From the rebirth of optical interferometry to its future in astronomy

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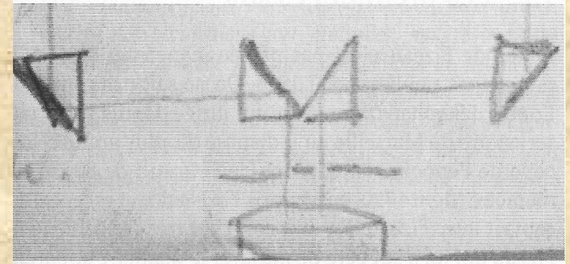
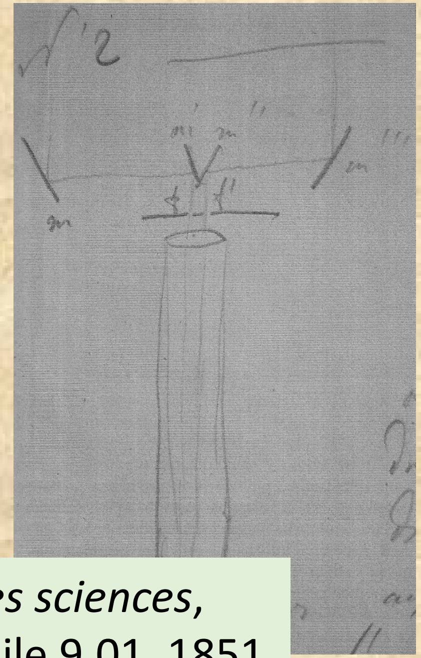
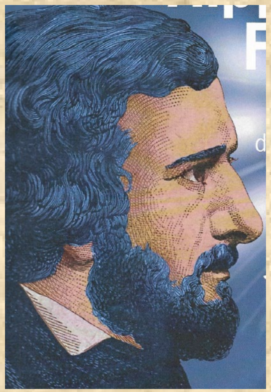
CHARA Science Meeting. - Nice, April 28-30, 2025

Optical interferometry in astronomy : a clear filiation

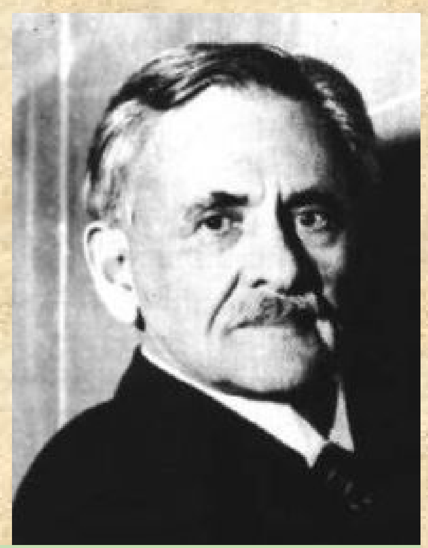
Hippolyte **Fizeau** (1851 to 1868), Albert Mi**chelson** (1891 to 1920), Antoine **Labeyrie** (1975 to today)



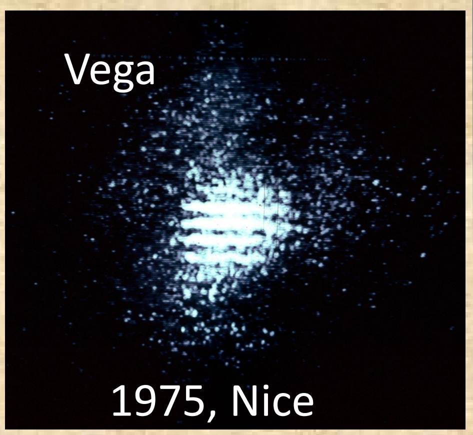


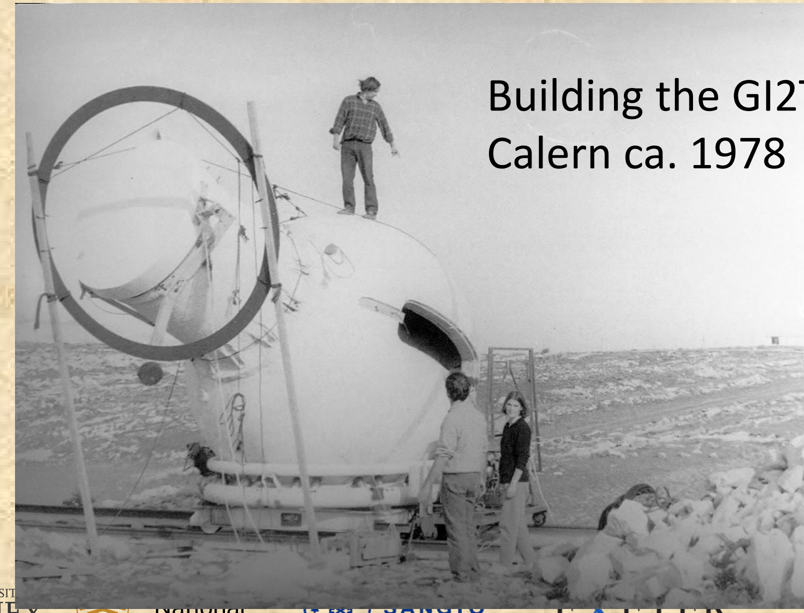


Archives *Académie des sciences*, Fonds 64J, H. Fizeau File 9.01, 1851



- Michelson, *Phil.Mag.*30, 1890
- Michelson, *Nature,* 45, 1891

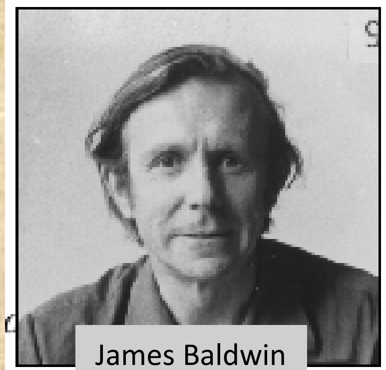




Two fertile interferometric decades (1980-2000)

Triggered by Labeyrie's success, small interferometers are built in Australia and USA, while Europeans plan for a VLT Interferometer : 4 telescopes (8-m) +4 (1.8-m)

Gerd Weigelt
Erlangen



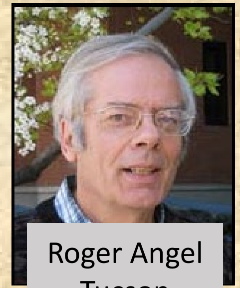
James Baldwin
Cambridge UK

Phase recovery and imaging

Exploring and solving critical issues

$r_o(\lambda) \propto \lambda^{6/5}$

$\tau_o(\lambda) \propto \lambda^{6/5}$

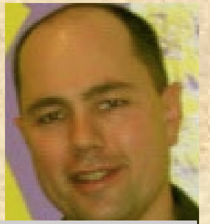


Roger Angel
Tucson

François Roddier
Nice, Tucson

D.L. Fried
Albuquerque

Seeing properties and λ dependence



Vincent Foresto
Meudon

Guy Perrin
Meudon

Spatial filtering & SM fibers

Reinhard Genzel
Garching

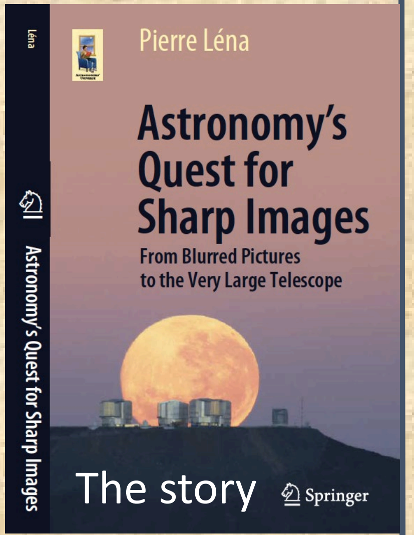
Speckle & Lucky imaging

Mike Shao
JPL

Dual feed & fringe tracking

2D - Infrared detectors
Format↑ Noise↓

Spectro-imaging
D.Bonneau, D.Mourard
Nice



The story

Adaptive optics is the key for the interferometric future

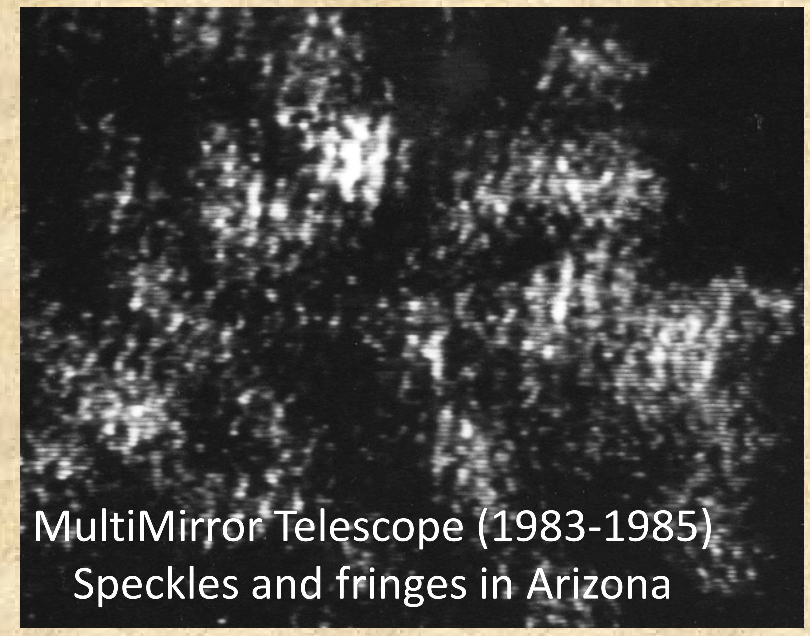
"The gambling taken by ESO in 1985 seems to have paid off"
Nature, October 1989

US Defence Programs : 1966-1992

RESTORATION OF ATMOSPHERICALLY
DEGRADED IMAGES
VOLUME 2
WOODS HOLE SUMMER STUDY
JULY 1966

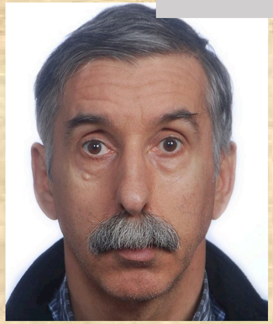
Advisory Committee to the
Air Force Systems Command

NATIONAL ACADEMY OF SCIENCES
NATIONAL RESEARCH COUNCIL

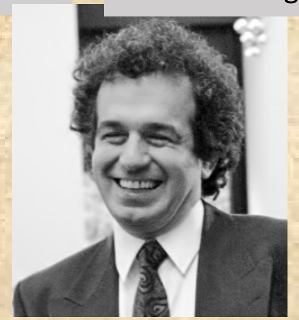


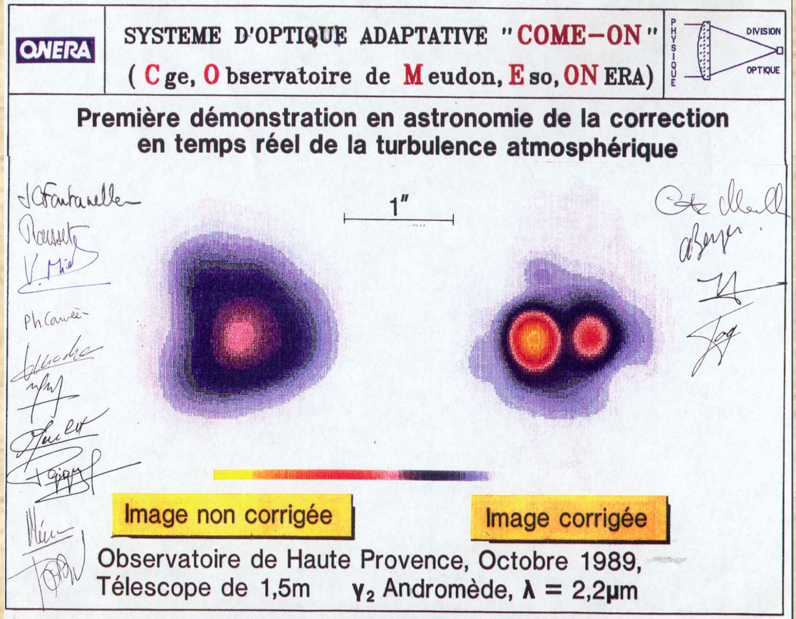
MultiMirror Telescope (1983-1985)
Speckles and fringes in Arizona

Gérard Rousset
Onera, Paris



Fritz Merkle
ESO Garching





1981 - 1985: Developments of ACE (*Atmospheric Compensation Experiment*) at MIT-LL.
Installed at AMOS 60-cm in 1982.
On loan to Mt Wilson in 1992 (astronomical use)
1992: Special issue of JOSA. Declassified results.
AO on Keck P. Wizinowich 2000

Mark III, Mt. Wilson (1986)
M. Shao & M. Colavita

COAST, Cambridge, UK
J. Baldwin (end 1980s)

Erlangen (Germany)
G. Weigelt (end 1980s)

IOTA, Cambridge USA (1990s)
W. Traub

CERGA (France) : I2T (1974), GI2T (1986), Soir d'Eté (hétérodyne)
A. Labeyrie et al, P. di Benedetto, J. Gay, F. Roddier

IRMA, Wyoming (1986)
M. Dyck, S. Ridgway

CHARA, Mt.Wilson, GSU
H. McAlister (end 1980s)

MMT, Arizona, a Fizeau interferometer (1983)
Keith Hege et al. , J. Beckers, F. Roddier

10.6 μm heterodyne @ **McMath (Arizona), Mt. Wilson** (1974..)
C. Townes

A small community,
but organized exchanges
ESO – NOAO
(Oracle, Ariz, 1987)

SUSI, Australia (1985)
J. Davis & W. Tango

A constant and fertile collaboration(1980-2000)
ESO - NOAO

The 2025 interferometric landscape

CHARA, LBT, MROI, NPOI, LBT in United States
VLTI in Europe

What is next ?

January 27-30, 2025, celebrating the 40th anniversary of VLTI start (1985)

Could some of these rich *Horizons* help shaping the future ?
Could one learn from some similarities with the 1980s
when ESO (for VLT) and NOAO (for NNTT) were exploring this future ?

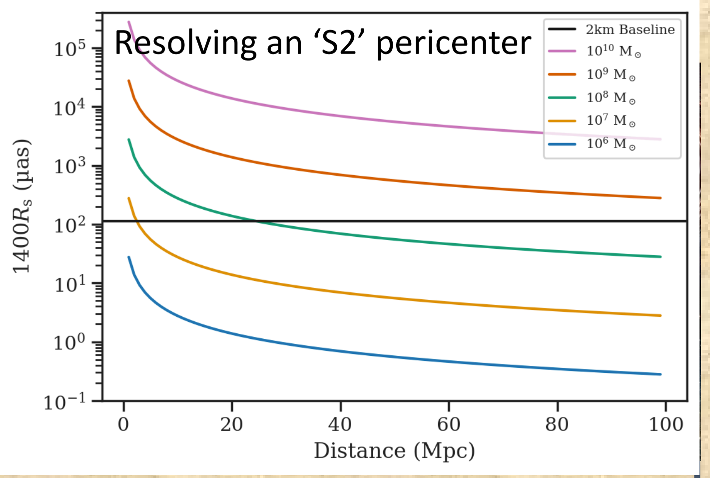
The next ESO Programme should be identified in line with ESO's vision and strategy. It should be a transformational facility in the 2040s landscape : http://next.eso.org (Mérand*, in *Horizons Conf. 2025*)

Preparatory phase	Call for ideas	Assessment phase	Decision
July 2024–Q3 2026	Q3 2026–Q2 2027	Q3 2027–Q3 2028	3–Q4 2028
• Present and explain the process to the community • Trigger dialogue about astronomy challenges & disruptive technologies in 2040s	• Launch of call: Q3 2026 • Letters of Intent due 1 Dec 2026 • Proposals due: 1 Jun 2027	• Performed by SSC and ESO Executiv • Transparently sha e what ideas are be ng proposed at a dedicated commun ty workshop	• Presented at STC a Finance Committee • ~~Council decision~~ • Decision is **not** the start of the new Programme

Horizons for Galactic & Extragalactic astronomy

Shimizu T (Garching), in *Horizons 2025*

- *J0920: First dynamically measured SMBH masses 10^8 $M_\odot$ at z=2.3 (Abuter+ 2024)
- The curious case of the *Little Red Dots* JWST (Matthee+ 2024)
- Resolving the accretion disks of SMBH
- * The S2 Experiment in other galaxies

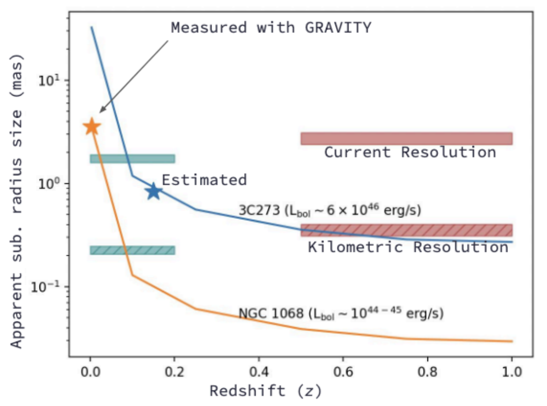


Eisenhauer F (Garching), in *Horizons 2025*

- Kilometers baseline interferometer
- Resolution 10 marcsec, Sensitivity m_{AB}=28

Isbell J (Tucson), AGN in the 2040, in *Horizons 2025*

- Shape and nature of the BLR



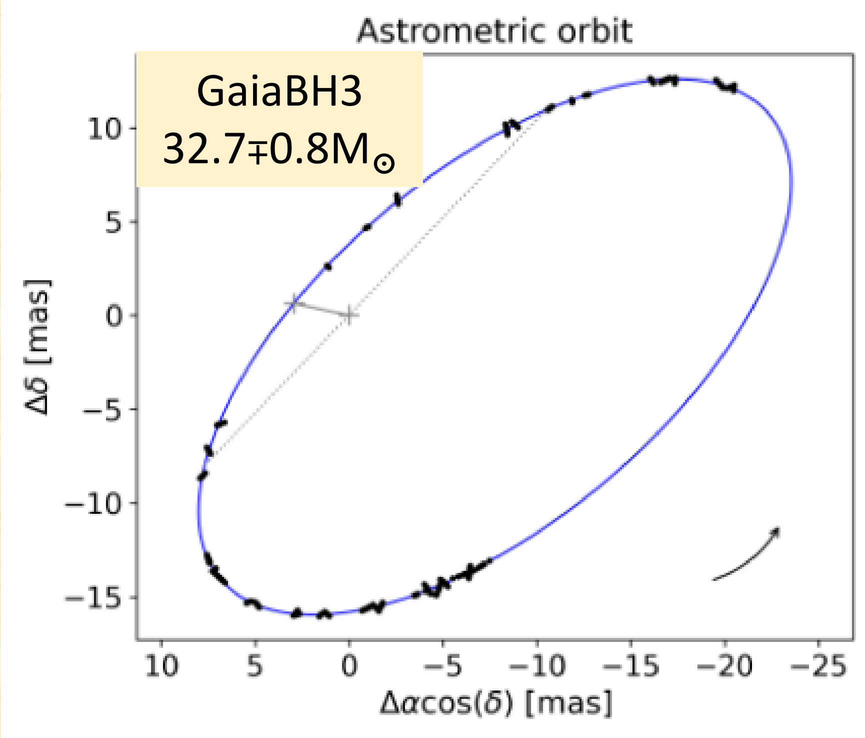
Genzel R (Garching), in *Horizons 2025*

- Massive black holes in galaxies (beyond Gravity, LIGO, EHT)

Horizons for Stellar astronomy

Kervella P (Meudon), in *Horizons 2025*

- Stellar activity
- Seeds of SMBH on Gaia astrometry

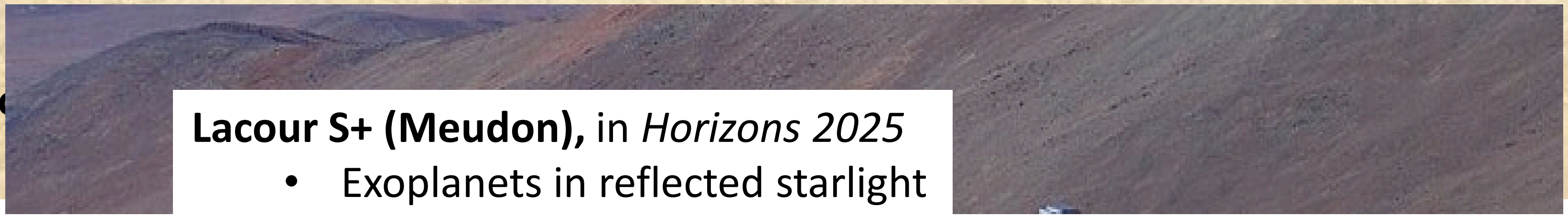


Panuzzo P+, Gaia Coll. 2024

Stellar physics and interferometry in the 2040s

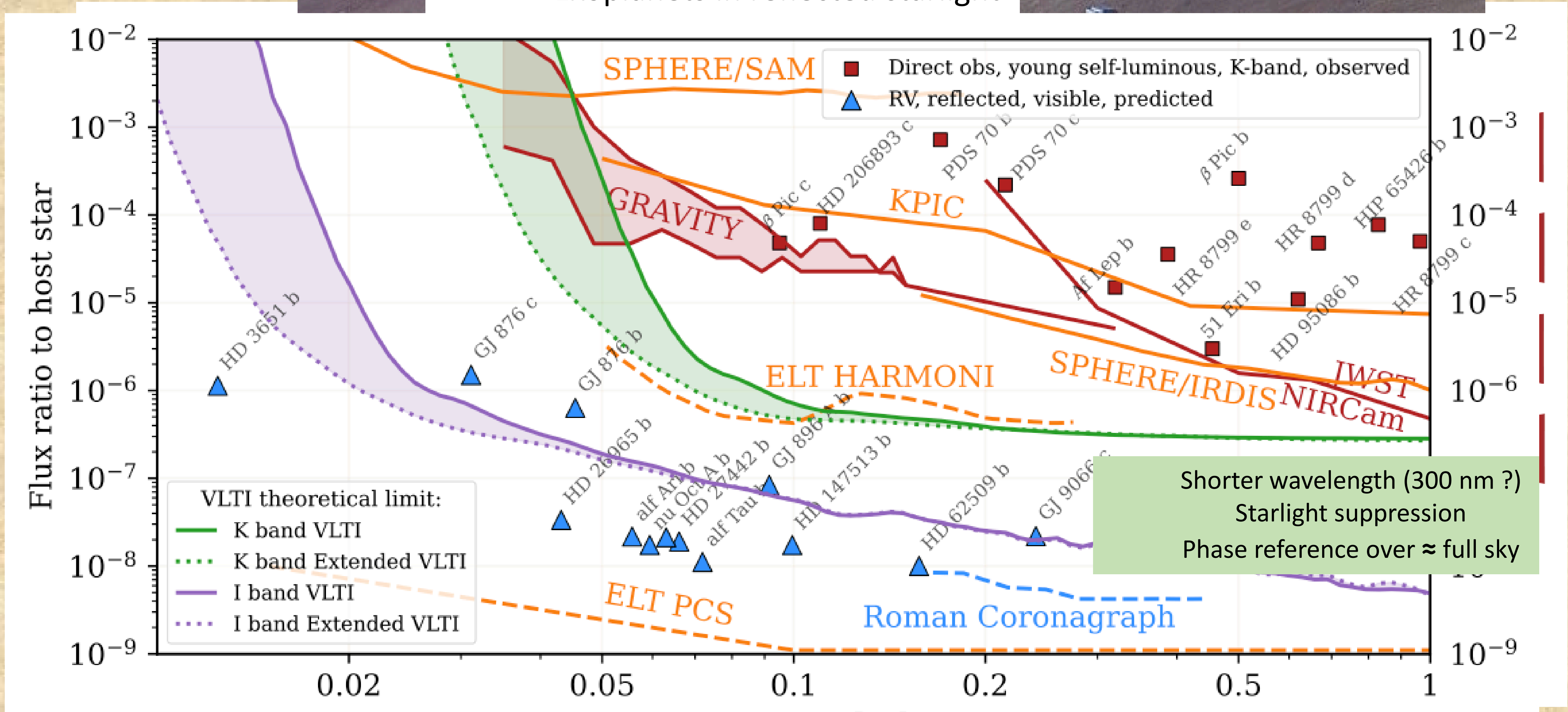
- **Many exciting scientific questions:**
  - Star formation, late stages of stellar evolution, angular momentum transport, convective energy transport, role of magnetic fields, stellar activity and star-planet interactions, most massive stars, Population III stars…
- **Key technical requirements:**
  - ***High spectral resolution mode (R~100,000)*** *broadband spectroscopy with exoplanet-level stability (spatially resolved RVs on stellar disks and binaries)*
  - ***High angular resolution (<100 µas)****, matching the interferometer sensitivity, to resolve fine surface structures, reach extragalactic objects, rare MW stars and compact objects*
  - ***Microarcsecond astrometry****, wide-angle phase referencing and* ***dual field*** *for Gaia follow-up and dynamical studies of multiple star systems*

Horizons for Planets, YSOs, Moons, Small bodies



Lacour S+ (Meudon), in *Horizons 2025*

- Exoplanets in reflected starlight



Adpated from Pourré et al. (2024)

Shorter wavelength (300 nm ?)
Starlight suppression
Phase reference over ≈ full sky

Some concluding remarks

During the 1980s, physics was clear, instruments were primitive, early scientific prospects were great, while **adaptive optics was the major stumbling block** and the community at large remained skeptical

Three major factors played favorably : some **key person's** vision, a **strong cooperation** on both sides of Atlantic and agreement to **postpone space interferometry** to a remote future

Adaptive optics was solved (1989) + Spatial Fitering (SM fibers)
CHARA, KECK and VLTI followed with superb engineers

At the 2040 Horizon
No question anymore on the science potential of an ambitious, ground-based interferometry program

FUTURE 1
Upgrading existing instruments
(CHARA, VLTI at ELT era) seems feasible

FUTURE 2
A new kilometric Array is a formidable and costly task
Stumbling blocks :
Km beam transport Phase delay compensation
Overall Throughput Sky coverage (dual beam)

Organize broad, transatlantic continuous exchanges (ESO, NoirLab)....
Dare exploring unconventional solutions (Quantum physics…)

The world interferometric community
1987, Oracle (Arizona)