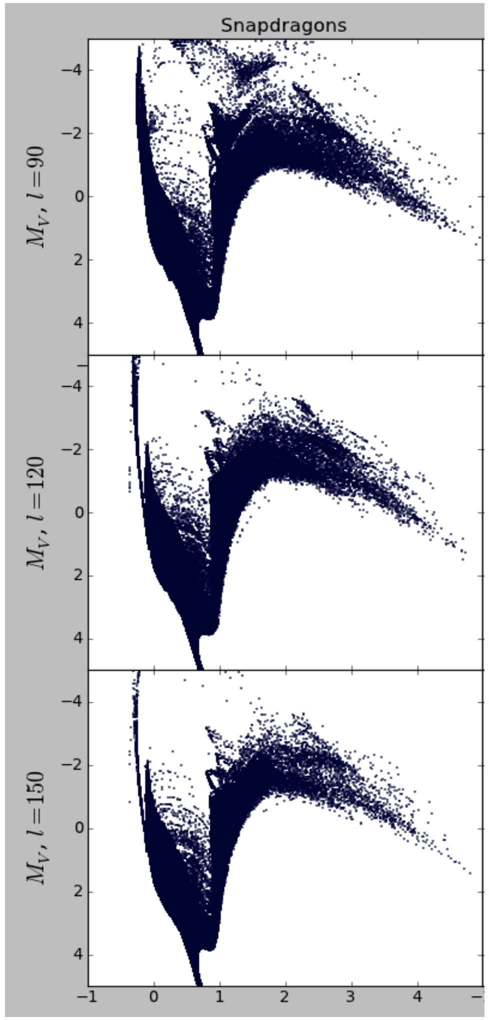
- Construct multi-component models (e.g. thin & thick disc).

Summary

- New self-gravity M2M tailored to Gaia data.
- Testing using mock Gaia data from N-body model.
- Results promising despite extinction & error, especially pattern speed.

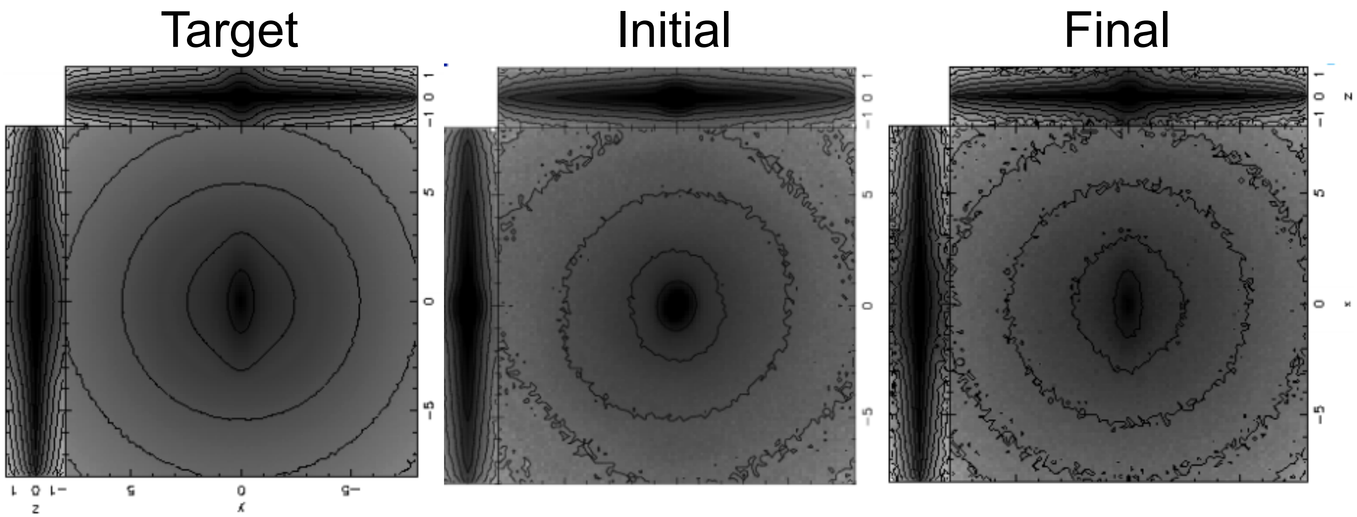
SNAPDRAGONS

- Resampling *N*-body particles into stars (Hunt et al. In prep)
- Adds extinction (from Galaxia maps) and Gaia error.
- No smoothing: clear particle <-> star relation.
- Can make mock Gaia stellar data.



Previous M2M example

- Bissantz et al. (2004), looks at the bulge.
- Mass model -> Dynamical model.
- No kinematic constraints.
- Matches kinematics in many bulge fields.



Gerhard (2009)
http://www.lorentzcenter.nl/lc/web/2009/355/presentations/Gerhard.pdf