Finding Tidal Tails of Star Clusters

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Why study tidal tails of star clusters?

- dynamically cold, compact, long-lived, extended (e.g. Carlberg 2009)

- probe the Galactic potential out to large radii (e.g. Koposov et al. 2010)

- dissolution diary (e.g. Koch et al. 2004)

- can have significant influence on the appearance of the cluster!

(Picture taken from Sueddeutsche.de, 30.03.07, „Da steckt eine interessante Geschichte dahinter!”)
Most prominent example: Palomar 5

![Diagram with contour lines and angles 10-22 deg]
Example No. 2: NGC 5466

Grillmair & Johnson (2006)

Belokurov et al. (2006)
Third example: GD-1 stream

Grillmair & Dionatos (2006)
How can we find tidal tails of star clusters?

How do they form?

How do they evolve with time?

So, how can we find them?
How can we find tidal tails of star clusters?

How do they form?

How do they evolve with time?

So, how can we find them?
Most star clusters are on Galactic orbits with orbital time scales of 150-300 Myr
Most stars evaporate with low velocities through the Lagrange points from the cluster.
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Due to the Coriolis & centrifugal force evaporated stars move on epicycles along the tails

\[ 3\pi R_J \]

Capuzzo Dolcetta et al. (2005)
Küpper et al. (2008, 2010)
Just et al. (2009)
Epicyclic movement leads to over- and underdensities within the tails.
Epicyclic movement can be observed in simulations

www.astro.uni-bonn.de/~akuepper/movies.html
Why do we see long tidal tails of only a few globular clusters, shouldn‘t they all have extended tails?

How do they form?

How do they evolve with time?

So, how can we find them?
For circular cluster orbits the structure of tidal tails is linked to tidal radius

\[ 3\pi R_J \]
But most globular clusters move on eccentric orbits

pericentre = fast

apocentre = slow
Still we see the formation of epicyclic overdensities

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On eccentric orbits the epicyclic trajectories get distorted due to the accelerated rest frame.
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Overdensities are close to the cluster in apogalacticon and far away in perigalacticon

![Graph showing the standard deviation of the perigalacticon and apogalacticon for different eccentricities.](image-url)
A quite realistic cluster orbit with eccentricity of 0.5

www.astro.uni-bonn.de/~akuepper/movies.html
For eccentric cluster orbits the structure of tidal tails is linked to mean 'edge' radius & orbital phase.
Clusters on eccentric orbits show ‘edge‘ which evolves only slowly with time

Küpper et al. (2010)
Why do we see long tidal tails of only a few globular clusters, shouldn‘t they all have extended tails?

How do they form?

How do they evolve with time?

So, how can we find them?
The orbital phase has strong influence on the surface density and the appearance of the tails

\[ \Sigma \propto R^{-4.5} \]
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\[ \sim R^{-4.5} \]
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We see the tidal tails of Palomar 5 because it is close to apogalacticon
We do not see tidal tails of Omega Cen because it is close to perigalacticon.
The appearance of tidal tails and of the outer cluster profile depends significantly on the orbital phase.

- Tidal tails exhibit dynamical substructure, even for eccentric cluster orbits.
- Visibility of tidal tails depends mainly on orbital phase.
- Inner surface density profile does not change during one orbital period.
- Slope of outer surface density profile is a good indicator for orbital phase.
Numerical simulations of Palomar 5 yield similar structure of tidal tails as observations