ZWICKY TRANSIENT FACILITY

Observing System Update

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20 May 2016
University of Maryland

Outline

- ZTF Observing System Overview
  - System Capabilities
- ZTF Program Status
- ZTF Technical Status
  - Detectors and Electronics
  - Cryostat
  - Optics
  - Filter Exchanger
  - Exposure Shutter
  - Instrument Software
  - Telescope Modifications
- ZTF Data System Status (Frank Masci's talk)

ZTF SYSTEM OVERVIEW

Zwicky Transient Facility

(Palomar Mountain)

ZTF builds on success of PTF / iPTF

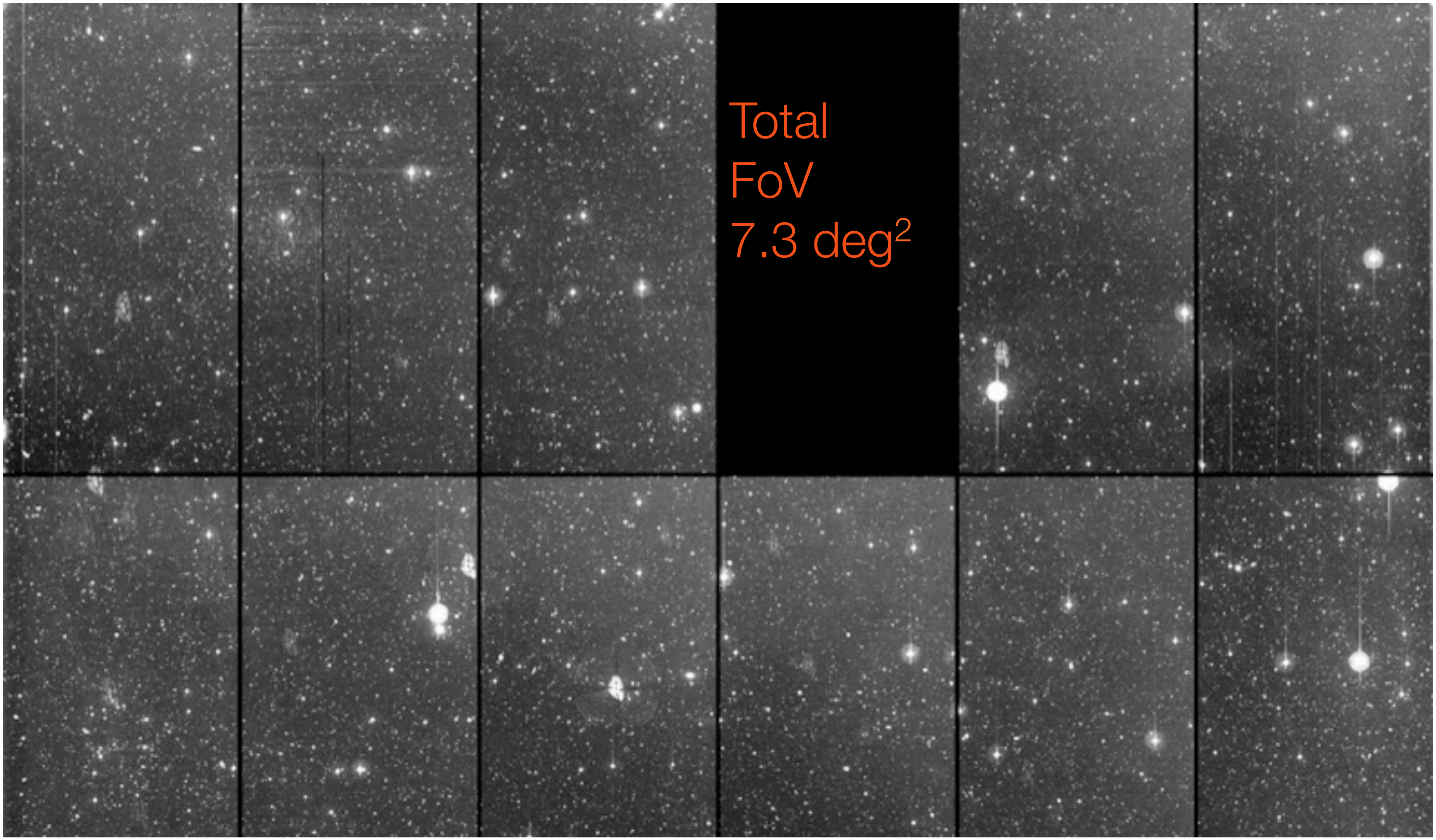
- Retain PTF strategy of a wide-field survey:
  - Limited filter set
  - High cadence
  - Sophisticated data pipelines
  - Deep follow-up capabilities

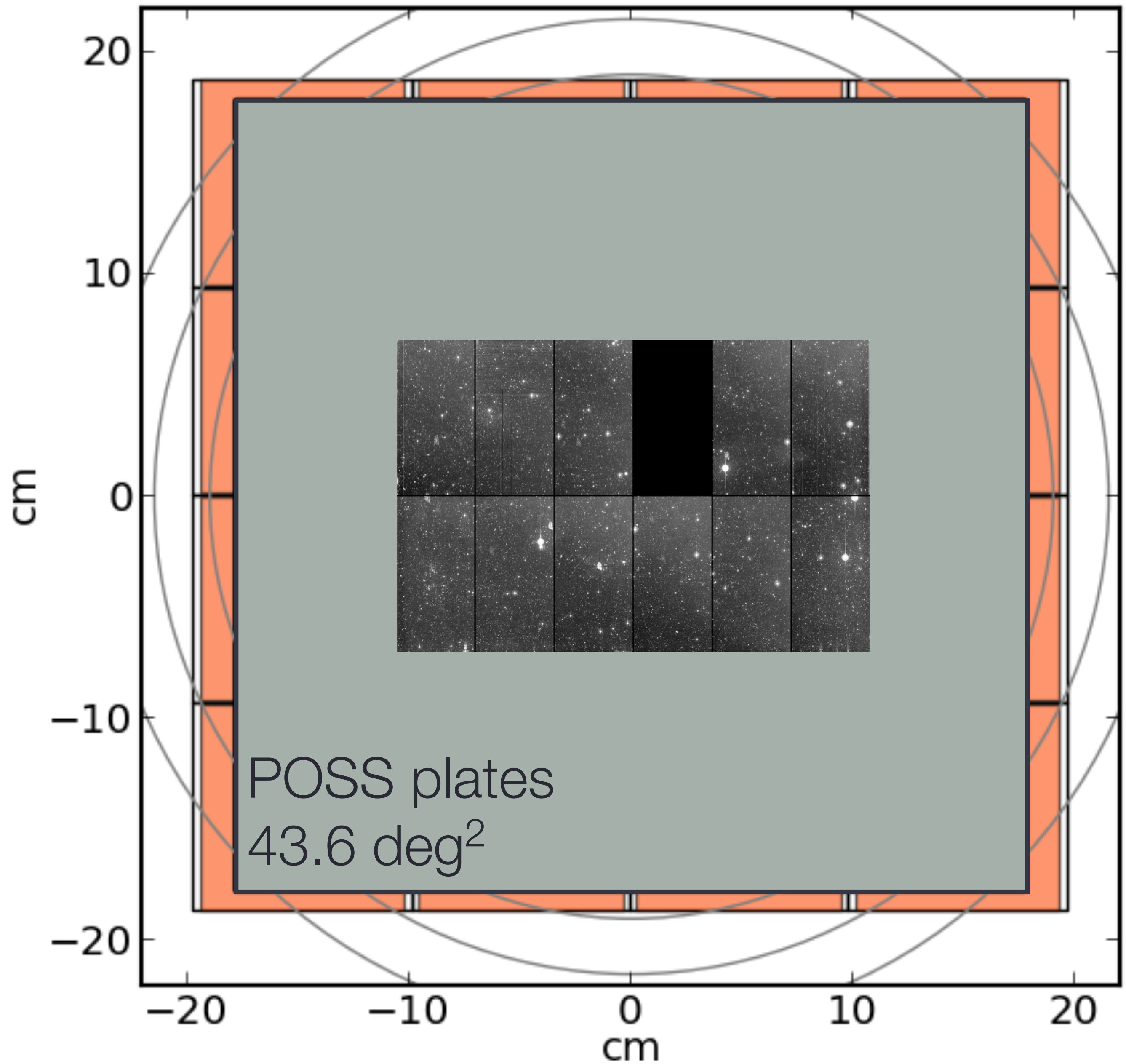
- Enable new parameter spaces
  - = Increase volumetric survey speed
    - *Spatial volume within which a transient of fixed absolute magnitude (-19) can be detected, divided by (exposure + overhead time) – E. Bellm*
      - Roughly proportional to transient detection rate

ZTF builds on success of PTF / iPTF

- Increase volumetric survey speed
- To do this:
  - Increase field of view
    - Maintain spatial sampling
  - Maintain transient magnitude limit $m_{apparent}$ = 20.5 suited to follow-up
    - Aperture, delivered image quality, sky background, detector QE and noise, optical transmission
  - Increase observing efficiency
    - Readout overhead, telescope slew, dome slew, windscreen
  - Increase productivity
    - Transient pipeline and data archive, *much* larger data processing and storage, flat-field screen

For all its success, PTF is small!




POSS plates
43.6 deg²
20
10
0
−10
−20
cm
−20
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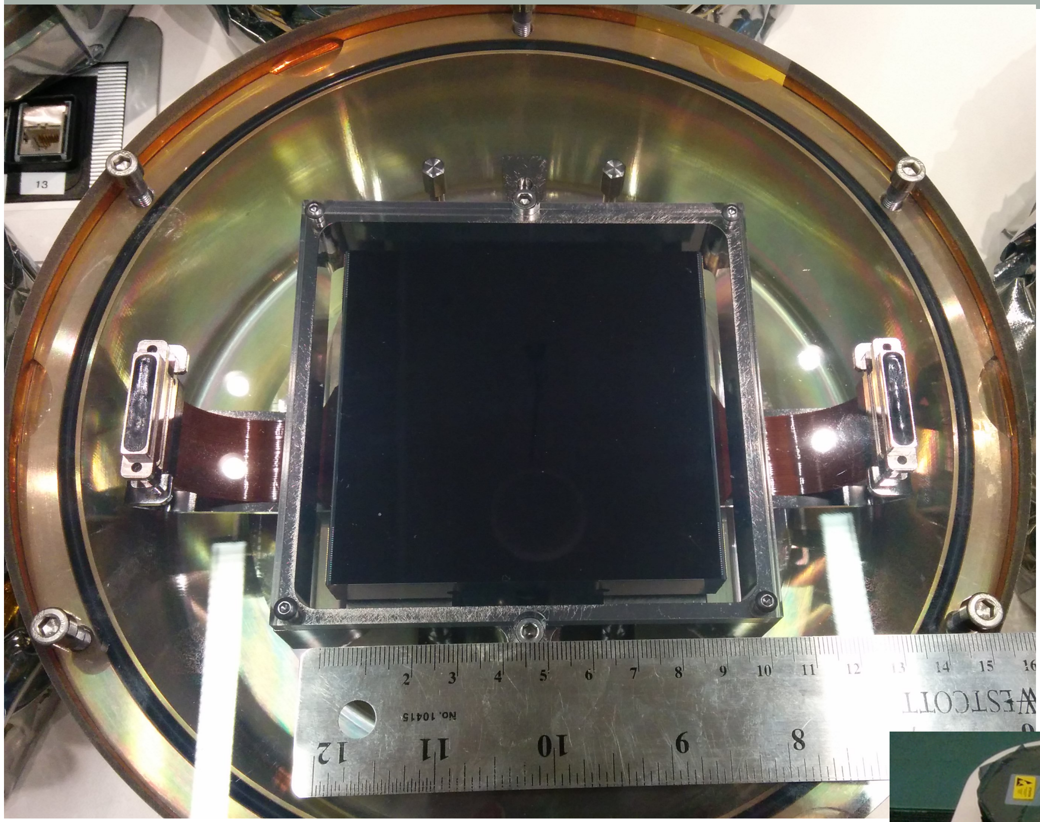
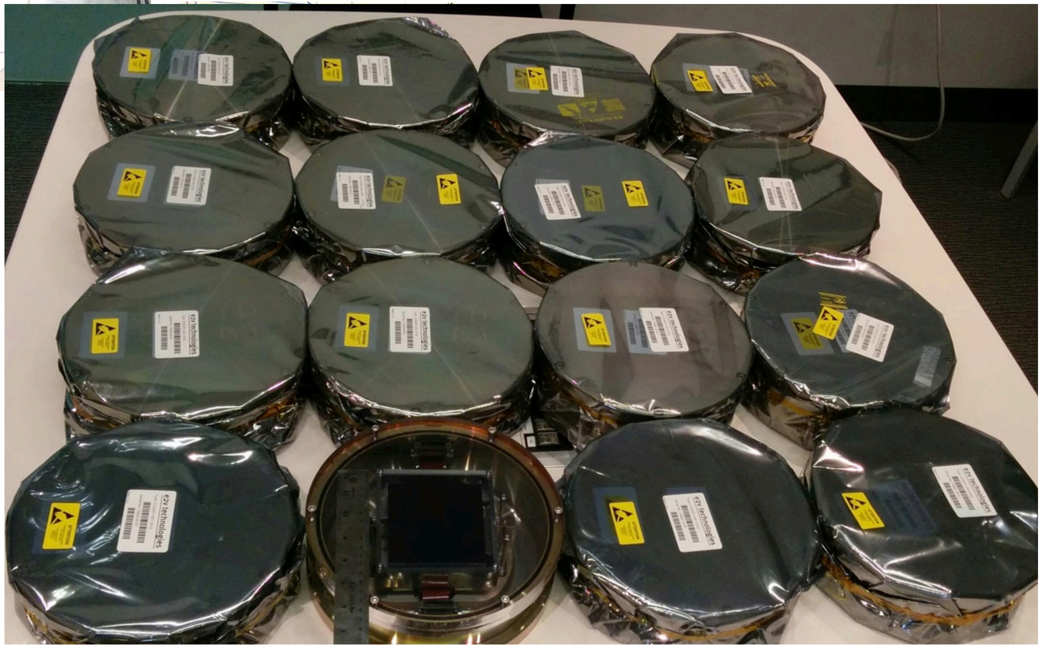
10
20
cm

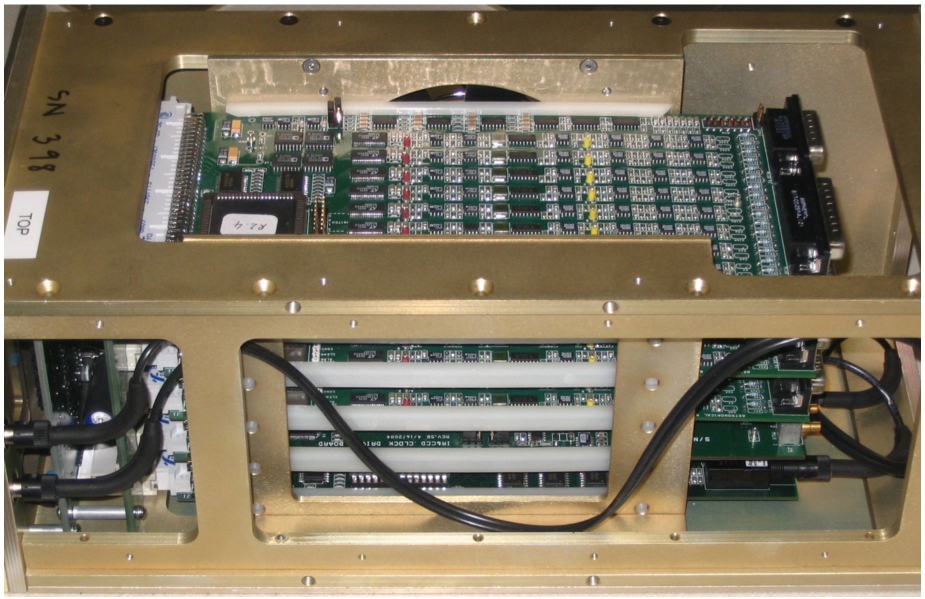


e2v CCD231-C6	
dimension	9.2 x 9.2 cm
pixels	6.1k x 6.1k
pixel size	15 micron
pixel scale	1”/pixel
outputs	4

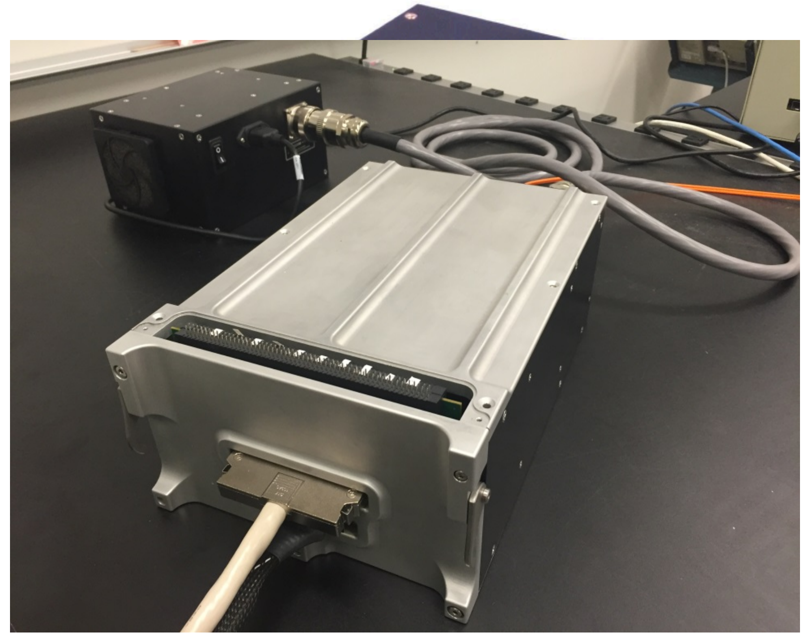


16 ZTF CCDs delivered
(plus one more for P200 WaSP camera)

ZTF will reduce readout overhead compared to PTF



PTF
2000-era Leach Gen-II controller
36 second readout of 96 Mpx

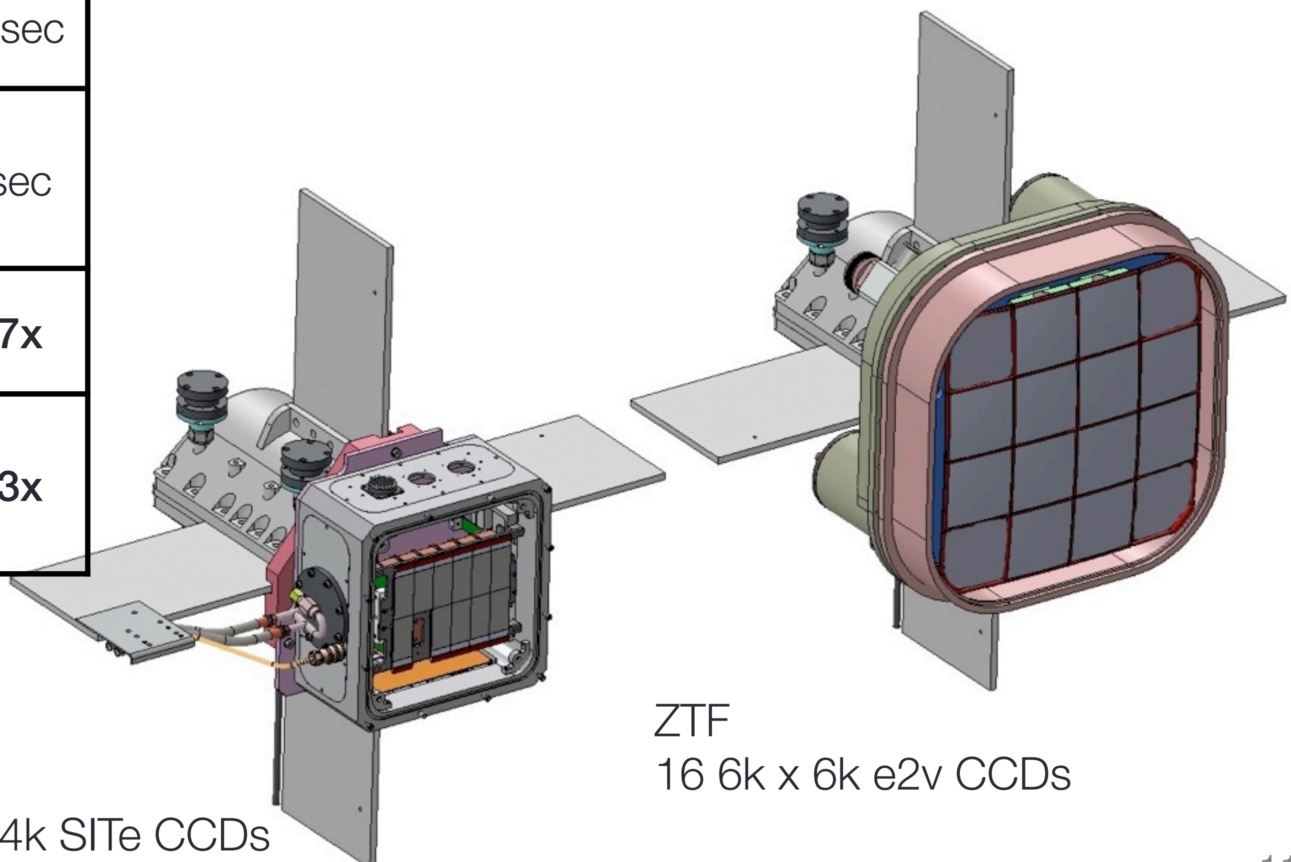


ZTF
2014-era STA Archon
10 second readout of 576 Mpx
(tested so far @ ~20 sec read)

ZTF surveys order-of-magnitude faster than PTF

	PTF	ZTF
Active Area	7.26 deg^2	47 deg^2
Overhead Time	46 sec	<15 sec
Optimal Exposure Time	60 sec	30 sec
Relative Areal Survey Rate	1x	**14.7x**
Relative Volumetric Survey Rate	1x	**12.3x**

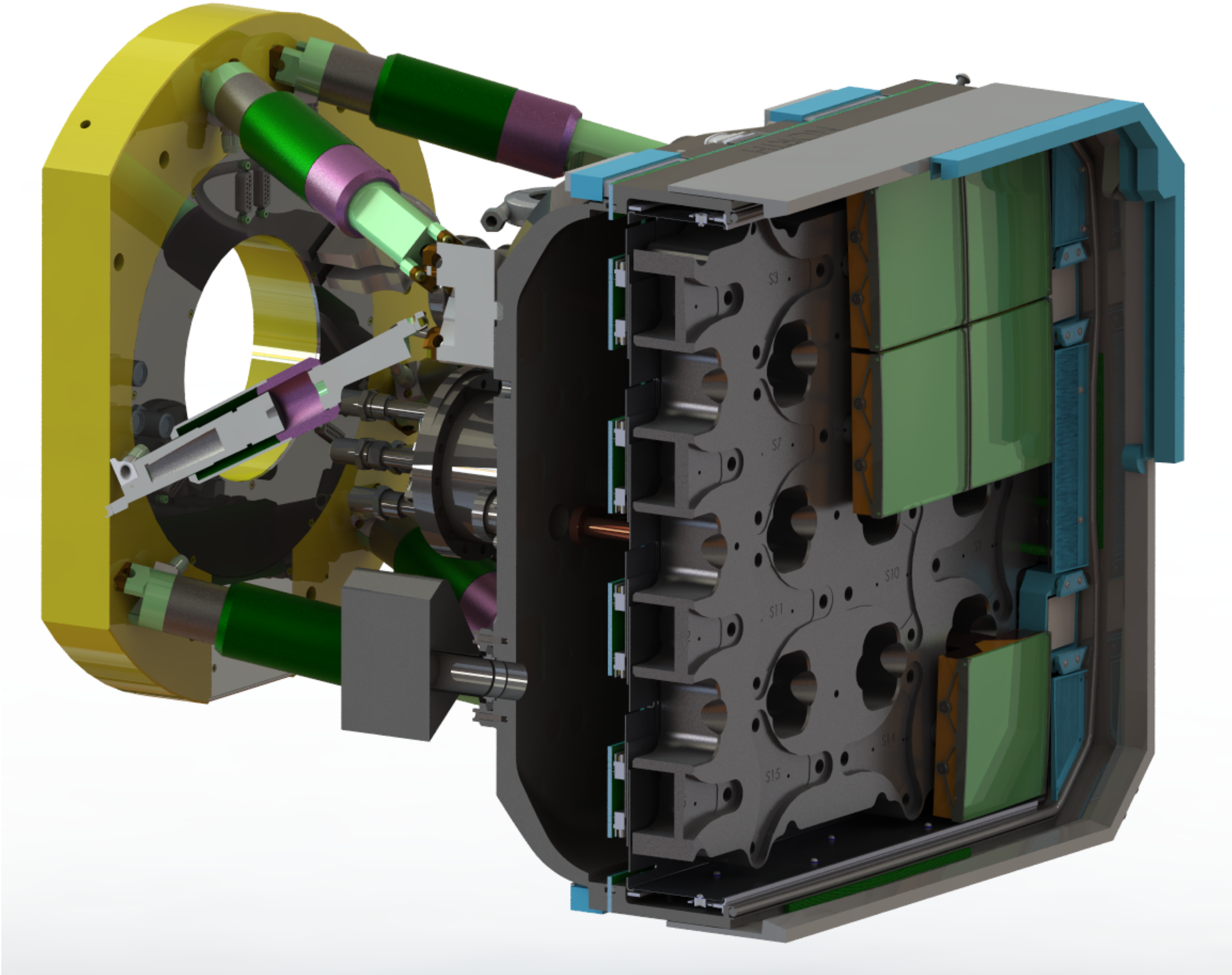
3800 deg^2/hour ⇒ 3π survey in 8 hours,
> 250 obs/field/year for uniform survey



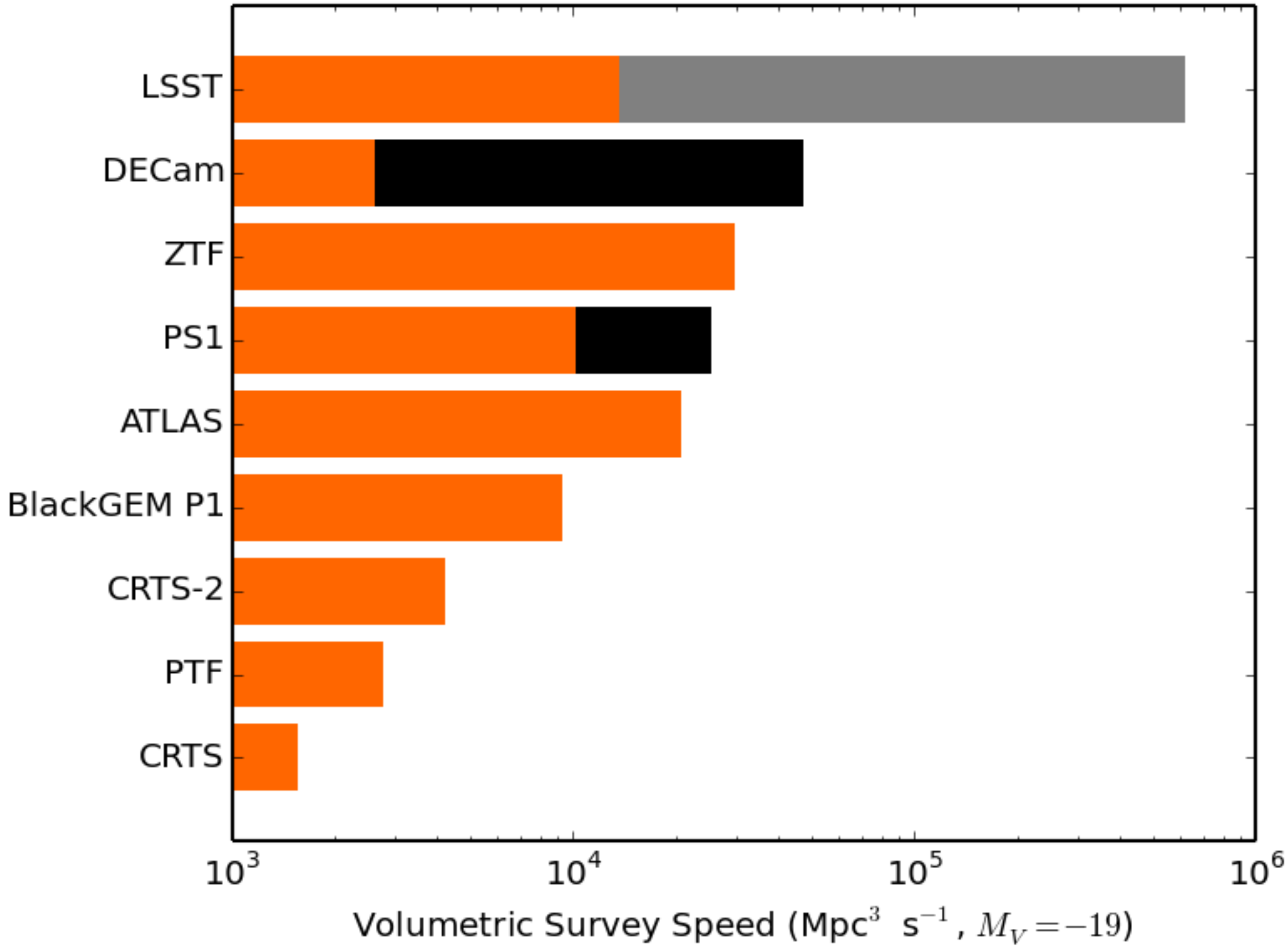
PTF
11 2k x 4k SITe CCDs

ZTF
16 6k x 6k e2v CCDs

ZTF cryostat and hexapod model



ZTF will lead finding spectroscopically-accessible transients



ZTF STATUS

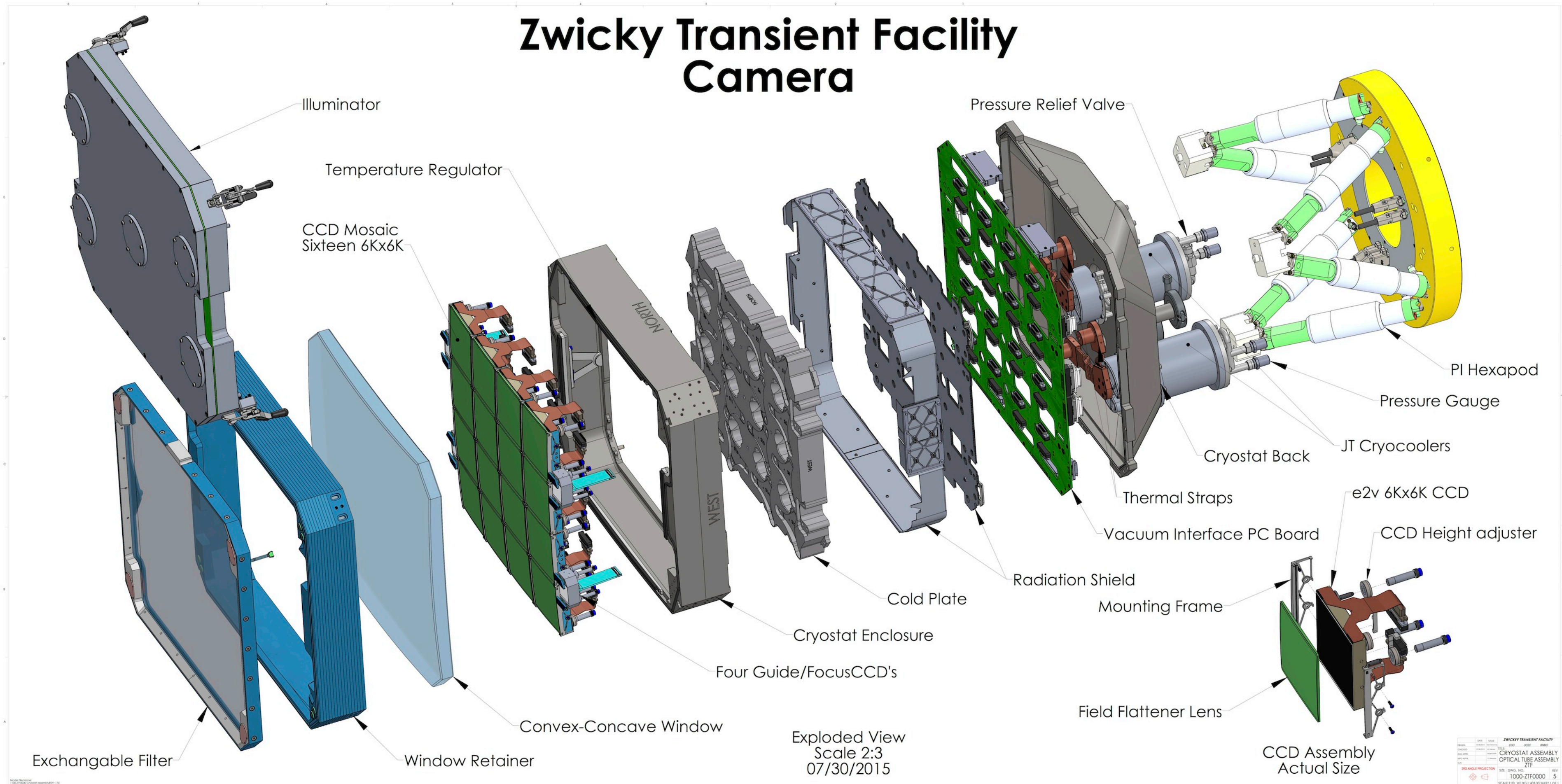
ZTF Program Status

- Technical progress
  - ZTF development is ~58% complete (by work-effort)
    - Observing System is 67% complete
      - All subsystems except filter exchanger are in I&T phase
    - Data System is ~35% complete
- Total project budget $18.1M (including 30% contingency goal)
  - Expenditure through Mar '16 is $8.2M
  - Revenue to date is $14.4M ($8.9 NSF + $5.5M partner funding)
  - In-hand cash balance ~$6.0M
  - Carried management contingency on remaining technical effort is 17% (up from 12% in Jan '16)
- ~ 22 full-time equivalent staffing (COO, IPAC, DESY)
- Current schedule
  - Expected decommissioning of iPTF Mar '17
  - Metrology tests of ZTF cryostat focal plane Apr '17
  - "First Light" of ZTF cryostat Jun '17
  - Beginning of survey operations (e.g. end of dev team activities) ~ Aug '17

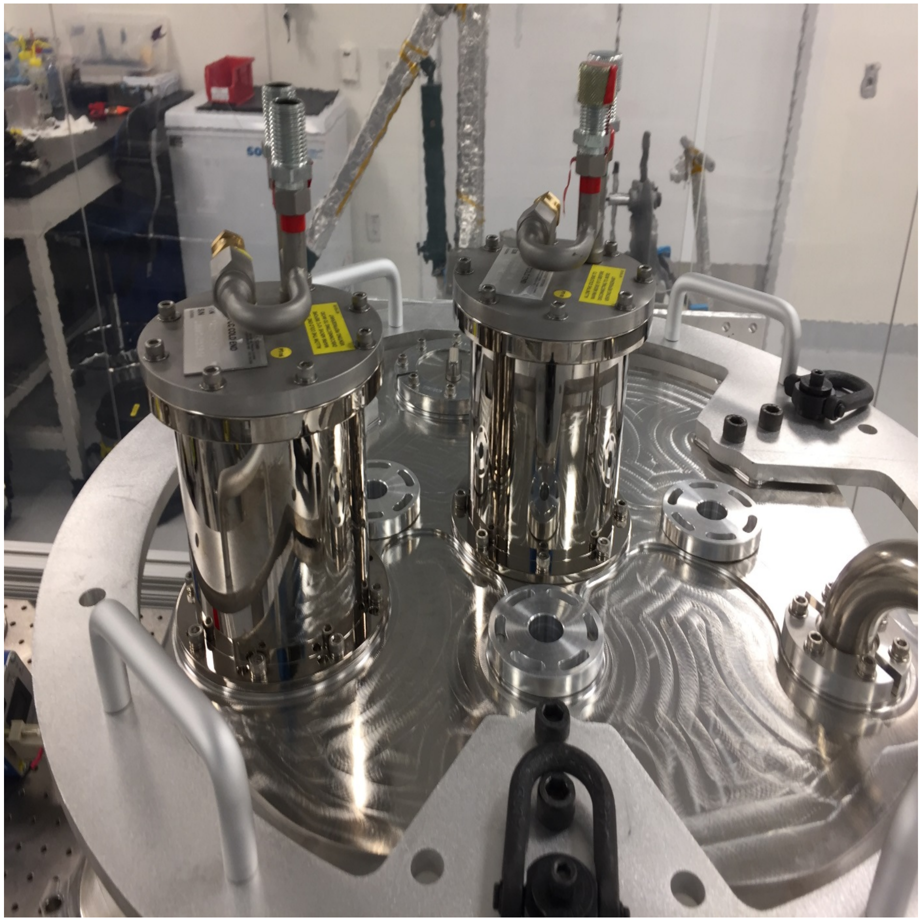
ZTF Observing System Development Status

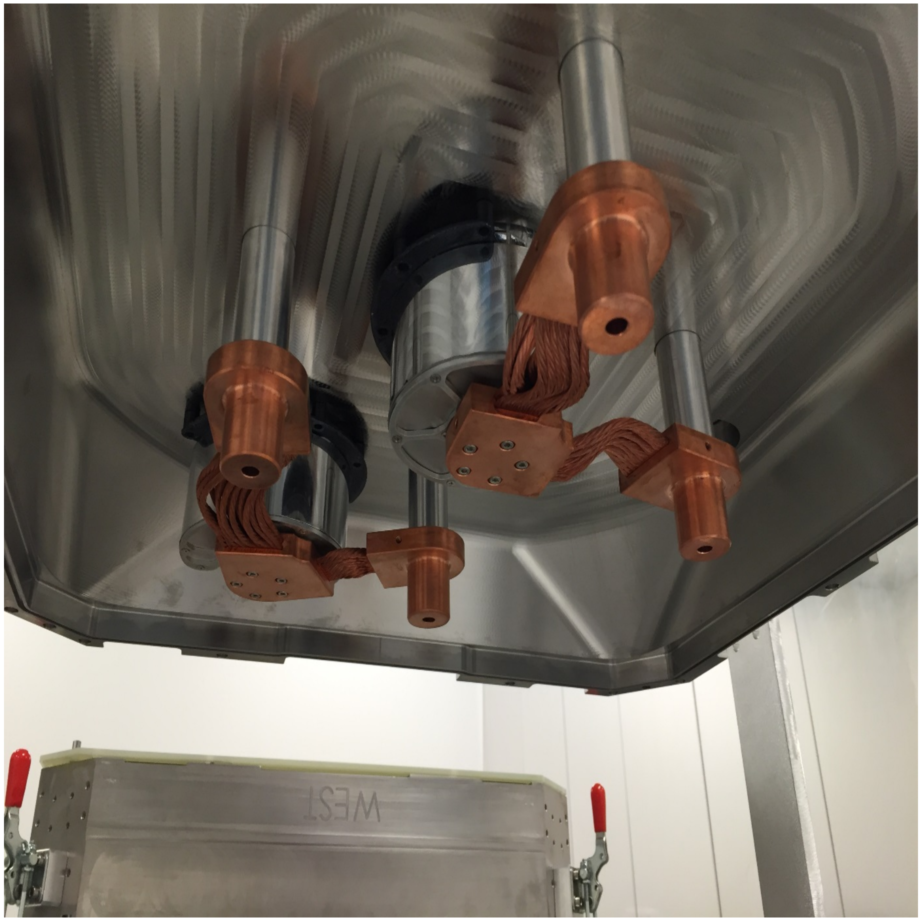
- Science CCDs not yet installed or operated; WaSP operational
  - Guide/focus CCDs expected Jun ’16; CCD I&T fixturing complete
- Electronics
  - CCD electronics tested; vacuum I/F board tested
- Cryostat mechanically assembled, vac & thermally tested

Exploded view of camera



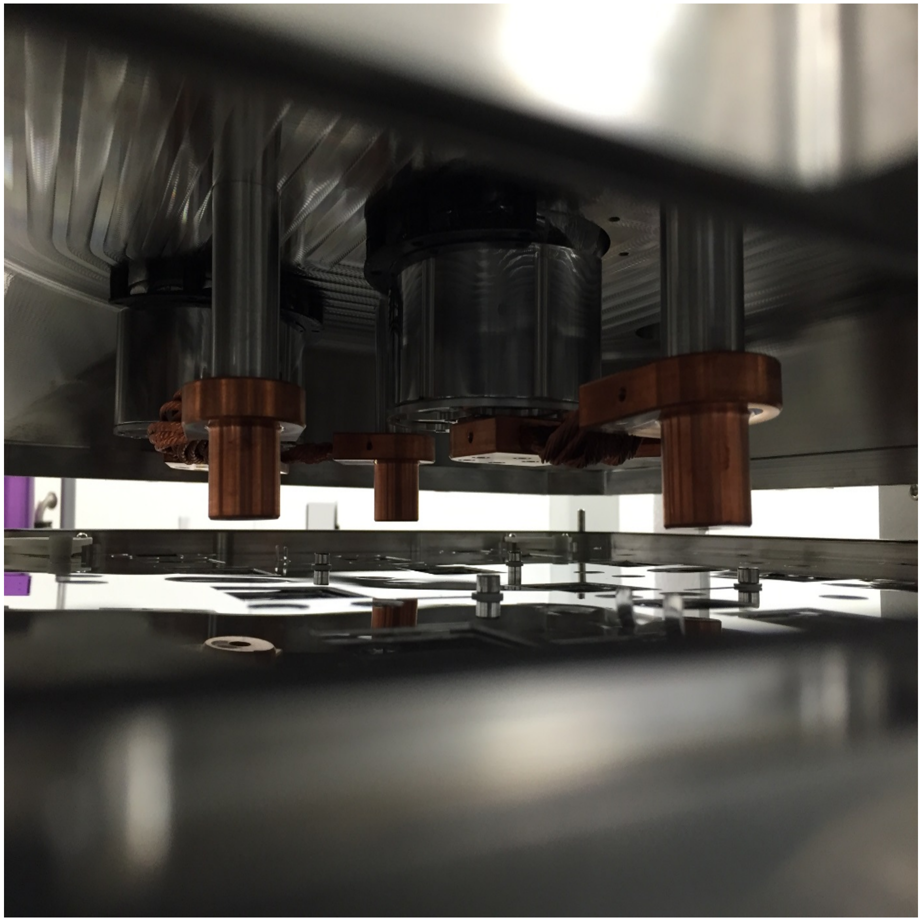
ZTF cryostat coolers and thermal links





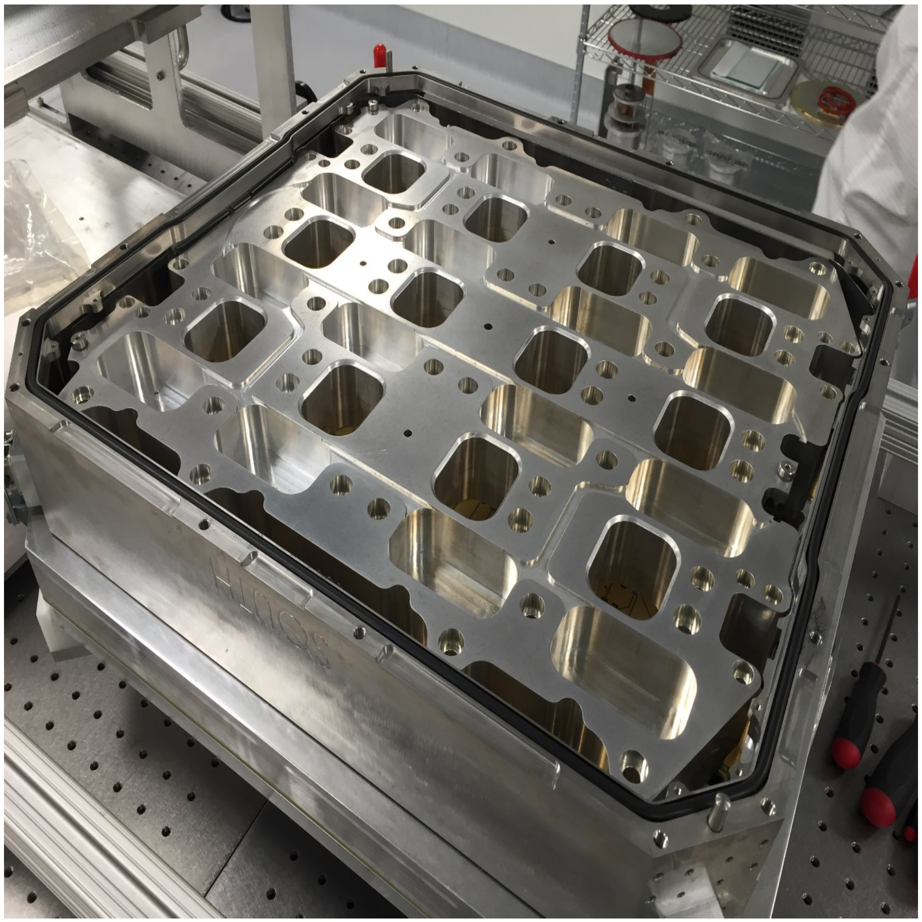
Backplate with installed cryo-coolers, charcoal getters,
thermal links (and installation posts)

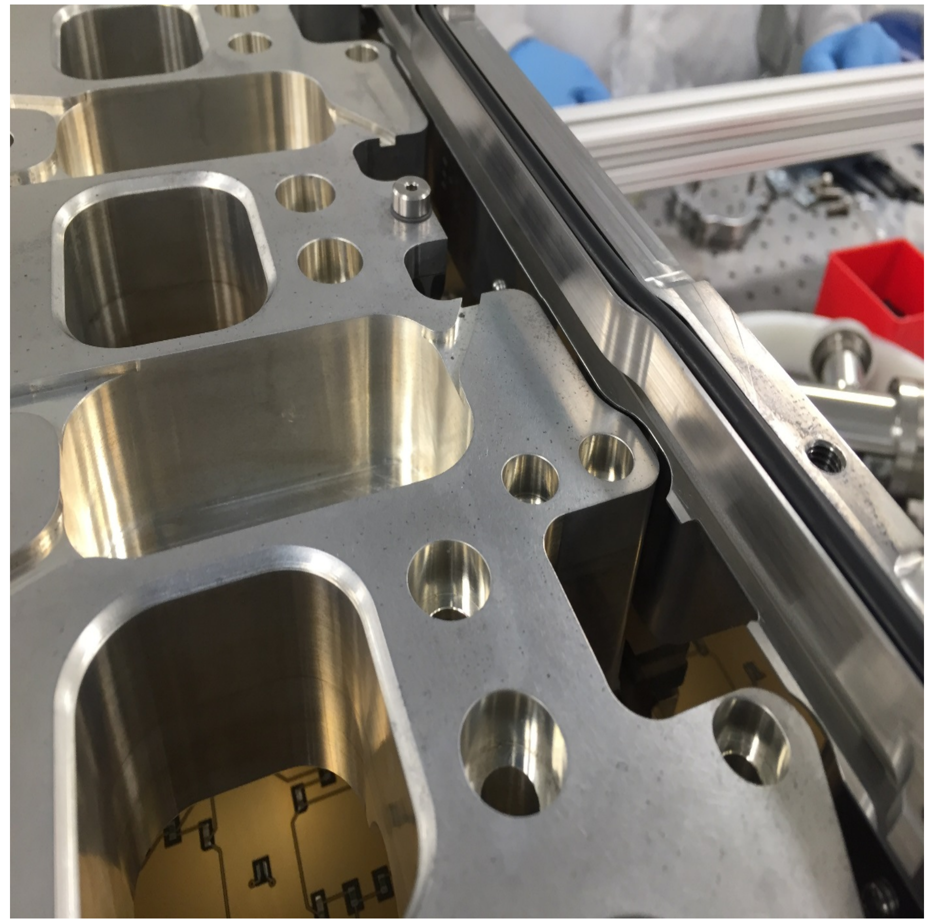
ZTF cryostat thermal links



Backplate with installed cryo-coolers, charcoal getters, thermal links (and installation posts). Thermal links pass through thermal shield and G10 science VIB successfully.

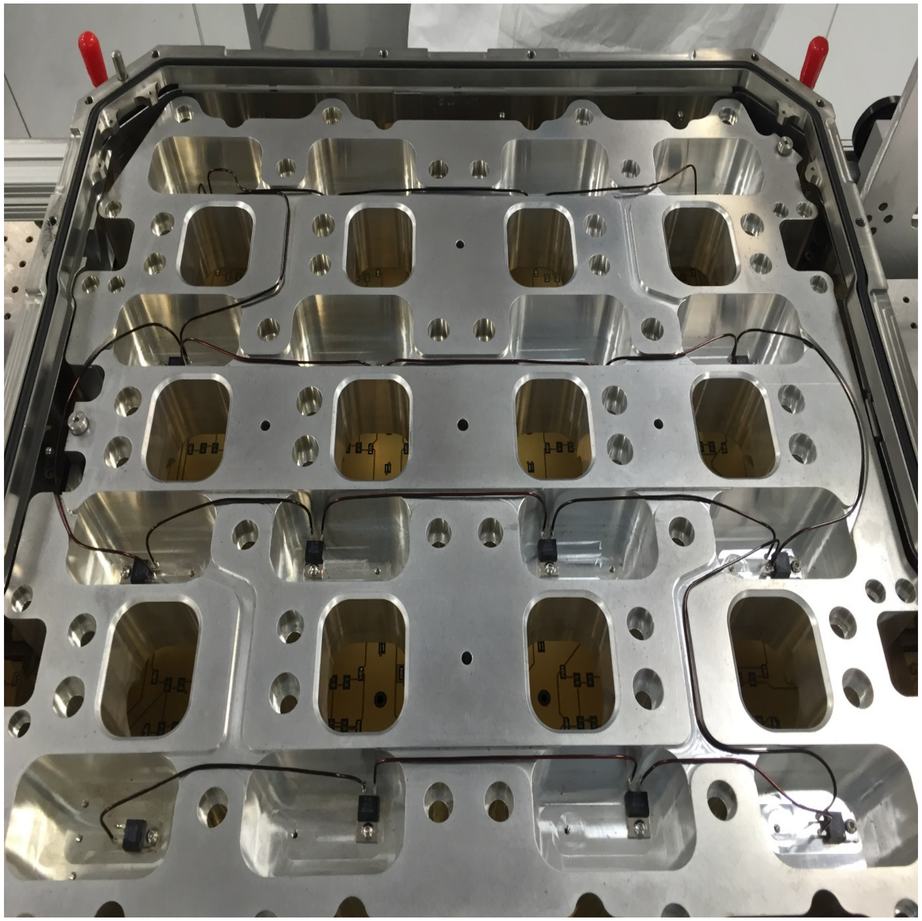
ZTF cryostat ass'ly – CCD cold plate

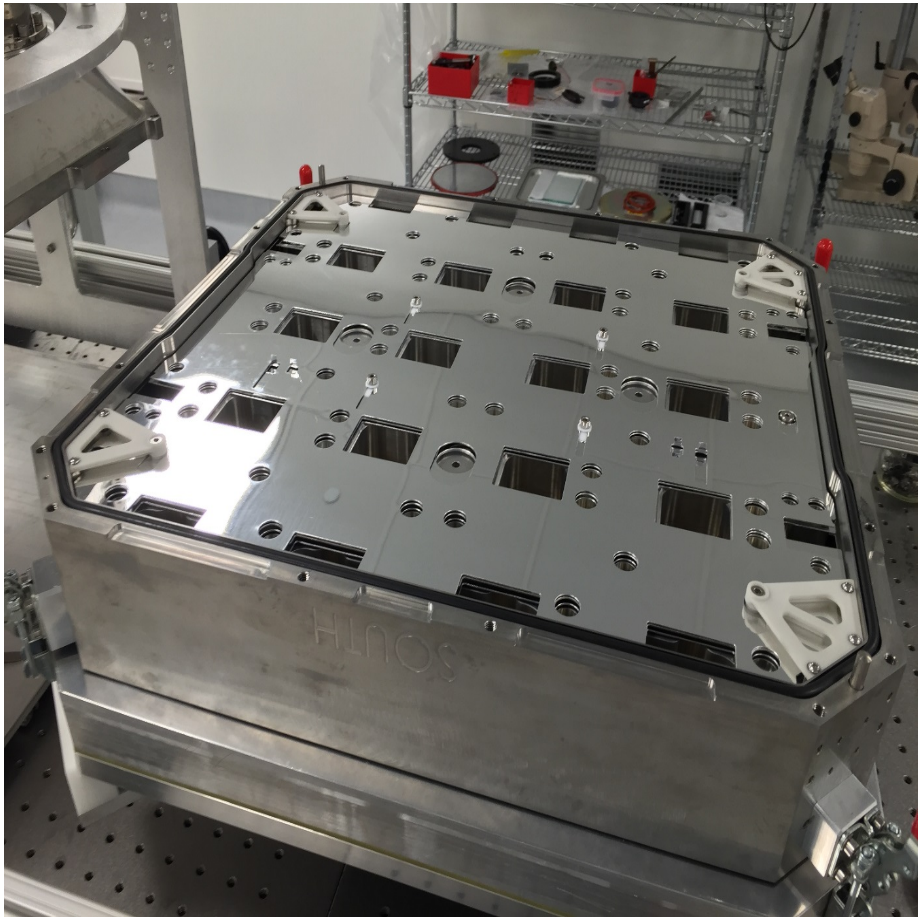




Coldplate installed with clearance around side thermal shield

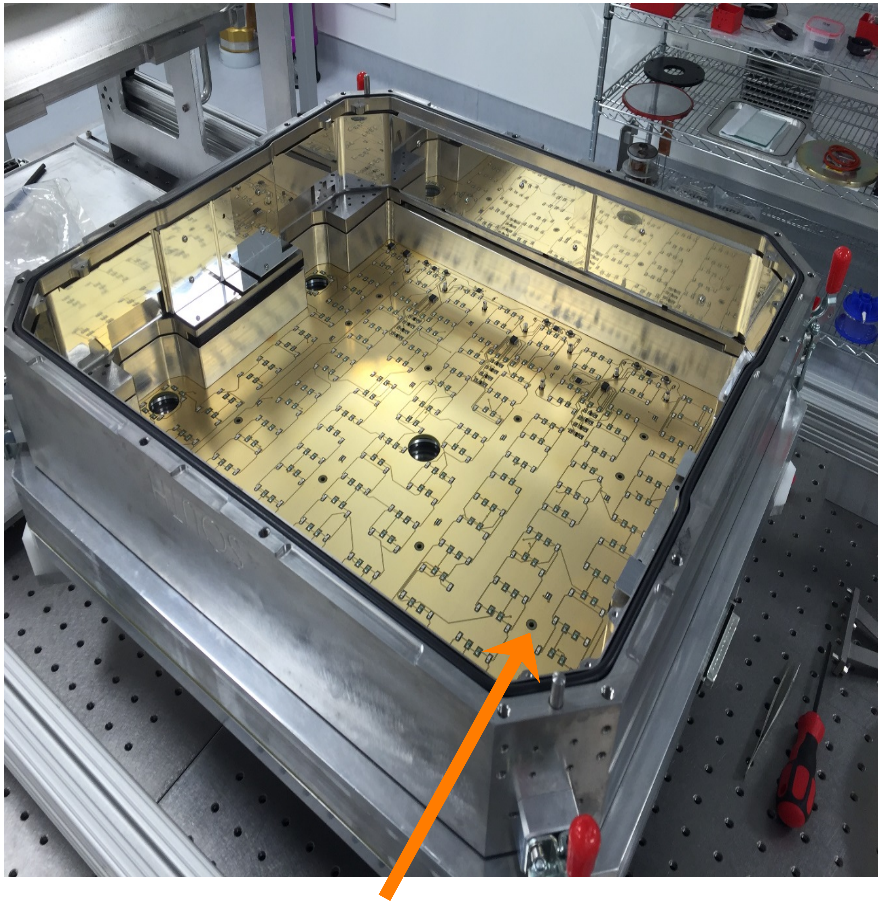
ZTF cryostat ass’ly – cold plate shield



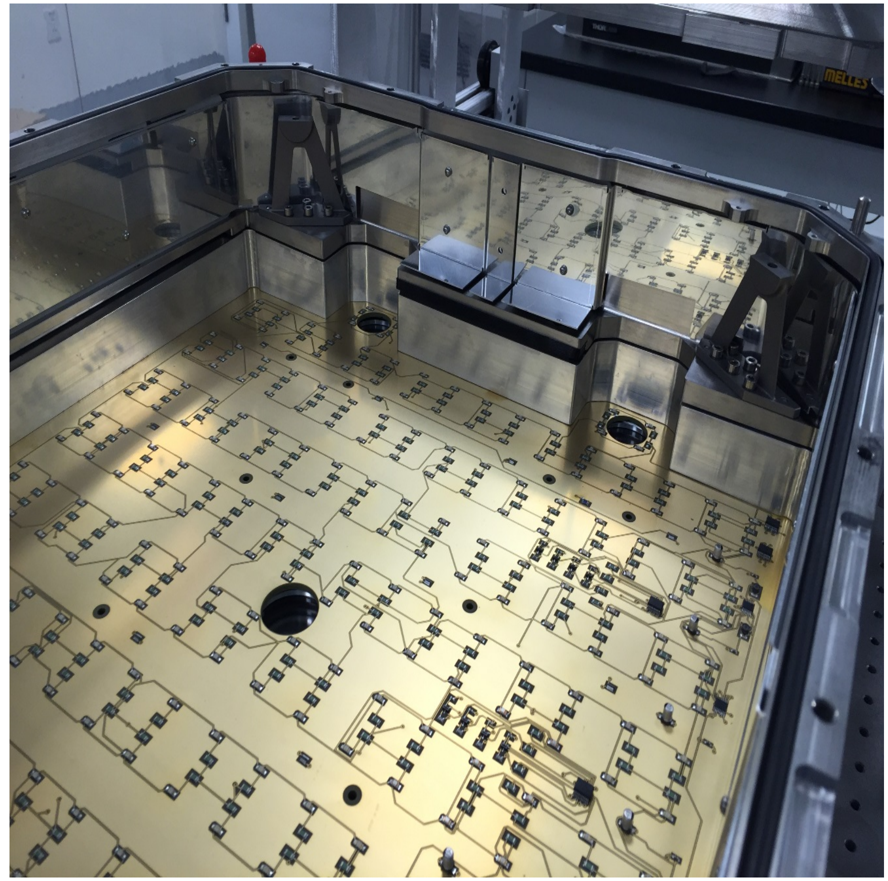


Heater resistor wiring harness installed and bottom thermal shield installed

ZTF cryostat ass'ly – thermal shields

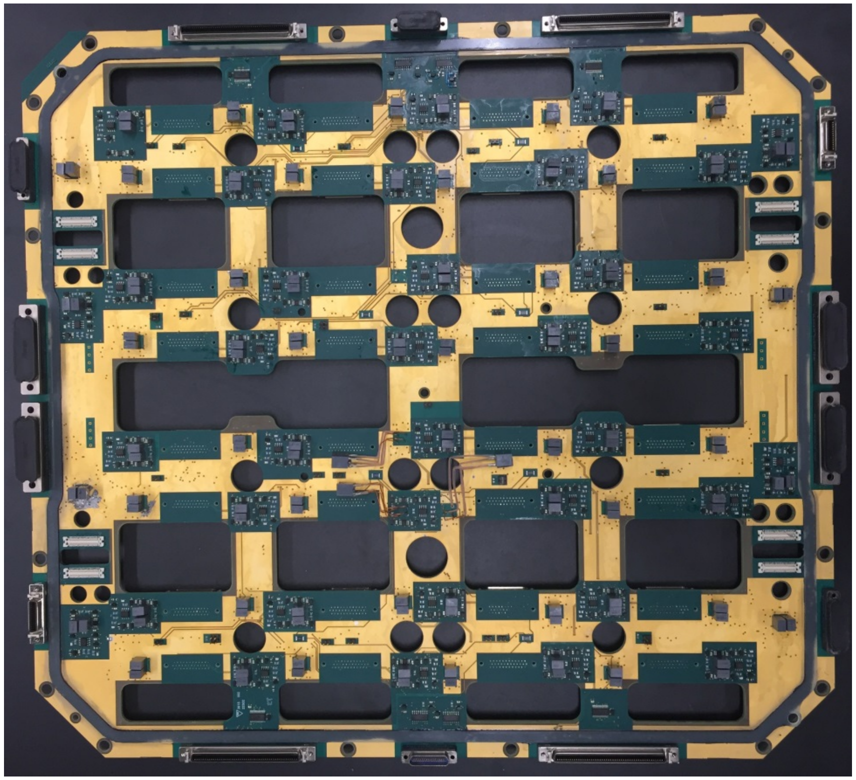


In-vacuum illuminator



Side thermal shields installed with coldplate bipods.

Vacuum Interface Board



- The VIB is an enabling technology for our compact Schmidt camera design
- It carries all the high speed detector data (differential, amplified) through the cryostat vacuum boundary & other key functions
- VIB currently undergoing signal checks prior to CCD installation

ZTF cryostat backplate ass'ly

Sliding rig for backplate and lifting fixture for enclosure.

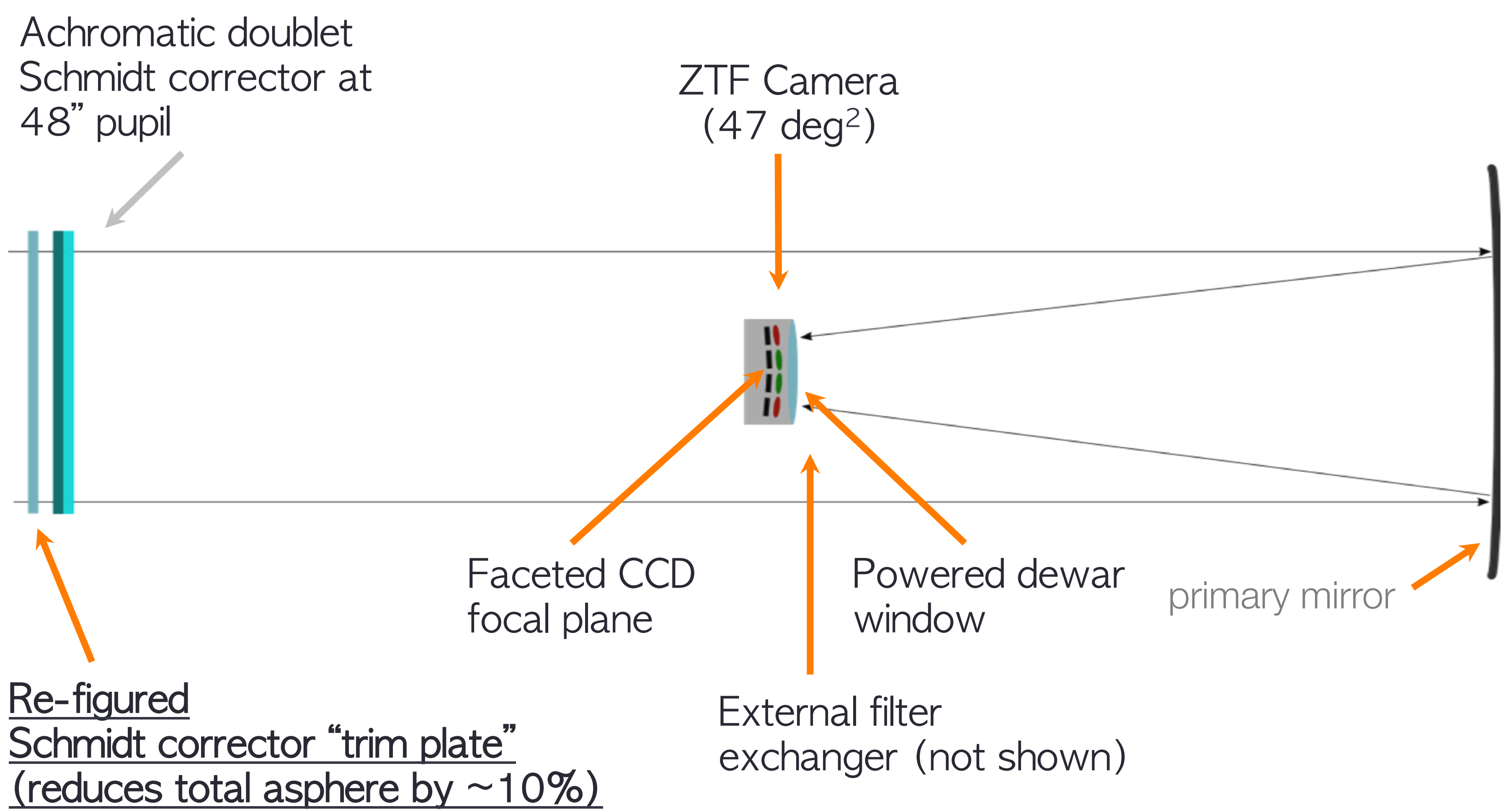
ZTF cryostat today

ZTF Observing System Development Status

- Science CCDs not yet installed or operated; WaSP operational
  - Guide/focus CCDs expected Jul '16; CCD I&T fixturing complete
- Electronics
  - CCD electronics tested; vacuum I/F board tested
- Cryostat mechanically assembled, vac & thermally tested
- Optics
  - CCD field flatteners & mounts complete, coated
  - Cryostat window polished, but uncoated, not yet vac tested
  - Filters: R and g' filters complete
  - Schmidt trim plate: Blank delivered to vendor, fabrication delayed

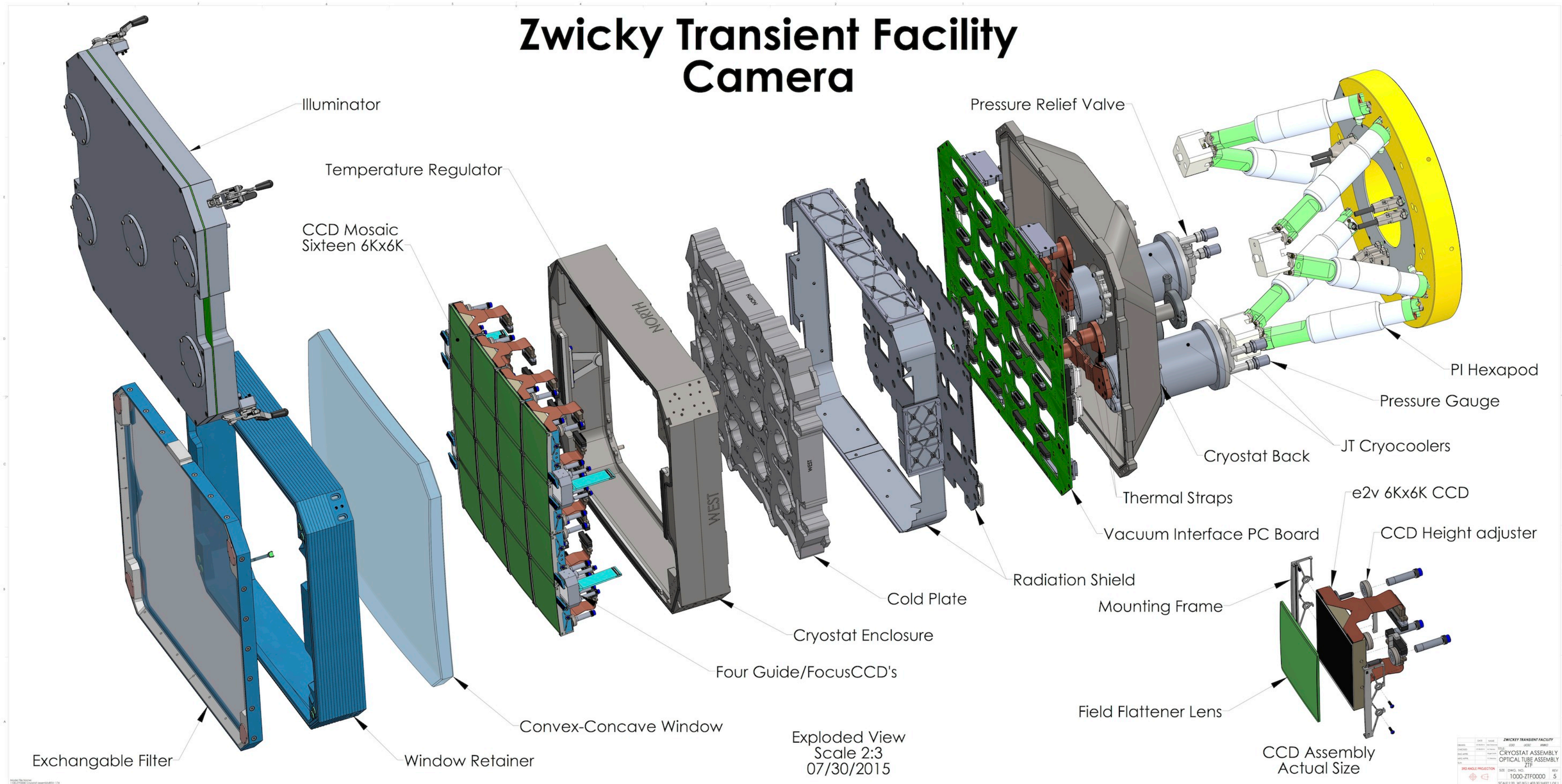
ZTF's large field of view requires new optics

for best image quality over full FoV

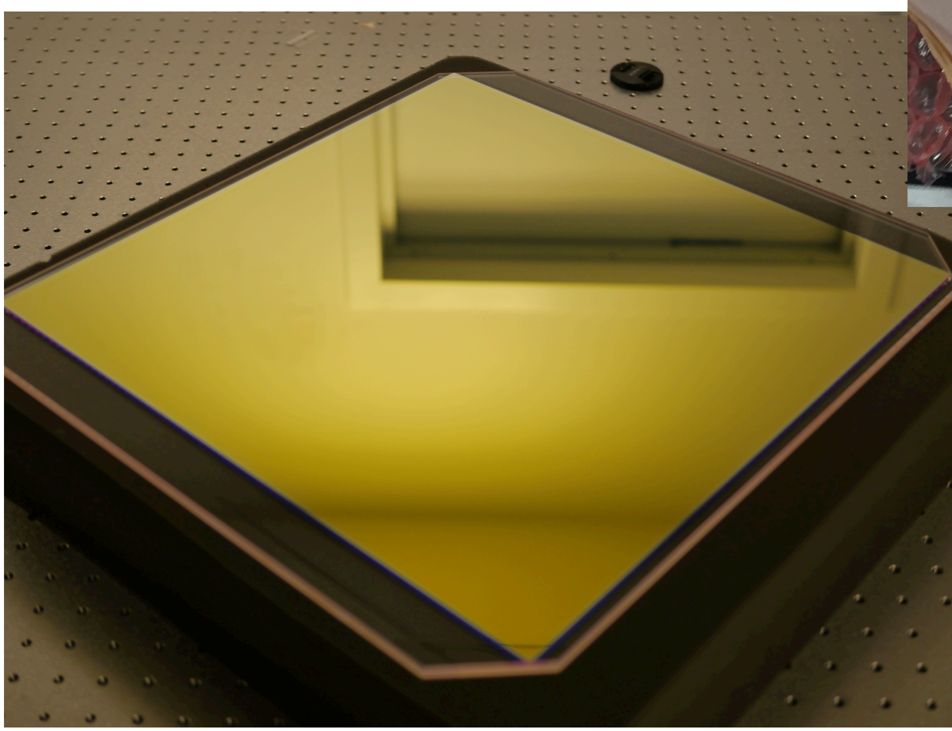


ZTF trim plate at Rayleigh Optical

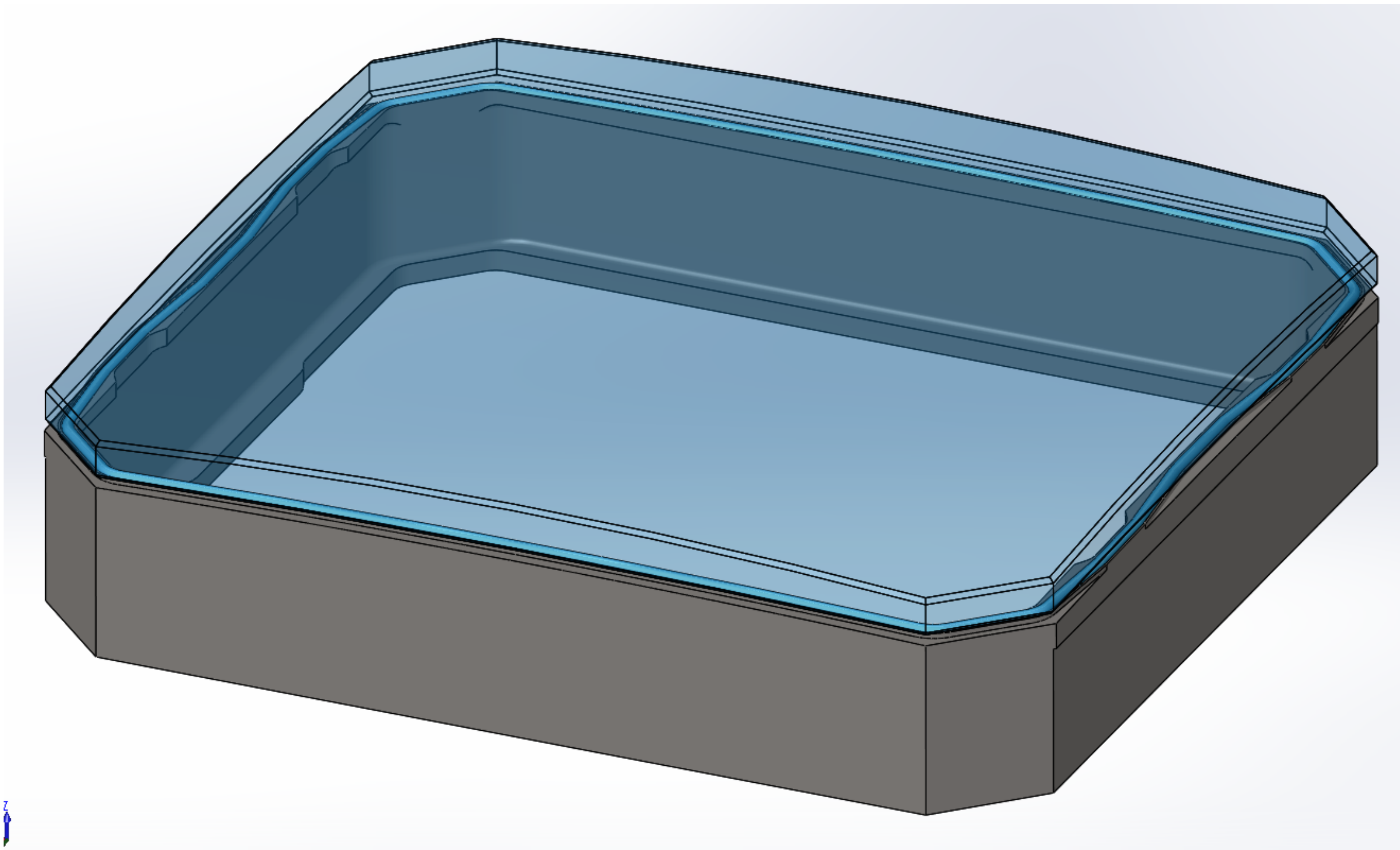
Exploded view of camera



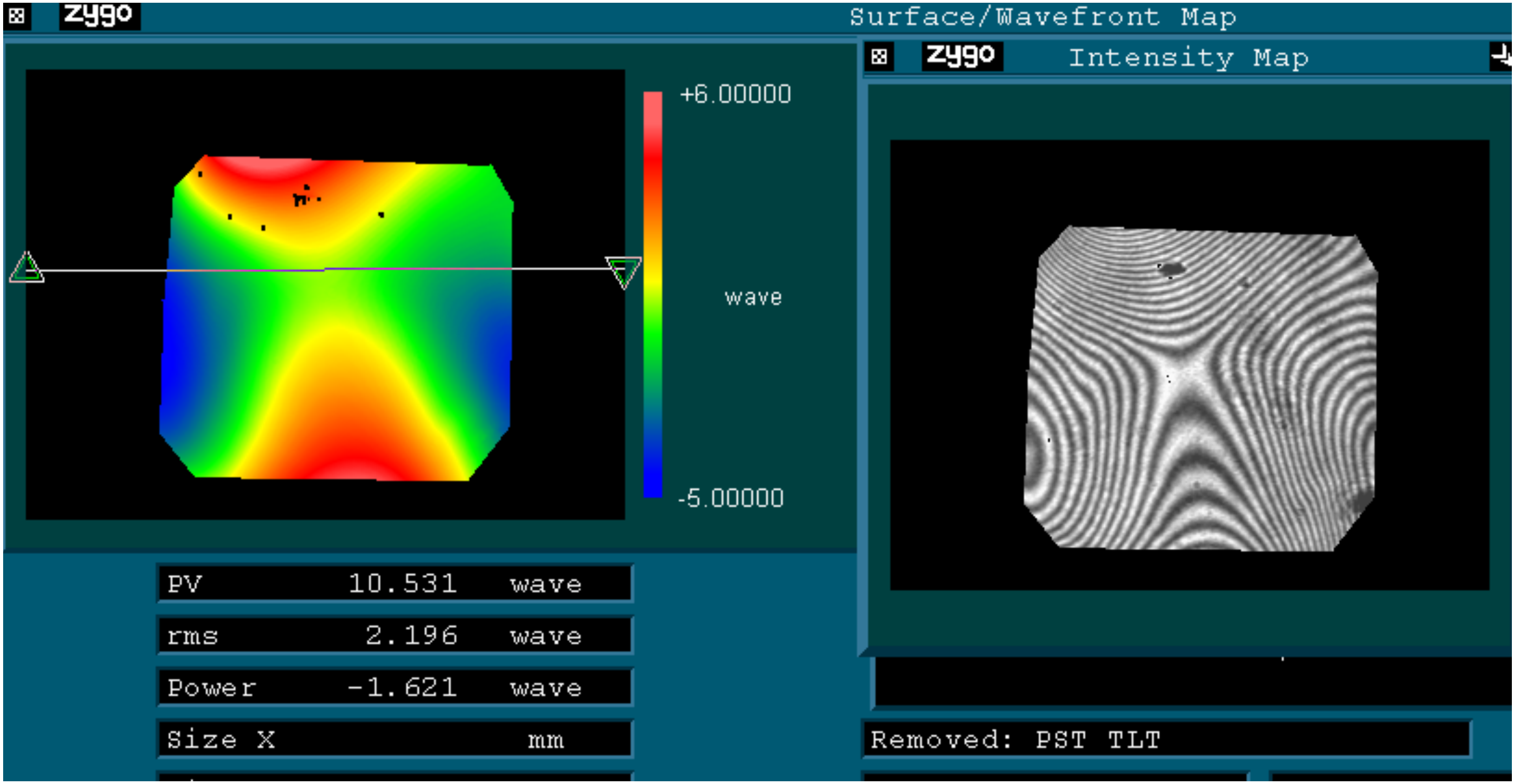
ZTF
R and g' band filters have been received



ZTF cryostat window O-ring and support



ZTF cryostat window polishing is complete



Window figure allocation to DIQ: ~ 0.15” FWHM out of 2”FWHM budget

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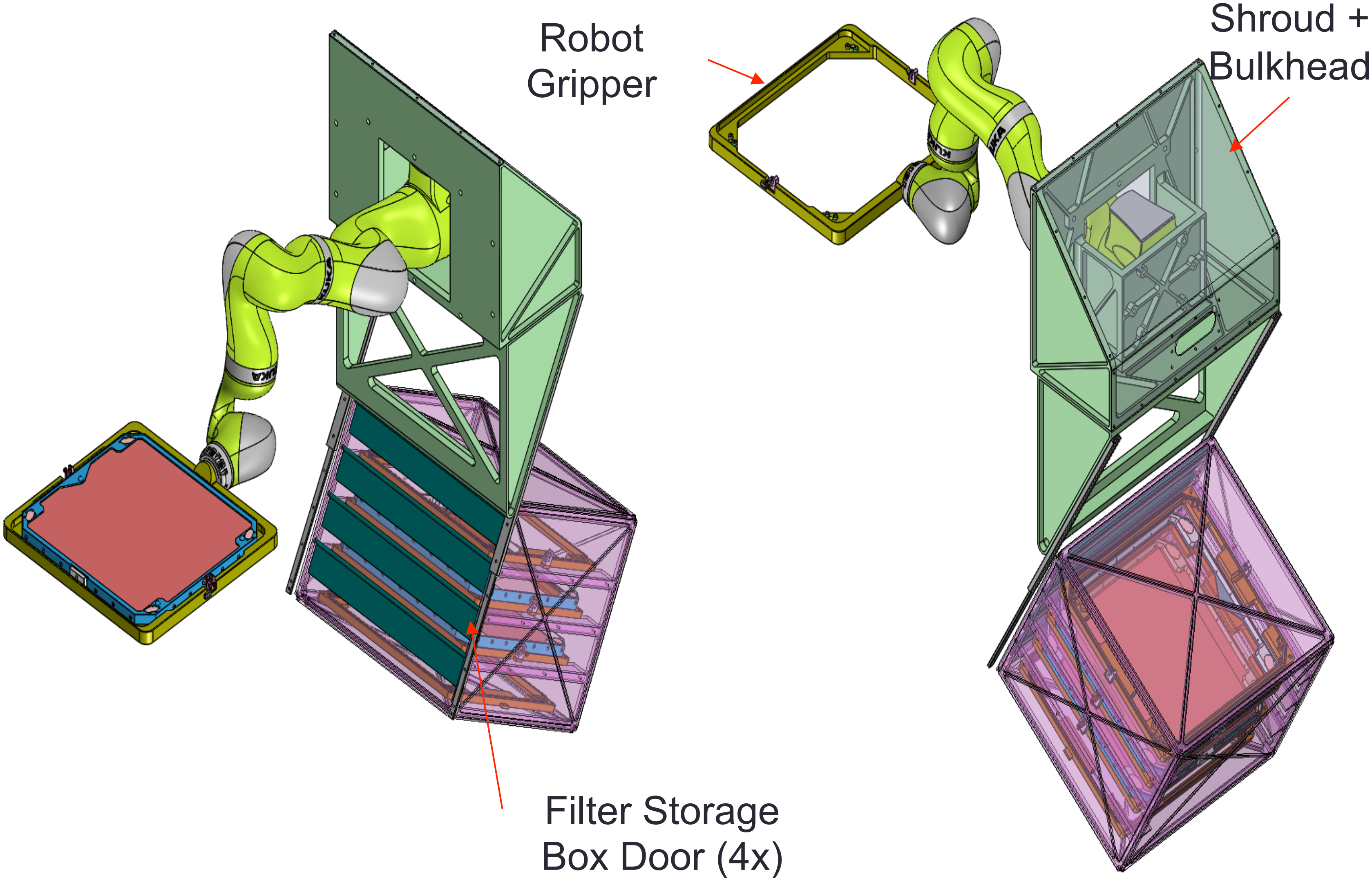
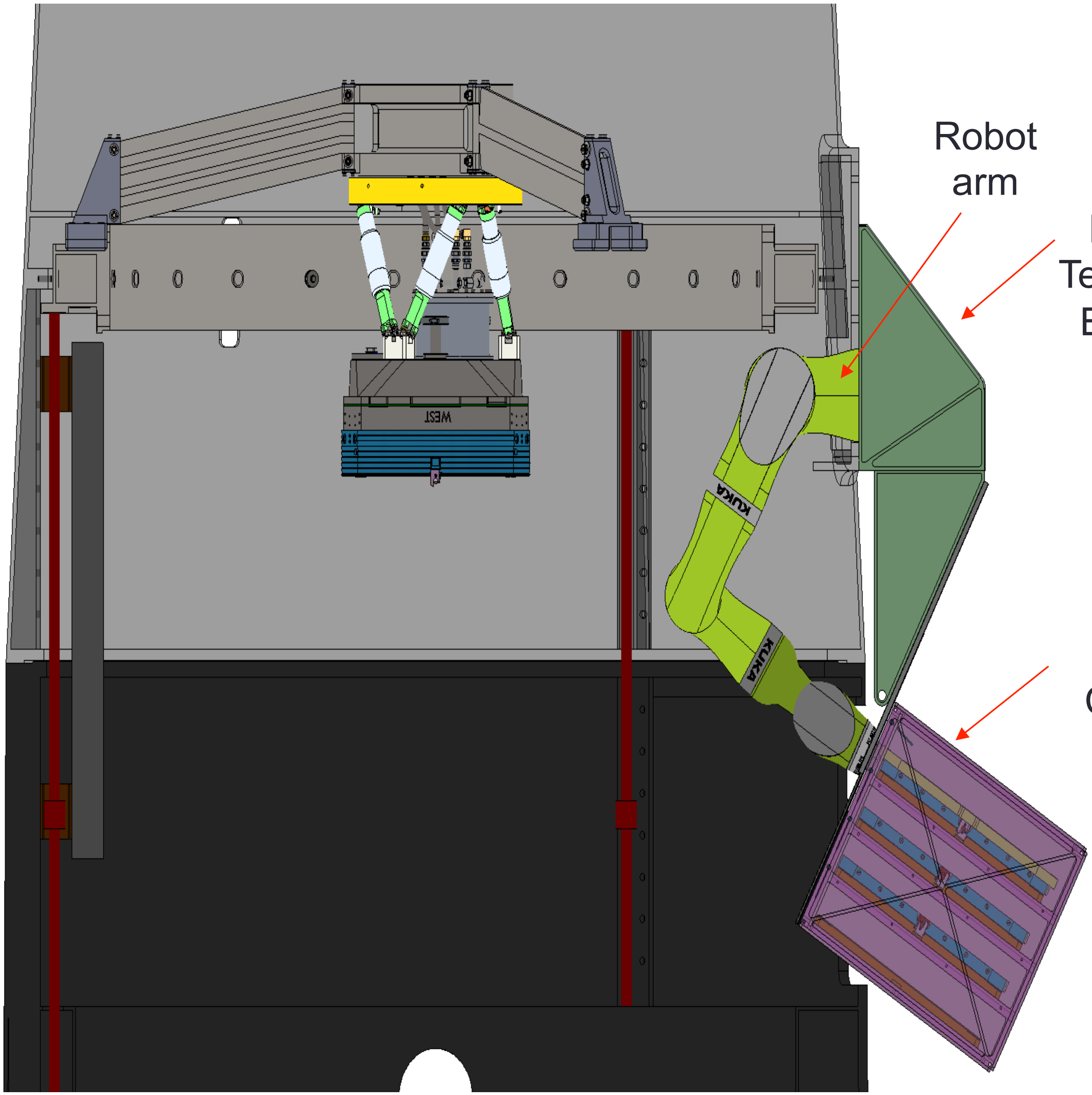
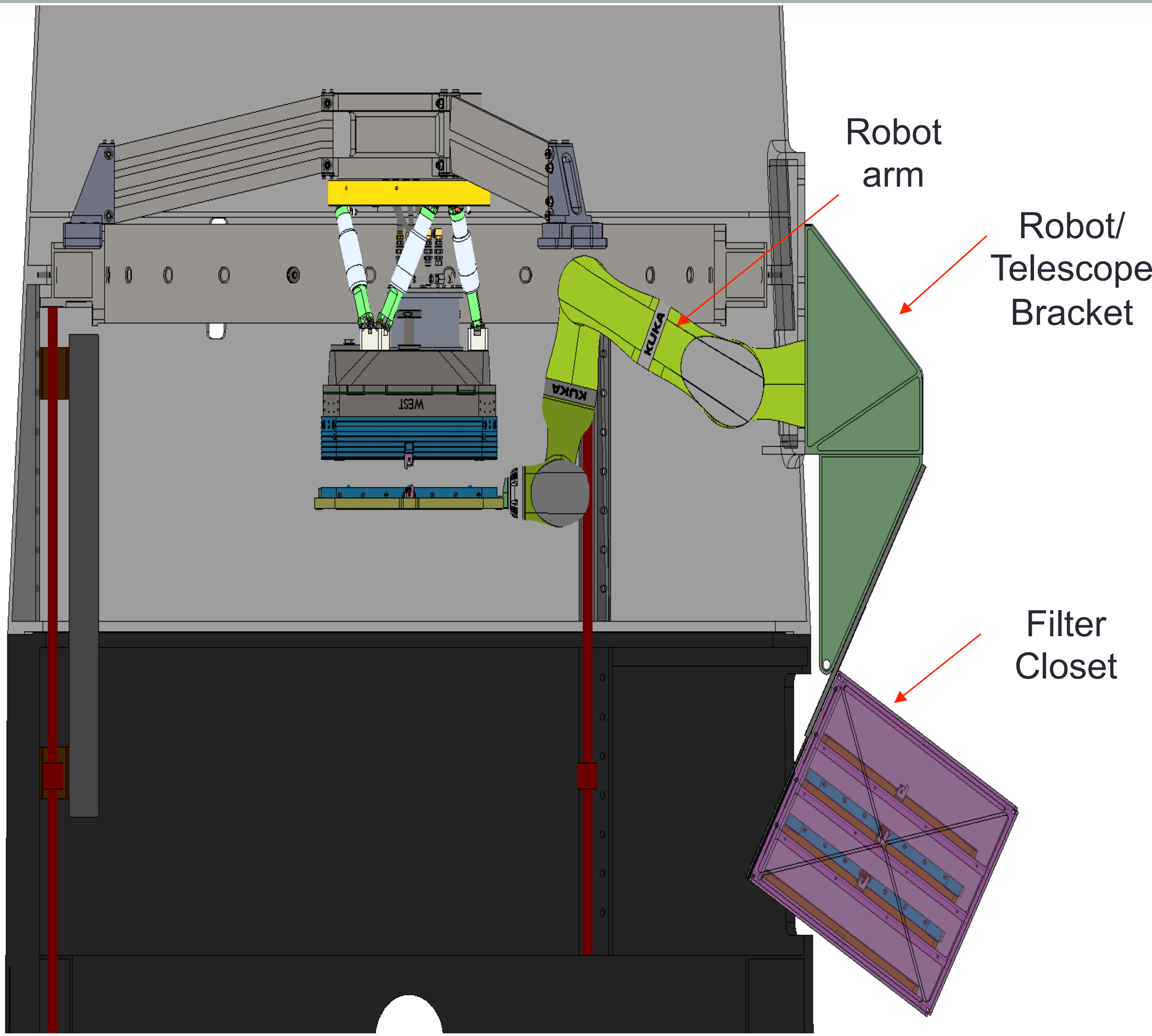
  - Added to project scope May ‘15; PDR held May ‘16

Filter Exchanger




Robot
arm
Robot/
Telescope
Bracket
Filter
Closet
KUKA
KUKA
WEST


Robot
arm
Robot/
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WEST

ZTF filter exchanger prototype latch testing at JPL

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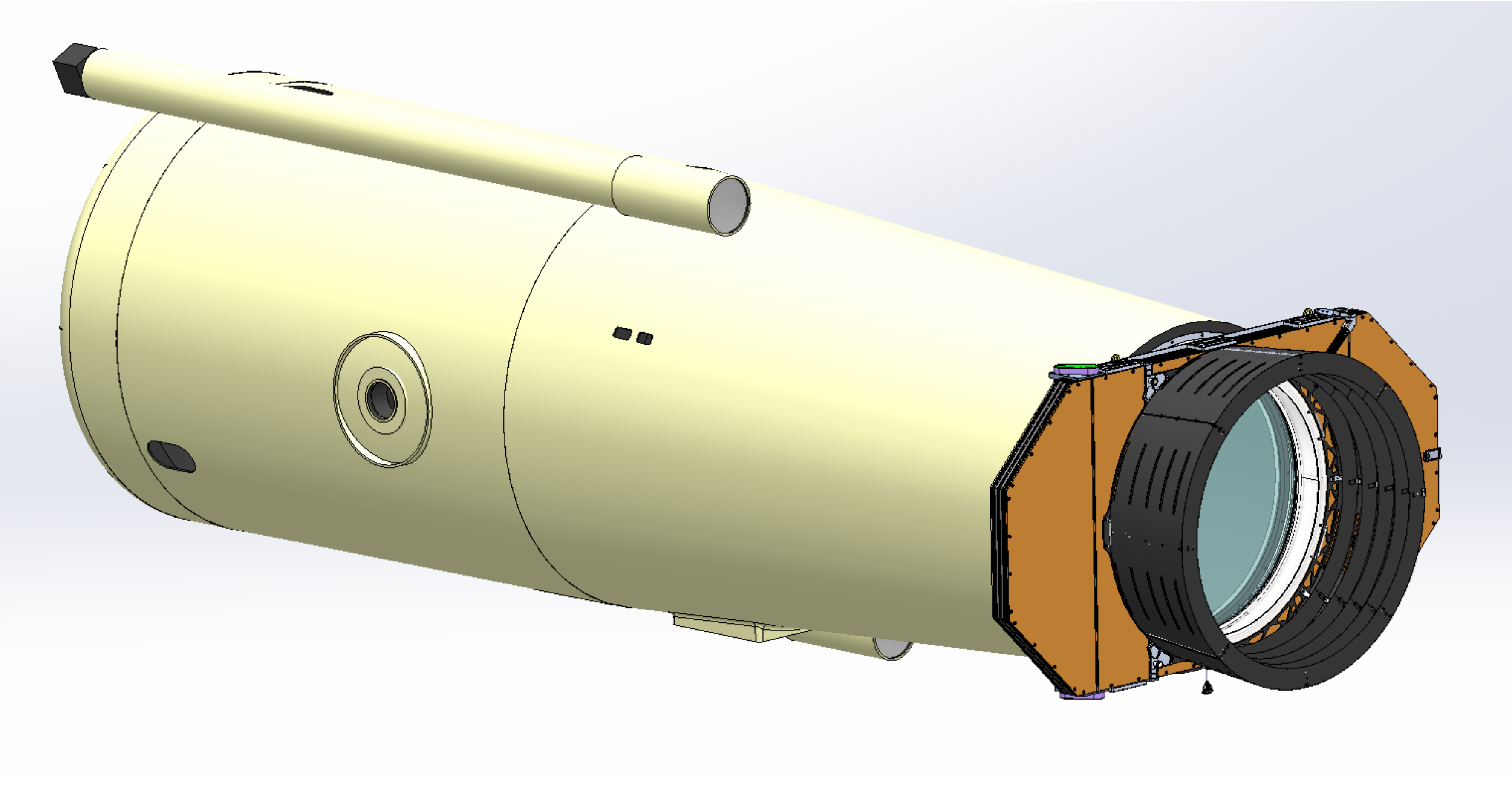
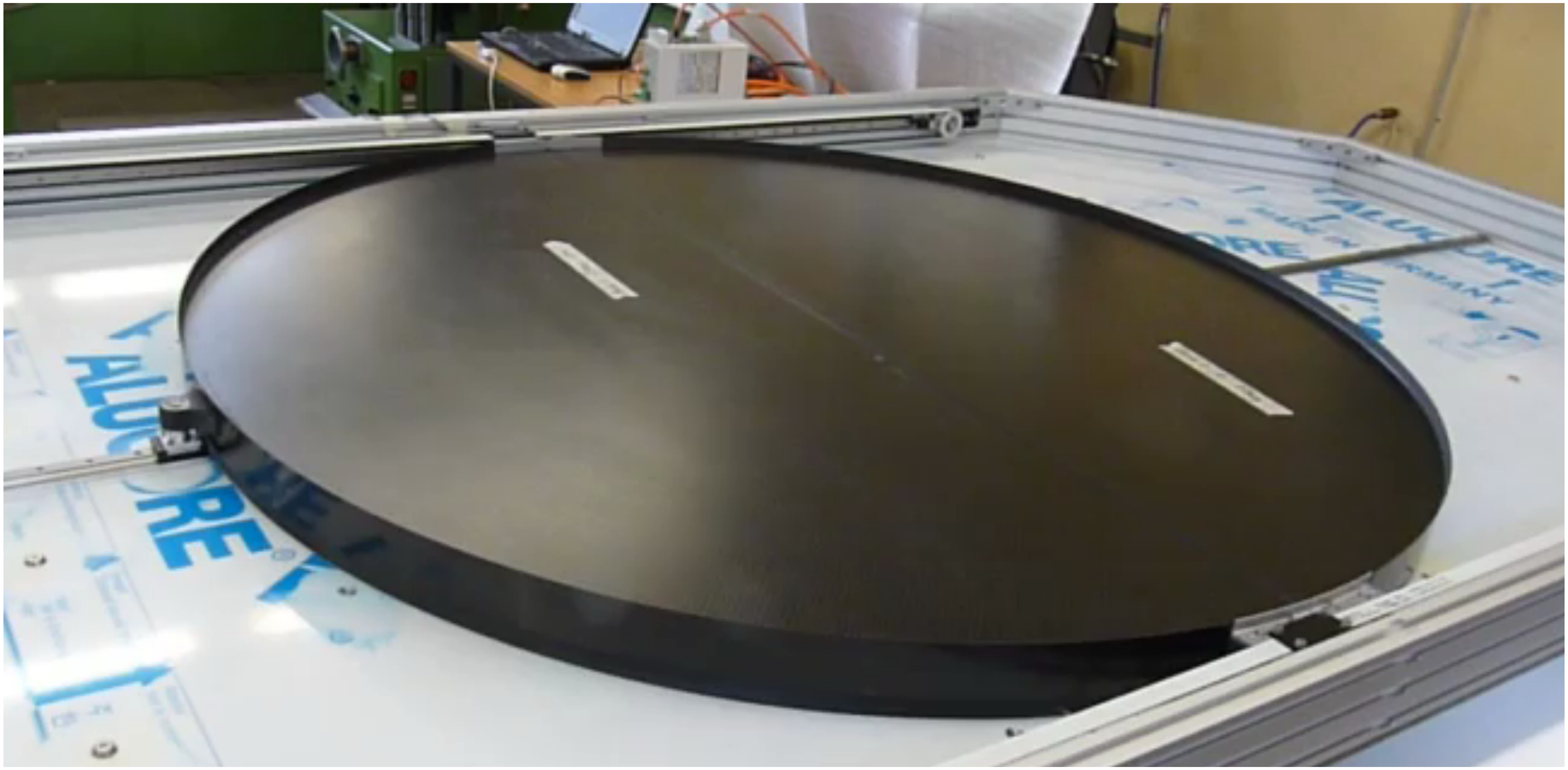
- Exposure Shutter in testing at Bonn; expected from DESY Aug ‘16

ZTF new top-end: baffle, shutter, trim plate



ZTF exposure shutter under test at Bonn



Expected to be shipped to DESY for quantitative evaluation shortly
Delivery to Palomar expected ~ November 2016

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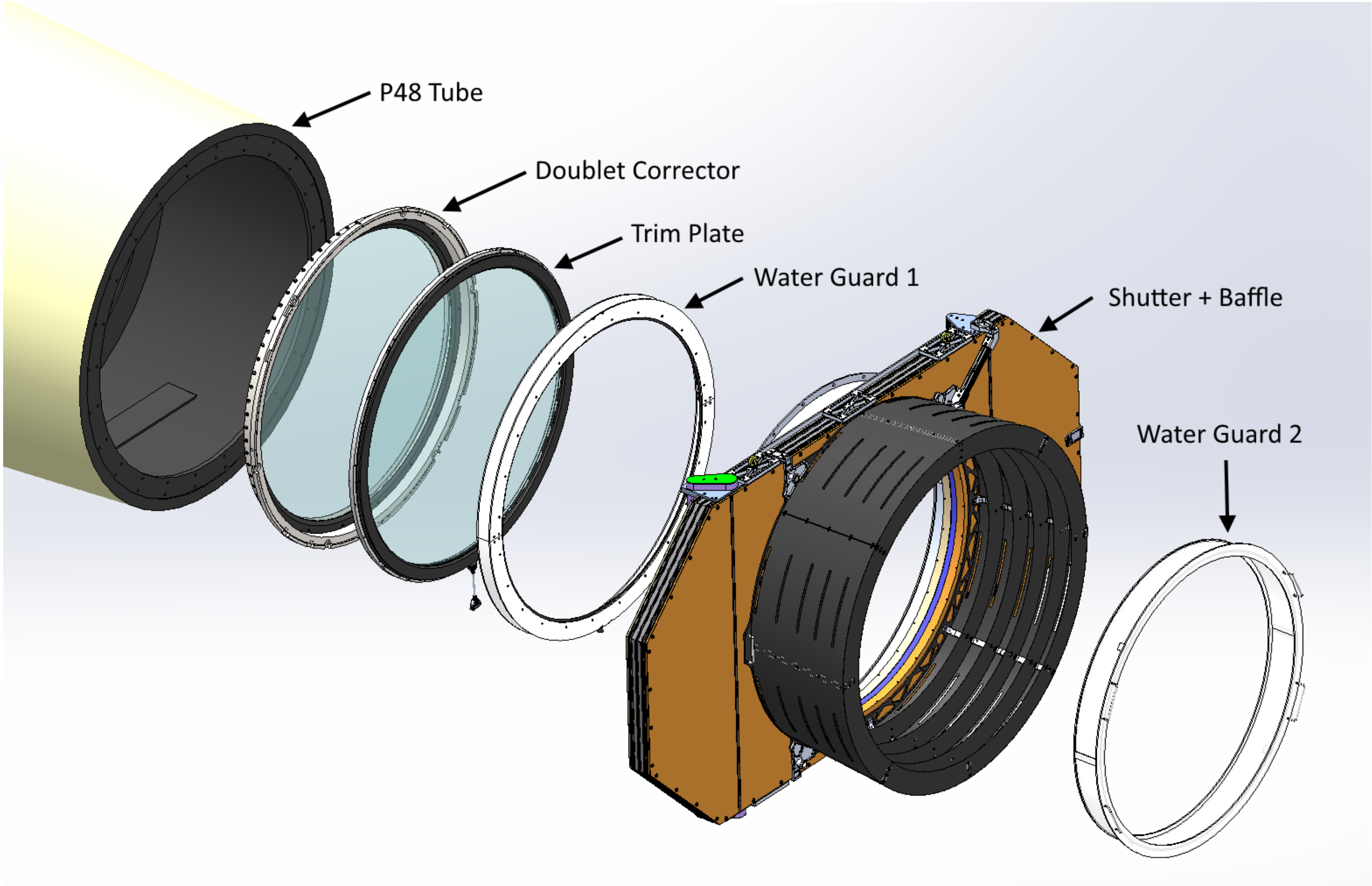
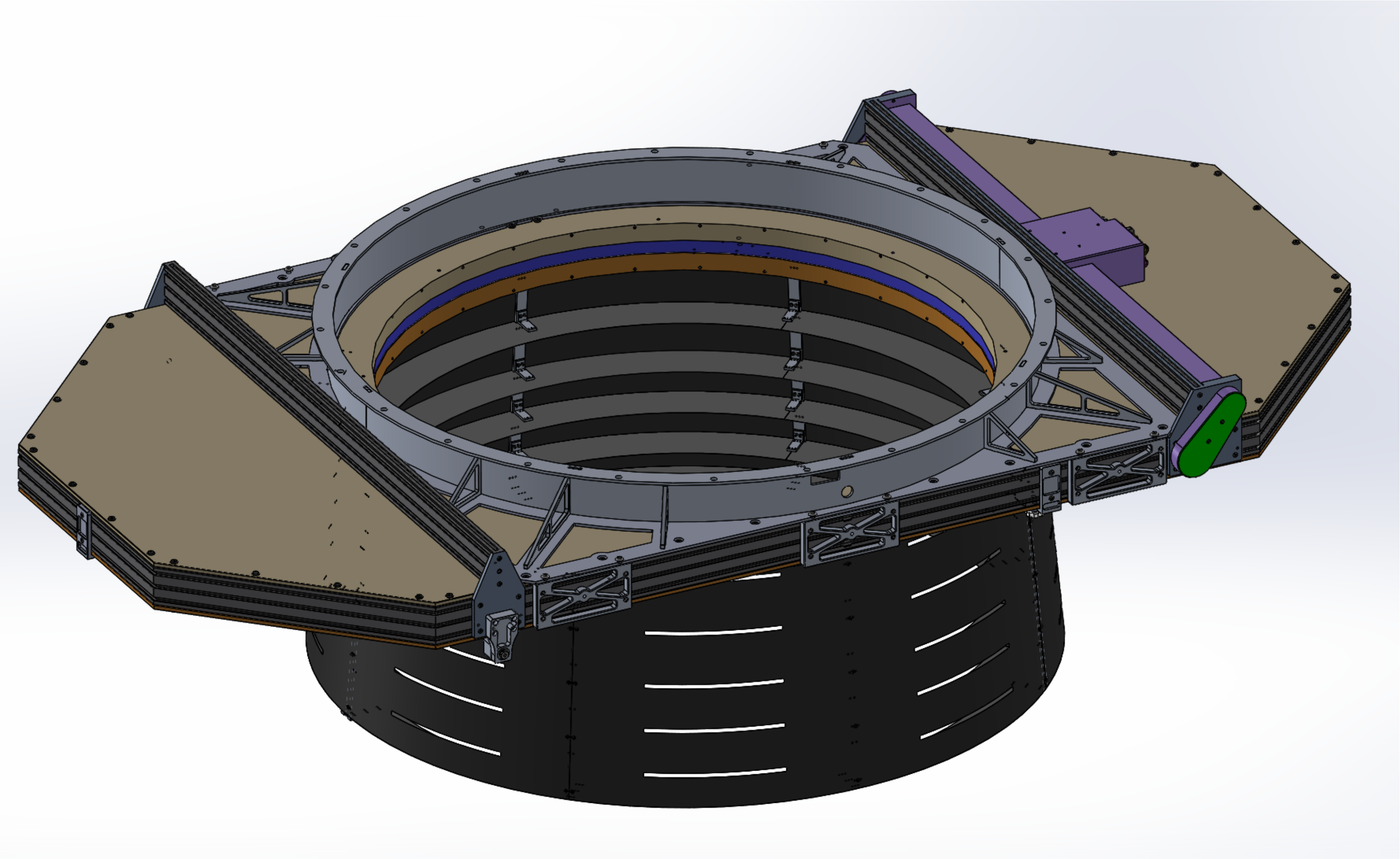
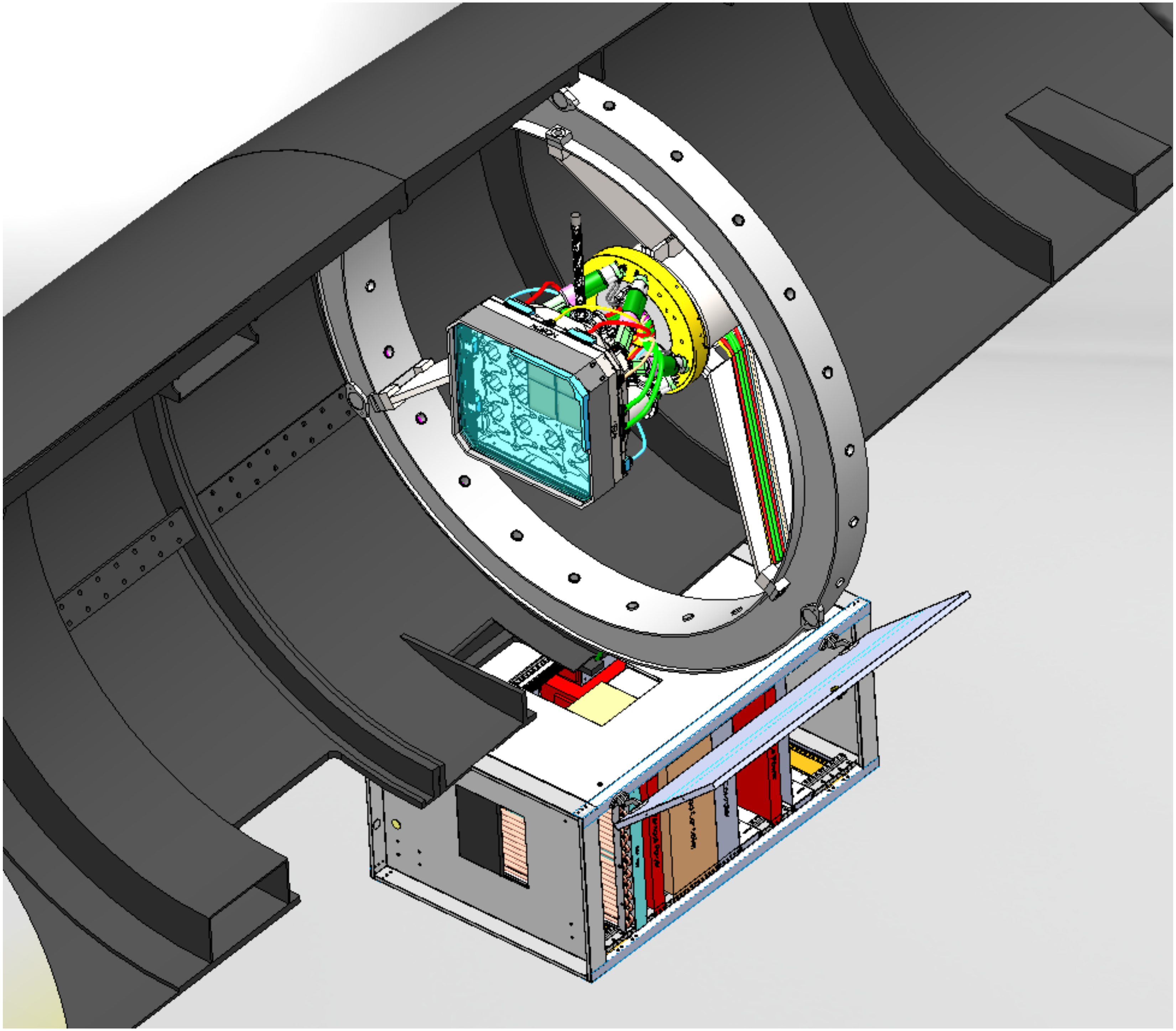
  - Added to project scope May ‘15; PDR held May ‘16
- Exposure Shutter in testing at Bonn; expected from DESY Aug ’16
- Instrument Software
  - Instrument control robot framework operational; hexapod control tested
- Telescope
  - Upgrades completed: Windscreen, dome drive, dec drive
  - Upgrades remaining: Electrical Jun ’16, TCS Aug ’16, shed Oct ’16
    - In design: Air handling, shutter I/F, spider, cabling, cooled e-rack,

ZTF top-end / shutter interface

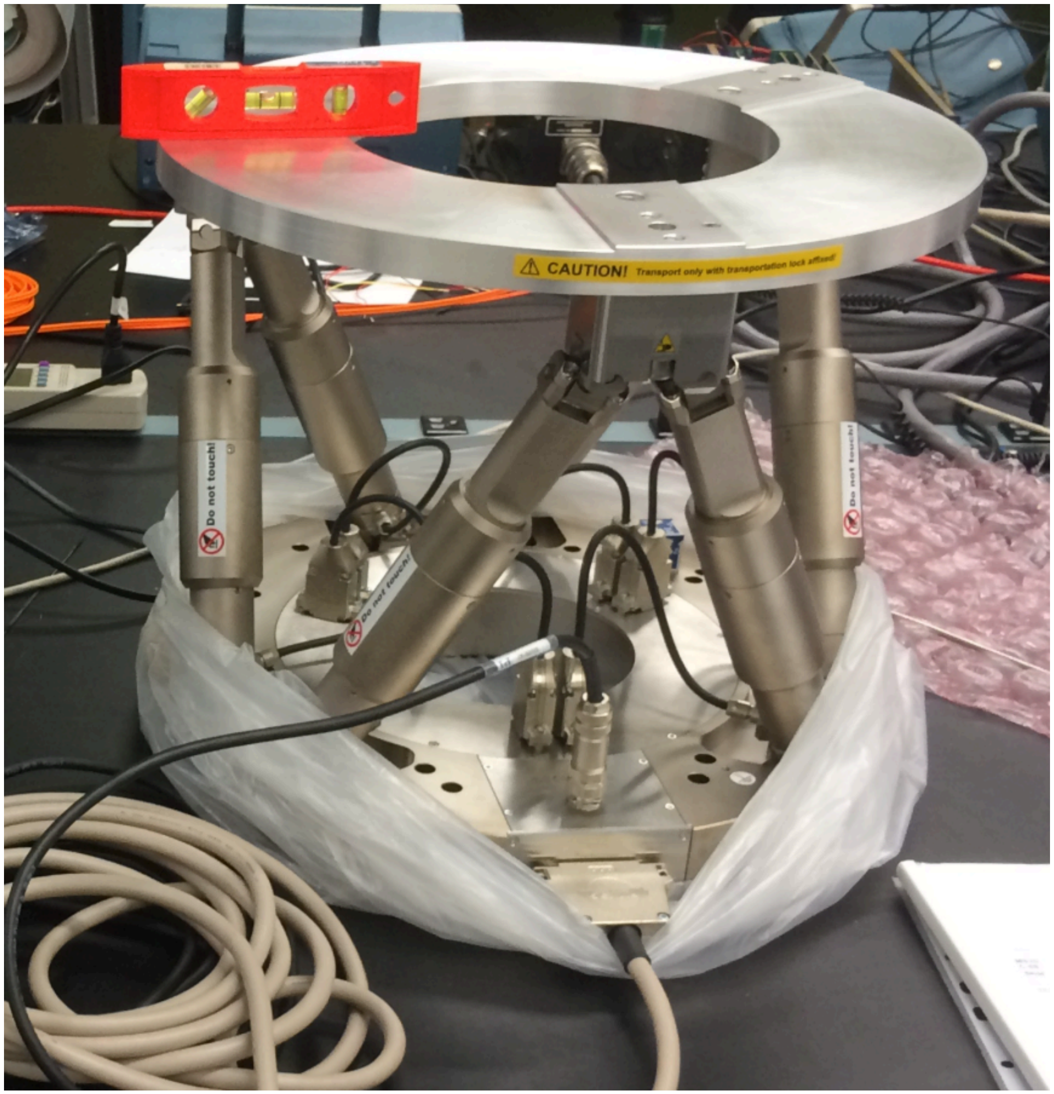


ZTF shutter interface





ZTF hexapod

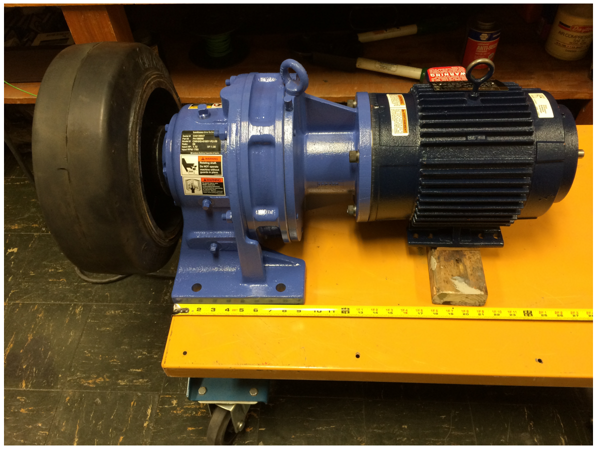


- Focus, tilt and collimation adjusted during every readout (0.5 mm/s)
- Model updated every exposure using three extra focal CCDs and one in focus, that could be used as guider though probably not required.
- Hexapod fully hidden behind instrument; powered down when not moving
- Does not back drive.

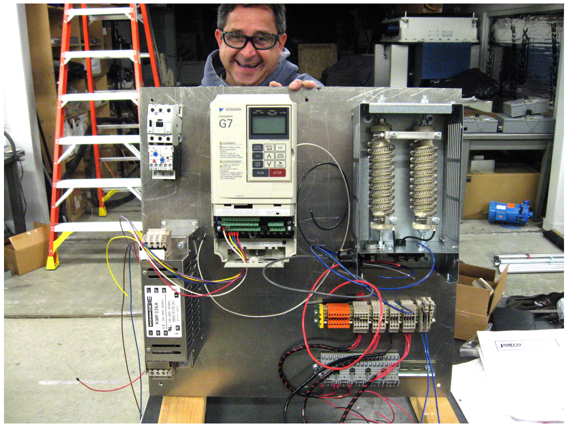
ZTF implementing many telescope upgrades

Refurbished windscreen; new drive; wireless control

New oil pump for Dec drive worm gear



New dome drive motor was installed Feb 2016:
→ More powerful
→ Servo controlled to give flat torque vs. speed
→ New gearbox and tire



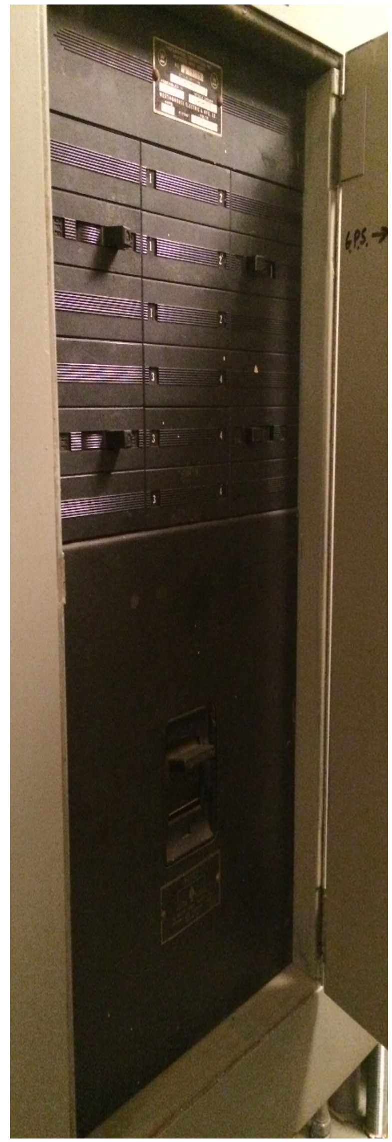
New variable frequency controller
→ Increased acceleration and top speed
→ Only runs as fast as required
→ Dynamic braking
→ Optimal settling (no overshoot)

48" Telescope Electrical System Upgrade

- Electrical switch gear, circuit breakers, and transformers are original, 1940's vintage equipment.
- We can no longer acquire replacements in case of failure
  - ➢ This creates a significant risk of extended downtime if repair or replacement is required.

- Related work to include lightning protection and grounding survey after electrical upgrade is complete;

Planned installation week of June 20, 2016.



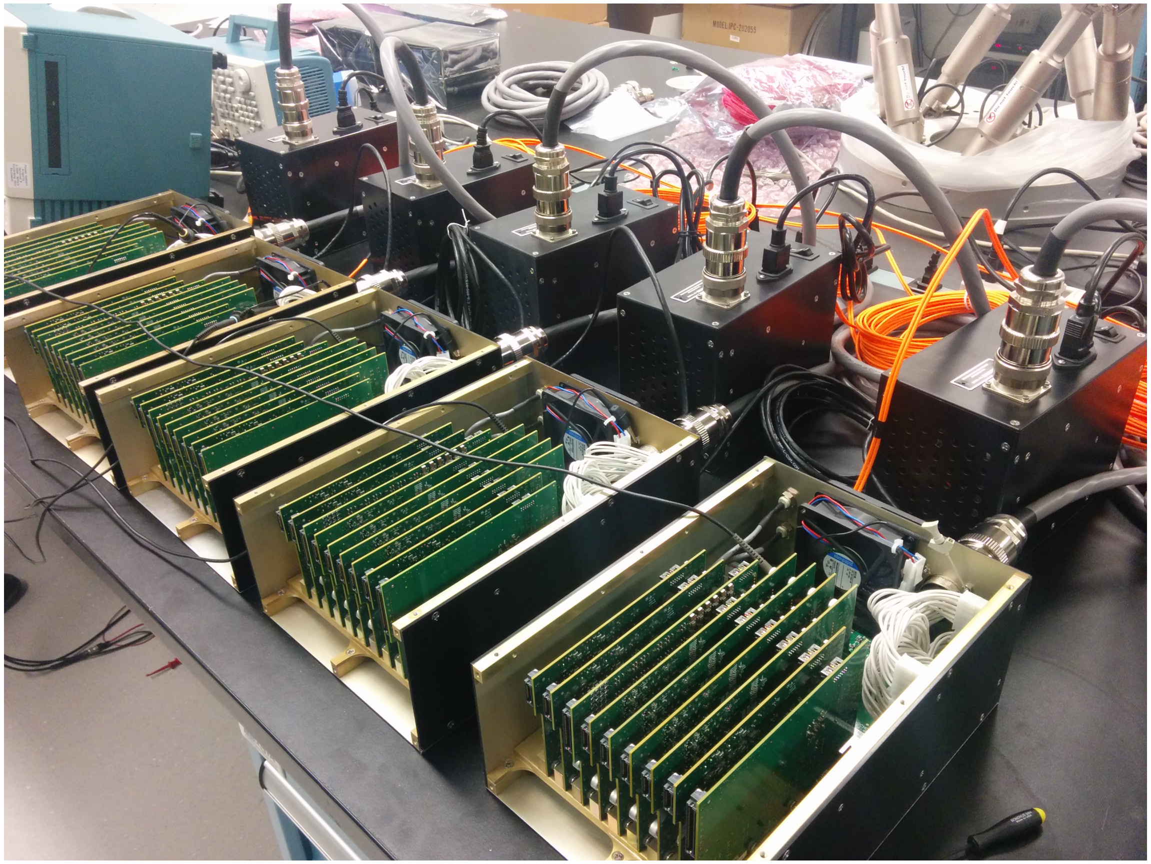
BACKUP SLIDES

ZTF RISK MITIGATION ACTIVITIES

ZTF Observing System Risk Mitigations

- Detectors
  - WaSP science CCD 1st light Feb ’16; guide / focus CCD 1st light Jun ’16
- Cryostat
  - Increased window thickness from 28 to 32 mm
  - Implemented ‘illuminator cover’ for cryostat test, including i-VIB
  - Mitigated Polycold vendor risk
    - Designed and proved new manifold J-T cooling architecture; developed alternative supply chain; established cryocooler test facility and gas analysis channels
  - Demonstrated < 10 micron CCD metrology accuracy using iPTF on-sky
- Exchanger & Shutter
  - Adopted commercial KUKA arm actuator for filter exchange
  - Performed impulse acceleration tests on P48 telescope / confirmed shutter req’s
  - Shutter testing at DESY
  - Developed accelerometer sensor capability on P48
- Software
  - Deployed robotic instrument software, basis for ZTF, at KPNO
- Telescope
  - Many reliability and maintainability upgrades
  - Implemented dome seeing measurement capability on P48

CCD controller automated testing

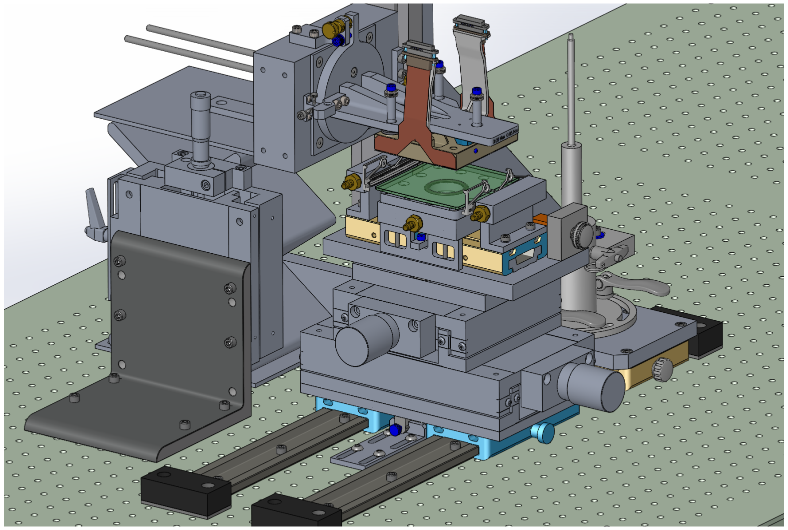


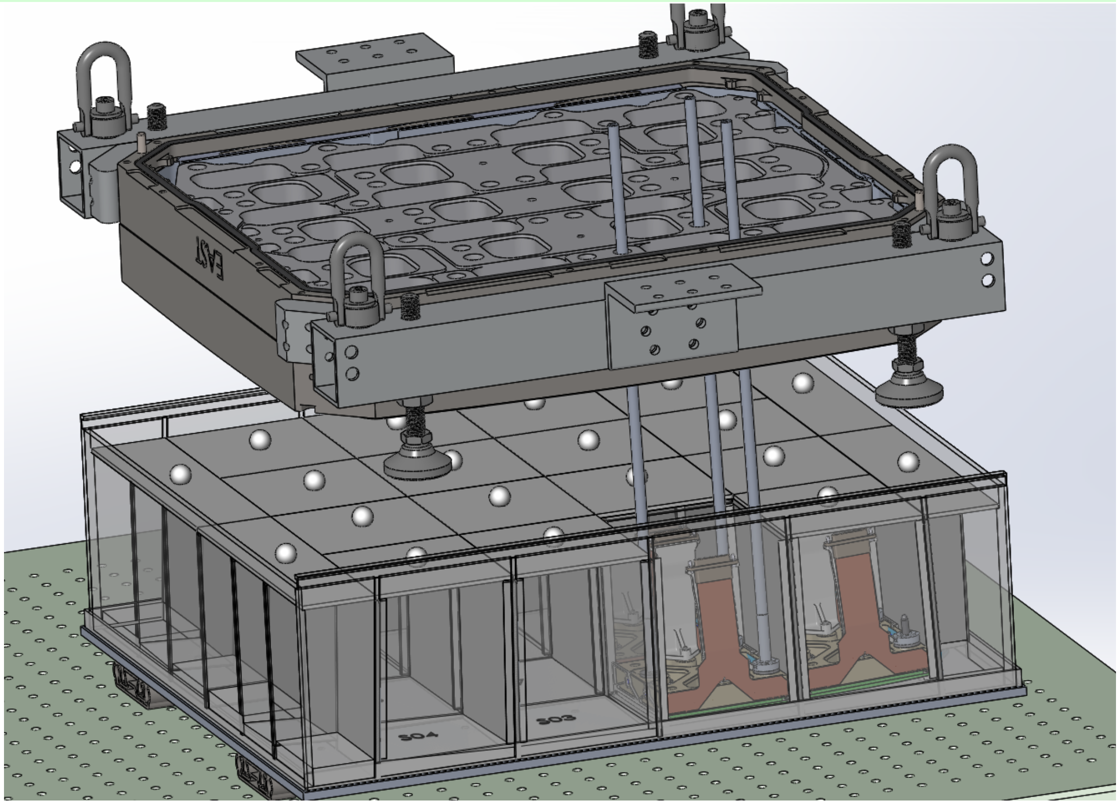
- Semiconductor Technology Associates, “Archon”.
- 5 controllers are fully independent.
- 80 ch at 1 Mpix/s each
- Common master clock: synchronized, low timing jitter.
- Data compression in real time prior to first disk write.
- Measuring excellent performance and reliability (no crashes)

- COO developing custom electronics and software to automate 80-channel controller validation and performance testing

CCD handling fixtures

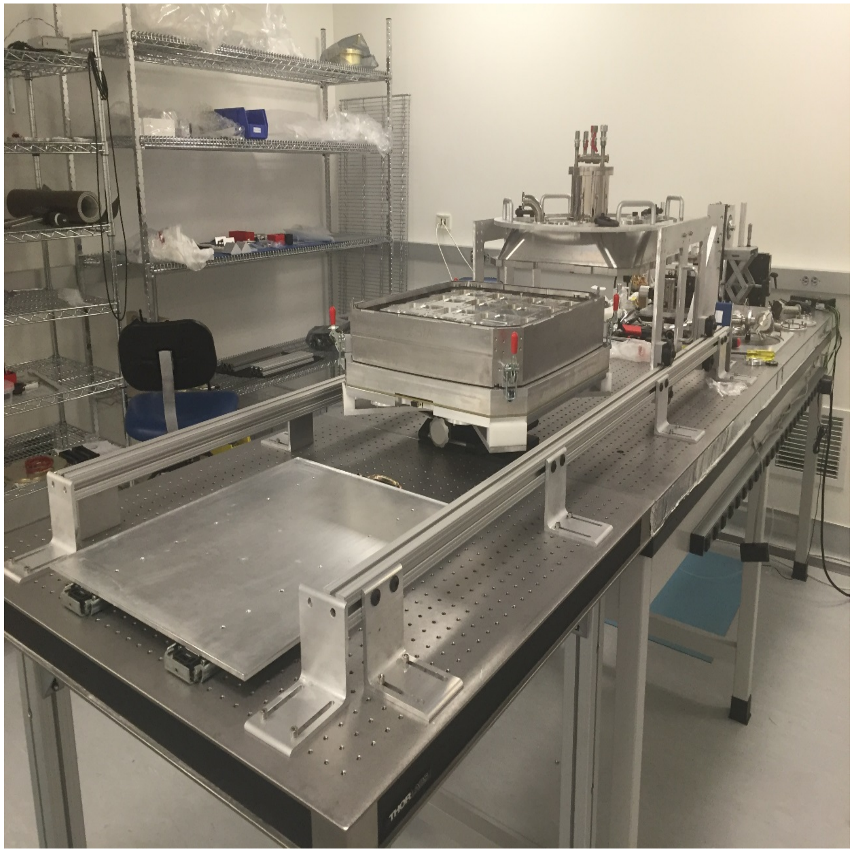
ZTF CCDs be removed and reinstalled to change shims, after through focus imaging on telescope, so great care has been taken to make process easy and safe.

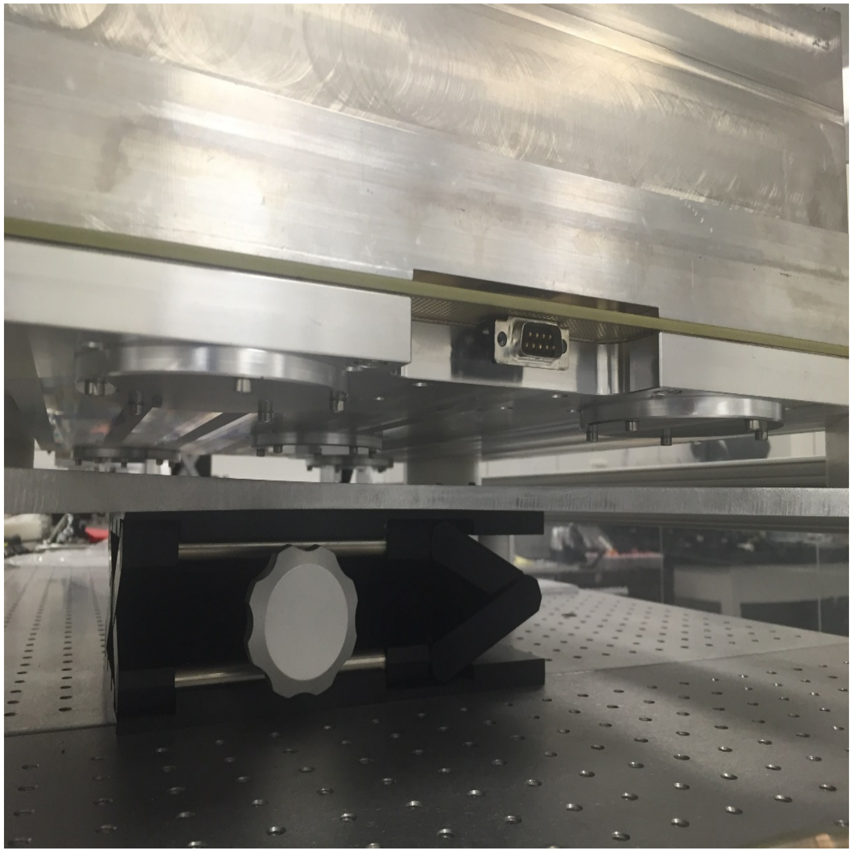




- Story board developed; parts design and procured.
- Assembly and testing in progress.

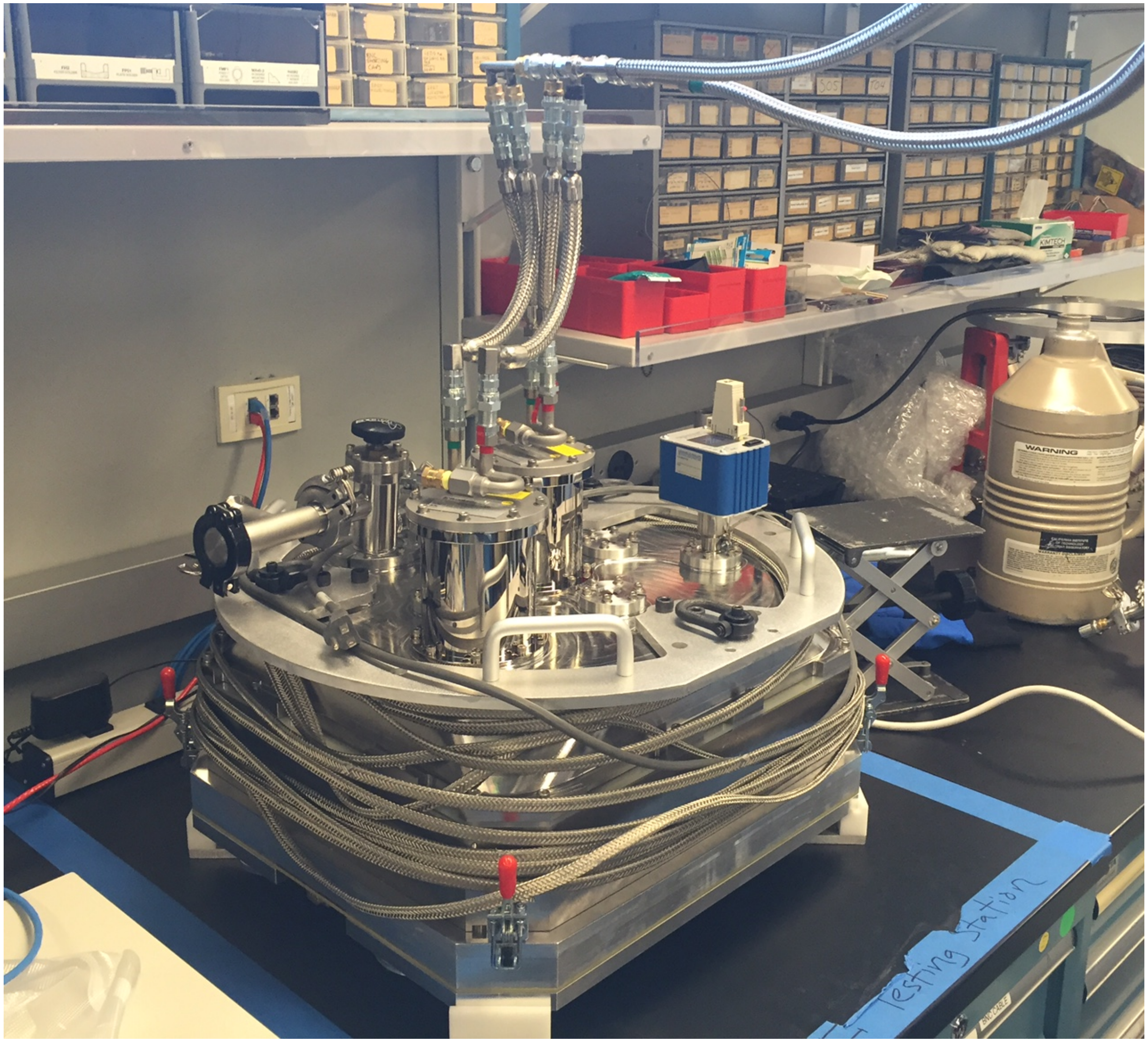
ZTF cryostat ass'ly fixturing



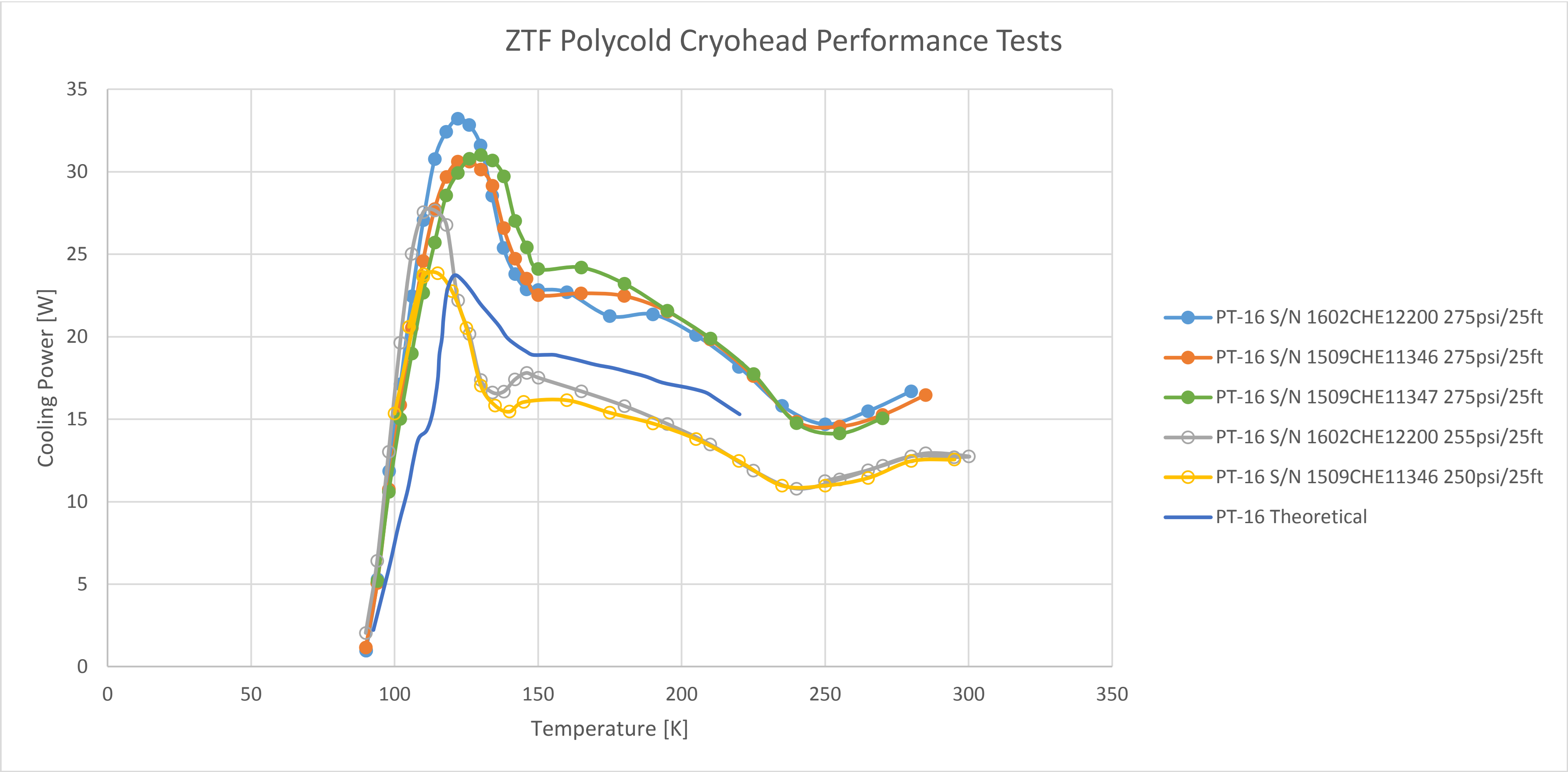


Sliding rig for backplate and lifting fixture for enclosure.

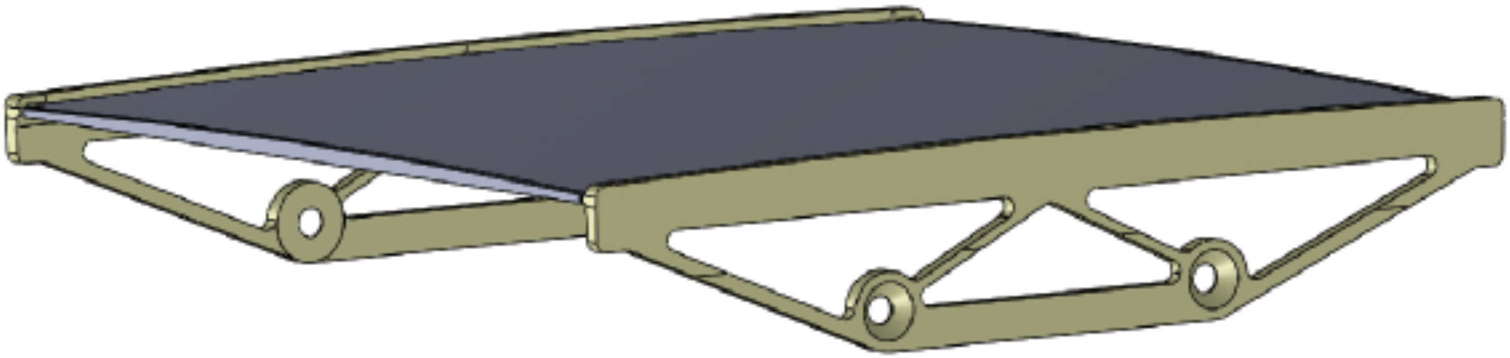
ZTF cryocooler test facility at COO



ZTF cryocooler exceed required performance



Filter frame detail

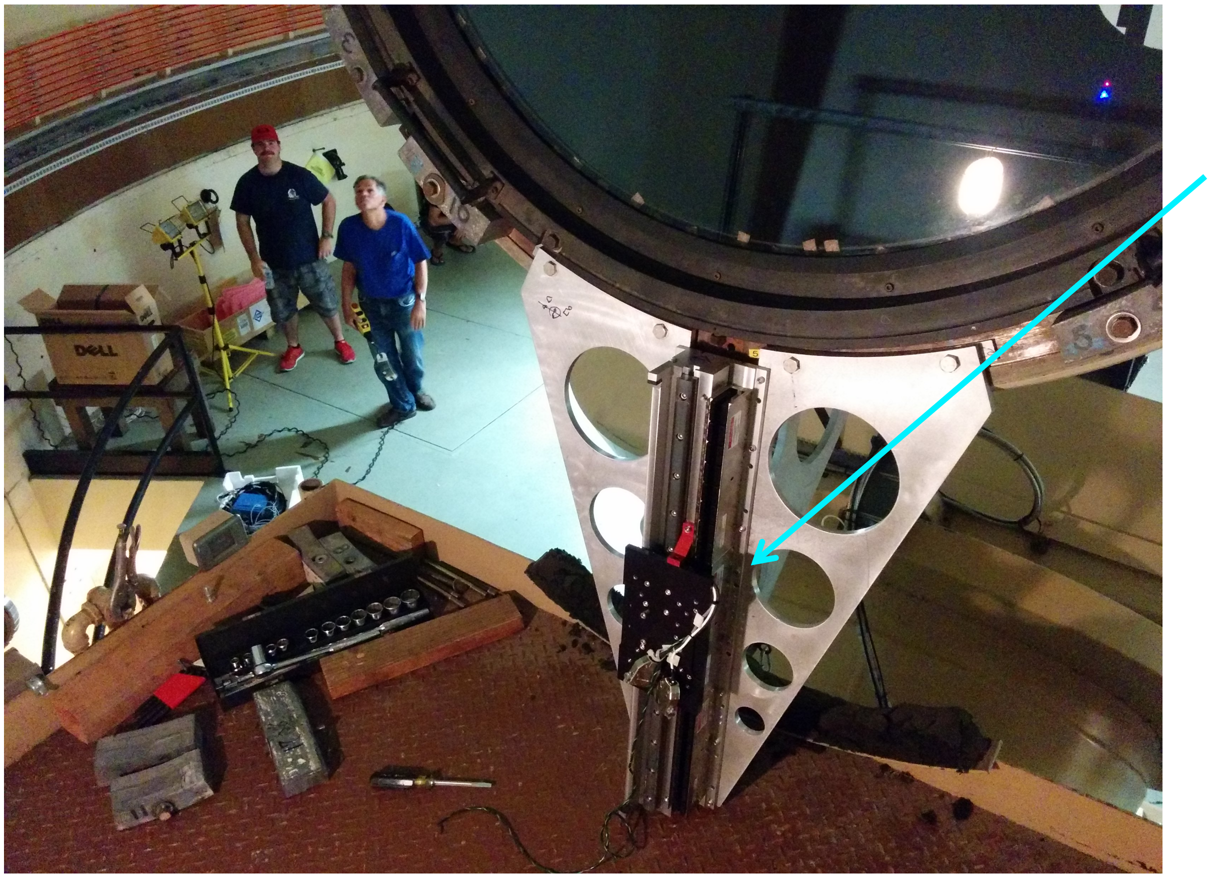


Prototype frame has been 3D printed in stainless, now under cryogenic evaluation

COO large vacuum oven

Multiple storage tanks support exchange of water with detergents for ultrasonic-cleaning either metals, optics or large printed circuits

Telescope resonances studied



Programmable input produced by reaction force from Aerotech linear motor

(direct drive with high resolution encoder)

Charge shifting on PTF CCDs (8 lines every ~ 15ms) turns each star into series of spots to allow centroid motions on both axes to be measured at 67 Hz for ~7 s.

DIQ ERROR BUDGET

Flow-down of DIQ allocation to optomech spec's

		u' filter	g' filter	R filter	i' filter	Notes	Allocated tolerance	Units		Result	Units
	Wavelength	3250-3550-3850	3980-4670-5360	5930-6580-7230	7195-8220-9245	given					
	QE	TBD	TBD	TBD	TBD	assumptions--presently unmodeled/unverified					
		Est. only			Est. only	potential for improvement?					
						dewar design constraints					
DIQ Goal (1D FWHM, arcsec)		N/A	2.20	2.00	N/A	Area-weighted average across focal plane. Only r' and g' drive design.					
Error Term	Allocation									R Seeing for other zeniths	
Atmospheric Effects (z = **30 deg**)		1.30	1.25	1.16	1.11					45	degrees
	Free Atmospheric Seeing	1.24	1.18	1.10	1.05	Based on 1.1" FWHM average (30 degees zenith angle) from 2006/07 P18 MASS/DIMM measurement for Palomar				1.24	arcsec
	Dome and Mirror Seeing	0.35	0.35	0.35	0.35	uncertain					
	Atmospheric Refraction	0.13	0.23	0.07	0.04	refraction from Fillipenko 82					
Telescope		0.99	0.97	1.02	1.02		ALLOCATED				
	M1 Figure	0.40	0.40	0.40	0.40	uncertain	TOLERANCES				
	Tracking Errors*	0.50	0.50	0.50	0.50	PTF Measured 0.92? TBC					
	Vibration	0.39	0.39	0.39	0.39	RMS temporal (high frequency) error =	10	microns	implies at F/2.45 and	0.39	arcsec
	Hub Tilt Rel to Optical Axis	0.40	0.40	0.40	0.40	PTF Measured: 0.27	17.7	microns	implies "	0.40	arcsec
	M1 (Optical Axis) Tilt Rel to Cell	0.39	0.39	0.39	0.39		10	microns	implies "	0.39	arcsec
	Schmidt Plate Axial Position	0.04	0.04	0.04	0.04		10000	microns	implies "	0.04	arcsec
	Schmidt Plate Decenter	0.10	0.10	0.10	0.10	(TBC feasibility w/ P. Gardner)	1000	microns	implies "	0.10	arcsec
	Schmidt Plate Tilt	0.10	0.03	0.10	0.10		34.9	milliradians	implies "	0.10	arcsec
	Schmidt Plate Aspheric Coeff	0.19	0.09	0.19	0.19		5%		implies "	0.19	arcsec
	Schmidt Plate Index of Refraction	0.17	0.17	0.28	0.28		0.05	index uncertainty	results in	0.28	arcsec
	Schmidt Plate Abbe Number	0.13	0.13	0.21	0.21		1.00	Abbe V uncertainty	results in	0.21	arcsec
Instrument		1.84	1.57	1.14	1.61						
	Optical Design IQ (full field avg)	1.60	1.29	0.83	1.40	based on ZTF spot size .zpl macro					
	Cryostat Decenter	0.18	0.18	0.16	0.18		150	microns (1-D)	results in	0.18	arcsec
	Deviation from Best Focus (Hub motion)*	0.31	0.28	0.31	0.31		10	microns	implies "	0.31	arcsec
	Cryostat Window Rel to FPA	0.10	0.10	0.03	0.10		290	microns (1-D)	results in	0.10	arcsec
	Cryostat Window Opt v. Mech Axis	0.19	0.19	0.05	0.19		500	microns (1-D)	results in	0.19	arcsec
	Cryostat Window Center Thickness	0.12	0.12	0.07	0.12	assume telescope refocus	100/-500	microns		0.12	arcsec
	Cryostat Window Glass Melt Index, n	0.12	0.12	0.08	0.12		0.002	index	results in	0.12	arcsec
	Cryostat Window Thermal Variation in n	0.06	0.06	0.06	0.06		30	K radial gradient	results in	0.06	arcsec
	Optics Manufacturing Surface Errors	0.23	0.23	0.23	0.23	Amplitude (1/2 P-V) error =	10	microns	implies "	0.23	arcsec
	Mosiac Tilt Rel to Cryostat	0.21	0.21	0.21	0.21	Amplitude (1/2 P-V) tilt over 373 mm at	0.05	milliradian error	implies "	0.21	arcsec
	CCD Surface Relative to Plate	0.27	0.27	0.27	0.27	Amplitude (1/2 P-V) flatness =	12	microns	implies "	0.27	arcsec
	FPA Plate Height Relative to Hub	0.11	0.11	0.11	0.11	Amplitude (1/2 P-V) flatness =	5	microns	implies "	0.11	arcsec
	Field Flattener Tilt	0.10	0.10	0.05	0.10		9.4	milliradian error	results in	0.10	arcsec
	Field Flattener Decenter	0.10	0.07	0.10	0.10		310	microns (1-D)	results in	0.10	arcsec
	Field Flattener Opt v. Mech Axis	0.16	0.12	0.16	0.16		500	microns (1-D)	results in	0.16	arcsec
	Field Flattener Power	0.10	0.10	0.10	0.10		10%	error	results in	0.10	arcsec
	Field Flattener Final Temperature	0.02	0.02	0.02	0.02		10	K uncertainty	results in	0.02	arcsec
	CCD Lateral Diffusion	0.63	0.63	0.48	0.42	uncertain (esp. vs. wavelength)					
Margin (Unmodelled / Implimentation Errors)		0.25	0.25	0.56	0.25	Allocation					
RMS Total DIQ		2.47	2.24	2.00	2.22	arcsec FWHM	assuming all terms are Gaussian				

ZTF CRYOSTAT WINDOW

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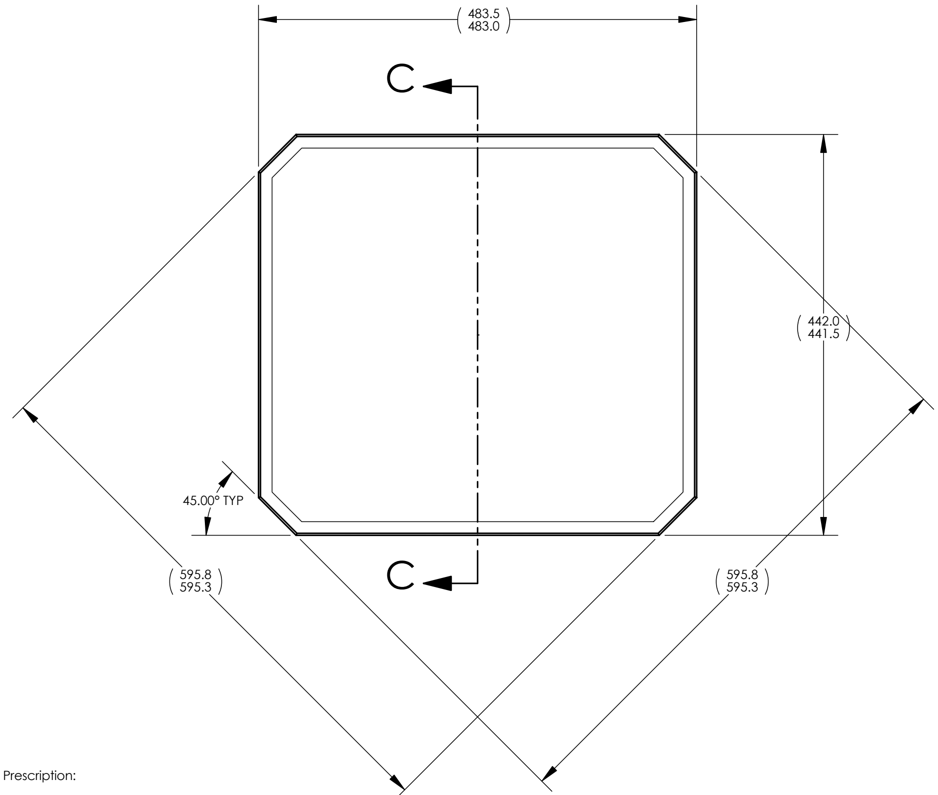
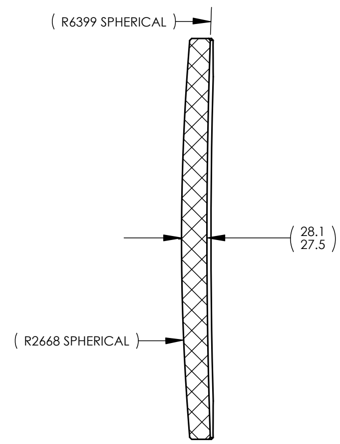
REVISIONS				
ZONE	REV.	DESCRIPTION	DATE	APPROVED
	A	Released for fabrication	9/16/2014	S,P. Callahan
	B	Add Coating Prescription	10/14/2014	S.P. Callahan





SECTION C-C

B

Coating Prescription:

1. Quantity required: 1 piece.
2. Interpret drawing in accordance with ASME Y 14.100.
3. Substrate: Fused Silica (Corning HPFS 7980 Grade 3C or better)
4. Incident medium: Air on convex side (side 1), vaccum on concave side (side 2)
5. Angle of incidence: 0-12 deg.
6. Transmission bands:
   band 1: 398-536nm
   band 2: 593-723nm
7. Reflectivity specification:
   In bands 1 and 2: <0.5% reflectivity in unpolarized light, averaged over angle and wavelength
   In bands 1 and 2: <1.0% maximum refelctivity in unpolarized light, over angle and wavelength
8. Clear aperture: Mecianical aperture minus a 15mm annulus
9. Cosmetics: 60/40
10. Durability: Must pass all requirements in Section 8 of MIL-C-675A, including 3.8.4.1, Eraser test

MODEL FILE NAME:
1100-ZTF3401 Cryostat Window 140910REV:7

UNLESS OTHERWISE SPECIFIED:		DATE	NAME
	DRAWN	9/16/2014	S.P.Callahan
	CHECKED	9/17/2014	D. Reiley
	ENG APPR.	9/16/2014	S.P.CALLAHAN
	MFG APPR.	9/16/2014	R. Dekany
INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5M-1994 (R2002)	Q.A.		
MATERIAL See Note 3	3RD ANGLE PROJECTION		
FINISH Notes 4-10			

1000-ZTF0001	
NEXT ASSY	USED ON
APPLICATION	

Zwicky Transient Facility
Caltech Optical Observatories

TITLE:
Cryostat window
1100ZTF-0000
ZTF

SIZE	DWG. NO.	REV
B	1100-ZTF3401	B

SCALE: 1:5 | WT (KG.): 11.18 | SHEET 3 OF 3

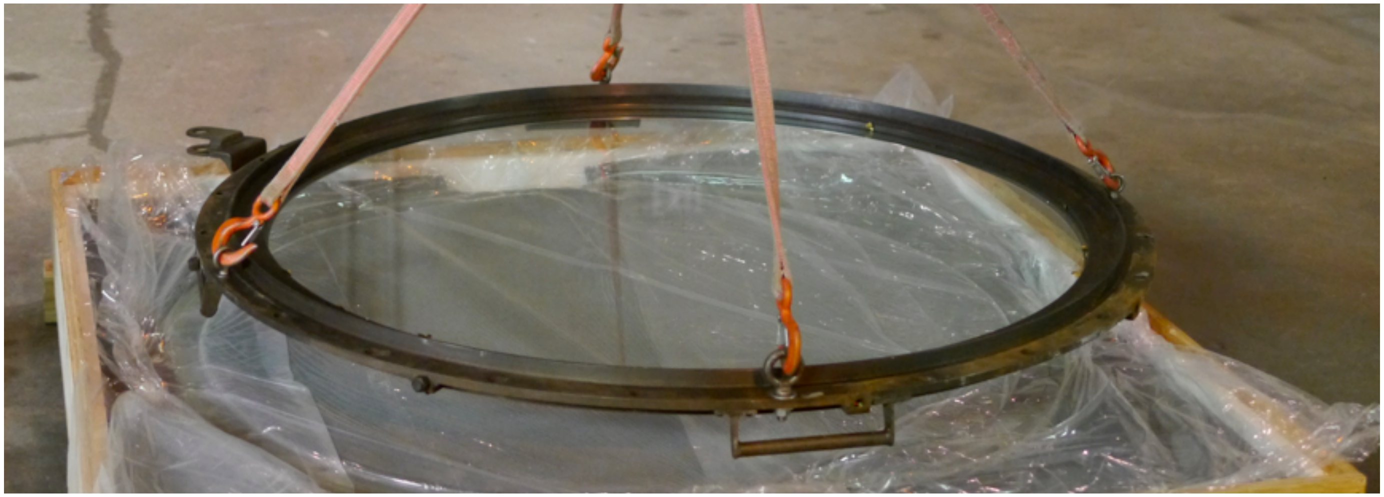
ZTF SCHMIDT CORRECTOR TRIM PLATE

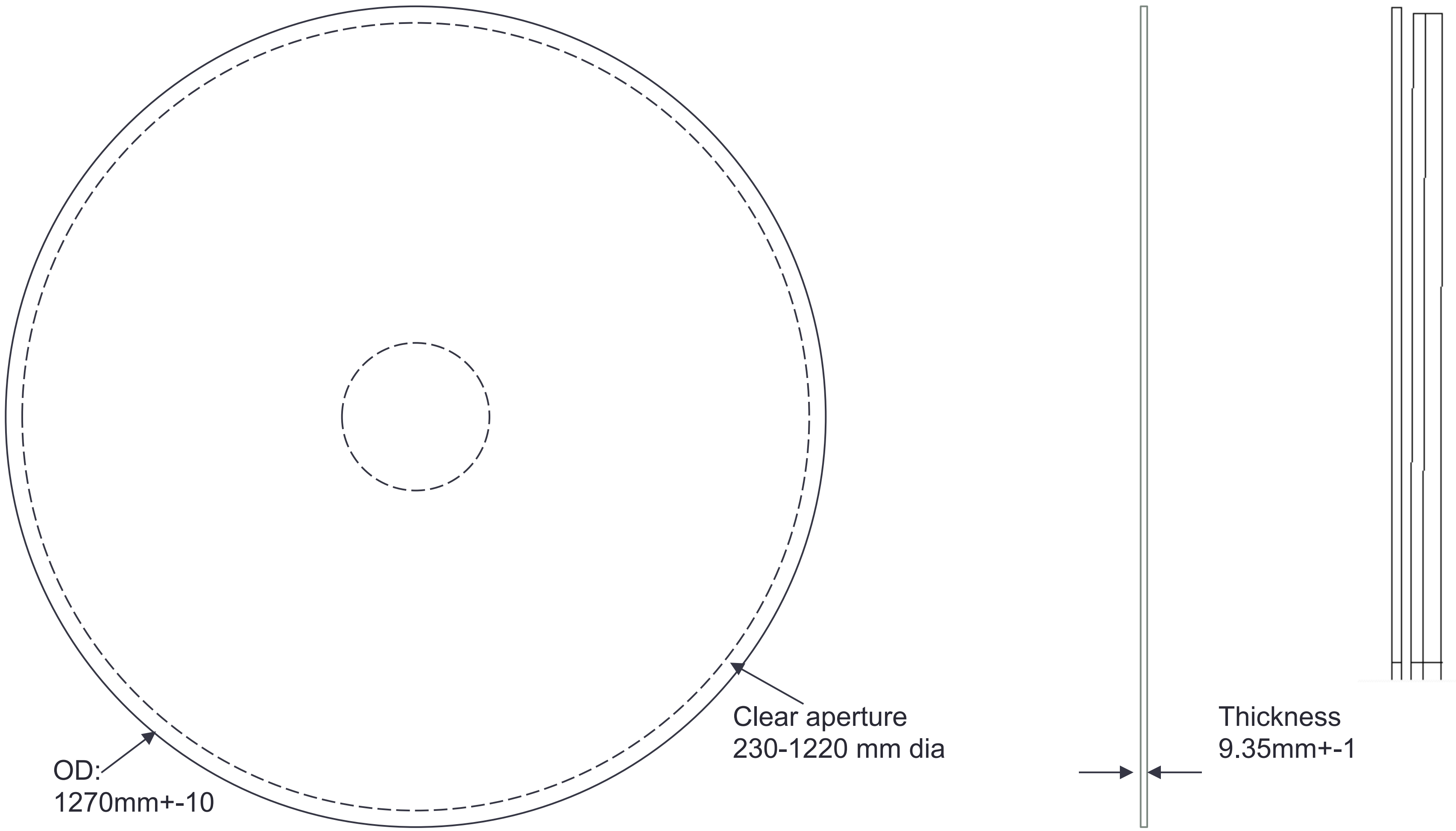
Trim plate found in 200” basement

Discovery Image!

Recent optomech progress (Aug - Oct '13)

- Caltech measured index of refraction of Schmidt blank at Palomar
  - Two techniques yield index n=1.501 and n=1.555
  - Next step: Final optical design optimization, incl. exact CCD locations





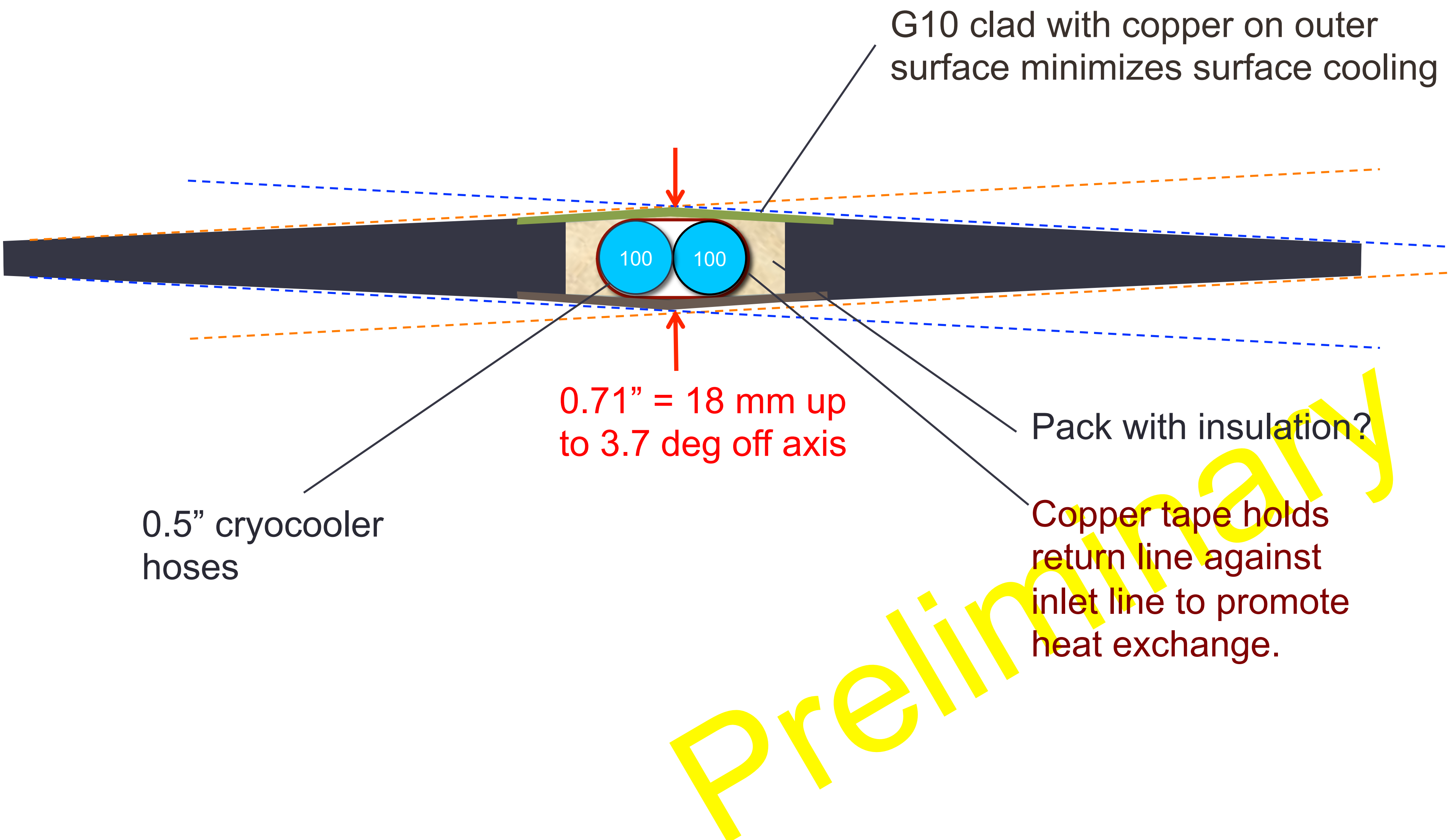
Material: Optical glass – see notes
Coating: none
Surface quality: 60-40
Side A: flat
Side B:aspheric profile – see notes

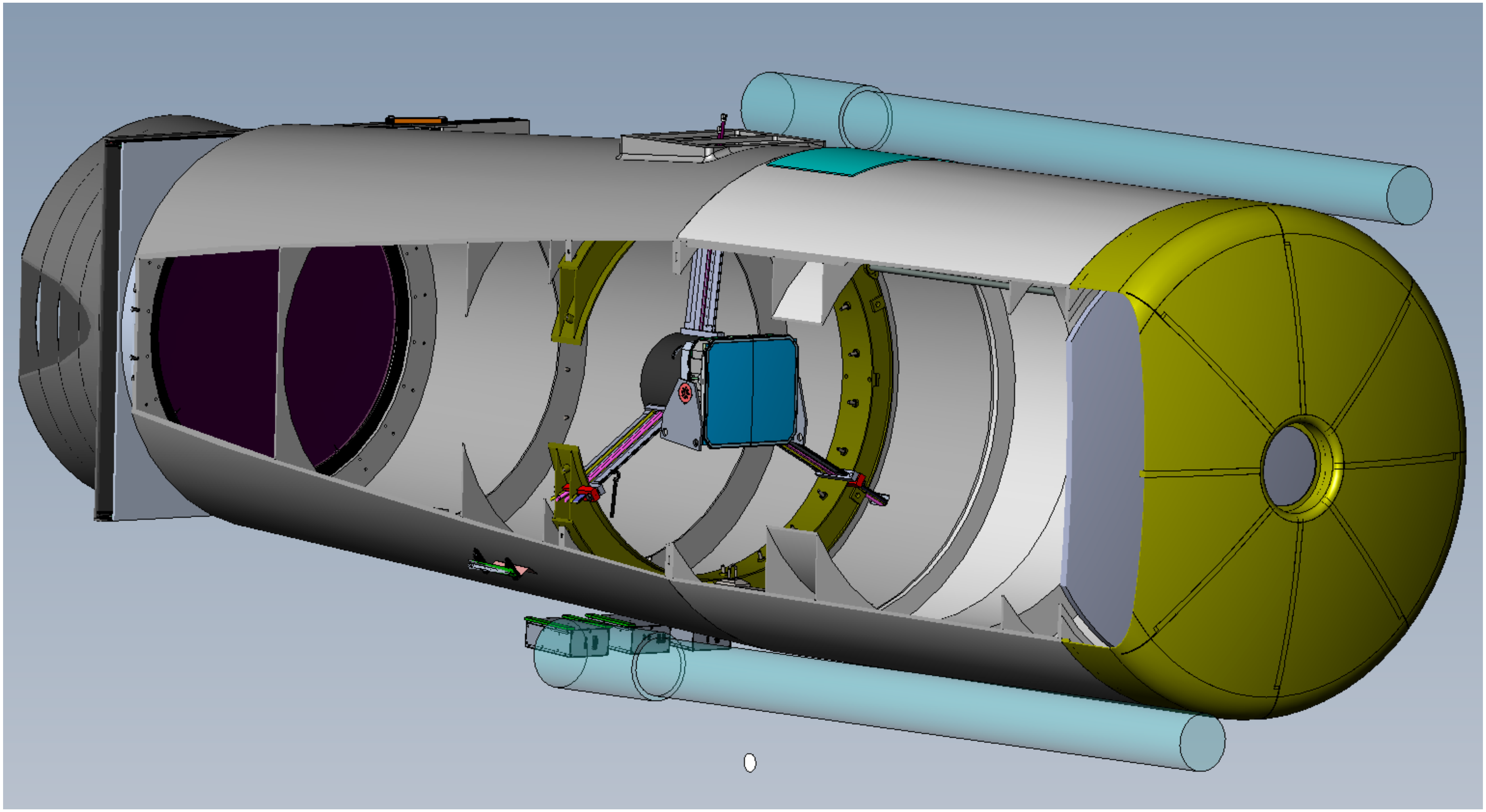
<u>50” Schmidt Corrector</u>
drawing # DJR032213-rev1 (page 1 of 2)
Caltech Optical Observatories
March 23, 2013
Contact:
Dan Reiley   (626)395-4033
djr@astro.caltech.edu

ZTF trim plate at Rayleigh Optical

ZTF CAMERA
CABLE ROUTING: SPIDERS

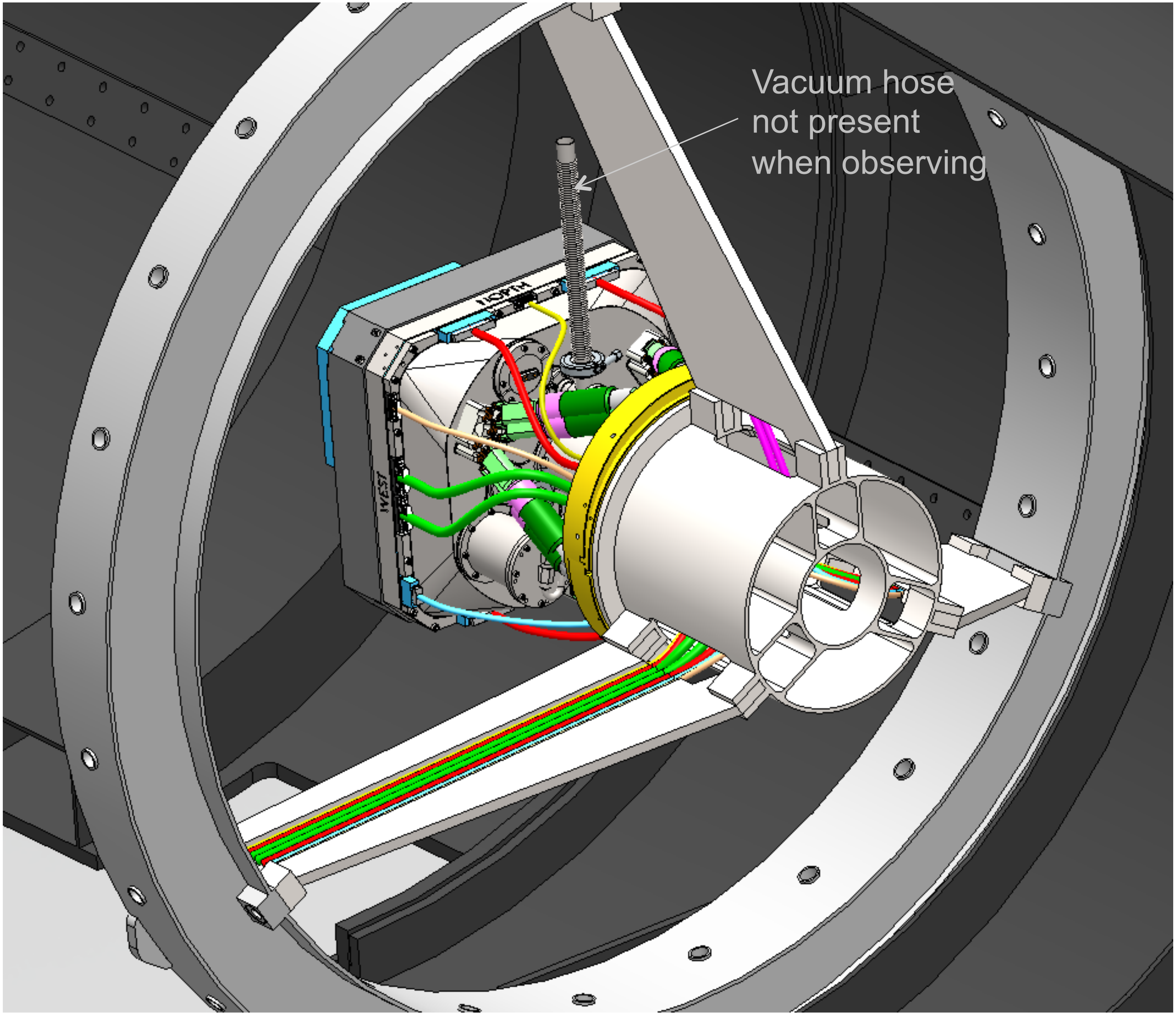
East-West spiders





The Caltech engineers have been developing

- New spiders, incl. ring
- New articulated ZTF camera mount
- New access hatches
- Bonn shutter interface
- Schmidt trim plate mount
- New baffles
- Cable routing
- Tube balance


Vacuum hose
not present
when observing

ZTF BUDGET

WBS No.	WBS Element	% Total Labor	% Total Cost	Estimated ZTF Project Totals: ZTF Plan Labor (wk-hrs)	Estimated ZTF Project Totals: ZTF Plan Cost	Pre-Award Period (inception to 8/31/14): Expended Labor (through 1/31/2014)	Pre-Award Period: Expended Cost	Pre-Award Period: Estimated Labor (2/1/14 - 8/31/14)	Pre-Award Period: Estimated Costs	Award Period+ (9/1/14 - 12/31/19): MSIP Labor (wk-hrs)	Award Period+: MSIP Cost	Award Period+: Estimated Partner Labor	Award Period+: Estimated Partner Cost	Contingency contribution on remaining work (no MSIP request)	
1	**Management**	16%	9%	14758	$1,414,632	644	$88,186	1711	$277,653	12058	$1,016,794	346	$32,000	5%	$66,700
1.1	Project Management			5878	$852,489	644	$88,186	1711	$277,653	3523	$486,651	0	$0	6%	$45,858
1.2	Undergraduate Summer Programs			7495	$438,707	0	$0	0	$0	7495	$438,707	0	$0	3%	$13,161
1.3	Community Workshops			1039	$91,436	0	$0	0	$0	1039	$91,436	0	$0	7%	$6,401
1.4	Palomar E/PO			346	$32,000	0	$0	0	$0	0	$0	346	$32,000	4%	$1,280
2	**Systems Engineering**	12%	6%	11256	$990,314	1804	$207,425	900	$127,574	8553	$655,315	0	$0	15%	$118,985
2.1	Systems Engineering and Documentation			3580	$521,290	1804	$207,425	900	$127,574	877	$186,291	0	$0	14%	$43,941
2.2	Commissioning			7676	$469,024	0	$0	0	$0	7676	$469,024	0	$0	16%	$75,044
3	**ZTF Observing System**	45%	49%	40956	$7,791,052	3088	$1,065,573	7977	$1,992,426	27285	$4,069,070	2605	$663,983	14%	$913,908
3.1	**Camera**			33553	$6,219,665	3088	$1,065,573	7281	$1,816,056	23183	$3,012,178	0	$325,858	10%	$511,373
3.1.1	Cryostat			4765	$716,368	1880	$298,790	2569	$267,868	316	$36,753	0	$112,957	24%	$100,219
3.1.2	Camera Optics			1630	$605,736	934	$88,186	661	$157,415	34	$147,235	0	$212,901	18%	$93,159
3.1.3	Science CCDs			1124	$2,268,689	120	$663,900	411	$776,233	593	$828,555	0	$0	4%	$64,192
3.1.4	Autoguider/focusser			565	$159,685	0	$0	315	$96,353	250	$63,333	0	$0	12%	$19,162
3.1.5	CCD Readout Electronics			1978	$699,540	155	$14,698	358	$158,441	1465	$526,401	0	$0	10%	$68,484
3.1.6	Non-CCD Electronics			3375	$403,893	0	$0	1482	$202,431	1893	$201,461	0	$0	14%	$56,545
3.1.7	Camera Software			4110	$391,473	0	$0	1410	$134,554	2700	$256,919	0	$0	28%	$109,612
3.1.8	Ass'ly, Integration & Test (AIV)			16007	$974,282	0	$0	75	$22,761	15932	$951,521	0	$0	30%	$292,285
3.2	**Oschin Telescope**			7403	$1,571,388	0	$0	696	$176,370	4103	$1,056,893	2605	$338,125	26%	$402,536
3.2.1	Schmidt Trim Corrector			365	$369,670	0	$0	265	$110,170	100	$259,500	0	$0	18%	$66,541
3.2.2	Exposure Shutter			2985	$376,175	0	$0	381	$38,050	0	$0	2605	$338,125	28%	$105,329
3.2.3	Telescope Software Upgrades			300	$24,300	0	$0	50	$8,000	250	$16,300	0	$0	26%	$6,318
3.2.4	Telescope Hardware Upgrades			3753	$801,243	0	$0	0	$20,150	3753	$781,093	0	$0	28%	$224,348
4	**Data System**	16%	30%	14922	$4,719,582	0	$0	0	$0	9849	$3,112,019	5073	$1,607,562	8%	$387,670
4.1	DS Architecture			3234	$1,426,687	0	$0	0	$0	2134	$1,088,344	1099	$338,344	6%	$85,601
4.2	Pipeline Development			3159	$1,380,610	0	$0	0	$0	2085	$1,067,534	1074	$313,077	10%	$138,061
4.3	Archive Development			5281	$1,231,767	0	$0	0	$0	3485	$615,883	1795	$615,883	10%	$123,177
4.4	Pipeline Operations			3248	$680,517	0	$0	0	$0	2144	$340,259	1104	$340,259	6%	$40,831
5	**Survey Operations**	10%	6%	8900	$890,481	0	$0	0	$0	1559	$126,822	7341	$763,659	9%	$80,484
5.1	Data Link			0	$45,000	0	$0	0	$0	0	$0	0	$45,000	6%	$2,700
5.2	Observation Planning Software			3560	$338,192	0	$0	0	$0	0	$0	3560	$338,192	14%	$47,347
5.3	Survey Execution			5340	$507,289	0	$0	0	$0	1559	$126,822	3781	$380,466	6%	$30,437
	ZTF Baseline Program Cost	100%	100%		$15,806,061		$1,361,184		$2,397,652		$8,980,020		$3,067,204	11%	$1,567,748
	Contingency on future work; non-fixed-price items (see §5.1)				$1,567,748										$1,567,748
	ZTF Planning Cost (incl. contingency)			90792	$17,373,808	5536	$1,361,184	10588	$2,397,652	59303	$8,980,020	15365	$3,067,204		

ZTF Full Lifecycle Cost
from 2014 MSIP Proposal ZTF Management Plan

ZTF Financial Summary as of 2/29/16