N-body Simulations of Star Clusters and Observational Comparisons

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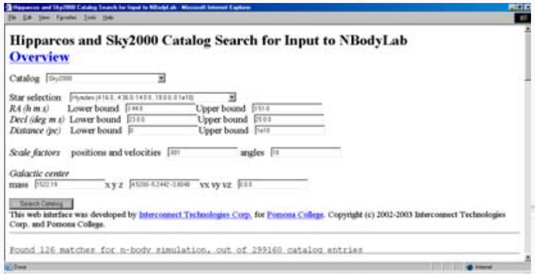
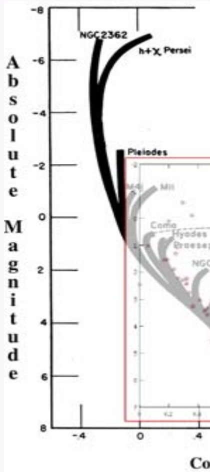
Catalog Selection and HR Diagram Generation





Absolute magnitude versus Color index plots from Alan Sandage's original paper and from the selected catalog data for Hyades.

Overview

An approach is presented for performing N-body simulations of star cluster data obtained from Hipparcos or Sky Catalogue 2000, and comparing it with observational data. These capabilities were developed as part of the Astronomical Computing Initiative at Pomona College to help students and researchers learn to find and use sources of astrometric data, perform coordinate transformations, make estimations where data is unavailable, such as estimating masses from brightness, and to compare the results to standard models and observations.

Capabilities include:

- Choosing target region and distance from Hipparcos or Sky2000 Catalogue
- Creating HR diagrams and diagnostic plots
- Computations

  Converting equatorial coordinates to Cartesian

  $(\alpha, \delta, \rho \rightarrow x_i, y_i, z_i)$

  Calculating velocity vectors

  $(m_\alpha, m_d, V_r, \rho \rightarrow Vx_i, Vy_i, Vz_i)$

  Estimating the masses
- Calculating relative location and intensity for the galactic potential (Φ_g)
- Creating a data file for NBodyLab from estimated positions and velocities masses for each cluster member
- Performing N-body simulation
- Generating simulation diagnostics and visualization products

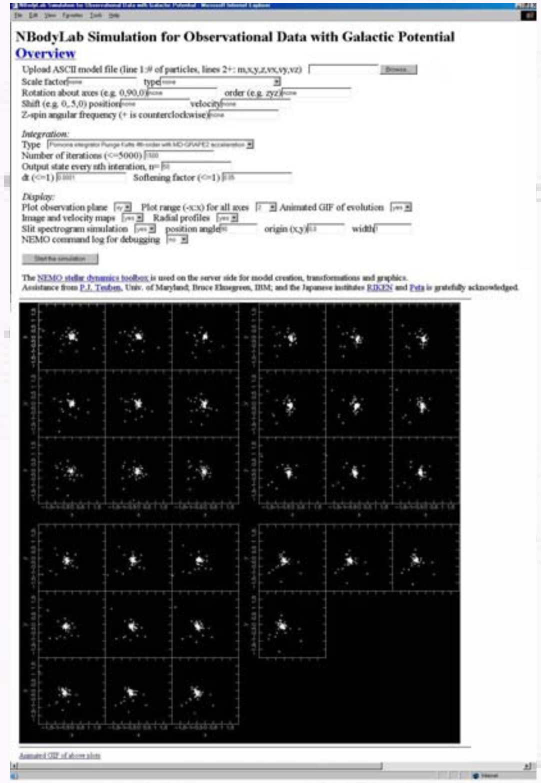
HR Diagram

To estimate the surface temperature (T_{eff}) and absolute magnitudes (M) for each spectral type and luminosity class, linear and logarithmic curve fits are used. Corresponding luminosities (*L*) and color indexes (B-V) are calculated from these values (T_{eff}, M).

Following approximations were made:

- Exotic stars are ignored
- Intrinsic variability is ignored
- Luminosity class IV is adjoined to main sequence
- Class I is adjoined to III
- For super giants (class I) Ia and Ib data are not separated, mostly Ia is being used
- Visual magnitudes are preferred over bolometric due to abundance of data.

N-body Evolution and Diagnostics



Computations for Input Data

Step 1 Stellar Distances:

The distance of the star can be measured from the parallax. The upper limit for ground-based parallax measurement is ~0.02" farthest stars we can measure are less than 50 parsecs. Satellite Hipparcos has measured the parallax of 120,000 stars to better than 0.002" which, is approximately less than 500 parsecs. If the parallax is not available, the software uses spectroscopic parallax to estimate the distance of the object. The same method used in estimating absolute magnitudes in HR diagram is used. Estimated absolute magnitude helps obtaining distance modulus.

Step 2 Coordinate Transformations:

Equatorial coordinates for a star are listed in star catalogs.

After conversion of catalog data Cartesian coordinates are derived:

$X = \rho \cos\delta \sin\alpha$

$Z = \rho \cos\delta \cos\alpha$

$Y = \rho \sin\delta$

Step 3 Velocity Vectors:

In order to calculate velocity vectors, precise proper motion and radial velocities are needed. If these values for the target star are not measured observationally, software ignores the star.

Transverse (linear) velocities derived:

$$V_{TA}(km/sec) = \mu_\alpha(arc\ sec/yr) * d * 4.74$$
$$V_{TD}(km/sec) = \mu_\delta(arc\ sec/yr) * d * 4.74$$

Then the vector components for each axis derived:

$$V_x = (V_r * \cos\delta * \cos\alpha) - (V_{TA} * \sin\alpha) - (V_{TD} * \sin\delta * \cos\alpha)$$
$$V_y = (V_r * \cos\delta * \sin\alpha) - (V_{TA} * \cos\alpha) - (V_{TD} * \sin\delta * \sin\alpha)$$
$$V_z = V_r * \sin\alpha + V_{TD}\cos\delta$$

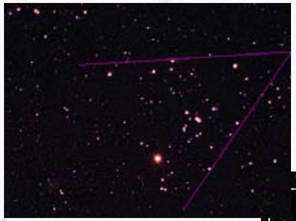
Step 4 Mass Estimations:

Mass estimation is based on Mass-Luminosity relationship. Using the luminosities calculated for the HR diagram, the software estimates individual masses of the model cluster. All stars are assumed to belong to one of the following mass groups.

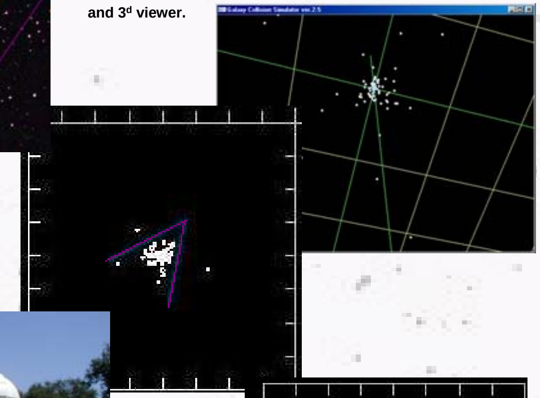
The Galactic Potential (Φ_g)

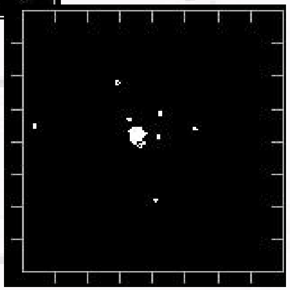
In order to increase precision, the gravitational pull of the Milky Way is also added to the model. The last data point shows the relative position of the galactic center. The mass of the galaxy is scaled down inversely proportional to the distance of the selected region.

Observational Comparisons



Hyades cluster from Pomona College Observatories and NBodyLab simulator (at t=0) and 3rd viewer.





Hyades cluster after 1500 iterations

Conclusions

- Using catalog data still presents many limitations due to presence of binary star systems with uncatalogued components. Brown dwarfs and interstellar material data are not available from current catalogues.
- Accuracy of spectroscopic parallax is limited due to lack of perfect correlation between absolute magnitude and luminosity classes. For a small number of stars, the distance and absolute magnitude must be approximated (uncertainty in the distance by 1.6 for ±1 magnitude scatter).
- The plots indicate expected motions of moving clusters.
- HR diagrams indicate expected turnouts from Zero Age Main Sequence for all star clusters.
- Test runs on several clusters yielded on the order of 100 members of the system, which was sufficient for exploratory Nbody simulations.
- Overall HR graphs and Nbody simulations showed promising results. These will improve as the new generation of star catalogs become available (such as SIMS)
- Our model did not take errors in measurements into consideration and assumes all stars belong to 3 luminosity classes (Ia, III, V)

Over the Horizon

Future refinements are expected to include:

- Mass estimation methods for different spectral types and luminosity classes
- Evolutionary parameters
- Galactic potential fields and models
- Inclusion of data from new missions like SIM and Sloan Digital Sky Survey
- Comparison with high precision open cluster models from the stellar dynamics community

References

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- Sterne, T., E. An Introduction to Celestial Mechanics, 1960

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