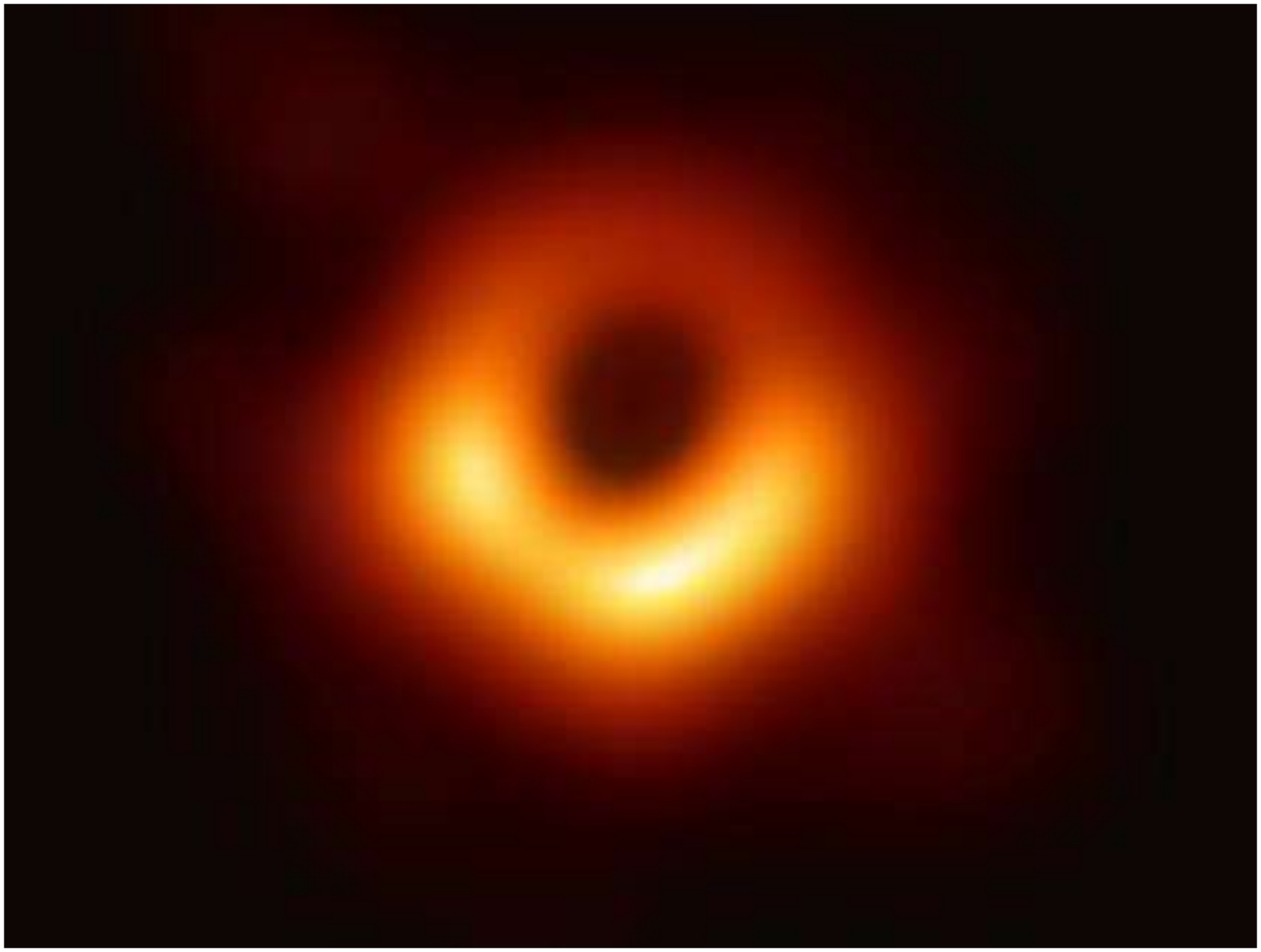
Hogyan készült kép a fekete lyuk árnyékáról?

Gabányi Krisztina (ELTE TTK Csillagászati Tanszék, MTA-ELTE Extragalaktikus Asztrofizika Kutatócsoport, Csillagászati és Földtudományi Központ Konkoly-Thege Miklós Csillagászati Intézet)

Event Horizon Telescope

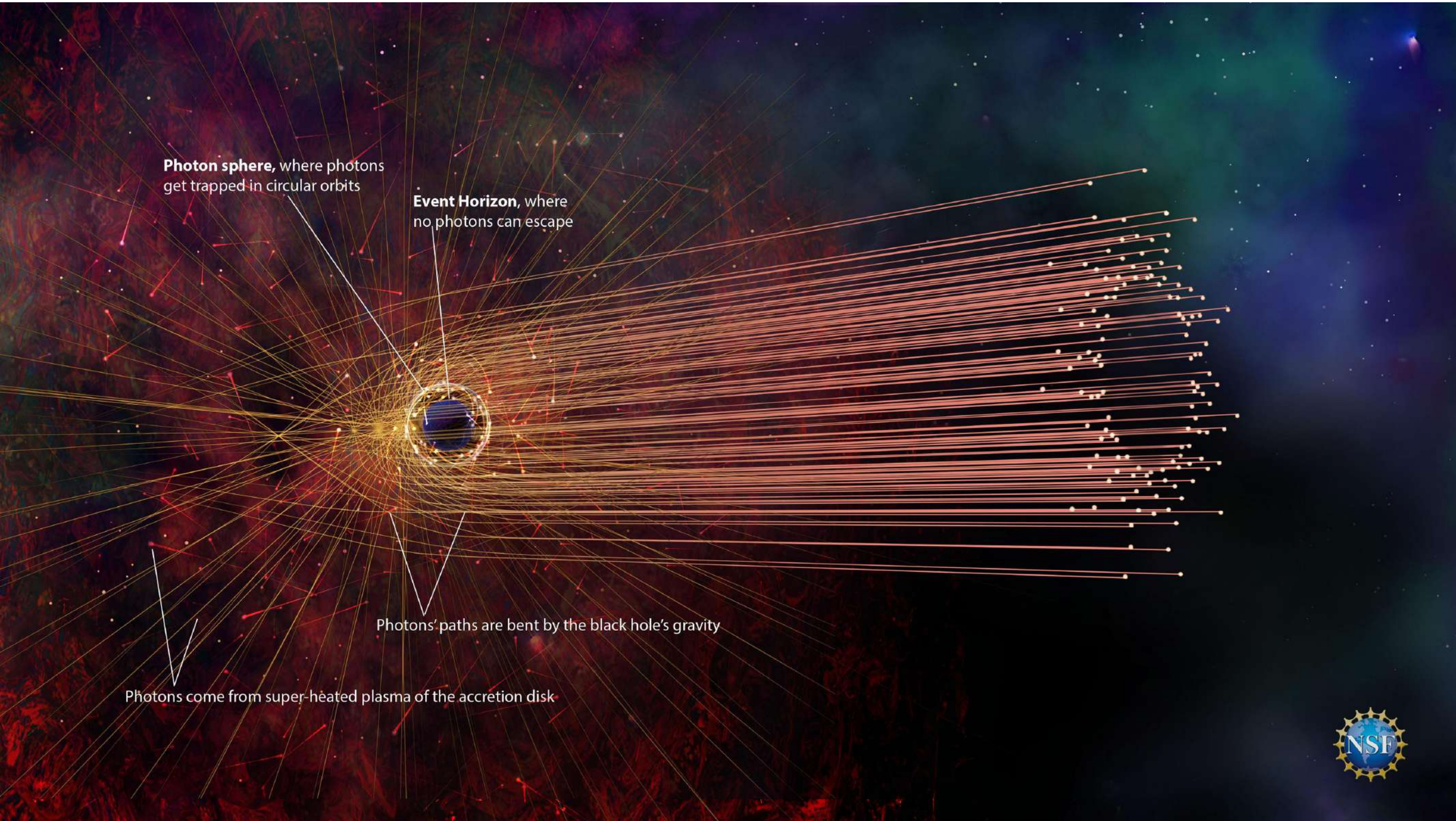
6,5 milliárd naptömegű
fekete lyuk

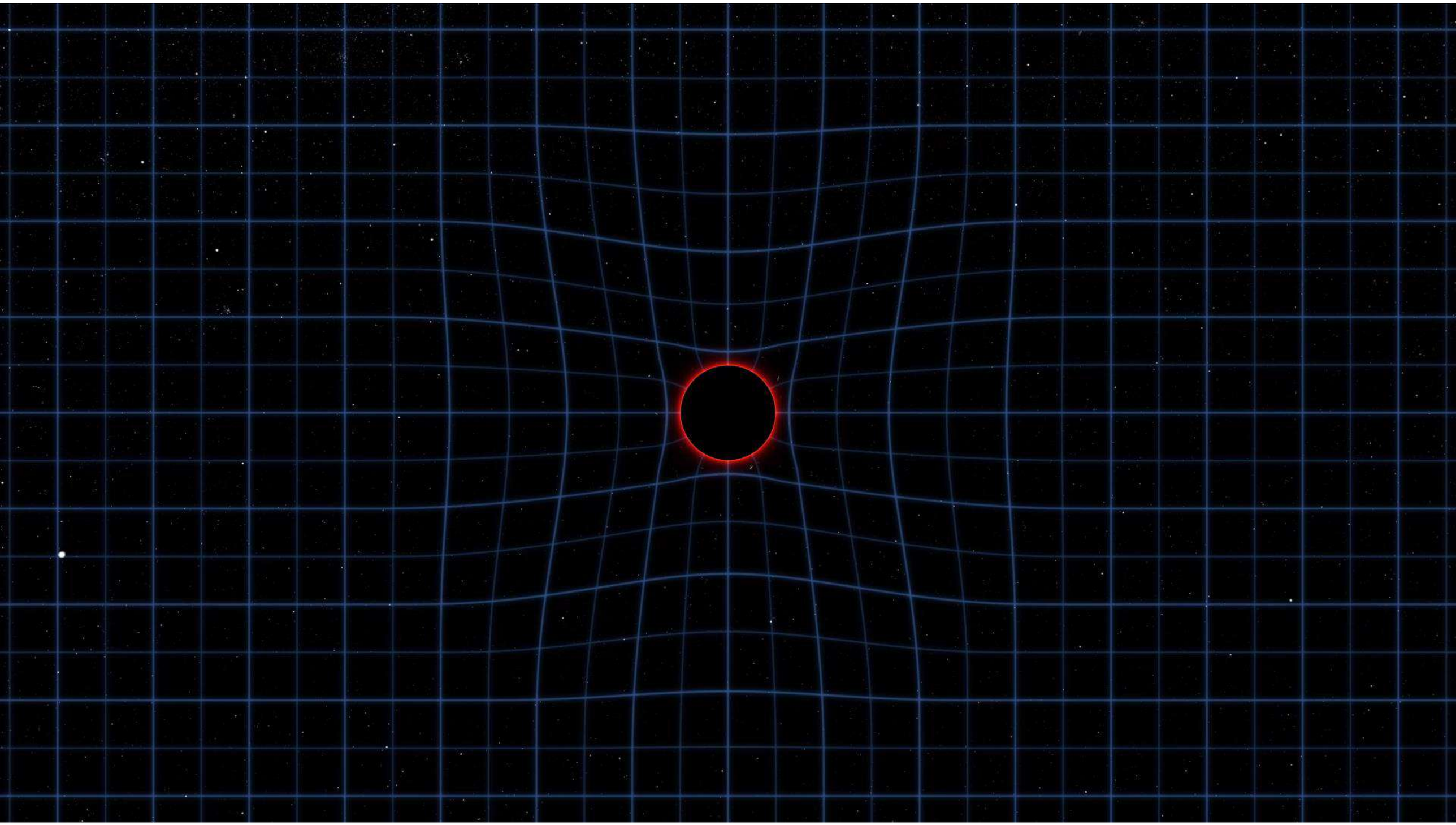


Kép egy fekete lyukról?

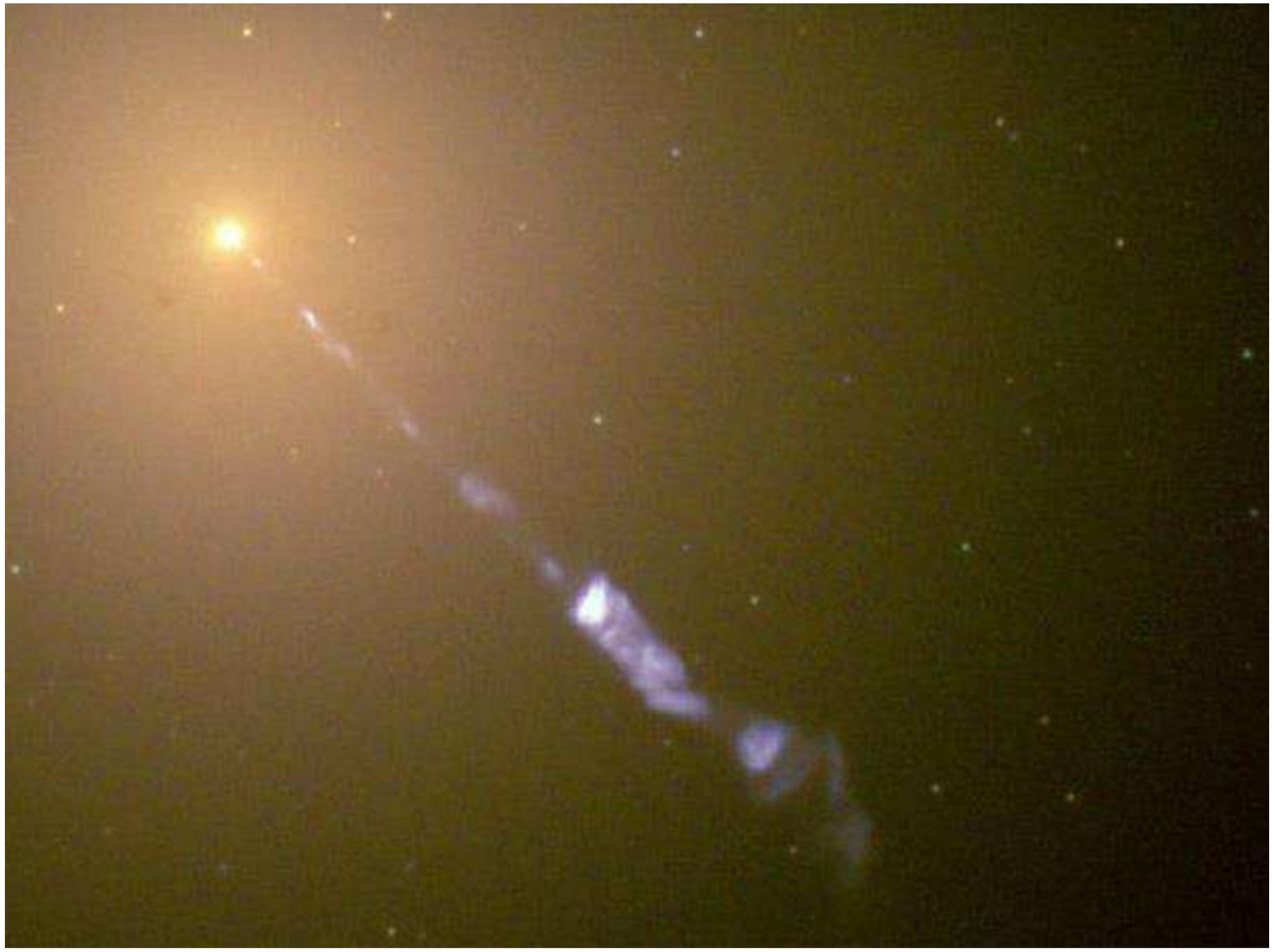
- Miről tudunk képet alkotni, ha ez egy fekete lyuk?
- Hogyan tudunk képet alkotni valamiről, ami ennyire kicsi?

Miről alkotunk képet?





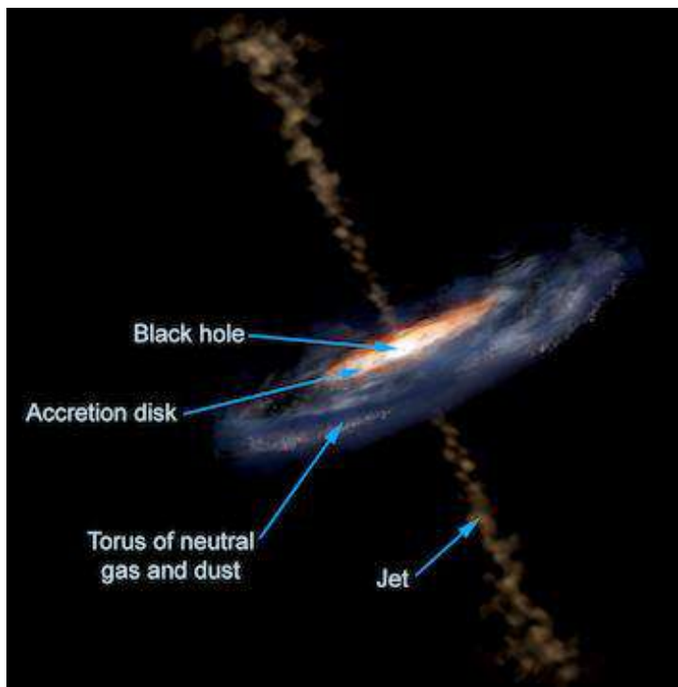
Hubble-űrtávcső felvétele



31 ívmásodperc ≈ 8000 fényév

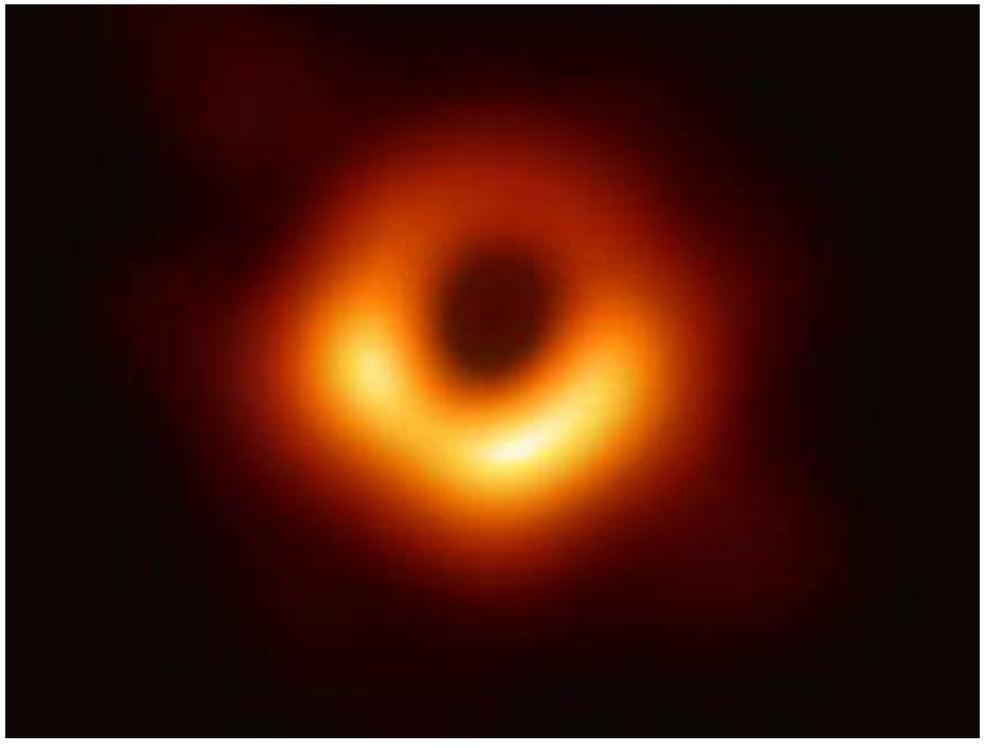
M87

55 millió fényévre
Óriás elliptikus galaxis a Virgo halmazban
1918 - H.D. Curtis: „furcsa egyenes nyaláb”
1950: Virgo A az egyik legfényesebb rádióforrás az égen
6,5 milliárd naptömegű fekete lyuk



Az eseményhorizont sugara ≈127 cs.e.

Összehasonlításképp: A Voyager–1 űrszonda 150,5 cs.e. távolságban van a Földtől jelenleg



Átmérő: $\sim 5\frac{2GM}{c^2}$

Schwarzschild-sugár

55 millió fényév távolságban,
40 milliomod ívmásodperc
szögméretnek felel meg

Ennél nagyobb szögméretű ismert fekete lyuk árnyék csak a
Tejútrendszer közepén található fekete lyukhoz tartozik:
Sagittarius A , ≈4 millió naptömeg, ≈26700 fényévre a Földtől*

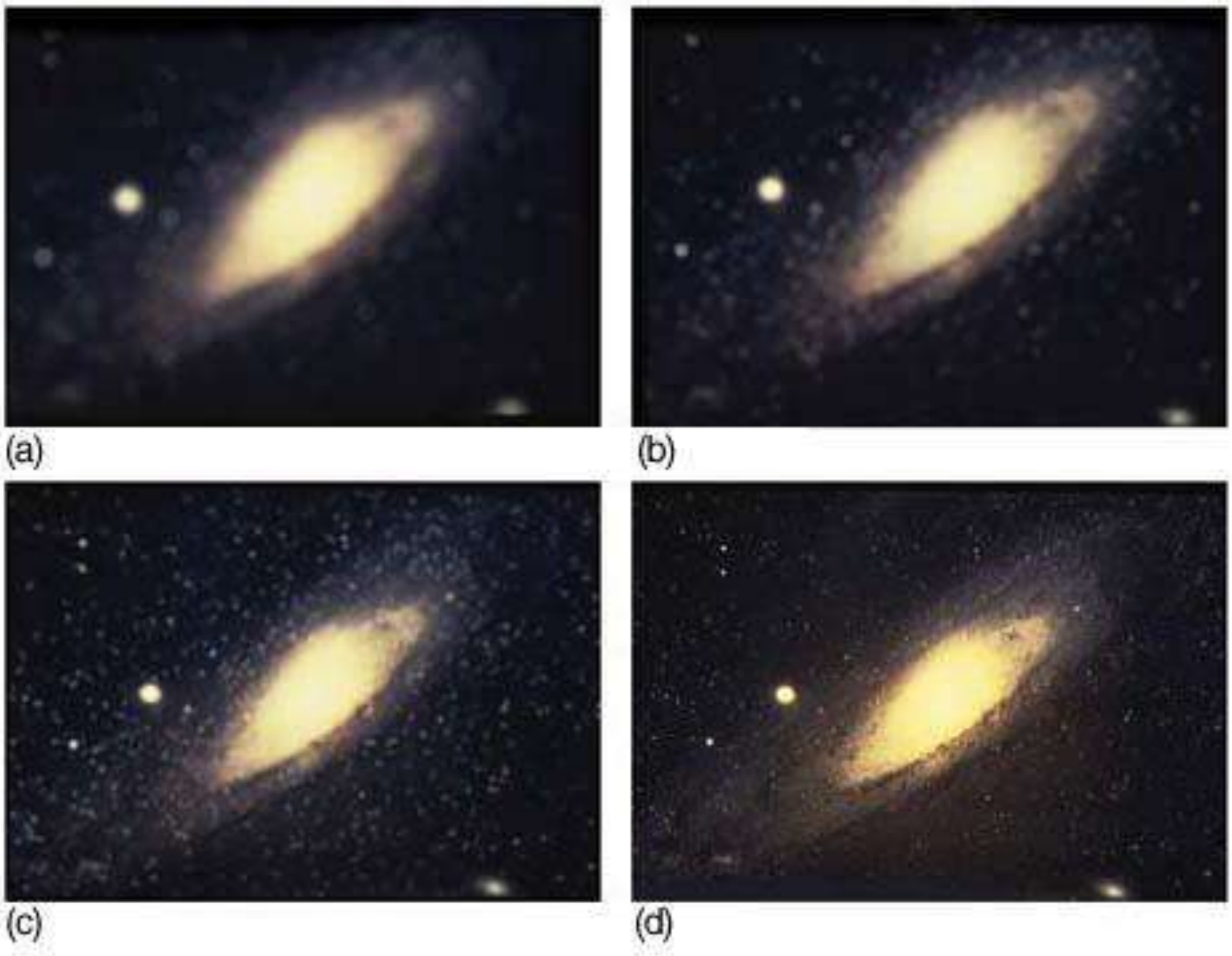
A Hold szögmérete 0,5 fok
(45 milliószor nagyobb)

Felbontóképesség

$$\theta \sim \frac{\lambda}{D}$$

hullámhossz

átmérő

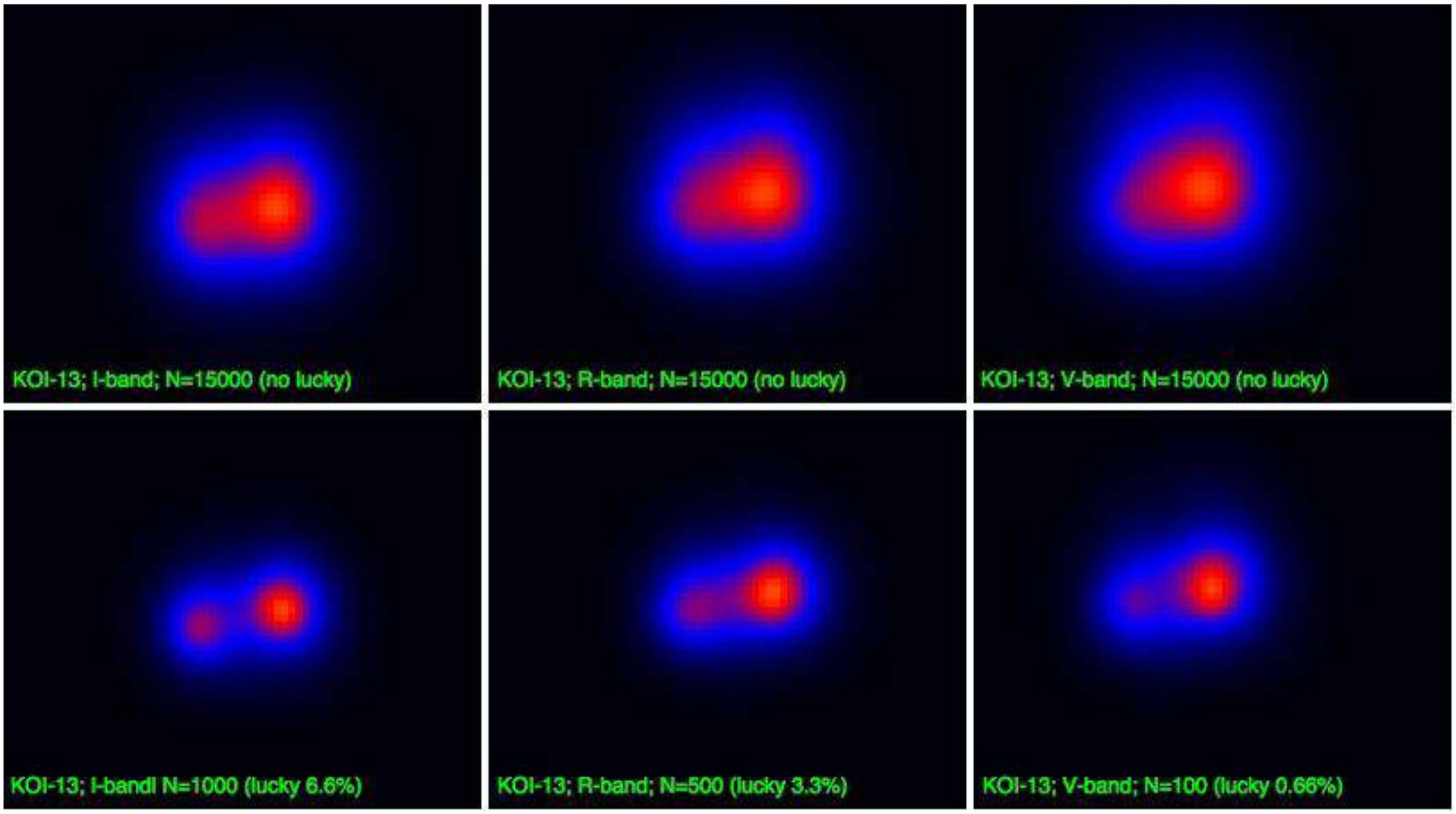


Felbontóképesség

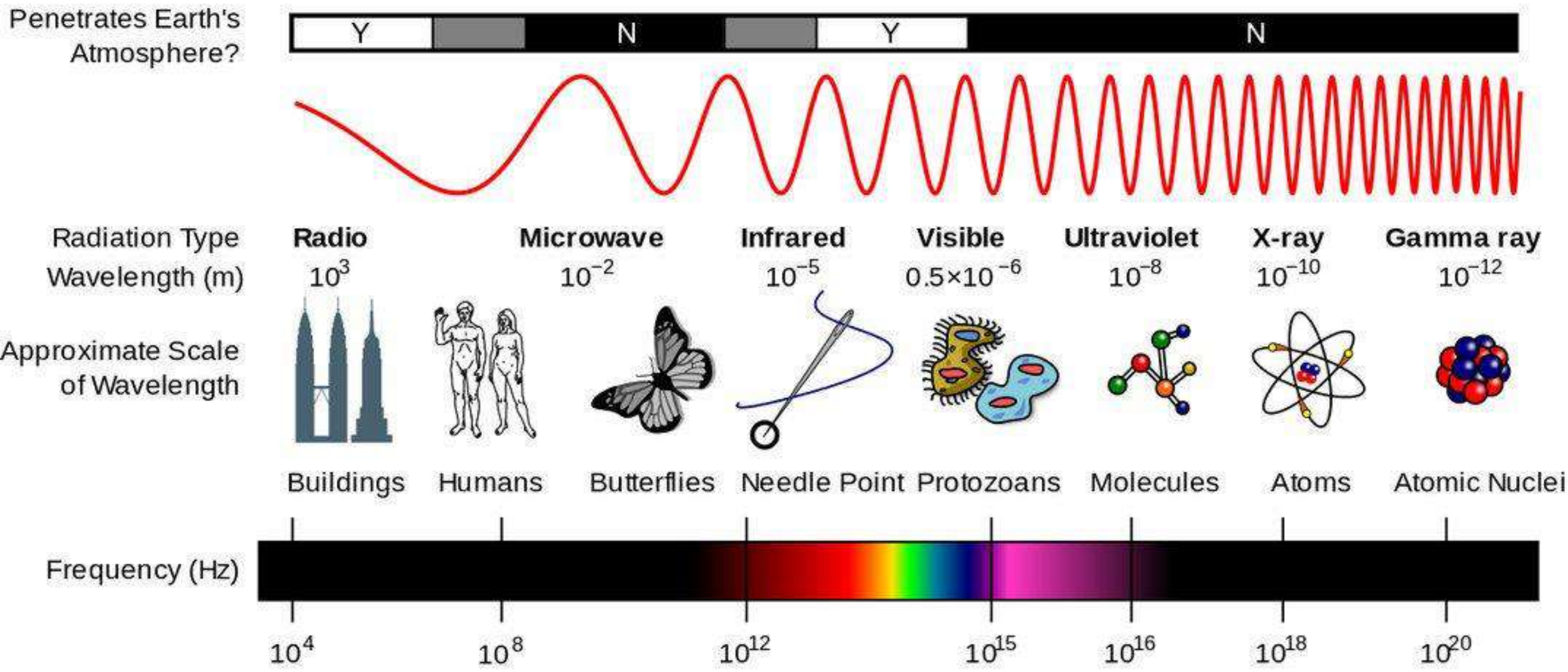
$$\theta \sim \frac{\lambda}{D}$$

hullámhossz

átmérő

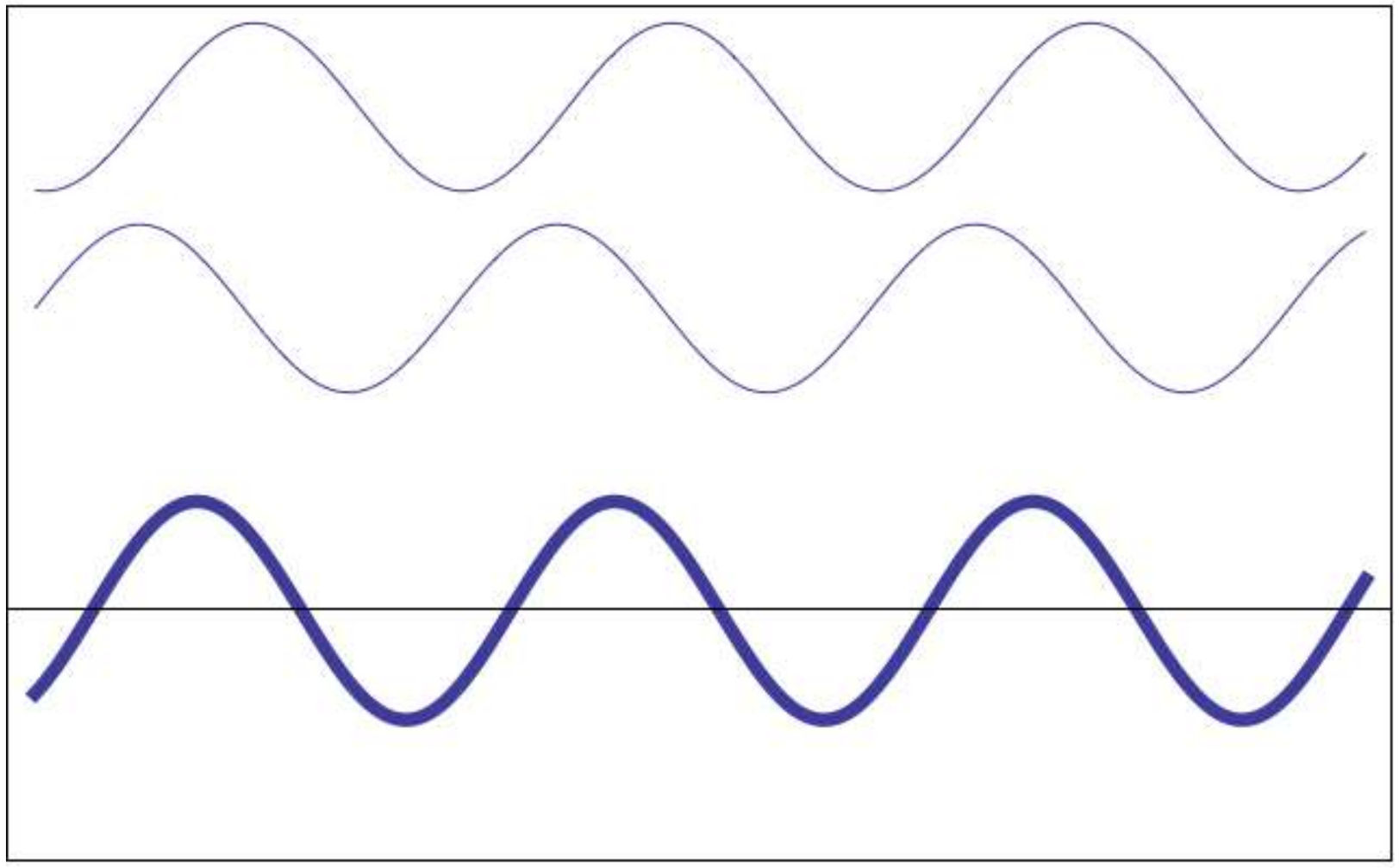


Hullámhossz



Interferometria

$$Szögfelbontás \sim \frac{hullámhossz}{bázisvonalhossz}$$



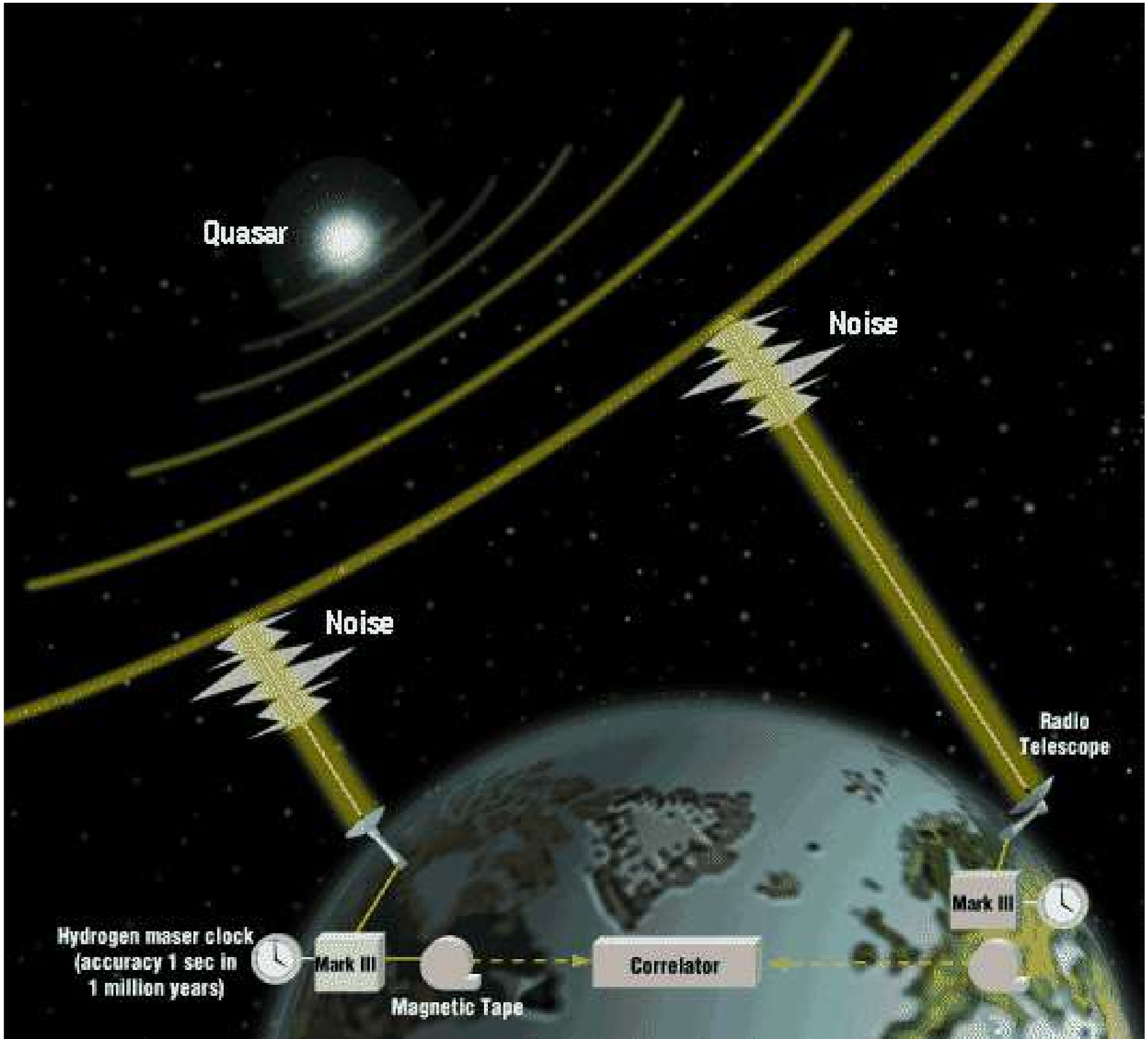
Nagyon hosszú bázisvonalú interferometria

Very Long Baseline Interferometry

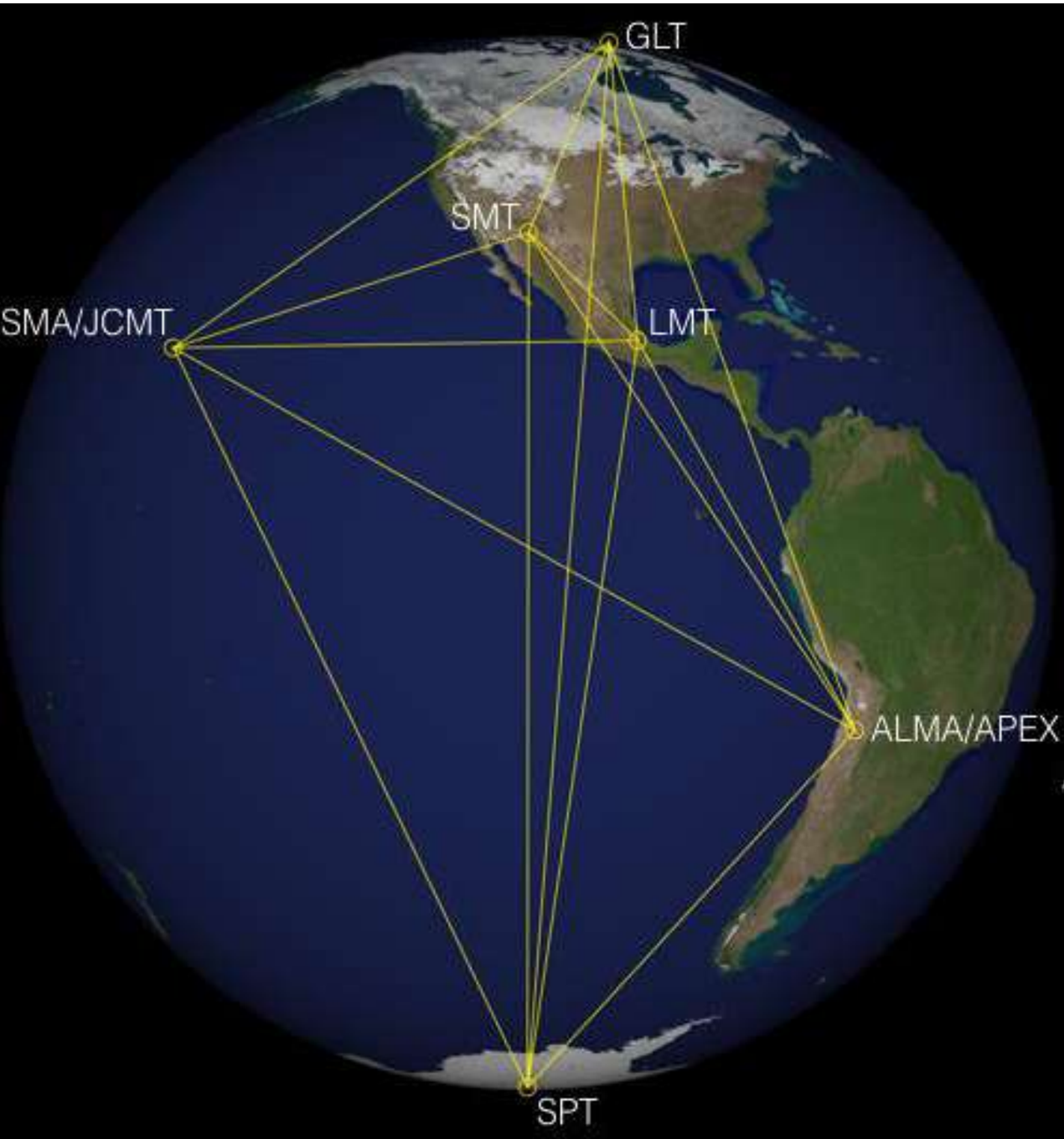
$$\theta \sim \frac{\lambda}{b}$$

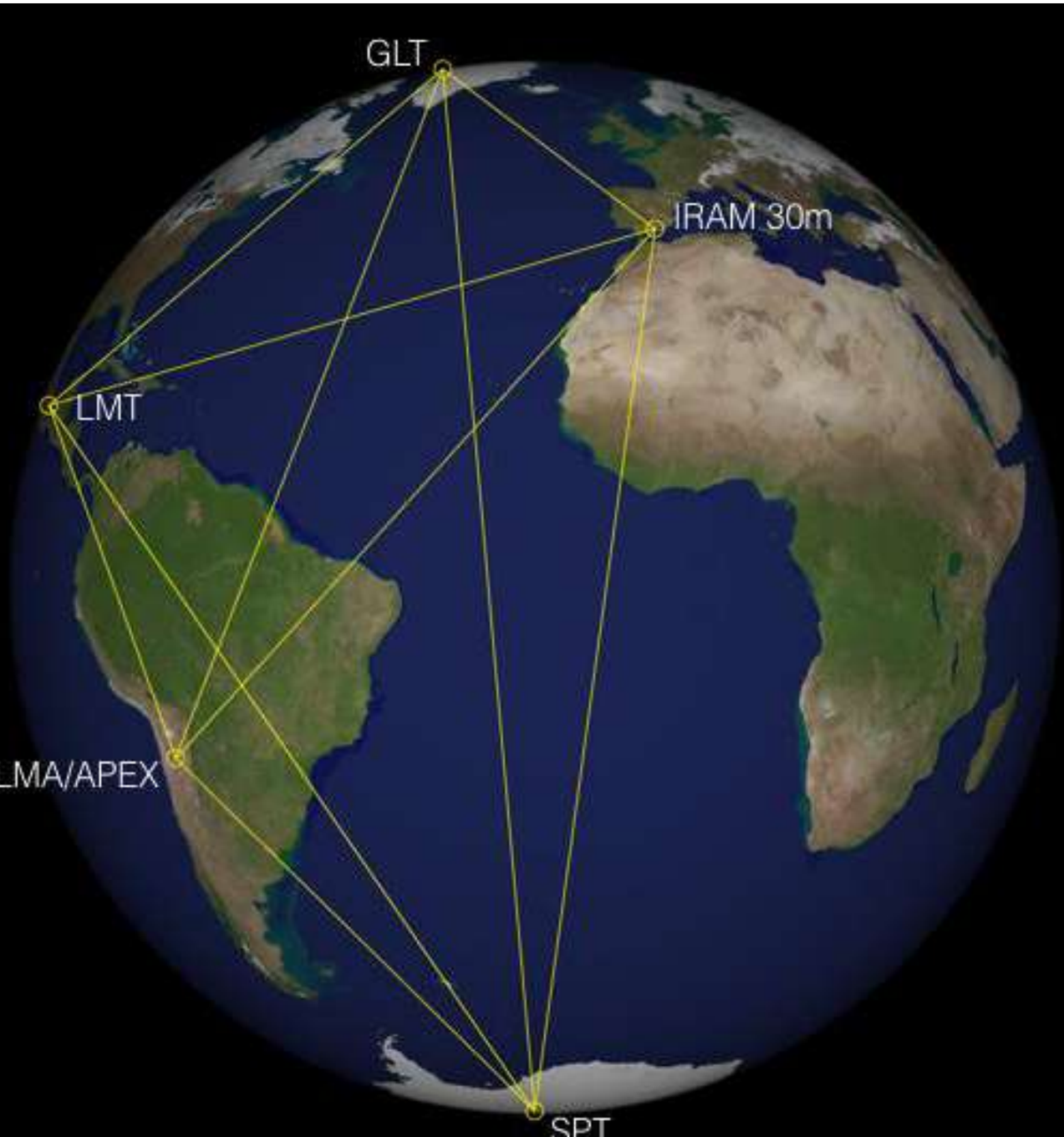
Hosszabb bázisvonal (b) ⇒ finomabb szögfelbontás

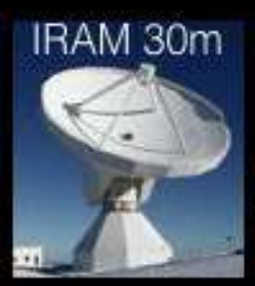
Rövidebb hullámhossz (λ) ⇒ finomabb szögfelbontás

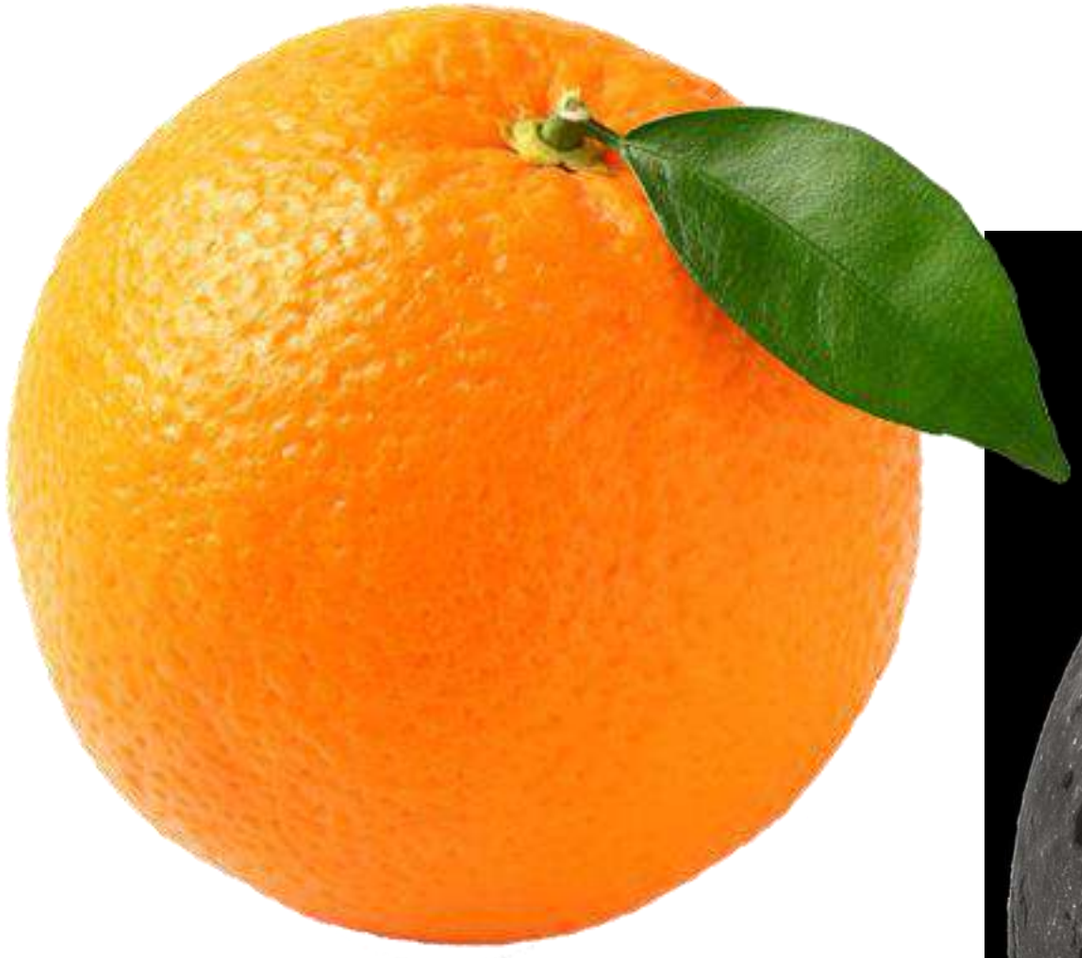


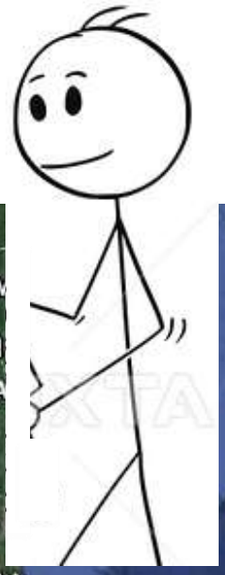
λ=1.3 mm, b=10700 km $\Rightarrow \vartheta$ = 25 μas







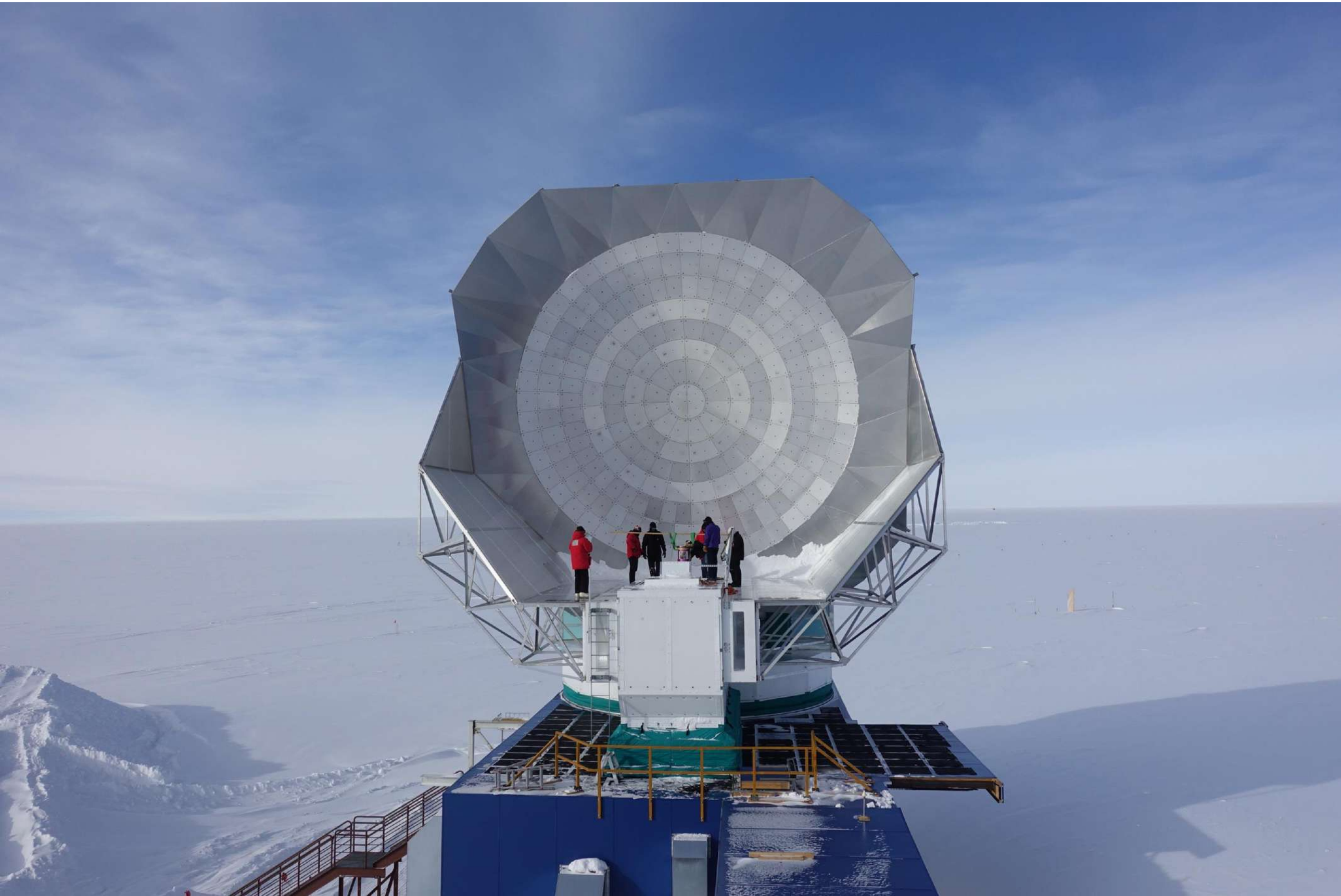




MONTANA
NORTH DAKOTA
MINNESOTA
OREGON
IDAHO
SOUTH DAKOTA
WISCONSIN
MICHIGAN
NEW YORK
WYOMING
IOWA
PENNSYLVANIA
NEBRASKA
NJ
OHIO
DE
ILLINOIS
INDIANA
UTAH
United States
WEST VIRGINIA
COLORADO
VIRGINIA
KANSAS
MISSOURI
KENTUCKY
NORTH CAROLINA
TENNESSEE
OKLAHOMA
SOUTH CAROLINA
ARIZONA
ARKANSAS
NEW MEXICO
MISSISSIPPI
ALABAMA
GEORGIA
BAJA CALIFORNIA
TEXAS
SONORA
LOUISIANA
CHIHUAHUA
FLORIDA
COAHUILA
Google
Map

ALMA – Atacama Large Millimeter/Submillimeter Array

SPT – South Pole Telescope



LMT – Large Millimeter Telescope

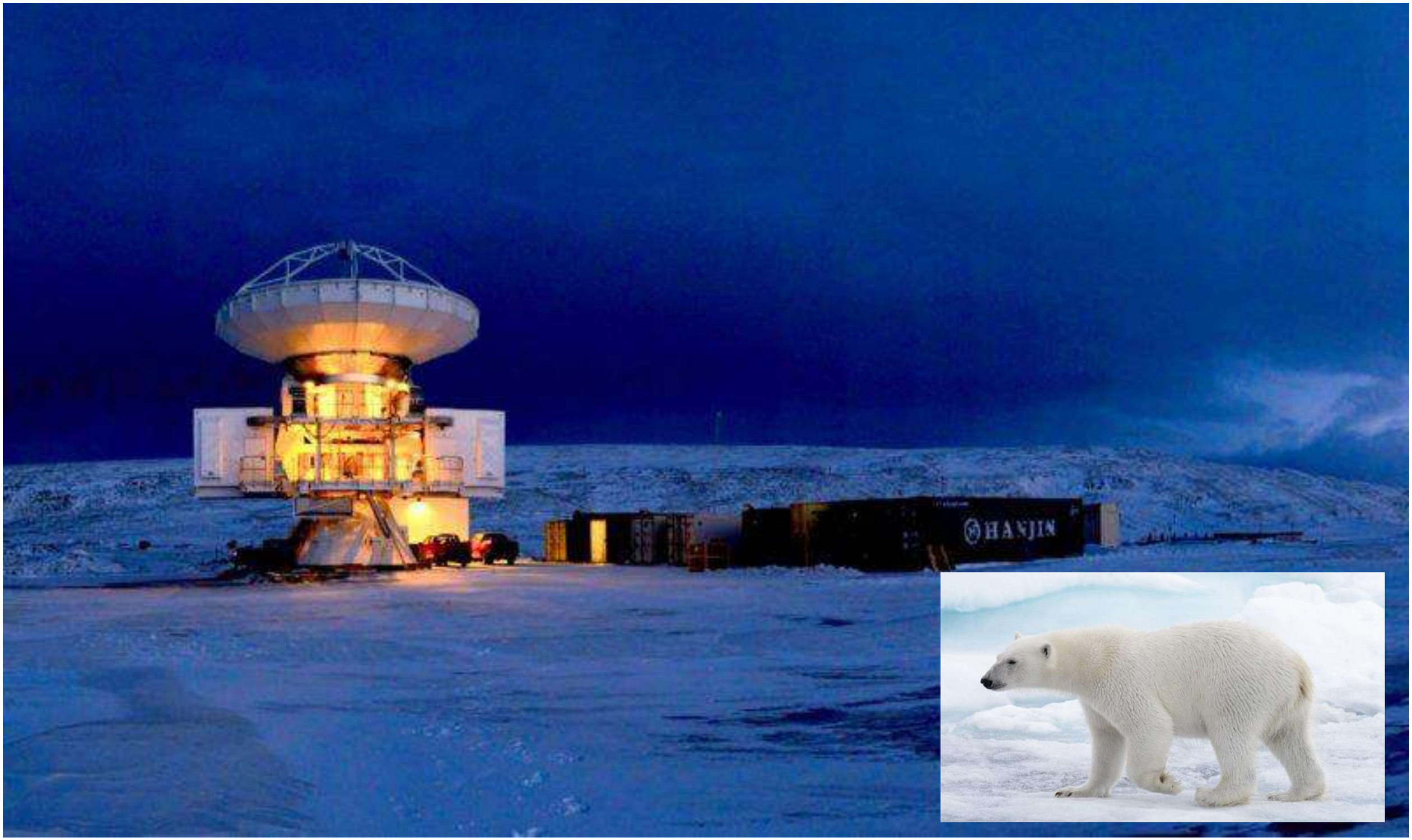
Large Millimeter Telescope (Mexico) által mért adatok fele, ½ petabyte

=

Egy emberöltő alatt készített szelfik mennyisége 5000 ember esetén

IRAM – Pico Veleta (Spanyolország)

GLT – Greenland Telescope (várhatóan 2021-től kapcsolódik be a mérésekbe)



ACADEMIA SINICA

THE UNIVERSITY OF ARIZONA

THE UNIVERSITY OF CHICAGO

GOETHE UNIVERSITÄT FRANKFURT AM MAIN

iram Institut de Radioastronomie Millimétrique

Max-Planck-Institut für Radioastronomie

James Clerk Maxwell Telescope East Asian Observatory

Large Millimeter Telescope *Alfonso Serrano*

Massachusetts Institute of Technology

MIT HAYSTACK OBSERVATORY

NAOJ National Astronomical Observatory of Japan

PERIMETER INSTITUTE

Radboud University

Smithsonian

CENTER FOR ASTROPHYSICS HARVARD & SMITHSONIAN

Aalto University School of Electrical Engineering

Brandeis University

BOSTON UNIVERSITY

Los Alamos NATIONAL LABORATORY

Caltech

CIFAR

CITA | ICAT

NAOC

CHALMERS UNIVERSITY OF TECHNOLOGY

CONACYT

Google AI

広島大学

CSIC

INAOE

IRyA

INFN

JIVE Joint Institute for VLBI ERIC

Korea Astronomy and Space Science Institute

工学院大学 KOGAKUIN UNIVERSITY

國立中山大學 National Sun Yat-sen University

NWO Netherlands Organisation for Scientific Research

Universiteit Leiden

MPE

NOAO

NRAO

SOKENDAI

UCSB

東京大学 大学院 理学系研究科・理学部

RHODES UNIVERSITY Where leaders learn

서울대학교

TOHOKU UNIVERSITY

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統計数理研究所 The Institute of Statistical Mathematics

University of Massachusetts Amherst

VNIVERSITAT DE VALÈNCIA

Observatori Astronòmic

UCL MULLARD SPACE SCIENCE LABORATORY

ILLINOIS

UNIVERSITY OF WATERLOO

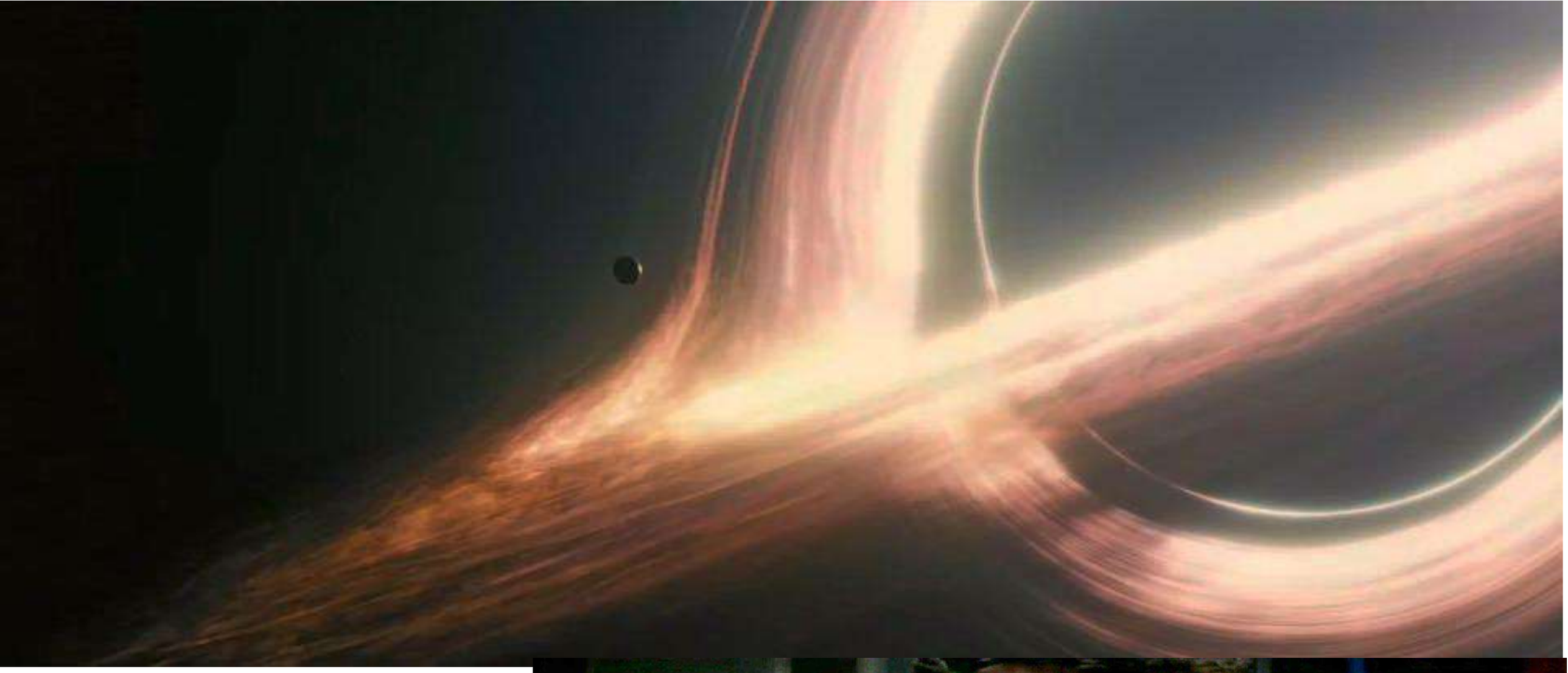
ASTRONOMÍA

UST UNIVERSITY OF SCIENCE & TECHNOLOGY

Berkeley

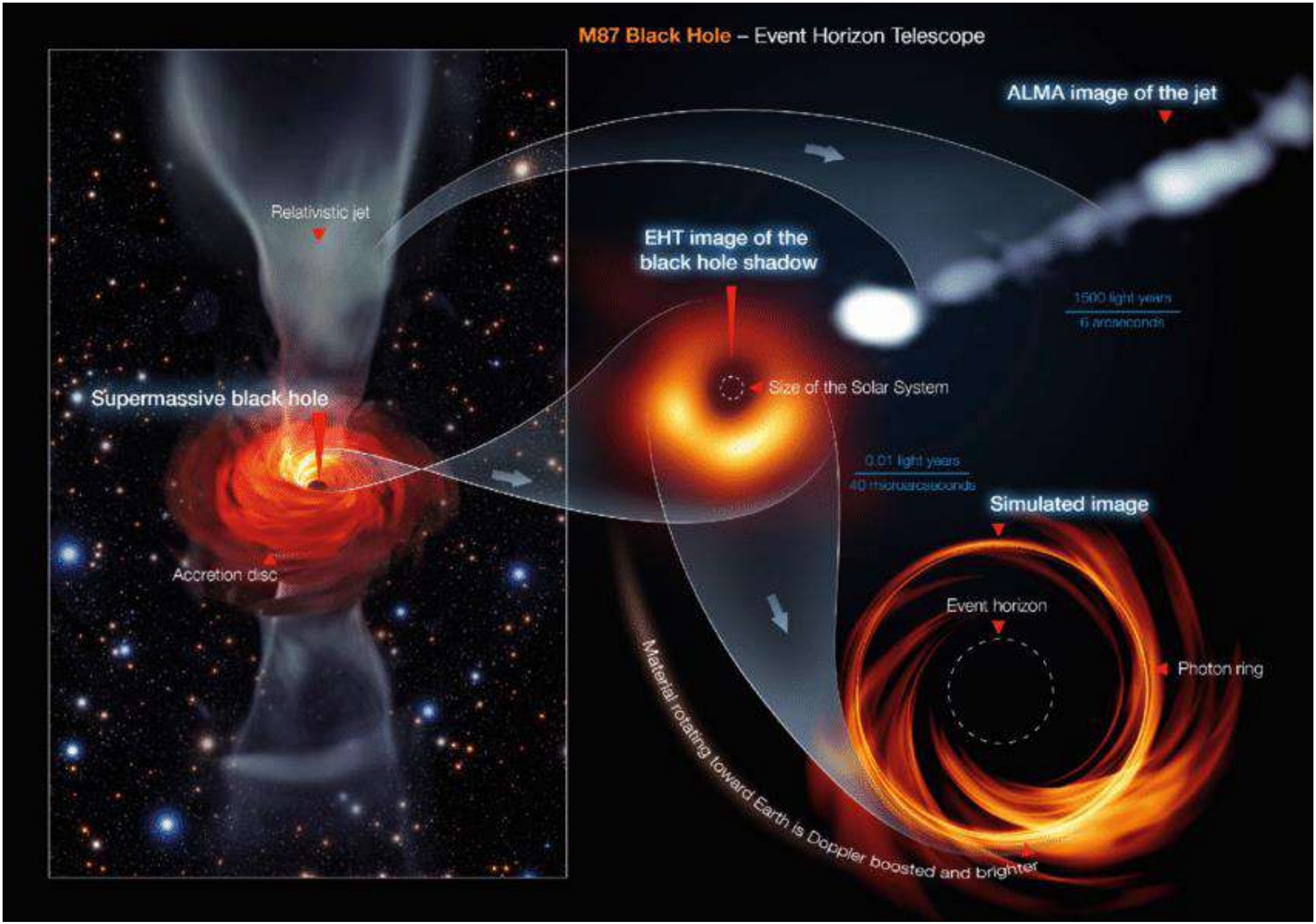
Dunlap Institute for Astronomy & Astrophysics UNIVERSITY OF TORONTO

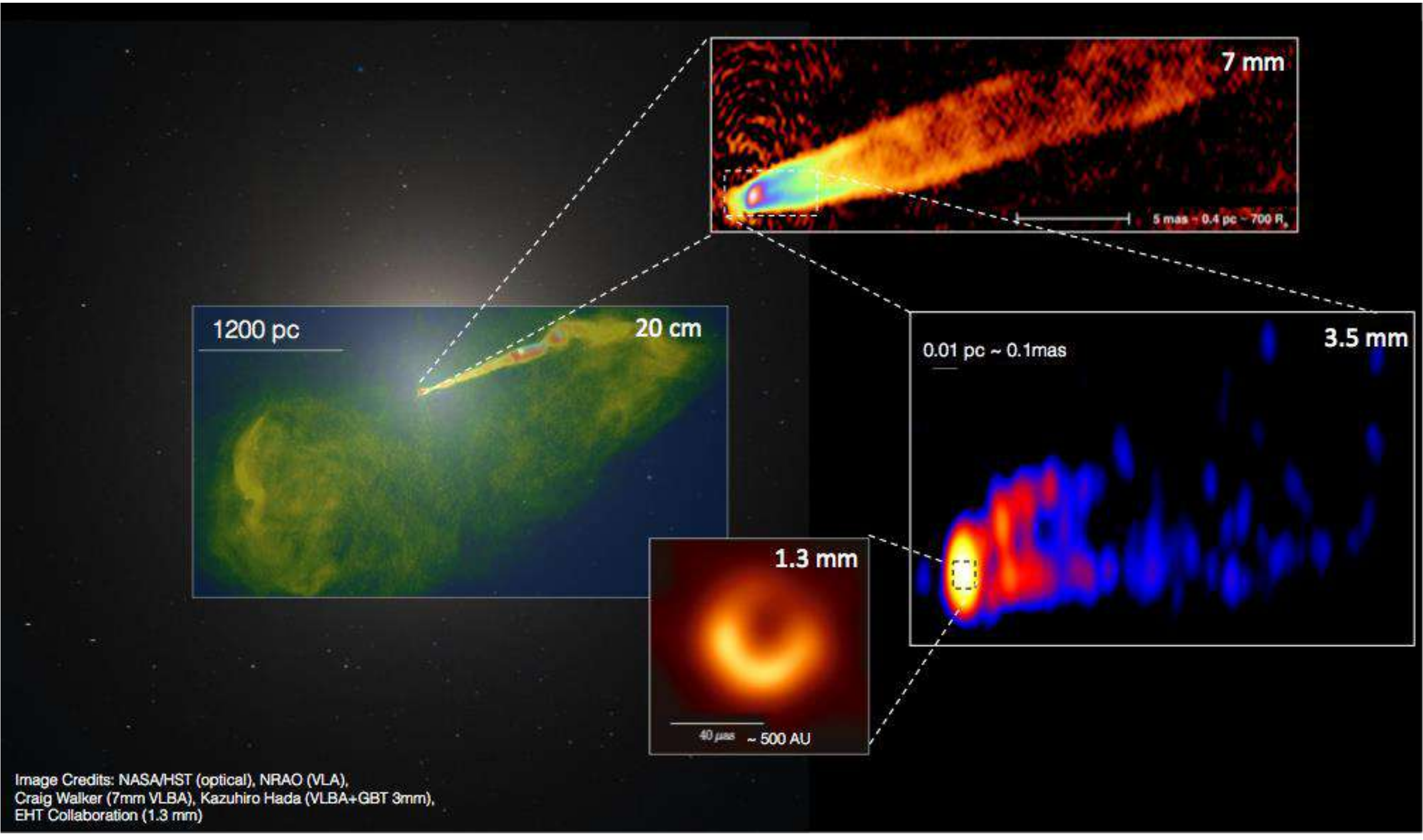
FEDERICO II



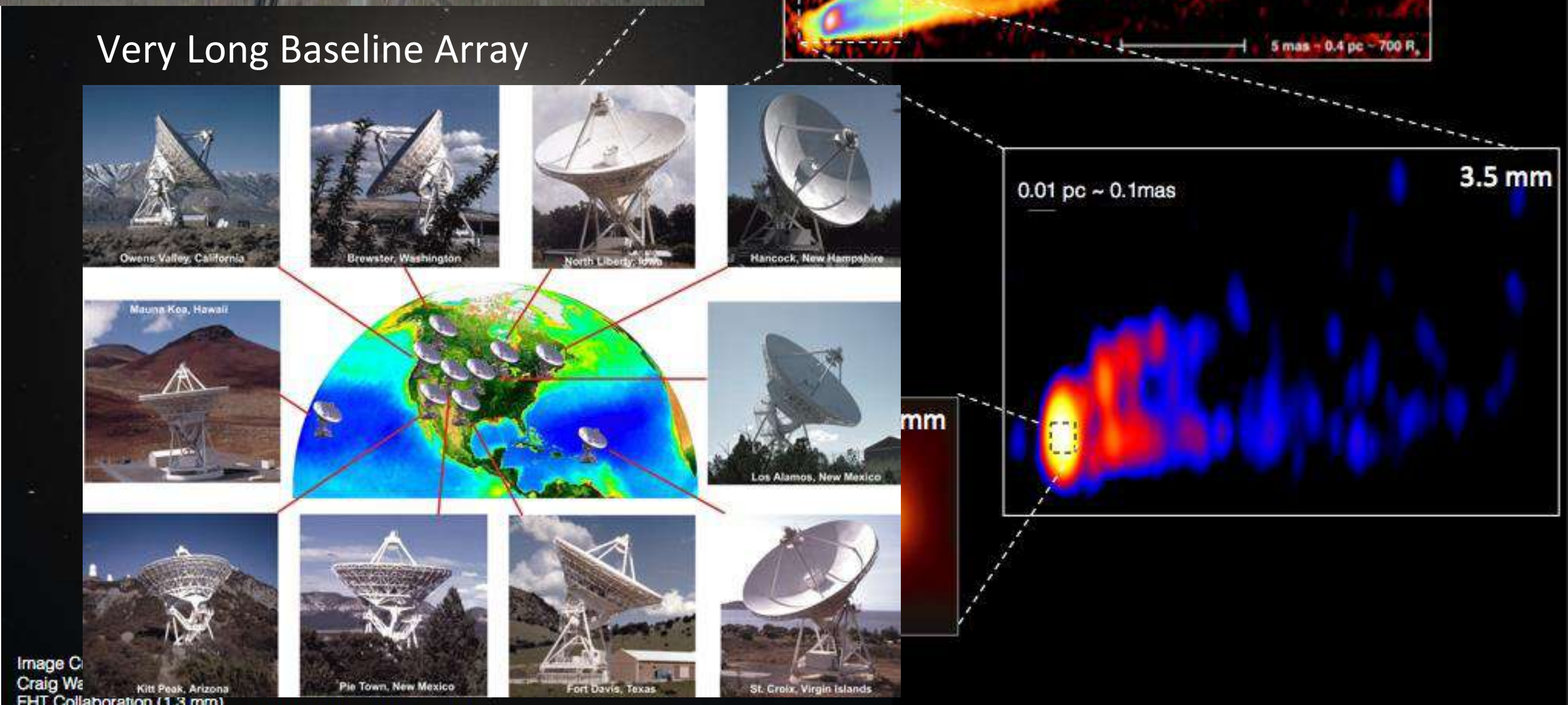

The Black Hole Shadow in M87


Event Horizon Telescope
Collaboration Meeting
Event Horizon Telescope
Collaboration Meeting


M87 Black Hole – Event Horizon Telescope
ALMA image of the jet
Relativistic jet
EHT image of the black hole shadow
1500 light years
6 arcseconds
Supermassive black hole
Size of the Solar System
0.01 light years
40 microarcseconds
Simulated image
Accretion disc
Event horizon
Photon ring
Material rotating toward Earth is Doppler boosted and brighter


7 mm
5 mas ~ 0.4 pc ~ 700 R
1200 pc
20 cm
0.01 pc ~ 0.1mas
3.5 mm
1.3 mm
40 μas
~ 500 AU
Image Credits: NASA/HST (optical), NRAO (VLA),
Craig Walker (7mm VLBA), Kazuhiro Hada (VLBA+GBT 3mm),
EHT Collaboration (1.3 mm)

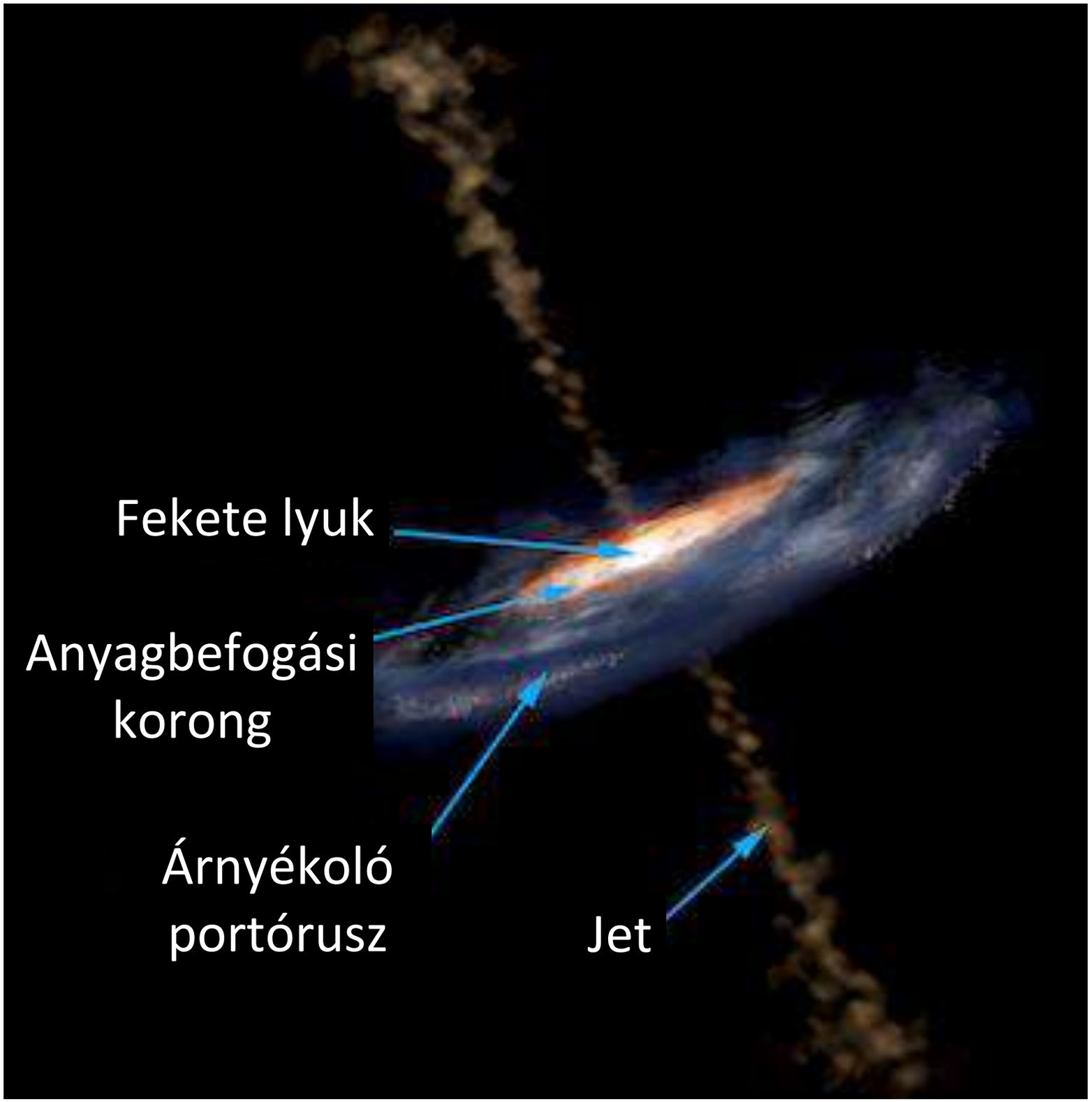

Karl G. Jansky Very Large Array


Very Long Baseline Array
Owens Valley, California
Brewster, Washington
North Liberty, Iowa
Hancock, New Hampshire
Mauna Kea, Hawaii
Los Alamos, New Mexico
Kitt Peak, Arizona
Pie Town, New Mexico
Fort Davis, Texas
St. Croix, Virgin Islands
7 mm
5 mas ~ 0.4 pc ~ 700 R
3.5 mm
0.01 pc ~ 0.1mas
mm
Image C
Craig Wa
EHT Collaboration (1.3 mm)

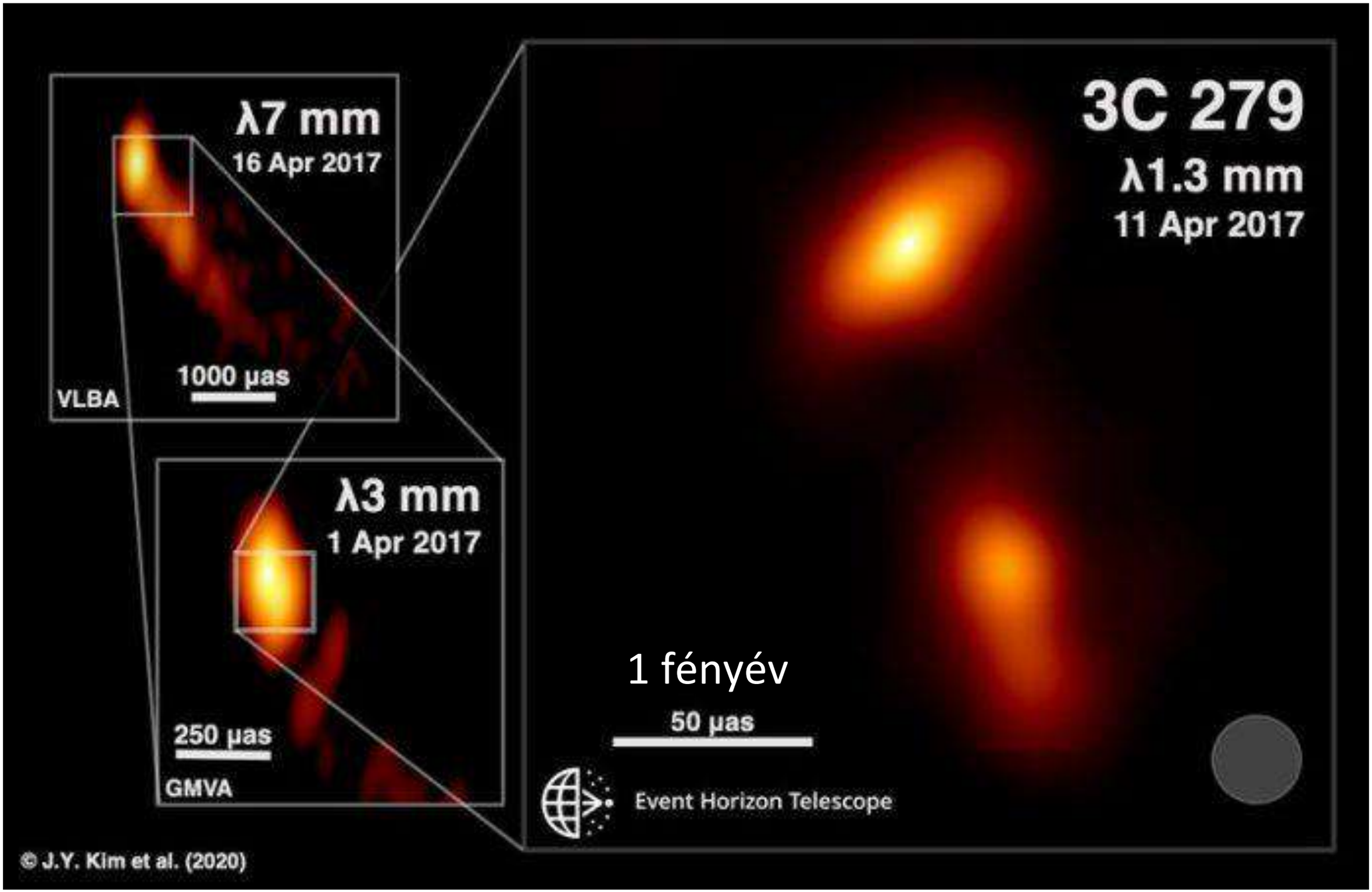
JIVE
Joint Institute for VLBI ERIC

EUROPEAN VLBI NETWORK

Image by Paul Boven (boven@jive.eu). Satellite image: Blue Marble Next Generation, courtesy of Nasa Visible Earth (visibleearth.nasa.gov).


Fekete lyuk
Anyagbefogási korong
Árnyékoló portórusz
Jet

3C 279 – 5 milliárd fényévre



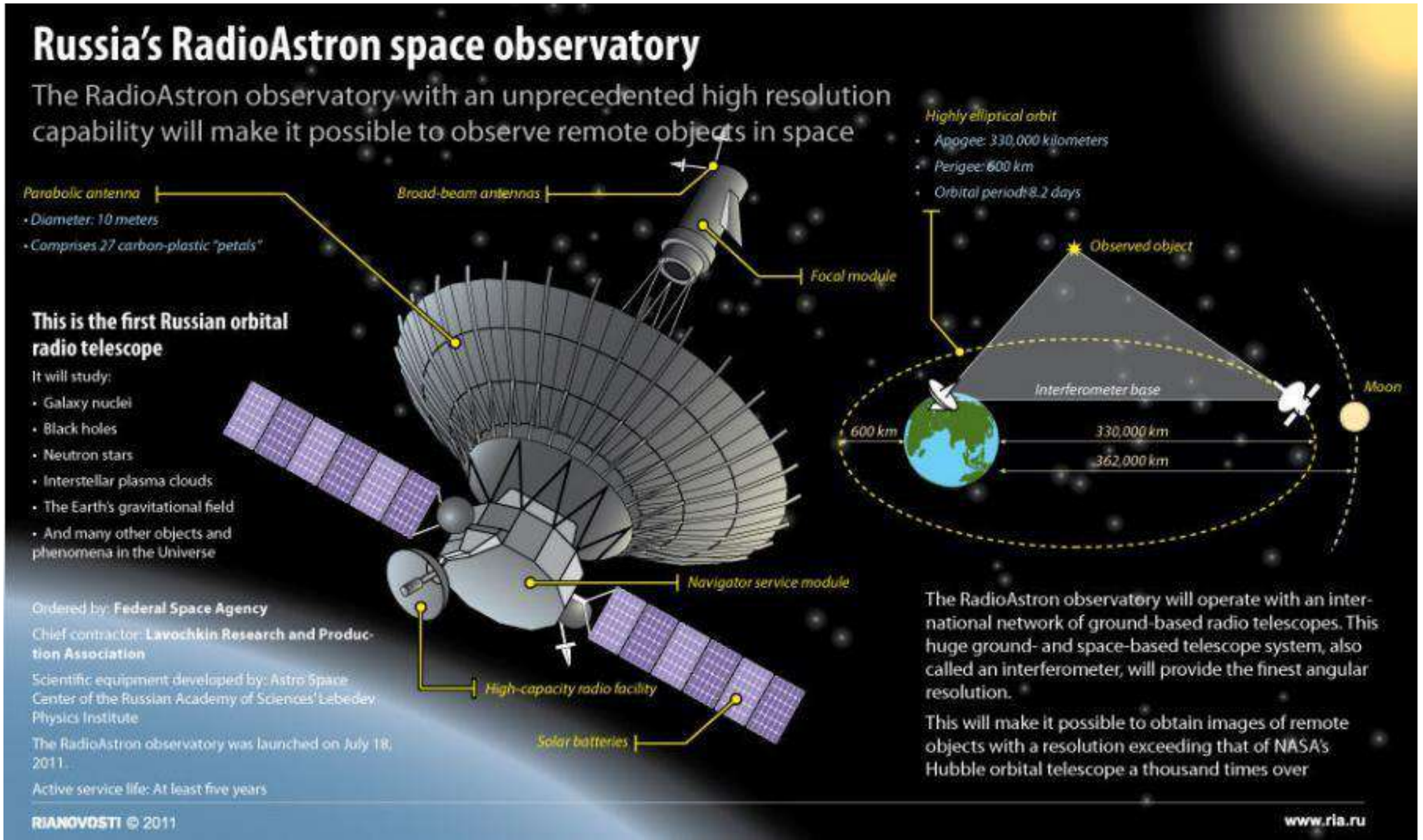
EHT-val érhető el a legfinomabb szögfelbontás?

Nem!

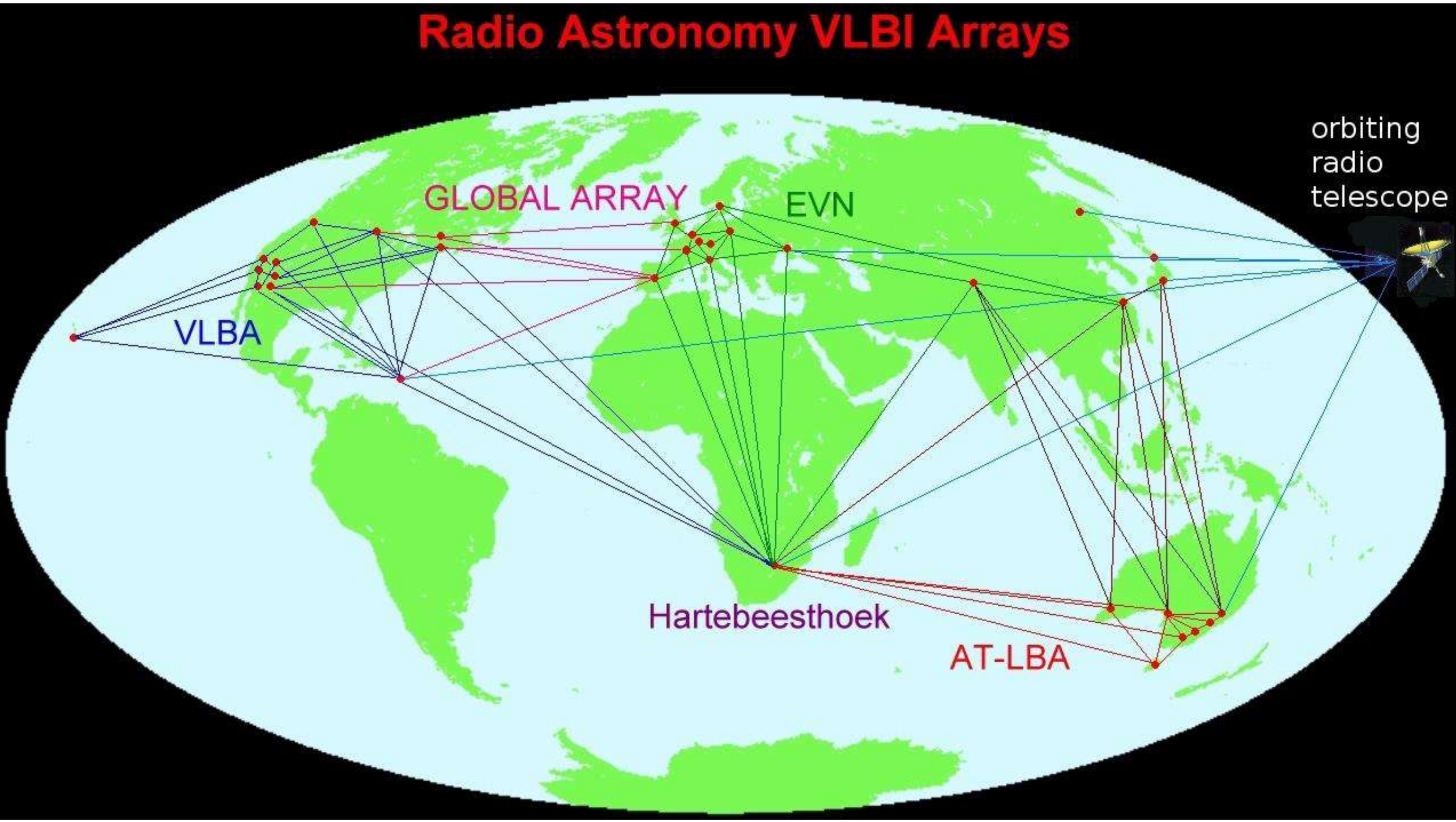
EHT-val érhető el a legfinomabb szögfelbontás?

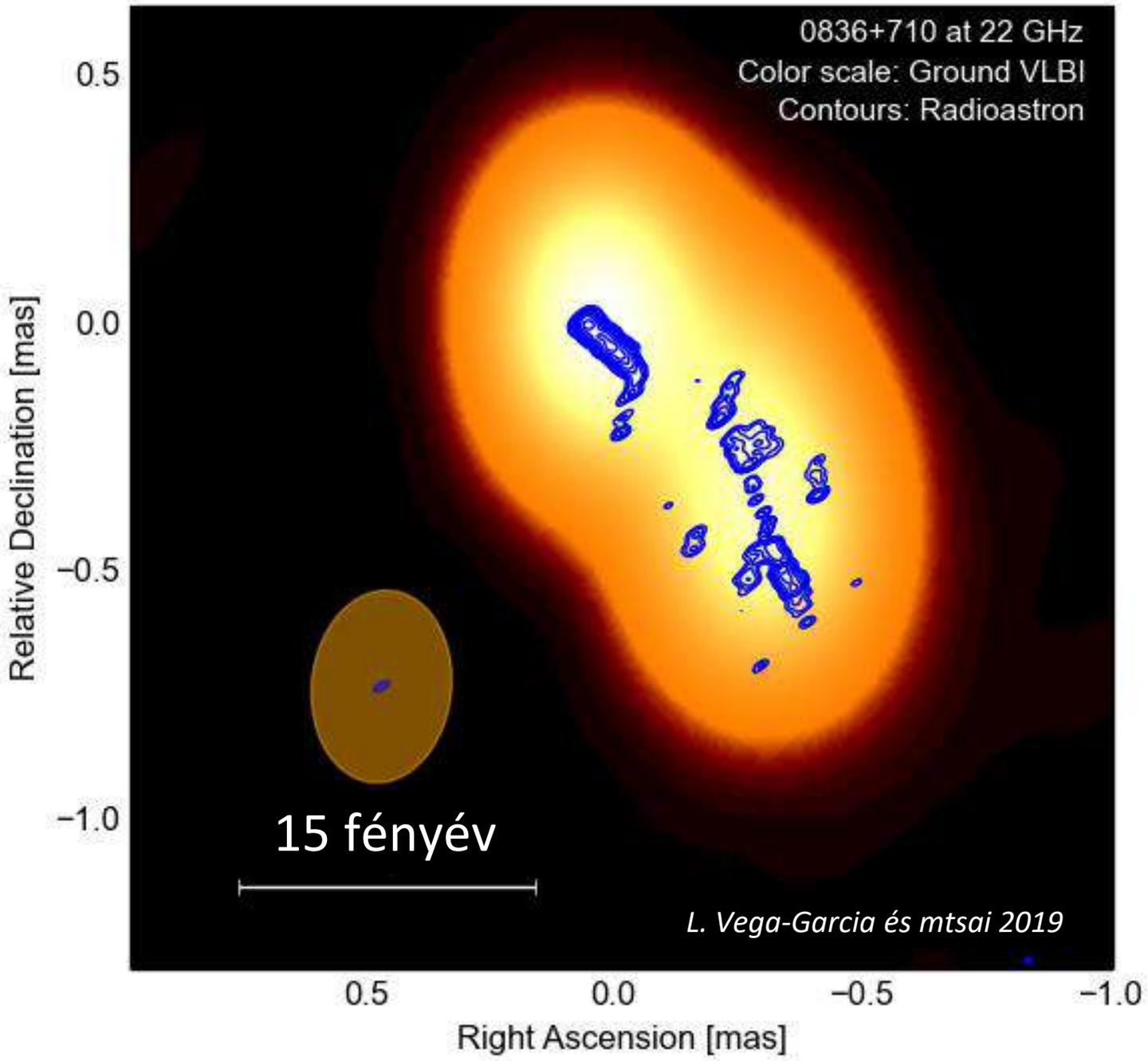
Nem!

Űr-VLBI *2011-2019*



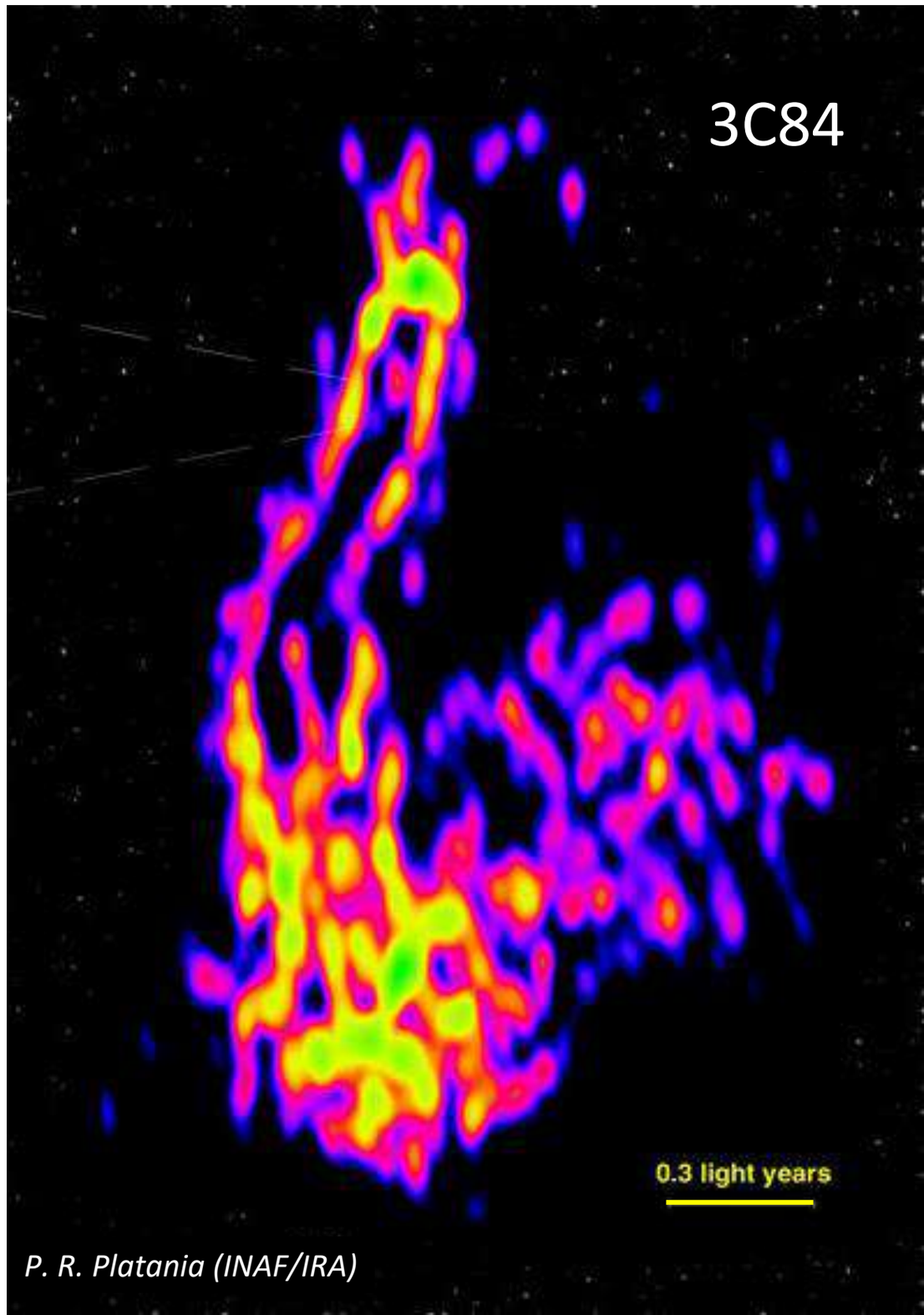
Radio Astronomy VLBI Arrays

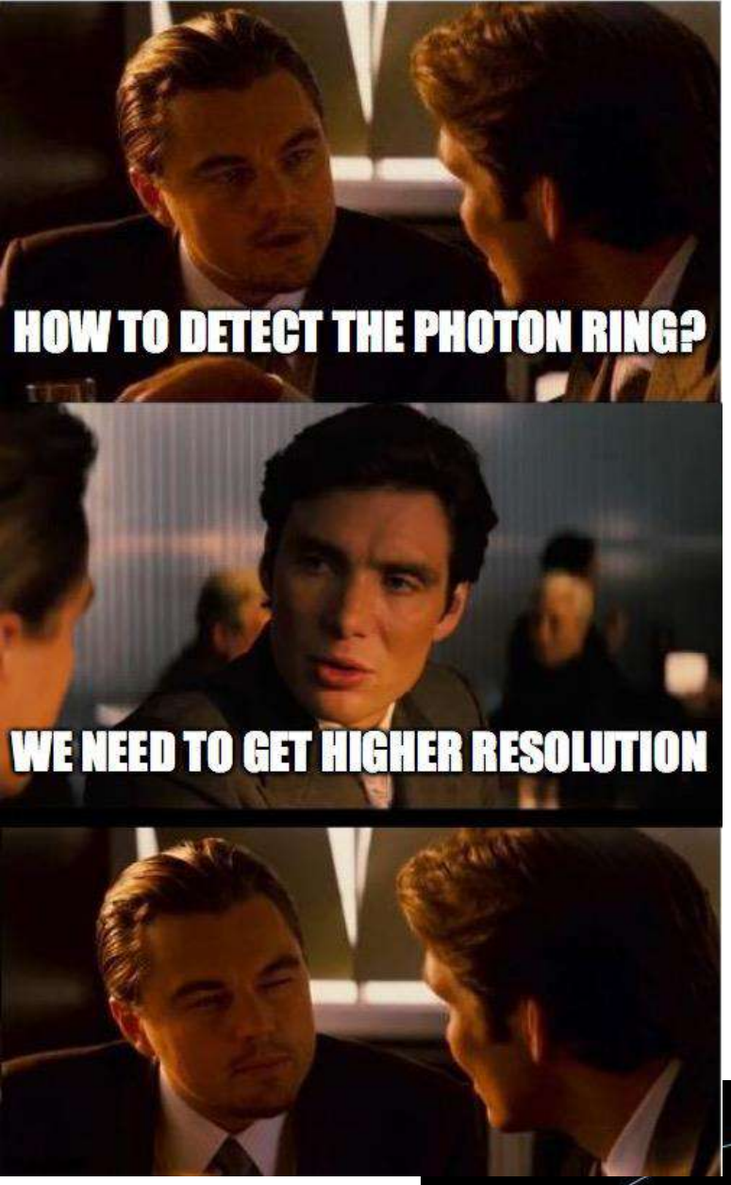


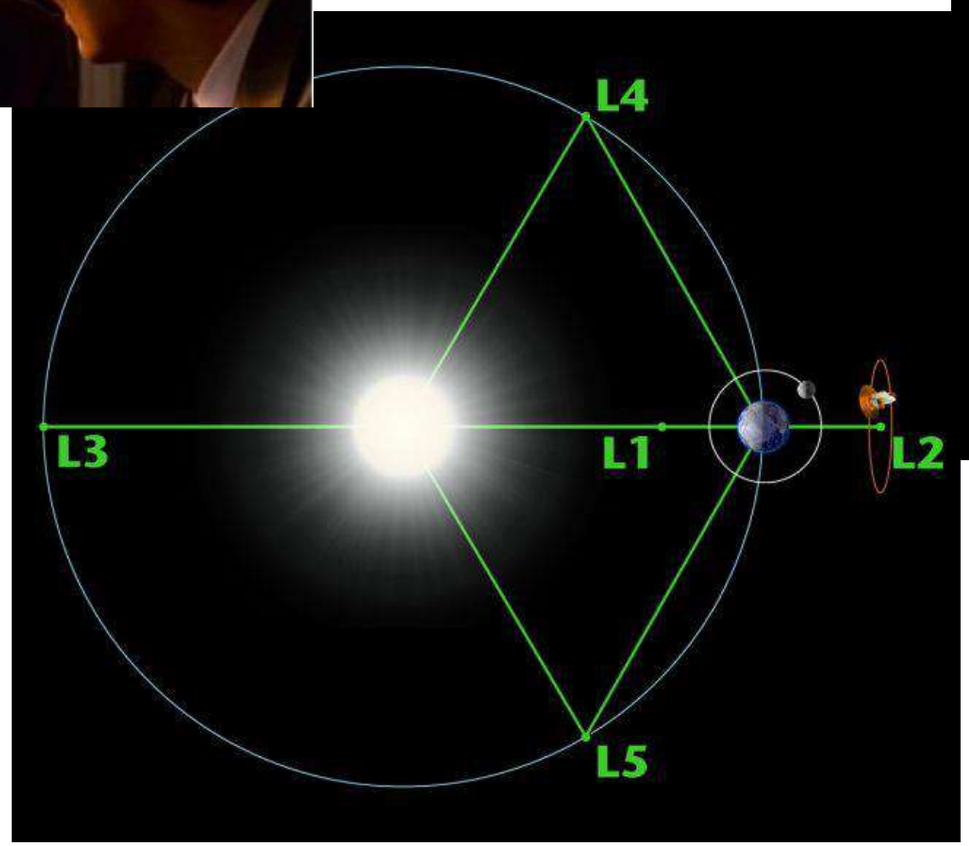


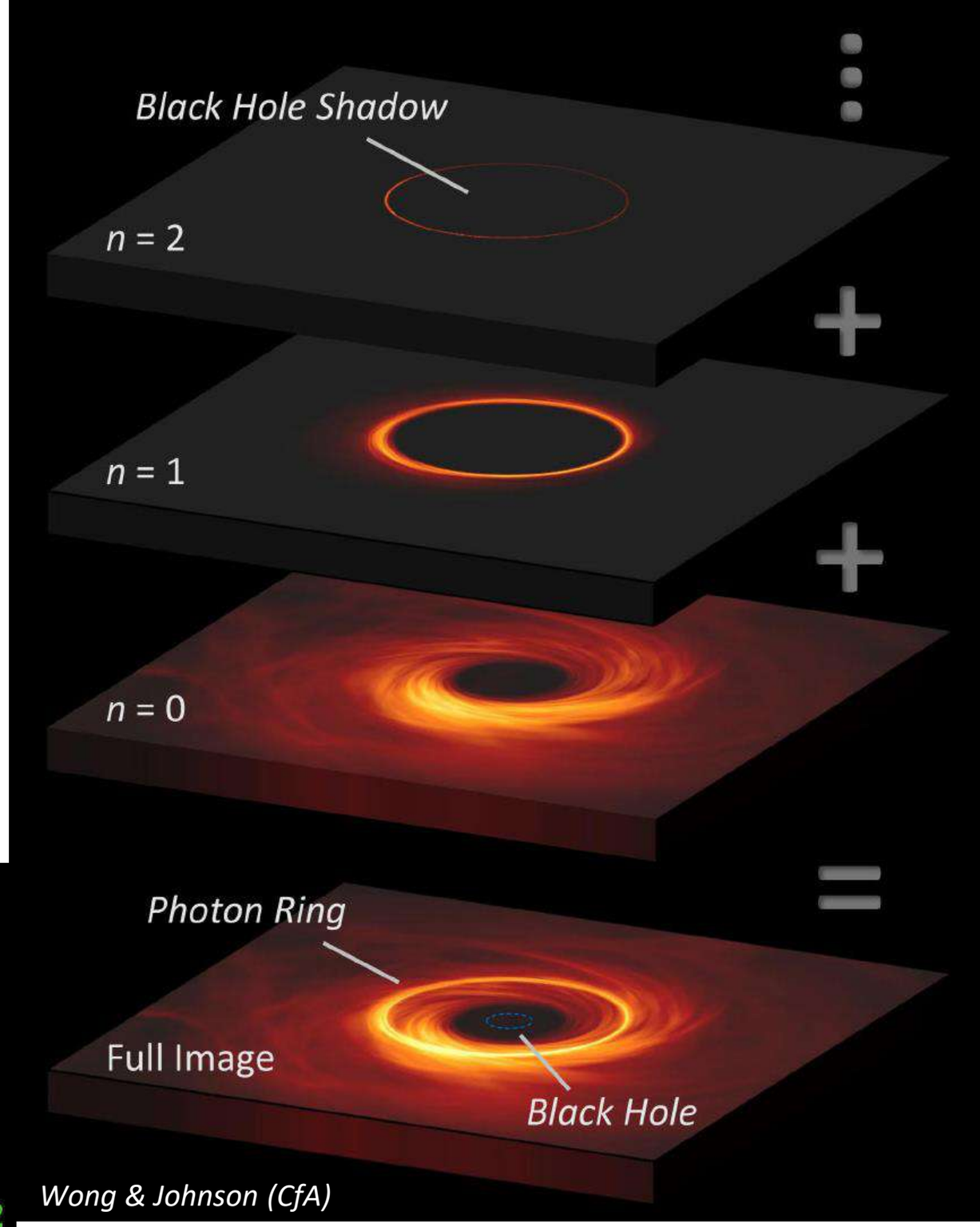
Távolság: 10 milliárd fényév

Távolság: 230 millió fényév



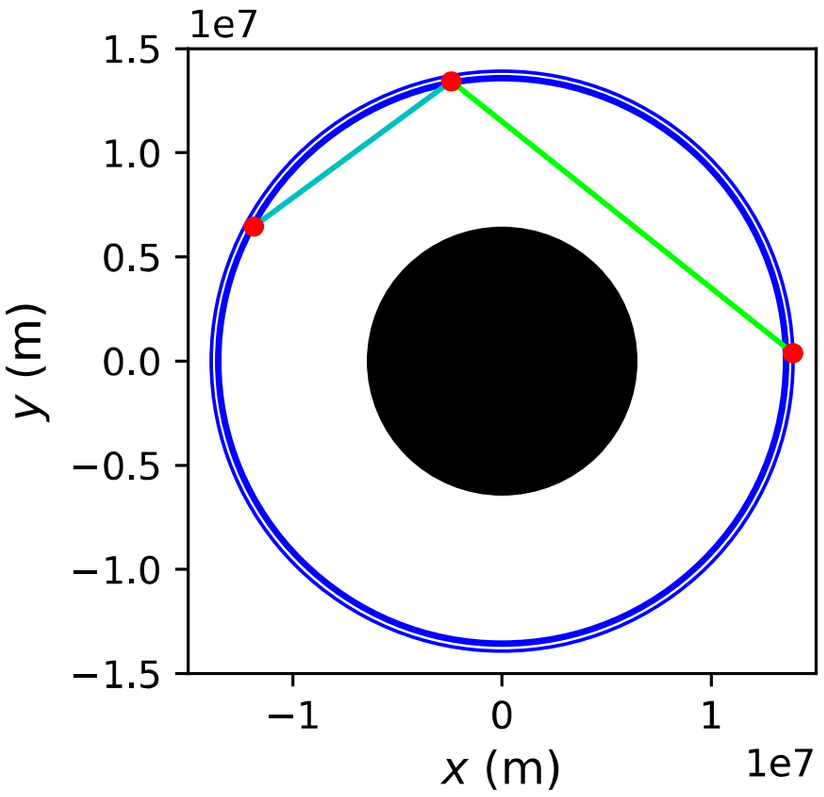






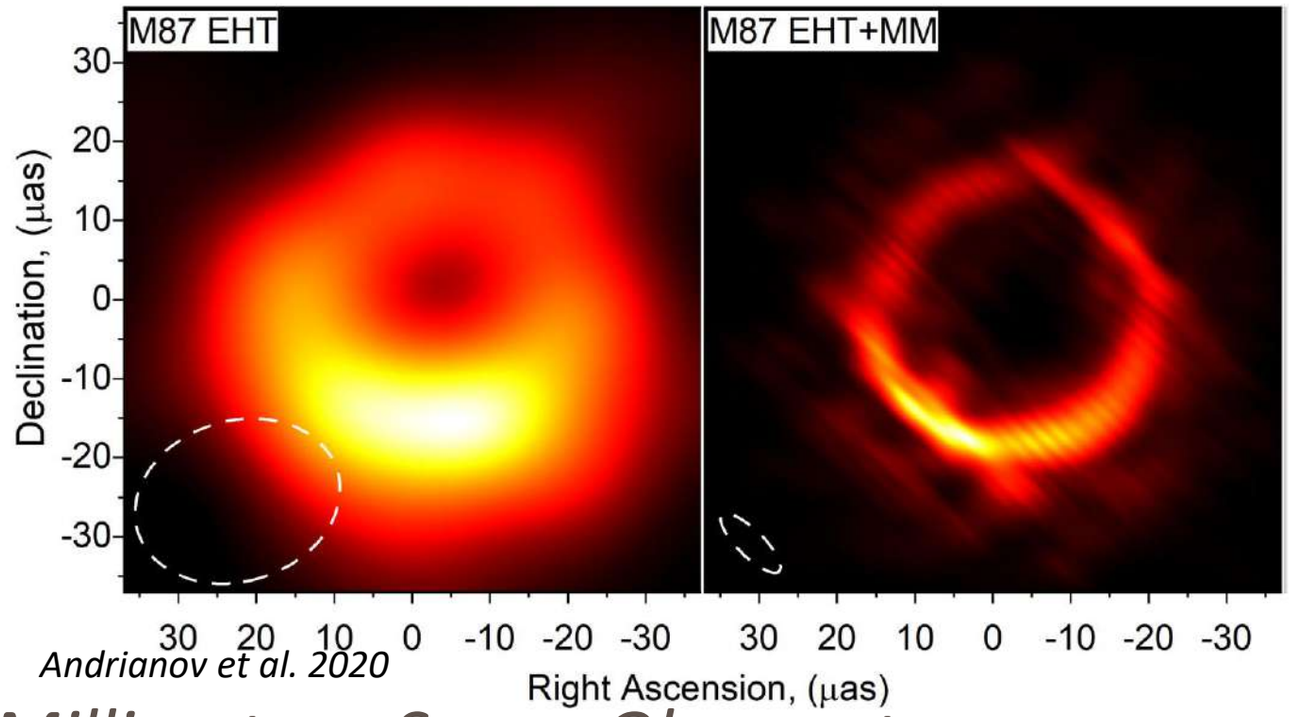
Wong & Johnson (CfA)

Javasolt űr-VLBI projektek mm-es hullámhosszon

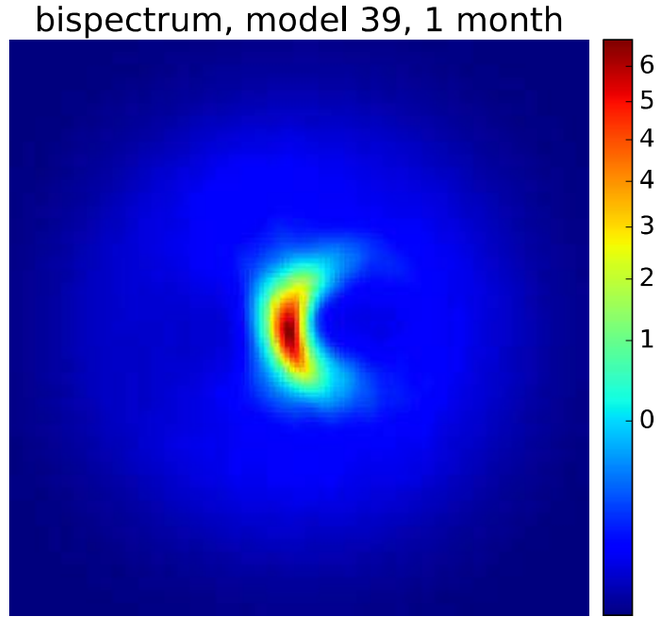


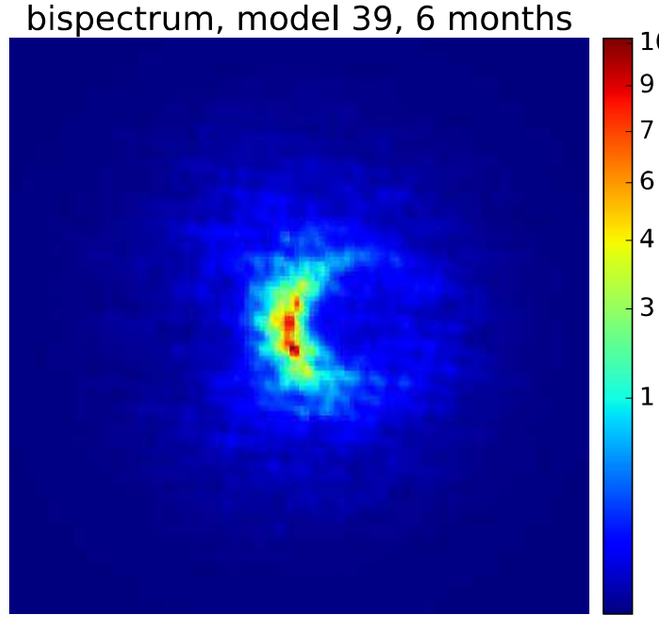
Event Horizon Imager: 3 keringő antenna

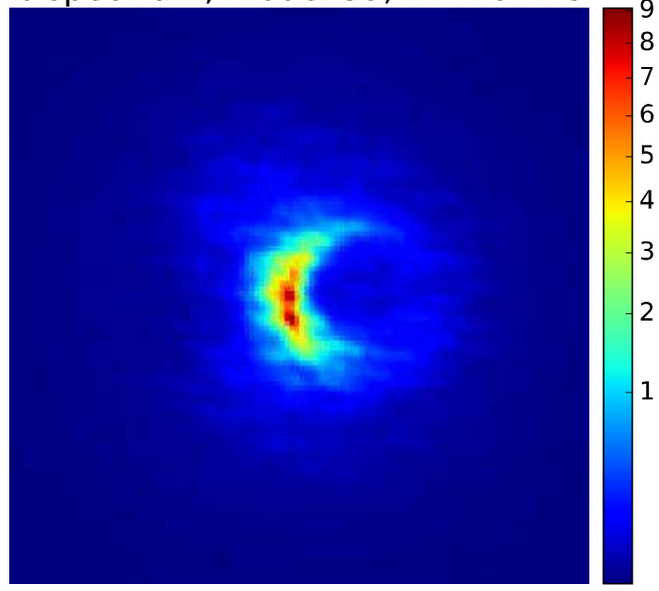
Mérés 690 GHz-en



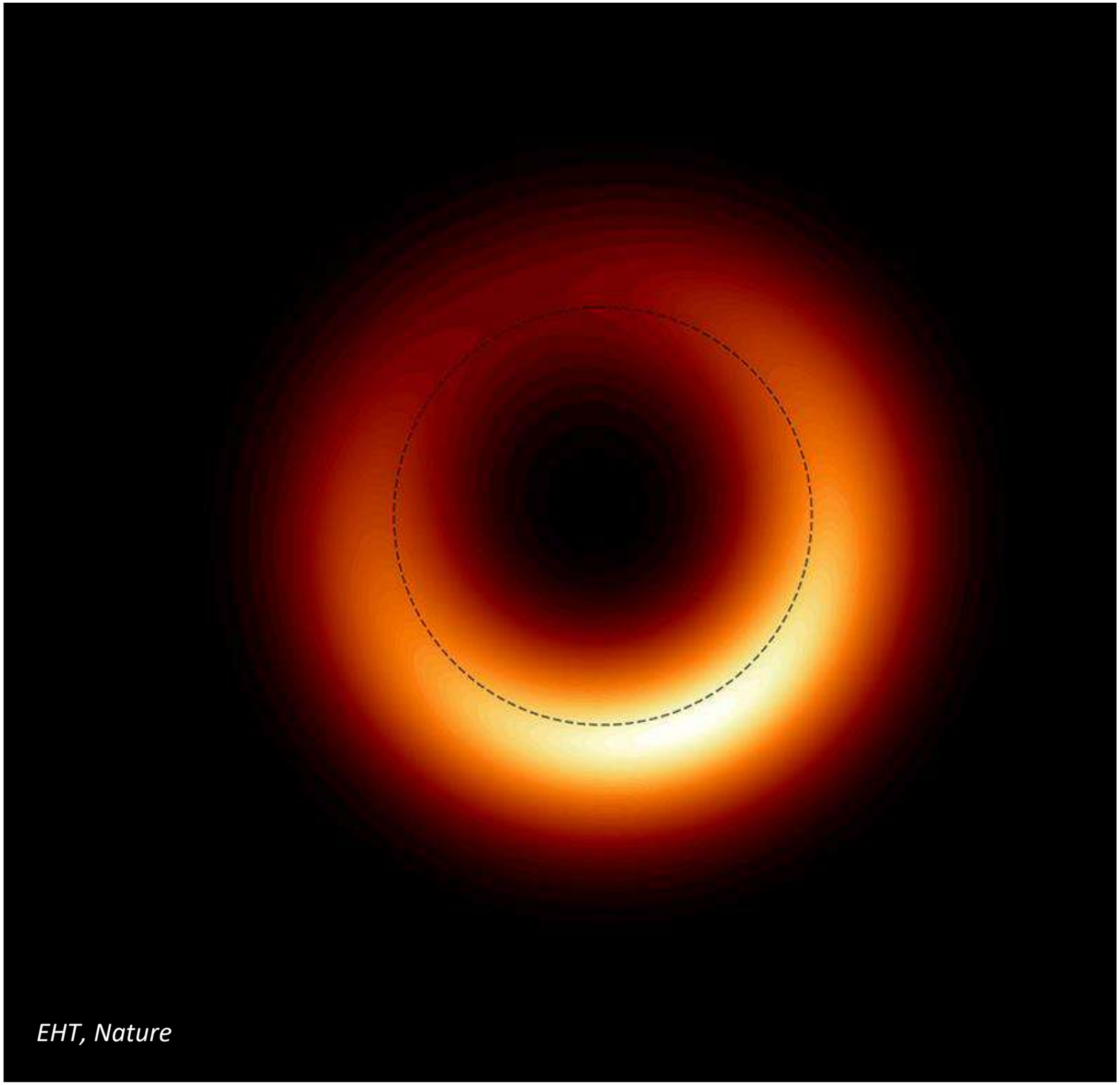
Andrianov et al. 2020







Millimetron Space Observatory



EHT, Nature

Event Horizon Telescope

M 87*

2009 2011 2012 2013 2017

MODELS

IMAGE

40 μas

JCMT CARMA SMT

JCMT SMA CSO CARMA SMT

JCMT SMA CARMA SMT

JCMT SMA CARMA SMT APEX

JCMT SMA SMT LMT IRAM 30m ALMA APEX SPT

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