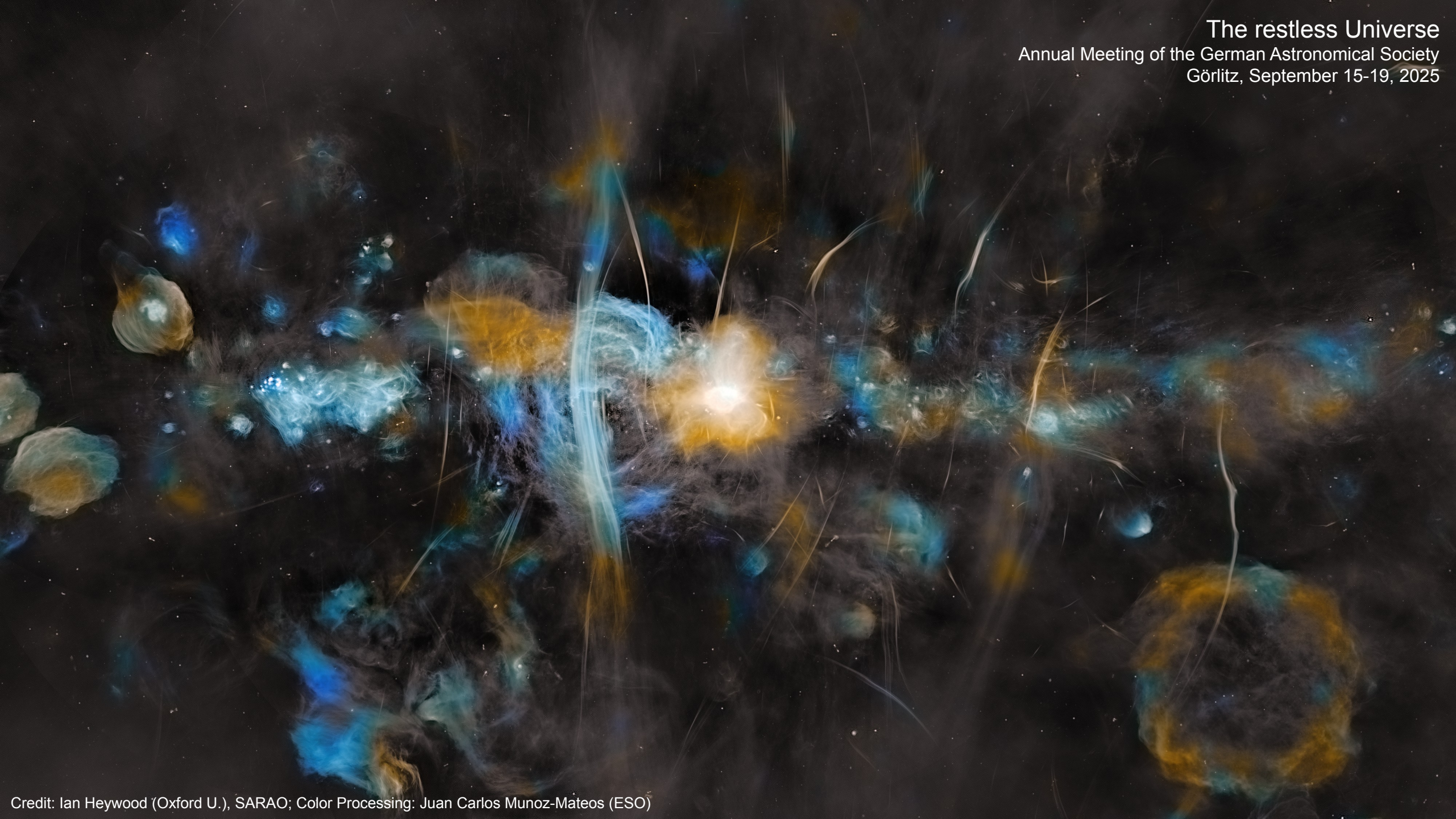


The restless Universe
Annual Meeting of the German Astronomical Society
Görlitz, September 15-19, 2025



Ten-Kilometer Baselines Thousands m² Collecting Area Optical / IR

The restless Universe
Annual Meeting of the German Astronomical Society
Görlitz, September 15-19, 2025

Kilometers Baseline Interferometer

Special thanks



Ten-Kilometer Baselines Thousands m² Collecting Area Optical / IR

Roadmap to the next-generation
infrared interferometric facility



Royal
Astronomical
Society

March 2024

Horizons for Optical
Long Baseline Interferometry

Towards a Whitepaper on Expansion

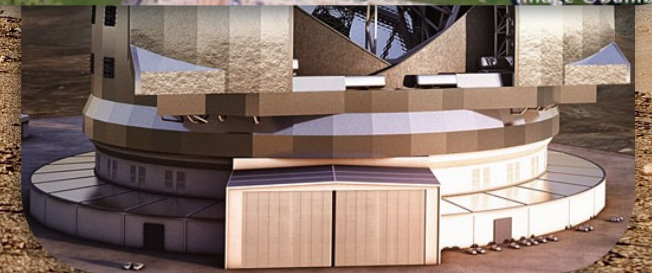
From GRAVITY+ Towards a Kilometers Baseline, Large Telescopes

Yu Tang, Yi Lu, and ESO/H. Heyer



Meudon, 27th -30th January 2025

image ©bambar



Ten-Kilometer Baselines

Thousands m² Collecting Area

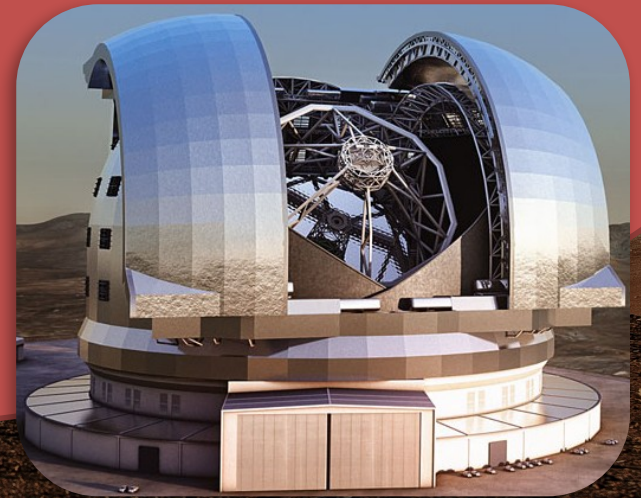
Optical / IR

Resolution $\sim \lambda/B = 10 \mu\text{as}$

Sensitivity $\sim \text{ELT} \times 10^{28} (2 \mu\text{m}) 9_{\text{AB}}$

Point Source Imaging (Spectroscopy) 10σ

Astrometry $\sim 0.1 \mu\text{as}$



From GRAVITY(+) Towards a Kilometers Baseline, Large Telescope Interferometer

Ringberg Workshop
June 2024

10 μ s angular resolution

Fundamental Physics

Cosmology

Galaxies

>1 Gpc 1/10 pc SN1987A

Black Holes

100 Mpc 1000 AU TDEs

1 Mpc 10 AU Saturn Orbit

Stars/-formation

10 kpc 0.1 AU = 1 Schwarzschild R.

Exoplanets

10 pc

Earth

150 km

astrometry

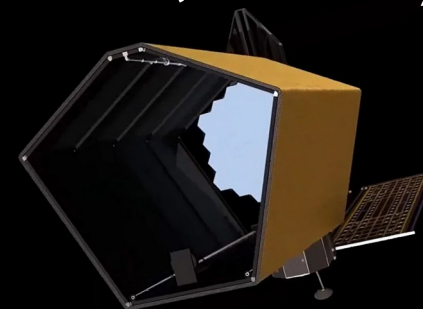
1 pc

1500 km Sweden

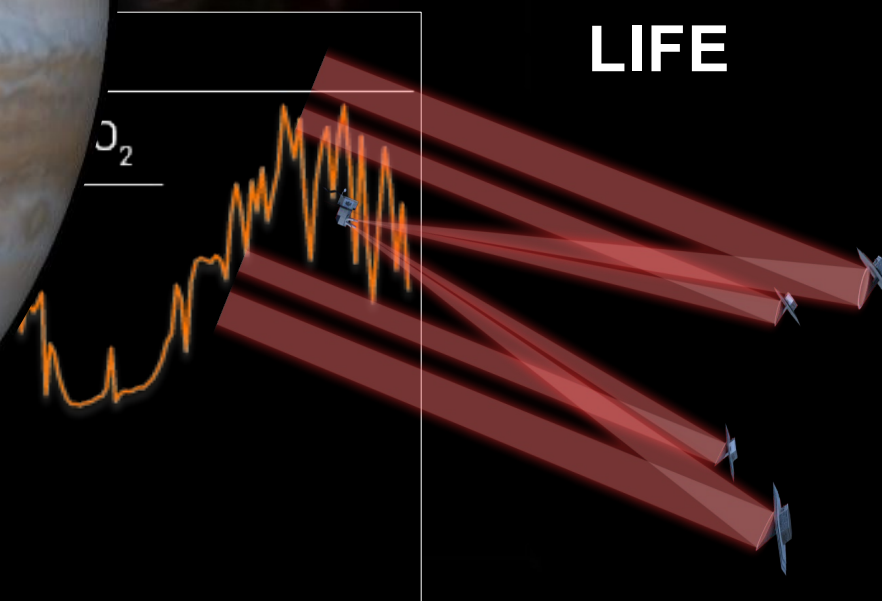
15 km

Images of Exoplanets

Habitable Worlds
Observatory
(LUVOIR, HabEx)

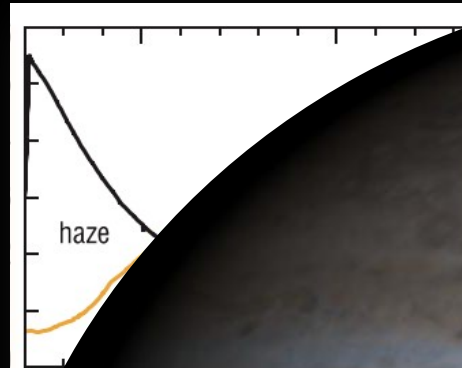


LIFE



wavelength (μm)

18 The LUVOIR Team 19, Gaudi+ 20, Quanz+ 22

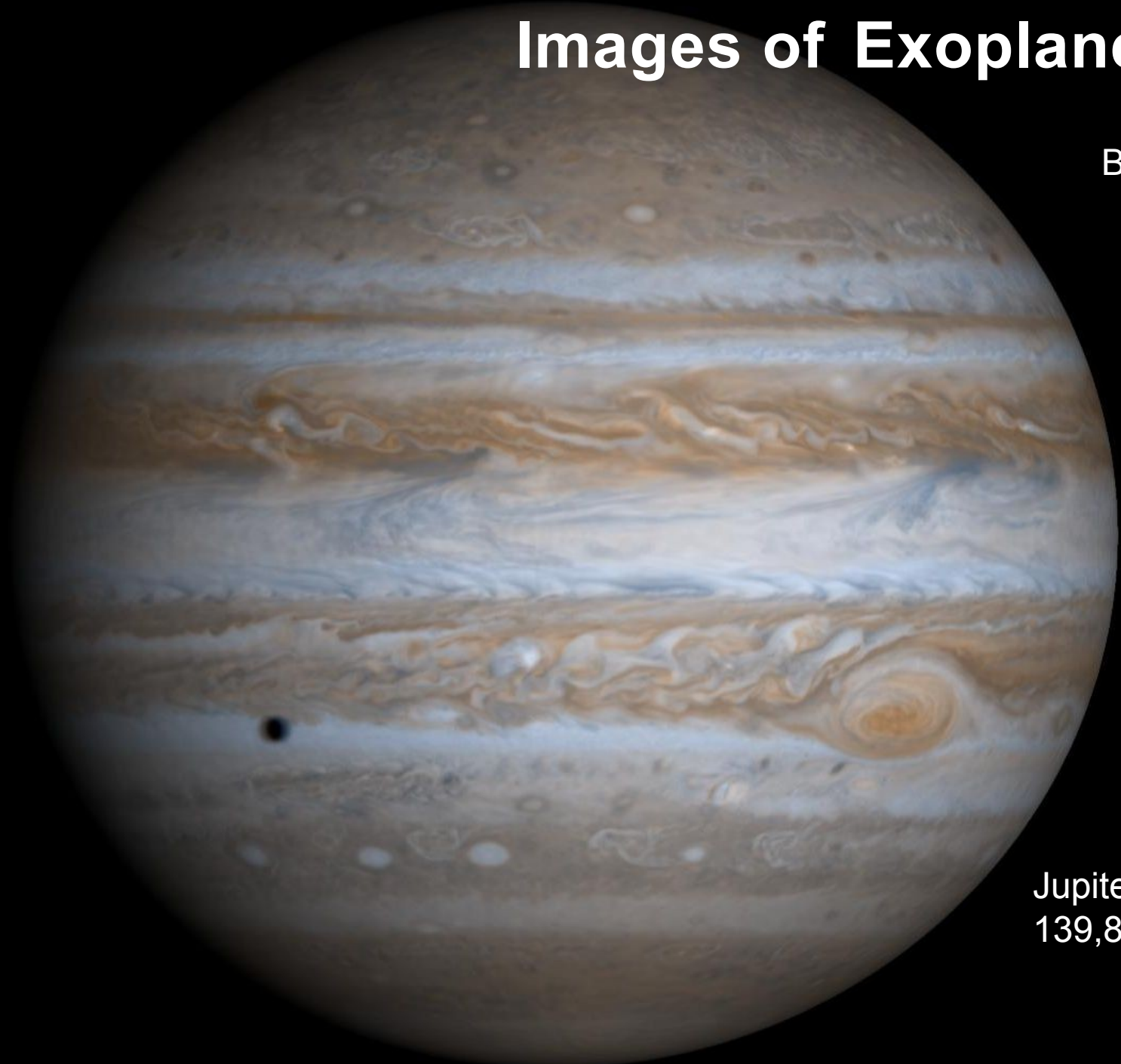


Lacour+



JWST

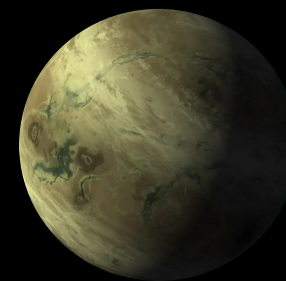
Images of Exoplanets



Beam 6,000 km
@ 4 pc



Beam 2,000 km
@ 1.3 pc



Super-Earth
25,800 km



Earth
12,800 km



Moon
3,500 km

Jupiter
139,800 km

**Earth-like Moons within
the Habitable Zone also
by Astrometry**

Winterhalder+ 25

Supermassive Black Holes

Beam 1 RS



**Watching
the Launch
of a Flare**



Credit: NASA JPL

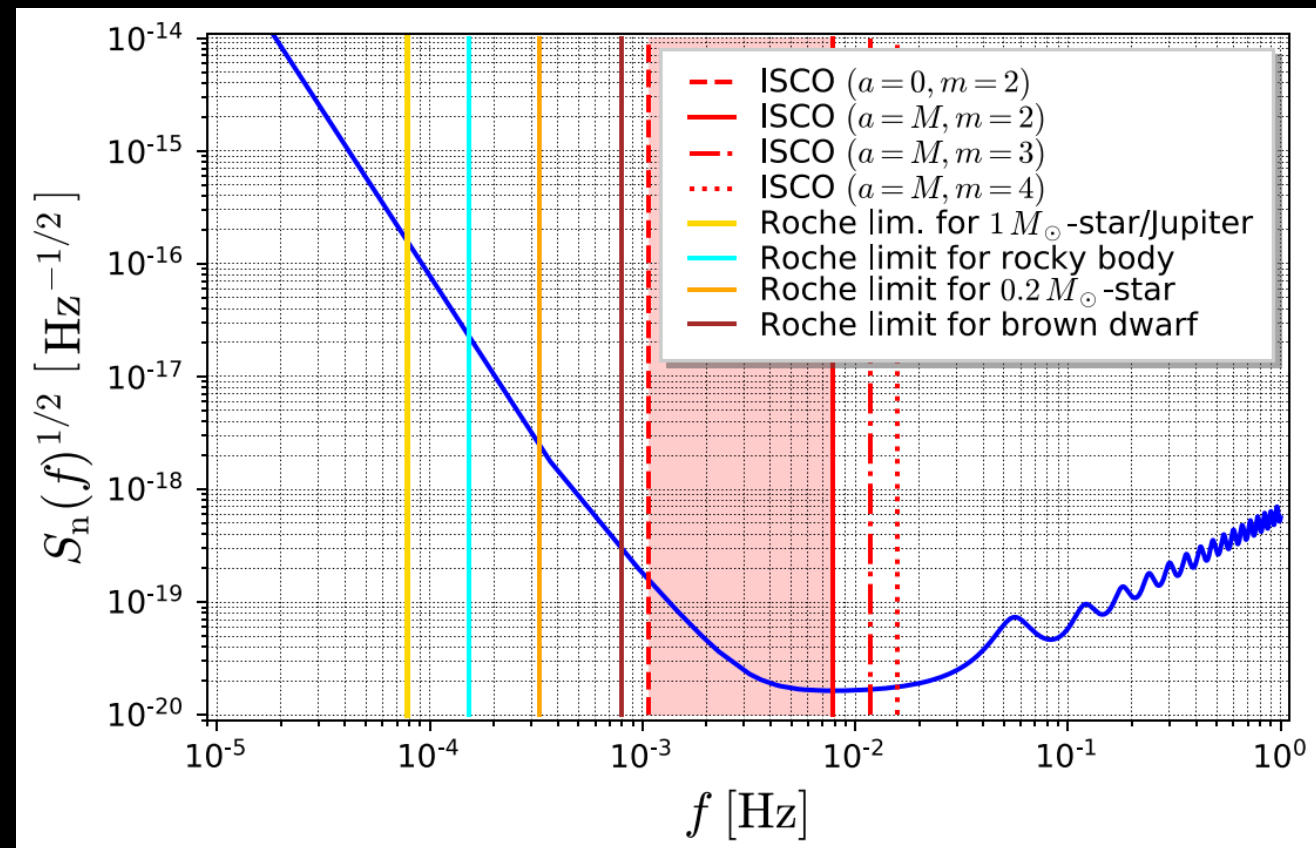
Supermassive Black Holes

Observing the Orbit
of Objects Creating
Gravitational Waves

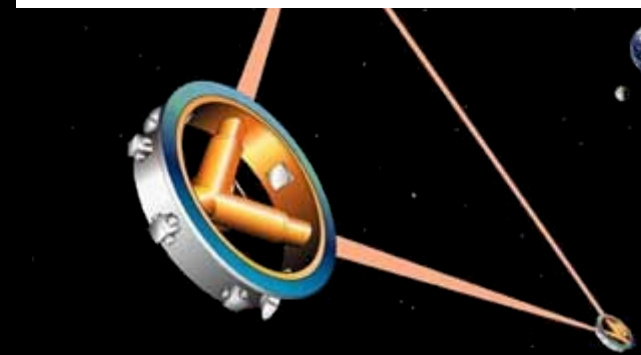
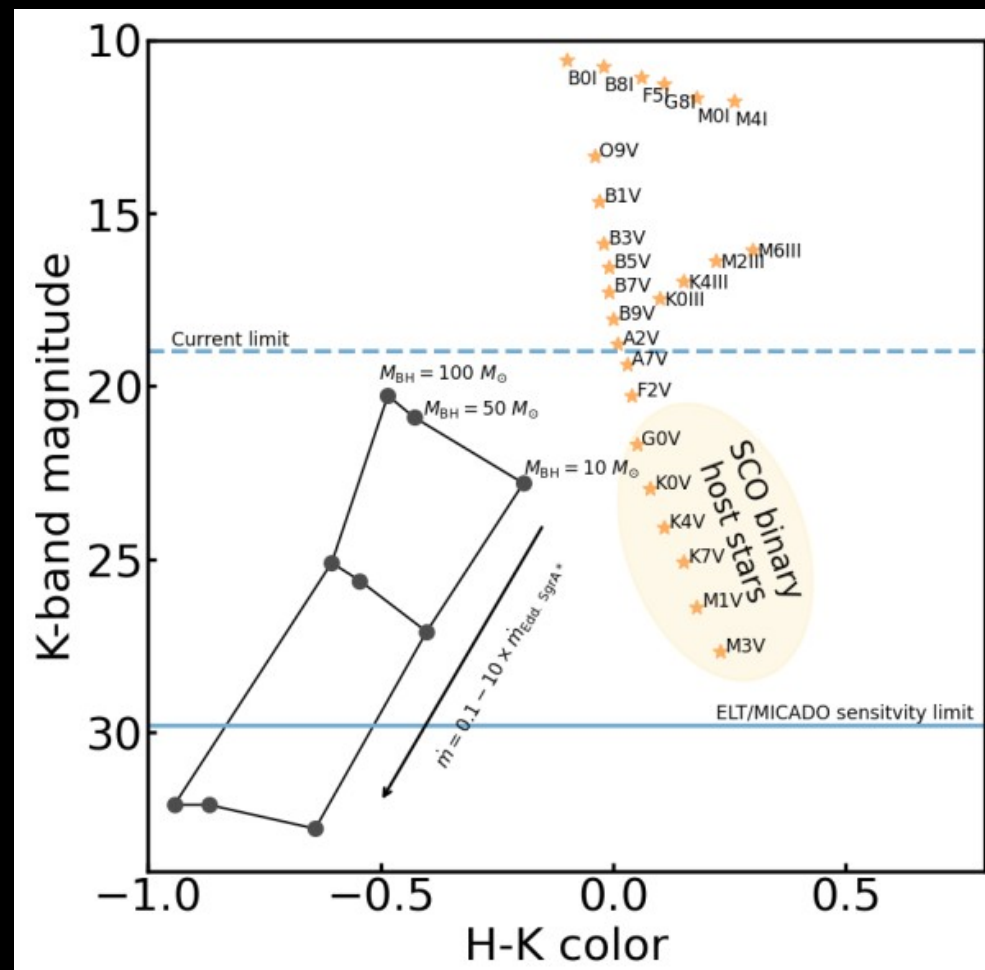


Supermassive Black Holes

Observing the Orbit of Objects Creating Gravitational Waves

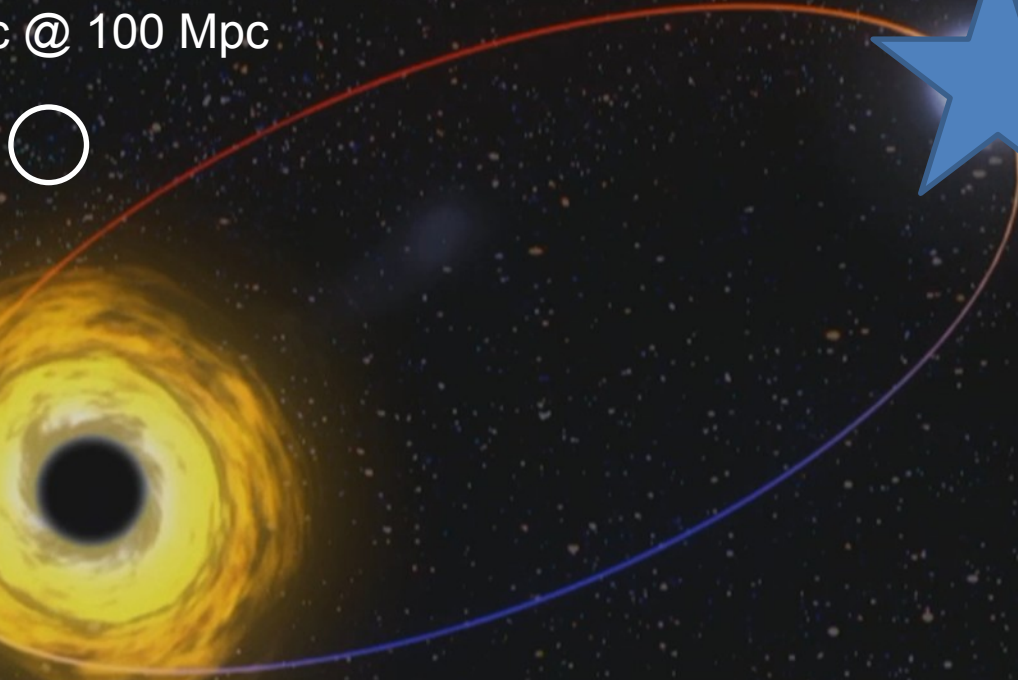


Gourgoulhon+ 19



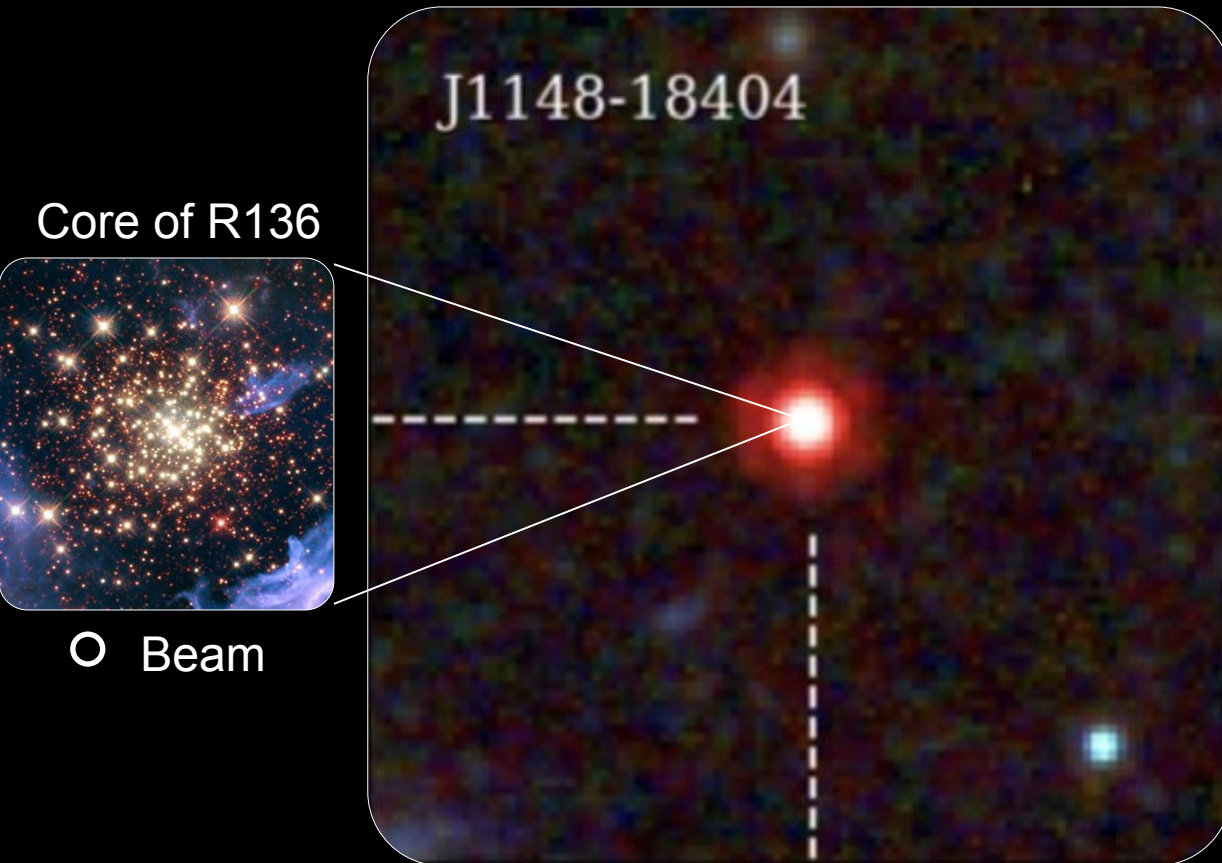
Imaging Time Domain Astronomy – Tidal Disruption Events

Beam
5 mpc @ 100 Mpc



Primordial Black Holes or Not ... Last Parsec Problem

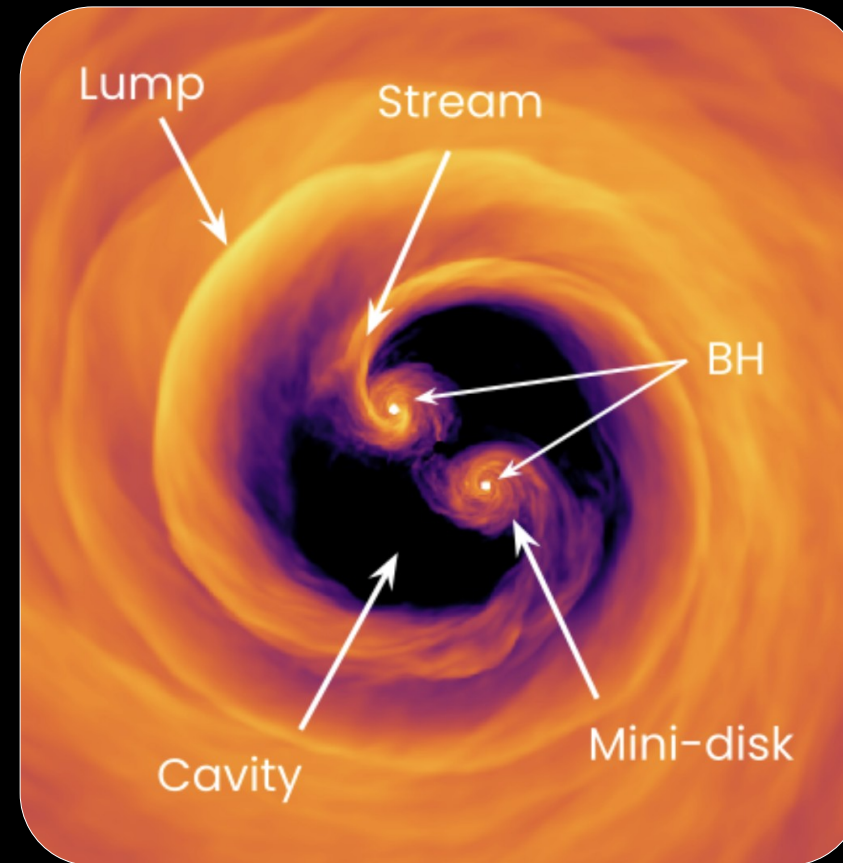
“Little Red Dots”



e.g. Matthee+24, Kokorev+ 24, Kocevsk+ 24, Akins+ 24, Chen+ 24

Beam
50 mpc @ $z \sim 10$

Massive Binary Black Holes



Begelman 80, Shongsheng+ 19, Dexter+ 20, Gutiérrez+24

Beam
5 mpc @ 100 Mpc

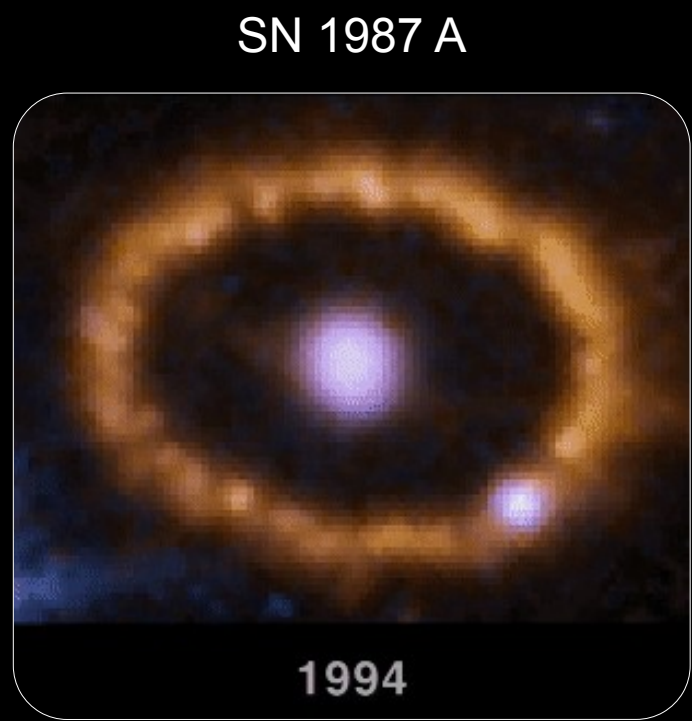
Period ~ 25 yr

$M_1/M_2 = 3.6; e = 0.0$

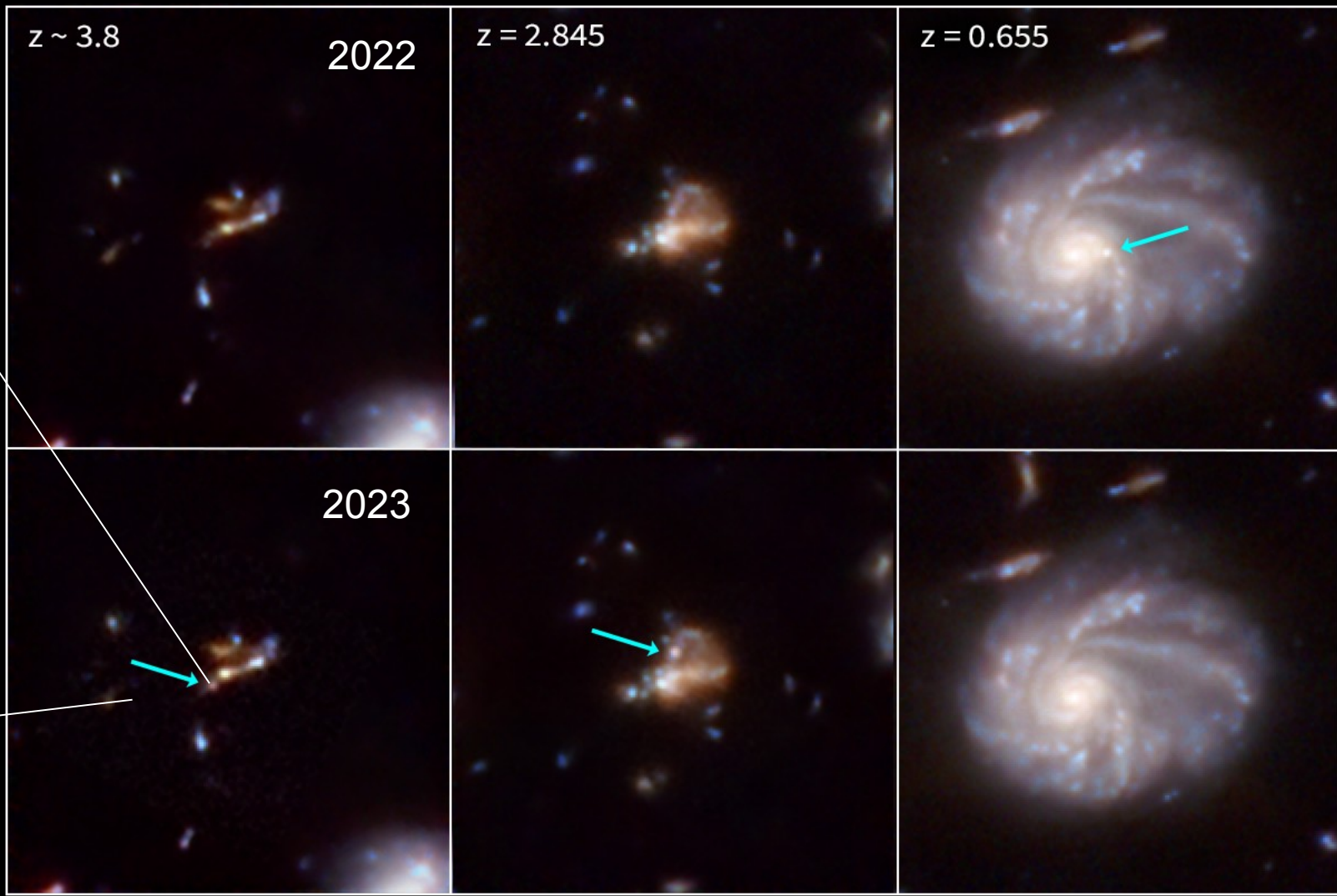
for $10^8 M_\odot$
and 0.02 pc

Cosmology – Geometric Distances throughout the Universe

Hubble Constant



○ Beam

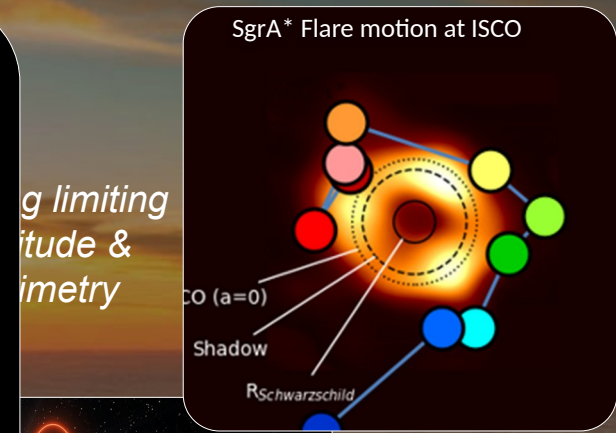
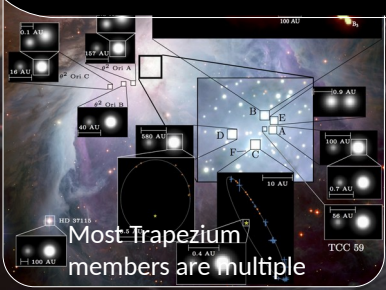
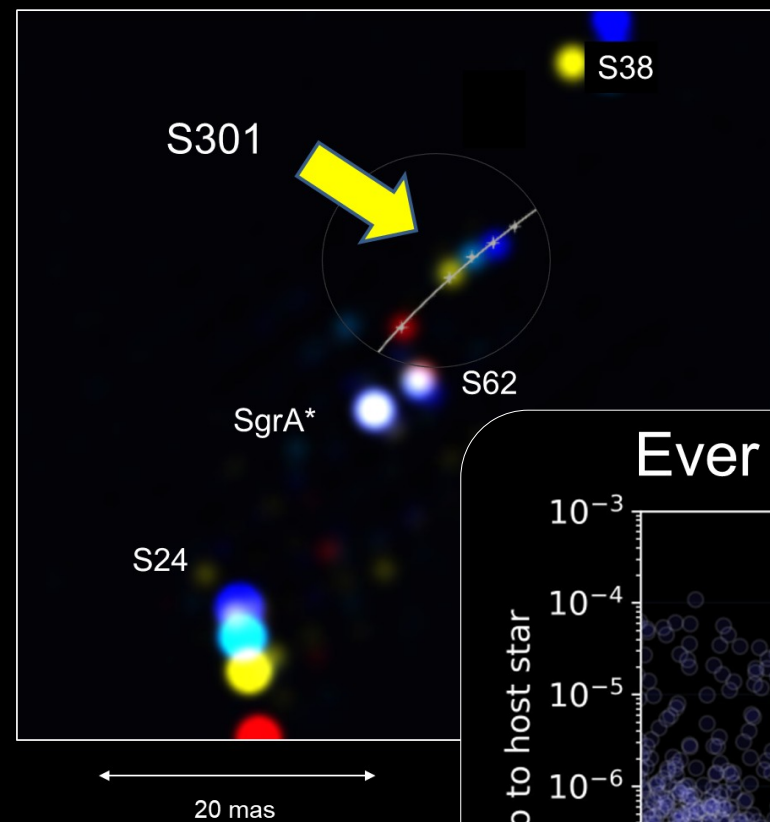


Beam
10 mpc @ $z \sim 10$

Credit: NASA, ESA, CSA, STScI, Christa DeCoursey
(University of Arizona), JADES Collaboration

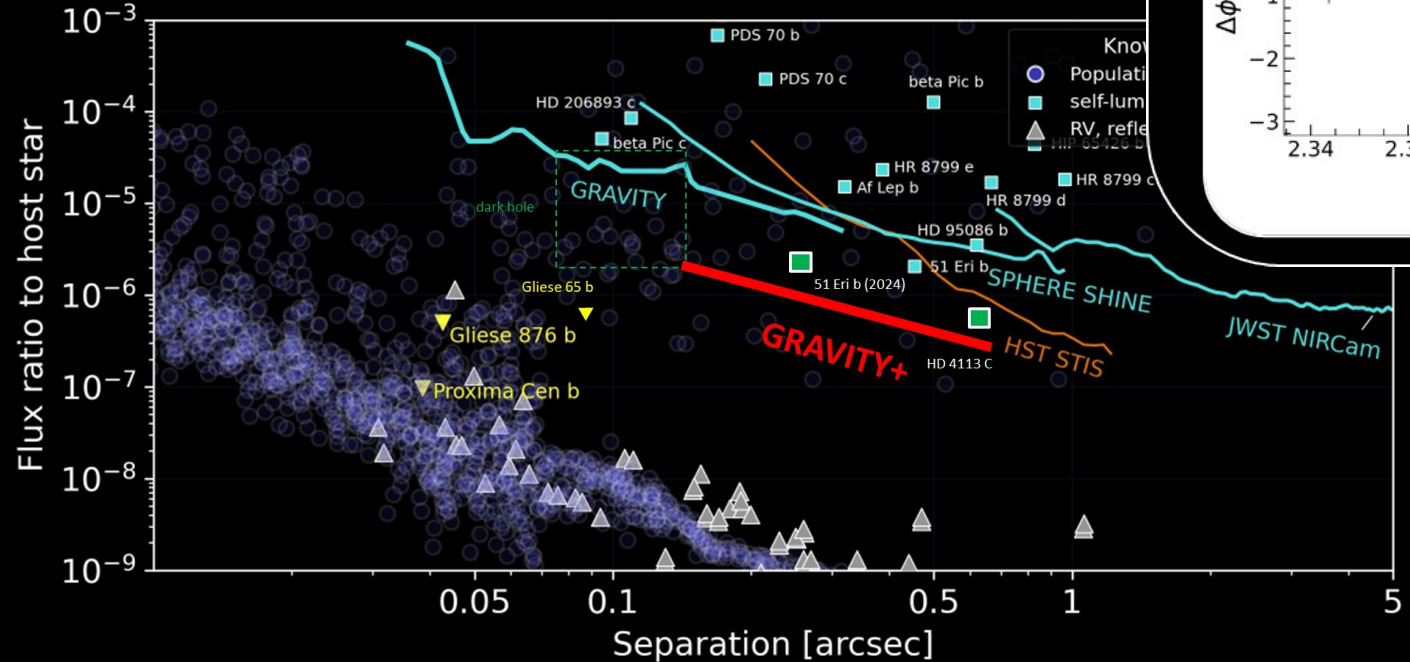
GRAVITY Revolution in High Angular Resolution Astronomy

Ever Closer Stars around SgrA*

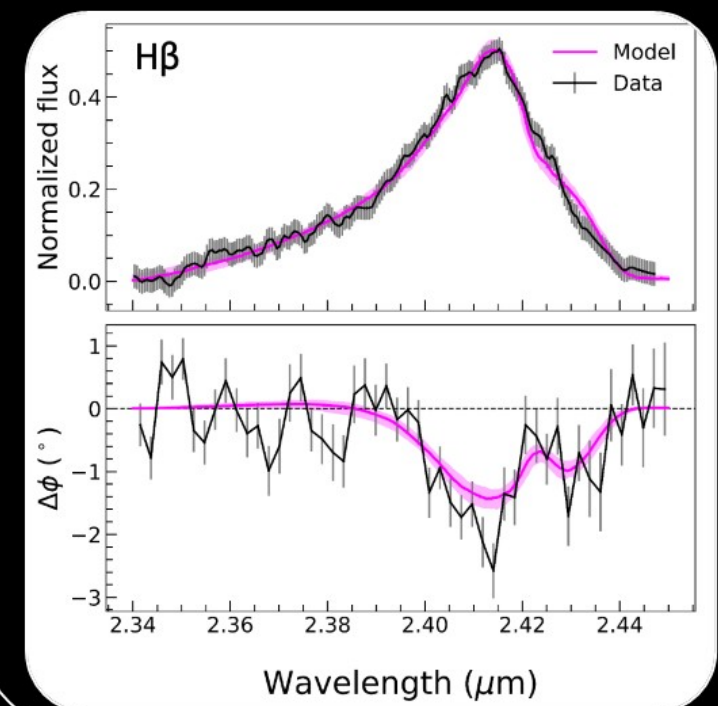


NGC1068 image

Ever fainter Exoplanets ($m_K > 20.5$)



Redshift $z=4$ Quasar

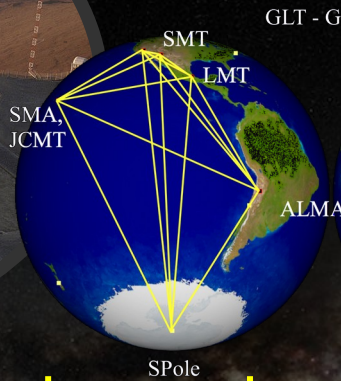
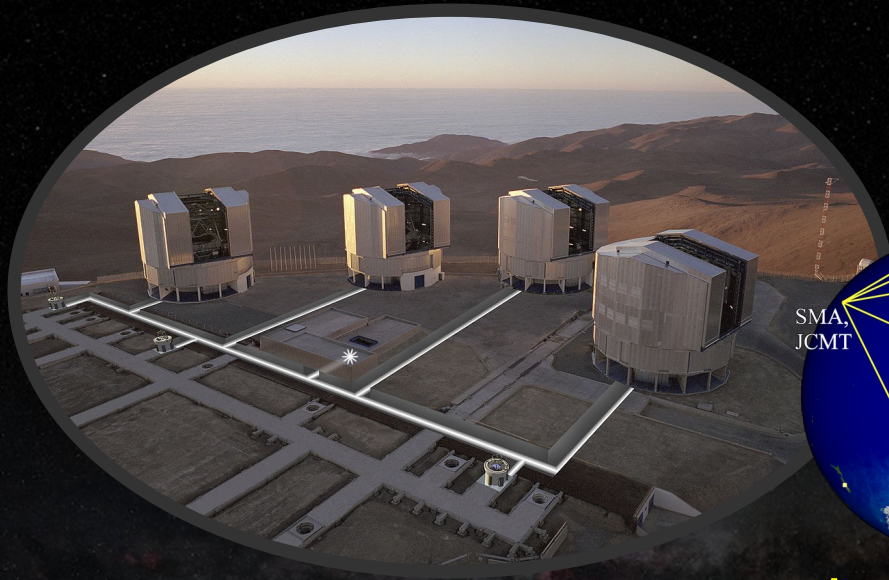
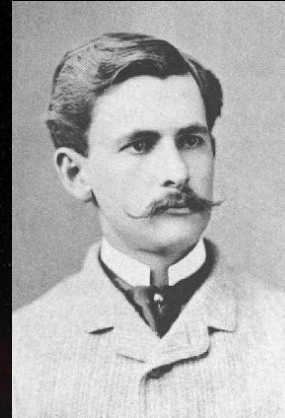


Dong+ 19, Cassan+ 22

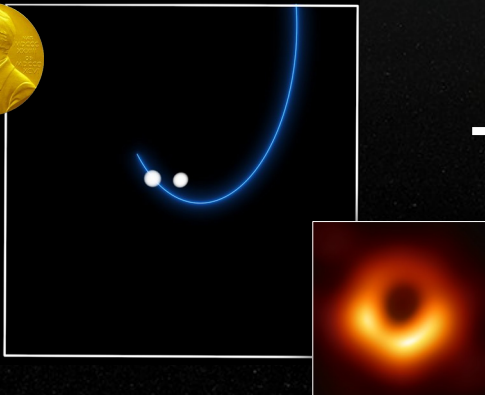
Lacour+ 20

130 Years after Albert Michelson

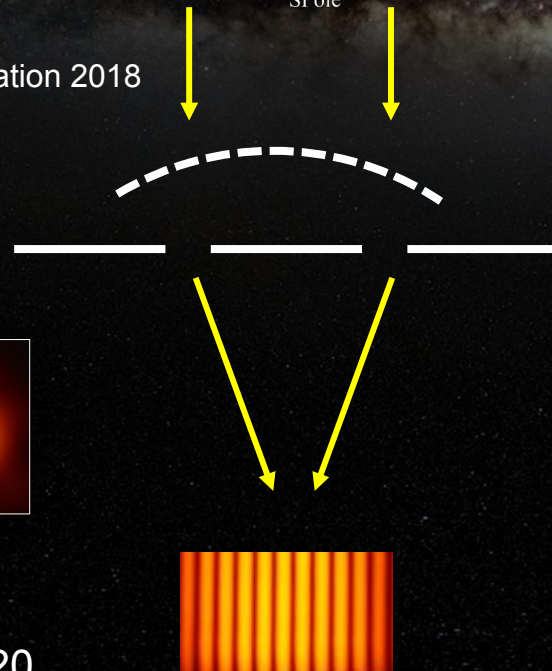
1852-1931



GRAVITY Collaboration 2017, EHT Collaboration 2018



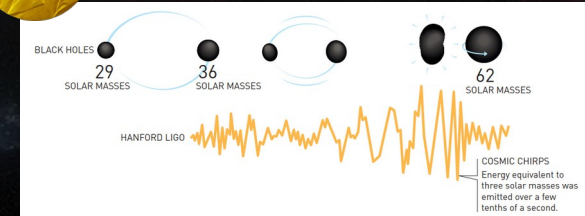
Fizeau 1867
Stephan 1873
Michelson 1891, 1920



Michelson-Morley 1887

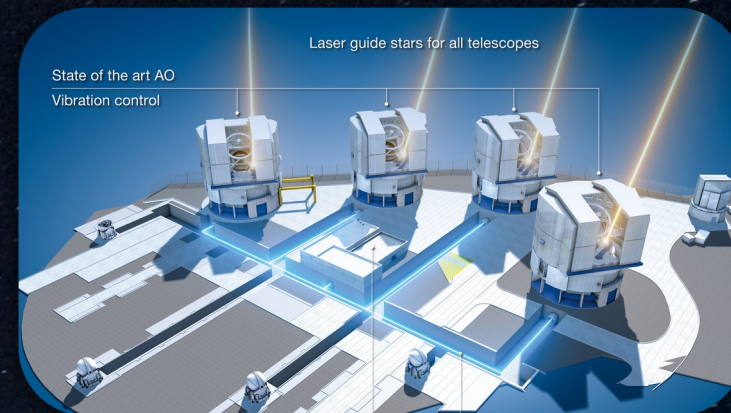
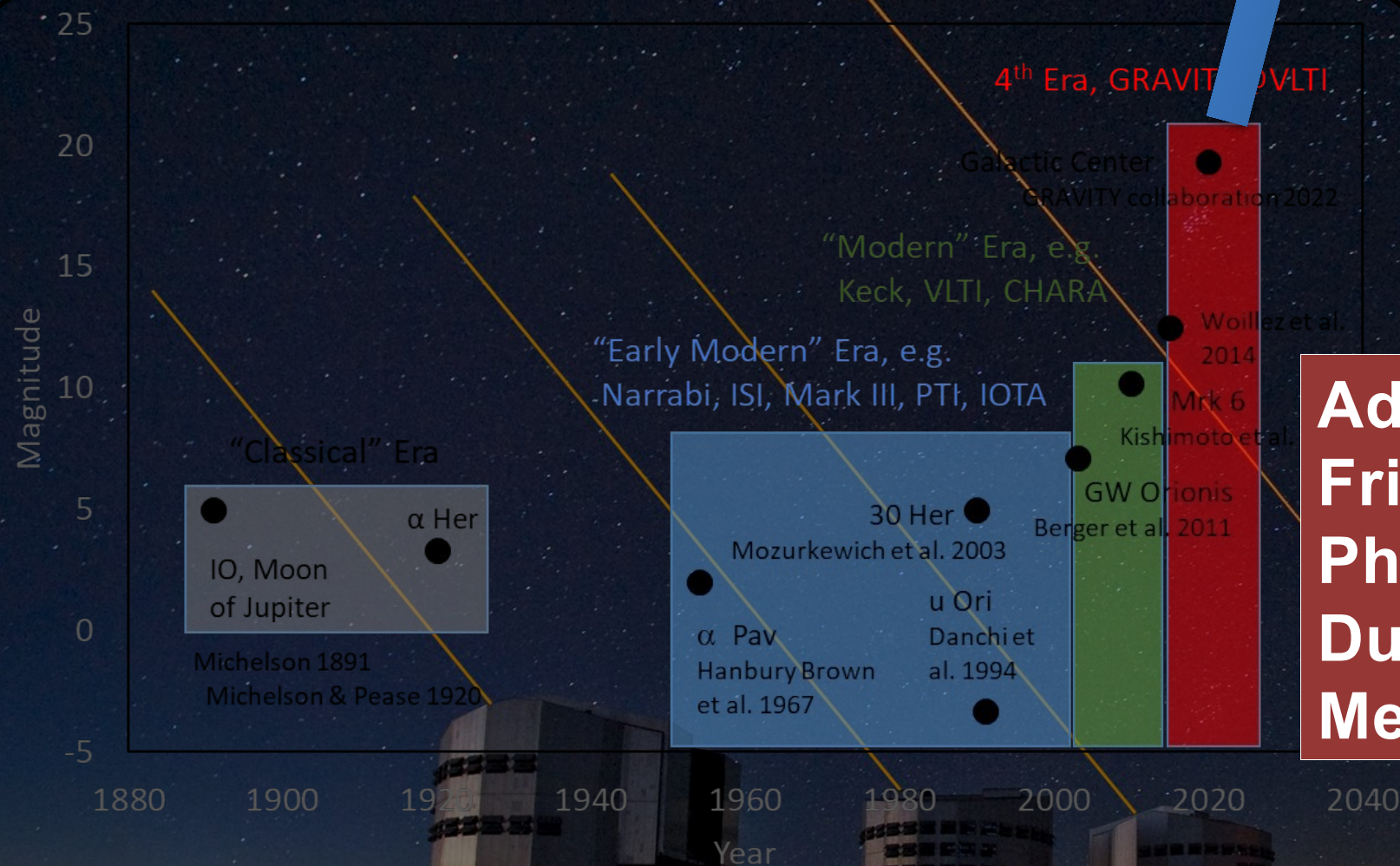


LIGO / VIRGO Collaboration 2016



130 Years after Albert Michelson

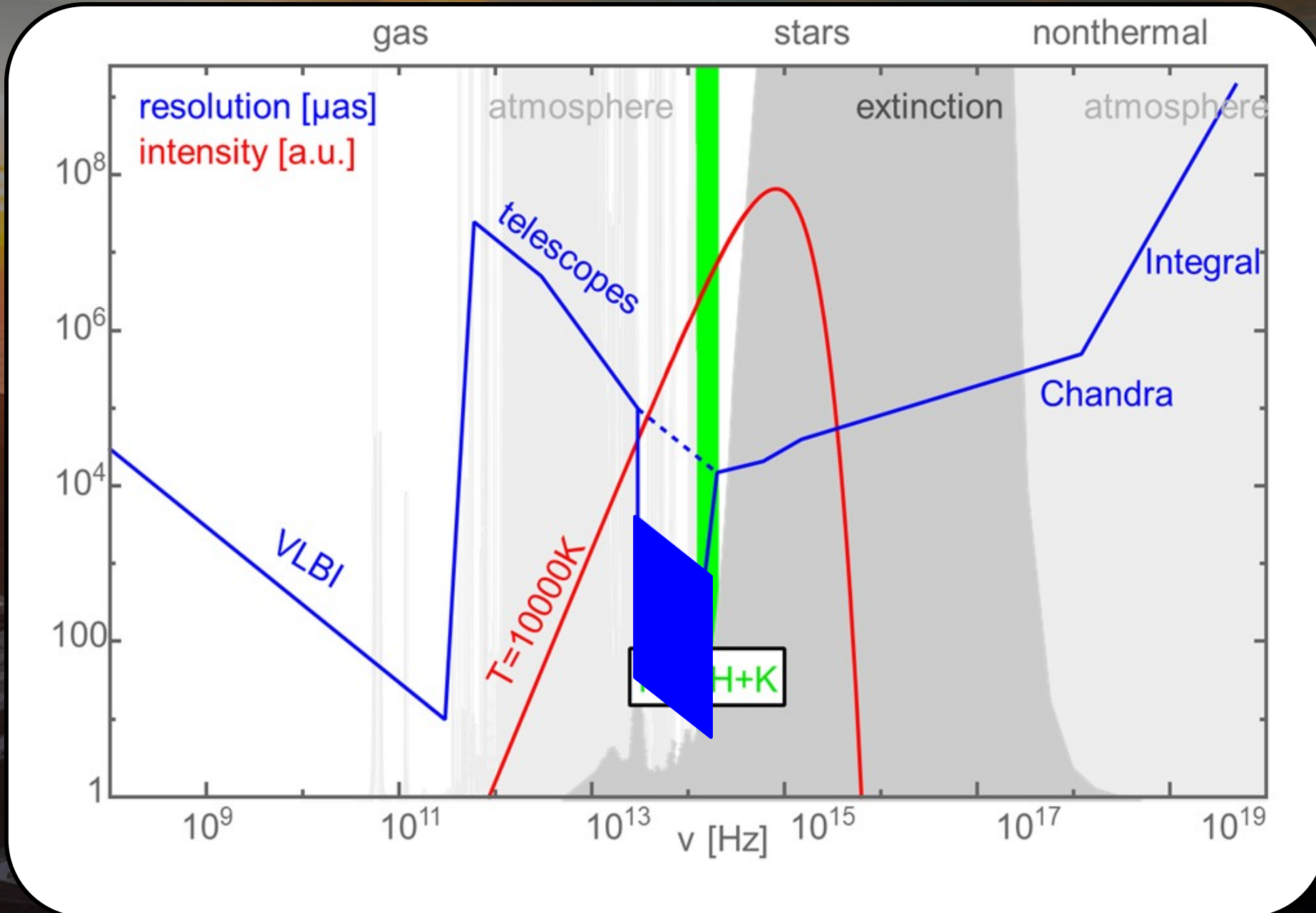
VLTI / Paranal is Worldwide Unique



**Adaptive Optics
Fringe Tracking
Phase-referencing
Dual Beam
Metrology**

**Four Large
Telescopes**

At Least a Factor Ten to Hundred Kilometer Spotscope

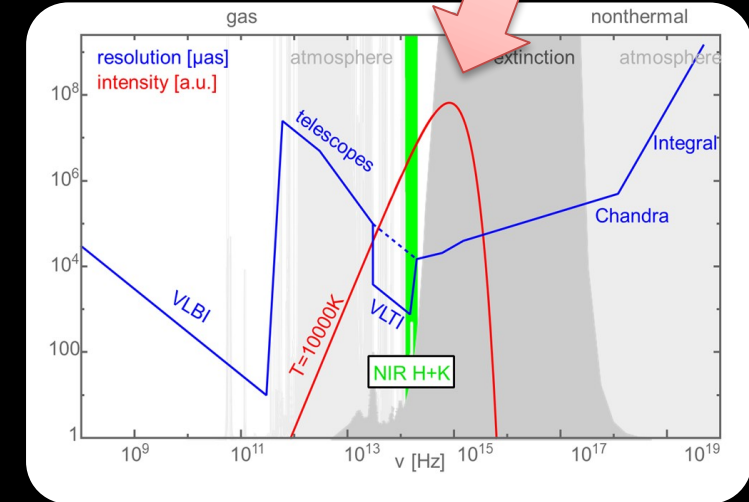
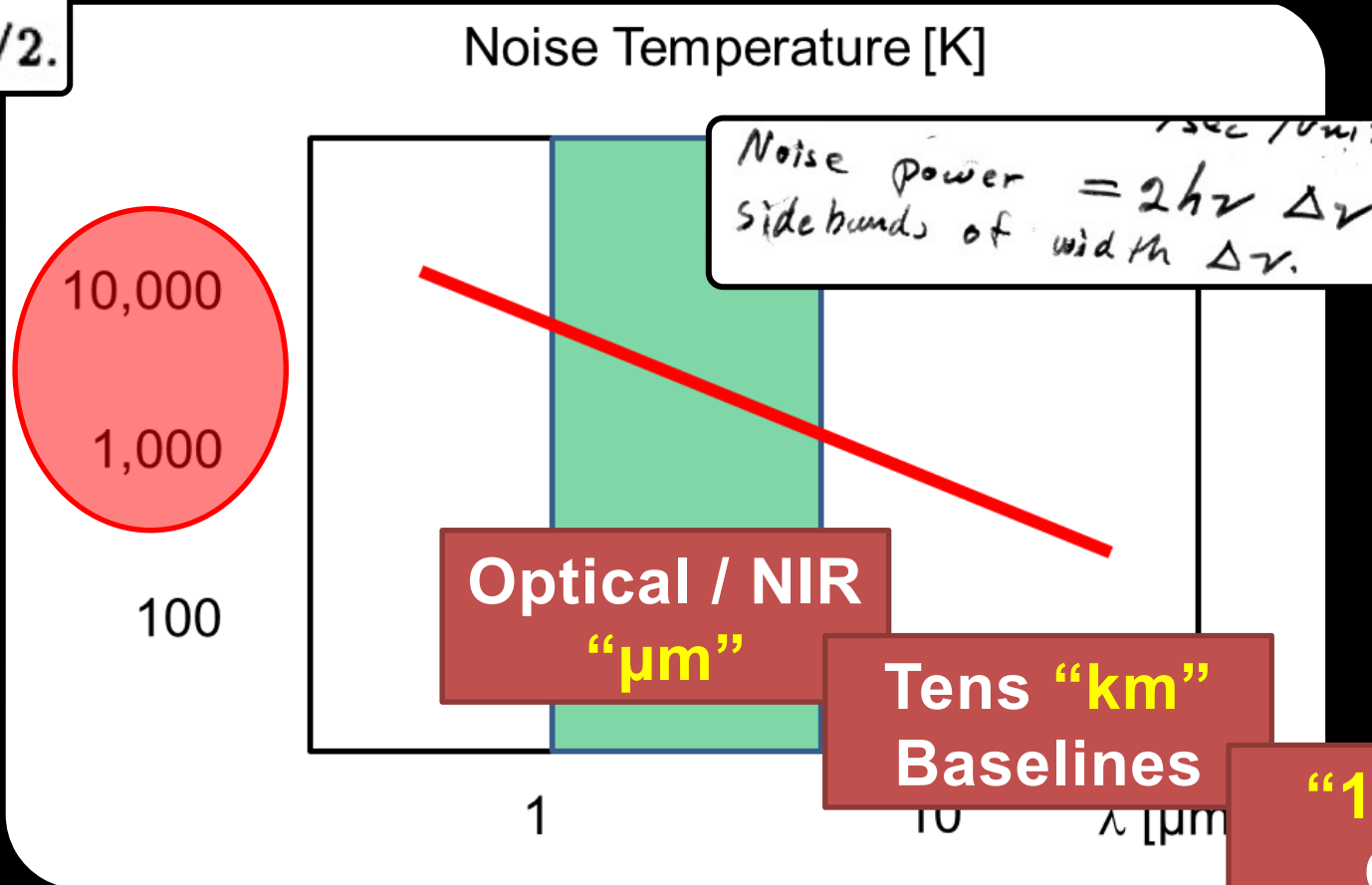


Thoughts on Parameter Space

COHERENT AND INCOHERENT DETECTION

e.g. Harris 1990

$$\Delta n \Delta \phi \geq 1/2.$$



*Intensity
Interferometry*

$$\langle E^*(t)E^*(t+\tau)E(t+\tau)E(t) \rangle$$

Direct detection

$$\langle E^*(r_1, t_1)E(r_2, t_2) \rangle$$

"Michelson"
Interference

"10-40m"
Class
Telescopes

Baseline Length and Telescope Size

Stars = Discs radiating **thermal emission** with 3,000 – 30,000 K

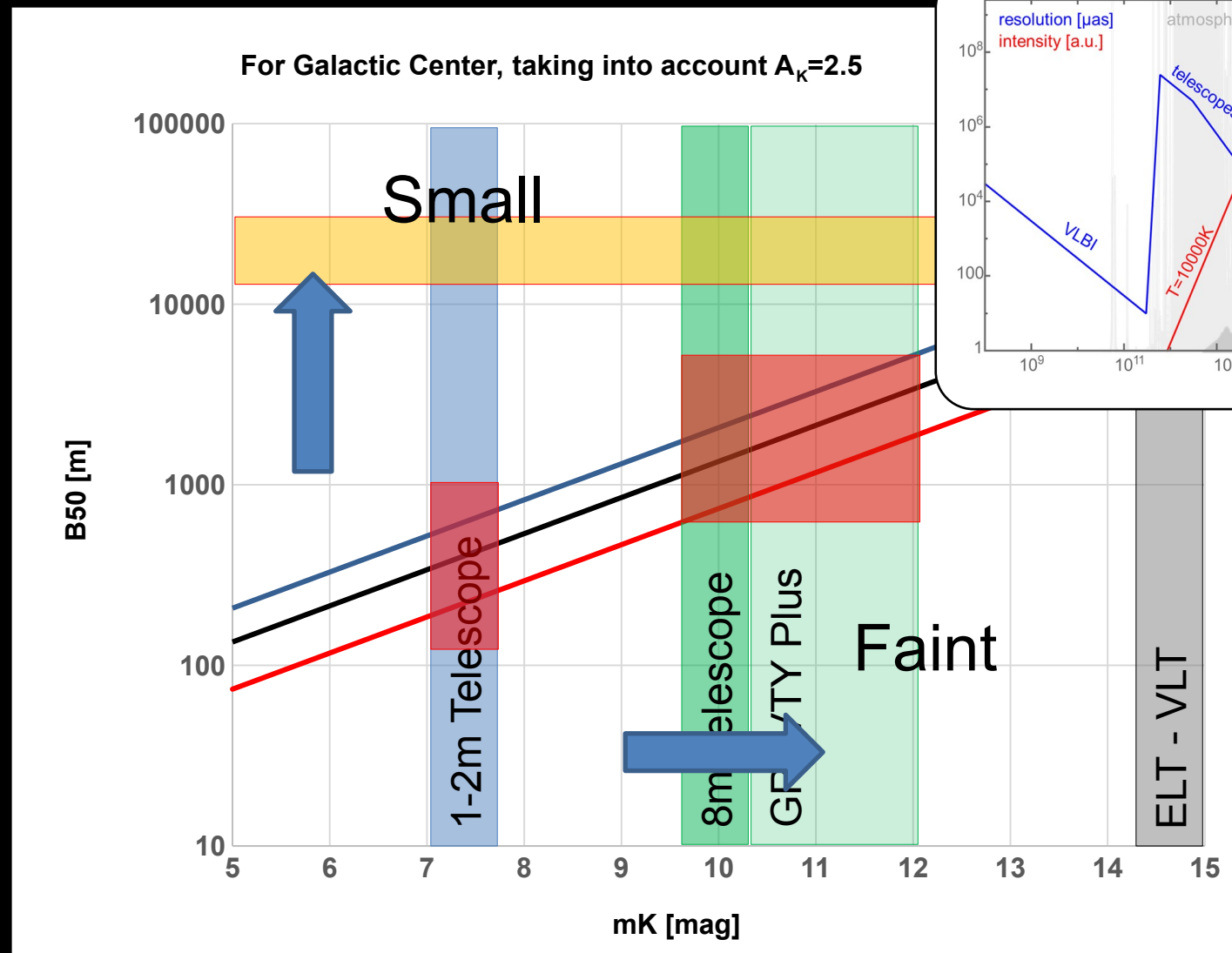
Long Baselines
require large
Telescopes!

Typical:

10-40m for tens km

8m tel. for few km

1-2m tel. for few
hundred



How to Arrive at KBI ?

What's missing ?

Demonstration of Kilometer Baselines
Technology Tradeoff for Cost Reduction
Combination of Different Telescope Designs

Feasibility Demonstrated !

Large Telescopes
Adaptive Optics and Laser Guide Stars
Beam Combination
Fringe tracking and Phase-referencing



Phased Implementation



EXPANDING
HORIZONS

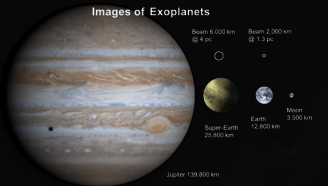
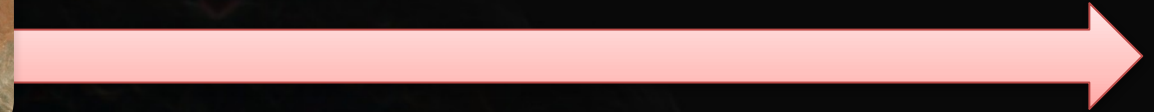
Phased Implementation – More than One



National Funding
and ESO TechDev

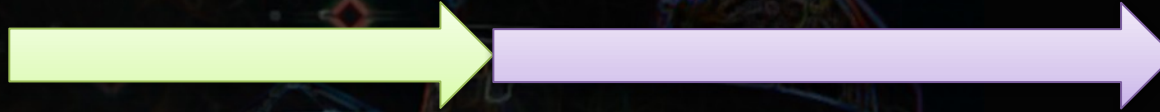


KBI



KBI Demonstrator
on Paranal

E-VLTI



Community
Whitepaper

Horizons Project 2



2025

2026

2030

2035

2045

Kilometer Baseline Demonstrator

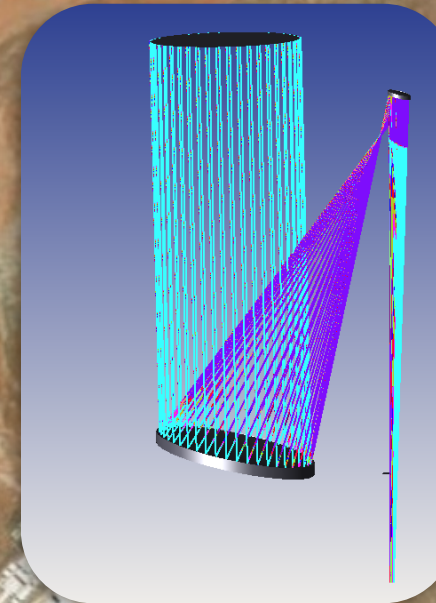
Outrigger Telescope on VISTA peak

Member State Initiative & Partner Institutes

Commercial 2-4m Telescope

Off-Axis Prototype Telescope

Combination of Different
Telescope Designs



Simonnet, Bourdarot, MPE



Azzaroli, Esposito,
Ragazzoni, INAF

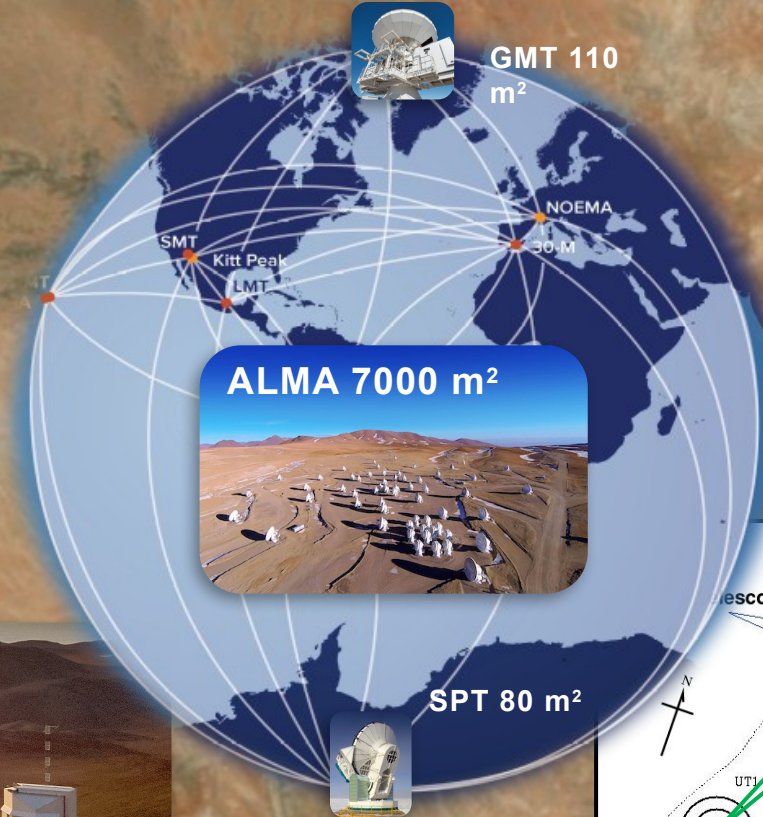


Kilometer Baseline Demonstrator

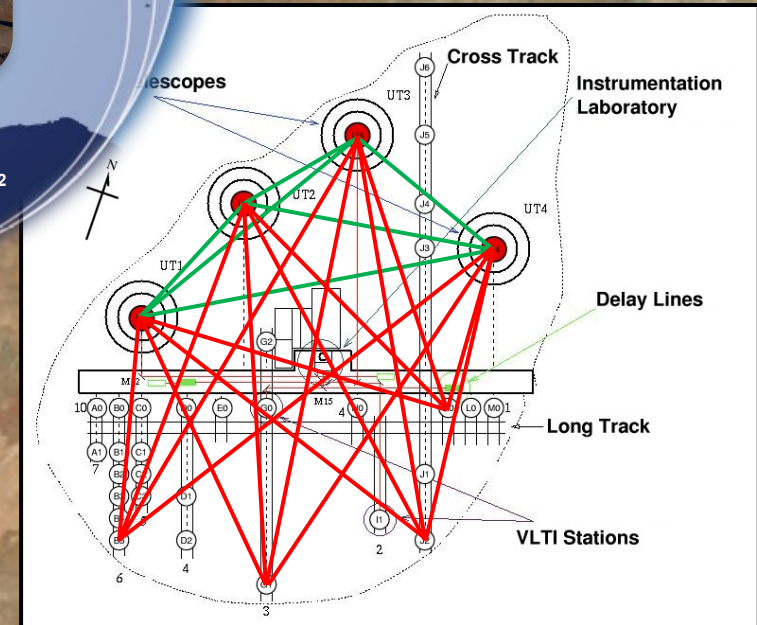
The “BIG” carries the small

$$SNR \sim \sqrt{I_1 I_2}$$

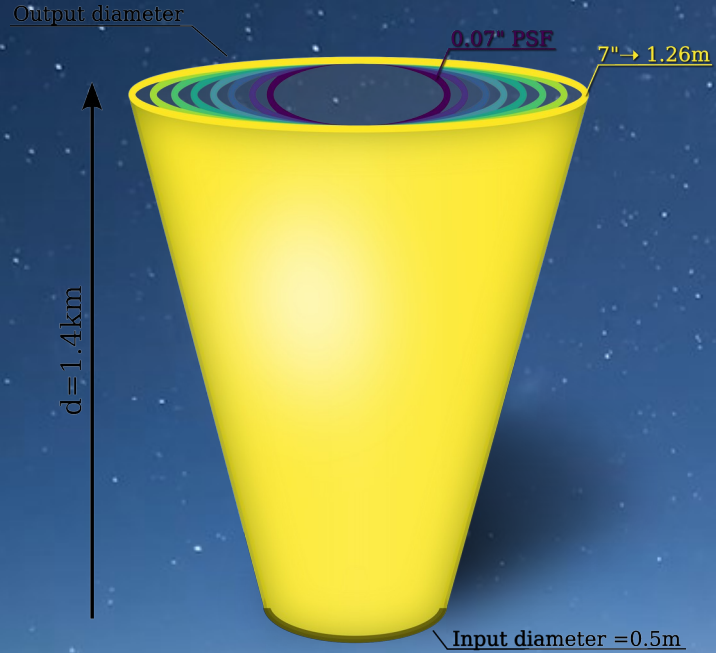
Combination
Telescope



Radio-like
Imaging



Beam Transport

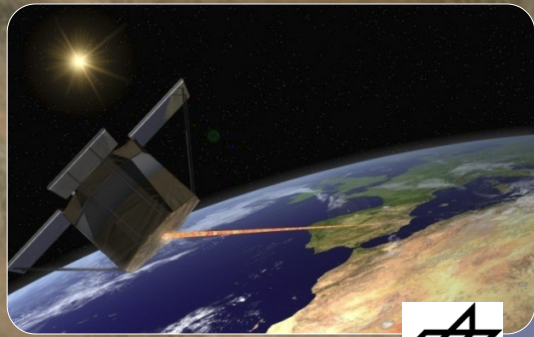


$d = 1.4\text{km}$

VLT

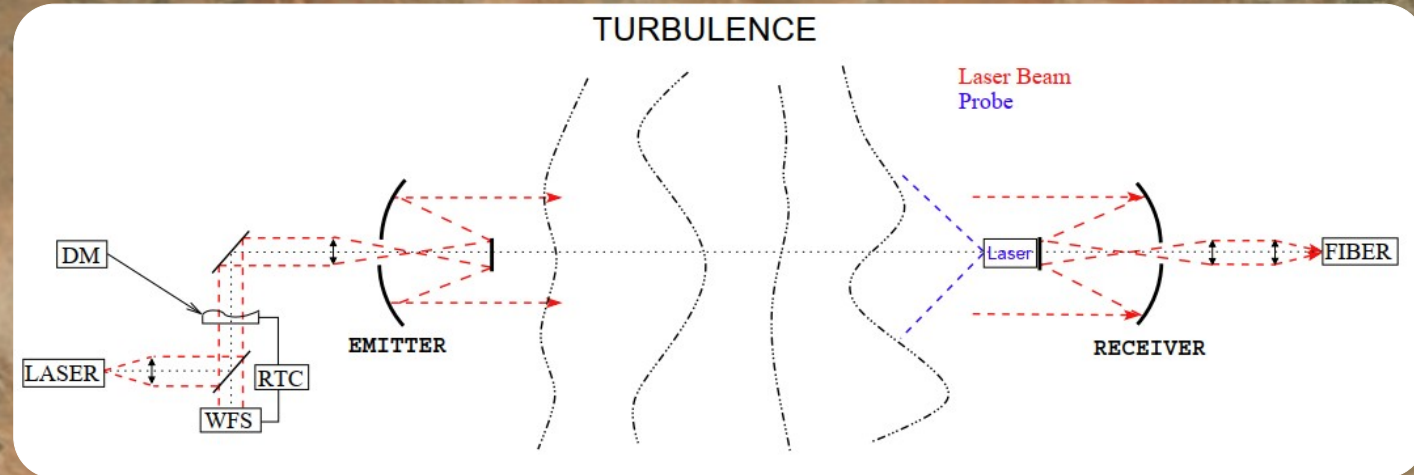
VISTA

$\sim 0.5\text{m}$

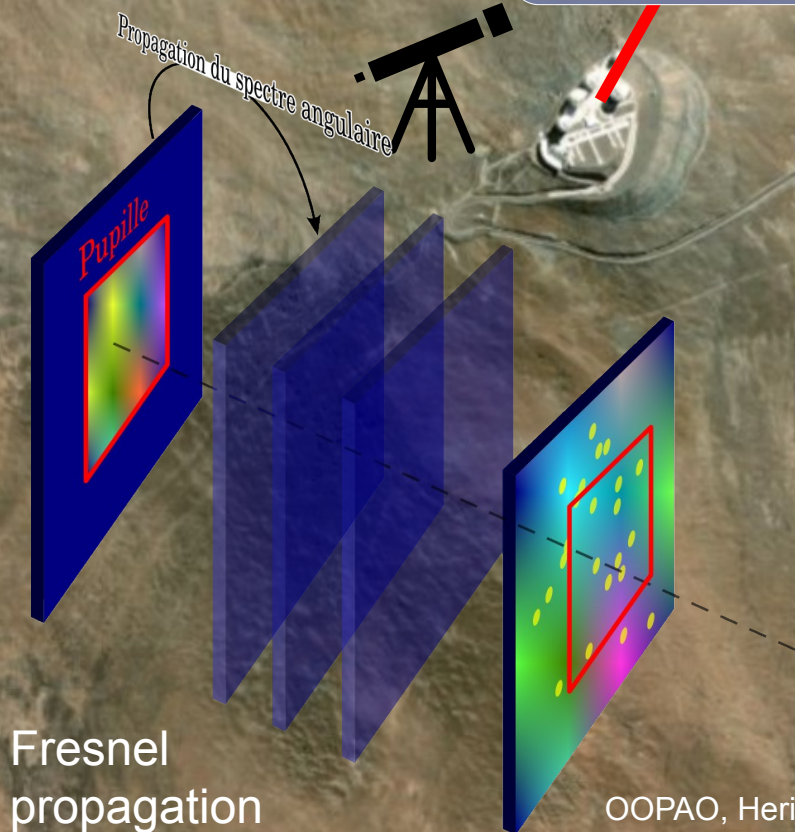


Beam Transport by Adaptive Optics

Legacy from Optical Communication

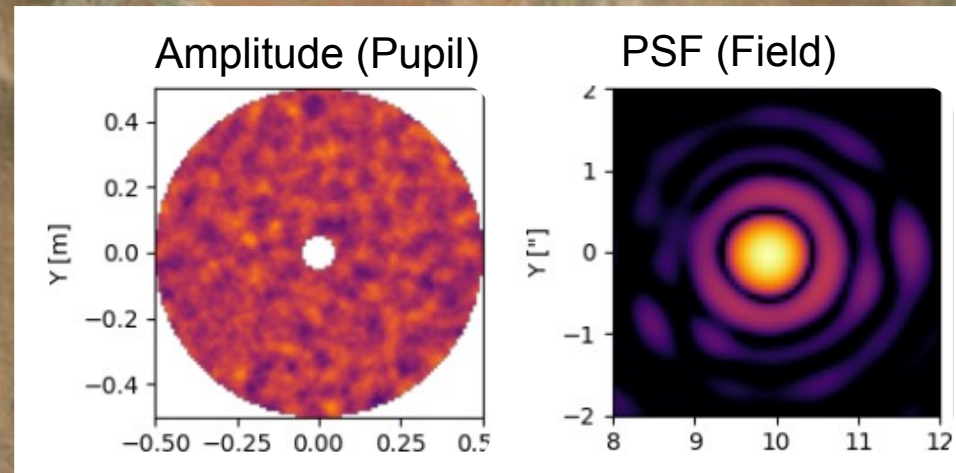


Schwartz+09, Knapik 10



Fresnel propagation

OOPAO, Heritier+ 23



No catastrophic scintillation

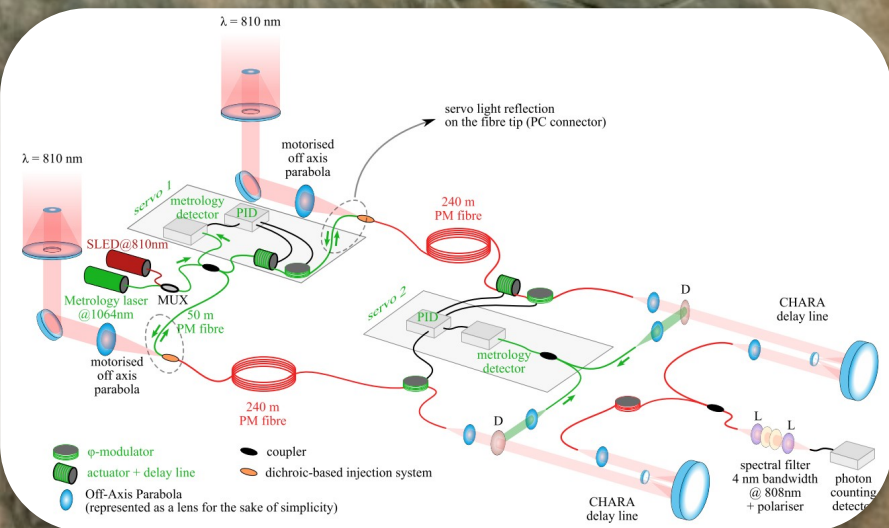
Pichon, Bourdarot, MPE, Neichel, LAM



OHANA

Perrin+ 04

ALOHA @
CHARA



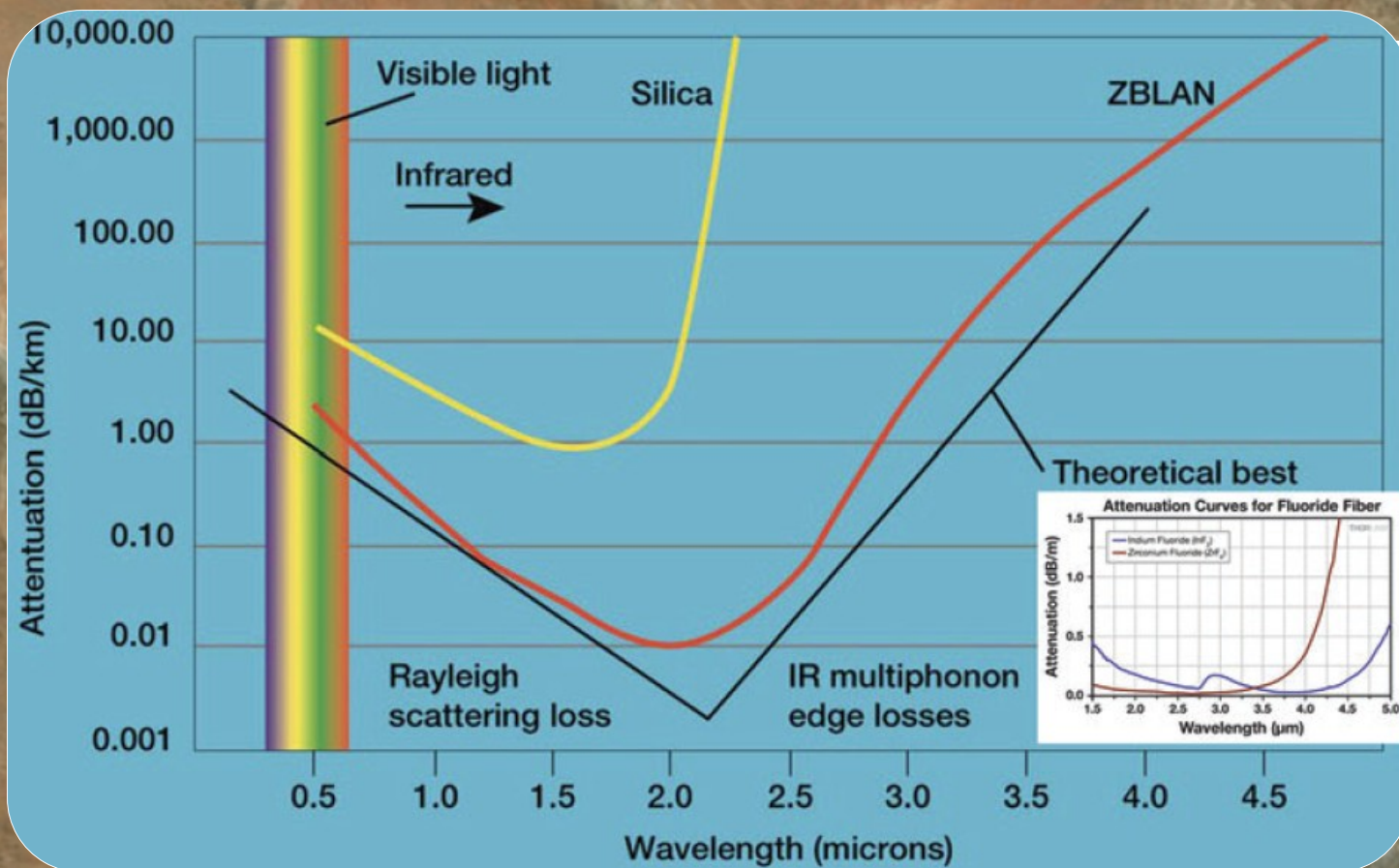
Magri+ 25

Beam Transport by Fibers

GRAVITY Fibers

is 6.63 dB km^{-1} at $2 \mu\text{m}$ and 3.65 dB km^{-1} at $2.4 \mu\text{m}$,
differential dispersion (less than $2.04 \mu\text{rad cm}^2$ at zero extension

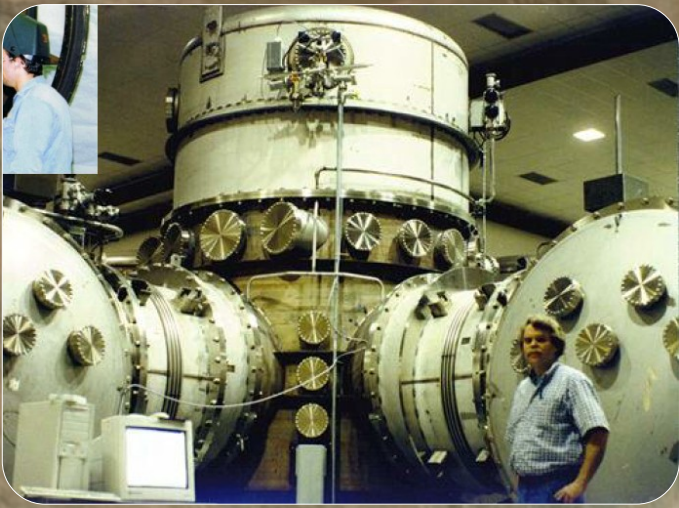
Perrin+24



Cozmuta & Rasky 17, Tamura+18

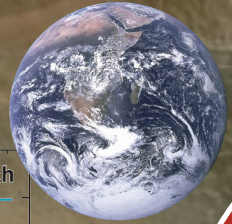
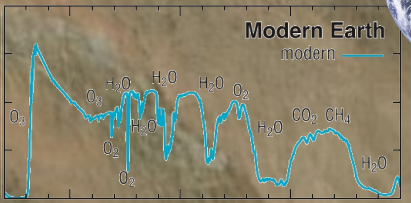
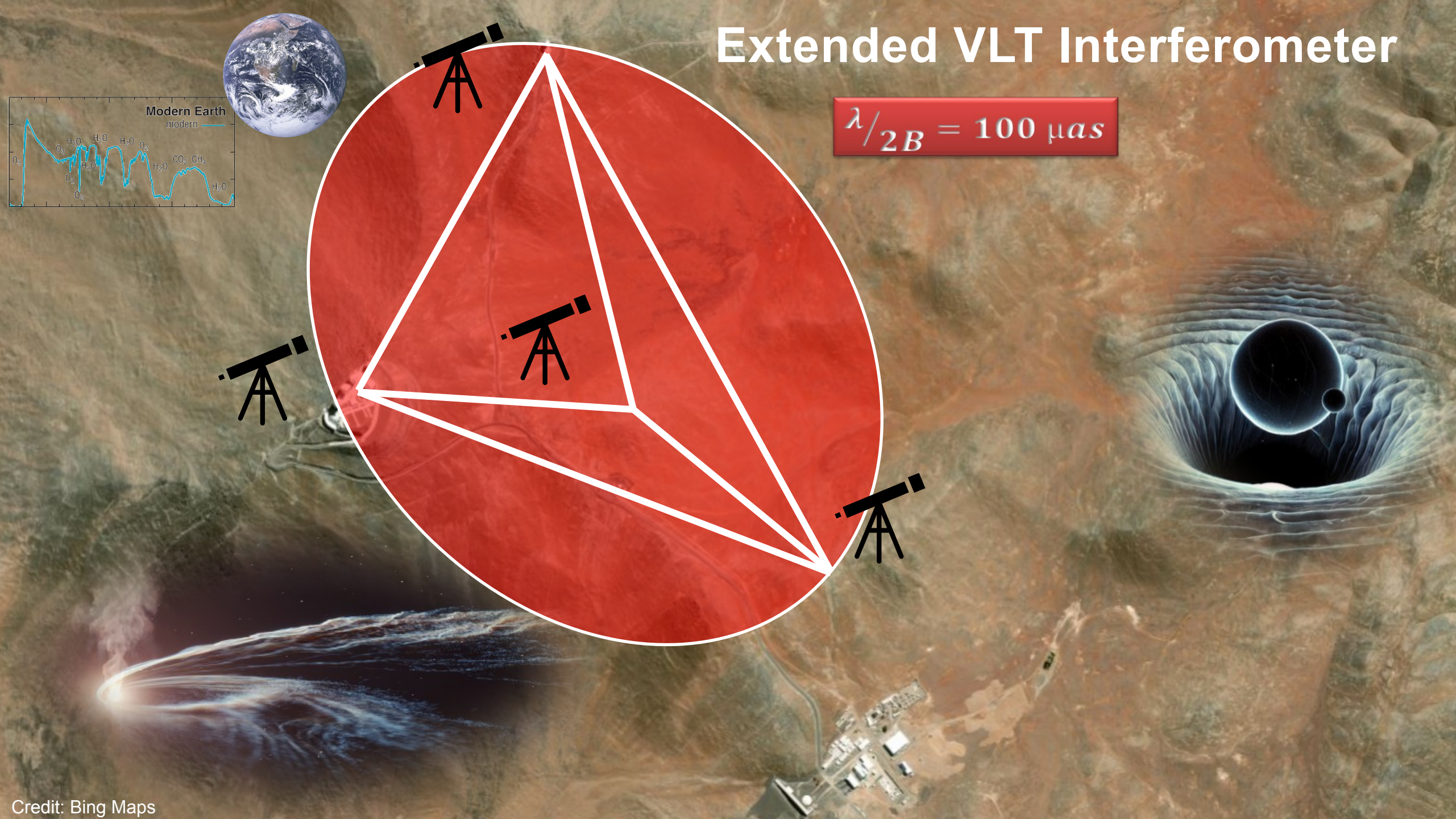
Beam Transport by Vacuum Tubes

Extensive Experience in
Gravitational Wave and
Particle Physics



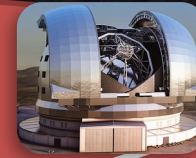
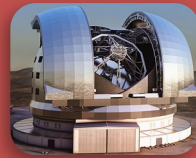
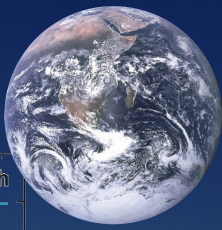
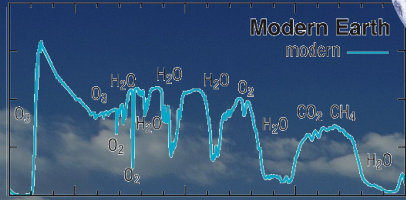
Extended VLT Interferometer

$$\lambda/2B = 100 \mu as$$



Kilometer Baseline Interferometer

$$\lambda/2B = 10 \mu as$$



10 km





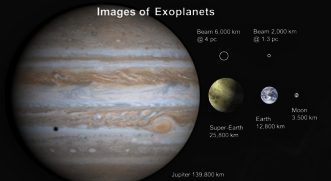
MAX PLANCK INSTITUTE
FOR EXTRATERRESTRIAL PHYSICS

Kilometer Baseline Interferometer



National Funding
and ESO TechDev

Thank you very much



KBI Demonstrator
on Paranal



KBI

E-VLTI



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2035

2045