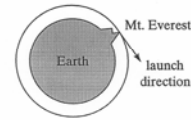


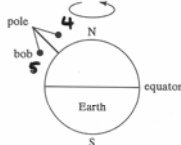
Q23. Suppose Earth had no atmosphere and a ball were fired from the top of Mt. Everest in a direction tangent to the ground. If the initial speed were high enough to cause the ball to travel in a circular trajectory around Earth, the ball's acceleration would



1. be much less than  $g$  (because the ball doesn't fall to the ground).
2. be approximately  $g$ .
3. depend on the ball's speed.

**Answer**  
2

Q24. A pendulum bob is suspended from a long pole somewhere on the northern hemisphere. When the pendulum is at rest, the combined action of gravitation and Earth's rotation makes the bob



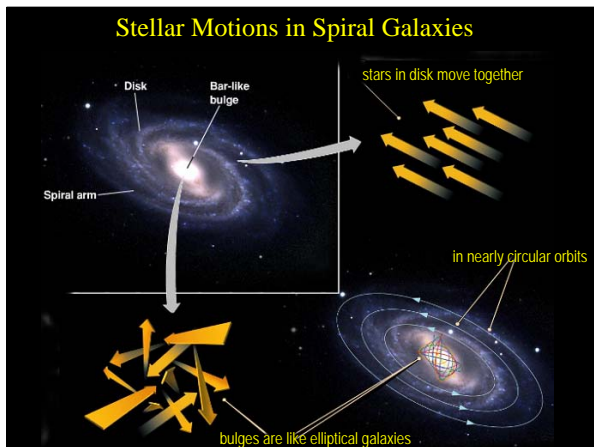
1. point straight down toward the center of Earth.
2. deviate toward the east.
3. deviate toward the west.
4. deviate toward the north.
5. deviate toward the south.
6. none of the above

**Answer**  
5

Q25. The Moon does not fall to Earth because

1. It is in Earth's gravitational field.
2. The net force on it is zero.
3. It is beyond the main pull of Earth's gravity.
4. It is being pulled by the Sun and planets as well as by Earth.
5. all of the above
6. none of the above

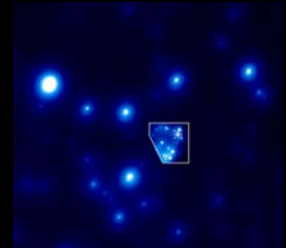
**Answer**  
6





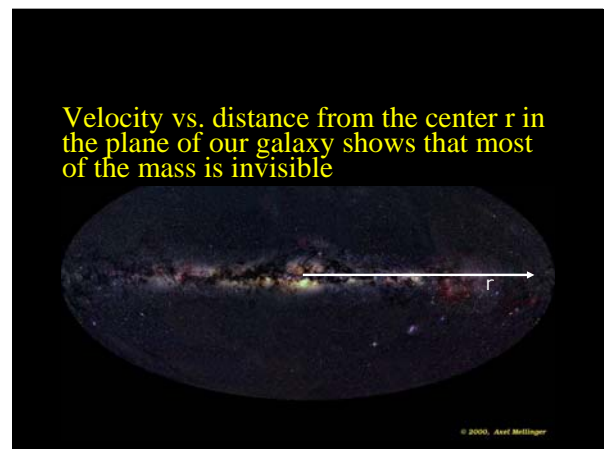
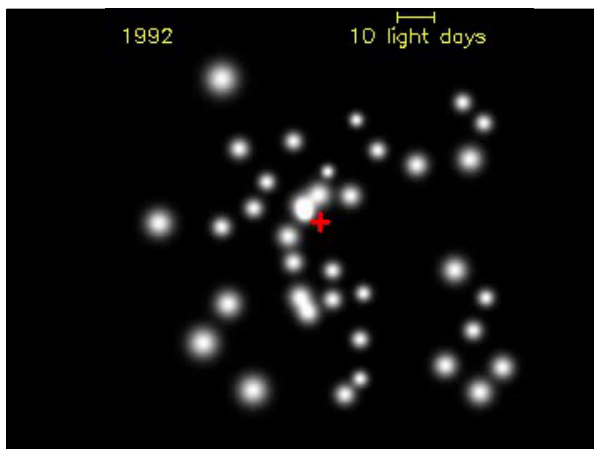
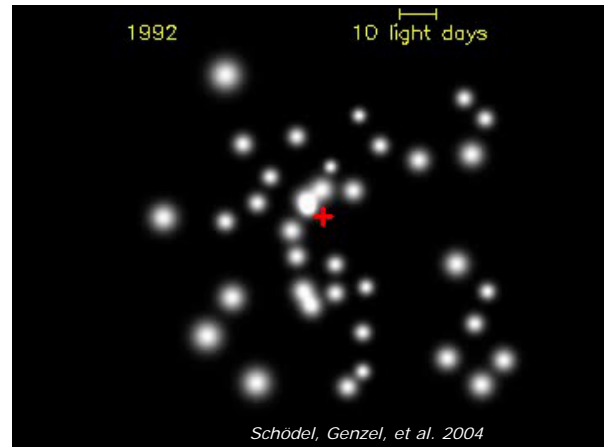
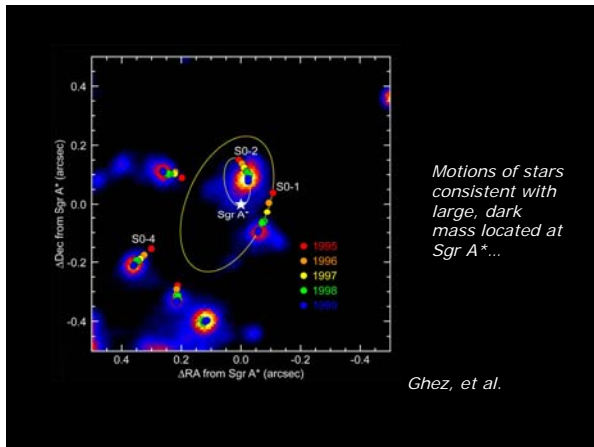
There's a supermassive black hole at the center of our galaxy...

- Modern large telescopes can track individual stars at galactic center
  - Use infrared light to penetrate dust.
  - Use adaptive optics to achieve high resolution.
- and have been observing for past 10 years...

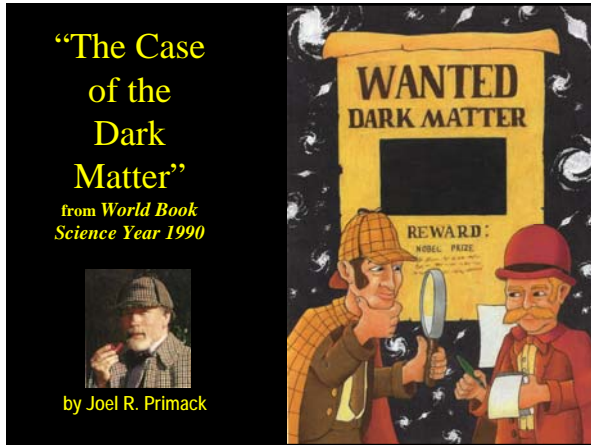
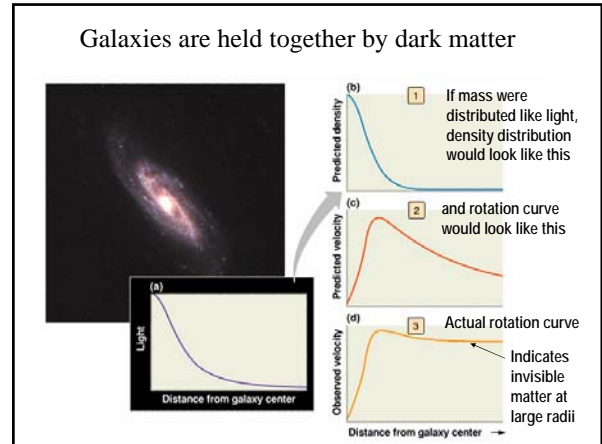
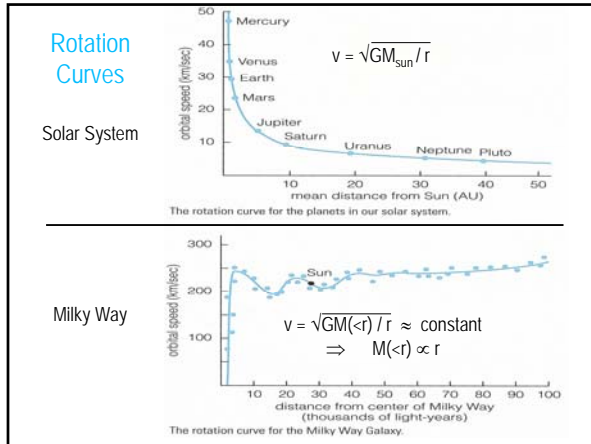


Keck, 2  $\mu$ m

Ghez, et al.



# Physics 5A Lecture on Gravity, Galaxies, and Dark Matter

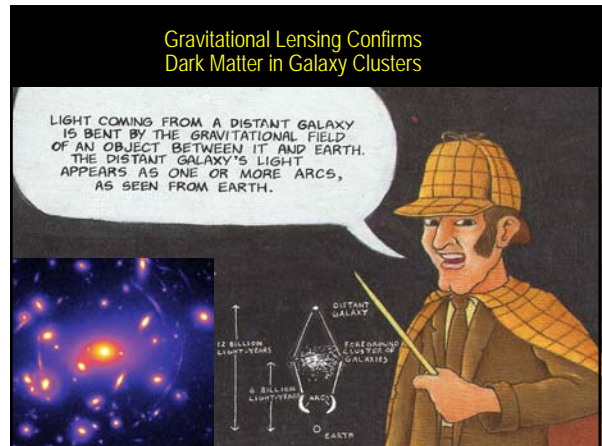


# Physics 5A Lecture on Gravity, Galaxies, and Dark Matter

## The Milky Way Within Its Dark Matter Halo



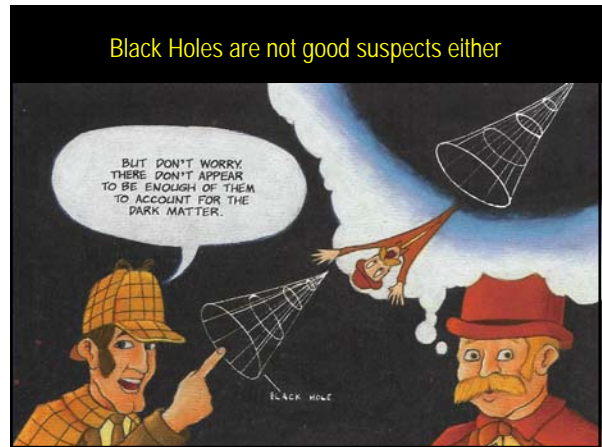
## Gravitational Lensing Confirms Dark Matter in Galaxy Clusters



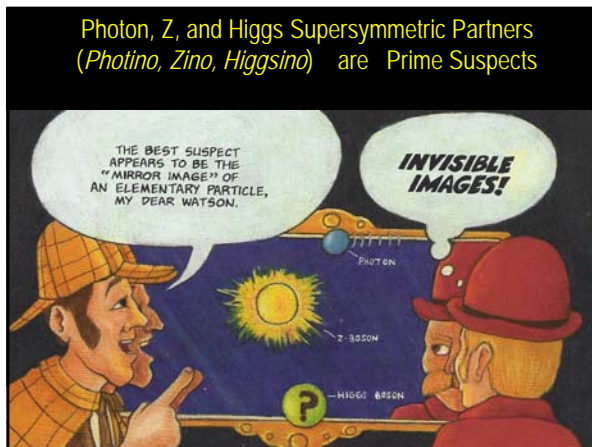
## Jupiter-sized objects are not good dark matter suspects



## Black Holes are not good suspects either

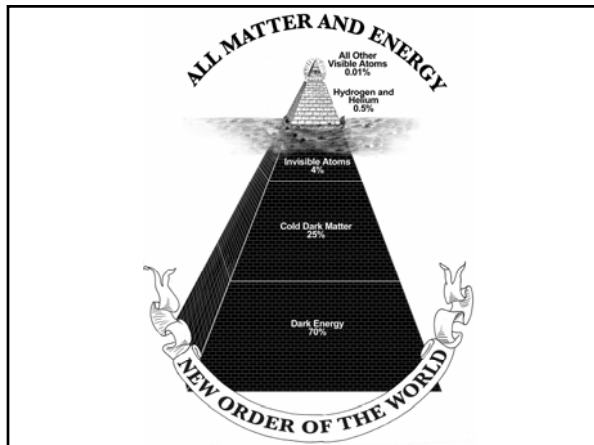
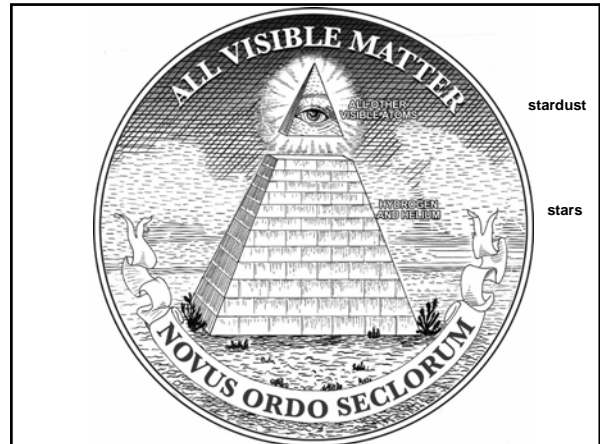
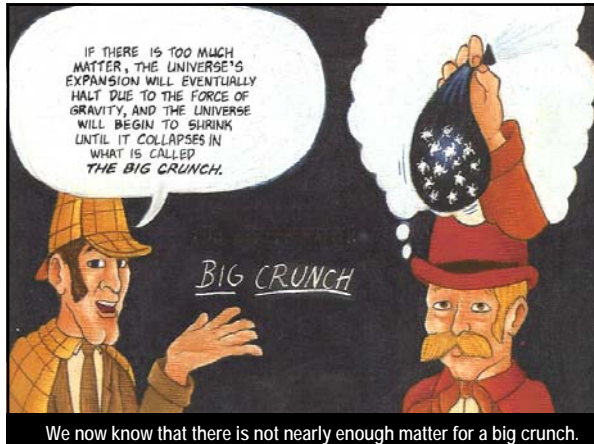


## Photon, Z, and Higgs Supersymmetric Partners (Photino, Zino, Higgsino) are Prime Suspects



## An Open or Shut Case





### Modern Cosmology

- We now know the cosmic recipe. The earth and its inhabitants are made of the rarest stuff of all: stardust (0.01%). Everything that we can see makes up only about 1/2% of the cosmic density, and invisible atoms about 4%. Most of the universe is invisible stuff called "nonbaryonic dark matter" (25%) and "dark energy" (70%).
- The  $\Lambda$ CDM Cold Dark Matter ("Double Dark") theory based on this appears to be able to account for all the large scale features of the observable universe, including the details of the heat radiation of the Big Bang and the large scale distribution of galaxies.
- Constantly improving data are repeatedly testing this theory. The main ingredients have been checked several different ways. There exist no convincing disagreements. Although there are possible problems on galactic scales, these may be due to the poorly understood physics of gas, stars, and the massive black holes at the centers of massive galaxies.
- **But we still don't know what the dark matter and dark energy are, nor understand in detail how galaxies form and evolve. Maybe you can help answer these questions!**

In our **Cosmology and Culture** course at UCSC and in our forthcoming book, to be published in April 2006 by Riverhead/Penguin, Nancy Abrams and I present the modern cosmos – but we also address its possible meaning by trying to explain how we humans fit in.

We show, for example, that we humans are central to the modern cosmos not in a simple geographic sense but in at least seven deep and unexpected ways, all of which follow directly from astronomy and physics.

from

seven ways we are central or special

- 1) We are made of the rarest material in the universe: stardust.
- 2) We live at the center of our Cosmic Spheres of Time, because every place is the center of its own cosmic spheres of time. The finite speed of light makes this inevitable in a uniformly expanding universe.
- 3) We live at the midpoint of time, which is also the peak period in the entire evolution of the universe for astronomical observation. Most nearby galaxies are middle aged, past their violent youths but not yet senescent and finished with star formation. The most distant galaxies – which we have just acquired the technological ability to see – are beginning to disappear over the cosmic horizon now that the on-e-slowing expansion of the universe has begun instead to accelerate. The universe as we are observing it today will truly become mythic, since it will become the lost Golden Age – a fabulously rich sky that our distant descendants will know, actually existed but will never be seen again.
- 4) We live at the middle of all possible sizes – in Midgard, where the possibility of tremendous variety and complexity coming in small packages keeps life interesting. Life of our complexity could bloom on no other size scales of the Cosmic Cosmos.
- 5) We live in a universe that may be a rare bubble of spacetime in the infinite, seething cauldron of the eternal superuniverse. Outside our absolutely unique and isolated bubble, which we call the Big Bang, there is neither space nor time as we know it. But here inside, there is time for evolution and history, and there is space across which consciousness can form and structures can develop. We are not geographically central in eternal inflation, but we are very special.
- 6) We live on one or less the midpoint in the life of our planet. It formed, along with the sun and other planets, about four and a half billion years ago. It has about six billion more to go before it is swathed when our sun swells into a red giant star. We also live in the middle of the billion year period during which Earth is most hospitable to complex life. From the point of view of our species, whose recorded history is a mere 5000 years, today is late enough to have evolved to our present abilities while early enough still to have a potential future so vast it beggars the imagination.
- 7) We live at a turning point for our species. From the point of view of the generations alive at this moment, it is late enough that we are sobering up to the scale of our problems, but not so late that we have lost all chance to solve them. This is a very special time that will never come again.