Title: The Invisible Universe

Speakers: Priyamvada Natarajan

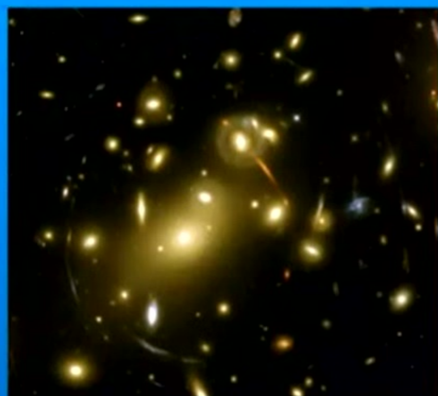
Collection: Perimeter Public Lectures

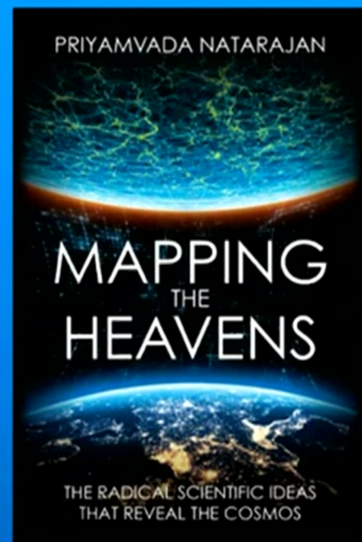
Date: March 03, 2021 - 7:00 PM

URL: https://pirsa.org/21030044

Abstract: In her live Perimeter Public Lecture webcast on March 3, 2021, Priyamvada Natarajan guided the audience through what we currently know about the nature of dark matter and black holes. Natarajan is a professor in the Departments of Astronomy and Physics at Yale University, noted for her seminal contributions toward mapping the distribution of dark matter and tracing the growth history of black holes.

THE INVISIBLE UNIVERSE
searching for our place in the cosmos





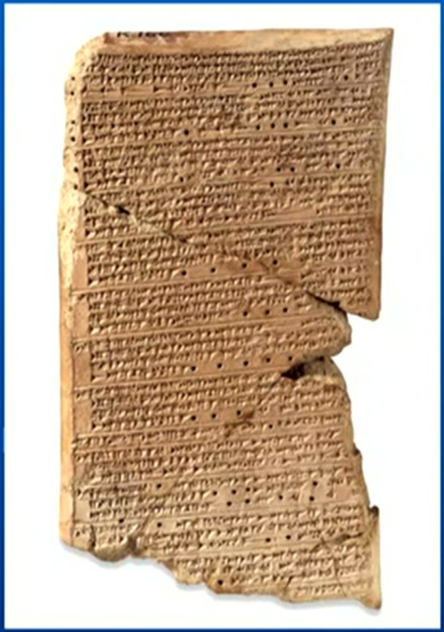
Priyamvada Natarajan
Departments of Astronomy & Physics, Yale University

PERIMETER INSTITUTE
3 MARCH 2021

MAPPING THE INVISIBLE UNIVERSE
searching for our place in the cosmos

Nebra Sky Disk
2000-1600 B.C

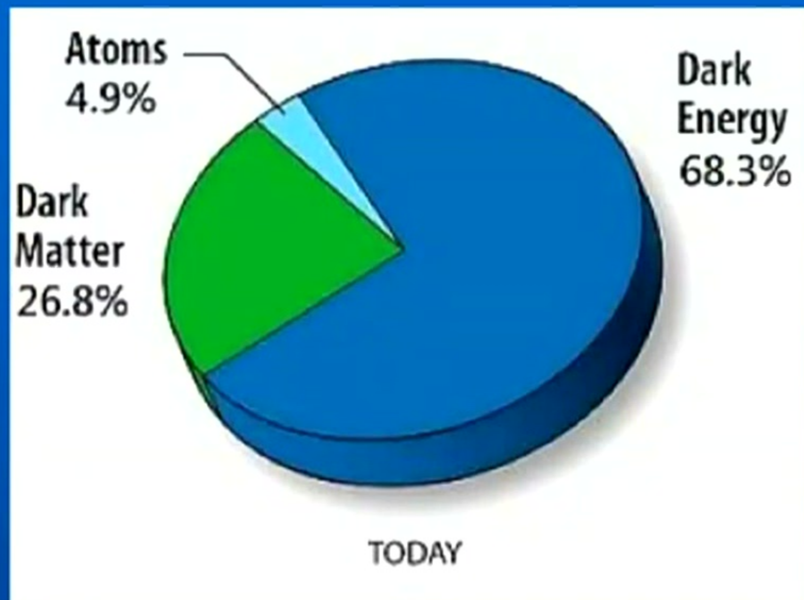
Venus Sky Tablet
700 B.C.



Catalan Atlas
1375 A.D.

OUR EVOLVING COSMIC VIEW

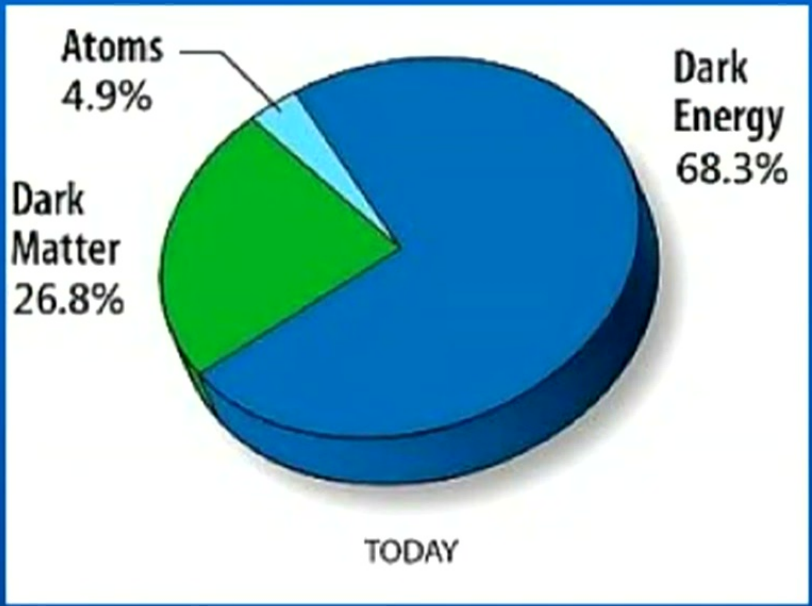
CURRENT INVENTORY OF THE UNIVERSE



Evidence for Dark Matter

Impact on motions of stars
Impact on our cosmic messenger – light - the bending of light

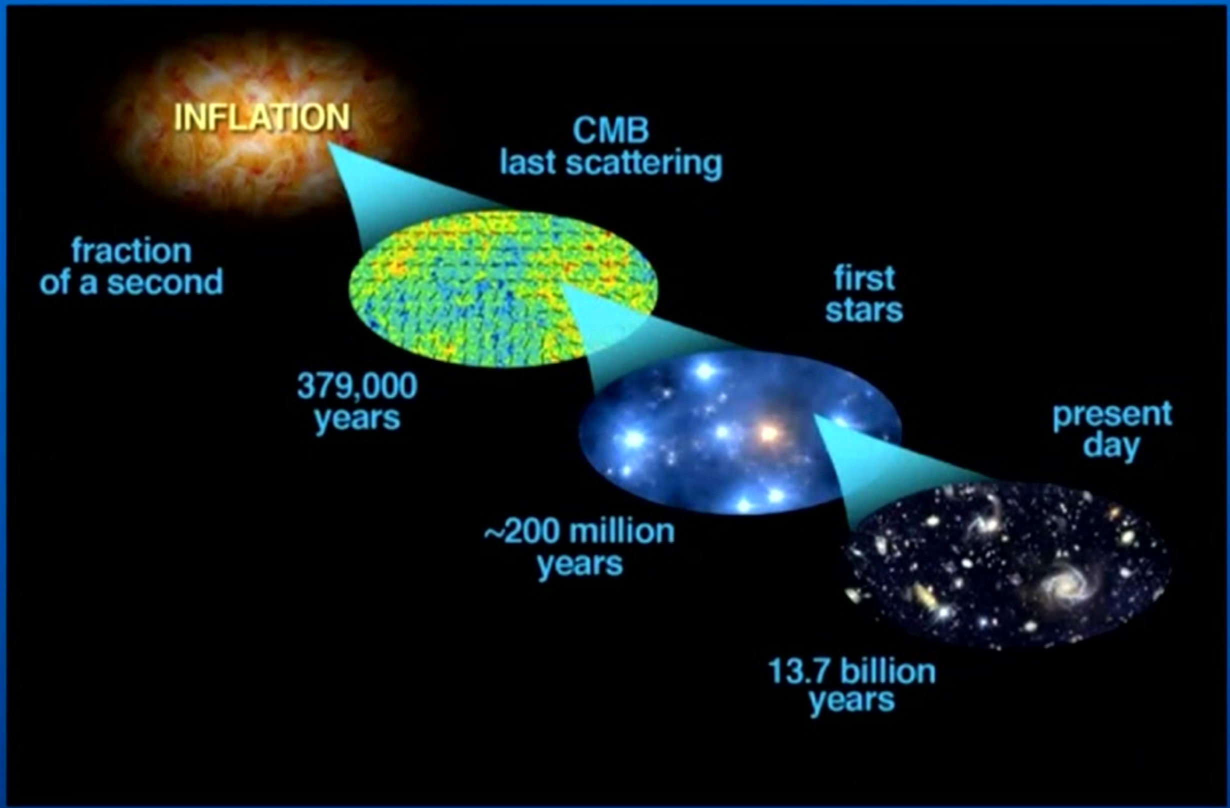
CURRENT INVENTORY OF THE UNIVERSE



Evidence for Dark Matter

Impact on motions of stars
Impact on our cosmic messenger – light - the bending of light

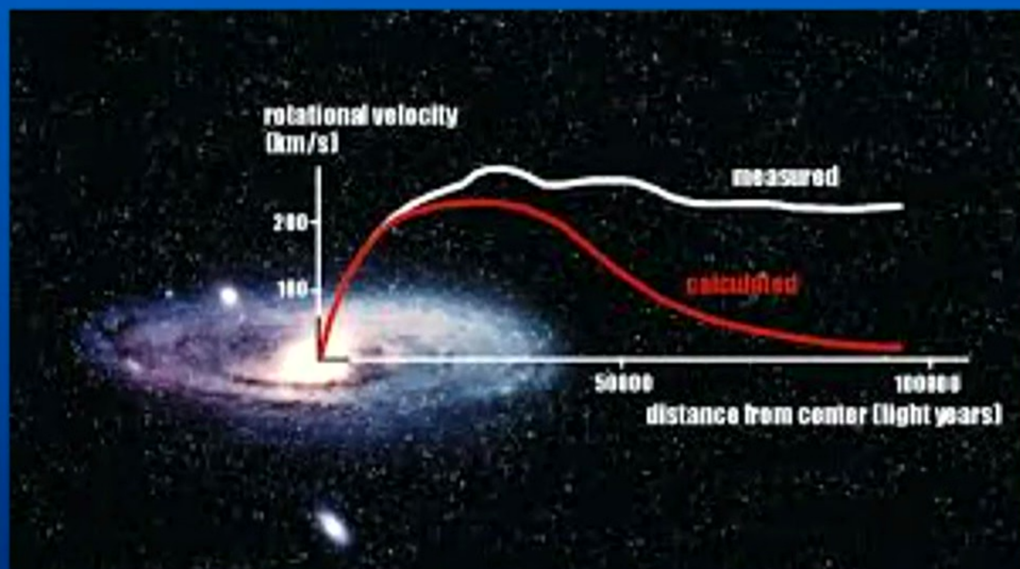
BRIEF HISTORY OF THE UNIVERSE



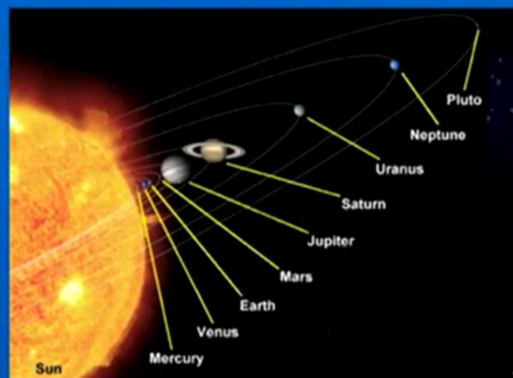
ZWICKY'S DUNKLE MATERIE

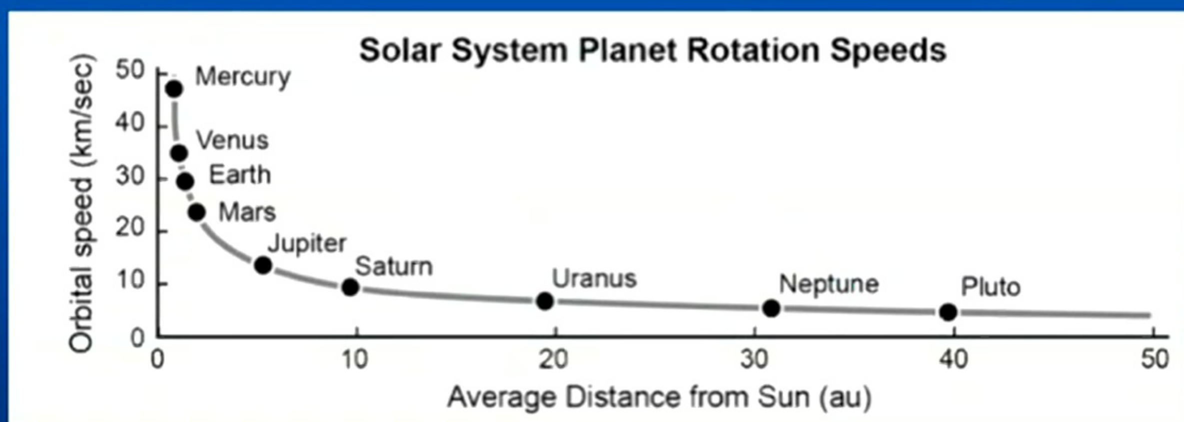
1933 Coma cluster galaxy speeds
1937 Light deflections by clusters

MOTIONS OF STARS IN GALAXIES

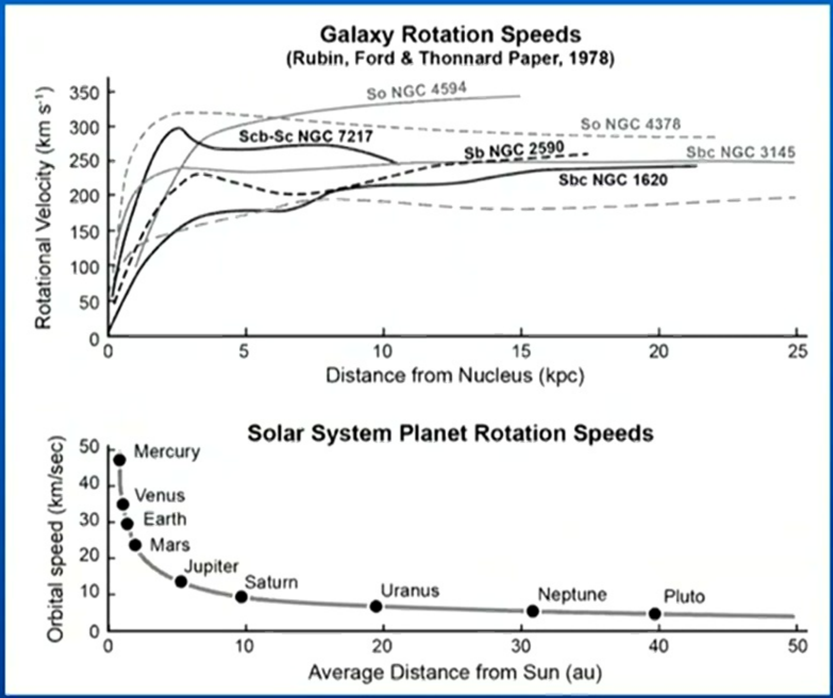


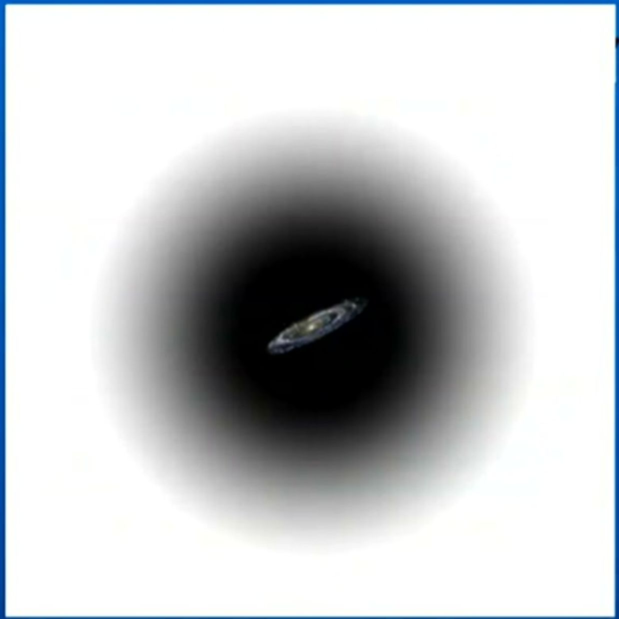
GRAVITY IN THE SOLAR SYSTEM

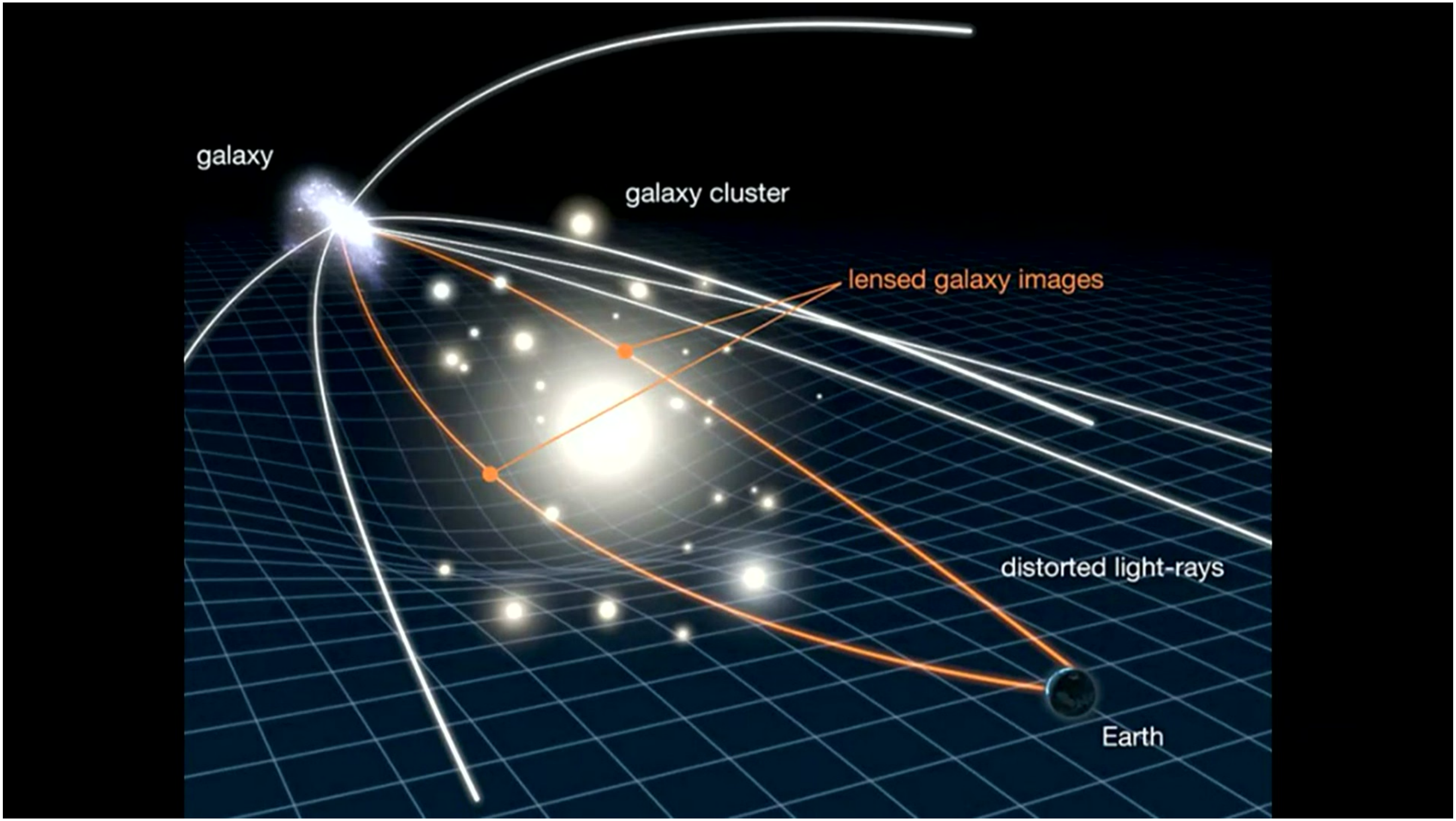




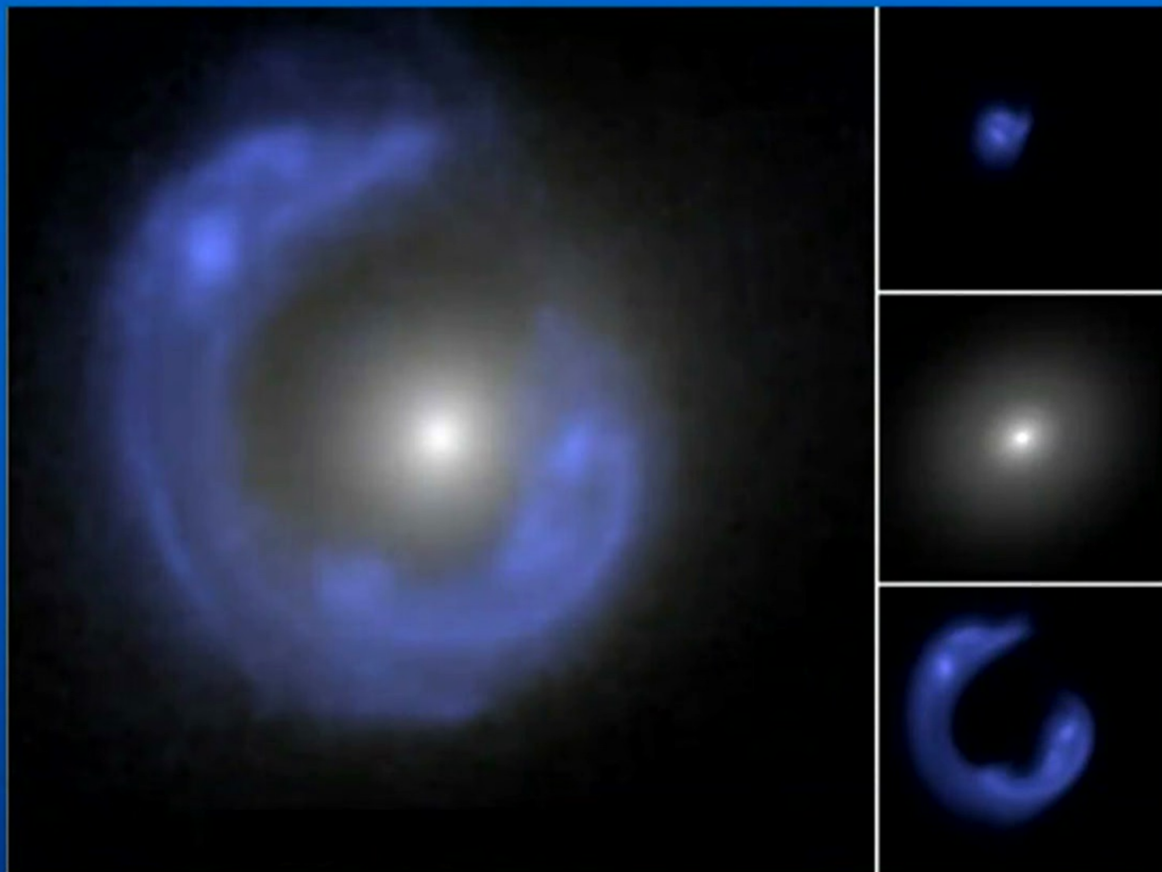
CURRENT CONCEPTION OF GALAXIES

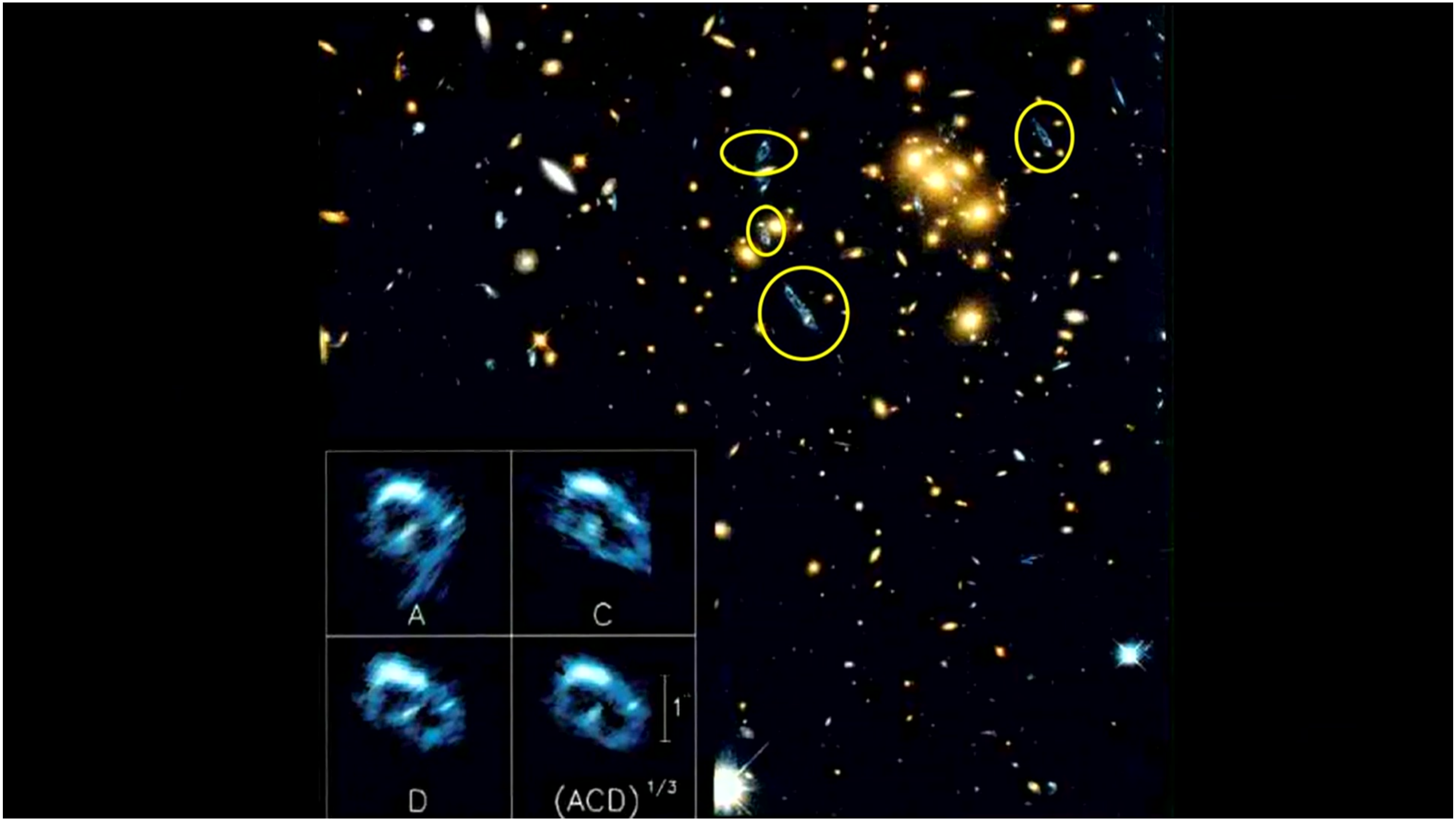





galaxy
galaxy cluster
lensed galaxy images
distorted light-rays
Earth

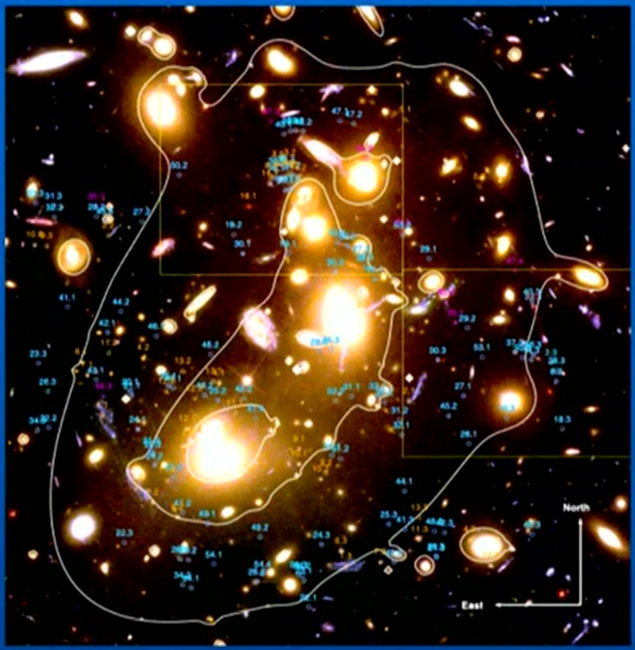
OBSERVED LIGHT BENDING

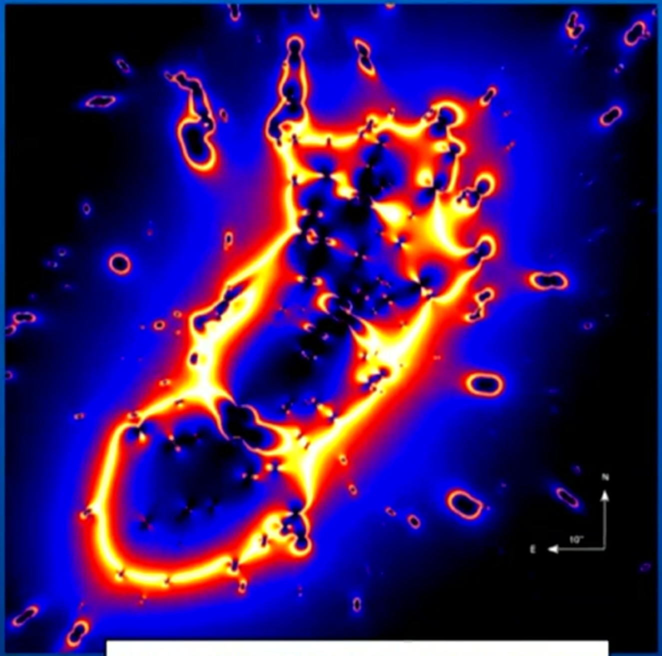



A
C
D
(ACD) 1/3
1"

Galaxy Cluster Abell 2218

CALIBRATING NATURE'S LENSES

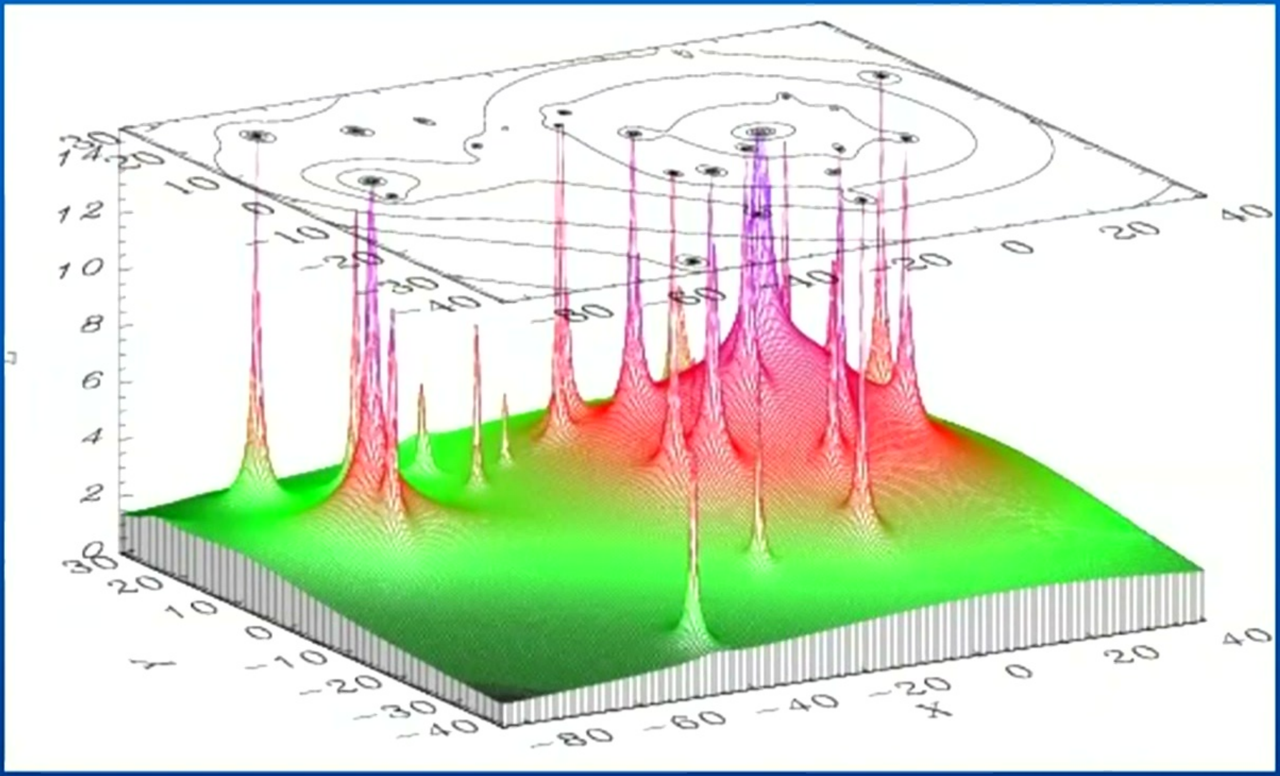


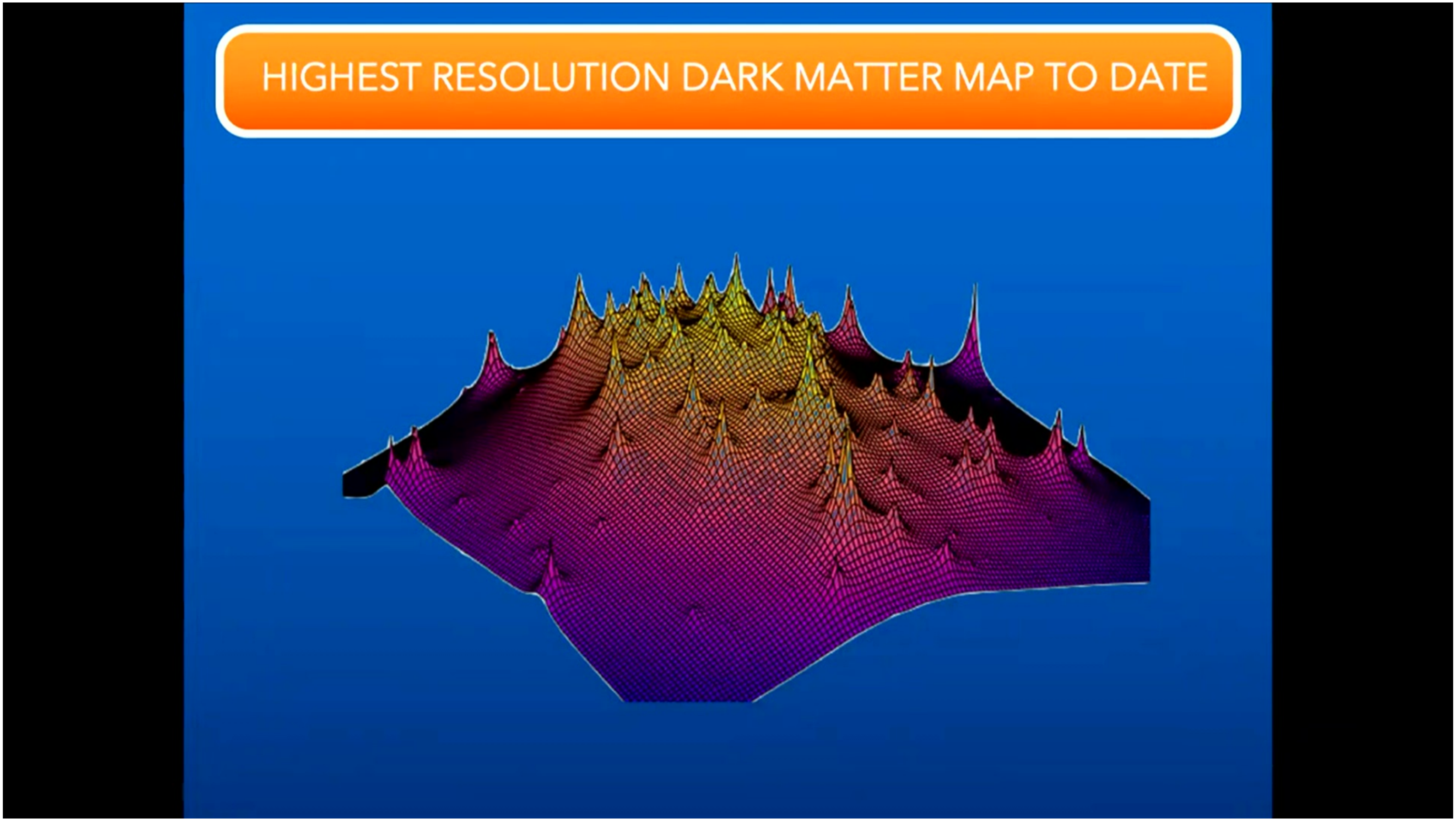


Magnification map (mags)

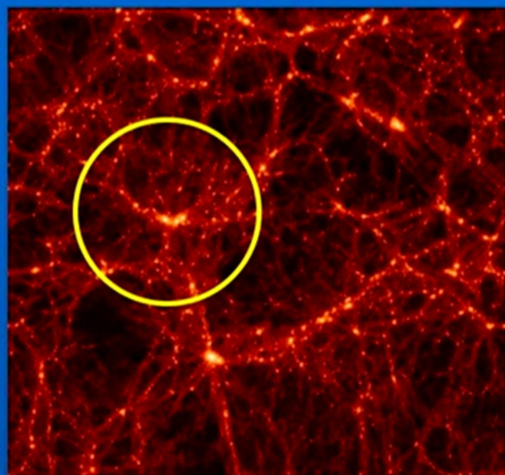
THE UNIVERSE IS REPLETE WITH DARK MATTER!

MAPPING THE CLUMPING OF DARK MATTER




HIGHEST RESOLUTION DARK MATTER MAP TO DATE

PROBING THE NATURE OF DARK MATTER IN THE UNIVERSE



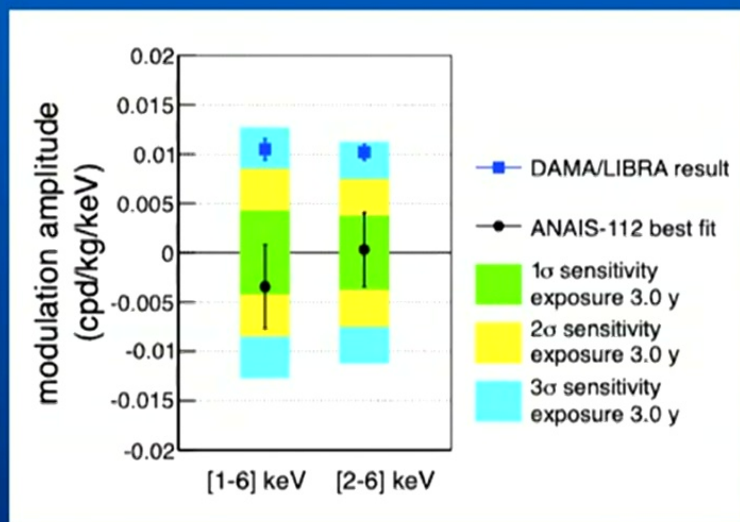
CLUMPINESS & NATURE OF DARK MATTER

WHAT IS THE DM PARTICLE?

Weakly Interacting Massive Particles WIMPS, Axions

Inferred properties
Cold, Collision-less, almost no interactions

DIRECT DETECTION & INDIRECT DETECTION

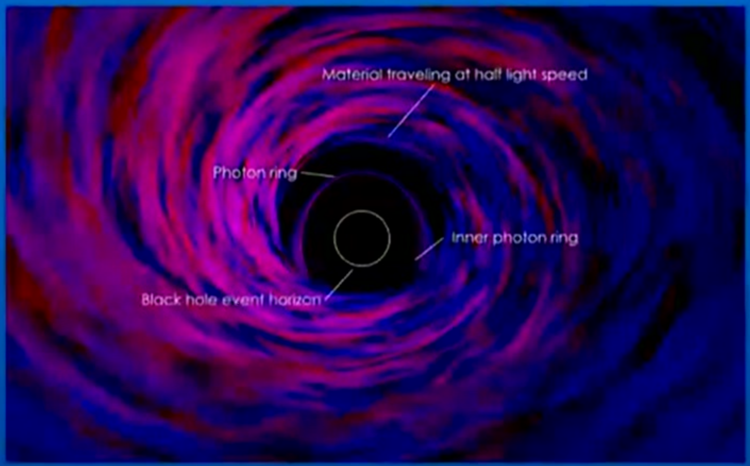


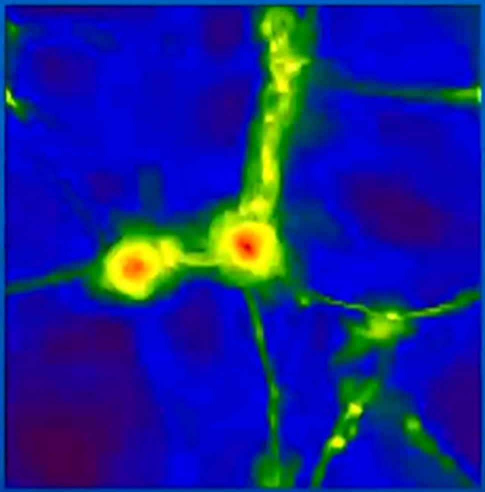
claimed
DAMA-LIBRA
detection
NaI crystal

Duplication studies
fail to detect

COSINE
ANAIS

TRACING THE ORIGIN & GROWTH OF BLACK HOLES





BLACK HOLE OF CALCUTTA (1756)

BLACK HOLE OF CALCUTTA (1756)

BHs: THREE WAYS TO THINK ABOUT THEM

1 – STRENGTH OF THE PULL OF GRAVITY

Notion of escape speed: $v_{escape} = (2\ G\ M/R)^{1/2}$

If $v > v_{escape}$ then the object will escape the gravitational pull of mass M and coast to infinity!

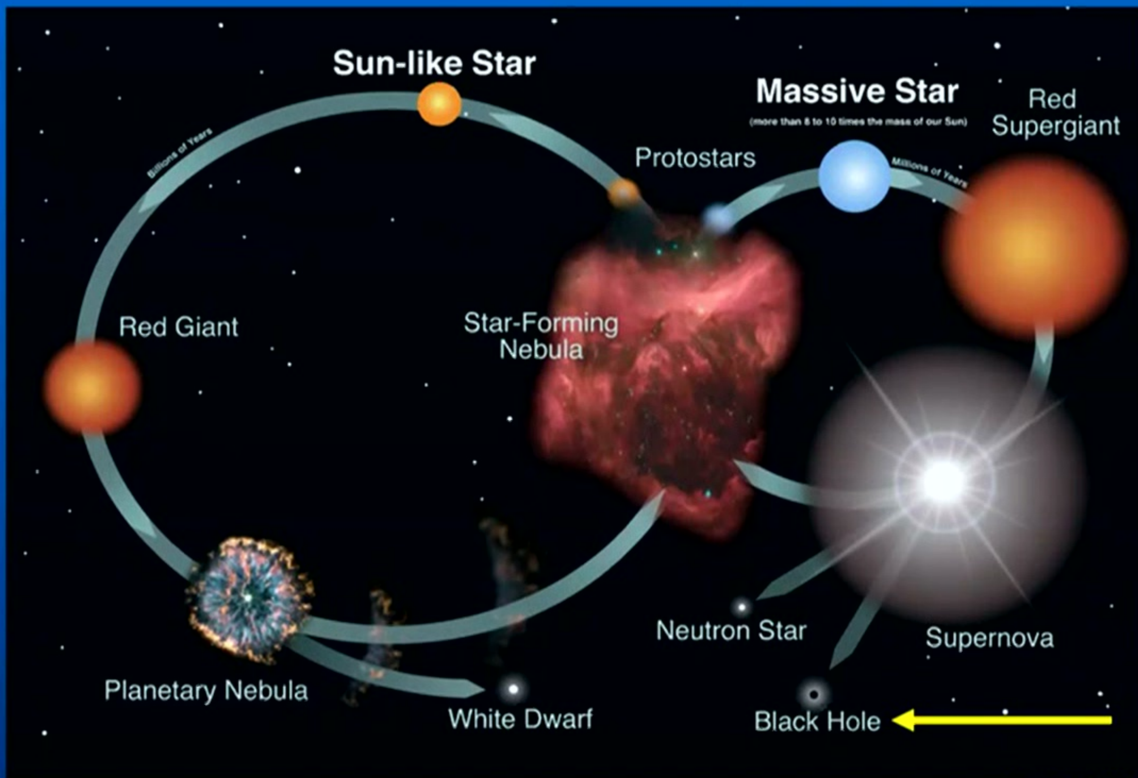
WHAT IF THE ESCAPE VELOCITY SPEED OF LIGHT = c?
Escape speed from Earth 11.2 km/s

FOR THAT CASE R = Schwarzschild radius = $2\ GM/c^2$
not even light can escape!

FOR THE EARTH R = 0.89 cm; SUN R = 3.0 km

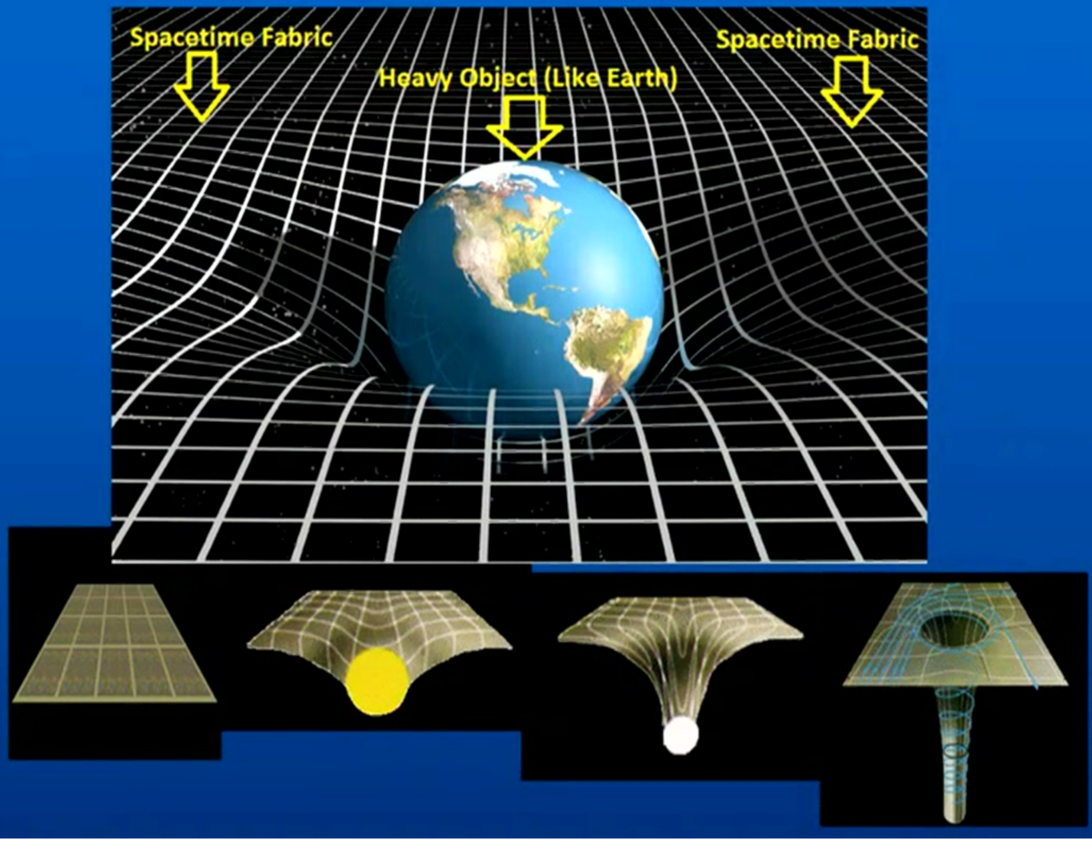
BHs: THREE WAYS TO THINK ABOUT THEM

2 – DENSE CORPSES OF MASSIVE STARS

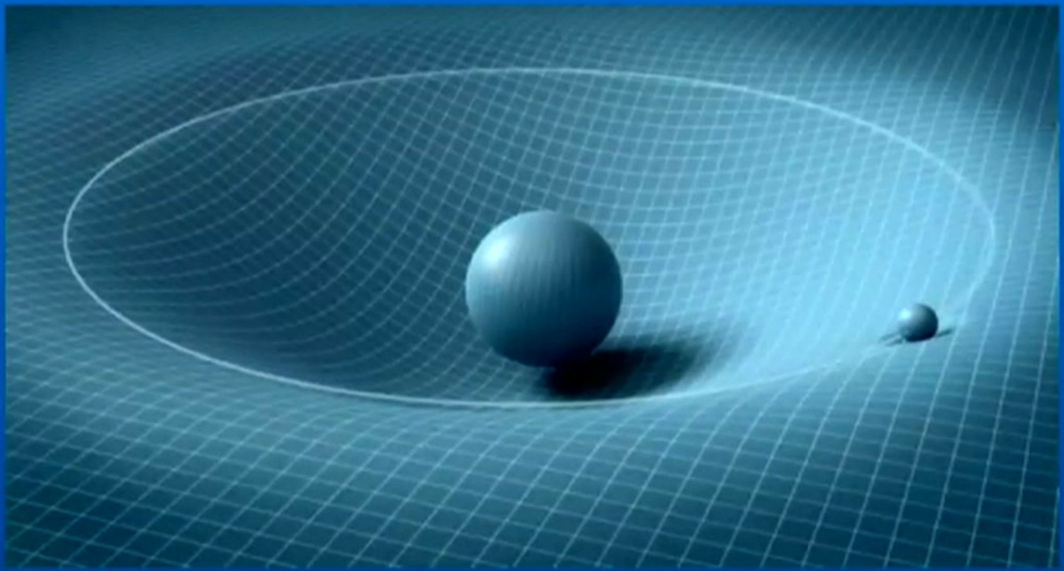


BHs: THREE WAYS TO THINK ABOUT THEM

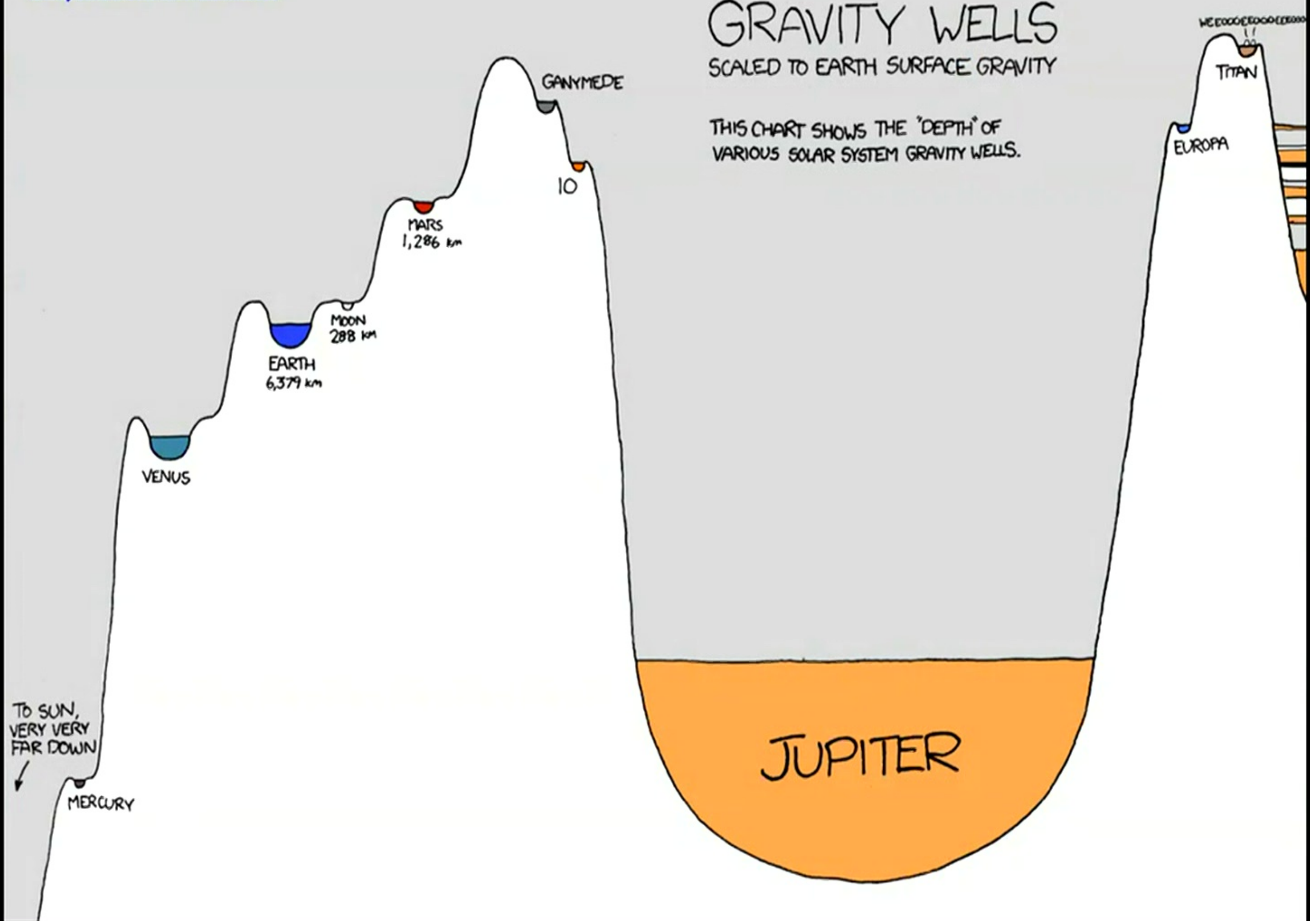
3 – PUNCTURES IN SPACETIME



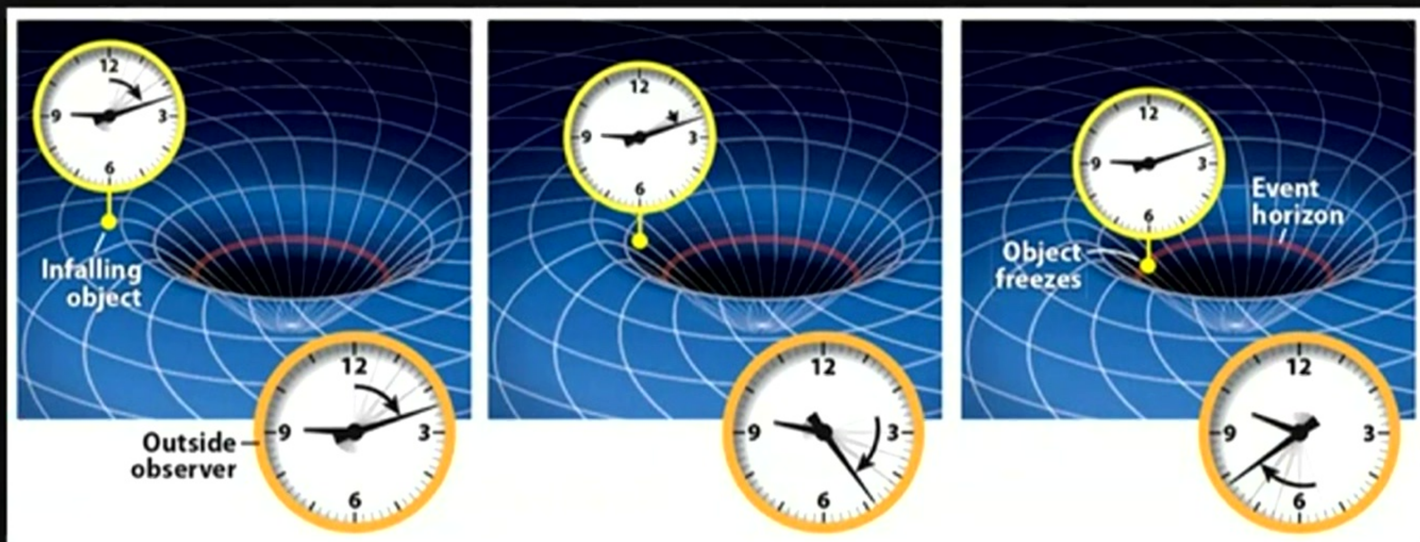
RELATIONSHIP BETWEEN MATTER & SHAPE OF SPACE
Einstein's Theory of General Relativity



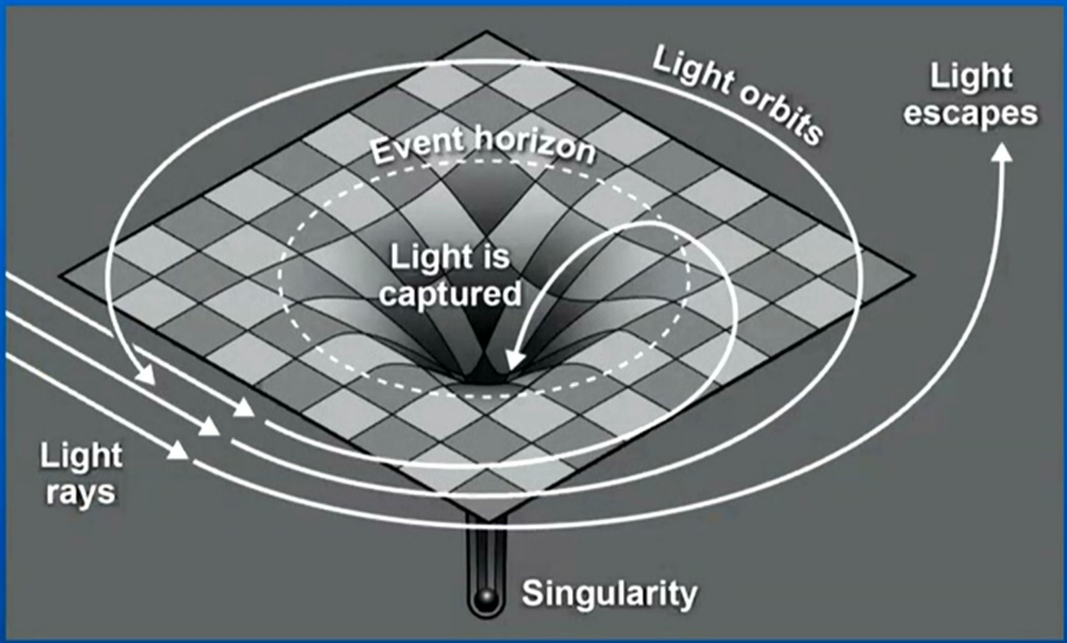
https://xkcd.com/681



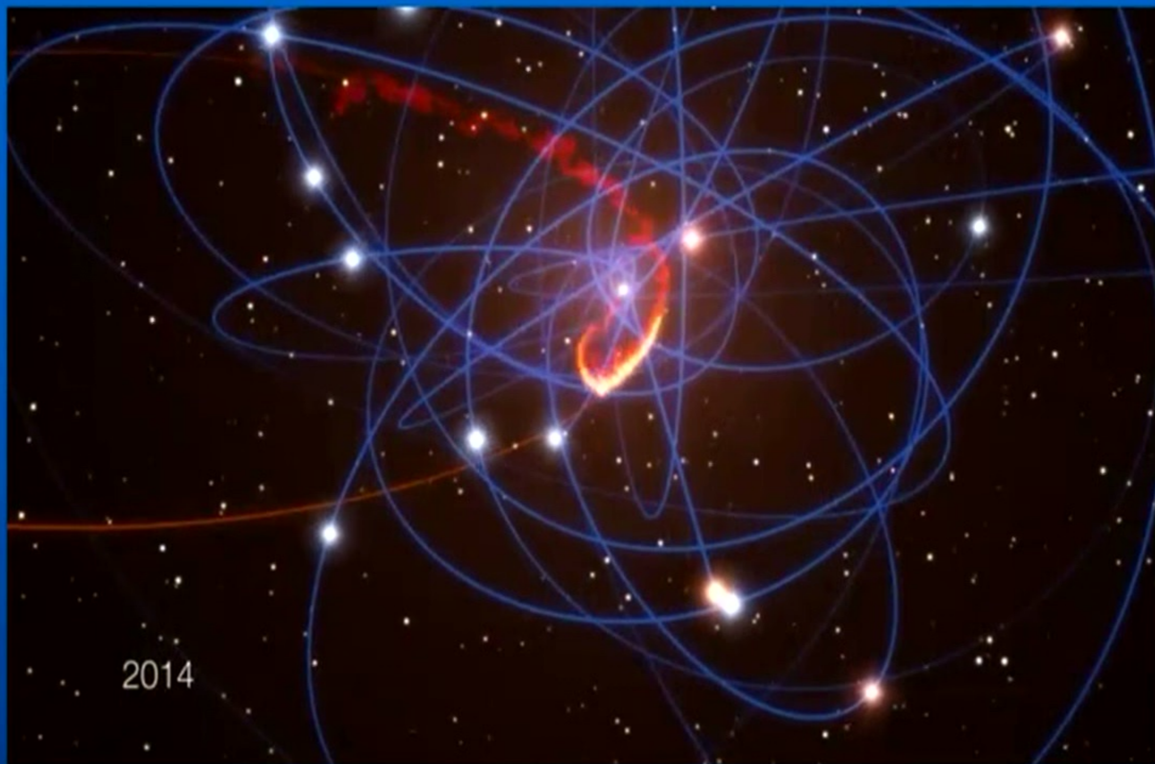
NATURE OF TIME ALTERED NEAR A BH
Time slows down for an observer falling into a BH



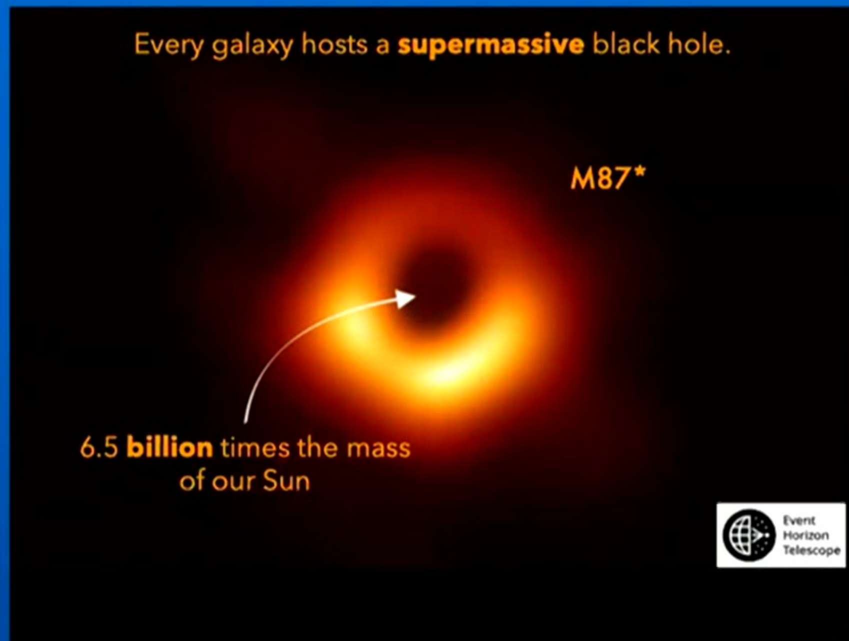
WHAT IS A BLACK HOLE?



MOST COMPELLING EVIDENCE FOR A BH
motions of stars at our galactic center



EVENT HORIZON TELESCOPE PROJECT
Mapping the shadow of the MW BH



Focus on the First Event Horizon Telescope Results

Shep Doeleman (EHT Director) on behalf of the EHT Collaboration

April 2019

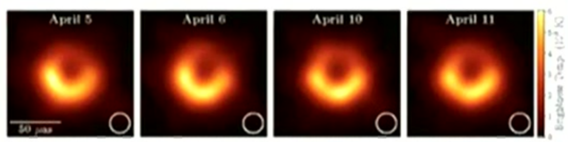
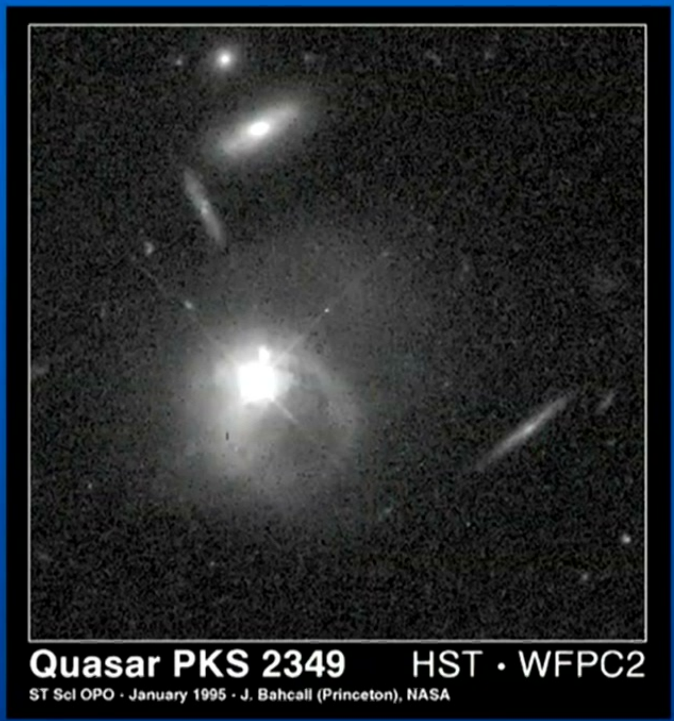


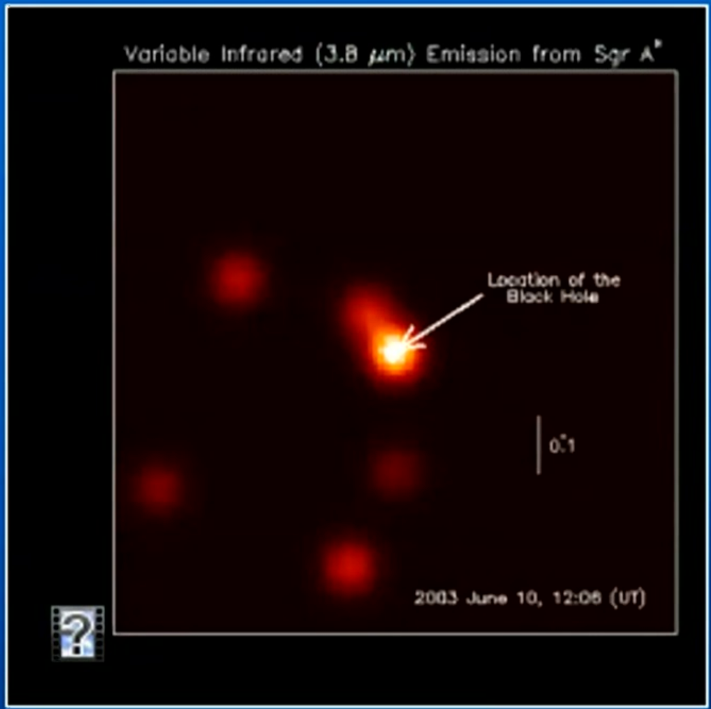
Figure 1. EHT images of M87 on four different observing nights. In each panel, the white circle shows the resolution of the EHT. All four images are dominated by a bright ring with enhanced emission in the south. From Paper IV (Figure 15).

WHERE DO SUPERMASSIVE BLACK HOLES RESIDE

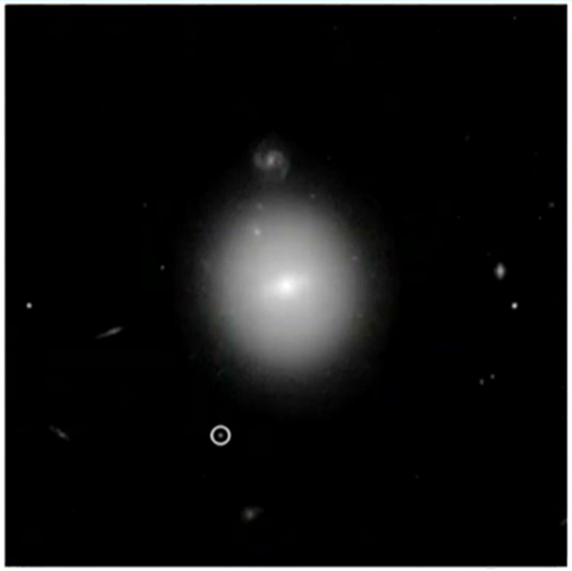
WHERE DO SUPERMASSIVE BLACK HOLES RESIDE

FASTING & FEASTING BLACK HOLES



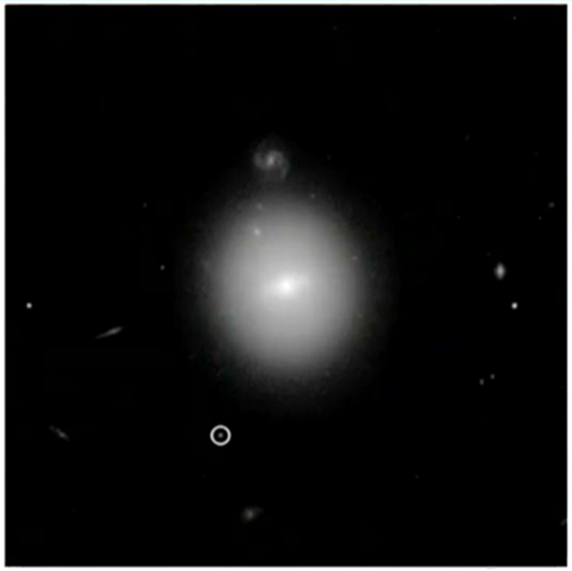


BLACK HOLE BESTIARY
STELLAR MASS, INTERMEDIATE MASS, SUPERMASSIVE & ULTRAMASSIVE BHs



This Hubble Space Telescope image identified the location of an intermediate-mass black hole, weighing 50,000 times the mass of our Sun (making it much smaller than supermassive black holes found in the centers of galaxies). The black hole, named 3XMM J215022.4−055108, is indicated by the white circle. The elusive type of black hole was first identified in a burst of telltale X-rays emitted by hot gas from a star as it was captured and

BLACK HOLE BESTIARY
STELLAR MASS, INTERMEDIATE MASS, SUPERMASSIVE & ULTRAMASSIVE BHs



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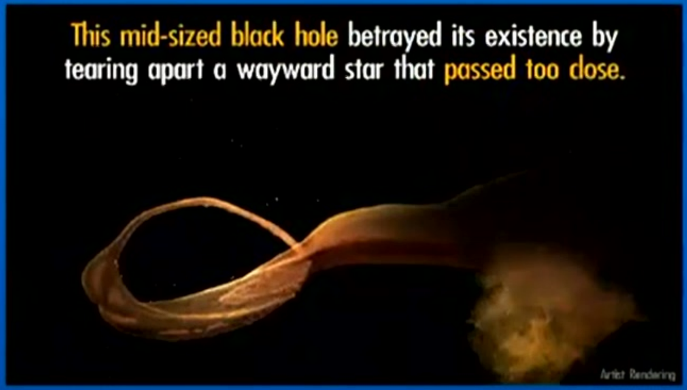
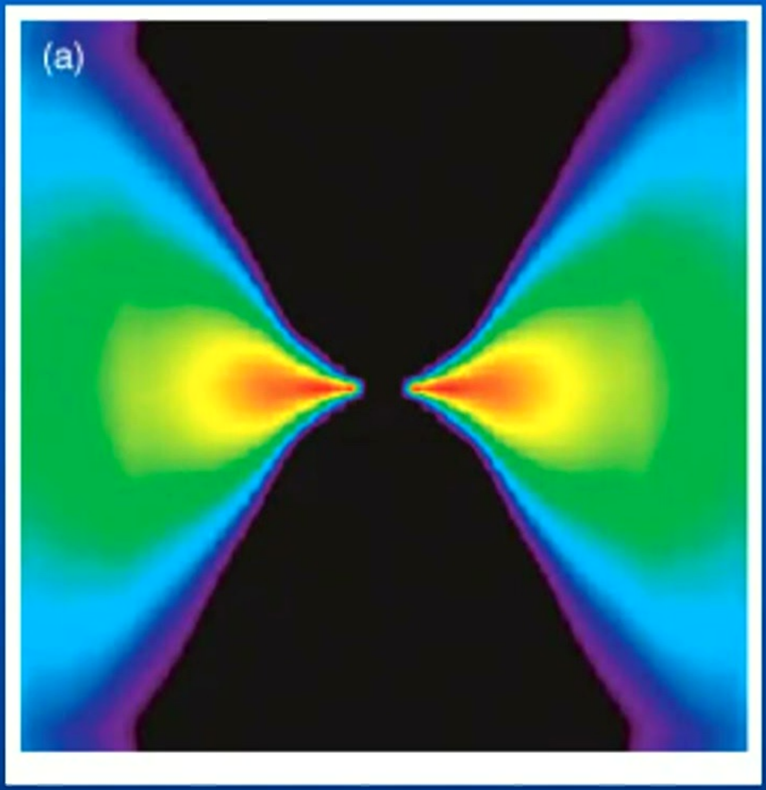
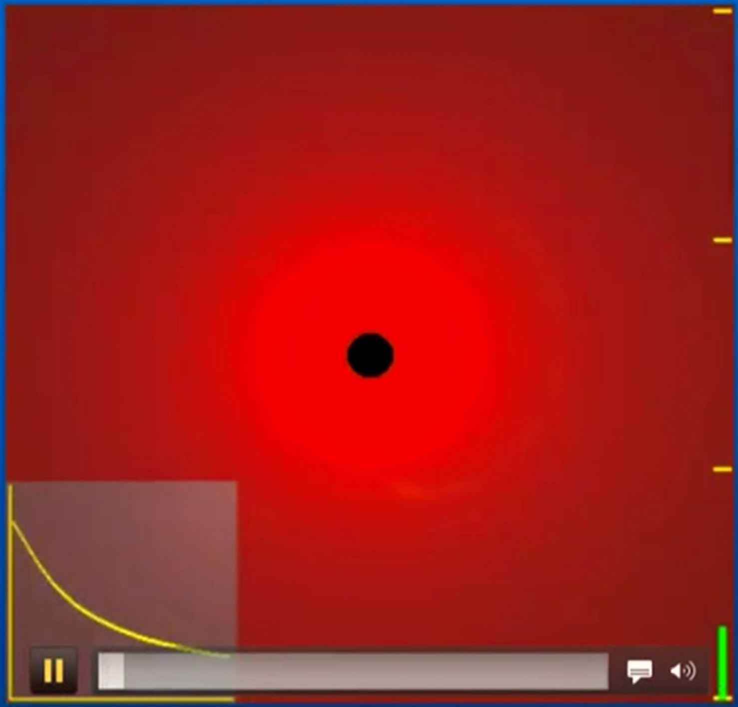


TRACKING GAS FLOW INTO BLACK HOLES

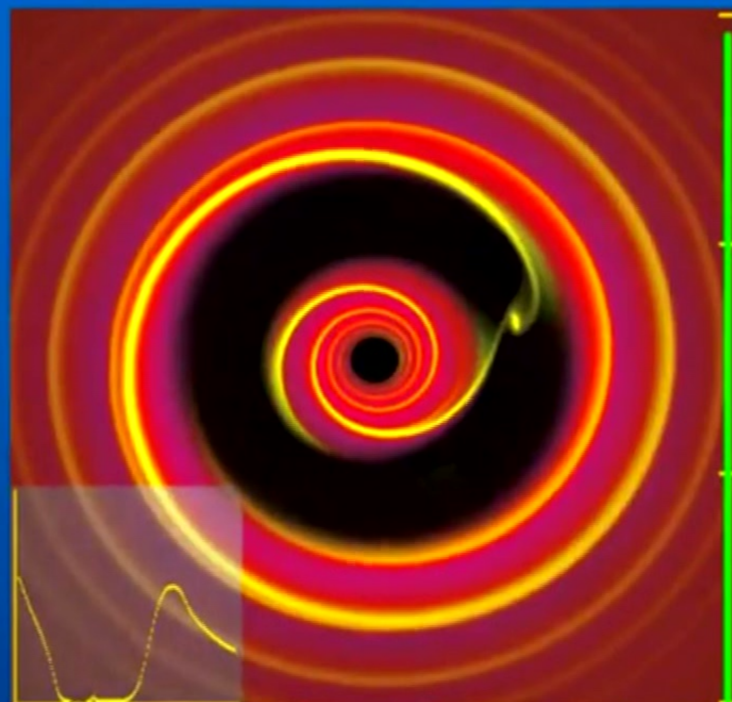


FOLLOWING BLACK HOLES AS THEY MERGE

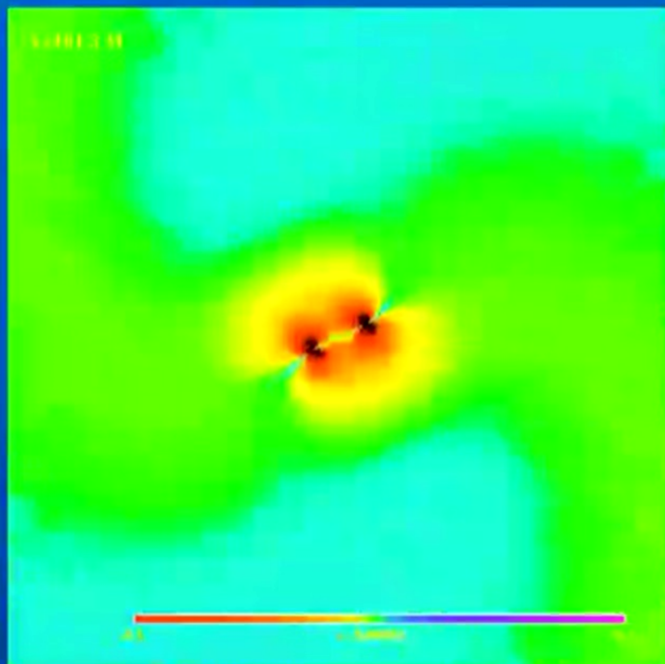
ZOOMING RIGHT IN ON THE MERGING BLACK HOLES



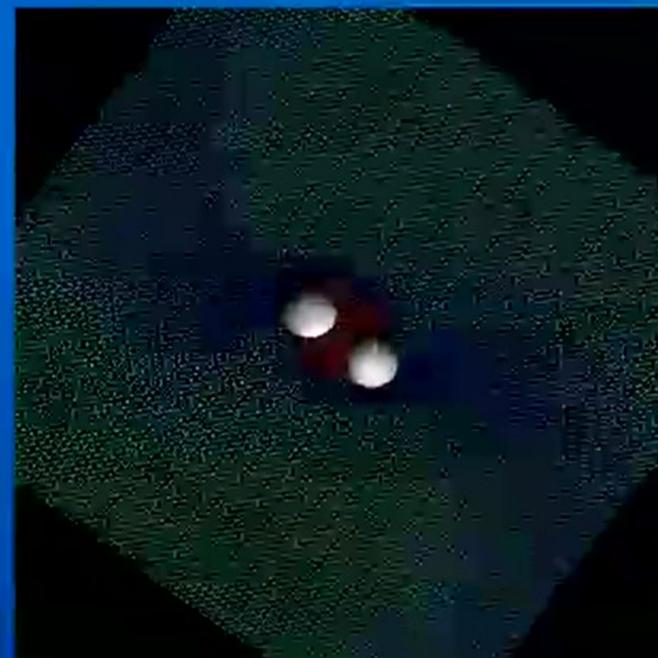
ZOOMING RIGHT IN ON THE MERGING BLACK HOLES



THE DYING GASPS OF MERGING BLACK HOLES

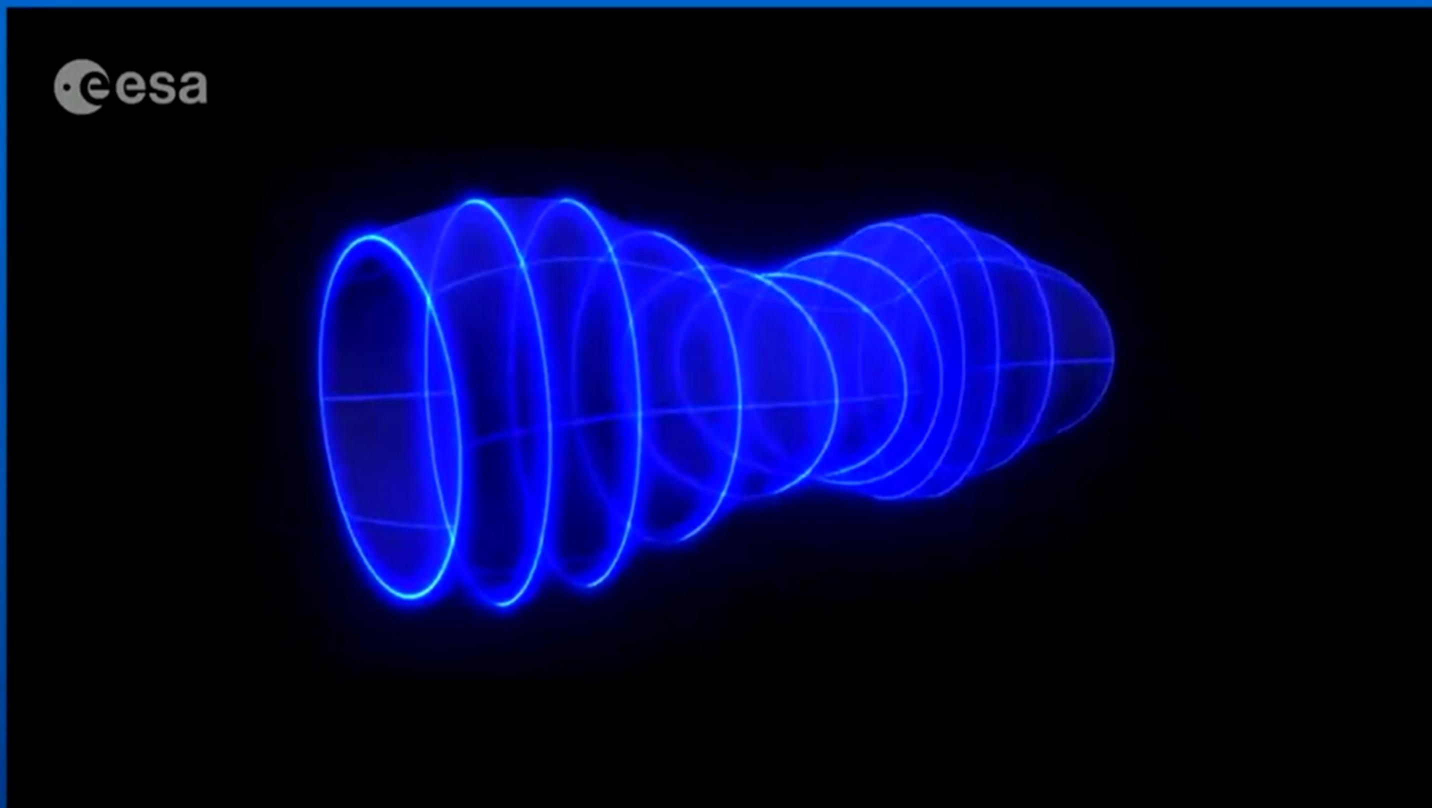


Pretorius+

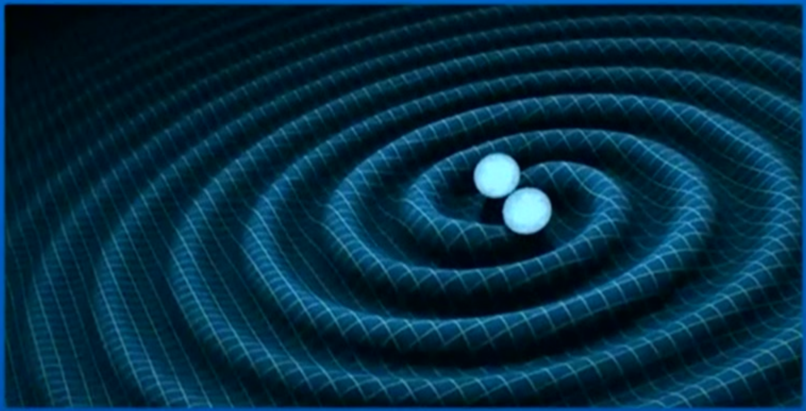


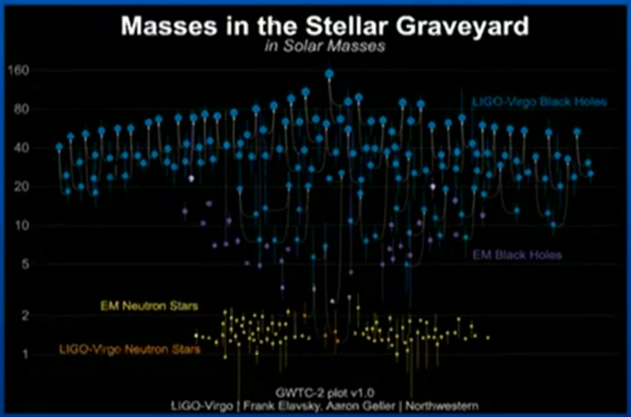
Campanelli+

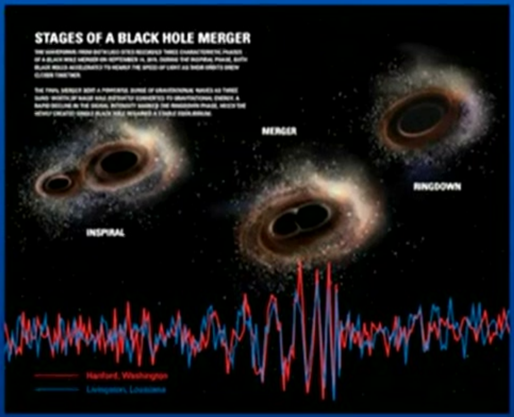
VISUALIZATION OF GRAVITATONAL WAVES FROM MERGING BHs



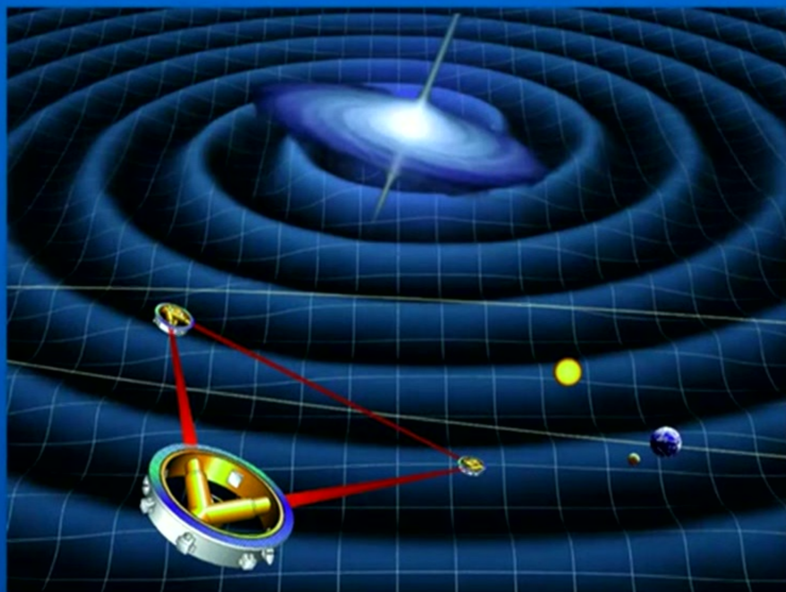
LIGO: FIRST DETECTION OF GRAVITATIONAL WAVES

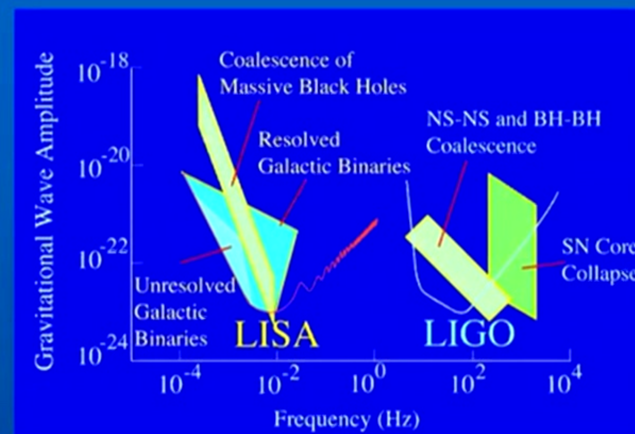






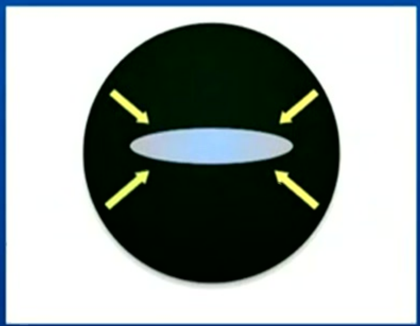
DETECTION OF GRAVITATONAL WAVES FROM MERGING BHs
DETECTORS IN SPACE LISA MISSION

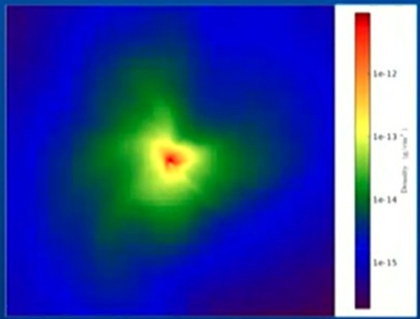


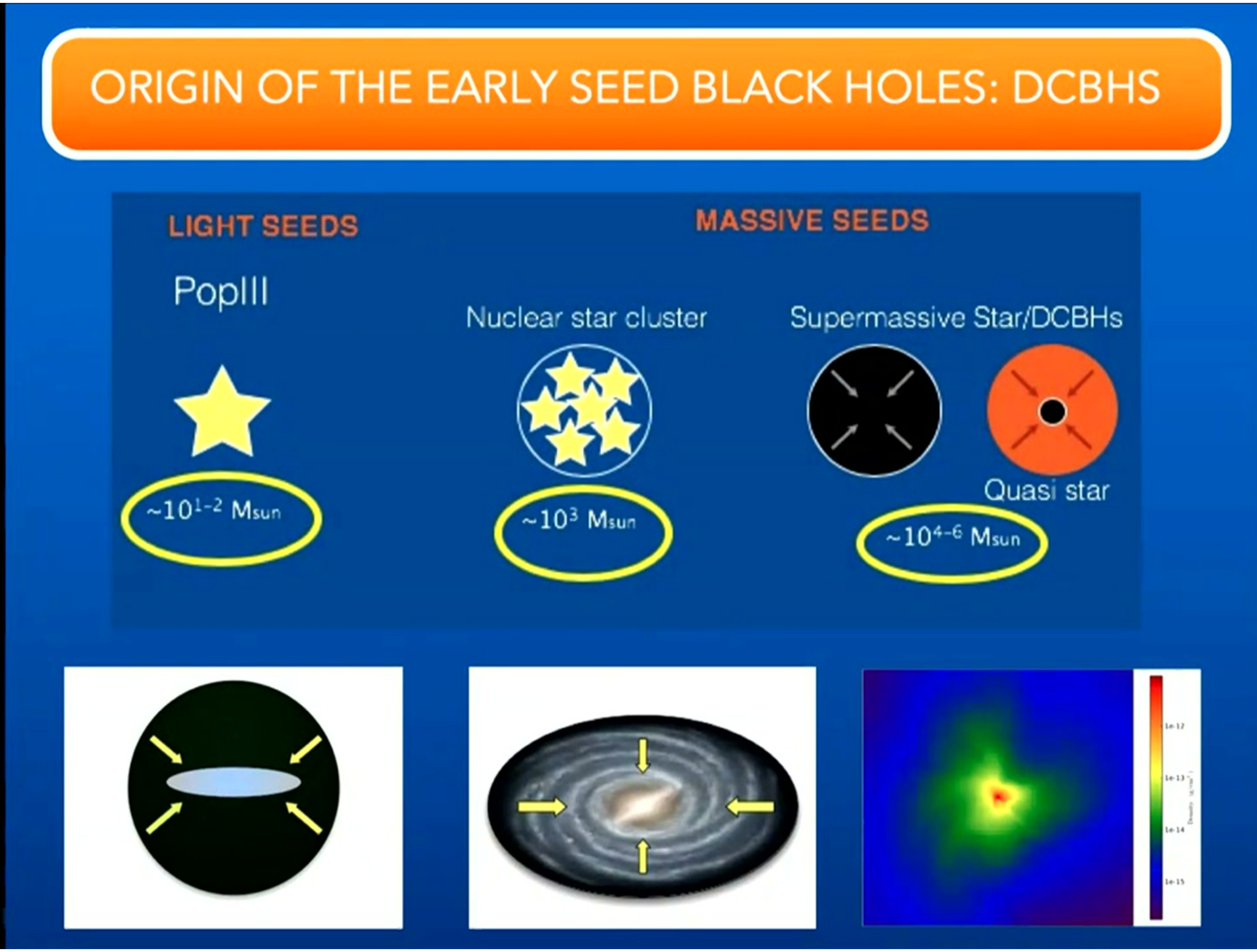


From LIGOs 4 km arms ----→ 2.5 MILLION kilometer arms!

ORIGIN OF THE EARLY SEED BLACK HOLES: DCBHS

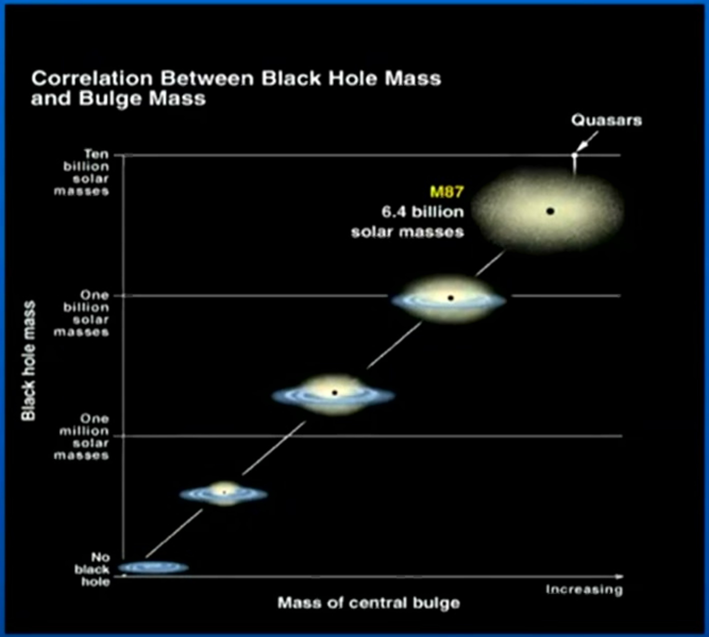


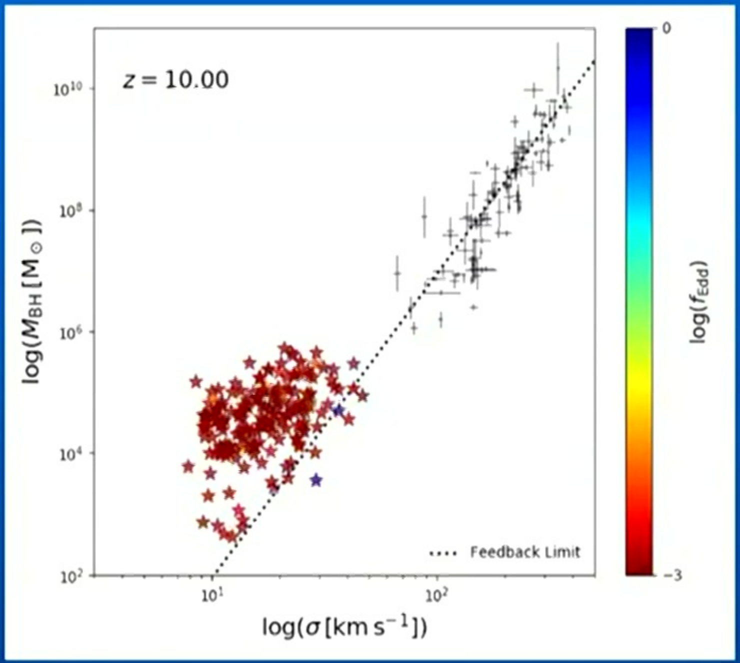



ORIGIN OF THE EARLY SEED BLACK HOLES: DCBHS
LIGHT SEEDS
MASSIVE SEEDS
PopIII
Nuclear star cluster
Supermassive Star/DCBHs
~10^1-2 Msun
~10^3 Msun
Quasi star
~10^4-6 Msun


How far back in time will James Webb see?
SPACE TELESCOPE
13.7 BILLION YEARS: PRESENT DAY
9 BILLION YEARS: OUR SUN FORMS
A FEW BILLION YEARS: QUASAR ERA
A FEW HUNDRED MILLION YEARS: FIRST GALAXIES
BIG BANG
1.5 million km from Earth

TRACKING BH GROWTH OVER COSMIC TIME: MODELS





BLAST FROM THE PAST: predictions from 20 yrs ago!

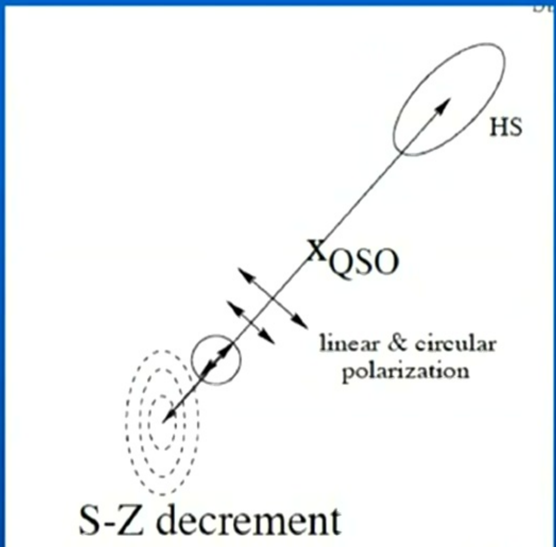
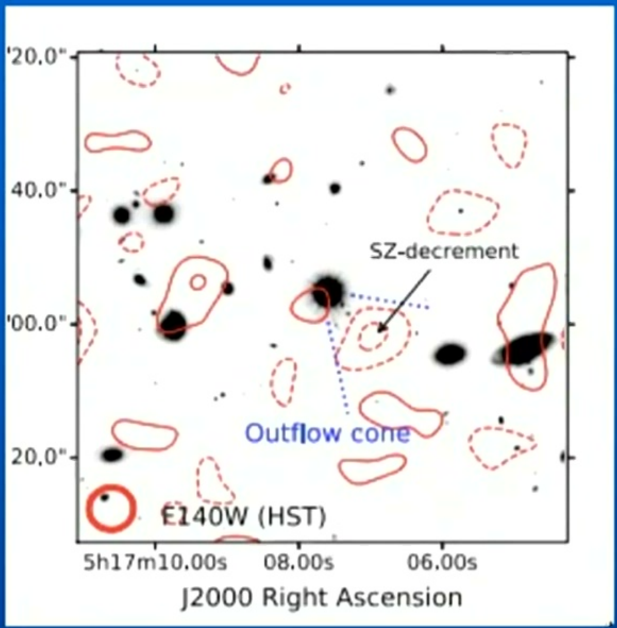
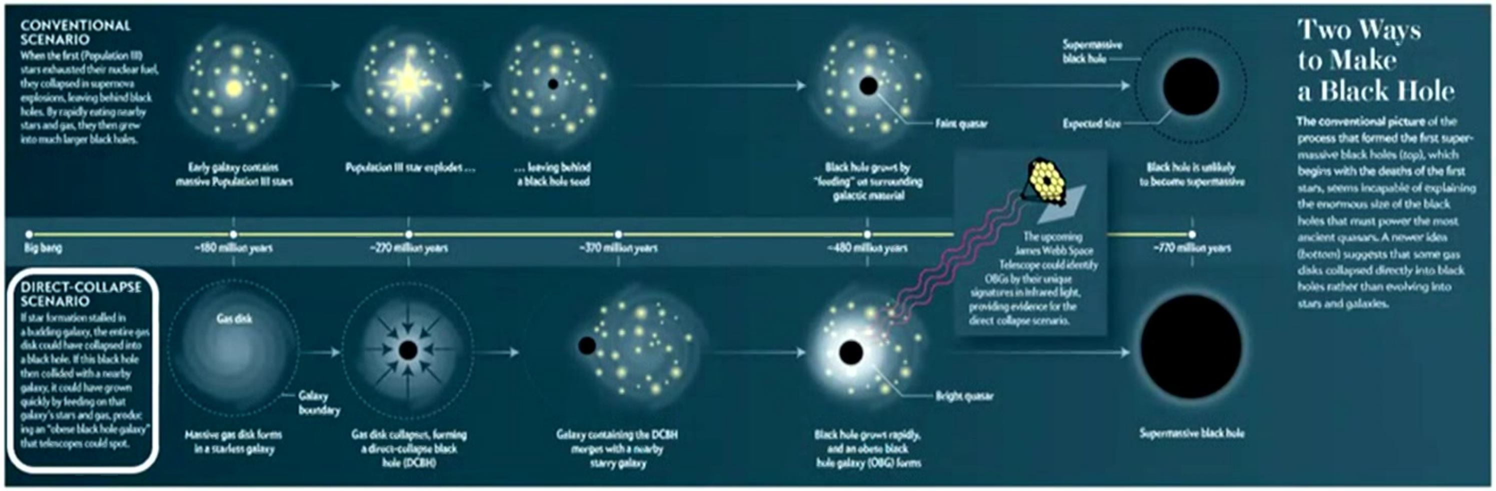


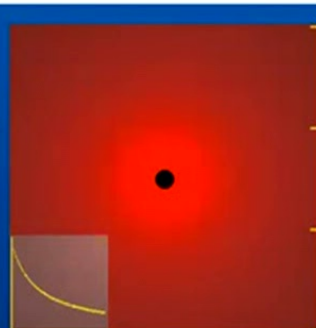
Figure 2. Schematic of the configuration showing the relative positions on the sky of the QSO; the observed S-Z decrement CS; the predicted temperature increment HS.



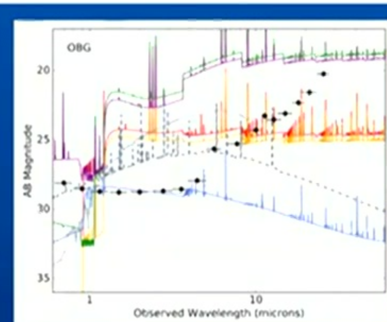
BLACK HOLES: FORMATION, FUELING & FEEDBACK

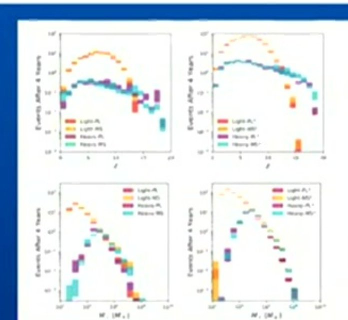


THEORY



SIMULATIONS





OBSERVATIONAL PREDICTIONS

TRACKING GROWTH HISTORY OF BLACK HOLES OVER COSMIC TIME