

Who/why/where/what is Dark Matter

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Inspirational Physics
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Questions for today

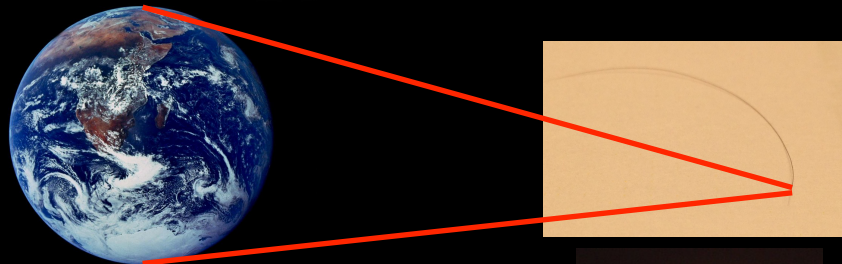
- **Who** discovered dark matter?
- **Why** do we think dark matter exists?
- **Where** is the dark matter in our Galaxy?
- **What** is dark matter?





Crash course on distances

- If we made the Earth as wide as a human hair...



- The Sun would be 40 centimeters away
- Voyager 1 would be 27 meters away
- 1 light year would be 12.6 kilometres away
- 1 parsec would be 41 kilometers away
- The nearest star would be 55 kilometers away, beyond London
- The center of the Milky Way would be at the moon



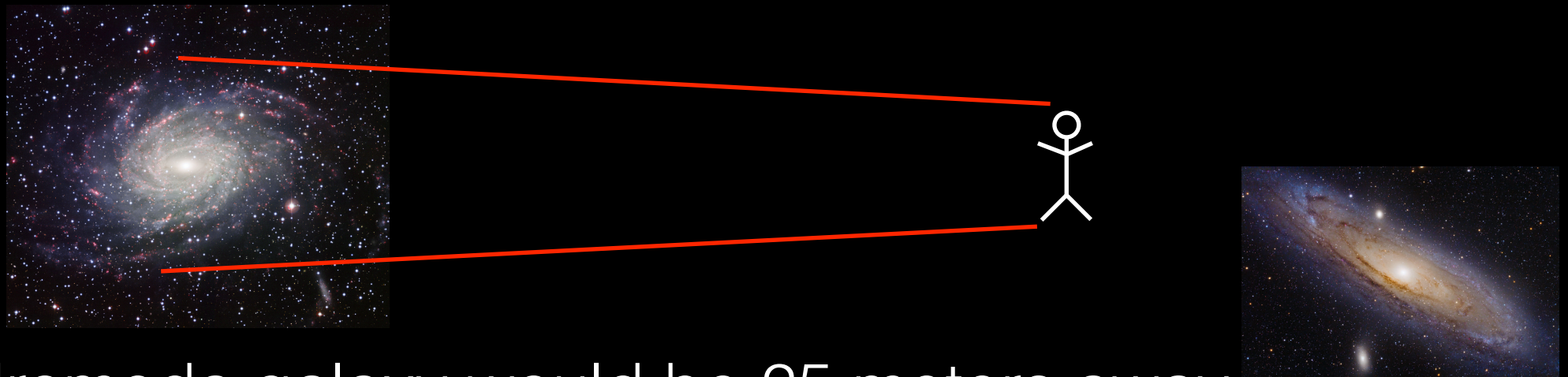
NASA/JPL



So the Milky Way is pretty big compared to Earth

Crash course on distances

- If we made the Milky Way as big as you...



- The Andromeda galaxy would be 25 meters away
- The size of the observable universe would go out to Edinburgh, 480 kilometers away
- I will give all distances in terms of the disk of the Milky Way



The universe is not that big compared to the Milky Way

Who discovered dark matter?



Fritz Zwicky
1933



Vera Rubin
1970s

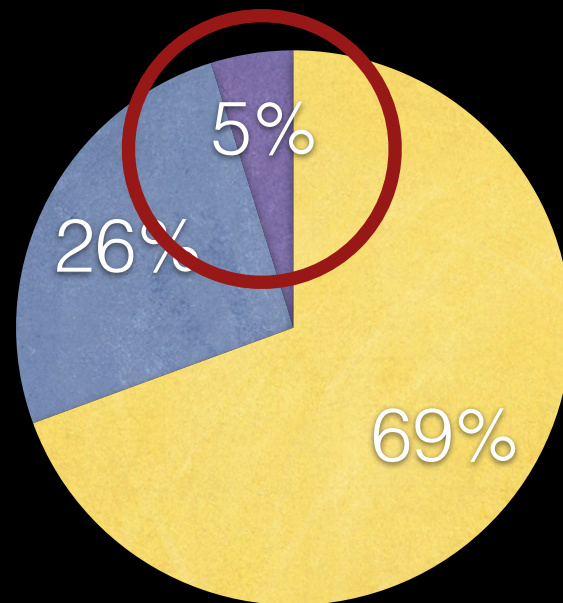
- Proposed by Zwicky in 1933
- First robust evidence by Vera in 1970s

Why do we think dark matter exists?



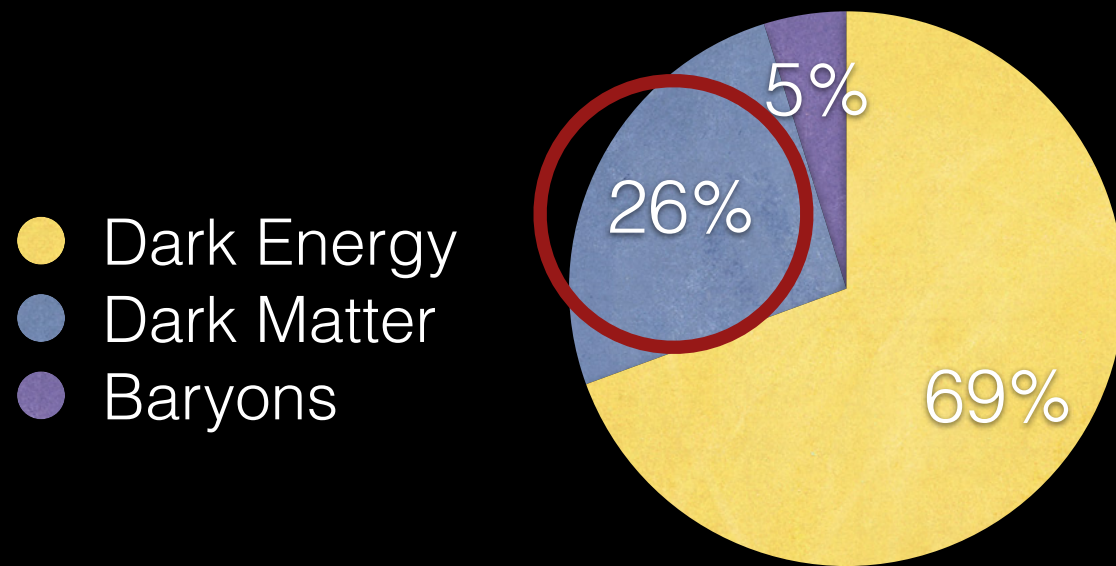
Image credit: NASA

- Dark Energy
- Dark Matter
- Baryons



The matter you know and love

Why do we think dark matter exists?



Just like regular matter but
doesn't interact with light
(it's invisible!)

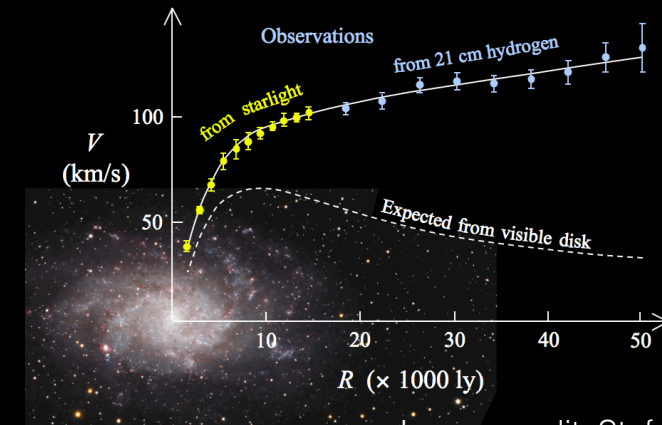


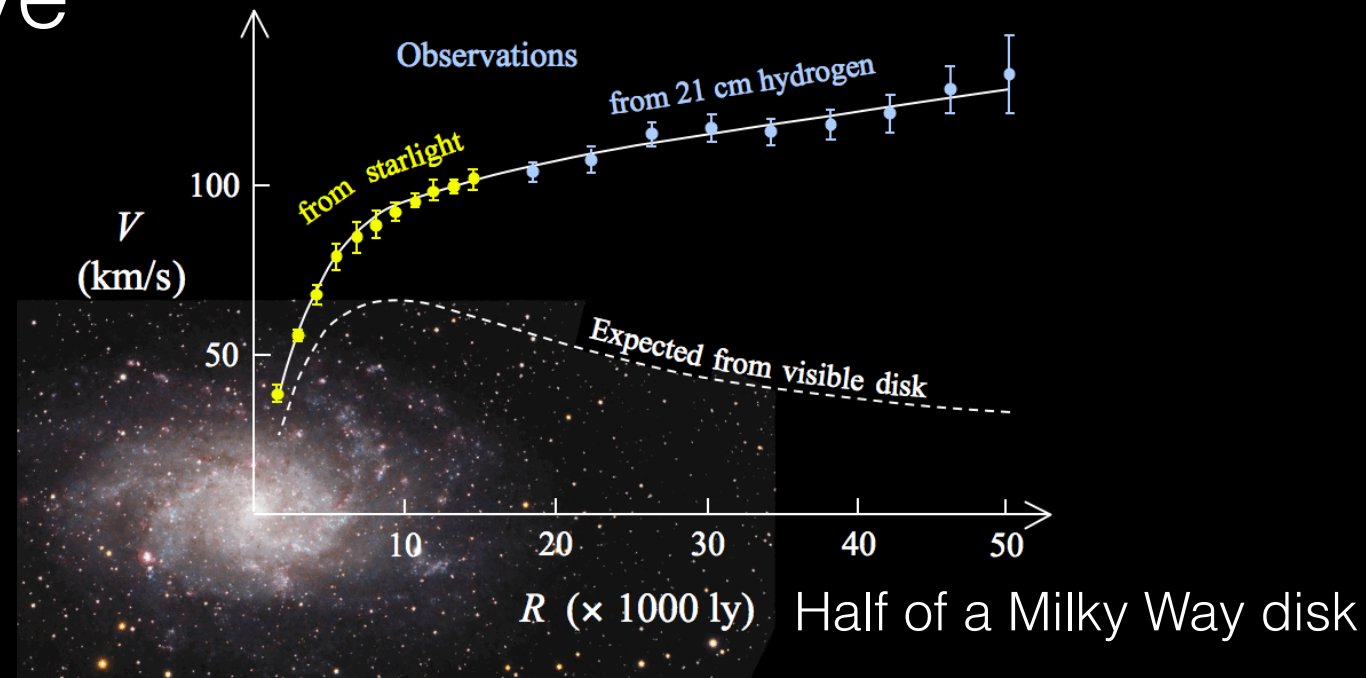
Image credit: Stefania Deluca



Why do we think dark matter exists?

Galaxies rotate faster than expected

M33 rotation curve



Vera Rubin

Image credit: Stefania Deluca

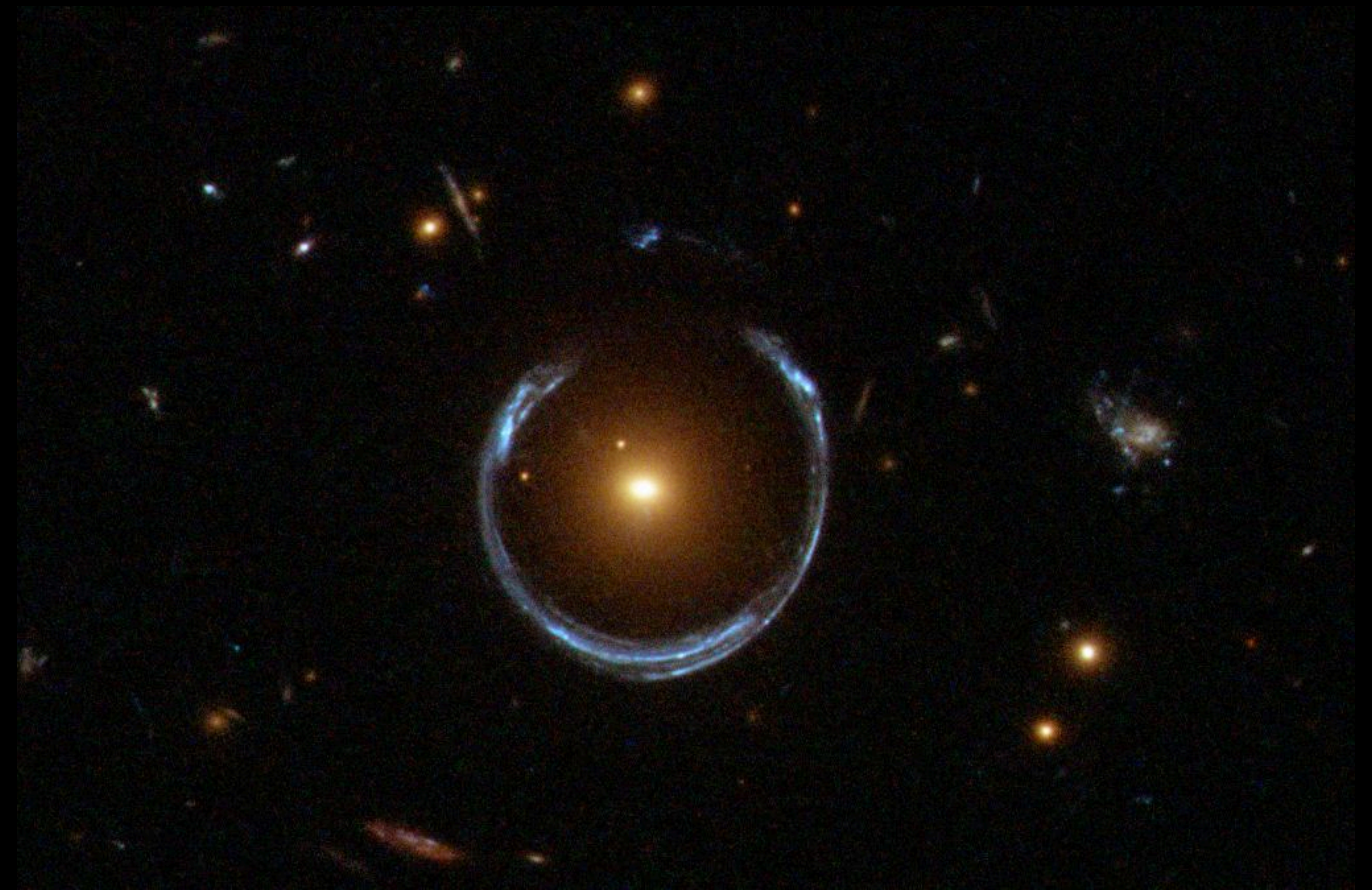
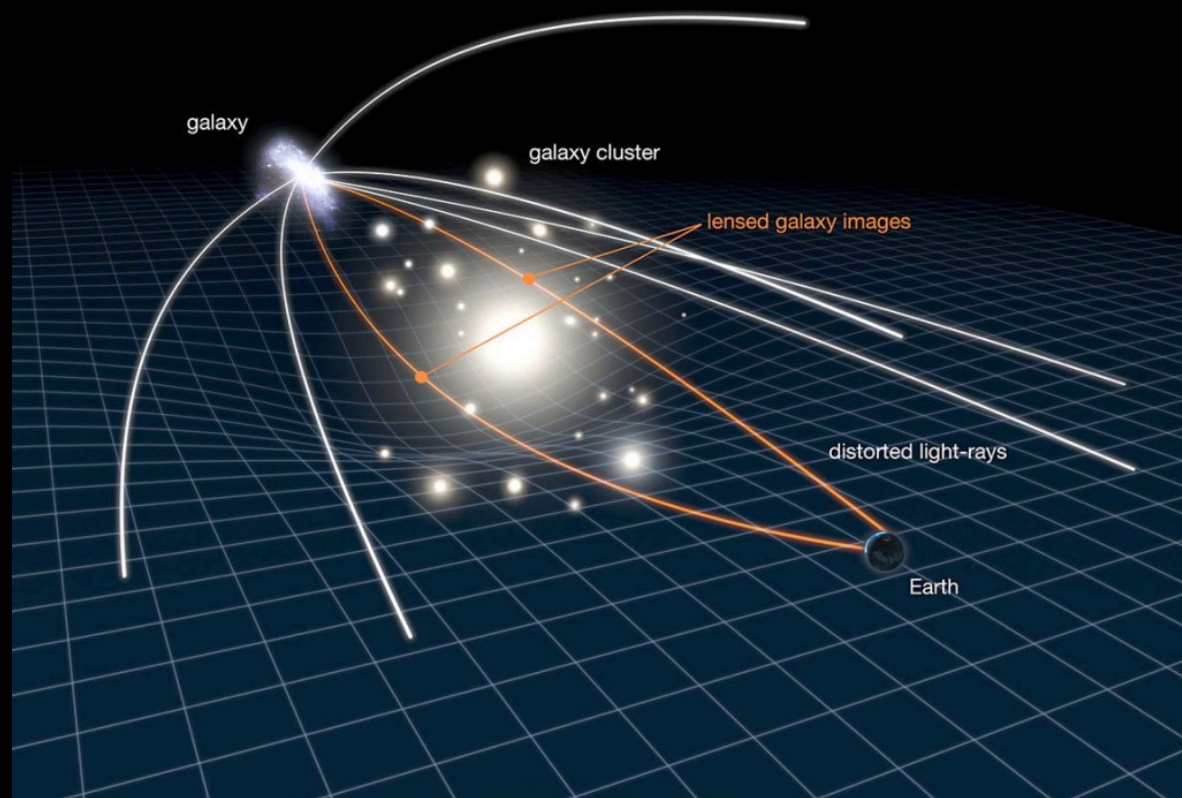
Centripetal acceleration = Gravitational acceleration

Velocity tells us the mass!

Why do we think dark matter exists?

Gravitational lensing

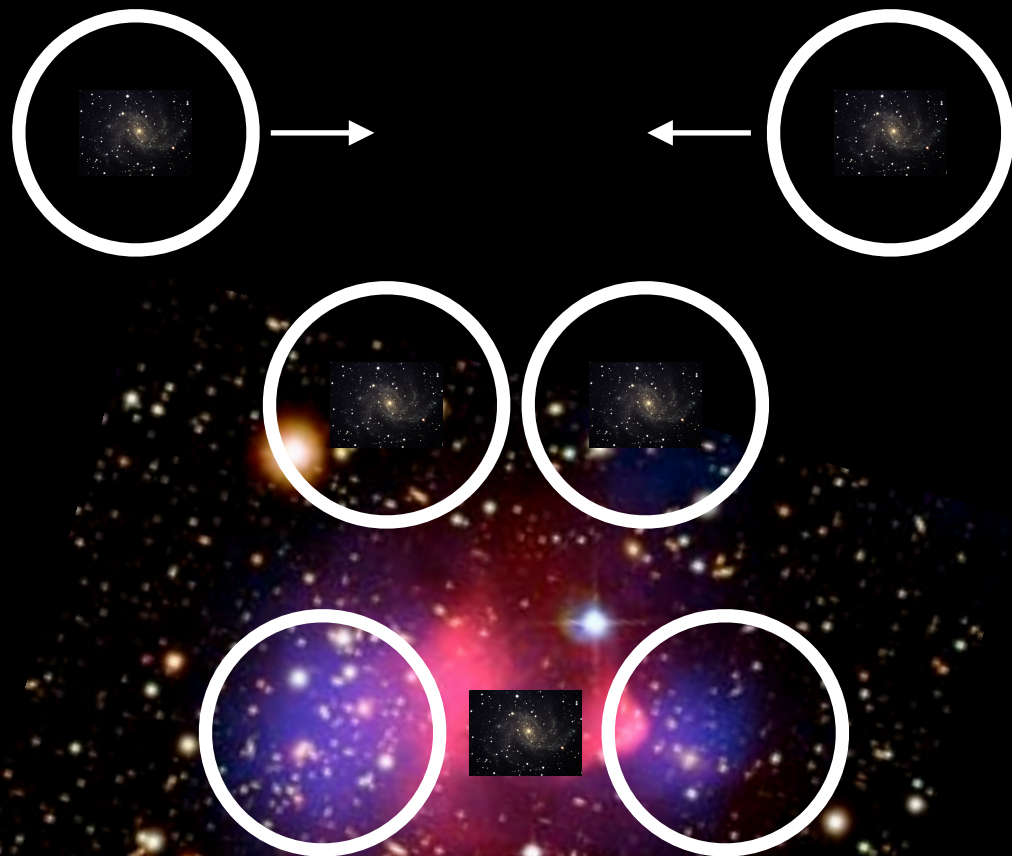
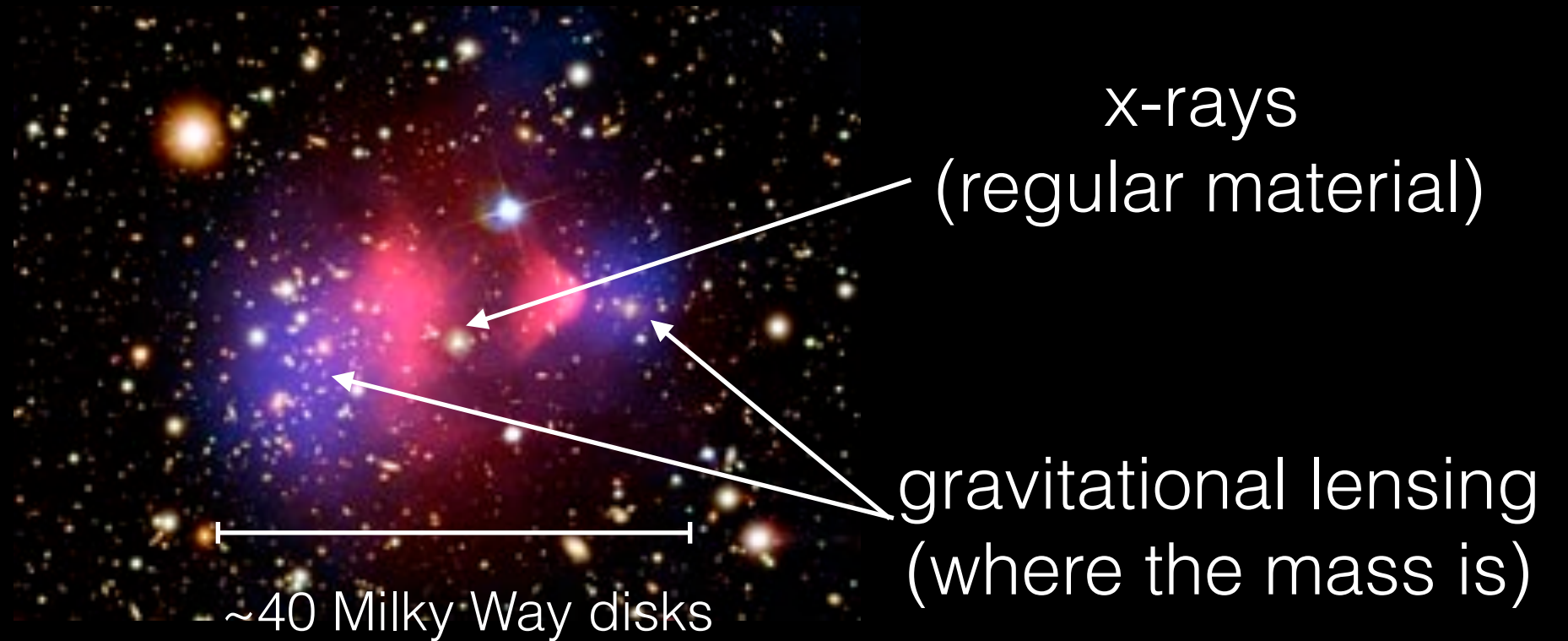
Horseshoe lens



Much more mass than seen from light

Why do we think dark matter exists?

Bullet cluster



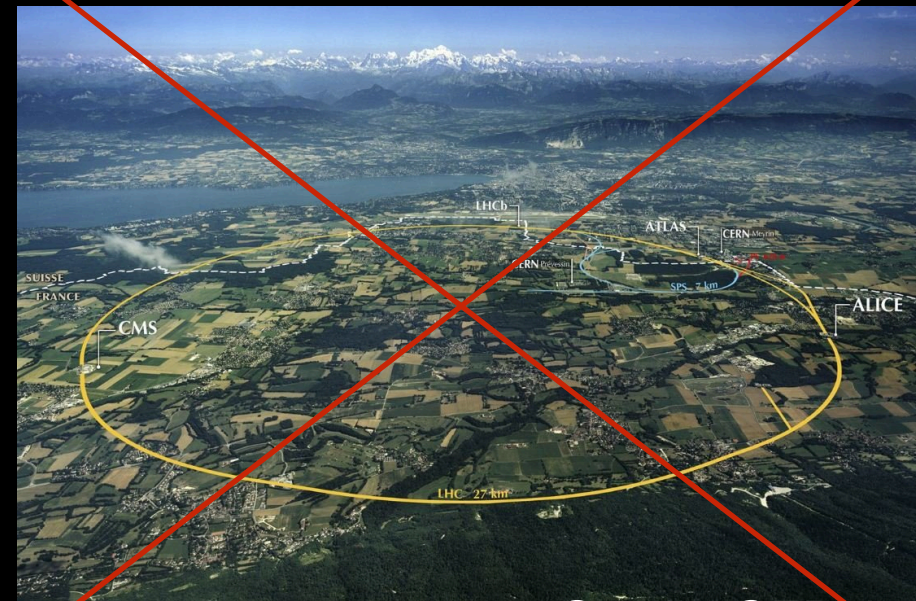
Why do we think dark matter exists?

Large Underground Xenon detector

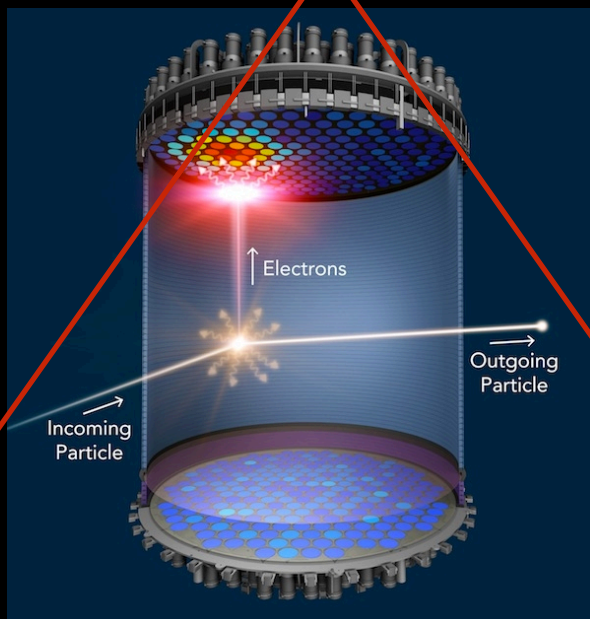


Credit: M. Kapust

Large Hadron Collider (LHC)



Credit: CERN



Credit: SLAC

No direct detection of dark matter particle

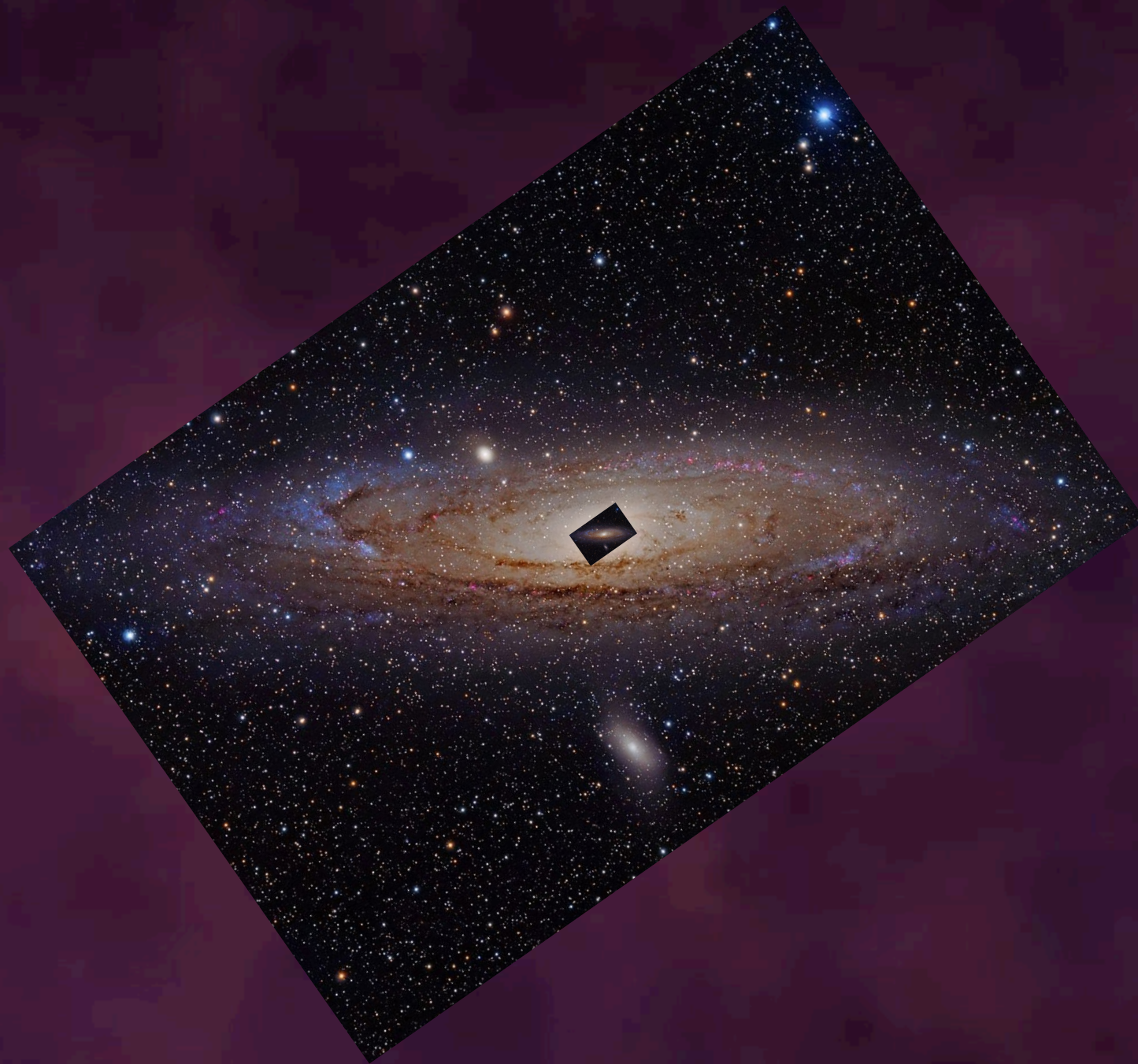
We only know about dark matter through gravity!

Where is the dark matter in our
Galaxy?



$z = 48.4$

$T = 0.05 \text{ Gyr}$



17 Milky Way disks

500 kpc

Where is the dark matter in our Galaxy?



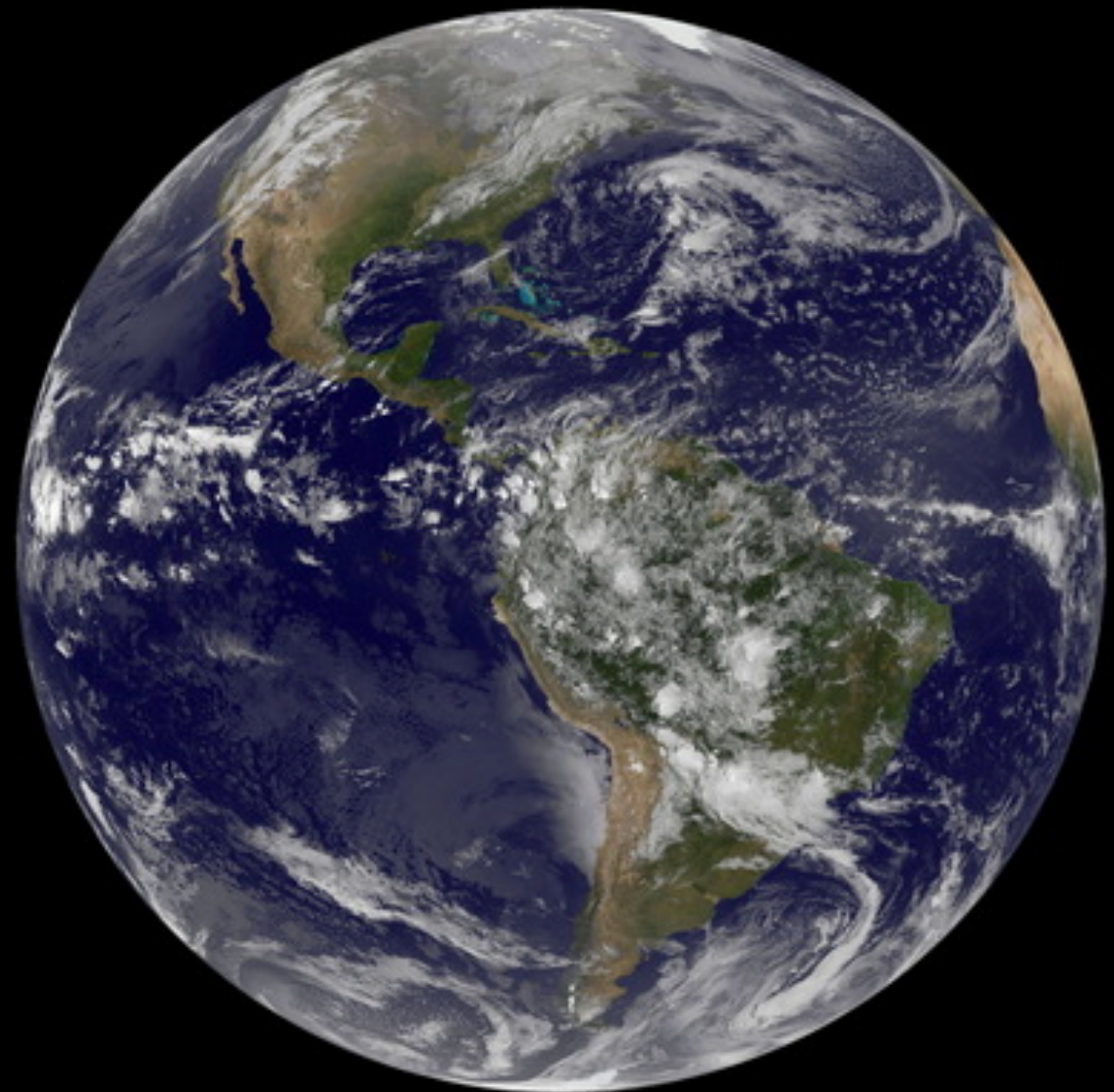
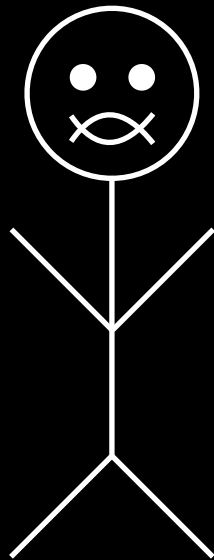
Mostly a smooth halo
~10% in clumps

Density = 0.3 proton/cm^3
Air = $10^{21} \text{ proton/cm}^3$

Where is the dark matter in our Galaxy?

Density = 0.3 proton/cm^3

Air = $10^{21} \text{ proton/cm}^3$



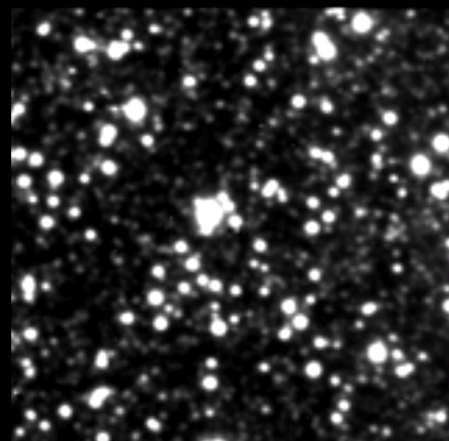
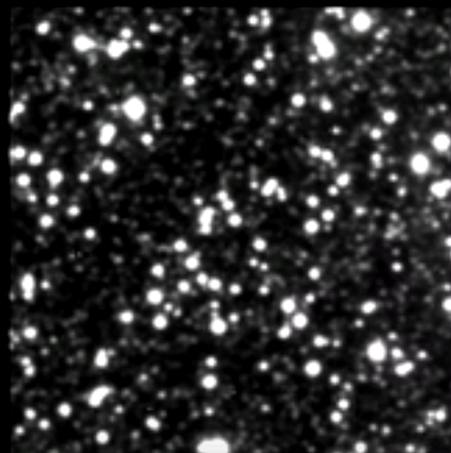
What is dark matter?

- No one knows yet
- It has mass and interacts with gravity
- It doesn't interact with light
- It doesn't interact much with itself

?

What is dark matter?

- It is not made of compact objects (e.g. planets or black holes)
- Not made of any known substance
- It must weigh more than $1/100$ of an electron mass



Dong et al. 2009

Questions for today

- **Who** discovered dark matter?
 - Fritz Zwicky and Vera Rubin
- **Why** do we think dark matter exists?
 - From how fast galaxies rotate
 - Gravitational lensing
 - Bullet cluster
- **Where** is the dark matter in our Galaxy?
 - Mostly in the smooth halo but 10% in clumps
 - In this room with us but much less dense than gas
- **What** is dark matter?
 - No one knows yet, it has mass but is invisible

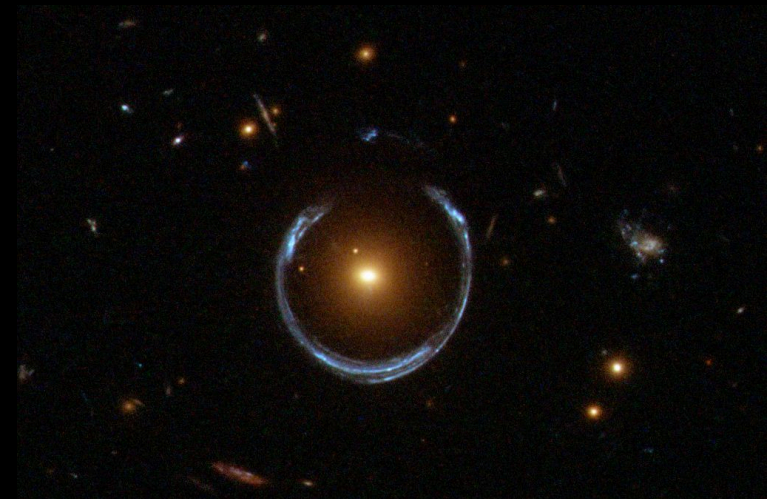


Image credit: ESA/NASA



Image credit: NASA