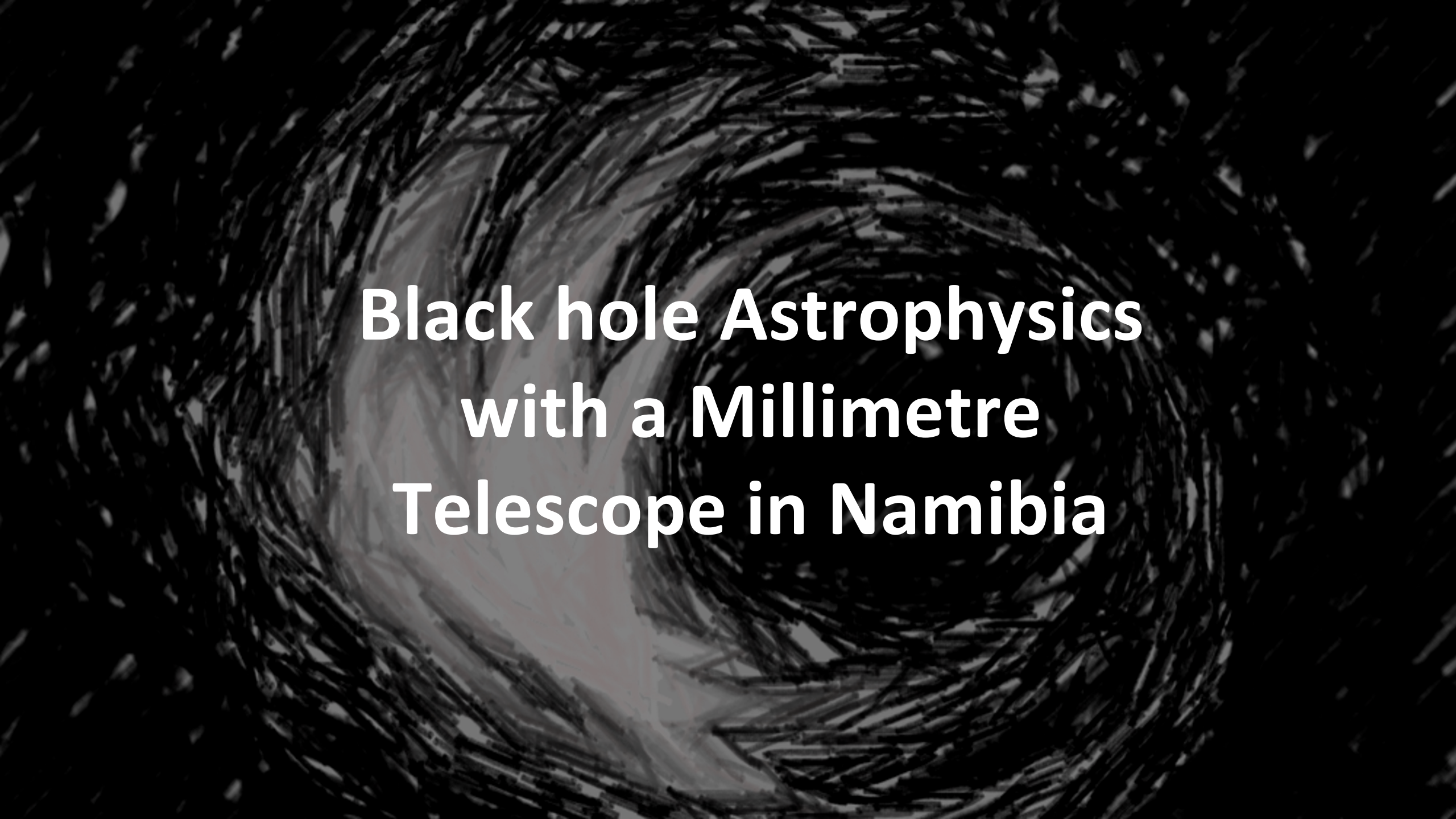
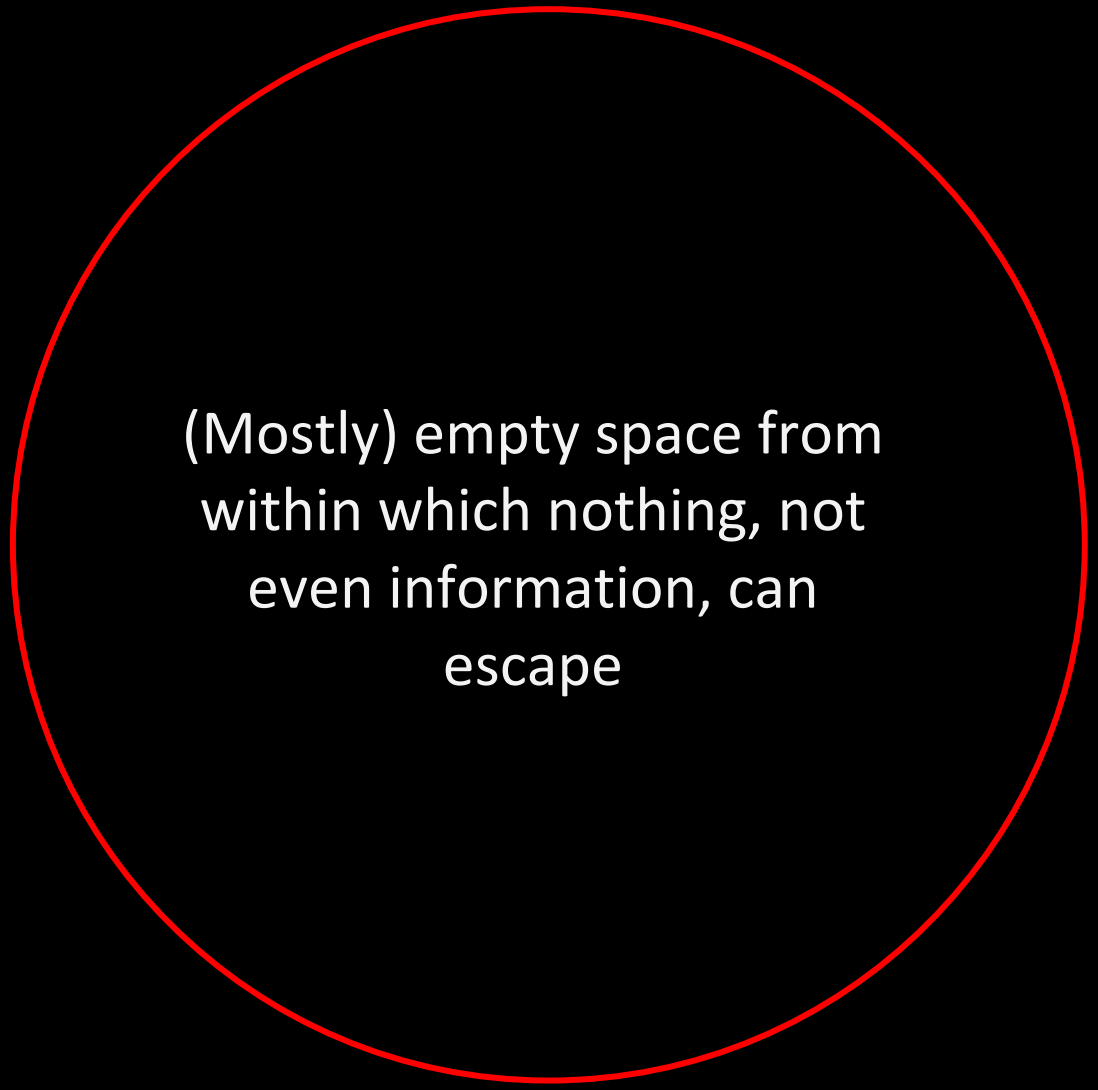

Black hole Astrophysics
with a Millimetre
Telescope in Namibia


What are black holes?

Why are black holes so different from all other objects in the the macroscopic Universe? Why are they, and they alone, so elegantly simple? If I knew the answer, it would probably tell me something very deep about the nature of physical laws. But I don’t know.

Kip Thorne, Nobel Laureate 2017

What is a black hole?

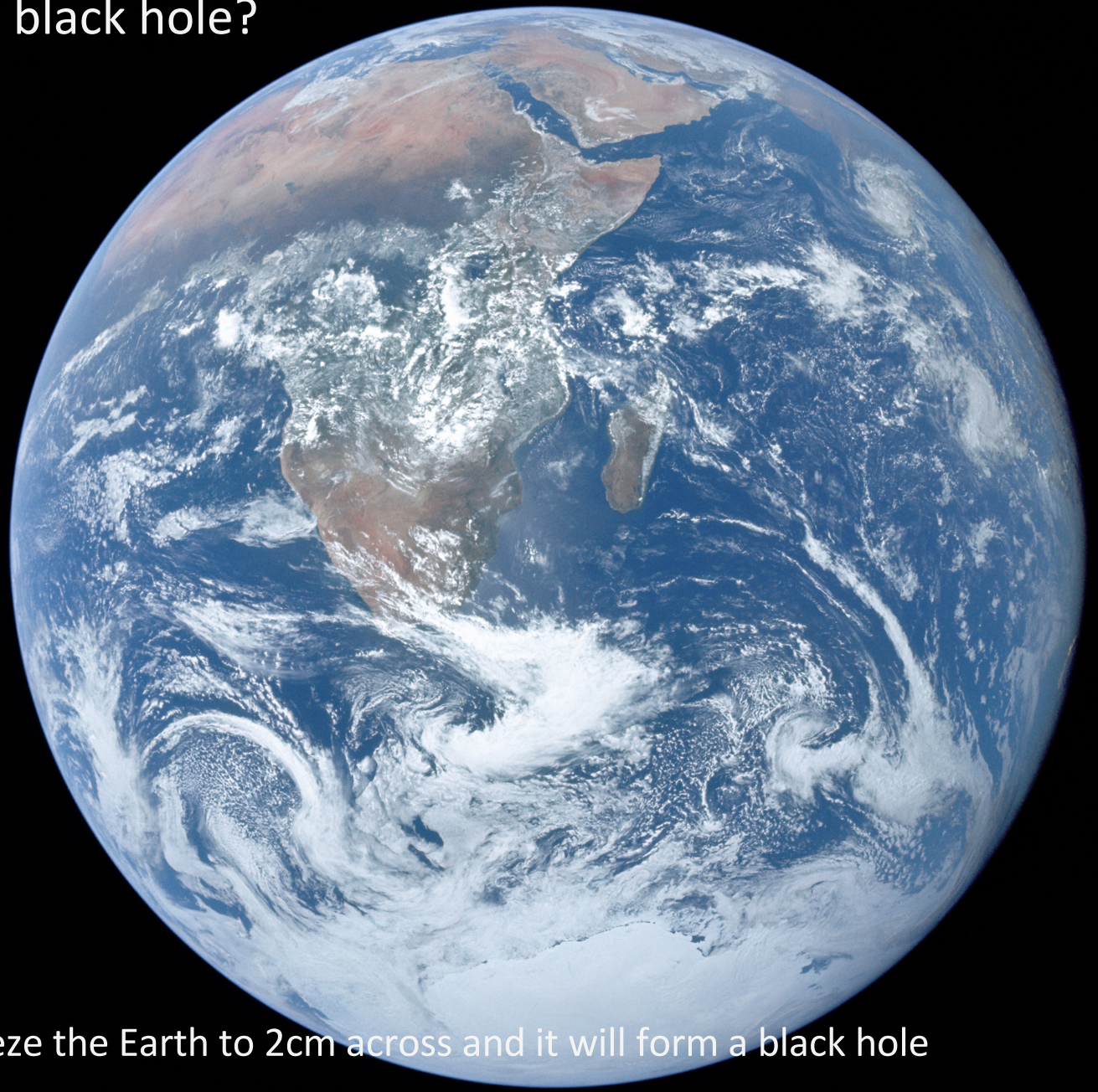


How do you make a black hole?

Take some mass and squeeze it

Beyond a certain density it will collapse and form a black hole *around it*

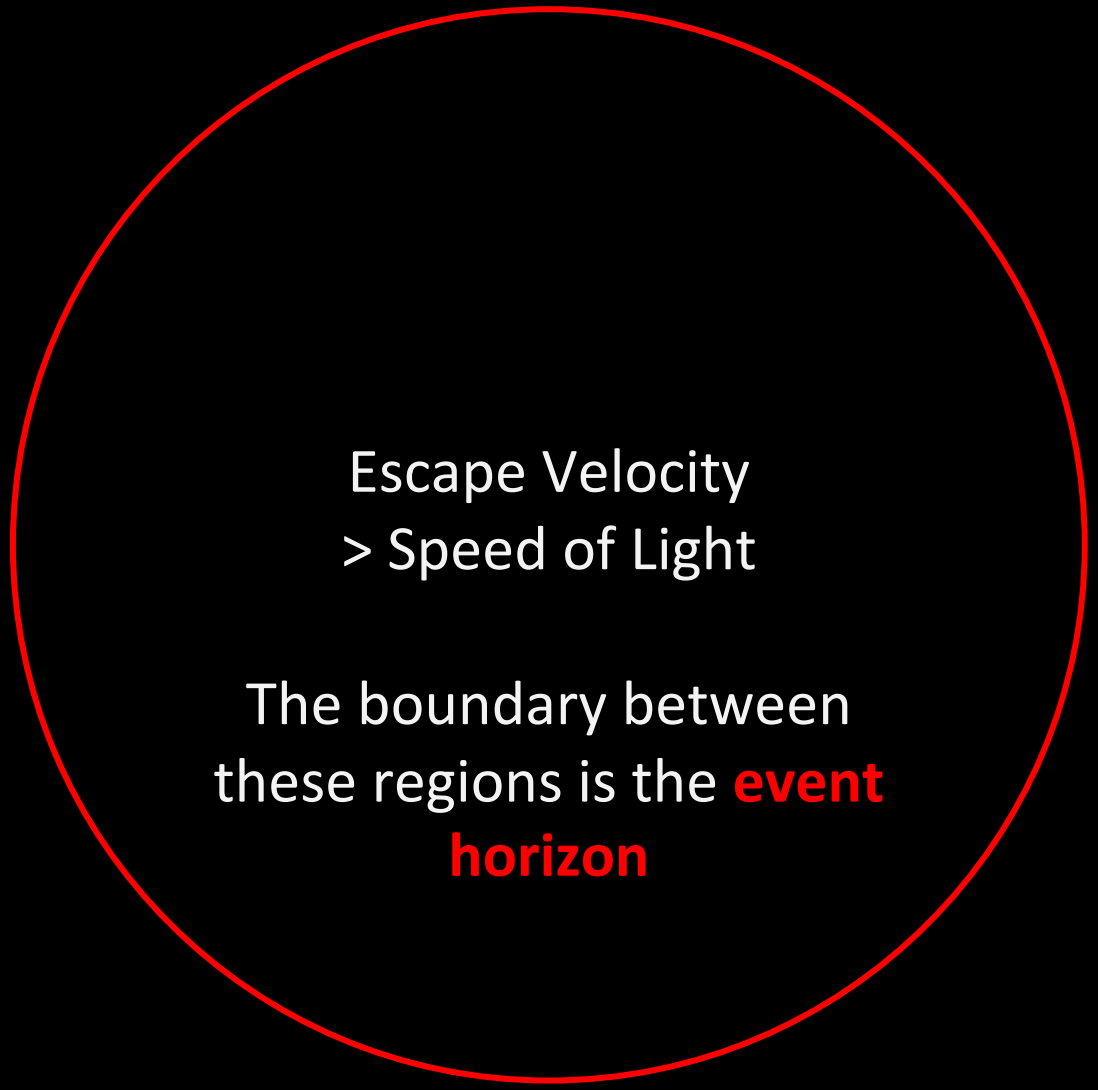
In the present-day Universe the only process which naturally produces black holes is the death of a massive star



Squeeze the Earth to 2cm across and it will form a black hole

What is a black hole?

‘Normal’ space
Escape Velocity
< Speed of Light



‘Normal’ space
Escape Velocity
< Speed of Light

What is a black hole?

All the mass is at a point called the singularity

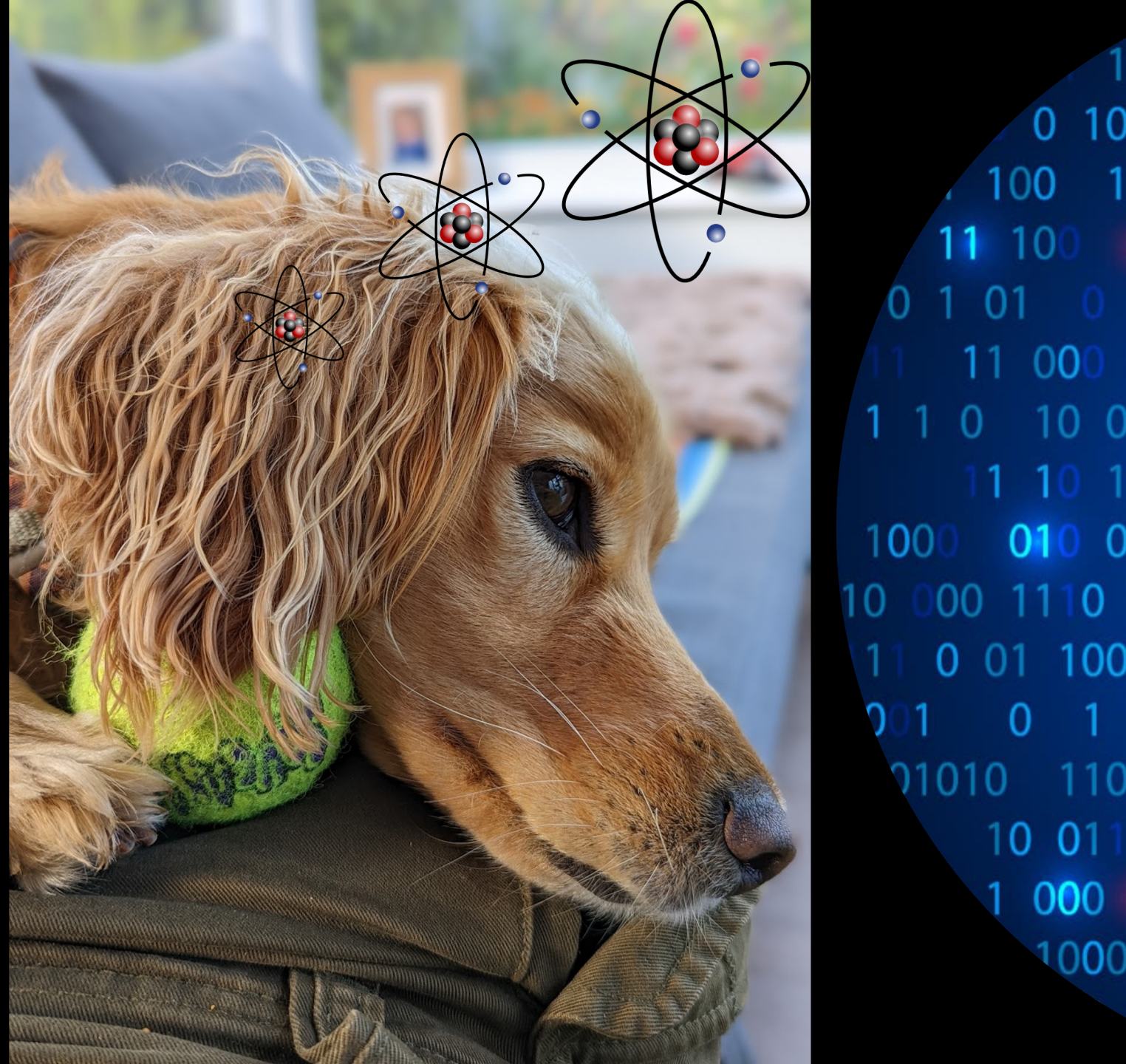
Everything which crosses the horizon ends up here

Our universe **began** in a singularity

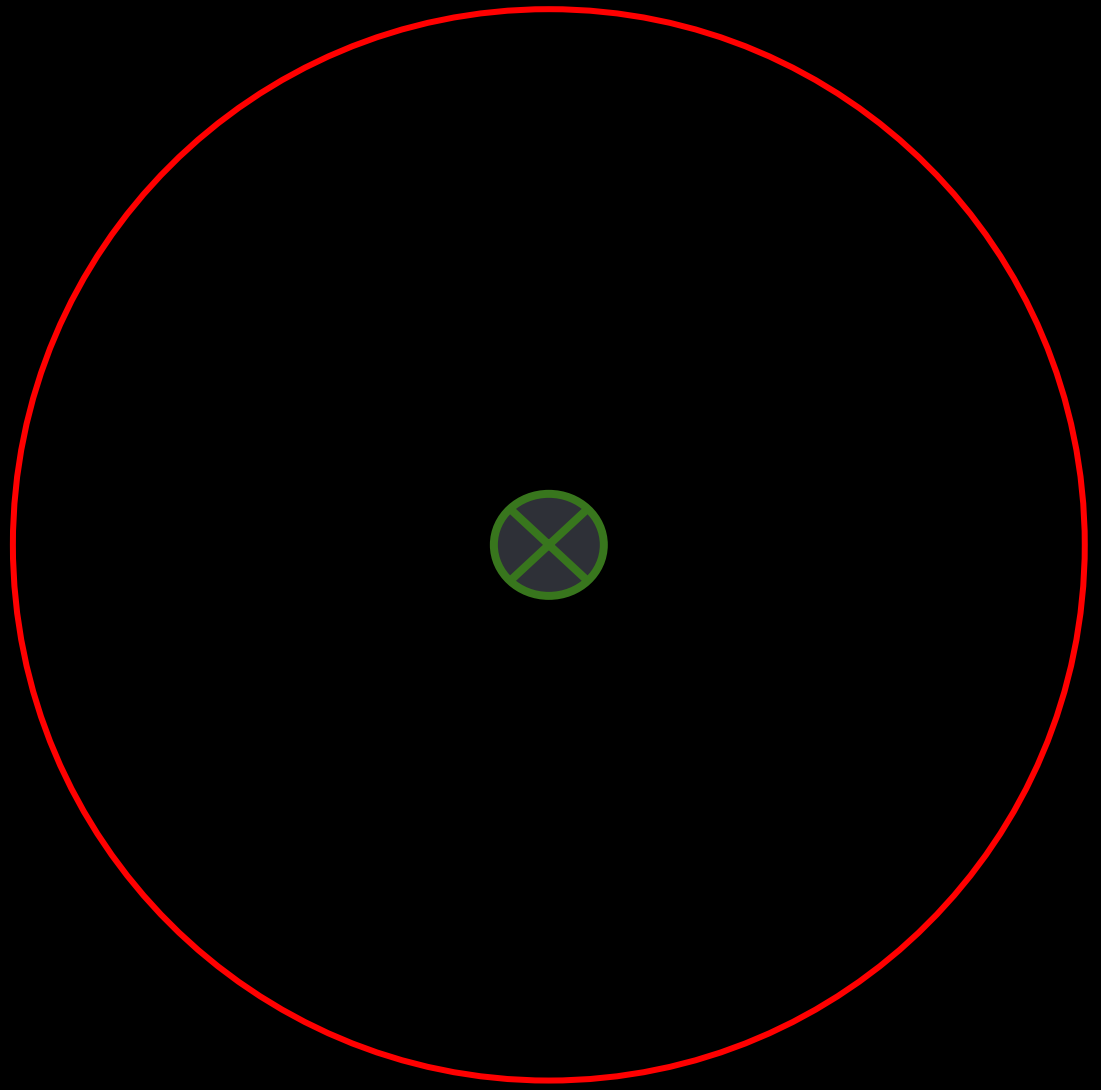
The number of pieces of information required to describe every day macroscopic objects is very large, approximately

600 000 000 000 000 000 000 000 000

pieces of information per gram of stuff



A black hole is entirely described by **three** numbers: mass, spin, charge



Cygnus X-1

Mass = 12 solar masses

Spin = 0.9

Charge = 0

The **event horizon** is the boundary of the black hole

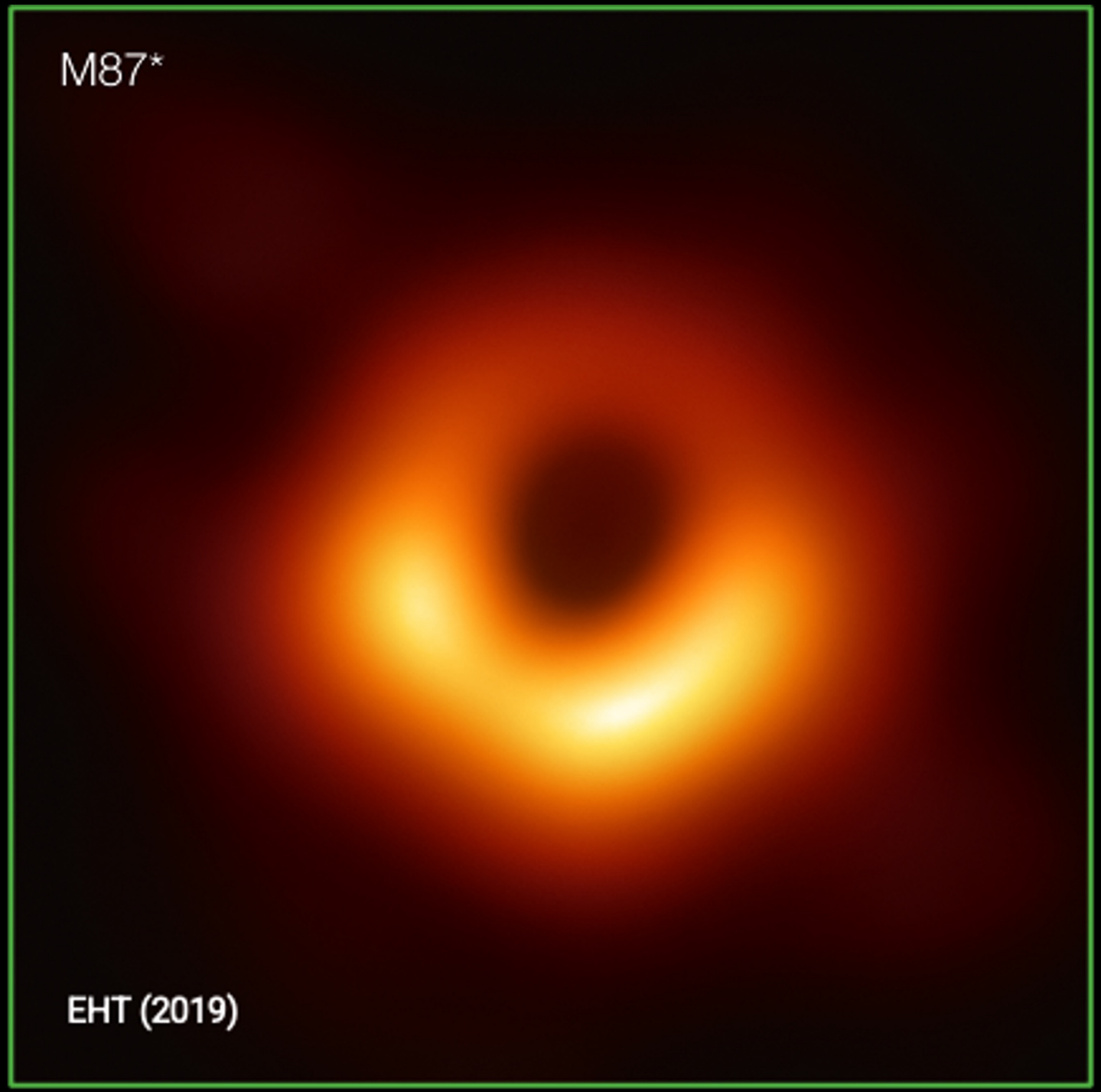
Here information seems to be lost

The **singularity** is where all the mass is

Forces go to infinity as distances go to zero

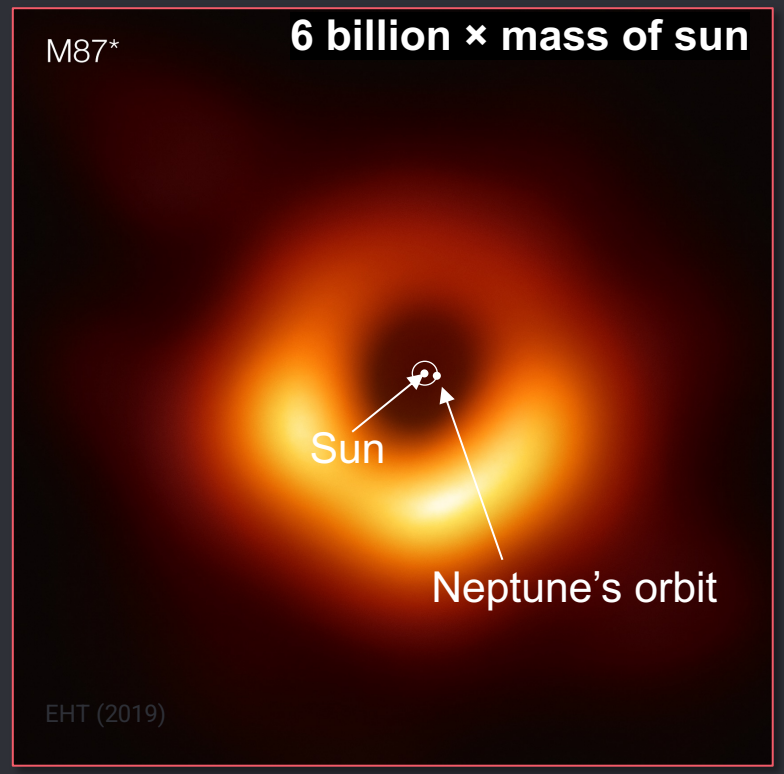
New Physics is required!

They are real



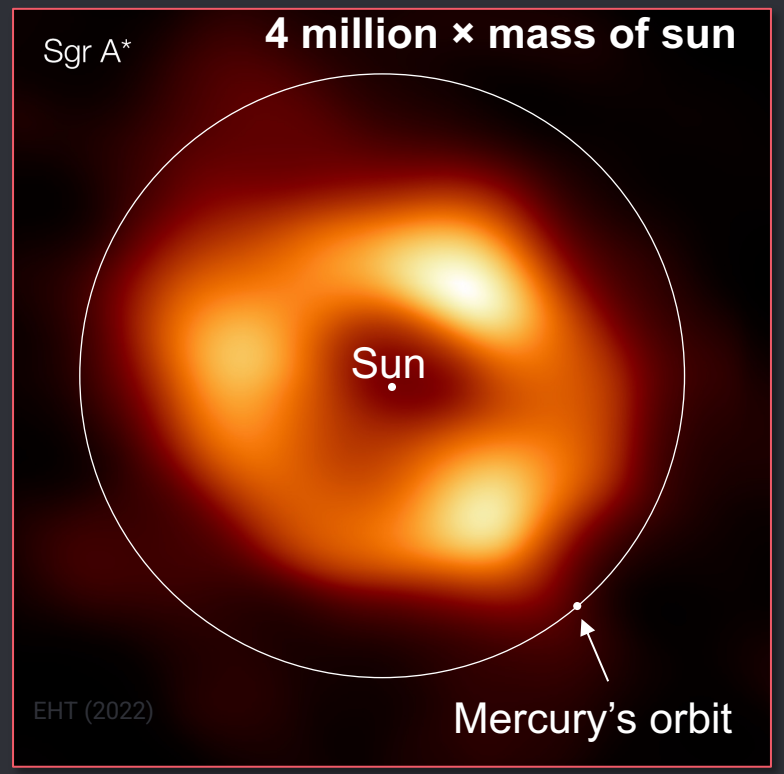
Black holes **also** produce relativistic jets that move **away** from them

Giant galaxy (M87*)



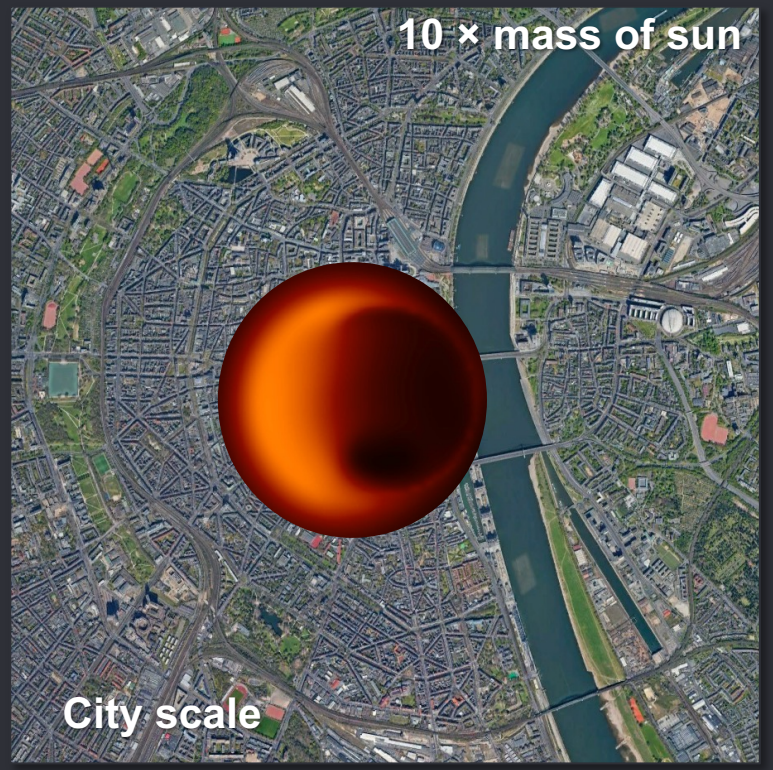
EHT (2019)

Our Milky Way (Sgr A*)



EHT (2022)

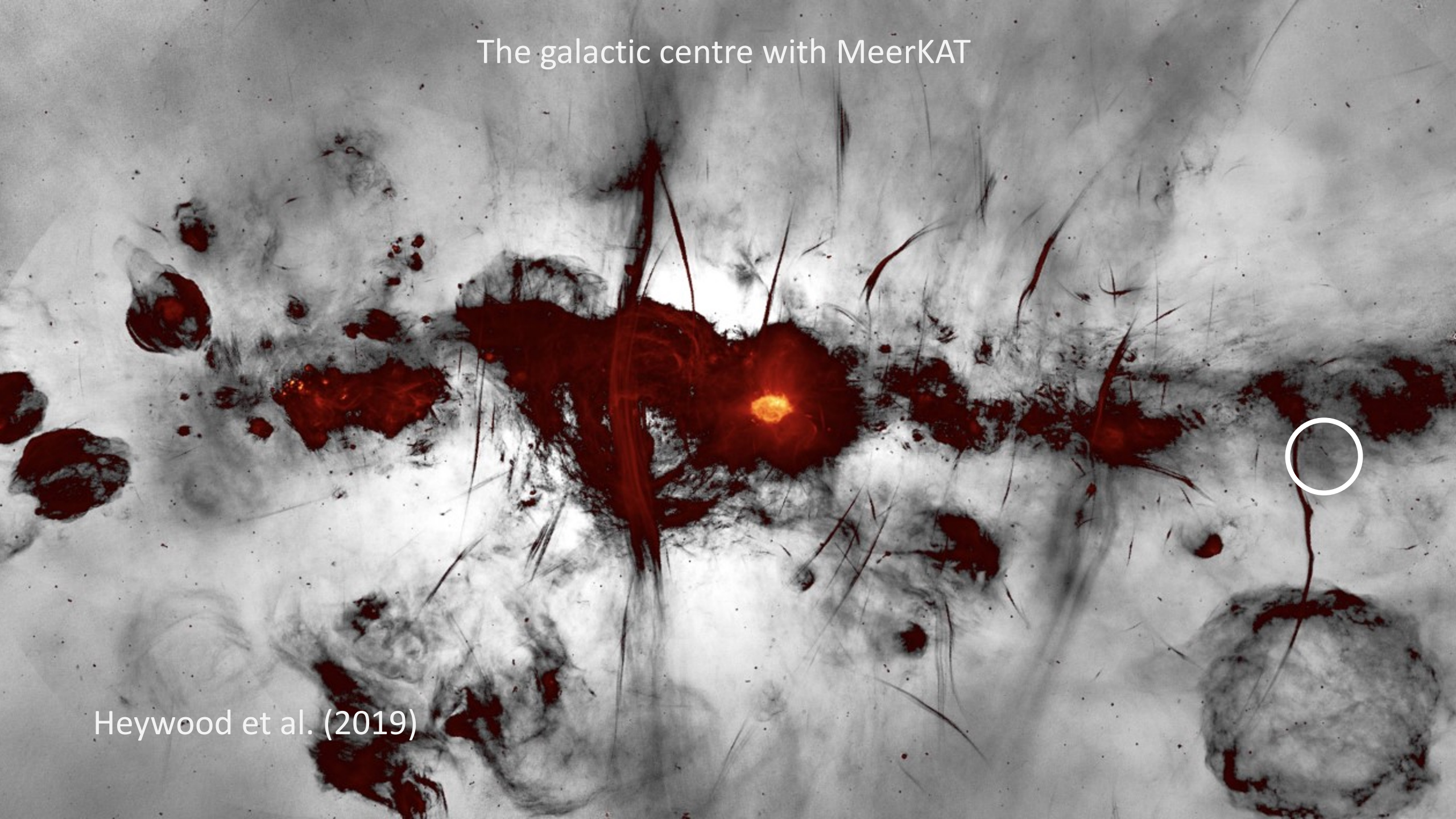
‘Stellar mass’ black hole



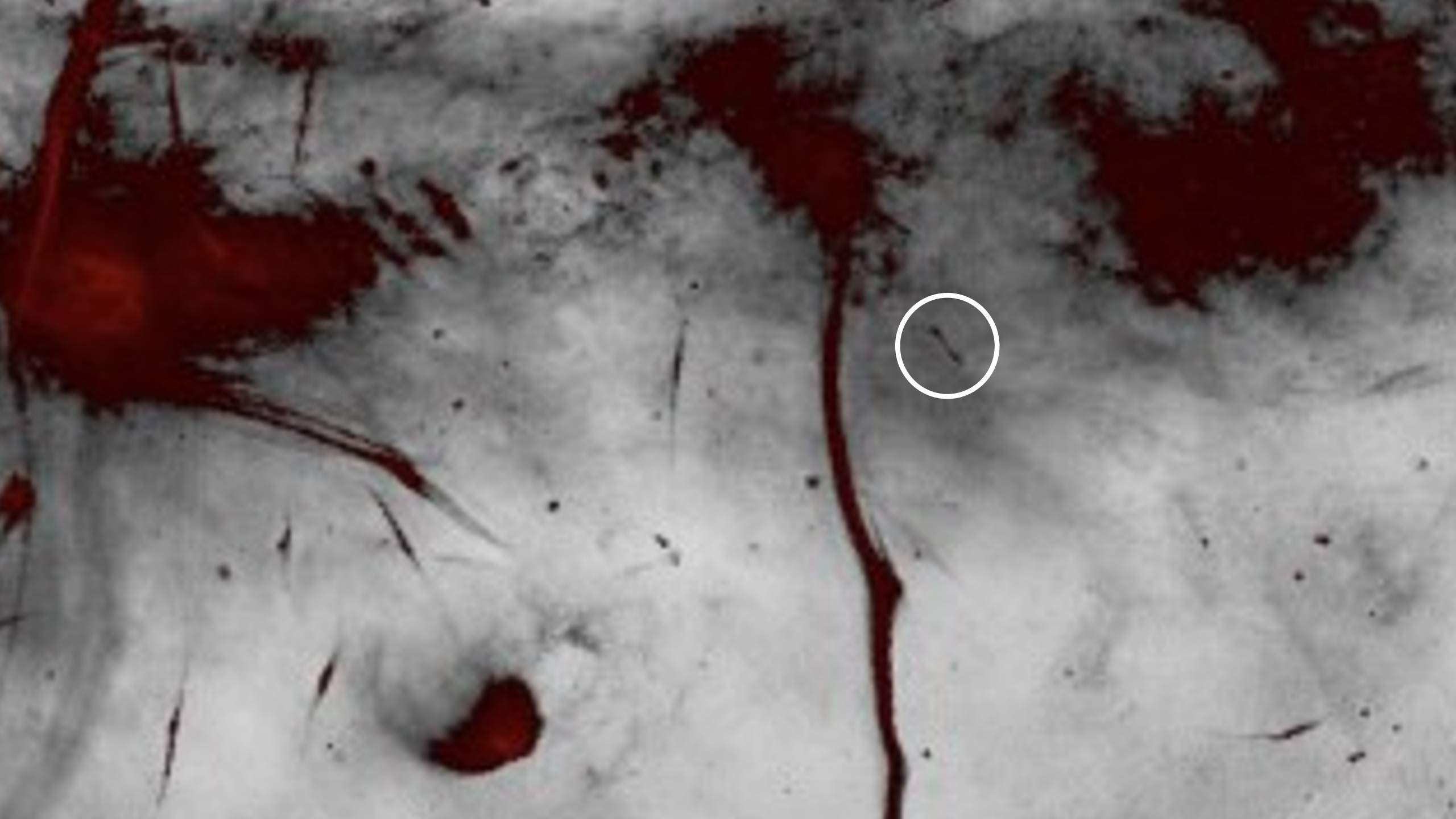
Mankind (2200)?

Stellar-mass black holes with MeerKAT

The galactic centre with MeerKAT



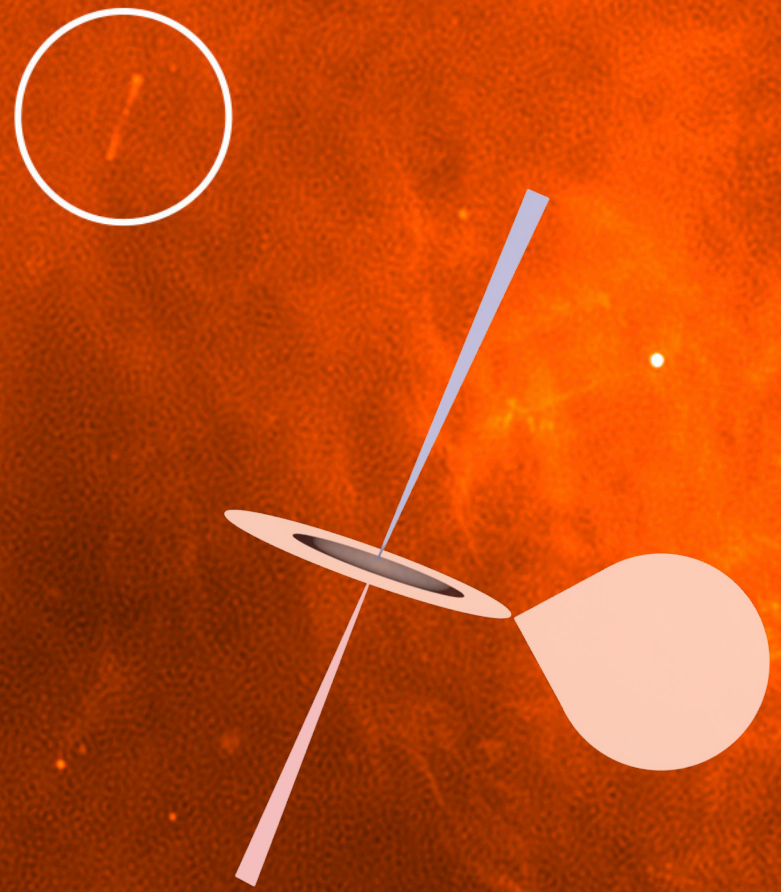
Heywood et al. (2019)



This object is a ~10 $M_{\odot}$ ‘stellar mass’ black hole, one of ~10^8 in our galaxy

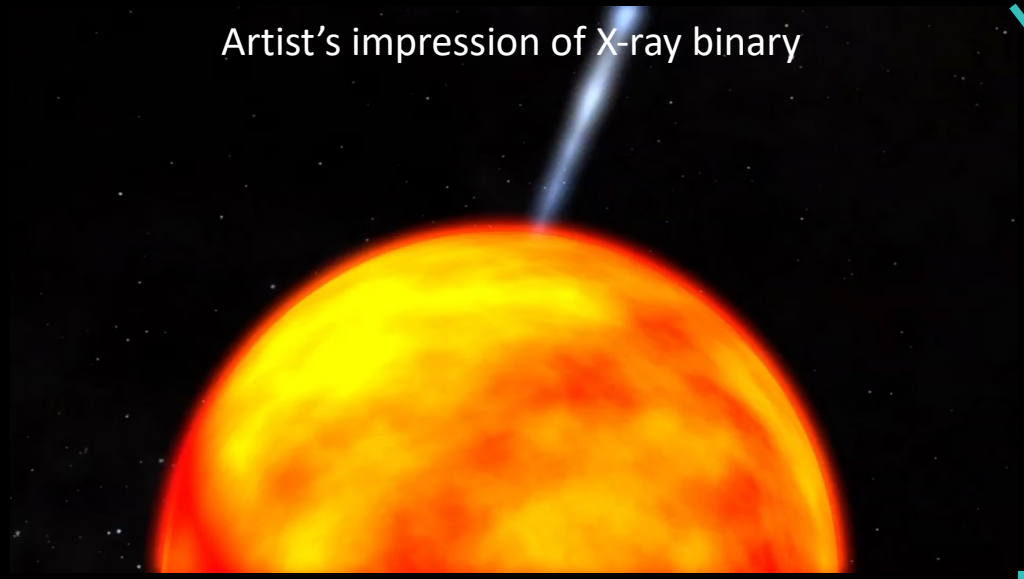
One in 100,000 are in close binaries with orbital periods as short as hours to days leading to mass transfer and ultimately accretion on the black hole

These are the ‘**X-ray binaries**’



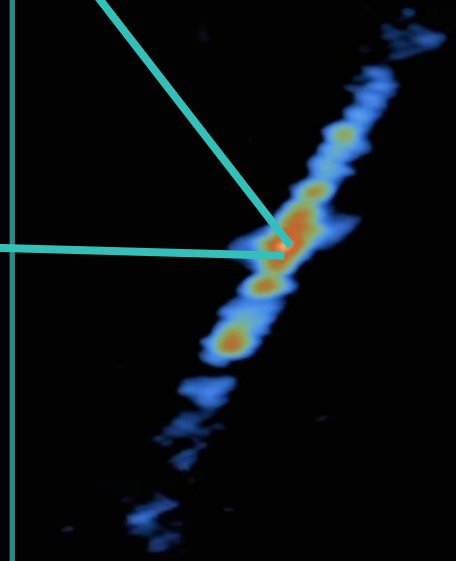
Radio variability from a black hole means relativistic jets are being formed

Artist's impression of X-ray binary



No images but horizon-scale X-ray flickering

Radio Imaging



Stellar mass black hole (dynamic)

Supermassive mass black hole (static)

The **ThunderKAT** project 2018-2023 studied these X-ray binaries to follow occurences of jet formation by black holes (and neutron stars) within our galaxy systematically over a five year period.

Led by Fender (Oxford) and Woudt (Cape Town)

Project continues as **'X-KAT'** (led by Fender)

ThunderKAT meeting 2022

Cape Town

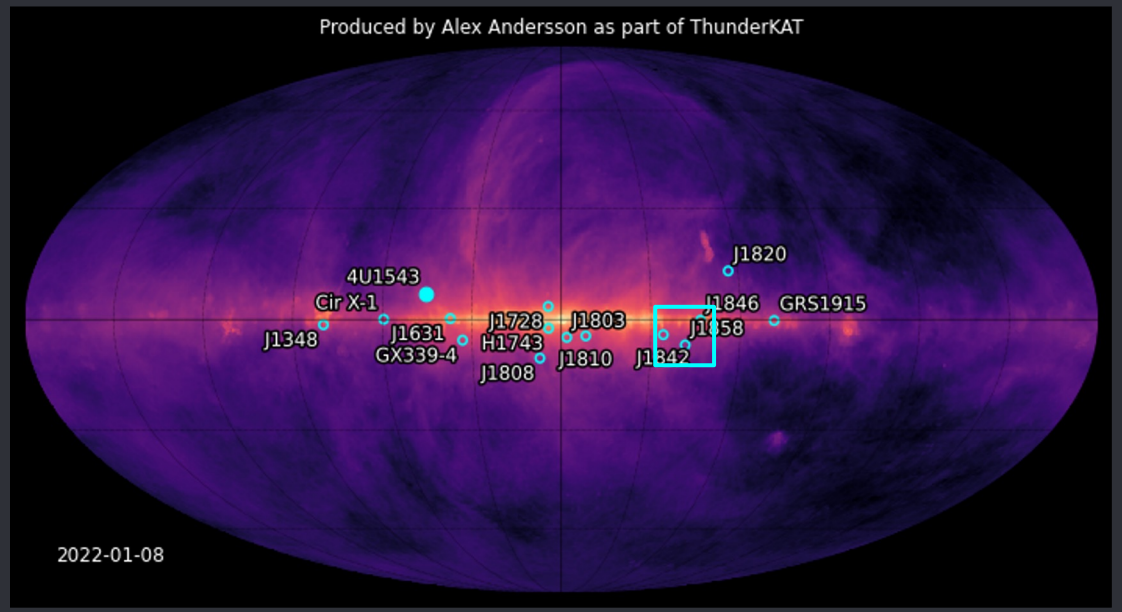
The dynamic radio sky: Five years of radio monitoring X-ray binaries with MeerKAT

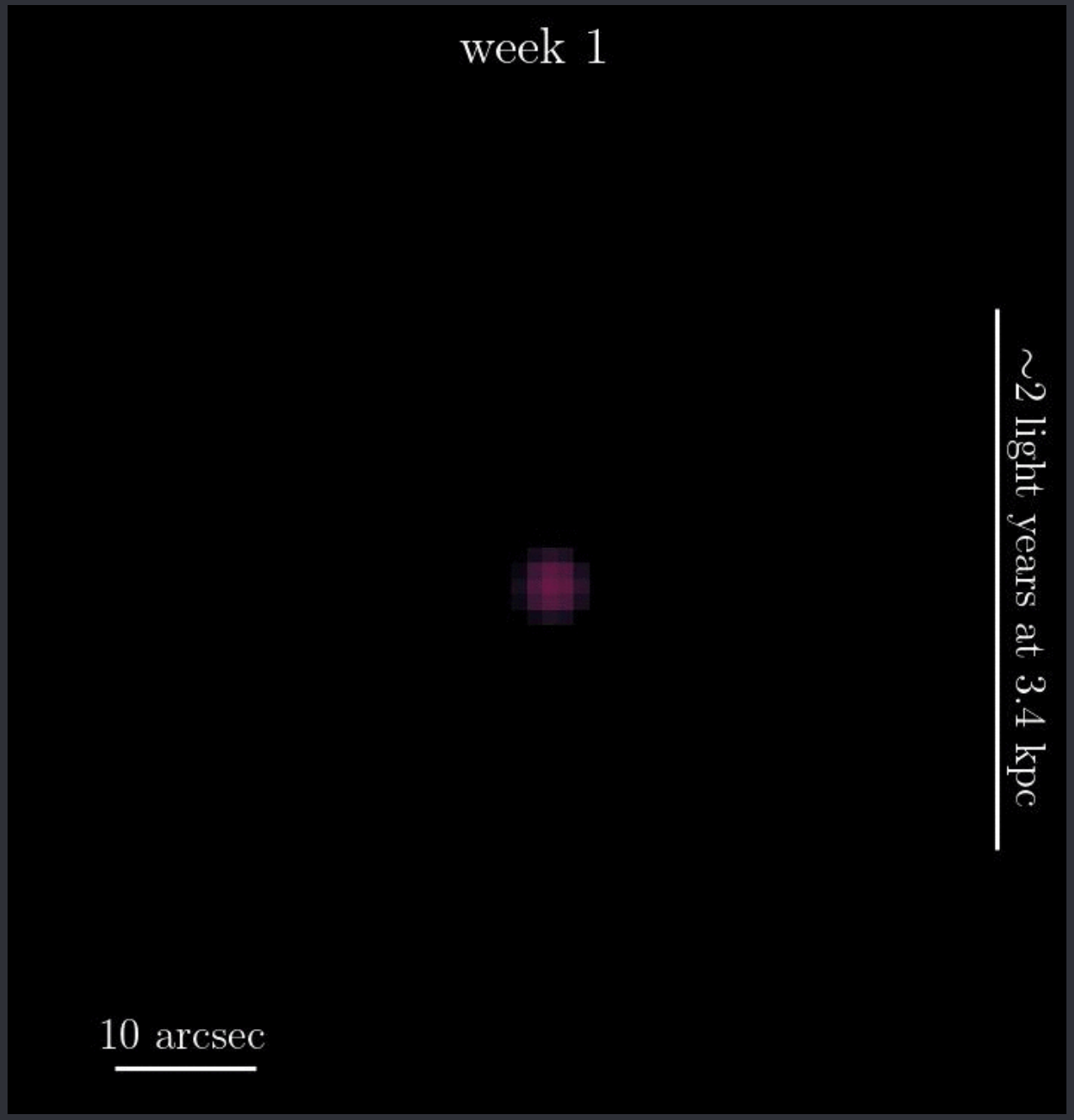
Part of the ThunderKAT project (PIs Rob Fender [Oxford]) and Patrick Woudt [Cape Town])

Movie credits Alex Andersson and Fraser Cowie, Oxford

JETS IN A GLOBULAR CLUSTER: MAXI J1848 (WEEKLY TRACKING FOR OVER 2 YEARS)

BAHRAMIAN ET AL. (2023)

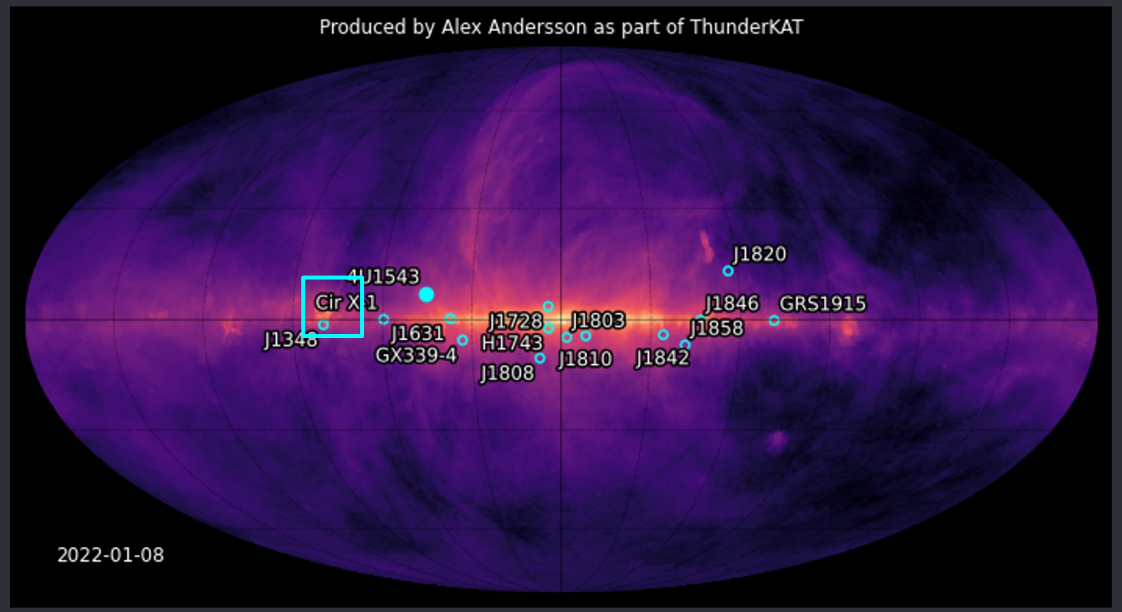


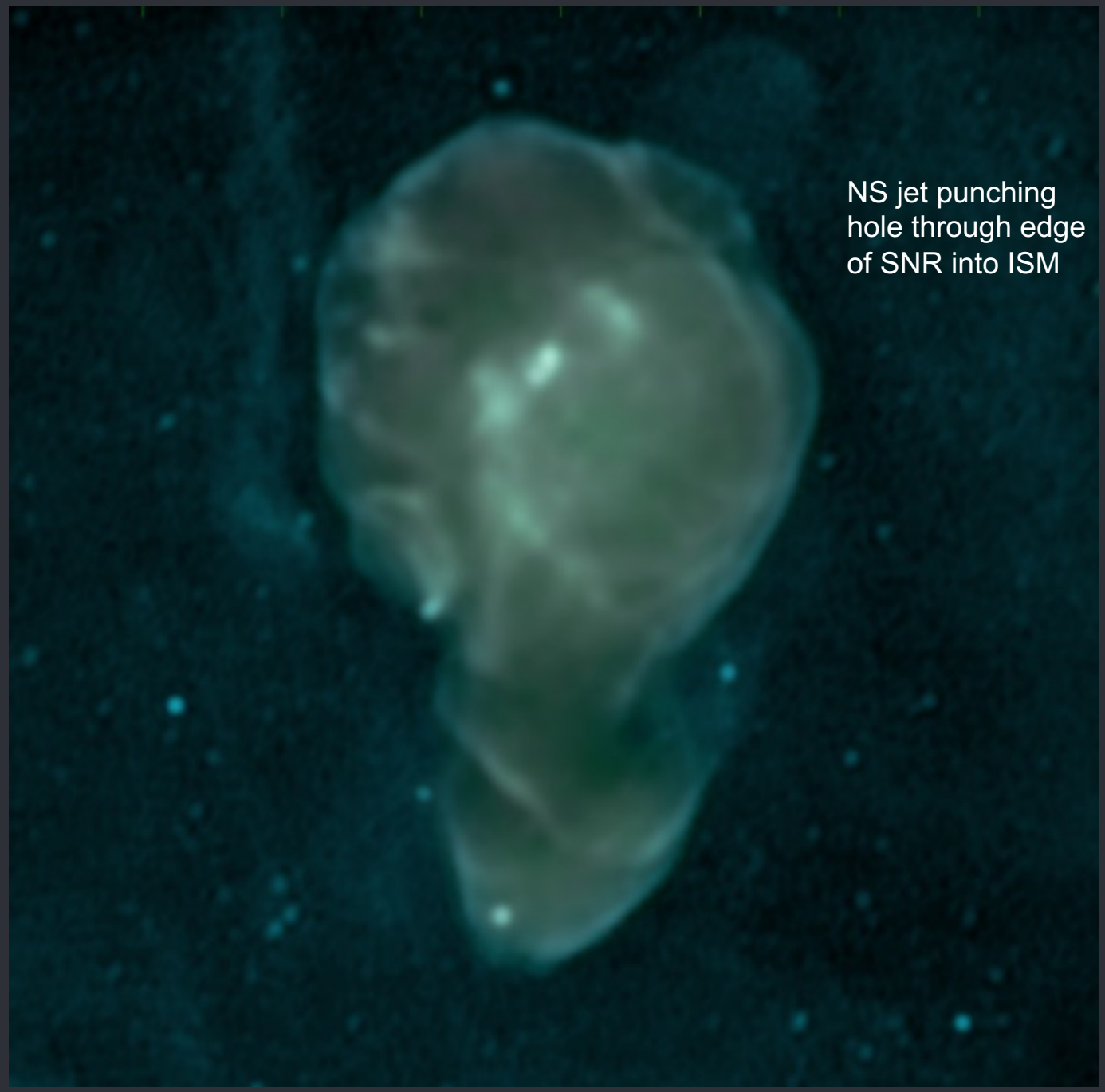


JET-POWERED NEBULA AROUND **NEUTRON STAR** CIR X-1

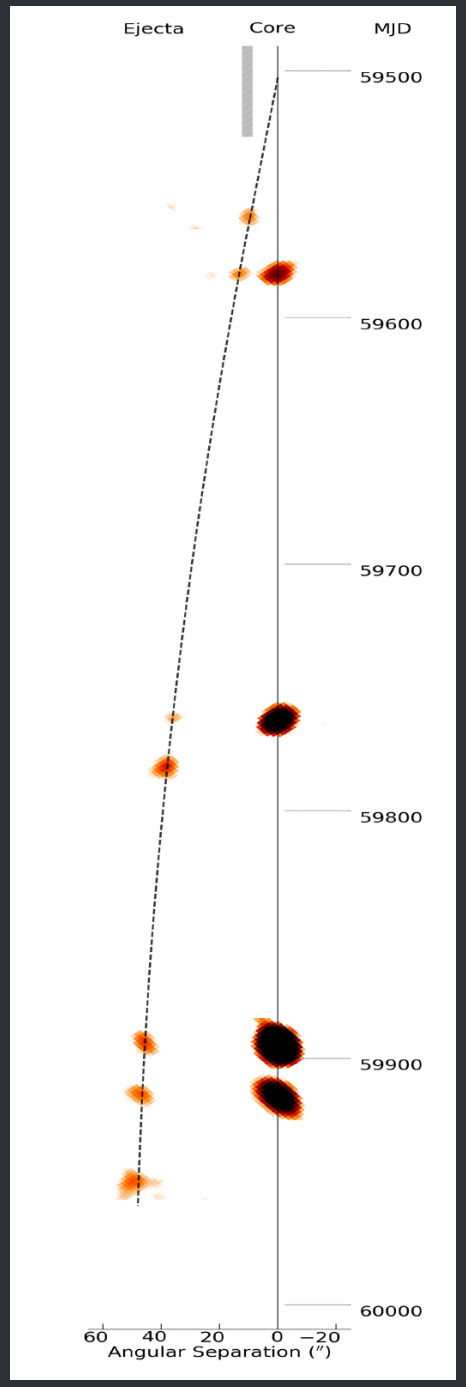
A SOUTHERN SS433

GASEALAHWE ET AL. (IN PREP)





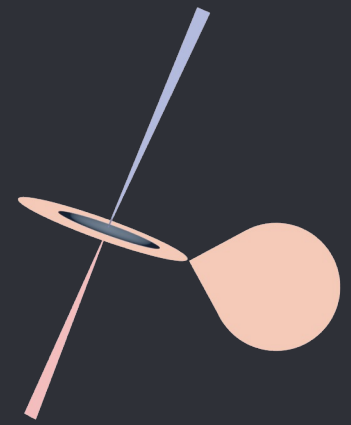
NS jet punching hole through edge of SNR into ISM



4U 1543 -47: The fastest thing ever seen in our galaxy!

The jets from this stellar mass black hole are moving so fast they appear to move five times faster than the speed of light on the sky!

The energy contained in the ejections is enormous: in less than an hour the black hole produces an event with as much energy as 10,000 years of the total power output of the Sun



Zhang et al. (in prep)

The Africa Millimetre Telescope in Namibia

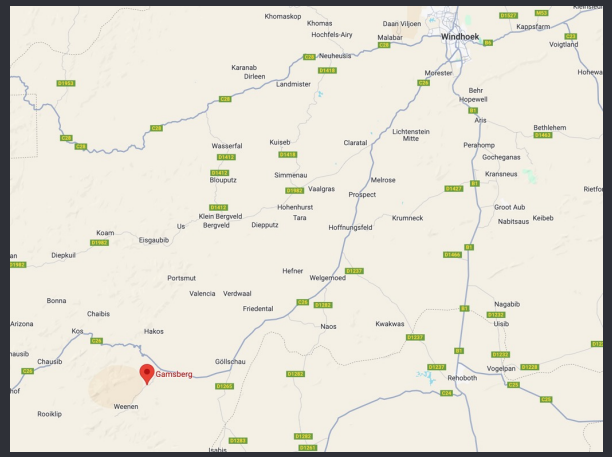
AFRICA MILLIMETRE TELESCOPE

In 2021, The Universities of Oxford and Amsterdam joined the project.

In 2022 principal investigators Falcke (Radboud), Markoff (Amsterdam) and Fender (Oxford) were awarded ~14MEuro by the European Research Councial to complete the AMT project and produce a new, ground-breaking approach to understanding black holes and jet formation.

For nearly a decade, The University of Namibia and Radboud University have been working towards the establishment of a new millimetre telescope in Namibia.

This telescope was primarly conceived to provide important additional coverage for the Event Horizon Telescope.



Visit to Gamsberg (and H.E.S.S.)
Feb 26, 2024

L to R: Zandré Duvenhage, Delight Namene, Michael Backes, me

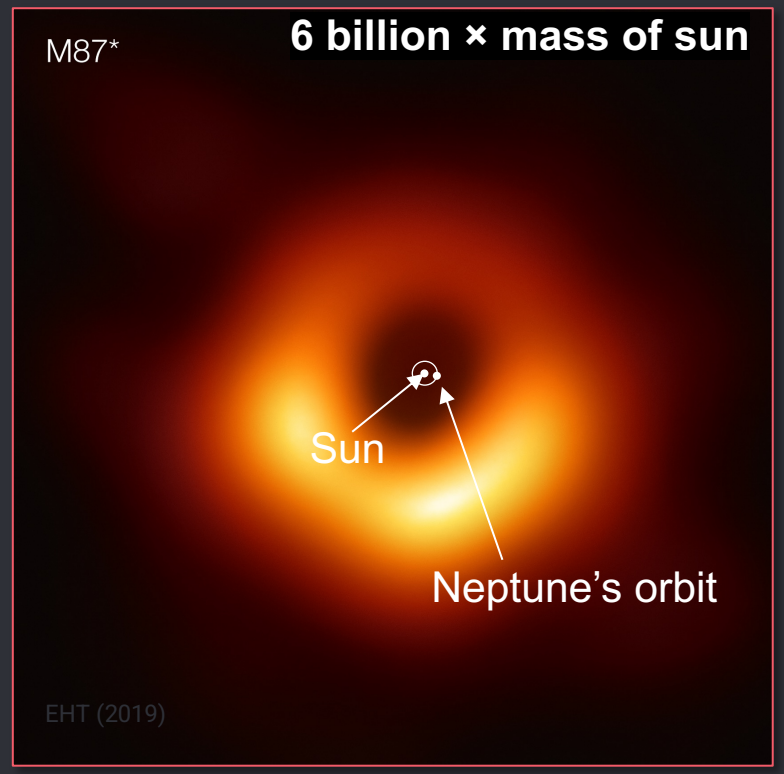
The Earth as viewed from Sgr A*, the black hole at the centre of our galaxy.

The AMT ‘fills in’ gaps in our coverage.

AMT will be a 15-m dish operating at frequencies up to 350 GHz

We want to see a black hole rotating!

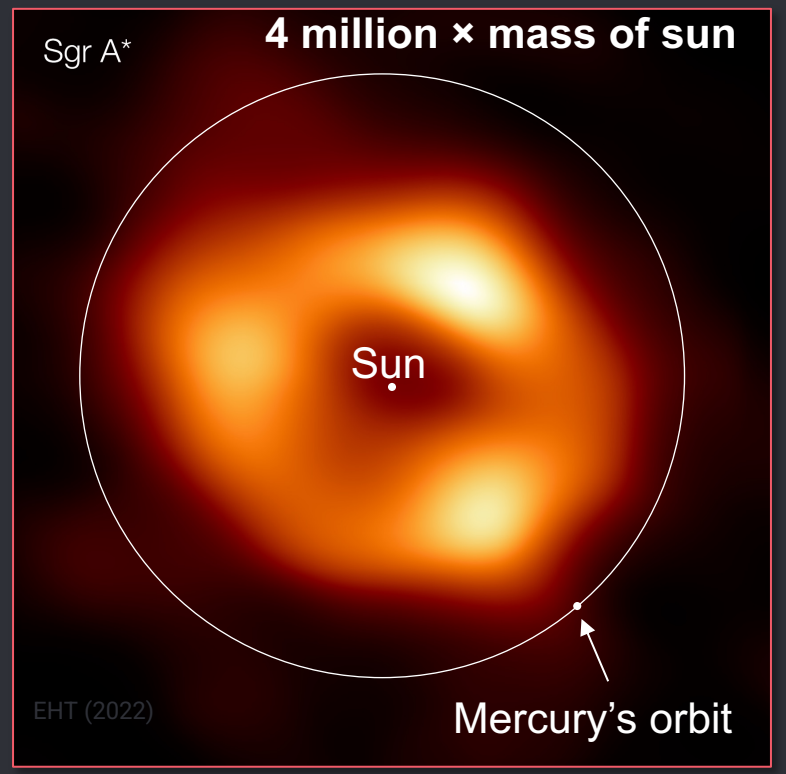
Giant galaxy (M87*)



Rotation time ~ month

Too slow to track!

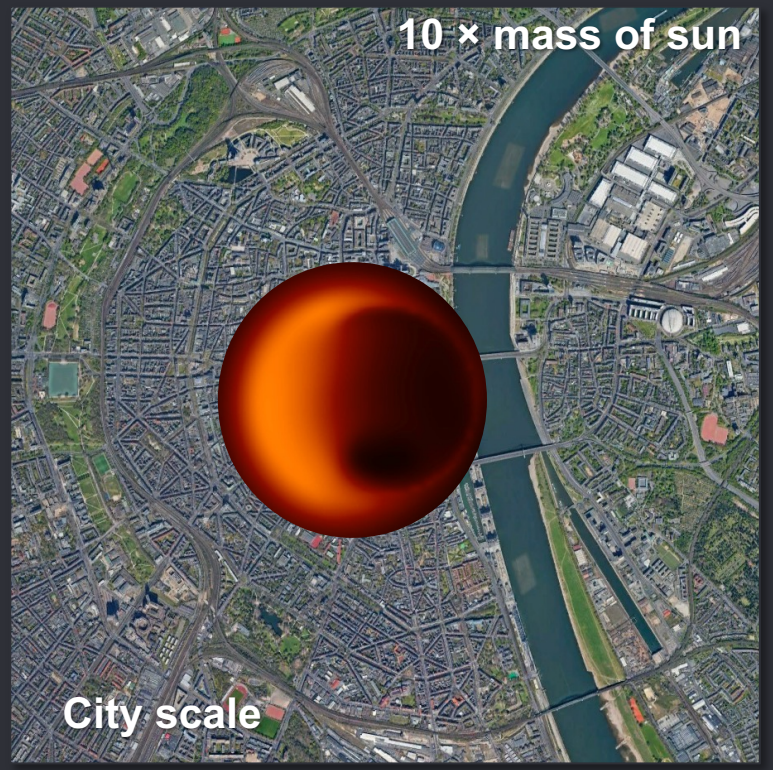
Our Milky Way (Sgr A*)



Rotation time ~ hour

We can do this

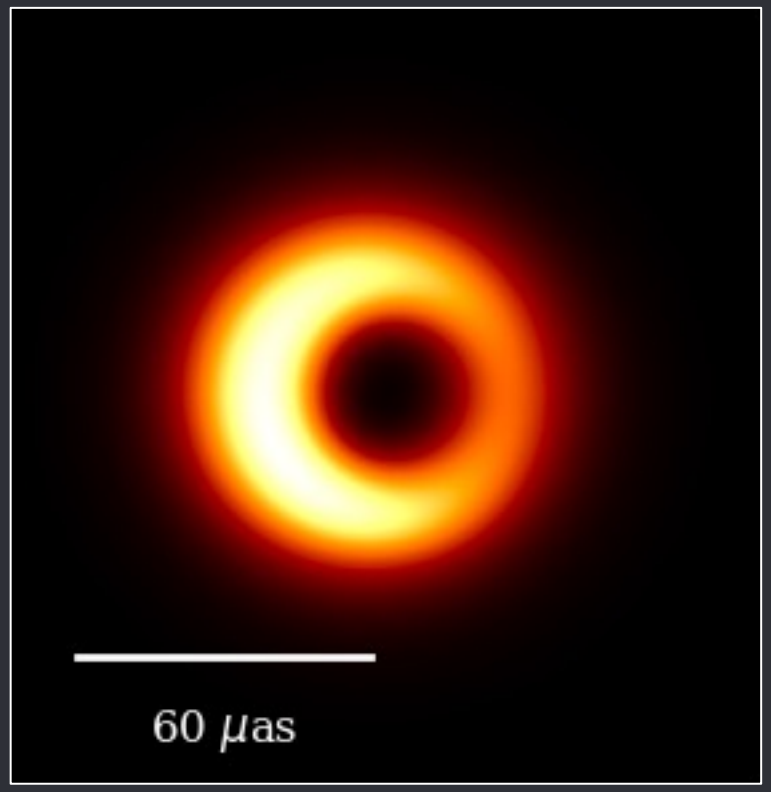
Stellar mass black hole



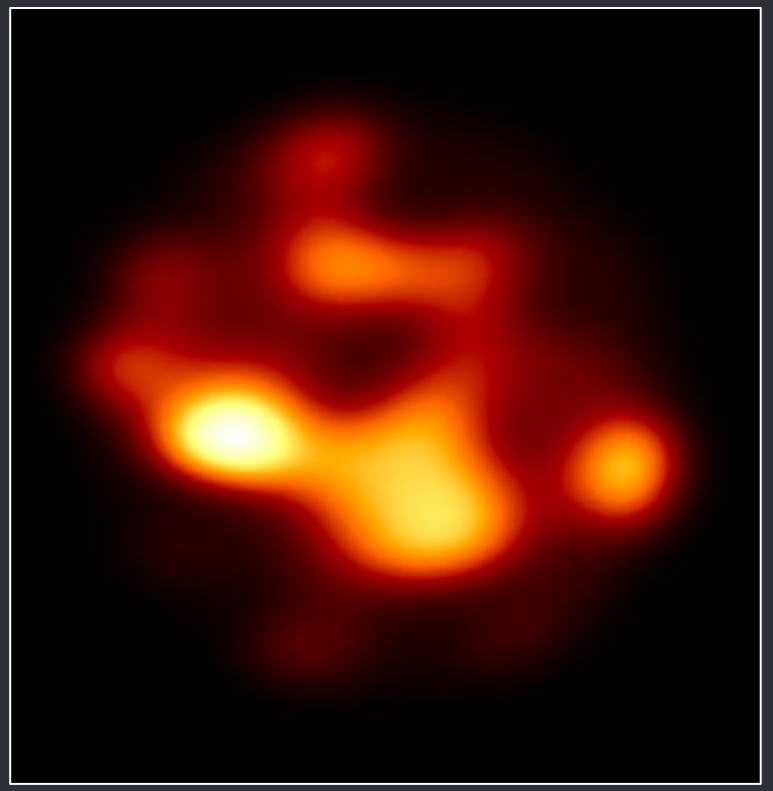
Rotation time ~ milliseconds

But too small to image!

How much improvement does AMT provide?



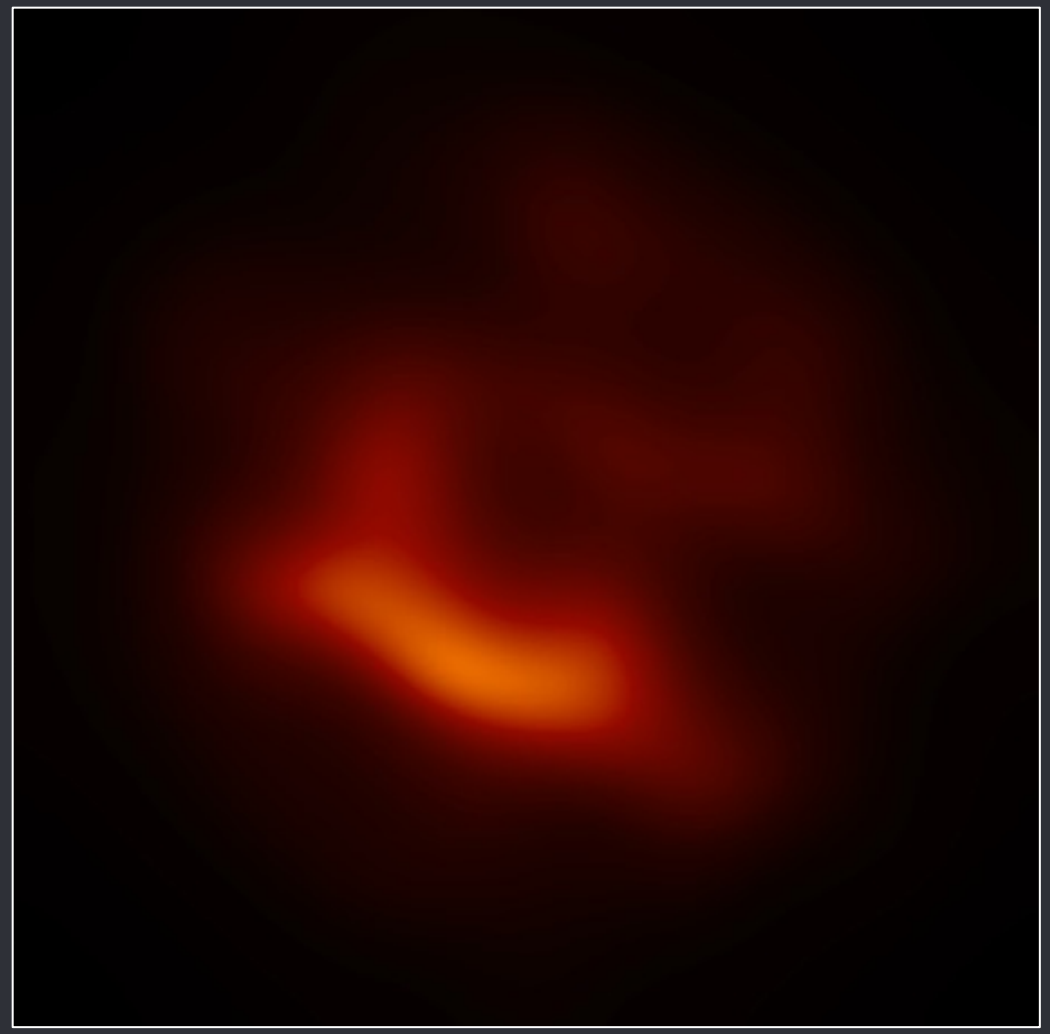
model



Eastern EHT now
(1st 7 hours)

Eastern EHT +
AMT

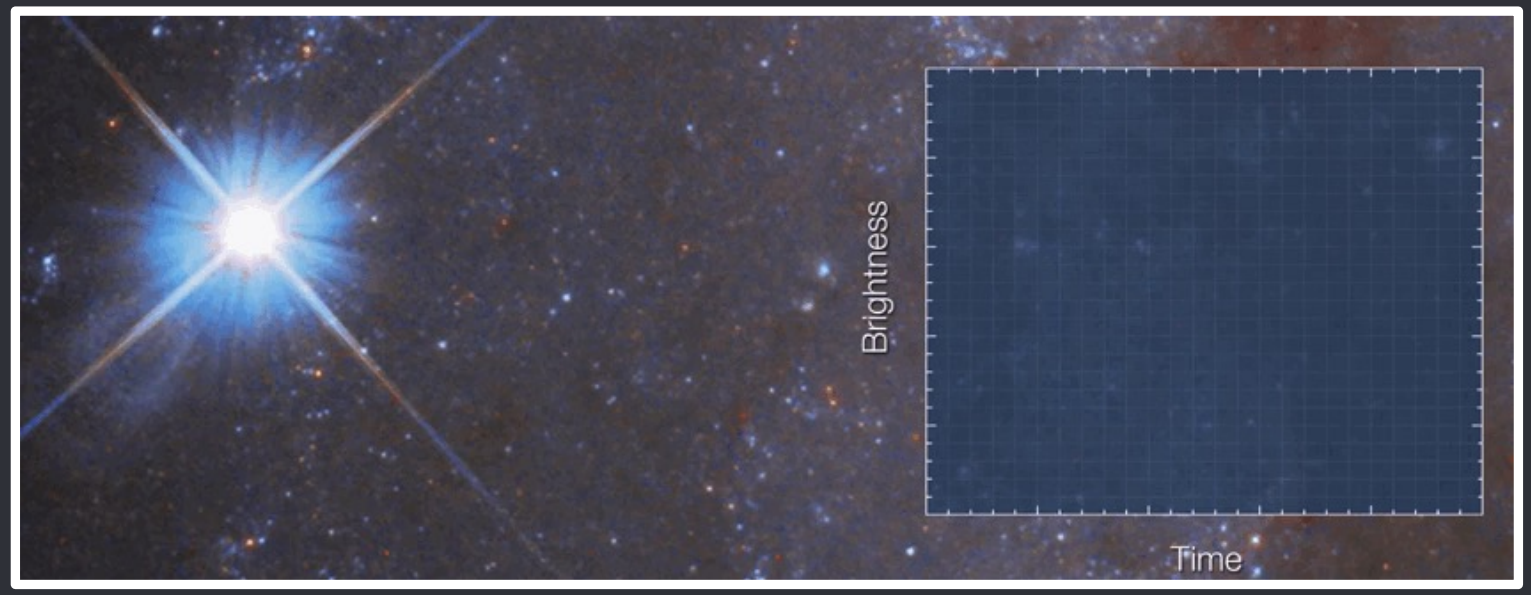
Idealised input model for rotating Sgr A*



Simulated image reconstruction for EHT + AMT

EHT takes up ~20% of AMT time.. what else will AMT do?

We will chase astrophysical transients!



We may also ‘trigger’ AMT based upon radio monitoring observations with MeerKAT in South Africa

The deep astronomical sky is full of ‘transients’ – things which suddenly brighten and fade.

These phenomena are often associated with the most extreme physics in the Universe.

Stellar mass black holes (as in the ThunderKAT programme) are a subset of astrophysical transients, other classes include other classes of black holes, neutron stars, white dwarfs, exploding stars and gravitational wave bursts!

Gamma-ray bursts are an extremely exciting target for millimetre observations.

Recent observations and calculations by my group have shown that if we can point at a GRB within about 30 min of burst detection (in space!) we will see a very bright millimetre source and probe new astrophysics.

AMT will operate to respond very rapidly to new GRBs and other astrophysical transients: **no other millimetre telescope in the world has a dedicated transients programme.**

Summary

The most extreme astrophysics in our universe is associated with black holes and astrophysical transients.

Huge ongoing programmes, including with the MeerKAT radio telescope in South Africa, are providing us with incredible new data sets and stress-testing our models.

The development of the AMT in Namibia will allow us to take the next steps: movies of a rotating super-massive black holes and more!