How do you make an image of an object?

Use a camera to take a picture!

But what if the object is hidden?
...or invisible to the human eye?
...or too far away to see enough detail?

Build instruments that use electromagnetic and sound waves to gather information about the object, and make an image / map / picture.

=> This is called ‘Remote Sensing’
Electromagnetic Waves

Reflection of ambient signal
Refraction and Absorption of background signal
Intrinsic Emission from the object
Artificial Illumination of the object

Detector & Receiver System

Data Processing

Image Spectrum Time Series

Transmitter

Structure
shape, brightness, size

Properties
mass, velocity, temperature, density, magnetic fields....

Chemistry
$\text{CH}_3\text{OH}$, $\text{H}_2\text{O}$, $\text{NH}_3$....
Space is a unique laboratory to observe extreme physics in action

=> Can study processes that cannot be re-created on Earth
Looking farther away == Looking back in time

=> Can probe the history and evolution of the universe

Measuring the chemical composition of matter in space

=> Can search for organic compounds to probe the origins of life
Make images at multiple wavelengths => Understand the larger picture

Crab Nebula

X-ray
Optical (visible)
Infra-Red
Radio
The Electromagnetic Spectrum

Objects can look different at different wavelengths (colours vs shades of grey)

=> Make images at all wavelengths with the same level of detail.

Fixed Resolution

Short Wavelengths
=> Small detector

Wavelength Resolution = __________________
Size of Detector

Long Wavelengths
=> Large detector
Detectors at Multiple Wavelengths (Astronomy)

GBT  WMAP  SPITZER  SWIFT

Longer Wavelengths (50m - 0.5m)

Cannot build larger dishes !!
How do you build a really large detector?

Artificially create a large “dish” using many smaller ones...

... this is called ‘Aperture Synthesis’...

... used in many Remote Sensing applications.
How do you synthesize a large ‘dish’ (aperture)?

Single Dish

16 dishes, arranged in a ‘Y’

Synthesized aperture

As the Earth rotates...

Final diameter = Largest separation between antennas

... the aperture fills up.

But ... this large ‘dish’ is not a real ‘reflecting surface’....

So how do you make it behave like one?

... by imitating how an ordinary lens works.
Measure interference fringes

Young's Double-Slit Experiment

Distance between slits controls the wavelength of interference fringes

One dish == One slit

=> Each pair of antennas measures a different 2D fringe.
Fourier Synthesis

Measure and add up enough different fringes

=> Good reconstruction of the image
Each Pair of Antennas:

=> Measures one 2D fringe”

“fringe spacing,” orientation,” “amplitude,” “phase”
(1) Editing

=> Need to Identify and remove "bad data".

Stray signals: TV, Air-Traffic-Control, Radio stations, Cell phone services, satellite communication signals, etc....
(2) Instrument Calibration

Fourier Optics needs ideal conditions

=> Need to model and remove instrumental effects

(3) Image Reconstruction

Artificially interpolate between measured Fourier terms to create the final image.

Steps (2) and (3) are done by "non-linear model fitting".
At even longer wavelengths, even single dishes cannot be built.

“Dishes” are built electronically from “dipoles”...
A Career in Astrophysics?

**Physics**
- Interferometry, Astrophysics of objects in space ...

**Instrumentation:**
- Antennas, detectors, sensors, receivers ...

**Signal and Image Processing:**
- Signal Processing, Numerical Math ...

**Computer Science:**
- High-performance computing ...