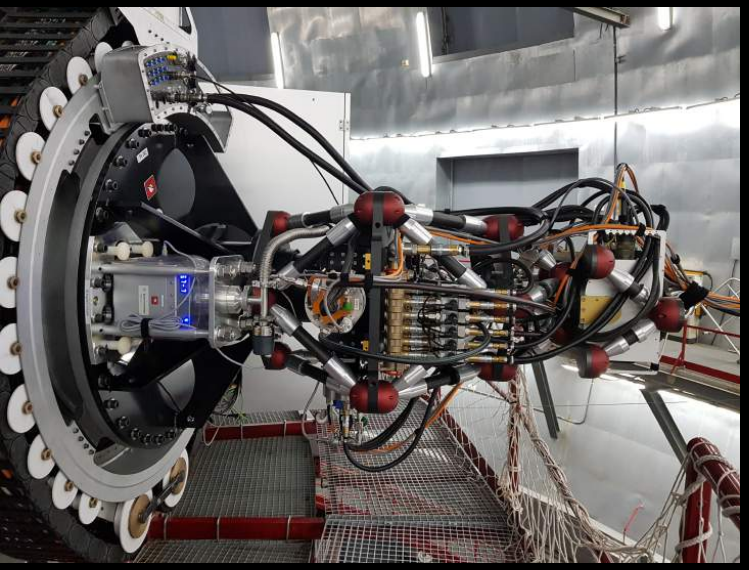


HiPERCAM on the GTC

Vik Dhillon

Sheffield/IAC

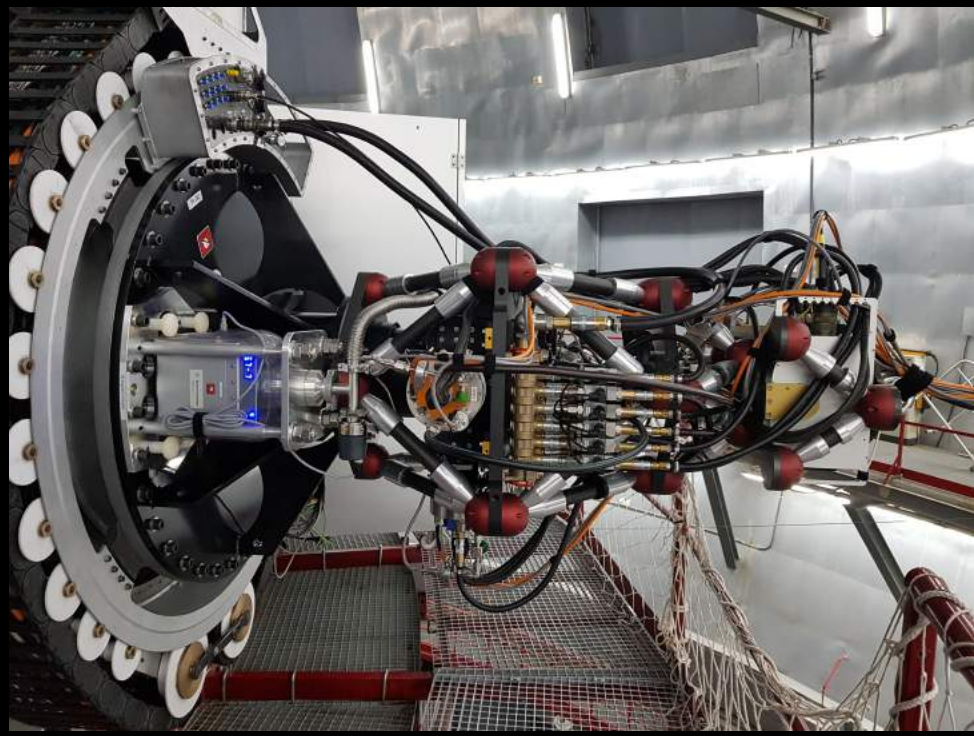
With thanks to the HiPERCAM team at Sheffield, IAC, Warwick, UKATC, ESO, Durham, IAA and GTC

OUTLINE

- What is HiPERCAM?
- Performance on GTC
- Science results
- Future plans
- (The role of GOTO)

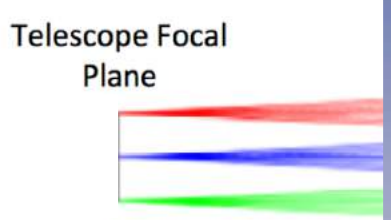
HiPERCAM

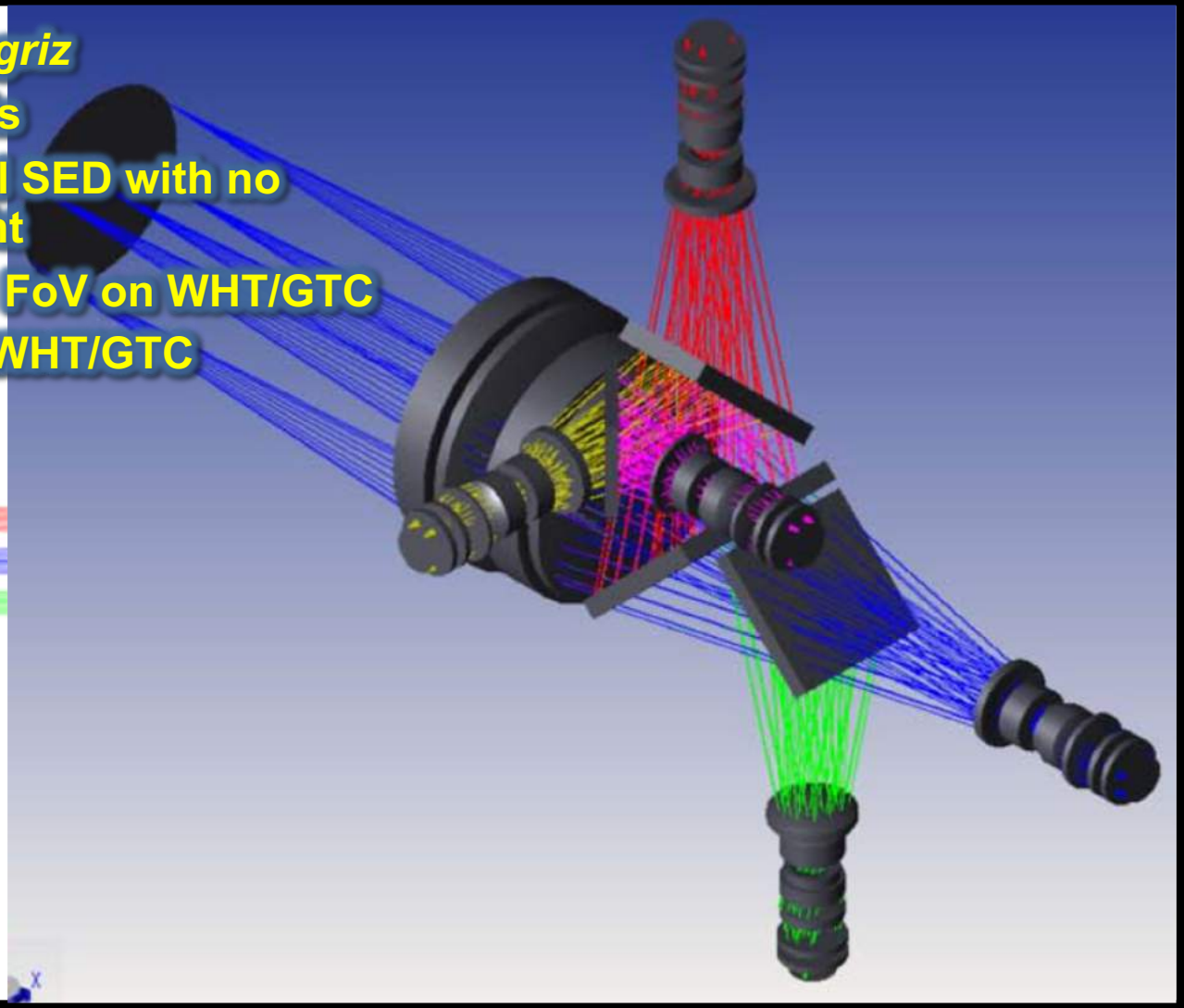
- High PERformance CAMera.
- General-purpose quintuple-beam (*ugriz*) CCD imager, with high-speed capability.
- Visitor instrument, building on heritage of ULTRACAM and ULTRASPEC.
- Funded by ERC Advanced Grant for 3.5M€ (PI: Dhillon), started in 2014.
- First light on the WHT in 2017, on budget and on time.
- First light on the GTC in 2018. Observed ~50 science nights to date.



OPTICS

- 5 arms covering *ugriz*
- 48 optical elements
- Single-shot optical SED with no wasted optical light
- 11.4'/3.1' diagonal FoV on WHT/GTC
- 0.3/0.08"/pixel on WHT/GTC



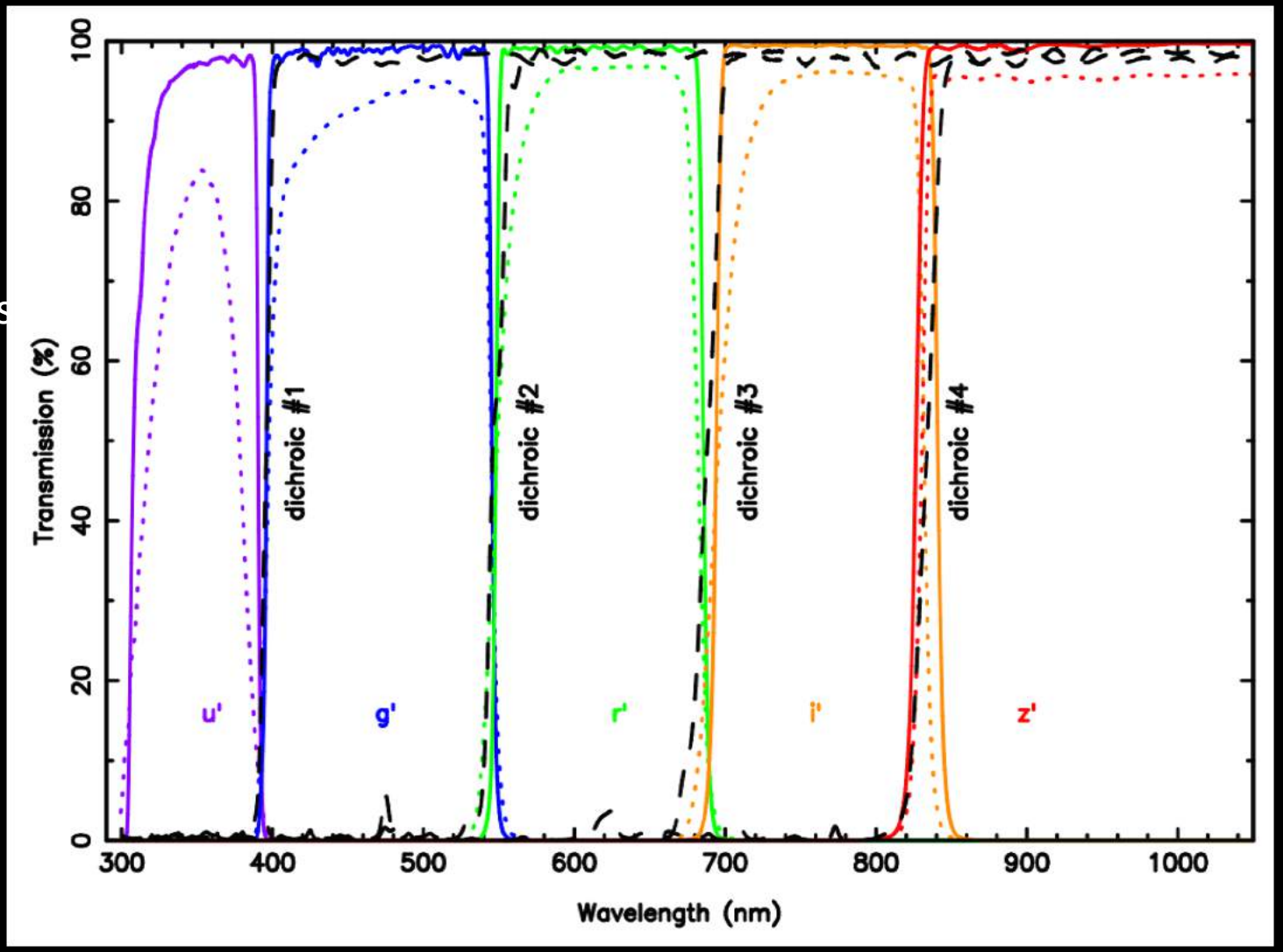


OPTICS

High-performance dichroic beamsplitters.

"Super-SDSS" filters with enhanced throughput:

u_s 41%
g_s 9%
r_s 6%
i_s 9%
z_s 5%

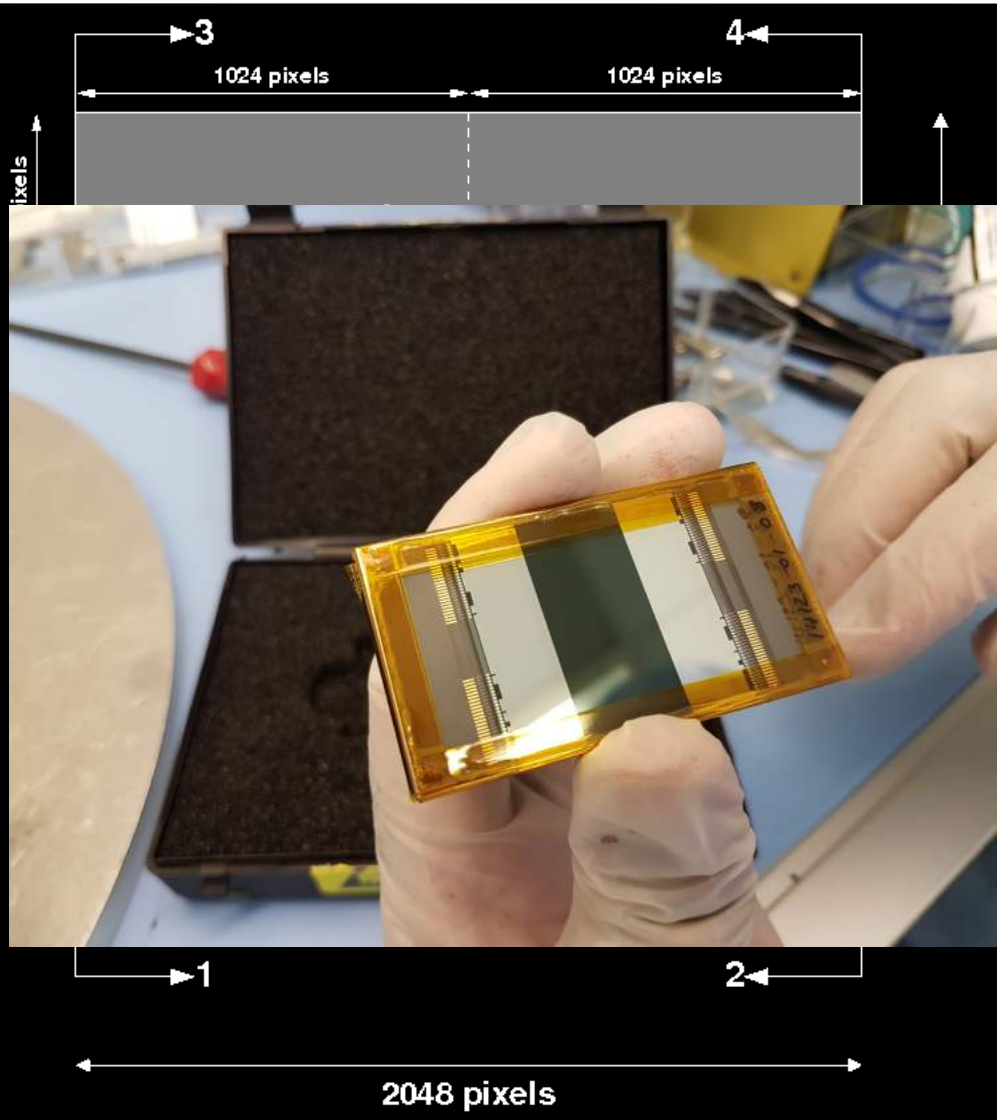


OPTICS

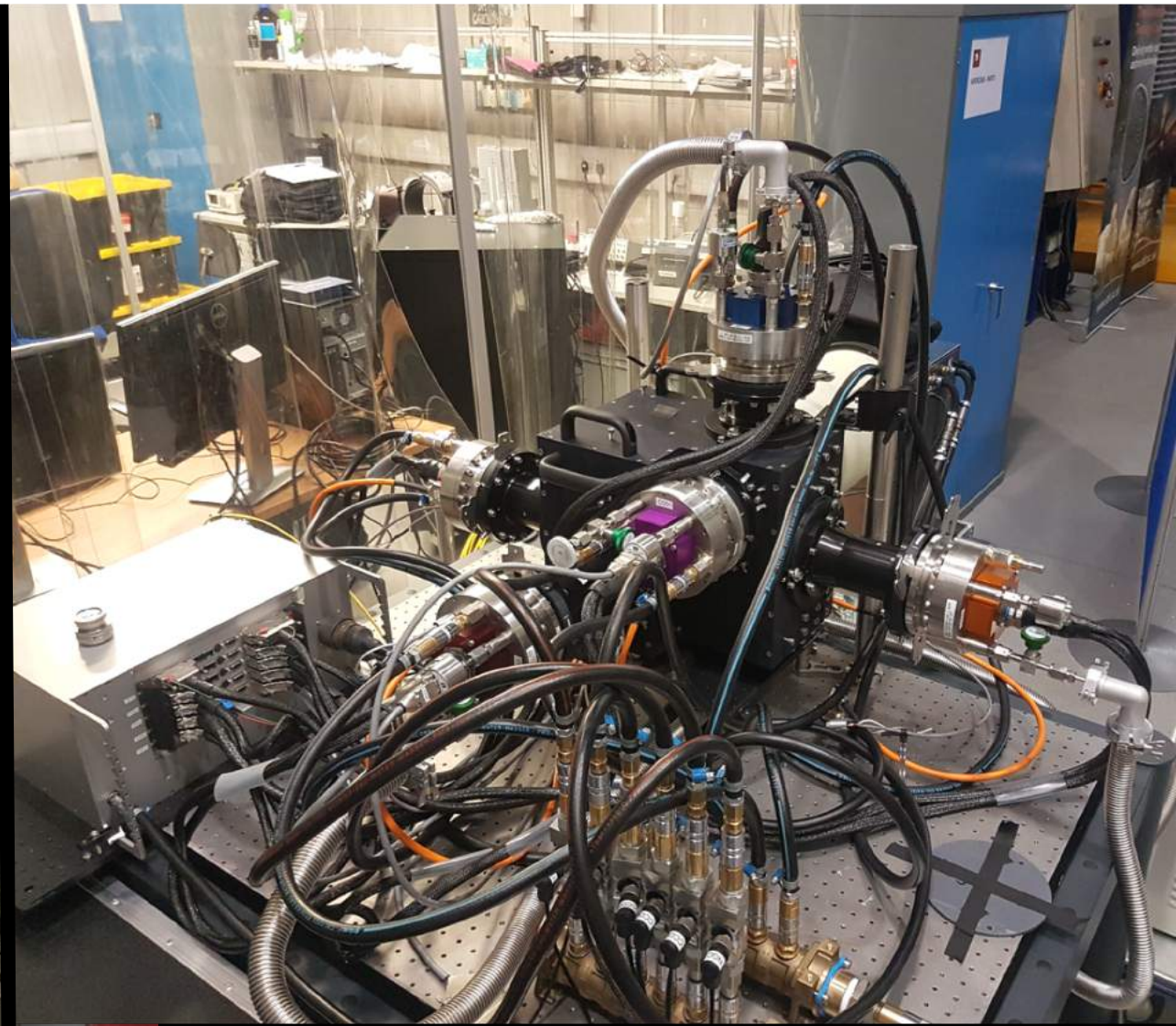
- Dichroics housed inside a “hull”.
- Collimator and five re-imaging camera barrels mounted on hull.
- Filters cartridges and CCD heads mounted on ends of camera barrels.
- Sealed optical system against ingress of light and dust.

HIPERCAM CCDs

- Custom (1M€) Teledyne-e2v back-thinned CCD231-42 grade 1 devices.
- Split frame-transfer with 4 outputs, 2048x1024 image area, 15µm pixels.
- <100 e^-/pix/hr dark current at 183 K, NIMO.
- 4e^- RNO at 125 kHz pixel rate (with differential outputs).
- 2 phase devices, 10µs row time, 0.1µs/pix serial clocking, split serial clocking, 100 ke^- full well.
- Full frame time 1.25s, drift mode frame rate >1000Hz (24x24 pix windows).
- Fringe suppression (0.1% in *i*, 1% in *z*).
- Optimised AR coating and Si type for each CCD.

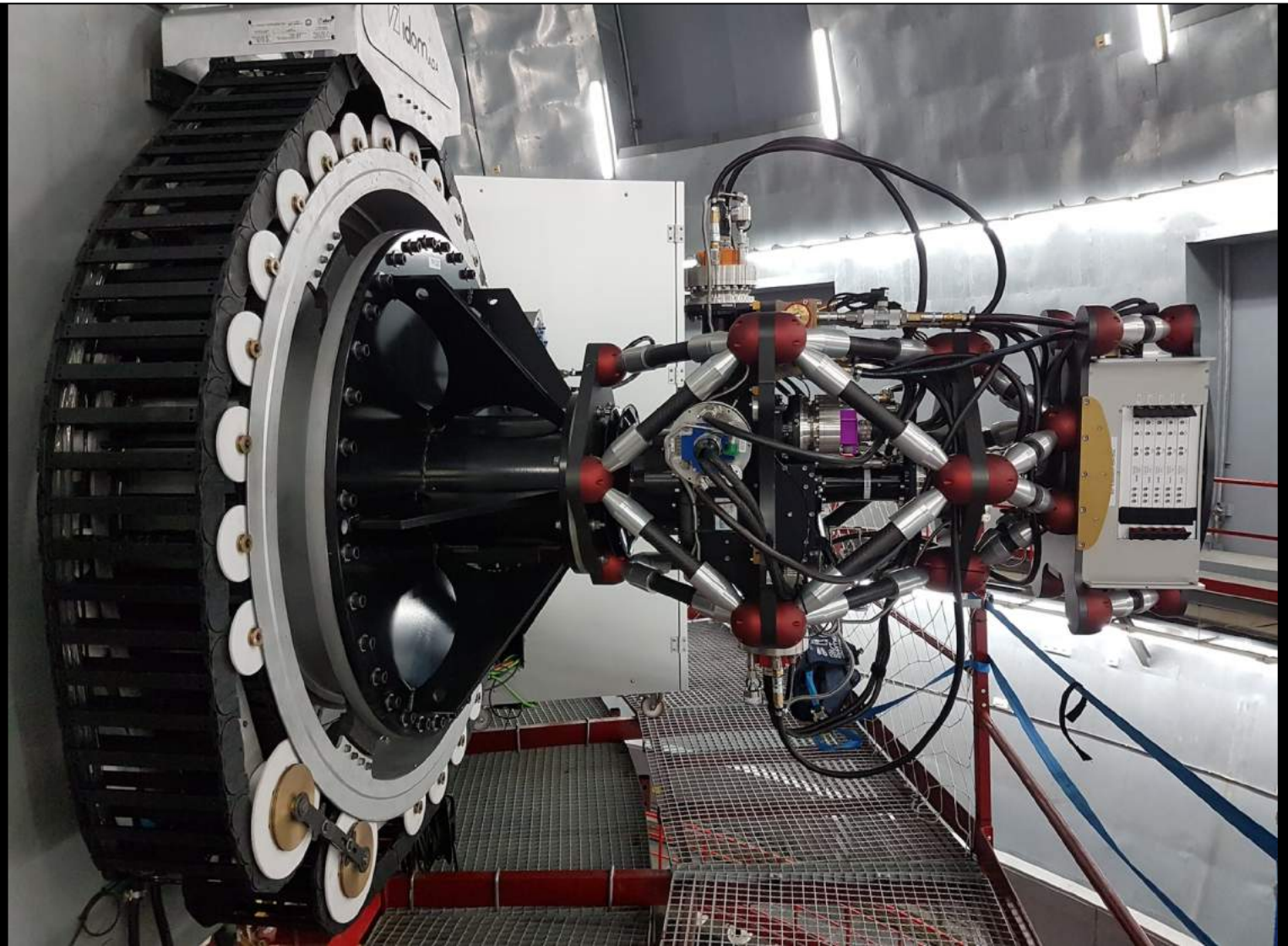


TEC CCD HEADS

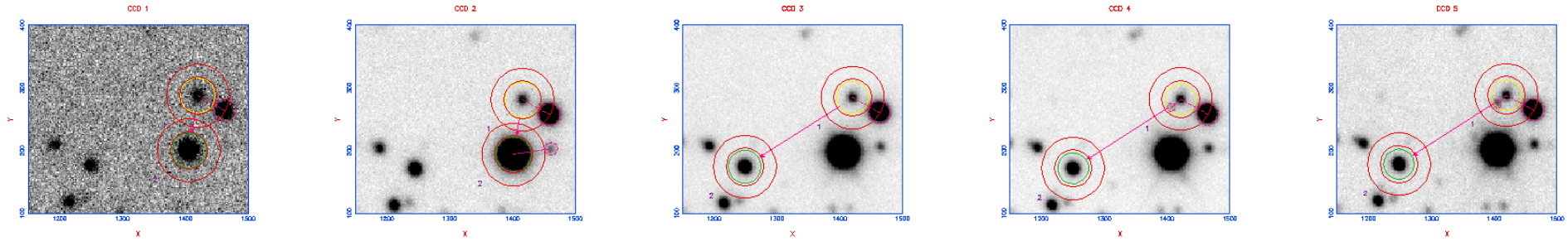


MECHANICAL STRUCTURE

10.4m GTC, La Palma



DATA REDUCTION SYSTEM



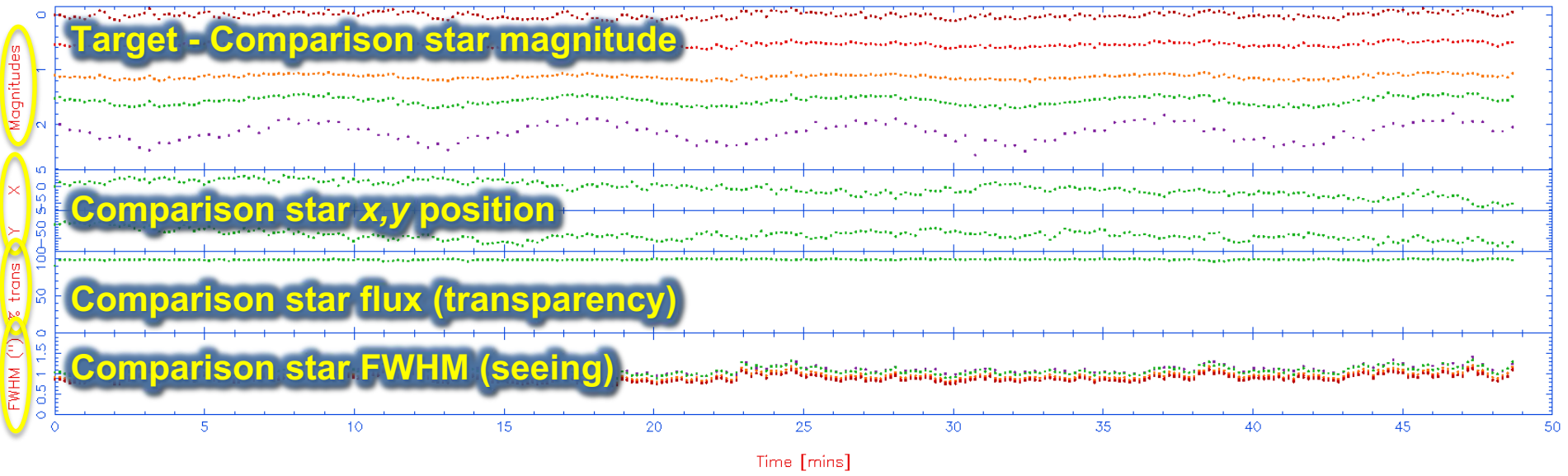


IMAGE QUALITY

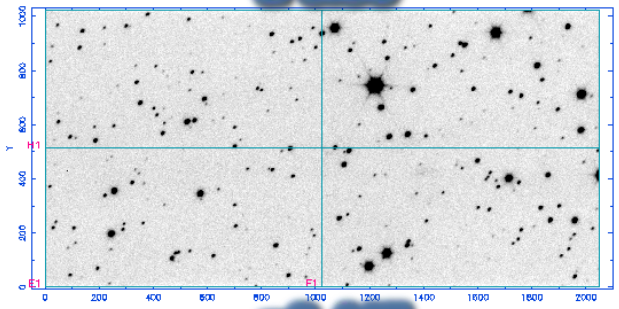
No discernable ghosting.

Platescale uniform as function of wavelength.

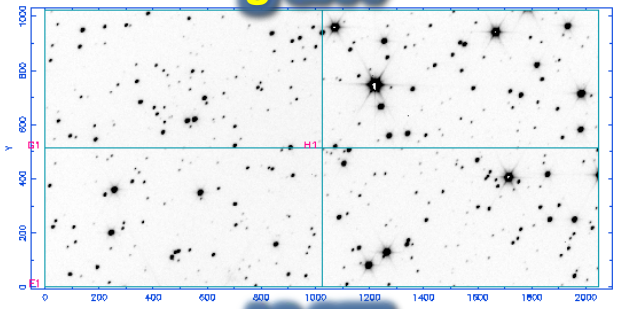
No discernible vignetting.

PSFs are seeing limited across field of view in <0.4” seeing.

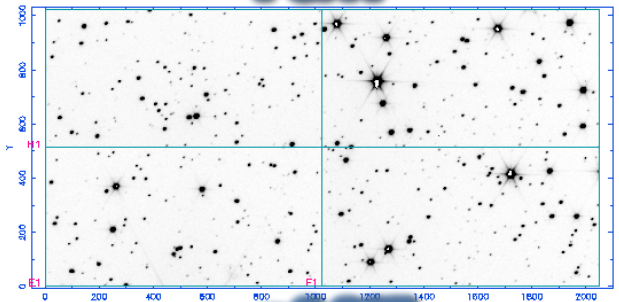
u 0.56”



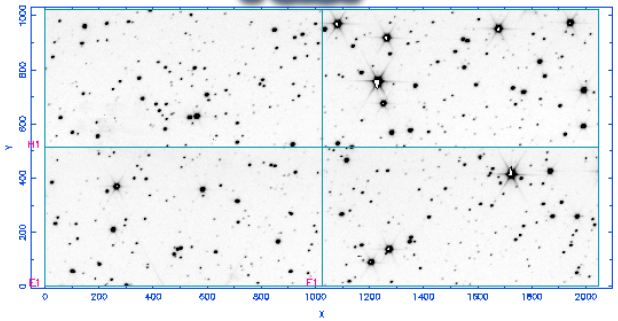
g 0.44”



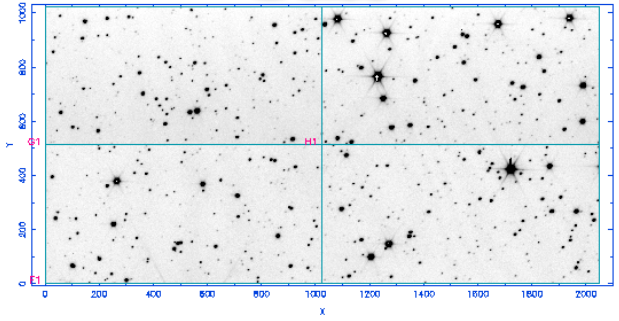
r 0.41”



i 0.37”



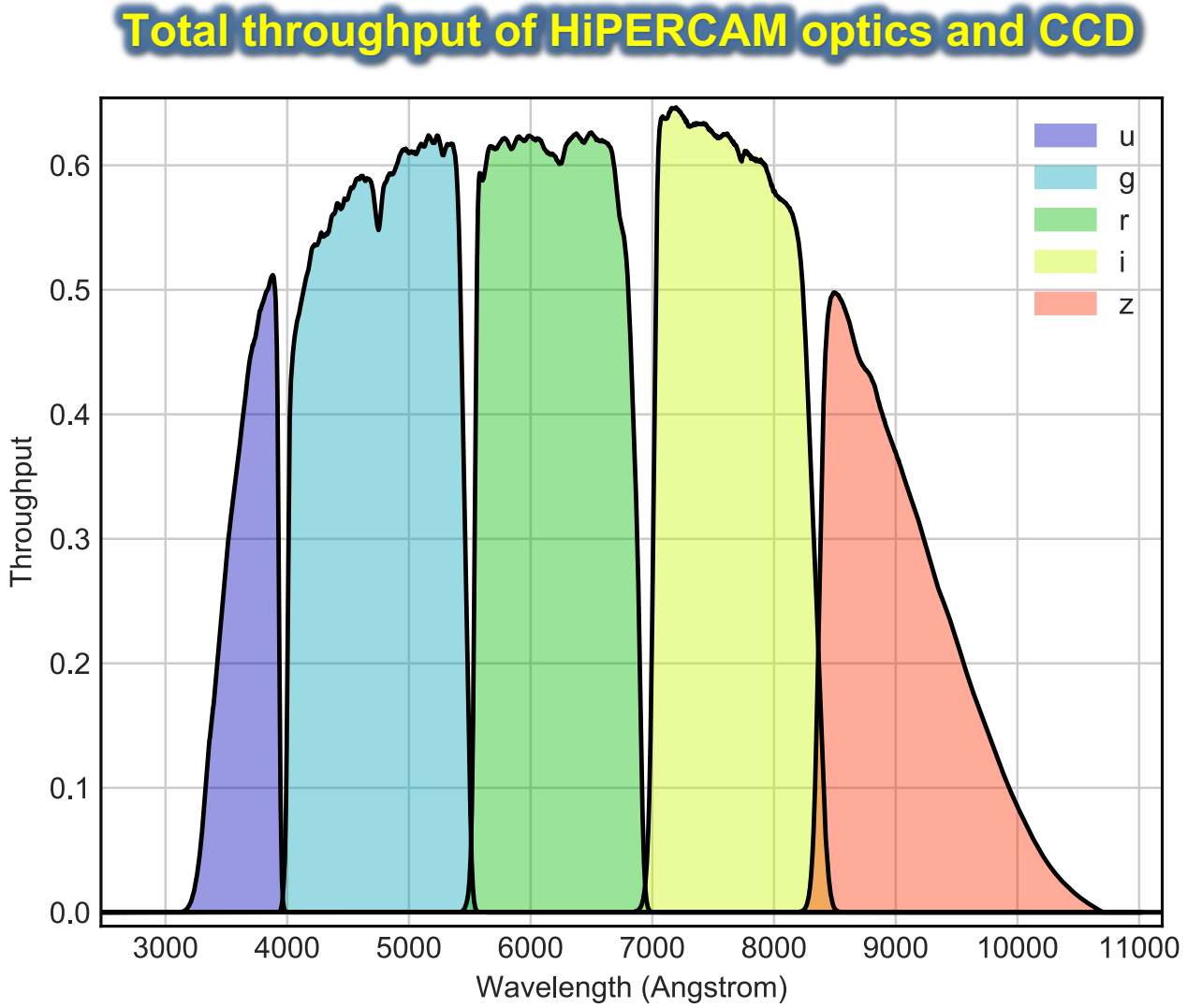
z 0.36”



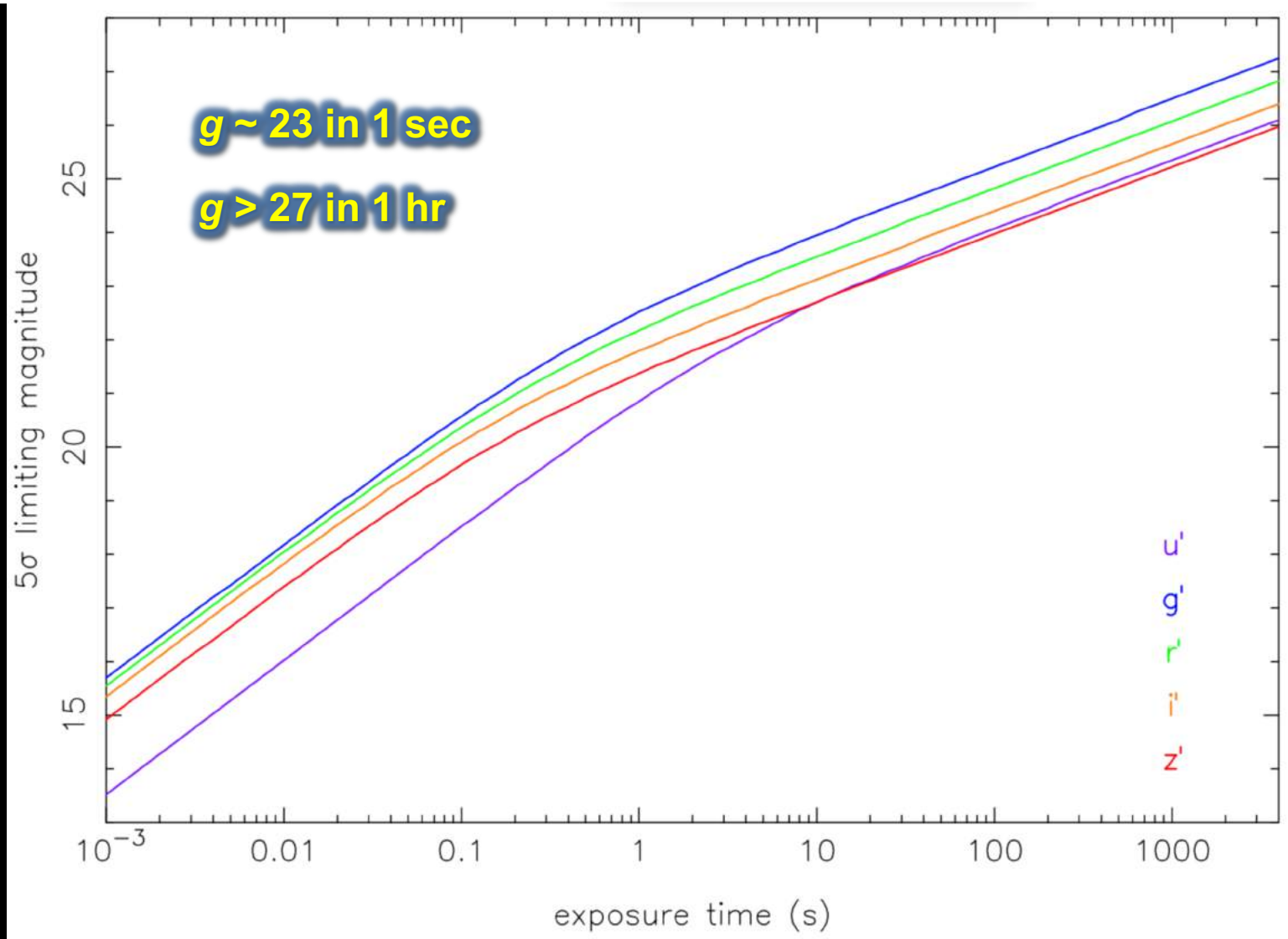
THROUGHPUT

HiPERCAM zero points (mag giving 1e^-/s above atmosphere), with OSIRIS in brackets:

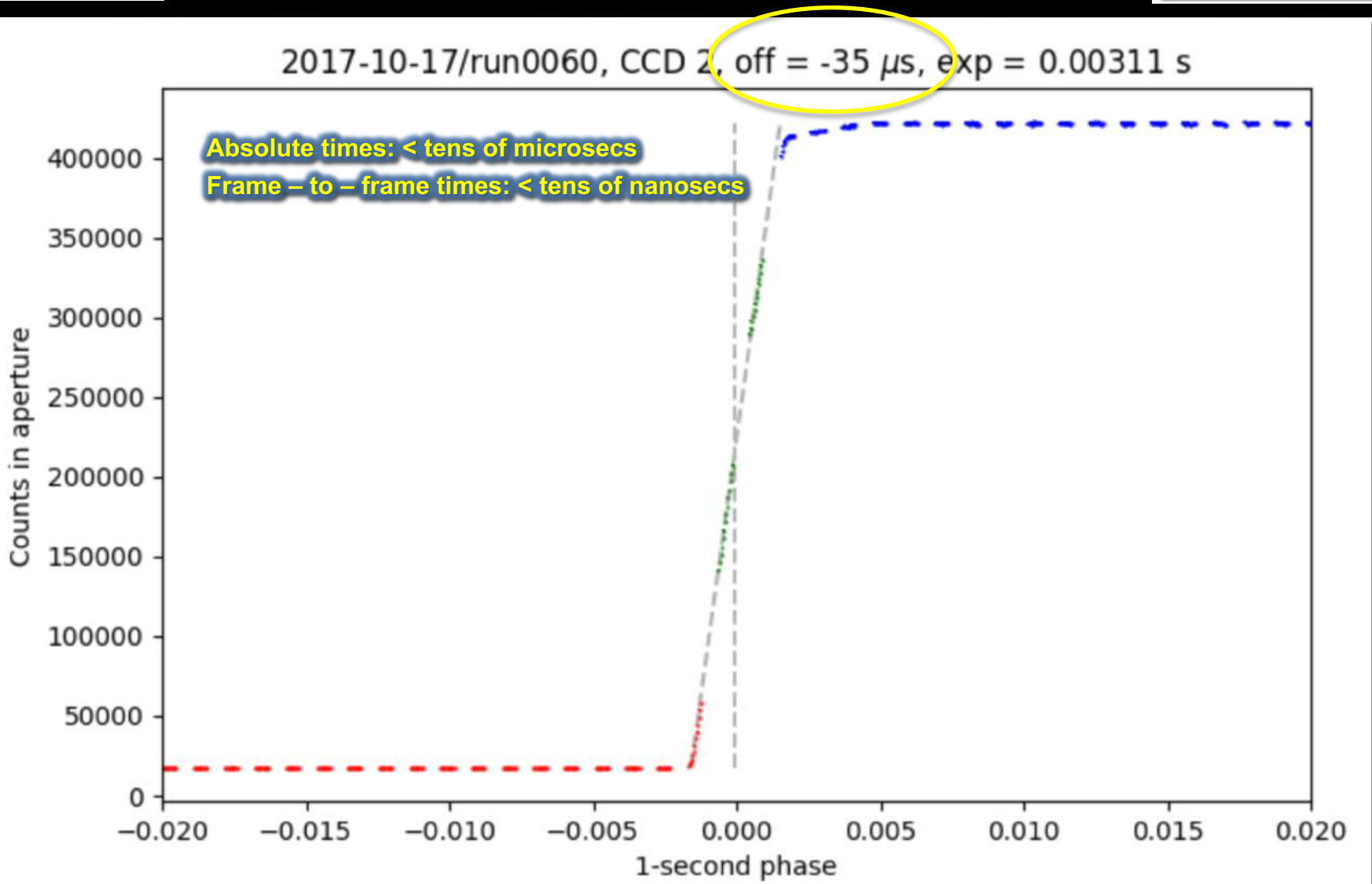
u: 28.17 (25.76)
g: 29.25 (28.71)
r: 28.76 (29.05)
i: 28.43 (28.60)
z: 27.95 (28.04)



LIMITING MAGS ON GTC

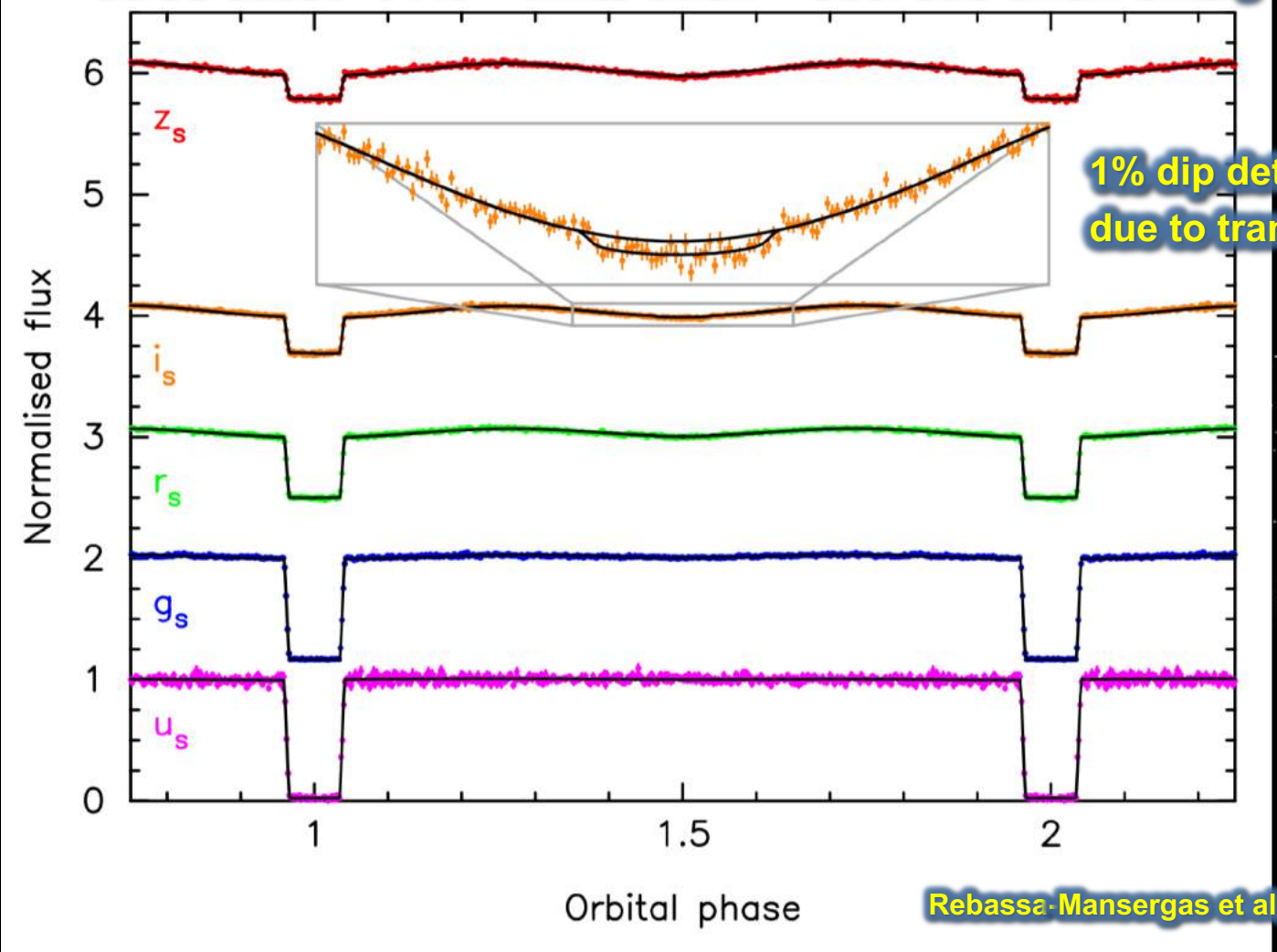


TIMING ACCURACY

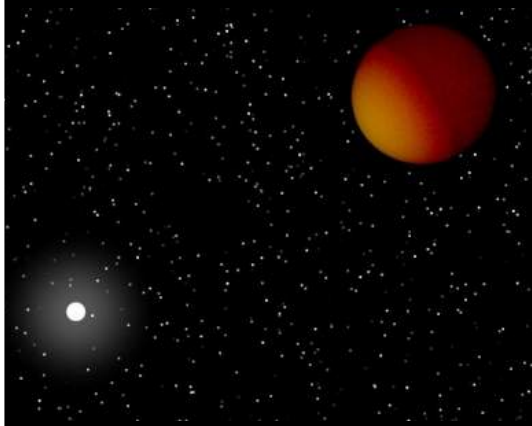


SCIENCE RESULTS

SDSS J2355+0448 – white dwarf + cool sub-dwarf binary



1% dip detected at i~19 mag
due to transit of Earth-sized object

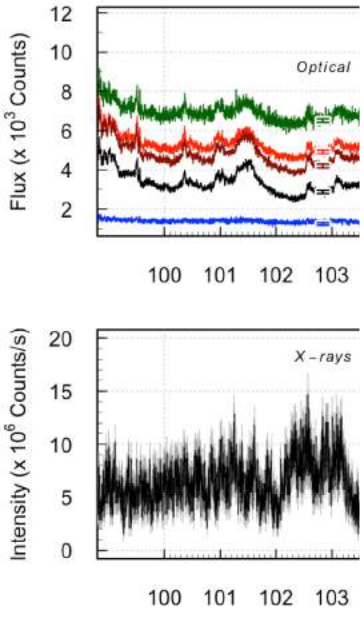


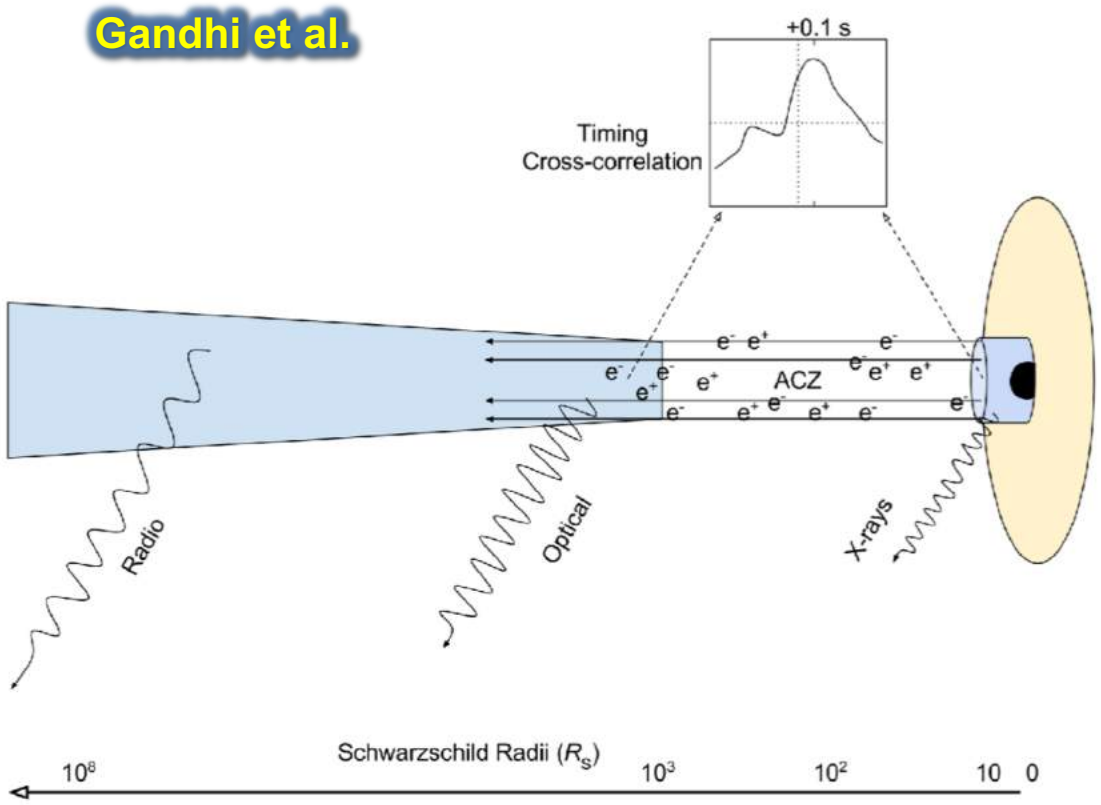
Rebassa-Mansergas et al, 2019, Nat Ast, arXiv 1903.02897

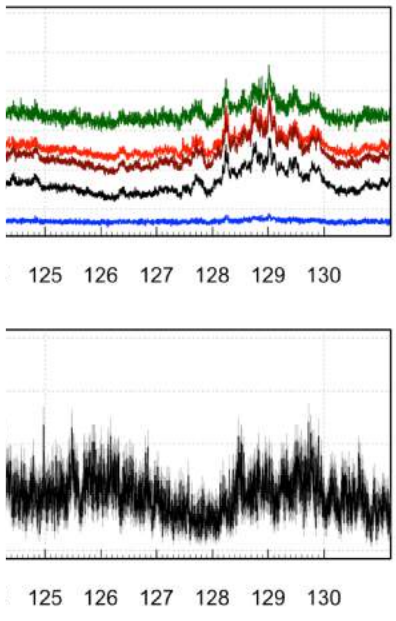
SCIENCE RESULTS

MAXI J1820+070 – black-hole X-ray binary

Gandhi et al.







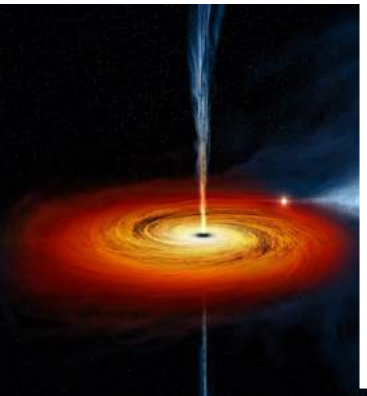
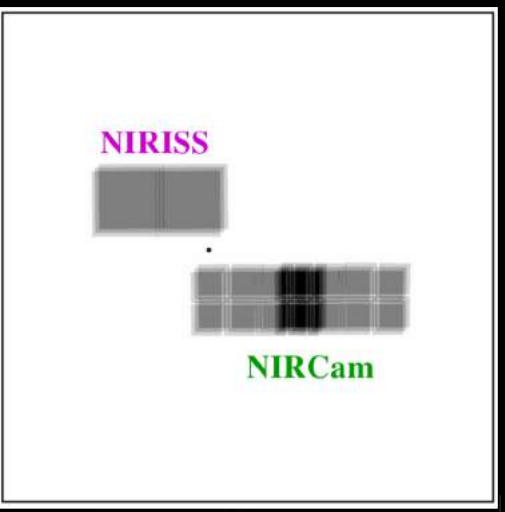
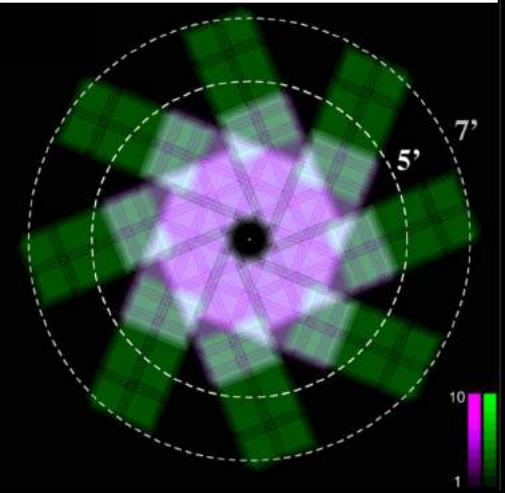


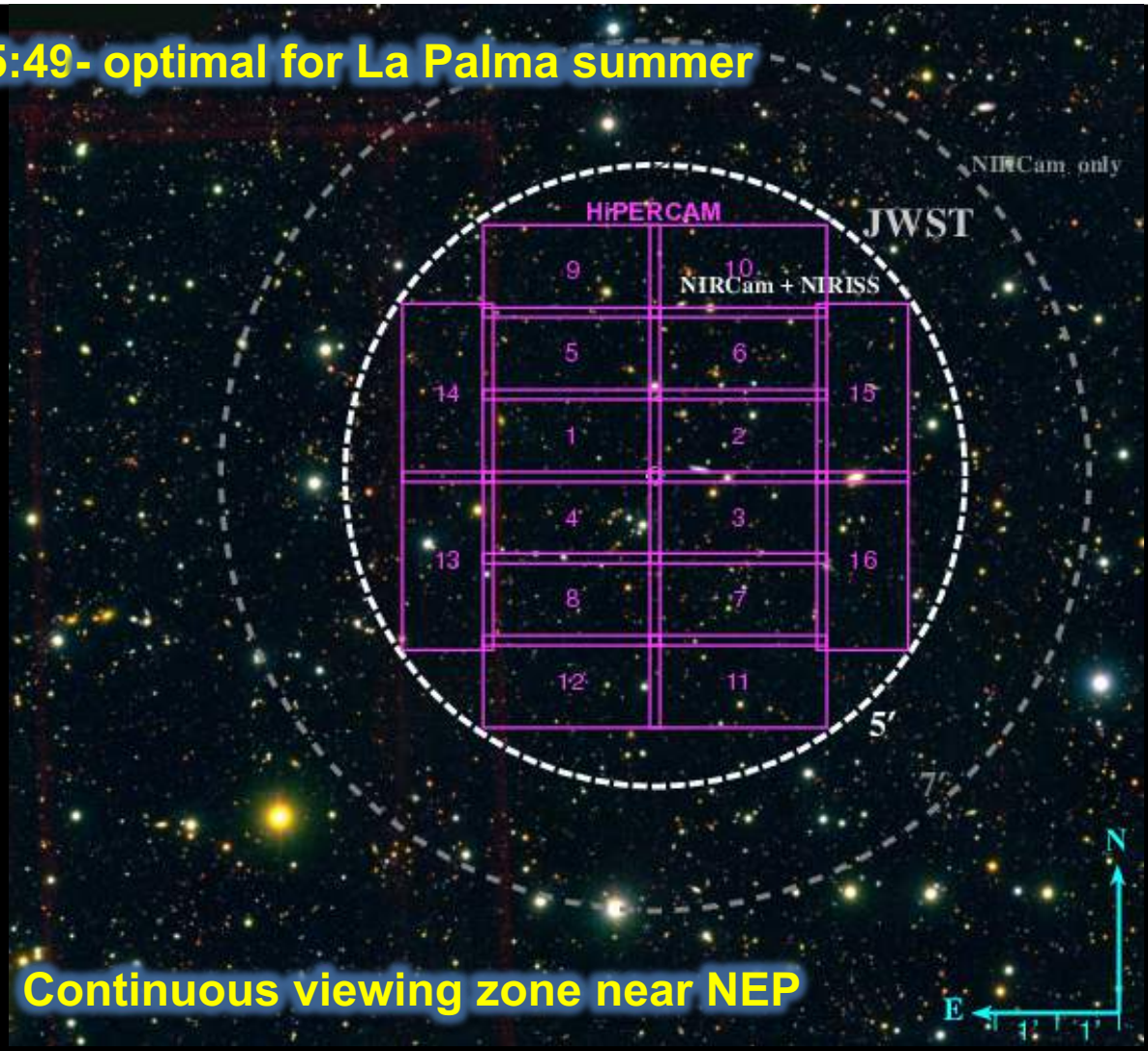
Figure 3: Schematic of the post-transition accretion and jet geometry of V404 Cygni. The black hole and accretion disc are situated off to the right. X-rays originate in a compact region within ~5 R_S of the black hole due to Comptonisation (either jet or coronal). Optical photons are delayed with respect to X-rays by ~0.1 s. This 'optical base' lies $\lesssim 10^3$ R_S from the X-ray core, and should power broadband synchrotron radiation extending to high frequencies. The above time delay limits the extension of the putative acceleration and collimation zone (ACZ), which is likely to be Poynting-flux dominated. Beyond the optical base, shocks in the longitudinally and laterally expanding jet inject energy that power the broadband lower frequency radiation down to the radio.

JWST TIME-DOMAIN FIELD (TDF)

TDF lies at RA, Dec = 17:23, +65:49- optimal for La Palma summer





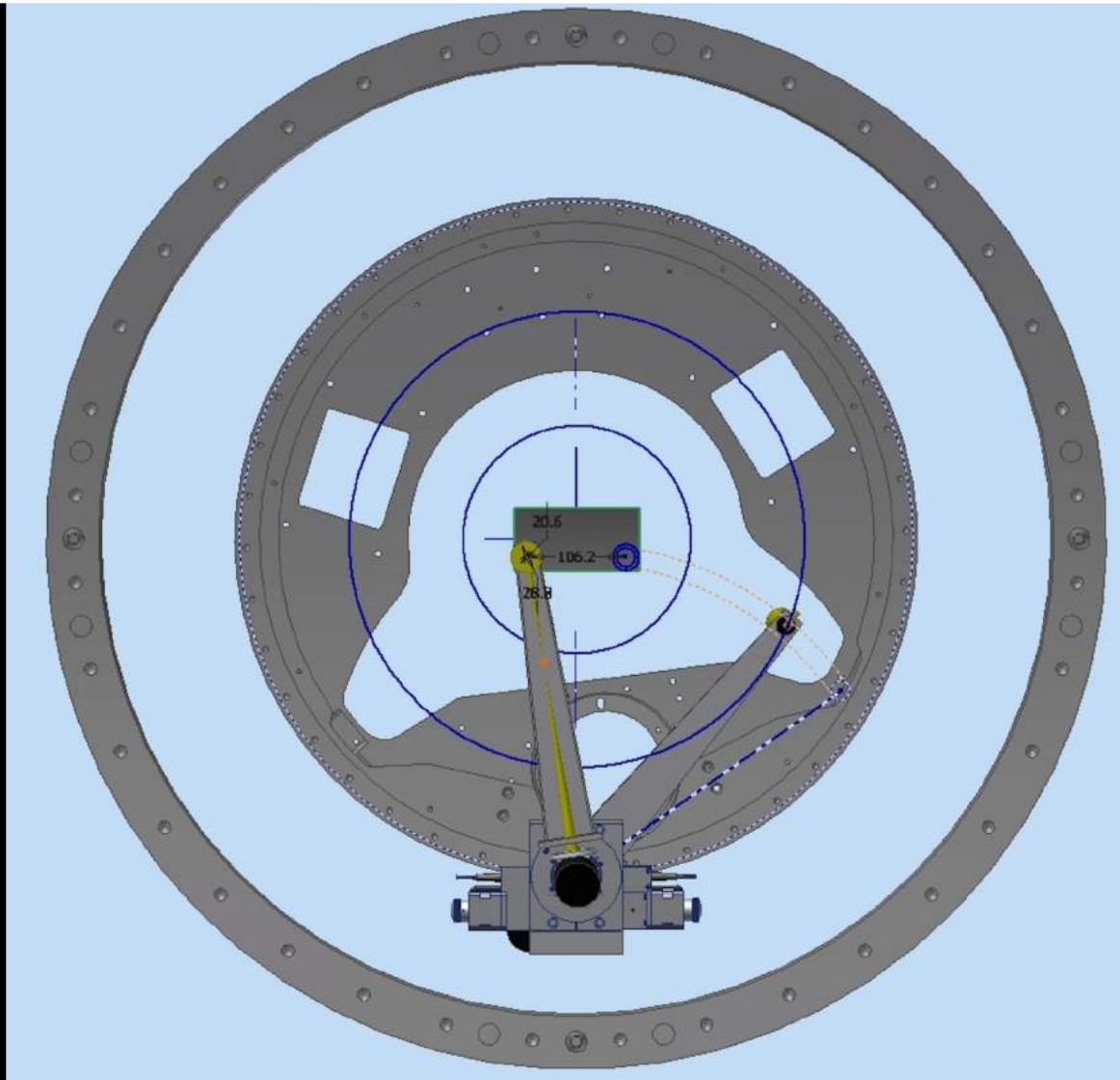


Continuous viewing zone near NEP

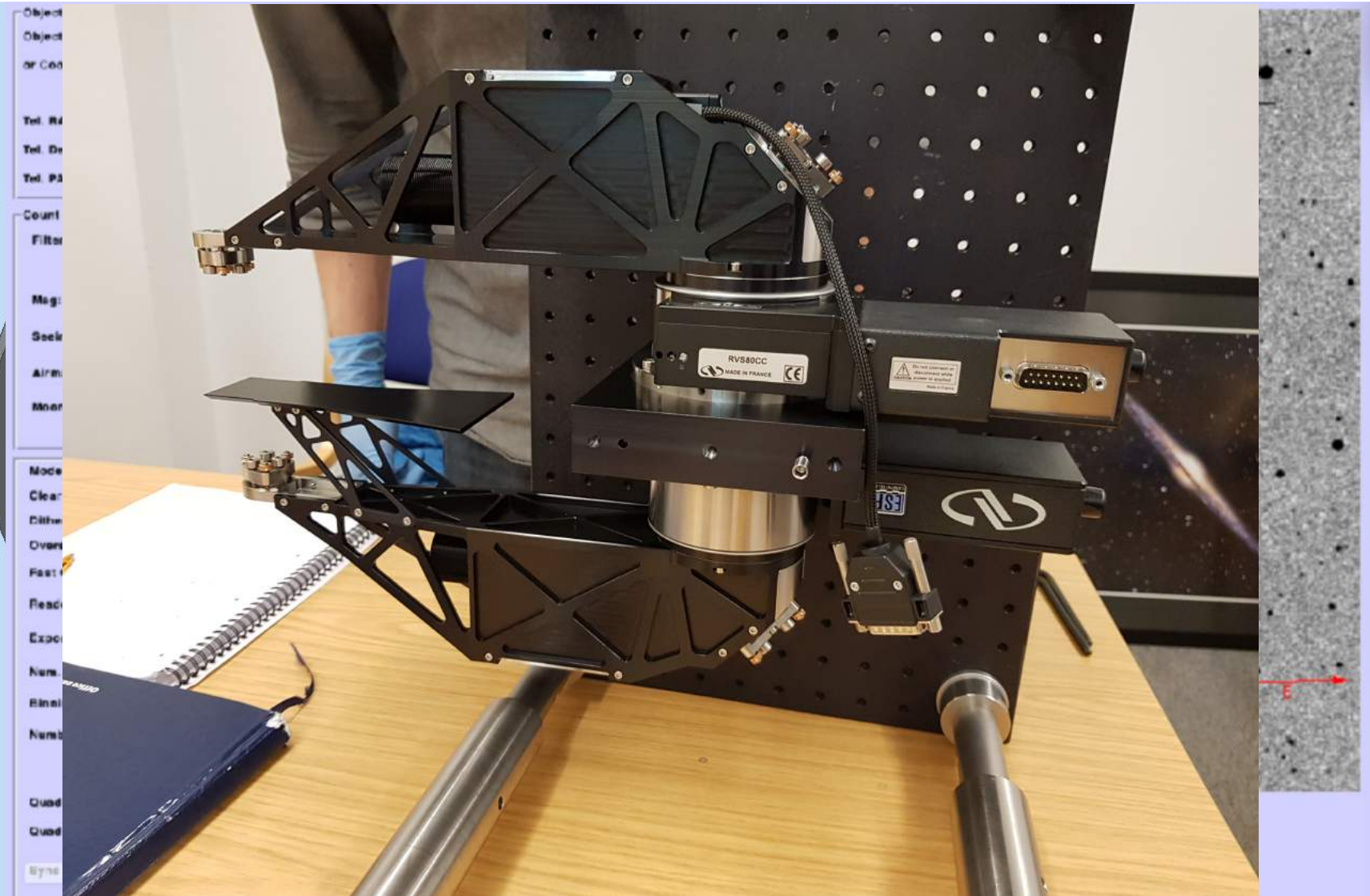
ENHANCEMENTS: COMPO

COMPO = COMparison star Pick Off

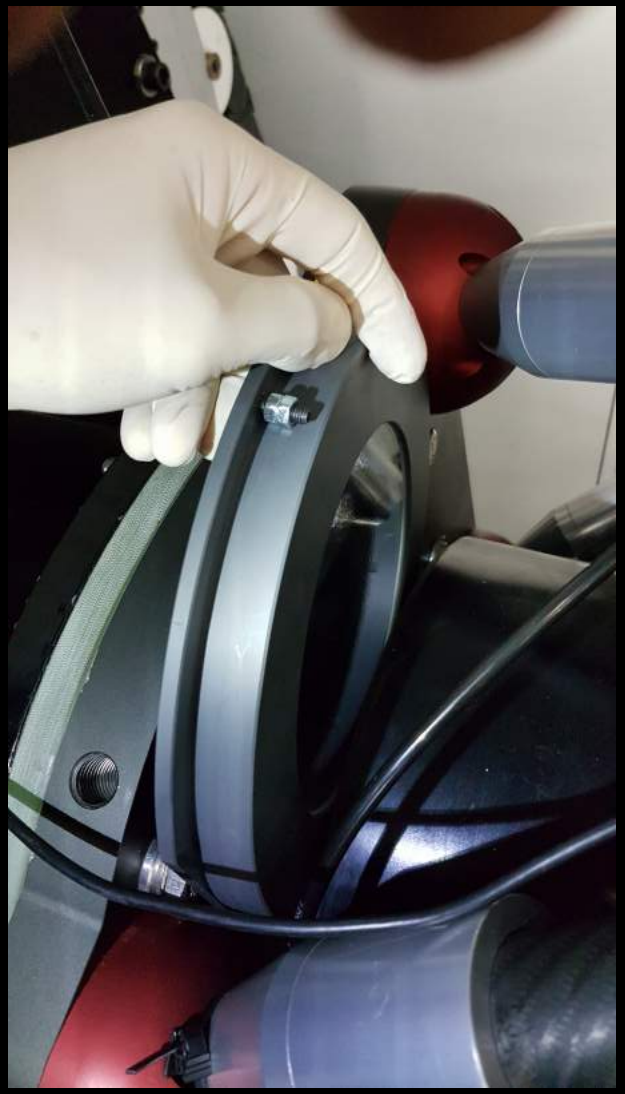
- 3.1’ FoV and 0.081”/pix on GTC with current collimator:
  - >90% chance of *r*=14 mag comparison star.
- 4.3’ FoV and 0.113”/pix with new (expensive!) collimator:
  - >90% chance of *r*=13 mag comparison star.
- 6.5’ “FoV” available with COMPO system:
  - >90% chance of *r*=12 mag comparison star.



ENHANCEMENTS: COMPO



ENHANCEMENTS: DIFFUSER



FUTURE PLANS

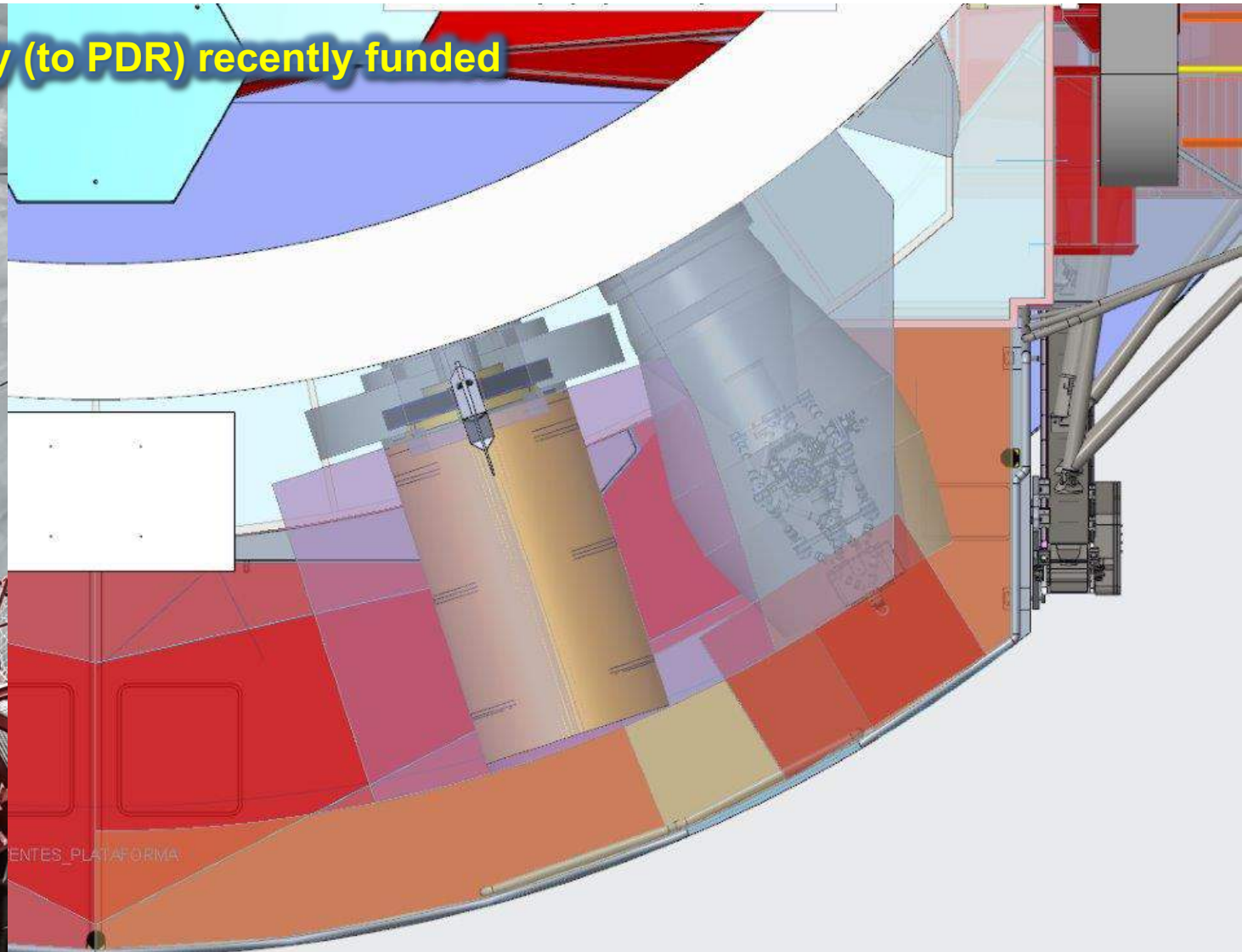
- We had 12 science runs on the GTC in 2018-19: Feb/Apr/May/Jun/Oct/Nov 2018, Jan/Jun/Jul/Aug/Sep 2019 Total: ~50 nights.
  - Wide range of science performed: Black holes, white dwarfs, neutron stars, brown dwarfs, extrasolar planets/asteroids, AGN, FRBs, GRBs, SNe, ultra-diffuse galaxies, JWST TDF, stellar occultations by solar system objects
- Spring 2020: Temporarily mount HiPERCAM on the Cassegrain focus of the GTC?
- 2021+: Mount HiPERCAM permanently on the GTC on its own Folded Cassegrain focus?

ENHANCEMENTS: NEW ROTATOR

£90k design study (to PDR) recently funded

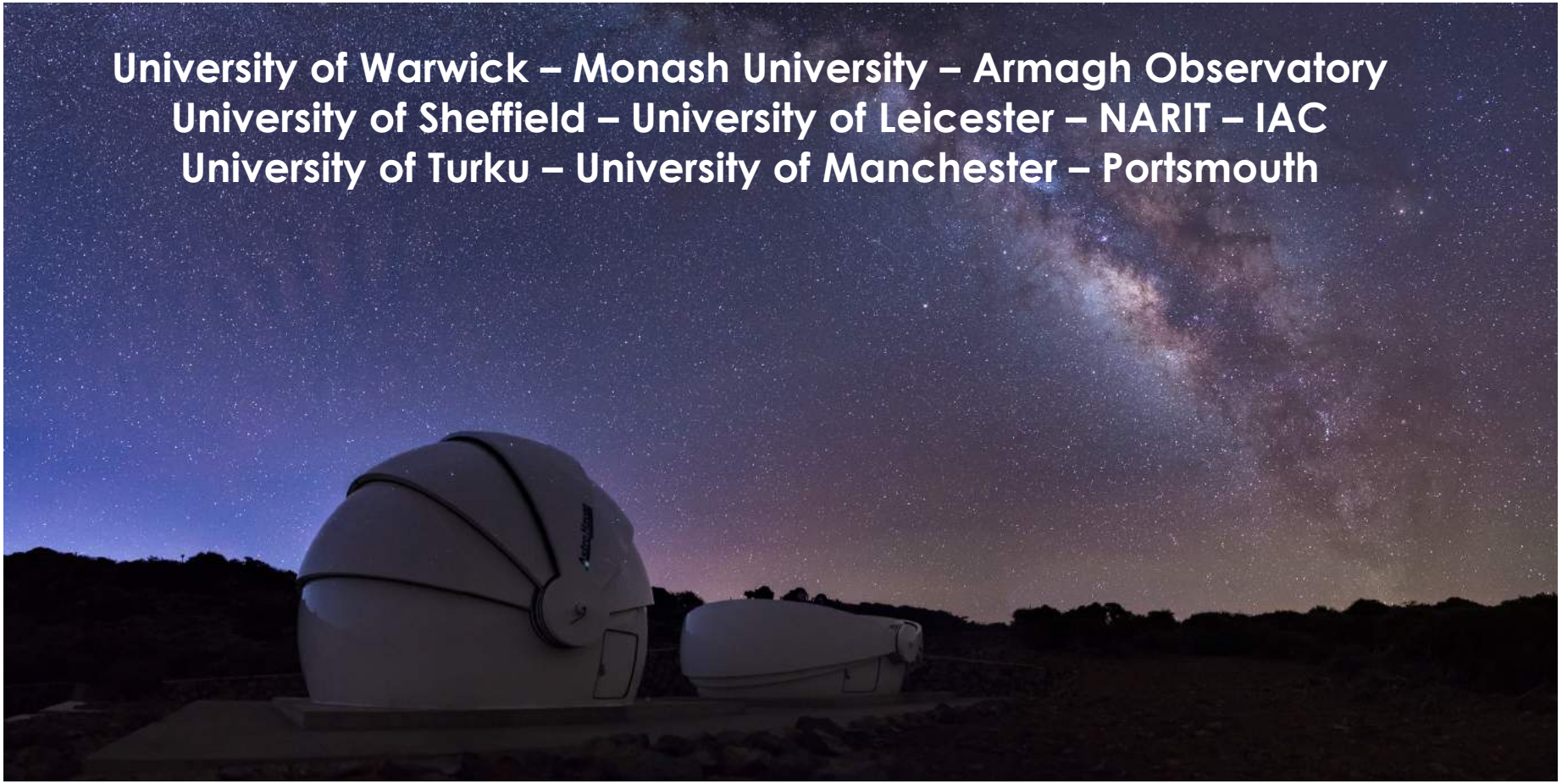
This will make the study of transients and simultaneous observations with other facilities much easier, e.g.

- **GW alerts.**
- **FRBs with radio telescopes.**
- **XRBs with X-ray satellites.**
- **CTA!**



GOTO

GRAVITATIONAL-WAVE OPTICAL TRANSIENT OBSERVER




GOTO
GRAVITATIONAL-WAVE OPTICAL TRANSIENT OBSERVER
Astro Haven
Observe whole (visible) sky once every 2 days to a depth of 20th mag

GOTO status

GOTO
GRAVITATIONAL-WAVE OPTICAL TRANSIENT OBSERVER

Phase I (now): 4x0.4m, ~20 sq. deg.

Phase II (early 2020): 8x0.4m, ~40 sq. deg.

Phase III (late 2020): 16x0.4m, ~80 sq. deg.

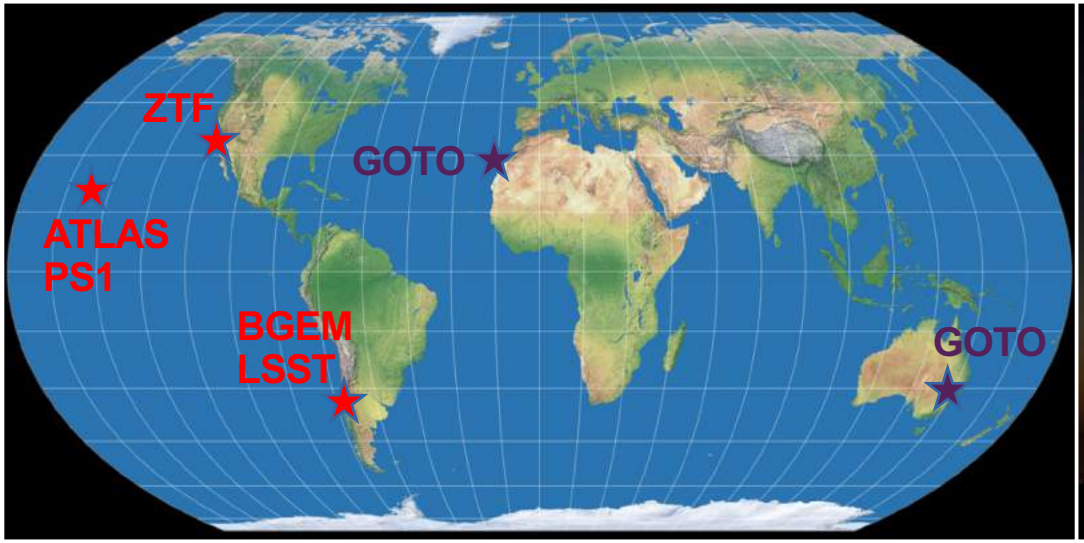
GOTO in LIGO-VIRGO O3 Science Run

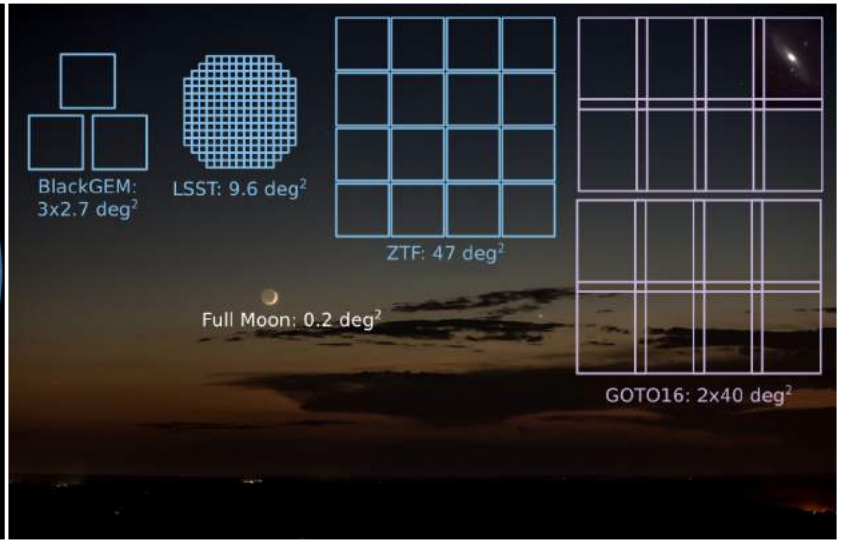
GOTO
GRAVITATIONAL-WAVE OPTICAL TRANSIENT OBSERVER

Event	GW event detection	Alert received	Observations start	ΔT (h)	N_{obs}	Notes
S190405ar	2019-04-05 16:01:30	2019-04-12 15:07:26	—	—	0	*(Retracted before sunset)*
S190408an	2019-04-08 18:18:02	2019-04-08 19:02:50	2019-04-09 05:40:39	10.63	17	
S190412m	2019-04-12 05:30:44	2019-04-12 06:31:39	2019-04-12 20:28:35	13.95	36	See GCN 24116 (Steeghs et al. 2019a)
S190421ar	2019-04-21 21:38:56	2019-04-22 16:26:24	2019-04-23 21:54:59	29.48	49	
S190425z	2019-04-25 08:18:05	2019-04-25 09:00:56	2019-04-25 20:38:22	11.62	306	See GCN 24224 (Steeghs et al. 2019b)
S190426c	2019-04-26 15:21:55	2019-04-26 15:47:11	2019-04-26 20:38:45	4.86	96	See GCN 24291 (Steeghs et al. 2019c)
S190503bf	2019-05-03 18:54:04	2019-05-03 19:30:15	—	—	0	*(Never visible from La Palma)*
S190510g	2019-05-10 02:59:39	2019-05-10 04:21:59	2019-05-10 04:22:55	0.02	7	Visible immediately, $\Delta T =$ **56 s**
S190512at	2019-05-12 18:07:14	2019-05-12 18:59:01	2019-05-12 20:53:20	1.91	201	
S190513bm	2019-05-13 20:54:28	2019-05-13 21:21:51	2019-05-13 21:26:19	0.07	38	Visible immediately, $\Delta T =$ **4 min**
S190517h	2019-05-17 05:51:01	2019-05-17 06:26:48	2019-05-17 21:42:06	15.26	9	
S190518bb	2019-05-18 19:19:19	2019-05-18 19:25:49	—	—	0	*(Retracted before sunset)*
S190519bj	2019-05-19 15:35:44	2019-05-19 17:01:40	2019-05-19 20:55:19	3.89	139	
S190521g	2019-05-21 03:02:29	2019-05-21 03:08:49	2019-05-21 03:09:17	0.01	58	Visible immediately, $\Delta T =$ **28 s**
S190521r	2019-05-21 07:43:59	2019-05-21 07:50:27	2019-05-21 22:54:03	15.06	90	
S190524q	2019-05-24 04:52:06	2019-05-24 04:58:40	2019-05-24 04:59:33	0.01	2	Visible immediately, $\Delta T =$ **53 s**
S190602aq	2019-06-02 17:59:27	2019-06-02 18:06:01	—	—	0	*(Never visible from La Palma)*
S190630ag	2019-06-30 18:52:05	2019-06-30 18:55:47	2019-06-30 21:14:49	2.32	149	
S190701ah	2019-07-01 20:33:06	2019-07-01 20:38:06	—	—	0	*(Never visible from La Palma)*
S190706ai	2019-07-06 22:26:41	2019-07-06 22:44:31	2019-07-06 22:45:09	0.01	70	Visible immediately, $\Delta T =$ **38 s**
S190707q	2019-07-07 09:33:26	2019-07-07 10:13:24	2019-07-07 21:54:47	11.69	116	
S190718y	2019-07-18 14:35:12	2019-07-18 15:03:13	2019-07-18 21:08:53	6.09	135	
S190720a	2019-07-20 00:08:36	2019-07-20 00:11:26	2019-07-20 00:11:57	0.01	175	Visible immediately, $\Delta T =$ **31 s**
S190727h	2019-07-27 06:03:33	2019-07-27 06:12:02	2019-07-27 21:03:40	14.86	94	
S190728q	2019-07-28 06:45:10	2019-07-28 06:59:32	2019-07-28 21:29:58	14.51	36	
S190808ae	2019-08-08 22:21:21	2019-08-08 22:28:00	2019-08-08 22:28:31	0.01	75	Visible immediately, $\Delta T =$ **31 s**
S190814bv	2019-08-14 21:10:39	2019-08-14 21:31:44	2019-08-14 22:59:27	1.46	141	See GCN 25337 (Steeghs et al. 2019d)
S190816i	2019-08-16 13:04:31	2019-08-16 13:11:35	—	—	0	*(Retracted before sunset)*
S190822c	2019-08-22 01:29:59	2019-08-22 01:37:00	2019-08-22 01:37:30	0.01	17	Visible immediately, $\Delta T =$ **30 s**
S190828j	2019-08-28 06:34:05	2019-08-28 06:50:14	2019-08-28 22:38:25	15.80	54	
S190828l	2019-08-28 06:55:09	2019-08-28 07:17:46	2019-08-28 23:48:38	16.51	56	
S190829u	2019-08-29 21:05:56	2019-08-29 21:17:14	—	—	0	*(Retracted before sunset)*

GOTO competition

GOTO
GRAVITATIONAL-WAVE OPTICAL TRANSIENT OBSERVER





Facility:	Aperture: (m)	Field: (deg^2)	Depth: (limit mag)	Cost: (M$)	Etendue: (m^2deg^2)	Etendue/cost
ATLAS	0.5×2	60	g = 19.3 (30 s)	2.0	12	6.0
Pan-STARRS1	1.8	7.0	g = 22.0 (43 s)	25.0	18	0.7
ZTF	1.2	47.0	g = 20.8 (30 s)	24.0	53	2.2
BlackGEM	0.65×3	8.1	q = 23 (300 s)	3.0	3	1.0
LSST	8.4	9.6	g = 25.6 (15 s)	500	325	0.65
GOTO-4	0.4×4	18.0	g = 20.5 (180 s)	1.0	2.5	2.5
GOTO-8	0.4×8	40.0	g = 20.5 (180 s)	1.5	5	3.3
GOTO-16	(0.4×8)×2	80.0	g = 20.5 (180 s)	2.0	10	5.0
GOTO-32	(0.4×8)×4	160.0	g = 20.5 (180 s)	3.0	20	6.7

The End.

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