Some Possible Science with OBSS, V1.1

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Several OBSS Key Projects come to mind:

1) Mapping out the Proper Motion Field of the Galactic Plane
   The preferred mode of operation is the "Targeted Fields: 15 sec"
2) Determining the (radial) mass distribution of the Milky Way
   The preferred mode of operation is the "Targeted Fields: 15 sec"
3) Determining the vertical mass distribution of the Milky Way
   The preferred mode of operation is the "Targeted Fields: Standard"
4) Mapping out the Proper Motion Field of the Galactic Halo
   The preferred mode of operation is the "Targeted Fields: Standard"
5) Determining the Proper Motions of our Galactic Neighbors
   The preferred mode of operation is the "Targeted Fields: Deep"

Below I assume that the above 5 projects together can count on about 5,250 "square degrees" of targeted observations. For the sake of simplicity, I assume that each "pointing" yields 1 deg^2 of useful astrometric data. [The field is actually 1.16x1.16 deg = 1.35 deg^2, while 5% is devoted to the photometric instrument. Thus, in the analysis presented below, I overestimate the number of required pointings by 28%.]

Some of the Key Projects proposed here will benefit greatly from alternative observing schemes as those proposed in the Baseline Document. This is most easily described in terms of the Observing Time Unit (OTU) analogous to the system proposed by Dorland (2005). For convenience, I define the OTU as the time spent to perform one observation in the "Targeted Field: Standard Exposures," (TFSE) excluding the contribution from the OBSS-Survey/25%. Thus, one OTU comprises (446-28)=418 observing sequences of 1.5 and 15 seconds, plus two readout times of 10 seconds each. The total cost then amounts to 36.5 seconds per "observation." The additional schemes I'd like to introduce are: "Targeted Fields: 5 seconds Only," or TF05S, and "Targeted Fields: 15 seconds Only," or TF15S. Both schemes are specialized modes: the first one for projects where stars at intermediate brightness are most important, the second one for projects aimed at faint objects only (the short exposure data could be recovered from the GAIA database, if it were to be published). The cost of an TF05S unit is 15 seconds, or 0.411 OTUs (a saving of 58.9%), and the cost of an TF15S unit is 25 seconds, or 0.685 OTUs (a saving of 31.5%).

The "Targeted Fields: Deep Exposures" (TFDE) are only used for Key Project #5: the proper motions of the Local Group Galaxies.

#1 would cover 460 deg^2, and would cost 315 to 460 OTUs
#2 would cover 1,440 deg^2, and would cost 986 to 1,440 OTUs
#3 would cover 2,672 deg2, and would cost 1,098 to 2,672 OTUs
#4 would cover 500 deg^2, and would cost 500 to 500 OTUs
#5 would cover 1,200 deg^2, and would cost 1,080 to 1,500 OTUs
---TOTAL---- 6,572 deg^2, and would cost 3,980 to 6,500 OTUs

- @1) Several aspects of the dynamics of the disk of the Galaxy are of importance
  - To determine the first order the rotation curve [V(R)] of the Galaxy, as derived with the assumption of a azimuthally symmetric velocity field. That is to say, the rotation curve due to an azimuthally symmetric mass distribution [M(R,z)] in radial distance from the Galactic center [R] and height above the plane (z)
  - To determine the azimuthal (phi) dependence of V(R). Azimuthal perturbations are expected to arise due to "additional physics." Among others, the bulge/bar in the inner Galaxy, spiral density waves, interactions with neighboring (dwarf) galaxies, warps et cetera. Thus, V(R,phi) will tightly constrain each physical model that includes more than just the simple M(R,z) mass model of the Milky Way.
    - Of course, these "additional physics" terms are very interesting as they relate to other parts of astrophysics
      - Bar formation is poorly understood, yet the bars and the bulges in which they reside are the parts of spirals with the largest surface brightness. It is those parts that are picked up in surveys of high-redshift galaxies
      - The origins of spiral structure are not fully understood: galaxy images taken at blue to near-IR wavelengths show that apparent spiral structure is in large part due to the large number of young/bright stars formed in the arms. Again, at large redshifts, these bright spiral arms may be mistaken for separate galaxies.

    If spiral arms are formed due to propagating star formation, then the spiral arms could be "massless." On the other hand, radial velocity measurements indicate that spiral arm streaming motions up to 30% of the rotation speed exist, indicating rather massive spiral arms.
  - To determine the small-scale (local) velocity field of the Milky Way. That is to say, look for coherent structures in phase space that are not caused by global effects. Such structures could be disrupted galactic clusters or cannibalized galactic neighbors.

- @2) Of course, no one really knows the stellar mass distribution in galaxies since we only measure the projected light distribution of the ensemble of stars. The light distribution is typically dominated by giant stars (or early type MS stars), which make up only a small fraction of the stellar mass. Measured parallaxes, luminosities and colors of stars yield approximate stellar masses, and allow for the distinction between main-sequence stars and giants. Thus, for the first time, a “direct” measurement of the radial mass distribution can be made.

- @3) The vertical mass density distribution of the Milky Way is key to understanding the dark matter density distribution. Stellar motions vertical to the Galactic plane (in the z-direction) are sensitive to the total mass distribution [$\Sigma_{tot}(z)$]. Subtracting the contributions of luminous matter (stars & gas) yields the dark matter profile. The Milky Way galaxy is the only galaxy where this can be done. The current state of the art is that $\Sigma_{tot}(z)$ is determined to $\pm$ 10% out to about 1.1 kpc. A better determination of $\Sigma_{tot}(z)$ allows for a much better determination of the dark matter distribution and it's shape.

- @4) The Galactic Halo is an important part of the Milky Way because it is thought to be the oldest part of the Milky Way and it's detailed measurement will reveal important clues as to the origins of our Galaxy. Also, the dynamics of the halo stars can determine the exact radial dependence and shape of the potential out to tens of kpc. Thus, the Galactic halo stars offer one of the few possibilities to study in detail the three-dimensional distribution of dark matter in galaxies.

- @5) The proper motions, combined with radial velocities, of our Galactic neighbors tell us a great deal about the formation history of the Local Group, and hence about the very interesting period of the history of the universe during which a gravitational instability formed, collapsed and formed individual galaxies. Such in in-situ study of the dynamics of a small group of galaxies is very important for modelers of galaxy formation. Currently, they seem to have a hard time to form groups such as the MW/M31 pair and their dwarf companions.

Practicalities & Possibilities

- @1) The Proper Motion Field of the Galactic Plane: For this project, a large number of tracer stars, spread out over as large a part of the Galaxy and out to as large distances as possible are required. Also, color and extinction information is important to be able to separate extincted early-type MS stars from less-obscured late-type giants. This is important because early-type MS stars “follow the dynamics of the gas from which they were recently born.” As such, they measure, in large parts, the dynamics of the interstellar medium (ISM). The late-type giants on the other hand are a mixture of young and old stars, where the old stars have been bopping around long enough in galactic potential to have lost the dynamical imprints of their births, or so it is assumed.

- The majority of stars on the giant branch reside in the region of the red clump, around M_V=0: they are of type KIII. Main-sequence stars with similar luminosities are A-type. These two populations trace out the Galaxy to similar distances, where the AV's are young and the red clump giants (RCGs) are a mixture of young and old.
  - The parallax error requirements are of order 10%
  - In the tables below, I translate the scientific proper motion requirements to a position requirement because the OBSS capabilities are stated in terms of positional accuracies. To do so, I use the fact that the proper motion accuracy is approximately given by: $REQ_{PM} \sim (\sqrt{2} * REQ_{POS}) / T_{MISS}$, where REQ_{POS} is the equivalent position requirement, and T_{MISS} the mission duration. With T_{MISS}=5 years, REQ_{POS} = 3.53 REQ_{PM}.
  - The proper motion requirements are to measure 1/10th of the amplitude of galactic rotation (6 mas/yr) at an accuracy of 10%. Thus the pm requirement is to measure 600 muas/yr, independent of distance, with an accuracy of 10%
  - **The parallax requirements (Plx.Req.) and position requirements (Pos.Req.) listed in the tables below are the required parallax and position values, divided by ten. That is to say, I assume that those values need to be determined to an accuracy of 10%.**
  - The combined effects are listed in ***Table I*** below for an average extinction of 1.5 mag per kpc. The Δ_{OBSS} values OBSS' mission accuracies achieved in various modes (copied/interpolated from Table 2 of the OBSS Baseline, v0.20). The "strike through" entries do not satisfy either the parallax or the position requirements.

TABLE I (*A_V=1.5*D*) *(DISK)* *D [kpc]*	***V*** *M_V=0* *[mag]*	*Δ_{OBSS}* ***SURVEY***	*Δ_{OBSS}* ***TFSE***	*Δ_{OBSS}* ***TFDE***	***Plx.Req.*** *[μ'']*	***Pos. Req.*** *[μ'']*
1.0	11.5	24.0	8.0	24.0	100.0	212.1
2.0	14.5	24.5	8.0	21.0	50.0	212.1
3.0	16.9	30.8	9.0	24.9	33.3	212.1
4.0	19.0	~~71.4~~	18.1	~~35.0~~	25.0	212.1
5.0	21.0	~~229.3~~	~~56.8~~	~~40.0~~	20.0	212.1
6.0	22.9	~~320.0~~	~~81.0~~	~~73.8~~	16.7	212.1

TABLE I **(*A_V*=1.5*D)** ***(DISK)*** ***D [kpc]***	***V*** ***M_V=0*** ***[mag]***	Δ_{OBSS} ***SURVEY***	Δ_{OBSS} ***TFSE***	Δ_{OBSS} ***TFDE***	***Plx.Req.*** ***[μ"]***	***Pos. Req.*** ***[μ"]***
7.0	24.7	~~N/A~~	~~N/A~~	~~187.9~~	14.3	212.1

For favorable lines of sight, with low extinction of, say, ½ mag/kpc, ***Table II*** is appropriate.

TABLE II ***(DISK)*** ***(A_V=½*D)*** ***D [kpc]***	***V*** ***M_V=0*** ***[mag]***	Δ_{OBSS} ***SURVEY***	Δ_{GAIA}	Δ_{OBSS} ***TFSE***	Δ_{OBSS} ***TF15S***	***Plx. Req.*** ***[μ"]***	***Pos. Req.*** ***[μ"]***
1.0	10.5	33.0	9.8	10.0	7.6	100.0	212.1
2.0	12.5	24.0	10.3	8.0	7.6	50.0	212.1
3.0	13.9	24.0	12.3	8.0	7.6	33.3	212.1
4.0	15.0	25.0	18.4	8.0	7.6	25.0	212.1
5.0	16.0	~~29.0~~	~~28.0~~	9.0	7.6	20.0	212.1
6.0	16.9	~~30.8~~	~~42.5~~	9.0	8.6	16.7	212.1
7.0	17.7	~~40.0~~	~~63.4~~	11.1	12.4	14.3	212.1

The tables above show that an abundant tracer such as red- clump giants can be used out to roughly 5 kpc, where a cadence similar to “Targeted Standard” is most suitable. At the solar circle, the RCG surface density equals about 4,000 stars/kpc^2, so that there are 314,000 RCGs within 5 kpc from the Sun. Working with an average extinction of 1.5 magnitude per kpc in the Galactic plane, at distances of 1, 2, 3, 4, and 5 kpc, the interstellar extinction has reddened the stars by 0.48, 0.96, 1.45, 1.93 and 1.41 magnitudes, respectively [at 2 kpc, an AV star has the color of a KIII star.] Thus, it is crucial to know the extinction between the target star and ourselves so as to be able to assess the true nature of the star. Without that knowledge, the sample definition is poor, and the results will be degraded. Some help can be obtained from the 2MASS data since the extinction at K-band is roughly ten times smaller than in the V band.

If we assume that the 460 deg^2 are to be used for this project, I would use 360 deg^2 to “survey” the whole “Galactic plane” to get the azimuthal behavior of the Galaxy. This survey can be taken either along *b*=0, or possibly at latitudes where the local extinction is somewhat smaller to achieve longer lines of sight. However, the effects of such a selection procedure on the expected quality of the determined velocity field of the Milky Way will need some significant amount of further study.

Special parts of the Galaxy need extra coverage, such as the Galactic center, the Galactic anti- center and the directions of rotation and anti-rotation. For those areas, I would put a 5x5 box, or a total of 20 extra fields on these special positions to cover a continuous region in both longitude and latitude. In this scenario, one extra field remains to be allocated. Additional interesting points are of course the Galactic poles, which could both be sampled with 3x3 boxes leaving 7 deg^2 in reserve. Alternatively, the SDSS SEGUE fields could be chosen.

The preferred mode of operation is the "Targeted Fields: Standard," or 31.5% "cheaper," the TF15S mode.

- @2) <u>The (radial) mass distribution of the Milky Way:</u> To determine the azimuthal dependence of the radial mass distribution [M(R,phi)] of the Milky way, there are already 4 positions that sample 25 deg^2 at 90 degrees separation in longitude. I would additionally sample the four points at the 45^o locations. Al all those positions, I suggest to take 10 degree strips (80^o in total), with additional pointings at higher latitudes, say at ± ½, 1½ , ... 9½ degrees or 20 additional strips. The total number of fields would be 80*20=1,600 pointings of which 80+4*20=160 have already been taken for program #1, so that 1,440 new pointing remain.

  Although this seems quite a large amount of mission time spent, it is a quite important project: by sheer counting stars as a function of position, distance and "color," we will obtain an exhaustive inventory of the stellar content, and hence the mass to light ratio of the Milky Way disk. Furthermore, the significant range in longitude covered allows us to probe both arm and inter- arm regions for several different arms, thus eliminating the risk that only "special" regions of the Milky Way are probed. Probing the vertical extend of the disk is required so as to obtain not only a good estimate of the local stellar *volume* density, but also of the total *column* density [10^o at 3 kpc extends to 520 pc, or to about twice the vertical scaleheight of the (old) disk].

  Using AV stars and RCGs, the radial distribution can be checked for very young stars as well as for a mixture of young and old giant stars. To survey a representative sample of long- lived main- sequence stars, we need to look at late F or early G type MS stars, let's say G0V, with absolute magnitude of M_V=4.4, for which the magnitude- distance tables needs to be revised to ***Table III*** and ***Table IV*** below, with 1.5 and 0.5 mag/kpc of extinction, respectively. Inspecting Tables III & IV, it appears that for early G-type main- sequence stars to be observed in the Galactic plane, a practical distance limit is 3 to 4 kpc. Note that the GAIA distance limit is roughly 1 kpc, so that the OBSS database yields about 12.5 times more G dwarfs with accurate distances than GAIA. *OBSS makes these accurate distance measures over 80 degrees in longitude, as compared to GAIA* *over 360 degrees. I thus expect OBSS to net approximately three times as many GV's with parallax errors less than 10% than GAIA in the strip extending ±10 degrees from the Galactic plane.*

***TABLE III* (Disk, GV) (A_V=1.5*D) D [kpc]**	***V M_V=4.4 [mag]***	***Δ_{OBSS} SURVEY***	***Δ_{GAIA}***	***Δ_{OBSS} TFSE***	***Δ_{OBSS} TF15S***	***Δ_{OBSS} TFDE***	***Plx.Req. [μ″]***
0.125	10.1	33.0	9.8	10.0	7.6	33.0	800.0
0.25	11.8	24.0	9.8	8.0	7.6	24.0	400.0
0.5	13.6	24.0	11.1	8.0	7.6	21.0	200.0
1	15.9	28.6	26.8	8.9	7.6	23.0	100.0
2	18.9	~~67.9~~	~~122.7~~	17.3	22.8	34.5	50.0
3	21.3	~~277.8~~	~~580.6~~	~~69.7~~	~~99.6~~	~~40.0~~	33.3

However, there is a difference between the OBSS and GAIA performance that goes beyond a simple comparison of number of targets. The GAIA data will reach just beyond the closest spiral arms, while the OBSS data may reach just beyond the **2nd** spiral arm. Thus, because the GV stars cover the whole range of stellar ages, it will be possible to assess whether the spiral arms are truly spiral density waves (stars of all ages participate [with an amplitude depending on their velocity dispersion] in the wave), or that spiral arms are just a wave of star formation (only the youngest stars participate in the wave). Since this test can be made over several arm segments, the differentiation between massive and massless spiral structure can be definitively made employing the OBSS data.

Note that to do so, radial velocities of all these GV stars will be needed. *This is so because the degree of participation of stars in a spiral density wave depends on velocity dispersion of the ensemble. And since a large range in longitudes is covered by the data, the proper motion data will yield a longitude- dependent fraction of the radial velocity dispersion (the component that matters).*

TABLE IV ***(Disk, GV)*** ***(A_V=0.5*D)*** ***D [kpc]***	***V*** ***M_V=4.4*** ***[mag]***	***Δ_{OBSS}*** ***SURVEY***	***Δ_{GAIA}***	***Δ_{OBSS}*** ***TFSE***	***Δ_{OBSS}*** ***TF15S***	***Δ_{OBSS}*** ***TFDE***	***Plx.Req.*** ***[µ"]***
0.125	10.0	33.0	9.8	10.0	7.6	33.0	800.0
0.25	11.5	24.0	9.8	8.0	7.6	24.0	400.0
0.5	13.1	24.0	10.3	8.0	7.6	21.0	200.0
1	14.9	24.9	17.7	8.0	7.6	21.0	100.0
2	16.9	30.8	42.7	9.0	8.6	24.9	50.0
3	18.3	~~50.4~~	~~86.9~~	13.5	16.6	31.4	33.3
4	19.4	~~91.0~~	~~166.1~~	22.8	~~30.1~~	~~36.6~~	25

The preferred mode of operation is the "Targeted Fields: Standard," or 31.5% "cheaper," TF15S.

- @3) The vertical mass distribution of the Milky Way: the vertical distribution requires mapping to higher z- values than the 8 selected areas of Key Projects #1 & #2 accomplish.

  So I propose to image 8 great circles (through the Galactic poles and the 8 selected longitudes of Key Project #2), which require 8*360=2,880 fields. However, 21 degrees are already done at the Galactic plane (KP2), and 5 degrees at each of the poles (KP1), leaving just 8*(360- 21- 5) =8*334=2,672 new deg^2. As follows from ***Table V*** below, the most useful observing mode is TFSE, but because "Targeted Fields: 5 seconds Only" only takes 41.1% of the time of TFSE, and the distance difference is just 1 kpc, I'd suggest to use the TF05S mode. Because most observations will be taken at high Galactic latitude with very low extinction, I will assume ZERO for simplicity.

TABLE V ***(Σ_{tot}(z) GV)*** ***(A_V=0)*** ***D [kpc]***	***V*** ***M_V=4.4*** ***[mag]***	***Δ_{OBSS}*** ***SURVEY***	***Δ_{GAIA}***	***Δ_{OBSS}*** ***TFSE***	***Δ_{OBSS}*** ***TF05S***	***Δ_{OBSS}*** ***TFDE***	***Plx.Req.*** ***[µ"]***
0.25	11.4	25.75	9.80	8.40	5.90	25.75	400.0
0.5	12.9	24.00	10.30	8.00	5.90	21.30	200.0
1	14.4	24.40	14.70	8.00	5.90	21.00	100.0
2	15.9	28.59	26.80	8.90	7.30	23.70	50.0
3	16.8	30.56	~~40.50~~	9.00	11.10	24.78	33.3

TABLE V ***($\Sigma_{tot}(z)$ GV)*** ***(A_V=0)*** ***D [kpc]***	***V*** ***M_V=4.4*** ***[mag]***	***Δ_{OBSS}*** ***SURVEY***	***Δ_{GAIA}***	***Δ_{OBSS}*** ***TFSE***	***Δ_{OBSS}*** ***TF05S***	***Δ_{OBSS}*** ***TFDE***	***Plx.Req.*** ***[μ"]***
4	17.4	~~35.79~~	~~54.40~~	10.13	14.90	~~26.94~~	25.0
5	17.9	~~42.41~~	~~70.40~~	11.64	19.50	~~29.43~~	20.0

Comparing the expected results delivered by GAIA versus those by OBSS, I note that OBSS will reach 2.5 higher from the galactic plane to over 5 kpc. This height comprises 17 vertical scaleheight of the old disk population and roughly 5 scaleheights of the thick disk. Thus, the vertical *mass* distribution of both of these populations will be be extremely well determined.

Furthermore, because the vertical profiles are determined at a range of distances from us, our understanding of the vertical profile will be enormously better with the OBSS data obtained in a limited longitudinal regime than with the GAIA data covering the whole sky. For example, at a distance of d_P=1 kpc (in the plane), the GAIA data will reach a distance of about 2.5 kpc, or a height of z=SQRT($2.5^2 - 1^2$)=2.3 kpc. OBSS at the same d_P=1, will reach up to 4.9 kpc. At d_P=2, we get z_{GAIA}=1.5 kpc and z_{OBSS}=4.6 kpc, and at d_P=4, z_{OBSS}=3 kpc, which is about 10 times the disk scale-height.

The preferred mode of operation is the "Targeted Fields: Standard," but the TF05S mode is almost as good, while the observing cost is much smaller.

- @4) Structure and Dynamics of the Galactic Halo: As for tracing the dynamics of the disk, red-clump giants comprise a prominent tracer population. In contrast to disk studies, the extinction towards the halo is close to zero magnitudes per kpc, with a total of maybe 0.1 mag towards the Galactic poles. As an approximation, I will use A_V=0 mag/kpc. Furthermore, the random motions in the halo are much larger than in the disk: about 200 km/s, so that an experimental velocity error of 1/10th of ½ of 200 km/s, or 10 km/s is sufficiently accurate to study halo dynamics. That is to say, the halo dynamics on large scales. To study tidal streams, which have rather small internal velocity dispersions of just a few km/s, the requirements to identify the members of such streams are quite a bit tighter. Finally, because the stellar population is rather homogeneous in the halo, and due to the absence of significant extinction, photometric parallaxes are much more reliable in the halo than in the disk. Thus, I estimate that the availability of astrometric parallaxes are less crucial to the understanding of the halo dynamics than they are for unraveling the dynamics of the disk. I would thus propose to only impose a proper-motion requirement, and not a parallax cutoff. With these assumptions, I arrive at the equivalent of Tables I & II for the halo. In this table, I use an "outline" format to indicate which entries do satisfy the 10 km/s requirement set by the halo dynamics, but which fail the more stringent tidal-stream membership requirement of about 1 km/s. Thus, red-clump giants can be used to out to about 150 kpc to accurately trace the dynamics and distribution of the large-scale structure of the Galactic halo, and out to about 32 kpc to establish definite membership of tidal streams.

TABLE VI ***(HALO)*** ***(A_V=0)*** ***D [kpc]***	***V*** ***M_V=0*** ***[mag]***	***Δ_{OBSS}*** ***SURVEY***	***Δ_{OBSS}*** ***TFSE***	***Δ_{OBSS}*** ***TFDE***	***Plx.Req.*** ***[µ"]***	***Pos. Req.*** ***[µ"]***
1	10.0	33.0	10.0	33.0	~~100.0~~	7,458.9
2	11.5	24.0	8.0	24.0	~~50.0~~	3,729.5
4	13.0	24.0	8.0	21.0	~~25.0~~	1,864.7
8	14.5	24.5	8.0	21.0	~~12.5~~	932.4
16	16.0	29.0	9.0	24.0	~~6.3~~	466.2
32	17.5	37.3	10.5	27.5	~~3.1~~	233.1
64	19.0	72.3	18.3	35.1	~~1.5~~	116.6
128	20.5	~~176.5~~	43.6	39.5	~~0.8~~	58.3
145	20.8	~~206.0~~	51.0	39.8	~~0.7~~	51.4

The preferred mode of operation is either "Targeted Fields: Standard," or "Targeted Fields: Deep." The latter is only recommendable if color information is not required for the studies.

- @5) <u>Proper Motions of our Galactic Neighbors:</u> Space motions in the Local Groups of galaxies are of order 100 to 300 km/s (½ to √2 times the Galactic rotation speed). These space velocities correspond to about 2,500 and 30 µas/yr for the nearest (8 kpc) and most distant (2 Mpc) of the Local Group galaxies (LGGs). I will use a requirement that a velocity of 100km/s needs to be determined with an accuracy of 10%.

  Stars at the tip of the red-giant branch (TRGB) are typically most prominent among the brightest stars in young and old galaxies. Their absolute magnitude is roughly M_V=- 2.5, and I assume that we will need to detect stars at M_V=- 1.5, to get a large enough sample of stars to be able to do determine the proper motion of the galaxy. With these assumptions, I use the compilation by Mateo (1998, ARAA, 36, 435) to investigate the magnitude, distance and proper motion distribution of 40 LGGs (including M 31, NGC 55, NGC 3109, IC 5152).

The total area of these systems is about 1000 square degrees, most of it spent on the LMC (453 deg^2), Sextans A (179 deg^2), the SMC (127 deg^2), M 31 (100 deg^2), Sculptor (40 deg^2) etc. Note that these surface areas include a safety margin of a factor of two. However, the median galaxy area is just 0.6 deg^2, so that most galaxies will do with just a single OBSS pointing for the astrometry, and 15 pointings for the photometry (as compared to 32 pointings to map out the whole FOV).

The results are plotted in the left- hand column of figure I, while the right- hand panels give the estimated proper motion as a function of distance (top) and magnitude (middle). Also plotted are the capabilities of OBSS in it's various operational modes: 100% Survey (red dotted line), 25% Survey (green dashed line), Targeted Fields, Standard exposures (blue dot- dashed line), and Targeted Fields, Deep Exposures (TFDE; cyan full line). The lines with the shape of the TFDE experiment are derived assuming that 1, 10, 100, 1000, and 10,000 stars are observed per galaxy for the full, dotted, dashed, dashed- dotted and dashed- double- dotted cyan curves. Some interesting galaxies are indicated by name. How likely is it to find enough TRGBs in a given galaxy? The answer is hard to give since it depends on the mass, type and distance of the galaxy. However, finding several thousands of such stars is not impossible as can be inferred from the Mendez et al. (2002, AJ, 124, 213) data, which lead to about 100, 300, 1800, 2500, 2500 and 1000 TRGBs in the following galaxies: Leo I (260 kpc), Sextans B (1.34 Mpc), NGC 3190 (1.27 Mpc), UGC 7577 (2.5 Mpc), NGC 1313 (4.1 Mpc) and UGC 6456 (4.3 Mpc)].

For all cases, it is assumed that the proper motion of the galaxy needs to be determined to 10 percent accuracy. Using more than one star per galaxy can be achieved by either: 1) centroiding all resolved stars separately and taking the weighted average, or 2) by stacking those stars on top of each other, and then performing the centroiding analysis. the distance- magnitude- propermotion relations for TRGB stars are presented in ***Table VII*** below.

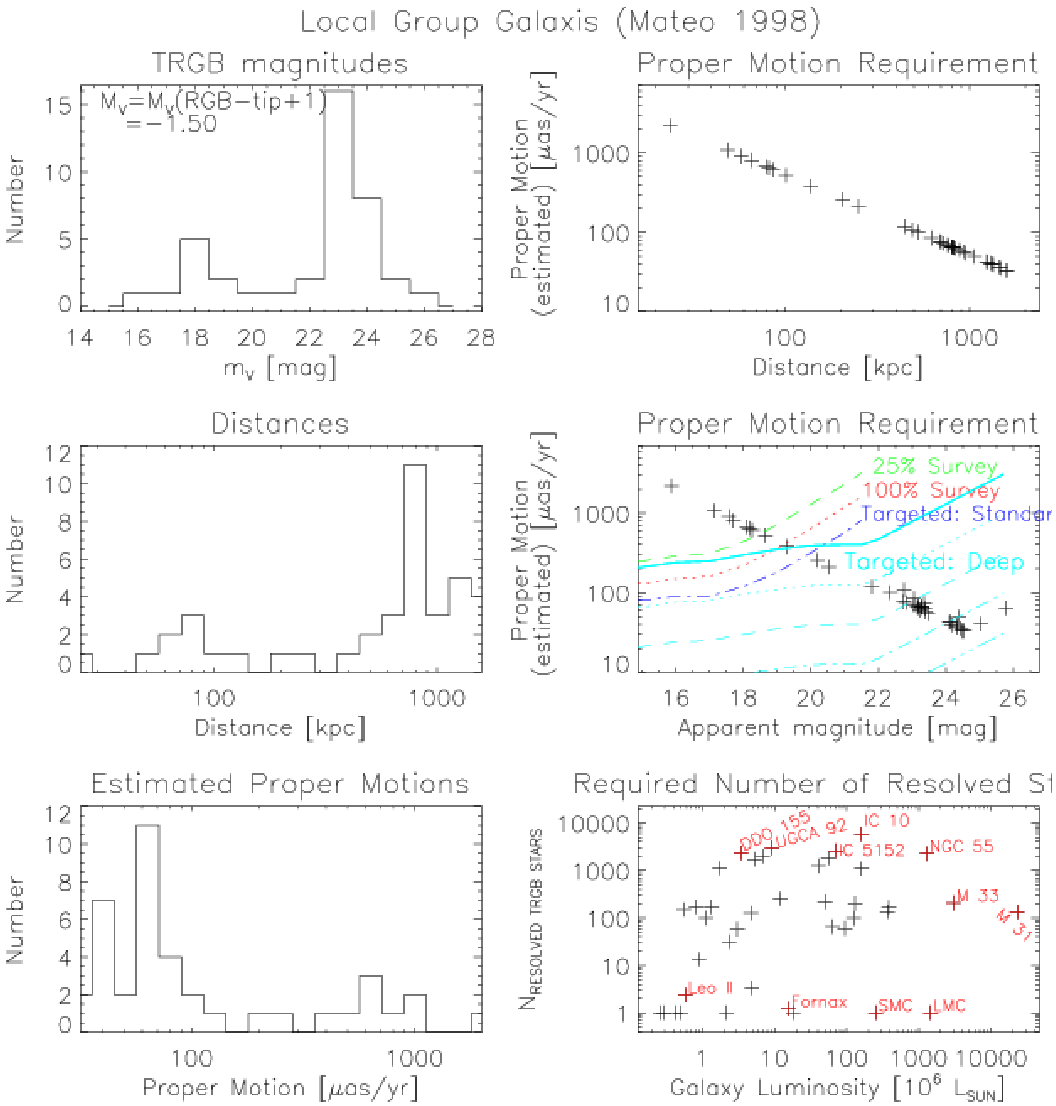

Figure 1: Properties of Local Group Galaxies

TABLE VII (Local Group Galaxies) *(A_V=0)* ***D [kpc]***	***V*** ***M_V=- 1.5*** ***[mag]***	***ΔOBSS TFDE (N=1)***	***ΔOBSS TFDE (N=100)***	***ΔOBSS TFDE (N=10 ³)***	***ΔOBSS TFDE (N=10 ⁴)***	***Pos. Req. [μ"]***
8	13.0	21.0	2.1	1.4	1.4	932.4
16	14.5	21.0	2.1	1.4	1.4	466.2

TABLE VII ***(Local Group Galaxies)*** ***(A_V=0)*** ***D [kpc]***	***V*** ***M_V=- 1.5*** ***[mag]***	***Δ_{OBSS}*** ***TFDE*** ***(N=1)***	***Δ_{OBSS}*** ***TFDE*** ***(N=100)***	***Δ_{OBSS}*** ***TFDE*** ***(N=10^3)***	***Δ_{OBSS}*** ***TFDE*** ***(N=10^4)***	***Pos. Req.*** ***[µ'']***
32	16.0	24.0	2.4	1.4	1.4	233.1
64	17.5	27.5	2.8	1.4	1.4	116.6
128	19.0	35.1	3.5	1.4	1.4	58.3
256	20.5	~~39.5~~	4.0	1.4	1.4	29.1
512	22.1	~~48.1~~	4.8	1.5	1.4	14.6
1024	23.6	~~103.4~~	~~10.3~~	3.3	1.4	7.3
2048	25.1	~~222.4~~	~~22.2~~	~~7.0~~	2.2	3.6

The preferred mode of operation is the "Targeted Fields: Deep"

Alternatively, one may use luminous O & B-type main-sequence or supergiant stars (Olling & Peterson, 2000, astro-ph/0005484) with masses of around 25 M_{SUN} and absolute magnitudes around M_V=-6 (equivalent to 60 TRGB stars) or the most luminous supergiant stars (M_V~-8.5) or globular clusters (equivalent to 400 TRGB stars) or even the cores of the galaxies themselves (Shaya 2005, private communications). However, such bright stars or stellar systems are rare. For example, a practical upper limit to M_V for supergiants is of order -8.5 (the actual value depends on the size of the galaxy [small-number statistics]), while several 100 supergiants may be found with -5 < MV < -8.5 or so (Sohn & Davidge, [1996, AJ, 112, 2559; and 1998, AJ, 115, 130]). Globular Clusters attain similar brightness: the Globular Cluster Luminosity Function (GCLF) has a mean absolute magnitude of M_V=-7.4 and a dispersion of about 1.3 mag (Harris, 1991, ARAA, 29, 543) while the number of GCs per galaxy may be 175 (Chandar et al., 2004, ApJ, 611, 220). Thus, the number of GCs significantly brighter than M_V=-8.5 is rather small (maybe several dozen).

In summary, at an absolute magnitude of M_V=-7.5, there seems to be reasonably large number (10's to 100's) of luminous supergiant stars and/or globular clusters. Thus, for the further analysis, I will assume an absolute magnitude of M_V=-7.5

For these more distant galaxies, members of the Local Super Cluster, it is reasonable to relax the proper motion requirement somewhat, say to 500 km/s, because the expected velocities are larger. For example, the infall velocity of the Local Group towards the Virgo cluster is about 1,000 km/s.

The resulting requirements and OBSS deliverables are tabulated in ***Table VIII*** below. This table indicates that a practical limit to obtaining significant proper motions will be about 10 Mpc, or just short of the Virgo Cluster of galaxies at 16 Mpc. However, the cluster galaxies are predominantly ellipticals, which are more massive than spirals and will hence have more globulars (and a larger dispersion in the GCLF), so that the likelihood of brighter GCs also increases. [For example, inspecting data tables in "*Allen's Astrophysical Quantities*," I find that the brightest Ellipticals in the Virgo cluster have ~3,000 GCs per galaxy, with M87 (the central cD) 13,000]. Thus, I expect that both the internal motions and the systemic proper motion of the Virgo cluster will be measurable with OBSS. The Elliptical in the Fornax cluster, at a similar distance as Virgo, have about 10 times fewer GCs, so that the internal motions can not be measured, while the central cD galaxy (NGC 1399) has about 5,300: sufficient to determine it's proper motion.

TABLE VIII ***(Local Super Cluster)*** ***(A_V=0)*** ***D [kpc]***	***V*** ***M_V=- 7.5*** ***[mag]***	***Δ_{OBSS}*** ***TFDE*** ***(N=1)***	***Δ_{OBSS}*** ***TFDE*** ***(N=10)***	***Δ_{OBSS}*** ***TFDE*** ***(N=100)***	***Δ_{OBSS}*** ***TFDE*** ***(N=3,000)***	***Pos. Req.*** ***[μ"]***
256	14.5	21.0	6.64	2.10	1.41	145.68
512	16.1	24.1	7.60	2.40	1.41	72.84
1,024	17.6	27.6	8.74	2.76	1.41	36.42
2,048	19.1	~~35.2~~	11.14	3.52	1.41	18,21
4,096	20.6	~~39.6~~	12.51	3.98	1.41	9.11
8,192	22.1	~~48.6~~	~~15.38~~	~~4.86~~	1.41	4.55
16,384	23.6	~~104.5~~	~~33.04~~	~~10.45~~	1.91	2.28

The galaxies in the local supercluster (including the Virgo and Fornax clusters) would add 100's of galaxies, albeit small ones. Given that these distant galaxies represent the single most important class of OBSS targets that are completely inaccessible by any other mission, I would propose to spend more time (equivalent square degrees) on this group of galaxies to maximize the science result for this group. This is particularly important since obtaining the required photometry [GCs and supergiants are identified in (multiple) color- color plots] takes a significant amount of overhead in the "Targeted Fields: Deep Exposure" mode.