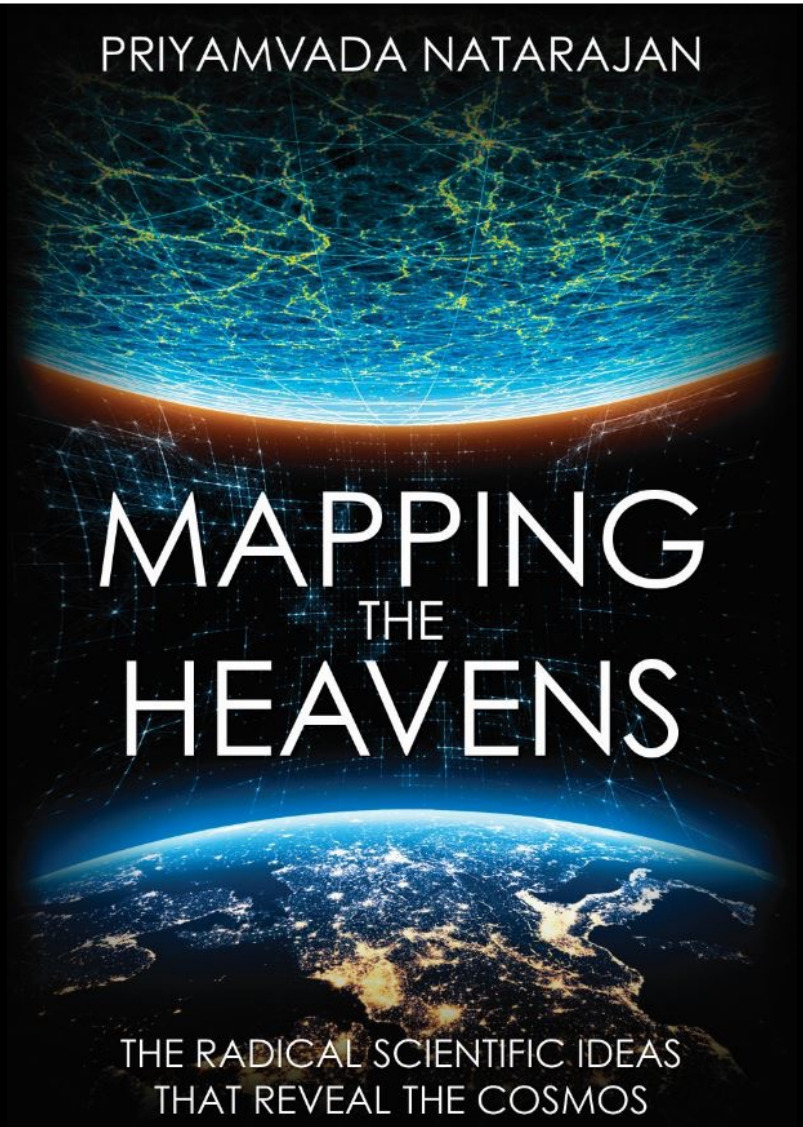


FERMILAB PUBLIC TALK SERIES

May 5, 2017

TWITTER HANDLE @SheerPriya

Arc of acceptance of radical ideas

How science works

Human and psychological side of science

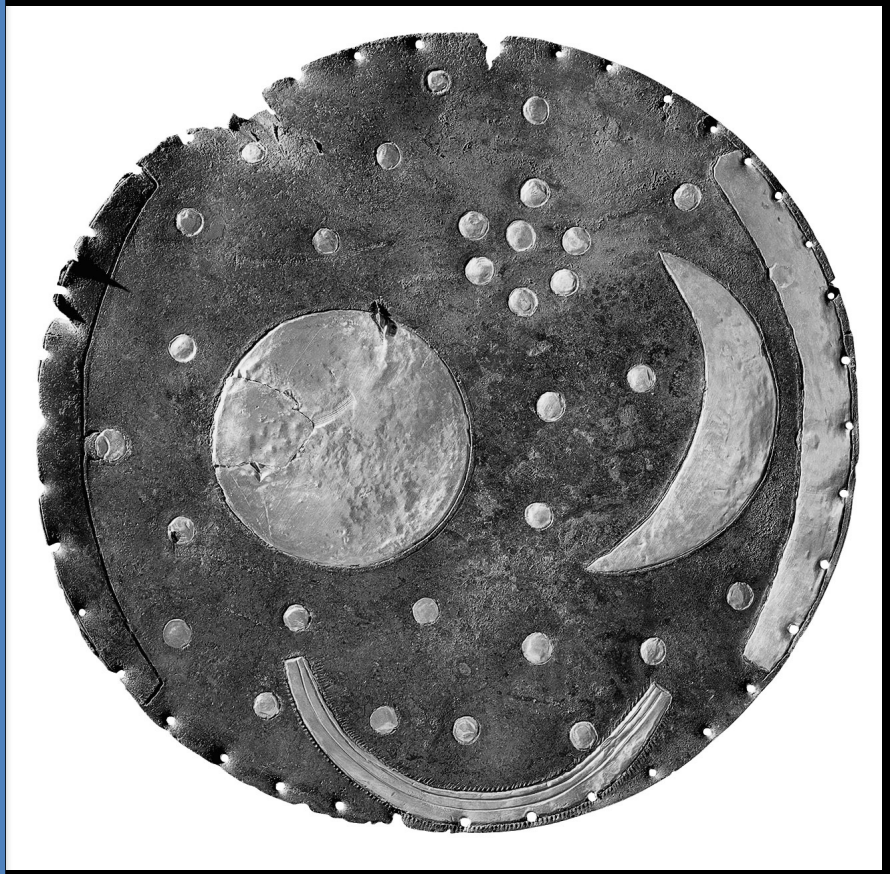
Journey from proposal to acceptance

Use maps as literal and metaphorical devices

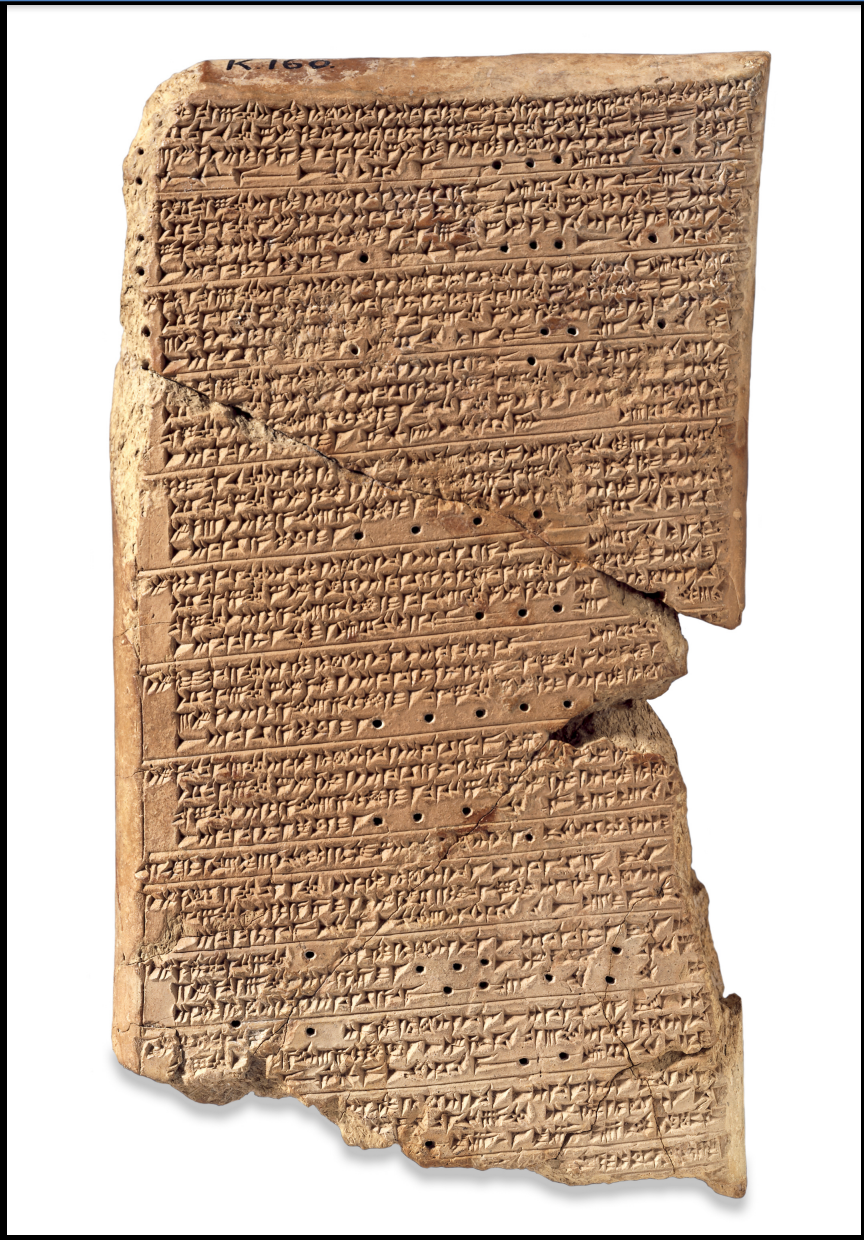
Resistance from within the scientific community

Case studies – and why this is relevant now

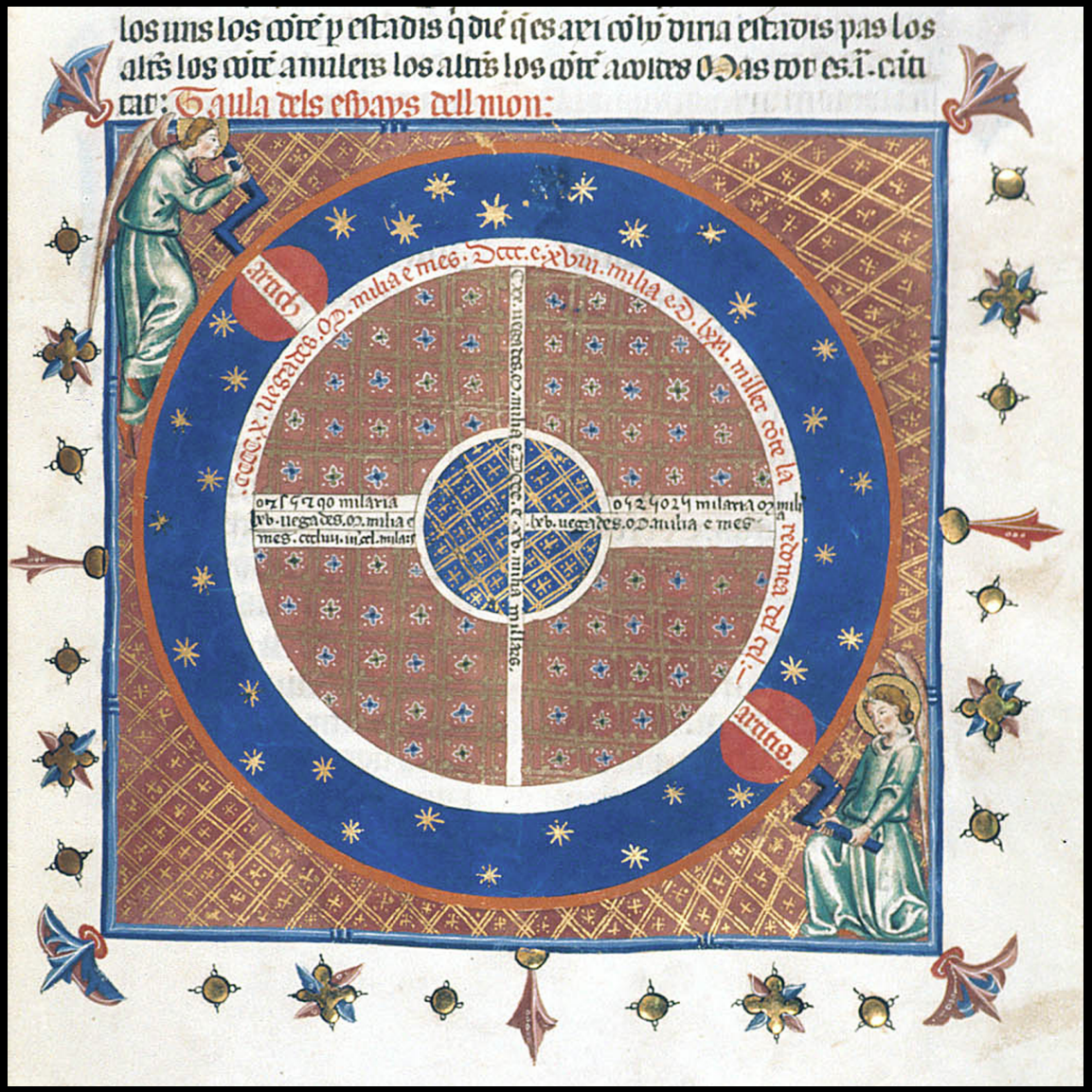
Interplay of ideas and instruments



Nebra Sky Disk
2000-1600 BCE

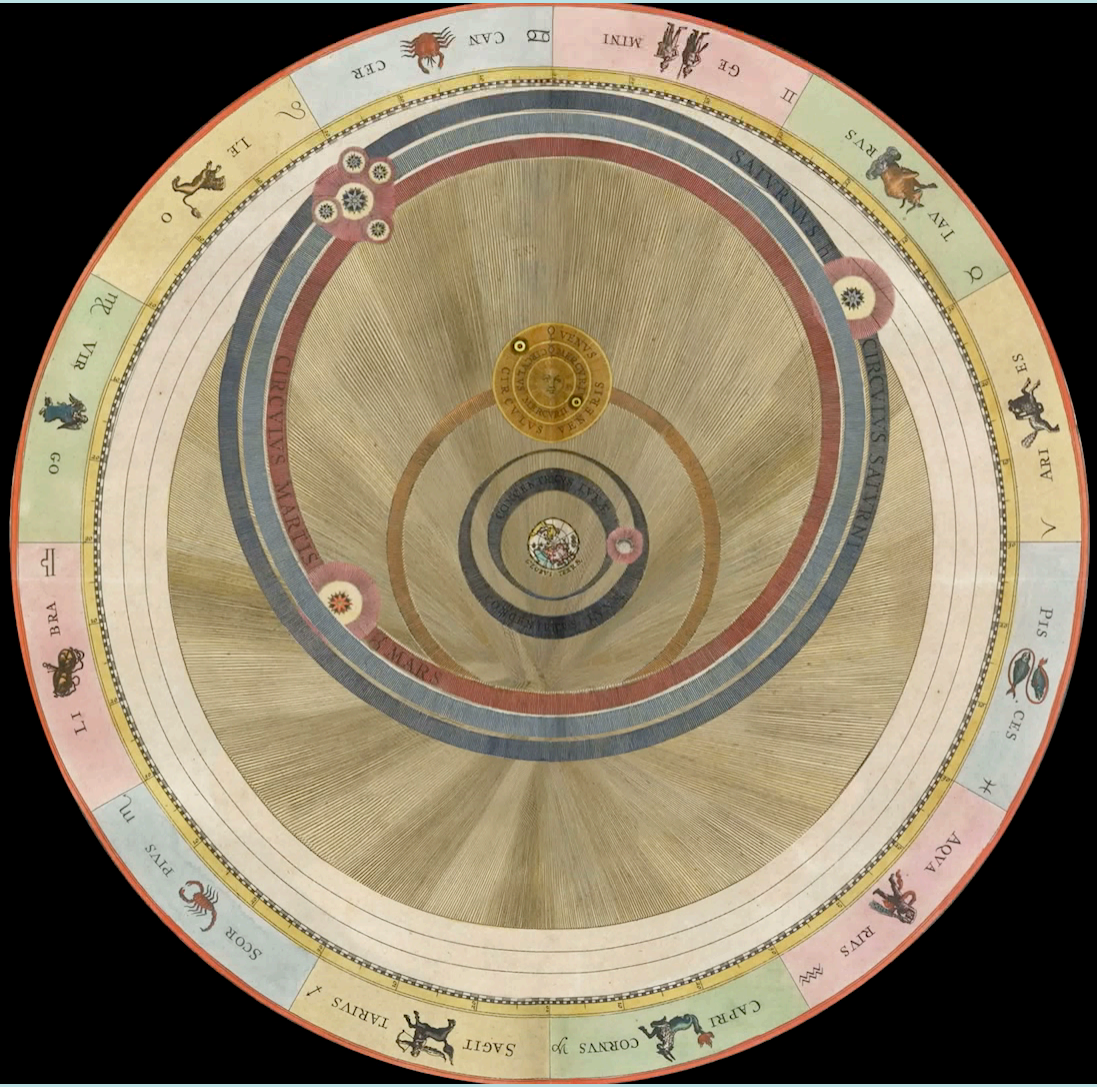


Venus Tablet
7th C BCE



Illuminated Map 1375-1400
Aristotelian-Ptolemaic cosmos, sphere of the moon – mutable and corruptible

RICCIOLI (1651) Urania weighing Copernican vs. his model
Mercury, Venus, Mars orbit the Sun which in turn orbits the Earth



CALIFORNIA ACADEMY OF SCIENCES

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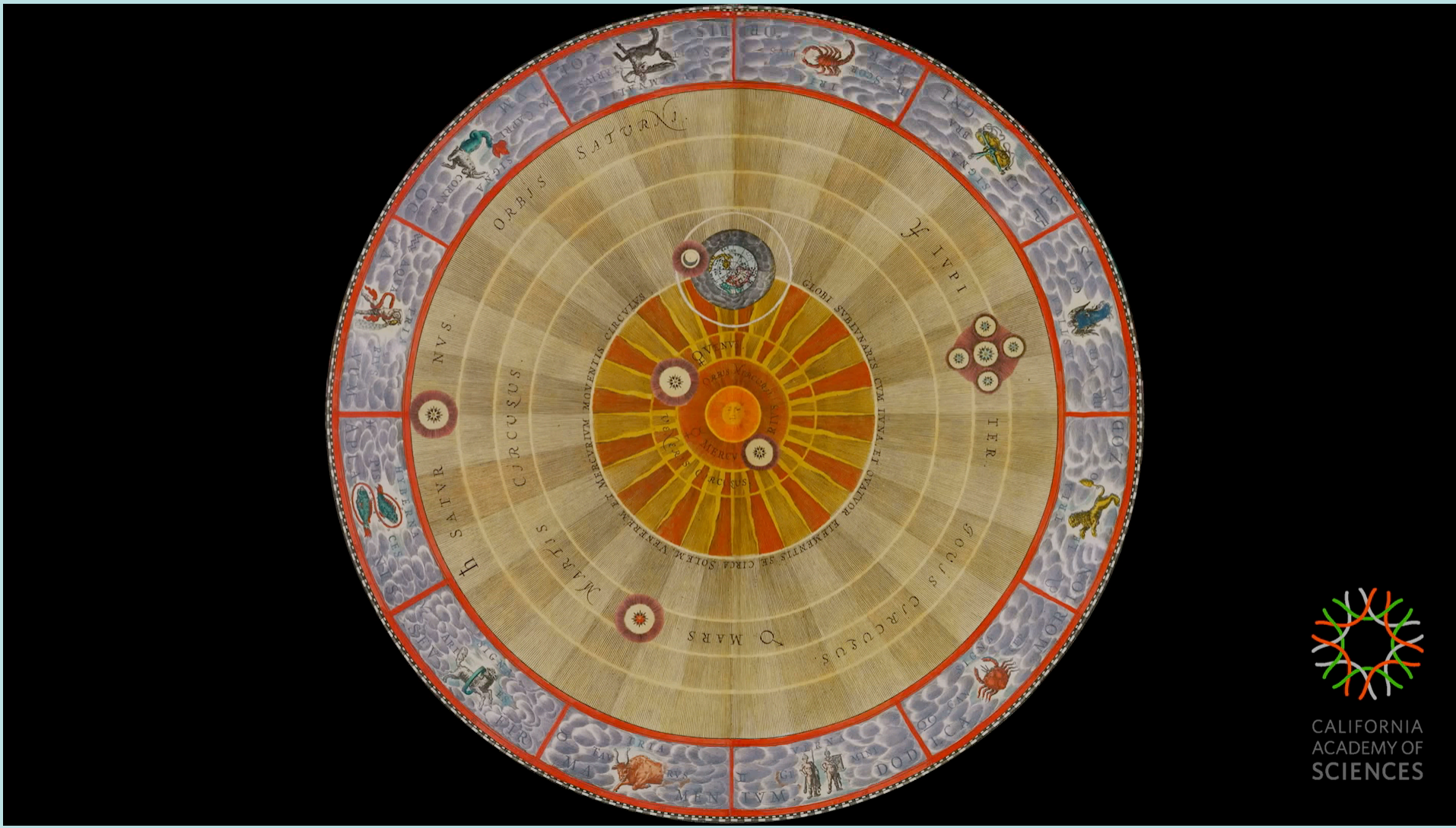

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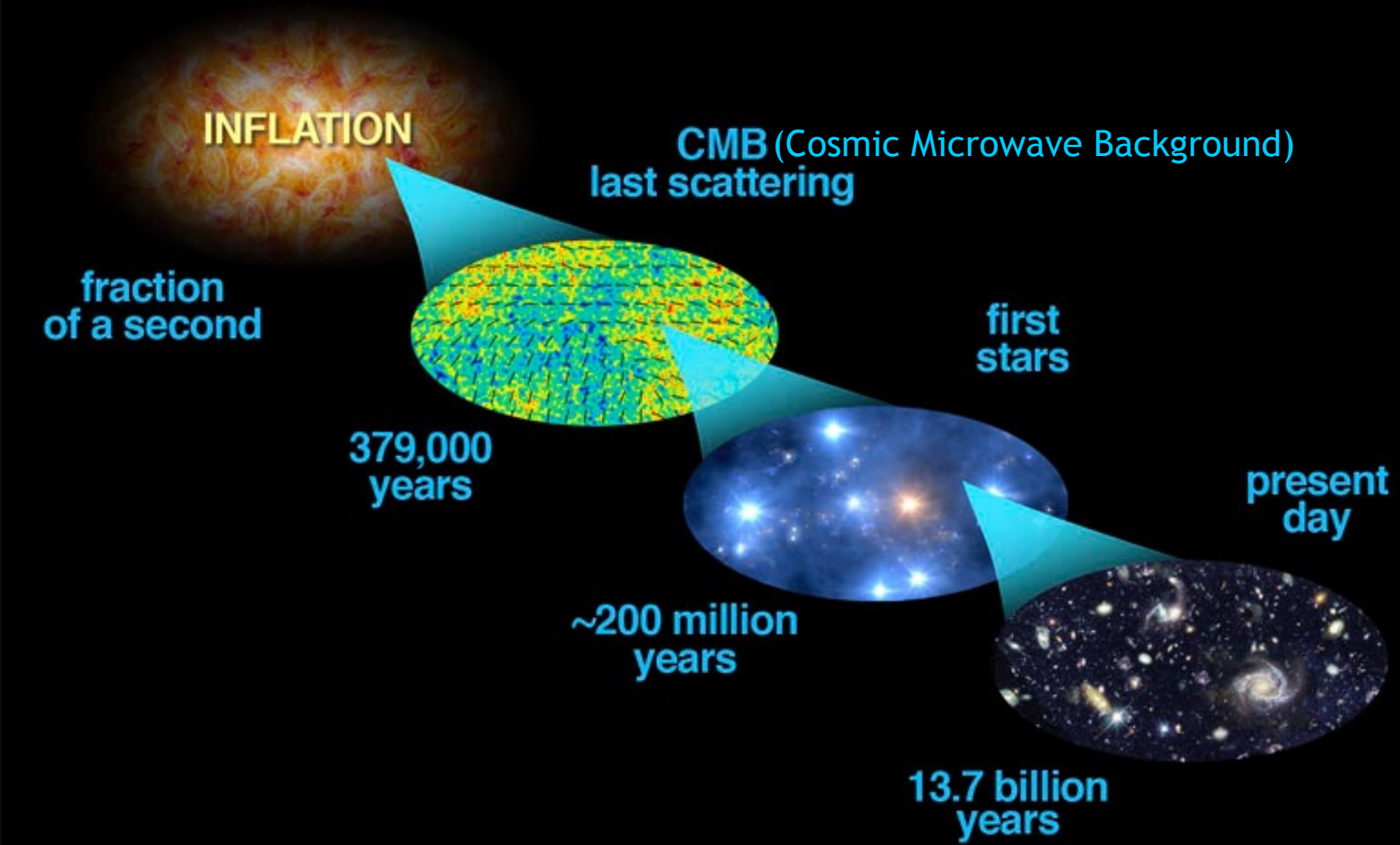
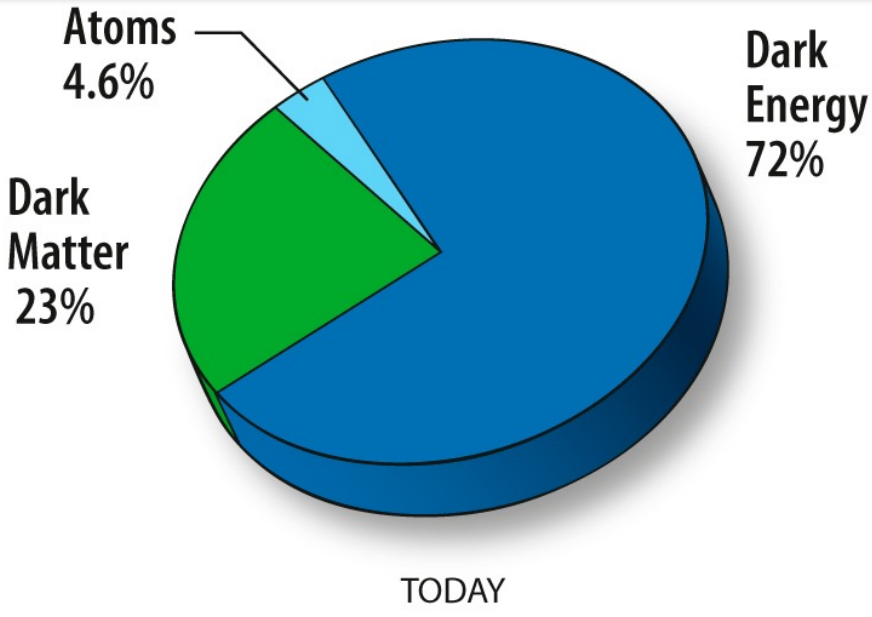
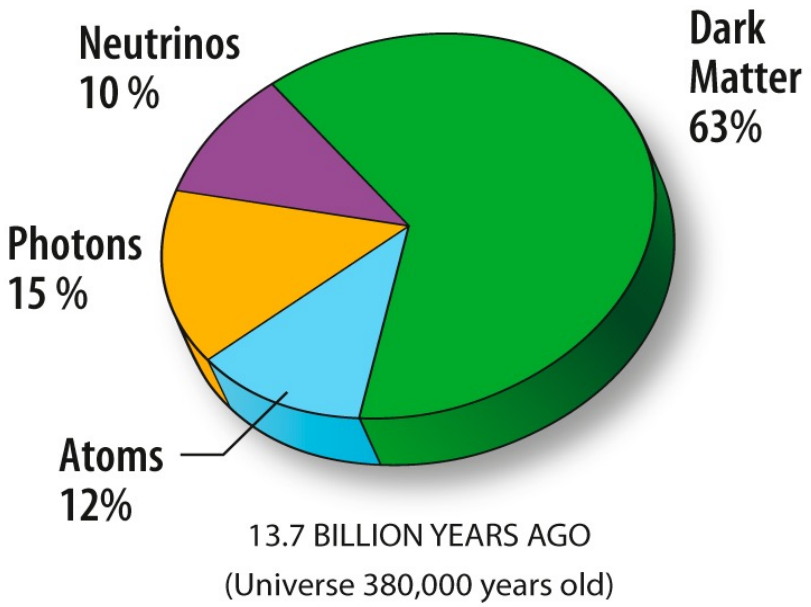
Brief (Graphic) History of the Universe



Contents of the Universe



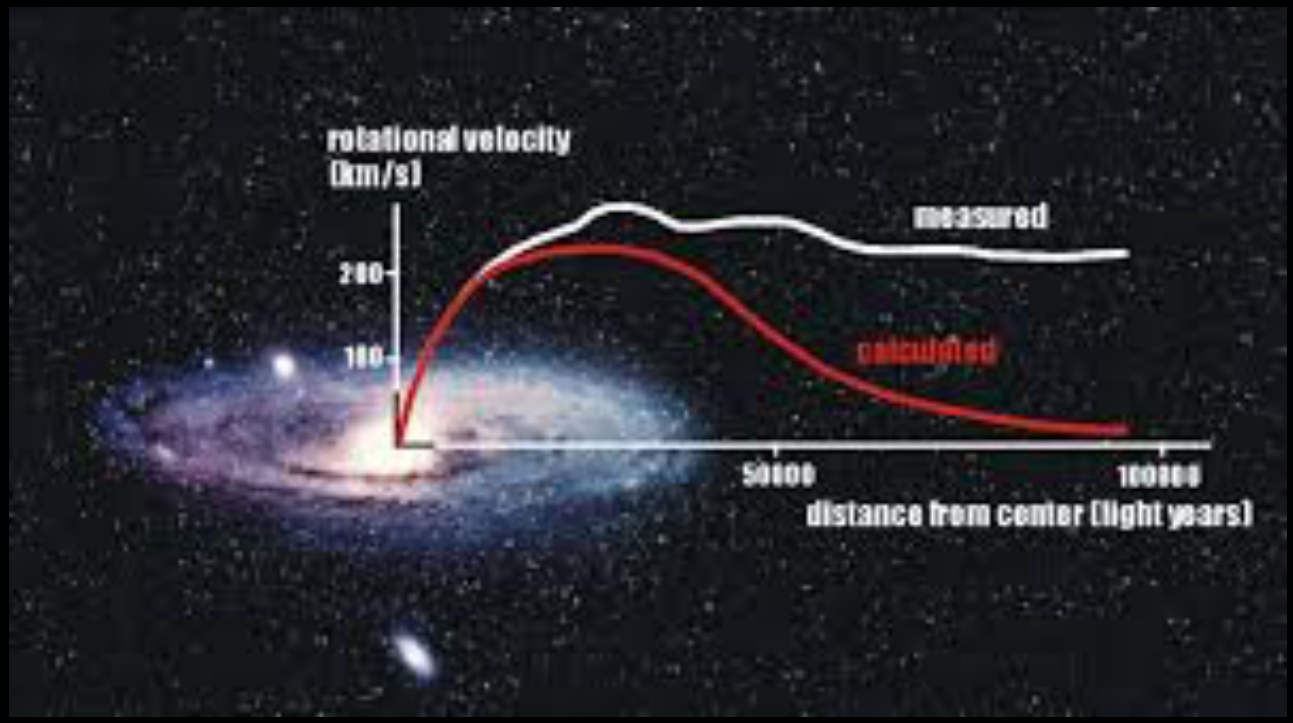


Evidence for dark matter

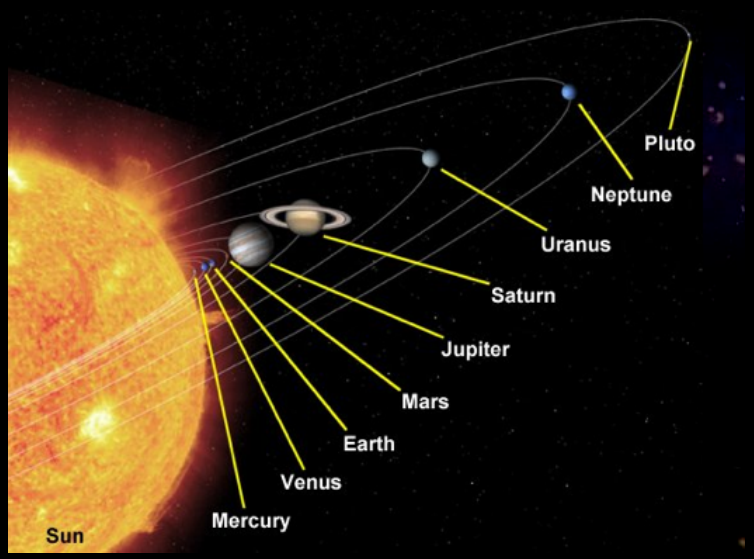
- Impact on dynamics – motions of stars
- Impact on our cosmic messenger – bending of light rays

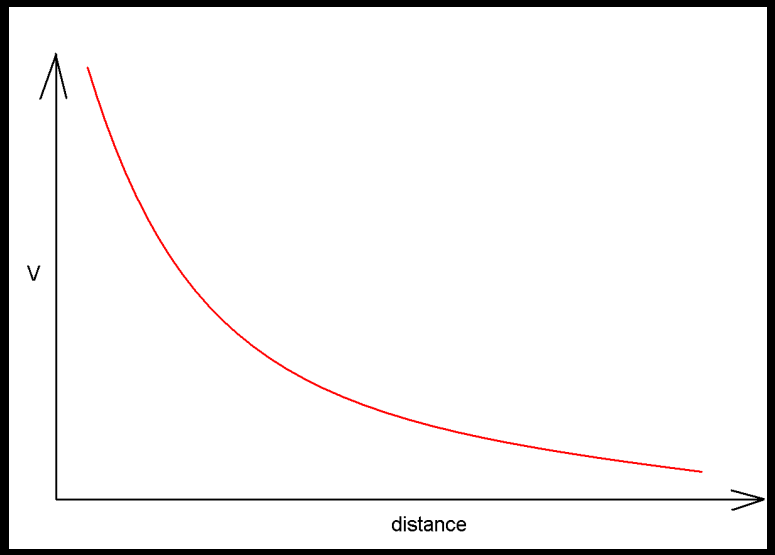
ZWICKY's DUNKLE MATERIE

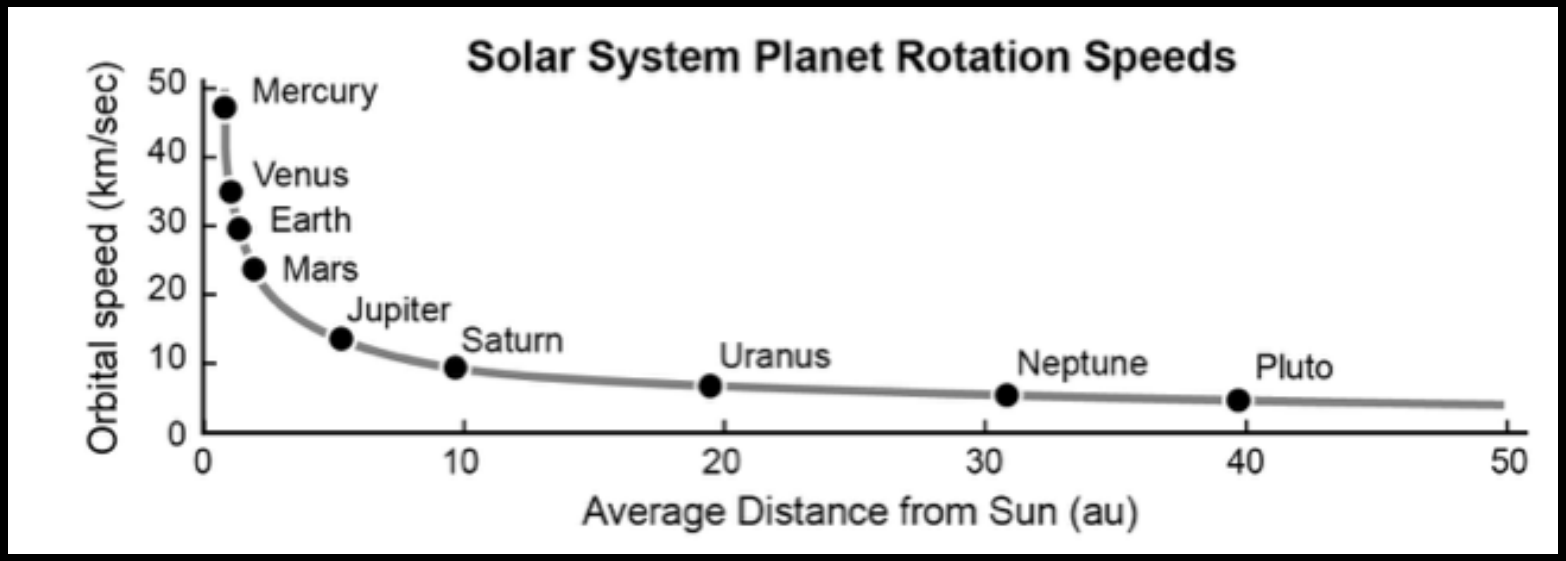
1933 Coma cluster galaxy speeds
1937 Light deflections by clusters


rotational velocity
(km/s)
200
100
measured
calculated
50000
100000
distance from center (light years)

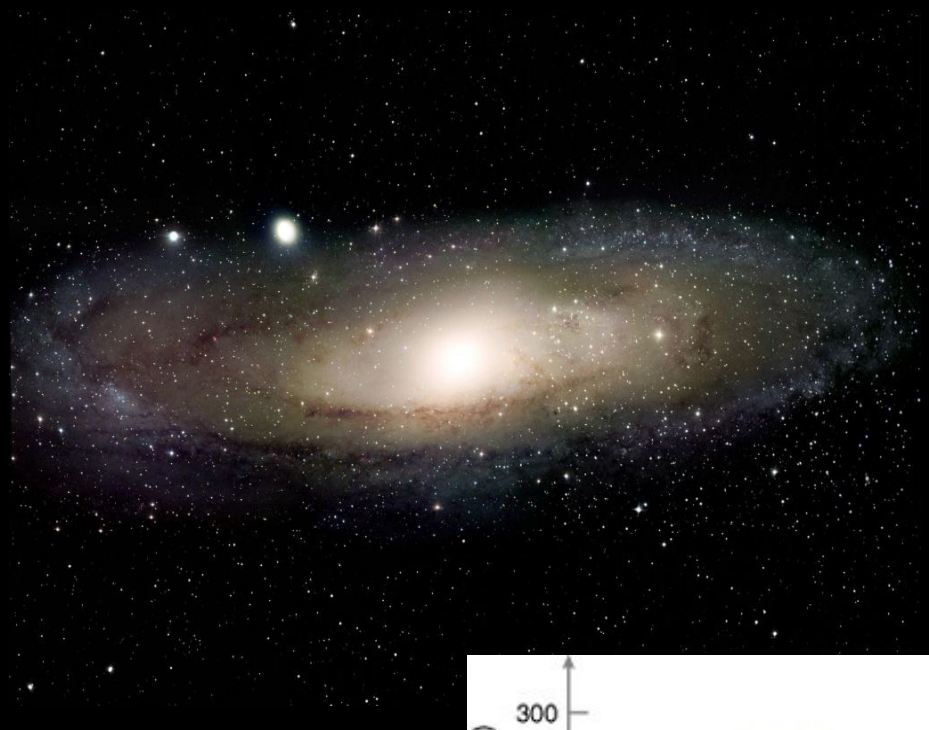
Gravity in the solar system

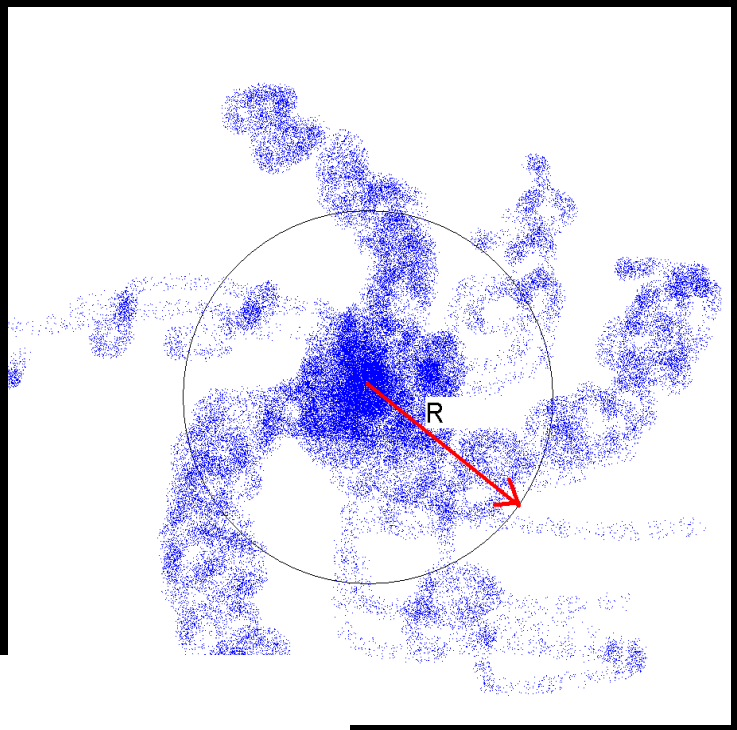


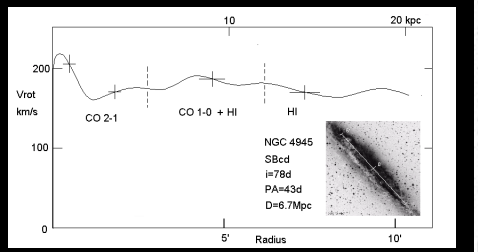


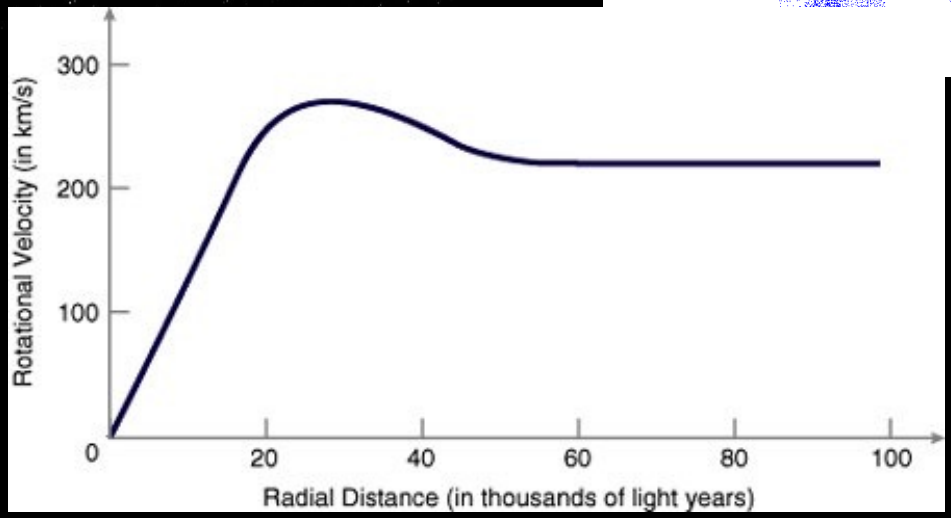


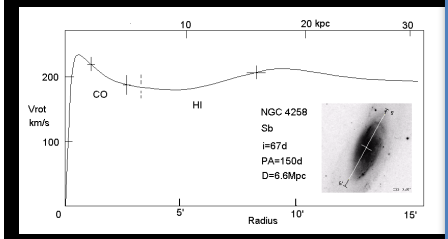
Measuring speeds of stars in galaxies

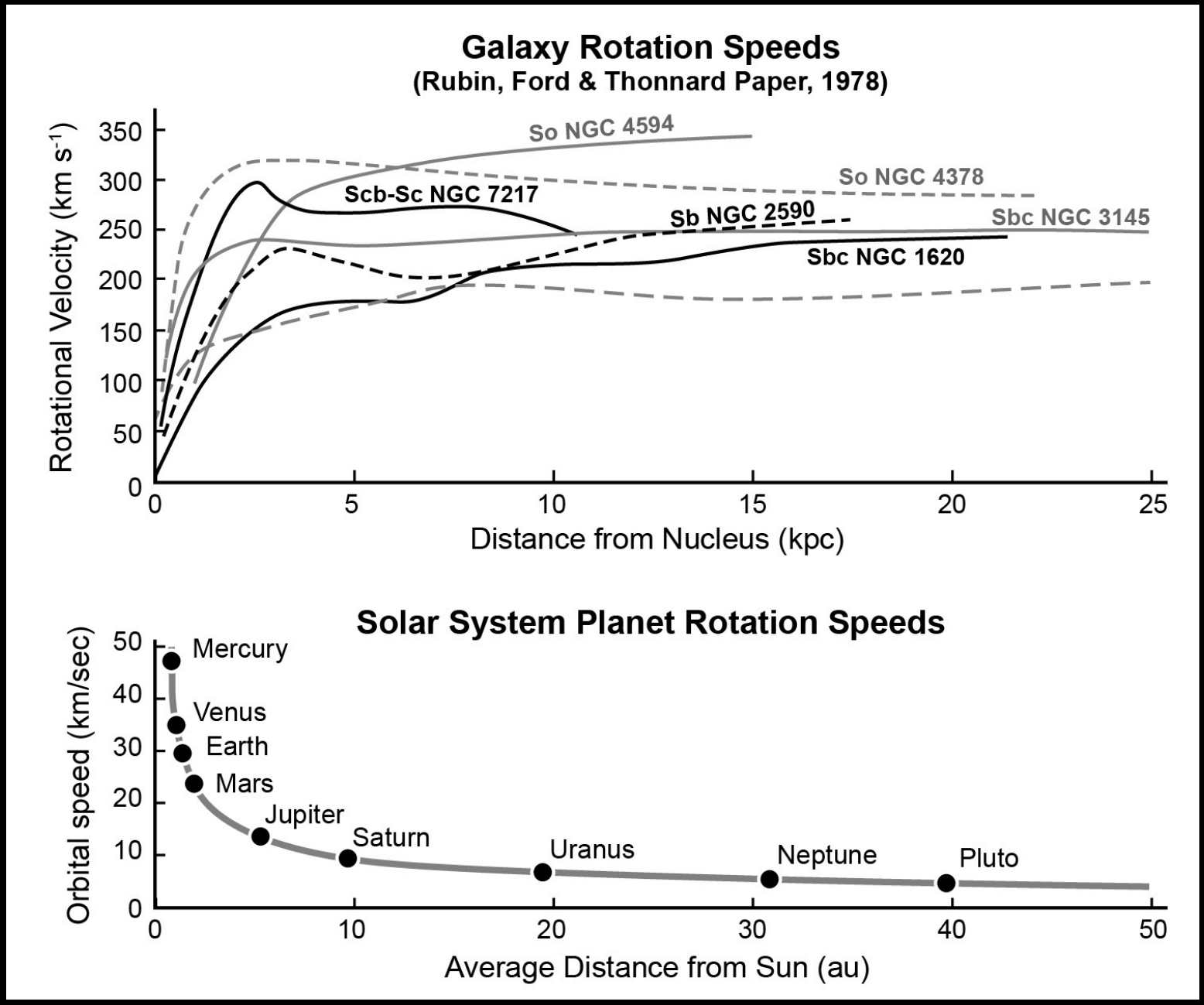




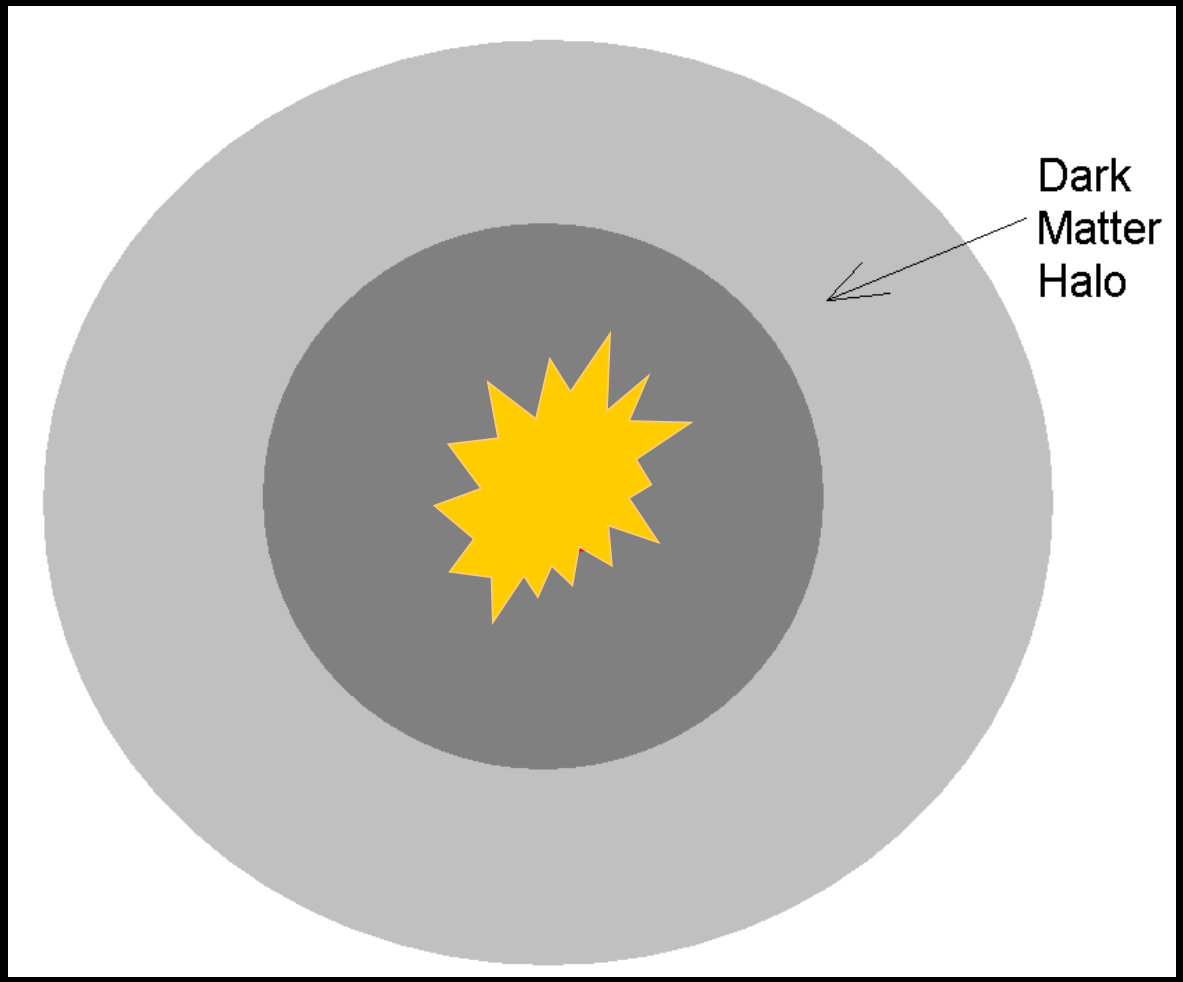






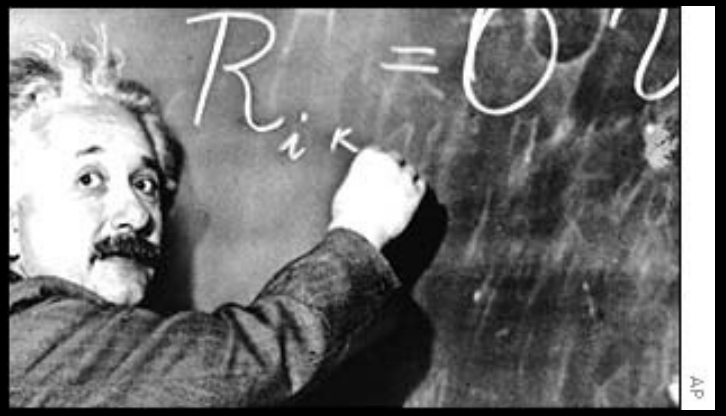

Galaxy Rotation Speeds
(Rubin, Ford & Thonnard Paper, 1978)
Rotational Velocity (km s-1)
350
300
250
200
150
100
50
0
0
5
10
15
20
25
Distance from Nucleus (kpc)
So NGC 4594
So NGC 4378
Scb-Sc NGC 7217
Sb NGC 2590
Sbc NGC 3145
Sbc NGC 1620
Solar System Planet Rotation Speeds
Orbital speed (km/sec)
50
40
30
20
10
0
0
10
20
30
40
50
Average Distance from Sun (au)
Mercury
Venus
Earth
Mars
Jupiter
Saturn
Uranus
Neptune
Pluto

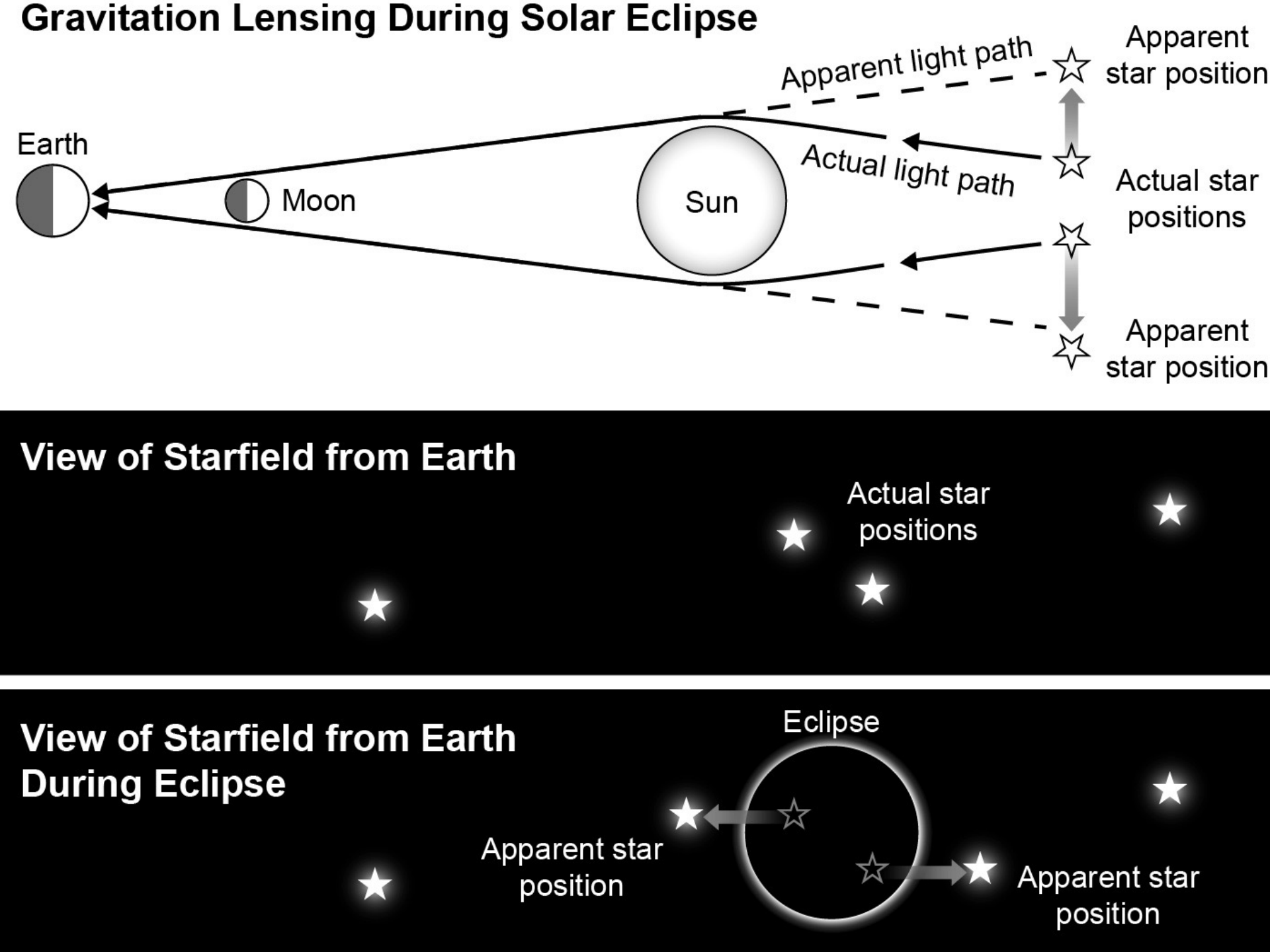
Current conception of galaxies

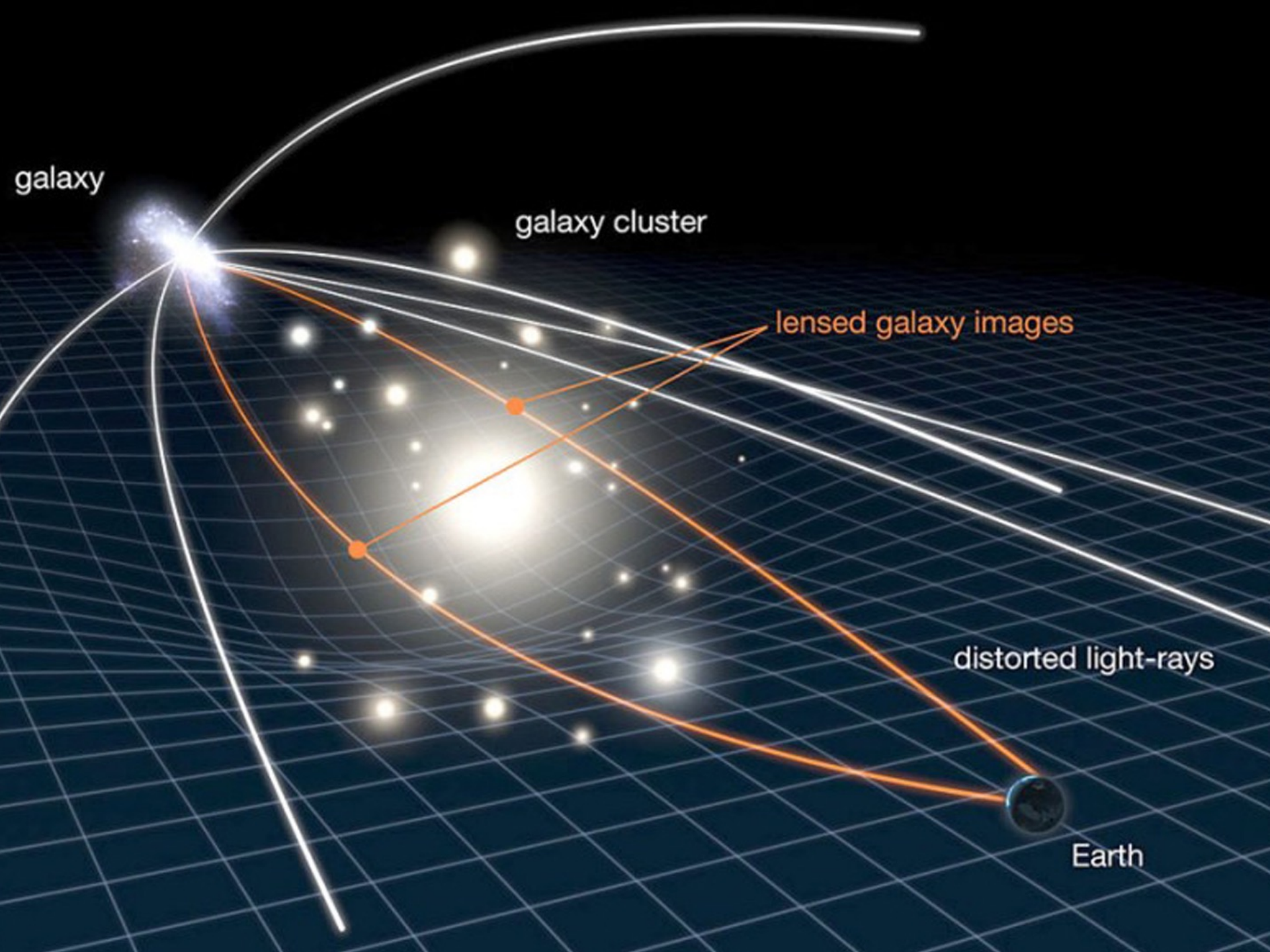


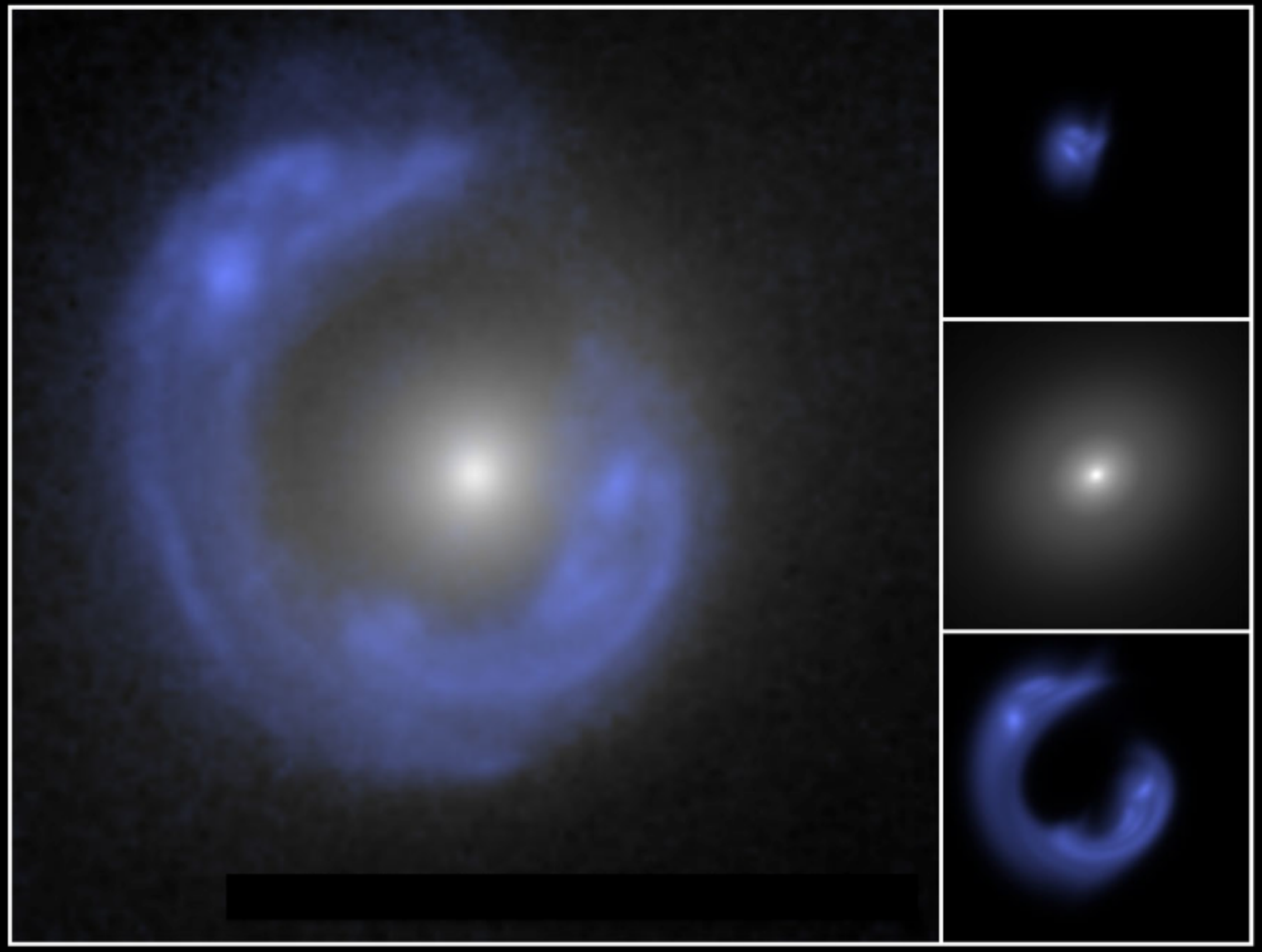
Discovery of light deflection

- Suspected by Newton and Laplace - in the context of the corpuscular theory of light
  - Soldner (1804) calculated deflection angle
- Einstein (1915) applied his General Theory of Relativity
- Eclipse experiment (1917)
  - confirms Einstein's result

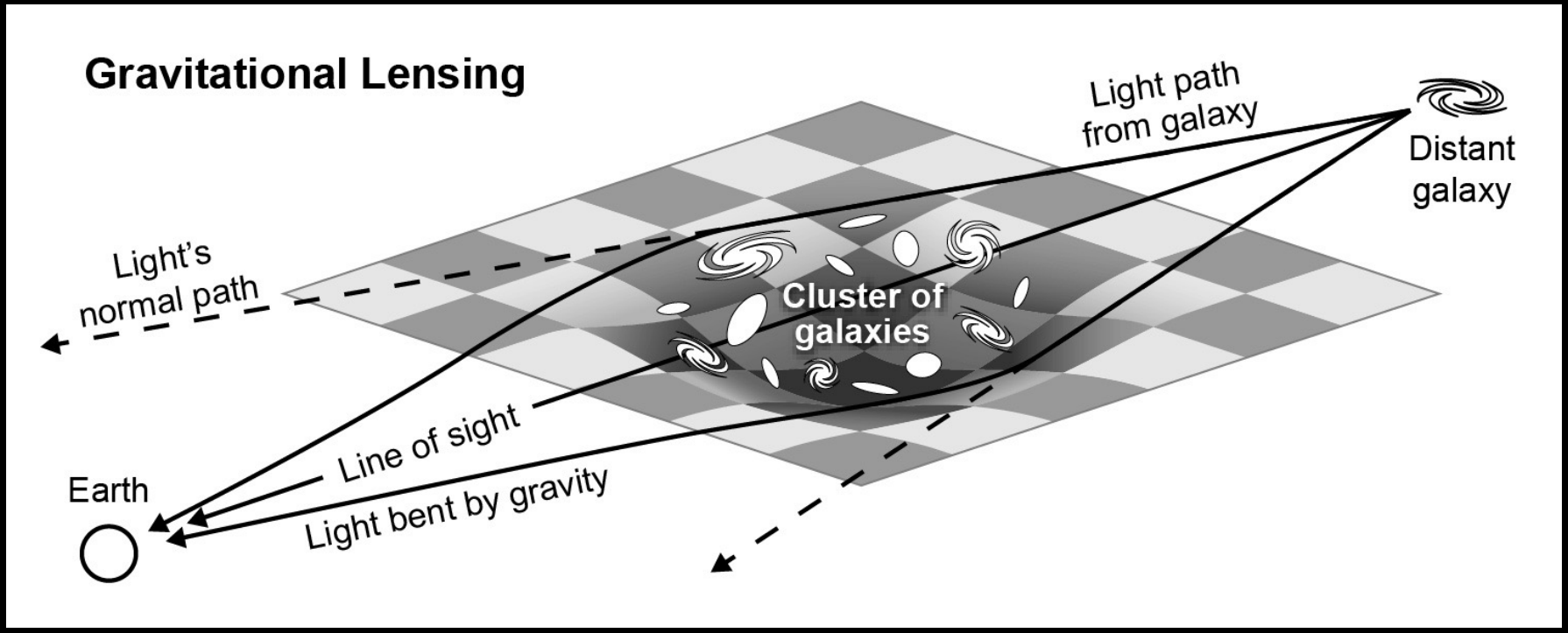


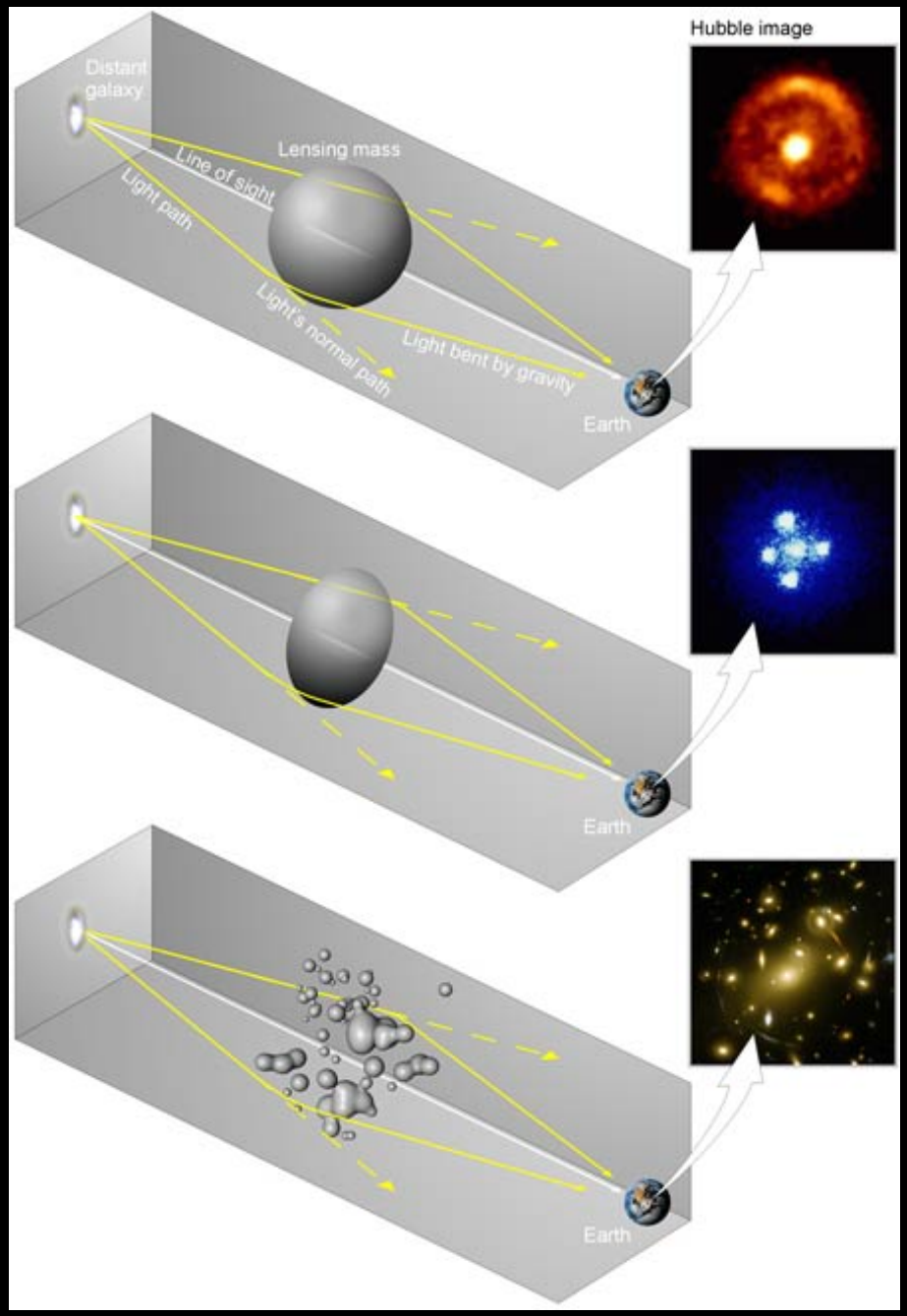

Gravitation Lensing During Solar Eclipse
Apparent light path
Apparent star position
Earth
Moon
Sun
Actual light path
Actual star positions
Apparent star position
View of Starfield from Earth
Actual star positions
View of Starfield from Earth During Eclipse
Eclipse
Apparent star position
Apparent star position

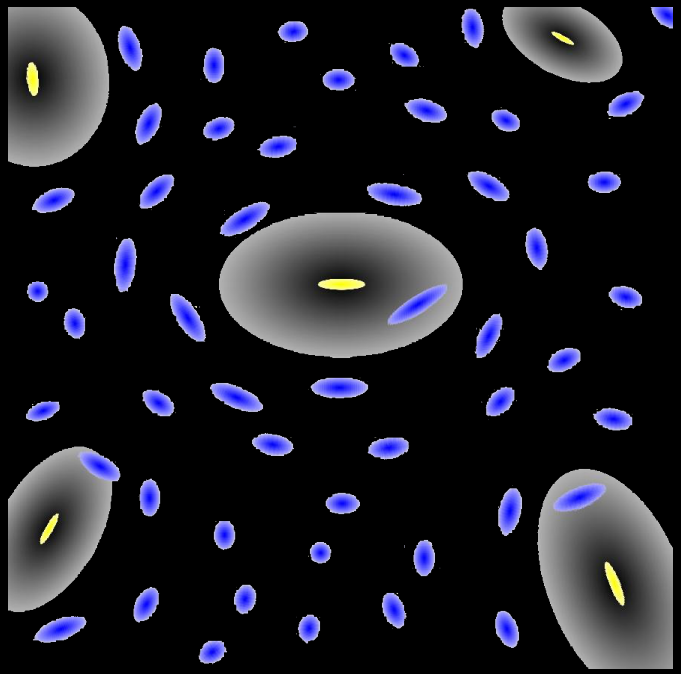

galaxy
galaxy cluster
lensed galaxy images
distorted light-rays
Earth

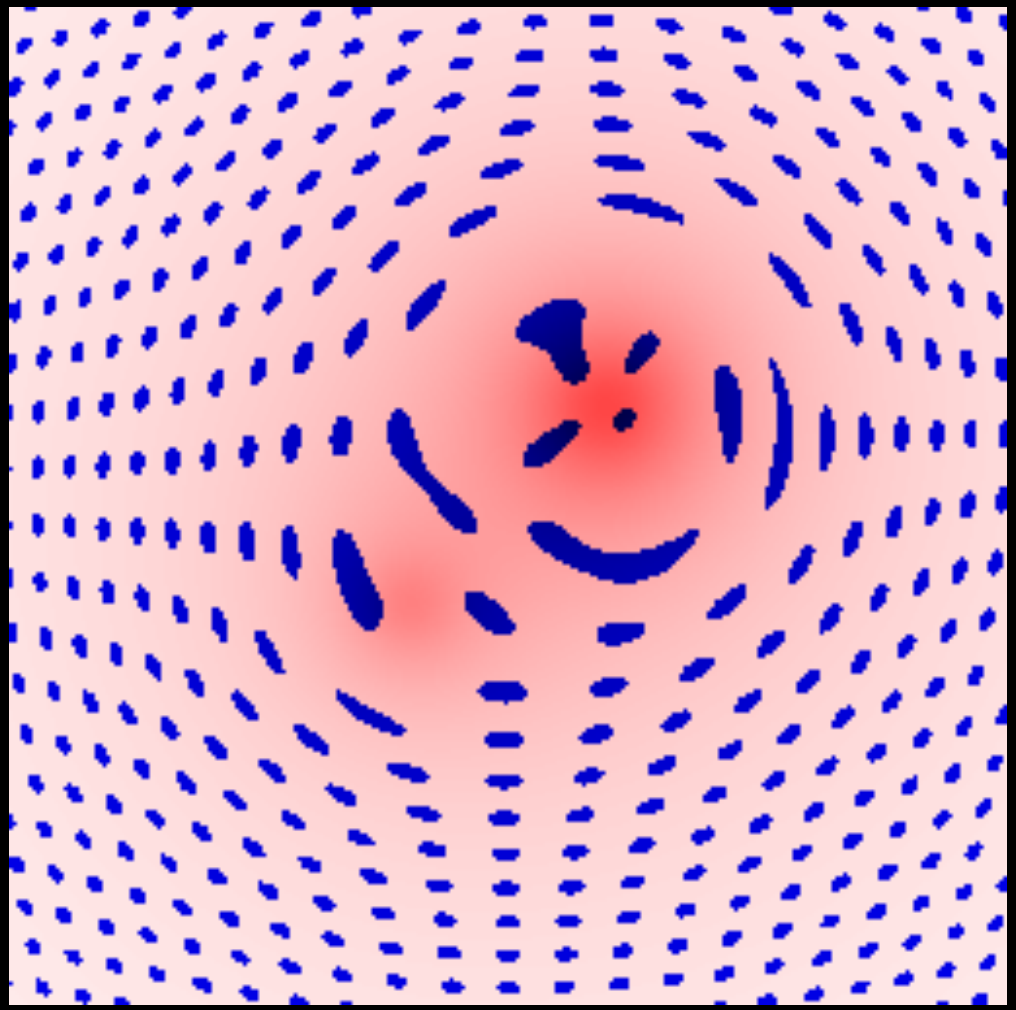


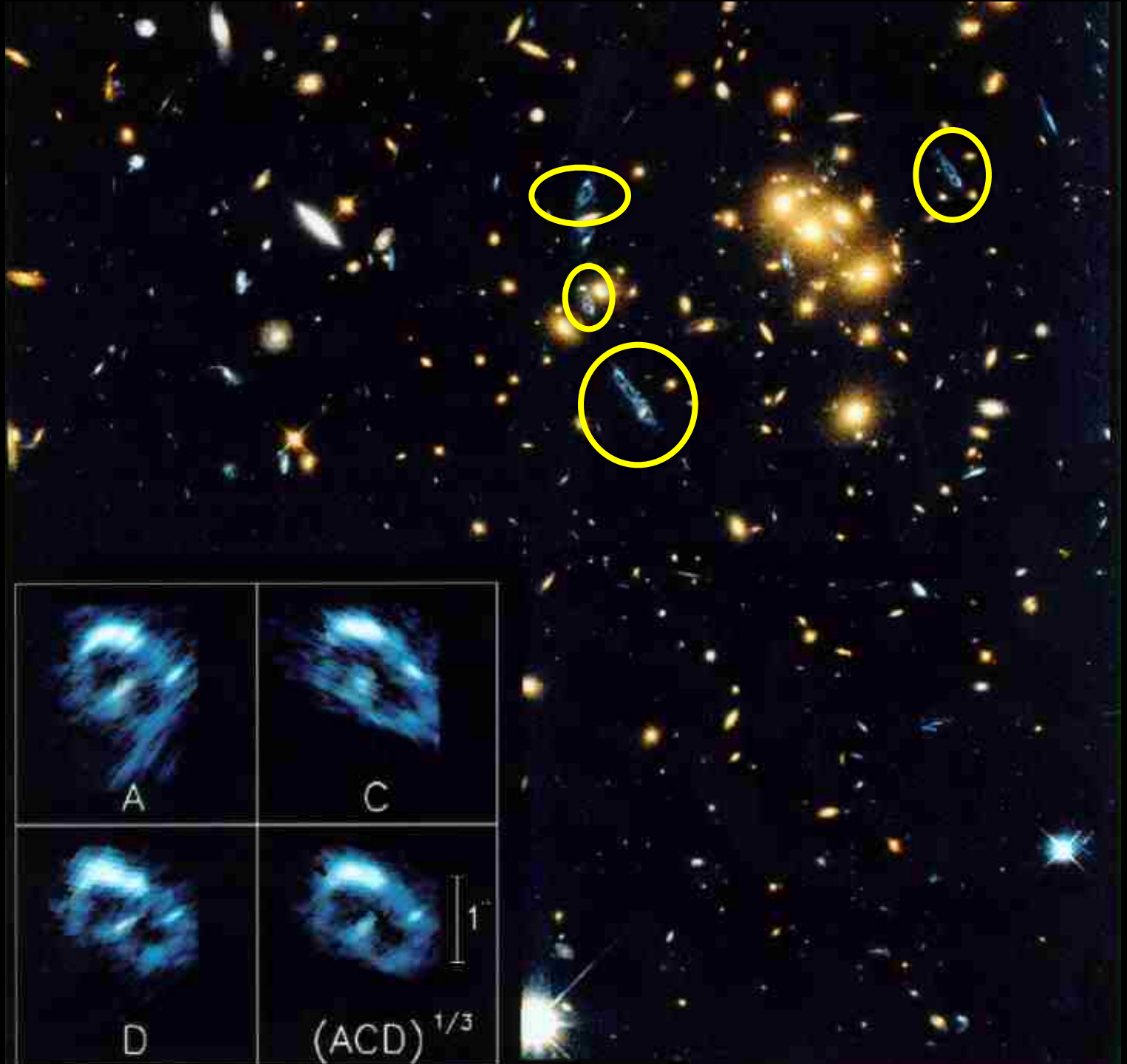
Lensing by clusters



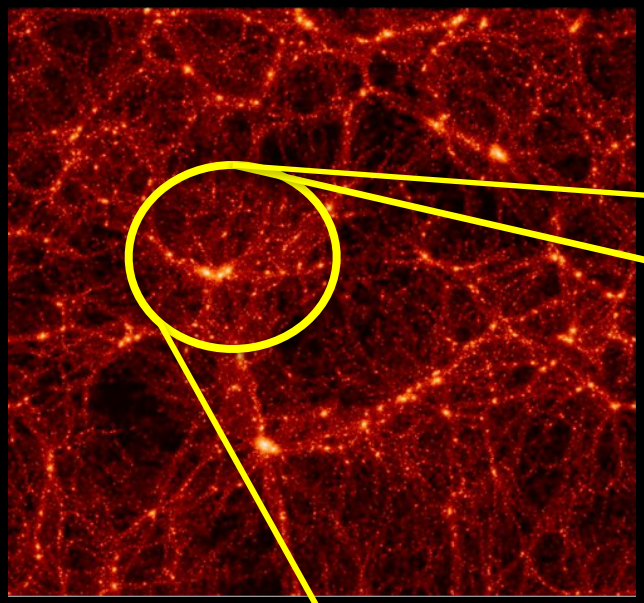

Hubble image
Distant galaxy
Lensing mass
Line of sight
Light path
Light's normal path
Light bent by gravity
Earth
Earth
Earth






A
C
D
(ACD) 1/3
1"

Galaxy Cluster Abell 2218

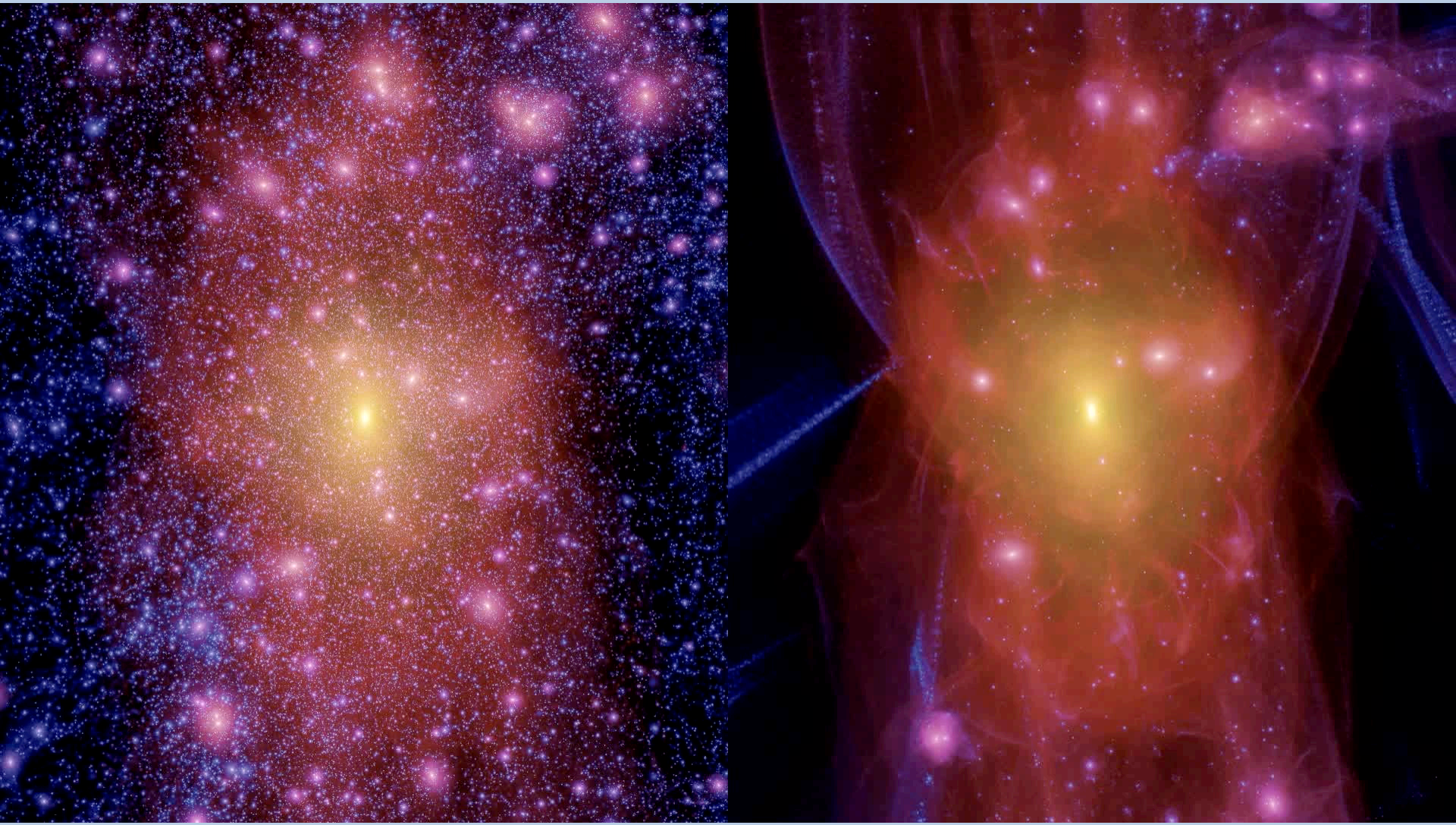


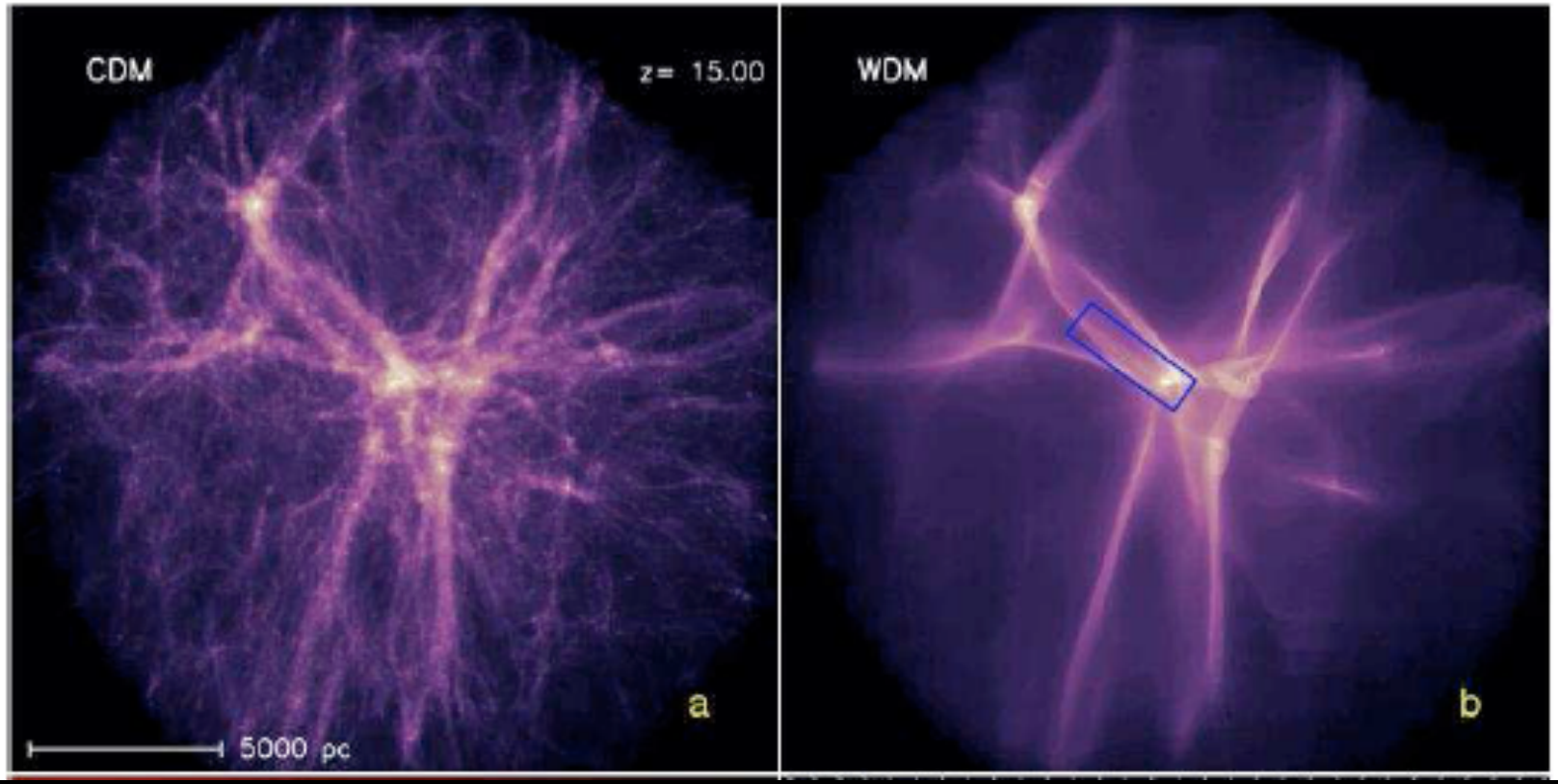
R = 6.0 Mpc

z = 10.155

a = 0.090

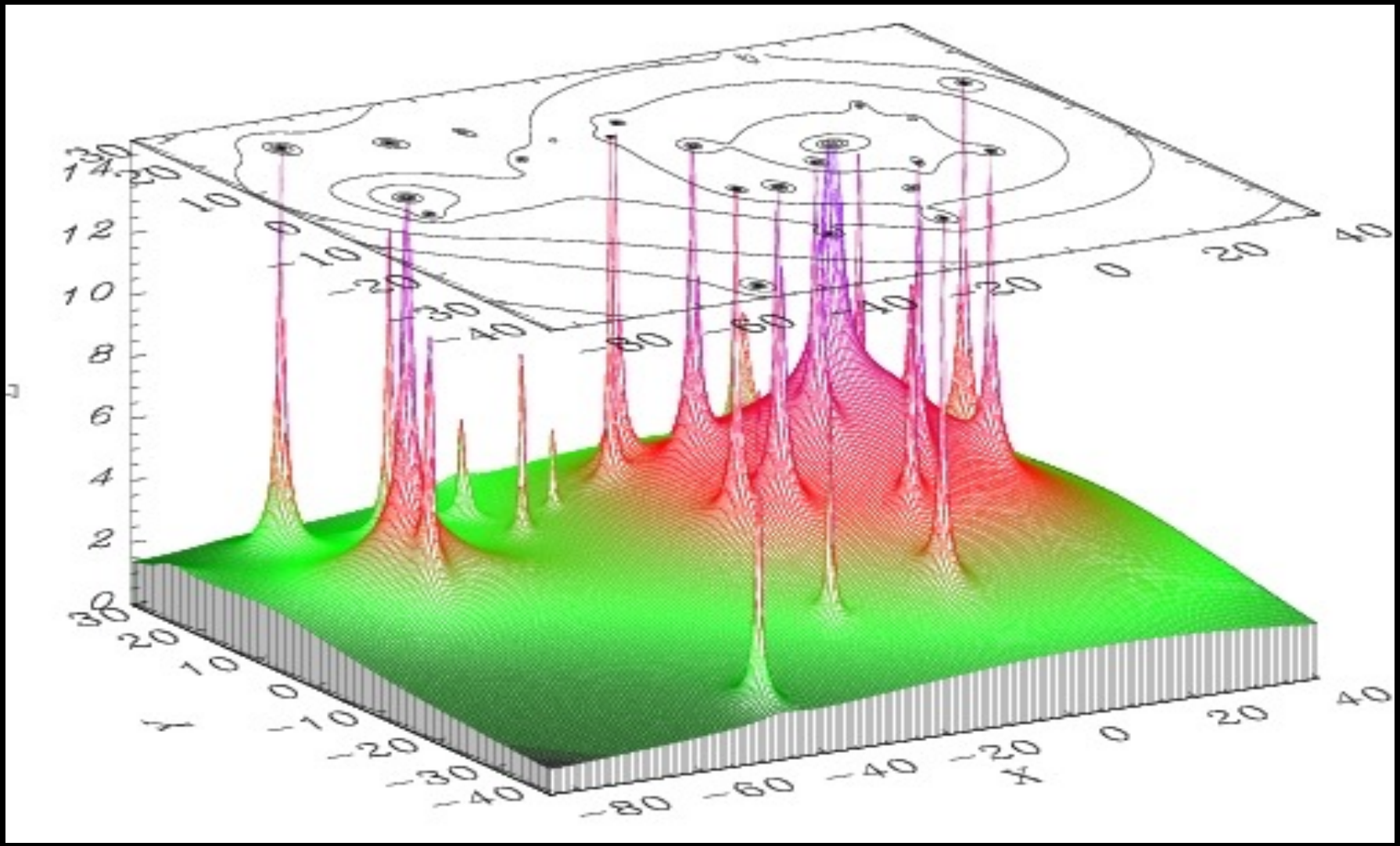
diemand 2003



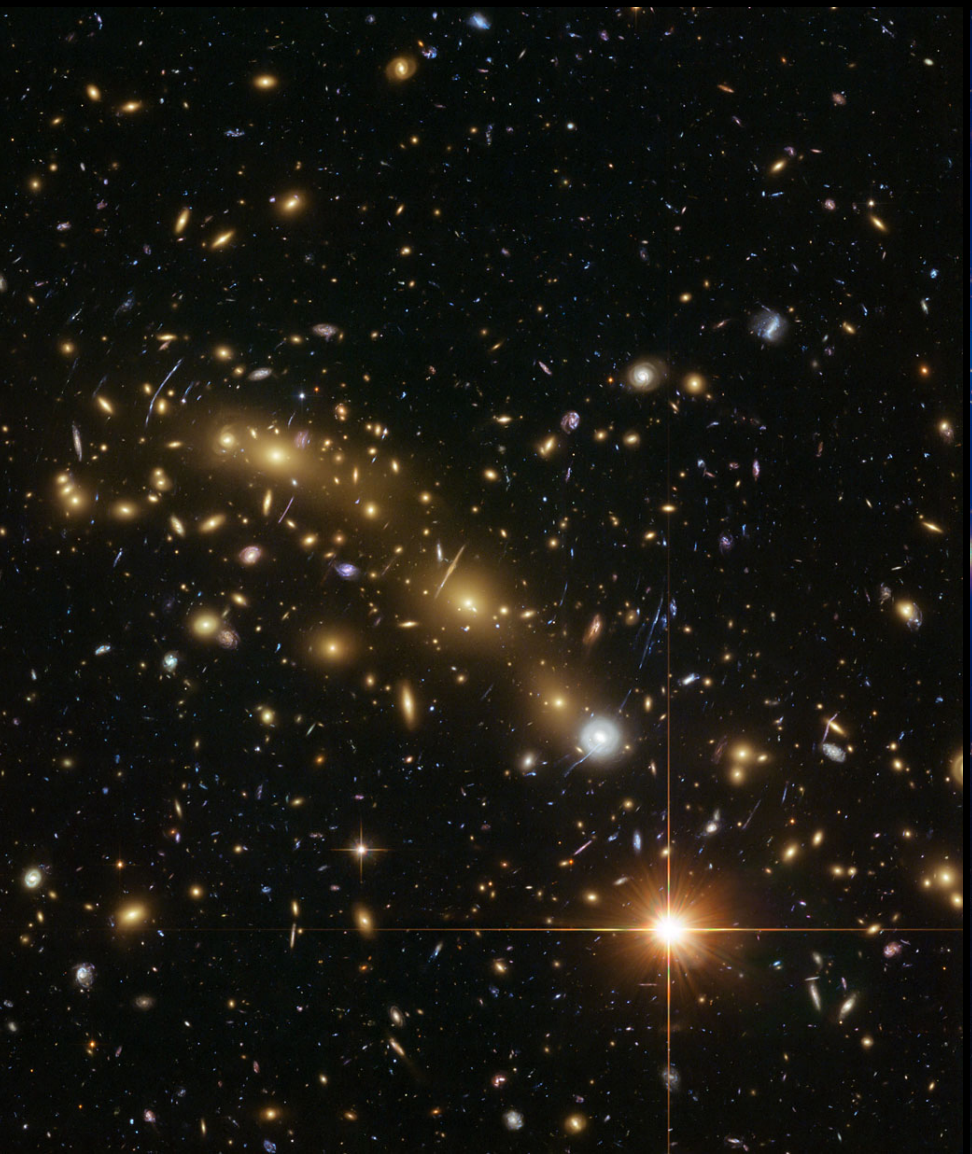

CDM
z = 15.00
a
5000 pc
WDM
b

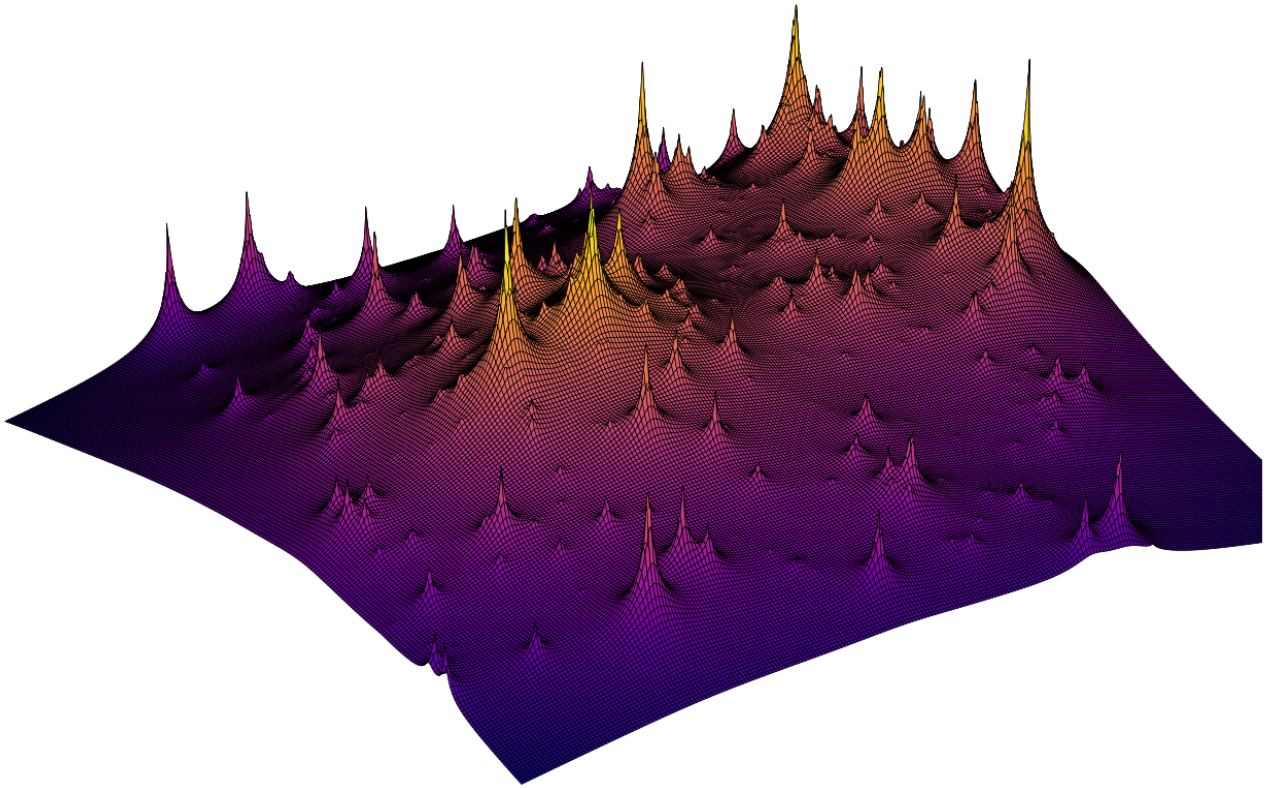
Galaxy Cluster Abell 2218

100
50
0
−50
−100
x(arcsec)
y(arcsec)


14
12
10
8
6
4
2
30
20
10
0
−10
−20
−30
−40
Y
−80
−60
−40
−20
0
20
40
X

HUBBLE FRONTIER FIELDS



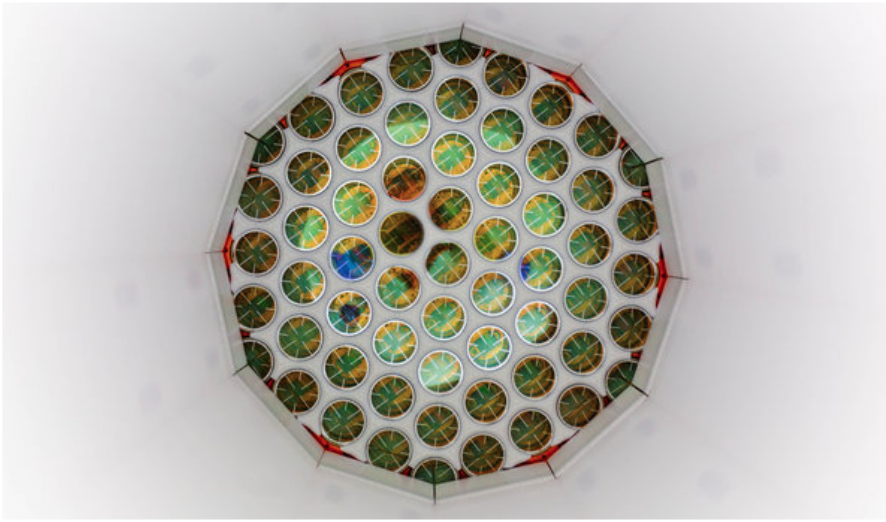


DETECTING DARK MATTER

HAVE WE DETECTED DARK MATTER YET?

NOPE, RECENTLY THE UNDERGROUND XENON DETECTOR EXPERIMENT LUX RELEASED THEIR FIRST RESULTS – NO SIGNATURE OF DARK MATTER YET...

Dark Matter Experiment Has Detected Nothing, Researchers Say Proudly



Matthew Kapust/South Dakota Science and Technology Author

Inside the Large Underground Xenon dark matter detector.

By DENNIS OVERBYE
Published: October 30, 2013

The former Homestake Gold Mine in Lead, S.D., has a hallowed place in the history of physics as a spot where nothing happens.

FACEBOOK
TWITTER
GOOGLE+

NATURE | NEWS

Controversial dark-matter claim faces ultimate test

Multiple teams finally have the material they need to repeat enigmatic experiment.

Davide Castelvecchi

05 April 2016 | Corrected: 07 April 2016

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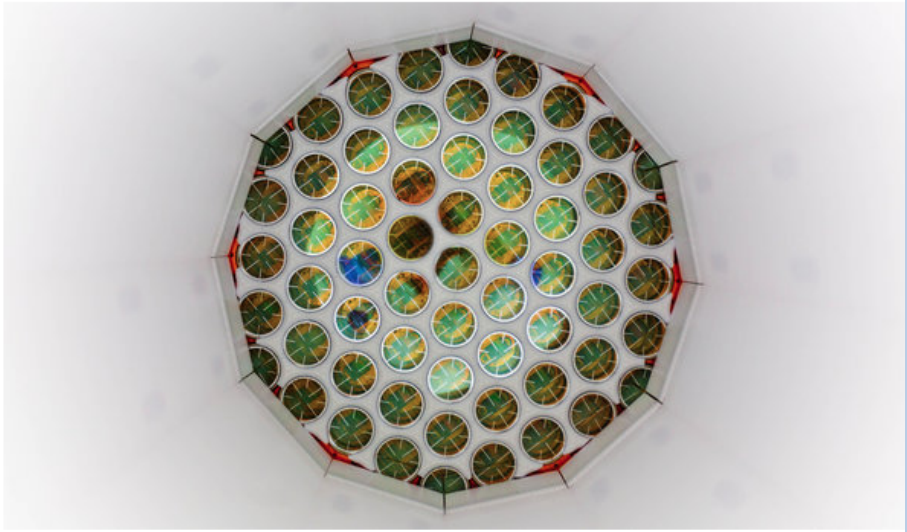

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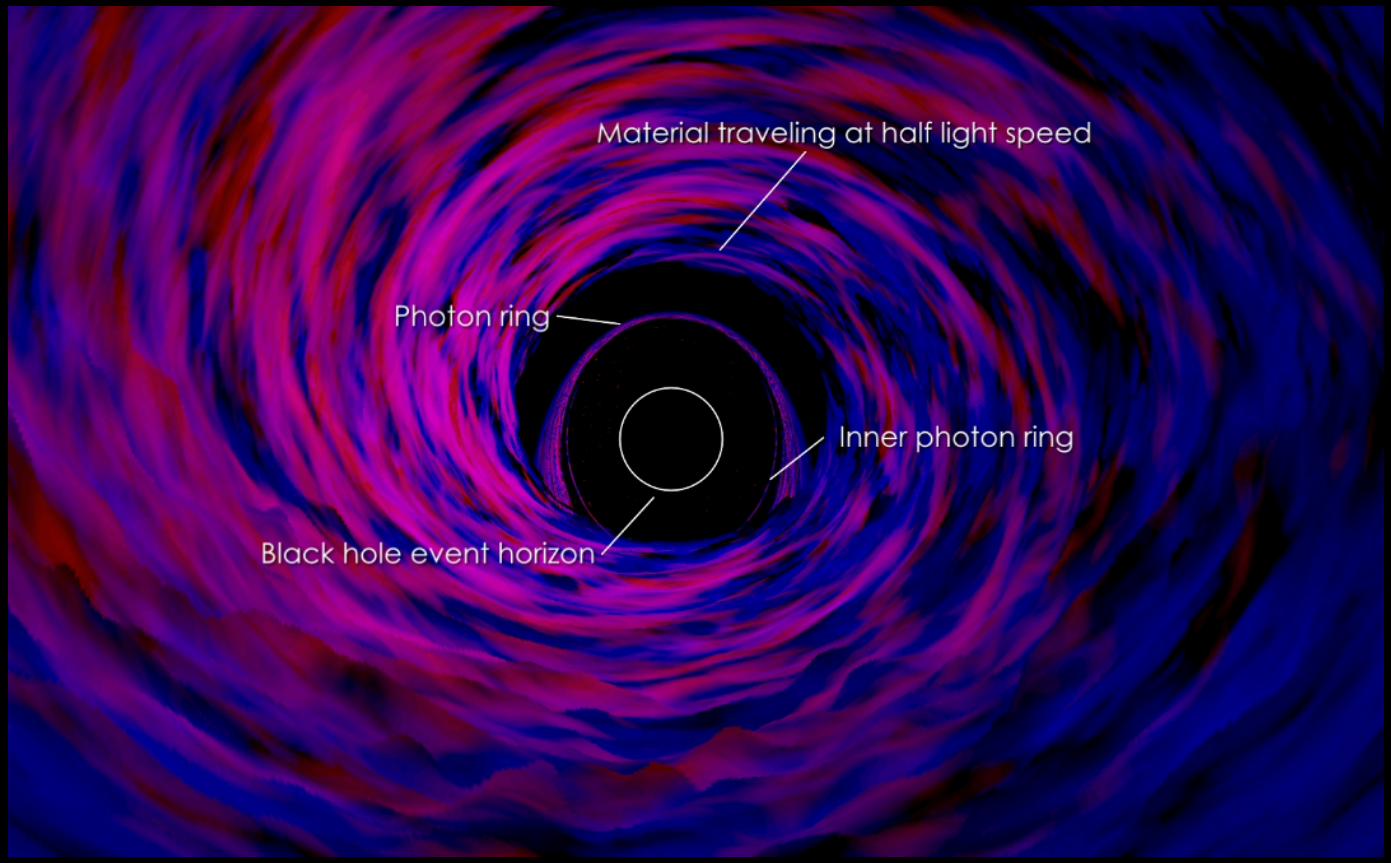
FACEBOOK
TWITTER
GOOGLE+

HOW BLACK HOLES BECAME REAL



ORIGIN OF THE IDEA

Dark Star John Michell & Laplace 1780-90s

Astrophysical use John Wheeler 1964

Discovery of pulsars Bell & Hewish

Discovery of quasars Schmidt

BLACK HOLE OF CALCUTTA (1756)

WHAT IS A BLACK HOLE?

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!

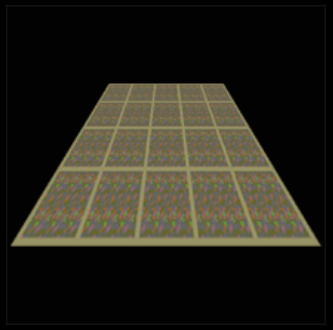
WHAT IF THE ESCAPE VELOCITY = SPEED OF LIGHT = c?

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

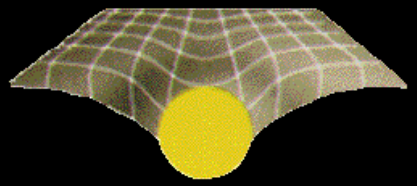
FOR THE EARTH R = 0.89 cm; SUN R = 3.0 km

Gravity: Einstein's reconception of Newton
more mass (density) = more spacetime curvature

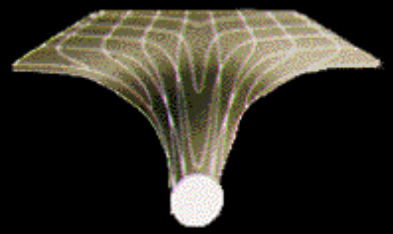
Flat space



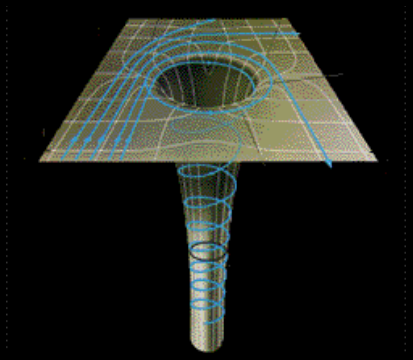
The Sun



Neutron star

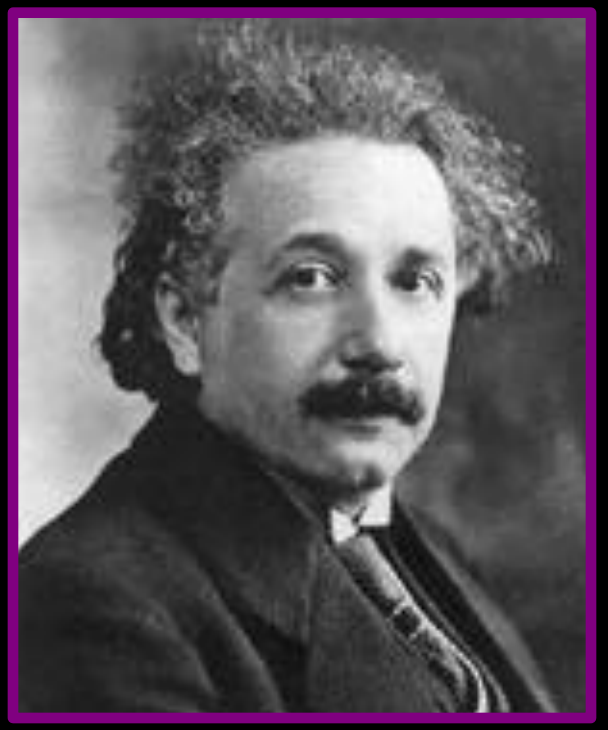


Black hole

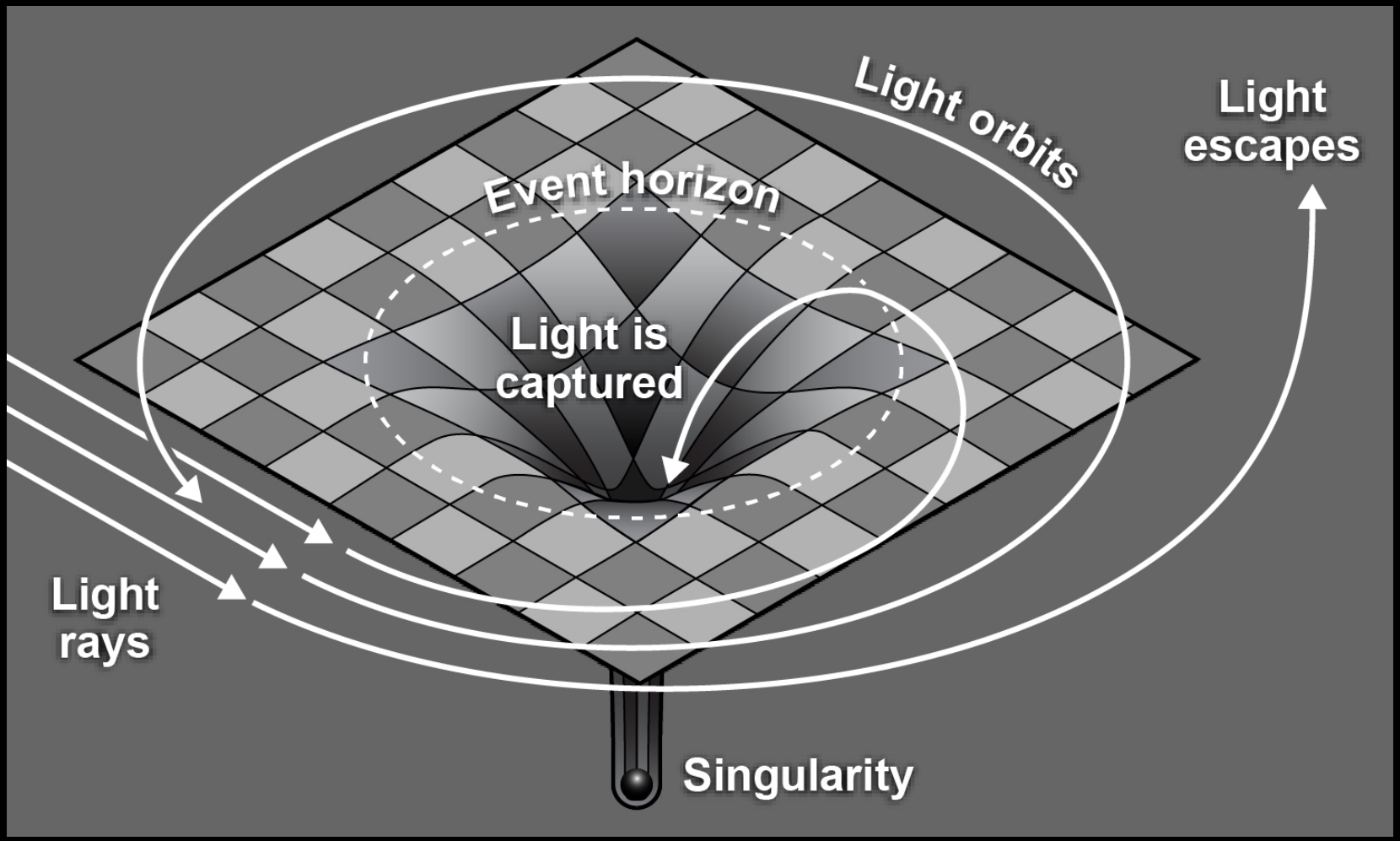


A New Theory of Gravity

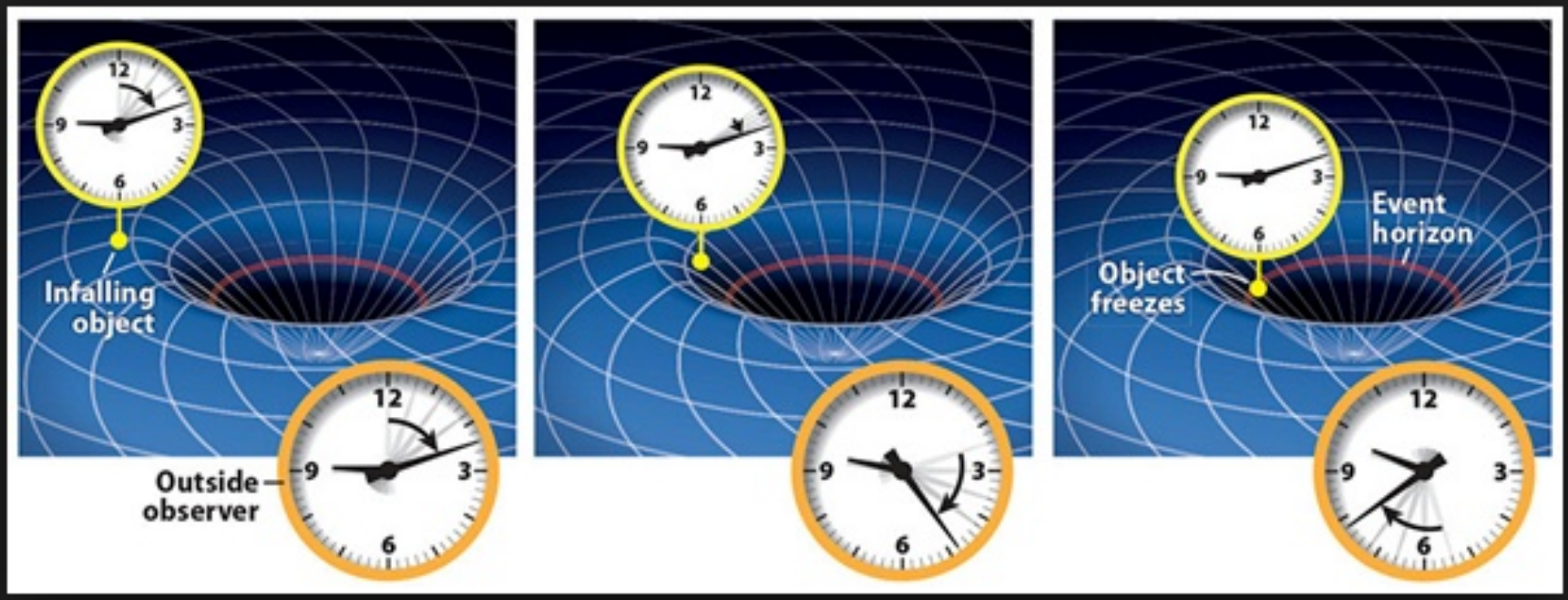
- General Relativity (GR)
  - published by Einstein in 1916
  - GR describes all gravitational systems
    - black holes
    - planetary systems
    - the universe
- Connections between mass and space
  - mass creates curvature in space
  - space curvature tells masses how to move- gravitational acceleration

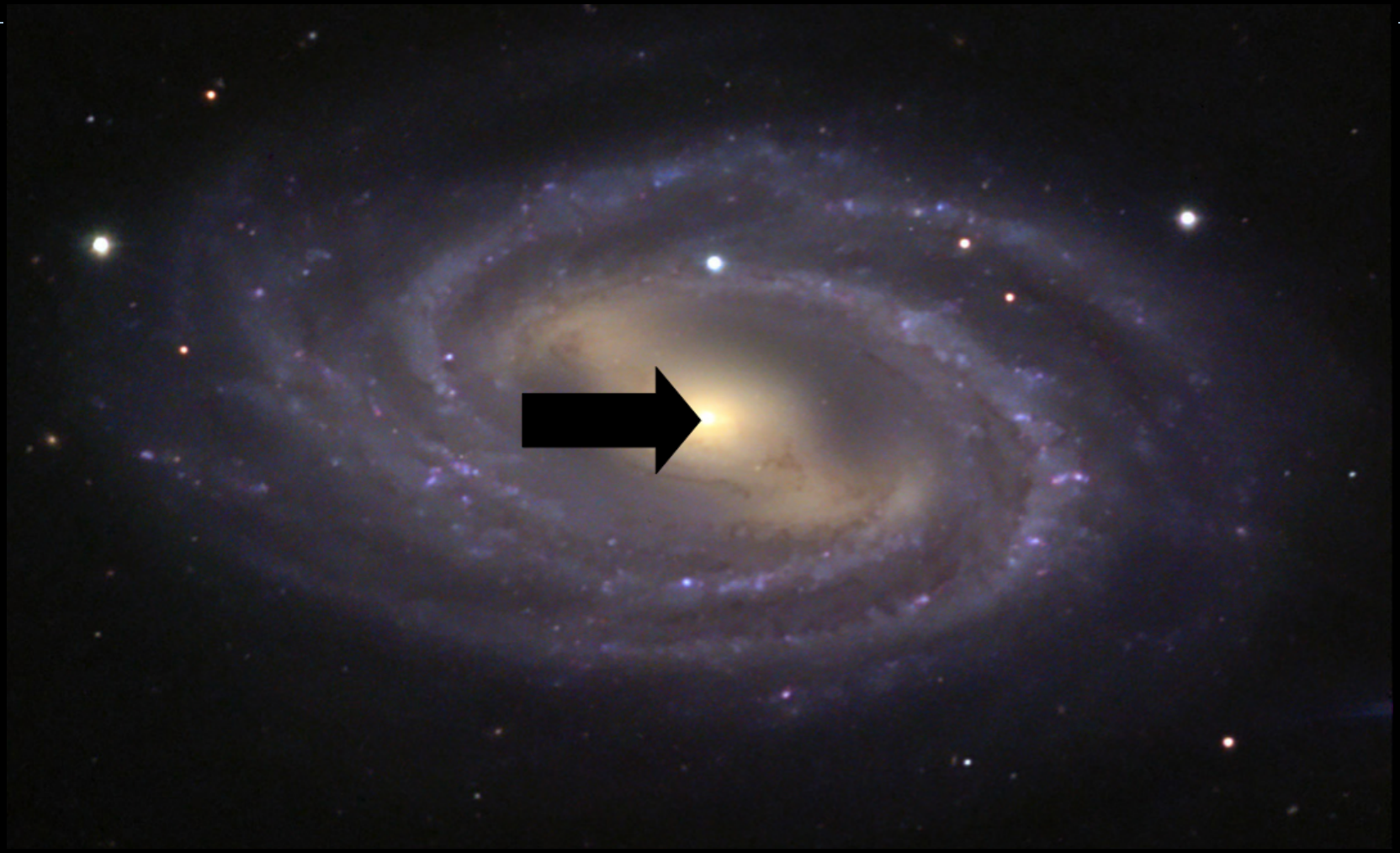


Schwarzschild solution to Einstein's Field Equations



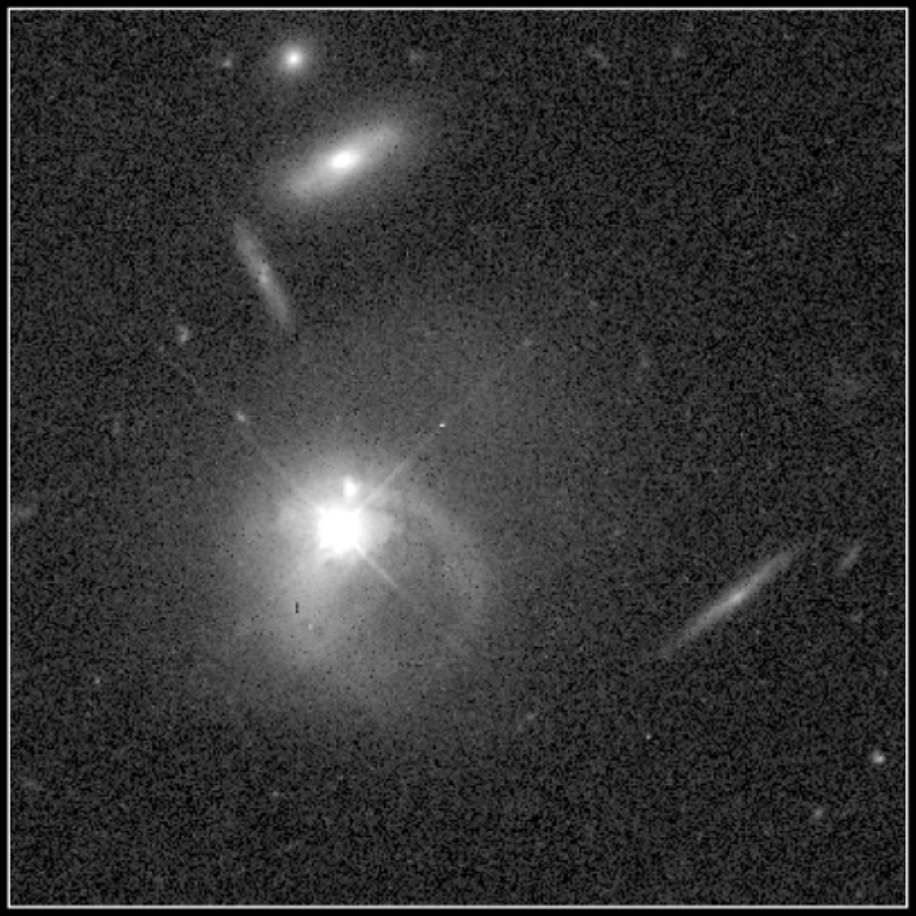
Time slows down for an observer near a BH





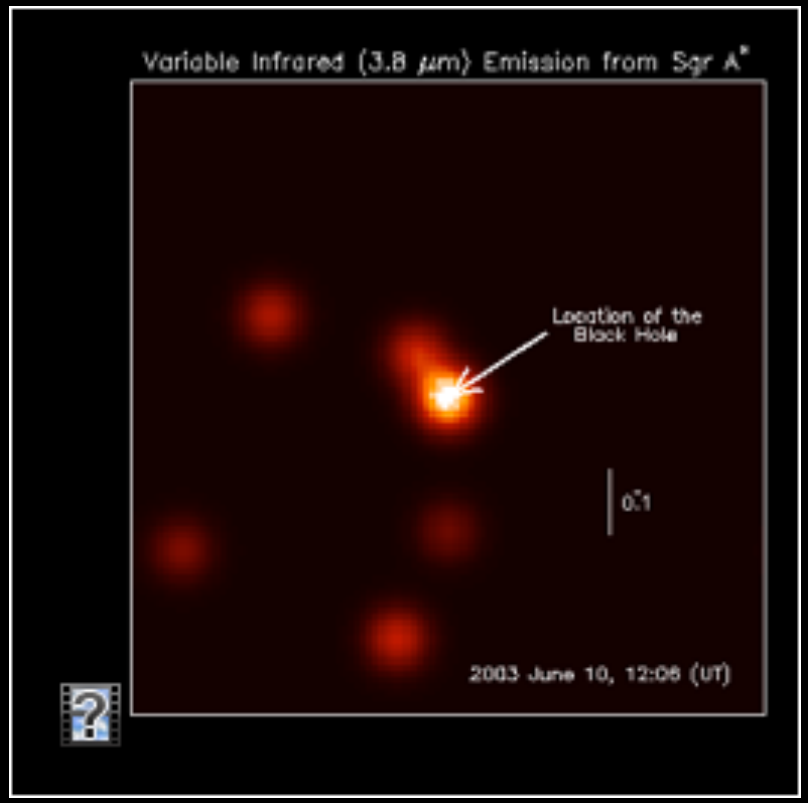
Where do black holes reside?

FEASTING BH FASTING BH



Quasar PKS 2349 HST • WFPC2

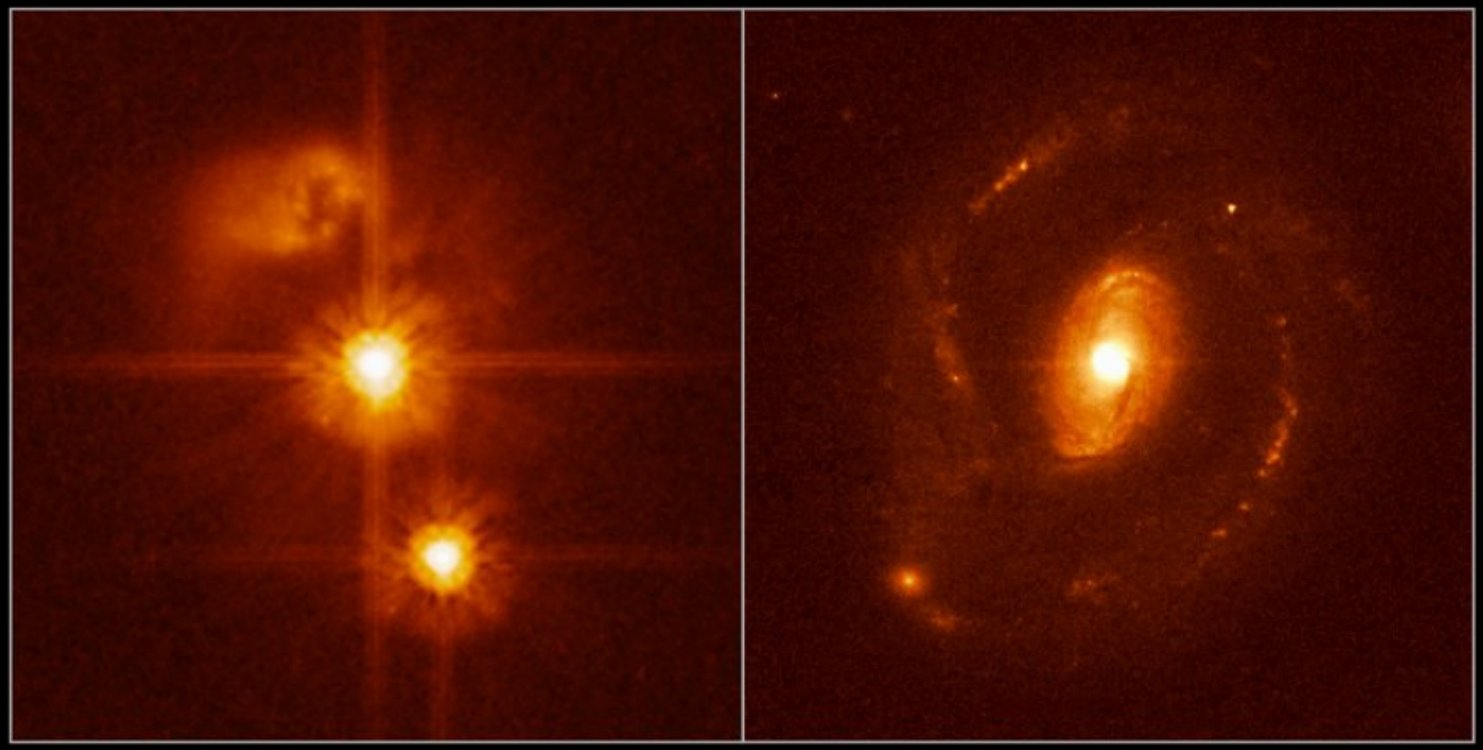
ST ScI OPO • January 1995 • J. Bahcall (Princeton), NASA

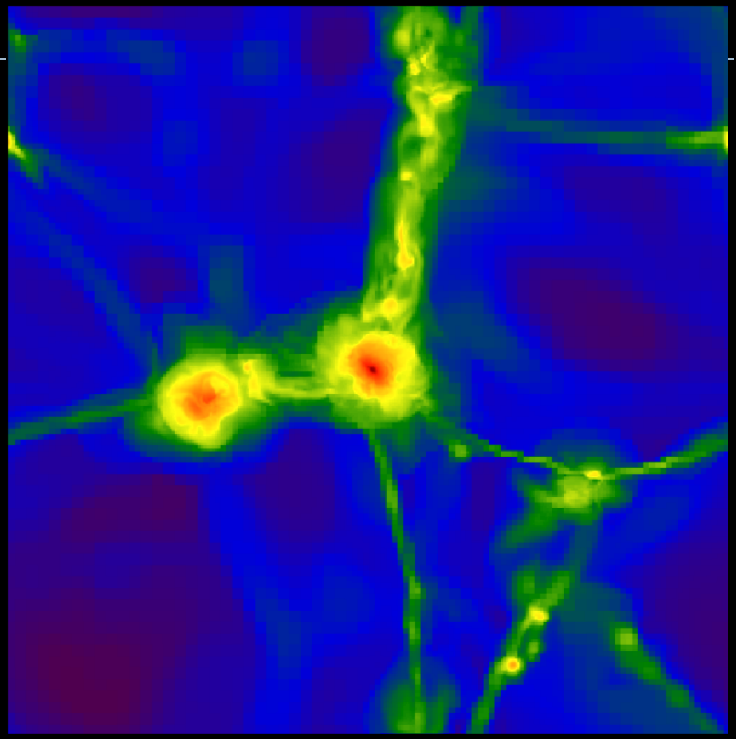


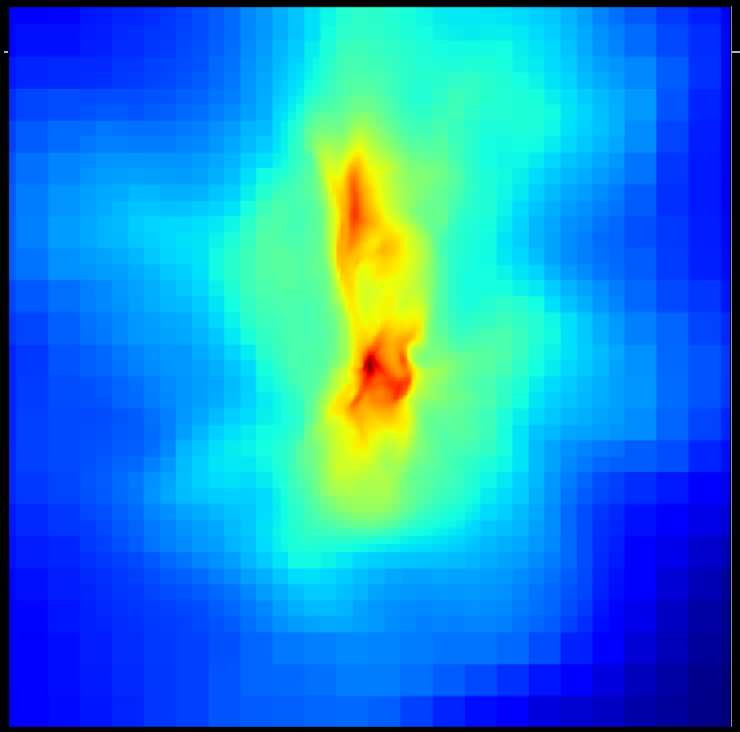
$M_{bh} \sim 10^{6}$ Msun

$M_{bh} \sim 10^{8\text{-}9}$ Msun

Bright quasars are growing BHs

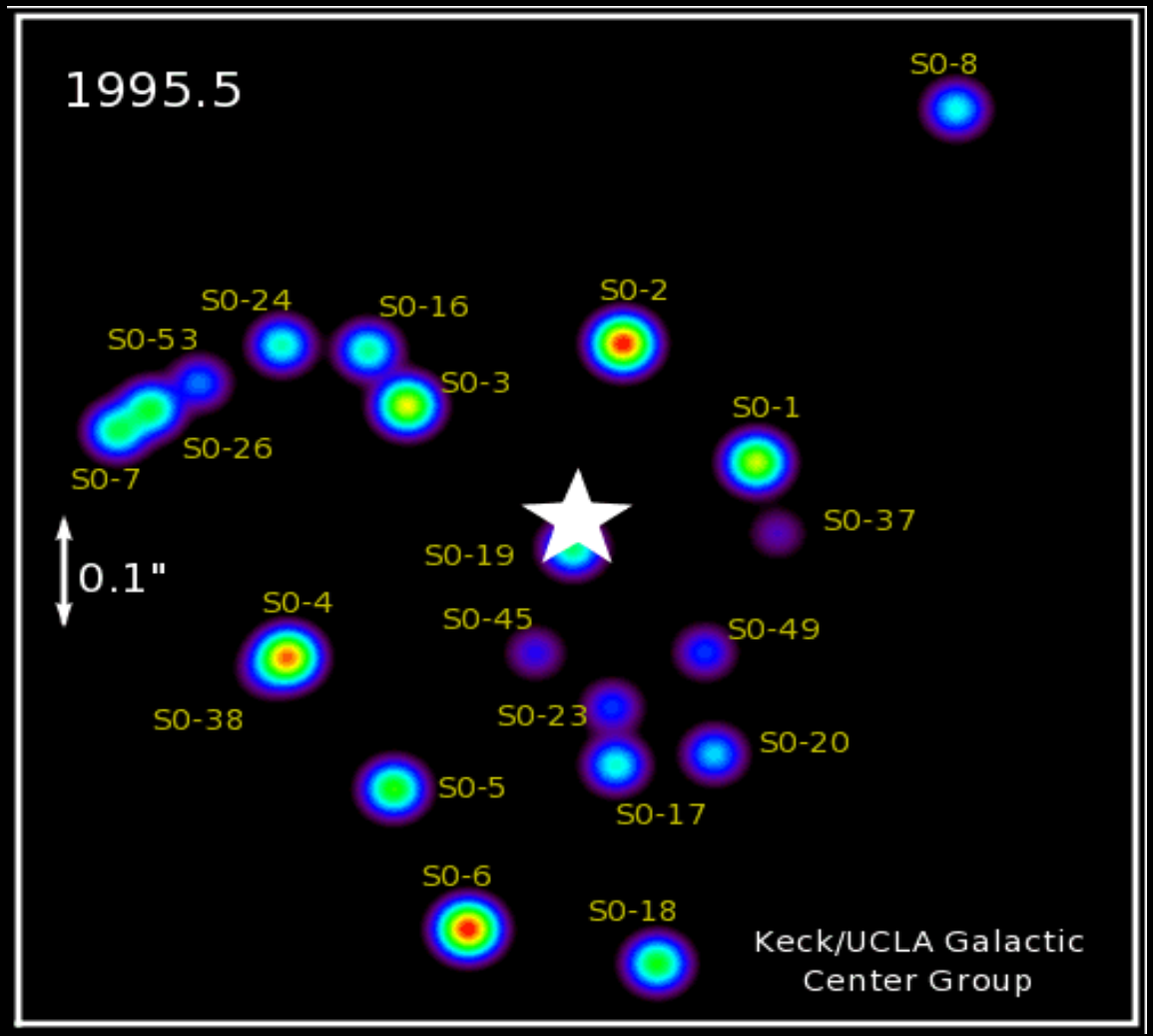




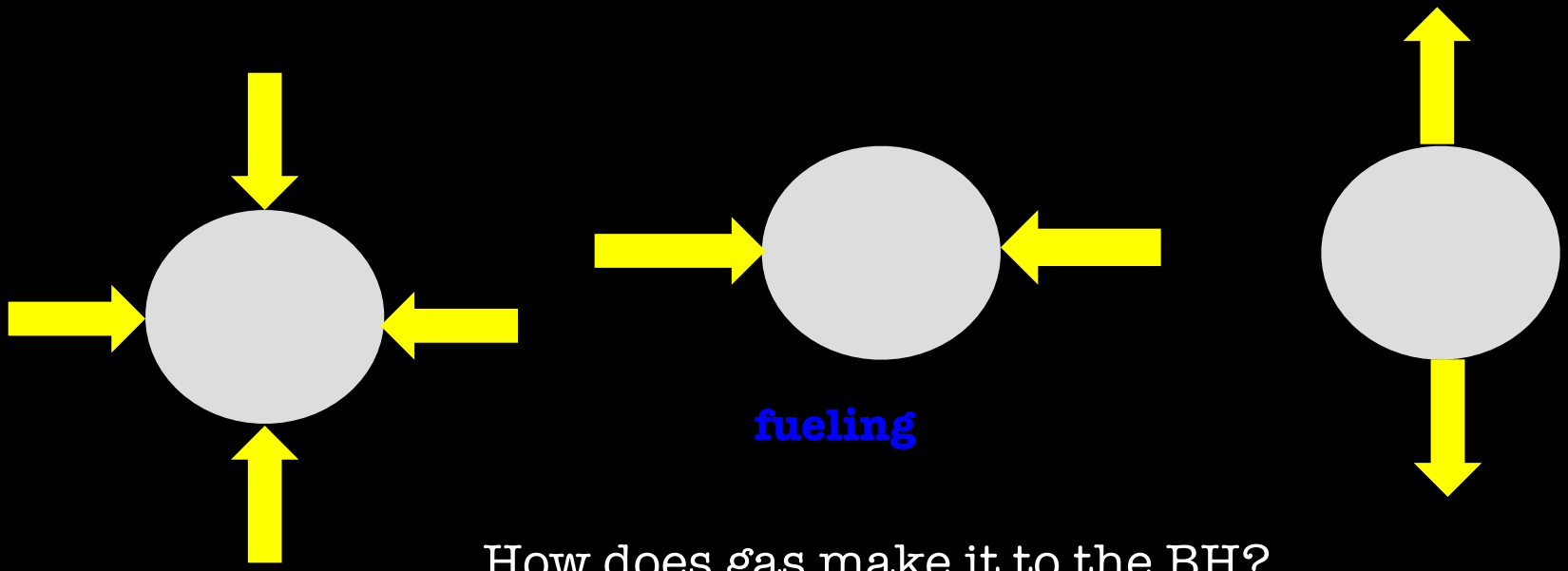


Gas flows into and around forming BH seeds

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



Challenges in understanding SMBHs



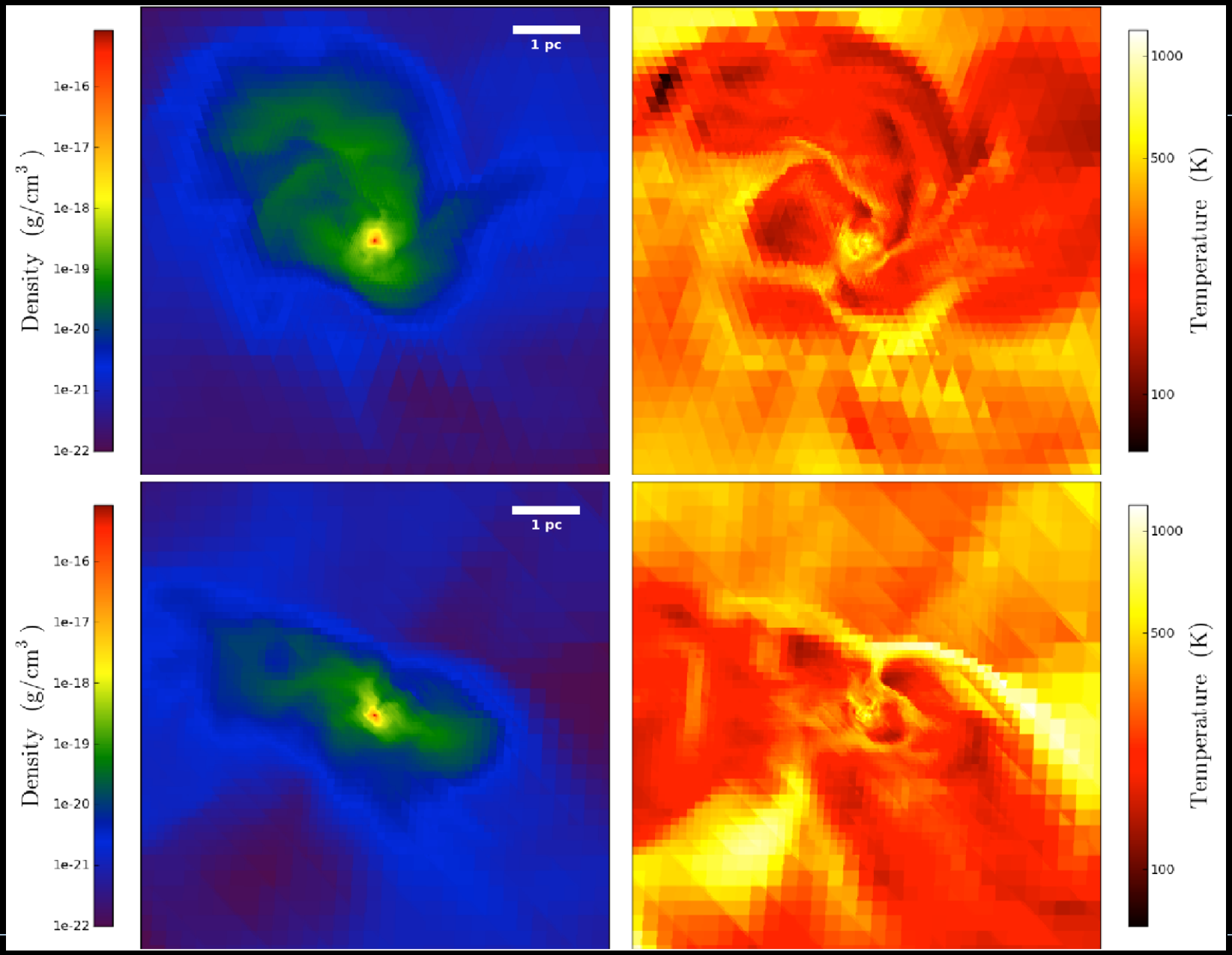
formation

How & where do BH seeds form?

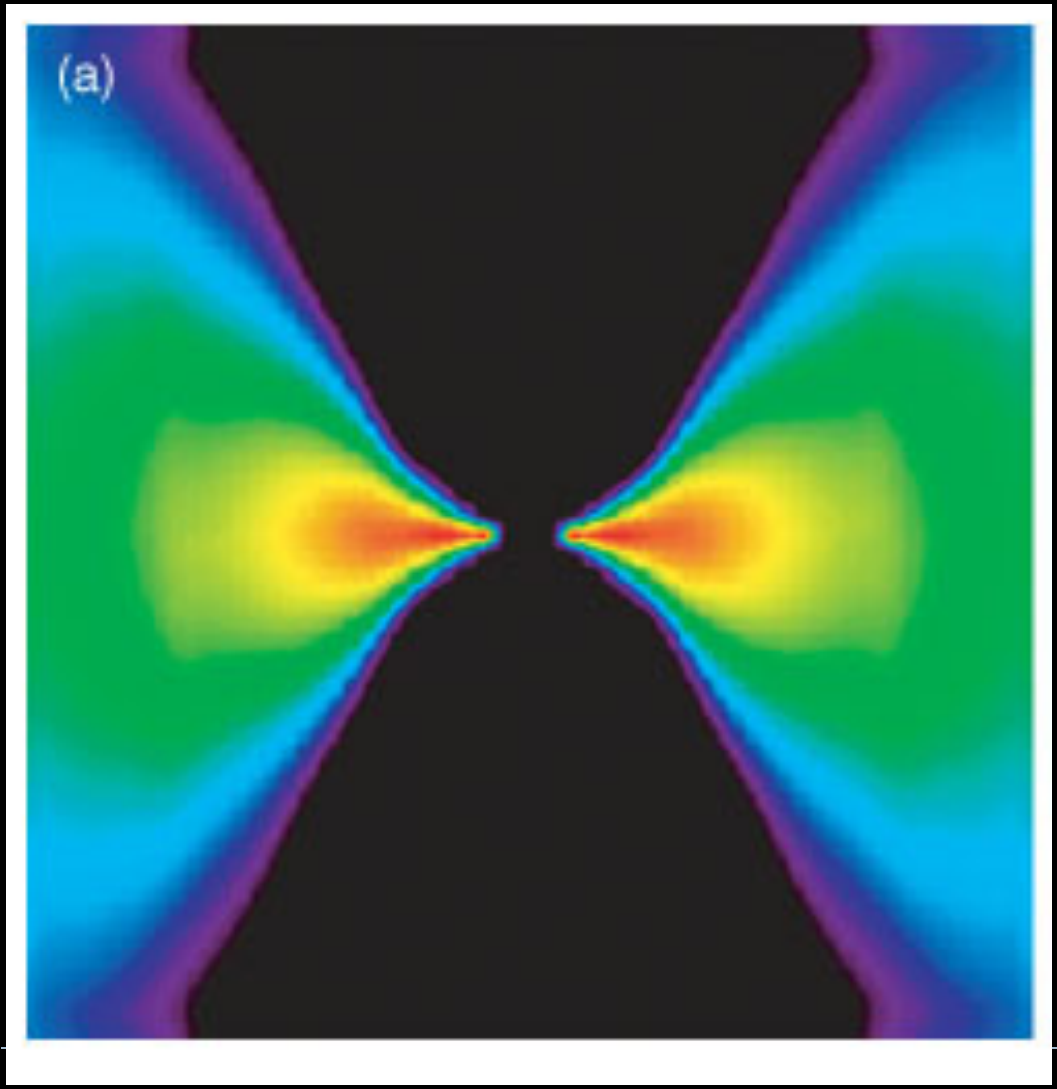
How does gas make it to the BH?

feedback

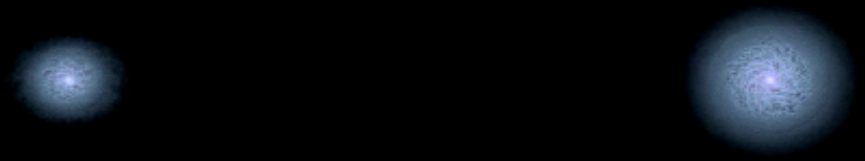
Impact of the BH


1 pc
1e-16
1e-17
1e-18
1e-19
1e-20
1e-21
1e-22
Density (g/cm^3)
1000
500
100
Temperature (K)
1 pc
1e-16
1e-17
1e-18
1e-19
1e-20
1e-21
1e-22
Density (g/cm^3)
1000
500
100
Temperature (K)

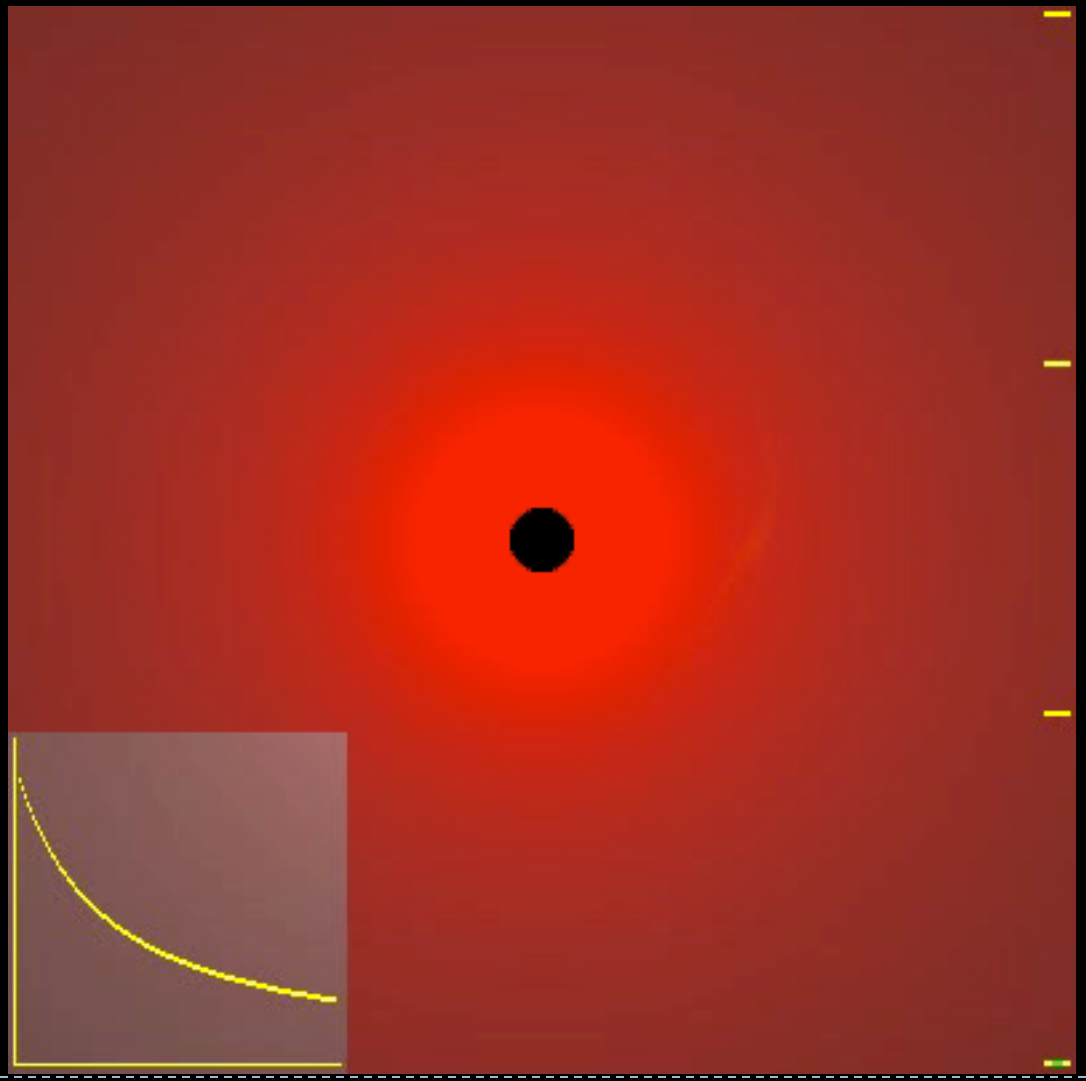
How does gas feed onto a BH?



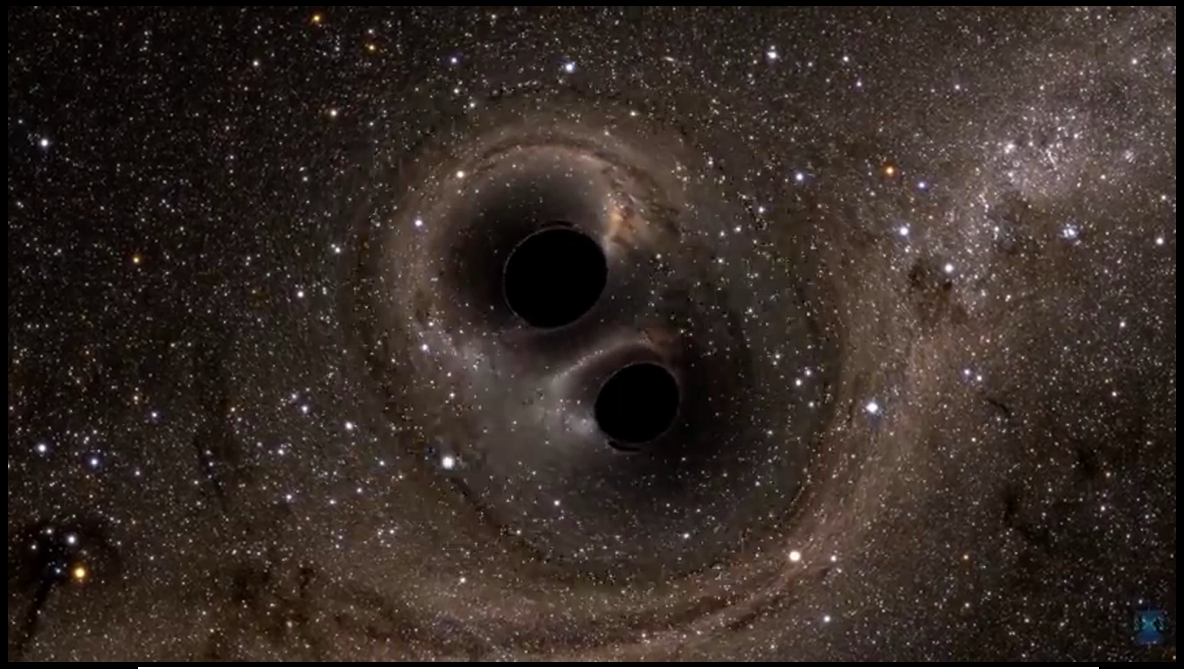
BH FEASTING EPISODE DURING GALAXY COLLISIONS

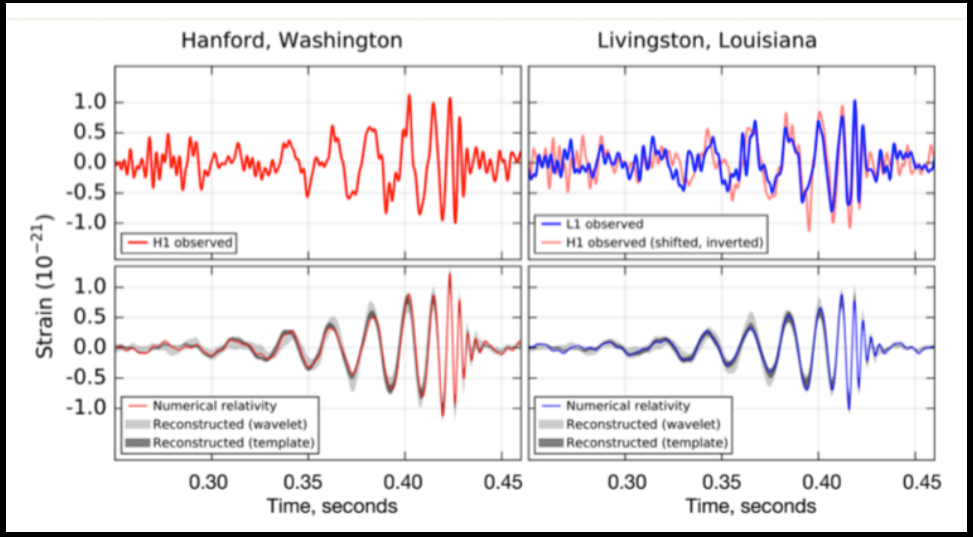


ZOOMING RIGHT IN.....

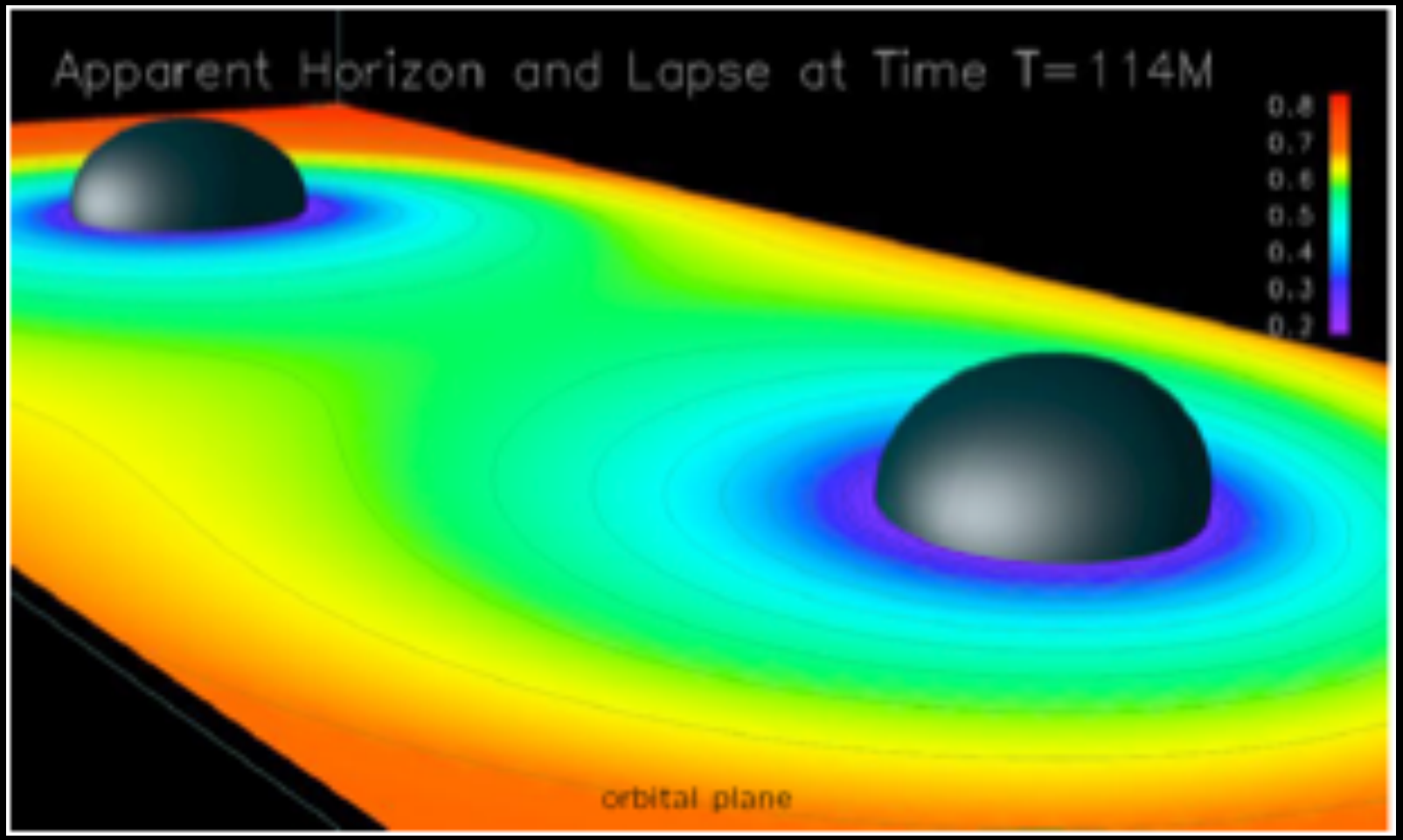


GWs from merging BHs LIGO detection

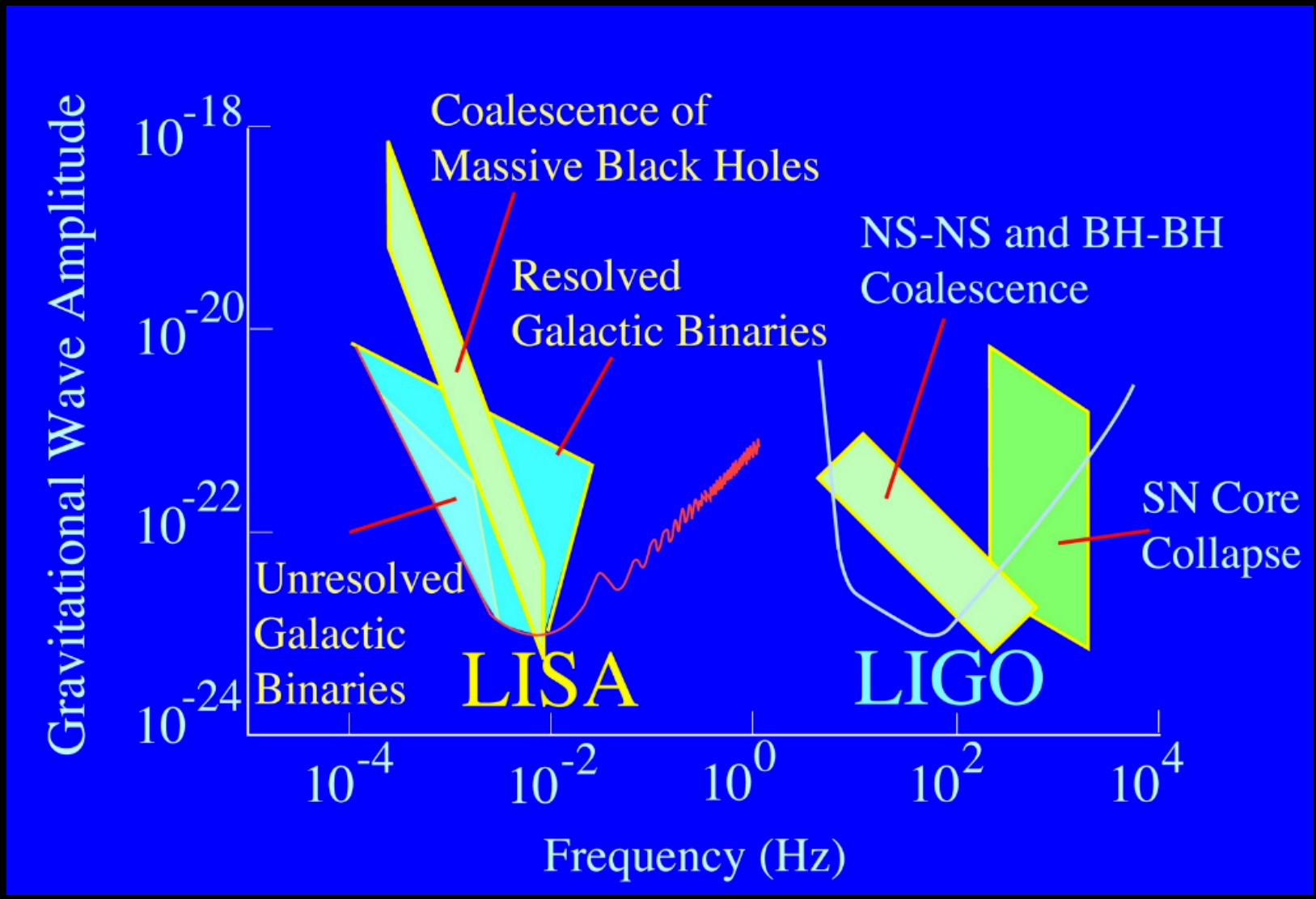




BREAKTHROUGH IN COMPUTATIONAL GR



GRAVITATIONAL WAVES FROM SMBH MERGERS



Testing gravity: why look for gaps?

Deviation in the orbit of Uranus from Newton's prediction
Urbane Le Verrier predicted presence of another planet
Neptune was discovered

Deviation in the orbit of Mercury from Newton's prediction
Urbane Le Verrier predicted presence of another planet
Vulcan was not found, doesnt exist
Upended Newton's view of gravity explained by Einstein's GR

DARK MATTER

BLACK HOLES