Modelling tidal streams using N-body simulations

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Tidal streams (Rodrigo Ibata)

Notes:

- Stars from a bound stellar system gain Kinetic energy to become unbound (e.g. after a pericentric interaction)
- They escape through the Lagrange radii forming leading and trailing tails
- The leading (trailing) tail precedes (follows) and has **slightly** lower (higher) energy and angular momentum than the progenitor system
- Stream stars follow similar (but not equal) orbits to their progenitors

↓

Streams are tracers of the orbit of the disrupting systems

↓

Galactic potential

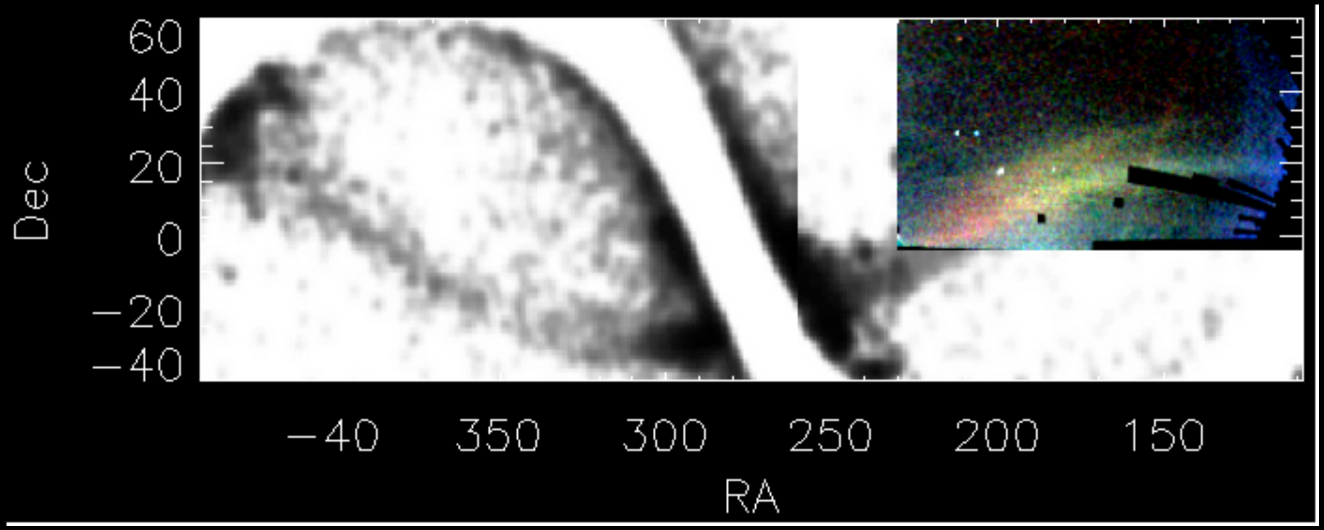
The modelling

- There is **no unique** method
- Modelling depends on the particular characteristics of a stream

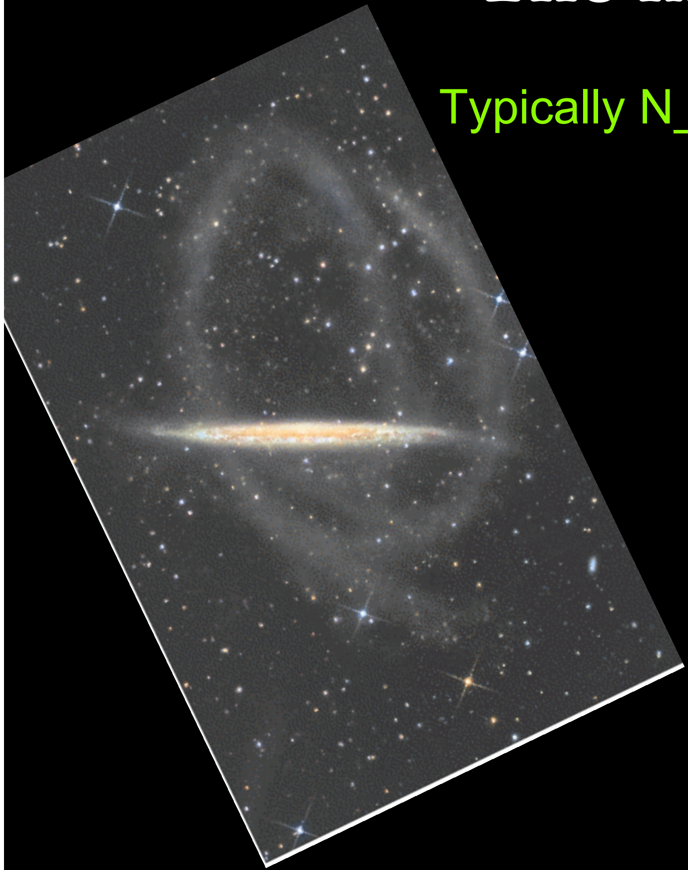
for example:

- streams with unknown progenitors (e.g. Monoceros stream)
- incomplete observational coverage (e.g all :)
- different observational constraints (distances? radial velocities? … etc)
- unclear membership of stream pieces

……. etc



The modelling



Typically N_unknowns >> N_constraints = **degenerated solutions**

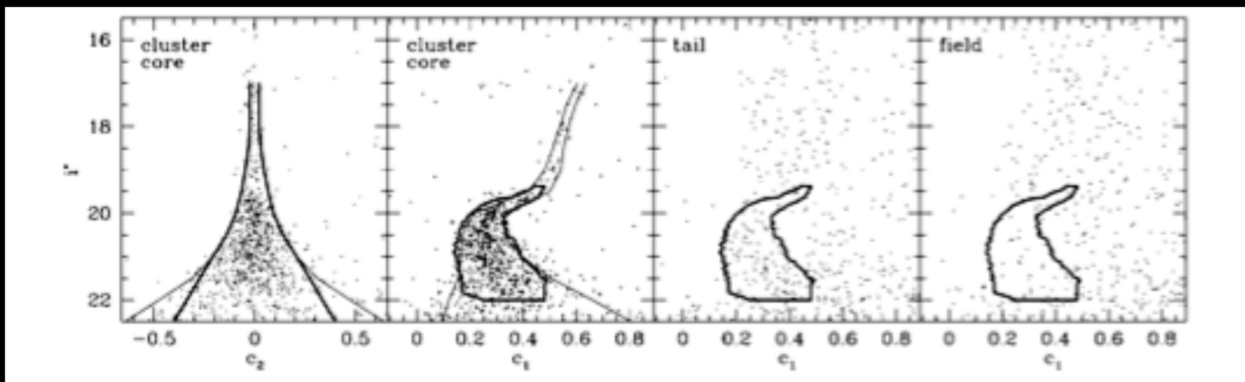
Free parameters:

- ✓ Shape (triaxial halo?) of the host potential
- ✓ Inclination of the host disc vs line-of-sight
- ✓ Orbital apocentre
- ✓ Orbital inclination
- ✓ Orbital eccentricity
- ✓ Satellite's DM halo mass and concentration
- ✓ Distribution of stars within DM halo
- ✓ Satellite luminosity
- ✓ Accretion time
- ✓ Orbit projection angle vs line-of-sight
- ✓ Present progenitor position (3 param.)

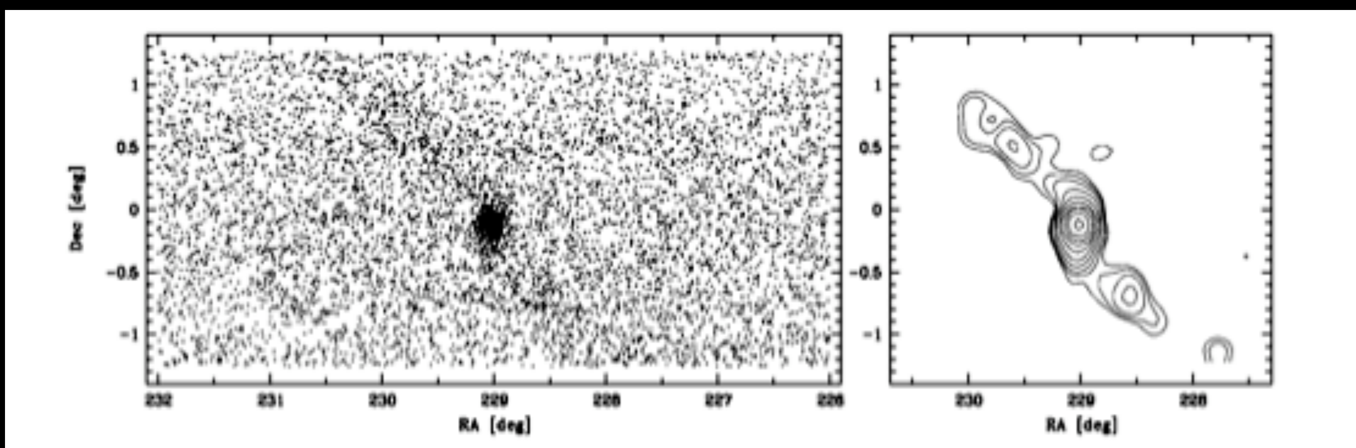
Available information:

- ✓ Projected geometry
- ✓ Progenitor position?
- ✓ Total luminosity
- ✓ Kinematics? (e.g. planet.neb. Globular clusters, …,etc)

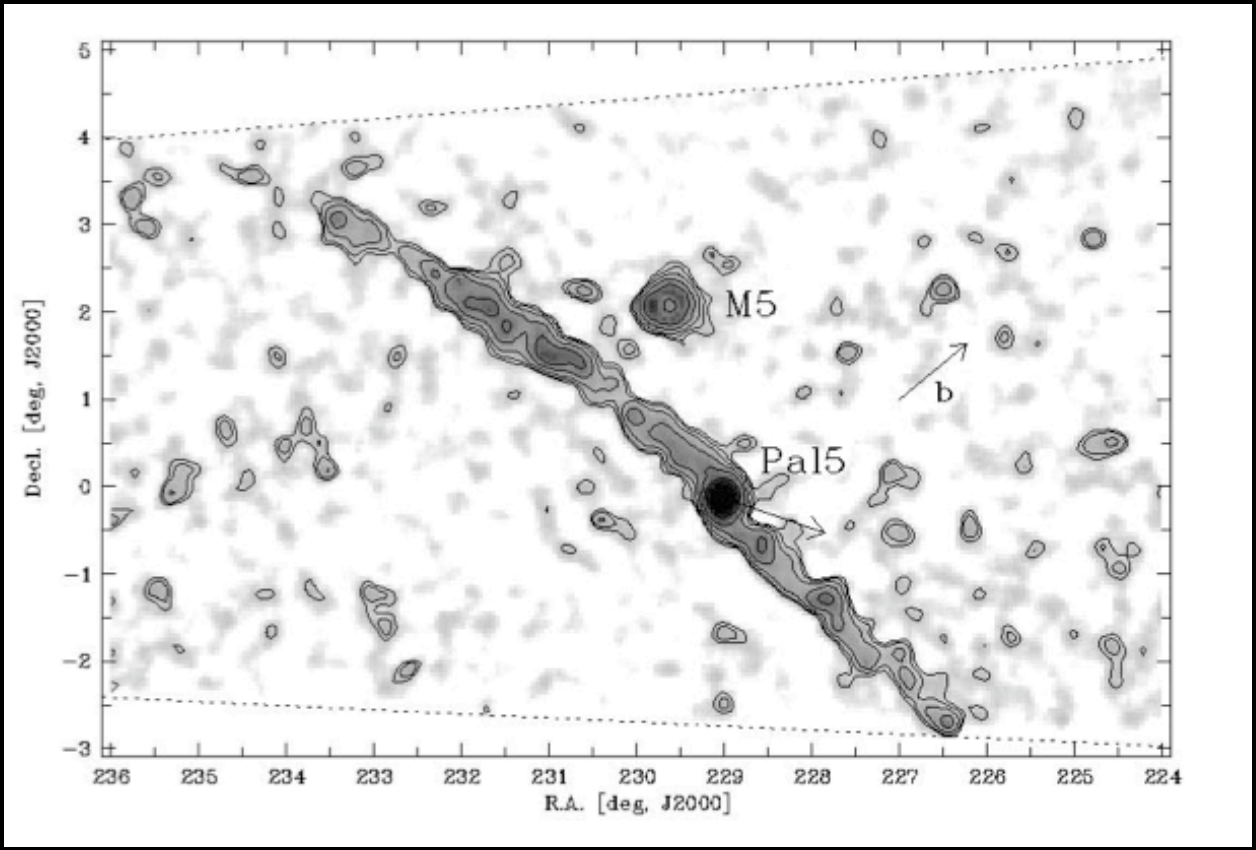
A beautiful case: the tidal stream of Pal 5



Odenkirchen et al. 2001



A beautiful case: the tidal stream of Pal 5

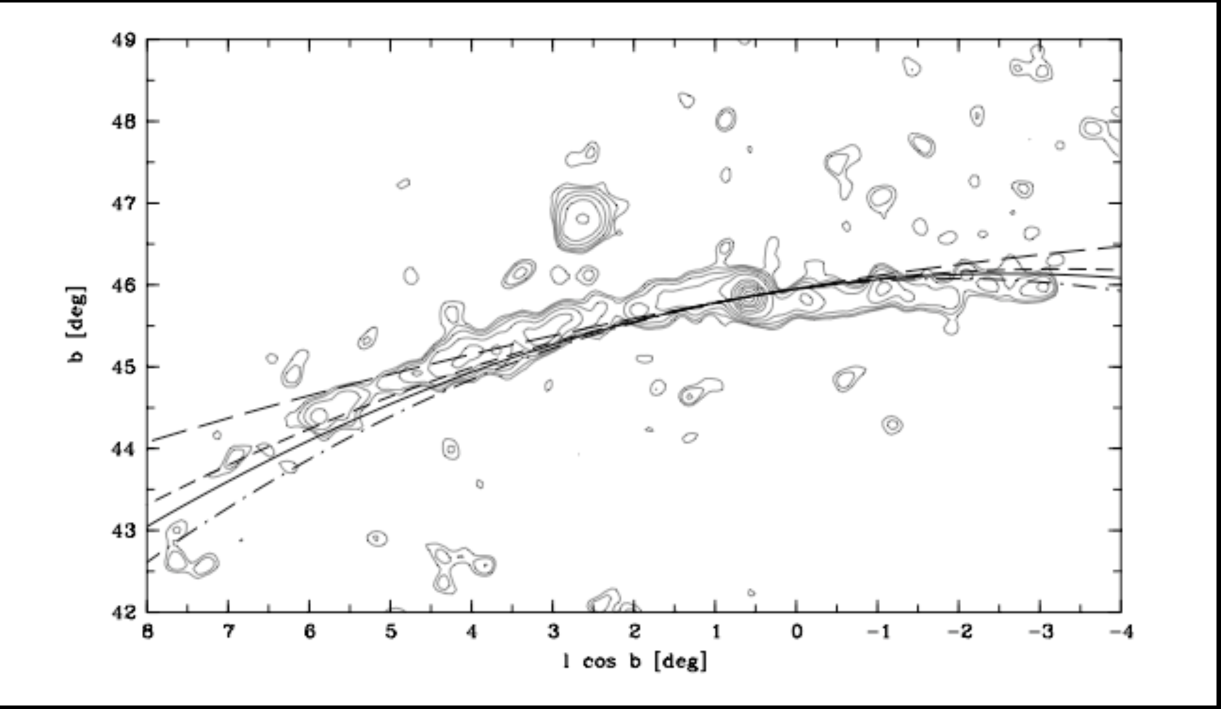


Odenkirchen et al. 2003

A beautiful case: the tidal stream of Pal 5

Cluster's position + velocity vectors:

- $D = 23.3$ kpc (Harris 1996)
- $(\alpha,\delta) = (229.0\ ,\ -0.1)$
- $v_{h,rad} = -58.7$ km/s (Odenkirchen et al. 2002)
- $(\mu_\alpha\ ,\ \mu_\delta\ ) = (-2.44, -0.87)$ mas/year (Dinescu, Girard & van Altena 1999)



Modelling method

1. Semi-analytic orbits to explore the parameter space (today, 17th Nov)
2. N-body realization of the best-fitting orbit (Tueday, 25th)

↓

Dynamical model of the Milky Way

download codes from: **http://www.ast.cam.ac.uk/~jorpega**

Part 1: Semi-analytic orbits

Galactic potential

1. **Miyamoto-Nagai (1975) disc** $\Phi_d = - GM_d / \{ R^2 + [a+(z^2+b^2)]^2 \}^{1/2}$

2. **Hernquist (1993) bulge** $\Phi_b = - GM_b / \{ R + c \}$

3. **NFW (1987) dark matter halo** $\Phi_h = - V_{max}^2 r_{max} \ln\{ 1 + r / r_s\} /r$

Parameters chosen to reproduce Vc(r)

Orbit integration

Leap-frog method:

$$-d\Phi/dr = m\, d^2\underline{r} / dt^2 = m\, d\underline{v}/dt$$

$$d\underline{r}/dt = \underline{v}$$

$$\underline{v} \rightarrow \underline{v}' = \underline{v} + d\underline{v}/dt * \Delta t$$

$$\underline{r} \rightarrow \underline{r}' = \underline{r} + v' * \Delta t$$

Δt chosen so that $\Delta E/E_0 << 1$, $L_z/L_{z,0} << 1$ $(\sim 10^{-6})$

Leading-trailing tails:

$\Delta t > 0$ leading tail

$\Delta t < 0$ trailing tail

Approximation: tails have the same E, L_z as the progenitor system

Best-fitting orbit

Heliocentric coordinates :

$(D, \alpha, \delta, V_{h,rad}, \mu_\alpha, \mu_\delta)_{cluster}$

↓ $(X, Y, Z, U, V, W)_\odot$

Galactocentric coordinates:

$(X, Y, Z, U, V, W)_{orbit}$

↓ $(X, Y, Z, U, V, W)_\odot$

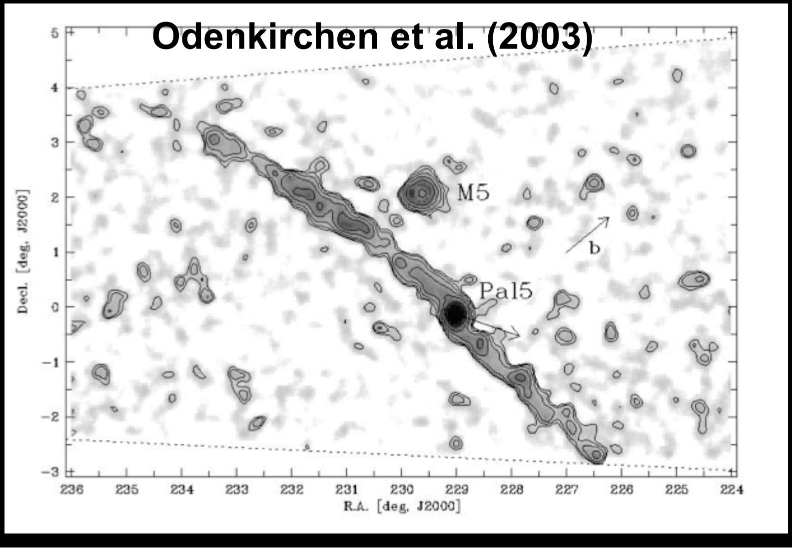
$(D, \alpha, \delta, V_{h,rad}, \mu_\alpha, \mu_\delta)_{orbit}$ ⟷ $(D, \alpha, \delta, V_{h,rad}, \mu_\alpha, \mu_\delta)_{tails}$

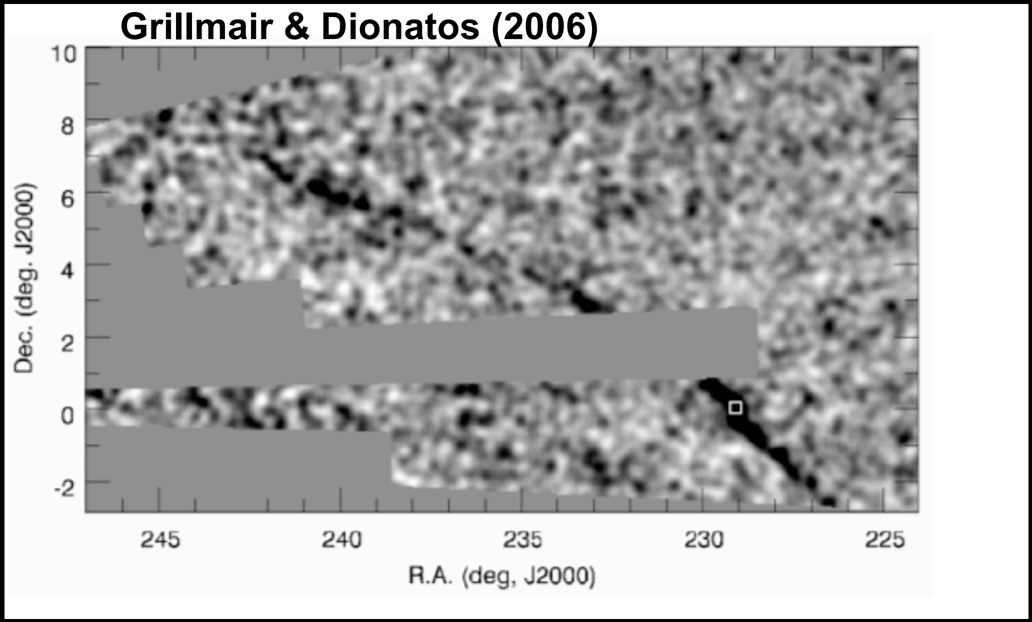
χ^2

exploring

μ_α, μ_δ

Exercise:





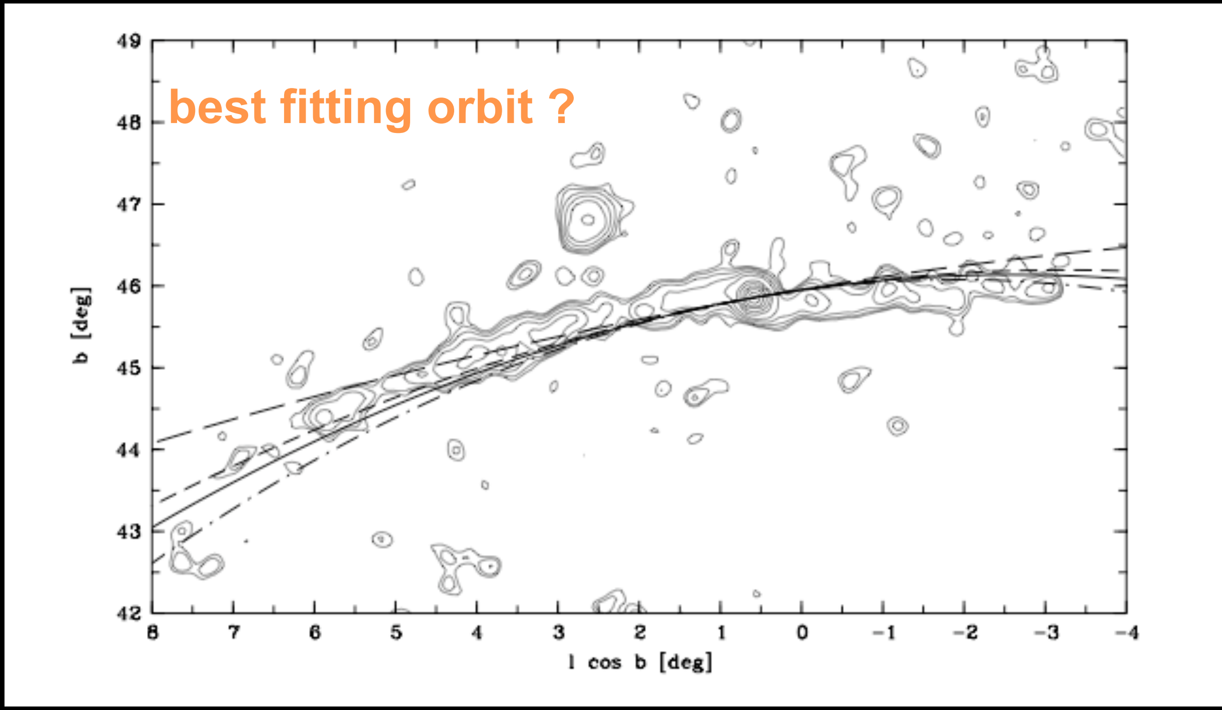
Goal:

μ_α vs μ_δ χ^2-countours

Extended detections:

new contours

Exercise:



send results to:
jorpega@ast.cam.ac.uk

The end of Part 1