TELESKOPI I INSTRUMENTI

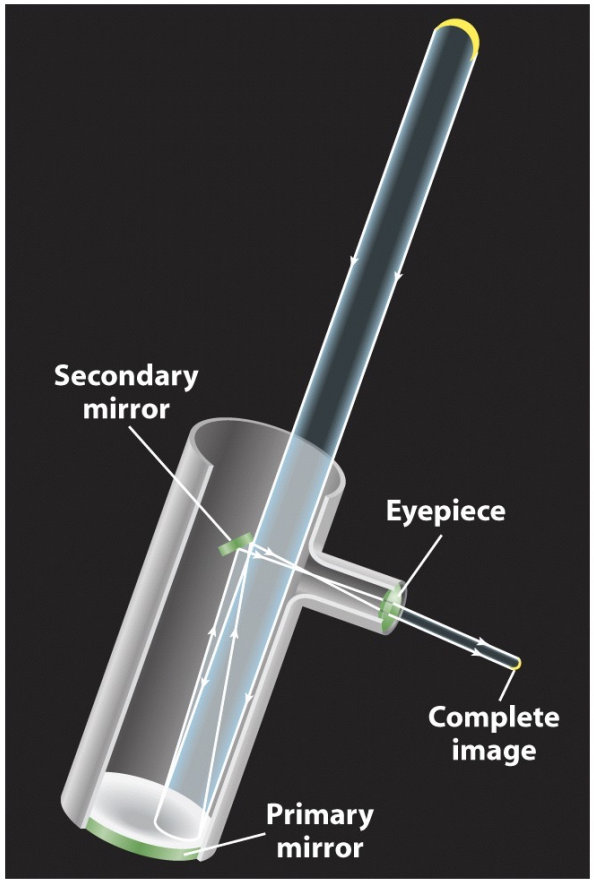
Dragana Ilić

TELESKOPI

Najbitniji astronomski instrumenti

Zadatak teleskopa

1. Sakupi što više svetlosti
2. Projektuje što oštriju sliku kroz okular ili na drugi uređaj



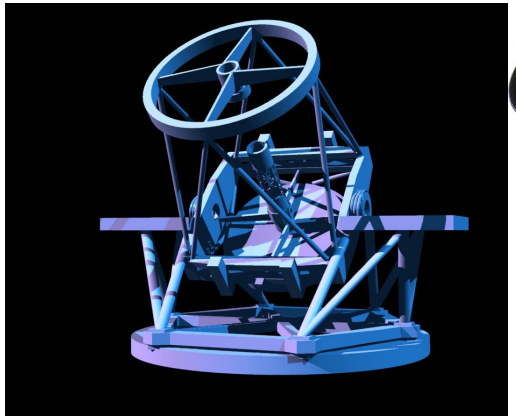
TIPOVI TELESKOPA

Refraktori (koriste sočiva)

- Dugački
- Stariji
- Ograničena veličina težinom

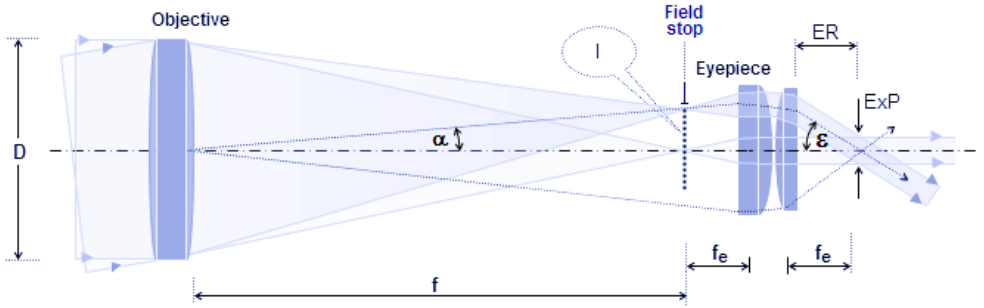
Reflektori (koriste ogledala)

- Kraći
- Noviji
- Ograničeni veličinom ogledala iz jednog komada

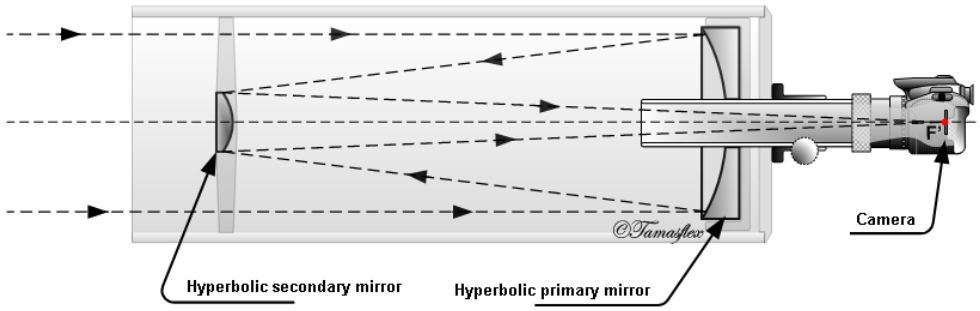


DIZAJN TELESKOPA

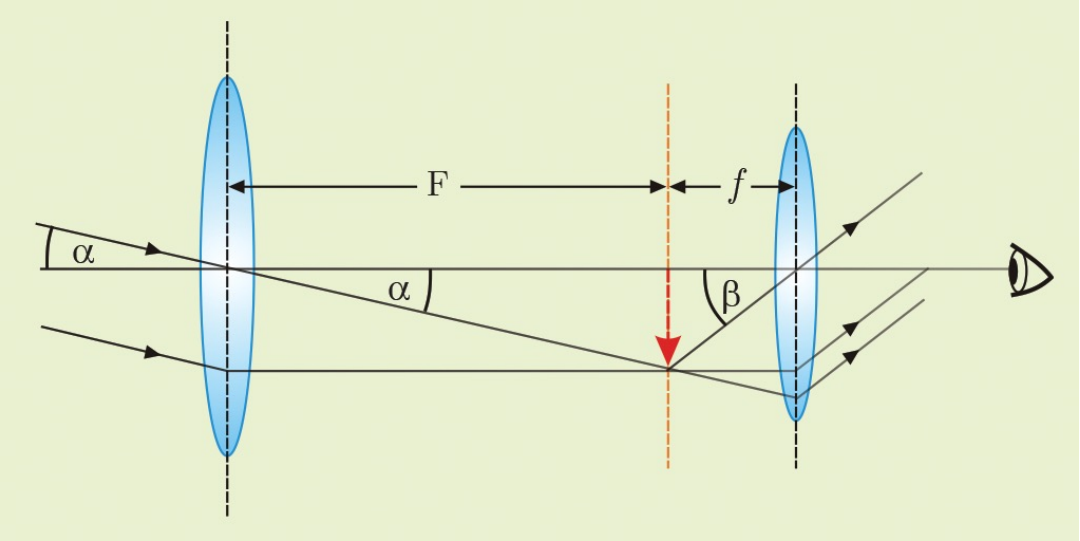
Refraktor (sočivo)



Reflektor (ogledalo)



1. 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

2. SVETLOSNA MOĆ TELESKOPA = SAKUPLJANJE SVETLOSTI

Najbitnije jer uglavnom dobijamo malo svetlosti od nebeskih tela

Površina teleskopa!

Ljudsko oko ~5 mm,

Ogledalo Subaru teleskopa – 8.3 m

- 3 miliona veća površina od oka!

2. SVETLOSNA MOĆ TELESKOPA

količina svetlosti koju teleskop može da sakupi

proporcionalna površini objektiva, odnosno kvadratu prečnika

objekat sjaja m, daje osvetljenost E na teleskopu, odatle dobijamo svetlosnu moć:

$$\Phi = E\frac{\pi D^2}{4} \propto D^2$$

teleskop prečnika 1m, sakupi oko 15,000 više svetlosti nego oko

3. REZOLUCIJA ILI RAZDVOJNA MOĆ

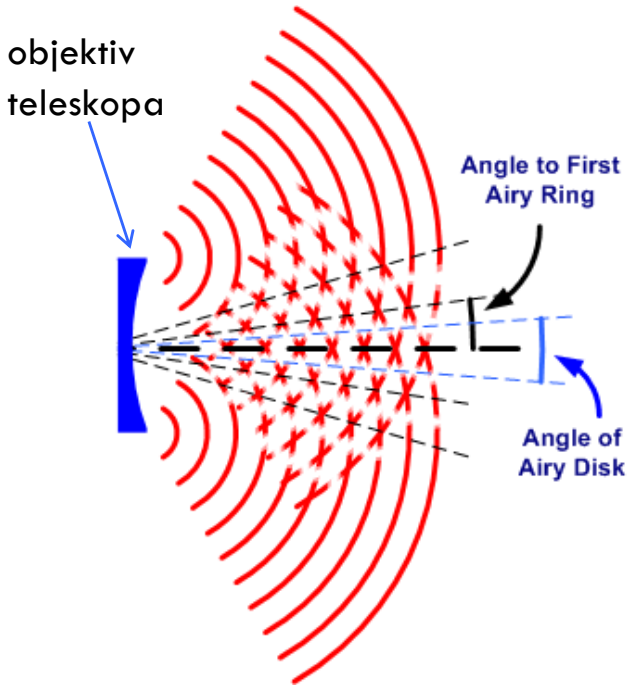
Uglovna rezolucija:

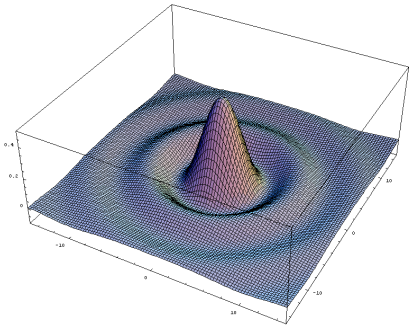
- Određuje najmanju veličinu detalja koji nije razmrljan
- Najmanji ugao pod kojim se dve zvezde vide razdvojeno
  - Npr. Rezolucija ljudskog oka = 1 lučni minut
  - Rezolucija Habl teleskopa < 0.1 lučne sekunde

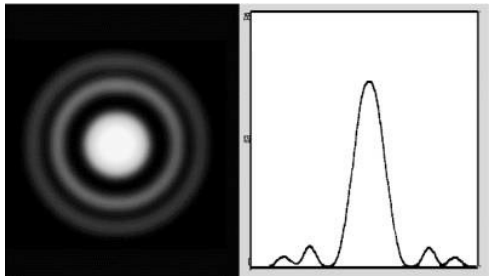
LIK ZVEZDE U TELESKOPU

dolazi do difrakcije

svetlosti na objektivu







lik tačkaste zvezde posle prolaska kroz teleskop nije tačka – difrakcioni lik

3. TEORIJSKA REZOLUCIJA/RAZDVOJNA MOĆ

radijus difrakcionog lika proporcionalan je talasnoj dužini, a obrnuto proporcionalan prečniku teleskopa D:

$$\theta[\text{rad}] = 1.22\frac{\lambda}{D}$$

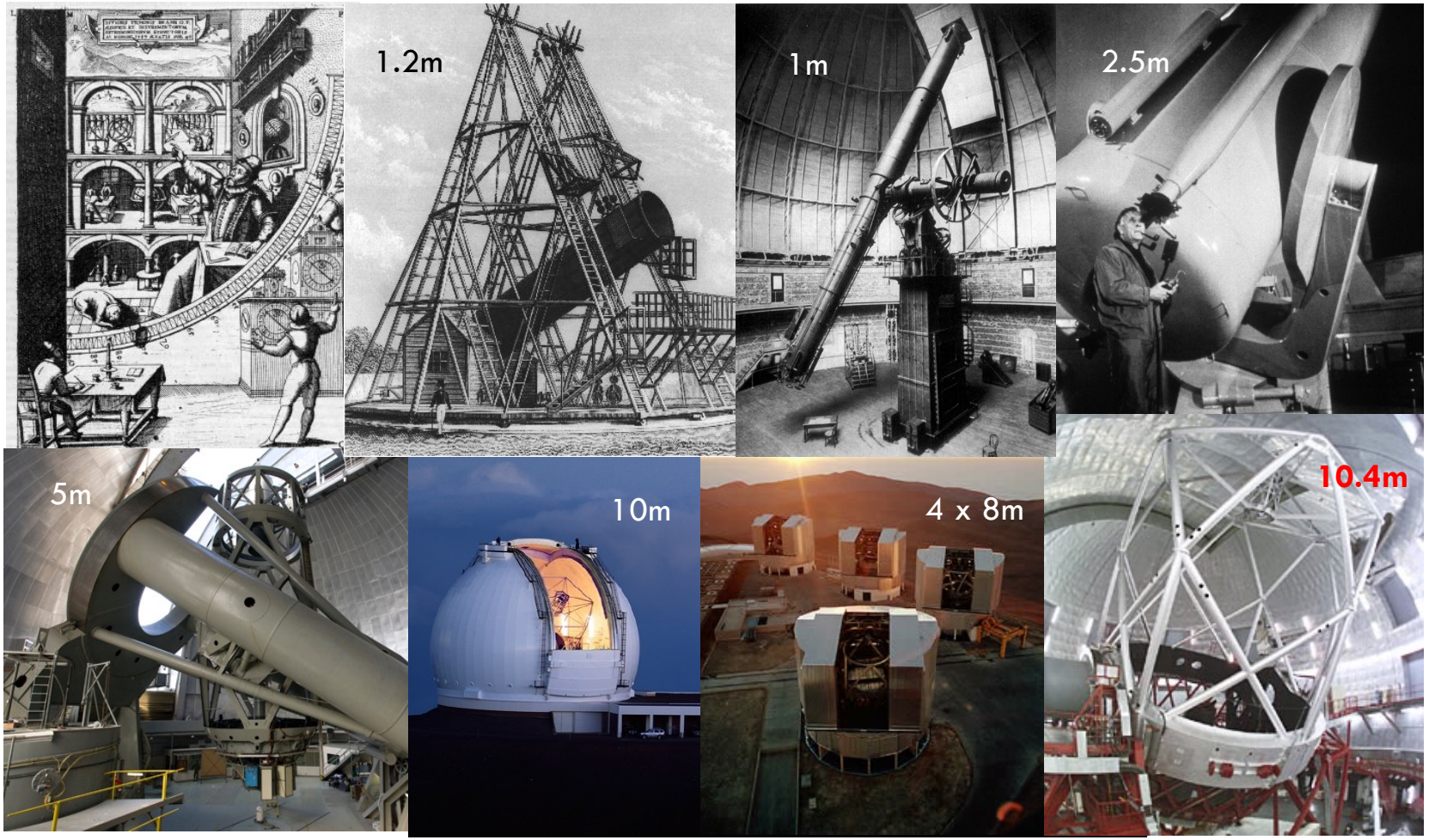
bolje vidimo detalje sa većeim teleskopom!

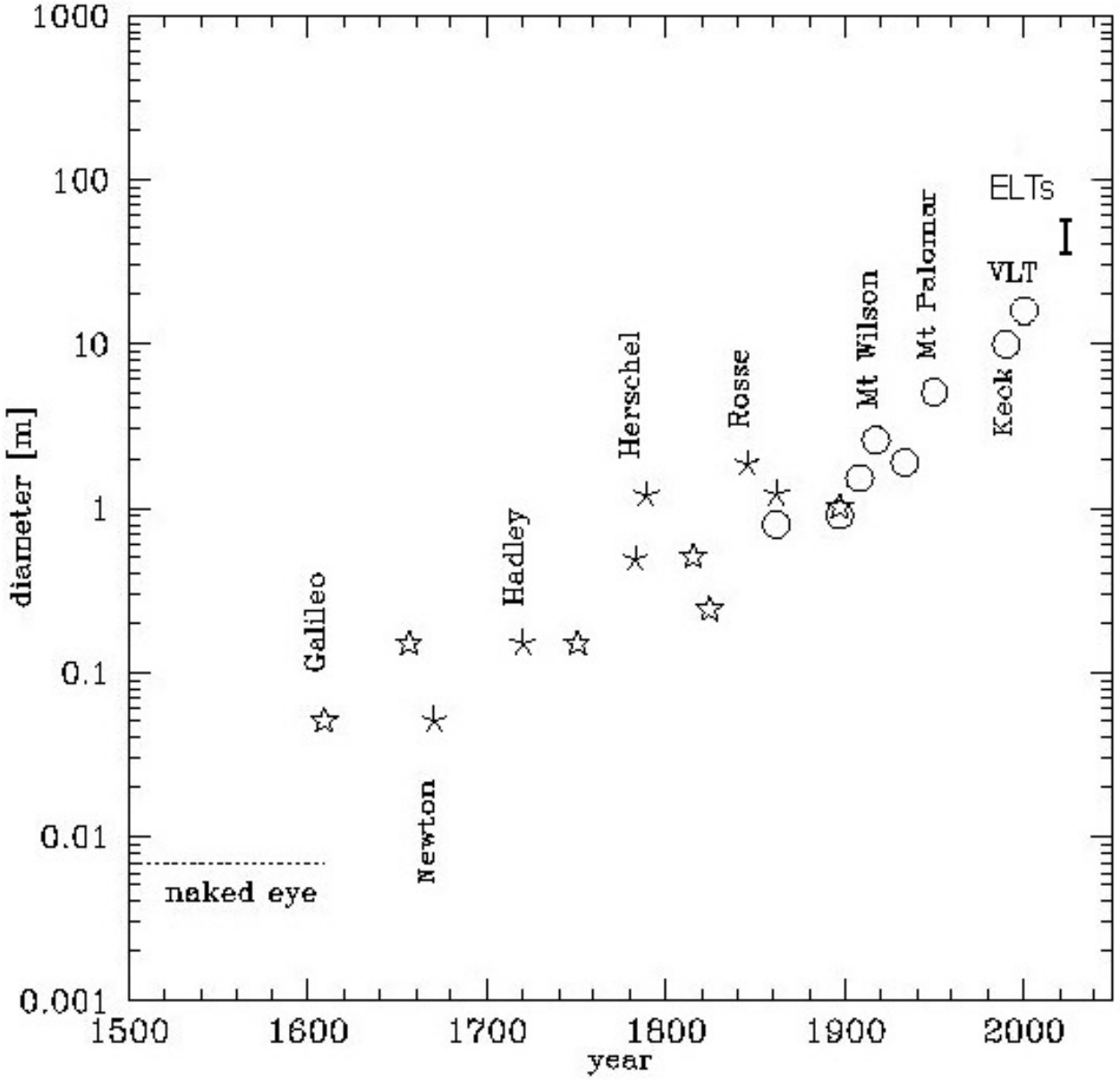
za vidljivo zračenje, na tal.dužini od 550nm:

$$\theta[“] = \frac{14}{D[\text{cm}]}$$

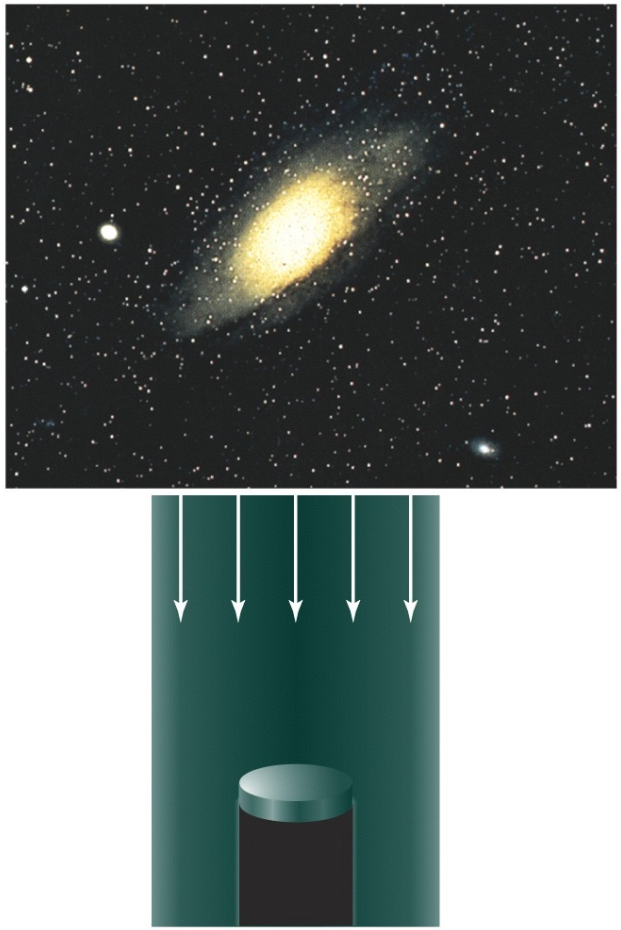
kolika je rezolucija oka, prečnika zenice od 0.8cm?

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

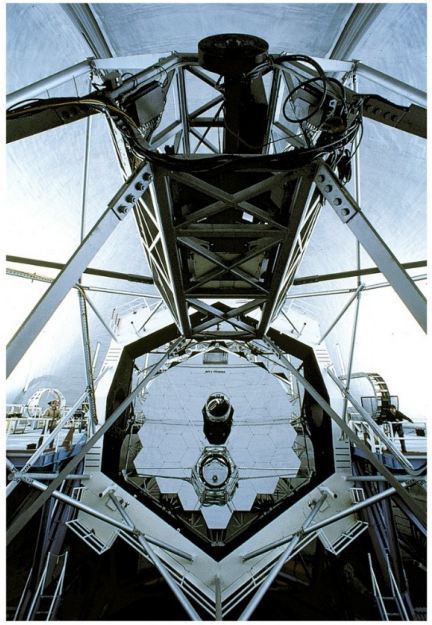
VEĆE JE BOLJE!

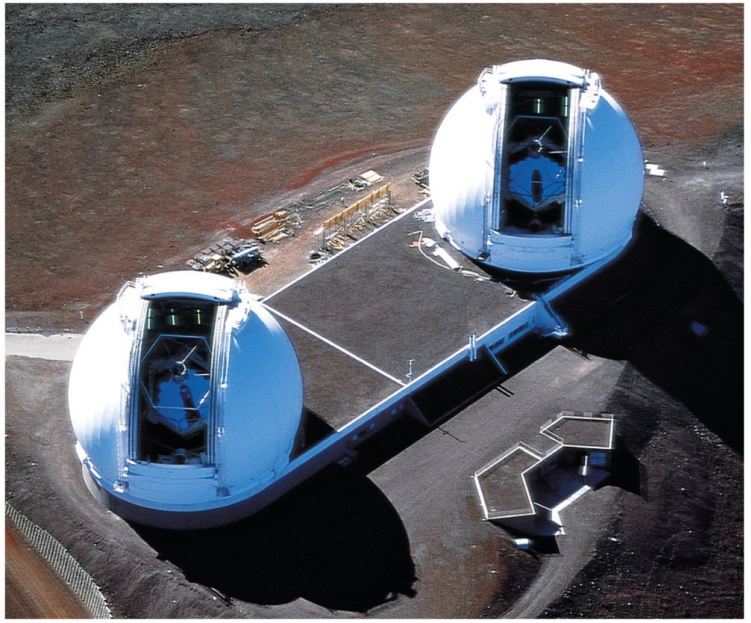


VELIKI TELESKOP NA KANARIMA (GTC)

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

KEK (*KECK*) OPSERVATORIJA, HAVAJI

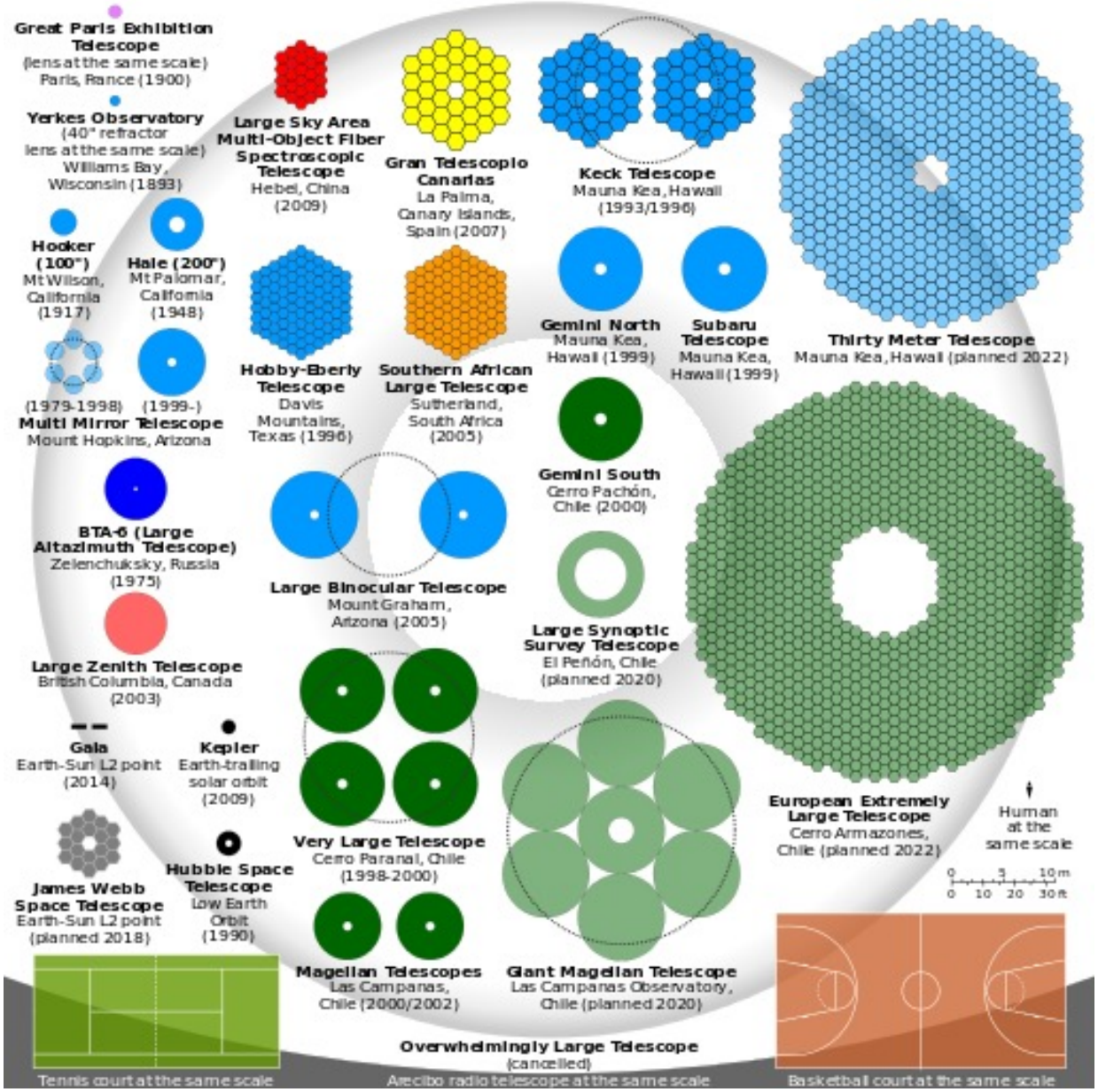




Dva reflektorska teleskopa od po 10m

Završeni 1993. & 1996.

Drugi najveći reflektori na svetu

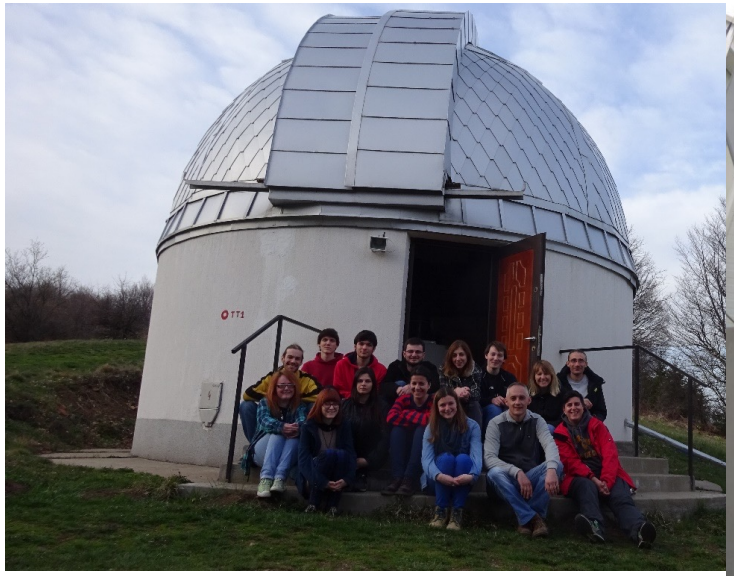

Great Paris Exhibition Telescope
(lens at the same scale)
Paris, France (1900)
Yerkes Observatory
(40" refractor lens at the same scale)
Williams Bay, Wisconsin (1893)
Hooker (100")
Mt Wilson, California (1917)
Hale (200")
Mt Palomar, California (1948)
(1979-1998)
(1999-)
Multi Mirror Telescope
Mount 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)
European Extremely Large Telescope
Cerro Armazones, Chile (planned 2022)
Human at the same scale
0 5 10 m
0 10 20 30 ft
Very Large Telescope
Cerro Paranal, Chile (1998-2000)
Magellan Telescopes
Las Campanas, Chile (2000/2002)
Giant Magellan Telescope
Las Campanas Observatory, Chile (planned 2020)
Overwhelmingly Large Telescope
(cancelled)
Tennis court at the same scale
Arecibo radio telescope at the same scale
Basketball court at the same scale

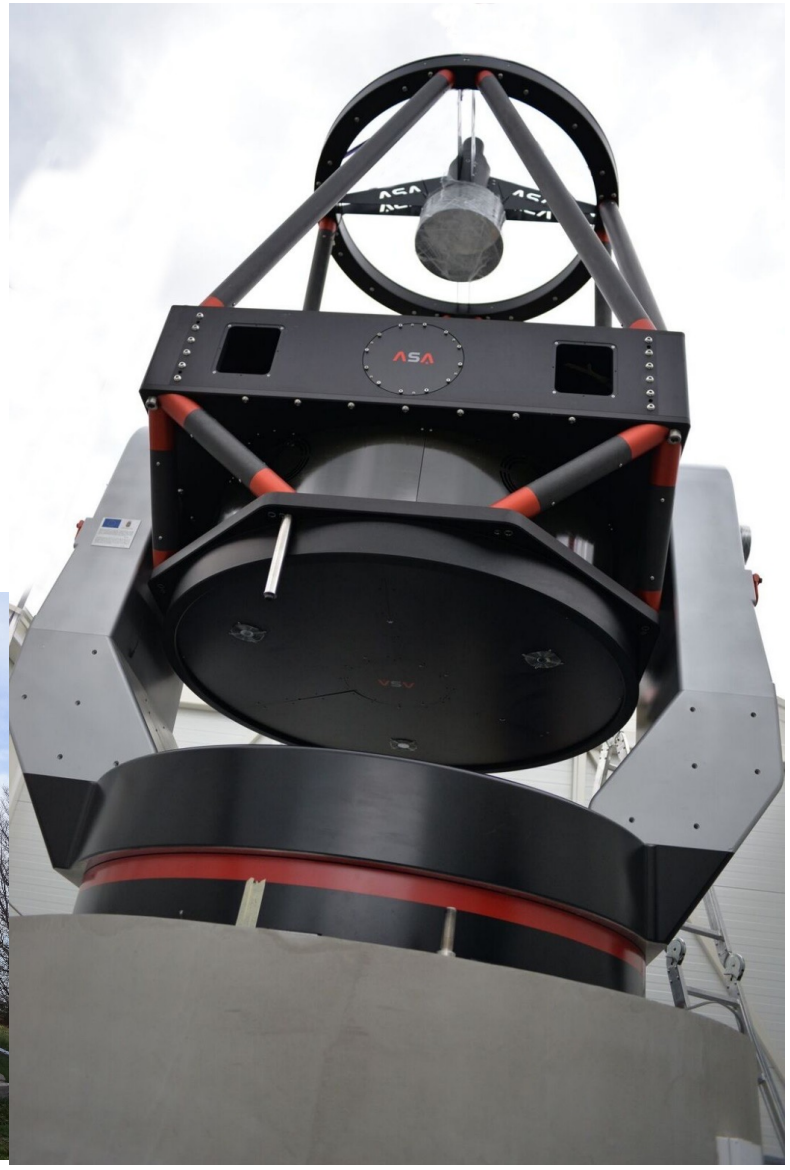
NAJVEĆI TELESKOPI U SRBIJI

Milanković teleskop, Vidojevica (kod Prokuplja)

Ogledalo prečnika 1,4m (i manji od 0,6m)

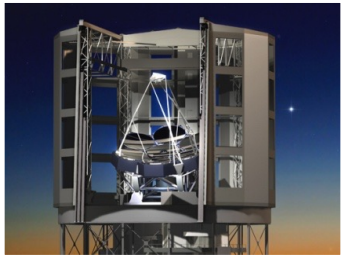
Počeo sa radom 2016.



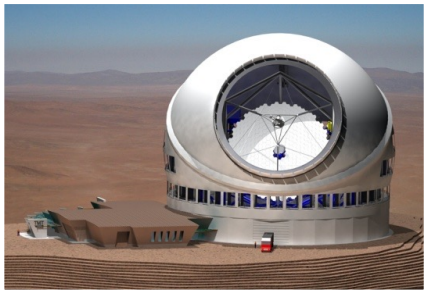


BUDUĆI VELIKI TELESKOPI NA ZEMLJI

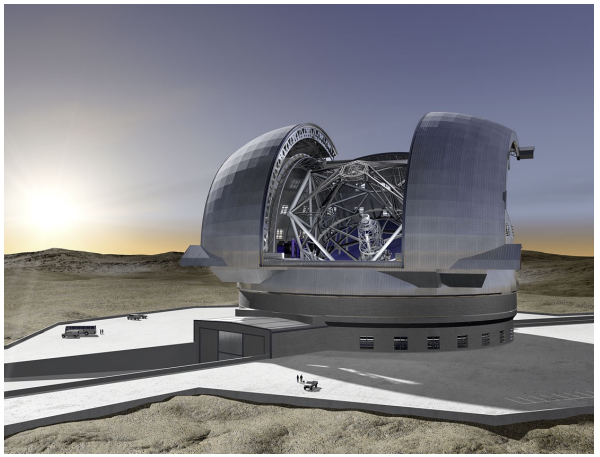
GMT



TMT



E-ELT



Dijametar	25.4 m	30 m	39.4 m
Površina ogle:	382 m^2	655 m^2	978 m^2
Difrak. limit 1μm:	9.9 mas	8.4 mas	6.4 mas

EVROPSKI IZUZETNO VELIKI TELESKOP – E-ELT

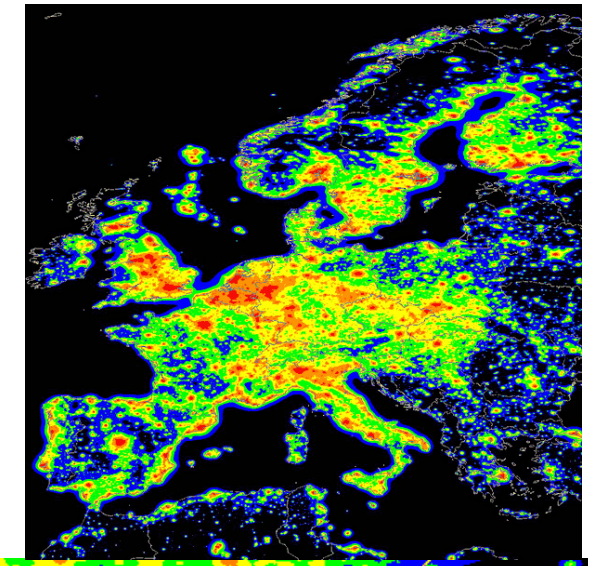
SVETLOSNO ZAGAĐENJE

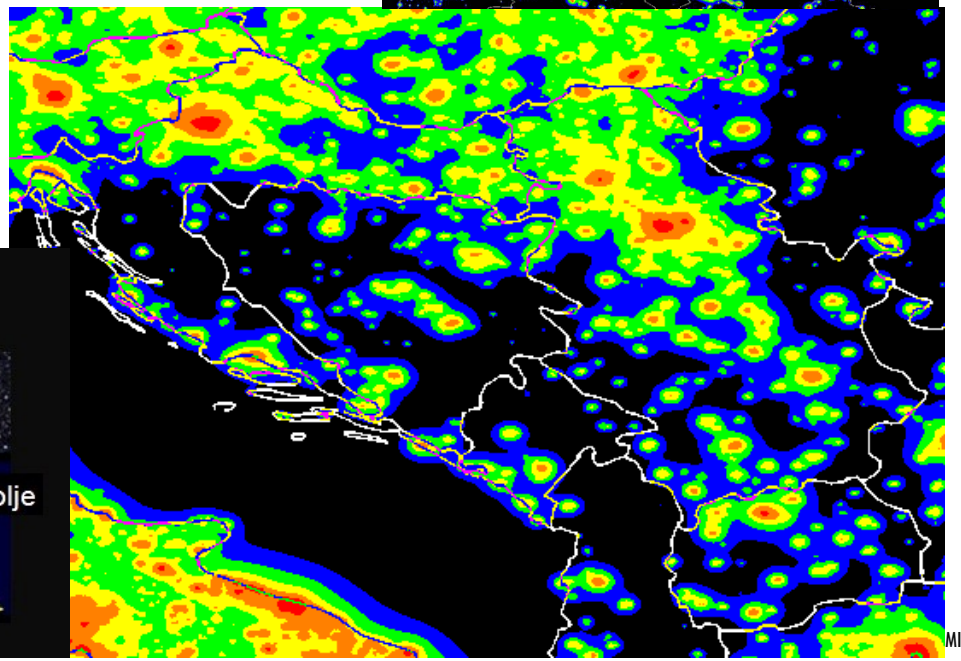
Veliki problem za astronome

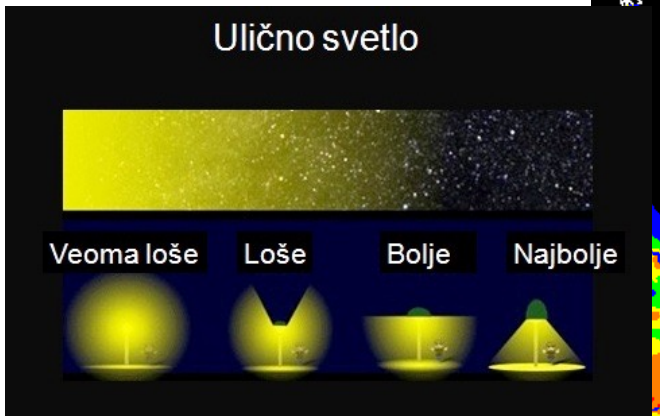
Gradska svetla podižu pozadinski nivo svetla

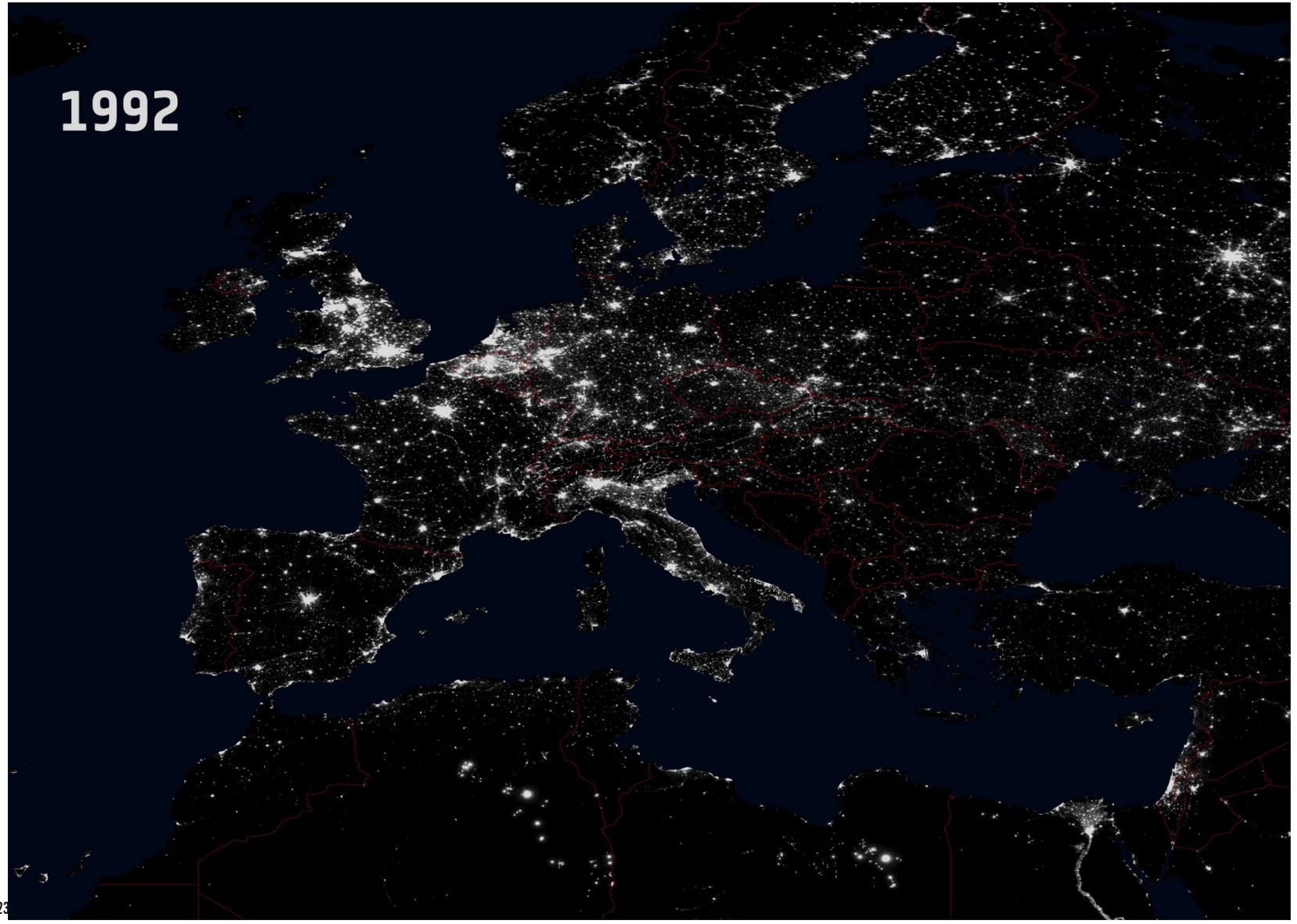
Otežava sakupljanje svetlosti od zvezda

Postaje sve gore!

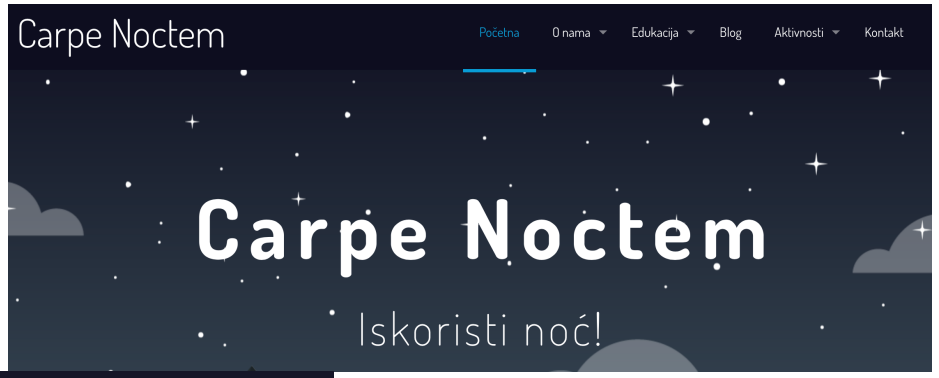







1992

AKTIVNOSTI KOD NAS



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

https://carpenoctem.rs

POSMATRAČKA STANICA ASTRONOMSKE OPSERVATORIJE U BEOGRADU

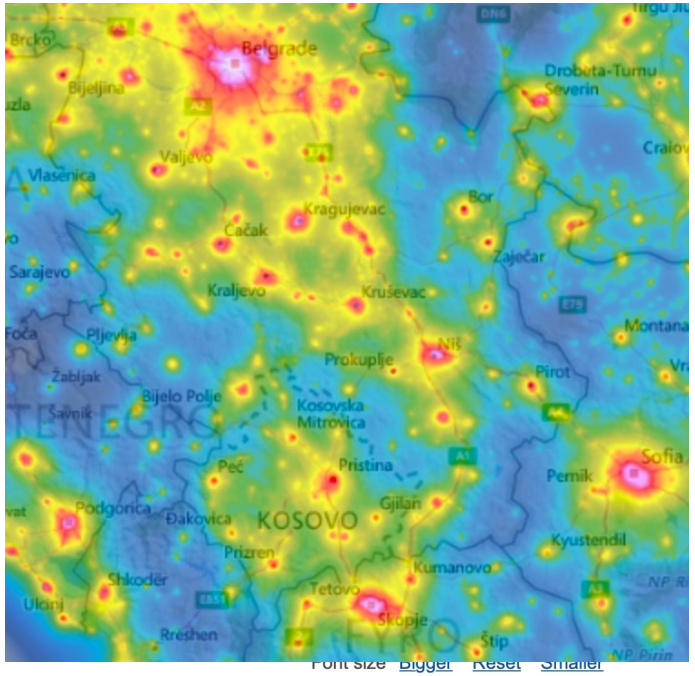
Astronomska stanica Vidojevica

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

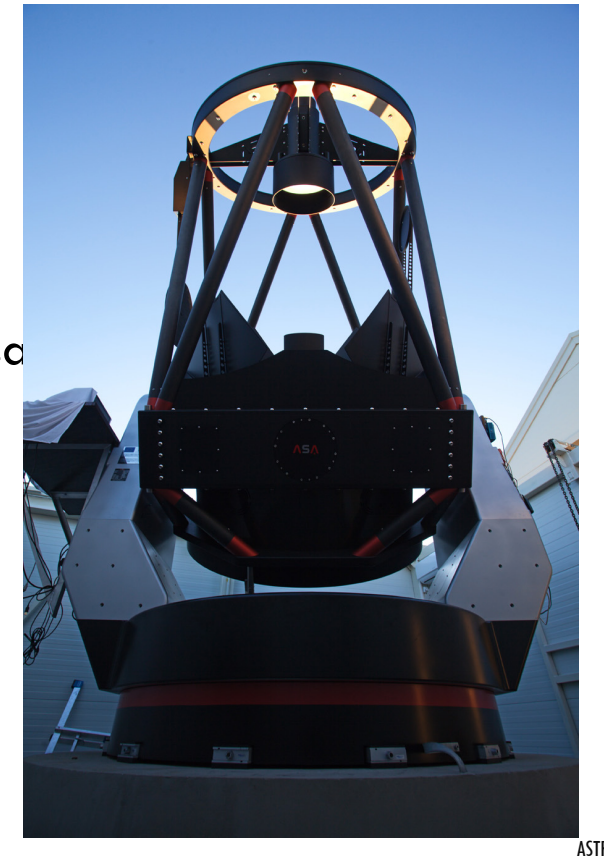
Žižna daljina: 11.2 m (f/8) – reduktor fokusa

Montaža: alt-azimuth

Težina: 8.5 tona

Visina : 4.5 metra

Nasmit i “savijen” Kasegren fokus



PROBLEM: ZEMLJINA ATMOSFERA

koliko iznosi teorijska rezolucija za teleskop od 10m?

zašto je onda prosečna rezolucija (vidljivost = seeing) oko 1 lučne sekunde?

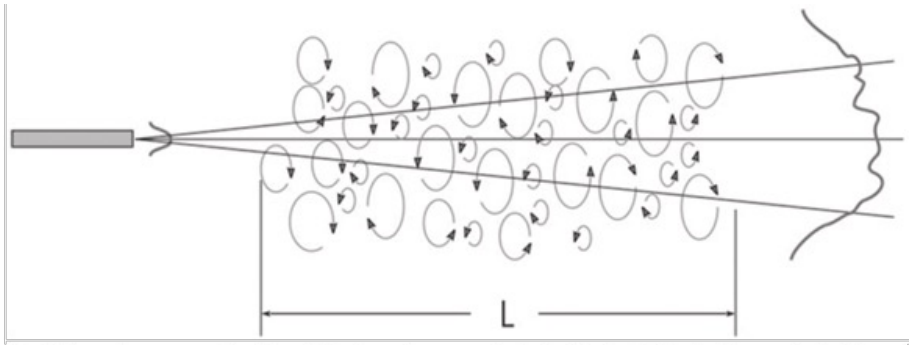
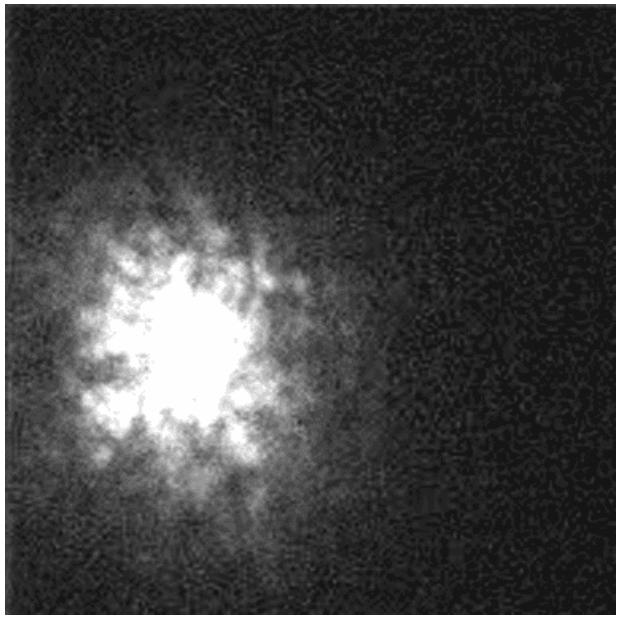
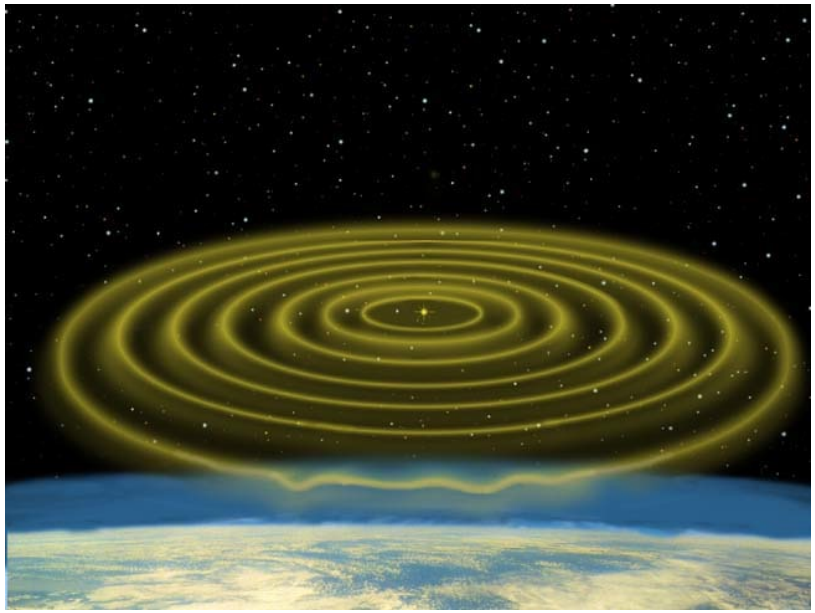


Fig. 1. A laser beam propagating through the atmosphere spreads due to diffraction but is also influenced by turbulence in the form of randomly varying eddies. This causes the laser beam some distance away to vary randomly in position, size and intensity.

NEIZBEŽAN PROBLEM: ATMOSFERA ZEMLJE

Apsorpcija i smanjenje kvaliteta slike (turbulencije)





Atmosfera kvari idealan talas svetlosti koji stiže od zvezde

HABLOV SVEMIRSKI TELESKOP (OD 1990)

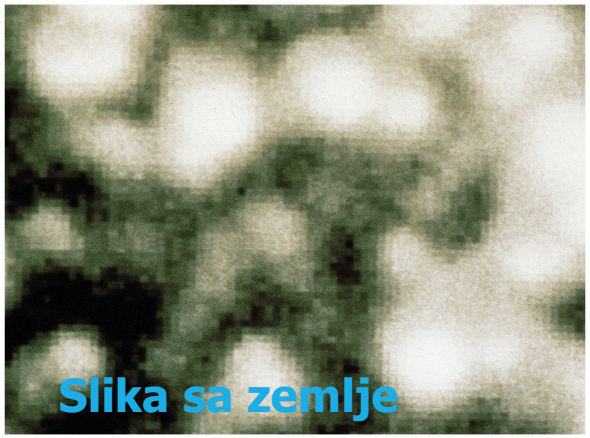
HABL SVEMIRSKI TELESKOP

HTTPS://TWITTER.COM/HUBBLETELESCOPE

Reflektorski teleskop sa ogledalom 2,5 m u Zemljinoj orbiti

Iznad atmosfere

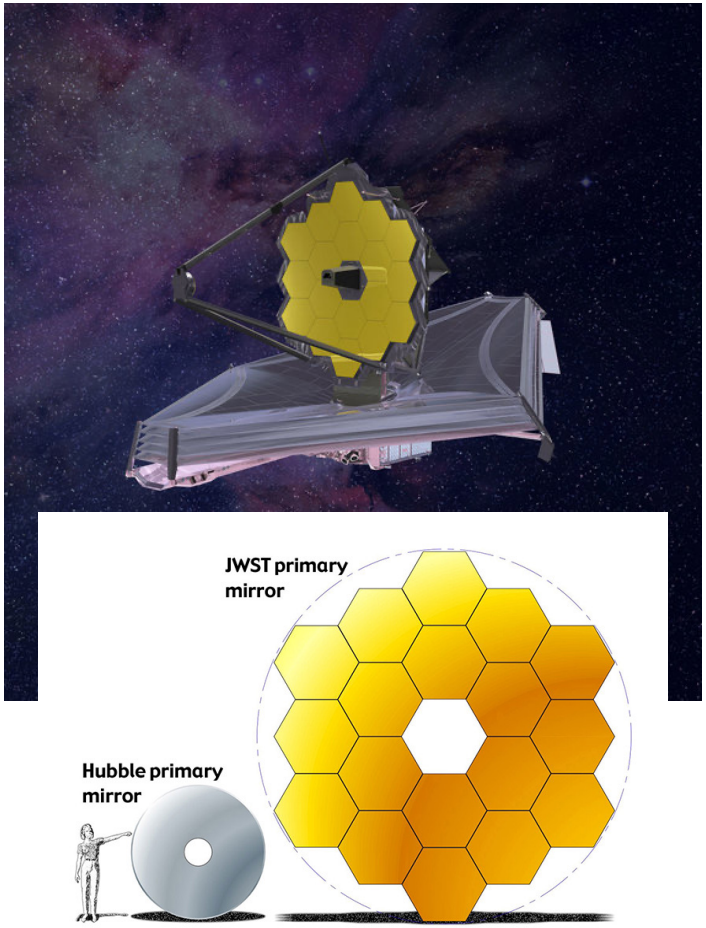
- Nema treperenja
- Nema svetlosnog zagađenja



HABLOV TELESKOP: RAĐANJE ZVEZDA

DŽEJMS VEB TELESKOP: HABLOV NASLEDNIK

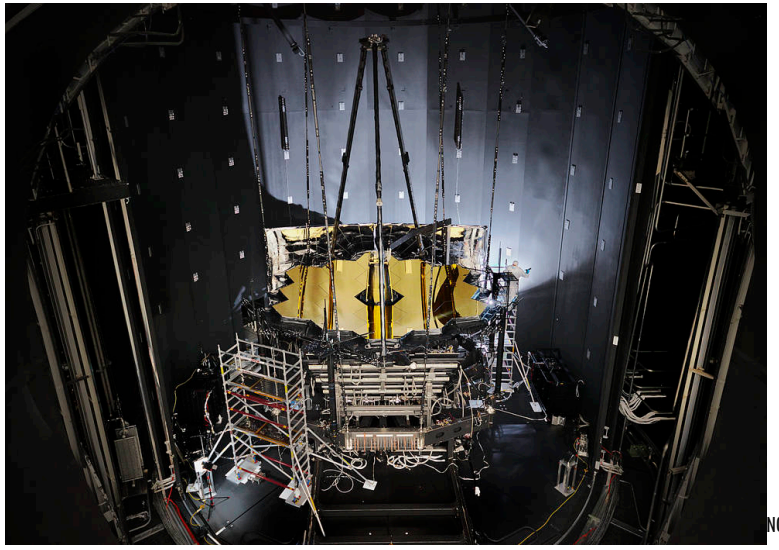
HTTPS://TWITTER.COM/NASAWEBB



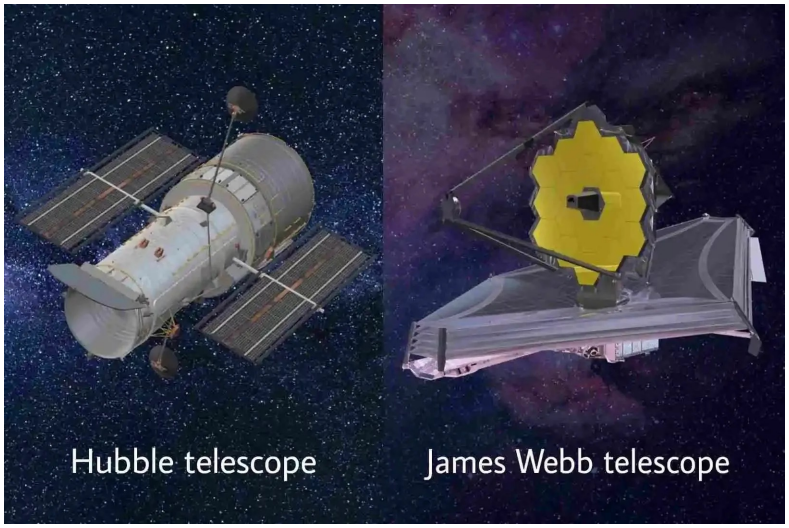
Lansiran pred kraj 2021.

Poslat u L2 tačku

Ogledala prekrivena zlatom (odlično reflektuje infractvenu svetlost)



SPACE MISSIONS



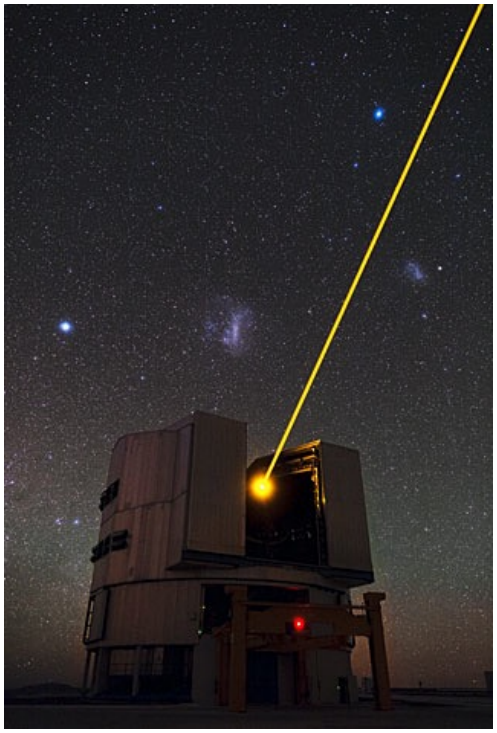
2.4m vs 6m Mirror

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.

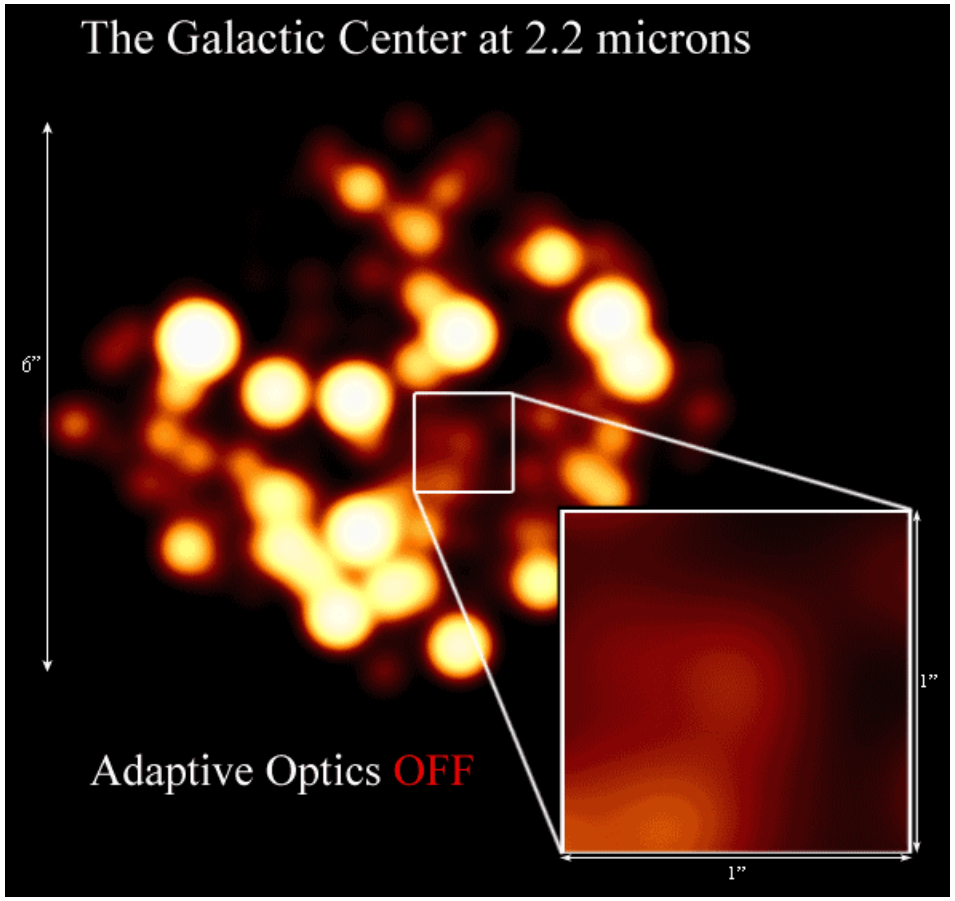
Left: Hubble. Right: Webb. Credit: ESA/NASA/STSCI

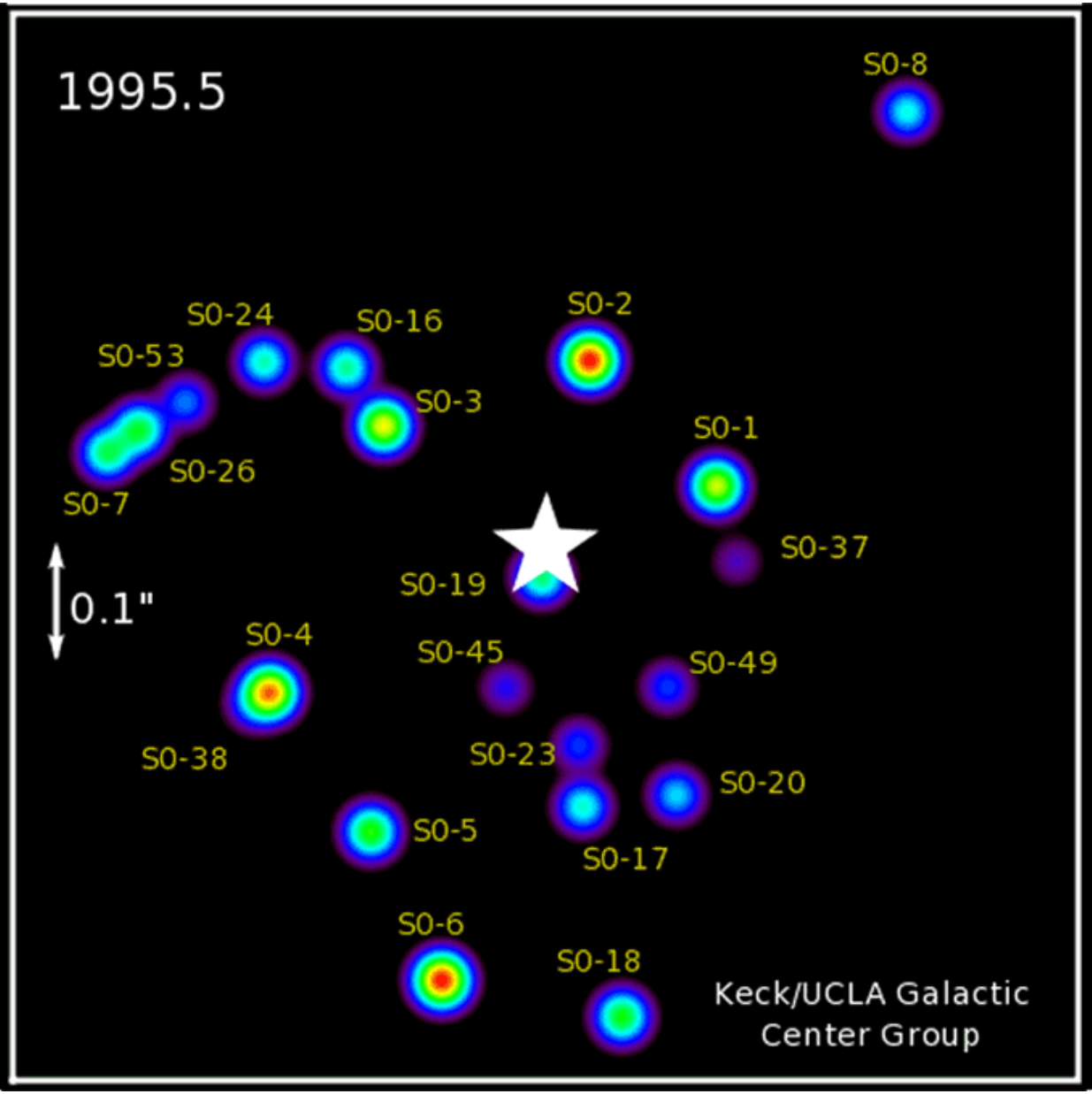
Optical vs. near Infra Red light

SISTEM ADAPTIVNE OPTIKA

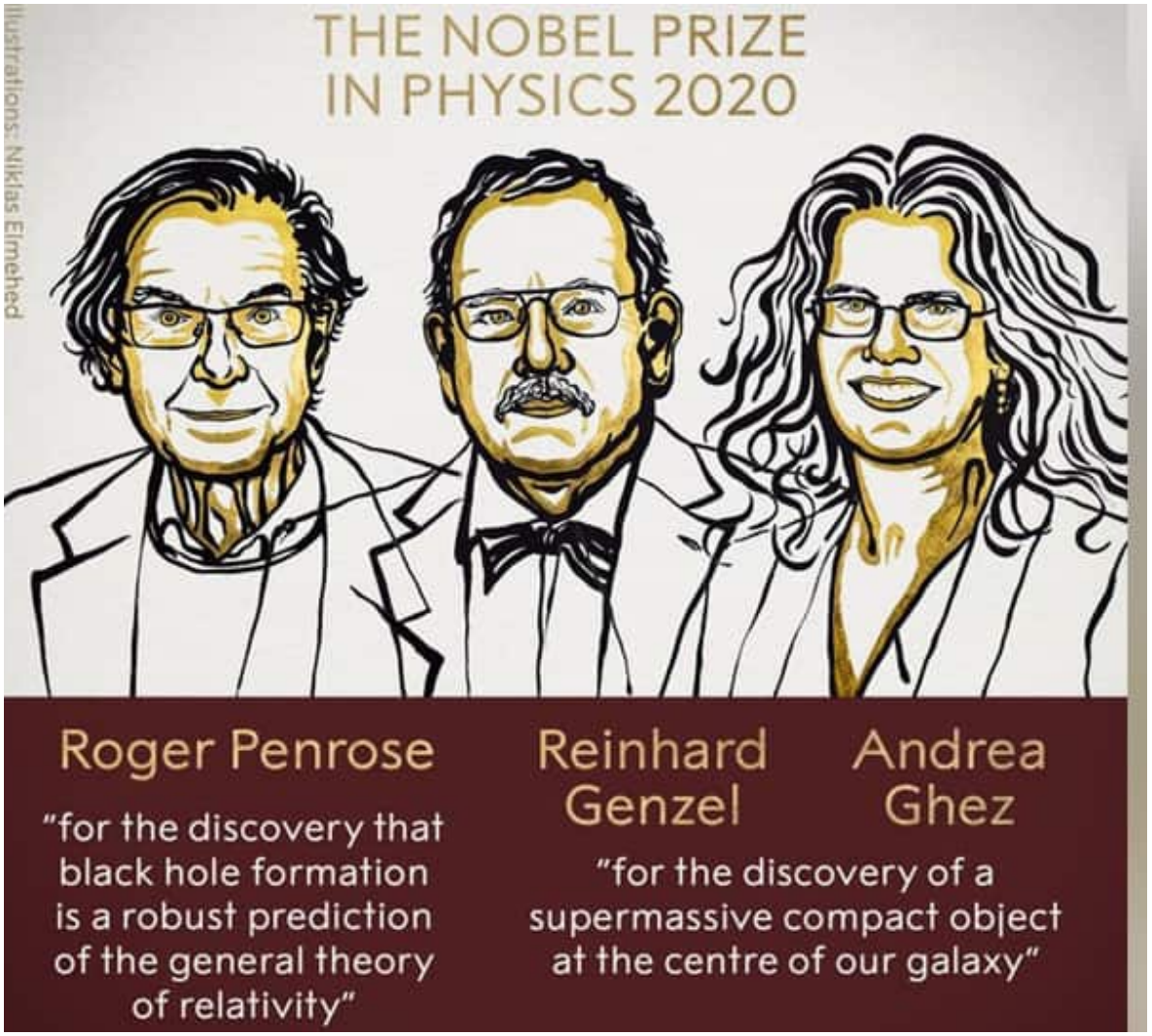


Sistem određivanja nepravilnosti u atmosferi (laserske zvezde) i prilagodljivih ogledala za korekciju.




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

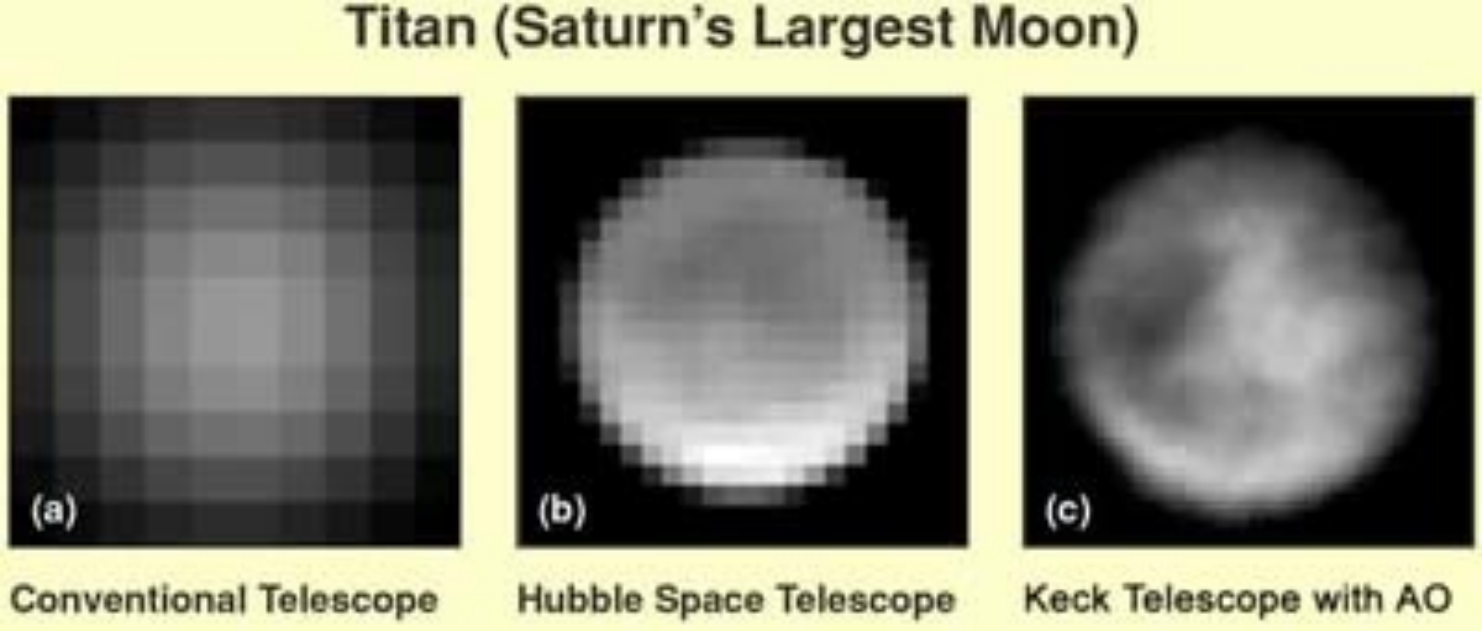
NOBELOVA NAGRADA ZA FIZKU 2020



ADAPTIVNA OPTIKA NA DELU

Prevaziđen čak i Hablov teleskop:

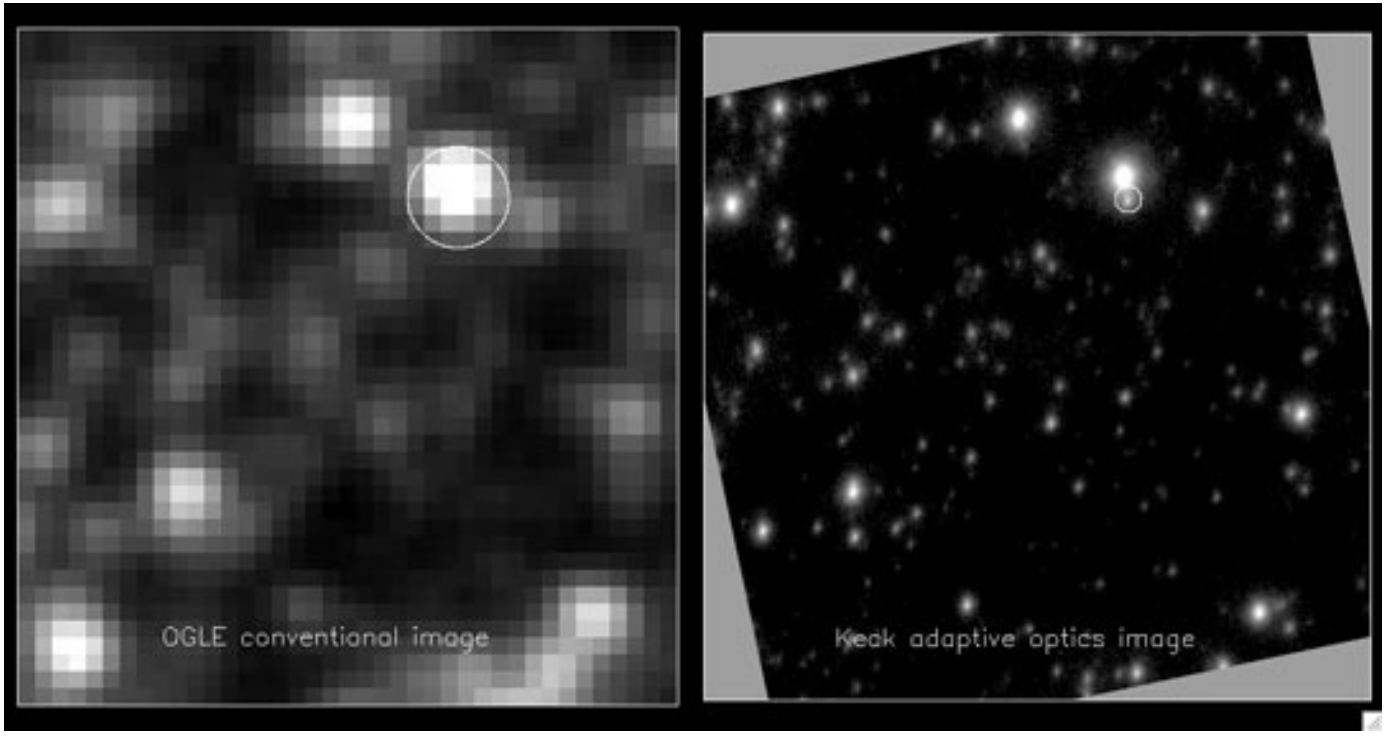
- npr. Kek teleskop košta 20x manje, 20x više svetlosti primi i potencijalno 4x bolju rezoluciju (uz adaptivnu optiku)



ADAPTIVNA OPTIKA NA DELU

Prevaziđen čak i Hablov teleskop:

- npr. Kek teleskop košta 20x manje, 20x više svetlosti primi i potencijalno 4x bolju rezoluciju (uz adaptivnu optiku)



“POVRATAK NA POVRŠINU ZEMLJE”

Very Large Telescope, Paranal opservatorija, Čile, 2600m

VLT / VERY LARGE TELESCOPE

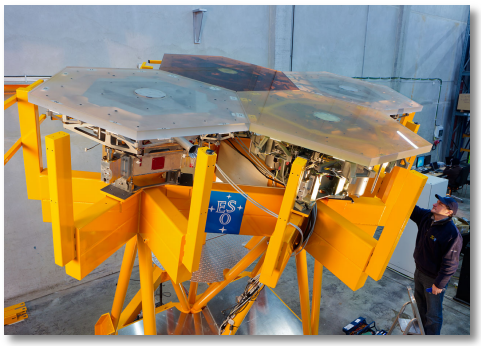
MODERN INSTRUMENTS

European Southern Observatory

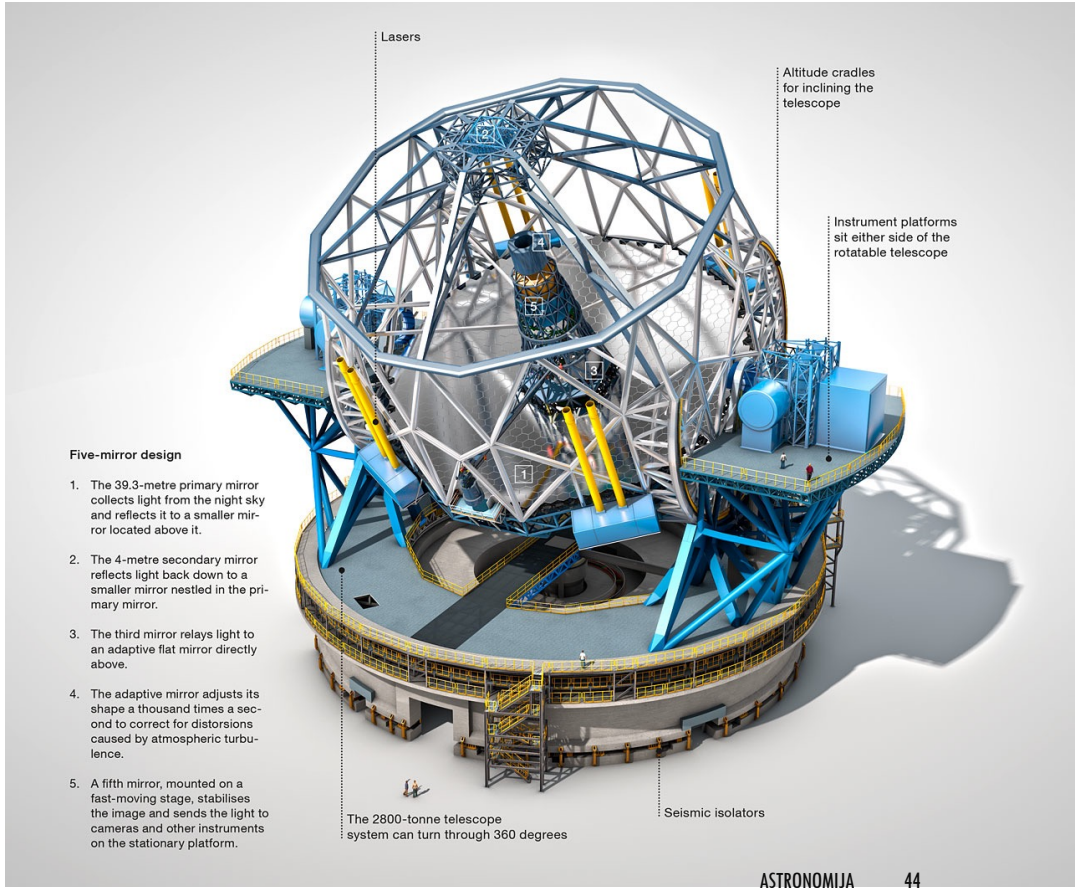
www.eso.org

Frontiers of Science and Technology

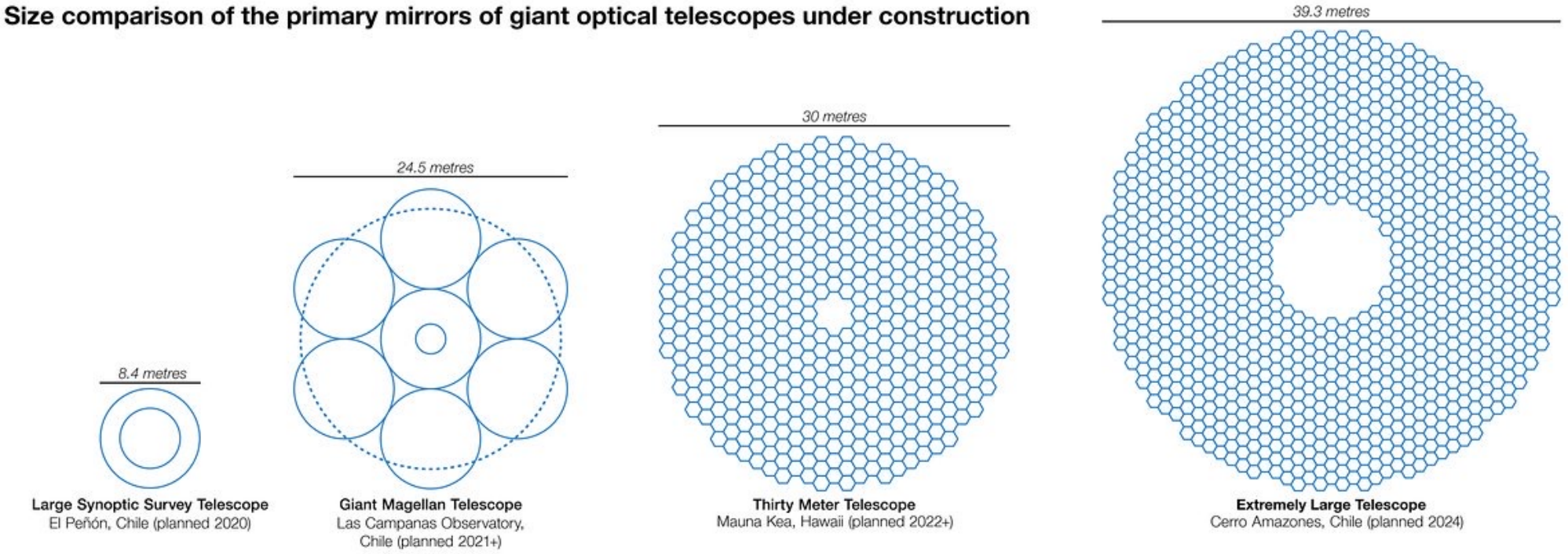
39.4m size mirror
800 x 1.4m mirrors=980m2



3000t of moving components

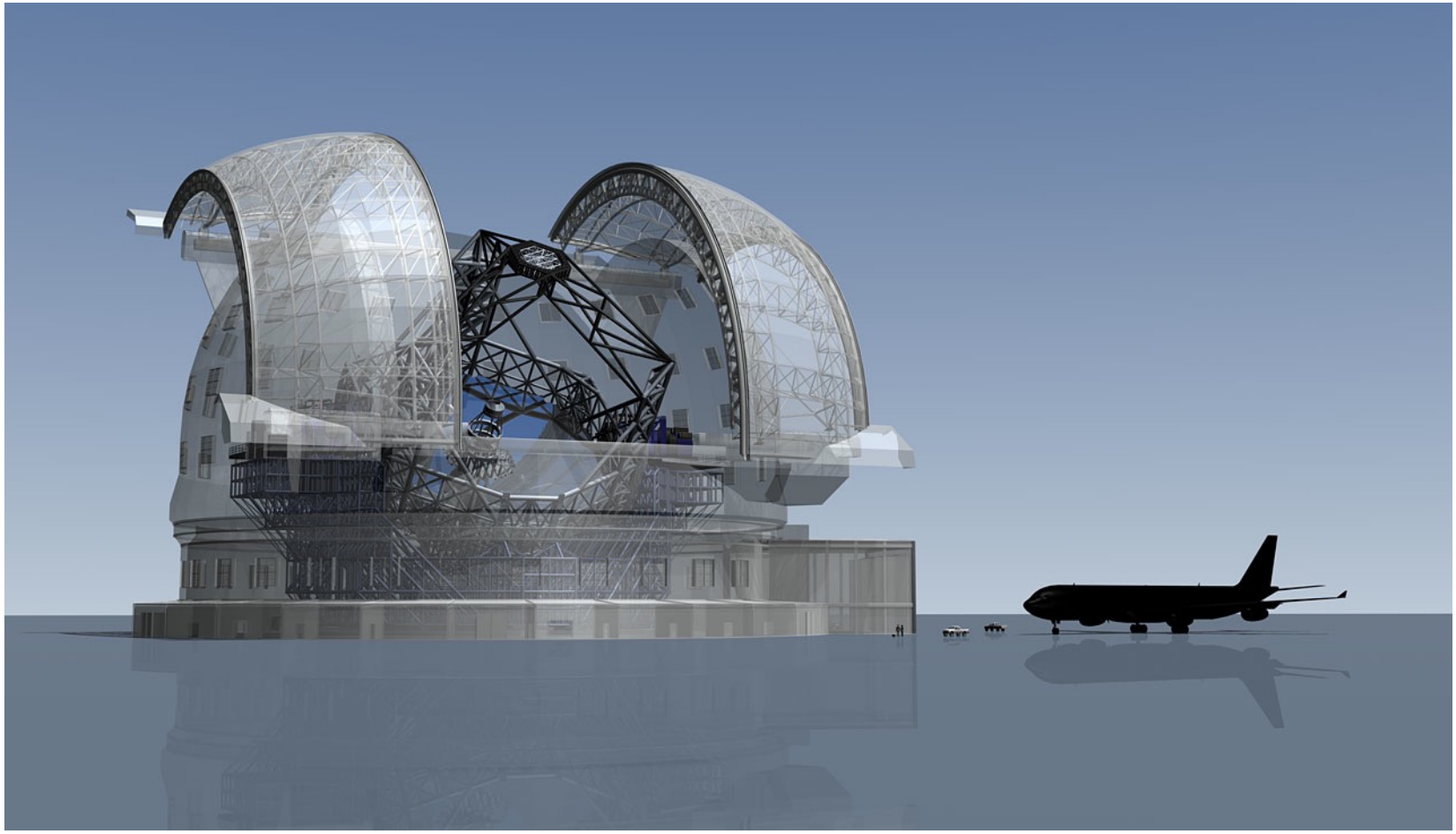


THE GIANTS

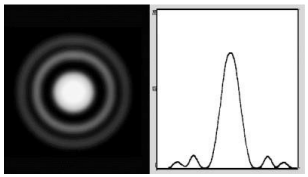

Size comparison of the primary mirrors of giant optical telescopes under construction
8.4 metres
Large Synoptic Survey Telescope
El Peñón, Chile (planned 2020)
24.5 metres
Giant Magellan Telescope
Las Campanas Observatory,
Chile (planned 2021+)
30 metres
Thirty Meter Telescope
Mauna Kea, Hawaii (planned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

IZUZETNO VELIKI TELESKOP

ELT



ASTRONOMY DRIVING TECHNOLOGY



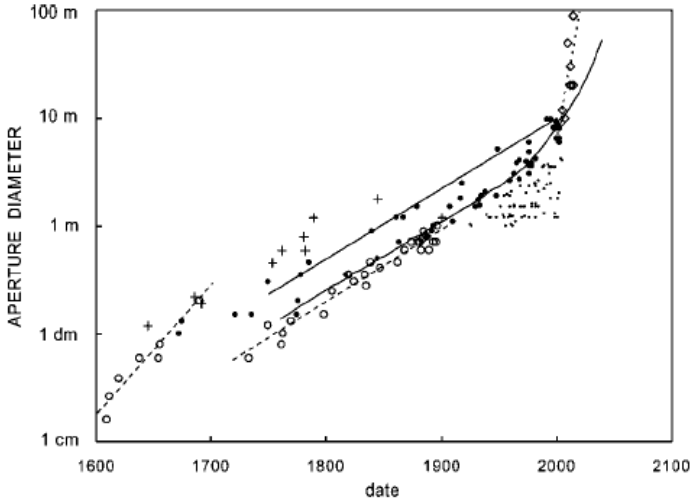
$$\Delta\theta = 1.22\frac{\lambda}{\mathrm{D}}$$

Two main drivers:

1. increase the sensitivity ~ D^2

2. increase of spatial resolution ~ 1/D

Both achivied with
increase of size
- diameter D



Rene Racine 2004, PASP, 116, 77

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

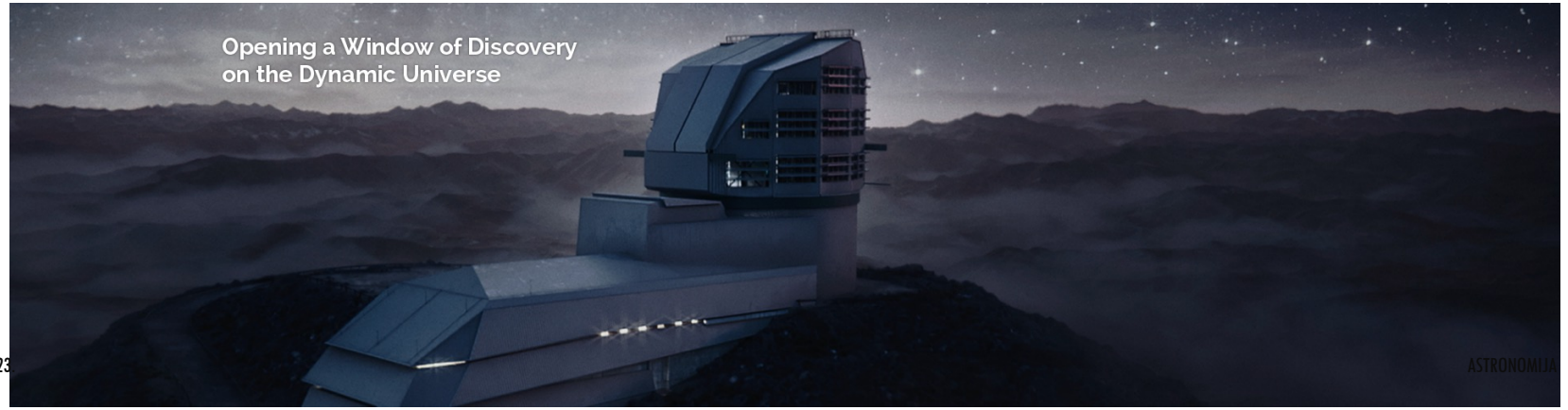
3200 megapixel camera → Each image the size of 40 full moons

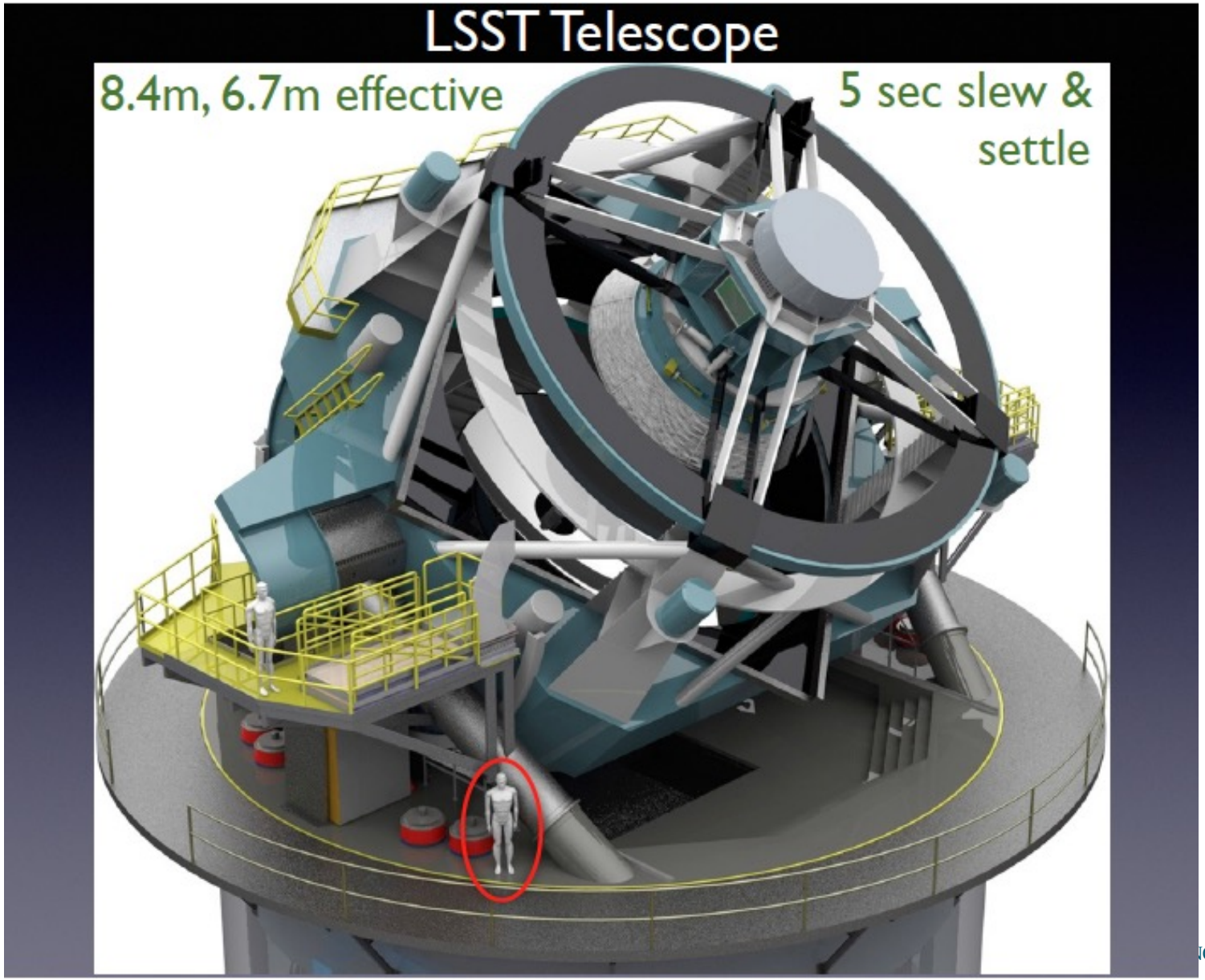
37 billion stars and galaxies

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

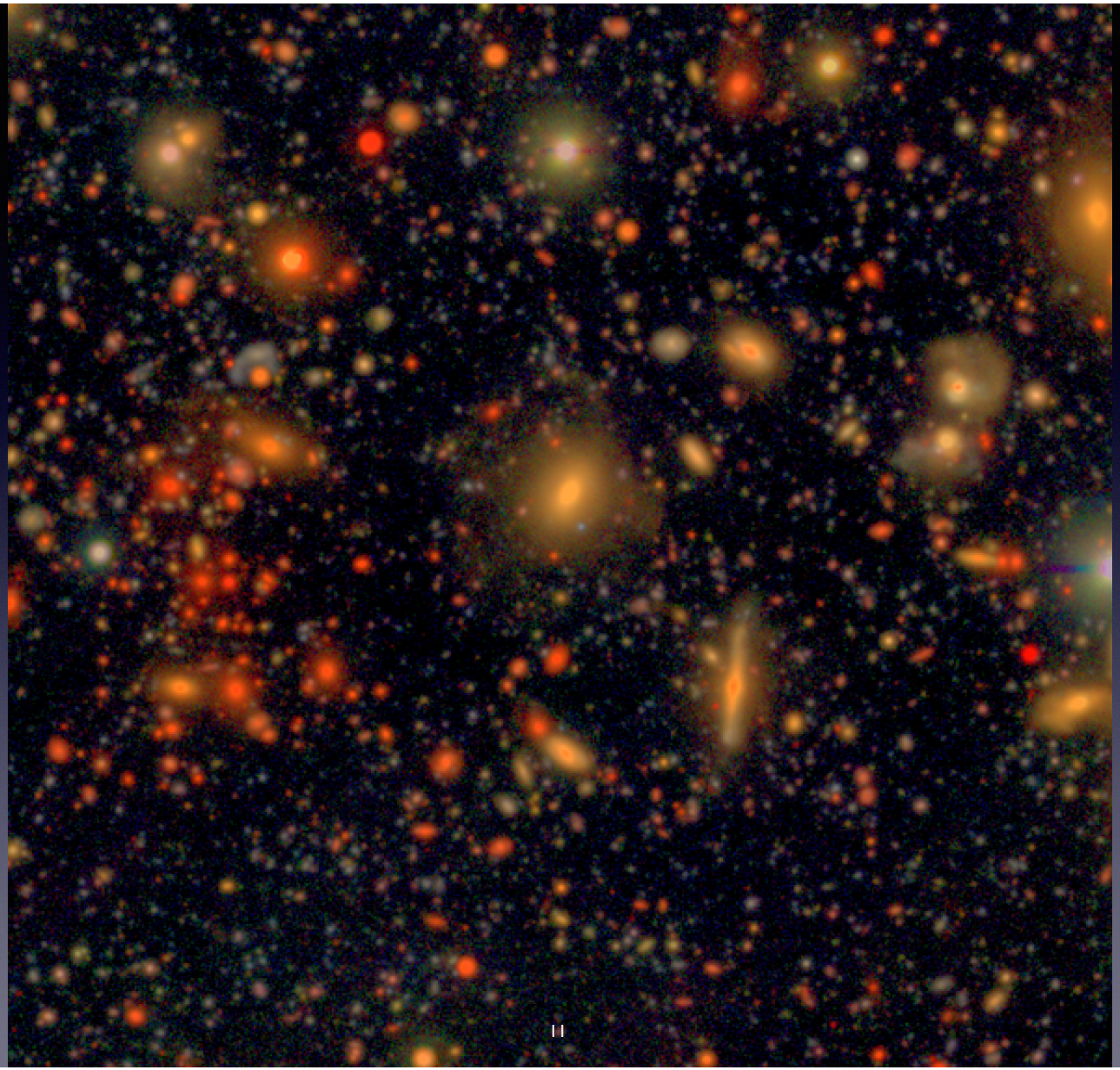



LSST Telescope
8.4m, 6.7m effective
5 sec slew &
settle


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



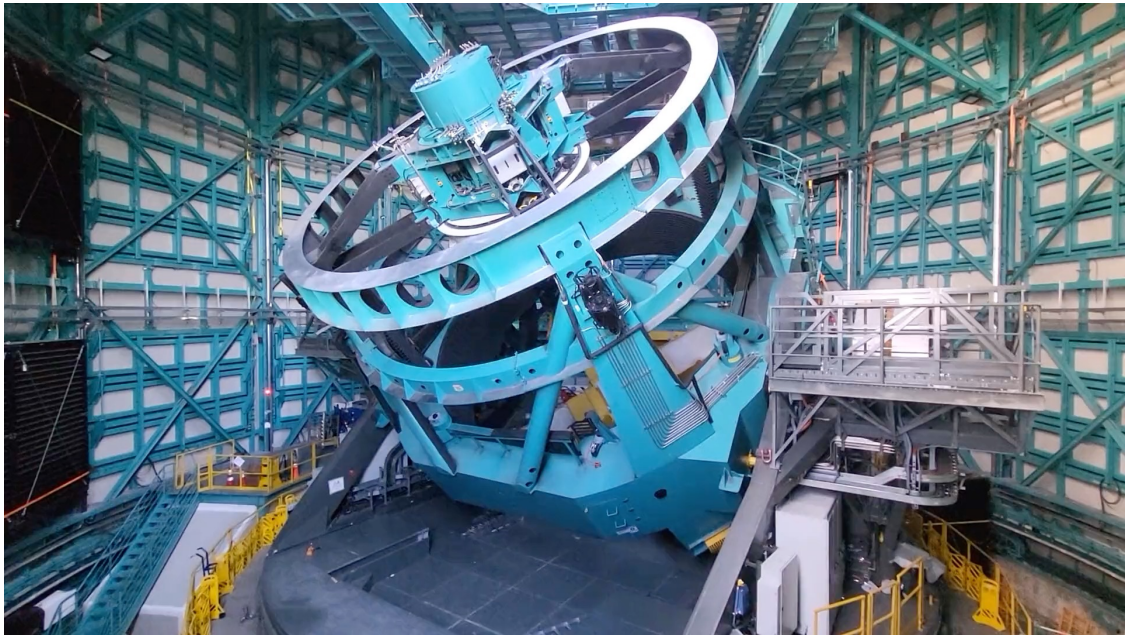
SIMONYI SURVEY TELESCOPE

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

VERA C. RUBIN OBSERVATORY

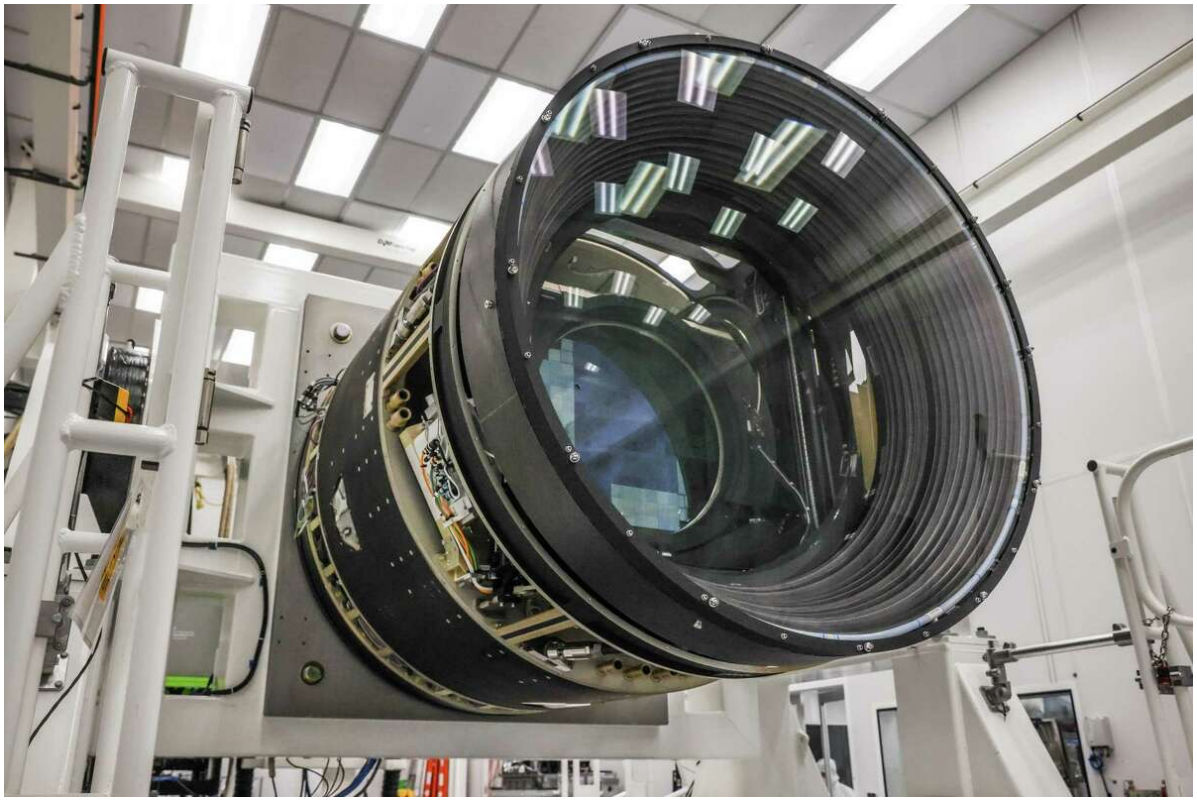
LEGACY SURVEY IN SPACE AND TIME = LSST

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 camera



VERA C. RUBIN OBSERVATORY

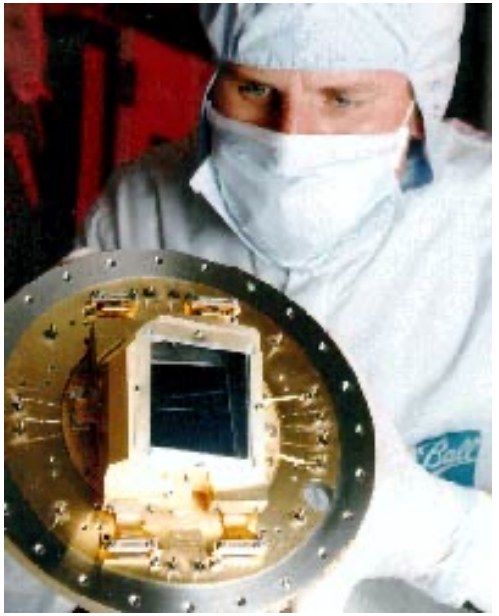
DETEKCIJA SVETLOSTI

Da sačuvamo i analiziramo svetlost treba nam detektor

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

Fotografske ploče
- Akumulira svetlost
- Trajno čuva slike

Elektronski “film” (CCD čip)
- Mnogo osetljiviji od fotografske ploče
- Digitalni podaci, velika efikasnost
- Nastao zbog potrebe astronoma
- Osnovni element svakog digitalnog fotoaparata I telefona



CCD čip sa Habla

CCD KAMERA

matrica fotoosetljivih ćelija (piksela)

napravljena od silicijuma

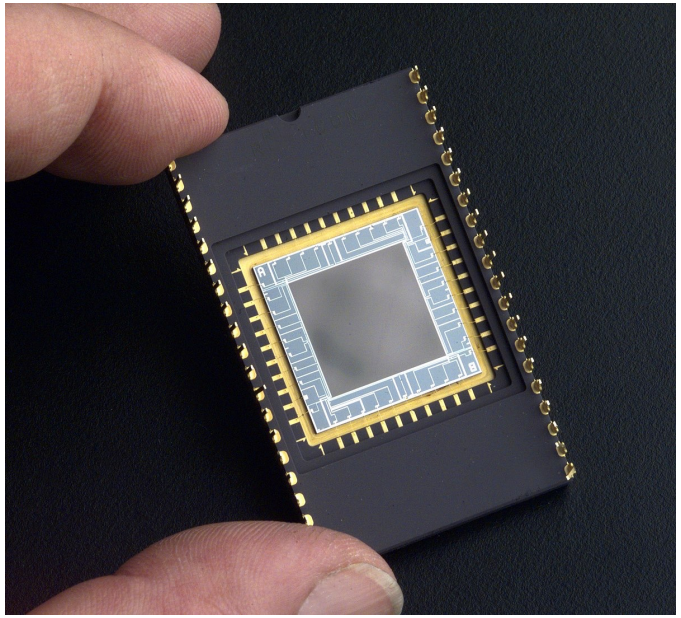
radi na principu fotoelektričnog efekta

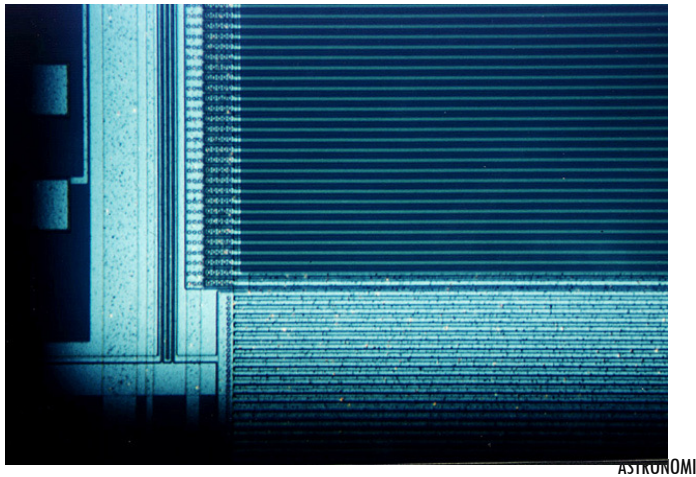
mnogo bolja osetljivost

veći opseg talasnih dužina

mogućnost sakupljana više svetlosti u toku vremena

linearni odgovor – koliko fotona toliko proporcionalno elektrona



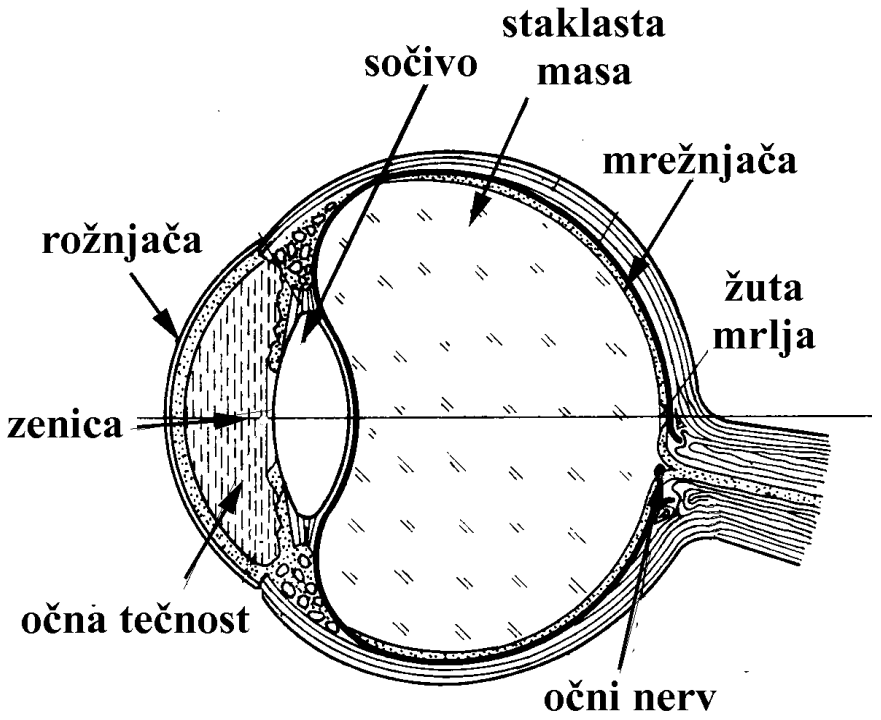


OKO

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)

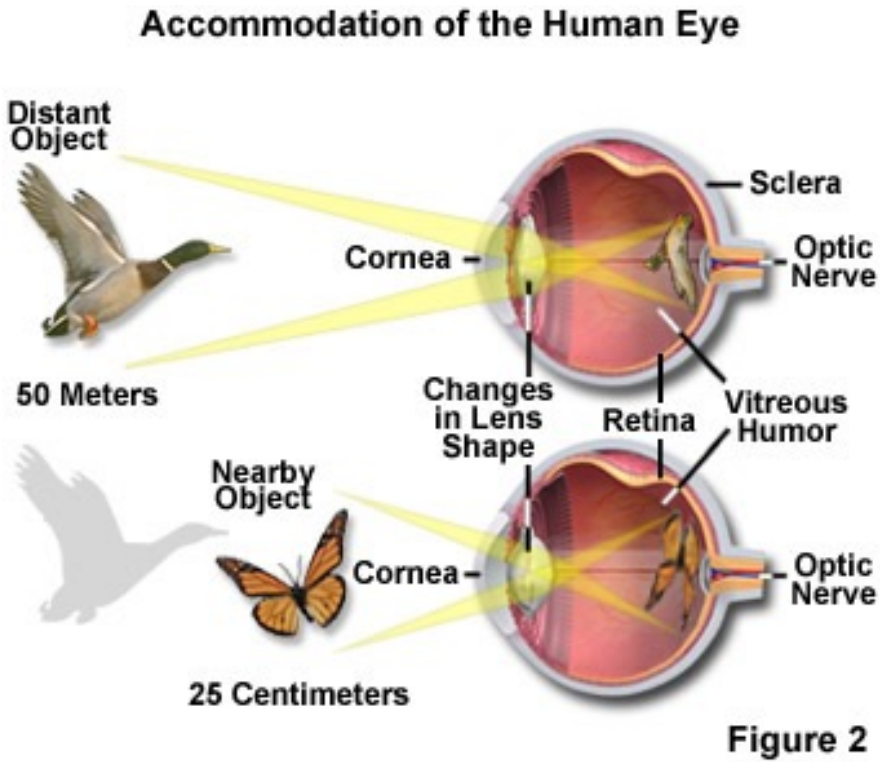


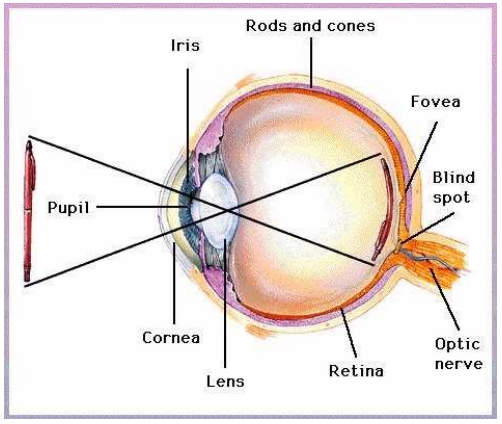
Figure 2

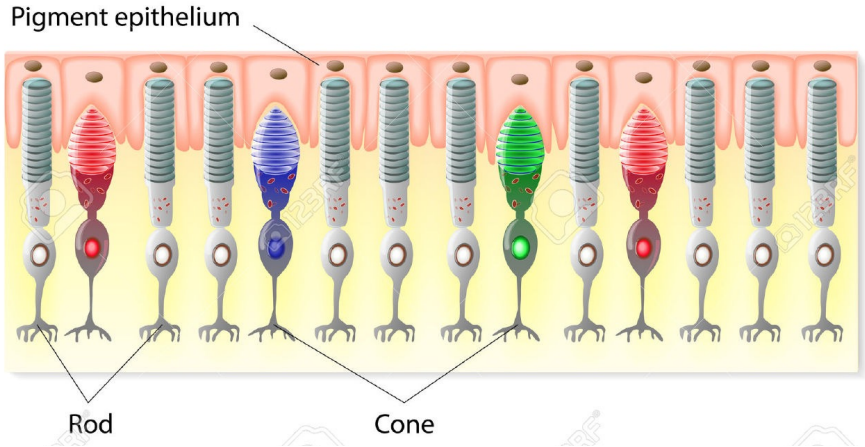
MREŽNJAČA = DETEKTOR

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





OŠTEĆENJA OKA

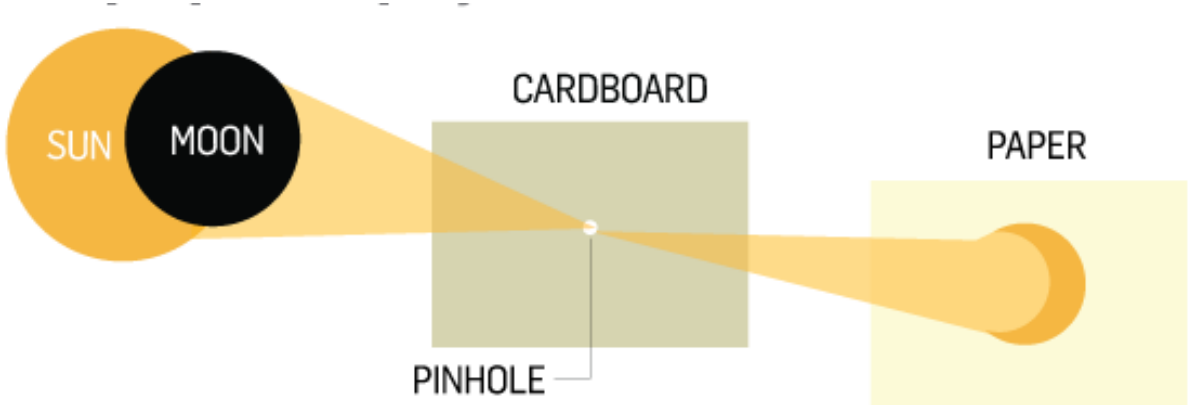
za oštećenja oka najvažnije razmatrati uticaj Sunca

SUNCE SE NE SME GLEDATI NEZAŠTIĆENIM OKOM!

- posmatranje Sunca nezaštićenim okom duže od jedne sekunde izaziva privremeno, a duže od nekoliko sekundi trajno oštećenje vida

posebno važno za pomračenje Sunca

- najbolje posmatrati projekciju Sunca



TELESKOPI NEVIDLJIVOG ZRAČENJA

NEVIDLJIVA ASTRONOMIJA

Astronomi žele da detektuju sve vrste svetlosti

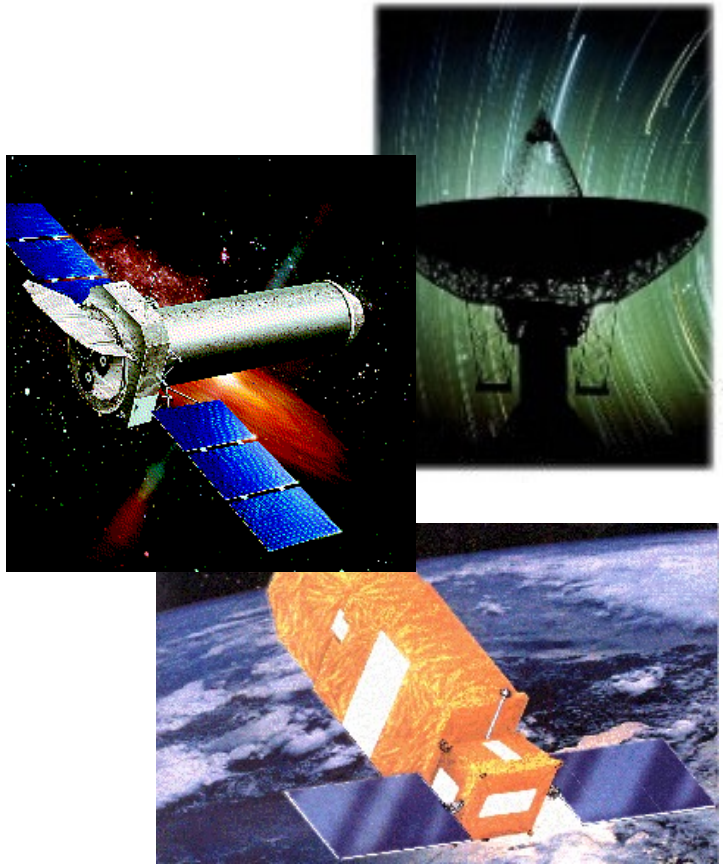
Otkrivaju različite procese i objekte

Većina teleskopa koristi sličan princip

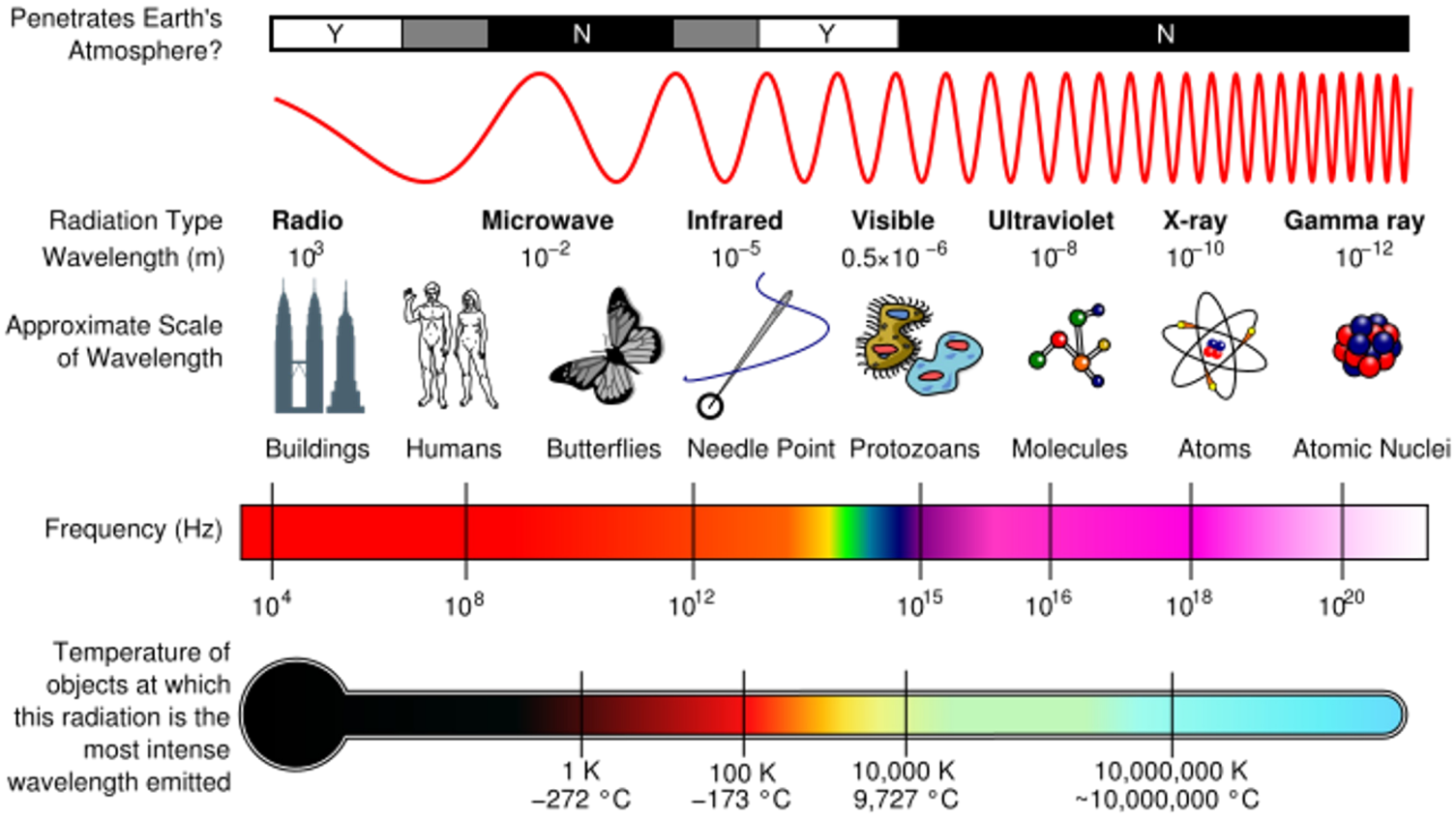
Većina su reflektori

- Svetlost se odbija o ogledala i sakuplja u žiži

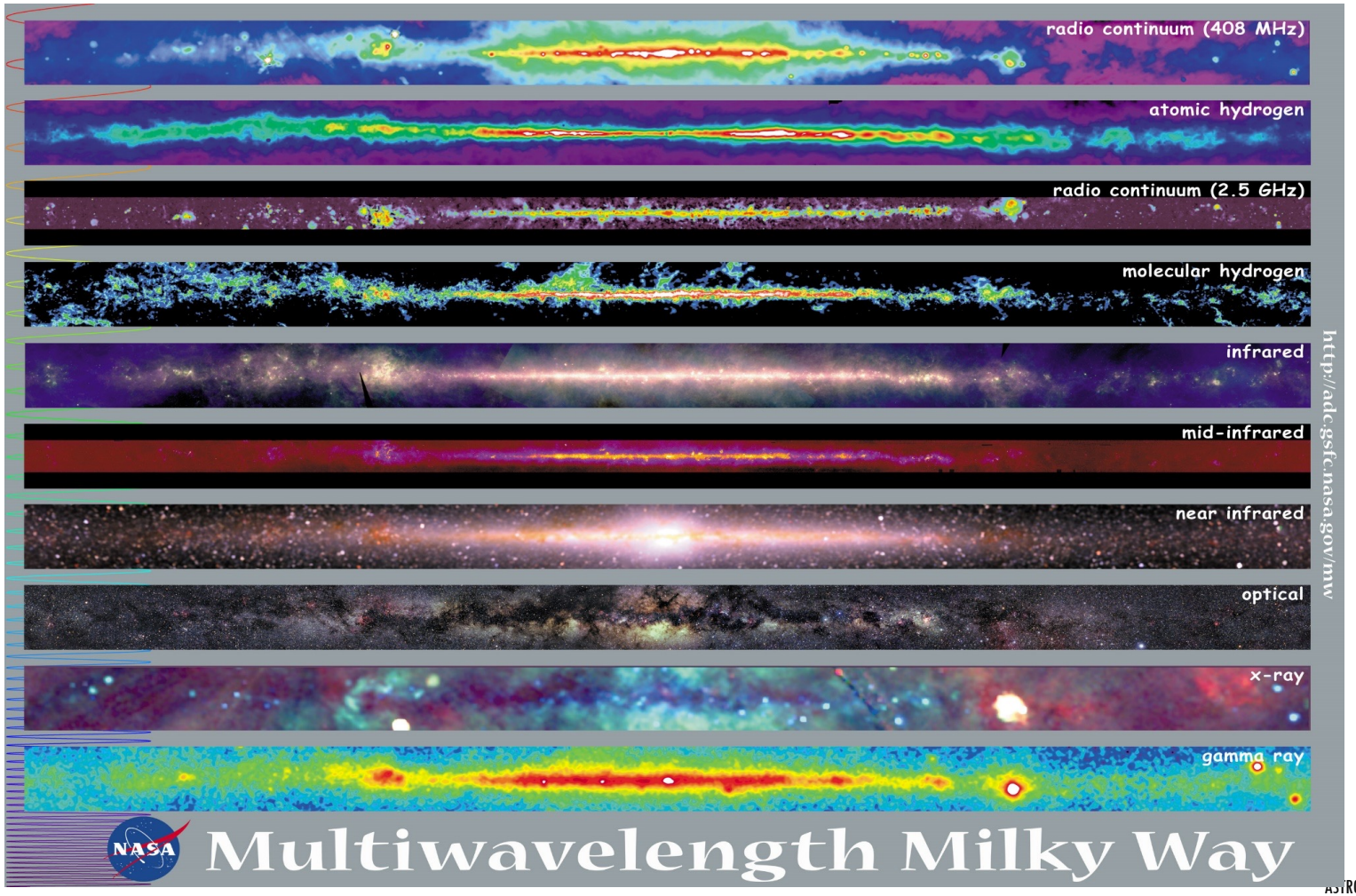
Ali radio i gama teleskopi su drugačiji

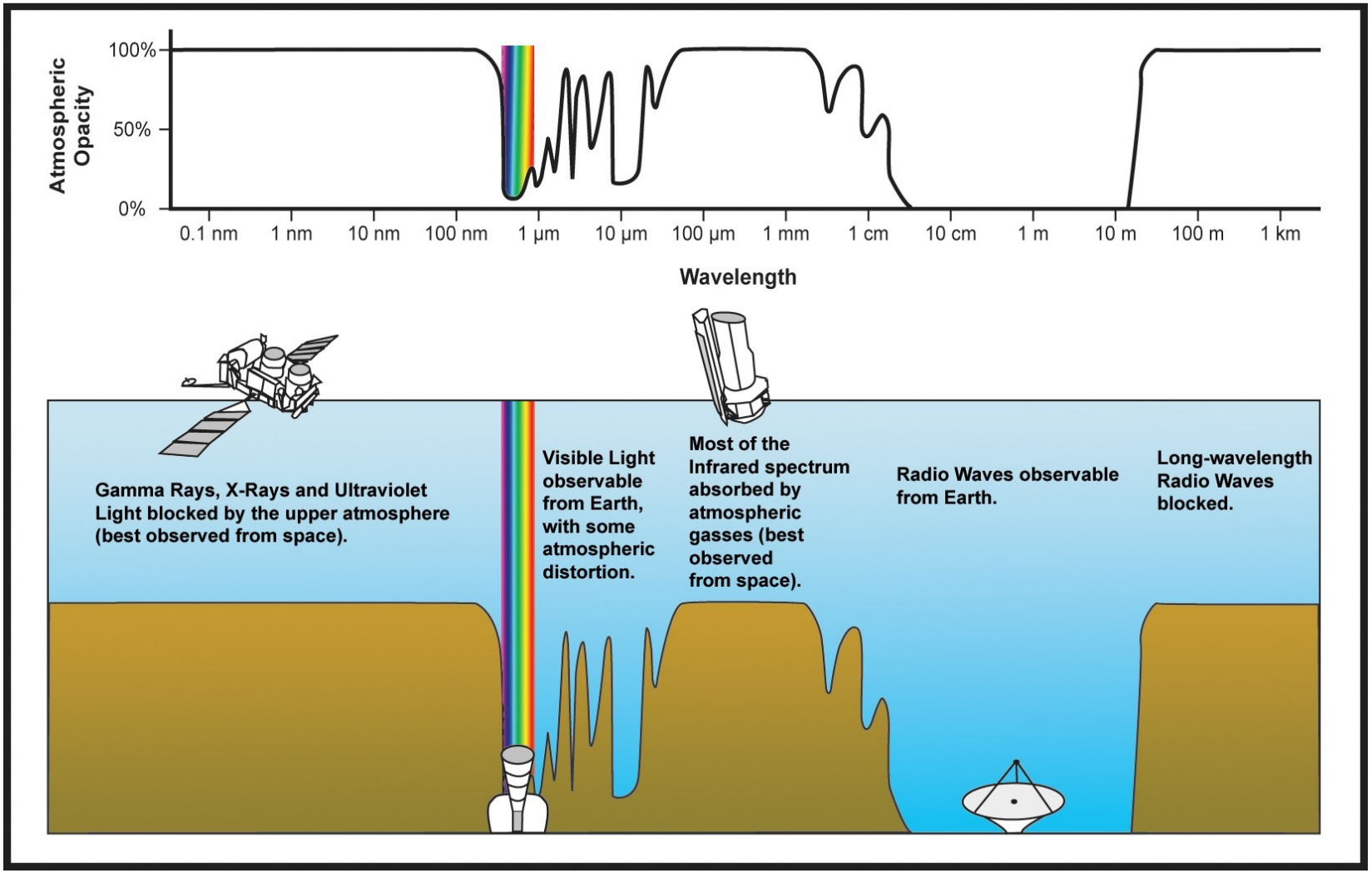


POSTOJE POSEBNI TELESKOPI ZA SVE DELOVE SPEKTRA!

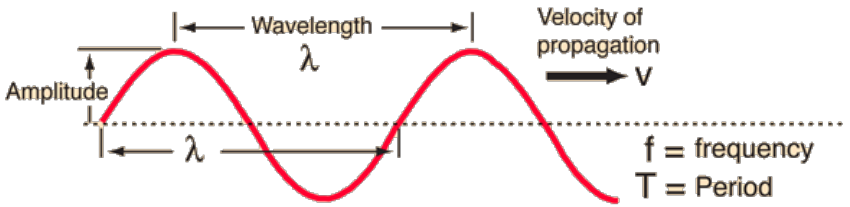


MLEČNI PUT KROZ CEO SPEKTAR

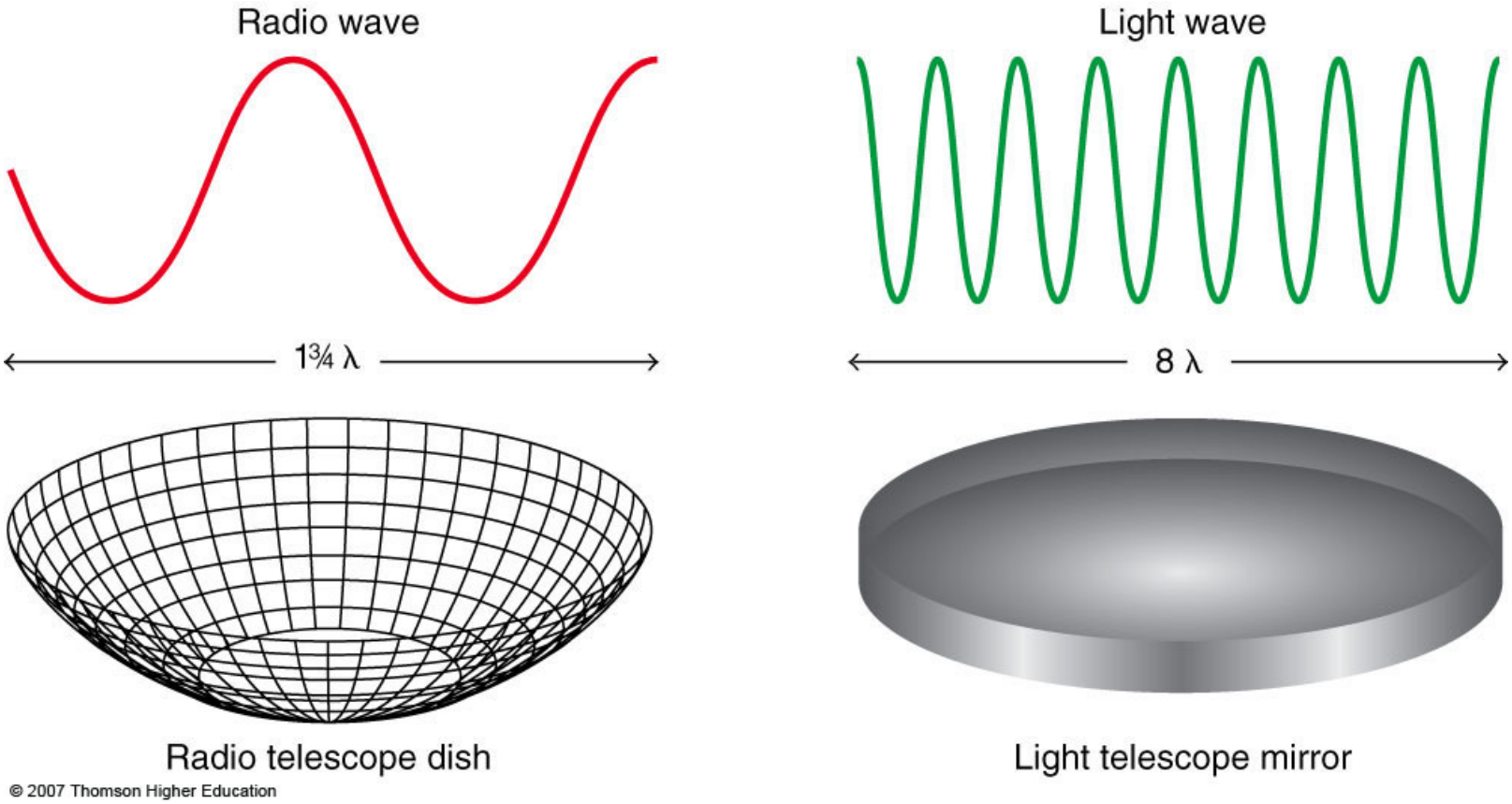



Atmospheric Opacity
100%
50%
0%
0.1 nm
1 nm
10 nm
100 nm
1 μm
10 μm
100 μm
1 mm
1 cm
10 cm
1 m
10 m
100 m
1 km
Wavelength
Gamma Rays, X-Rays and Ultraviolet Light blocked by the upper atmosphere (best observed from space).
Visible Light observable from Earth, with some atmospheric distortion.
Most of the Infrared spectrum absorbed by atmospheric gasses (best observed from space).
Radio Waves observable from Earth.
Long-wavelength Radio Waves blocked.

VELIKE TALASNE DUŽINE



RADIO TELESKOPI



Mnogo veći od optičkih.

REZOLUCIJA

•Najmanje ugao pod kojim vidimo stvari razdvojene

•Zavisi od prečnika teleskopa

$$\theta = 1{,}22\frac{\lambda}{D}$$

• Što je veći teleskop, bolja je rezolucija

RADIO-TELESKOP 500M, KINA, 2016.GOD

FAST - Five 100m Aperture Spherical Telescope

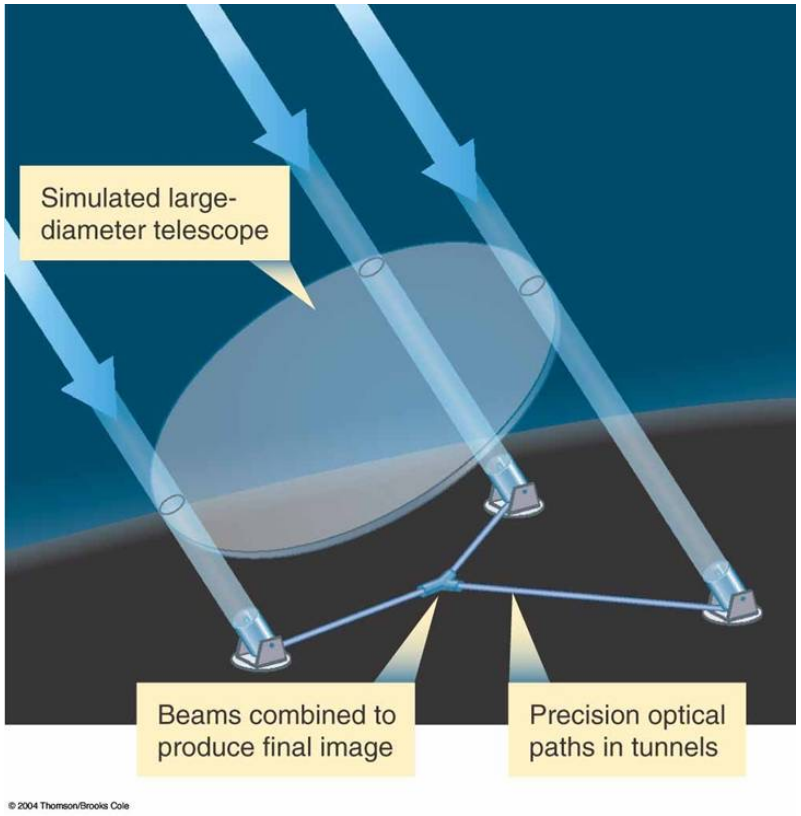
sličan Aresibo teleskopu, ali prilagodljiv oblik tako da može da posmatra i do z=40°

4600 segmenata

RADIO INTERFEROMETRIJA

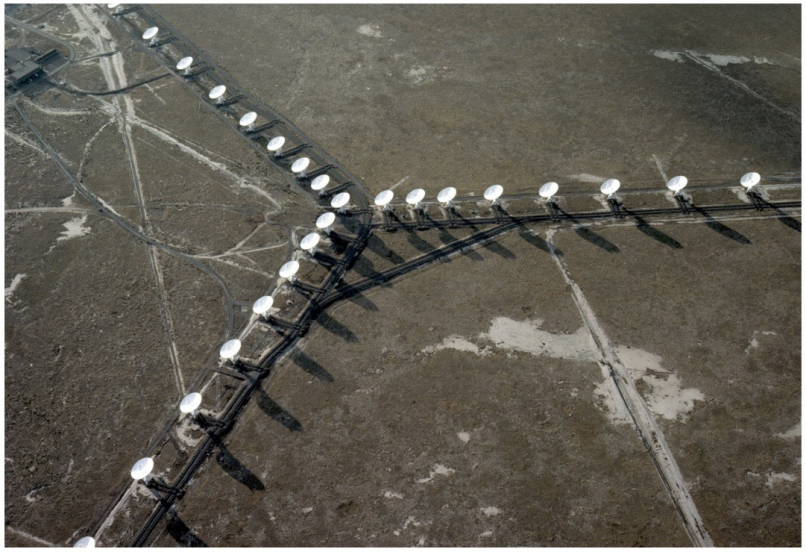
•Velika talasna dužina – dobra rezolucija je problem za radio teleskope

- **Interferometrija**
  - rezolucija kao kod teleskopa prečnika jednakog rastojanju dve najudaljenije komponente
  - •Signal se kombinuje
  - ali gubimo efektivnu površinu kolektora



RADIO INTERFEROMETRI

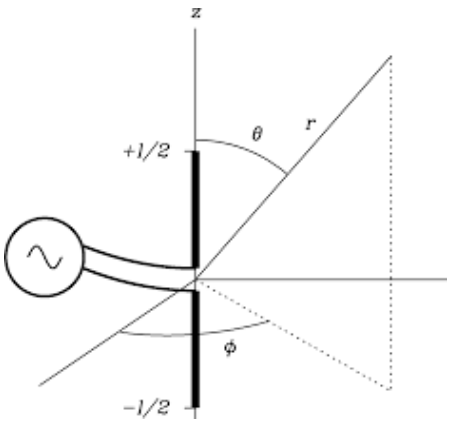
- Više malih teleskopa koji rade zajedno kao jedan veliki
- Odlična rezolucija
  - Very Large Array, Novi Meksiko, 27 kombinovanih 25m antena – max baza od 36 km

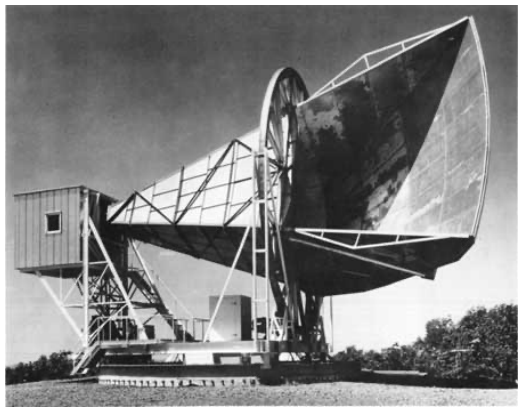



The Global VLBI – Array
Brewster
North Liberty
Hancock
Green Bank
Jodrell Lovell
Jodrell Mk2
Cambridge
Onsala 25m and 20m
Metsähovi
Los Alamos
Owens Valley
Pie Town
Mauna Kea
Kitt Peak
Urumqi
Shanghai
Westerbork
Medicina
Noto
EVN
VLBA
European VLBI Network (EVN)
Very Long Baseline Array (VLBA)
High Sensitivity Array (HSA)
Ft. Davis
St. Croix
V L A
Arecibo
Effelsberg
Yebes
Wettzell
Torun
Hartebeesthoek

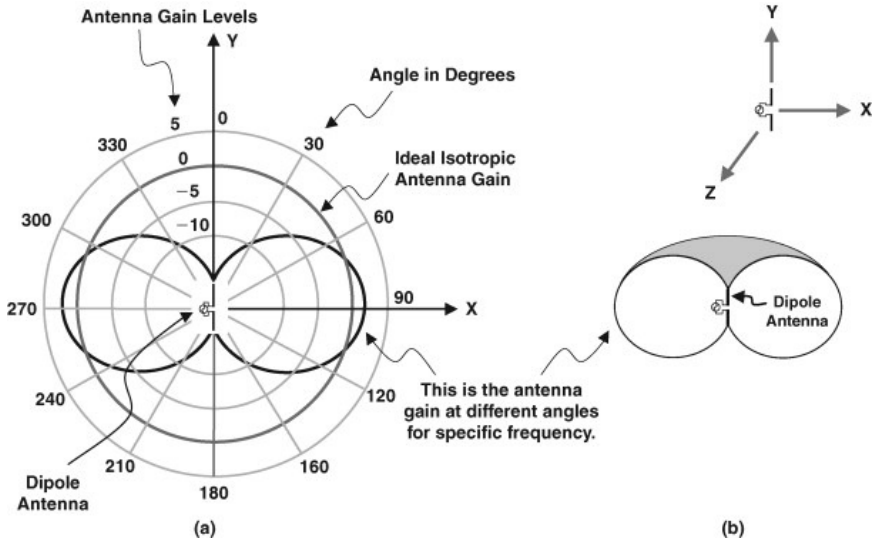
RADIO ANTENA

- antena dipol, najprostiji tip prijemnika





Horn antennas, Penzias and Wilson detection of the CMB radiation, proof of Big Bang



- izgleda prijema zracenja

NOVEL TECHNIQUES

Radio Interferometry, Aperture Synthesis

– 8 Nobel Prizes in radio astronomy

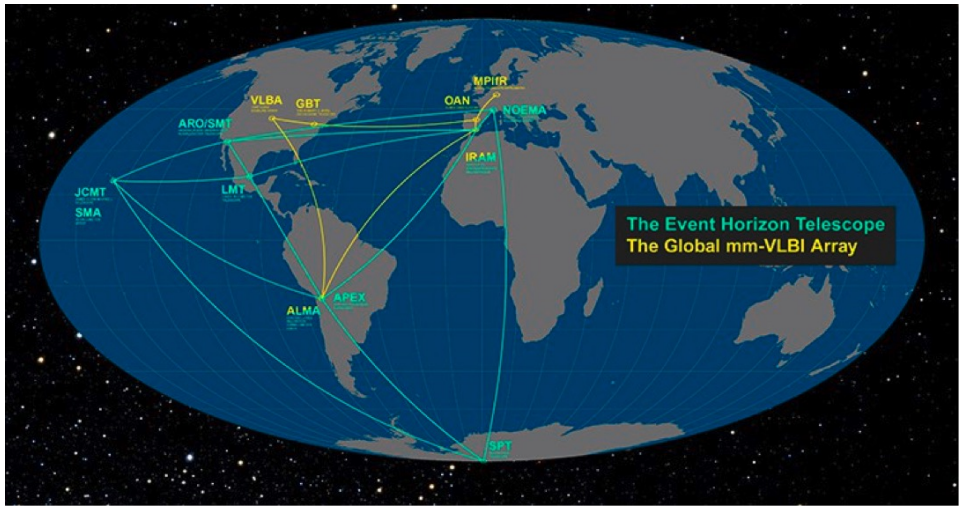
Very Large Array (VLA), 27 Antenas

EVENT HORIZON TELESCOPE (EHT)

Very Long Baseline Interferometry (VLBI)

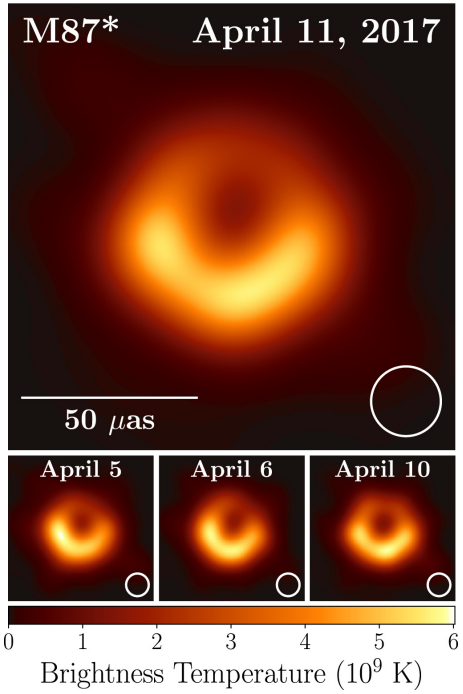
Simulate a telescope of Earth size

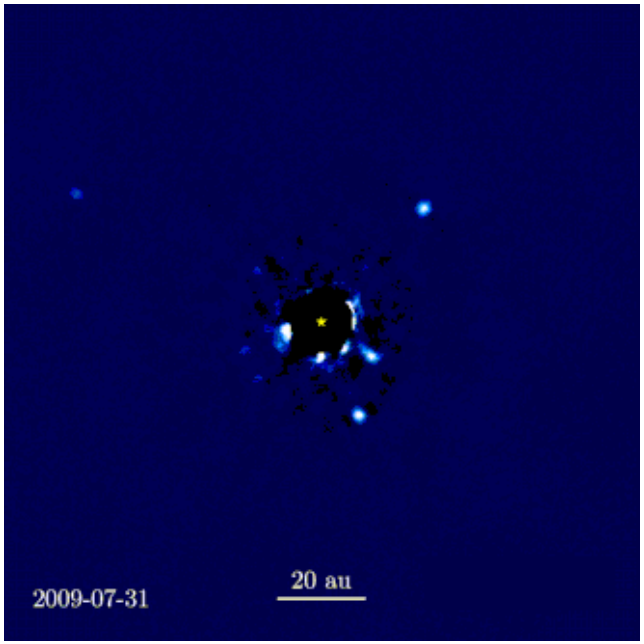
Angular resolution of 20 μas at wavelength 1.3 mm (230 GHz) – i.e., size of an apple on the Moon seen from the Earth



BLACK HOLE SHADOW

Event Horizon Telescope – network of 7 radio telescope, observed for the first time supermassive black hole in M87 active galaxy.





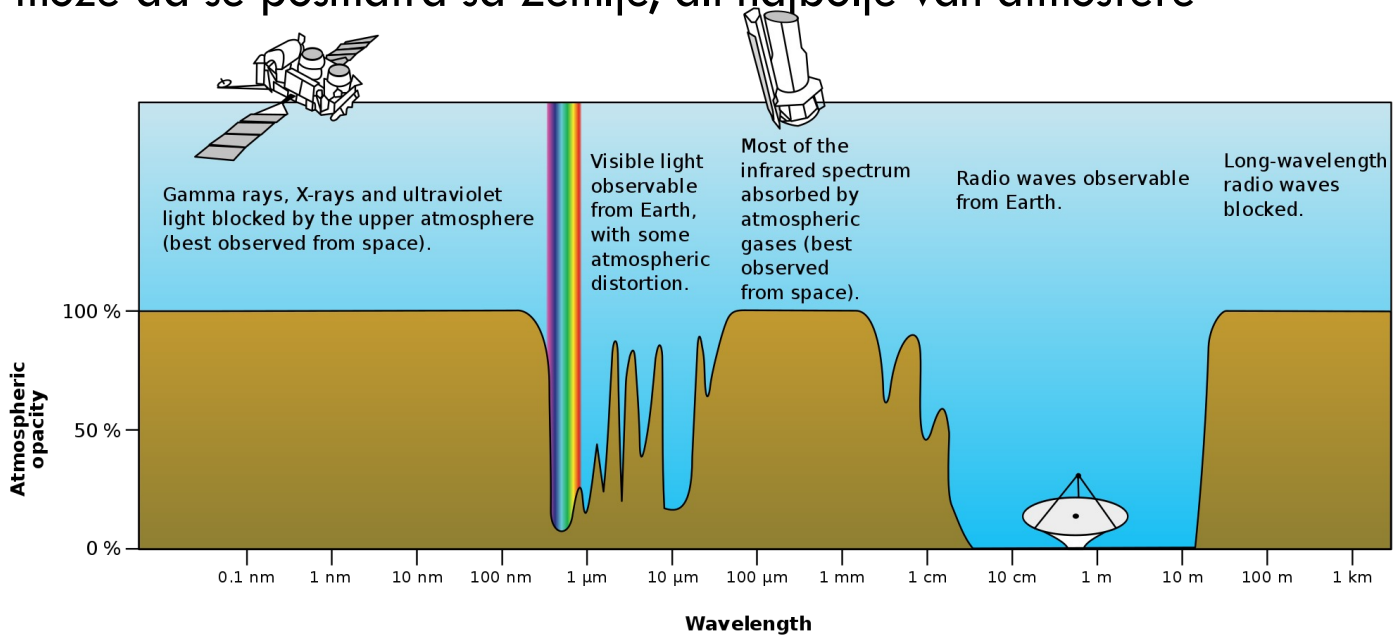
Four exoplanets orbiting counterclockwise with their host star (HR 8799) – Keck Observatory

INFRACRVENI TELESKOPI

sve zrači u IC domenu, veliki šum

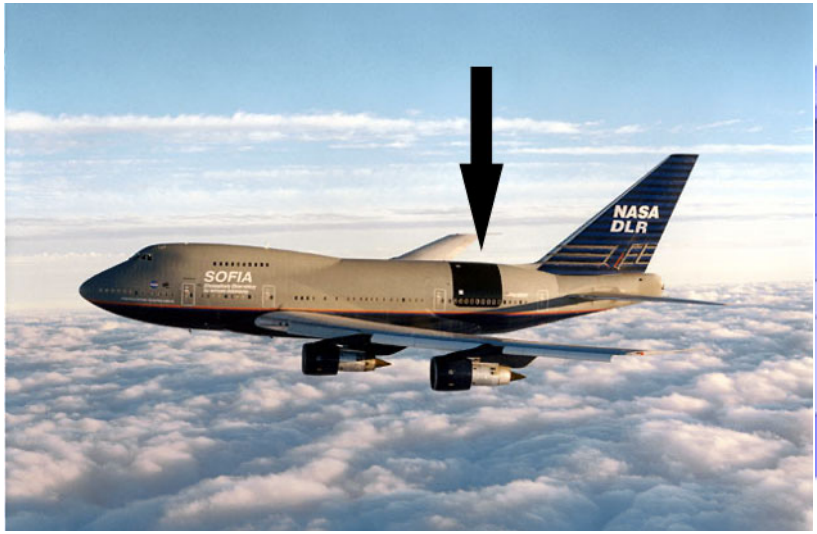
najveći problem Zemljina atmosfera koja je na temperaturi oko 300 K, što pada u IC domen

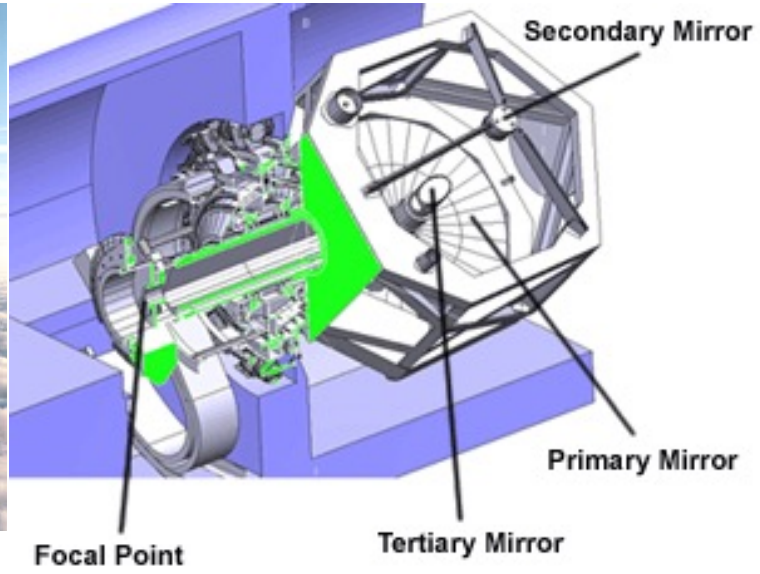
može da se posmatra sa Zemlje, ali najbolje van atmosfere



teleskop se nalazi u zadnjem delu aviona, gde je napravljen otvor kroz koji se vrše posmatranja

objektiv teleskopa ima prečnik od 2.5 m i nalazi se u komori koja je izolovana od ostalog dela aviona





GAMA TELESKOPI

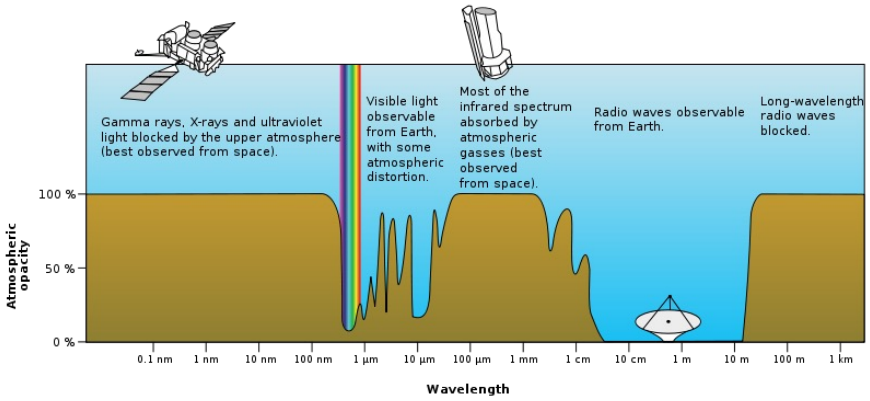
Suštinski drugačiji od ostalih teleskopa

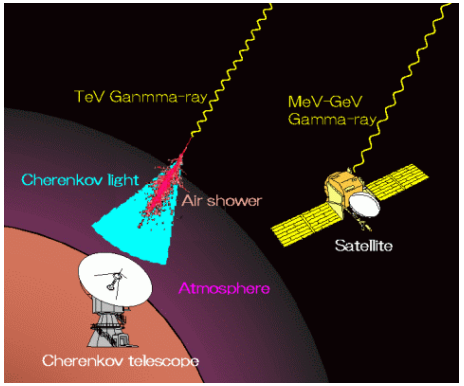
- Međuatomska rastojanja su mnogo veća od talasne dužine gama zračenja koje zato ne može biti reflektovano (ovo važi i za deo X-zračenja)

Detektori – koriste interakcije gama zračenja sa materijalom detektora

DETEKCIJA GAMA ZRAČENJA

Atmosfera ne propušta gama zračenje





Dve opcije:

- **Direktna detekcija – gama teleskopi na satelitima**
- Indirektna detekcija – atmosferski čerenkovljevi teleskopi

GAMA TELESKOPI NA SATELITIMA

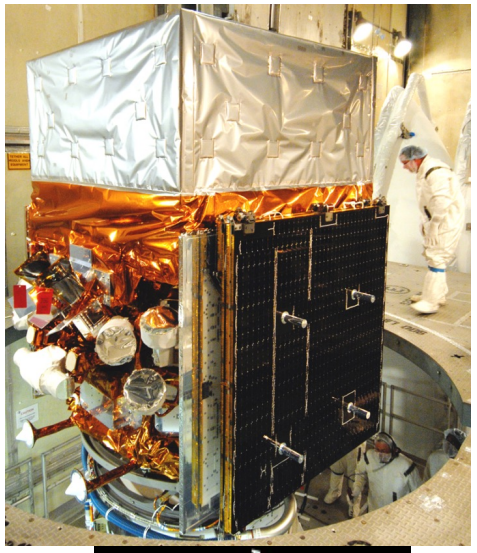
Niske-srednje energije

Gama zračenje se pretvara u

nešto drugo

1. Proizvodnja elektrona
2. Proizvodnja svetlosti npr. (scintilacija) u kristalima

Najveći problem – razlikovati ga od kosmičkog zračenja (čestica iz svemira) kog ima bar 1000x više



FERMI OPSERVATORIJA

Large Area Telescope + Gamma-Ray Burst Monitor

Lansiran 11. juna 2008.

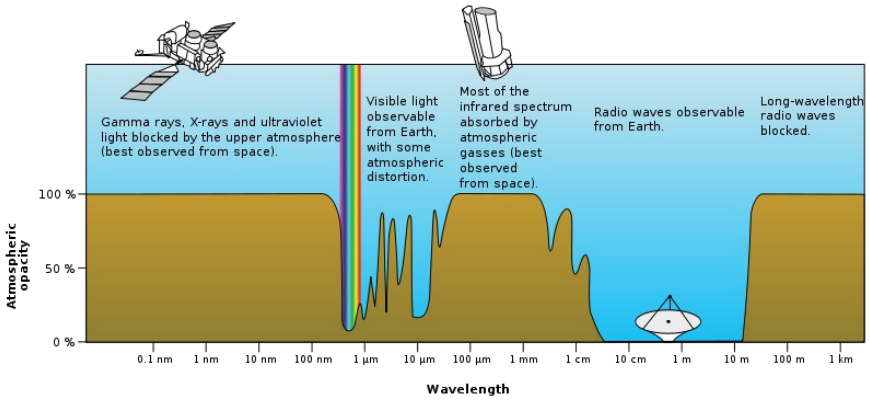
Vidi 20% neba

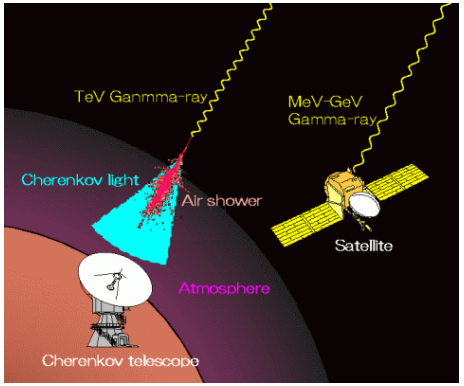
Snimi celo nebo za 3h

Pogled u “neotvoren prozor” do 10-300 GeV

DETEKCIJA GAMA ZRAČENJA

Atmosfera ne propušta gama zračenje





Dve opcije:

- Direktna detekcija – gama teleskopi na satelitima
- **Indirektna detekcija – atmosferski čerenkovljevi teleskopi**

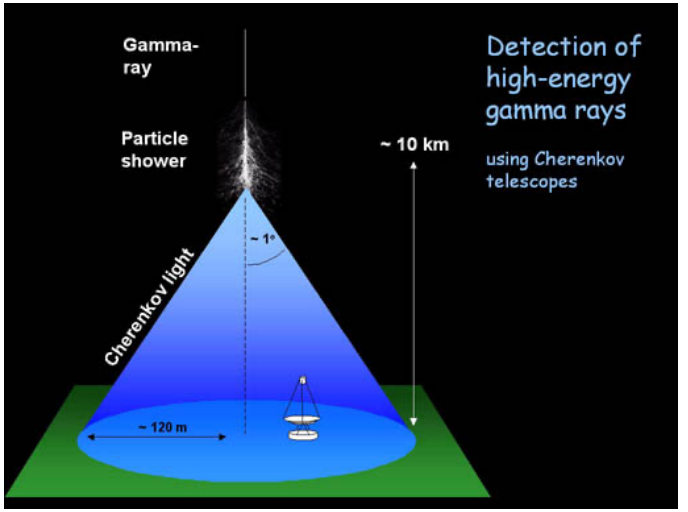
ATMOSFERA KAO DETEKTOR!

Gama zračenje u atmosferi izazove pljusak čestica

Čestica se kreće **brže od svetlosti** (za vazduh)

Emituje plavičastu svetlost = **čerenkovljevo zračenje**

Kao probijanje zvučnog zida za avione

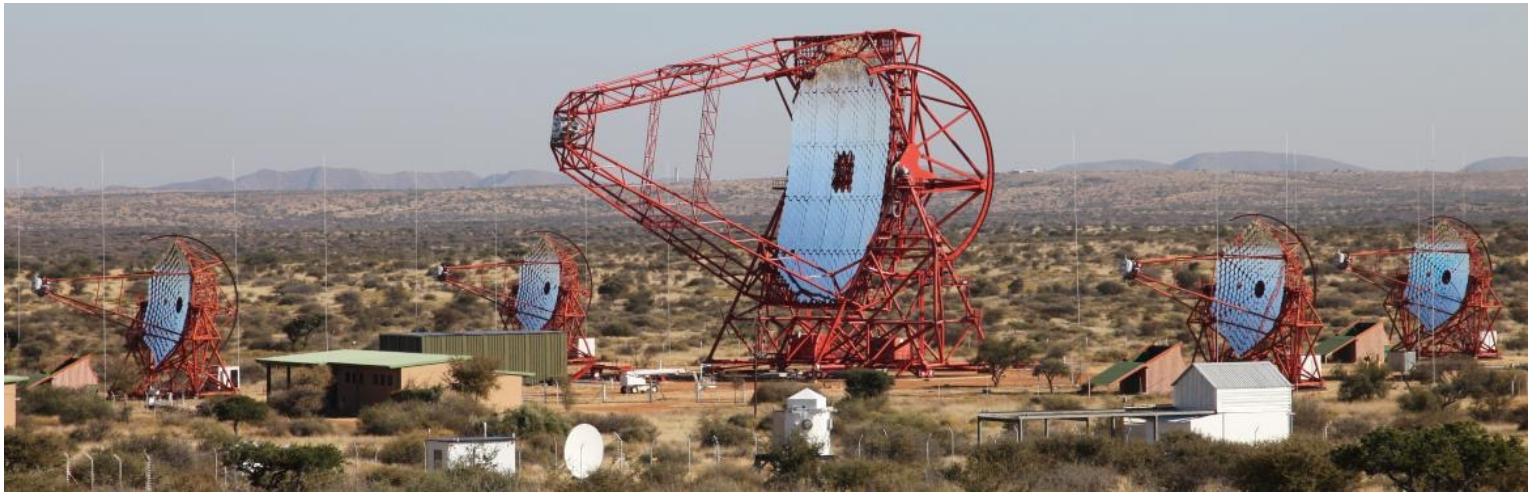


GAMA ZRAČENJE U VIDLJIVO ZRAČENJE U ATMOSFERI

Optički teleskopi (reflektori) detektuju tu plavičastu svetlost što proizvede gama zračenje

Potrebno jako vedro nebo

H.E.S.S. teleskop, Namibia - više teleskopa zajedno

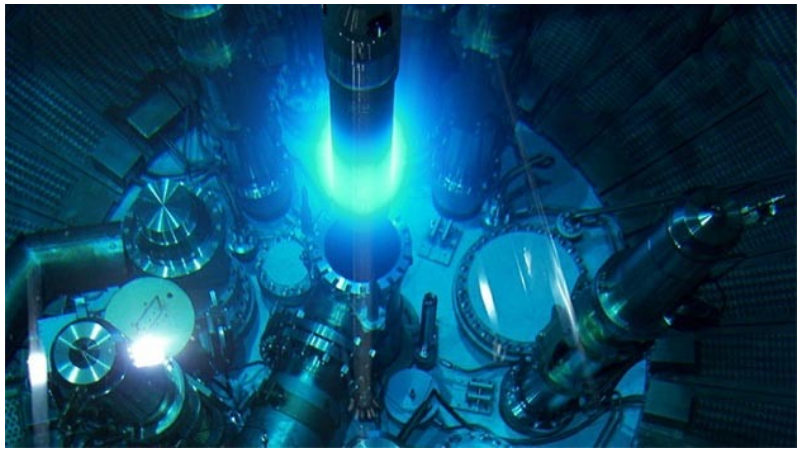


BAZENI KAO GAMA TELESKOPI

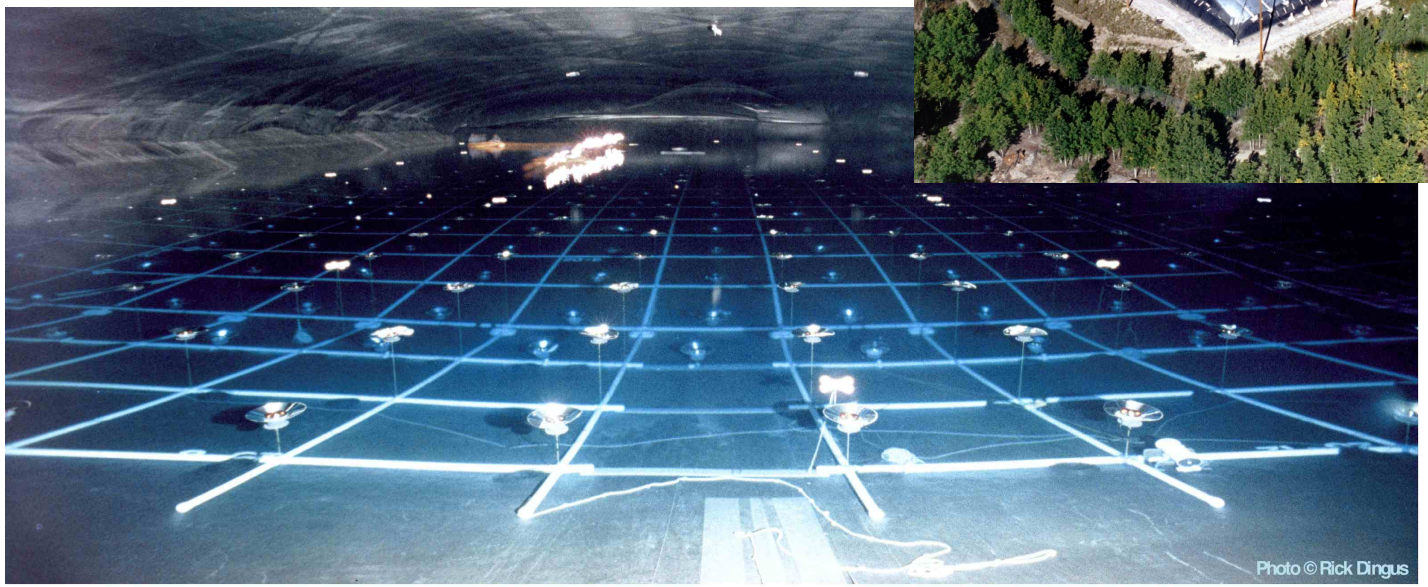
Gama zračenje proizvede pljusak čestica

Čestice ulete u bazen brzinom većom od brzine svetlosti za vodu

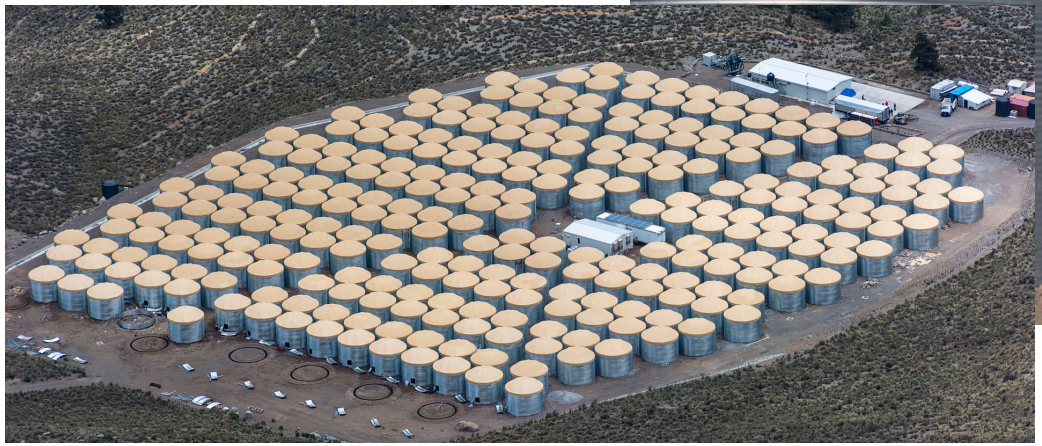
Plavičasta svetlost emitovana u vodi snima se fotodetektorima



MILAGRO TELESKOP, NOVI MEKSIKO



HAWC TELESKOP, MEKSIKO



DETEKCIJA OSTALIH NOSICA INFORMACIJA

1. čestice - kosmičko zračenje (visoko energetska jezgra čestica, najviše protona, jezgra helijuma i elektrona)
2. neutrini
3. gravitacioni talasi

danas era ”*multi-messenger*” astronomije

NEUTRINI

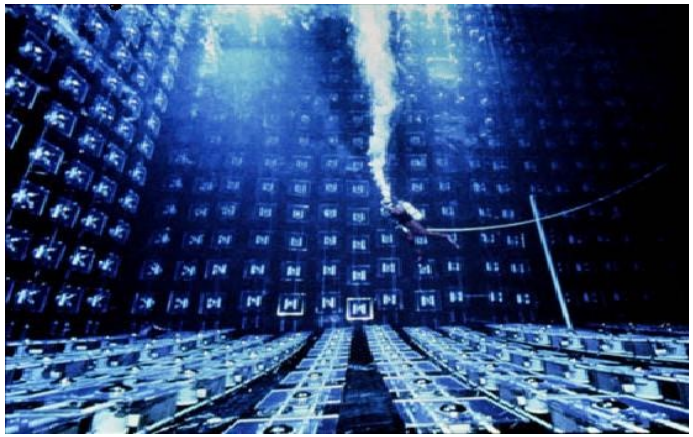
samo dva diskretna izvora neutrina do sada posmatrana:
Sunce i SN 1987A u Velikom Magelanovom Oblaku

slabo interagujuće čestice nulte ili vrlo male mase, bez naelektrisanja, spin 1/2

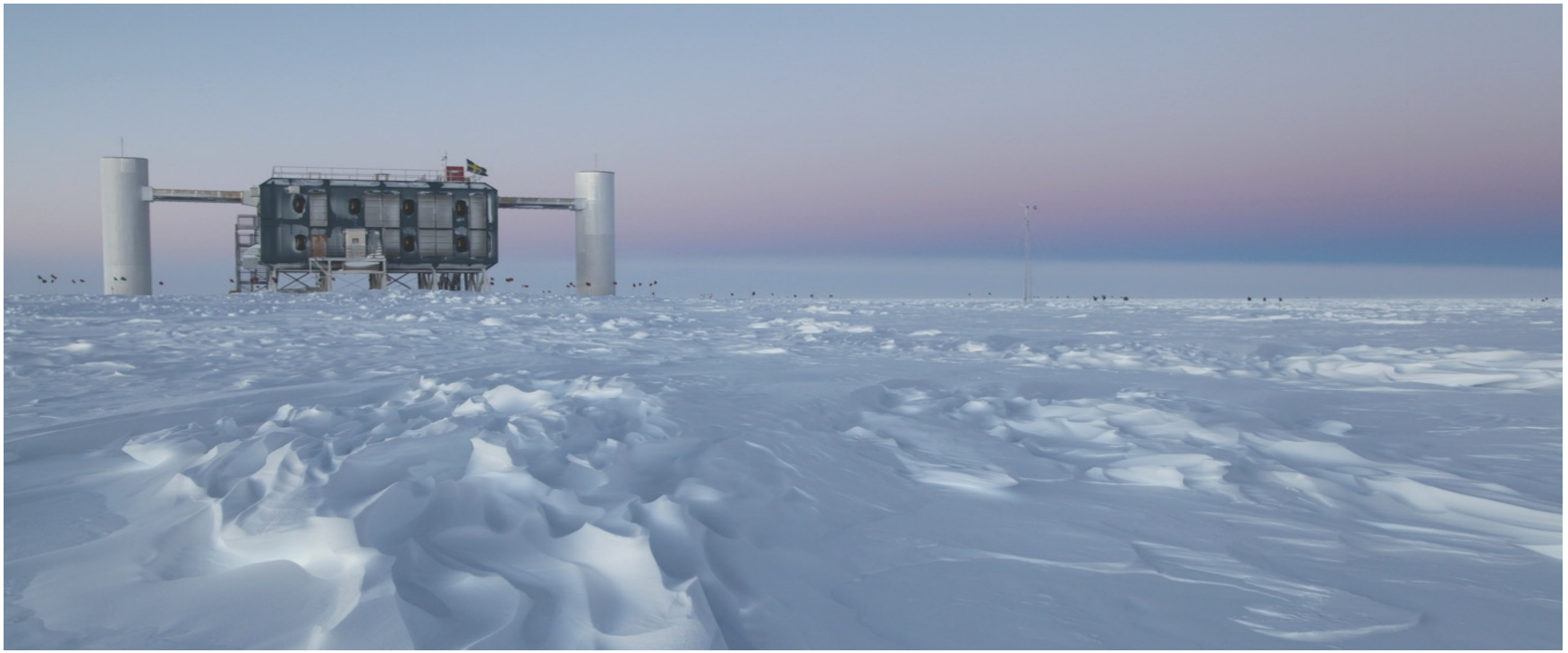
detektori neutrina (veliki rezervoari tečnosti):

- detektori na bazi hlora ili galijuma
- vodeni detektori (isto mere Čerenkovljevo zračenje)
- scintilatori

problem fluksa Sunčevih neutrina

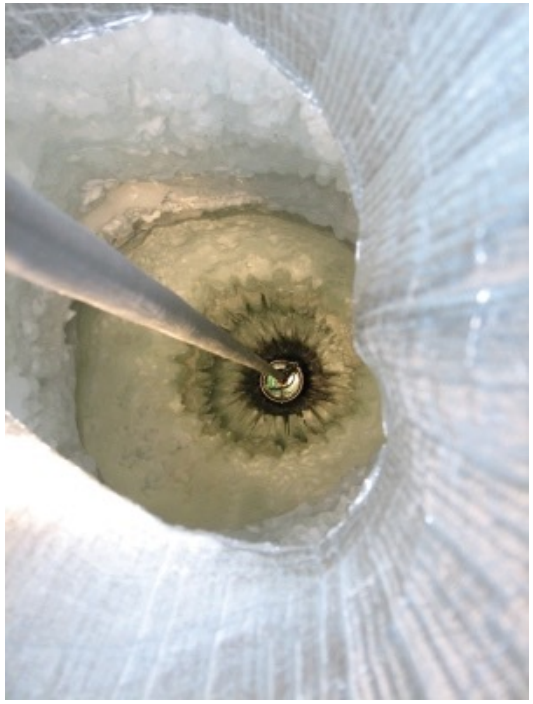


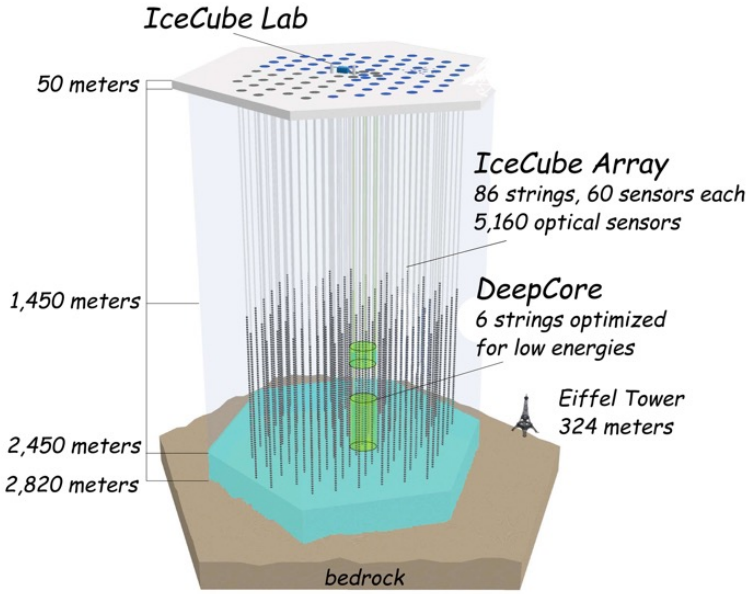
ICE CUBE, JUŽNI POL



ICE CUBE: DETEKTOR NEUTRINA

- meri Čerenkovljevo zračenje
- kubni kilometar ultračistog leda 1.5km ispod Južnog pola
- 5160 detektora okačenih na 86 sajli





GRAVITACIONI TALASI

nastaju kao posledica pomeranja mase u sistemu, što dovodi do promene gravitacionih efekata na drugo telo → informacija o promeni gravitacionog polja se prenosi kroz prostor-vreme brzinom svetlosti

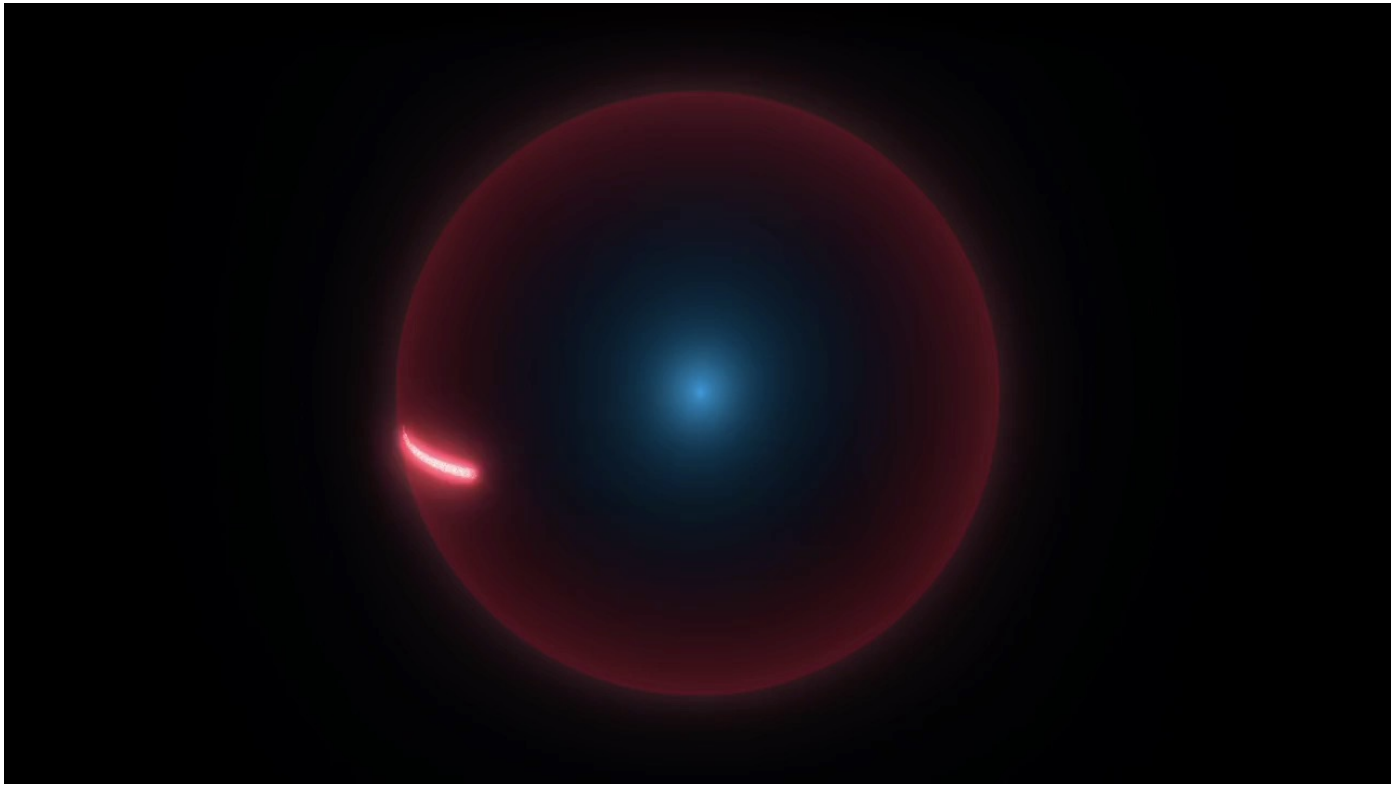
jako teško detektovati jer su jako slabi

npr. sistem Sunce-Zemlja:

- snaga gravitacionog zračenja ~ 200 W
- snaga elektromagnetnog zračenja Sunca ~ 10^{26} W

promena pod dejstvom grav.talasa izaziva promene tela veličine dela protona

MERENJE DEFORMACIJE VELIČINE DELA PROTONA

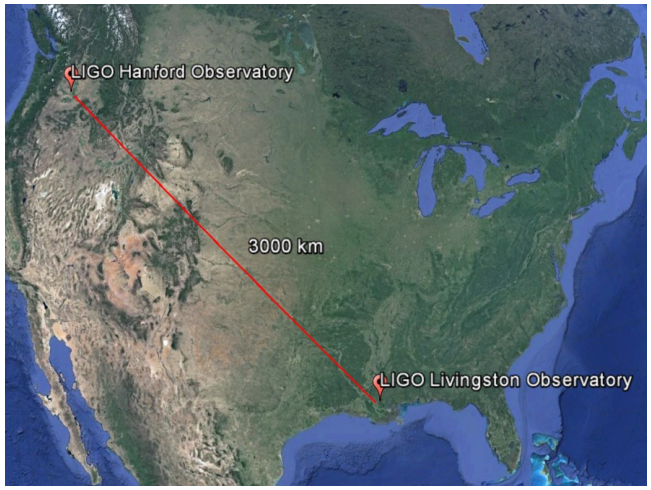


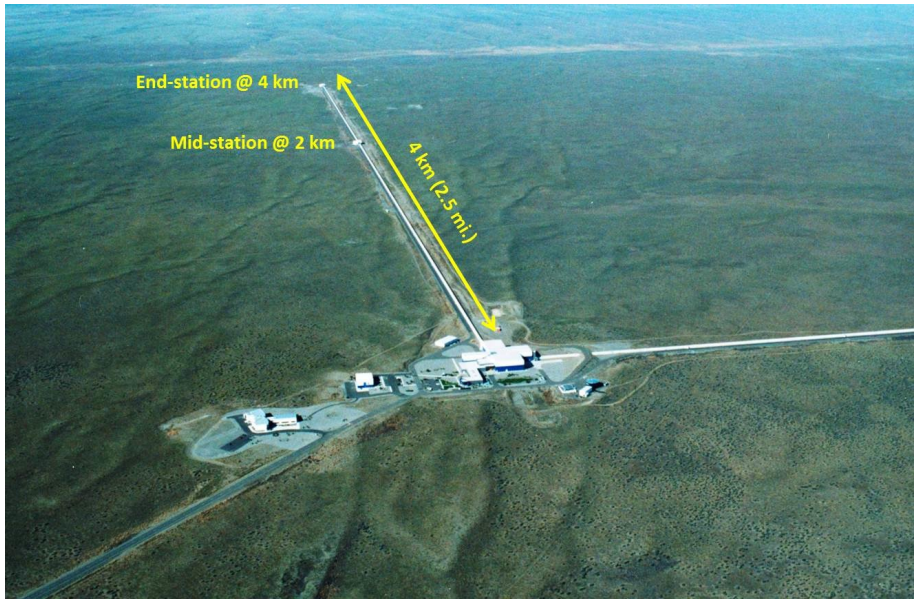
LIGO

Laser Interferometer Gravitational-Wave Observatory

aLIGO – od 2015. god (advanced LIGO)

- Livingston
- Hanford



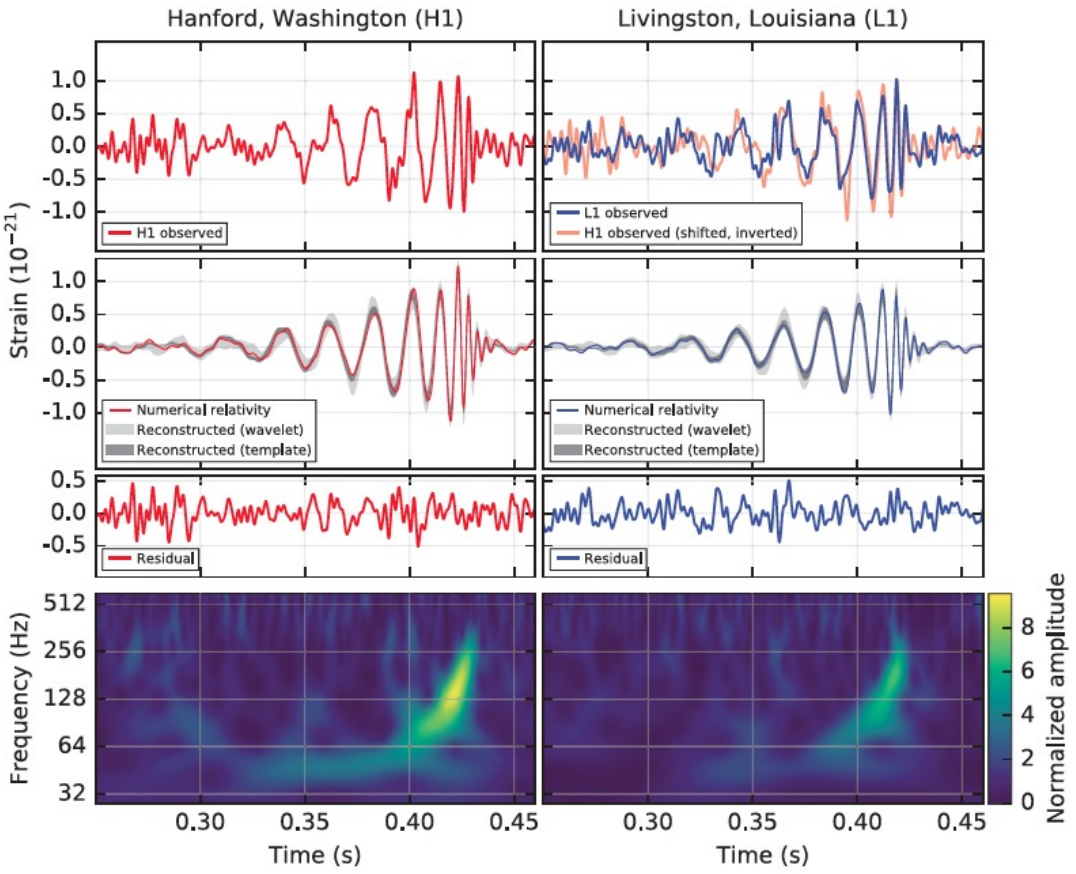


LIGO, 14. SEPTEMBAR 2015, GW150914

signal sudara dve crne rupe masa 36 i 29 masa Sunca

finalna crna rupa 62 Msun
=> emitovana energija ekvival. 3 Msun

na z=0.09

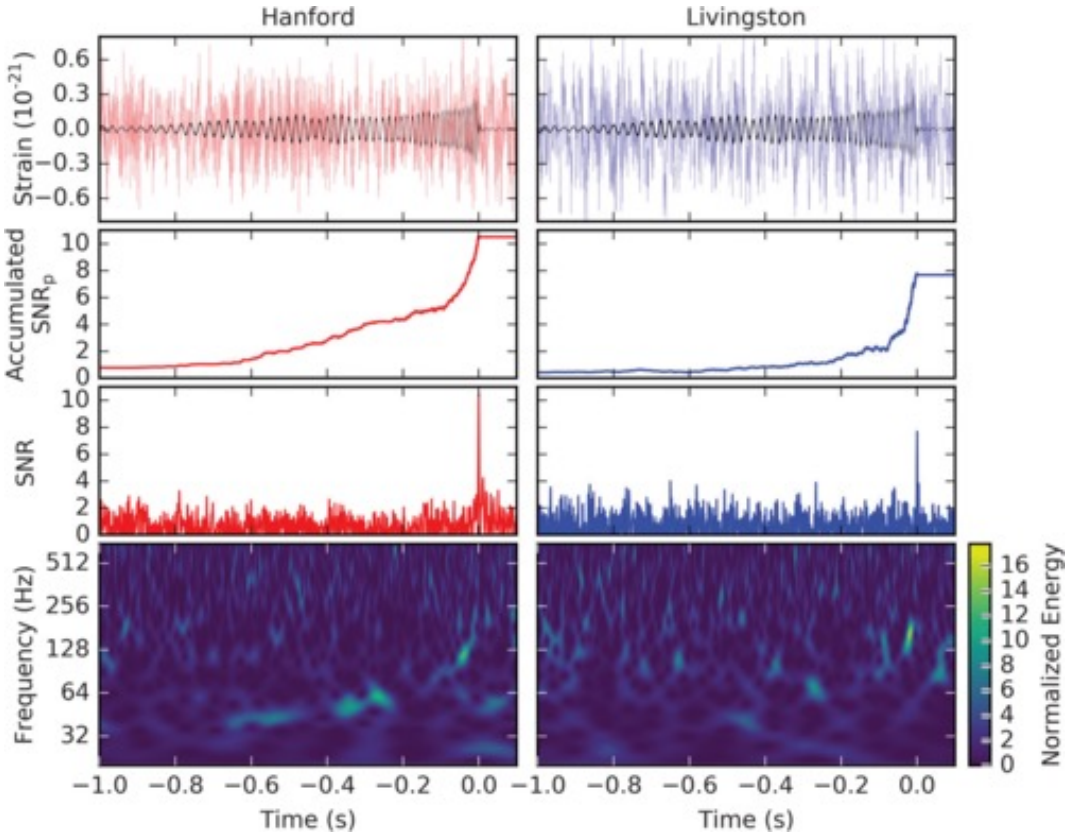


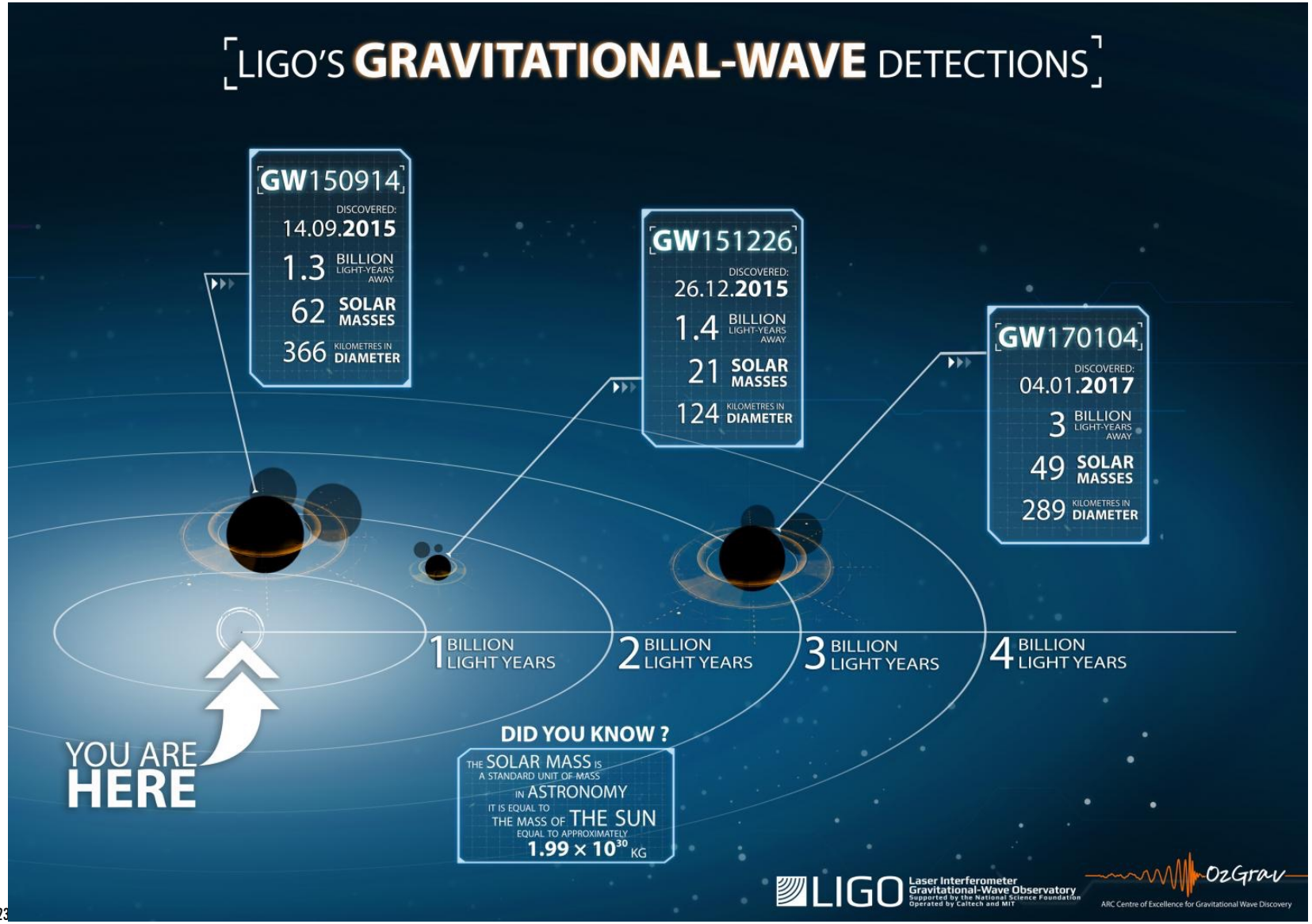
LIGO, 25. DECEMBAR 2015, GW151226

signal sudara dve crne rupe masa 14 i 7 masa Sunca

finalna crna rupa 20 Msun
=> emitovana energija ekvival. 1 Msun

na 440 Mpc




LIGO'S GRAVITATIONAL-WAVE DETECTIONS
GW150914
DISCOVERED:
14.09.2015
1.3 BILLION LIGHT-YEARS AWAY
62 SOLAR MASSES
366 KILOMETRES IN DIAMETER
GW151226
DISCOVERED:
26.12.2015
1.4 BILLION LIGHT-YEARS AWAY
21 SOLAR MASSES
124 KILOMETRES IN DIAMETER
GW170104
DISCOVERED:
04.01.2017
3 BILLION LIGHT-YEARS AWAY
49 SOLAR MASSES
289 KILOMETRES IN DIAMETER
1 BILLION LIGHT YEARS
2 BILLION LIGHT YEARS
3 BILLION LIGHT YEARS
4 BILLION LIGHT YEARS
YOU ARE HERE
DID YOU KNOW ?
THE SOLAR MASS IS A STANDARD UNIT OF MASS IN ASTRONOMY
IT IS EQUAL TO THE MASS OF THE SUN
EQUAL TO APPROXIMATELY
1.99 × 10^30 KG
LIGO Laser Interferometer Gravitational-Wave Observatory
Supported by the National Science Foundation
Operated by Caltech and MIT
OzGrav
ARC Centre of Excellence for Gravitational Wave Discovery