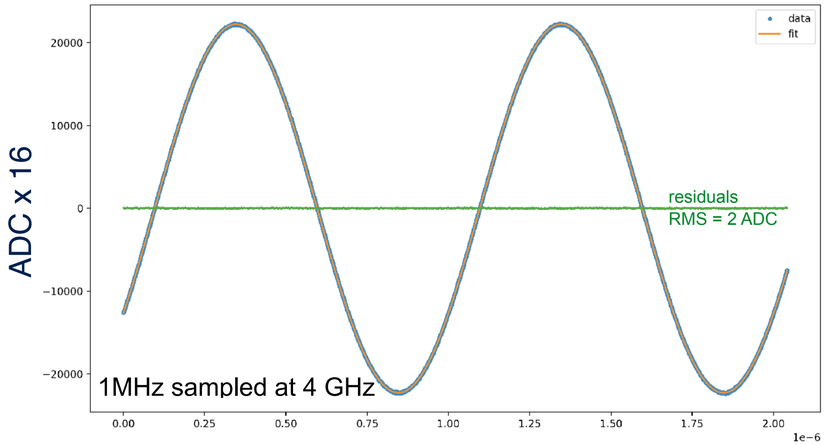
FPGA based intensity interferometry

UNIVERSITÉ DE GENÈVE
FACULTÉ DES SCIENCES
Département d'astronomie

EPFL
Processor Architecture Laboratory

→ High speed (4GHz)
→ Many baselines (2MAGIC+4LST)
→ Low correlated noise

Xilinx ZYNQ ZU38DR 8 ADC (12 bits) 4 GHz
4 ARM cores + 2 real time ARM cores



What works:

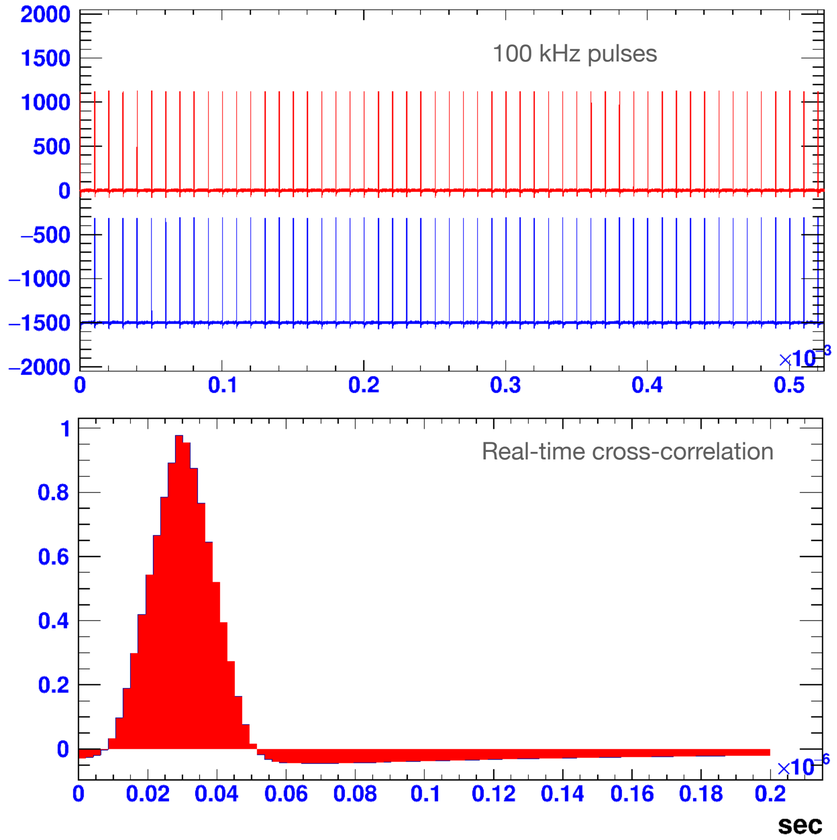
- ADC readout at 4 GHz
- Real time cross-correlation calculation on each channel pair
- Transfer results to ethernet & disk at full speed
- Real time monitoring
- Adaptive cross-correlation window

Very near future:

- Test with two MAGIC at the next full moon (mid February)
- Increase to 15 baselines on a single card (4LST+2MAGIC)

Longer term:

- Transfer of data between several cards (optical links)
- Triple correlations



CTA Swiss day 2021

Resolving accretion disks ?

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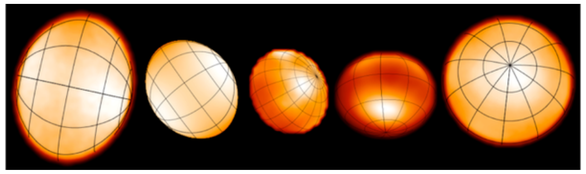
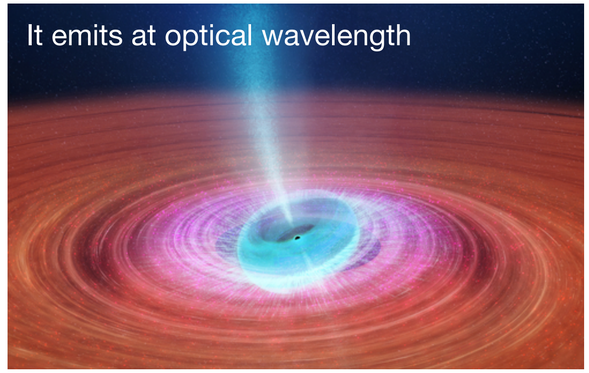
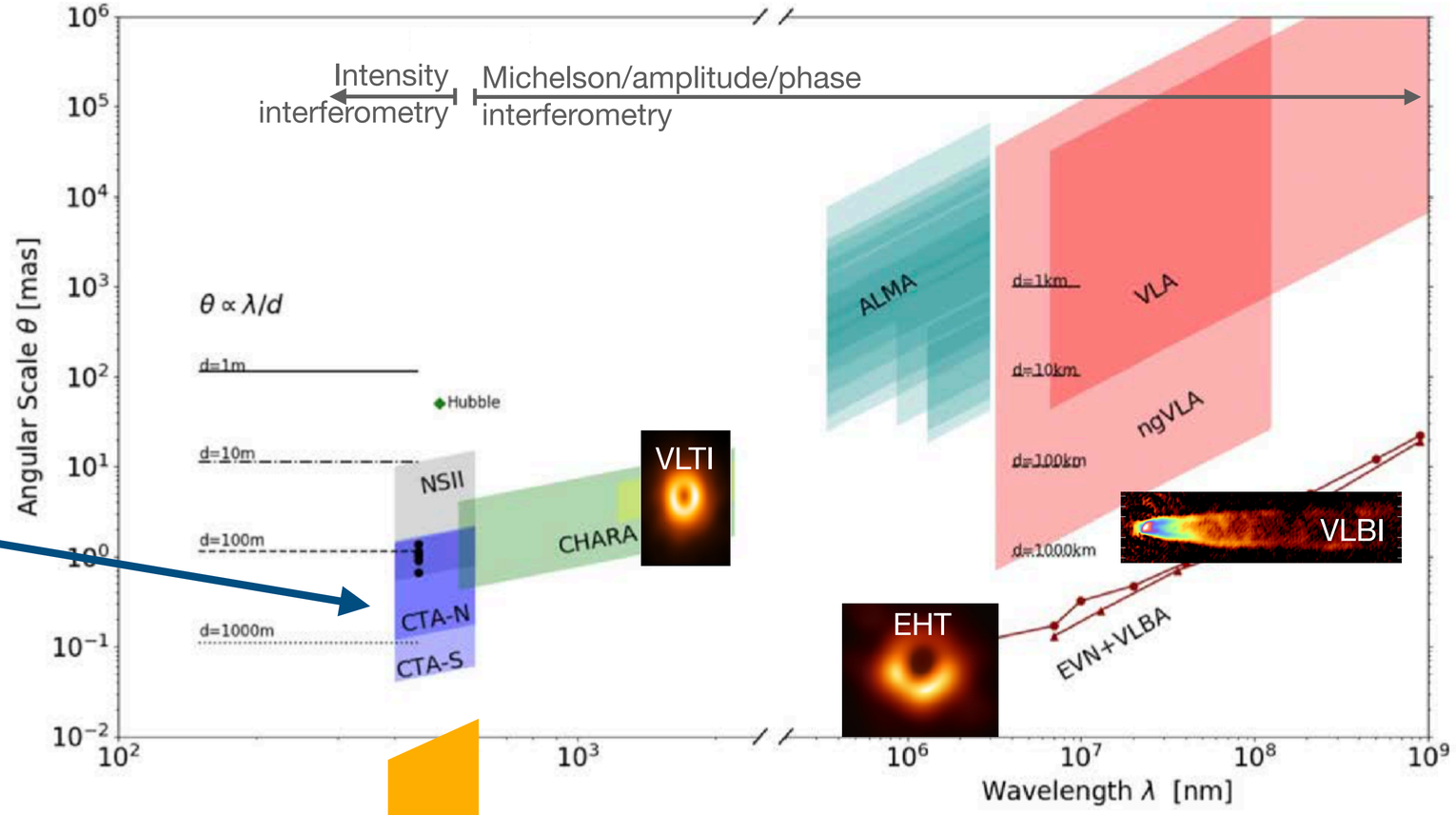


Stellar radia, oblateness, spots





Accretion disks/jets: CV+AGN

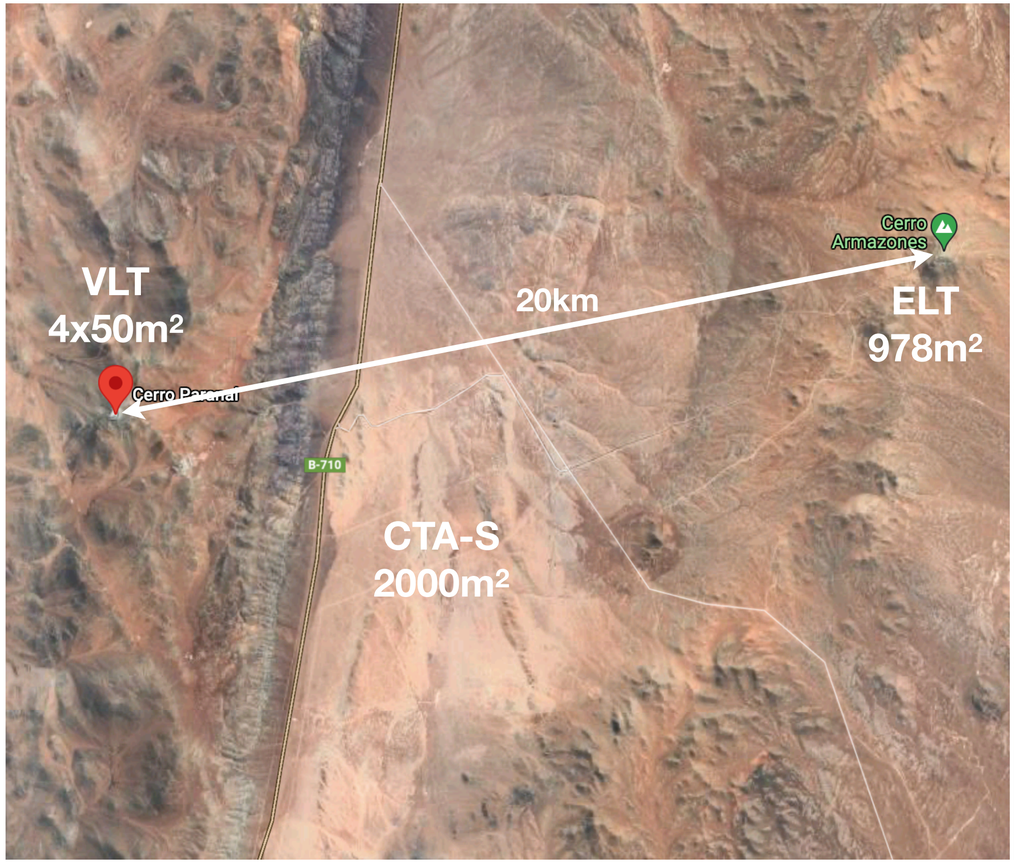
Accretion disks: LMXB

10^{-6} arcsec = nano degree

10^{-8} arcsec = pico degree

at magnitude 8-14

In the optical, a baseline of 4km provides the same resolution as 10’000km in the radio (EHT)



6000m² over 10’000km
CTA-N + CTA-S + ELT + TMT ⇢ pico-degrees

on proxima b

/

the thickness of a hair on the Moon

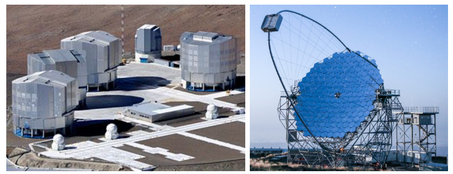
How to make it work

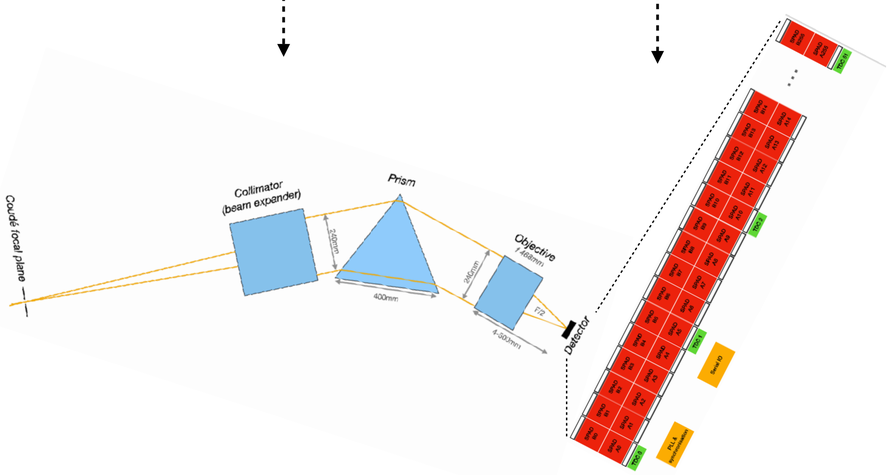
$$t_{\mathrm{exp}} = \frac{(1 + B_1/\Phi)(1 + B_2/\Phi)\sqrt{\Delta t_1 \Delta t_2}}{A_{\mathrm{eff},1}\, A_{\mathrm{eff},2}\, N_{\mathrm{chan}}\, \Phi^2\, |V(\boldsymbol{x}_1 - \boldsymbol{x}_2)|^4}\, SNR^2$$

Large telescopes
500 m²

Many narrow wave bands
~1000
~ 1MHz/channel

High time resolution
12 ps





Atmosphere
30 ps

It is the right time to built the perfect intensity interferometer !

Walter et al, submitted

An Advanced Grant proposal (i.e. ERC adanced) has been submitted to SNF to equip two 5-10m class telescopes by 2027

Minor investment on LSTs

Resolving accretion disks (2027)

Advanced Grant proposal to SNF

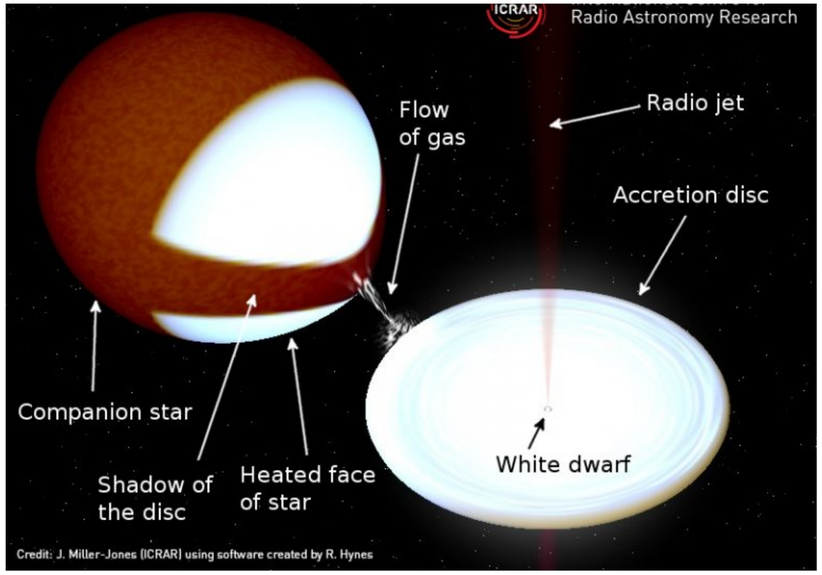
Little additional funds to CTA

2 VLTs + 1 LST combination:

A_{eff} = 440 m^2 ; r_{cd} = 7km

Resolution = 5000Å / 7km = 15 μas

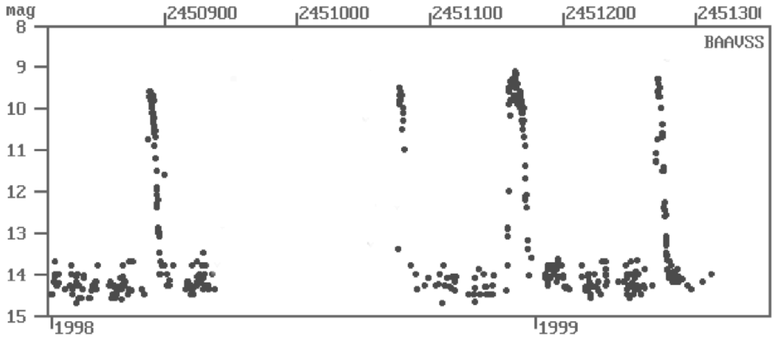
Cataclysmic variables:



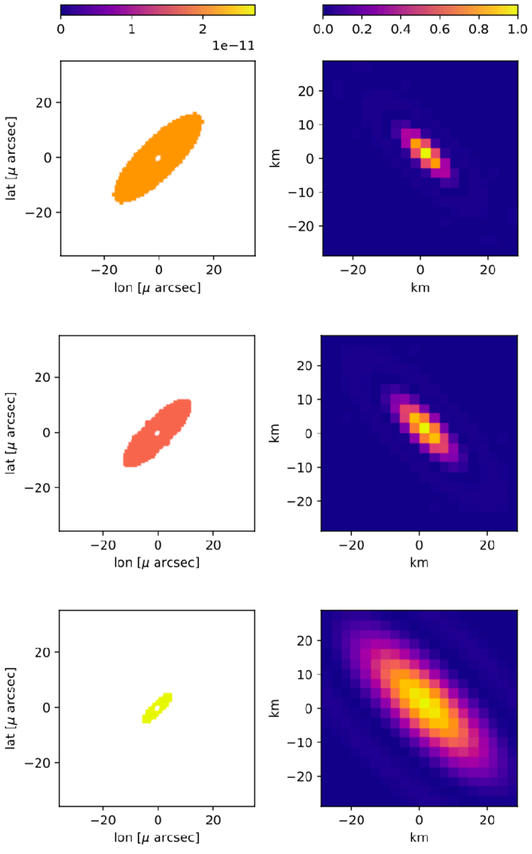
Name	m_V	P_{orb} days	R_{max} μarcsec
U Gem[r]	8.2	4.3	32
GW Lib	8.2	1.3	13
VW Hyi[r]	8.4	1.8	28
IX Vel	9.1	4.7	30

Exosure per amplitude (5σ) = 1 hour

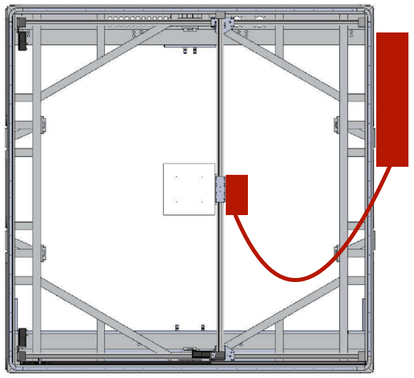
With 20 channels on the LST : 6 minutes

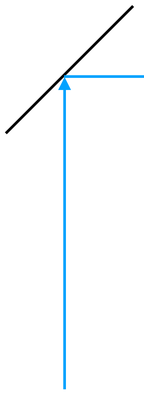


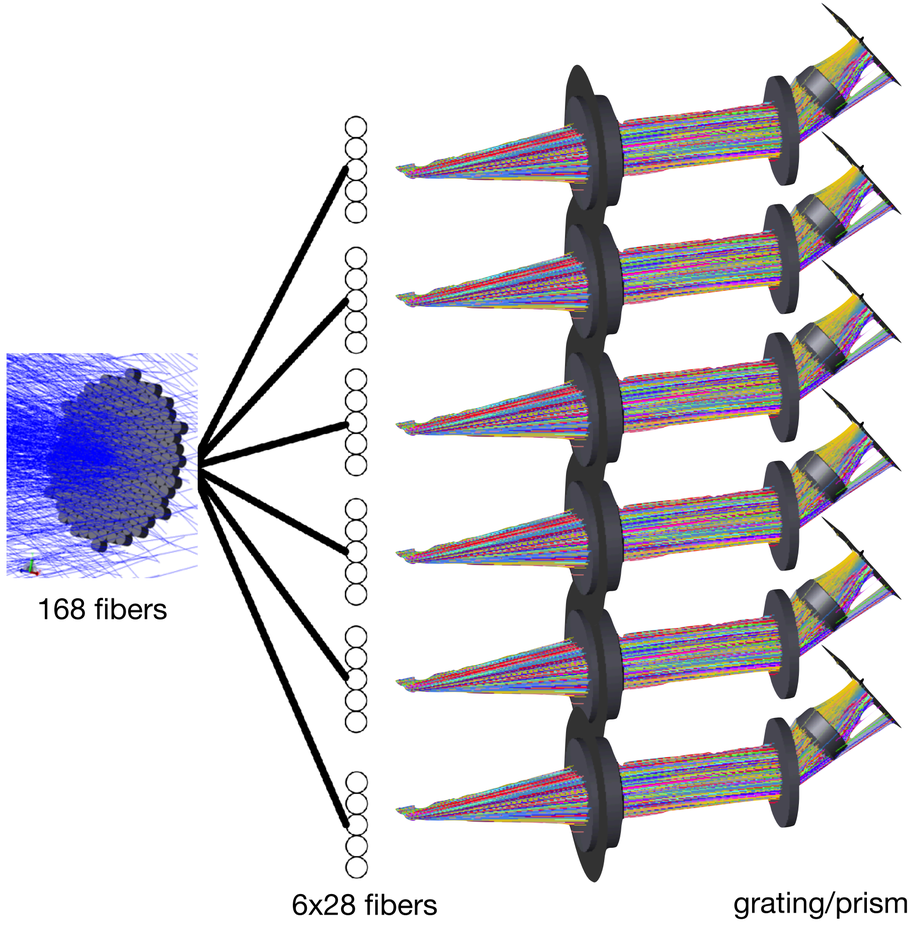
two weeks

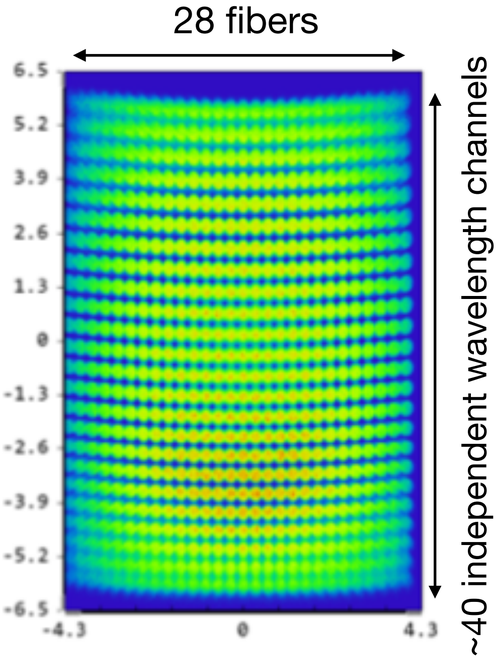


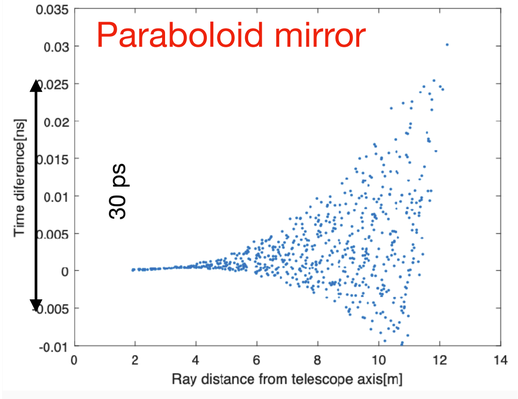
Wavelength channels on the LST











Number of spots : 6720

<u>For the sum of all channels:</u>

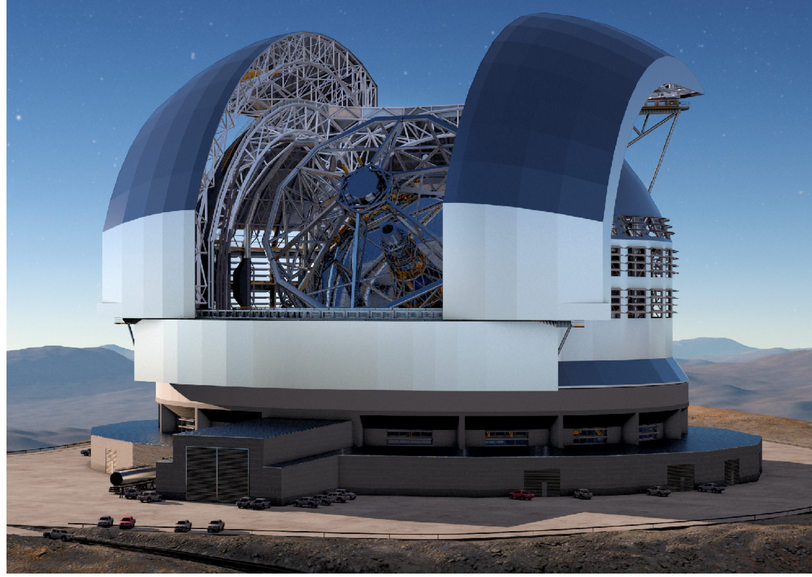
Dark count rate : 10^6 Hz

Dark count rate if cooled : 10^5 Hz

Photon rate for mag 8 : 10^{10} Hz

Photon rate for mag 10.5 : 10^9 Hz

Resolving accretion disks (2030)

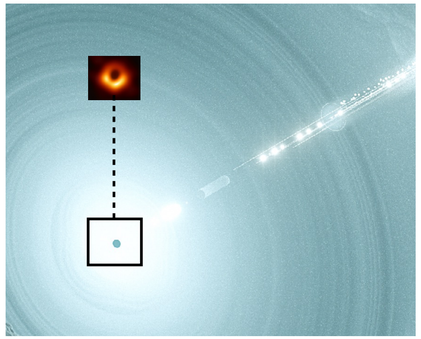


ELT + VLT + 4 LST

A_{eff} = 440 m^2 ; r_{cd} = 20km

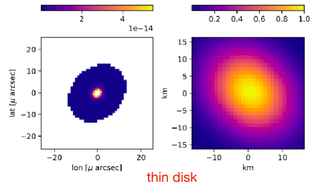
Resolution = 5000Å / 20km = 5 μas

Seyfert 1 galaxies:

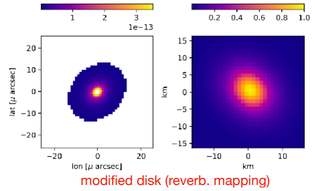


Name	m_V	R_{disc} μarcsec	Exp. ksec
NGC 3227	11.8	62	0.2
NGC 5548	12.8	15	1.2
NGC 1386	12.8	36	1.3
3C 273	12.9	3	1.4
NGC 7469	13.0	8	1.9
ESO 377-G24	13.1	15	2.1
NGC 7314	13.1	16	2.1
MRK 509	13.1	10	2.2
NGC 1566	13.2	32	2.4
LB 1727	13.2	5	2.5
PGC 64989	13.3	8	3.0
RXS J11032-0654	13.3	6	3.2
NGC 3783	13.4	21	3.8

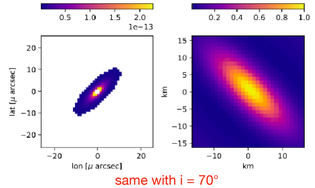
NGC 5548



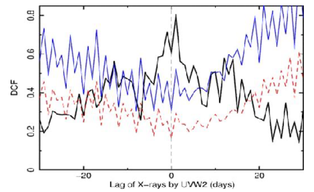
thin disk



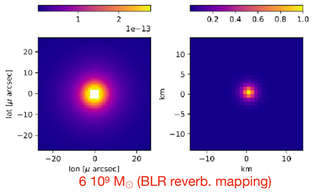
modified disk (reverb. mapping)



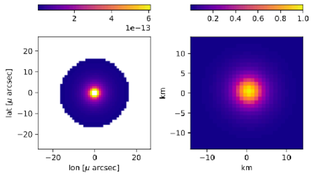
same with i = 70°



3C 273

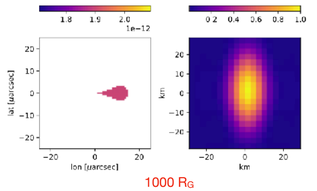


6 10^9 M$_\odot$ (BLR reverb. mapping)

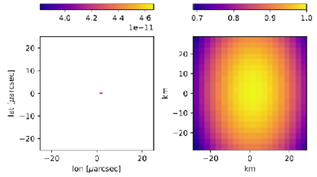


3 10^8 M$_\odot$ (BLR velocity)

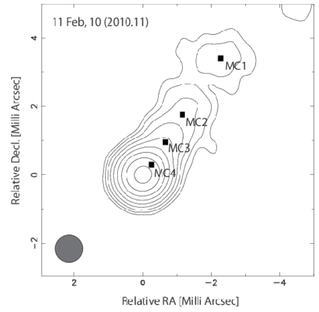
MRK 421



1000 R$_G$



100 R$_G$



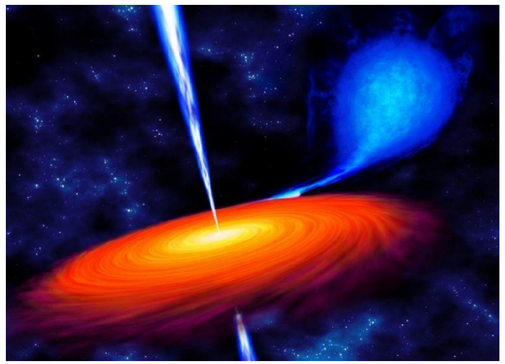
Resolving accretion disks (2035)

ELT (Amazones) + GMT (Las Campanas) combination:

A_{eff} = 511 m^2 ; r_{cd} = 700km

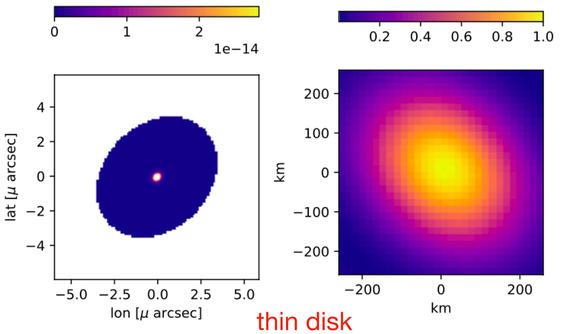
Resolution = 5000Å / 700km = 0.14 μas (30 pico-degree)

LXMBs:

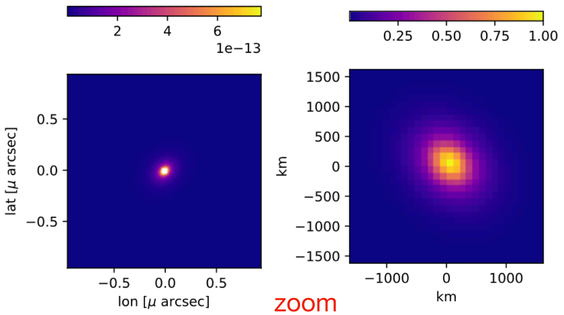


Name	m_V	P_{orb} days	R_{max} μarcsec	Exp. ksec
V4641 Sgr	8.8	2.8173	13.7	0.0004
V616 Mon	11.2	0.3230	6.8	0.03
V404 Cyg	11.5	6.4714	24.7	0.07
KV UMa	12.5	0.1699	1.1	0.4
V518 Per	12.6	0.2121	2.3	0.5
Cen X-4	12.8	0.6290	4.5	0.7
Sco X-1	13.4	0.7873	4.1	1.9
N Mus 1991	13.4	0.4326	1.8	1.9
MM Vel	13.8	0.2852	1.4	4.1

Sco X-1



thin disk



zoom