Sagan **P**olar **O**rbiting **C**oronagraph **C**amera for **I**maging **E**xoplanets

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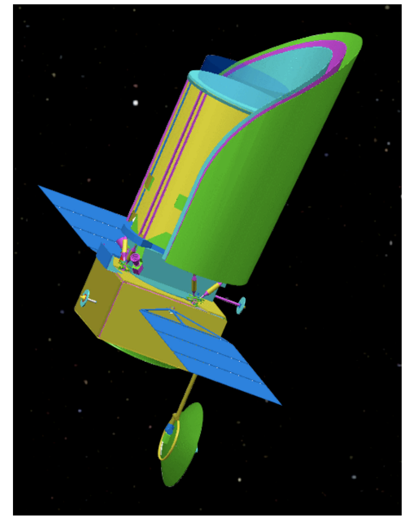
SPOCCIE Overview

- D = 1.8 meter polar-orbiting space telescope
- Coronagraph with ~1e-9 contrast
  - 3 λ/D Band-limited Lyot + spectrograph
  - ~1 milliarcsec spacecraft pointing
- Optical wavelengths
  - 0.3 to 1.0 micron
- 3 year mission
  - Directly image targets ~10 pc
  - Rocky planets, gas giants, disks
  - Launch 2014



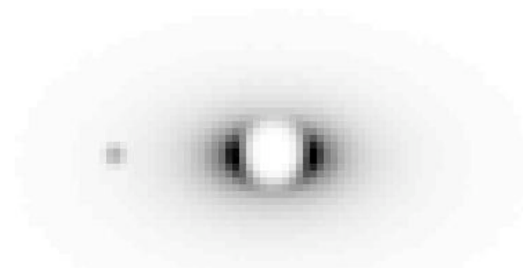
Wavelength (um)	3 λ/D IWA (arcsec)	15 λ/D OWA (arcsec)
0.30	0.100	1.50
0.50	0.170	2.50
1.00	0.340	5.00

Main Science Goal

- Characterize physical properties of **gas giant** and **large rocky exoplanets** with orbits > 1 AU around stars up to at least 10 pc away

- Exoplanet characteristics for potential investigation:
  - Orbit
  - Atmospheric composition
  - Albedo as function of wavelength
  - Effective temperature
  - Clouds and their height above the surface
  - Potentially rotation period, weather
  - Presence of rings
  - Clues about surface, such as liquid water

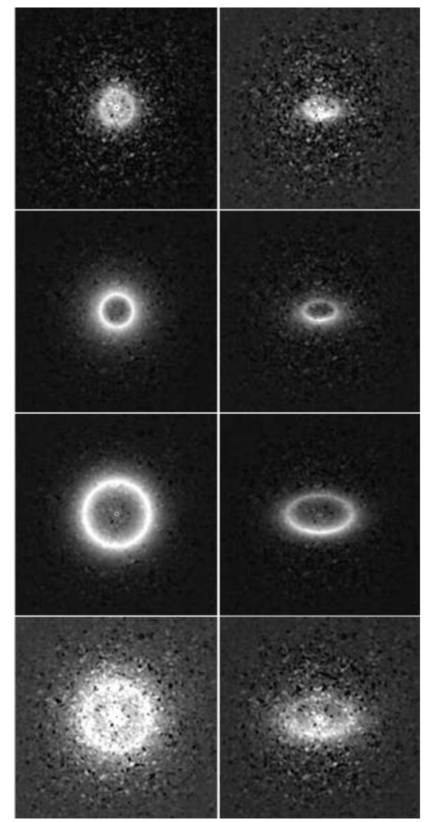
Jupiter around Sun at 10 pc



Super-Earth around Alp Cen A

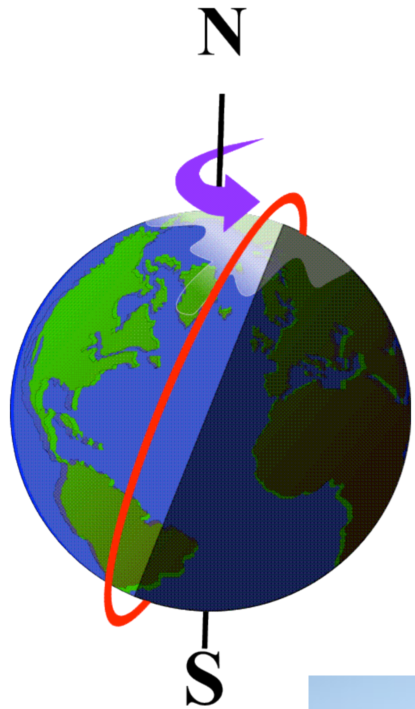
Secondary Science Goals

- Exoplanet system characterization
  - Exo-zodiacal dust
  - Comets
  - Asteroid belts
  - Debris disks (such as Kuiper belts)
- Protoplanetary disk characterization
  - Disk structures and their dynamics
  - Grain size distribution
- Stellar properties and variability
  - Using occulted light



1" and 2" ring-like disk simulation
G. Schneider

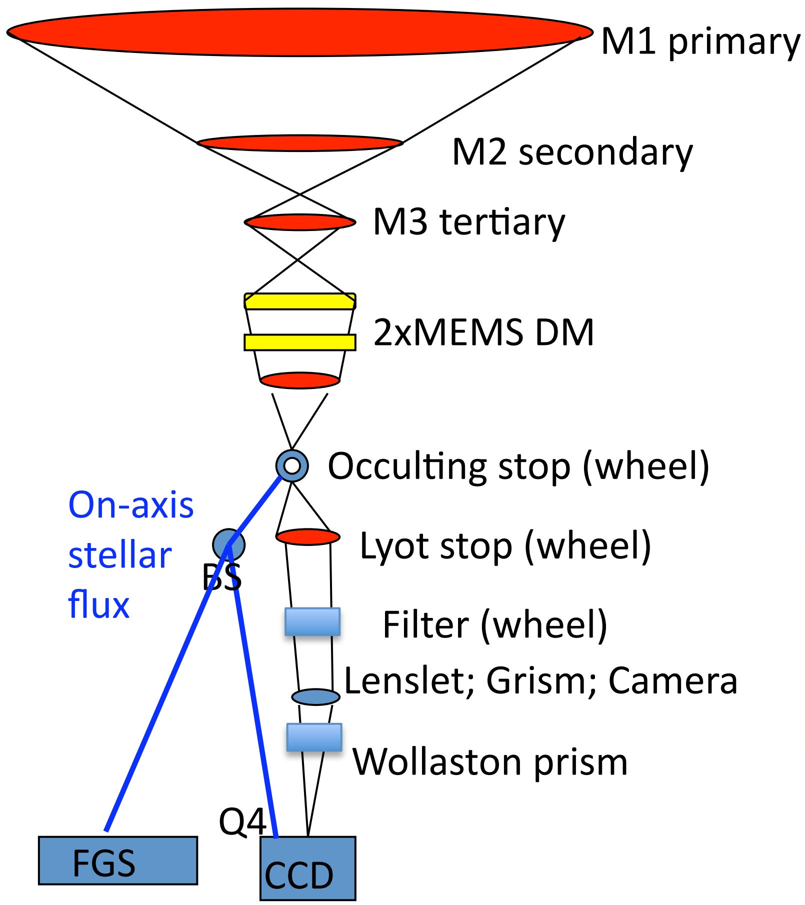
Launch and Orbit

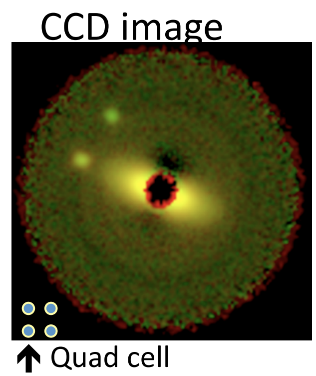


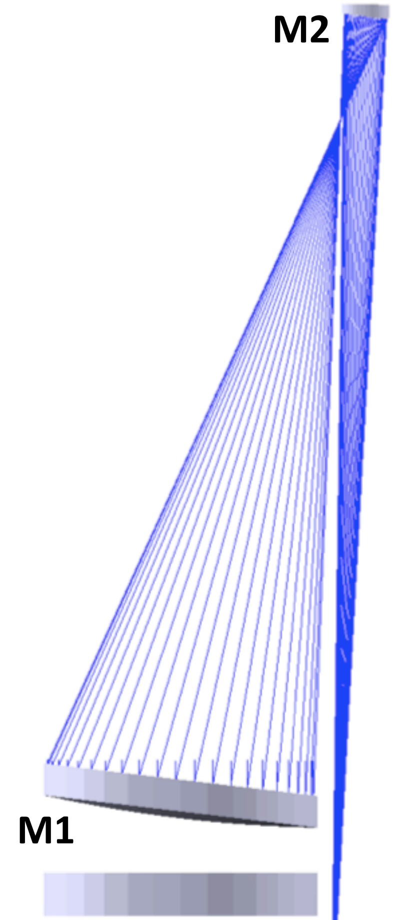
- Launch Vehicle “B”
  - Up to 6800 kg
  - Delta II-like → ~2.5 m fairing
- Polar Orbit
  - Launch from Vandenberg
  - 700 km altitude
  - ~90 minute orbit
    - ~45 min observations
  - Magnetic torquers
    - Point away Earth
- Mission duration 3 years
  - View of whole sky > 2 times

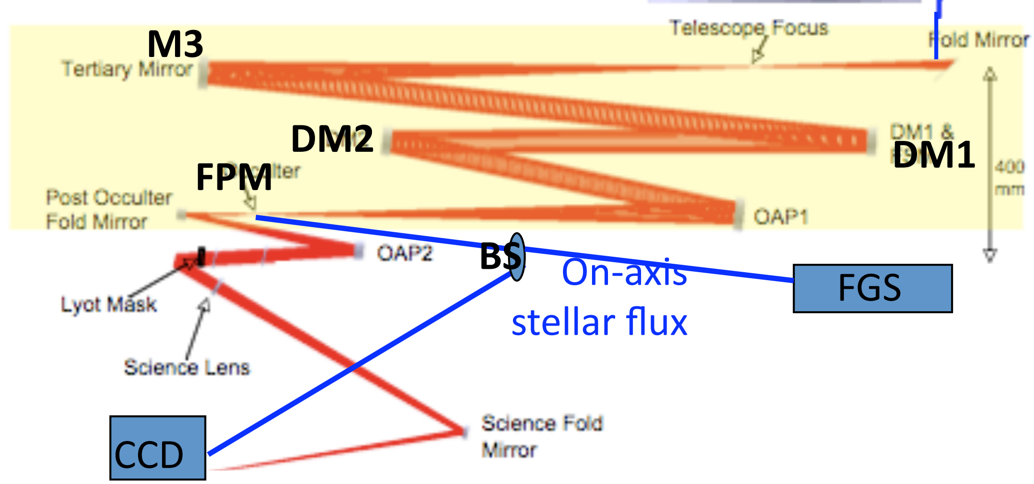
Optical Layout

Off-axis Gregorian; Wavefront sensing via phase diversity; Phase & amplitude conjugation via 2 MEMS deformable mirrors; On-axis stellar flux used for fine guidance (quad cell) and fine guidance wavefront sensing; Wollaston prism





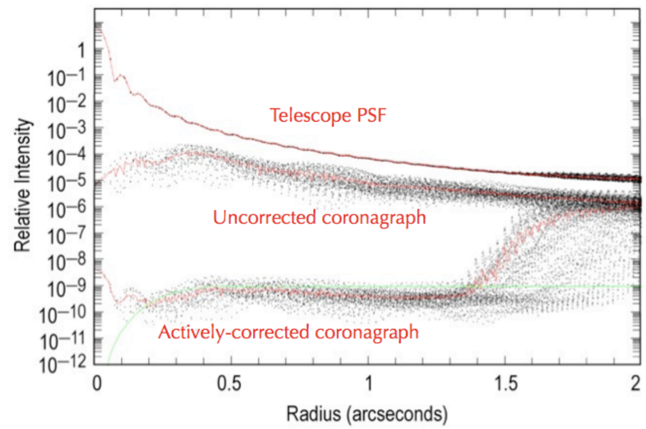




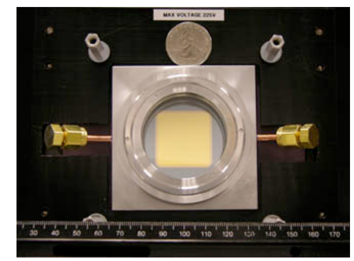
Optical layout details

1.8m primary; 2k x 2k CCD; Two 44 x 44 actuators MEMS DMs; Visible wavelengths

- Suppressing stellar flux:
  - Band-limited Lyot coronagraph
  - 1e-9 contrast
  - Wavelength-dependent
- Sampling and plate scale:
  - Nyquist in B (Plate scale: 70 mas/pix)
  - Field of view: OWA up to 10” at 70 mas/pix = 142 pix max – plus room for spectra R~20
  - 2000 pix detector: plenty of real estate left over for fine-guidance sensing in corner
- Coronagraphic astrometry:
  - Calibrate with sine on MEMS
  - Measure with FGS star in corner of CCD



λ (nm)	IWA	OWA
300	0.10”	1.5”
500	0.17”	2.5”
1000	0.34”	5.0”



<u>Phase conjugation:</u>
MEMS DM
44x44 actuators
2 DMs for phase and amplitude

<u>Wavefront sensing:</u>
phase diversity
Plus FGS

Integral Field Spectrograph

(based on OSIRIS, SPHERE, P1640, GPI, POISE, etc.)

• Lenslet array (after Lyot stop) disperses light from subregions of the pupil plane onto detector

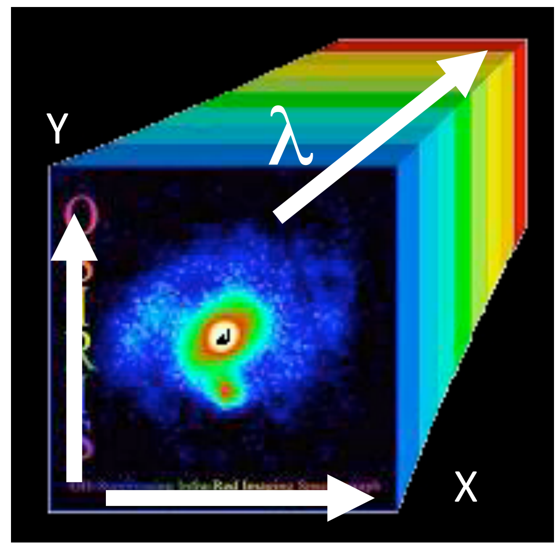
• No moving parts after lenslet array

• Hexagonal lenslets maximize filling factor (from SPHERE design)

• Raw data requires sophisticated post-processing

• Speckles vary spatially with wavelength: speckle suppression method

• R ~ 20, comparable to coronagraphic ground-based IFUs in NIR



• Possible addition of polarimeter after lenslets for marginal additional cost ($100k)

• Visible IFS compliments many NIR instruments on ground-based telescopes

Targets and Observing Plan

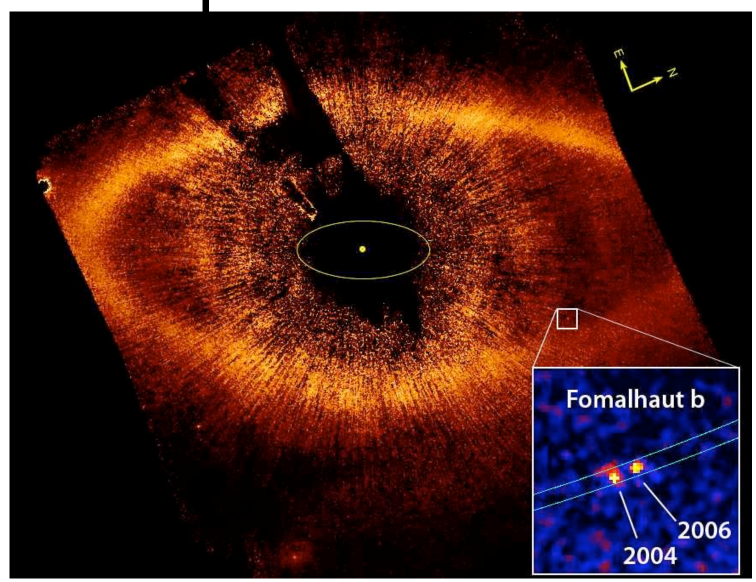
- 23 already detected planets with angular separation larger than 0.1 arcsec

  eps Eridani b, GJ 832 b, 55 Cnc d, HD 160691e, Gj849b, HD190360 b, 47 Uma c, HD 154345 b, ups And d, HD62509b, HD39091 b, 14 Her b, 47 Uma b, gamma Cephei b, HD 217107c, HD89307b, HD 10647 b, HD 117207 b, HD 181433 d, HD 70642 b, HD 128311 c, GJ 317 b, HD 216437 b (exoplanet.eu)

- FGKM metal rich stars @ 0 – 100 pc
- Nearby stars with debris disks

  ~100 objects known to be within 100 pc

  Debris Disk Database:
  http://www.roe.ac.uk/ukatc/research/ddd/query3.php



Kalas et. al. (2009)

Mass and Power

	Mass Fraction	Mass (kg)	Subsys Cont. %	CBE + Cont. (kg)	Power (W)
Payload on this Element					
1.8 m Telescope	46%	500.0	35%	675.0	215
BL Lyot Coronagraph	14%	150.0	43%	214.5	50
BL Lyot Camera	1%	10.0	43%	14.3	10
Vis Spectrograph	5%	50.0	43%	71.5	30
Payload Total	65%	**710.0**	37%	**975.3**	**305**
Spacecraft Bus			do not edit formulas below this line, use the ca		
Spacecraft	32%	350.0	30%	455.0	
S/C-Side Adapter	2%	25.0	5%	26.3	
Bus Total		375.0	28%	481.3	
Thermally Controlled Mass				481.3	
Spacecraft Total (Dry)		1085.0	34%	1456.6	
Subsystem Heritage Contingency		371.6	34%	34%	
System Contingency		95.0	9%	9%	131
Spacecraft with Contingency		**1552**	of total	w/o addl pld	**131**
Propellant & Pressurant1	4%	67.0			
Spacecraft Total (Wet)		**1619**			
L/V-Side Adapter		25.0			
Launch Mass		**1644**			
Launch Vehicle Capability		**6800**			
Launch Vehicle Margin		**5156.5**			
JPL Design Principles Margin		**84%**	**30% required**		

Data rates well within spacecraft downlink capacity of
80,000 kbps X band
8 min downlink
per 90 min orbit
38400 Mb

S/C + instrument data
21222 Mb/orbit

17178 Mb/orbit for CCD reads

S/C data storage capacity
100,000 Mb

- Using "Spacecraft D" modified ($) to accommodate a bit more mass.
- Power within bus limit.
- Spacecraft wet mass well within launch vehicle margins.

Cost

Cost Summary (FY2009 $M)	Total: 1086 M
Development Cost	**888 M**
01.0 Project Management	31 M
02.0 Project Systems Engineering	31 M
03.0 Mission Assurance	25 M
04.0 Science	10 M
05.0 Payload System	450 M
05.1 BL Lyot coronagraph	70 M
05.2 Visible spectrometer	30 M
05.3 1.8 meter primary off-axis	350 M
06.0 Flight System	150 M
07.0 Mission Operation Preparation	15 M
08.0 Ground Data System	15 M
09.0 ATLO	41 M
10.0 Education and Public Outreach	3.2 M
11.0 Mission and Navigation Design	7 M
Development reserves	120 M
Operations Cost	**51.75 M**
Operations	45 M (for 3 yrs)
Operations reserves	6.75 M
Launch Vehicle (Vehicle B)	**136 M**

Risks

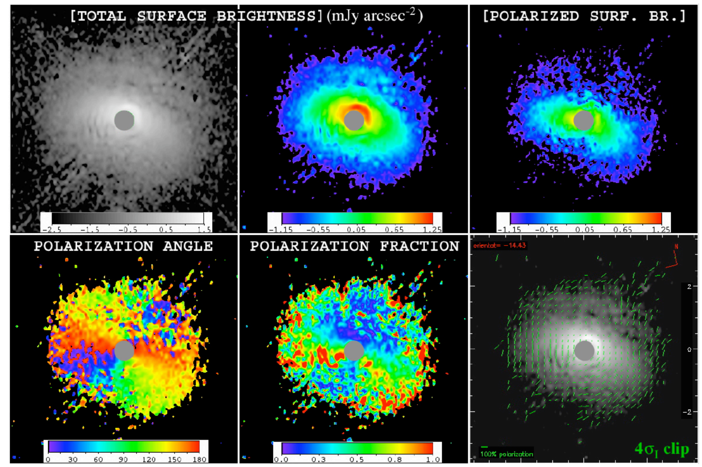
- Coronagraph technology development (not issue)
  - Already achieved for BL Lyot at 3 L/D
    - Mission science performance/spectrograph not at risk
  - Deformable Mirrors TRL 6 but need flight qual (moderate)
    - Can use Xinetics DMs or Boston MEMs DMs
  - Phase diversity proven in lab, will demonstrate in flight (moderate)

- Pointing control (moderate)
  - Already achieved body-pointing w/spacecraft bus
  - Instrument fine-control feedback loop with spacecraft

- Thermal and mechanical stability in LEO (low)
  - Reduced by riding terminator in polar orbit
  - Mag torquers used for Earth avoidance (minimal interference)
  - Momentum wheels operate only in acceptable regime

Summary

- Mature technology coronagraph
- Ready for 2014 launch
- Smallest IWA for optical space-based coronagraph
  - 3 λ/D, 1e-9 contrast
- With spectrograph, R~20 from 0.3 to 1.0 um



- Will study 100s of nearby stars in 3 year mission
  - Characterize tens of previously-detected planets
  - Large terrestrial planets, gas giants, disks
    - See disks over 100 times fainter than Spitzer
- Complements JWST, extends spectral coverage
- Follow-up & characterize new RV detected planets

Acknowledgments

- **Live Long and Prosper!**
- Acknowledgments: NExScI, JPL Team-X