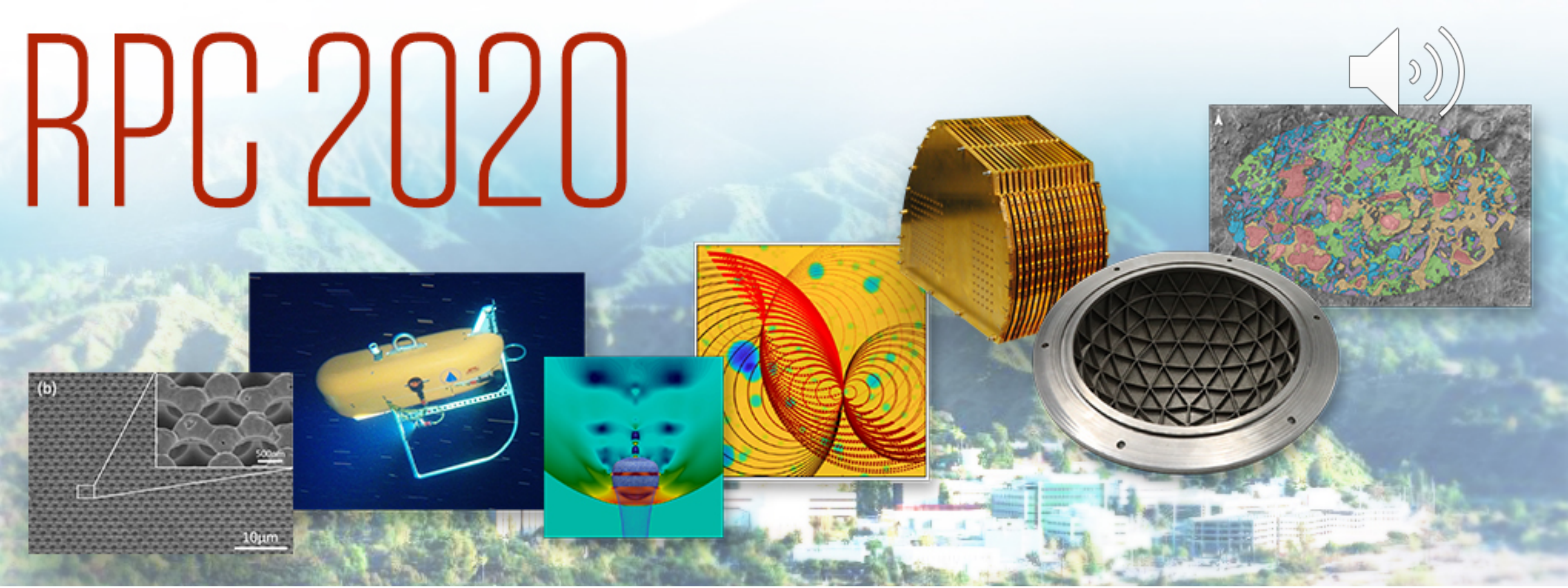


# Virtual Research Presentation Conference

## Microarcsecond Astrometry Telescope Instrument on Small Satellite

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**Program: Topical R&TD**

Assigned Presentation #RPC-102

**Jet Propulsion Laboratory**
California Institute of Technology

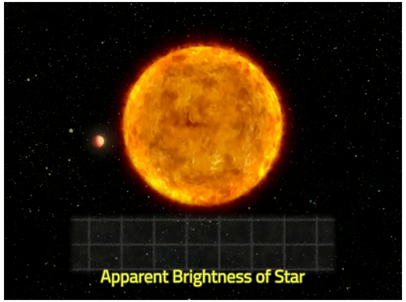
# Introduction


## Abstract

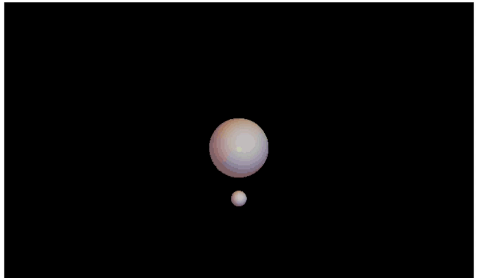
"MASS" (Micro-arcsecond Astrometry Small Satellite) is an astrophysics mission designed to produce the first survey of the habitable zone (HZ) planets in the nearby stellar neighborhood. MASS is based on differential astrometry (angle measurements) of a target star relative to a background of reference stars.

While both radial-velocity and transit techniques have been successful at finding planets more generally, they have been ineffective at reaching Earth-mass planets in the HZ of nearby Sun-like stars due to the inherent constraints of these methods. Our astrometric approach overcomes these limitations.

This mission idea is based on the key focal plane calibration technique previously demonstrated in our laboratory using 80x80 pixel camera. The new MASS mission concept requires a large size CMOS detector (~150Mpx) calibration to achieve the micro-arcsecond level accuracy.

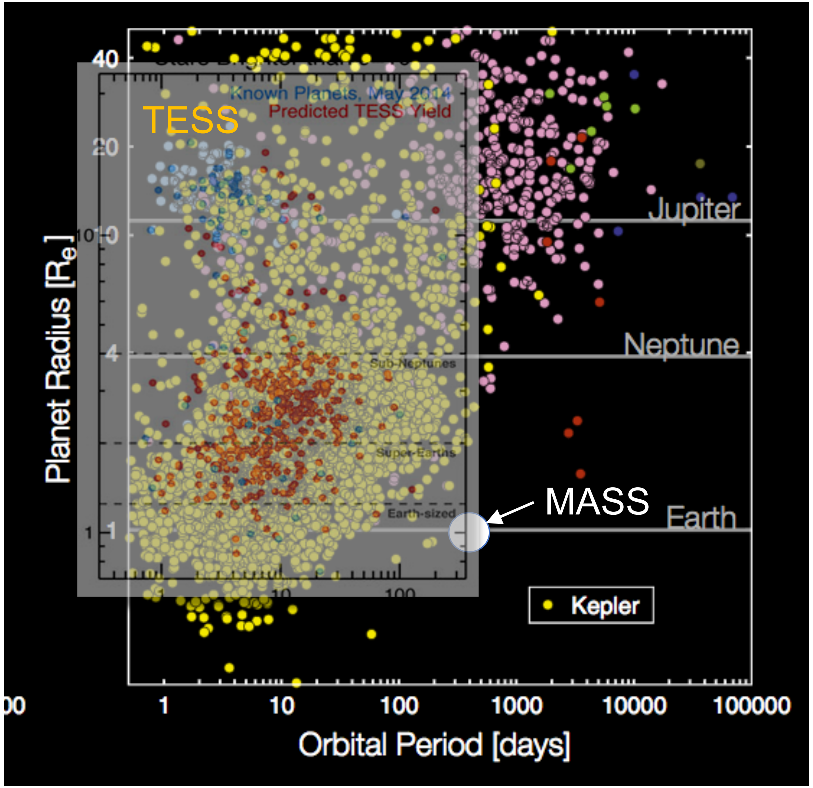

- **Transit method** can NOT detect non-transit planet
- **RV method** will have ”M*Sin(i)” ambiguity
- **Astrometry method** (wobble) will detect both non-transit/transit, and enhance planet mass estimation



# Introduction

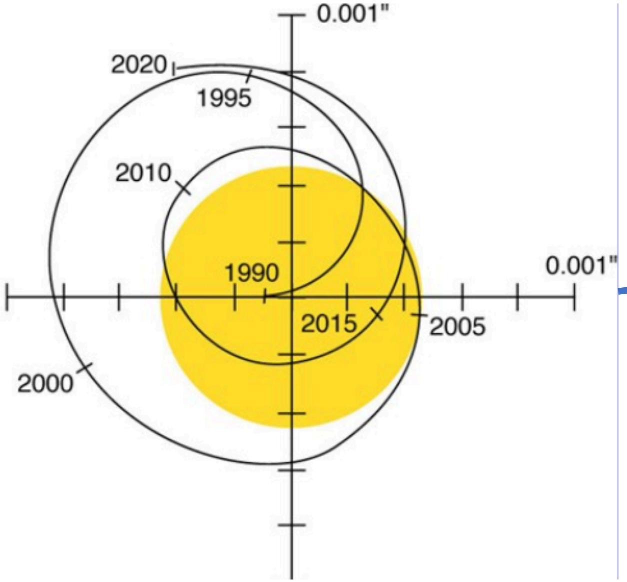
- KEPLER and TESS
  - Will not search an Earth like planet around G stars in 1 year orbit
  - Not astrometry mission (transit methods)

- MASS will be the First Astrometry mission, designed to search for Earth like planets around nearby 20 FGK stars
  - 1 AU, 1-3 Earth Masses
  - Thousands of observations / three year
  - Achieve 2 orders of magnitude improvement in astrometric precision over ESA's Gaia mission.

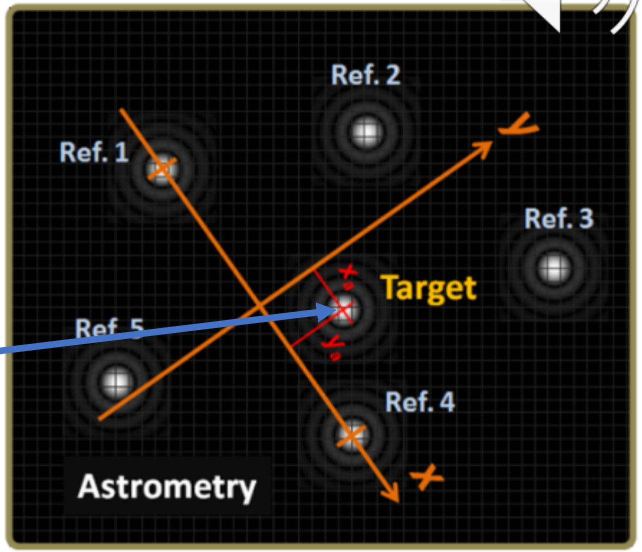



http://www.pnas.org/cgi/doi/10.1073/pnas.1304196111

# Differential Astrometry




Solar wobble example



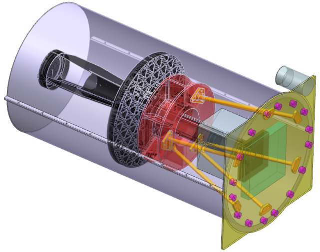

- MASS is a targeted-astrometry mission. It will measure the position of a target star relative to ~100 reference stars in the same field. This is “relative” astrometry, as compared to *Gaia*’s “absolute” astrometry.

- MASS will not measure the *absolute position* of the target star at the μas-level but rather measure the *motion* of the target star at the μas-level.

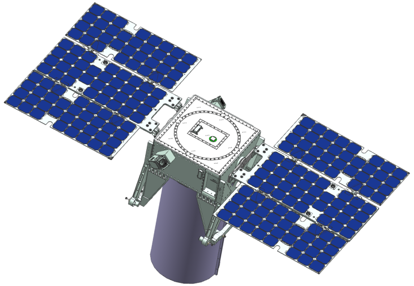
# MASS Overview

- Goal is ~4uas (1hr) astrometric precision
- Search for Earth mass planets
  Around ~20 nearest FGK stars

  ~five of 1M and ~twelve of 2M Planets in the mid Habitable Zone
- Low cost mission taking advantages of low cost commercial spacecraft, SiC telescope



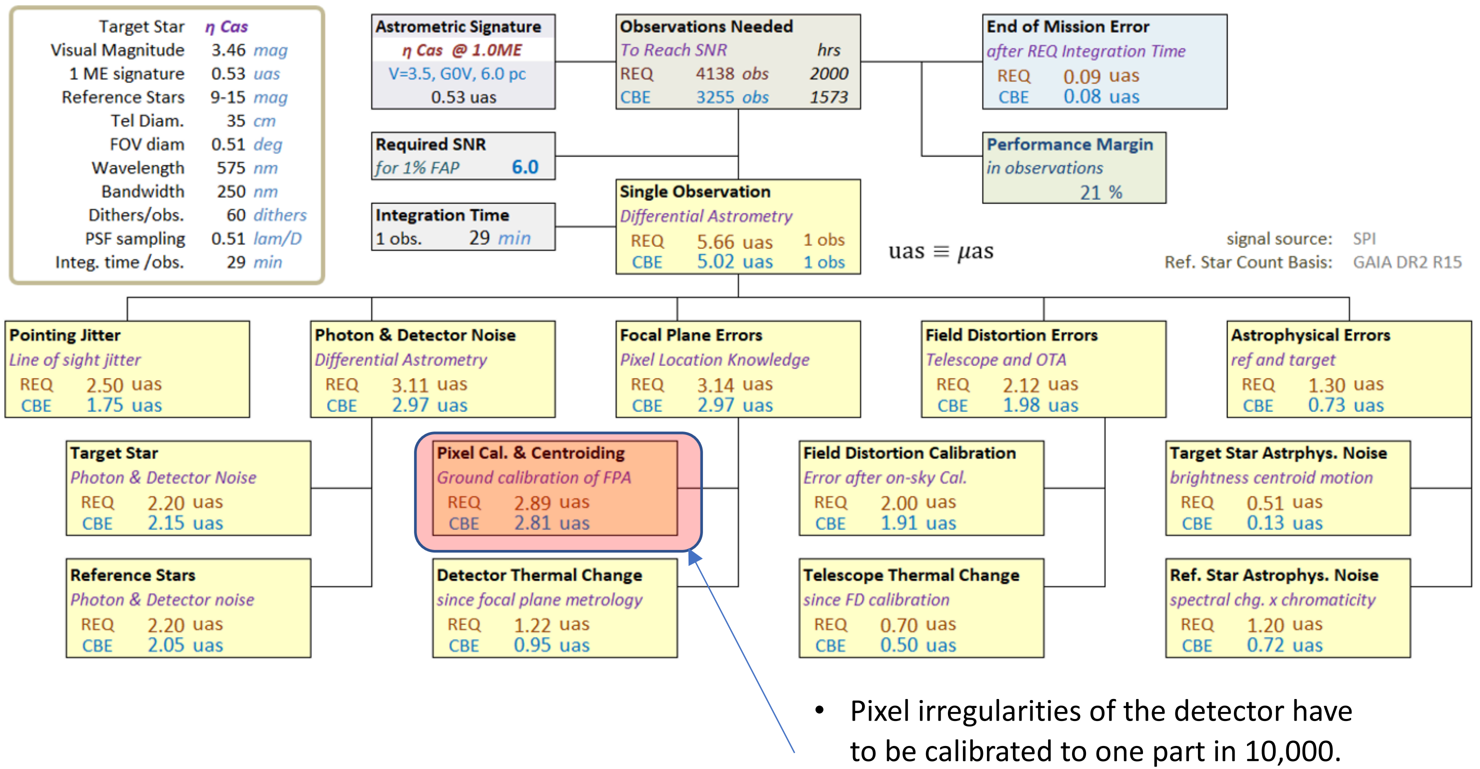
- A commercial, 35 cm aperture, SiC corrected RC telescope
- 6 µas accuracy over 30 min observation
- Detector calibration pre-launch



- 2x 200W solar panels
- 110 kg total mass
- ESPA-Grande compatible
- Propulsion for station-keeping

| HIP | Name | Depth, ME | V mag | Spect. Type | Dist., pc | signature µas | Ref Stars | hours to SNR=6 | cumul. hours |
|---|---|---|---|---|---|---|---|---|---|
| 71683 | α Cen A | 1 | 0.0 | G2V | 1.3 | 2.42 | 1228 | 59 | 59 |
| 71681 | α Cen B | 1 | 1.4 | K1V | 1.3 | 1.71 | 1228 | 121 | 180 |
| 2021 | β Hyi | 1 | 2.8 | G2IV | 7.5 | 0.55 | 105 | 957 | 1136 |
| 3821 | η Cas | 1 | 3.5 | G0V | 6.0 | 0.53 | 488 | 1530 | 2667 |
| 77952 | β TrA | 1 | 2.8 | F1V | 12.3 | 0.44 | 999 | 1511 | 4178 |
| 99240 | δ Pav | 2 | 3.6 | G8IV | 6.1 | 0.99 | 119 | 444 | 4622 |
| 22449 | π3 Ori | 2 | 3.2 | F6V | 8.0 | 0.98 | 139 | 543 | 5164 |
| 27072 | γ Lep | 2 | 3.6 | F6V | 9.0 | 0.84 | 127 | 602 | 5766 |
| 746 | β Cas | 2 | 2.3 | F2III | 16.7 | 0.87 | 372 | 703 | 6469 |
| 96100 | σ Dra | 2 | 4.7 | K0V | 5.8 | 0.79 | 133 | 1236 | 7705 |
| 14632 | ι Per | 2 | 4.1 | G0V | 10.5 | 0.69 | 231 | 1377 | 9081 |
| 12777 | θ Per | 2 | 4.1 | F8V | 11.2 | 0.67 | 328 | 1591 | 10673 |
| 19849 | 40 Eri | 2 | 4.4 | K1V | 5.0 | 0.89 | 77 | 1652 | 12325 |
| 105858 | γ Pav | 2 | 4.2 | F9V | 9.2 | 0.72 | 94 | 1701 | 14026 |
| 8102 | τ Ceti | 2 | 3.5 | G8V | 3.6 | 1.31 | 28 | 1715 | 15741 |
| 108870 | ε Ind | 2 | 4.7 | K5V | 3.6 | 0.96 | 65 | 1950 | 17691 |
| 1599 | ζ Tuc | 3 | 4.2 | G0V | 8.6 | 1.10 | 68 | 1238 | 18929 |
| 78072 | γ Ser | 3 | 3.9 | F6V | 11.1 | 1.07 | 62 | 1340 | 20269 |
| 57757 | β Vir | 3 | 3.6 | F9V | 10.9 | 1.14 | 41 | 1453 | 21722 |
| 64924 | 61 Vir | 3 | 4.7 | G7V | 8.5 | 0.97 | 121 | 1661 | 23383 |
| 15510 | e Eri | 3 | 4.3 | G6V | 6.1 | 1.28 | 51 | 1961 | 25344 |
| 64394 | β Com | 3 | 4.2 | G0V | 9.2 | 1.06 | 31 | 3419 | 28763 |

# MASS Error budget and key calibration requirement




- Pixel irregularities of the detector have to be calibrated to one part in 10,000.
- Laser interferometer fringes are used to calibrate pixel positions.

# R&TD objectives

(1) To design conceptually the MASS instrument on Small Satellite

(2) To study the science capabilities/error budget for the MASS and perform simulation of its expected science impact

(3) To demonstrate the key laser pixel metrology calibration technique using a large state-of-the-art 150Mpix sCMOS detector

# Laser interferometer metrology for calibration

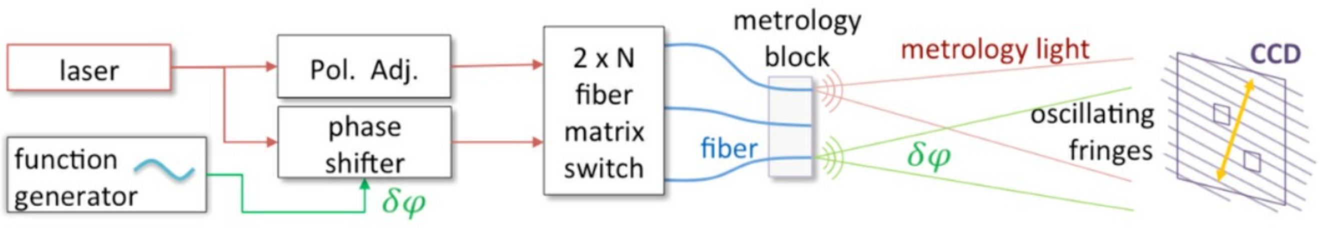
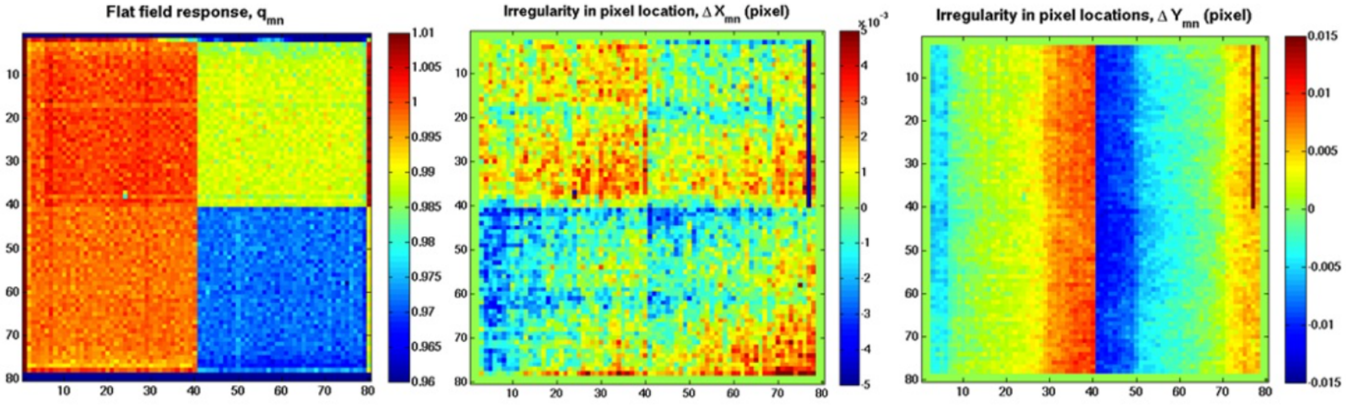
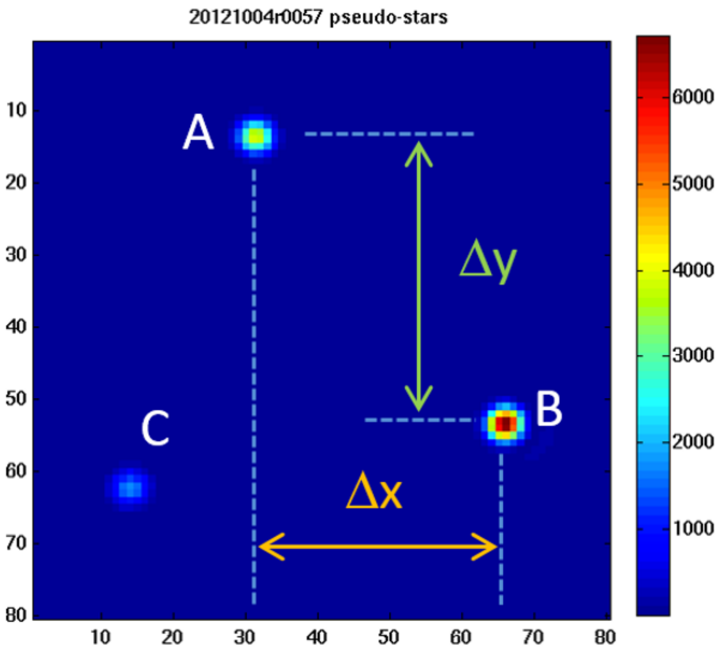
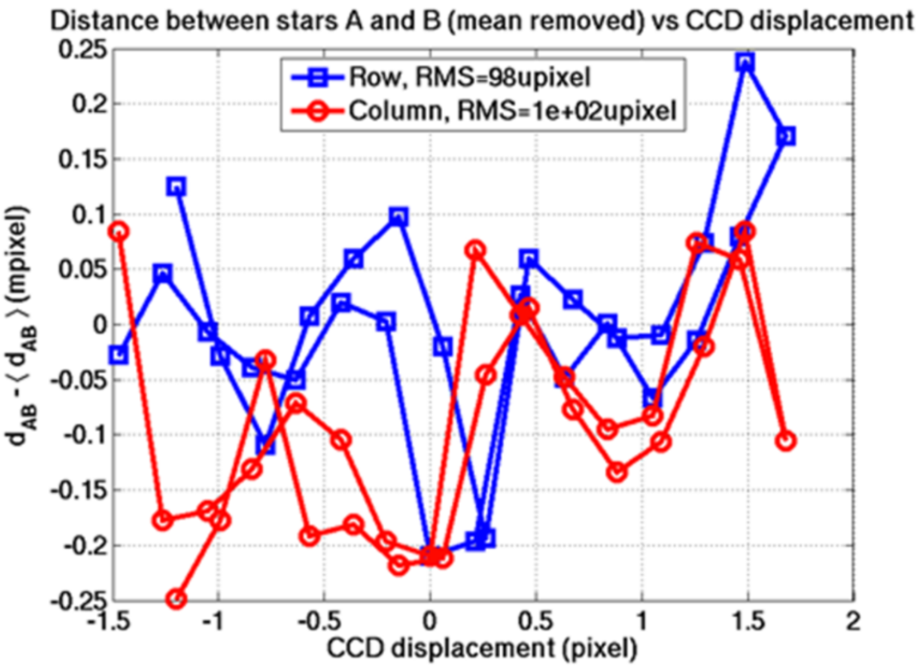



**Figure 3.** Laser metrology for calibrating irregularities in pixel locations.

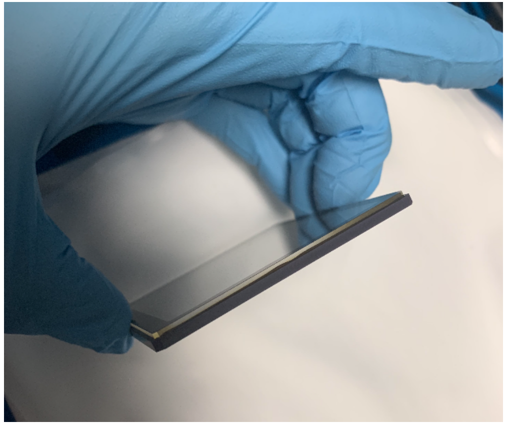





(Left) An astrometric test measures the consistency of inter-star distances on the focal plane as the line of sight is changed. (Right) Results of an astrometric test: centroid distance between pseudo-stars A and B in row and column directions, with mean removed, versus the displacement of the CCD.

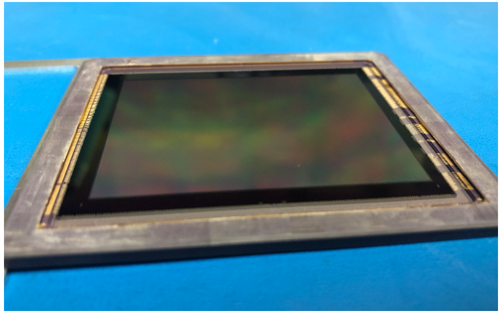
# Large detector calibration

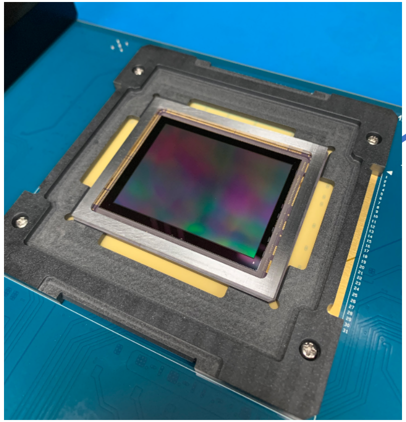


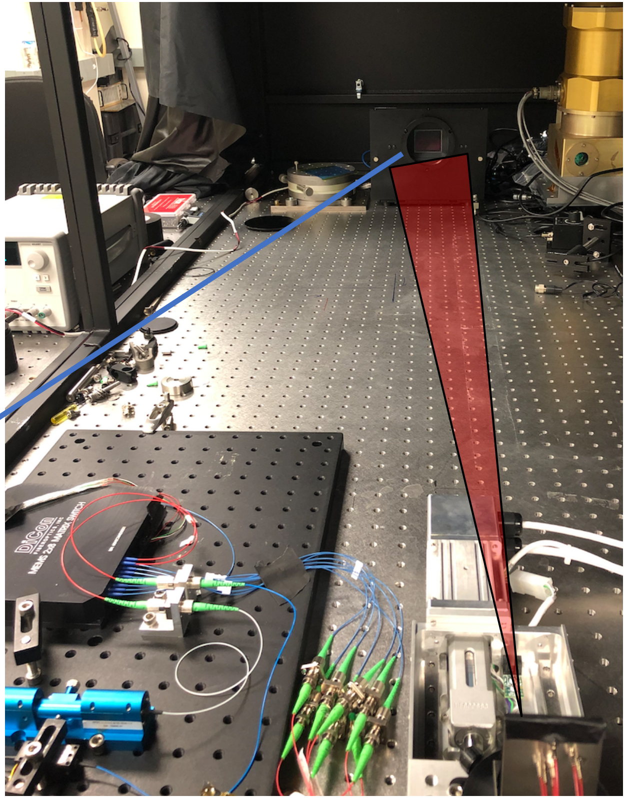
Sony IMX411

~150 Mpix, 3.76 $\mu$m,
backside illuminated,
< 2e− read noise

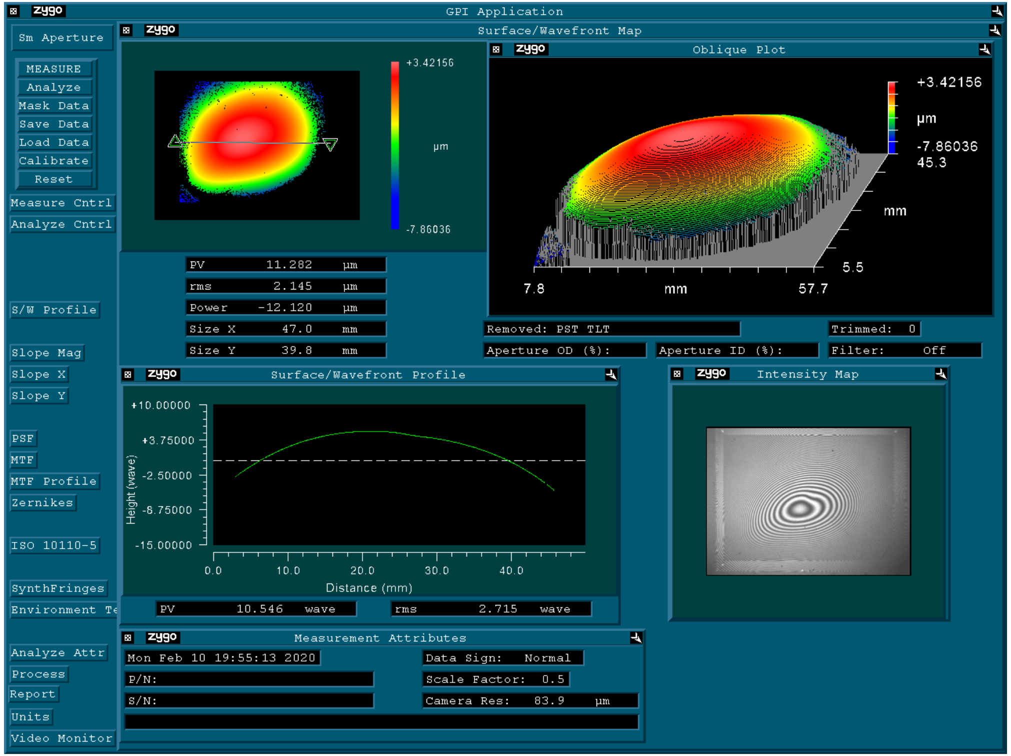
Glass window is removed





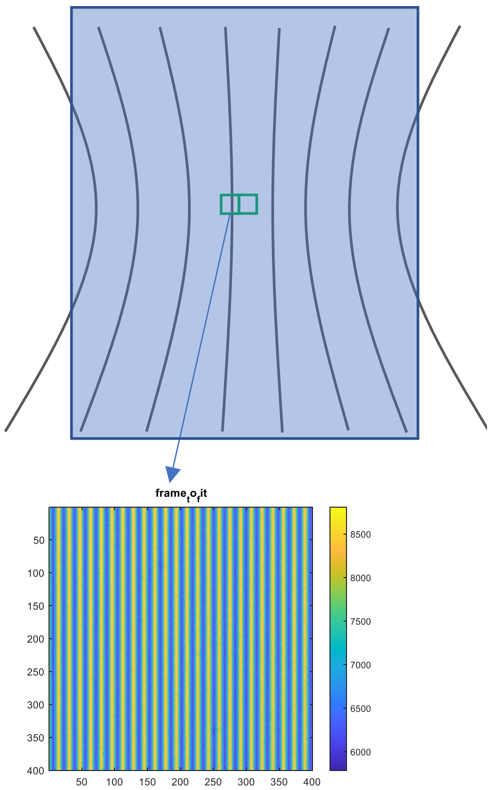


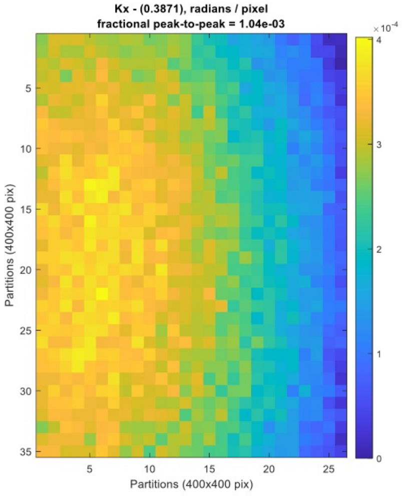
# Chip mount distortion measurement

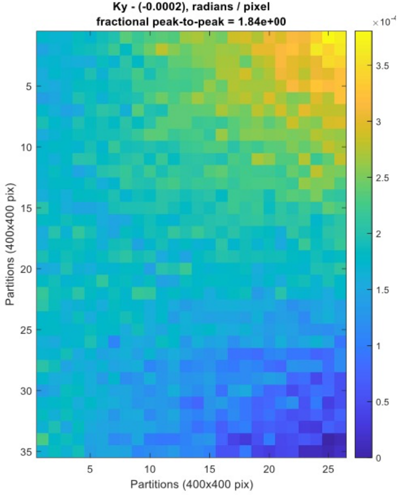


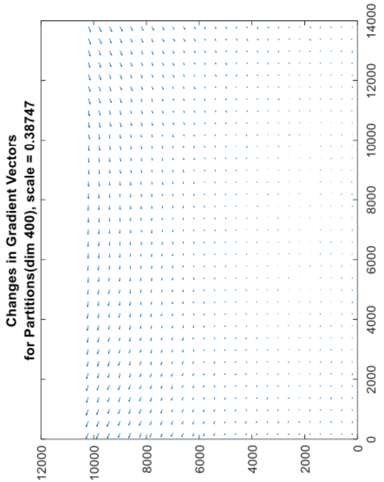

~11 micron distortion (3 pixel over 12000 pixels ~ 1.6x10^-4) in z-direction has to be corrected for the final metrology analysis

# Non-linear fringe effects




Full frame data were taken ~(10,000 x 14,400)

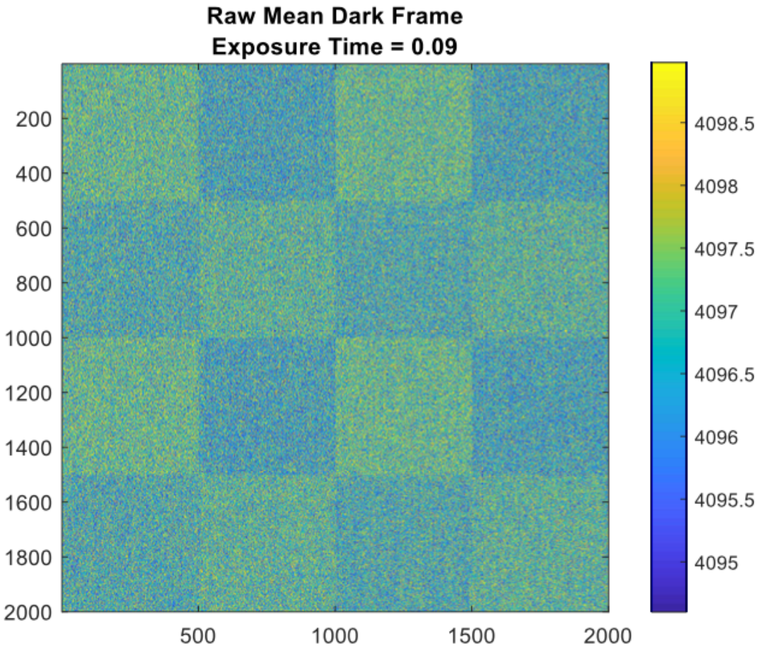
Partitioned into 400 x 400 regions (26 x 35 measurements of K)

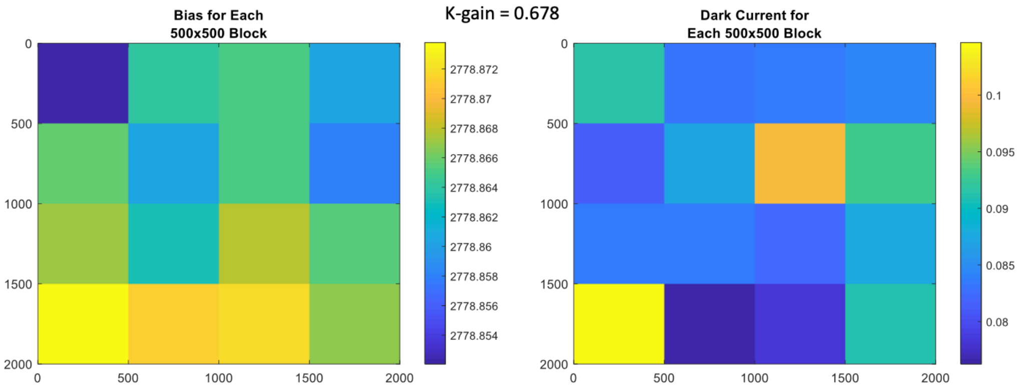
The analysis of the local K vector revealed the non-linear effects.

$$\vec{K} = \frac{2\pi}{\lambda} \vec{\nabla}\text{OPD}$$

The effect is at 10^-4 level across the chip, which has to be taken into account for the pixel irregularity determination.

# Birthmark Features




Dark frame image showed a 500x500 pixel block pattern

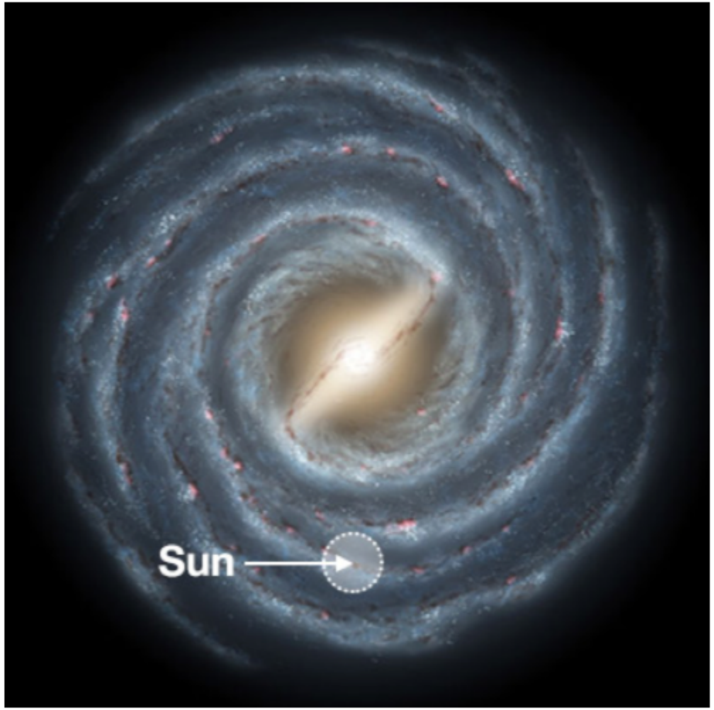
# Summary

**Significance**

- The concept of the MASS mission was submitted to 2019 Astrophysics Explorers Mission of Opportunity.
- “MASS will be a game-changer for NASA’s goal of exploring Earth analogs by pioneering space base astrometric detection and characterization of exoplanet, and the mass measurement of the identified planets is essential for interpretation of spectra for future direct-imaging missions.” -reviewer
- ”pixel metrology demonstration with a large size detector is required” -reviewer

**Next Steps**

- The task was halted during the mandatory lab closure due to COVID-19
- The unfinished activities are (1) taking the metrology data in various experimental set up (2) data analysis, (3) publication of the results




The sun and our solar system in relation to the Milky Way galaxy. The white circle indicates the area where the majority of exoplanets have been found with current telescopes. Credit: NASA/JPL-Caltech/T. Pyle