

Polar Trench

# A?

Aalto University  
School of Electrical  
Engineering

Superlaser  
Focus Lens

Ion Drive  
Arrays

Quadanium Steel  
Outer Hull

Hangar Bay  
327

Equatorial  
Trench

City Sprawls

# Future missions

Space instrumentation, 29.10.2020

*Joni Tammi (joni.tammi@aalto.fi)*

*Aalto University Metsähovi Radio Observatory*

# This week's topics

## 1. Trends / aims / interests

What's currently going on with space telescopes

## 2. Near-future missions & plans

What's going to happen next

## 3. Far-future possibilities

Thinking outside the box

## 4. Group work

A closer look at a few interesting space observatories





# Some space observatories now and soon

+ e.g. RadioAstron

+ MIDEX/MO (2023),  
SMEX/MO (2025), etc.

■	Formulation
■	Implementation
■	Primary Ops
■	Extended Ops



Spitzer  
8/25/2003



Kepler  
3/7/2009  
10/30/2018 EOM



WFIRST  
Mid 2020s



Euclid (ESA)  
2022



Webb  
2021



Chandra  
7/23/1999



XMM-Newton (ESA)  
12/10/1999



TESS  
4/18/2018



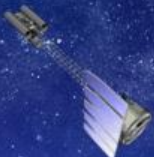
Swift  
11/20/2004



NuSTAR  
6/13/2012



Fermi  
6/11/2008



IXPE  
2021



XRISM (XARM) (JAXA)  
2022



SPHEREx  
2023



Hubble  
4/24/1990



ISS-NICER  
6/3/2017  
ISS-CREAM  
8/14/2017  
2/15/2019 EOM



SOFIA  
Full Ops 5/2014



GUSTO  
2021

+ Athena (late 2020s),  
LISA (mid 2030s)

# What are we trying to see/do?

## Hot topics:

- Dark energy & cosmology
- Exoplanets & extraterrestrial life
- Gravitational astronomy

## Continuous improvement

- Sensitivity
- Resolution
- Coverage (time and sky-area)
- But: survey vs. observatory (Cf. Merja's lecture)

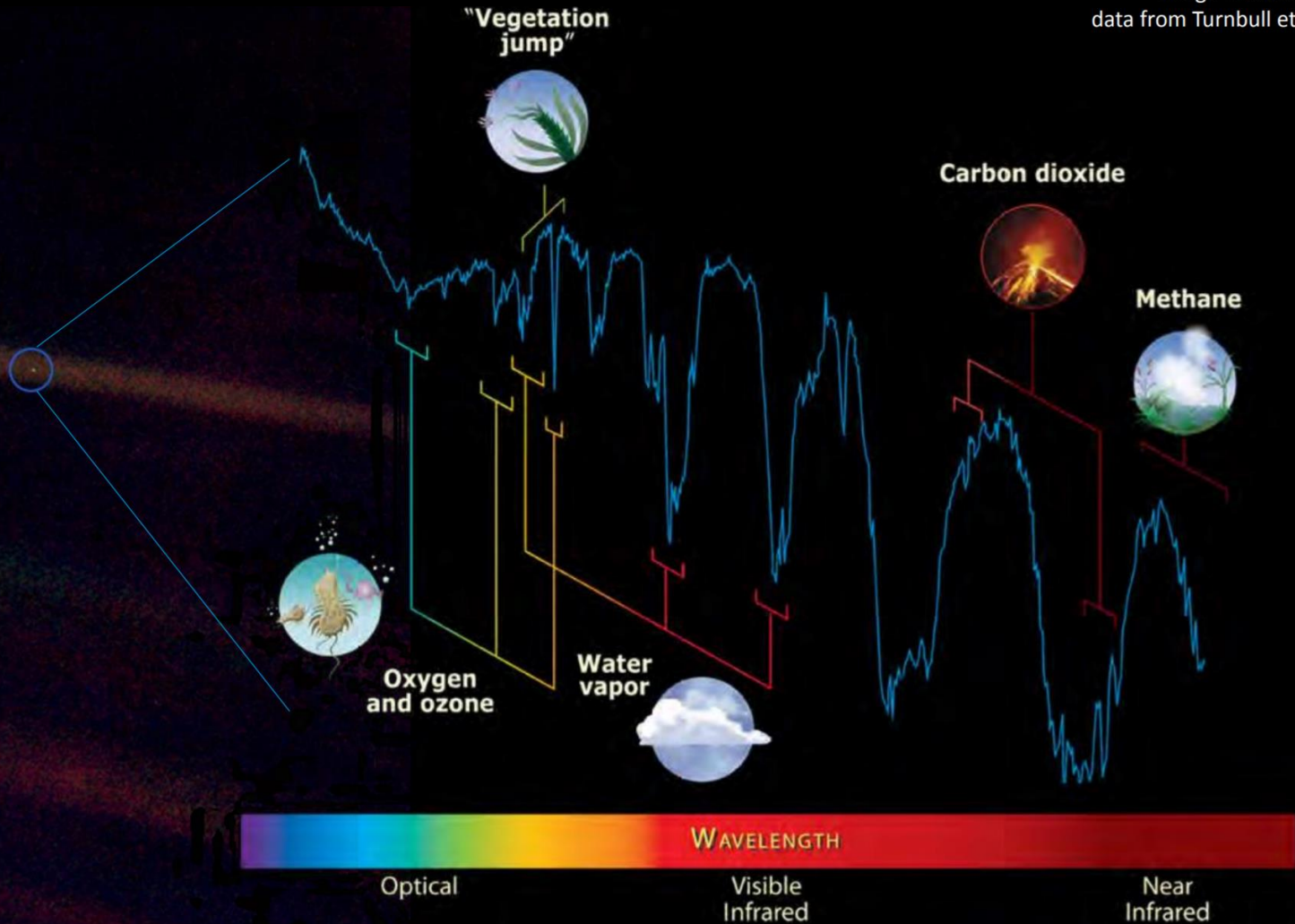
## New venues

- Gravitational waves
- Properties of exoplanets
  - *E.g. biomarkers in the atmosphere*
  - *Cf: 14.9.2020: "Possible Marker of Life Spotted on Venus"* <https://www.almaobservatory.org/en/press-releases/possible-marker-of-life-spotted-on-venus/>

# Example: Exoplanets

[https://sites.nationalacademies.org/cs/groups/ssbsite/documents/webpage/ssb\\_176470.pdf](https://sites.nationalacademies.org/cs/groups/ssbsite/documents/webpage/ssb_176470.pdf)

Image from STScI  
data from Turnbull et al.

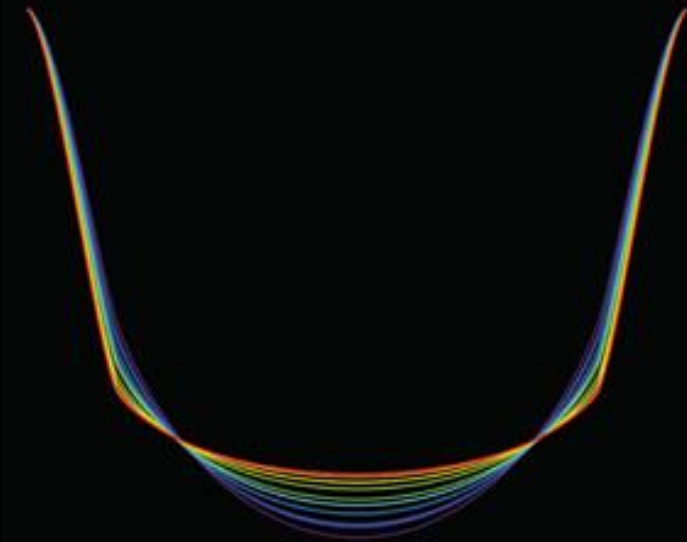
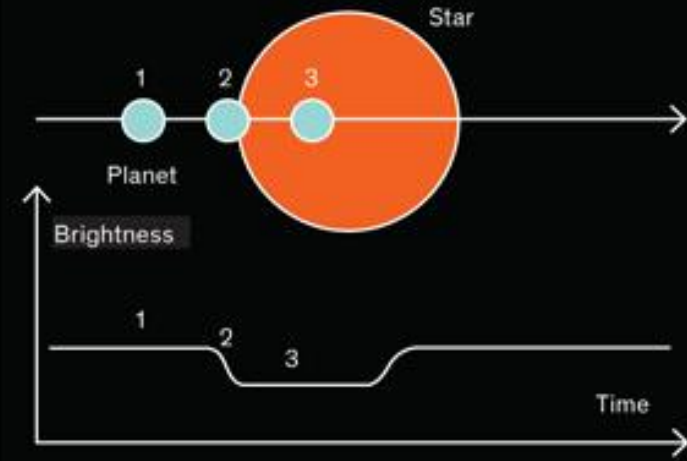





# Example: Exoplanets

## Transits

- One detection method
  - Dip in the total brightness
  - If the planet has atmosphere, it absorbs different amounts of the star's light at different wavelengths
- *differences in the observed light tell us about physical properties and composition.*

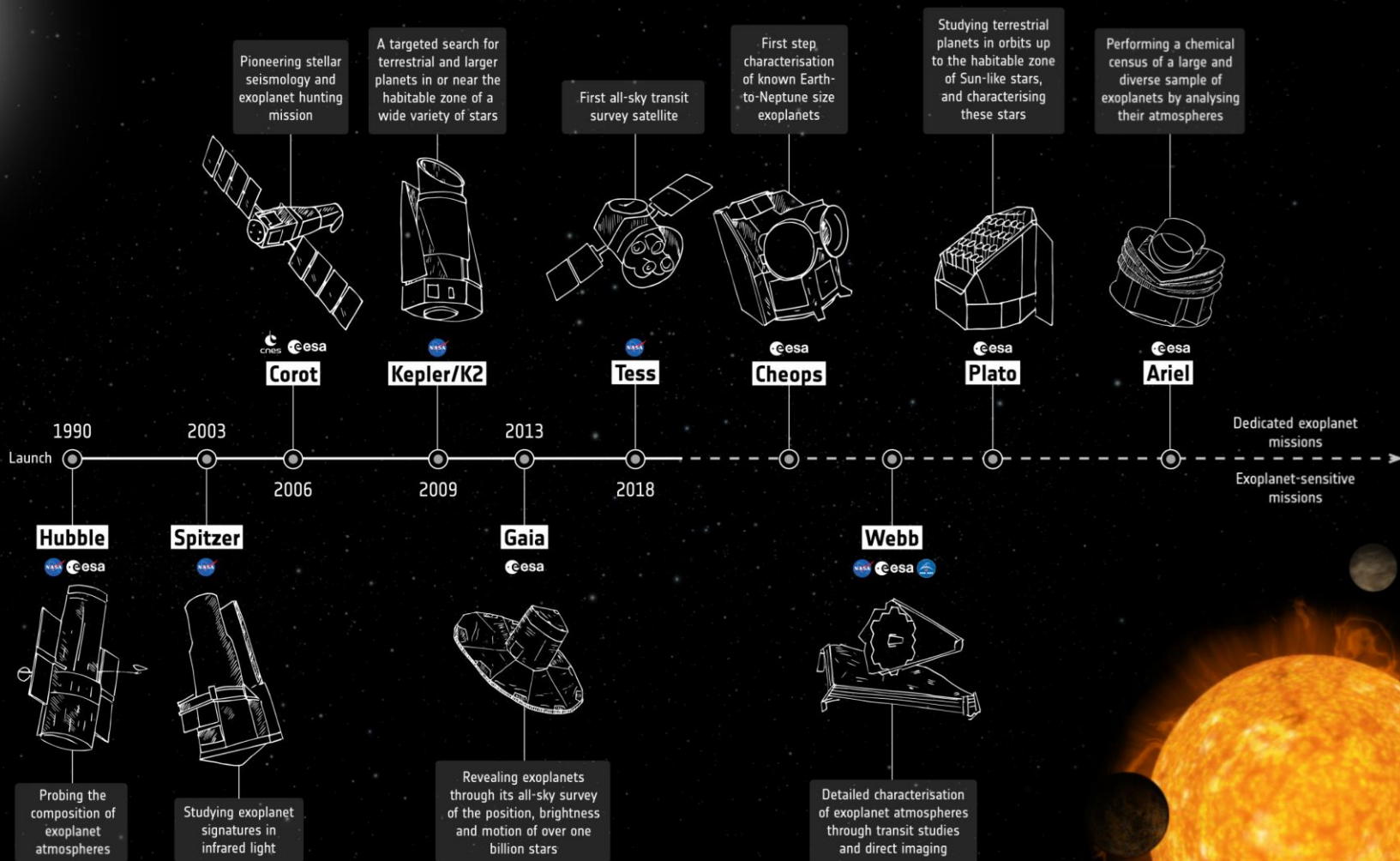


# Example: Exoplanets



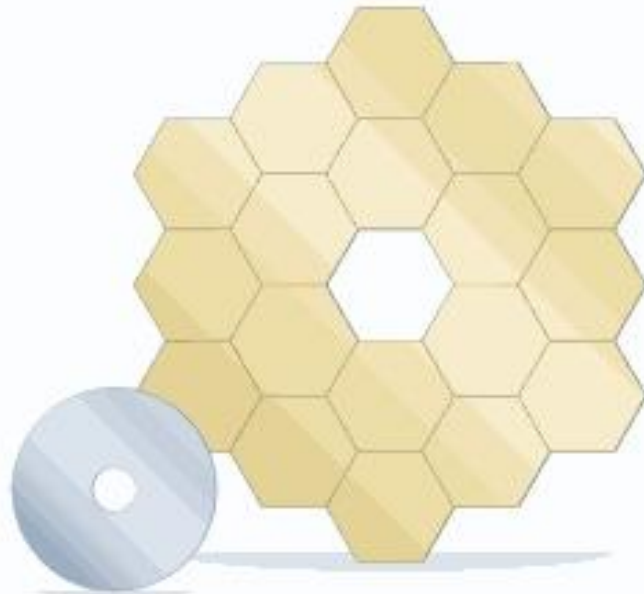
**Ground-based observatories**

First discoveries of exoplanets in the 1990s opened up the field of exoplanet research. New innovations and discoveries continue to this day

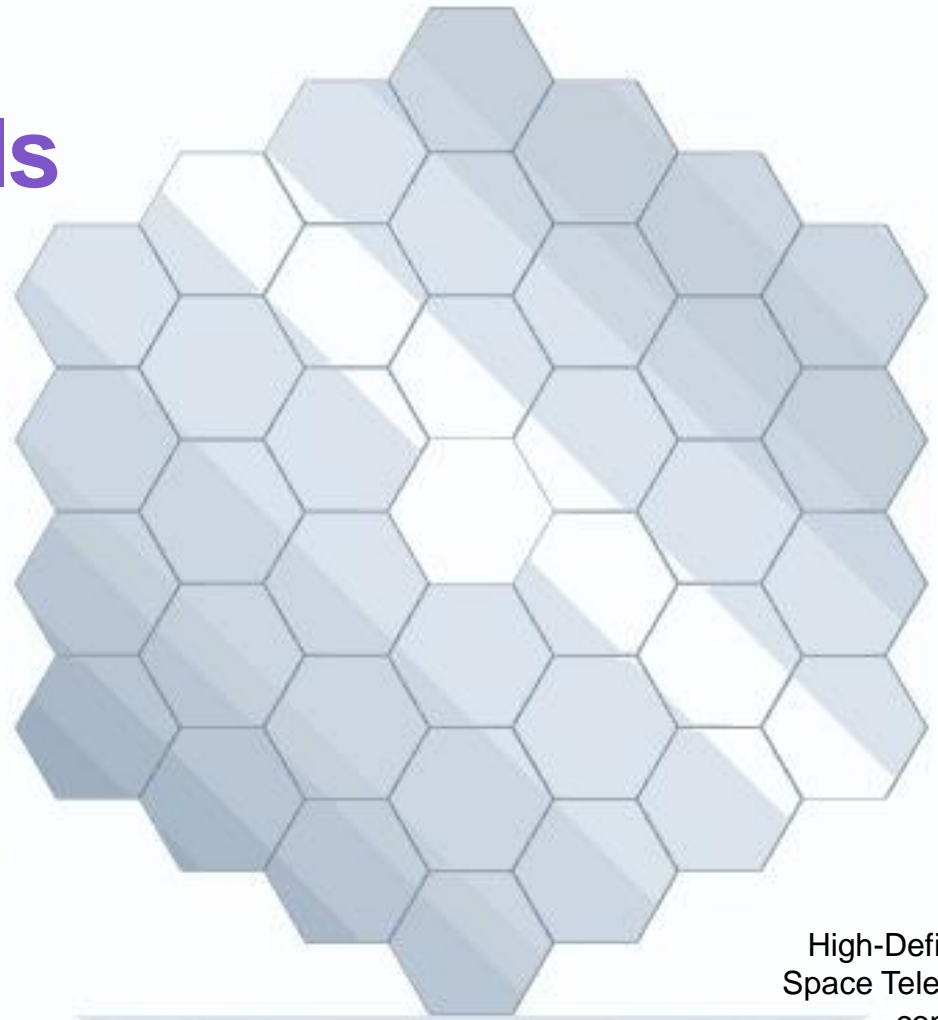


# Improvements / new solutions/tools

- **Just make things bigger**



*Hubble 2.4 m JWST 6.5 m*



*HDST 11.7 m*

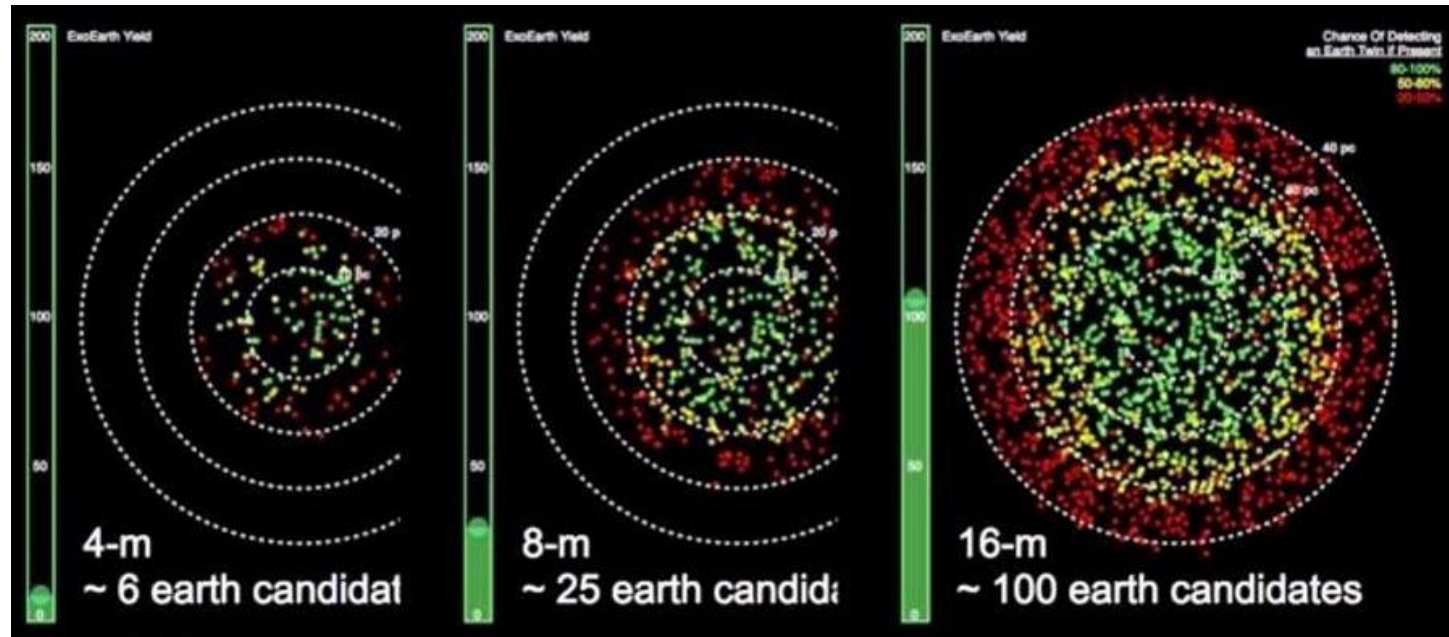
High-Definition  
Space Telescope  
concept:  
[www.hdstvision.org](http://www.hdstvision.org)



# Improvements / new solutions/tools

- **Just make things bigger**

ExoEarth  
candidates  
as function  
of aperture



[https://sites.nationalacademies.org/cs/groups/ssbsite/documents/webpage/ssb\\_176470.pdf](https://sites.nationalacademies.org/cs/groups/ssbsite/documents/webpage/ssb_176470.pdf)

# Improvements / new solutions/tools

- **Just make things bigger**
- **Improve quality / reduce disturbances**



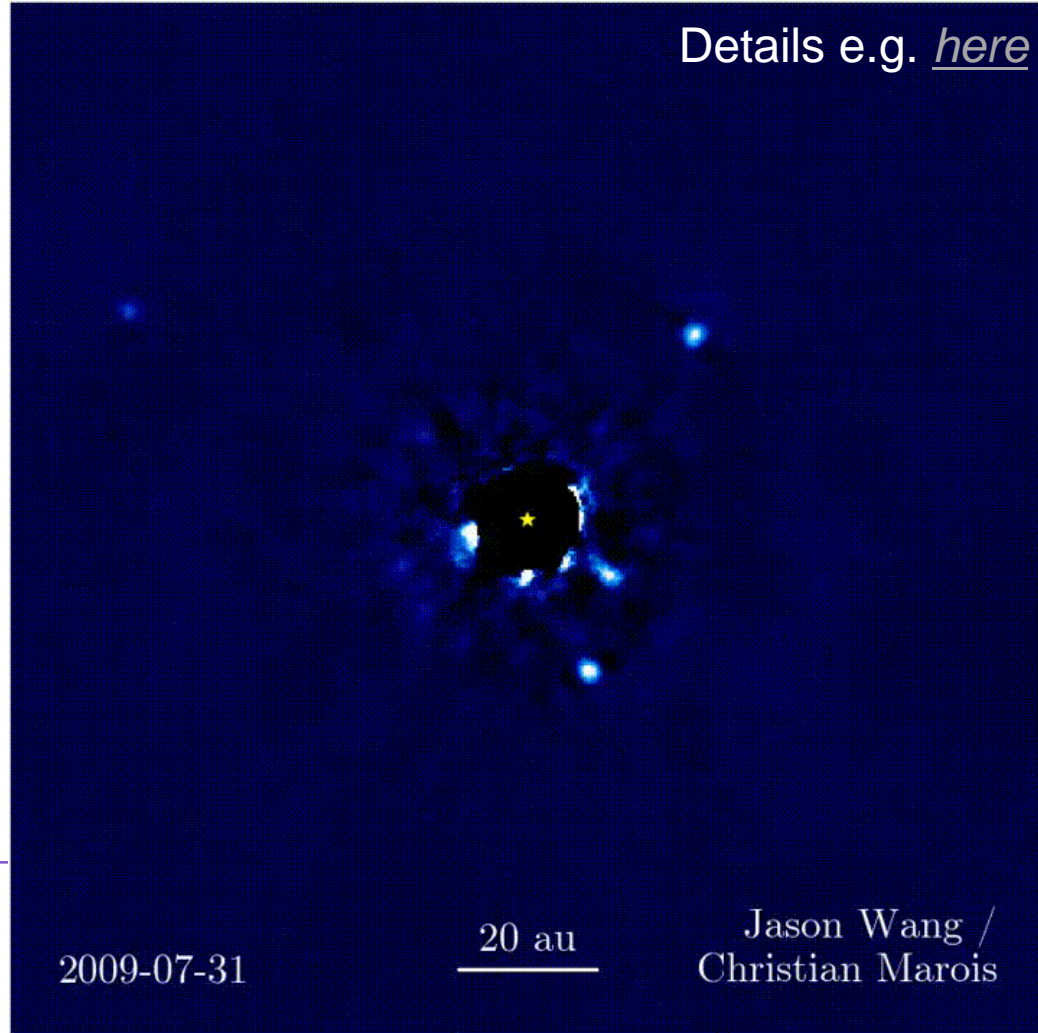
# Improvements / new solutions/tools

- Just make things bigger
- Improve quality, reduce disturbances
- Focus better on the interesting stuff
  - E.g. Earth-Sun contrast ratio around  $1:10^{10}$
  - **How?**
  - Coronagraphs & starshades

Coronagraph: [youtube/czD5YcR1G4M](https://www.youtube.com/watch?v=czD5YcR1G4M)

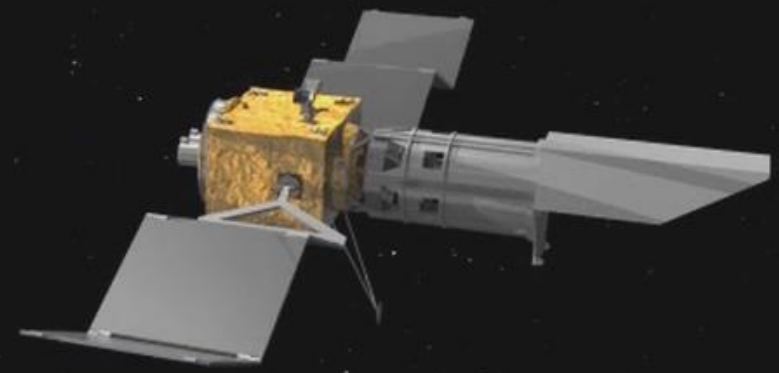
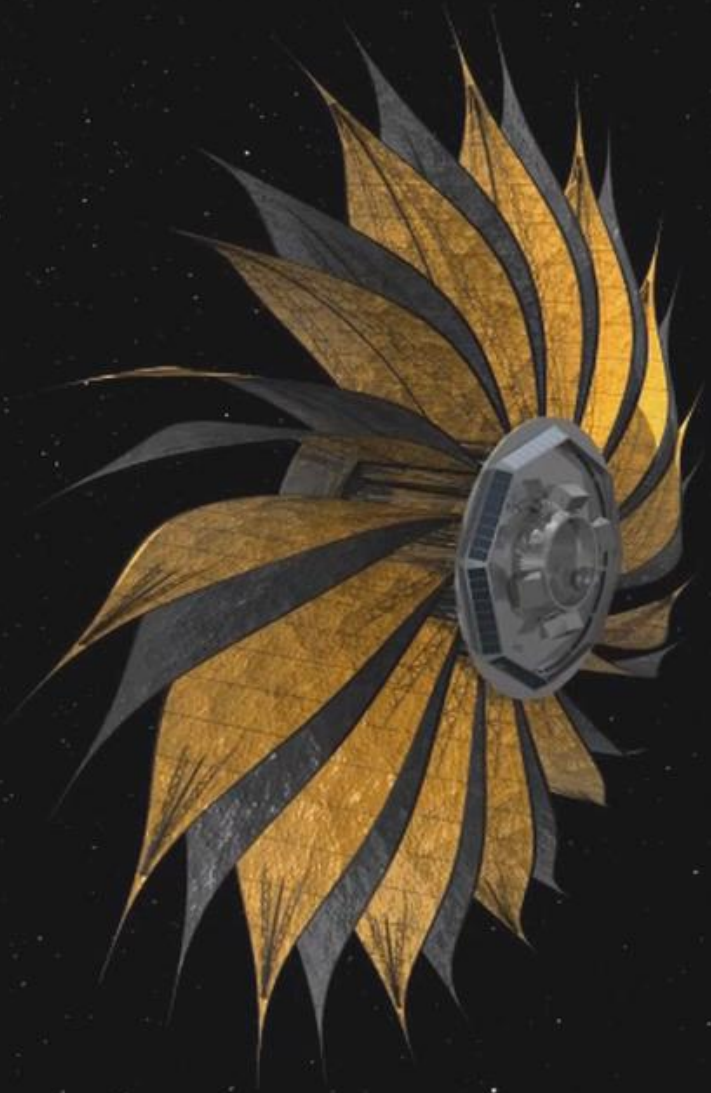
Starshade: [youtube/ALGIoexo-ac](https://www.youtube.com/watch?v=ALGIoexo-ac)

Details e.g. [here](#)











*“A 10-m prototype of the starshade’s inner disk is demonstrated at NASA’s Jet Propulsion Laboratory.” (Source)*



# Also “space” telescopes

+ MIDEX/MO (2023),  
SMEX/MO (2025), etc.

- Formulation
- Implementation
- Primary Ops
- Extended Ops

Spitzer  
8/25/2003

Kepler  
3/7/2009  
10/30/2018 EOM

WFIRST  
Mid 2020s

Euclid (ESA)  
2022

Webb  
2021

Chandra  
7/23/1999

XMM-Newton (ESA)  
12/10/1999

TESS  
4/18/2018

Swift  
11/20/2004

NuSTAR  
6/13/2012

Fermi  
6/11/2008

IXPE  
2021

XRISM (XARM) (JAXA)  
2022

ISS-NICER  
6/3/2017

ISS-CREAM  
8/14/2017  
2/15/2019 EOM

SOFIA  
Full Ops 5/2014

GUSTO  
2021

SPHEREx  
2023

Hubble  
4/24/1990

+ Athena (late 2020s),  
LISA (mid 2030s)

# SOFIA (Stratospheric Observatory For Infrared Astronomy)

26.10.2020: SOFIA detects water on sunlit surface of the Moon;

<https://www.nasa.gov/press-release/nasa-s-sofia-discovers-water-on-sunlit-surface-of-moon>

<https://www.nature.com/articles/s41550-020-01222-x>



- 2.7-metre telescope
- 12-15 km altitude
  - Above 99% of atm. & H<sub>2</sub>O vapor
- 8 hour observations thrice a week
- Main benefit: not in space
  - Maintainable and highly adaptable

29.10.2020

# Not just ESA & NASA

- Hard X-ray Modulation Telescope (HXMT) (June 2017)
  - China ('s first space telescope)
  - Scan for new transient sources, monitor known variable sources, observe X-ray binaries
- Spektr-RG (SRG) (~~1995, '96, '97, '98, '99, 2000, '02, '03, never, '08, '18, July 2019~~)
  - "Spectrum + Röntgen + Gamma"
  - Russia + ESA, MPI, ...
  - Galaxy clusters, active galactic nuclei, evolution of supermassive black holes, dark energy, expansion of the universe



# Near-future

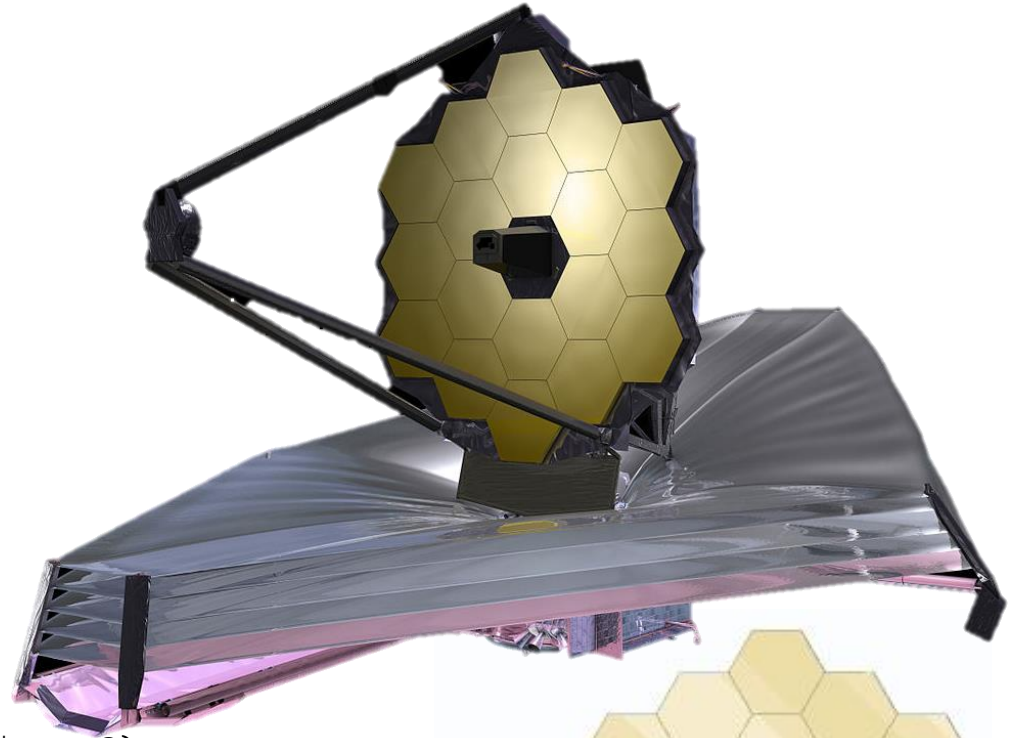
*What's next in space telescopes*



Aalto University  
School of Electrical  
Engineering

# JWST

- <https://www.jwst.nasa.gov/>
- **James Webb Space Telescope**
- “Hubble 2.0”
- **Set time frame**
  - Only enough fuel for 10 years.
- **Budget problems:**
  - Initially: 1-3.5 B\$, launch 2007-2011
  - Now: >10 B\$, launch Oct 31 2021? (LUVOIR: 20 B\$; NASA cap 2-5 B\$ 2018)



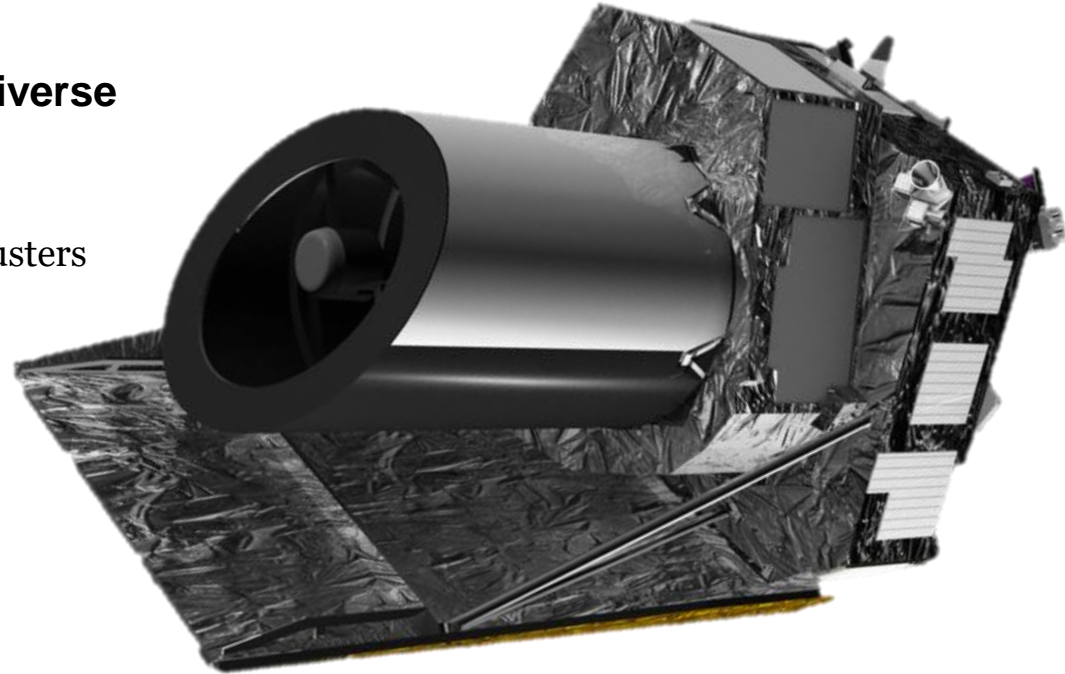
Hubble 2.4 m JWST 6.5 m





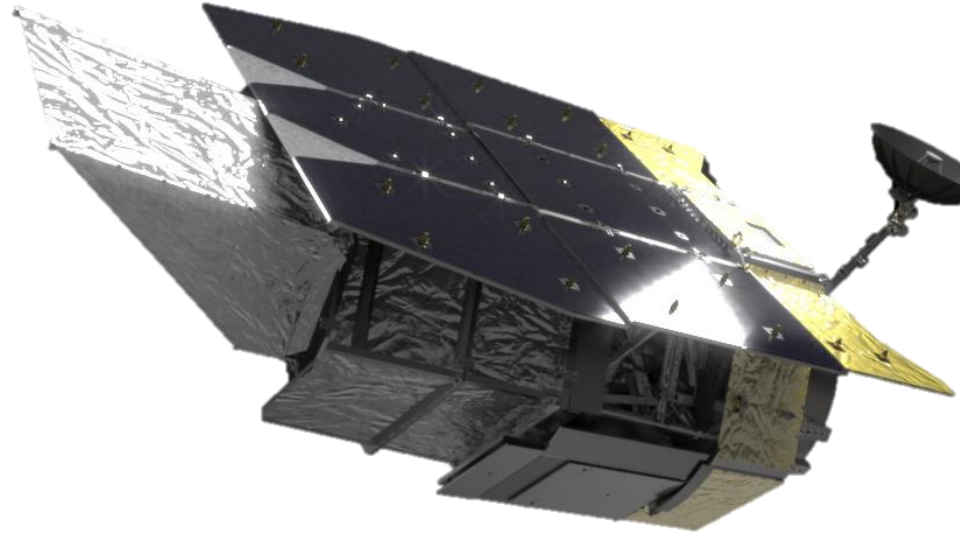
# Euclid

- <https://sci.esa.int/web/euclid>  
<https://www.euclid-ec.org/>
- **Cosmology: Expansion of the universe – contribution of DM & DE**
  - What is dark matter?
  - Acoustic oscillations – from galaxy clusters
  - Weak gravitational lensing
- **Surveys: deep + wide**
- **H2/2022**
- **Visible and NIR**
- **L2 point, 6 years**



# Roman Space Telescope (né WFIRST)

- <https://roman.gsfc.nasa.gov/>
- **Nancy Grace Roman Space Telescope**
- **Wide Field Infrared Survey Telescope (hence WFIRST)**
  - 100 times the field of view compared to Hubble in a single observation
- **2025**
- **Limited lifespan: fuel for ~5-6 years**
- **Coronagraph. Possibly starshade**
- **Survey**
  - Doesn't see small exoplanets
- **Dark matter, Dark Energy, exoplanets**



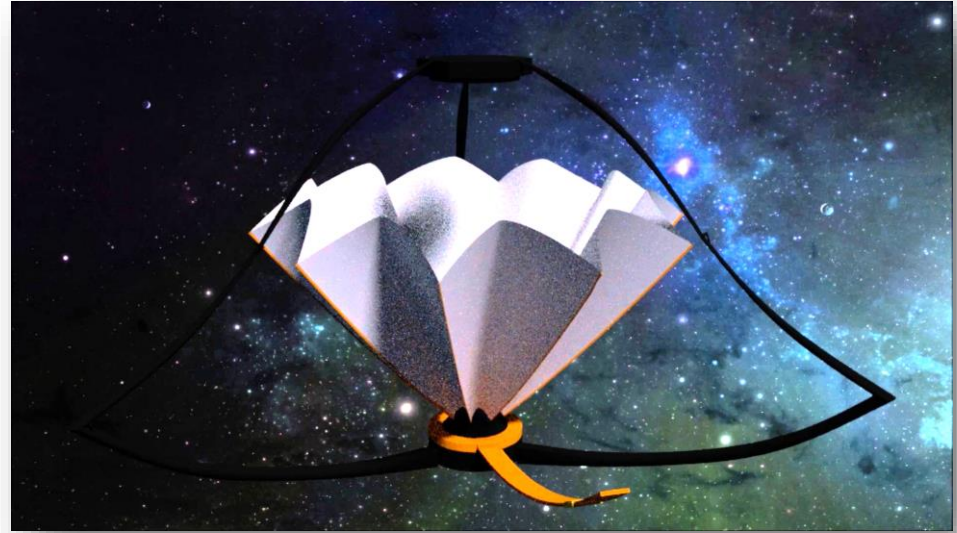
# Thinking outside the box



Aalto University  
School of Electrical  
Engineering

# Aperture

- **Foldable mirror**
- **16-metre**
- NASA Innovative Advanced Concepts (NIAC)
- **Surface-correction after deployment by magnetic read-head**





# Aperture



# Imaging using Solar Gravitational Lens

The **solar gravitational lens** (SGL) [...] offers **brightness amplification** of up to a factor of  $\sim 1e11$  (at 1  $\mu\text{m}$ ) and **extreme angular resolution** ( $\sim 1e-10$  arcsec). As such, it allows for extraordinary observational capabilities for direct **high-resolution imaging and spectroscopy of Earth-like exoplanets**. [...] a mission to the strong interference region of the SGL (beyond 547.6 AU) carrying **a meter-class telescope with a solar coronagraph** would directly image a habitable Earth-like exoplanet within our stellar neighborhood. For an exo-Earth at 30 pc, the telescope could measure the brightness of the Einstein ring formed by the exoplanet's light around the Sun. [...] in 6 months of integration time one can reconstruct the exoplanet image with  **$\sim 25$  km-scale surface resolution**, enough to see surface features and signs of habitability.

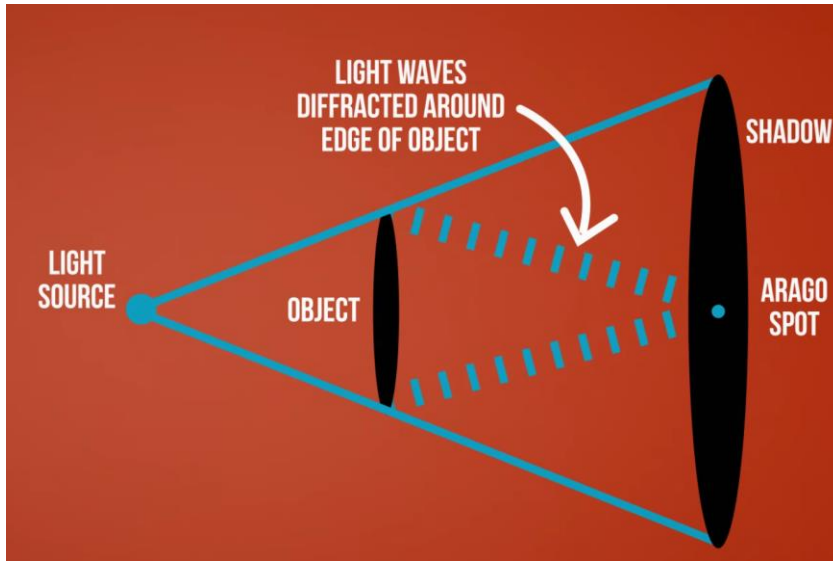


# “Orbiting rainbows”



NIAC: “In the proposed Orbiting Rainbows system, the **small cloud of glitter-like grains** would be trapped and **manipulated with multiple laser beams**. The trapping happens because of pressure from the laser light [...] shapes the cloud and pushes the small grains to align in the same direction. In a space telescope, the tenuous cloud would be formed by **millions of grains, each possibly as small as fractions of a millimeter in diameter**. [...] Because a cloud of glitter specks is not a smooth surface, the image produced from those specks in a telescope will be noisier -- with more speckled distortion -- than what a regular mirror would generate. That's why researchers are **developing algorithms** to take multiple images and **computationally remove the speckle effect** from the glitter.”

# Aragoscope



- **Still purely a concept, but a real possibility (NIAC programme)**
- **Light waves diffracts around a disk**
  - → Interference
  - → Arago spot behind a perfectly circular disc
  - Same resolution than with a same-size lense
- **Space telescope and an opaque disk (e.g. 500m diameter)**
  - 1000 x Hubble resolution (but not sensitivity!)

<https://www.nasa.gov/content/the-aragoscope-ultra-high-resolution-optics-at-low-cost>



# Three future missions and concepts



Aalto University  
School of Electrical  
Engineering

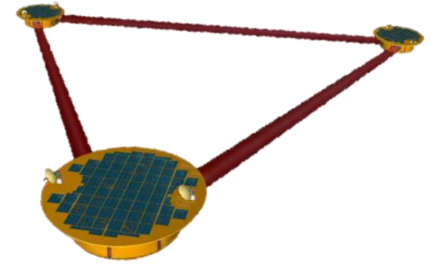
# Group work

## Missions, concepts, ideas

- What?
- Why?
- When, where?
- How?
- What's new?

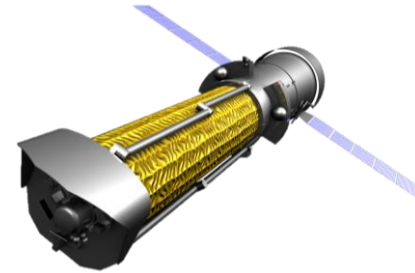
### LISA

*“will be the first space-based gravitational wave observatory”*



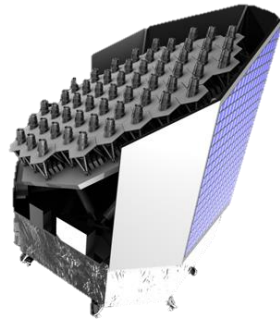
### ATHENA

*“The next-generation X-ray telescope will address key questions in astrophysics”*



### PLATO

*“to find and study a large number of extrasolar planetary systems, with emphasis on the properties of terrestrial planets in the habitable zone around solar-like stars”*



# Group work instructions

## **Part 1: Preparation [10 min]**

1. Soon you'll be put in mission-specific breakout rooms. Your group will specialize in one mission well enough to present it to the other groups.
2. Each member starts by specializing in one small part of the mission. Parts are taken in alphabetical order by member's Zoom names.
  1. *Antti: **Purpose / science questions***
  2. *Bettina: **Schedule / time frame***
  3. *Christina: **Orbit / path***
  4. *Dave: **Instrumentation / technology***
  5. *Esko: **Unique or novel tech. or science***
3. To find answers:
  1. *MyCourses page > Mission plans*
  2. *Internet (ESA, NASA, caution wih Wikipedia)*

## **Part 2: Collecting [10 min]**

1. Go to **flinga.fi** and use access code **FM3MXEE**
2. On the Flinga whiteboard each group/mission has their own area, and each topic has a section waiting.
  1. *Begin by adding your name under your mission title.*
  2. *Then go on filling your topic. Maybe use a text editor on your computer and copy-paste a longer answer to Flinga.*
  3. *You can also add pictures or draw.*
  4. *Make sure your part is OK before looking at others.*

## **Part 3: Coordination [10 min]**

1. Together, in your Zoom room, start looking at your mission as a whole.
  1. *Go through each point; the person(s) responsible for them explain them to others. Ask questions if needed.*
  2. *Is all clear? Is everything answered? Is this a clear overview of the mission?*
  3. *Fill in possible gaps, or edit/move the text and other elements if need be, so that the "presentation" is clear and logical.*

## **Part 4: Presentation [15 min]**

1. Get back to the main Zoom session (breakout rooms will close).
2. One group at time, present your mission to others.
  1. *Use the Zoom voice for telling what your mission is about. Go through at least all the parts mentioned above.*
  2. *Note that everyone will have the Flinga board open and can follow the text and illustrations there while hearing you on Zoom.*
3. When other groups present their missions, pay attention and ask clarifications if needed.

# Group work instructions

## Part 1: Preparation [10 min]

1. Soon you'll be put in mission-specific breakout rooms. Your group will specialize in one mission well enough to present it to the other groups.
2. Each member starts by specializing in one small part of the mission. Parts are taken in alphabetical order by member's Zoom names.

## Part 2: Collecting [10 min]

1. Go to **flinga.fi** and use access code **FM3MXEE**
2. On the Flinga whiteboard each group/mission has their own area, and each topic has a section waiting.
  1. *Begin by adding your name under your mission title.*
  2. *Then go on filling your topic. Maybe use a text editor on your computer and copy-paste a longer answer to Flinga.*
  3. *You can also add pictures or draw.*
  4. *Make sure your part is OK before looking at others.*

START HERE

TEST AREA

ATHENA

LISA

PLATO

Purpose

## min]

room, start looking at your mission as a whole. The person(s) responsible for them explain them to the others.

answered? Is this a clear overview of the mission? If not, edit/move the text and other elements if need be, so that it is clear and logical.

and above.

while hearing you on Zoom.

if needed.



# Summary



Aalto University  
School of Electrical  
Engineering

# A?

Aalto University  
School of Electrical  
Engineering



ATHENA



Michael Parhvi



Juhani Heiskanen



## Purpose

• Provides  
satellite to monitor  
cosmic rays and  
gamma rays  
on the ground

• How do  
black holes  
grow and  
shape the  
Universe?

Will also have a few targets of opportunity  
observational flexibility, monitoring studies and range  
of CIBs and other transient phenomena

## Schedule

Launch in  
early 2030s

Normal mission  
lifetime of 5  
years

3 years to test complete external growth components  
will be enough to extend 5 more years

## Orbit/path

Orbit in  
highly elliptical  
orbit around Earth  
to allow for  
high energy  
gamma rays



## Instruments / technology

X-ray  
detector

Telescope with following requirements:

Effective area  $> 1 \text{ m}^2$

Effective area  $> 1 \text{ m}^2$

Point Spread Function (PSF)

LISA



Arttu



Elin

## Purpose

Gravitational wave detector

Detect massive black holes

Enables the detection of low-frequency gravitational  
waves not detectable from the Earth

Detecting low-frequency waves enables the  
discovery of very large black holes, not otherwise  
detectable

Detecting gravitational waves enables precision  
phenomena not detectable in electromagnetic waves

LISA helps form a view of the Gravitational Universe

Will map the structure of spacetime around the  
massive black holes

## Schedule

Launch  
before  
2030

Mission/normal duration: 6 years

But design should be able to be extended: 10 years

Earth-  
orbiting  
satellite  
orbiting LISA

80-60 million km



## Instruments / technology

Three identical spacecraft in triangle form, 3.5 M km  
apart

PLATO



Lauri



Shubhshi



Claire

## Purpose

Collecting  
information  
about exoplanets  
in the  
habitable zone of  
stars

Provide  
information  
about exoplanets  
in the  
habitable zone of  
stars

Are there potentially habitable planets?

In our solar system we know there are others

How common are worlds like ours, and what are they  
suitable for the development of life?

Characterize  
exoplanets  
in the  
habitable zone  
of stars



## Schedule

Launch:  
2025

Mission  
time: 4.25 y

Transfer: 3  
m

Science: 4 y

## Orbit/path

Eclipse-free

Libration  
orbit about the L2 point



## Instruments / technology

Main  
instrument:  
24 x 2  
telescope  
cameras

24 "star"  
cameras take  
pictures every  
20 s for 100 days  
continuously  
imaging 1

2 "fast"  
cameras (2  
x 5) provide  
pointing  
data

24 x 24 x 2  
telescope  
cameras

total FOV  
23.32 deg<sup>2</sup>

24 x 24 x 2  
telescope  
cameras

arrays of 24 x  
CCD (MCCD  
not colored)  
organized in 8  
different  
angles