

Gaia Challenge Workshop Programme

Main talks will be in lecture Theatre F (please see the campus_map.pdf on the Gaia Challenge Wiki).
Working group sessions will be in Theatre J (spherical/triaxial); Theatre H (discs); Theatre F (streams/halo stars); and Theatre B (collisional systems).

Monday	Chair: Justin Read	Welcome; Gaia Review
9 - 9.30am	LOC	Welcome [1]
9.30 - 10am	Anthony Brown	Gaia: Counting down to launch [2]
10.00 - 10.30am	Gerry Gilmore	Gaia Science
10.30 - 11am	Coffee	
11am - 12.30pm	Structured working groups	Working group discussions [3]
12.30 - 1.30pm	Lunch	
1.30pm - 3pm	Structured working groups	
3 - 3.30pm	Coffee	
3.30pm - 4pm	Annie Robin	Gaia Challenge Mock Catalogue
4 - 4.30pm	Sanjib Sharma	Generating Mock Data From Models [4]
4.30 - 4.50pm	Stefano Pasetto	Star count modelling [5]
4.50 - 5.10pm	Andreea Font	Pathways to forming disc galaxies in a hierarchical cosmology [6]
5.10 - 5.30pm	Giacomo Monari	3D test particle simulations of the Galactic disks. The kinematical effects of the bar [7]
5.30 - 5.50pm	Santi Roca-Fàbrega	On galaxy spiral arms' nature as revealed by rotation frequencies [8]
5.50 - 6.10pm	Daniel Pfenniger	The bar corotation, a bridge between the bar and the thick disk [9]
6.10 - 6.30pm	LOC	Report back from working groups
6.30pm	Dinner	
Tuesday	Chair: TBD	Spherical/Triaial systems
9 - 9.30am	Matt Walker	My Struggles with Jeans Modelling
9.30 - 10am	Mark Wilkinson	Distribution function modelling
10am - 10.30am	John Magorrian	Bayes versus the virial theorem [10]
10.30 - 11am	Coffee	
11am - 12.30pm	Structured working groups	Working group discussions [11]
12.30 - 1.30pm	Lunch	
1.30pm - 3pm	Structured working groups	
3 - 3.30pm	Coffee	
3.30pm - 4pm	Walter Dehnen	Made to Measure
4 - 4.20pm	Thomas Richardson	Modelling dSphs with higher moments of the Jeans Equations [12]
4.20 - 4.40pm	Pascal Steger	Non-parametric Jeans modelling [13]
4.40 - 5pm	Chervin Laporte	Measuring the slope of mass profiles for dSphs in triaxial CDM potentials [14]
5 - 5.20pm	Klaudia Kowalczyk	Can we measure the slopes of density profiles in dwarf spheroidal galaxies?
5.20 - 5.40pm	Adriano Agnello	Dynamics of the GC system of M87
5.40 - 6pm	LOC	Report back from working groups
6.30pm	Dinner	
Wednesday	Chair: Daisuke Kawata	Discs
9 - 9.30am	Glenn van de Ven	The Gravitational Potential Near the Sun
	Alex Buedenbender	
9.30 - 10am	Jo Bovy	A dynamical disk-halo decomposition in the inner Milky Way [15]
10 - 10.30am	Paul McMillan	How to find the Milky Way potential from the disc - don't use an orbit library [16]
10.30 - 11am	Coffee	

11am - 11.20am	Richard Long	Made-to-measure galaxy models: Modelling with Milky Way observations [17]
11.20 - 11.40	Jason Hunt	A Particle by Particle M2M Algorithm: PRIMAL [18]
11.40 - 12pm	Laurent Chemin	Milky Way Disc Kinematics and Dynamics [19]
12 - 12.20pm	Shigeki Inoue	Can Gaia conclude the local dark matter density problem? [20]
12.20 - 12.40pm	Marcus Weber	The local dark matter density in the light of recent Fermi and AMS-02 data [21]
12.40 - 1.30pm	Lunch	
1.30pm - 6.30pm	Free for work/activities	
6.30pm	Workshop dinner	
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Thursday	Chair: Andreea Font	Halo/Streams
9 - 9.30am	Amina Helmi	TBD
9.30 - 10am	Jorge Penarrubia	Statistical Mechanics of tidal streams [22]
10am - 10.30am	Victor Debattista	The Milky Way in its Triaxial Halo [23]
10.30 - 11am	Coffee	
11am - 12.30pm	Structured working groups	Working group discussions [11]
12.30 - 1.30pm	Lunch	
1.30pm - 3pm	Structured working groups	
3 - 3.30pm	Coffee	
3.30 - 3.50pm	Jason Sanders	Constraining the Galactic potential with streams in angle-action space [24]
3.50 - 4.10pm	Nathan Deg	Streams and the Single Particle Approximation [25]
4.10 - 4.30pm	Daniele Fantin	Constraining the Galactic potential with streams [26]
4.30 - 4.50pm	Ana Bonaca	Most Valuable Progenitor: How to constrain the Galactic potential using tidal streams? [27]
4.50 - 5.10pm	Andreas Küpper	Orbital information encoded in stream substructure [28]
5.10 - 5.30pm	Hans Buist	Tracing back the effect of a smoothly growing galaxy on streams [29]
5.30pm - 5.50pm	Rachel Kennedy	Stellar Haloes: Models and Mocks [30]
5.50 - 6.10pm	Adrian Price-Whelan	Probing the Galactic potential with 6D information
6.10 - 6.30pm	LOC	Report back from working groups
6.30pm	Dinner	
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Friday	Chair: Mark Gieles	Collisional systems
9 - 9.30pm	Brad Gibson	(Non-)Cosmological Disks: Metal Distributions and Tracking Cluster Debris [31]
9.30 - 10.00pm	Antonio Sollima	The comparison of luminous and dynamical masses in low mass stellar systems [32]
10 - 10.30pm	Anna Lisa Varri	Self-consistent non-spherical models for quasi-relaxed stellar systems [33]
10.30 - 11am	Coffee	
11 - 11.20pm	Vincent Henault-Brunet	Dynamics of young massive clusters [34]
11.20 - 11.40	Michiel Cottaar	Measuring the radial velocity dispersion of a cluster corrected for binary orbital motions [35]
11.40 - 12pm	Richard Parker	Modelling young star clusters in the GAIA era [36]
12 - 12.20pm	Alice Zocchi	Observational tests of the dynamics of small stellar systems [37]
12.20- 12.40pm	Laura Watkins	Discrete dynamical modelling of Omega Centauri [38]
12.40pm - 1.30pm	lunch	
1.30 - 2.30pm	Structured working group	
2.30 - 3pm	LOC	Final report back from working groups [39]
3 - 3.30pm	Coffee	

1. Welcome to Gaia Challenge

Authors: DK, JR, MG and AF.

Abstract:

- Welcome and practical information.
- Explain the purpose and scope of GC.
- Short intro from each working group leader.

2. Gaia: Counting down to launch

Abstract:

ESA's Gaia mission is the next European breakthrough in astrophysics aimed at producing the most accurate 3D map of the Milky Way to date. The resulting stereoscopic census of our Galaxy will represent a giant leap in astrometric accuracy complemented by the only full sky homogeneous photometric survey with an angular resolution comparable to that of the Hubble Space Telescope, as well as the largest spectroscopic survey ever undertaken. The scientific bounty will be immense, not only unravelling the formation history and evolution of our Galaxy but also revealing and classifying thousands of extra-solar planetary systems, minor bodies within our solar system and millions of extragalactic objects, including some 500000 quasars. Moreover, such a massive survey is bound to uncover many surprises that the universe still holds in store for us.

Gaia will be launched very soon (September 2013 being the current target date) and preparations by ESA and the Gaia Data Processing and Analysis Consortium (DPAC) are in full swing. I will provide an overview of the Gaia spacecraft status, the data processing, and the expected scientific performances of the mission. I will also look ahead to the exciting time just after launch when Gaia will be commissioned and we will get a first glimpse of its actual capabilities. Finally, I will discuss the plans for intermediate data releases as well as the plans for providing you with access to the Gaia catalogue and archive.

3. Working group discussions

- What are the (best) test problems?
- Who will generate mock data?
- Who will run models?
- What data format is best for the mocks?
- Preliminary results (please post on the wiki).

4. Generating Mock Data From Models

Abstract: We are in an era where systematic surveys of the Milky Way are giving information about the properties of a large number

of stars. Proper interpretation and analysis of the data requires comparing the data with models. This is best done by converting models to the observational space rather than other way around. To this end we discuss efficient techniques for converting models to synthetic data. First we discuss techniques for sampling analytic models and then N-body models.

In order to sample N-body models, we present a scheme that disperses the stars spawned by an N-body particle, in such a way that the phase space density of the spawned stars is consistent with that of the N-body particles.

5. Star count-modelling technique for Gaia challenges

Abstract: I present the ongoing work to upgrade the Padua Galaxy model. My goal is to interpret in great detail the upcoming Gaia data. I will review the synthetic CMD generation technique updated by Pasetto et al. 2012a in order to easily handle high number of stars as required by Gaia. I will discuss the implemented Poisson solver that, combined

with a Boltzmann collisionless equation cumulants (Pasetto et al. 2012b) synthetically generates the phase-space of the Milky Way model. The major differences from the already available on-line star count models (Besançon, Trilegal etc.) will be reviewed in detail. The model is undergoing major revision and will be advertised on-line after the Gaia launch. Further details are available in (Pasetto et al. 2012a, A&A, 545, 14, Pasetto et al. 2012b, A&A, 547, 70, Vallenari, Pasetto et al 2006, A&A, 451, 125).

6. Pathways to forming disc galaxies in a hierarchical cosmology

Abstract: The observed ubiquity of disc galaxies in the Universe may be reconciled with the high rate of disc-damaging mergers predicted in a LCDM model, if mitigating gas processes are taken into account. The GIMIC cosmological gas-dynamical simulations show explicitly that realistic disc galaxies can form in abundance by $z=0$ while experiencing merger histories representative of a LCDM model. Many of these mergers can destroy galaxy discs, particularly those more massive than the total stellar component of their hosts. We find that a significant fraction of present-day disc galaxies have had such active merger histories since $z=2$, e.g. about half of Milky Way-like galaxies had mergers more massive than the stellar mass of their host and a third had mergers three times as massive. This demonstrates that extended quiescent merger histories are not a prerequisite to form large disc galaxies like the Milky Way. Overall, the correlation between merger histories of galaxies and present-day disc morphologies is much weaker than predicted by collisionless studies. This suggests that the prospects of reconstructing the merger activity of the Milky Way from the present-day structure of its disc need to be re-evaluated.

7. 3D test particle simulations of the Galactic disks. The kinematical effects of the bar.

Authors: Giacomo Monari, Teresa Antoja, Amina Helmi

Abstract: I present one of the first 3D test particle simulations of the thin and thick disks in a Galactic potential including a rotating Ferrer's bar. Our goal is to study the imprints of the bar on the kinematics of stars throughout the Galaxy. We aim to quantify how much of the evolution of the disks is driven by secular mechanisms in contrast to external processes, such as accretion. We find that the velocity distributions of both thin and thick disk change when the bar is included, and that strong transient effects are present for ~ 10 bar rotation periods after its adiabatic growth. On longer (more realistic) timescales, the effects of the bar are stronger on the kinematics of thin disk stars, and weaker on those in the thick disk, but in any case significant. Furthermore, we find that it is possible to trace the imprints of the bar at least up to $z \sim 1$ kpc and 2 kpc for the thin and thick disk respectively.

8. On galaxy spiral arms' nature as revealed by rotation frequencies

Authors: S. Roca-Fàbrega, O. Valenzuela, F. Figueras et al.

Abstract: We will present how high-resolution N-body simulations using different codes and initial condition techniques reveal two different behaviours for the rotation frequency of transient spiral arms like structures. Our results show that whereas unbarred discs present spiral arms nearly corotating with disc particles, strong barred models (bulged or bulgeless) quickly develop a bar-spiral structure dominant in density, with a pattern speed almost constant in radius. As the bar strength decreases the arm departs from bar rigid rotation and behaves similar to the unbarred case. In strong barred models, we detect in the frequency space other subdominant and slower modes at large radii, in agreement with previous studies, however, we also detect them in the configuration space. We propose that the distinctive behaviour of the dominant spiral modes can be exploited in order to constraint the nature of Galactic spiral arms by the astrometric survey Gaia and by 2D spectroscopic surveys like Calar Alto Legacy Integral Field Area Survey (CALIFA) and Mapping Nearby Galaxies at APO (MANGA) in external galaxies. Furthermore we will show our first results using ART plus hydrodynamics code.

9. The bar corotation, a bridge between the bar and the thick disk

Abstract: Bars are ubiquitous in spirals, and one of the most powerful internal dynamical feature in term of capability to modify the disk radial and vertical profiles producing a thick disk like component. The basic dynamics of the bar corotation explaining why it is so will be reviewed.

10. Bayes versus the virial theorem

Abstract: For many purposes each stellar population with a galaxy is completely described by two unknown functions: the phase-space distribution function (DF) $f(x,v)$ and the underlying gravitational potential $\Phi(x)$. An outstanding challenge in stellar dynamics is how best to constrain Φ given only some limited information about the population's DF f (e.g., from Gaia or other catalogues). I present a general scheme for calculating the likelihoods of different potentials by marginalising the unknown DF and demonstrate that the scheme works in practice. One way of thinking of this new method is as a development of Schwarzschild's method with the inclusion of two new ingredients.

11. Working group discussions

Either:

a) Show and compare latest results from running mocks;

And/or:

b) Chalk and talk about different methodologies:

- How to generate mock data?
- How does Jeans/M2M/Schwarzschild etc. really work?
- Strengths and weaknesses of different methodologies?
- A new "super" method?
- What is the ideal data?

12. Modelling dSphs with higher moments of the Jeans Equations

Abstract: Under the assumption of dynamic equilibrium the Jeans equations provide constraints on the gravitational potential of spherical systems via the moments of the line-of-sight velocity distribution rather than the more cumbersome six dimensional phase distribution of the tracers. The cost for this simplicity is that with a truncated series of moment equations one cannot guarantee that the solutions enable physical phase space distributions and additionally there exists a degeneracy between the unknown anisotropy of velocity moments and the mass profile which we hope to extract. One means to try and break the degeneracy, that is increasingly feasible with larger data sets, is to fit both the second (variance) and fourth (kurtosis) moments of LOS velocity data. While such methods have been used before we describe a new method that for the first time is as general in the description of anisotropy as the traditional Jeans analysis of LOS dispersions. Results of an application to MW dwarf spheroidals are discussed and compared to other methods in the literature.

13. Non-parametric Jeans modelling

Abstract: We propose a new non-parametric method to determine the mass distribution in spherical systems. A high dimensional parameter space encoding tracer density, line of sight velocity dispersion and total mass density is sampled with an Monte Carlo Markov Chain. Without assumptions on the functional form of any of these profiles, we can reproduce reliably the total mass density of mock dwarf galaxies, and disentangle the degeneracy between dark matter density and tracer velocity anisotropy. We show early applications to observed dwarf galaxies.

14. Measuring the slope of mass profiles for dSphs in triaxial CDM potentials

Abstract: We generate stellar distribution functions (DFs) in triaxial haloes in order to examine the reliability of slopes inferred by applying mass estimators assuming spherical symmetry to two stellar sub-populations independently tracing the same gravitational potential. The DFs take the form $f(E)$, are dynamically stable, and are generated within triaxial potentials corresponding directly to subhaloes formed in cosmological dark-matter-only simulations of Milky Way and galaxy cluster haloes. Additionally, we consider the effect of different tracer number density profiles (cuspy and cored) on the inferred slopes of mass profiles. For the isotropic DFs considered here, we find that halo triaxiality tends to introduce an anti-correlation between effective radius R_e and dispersion when estimated for a variety of viewing angles. The net effect is a negligible contribution to the systematic error associated with the slope of the mass profile, which continues to be dominated by a bias toward greater overestimation of masses for more-concentrated tracer populations. We demonstrate that simple mass estimates for two distinct tracer populations can give reliable (and cosmologically

meaningful) lower limits for the logarithmic cusp slope of the dark matter profile, irrespective of the degree of triaxiality or shape of the tracer number density profile.

15. A dynamical disk-halo decomposition in the inner Milky Way

Abstract: The Milky Way's (MW) density distribution in its inner parts and its decomposition into disk and halo components are fundamental to our understanding of the MW's formation and evolution and to determining the importance of dark matter within the inner parts of galaxies. However, currently only the circular velocity curve is well known while the density distribution away from the Galactic mid-plane is poorly constrained, especially away from the solar radius. I will present a new dynamical measurement of the MW's surface density between 4 and 10 kpc, obtained by rigorous 3-integral modeling of the vertical kinematics of abundance-selected stellar samples from the SDSS/SEGUE. Combined with the latest measurements of the MW's rotation curve, this allows us to separate the disk and halo contributions to the gravitational potential and to determine the radial profile of the dark matter halo. Our results show that action-based distribution-function modeling is now a feasible approach that will be fruitful for interpreting Gaia data.

16. How to find the Milky Way potential from the disc - don't use an orbit library.

Abstract: Methods using orbit libraries, such as Schwarzschild modelling, are widely used to determine the potentials of external galaxies. I'll show, using the example of torus modelling of orbits, that this approach leads to an unacceptably high level of numerical noise when working data from the Milky Way. I'll show that an alternative approach, which relies upon the ability to find the phase-space density of a dynamical model at a given position and velocity, can reduce this noise to manageable levels.

17. Made-to-measure galaxy models: Modelling with Milky Way observations

Abstract: We demonstrate how the Syer & Tremaine made-to measure method of stellar dynamical modelling can be adapted to model a rotating galactic bar. We validate our made-to-measure changes using observations constructed from the existing Shen et al. (2010) N-body model of the Milky Way bar, together with kinematic observations of the Milky Way bulge and bar taken by the Bulge Radial Velocity Assay (BRAVA). Our results for a combined determination of the bar angle and bar pattern speed (~ 30 degrees and ~ 40 km/s/kpc) are consistent with those determined by the N-body model. Whilst the made-to-measure techniques we have developed are applied using a particular N-body model and observational data set, they are in fact general and could be applied to other Milky Way modelling scenarios utilising different N-body models and data sets. Additionally, we use the exercise as a vehicle for illustrating how N-body and made-to-measure methods might be combined into a more effective method.

18. A Particle by Particle M2M Algorithm: PRIMAL

Abstract: We have developed our particle-by-particle adaptation of the made-to-measure (M2M) method, with the aim of modelling the Galactic disc from upcoming Galactic stellar survey data. In our new particle-by-particle M2M algorithm, PRIMAL, the observables of the target system are compared with those of the model galaxy at the position of the target stars. The mass of the model particles are changed to reproduce the observables of the target system, and the gravitational potential is automatically adjusted by the changing mass of the particles. We applied PRIMAL to mock barred disc galaxy data created by an N-body simulation in a known dark matter potential, with the expected Gaia errors in the observables, using bright stars as tracers. We show that PRIMAL can recover the structure and kinematics of the target discs, along with the apparent bar structure and pattern speed of the bar despite the error in the target data.

19. Milky Way Disc Kinematics and Dynamics

Abstract: Results from the analysis of mock data from the Disc suite and from the Gaia Universe Model Snapshot will be presented. In particular, I will try to answer whether one can apply an "extragalactic" view of observables to determine kinematical quantities.

I will also present provisional results of the analysis of thin Disk spectroscopic data from the Gaia-ESO survey. Finally I will introduce the

basis of a new VLBI astrometry project that could probe the kinematics of the most obscured inner regions of the Galaxy, and help constraining the inner rise of the rotation curve or the bar pattern speed at very low Galactic latitudes.

20. Can Gaia conclude the local dark matter density problem?

Abstract: To determine the local dark matter density (LDMD) of the solar system is a classical problem in astronomy but still under debate. Recently, Garbari et al. (2011, 2012) have devised a novel method of determining the LDMD from stellar distribution and vertical velocity dispersion profiles. This method has the advantage of abolishing conventional approximations and using only a few assumptions. This study is aimed at carefully scrutinizing this method and examining influences by uncertainties of astrometric observations. I created mock observation data for stellar dynamical tracers based on an analytical galaxy model and applied parametrized observational errors to the mock data. I find that the Garbari et al. method is capable of determining the LDMD with accuracy if the sample size and observational precisions are satisfactory. I estimate the required precisions of the parallax measurements to be approximately 0.1-0.3 milliarcseconds at 1 kpc away from the Sun. From this result, I expect that Gaia will provide data precise enough to determine the LDMD using the Garbari et al. method.

21. The local dark matter density in the light of recent Fermi and AMS-02 data

Abstract: The rotation curve, the total mass and the gravitational potential of the Galaxy are important tracers of the dark matter halo profile. In the present talk the total density distribution is constrained by astronomical observations: 1) the total mass of the Galaxy, 2) the total matter density at the position of the Sun, 3) the surface density of the visible matter, 4) the surface density of the total matter in the vicinity of the Sun, 5) the rotation speed of the Sun and 6) the shape of the velocity distribution within and above the Galactic disc. The mass model of the Galaxy is mainly constrained by the local matter density (Oort limit), the rotation speed of the Sun and the total mass of the Galaxy from tracer stars. The change of slope in the rotation curve may be a hint for substructure in the dark matter profile and is in agreement with structure in the gas flaring. Such substructure influences the dark matter annihilation flux which is proportional to the density squared. Therefore, hints for substructure are important for the interpretation of the recent Fermi and AMS-02 data, as will be discussed quantitatively.

22. Statistical Mechanics of tidal streams

Abstract: Tidal streams trace the trajectory of their progenitor systems through phase space, a property that has been extensively used to constrain the host's gravity via the construction of dynamical models that best match the location of stream stars in phase space. However, this approach suffers from two limitations: as the host evolves hierarchically so does its overall gravitational potential, hence none of the integrals of motion remains constant. Furthermore, dynamical methods require solutions to the equations of motion, which tends to be a thorny task in modified gravity theories. In this talk I will show that mechanical statistics provide a complementary approach which does not suffer from the above limitations. Combined with the construction of dynamical invariants, i.e. quantities that are conserved throughout the motion of stars, statistical mechanics furnish a powerful methodology for studying the evolution of tidal substructures in time-dependent potentials under generic gravity models.

23. The Milky Way in its Triaxial Halo

Abstract: I examine the claim that the Milky Way disc is perpendicular to the intermediate axis of its triaxial halo. I show that this is very unlikely and suggest instead that the disc may be tilted relative to the halo.

24. Constraining the Galactic potential with streams in angle-action space

Abstract: Angle-action coordinates offer a pleasingly simple way to view stream formation. Only in the correct potential will the angle-action structure of the stream look correct. We present a probabilistic model for parameters of the potential given stream observations by exploring the expected correlations in angle-action space. We show that this can be used to constrain the parameters of the potential successfully with realistic stream observations, and show what we can do

without full 6D data.

We hope to present results obtained using the provided Gaia Challenge stream dataset.

25. Streams and the Single Particle Approximation

Abstract: The simplest approximation of a stellar stream is that of a single particle orbiting in a fixed potential. We examine the success of this approximation using a three component Milky Way model and Bayesian statistics. In particular, we focus on how well the shape of the halo can be inferred for streams of differing angular sizes and temperatures. We show some of the inherent difficulties of using the single particle approximation and how they may also apply to more complicated stellar stream modelling techniques. Finally, we examine the benefits of combining observations of multiple streams to constrain the Milky Way model.

26. Constraining the Galactic potential with streams

Abstract: During the past 20 years, numerous stellar streams have been discovered in both the Milky Way. These streams have been tidally torn from orbiting systems, which suggests that most should roughly trace the orbit of their progenitors around the Galaxy. As a consequence, they play a fundamental role in understanding the formation and evolution of our Galaxy. In the talk I will present the results obtained by testing the orbit-fitting technique developed by Binney in 2008 by using the substructures in the Milky Way stellar halo detected applying the “modified great circle cell method” (Mateu et al, 2011) to the mock Gaia catalogue of Brown et al. 2005. This catalogue includes a realistic Galactic background and observational errors, with the addition of detailed star formation histories for N-body simulated dwarf galaxies. The simultaneous application of the technique to multiple, nearby streams will hopefully allow to severely reduce the degeneracy and to strongly constrain the potential of the Galaxy.

27. Most Valuable Progenitor: How to constrain the Galactic potential using tidal streams?

Abstract: Tidal streams discovered in the Galactic halo have been used to constrain the underlying gravitational potential. Although there has been some success in measuring the inner halo potential, there remain many uncertainties regarding the halo shape on the global scale. The existing debates are expected to be resolved with more data on the streams. However, given the wide extent of the streams on the sky, such follow-up campaigns are very time consuming. In order to maximize their scientific return, it is prudent to identify which stream properties provide the most stringent constraints on the potential and focus the observational efforts accordingly.

We address this question by analyzing cold tidal streams with Palomar 5-like progenitors in the Via Lactea II (VL2) simulation. Our sample includes a total of ~10,000 streams formed during the last 6 Gyr on a range of orbits, spanning galactocentric distances out to 150 kpc. These streams are modeled using the streakline method, assuming a parametric representation of the VL2 potential. For each stream, the best-fit potential is obtained through Bayesian sampling of the parameter space. We identify the properties of streams that lead to a fast potential convergence. We also discuss how these optimal properties change after taking into account the accuracy of the current and upcoming observational data.

28. Orbital information encoded in stream substructure

Abstract: Exact orbital information of galactic satellites is crucial for modeling their dynamical evolution, their dissolution and hence the formation of their tidal streams. Tidal streams of dynamically cold satellites like globular clusters are expected to contain epicyclic substructure. This substructure contains detailed orbital information, encoded as over- and under-densities. On the example of Palomar 5, we show how this substructure can be identified and used in the modeling process to constrain the satellite's orbit and the underlying galactic potential.

29. Tracing back the effect of a smoothly growing galaxy on streams

Authors: Hans Buist, Amina Helmi

Abstract: We investigate the effect on streams of a smoothly growing galaxy using test-particle simulations and a phase-space evolution code. Streams consist of stars that orbit the galaxy on similar trajectories, therefore responding quite

directly to the galactic potential. As the galaxy accretes mass, the potential changes at the position of the stream. We find this to have an effect on the evolution and properties of the stream. Unlike most studies in the literature, we use a time-dependent potential that is cosmologically motivated and at the same time preserves the notion that galaxies (and their halos) grow inside out.

30. Stellar Haloes: Models and Mocks

Abstract: The accreted component of a galactic stellar halo offers a unique record of the galaxy's assembly history. However, only a small fraction of the total stars in the galaxy resides in the halo. Hydrodynamical simulations are unable as yet to resolve the detailed stellar streams and structure that LCDM predicts should be present. Instead, in this talk we use a particle tagging technique to study the structure of the accreted halo and show how it can be dominated by single objects. In order to allow comparisons to observations we have created a set of mock catalogues using a combination of a stellar population synthesis model together with a phase-space sampling technique. These catalogues will be publicly available and allow the testing and interpretation of current and future observational strategies.

31. TraCD: Tracking Cluster Debris

Authors: Brad Gibson, Chris Flynn, Jarrod Hurley, Guido Moyano Loyola, Chris Brook, Gareth Few, Jeremy Bailin

Abstract: We describe the new Tracking Cluster Debris (TraCD) programme, making use of ~1,000 simulated NBODY6 open clusters and associations, dissolved in a realistic Milky Way potential. By chemically-tagging each parent cluster/association, we track the orbital dynamics of millions of individual stars, each carrying their parent's chemical "fingerprint", convolved with empirical uncertainties drawn from both Gaia and GALAH expectations. The debris experience secular heating and churning, and via the use of higher-order group-finding algorithms (CLIQUE, Cluster3.0, and EnLink), attempts are made to associate the debris to their parent birth locations. In parallel, we describe our application of Synthetic CMD Generators to our suite of ~50 fully cosmological, chemo-dynamical disks, realised as part of the RaDES, MUGS, and MaGICC collaborations; by re-sampling our composite star particles as such, users will be able to explore these simulations in a manner similar to that as an observer, with realistic luminosity and colour cuts applied for an arbitrary observer placed within the data. We will provide the community with these potentially useful testbeds for Gaia analysis.

32. The comparison of luminous and dynamical masses in low mass stellar systems

Abstract: I review the advancements in the determinations of dynamical and luminous masses in low mass stellar systems like dwarf galaxies and star clusters. The mismatch between these two quantities has deep relevance in the context of the dark content of these stellar systems with important implication on their formation mechanism and their role in the process of hierarchical formation of large size galaxies. I show the result of the comparison of specifically developed dynamical models to a set of Galactic globular clusters. The generally observed overestimate of dynamical mass (up to 40%) is interpreted in terms of the abundance and efficiency of retention of dark remnant, and on the possible presence of a modest amount of dark matter in these objects. The impact of GAIA on the future perspectives of this topic is also discussed.

33. Self-consistent nonspherical models for quasi-relaxed stellar systems

Authors: Anna Lisa Varri (Indiana University, USA / University of Edinburgh, UK)

Abstract: To fully understand the internal dynamics of globular star clusters, a number of important physical ingredients, in particular the three-dimensional effects of external tides, internal rotation, and anisotropy in velocity space, should be added to the traditional paradigm that primarily relies on spherical non-rotating models of quasi-relaxed stellar systems. New wide-field high-precision photometric and spectroscopic observations and HST proper motion studies of thousands of stars are beginning to reveal detailed information about the internal structure and kinematics of selected Galactic globular clusters. In this context, the future mission GAIA will reveal a view of the phase space of numerous star clusters with unprecedented accuracy.

Driven by these motivations, I will review some recent results on the development of more realistic self-consistent models for quasi-relaxed stellar systems, and their application to the interpretation of the internal dynamics of selected Galactic globular clusters. In particular, I will present a family of triaxial models that incorporate in a self-consistent way the tidal

effects of the host galaxy. I will also discuss the effects of the presence of internal rotation and pressure anisotropy, studied by means of two new families of axisymmetric equilibria, flattened by either solid-body or differential rotation.

Within this new dynamical framework, several observational and theoretical issues can be addressed, including and role played by the degree of relaxation in shaping the observational properties of star clusters and the dynamical interplay between angular momentum transport and two-body relaxation processes.

34. Dynamics of young massive clusters

Abstract: The few nearby young massive clusters for which individual stars can be resolved provide important insights into the early dynamical evolution of dense stellar clusters and the initial conditions for their longer term evolution. I will review the current constraints on the dynamics of these systems (velocity dispersion and systemic rotation) coming from multi-epoch radial velocity surveys or precise proper motion measurements. I will also discuss the challenges introduced by the fact that most obvious tracers are luminous massive stars, a high fraction of which are found in binary systems.

35. Measuring the radial velocity dispersion of a cluster corrected for binary orbital motions

Abstract: Measuring the velocity dispersion of a stellar cluster is crucial to determine its virial state (for young clusters) or its dynamical mass (for older clusters). Spectroscopic binaries can significantly broaden the observed radial velocity distribution, inflating the measured velocity dispersion for intrinsic velocity dispersions below ~ 10 km/s. Correcting for these binary orbital motions is crucial to determine a cluster's dynamical state from radial velocities alone (i.e. when no proper motions are available) or to fully exploit the 3-dimensional velocity space, which Gaia will provide. Multi-epoch data can partially resolve this by detecting some spectroscopic binaries, however others will remain undetected (for any reasonable measurement uncertainty and baseline). We present a maximum-likelihood procedure to compute the velocity dispersion corrected for the effect on the observed radial velocity distribution from these undetected spectroscopic binaries given single- or multi-epoch radial velocity data. If the binary properties are well constrained (e.g. for solar-type stars) velocity dispersions below the 1 km/s can be accurately measured (Cottaar et al., 2012, A&A, 547, A35). If the binary properties are very uncertain (e.g. for OB stars) multi-epoch data is needed to accurately measure the velocity dispersion (Cottaar & Henault-Brunet, 2013, in prep). We discuss the required baseline and measurement uncertainty to accurately measure the velocity dispersion corrected for binary orbital motions and if the multi-epoch radial velocity observation from GAIA will match these requirements.

36. Modelling young star clusters in the GAIA era

Abstract: How ready is the young star cluster community for GAIA? Significant progress is being made on the observational side, but on the modelling and theory side, a coherent effort is distinctly lacking. Indeed, an oft quoted statement is that "GAIA will solve problem X" in relation to star clusters, but in reality very little modelling effort is being devoted to assessing the questions on young star clusters that GAIA will be able to address. In this contribution I will present recent results on modelling young clusters in the era of GAIA, and discuss potential avenues of further research.

37. Observational tests of the dynamics of small stellar systems

Abstract: As gas-free, self-gravitating systems, globular clusters (GCs) are excellent laboratories for studies of stellar dynamics and ideal targets for N-body simulations. Even though GCs are now recognized to be rather complex systems, their dynamical properties are still commonly studied by means of idealized spherically symmetric, isotropic, single-mass King models. New, more realistic dynamical models have recently become available, allowing us to measure more accurately the structural properties of these systems, to classify their complexity, and thus to shed light on the relevant formation scenarios. It is therefore particularly important to carry out thorough tests of the different dynamical models, by using all the information that can be obtained from dedicated photometric and spectroscopic observations. In this context, the advent of Gaia will make it possible to accurately measure proper motions for a large number of stars in GCs, opening the possibility of some decisive tests.

38. Discrete dynamical modelling of Omega Centauri

For objects in the Local Group, we are in the fortunate position of having discrete, resolved datasets - often of both high quality and high quantity - yet the dynamical modelling techniques employed typically degrade the data by spatially binning, are often overly simplified, and make assumptions that are not always (astro)physically justified. To address

these issues, we are developing discrete dynamical modelling tools that use maximum-likelihood analysis to fully exploit the resolved nature of the data. Such an approach avoids the loss of information due to spatial binning and allows contaminant populations to be included directly in the models for better membership identification. With these models, we hope to better constrain the dark matter content of dwarf galaxies and address the question of the presence of intermediate-mass black holes and dark matter in globular clusters. The work I will describe is some of the steps we have taken towards this goal. This includes the application to the globular cluster Omega Centauri, which is a calibration object for HST/WFC3 and, as such, has a wealth of high-quality data available. In particular, I will present new insights regarding a central IMBH.

39. Final report back from working groups

We will use the wiki site to give:

- Status report of mocks and tests
- What remains to be done?
- Discussion on should we publish, if so what, and by when?
- Publication policy?
- Usage policy for GC mocks
- Next workshop?
- What next?