Space Interferometry Mission: Dynamical Observations of Galaxies (SIMDOG)

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Space Interferometry Mission (SIM) will be used to obtain proper motions for a sample of 27 galaxies; the first proper motion measurements of galaxies beyond the satellite system of the Milky Way. SIM measurements lead to knowledge of the full 6-dimensional position and velocity vector of each galaxy. In conjunction with new gravitational flow models, the result will be the first total mass measurements of individual galaxies. The project includes development of powerful theoretical methods for orbital calculations. This SIM study will lead to vastly improved determinations of individual galaxy masses, halo sizes, and the fractional contribution of dark matter. Astronomers have struggled to calculate the orbits of galaxies with only position and redshift information. Traditional N-body techniques are unsuitable for an analysis backward in time from a present distribution if any components of velocity or position are not very precisely known.

Peebles made a major advance in this field when he introduced numerical action methods (NAM) to cosmology. Peebles noted that six components of phase space are accurately known: right ascensions, declinations, and redshifts of galaxies today and the initial condition of effectively zero peculiar velocities. At early times, the mass parcels that would eventually turn into galaxies simply followed the Hubble Law of expansion for that epoch. The NAM provide explicit numerical procedures that transforms cosmological N-body orbit calculations into a non-chaotic boundary value problem. SIM offers an exciting prospect – access to three more elements of phase-space for each galaxy. These extra constraints are vital since the dynamical gravitation problem naturally leads to several families of solutions for orbits and masses. SIM measurements will discriminate between orbit families, which will strongly constrain total masses and make a locally determined estimate of the global mass density of the Universe. We will have sufficient information to measure dark matter mass to the outermost edges of galaxies, and to discern the sizes of extended halos. These halos may extend far beyond the stars and gas of the observable galaxies. Accurate distances are needed to complement proper motions and will be obtained through a parallel program of observations.

Through other Key Projects, SIM will determine precise distances to Cepheid variable stars and the red giant and horizontal branch stars that serve as standard candles. Bootstrapping on these calibrations, and in the course of a program of support observations for SIM, our team will derive distances at the level of 7 percent for all our target galaxies from two methods: from the luminosity of the tip of the red giant branch of old metal-poor stars and from the Balmer line equivalent widths of A,B supergiants, the very stars used for the SIM proper motion studies. With this anticipated level of accuracy, we will locate galaxies to better than 300 kpc across the ~ 4 Mpc region of interest. This galaxy localization undertainty is comparable to the anticipated dimensions of halos. One can expect to resolve the mass of groups into the masses of individual galaxies. We are planning an observing campaign prior to the launch of SIM in order to select target stars. Color magnitude information about many of the brightest candidate stars have already been published, although usually only parts of the host galaxies have been surveyed. In a small minority of cases here are spectroscopic studies that confirm that the candidates from photometric studies are evolved supergiants in the host galaxies, the kinds of stars needed for SIM observations. Hence, the practicality of this SIM Key Project is established, but there will have to be spectroscopic and photometric monitoring of several hundred stars before we can make the final selection of program targets. A range of analytical techniques will be applied to the set of SIM proper motions, inlcuding N-body simulation statistics, the cosmic virial theorem, Zel'dovich approximations, and numerical action methods. Over the next decade, we will advance these techniques and adapt them to the special case of our Local Group and neighboring groups. Within the vicinity of the Local Group, gravity perturbations are large so orbits have evolved into the non-linear domain. Most dynamical studies in cosmology avoid this regime. Our team initiated, and has been closely involved in the development of NAM, the Numerical Action Method, the only mathematical tool that solves for orbits in the fully non-linear regime. The investigators are experienced in data handling, format issues, and data reduction.

This Key Project directly addresses the first and second fundamental questions of the NASA OSS Strategic Plan for "Origins, Evolution, and Destiny" : 1) How did the Universe begin and what is its ultimate fate? and, 2) How do galaxies, stars, and planetary systems form and evolve? On large scales, these processes are controlled by dark matter. Full 3-dimensional information on the orbits of galaxies, albeit initially only for the nearest galaxies, leads to an understanding of the mass composition and evolution of galaxies and large-scale structure. We also learn about the future paths of galaxies, which tells us how rapidly galaxies in groups are merging into fewer, more massive systems and, specifically, when the Andromeda galaxy will collide with the Milky Way.

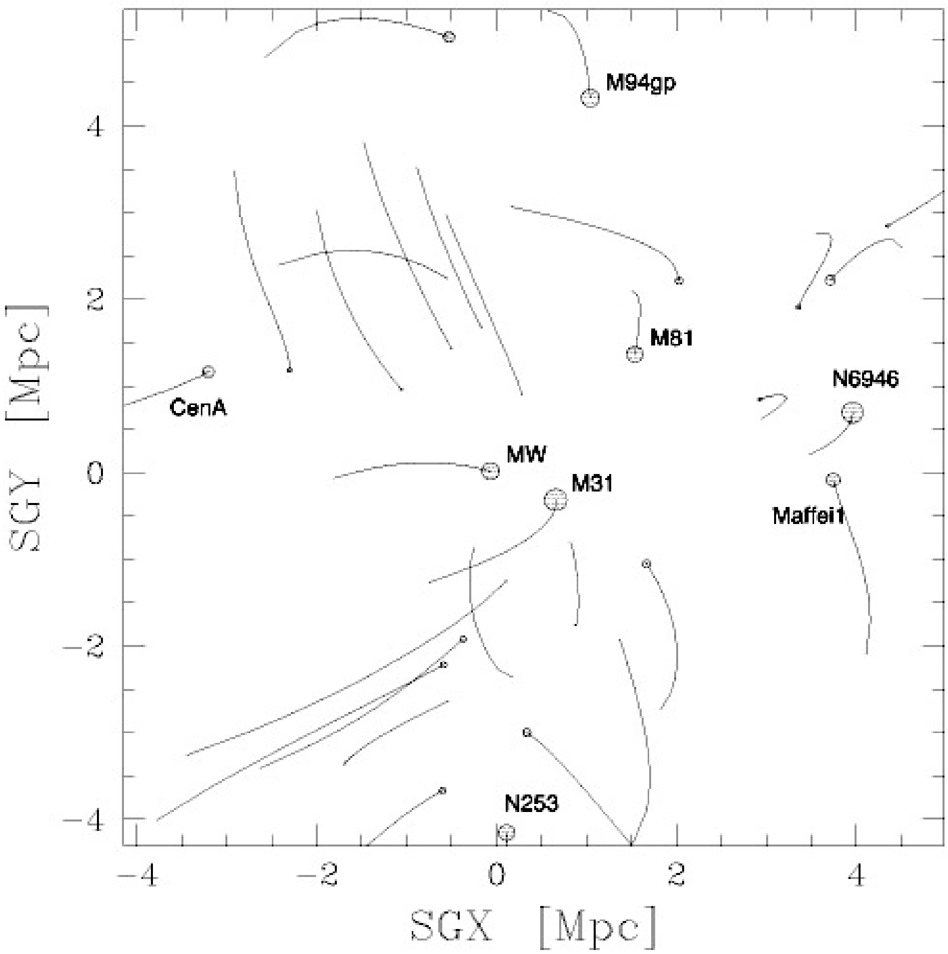

Figure 1: The trajectories of galaxies within 5 Mpc of the Milky way. The 52 orbits are from solutions with 12 masses adjusted to best fit the present distances. Present positions are circles. The sizes of the circles are proportional to masses. Distance measurements for 37 galaxies were available and guided the mass solutions. Note that the crossing times are comparable to the age of the universe so the orbits are relatively simple.