High Precision Astrometry with Moderate Sized Telescopes

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Ultimate Science Goal

Drain the Lake for Exo-Earths:

Survey <u>200 nearby stars</u> for 1 M_{Earth} planets in the <u>Habitable Zone</u>

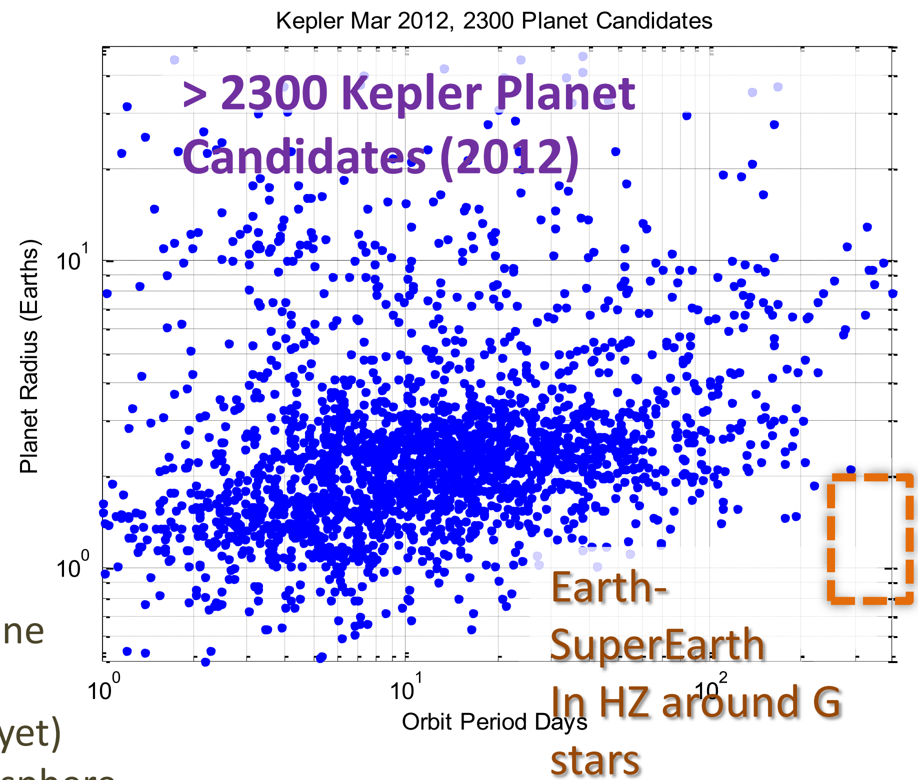
- These are < 30pc, <7 mag, < 5 yr orbit
- Expect to Find:

  ~14 Earth + SuperEarth planets in the HZ

  ~10 Earth like planets

  (exclude superEarths M > 5 MEarth)

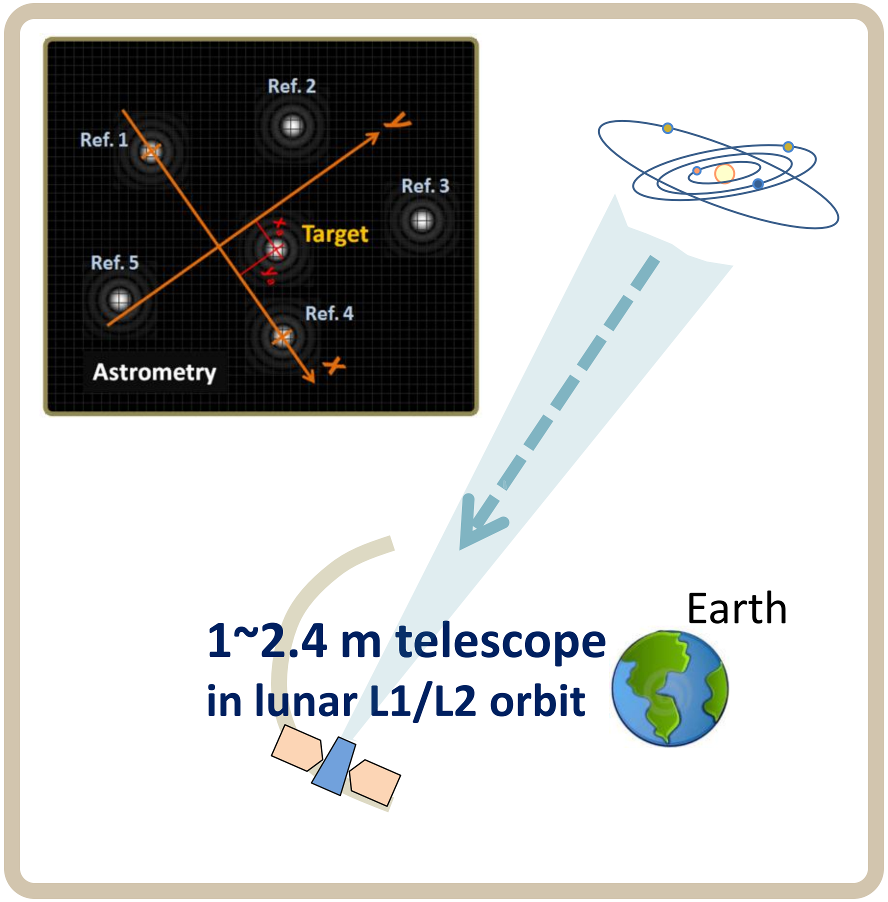
  Search the nearest ~20 Stars down to ~0.5 M_{earth}



From the Kepler 2013 data:

- ~45% of sunlike stars have Earth+SuperEarths
- ~7% of stars have Earth-SuperEarth the habitable zone (0.5~10 M_{Earth}, @ 0.8~1.6 AU)
- No Earths in HZ of solar-like stars have been found (yet)
- SuperEarths > ~5 M_{earth} capable of having a H_2 atmosphere

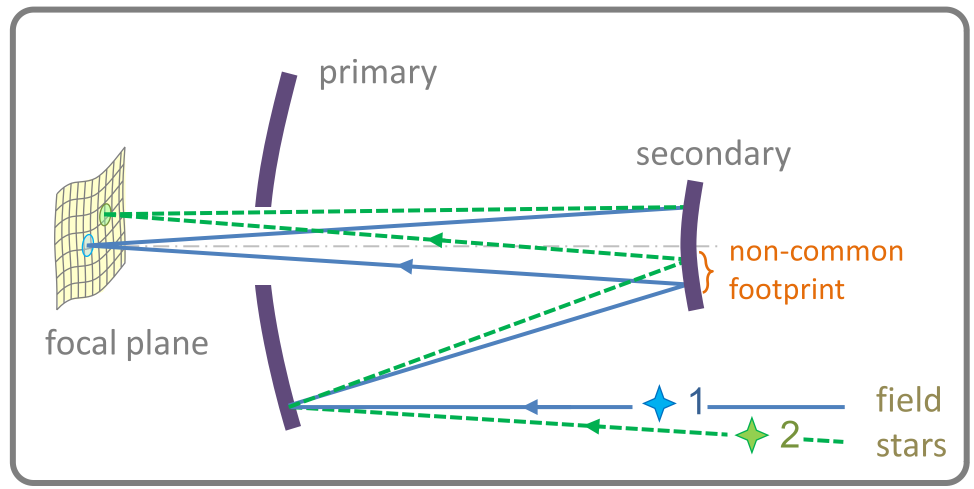
Astrometric Search for Exo-Earths



Stellar Image Positions @ 10^{-5} λ/D Precision

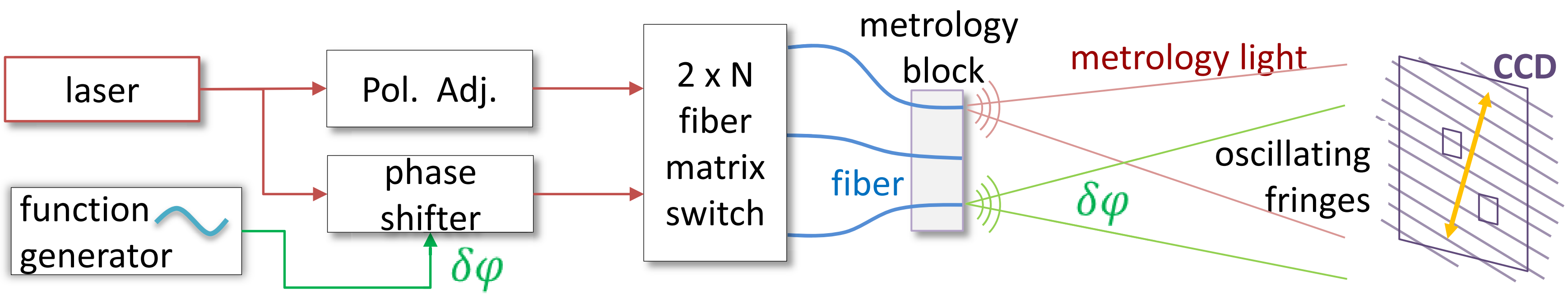
→ **would allow astrometry at**

- **0.45 μas on a 2.4 m telescope,**
- **1.0 μas on a 1m (NEAT, ESA),**
- **2.2 μas on a 50 cm telescope**
- **In 1hr**

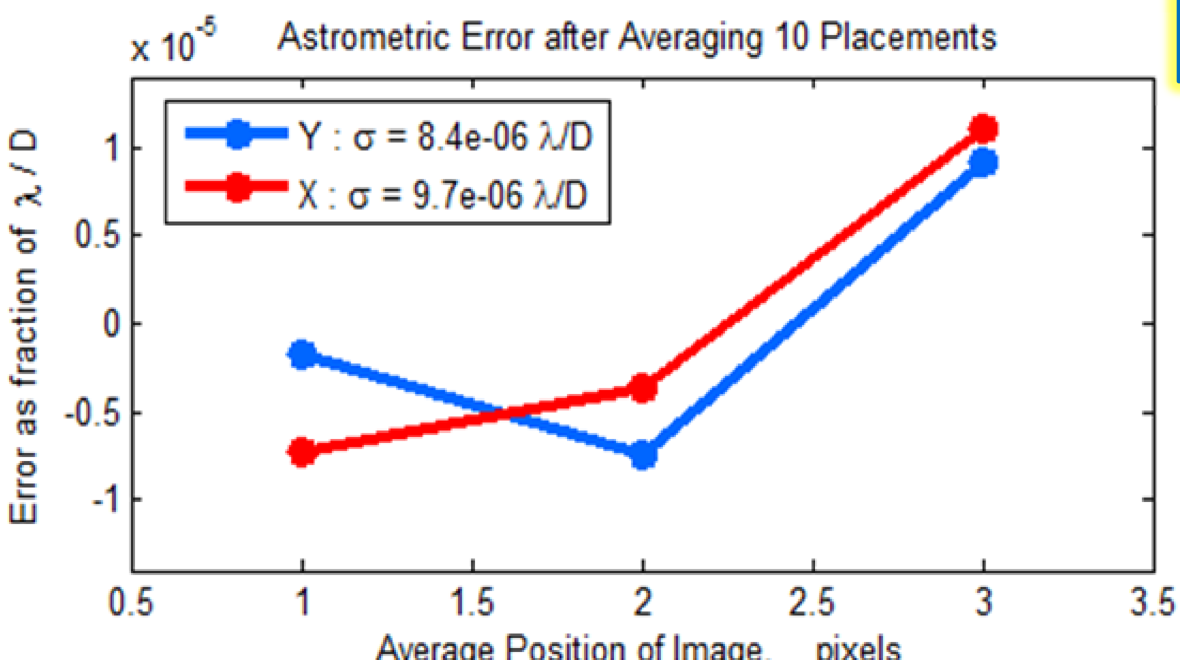


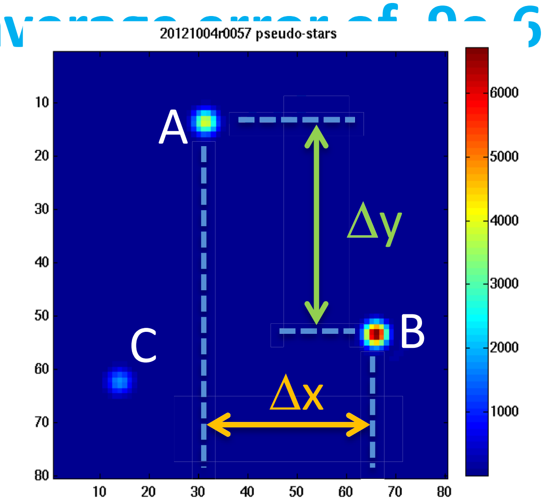
1uas in 1hr => ~1 Me, 1yr planet around the nearest ~100 stars

Enabling Technologies I
CCD calibration and centroiding to ~10^{-5} λ/D



Demonstrated Performance:





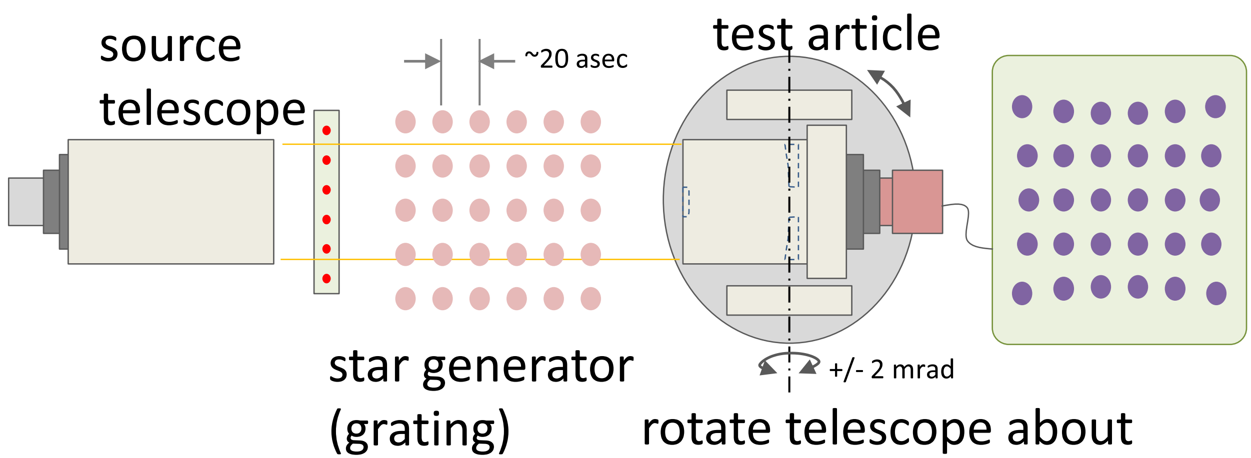
- Notes for prior slide
- 1) Fibers provide fringes across ccd to calibrate CCD, calibration data used in data analysis of star centroid positions
- 2) white light stars (3 of them) place on CCD. The 3 stars were moved ~3 pixels across the ccd (by translating the CCD by 75um)
- 3) the separation between stars A, B should be constant.

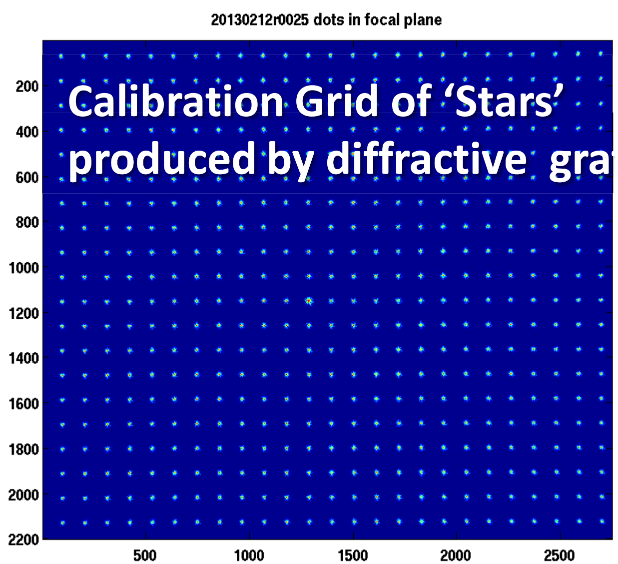
- Necessary conditions for 10-5 l/D centroiding
- Accurate background subtraction, flat field, images nyquist sampled, average many exposures to beat down photon noise.
- Because the images are nyquist sampled we have the “true” psf instead of needing to “guess” the true PSF.

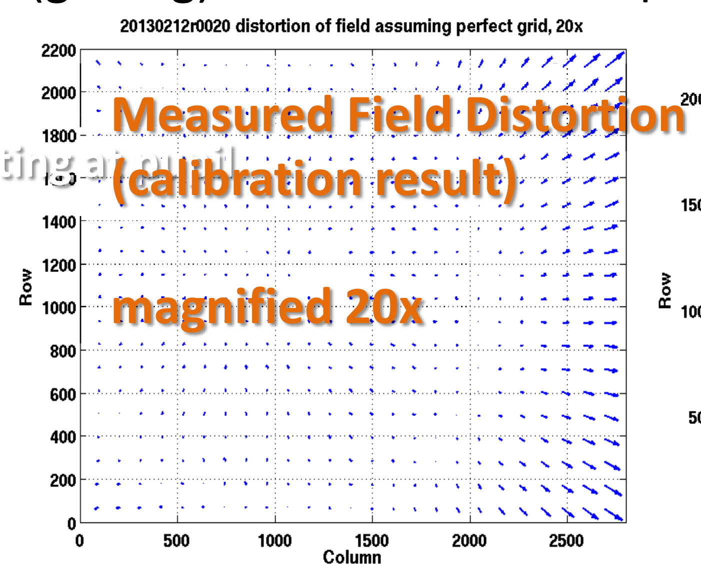
Key Technology II

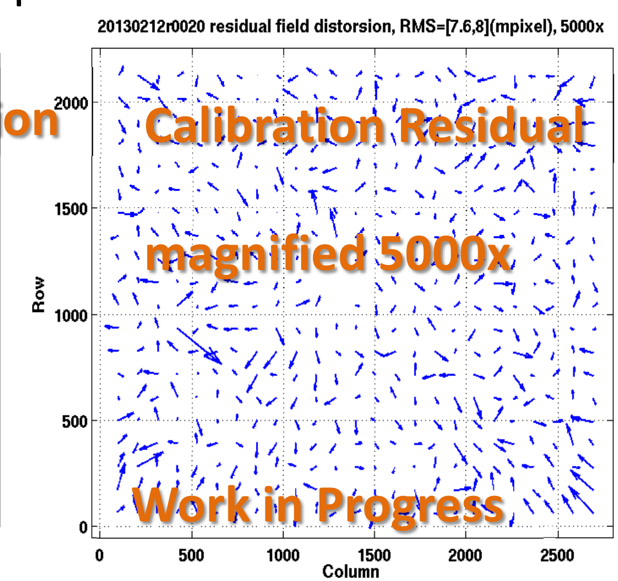
Beam Walk Calibration

using diffractive pupil (test)









A Variant of O. Guyon's Diff Pupil Astrometric Calibration

- Test setup
  - ~25cm collimator to generate a collimated beam
    - Manufactured at JPL's MDL (10's nm accuracy)
  - 25cm set of holes (180um holes ~6mm separation) That produces a diffraction pattern in the image plane with stars ~20arcsec apart.
    - Near perfect square grid of stars
  - Telescope under test, with Camera is rotated in Az, El by 10's of arcsec
  - The location of 1000's of diffractive stars are compared to solve for
    - Field distortion
    - Imperfection in the square grid of stars

Current status (Field distortion Calib)
(activity still underway)

- Field distortion of this telescope, quite large, > 1 pix at edge of the field. (mostly pincushion) ~ 0.1 arcsec
- Initial results calibrated distortion to ~1e-3 pixels (4e-4 λ/D) (~0.1% cal of field distortion)
- Identified issues, hardware replacements have arrived new results in ~1 month
  - We had to move from our small 80*80 pix backside CCD to a large format (multi-megapixel) CCD. The detector had to be read out moderately fast (to average 1000's frames). Can't afford 20sec read outs.
  - Most current large format CCD that read out fast often use lenslet arrays to improve QE and camera using these chips have windows.
  - Under these conditions, the QE(I,j) is a function of angle the light hits the CCD. We find that pixel position and intra-pixel QE is also a function of angle.
  - We have now received a new detector that is lenslet free, no window, and can be read out in < 1/10 sec.
- Expect significant improvement beyond 1e-3 pixels, hope to get close to 1e-5.

- Field distortion calibration is needed for uas astrometry using Cass/TMA telescopes. It is not needed for missions that have a camera at prime focus.