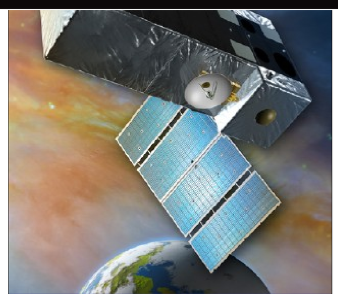
Rotational Parallax for Distance, Internal Dynamics, and Luminosity Calibration of Nearby Galaxies

Ed Shaya & Rob Olling / U. of Maryland



SIM Lite ASTROMETRIC OBSERVATORY

Rotational Parallax Method

The Space Interferometry Mission (SIM-Lite) can provide astrometric data of such high quality that it will be possible to determine geometric (luminosity-independent) distances to the nearest spiral galaxies. The method for this is the "Rotational Parallax Method" [RP; Peterson & Shao (1997); Olling & Peterson (2000) and Olling (2007)]. 1 Percent-level distances for M31 and M33 are within reach of SIM-Lite with modest ground-based RV program.

The RP method employs the fact that velocity (V), distance (D) and proper motion (μ) are related via: m = V/(κD), where κ is a constant related to the choice of units. Along major and minor axes and circular motion, the formulae are simple, but the distance can also be recovered from a star at an arbitrary location since everywhere there are *three unknowns* (D, V_C and inclination) and *three observables* (the radial velocity and the two proper motions), assuming motion is circular.

Why Measure 1% Distances?

- Reduce zero-point error in distances indicators:
  - Simultaneous zero-points on Cepheid, RR Lyrae, Red Clump, etc.
- Double check on determinations of H_o from CMB data sets and luminosity dependent methods.
- Obtain 5D phase-space coordinates of stars in galaxies for (spiral density wave) galaxy dynamics.
- Provide 2% absolute luminosities of all stellar types for accurate ages and stellar evolution constraints.

Accuracies and Observing Time on SIM Lite

- In M 31, with 363 (232) stars (V < 16.3 (15.9) mag) at 8 μas/yr per star, SIM-Lite achieves distance errors of: 0.43% (0.53%) in 32 (16) days of observing time.
- In M 33, with 155 stars (V < 16.5 mag) at 8 μas/yr per star, SIM-Lite achieves distance error of 0.9% in 16 d.
- Gaia's accuracy could be about the same as a SIM-Lite program.
  - However, the Gaia-based project would employ 10,000 stars as faint as V=19.1. An RP project also needs ground-based radial velocities with accuracies of 1-2 km/s, for *all* program stars.

Working with Real Galaxies

Real galaxies have complicated potentials, therefore orbits, even of Population I stars, are not circles. One expect warps, arms and bars to cause perturbations to circular motions.

With enough stars one can map out these complex potentials. The potential of the galaxy can be approximated by the potential derived from rotation profile plus spherical harmonics up to some maximum l and m determined by the number of stars.

These perturbations to the potential are derived by assuming, on average, young stars' positions and velocities reside on the locally defined center of plane . Then the individual velocities can be used to follow the orbits back in time. One can calculate the kick received by passing density waves.

18 Parameters to Solve for, 5 observed

$\mathbf{v}_{peculiar}$, *x, y, z* per star, $\boldsymbol{\sigma}_v$ per group of stars, and $\mathbf{v}_{sys}$, x_0, y_0, z_0, position angle, inclination, V_c, and distance for galaxy. Observe only 5 per star: V_R, μ_X, μ_Y, right ascension, and declination. Works because can assume z′=0 and $v^{z'}_{peculiar}$= 0.

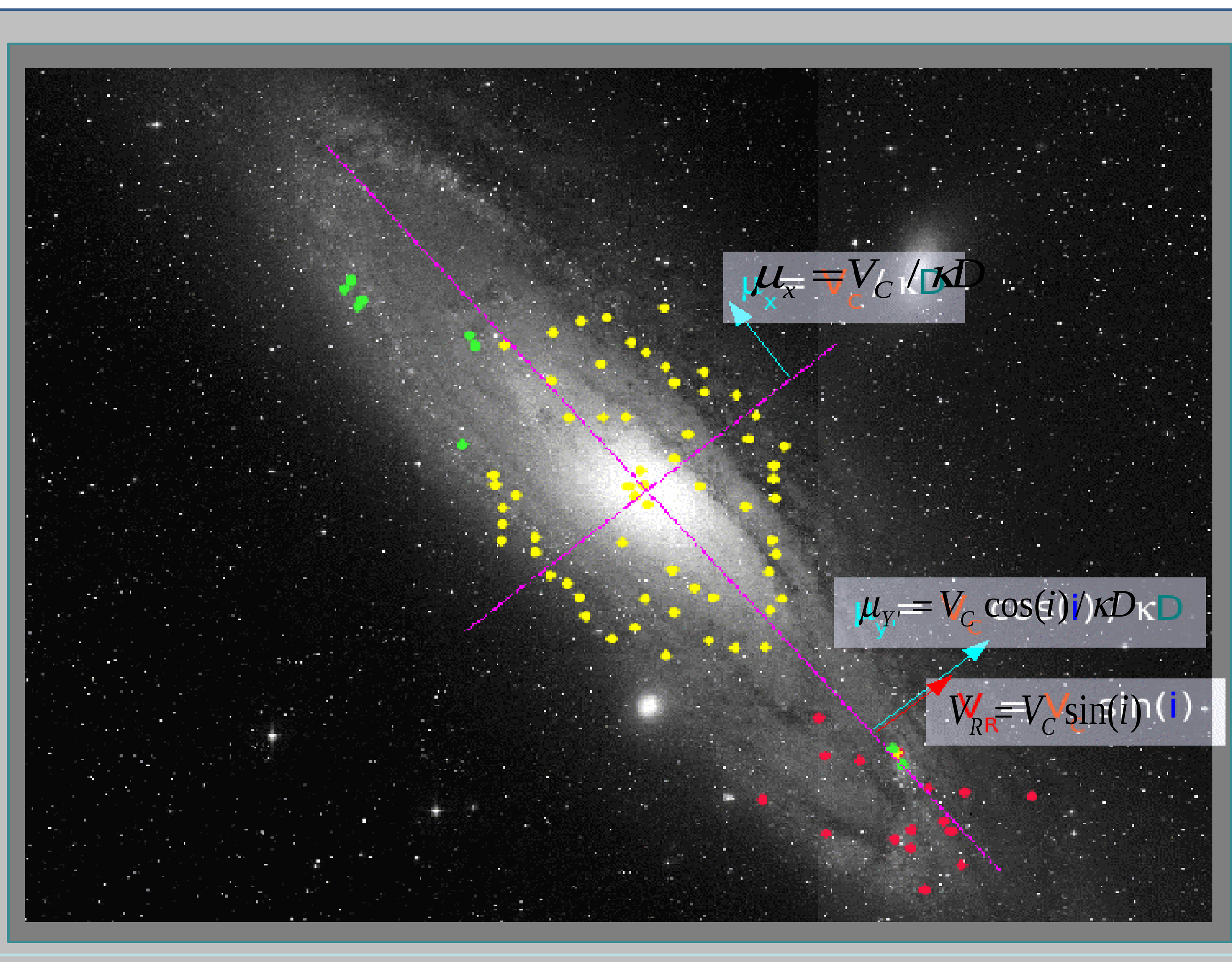


Fig. 1 — A DSS image of M31 showing the relationship between proper motions and radial velocity for objects on the major and minor axes. Also shown are the bright AB supergiants already identified in M31 (courtesy: D. Peterson).

For Circular Orbits:

Estimate pm along Minor Axis:

M 31 (Andromeda): *i* ~ 77°, D ~ 0.84 Mpc, V_C ~ 270 km/s

⇒ μ_x ~ 68 μas/yr

M 33 (Triangulum): *i* ~ 55 , D ~ 0.86 Mpc, V_C ~ 103 km/s

=> μ_x ~ 25 μas/yr

Minor axis: $\mu_X = V_c/(\kappa D)$

Major axis: $\mu_{Y'} = V_c \cos(i) / (\kappa D)$

Major axis: $V_R = V_c \sin(i)$

Three measurables per star: μ_X , $\mu_{Y'}$, V_R

Can determine three unknowns per star: D, *i*, V_c

At any point:

$$D = \frac{V_R}{\kappa}\sqrt{-\frac{y'/\mu_{y'}}{x\mu_x + y'\mu_{y'}}}$$

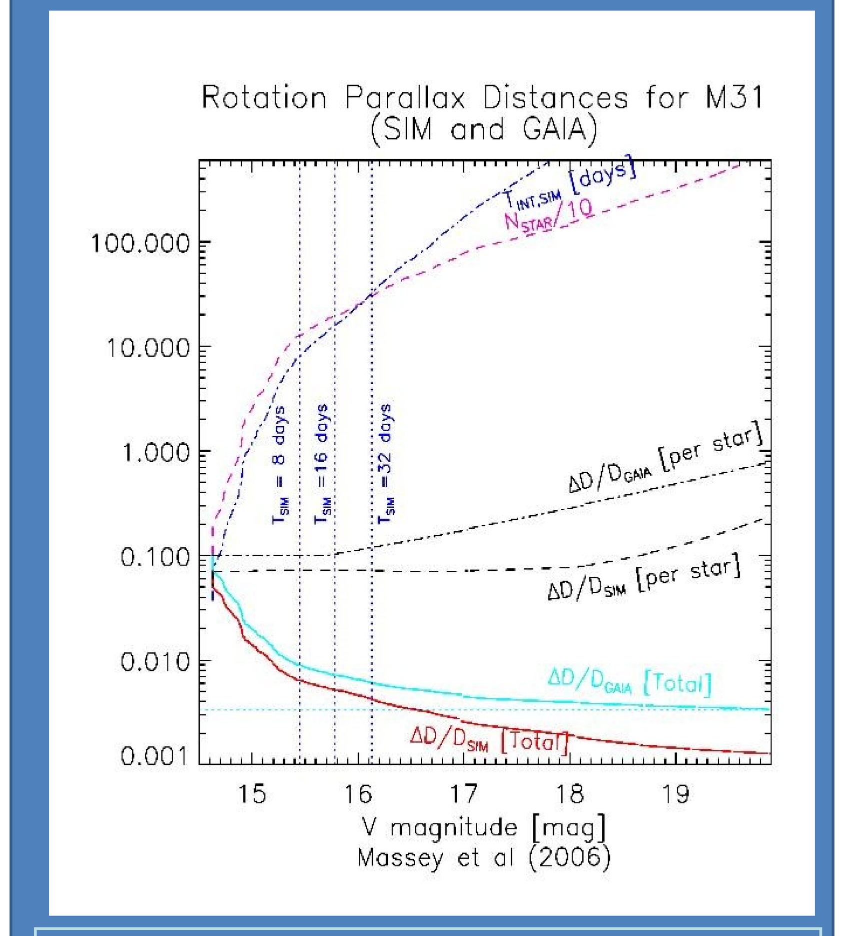


Fig. 2 — Fractional error in distance resulting from SIM-Lite observations with 8 μas/yr proper motion of all stars brighter than given V-band magnitude.