How to build an instrument for Astronomers

National Astronomy Meeting, Durham, UK, July 7th-11th 2025

Photo by Greg Rakozy on Unsplash

Who we are

Deborah Malone

Adaptive Optics Scientist

Accidentally ended up in Astronomy because she was bored one day.

Emily Ronson

Mechanical Engineer

Meryem Dag

PhD Candidate in Astronomy and Space Instrumentation

Electronics Engineer but loves the stars just a little more than circuits.

Jürgen Schmoll

Senior Optical Engineer

Loves playing with telescopes since 1980

Joss Guy

Senior Mechanical Engineer

Victim of Tolerance Stackups

Aims

After this workshop, you should be able to:

- Understand constraints when building an astronomical instrument.
- The potential trade-offs you can consider, to meet both science and engineering goals.

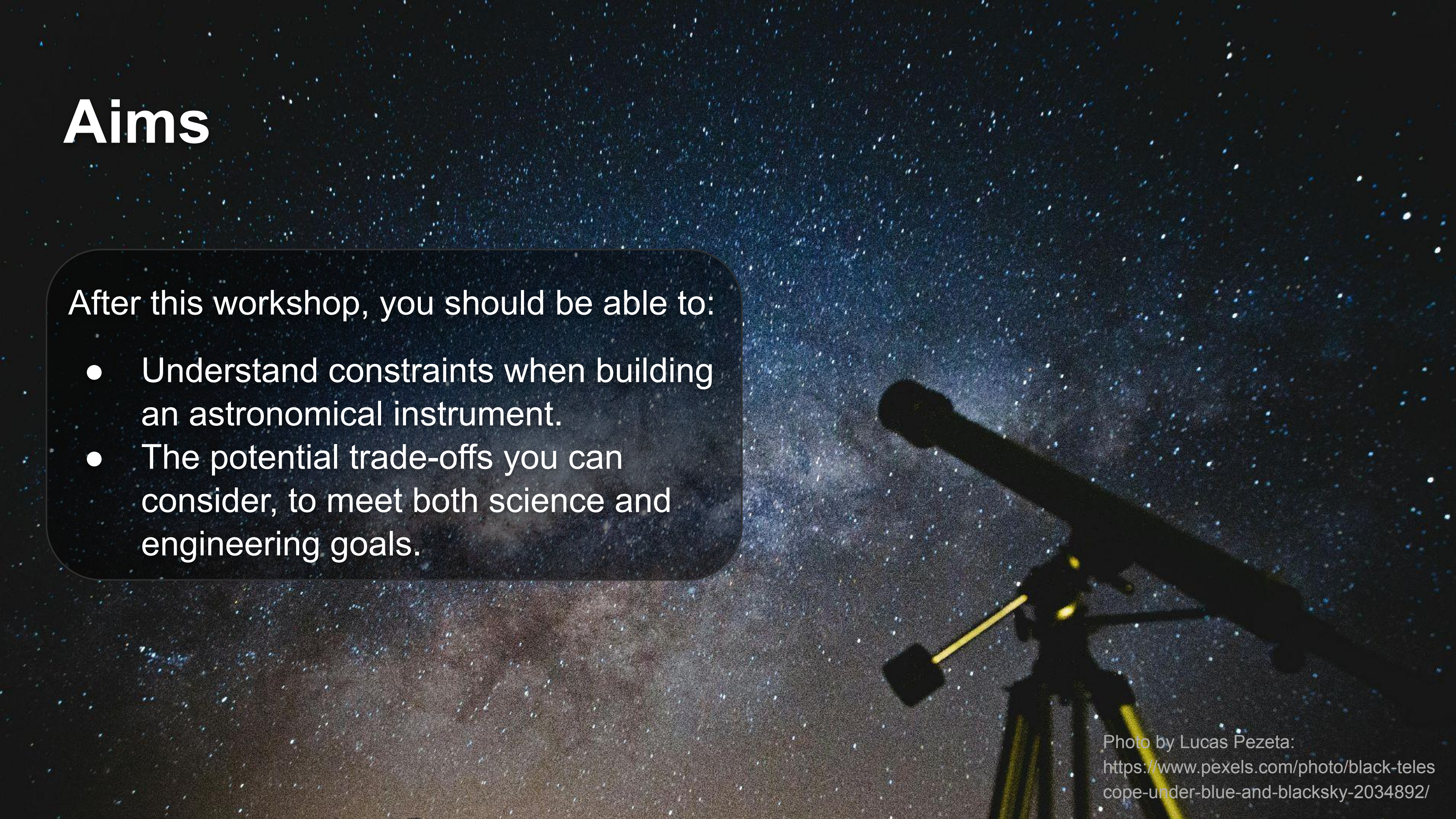


Photo by Lucas Pezeta: https://www.pexels.com/photo/black-telescope-under-blue-and-blacksky-2034892/


Introduction to Astronomical
Instrumentation

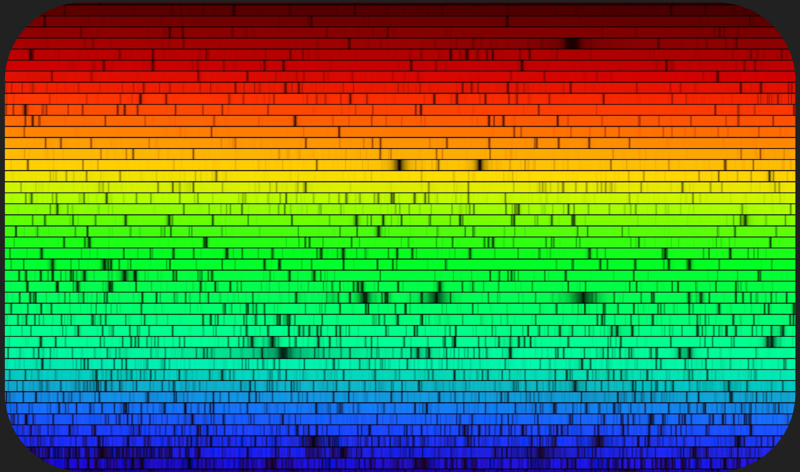
What is Astronomical Instrumentation?

- The tools and devices used by astronomers to observe outer space.
- Telescopes, Detectors, Spectrographs, Photometers/Imagers, Adaptive Optics.
- These need to work together to collect data to advance our understanding of the universe.
- Telescopes collect the light from astronomical objects.
- Some of the light to sent to the adaptive optics system to correct turbulence caused by the atmosphere.
- The remainder of the light is then sent to a spectrograph or imager, and the resulting data recorded on the detector.
- This data is then processed by software.

Types of Instruments

Spectrographs

Used to determine composition, Doppler effect, temperatures, redshift, etc.



http://spiff.rit.edu/richmond/asras/chemcomp_i/chemcomp_i.html

Imagers

Direct images of the sky, maps structures, monitoring brightness changes, etc

https://www.flickr.com/photos/nasawebbtelescope/albums/72177720300469752/

Types of Spectrographs

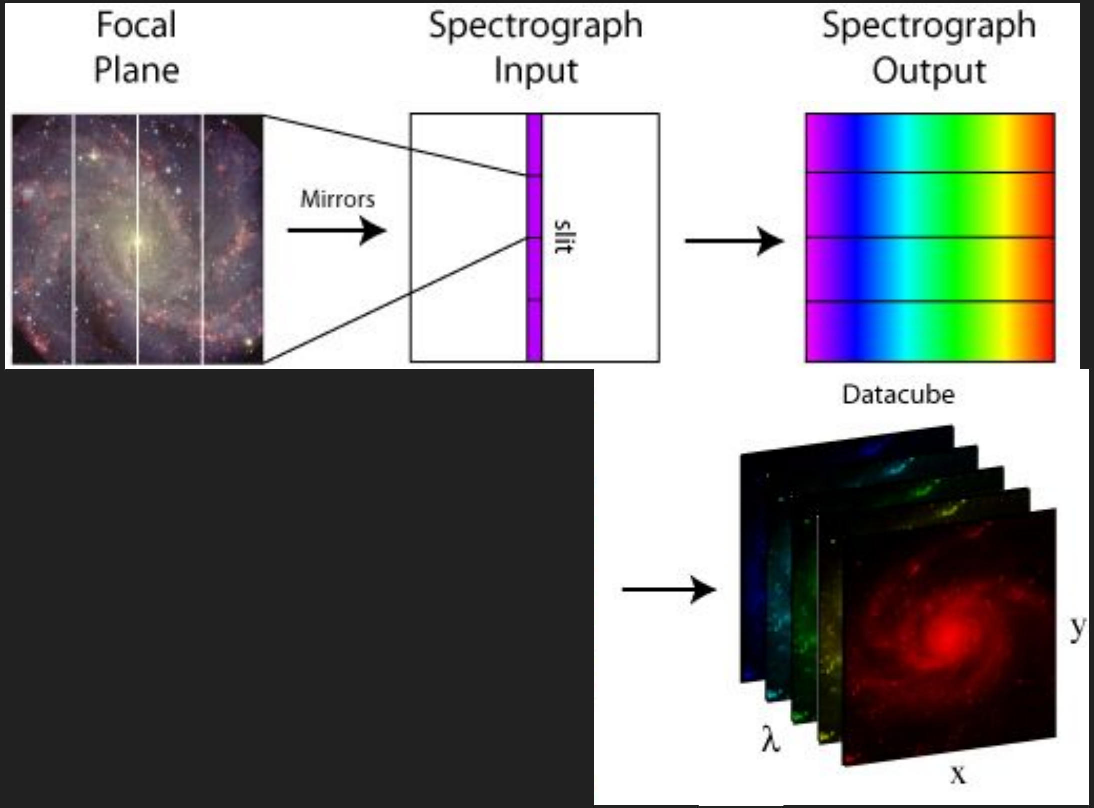
IMAGE SLICER

Slices a 2D field into narrow strips, rearranges them to be fed into a spectrograph.

High resolution, high efficiency.

Requires complex optics.

Best used for high resolution spectroscopy of smaller objects, stars, AGN, etc.



Credit: M. Westmoquette, adapted from Allington-Smith et al. 1998

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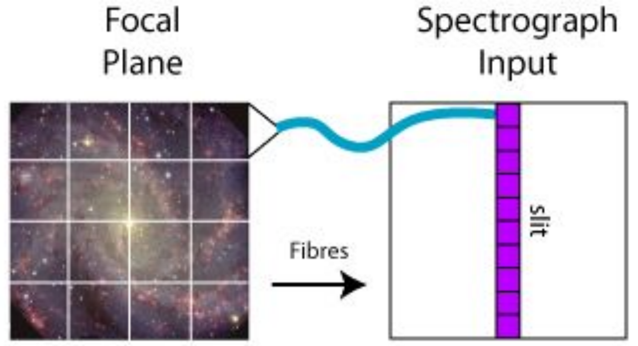
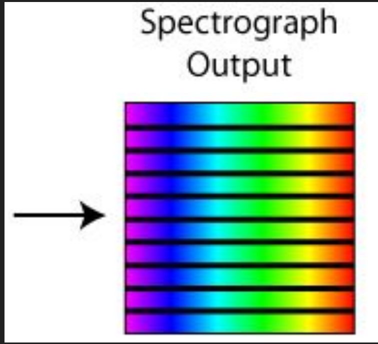




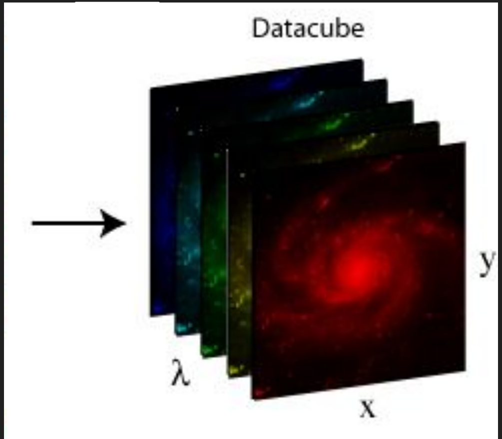
FIBRE-FED

Light on the focal plane is transmitted via fibres to the spectrograph.

Can observe many objects at once.

Light lost in fibre, limited resolution.

Best for large surveys / multiple objects.



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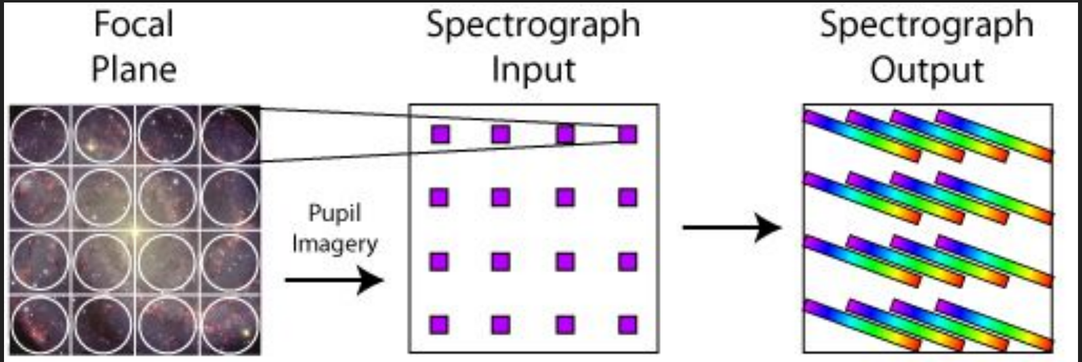

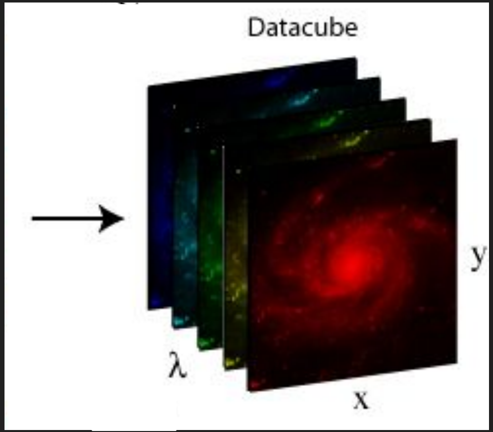

MICROLENS ARRAY

Many lenslets focus light into many spots, forming a pseudo-slit.

Can be compact, more light throughput than fibres.

Complex to calibrate.

Good for extended objects, galaxies, nebulae, etc.

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Types of Imagers

VISIBLE

Detects light in the 400–700 nm range using CCD/CMOS sensors

High resolution and well-developed technology

Affected by weather, light pollution

Helix Nebula - Image credit: Space Telescope Science Institute

Types of Imagers

INFRARED

Detects heat and light beyond visible (700nm to 1mm)

Sees through dust; good for cool objects. Can visualise star-forming regions, proto-planetary disks etc.

Needs cooling; atmospheric absorption. So not good for humid environments

NASA, ESA, and the Hubble Heritage Team (STScI/AURA)

Types of Imagers

UV / X-RAY ETC

Captures high-energy photons (shorter than 400 nm)

Reveals energetic processes (e.g., black holes, hot stars)

Requires space-based platforms, as the atmosphere blocks the UV and X-rays.

Image Credit (right) X-ray: NASA/CXC/SAO; Infrared: NASA/ESA/CSA/STScI/D. Milisavljevic (Purdue Univ.), I. De Looze (UGent), T. Temim (Princeton Univ.); Image Processing: NASA/CXC/SAO/J. Major, J. Schmidt and K. Arcand Image credit (left):NASA/CXC

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Adaptive Optics

Imaging through the Atmosphere

Atmospheric turbulence is bad for astronomy because it:

- Blurs images and reduces resolution.
- Absorbs wavelengths including most UV, some infrared and all the X-rays
- Adds background signal from light pollution
- Refraction of the wavelengths alters the apparent position of the objects.
- Weather conditions limit seeing time

"Airglow Over the Indian Ocean". NASA Earth Observatory. 2020-10-08. Retrieved 2025-06-03.

Adaptive Optics

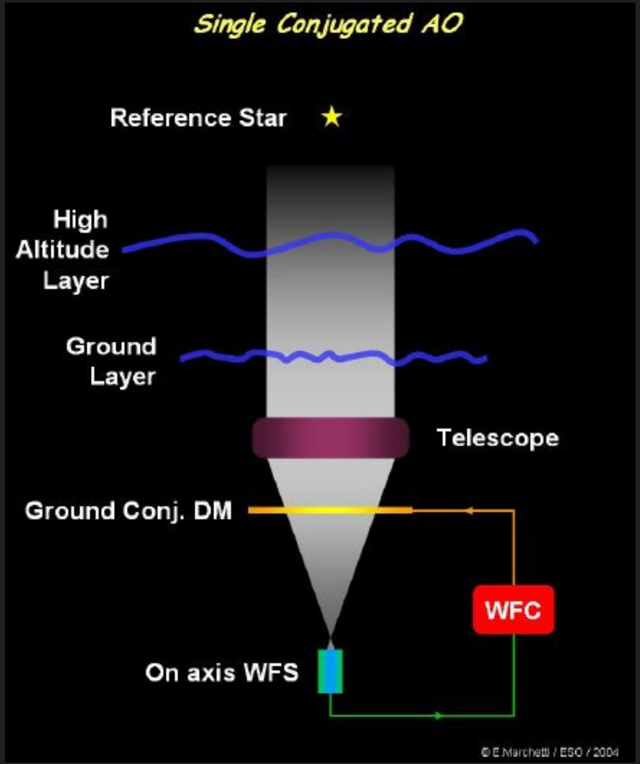
SCAO

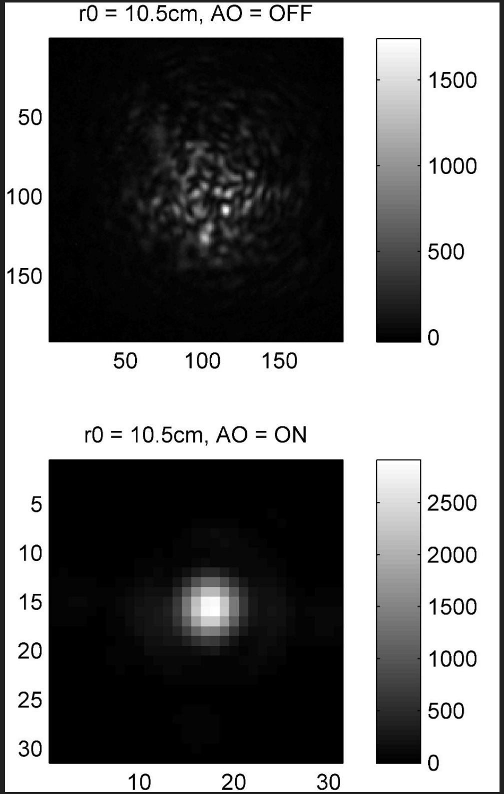
Uses one deformable mirror and one guide star.

Simple and high correction near guide star

Can only manage a very small corrected field

Can't be used when no bright guide star near target





https://www.eso.org/sci/facilities/develop/ao/ao_modes/.html

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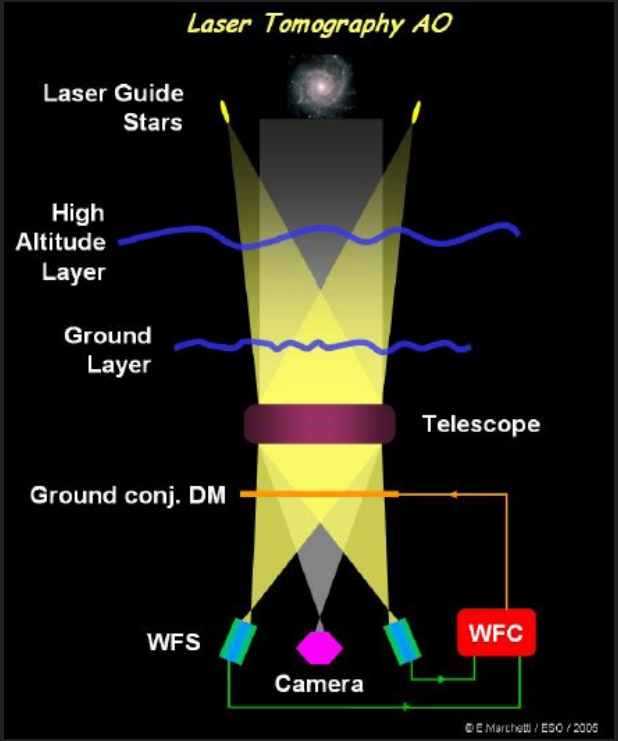

LTAO

Uses multiple laser guide stars to model turbulence along line of sight

Enables correction without a nearby natural guide star

Still limited to single-object correction and a small field of view.

Can't be used for wide-field imaging or extended sources

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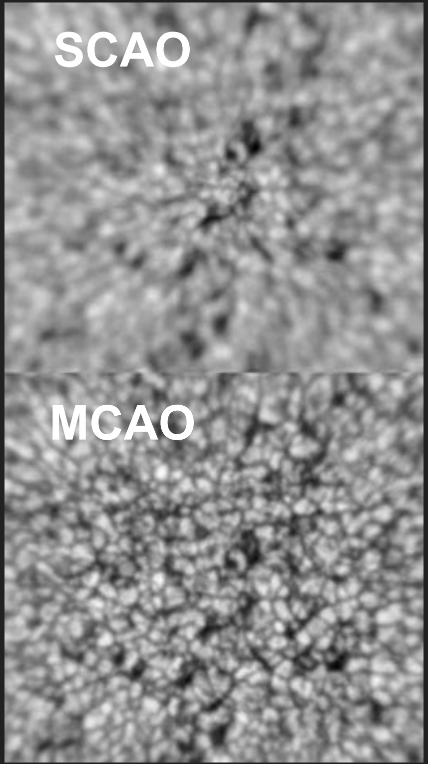

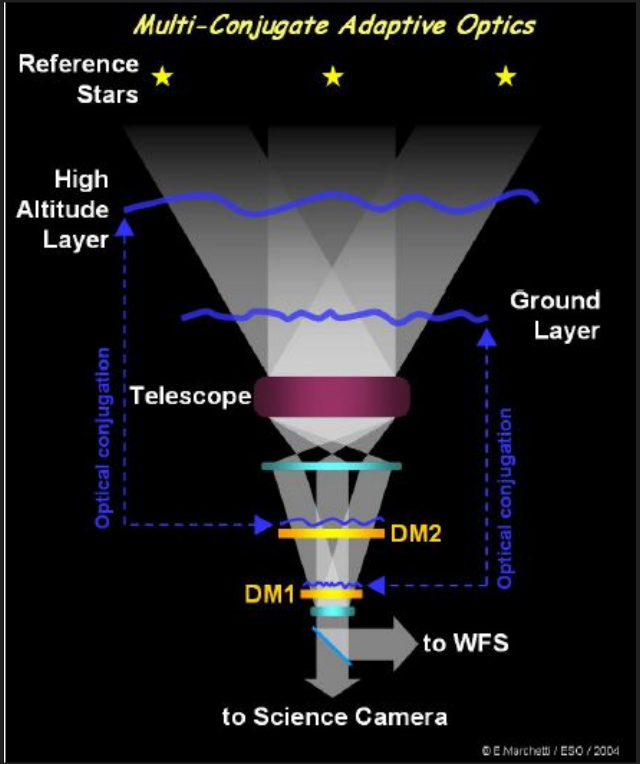

MCAO

Uses multiple deformable mirrors conjugate to different altitudes

Corrects over a wide field of view

Complex and expensive

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How to Build an Instrument

Game

How to Play

Divide into teams of 3-5 people.

Follow the steps in your worksheet to choose your observation target and then pick the specification of your instrument.

Go wild and choose the instrument of your dreams. Then work through the sheet again to decide what you would be prepared to compromise to make it more feasible.

Step 1: Pick an observation target

Step 2: Pick and Instrument type

Step 3: What type of detector do you need and how efficient does it need to be?

Step 4: Resolution required?

Step 5: Size of the telescope.

Step 6: Telescope location?

Step 7: Do you need adaptive optics

Game

Decide on your answers for your dream telescope as a group and when you are ready complete the Google form with your dream design. The QR code and short code are to the right and on your worksheet.

You will present your answers for your dream design and comment on how you would make it feasible in the next section.

SCAN ME

https://forms.gle/gDjJEFxNMTwVaNVq7

Your time starts now…

10:00

SCAN ME

Feasible option

Take a look back over your instrument - would you fund it?

What could you compromise on your design to make is feasible, here are some criteria to get you started:

- Reduce the cost
- Reduce the complexity
- Alter the requirements to make it buildable (physically and logistically) e.g. is there already a telescope you could use for this instrument?

Fill in your worksheet with your original and feasible design options to submit to the judges.

Here are your results

Drumroll please…