Top Ten Signs
Your Astronomy Professor May Be Nuts

(based on Lee Carkner List)

10) The title of every lecture is: "Man, Them Stars is Hot!".
9) His so-called "telescopes" are really just paper towel rolls covered in aluminum foil.
8) To illustrate the vastness of the universe, he makes everybody walk to Springfield.
7) Thinks he's married to the slide remote.
6) Your grade is based entirely on how many ping-pong balls you can fit in your mouth.
5) His so-called Drake Equation video is really just an old episode of Alf.
4) He makes everyone wear a soup pot on their head to protect the class from "Klingon mind control lasers".
3) About 90% of all classes involve dressing monkeys up to look like Frank Drake.
2) When you go to his office hours, he is always hiding under the desk so that the "space squirrels" can't get him.
1) The only observing advice he ever gives is, "Keep an eye out for the mothership."

Astronomy 330

This class (Lecture 22):
Lifetime
Alex Bara

Next Class:
Communication
Mark Rivera

Rough Drafts due next class!!
HW 9 due Thursday night.

Music: *It's the End of the World as We Know It* – R.E.M.

Paper Rough Draft

- Worth 1% of your grade, but really worth more.
- Due on Thursday! (Hard date!)
  - Beginning of class, else considered late.
- Should pretty much be the final paper.
- Will be looking for scope, ease-of-read, scientific reasoning, **proper citation**, and general style.
- 6 to 8 pages double-spaced 12-point font, not including references.

Presentations

- Alex Bara
  Nuclear Propulsion

Outline

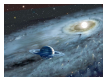
- Lifetime of alien civilizations.
  - Could be a whole class (oh it is..)
  - Quick discussion

Drake Equation

Frank Drake

That's 2.24 Communicating life/century








$$N = R_* \times f_p \times n_e \times f_l \times f_i \times f_c \times L$$

# of advanced civilizations we can contact in our Galaxy today	Star formation rate	Fraction of stars with planets	# of Earthlike planets per system	Fraction on which life arises	Fraction that evolve intelligence	Fraction that commun-icate	Lifetime of advanced civilizations
	15 stars/ yr	0.65 systems/ star	1.3 x 0.1 = 0.13 planets/ system	0.125 life/ planet	0.175 intel./ life	0.8 comm./ intel.	yrs/ comm.

Tunguska, Russia 30 June 1908

- Something big seems to have exploded in the atmosphere
- The exact cause is uncertain, but we suspect a comet or a meteor

Aerial view of Tunguska Natural Reserve

Eye Witness

I suddenly saw the sky split in two and fire appeared high and wide over the forest. The split in the sky grew larger, and the entire northern side was covered with fire. At that moment, I became so hot that I couldn't bear it, as if my shirt was on fire; from the northern side, where the fire was, came strong heat. I wanted to tear off my shirt and throw it down, but then the sky shut closed, and a strong thump sounded, and I was thrown a few yards. I lost my senses for a moment, but then my wife ran out and led me to the house. After that such noise came, as if rocks were falling or cannons were firing, the earth shook, and when I was on the ground, I pressed my head down, fearing rocks would smash it. When the sky opened up, hot wind raced between the houses, like from cannons, which left traces in the ground like pathways, and it damaged some crops. Later we saw that many windows were shattered, and in the barn a part of the iron lock snapped.

http://en.wikipedia.org/wiki/Tunguska_event

Theories?

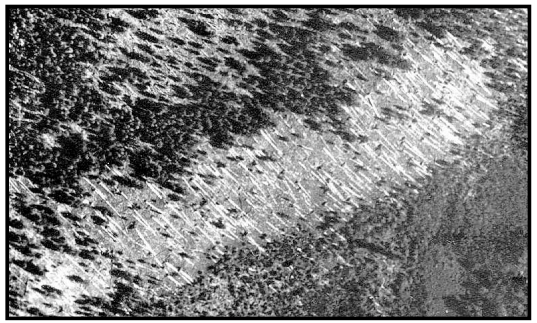
"Perhaps the earliest widely-held theory for the Tunguska explosion was that the world was about to end. As the minutes passed, this theory was dropped in favor of other, less final theories, until today one is hard-pressed to find anyone who truly believes the world ended on the morning of June 30, 1908.."

http://en.wikipedia.org/wiki/Tunguska_event

What happened?

- The object's entry appeared to be at an angle of 30-35°
- The object shattered in a series of explosions at about 8 km altitude

Tree blowdown from the explosions; Note parallel alignment of the trees



Big fires

- In the central region, forests flashed to fires that burned for weeks
- A herd of 600-700 reindeer was incinerated

Tunguska, Siberia, June 30, 1908

Black and white photos taken during field expedition in 1927; color photo taken in 1990

Aligned trees

- Trees were felled in a radial sense
- About 2,000 km^2 were flattened by the blasts

What happened?

- Our best scientific guess is that it was part of a comet 20-60 meters in diameter…
- …no crater was found…
- …and no meteoritic debris has been found

Felled trees aligned parallel to each other

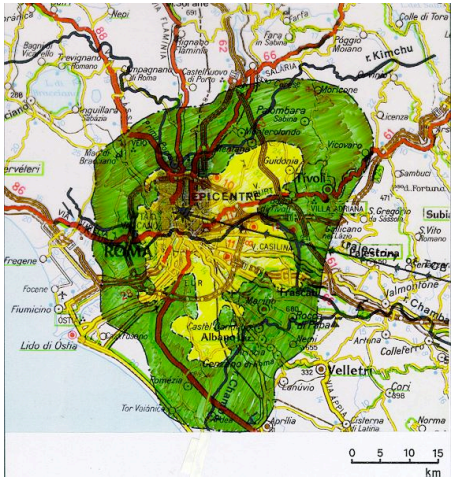
Tunguska, Siberia: June 30, 1908
A ~40 meter object disintegrated and exploded in the atmosphere

The energy of the explosion was equivalent to 1,000 Hiroshimas

Several hundred square miles of forest were destroyed.
What if this had happened over a city?

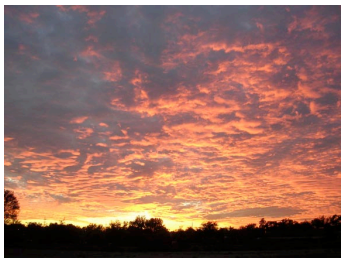
Area of devastation superimposed on a map of Rome.
Yellow=charred trees; Green=felled trees

- Devastation!
- Over a city, it could kill millions.



A Global View

- Soot from fires circled the globe, producing spectacular sunrises and sunsets for months afterward
- The Tunguska event was the largest known comet/asteroid event in the history of civilization
- http://www.youtube.com/watch?v=mQSwVMBIeKg
- We expect such events every 100 years or so!



http://visionoftheworld.com/_wsn/page4.html

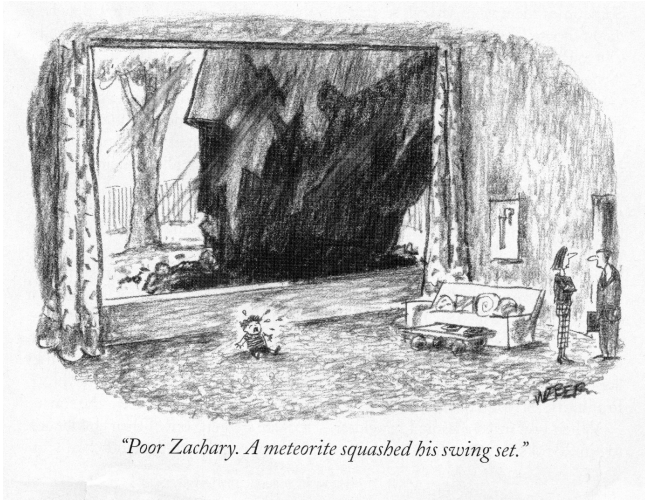
If something like Tunguska happens every ~100 years, how come we haven't heard about it? Why haven't more people been killed by asteroid impacts in the past?

- Before the 20th Century, human population was much lower, so likelihood of someone being affected is lower.
- If someone did see a Tunguska, less likelihood of word getting around -- news didn't disperse as easily back then.

Massive Impacts = Extinctions?

- Asteroids and comets have hit the Earth.
- A major impact is only a matter of time: not IF but WHEN.
- Major impacts are very rare: For an extinction level event, you have to wait millions of years.
- But! For an event that causes major damage, you have to wait only roughly tens to hundreds of years.

Effects upon children



"Poor Zachary. A meteorite squashed his swing set."

4. Natural Catastrophes

- Common?
  - 5-10 m asteroid hits Earth every ~1 years.
  - 50 m asteroid hits Earth every ~1,000 years (Tunguska).
  - 1km asteroid hits Earth every ~500,000 years.
  - 5km asteroid hits Earth every ~10 million years.
  - >10 km asteroid hits Earth … last one was 65 million years ago
- Not a clock, just random events

Lifetime Chances?

Clark R. Chapman
Southwest Research Institute

Cause of Death	Chance: 1 in
Motor vehicle accident	90
Suicide	120
Homicide	185
Falls	250
Terrorism (Middle East)	1,000
Fire or smoke	1,100
Electrocution	5,000
Drowning	9,000
Flood	27,000
Airplane crash	30,000
Lightning strike	43,000
Asteroid impact (global)	**75,000**
Terrorism (non Mid-East)	80,000
Insect bite or sting	100,000
Natural tsunami	100,000
Earthquake	130,000
Asteroid impact (regional)	**1,600,000**
Food poisoning (botulism)	3,000,000
Asteroid impact (local)	**5,700,000**
Shark attack	8,000,000

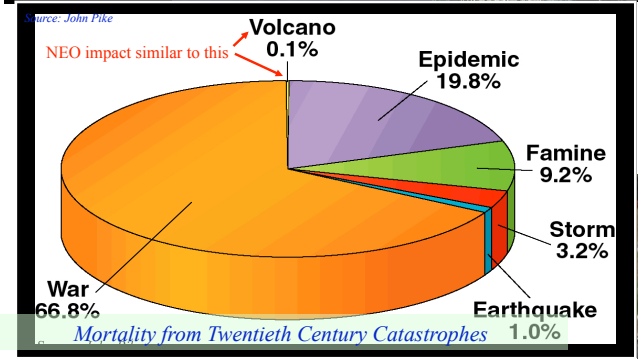
Lifetime Chances?

Clark R. Chapman
Southwest Research Institute

Cause of Death	Chance: 1 in
Motor vehicle accident	90
Suicide	120
Homicide	185
Falls	250
Terrorism (Middle East)	1,000
Fire or smoke	1,100
Electrocution	5,000
Drowning	9,000
Flood	27,000
Airplane crash	30,000
Lightning strike	43,000
Asteroid impact (global)	**75,000**
Terrorism (non Mid-East)	80,000
Insect bite or sting	100,000
Natural tsunami	100,000
Earthquake	130,000
Asteroid impact (regional)	**1,600,000**
Food poisoning (botulism)	3,000,000
Asteroid impact (local)	**5,700,000**
Shark attack	8,000,000

This is hard to understand as there is very little chance that anyone in your lifetime will die from an impact. BUT, if a global impact occurs within the next 100 million years, billions of people will die, so the average per year is still relevant. Low chance, but high risk events!

How Important is NEO Threat? We've Many Other Things to Worry About!



Comparing NEO Impacts and Climate Change

NEO Impact

Similarities…

- They can potentially affect the globe
- Asteroids can be deflected to miss Earth

Dissimilarities…

- Global effects within 2 hours, global climate change within months
- Extremely unlikely to happen this century

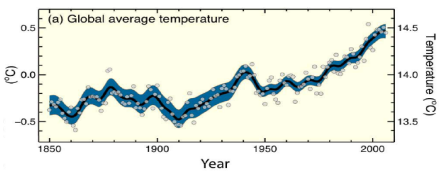
Climate Change

Similarities…

- Global warming is planetary in scale
- Society can reduce greenhouse gases

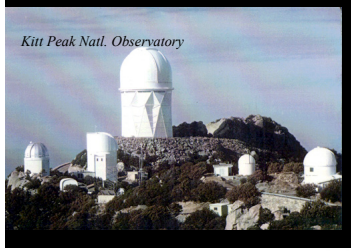
Dissimilarities…

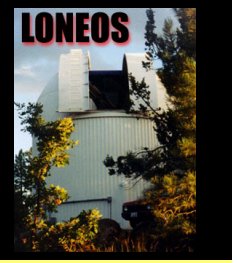
- Timescale for major changes: about one century
- Actually underway right now

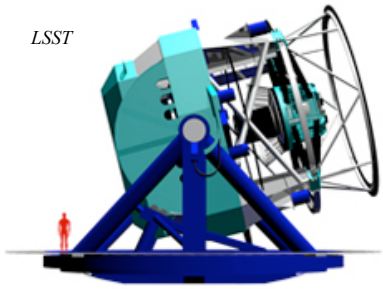


Near Earth Object Program

http://neo.jpl.nasa.gov/



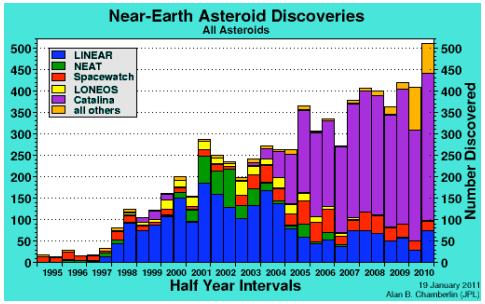




- Survey: 1998 to 2010, find >90% of NEOs >1 km diameter (Near Earth Objects)
- Congress ordered NASA to find 90% of NEOs >140 m by 2020
- http://www.youtube.com/watch?v=9_EZfxvTmNA

Killer Asteroids

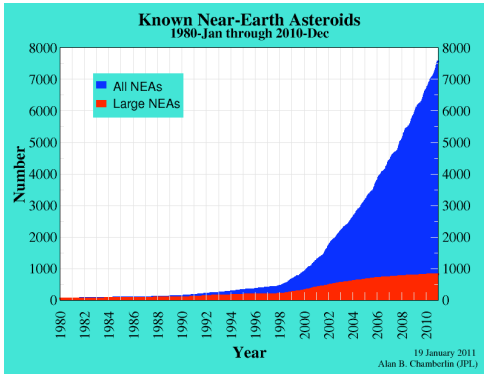
- As of April 2011, 7,966 NEAs (>50 meters, so asteroids) are known.
- 824 of these are > 1km
- 1217 of these are classified as Potentially Hazardous Asteroids (PHAs)



http://neo.jpl.nasa.gov/faq/

Killer Asteroids

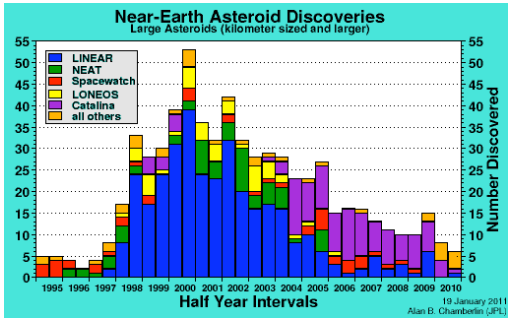
- As of April 2011, 7,966 NEAs (>50 meters, so asteroids) are known.
- 824 of these are > 1km
- 1217 of these are classified as Potentially Hazardous Asteroids (PHAs)



http://neo.jpl.nasa.gov/faq/

Killer Asteroids

- As of April 2011, 7,966 NEAs (>50 meters, so asteroids) are known.
- 824 of these are > 1km
- 1217 of these are classified as Potentially Hazardous Asteroids (PHAs)

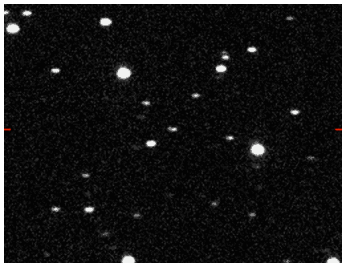


Note, these are all current NEOs, but new ones can come.

http://neo.jpl.nasa.gov/faq/

The Asteroid with Our Name on It: The Deadly Impactor

- We haven't seen it yet.
- But we want to find all the "potentially hazardous" asteroids, to be sure nothing's coming soon…. (Though statistics are on our side.)

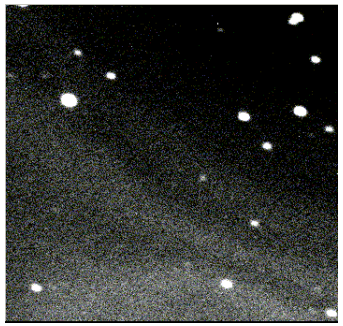


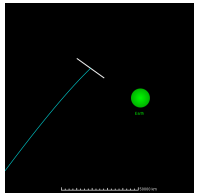
Asteroid 2004 FH. 30 meters in diameter. About 1 Megaton of TNT energy in an Earth impact! Passed within 7 Earth radii of Earth. Hiroshima was 15 kilotons.

http://antwrp.gsfc.nasa.gov/apod/ap040322.html

The Asteroid with Our Name on It: The Deadly Impactor

- The most famous "close call" is asteroid Apophis (which might have hit us in 2036).
  - 250 meters in diameter, approx.
  - There was a scare for a while because the chance of a hit was 1 in 300.
  - Currently the chance is only 1 in 45,000.
  - Highest Ranked on the Torino Scale



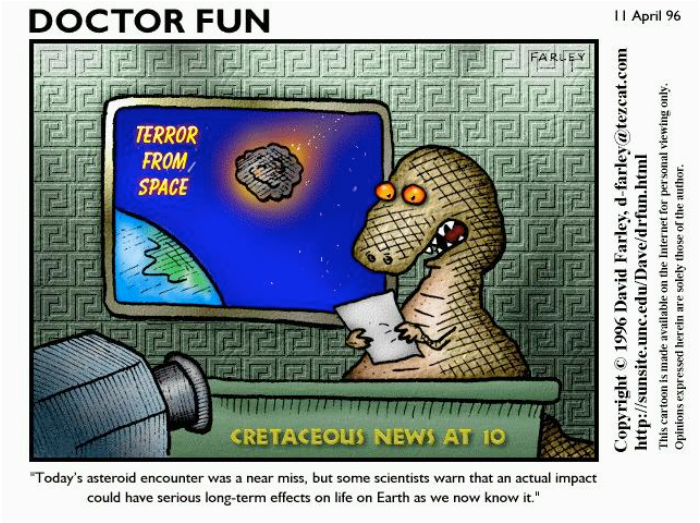


Killer Asteroids

- The most dangerous known is 1950 DA (~1km), will get close in March 2880 (0.33% chance of collision).
- We can not accurately predict orbits more than 20 years in advance, but 1950 DA would have 100,000 Megatons of energy.

http://neo.jpl.nasa.gov/1950da/

Be Aware



Killer Asteroids

- The Dino Killer was about 10 km in diameter.
- And, there are many asteroids out there that we still do not know about.
- On the long time-scale one of them will hit the Earth.
- What can we do if there is an immediate threat? There may be little time.

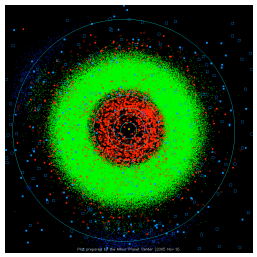
http://www2.ifa.hawaii.edu/newsletters/article.cfm?a=88&n=10

http://neat.jpl.nasa.gov/

http://www.ll.mit.edu/LINEAR/

Killer Asteroids

- Diversion or destruction of object.
- With sufficient warning it doesn't take too much to miss the Earth.
- One example is to change reflectivity of surface.
- Nuclear explosions may result in many small asteroids.
- Expensive and difficult, but advanced civilizations should be able to do it.



http://neat.jpl.nasa.gov/

http://www.ll.mit.edu/LINEAR/

Question

A larger asteroid will eventually hit the Earth again, what is the best way to avert it.

a) Bomb it.
b) Move to Mars
c) One word: lasers
d) Discover it years in advance.
e) There is already a secret project in place to avert any large asteroid– loose lips sink ships.

So can we ignore the risks?

- Well, an asteroid impact would be like a plane crash…. It doesn't happen very often at all -- air travel is very safe -- but when it does happen, a bunch of people die at once.

- It all depends on what risks humanity is willing to live with (e.g. cars kill lots more people, but no-one wants to ban them…).

What do you think?

Right now, the US Government is spending money on finding potentially hazardous asteroids -- asteroids that would not necessarily cause a mass-extinction but would probably wipe out millions to billions of people and decimate civilization.

As we saw, the chance of an asteroid doing this in the next few thousand years is remote…. But if it comes, it would be a big problem!

How much money should we be spending on this issue?

A. $0 per year -- we've got bigger problems to worry about.
B. Few million $ per year -- get some people working on it, and this cost is a drop in the bucket compared to e.g. DoD.
C. Few billion $ per year -- given the consequences, this requires lots of resources.
D. Few trillion $ per year -- Holy Crap, this should be our top priority!

What do you think?

A more immediate problem are the small asteroids that cause Tunguska like events. On a city they'd cause thousands to millions of deaths, but civilization would not be destroyed. Something like this could very well happen within the next hundred years…. Or it might not…

How much money should we be spending on this issue?

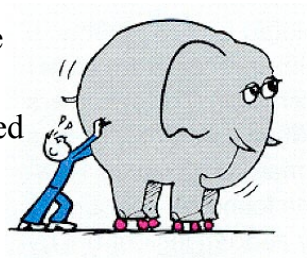
A. $0 per year -- we've got bigger problems to worry about.
B. Few million $ per year -- get some people working on it, and this cost is a drop in the bucket compared to e.g. DoD.
C. Few billion $ per year -- given the consequences, this requires lots of resources.
D. Few trillion $ per year -- Holy Crap, this should be our top priority!

Mitigation

- The problem is the possibility of little or no warning
- There are proposals to use nuclear weapons and satellites to "shoot down" or destroy such killer objects (good idea?)
- For further edification, rent "Armageddon" (1998)
- http://www.youtube.com/watch?v=iq6q2BrTino

Early Detection is Key

- The earlier we can detect a threat, the easier it is to mitigate the danger.
- A very small change in velocity (speed or direction) can make a huge difference in months.
- Remember inertia (the resistance of mass to change motion), and these things are massive.
- So it is a difficult problem.
- And new comets would only have warnings of a few months!



http://sol.sci.uop.edu/~jfalward/physics17/chapter2/chapter2.html

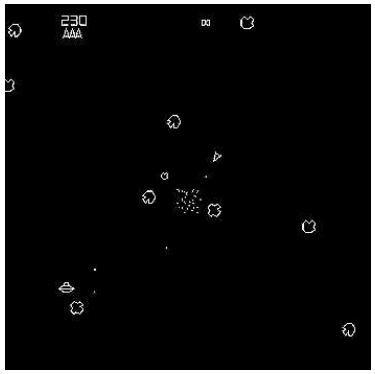
So How to Mitigate?

- Two main options:

- Destroy
  - Can be problematic
  - Fragment into many pieces (all in the same orbit).. Have to track hundreds or thousands of objects now!
- Delay
  - Earth is moving 30 km/s, or 1 Earth diameter every 7 minutes.

Blow the Mother Up!

- Typical option discussed is nuclear missiles.
- Might work, vaporizes or at least reduce mass.
- But, need to make sure not to fragment into many still dangerous pieces.
- Imagine twenty-five 50m pieces in the same orbit, would be hard to stop!



Blow-Up Job

- Other option is to blow up a nuclear weapon near the asteroid.
- But not too near to fragment it.
- Imparted energy could be enough to change orbit.
- Neutron bomb (nuclear blast where large fraction of energy is in neutrons) is thought to be most efficient, biggest transfer of energy maybe only chance for last minute threats.

http://www.projectrho.com/rocket/rocket3x.html

http://www.youtube.com/watch?v=XPS-m_sI7_k

Kinetic Energy Deflection

- Impact the asteroid or attach rockets.
- May still fragment, but most have impacts, so less likely
- Actually an ESA mission to test this is occurring in 2011!
- The aptly-named Don Quijote mission

http://www.esa.int/SPECIALS/NEO/SEMZRZNVGJE_1.html

Don Quijote

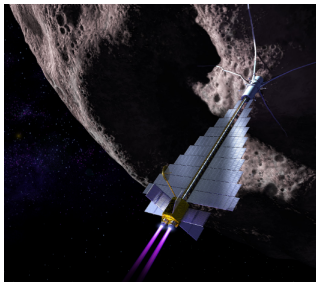
Two components:

- Sancho: orbits and accurately measures position
  - Plus the Autonomous Surface Package Deployment Engineering eXperiment, which checks out the impact site
- Hidalgo: impactor (10km/s)

http://www.esa.int/SPECIALS/NEO/SEMZRZNVGJE_1.html

The Ole' Space Tug

- Put a rocket on the asteroid!
- This can eventually move the rock, but
  - Rockets don't provide too much thrust
  - Will likely need many steerable rockets.
  - Remember that asteroids are rotating!
  - How to attach to a tumbling, rotating asteroid that may only be a big pile of rubble?

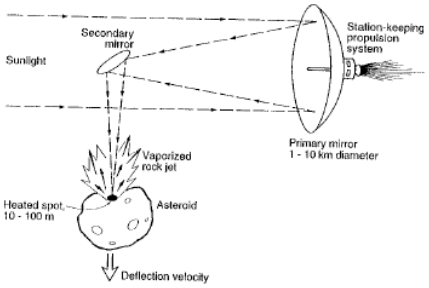


Gravity Tractor

- Put an object near the asteroid!
- Using gravity, the asteroid is attracted to spacecraft.
- Spacecraft uses rockets to keep away, so slow pull.
- Would take ~10 years for moderate mass asteroid
- Works no matter the composition– rubble piles not fragmented.

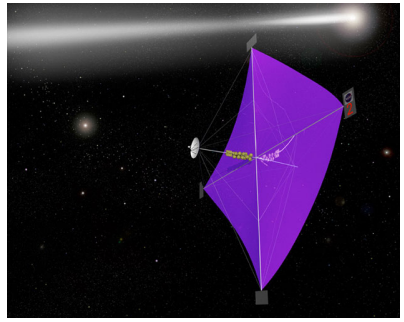
Focus the Sun on it!

- Use the Sun to melt the asteroid surface.
- This removes material and creates a jet.
- http://www.youtube.com/watch?v=dcqFy1zjdys



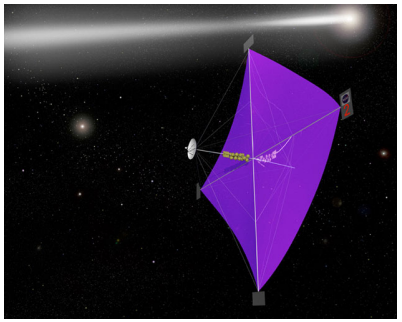
Other Propulsion: Light Sails

- Imagine a space sailboat but with photons of light hitting the sails and pushing it forward.
- Photons have energy but no rest mass.
- But, they do carry momentum!
  - It is related to the energy such that $p = E / c$
- So, such a craft is not propelled by solar winds!
- But by light bouncing off, like a mirror.



Other Propulsion: Light Sails

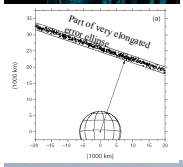
- Attach to an asteroid?
- It can work, but it would be slow.
- How to attach to a tumbling, rotating asteroid that may only be a big pile of rubble?



Other Ideas

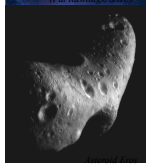
- Paint it or wrap it in a reflective coating.
  - Hard to do, tumbling asteroid again, plus only pushes in direction opposite to Sun.
- Opposite idea is to sprinkle with soot to reduce Sun pressure (also Yarkovsky effect).
- Asteroid braking. Perhaps a cloud of steam in front of the asteroid to slow it some.
  - Steam? Nuke a comet.

Common Misperceptions

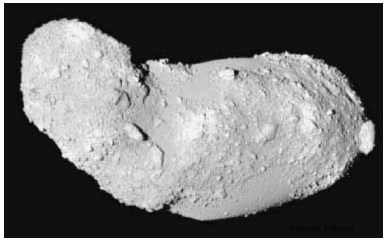


- Long waiting time until next impact
  - Instead, we should think of *chances* of disaster and our responsibilities "on our watch"
- Judging consequences quantitatively
  - Civilization-ending impact vs. K/T mass-extinction
  - "one death" vs. 100 deaths/yr vs. 3000 9/11 dead vs. we will *all* die in next 100 years (what are our values?)
  - Shoemaker-Levy 9 Jupiter impacts overshadowed the Rwanda genocide in the news (July 1994)
- "Blow it up" on the way in
  - Movies misrepresent reality of decades lead-time
- NEA is "on an impact course with Earth"
  - NEA discovery process, error ellipses, NEA orbits the Sun many times before impact: *not intuitive*!

Asteroids are Not Likely to Destroy our World…



- …but we can contemplate the NEO hazard as the most extreme environmental disaster, and put the lesser, more likely ones into context…
- …and distinguish between societal issues like global warming and true, sudden catastrophes.
- Many threats to society and our lives (flu, war, famine… global warming) are here today.
- Asteroids *are* in our future…as places to travel to, as fuel stations for a spacefaring civilization …let's hope they don't come to us first!



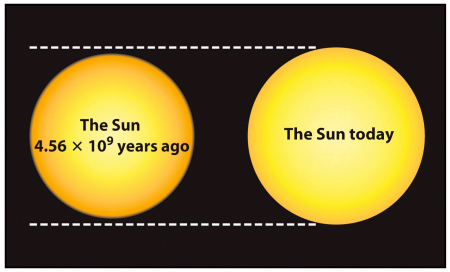
4. Natural Catastrophes

3. Stellar Evolution
   - The Sun is halfway through its lifetime on the main sequence.

http://www.astroimages.net/Media/SolarSys/AR03.html

Life of a Low Mass (Sun-like) Star

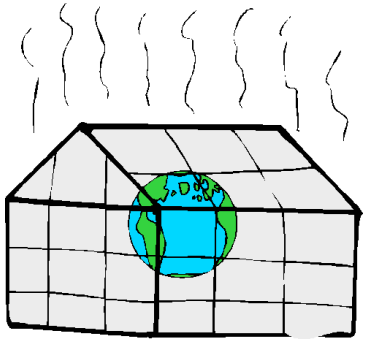
- Most of its life is spent in the happy pursuit of burning H ⇒ He
- With time, luminosity and temperature evolve gradually in response
  - Stays on the Main Sequence, but still evolves..
- The Sun is now 40% brighter and 6% bigger than zero age MS.



http://wings.avkids.com/Book/Myth/Images/ocean_sun.gif

Life of Our Sun

- Over the next billions of years, our Sun will continue to increase in luminosity.
- So in 1+ billion years, our Sun will be 10% more luminous.
- This will cause a "moist" greenhouse effect adding 10 degrees F to the average temp.



http://www.solcomhouse.com/Greenhouse_Effect.gif

Life of Our Sun

- This increase in total energy will have a major impact on the Earth!
  - Ice caps melt
  - Costal regions flood
  - Equator becomes inhabitable
  - Antarctica becomes warm

http://changeyourways.wordpress.com/2009/06/12/what-on-earth/

Life of Our Sun

- Increased temperature means that the lighter elements, like water molecules in the air, will have enough speed to escape Earth completely.
- The water of Earth begins to pack up and leave!
- In 1.1 billion years, the continents will be deserts and the oceans are beginning to evaporate.

http://www.esquire.com/cm/esquire/images/Gd/desert-1108-lg.jpg

Life of Our Sun

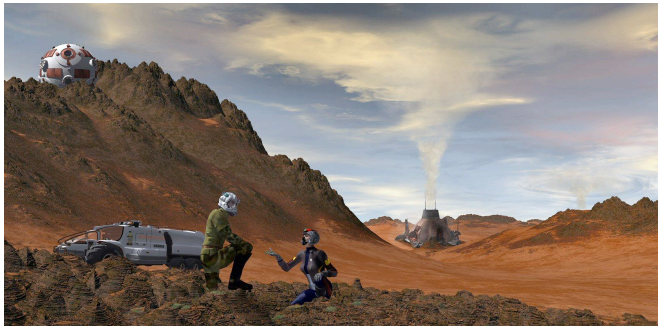
- As the Sun, uses up the hydrogen in the core, the Sun increases by 40% in brightness in 3.5 billion years.
- By that time, all of the oceans are gone!
- The baking sediments at the bottom of the oceans, release CO2
- Earth will become Venus-like!
- Then the heat makes even those heavier molecules leave the Earth.
- The Earth will be a barren rock in about 4 billion years!

http://wings.avkids.com/Book/Myth/Images/ocean_sun.gif

Mitigation

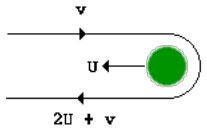
1. Move the population
   - I hear that Mars could be a nice place to live.
   - Need to terraform Mars, which could take a while.

http://www-cache.daz3d.com/sections/contests/upload_files/3195.jpg



Mitigation

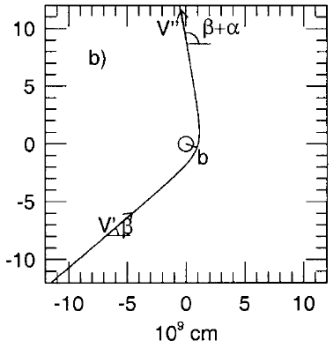
2. Move the Earth
   - There is no place like home, so move it to a nicer place, farther away from the Sun.
   - Use gravity assist or the sling shot technique.



http://upload.wikimedia.org/wikipedia/commons/8/8e/Grav_slingshot_simple_2.gif

Mitigation

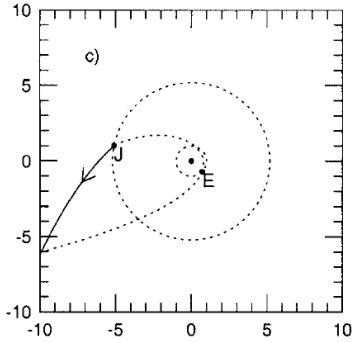
2. Move the Earth
   - Asteroids to the rescue?
   - Move many large asteroids in front of the Earth, sends them toward the Sun and the Earth outwards.
   - Need to do this every 6000 years to make Earth survive until the Sun hits the Red Giant phase.



Korycansky et al. 2001

Mitigation

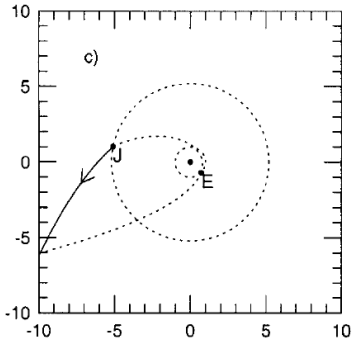
2. Move the Earth
   - For billions of years!
   - We don't have enough large asteroids.
   - We'll have to recycle.
   - The idea is to transfer energy from Jupiter's orbit to Earth's orbit.



Korycansky et al. 2001

Mitigation

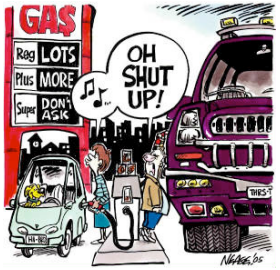
2. Move the Earth
   - Could keep us safe for a good 6 billion years!



Korycansky et al. 2001

How much Gas do we have left?

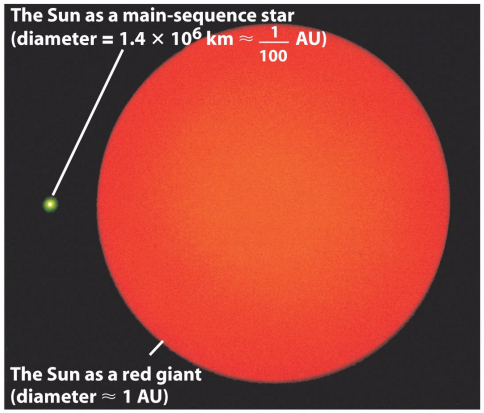
- Even if we could save the Earth during this time of increased brightness, eventually the Sun runs out of fuel.
- Total energy available is easily calculated by mass of hydrogen in Sun and energy released by each hydrogen conversion.
- We only have about 6 billion years left!



http://skeptically.org/sitebuildercontent/sitebuilderpictures/.pond/suv-econ-gas-pump.jpg.w300h294.jpg

In 6-7 Billion years

- The Sun will expand to 100-250 times bigger than it is now!
- The same mass but now it's bigger.



The Sun today and as a red giant

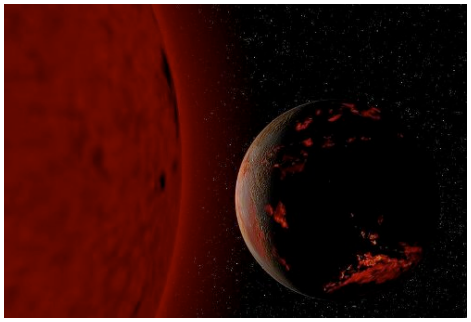
In 6-7 Billion years

- The surface gravity decreases and the Sun has more luminosity.
- The solar wind turns into a stellar wind, and it looses material as it expands, about 10^7 times more than now.
- It's blowing it all away!

http://www.astropix.com/wp/wp-content/uploads/2006/12/2006_02.JPG

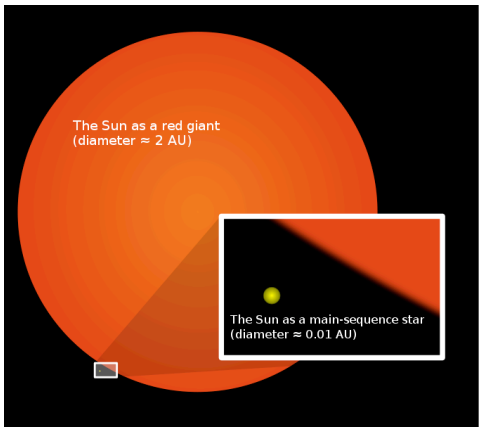
In 6-7 Billion years

- During the time it expands the Sun loses a significant fraction of mass.
- So, the planets move outward.
- Planets race away as the Sun expands.
- Who wins?
- We aren't yet sure.



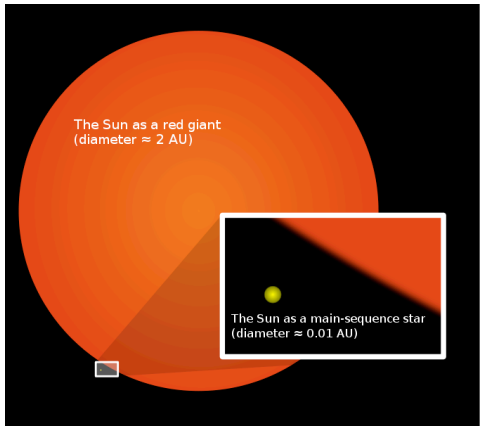
In 6-7 Billion years

- We use to think that the Sun would gobble the Earth.
  - Mercury gone
  - Venus probably gone
  - Earth?
- BUT even if not, with the Earth's oceans and atmosphere gone, crust still melts.
- Not good…



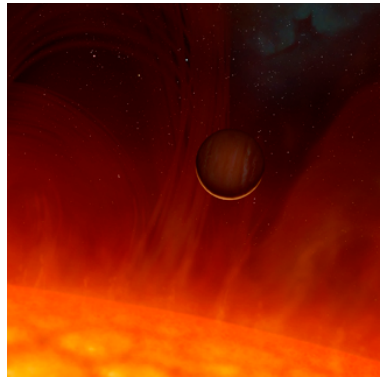
In 6-7 Billion years

- Mars?
  - For sure too hot.
- Jupiter's Moons?
  - Still too hot
  - Europa's water vaporizes
- Even the moons of Uranus and Neptune may be too hot.



Mitigation

- We would have to move the Earth out to Pluto or further!
- Probably not possible.
  - Interactions with Jupiter may eject us from Solar System
- Even then, Sun no longer in equilibrium, may oscillate in size or brightness.
- BUT, we got billions of years to figure it out!



http://www.sciam.com/media/inline/FA992809-E7F2-99DF-30B7058698177187_1.jpg

Natural Catastrophes

3. Stellar Evolution
   - Advanced civilization can likely find solutions.
   - Eventually, we would have to leave the Earth, move the Earth, or move to Mars.

http://www.boulder.swri.edu/~terrell/dtart_old.htm

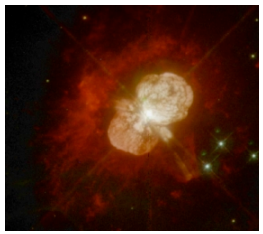
Question

In 5 billion years, our Sun will begin to turn into a red giant, on its way to a white dwarf. But never fear,

a) An advanced civ can stop the Sun from evolving.
b) We can always move to Venus.
c) An asteroid will probably hit and destroy the Sun first.
d) The Moon will be fine.
e) The Earth's oceans will evaporate before then.

4. Natural Catastrophes

4. Killer Supernovae!
   - Death of a nearby massive star would be bad news.
   - Explosion within 30 ly would destroy ozone layer.
   - Right now, no candidates.
   - Unlikely to happen in time scales of less than 2 billion years.
   - A supernova event ~2 Myrs ago may account for an extinction event.



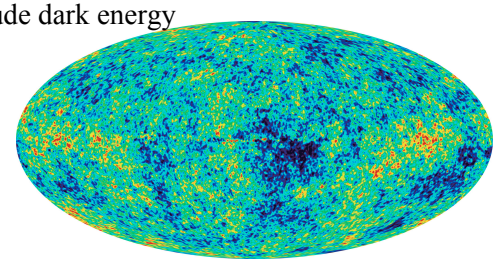
Question

A nearby killer supernova

a) is the most scary, as we won't know about it.
b) would have to be very close, but it could destroy the ozone layer .
c) is a supernova in our Galaxy.
d) would not cause any real damage, no matter how close it was.
e) will evaporate the oceans.

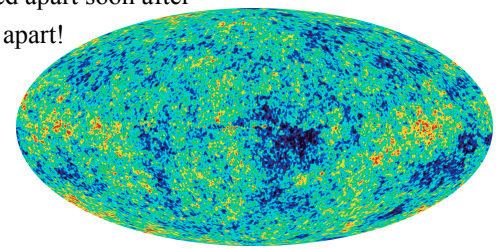
4. Natural Catastrophes

5. Ultimate limit to L!
   - Fate of the Universe.
   - A Big Crunch: 10^{12} years (a trillion years)
   - But, WMAP results from the cosmic microwave background suggest that we are in a flat universe.
   - Which does include dark energy



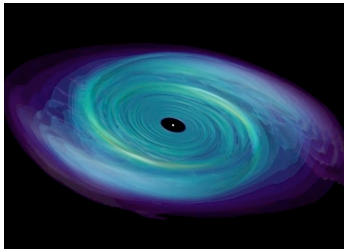
4. Natural Catastrophes

5. Ultimate limit to L!
   - The Big Rip?
     - If repulsive force increases– Brooklyn may expand too.
     - Gravity/E&M forces can not hold Galaxies rip apart
     - Could rip the MilkyWay apart in ~1 billion years
     - Earth gets ripped apart soon after
     - You get ripped apart!



4. Natural Catastrophes

5. Ultimate limit to L!
   - Big Rip seems unlikely
   - We'll know soon.
   - If we are just in a flat Universe, then it is a matter of energy.

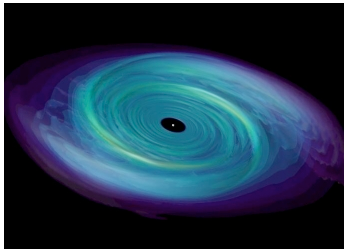


http://www.youtubeom/watch?v=oGVYG0ce1Ps

http://homepages.wmich.edu/~korista/web-images/accretion_ncstate.jpg

4. Natural Catastrophes

5. Ultimate limit to L!
   - The end of the Universe… the death of the dark.



http://homepages.wmich.edu/~korista/web-images/accretion_ncstate.jpg

Stelliferous Age: 10^8 to 10^{15} years

- Last stars to form will happen in a few hundred billion years.
- Stars age and die
- In about trillion years all Sun-like stars are gone from the Universe forever.
- Only stars left are low-mass red dwarfs (~0.1 solar masses), which can live for trillions of years
  - Lots of these stars and they get brighter with age, so Galaxy brightness doesn't change too much

Stelliferous Age: 10^8 to 10^{15} years

- In 7-8 trillion years, in our Galaxy (Milkomeda), the last red dwarf stops fusing, becoming a white dwarf.
- These tiny white dwarfs will stay hot for quite some time.
- Wait another few trillion years and they fade.
- So when the Universe is 100 trillion years old, the Universe goes dark.

Really Dark

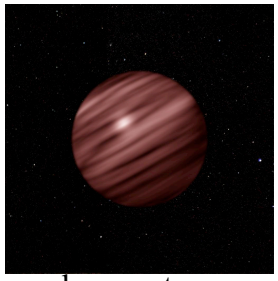
- If the Universe keeps expanding, it get worse for astronomers.
- The Galaxies we can see now, far away galaxies move out of our view.. Too far to see given the age of the Universe… out of our horizon.
  - The observable Universe is less and less
- The one giant elliptical galaxy (all that is left from our local group) is all that can be seen.
- The Universe appears empty!

Humans?

- We have 100 trillion years!
- Maybe longer, by smashing stars together to make fusion last longer.
- Won't last too long.
- When the Universe is slightly older than 100 trillion years old, the human race is out of fuel, out of stars, and out of luck.
- But the Universe isn't done!

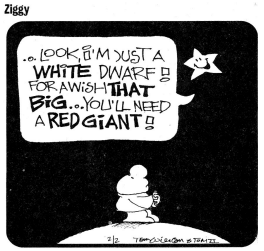
The Degenerate Era: 10^{15} to 10^{40} years

- Stellar corpses are all around the Galaxy.
- Every once in a while, a black hole will accrete a compact object, creating light again.
- Corpses may collide (remember we are talking 100 trillion years of time not the measly 13.7 billion of the Universe so far), and create new stars.
- Brown dwarfs, which did not have enough mass to fuse, can collide, making new stars.
- New life? Different Universe..



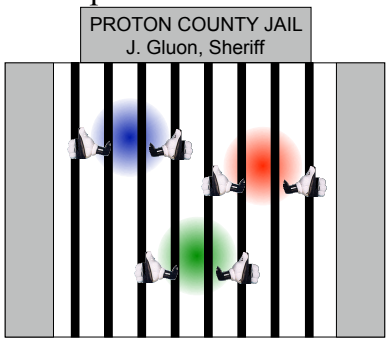
The Degenerate Era: 10^{15} to 10^{40} years

- But after a trillions, then quadrillions, and then quintillions of years, everything that can ever burn has happened.
- The Galaxy starts to lose weight.
  - Interactions with the stellar corpses, cause all the low-mass objects to be ejected from Galaxy.
  - High-mass objects fall to the center.
  - Supermassive Black Hole feeds!
- If the Earth still orbited the dead Sun (white dwarf) it is likely kicked out of the Sun and the Galaxy– a frozen dead planet in intergalactic space.



Proton Decay

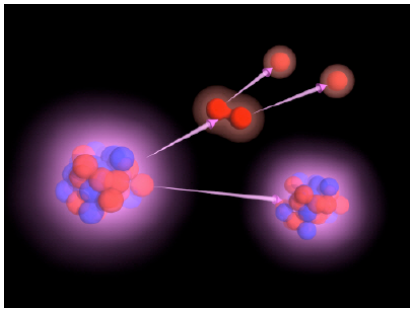
- Remember when quarks were imprisoned?
- We think that protons are radioactive.
- Except that they decay with a half-life of about 10^{37} years.
- Time is all that is left.



10^{31} years to life
Little chance of parole

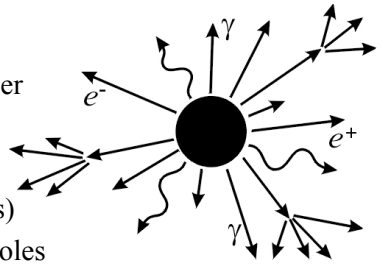
Proton Decay

- This proton decay creates heat again, feeble heat.
- What does non-proton life do?
- White dwarfs will evaporate
  - At -454 F, they are the hottest thing around!



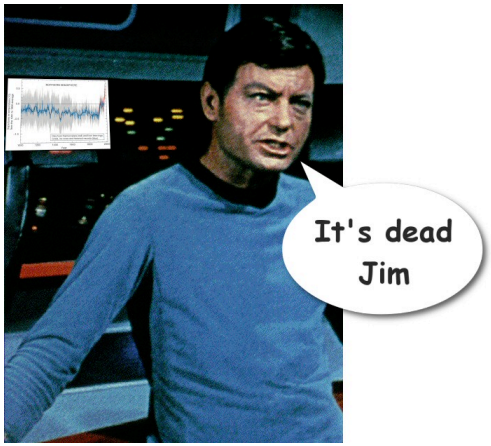
The Black Hole Era: 10^{40}-10^{92} years

- Black Holes survive.
  - Not made from matter, remember
- Galaxy is
  - The Supermassive Black Hole (1-10% of original Galaxy mass)
  - Trillions of stellar mass black holes
  - Lower mass stuff that was thrown out, so very far away.
- Hawking radiation is slow, but it will begin to evaporate the black holes
  - Slow, but lots and lots of time



The Dark Era: 10^{92}- Infinity

- 10^{92} is crazy!
- I mean really, really crazy!
- The weight of a single proton to the rest of the Universe is only 10^{79}!
- Still, at this point, the Universe is dead!
- Dead Jim!



The Dark Era: 10^{92}- Infinity

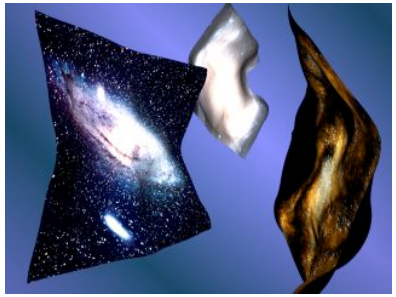
- Beyond this, two particles will once in a great while interact, but nothing will really happen.
- Universe is dead, randomized, and silent.
- Nothing really will ever happen again..
- Or will it?

The Dark Era: 10^{92}- Infinity

- Rebirth?
- We don't know what caused the Big Bang.
- Maybe it happens again?
- Maybe it already has?

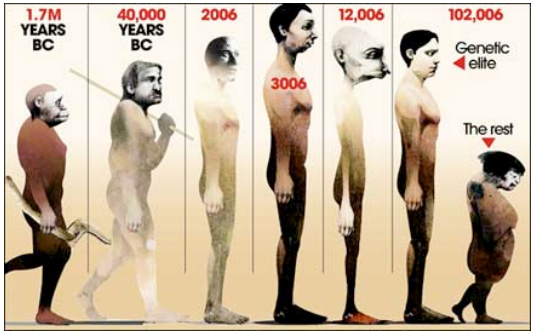
Branes, Branes!

- One idea is that the Universe has 11 dimensions
  - Our 4 dimensional Universe floats around in this space
  - Other universes float there too (called branes, short for membranes)
  - Sometimes they collide
  - Violently disturbed, energy/matter heat up, expanding space
  - Sounds familiar..



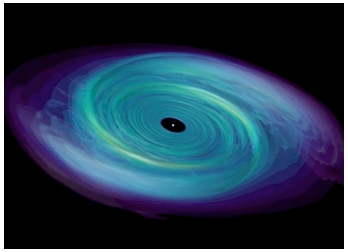
Mitigation

- Are you kidding me?
- If humans live this long, they won't be anything we'd recognize as human.



4. Natural Catastrophes

5. Ultimate limit to L!
   - Bottom line is that the maximum age is speculative.



http://homepages.wmich.edu/~korista/web-images/accretion_ncstate.jpg

Top 10 Ways Astronomy Can Kill Humans

1. Impacts
2. Sun Evolution/Coronal Mass Ejections
3. Supernovae
4. Gamma-Ray Bursts
5. Rogue Black holes
6. Rogue White Dwarfs
7. Galaxy Collisions
8. Cosmology
9. Quasars
10. Aliens

L-ing it

- We are talking about the amount of time that an advanced civilization (averaged over time) can communicate.
  - They may not want to for long periods of time
  - They may give up
  - They may be killed off
  - They may run out of resources
- Solving our energy problem (cheap energy) will give the largest lifetimes.

What is L?

- How long on **average** can an advanced civilization exist?
- Again, we only have a sample of 1 from which to discuss. What is our civilization's lifetime?
  - Short Term (100-1000 yrs)
    - Give up on communication due to budgets.
    - Depletion of resources.
    - Population.
    - War.
  - Long Term (10^5 to 5 x 10^9 yrs– age of galaxy is 10^{10} yrs and we took half of that to evolve)
    - Stellar Evolution.
  - Don't forget the random volcano, asteroid, or supernova.
  - Still in many cases an advanced civilization may be prepared for many of the issues!