

Scientific Background

(1) Objective

The objective of this program is to verify the astrometric stability of a catalog of stars to be used as the reference grid for SIM's wide-angle astrometric science. The final catalog will comprise a minimum of 1306 stars, distributed quasi-uniformly across the sky. Grid stars serve as the fundamental reference for the SIM instrument as it performs astrometric observations. (A description of the SIM instrument and its observing modes may be found on the SIM web site at <http://sim.jpl.nasa.gov>.)

This program addresses a key aspect of the performance of SIM: the ultimate accuracy of global astrometry with SIM will be limited, in part, by the stability of the grid stars themselves. The program is limited to investigating astrophysical sources of 'jitter' in the star positions. (The SIM Project is responsible for the design and construction of the SIM instrument to meet its measurement accuracy requirements.)

Sources of 'astrophysical jitter' include stellar motion about the system center-of-mass for binary or multiple star systems and surface activity (starspots) resulting in a shift of the star's photocenter. Luminosity changes in either the grid candidate or companion star ('Variability-Induced Movers') will not have significant effect on grid star astrophysical stability.

Initial work on the grid star problem began in 1998 through the SIM Preparatory Science Program (<http://sim.jpl.nasa.gov/research-opps.html>). The results of that program are a list of candidate SIM grid stars. The selected candidate stars are metal-poor K-giants at a typical distance of 1-2 kpc. Low-resolution spectroscopic follow-up is underway to confirm the metal-poor K-giants selection. Additional candidates will be found from catalog searches.

The Program described here will verify the suitability of each candidate star for inclusion in the grid, or to reject it, if it fails to meet the necessary criteria. This will require large observing programs. The full-sky radial velocity (RV) monitoring program should deliver at least 17000 RV measurements on $R=12$ stars, at a precision of at least 50 m/s, with most of the observations taken within the first 3 years. The photometric variability studies require on the order of 6500 observations at a precision of at least 50 millimagnitudes.

(2) Requirements on the candidate grid catalog

SIM requires grid stars to be stable to better than 4 microarcseconds (muas) at any epoch during its nominal 5-year mission, in a quasi-inertial reference frame. SIM will observe a number of quasars to 'anchor' the grid against a rigid rotation of the entire reference

frame. Tying the grid to an inertial frame is the responsibility of the SIM Science Team (http://sim.jpl.nasa.gov/ao_support/ao_abstracts.html) and the SIM Project, and is not part of the SIM Grid Star Verification program.

The stability requirement of 4 μ as is set to be less than the expected accuracy of individual SIM measurements, which are nominally 10 μ as in one dimension. Therefore, by design, errors in the measurements by SIM dominate over all sources of 'astrophysical jitter'. The SIM grid performance, and hence the ultimate global astrometry accuracy, should be limited by the instrument, not 'noise' in the grid star positions. Overall, the mid-epoch positional accuracy of the SIM grid, given a scenario of multiple observations of each star, will be 4 μ as in one dimension.

Grid stars will have R-band magnitudes in the range $R = 11.0 - 12.5$. Closer K-giants are brighter, but their astrometric jitter due to companions is poorer. Fainter stars require longer integration times to achieve the nominal 10 μ as single measurement accuracy; magnitudes down to about $R = 13.0$ are feasible. However, we expect a more practical limitation to be the total required ground-based observation time needed for the verification program. This will limit the candidate magnitudes to $R = 12.5$.

(3) Verification of grid candidates

This RFP solicits proposals for two kinds of astronomical observations: (i) precision radial velocity (RV) monitoring observations of grid star candidates, and (ii) photometric variability studies:

(i) Radial velocities will be used to screen the grid stars for planetary sub-stellar and stellar companions over orbital periods ranging from days to years. Very short period companions are not a concern, because the corresponding astrometric jitter is small. Long-period companions are a concern for SIM's science program, because RV data are insensitive to long-period orbits.

Screening candidates adequately will require a minimum of four measurements to a precision of 50 m/s, referred to the Local Standard of Rest (LSR). To probe the period space adequately, measurements will be performed (approximately) at four epochs spaced at $t=0$, $t=4$ months, $t=2$ years, and $t=5$ years. The basic contract will cover the first three epochs; JPL expects to extend the contract(s) to cover the final epoch and observations of any replacement candidates. JPL may extend the contract by a further one year option if the candidate failure rate is significantly higher than expected.

(ii) Photometric variability studies will be used to bound astrometric variability due to starspot activity and other similar phenomena. Since the purpose of photometric monitoring will be to reject grid candidates which are variable, a program to do this work can be concluded in one or two years.

Stability to SIM requirements requires relative photometry to 50 mmag. All candidate objects must be observed 4 times within a 6 month period, with observations separated by at least one week.

The observation programs will be subdivided into smaller 'work packages' (see Exhibit II). Groups may propose for RV work, photometric work, or a combination of the two.

Because of the critical importance of the grid to SIM's science objectives, the Project requires a high level of confidence in the grid performance at SIM launch. The Grid Star Verification Program must not only deliver a catalog of grid stars for SIM to observe, but also estimate the confidence that the RMS stability actually observed by SIM meets the original specification, with a high degree of confidence.

To improve confidence in the catalog at launch, the initial catalog will be overpopulated. The starter catalog will contain ten possible candidate stars for each possible grid star, or 13,060 objects. The SIM Project will choose the four or five top candidates for each brick to be observed during Epoch 0, for a total of up to 6,530 stars. The top three candidates will be observed four months later (Epoch 1); if any candidates fail, they will be replaced so that at least three survive to Epoch 2. Two candidates surviving Epoch 2 and Epoch 3 of Option No. 1 will leave a prime and backup grid star candidate. If the attrition rate is low, then the SIM project will select stars based on their performance margin against the acceptance criteria.

If the rate of candidate attrition is high (projecting more than 75% rejection by launch), RV and photometry on a 'secondary candidate' list will be initiated as early as possible. This will be done by substituting fresh candidates in the same region of sky to replace the rejected candidates. The table below compares different observing scenarios for different attrition rates:

Time	50% Failure Rate in initial catalog			Action	80% Failure Rate in Initial catalog		
	Candidates				Candidates		
	Observed	Failed	Added		Observed	Failed	Added
t=0	ABCDE	n/a		Pick top 3 candidates to observe in the following epoch	ABCDE	n/a	
4 months	ABD	BD	CE	Replace any failed candidates with 1) backups from 5 observed at t=0, or 2) backups from original list of 10.	ABD	B,D	C,E
8 months	CE			Observe replacements. Replace any failed candidates as above.	C,E	C	F
12 months	—			Observe replacement	F		
16 months	—			Observe replacement	F		
2 years	AC	A	E	Pick top 2 candidates to observe at the two year epoch. Replace failed candidates	AE		
2 yr 4 months	E			Observe replacement			
5 years	CE			Replace any failed candidates as above.	AE	AE	F
5 years 4 months				Observe replacement	F		
Final Catalog	CE				F		
Total Measurements	15				17		

For the above observing scheme, we expect to make between 15-20 RV measurements for every two of the 2600 grid stars that survive to enter the catalog at SIM launch. Thus the RV monitoring program is large. Even with no dropouts, it must deliver a minimum of 17000 RV measurements on R=12 stars, at a precision of 50 m/s, with most of the data taken within 3 years.

(4) Role of the selected Grid Groups

The SIM Project is ultimately responsible for ensuring the grid meets the Project's goals. The successful proposers, referred to here as 'Grid Groups', will be expected to work closely with JPL toward the Project's goals, but their formal responsibility is limited to delivering the products defined in their contracts with JPL, per the Statement of Work in the Specimen Contract.

Please note that scientific analysis beyond that needed for the SIM grid, and publication costs, time to write scientific articles, and travel costs to general conferences will be deemed beyond the scope of the contract with JPL.

Proposers are encouraged to be 'creative' in developing their observing plan. This might include, for instance, the purchase of observing time from an institution that operates a suitable telescope via this means of operation. Or it might include the provision of, or shared development and building of, a facility instrument in exchange for sufficient observing time for SIM's needs. Such arrangements, even if only tentative, should be included as part of the proposal, with a corresponding estimate of the required budget.

This represents a departure from the traditional means of securing observing time for astronomy. The sheer size of the expected SIM grid program, plus the fact that this work is essential to the success of a NASA mission with a significant public investment, requires approaches to instrumentation and observing which better match the needs of SIM.

Proposals will be evaluated using the evaluation criteria and factors given in the RFP sections "Volume I: Technical Instructions" and "Volume II: Management Instructions." Please note that scientific merit of any research based on observations supported under this RFP is not part of the evaluation. Scientific expertise is considered. 'Creative' arrangements will be evaluated on the basis of meeting SIM's grid requirements, not scientific merit, although the Project will encourage the scientific use of the results from such a large observing program.

Initial contracts will be made for 2.5 years. However, JPL recognizes that the scientific validation of grid stars is best served by a long-term monitoring program, and that continuity of observing and analysis methods is important, and that is why JPL has included two options in the Contract to potentially extend it to five and six years, respectively.

(5) Budget resources

There are no pre-determined allocations of funds to the six work packages. The actual total will depend on the recommendations of the proposal review team, and also the number of Grid Groups that are selected. JPL recognizes that the most effective overall program may require the work packages to be funded at very different levels, depending on availability and cost of required resources.

(6) SIM Project Milestones and Schedule

Date	Milestone
December 2002	RFP issued
January 2002	Letters of Intent to propose due at JPL
February 2002	Proposals due
March 2003	Selection of contracts announced
April 2003	Contracts funded and grid work begins
December 2005	Nominal end of basic Contract period
April 2008	Nominal end of Option No. 1.
December 2009	SIM launch
June 2010	Start of full science operations
June 2015	Nominal end of mission

- 1.2.2 Obtain replacement observations as in 1.2.1 for observations lost to bad weather.
- 1.2.3 Achieve relative photometric accuracies of 50 millimagnitudes or better in the execution of paragraphs 1.2.1 and 1.2.2
- 1.3 Present results and status reports at periodic meetings and reviews as follows:
 - 1.3.1 ***Sim Project Meetings:***¹ Meetings with the SIM Project and representatives from all Grid Groups at or near JPL or at a location arranged by the SIM Project.
 - 1.3.2 ***Grid Group Reviews:***² Reviews of each Grid Group shall be held. The first two reviews will be held at or near JPL or at a location arranged by the SIM Project in conjunction with the Sim Project Meetings described in paragraph 1.3.1. In subsequent years, one review will be held in conjunction with the Sim Project Meeting of paragraph 1.3.1 above, with the other Grid Group Review held via telecon.
- 1.4 Deliver observation results of paragraphs 1.1 and 1.2 to the ISC in computer-readable ASCII as stated below. The specific format will be specified by the Interferometry Science Center prior to deliverable deadline as follows:
 - 1.4.1 Deliverables are ***Interim Observational Reports***³ at intervals of six months, which are to contain a list of stars with spectra (raw data), calibrated spectra, and calibrated radial velocities in units of meters/second (Local Standard of Rest) or calibrated photometry in units of millimagnitudes, delivered to the cognizant JPL Technical Manager.
 - 1.4.2 All the ***data of the Interim Observational Reports***⁴ shall be released to the public.
- 2. JPL will:
 - 2.1 Provide the Contractor with a list of Candidate Stars upon which measurements of radial velocity and photometric stability are to be made. These stars will range in brightness from magnitude 10.5 to 12.5. There will be 6530 stars in the initial all-sky Candidate list.
 - 2.2 Update the list of Candidate Stars and drop objects from candidacy.

¹ Every twenty-sixth week after date of Contract (ADOC).

² Every twenty-sixth week ADOC.

³ Every twenty-sixth week ADOC.

⁴ Upon SIM Launch

STATEMENT OF WORK AND DELIVERY/PERFORMANCE SCHEDULE

1. In support of the Space Interferometry Mission (SIM), the Contractor shall participate in the SIM Grid Star Verification Program, whose purpose is to verify that a catalogue of stars (the SIM Grid Star catalogue) is astrometrically stable enough to be used as the reference source for SIM's wide-angle astrometric science. The Grid Star Verification Program is limited to investigating the astrophysical "jitter" in the positions of candidate Grid Stars. The footnoted dates are "on or before" delivery/milestone dates. In performance thereof, the Contractor shall perform in accordance with the information contained in Exhibits I and II, and shall:
 - 1.1 Perform radial velocity measurements on the Candidate Stars comprising the Work Packages of Exhibit II assigned by JPL to the Contractor.
 - 1.1.1 Obtain two measurements per star during calendar years 2003 and 2004, the two measurements ("Epoch 0" and "Epoch 1") separated by at least 4 months but no more than 5 months. The first measurement should be made no later than 12 months after the date of the Contract.
 - 1.1.2 Obtain two measurements per star for replacement candidate stars as specified by the SIM Project, temporally separated as in paragraph 1.1.1. The first measurement should be scheduled as soon as possible following Epoch 1, but no later than four months after Epoch 1.
 - 1.1.3 Obtain one additional measurement per surviving candidate star at "Epoch 2." Epoch 2 shall occur two years after Epoch 0.
 - 1.1.4 Obtain at least two additional measurements per star for a selected circumpolar subset of 200 stars in the hemisphere(s) within the assigned Work Packages for calendar year 2003, spaced approximately 4 months apart.
 - 1.1.5 Achieve single measurement accuracies of 50 to 53 meters per second or better in the execution of paragraphs 1.1.1. thru 1.1.4 above.
 - 1.2 Perform photometric measurements on a subset of the Candidate Stars investigated under (1) above.
 - 1.2.1 Obtain four observations separated by at least one week over a six month period during the 24 months following the date of the Contract.

2.3 Reserve the right to add additional candidate stars if attrition rates exceed 75% of initial samples, based on data provided by the Grid Groups.

3. Exhibits

The following exhibits are attached hereto and made a part of this Contract:

3.1 Exhibit I, Scientific Background, dated 11/15/02.

3.2 Exhibit II, Work Packages, dated 11/15/02.