Unsichtbares wird Sichtbar

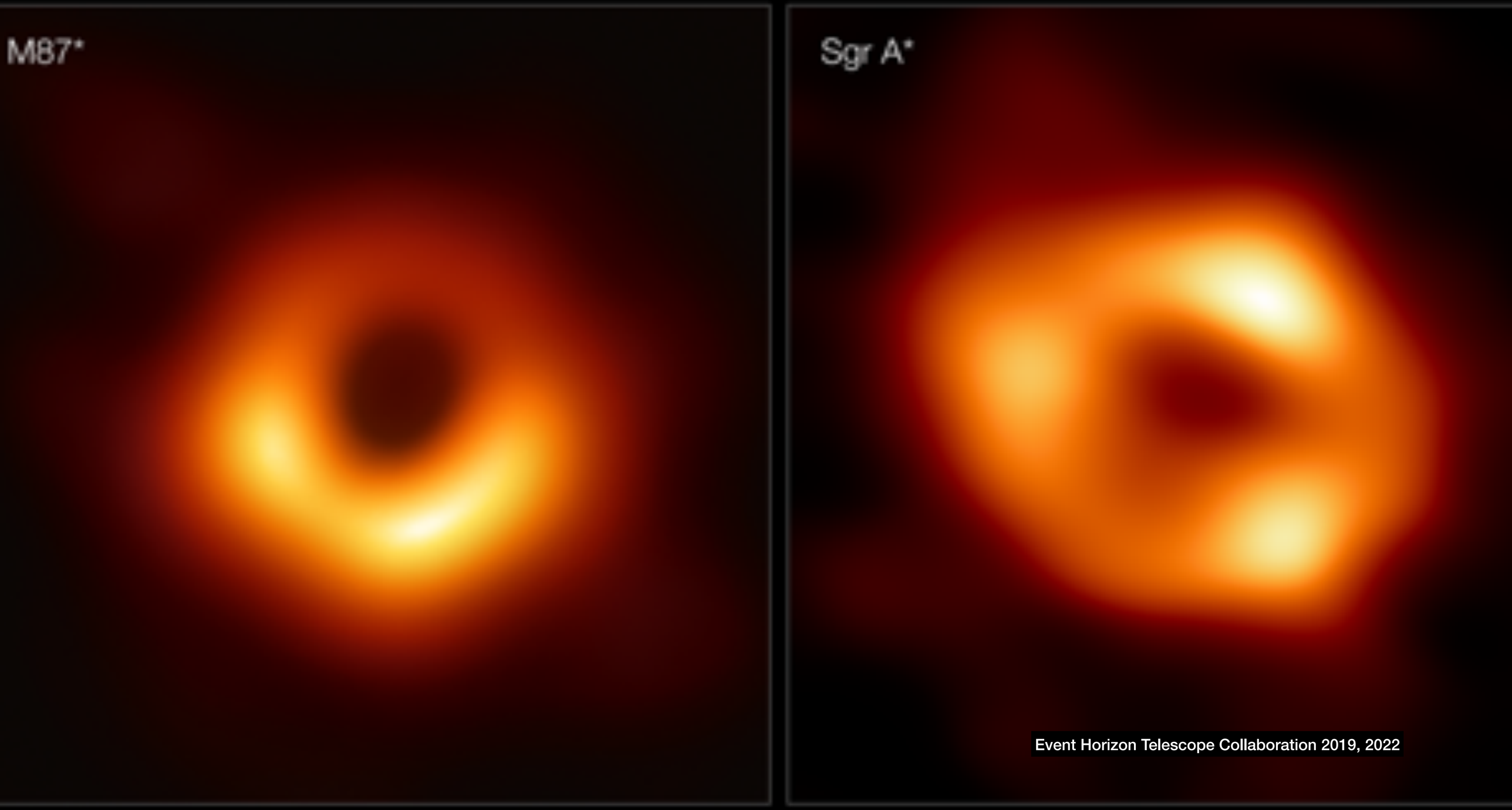
Schwarze Löcher

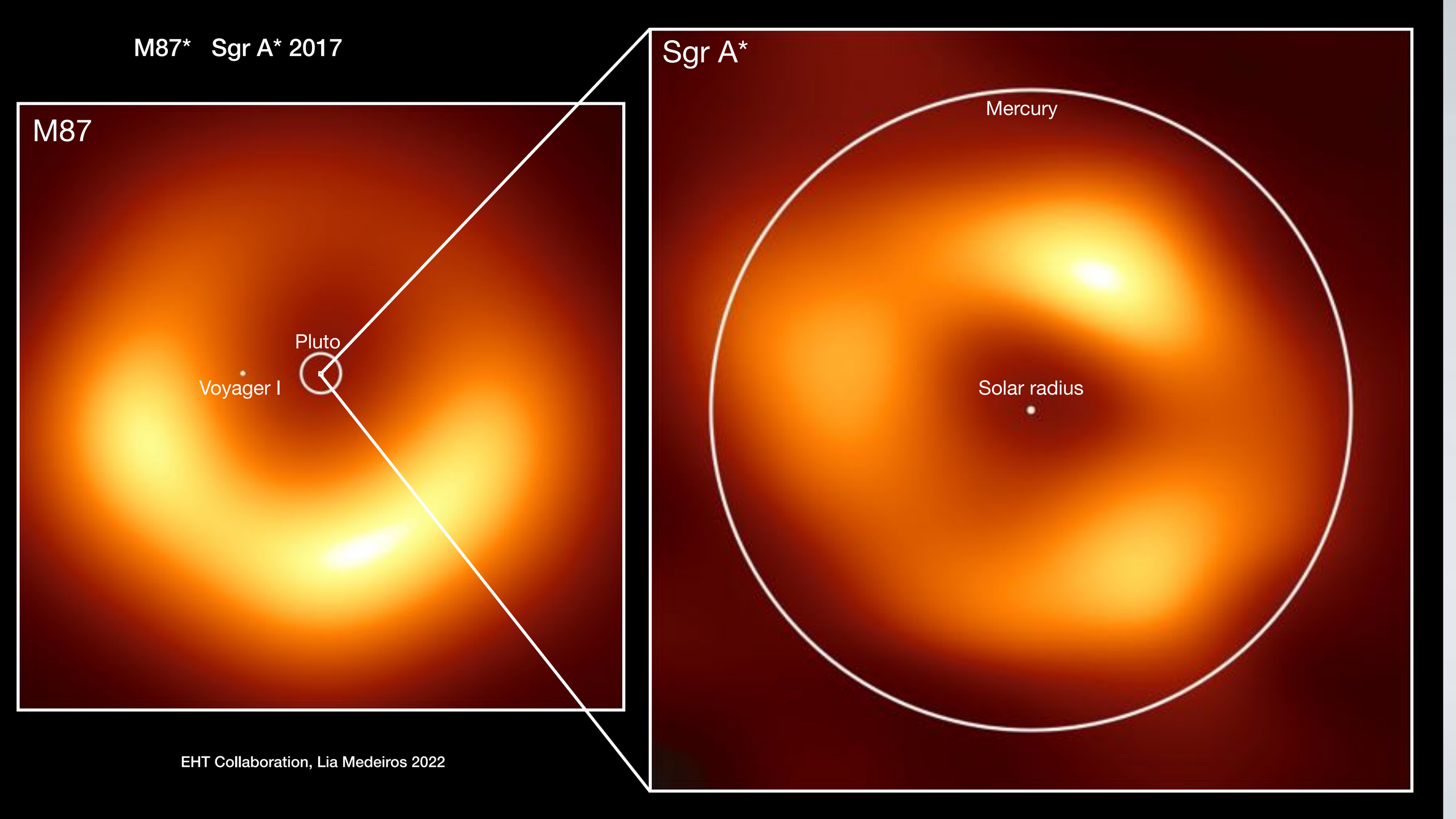
Anton Zensus

Max-Planck-Institut für Radioastronomie

Netzwerk Teilchenwelten
2. November 2022

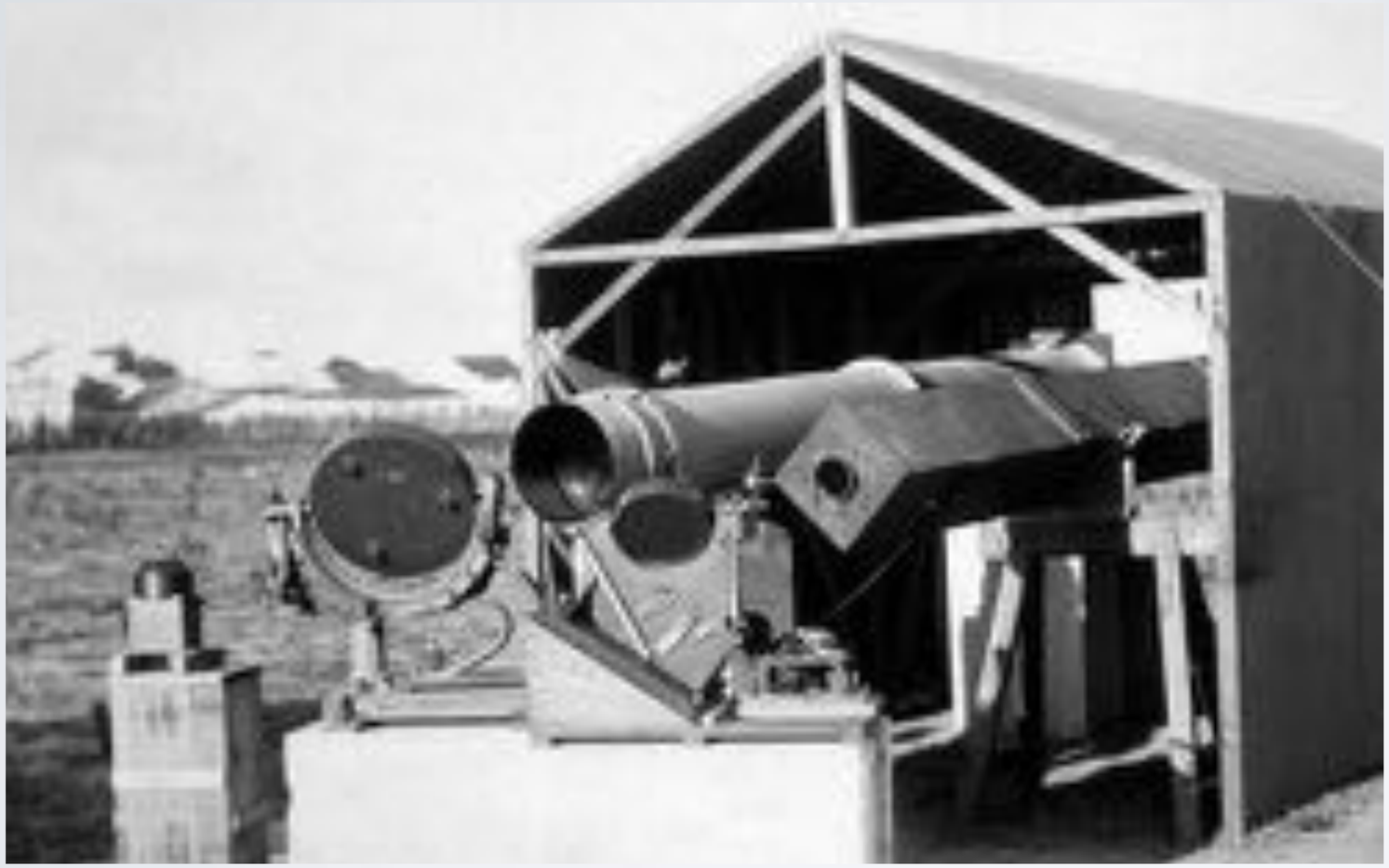
antonzensus.de


M87*
Sgr A*
Event Horizon Telescope Collaboration 2019, 2022

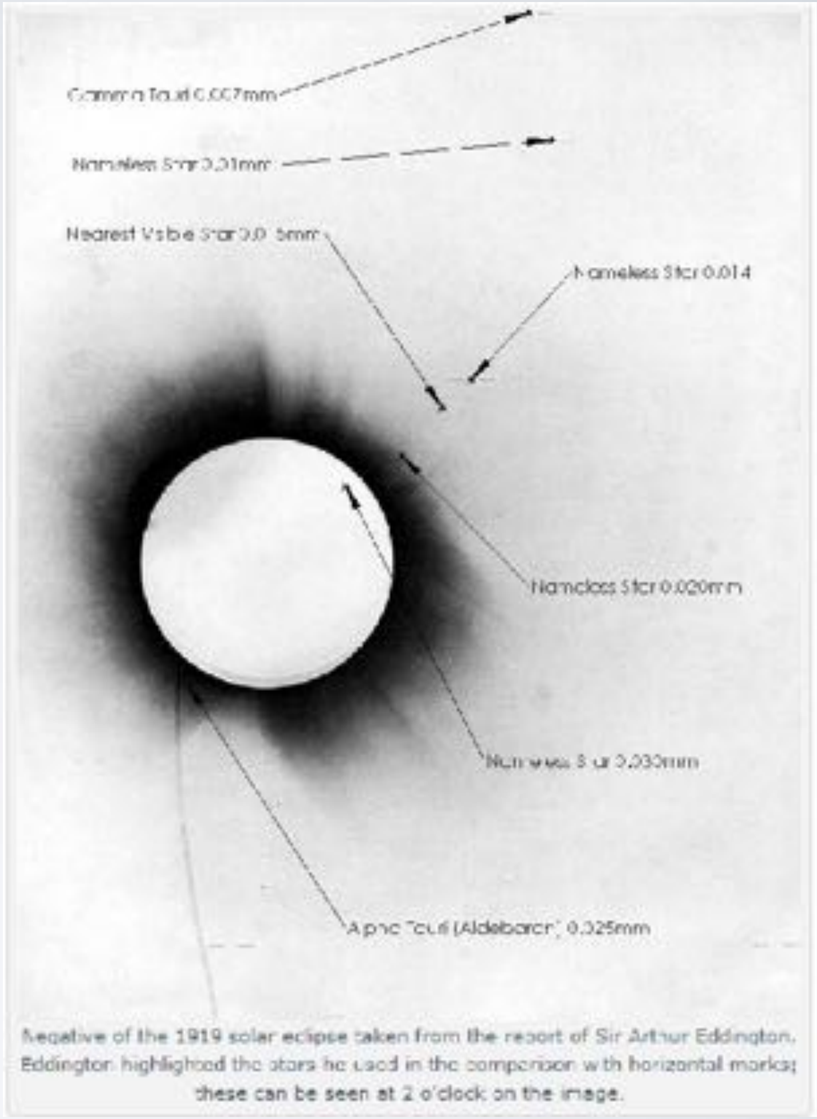

M87* Sgr A* 2017
M87
Pluto
Voyager I
Sgr A*
Mercury
Solar radius
EHT Collaboration, Lia Medeiros 2022

A hundred years ago the English astronomer Arthur Eddington led an expedition to observe the darkening of the sun by the moon

The goal was to measure the displacement of stars near the sun during the eclipse predicted by Albert Einstein



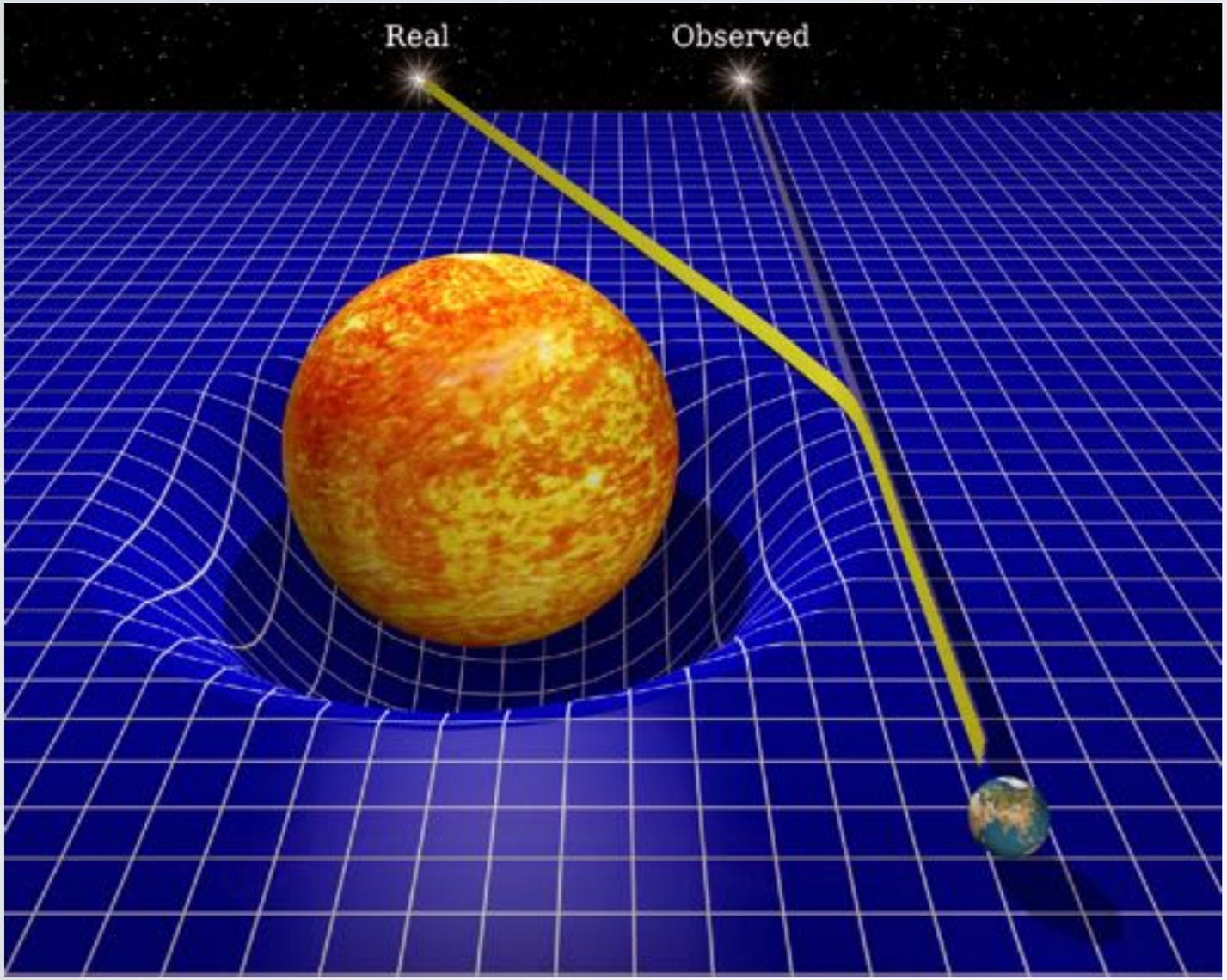
Equipment in Sobral, Brazil



Negative of the 1919 solar eclipse taken from the report of Sir Arthur Eddington. Eddington highlighted the stars he used in the comparison with horizontal marks; these can be seen at 2 o'clock on the image.

Positions of stars in the Hyades cluster were measured

Eddington confirmed a prediction of Albert Einstein's Theory of General Relativity



The light from the star is bent by less than 2" - yet twice the amount predicted by Newtonian theory

The mass of the sun changes space and time in its vicinity

pesieridelluniverso.blogspot.com

Eddington's result was a scientific milestone and a media sensation of the early 20th century

LIGHTS ALL ASKEW IN THE HEAVENS

Men of Science More or Less Agog Over Results of Eclipse Observations.

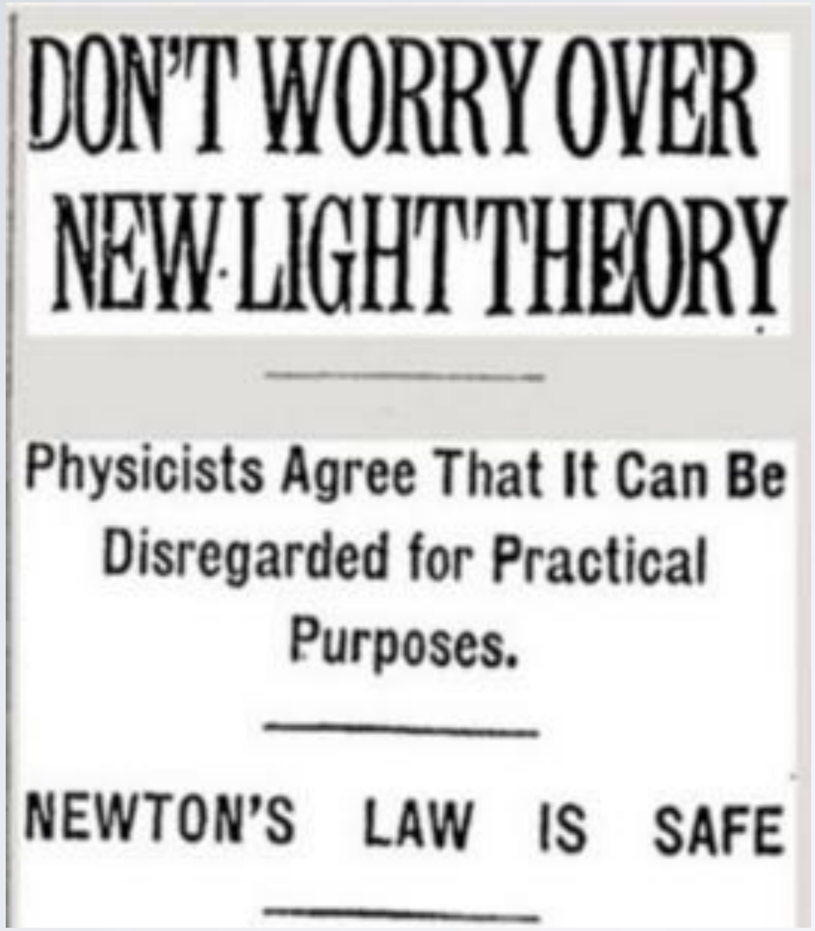
EINSTEIN THEORY TRIUMPHS

Stars Not Where They Seemed or Were Calculated to be, but Nobody Need Worry.

New York Times 10. Nov. 1919

Albert Einstein and Arthur Eddington

Not dreamed of in1919:
the relevance of relativity to everyday life



DON'T WORRY OVER
NEW LIGHT THEORY

Physicists Agree That It Can Be Disregarded for Practical Purposes.

NEWTON'S LAW IS SAFE

New York Times 16. Nov. 1919

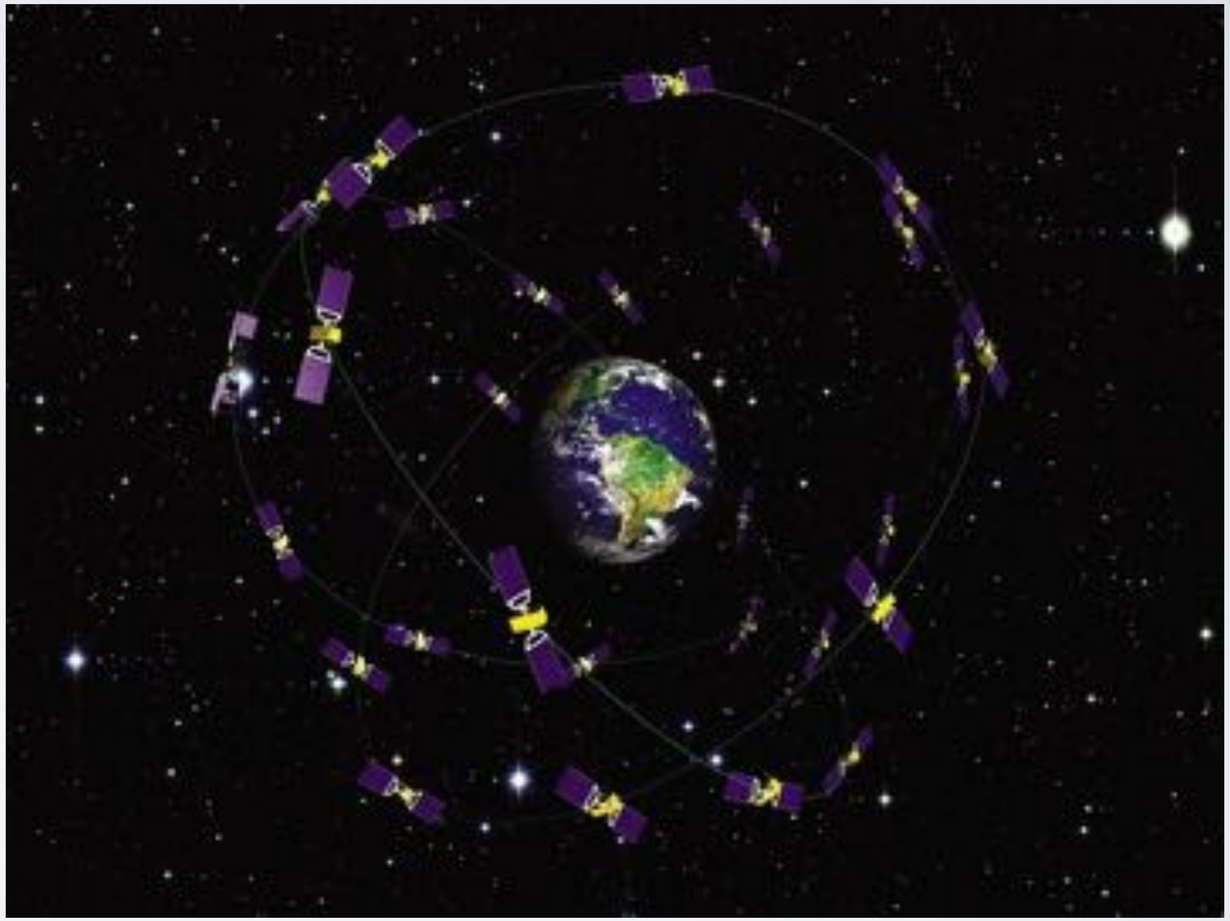
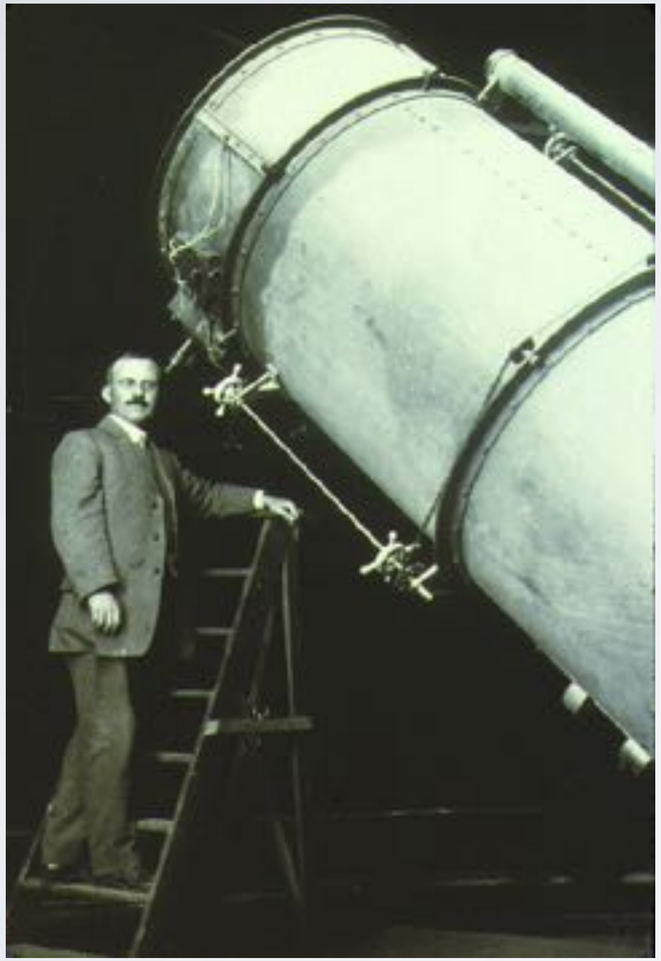


Foto: ESA

GPS navigation is possible with satellites and atomic clocks in Earth's gravitational potential

Also 100 years ago:
Mysterious observation in the nebula M 87



US Astronomer
Heber Curtis 1918

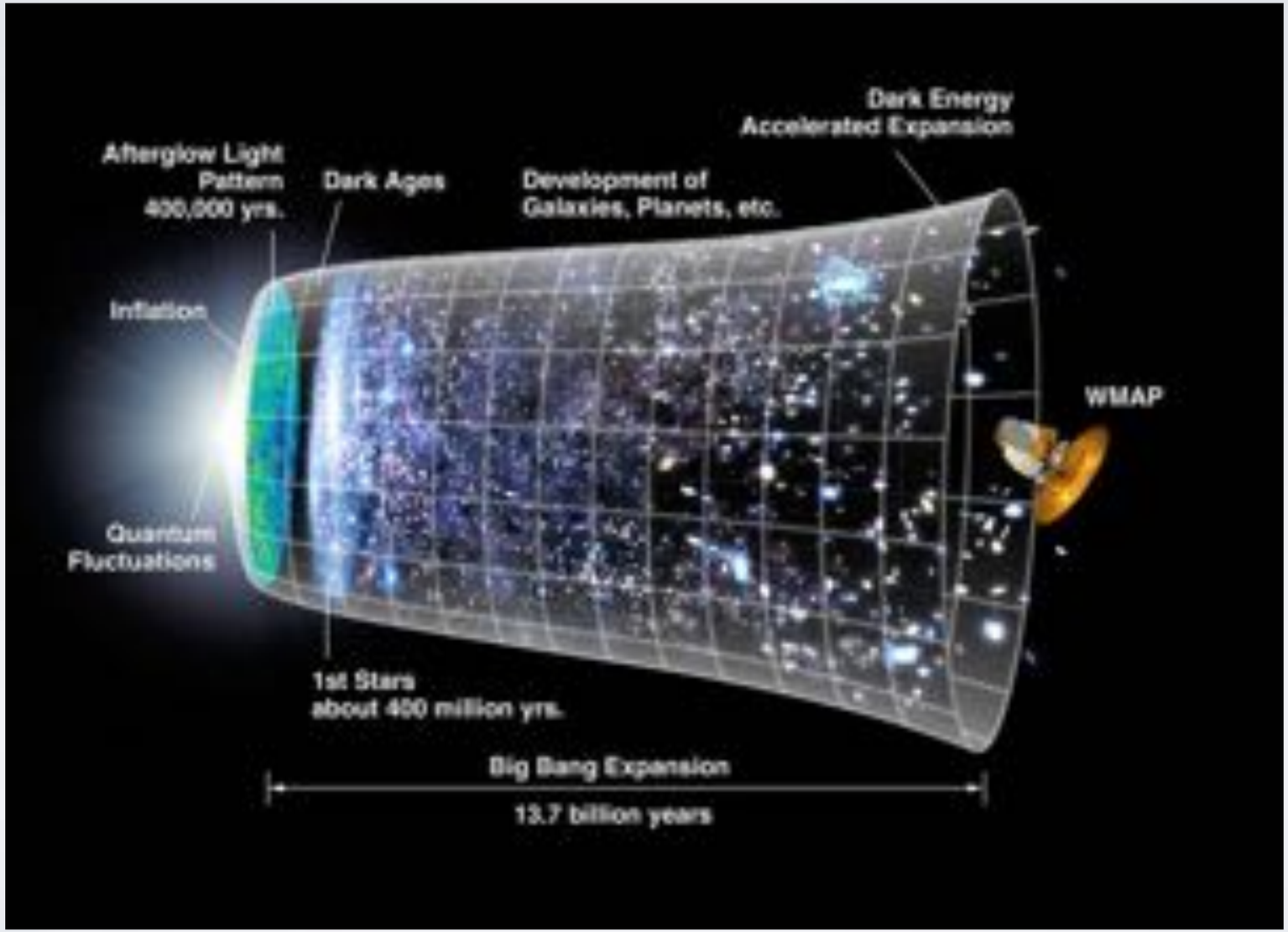
Curtis, Pub. Lick Obs 13, 9, 1918

4486	12	25.8	+12	57	Exceedingly bright; the sharp nucleus shows well in 5m exposure. The brighter central portion is about 0.5 in diameter, and the total diameter about 2′; nearly round. No spiral structure is discernible. A curious straight ray lies in a gap in the nebulosity in p.a. 20°, apparently connected with the nucleus by a thin line of matter. The ray is brightest at its inner end, which is 11″ from the nucleus. 20 s.n.

A glimpse of the Universe with the *James Webb Space Telescope*

Galaxy Cluster SMACS J0723.3–7327, released by the *James Webb Space Telescope* on July 12, 2022

The expanding Universe is thought to originate from the Big Bang 13.7 billion years ago with first stars forming after 400 million years followed by galaxies



NASA

Most astrophysicists agree:
Messier 87 is hiding a giant black hole

Credit: Newsweek

The black hole - characterized by the event horizon - is fed with matter from a hot, rotating disk in the centre of the galaxy

The "mysterious" stray of matter originates in the environment of the black hole.

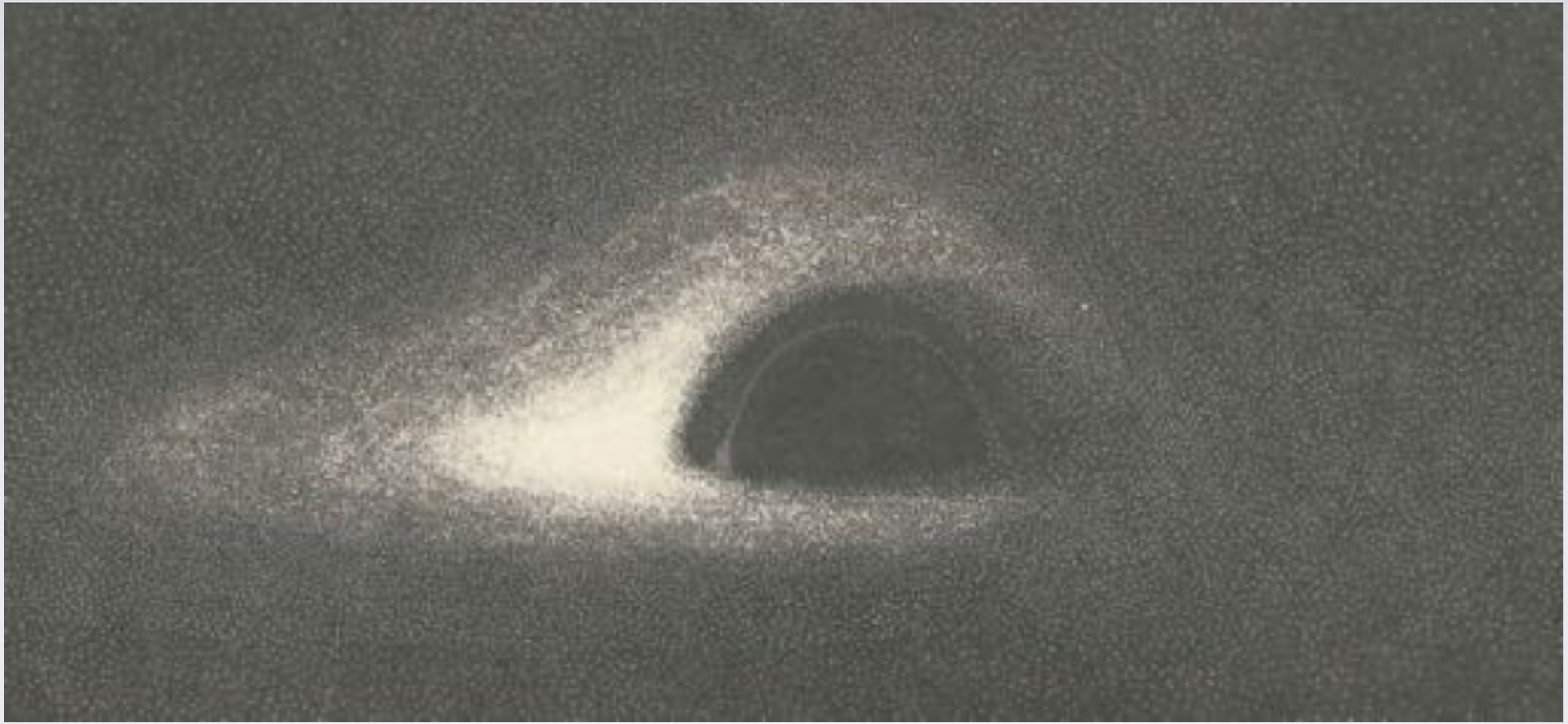
6-7 Billion Solar Masses - concentrated in the size of our Solar System!

The theory of general relativity leads to black hole paradigm

Nobel Price Physics 2020 to Ghez and Genzel: Motion of the star S2 around the centre of the Milky Way

ESO/ M. Kornmesser

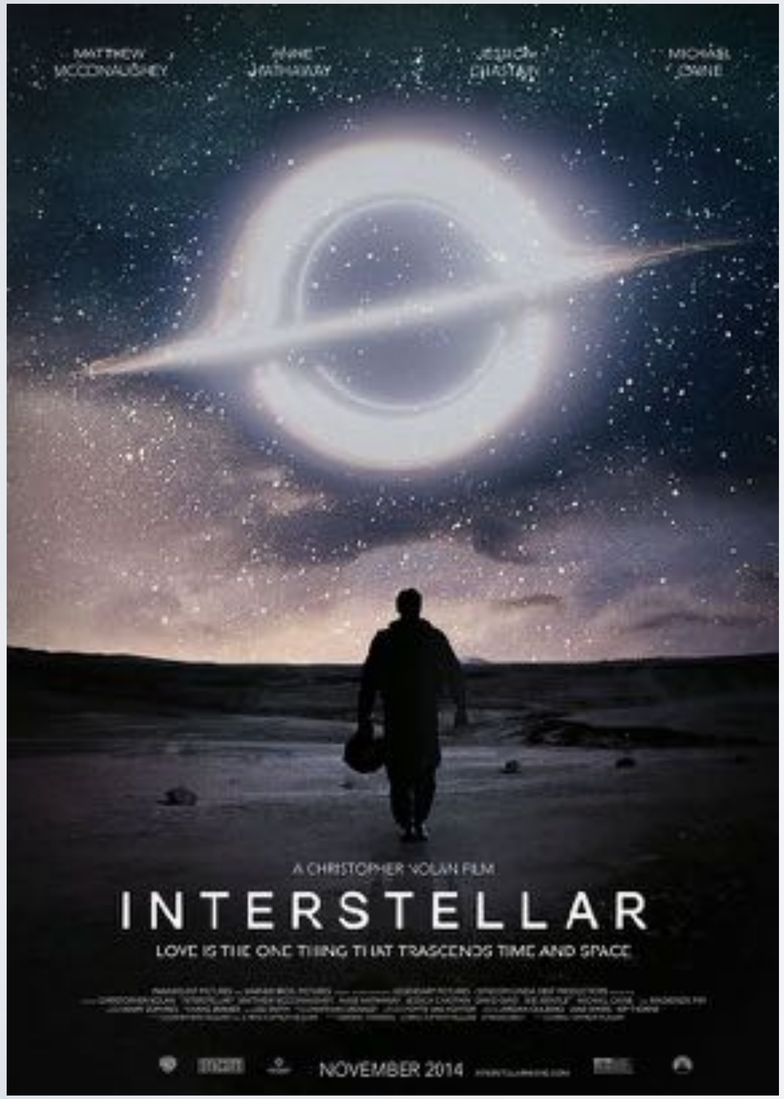
How can one see something that does not emit light?



French astrophysicist J.P. Luminet, 1979

- done on a computer - drawn by hand

The bold goal:
Making a direct image of a black hole



Paramount

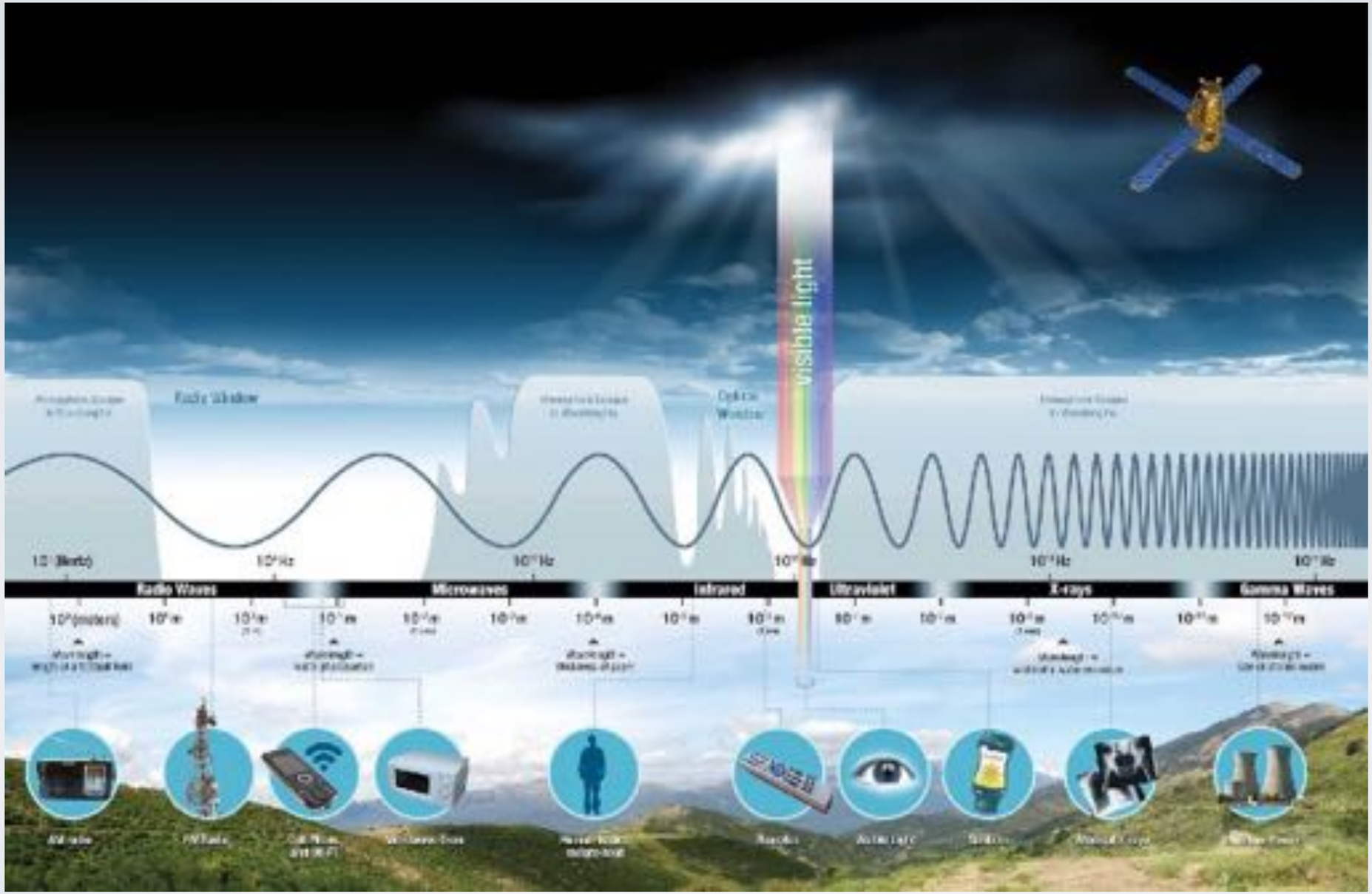
The General Theory of Relativity describes the bending of light of a hot accretion disc in the gravitational potential of the giant black hole and would be confirmed by a picture

The movie showed in 2014 realistic simulations generated by Nobel Prize winner Kip Thorne

Der Photonenring des schwarzen Lochs

Center for Astrophysics, Harvard & Smithsonian

Nur sichtbares Licht und Radiowellen sind von der Erde messbar



Credit: NASA

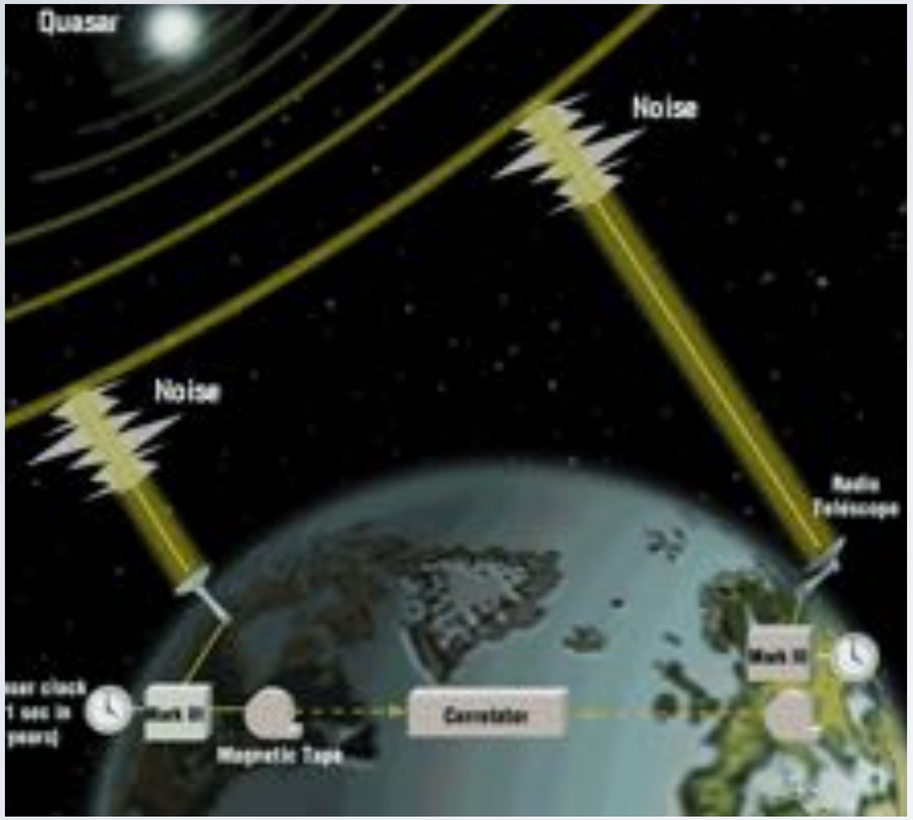
Radioteleskope messen Mikrowellen aus dem All

100m-Radioteleskop
Effelsberg, Eifel

Max-Planck-Institut für Radioastronomie

Max-Planck-Institut für Radioastronomie

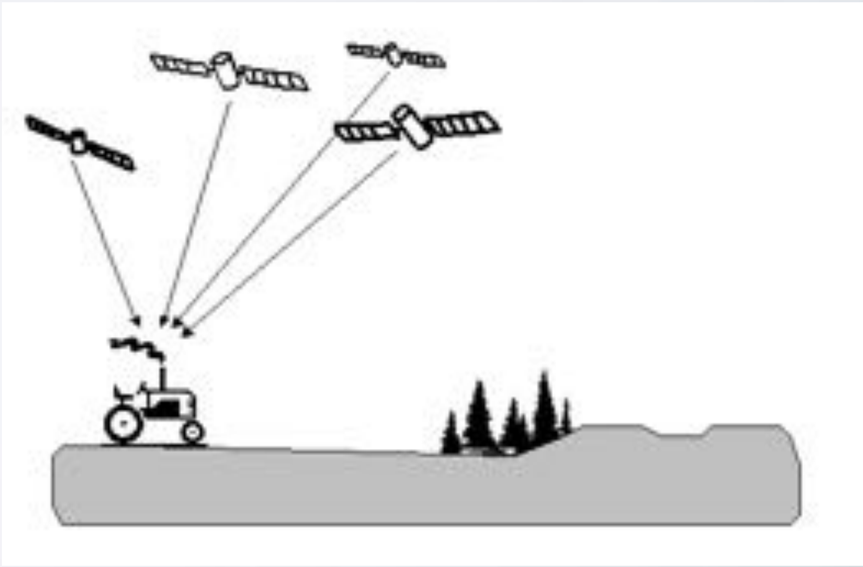
The trick:
radio signals are recorded and combined (correlated) later



NASA

The combined signals yield positions of the source on the sky and eventually even images

GPS works the other way:
The location of the GPS receiver is computed from the position of satellites and the arrival time of the signals.

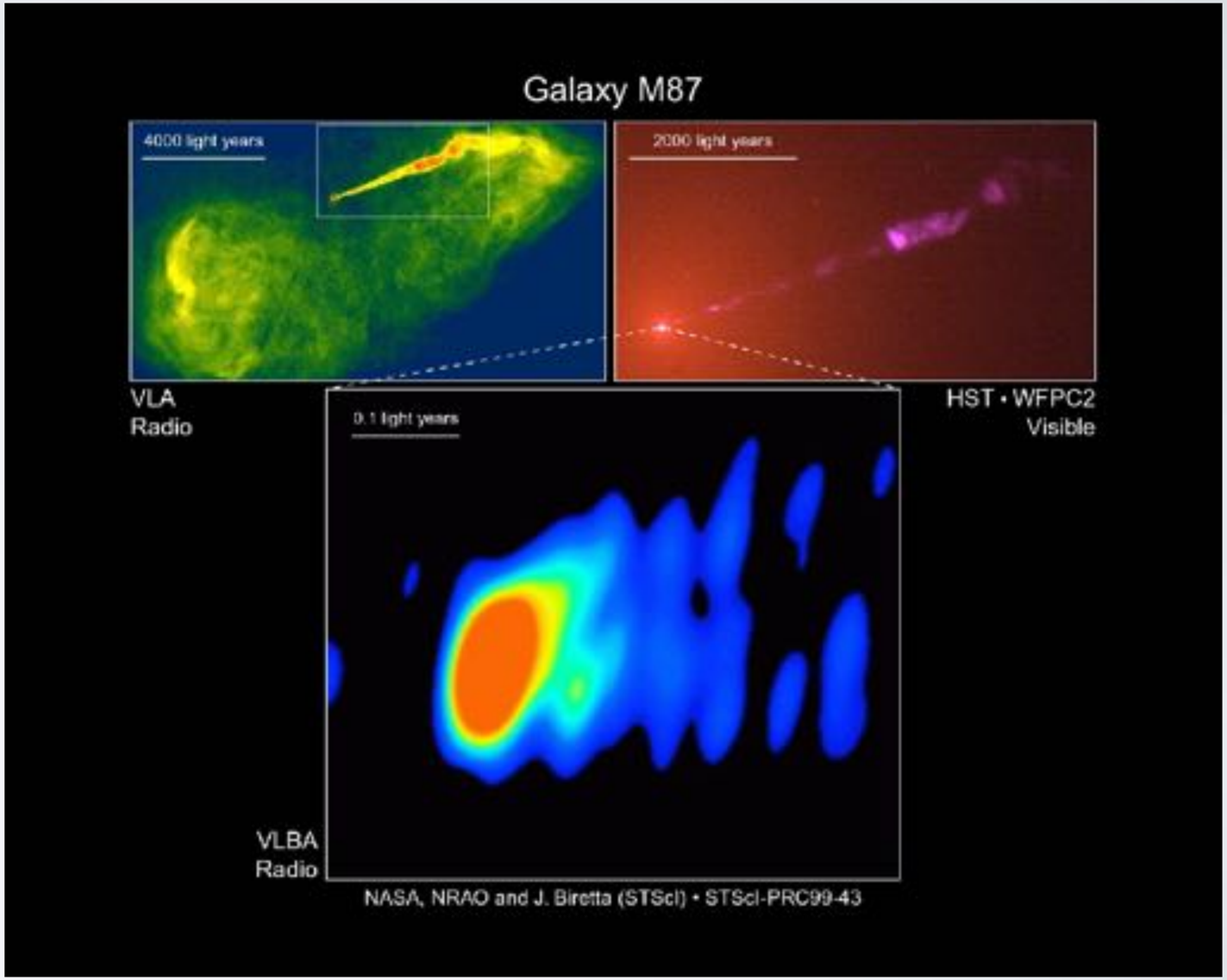


GMVA @ 3mm

Collage: H. Rottmann (MPIfR)

Innovative "Big" technology at radio waves open a new finer view at the Universe

The radio image is now 10,000x sharper than the optical image



EVENT HORIZON TELESCOPE - EHT: RADIO CAMERA TO IMAGE A BLACK HOLE

Event Horizon Telescope Collaboration

Challenge:
Organize a global collaboration

The EHT works like the United Nations:
goals and interests are negotiated

Autonomous observatories, different technology standards and scientists need to be coordinated

Challenge:
Manage masses of data

One observation requires processing
5 Petabyte = 5 million gigabytes

Each telescope sends
700 terabyte = 700 thousand gigabyte
to Bonn (even from South Pole)
for a total 500kg hard discs

The data link can do 16 gigabyte/s

Challenge:
Combine the data and calculate the image

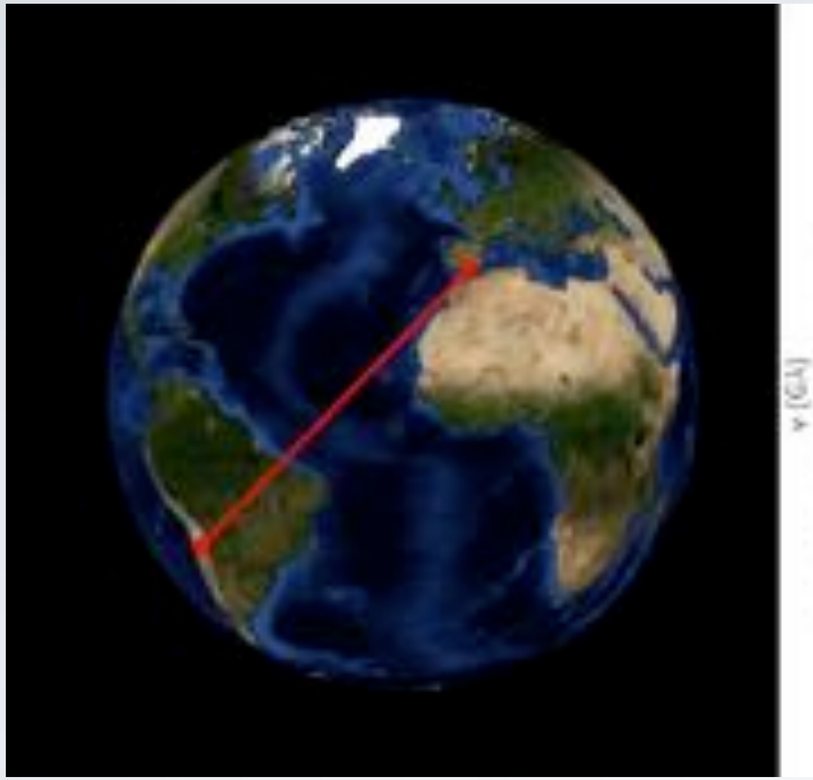
The Bonn compute cluster:
68 Computer 2 processors each, each with 10 cores = 1360 cores
= 40 teraflops
1,3 million GB scratch space

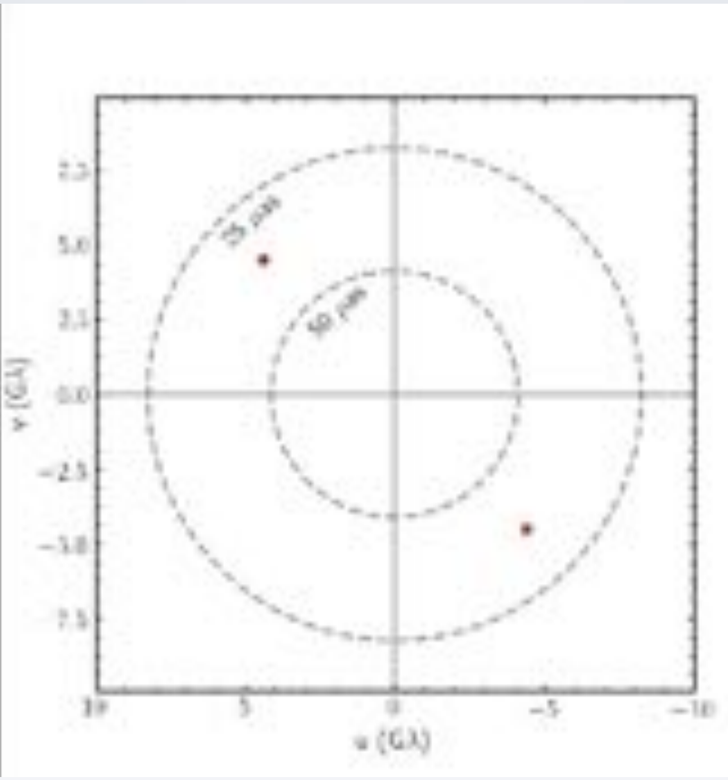
Max-Planck-Institut für Radioastronomie

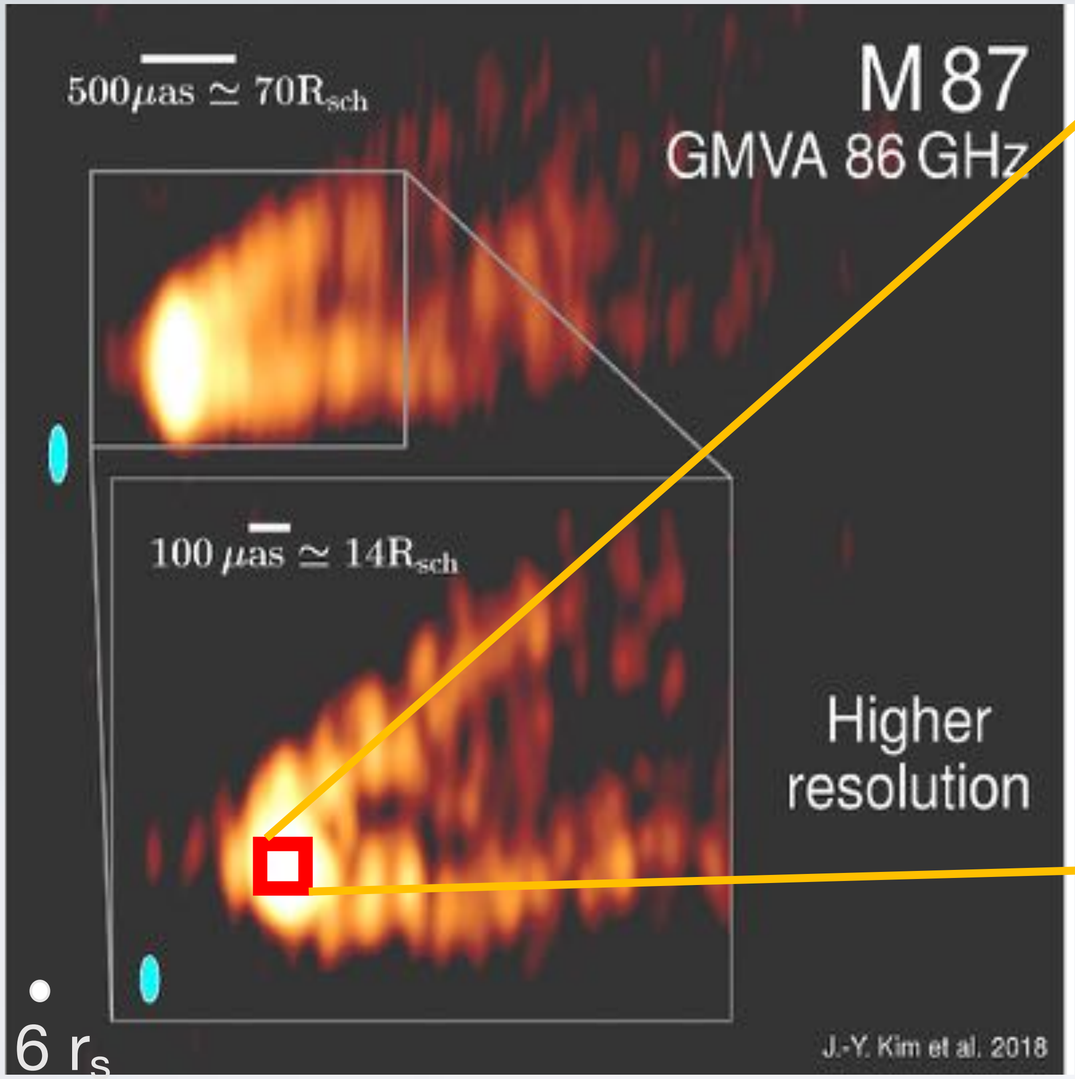
Challenge: The weather needs to be good at all stations

ESO

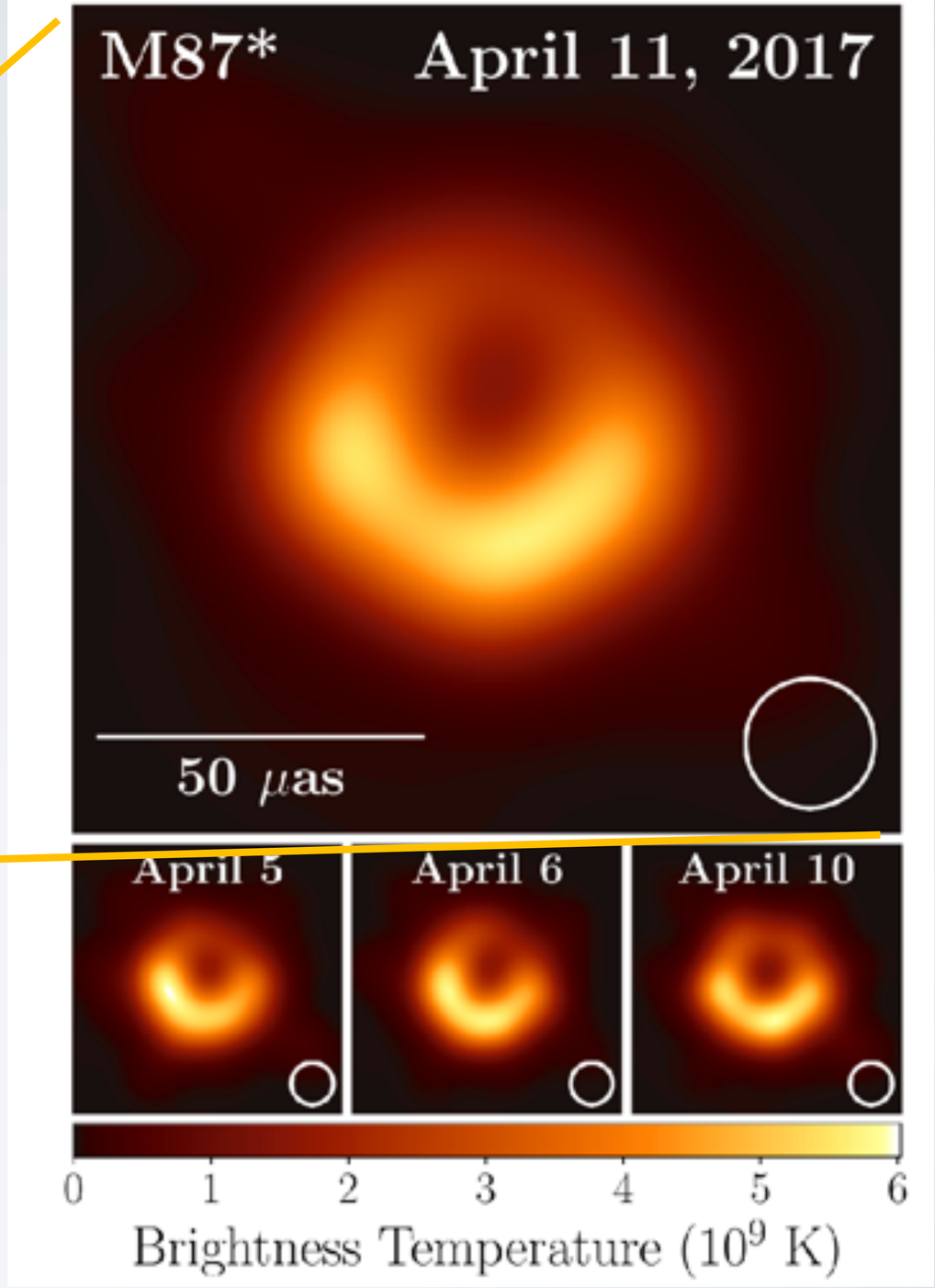
Filling the UV plane



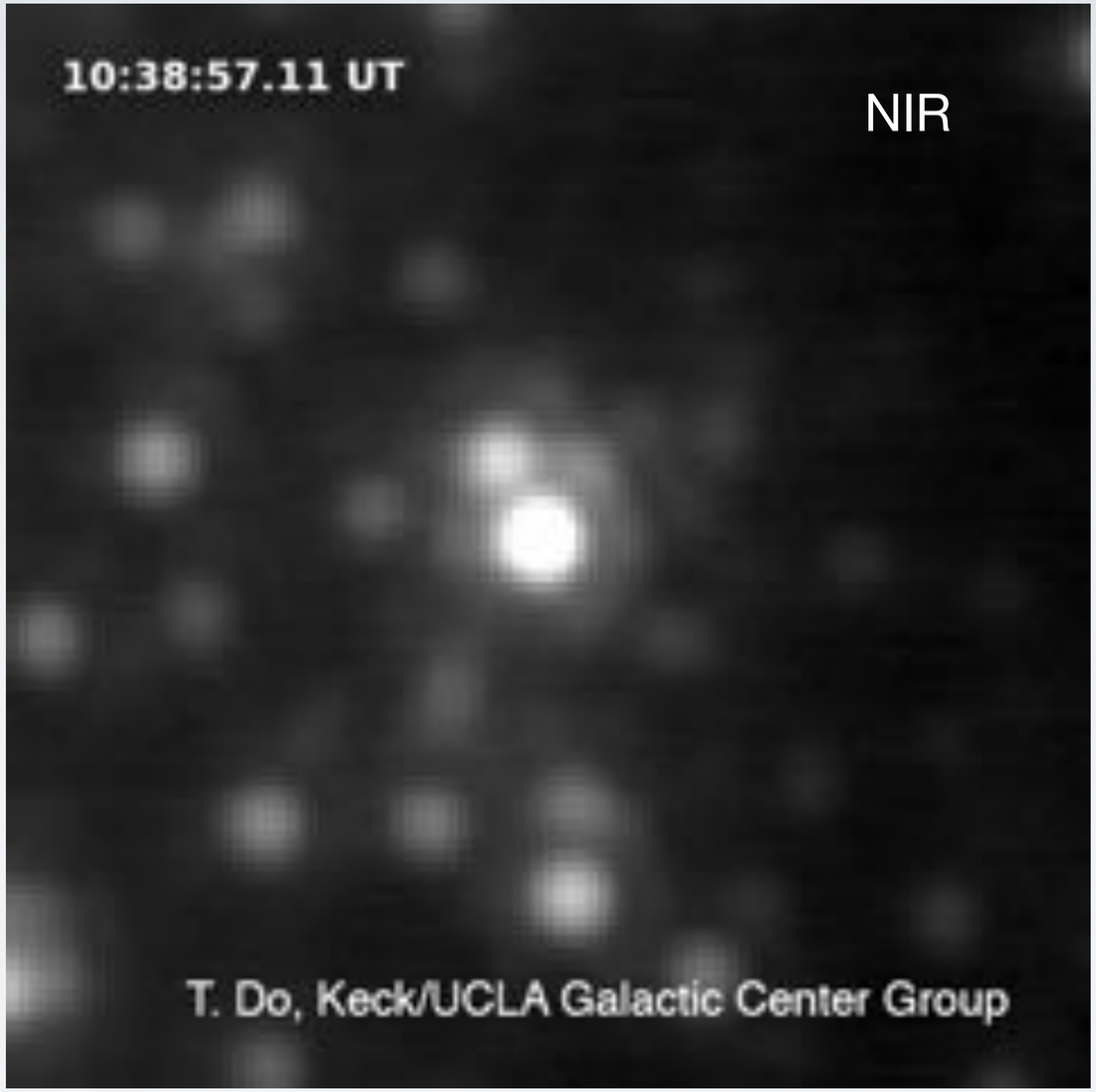




Kim et al. A&A 616 A188 (2018)

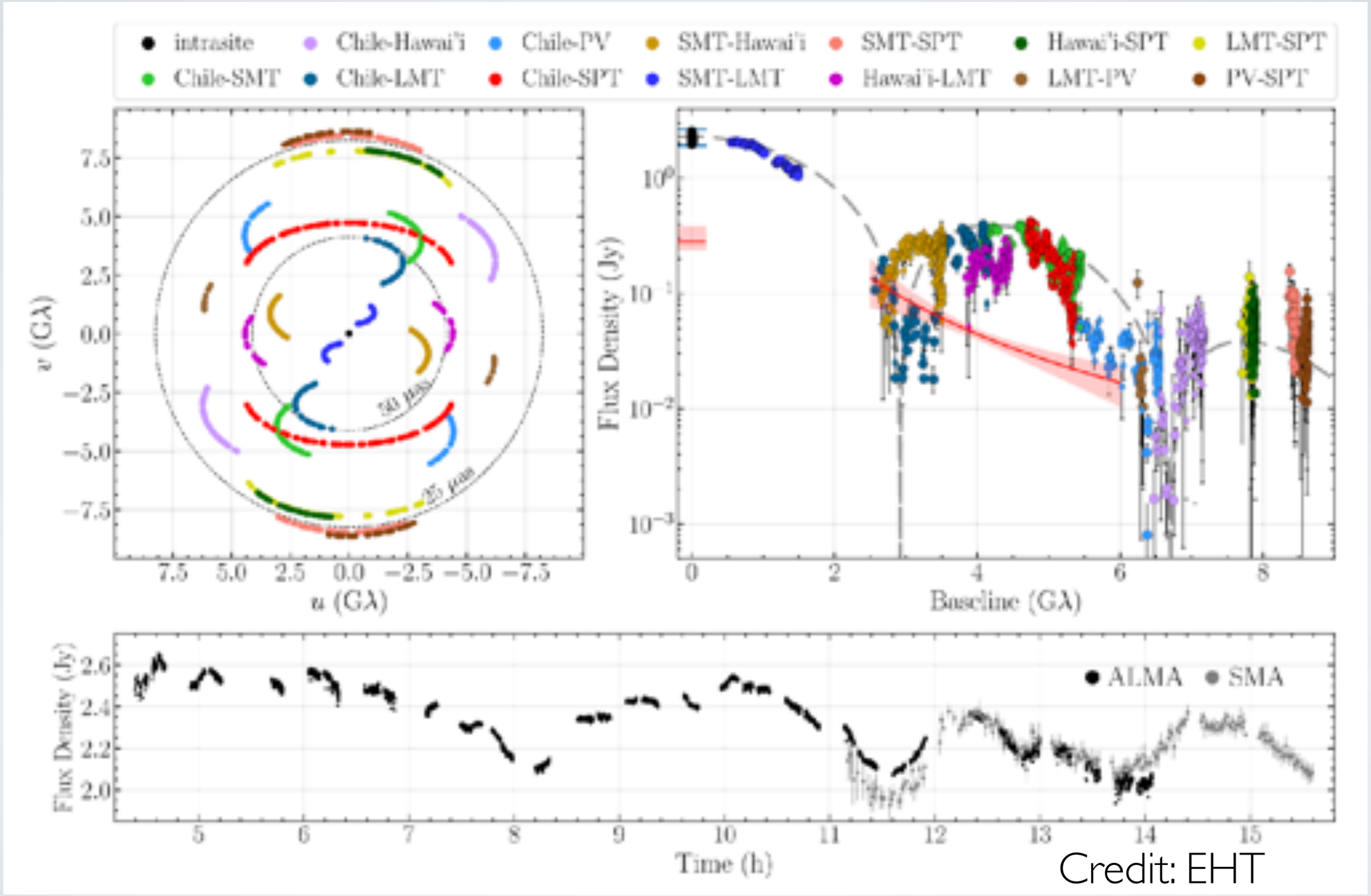


Sgr A*: Variable on shortest timescales

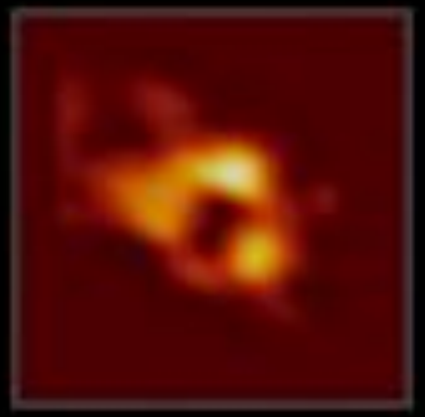


Do, Witzel et al. 2019

Sgr A* 2017

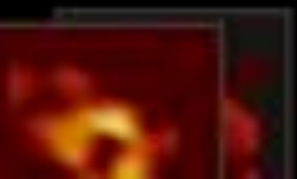


Credit: EHT

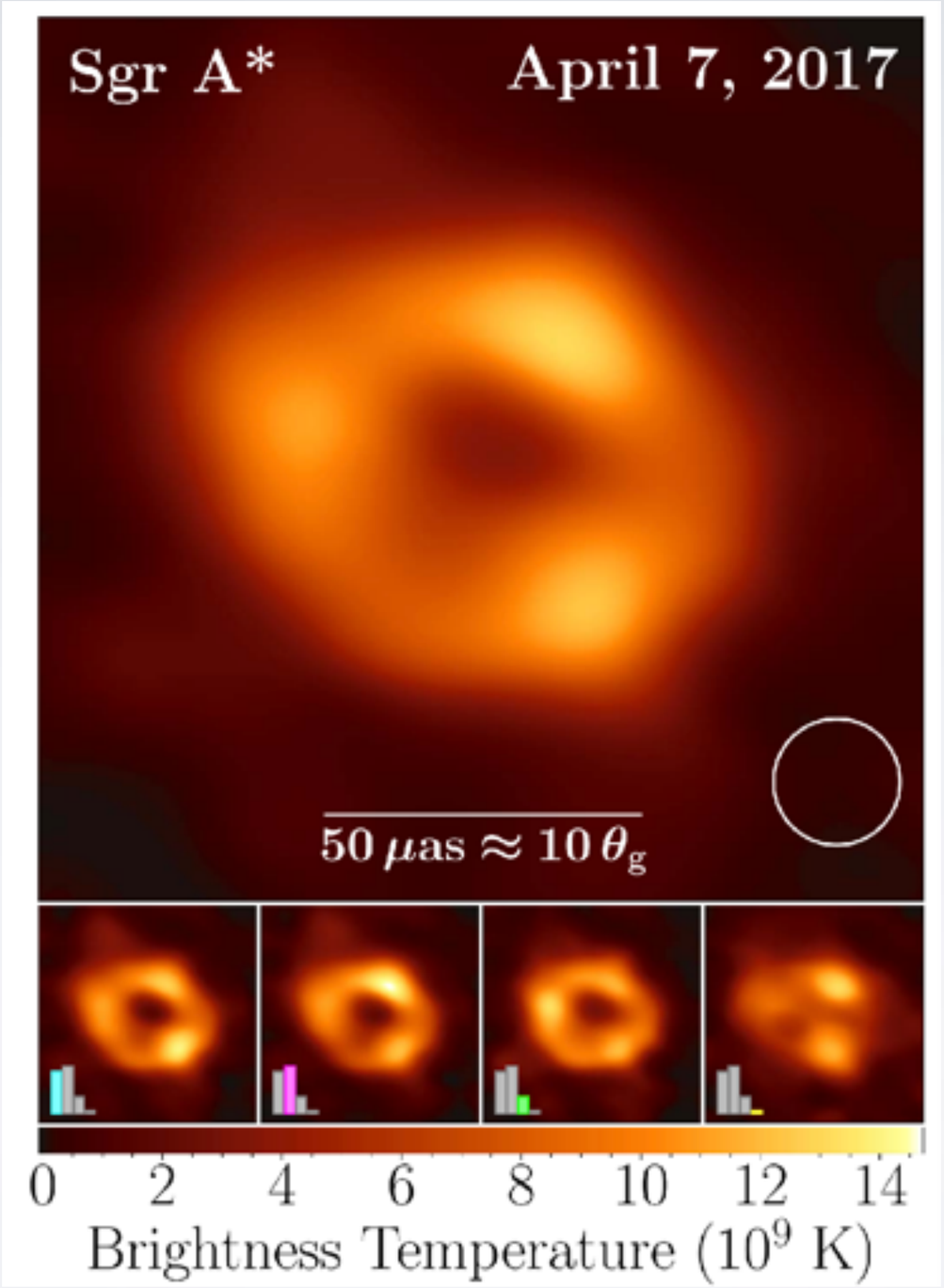


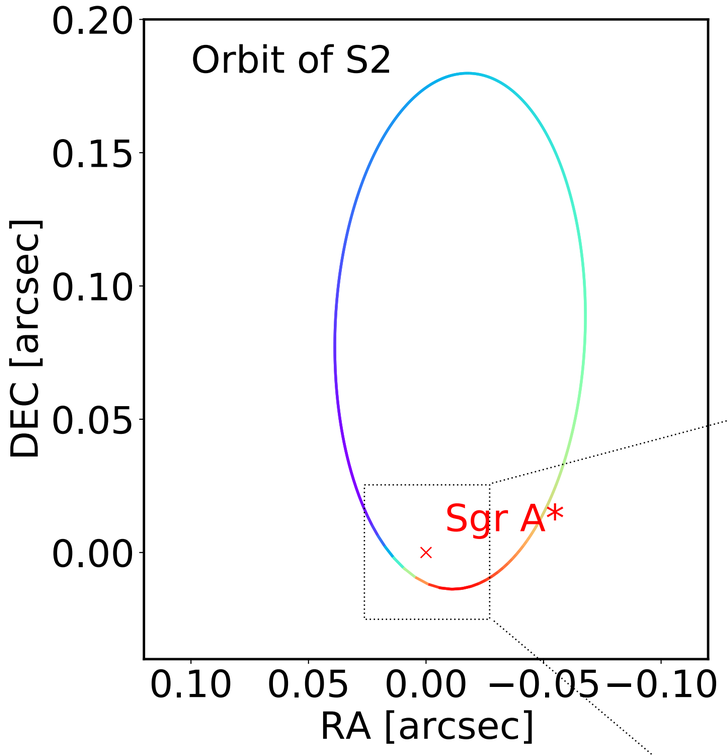






Sgr A* 2017


Sgr A*
April 7, 2017
50 μas ≈ 10 θg
0
2
4
6
8
10
12
14
Brightness Temperature (10^9 K)

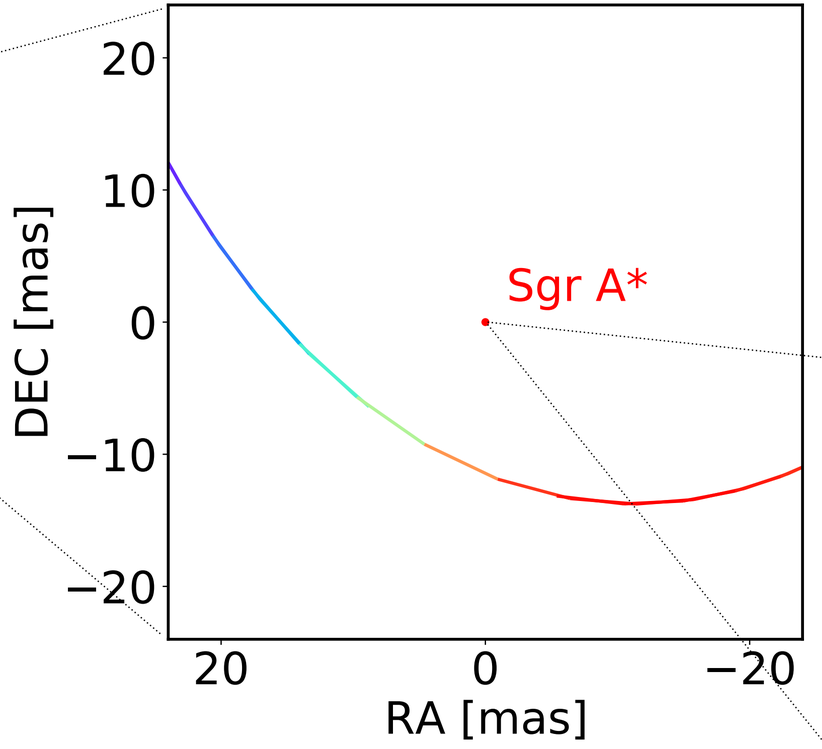


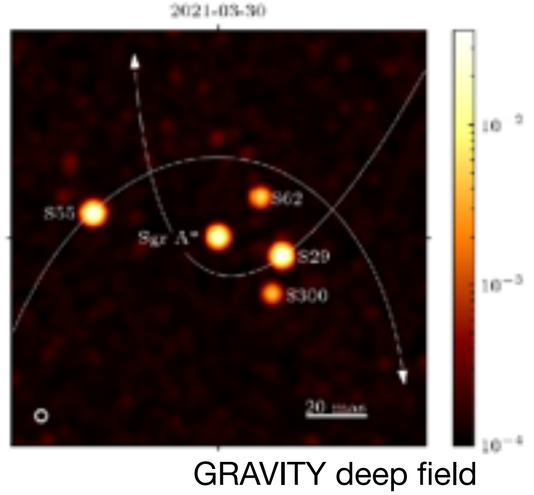
VLT/NaCo
Keck/NIRC2
50-60 mas resolution
<1mas astrometric precision

Keck/NIRC2

VLTI/GRAVITY
3 mas resolution
<65 μas astrometric precision

x5



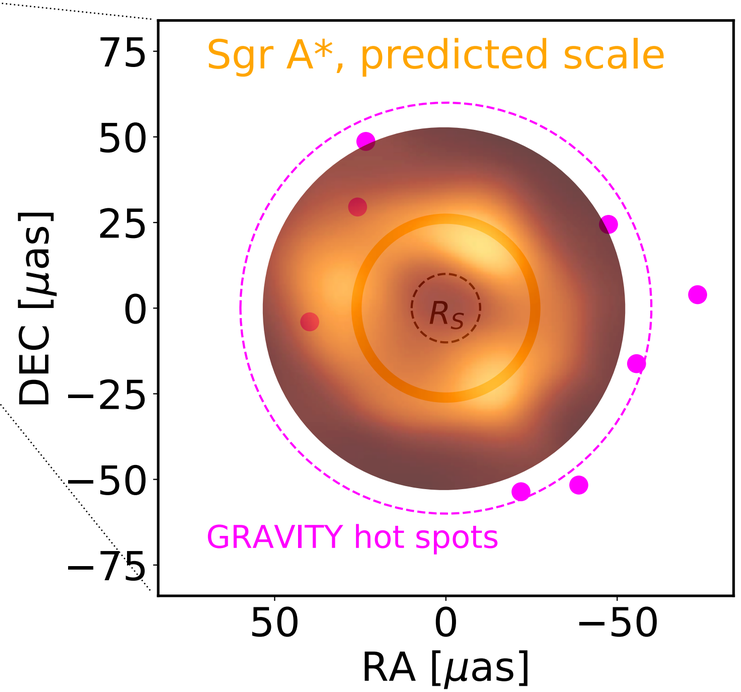


GRAVITY deep field

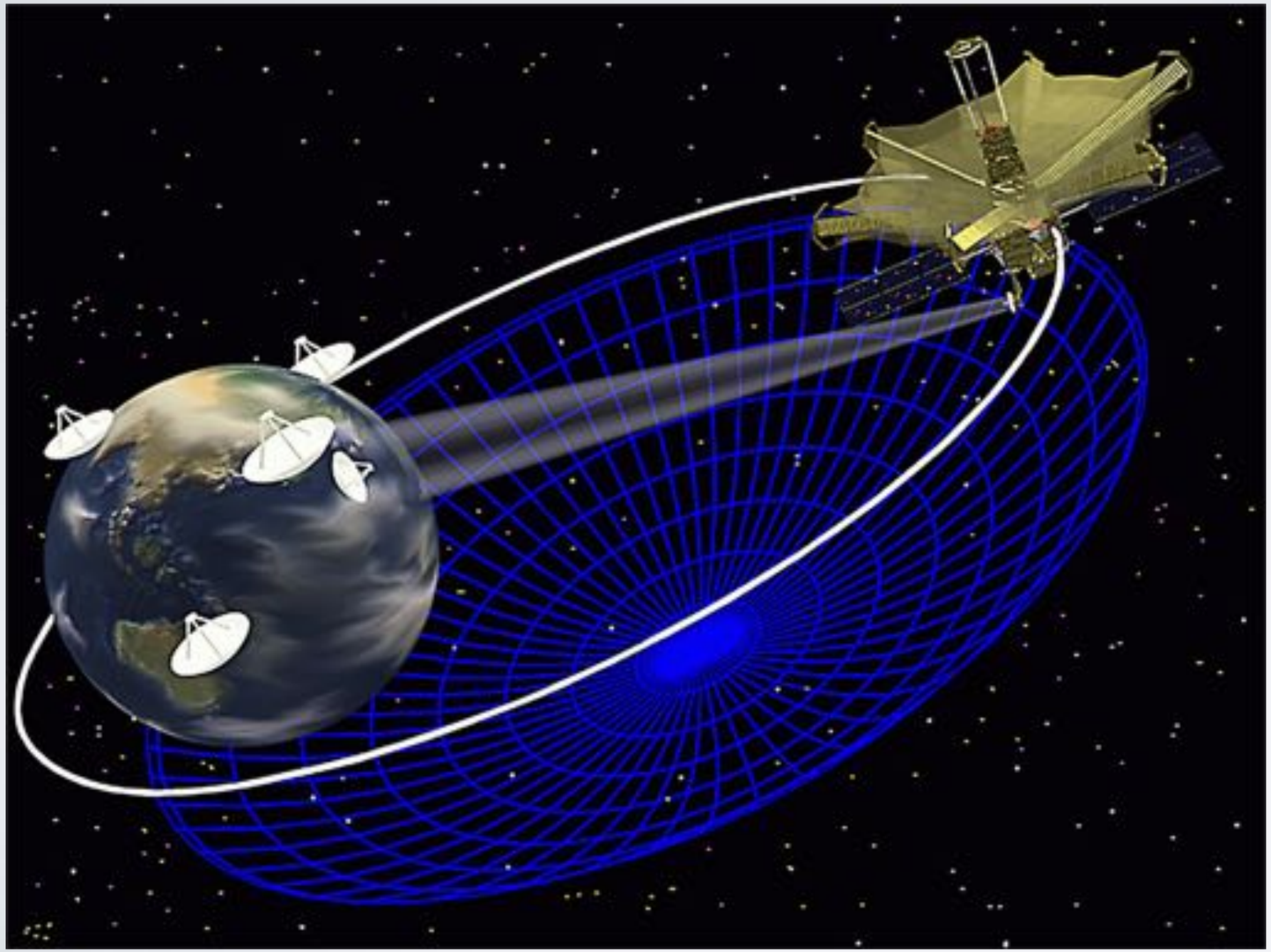
VLTI/GRAVITY

EHT
20 μas resolution

x400



The Earth is not big enough for the telescope we need to build

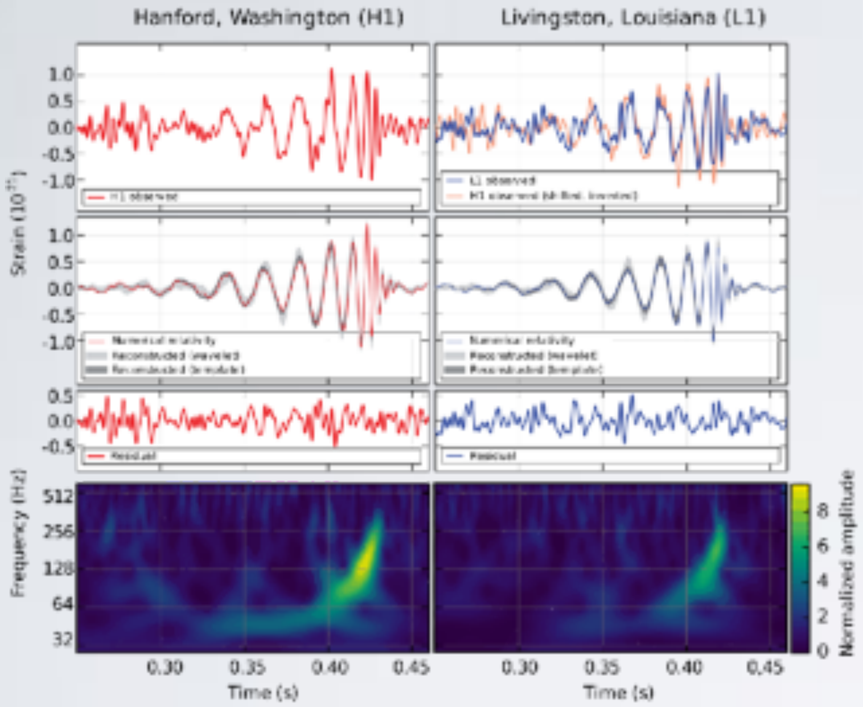


An antenna in space extends the ground network to a system of up to 350.000 km in diameter.

observing wavelength and size of the telescope are important:

resolution = wavelength / diameter

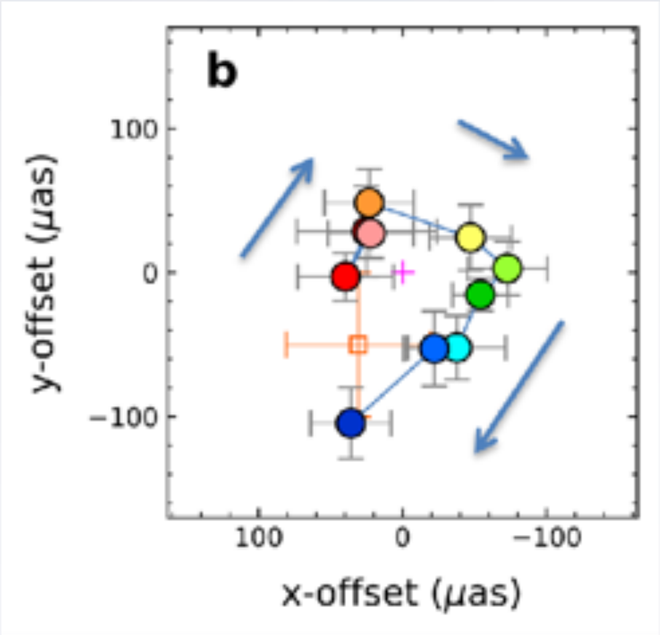
There has not been a better time for experimental black hole research



LIGO/Virgo

gravitational wave detection

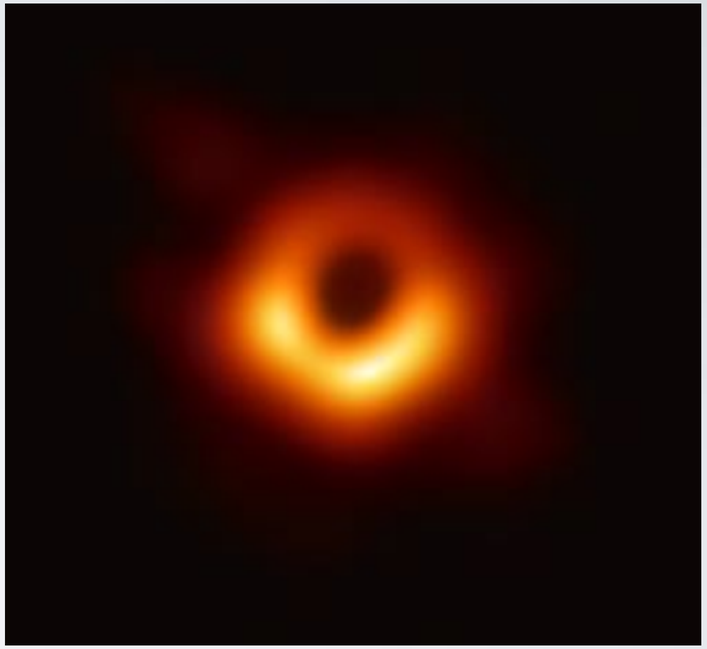
B. P. Abbott et al. 2016



GRAVITY interferometer,

Sagittarius A*

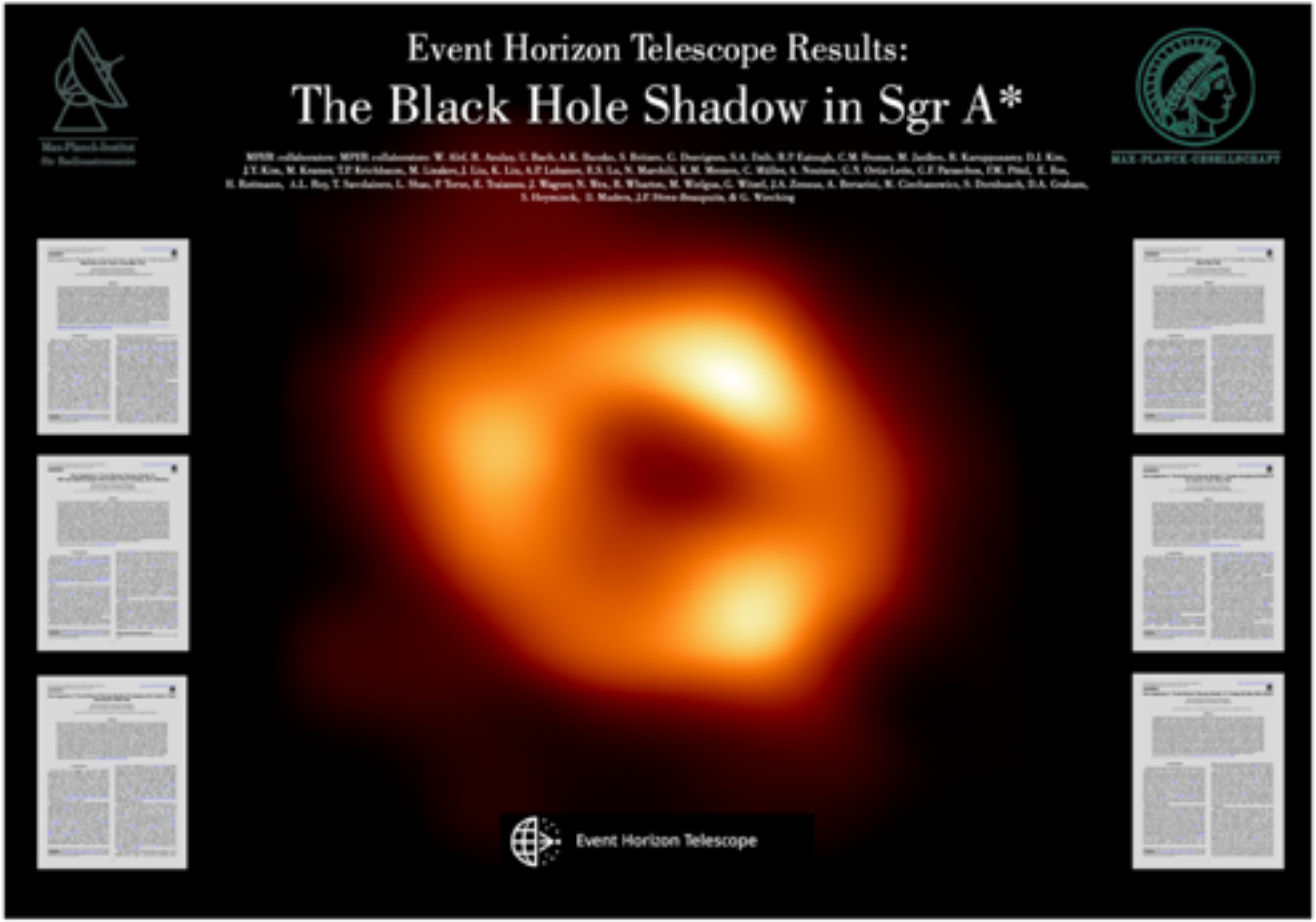
GRAVITY Collaboration 2018



Event Horizon Telescope

M87

EHT Collaboration 2019


Event Horizon Telescope Results:
The Black Hole Shadow in Sgr A*
Event Horizon Telescope

The Event Horizon Telescope: A Complex Global Collaboration

13 stake holders with over 300 members
From over 60 institutions in 20 countries & regions

working groups - management teams - task forces
science council - board

EHT Collaboration Meeting, Hilo HI, USA Dec 2019

DER SPIEGEL

Nr. 16
13. 4. 2019

Am Ende von Raum und Zeit

Was uns schwarze Löcher über die Geheimnisse des Universums verraten

HÄUSERKAMPF Wie viel Kapitalismus verträgt der Wohnungsmarkt?

EHT Cover Pages

M 87* - April 2019

Sgr A* - May 2022

Cover pages compiled by Eduardo Ros