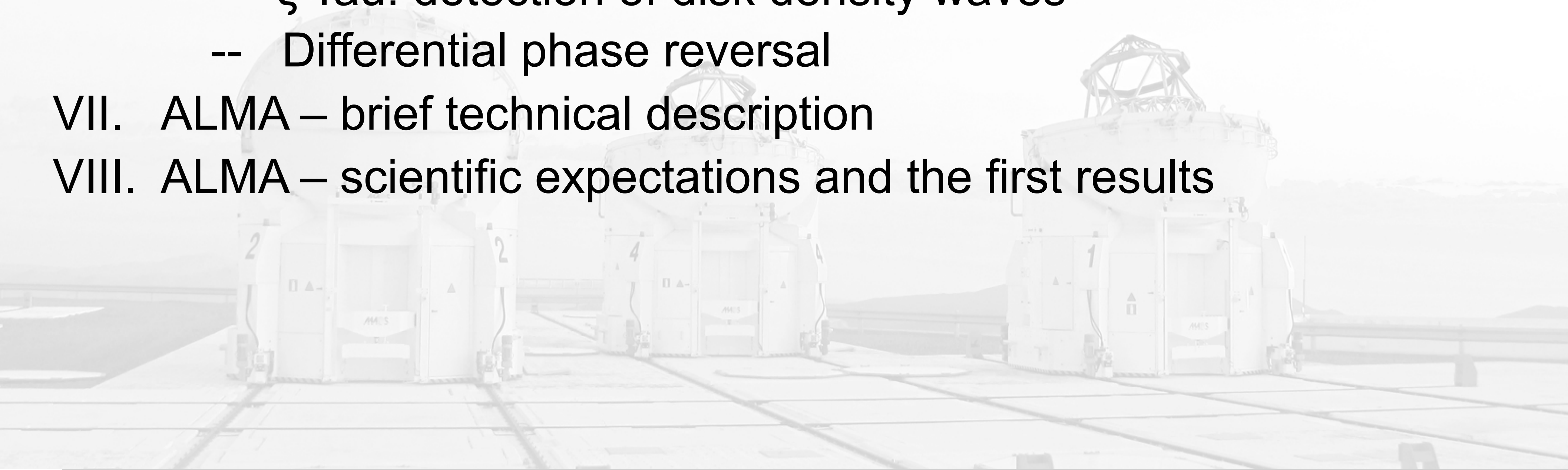
Near-IR and mm interferometry: Introduction, VLTI, ALMA

Stanislav Štefl (ESO / JAO)

Prague; April 17, 2014

Outlook:

I. Angular resolution in astronomy, why do we need interferometry
II. Common principles of interferometry
III. Basic differences and limitations of the near-IR and radio interferometry
IV. Atmospheric effects
V. ESO VLT interferometer
VI. Examples of VLTI Be star projects
  – ζ Tau: detection of disk density waves
  -- Differential phase reversal
VII. ALMA – brief technical description
VIII. ALMA – scientific expectations and the first results



Why do we need interferometry?

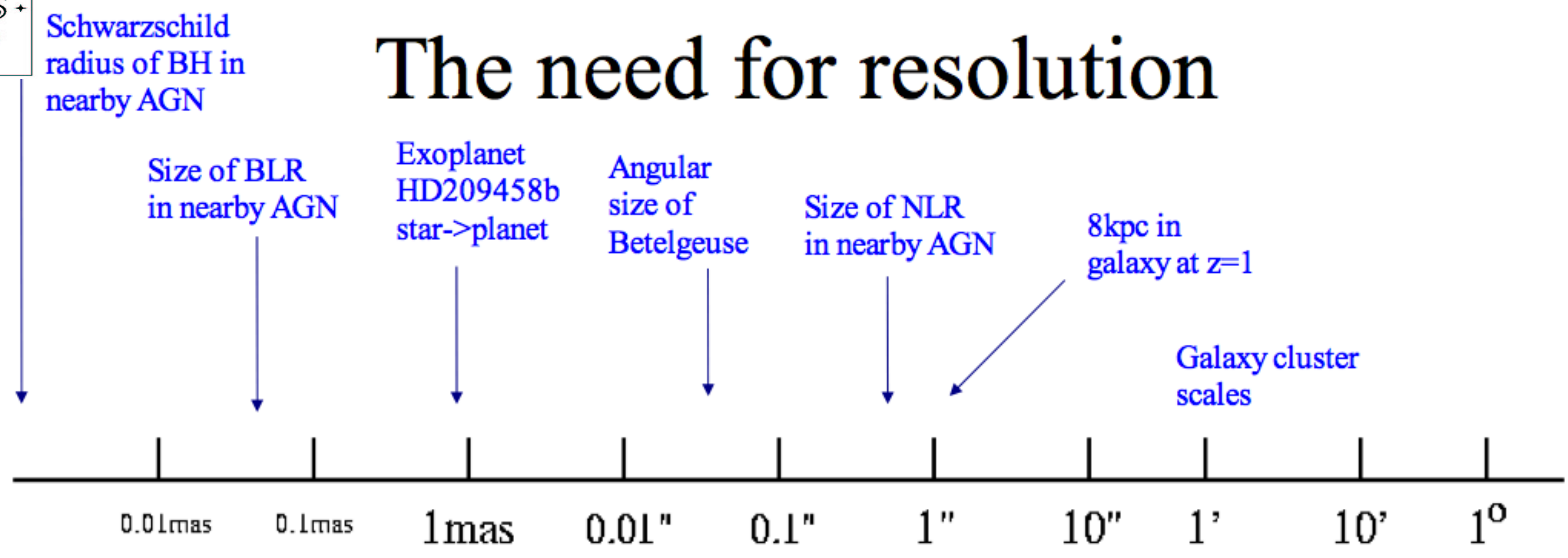
diffraction limited angular resolution of a single telescope
(Rayleigh criterion)

$$\theta = 1.22\, \lambda / D \quad [\mathrm{rad}]$$

factor 1,22 appropriate for the circular aperture

	Visible	Near-IR	Mid-IR	Radio
	0.4-1 µm	1-5 µm	10-20 µm	1mm
D=8m	18 mas	77 mas	400 mas	26600 mas
D=100m	1.4 mas	6 mas	30 mas	2000 mas

The need for resolution



Schwarzschild radius of BH in nearby AGN

Size of BLR in nearby AGN

Exoplanet HD209458b star->planet

Angular size of Betelgeuse

Size of NLR in nearby AGN

8kpc in galaxy at z=1

Galaxy cluster scales

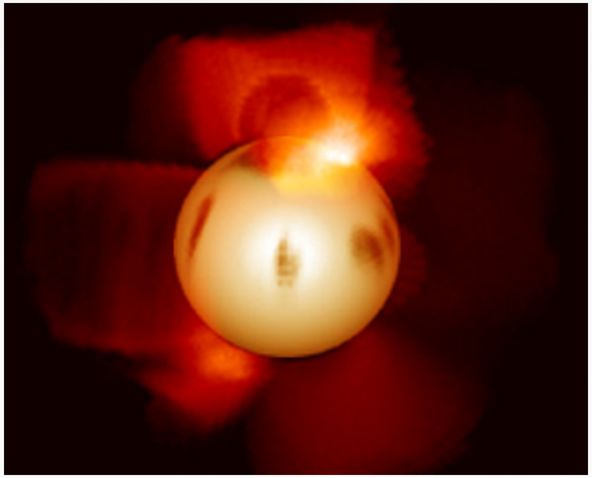
More examples: circumstellar disk of a Be star:

- ζ Tau, distance ~ 126 pc
  θ(H α) Major axis ~ 1.79 mas (CHARA, Touhami et al. 2011)
- 48 Lib, distance ~ 143 pc
  θ (H cont.) ~ 1.72 mas (Pionier, Stefl et al. 2009)
- typical diameters of close calibrator B – F stars for IR interferometry
  θ ~ 0.2 – 0.5 mas

… and we want to see the detailed t stellar structure !

The evolved star Mira

imaged by HST in the UV.



Indirect reconstruction
of AB Dor
(magnetic spots)

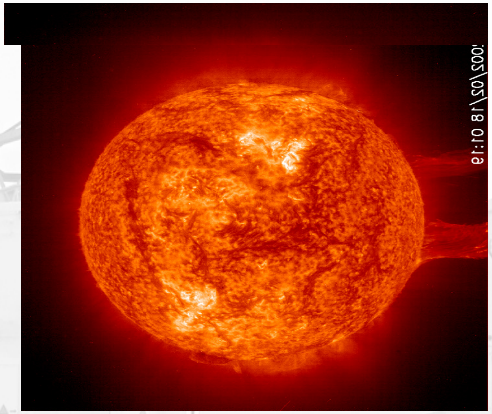
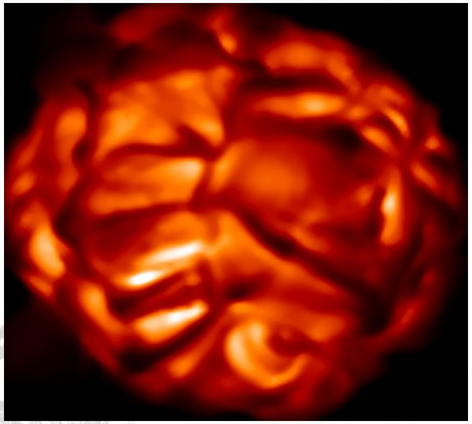


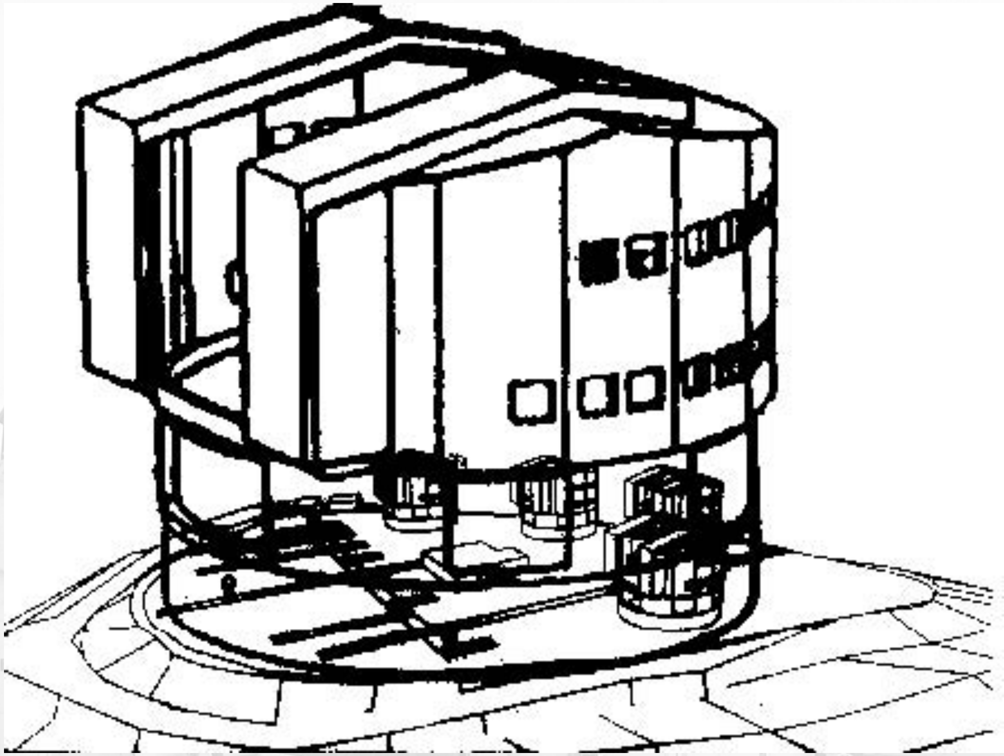
Image other stars as we
image the Sun !



Betelgeuse
(model of convection)

…….solution ?

ELT - “only” 39m, many technical problems

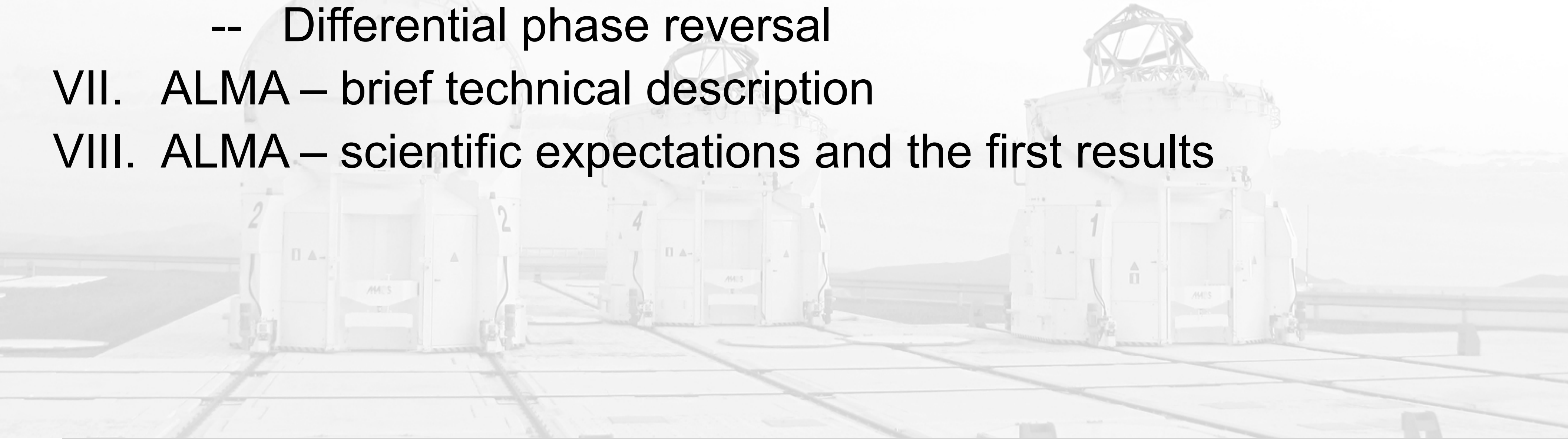


Interferometry

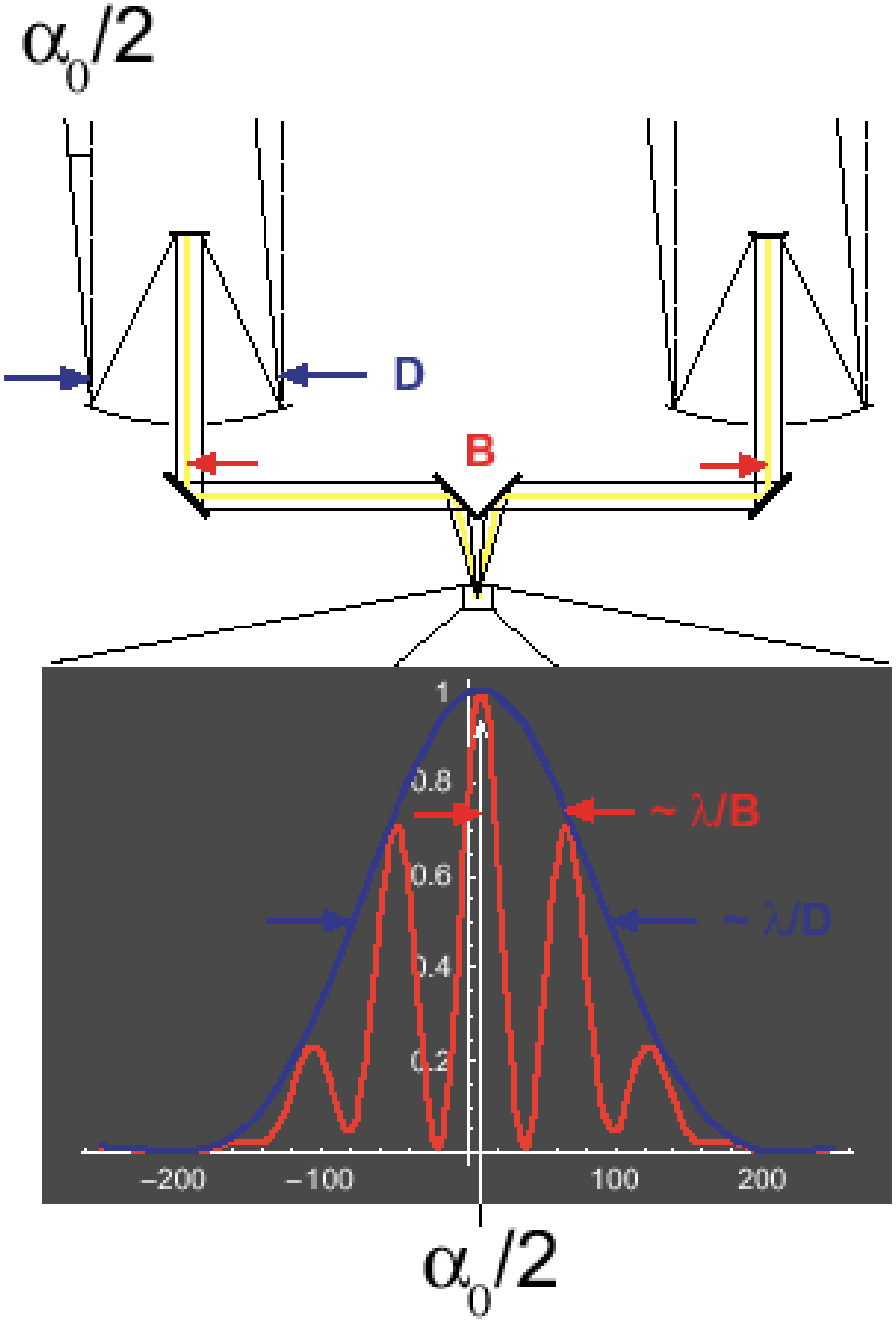
Combining beams of individual telescopes

Outlook:

I. Angular resolution in astronomy, why do we need interferometry
II. Common principles of interferometry
III. Atmospheric effects
IV. Basic differences and limitations of the near-IR and radio interferometry
V. ESO VLT interferometer
VI. Examples of VLTI Be star projects
  – ζ Tau: detection of disk density waves
  -- Differential phase reversal
VII. ALMA – brief technical description
VIII. ALMA – scientific expectations and the first results



Michelson stellar interferometer



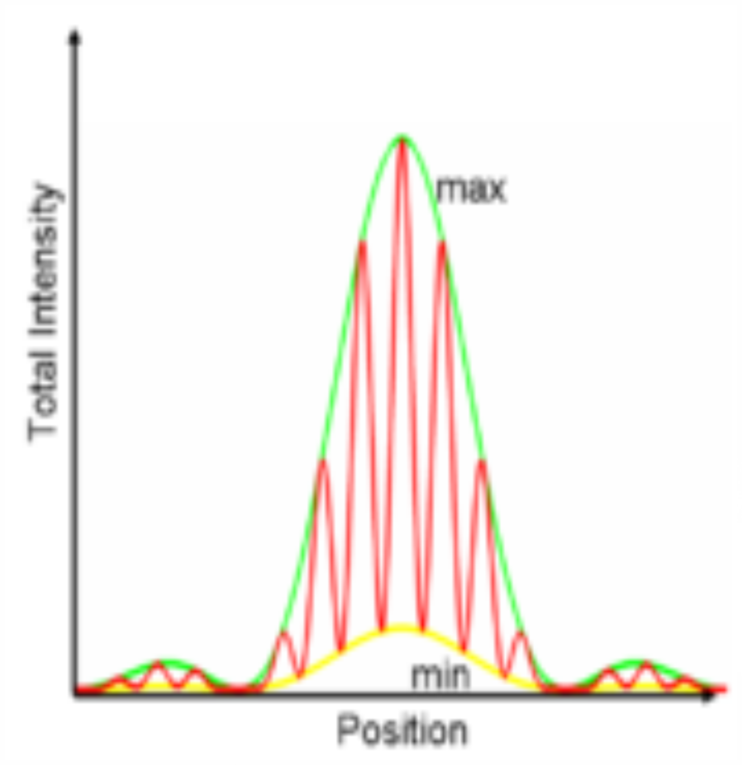
- Stellar source with angular size α_0
- Add fringe patterns (i.e. intensities) between $\pm\alpha_0/2$

Visibility definition

Michelson defined the quantity
"Visibility" as:

$$V = \frac{I_{max} - I_{min}}{I_{max} + I_{min}}$$

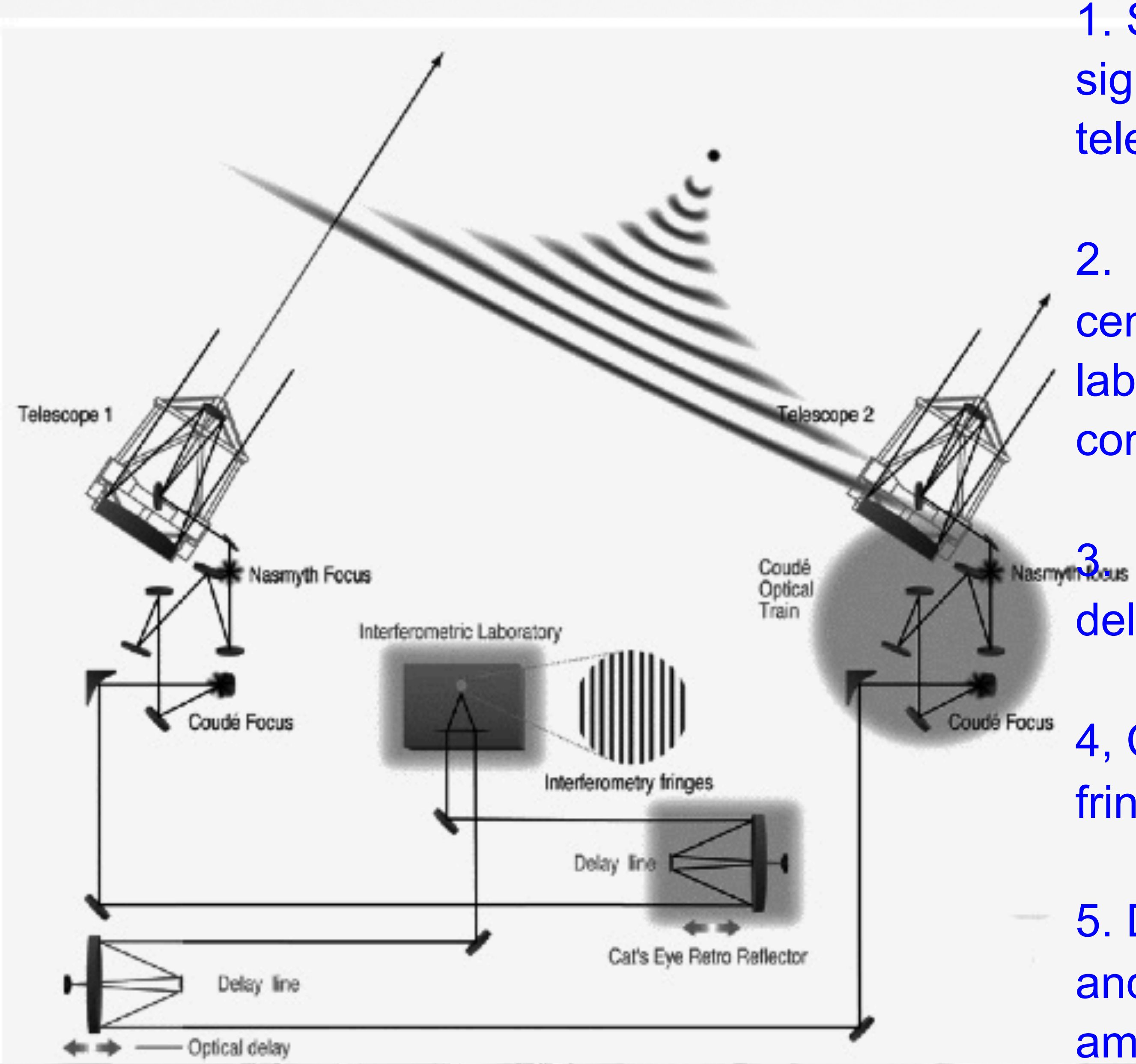
The basic observable for an interferometer.



fringe separation = λ / B

polychromatic fringes - modulation by sin function, centered at D=0, coherence length = $\lambda_0^2 / \Delta\lambda$

Basic task of interferometry



1. Sampling of the light/signal signal by two (several) telescopes/antennas

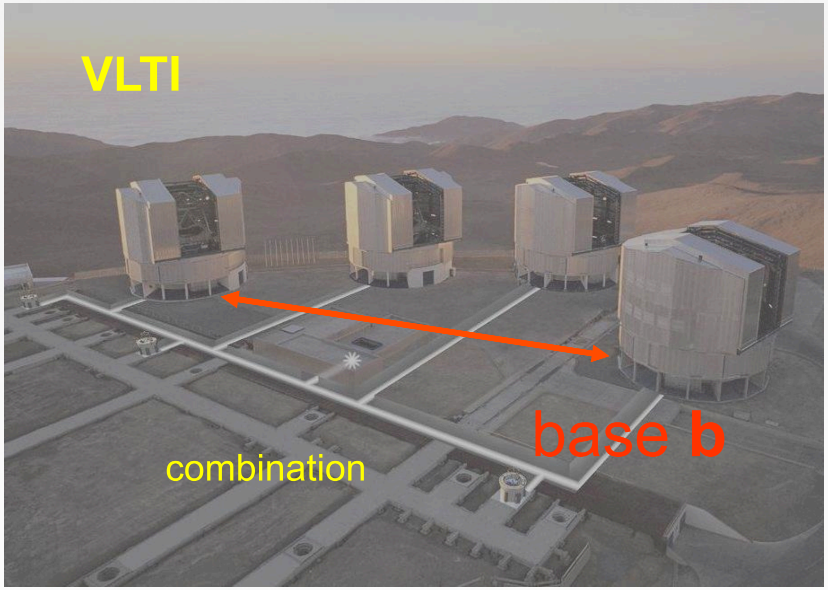
2. Relay of the beams to the central beam-combining laboratory (beam-combiner, correlator)

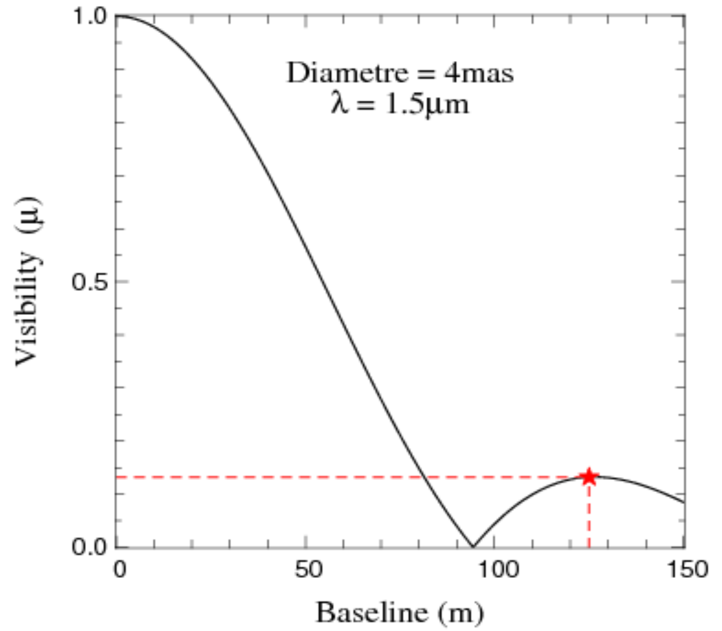
3. Correction for the geometrical delay between the beams

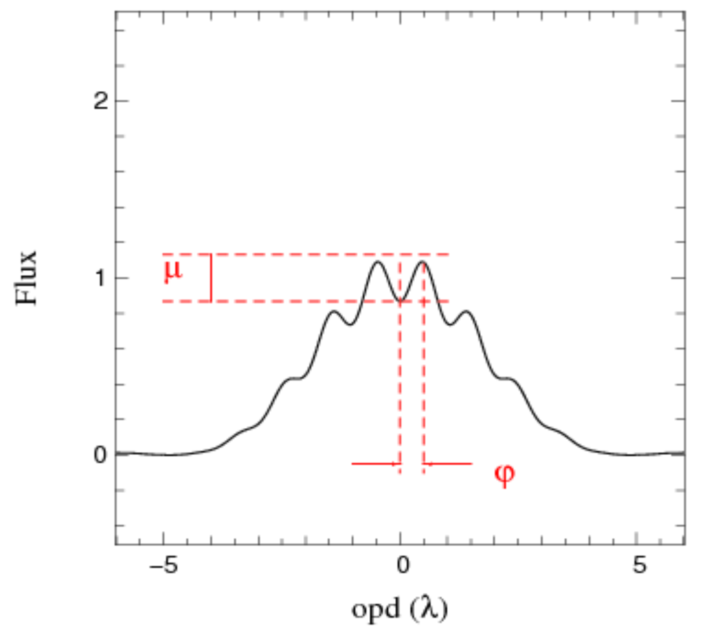
4, Combining signals to form the fringe pattern

5. Detection of the fringe pattern and estimation of the fringe amplitude and phase

Interferometric characteristics







Interferometric observables

Visibility V and phases φ

function of the target shape :

$$V e^{i\varphi} = TF\{ \text{objet} \} (\mathbf{b}/\lambda)$$

From the visibility to an image

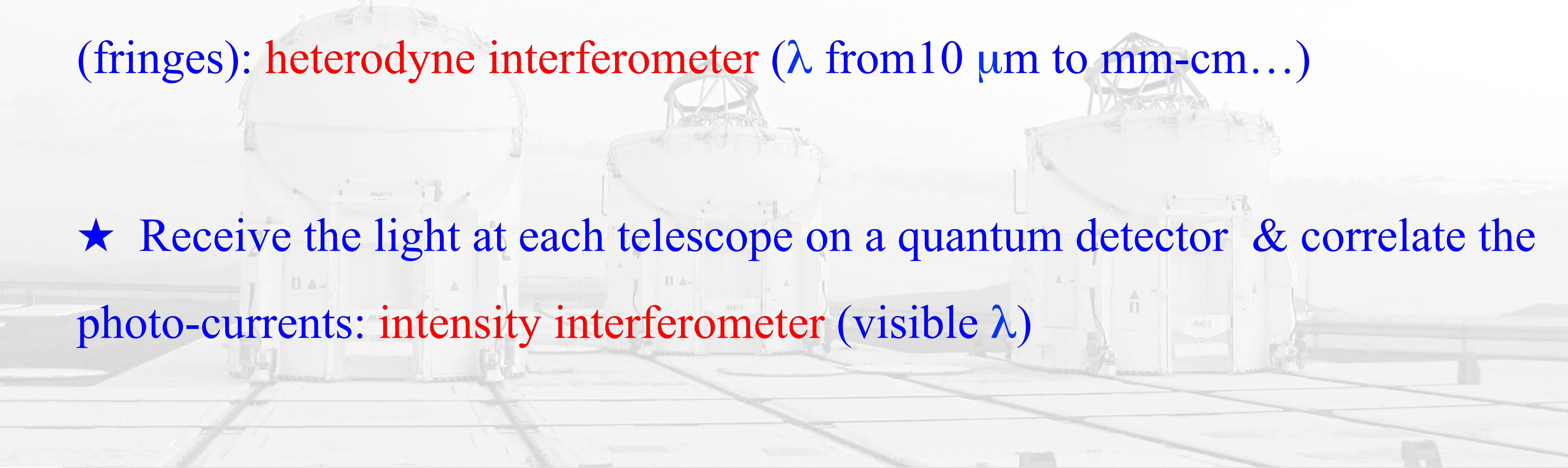
- Multiple baselines & synthetized pupil
- The Single Telescope/Antenna MTF (Primary Beam)
- The Interferometer MTF (Dirty Beam)
- From Fourier space (visibilities) to image space : (N -> N)
- Filling holes of the MTF : deconvolution techniques (« cleaning »)
- Restoring a good PSF : the *densified* pupil

Three methods to achieve coherent combination of light :

★ Carry the light from each telescope to a common focus & combine coherently, then detect interferometric signal (fringes): direct interferometer (optical λ)

★ Change the frequency of light at each telescope, carry to the common focus an Intermediate Frequency (IF) Signal, & combine all these signals (fringes): heterodyne interferometer (λ from10 μm to mm-cm…)

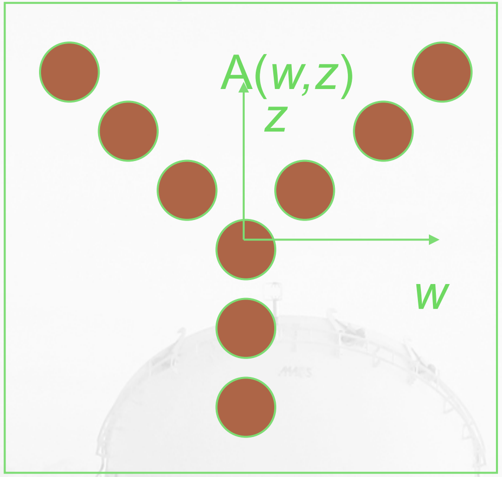
★ Receive the light at each telescope on a quantum detector & correlate the photo-currents: intensity interferometer (visible λ)



Object transformation

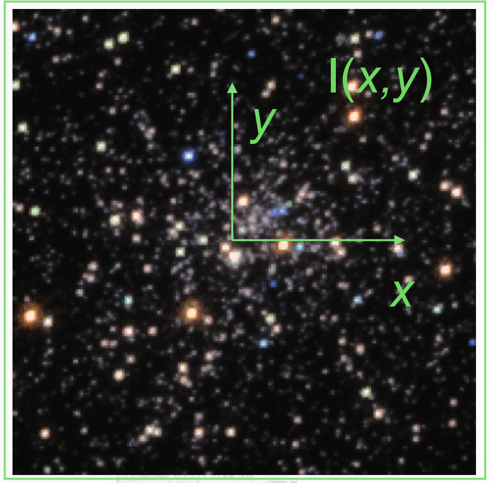
The game of three “spaces.”

Aperture



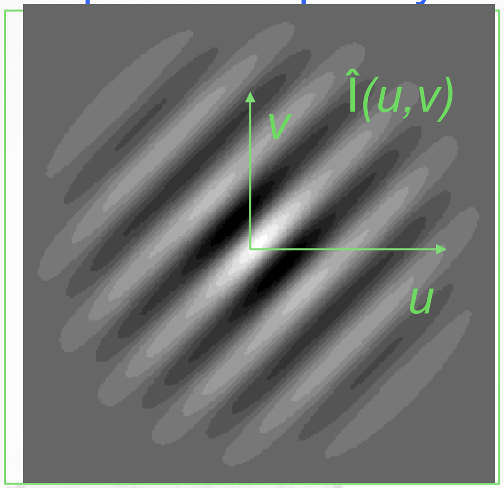
(w,z)

Image



(x,y)

Spatial Frequency

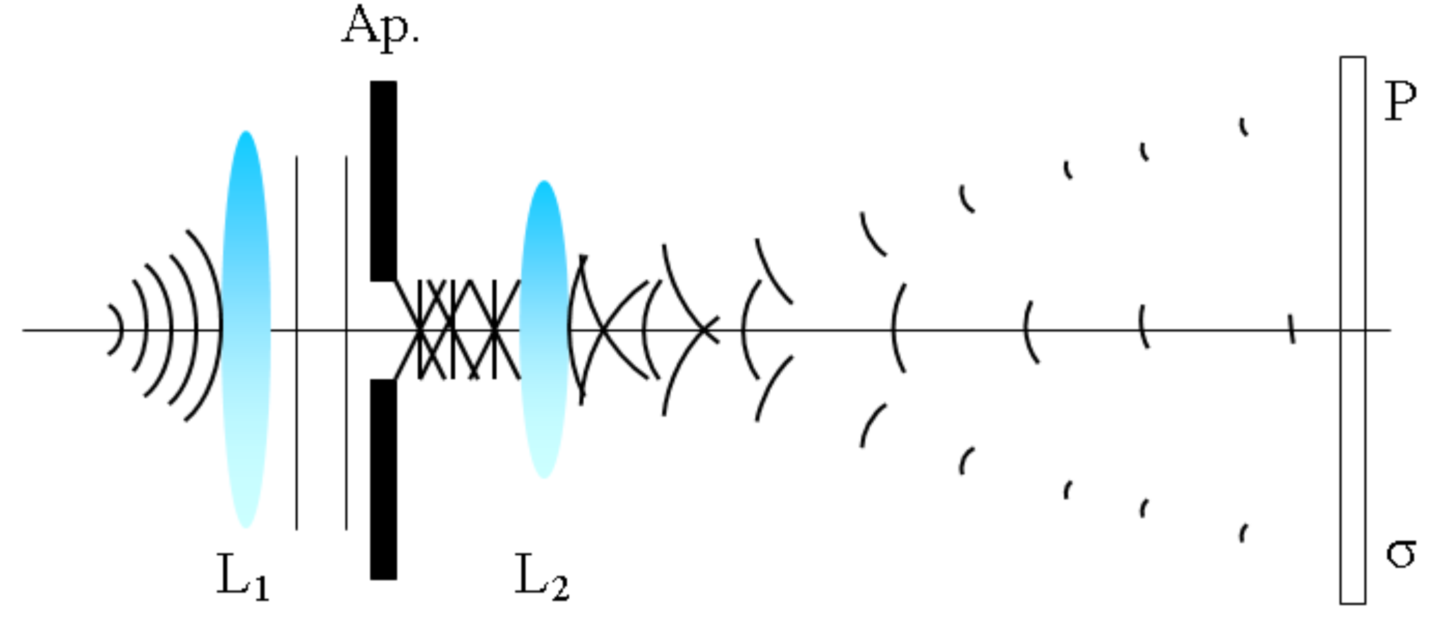


(u,v)

Fraunhofer Diffraction

Image of a point source formed by a general aperture is the modulus square of the Fourier transform of the aperture. Connects (*w*,*z*)-plane to (*x*,*y*)-plane.

$$I(x,y) = |FT(A(w,z))|^2$$



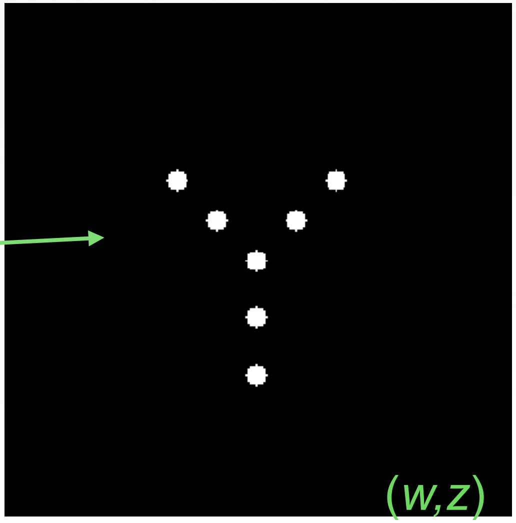
Baselines: Van Cittert-Zernike Theorem

Define a baseline vector (B). That baseline contributes to 1 and only 1 Fourier component (β) of the image.

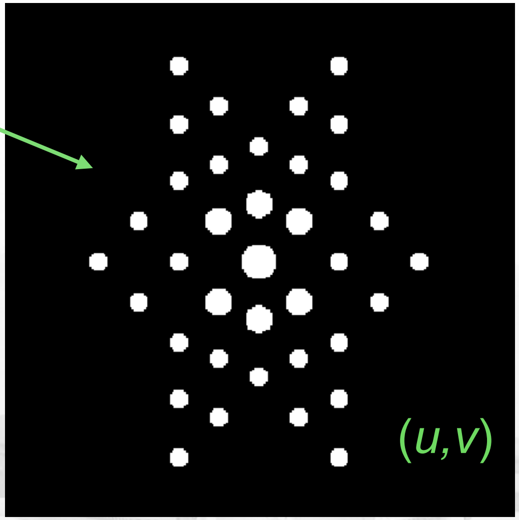
Connects (*w*,*z*)-plane to (*u*,*v*)-plane.

Aperture Synthesis

Multiple-baseline interferometer.

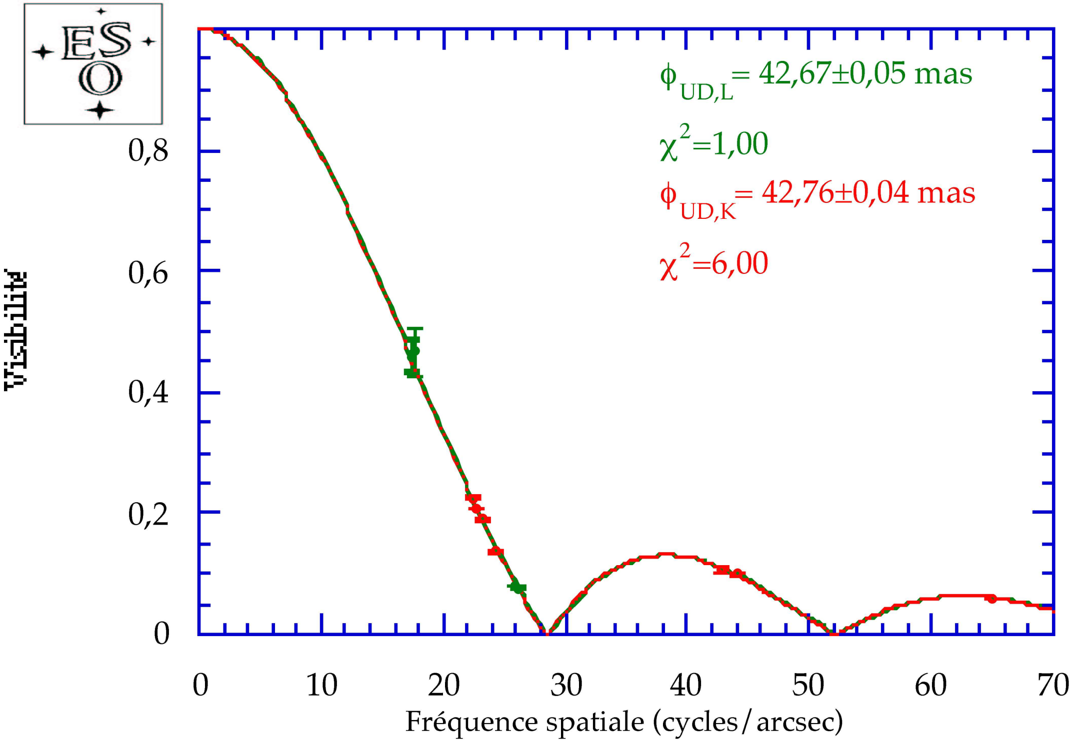


“Sparsely fill” (u,v)-plane.



Reconstruct high-resolution images through Fourier inversion.

Measuring spatial coherence : visibility amplitudes

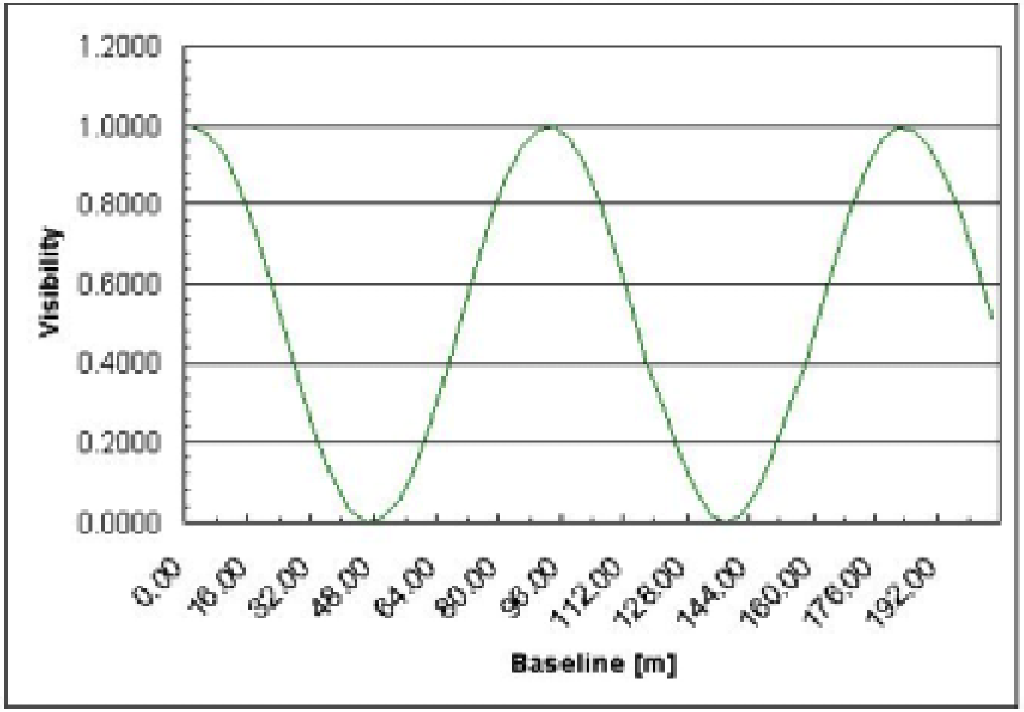


Uniform disc star

(Perrin,G. et al)

Binary star:

(separation 5 milliarcsec)



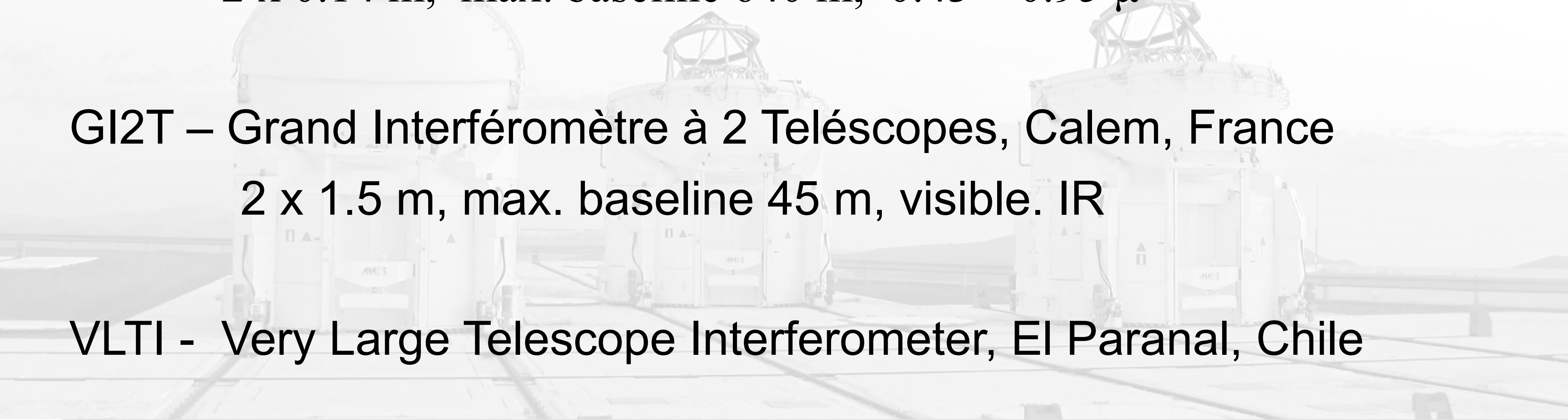
From A. Glindeman's VLTI tutorial

Selected optical and near-IR interferometers:

CHARA – Center for High Angular Resolution Array, Mt. Wilson, USA
6 x 1m, max. baseline 331m, 0.45 – 2.4 μ

IOTA – Infrared-Optical Telescope Array, Mt. Hopkins, USA
6 x 0.12 (0.35) m, max. baseline 437 m, 0. 45 – 0.85 μ

SUSI – Sydney University Stellar Interferometer, Narrabri, Australia
2 x 0.14 m, max. baseline 640 m, 0.43 – 0.95 μ

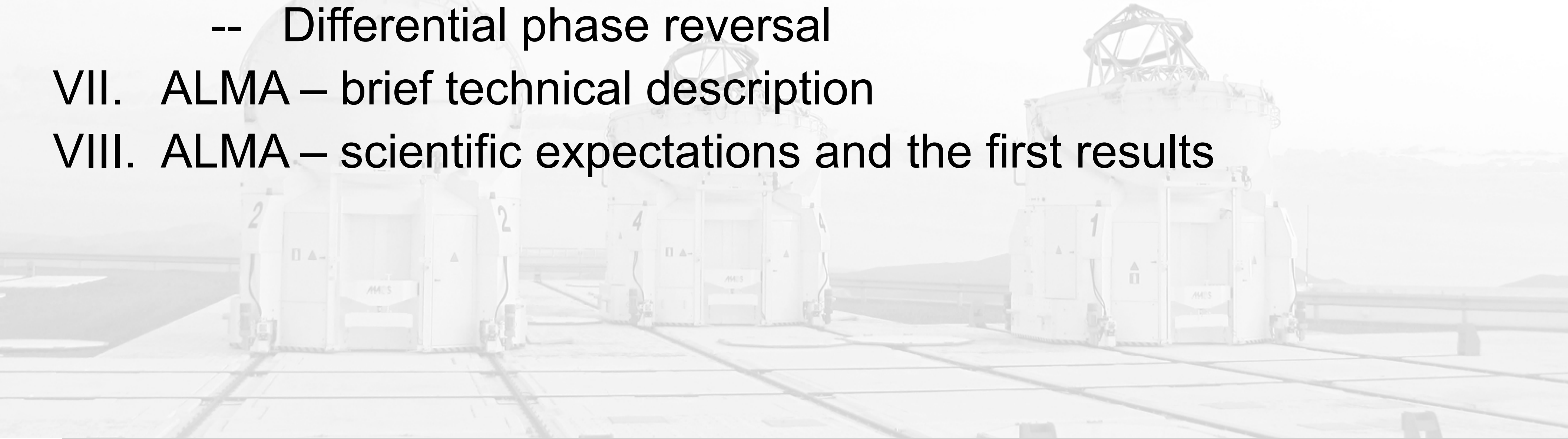


GI2T – Grand Interféromètre à 2 Teléscopes, Calem, France
2 x 1.5 m, max. baseline 45 m, visible. IR

VLTI - Very Large Telescope Interferometer, El Paranal, Chile

Outlook:

I. Angular resolution in astronomy, why do we need interferometry
II. Common principles of interferometry
III. Atmospheric effects
IV. Basic differences and limitations of the near-IR and radio interferometry
V. ESO VLT interferometer
VI. Examples of VLTI Be star projects
  – ζ Tau: detection of disk density waves
  -- Differential phase reversal
VII. ALMA – brief technical description
VIII. ALMA – scientific expectations and the first results



Atmospheric turbulence and piston

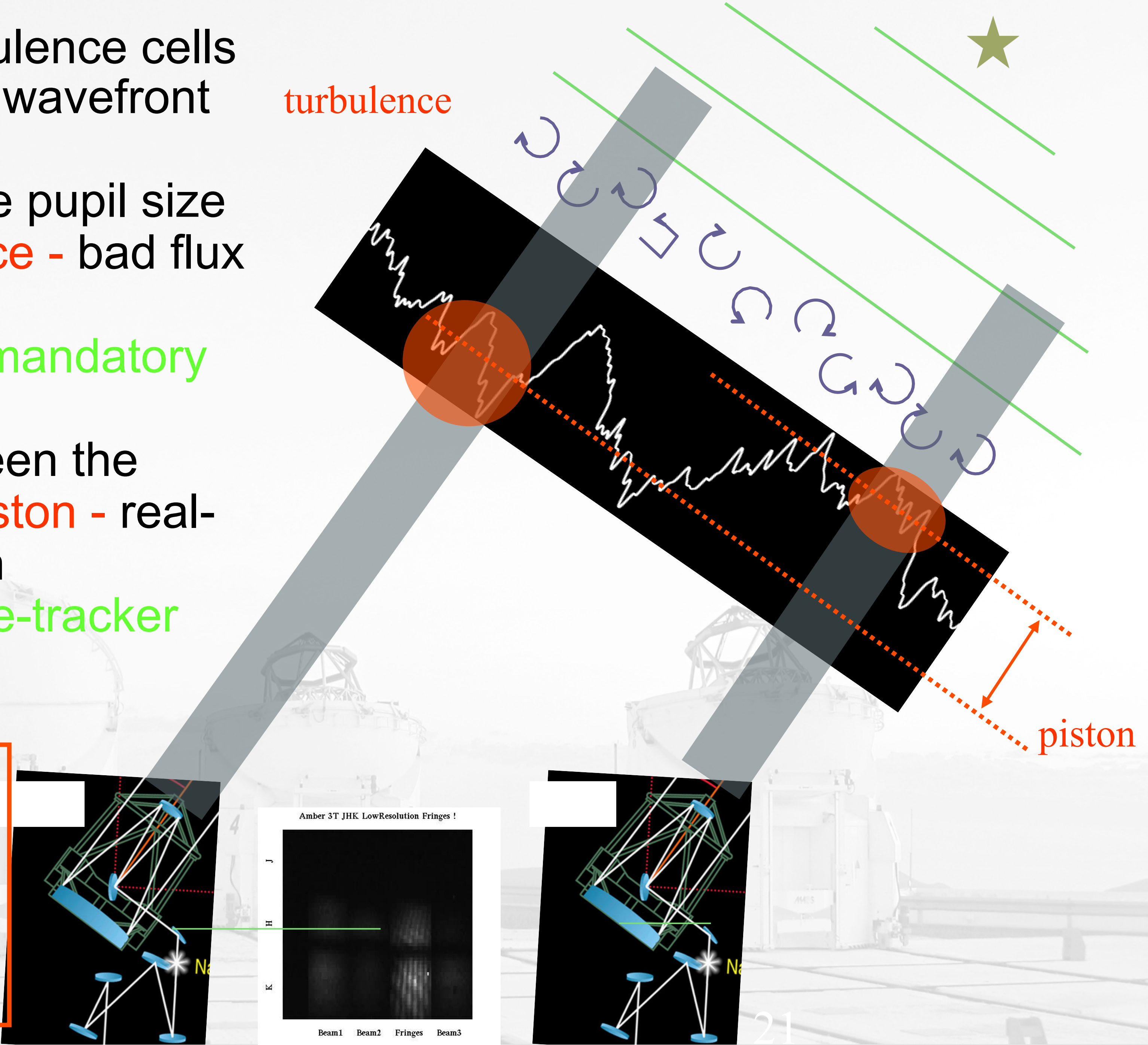
Atmospheric turbulence cells
distort the stellar wavefront

Distortion over the pupil size is called turbulence - bad flux injection

tip/tilt or AO mandatory

Global shift between the pupils is called piston - real-time fringe motion

small DIT or fringe-tracker mandatory



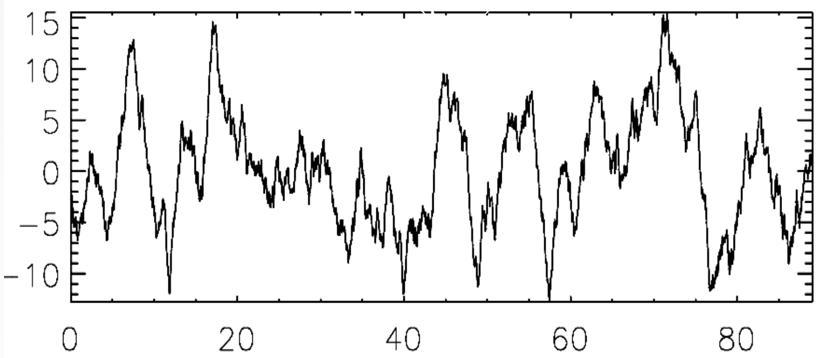
Random piston has amplitude: Δ ~ 50 µm

Piston: fringe motion and blurring

Piston jitter during an exposure blur the fringes visibility:

use short exposure only (50ms)

use a fringe tracker

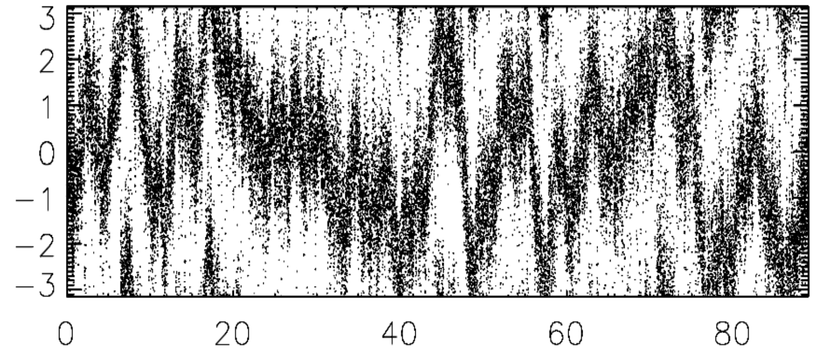


Fringes are displaced by the averaged piston value during the exposure:

measured phase is meaningless

➔ differential phases

closure phases



Closure phase

- In the sum of the three phases the random fluctuation is eliminated:

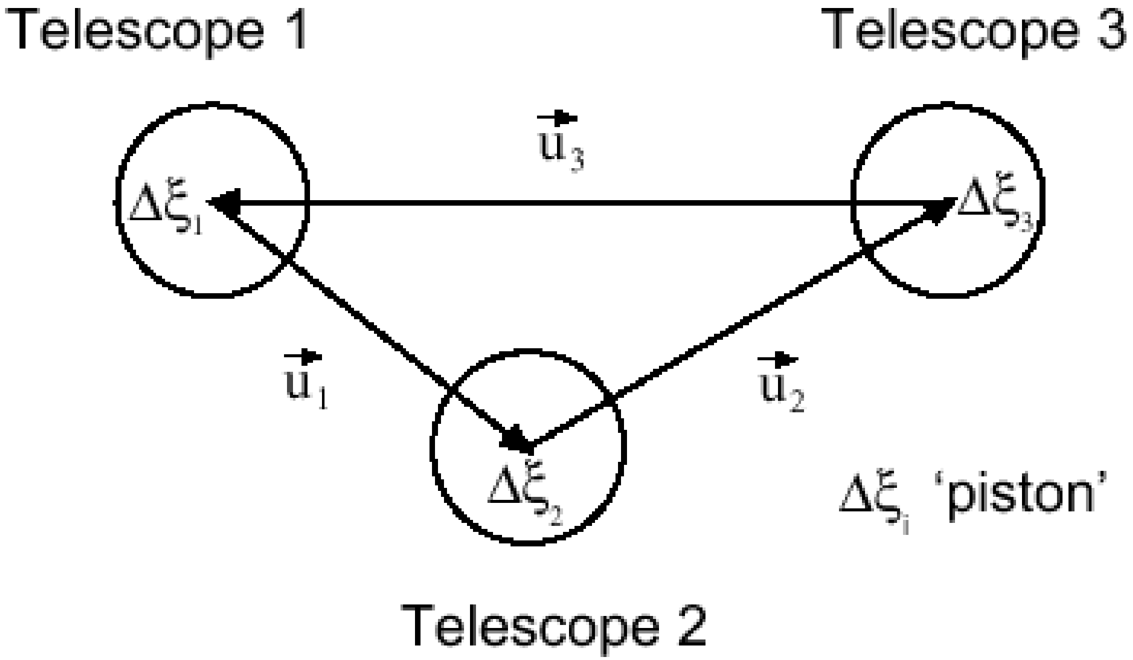
$$\psi_1 (u_1) = \phi_1 (u_1) + \Delta\xi_1 - \Delta\xi_2$$

$$\psi_2 (u_2) = \phi_2 (u_2) + \Delta\xi_2 - \Delta\xi_3$$

$$\psi_3 (u_3) = \phi_3 (u_3) + \Delta\xi_3 - \Delta\xi_1$$

$$\psi_1 + \psi_2 + \psi_3 = \phi_1 + \phi_2 + \phi_3$$

- Many baselines required to determine individual phases.
- The exposure time is limited, again by the individual fringe motion..

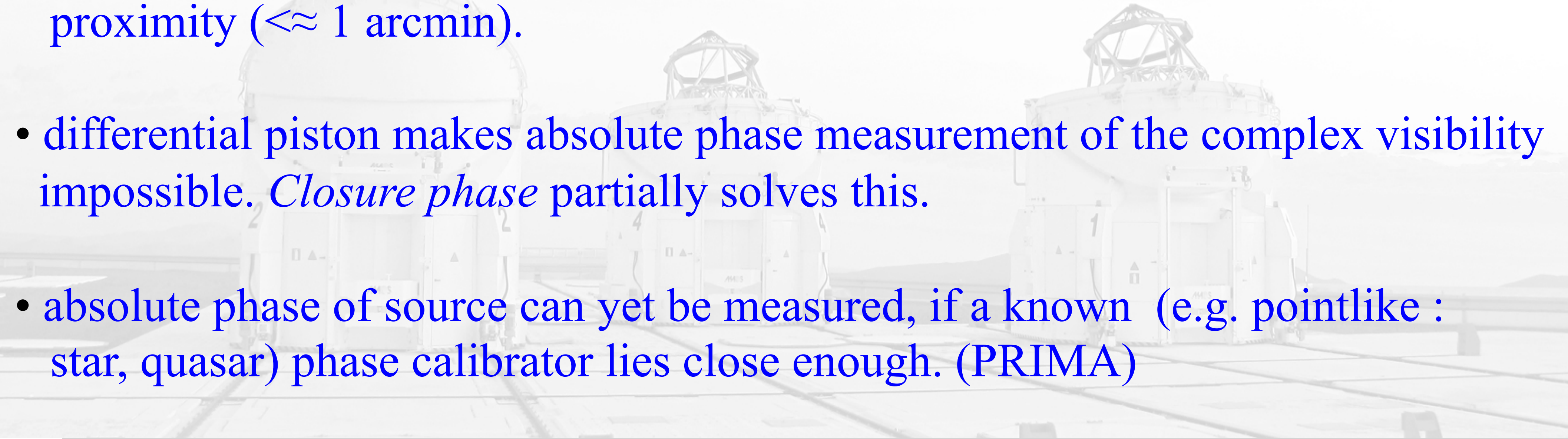


Summary of atmospheric effects on interferometric observations

- adaptive optics on individual telescopes is needed. But Strehl S <1 leads to visibility amplitude loss and visibility noise, limiting accuracy.

- piston noise between telescopes can not be compensated. Limits exposure time, hence restricts observation to «bright» objects & adds noise onto visibility amplitude measurement.

- if differential piston is tracked on a «bright» source, long time integration can be achieved to determine V of a «faint» source, but atmosphere imposes a proximity (<≈ 1 arcmin).

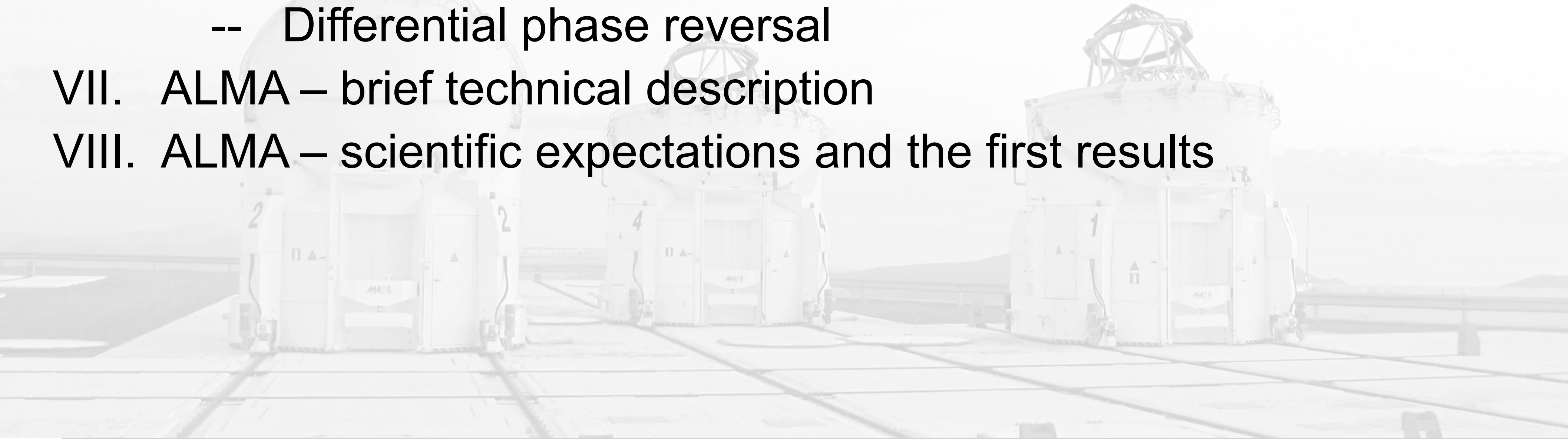


- differential piston makes absolute phase measurement of the complex visibility impossible. *Closure phase* partially solves this.

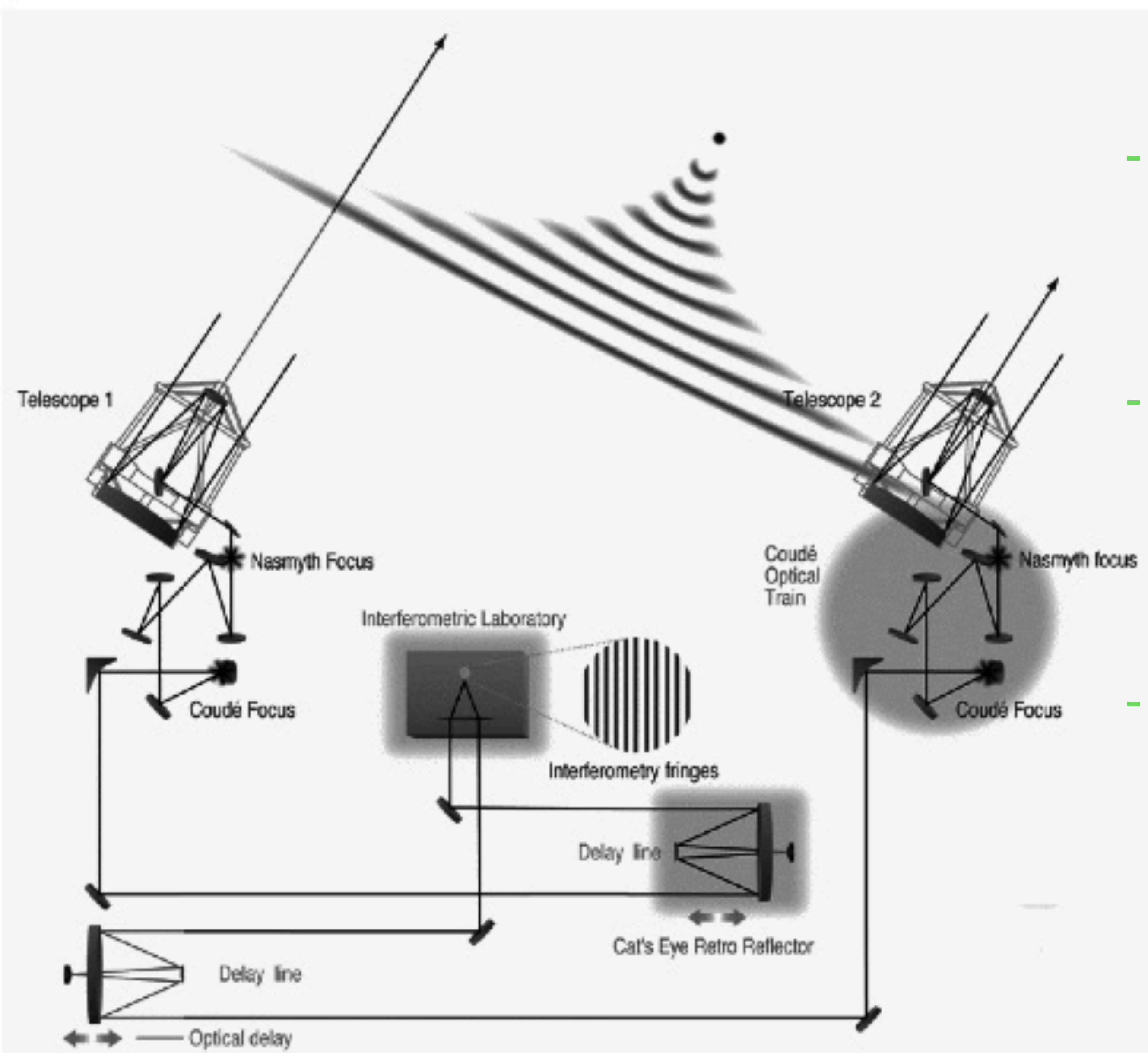
- absolute phase of source can yet be measured, if a known (e.g. pointlike : star, quasar) phase calibrator lies close enough. (PRIMA)

Outlook:

I. Angular resolution in astronomy, why do we need interferometry
II. Common principles of interferometry
III. Atmospheric effects
IV. Basic differences and limitations of the near-IR and radio interferometry
V. ESO VLT interferometer
VI. Examples of VLTI Be star projects
   – ζ Tau: detection of disk density waves
   -- Differential phase reversal
VII. ALMA – brief technical description
VIII. ALMA – scientific expectations and the first results



Specific for near-IR interferometry - direct interferometer



- signal is digitized only at the fringe detector, we cannot amplify or multiply it
- a significant part of the signal is lost at the reflections, and for auxiliary instruments
- optical delay is corrected "mechanically" in the delay-line tunnel, challenging metrology

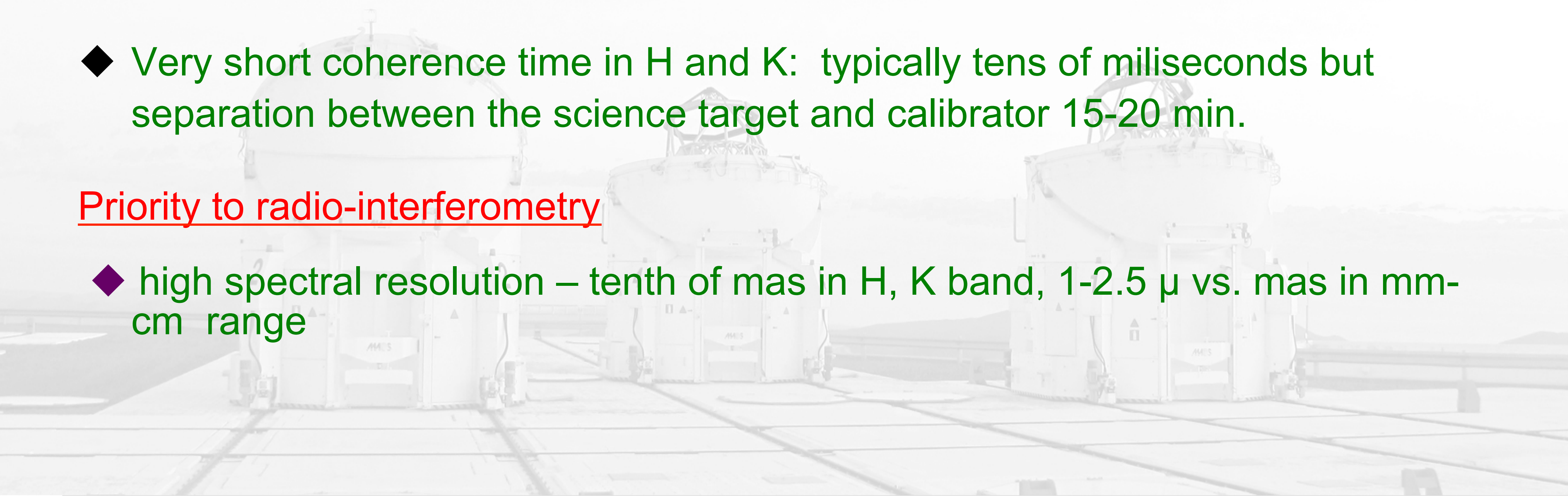
Limitations of the near-IR interferometry

- Only small number of telescopes can be combined (VLTI: MIDI - 2, AMBER – 3, Pionier – 4, CHARA/MIRC - 6) => imaging hardly possible or very time consuming, mostly model fitting. No direct image of circumstelar disk achieved up to now (but CHARA is close to it for some Be stars)

- We can get fringes only for bright targets - why?
  The light/signal is digitized only when fringes are recorded.

- Visual, H or K band can see only hot matter

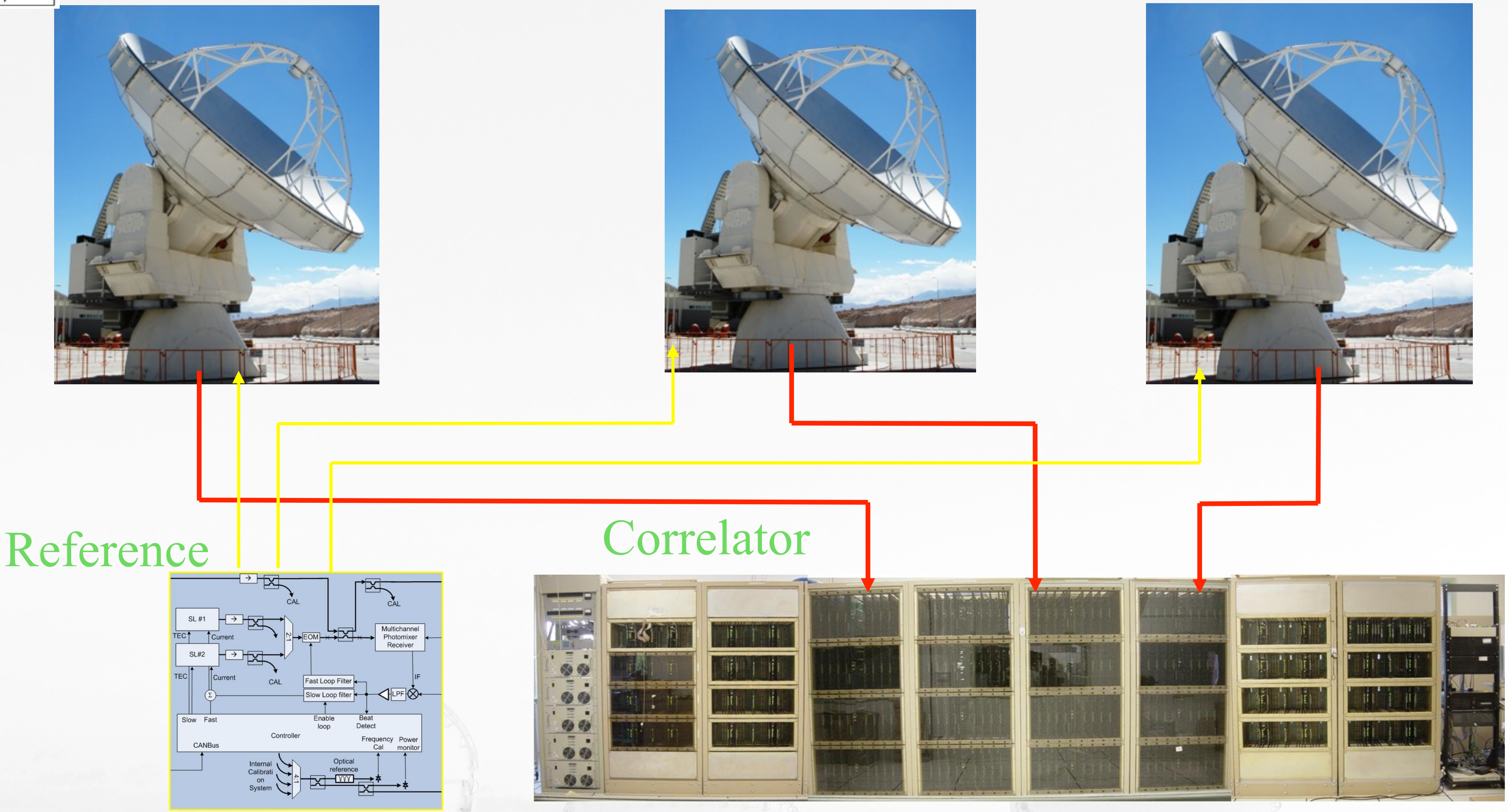
- Very short coherence time in H and K: typically tens of miliseconds but separation between the science target and calibrator 15-20 min.



Priority to radio-interferometry

- high spectral resolution – tenth of mas in H, K band, 1-2.5 μ vs. mas in mm-cm range

Specific for radio interferometry - heterodyne interferometer


Reference

Correlator

The signal is digitized already in the the focus (front end) of each single antenna

The signal can be amplified and multiplied

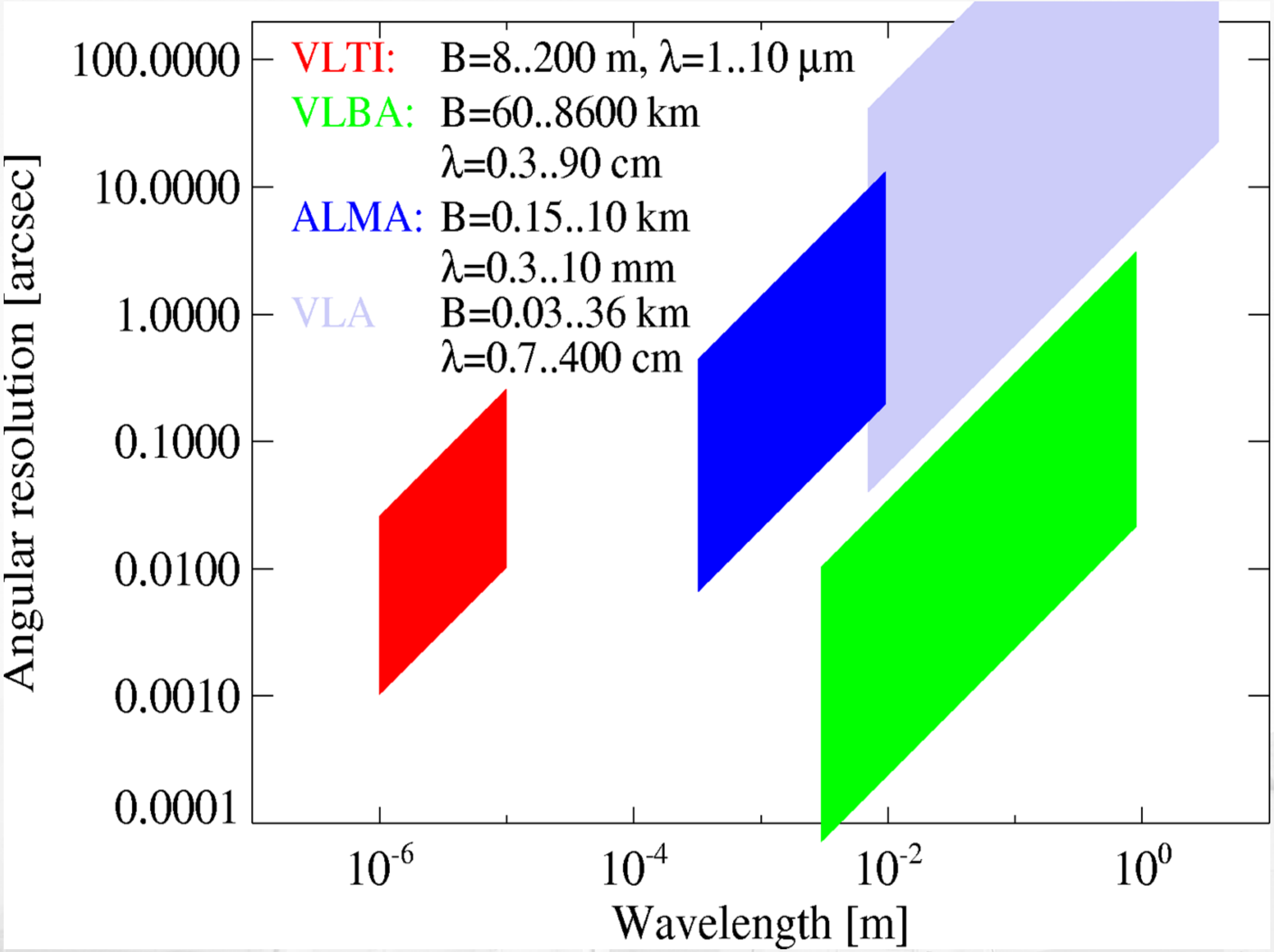
Limitations of the radio interferometry

- The spatial resolution for radio waves is low, we need long baselines

Priority to the near-IR interferometry

- mm and cm wavelengths can see the cool matter (tens of K)
- Signals from individual antennas can be amplified, consequently we can combine many antennas in the array – IMAGING
- The coherence time of the atmospheric effects is of the order of tens of minutes – enough for phase calibration

Comparison of VLTI, VLBA, and ALMA



- VLTI, VLBA, and ALMA can observe the same targets in terms of angular resolution and sensitivity.
- They provide complementary information on different components and regions.

VLTI : 4 x 8m + 4 x 1.8 m

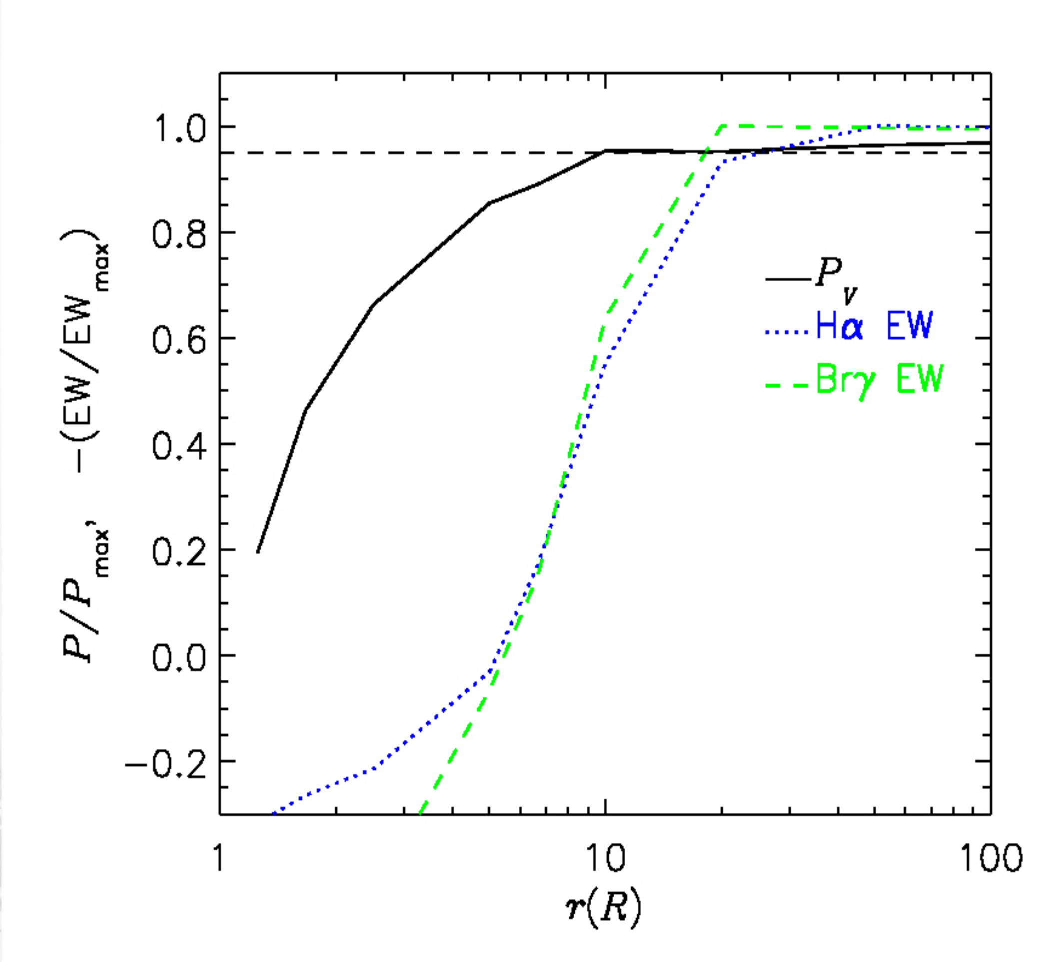
ALMA : 66 x 12/7 m

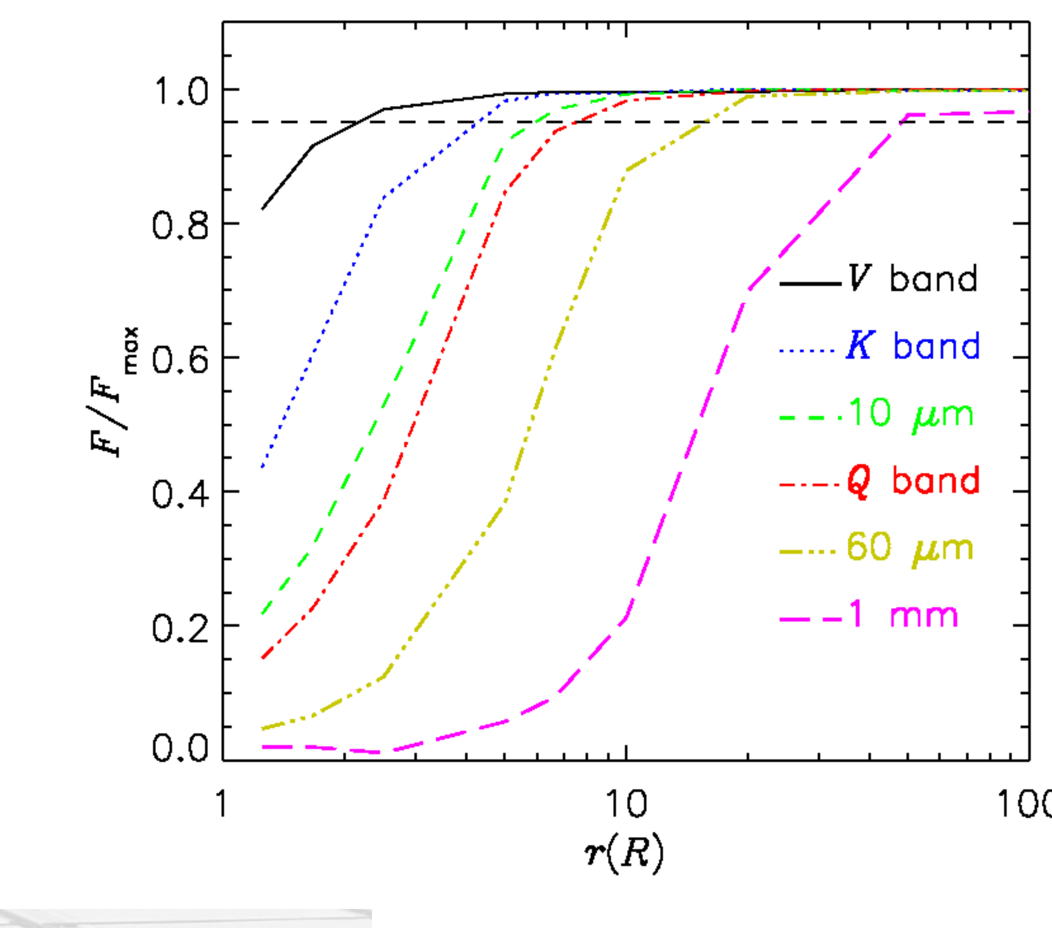
VLBA : 10 x 25 m

VLA : 27 x 25 m

However, I different wavelength, even in a single object we can see different parts in different wavelengths - gaseous disk of a Be star vs. dusty proto-planetary disk

Example: circumstellar disk of a Be star: where he continuum and individual emission lines are formed?





from Carciofi et al. 2011

Outlook:

I. Angular resolution in astronomy, why do we need interferometry

II. Common principles of interferometry

III. Atmospheric effects

IV. Basic differences and limitations of the near-IR and radio interferometry

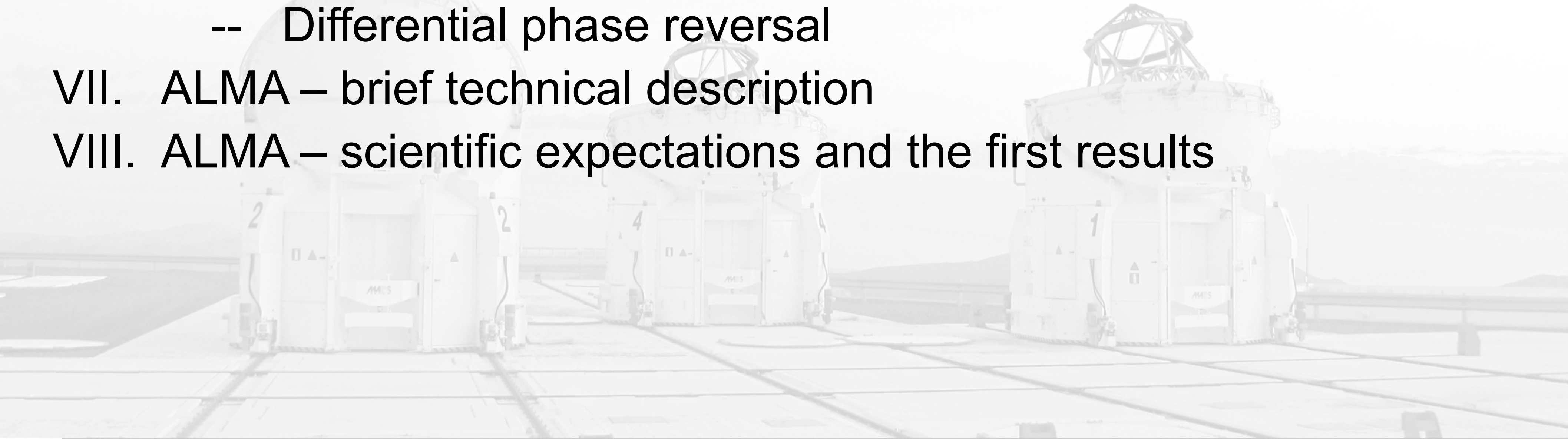
V. ESO VLT interferometer

VI. Examples of VLTI Be star projects

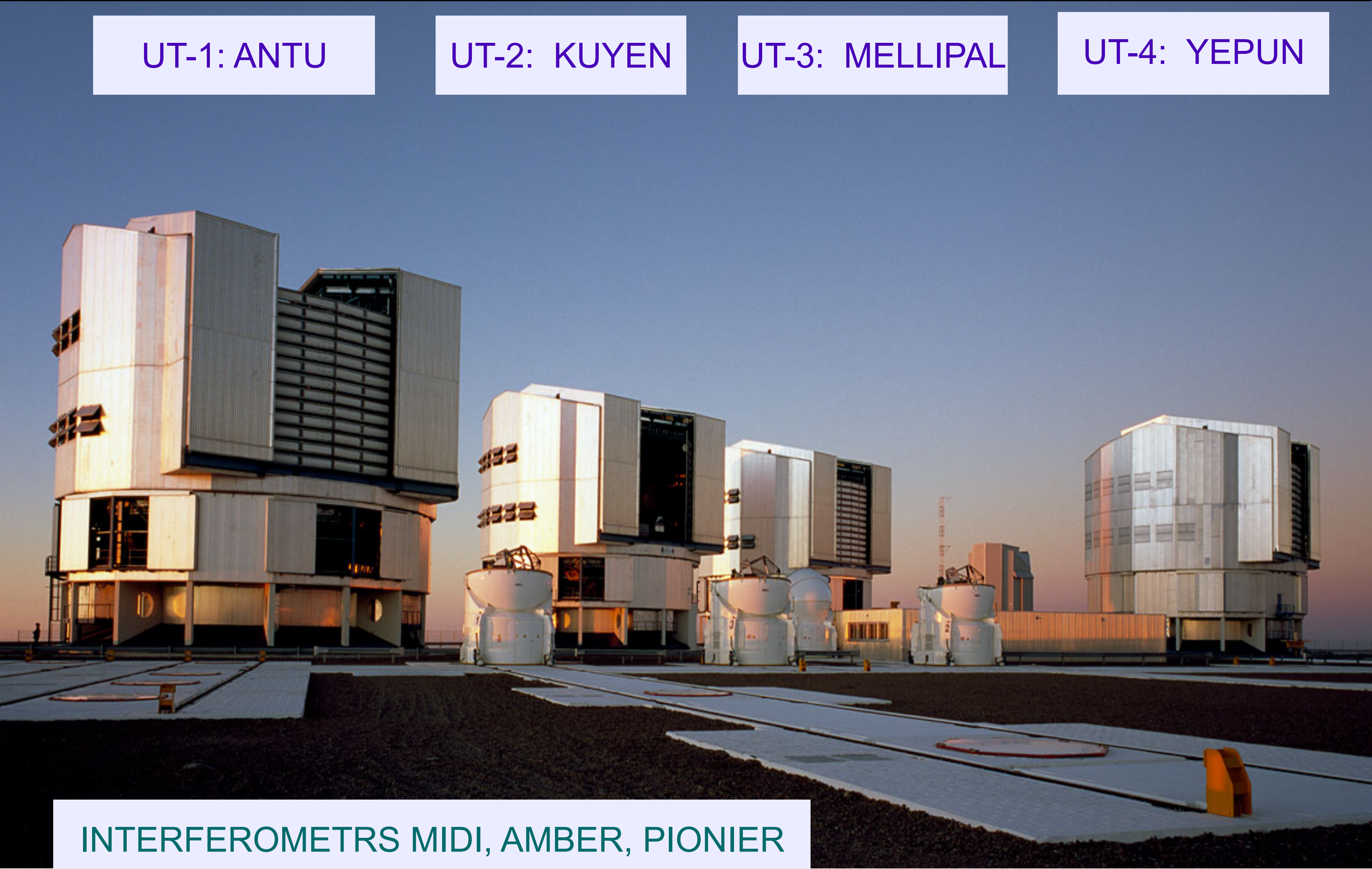
  - ζ Tau: detection of disk density waves
  - -- Differential phase reversal

VII. ALMA – brief technical description

VIII. ALMA – scientific expectations and the first results



VLTI – ESO/ Paranal



UT-1: ANTU

UT-2: KUYEN

UT-3: MELLIPAL

UT-4: YEPUN

INTERFEROMETRS MIDI, AMBER, PIONIER

The VLT Interferometer

Four 8.2-m Unit Telescopes. Baselines up to 130m

Four 1.8-m Auxiliary Telescopes. Baselines 8 – 200m

Near-IR to MIR (angular resolution 1-20 mas)

Excellent uv coverage Instruments

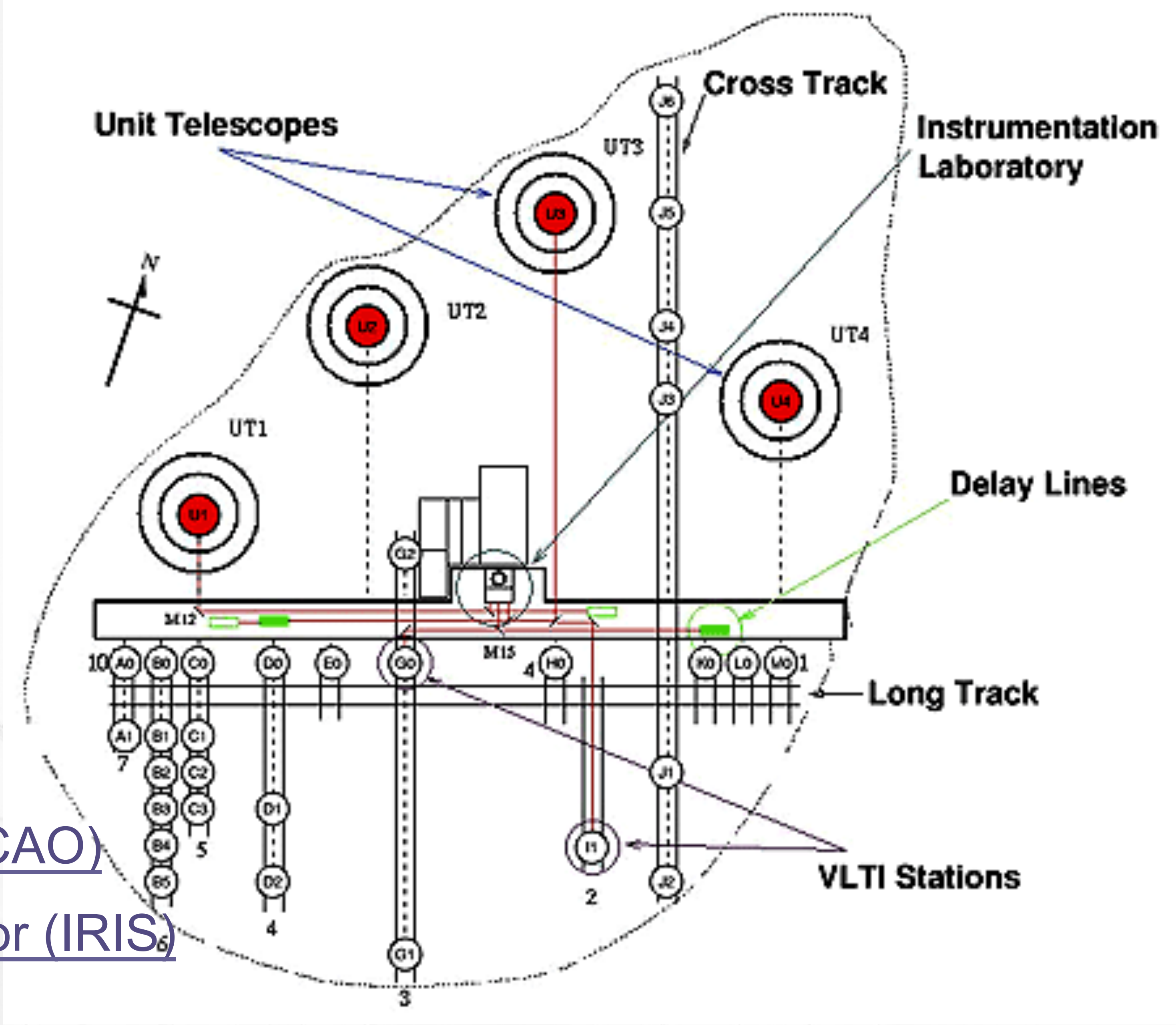
IR tip-tilt in lab (IRIS)

Adaptive optics with
    60 actuators DM, Strehl >50% in K -Guide Star $m_V < 16$ (MACAO)

FINITO fringe Tracker

PRIMA ?

VLTI layout



VLTI subsystems

Unit Telescopes

Auxiliary Telescopes

Delay Lines

Control System

Adaptive optics (MACAO)

Infrared Image Sensor (IRIS)

FINITO

Delay-line configurations

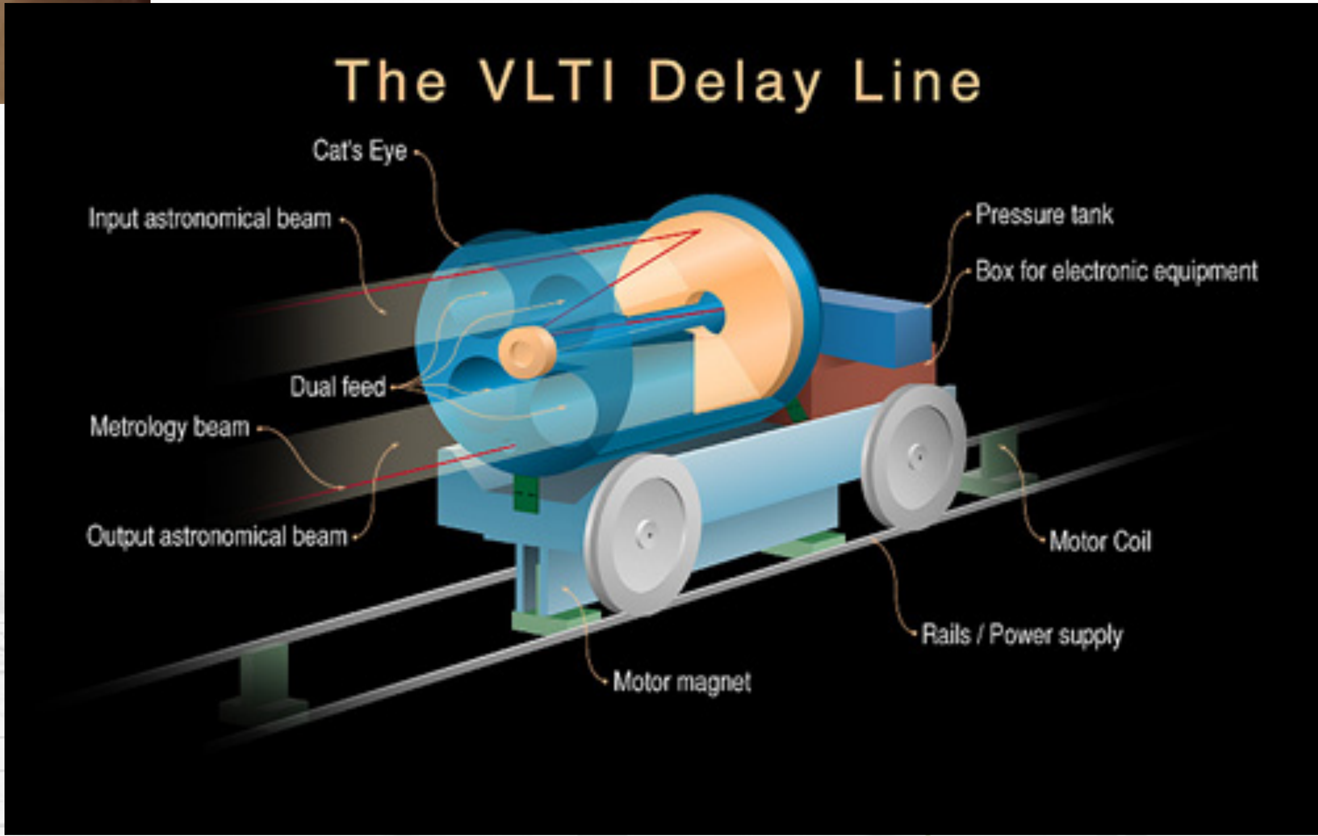
VLTI – Auxiliary telescopes

Used only for interferometry
M1: 1.8m, movable to 30 pads at the VLT platform, several interferometric configurations.
No active optics, no wind protection during observations

Delay lines

- 6 laser controlled delay lines
- Accuracy of the fringe tracking 20-30µ

Variable curvature mirrors – fixed pupil image

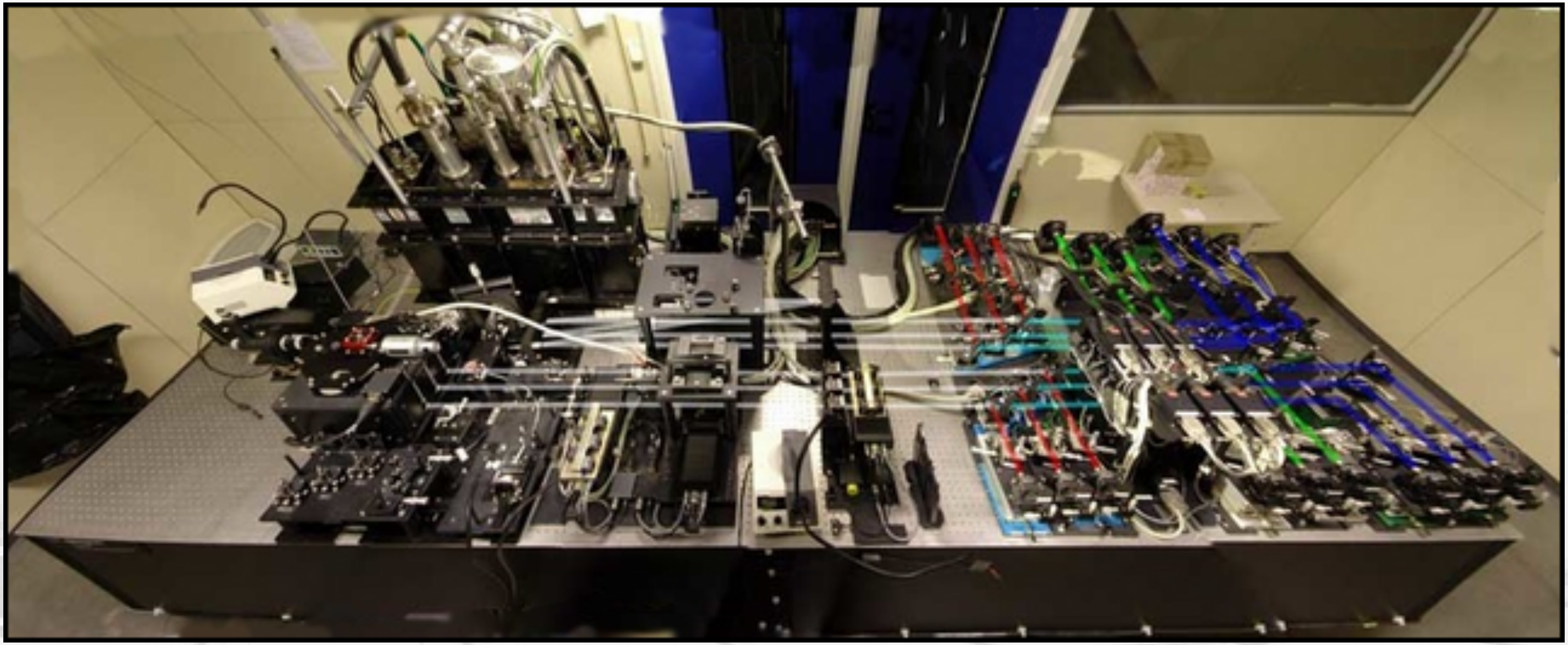


AMBER interferometer

Near-IR (J, H, K; 1-2.5 μm) 3-way beam combiner.

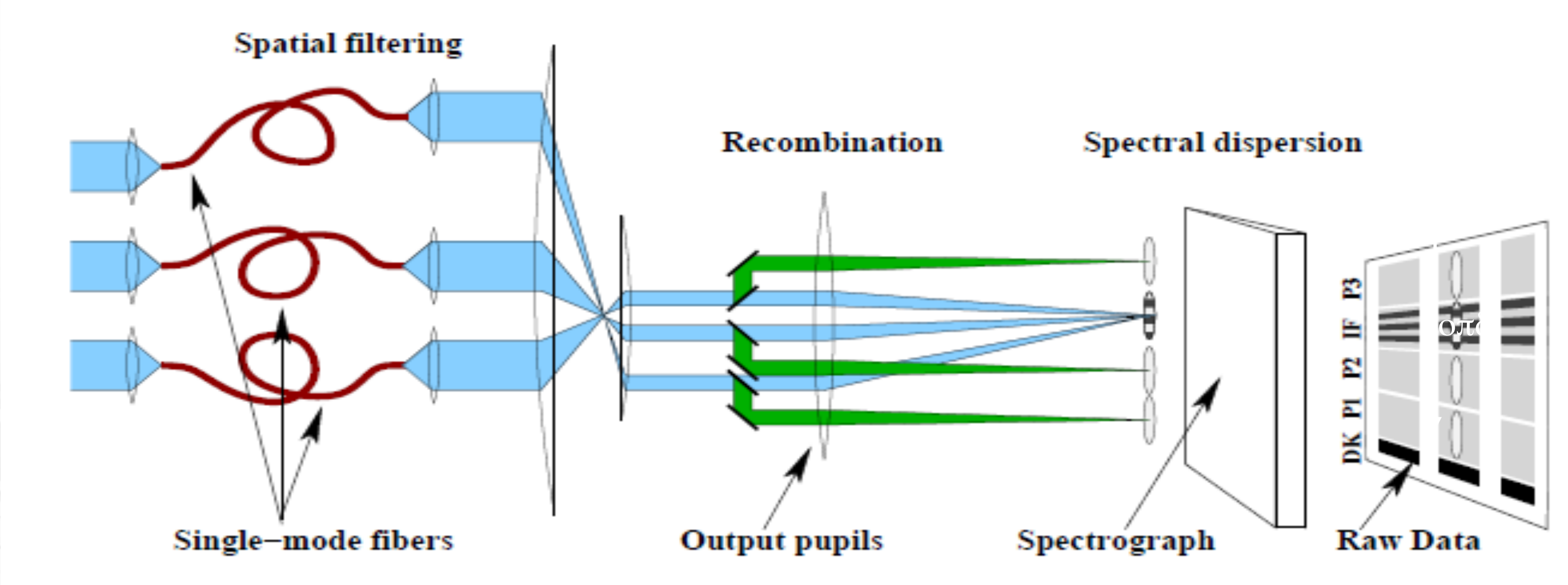
Spectral resolution:

R=30 (low res.), 1500 (medium res.), 1200 (high res.).



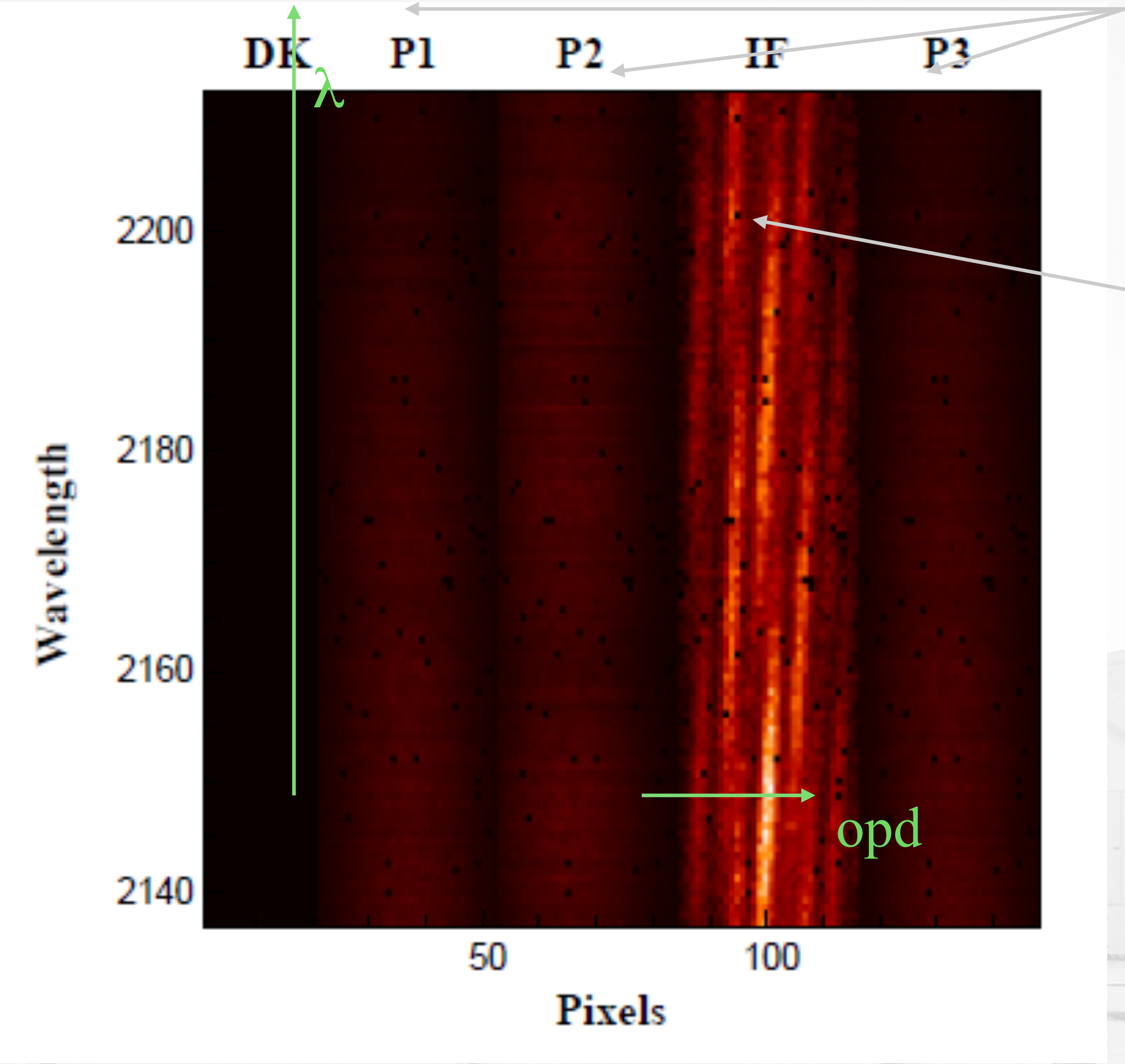
AMBER interferometer

- Use 3 telescopes of VLTI
  - closure-phase
- Near-IR: J, H and K bands
  - Single-mode filtering
  - Simultaneous photometry monitoring
- Spectral dispersion (y-axis on detector)
  - differential visibilities / phases
- Spatial combination (opd is x-axis on detector)



AMBER: 3 fringes in a single beam

and 3 photometric beams



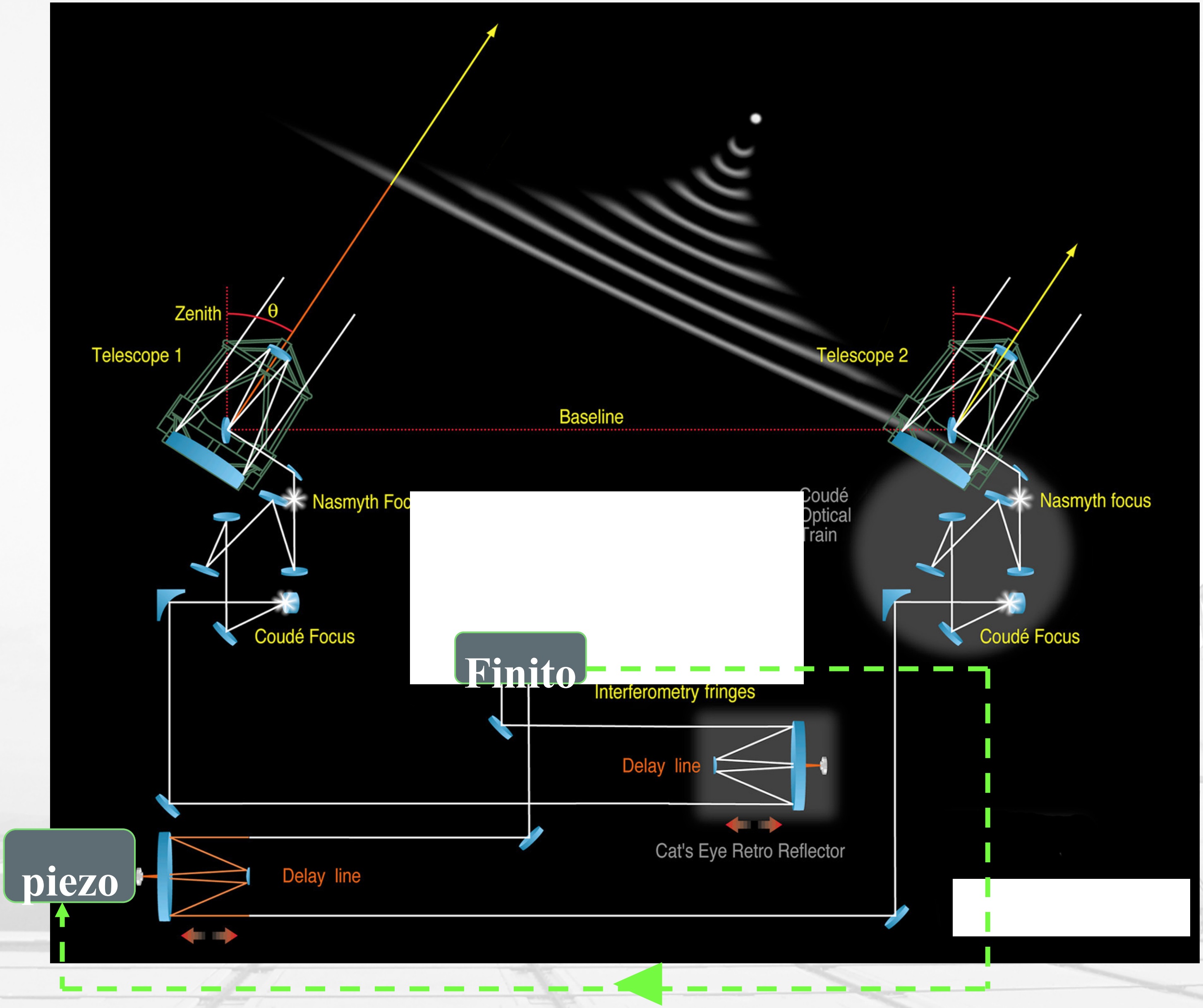
Photometric beams

Mix of 3 fringe patterns:

- 1-2
- 1-3
- 2-3

Medium resolution

FINITO fringe Tracking



FINITO:

measures the phase sends correction to the DLs

Fringe are locked:

Longer DIT larger spectral resolution available, better fringe quality = better dynamical range

But brings calibration problems

MIDI Interferometer

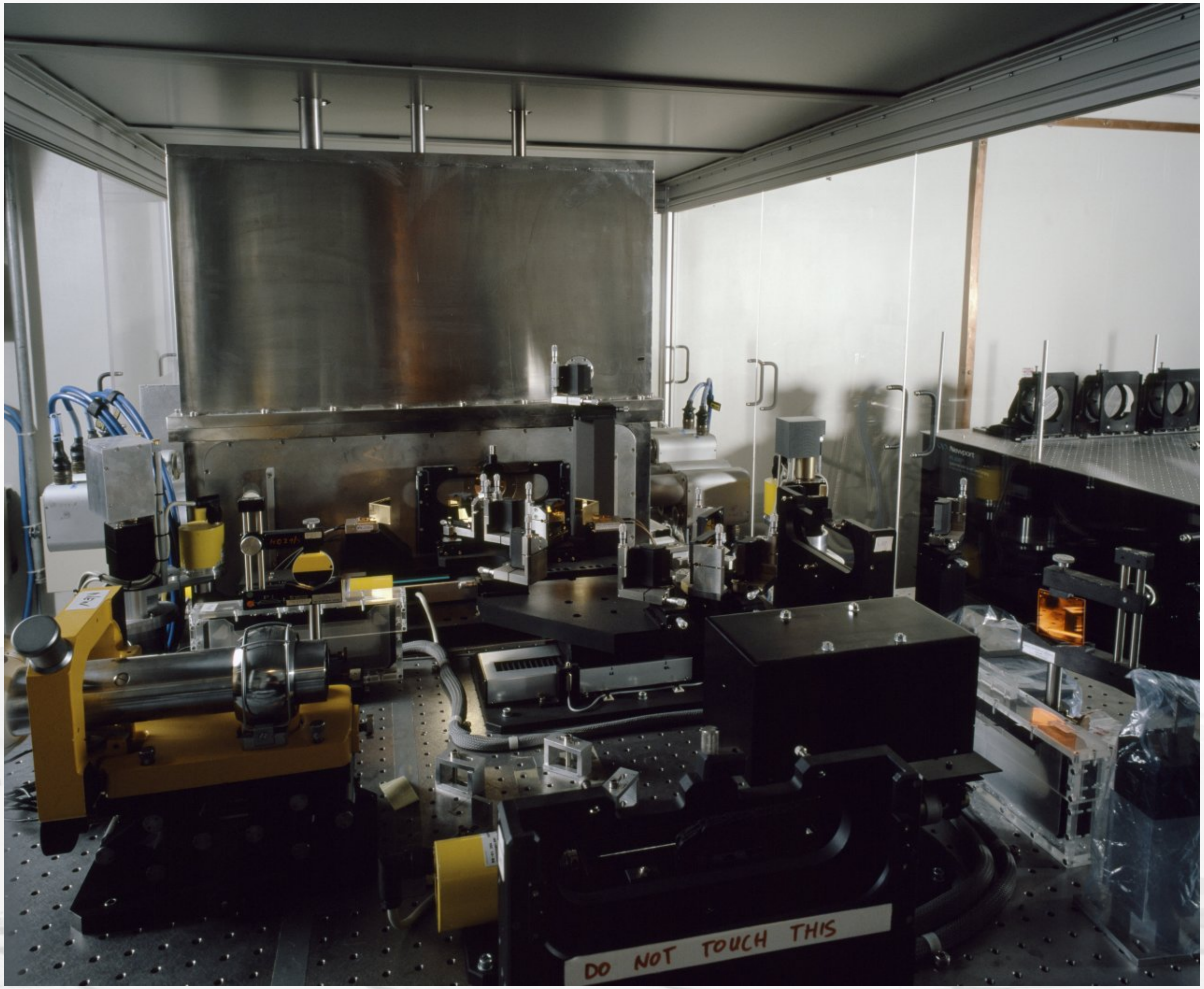
Mid-Infrared (8-13 μm) 2-way beam combiner.

Spectral resolution R=30 (prism), R=230 (grism)

- Turbulence is smaller at 10μm, it is less an issue than for AMBER
- Main issue is the thermal background!

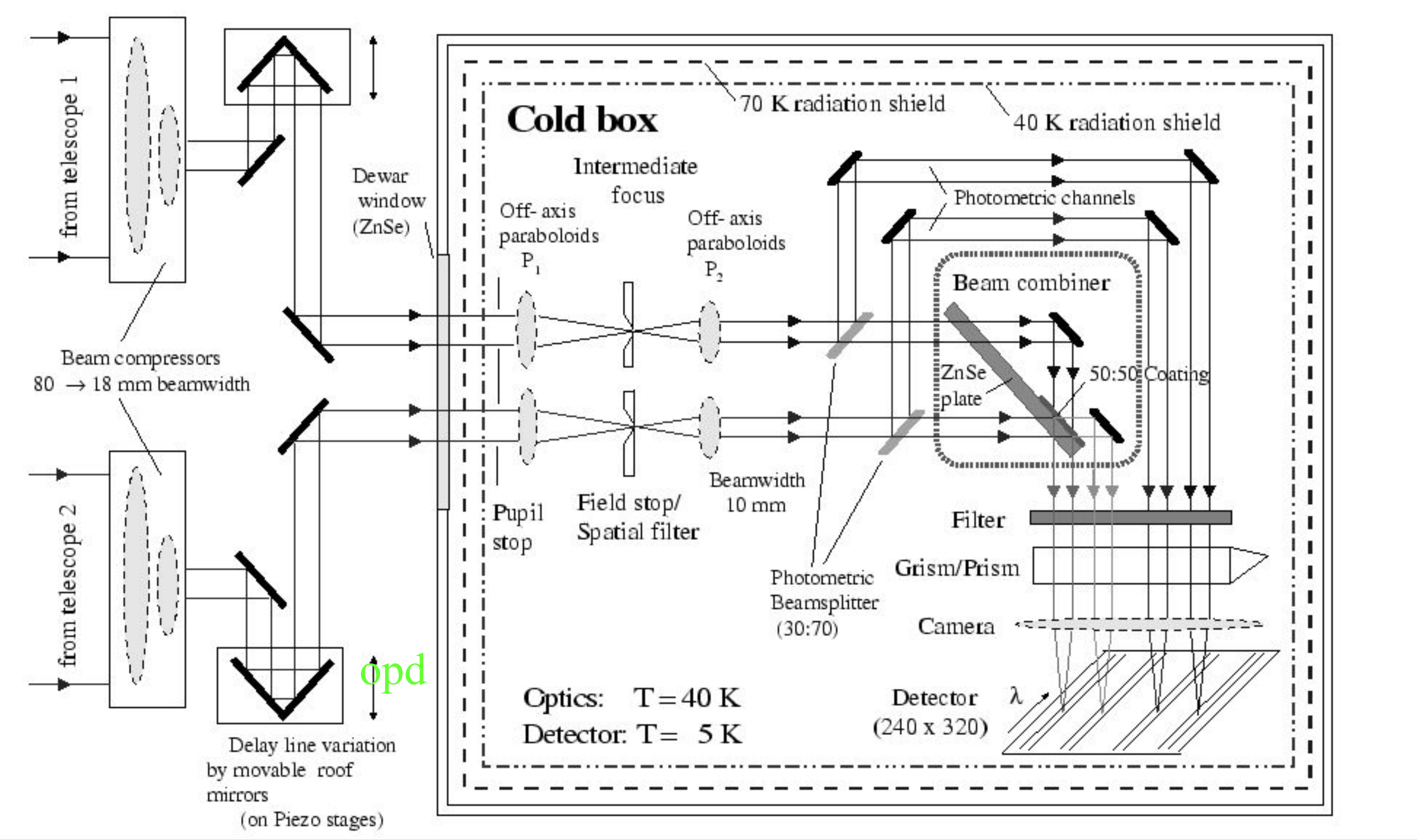
Observation sequence:

Fringe data (opd modulation
  HIGH_SENS (no chopping)
  SCI_PHOT (chopping)
Photometry (chopping on)



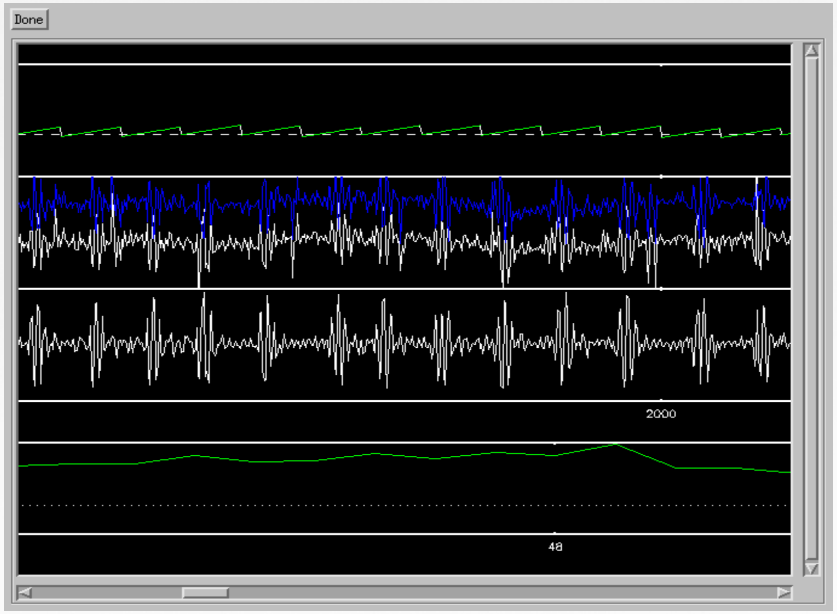
The MIDI instrument

Use 2 telescopes of the VLTI, thermal-IR → telescope chopping



MIDI HIGH-SENS mode

1.



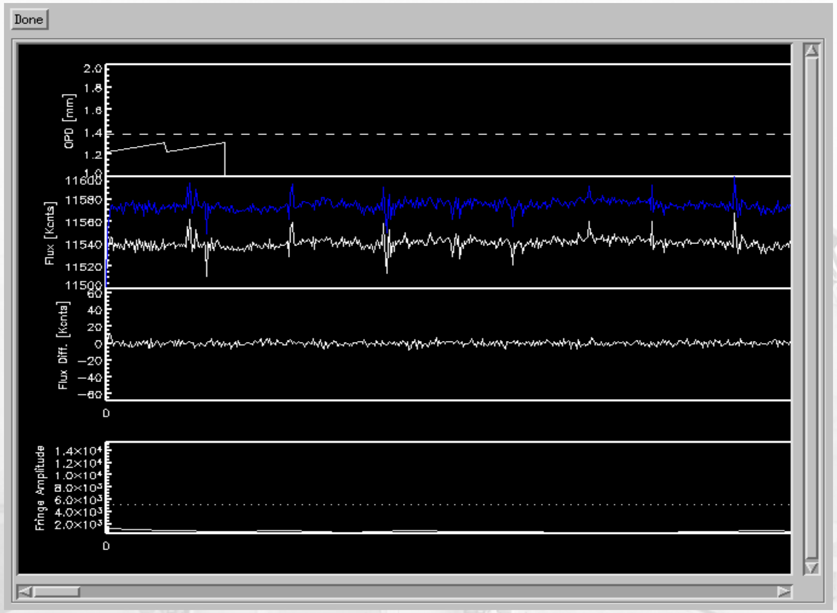
Observe fringes:

- opd modulation without chopping: background is removed by doing $\mathbf{I} = \mathbf{I}^{+}$ -

Observe the photometries:

- no opd modulaiton
- shutter in beam A and then B
- chopping required

2.



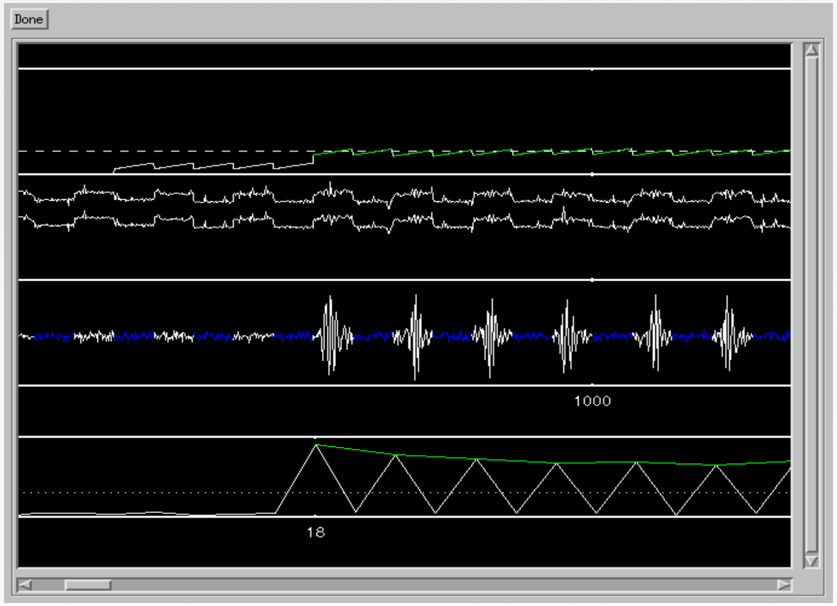
Good sensitivity

Photometry non simultaneous
⇒ bias in the visibilities

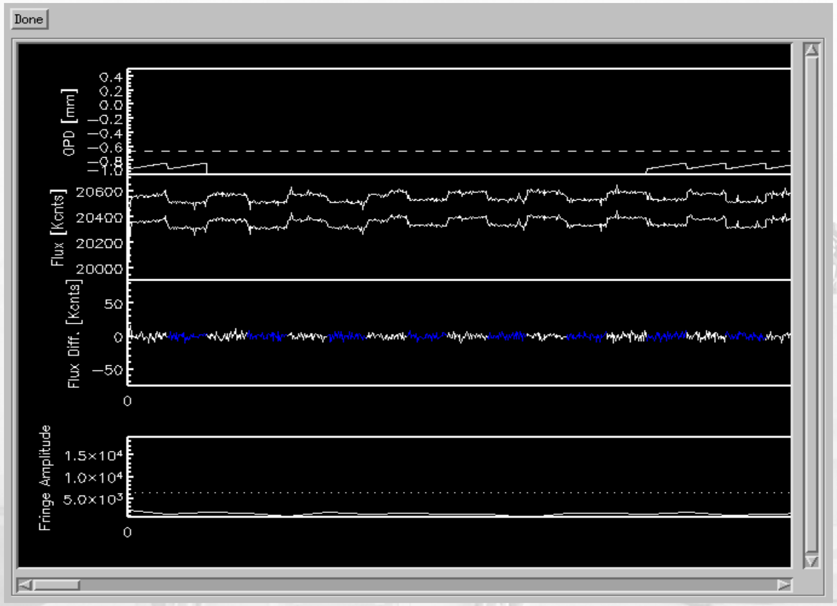
Dedicated to faint objects

MIDI SCI-PHOT mode

1.



2.



Observe fringes and photometry:

- opd modulation
- chopping required

Observe the photometries:

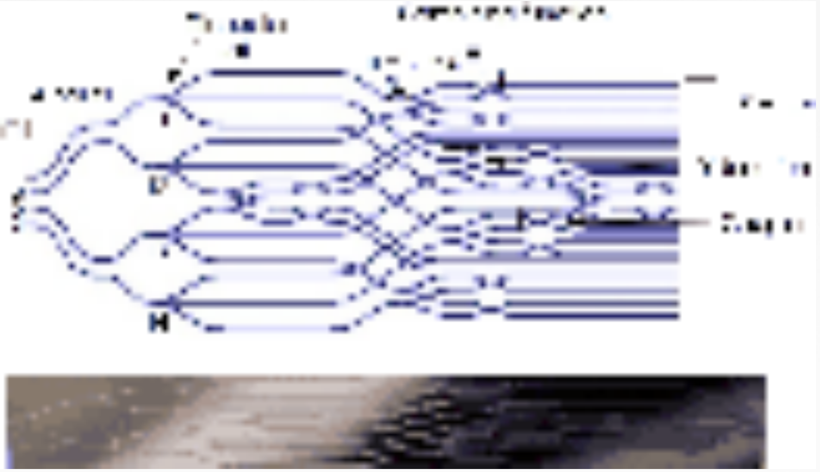
- shutter in beam A and then B
- chopping required
- only used to know the splitting ratio photometry / fringes (Kappa matrix)

Less sensitivity since the flux is split between photometry **and** fringes

Photometry simultaneous with fringes ➔less bias in the visibilities, less photometric noise

Dedicated to bright objects

PIONIER interferometer

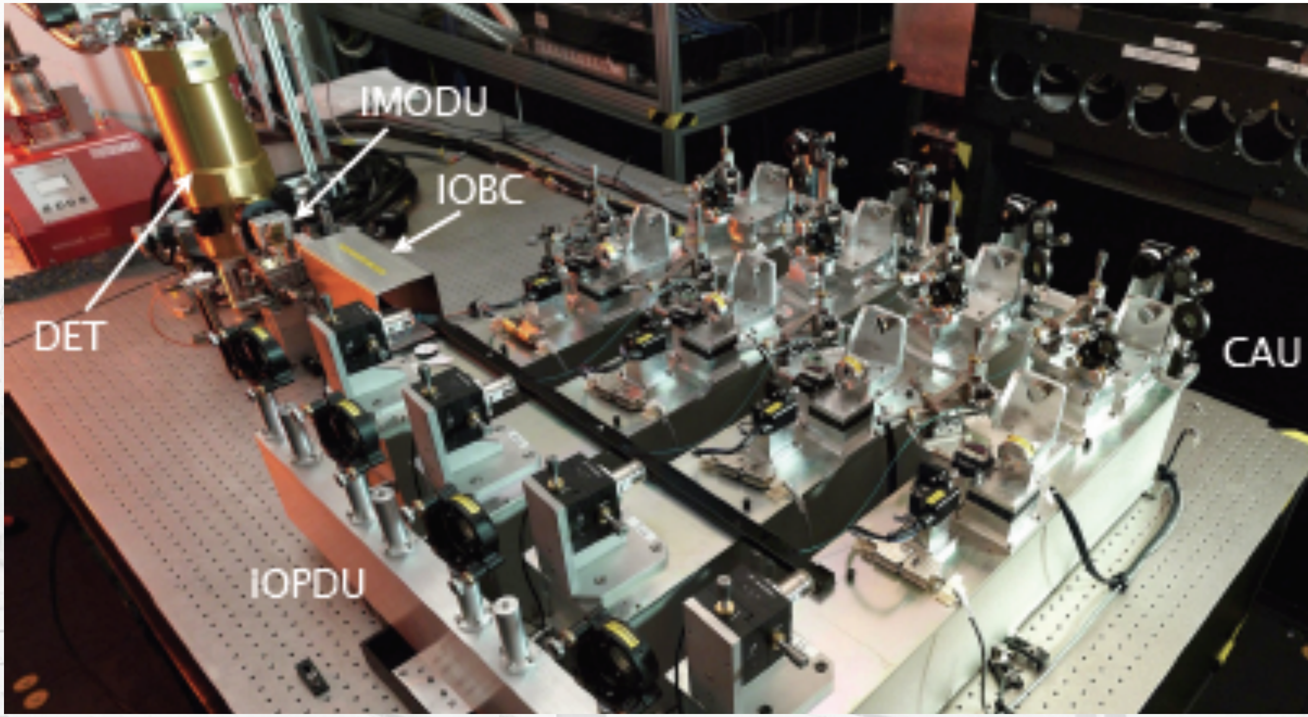


Precision Integrated-Optics Near-infrared Imaging ExpeRiment

IPAG guest instrument, can combine 4 AT or UT telescopes, very high closure phase accuracy (< 0.5°), polarization compensated by a Lithium-Niobate plate

beam combiner integrated in a small plate, it delivers 24 interferometric outputs

H,K bands
low R = 40
Commissioned 2010



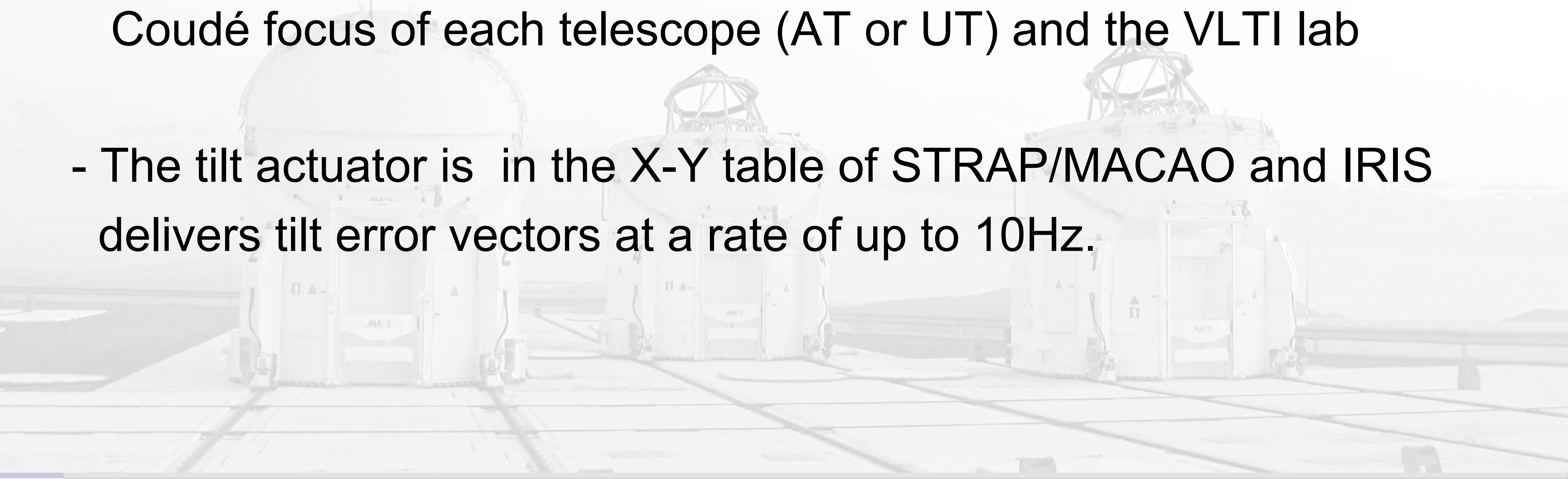
VLTI auxiliary subsystems

Infrared Image Sensor (IRIS):

- a tilt sensor , measures the tilt of up to 4 stellar beams simultaneously in 3 possible spectral bands, J or H or K

- monitors the image drift introduced inside the VLTI between the Coudé focus of each telescope (AT or UT) and the VLTI lab

- The tilt actuator is in the X-Y table of STRAP/MACAO and IRIS delivers tilt error vectors at a rate of up to 10Hz.



VLTI auxiliary subsystems

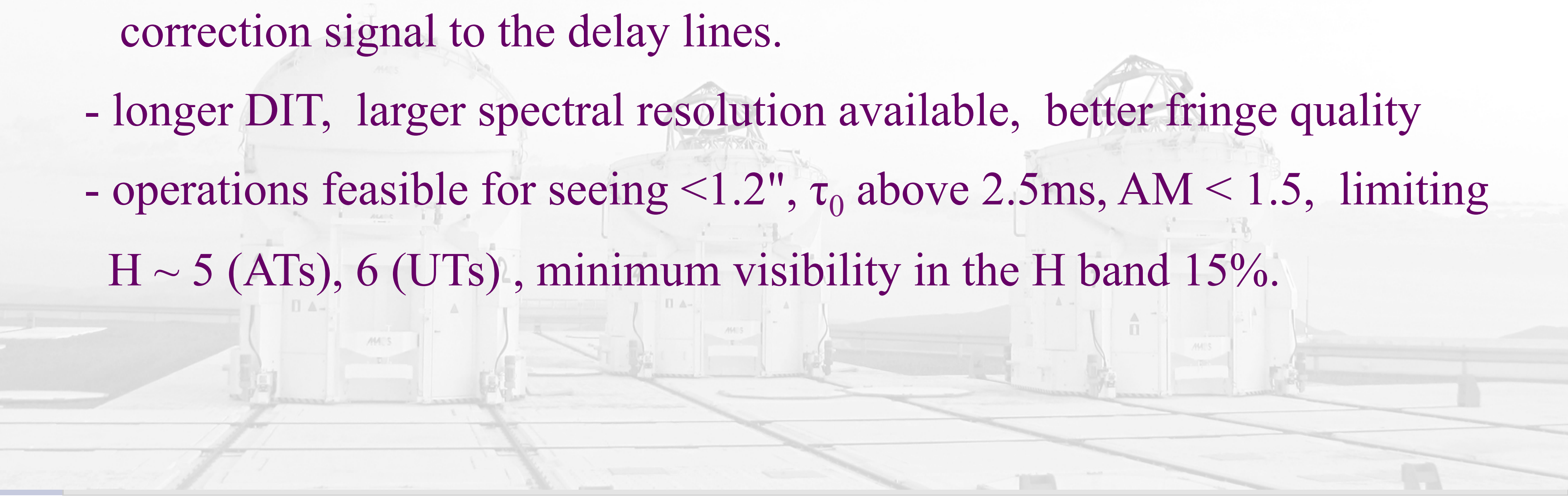
- **FINITO, Fringe-tracking Instrument of NIce and TOrino**

  - three beam fringe tracker, operates in the H-band

  - measures the relative phase difference between the light beams, identifies the piston disturbances due to atmospheric turbulence. An error signal is sent to the OPD Controller which in return sends a correction signal to the delay lines.

  - longer DIT, larger spectral resolution available, better fringe quality

  - operations feasible for seeing <1.2", τ_0 above 2.5ms, AM < 1.5, limiting H ~ 5 (ATs), 6 (UTs) , minimum visibility in the H band 15%.



2nd Generation VLTI instruments

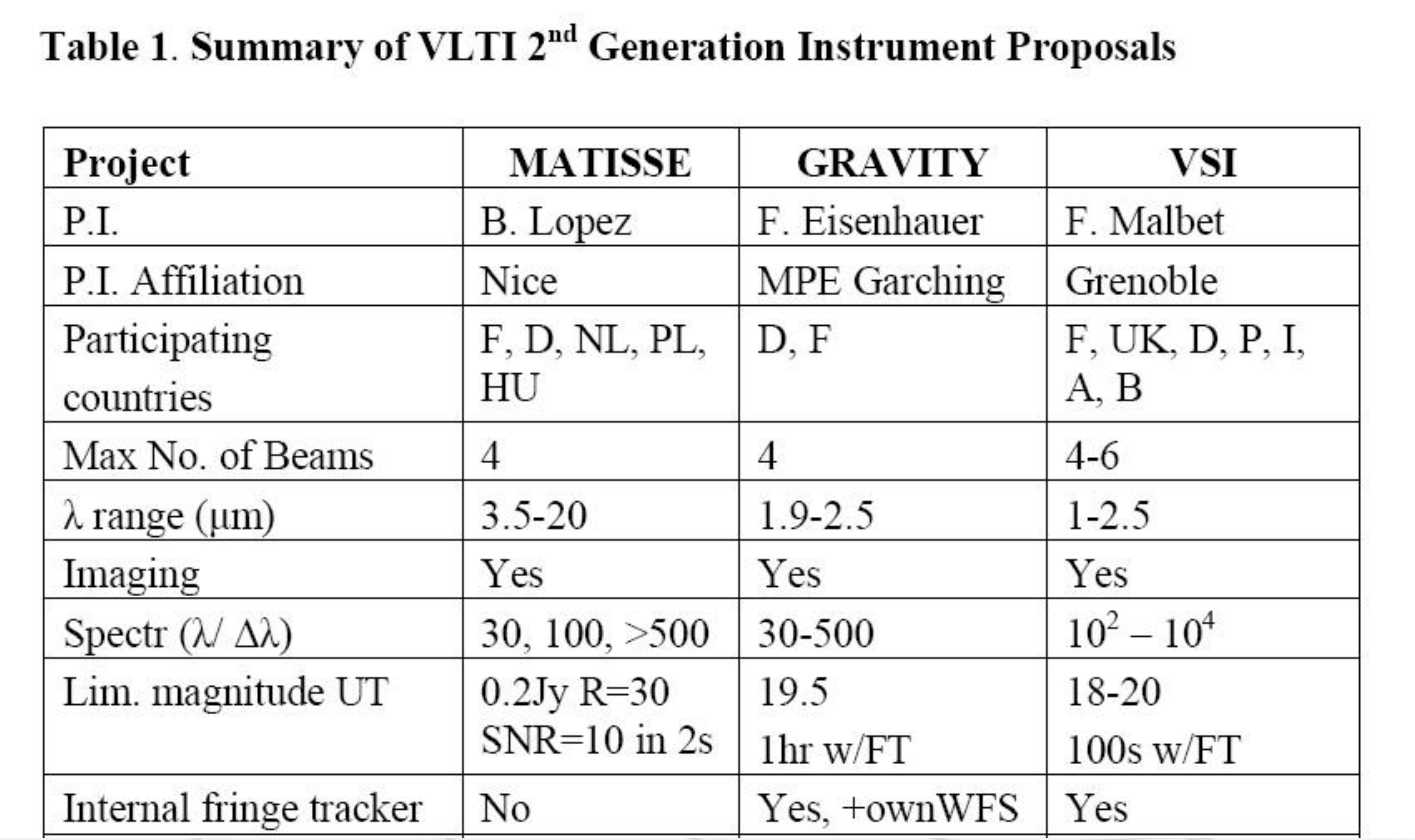


Table 1. Summary of VLTI 2nd Generation Instrument Proposals

Project	**MATISSE**	**GRAVITY**	**VSI**
P.I.	B. Lopez	F. Eisenhauer	F. Malbet
P.I. Affiliation	Nice	MPE Garching	Grenoble
Participating countries	F, D, NL, PL, HU	D, F	F, UK, D, P, I, A, B
Max No. of Beams	4	4	4-6
λ range (μm)	3.5-20	1.9-2.5	1-2.5
Imaging	Yes	Yes	Yes
Spectr ($\lambda / \Delta\lambda$)	30, 100, >500	30-500	$10^2 - 10^4$
Lim. magnitude UT	0.2Jy R=30 SNR=10 in 2s	19.5 1hr w/FT	18-20 100s w/FT
Internal fringe tracker	No	Yes, +ownWFS	Yes

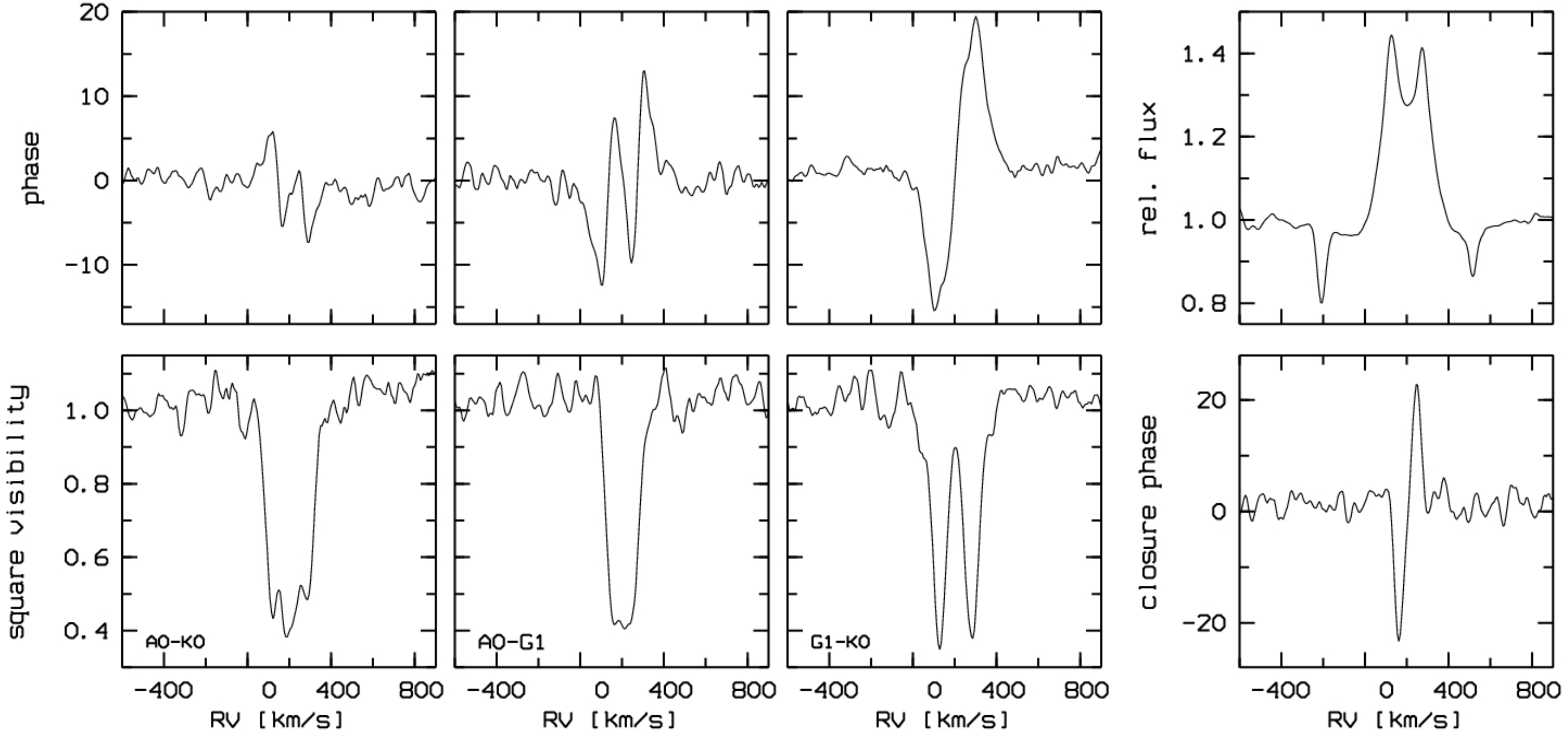
Outlook:

I. Angular resolution in astronomy, why do we need interferometry
II. Common principles of interferometry
III. Atmospheric effects
IV. Basic differences and limitations of the near-IR and radio interferometry
V. ESO VLT interferometer
VI. Examples of VLTI Be star projects
  – ζ Tau: detection of disk density waves
  -- Differential phase reversal
VII. ALMA – brief technical description
VIII. ALMA – scientific expectations and the first results

High-resolution spectro-interferometry

Each bin across the spectral line represents a projection on the sky in the given RV range. Emission lines of Be stars determine dynamical profile of the circumstellar disk.

Be stars: Broad line due to fast rotation. Pole-on stars (28 CMa) 15 spectral bins over Br γ, equator-on seen Be stars - 40-50 bins at the AMBER HR (12000) resolution



Br γ VLTI/AMBER observations of the Be star β CMi Stefl et al., 2011

Modeling of HR data

…. talk by R. Klement

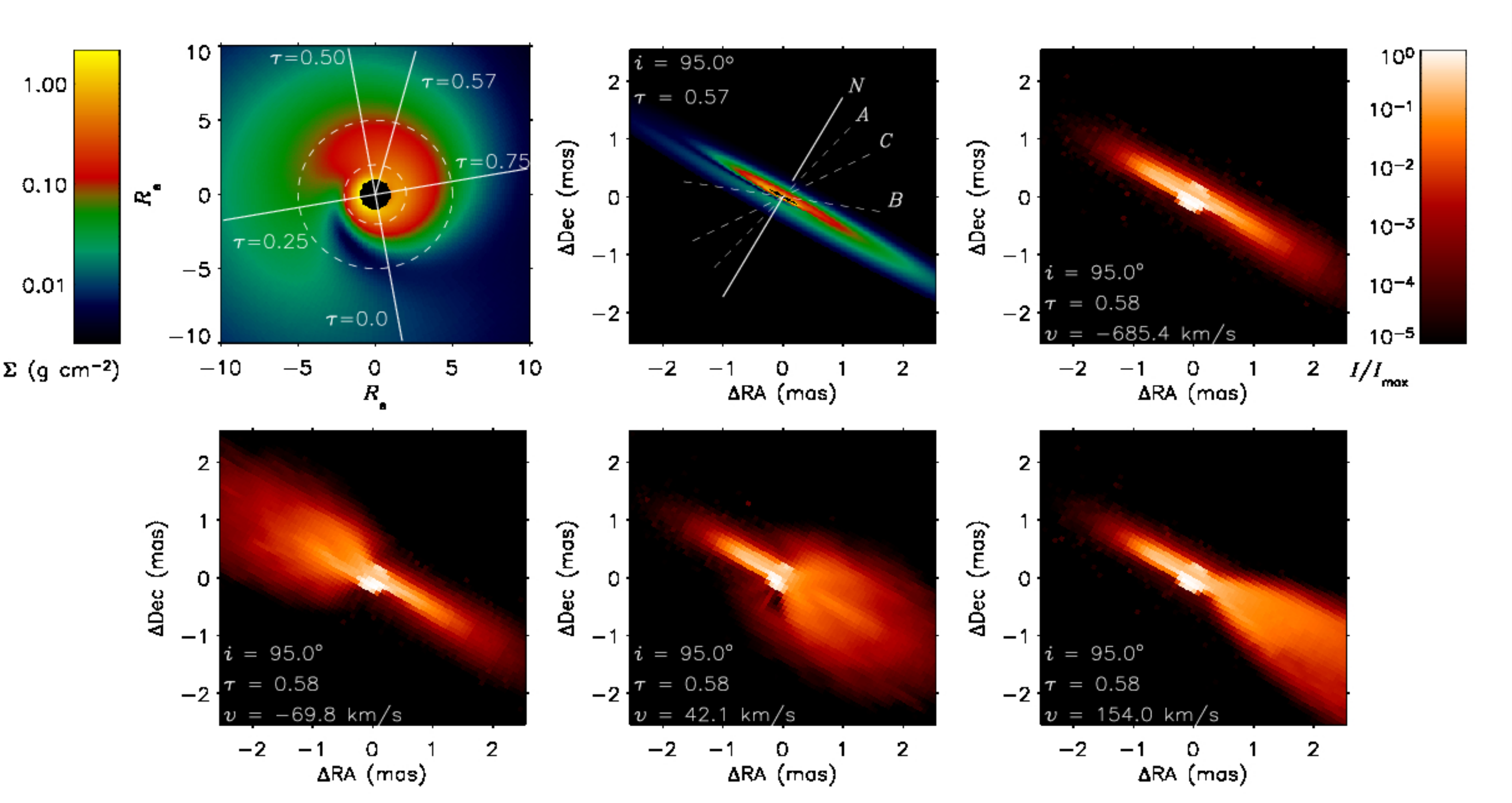
No simple models e.g. In LITpro, physical models necessary

HDUST - viscous excretion dis model: Carciofi & Bjorkman (2006, ApJ 639, 1081, Carciofi 2010, IAU Symp 172, 325)
+ ongoing modifications

- 3-D, NLTE code solving coupled problems of radiative transfer, radiative and statistical equilibrium for arbitrary gas density and velocity distribution.

- NLTE Monte-Carlo simulations solves the temperature and density disk profiles. The only input are stellar parameters, disk inclination and stellar mass-loss

Detection of density waves in ζ Tau



Modeling of the ζ Tau density wave (from Carciofi et al. 2009) at the time of AMBER observations. Top: seen pole-on, in the disk plane and as an synthetized image at 2.16 µm. Bottom: synthetic images at RV= -70, +42 and +154 km/s.

Detection of density waves in ζ Tau

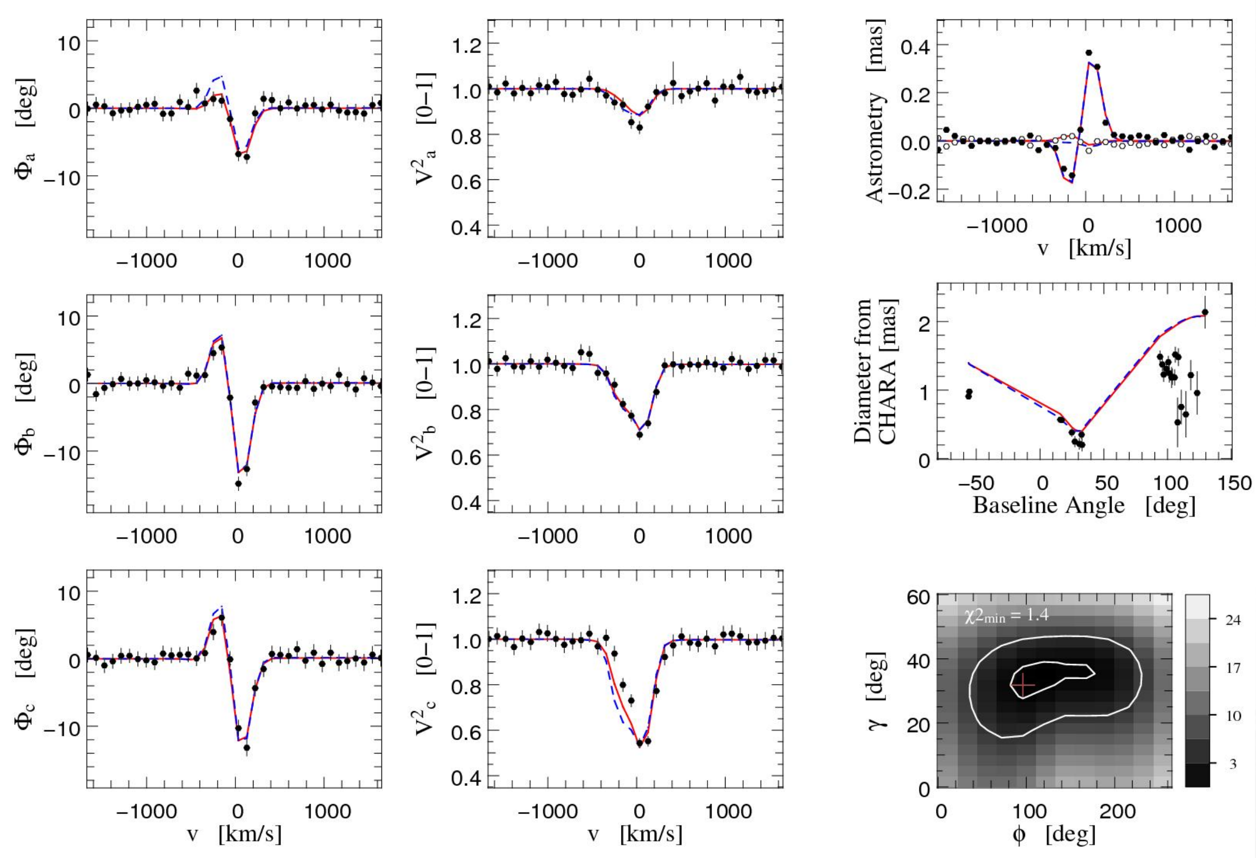
ζ Tau: HD 37202, B2IV   AMBER MR (1500), Dec 2006, Br γ
Ŝtefl et al. 2009 (A&A 504, 929), Carciofi et al. 2009 (A&A 504, 915)

- AMBER data analyzed and modeled together with extended spectroscopic and polarimetric datasets

- the disk position angle and rotation vector derived

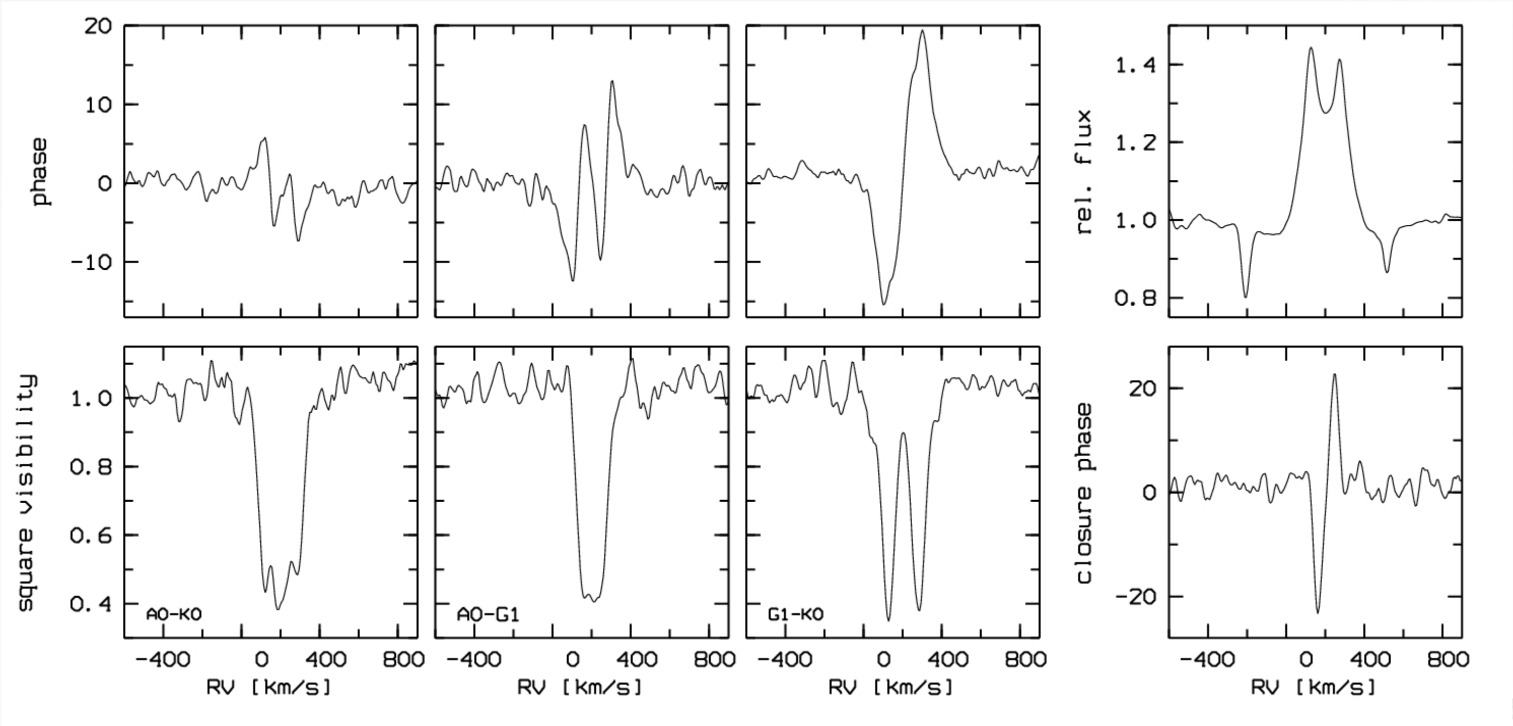
- the consistent fit of AMBER data and spectroscopic variations over 12 years

- the first quantitative test of the density wave model



HDUST fits of differential visibilities and phases of ζ Tau (Carciofi et al. 2009)

Differential phase reversal

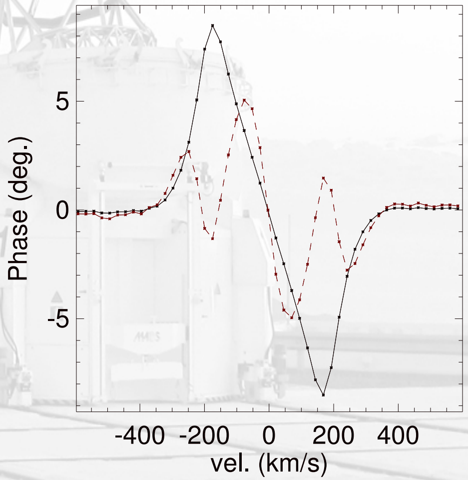


α Col: AMBER Strong phase reversal at two baselines.

Ŝtefl et al. 2011 – Phase reversal detected in five of 8 Be stars observed with AMBER in HR

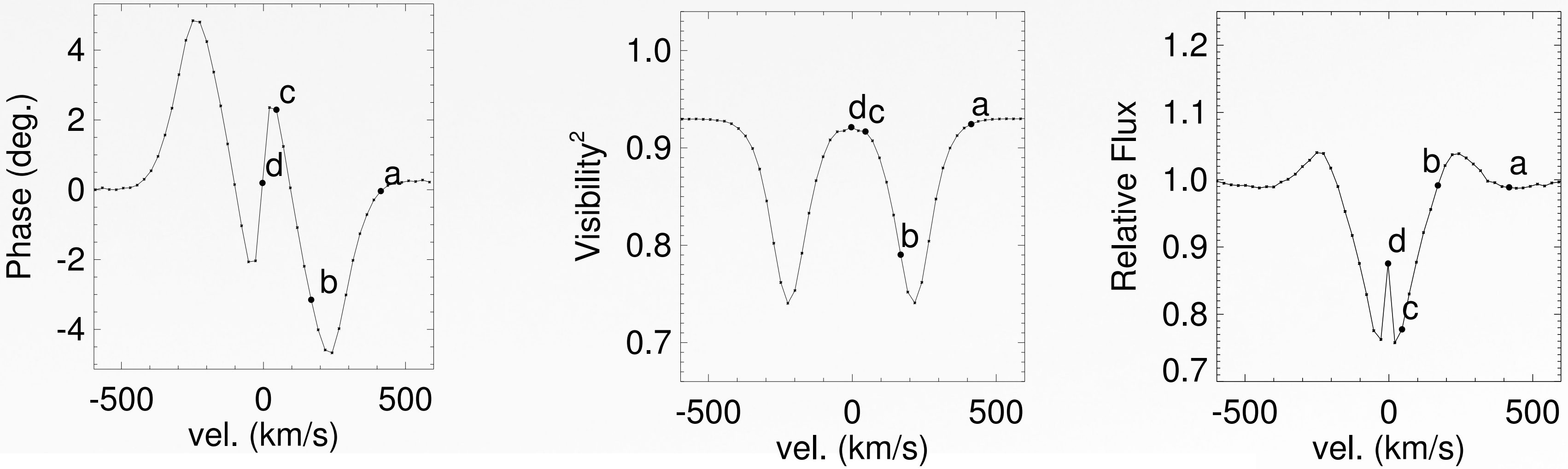
Kraus et al. 2012: Phase reversals are just the interferometric effect at the lobe transition for over-resolved disks

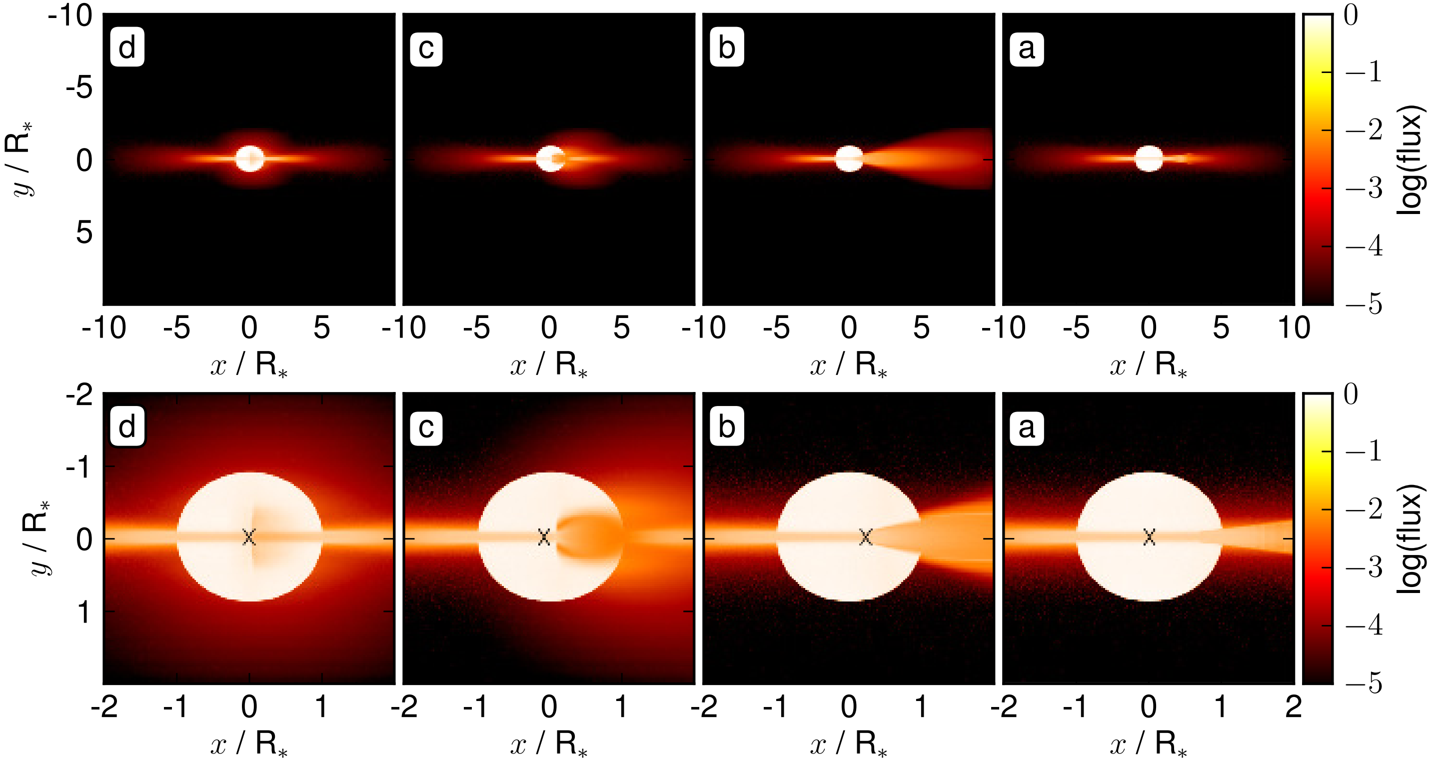
(from Faes et al. 2013)



phase reversal - cont.

Faes et al. 2013: the origin of the effect lies in the velocity-dependent line absorption by the disk of photospheric radiation.





Analogy to quasi-emission bumps, Rivinius, Stefl & Baade, 2003) – CQE-PS

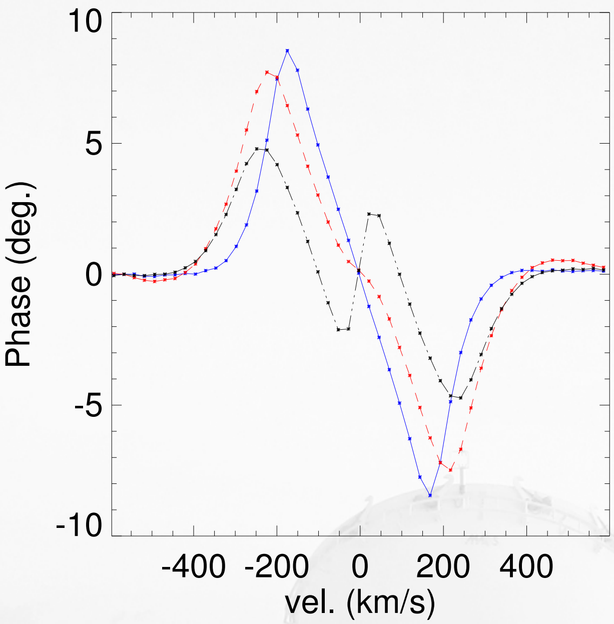
Model for B1e star

Rotation rate:
$\Omega / \Omega_{crit} = 0.8$

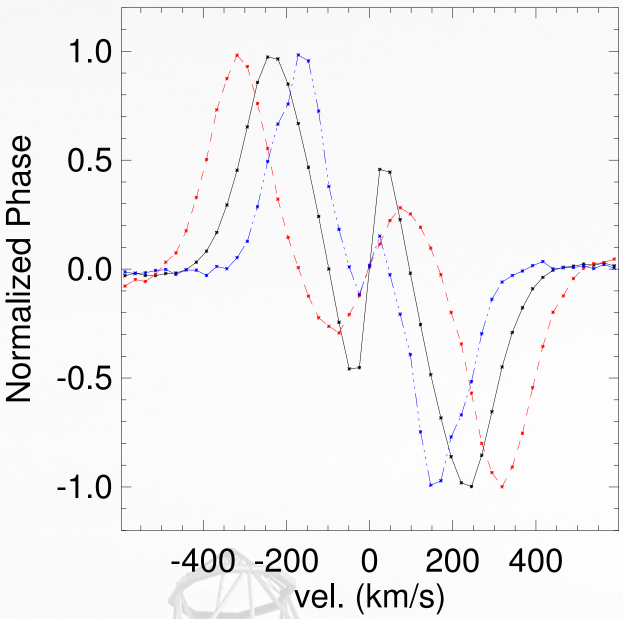
disk inclination:
$I = 90°$

phase reversal - cont.

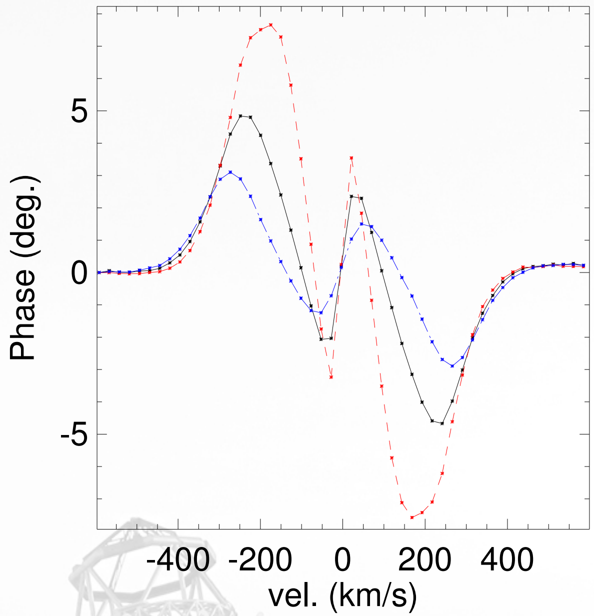
CQE-PS – great diagnostic potential on a scale smaller than the special resolution:



CQE-PS vs. disk inclination *i*:
90°, 75°, 45°



CQE-PS vs disk density:
10^{12} cm^{-3} , 10^{13} cm^{-3} ,
10^{14} cm $^{-3}$



CQE-PS vs. radial density exponent *m*:
3.0, 3.5, 4.0

Outlook:

I. Spatial resolution in astronomy, why do we need interferometry

II. Common principles of interferometry

III. Atmospheric effects

IV. Basic differences and limitations for the near-IR and radio interferometry

V. ESO VLT interferometer

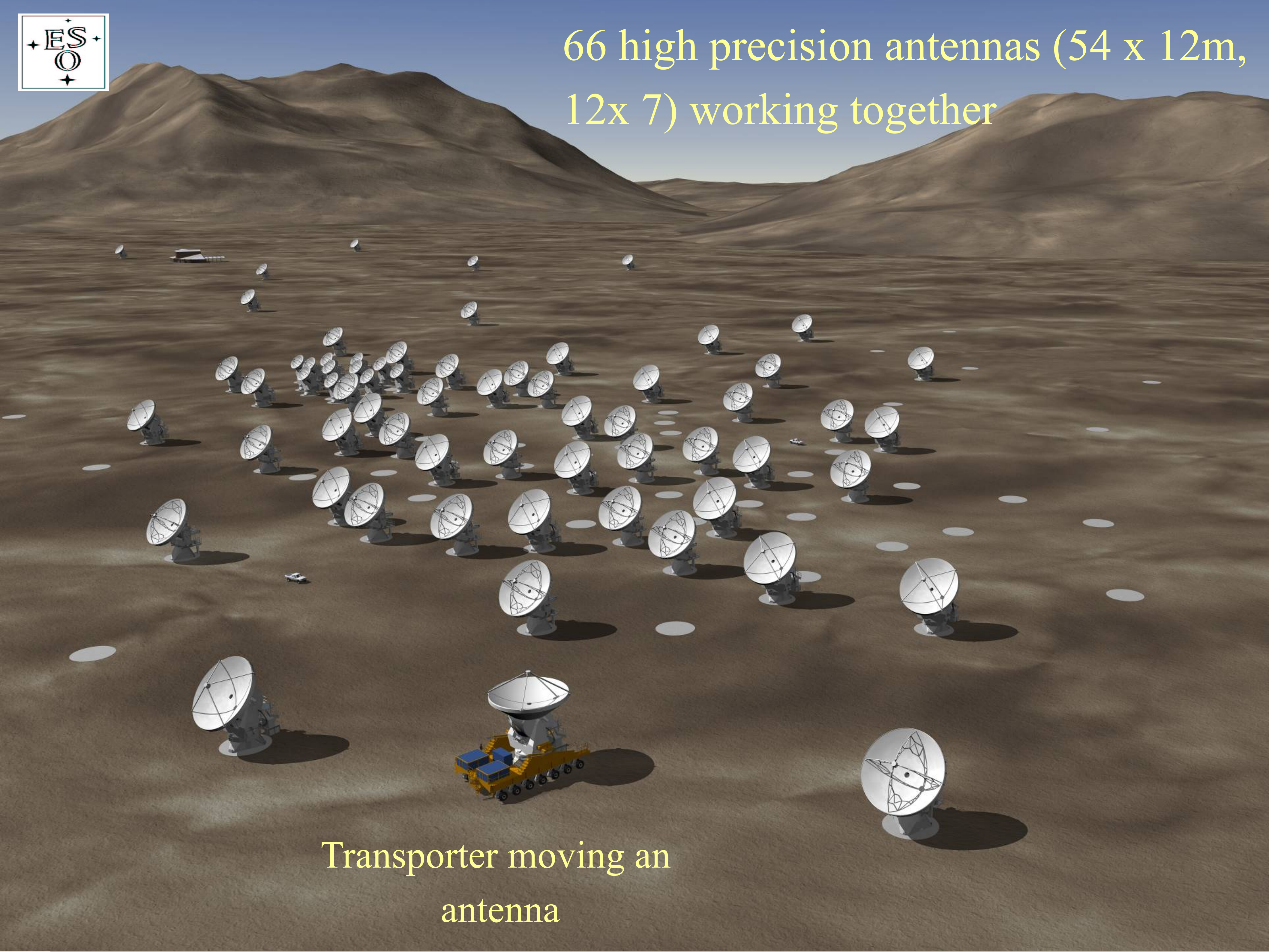
VI. Examples of VLTI Be star projects
  - ζ Tau: detection of disk density waves
  - -- Differential phase reversal

VII. ALMA – brief technical description

VIII. ALMA – scientific expectations and the first results

ALMA: Joint ALMA Observatory (JAO)

The largest astronomical international project:
ESO, USA (NSF), Canada (NRC), Japan (NINS), Tai-wan (AS), Chile



66 high precision antennas (54 x 12m, 12x 7) working together

Transporter moving an antenna

ALMA antennas

Special transporters to move antennas when the interferometric configuration is changed

Separation: 150 m to 16 km

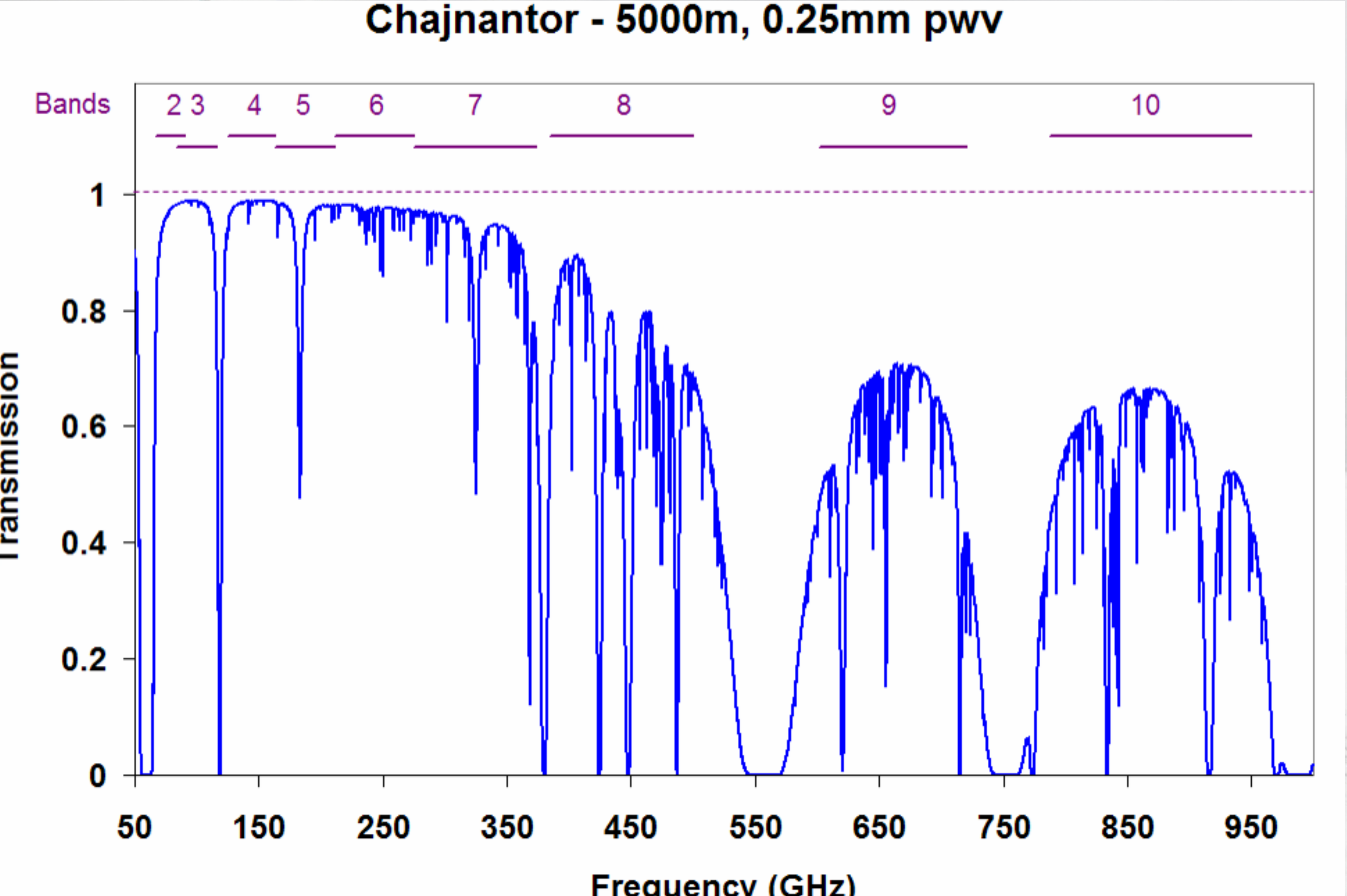
Maximum deviation from the ideal parabolic shape: 0.0025mm

Freqency: 31 – 950 GHz
(λ = 0.32 – 9.6 mm),
10 frequency bands

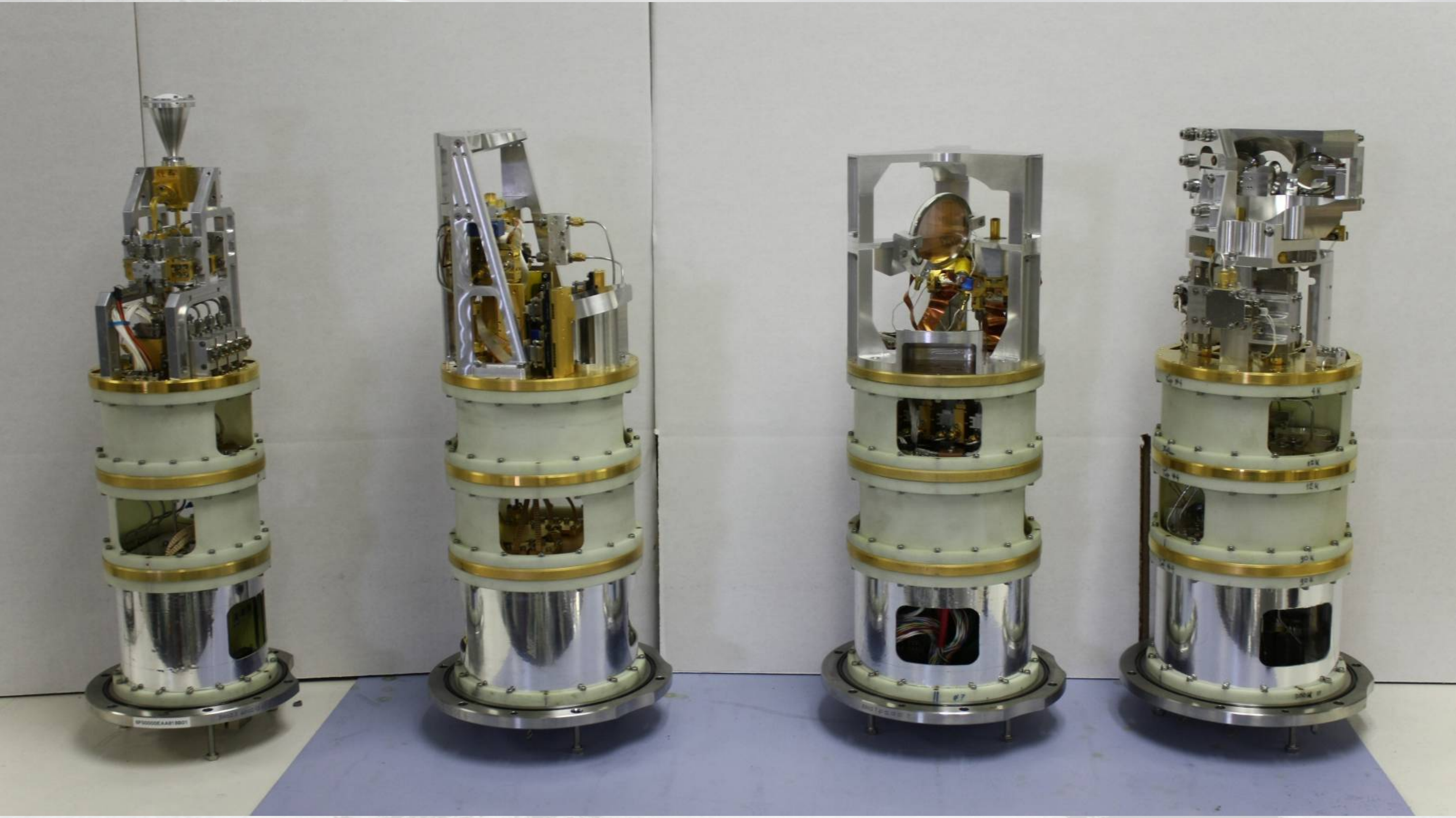
Spatial resolution:
40 mas at 100 GHz
5 mas at 800 GHz

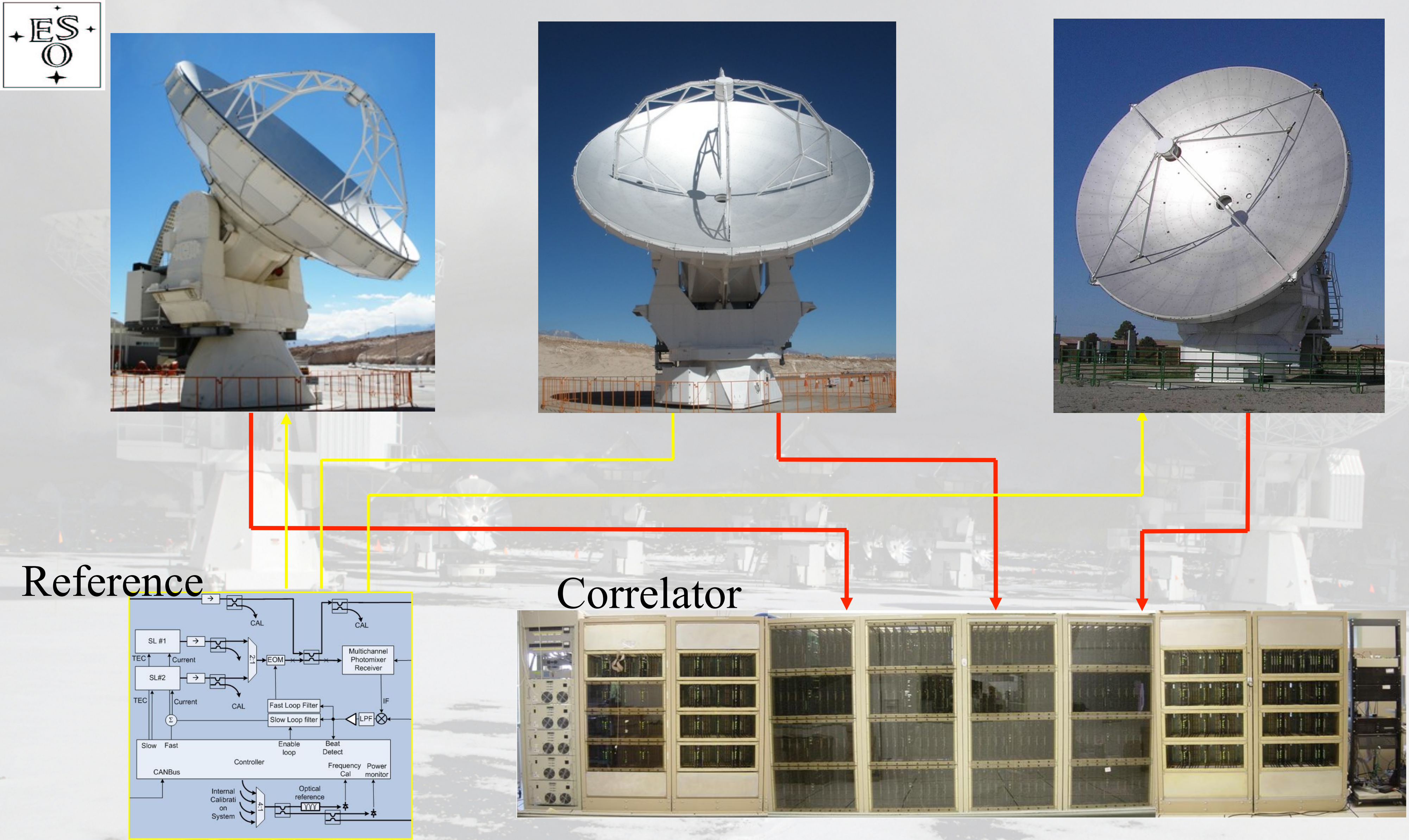
Sensitivity: ~ 10 μJy

Receivers–up to 10 cartridges in one cryostat



Bands 3 (84-116 GHz), 6 (211-275 GHz), 7 (275-373 GHz), and 9 (602-720 GHz) SIS “cartridges”





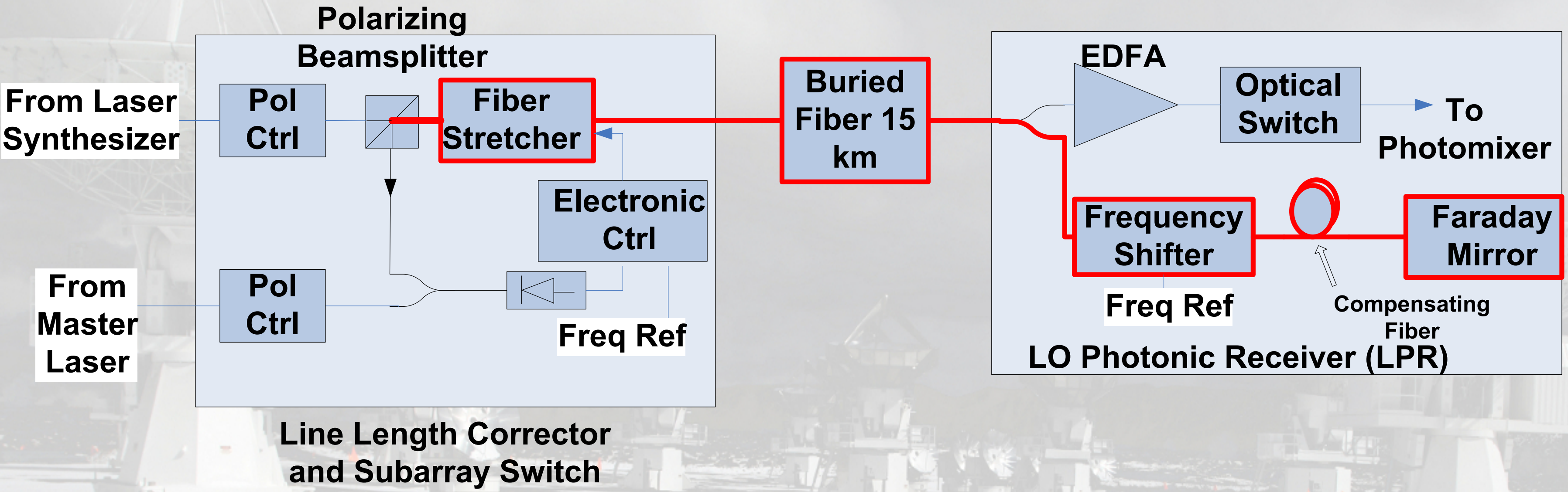
Reference

Correlator

Signals are amplified and digitized at the antennas and then combined in two big correlators. 120 Gb/s per antenna!

Extensive use of <u>photonics</u> for this and to synchronize the receivers which has to be done at the ~25 nano-second level.

Round Trip Phase Correction



The fiber path to each antenna is stabilized by an optical interferometer.

Phase correction is by a Fiber Stretcher.

Returned light-wave is orthogonally polarized to the outgoing wave.

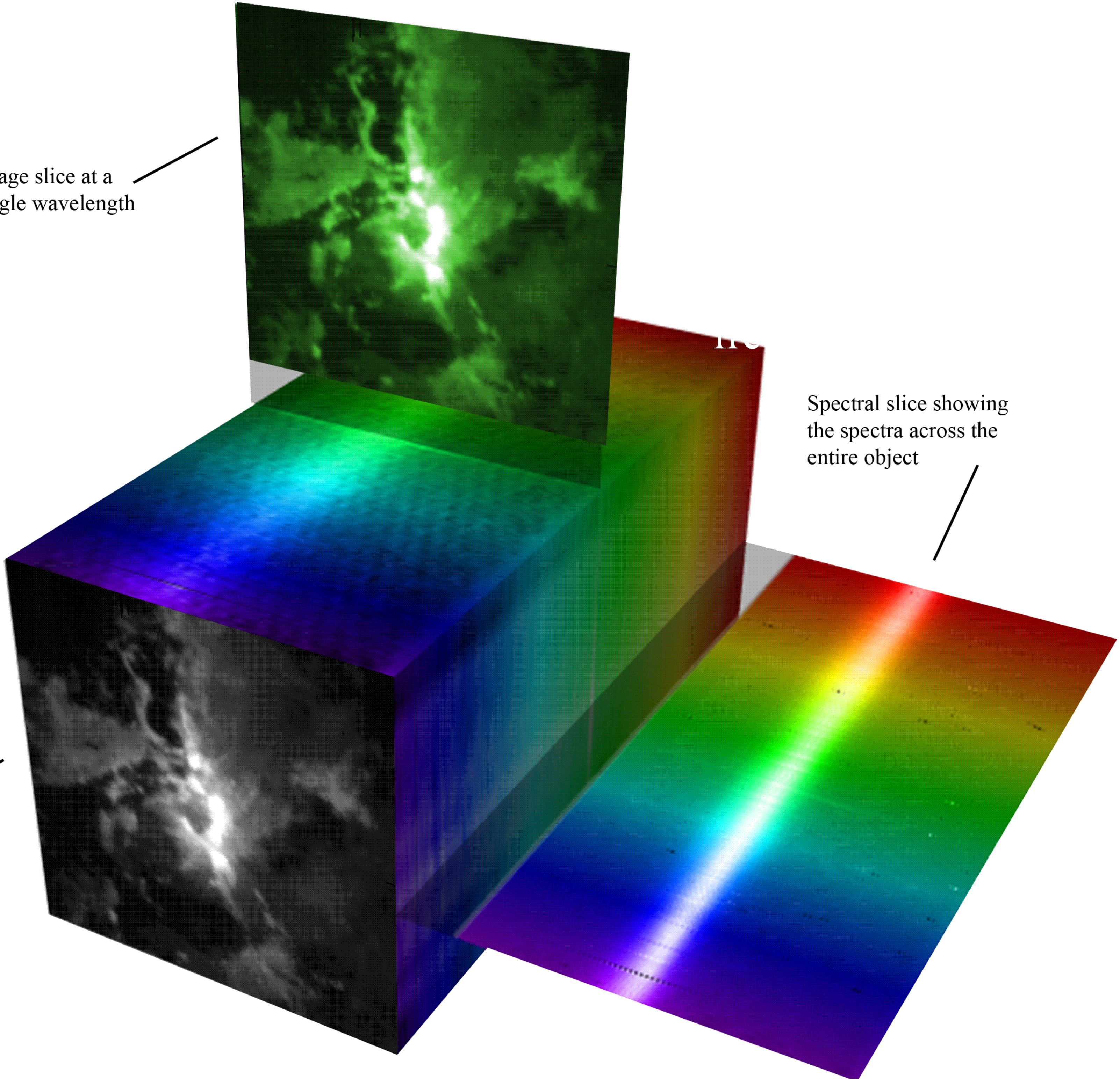


Image slice at a single wavelength

Spectral slice showing the spectra across the entire object

Object seen in combined light

Outlook:

I. Spatial resolution in astronomy, why do we need interferometry

II. Common principles of interferometry

III. Atmospheric effects

IV. Basic differences and limitations for the near-IR and radio interferometry

V. ESO VLT interferometer

VI. Examples of VLTI Be star projects

- ζ Tau: detection of disk density waves
- -- Differential phase reversal

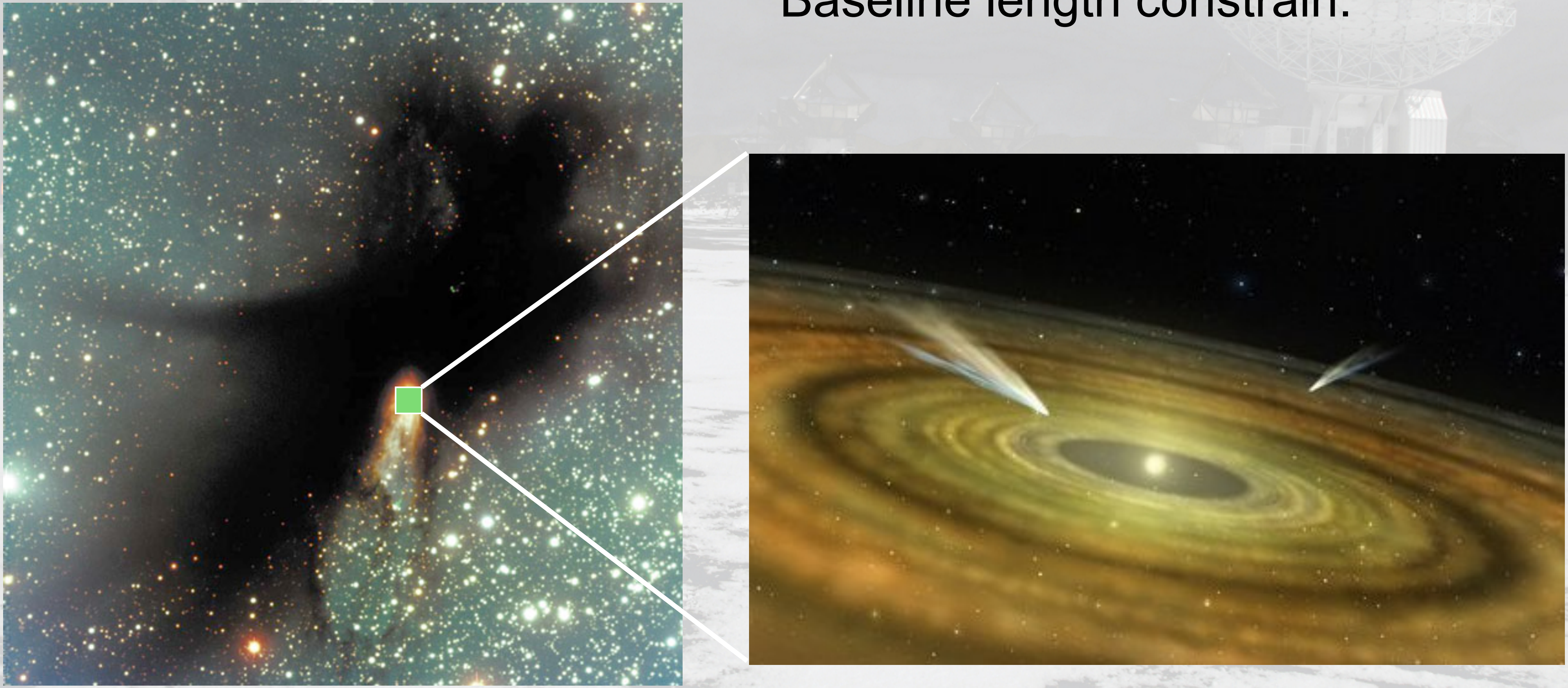
VII. ALMA – brief technical description

VIII. ALMA – scientific expectations and the first results

ALMA task 1:

To image gas kinematics in a protostellar and protoplanetary disk with the diameter equivalent to the Jupiter orbit in a distance of 150 ly. This corresponds to a angular diameter of 0.03 mas.

Baseline length constrain.

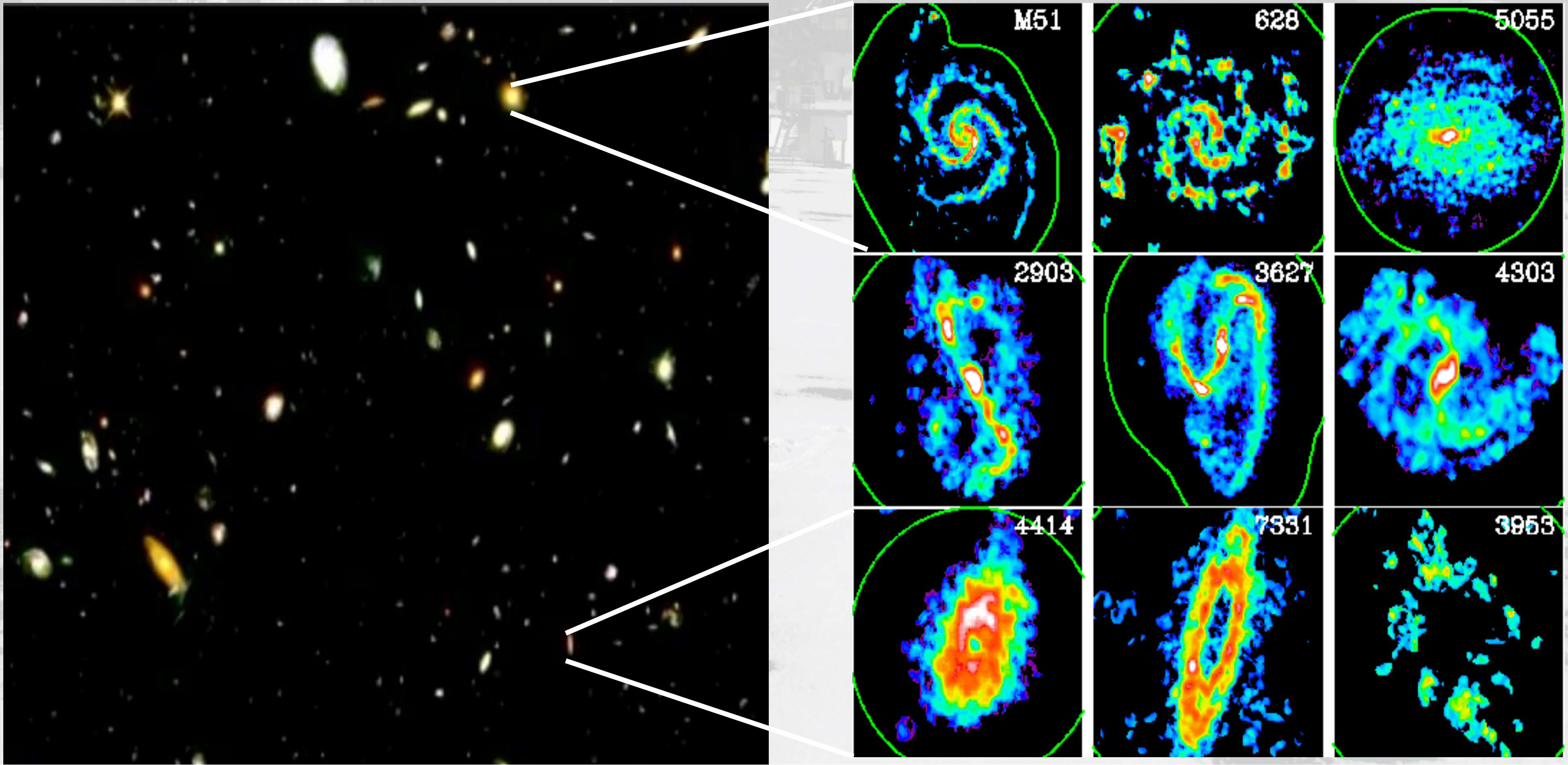


ALMA task 2:

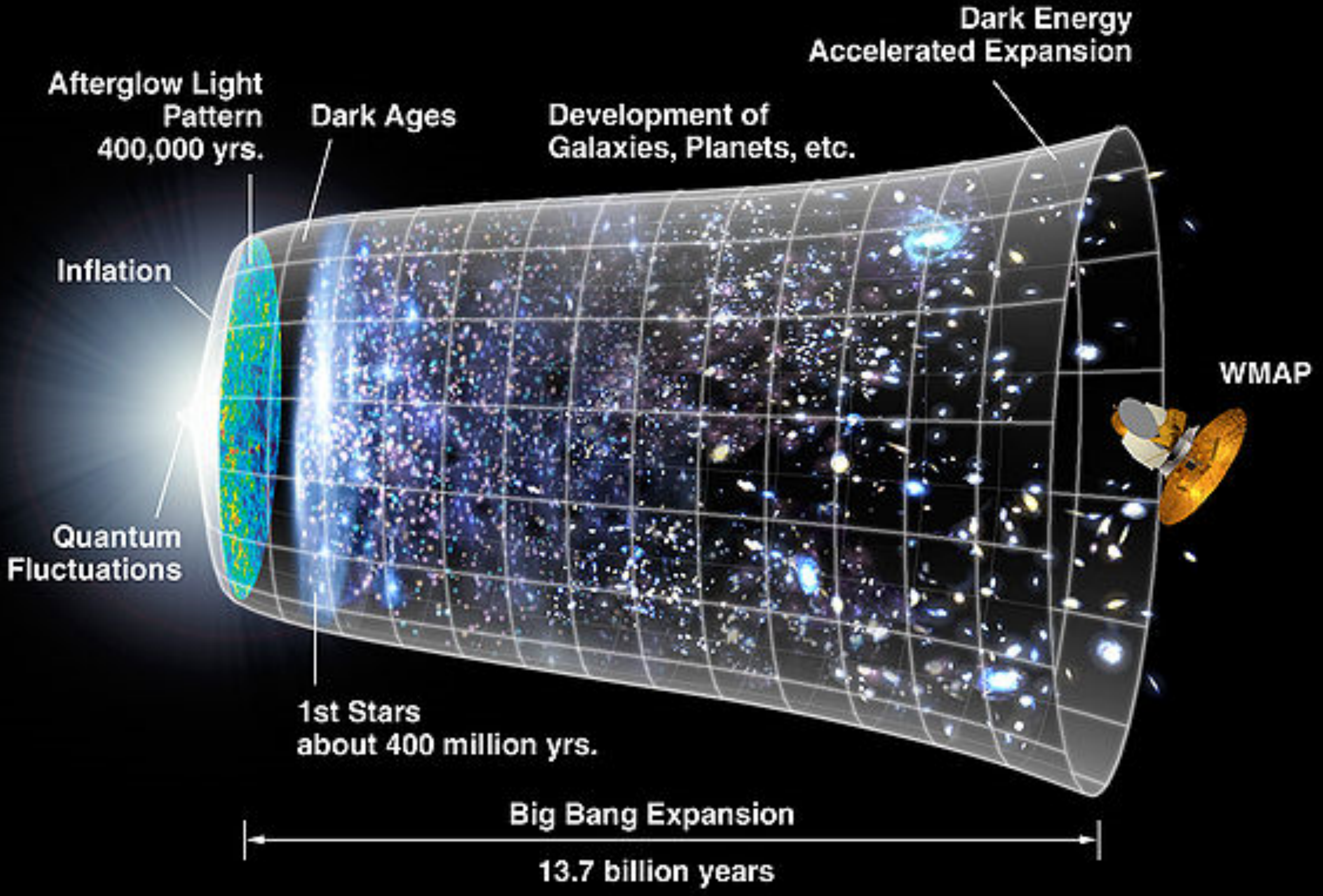
To detect molecular CO emission in a MW-type galaxy of z = 3 during less than 24 hours. Antennas collective area constrain.

Hubble image of distant galaxies

Mm-wave images of near galaxies



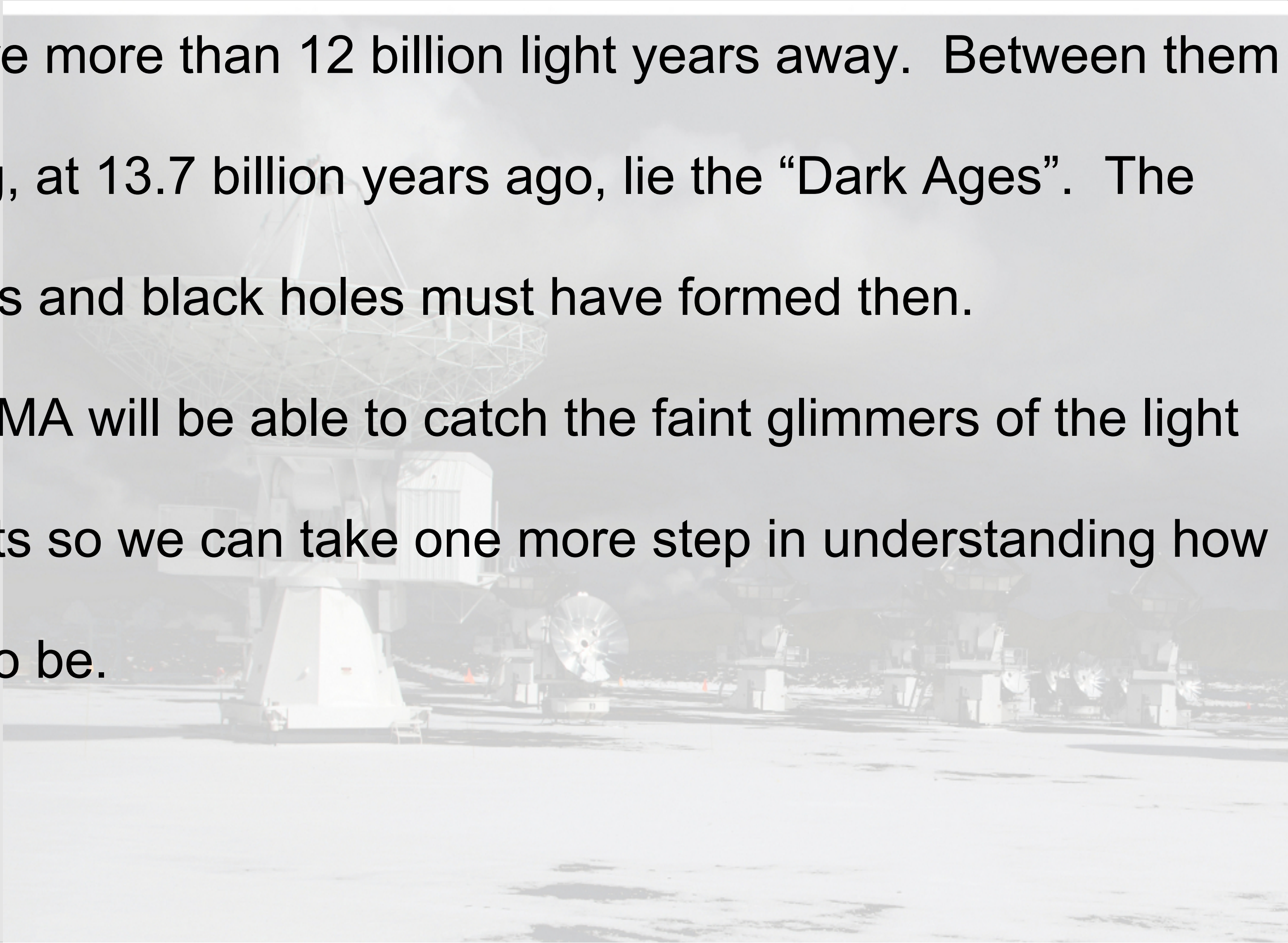
Cosmology - from the Big Bang to the Present Day



Cosmology - what ALMA is expected to do

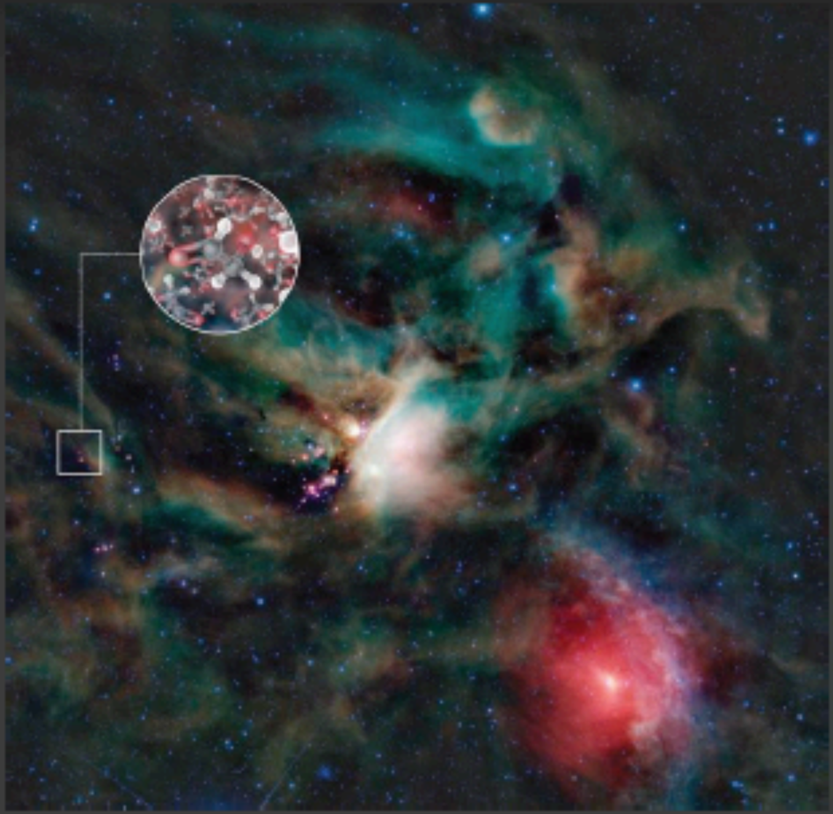
The most distant galaxies that we have seen so far lie at a red-shift of about 8. They are more than 12 billion light years away. Between them and the Big Bang, at 13.7 billion years ago, lie the “Dark Ages”. The first stars galaxies and black holes must have formed then.

We hope that ALMA will be able to catch the faint glimmers of the light from these objects so we can take one more step in understanding how our world came to be.



ALMA Cycle 0 first results

"Sweet result from ALMA"

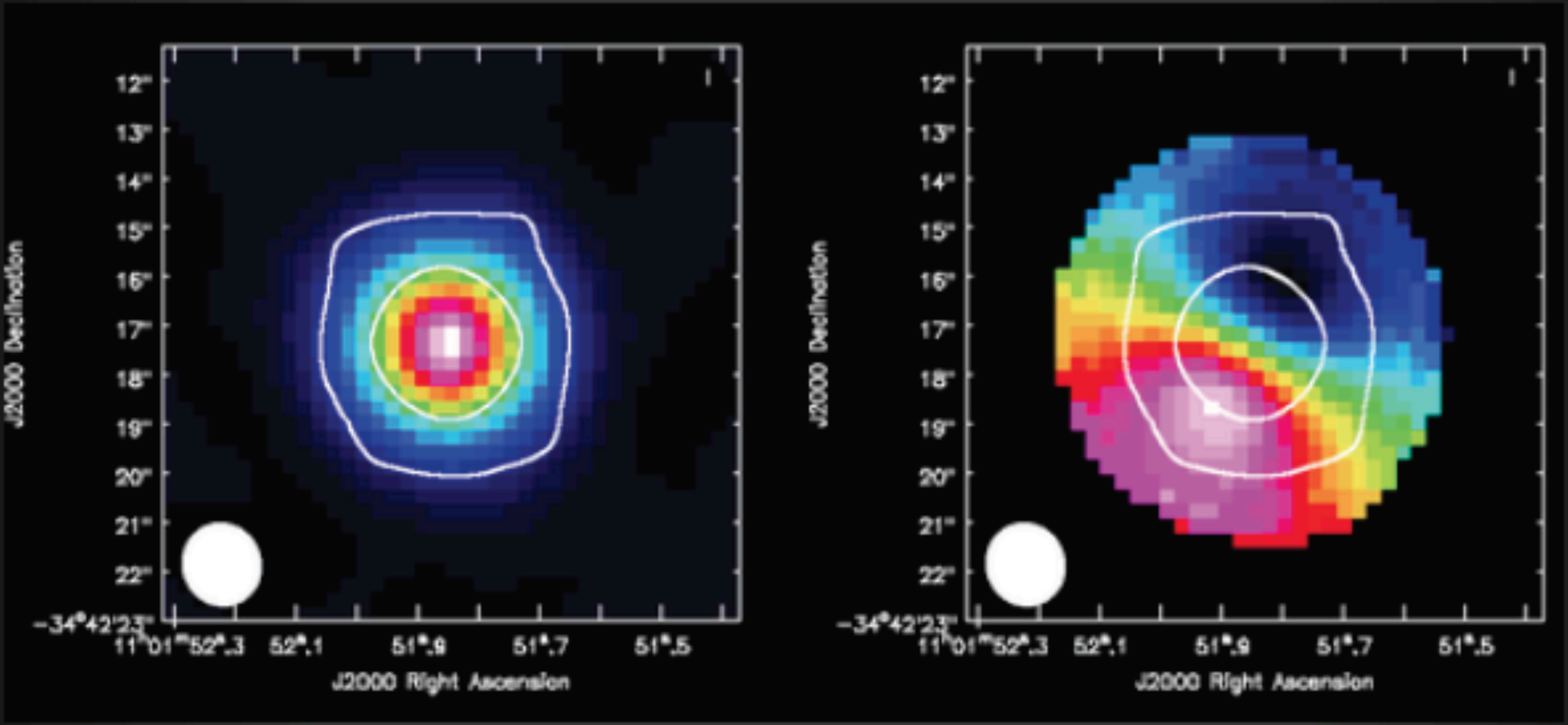


Glycolaldehyde, a simple sugar, was discovered in the disc of gas and dust surrounding this newly formed star in IRAS16293-2422, a region where multiple stars similar to our Sun are being formed.

Astrobiological implications (building blocks of life): RNA contains a ribose sugar.

ALMA Science verification

TW Hya: a face-on protoplanetary disk



ALMA SV data HCO+(4-3) band 7

Left: integrated emission
Right: Velocity field

Summary:

Interferometry is hard because

- it is technically demanding
- you have to worry about atmospheric effects

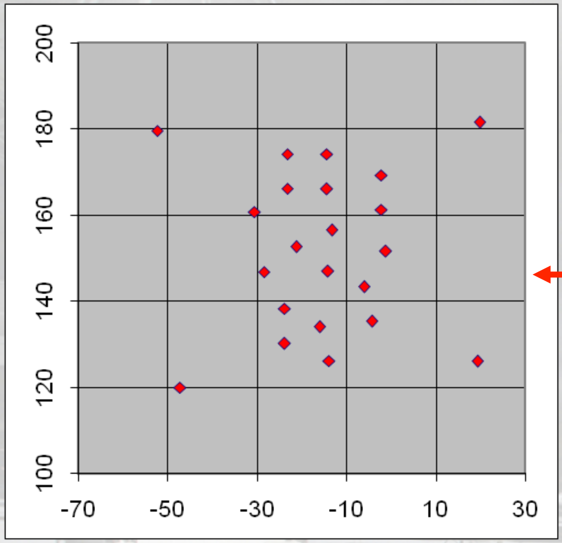
Interferometry is worthwhile because

- it is the only way to obtain the high resolution needed to observe a vast range of astrophysical phenomena

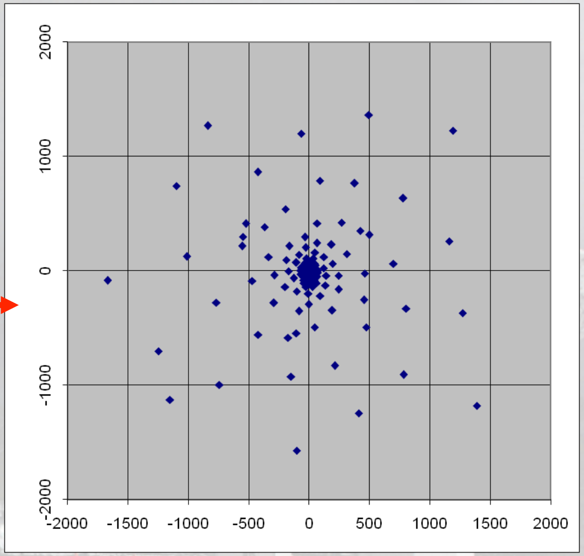
Interferometry should be developed in the CR because

- it is necessary to solve astrophysical problems of the highest priority
- it is expensive and we pay for it (VLTI, ALMA)

By sampling many points on the wavefront we can build up an image of the object we are looking at.

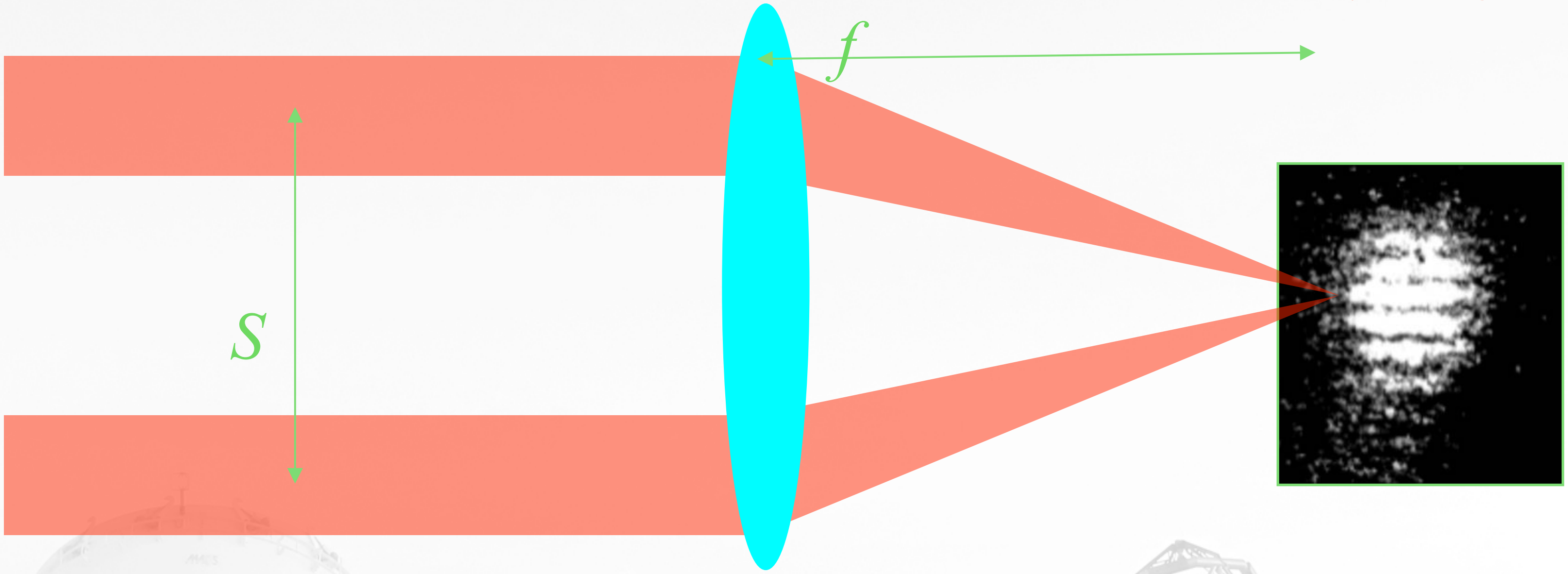


Antennas



Combination types: Image-plane or Fizeau

Overlap the beams with a lens:



1974 Labeyrie fringes (Vega)

$I \sim V \,.\, \cos(2\pi\, S.f / \lambda \,.\, x + \varphi)$ $\quad$ $\mathrm{opd} \sim x \,.\, S/f$

Each beam is focused to make an image on the sky, images are superimposed, fringes formed across the combined image

The opd is spatially modulated: Fringe spacing and modulation pattern are given by the combination baseline S

Fringe size: order of magnitude…

$I \sim V \,.\, \cos(2\pi\ opd/\lambda\ +\ \varphi)$

The fringe spacing is the wavelength of the light, so few μm in the near-IR

Precise instrumentation
Mechanical vibrations are “killers”

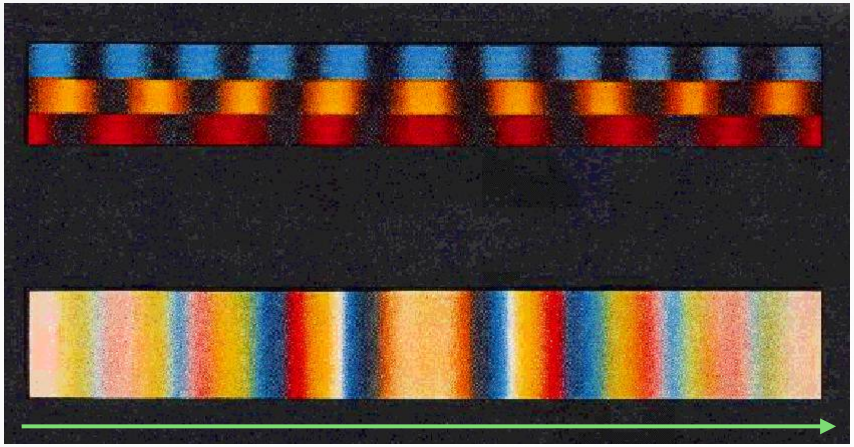
When observing with a large spectra bandwidth, the fringe packet becomes small:

R=500 → $\Delta \sim 0.75$mm
R=25 → $\Delta \sim 7.5\ \mu$m

Important to observe close to the zero opd position, which requires a precise knowledge of:

→ the position on the star on sky

→ the internal opd of the instrument



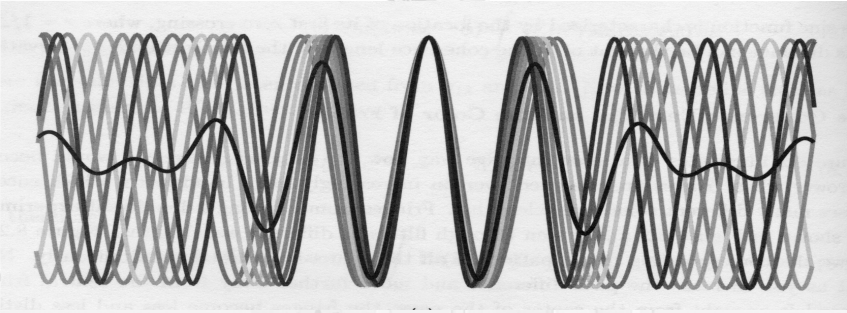
sum of monochromatic fringes

opd (m)

Δ = R.λ

= real fringe packet

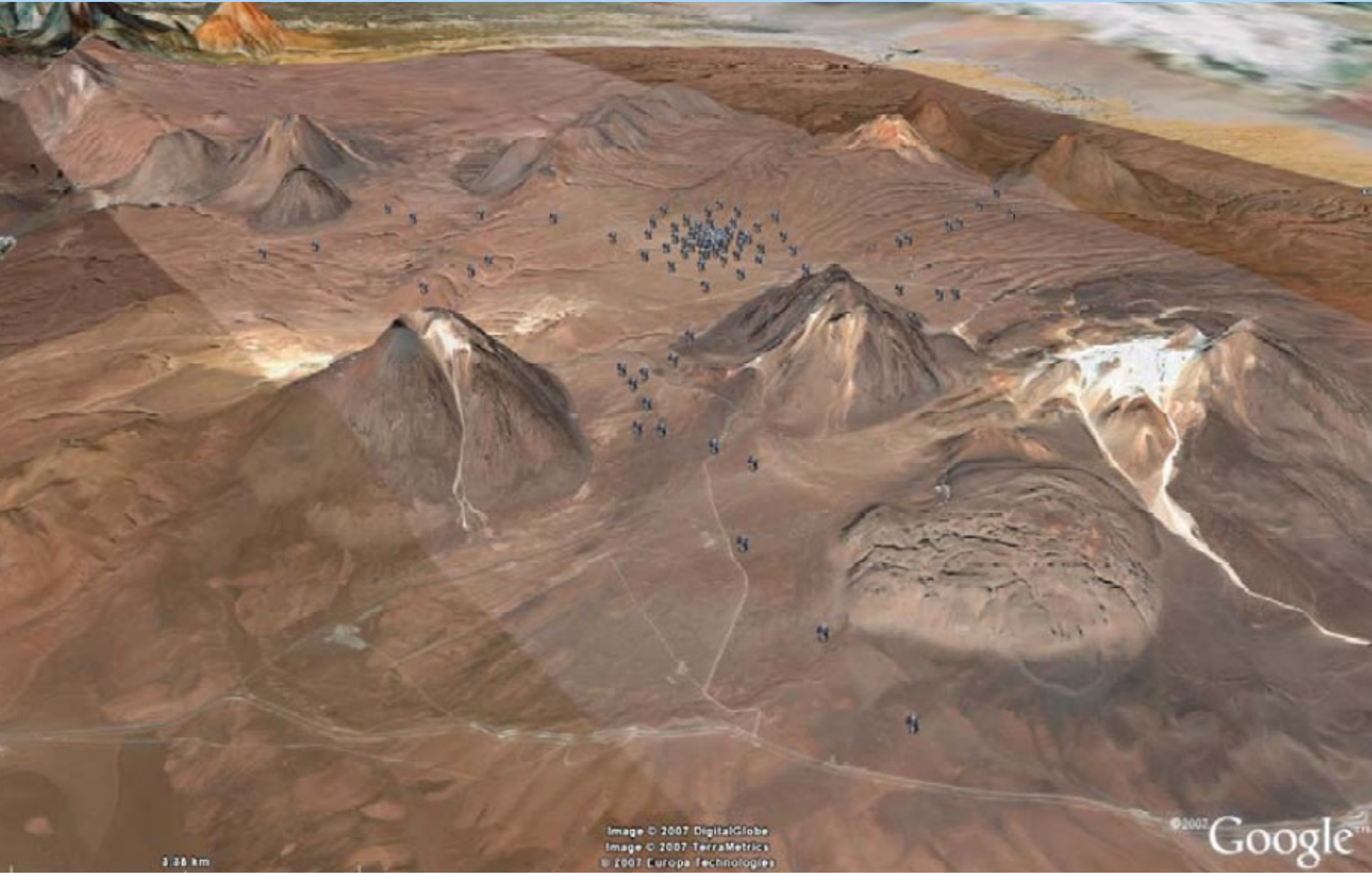
packet size



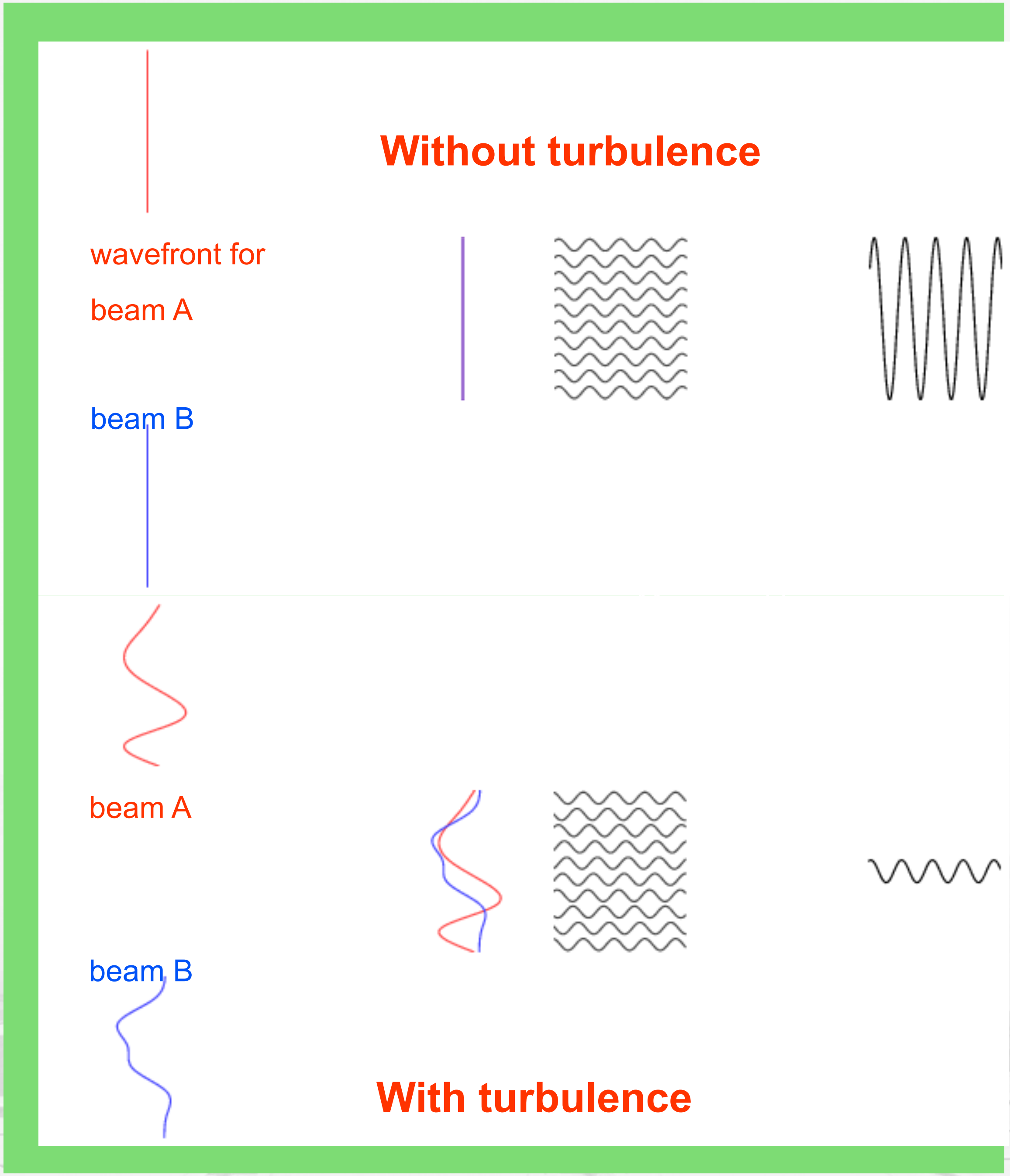
fringe size: $\lambda \sim 2\mu$m

opd (m)

Google-Earth view of site with antennas in the most extended configuration – baselines up to 16km



What are we fighting against: Turbulence: fringe blurring



Visibility is reduced by the wavefront variance over the pupil.

Do nothing if the turbulence is small (IR – interferometry)

Reduce the telescope pupils

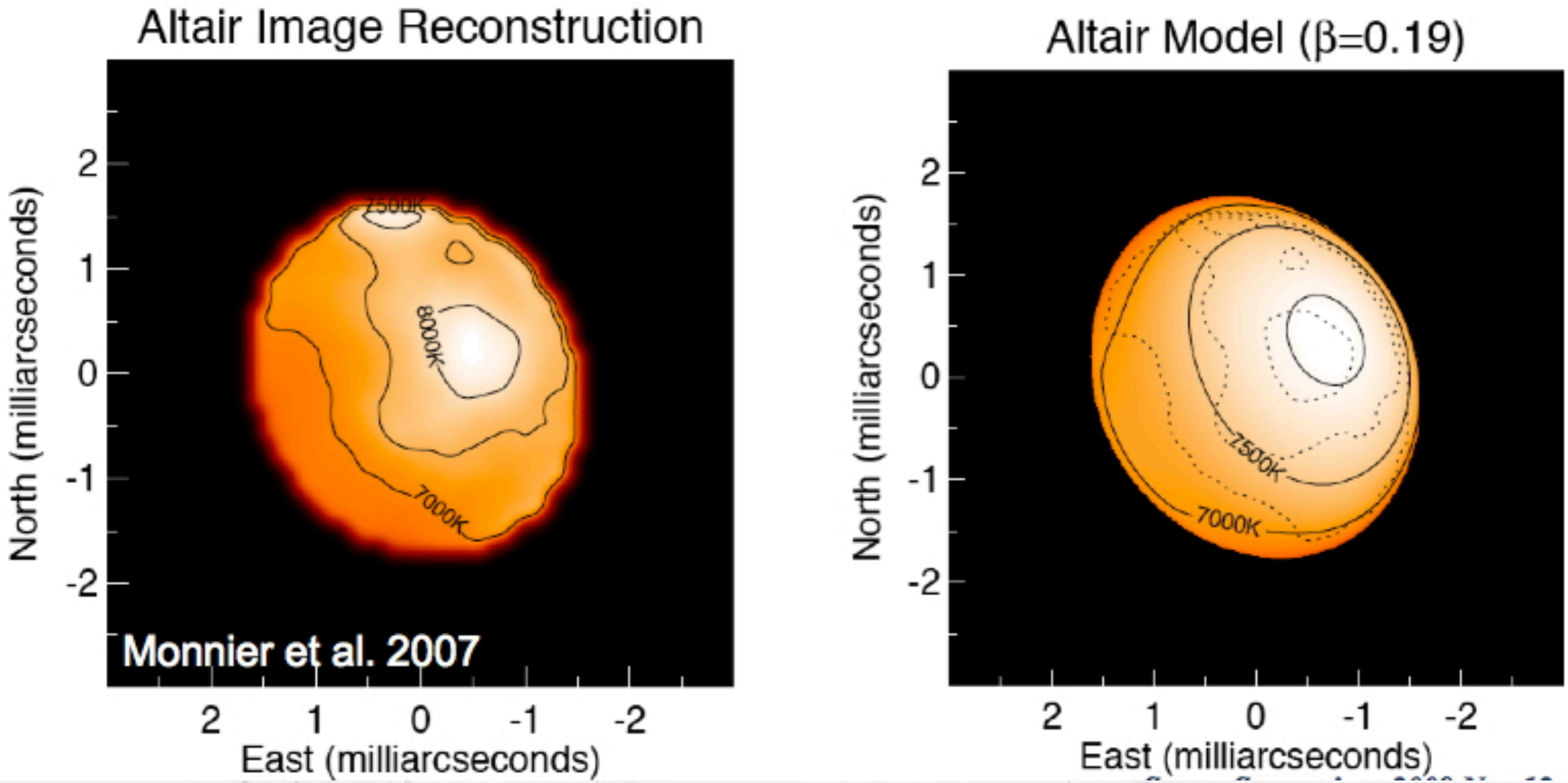
Use a perfect Adaptive Optics system (the best solution)

Use another technique to flatten the wavefronts

The “turbulent” visibility loss should be calibrated frequently

Speed of the observations – VLTI, new remember-goback mode implemented

CHARA imaging:



Altair flattened stellar disk (from Zao, 2009)

CHARA/MIRC imaging done for several close (super-)giant stars in H continuum, emission-line imaging of circumstellar disks in progress