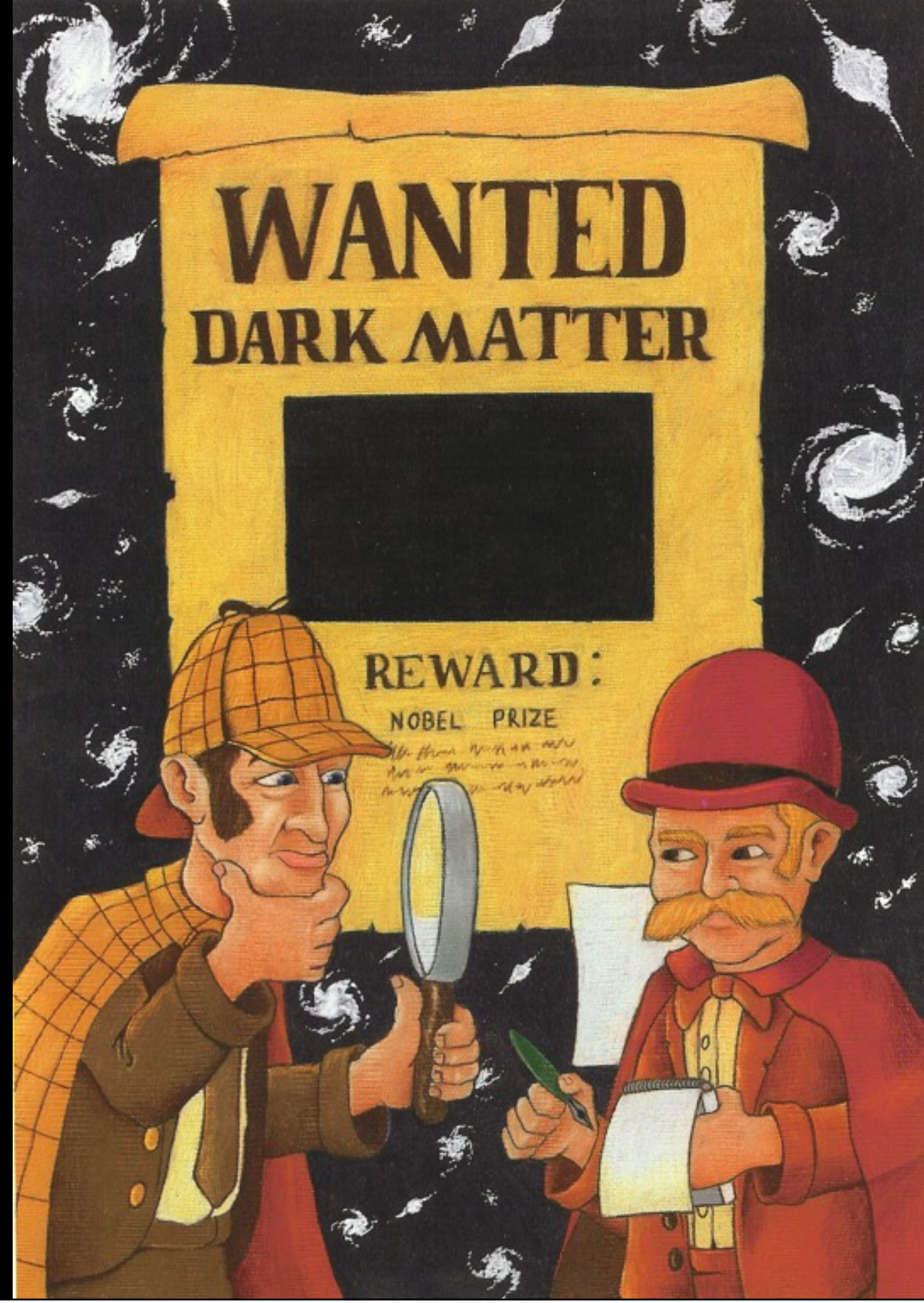
Physics 51 LECTURE 5 October 28, 2011

- More about Galaxies and Dark Matter
- More about Special Relativity

“The Case of the Dark Matter”

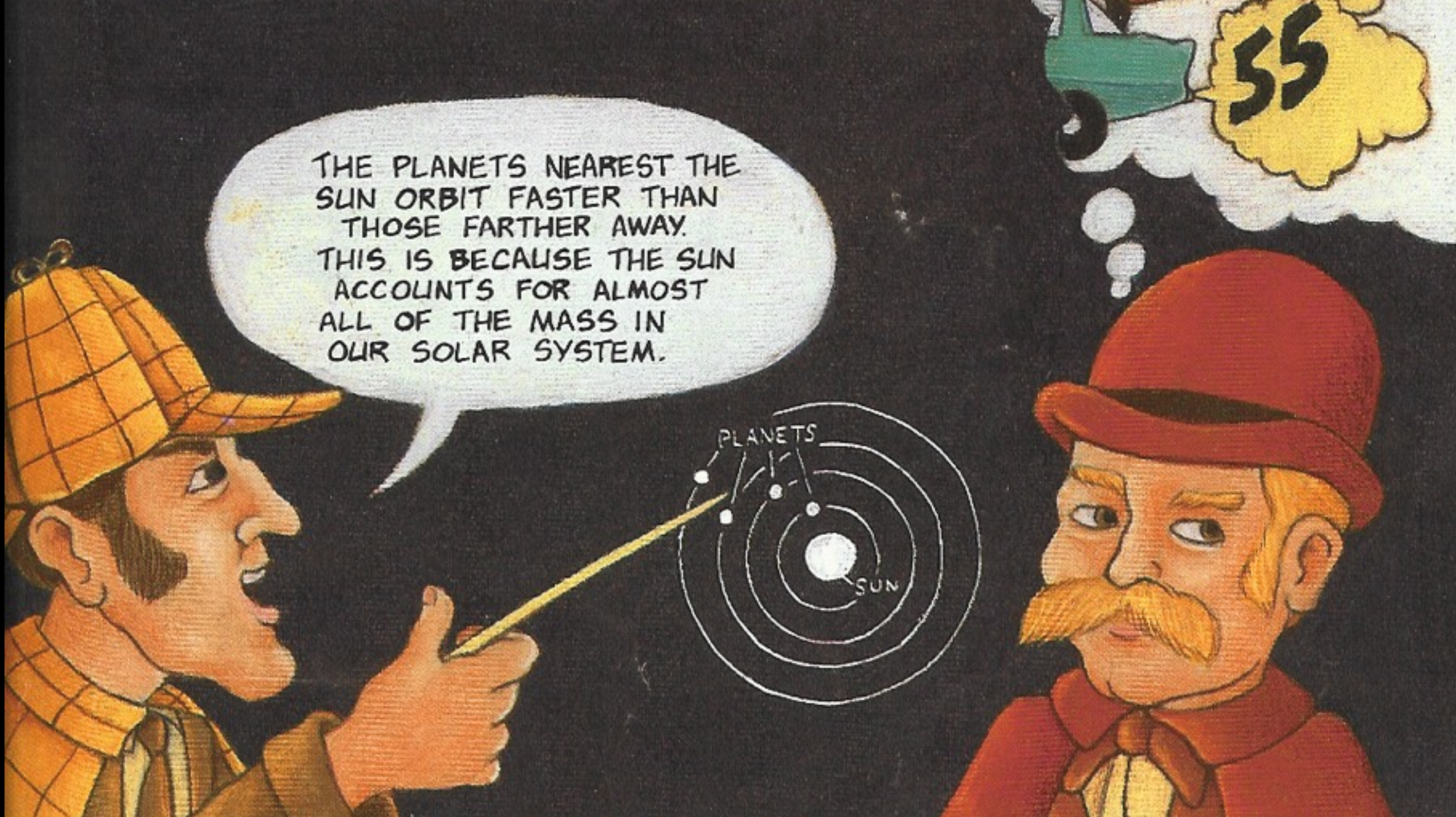
from *World Book Science Year 1990*

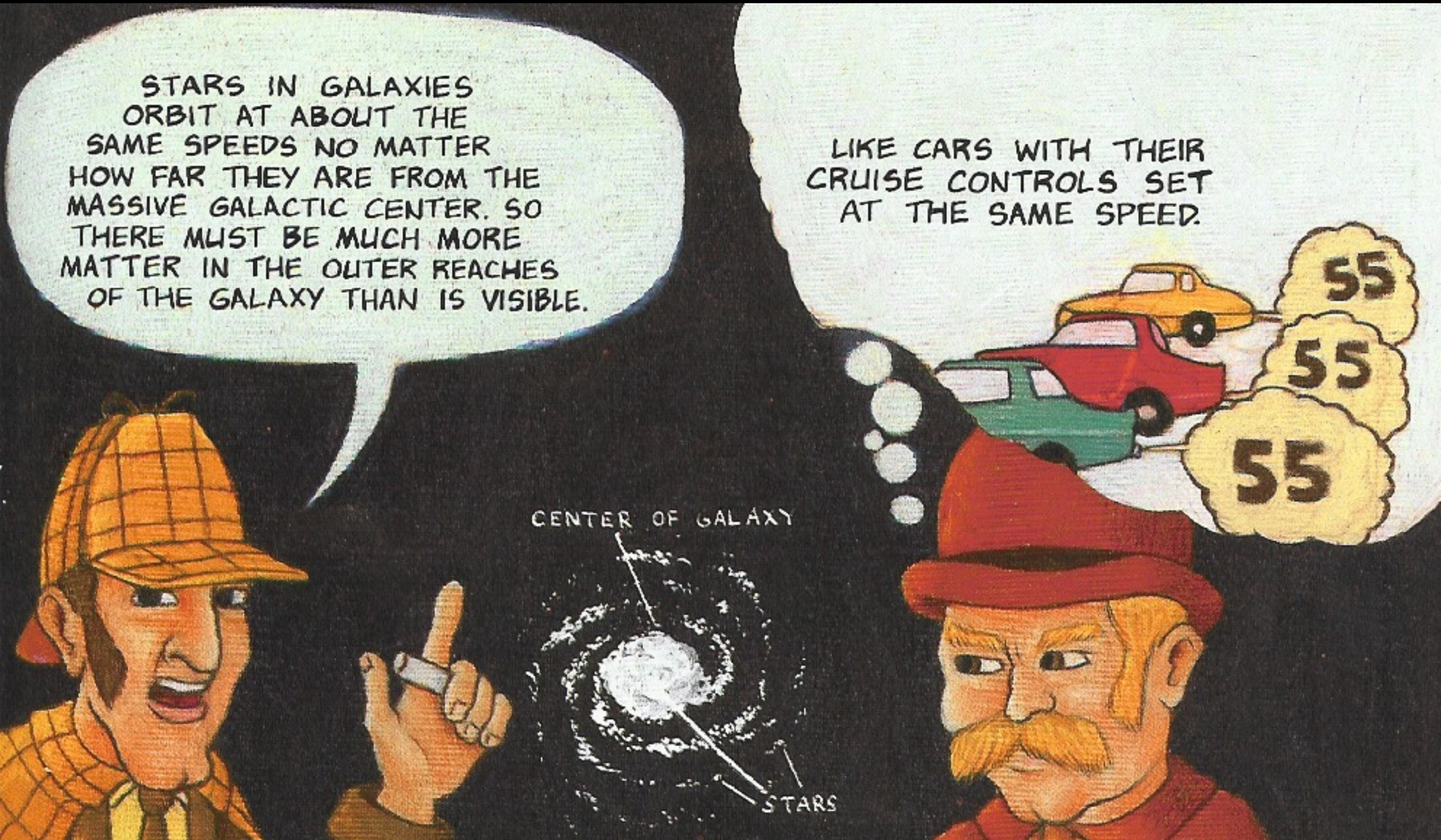
by Joel R. Primack



Evidence for Dark Matter

Evidence that there is more matter in the universe than is visible rests on a theory of gravity, the force that keeps planets, stars, and other celestial objects in their orbits. The strength of this force depends on the mass of the orbiting objects and the distance between them. The amount of mass in the objects and their distance from each other determine the orbital speeds of the objects. Knowing orbital speeds and the distance between objects, astronomers can calculate the total mass in the orbital system.

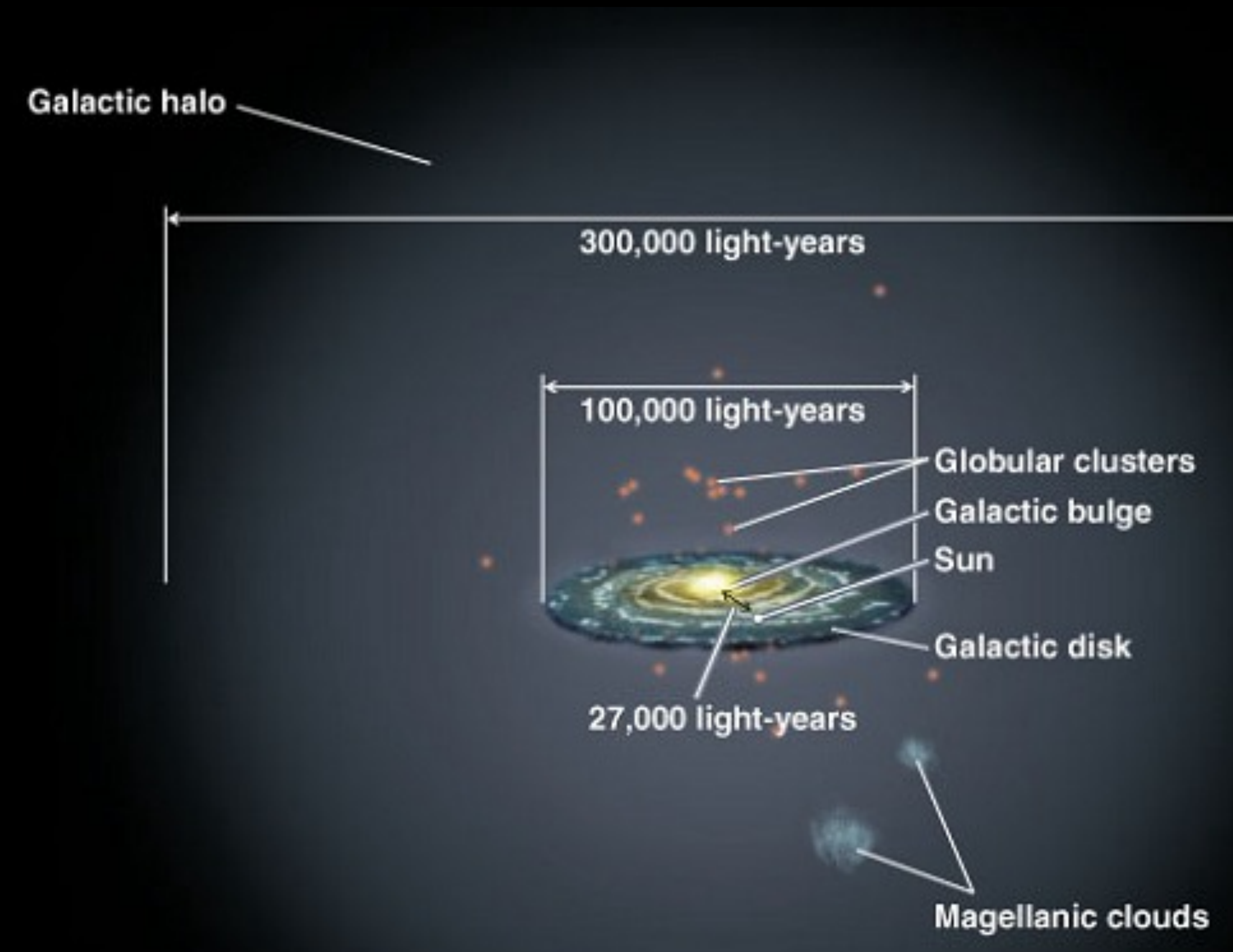



STARS IN GALAXIES ORBIT AT ABOUT THE SAME SPEEDS NO MATTER HOW FAR THEY ARE FROM THE MASSIVE GALACTIC CENTER. SO THERE MUST BE MUCH MORE MATTER IN THE OUTER REACHES OF THE GALAXY THAN IS VISIBLE.
LIKE CARS WITH THEIR CRUISE CONTROLS SET AT THE SAME SPEED.
55
55
55
CENTER OF GALAXY
STARS

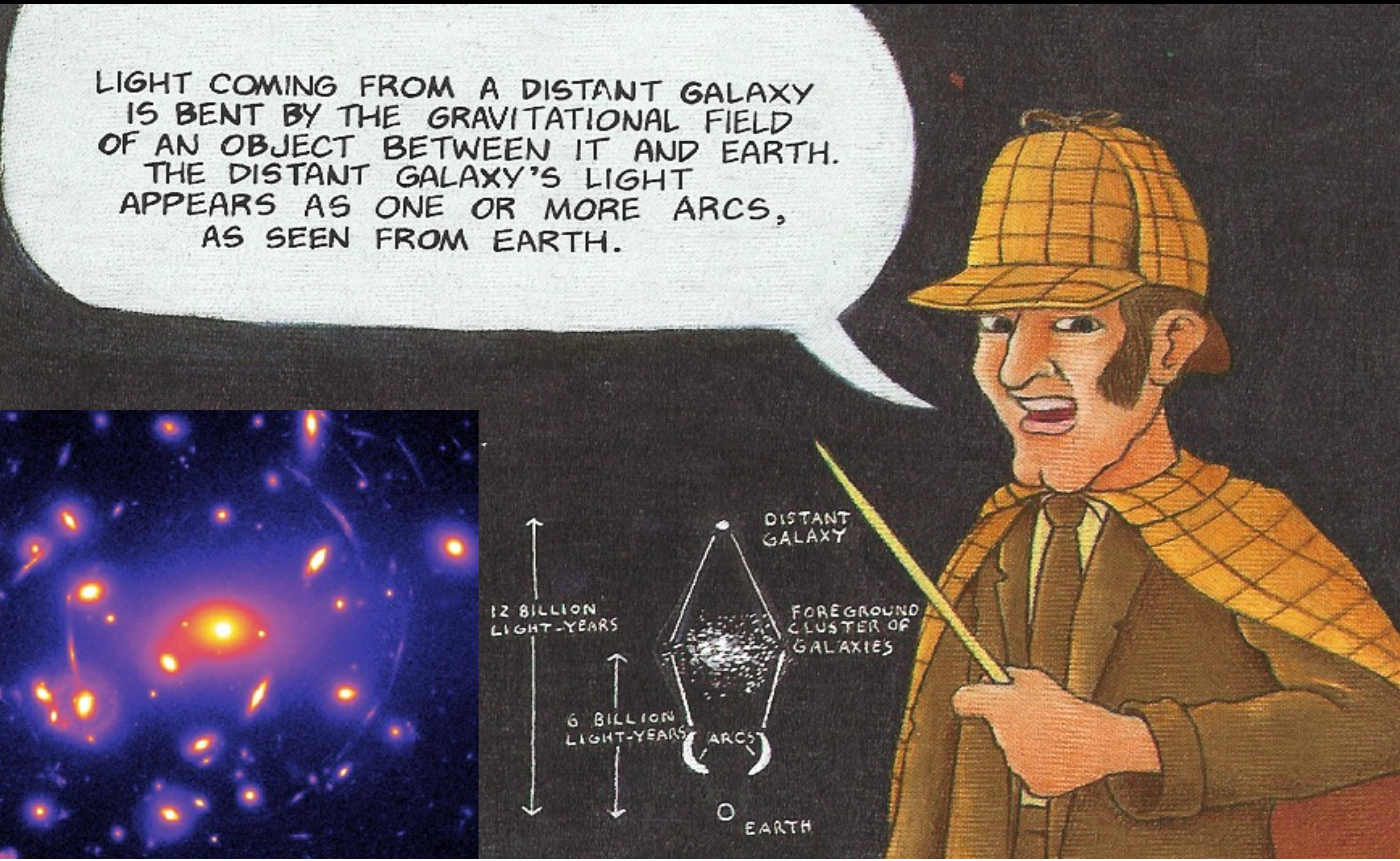
Most of the Mass is in the Dark Matter Halo

(denser in center)

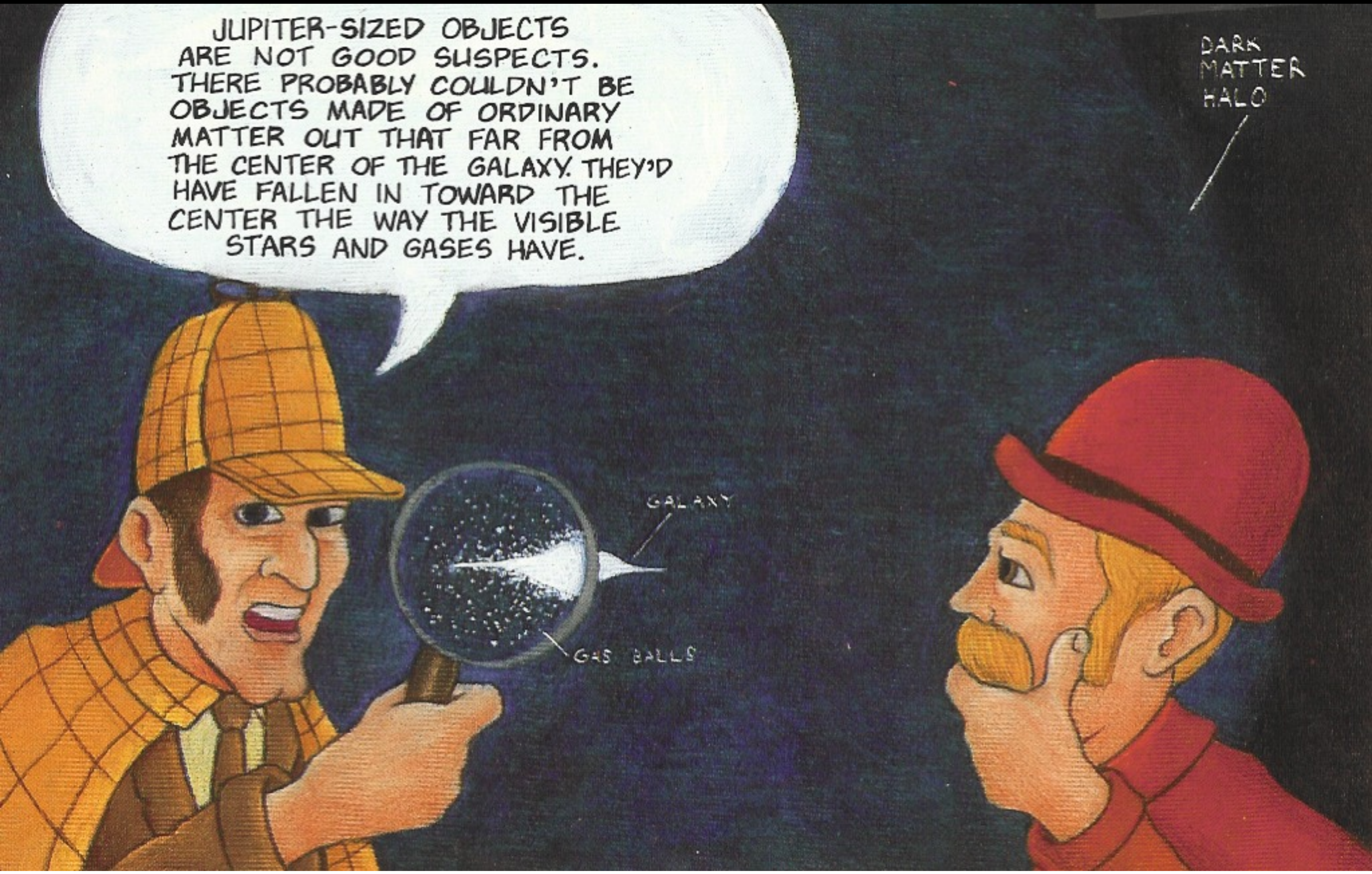
The Milky Way Within Its Dark Matter Halo



Gravitational Lensing Confirms Dark Matter in Galaxy Clusters

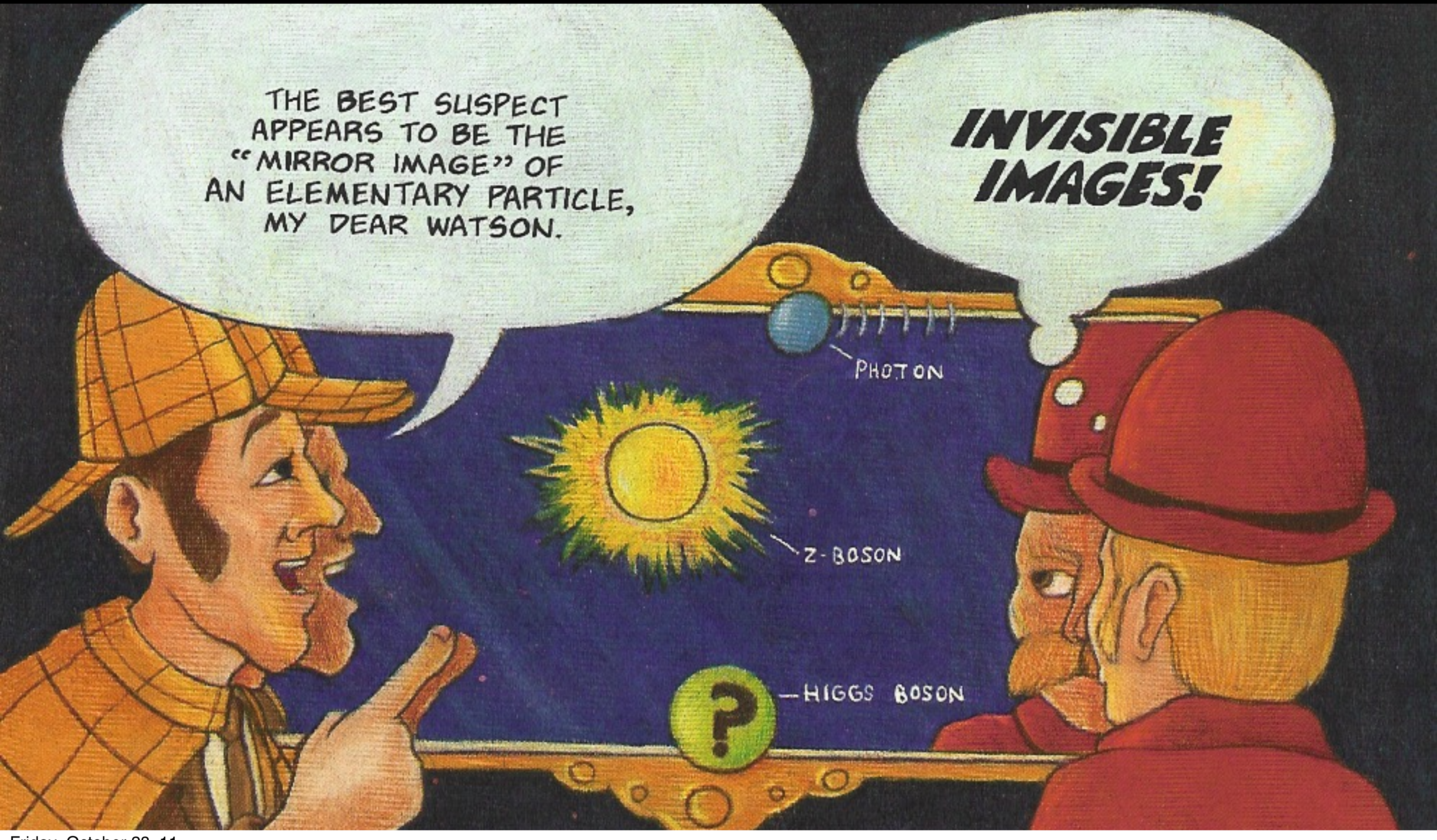


Jupiter-sized objects are not good dark matter suspects



Black Holes are not good suspects either

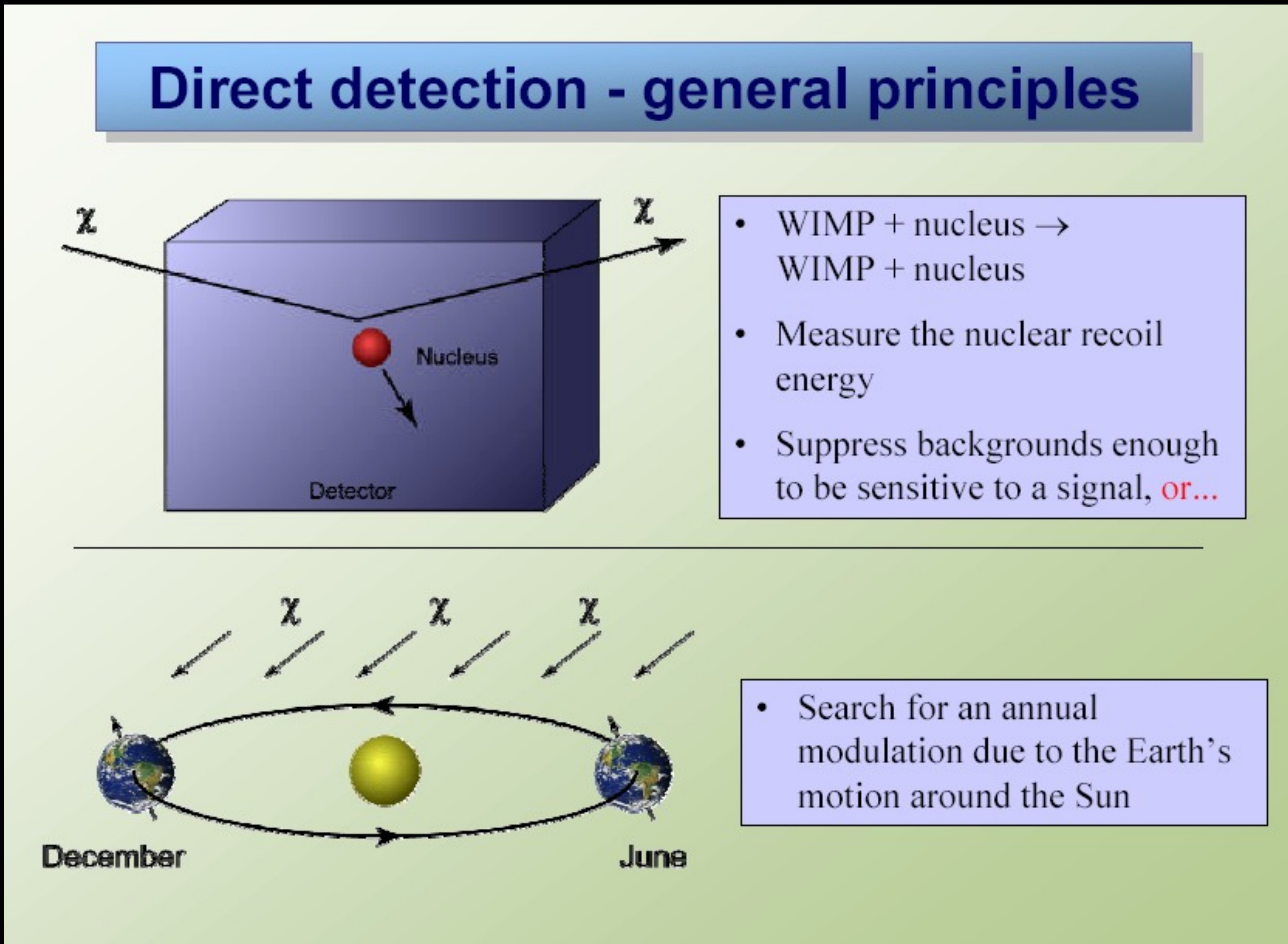
Photon, Z, and Higgs Supersymmetric Partners (*Photino, Zino, Higgsino*) are Prime Suspects



Supersymmetry is the basis of most attempts, such as superstring theory, to go beyond the current “Standard Model” of particle physics. Heinz Pagels and Joel Primack first pointed out in 1982 that the lightest supersymmetric partner particle is a good candidate for the dark matter particles – weakly interacting massive particles (**WIMP**s).

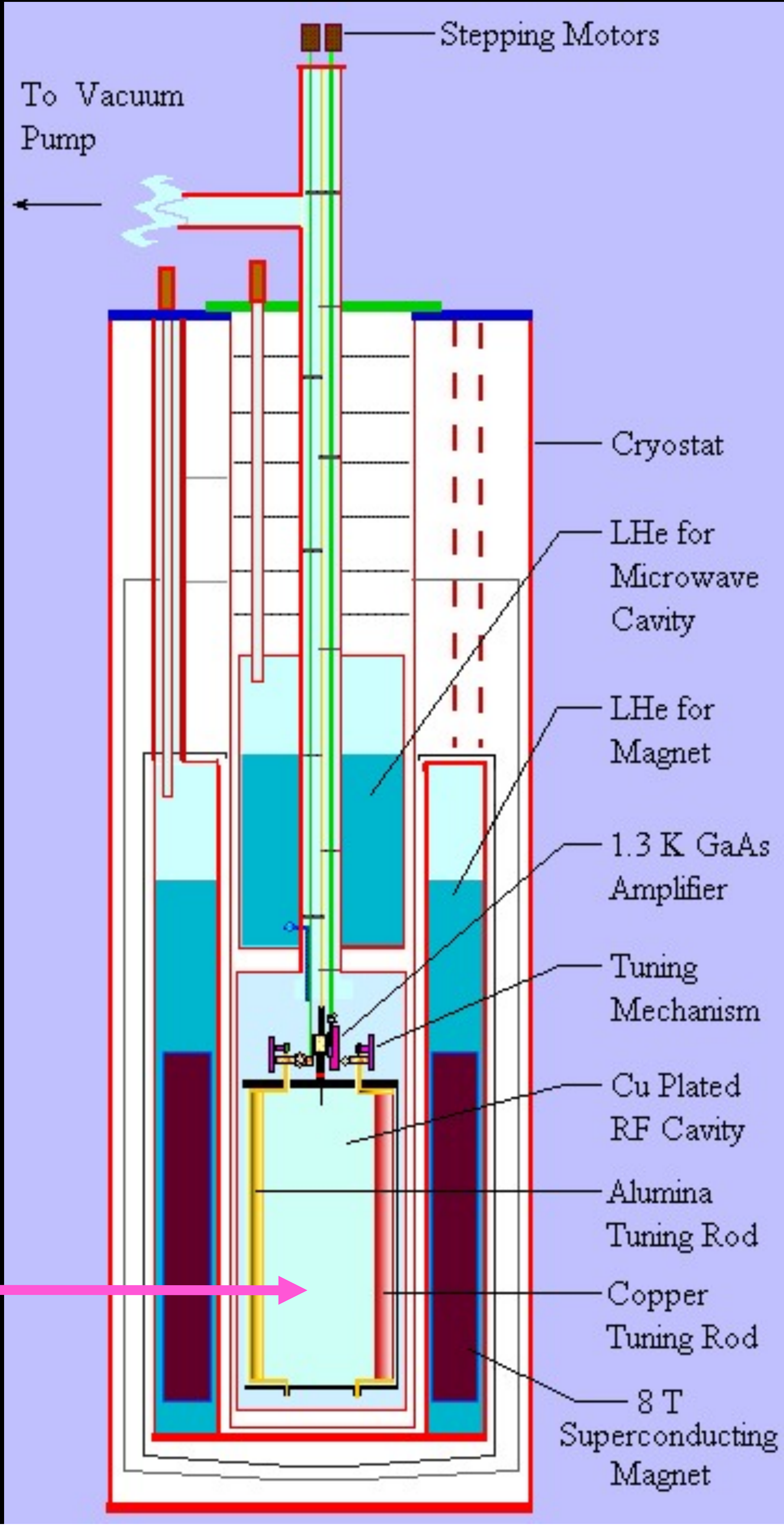
Michael Dine and others pointed out that the **axion**, a very low mass particle needed to save the strong interactions from violating CP symmetry, could also be the dark matter particle. Searches for both WIMPs and axions are underway.

Experiments are Underway for Detection of WIMPs

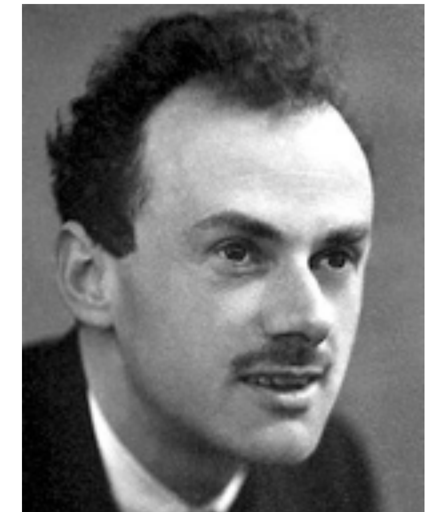


and also AXIONs

The diagram at right shows the layout of the axion search experiment now underway at the University of Washington. Axions would be detected as extra photons in the Microwave Cavity.



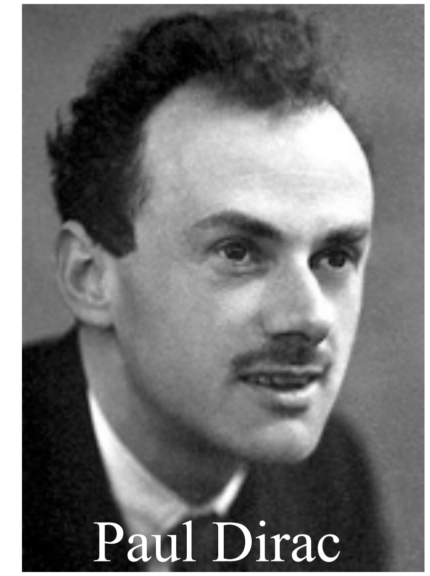
Supersymmetric WIMPs


Paul Dirac

When the British physicist Paul Dirac first combined Special Relativity with quantum mechanics, he found that this predicted that for every ordinary particle like the electron, there must be another particle with the opposite electric charge – the anti-electron (positron). Similarly, corresponding to the proton there must be an anti-proton. Supersymmetry appears to be required to combine General Relativity (our modern theory of space, time, and gravity) with the other forces of nature (the electromagnetic, weak, and strong interactions). The consequence is another doubling of the number of particles, since supersymmetry predicts that for every particle that we now know, including the antiparticles, there must be another, thus far undiscovered particle with the same electric charge but with *spin* differing by half a unit.

Spin	**Matter** (fermions)	**Forces** (bosons)
2		graviton
1		photon, $W^{\pm}, Z^0$ gluons
1/2	quarks u,d,... leptons $e, \nu_e, \ldots$	
0		Higgs bosons axion

Supersymmetric WIMPs


Paul Dirac

When the British physicist Paul Dirac first combined Special Relativity with quantum mechanics, he found that this predicted that for every ordinary particle like the electron, there must be another particle with the opposite electric charge – the anti-electron (positron). Similarly, corresponding to the proton there must be an anti-proton. Supersymmetry appears to be required to combine General Relativity (our modern theory of space, time, and gravity) with the other forces of nature (the electromagnetic, weak, and strong interactions). The consequence is another doubling of the number of particles, since supersymmetry predicts that for every particle that we now know, including the antiparticles, there must be another, thus far undiscovered particle with the same electric charge but with *spin* differing by half a unit.

after doubling

Spin	**Matter** (fermions)	**Forces** (bosons)	**Hypothetical Superpartners**	**Spin**
2		graviton	gravitino	3/2
1		photon, $W^{\pm}, Z^0$ gluons	<u>photino</u>, winos, <u>zino</u>, gluinos	1/2
1/2	quarks u,d,... leptons $e, \nu_e, \ldots$		squarks $\tilde{u}, \tilde{d}, \ldots$ sleptons $\tilde{e}, \tilde{\nu}_e, \ldots$	0
0		Higgs bosons axion	<u>Higgsinos</u> <u>axinos</u>	1/2

Note: Supersymmetric cold dark matter candidate particles are <u>underlined</u>.

Supersymmetric WIMPs, continued

Spin is a fundamental property of elementary particles. Matter particles like electrons and quarks (protons and neutrons are each made up of three quarks) have spin ½, while force particles like photons, W, Z, and gluons have spin 1. The hypothetical supersymmetric partners of electrons and quarks are called selectrons and squarks, and they have spin 0. The supersymmetric partners of the force particles are called the photino, Winos, Zino, and gluinos, and they have spin ½, so they might be matter particles. The lightest of these particles might be the photino. Whichever is lightest should be stable, so it is a natural candidate to be the dark matter WIMP. Supersymmetry does not predict its mass, but it must be more than about 100 times as massive as the proton since it has not yet been produced at accelerators. But since there are good reasons why its mass should not be more than about 1000 times the proton mass, the Large Hadron Collider should be able to make it in the next few years, if it exists!

An Open or Shut Case

Astonomers want to know for sure whether dark matter exists so they can calculate how much matter there is in the universe. The total amount of matter will determine the ultimate fate of the universe, which right now is expanding rapidly in all directions like an enormous balloon.

We now know that there is not nearly enough matter for a big crunch.

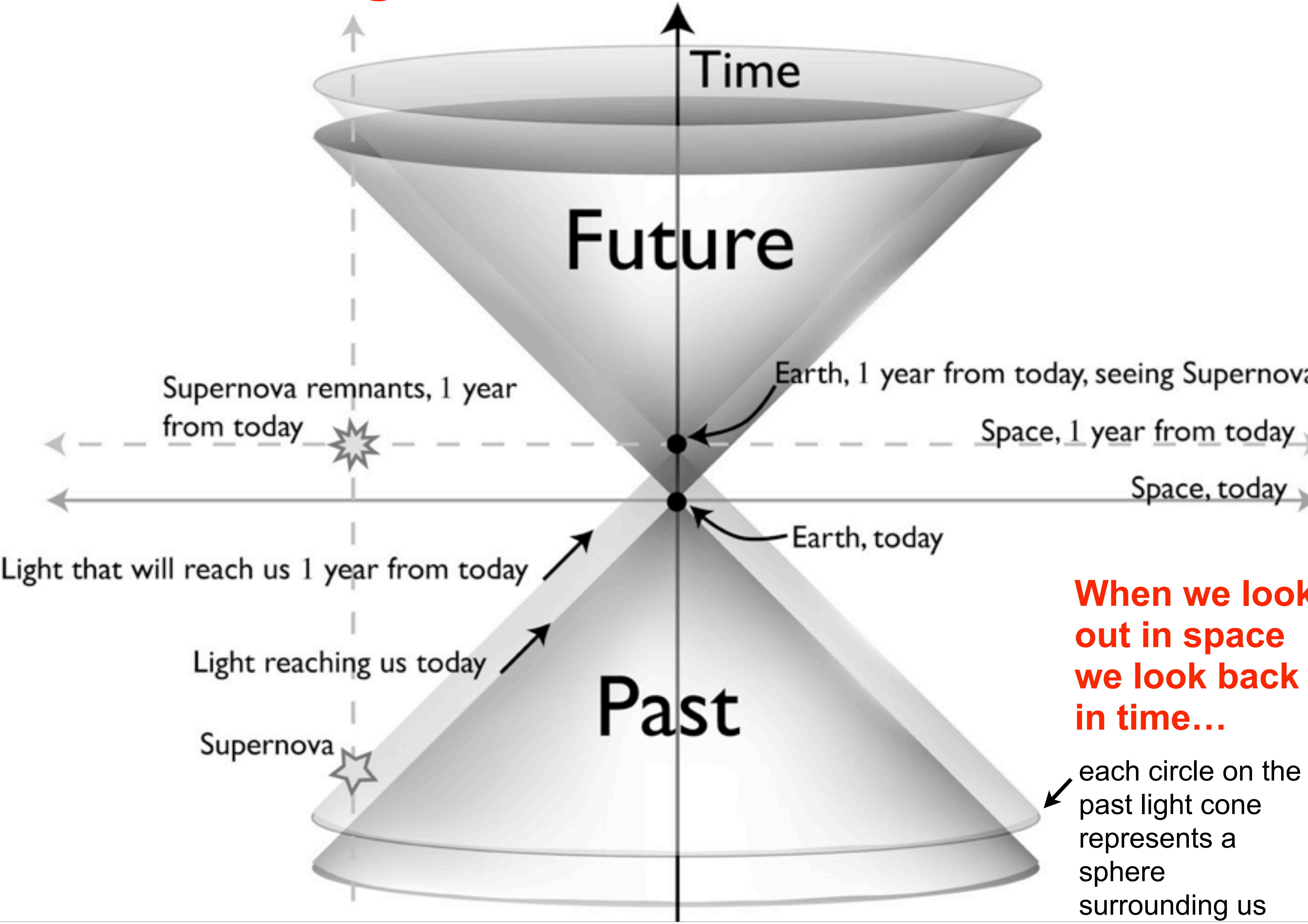
Einstein's Special Theory of Relativity

Special Relativity is based on two postulates:

1. The Principle of Relativity: If a system of coordinates K is chosen so that, in relation to it, physical laws hold good in their simplest form [i.e., K is an inertial reference system], the same laws hold good in relation to any other system of coordinates K' moving in uniform translation relatively to K.

2. Invariance of the speed of light: Light in vacuum propagates with the speed *c* in terms of any system of inertial coordinates, regardless of the state of motion of the light source.

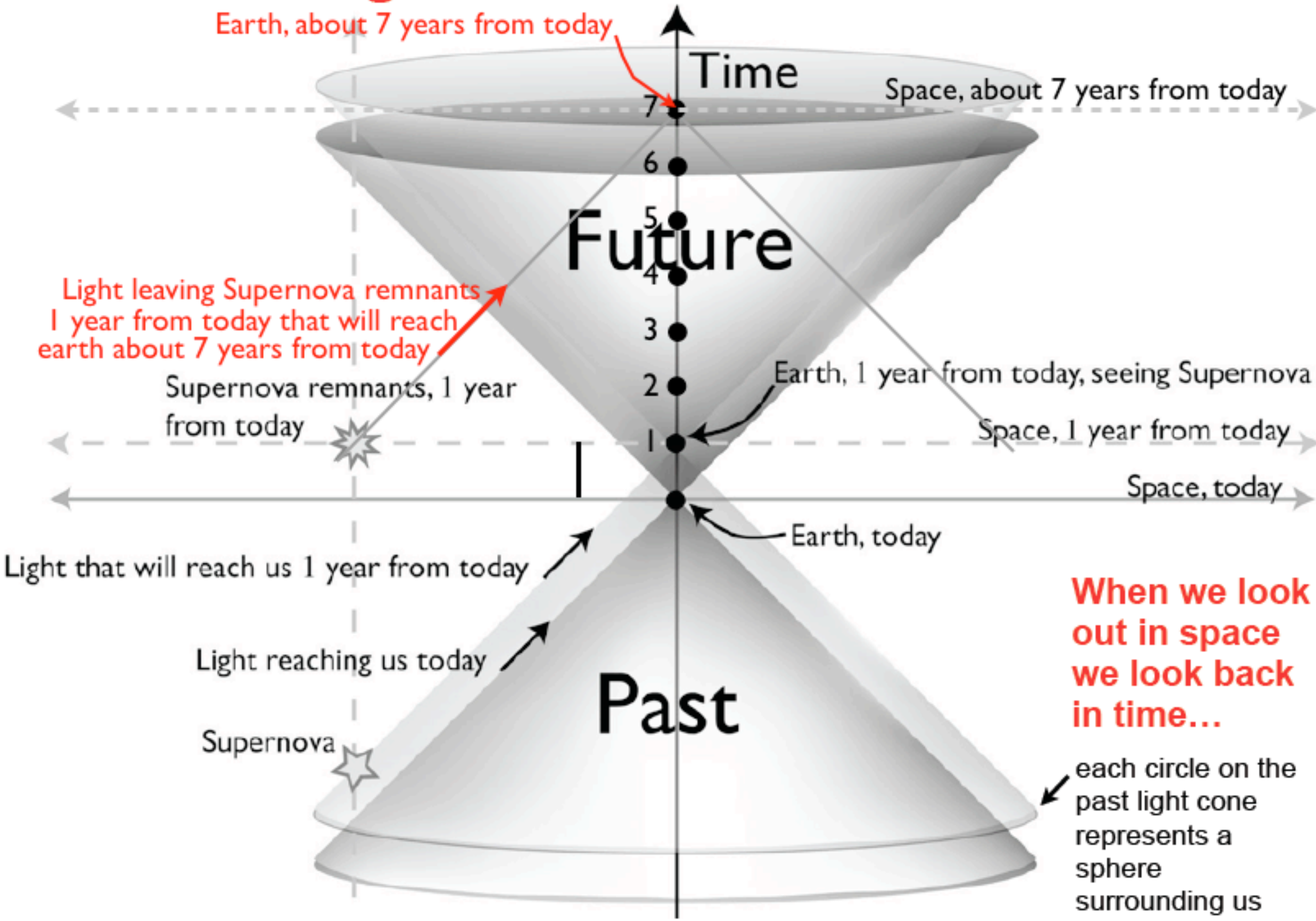
Lightcone of Past and Future



When we look out in space we look back in time…

each circle on the past light cone represents a sphere surrounding us

Lightcone of Past and Future



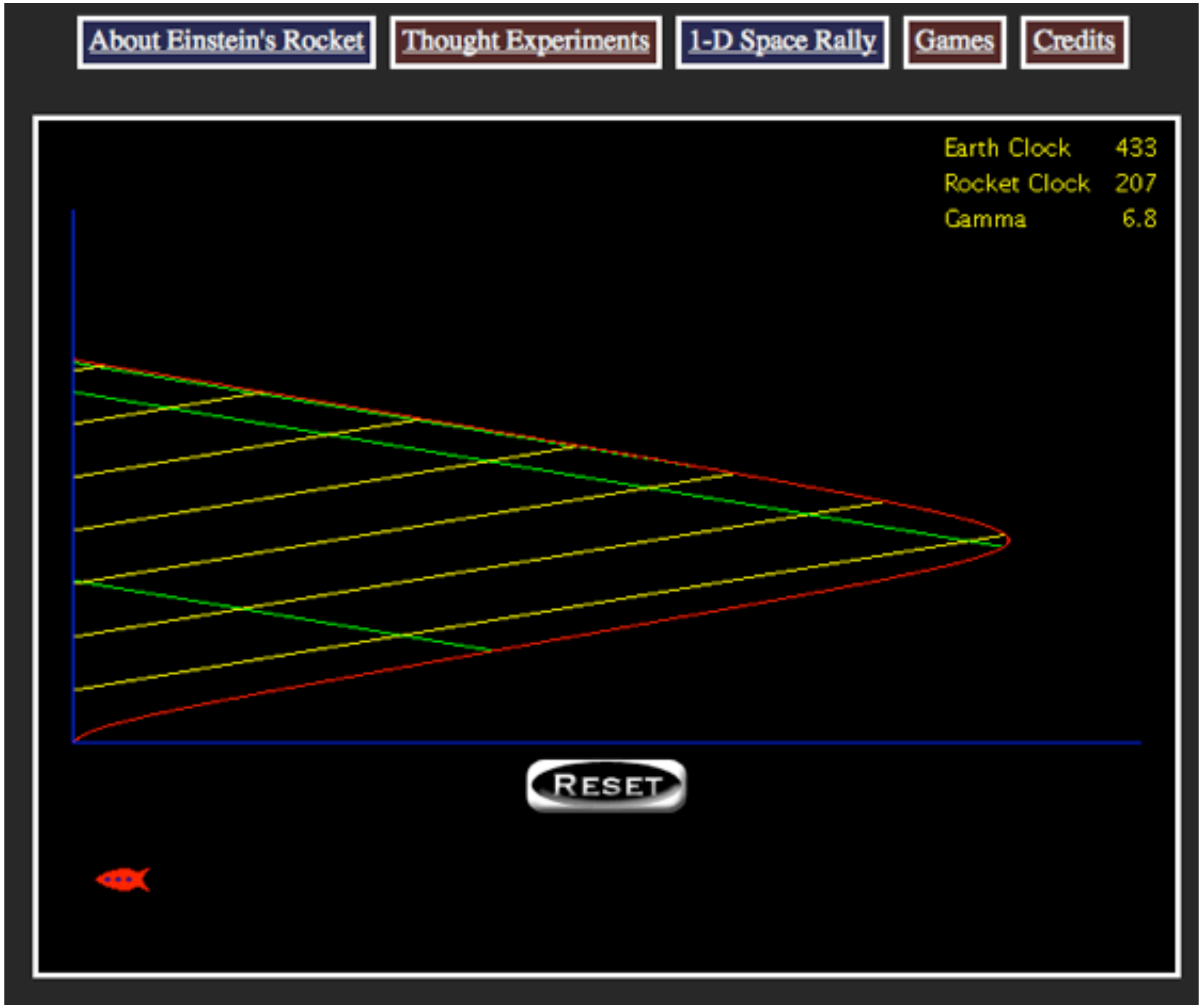
When we look out in space we look back in time…

The "twin paradox" of Special Relativity

If Albert stays home and his twin sister Berta travels at high speed to a nearby star and then returns home, Albert will be much older than Berta when he meets her at her return.

But how can this be true? Can't Berta say that, from her point of view, it is Albert who traveled at high speed, so Albert should actually be younger?

To clarify why more time elapses on Albert's clock than on Berta's, we can use the Einstein's Rocket "1-D Space Rally".



Einstein's Special Theory of Relativity

http://physics.ucsc.edu/~snof/er.html