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# OBSS/A & NASA's Origin's Research Topics: A Detailed Comparison

## 1) OBSS Science: Introduction

The OBSS mission will revolutionize the understanding of our origins. This is possible because OBSS will, for the first time, bring high accuracy (˜1%) to virtually all fields of Astrophysics, including most of the "Origins" research topics.

The key features of the OBSS mission is that it employs several types of near-simultaneous measurements, all at very high accuracy. These types of measurements are: A) position measurements, B) broad-band photometry, C) spectral measurements and D) temporal variation of (A), (B) and (C). The physical properties [T_eff, [Fe/H], log(g)] of stars will be determined from (B) and (A). While an accurate catalog of one of these properties would be useful, the synergy of them allows for a revolutionary increase of astrophysical knowledge.

To understand our origins, it is crucial to have knowledge of the HISTORY (or EVOLUTION) of: galaxies formation rates, the star formation activity, the chemical abundance of the interstellar medium (ISM), stellar luminosities, the abundance of extra-solar planets.

Now that WMAP has determined H_0 and the density parameter Omega, we we can easily determine the ages of distant (high redshift) galaxies. However, the available angular resolution and sensitivity limits our understanding of the processes going on in these distant systems. As a result, the Origins Processes (OPs) described above are hard to infer.

On the other hand, the very same physical processes can be studied in great detail in our own Milky Way, after we have determined stellar ages to reasonable precision. After all, the evolution of the Origins Processes is recorded in the physical properties of the stars of the Milky Way. For example, the formation rate of the Milky Way's thin disk, thick disk and spheroid can be recovered from "simply" counting the number of stars as a function of stellar age. Likewise, the chemical evolution of the MW's stellar populations and interstellar medium follow from analyses of the (distribution of) abundance as a function of stellar age.

### 1.1) High Resolution Galactic Evolution

Determining stellar ages has been notoriously difficult, mostly because the physical parameters of (ALL-1) stars are poorly determined. The most important parameters for determining stellar age are mass (M), luminosity (L), radius (R), distance (d), effective temperature (T_eff), Helium abundance (Y), metallicities ([Fe/H]), and surface gravity [log(g)]. Except for the Sun, there are no stars for which all these physical parameters are known at the percent level. As a result, it is very hard to determine accurate absolute ages of stars other than the Sun.

OBSS will very accurately (1%) determine distance and luminosity for a very large number of stars (1 to 3 million GV, KV and MV stars each, as well as one million FV, 100,000 AV and 10,000 BV stars). Most of these stars are brighter than V=15, so OBSS's multi-color photometry will be used to determine T_eff, [Fe/H] and log(g) to reasonable accuracy (2%, 0.1 dex, 0.25 dex).

The remaining parameters can be determined for a small subset (0.86%) of detached eclipsing binaries (DEBs). The OBSS sample of DEBs allows for an accurate determination of _ALL_ physical parameters for these stars, and hence also their absolute ages. The radius of these stars follows from time-resolved photometry, and their masses from ground-based spectroscopic follow up. This sample of DEBs will be the Rosetta Stone for stellar evolution, as these stars will allow for an accurate (at the percent level) and self-consistent calibration of the models of stellar structure and evolution, and stellar atmospheres (spectra). Even the Helium abundance can be inferred for many DEBs, where Y can not be determined spectroscopically. With the assumption that the two components of the DEBs are coeval and have the same Y values, in the vast majority of circumstances, there will be only one combination of age and Helium abundance for which the two components will have the observed mass, luminosity and radius. This procedure is being tested on Hipparcos DEBs, but none of them have the required astrometric accuracy.

Current stellar evolution models tell us that luminosity changes steadily during main-sequence evolution at a rate of about [(10+2*L/L_Sun) +/- 5] percent per Gyr. Thus, for a Sun-like star that is member of a DEB, a 1% distance (2% luminosity) error corresponds to an age accuracy of delta_tau=2/12*1000=167 Myr. This sample of DEBs allows us to unravel the evolution of the Origins Processes at high temporal (and spatial) resolution.

From the thin disk, thick disk and halo we expect the following numbers of DEBS measured at the 1% accuracy level (A_V=1 mag/kpc assumed):

| SPT | dist [pc] | V_max [mag] | Thin disk | Thick disk | Spheroid | per_star_ delta_tau [Myr] | |
|---|---|---|---|---|---|---|---|
| BV | 490 | 7.7 | 100 | 0 | 0 | 1 | travel ~1 pc @ 1 km/s |
| AV | 490 | 10.6 | 1,110 | 0 | 0 | 49 | |
| FV | 490 | 11.9 | 9,260 | 0 | 0 | 122 | |
| GV | 490 | 13.4 | 26,870 | 1,660 | 49 | 172 | |
| KV | 370 | 14.6 | 26,980 | 1,530 | 44 | 194 | + ~1 Galactic rotation |
| | | | 65,290 | 3,190 | 93 | --- | |
| MV | 230 | 15.5 | 22,610 | 1,140 | 31 | 198 | DO NOT USE |
| RGB | 488 | 8.2 | 990 | 65 | 2 | - | + DO NOT USE |
| | | | 87,900 | 4,400 | 125 | | |

A first application would be to determine the ages of the three stellar components:

* 1% of the thin disk stars ( 653) yield: Delta T_TnD = 7.6 Myr
* 33% of the thick disk stars (1,063) yield: Delta T_TkD = 6.0 Myr
* 100% of the spheroid stars ( 93) yield: Delta T_TkD = 20.1 Myr

For the long-lived stars, a maximum age of 13 Gyr for the Milky Way corresponds to 65 consecutive epochs of 200 Myr, where 200 Myr also approximately equals the dynamical time of the MW.

Note that the age of the Universe as determined by WMAP is accurate to approximately 200 Myr, so that the OBSS stellar ages will place significant constraints on cosmological models.

Note that the age determination of _individual_ stars is less accurate at lower astrometric accuracies: delta_tau \propto delta_astrometry. However, as the number of DISK stars increases approximately as delta_astrometry^2, ensembles of stars at larger distances can still yield good age determinations [assuming 1/SQRT(N) holds].

Thus, the evolution of the Origins Processes of more distant parts of the Galaxy can still be studied at the resolution of a dynamical time, albeit that statistical tools need be employed.

## 1.2) Low Resolution Galactic Evolution

Stellar ages can also be determined for individual stars, albeit more crudely. Stellar masses can be determined from individual stars from the Stefan-Boltzmann law, and Newton’s law of gravity:

M_star = g * L / (4*PI*G*sigma * T_eff^4) ,

with g the acceleration, L luminosity, G Newton’s constant and sigma the Stefan-Boltzmann constant. Error analysis shows that stellar masses can be determined to several percent if g, L and T_eff are determined at the percent level. Such can only be done after the stellar evolution/atmosphere models have been calibrated by the DEB sample. Even so, the MS lifetime is a strong function of initial mass:

LOG(tau_MS) ~ 0.94 - 3.77*LOG(M_star) + 1.18*LOG(M_star)^2

so that for 1 solar mass star, a 5% error in the mass determination amounts to a 20% error in the MS lifetime.

Another approach would be to determine the age as a function of directly observable parameters only: age = f( T_eff, L, log(g), [Fe/H]). Such approach will probably work in some parts of parameter space, but most likely not everywhere.

## 1.2) Observing Strategy

OBSS has a unique observing strategy that aims at maximizing the number of observations under the constraint of accurate mission-end astrometry. With a rotation period of 60 minutes and a precession period of 20 days, every point on the sky is observed about twenty times in a 2-3 hour period every precession period, on average.

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- - Now let’s look at individual Origins Research Topics -
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- - OBSS/A & NASA’s Origin’s Research Topics -
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Research Area 1:

Investigation 1:

- [Fe/H] and Helium abundance Y will be measured as a function of stellar age and stellar population (thin and thick disks and spheroid). Extrapolation to t=0 will yield the most accurate [Fe/H] and Y values. The details of Y(t) and [Fe/H](t) at early epoch will place strong constraints on the enrichment due to the first generation of stars. Also, extrapolating Y to t=0 can be compared with the cosmological prediction.

Investigation 3:

- The assembly history of our own Milky Way will be determined at high temporal resolution.

- The 125 spheroid stars reveal the star formation rate of halo DEBs at a resolution of ~200 Myr. The sub-group of ~28 stars with 0.5% astrometry could push the temporal resolution down to 100 Myr.

- The Thick disk: The formation of the thick disk can be studied in some detail via the temporal variation of the number of DEBs, their composition, as well as their dynamical properties (average rotation speed, velocity dispersion, streaming motions). The larger number of thick disk stars allows for even higher temporal resolution: 1000 (250) [15] DEBs @ delta_tau=100 (50) [20] Myr

- The thin disk: The evolution of the Milky Way's thin disk can be studied in great detail due to the large number of stars (88k) with ages accurate to ~200 Myr. A very interesting application is to look for periods of enhanced star formation, for episodes where the kinematics of the stars formed deviates from "the norm," indicating possible Galactic cannibalism.

The evolution of the physical properties of the Milky Way proceeds at the dynamical time. In the past, when the Galaxy was smaller, the dynamical time was shorter. If stars formed during these initial phases are in the immediate solar neighborhood, OBSS data allow for a probe into the earliest phases of thin-disk formation at a resolution as low as 20 Myr.

| delta_pi | delta_tau | N_DEB |
|---|---|---|
| 1.00% | 200 Myr | 88k |
| 0.50% | 100 Myr | 23k |
| 0.25% | 50 Myr | 5k |
| 0.1% | 20 Myr | 400 |

Research Area 2:

Investigation 4:

- The expose on the formation history above also tells us the Galactic evolution of the chemical elements directly, rather than trying to infer it from observations of distant galaxies.

- At lower temporal accuracy, more distant parts of the Milky Way can be studied statistically to yield results at approximately the same age resolution.

Investigation 5:

- Thus, the radial dependence of the star-formation history and chemical evolution of the Galaxy can be studied in great detail. This data will allow the determination of the evolution of the Galactic Habitable Zone.

Research Area 3:

Investigation 6:

- OBSS will determine distances to and ages of nearby star formation regions to high accuracy.

Investigation 7:

- The Galactic Extinction Map generated from the OBSS data will allow us to look for regions of high extinction without current star formation. Studies of many such regions will reveal the process of star formation in the pre-protostar phase.

Research Area 4:

Investigation 9:

Investigation 10:

- The OBSS mission will search for planets employing two techniques: 1) the photometric detection of planetary transits, and 2) the astrometric detection of the reflex motion of the parent star.

The photometric signal of a planet transiting the disk of the parent star is directly related to the (square of) ratio of the radii of star and planet. The case of HD 209458b (a planet with Jupiter-like diameter transiting a Sun-like star) may be typical with an eclipse depth of about 1% (10 milimagnitudes). Folding the geometrical probability for an edge-on orbit with the probability that a star has a close-in extra-solar giant planet (ESGP), one expects that about one out of every 1000 stars will show planetary-transit events.

If we require a 5 sigma detection per focal-plane transit, we can
* detect such transits down to R=13.5, or for about 16 million stars. About 55% of these stars are MS stars, and about 50% of the MS stars have low enough intrinsic variability that planetary transits can be detected: we end up with 4.4 million suitable target stars, and about 4,400 target stars with transits.

Folding the the OBSS scanning law with the distribution of ESGP period distribution, we expect to detect more than two (three) transits in about 60% (40%) of these systems. That is to say, for of order 2,000 stars will OBSS detect a planetary transit.

These detection will be secure with:

- about nine 5-sigma detections during ~2 hours (the approximate duration of the transit)
- two or more repeats
- about 120 "out-of-transit" observations.

Many more systems will be detected where the companion is not a ESGP but rather something else such as grazing stellar transits or brown dwarfs. These systems will be weeded out with the radial velocity instrument, as the radial velocity signal is 10-1000 times larger for a star-star systems than for star-planet systems.

-Astrometrically, the per-epoch astrometric accuracy is about 200 muas for all star brighter than V=14.5 (~30 million stars). To _determine_ a planetary orbit we demand a per-epoch 5-sigma detection capability, so that the astrometric signature must exceed 1 mas.  To _detect_ the presence of an ESGP, we can relax the threshold by a factor of two.

- (Both criteria are rather crude and can be refined, which I've done for the Maryland poster for AMEX. However, I need to redo the calculations with the OBSS scanning law & magnitude limits. This exercise will also predict an actual number of planets. This will take some time).

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-Thus: Detection out to: d < 12 (T_5yr/M_tot)^(2/3) * M_planet [pc]
-Thus: Orbit     out to: d <  6 (T_5yr/M_tot)^(2/3) * M_planet [pc]
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Research Area 5:

Investigation  11:

OBSS will provide a target list for the further study of about 1000 transiting ESGPs, brighter than about V=14 and closer than 600 pc (300 brighter than V=11 and closer than 300 pc).  OBSS will provide the astrophysical parameters of these stars, including a stellar age. The OBSS targets are significantly closer and brighter than the KEPLER detections, allowing much easier follow up. OBSS will also screen all nearby potential SIM & TPF targets for massive ESGPs in long-period orbits.

Research Area 6:

Investigation 12:

-The presence of massive planets on near-circular orbits in planetary systems stabilizes the orbits of Earth-mass planets. Also, such massive planets can/will eject asteroids creating a system less dangerous for intelligent life.

Also, the orbit(s) of (a) massive planet(s) determine potential locations of the habitable zone (where the perturbations are minimal), so that the OBSS ESGPs will pre-screen planetary systems for TPF & SIM observations.

Investigation 12:

-Thus, with the OBSS data, we can determine in which planetary systems there is "room to live." That is to say, where one might find a habitable planet.

Additional Science

1) Solar System Objects:

- The excellent temporal characteristics make OBSS an ideal instrument to detect Earth-Crossing asteroids when they are actually close to Earth, and hence bright (see Hill & Leonards,1995, AJ, 109, 401). Current searches tend to look for Potential Hazardous Asteroids (PHAs) at opposition (when they are far from Earth, faint and have small proper motions).

- !!!!CORRECTED in V3!!!! The Etendu=A*Omega metric (collecting area times field of view) for OBSS (=2.2 m^2 deg^2) is substantial smaller than that of PANSTARRS-PS1 (=20 m^2 deg^2) or LSST (=350 m^2 deg^2). However, the "daily" field of view [A*Omega] for OBSS equals 77,760 deg^2 [58,320 m^2 deg^2] as compared to 6,000 [15,270] and 20,000 [1,082,000] for PANSTARRS & LSST, respectively

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- "Area" observed  per day
  Omega_OBSS_day = (  1 degree X-scan                      ) *
                   (360 degrees/spin                       ) *
                   ( 24 spins/day                          ) *
                   (  3 detections/focal plane crossing) *
                   (  3 FOVs                               )
                = 77,760 square degrees per day
- Per Precession Period (PP=20 days)
  Omega_OBSS_PP = Omega_OBSS * 20 days = 1,555,200 deg^2

- At 45 deg sunangle, 70% of sky is observed per PP, so that
  N_obs_day_PP = 1,555,200 / (0.7*41,253) ~ 54
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- It is estimated that about 6,000 NEO’s larger than 100 meters come to within 0.06 AU of the Earth, every year, or about 16.4 per day, while it takes about 20 days for a NEO at 10 km/s to approach from and recede to 0.06 AU. In 20 days, OBSS precesses once around the Sun-spacecraft vector sweeping out the whole sky except the Sun-centered and anti-Sun-centered caps, each with a radius of 45 degrees. Thus, OBSS scans about 70% of the sky per precession period. However, a simplified sensitivity calculation (see below) indicates that OBSS can detect such whizzing NEOs only in 33% of the time, or in a total of 23% of the sky.

- Thus, OBSS has a NEO detection probability of ˜23%. Thus, to 1st order, it takes 1/0.23=4.3 years (less than the OBSS mission duration) to detect ALL >100 meter NEOs.

- During a focal plane passage (three CCD transits) the NEO will have moved at least 33 pixels, and it’s 1D proper motion will be known to 0.15%. Due to OBSS’s scanning law, such a NEO will be observed about 20 times during a two hour period, allowing for many confirmations. After the 1st (last) possibility for confirmation at 15 minutes (2 hours) the NEO has moved 90 (720) arcseconds, and is still well within OBSS’s FOV: it’s 1D pm will be very well determined indeed: to one part in 29,000 (230,000).

- OBSS can detect and determine the proper motion of the fast moving NEARs when they are closer than about 0.06 AU. At this distance, a 100 meter NEO with an albedo of 20% has a brightness of V <= 18 at a sunangle of >˜ 100 degrees. It’s proper motion between 200 and 300 arcsec/hr will smear this brightness over ˜16 pixels (6.7 PSFs), so that the effective point source brightness equals V <= 20. Such a NEO is easily detectable by OBSS: the per-trail measurement accuracies are: 6 mas (1/30th of a pixel) astrometric and 0.05 magnitudes.

- Extraction of these events from the data stream will require special processing.

2) Galactic Astrometry
More later

3) Extra-Galactic Astrometry
More later