MAO

ミリ波補償光学の創成

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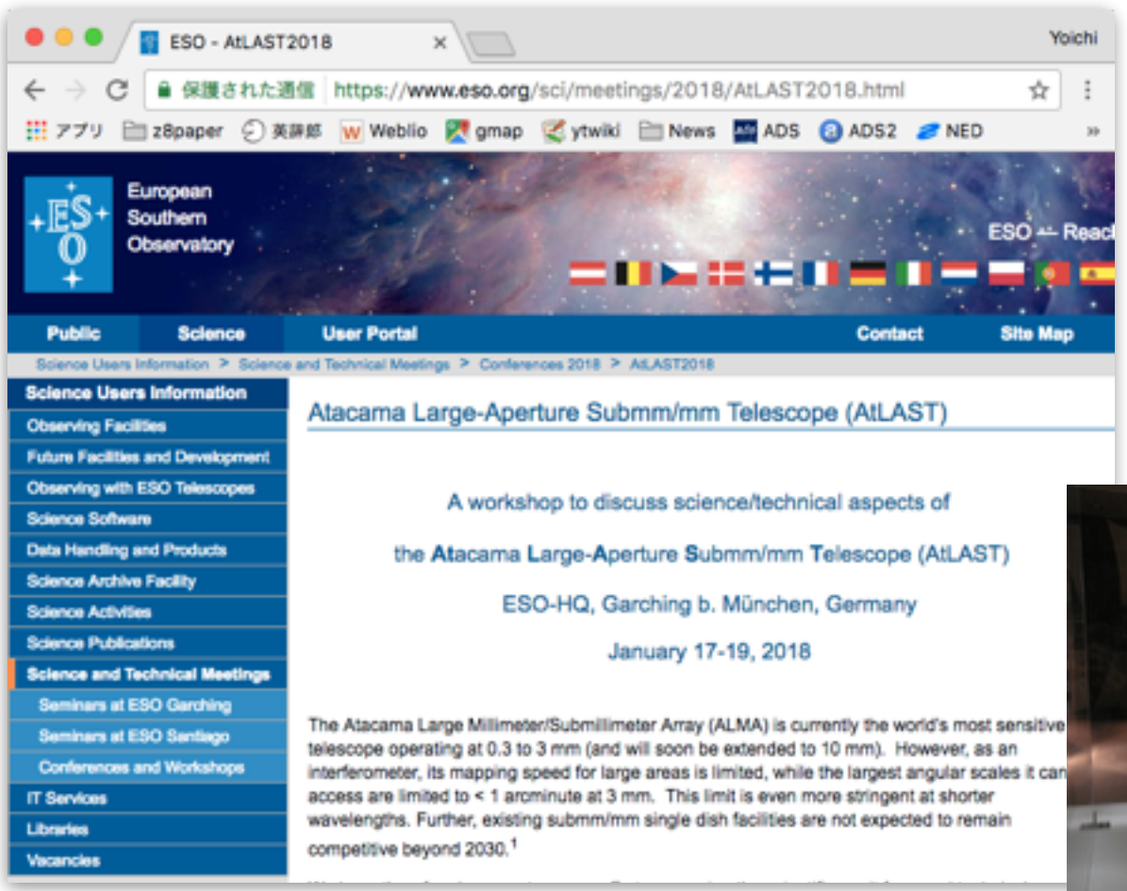
宇宙電波懇談会シンポジウム FY2017「未来を拓く技術開発とその将来展望」

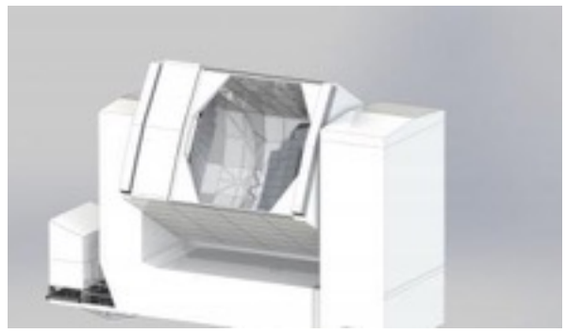
20-Mar-2018

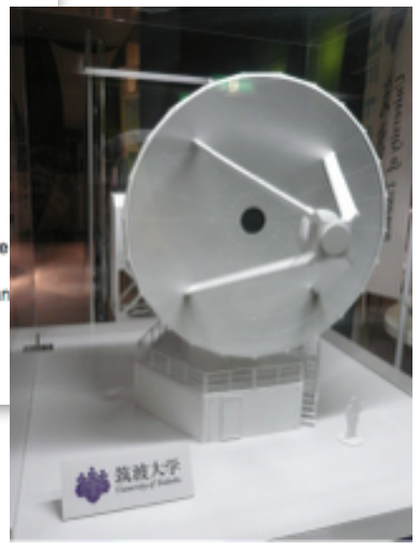
1. What Limits Performance of Single-Dish Telescopes?

Submillimeter SD Telescope TNG

- Building The Next Generation large single dish telescopes with high accuracy is the most challenging task.

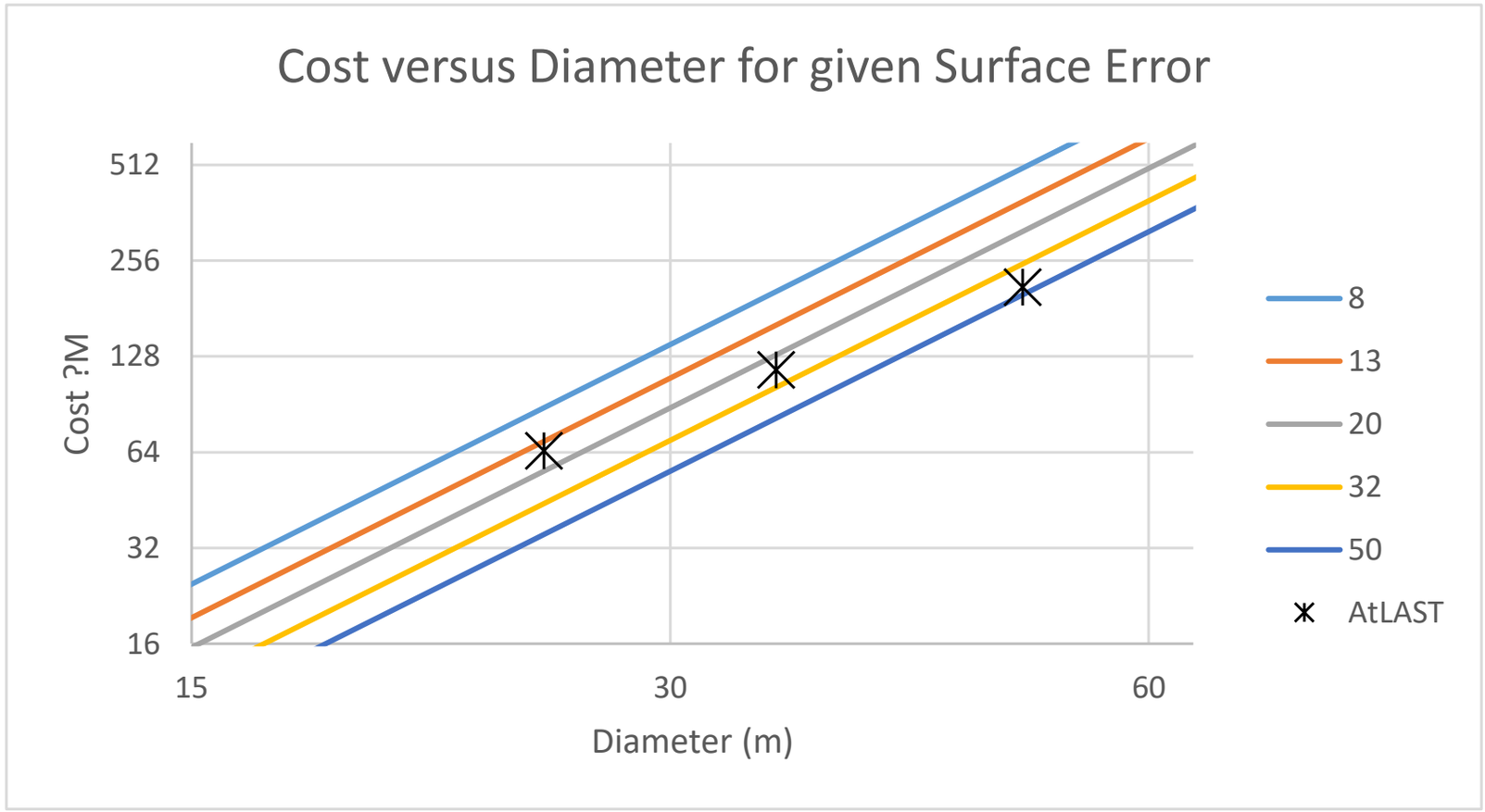






Plots of the historic cost equation - not to be taken seriously!

- Cost ∝ $D^{2.5} / \lambda_{min}^{0.5}$
- Telescope ONLY perhaps 50% of project? (25% for instruments, 25% for infrastructure, management, etc)
- Ignores added costs for higher sites.
- Assumes “non-political” procurement process.



- Normalized by assuming that a 25m diameter with a 25um surface costs 50?M.

Pete Hargrave+ (AtLAST Optics WG)

Cost scaling law

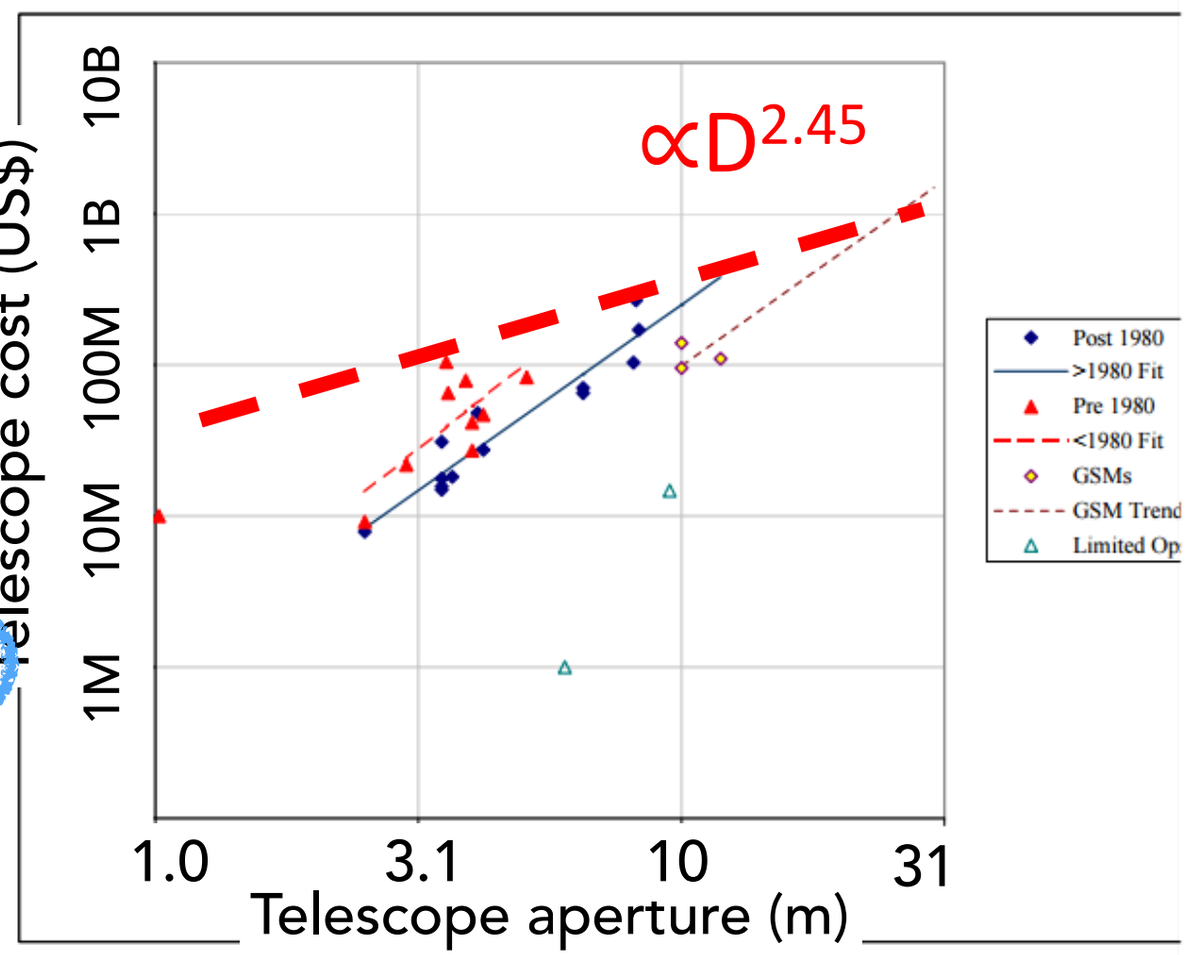
In optical telescope, innovations happened in

- mount type(Equatorial to Alt-Az mount)
- F-ratio (3 to ～1)
- Mirror configuration (monolithic to segment or multiple mirror)

National foundation is weakly limited

Technology to break size limitation is more meaningful than technology to cost reduction

Belle & Meinel 2004



Kurita-san's viewgraph (LST WG)

Need something that triggers "innovation"

What Limits Telescope Efficiency?

Temperature fluctuation in upper atmosphere crucially affects.

Atmosphere?

Doesn't matter.

Doesn't matter.

Optics?

Wind load and temperature variation crucially affect. Radome is too expensive.

lable.

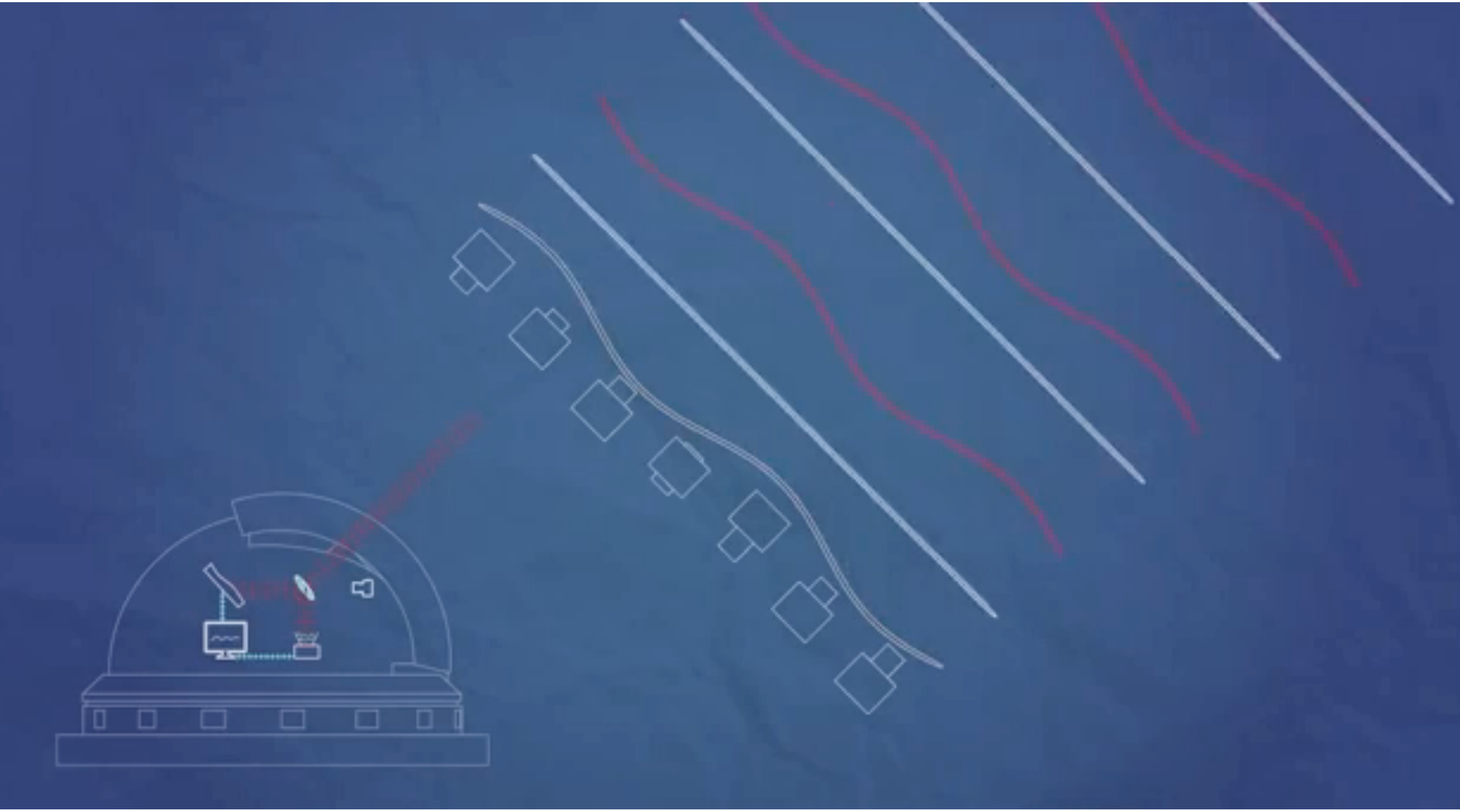
Enclosure: arguments

- Cost probably scales at nearly D^3, so becomes prohibitive at large sizes.

Pete Hargrave+ (AtLAST Optics WG)

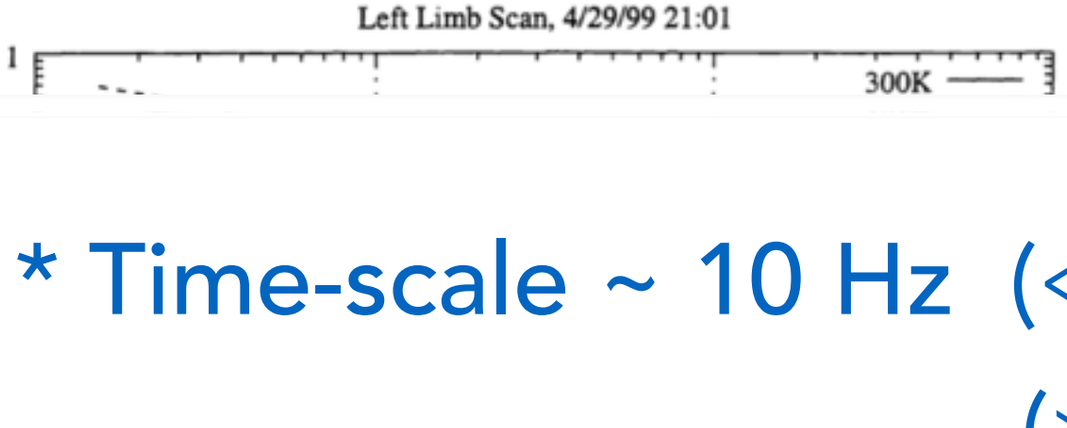
What is adaptive optics (AO)?

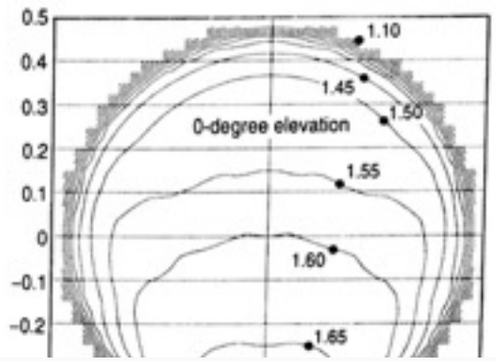
UK Astronomy Technology Centre (https://www.youtube.com/watch?v=gDGvNyVApgg)



Time/spatial-scale of Mirror Deformation

NRO 45m “pointing” PSD (Smith et al. 2000)





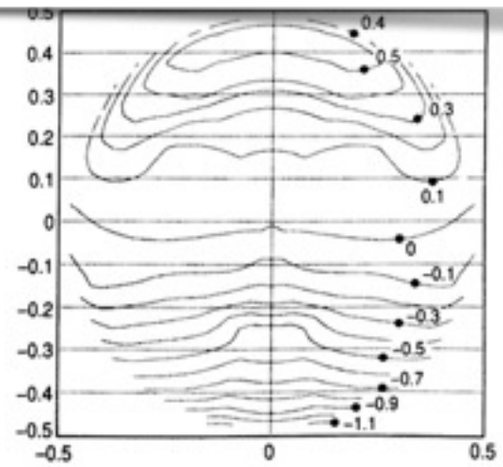
EL=0°

* Time-scale ~ 10 Hz (≪ Opt/NIR)
(≫ Holography etc.)

* Spatial-scale ~ 1 m (≫ Opt/NIR)

EL=60°

FEM prediction of wind load deformation (Revy 1996)



EL=90°

What is Technical Issue with AO?

Wavefront sensor?

- Yes. There are low-cost sensors with large-format array detectors (e.g. SH sensor)
- Yes.
- Yes.
- Yes, natu
  laser guic
  available.
- No. Building a large-format array itself is a challenging task.

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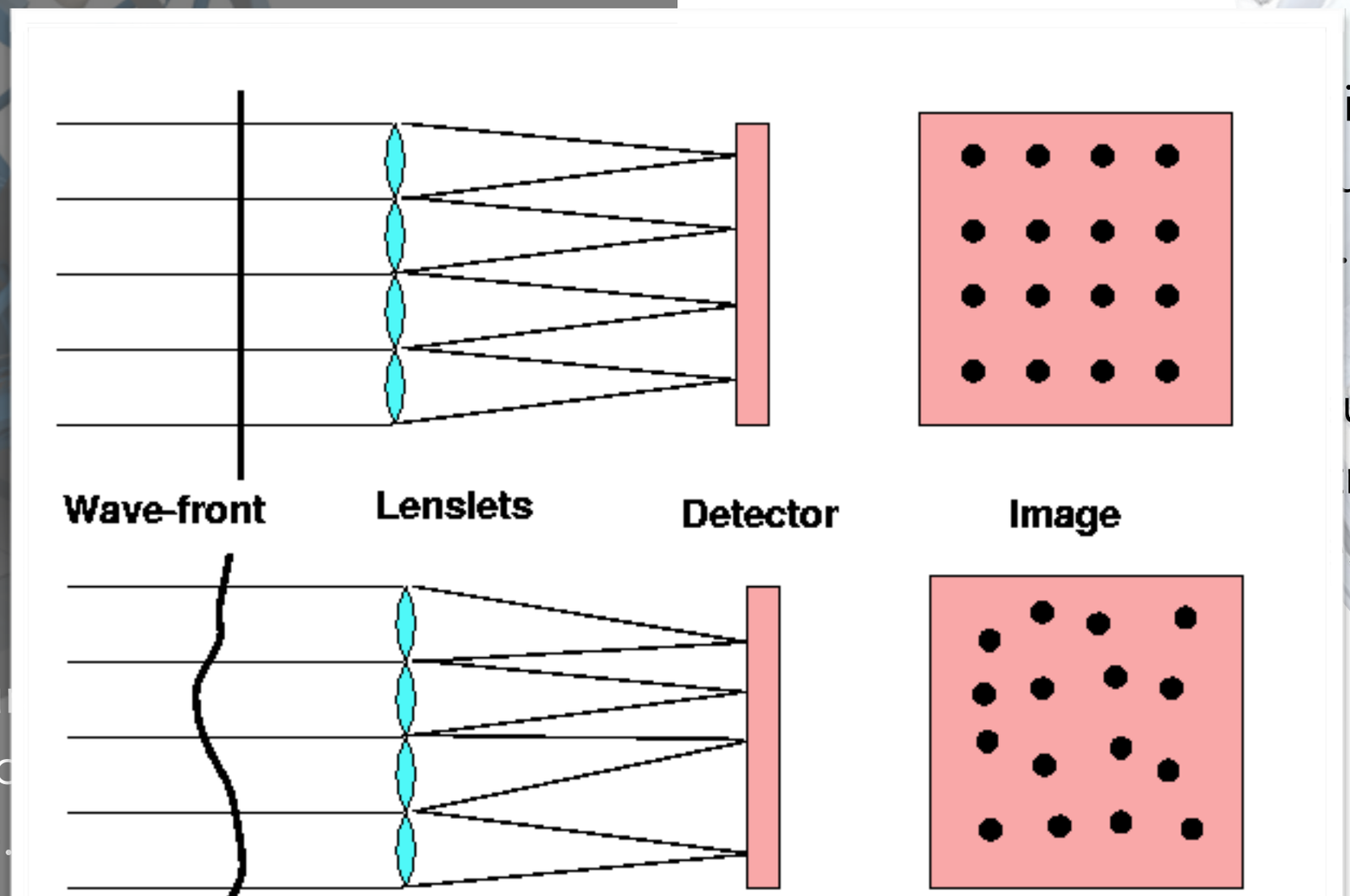


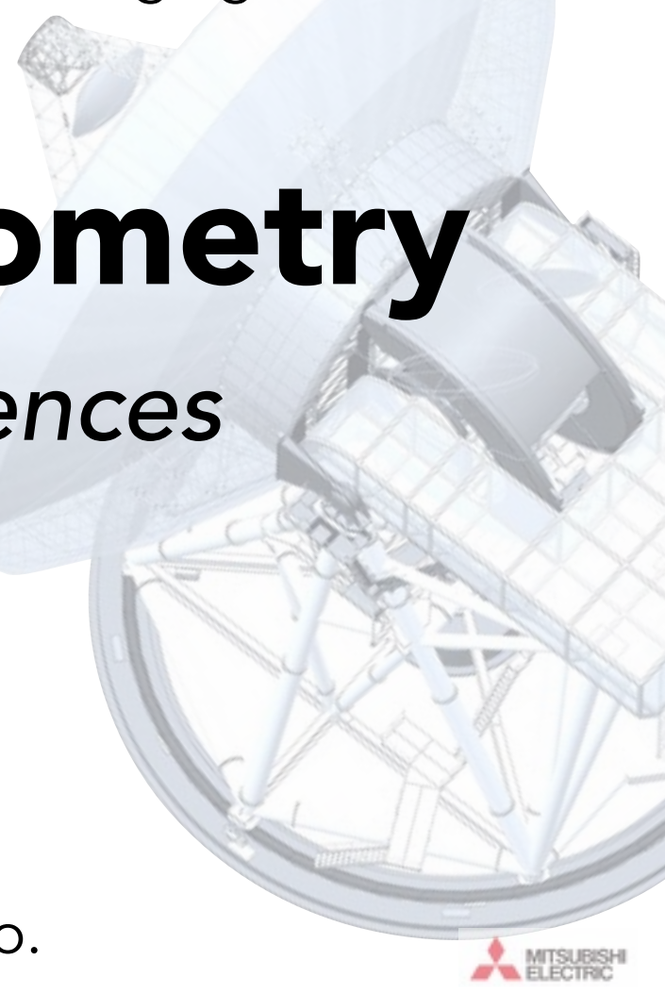
Adaptive optics tutorial at CTIO (http://www.ctio.noao.edu/~atokovin/tutorial/)

Millimetric Adaptive Optics: Concept

Wavefront sensor?

↓

No. Building a large-format array itself is a challenging task.



Aperture Plane Interferometry

Interferometry with phase references placed across the aperture

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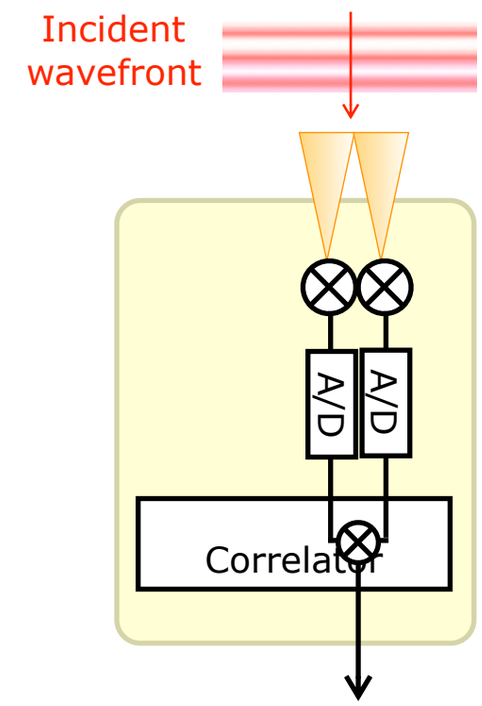
Wavefront reference?

No.

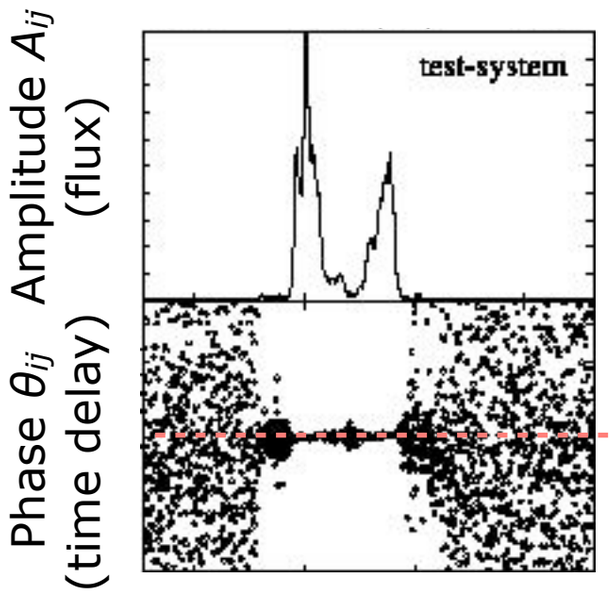
2. Millimetric Adaptive Optics (MAO)

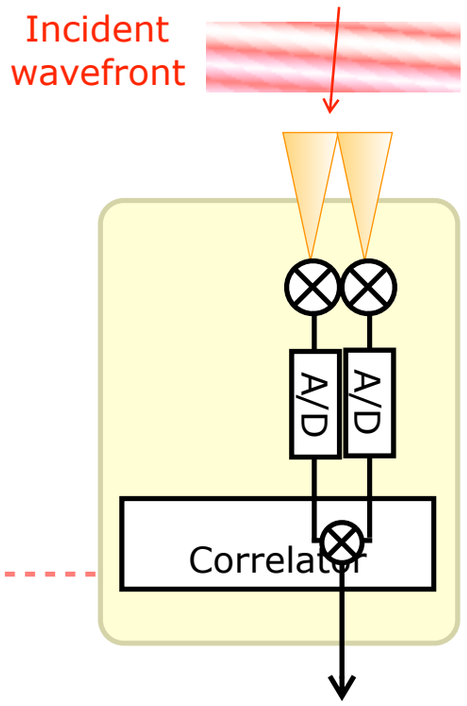
Detecting wavefront slope



$$C_{ij} = A_{ij} \exp\left(i\theta_{ij}\right)$$

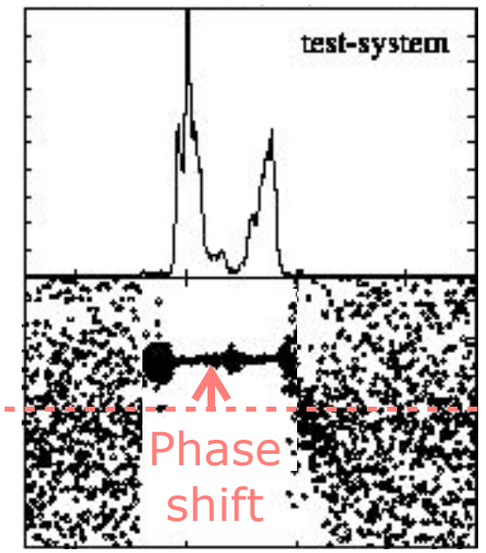
In-phase state





$$C_{ij} = A_{ij} \exp\left(i\theta'_{ij}\right)$$

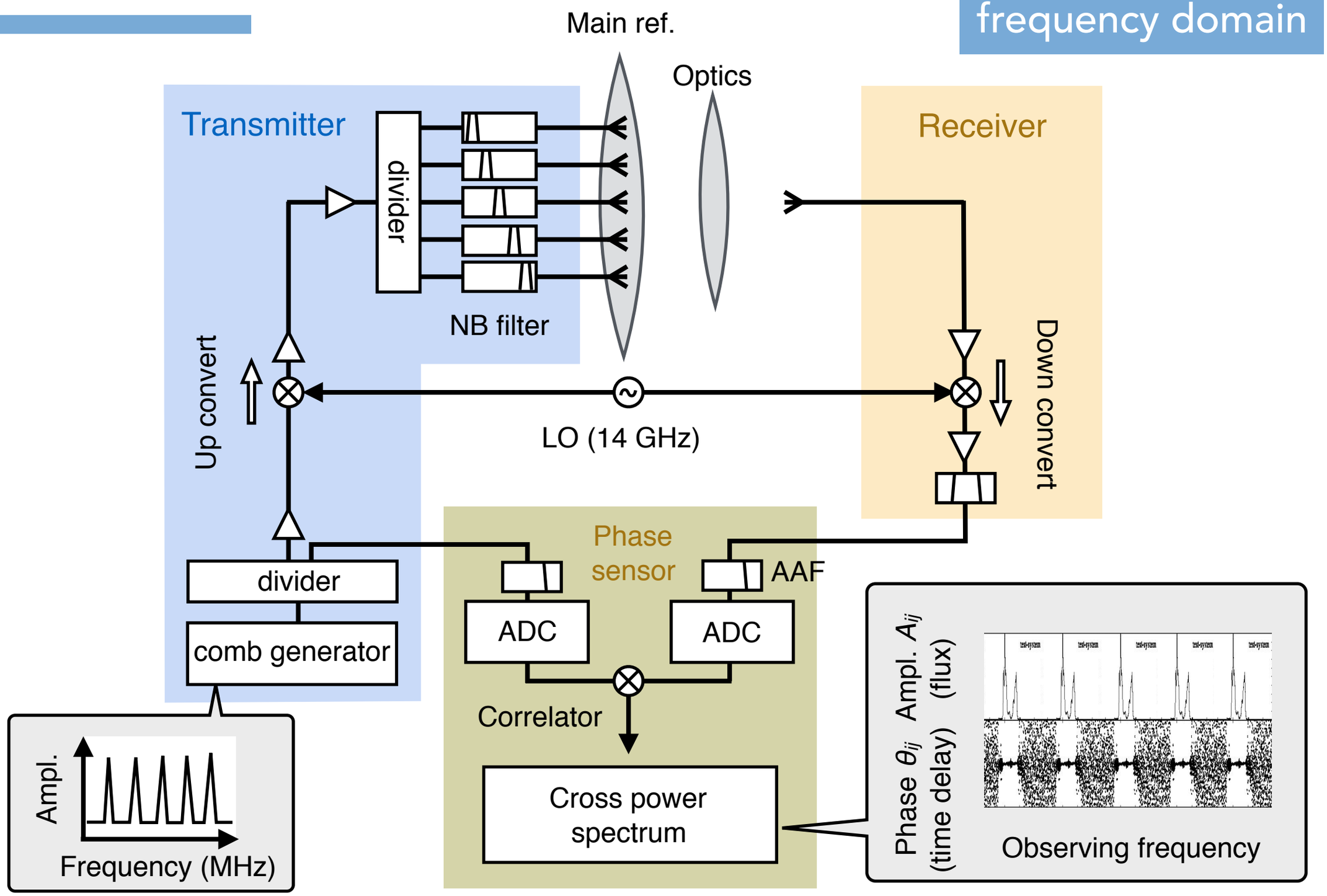
If the system detects wavefront gradient, ...



- Interferometer is a wavefront sensor that measures the time difference of detections of incident electromagnetic wave between two receivers.
- A phase shift of a complex correlation coefficient exactly means the time difference of wavefront arrival between two receiver elements, which is accordingly converted to the local deformation of optics (primary mirror).
- Phase measurement is much easier than amplitude measurement because a single degree of freedom is required for phase measurement.

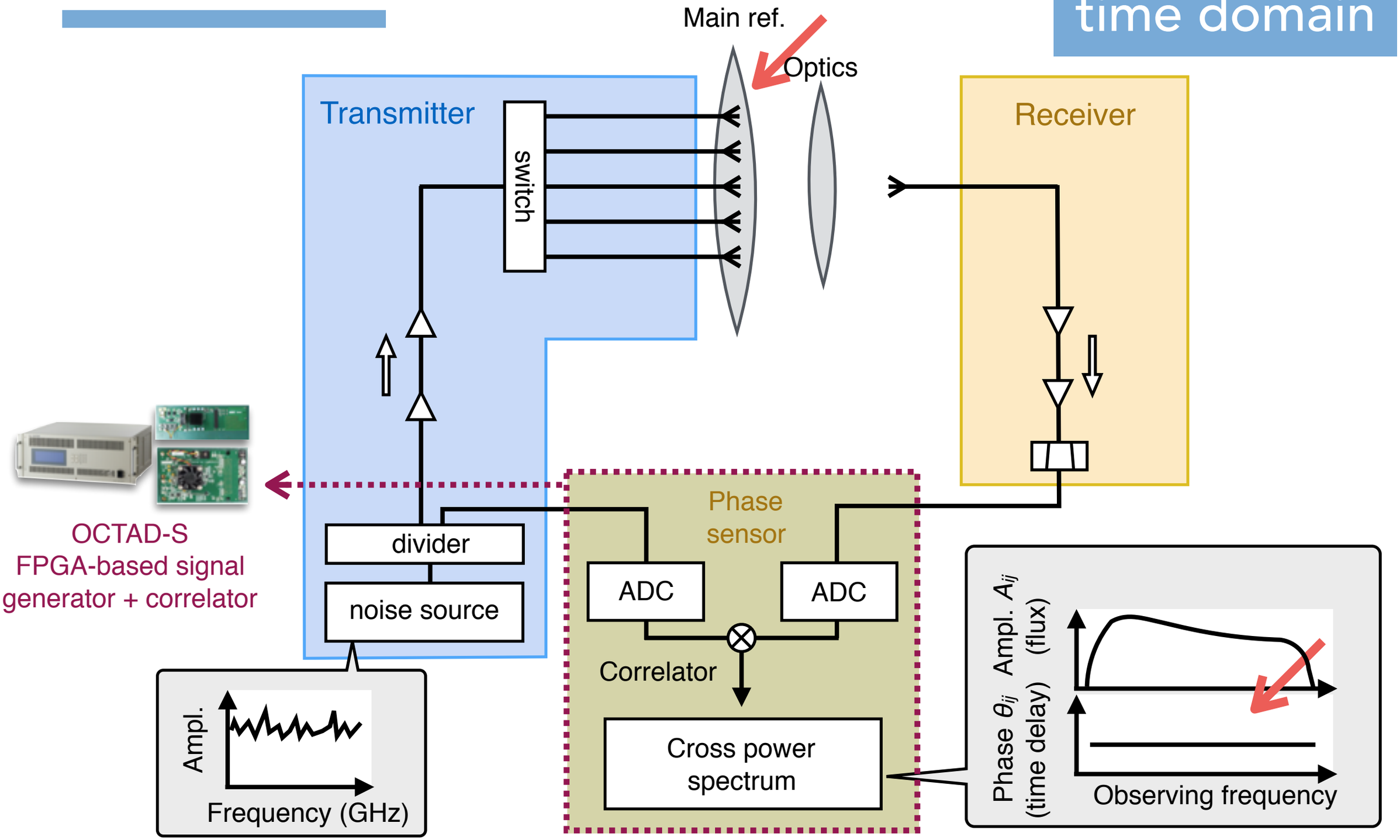
How Does MAO Work?

frequency domain



How Does MAO Work?

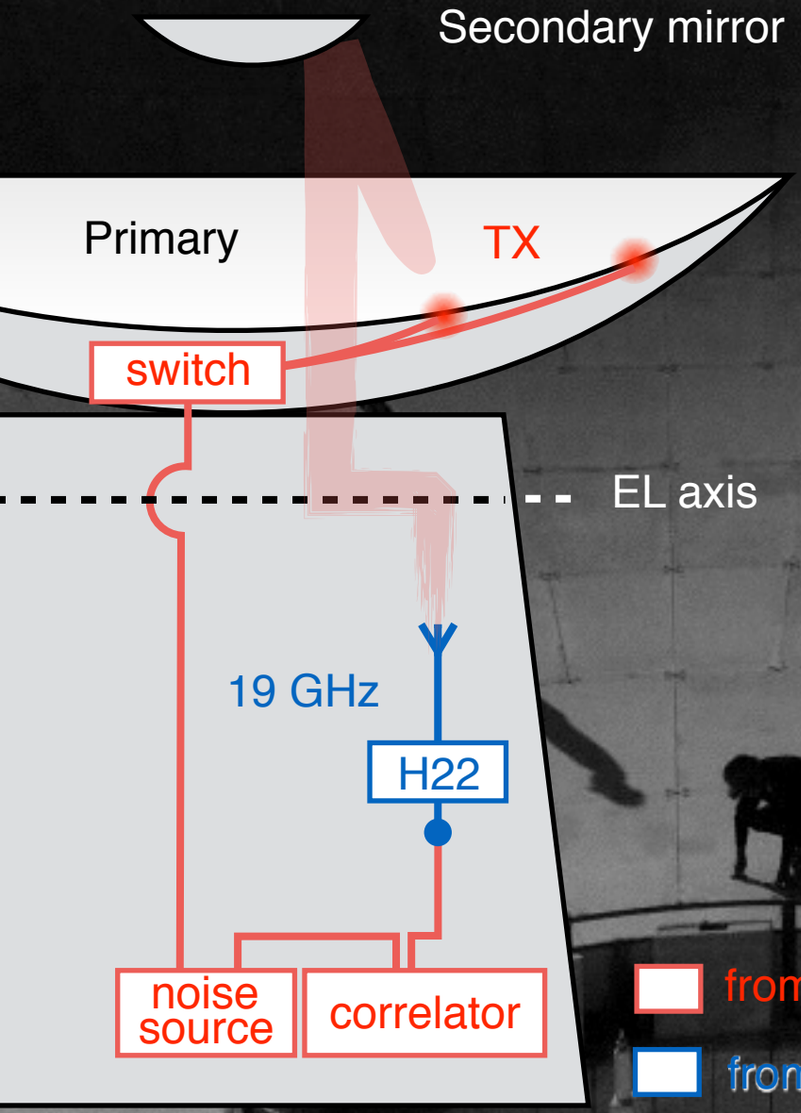
time domain

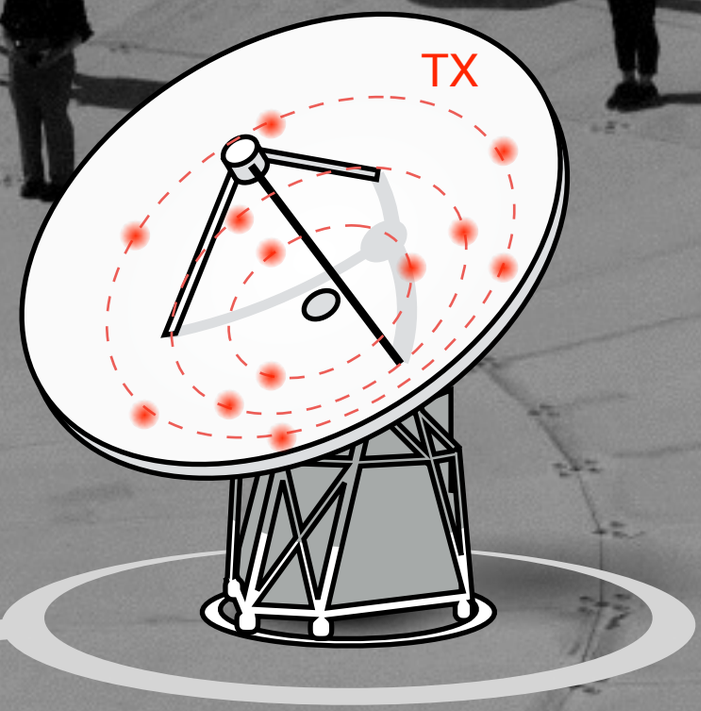


OCTAD-S
FPGA-based signal generator + correlator

Microwave Wavefront Sensor at the 45 m

- Top-level science requirement: High-accuracy phase measurement with $\sigma(\theta) = 1$ deg r.m.s. at 20 GHz, corresponding to 40 μm r.m.s.
- H22 receiver
- *N*-element ($N \geqq 5$) 20 GHz transmitters on the surface of the 45 m primary
- Accelerometers





Project Plan

2015 Brainstorming…

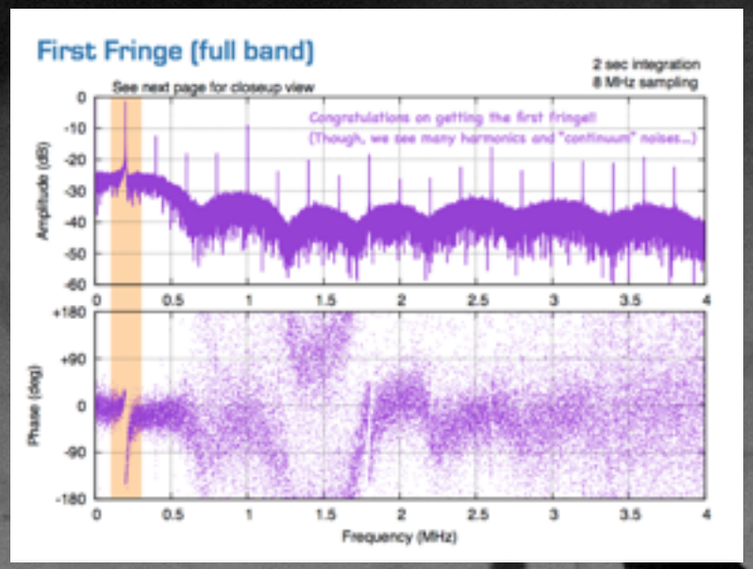
2016 Conceptual Design

NAOJ Joint Research & Development: ¥4M
JSPS Challenging Research (Pioneering): ¥20M

2017 Budget

Correlator R&D

Transmitter R&D



2018 Commissioning

Wavefront Sensing Experiment

2019 Step to Future SD Telescopes

Summary

- We propose Millimetric Adaptive Optics.
- We initiate development of a microwave wavefront sensor based on “Aperture Plane Interferometry.”
- Demonstration at the 45m telescope is being planed.
- MAO is applicable to and benefits EVERY existing / future SD telescopes in the world.