20050509
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POM_V01

OBSS "Photometric" Observing Modes

ABSTRACT

In this memo I discuss the impact of the requirement that the LRSI needs to provide accurate photometric information for all stars. Two derived requirements/consequences are investigated: 1) the effects on the astrophysical return, 2) the effects on the astrometry.

Throughout this memo, I assume that there is some imperative to obtain the photometric information sooner rather than later, so that a full calibration of the instrument can be achieved as quickly as possible.

With the current instrumental parameters, the LRSI saturates in “most” bands for “most” stars brighter than V=15 (section 4.0) for a 15 second exposure and V=12.5 for a 1.5 sec exposure. It is TBD as to whether this saturation will impede color determination for astrometric purposes. From the astrophysical standpoint, it is unfortunate that the saturation limit practically coincides with the magnitude where precision astrophysics is possible (section 4).

Spin-off of this investigation is the suggestion for an alternative to the OBSS/25 mode. This alternative mode is actually a combination of three different modes: 1) An Initial Photometric Survey (ISP), 2A) a Limited Imaging Photometric Survey (LISP) , 2B) a Mini IPS (MIPS), and 3) an OBSS Key Project to study high-galactic latitudes (sections 2 & 3).

> The first survey, IPS, comprises a 260 days full-sky survey that is tailored at providing the required photometric information as soon as possible into the mission.
>
> > The cadence of this survey can be set up in such a way that eclipsing and/or transiting objects are easily identified. Such can be achieved by taking about two weeks to map a single Field of View of the Astrometric Instrument (FOV_{AI}) with the photometric instrument, rather than taking 25 “dithers” in succession. Such a scheme collects one photometric & 24 astrometric observations per star in a period of about two weeks.
> >
> > > *Given the small FOV of the LRSI, it takes 25 LRSI pointings to map out the FOV of the astrometric instrument. That is to say, when*

taking photometric observations, the observatory is in 24-fold overlap mode as far as the AI is concerned.

This mode is also tailored to finding short-period astrometric binaries (12% of stars) and variable stars. Since the colors of variable stars often vary with phase, the temporal characteristics of the IPS are also well suited to identify variable stars as potential problem stars for astrometry.

For example, Cepheids have $\delta_{COLOR} \sim 0.7 * \delta_{AMPLITUDE}$*, while the amplitudes can easily reach one magnitude.*

After the completion of the IPS, the observatory is ready to start reducing targeted observations with full knowledge of the color-dependent terms.

Following up on the IPS there would be, about once per year, a limited IPS for studies of the Galactic plane ($\pm 17^{o}$) where the vast majority of the stars are found. Such a LIPS would take ~78 days, but could be scheduled as several MIPS of shorter duration.

The IPS/LIPS combination would take about 31% of the total observing time, but would significantly decrease (10% or 192 days) the overall observing-time requirements because the IPS/LIPS data would reduce the amount of required observing time for OBSS Galactic Plane Surveys (GPS).

Last, to retain astrometric integrity of the overall reference frame, scans perpendicular to the Galactic plane need to be performed. It is not clear as to the proposed observing strategy can achieve the rigidity of the reference frame

I envision that the roughly 2,000 observing time units (OTUs) that could be spend on studying the vertical density distribution of stars and dark matter could be used for this purpose. Additionally, the 10% savings realized by the IPS/LIPS/GPS (192 days, or 1,600 OTUs) could be spend on this task.

These vertical extensions of the LIPS (VIPS) are equivalent to 14 great circles of 1.16 degrees wide, covering an area of 5,292 deg^2 *away from the Galactic plane (18% of non-GPS sky).*

No constraints resulting from an astrometric cadence requirement have been incorporated in this study since information on those requirements is unavailable to me.

Working the numbers derived in section 2, I find that the OBSS/25% survey would yield 1.72 LRSI observations per star, and that targeted observations can only beef up the photometric performance at the cost of astrometric accuracy (40% reduction in accuracy). Such is likely to be required for projects that require photometry for target identification (section 0.0).

Without further action, the LRSI performs about 7.5 times worse than the GAIA system (section 1.1.1).

0.0 Introduction

In this document, I analyze what (some of) the effects are of obtaining photometric information of a small number of connected pointings by the astrometric instrument. In particular, I will develop the limit of a single field of view (FOV). Such would be important for projects where 1) one doesn't know the targets of interest in advance, 2) where those targets need to be identified by their observed colors, 3) where the photometry and accurate astrometry need to reach faint limiting magnitudes, 4) where high angular resolution is required (i.e., ground-based photometry is unavailable) and 5) where the "contaminants" can not be identified by means of a measurable parallaxes. Examples are: 1) the quasars, background galaxies, foreground thick disk or halo stars, globular clusters and stars in and around the galaxies in the local super cluster, 2) finding regions of small extinction that probe as deep as possible into the Galaxy in, for example, the Galactic Center and anti-center regions, 3) separating stars internal to nearby galaxies from Galactic contamination, especially those at "low" Galactic latitude [Sagittarius dwarf, M 31, M 33, ...].

Two different points of view, at the ends of interpretation space, are helpful in understanding the effects of the "interaction" between the small FOV of the Low Resolution Spectroscopic Instrument (LRSI) and the large FOV of the Astrometric Instrument (AI).

First, let's assume that the photometry is not required to obtain maximally useful astrometry. Because the FOV of the LRSI "pokes a hole" in the astrometric FOV, one better makes sure that the LRSI hole doesn't contain significant numbers of objects of interest when designing an observing program. With the LRSI hole in the center of the FOV, one can be pretty much assured that this is not the case. For example, programs that need the highest possible astrometric accuracy will want to have the object of interest in the center of the FOV where the distortions are smallest.

> *Examples of such programs are the search for planetary companions or the determination of the proper motion of an external galaxy.*

Such programs also need as many reference "stars" as possible, in locations with the lowest possible distortion.

> *A possible solution would be to "dither" the field center around the point of interest, for example each offset by 1 FOV$_{LRSI}$ to the North, East, South and West, from the field center. I that case, the point of interest would always be mapped with a part of the FOV that lies half-way to the edge of the field of the AI. Following this strategy, after the 4 pointings were done, the FOV$_{AI}$ would have*

> *had 4 astrometric observations, except the N1, E1, S1, and W1 cells, which would all have 3 observations. The cells with 3 astrometric observations would also have one photometric observation.*

Thus, a reasonable solution is possible, although it seems that from the astrometry-only point of view, a LRSI located at the edge of the FOV would be preferable as compared to a central LRSI.

Second, if the photometry is an important part of the scientific puzzle and/or if photometry is required for astrometric calibrations, then it is imperative to map out the astrometric field of view sooner rather than later with the LRSI so that: 1) scientific judgment can be made which are the most interesting fields for the rest of the observing program, 2) which need ground-based follow up, and 3) instrumental performance of the AI can be quickly and adequately evaluated.

1.0 The Number & Quality of Photometric Observations

Given the small size of the FOV of the LRSI, it takes quite a long time to map the whole sky just once. The current **LRSI** parameters imply that it takes **14.1 hours to map out one great circle** and that it takes **260 days (8.5) months to image the whole sky.** Also, the achievable photometric accuracies of such an OBSS survey are significantly worse than those aimed for by GAIA. The remainder of this memo is aimed at trying to turn these limitations into a virtue that OBSS should exploit.

The calculations presented in this memo are based on the "OBSS Baseline (Working), v0.20"

1.1 Number of Observations

The field of view (FOV) of OBSS is 1.16 degrees on a side, while the LRSI occupies 5% of the focal plane, or 0.259 degrees on a side. In Survey mode (1.5 sec & 15 sec exposures plus 20 sec readout = 36.5 sec per pointing), it takes 360.0/0.259 * 36.5/3600 = **14.09 hours to go around a great circle once**: that is to say, to map out 360*0.259=93.24 deg^2. **The LRSI "scan rate" equals 6.61 deg^2 per hour.**

> *In the remainder of this memo, I assume that the observatory is operated in a UCAC-like mode where a strip of the width of the focal plane is "scanned" over the full 360 degrees length. Following strips are offset in the direction perpendicular to this strip in what is called the cross-scan direction. Unlike the Hipparcos or GAIA scanning law, the adjacent strips do not intersect as would be required if each strip were a great circle. Instead, adjacent strips are small circles that do not overlap with previous strips.*

To map out the whole sky thus takes: 41,253/6.61 hrs = **260 days, or 8.52 months** [totaling 615,215 pointing]. During this period, the astrometric instrument observes 0.95 * (1.16^2) * 615,215= 927,880 deg^2, or **22.5 times the whole-sky area**.

1.1.1 OBSS versus GAIA

Thus, after 8.5 months, all stars have been observed for 16.5 seconds with a 1.5x1.5 meter mirror. At this point, OBSS is 7.54 times less efficient in collecting photometric photons than GAIA (after 5 years). Thus, if OBSS achieves a given science goal at magnitude, GAIA will be able to achieve the same goal for stars 2.2 magnitudes fainter.

> *GAIA has a 0.25 m^2 mirror, and produces 93.7 photometric observations per band, each 11.95 seconds long. Thus, expressed in OBSS units, GAIA is 0.25/(1.5^2) *(11.95/16.5) *(93.7/1) = 7.54 times more efficient than OBSS. That is to say, GAIA reaches 2.2 magnitudes fainter than OBSS in 16.5 seconds.*

To compete with GAIA, OBSS would need to produce at least 7.54 times more observations, for a total of 7.54*16.5=113.1 seconds. Such can be achieved by OBSS, but only in a smallish part of the sky. If this smallish part of the sky is chosen to be the Galactic plane [± 17 degrees], then the vast majority of stars would receive sufficient photometric attention by OBSS to surpass the GAIA data.

1.2 Astrometric & Photometric Coverage: Astrometric Efficiency after full Photometric Coverage of Small Fields

In the tables below, each cell in the spreadsheets/tables represents the size of the photometric FOV, where the astrometric FOV comprises 5x5 such cells. In each cell, I list the number of times a given sub-field is observed astrometrically when the central 5x5 sub-fields have been covered with the photometric instrument.

Note that full photometric coverage does not need to be obtained "instantly." It merely means that when revisiting the same part of the sky as part of an observing program, the pointings need to be arranged such that "the next" photometric FOV will be measured. Another way of looking at this is that, presumably, one would want to fill in the hole in the astrometric coverage that arises due to the LRSI.

> *For mathematical convenience, I assume that the photometric FOV equals exactly 1/5th of the diameter (1.16°) of the astrometric instrument, or 0.232 degrees, rather than the exact size of 0.259 degrees. With this simplification, it takes exactly 25 pointings to cover the astrometric FOV with the photometric instrument. As a result, I underestimate the number of photometric observations by a factor of $(0.259/0.232)^2$ = 1.25*

From these tables, it is obvious that the number of astrometric observations per cell varies greatly. **TABLE I** below shows that after the astrometric FOV is uniformly covered by the photometric instrument, **the mean number of astrometric observations per cell equals 13.44 ± 4.14 (σ = 31%). The astrometric efficiency thus equals (13.44 observations) / (25 pointings) = 54%**, while the ratio of maximum to minimum equals three **(P2P=3)**. Note that the coverage is much more uniform in the central part of the FOV: **the central 36% of the FOV** (the 3x3 box) has: **17.77 ± 3.1 (σ = 17%), and P2P=1.6.**

1	*2*	*3*	*4*	*5*	*4*	*3*	*2*	*1*	
2	*3*	*4*	*5*	*6*	*5*	*4*	*3*	*2*	
3	*4*	**8**	**11**	**14**	**11**	**8**	*4*	*3*	
4	*5*	**11**	**15**	**19**	**15**	**11**	*5*	*4*	
5	*6*	**14**	**19**	**24**	**19**	**14**	*6*	*5*	
4	*5*	**11**	**15**	**19**	**15**	**11**	*5*	*4*	
3	*4*	**8**	**11**	**14**	**11**	**8**	*4*	*3*	
2	*3*	*4*	*5*	*6*	*5*	*4*	*3*	*2*	
1	*2*	*3*	*4*	*5*	*4*	*3*	*2*	*1*	

TABLE I *The Number of astrometric observations accumulated after the central 5x5 box has been uniformly covered by the photometric instrument. This took 25 pointings (dithers). The average & RMS number of astrometric observations equals: 13.44 ± 4.14 (σ=31%). The average Astrometric efficiency equals 54%*

More observations can be added to make the astrometric coverage more uniform. For example, one could add five pointings such that the green 5x5 area, plus twice the pointing that has as the top row the blue strip, plus twice the pointing that has the red strip as the bottom part. Adding similar sequences on all four sides of the FOV yields a total of **45 pointings, with an average of 18.88 ± 3.4 (σ = 18%), while the average astrometric efficiency equals 42%, and the P2P variation equals a factor 1.7.** Again, the central region **is much more uniformly covered with an average of: 22.5 ± 1.6 (σ = 7%), and a P2P variation of a 15%.** The resulting astrometric coverage of the central 5x5 boxes is shown in **TABLE II** below.

14	17	19	17	14
17	21	24	21	17
19	24	24	24	19
17	21	24	21	17
14	17	19	17	14

__TABLE II__ *The Number of astrometric observations accumulated after the central 5x5 box has been uniformly covered by the photometric instrument, PLUS 20 extra pointings to decrease the variation in the number of astrometric observations. For the total 45 pointings, the number of astrometric observations equals: 18.88 ± 3.37 (σ = 17.8%), the astrometric efficiency equals 42%, and the peak-to-peak variation is a factor of 1.7*

More and more pointings could be added, and when done properly, the limit would be that the central FOV would have uniform astrometric coverage, and that around this central FOV, there would be an “annulus” with an approximate width of 0.928° (4/5*FOV), where the number of astrometric observations would gradually decrease to zero.

Given the above noted inefficiencies, the number of astrometric observations listed in Table 2 of the OBSS Baseline document should be modified (at some point) for cases where deep photometry is also required. If the full astrometric FOV needs to be mapped several times with the LRSI, the 25-pointing (25P) and 45-pointing (45P) modes would modify the astrometry in those fields as follows. The total number of pointings added in “Targeted Fields, Standard Exposures” (TFDE) equals 446 minus 28 obtained in OBSS survey (25%) mode, or a total of 418. Splitting this number in groups of 25 (45) leads to 16.72 (9.3) groups in 25P (45P) mode.

> *Note: the cells in these groups do __not__ have to be observed in quick succession, although for some programs such as transit finding and determination of the orbits of short-period binaries, this may be an advantage (see section 3)*

As a result of scanning the full astrometric FOV by the photometer, the number of photometric observations equals 16.72 plus one from OBSS/25% (10.4) in 25P (45P) mode. Thus, the GAIA photometric observations will be surpassed by a factor of 17.72/7.54 = 2.35 (1.38) in 25P (45P) mode.

The reduced astrometric efficiency leads to the following number of astrometric observations in the central FOV: 28+418*0.54=254 and 28+418*0.42=204 for the 25P and 45P modes, respectively. For those cases, the attainable astrometric accuracies are reduced, with respect to the baseline, by factors of SQRT(446/254)=1.33 and 1.48, respectively. Note that such reduction of astrometric accuracy would bring the accuracies from the TFDE cadence to roughly the OBSS/100% cadence.

> *In the "Targeted Field, Deep Exposures" mode, there would just be 18.4 extra observations. Thus, in TFDE mode, only a small portion of the FOV can be mapped to the maximum photometric accuracy.*

1.2.1 Astrometric Coverage in “Survey” Modes

The “lost pointings” that result from dithering around a given point of interest appear in the fields *next to* the point of interest. Thus, if a larger field of view is of interest than a single AI pointing, then the dithers around these adjacent points of interest will add astrometric smoothness to the 1st point of interest.

> *Examples of such situations are when long narrow strips are of scientific interest such as a Galactic Plane survey.*

In this case, the relative astrometric coverage numbers are (I think), 14:19:24:19:14 for the five cells in the cross- scan direction (see *Table I*). For such a survey, the astrometric efficiency is 100%, while **N_{ave} = 18 ± 4.1 (σ = 23%), and a P2P variation of a factor 1.7.** These numbers are close to what one gets in the central 3x3 region if only a single pointing is considered (see *Table I*).

In the limit of wanting to observe the whole sky, the inefficiencies discussed above are irrelevant.

2.0 Limited Initial/Imaging Photometric Surveys (LIPS)

I suggest to perform a “photometric” survey right at the start of the observing program. Such an Initial Photometric Survey (IPS) would determine the colors of all stars so that the proper color corrections can be performed on the astrometry. Following the initial “photometric survey,” I recommend to perform, “once a year,” a limited IPS (**LIPS**) that covers, say, **30% of the sky** ($-17^{\circ} <= b <= 17^{\circ}$). [see section 3 for more details]. Such a limited survey would cover the vast majority of the stars and for those covered, would yield 5 photometric observations, so that the GAIA sensitivity is approached. Furthermore, such a coverage would allow for the photometric determination absolute the magnitudes of red giant branch (RGB) stars with an accuracy of 0.55 mag (see section 4 below).

Performing several LIPS has numerous other advantages that I bulletise below and work out in more detail in the following subsections.

1. LIPS can be used to search for transiting planets and other short period phenomena such as eclipsing binaries and variable stars
2. The LIPS survey will provide a good start for any OBSS Key Project aimed at understanding Galactic processes (dynamics, stellar properties etc.) that target the Galactic plane.
3. I estimate that the LIPS surveys would save 10.5% of the total mission time (192 days).

4. LIPS data will identify many short period astrometric binaries (12% of stars) with periods up to 150 days in the solar neighborhood (d <~ 200 pc).
    1. The data becomes available very quickly (timescale of weeks)and will provide immediate opportunity for public outreach and scientific results
    2. Traditionally, such binaries have only been discovered spectroscopically
    3. The most suitable short- period astrometric binaries can be followed up with ground- based spectroscopic observations to yield large numbers of very accurate (1%) stellar masses, luminosities and ages for stars all over the HR diagram
    4. The astrometric signal of these binaries is very large to OBSS' accuracy. If the timescales of the orbits are not resolved astrometrically, then these stars will exhibit an enormous amount of excess astrometric “noise.”
    5. The LIPS data is crucial for navigational purposes as it will eliminate the “noisy,” unreliable star.

2.1 LIPS Details

It takes about 14.1 hours to make one loop over the sky, and planetary transits require about a three hour observing epoch. Because it takes about 5 "dithers/moves" of the photometric FOV to cross the astrometric FOV, it would be possible to take one photometric observation and then skip 4 dithers in the "in scan" direction. This way, one observes only 1/5th of the annulus per loop, which takes just 14.1/5=2.82 hours to complete. After one 1th loop, one repeats the same loop 4 times such that the gaps are filled in completely after 14.1 hours.

As a result, every point in the 0.259 degree photometric strip is observed once with the LRSI, and 4 times with the astrometric instrument (AI), during a 14.1 hour "epoch," an almost perfect cadence for detection planetary transits and eclipsing binaries, with an average separation between observations of 3.52 hours.

> *In the "cross- scan" direction, on either side of the photometric FOV, there are two astrometric strips of (1.16- 0.259)/2=0.901/2=0.4505 degrees wide that are observed 5 out of 5 visits (rather than the 4 out of 5 for the photometric FOV). For these strips, the average separation is 2.82 hours.*
>
> *We also need to apply this “skip- 4” technique in the cross- scan direction such that the next 4 strips of the AI would NOT OVERLAP any of the previous AI strips. Thus, one would return the the strip adjacent to the 1st LRSI strip after 5*14.09 hr = 2.93 days.*

In this scenario, OBSS would generate five 14.1 hour observing epochs separated by about three days to form a **"super-epoch"** of duration 5*2.93= **14.65 days**. During this period, **one LRSI** observation and **24 AI** observations would be obtained.

The effectiveness of such a survey for planetary transits will be evaluated some time in the future. But, from experience, it seems that this cadence would be quite effective in finding short-period periodic events. Of course, OBSS' major obstacle to finding planetary transits is its limited dynamic range for this particular application.

2.2 Astrometric LIPS

Astrometrically, it may also beneficial to have a number of observations stacked up in a two-week period. 1st) It will produce a 1st epoch observation with a precision of roughly 1/5th of a single-measurement, so that accurate long-term proper motions can be obtained immediately in combination with Hipparcos, GAIA and/or SIM data. 2nd) During this time of intense astrometric sampling, all short-periods astrometric binaries (P <~ twice the super-epoch duration, about 30 days) will be recognized as such. That is to say, if the semi-major axis of the photocenter exceeds the detection threshold. These short period binaries make up ~6.8% of all stars. Repeating the LIPS "once per year" yields a period of 5*14.65=73¼ days of frequent sampling, so that the orbits of binaries with periods up to 146½ days can be determined. Such binaries make up 12% of all stars.

Because the parallax effect is virtually zero during a two-week period, the orbital elements of such short period systems will roll-out fairly easily and quickly.

> *Note that this LIPS survey will be performed in 25-fold (5-times in X & 5-times in Y) overlap mode as far as the AI is concerned. Thus, this survey will also allow an accurate calibration of the astrometric instrument.*
>
> *Assuming that the 5 observations obtained in each 14.1 hour epoch can be averaged, the per-epoch accuracies are 120/SQRT(5.0)=53.7 μas, while the per-superepoch accuracies are 120/sqrt(25)=24 μas.*

Using these values for the astrometric accuracy, and the methodology developed in my "Astrometric Detection of Cold Jupiters" paper (Olling 2005), I find that for primaries of 1 M_{SUN}, all such short-period binaries within a distance of d_{RES} parsec will be resolved at the 10-sigma (3rd & 5th columns of *TABLE III*) or 5-sigma (4th & 6th columns) level. The results are tabulated in *TABLE III* below. *Note that "resolved at the 5-sigma [10-sigma] level" means that the semi-major axis of the orbit of the primary around the center-of-mass exceeds 5*24=120 (10*24=240) μas.*

TABLE III		**M_{PRIM} = 1 M_{SUN}**			
		M_{SEC} = 0.1 M_{SUN}		**M_{SEC} = 0.25 M_{SUN}**	
Period Range	Fraction of Binaries	d_{RES} [10-σ]	d_{RES} [5-σ]	d_{RES} [10-σ]	d_{RES} [5-σ]
[days]	[%]	[pc]	[pc]	[pc]	[pc]
0.1 – 1	1.26	5.7	11.4	13.1	26.2
1 – 2	0.68	9.0	18.1	20.8	41.6
2 - 4	0.88	14.3	28.7	33.0	66.0
4 - 8	1.11	22.8	45.6	52.4	104.8
8 - 16	1.39	36.2	72.4	83.2	166.4
16 - 32	1.70	57.5	115.0	132.1	264.2
32 - 64	2.05	91.2	182.6	209.7	419.4
64 - 128	2.43	144.8	289.6	332.9	665.6
TOTAL **/ AVERAGE**	***11.5***	**41.8**	**83.6**	**96.1**	**192.2**

Thus, depending on the period and mass of the secondary, short-period GV binaries will be recognizable as such out to distances of 10s to 100s of parsec, covering a wide magnitude range. Thus OBSS will be significantly efficient in discovering "spectroscopic binaries." In fact, these systems will be visual binaries as well if their secondary is not too faint. Of course, these systems are all very important for the determination of accurate stellar masses across the Hertzsprung-Russel diagram, as well as for catalog construction and hence navigational purposes.

3.0 The OBSS/25 Survey

The standard OBSS/25 Survey mode calls for scanning the skies in survey-like manner for a period of 1.25 years (456 days). Given that 260 days would have been used already for the 1st LIPS, 196 days remain. During this time, the number of astrometric observations collected equals: 0.95 * 196*86400/36.5 * 1.16^2 / 41,253 = 14.4 per star, summing to a total of 22.5+14.4=36.9 Also, the photometric instrument would observe 14.4*5% =72% of the sky a second time.

3.1 LIPS and MIPS as an Alternative to OBSS/25 ?

Instead, it seems that it would be better to repeat the LIPS "once a year," but limited to, say, 30% of the sky where the vast majority of stars are located (-17^o <= b <= 17^o). Such a small IPS (SIPS) would take 78 days (30% of the the full IPS duration [=260 days]).

> *To avoid observing the same part of the sky in the same part of the year, the exact start/end times of these LIPSs would have to be chosen with some care.*

In practice, it might be better to perform mini IPS (MIPS) sessions, where a MIPS is designed with photometric coverage and temporal characteristics in mid. To retain the astrometric integrity of the astrometric solution, MIPS would probably need to be alternated with astrometric "scans" perpendicular to the Galactic plane (Zacharias 2005, private communications). Scans perpendicular to the Galactic plane are also required for studies of the determination of the vertical dark matter density profile of the Milky Way. Such a program would require quite a bit data out off the plane (~2,000 OTUs, or ¼ of the time allocated to targeted studies). Thus, it seems that a self-consistent "scanning law" might be set up that satisfies both the scientific requirements and the astrometric needs.

> *Given OBSS constraints on observing time, I estimate that the vertical structure of the disk of the Milky Way is best studied by observing a limited number (say 8) of great circles going through both Galactic poles. The great circles would be approximately 22.5 degrees apart. The width of these strips would be 1 FOV. Such a project would cost about 2,000 OTUs. At this point, it is unclear is such an observing strategy would satisfy the astrometric requirements of grid stability.*

After 5 years of operation and 5 LIPS, the total amount of time spent in LIPS mode equals 260+4*78=572, or **31% of the total observing time**. A full IPS survey, in the ± 17 degree area, would yield five LRSI and 5*22.5 = 112.5 AI observations.

> *The resulting number of astrometric observations is very close to that what would be obtained for a dedicated (100%) OBSS survey, but at a cost of only 30% of the total observing time, and at a cost of only 30% of sky coverage.*

The resulting astrometric accuracies from the LIPS survey will indeed be quite good, hovering around **13 μas** for 11.5 <= V <= 15 (Table II of OBSS baseline). In fact, the accuracies of the LIPS survey compares well with the GAIA survey, in the region of overlap. Thus, because the accuracies of the GAIA and LIPS data are comparable, their data can be sensibly combined to produce a longer baseline for the detection of interesting astrometric variables such as long-period binaries and extra-solar planets.

3.2 Cost Savings Resulting from LIPS

For those OBSS (Key) Projects that are (in large parts) dedicated to studies of the Galactic Plane region (e.g., the Galactic Velocity Field, the Galactic Mass distribution and the shape of the dark matter distribution), the number of additional observations required is reduced significantly because the LIPS data would provide 112 observation, rather than the 28 provided by OBSS/25. In fact, to reach the goal of 8 μas as in the TFSE mode, only $(13/8)^2$=2.64 times as many observations would be required as collected in the LIPS. Thus, a saving of 446-(2.64*112)=150 observing time units (OTUs), or 33% is achieved.

If 50% of OBSS' targeted mode is spent in the Galactic plane area, LIPS would provide a time saving of 16.5 percent of the total mission time. Since LIPS costs 6% more than OBSS/25, the total saving are 10.5% of the mission time, or 192 days.

Again, note that astrometric integrity perpendicular to the Galactic plane could be maintained by data obtained under an OBSS Key Project aimed at determining the vertical distribution of dark matter in the Milky Way.

3.3 Summing Up

The proposed LIPS/MIPS scenario would comprise an initial OBSS survey phase (IPS) that is designed with special attention to the temporal cadence and fully mapping the sky with the LRSI. This part would take 260 days.

After that, the LIPS/MIPS would be used to “scan” the 30% of the sky closest to the Galactic plane on average once a year to obtain 5-fold photometric coverage, and to obtain (at mission-end) astrometric data for the full Galactic plane with an accuracy comparable to an OBSS/100% survey or to the anticipated GAIA results.

Such LIPS/MIPS need to be interwoven with surveys stretching to high galactic latitudes so as to maintain astrometric integrity of the “global solution.” This data could be obtained as part of the OBSS Key Project that aims to determine the vertical structure of the Galactic disk.

4.0 Astrophysics with the LRSI

The science requirement for OBSS' LRSI call for an average photometric *accuracy* of 3.9 mmag in a 7-band system, for a single 16.5 second photometric observation. Such would be the case for the standard (astrometric) OBSS observing strategy.

An accuracy of 3.9 mmag translates to the ability to determine the stellar surface gravity [log(g)] with an accuracy of 0.25 dex (Olling, 2003, FTM2003-01). Such an accuracy is the current state of the art for the determination of log(g) from high-resolution spectra.

> *High-res spectra are not required to determine log(g) or the other astrophysical parameters. To determine these parameters at lower resolution (e.g., with a 7-band system) merely requires higher signal-to-noise ratios [Bailer-Jones 2000, A&A, 357, 197]. If more bands are used, the photometric error per band can be smaller [Bailer-Jones 2000, A&A, 357, 197], as long as the 7-band equivalent requirement is reached.*

The log(g) accuracy of 0.25 dex allows for a fairly accurate determination of the location of a star in the HR diagram. On the Giant Branch, a variation of log(g) of 0.25 dex amounts to an uncertainty of 0.55 magnitude in M_V. Although this uncertainty seems large, remember that the most common red giants can have luminosities anywhere between $M_V=4$ and $M_V=-2.5$, while the most luminous supergiants can reach $M_V=-8.5$. Thus, on the red giant branch (RGB), an accuracy of 0.55 in M_V translates to a dynamic range in M_V of 6.5/0.55=11.8, while an uncertainty of 0.55 magnitudes translates to a photometric-distance uncertainty of 30%.

> *On the main-sequence, early G-type stars (1.1 M_{SUN}) experience a change in log(g) of 0.5 dex during their MS lifetime of ~6 Gyr, so that an error of 0.25 dex in log (g) will allow an age determination of ~3 Gyr.*

Distant RGB stars play a crucial role in the OBSS science goals since these stars are among the brightest and most abundant stars in any stellar population (young or old). Therefore, these are the targets of choice for many studies of the Milky Way halo and the Galactic disk.

For OBSS, useful photometric parallaxes (better than 30%) will always be worse than the astrometric parallaxes. This is in contrast to the FAME mission, where accurate photometric parallaxes would extend much beyond the astrometric distance limit.

> *In the MW halo (no extinction), a 30% parallax error for a $M_V=0$ RGB star occurs at a distance of 30 kpc (V=21.0) [assuming OBSS Targeted Standard mode]. In the galactic disk, with 1.5 mag of extinction per kpc, this accuracy occurs at a much closer distance (5.0 kpc and V=17.4). Both magnitudes are well beyond the magnitude where the OBSS photometry can deliver 30% photometric parallax errors (V=15 for a single exposure). If a full LIPS is implemented with five photometric exposures, then OBSS would reach V=16.4*

The current OBSS LRSI instrument is baselined to have 16 bands with an average photometric error of about 6 mmag per band at V=15, *for "a single" 16.5 second integration* (Dorland 2005, private communication). This is equivalent to 6/SQRT(16/7)=3.97 mmag in a 7-band system. Thus, the OBSS LRSI instrument seems to be able to deliver good astrophysics down to V=15, assuming a single 16.5 second exposure. However, given the experience with photometric accuracies for the planetary transits, I am worried about saturation effects for the photometry.

4.1 Required Accuracy & Saturation

For simplicity, assume that an accuracy of 6 mmag in the 16-band system corresponds to a S/N of $(1/0.006)^2$ =166.6, leading to a requirement of at least $(S/N)^2$ = 27,777 detected photons. About 50% of the bands will have significantly better accuracies of 1.5 mmag [3 mmag] for late-M [late G] stars leading to 444,000 [111,000] photons (Dorland 2005, private communications). This number of photo electrons is well above the photometric-saturation limit of the detector (~110,000 e^-) for late-M stars, and is just about feasible for late-G and earlier stars.

Thus, it appears that the minimal brightness limit (6 mmag accuracy) coincides with the photometric-saturation limit. That is to say, there are (virtually) no stars for which there are enough unsaturated photons to reach the 0.25 dex accuracy requirement in log(g)

> *Note that, as for the case of planetary transit photometry, the dynamic range restriction is independent of integration time. It just depends on the number of detected photons per integration. Changing the integration time just shifts the magnitude where the requirement is met, which still happens to be the magnitude where saturation occurs.*

The above calculations assume that **all** detected photons end up in a single pixel, which is approximately the case for the LRSI which is under sampled by a factor of four (160 mas pixels versus 40 mas pixels for the fully sampled PSF of the AI). The “saturation problem” could be avoided/relaxed by several means:

) Relax the science requirement

Relaxing the log(g) accuracy to 0.5 dex still provides reasonable accuracy on the RGB (1.1 mag or a dynamic range of a factor of 6.5/1.1=5.9), while all discriminatory power on the MS is lost. Such a requirement translates to δV_7=14 mmag, or 9.3 mmag for the 16-band system. This requires 11,560 photons in the average band, and 46,248 e^- for those bands with the best S/N. Note that accuracies of 9.3 mmag can (almost) be achieved by ground-based systems.

This "solution" creates a dynamic range of 110,000/46,248=2.3, or about 0.95 magnitudes (V in [14.05,15.0]) at no extra costs.

2) Employ the LIPS strategy

This will yield 5 observations for most stars, so that a dynamic range of a factor of 5 (1.7 mag) is achieved.

This “solution” comes at no extra cost, but the range in magnitudes over which precision astrophysics can be performed is rather limited

3) Linearly Slew during LIPS operations

For example, slewing by 100 pixels during an exposure will create stellar trails 100 pixels long. On the bright end, photometry will be hardly affected because read noise is small as compared to photon noise. At the faint end, slewing will loose a bit.

Astrometrically, slewing slowly during the LIPS will turn a nice pointy PSF into a stellar trail that can be astrometered in (at most) one dimension

4) Employ full sampling of the PSF.

In this case, the Peak_flux to Total_flux ratio is about 0.107 [Sinc^2 PSF], so that a Total_flux of 110,000 (3 mmag at V=15) leads to a peak flux of 11,800. In this case, the dynamic range equals 110,000/11,800=9.3, or about 2.4 magnitudes.

The cost of this solution would be to increase the size of the photometric CCDs by a factor of $4^2=8$ to restore full sampling

5) A combination of (1), (2), (3) and (4)