High Time Resolution in the Optical domain

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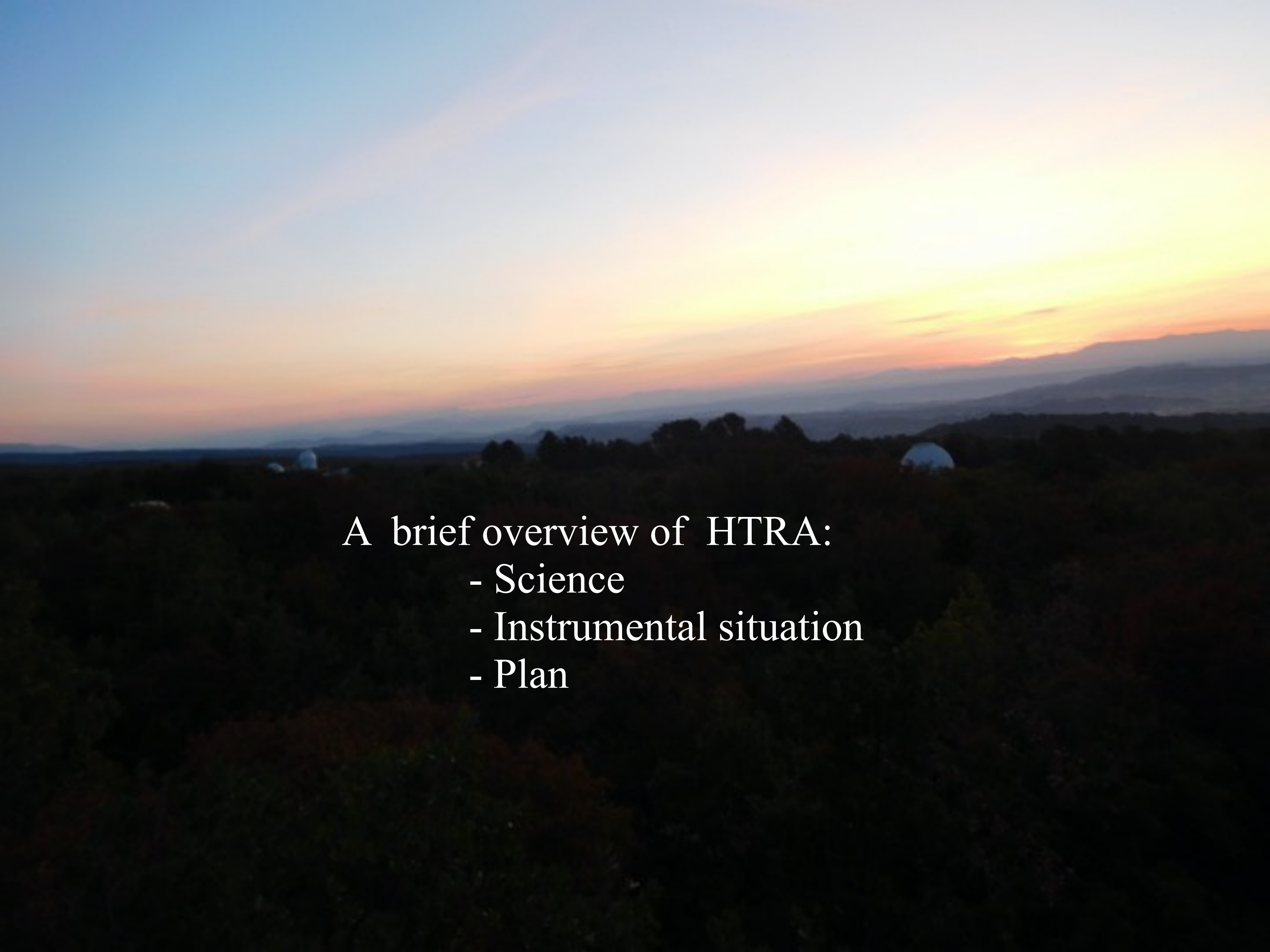
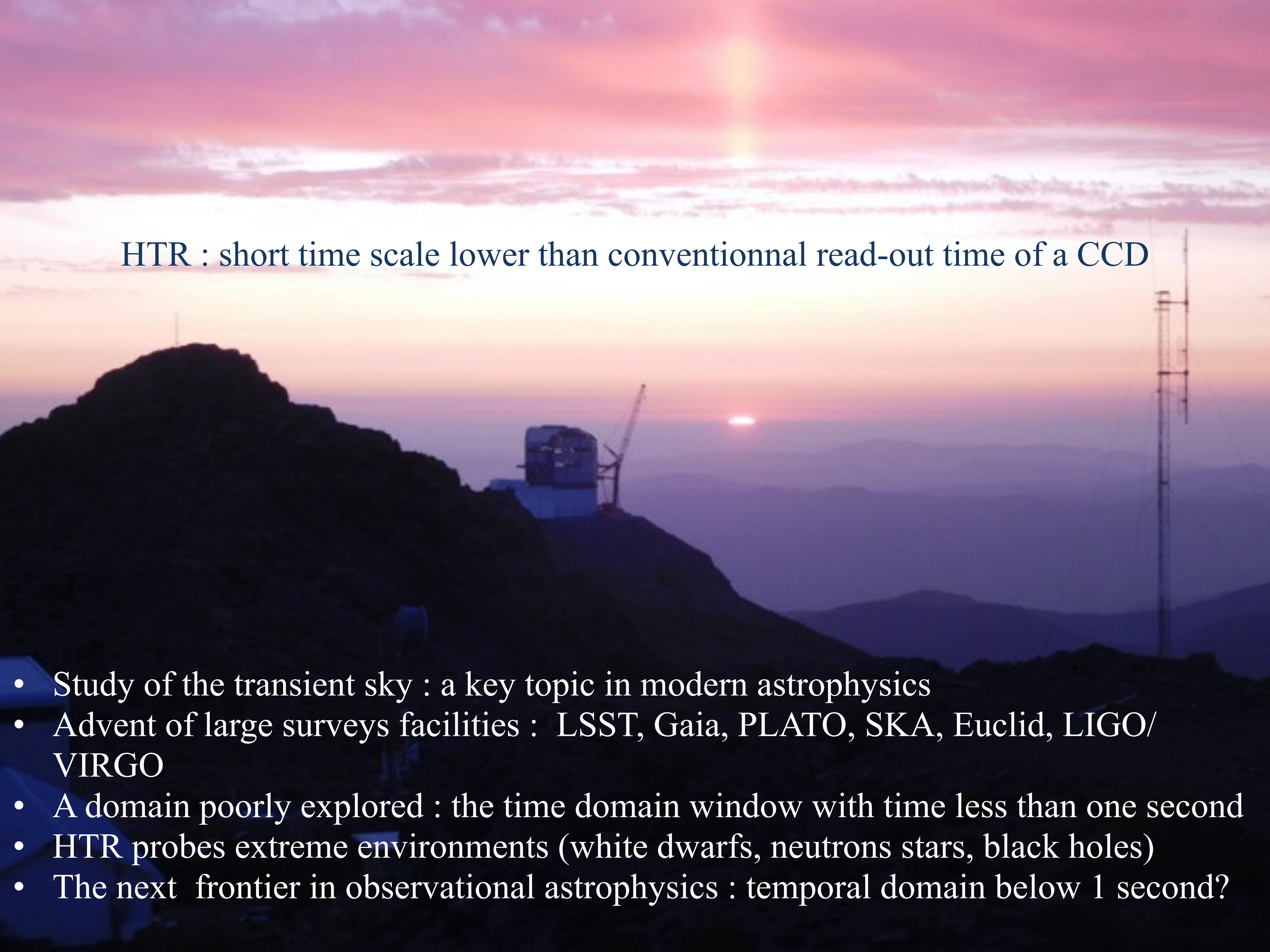


A brief overview of HTRA:

- Science
- Instrumental situation
- Plan

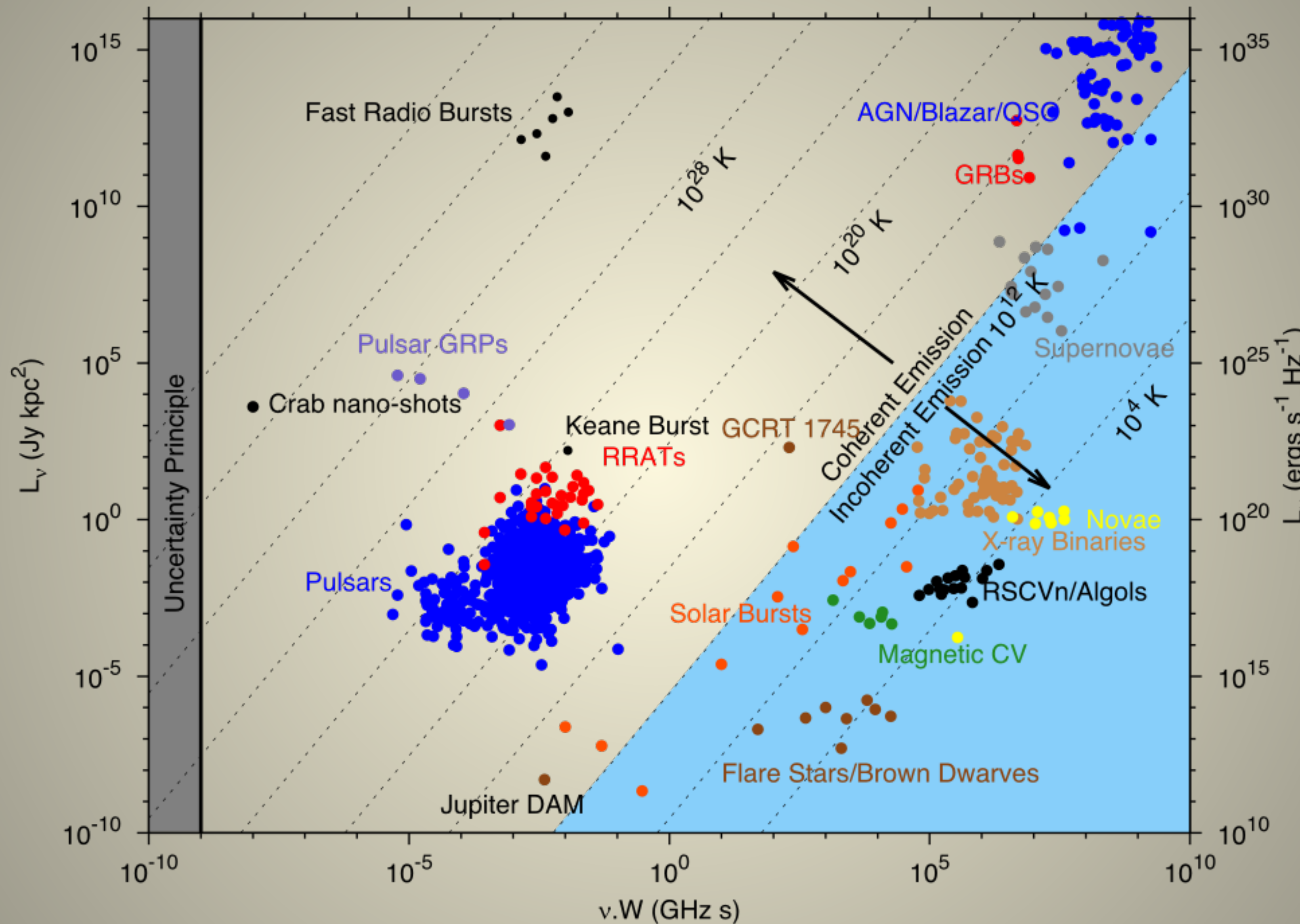


HTR : short time scale lower than conventionnal read-out time of a CCD

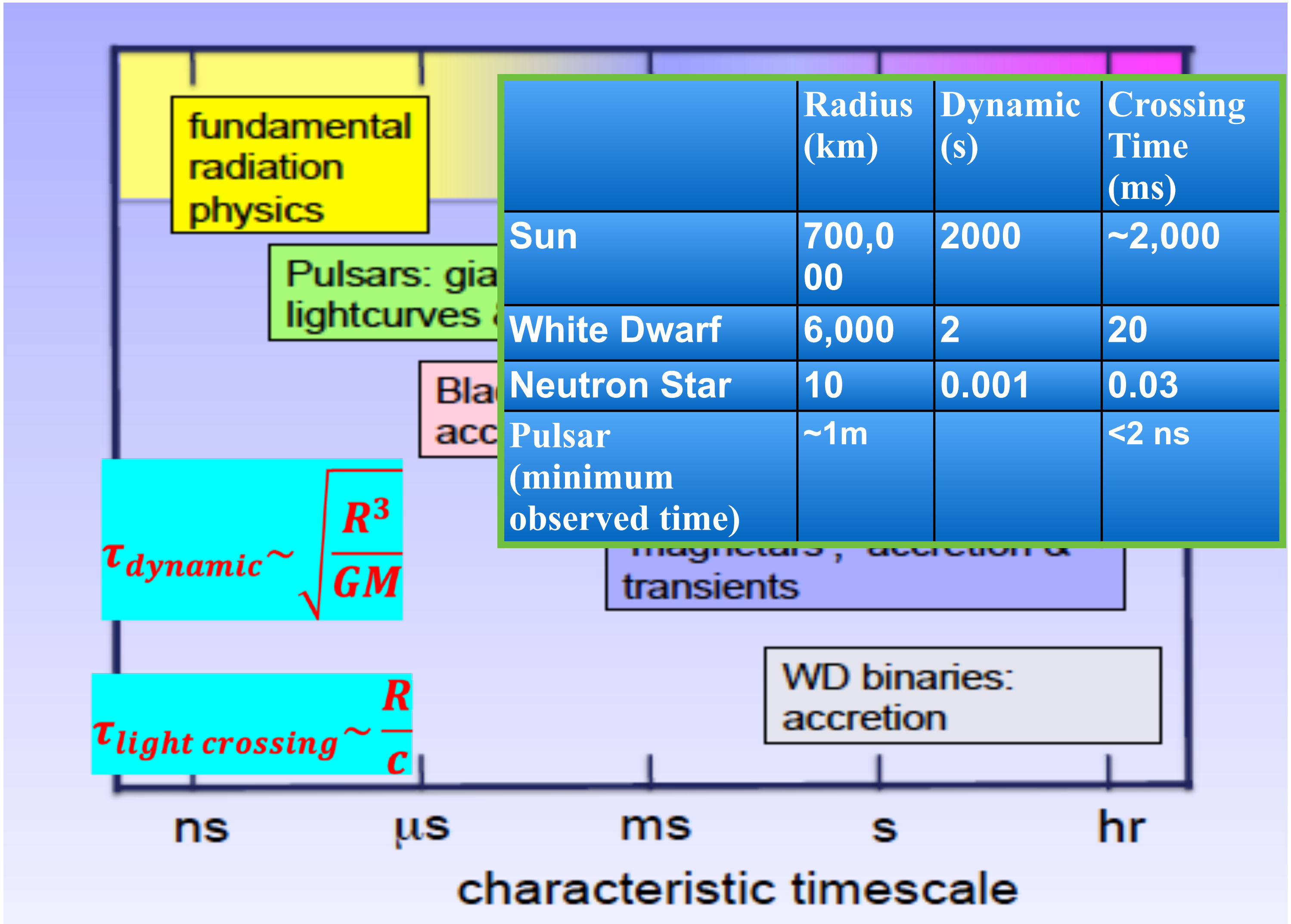
- Study of the transient sky : a key topic in modern astrophysics
- Advent of large surveys facilities : LSST, Gaia, PLATO, SKA, Euclid, LIGO/VIRGO
- A domain poorly explored : the time domain window with time less than one second
- HTR probes extreme environments (white dwarfs, neutrons stars, black holes)
- The next frontier in observational astrophysics : temporal domain below 1 second?

Science Time Scales now and into the extremely large telescope era

		Time-scale (now)	Time-scale (ELT era)
Stellar flares and pulsations		Seconds/ Minutes	10-100ms
Stellar surface oscillations	White Dwarfs Neutron Stars	1-1000 μsec	1-1000 μsec 0.1 μsec
Close Binary Systems (accretion and turbulence)	Tomography Eclipse in/egress Disk flickering Correlations (e.g. X-ray & optical)	100ms++ 10ms+ 10ms 50ms	10 ms+ < 1ms < 1ms <1ms
Pulsars	Magnetospheric Thermal	1μsec-100ms 10 ms	nsec(?) <ms
AGN		Minutes	Seconds(?)



Pietka et al, 2015



	Radius (km)	Dynamic (s)	Crossing Time (ms)
Sun	700,000	2000	~2,000
White Dwarf	6,000	2	20
Neutron Star	10	0.001	0.03
Pulsar (minimum observed time)	~1m		<2 ns

$$\tau_{dynamic} \sim \sqrt{\frac{R^3}{GM}}$$

$$\tau_{light\ crossing} \sim \frac{R}{c}$$

HTRA : High Time Resolution Astrophysics

- magnetars, pulsars and neutron stars
- black hole binary systems
- white dwarf binary systems
- gamma ray bursts and supernovae
- normal stars - stellar oscillations
- solar system objects through transits and occultations
  - Planets and satellites
  - Kuiper belt objects
- Fast radio bursts

Shearer et al, 2010 , White paper on HTRA

Snapshots of a few scientific interest in HTR
- X-ray binaries
- GRBs
- Pulsars

Snapshots of a few scientific interest in HTR

- X-ray binaries
- GRBs
- Pulsars

X-rays binaries and the multiwavelength campaigns

C. Motch et al.: Fast Optical Activity of GX 339-4

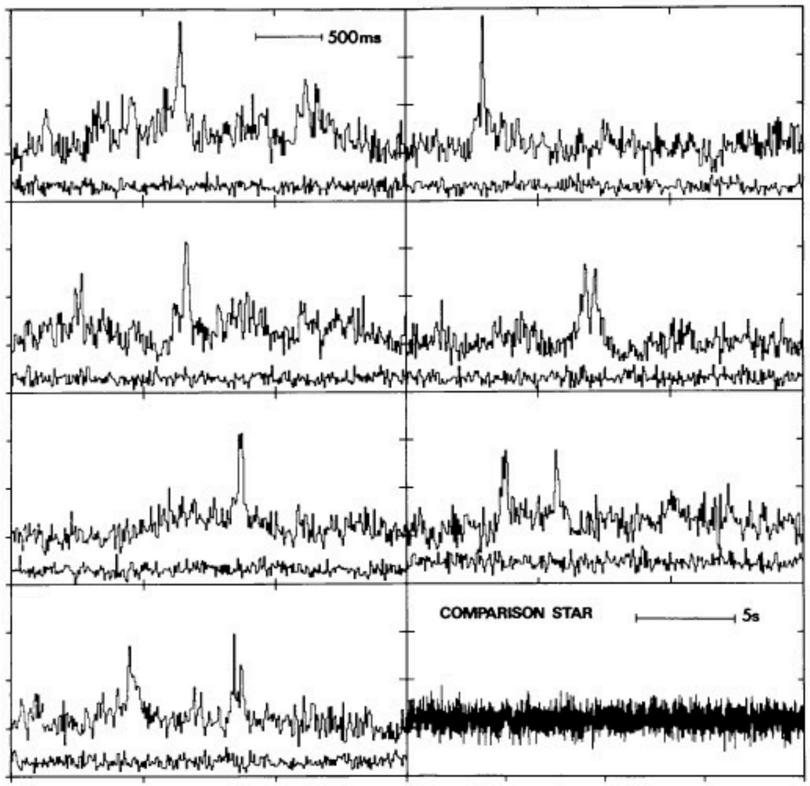


Fig. 3: A sample of flares picked up in data from the two nights with 10 ms resolution time. Sky data from the other channel are also plotted. The ordinate (count rate) ranges from 0 to 240. The data at the bottom right are from the comparison star allowing distinction between intrinsic activity and photon counting noise.

1.54Danish + 2 channel photometer, 10 msec time resolution

Motch et al, 1982

Simultaneous X-ray/optical observations of GX339-4 during the May 1981 optically bright state*

C. Motch[1], M. J. Ricketts[2], C. G. Page[2], S. A. Ilovaisky[3], and C. Chevalier[3]

[1] European Southern Observatory, D-8046 Garching bei München, Federal Republic of Germany
[2] Leicester University, University Road, Leicester LEI 7 RH, England
[3] Observatoire de Meudon, F-92190 Meudon, France

Astron. Astrophys. 119, 171–176 (1983)

Scientific interests of simultaneaous observations and discovery of their complicated organizations

Variations on different timescales show different behavior – correlation or anti correlation – depending of the energy of the X-rays photons

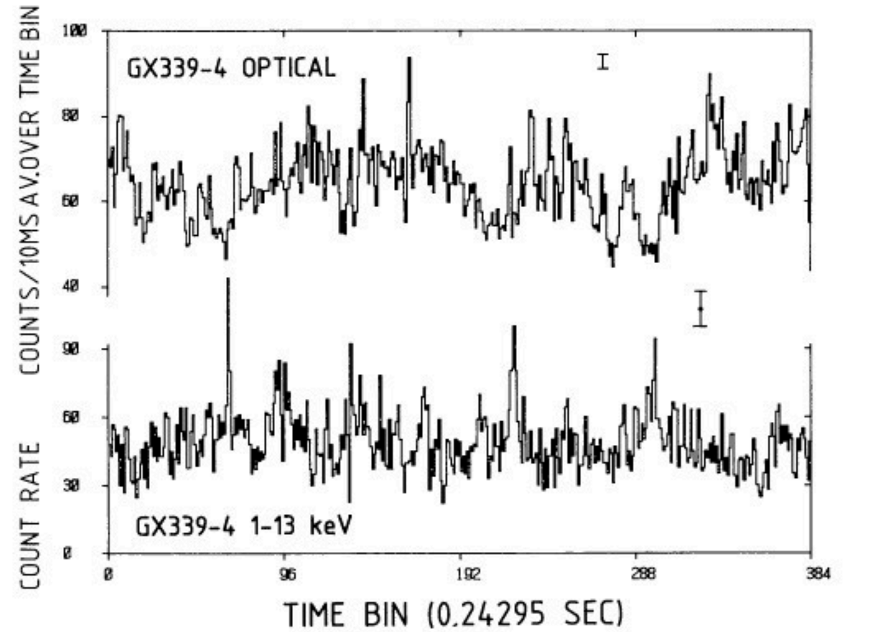
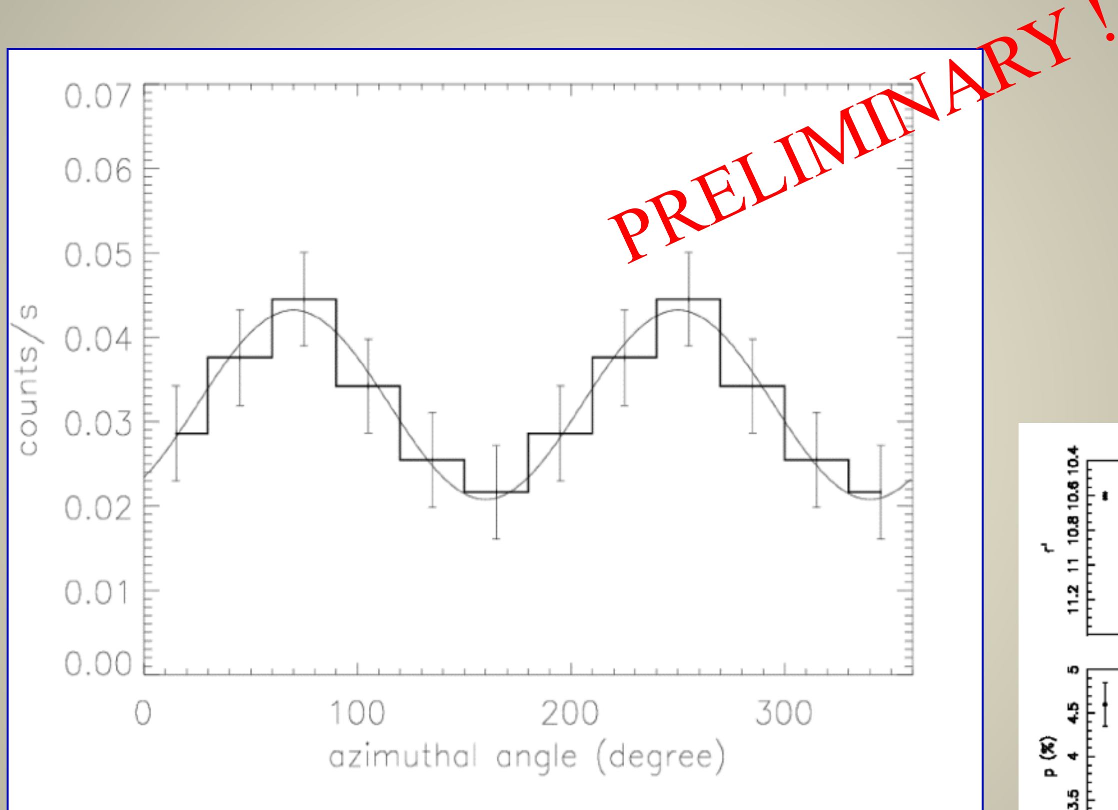
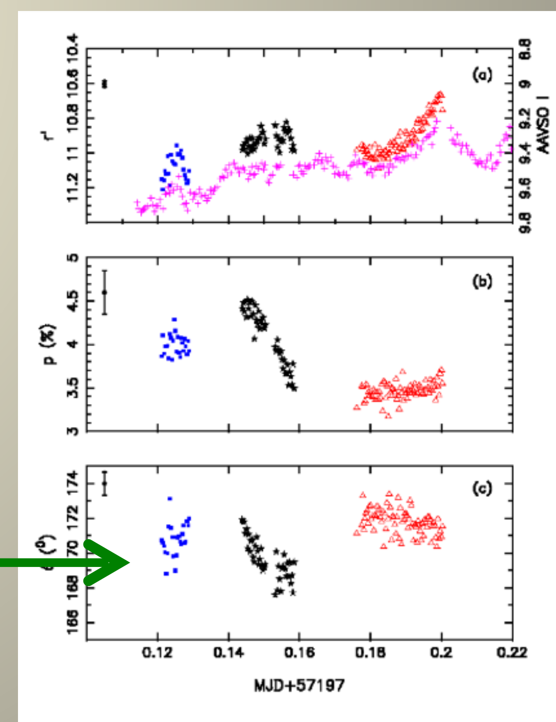


Fig. 1. Simultaneous X-ray and optical data plotted with 0.25 s resolution time. Typical $\pm 1\sigma$ error bars are indicated. Note the simultaneity between X-ray flares and optical dips

V 404 Cygni polarisation (450 - 2000 keV)

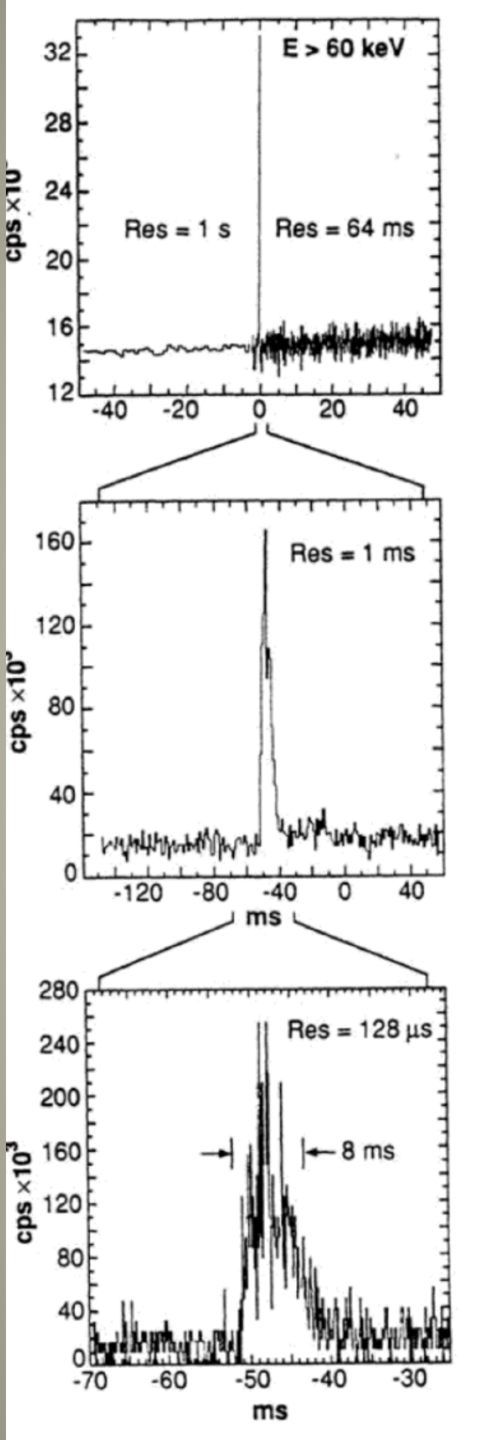
June 2015
149 ks of data:
$\Theta = 160 \pm 15°$
$PF = 95 \pm 35\ \%$





$\Theta = 171°$
NIR (Shahbaz et al. 2016)

=> Coordinated observations in radio, optical, NIR



GRB910711

Evidence for sub-millisecond structure in a γ-ray burst

…We detected a narrow spike of duration 200 μs in the light curve; variations on this timescale have not previously been observed in GRBs, and their explanation should be a stringent test of any GRB theory.

Bath et al, Nature, 1992

2.3. *GRB 060111: the first continuous light curve of the prompt optical event*

One of the problem facing the "rapid" optical observer is the deadtime associated with the readout of the CCD cameras. It is of course possible to use other devices such as EMCCDs, but in addition to their high price, these cameras are still limited in size and difficult to operate in the environment of a rapid GRB telescope.

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International Journal of Modern Physics: Conference Series
Vol. 12 (2012) 48–57

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RAPID OPTICAL FOLLOW-UP OBSERVATIONS OF GAMMA-RAY BURSTS

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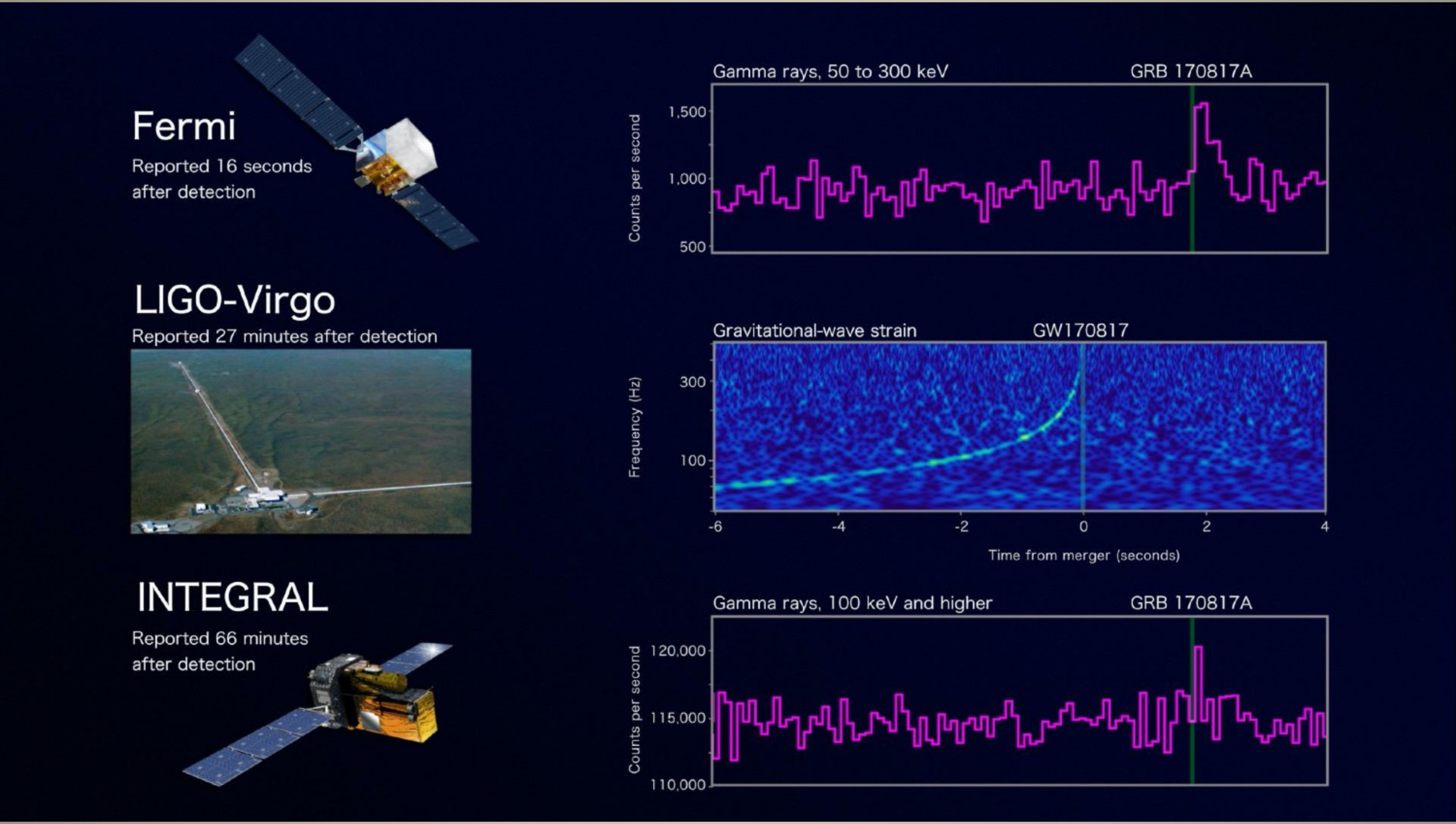
The prompt emission of gamma-ray burst sources is still the main means of detection, and a privilegied access to the souce dynamics. It is detected from radio to GeV energies, and its study is crucial for the overall understanding of the phenomenom. We present here a panorama of the rapid optical observations, and what can be infered from the data. We will discuss also the new instruments which are planned for the observation of the prompt and early afterglow at optical and infrared wavelengths, with spectral capabilities.

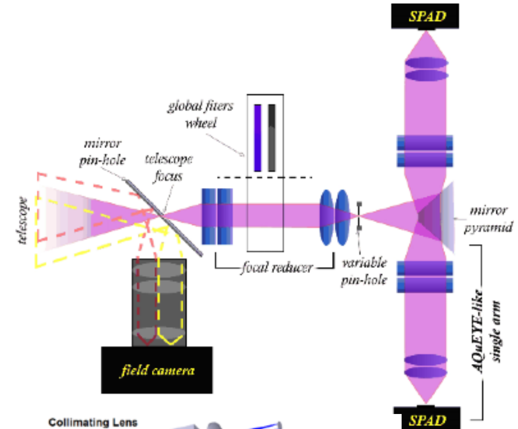
Keywords: Gamma-ray bursts.

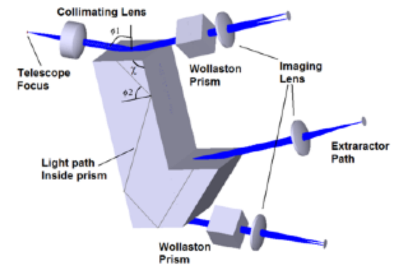
GW170817/GRB180717A



Instrumentation

Instrument	Detector	Group	τ (ms)	Type
UltraCam	Frame Transfer	Sheffield/ Warwick	5ms	Imager (3-Band)
UltraSpec	EMCCD	Sheffield/ Warwick	1ms	Spectrograph
GASP	EMCCD	Galway	600μs	Polarimeter
Optima	APD	MPE	1 ns	Photoncounter / polarimeter
Iqueye	APD	Padua	0.1 ns	Photon counter
Arcons	MKID	UCSB	20 ns	Imager



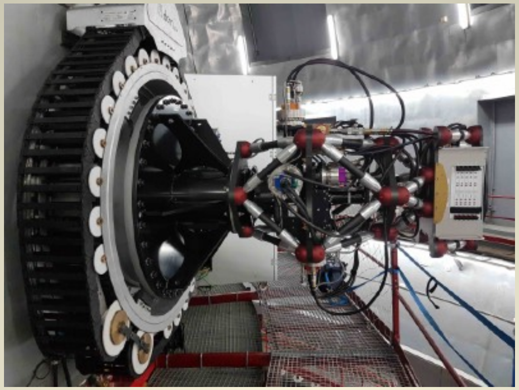


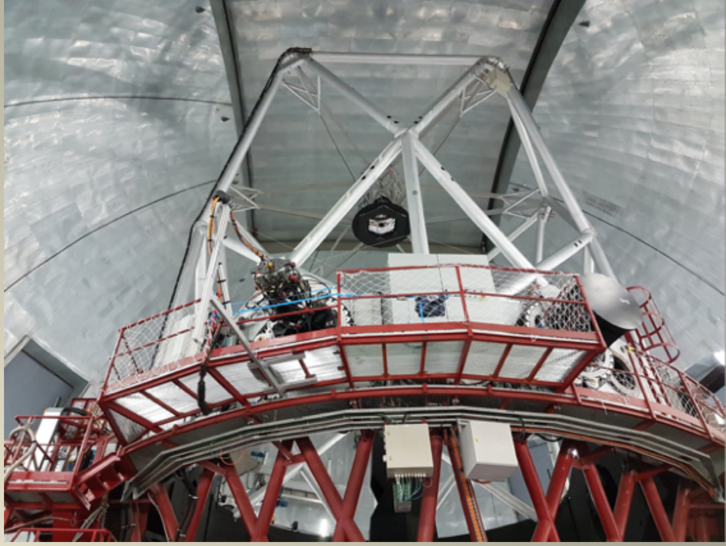
Instrument	Modes	Detector	Time Rate (Window)
VISIR	Burst	DRS	12.5 ms SF
SOFI	Burst, FastPhot	Hawaii	4 ms (8 x 8), 15 ms (32 x 32)
ISAAC	Burst, FastPhot	Hawaii-1, Aladdin	3 ms (32 x 32), 6 ms (64 x 64)
ISAAC	Burst	Hawaii-1, Aladdin	9 ms (1024 x16)
NACO	Cube	Aladdin	7.2 ms (64 x 64), 350 ms (1024 x 1024)
HAWK-I	Fast	Hawaii-2RG	6.3 ms (16 x 16)
FORS2	HIT	CCD (charge shift)	up to 2.3 ms
VLTI	Fast	Various	up to 1 ms

ESO - HTRA : Richichi et al 2009

HIPERCAM @ GTC

Ultracam - VLT

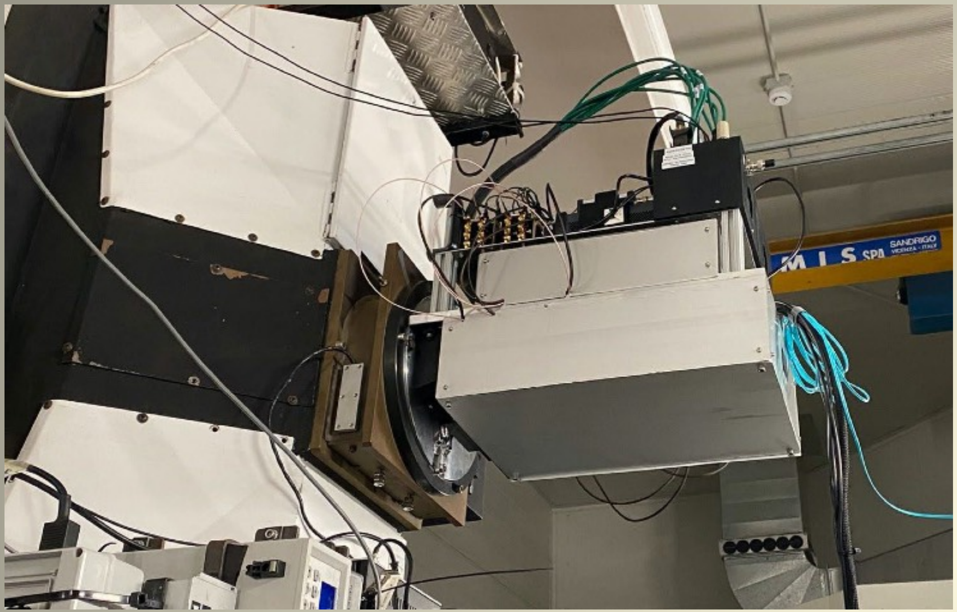


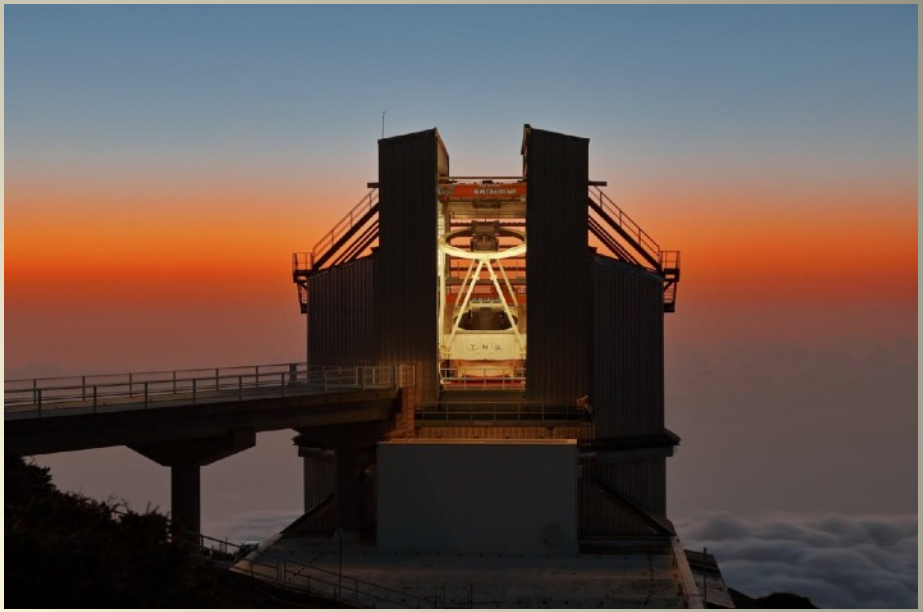


Hipercam – GTC -2018

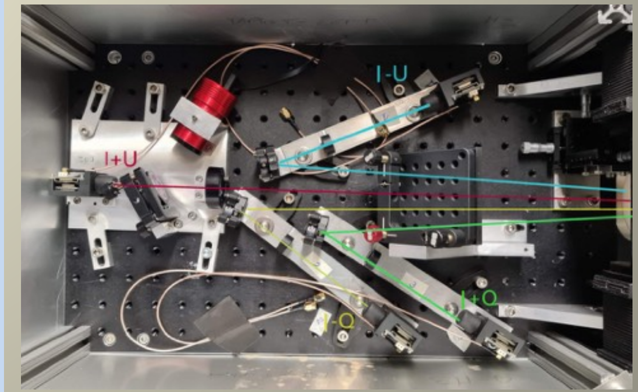
	ULTRACAM	HiPERCAM
Number of simultaneous bands	3 (ug + r/i/z)	5 (ugriz)
Readout noise	3e^- at 100kHz	4.5e^- at 263kHz
CCD operating temperature	233K	183K
Dark current	360e^-/pix/hr	100e^-/pix/hr
Longest exposure time	30s	1800s
Highest frame rate	400Hz	1050Hz
Field of view on WHT	5.1' x 5.1'	10.2'x5.1'
Field of view on GTC	-	2.8'x1.4'
Probability of r = 10 comparison	45%	78%
Comparison star pick-off	No	Yes
Dummy CCD outputs	No	Yes
Deep depletion	No	Yes
QE at 700/800/900/1000nm	83/61/29/5%	88/78/53/13%
Fringe suppression CCDs	No	Yes
Fringe amplitude in z	>10%	<1%

SiFAP2 – SiFAP4XP @ TNG





Acquiring mode:	Time Tag, Gated mode
Absolute timing accuracy:	< 60 μs
Relative time resolution *:	8 ns (Time Tag), 1 ms (Gated Mode)
Field of View:	7 arcsec x 7 arcsec
Bandpass:	320 - 900 nm (peaked @ 450 nm with 40% efficiency, @900 nm 5% efficiency)
Linearity:	< 10 Mcps (detector saturation @ 15 Mcps)
Count rate/Vmag:	10-(0.942*Vmag-18.67)1000.2 kcps
Maximum storing count rate:	< 2Mcps for Time Tag (otherwise throughput saturation) < 15 Mcps for Gated Mode (otherwise detector saturation)

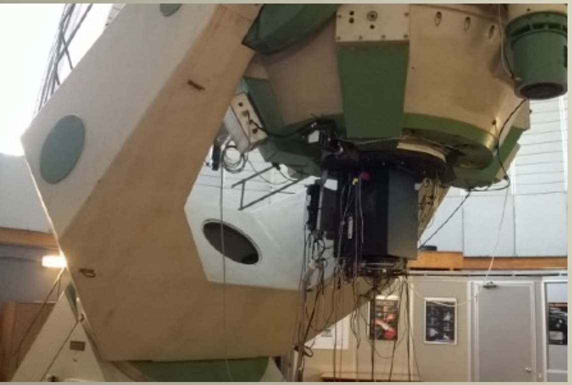


Aqueye+ and Iqueye
(Asiago Quantum Eye)

Single Photon Avalanche Detector (SPAD)

System sensitivity	Photon counting
Relative time accuracy	100 ps (for 1 h of continuous observation)
Absolute time accuracy	500 ps (for 1 h of continuous observation)
Dark count rate	<100 Hz
Maximum count rate	8 MHz
Dynamic range	>40 dB
Limiting magnitude	$m_V = 24$ with 2 h exposure time and $S/N = 10$
Effective field of view	(selectable) 3.5, 5.2, or 6.1 arcsec
Operative spectral range	$\Delta\lambda = [350, 925]$ nm (see Table 1 for filter details)
System total efficiency	33% (peak @ 550 nm)
	18% (average over $\Delta\lambda = [350, 925]$ nm spectral range)

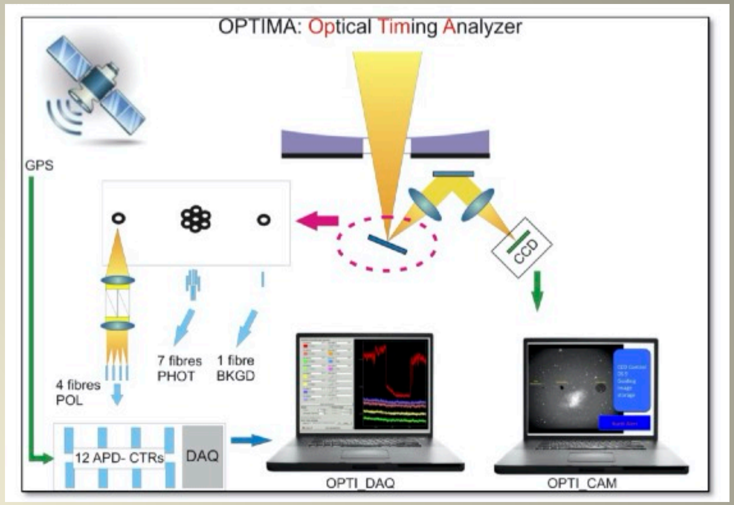
NTT

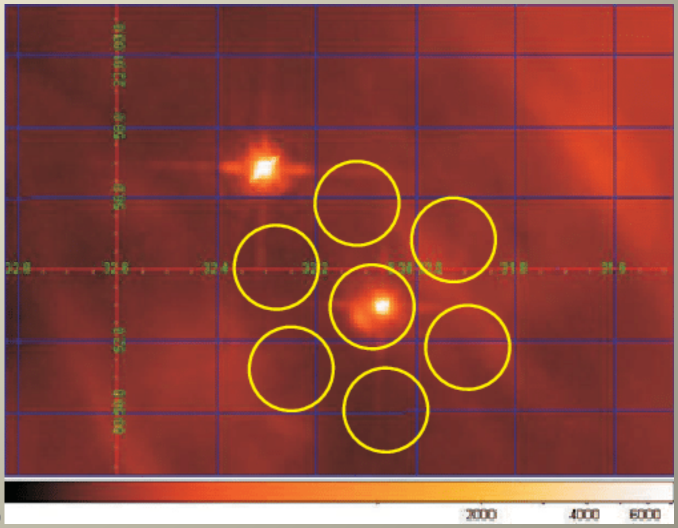


Aqueye+ is mounted at the 1.8 m Copernicus telescope

Iqueye is fiber-fed at the 1.2 m Galileo telescope

OPTIMA (OPtical TIMing Analyzer)



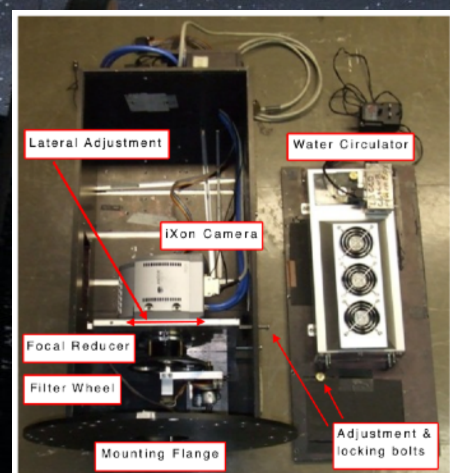


Galway Ultra-Fast Imager (GUFI) @ Vatican Advanced Technology Telescope

L3CCD system (Andor iXon DV887-BV)
- readout rates 1→10 MHz
- 512x512 pixels, 16μm size
- 31→244 frames/sec
- low light level sensitivity
- 30 ns RMS accuracy to UTC

Enclosure (50cm x 27cm x 24cm)
- single-filter wheel
  (Johnson *UBVRI, g',r',I',z'*)
- water cooled system

Visitor Instrument at VATT
- located at Mount Graham, Arizona
- 1.83m primary, f/1.0
- 3.0' field of view



OÉ Gaillimh
NUI Galway

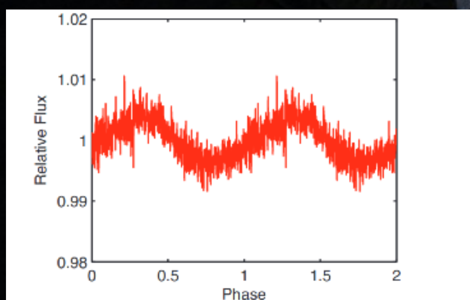
Aaron Golden, Ray Butler (National University of Ireland Galway)

Vatican
Observatory

Galway Ultra-Fast Imager (GUFI) @ Vatican Advanced Technology Telescope

Rotation periods of brown dwarfs

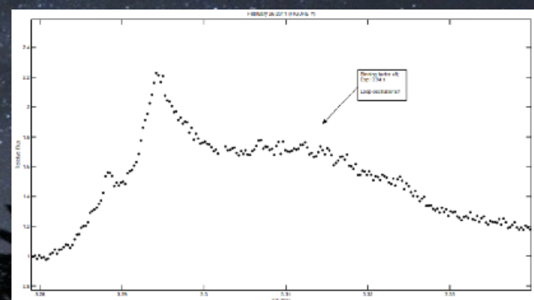
I-band lightcurve of M9 dwarf TVLM 513-46546 (period of 1.95958 hrs)



- long temporal baseline (~ weeks)
- detect periodicities from ~ 2 – 20 hrs
  - identify targets for radio observations to detect auroral emission
- can combine with vsini → i
  - test spin-orbit alignment of tight binaries

High-speed monitoring of flare stars

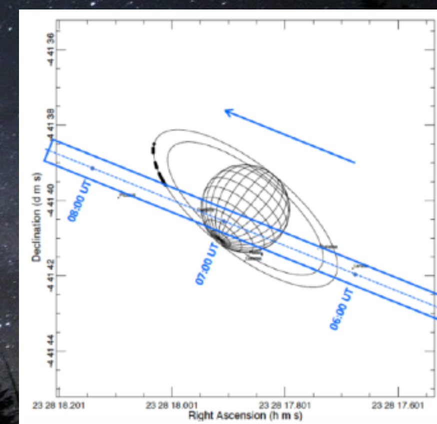
B-band lightcurve of flare from YZ CMi showing loop oscillations (~ 10–15 sec)



- provides temporal resolution to sample fine structure in impulsive flare events
- can be coordinated with other ground (spectroscopic), space-based (X-ray) facilities
- constrains flare model physics

Occultations/NEOs/Active Asteroids

7th October 2021 Stellar Occultation of the Neptunian System



GUFI/VATT part of Lucky Star collaboration (LESIA/Observatoire de Paris), observations made with CH_4 filter

OÉ Gaillimh NUI Galway

Aaron Golden, Ray Butler (National University of Ireland Galway)

Vatican Observatory

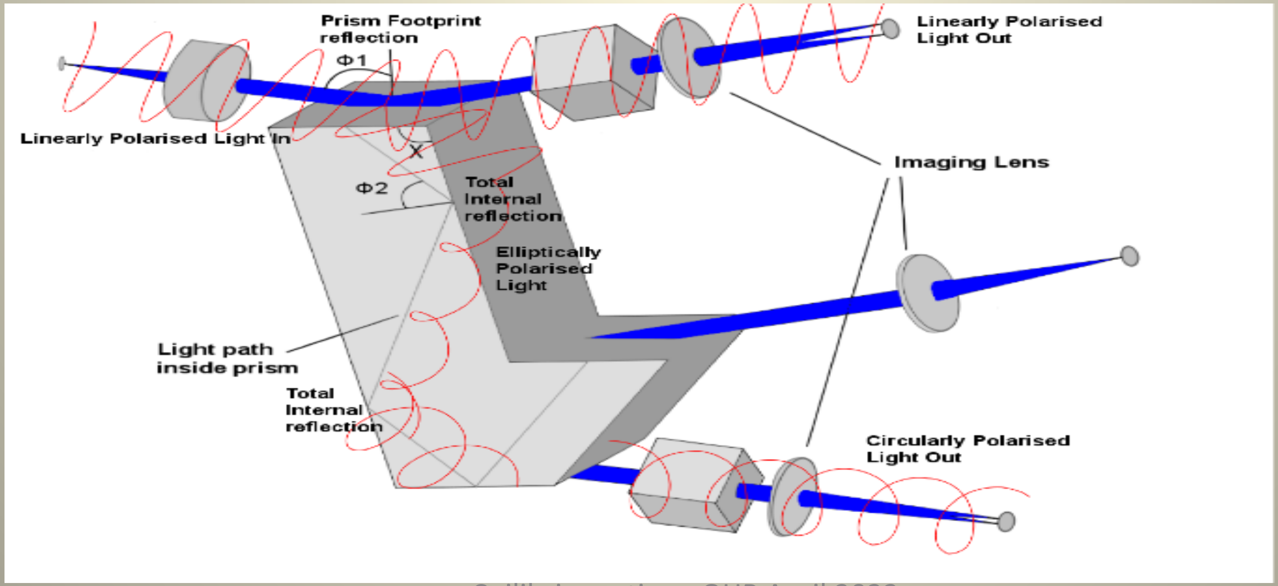
Optical Polarisation with the Galway Astronomical Stokes Polarimeter (GASP)

- Ultra-high speed, Full Stokes, Astronomical Imaging Polarimeter

- Division of Amplitude Polarimeter (DOAP)

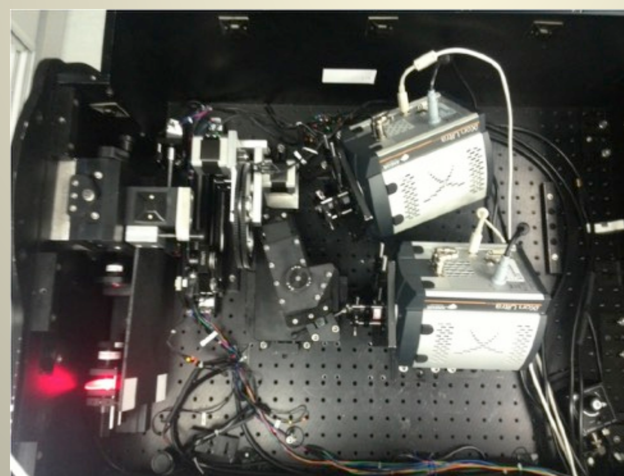
- Linear & Circular polarisation

- Studies (~ms) variations in optical pulsars and magnetic CVs



Optical Layout of GASP: light path through DOAP from telescope focus to detectors (*Kyne et al. 2012)*

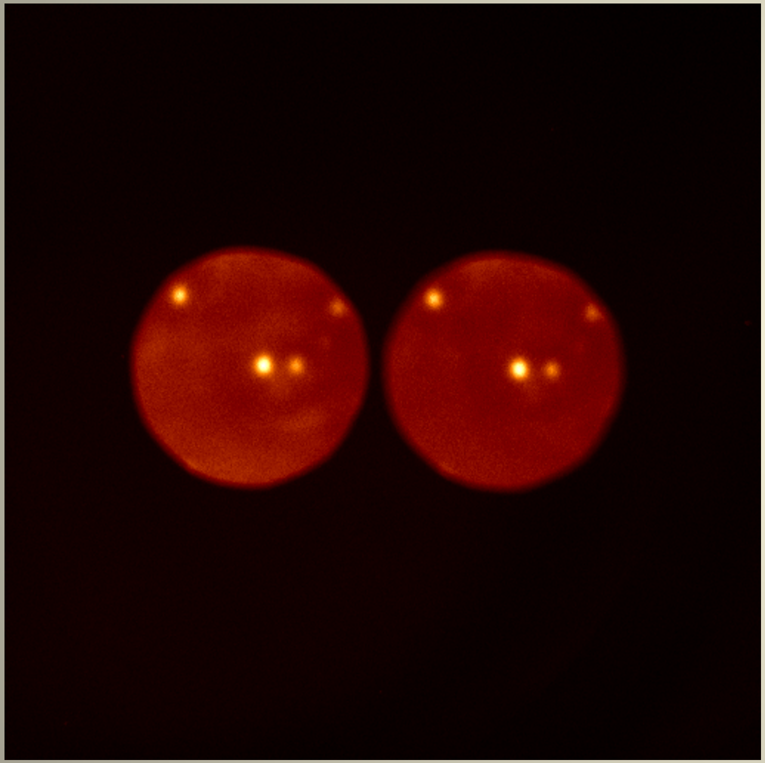
GASP used at several telescopes

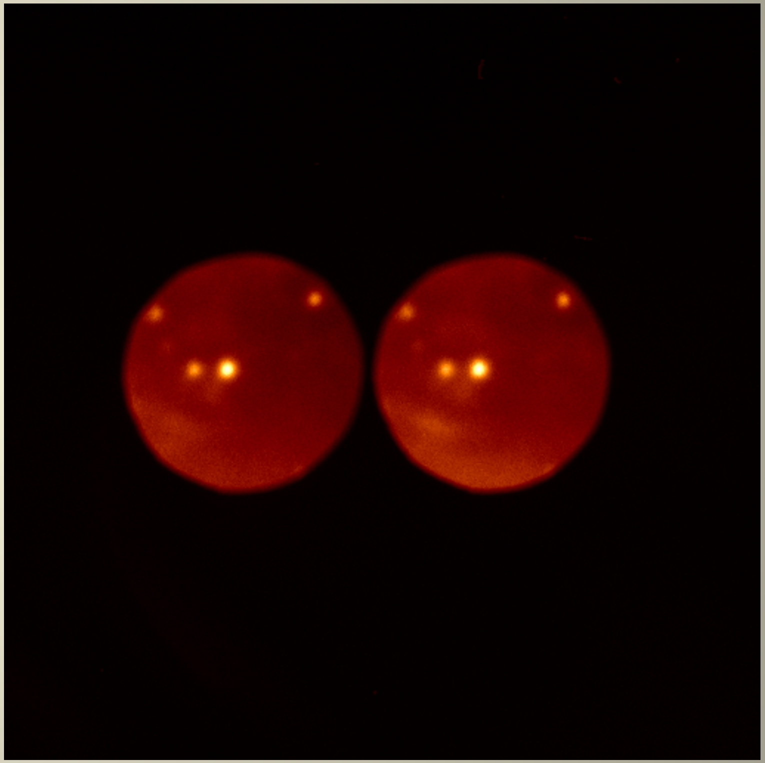


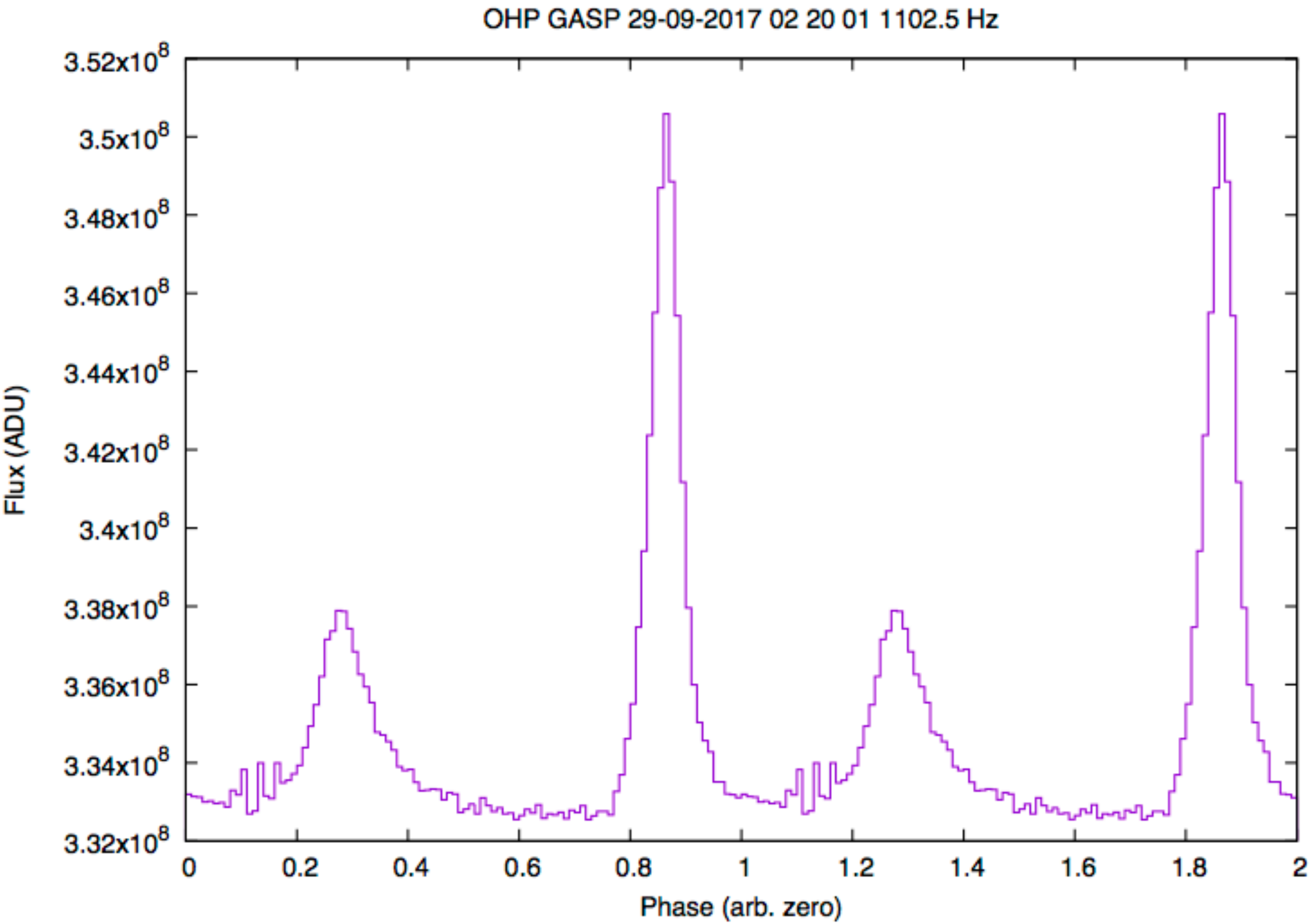
T193cm
Observatoire de Haute Provence (OHP), France

and at OHP

Crab at OHP193cm+GASP

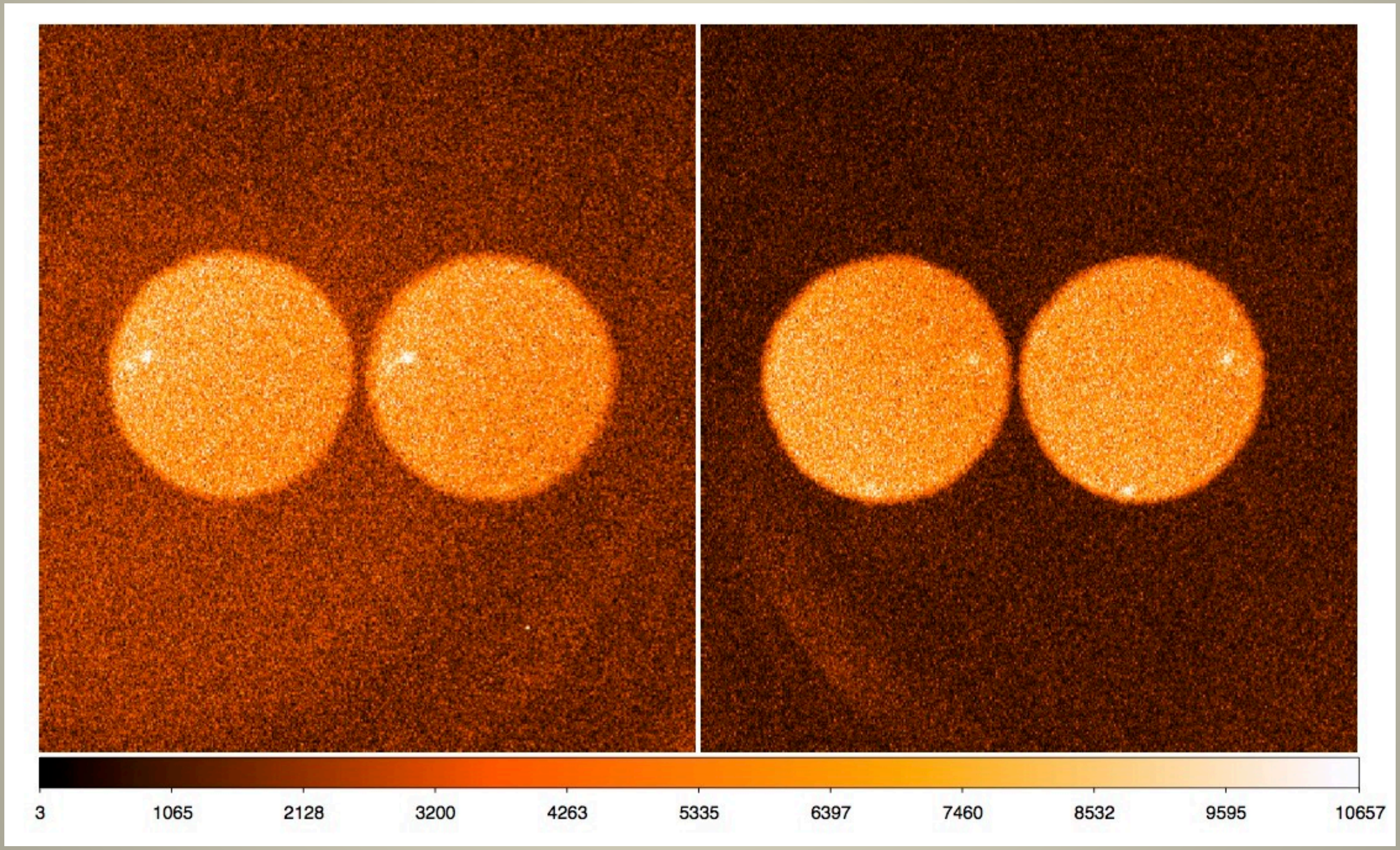


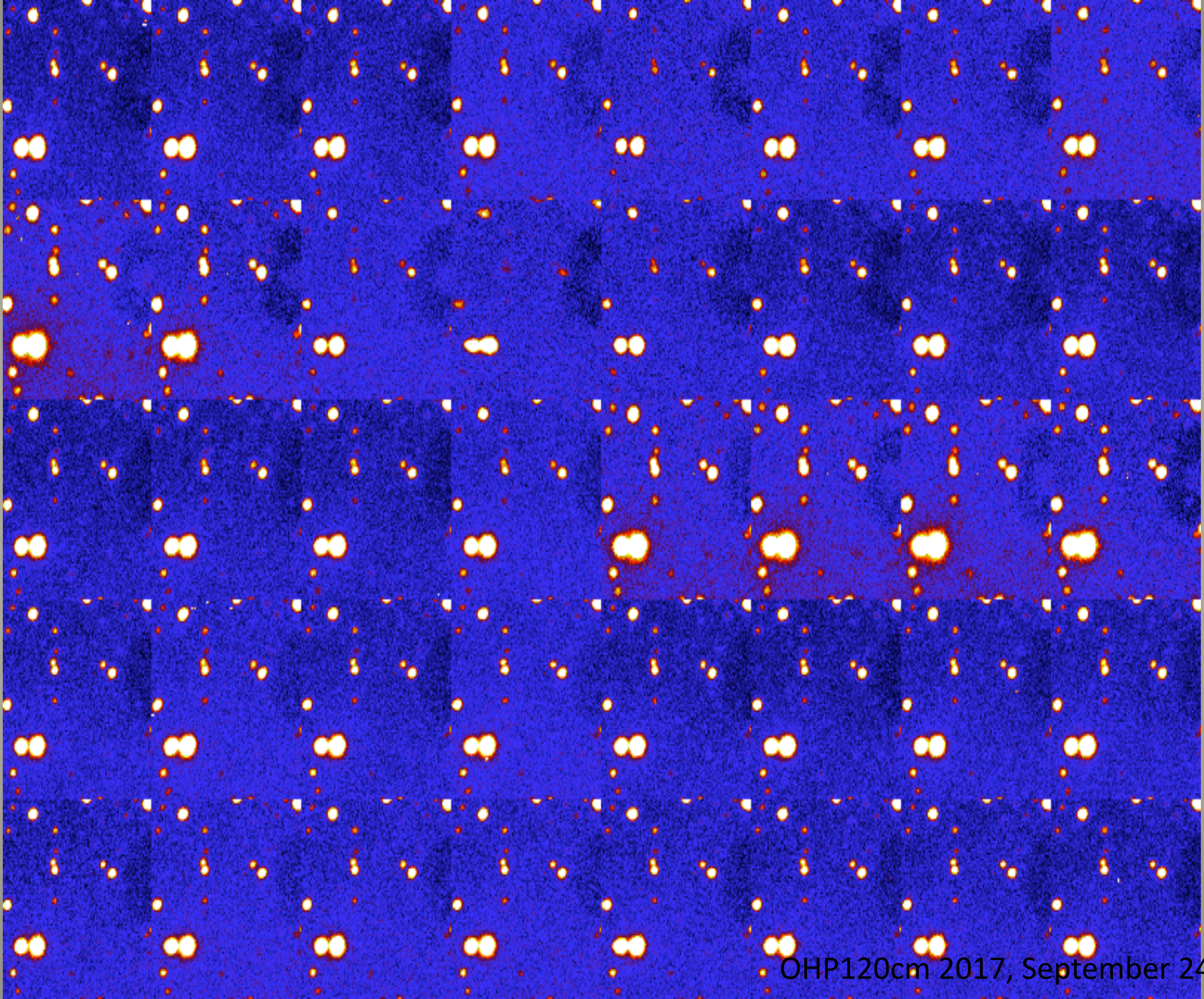



OHP GASP 29-09-2017 02 20 01 1102.5 Hz
3.52x10^8
3.5x10^8
3.48x10^8
3.46x10^8
3.44x10^8
3.42x10^8
3.4x10^8
3.38x10^8
3.36x10^8
3.34x10^8
3.32x10^8
Flux (ADU)
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
Phase (arb. zero)

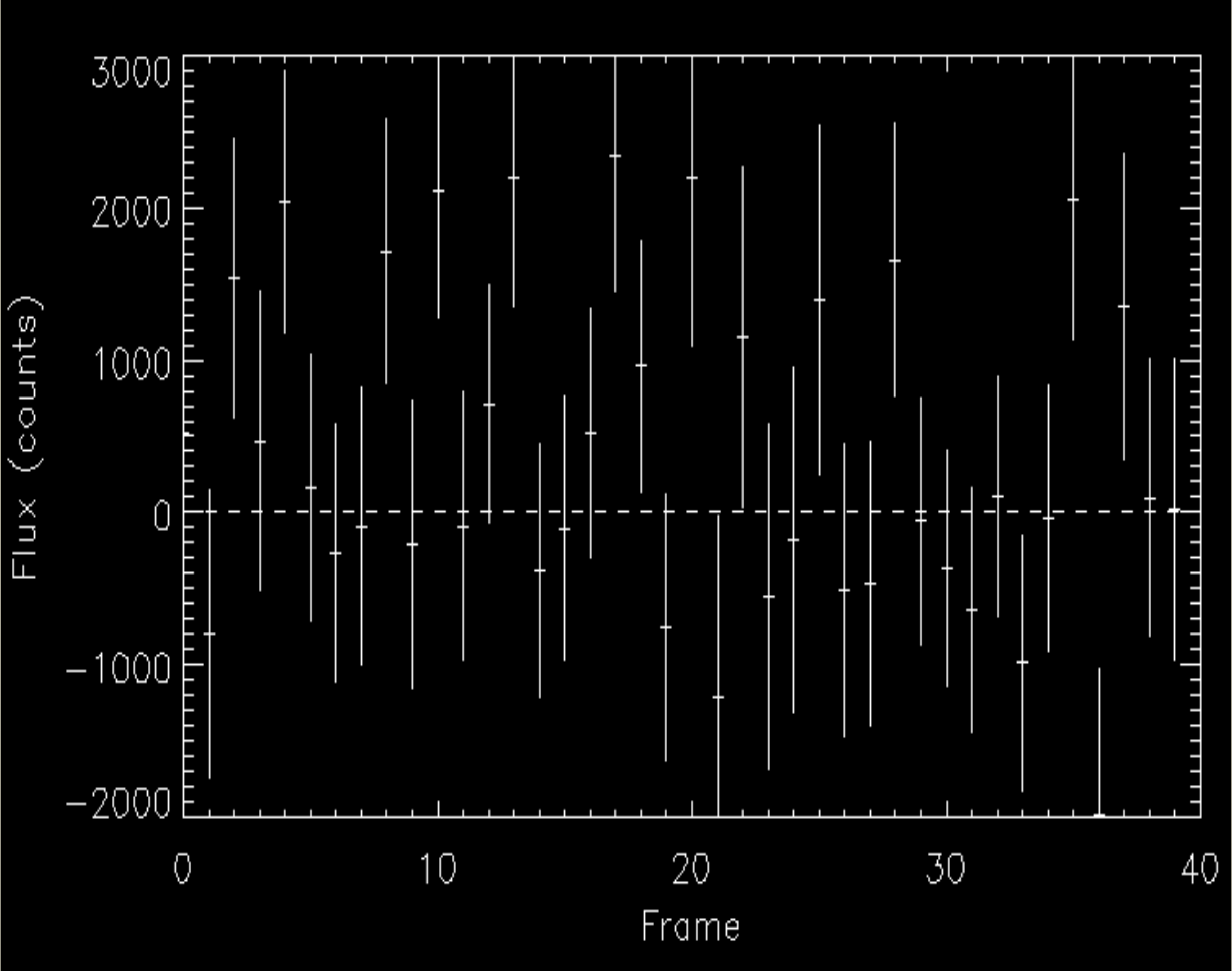
FRB121102

GASP@OHP 2017, September

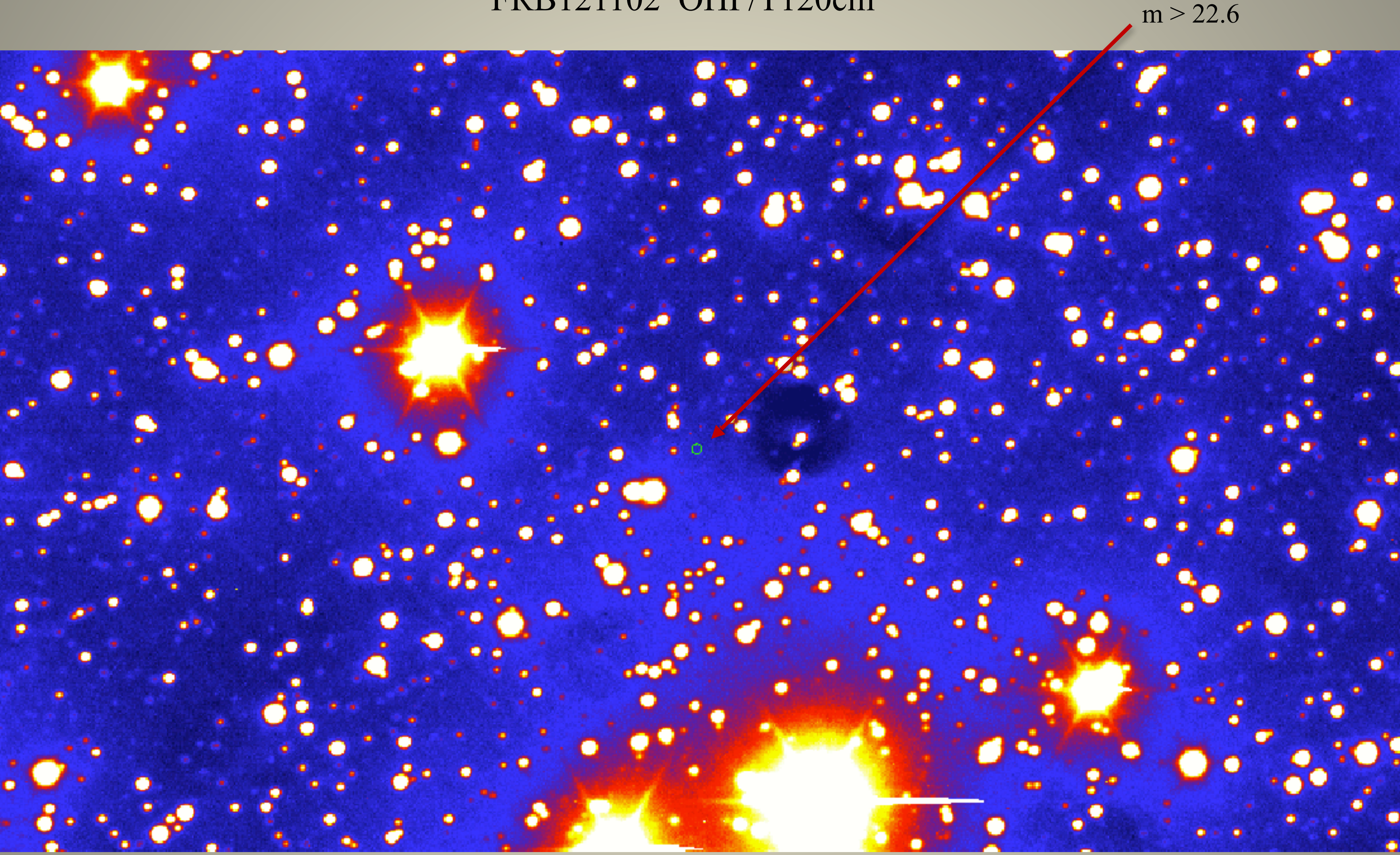




OHP120cm 2017, September 24 5m


3000
2000
1000
0
−1000
−2000
Flux (counts)
0
10
20
30
40
Frame

FRB121102 OHP/T120cm



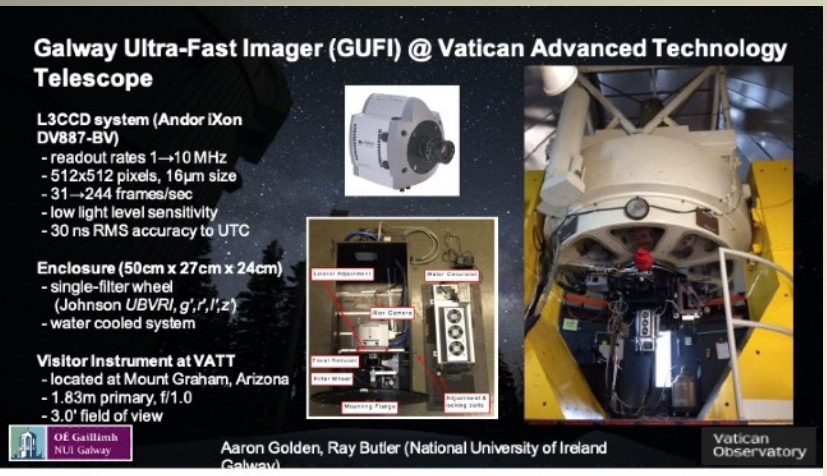
2017, Sept. 24 40x5min E. Le Floc'h

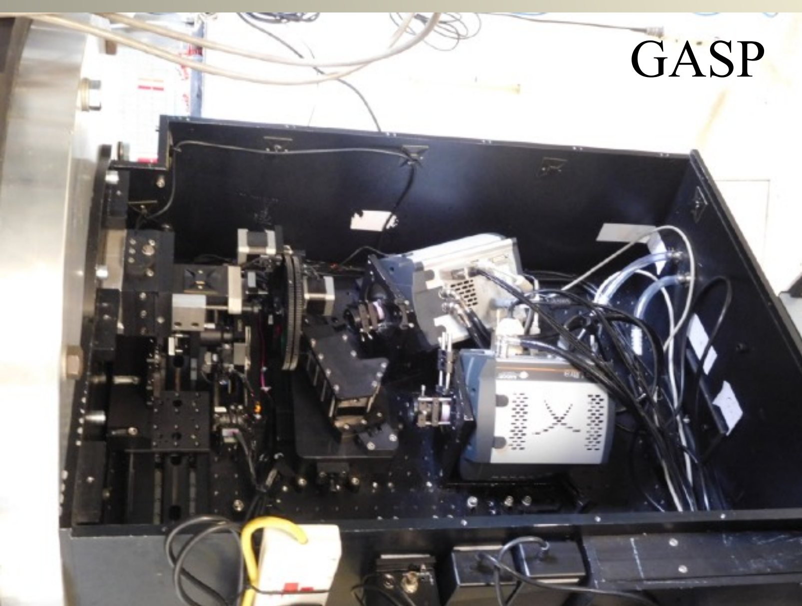
Thoughts

HTRA

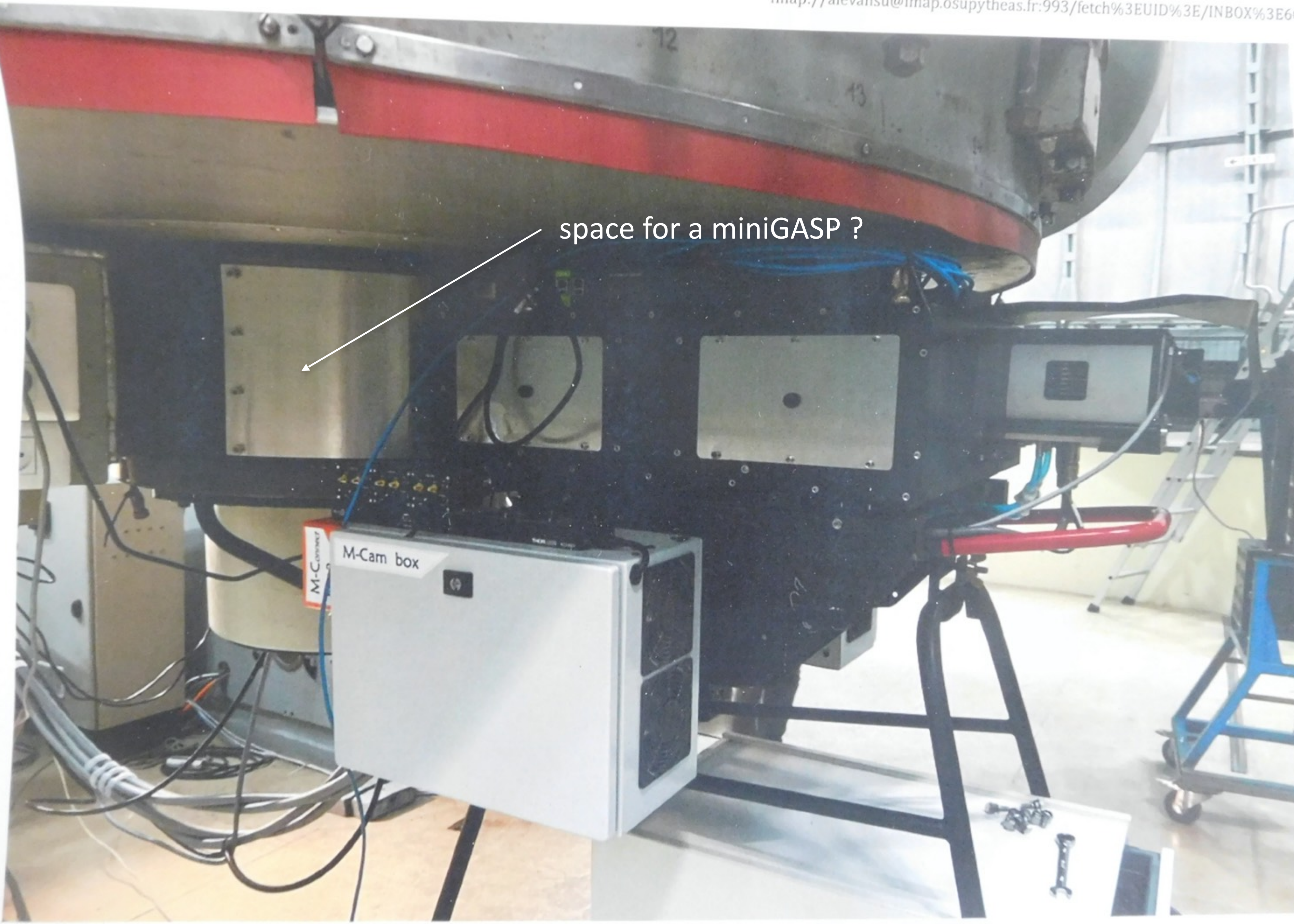
- Science potential convincing (I hope)
- Instrumentation improving (IR high speed devices expected)
- Intruments exit but acces somehow not easy (immediat implication : quick reaction for ToO, etc difficult to conduct/execute)
- A comment: No HTR instrument and/or option at ELT at the moment !
- So do it yourself

Scientific and instrumental background in HTRA





GASP at WHT, ESO, Gemini, Palomar, OHP


space for a miniGASP ?
M-Cam box

THANK YOU FOR YOUR ATTENTION