# Odabrana Poglavlja Astronomije
# Lekcija 10: Teleskopi

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# Šta smo naučili do sada:

- **Astronomija** se bavi merenjem položaja (prvih deo) nebeskih tela i njihovim zračenjem (drugi deo)

- Na osnovu merenja položaja i sjaja (i spektara), imamo uvid u **fizičke procese** koji se dešavaju u svemiru

- Astronomija: Opisivanje

- Astrofizika: Razumevanje (Mada su danas astronomija i astrofizika sinonimi)

- Za merenje svega ovoga mi koristimo **teleskope!**

- **Uloga teleskopa je dvojaka:**

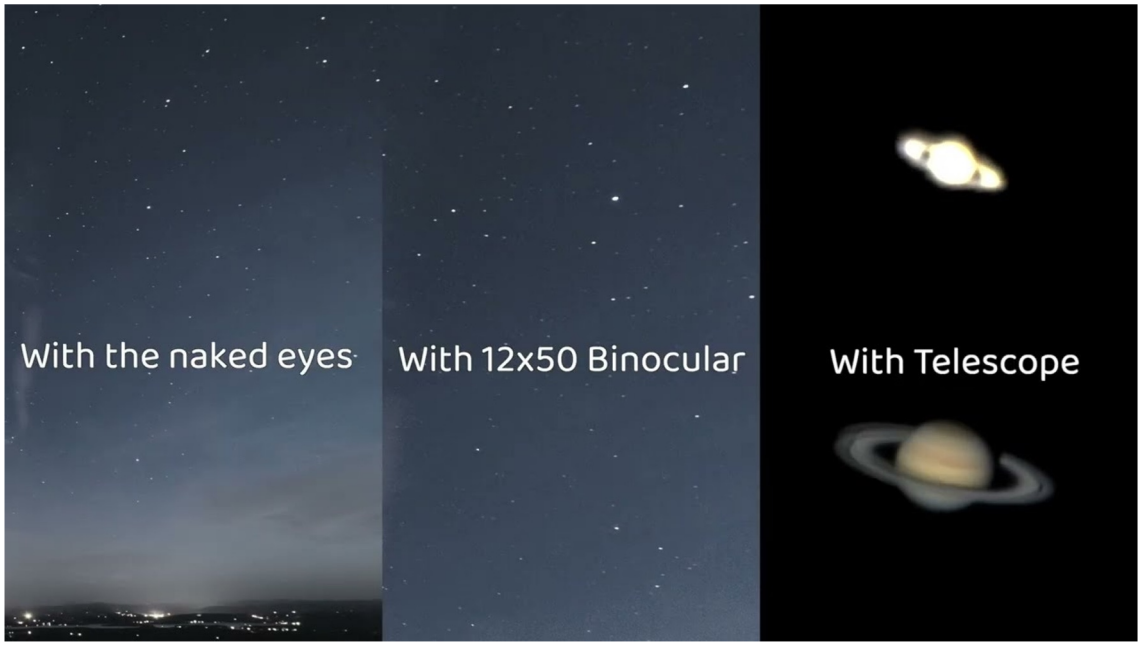
**1) Vidimo manje sjajne objekte (“više svetlosti”)**

**2) Možemo da vidimo manje objekte (“bolja ugaona rezolucija”)**

Npr:

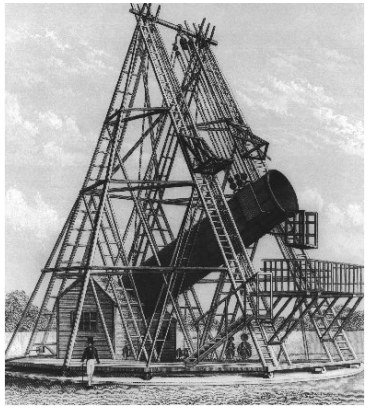
Npr:

- **Ekstremno važno:** Slika desno **nije** samo “zoom” ili “crop” slike levo.
- Svaki instrument (oko, dvogled, pa i teleskop) ima fundamentalni limit koliko male detalje može da vidi
- Drugačije rečeno: Nije bitan “broj piksela” već “kvalitet optike”
- *Mada nije u pitanju samo kvalitet već i veličina ogledala / sočiva*

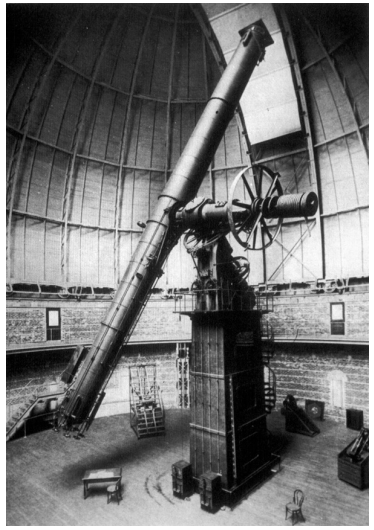


# ASTRONOMIJA pokreće razvoj tehnologije

- New technology always required → 1609: Galileo first telescope

1789: William Herschel, 1.2m Mirror



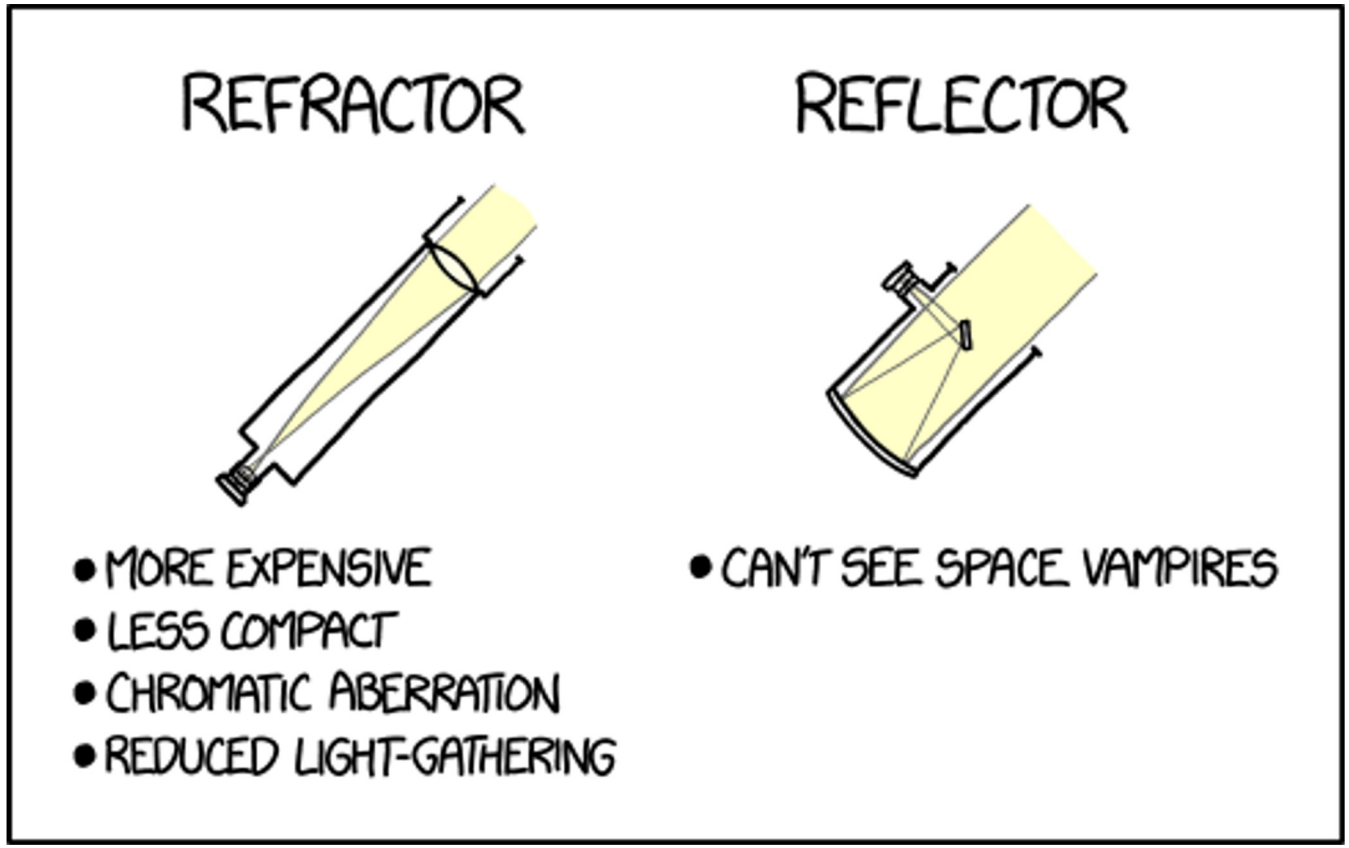
1897: Yerkes Observatory, 1m Lens

1932: Great Refractor, AOB, Serbia - Zeiss 65cm

1948: Mt. Palomar, USA – 5m Mirror

## Kako teleskopi rade:

- Suština teleskopa je primarno ogledalo ili sočivo, koje **fokusira** svetlost koja pada na njega.
- Analizirajmo, kao primer, sabirno sočivo:



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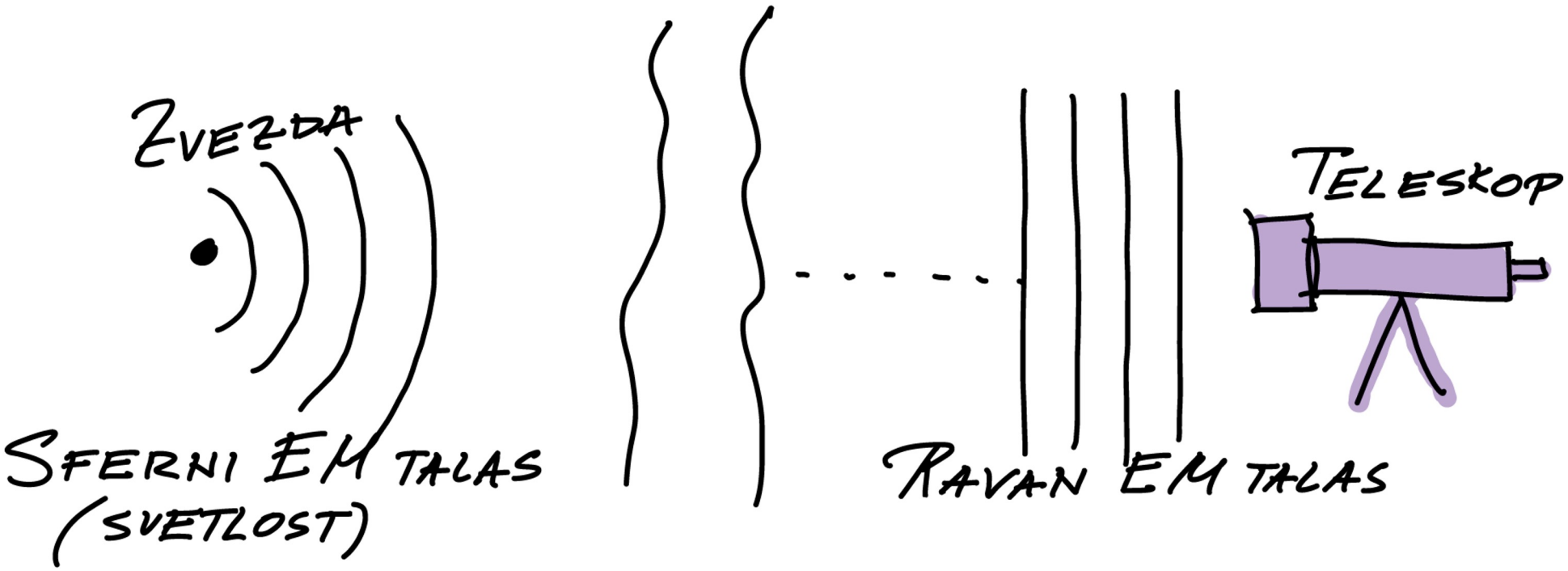


Svetlost ćemo, generalno zamišljati kao neki harmonijski idealan talas, na velikim rastojar

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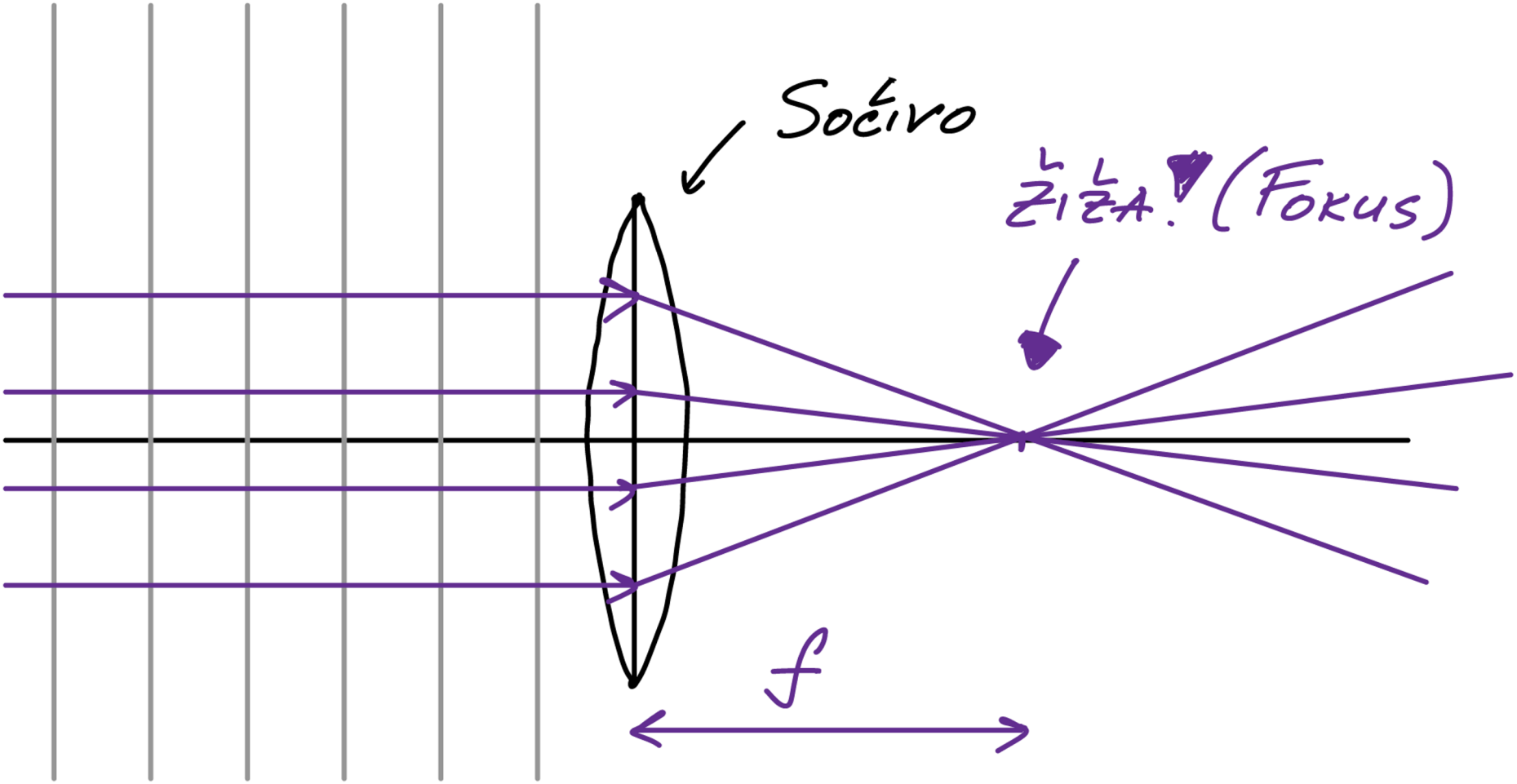

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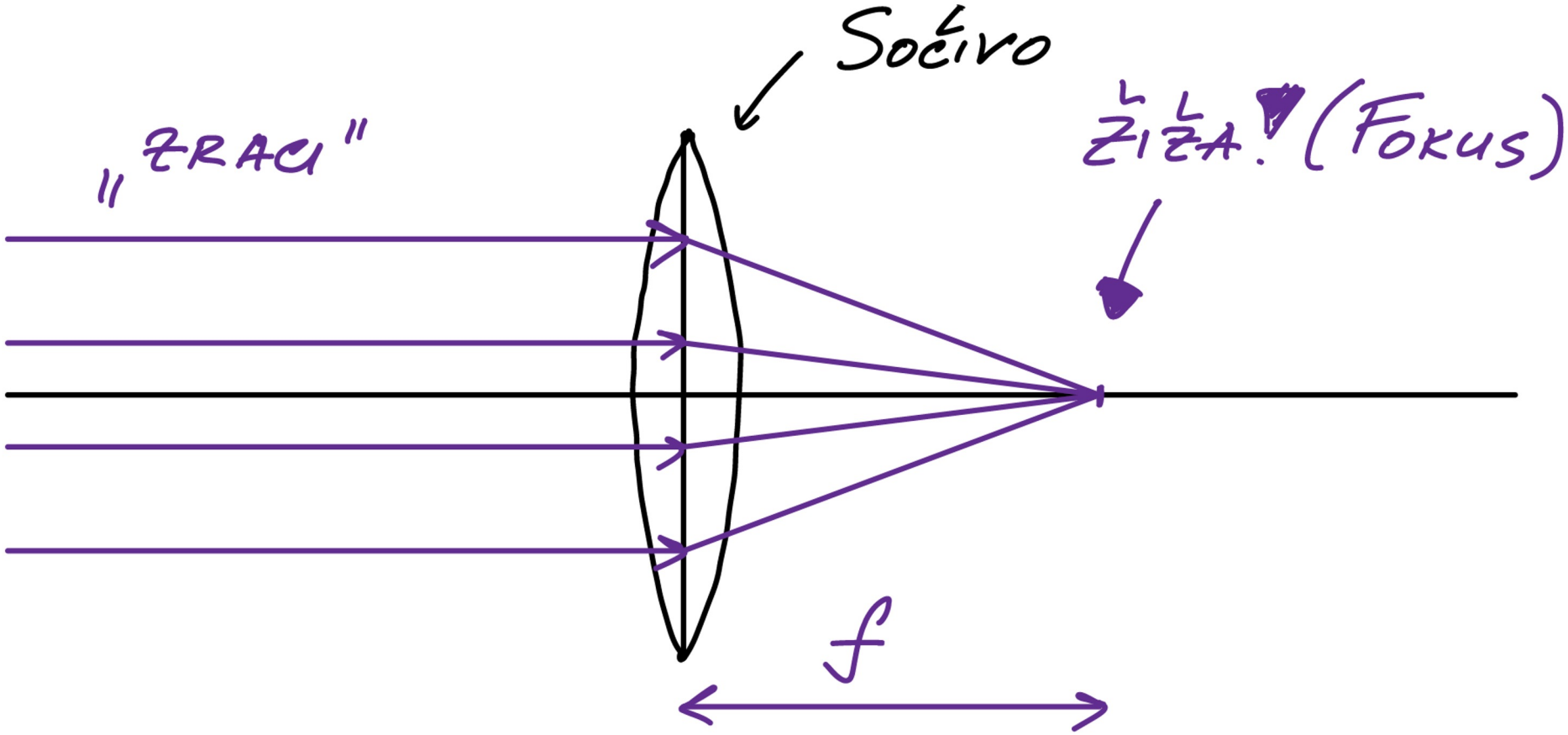


## Zbog ovoga zvezde izgledaju kao tačkice

- Zvezde su (uglavnom) veće od jednog piksela. Kako to kada su tačkice?
- Razumećemo uskoro.

## Zbog ovoga zvezde izgledaju kao tačkice

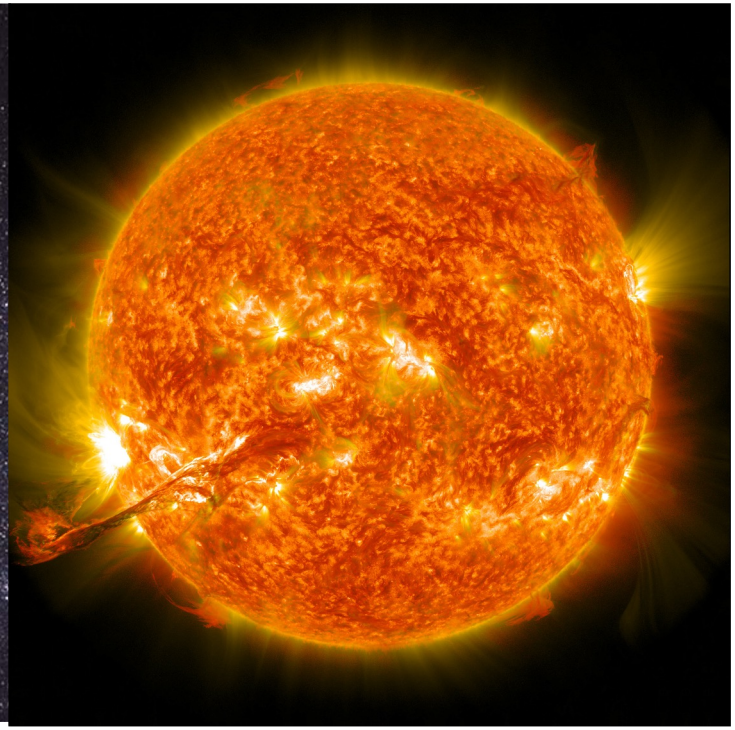
- Nijednu zvezdu sem Sunca ne možemo da “razlučimo” (tj. ne možemo da vidimo ništa više do tačku).

- Zbog ovoga je važno da istražujemo Sunce, kao nama najbliže zvezde!

# Kad smo već kod Sunca

- Očigledno je da Sunce nije fokusirano u jednu tačku, jer ga vidimo kao objekat sa nekim detaljima.

- Kako predstaviti formiranje slike **objekata konačne veličine** u našem teleskopu?



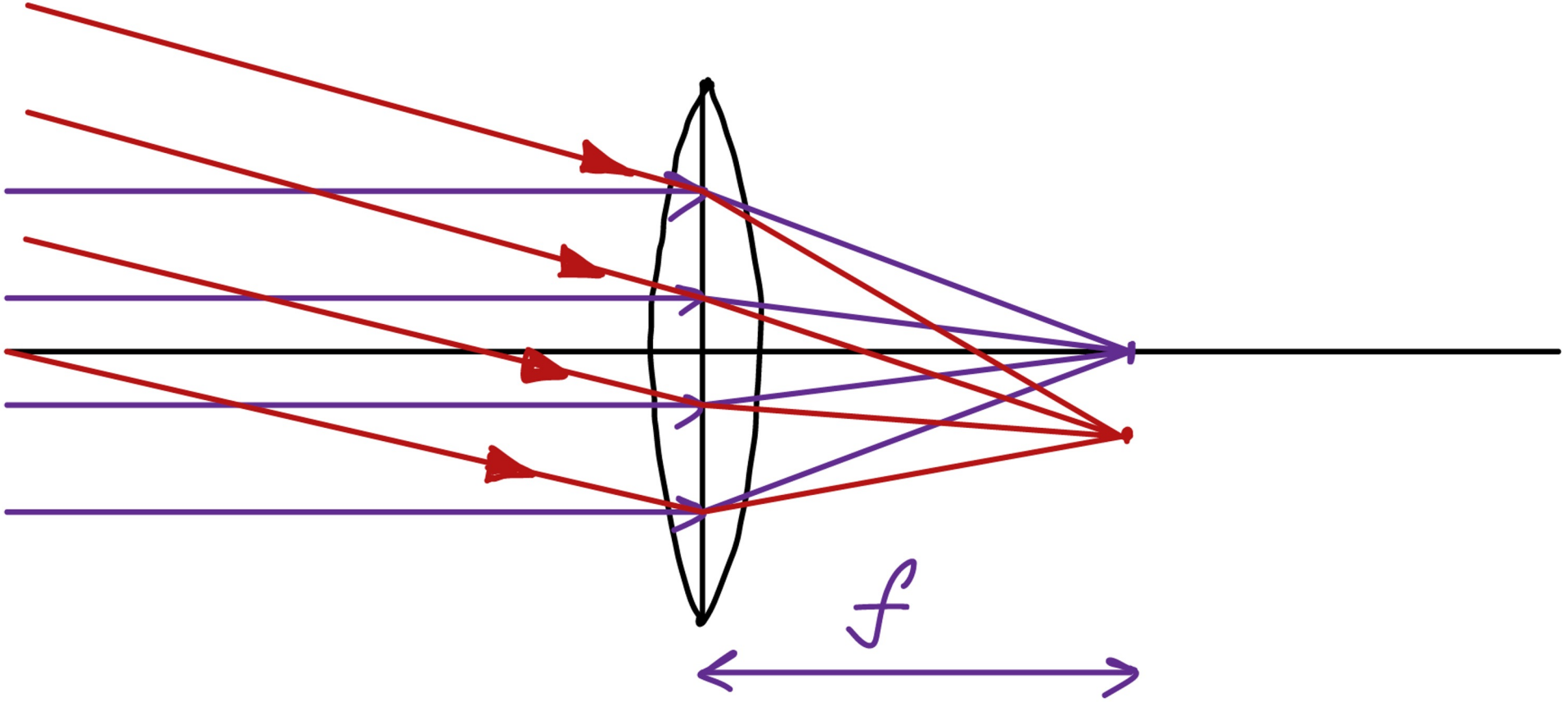
Na Suncu, sa najboljim teleskopima, možemo da vidimo detalje do nekih 20-50 km veličine.
Udaljenost do Sunca je 150 000 000 km!

# Dva izvora

- **Teleskopi** ne fokusiraju **svu svetlost** u jednu tačku

- Sva svetlost koja dolazi iz **istog pravca** je fokusirana u jednu tačku, ali različiti pravci odgovaraju različitim tačkama u **žižnoj ravni**

- Primer za dva izvora (zvezde):



# Objekti konačne veličine

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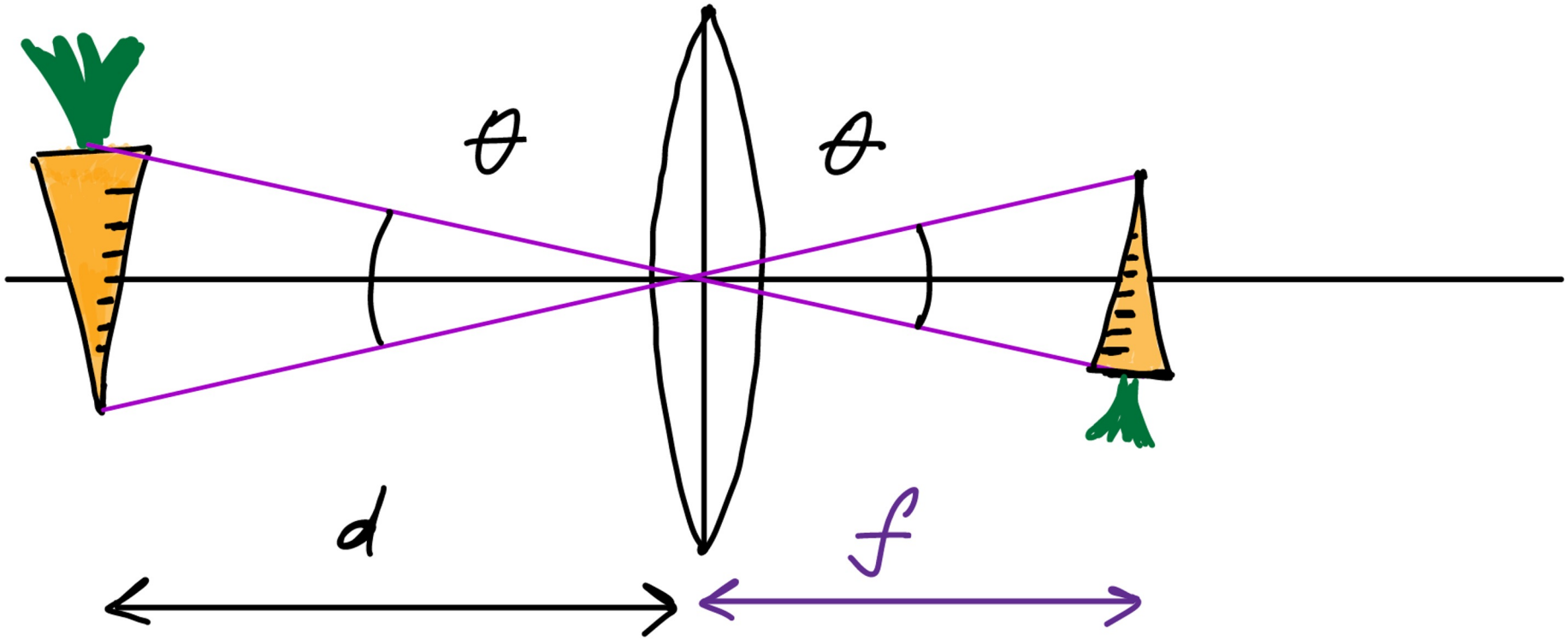
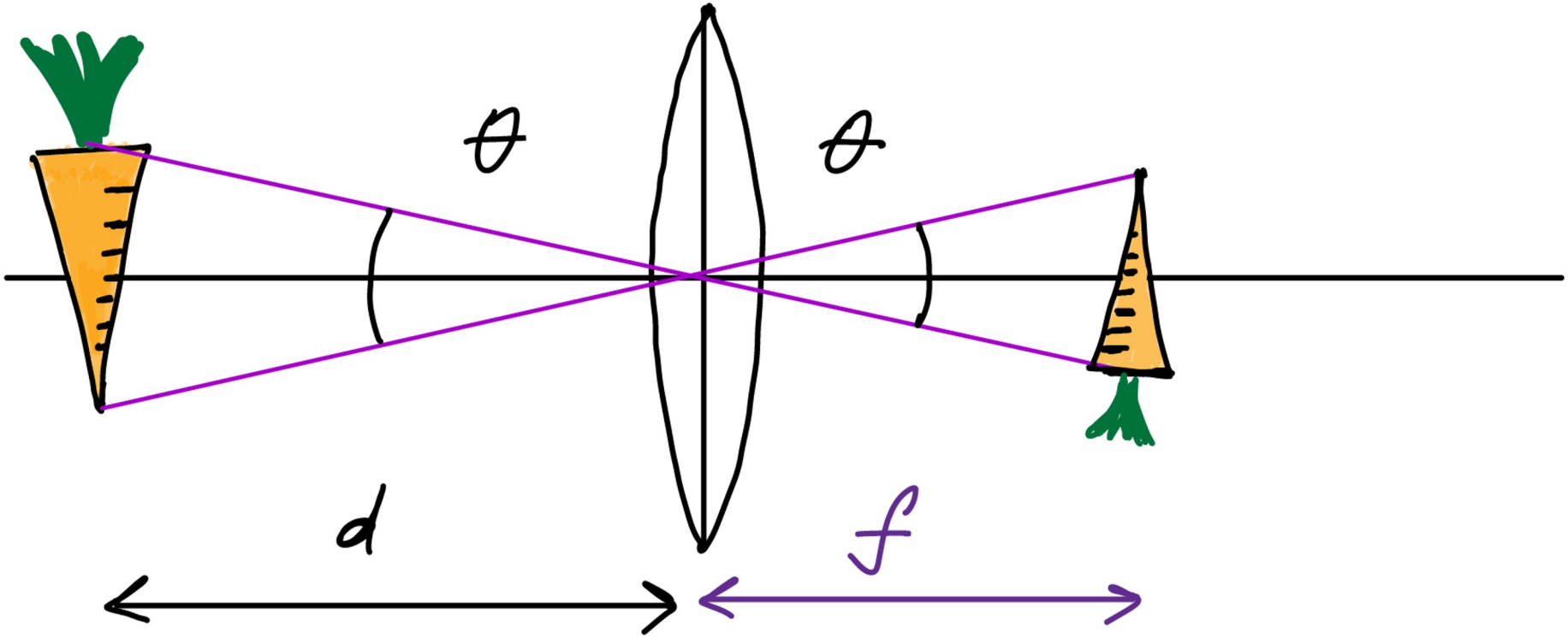
- Primer za objekat konačne veličine



## Objekti konačne veličine

- Ugao pod kojim se objekat vidi iz centra sočiva (praktično, udaljenost do objekta, pošto je u astronomiji sve jako daleko) = ugao pod kojim se lik vidi iz centra sočiva.

- Veća žižna daljina – objekti su veći u žižnoj ravni, pa zauzimaju više na našem detektoru (kamera, čip, film, CCD...)

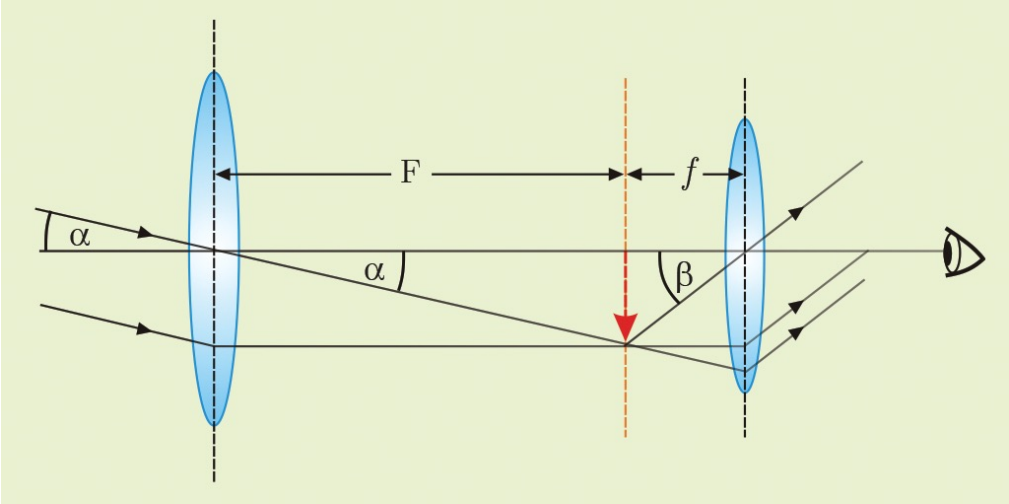


## Žižna daljina objektiva:

- Veća žižna daljina nam daje detaljniju sliku – važno za objekte koje hoćemo da vidimo u mnogo detalja: Sunce, magline, galaksije..

- Manja žižna daljina nam daje veće **vidno** polje – važno ako hoćemo da posmatramo mnogo zvezda odjednom ili snimamo objekat koji se brzo kreće

# Uvećanje teleskopa



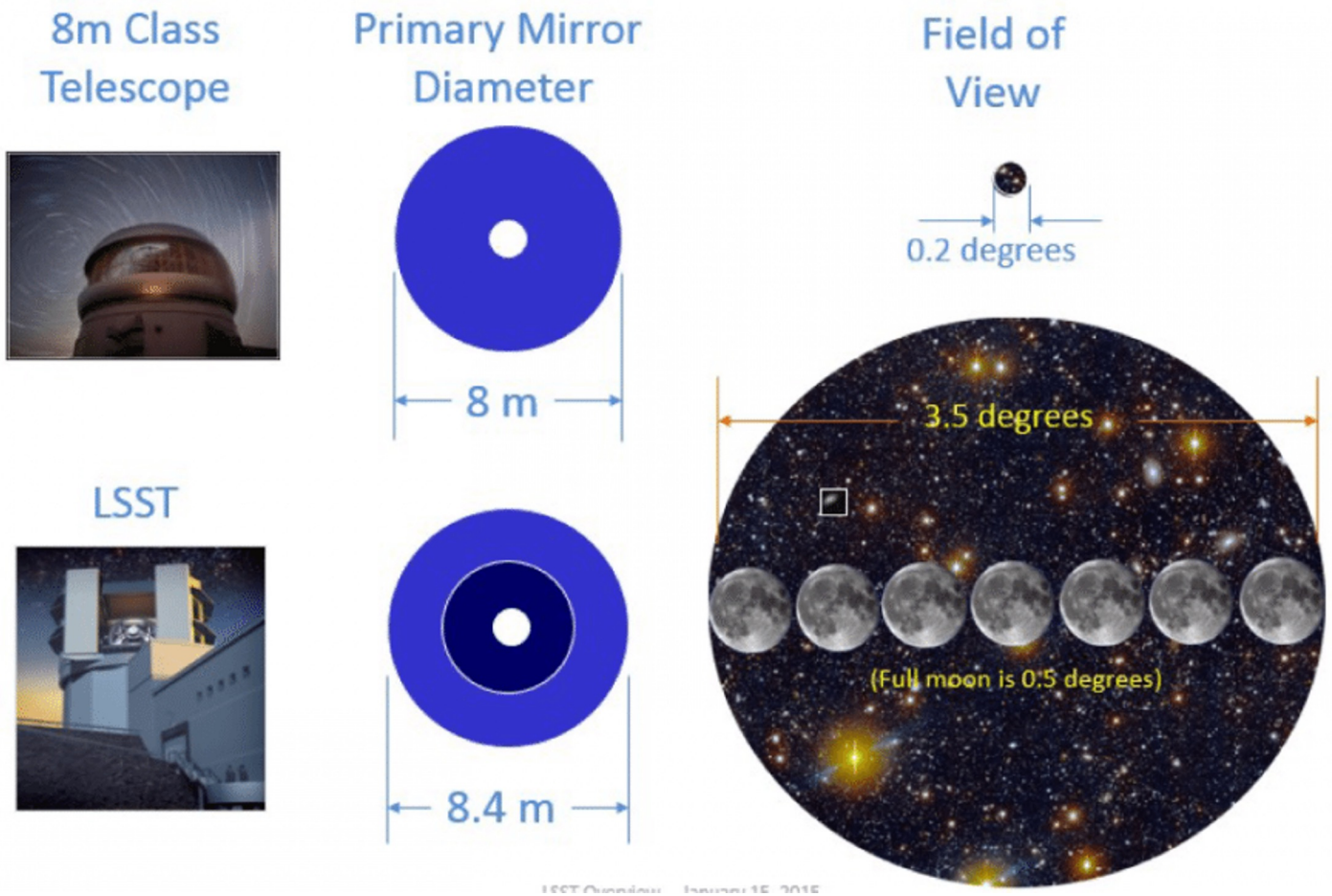

Uvećanje = F / f

- F je žižina daljina teleskopa – karakteristika teleskopa
- f je žižina daljina okulara
- Okular može da se menja pa tako i uvećanje

# Vidno polje (field of view)

- Srazmerno prečniku našeg teleskopa, obrnuto srazmerno žižnoj daljini

$$\theta_0 = \frac{D}{f}$$



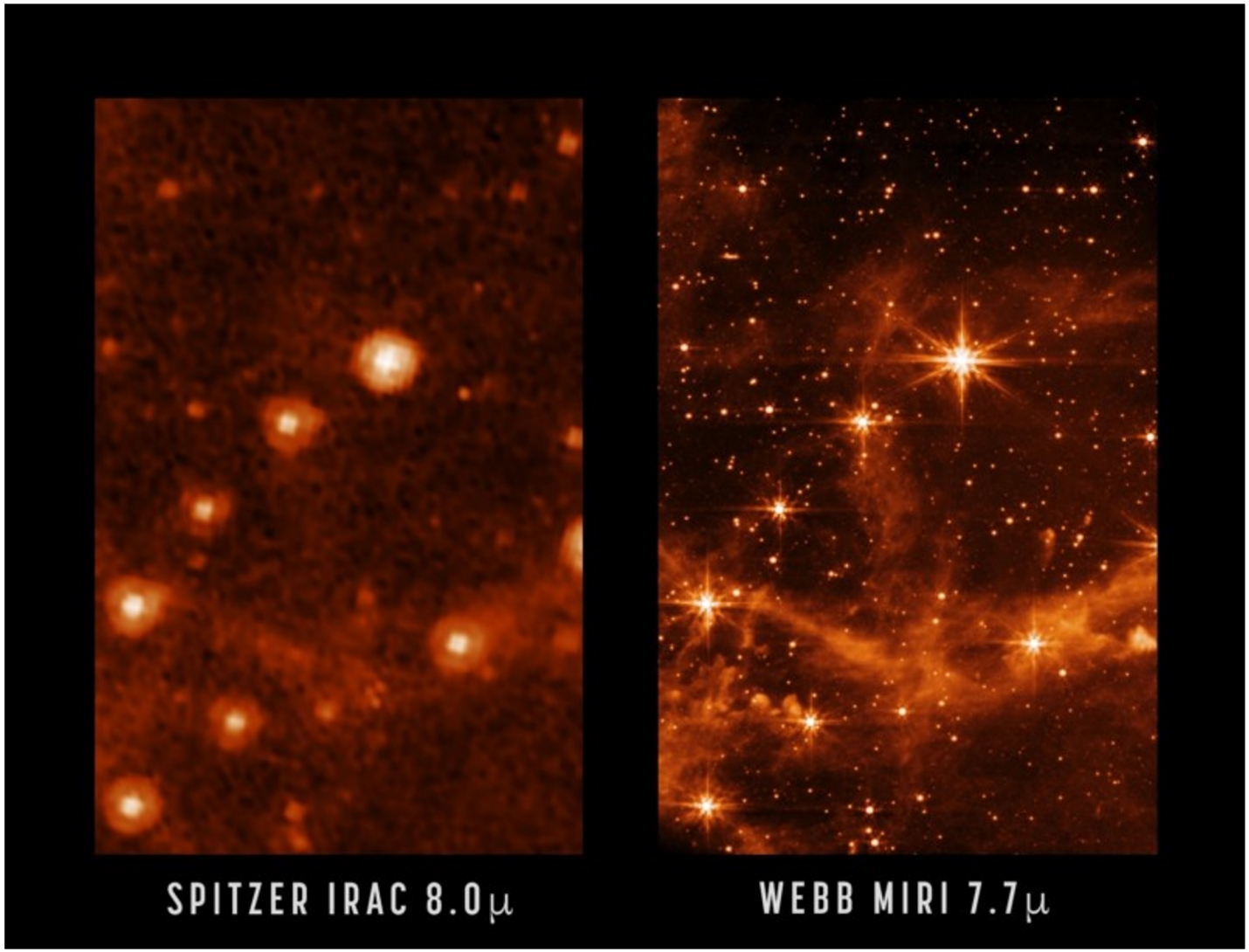
## Rekli smo da teleskopi skupljaju više svetlosti

- Koliko više svetlosti?
- Osvetljenost koju daje neko nebesko telo: $$\mathcal{E} = \frac{F}{4\pi d^2}$$
- Snaga koju skupljamo: $$P = \frac{F}{4\pi d^2} \times A = \frac{F}{4\pi d^2}\pi\frac{D^2}{4}$$
- 
- Teleskop u odnosu na naše oko: $$\frac{P_{\text{oka}}}{P_{\text{teleskopa}}} = \frac{D^2_{\text{zenice}}}{D^2}$$

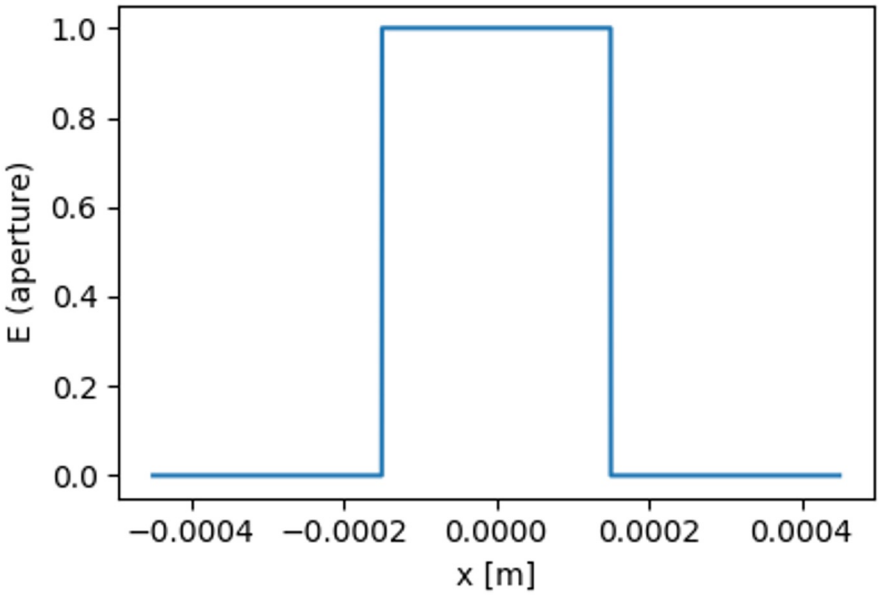
Ovaj odnos može da bude jedan naprema milion!

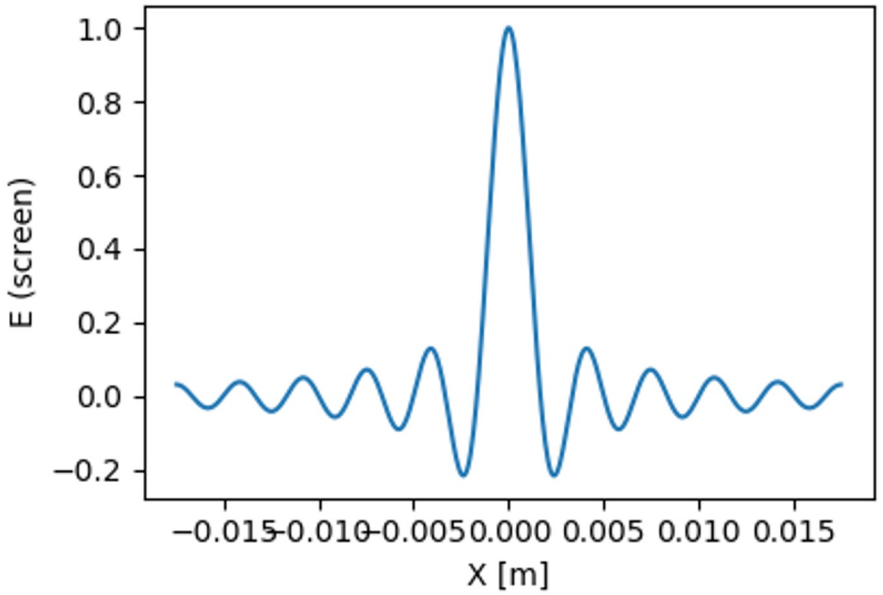
Zahvaljući velikim teleskopima mi možemo da vidimo manje sjajne objekte!

## Veći teleskopi  takodje daju oštriju sliku. Zašto?



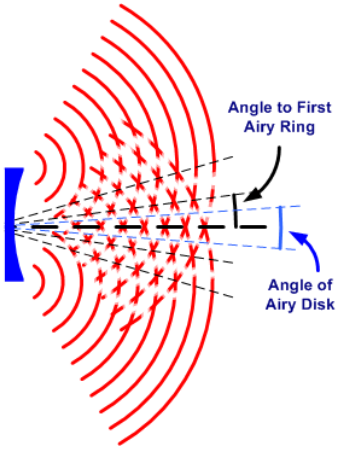
# Difrakcija na jednom pravougaonom otvoru (prorezu)

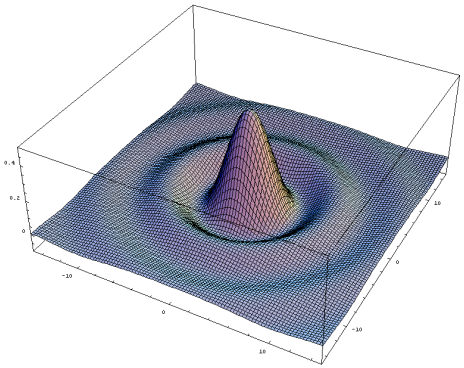


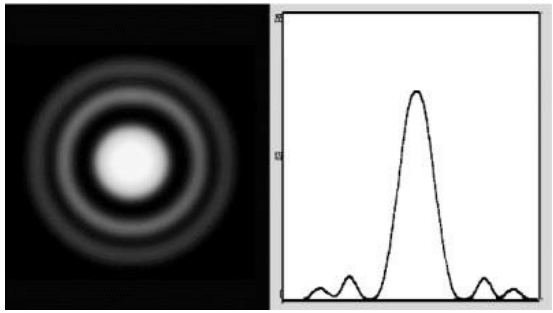




Difrakcija na jednom prorezu: Furijeova transformacija “cilindar” funkcije je sinc funkcija

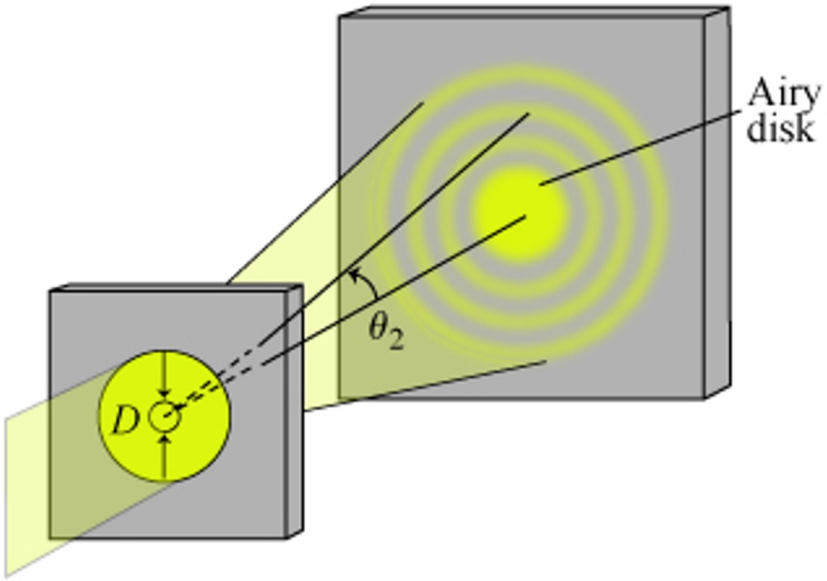
objektiv teleskopa



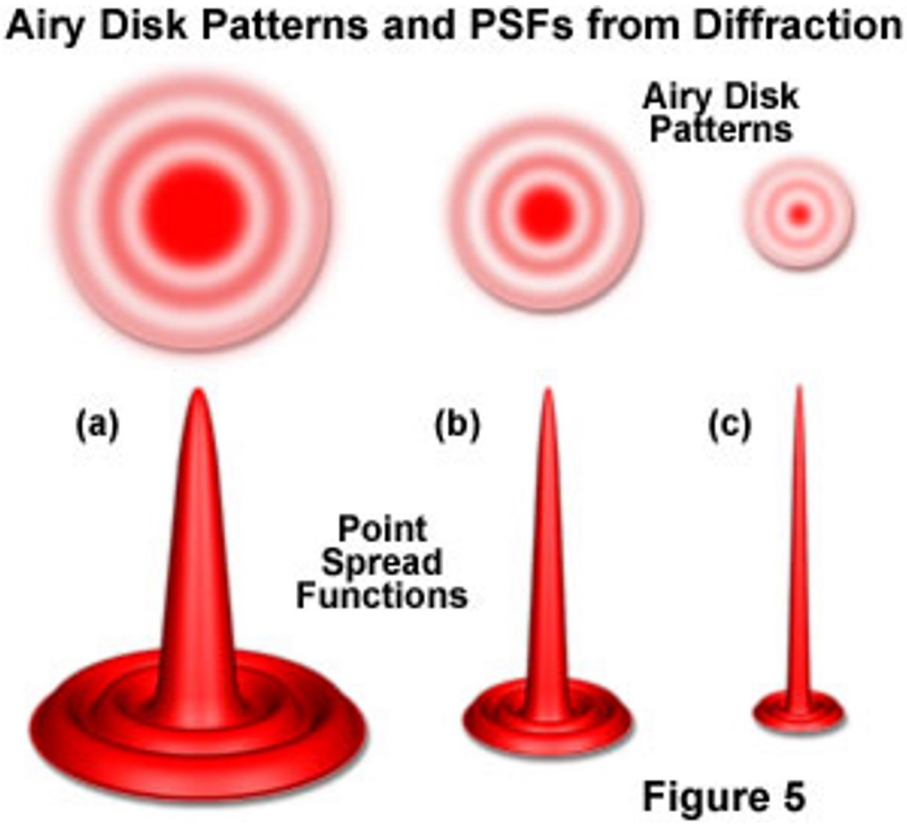





# Kako izgleda difrakcija na kružnom otvoru?

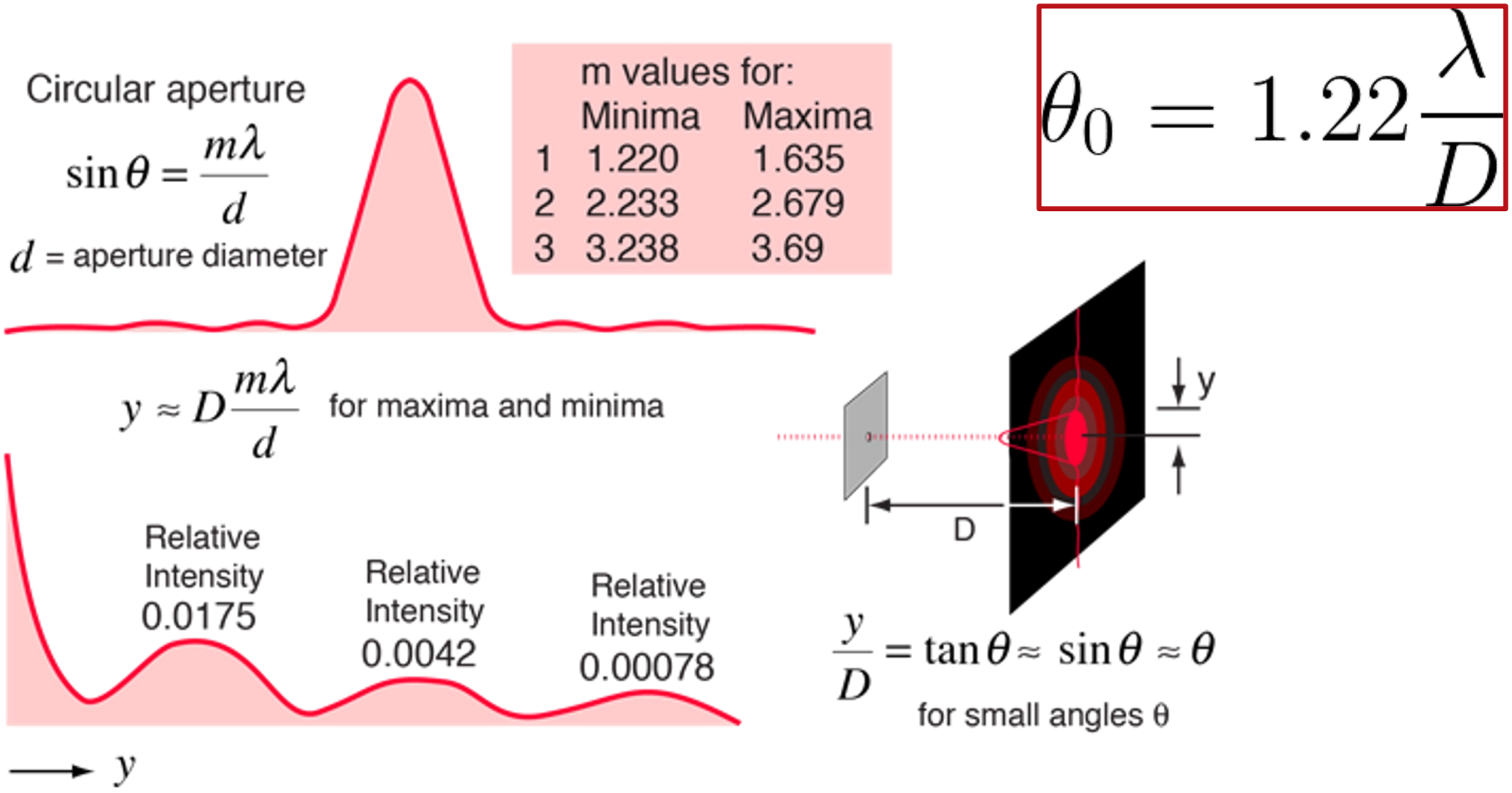



Zašto nas se ovo tiče? Zato što je naše ogledalo ili sočivo uglavnom kružno




$$I \propto \left[\frac{J_1(\rho)}{\rho}\right]^2 ; \quad \rho = k\theta a/2$$

# Airijev (Airy) disk

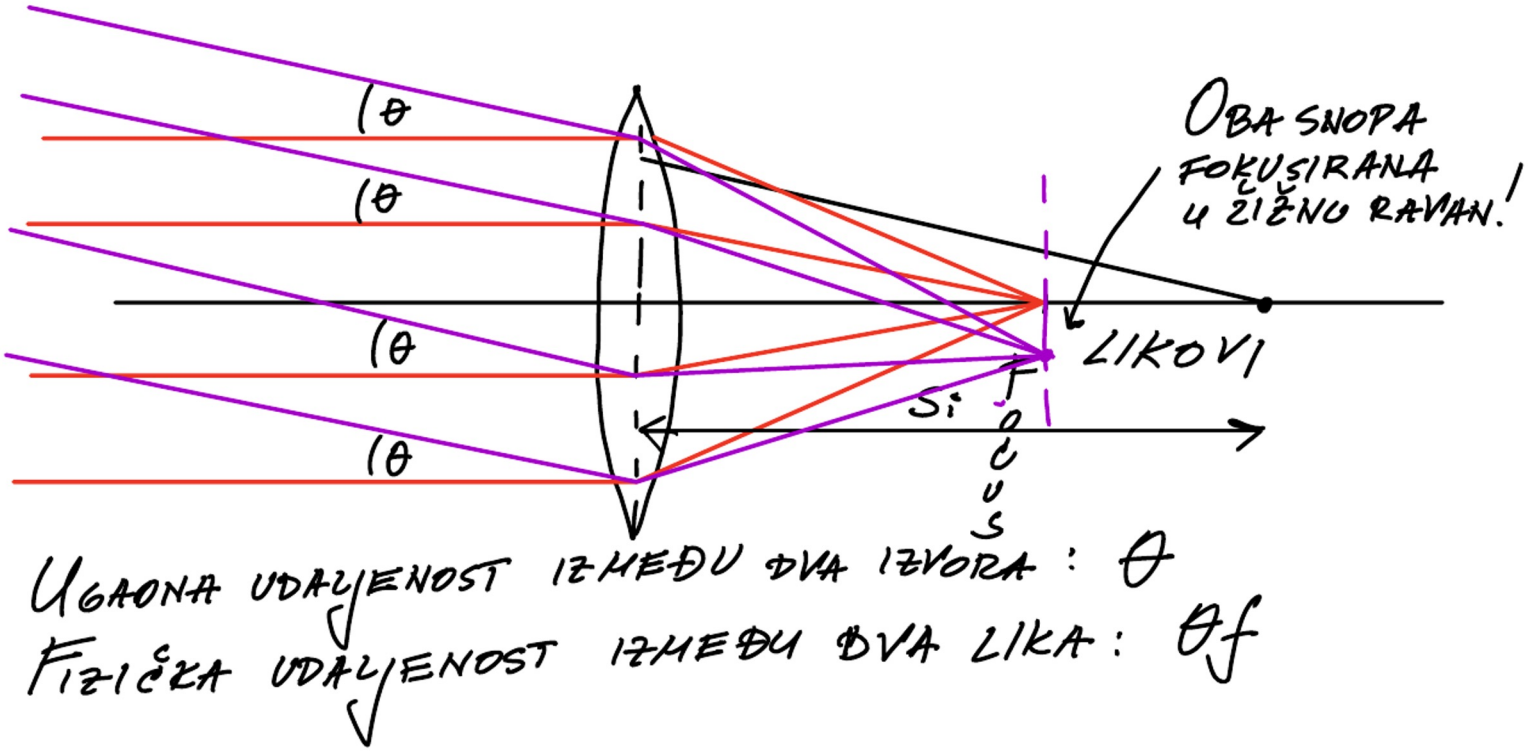



Credits: hyperphysics.phys-astr.gsu.edu

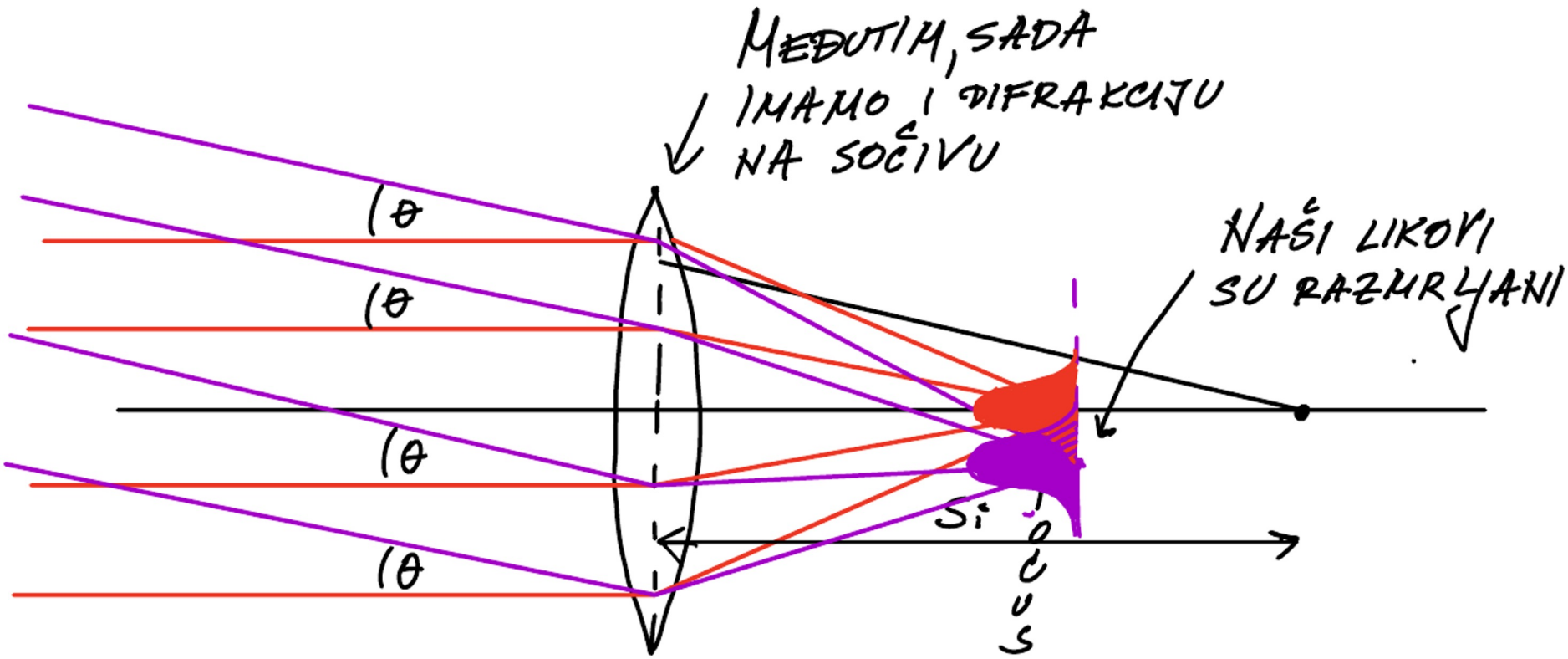
# Ok, šta dalje? Kako radi teleskop?

- Konkretnije pitanje:

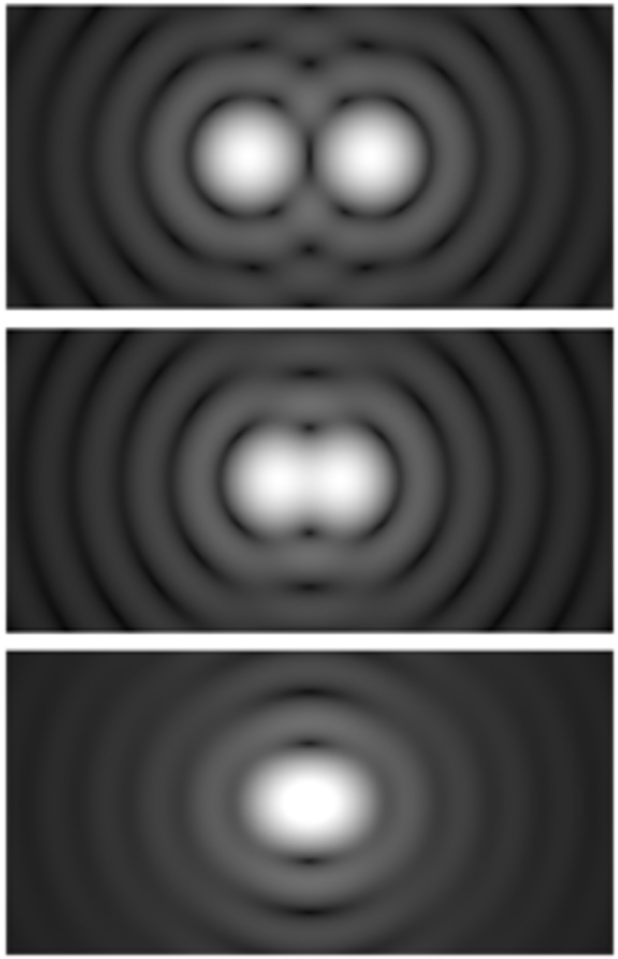
Dva snopa paralelnih zraka padaju na sočivo iz dva različita pravca, da li će ta dva snopa biti fokusirana u istu tačku? **NE**



## Dodajmo na to sada difrakciju



# Rejlijev kriterijum



Resolved

Barely resolved

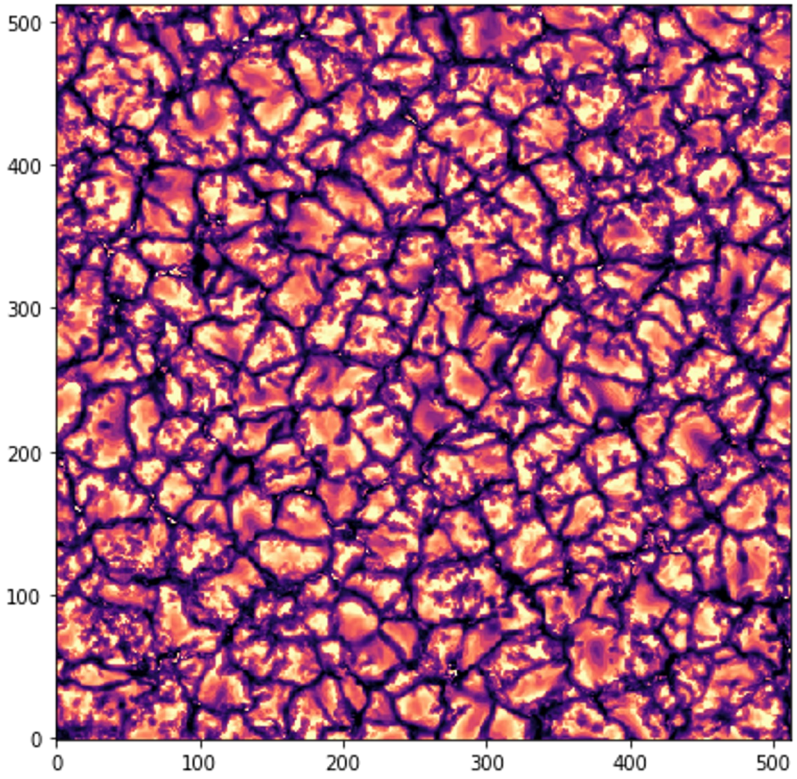
Unresolved

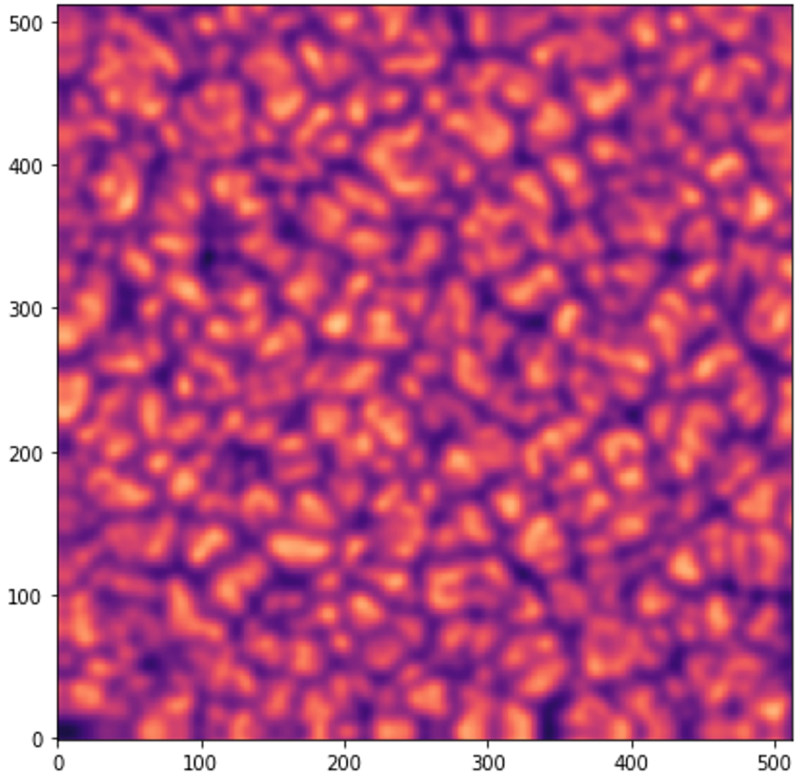
- Izvori moraju da budu na ugaonom rastojanju većem od udaljenosti prvog minimuma da bismo ih razlučili

$$\theta_0 = 1.22\frac{\lambda}{D}$$

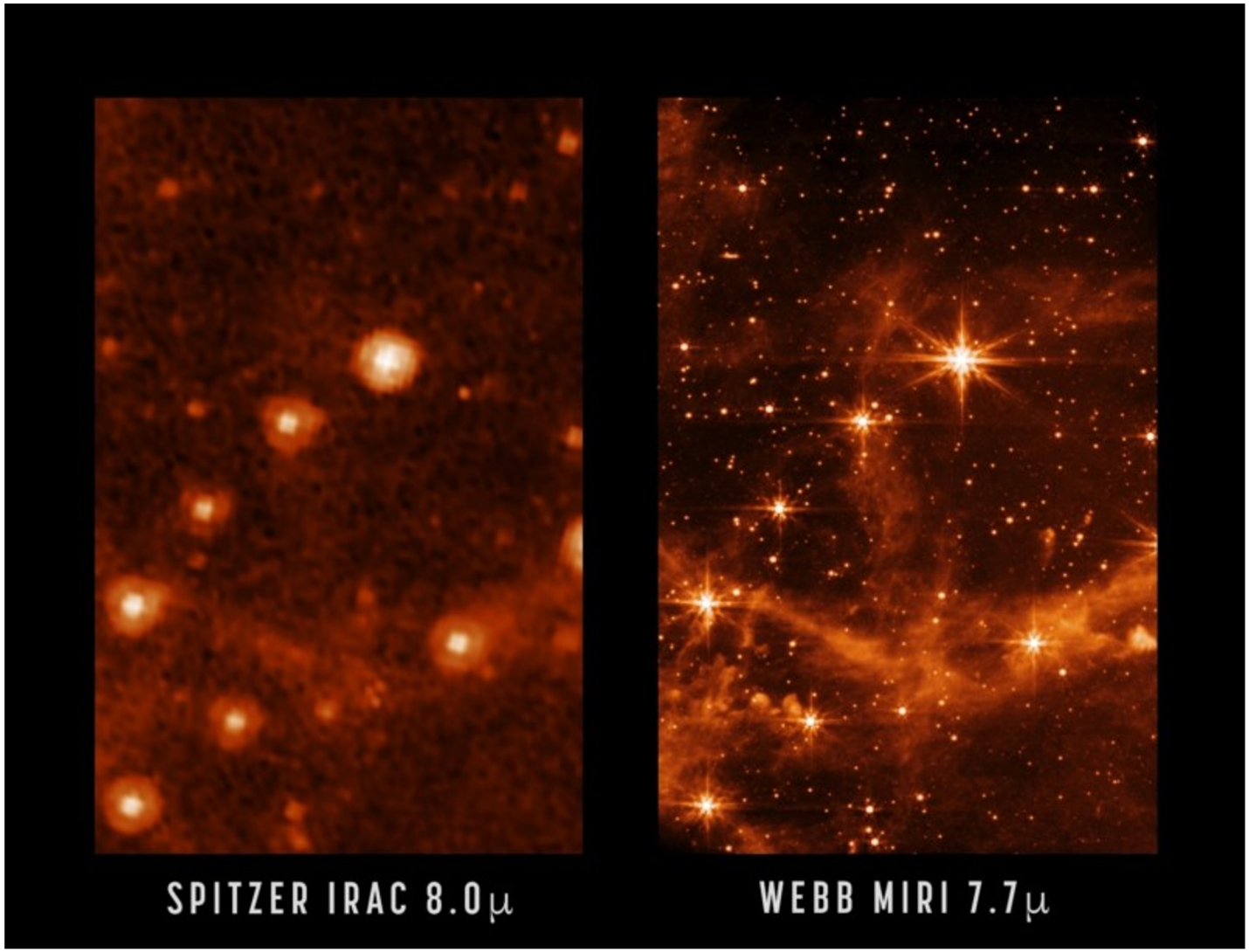
- Veća talasna dužina : gora rezolucija
- Veća primarna apertura : bolja rezolucija
- *Radio teleskopi imaju ogromne aperture ali ipak očajne rezolucije*

**Svaka tačka sa prve slike je razmrljana, to mešanje je matematički opisano “konvolucijom” slike sa takozvanom PSF (point spread function)**



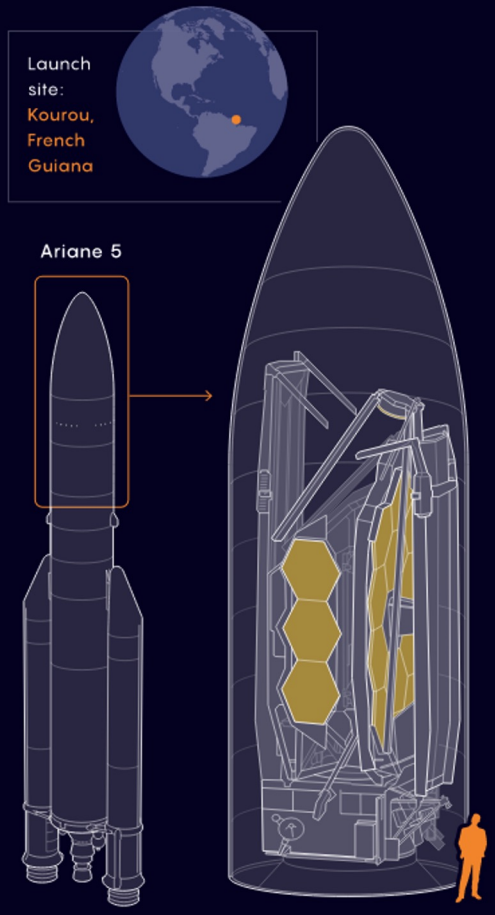



# Veći teleskop = Uži PSF = Oštrija slika



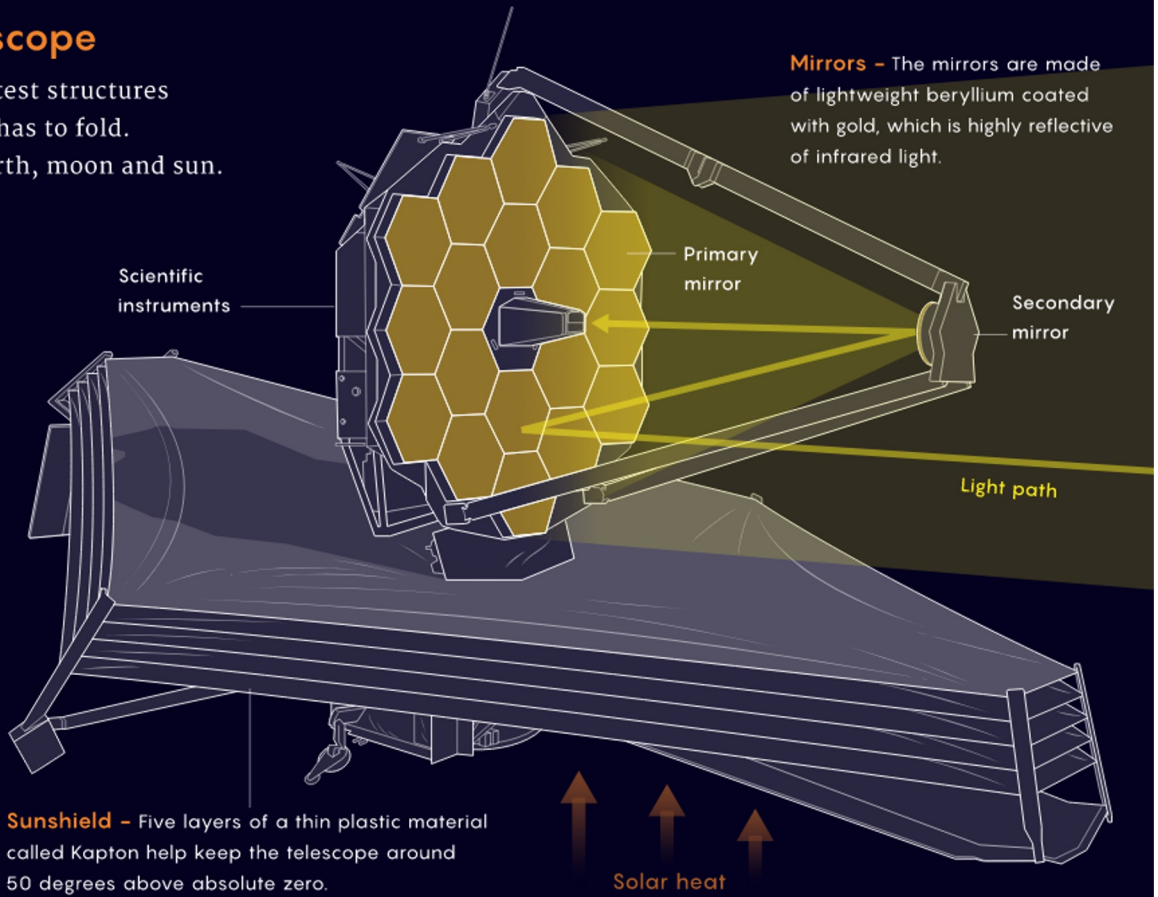
# The James Webb Space Telescope

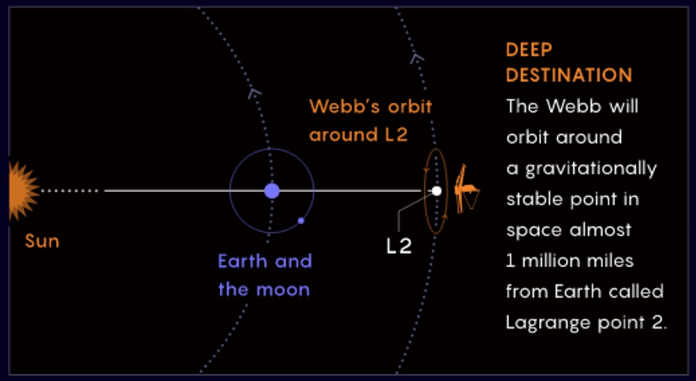
To collect enough infrared light to see the faintest structures in the cosmos, the JWST must be so big that it has to fold. It also needs to block heat coming from the Earth, moon and sun.




**ASTRO ORIGAMI**

The telescope's 6.5-meter-wide segmented mirror and 20-meter-wide sunshield fold to fit in the 5.4-meter-wide fairing of the European Space Agency's Ariane 5 rocket.



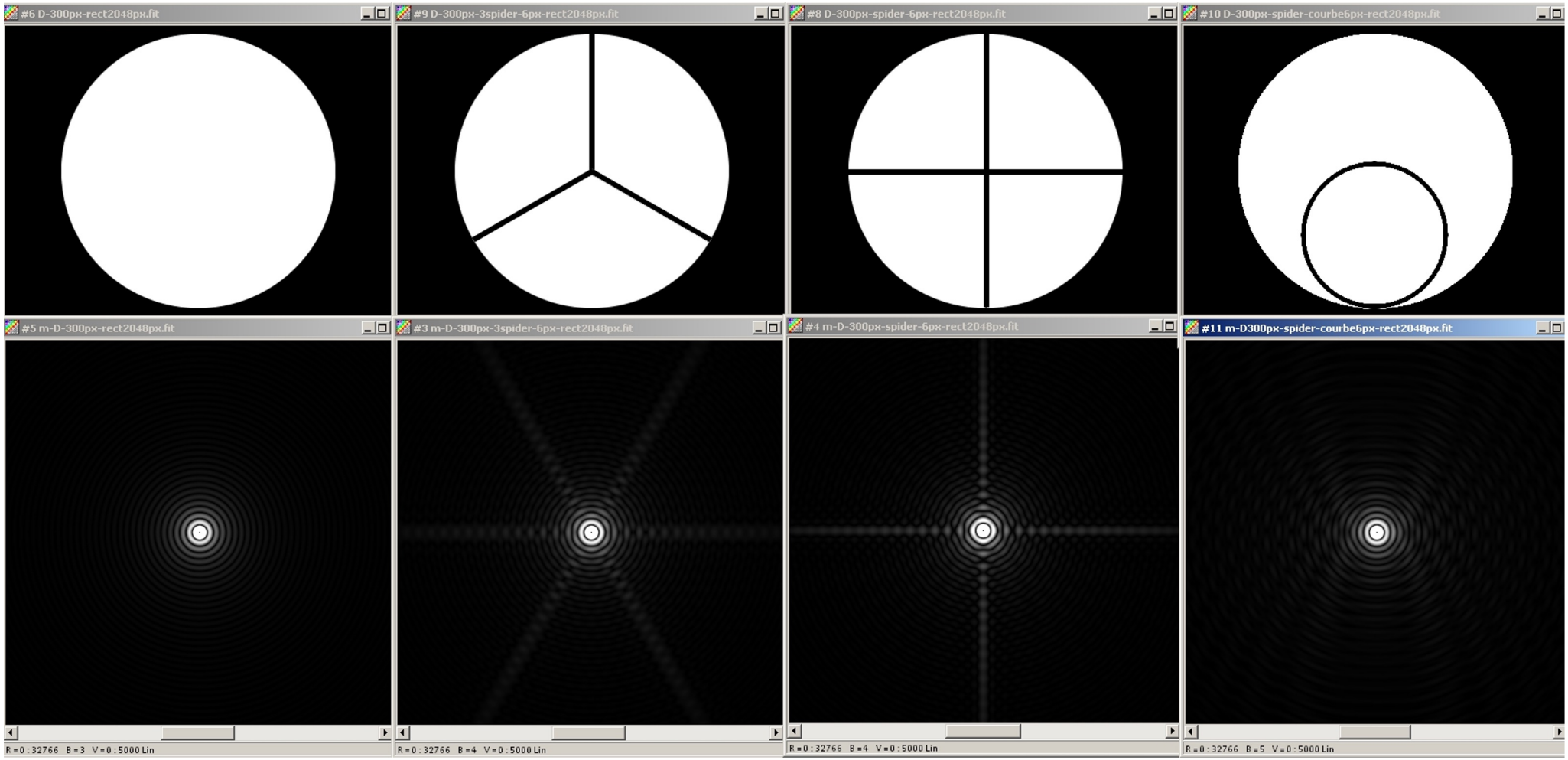

**DEEP DESTINATION**

The Webb will orbit around a gravitationally stable point in space almost 1 million miles from Earth called Lagrange point 2.

**ONBOARD INSTRUMENTS**

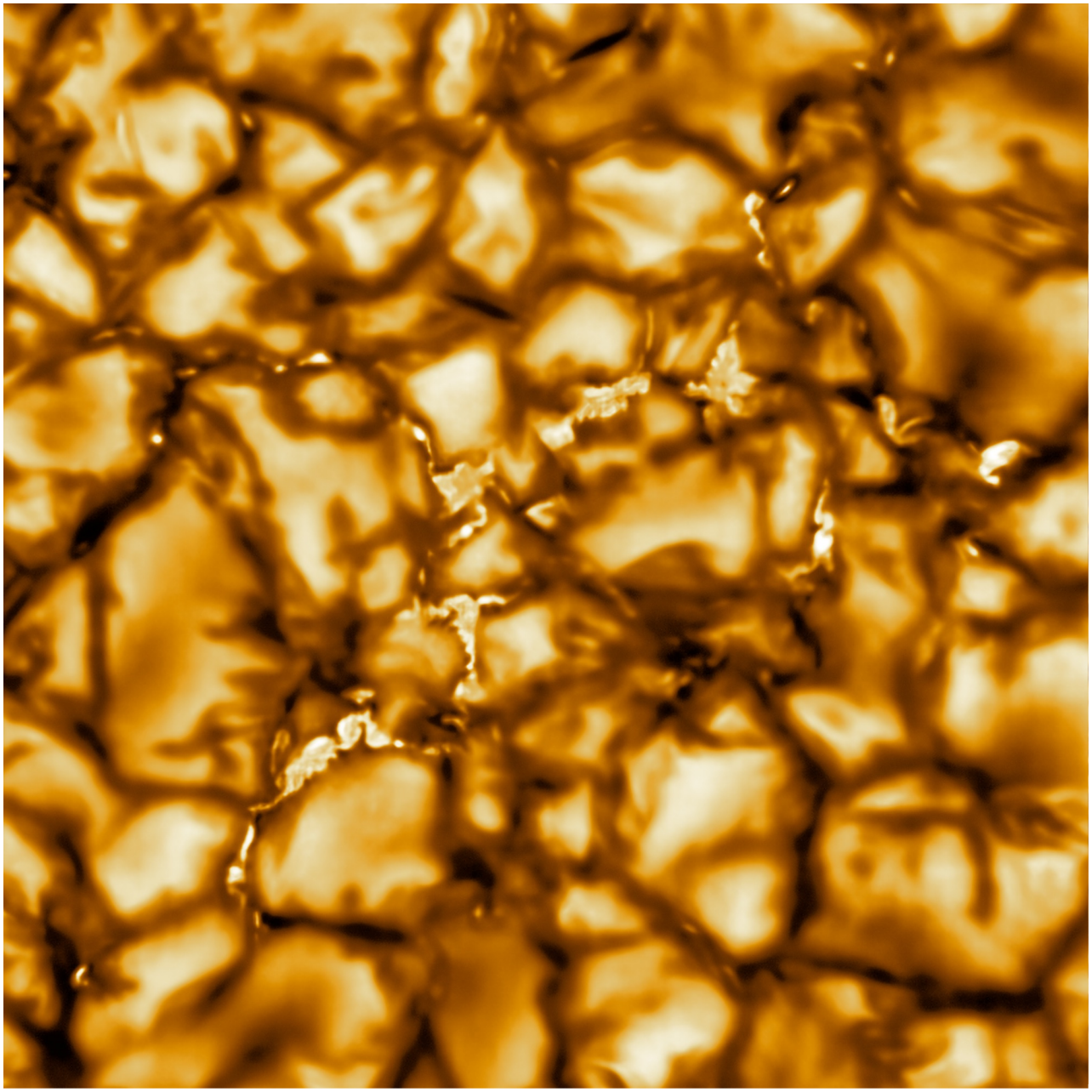
- **Near-Infrared Camera**
  Workhorse instrument; most sensitive.
- **Near-Infrared Spectrograph**
  Breaks starlight into its spectrum.
- **Mid-Infrared Instrument**
  Will collect light from the very first stars.
- **Near-Infrared Imager and Slitless Spectrograph**
  Extremely high-resolution planet finder.

# Tada otvor nije samo krug već nešto komplikovanije



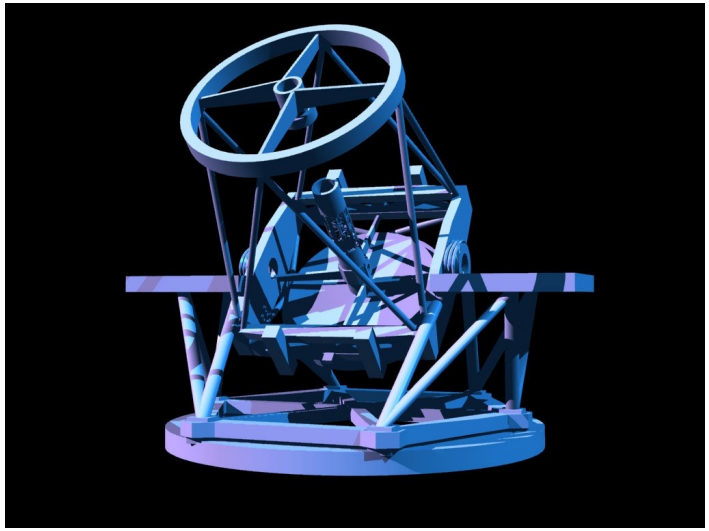
# Tako dobijamo ovako oštre slike!

- Ova slika je dobijena uz pomoć 4m Solarnog teleskopa
- Ovako izgleda Sunce kada vidimo detalje od ~ 20 km na njegovoj površini
- Uz sam teleskop, koristili smo razne tehnike za tzv. Restoraciju slike!



# Tipovi teleskopa

- Refraktori (koriste sočiva)
  - Dugački, klasičan dizajn
  - Ograničena veličina težinom
- Reflektori (koriste ogledala)
  - Kraći, noviji dizajn
  - Ograničeni veličinom ogledala iz jednog komada



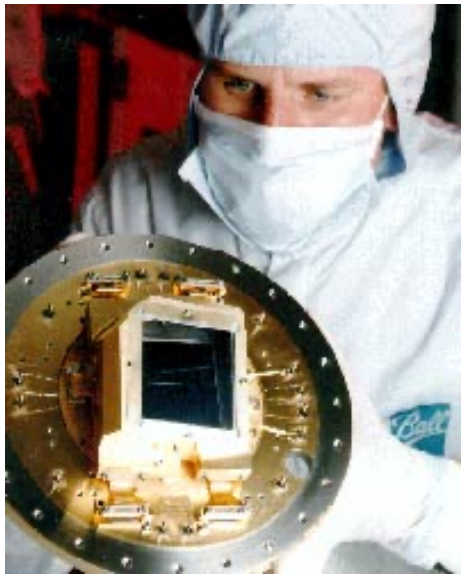
# DETEKCIJA SVETLOSTI

Da sačuvamo i analiziramo svetlost treba nam detektor

Ljudsko oko
- Manje osetljivo
- Ne možemo trajno da čuvamo slike

Fotografske/foto ploče
- Fotoemulzija na staklenoj ploči
- Akumulira svetlost
- Trajno čuva slike

Elektronski "film" (CCD čip)
- Mnogo osetljiviji od fotografske ploče
- Digitalni podaci idealni za računare
- Nastao zbog potrebe astronoma
- Osnovni elemnt svakog digitalnog fotoaparata I telefona



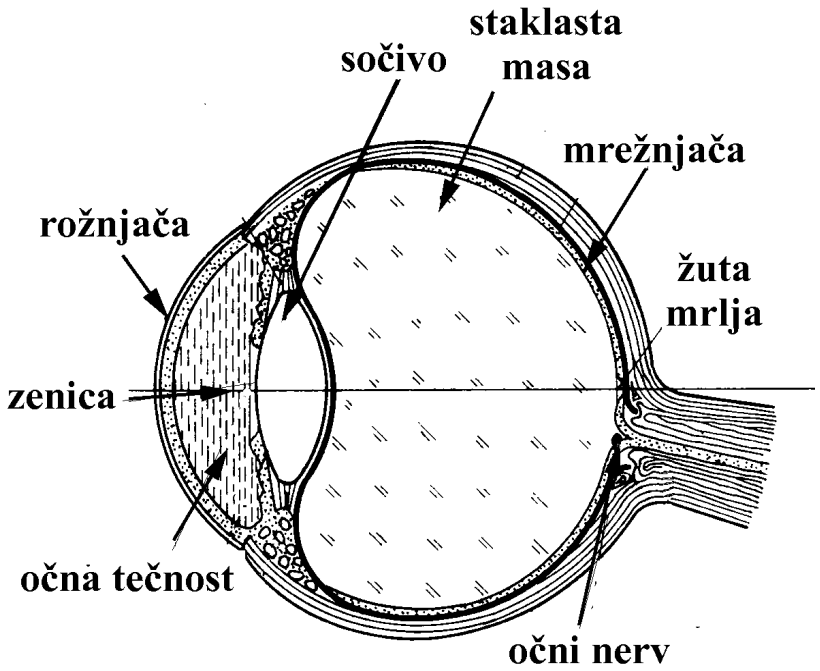
**CCD čip sa Habla**

# OKO / 400 GODINA JEDINI OPTIČKI INSTRUMENT

prirodni optički sistem koji se sastoji od

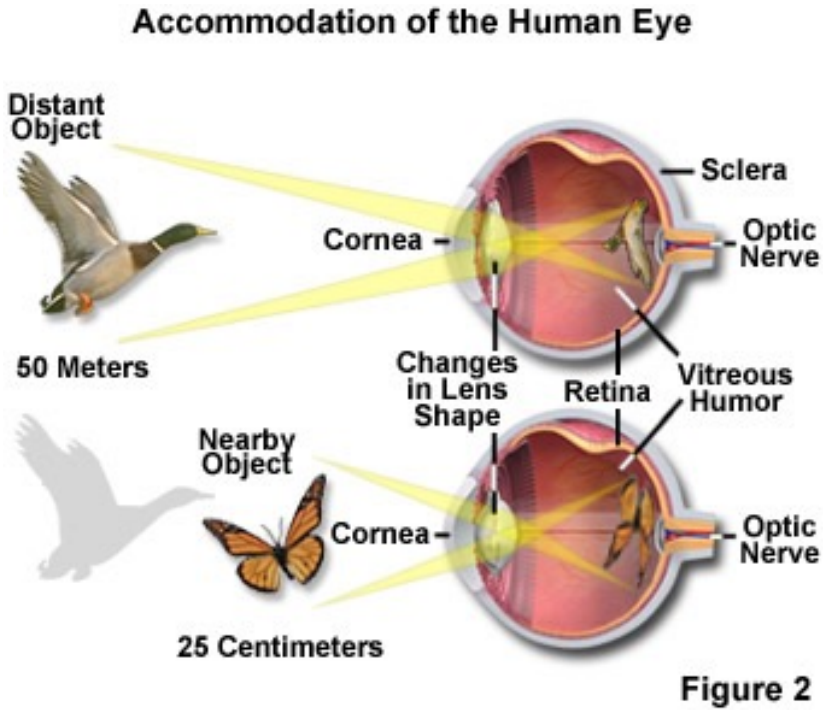
- optičkog dela koji stvara lik predmeta
- detektora

- rezolucija oko 60”



# AKOMODACIJA OKA

- stvaranje oštre slike predmeta koji se nalazi blizu oka (<5 m)
- radijus krivine prednje površine se smanjuje (i do oko 5 mm)

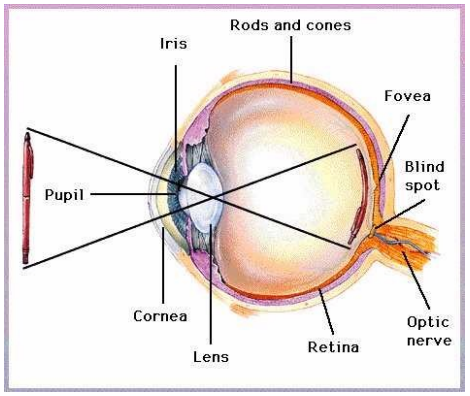


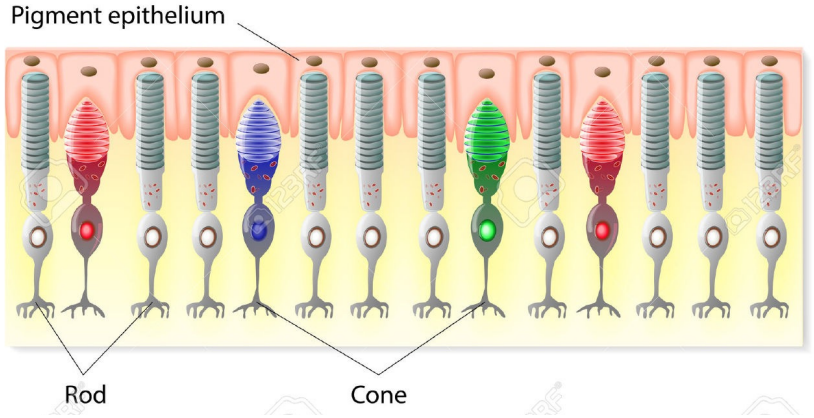
# MREŽNJAČA = DETEKTOR

nervne ćelije - čepići i štapići

žuta mrlja – mesto oštrog vida, najviše čepića, odgovorni za dnevno gledanje (kao i za to što vidimo u boji – postoje tri vrste)

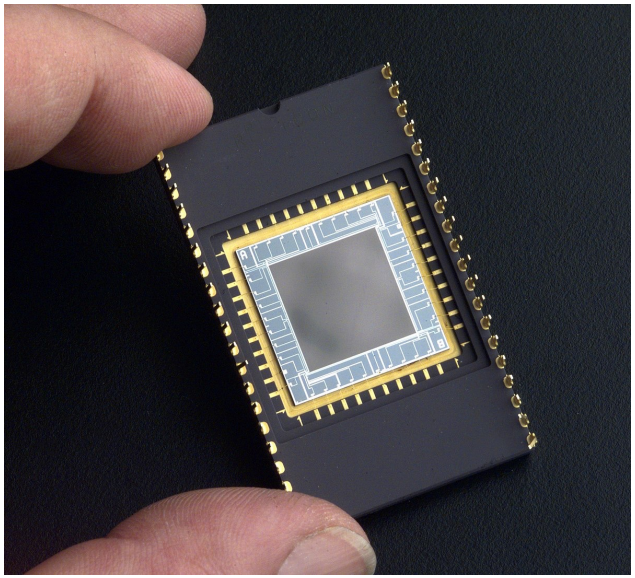
u ostatku mrežnjače više štapića, osetljiviji, služe za noćno gledanje



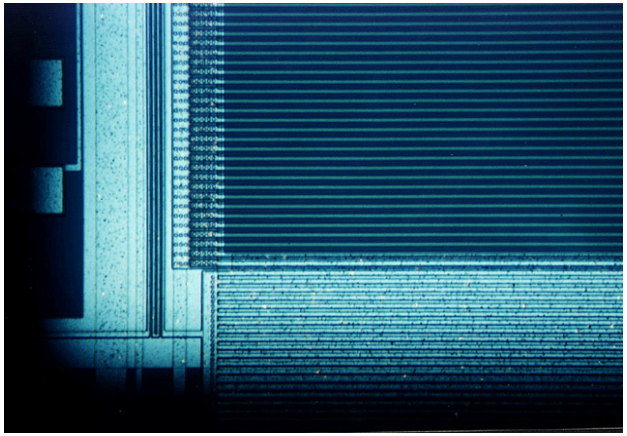



# CCD kamera

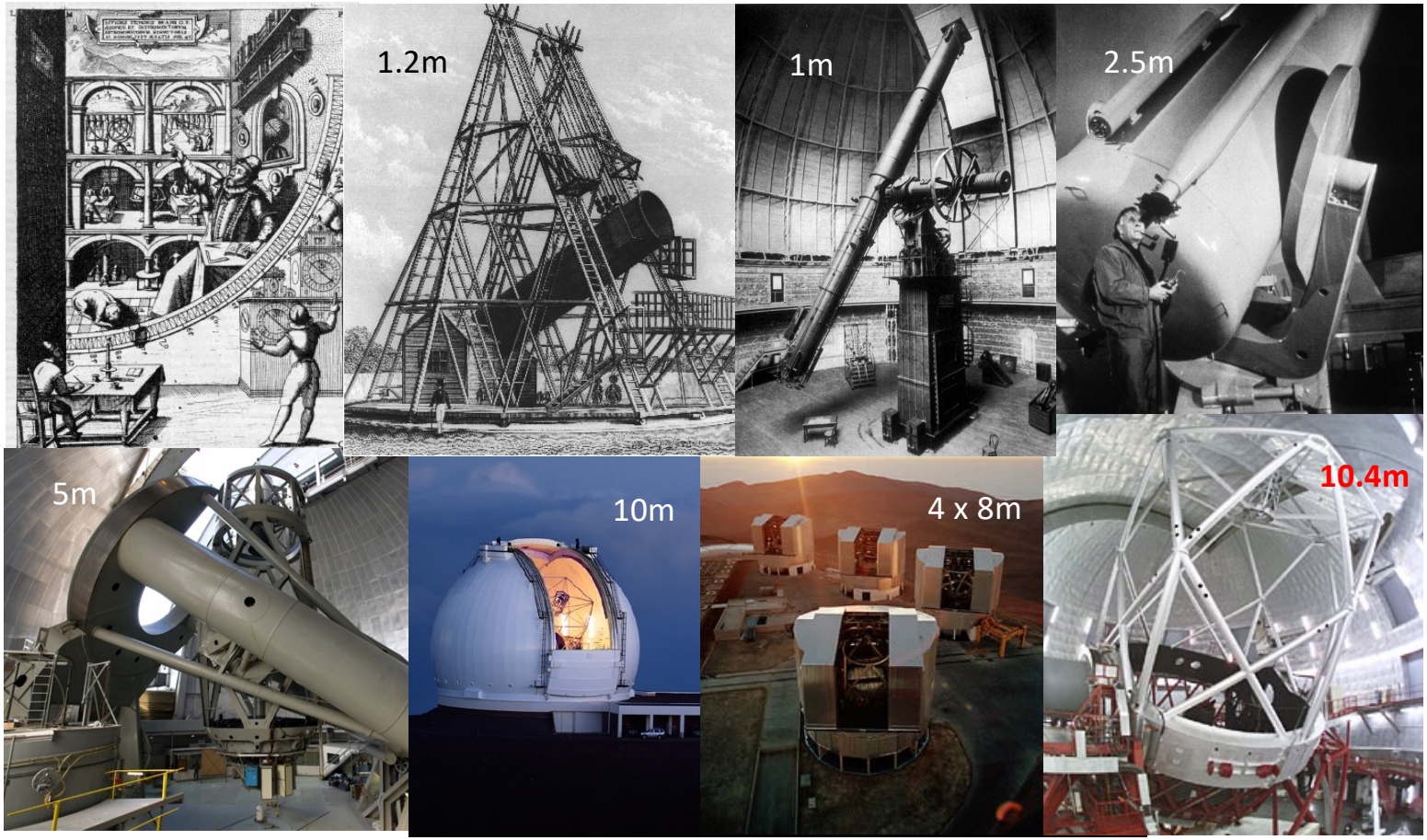
- matrica fotoosetljivih ćelija (piksela)
- napravljena od silicijuma
- radi na principu fotoelektričnog efekta

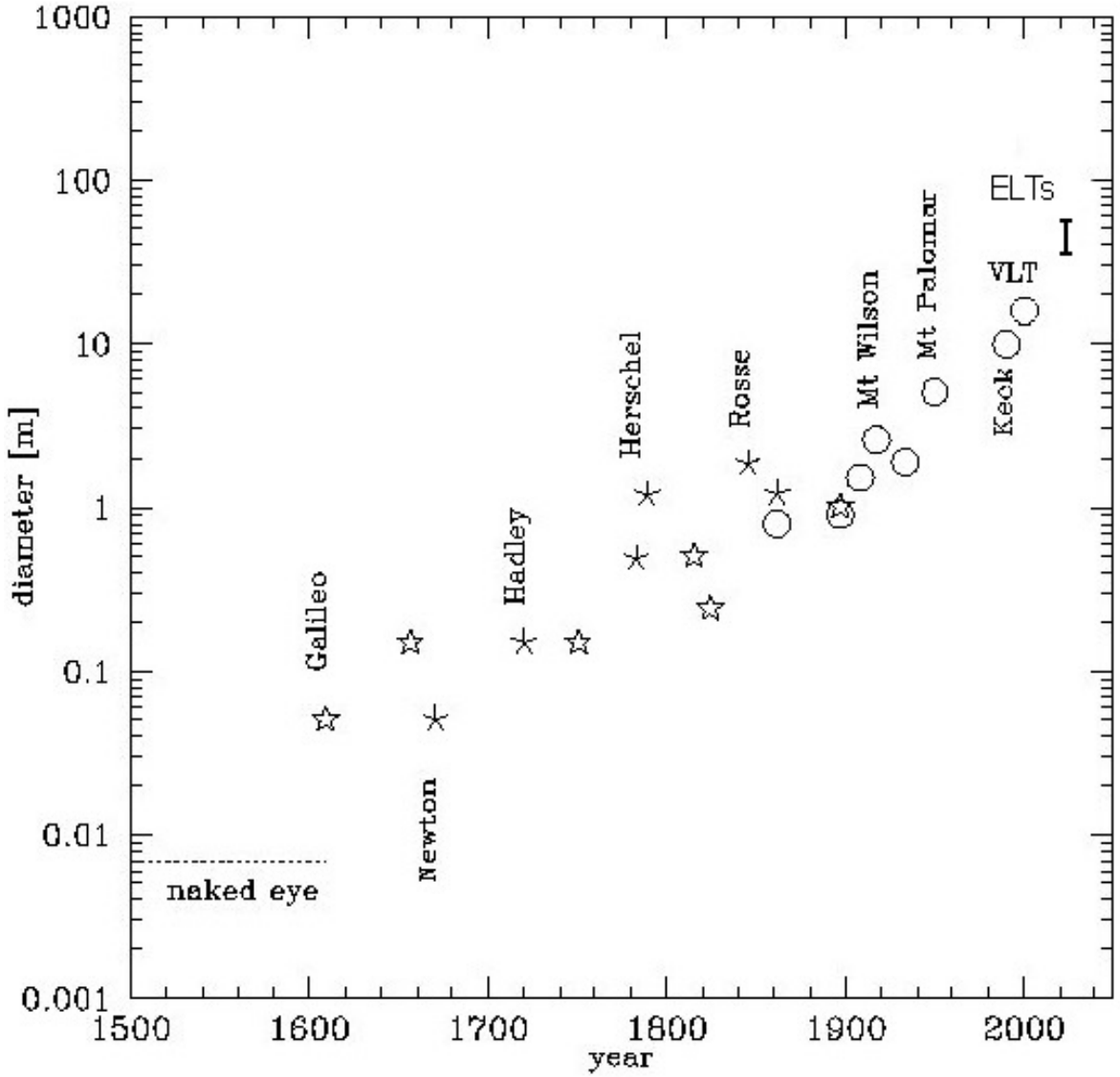


- mnogo bolja osetljivost
- veći opseg talasnih dužina
- mogućnost sakupljana više svetlosti u toku vremena
- linearni odgovor – koliko fotona toliko proporcionalno elektrona



# Pravljeni sve veći i veći teleskopi

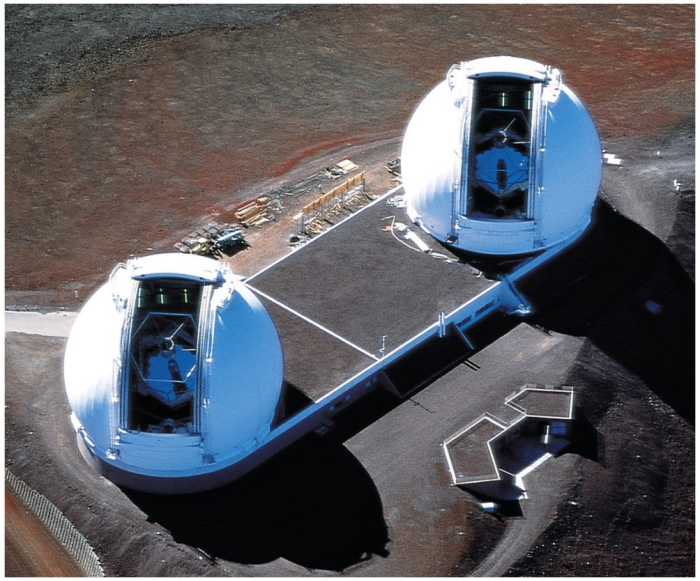



1000
100
10
1
0.1
0.01
0.001
diameter [m]
1500
1600
1700
1800
1900
2000
year
Galileo
Newton
Hadley
Herschel
Rosse
Mt Wilson
Mt Palomar
Keck
VLT
ELTs
naked eye

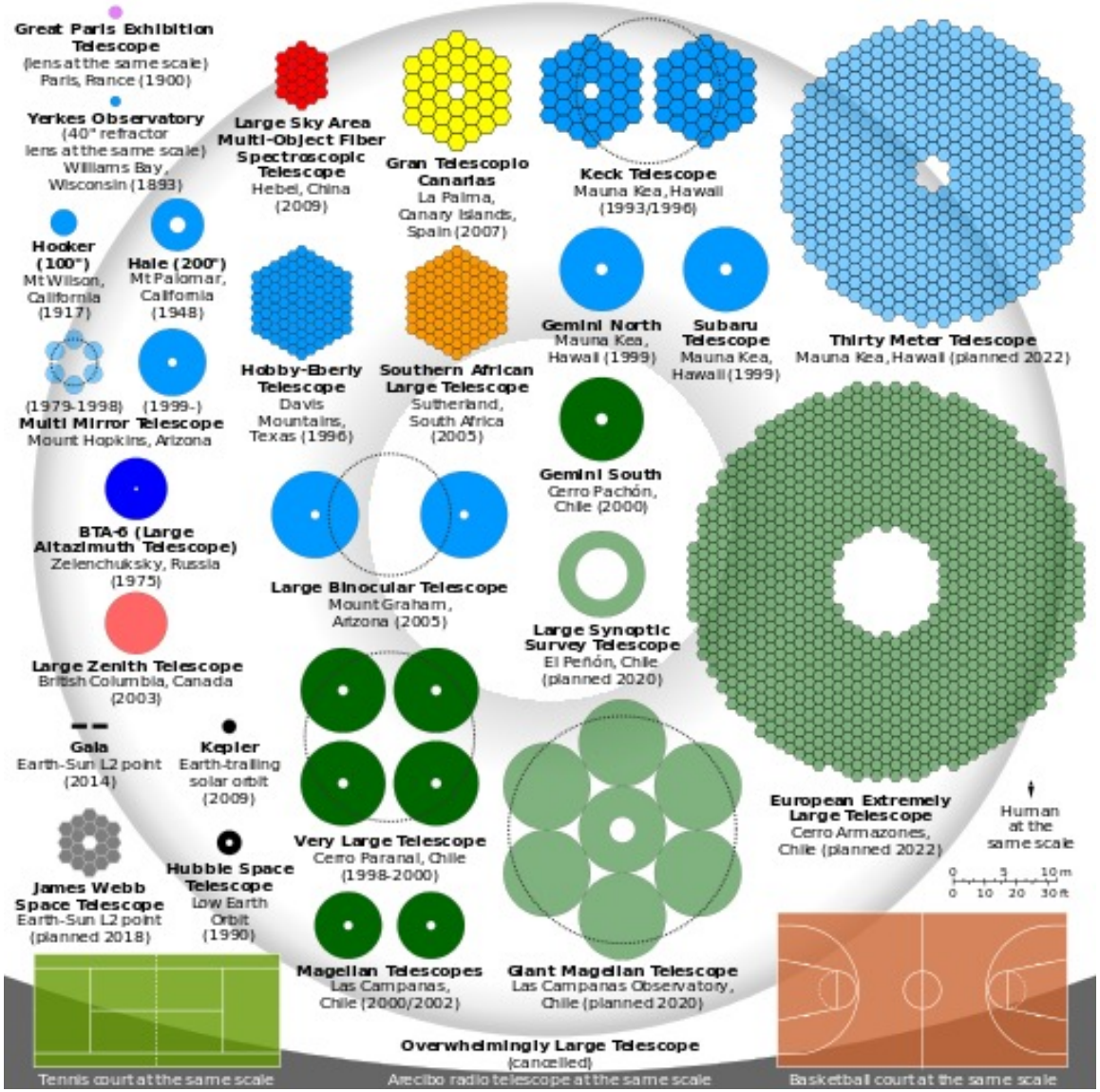
# Veliki teleskop na Kanarima (GTC)

- Kanarska ostrva, La Palma
- Počeo sa radom 2007.
- Ogledalo prečnika 10.4m

# Kek (*Keck*) opservatorija, Havaji



- Dva reflektorska teleskopa od po 10m
- Završeni 1993. & 1996.
- Drugi najveći reflektori na svetu

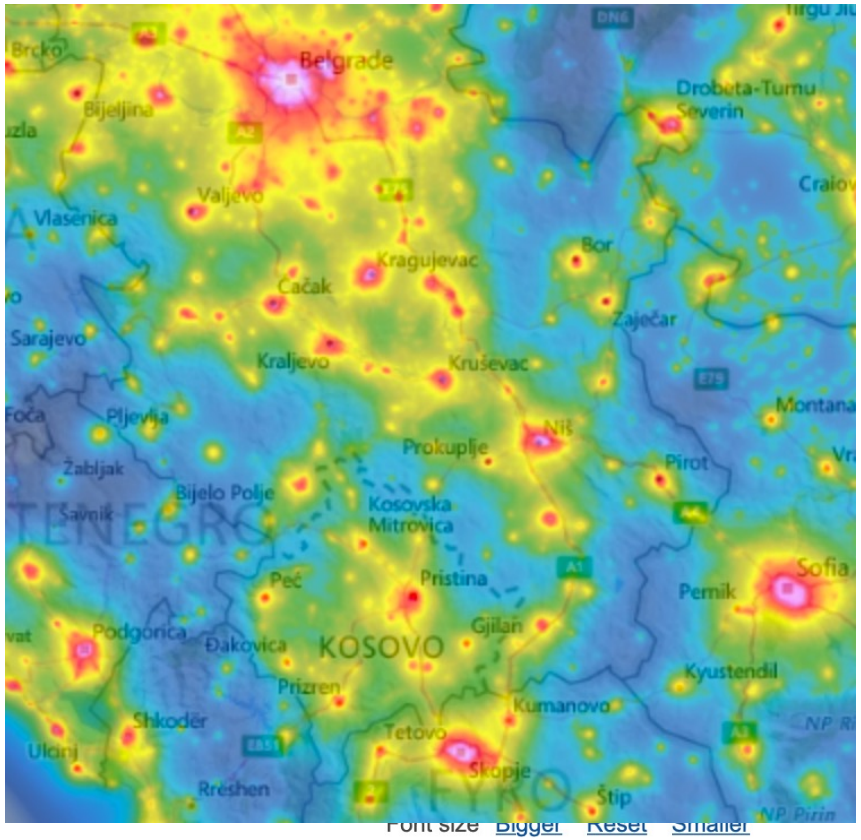

Great Paris Exhibition Telescope
(lens at the same scale)
Paris, France (1900)
Yerkes Observatory
(40" refractor lens at the same scale)
Williams Bay, Wisconsin (1893)
Hooker (100")
Mt Wilson, California (1917)
Hale (200")
Mt Palomar, California (1948)
(1979-1998)
(1999-)
Multi Mirror Telescope
Mount Hopkins, Arizona
BTA-6 (Large Altazimuth Telescope)
Zelenchuksky, Russia (1975)
Large Zenith Telescope
British Columbia, Canada (2003)
Gaia
Earth-Sun L2 point (2014)
Kepler
Earth-trailing solar orbit (2009)
James Webb Space Telescope
Earth-Sun L2 point (planned 2018)
Hubble Space Telescope
Low Earth Orbit (1990)
Large Sky Area Multi-Object Fiber Spectroscopic Telescope
Hebei, China (2009)
Gran Telescopio Canarias
La Palma, Canary Islands, Spain (2007)
Keck Telescope
Mauna Kea, Hawaii (1993/1996)
Hobby-Eberly Telescope
Davis Mountains, Texas (1996)
Southern African Large Telescope
Sutherland, South Africa (2005)
Gemini North
Mauna Kea, Hawaii (1999)
Subaru Telescope
Mauna Kea, Hawaii (1999)
Thirty Meter Telescope
Mauna Kea, Hawaii (planned 2022)
Gemini South
Cerro Pachón, Chile (2000)
Large Binocular Telescope
Mount Graham, Arizona (2005)
Large Synoptic Survey Telescope
El Peñón, Chile (planned 2020)
Very Large Telescope
Cerro Paranal, Chile (1998-2000)
Magellan Telescopes
Las Campanas, Chile (2000/2002)
Giant Magellan Telescope
Las Campanas Observatory, Chile (planned 2020)
European Extremely Large Telescope
Cerro Armazones, Chile (planned 2022)
Human at the same scale
0 5 10 m
0 10 20 30 ft
Overwhelmingly Large Telescope
(cancelled)
Tennis court at the same scale
Arecibo radio telescope at the same scale
Basketball court at the same scale

# Veliki refraktor, AOB

- 1932: Veliki refraktor Zeiss 65/1055 cm (tada četvrti po veličini instrument u Evropi)

# Posmatračka stanica Astronomske opservatorije u Beogradu

- Astronomska stanica Vidojevica
- Planina Vidojevica, u blizini Prokuplja




- Teleskop Milanković - 140 cm
- Teleskop Nedeljković - 60 cm
- Postavljen - 40 cm teleskop


http://vidojevica.aob.rs/

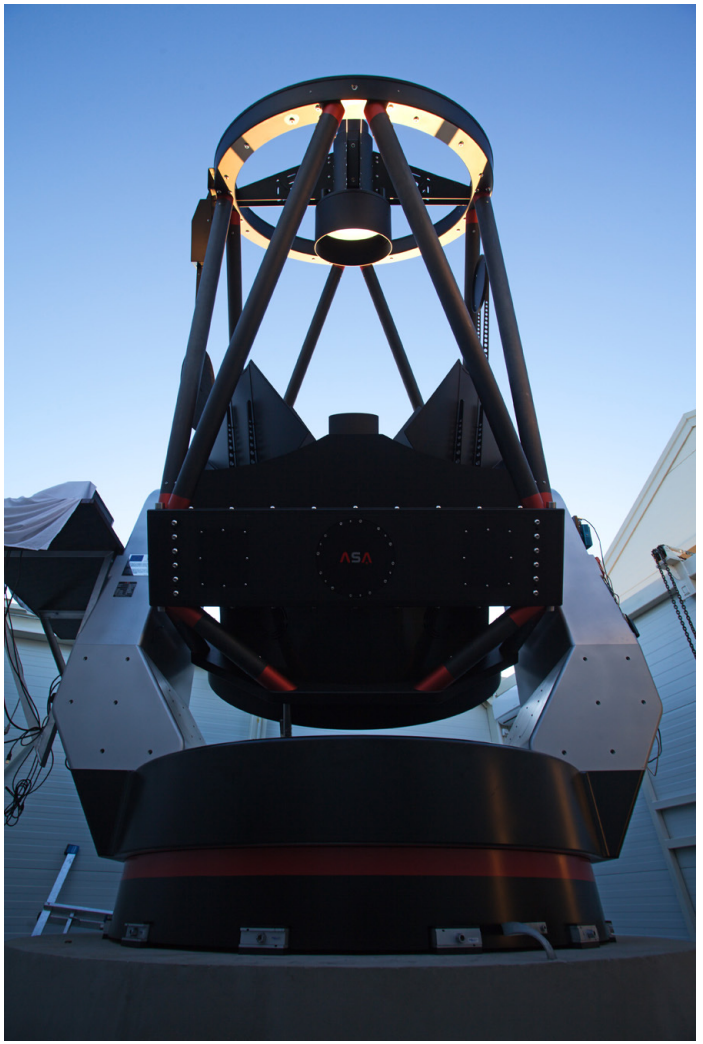

# Astronomical Station Vidojevica

is observation site established by Astronomical Observatory of Belgrade. ASV is located on Mt. Vidojevica in area with small light pollution, and good seeing conditions.

(long: 21° 33' 20.4", lat: 43° 08' 24.6", alt: 1150m)

# 1.4m Milankovic teleskop

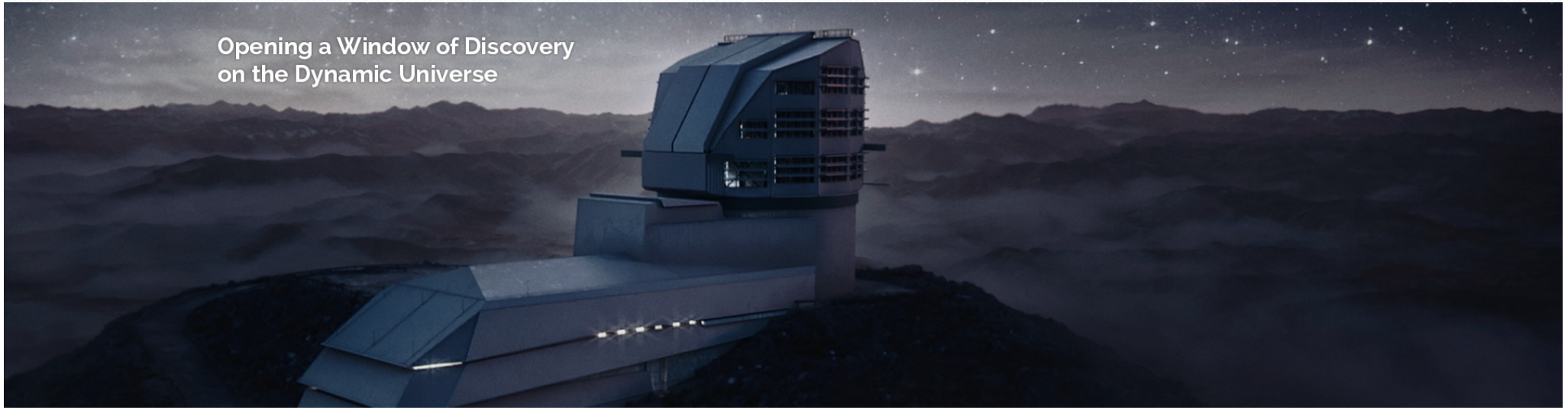
- Mehanika: ASA
- Optika: LOMO, St. Petersburg Russia
- Primarno ogledalo: 1.4 m
- Žižna daljina: 11.2 m (f/8) – reduktor fokusa
- Montaža: alt-azimuth
- Težina: 8.5 tona
- Visina : 4.5 metra
- Nasmit i “savijen” Kasegren fokus



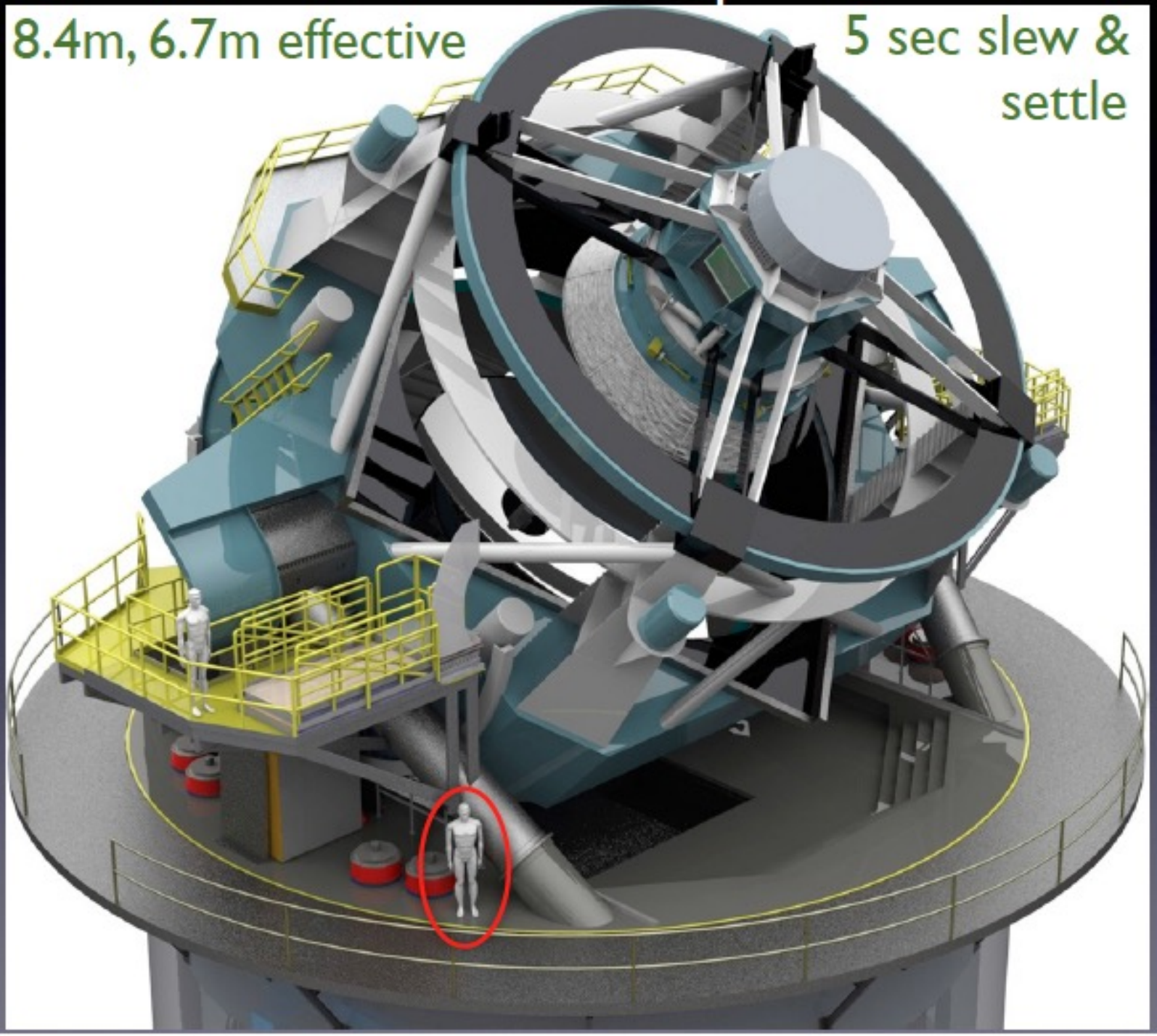
# Vera C. Rubin Opservatorija

**10-year Legacy Survey of Space and Time (LSST)**

- **will produce the deepest, widest, image of the Universe**
- 27-ft (8.4-m) mirror, the width of a singles tennis court
- 3200 megapixel camera → Each image the size of 40 full moons
- 37 billion stars and galaxies
- 10 year survey of the sky
- Up to 10 million alerts, 1000 pairs of exposures, 20 Terabytes of data .. every night!
- Goals: Understanding Dark Matter and Dark Energy, Hazardous Asteroids and the Remote Solar System, The Transient Optical Sky, The Formation and Structure of the Milky Way



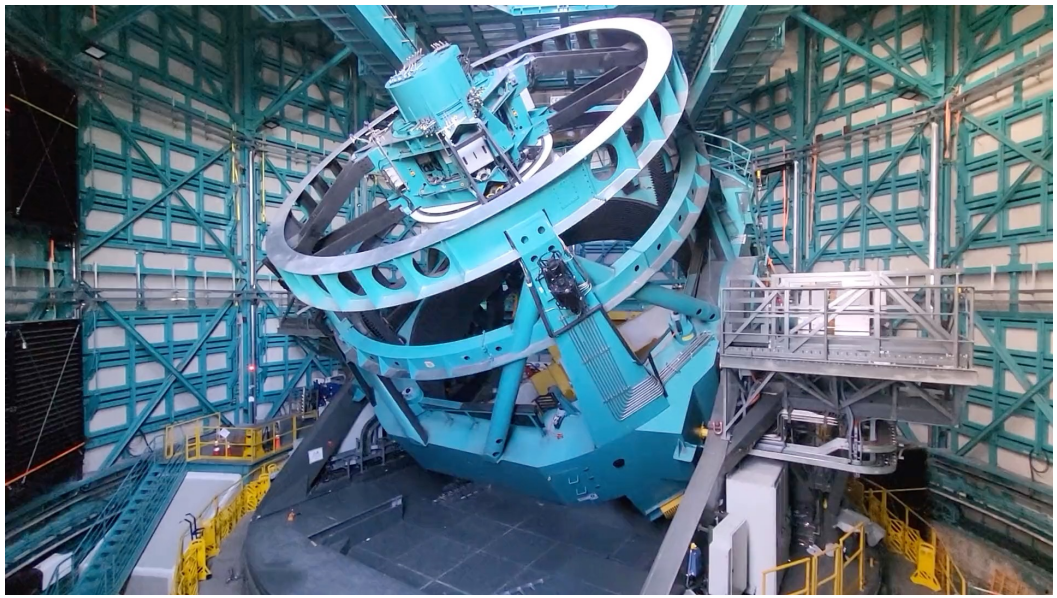
# LSST Telescope



# Simonyi Survey Telescope

This is real moving speed

- Simonyi Survey Telescope: 8.4-meter telescope with a novel, three-mirror design.
- Compact shape allows it to move quickly from one point in the sky to the next
- It will image the sky continuously each night, on an automated cadence, and over the course of the 10-year survey will collect about 800 images of each location in the sky.



https://twitter.com/mjuric/status/1706223278195343793?s=20

# Legacy survey in space and time = LSST

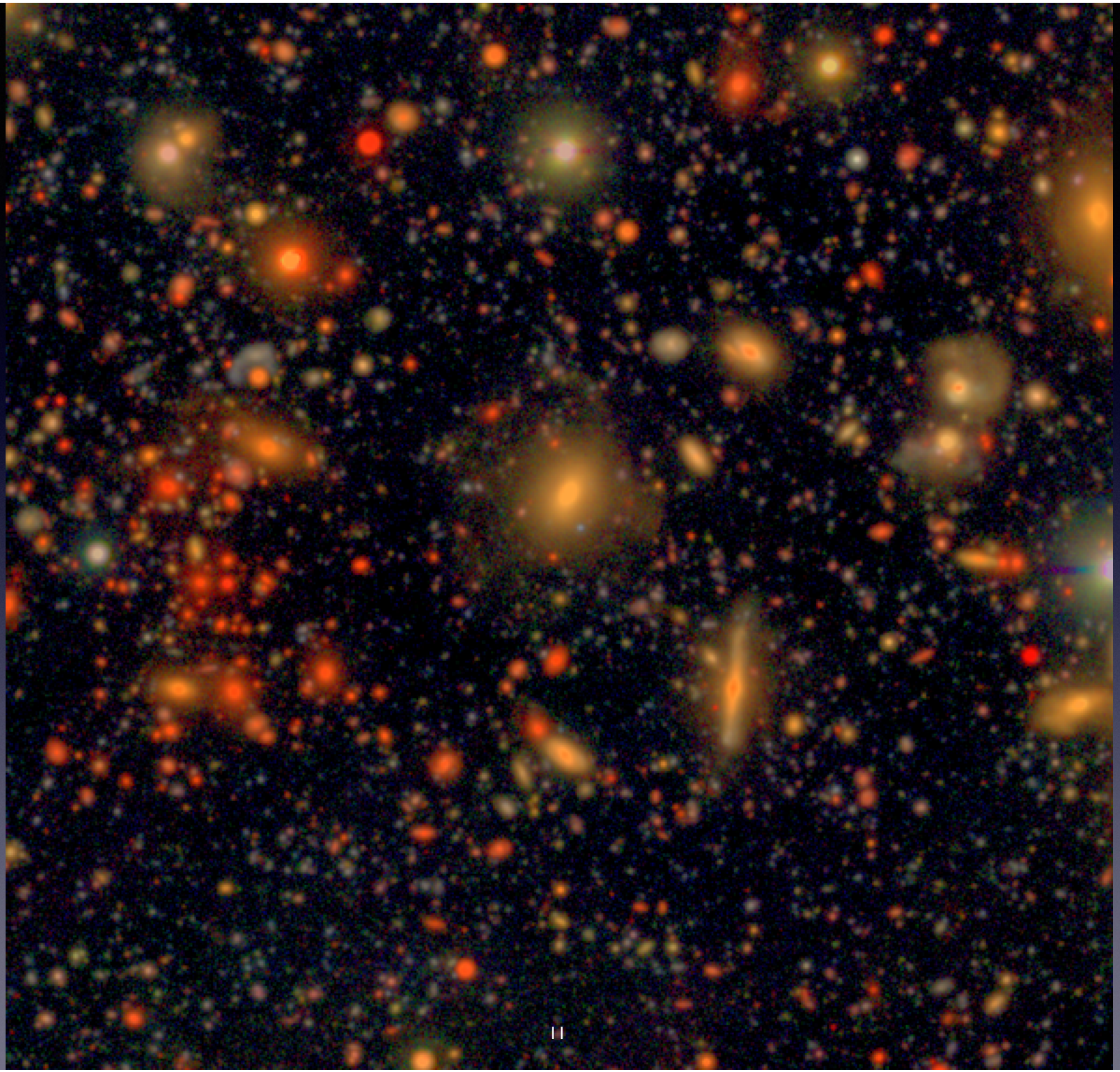
- LSST camera
- largest digital camera ever constructed for the field of astronomy
- size of a small car and weighing more than 3 tons
- 3200-megapixel cam

VERA C. RUBIN
OBSERVATORY

SDSS
gri
3.5'x3.5'
r~22.5

HSC
gri
3.5'x3.5'
r~27

Like LSST, but tiny area: LSST will deliver 5 million such images

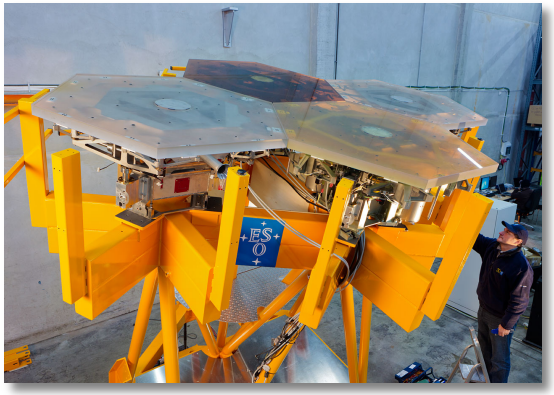


# Modern instruments

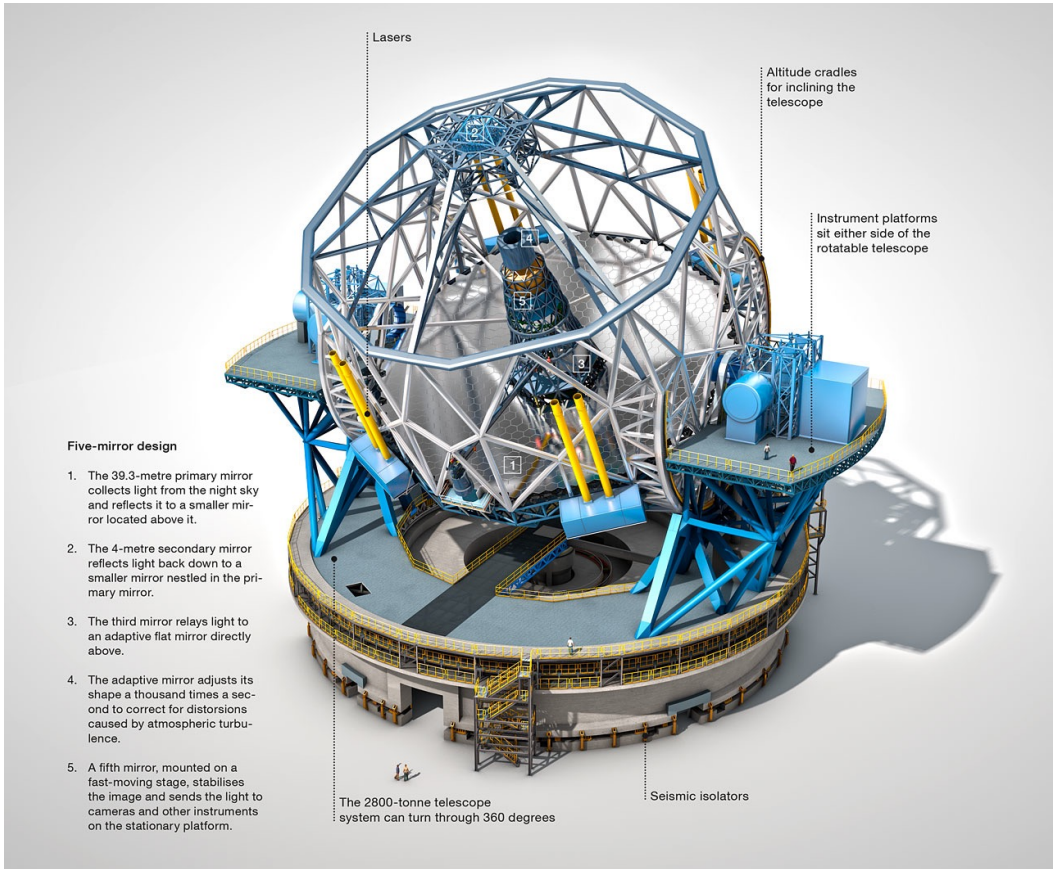
European Southern Observatory

www.eso.org

- **Extremly Large Telescopes**
- Frontiers of Science and Technology
- 39.4m size mirror
  800 x 1.4m mirrors=980m2



- 3000t of moving components

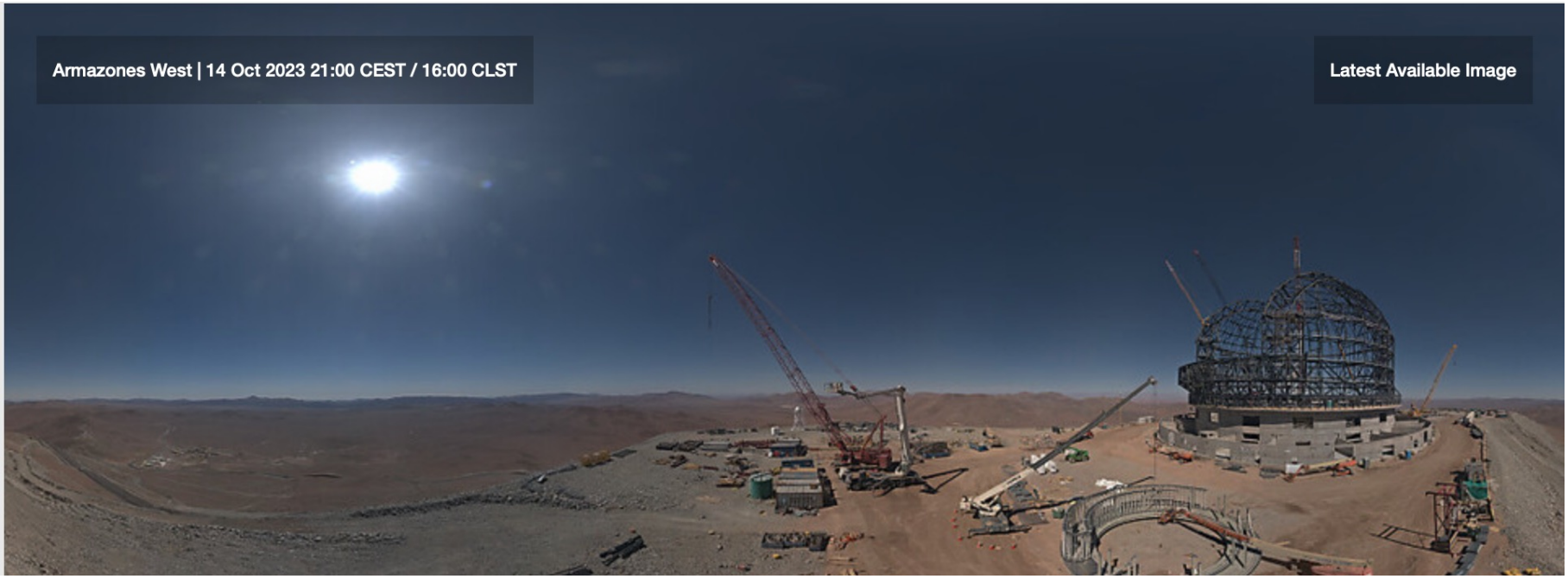


# Extremly Large Telescopes

European
Southern
Observatory

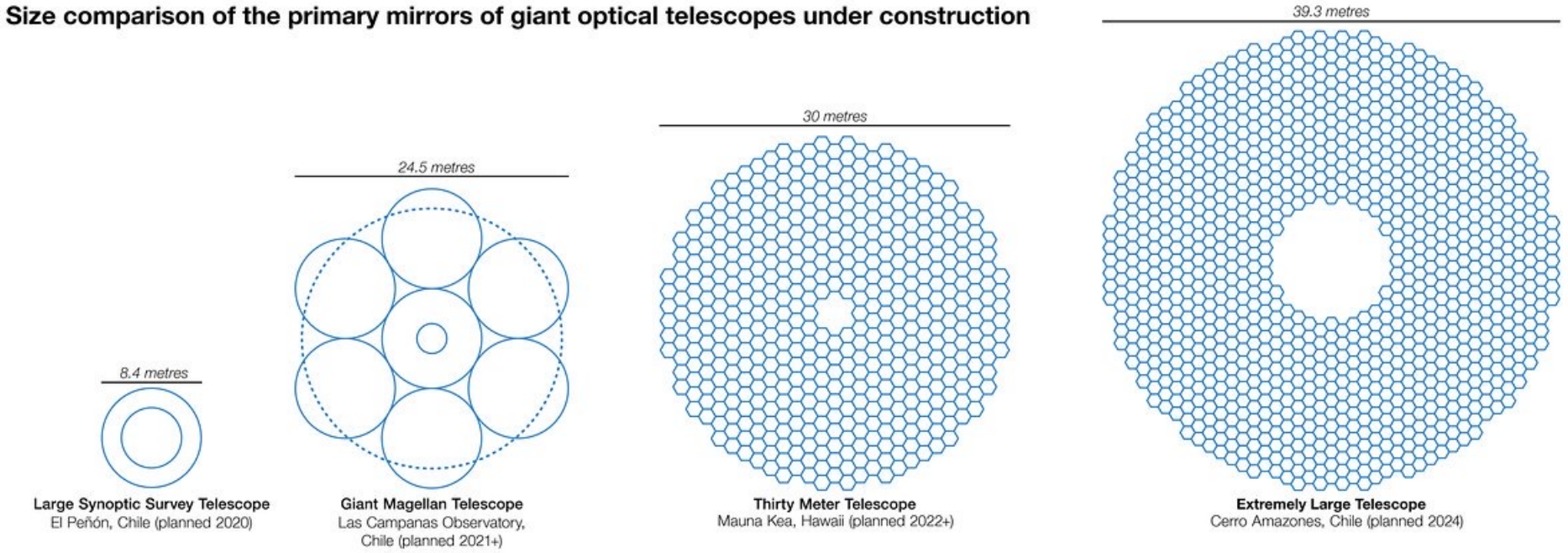
www.eso.org

https://elt.eso.org/about/webcams/

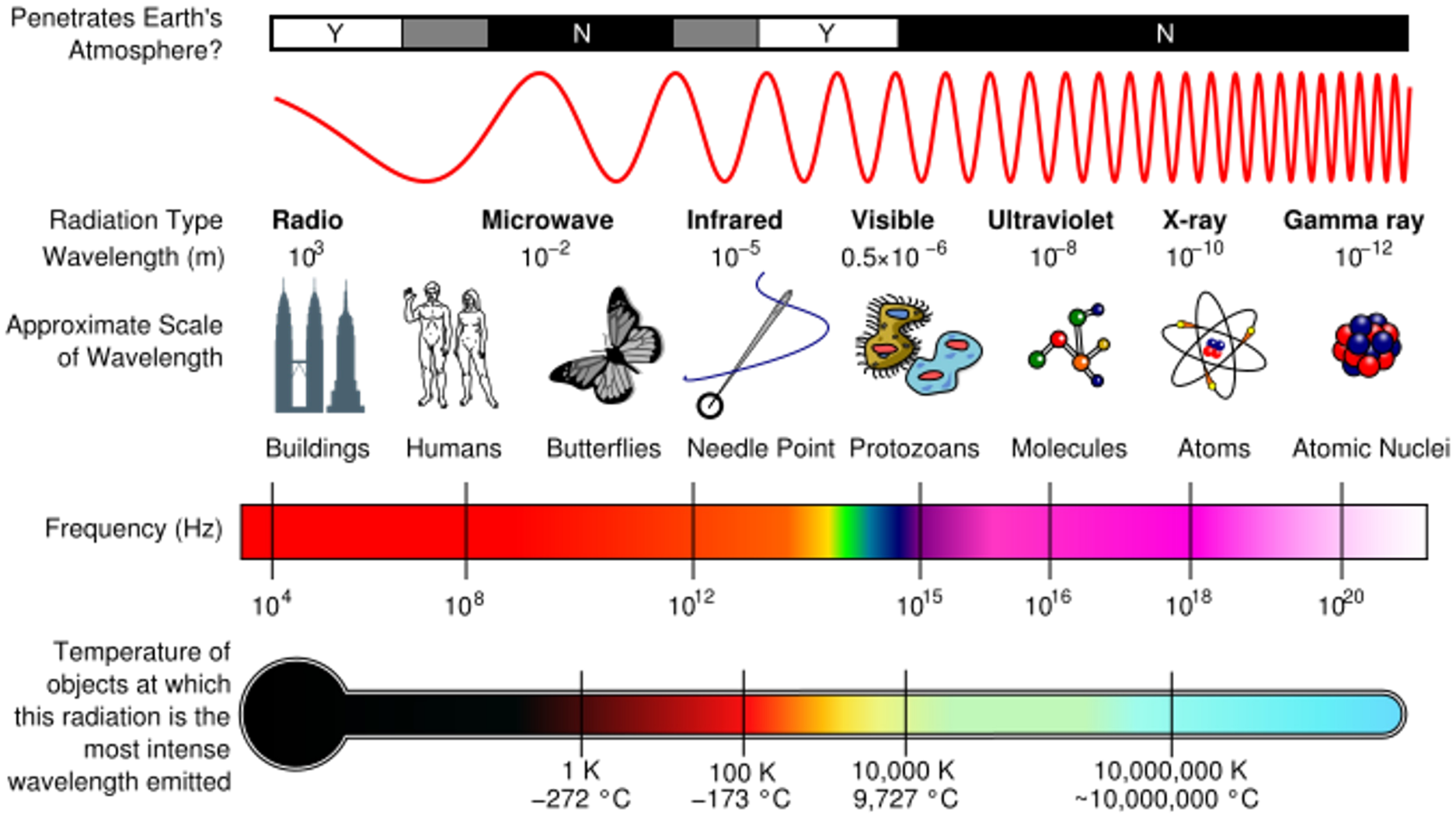



**The largest telescope that will ever be built***
https://www.youtube.com/watch?v=QqRREz0iBes

# THE giants

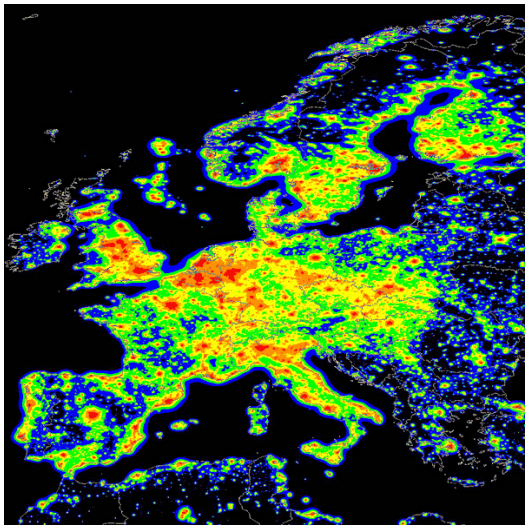

Size comparison of the primary mirrors of giant optical telescopes under construction
8.4 metres
Large Synoptic Survey Telescope
El Peñón, Chile (planned 2020)
24.5 metres
Giant Magellan Telescope
Las Campanas Observatory,
Chile (planned 2021+)
30 metres
Thirty Meter Telescope
Mauna Kea, Hawaii (planned 2022+)
39.3 metres
Extremely Large Telescope
Cerro Amazones, Chile (planned 2024)

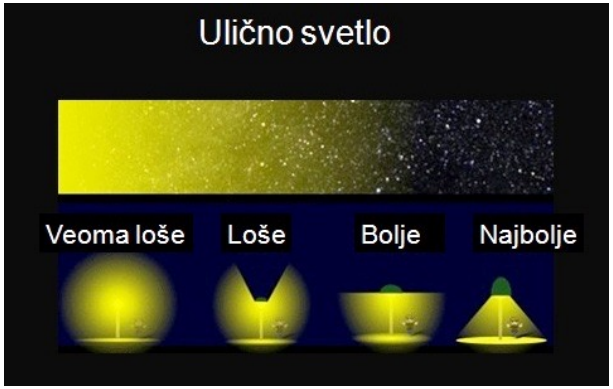
# Postoje posebni teleskopi za sve delove spektra!

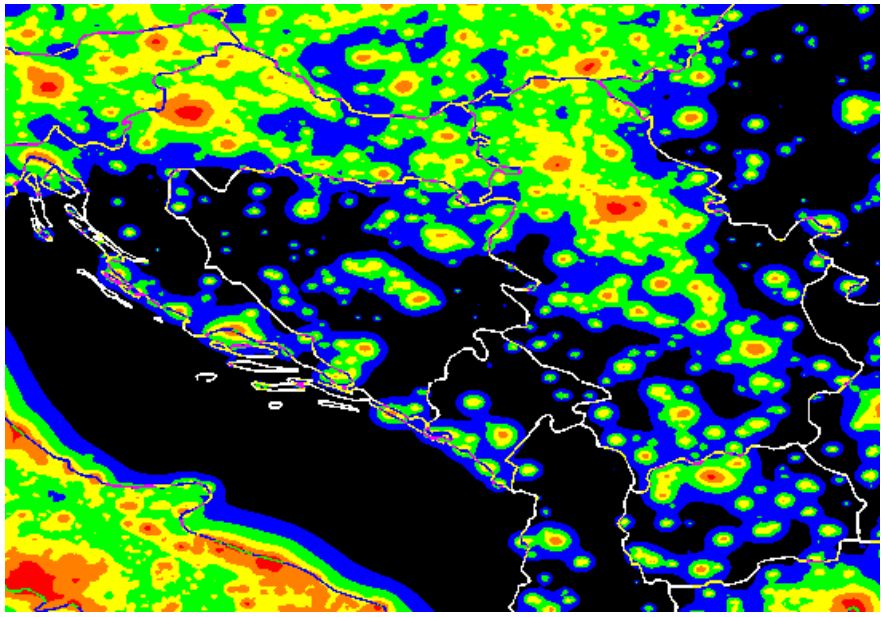


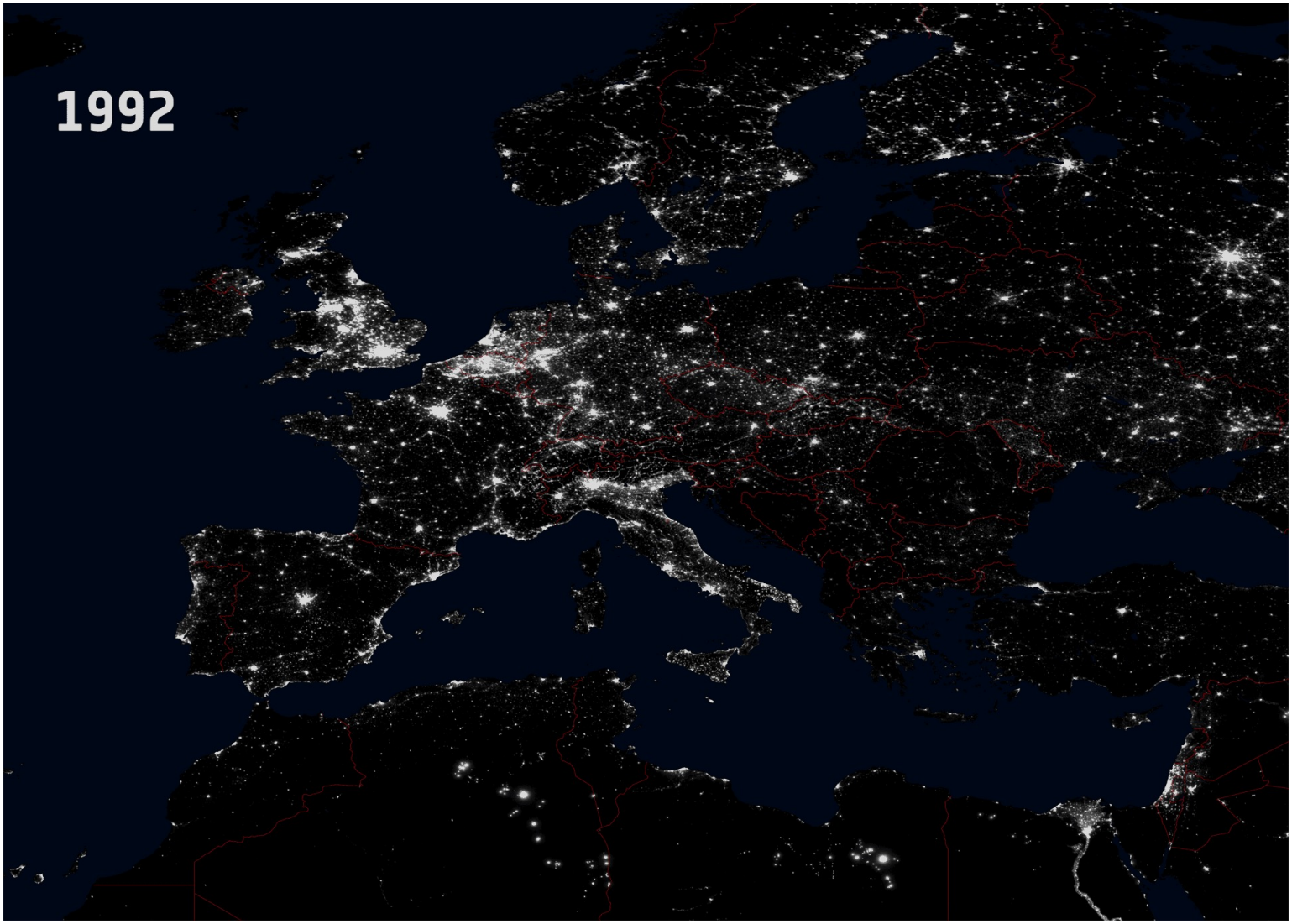
# Svetlosno zagađenje

- Veliki problem za astronome
- Gradska svetla podižu pozadinski nivo svetla
- Otežava sakupljanje svetlosti od zvezda
- Postaje sve gore!

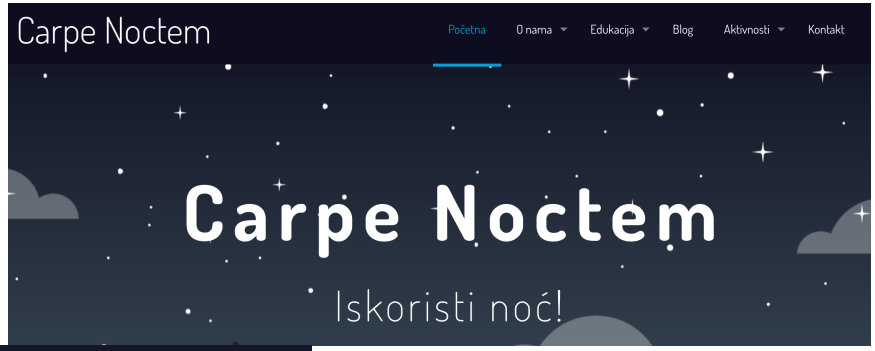





1992

# Aktivnosti kod nas





neprofitna organizacija, osnovana kao ekološko udruženje koje za glavni fokus ima problematiku svetlosnog zagađenja

https://carpenoctem.rs

# Problem: Zemljina atmosfera

- koliko iznosi teorijska rezolucija za teleskop od 10m?

- zašto je onda prosečna rezolucija (vidljivost = seeing)

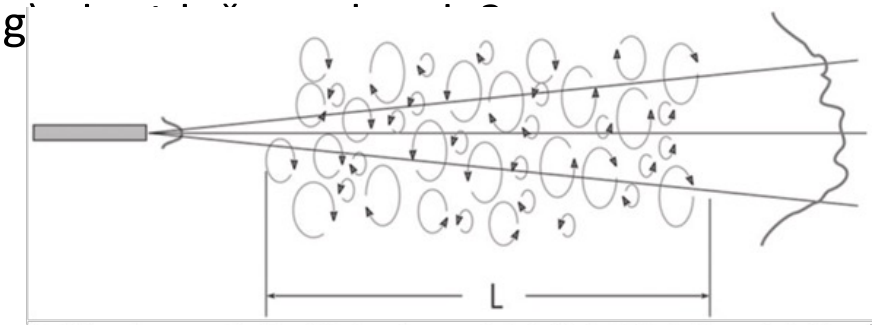
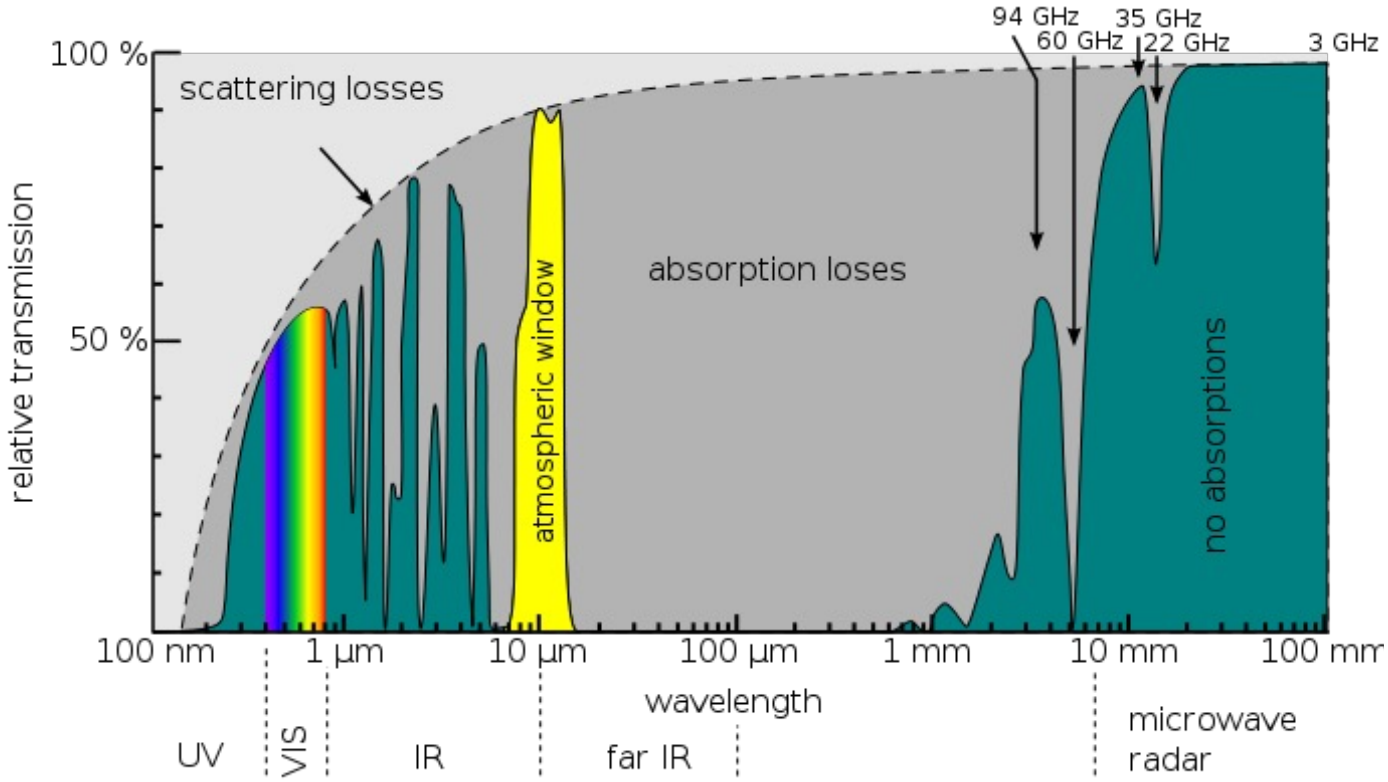


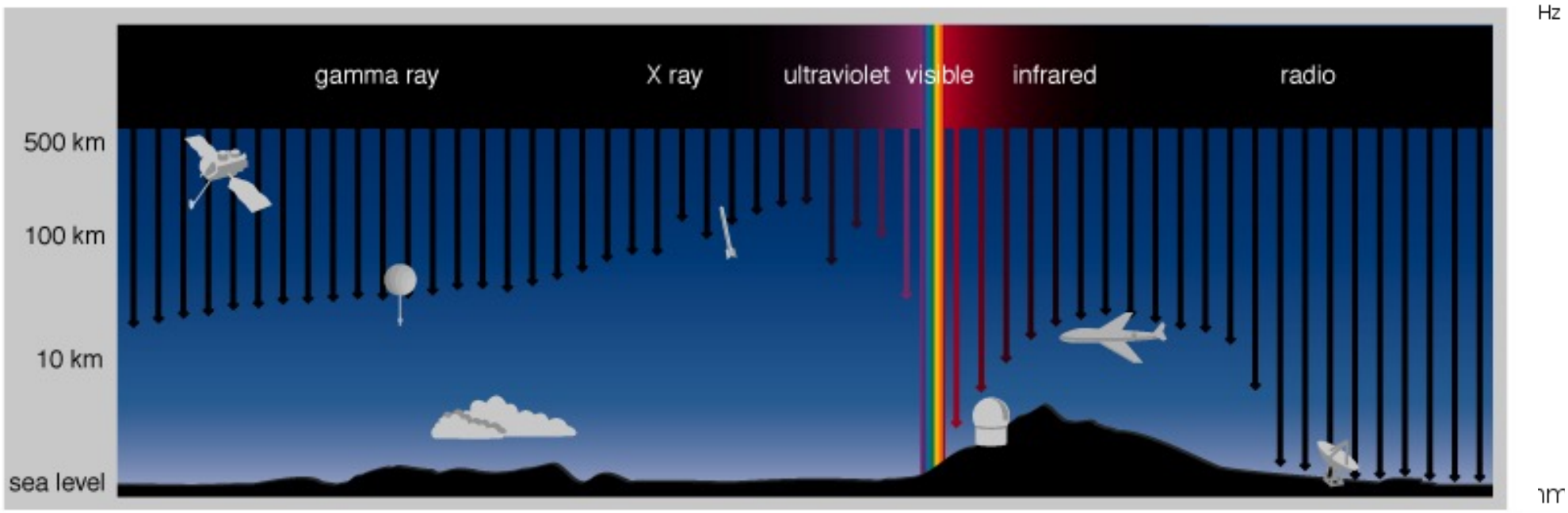

**Fig. 1.** A laser beam propagating through the atmosphere spreads due to diffraction but is also influenced by turbulence in the form of randomly varying eddies. This causes the laser beam some distance away to vary randomly in position, size and intensity.

# Earth atmosphere – global effect

- Absorbes and scatter radiation from celestial objects → loss of strength is inevitable

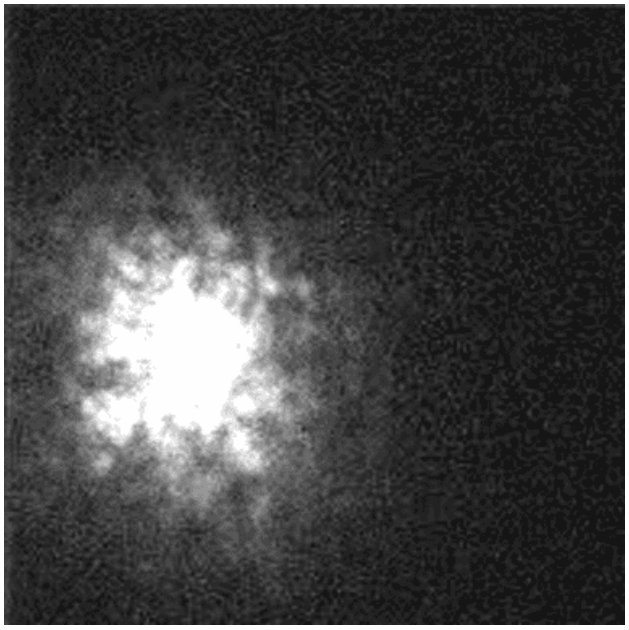


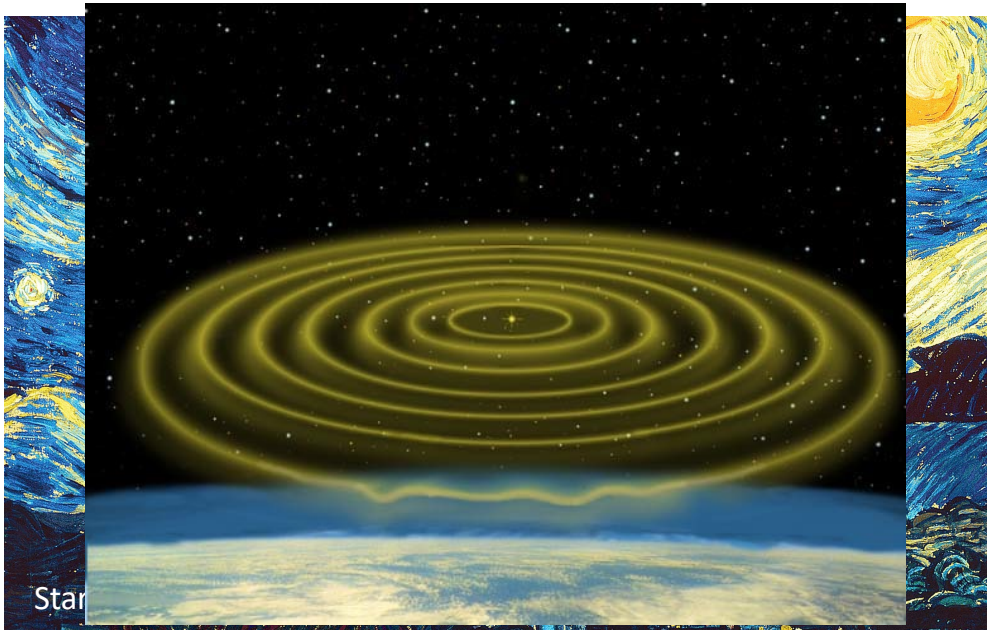
# Earth atmosphere – global effect



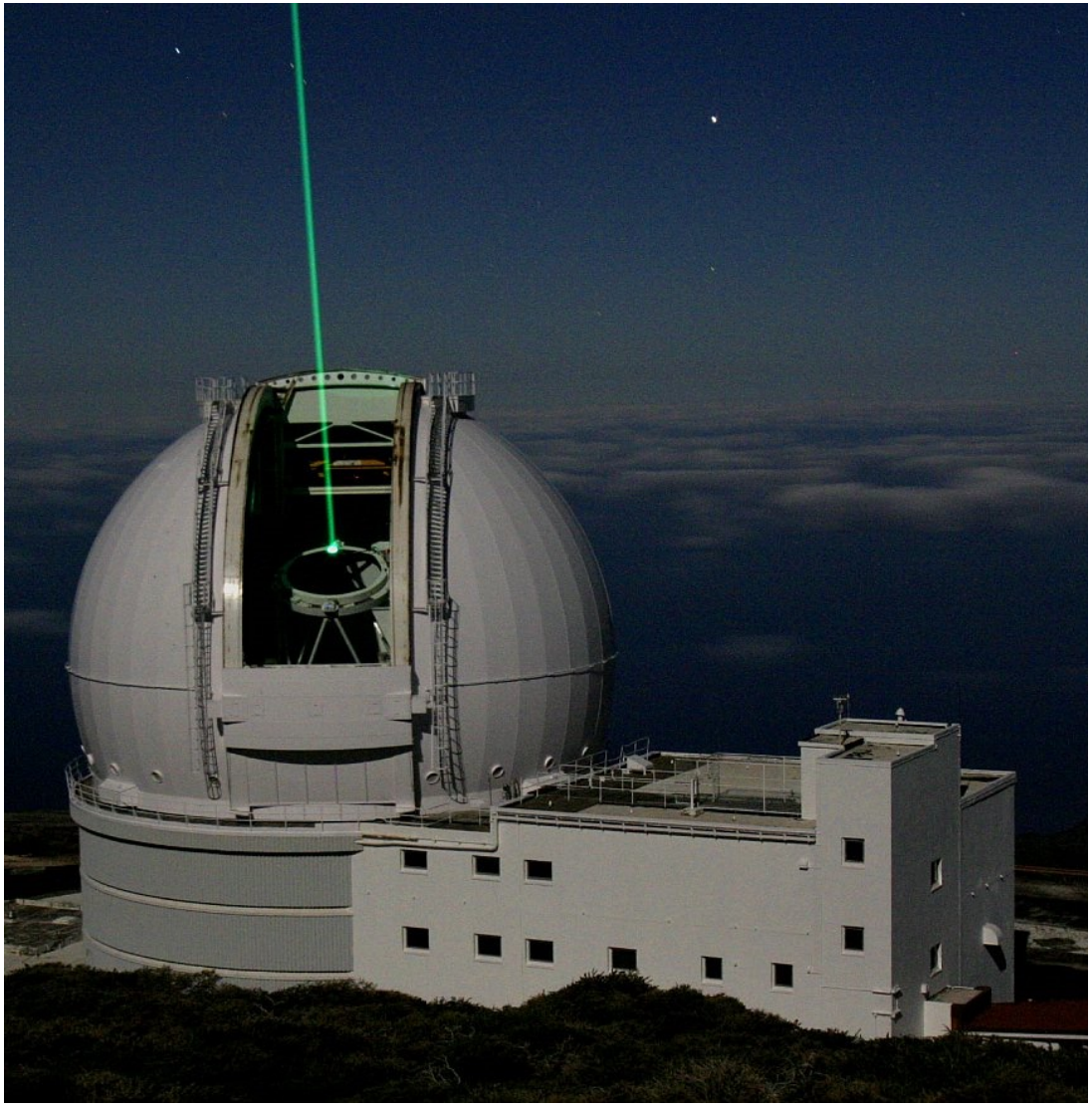
# Earth atmosphere – Local effect

- Turbulence distors the radiation → loss of resolution is inevitable

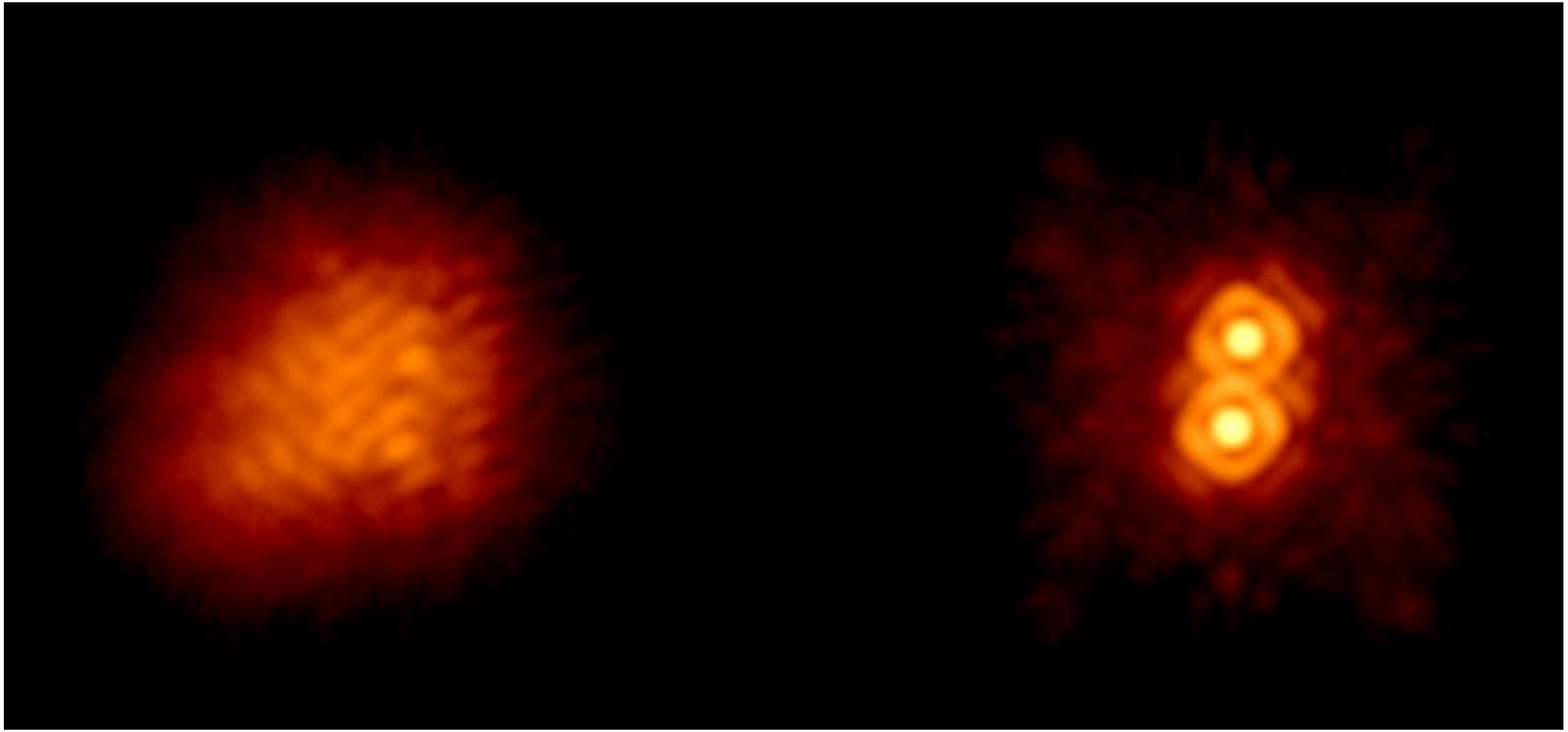


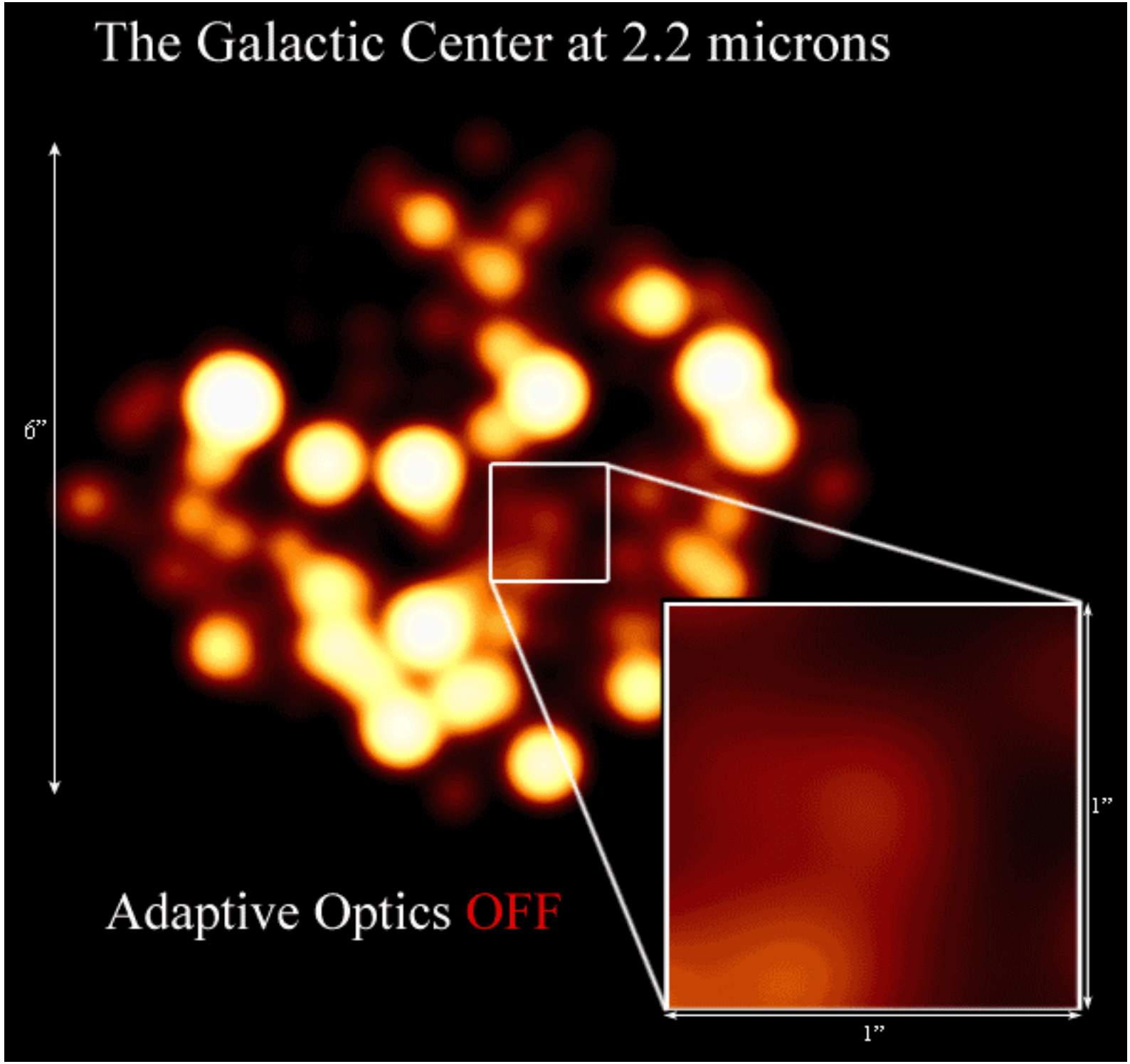


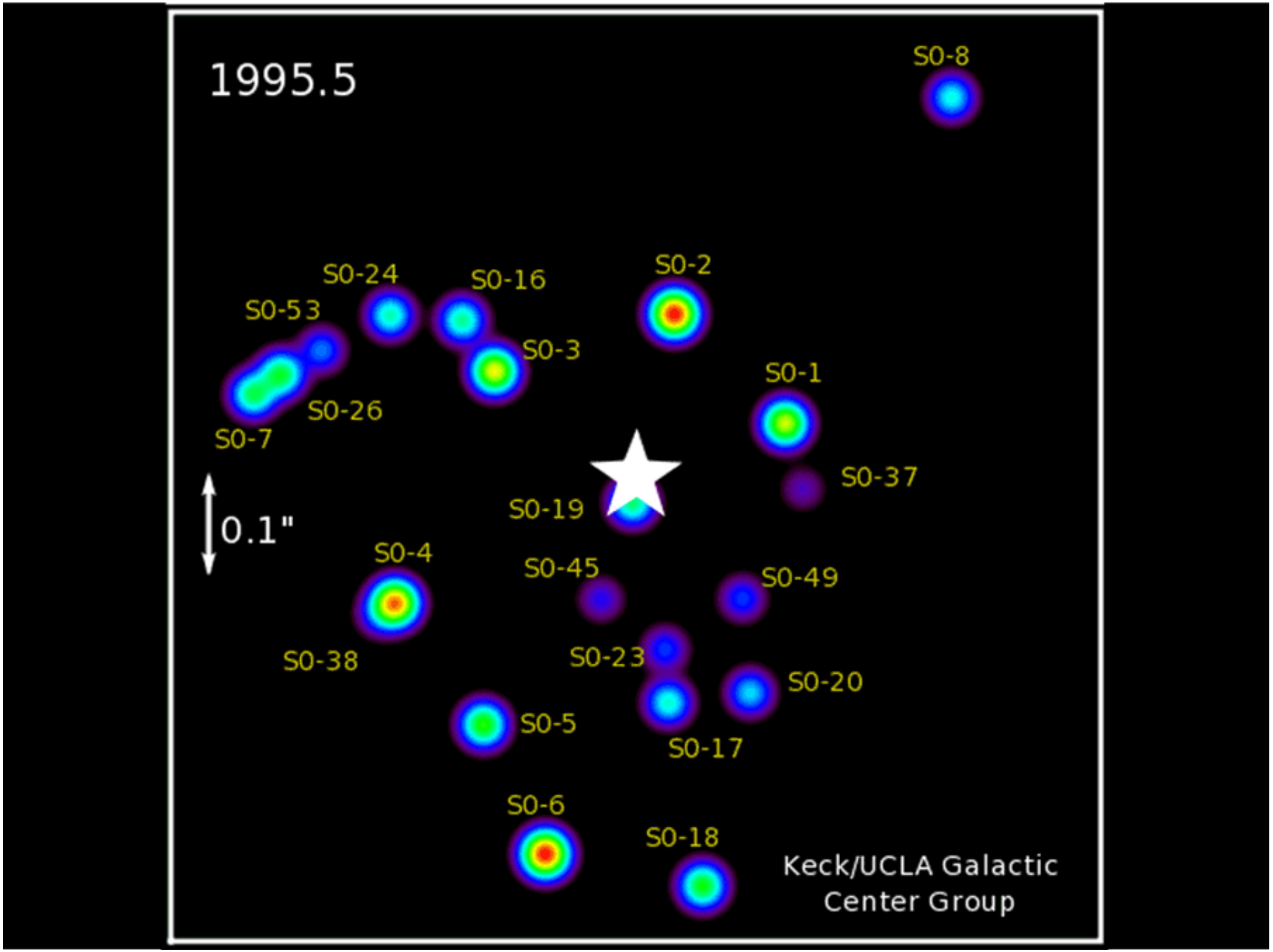
# Adaptivna optika



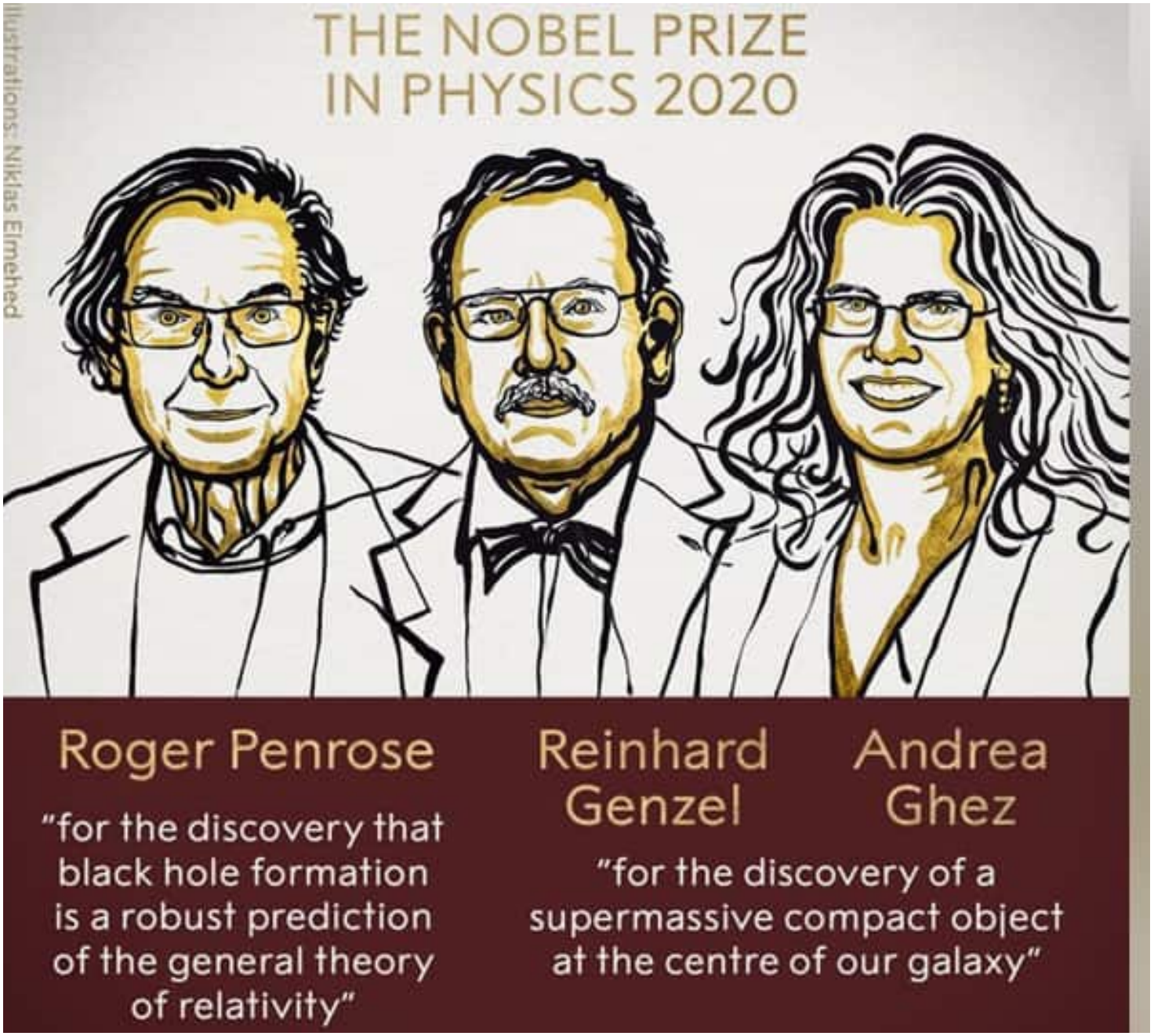
- The binary star IW Tau is revealed through adaptive optics. The stars have a 0.3 arc second separation.




The Galactic Center at 2.2 microns
6”
1”
1”
Adaptive Optics OFF


1995.5
S0-8
S0-24
S0-16
S0-2
S0-53
S0-3
S0-1
S0-26
S0-7
S0-37
0.1"
S0-19
S0-4
S0-45
S0-49
S0-38
S0-23
S0-20
S0-5
S0-17
S0-6
S0-18
Keck/UCLA Galactic
Center Group

Nobelova nagrada za fizku 2020

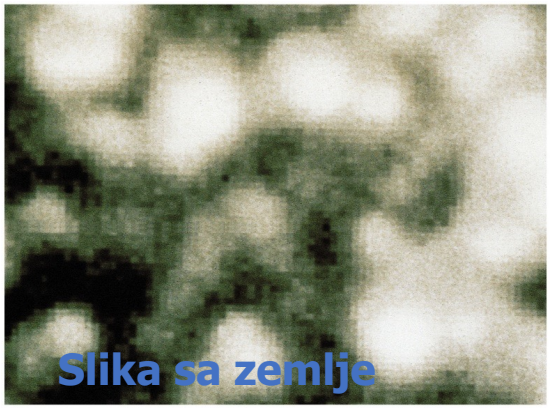


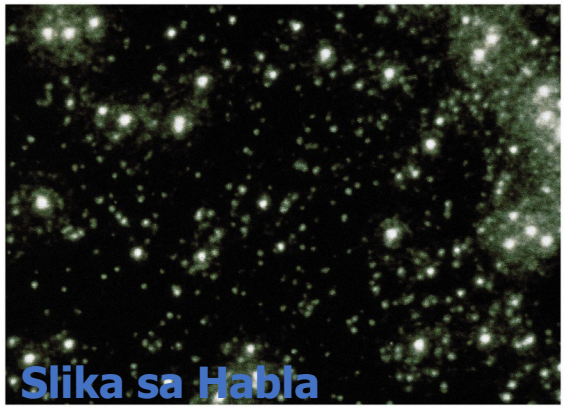
# Hablov svemirski teleskop (od 1990)

# Habl svemirski teleskop

https://twitter.com/HubbleTelescope

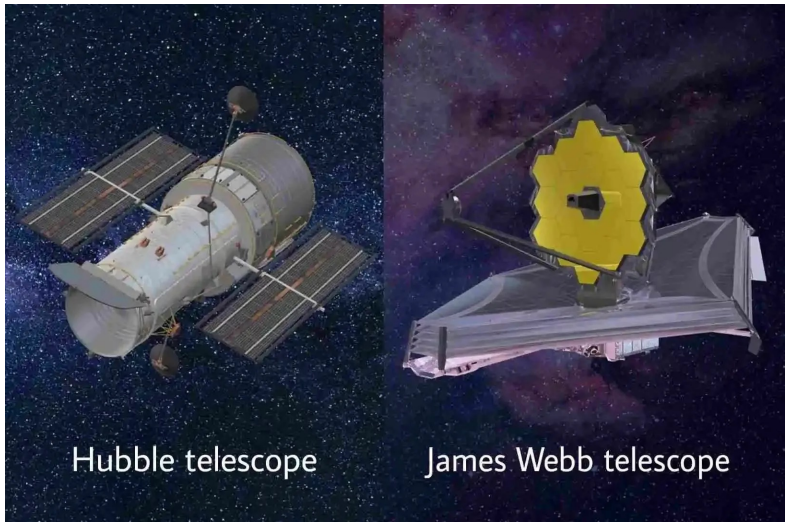
- Reflektorski teleskop sa ogledalom 2,5 m u Zemljinoj orbiti
- Iznad atmosfere
  - Nema treperenja
  - Nema svetlosnog zagađenja




Hablov teleskop:
rađanje zvezda

# Space missions

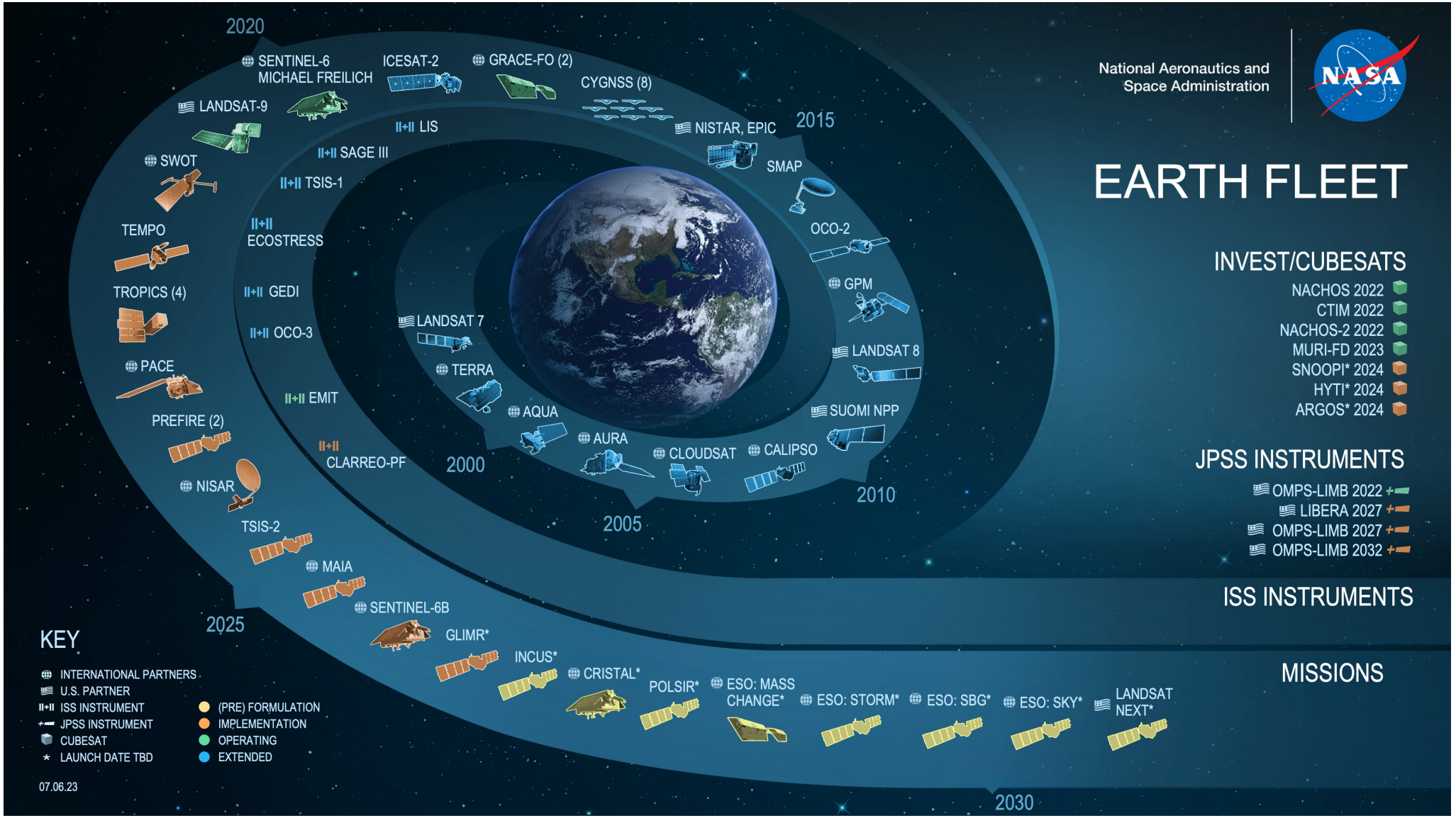



- 2.4m vs 6m Mirror

About 290 million light-years away, Stephan's Quintet is a group of five galaxies, located in the Pegasus constellation. It's notable for being the first compact galaxy group ever discovered in 1877.

Left: Hubble. Right: Webb. Credit: ESA/NASA/STSCI

Optical vs. near Infra Red light


National Aeronautics and Space Administration
NASA
EARTH FLEET
2020
2015
2010
2005
2000
2025
2030
SENTINEL-6 MICHAEL FREILICH
ICESAT-2
GRACE-FO (2)
CYGNSS (8)
LANDSAT-9
LIS
NISTAR, EPIC
SAGE III
SMAP
SWOT
TSIS-1
OCO-2
TEMPO
ECOSTRESS
GPM
TROPICS (4)
GEDI
LANDSAT 7
LANDSAT 8
OCO-3
TERRA
PACE
AQUA
SUOMI NPP
EMIT
AURA
CLOUDSAT
CALIPSO
PREFIRE (2)
CLARREO-PF
NISAR
TSIS-2
MAIA
SENTINEL-6B
GLIMR*
INCUS*
CRISTAL*
POLSIR*
ESO: MASS CHANGE*
ESO: STORM*
ESO: SBG*
ESO: SKY*
LANDSAT NEXT*
INVEST/CUBESATS
NACHOS 2022
CTIM 2022
NACHOS-2 2022
MURI-FD 2023
SNOOPI* 2024
HYTI* 2024
ARGOS* 2024
JPSS INSTRUMENTS
OMPS-LIMB 2022
LIBERA 2027
OMPS-LIMB 2027
OMPS-LIMB 2032
ISS INSTRUMENTS
MISSIONS
KEY
INTERNATIONAL PARTNERS
U.S. PARTNER
ISS INSTRUMENT
JPSS INSTRUMENT
CUBESAT
LAUNCH DATE TBD
(PRE) FORMULATION
IMPLEMENTATION
OPERATING
EXTENDED
07.06.23