OASIS: Optical All-sky Space Imaging Survey
Astrophysics

Overview:

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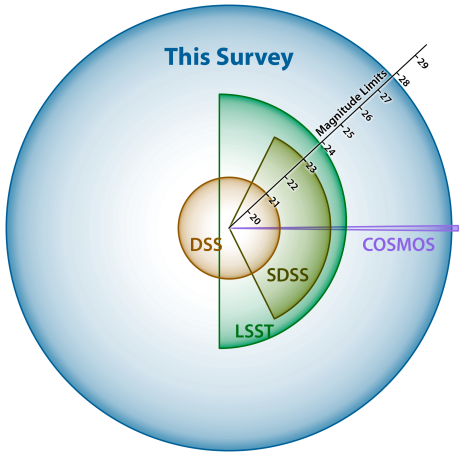
The mission will produce a high spatial resolution, multispectral image of the entire sky, with an accompanying multiband catalog including high quality photometry, astrometry, and synoptic information.

Will allow mapping of the dark matter distribution via weak lensing, measure the proper motion of stars throughout the Milky Way, enable complete studies of the detailed morphological information of all galaxies to a redshift of 3, and detect asteroids and Kuiper Belt Objects within the Solar system. Almost unlimited utility as a general resource for high resolution astronomy.



OASIS offers the best of all existing and planned surveys, for the entire sky:

•20,000x greater area than the largest surveys with this resolution and depth (from HST)
•100x greater depth and 10x greater spatial resolution than existing surveys of similar area (from the ground).

Description:

All-Sky, Multiband Optical/Near-UV Survey
0.1 arcsecond imaging with 30 minute total integration in multiple epochs.
Spacecraft slews to step and stare during orbital segments.

Sun-Synchronous Polar Earth Orbit.
3500kg spacecraft+payload.
Agile attitude control using control moment gyros.
2.1 square degree camera with 24 CCDs and field flatteners.
6 filters from 2000-9000 angstroms.
5-7 year mission lifetime.

TRL-7 or higher throughout – most systems in current flight S/C.
Potentially human repairable if manned polar launch capability exists.

Value to NASA:

Proposed mission cuts across multiple goals for astrophysics in the NASA Strategic Plan. These include:

- The Formation and Evolution of Galaxies
- The Galaxy-Black Hole Connection
- The IGM and Dark Matter
- Exploring the Milky Way and its Neighbors

Benefits include:

- High citation count, lasting science yield
- Relatively low risk design
- Low cost of operations
- Critical synergy with astronomical landscape in 2020s

OASIS: Optical All-sky Space Imaging Survey

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Primary Concept Goal Category: Astrophysics

Abbreviated Concept Summary: We propose a deep, high spatial-resolution space-based all-sky survey at six optical/ultraviolet wavelengths. The 2.4m telescope will be wedded to a dedicated, multiband camera and launched into a sun-synchronous polar Earth orbit. Over a 5-7 year mission, a complete image of the entire sky in multiple bands will be made. No other dataset will possess the simultaneous characteristics of high spatial resolution, depth, completeness, synoptic (time) and multiwavelength coverage. The data will have an immeasurable impact on astronomy for the next several decades. It will no longer be necessary to compete for vanishingly scarce or non-existent space telescope resources - the entire sky, everywhere, will be already mapped and available for all researchers.

Goal of the Proposed Application:

The primary data product from the mission will be a complete map of the sky at six wavelengths from 2000-9000Å. The data will have a spatial resolution of 0.1", photometric accuracy of 1%, and astrometric precision of 0.02". In addition, a complete catalog of all objects seen by the survey will be produced, along with derived shape parameters, etc. These will be produced by a science center, and delivered to the public through both a web and application programming interface (API).

Benefits of the Application:

OASIS is inspired by the unparalleled science legacy of the Palomar Observatory Sky Survey (POSS), followed in recent decades by the Sloan Digital Sky Survey (SDSS), and eventually the planned Large Synoptic Survey Telescope (LSST). In comparison to these ground-based surveys, OASIS offers:

• *Spatial Resolution* – All existing and planned future optical surveys of remotely similar areal extent are ground-based (POSS, SDSS, LSST). By being in space, OASIS offers an increase in spatial resolution of a factor of 10-20.

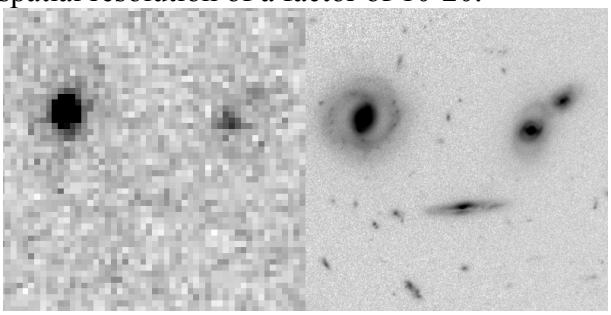

Figure 1 – A Sloan Digital Sky Survey image (left) compared to the same area of sky taken with HST/ACS at r-band (6000Å) and with the same spatial resolution and depth as OASIS (right). In addition to the vastly greater depth, the space-based data's superior spatial resolution reveals the detailed internal morphology of the galaxies.

• *Area/Completeness* – No survey with comparable spatial resolution exists with this angular scale. HST has performed areal surveys, but the largest (COSMOS) covers an area of only 2 square degrees. OASIS will cover the entire sky, i.e. 20,000 times more. Existing HST areal surveys are plagued by "cosmic variance", i.e. the underlying inhomogeneity in the galaxy distribution due to large-scale structure. OASIS would sample the sky on all angular scales.

• *Depth* – each individual image would reach a depth of 27.2 (AB) at 6000Å, and 27.8 when coadded. This is 100x deeper than the deepest existing sky survey (SDSS). The planned ground-based LSST project would reach similar depths, but only when all data are coadded, and would never possess the spatial resolution nor all-sky coverage.

• *Wavelengths Inaccessible from the Ground* – From space, OASIS has access to wavelength regimes inaccessible from the ground. OASIS will carry a near-uv filter extending to the usable blue range of the CCD detectors. The only competing all-sky survey at these wavelengths is GALEX. OASIS offers a 50-fold increase in spatial resolution and five magnitudes (100x) of additional sensitivity.

Science Directly Enabled — Many investigations flow directly from the unique

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OASIS dataset, some of which we highlight here:

• *Detailed Galaxy Morphology* – galaxies at high-z are typically a few arcsec in diameter. Ground-based surveys cannot resolve them, and lack the sensitivity to image their low surface brightness regions. Figure 1 illustrates dramatically that OASIS will do both, and with multiple colors will distinguish stellar populations within the galaxies. Galaxies evolve differently in different density environments, the details of which constrain the physical parameters of the universe. Studies to date focus on the densest clusters; OASIS will allow these studies in *all* environments.

• *Astrometric/Synoptic Surveys* – by staggering the coverages in each filter in the correct order, a synoptic component on year timescales can be added. Additionally, the polar overlap regions will be imaged once every few hours. With the planned depth and precision of OASIS, proper motion and parallax could be measured for all objects within 25 pc. This would include L&T-dwarfs, Kuiper Belt Objects, and others.

• *Ultradeep Field* – OASIS will produce the deepest optical image of the sky. The ecliptic poles are imaged every orbit. This will result in two ~1 square-degree regions with an accumulated equivalent of 1500 HST orbits in each band, or 10x deeper than the Hubble Ultradeep Fields, over a 1000x greater area. This allows a direct probe of the universe to z=6 and at least 2.5x fainter on the luminosity function than existing surveys.

• *Weak Galaxy Lensing* – analysis of the statistical changes in the shapes of galaxies allows mapping of the true (baryonic+dark) matter distribution of the universe. This is notoriously difficult from the ground due to the poor and variable spatial resolution resulting from atmospheric turbulence. Demonstrated on small scales from space, OASIS will allow this analysis for the entire sky. Understanding the relative spatial distribution of baryonic matter (stars) from dark matter is crucial to constraining galaxy formation models.

The Science Multiplier Effect — Sky surveys are one of the highest science-yield per dollar missions. For example, the SDSS is as cited as HST and the other great observatories, producing ~1500 citations per year. HST is oversubscribed by ~10:1. Access to it is a significant throttle on astronomy: most projects never acquire time, and if they do the yearly proposal process enforces a years-long time lag. OASIS would significantly unleash this pent-up demand. This is particularly important in the 2020s, when HST is likely to be non-functional but JWST and particularly LSST are operational. The flow of new discoveries from LSST will completely overwhelm a pointed space observatory; only a sky survey like OASIS will be capable of providing the supporting imaging needed to complement and enhance the new discoveries .

Top-level Description of the Design, Operation, and Results: The OASIS mission concept draws heavily from our past experience with space-based all-sky surveys such as WISE & GALEX, ground-based optical large-area synoptic surveys such as the Palomar Transient Factory, and space-based optical/UV imaging from HST. We also considered design studies for WFIRST and SNAP, and the capabilities of current Earth observing satellites such as GeoEye.

The science instrument is enabled by the development of wafer-scale CCDs. The baseline design consists of twenty-four STA1600B detectors (10560x10560, 9 μm pixel pitch, 4-edge abuttable) paving the usable area of the focal plane, and providing 2.1 square degrees of imaging with 0.1 arcsec/pixel (similar to that of HST/ACS) and a readout time in seconds. Although we lack the actual prescription for the primary and secondary mirrors, we anticipate an additional field-flattening mirror and transmissive

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foreoptics will be necessary. A rotational shutter mechanism will be employed. A filter exchanger will hold 6 filters, (baseline standard ugriz), as well as one shorter wavelength near-UV filter. A more detailed design study will examine the feasibility of using dichroics to allow spectral multiplexing, i.e. having two identical cameras observing simultaneously in a red and a blue filter.

The spacecraft will be placed in a polar, sun-synchronous Earth orbit similar to those used by previous sky surveys such as WISE. Data will be taken in a slew-survey mode akin to that used by GALEX, IRAS, and others. Each orbit, the spacecraft sweeps a circle orthogonal to the sun-earth vector. We assume a 90-minute orbit divided into nine 10-minute exposure segments. During each segment, the telescope maintains a fixed attitude via a continuous slew of the spacecraft body (the same as used by HST). Upon completion of this segment, the spacecraft rapidly slews to the next. As the earth goes around the sun, the viewing zone rotates at ~1°/day. This coincides closely with the natural width of the detector focal plane, providing the natural stepping of each scan leg. As an all-sky survey, absolute pointing requirements are extremely loose (60") since pointing can be reconstructed after the fact. However, pointing stability requirements will be high due to the small beam size (< 0.05" over ten minutes). Also, the "flyback" requirement to step the spacecraft to the next target position during the orbit demands a high slew rate of 1°/sec (the demand for detector area and the telescope optics preclude a scan mirror). This is within the capabilities of an "agile" spacecraft using control moment gyros and fine guidance sensors.

With this cadence, OASIS will survey 300 square degrees per day, or 4.5 months to survey the entire sky to a depth of 10 minutes. The focal plane produces 5GB of data per 10-minute exposure, or continuous (compressed) data rate of 4.2 MB/s. Due to radiation, a minimum of three exposures will be required per location on the sky. The survey will therefore require roughly one year per band to complete, to a depth of 30 minutes. In order to complete the survey in all bands, a mission duration of 5-7 years would be required. The spacecraft has no consumables, and should be able to meet this requirement. Filter priorities would begin with the near-UV channel (unobtainable from the ground), followed by r-band. Interleaving of the individual filter passes (in 4-month campaigns) provides the synoptic component.

We estimate the spacecraft mass at ~3,500 kg, easily within the launch capabilities of the Falcon 9 or Atlas V to LEO. The use of LEO results from the high telecom rate, although this complicates the attitude control system. OASIS could be moved to L2, simplifying operations and attitude control, but would have yet to be resolved telecom issues. Operations are highly simplified relative to a general-purpose space observatory, since the mission does essentially the same thing all the time. This is a substantial extended mission cost savings.

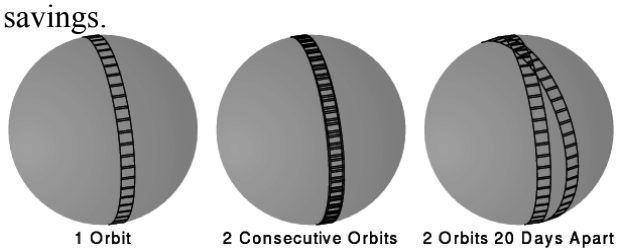

Figure 2 - illustration of a polar scan strategy, taken from WISE. OASIS is similar, but requires multiple orbits to fill the great circle on the sky.

Operations, data processing, and dissemination would occur at a central science center. Data products include images and catalogs. The raw and calibrated images will be mosaiced into readily retrievable tiles, with a cutout service, and would be released both on an individual, epochal basis, and as coadds to achieve the full depth. Catalog data will also be delivered. All would be accessible through GUI exploration tools as well as APIs, similar to those used by WISE and Spitzer.

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