Transneptunian Automated Occultation Survey TAOS II

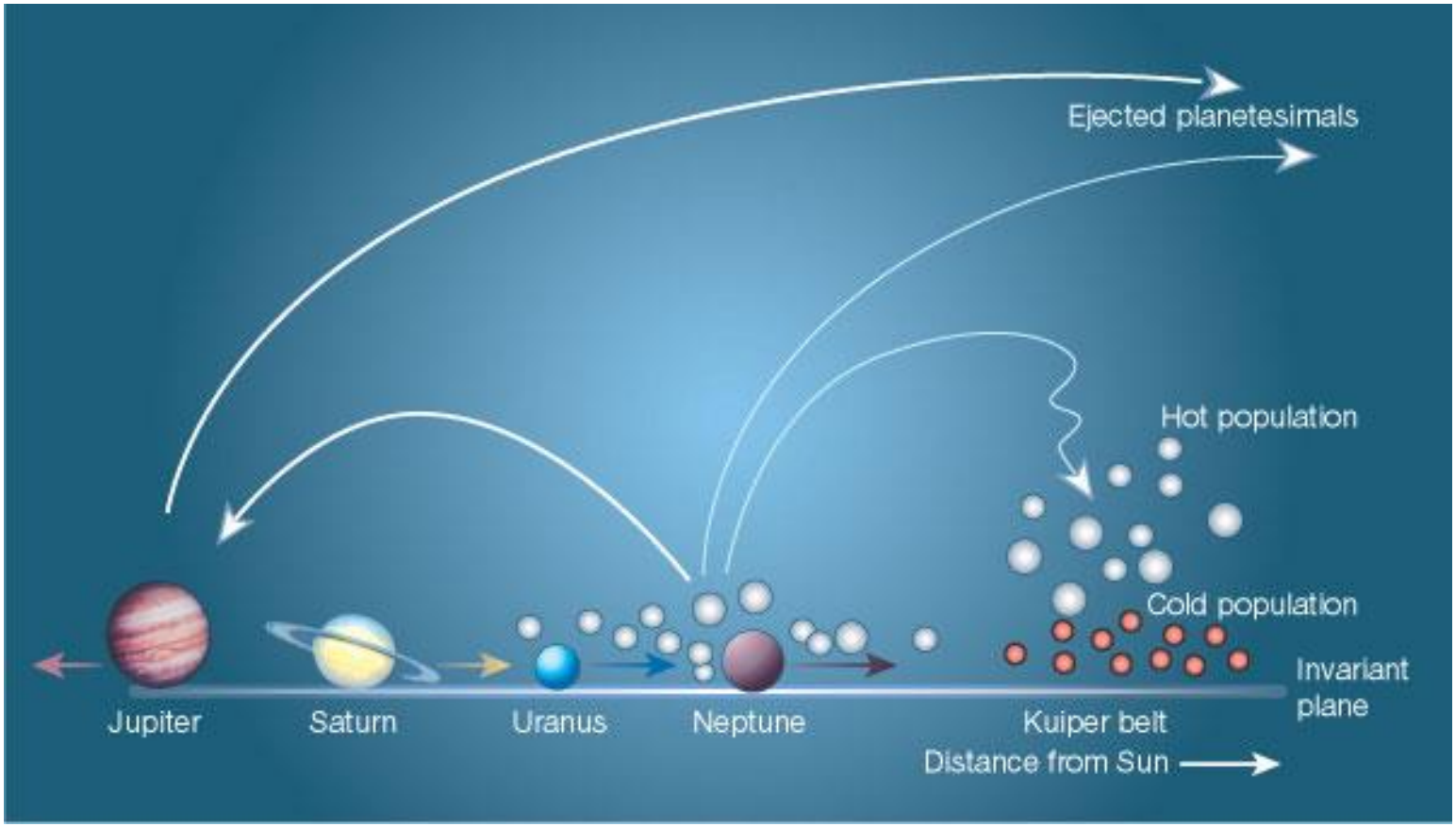
Shiang-Yu Wang and TAOS 2 team

ASIAA

TAOS 2 collaboration

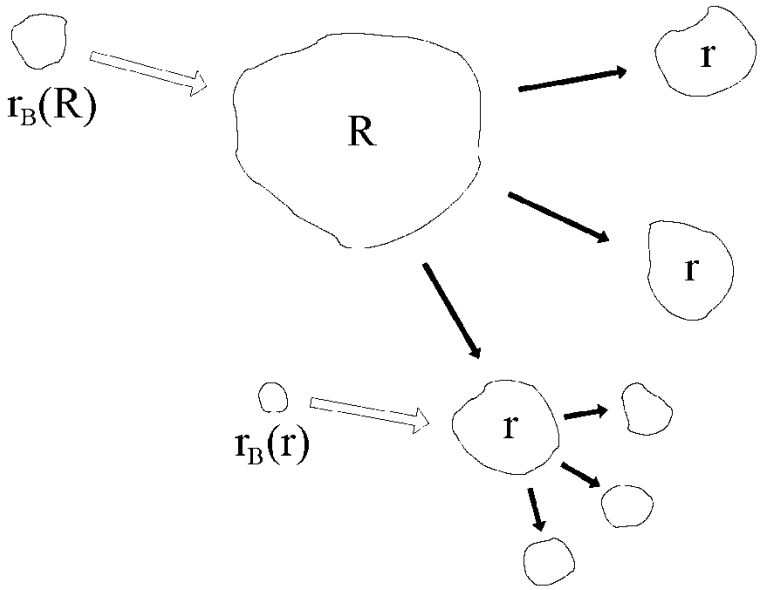
- ASIAA : Shiang-Yu Wang, Matt Lehner, Kiwi Zhang, Kem Cook, Dae-Won Kim, Wei-Lin Yen , Kevin Huang + Instrumentation lab
- UNAM: Mauricio Reyes Ruiz, Liliana Figueroa + SPM staff
- CfA: Tim Norton, John Geary, Steve Amato, Andrew Szentgyorgyi

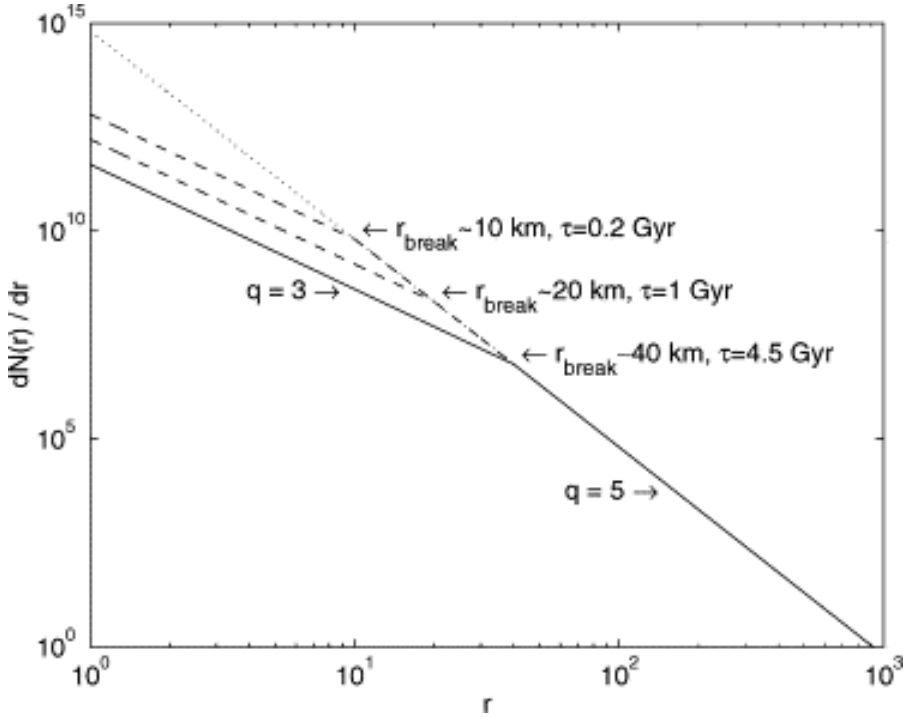
Evolution of the Outer Solar System



Morbidelli & Levison (2003)

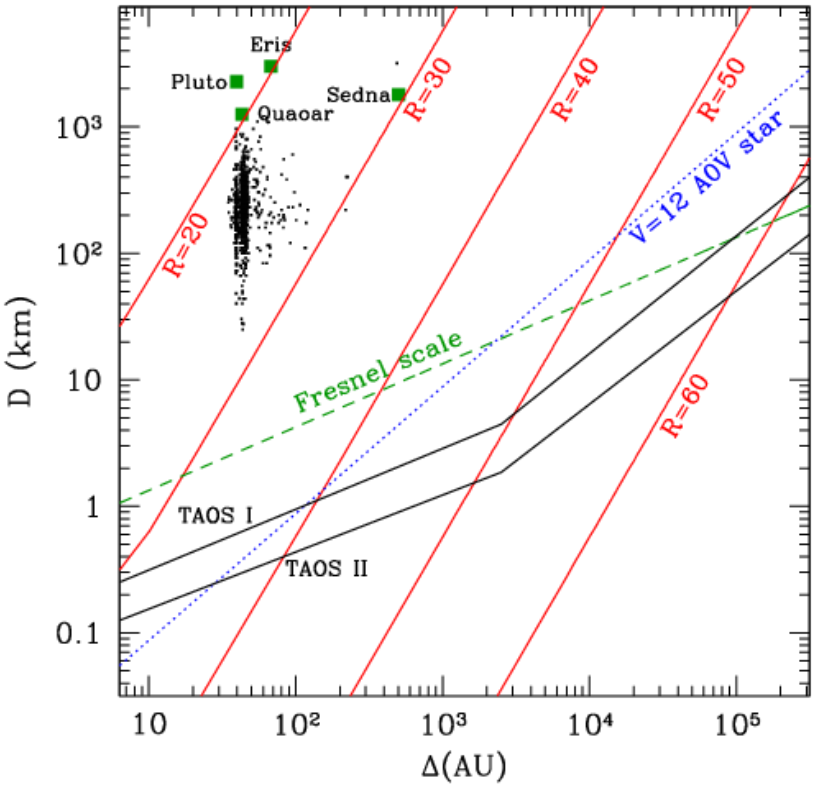
Collisional Erosion





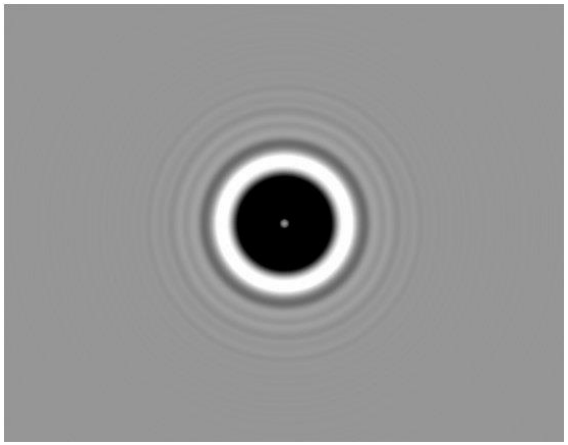
Small Size TNOs

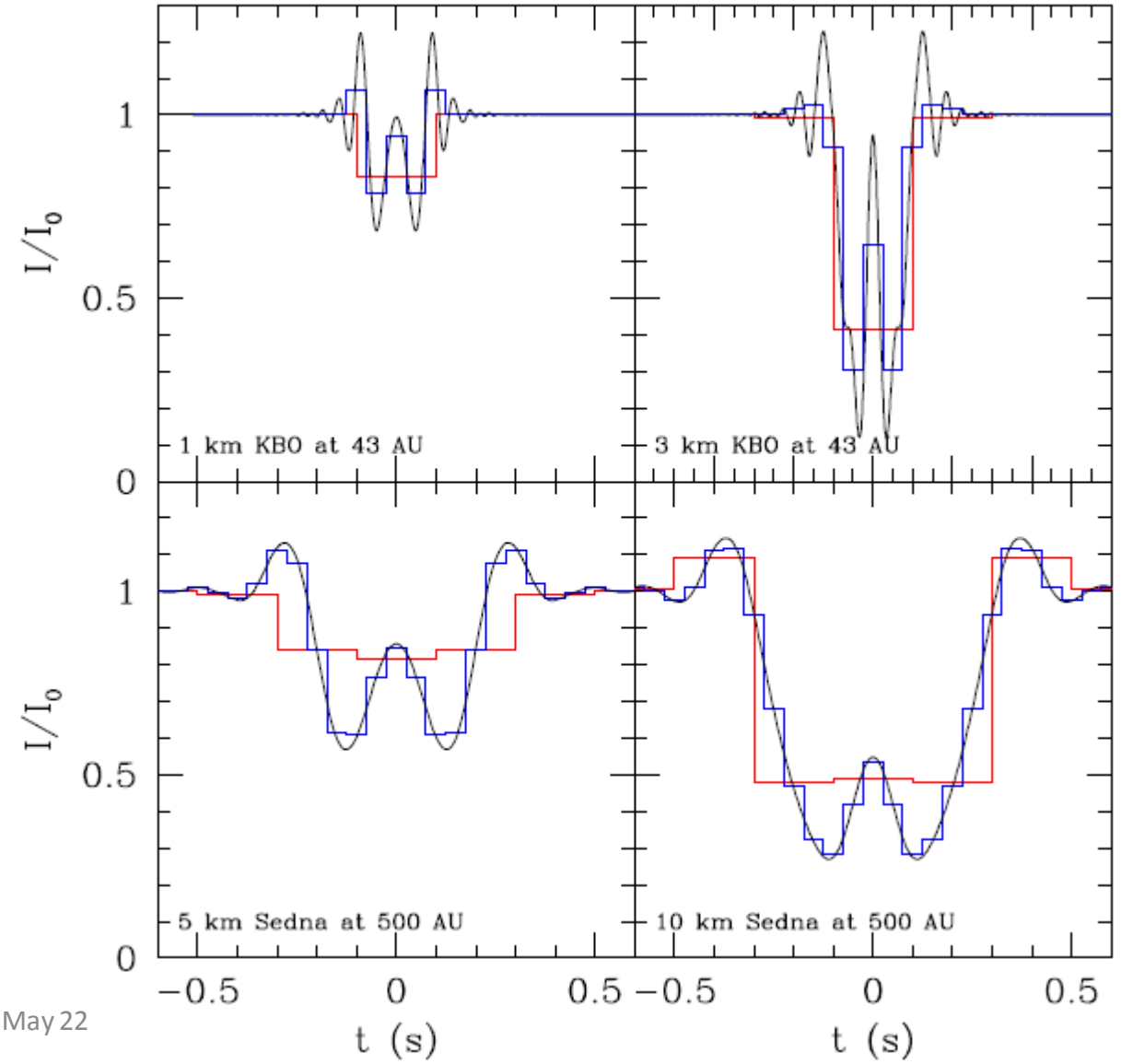
A blind occultation survey to detect faint (~1 km diameter) objects in the outer Solar System



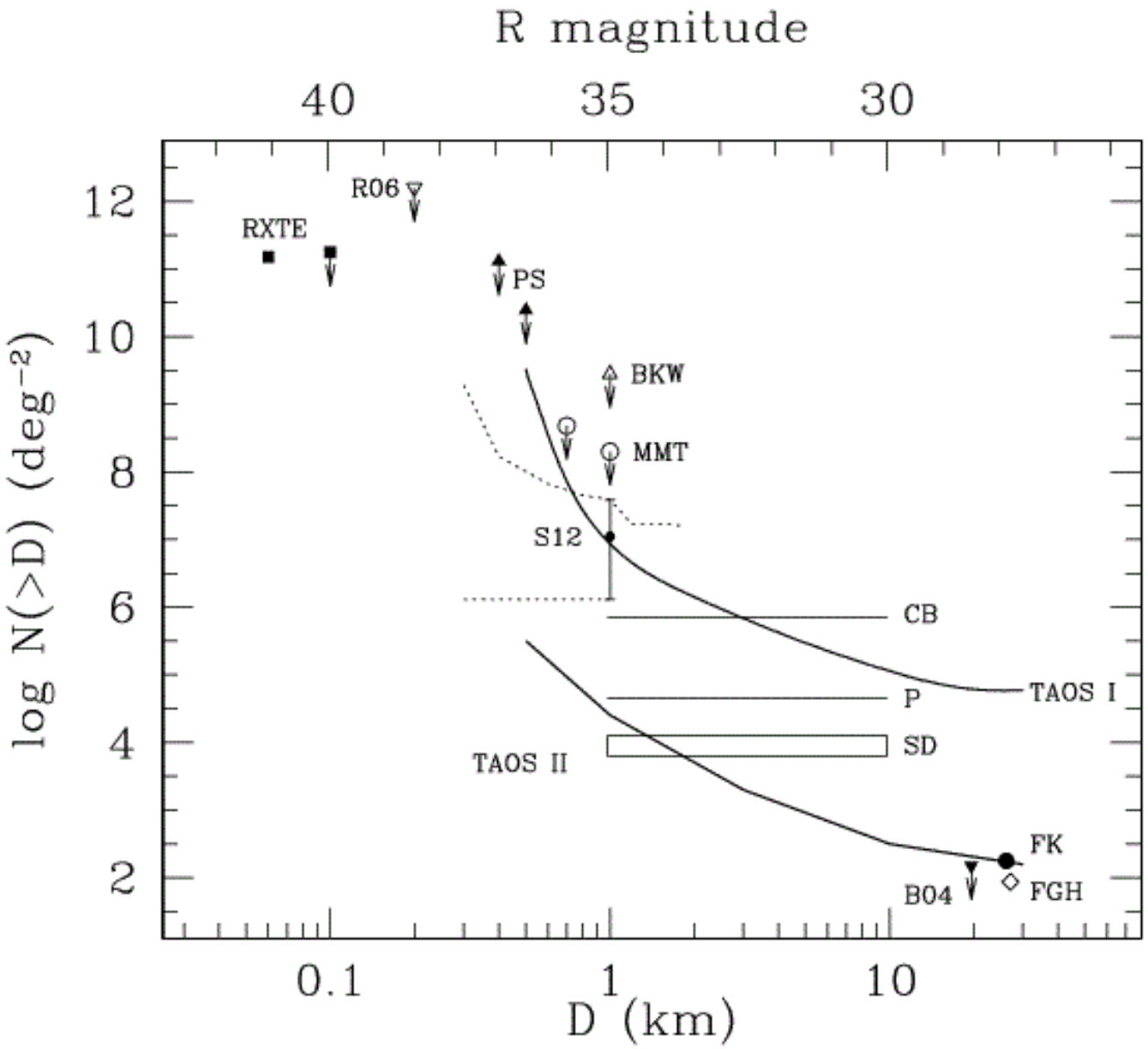
- Direct searches well-suited to objects larger than R ~30 km
- Occultations of bright stars can reveal smaller and/or more distant objects
- No orbital information
  - → Can measure inclination distribution if enough events.

Diffraction Shadow





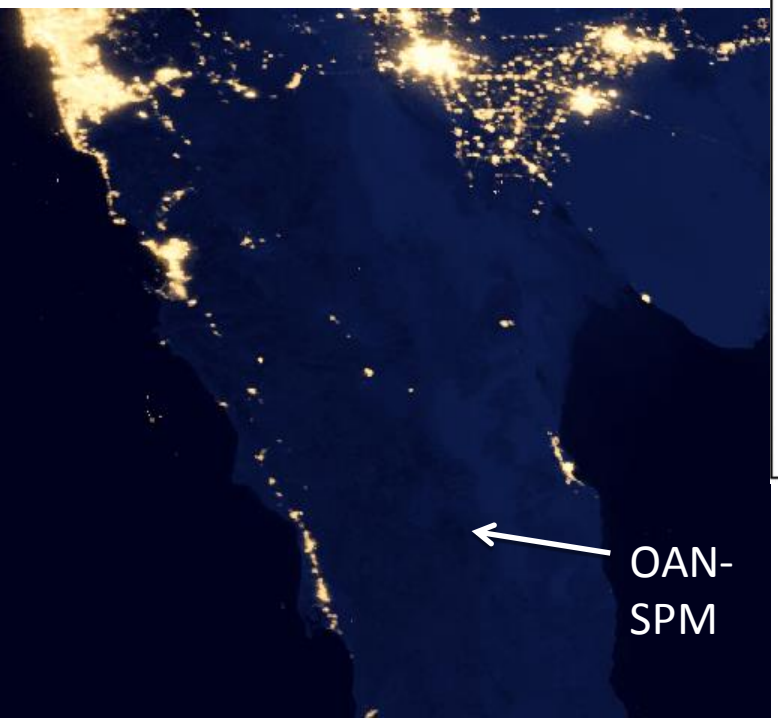
Taiwanese American Occultation Survey (TAOS I)

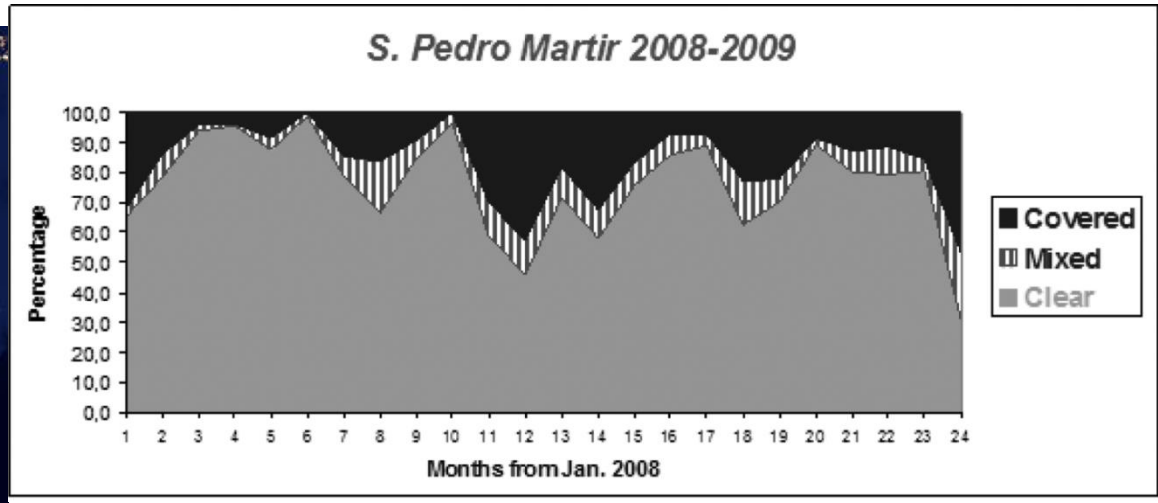

R magnitude
40
35
30
log N(>D) (deg^{-2})
12
10
8
6
4
2
R06
RXTE
PS
BKW
MMT
S12
CB
P
SD
TAOS I
TAOS II
FK
FGH
B04
0.1
1
10
D (km)

TAOS II System

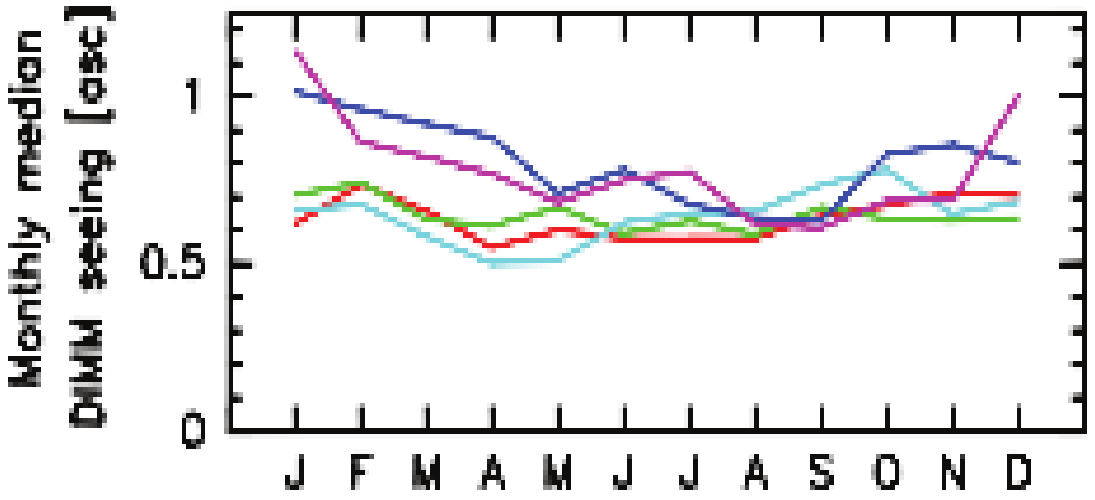
- Follow >10,000 stars simultaneously
  - Event rate <0.001/star/year
  - 1.3m, F/4, FoV 1.7 degree telescopes. R_{lim} = 17.5 @ 20Hz (5σ)
- 20-40Hz High speed imaging
  - Event duration ~200 ms, significant diffraction: 20 Hz sampling rate
  - Custom CMOS imagers: multiple sub-frame readout
- Minimize false positive rate with 3 telescopes
  - Require coincident detection in multiple telescopes
  - Telescopes separated by >100m to minimize false positives from scintillation
  - Three identical telescope systems separated by 130m to 320m

San Pedro Mártir

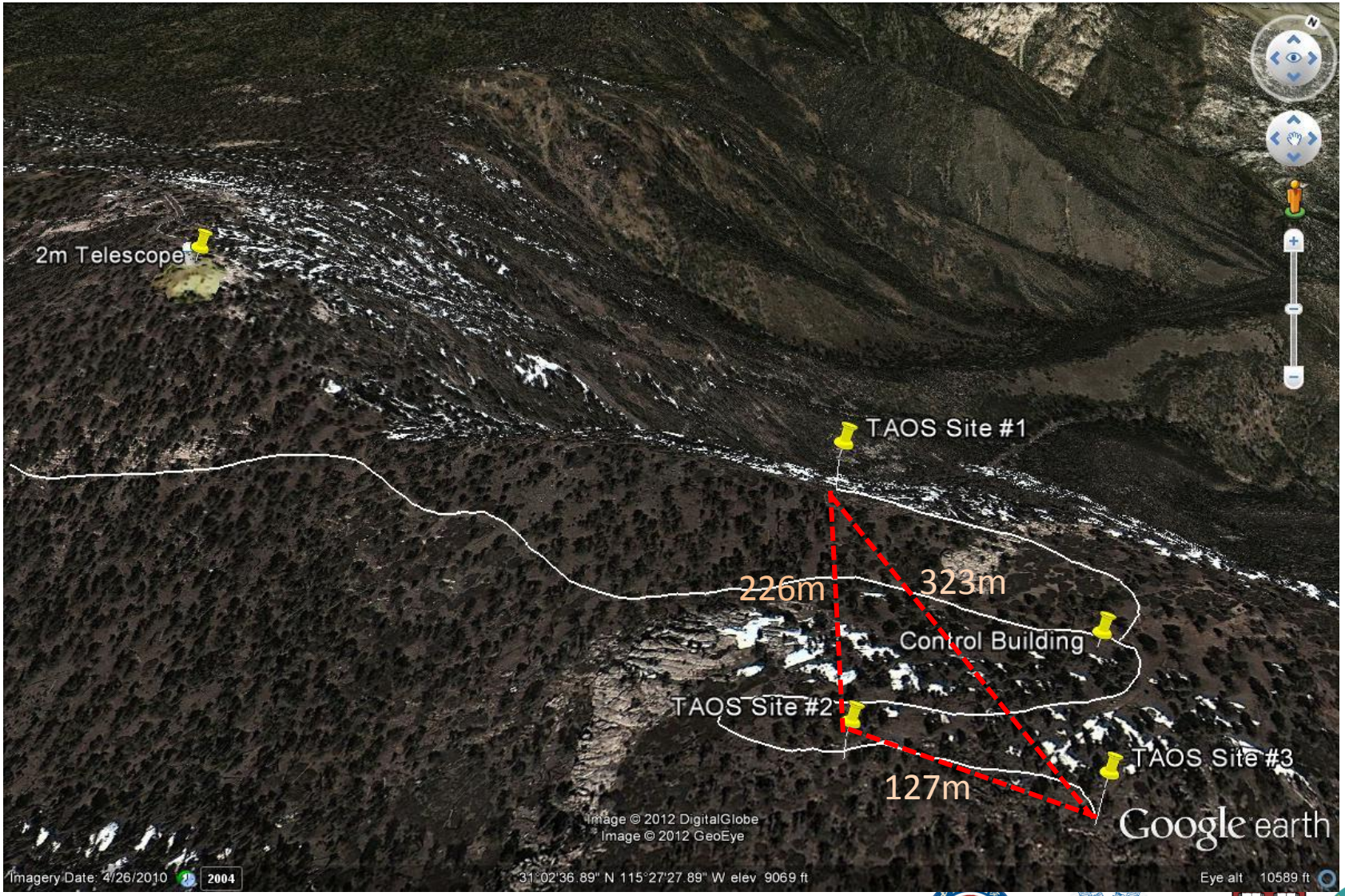




Filter	Average	Std.Dev.
U	21.49	0.60
B	22.23	0.34
V	21.45	0.36
R	20.90	0.46
I	19.52	0.90



Site Development




Site #1
Site #3
Site #2

Three TAOS II Telescopes Completed by DFM

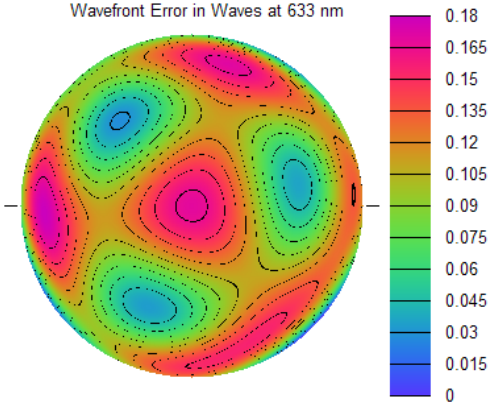
Telescope #1 (J705)

FringeXP Test Report

Mirror Description: J 705 System Test
Coma and Astigmstism Removed
Avrage of 5 Test N Rotated 45 Degrees counter clock wise
Tested by: Renee
Date: 6-27-13

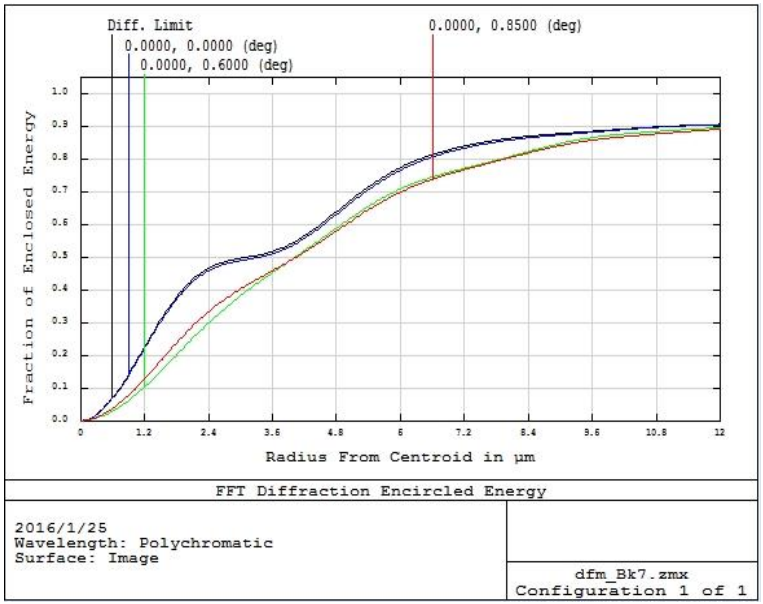
At 633 nm: RMS Wavefront Error = 1/28.8 waves
Strehl Ratio = 0.954
RMS Surface Error = 10.97 nm
P-V Wavefront Error = 1/5.558 waves

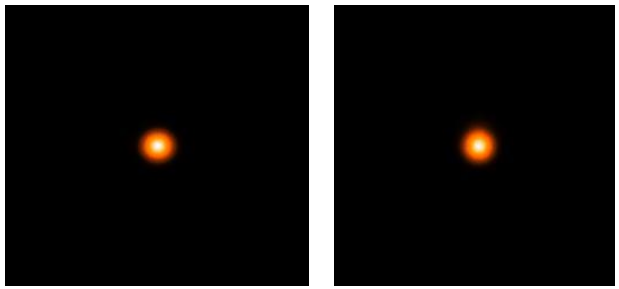
Wavefront Error in Waves at 633 nm

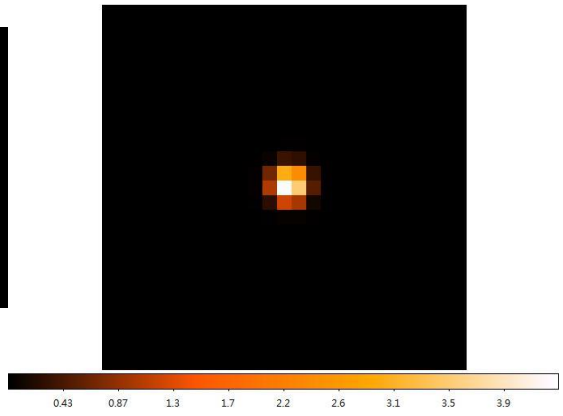


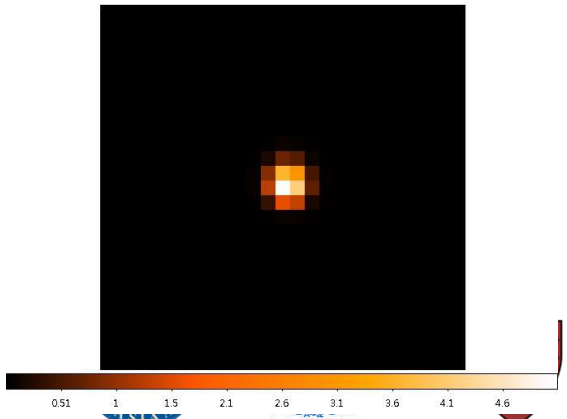
Zernike Coefficients

	X	Y		
Z0	4.56		Removed	Piston
Z1, Z2	-0.963	2.48	Removed	Tilt
Z3	-0.16		Removed	Defocus
Z4, Z5	0.142	0.0382	Removed	Astigmatism
Z6, Z7	0.0826	0.186	Removed	Coma
Z8	0.025			Sph. Ab.
Z9, Z10	-0.0354	0.00709		
Z11, Z12	-0.087	-0.0812	Removed	
Z13, Z14	-0.00886	0.0344	Removed	
Z15	-0.0531			
Z16, Z17	0.029	0.00225		
Z18, Z19	0.0584	-0.0376		
Z20, Z21	0.0362	0.0212	Removed	
Z22, Z23	-0.0195	0.0236	Removed	
Z24	-0.0147			





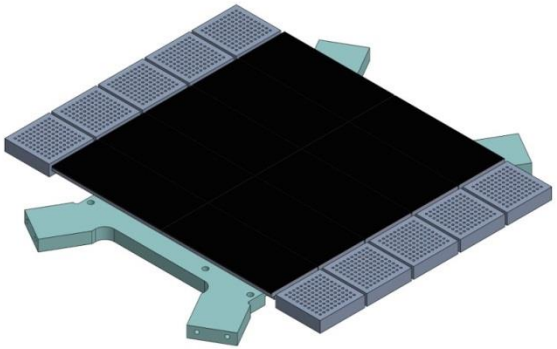


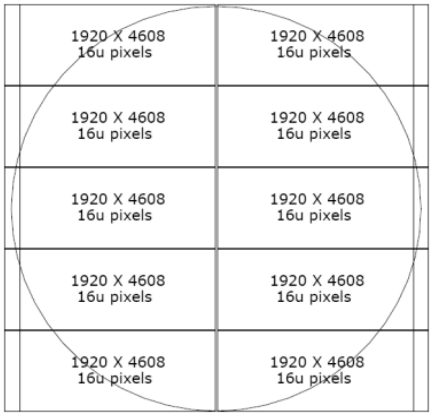


Cameras

- High speed readout with low noise
- Custom CMOS from e2v
  - 1920×4608 3-edge buttable
  - Back illuminated
  - Sub-aperture readout, onboard CDS

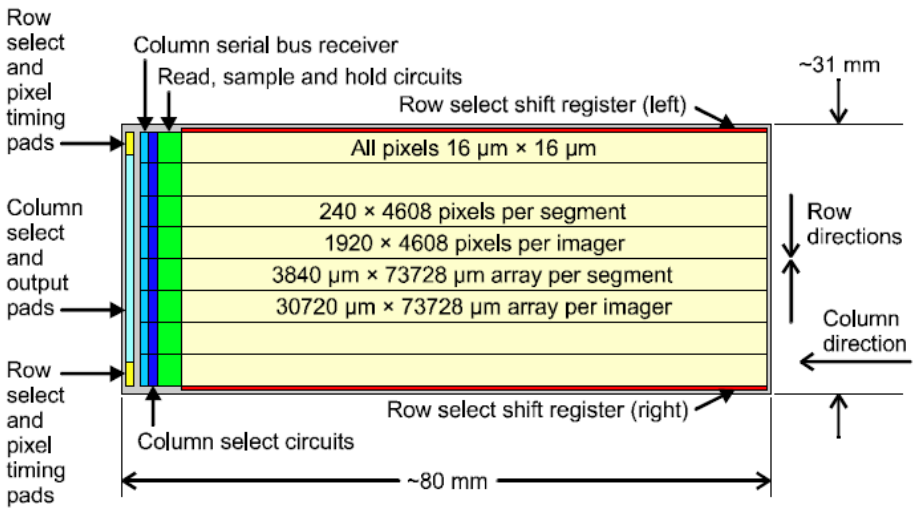
- One prototype cameras with test device
  - Smaller pixel 1Kx2K
  - For the control system tests on site
- Science camera with 10 mosaic CMOS sensors

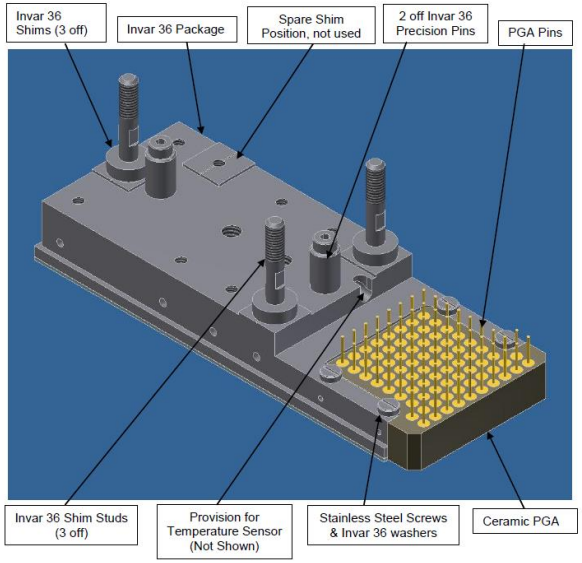


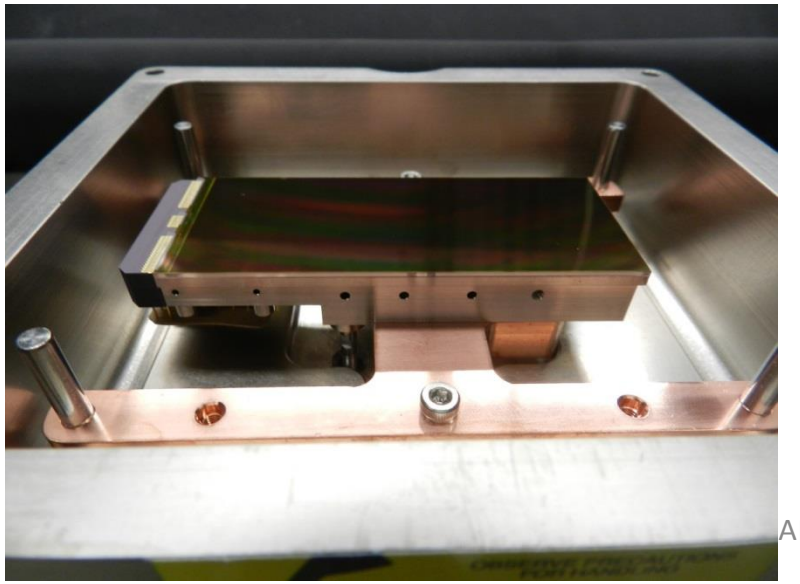


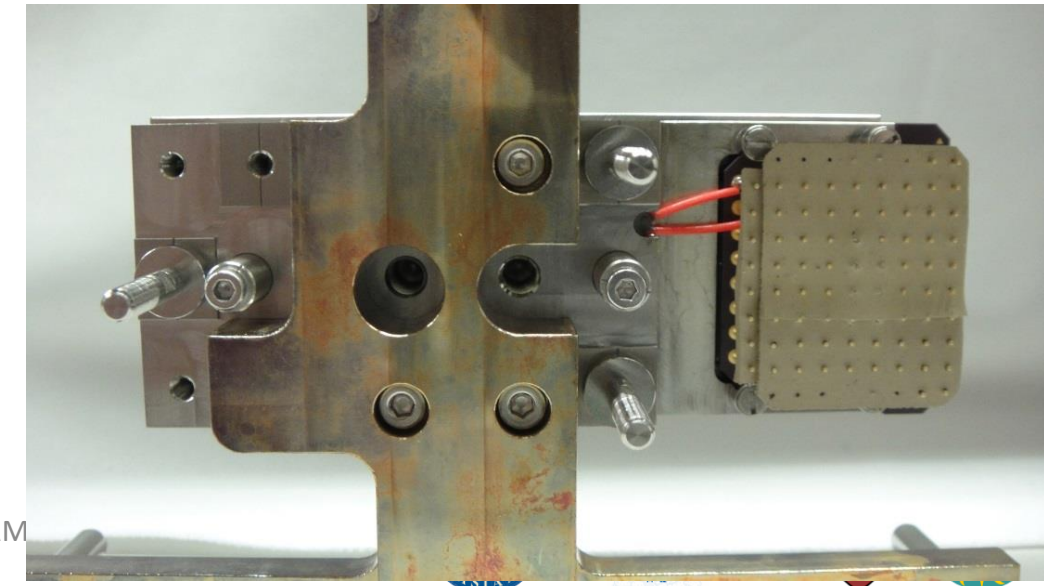
154 mm TAOS focal plane

Custom CMOS Devices from e2v (CIS 113)





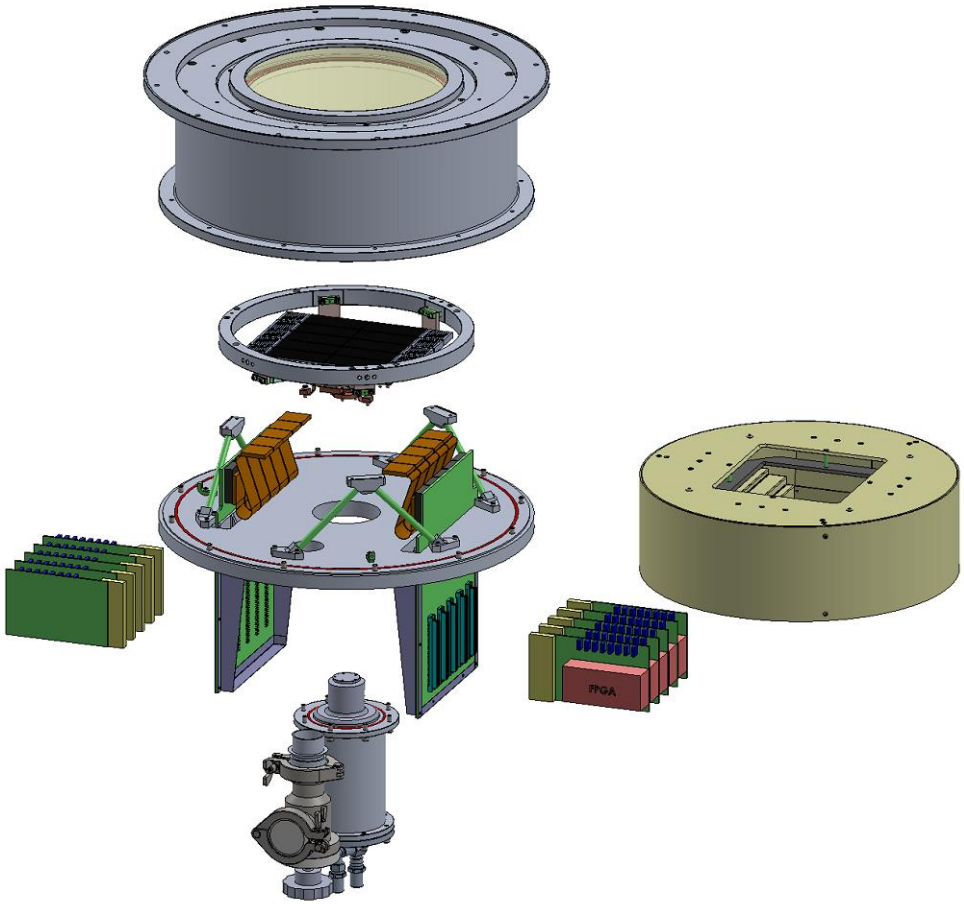


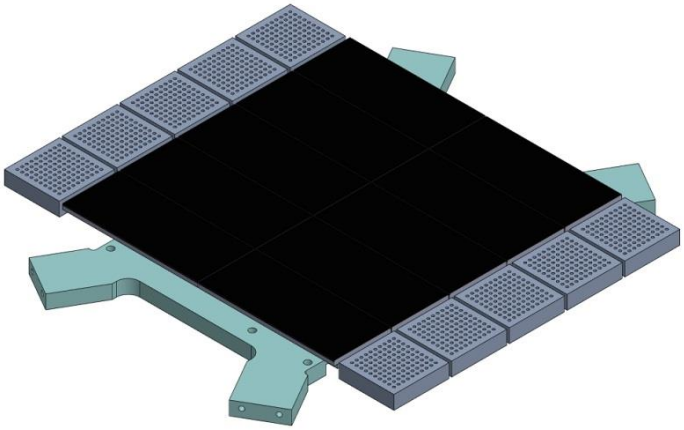


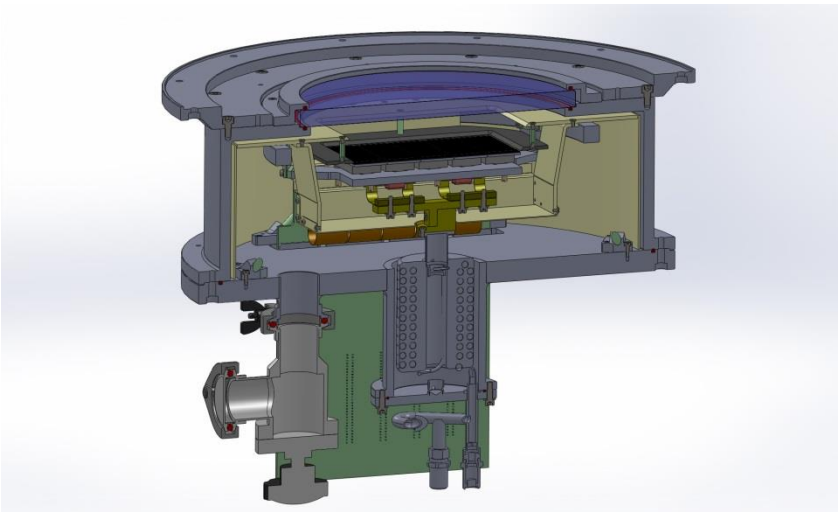
Test Results of CIS 113 Device by e2v

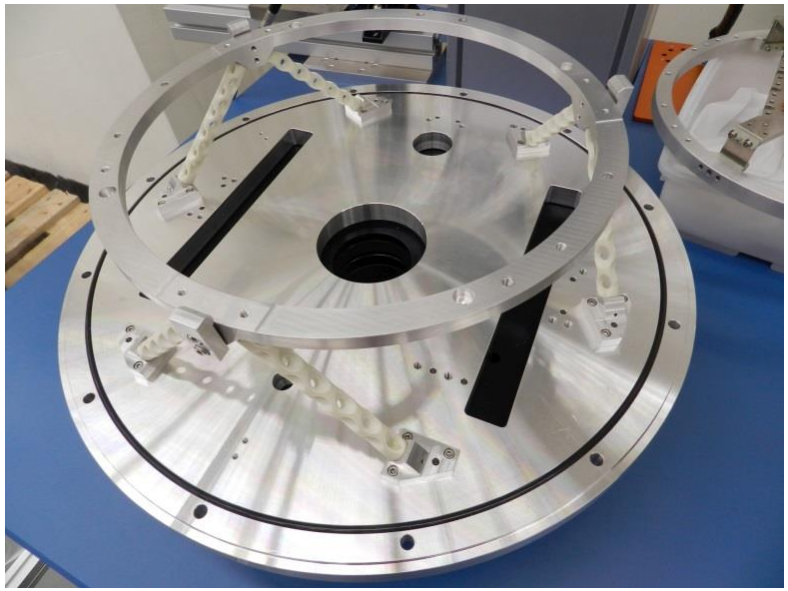
Parameter	Measured value	Specifications	Units
Q_{LIN}	15.5	15	ke^-
Q_{SAT}	19	17.5	ke^-
CVF	91	80	$\mu V/e^-$
Minimum Lag	**4.1**	1	%
RON	2.3	7	e^-_{RMS}
PRNU	2.0	3	$\%_{RMS}$
MOVS	1.61	1.4	V
QE @800nm	47	>20	%
FSR	1.2	1.2	V
Non Linearity	0.8	5	%
Dark current	0.14	0.5	e^- /pix/s @0°C
Dynamic Range	75.2	66	dB

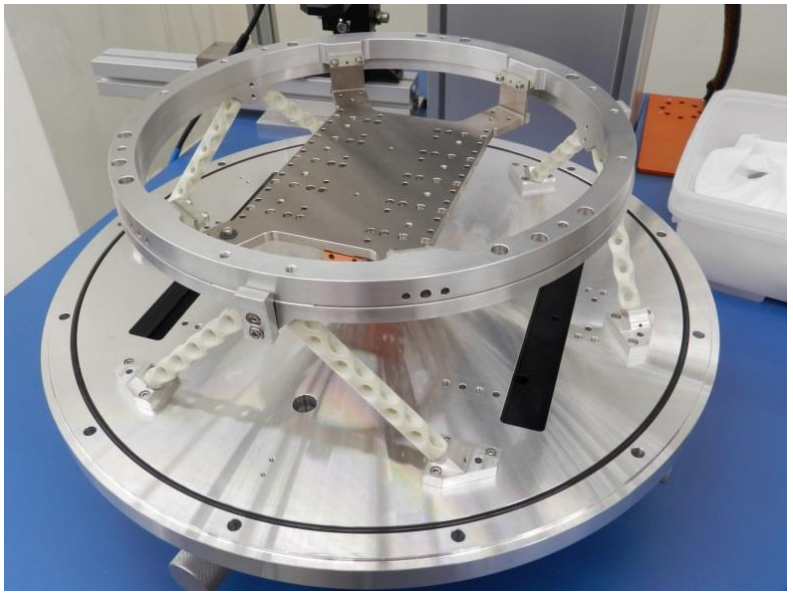
Camera Design

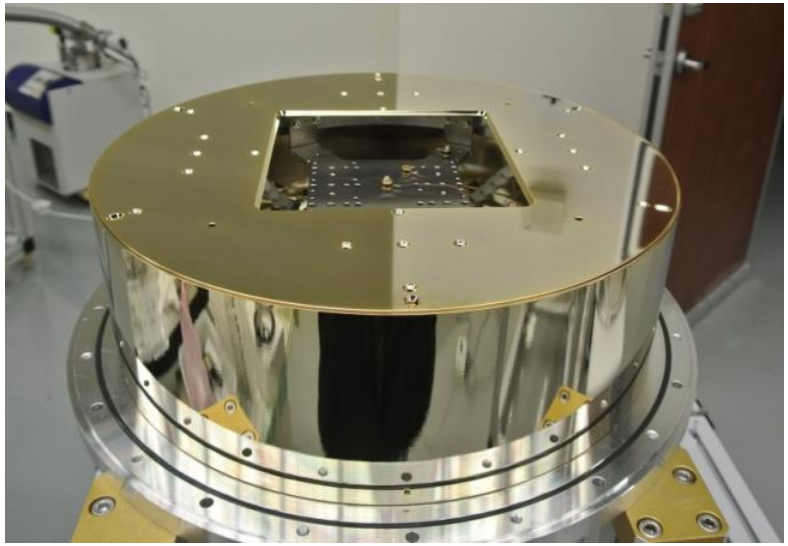


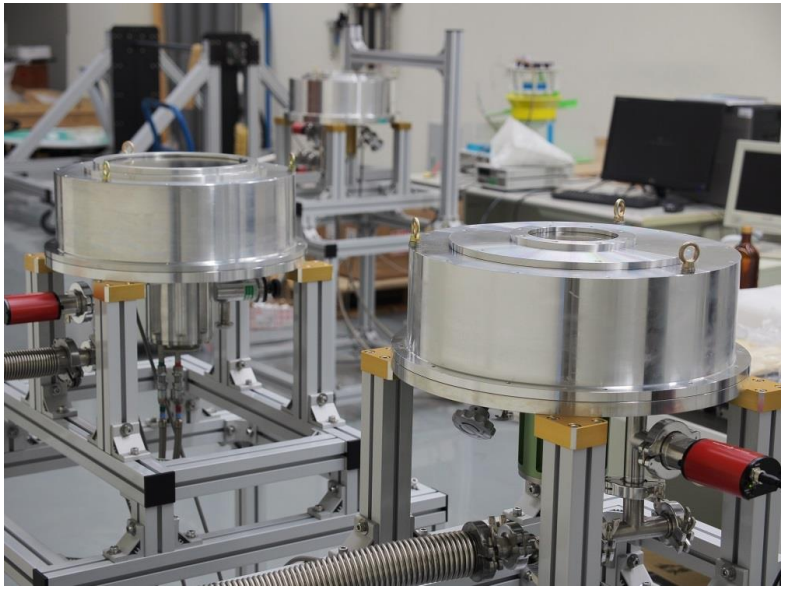










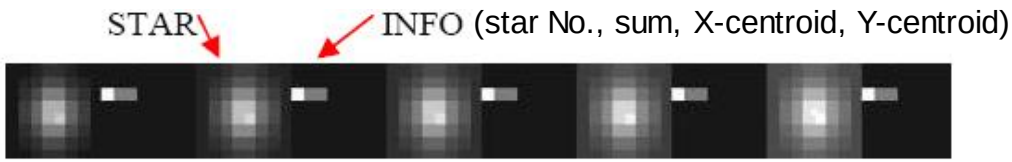


Data Volume

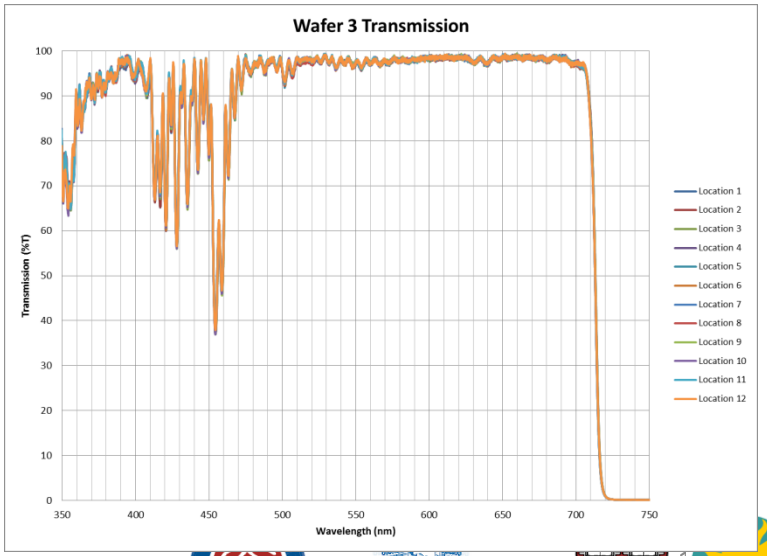
- ~150 bytes per star image
  - 7×7 aperture (nominal), 2 bytes per pixel
  - 24 bytes aperture photometry
  - 28 bytes PSF fit photometry
- 17 billion star images per night
  - 3 telescopes
  - 20 Hz (some stars at 40 Hz)
  - 10,000 stars
  - Average 8 hours per night
- 2.6 TB per night!
  - 1 to 1.5 TB compressed

TAOS 2 Data Set

- ~30 target fields
  - Stay in the same field for 2-3 hours
  - Long term monitoring of the photometry of 300000 stars at 20Hz or higher
  - At least for 3 years
  - Wide band (standard filter might be installed after we get enough data)
- Field acquisition and focus images
  - Can be stacked into deep images



8x8 star box pixel data with information package



Prospective

- Project readiness review April 2016
- Start enclosure construction Sep 2016
- Install telescopes Mar 2017
- Last delivery of CMOS devices by April 2107
- Finish cameras June 2017
- Start survey late 2017

Summary

- TAOS II development is in the final phase
- Science operation will start in late 2017
- Obtain small TNO size distribution in 2020
- Interesting data set will be generated for science topics other than TNOs
- Collaboration from EA countries are welcome