MICROARCSECOND SMALL SATELLITE (MASS)

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MicroArcsecond Small Satellite (*MASS*) is a mission concept designed to find Earth-like exoplanets around nearest FKG stars. The primary mission objective of *MASS* is to measure positions of stars brighter than 6-mag accurate to 4 μas in 1 hour of integration. The 4-μas capability of *MASS* will enable survey 22 nearby FGK stars for a 1-2 $M_\oplus$ planet in the middle of the HZ and directly measure their masses and system architectures. The target list for *MASS* is given in Table 1. *MASS* is designed to find *the first exo-Earth* around FGK star in our stellar neighborhood.

Table 1. *MASS* target list: nearby 22 stars.

HIP	Mass M_E	V mag	Dist., pc	Period, years	Signal, uas	time, hrs	Cumulative, hrs
71683	1	-0.01	1.35	1.21	4.79	100	100
71681	1	1.35	1.35	0.51	3.44	194	295
8102	1	3.49	3.65	0.56	1.32	1,325	1,619
2021	1	2.82	7.47	2.07	1.06	2,043	3,663
3821	1	3.46	5.95	1.10	1.05	2,102	5,765
99240	1	3.55	6.11	1.01	0.99	2,357	8,122
22449	2	3.19	8.03	1.91	0.96	625	8,747
108870	2	4.69	3.63	0.24	0.96	630	9,378
19849	2	4.43	5.04	0.47	0.89	725	10,102
15510	2	4.26	6.06	0.68	0.86	787	10,889
77952	2	2.83	12.31	4.05	0.83	827	11,716
27072	2	3.59	8.97	1.73	0.83	842	12,559
746	2	2.28	16.70	8.06	0.80	899	13,458
96100	2	4.67	5.77	0.49	0.79	913	14,371
57757	2	3.59	10.90	2.16	0.74	1,051	15,422
1599	2	4.23	8.59	1.11	0.73	1,084	16,506
105858	2	4.21	9.22	1.25	0.71	1,141	17,647
64394	2	4.23	9.15	1.19	0.70	1,169	18,816
78072	2	3.85	11.12	1.95	0.70	1,183	19,999
14632	2	4.05	10.53	1.57	0.68	1,250	21,249
12777	2	4.10	11.23	1.70	0.66	1,340	22,589
64924	2	4.74	8.53	0.79	0.64	1,389	23,978

The *MASS* science objectives are summarized below:

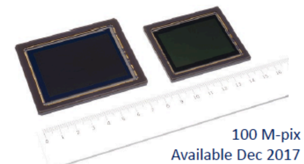
- *MASS* will survey search ~6 nearby stars in the search for 1$M_\oplus$ planets in 1 AU equivalent orbit (i.e., in the habitable zone - HZ), and
- *MASS* will survey additional ~16 nearby stars for the planets at 2$M_\oplus$ in the HZ.

In addition, *MASS* will provide the first direct measurements of the masses and inclinations of a large sample of Earth-like and super-Earth planets around nearest stars. *MASS* will provide the target list to improve the detection of potential habitats for complex exo-Life with the next generation of space telescopes and extremely large telescopes on the ground. Specifically, *MASS*-found planets would become targets for follow-up missions for direct imaging and spectroscopy (i.e., *HABEX*, *LUVOIR*), thus enabling detection of the signs of life and addressing the question "Are we alone?"

MASS is enabled by recent developments in consumer electronics and commercial space industry (Table 2), which has made enormous progress resulting in production of low-cost spacecraft and instruments capable of making significant advances in astrophysics science observations. The mission uses a commercially-available, mass-produced ESPA-class spacecraft from Blue Canyon Technologies (BCT) capable of accommodating a 35 cm telescope (Table 3).

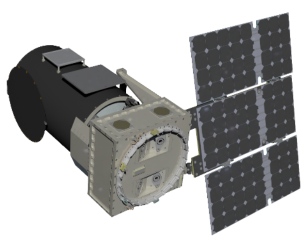
Table 2. Summary of measurements and instrument

- **Measurements**
  - The primary mission objective of MASS is to measure positions of stars brighter than 6 mag to 4 μas in 1 hour of integration
- **Instrument Type**
  - SiC telescope:
  - Commercial, flight-proven
  - Nyquist sampled focal plane
  - Aperture 33-35 cm,
  - f/12.3,
  - FoV > 0.5°,
  - Diffraction limited over the Full Field.
  - Mass < 7kg
- **Spacecraft**
  - An ESPA-class spacecraft from Blue Canyon Technologuie
- **Camera**
  - sCMOS focal plane (market 12/2017)
  - Sony IMX 461 sensor,
  - ~100 Mpix, 3.76 μm pixels, backside illuminated, < 2e– read noise
  - COTS (lab) cameras based on these devices available (12/2018)



For that, *MASS* will utilize a flight-ready 35 cm SiC telescope from the Aperture Optical Sciences (AOS). Their SmallSat Telescopes AP from Series Satellite is a good fit to *MASS* instrument requirements. These commercially-available COTS telescopes rely on a corrected Ritchey-Chrétien (RC) design and SiC materials for all critical mirror and structural components. Made out of SiC, they yield high resolution in an inherently low mass and athermal design. The primary features of these telescopes include: athermal optical performance, compact, low mass design, and possibility to work either in visible of IR wavelengths. They support a wide range of cameras and sensors. The *MASS* telescope will be COTS 35cm RC-product, with no modifications to the system. Only a mesh structure and thermal insulation needed to accommodate it on the BCT bus.

Table 3. Typical Capabilities of the BCTs ESPA/Microsat.



Class	Up to 250 kg
Available Payload Volume	45 x 45 x 80 cm
Pointing Accuracy	±0.002" (1-sigma), 3 axes, 2 Trackers
Energy Storage	300Whr
Solar Panels	400W
Mass / Volume for Avionics	25 kg / 40 cm x 40 cm x 20 cm
XACT-Bus Nominal Power	< 10 W (Excluding RF Comm)
Orbit Altitude / Orbit Lifetime	LEO and GEO / > 5 years

	AP-25	AP-35	AP-40	AP-50
Aperture	25 cm	35 cm	40 cm	50 cm
Mass	< 4 kg	< 5 kg	< 5.5 kg	< 6.5 kg
Athermal Range*	-10 to 30 C	-10 to 30 C	-10 to 30 C	-10 to 30 C
GSD @ 400 km LEO	< 1 m	< 0.75 m	< 0.65 m	< 0.5 m
Sensor	user defined	user defined	user defined	user defined
Satellite Interface	custom flexure	custom flexure	custom flexure	custom flexure

* May vary depending on customer mission profile **Based on optimally matched detector

Flight-proven SiC telescopes and optics from AOS

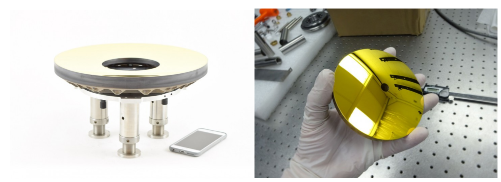


Figure 1. 35 cm RC telescope from AOS.

MASS will use a Nyquist sampled focal plane using a backside CMOS detector with ~10^8 pixels which is derived from a commercially developed Sony sensor for their high-end consumer/professional digital cameras. The camera will be provided by SpaceMicro Inc. The telescope/detector will have a 0.5° FOV that will provide reference stars to ~10-11 mag.

For its high-precision astrometric measurements, *MASS* will use well-established calibration techniques, including: i) the geometry of the focal plane detector and its subpixel imperfections will be calibrated with precision of <10^{-4} pixels by relying on the laser metrology technique developed at JPL; ii) a sparse diffractive pupil technique developed at the NASA Ames Research Center will be used to calibrate optical field distortion effects. We also incorporate the technique of improving the telescope pointing performance relying on approach developed at the BCT.

MASS will be located on a Sun-synchronous orbit (SSO terminator orbit) for a 3 years mission. The spacecraft will be accommodated on an ESPA ring on a launch vehicle that will be launched to the SSO relying on a number of available rideshare opportunities.

The total mission cost estimate (Phases A-E) is \$23M based on grassroot estimation using direct vendor quotes and applying standard WBS wrap factors, well within the cost envelope of the AS3 Call on \$35M. Costing the mission by analogy with other missions relying on spacecraft with a similar form-factor and comparable instruments launched within the last 15 years yielded a JPL Team X estimate of \$42 M at the 70% confidence level.

Most of the *MASS's* technologies are mature: All of the components, such as lasers, modulators, fibers have been flown in space, but the system was not flown. With minor improvements, *MASS* is a strong candidate for the NASA's Astrophysics SmallSat missions in 2021-2025.