Open and Globular Cluster Distances for Extragalactic, Galactic, and Stellar Astrophysics

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Executive Summary

This is a proposal for Education and Public Outreach Mission Scientist.

The science portion of this proposal is to obtain parallax distances to selected clusters (both open and globular) within the Milky Way in order to address issues of (1) extragalactic distance scale, (2) cluster ages, (3) stellar evolutionary isochrone calibration and the integrated light models used in extragalactic stellar population studies, (4) the chemical evolution of the galaxy and galaxies in general, and (5) valuable but partial information on horizontal branch and asymptotic giant branch evolution. The clusters were chosen on the basis of these criteria.

Education and public outreach will be accomplished in a ready-for-anything, opportunistic mode. I make several suggestions regarding maximizing leverage to reach a wider audience for our efforts. SIM's E/PO strengths are its connection to finding planets, its potential for addressing cosmology, and its (to the public) mind-bending interferometric technique. The biggest E/PO challenges are reaching minority ethnic groups and women and reaching into rural areas and urban areas far from universities or NASA centers.

Science Investigation and Technical Description

The final report of the SIM Science Working Group identified "Ages of Globular Clusters" as a topic of keen interest. I agree with that opinion. In this proposal, I assume that this topic will be included in someone else's Key Project, so that accurate distances will be derived to the 14 globular clusters listed in the SIMSWG final report.

Beyond the 14 SIMSWG clusters, there are several more astrophysically critical open and globular clusters for which SIM-accurate parallax distances would yield scientific breakthroughs. I propose to use SIM to obtain wide-angle astrometry for several stars in each of the following clusters. In the table "O" means open cluster, "G" means globular.

Cluster	D(kpc)	E(B-V)	[Fe/H]	Type
NGC 6791	4.2	0.1	+0.4	O
M 67	0.8	0.0	-0.1	O
Berkeley 39	4.0	0.1	-0.3	O
Melotte 66	2.9	0.2	-0.4	O
NGC 2204	4.3	0.1	-0.4	O
NGC 2477	1.2	0.3	0.0	O
NGC 6528	9.1	0.6	-0.2	G
Palomar 6	7.3	1.5	$\sim$0	G
NGC 6440	8.4	1.1	-0.3	G

Technical Description

These observations are standard wide-angle SIM astrometry for parallax (and proper motion) measurements. Five stars per cluster are planned for observation in case binary stars introduce extra error.

Technically, these observations are easy with a properly working SIM, with the following exceptions. One of the clusters, Palomar 6, is so distant and suffers such extinction that its brighter stars are at about 18th magnitude, somewhat near SIM's limit for wide-angle astrometry. All three globular clusters are in relatively crowded regions, but stars can be chosen with no bright neighbors within a dozen or more arcseconds, well within the primary beam of SIM's siderostats.

Science Objectives

The observing goal is to produce a set of clusters with unimpeachable distance estimates. From these distances plus available data, reddenings, abundances, and ages will be derived. As noted in the SIMSWG final report, age errors come primarily from assigning the correct luminosity to the main sequence region, so the derived ages will be self-consistent to high precision. Systematic errors in whatever isochrone set is used will probably become the main source of remaining error.

Given such a set of rock-solid standard clusters, there are several objectives that will be valuable to astronomy. First, there is the suitable calibration of stellar evolutionary isochrones, and thus the calibration of models for integrated light, and thus much better estimates of age and metal abundance in high-redshift galaxies, and thus a much better understanding of galaxy formation. Let me elaborate.

In ten years, theoretical opacities should have improved to the point where other physical effects (diffusion, convection, rotation) and astrophysical unknowns will dominate the errors in the calculation of stellar evolutionary isochrones. Also by then, stellar abundances will be available to a precision of 0.01 dex for the easily seen metallic lines given good quality high resolution spectra. A new generation of even-larger (20m?) ground telescopes will be planned or under construction, leading to the acquisition of good quality rest-frame optical-UV spectra for galaxies between $z = 1$ and $z = 2.5$. "Red envelope" studies of galaxies in this redshift range (such as Dunlop et al.'s 53w galaxies) will be revealing the early merging history of the universe of galaxies, and the reddest of these galaxies will give useful lower limit to the age of the universe as a function of redshift *if* we can measure their age. The estimation of age is a growth industry at the moment, with many groups using isochrones plus theoretical spectra in order to predict the spectral change of galaxies with stellar population age and abundance. Today's isochrones largely ignore real cluster data, especially as regards the rarer stages of stellar life: the tip of the first-ascent red giant branch, the morphology of the horizontal branch or clump, and the asymptotic giant branch. It is not only the luminosity function of these that matters, but also, and quite critically, the temperatures of the stars in the various phases (I estimate that we need to know temperatures to about 7 K in order to derive 5% ages from isochrone models using either color difference methods or integrated light methods). In short, then, we find an unexpectedly intimate connection between local clusters and questions of cosmic importance.

Second, SIM improves the cosmic distance scale in manifold ways, but one them rests on this standard cluster network almost entirely, and that is Tonry & Schechter's *surface brightness fluctuation*, or SBF, method of extragalactic distance estimation. The distance depends on observational error but also on the predicted behavior of the SBF magnitudes with underlying stellar population age and abundance, as well as the redshift of the galaxy. Well, all of these quantities rest on isochrone models, which would benefit enormously from a critical comparison to a set of truly reliable clusters, which SIM will provide in this project.

Third, in our Galaxy, the cluster network can be tied in to the photometry of the rest of the globular and open clusters in order to investigate the chemical and dynamical history of the galaxy. In external galaxies, this is also true, but filtered through the isochrone models.

Fourth, the cluster ages themselves are important. Perhaps the most important of all are the globular clusters because the oldest globular cluster must be somewhat younger than the universe, and this fact will continue to be used to rule out various cosmological models.

Fifth, the clusters were chosen to be as rich (populated with many stars) as possible, given the other constraints mentioned below. This means that intrinsically rare stars (RGB tip, some HB, and AGB stars) are well represented in these clusters, and can be used to illuminate the behavior of different evolutionary stages with star age and metal abundance.

Target Selection

The main goal is to generate a list of unimpeachable standard clusters for which distance, reddening, abundance, and ages are known. These standard clusters can then be used to compare with other clusters and with theoretical isochrones to leap to several fundamental topics in extragalactic, Galactic, and stellar astronomy, as explained above.

This objective translates into choosing clusters that occupy interesting niches in age, abundance, and richness (the latter because only globular-class clusters have enough stars in them so that the rarer stages of stellar evolution, like the asymptotic giants, are represented in sufficient numbers to study quantitatively). Wherever possible, the clusters should be well-studied already, with accurate multiband photometry and good spectroscopic abundances.

On the abundance axis, the low-metallicity end is well represented by the 14 SIMSWG globular clusters. However, 47 Tuc is the most metal-rich cluster in their list, and many applications of precision cluster information (like the study of elliptical galaxies) depends on more metal-rich objects. We therefore include three metal-rich globular clusters. (The most metal-rich cluster, Pal 6, is also the most challenging for SIM to observe.)

On the age axis, we need to choose clusters at a variety of ages in the same metallicity bin. Very young, very metal-poor clusters are rare, but NGC 2204 is relatively youthful and somewhat metal-poor, so we adopt this cluster to occupy the young, metal-poor niche. Messier 67, Melotte 66, and NGC 2477 fill in the parameter space, and Be 39, NGC 6791 represent the oldest open clusters, with

NGC 6791 resembling closely the age and metallicity thought to occur widely in elliptical galaxies.

The reason for spreading out over age and metallicity is to require a set of isochrones to fit *all* of the constraints before the set is considered successful. This will help to usher in the era where ages derived from integrated light become nearly as precise as ages derived from cluster color-magnitude diagrams.

Impact of a Successful FAME Mission

If the MIDEX-class mission FAME (Full Sky Astrometric Mapping Explorer), an all-sky astrometric survey, is successful to its planned limit, one of the clusters I list (M67) will already have fairly accurate parallax measurements since some of its stars are brighter than FAME's magnitude limit, and it is within FAME's 2.5 kpc parallax range. In this eventuality I will cheerfully drop M67 from the list.

Education/Public Outreach Statement of Participation

As E/PO Mission Scientist I would participate to the fullest. A description of my approach and qualifications is given below. In addition to the actions the team will adopt in the future, I plan to generate at least one SIM-based curriculum enhancement for the primary, secondary, and college level one levels. I plan to implement a leveraged speakers bureau activity to accelerate the rate at which volunteers visit elementary schools. These are also described below.

E/PO Mission Scientist Program Approach and Goals

My general approach to the role of mission scientist in education and public outreach (E/PO) is the same as the boy scout motto: "be prepared." The problem of education has a hydra-like structure, with many heads and many tails: not only does it require a variety of strategies and products from our (the space science) end, but these products are channelled to learners spanning all grades, from the kindergartener learning to tie her shoe to the college freshman taking "scopes for dopes." Public outreach requires preparedness also. Should a planetarium call, or *National Geographic World*, or the *Discovery Channel*, we need to be ready with clear and helpful materials and information. The implementor of SIM's E/PO effort must therefore be ready to oversee at least a dozen separate, concurrent projects.

SIM-specific E/PO Opportunities

At the risk of sounding less than magnanimous, I would opine that the title "Space Interferometry Mission" lands in the "huh?" category for most Americans. SIM also has the drawback of not producing arresting full-color images for public consumption. SIM's goal, to measure accurate distances to remote stars, is far more easily digested, and I think that this is one key to explaining to the public what this mission is about. The other obvious handle is the search for planets. For education, the mission is full of interest at all grades levels. I sketch some possible approaches and examples below.

Public Outreach: There are several themes about SIM that should capture public imagination. First, the interferometric technology of SIM is ripe for a

Popular Science article or something similar. We should be ready to help such an author with step-by-step diagrams of how SIM adds light waves, and with summaries of what we hope to learn from the mission. Second, the search for planets will remain high in the public interest for the foreseeable future. SIM is important not only for the planets that it might detect, but for proving the technology that will be used in future planet-finder missions. Third, issues pertaining to "the universe" always appeal to the public. For SIM, this means distance-scale refinements (which SIM accomplishes through Cepheid distances, "rotational parallaxes" in M31 and M33, and Galaxy proper motions) and also the refined maximum age of the universe from globular cluster age estimates.

Although we should have web sites and brochures for the public to browse upon request, we should also be ready for radio, TV, newspaper, and magazine coverage. Some of this borders on *public relations* rather than *public outreach.* Accordingly, I would work closely with the public relations center to coordinate material preparation so that effort is not duplicated. I would also unabashedly use PR material for E/PO if it is suitable.

Primary Grades: Through a number of interviews with elementary school teachers who have astronomy as part of their curriculum and through personal experience I have arrived at the conclusion that the single most effective aid for these teachers is to host a visiting scientist for an hour. This outreach technique seems just the opposite of the "highly leveraged" language of the OSS E/PO strategy document: with 1.9 million classrooms in the U.S. and only a rough dozen members of the SIM science team, it is clearly impossible for us to cover the whole territory ourselves. Therefore we will use the OSS E/PO brokers-facilitators to extend our reach beyond just ourselves, our postdocs, and our grad students. Further "leverage" can be obtained through a "speakers bureau" where the speakers get reimbursed for travel expenses. This requires considerable administrative overhead, which is explicitly included in the form of an administrative assistant in the budget. The toughest schools to reach are those in parts of the country that are far away from urban centers. We will therefore concentrate on (1) rural areas, (2) urban areas that are nevertheless remote from any major university or NASA center, and (3) areas with underutilized ethnic groups. My goal is to reach 10% of all schools with a personal visit: about 1000 schools over SIM's roughly 10-year mission.

That most elementary schools have not been directly touched by NASA's outreach efforts is seen at least anecdotally locally. The elementary teachers I have interviewed in Iowa report (1) never receiving or requesting any material from NASA and (2) not knowing where materials are available or how to get them. This is not true, for example, in Chicago, where an enthusiastic teacher may call the Adler Planetarium for help.

We should not overlook the opportunity to develop materials that can be used in the elementary curriculum. Example: a unit that discusses the difference between stars and planets and gives examples of known stars with planets.

High School: Many high schools teach physics, but an astronomy unit is rare. An opportunity related to SIM might therefore be to provide resources for the demonstration of the wave nature of light. Example: From commercial companies, a setup with a laser plus Michelson interferometer costs $1000, and a laser plus various slits for observing interference patterns costs $300. On the other hand, a laser pointer costs less than $100, and we could provide instructions for turning a pointer into a wave interference demonstration.

The search for planets is also exciting for this age group. Example: We should develop materials to (1) demonstrate the handful of methods for finding planets, and (2) a locator for finding stars in the night sky that are known to have planets.

College Year 1: The introductory *scopes for dopes* course is the only exposure most college graduate ever get to astronomy. Many such courses are taught with a "laboratory" section where the students solve problems in groups. We should definitely write lab modules for (1) finding parallax distances, 20th and 21st century, and (2) the search for planets.

My Qualifications for SIM E/PO Mission Scientist

My education credentials are examplary compared to the average space scientist. This probably stems from a life-long interest in education and from the fact that education is "in my family;" my wife and parents are all educators. I am presently chair of the department of physics, astronomy, and engineering at small, liberal arts St. Ambrose University, located where I-80 crosses the Mississippi river. This is a teaching college with only a few graduate programs. I serve on the teacher education committee, so I am familiar with the education of classroom teachers and the procedures for licensing. I have developed ties to the local and regional amateur astronomers. I also serve on the publications board of the ASP (Astronomical

Society of the Pacific). I was able to get the astrology horoscope dropped from the campus paper, and substituted a “What’s up in the sky” column that I write twice a month. I have been speaking in elementary schools since graduate school; career days, invited classroom visits, sunspot viewing parties. I have also been in several high schools, usually hunting for (and finding) micrometeorites in the parking lot. I have been teaching introductory astronomy for 9 years, developing a lot of my own material. I operate “Menke Observatory” for public viewing events, student lab sessions, and the “Eastern Iowa Star Party” for the amateur astronomers in the region.

Partnerships and Attaining National Scope

Here, I will give several examples of how I would apply “leverage” to broaden the impact of SIM-specific E/PO projects (since the actual E/PO plan will be decided later).

If we develop a laboratory exercise for college level one astronomy, first we would field test the exercise for a year by giving to our own classes and to any other volunteers that we can find. There would be an assessment form or quiz for the students, so that they can evaluate how they fared in the lab and give it a rating. We polish the product and make it available from the web. Next, we leverage the completed product by negotiating with (1) the Astronomical Society of the Pacific, (2) Sky & Telescope magazine, (3) the National Science Resource Center, (4) the NSF, and (5) the NASA Teacher Resource Centers to see if they could publish, advertise, or otherwise make our product more visible. The product should also be "advertised" and demonstrated at a AAS meeting and an ASP meeting.

As another example, perhaps we develop a curriculum enhancement for high school. To make it concrete, suppose we concoct a demonstration of the interference of light from a laser pointer, so we then have a "kit" of instructions and do-dads for the high-school teacher to lead the students to some discoveries about the nature of light. In this case, we proceed by calling the National Science Teachers Association (or by calling an OSS facilitator and asking advice) because we want to know if our interference kit *supports inquiry based systemic reform* consistent with National Science Education Standards. If our kit is up to spec, it should be field tested at our local high schools and then make available. Then we are ready to apply leverage: we contact the National Science Teachers Association and arrange to speak about our kit at their next meeting. We negotiate with other institutions with leverage, such as the Pacific Science Center, the Lawrence Hall of Science, and the National Science Resources Center.

As another example, perhaps we wish to produce a slide set. Once we are satisfied with the product, we should negotiate with the ASP, with Sky Publishing, and with Astronomy magazine to see if they will offer the slide set along with their other materials. We can also make sure that the availablity of the slide set is advertised alongside other NASA-produced slide sets. Slide sets are excellent gifts to amateur star parties, where door prizes are often given away. In all probabability, the slides will be shown at the next club meeting.

There are many other possibilities, but the examples I list hopefully show that I understand how leverage is used in the E/PO lexicon.

Involving SIM Science Team Members and Future Guest Observers

Each SIM science team member and future guest observer will have constructed his or her own education/public outreach plan. These plans will be optimized to the strengths or comfort levels of the individuals involved and these plans will have an effect on the final E/PO strategy that we adopt.

Once the E/PO plan is solidified, it will almost certainly be most beneficial to have one or two *training sessions* for all individuals that will be involved in the E/PO effort. These workshops will practical and focussed, with the intention of building skills and raising comfort levels. It will be my job to organize them, and their costs are included in my proposed budget.

Annother suggestion I have, to be ratified by the science team, is to present similar E/PO training workshops at future AAS or ASP meetings.

Dissemination of Products

It is the internet age. Links to E/PO brochures, lab exercises, or other resources will be provided from the SIM and OSS pages. HTML, PostScript, and RTF versions of labs and brochures will be made available from the web site directly. Orders for non-electronic material such as slide sets, books, or videos, can be received via cgi-forms. St. Ambrose University and/or the OSS distributor (forum) site for Origins (STScI) can be the archive for the non-electronic resources. For resources specific to teaching, NASA's *Teacher Resource Centers* should be utilized.

Evaluation of Products and Activities

Evaluation of E/PO success is conditional on the type of endeavor. For electronically disseminated materials, we should keep tracks of number of downloads. Anecdotal reviews that team members hear about any such product should be logged in a central (electronic) location (I suggest email to me, and I will keep them in a folder in my email box). Any curricular materials such as a high school physics unit or a college astronomy lab exercise should be field-tested before they are made public. After they are released, the number of units requested should be tracked, and reviews logged. If we are lucky enough to attract the Discovery channel or NOVA, I think we simply count our blessings. We should keep track of schools and classrooms that were visited.

Ideally, we would want some kind of before and after public poll to see if we are influencing public opinion, but I think that this is beyond the resources that we presently have available.