Univ. of Arizona
Jet Propulsion Laboratory
California Institute of Technology
LOCKHEED MARTIN
NASA Ames Research Center
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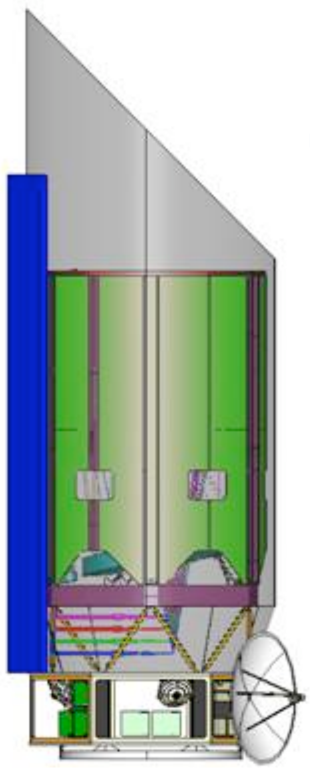
PECO overview

High contrast coronagraphic imaging of the immediate environment of nearby stars.

Characterization of planets (including Earths/SuperEarths) and dust in habitable zone



- 1.4m diameter off-axis telescope (sized for medium-class cost cap), 3 yr mission
- drift-away heliocentric orbit for maximum stability
- Uses high efficiency low IWA PIAA coronagraph
- 0.4 - 0.9 micron spectral coverage / R~20
- Active technology development program includes NASA JPL, NASA Ames, Subaru Telescope, Lockheed Martin

PECO **P**upil mapping **E**xoplanet **C**oronagraph **O**bserver

Earth/SuperEarths with a medium-class mission ?

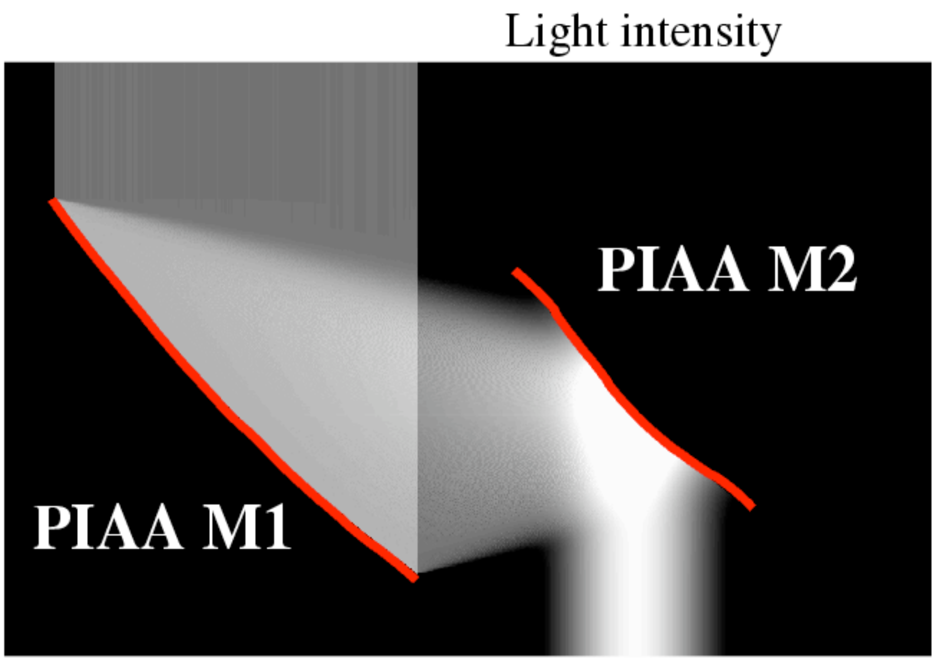
Yes, if:

- **High throughput** instrument & good detector
  - high throughput coronagraph
  - no photon lost, use dichroics instead of filters
  - combined imaging & spectroscopy
  - photon counting (no readout noise allowed)
- Small **Inner Working Angle** AND full telescope **angular resolution**
  - good coronagraph
  - use blue light for discovery & orbit determination
- Large amount of **observation time** on few targets
  - small sample of the easiest 10 to 20 targets
  - long exposure times & many revisits
- Accept risk of high exozodi & low Earth frequency
  - broader science case:
    - exoplanetary systems architecture
    - extrasolar giant planets characterization
    - exozodi disks imaging

PECO uses highly efficient PIAA coronagraph (equ. x2.5 gain in tel. diam.)

Utilizes lossless beam apodization with aspheric optics (mirrors or lenses) to concentrate starlight is single diffraction peak (no Airy rings).

- high contrast
- Nearly 100% throughput
- IWA ~2 l/d
- 100% search area
- no loss in angular resol.
- achromatic (with mirrors)



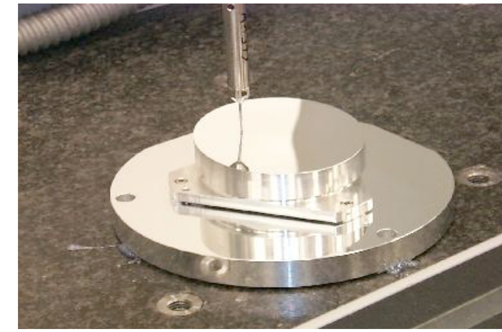
More info on :
www.naoj.org/PIAA/

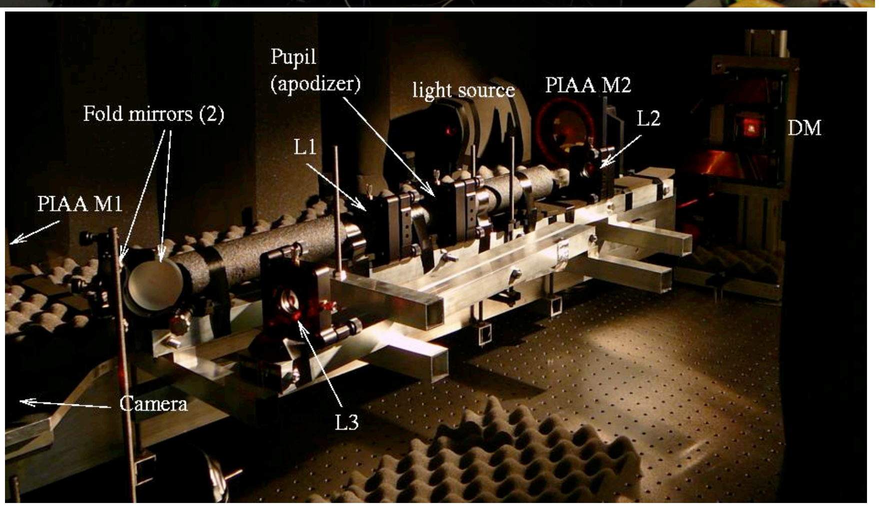
Guyon, Pluzhnik, Vanderbei, Traub, Martinache ... 2003-2006

PECO Pupil mapping Exoplanet Coron

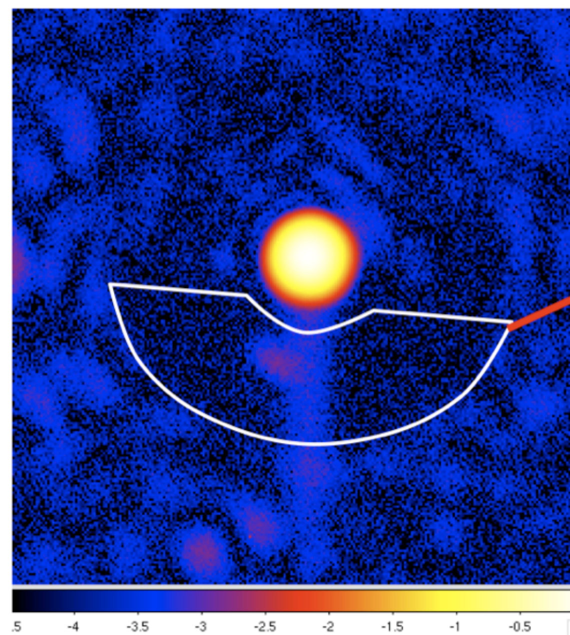
PIAA testbed at Subaru Telescope

Temperature-stabilized monochromatic testbed in air
Uses 32x32 actuator MEMs
Uses 1st generation PIAA mirrors, diamond turned Al

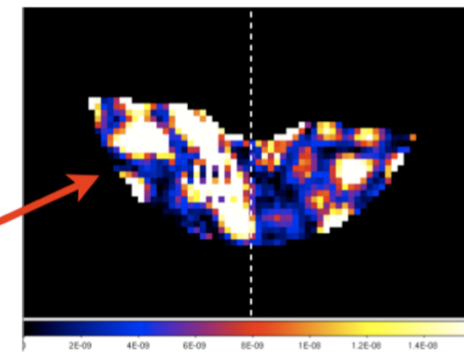




Raw image



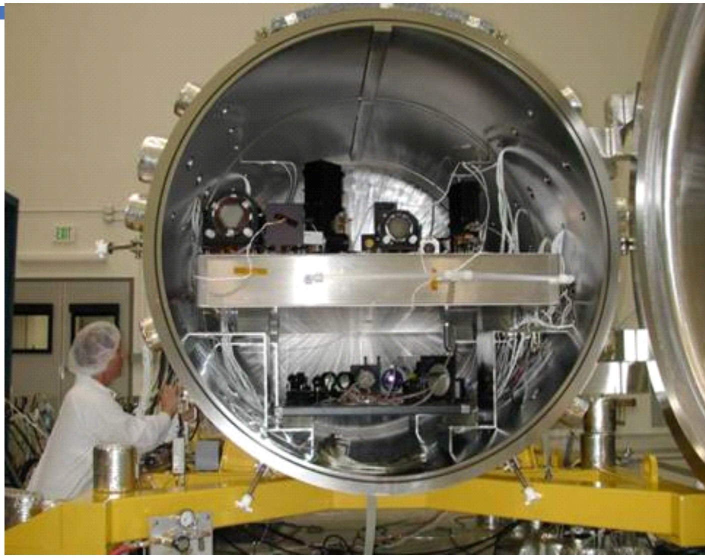
Coherent starlight



Average contrast in right half of the science field shown above (excludes the ghost on the left) = 7e-9

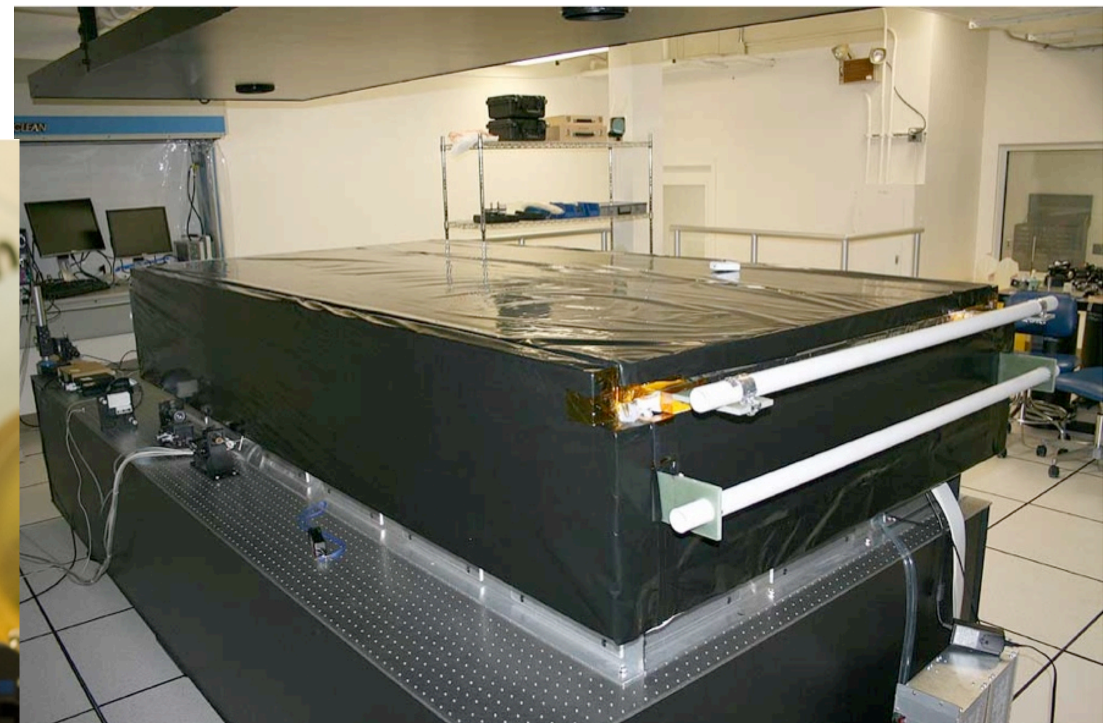
Contrast achieved in 2 to 5 l/D zone:
2e-7 incoherent halo ghost (equivalent to exozodi)
4e-8 coherent starlight speckles (turbulence, vibrations)

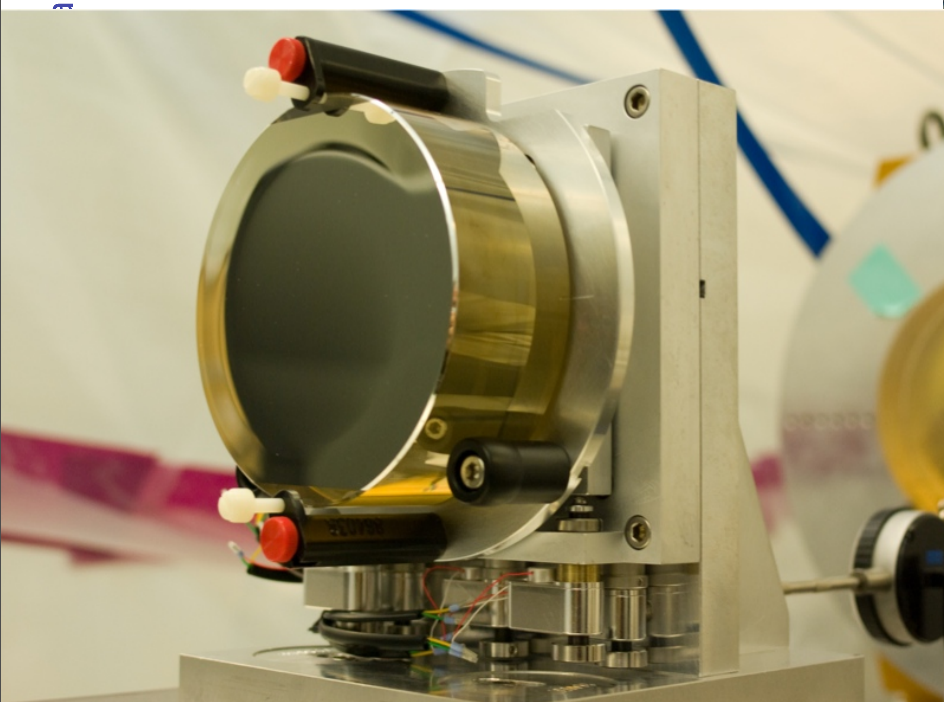
High contrast polychromatic PIAA demonstration in preparation (NASA Ames / NASA JPL)



PIAA gen2 will be tested in JPL's High Contrast Imaging Testbed in vacuum and polychromatic light.

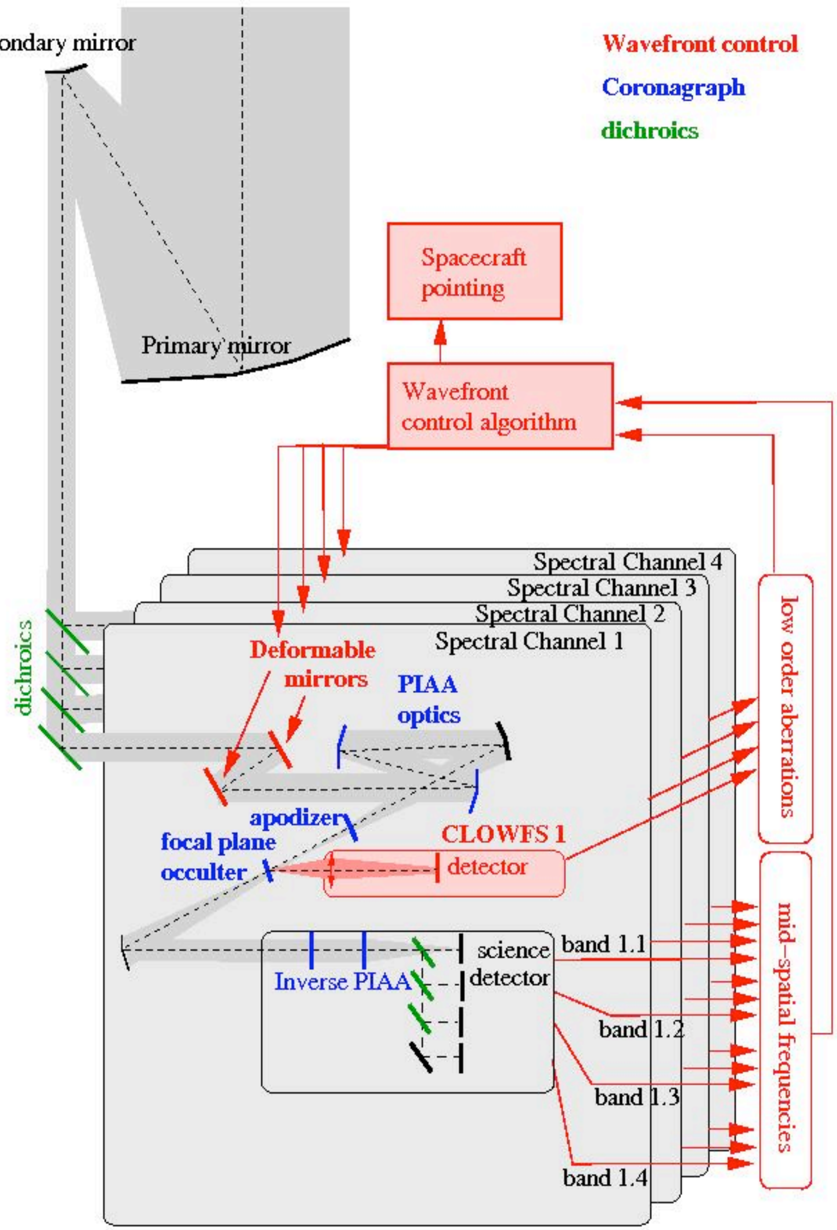
PIAA-dedicated testbed at NASA Ames testing WFC architectures & MEMs DMs.





PIAA system scheduled to be on-sky in Dec 2009 at Subaru Telescope

PECO approaches theoretically optimum coronagraph performance



High performance PIAA coronagraph

- IWA = 2 λ/D
- 90% coronagraph throughput
- No loss in telescope angular resolution: max sensitivity in background-limited case
- Full 360 deg field probed

Simultaneous acquisition of all photons from 0.4 to 0.9 μm in 16 spectral bands, combining detection & characterization

- High sensitivity for science and wavefront sensing
- polarization splitting just before detector (helps with exozodi & characterization)

Wavefront control and coronagraph perform in 4 parallel channels

- Allows scaling of IWA with lambda
- Allows high contrast to be maintained across full wavelength coverage

PECO Design Reference Mission
A Grand Tour of 10 nearby sun-like stars

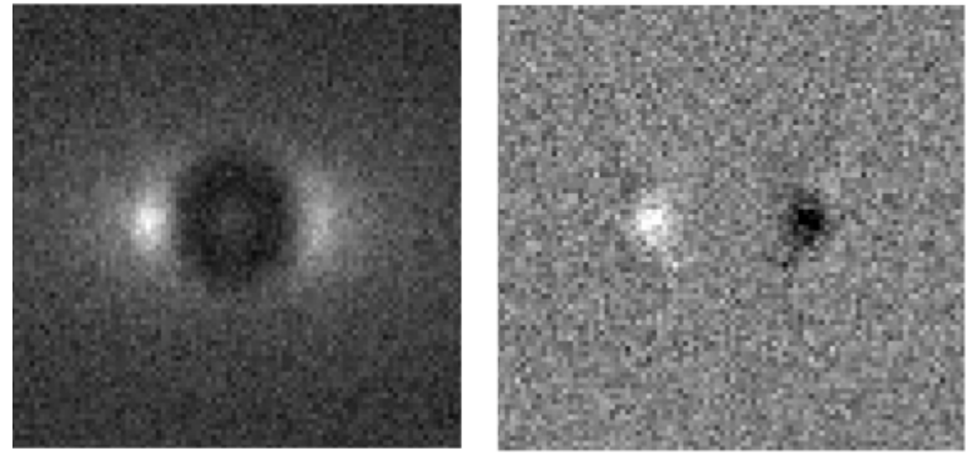
- **Conduct a "Grand Tour" of ~10 nearby stars searching for small (Earth & Super-Earth) planets in their habitable zones.**
  - Multiple (~10 or more) visits for detection
  - Characterization for ~5 days each to get S/N = 20-30 with ability to measure spectral features
  - exozodi distribution measurement
  - compile with other measurements (RV, Astrometry, ground imaging)
- **Study known RV planets, observing them at maximum elongation**
  - Detect at least 12 RV planets with single visits at maximum elongation
  - Characterize at least 5 RV planets for ~2-5 days each to get S/N > 30 with ability to measure spectral features
- **Snapshot survey of ~100 other nearby stars to study diversity of exozodiacal disks and search for / characterize gas giant planets.**

Number of Earths & Super Earths detected with PECO scales gracefully with aperture

Telescope D(m)	# Earths, 450 nm	# Earths, 672 nm
1.0	5	2
1.2	10	5
1.4	19	8
1.6	32	14
1.8	42	20
2.0	52	30

Earths still detectable at shorter wavelengths and smaller D

Telescope D (m)	# S-Earths, 450 nm	# S-Earths, 672 nm
1.0	15	5
1.2	28	13
1.4	43	20
1.6	70	33
1.8	87	44
2.0	131	61



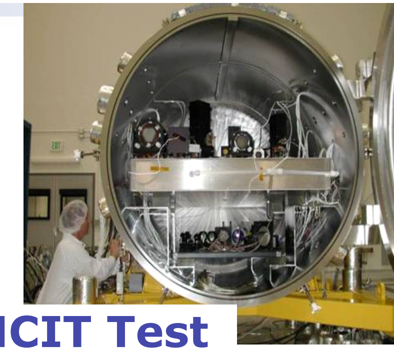
Left: a simulation of 24 hr of PECO data showing an Earth-like planet (a=0.2) around Tau Ceti with 1 zodi of exododi dust in a uniform density disk inclined 59 degrees. This is a simulation of λ= 550 nm light in a 100 nm bandpass PECO (1.4-m aperture). Photon noise and 16 electrons total detector noise for an electron multiplying CCD have been added.

Right: the PECO image after subtracting the right half from the left half, effectively removing the exozodiacal dust and other circularly symmetric extended emission or scattered light. The Earth-like planet is obvious as the white region on the left, and the dark region on the right is its mirror image artifact.

- Trade study shows number of Earths detected for different telescope diameters
- PECO simulation of Earth-radius planet with Earth albedo in habitable zone of candidate star
- Assumes detection in < 5 attempts of < 12 hr integration
- IWA of 2 lambda/D

PECO top 5 key technologies are identified and under study

- **PIAA Coronagraph System Path to TRL6**
  - PIAA mirror fabrication
  - Performance demonstrations in JPL HCIT
  - Brassboard component qualification
    - Note that existing PIAA coronagraph bench is the same scale as flight components
- **Broadband Wavefront Control**
  - Baseline Xinetics DM near TRL 6
  - MEMs DM technology in progress as potential cheaper alternative (NASA Ames Funding)
  - Algorithms tested in HCIT
- **Pointing Control Demonstration**
  - LOWFS provides fine guidance, to be tested in HCIT
  - Models predict 0.5 mas possible with existing technology (1 mas demonstrated with PIAA in the lab in air)
- **Thermal-Structural-Optical modeling**
  - Needed for final system verification
  - HCIT will validate optical models
  - SIM TOM testbed demonstrated thermo-structural
- **Photon-counting EMCCD Detectors**



JPL HCIT Test Facility

Xinetics 64x64 DM

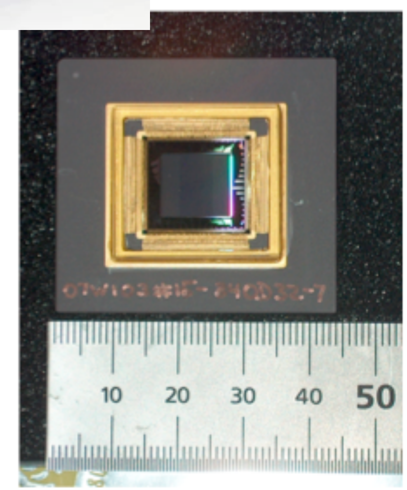


Figure 1: 1024 actuator (32x32) MEMs DM commercially available from Boston Micromachines (mm scale).

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Summary

- PECO study shows **direct imaging and characterization of Earths/ Super-Earths possible with medium-scale mission** and:
  - maps exozodi down to <1 zodi sensitivity
  - extrasolar giant planets
- "Conventional" telescope with off-axis mirror can be used (stability OK, wavefront quality OK). All the "magic" is in the instrument -> **raising TRL for instrument is key (coronagraph, wavefront control)**
  - technology development at ~$40M
- PECO could launch in 2016. Total mission cost ~$810M including technology development
- PECO architecture can be scaled to a flagship 3-4 m telescope without new technologies or new launch vehicles
- Technology and science (exozodi) precursors to larger missions are very valuable
  - pre-PECO ? see EXCEDE poster (SMEX mission)
  - PECO -> 3-4m flagship wide field telescope with PIAA for exoplanet science

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