Astronomical aperture synthesis with mid-infrared heterodyne interferometry

Collaborations
- LP-ENS C. Sirtori

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Thanks
- Y. Lecoq
- P.-E. Potie
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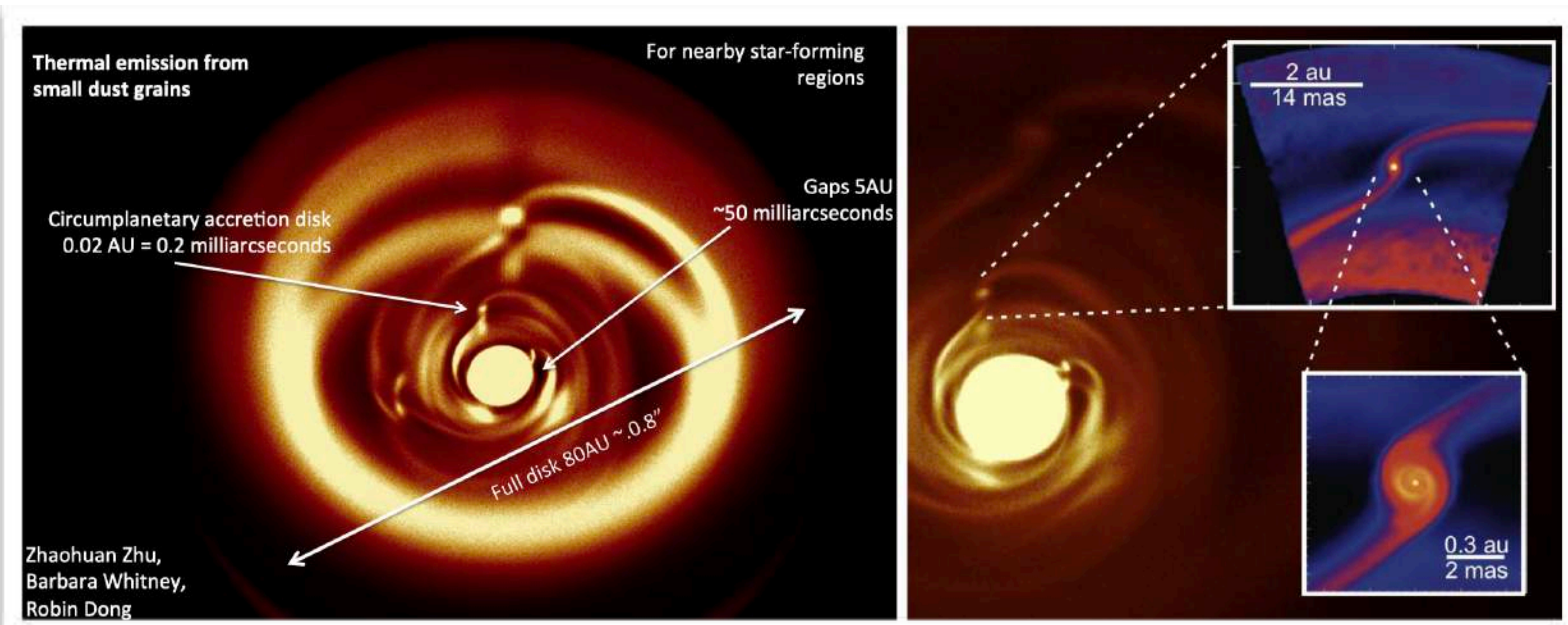
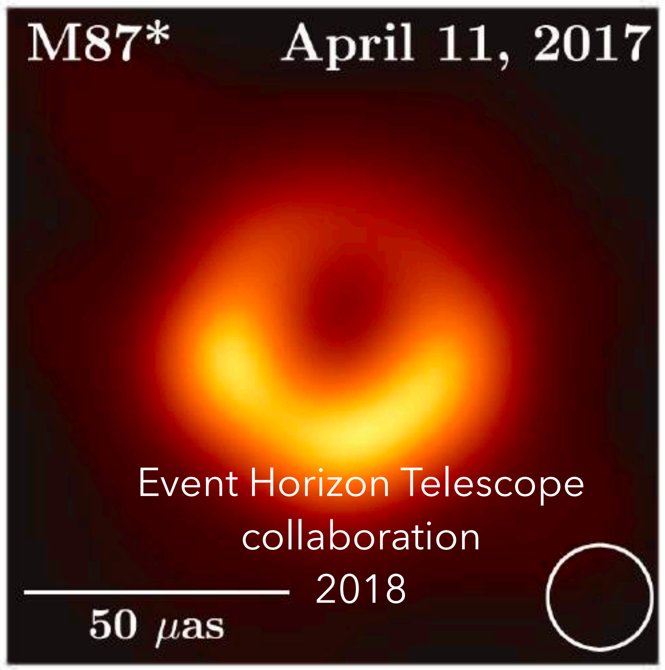


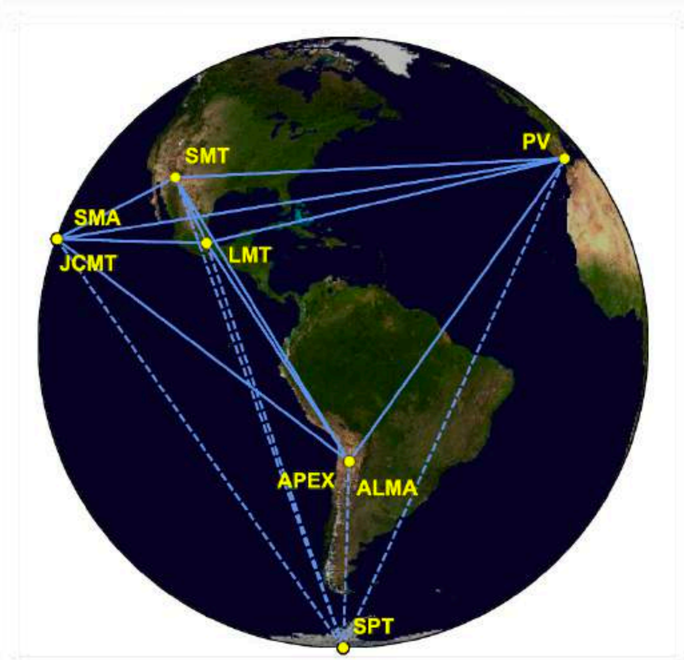
AG REFIMEV 20 Novembre 2020

Funding FOCUS Focal Plane Array for Universe Sensing INSU CNRS

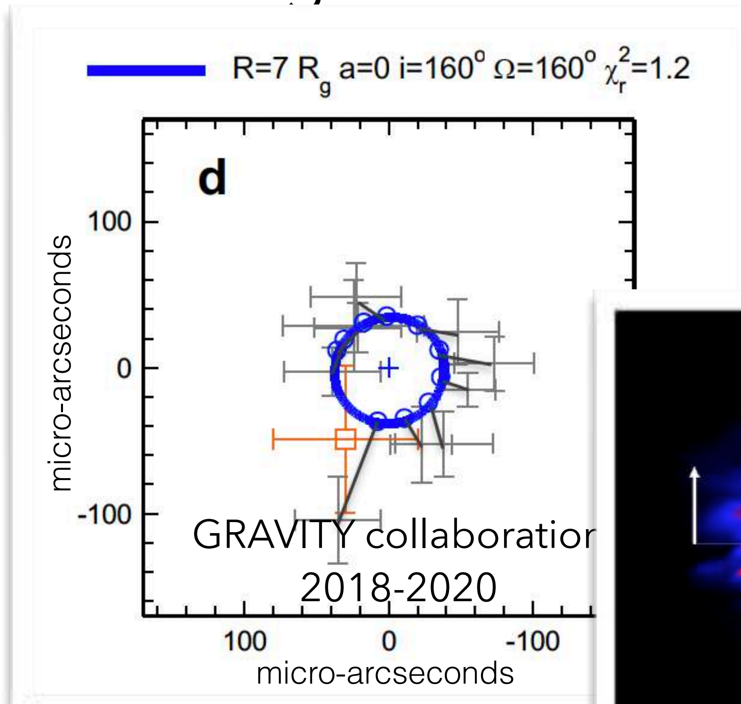
Direct detection of the close environment of two super-massive black-holes

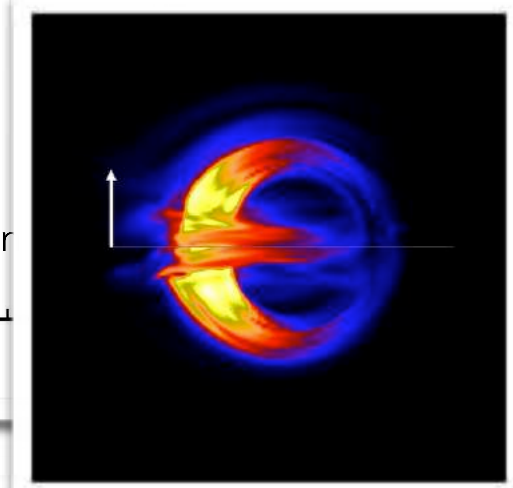
Wavelength= 1.3 mm

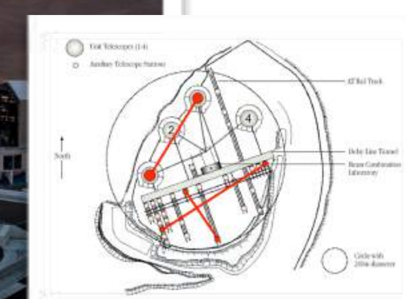




Wavelength= 2.2 microns

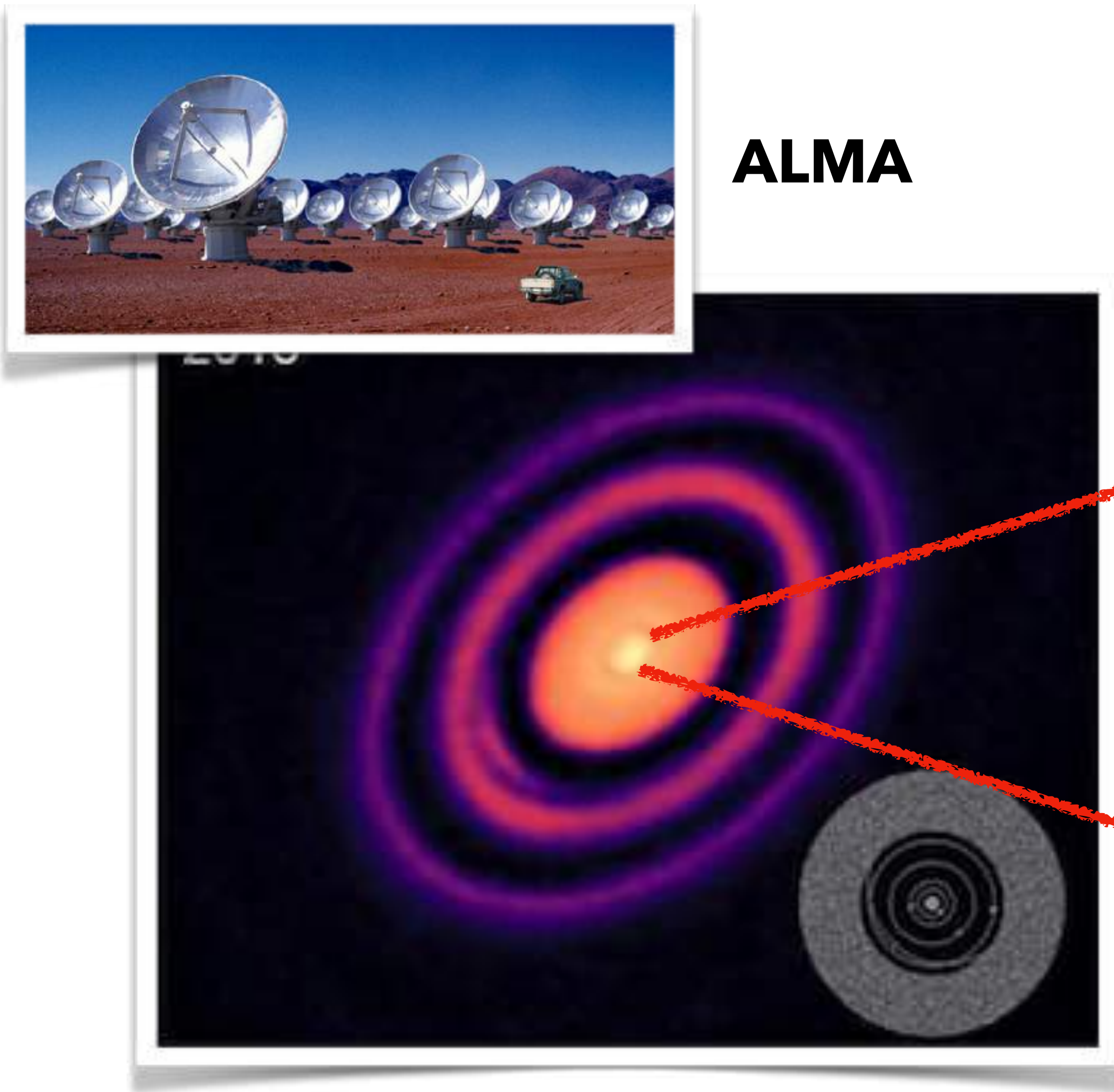






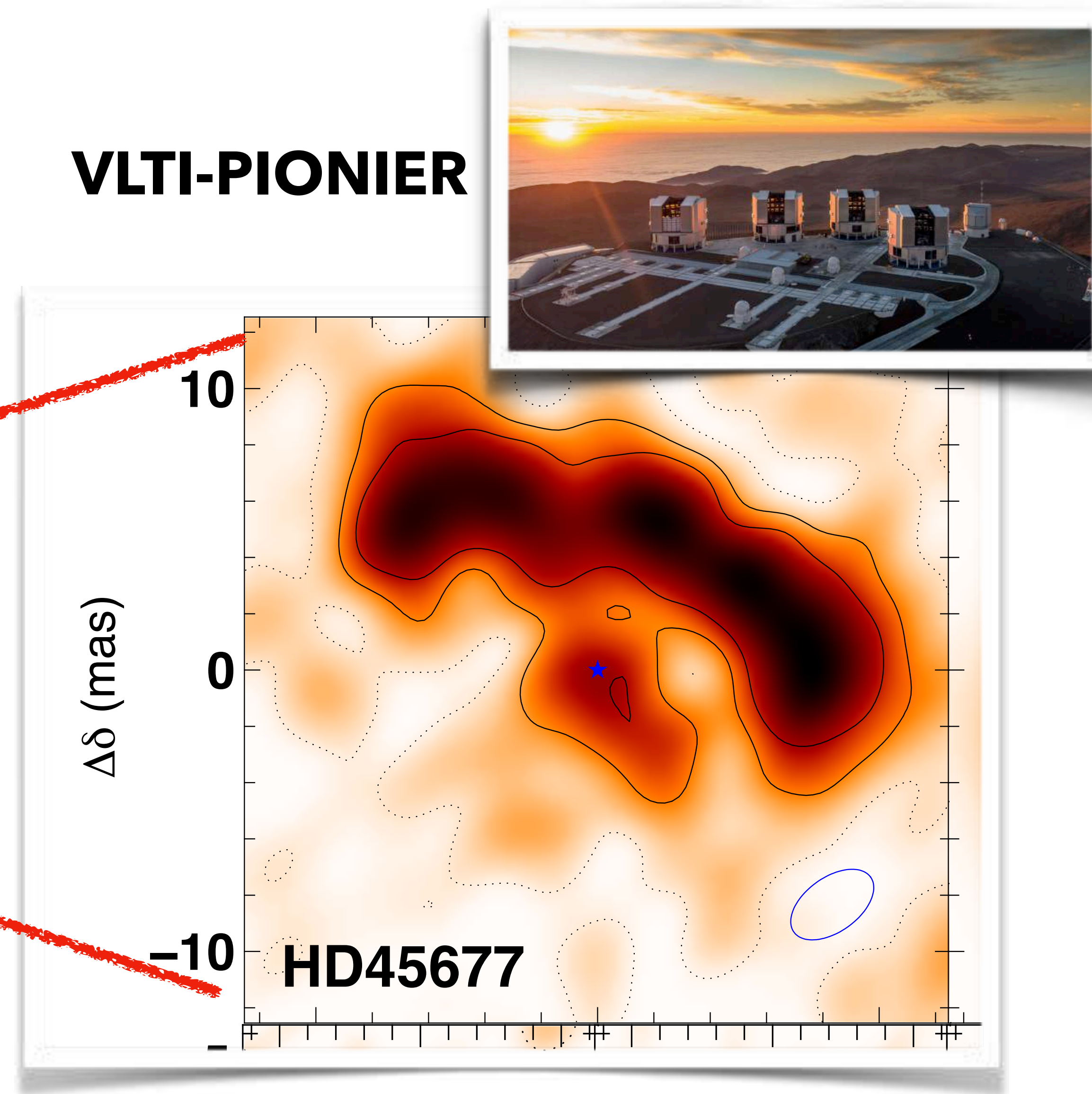
Infrared interferometry image complexity is limited by the number of telescopes

ALMA



Isella et al. 2018

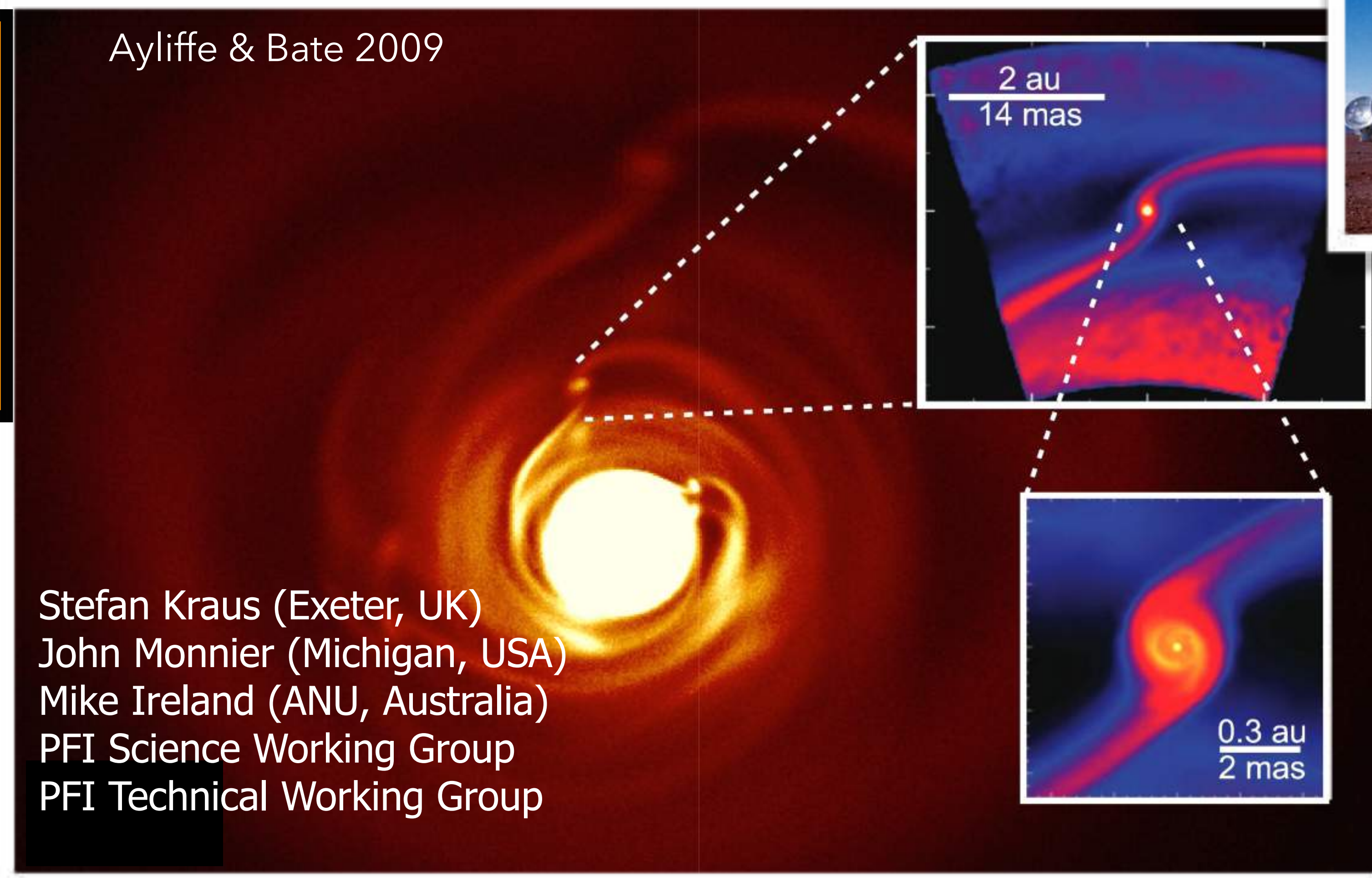
VLTI-PIONIER

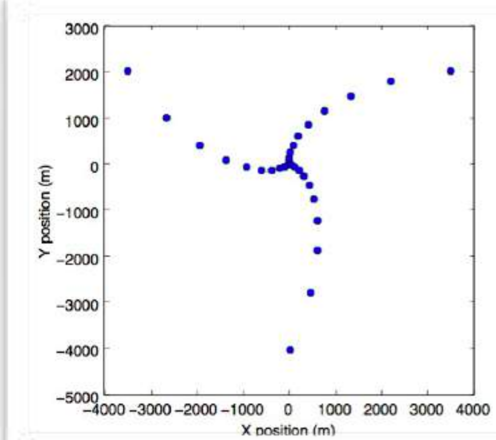


Kluska et al. 2020

Planet Formation Imager: a facility designed to image the key stages of planet formation

- PI: J. Monnier
- PS: S. Kraus
- IS: M. Ireland
- SW Group
- TW Group

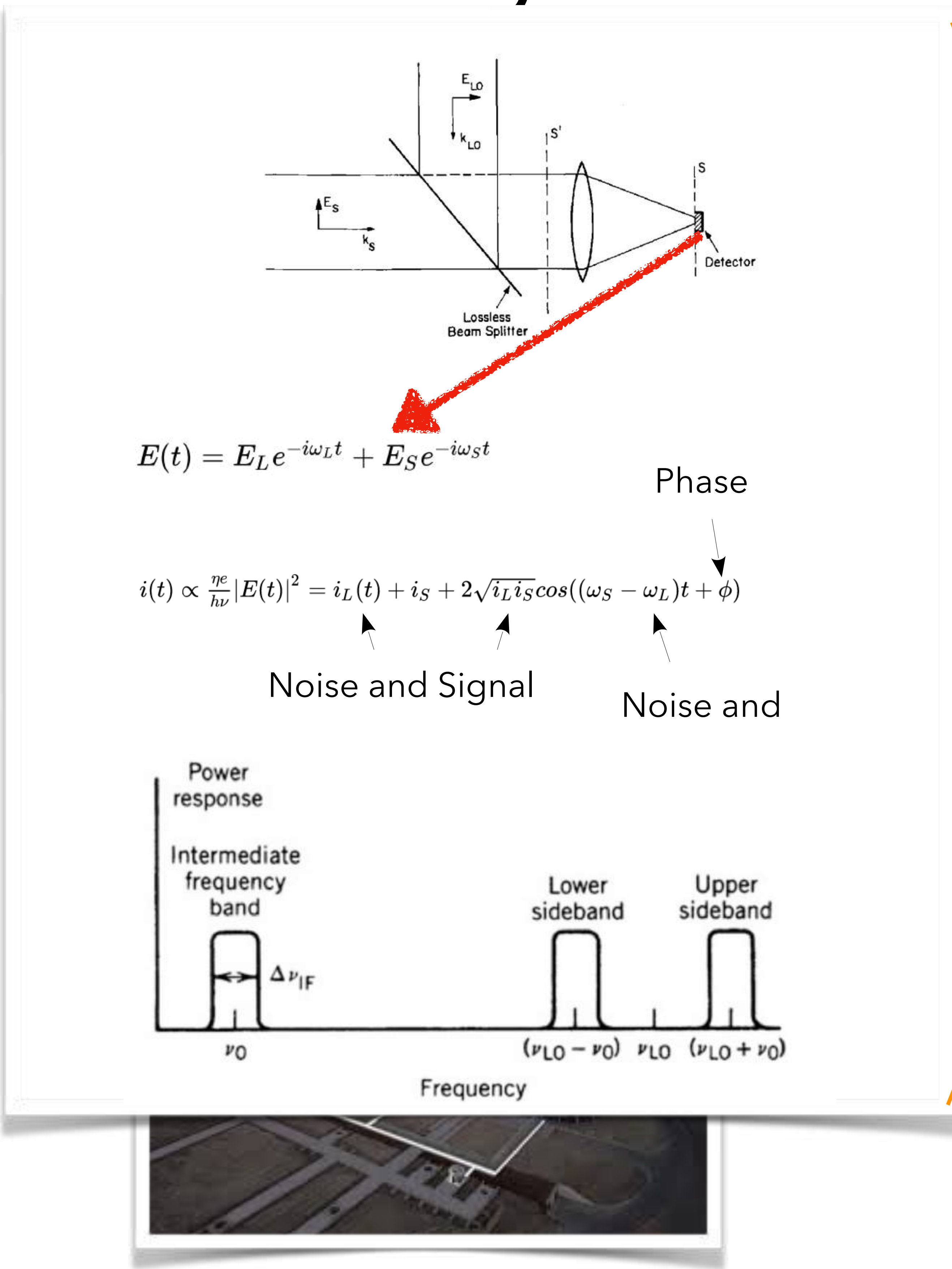




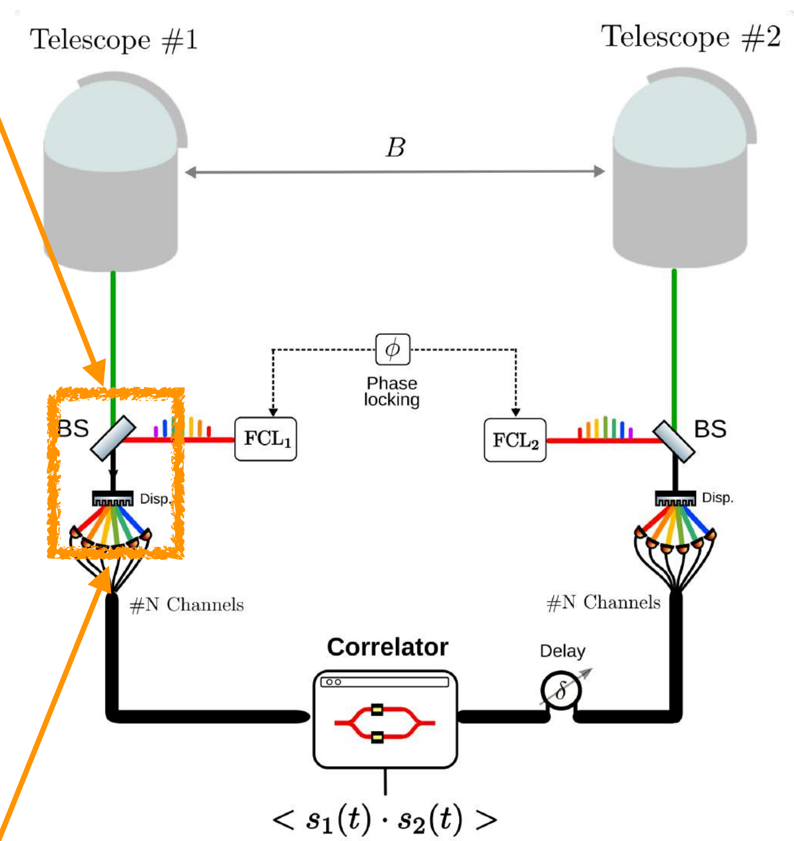
Top level science requirements

- Caracterising young exoplanets up to Taurus
- Resolving circumplanetary disks spatially and kinematically
- Mappping dust distribution and kinematics

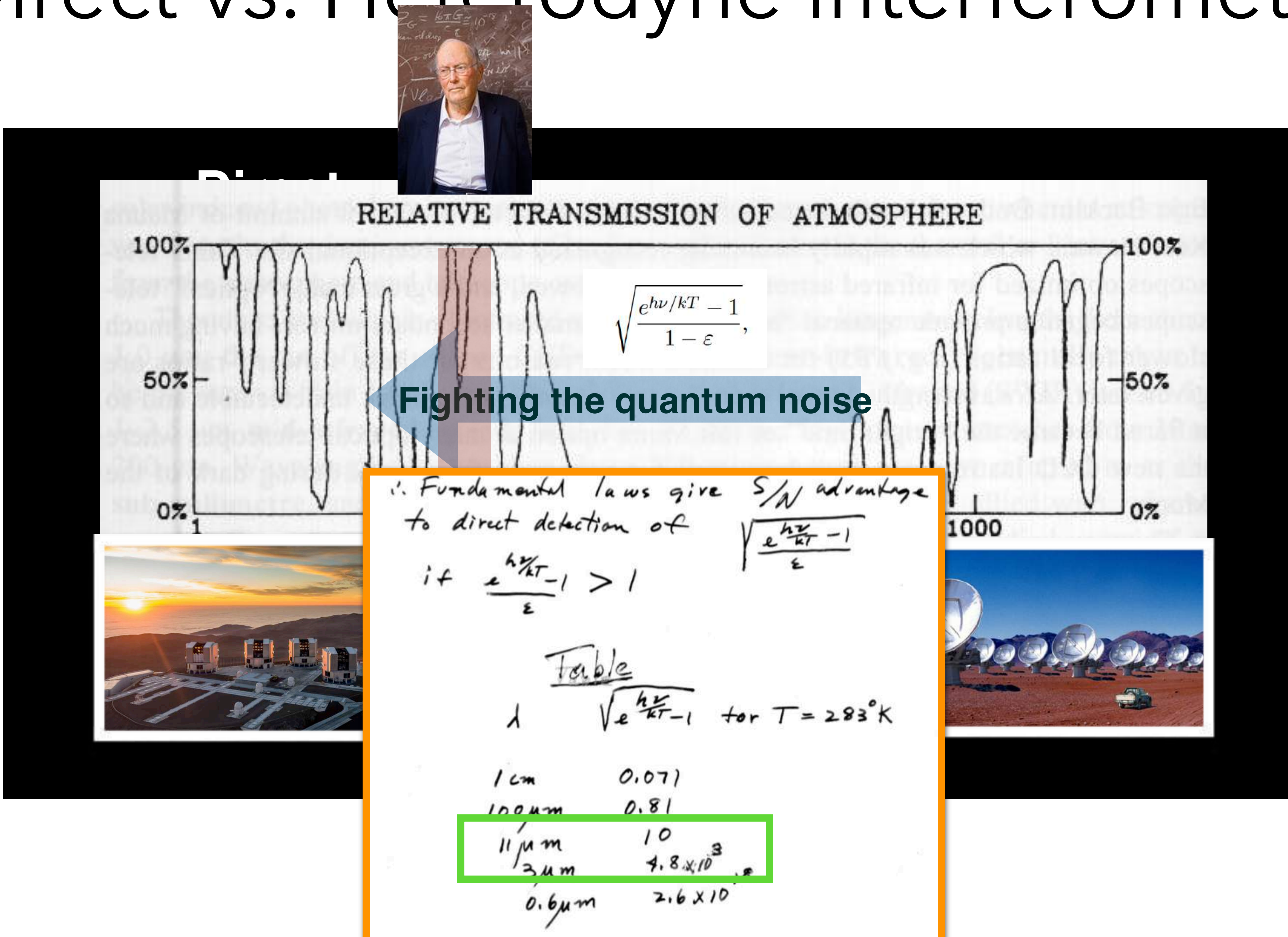
Two ways to do interferometry



Heterodyne interferometry



Direct vs. Heterodyne interferometry

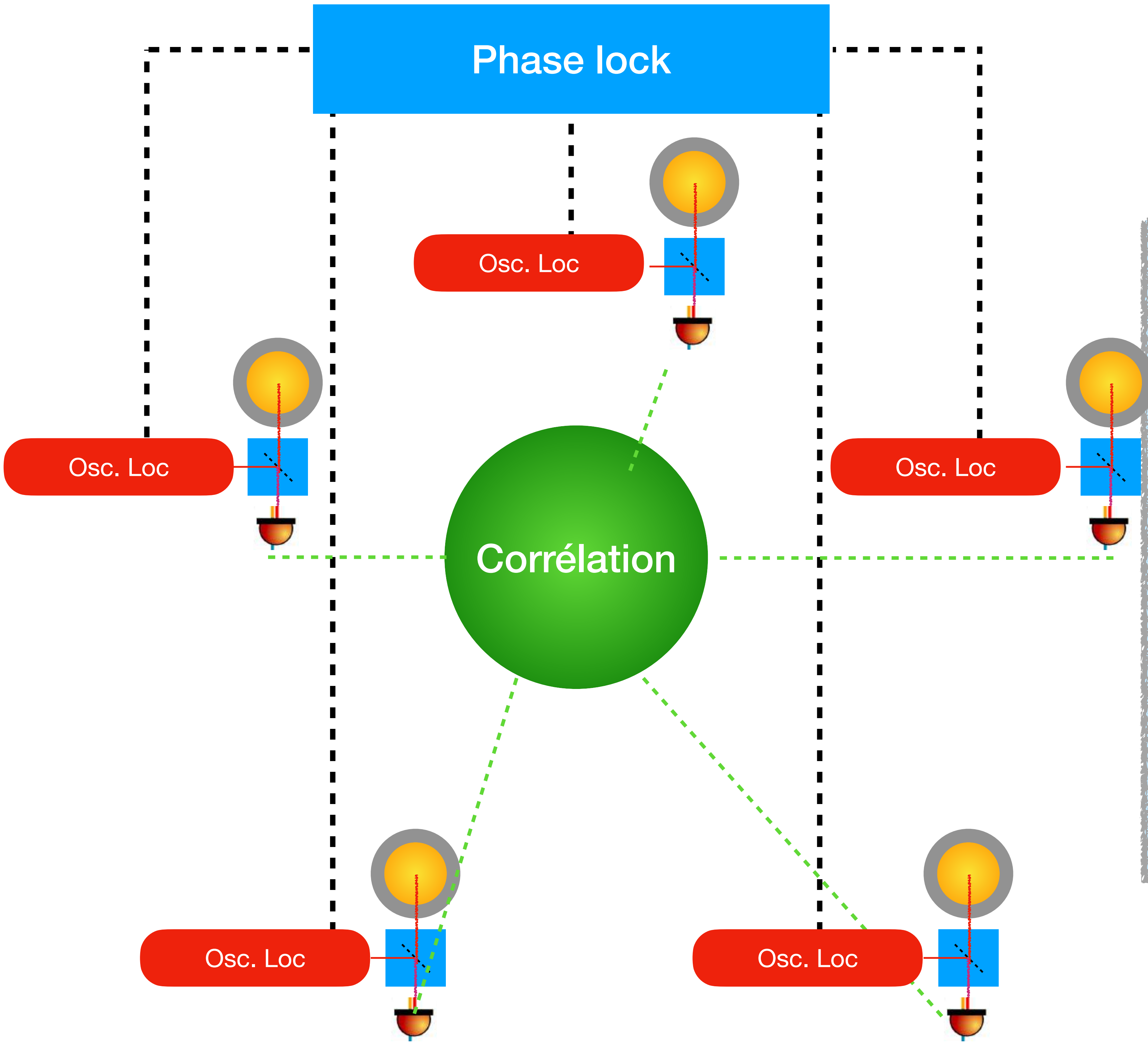


Direct vs. Heterodyne interferometry

- Intrinsically more sensitive BUT …
- Simpler instrumentation
- Broad band
- Complex and expensive infrastructure
- Loss of sensitivity with the number of telescopes

- Less sensisitive (quantum noise)BUT … Narrowband
- More complex instrumentation
- Simpler infrastructure
- Better adapted to a high number of telescope (can be amplified)

Can we expand the scheme for N > 10 telescopes over kilometric baselines ?



Challenges

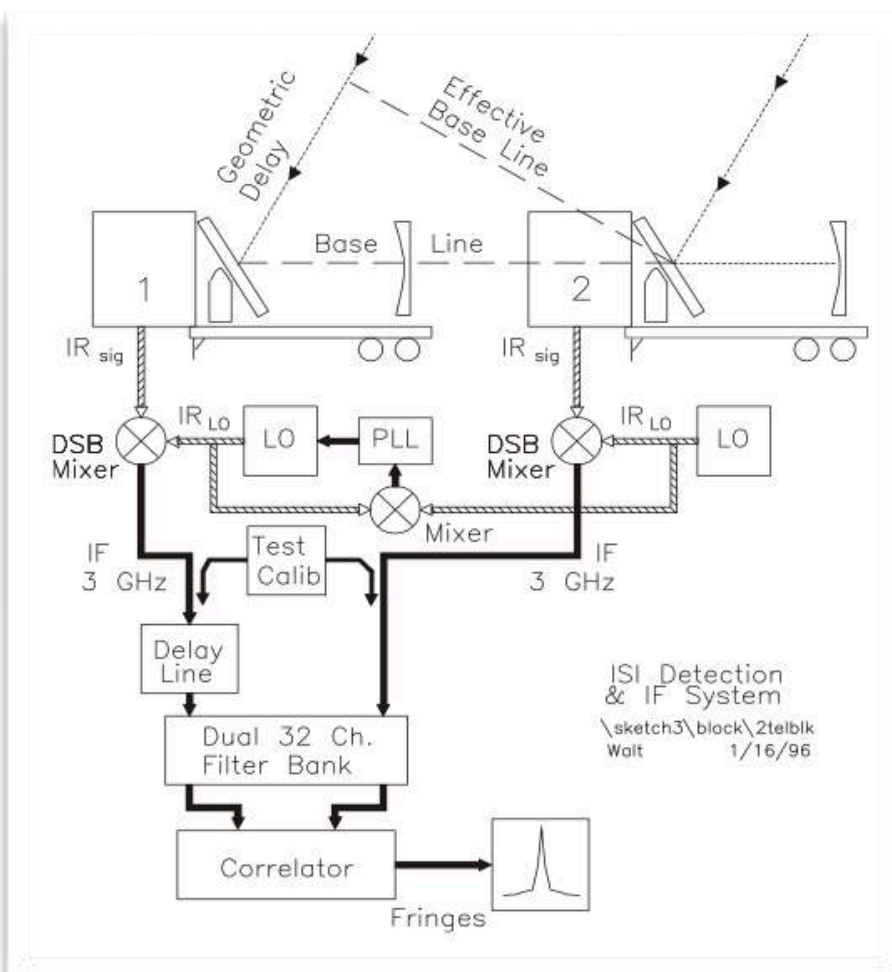
- Low-cost telescope technologies
- Sensitive high bandwidth detectors (~40 GHz)
- Mid-Infrared frequency combs
- Efficient "cheap" HR dispersers
- Phase lock over km baselines
- Correlators capable of handling > 10 Telescopes & 40 GHz signals

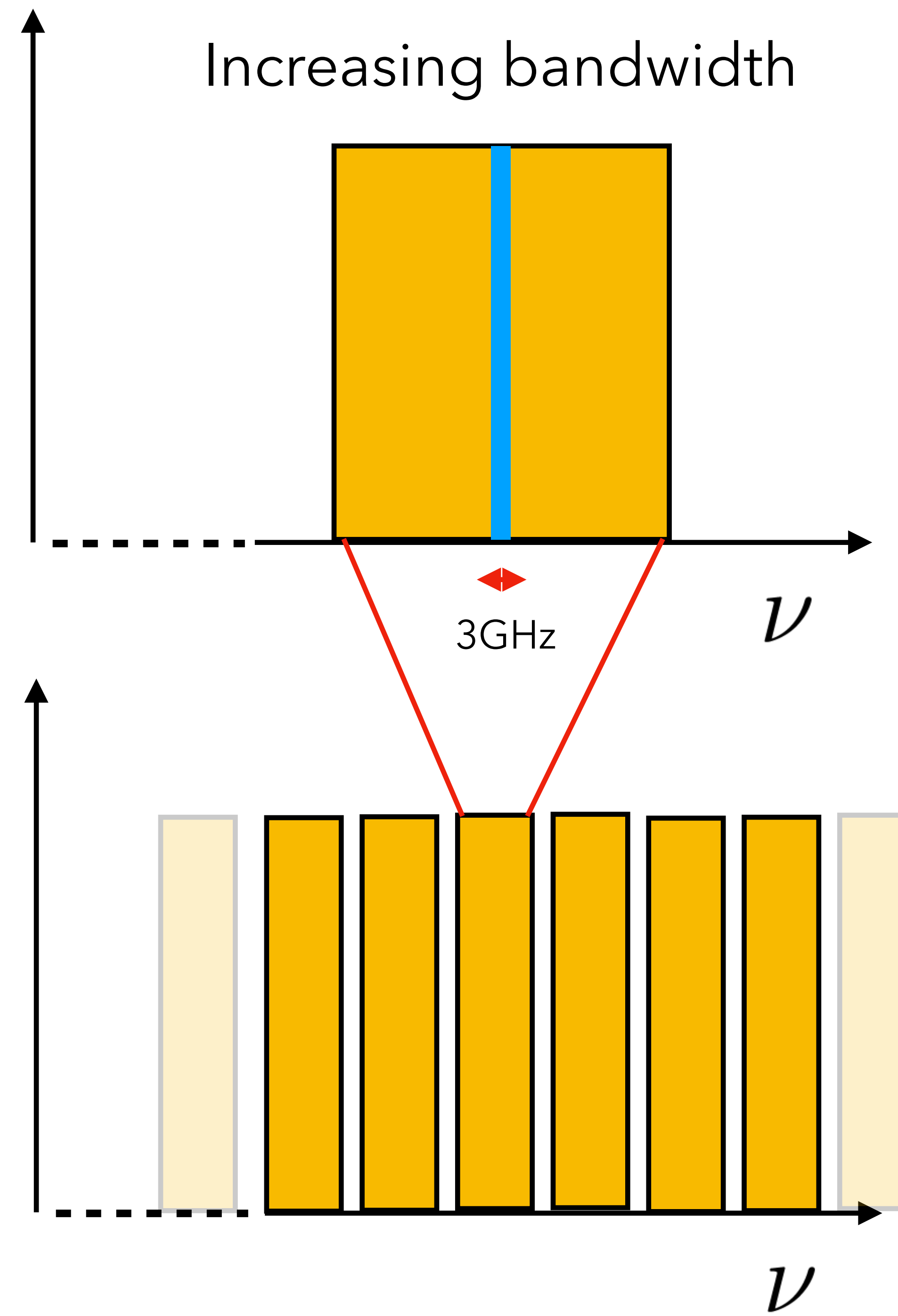
Technological vision: no free space propagationlimited "relay" infrastructure

Increasing sensitivity

Berkeley Infrared Space Interferometer

Hale et al. 2000, Danchi et al. 2003





Using frequency combs

Laser frequency comb

Specific constraint:
Comb with wide (~10GHz) separations

Advances in Optics and Photonics

Electro-optic frequency combs

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Frequency combs are optical spectra composed of a set of discrete equally spaced lines. Such spectra can be generated by diverse sources such as mode-locked lasers, resonators, or electro-optic modulators. This last possibility has shown a growing interest in the recent years for its advantageous features in providing high repetition rates, intrinsic mutual coherence, or high power per comb lines. Moreover, applications of electro-optic modulator-based combs have flourished in fundamental physics, spectroscopy, or instrumental calibrations. In this paper, we present the most recent progresses made on frequency combs generated by electro-optic modulators, along with the applications where these combs have shown a particular interest.

High bandwidth detection

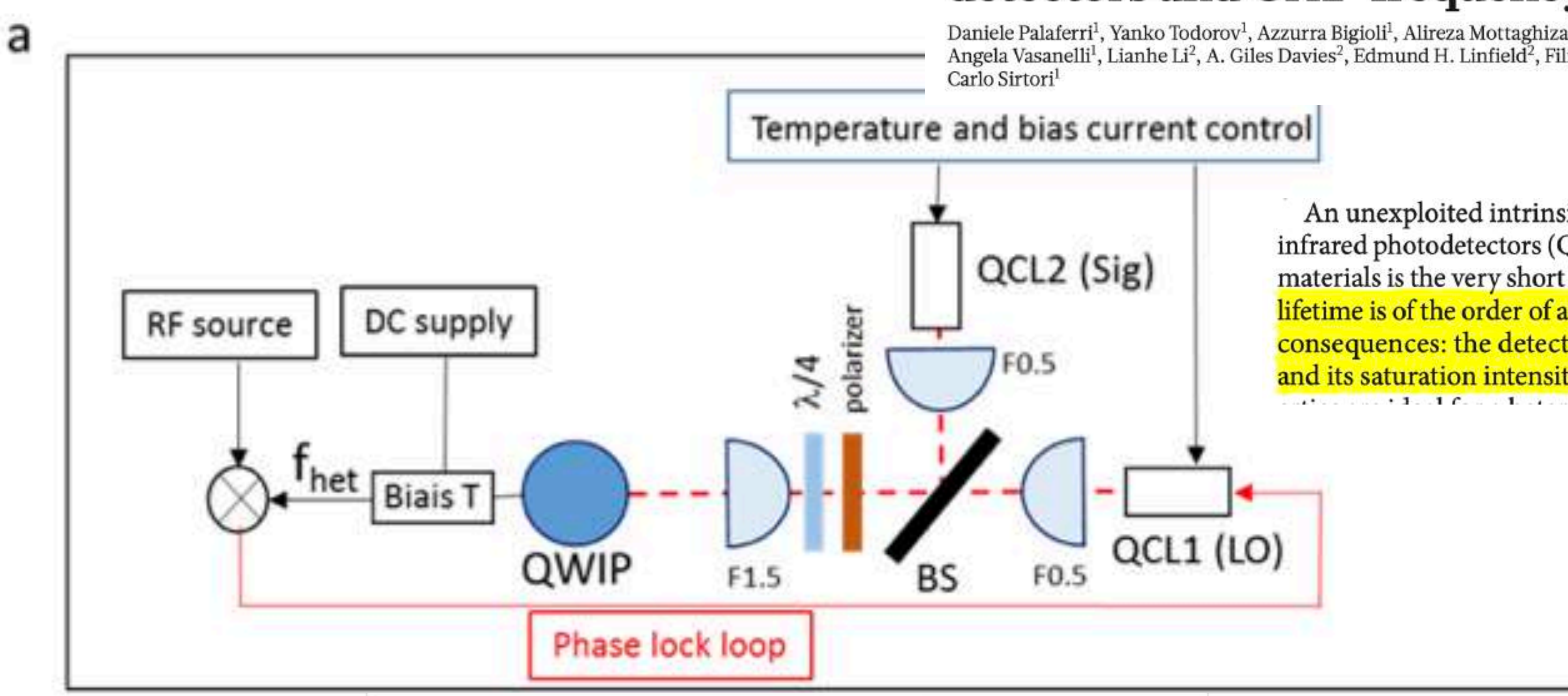
LETTER

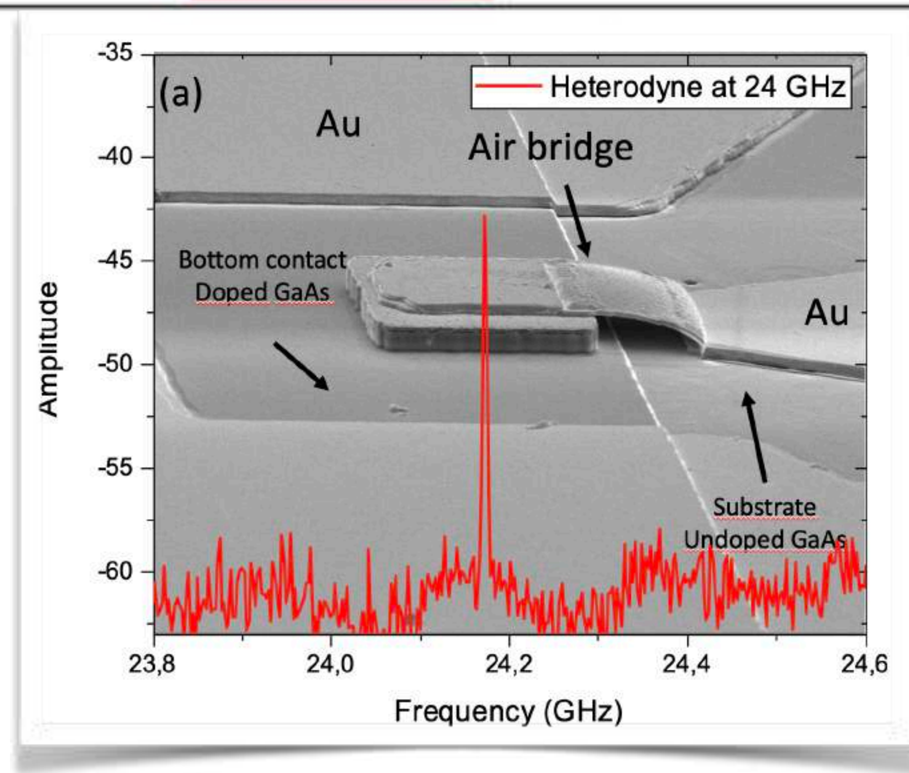
doi:10.1038/nature25790

Room-temperature nine-µm-wavelength photodetectors and GHz-frequency heterodyne receivers

Daniele Palaferri[1], Yanko Todorov[1], Azzurra Bigioli[1], Alireza Mottaghizadeh[1], Djamal Gacemi[1], Allegra Calabrese[1], Angela Vasanelli[1], Lianhe Li[2], A. Giles Davies[2], Edmund H. Linfield[2], Filippos Kapsalidis[3], Mattias Beck[3], Jérôme Faist[3] & Carlo Sirtori[1]

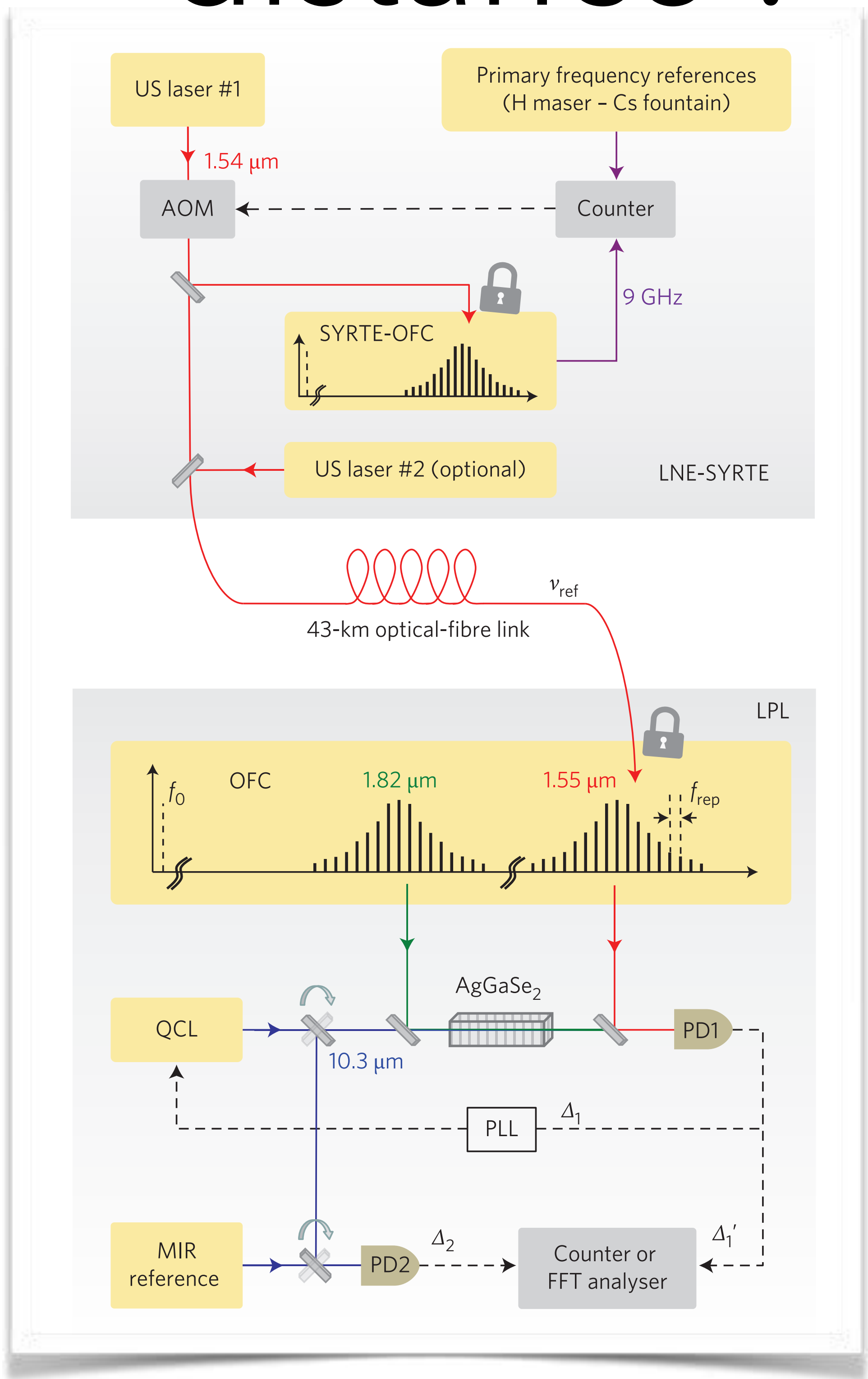
An unexploited intrinsic property of inter-subband quantum-well infrared photodetectors (QWIPs) based on group III–V semiconductor materials is the very short lifetime of their excited carriers. The typical lifetime is of the order of a few picoseconds[7], which has two important consequences: the detector frequency response can reach 100 GHz and its saturation intensity is very high[19] (10^7 W cm^{-2}). These prop-





C. Sirtori (LPENS) group, Palaferri et al. 2018, Gacemi et al. 2018, Bigioli et al. 2020

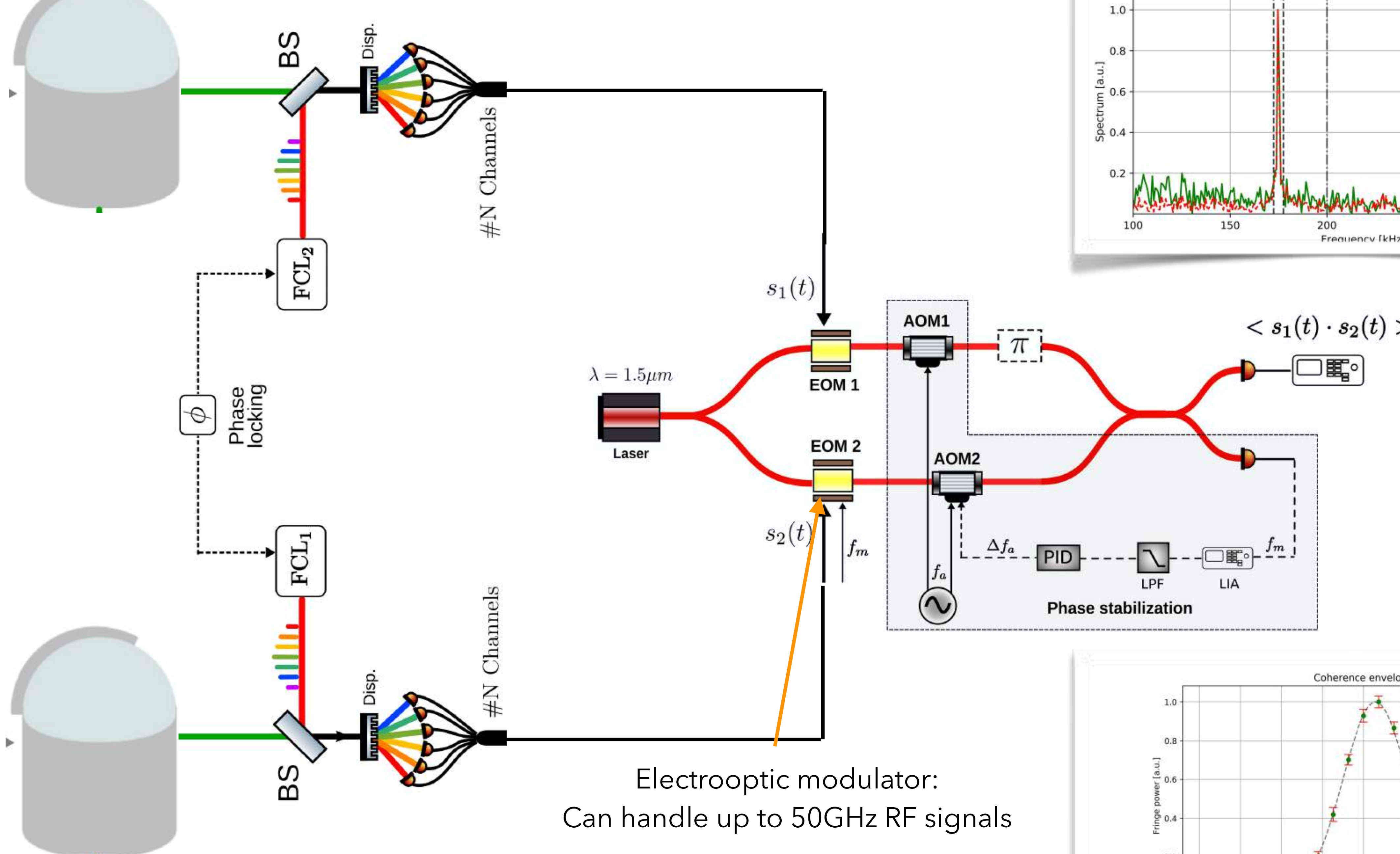
Locking a mid-IR laser at km distance !

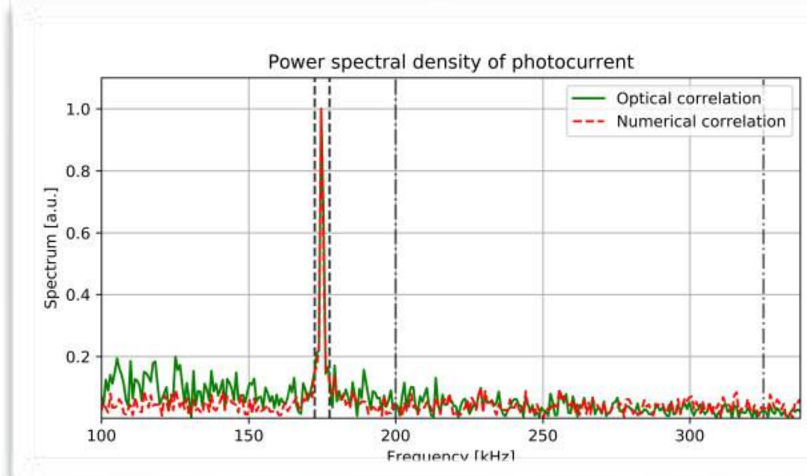


Argence et al. 2015

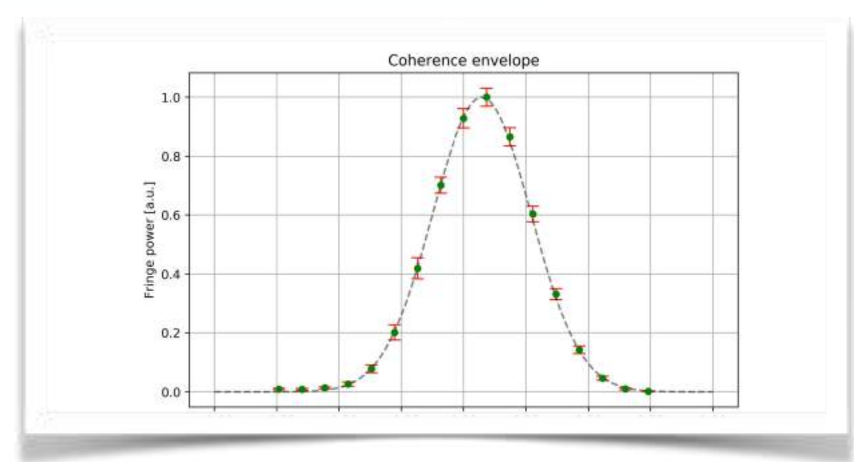
A photonics based correlator

Bourdarot et al. A&A 2020



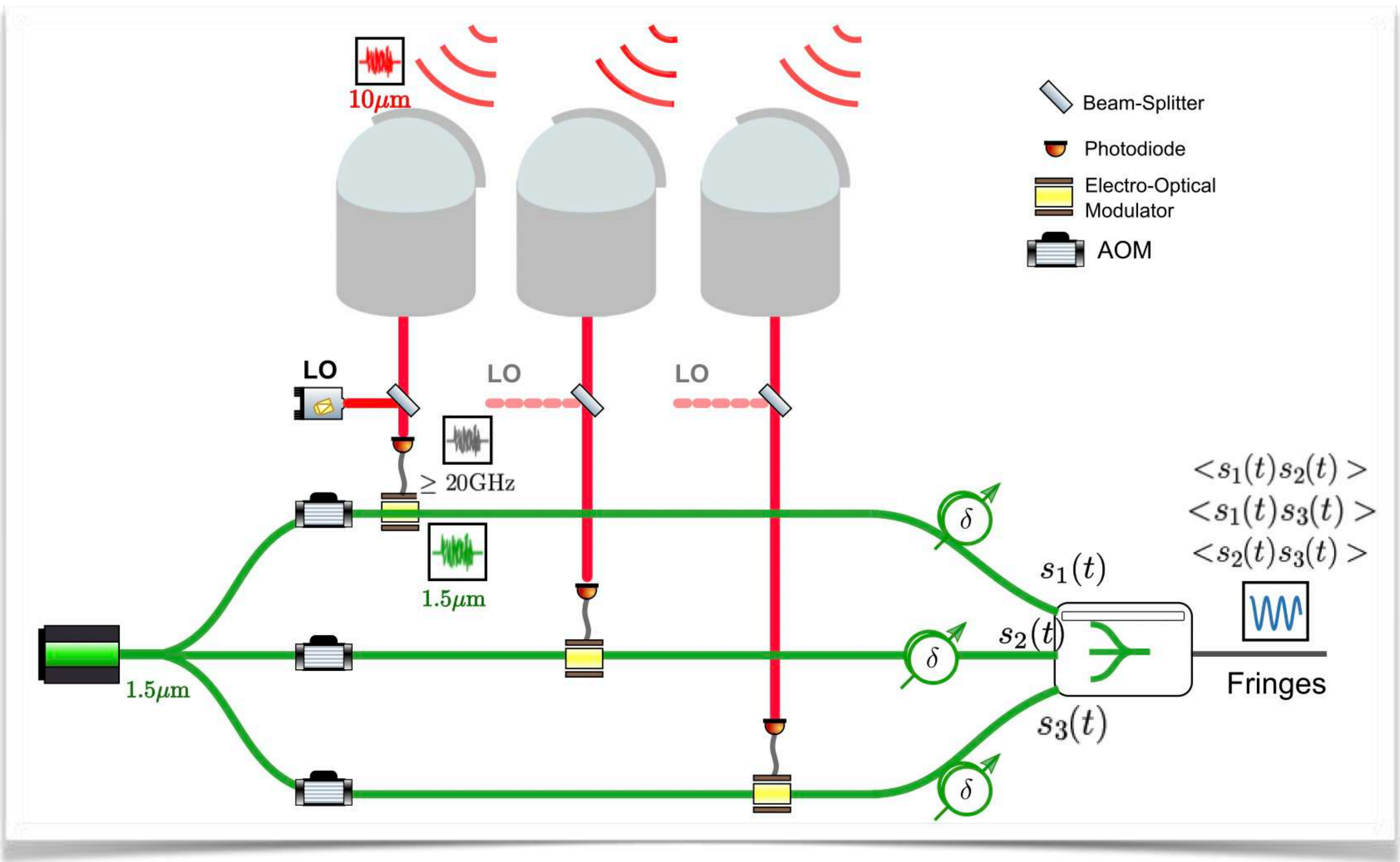


Electrooptic modulator:
Can handle up to 50GHz RF signals



Coll: H. Guillet de Chatellus

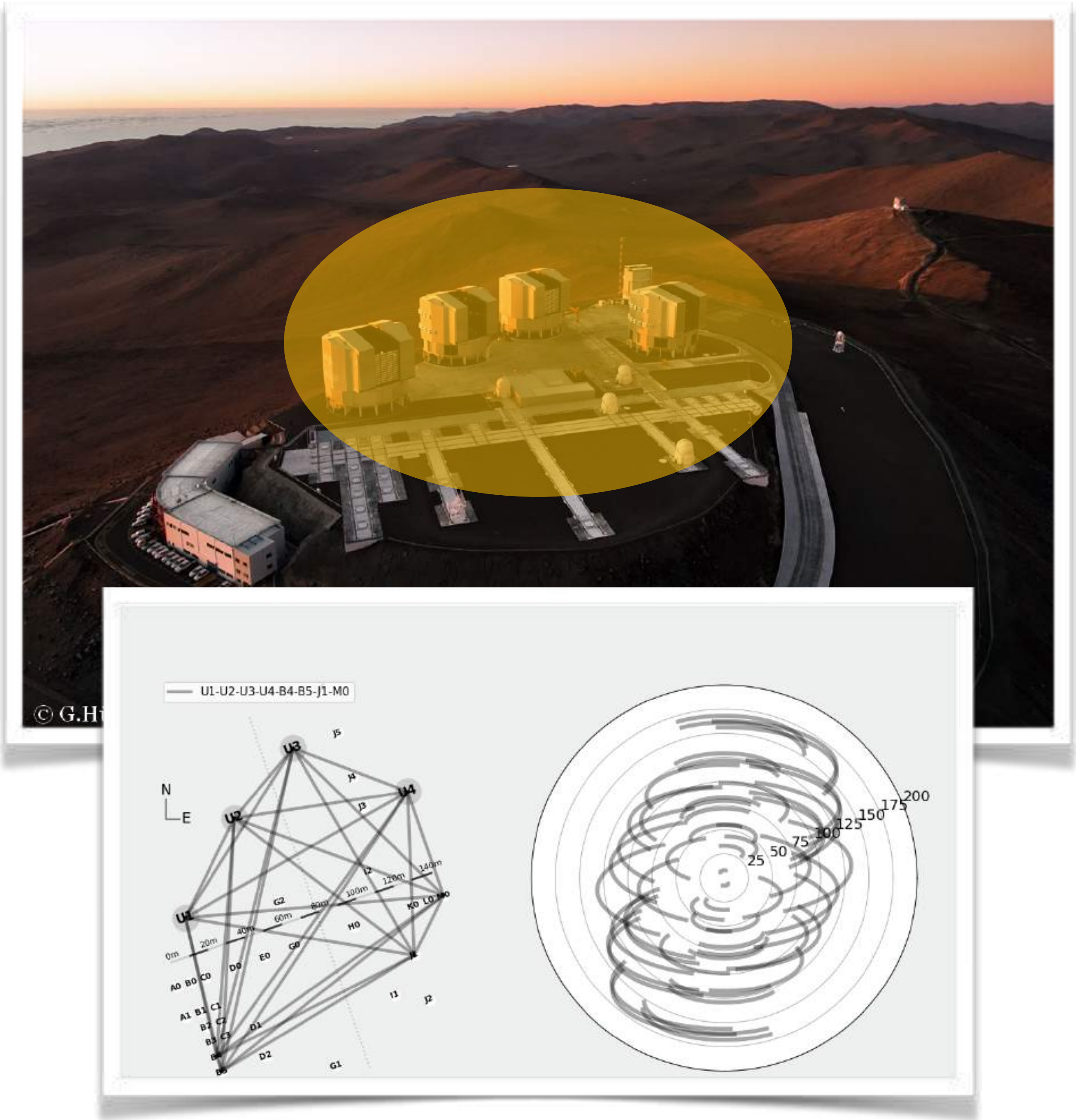
V3HI a 3 telescope precursor heterodyne instrument for the VLTI



Submitted to ANR 2021
Coll LIPHY : H. Guillet de Chatellus
Col LP ENS: C. Sirtori,

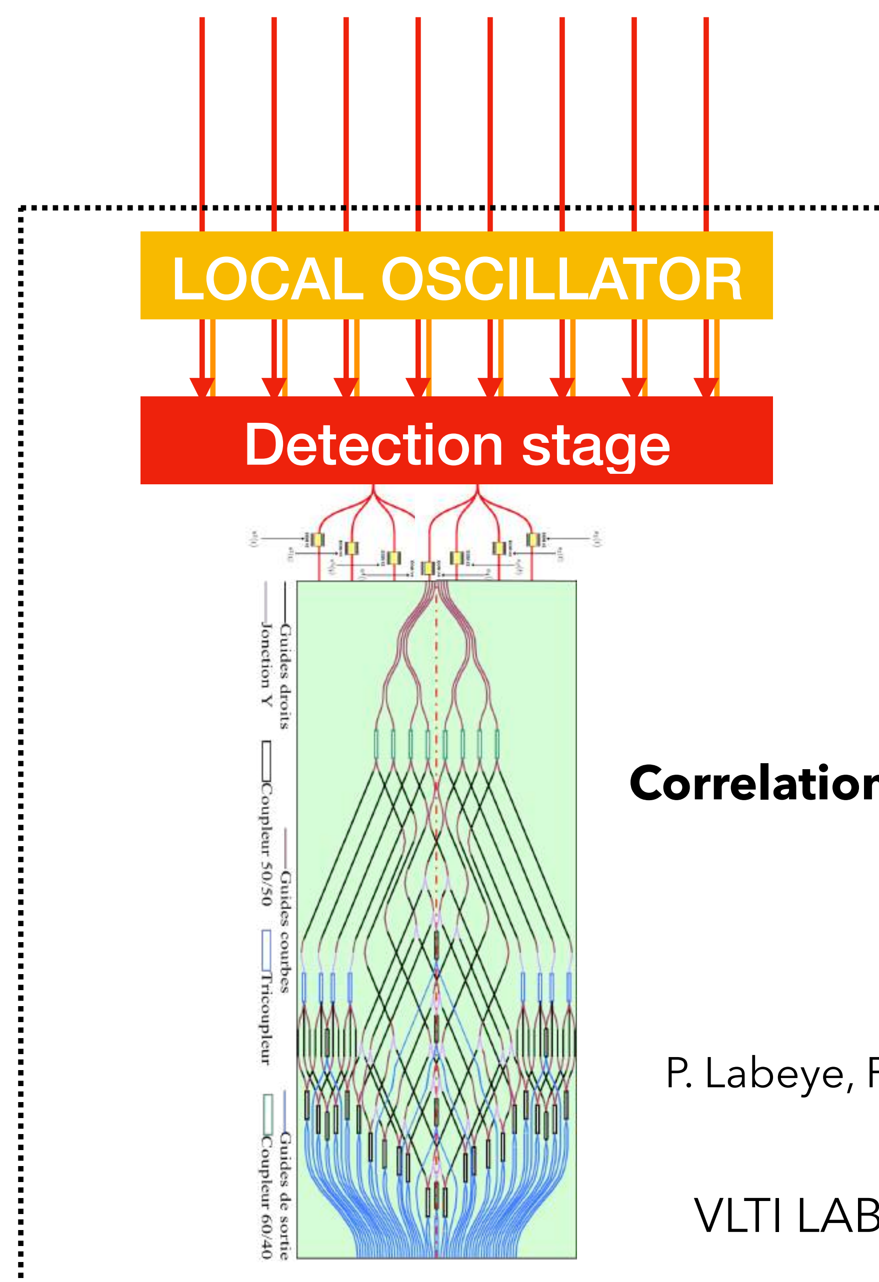
V8

An 8 telescope heterodyne combiner?



No delay lines full sky coverage

FROM TELESCOPES



Wrap up

- Astronomical community busy building big stuff: good time for interferometric R&D
- Mid-IR heterodyne interferometry likely competitive (sensitive & cost) in N and Q bands for # telescopes> 10
- Global physics/industry R&D pushing in the right direction (detection, combs, phase locking, computing power).
  - Expertise within REFIMEV collaboration is extremely interesting
- Heterodyne interferometry only way to exploit simultaneously the VLTI 8 telescopes. Great for bright objects and high spectral resolution
  - V8: a pathfinder for a future mid-infrared infrastructure ?