

QUASAR project & status

QUASAR project & status - Roland Walter
QUASAR HBT at 10 ps resolution - Gilles Koziol
QUASAR1 chip - Ivan Cardea
QUASAR timing and atmospheric synchronisation - Vitalii Sliusar
QUASAR correlator on telescope data - Etienne Lyard



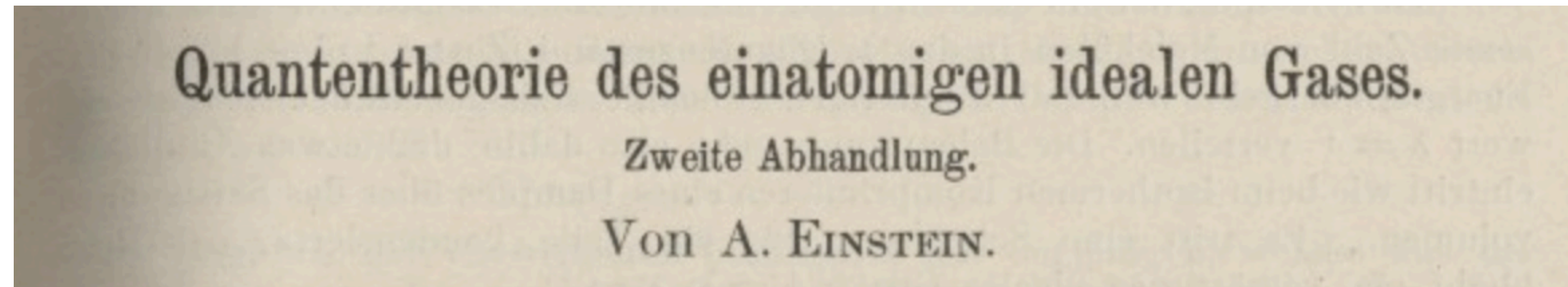
Roland Walter,^{a,*} Ivan Cardea,^b Edoardo Charbon,^b Daniel Florin,^c Benjamin Garcia,^a Ludovic Genolet,^a Andrea Guerrieri,^d Gilles Koziol,^a Etienne Lyard,^a Nicolas Produit,^a Aramis Raiola,^e Prasenjit Saha,^c Vitalii Sliusar,^a Lucijana Stanic,^c Achim Vollhardt^c and Domenico della Volpe^e



Boson statistics was predicted by Einstein in 1925

9 Physics Nobel prizes :

Clarke, Devoret & Martinis (**2025**) Macroscopic quantum tunnelling & quantisation
Aspect, Clauser, Zeilinger (**2022**): Entangled photons & ...
Glauber, Hall, Hänsch (**2005**): Quantum optics & optical combs
Abrikosov, Ginzburg, Leggett (**2003**) Theory of superconductors
Cornell, Ketterle, Wieman (**2001**) Bose-Einstein condensate
Bednorz, Müller (**1987**) Superconductivity in ceramic materials
Esaki, Giaever, Josephson (**1973**) Tunneling phenomena
Bardeen, Cooper, Schrieffer (**1972**) Theory of superconductivity
Onnes (**1913**) Low-temperature research and the discovery of superconductivity



1925

(inspired by the derivation of Planck's law by S. N. Bose in 2024)

$$\text{Variance of the number of particles : } \Delta N^2 = \langle N \rangle \left(1 + \frac{\langle N \rangle}{\text{number of quantum phase space elements}} \right) \quad (34)$$

1 liter of air: 10^{22} molecules
(ambient conditions)

$$\Delta N/N = 10^{-11}$$

Particles per quantum cells:

$$\frac{10^{22}}{V \left(\sqrt{mkT/h} \right)^3} \approx 10^{-6}$$

classical shot noise, a 10^{-11} effect

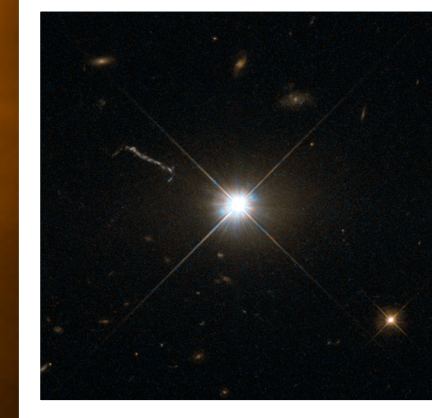
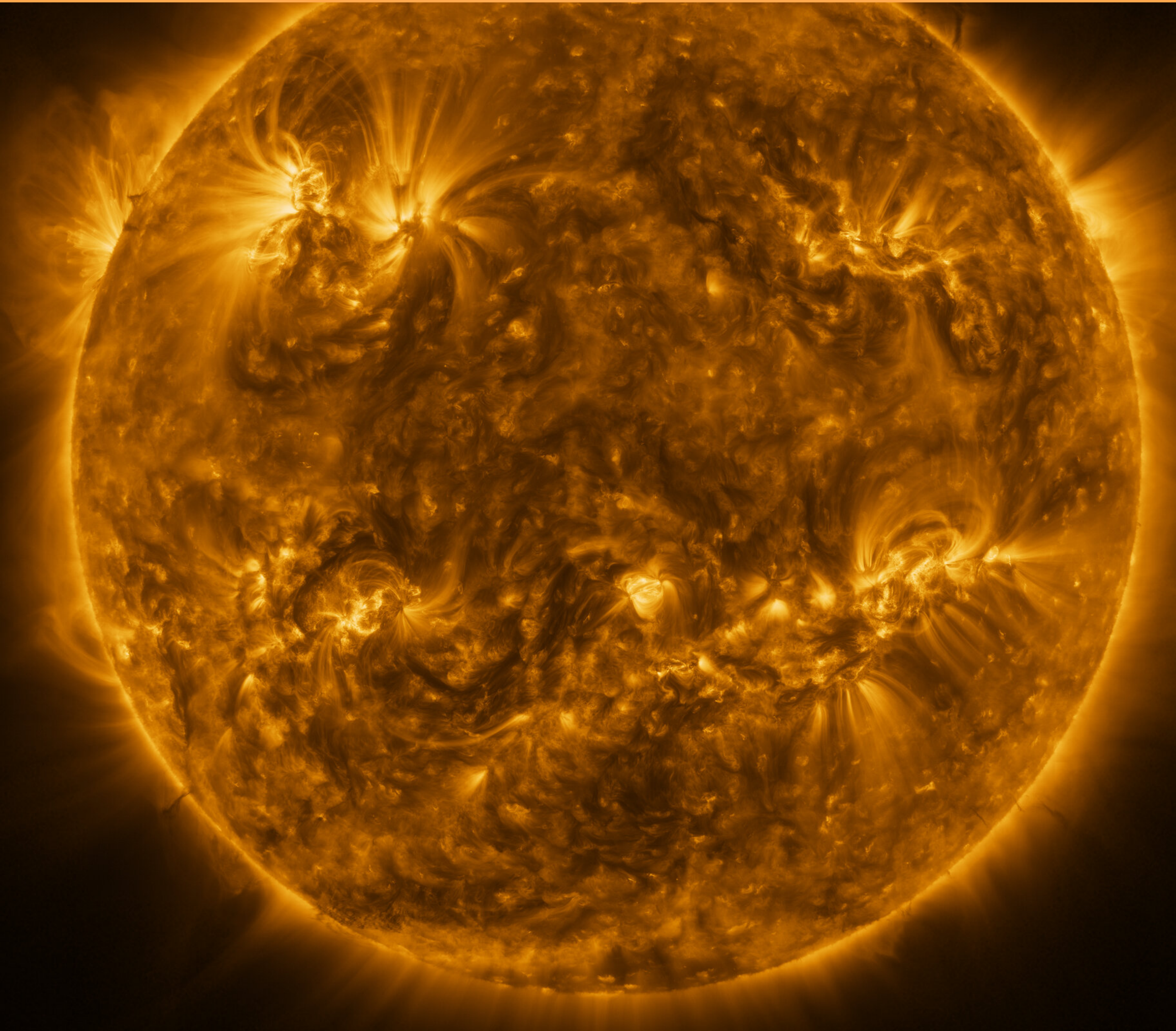
a 10^{-14} effect

When particle wave packets overlap in phase space they become indistinguishable

Photons overlap when their position and momentum vectors are close enough

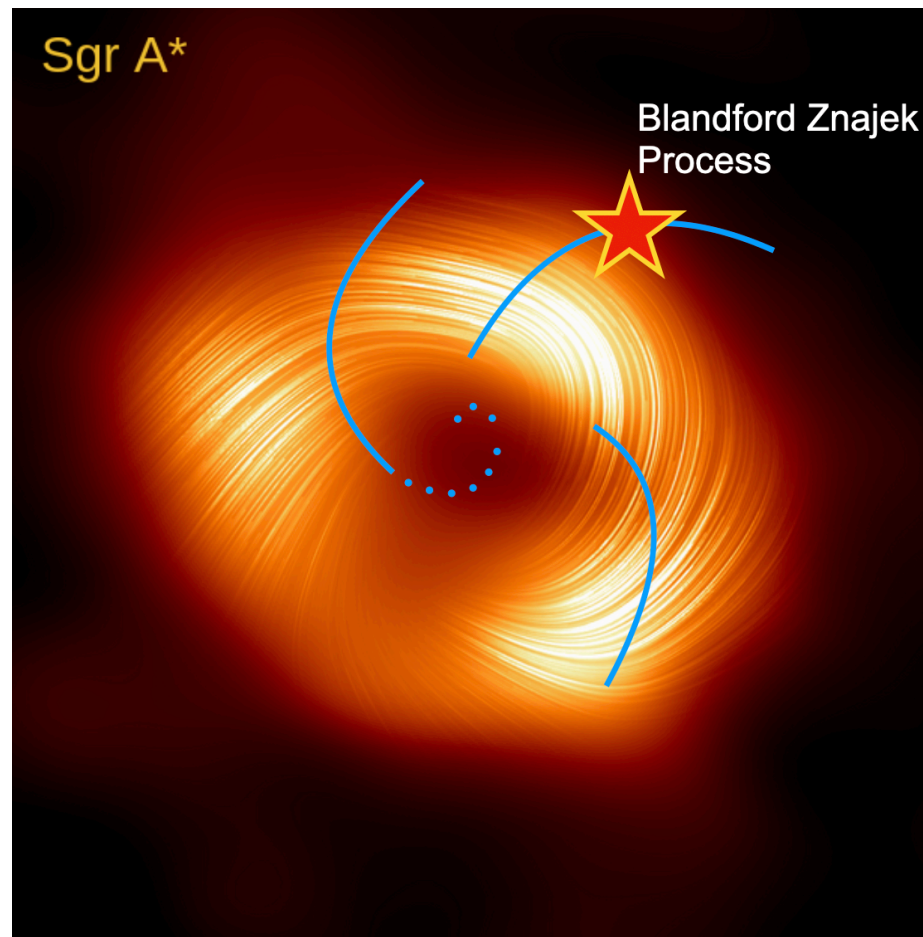
HBT 1956 : the first evidence of the quantum factor / Fano 1961: understanding $g^2=2$

Resolution is the key to astronomical understanding



Ceci n'est pas un disque d'accrétion.

The EHT confirms predictions of hot accretion models ($\dot{M} \ll \dot{M}_{Edd}$)



- Black-hole spin as a source of energy
- Electron temperatures have been measured
- The plasma is optically thin (we « see » the black-hole)
- Accretion is radiatively inefficient
- Signatures of the Blandford Znajek process

Great, because most black-holes in the Universe have low accretion rates

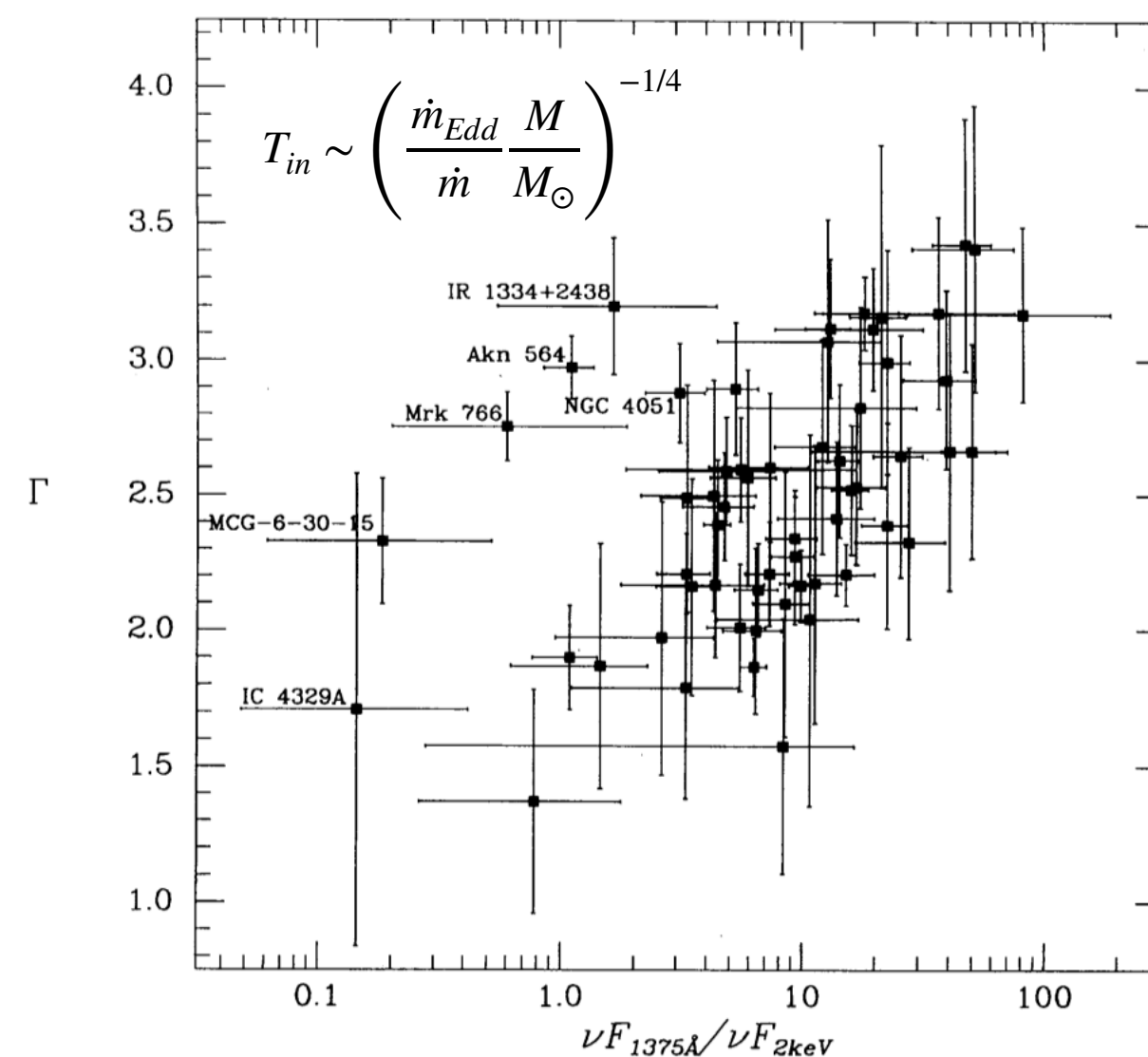
Observing synchrotron emission at high resolution (Gravity+, EHT+) will provide new insight

Do AGN with $\dot{M} \sim \dot{M}_{Edd}$ harbour accretion disks ?

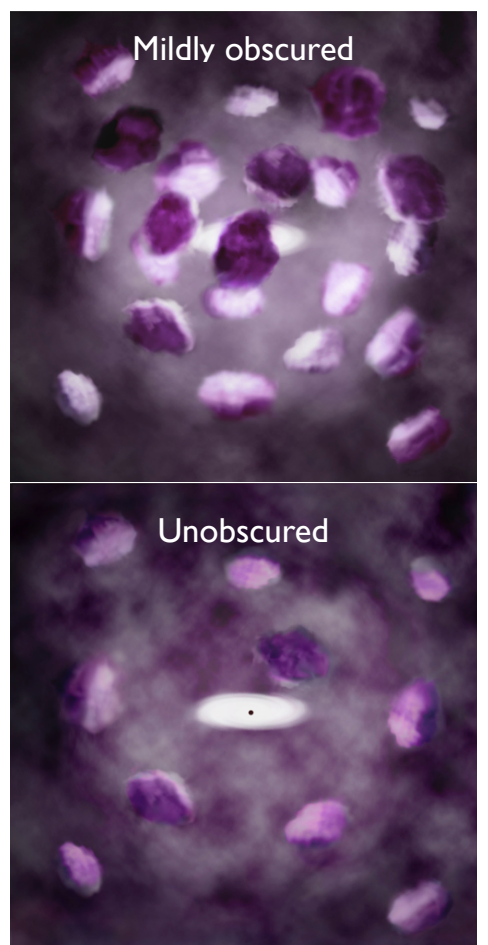
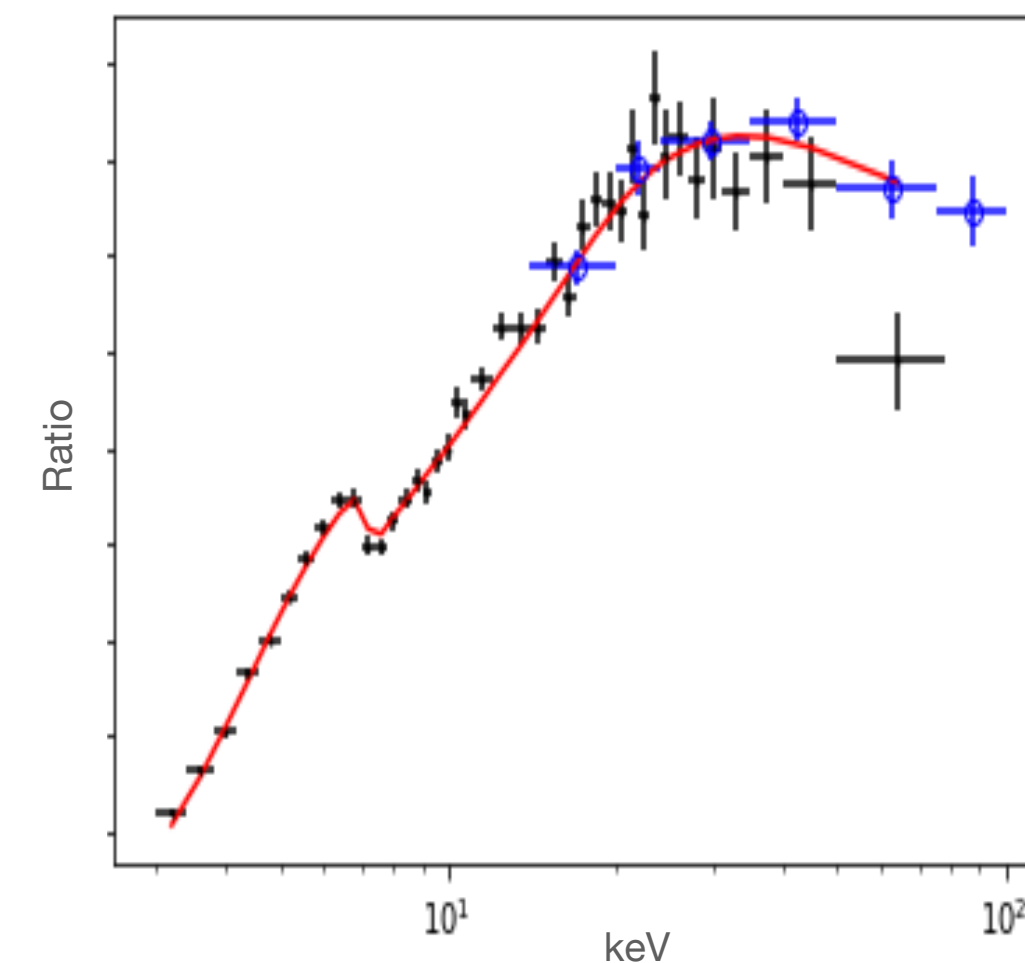
Variabilities do not match

Continuum delays 100x too short,
compared with viscous time scales

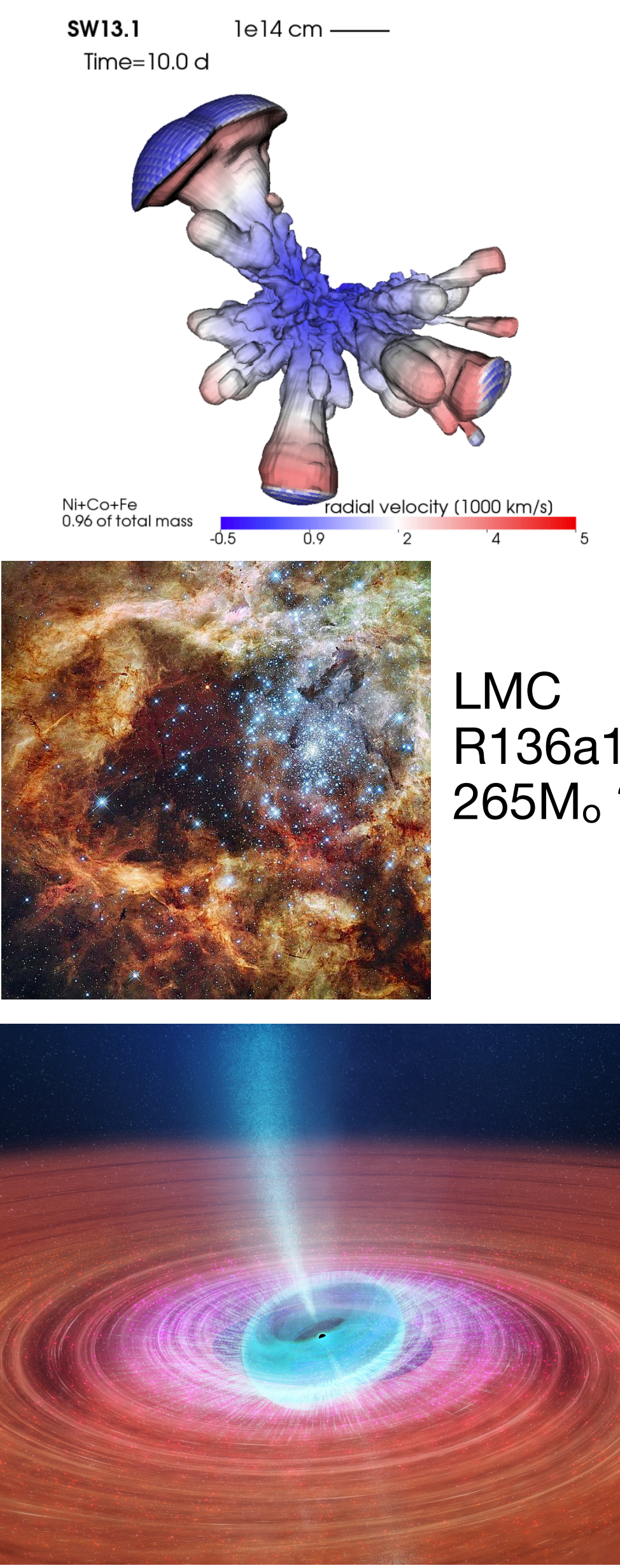
Spectral shapes do not match



Reflection does not match



Nano to pico degree optical resolution



Targets	Size (θ)	Baseline ($\lambda/\tan \theta$)
Micro to nano structures on the Sun	μ deg to ndeg	m-km
Sirius B (Robin)	8 ndeg	2.5 km
Stripped SN @ 50Mpc	1 ndeg	20 km
Supermassive star	1 ndeg	20 km
Accretion disk of U Geminorum (CV)	5 ndeg	2 km
Broad line region, TDE	1-100 ndeg	0.1-20 km
Horizon in M87	2 ndeg	5km
Accretion disk of 3C 273 (QUASAR)	1 ndeg	20 km
Disk & jet connexions	ndeg	20 km
Accretion disk of Sco X-1 (LMXB)	30 pdeg	600 km
0.01AU on α Centauri AB	2 μ deg	10 m
1km on α Centauri	1 pdeg	10'000 km



Optimizing all parameters

$$\text{SNR} = \sqrt{2} \sqrt{\epsilon_1 \epsilon_2} \sqrt{\frac{A_1 A_2}{(1 + B_{\nu 1}/F_{\nu})(1 + B_{\nu 2}/F_{\nu})}} \frac{F_{\nu}}{h\nu} V_{12}^2 \sqrt{N_{\text{chan}}} \sqrt{\frac{T_O}{\sigma_t}}$$

Problems to be solved (1ps/c = 0.3mm) :

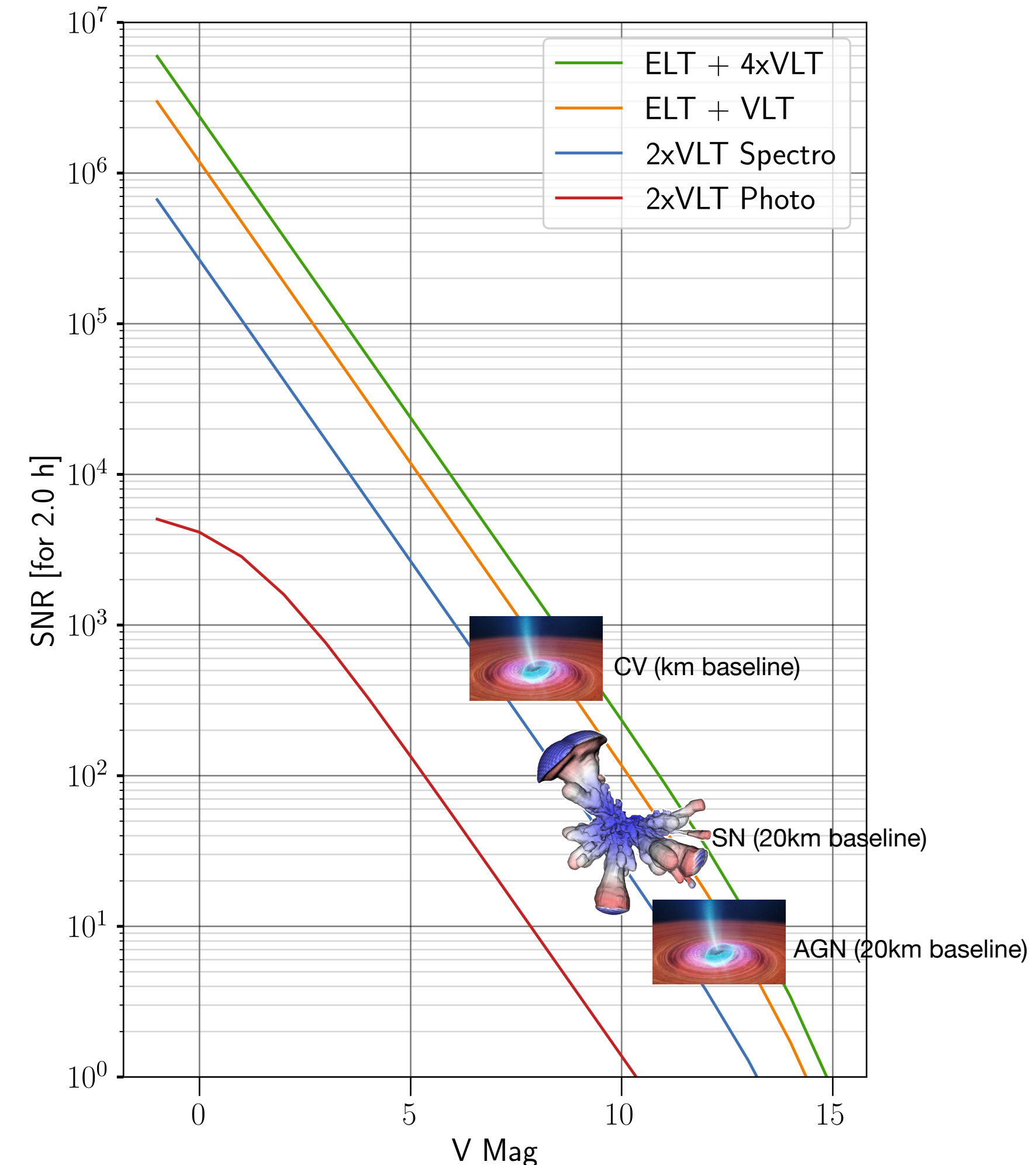
- ✓ Detector & TDC at high resolution
- ✓ Low systematic noise
- ✓ Clock synchronisation over many km
- ✓ High performance time tag correlator
- ✓ mm accuracy position of telescopes

Photometer has matured and can be used now

- ➔ Detector array
- ➔ Dewar & FPGA
- ➔ Synchronous optical spectrometer
- ➔ Atmospheric effects

Spectrometer to reach telescopes in 2027
➔ **quasars in 2030**

Simulations include source spectra, dispersion, slit, optical and quantum efficiencies, dead-time, fill factor, dark noise, cross-talk

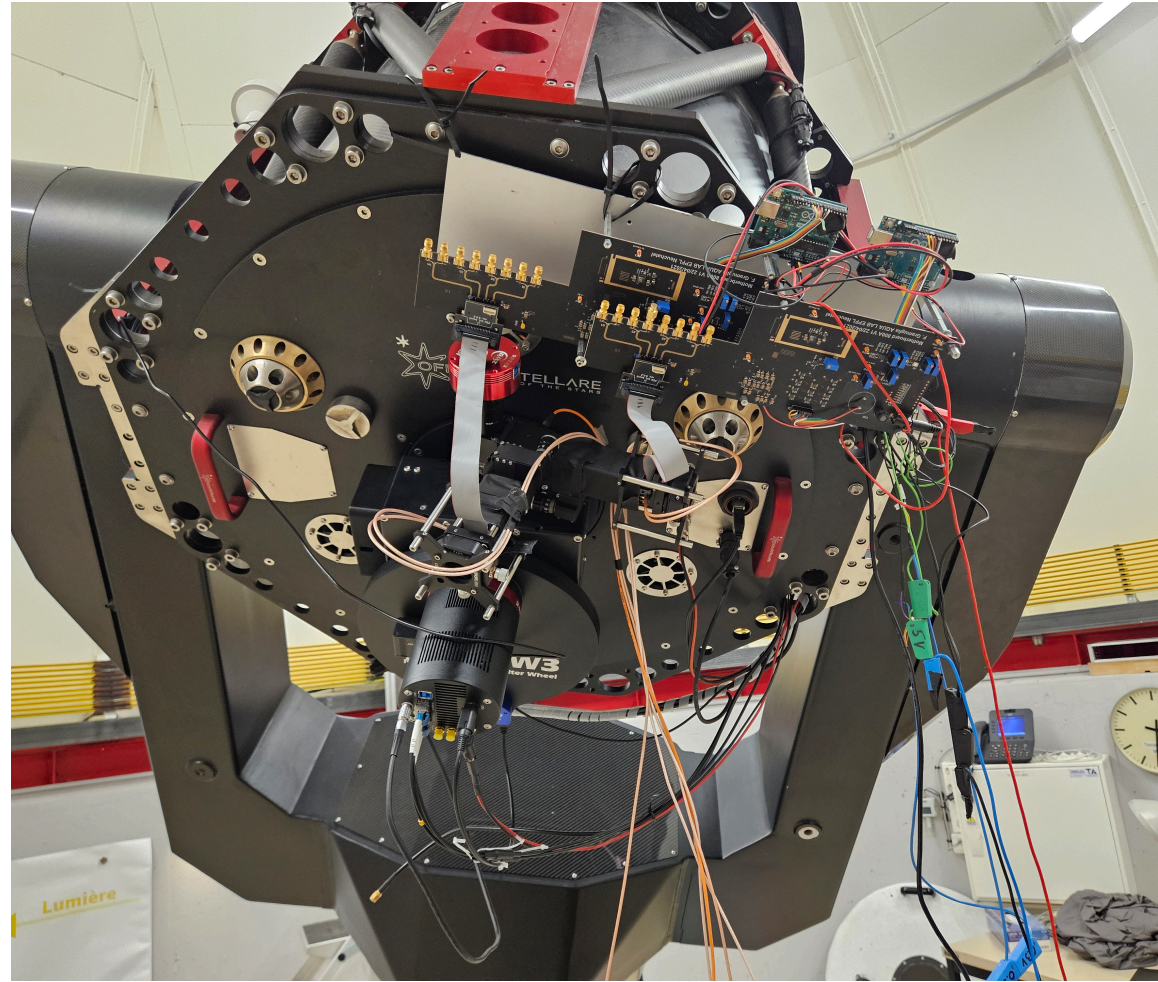


Improvements since the original Hanbury Brown & Twiss experiment:

- 10³ in mirror area
- 10³ in spectral channels
- 10³ in timing resolution

➔ **gain of 10¹² in exposure, compared to HBT**

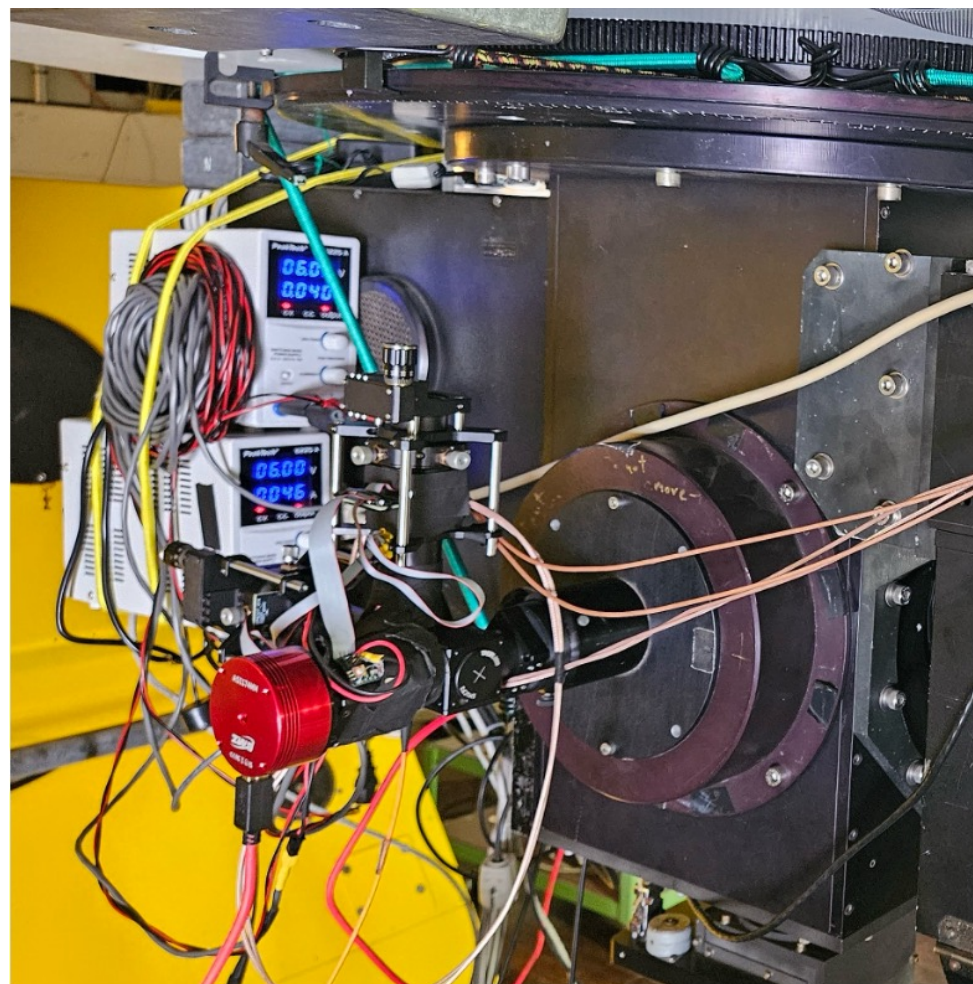
Photometer



Geneva



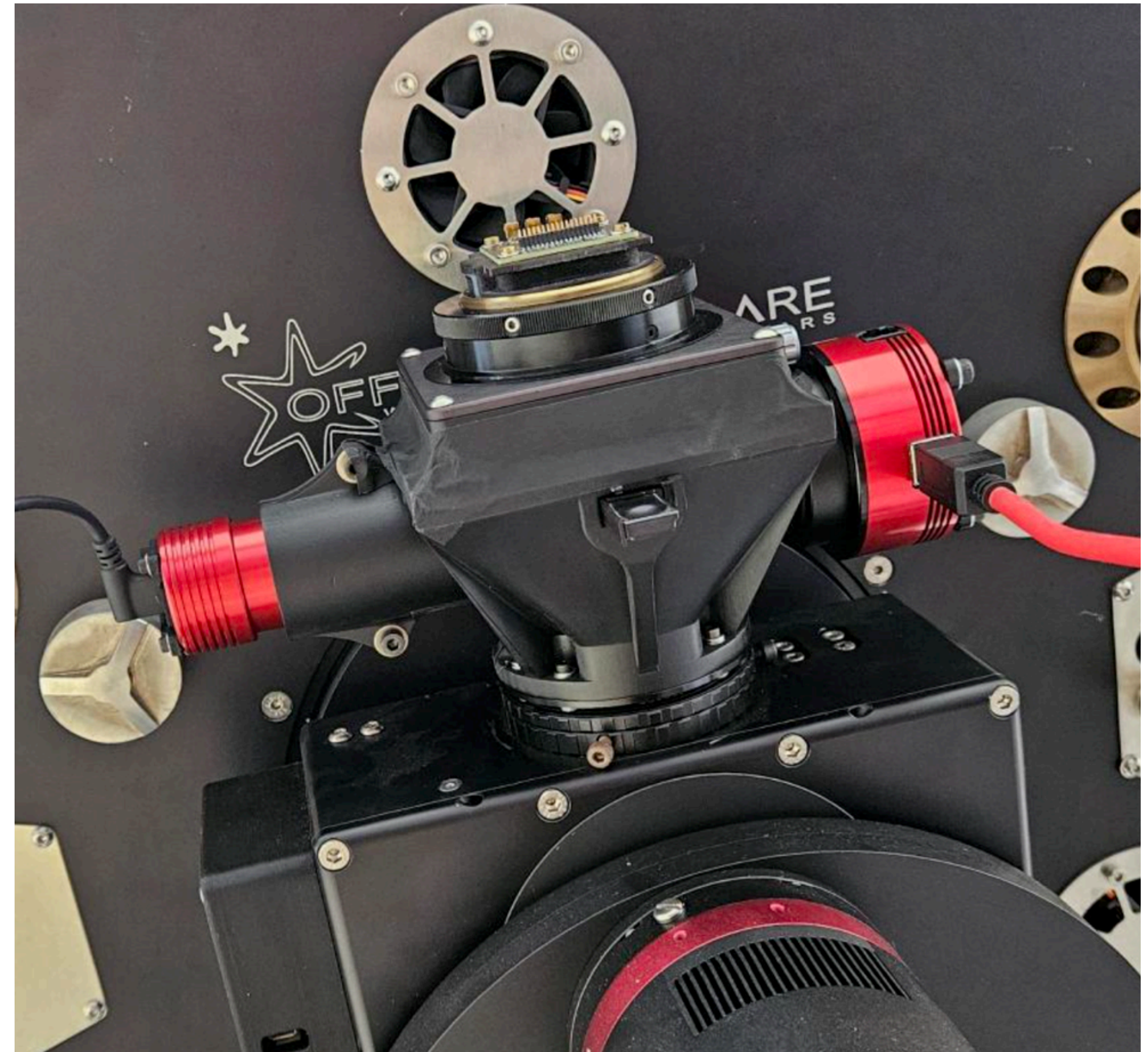
St-Luc



Skinakas (Crete)



C2PU Calern (France)

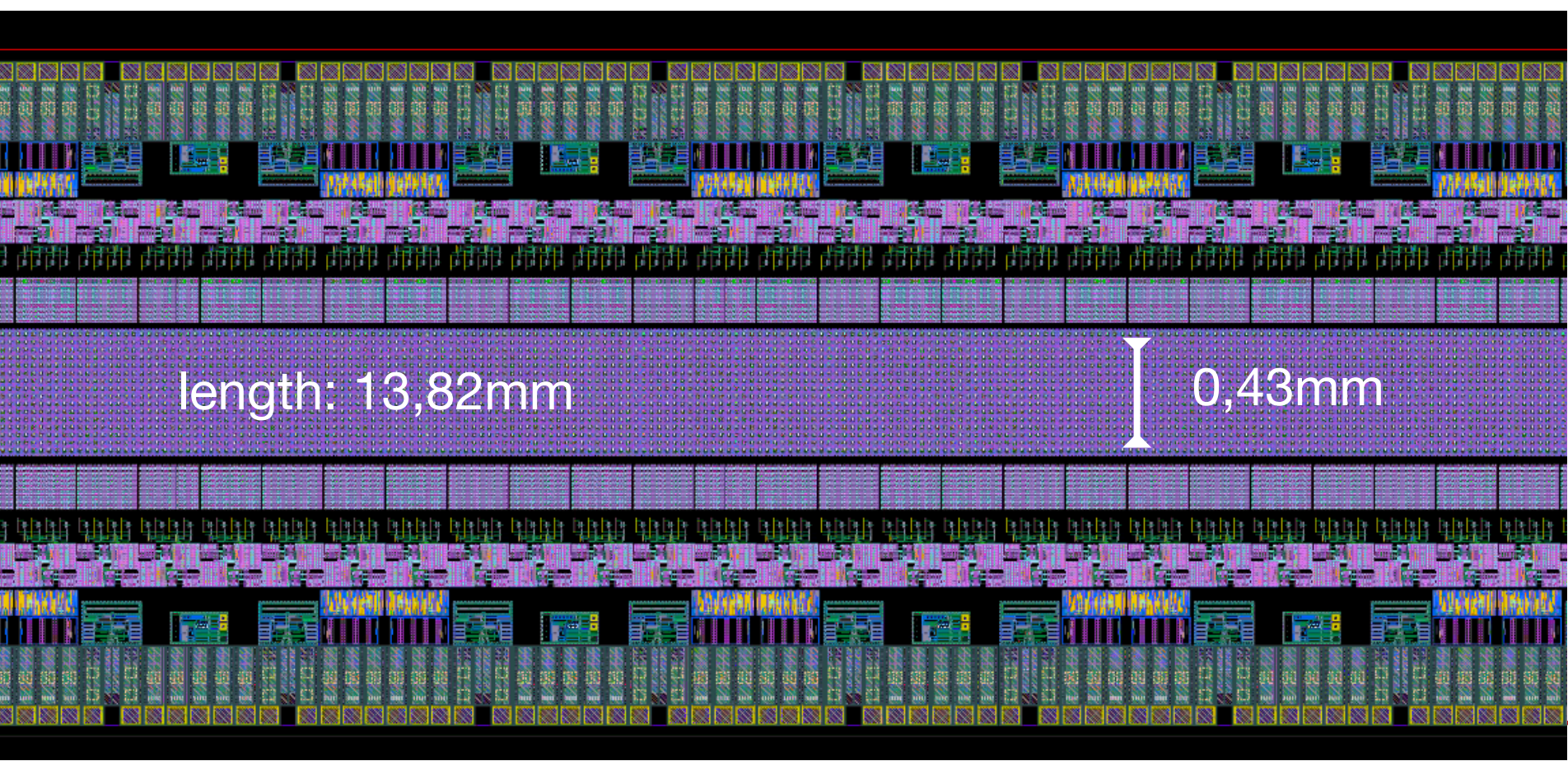


Photometer version 2

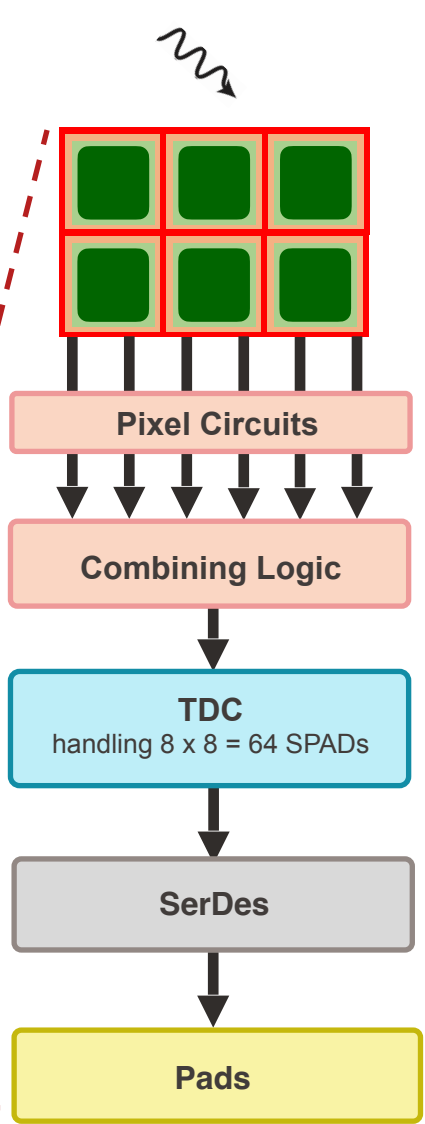
Spectrometer development

QUASAR1 chip *(at the foundry)*

528x16 spad array, ~1.4cm x 2mm, 0.5W, 60%filling factor
DCR ~ 1cps/pix@-30C, dead time quenching, cross-talk filtering,
132 time to digital converters, time stamps via 44 SERDES interfaces.

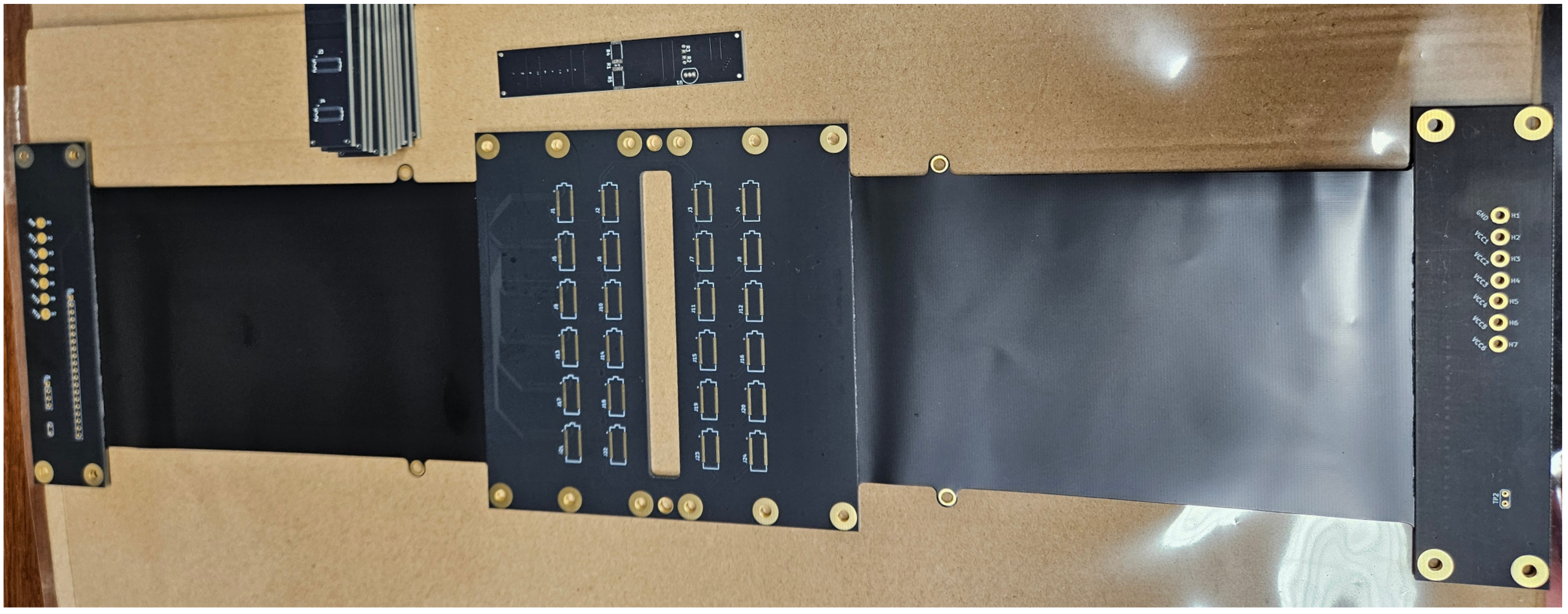


Ivan's talk



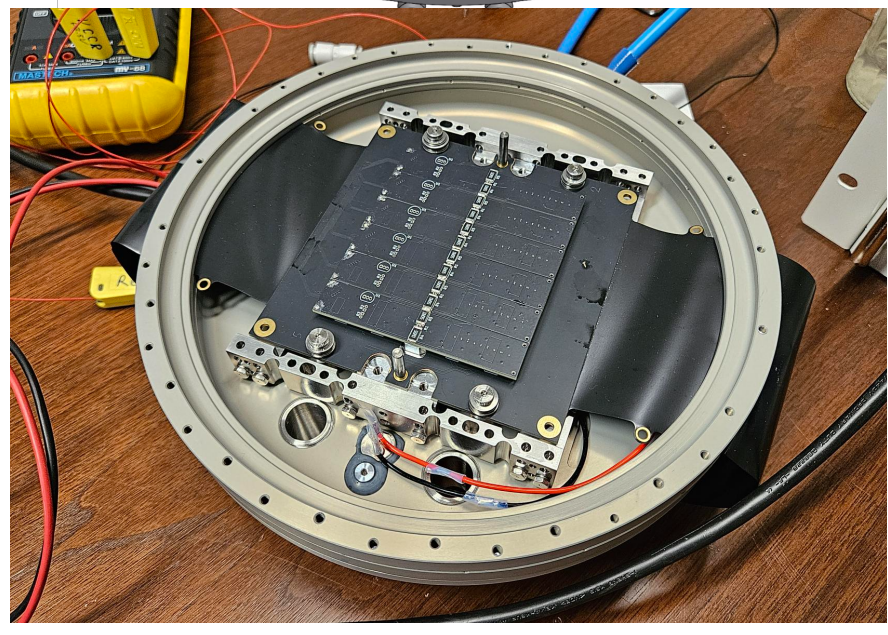
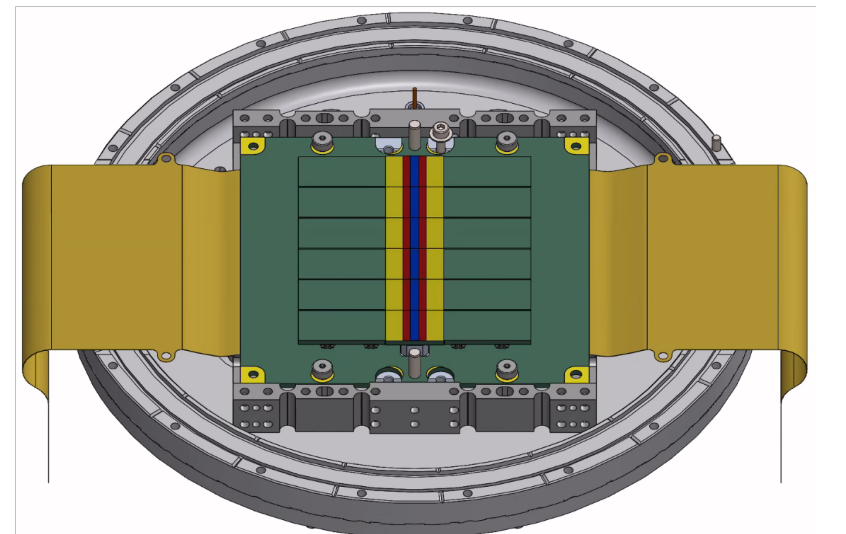
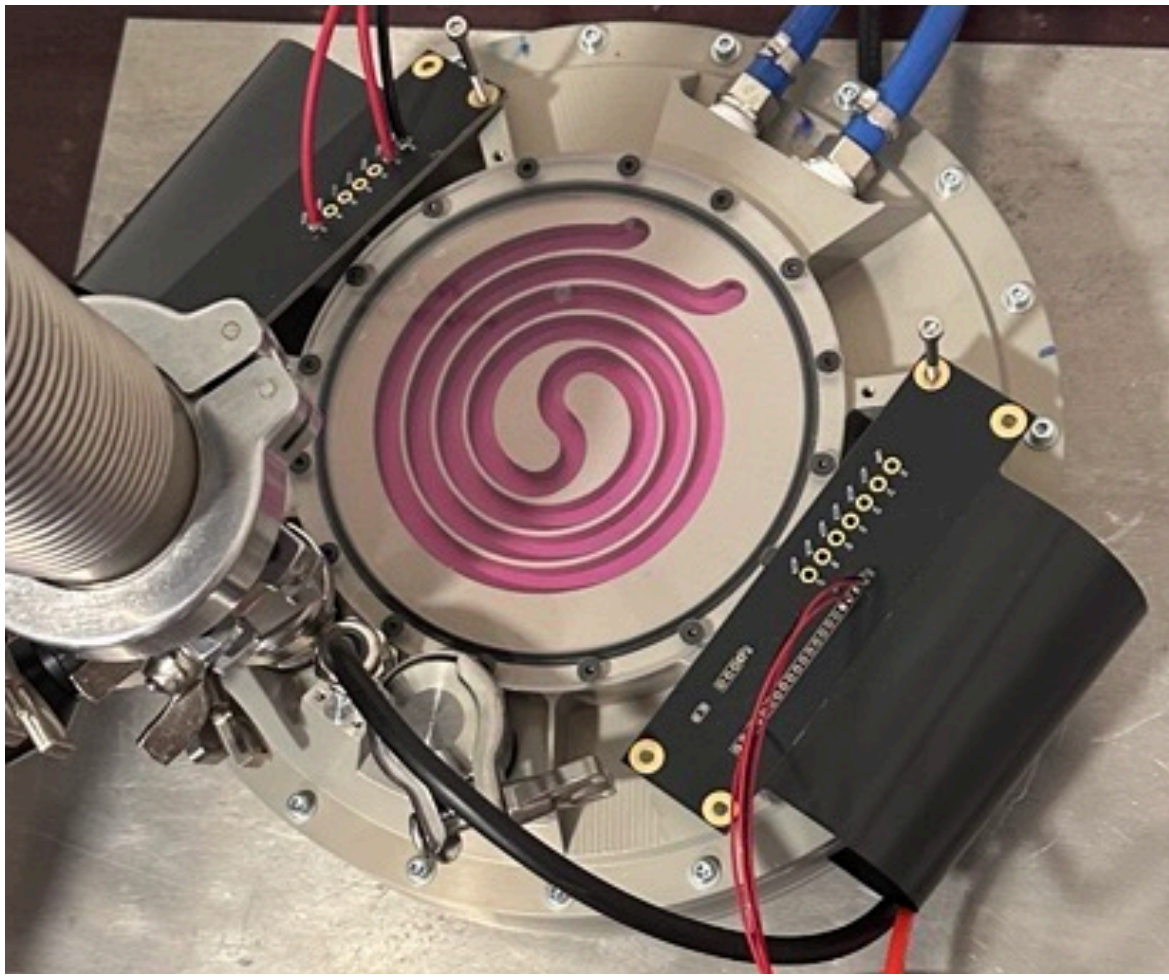
PCBs

6 QUASAR1 chips (3168x16 spads), 300Gbp
thermal sensors, power & timing distribution



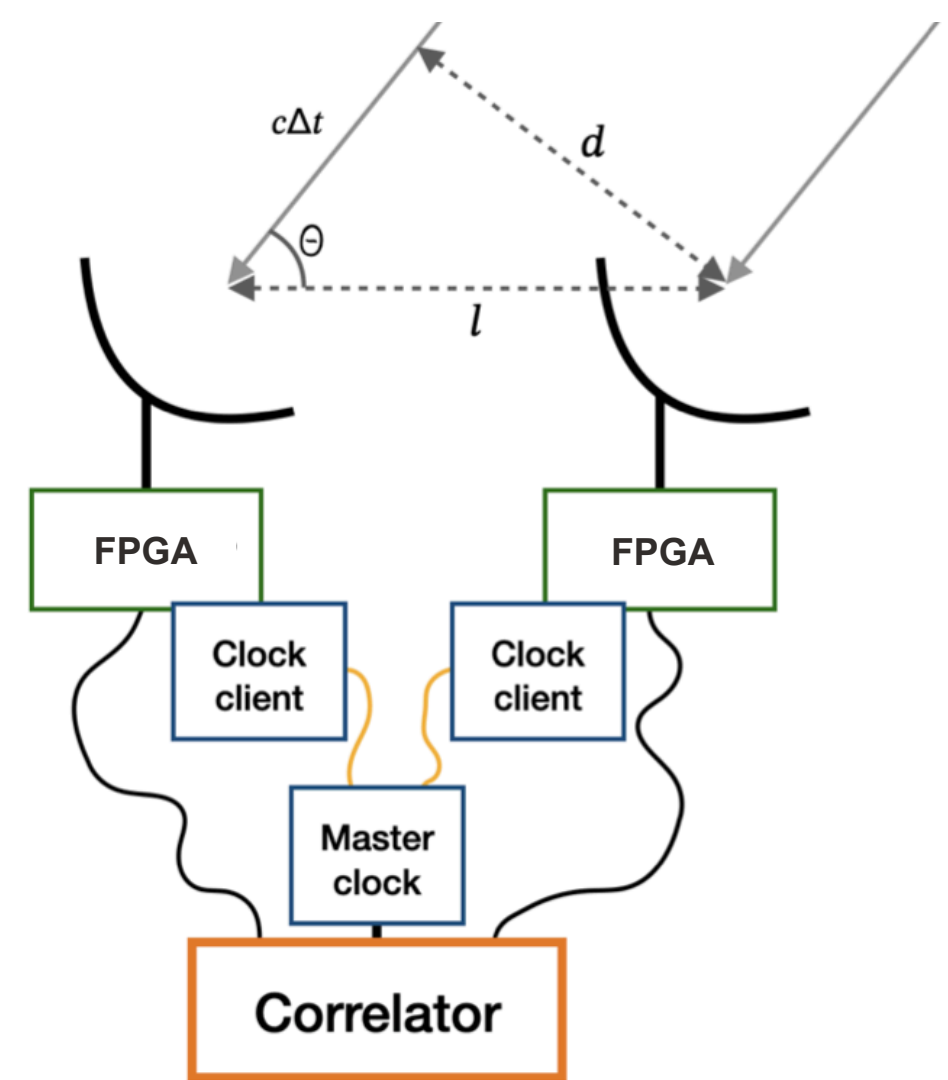
Dewar

cooled to -30C by Peltier, vacuum insulation



FPGA

Time stamps processing
& synchronisation



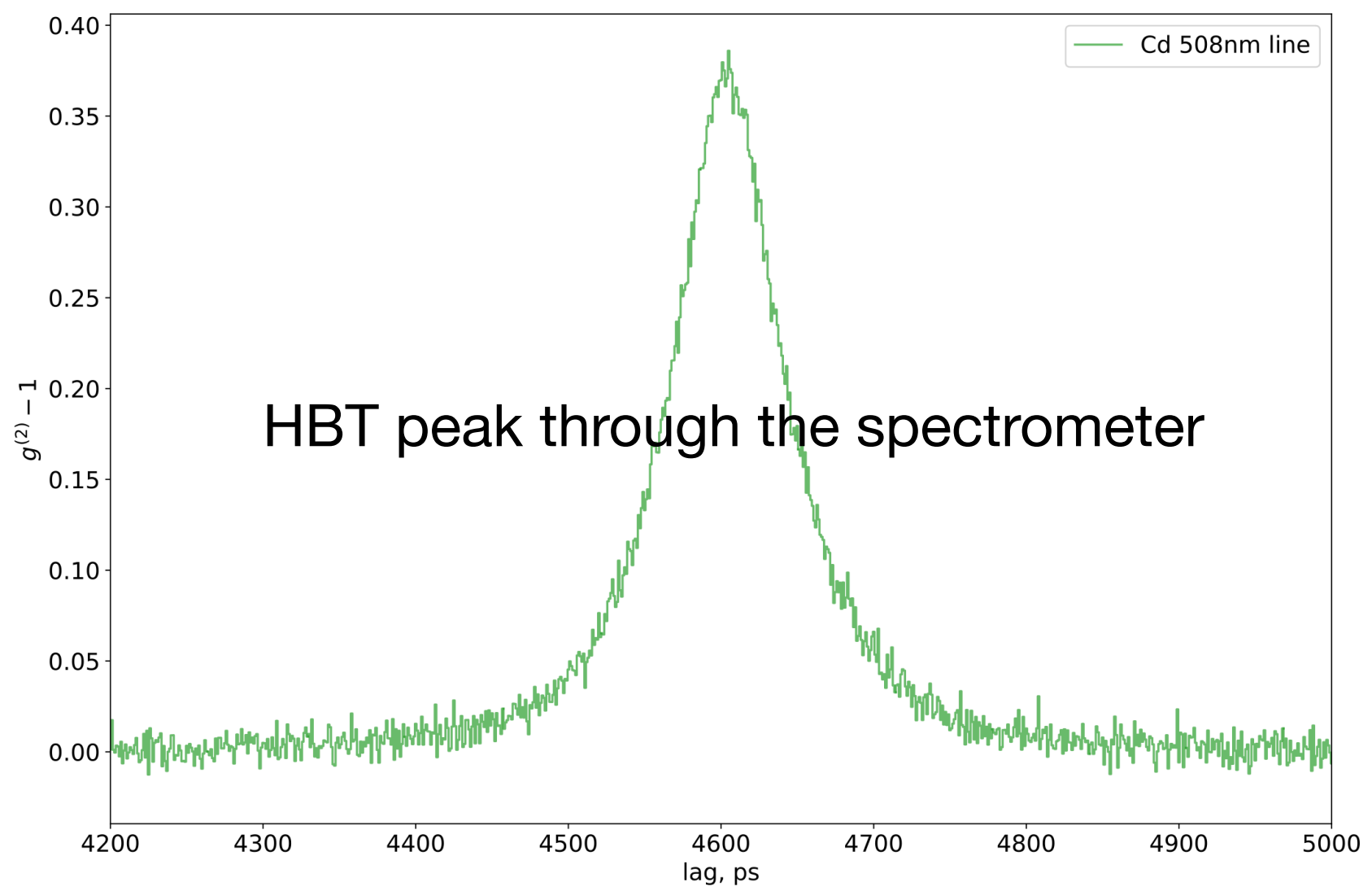
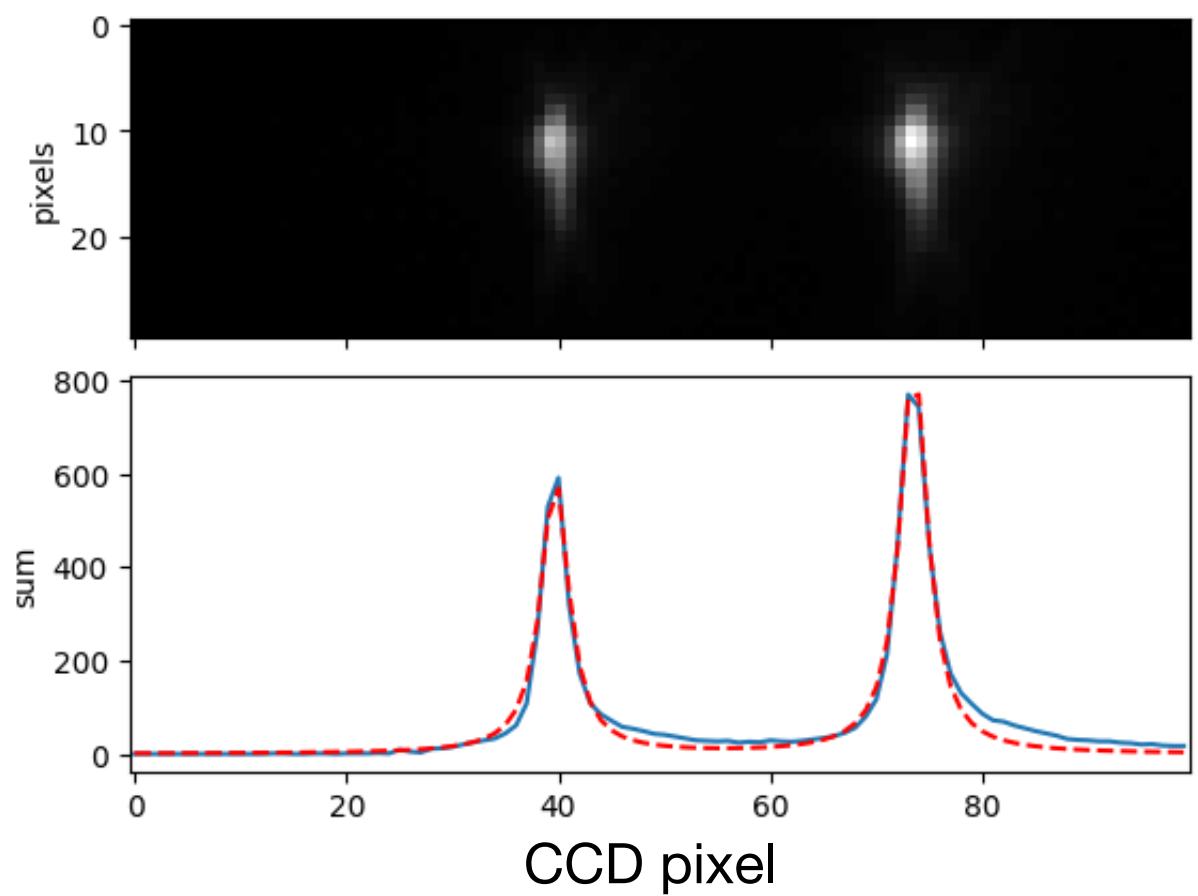
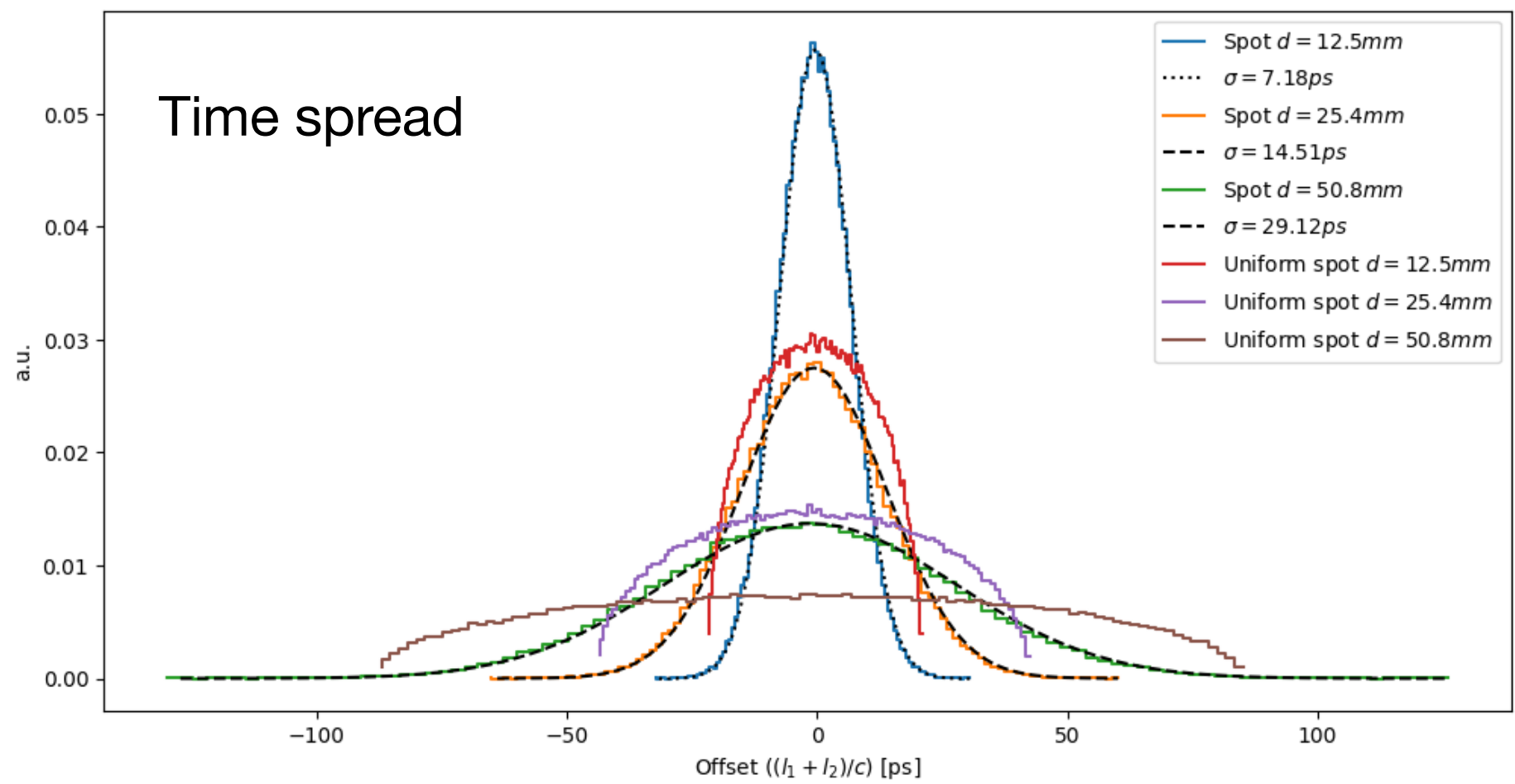
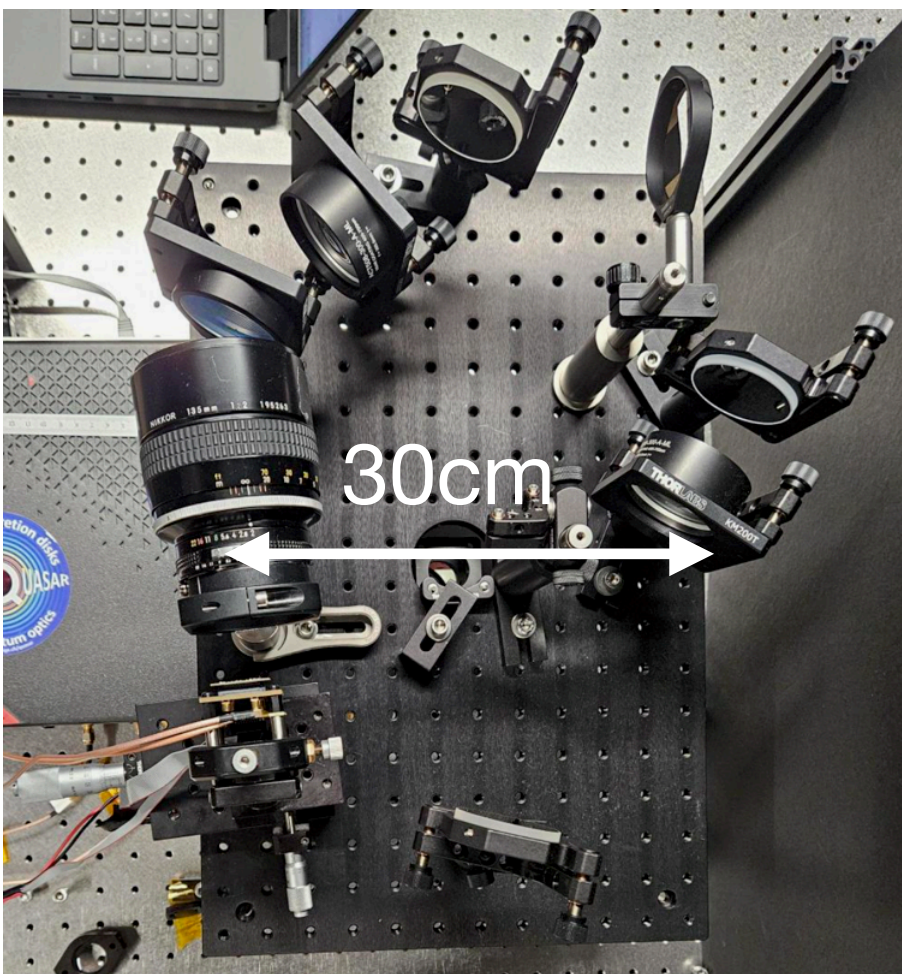
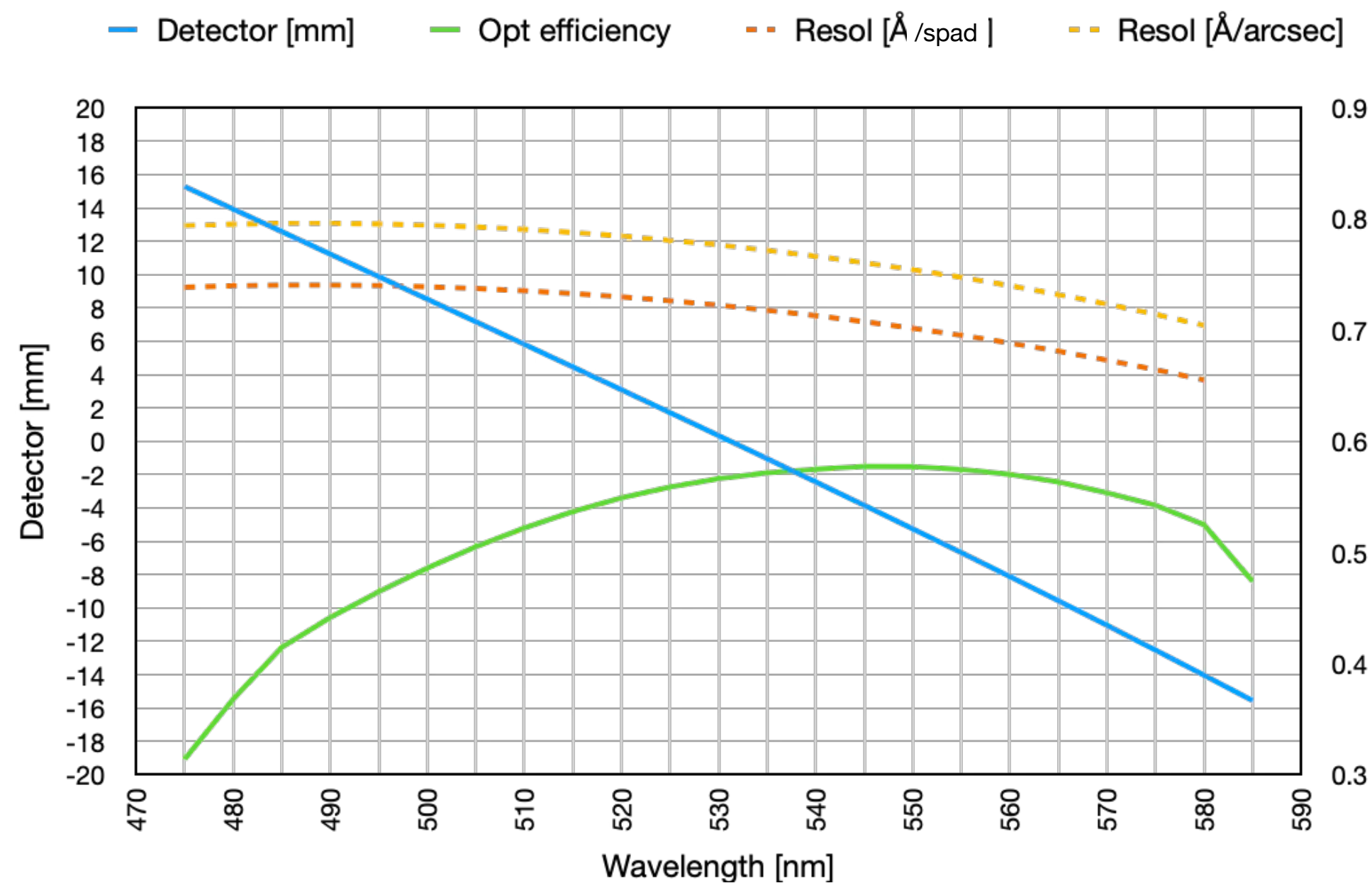
Vitalii's talk

Vitalii's talk

Etienne's talk

Spectrometer development

Optical performances



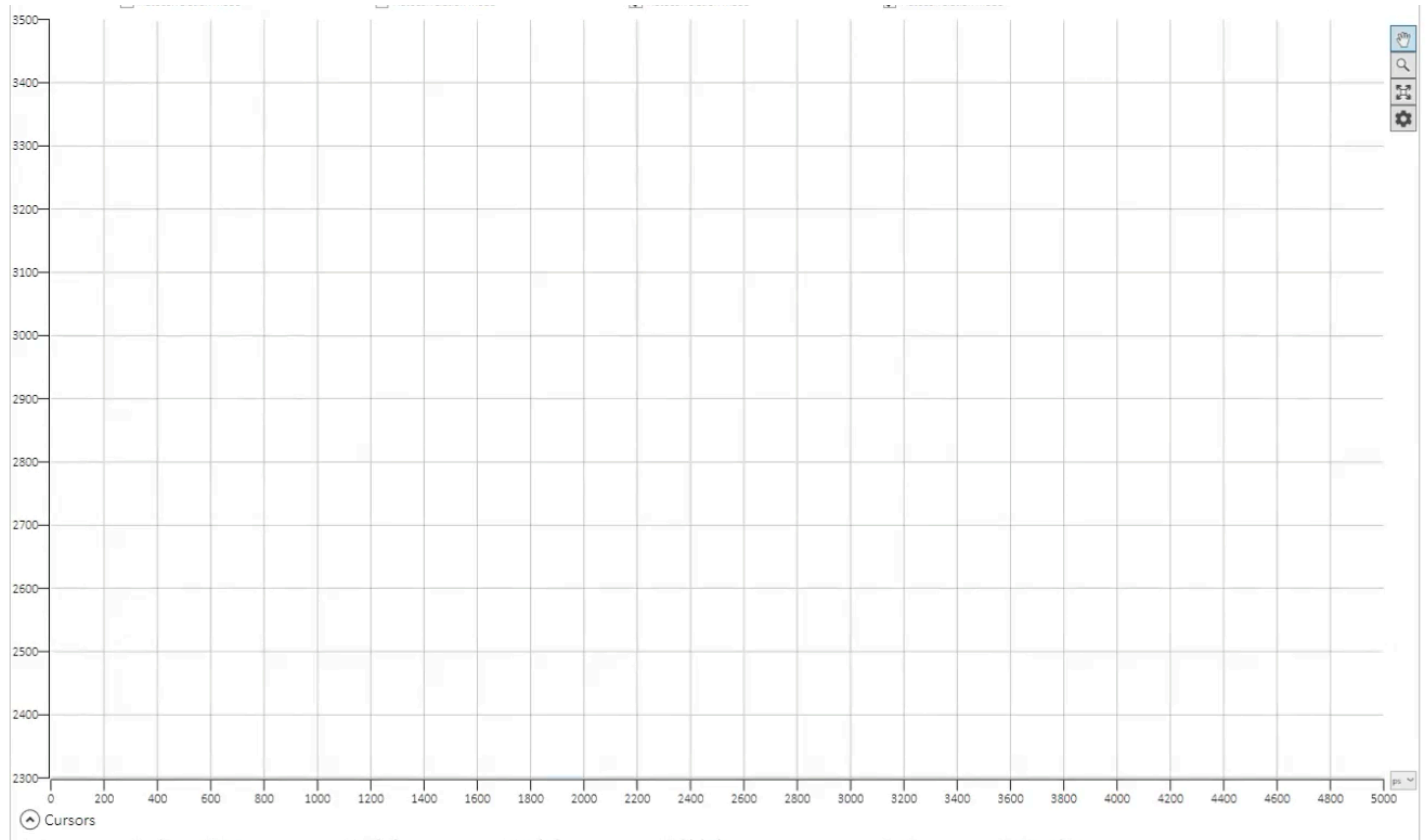
Specific optical
design

4.5ps

In real time

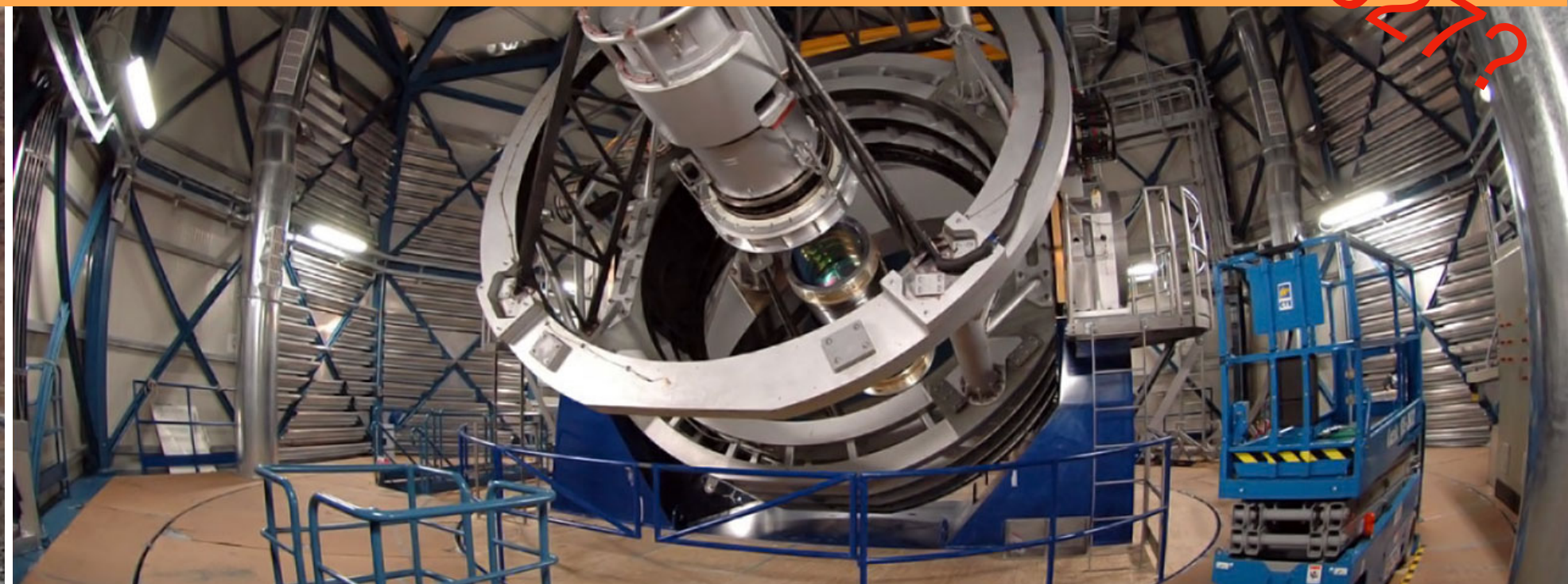
Photometer in the « laboratory »

...and mag 0 with spectrometers on ~1m telescopes

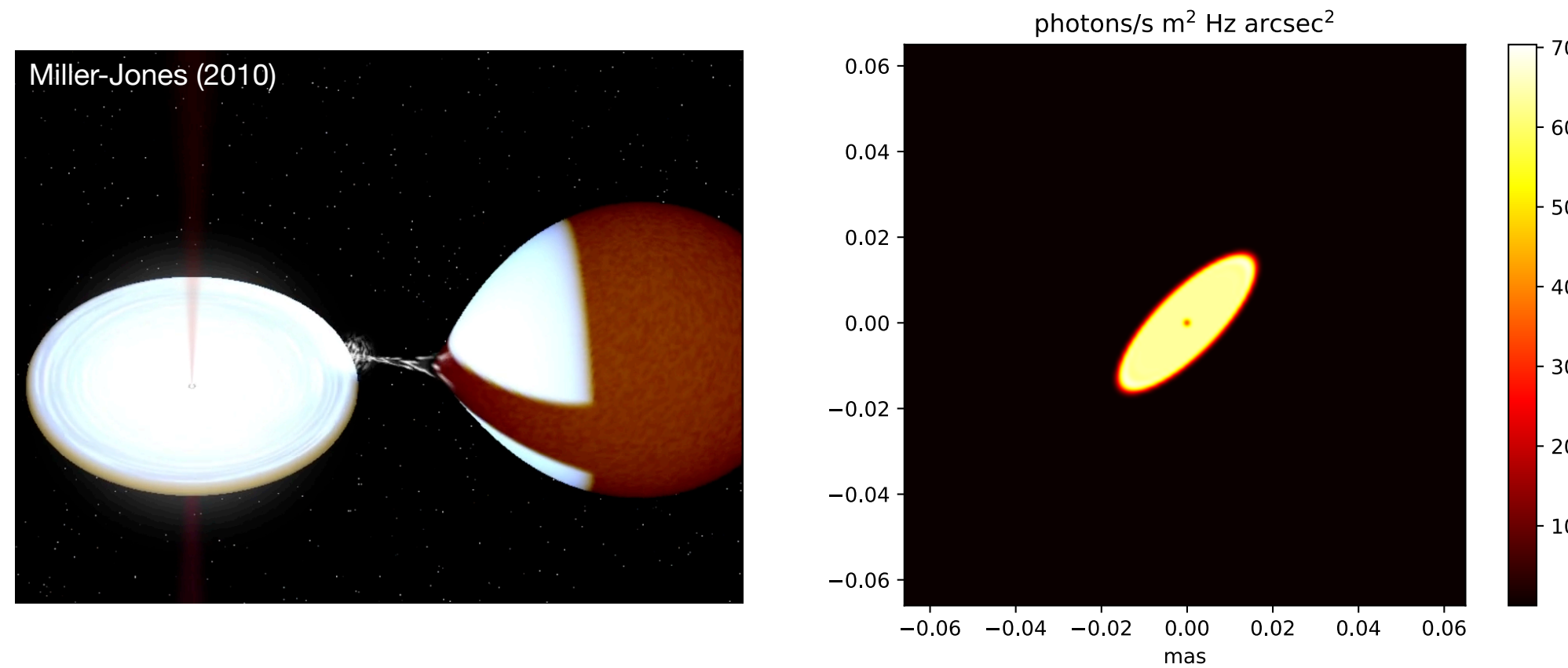


Resolving cataclysmic variables

From 2027?

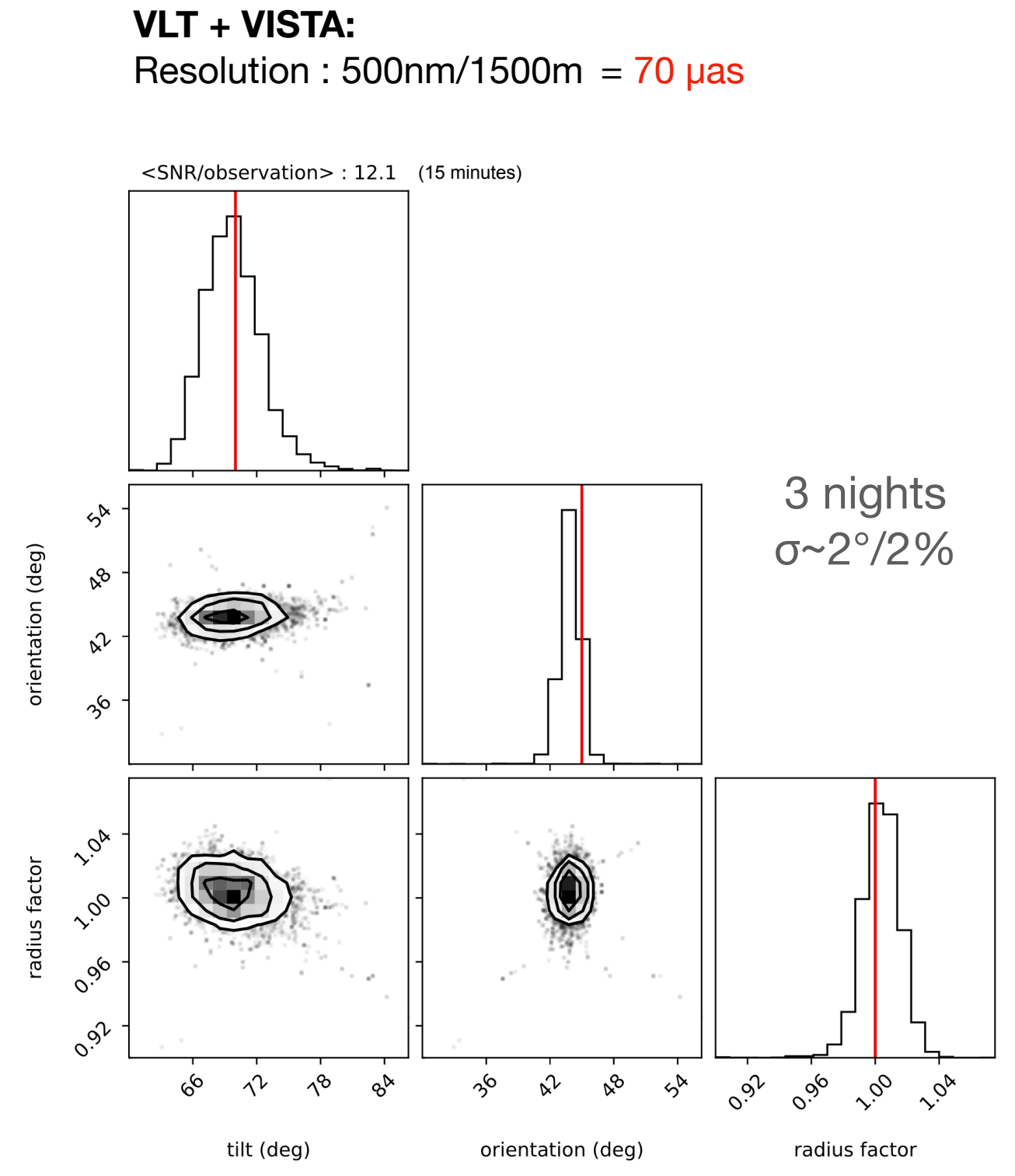
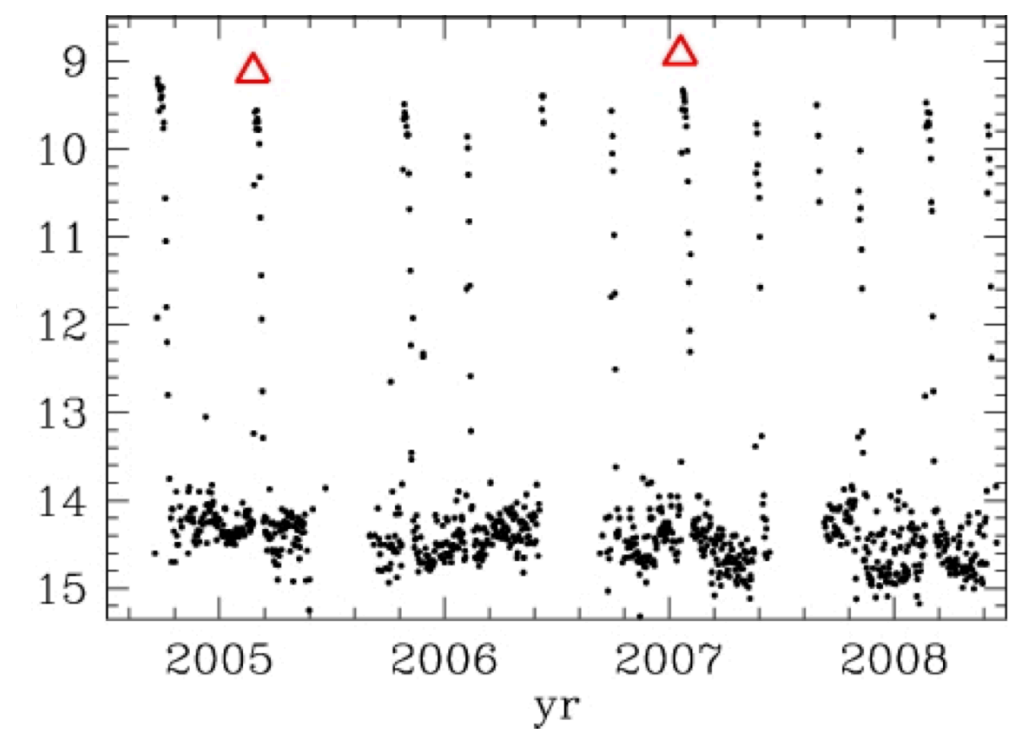


U Geminorum
93pc
 $P_{\text{orb}} = 4.1 \text{ h}$
Companion: M4V $0.5 M_{\odot}$



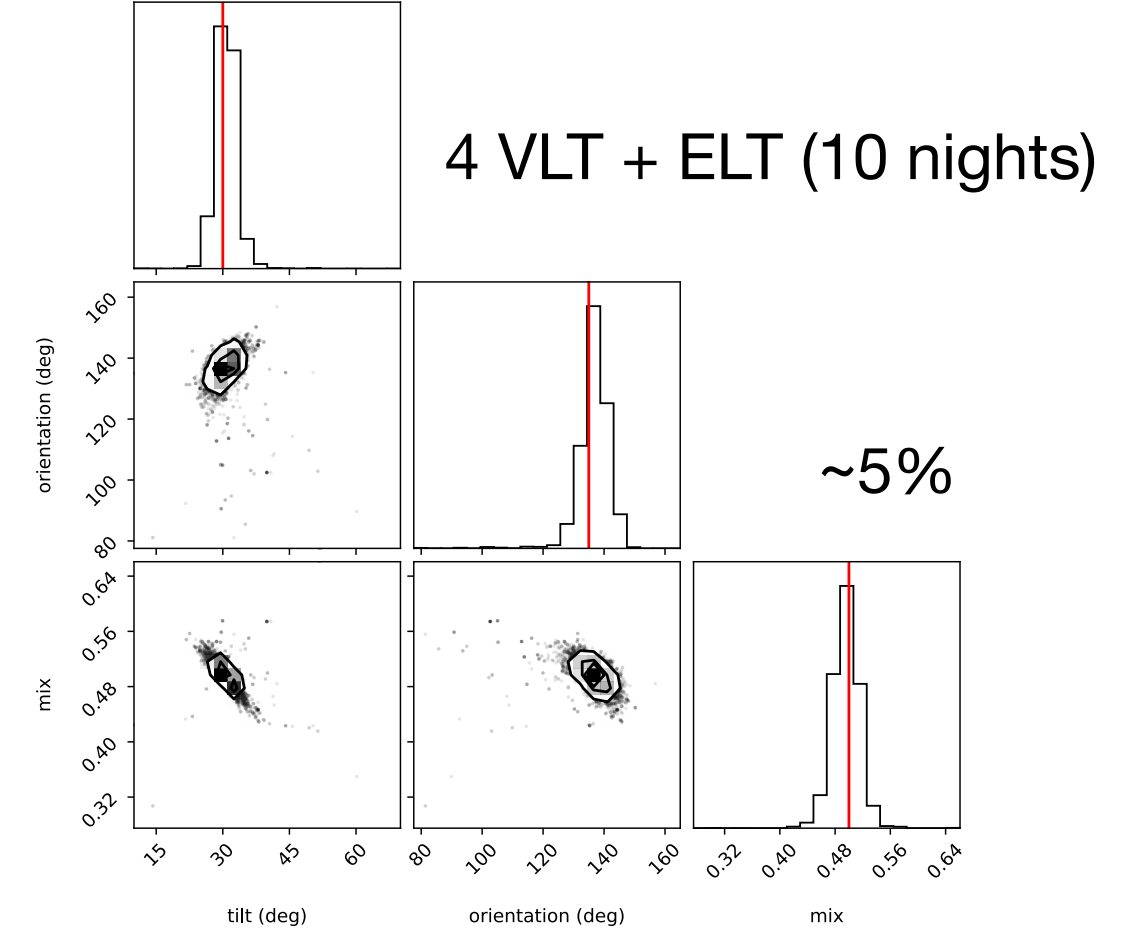
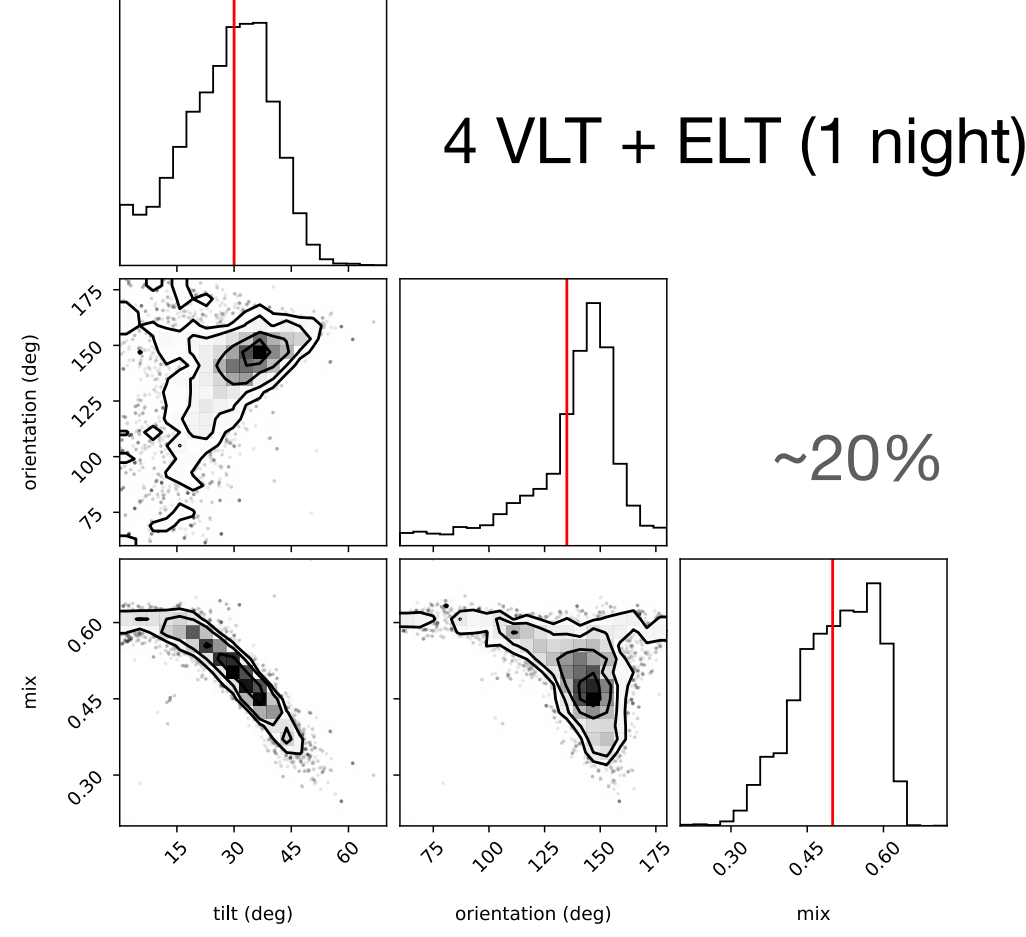
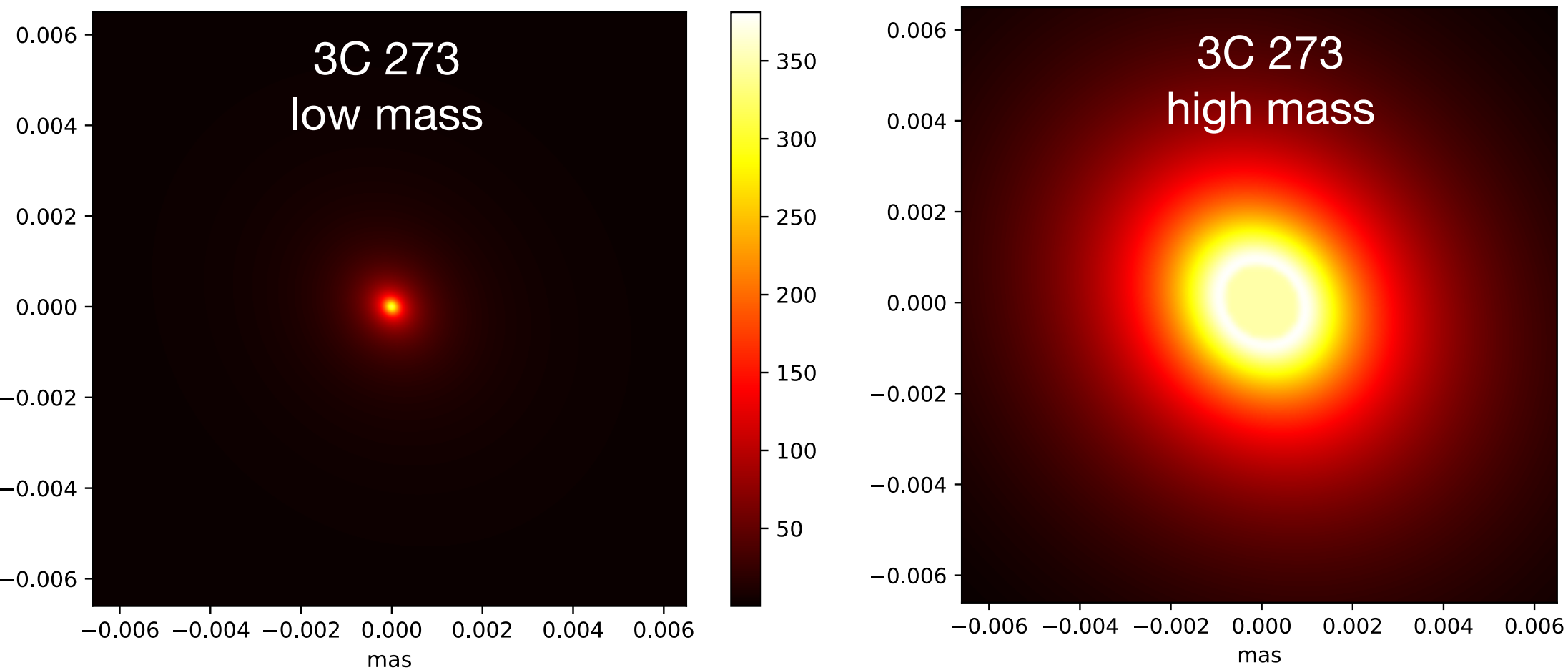
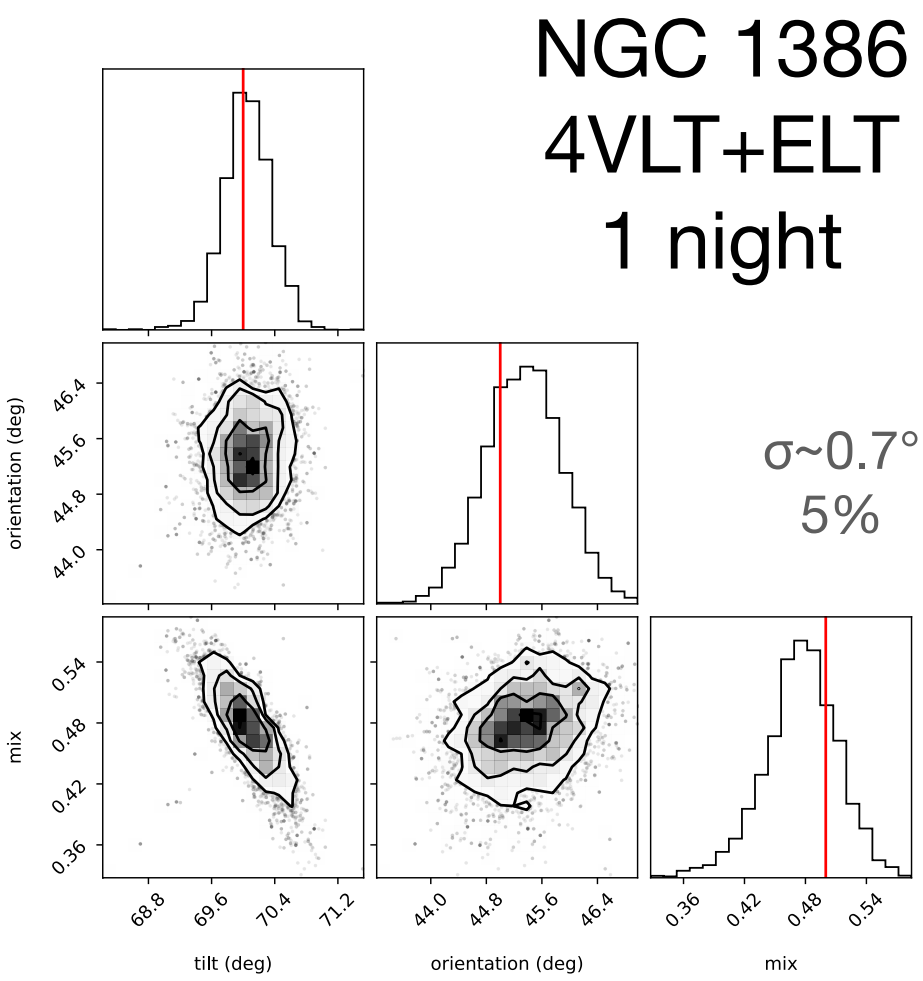
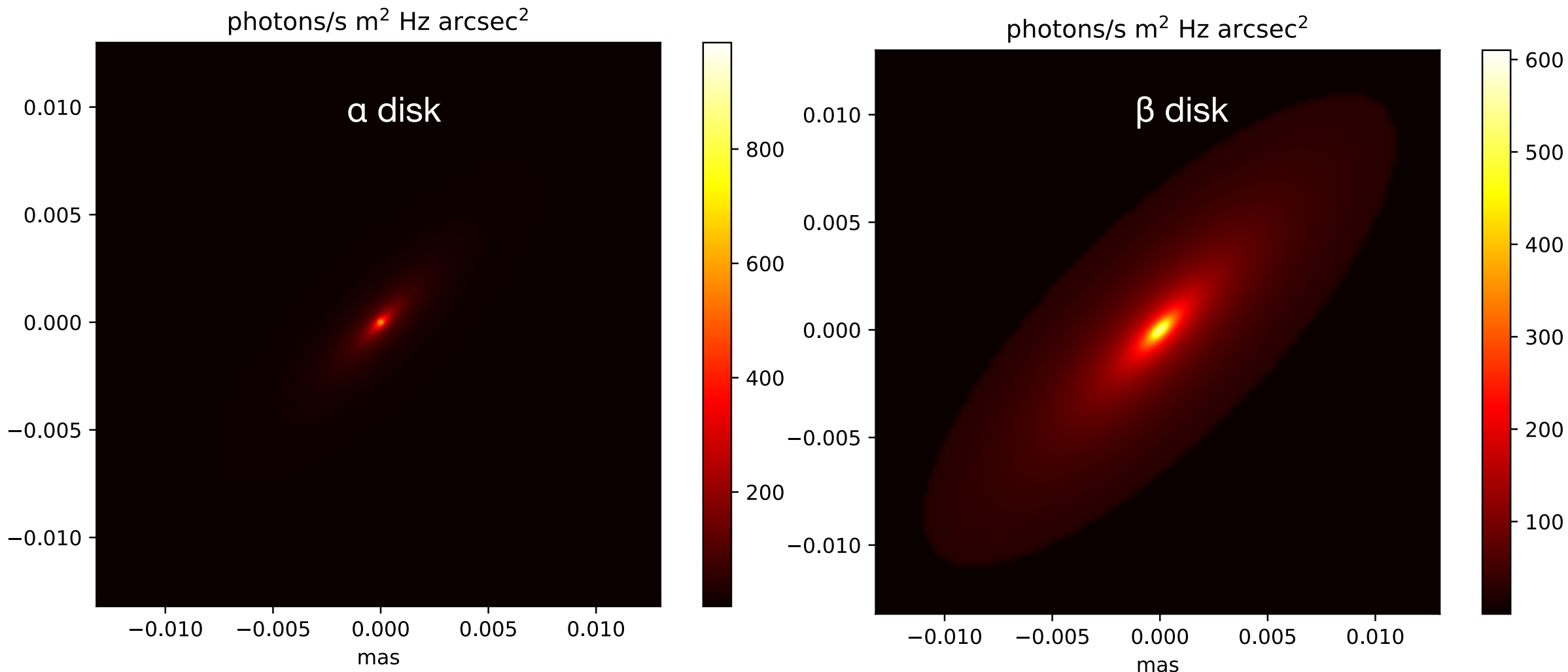
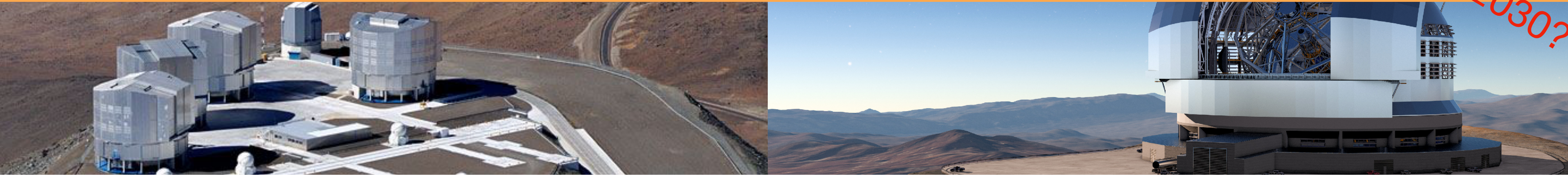
$$\dot{m} = \Sigma \cdot \left(3\pi\nu \left(1 - \sqrt{\frac{r_{in}}{r}} \right)^{-1} \right)$$

v_{cold} : neutral gas, molecular viscosity
 v_{hot} : ionised gas, magneto-rotational instability

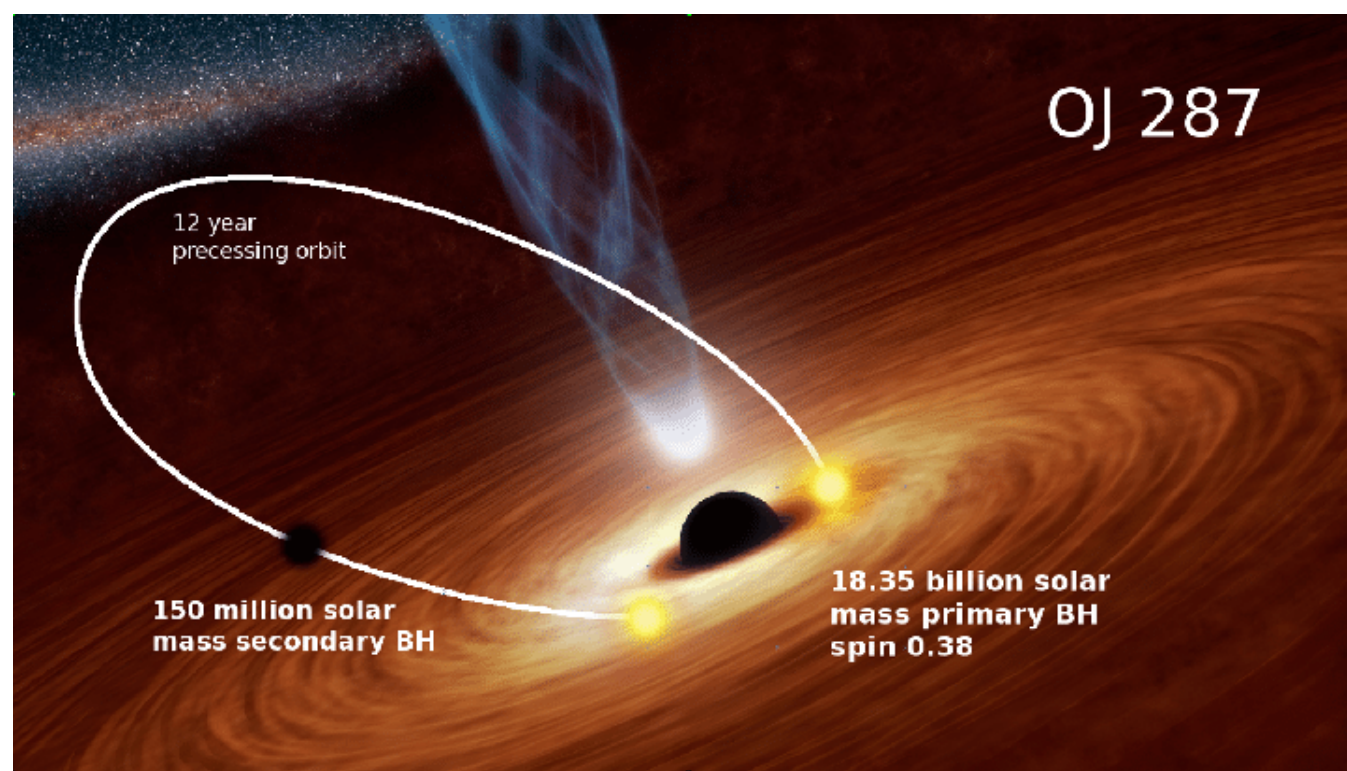


Resolving Seyferts and quasars

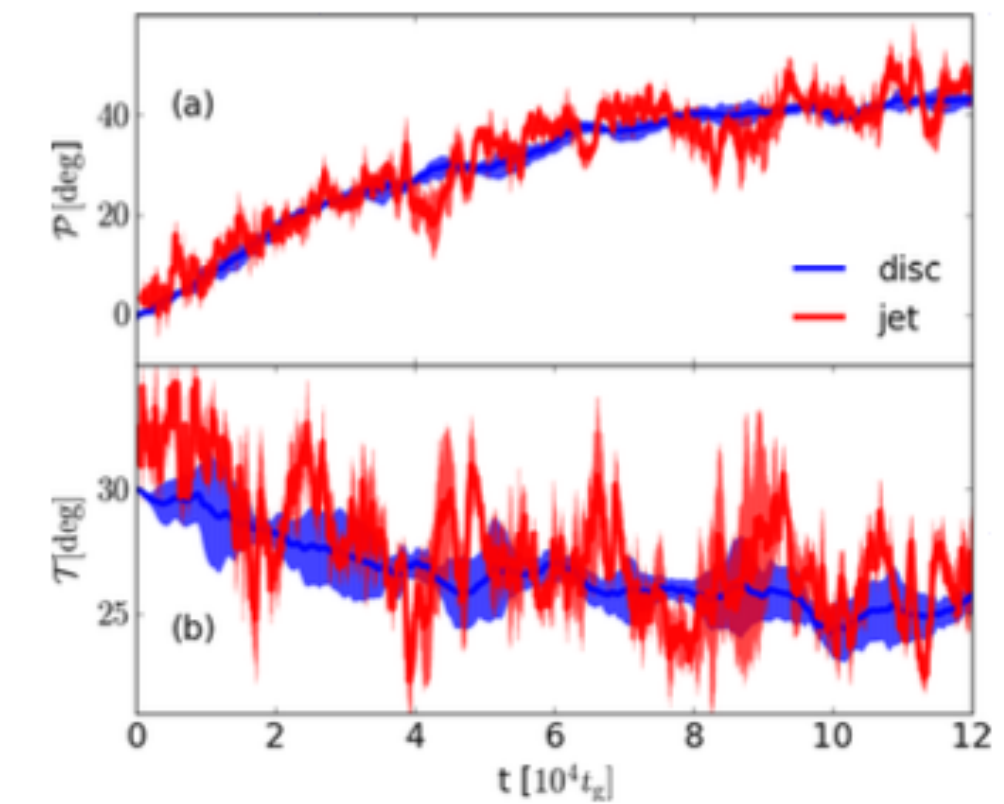
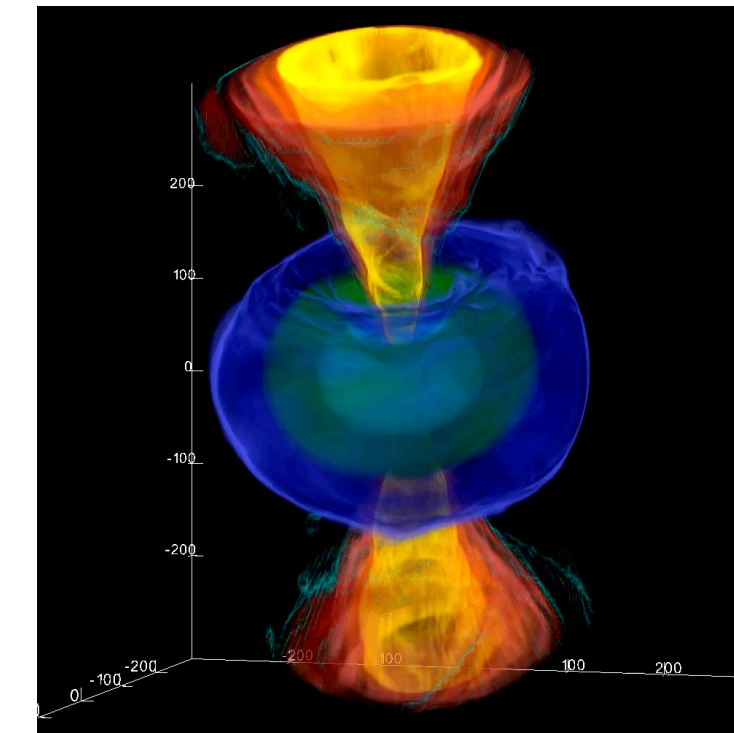
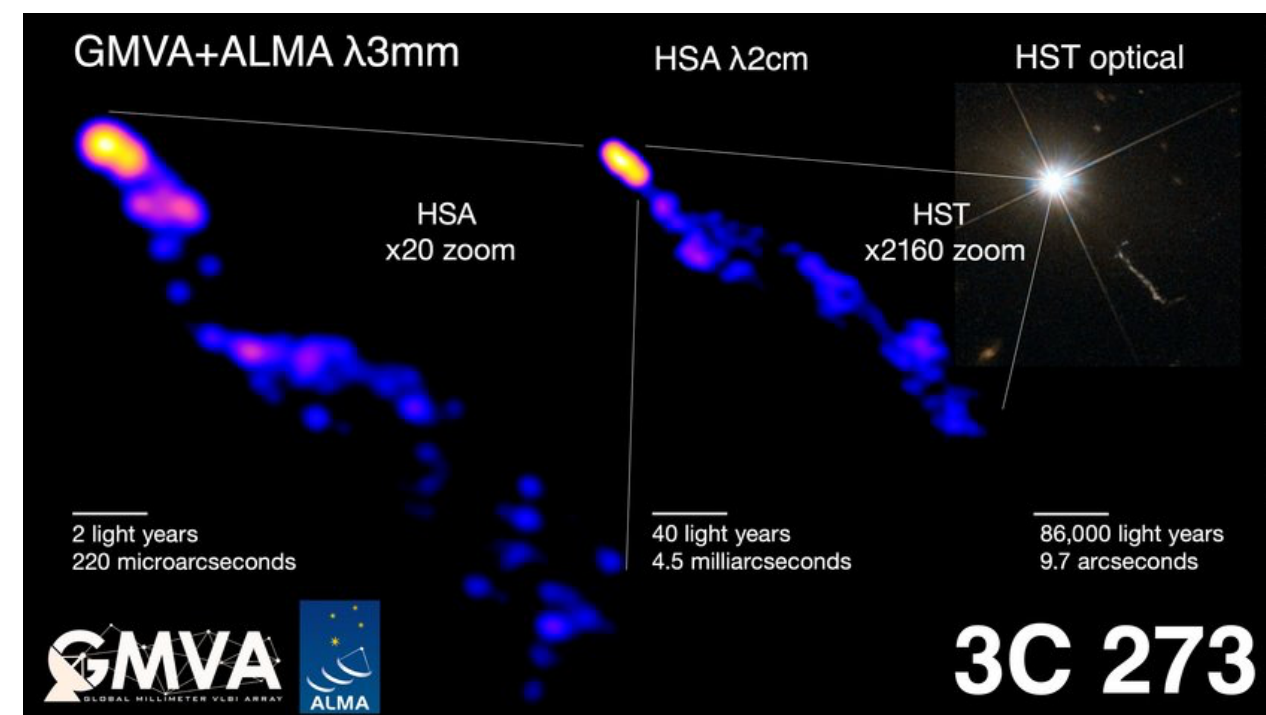
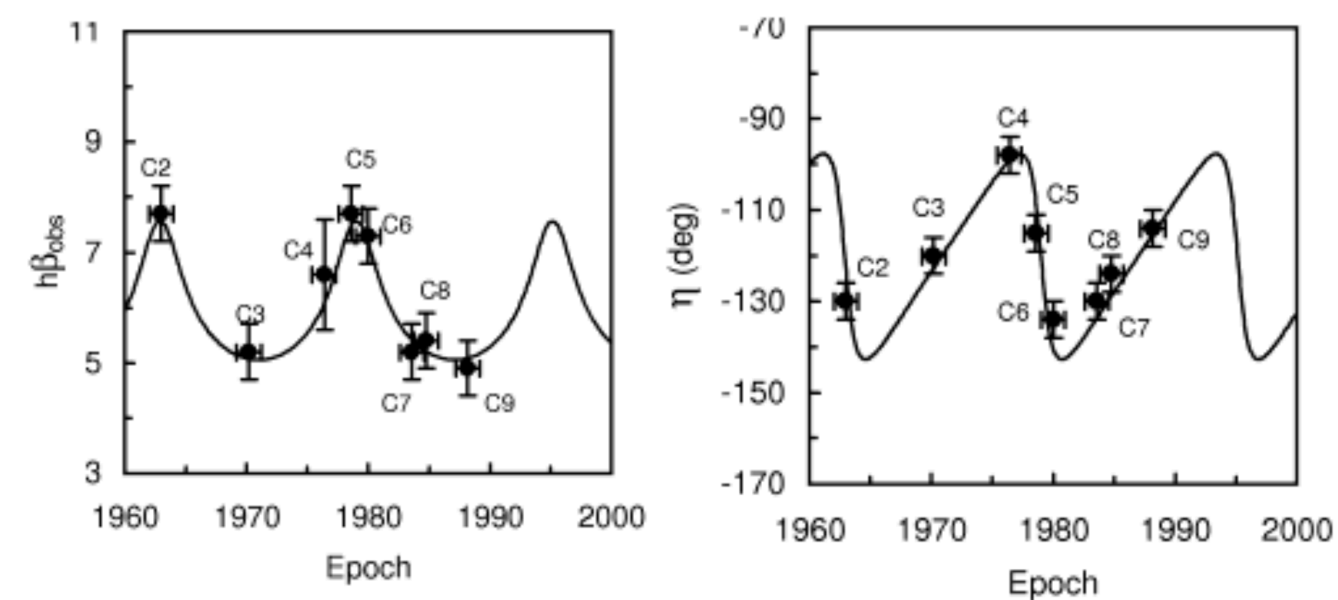
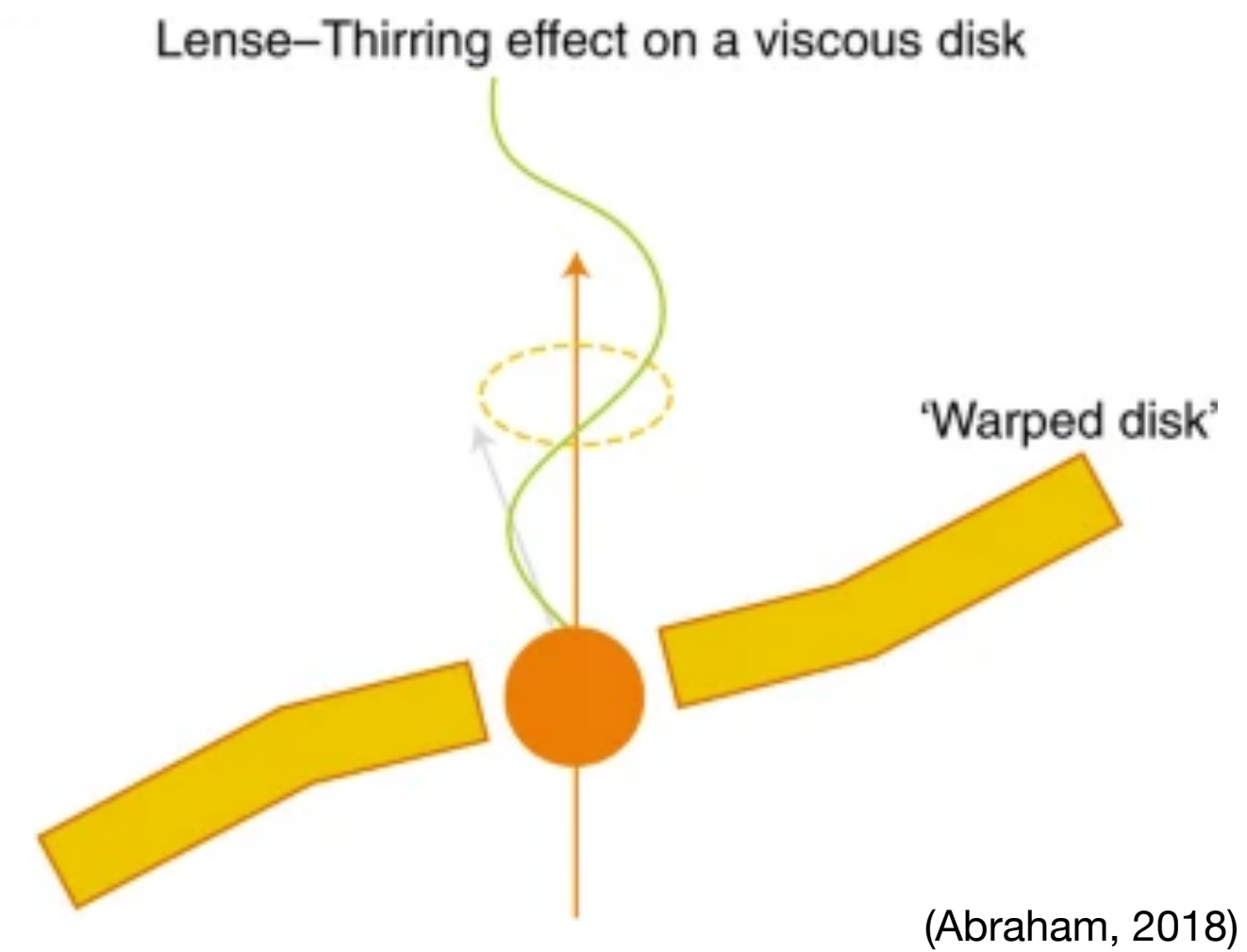
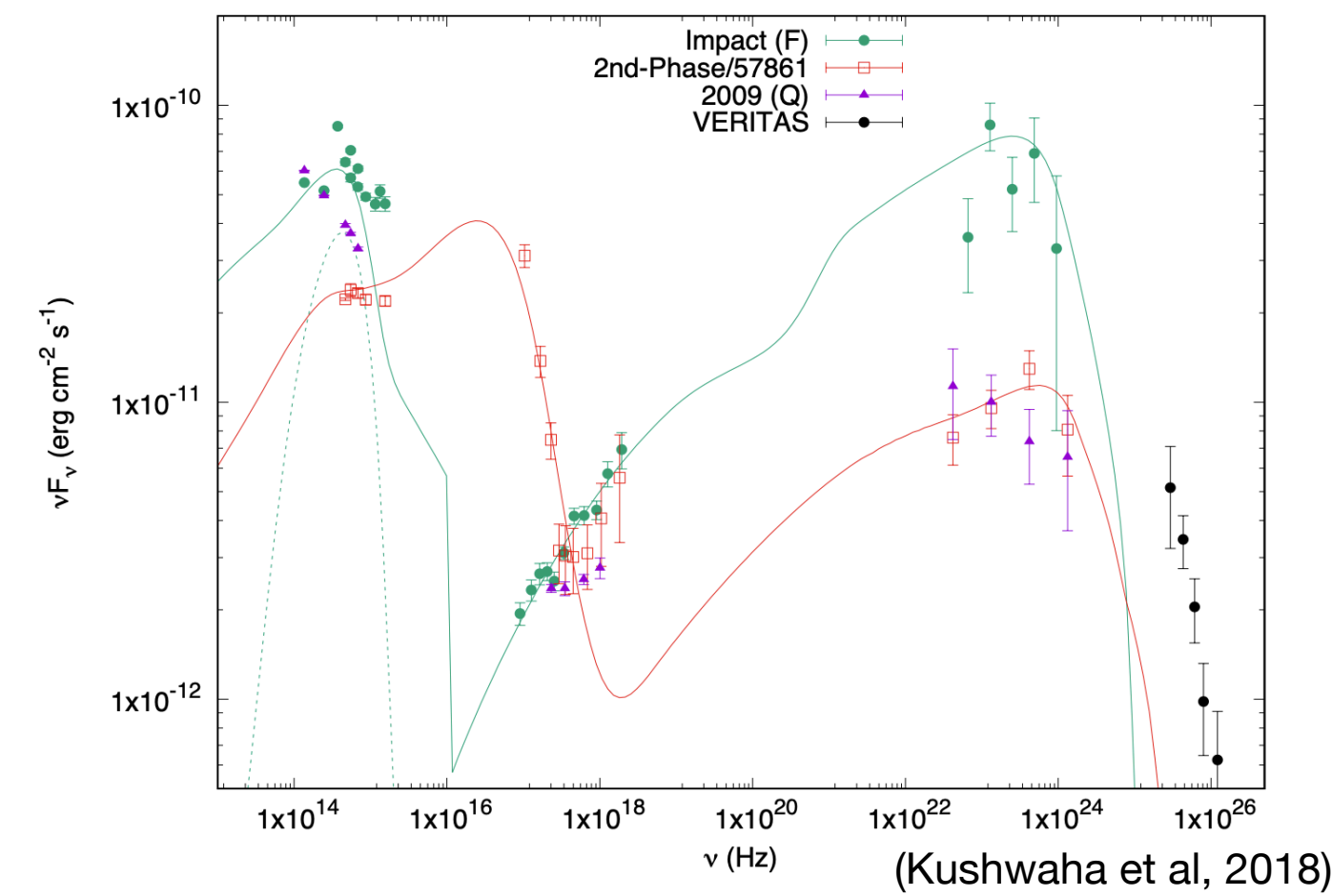
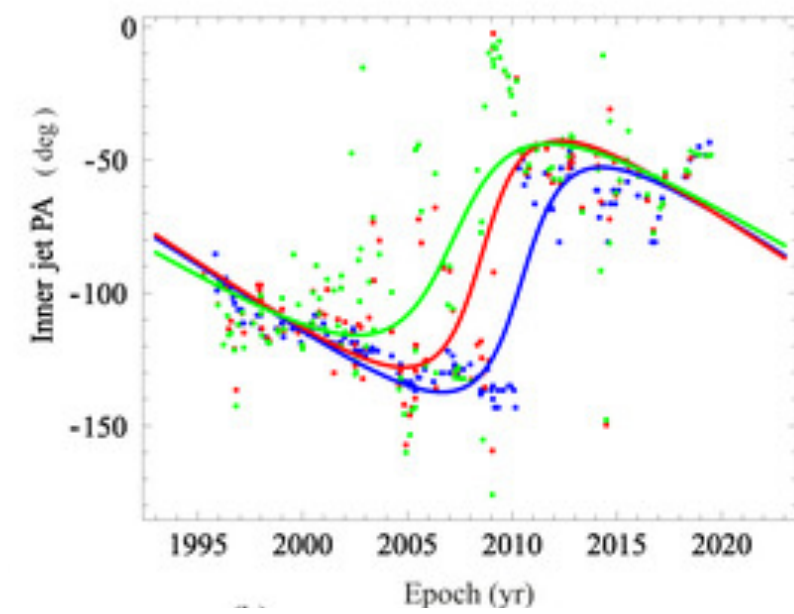
From 2030?



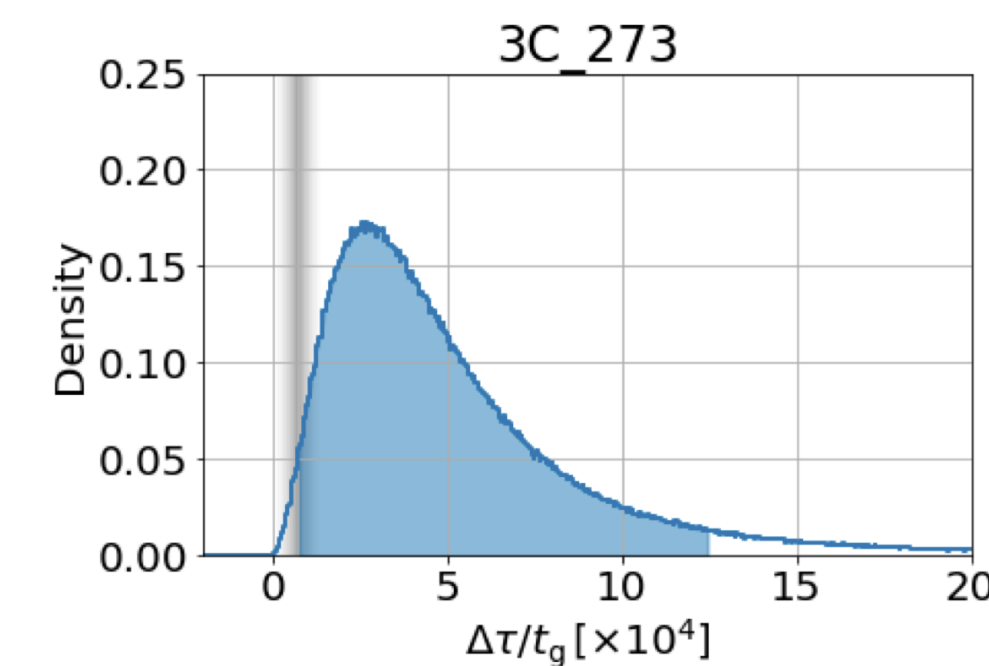
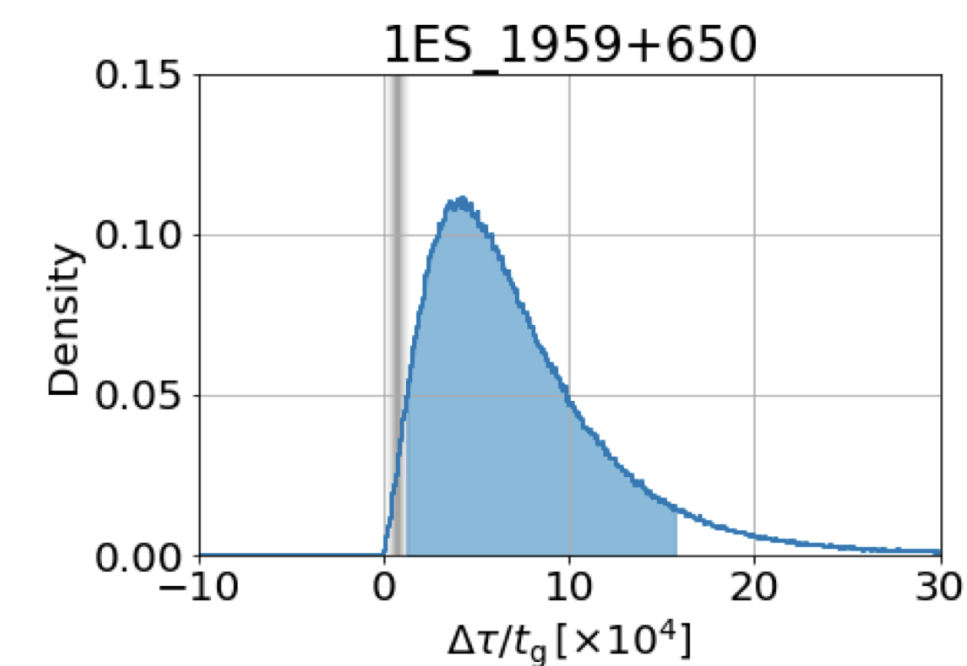
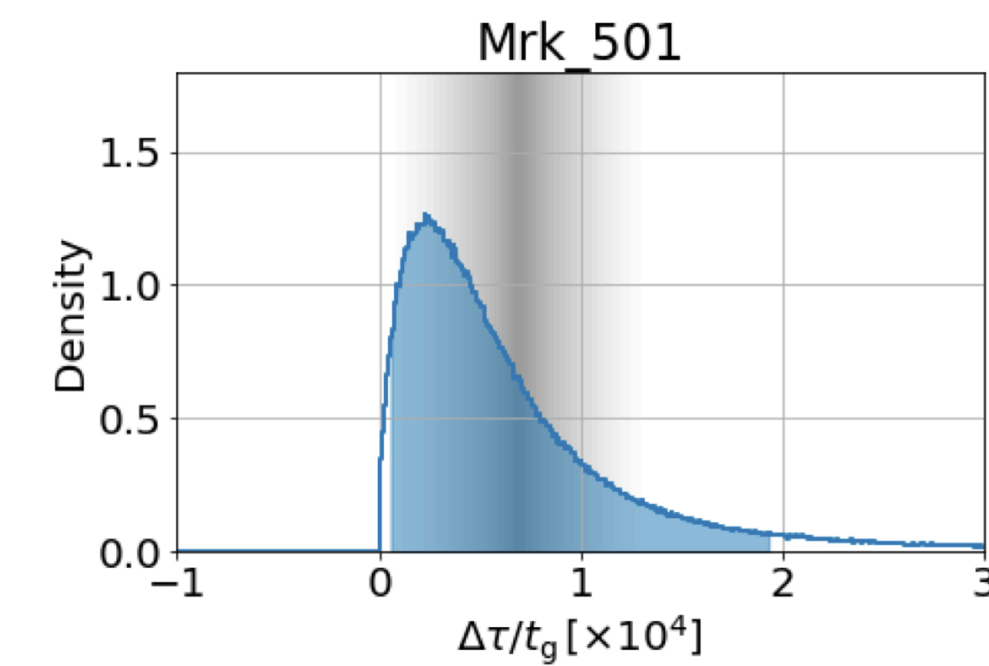
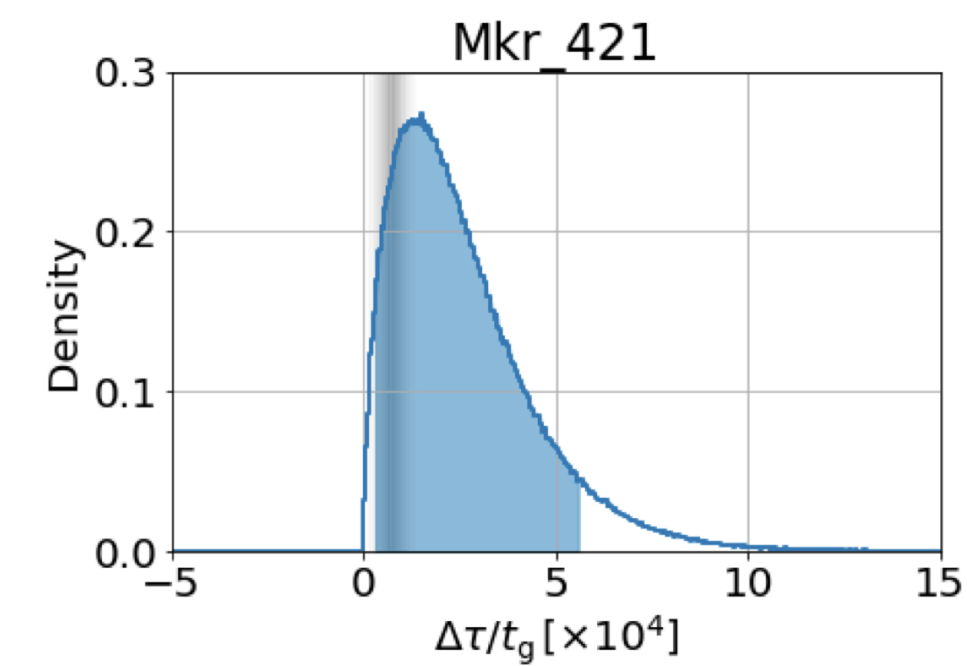
Disk-jet alignment and precession



($m_v=12$ during flares - $10^{8-10} M_\odot$ - 1 Gpc)



Liska et al. 2018



QUASAR Status

- ★ Photometer (22ps system jitter) could be adapted on various telescopes now
- ★ Spectrometer to be tested on telescopes in 2026-27
Mag 0 on 1m telescopes $\rightarrow SNR \approx 50\sqrt{\text{exposure in second}}$