The phases of a space project / What makes space so special?

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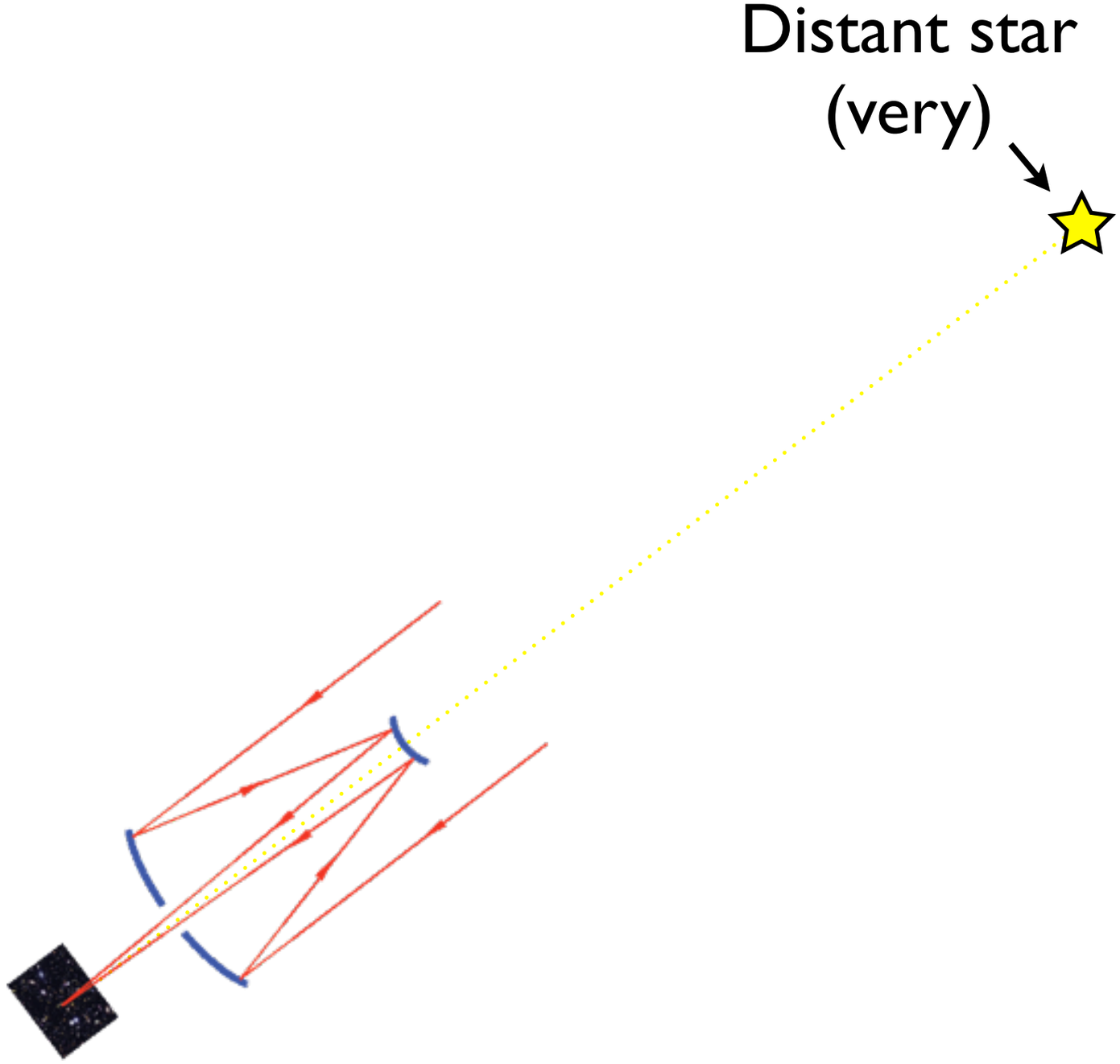
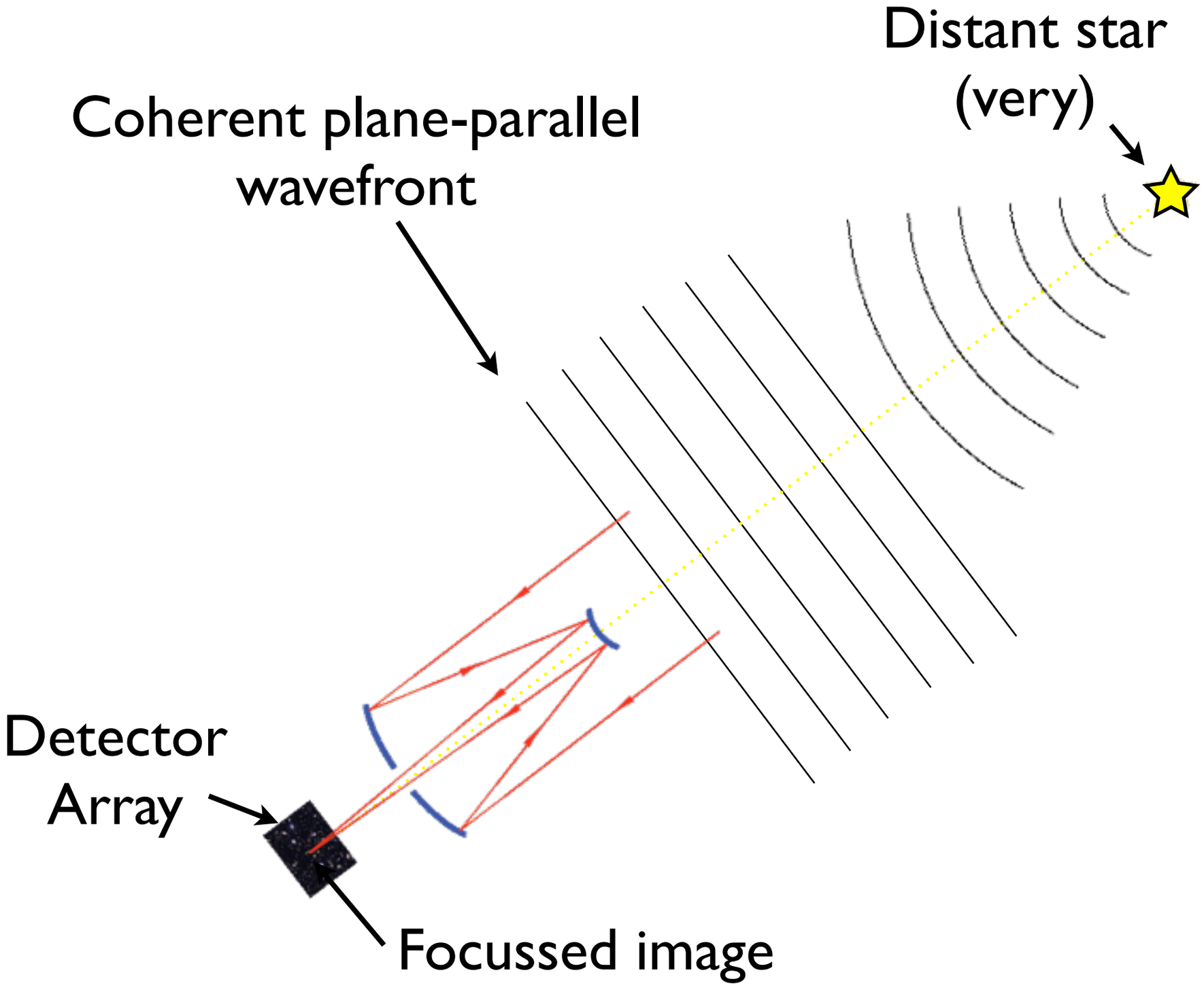
Why space in the first place?

The astronomical telescope

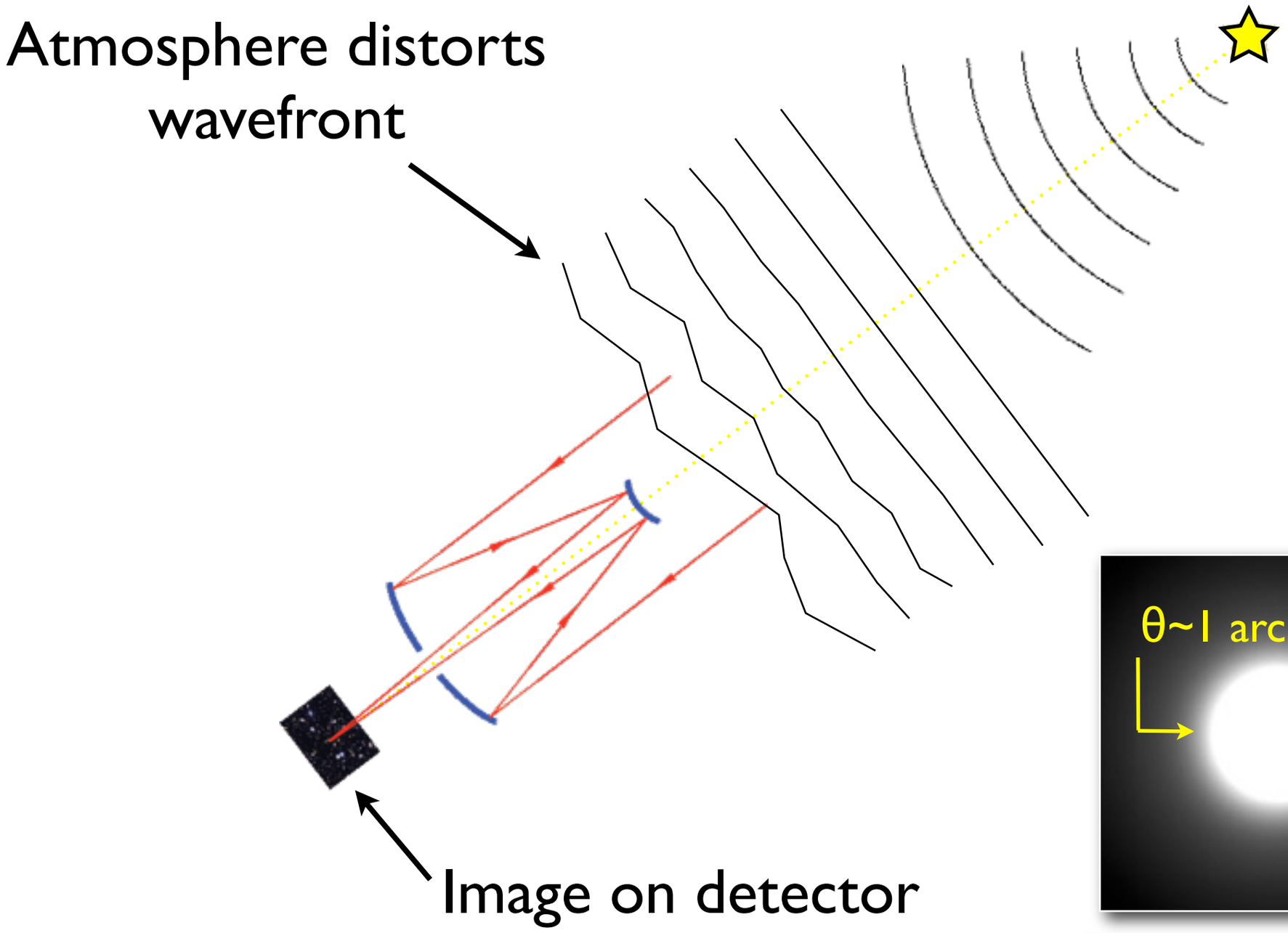


The astronomical telescope



Seeing-limited imaging

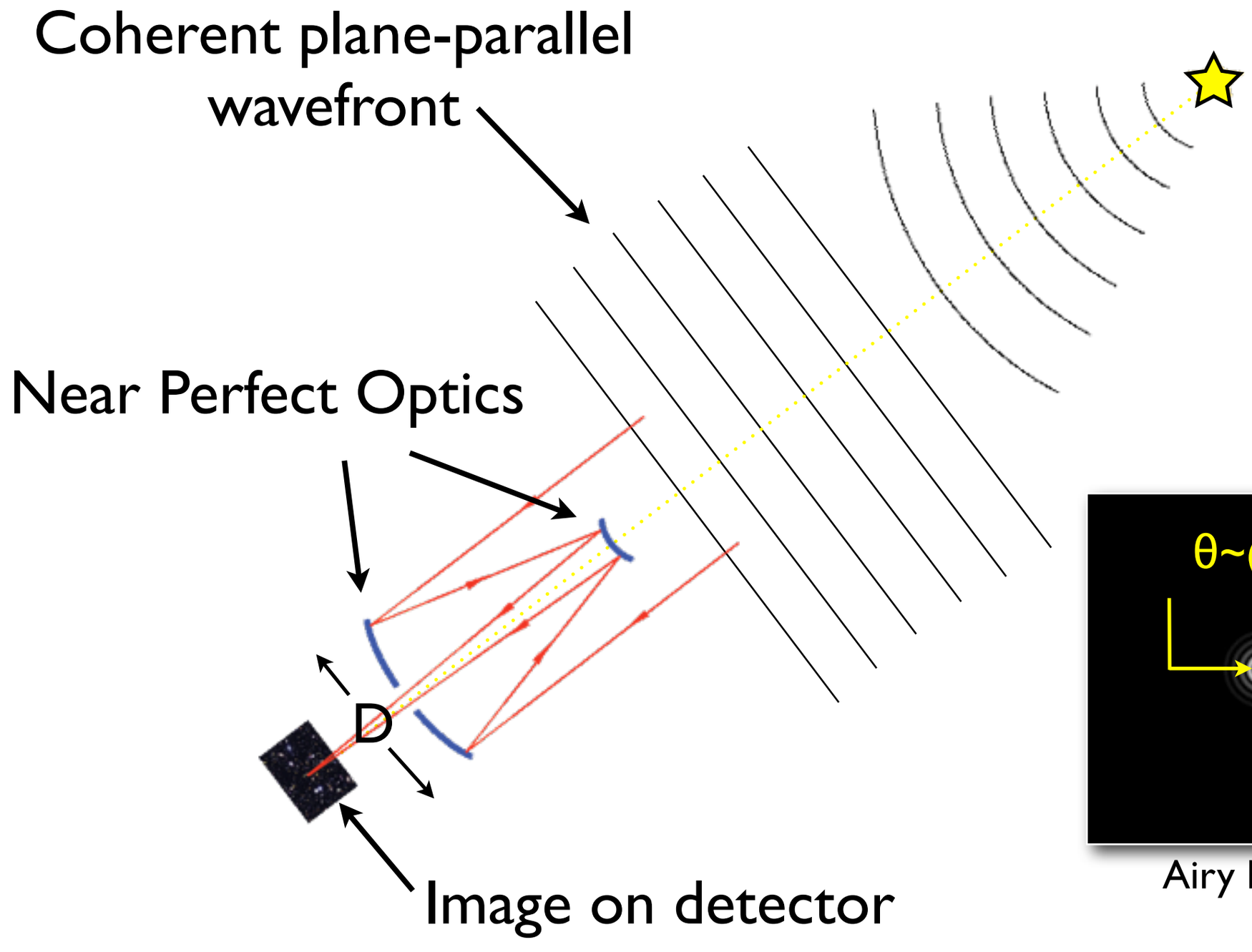
Ground-based astronomy

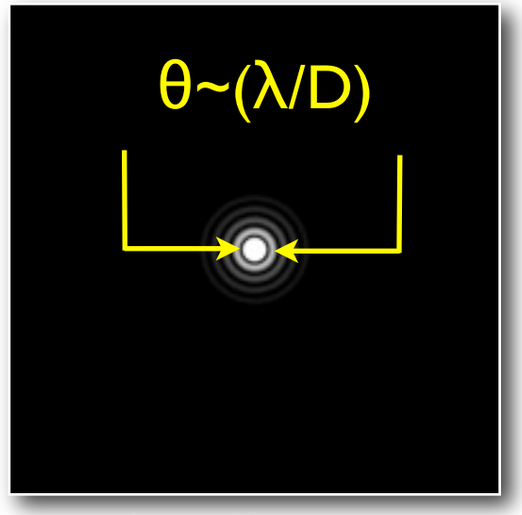


Time-averaged image

Diffraction-limited imaging

Space-based astronomy

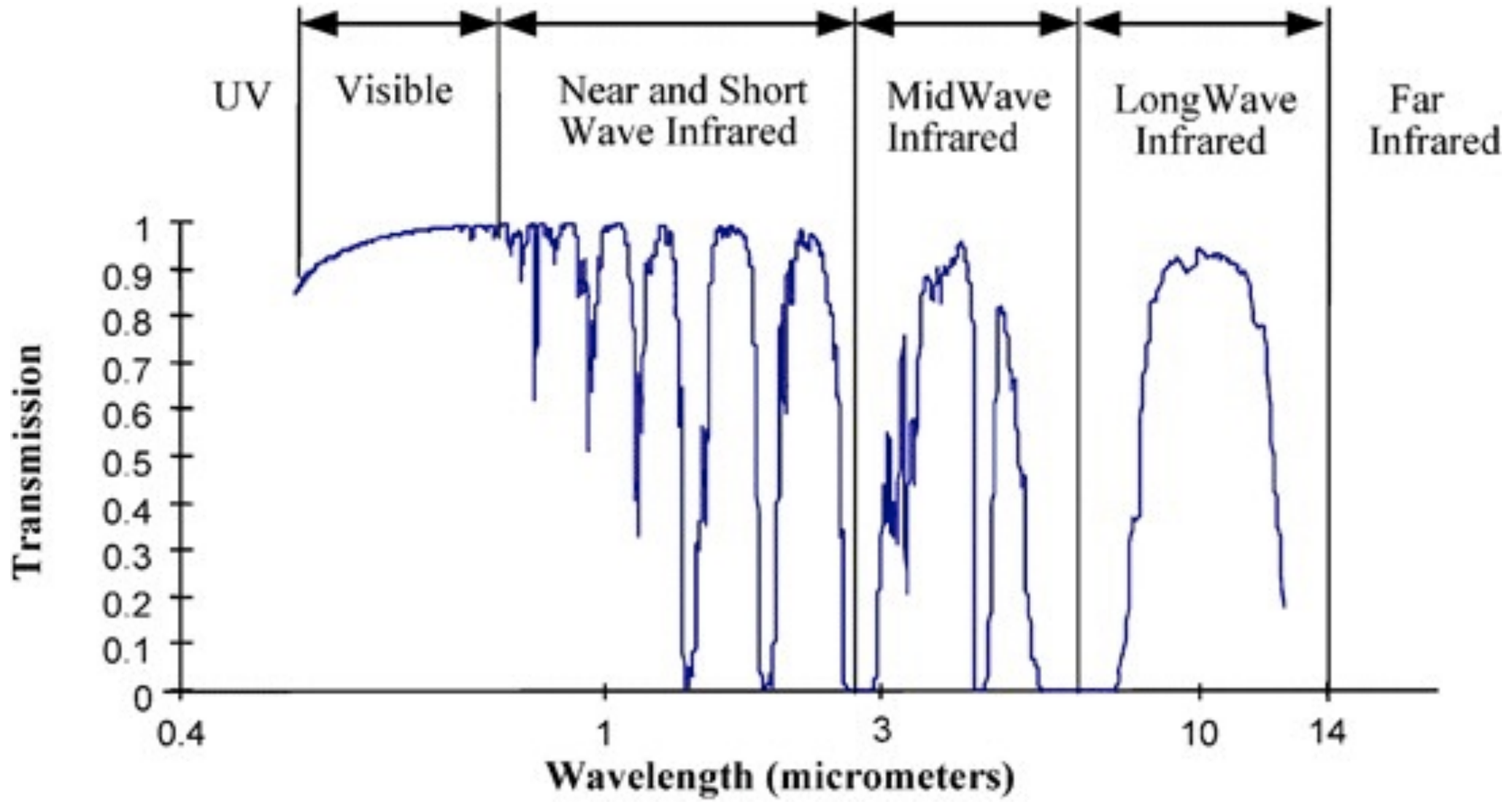




Airy Pattern

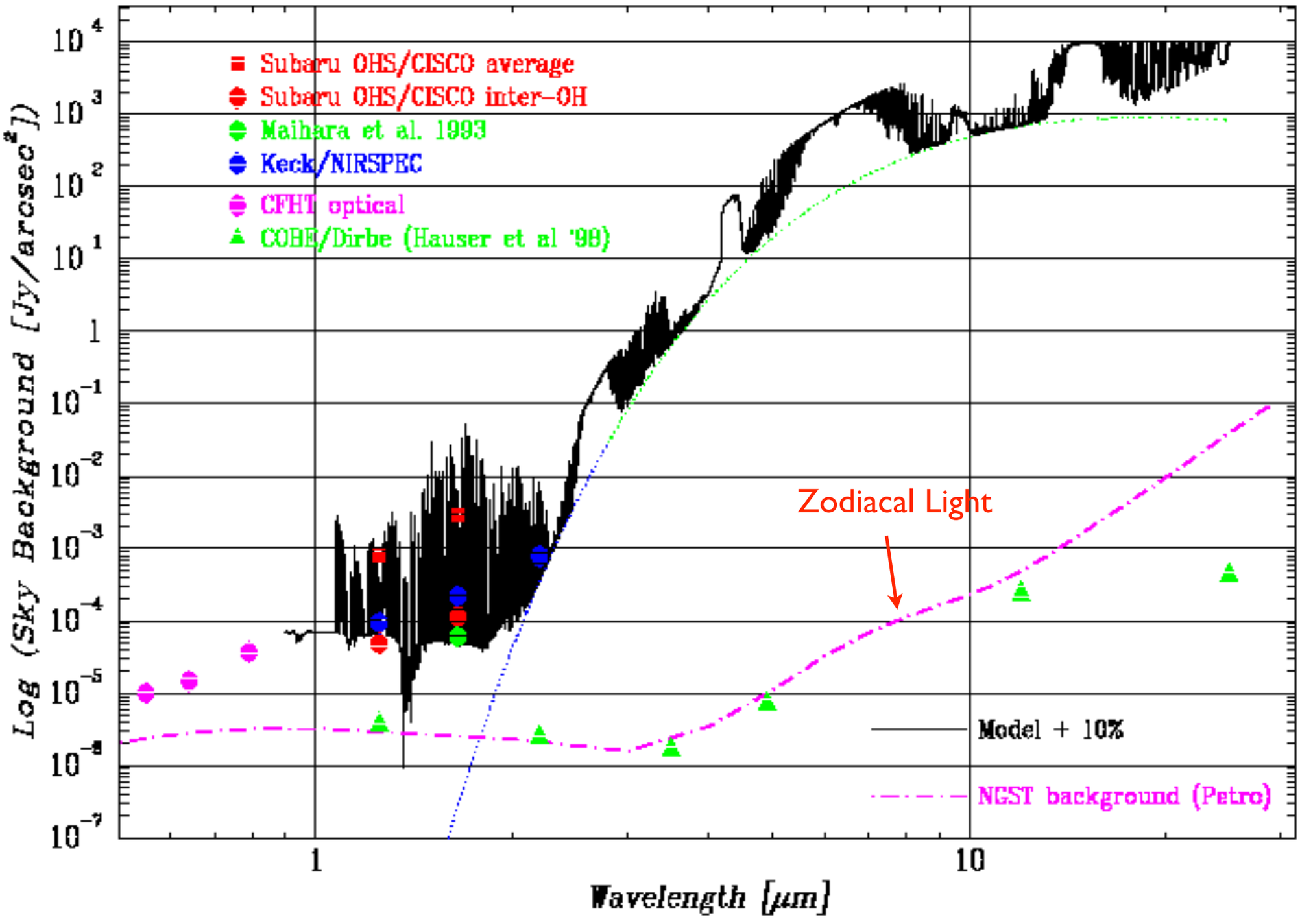
Other advantages of space

Transmission of atmosphere (ε)



Other advantages of space

Emission from atmosphere (I_B)



Space versus ground

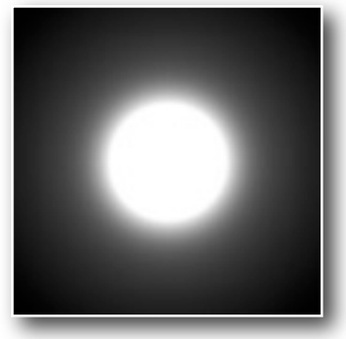
$$t \simeq \left(\frac{S}{N}\right)^2 \left(\frac{2I_B}{F_\star^2}\right) \frac{\Omega_\star}{A\ \epsilon}$$

Observational astronomy in a nutshell

(sky background-limited imaging - detector noise negligible)

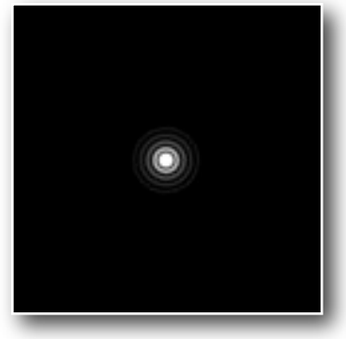
Seeing-limited telescope:

$$\Omega_\star \sim \text{constant} \quad \Rightarrow \quad t \propto \frac{1}{A} \propto \frac{1}{D^2}$$



Diffraction-limited telescope:

$$\Omega_\star \sim \left(\frac{\lambda}{D}\right)^2 \quad \Rightarrow \quad t \propto \frac{1}{D^2}\frac{1}{A} \propto \frac{1}{D^4}$$

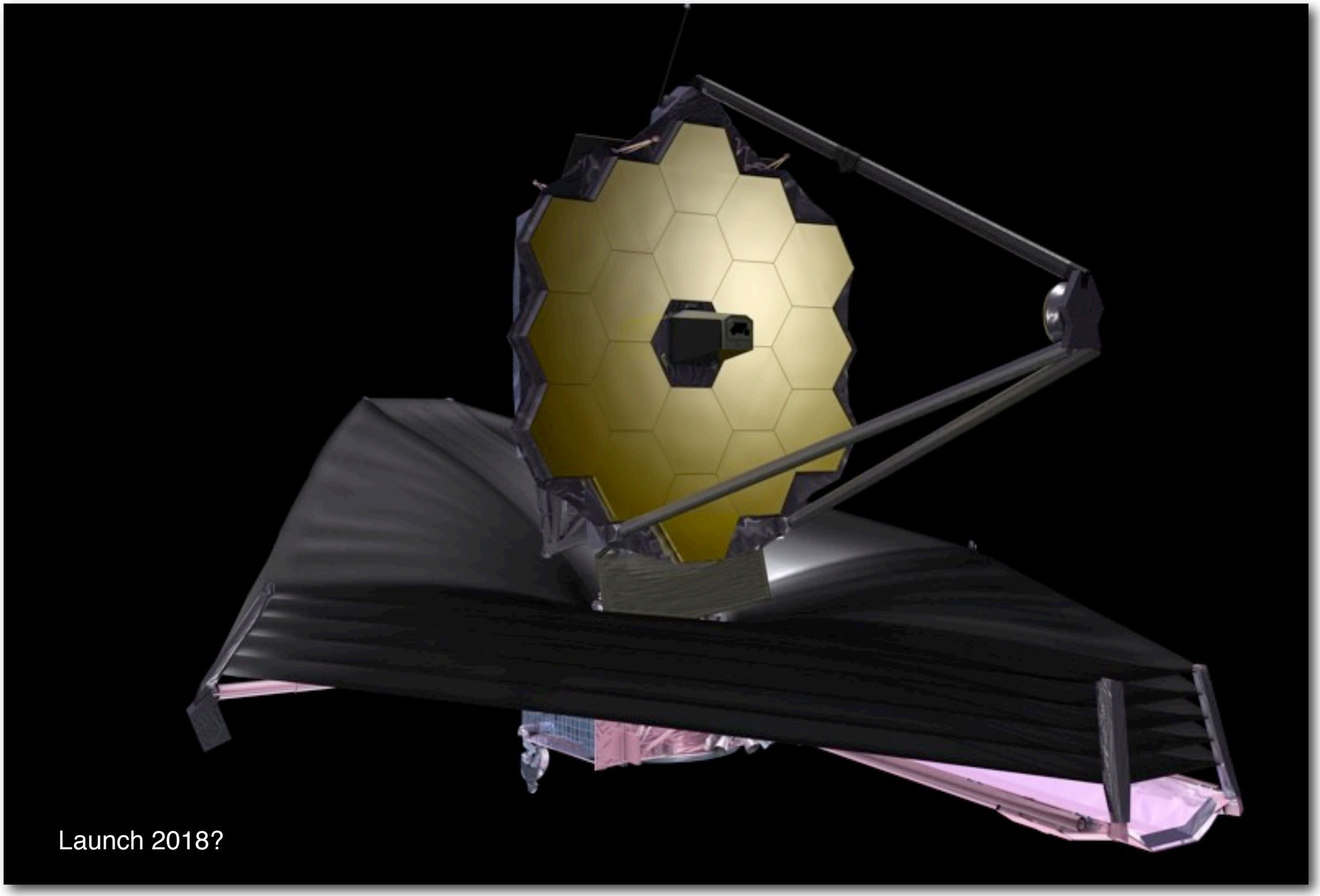


The proof

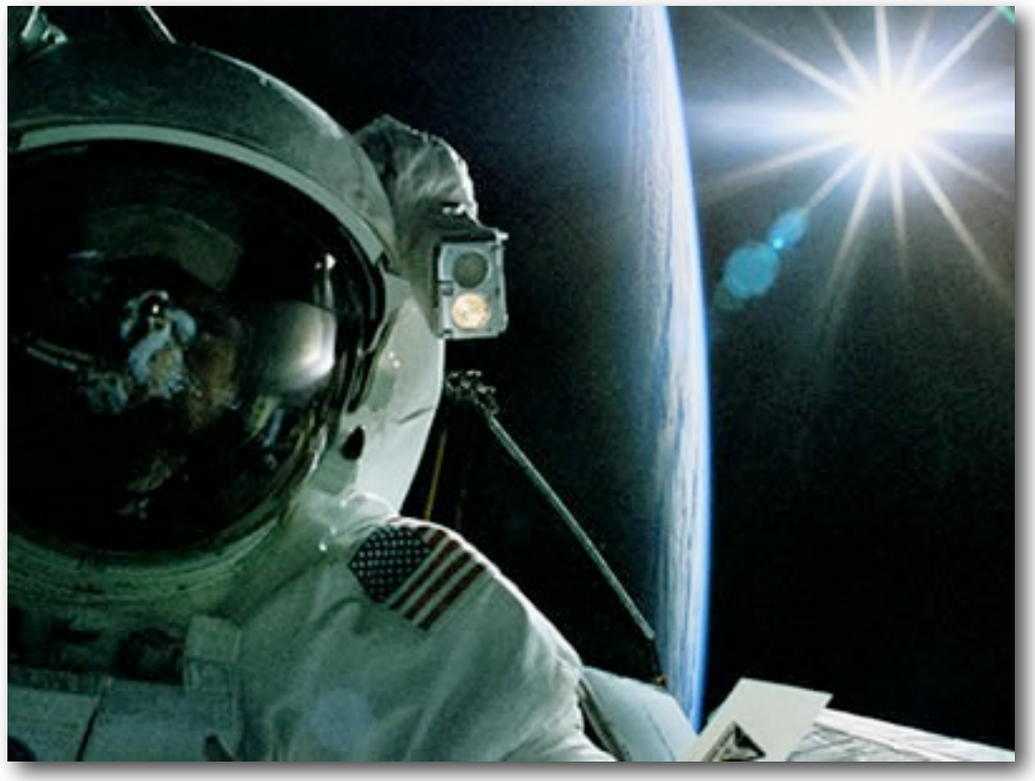
The proof

Hubble Ultra-Deep Field

The hope



The price



Why space is a pain

.. and so very expensive

(but worth it)

Getting into space

Riding a controlled explosion

Ariane V Launch

Extremely violent mechanical vibration

Extremely loud acoustic noise levels

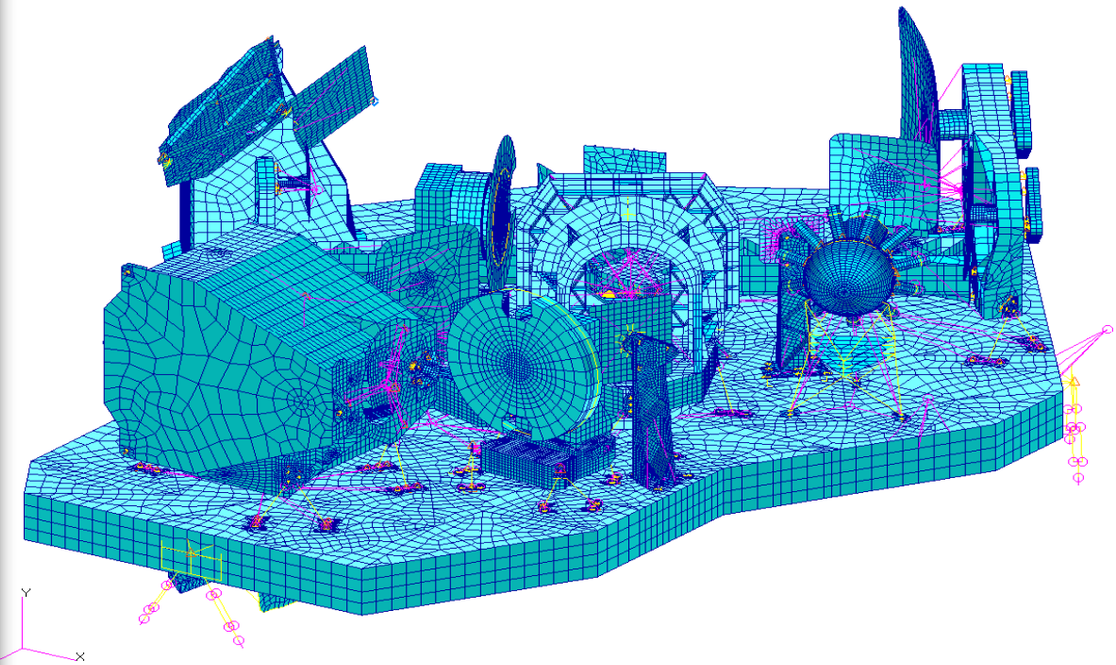
Lift capability and orbit set hard limit on total satellite mass

Beware of resonances

Shake, rattle and roll

ESTEC Shake Table

Acoustic Chamber

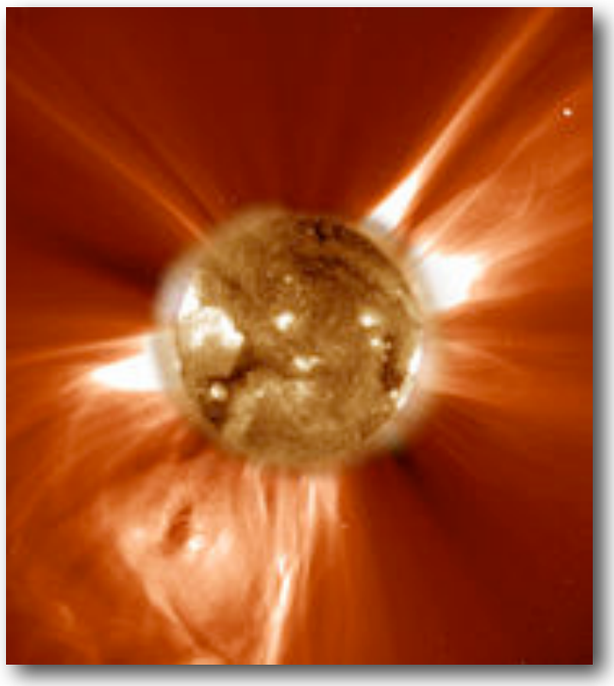


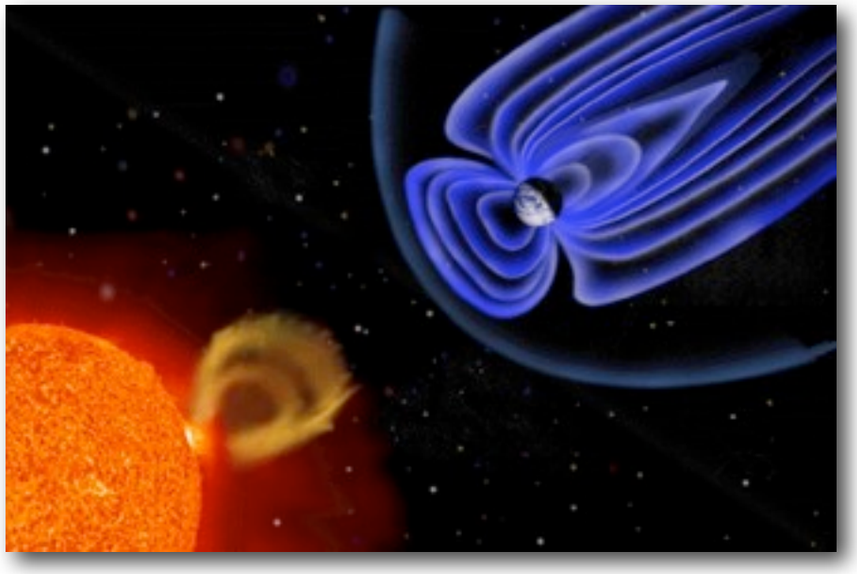
NIRSpec finite element model

Modeling, modeling, modeling. Testing, testing, testing.

The environment of space
Not just a vacuum anymore

- Galactic Cosmic Rays:
  - protons (85%)
  - α particles (14%)
  - heavy ions (1%)
- Solar activity
  - solar "flares" or "coronal mass ejections"
  - activity varies with 11-yr solar cycle
  - mostly high-energy (~ GeV) protons
- Van Allen radiation belts
  - e- (~10 MeV) and p (few 100 MeV) trapped in Earth's geomagnetic field
- Secondary particles
  - sometimes shielding is bad.....



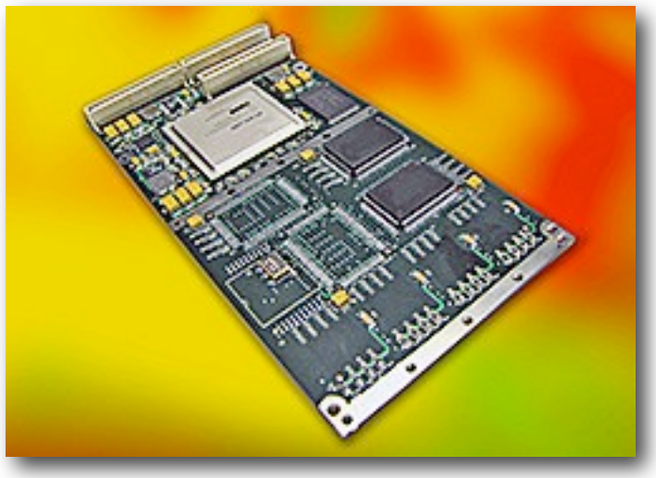


Radiation hard electronics

Fighting zap with less zip

- Energetic charged particles are harmful:
  - cause transient electronic effects (glitches, "single-event upsets")
  - damage electronics permanently (lattice displacement)
  - degrade detector performance

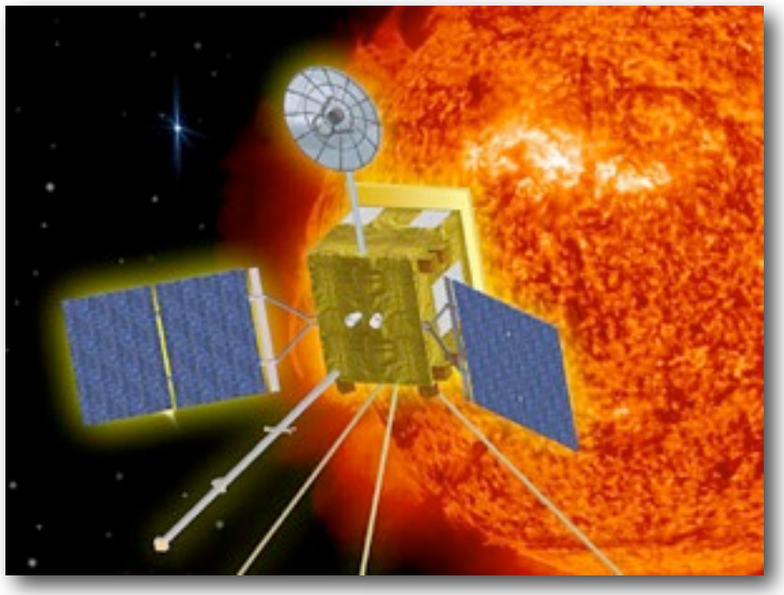
- Electronics must be "radiation hardened":
  - physically (e.g. insulating substrates, shielding, wide band-gap material)
  - logically (e.g. error-correcting memory, redundant elements)
  - always flying "obsolete" processors



Space is hot, space is cold

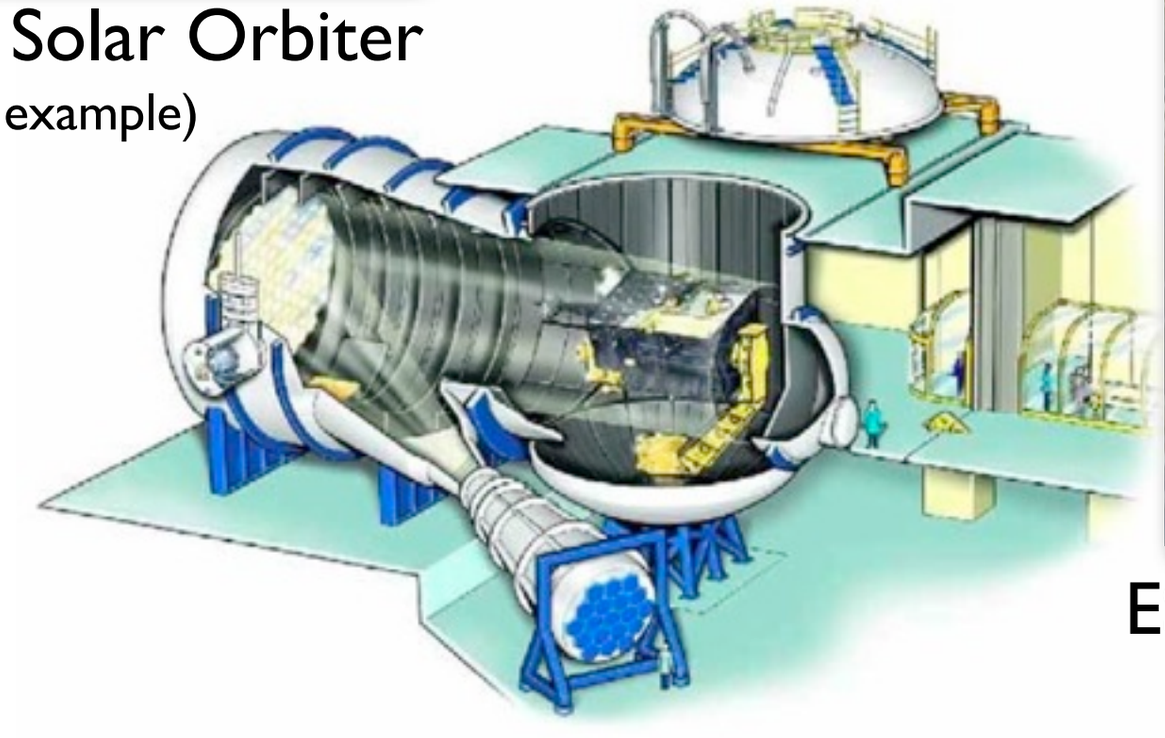
.. and Stephan-Boltzmann's law is your only friend

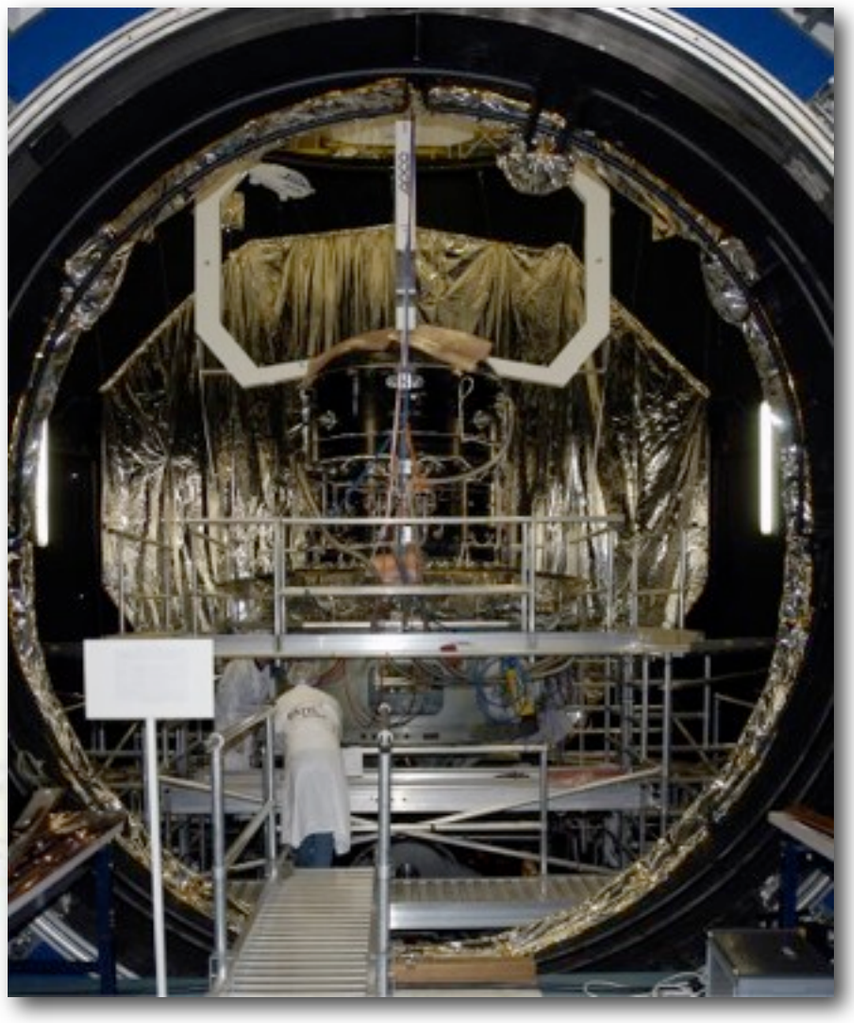
$$P = Area \times \sigma T^4$$



ESA/NASA Solar Orbiter

(Extreme example)

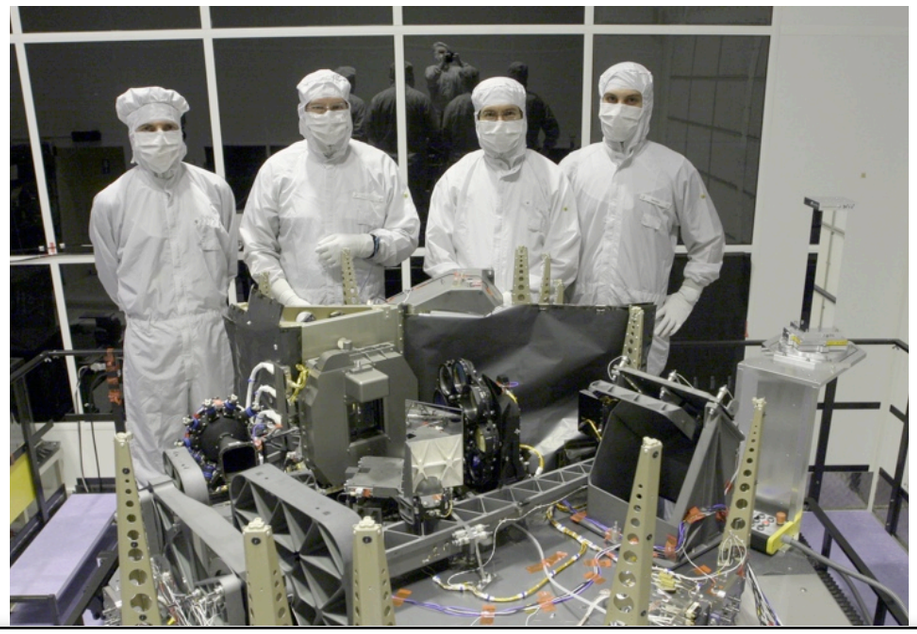




ESTEC Large Space Simulator

Contamination control

The mother of all cleanliness fetishes

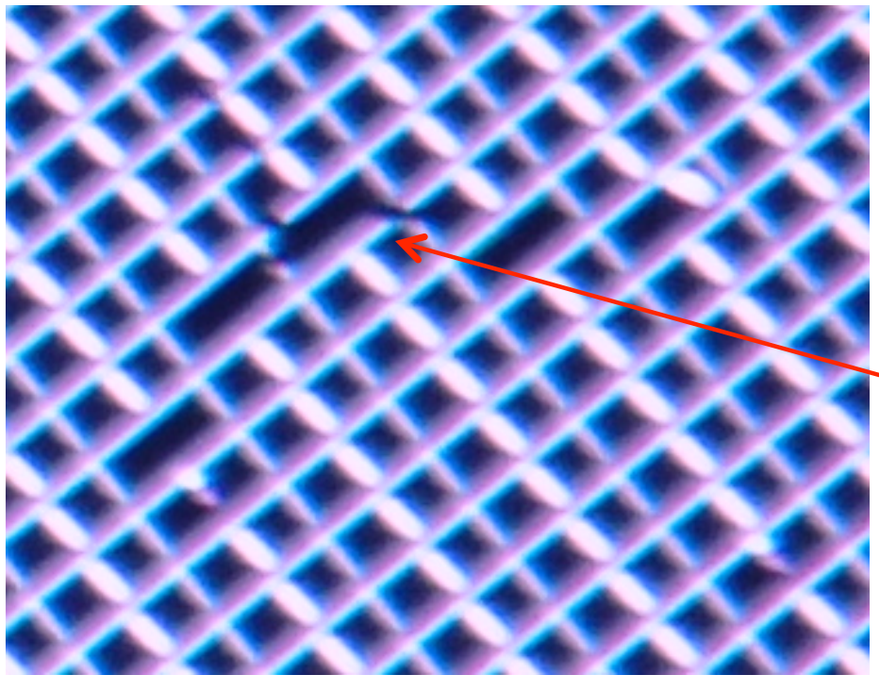


Clean Room Standards

Class	maximum particles/m³						US equivalent
	≥0.1 µm	≥0.2 µm	≥0.3 µm	≥0.5 µm	≥1 µm	≥5 µm	
ISO 1	10	2					
ISO 2	100	24	10	4			
ISO 3	1,000	237	102	35	8		Class 1
ISO 4	10,000	2,370	1,020	352	83		Class 10
ISO 5	100,000	23,700	10,200	3,520	832	29	Class 100
ISO 6	1,000,000	237,000	102,000	35,200	8,320	293	Class 1000
ISO 7				352,000	83,200	2,930	Class 10,000
ISO 8				3,520,000	832,000	29,300	Class 100,000
ISO 9				35,200,000	8,320,000	293,000	Room air

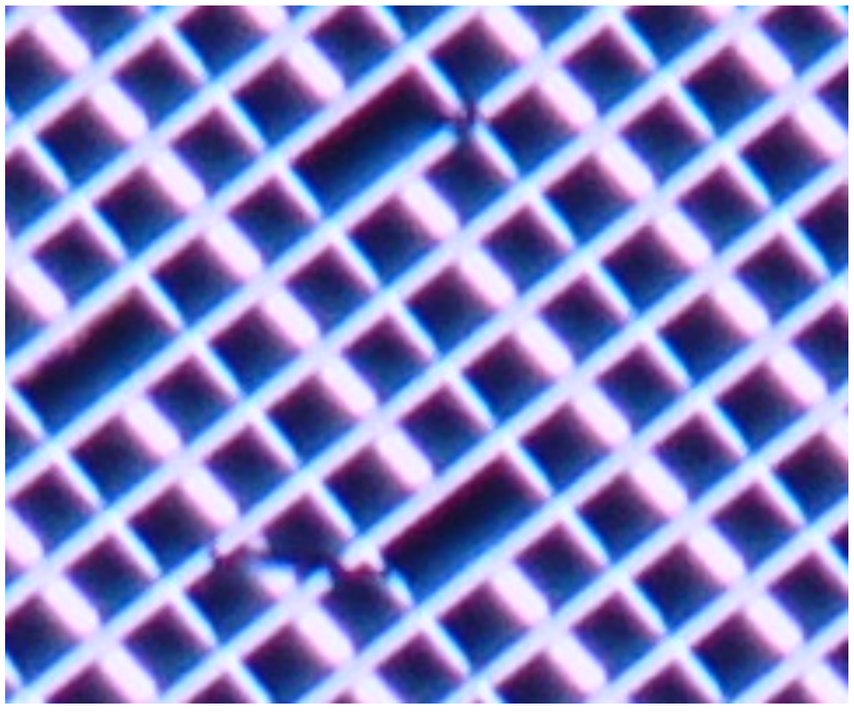
NIRSpec MSA fibres

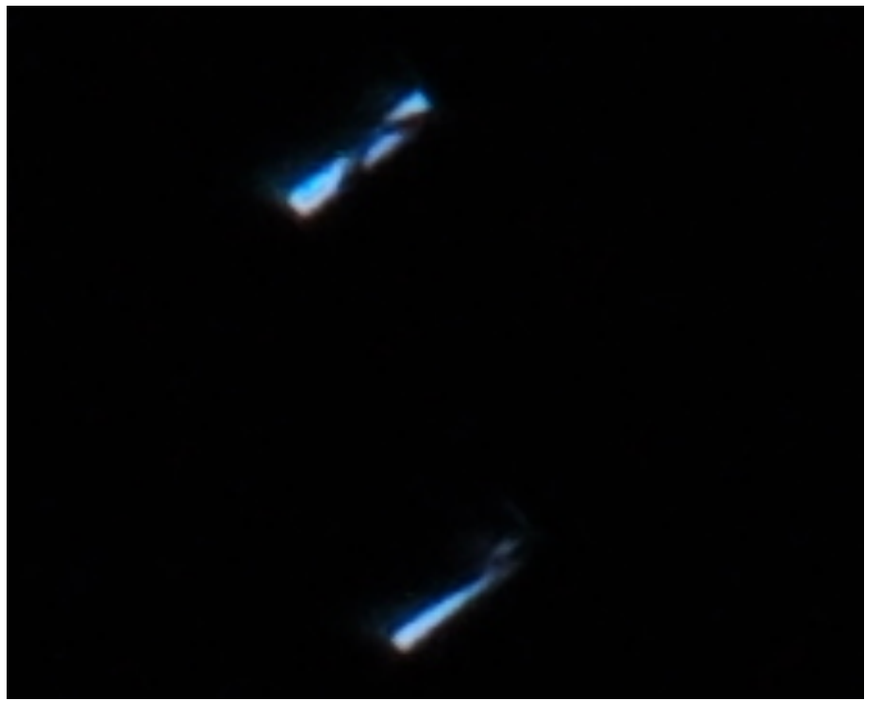
Embarrassment in the family



Q2 Post Vibe at Astrium.

Post Vibe Effected Shutter

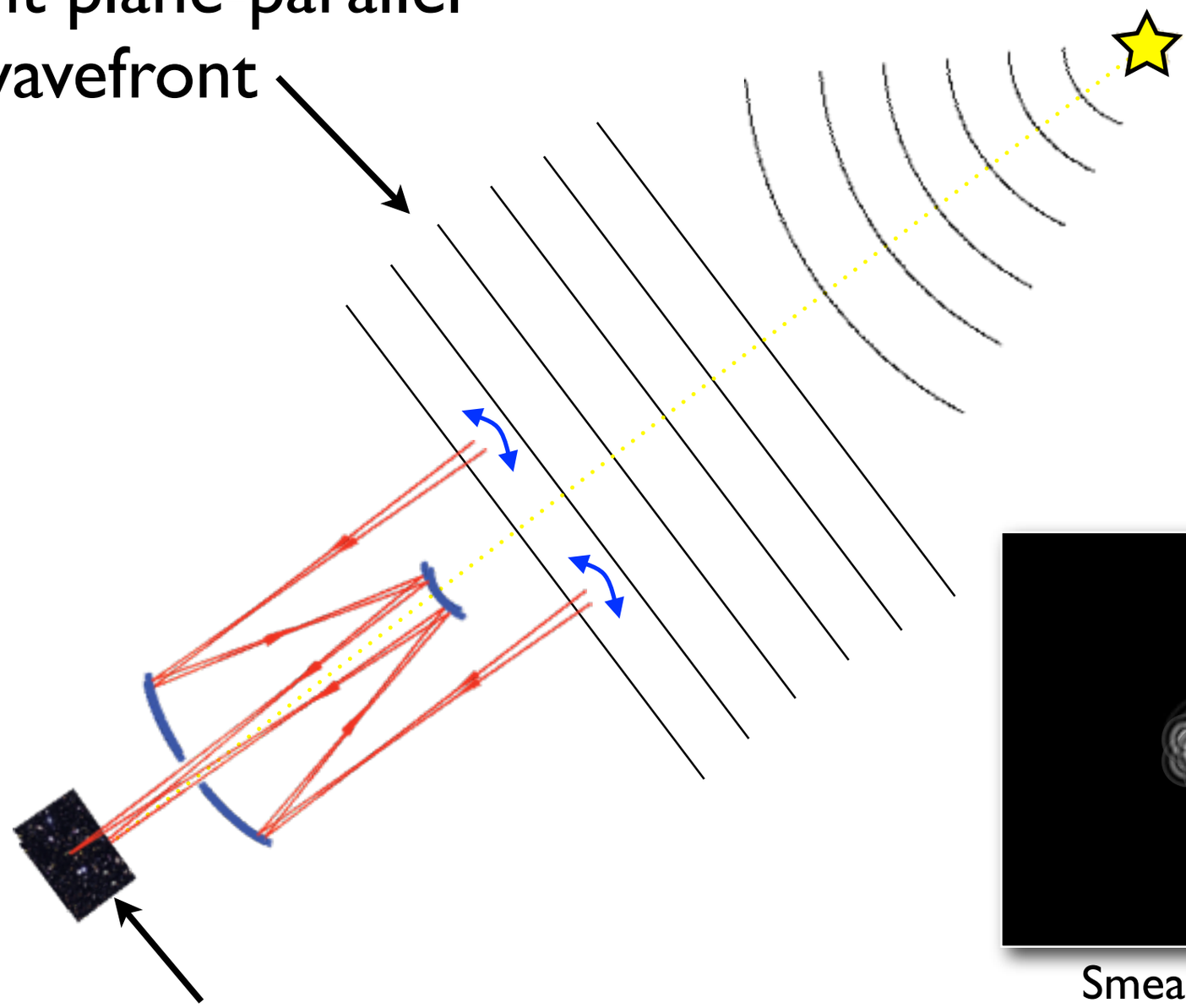




Pointing control

Keeping it steady

Coherent plane-parallel wavefront

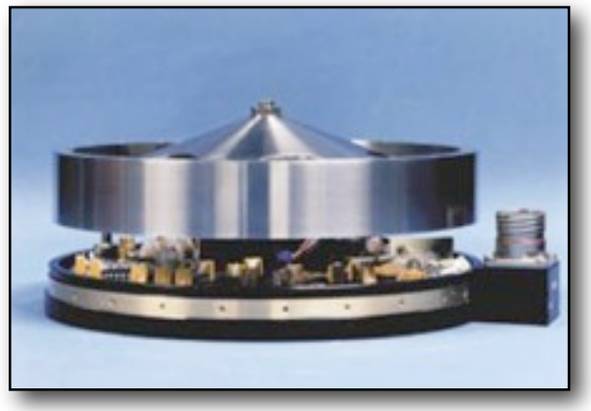


Smeared PSF

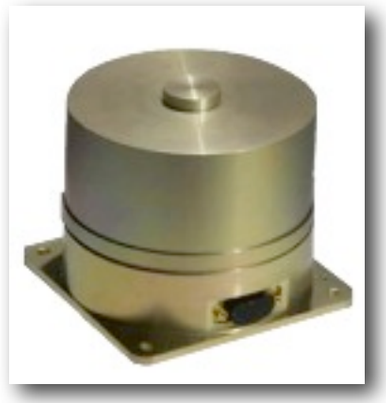
Smeared image on detector

How does one point a spacecraft?

Very carefully (obviously)



- Reaction wheels
  - Large speed controllable flywheels
  - Conservation of angular momentum
  - Three or more for each dimension



- In closed loop control with a hierarchy of directional sensors
- Thusters or magnetic-torquer for Momentum Dumping

Hierarchy of sensors

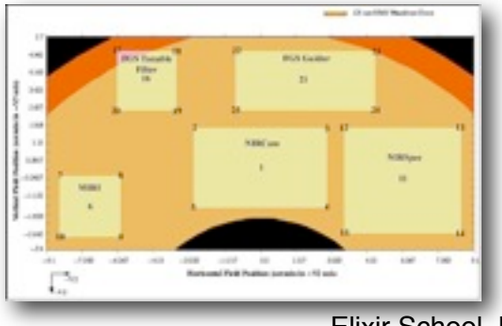
Avoiding getting lost in space

- Sun sensor
  - Safe Mode

- Gyroscopes
  - Slewing

- Fixed Head Star Trackers
  - Navigation
  - Coarse Pointing & Roll

- Fine Guidance Sensor
  - Fine Pointing in Pitch and Yaw
  - Looks through main telescope



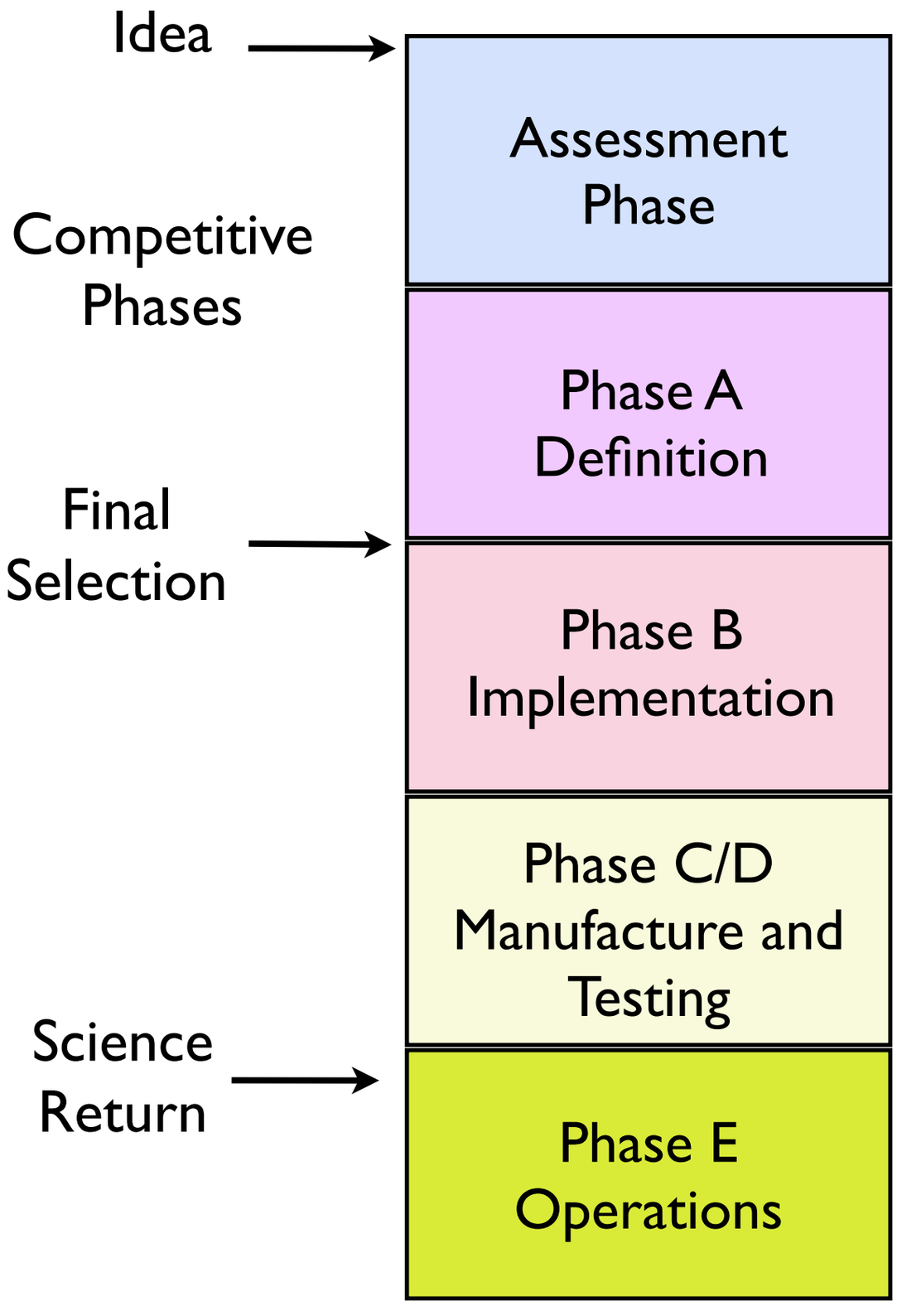
Operations

A long distance affair

- Telemetry & Commanding
- Orbit maintenance
- Data capture and storage
- Science planning and optimization
- Data analysis
- Trending

Lifecycle of a space mission

Space Bureaucracy



Formulate Science Goals

Trade-off mission concepts

Develop Initial Design Concept

Demonstrate Feasibility of Design

System Requirements Review (SRR)

Preliminary Design Review (PDR)

Freeze Design

Critical Design Review (CDR)

Test Readiness Review(s) (TRR)

Flight Readiness Review (FRR)

On orbit commissioning

Routine Operations

Decommissioning

Paying for it all

The suits are picking up the bill

Space politics in brief:

- Big Science
- Big Bucks
- Big Egos