

Astronomy from Space

Malcolm Fridlund

The Teacher

- Malcolm Fridlund – Swedish, lived in the Netherlands and Germany a total of 32 years
- Ph. D astrophysics, 1987, Stockholm but studied in Stockholm, Groningen and Onsala
- At ESTEC between 1988 and 2013
- Guest Professor in Berlin (DLR) 2013-2014
- Guest Professor in Heidelberg (MPIA) 2015
- Prof in Leiden (Space Observations of Exoplanets) since 2010
- Affiliated Prof at Chalmers (Radioastronomy and Astrophysics) since 2014
- Starformation, Interferometry, exoplanetology, stellar physics

The Teacher

- At ESTEC:
 - Study scientist for: Orbiting Planetary Telescope (OPT), Lunar Study, PRISMA, STARS, Darwin, GENIE, PLATO
 - Project Scientist for PCD Mk II, SMOG, CoRoT
 - Study Scientist for PLATO (2007-2013)
- Now: Member CHEOPS Science Team (2016-2019) and beyond

Objective with the course

- General overview enabling the student to access space astronomy assets.
- Knowledge on what is and will be available
- Information on how to use space facilities
- Interaction between ground- and space-facilities

Objective with the course

- Formulation of the scientific issues of a space mission with exo-planetary objectives
 - Stellar physics & Asteroseismology
 - Transit and radial Velocity observations
 - Follow-up science
 - Expected results
- Development of such a mission
 - Phases of mission studies and implementation, some orbital mechanics

Objective with the course

- Provide insight in the discussion and implementation of a space project as a member of the astronomical community
- Preparation and discussion of new projects
- Preparing for proposing new space missions
- Knowledge about space agencies and how to work with them

Structure and outline of course

- 9 lessons in HL 414 Thursdays 09:00 – 10:45
- 3 EC points level 400
- Form: Lectures, lecture notes (VG's) + a small number of articles/compendia and some exercises
- Written exam, some tasks during the course
- Teaching Assistant Vikram Radhakrishnan
- Contact: malcolm71@mac.com
 - Tel 0651-408529

Questions?

- 1. How many here have studied exoplanets at M sc level?
- 2. How many have studied asteroseismology at M sc level?
- 3. How many here have taken a course in stellar physics and evolution at M sc level?
- Special question: Why is a star hot?
 - Write down the answer (1 or 2 sentences max) and hand in the paper to me. No names

Questions?

- I would like to have your names and e-mails on this piece of paper:
- Write clearly, large letters and print name and e-mail – not handwritten

Supporting material

Lecture notes stellar Oscillations by
Christensen-Daalsgaard

Paper by Seager and Ormelas 2003
The Astrophysical Journal,
585:1038–1055, 2003 March 10

Course structure

For 2017, the course have been slightly changed (again). The emphasis on the scientific topics of exoplanets and stellar physics viewed together now forms the core for the scientific examples for space astrophysics.

The course is now built up around the following core elements:

#1 Introduction – 1 Lecture, 2h: History, Why observe from space?, The planet Earth environment (atmosphere including chemical composition, physical conditions, ionosphere, particle environment). Balloon astronomy, sounding rockets and launchers to deep space. Definition of a space project (scientific idea, scientific objectives, scientific requirements, general technical solution).

#2 - #4 The astrophysics of exoplanets and Stellar physics – 3 Lectures, 6h: exoplanets observations and interpretation, Orbital mechanics of binaries & exoplanets, stellar physics, asteroseismology, satellites

#5 - #7 The building of a Space Astronomy Mission using exoplanetary missions as examples – 2 Lectures, 4h: Previous space missions in exoplanetology, MOST, CoRoT, Kepler, K2 (HST, SPITZER), Future missions: TESS, CHEOPS, PLATO and beyond. The role and tasks of the scientist in assessment, technical implementation and scientific implementation. The PLATO mission will serve as an example

Course structure

#8a Available space resources and using them for your science – 1 Lecture, 1h: Preparing observing proposals. Handling data. Organisation of consortia. How to use data from space missions: Understanding space astronomy archives, defining projects, retrieving data, utilization of data.

#8b A special seminar with discussion on the different ways of reaching space with your equipment/problem – 1 Lecture, 1h: The space agencies (ESA & NASA) are providing space access at the moment, but this will not always be so. The future is important in this course because a) The timeline for space projects is usually 10-20 years, and b) because it is going to be YOU who form the future and it will be what you make of it.

The course is examined through one written exam and several tasks (to be defined)

Lesson 1

- Introduction
- History
- Why observe from space
 - Improvements vs difficulties
 - The planet Earth environment
 - The rotating platform
- Atmosphere
 - Chemical composition
 - Physical conditions, ionosphere, particle environment
- ‘The rotating platform’
 - Day and night
 - Continuous observations

Lesson 1

- Airplane astronomy
- Balloon astronomy
- Sounding Rockets
- Launchers to deep space
- Definition of a space project – the building of a mission
 - Scientific Idea
 - Scientific Objectives
 - Scientific Requirements
 - General Technical solution

Lesson 2-4

- Stellar physics,
- Asteroseismology
- Overview of exoplanet research and techniques
 - Transits and Radial Velocities
 - Orbital mechanics, binaries, planets, satellites
 - Ground based observations of exoplanets

Lesson 2-4

- Exoplanets from space
- The star
 - Understanding the relation between star and planet
 - Living with a star (the Sun and earth in perspective)
 - Stellar physics – Asteroseismology
 - Christensen-Daalsgaard kompendium (Provided with the approval of the author)
- Stellar physics – Spectroscopy and modeling

Lesson 5-6

- The building of a Space Astronomy Mission using exoplanetary missions as examples
 - Download the PLATO assessment report
<http://sci.esa.int/plato/53450-plato-yellow-book/#>
Required reading
- Previous space missions in exoplanetology, MOST, CoRoT, Kepler, HST, SPITZER, - The RESULTS
- Future missions: TESS, CHEOPS, PLATO and beyond
- Design of a mission – PLATO

Lesson 7

- IR and sub-mm missions
- IRAS, ISO, Spitzer, Herschel & Planck, JWST
- Satellite design, instrument design and realized instrumentation, science topics, trends, future (interferometry).

Lesson 8

- A special seminar on the future
- What will happen next – How will science from space develop
- Available space resources and how to use them:
 - How to use the space catalogues CoRoT, Kepler, HST, etc
 - How to write applications to e.g. HST

Lesson 9

- Repetition
- What will be on the exam

Lesson 1

Space Research - History

- The history of space research is intimately bound with the technology of rocketeering
- History goes back to Chinese rockets ~ 1000 years ago but space research as such begins in the early 1950's
- Until 1950 essentially only military purposes
- Examples
 - 1232 Chinese use war rockets against a mongol invasion
 - 1264 Celebration of imperial family members with fireworks
- More modern uses
 - 19:th century. British Navy uses rockets to set fire to Baltimore and Washington D.C.

Space Research - History

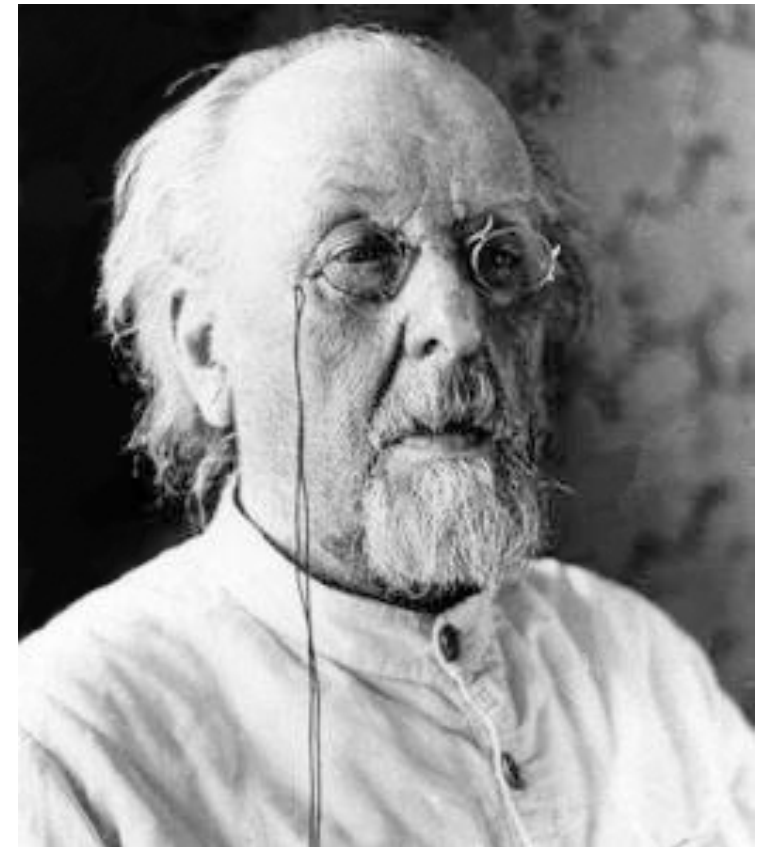
- US anthem: “The Star-spangled banner”
- But text is from “The defense of Fort M’Henry” (1814)
- And contains the line: “And the rockets red glare and bombs bursting in air”
- First mention of rockets used in war outside the east

What is a rocket?

- Uses action and reaction force of expanding gases and therefore works in vacuum
- Rocket engine exhaust is formed entirely from propellants and oxidizers carried within the rocket
- Oxidizer can be part of, or separate from fuel

Modern pioneers

- Konstantine Tsiolkovsky wrote 1903 the first modern scientific book about space and rockets: *“The Exploration of Cosmic Space by Means of Reaction Devices”*
- *He then published a work on multi-stage rockets in 1924*



Modern pioneers

- Robert H. Goddard wrote in 1920 “A method of reaching extreme altitudes”

The NYT wrote: "That Professor Goddard, with his 'chair' in Clark College and the countenancing of the Smithsonian Institution, does not know the relation of action to reaction, and of the need to have something better than a vacuum against which to react -- to say that would be absurd. Of course he only seems to lack the knowledge ladled out daily in high schools." —*New York Times*, 13 January, 1920”



NYT published a retraction and an apology on 20 July, 1969 –
Significance?



Modern pioneers

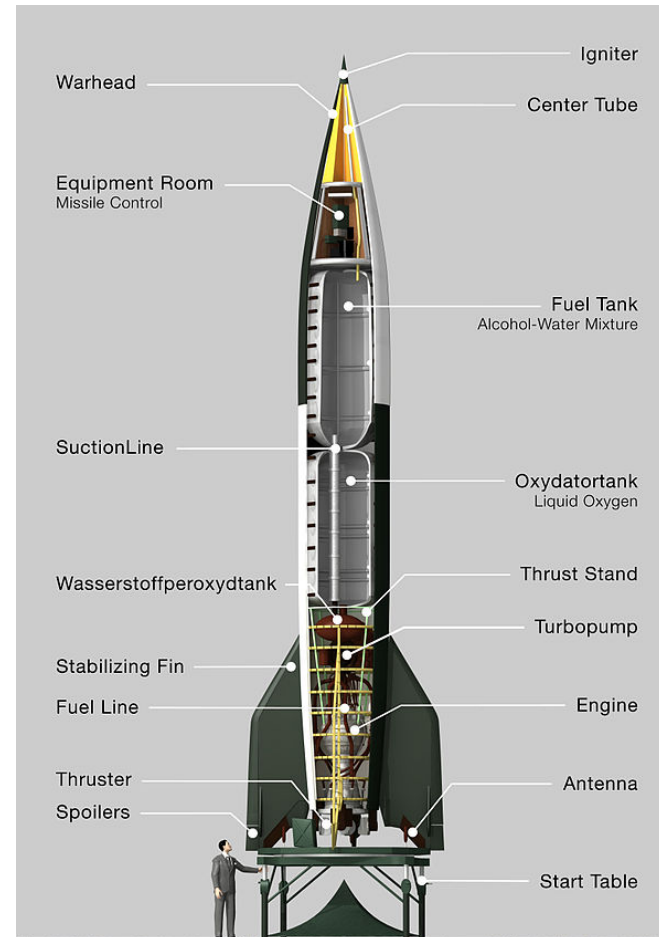
- Hermann Oberth, published the book "The Rocket into Planetary Space" in 1923.
- This was his doctoral theses, which just had been rejected by the University of Munich

World war II

- Advent of the V2 (or correctly the A4), a military ballistic missile
- Developed by Werner von Braun
- Could reach > 200 km altitude when launched vertically
- Where is the official limit for where space begins?
- 100 km

World war II

- First operational launch of a V2 took place ~ 5 km away from here



...We did it again in 1959



....18 pilots qualified as astronauts ($h > 80\text{km}$ –
1 (Joe Walker were 3 times $> 100\text{km}$

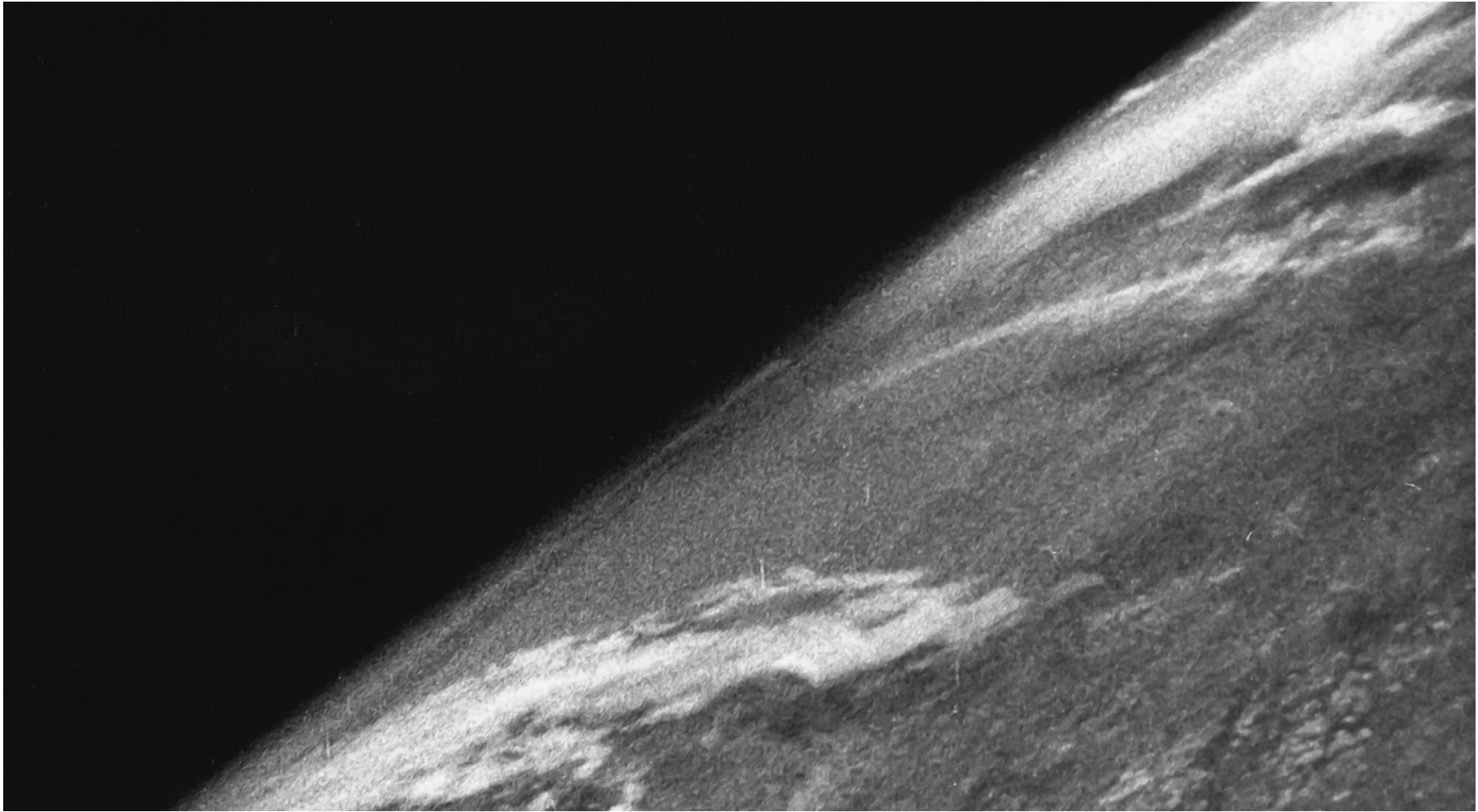
....Version 2017



World war II

- About 300 V2 rock shipped to the US Sands and began to images of the Sun)
- Ballon borne studi many decades
- In 1912, Victor Hes detector to 5.3km
4





Why observe from space?

- The lack of atmosphere
 - Possibility of achieving diffraction limited images
 - Possibility of observing across the electromagnetic spectrum with 100% transmission
 - Possibility of accessing information with no or almost no thermal background (in IR/ μ Wave)
 - Long uninterrupted durations
- Space programs, even the simplest are a major undertaking, costing enormous amounts of money and decades of the life of people involved
- Must be motivated by:
 - The importance of the objectives
 - The uniqueness of the space environment

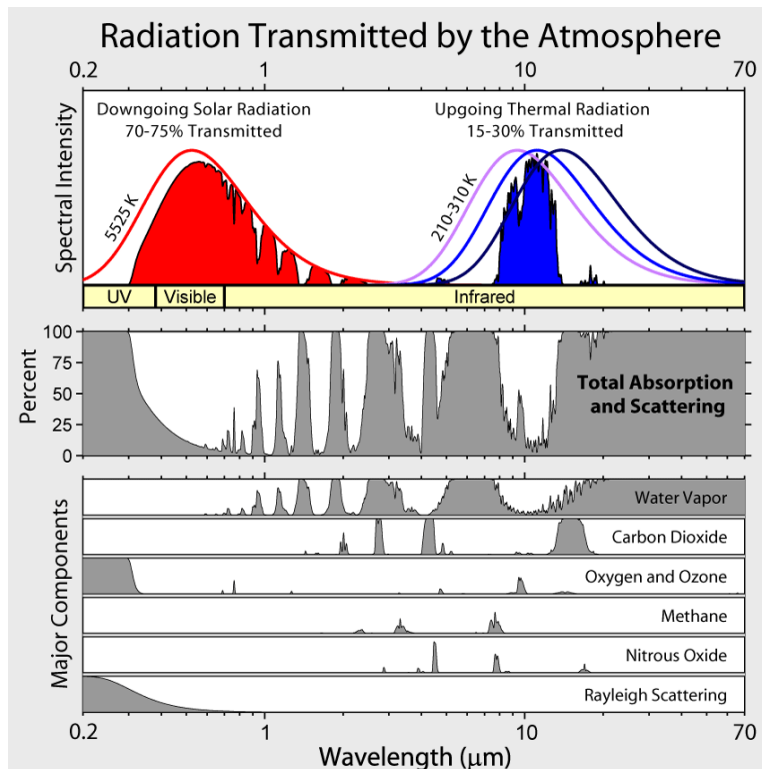
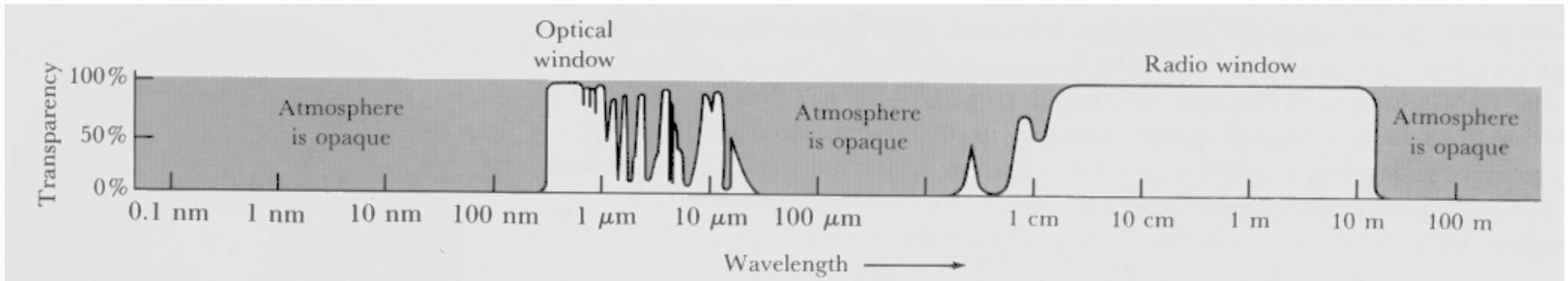
Alternatives to space?

- Atmosphere is opaque at relevant wavelengths
 - Consider mountain tops, airplanes, balloons
- You need extreme spatial resolution
 - Adaptive optics, changing wavelength region
- You need long duration (>> days) observations with no interruptions
 - Telescope networks (e.g. micro-lensing)
- All of the alternatives are cheaper, simpler and probably quicker to implement

The 'phases' of a space project

- Definition of a space project
 - Scientific Idea
 - E.g. “The Universe is round”
 - Scientific objectives
 - Measure ‘standard quasars’ at all z and all directions
 - Scientific requirements
 - Measure IR spectra of ‘standard quasars’ between 2 and 15 μm wavelength with $R=5000$ down to magnitude 31
 - Technical solutions
 - A 6m cryogenically cooled telescope

Alternatives to space?



- In some λ -ranges, one only need to go a little bit up in order to see an improvement, e.g. UV transmission increasing already a few km up (which is why one gets a nice tan in the alps by the way).
- FIR (Far-Infra Red) $\lambda \geq 70\mu\text{m}$ one may have to go to 15km to see anything and 30km is better
- UV, X-rays, γ -rays and cosmic rays: some improvement at balloon altitudes
- Other wavelength regions you need to go to space

Alternatives to space?

- Long duration observations
 - There are different types of science require long and uninterrupted series of data taking
 - Examples are exoplanetary transit searches (WASP, TReS), micro lensing (OGLE), Helioseismology (GONG). All of these are highly successful ground based networks, but compared to e.g. CoRoT, Kepler and SoHo there is a significant difference

So, What are the major problems with network observations?

Weather! The Earth's rotation

How can we mitigate this?

More telescopes/Units in more locations

Alternatives to space- Airplanes #1

Advantages: Repeatability, change of instruments, different topics, multiple flights, large telescope, man-operated, cost



Disadvantages: max altitude 15km, no high-energy observations, expensive to operate, safety restrictions, cost

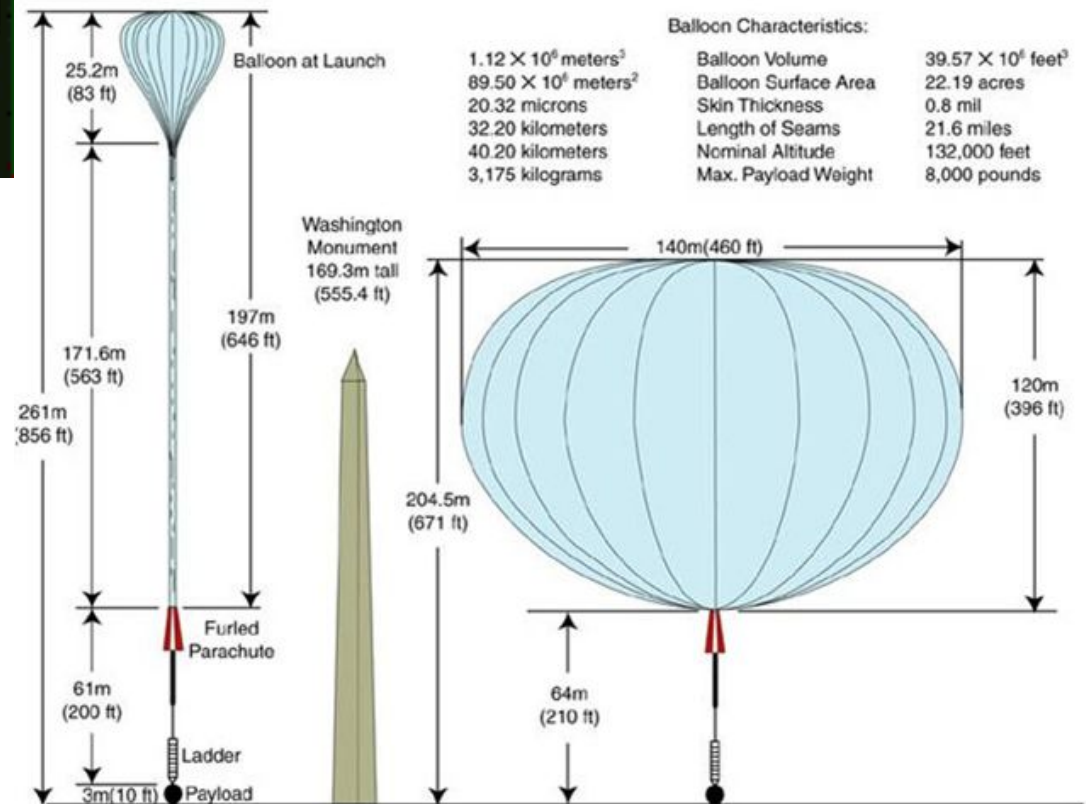
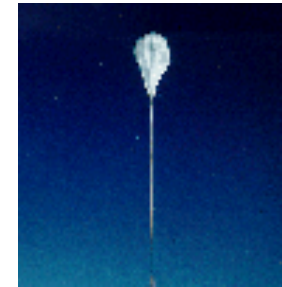
What do you think is the major cost driver of this observatory?

400 people vs 20! This has been challenged!

Alternatives to space? – Balloons #2

- Balloon astronomy
 - Infra Red, X-rays, Cosmic rays, γ -rays
 - Advantages:
 - Cost, complexity
 - re-flyable
 - Components are cheaper (simpler) and can be changed
 - flights of tens or even hundreds of days duration possible
 - Disadvantages: Not higher than $\sim 40\text{km}$

Alternatives to space? – Balloons #2



Alternatives to space? – Balloons #2

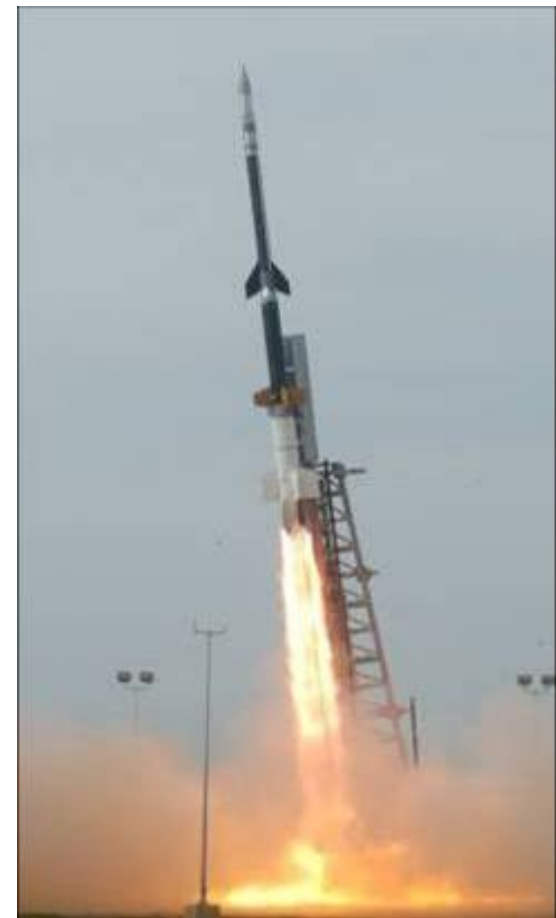
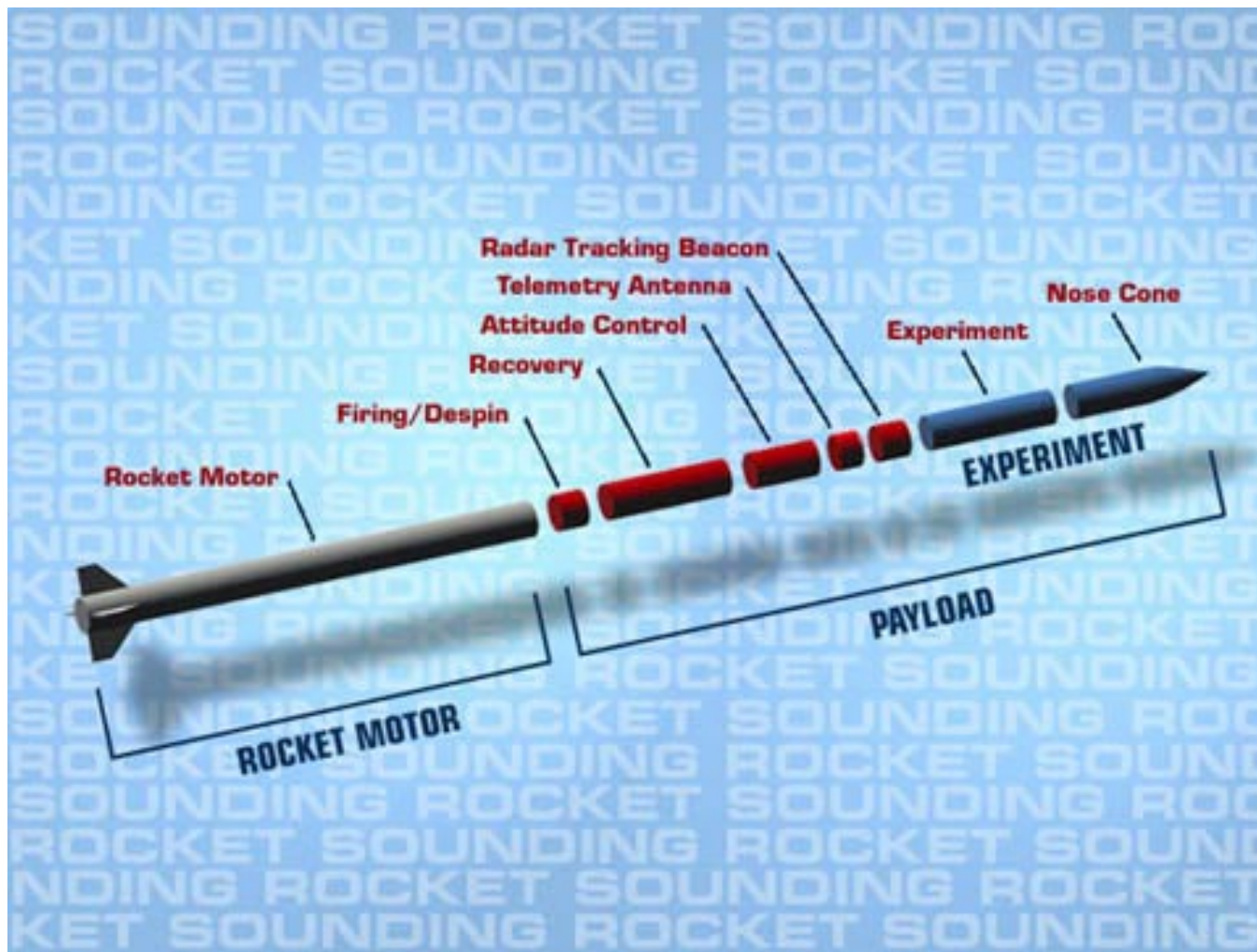


Alternatives to space (sort of) – sounding rockets #3

- Sounding rockets
 - Advantages:
 - Access to true space
 - Less expensive than satellite
 - Retrievable (recycle payload)
 - Disadvantages:
 - Short flight duration (5-10 minutes)
 - Components must be space qualified (expensive)
 - Small payloads

Alternatives to space (sort of) – sounding rockets #3

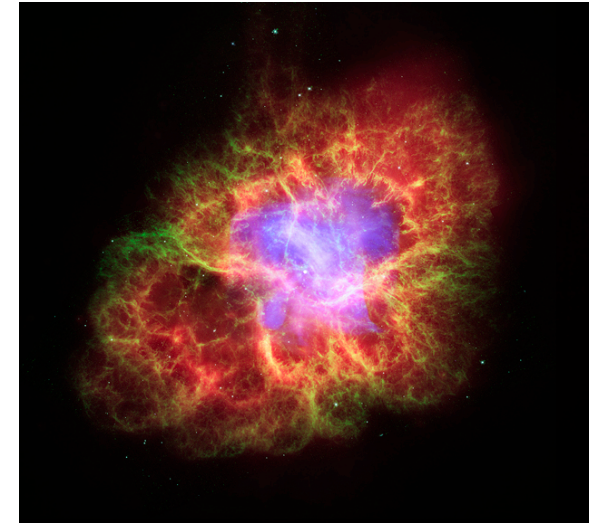
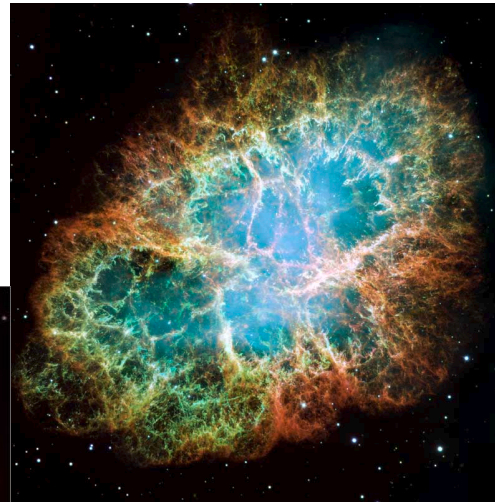
Early X-ray and UV astronomy, ionosphere, atmosphere, aurora, etc



The best of the best – Satellites

Other wavelengths

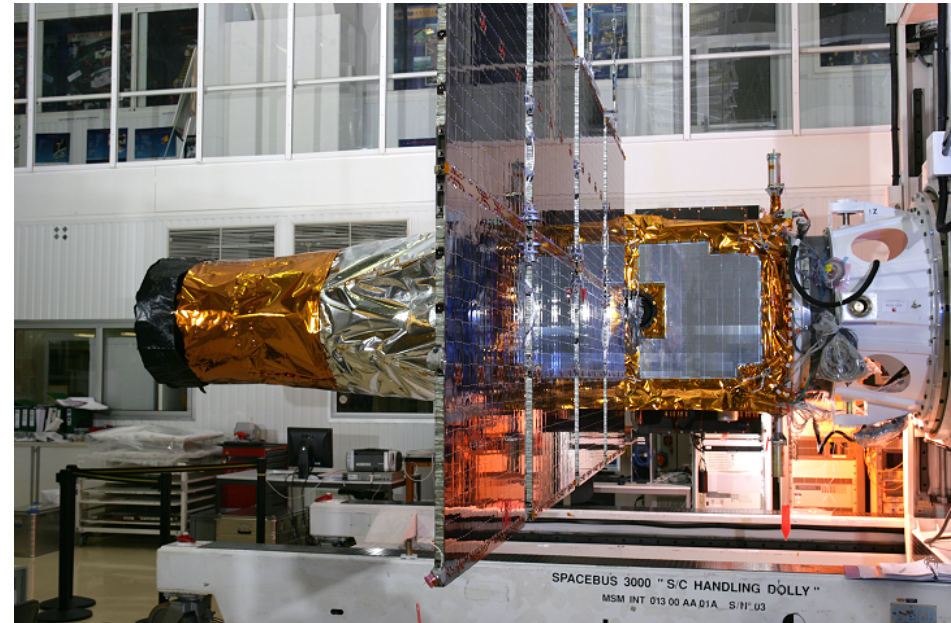
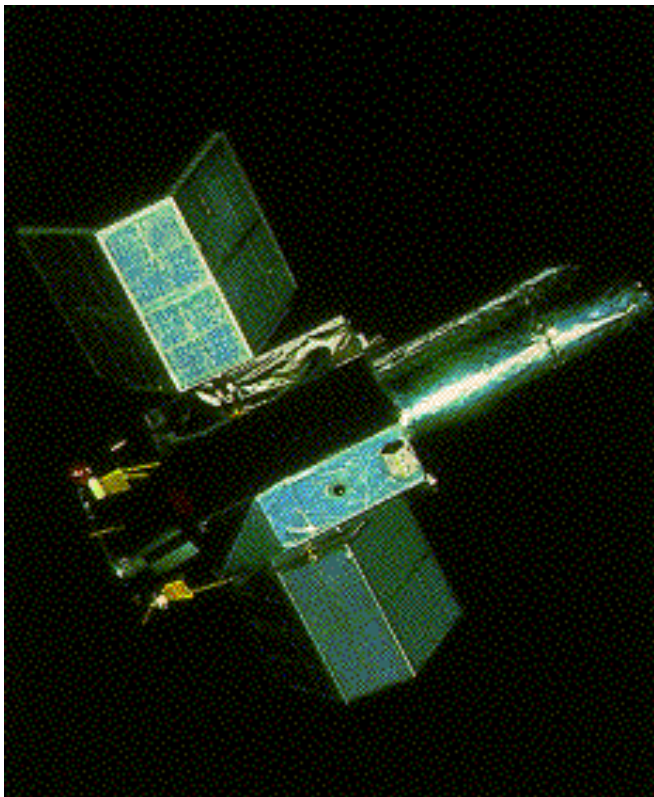
High spatial resolution



The best of the best – Satellites

High cadence

Long duration

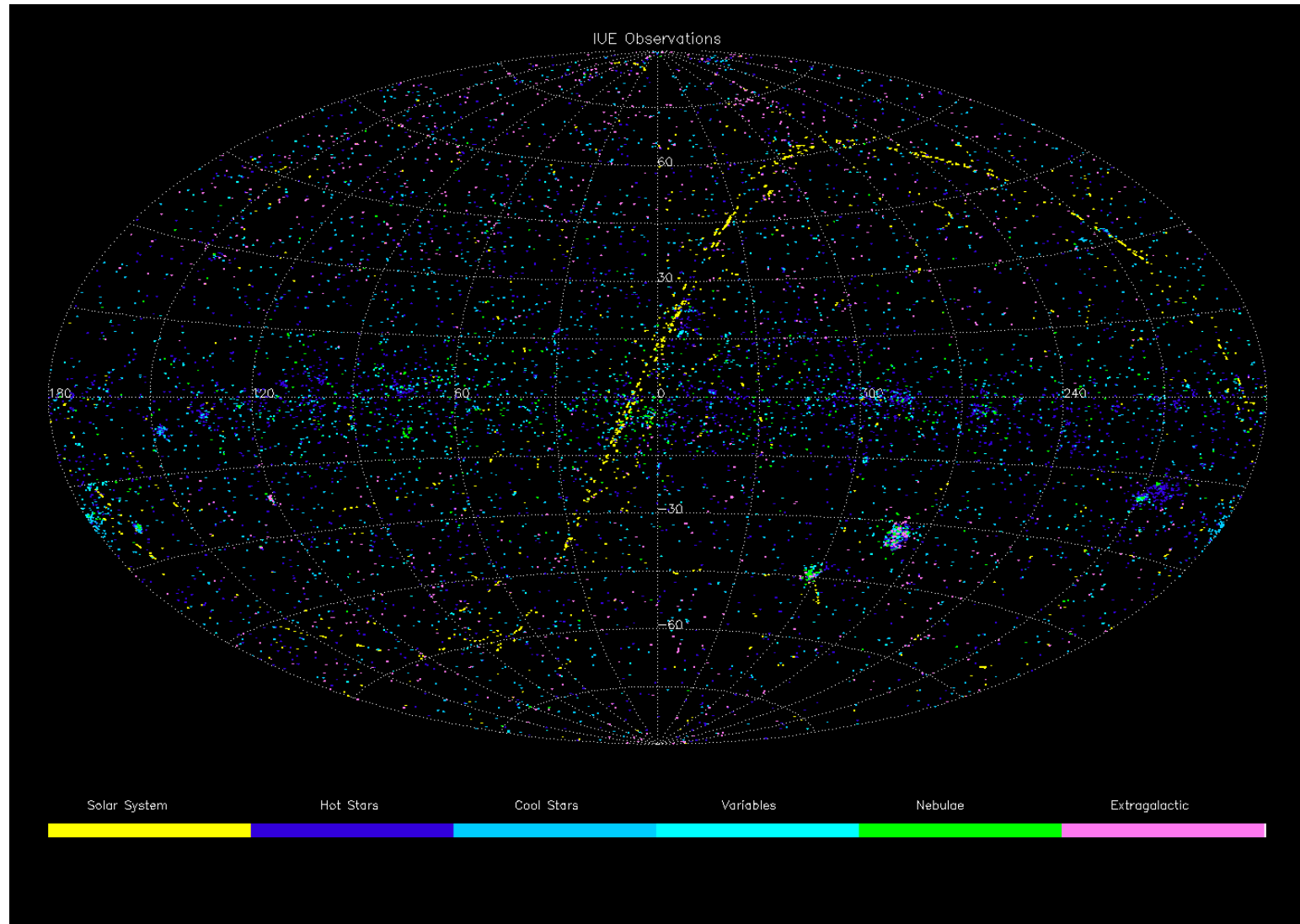


CoRoT: 95% cadence

IUE: Designed for 2 (5) years. Operated almost 19 years

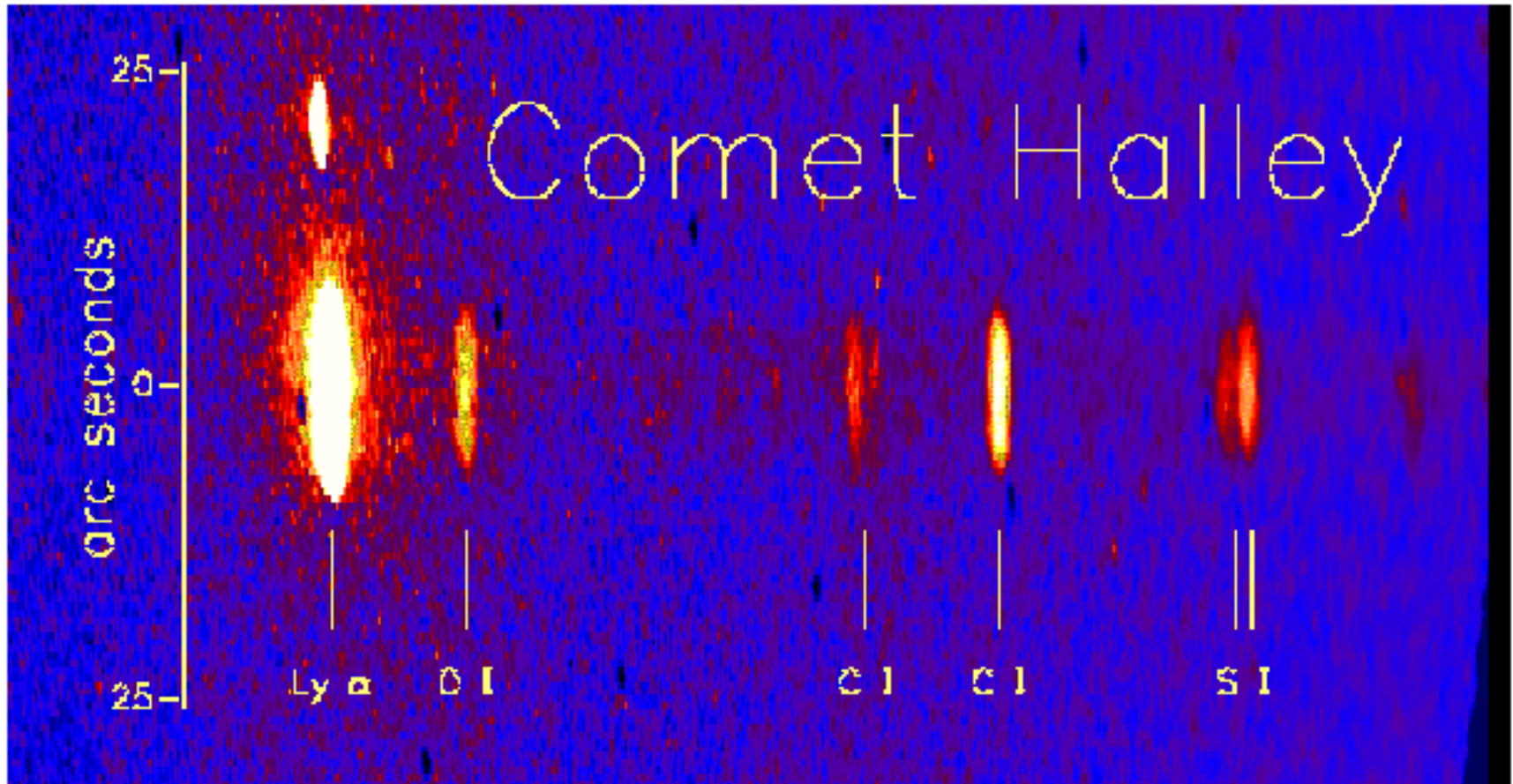
The best of the best – Satellites

IUE: observed targets



The best of the best – Satellites

IUE: observed targets



COROT, COncvection, ROtation & Transits exoplanétaires



NASA's Kepler mission



March 6, 2009



Why observe from space? Satellites

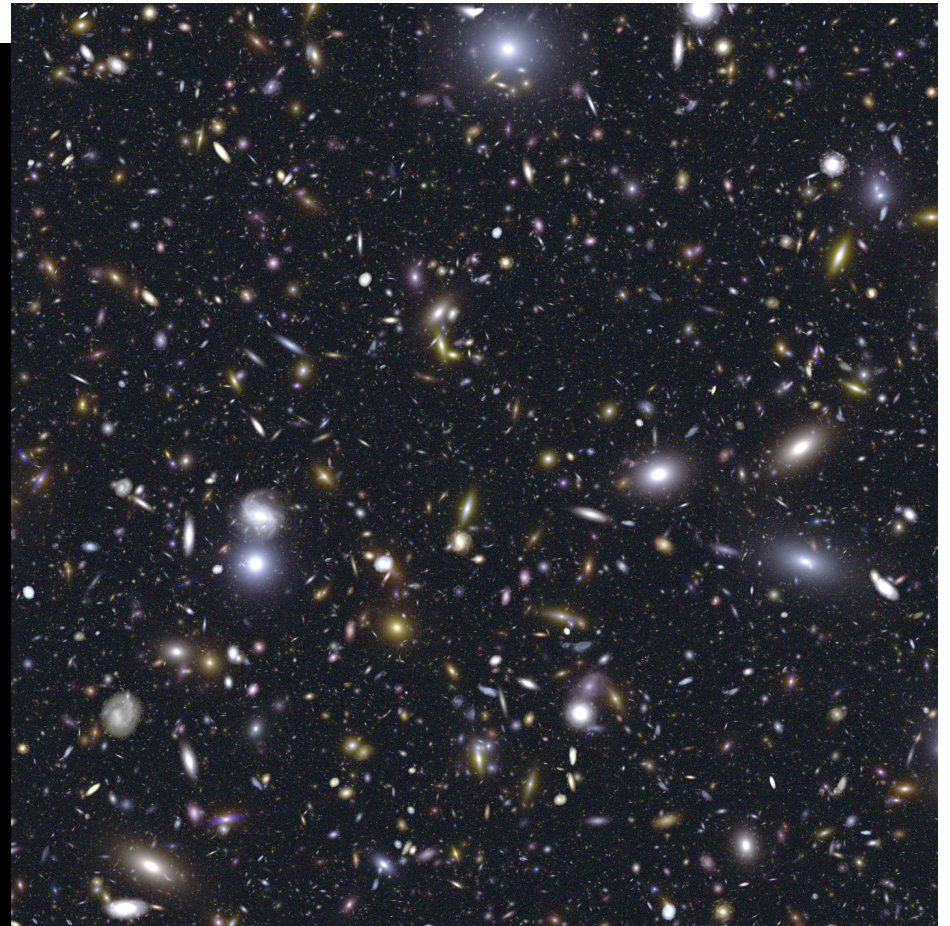
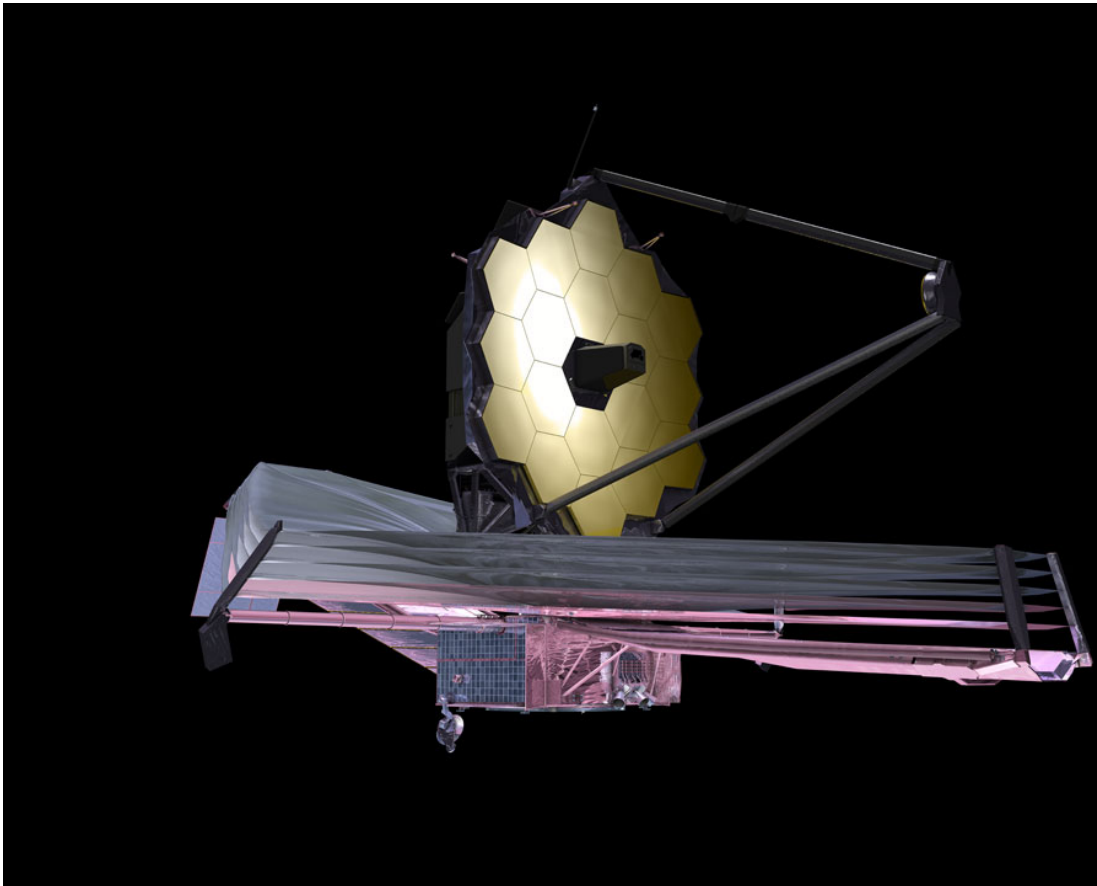
HST: Launched with shuttle 1990. 27 years of operations. There have been 5 service missions flown with the shuttle: Fundamental repairs, replacing instruments, etc

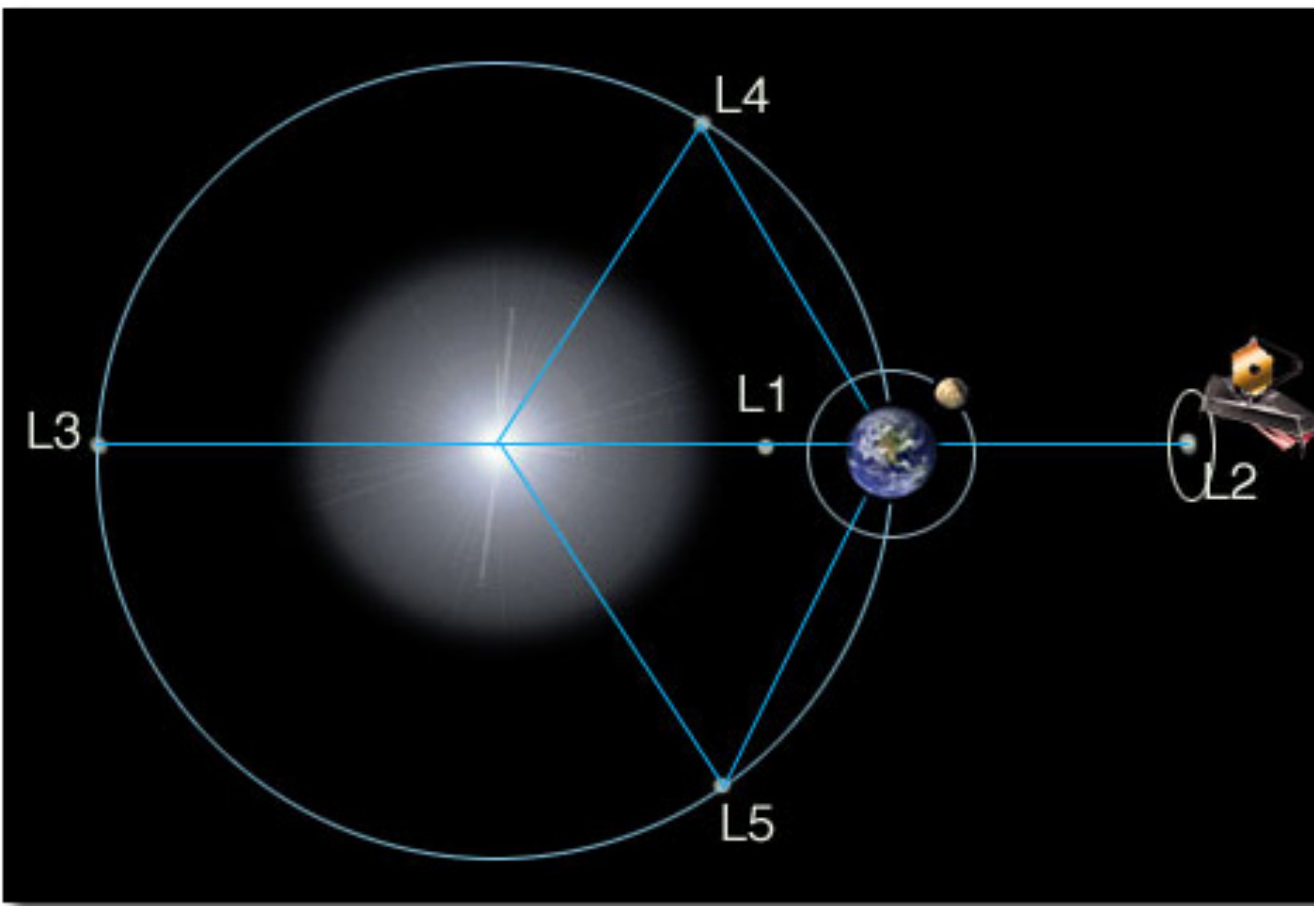
The cost has been – astronomical. Total cost since 1990 is ~17 to 20 G\$



Why observe from space? Satellites

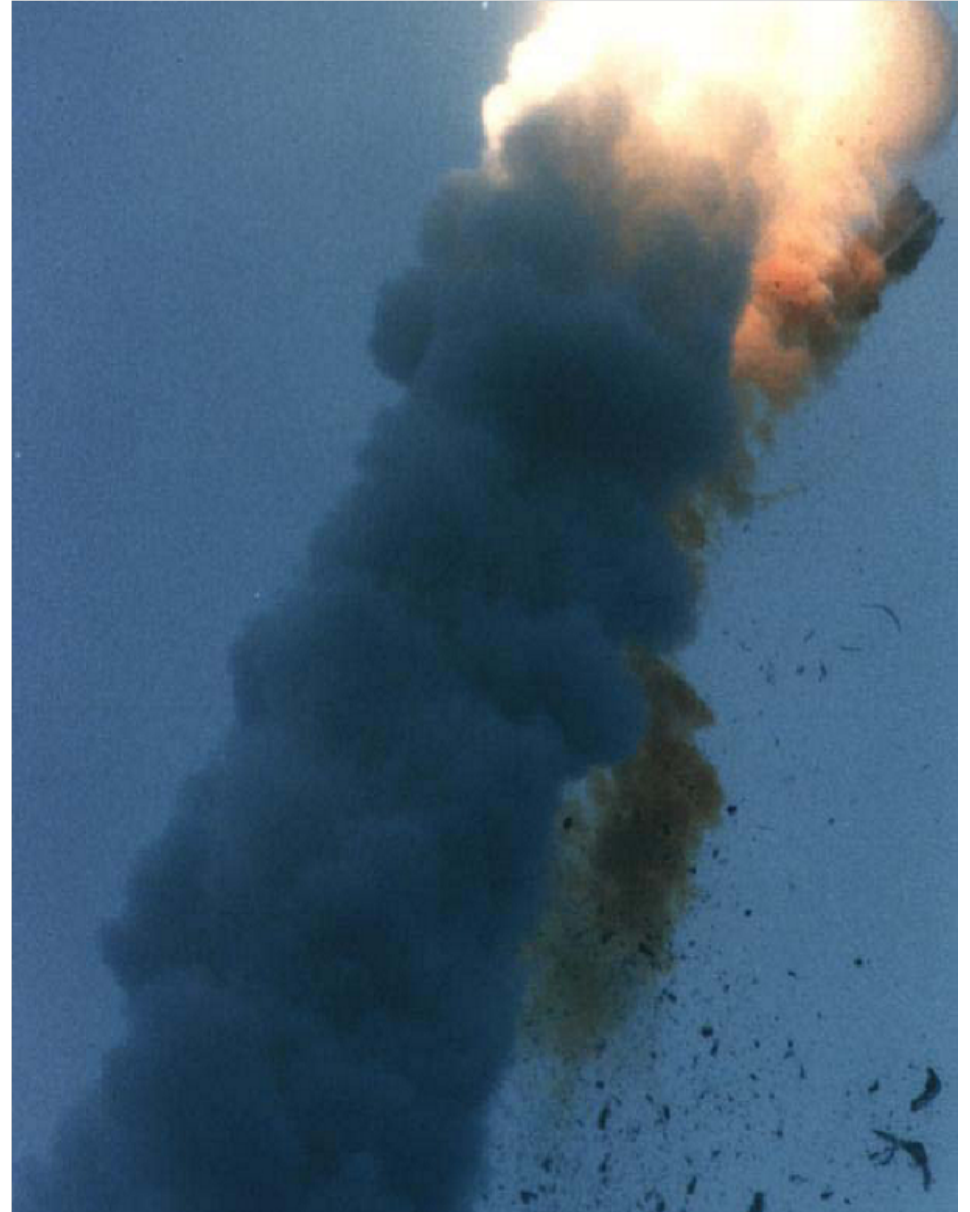
James Webb Space Telescope (JWST): Launch with Ariane 5
2018+. 25 years after HST. Currently no service missions
planned no shuttle: So no fundamental repairs, replacing
instruments, etc, Cost > 8.5G\$!!!! ...and its 2019



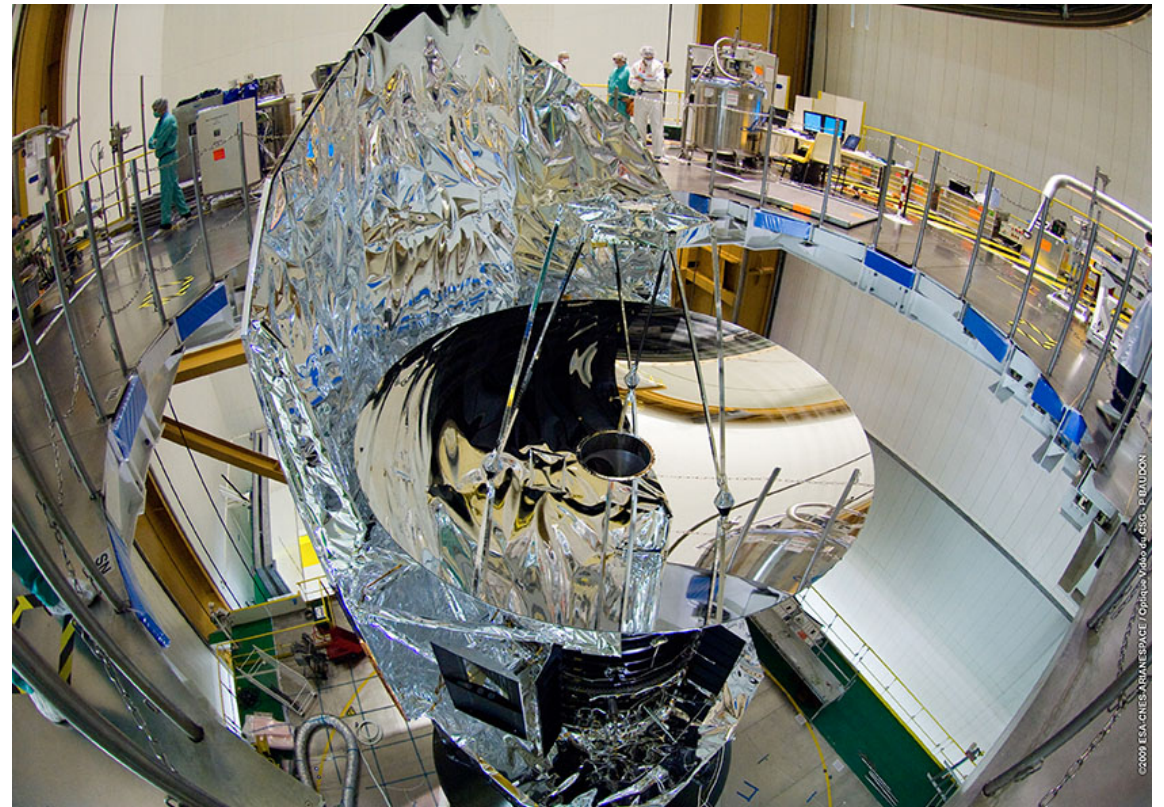


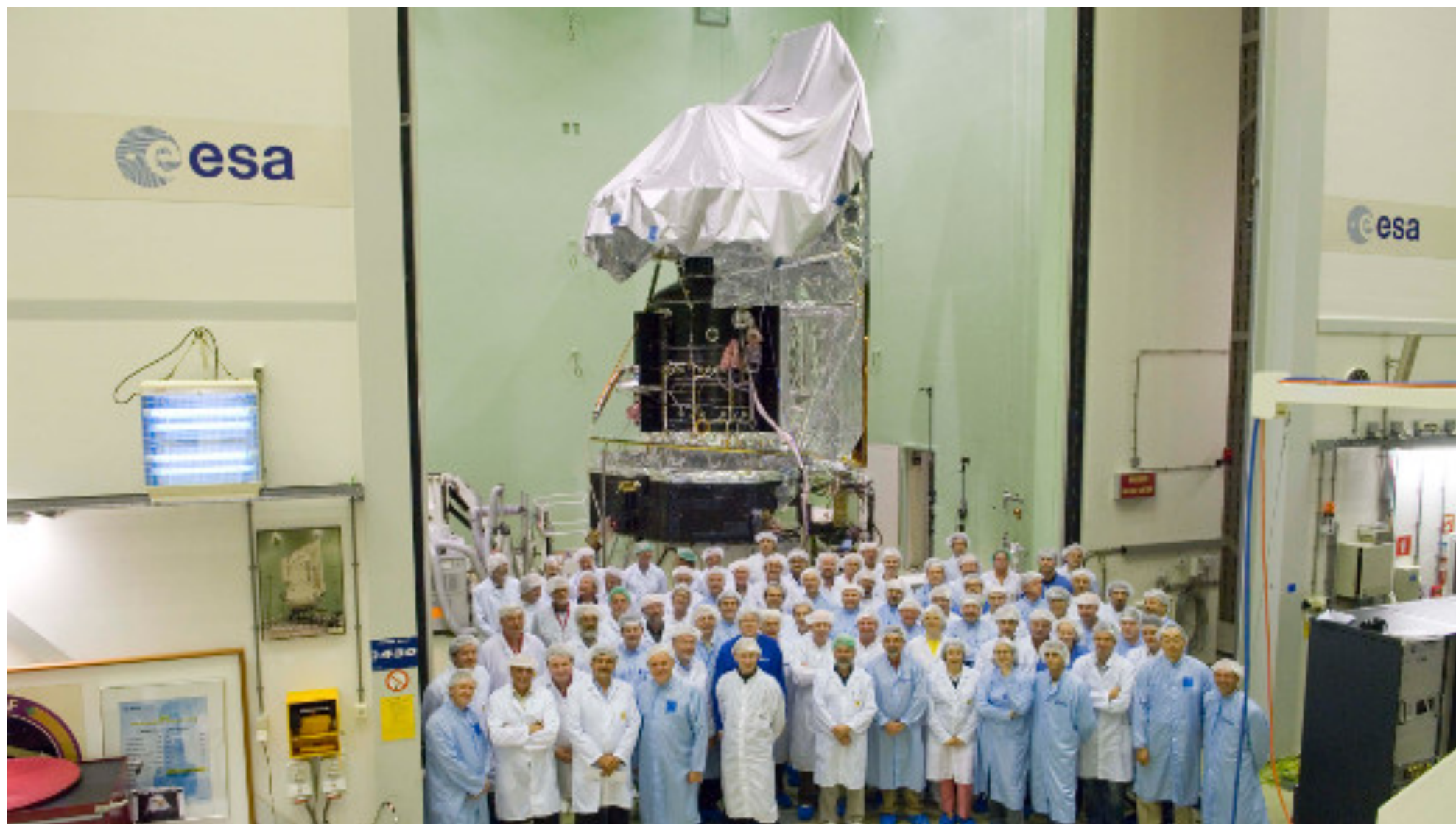
Use the most suitable orbit that is affordable!

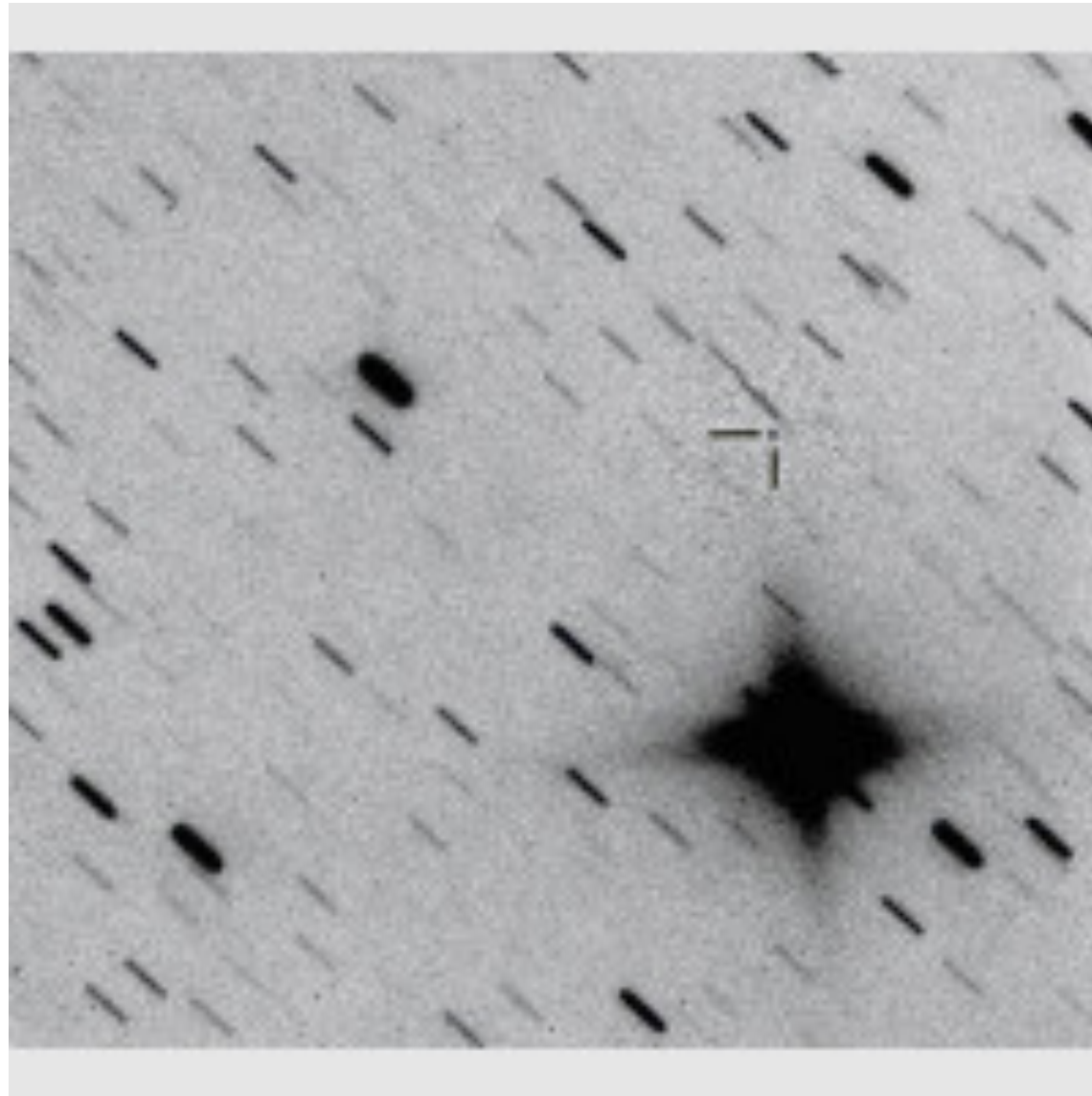
The risk with all space projects

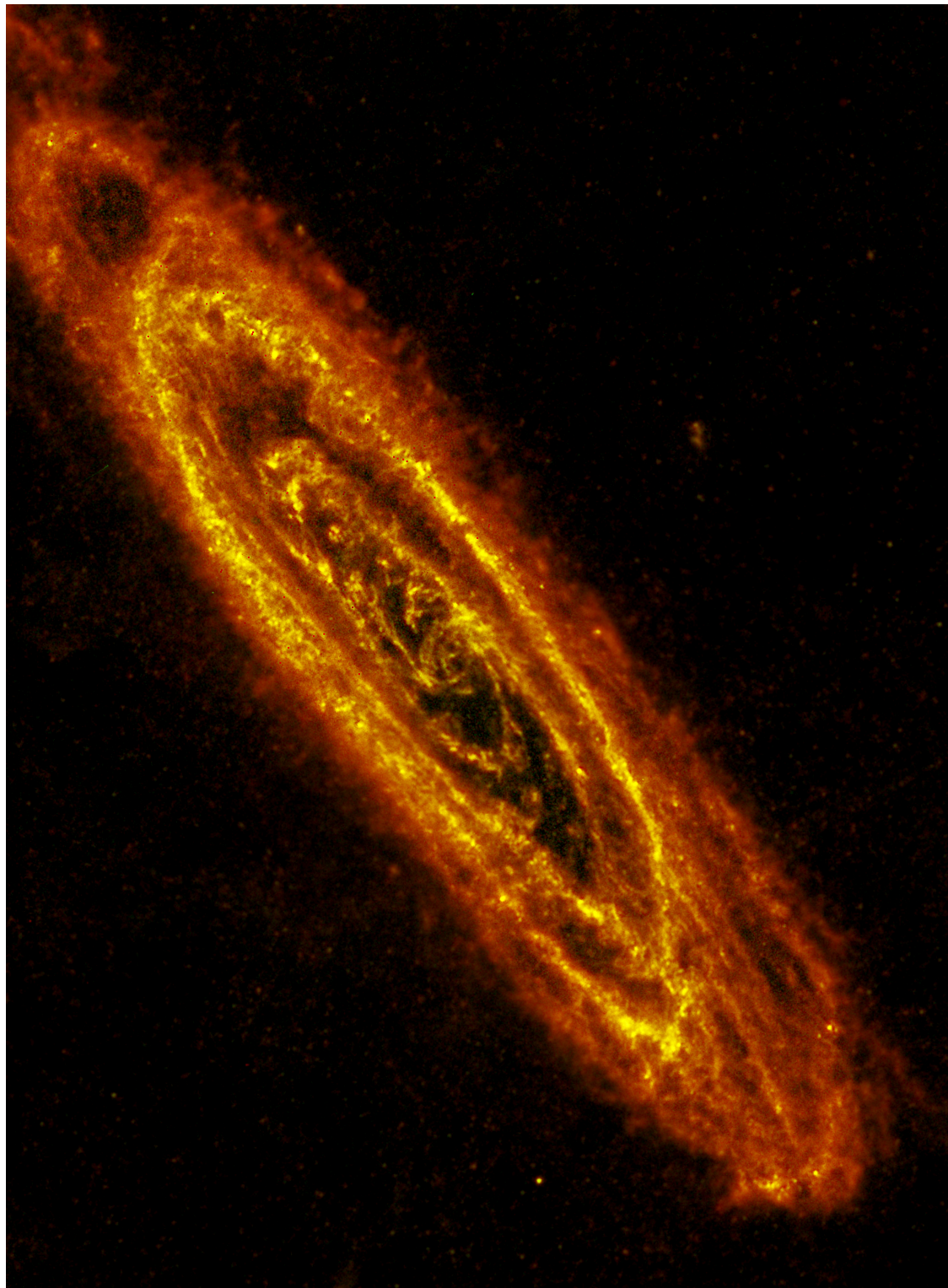


Usually things go well – after 20 years a successful launch and then operations







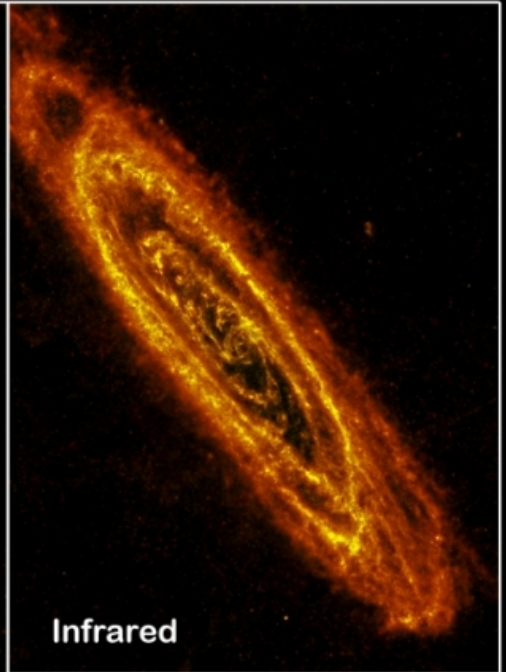




Optical



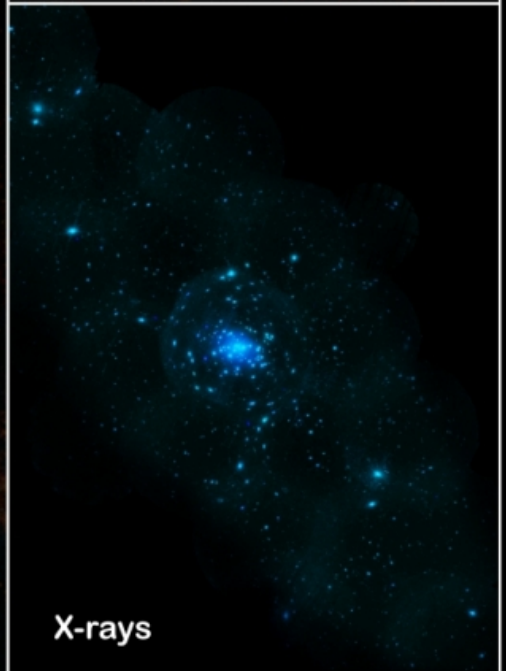
Infrared & X-rays



Infrared

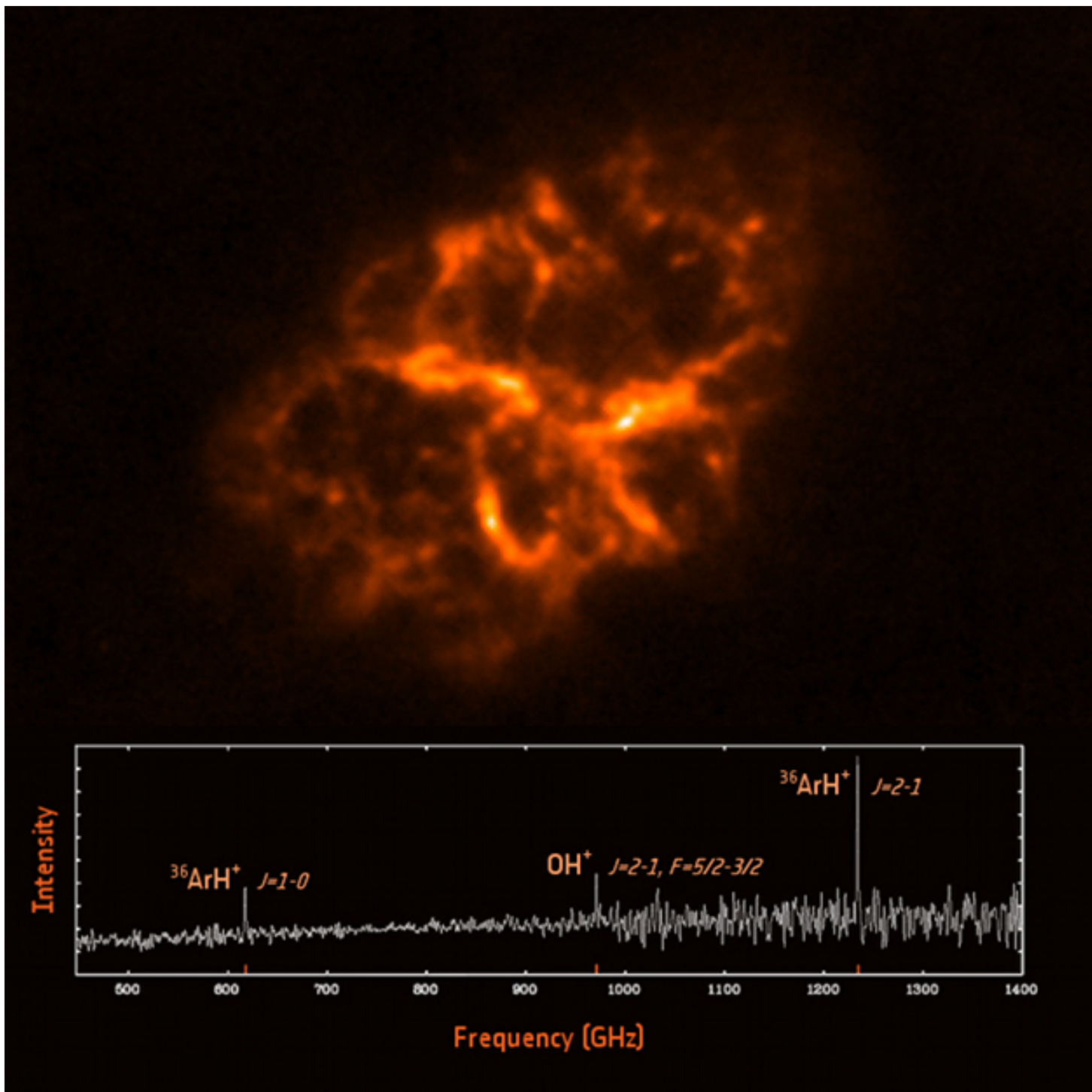


Composite

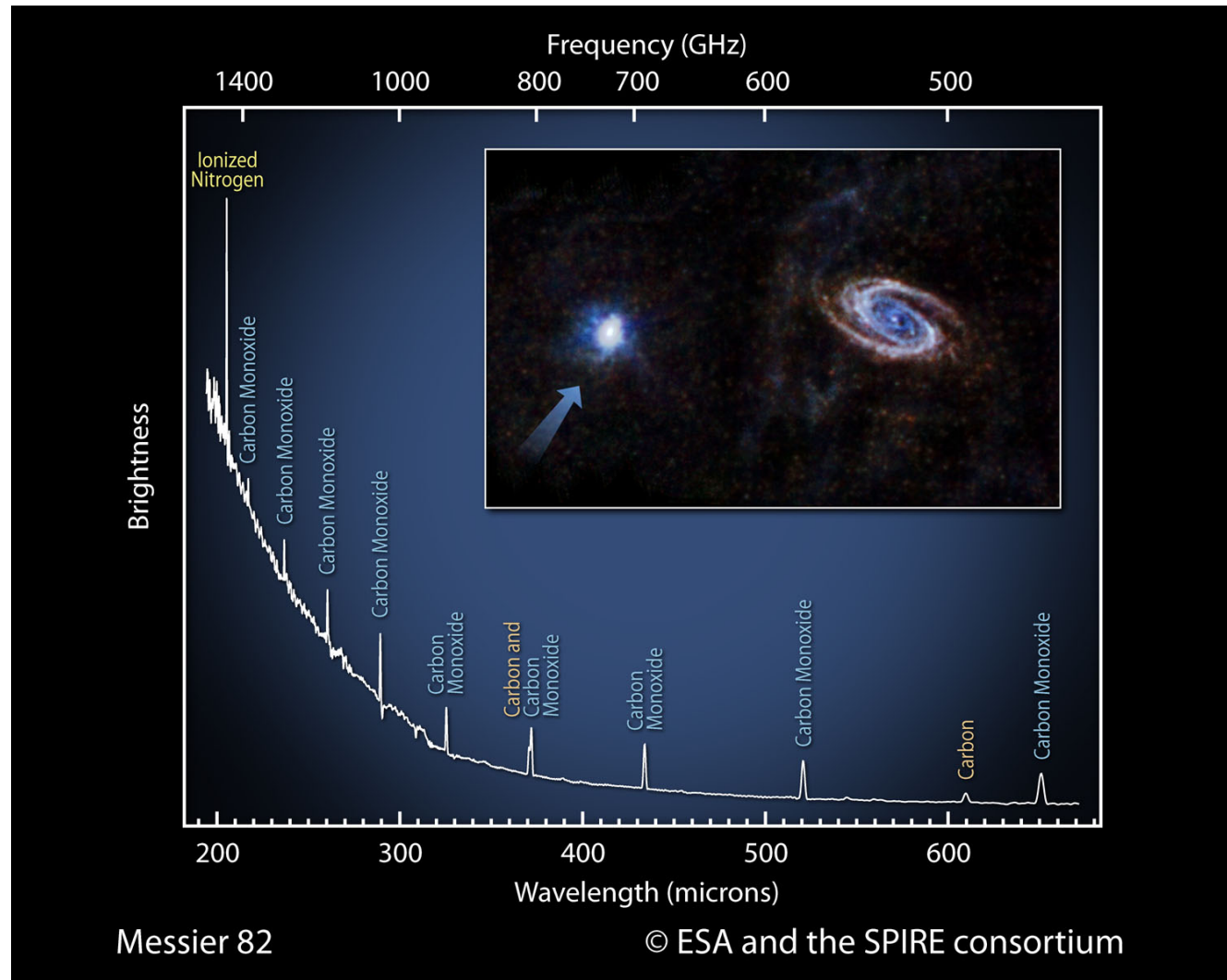


X-rays





The SPIRE spectrum of M82. The accompanying image is a spectacular three-colour composite picture of the M81 and M82 pair of galaxies made with the SPIRE camera. Now is this what you expected 20 years ago?





PLANCK

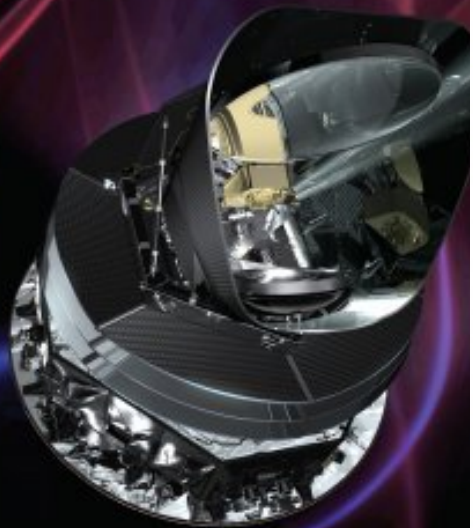
Looking back to the dawn of time



ESA's Planck telescope will look back to the dawn of time, close to the Big Bang, to observe the most ancient radiation in the Universe. The Cosmic Microwave Background (CMB) is the radiant heat left over from the initial event that scientists believe created the Universe we see today. By measuring tiny temperature variations in the CMB, scientists hope to determine which theories on the birth and evolution of the Universe are correct.

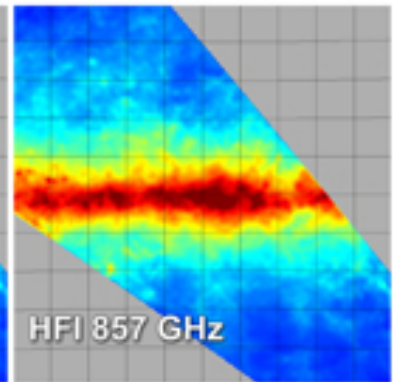
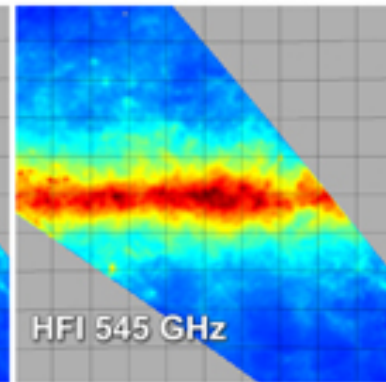
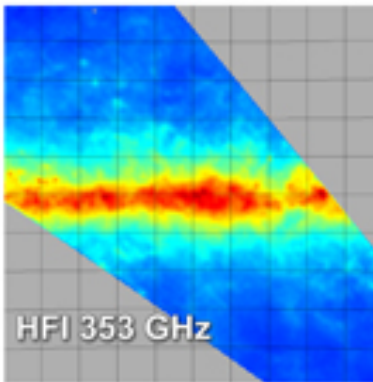
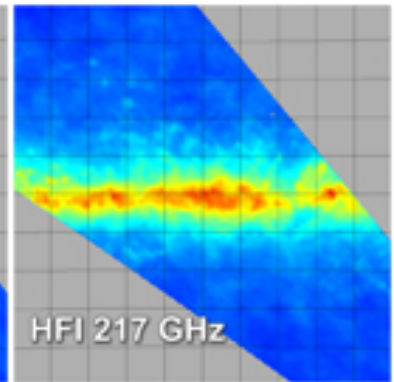
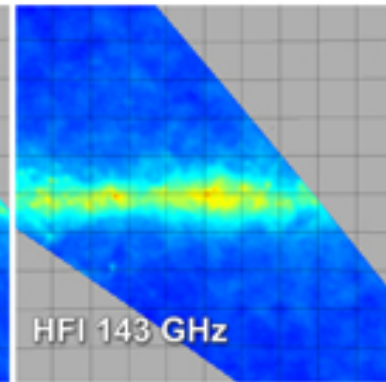
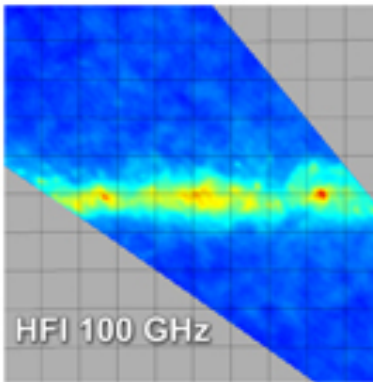
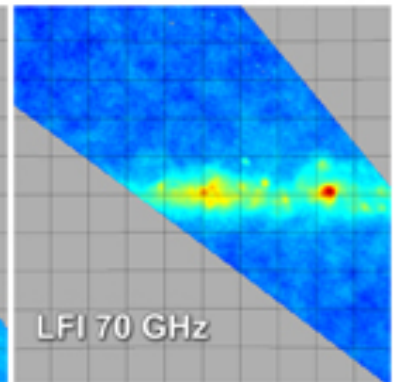
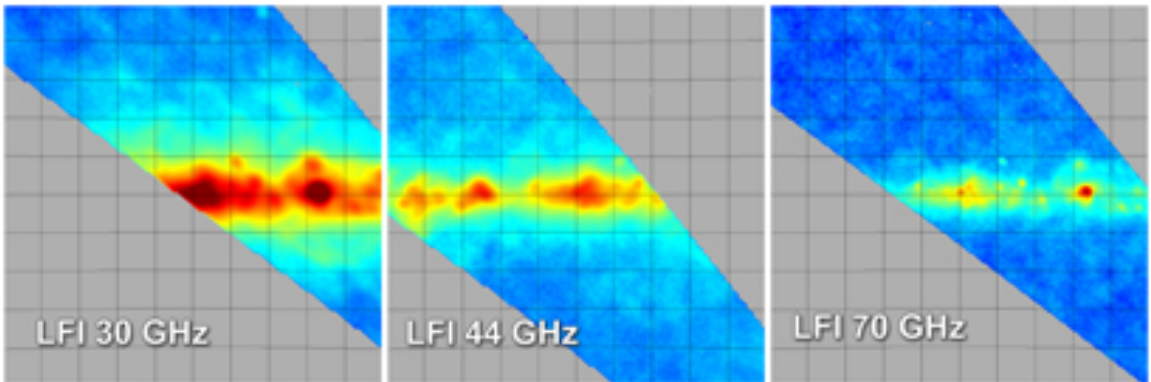
With these measurements, Planck can accurately measure all the basic parameters that characterise the structure and composition of our Universe. In so doing, it will provide the best ever constraints on some fundamental questions in cosmology:

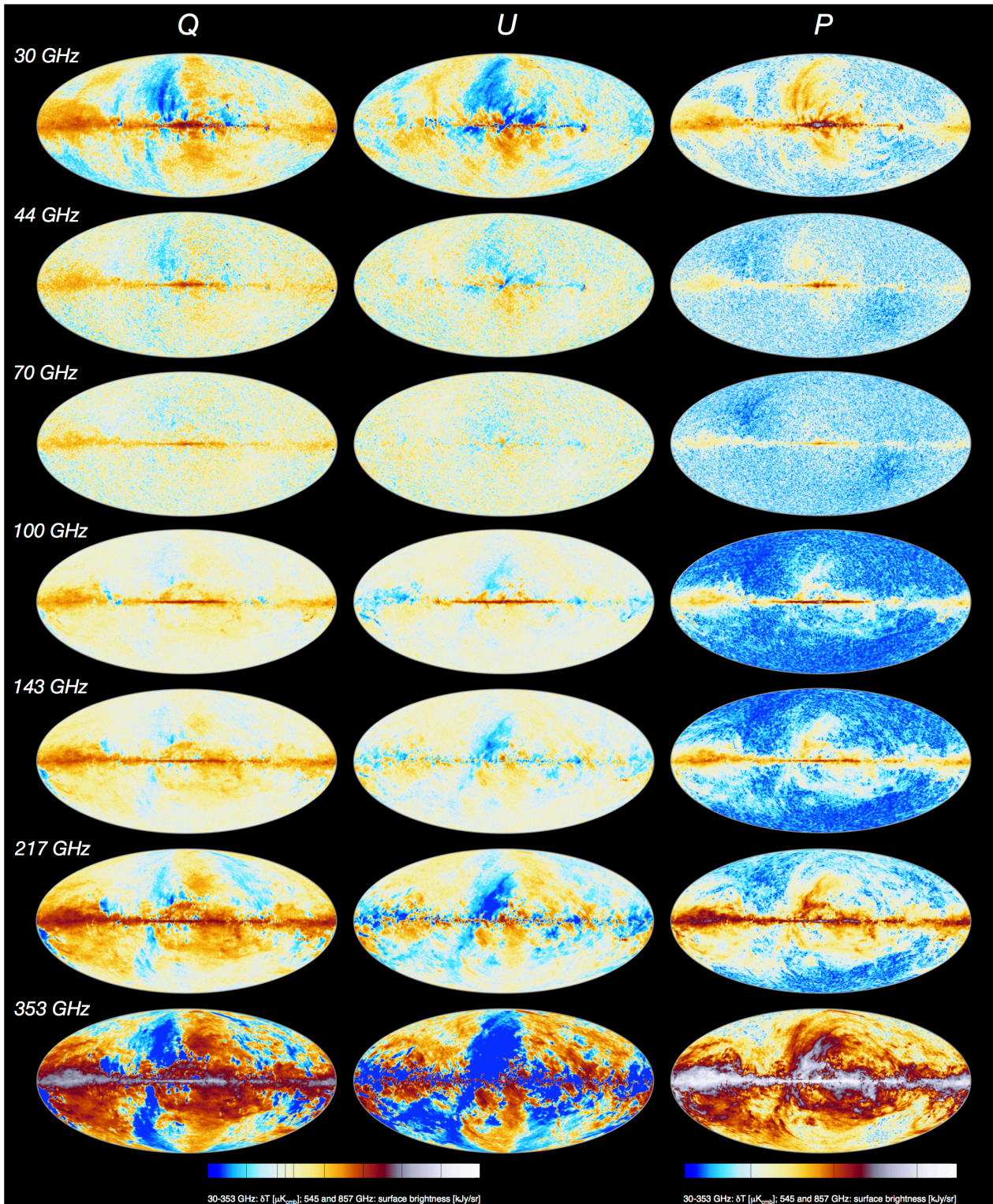
- How much dark matter exists? Dark matter is thought to represent 25% of the mass of the Universe - but it has never been directly detected.
- What is the nature of dark energy? Dark energy may account for 70% of the total energy in the Universe.
- Did inflation really occur? The early universe contained a period of rapid expansion that is believed to have shaped the Universe we see today.
- Do fundamental constants change with time?
- How did the luminous structures that we see today in the Universe, that is stars, galaxies, clusters of galaxies, form?

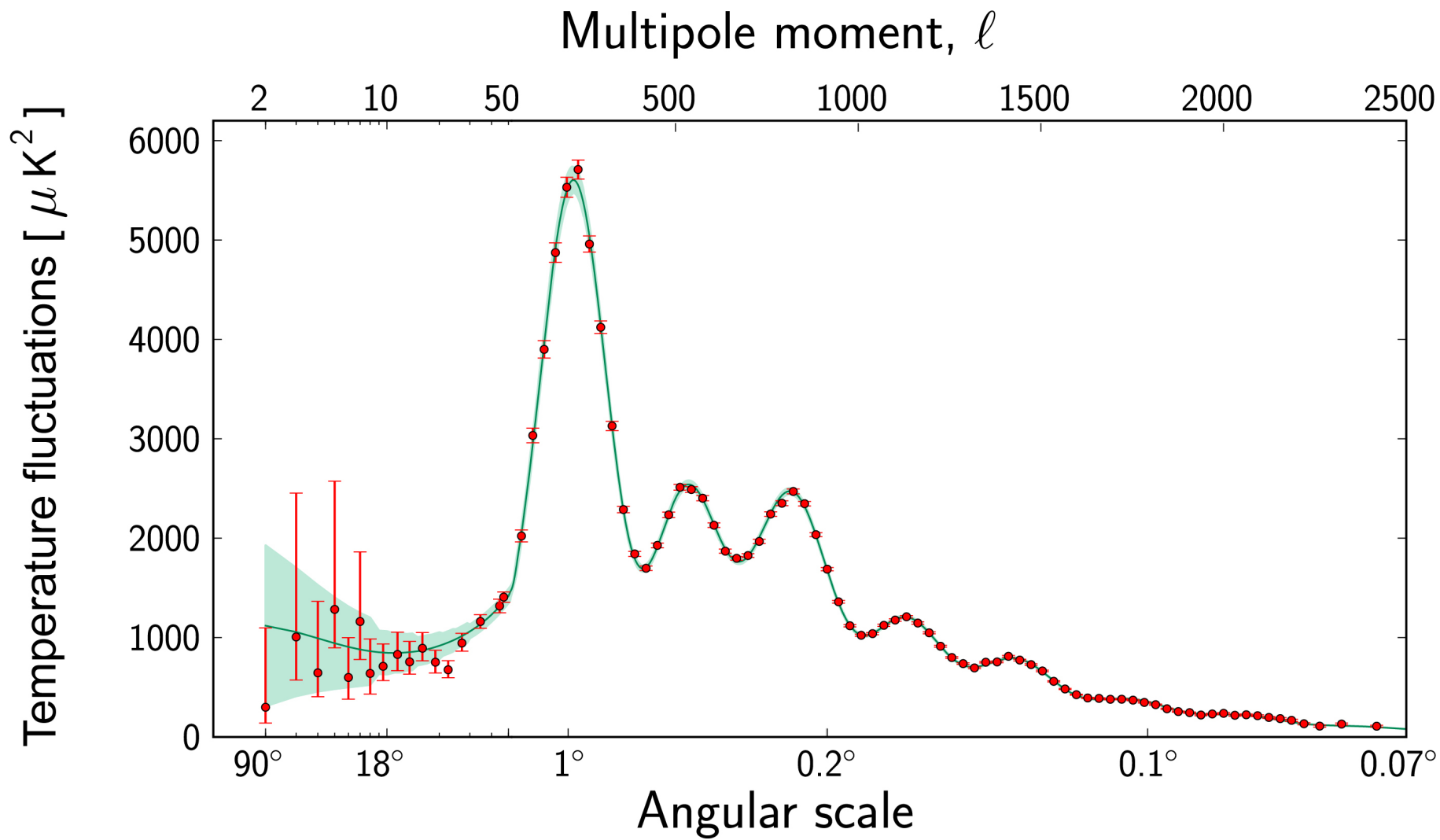


European Space Agency
Agence spatiale européenne

More information can be found on
<http://www.esa.int/missions/planck>



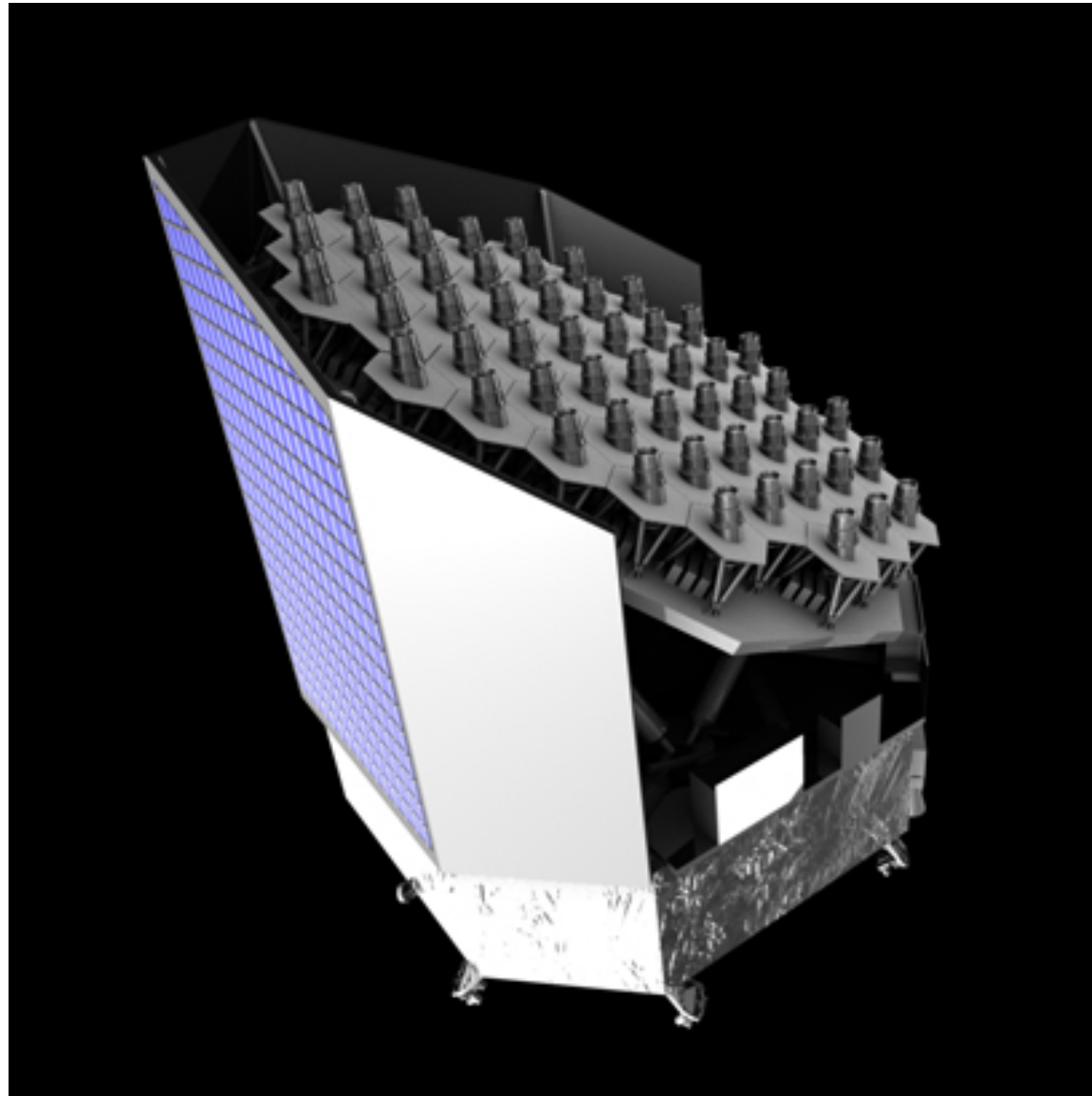




New challenges for space scientist

- Generally there are 2 major problems in Astrophysics
 - Are we alone in the Universe? Or: How unique is our Earth
 - The new physics, gravitational waves, dark energy and dark matter
- Major problems motivating major efforts
- Where are we today

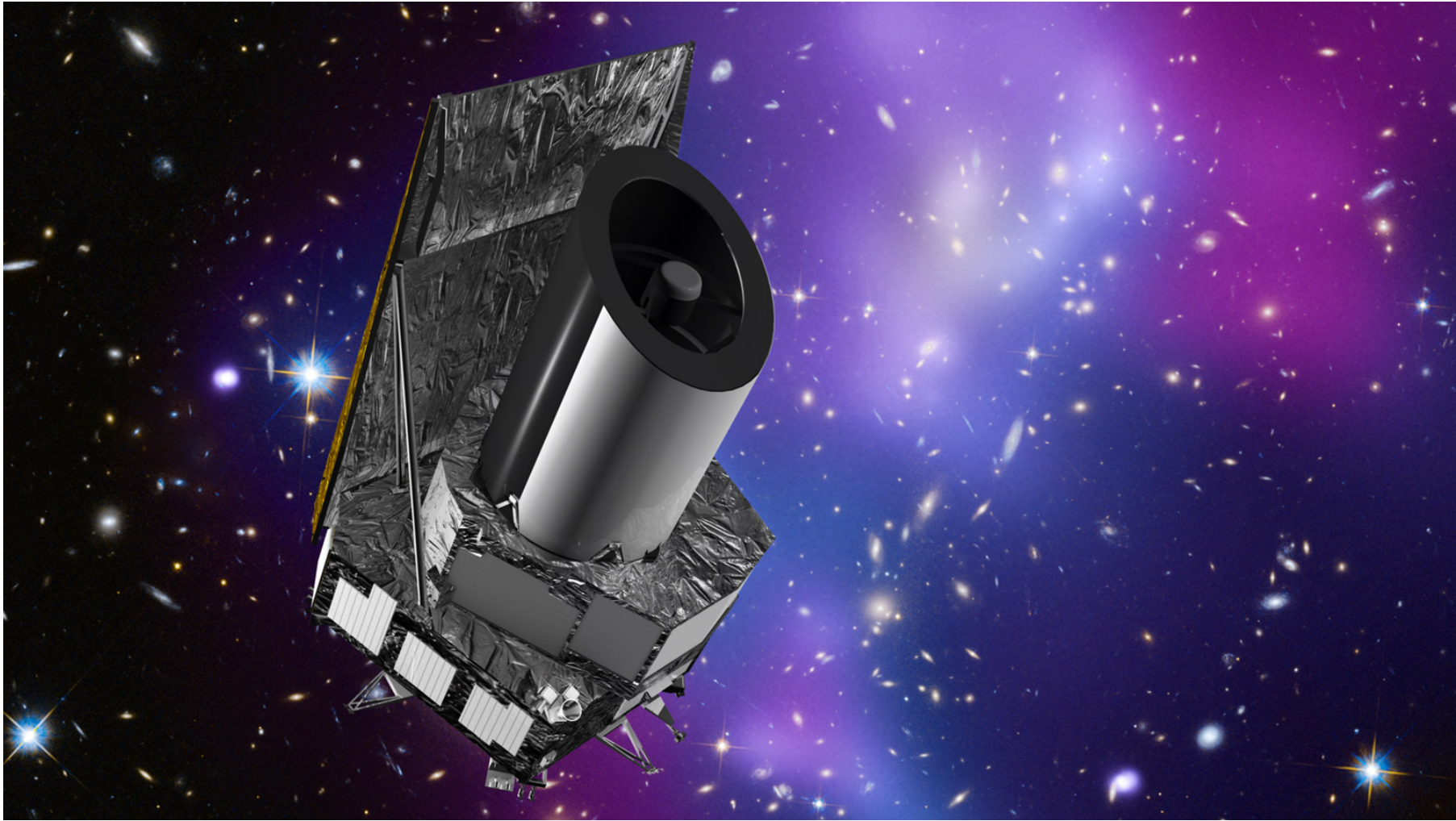
PLATO (2026 - 2033) - M3



Problem : The new physics

- EUCLID
 - Hyper sensitive cameras and spectrographs to study
 - Dark matter
 - Dark energy.
 - Two methods:
 - Study of gravitational lenses along line of sight to distant galaxies. This will trace dark matter and dark energy distribution
 - Baryonic Acoustical Oscillations which can be traced through the structure of galaxy clusters
 - This traces the expansion of the Universe and the effect of dark energy
- Euclid launch 2020

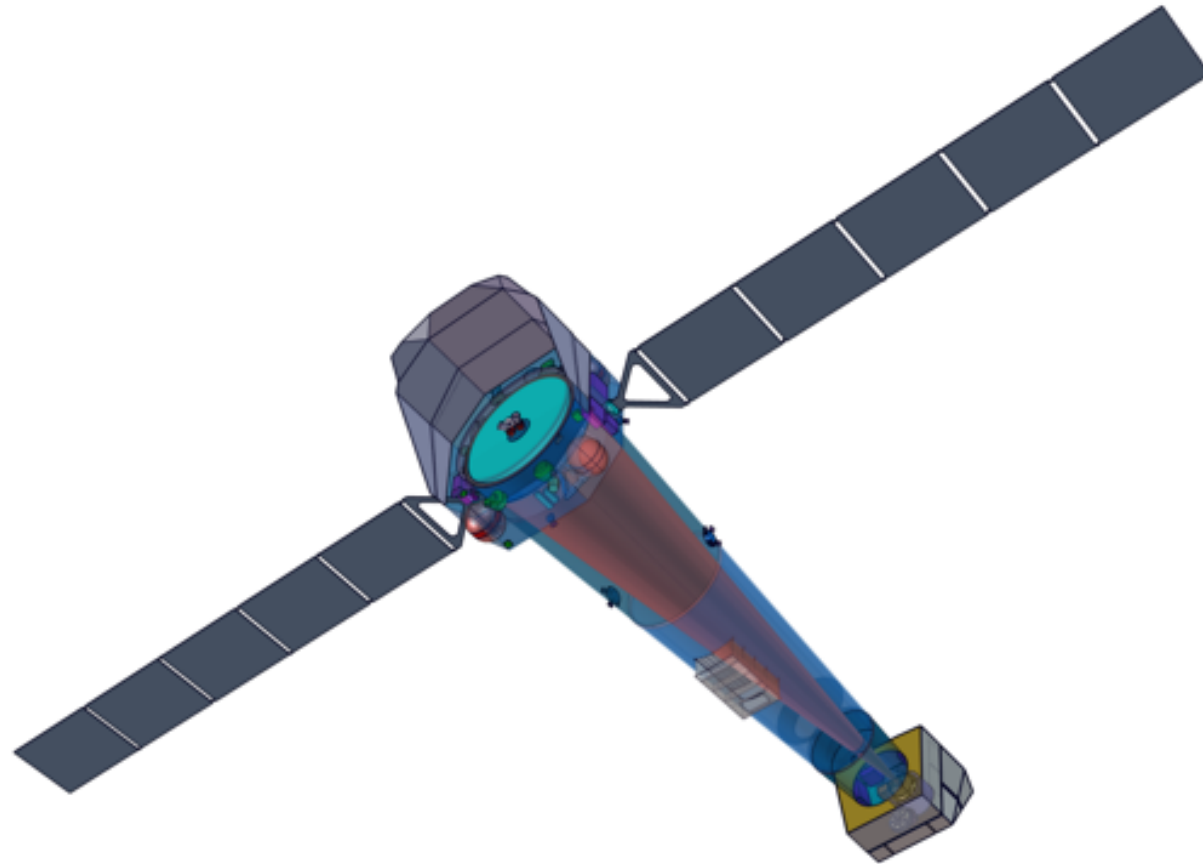
Euclid – M2



Athena – L2

Athena Advanced Telescope for High-ENERgy Astrophysics Spatially-resolved X-ray spectroscopy and deep, wide-field X-ray spectral imaging	
Cosmic Vision Themes	The Hot and Energetic Universe
Primary goals	Mapping hot gas structures and determining their physical properties Searching for supermassive black holes
Orbit	Halo orbit around L2, the second Lagrange point of the Sun-Earth system
Launch	2028
Lifetime	Five years, with possible five-year extension
Type	L-class mission

Athena – L2



Astronomy from Space

- The end of lesson 1