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The Dark Side of the Universe: Dark matter in the galaxy and Cosmos

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NGC1300
(Eridanus)

The Dark Side of the Universe:

Dark matter in the galaxy & Cosmos

Shane L. Larson
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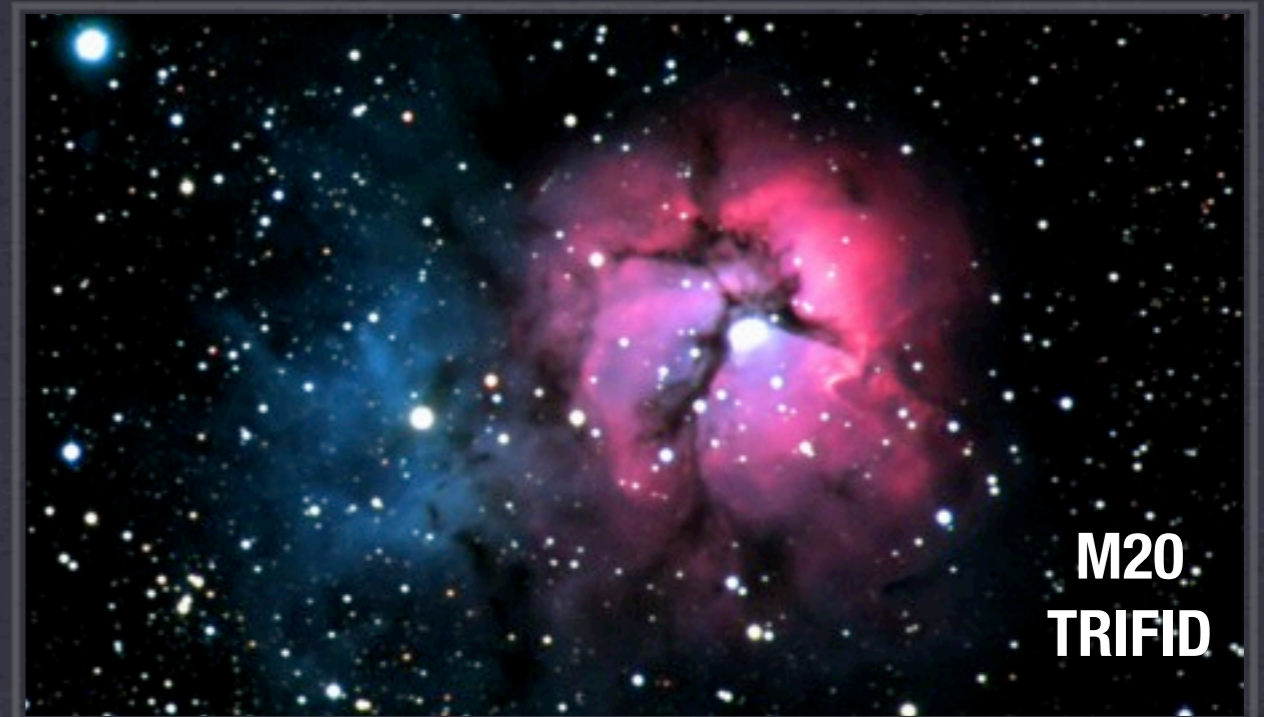
Spokane Astronomical Society
Spokane, WA
4 February 2011

Storyline

- Everything we know
- What is the Cosmos made of?
 - People, Rocks, Stars
- What else is there?
- Dark Matter
- Dark Energy

Darkness in the Cosmos

- We are used to seeing dark things in the night sky
- **Dark nebulae** are all ordinary matter that is not illuminated.
- They are visible because they **block light** from behind them



What are we talking about?

- **DARK MATTER**

- Does not emit any kind of light (visible, xrays, radio,...)
- Observe its gravitational effect on other objects

- **DARK ENERGY**

- Is not observable with telescopes
- Observe its gravitational effect on the expansion of the Cosmos



Composition of Organisms

- For every **10,000 atoms** in an average organism, there are:
 - **6500 oxygen atoms**
 - **1800 carbon atoms**
 - **1000 hydrogen atoms**
 - **300 nitrogen atoms**
 - **150 calcium atoms**
 - **100 phosphorus atoms**
 - **25 potassium atoms**
 - **25 sulfur atoms**
 - **15 chlorine atoms**
 - **15 sodium atoms**
 - **5 magnesium atoms**
 - **65: traces of other stuff...**



Composition of Rocks

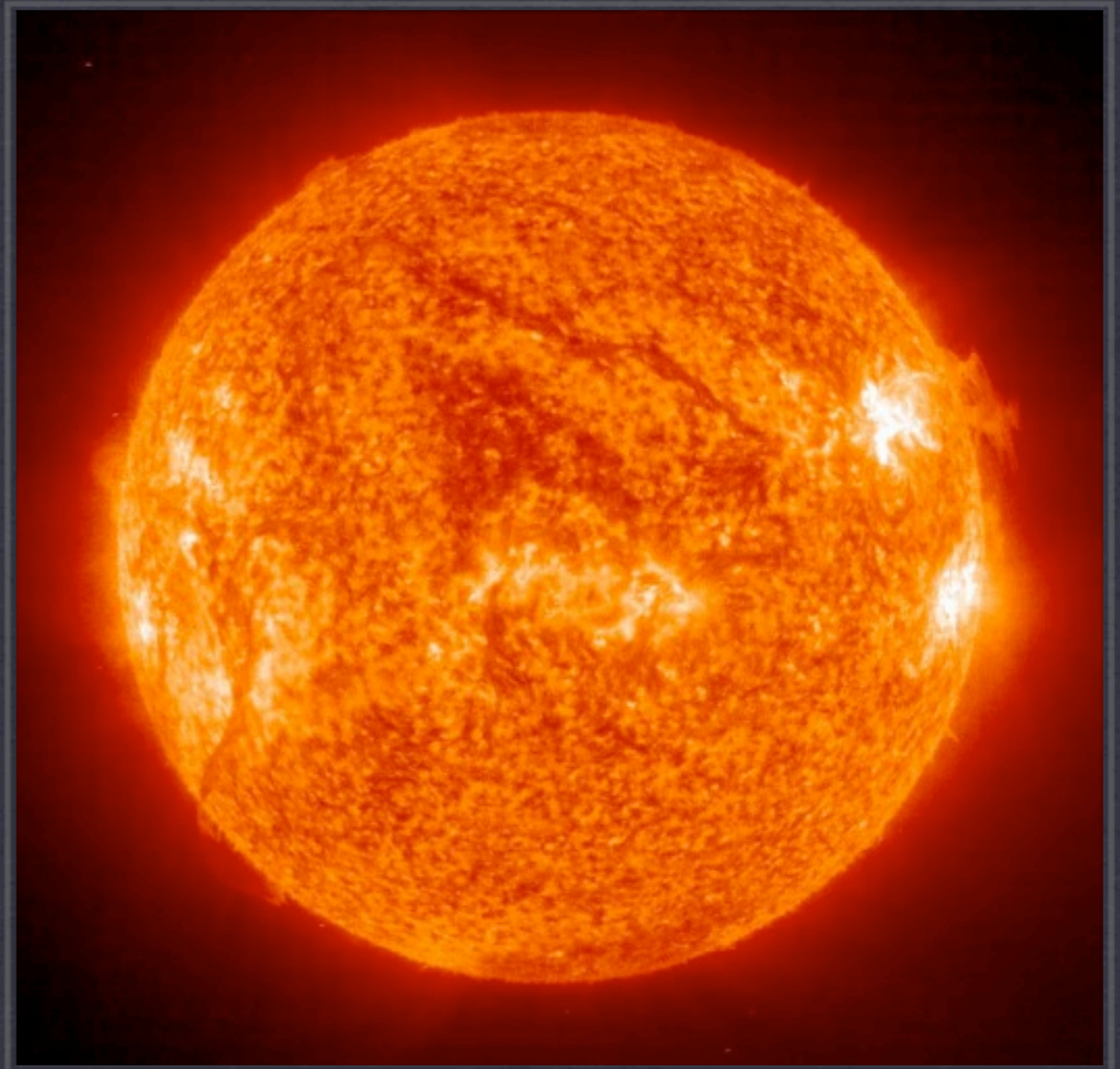
- For every **10,000 atoms** in the Earth's crust, there are:
 - **4640 oxygen atoms**
 - **2820 silicon atoms**
 - **830 aluminum atoms**
 - **560 iron atoms**
 - **410 calcium atoms**
 - **230 sodium atoms**
 - **230 magnesium atoms**
 - **210 potassium atoms**
 - **60 titanium atoms**
 - **10 hydrogen atoms**



Composition of the Stars

- For every **10,000 atoms** in the Sun, there are:

- **9149 atoms of hydrogen**
- **779 atoms of helium**
- **62 atoms of oxygen**
- **6 atoms of carbon**
- **3 atoms of neon**
- **1 atom of nitrogen**
- **and less of everything else.**



What stuff is made of...

PERIODIC TABLE OF THE ELEMENTS

<http://www.ktf-split.hr/periodni/en/>

PERIOD	GROUP 1 IA		GROUP 2 IIA		GROUP 3-10										GROUP 11 IB		GROUP 12 IIB		GROUP 13-18					
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18						
1	1 1.0079 H HYDROGEN																		2 4.0026 He HELIUM					
2	3 6.941 Li LITHIUM	4 9.0122 Be BERYLLIUM											5 10.811 B BORON	6 12.011 C CARBON	7 14.007 N NITROGEN	8 15.999 O OXYGEN	9 18.998 F FLUORINE	10 20.180 Ne NEON						
3	11 22.990 Na SODIUM	12 24.305 Mg MAGNESIUM											13 26.982 Al ALUMINIUM	14 28.086 Si SILICON	15 30.974 P PHOSPHORUS	16 32.065 S SULPHUR	17 35.453 Cl CHLORINE	18 39.948 Ar ARGON						
4	19 39.098 K POTASSIUM	20 40.078 Ca CALCIUM	21 44.956 Sc SCANDIUM	22 47.867 Ti TITANIUM	23 50.942 V VANADIUM	24 51.996 Cr CHROMIUM	25 54.938 Mn MANGANESE	26 55.845 Fe IRON	27 58.933 Co COBALT	28 58.693 Ni NICKEL	29 63.546 Cu COPPER	30 65.39 Zn ZINC	31 69.723 Ga GALLIUM	32 72.64 Ge GERMANIUM	33 74.922 As ARSENIC	34 78.96 Se SELENIUM	35 79.904 Br BROMINE	36 83.80 Kr KRYPTON						
5	37 85.468 Rb RUBIDIUM	38 87.62 Sr STRONTIUM	39 88.906 Y YTTRIUM	40 91.224 Zr ZIRCONIUM	41 92.906 Nb NIOBIUM	42 95.94 Mo MOLYBDENUM	43 (98) Tc TECHNETIUM	44 101.07 Ru RUTHENIUM	45 102.91 Rh RHODIUM	46 106.42 Pd PALLADIUM	47 107.87 Ag SILVER	48 112.41 Cd CADMIUM	49 114.82 In INDIUM	50 118.71 Sn TIN	51 121.76 Sb ANTIMONY	52 127.60 Te TELLURIUM	53 126.90 I IODINE	54 131.29 Xe XENON						
6	55 132.91 Cs CAESIUM	56 137.33 Ba BARIUM	57-71 La-Lu Lanthanide	72 178.49 Hf HAFNIUM	73 180.95 Ta TANTALUM	74 183.84 W TUNGSTEN	75 186.21 Re RHENIUM	76 190.23 Os OSMIUM	77 192.22 Ir IRIDIUM	78 195.08 Pt PLATINUM	79 196.97 Au GOLD	80 200.59 Hg MERCURY	81 204.38 Tl THALLIUM	82 207.2 Pb LEAD	83 208.98 Bi BISMUTH	84 (209) Po POLONIUM	85 (210) At ASTATINE	86 (222) Rn RADON						
7	87 (223) Fr FRANCIUM	88 (226) Ra RADIUM	89-103 Ac-Lr Actinide	104 (261) Rf RUTHERFORDIUM	105 (262) Db DUBNIUM	106 (266) Sg SEABORGIUM	107 (264) Bh BOHRRIUM	108 (277) Hs HASSIUM	109 (268) Mt MEITNERIUM	110 (281) Uun UNUNNIUM	111 (272) Uuu UNUNUNIUM	112 (285) Uub UNUNBIUM		114 (289) Uuq UNUNQUADIUM										

RELATIVE ATOMIC MASS (A)

GROUP IUPAC

GROUP CAS

ATOMIC NUMBER

SYMBOL

ELEMENT NAME

- Metal
- Semimetal
- Nonmetal
- 1 Alkali metal
- 2 Alkaline earth metal
- Transition metals
- Lanthanide
- Actinide
- 16 Chalcogens element
- 17 Halogens element
- 18 Noble gas

STANDARD STATE (25 °C; 101 kPa)

Ne - gas Fe - solid

Ga - liquid Tc - synthetic

LANTHANIDE

57 138.91 La LANTHANUM	58 140.12 Ce CERIUM	59 140.91 Pr PRASEODYMIUM	60 144.24 Nd NEODYMIUM	61 (145) Pm PROMETHIUM	62 150.36 Sm SAMARIUM	63 151.96 Eu EUROPIUM	64 157.25 Gd GADOLINIUM	65 158.93 Tb TERBIUM	66 162.50 Dy DYSPROSIUM	67 164.93 Ho HOLMIUM	68 167.26 Er ERBIUM	69 168.93 Tm THULIUM	70 173.04 Yb YTTERIUM	71 174.97 Lu LUTETIUM
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ACTINIDE

89 (227) Ac ACTINIUM	90 232.04 Th THORIUM	91 231.04 Pa PROTACTINIUM	92 238.03 U URANIUM	93 (237) Np NEPTUNIUM	94 (244) Pu PLUTONIUM	95 (243) Am AMERICIUM	96 (247) Cm CURIUM	97 (247) Bk BERKELIUM	98 (251) Cf CALIFORNIUM	99 (252) Es EINSTEINIUM	100 (257) Fm FERMIUM	101 (258) Md MENDELEVIUM	102 (259) No NOBELIUM	103 (262) Lr LAWRENCIUM
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(1) Pure Appl. Chem., 73, No. 4, 667-683 (2001)
Relative atomic mass is shown with five significant figures. For elements having no stable nuclides, the value enclosed in brackets indicates the mass number of the longest-lived isotope of the element.

However three such elements (Th, Pa, and U) do have a characteristic terrestrial isotopic composition, and for these an atomic weight is tabulated.

Editor: Aditya Vardhan (adivar@netflox.com)

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What stuff is made of...

BARYONS

“BARYONIC MATTER”

**IS GENERALLY TAKEN TO BE
MATTER MADE OF ATOMS.**

**PROTONS AND NEUTRONS
ARE THE MOST COMMON BARYONS**

The image shows a standard periodic table of elements. The title 'PERIODIC TABLE OF THE ELEMENTS' is at the top. A URL 'http://www.kkf-split.hr/periodni/en/' is visible in the top right. The table includes columns for 'GROUP IUPAC' and 'GROUP CAS', and rows for 'PERIOD'. Elements are labeled with their symbols and names. The text 'BARYONS', '“BARYONIC MATTER”', 'IS GENERALLY TAKEN TO BE MATTER MADE OF ATOMS.', 'PROTONS AND NEUTRONS', and 'ARE THE MOST COMMON BARYONS' is overlaid in large, bold, white letters across the center of the table.

Is that all there is?

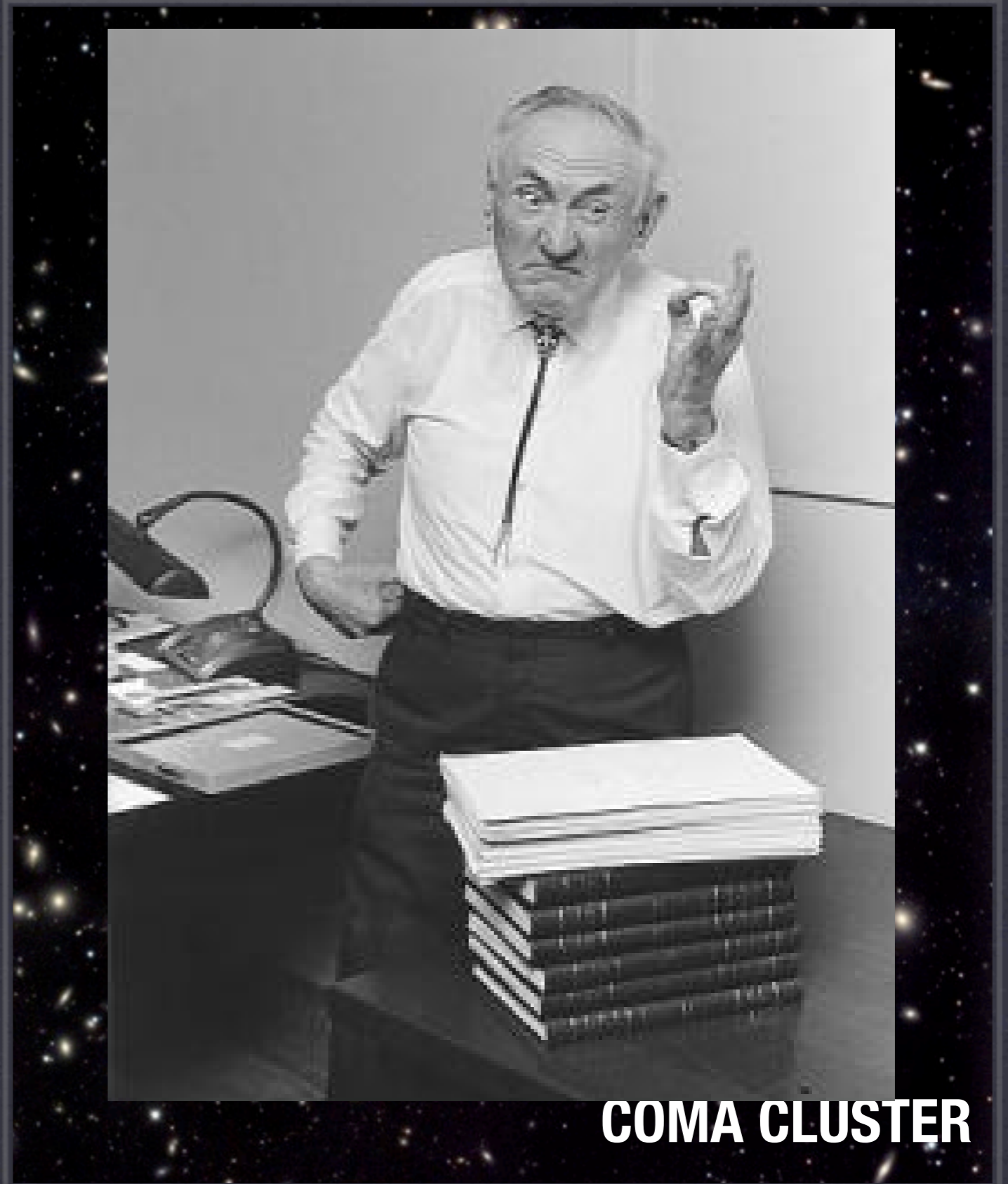
- Astronomers being what they are, kept looking around.
- In 1933, **Fritz Zwicky** looked at the motion of galaxies in the Coma Cluster
- He found there are not enough stars in the cluster's galaxies to hold the cluster together – **90% of the mass was missing!**
- The cluster should have flown apart a long time ago!
- There is some matter holding the galaxies together that **we can't see**



COMA CLUSTER

Is that all there is?

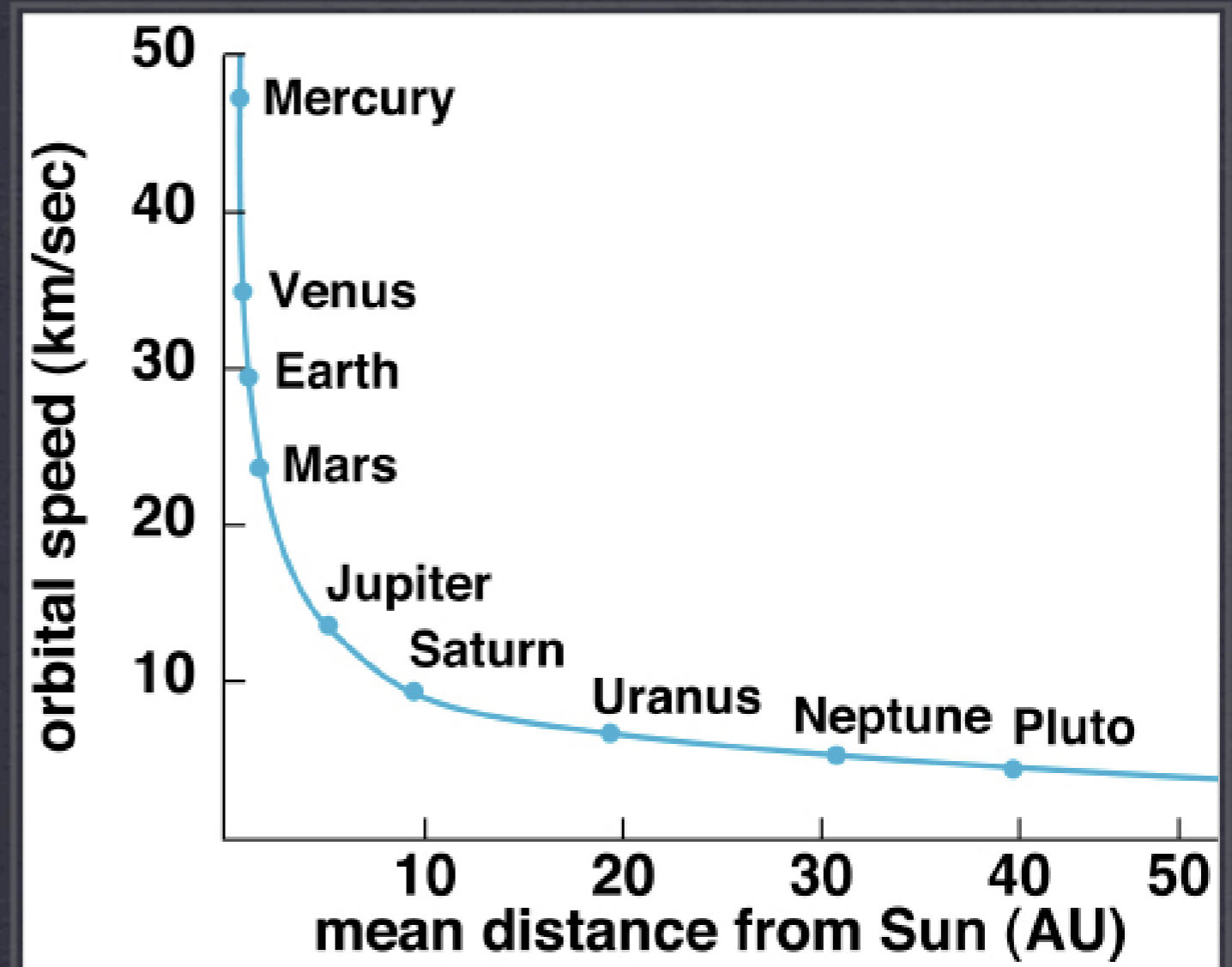
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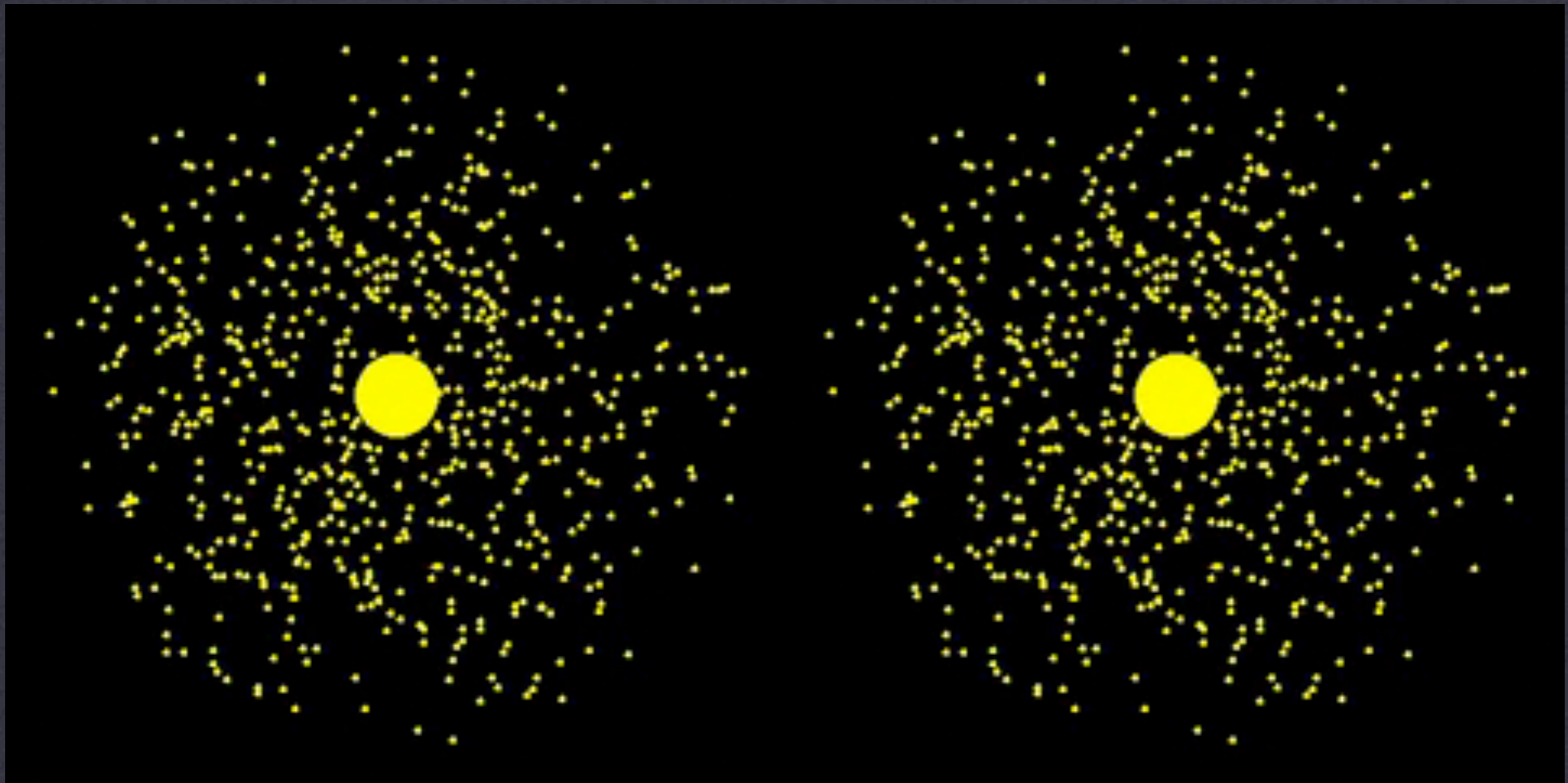
COMA CLUSTER

Gravity & Orbits

- Kepler's Laws say if I am farther from a source of gravity, my orbital speed gets slower
- The farther from the center of the galaxy, the slower you must move!



Gravity & Orbits



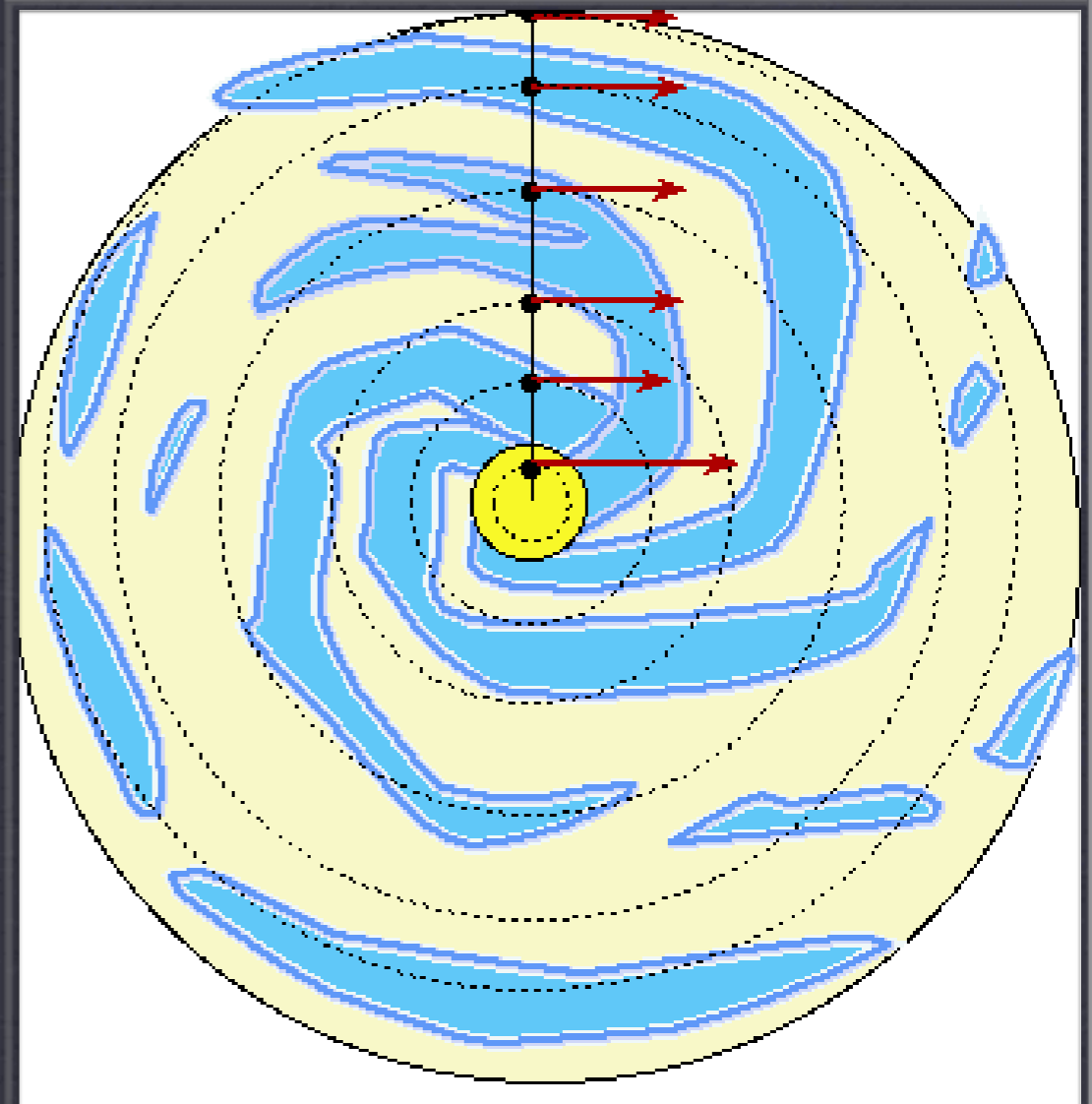
“KEPLERIAN”
STARS FARTHER OUT
ORBIT THE CENTER OF
THE GALAXY **SLOWER**

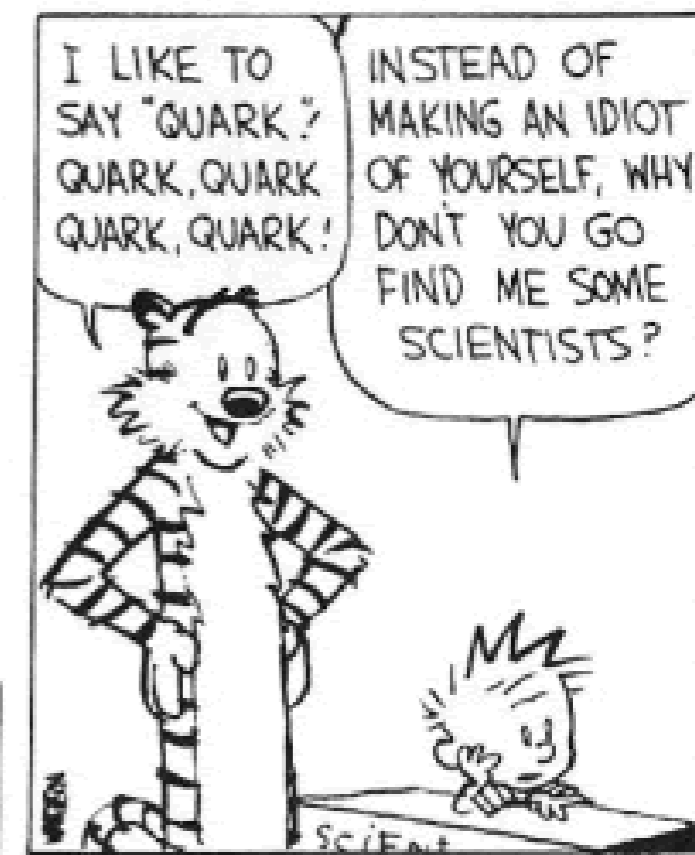
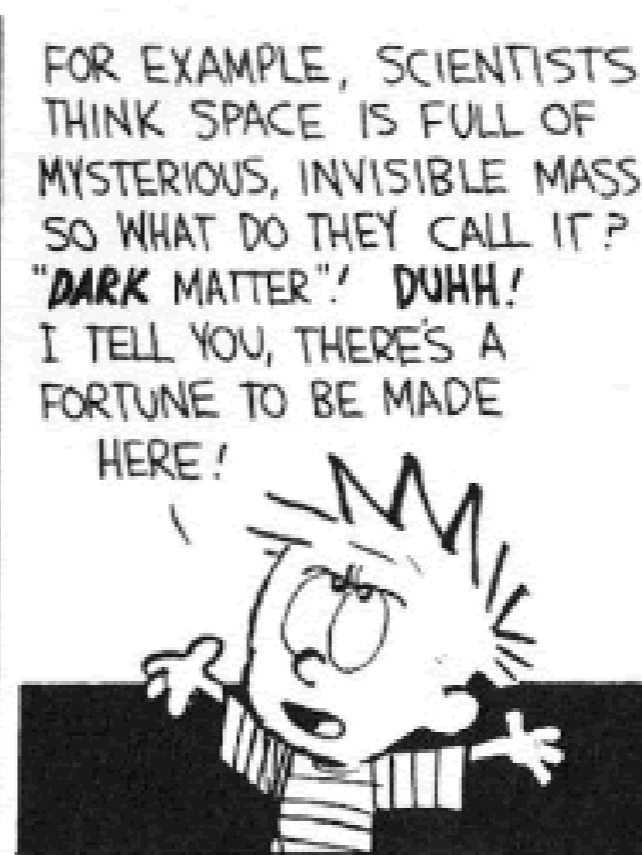
“FLAT ROTATION”
STARS FARTHER OUT
ORBIT **AT THE SAME SPEED**

Gravity & Orbits

- In the 1970s, **Vera Rubin** measured the speed of stars as a function of distance from the center of galaxies
- She found that far from the center, the stars move faster than they should
- This is known as the **galaxy rotation curve problem**
- The explanation: there is matter we cannot see providing enough gravity to make the stars move faster
- **Matter we can't see. Sound familiar?**

**DARK
MATTER**





What is the Dark Matter?

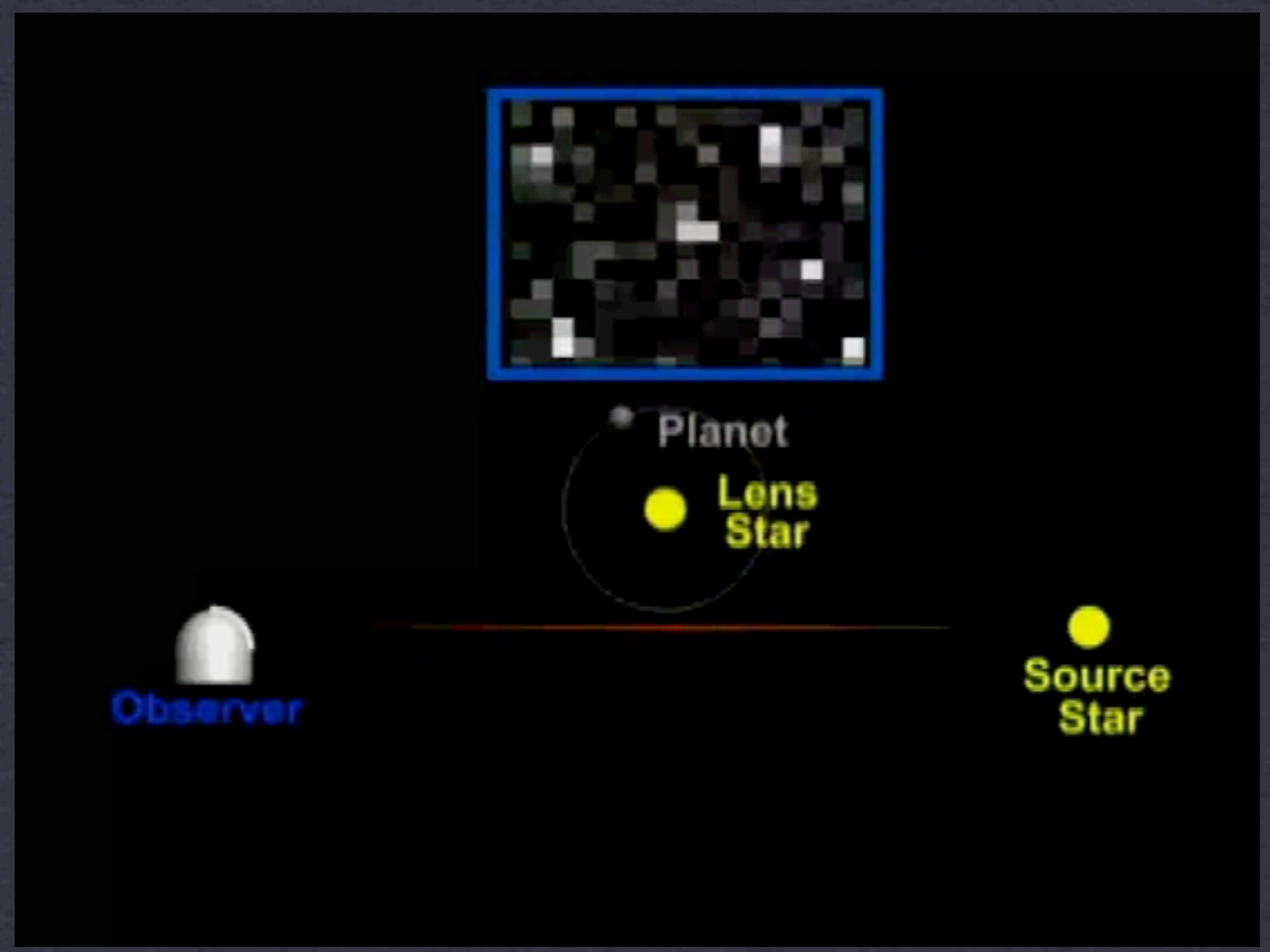
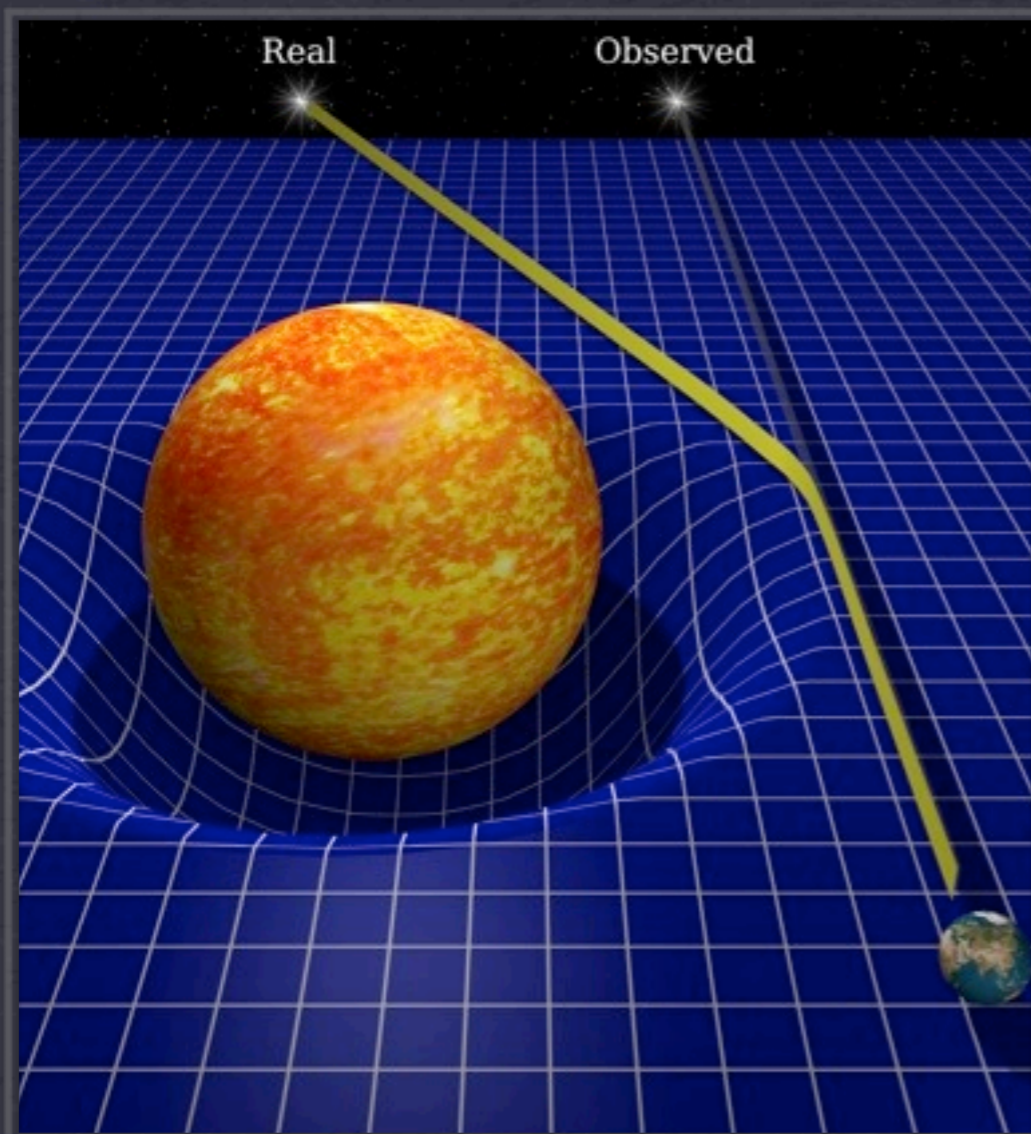
- We don't know! But we can **imagine some possibilities...**
- **MACHOs (Massive Astrophysical Compact Halo Objects)**. Ordinary black holes, neutron stars, or other “dark star-like object” swarming around the galaxy in a vast cloud (“**halo**”)



M104
SOMBRERO GALAXY

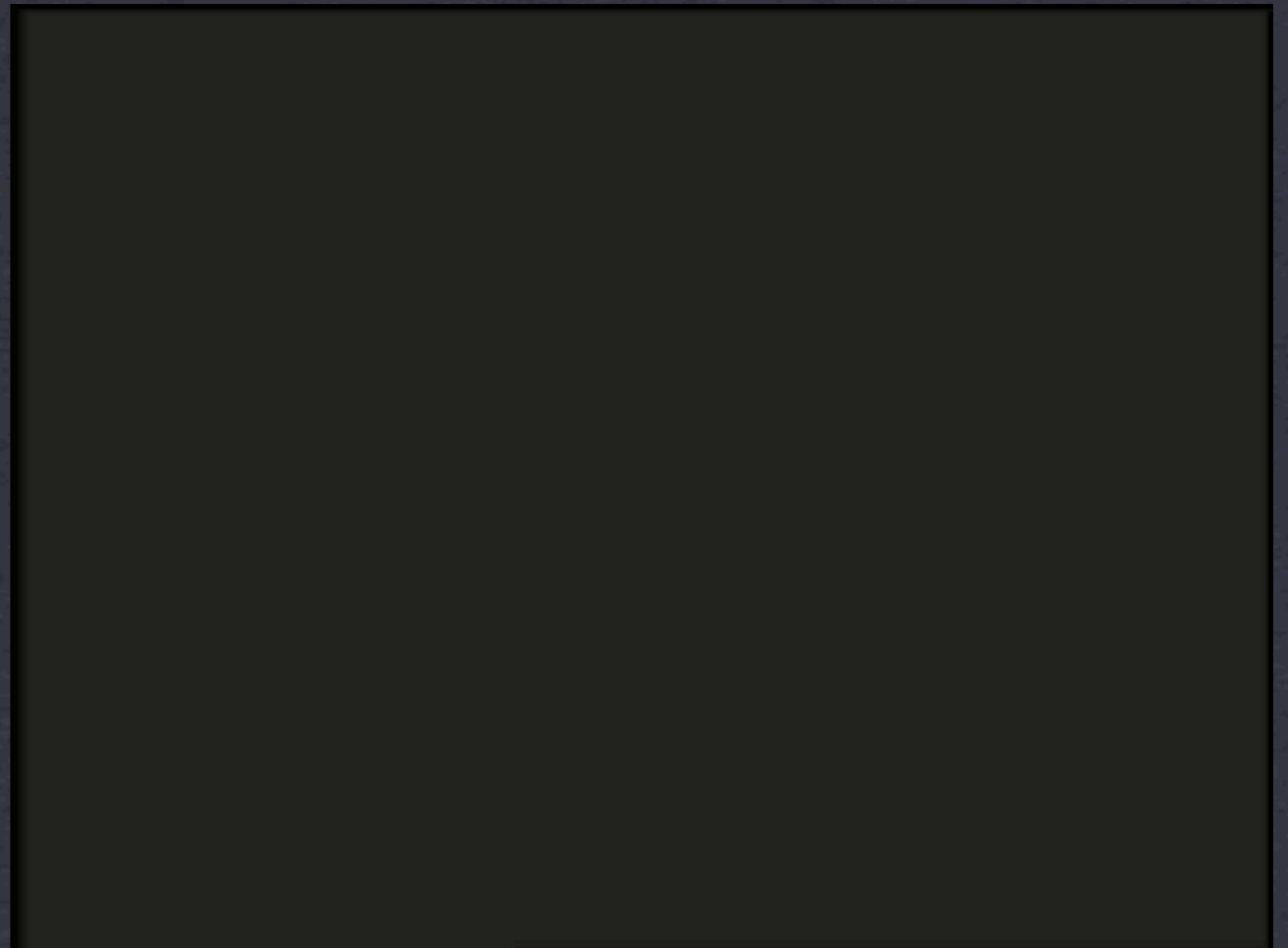
How can we find a MACHO?

- Gravity bends the paths that light travels along
- The MACHO will act like a **magnifying glass** for stars behind it
- This is called **gravitational microlensing**



MACHOs we've seen!

- Observed the LMC for 5.7 years
- Saw some MACHOs; **only ~20% of the galaxy's dark matter**
- Still debating, making new observations



What is the Dark Matter?

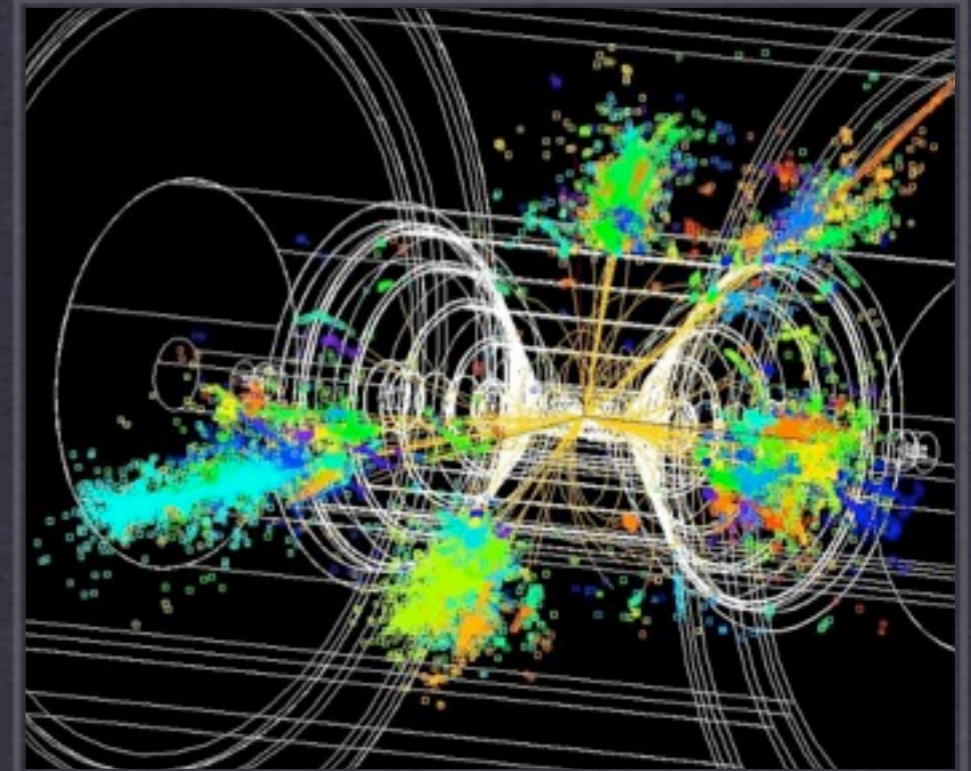
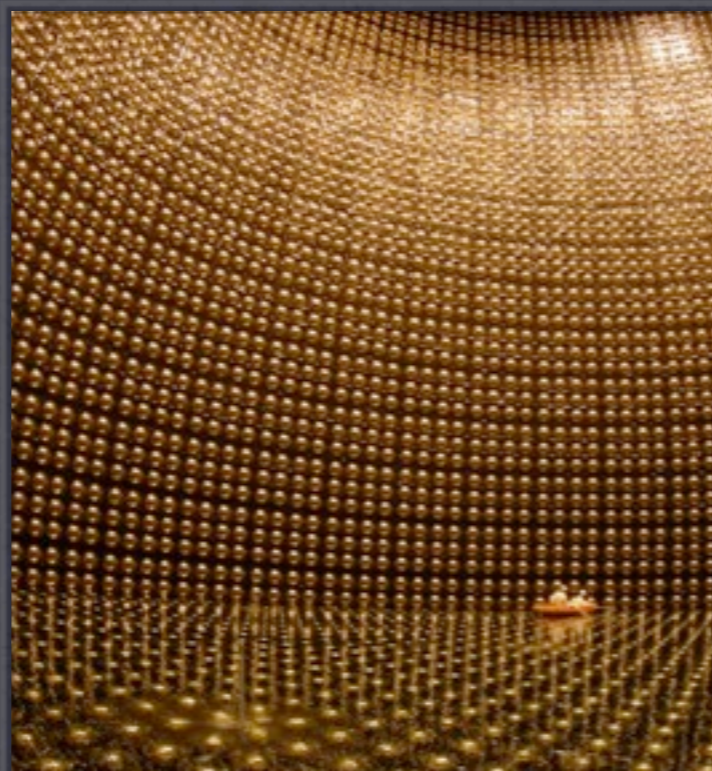
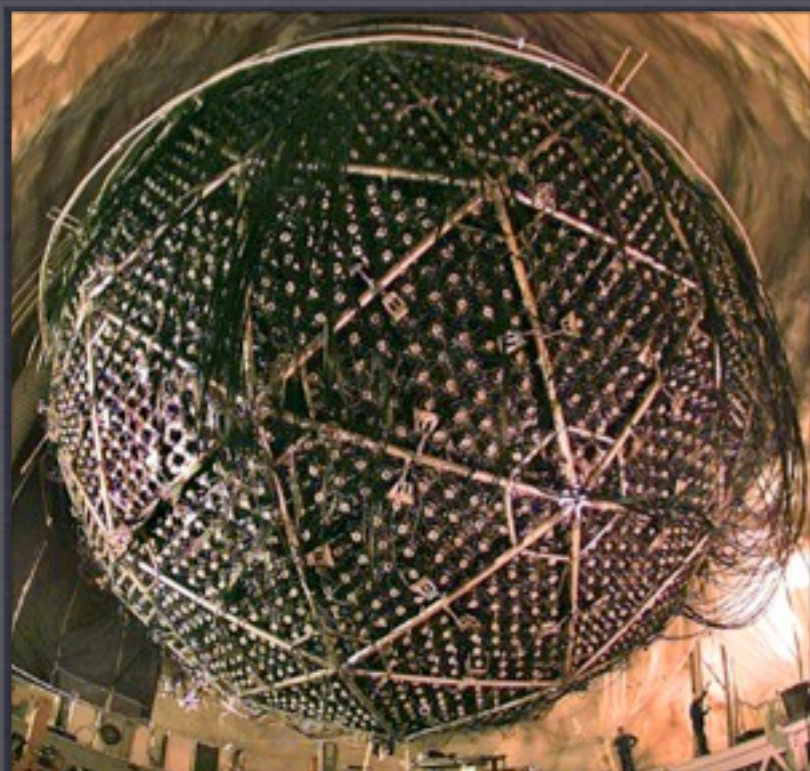
- We don't know! But we can imagine some possibilities...
- **MACHOs (Massive Astrophysical Compact Halo Objects)**. Ordinary black holes, neutron stars, or other “dark star-like object” swarming around the galaxy in a vast cloud (“**halo**”)
- **WIMPs (Weakly Interacting Massive Particles)**. Exotic subatomic particles that are difficult to see with experiments, swarming around the galaxy in a vast cloud (“**halo**”)



M104
SOMBRERO GALAXY

How can we find a WIMP?

- What about **neutrinos**? There are a **LOT** of neutrinos!
 - They're **too light to be the dark matter**
 - If WIMPs are the dark matter, then they are **something new**
- Look with particle detectors, but **no WIMPs have been found yet**



Is that all there is?

- Apparently not...
- Supernovae (Type Ia) are standard candles — **their brightness tells you their distance**

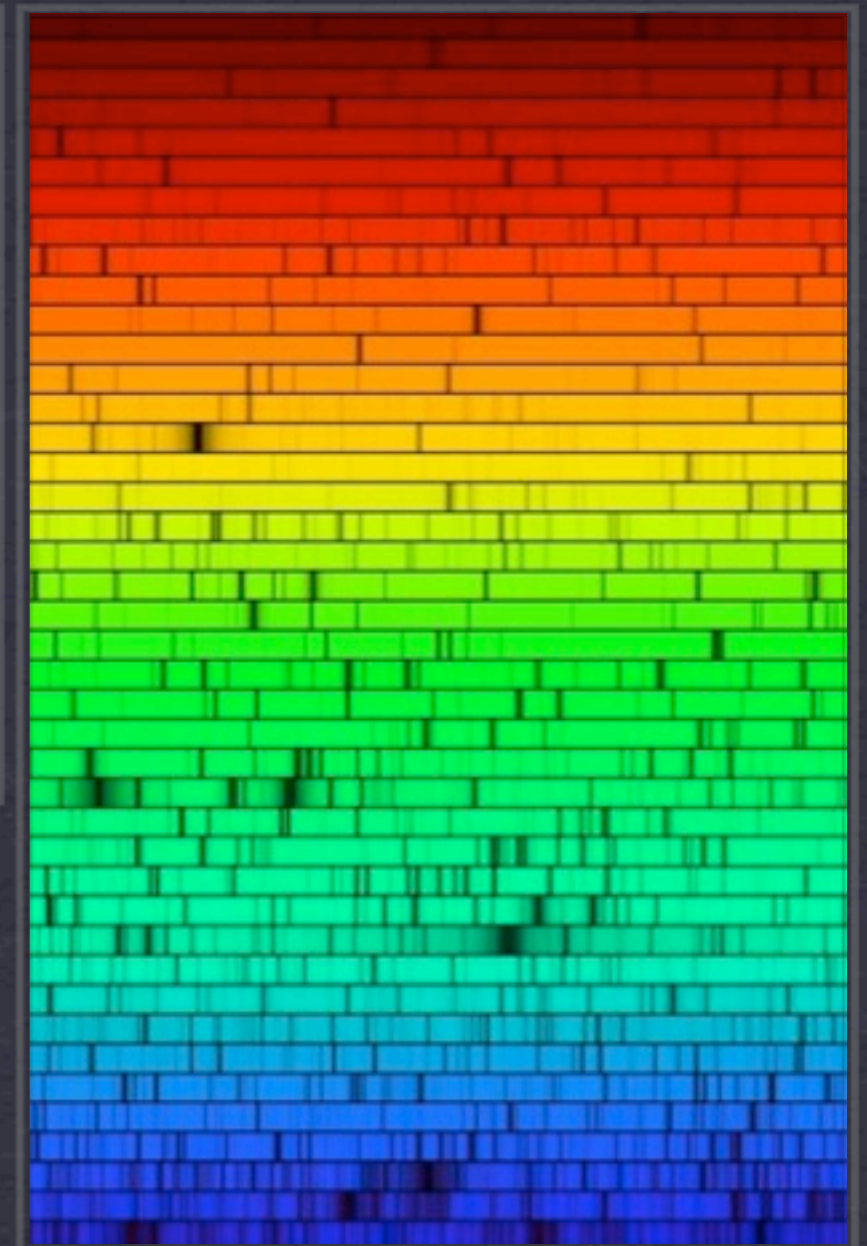


Cosmic Distances

- Hubble taught us about the **expansion of the Cosmos**
 - Everything is getting farther and farther apart!
- The **farther away you are, the redder your light looks**



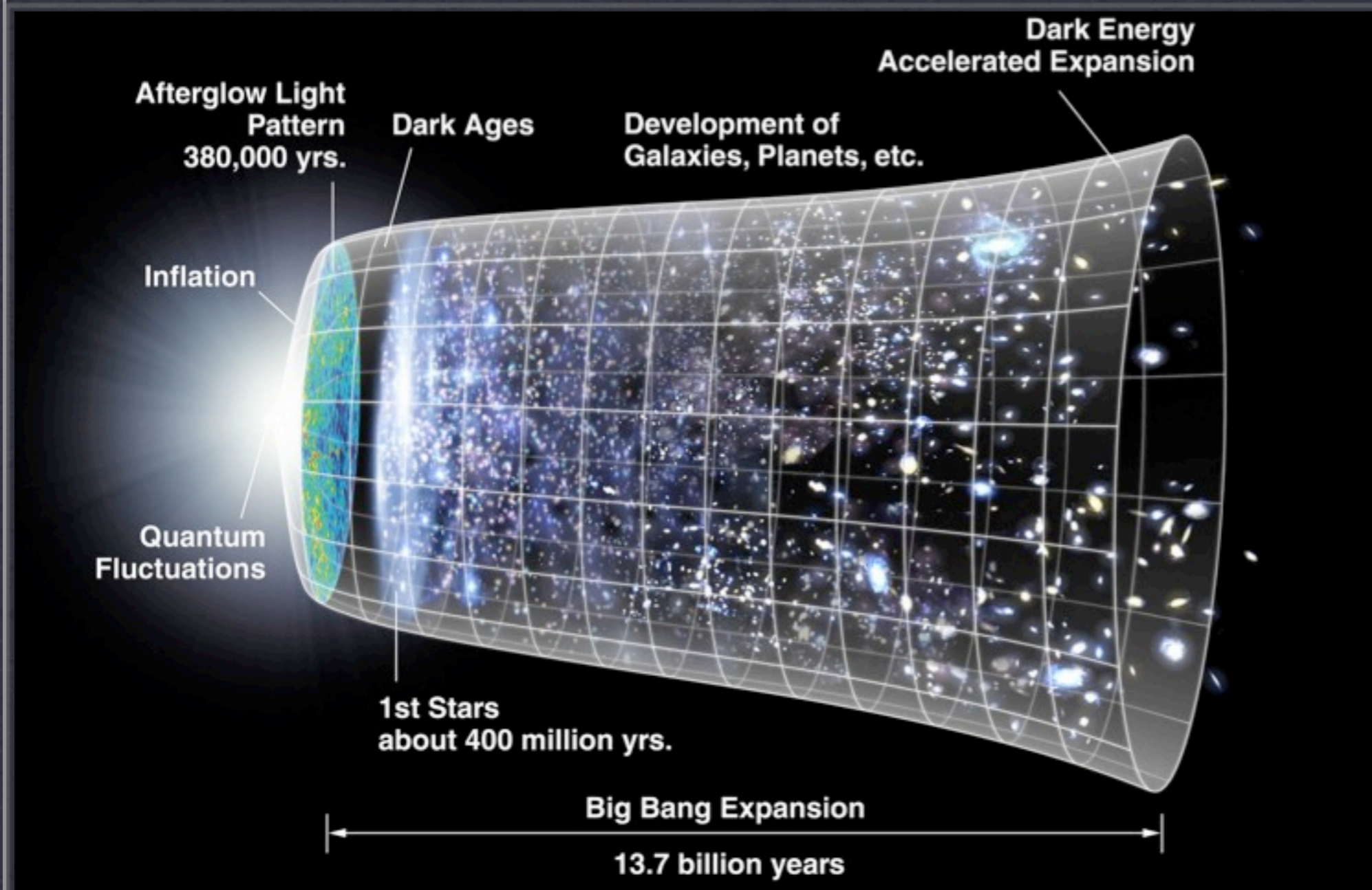
DOPPLER SHIFT
TELLS US HOW FAST
SOMETHING IS MOVING
AWAY FROM US



The Accelerating Universe

- Supernovae are DIMMER than they should be at their measured speed

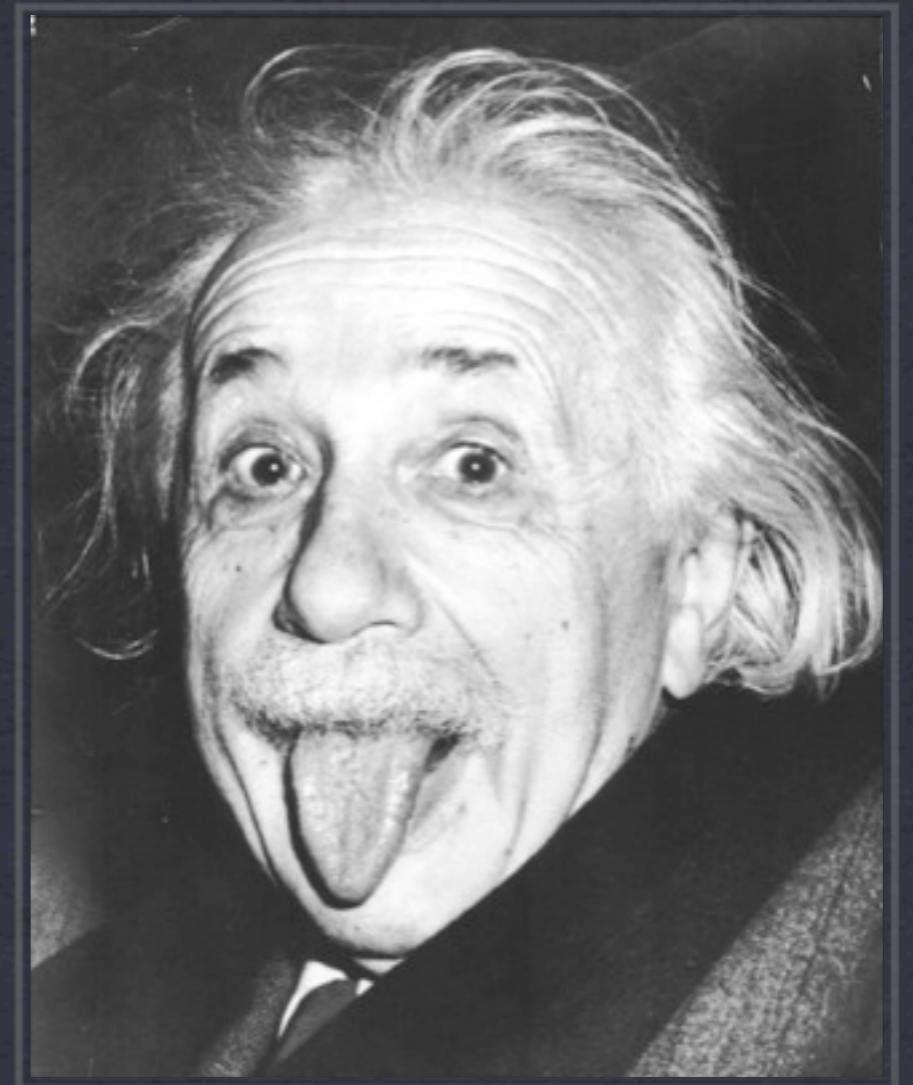
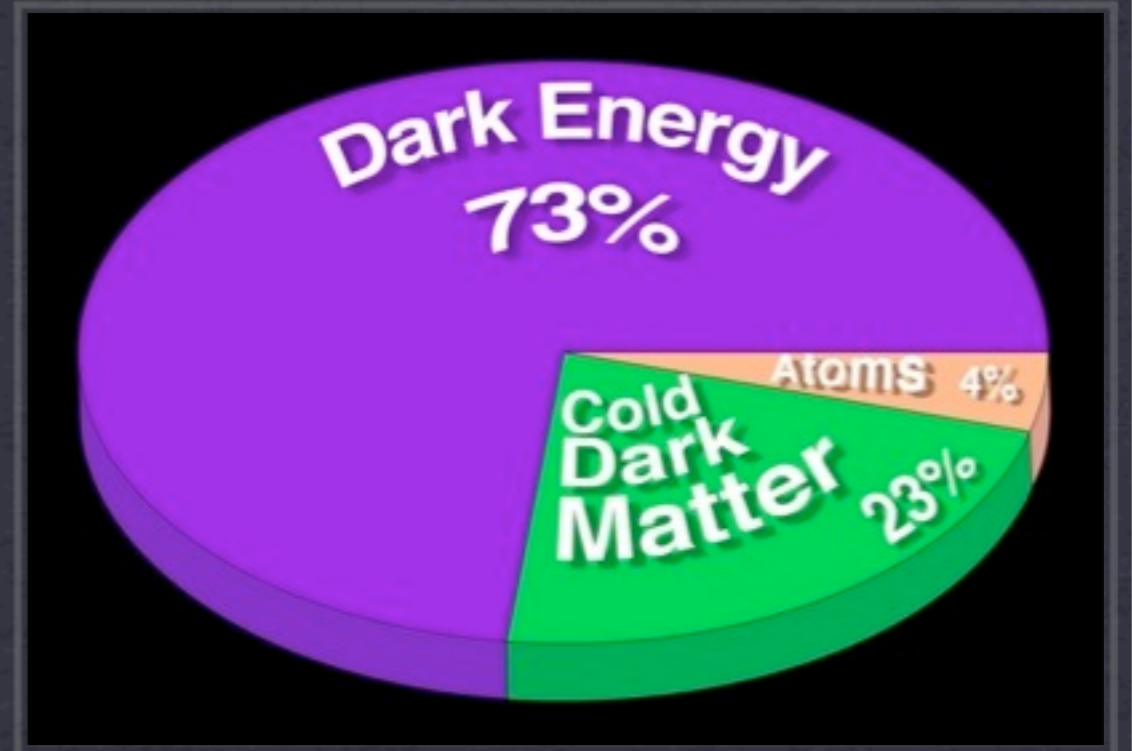
THERE IS A REPULSIVE FORCE THAT IS ACCELERATING THE EXPANSION OF THE UNIVERSE!



**DARK
ENERGY**

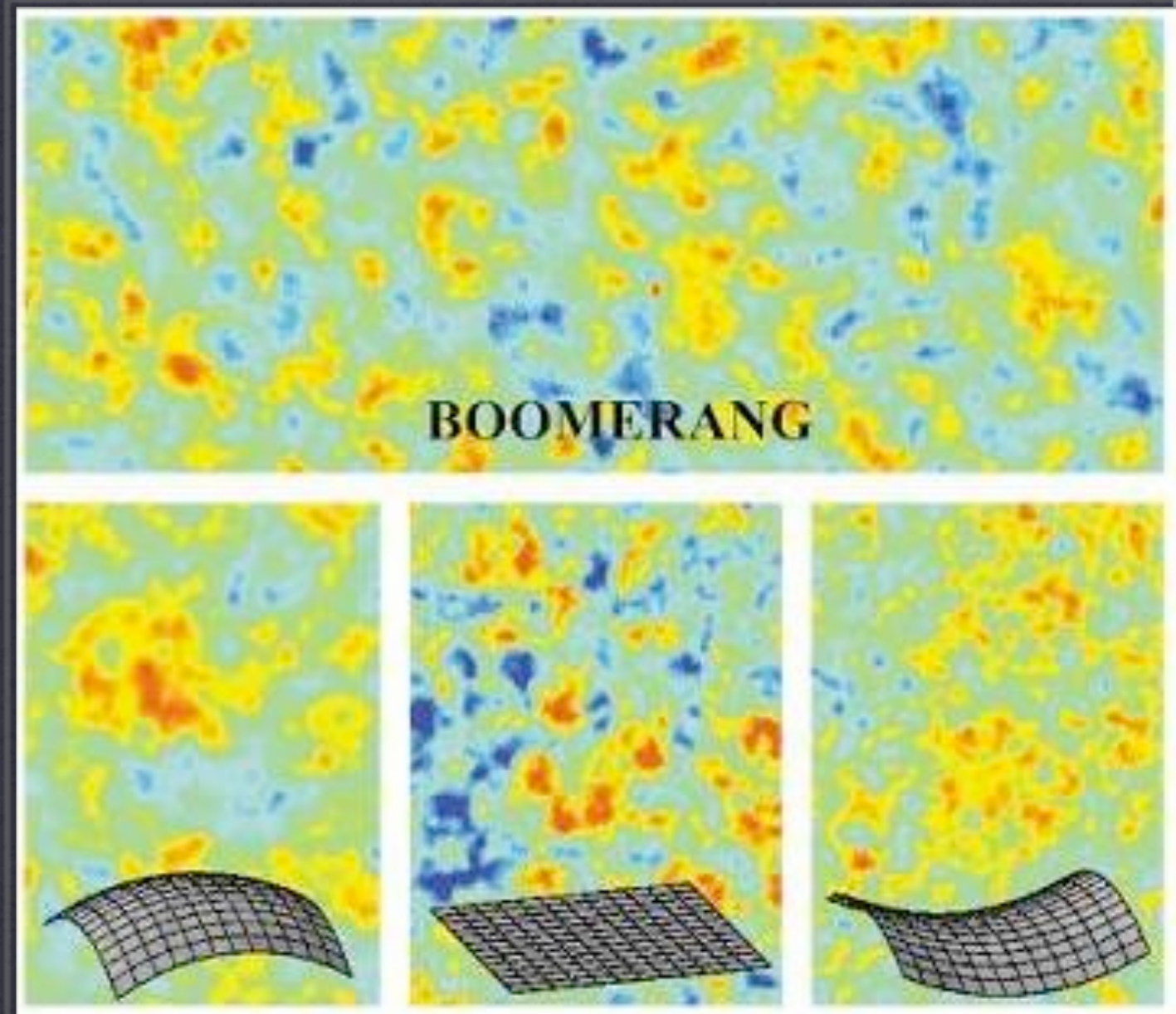
What is Dark Energy?

- **We don't know!** But we know it is there...
- This is the nature of science: we see something, we don't understand, so we keep looking until we understand!
- We have no idea what the Dark Energy is, though many **speculations** exist
 - **Maybe our observations are wrong**, and the expansion is not accelerating!
 - A funny form of **Einstein's Cosmological Constant**



Why do we care?

- The **Ultimate fate** of the Cosmos depends on what the Universe is made of
- There is just enough stuff (including **dark matter and dark energy**) that gravity can slow the expansion of the Universe.
- Current microwave observations suggest the Universe is **flat** — slowly coasting, never recollapsing



**Positive
Curvature:
Universe will
recollapse**

**Flat:
Universe
coasts**

**Negative
Curvature:
Universe
doesn't slow
down**

Last thoughts...

- **We have no idea what Dark Matter or Dark Energy are (though we have some ideas)**
- **96% of the known Universe is composed of stuff we have next to no knowledge of**
- **The Ultimate Fate of the Cosmos depends on what is out there!**

THANK YOU!