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

Shane L. Larson
Utah State University

NGC1300
(Eridanus)

The Dark Side of the Universe:

Dark matter in the galaxy & Cosmos

Shane L. Larson
Department of Physics
Utah State University

s.larson@usu.edu

Utah State University

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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 Oragnisms

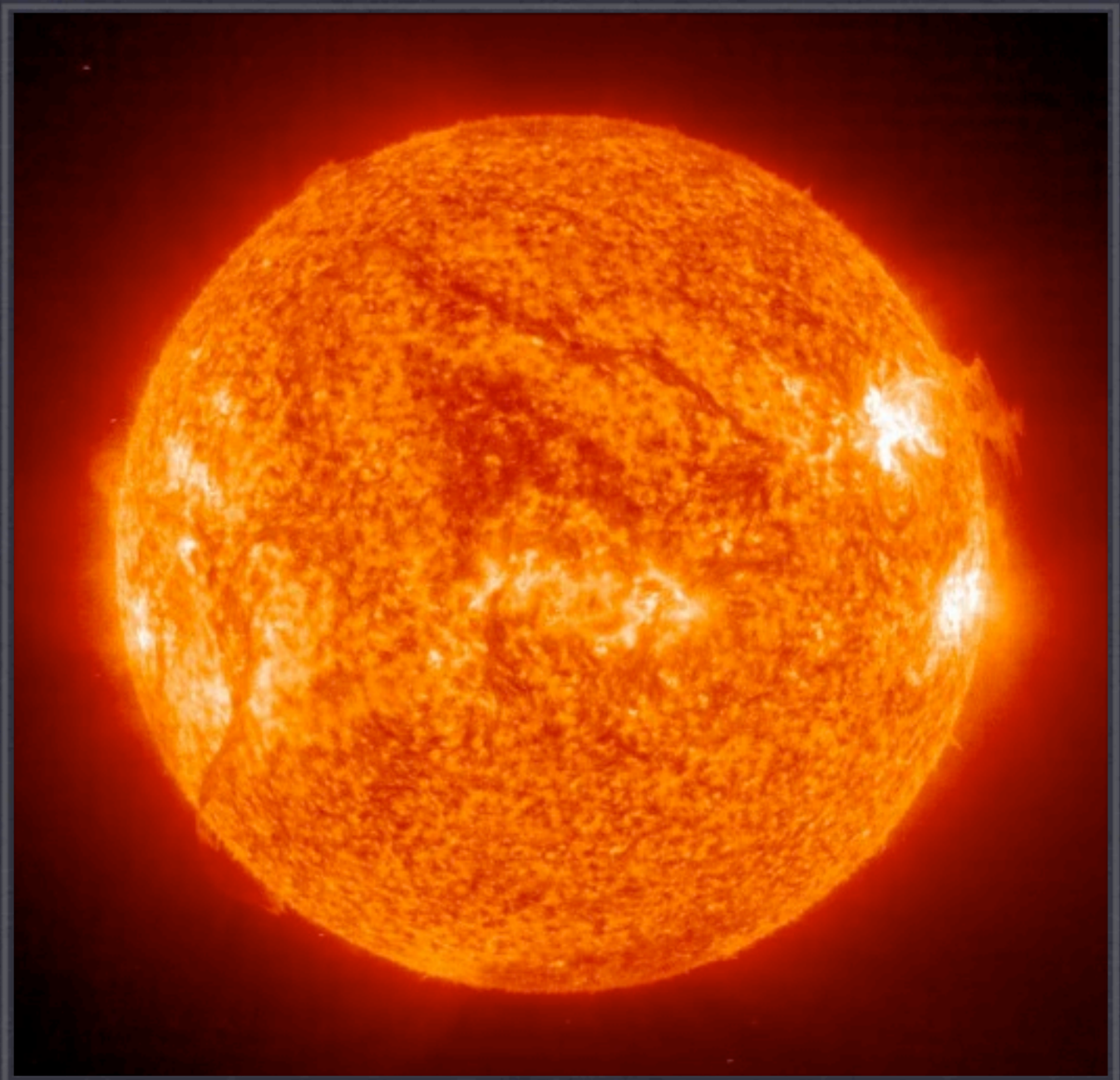
- For every **10,000 atoms** in an average organism, there are:
  - **6500 oxygen atoms**
  - **1800 carbon atoms**
  - **1000 hydrogen atoms**
  - **300 nitrogen atoms**
  - **150 calcium atoms**
  - **100 phosphorus atoms**
  - **25 potassium atoms**
  - **25 sulfur atoms**
  - **15 chlorine atoms**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

Composition of Rocks

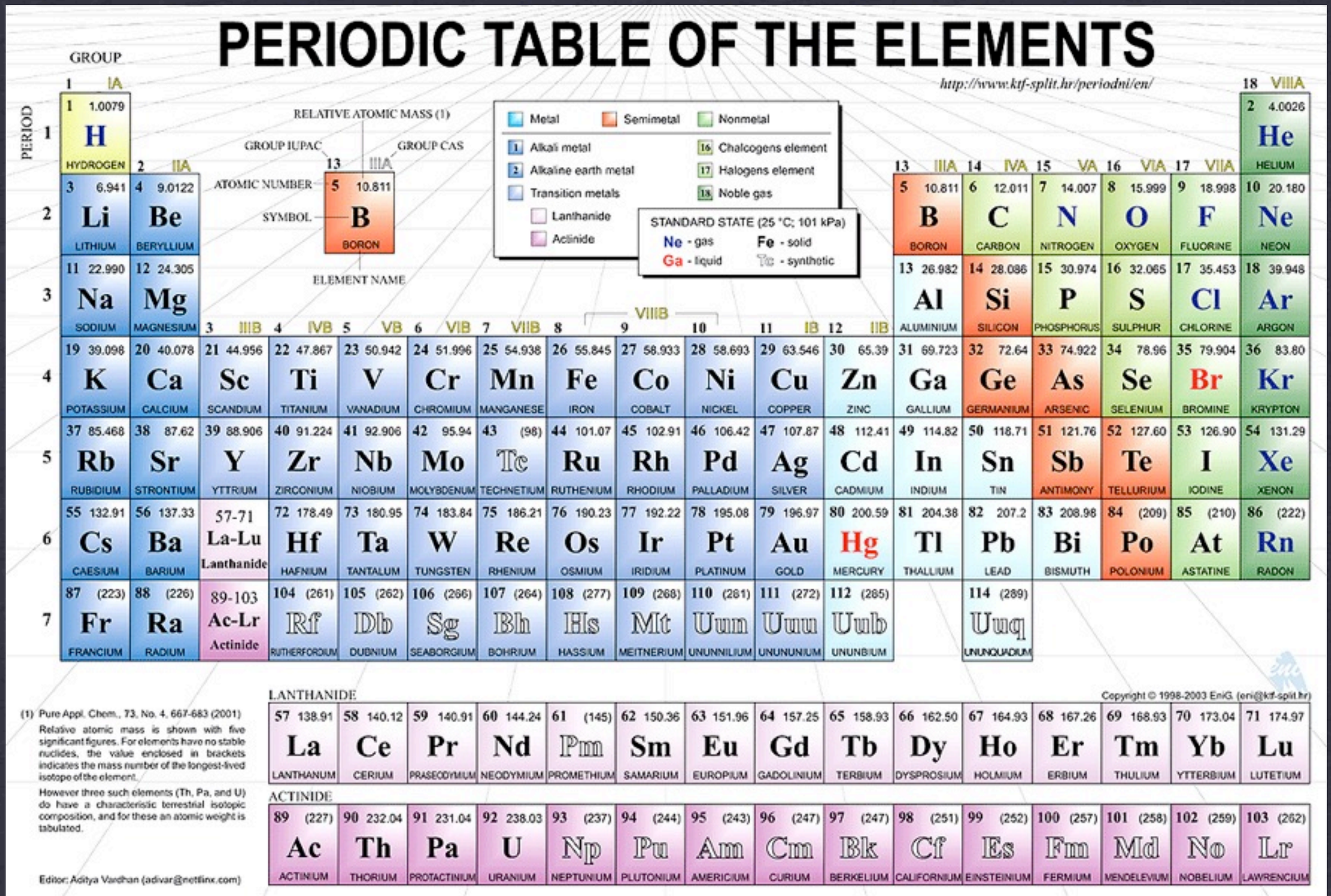
- For every **10,000 atoms** in the Earth's crust, there are:
  - **4640 oxygen atoms**
  - **2820 silicon atoms**
  - **830 aluminum atoms**
  - **560 iron atoms**
  - **410 calcium atoms**
  - **230 sodium atoms**
  - **230 magnesium atoms**
  - **210 potassium atoms**
  - **60 titanium atoms**
  -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



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

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**

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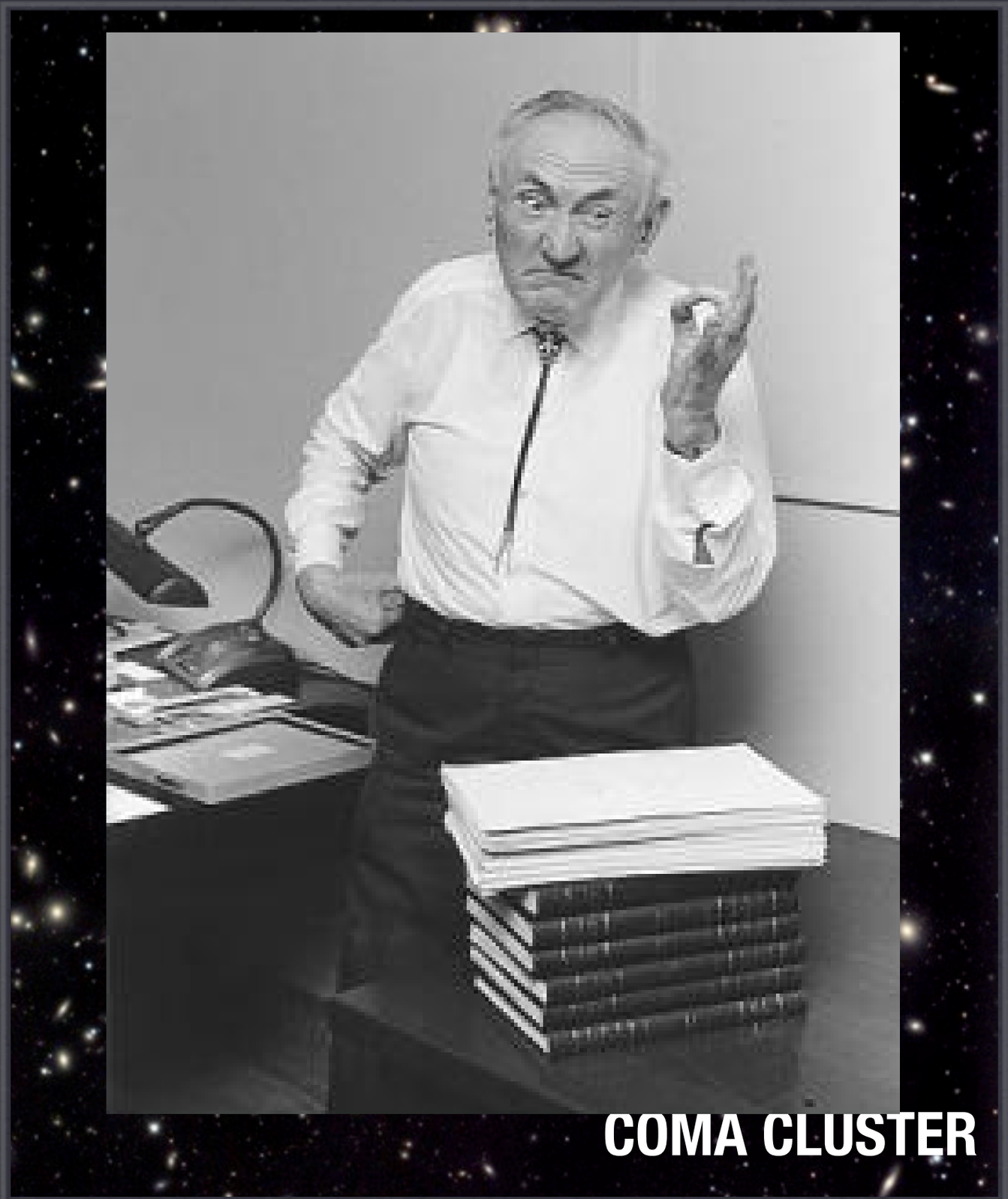
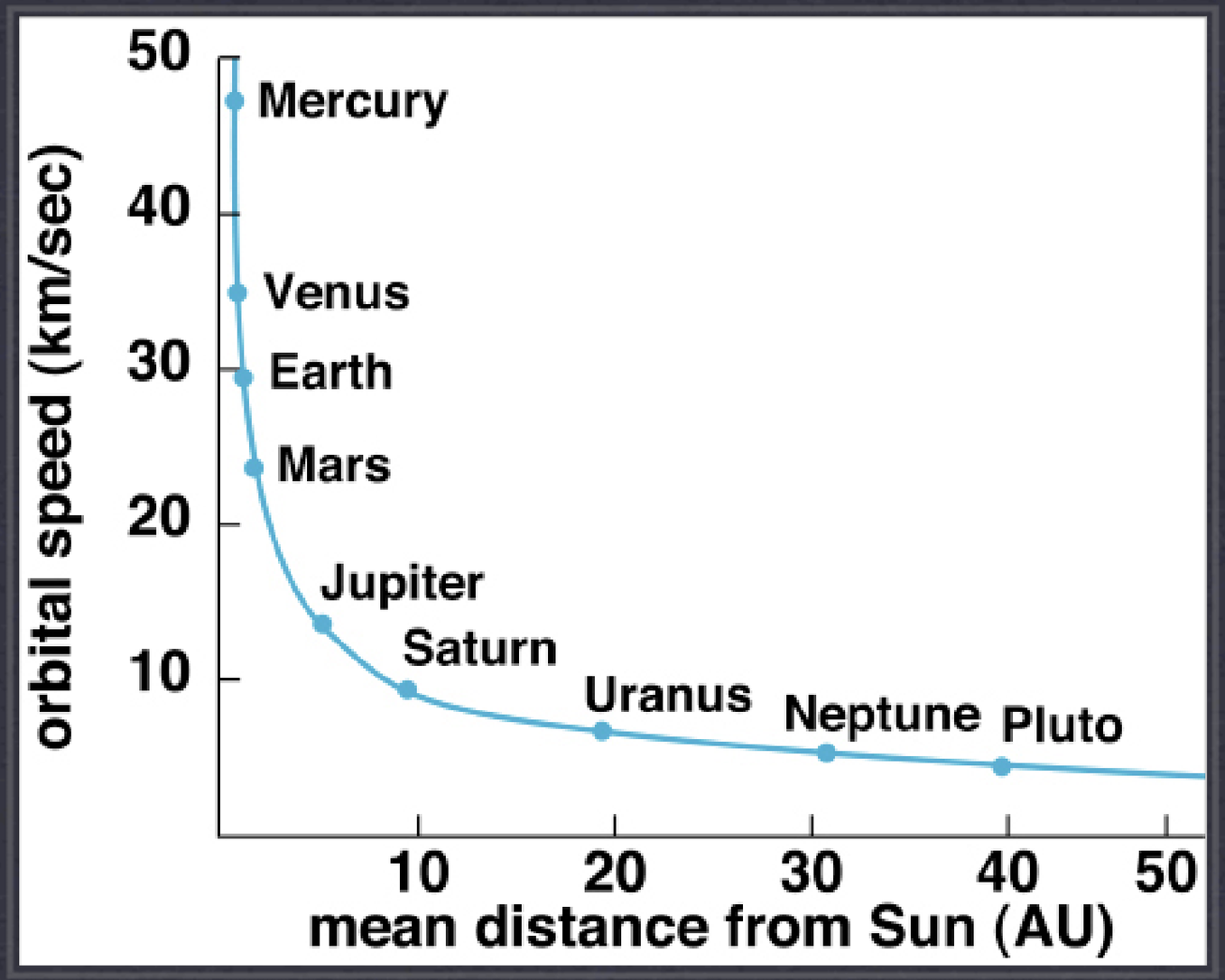


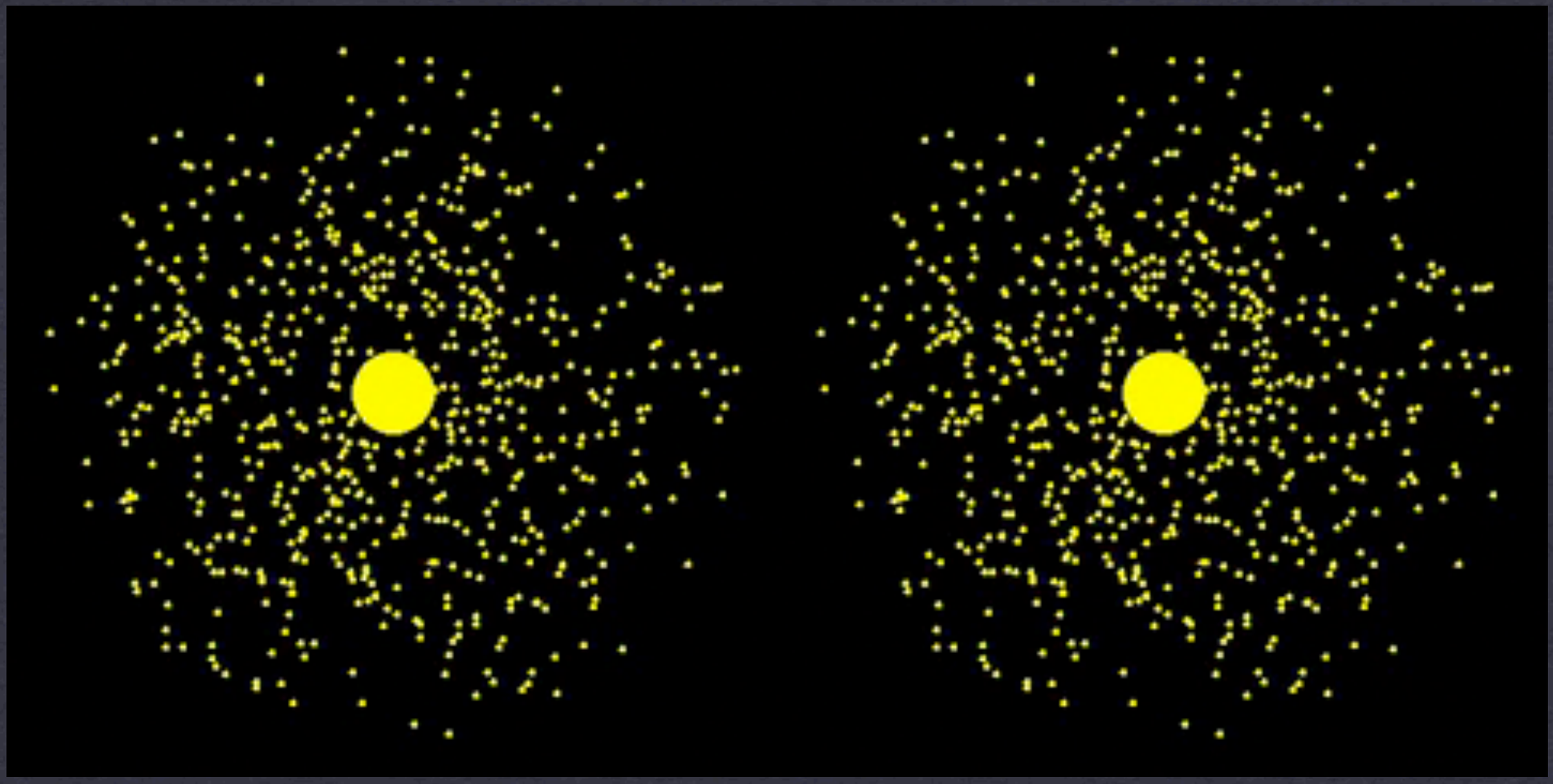
Gravity & Orbits

- 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



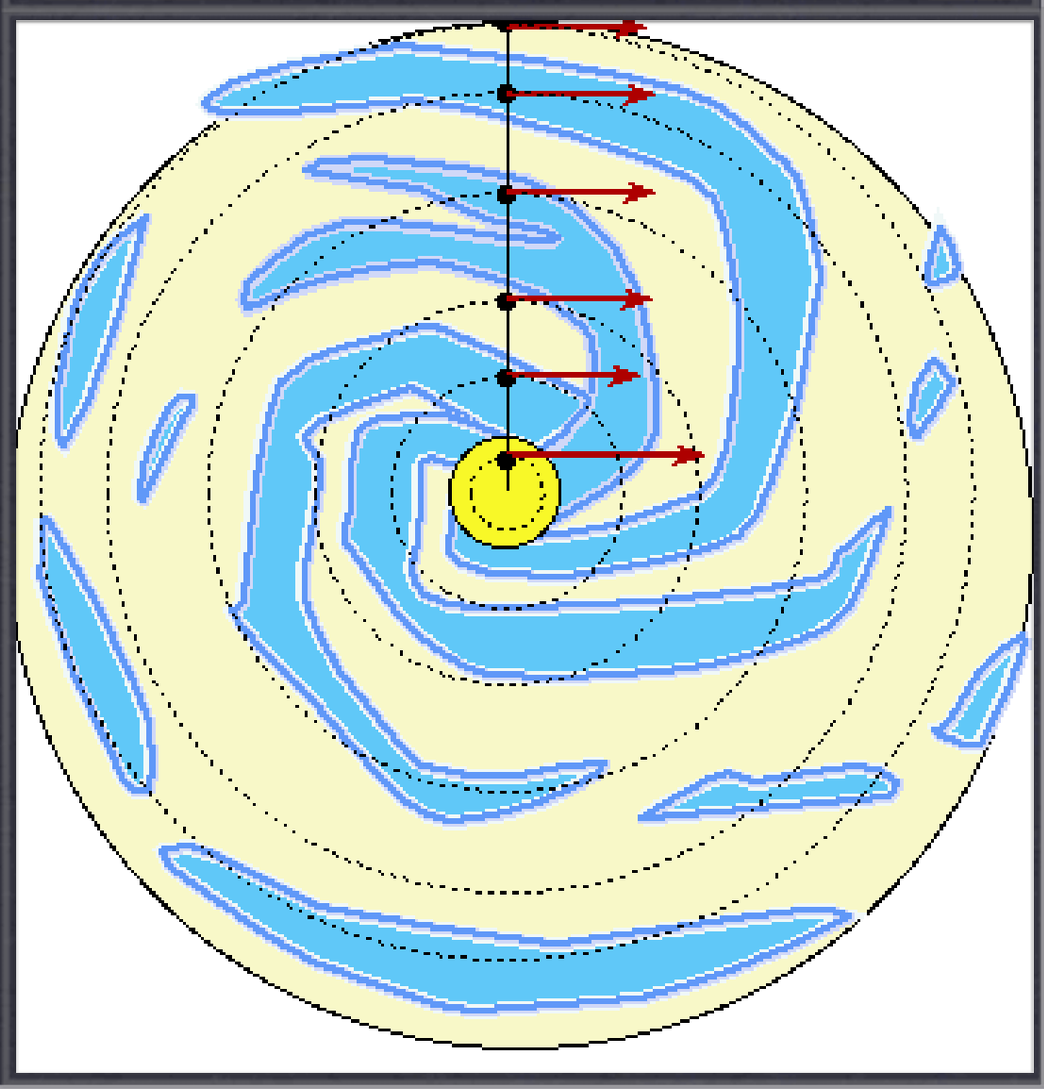
“KEPLERIAN”
STARS FARTHER OUT
ORBIT THE CENTER OF
THE GALAXY SLOWER

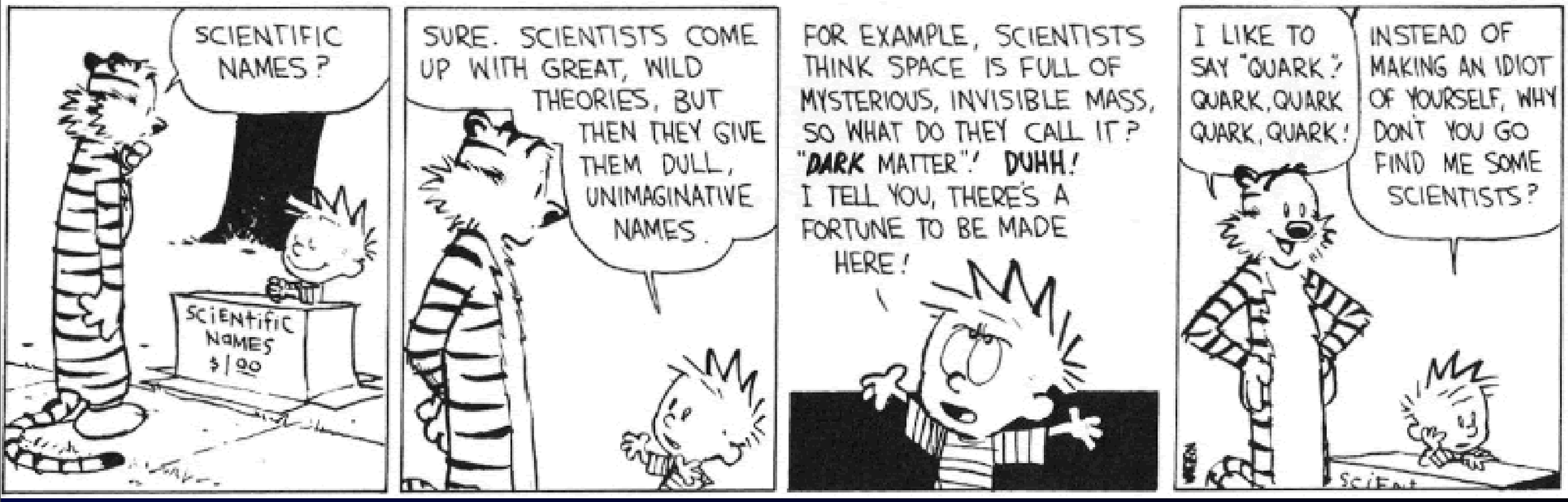
“FLAT ROTATION”
STARS FARTHER OUT
ORBIT AT THE SAME SPEED

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




SCIENTIFIC NAMES?
SCIENTIFIC NAMES $1.00
SURE. SCIENTISTS COME UP WITH GREAT, WILD THEORIES, BUT THEN THEY GIVE THEM DULL, UNIMAGINATIVE NAMES.
FOR EXAMPLE, SCIENTISTS THINK SPACE IS FULL OF MYSTERIOUS, INVISIBLE MASS, SO WHAT DO THEY CALL IT? "DARK MATTER"! DUHH! I TELL YOU, THERE'S A FORTUNE TO BE MADE HERE!
I LIKE TO SAY "QUARK"? QUARK, QUARK QUARK, QUARK!
INSTEAD OF MAKING AN IDIOT OF YOURSELF, WHY DON'T YOU GO FIND ME SOME SCIENTISTS?

What is the Dark Matter?

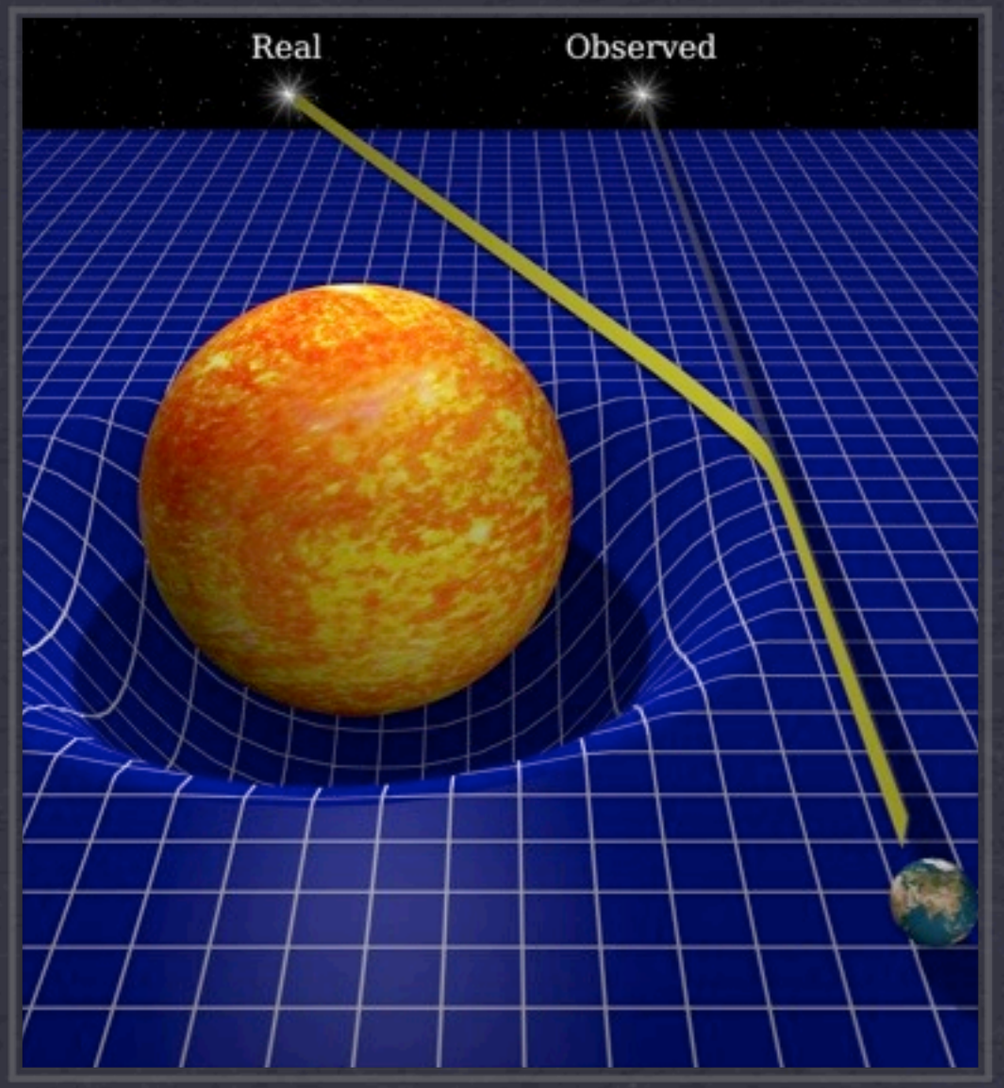
- We don't know! But we can **imagine some possibilities**…

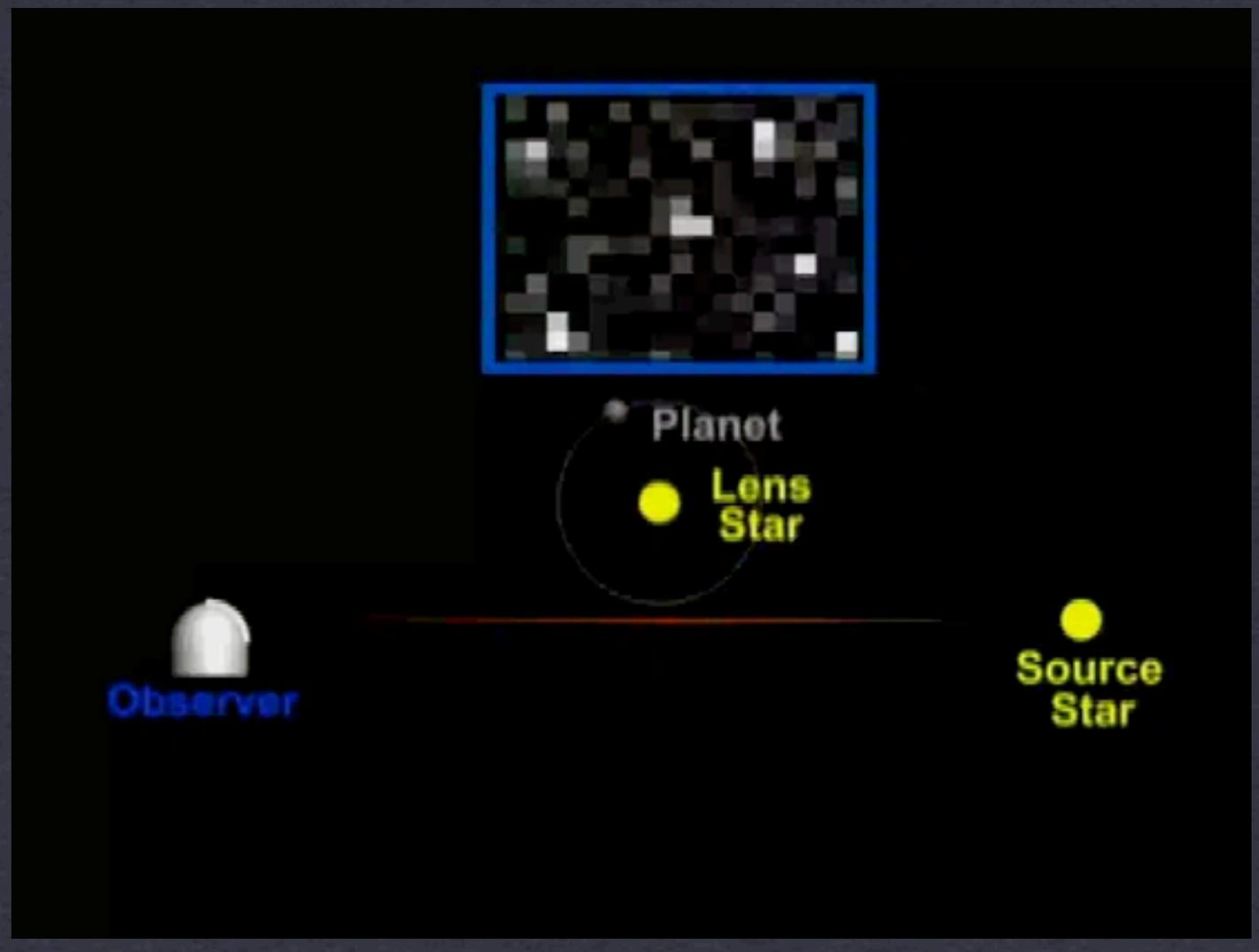
- **MACHOs (Massive Astrophysical Compact Halo Objects)**. Ordinary black holes, neutron stars, or other "dark star-like object" swarming around the galaxy in a vast cloud ("**halo**")

M104
SOMBRERO GALAXY

How can we find a MACHO?

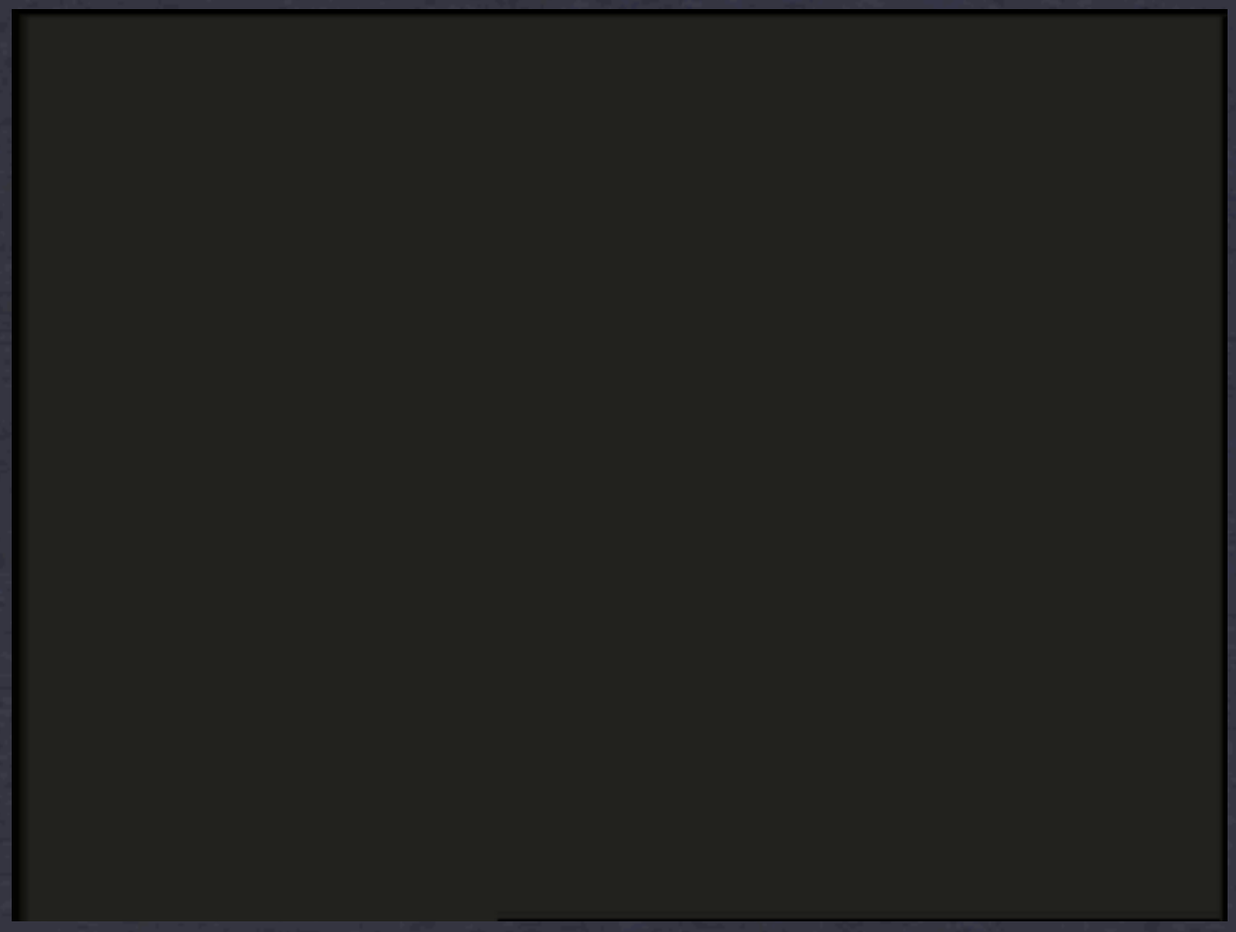
- Gravity bends the paths that light travels along
- The MACHO will act like a **magnifying glass** for stars behind it
- This is called **gravitational microlensing**





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?

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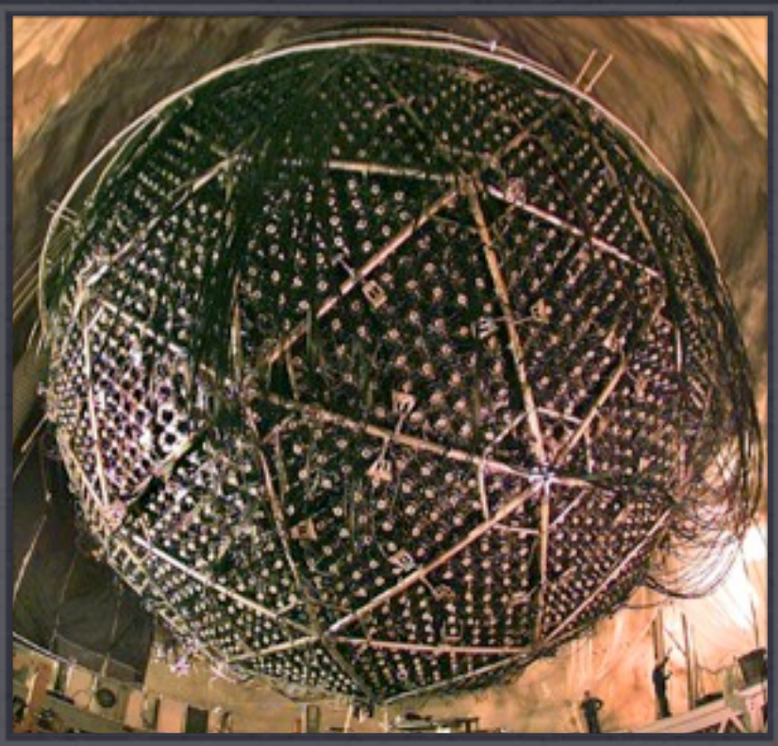
- **MACHOs (Massive Astrophysical Compact Halo Objects)**. Ordinary black holes, neutron stars, or other "dark star-like object" swarming around the galaxy in a vast cloud ("**halo**")

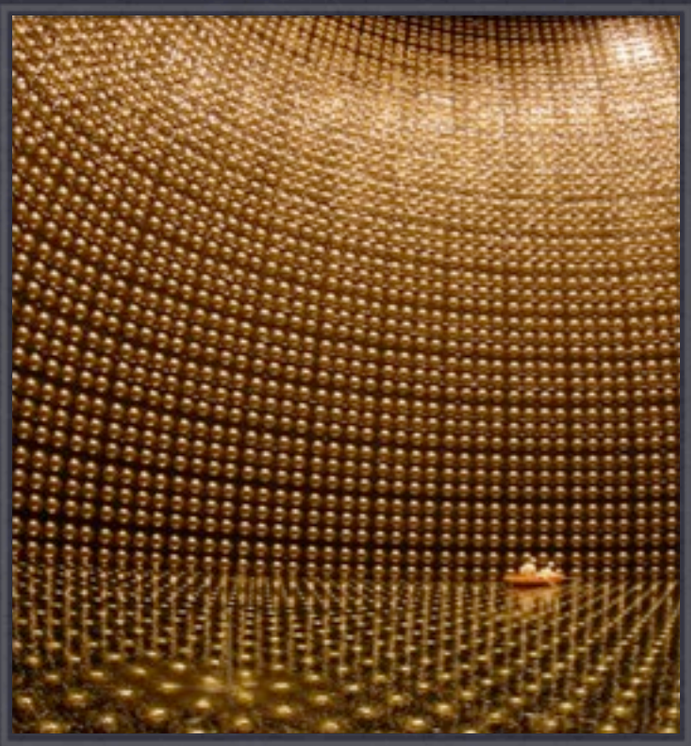
- **WIMPs (Weakly Interacting Massive Particles)**. Exotic subatomic particles that are difficult to see with experiments, swarming around the galaxy in a vast cloud ("**halo**")

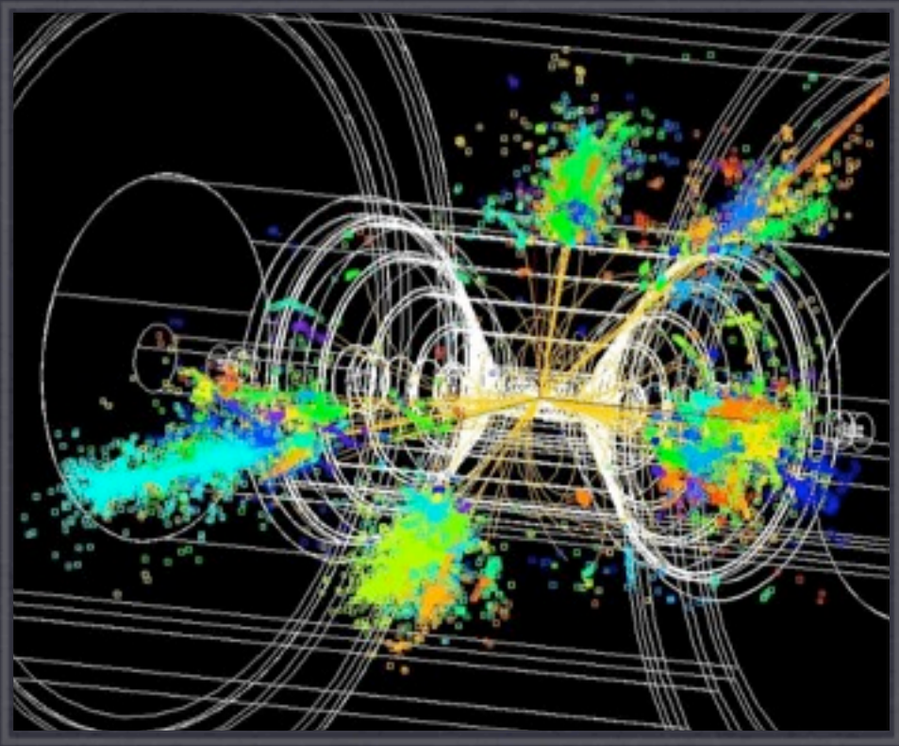
M104
SOMBRERO GALAXY

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**







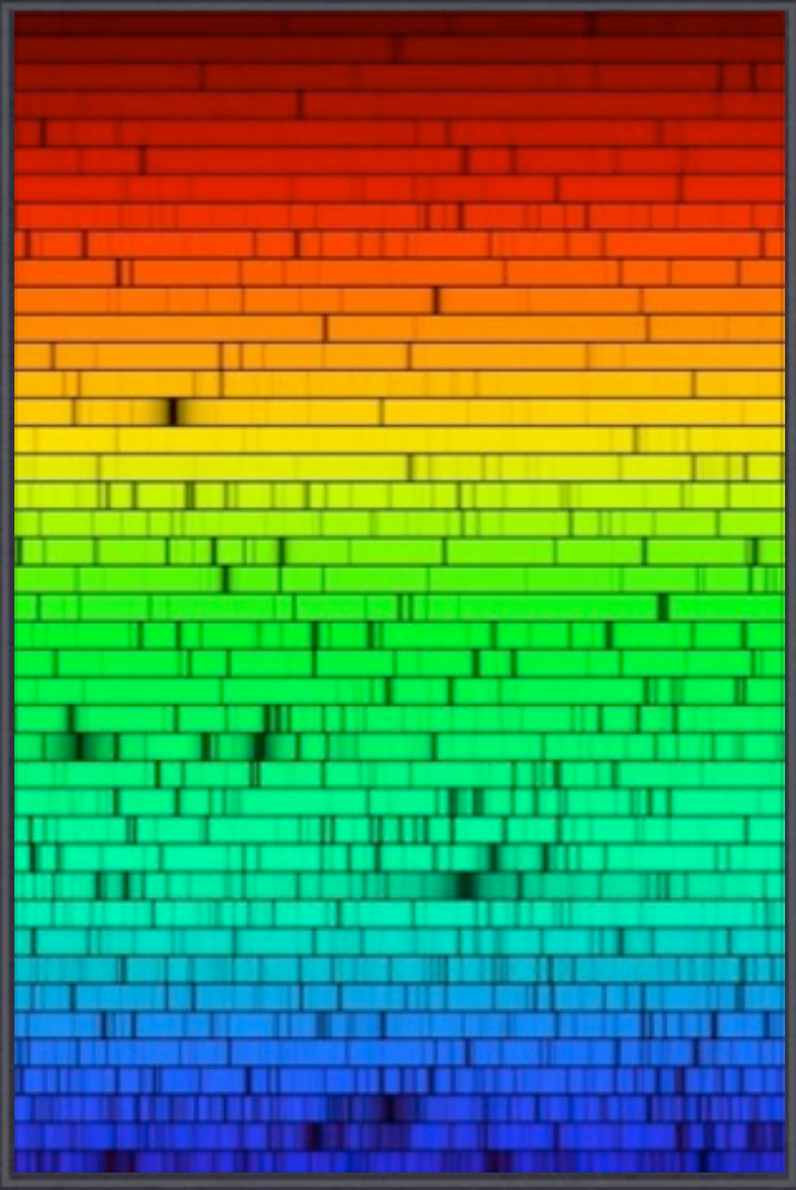
Is that all there is?

- 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**

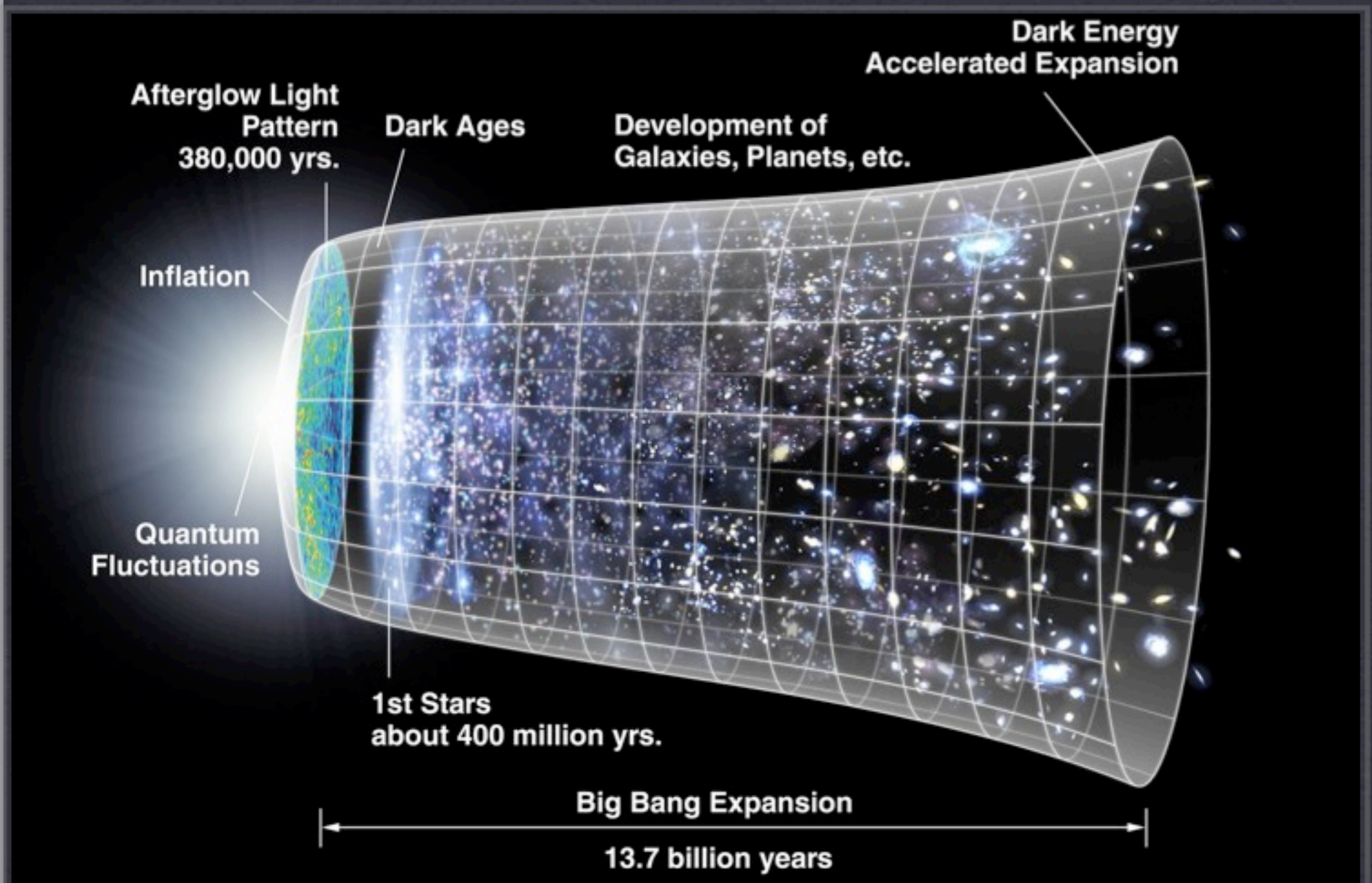
DOPPLER SHIFT
TELLS US HOW FAST SOMETHING IS MOVING AWAY FROM US



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!

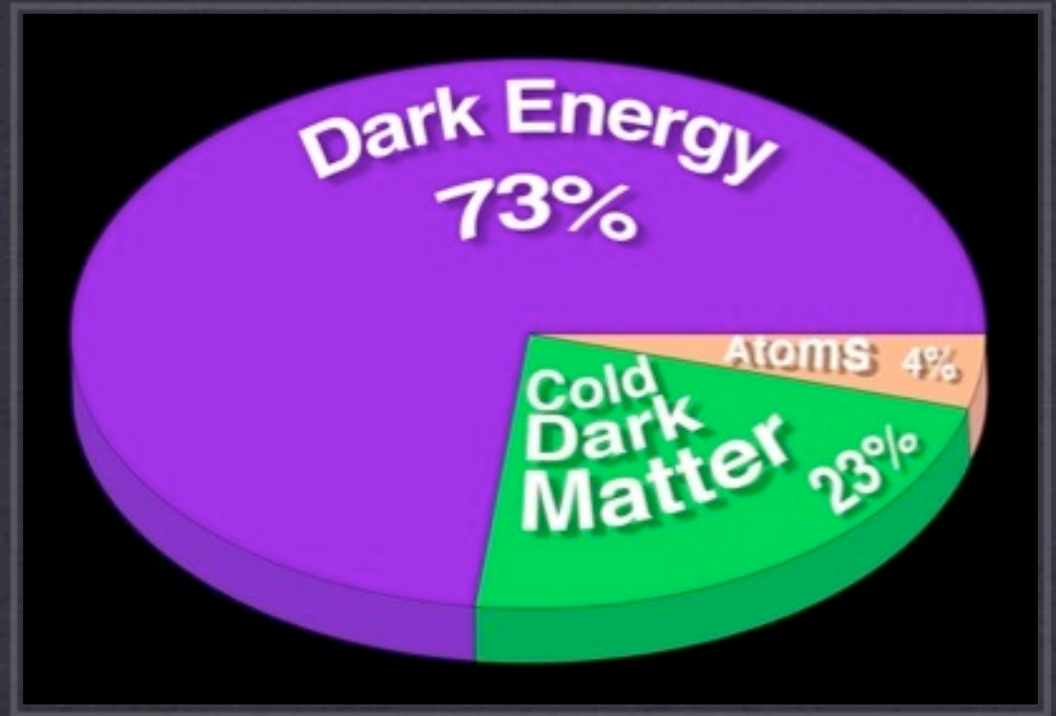


DARK ENERGY

What is Dark Energy?

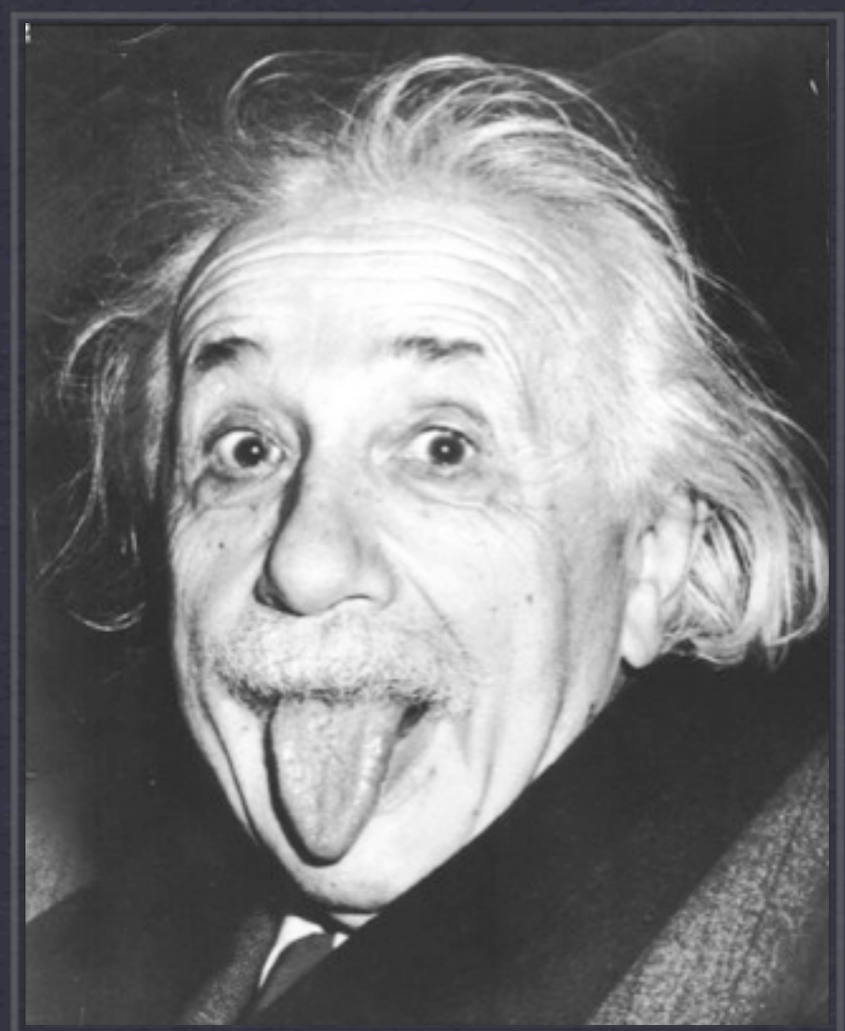
- **We don't know!** **But we know it is there...**

- This is the nature of science: we see something, we don't understand, so we keep looking until we understand!



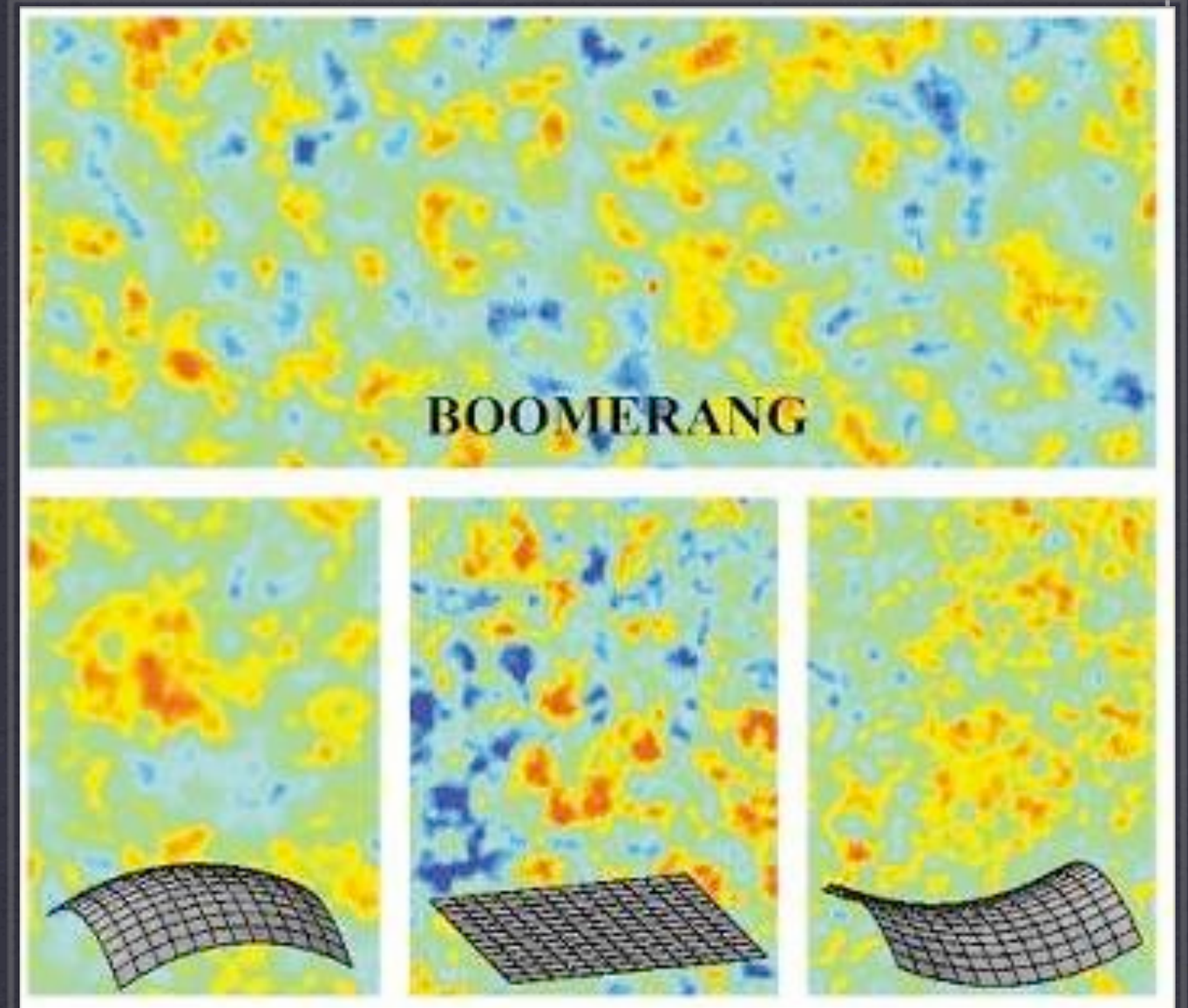
- We have no idea what the Dark Energy is, though many **speculations** exist

  - **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!