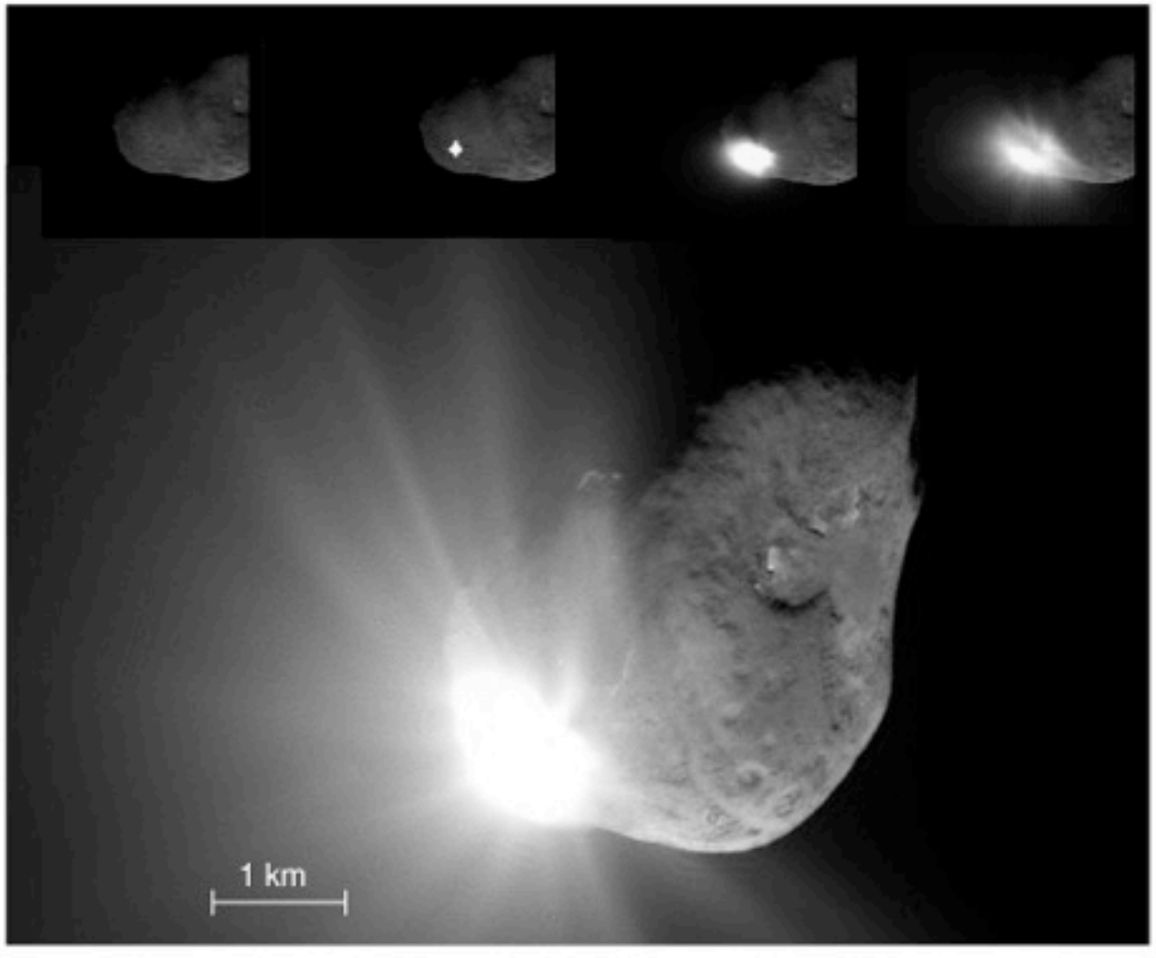
Astronomy 150: Killer Skies
Lecture 11, February 10

Assignments:

- Hour Exam 1 next Friday Feb 17, in class
  information on course website
- Planetarium: report due Feb 24
  extra show added this Thursday Feb 16
  or can go to a public show on "Black Holes" or on "Prairie Skies"

Last time: A Warning from Jupiter, and Hunting for Impactors

Today: Impact Mitigation, and a new threat--the Sun



Current Hazards: Update

Tornio scale:

ranks threat of known potentially hazardous objects

- 0=no threat
- 10=certain collision causing global catastrophe

Rankings change with time!

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- asteroid 2011 AG5, close approach Feb 2040

  size 140 m: 100 MT explosion, impact probability 0.16%

- asteroid 2007 VK184, close approach June 2048

  size 130 m: 150 MT explosion, impact probability 0.06%

Earth is in a cosmic shooting gallery!

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A Ride With The Earth

An animation centered on Earth showing the known objects that have approached to within 20 million km between July 2007 and June 2008. See the Animations Page on the MPC website for a description of the symbols used in this animation.

Asteroid Histories Sampler

- Billions of yrs ago (Mars-sized): Creation of Moon
- 65 Million yrs ago (~10 km): Dino-killer
- 15 Million yrs ago (~10 km): fragmented before impact, but ~1km objects impacted Bavaria, destroyed much of Europe
- 50,000 yrs ago (~50 m): Arizona meteor crater
- 1908 AD (~50 m): Tunguska

Asteroid Histories Sampler (Recent)

- 1972 (~ 10m): The Great Daylight 1972 Fireball, went through the atmosphere, getting as low as 58 km over Montana
- 1989 (~300 m): missed by 700,000 km (where the Earth had been 6 hours earlier)
- 2002 (~100 m): 1/3 Earth-Moon distance, 120,700 km, only discovered three days after pass!
- 2004 (~500 m): 400,00 km, rediscovered 1 week before.
- 2009 (~30 m): 60,000 km, discovered 1 month before.

Asteroid Histories Sampler (Future)

- 2029 (~ 450 m): Apophis will come within 40,000 km. In very dark sites, it will be visible with naked eyes (Europe, Africa, and W Asia).
- 2036 (~450 m): Apophis is back. We don't know how close it will get, possible impact. We'll know better soon.
- 2880 (~1.1 km): 1950 DA, huge miss or impact?

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- Response of human **psychology, sociology, political systems, and economies** to such a catastrophe.

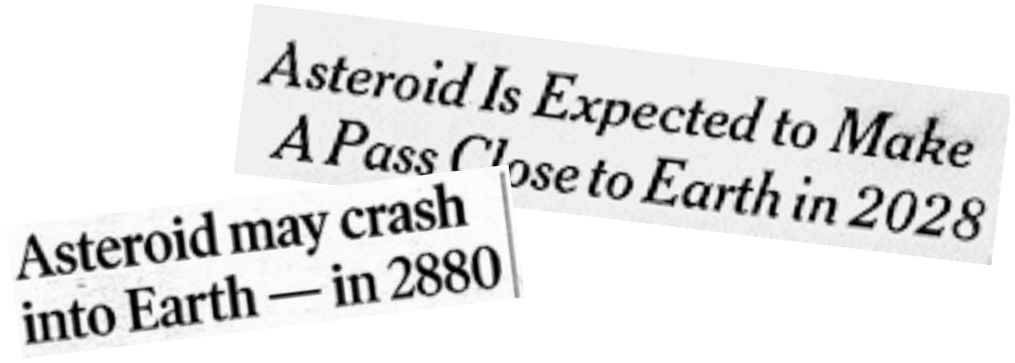
What Do We Know About the Impact Hazard?

WE KNOW THIS...

- Very Well — **How many asteroids and comets** there are of various sizes in Earth-approaching orbits (hence, impact frequencies are known).
- Very Well — **How much energy** is delivered by an impact (e.g. the TNT equivalence, size of resulting crater).
- Somewhat — How much dust is raised into the stratosphere and other **environmental consequences**.
- Poorly — **Biosphere response** (agriculture, forests, human beings, ocean life) to environmental shock.
- Very Poorly — Response of human **psychology, sociology, political systems, and economies** to such a catastrophe.

Secondary Consequences from Small, Likely Events

OVER IRAN? ISRAEL? KASHMIR?
HOW WOULD GOVERNMENTS RESPOND?



- Public and government hysteria after 9/11 (e.g. stock market volatility, homeland security overreaction) could be replicated by a modest, unexpected impact disaster.
- An otherwise harmless but brilliant bolide (fireball) could be mistaken for an atomic attack, causing a dangerous response.
- Even sensational journalism or a mistaken prediction about a possible future impact could be disruptive.

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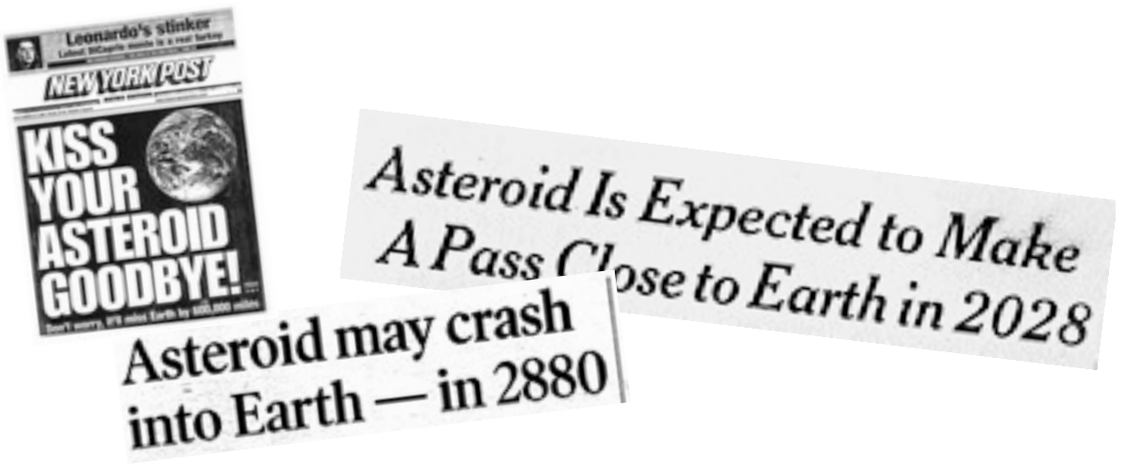

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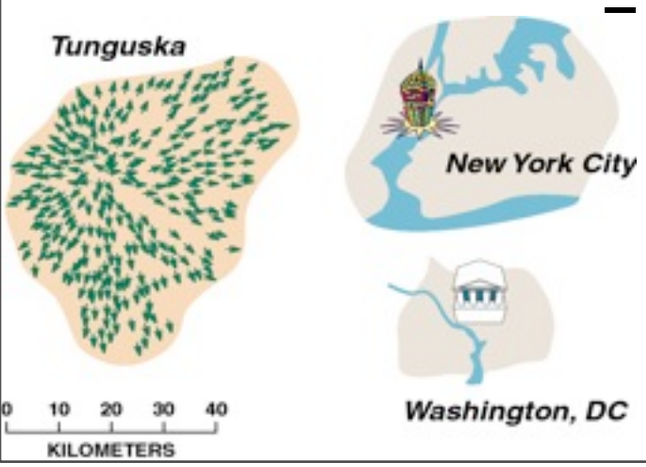
Impact Consequences in Perspective…

Meteorite punctured roof in Canon City, CO

- **Most effects are individually familiar (fire, wind, falling debris, seismic shaking…)**
  - **First-responders face nothing truly alien, no radiation**
  - **Synergy of many different effects in first 10 minutes**
- **Warning versus no warning (time and location)**
  - **Deaths and injuries dramatically reduced with warning**
  - **Property damage can be lessened somewhat**
  - **Even with no warning, individuals can reduce exposure by taking cover (within seconds to minutes) if they have been educated to recognize what's happening (Indian Ocean tsunami analogy)**
- **Impact disasters: local/regional versus global**
  - **Like Katrina, earthquakes, or wars…unaffected cities or nations can provide emergency response and recovery…**
  - **…Unless the consequences are global**



The impact threat is real, even if it is small

Earth has suffered many impacts in its past

It will suffer more in the future

The questions are:

- When will the next one happen?
- What can we do about it?

Early Detection is Key

The earlier we can detect a threat, the easier it is to mitigate the danger.

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

A very small change in velocity (speed or direction) can make a huge difference in months.

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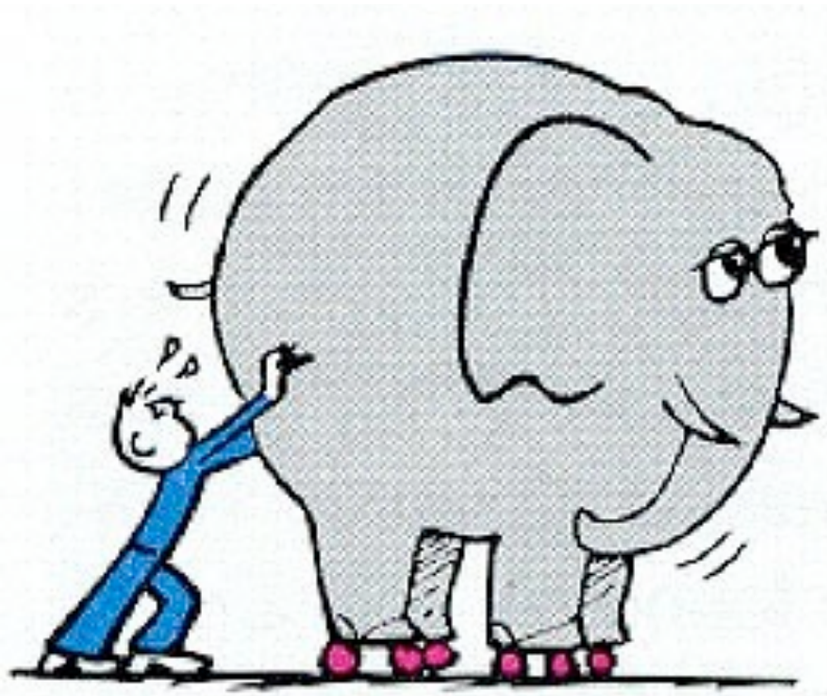

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Key issue: warning time

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

iClicker Poll
Asteroid vs Comet Threat

Consider two large impactors of the same size not already discovered

- an asteroid whose orbit has a small eccentricity
- a comet whose orbit has a large eccentricity

Which is likely to be detected with the least warning time before impact?

A. the asteroid

B. the comet

C. equal likelihood to detect both

So How to Mitigate?

Two main options:

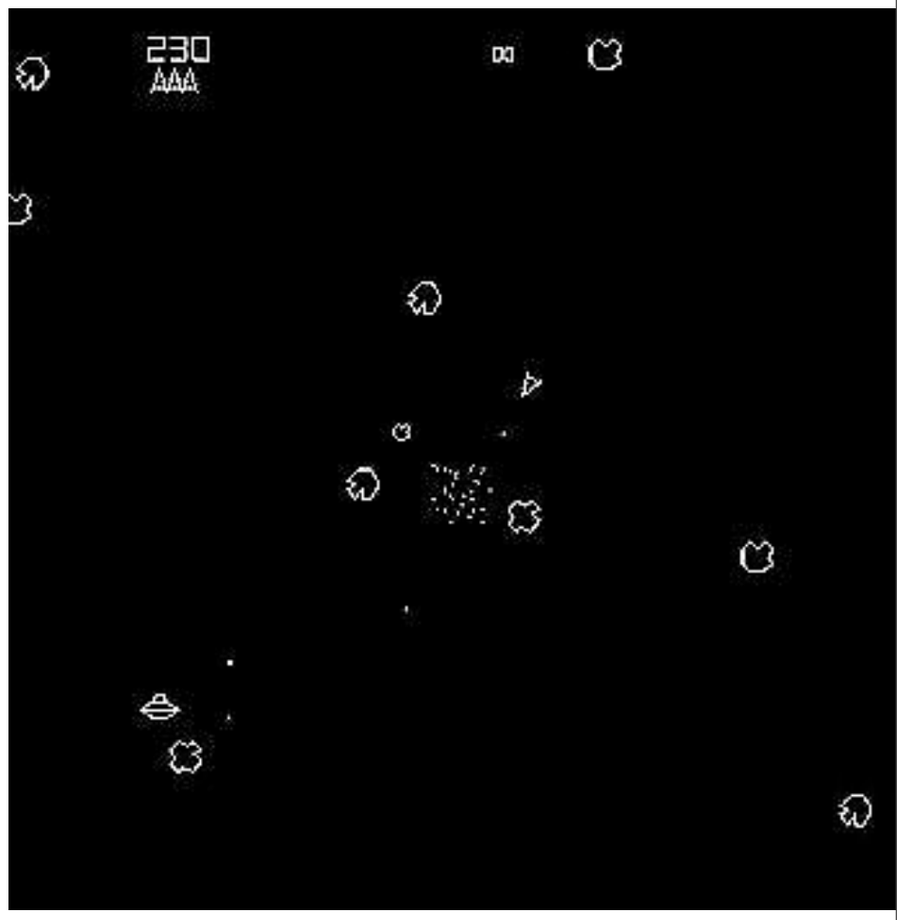
Destroy

- 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 explosion.

- Might work, vaporizes or at least reduce mass.
- Last resort--possibly the only option if impactor found with very little warning

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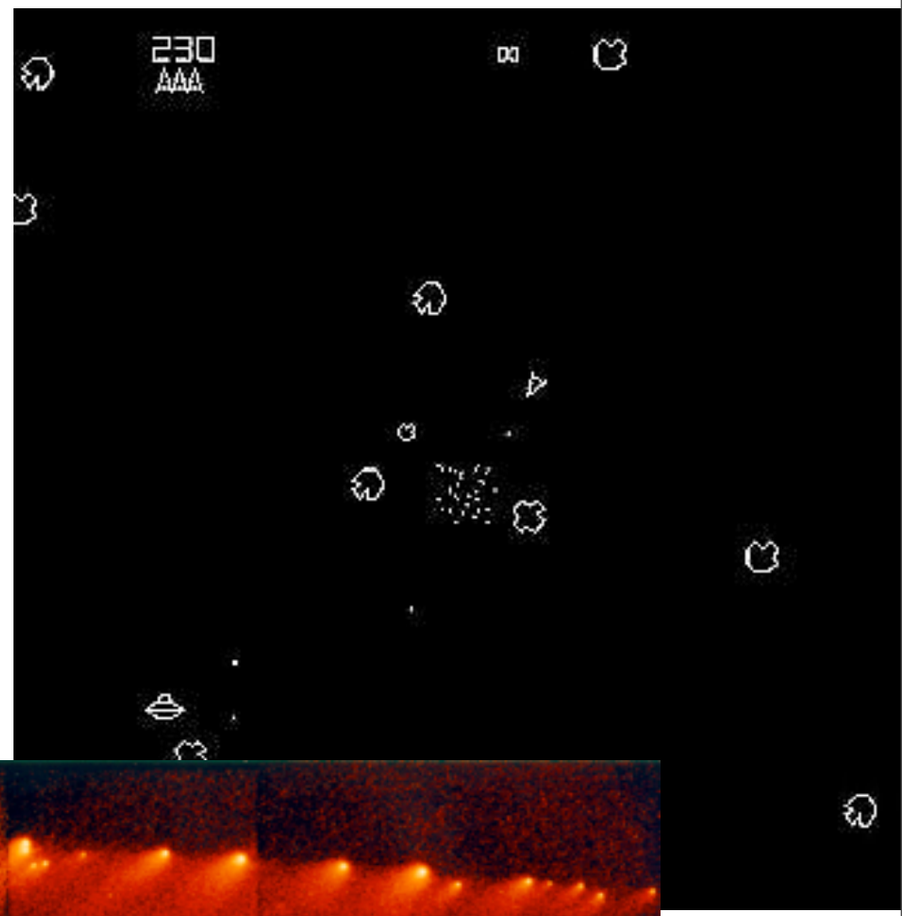
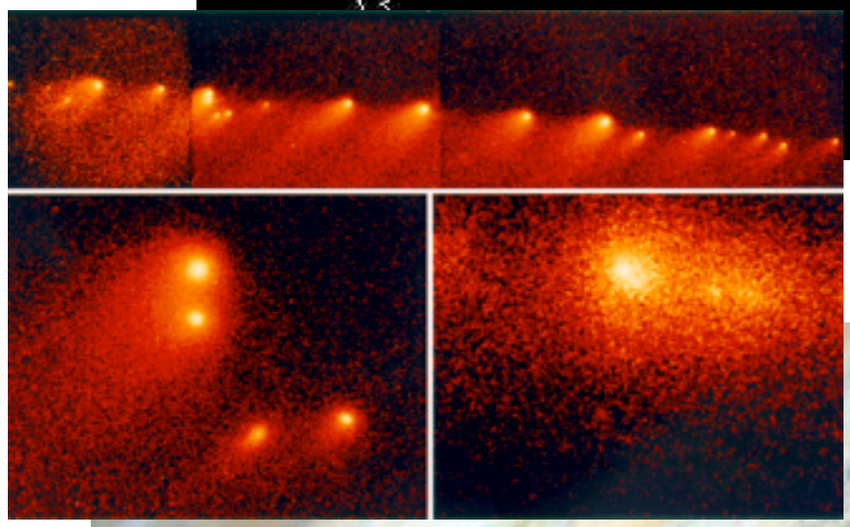
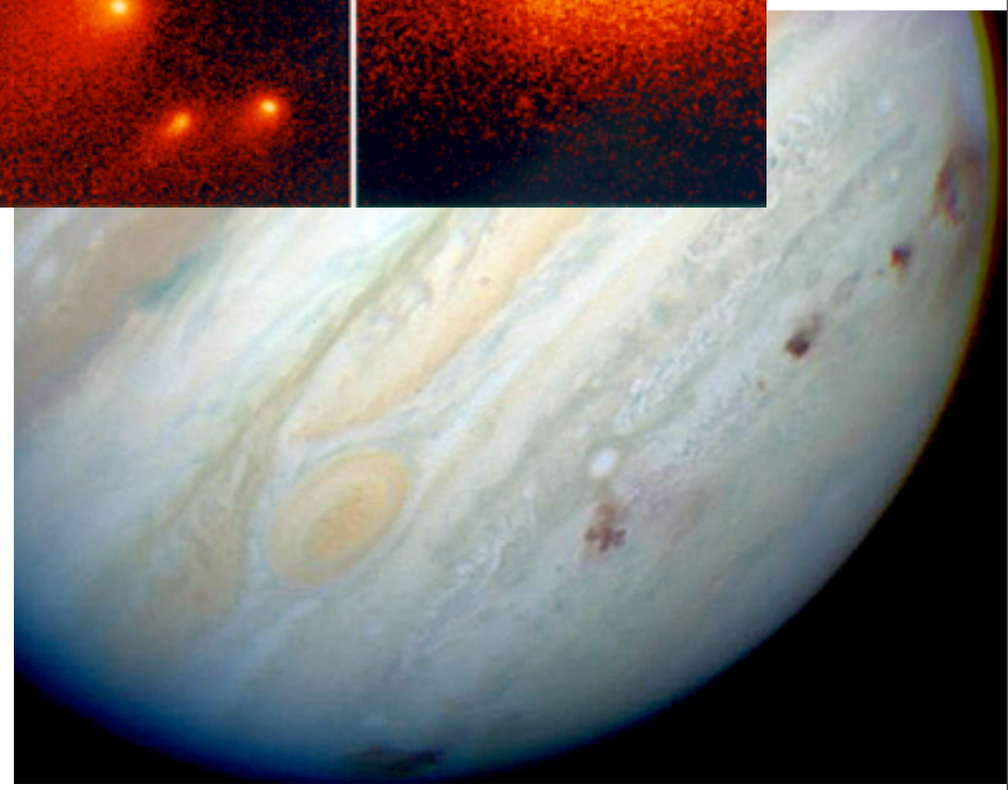
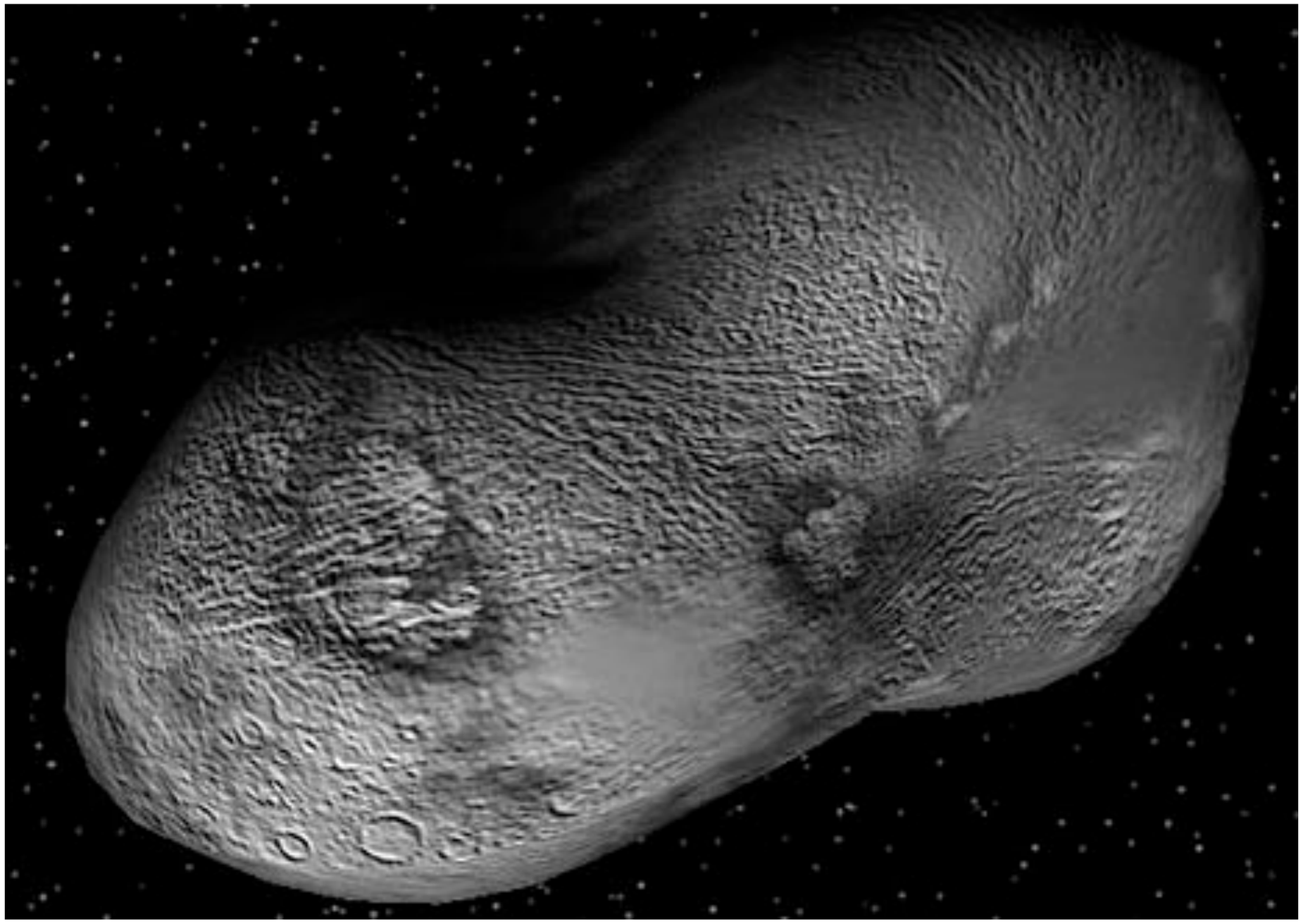
But, need to make sure not to fragment into many still dangerous pieces.

- Imagine twenty-five 50m pieces in the same orbit, would be hard to stop!
- Comet Shoemaker-Levy 9 had broken up into 20+ fragments, but still resulted in major impacts on Jupiter!









A single 250 meter asteroid like Apophis has enough material to make **over a hundred** 50 meter (i.e., Tunguska impactor sized) fragments!

Two types of mitigation options

Quick-Jolt Options

- Nuclear Deflection
- Kinetic Impact Deflection

Slow-Push Options

- Rockets/Mass Drivers
- Space Mirrors
- Yarkovsky effect
- Lasers/Particle Beams
- Gravity Tractor

Nuclear Deflection

Blow up a nuclear weapon near the asteroid/comet

- But not too near to fragment it
- Optimal height: 15-20 km

Imparted energy changes velocity by ~2 cm/sec

Is that enough?

Yes! If there is enough time!

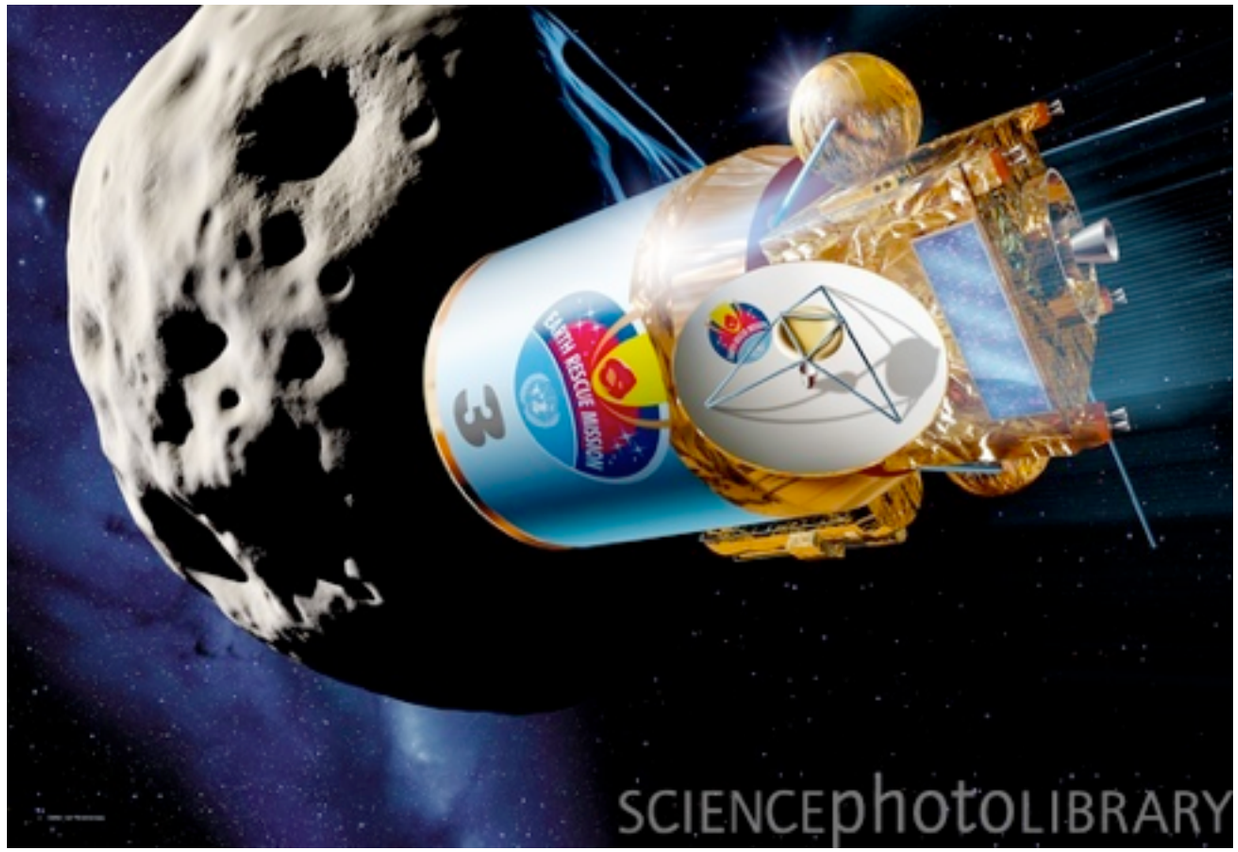
- If 10 years warning, change asteroids path by distance

$$d_{\text{deflect}} = v_{\text{deflect}} \times t$$
$$= (2 \text{ cm/s}) \times (10 \text{ years})$$
$$= 6 \times 10^8 \text{ cm} = R_{\text{earth}}$$

A nuclear weapon exploded next to an asteroid could alter its trajectory

Kinetic Impact

- Hit the impactor with a projectile
- Change in speed mostly from the ejecta of the impact
- 1-ton spacecraft hitting at 10 km/sec = 0.01% energy of nuclear bomb
- Smaller change in speed



The spacecraft will collide with the asteroid to deflect the asteroid away from an Earth-bound trajectory

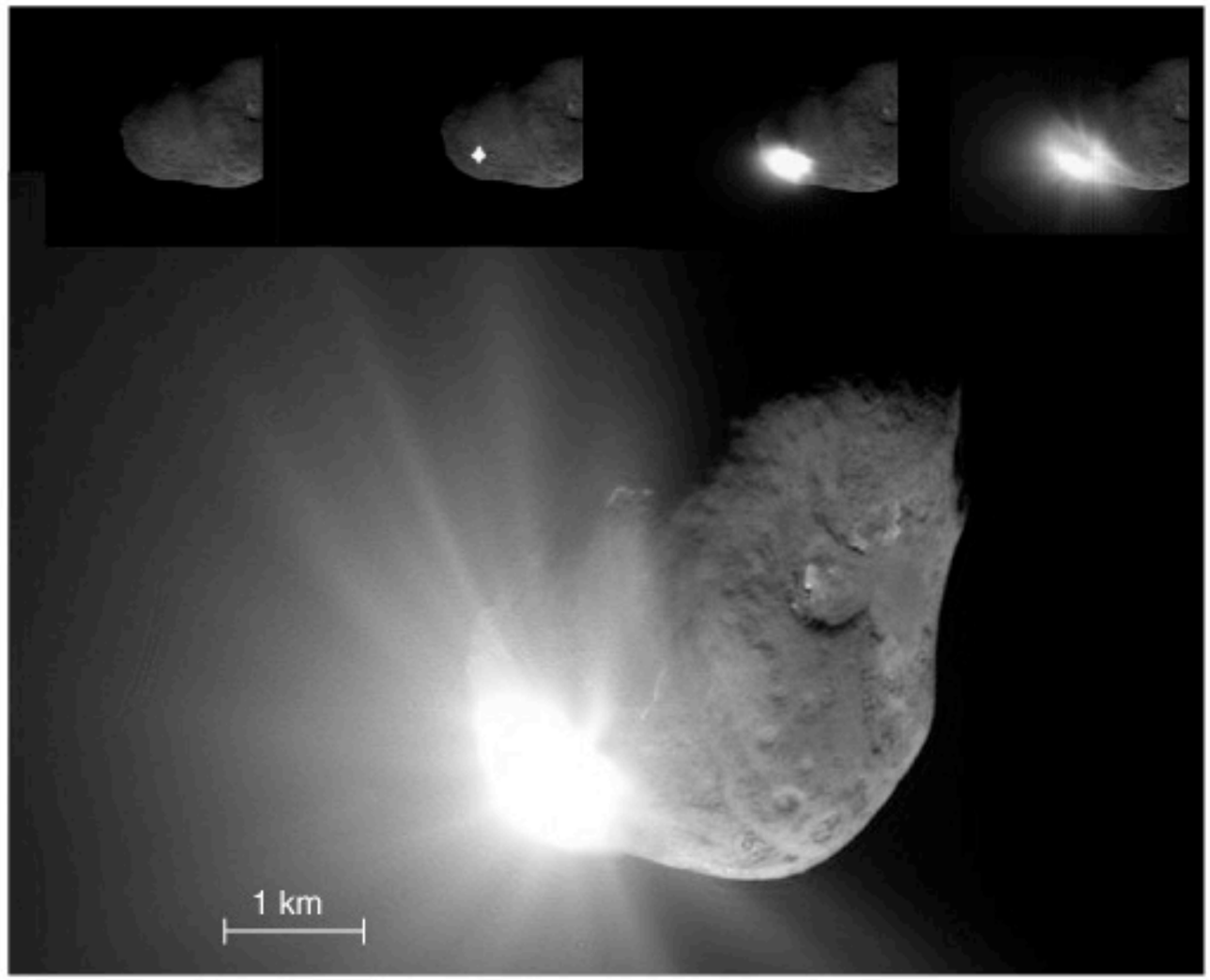
Deep Impact

7/4/05: Deep Impact probe collided with Comet Tempel 1

Projectile weighed 370 kg (816 lbs)

15-30 million kg of material outgassed from impact site!

Outgassing lasted for 13 days!



Attaching rockets to an asteroid

Rocket thrust nudges the asteroid from an Earth-bound trajectory

The main shuttle engine could, in theory, deflect a 1 km asteroid, with enough warning (~30 years from impact)

Rockets firing from the surface of a near-Earth asteroid

Mass-drivers

Robot drills into the asteroid and electromagnetically catapults material into space

Ejecting material creates thrust

- like a rocket
- but fuel is asteroid material

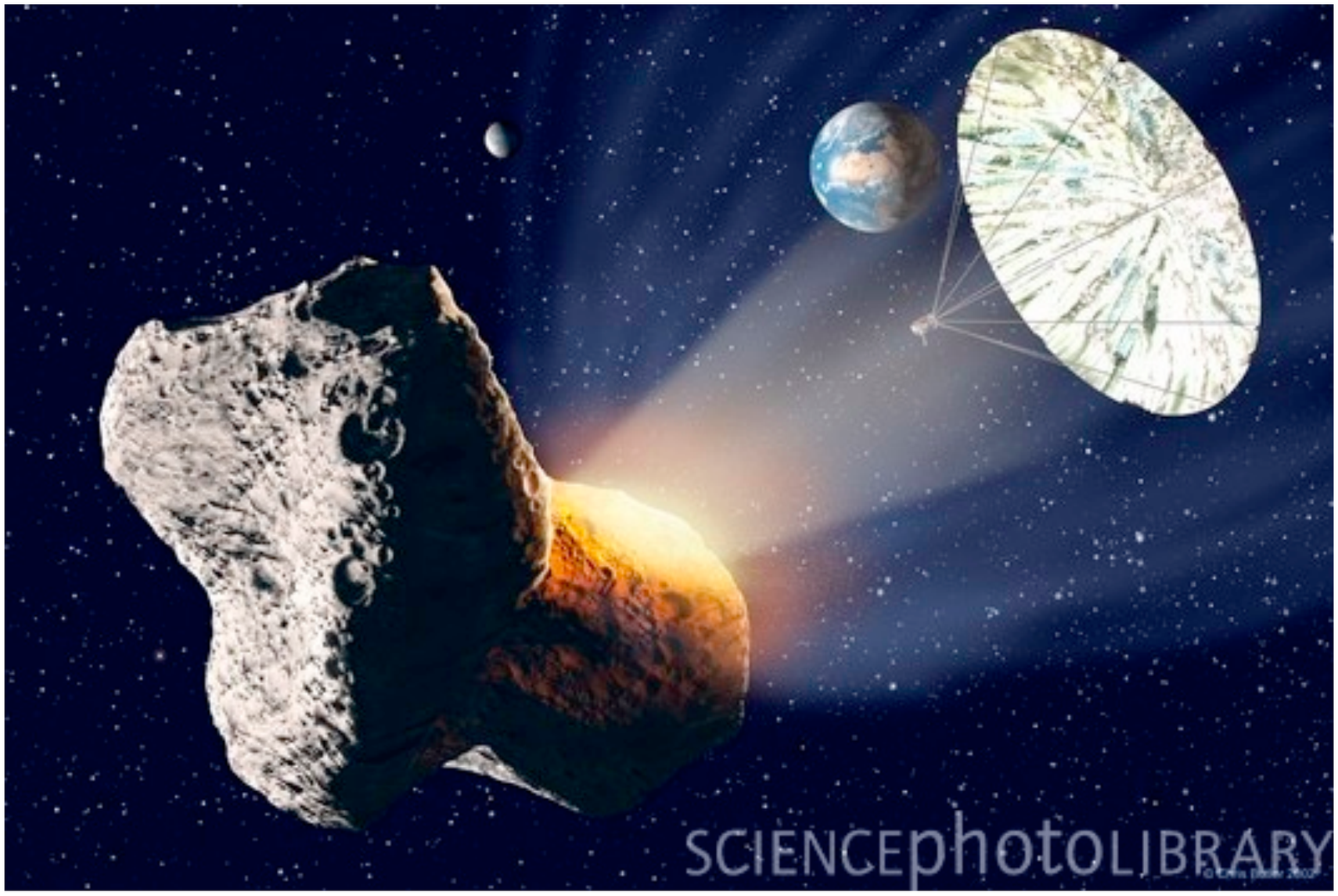
Slowly nudges asteroid away from an Earth-bound orbit

Newton's 3rd Law!

Another issue: Asteroids ‘tumble’

How do you ensure the thrust is in the right direction?

Space Mirrors



Use the Sun to melt the asteroid surface

This removes material and creates a jet

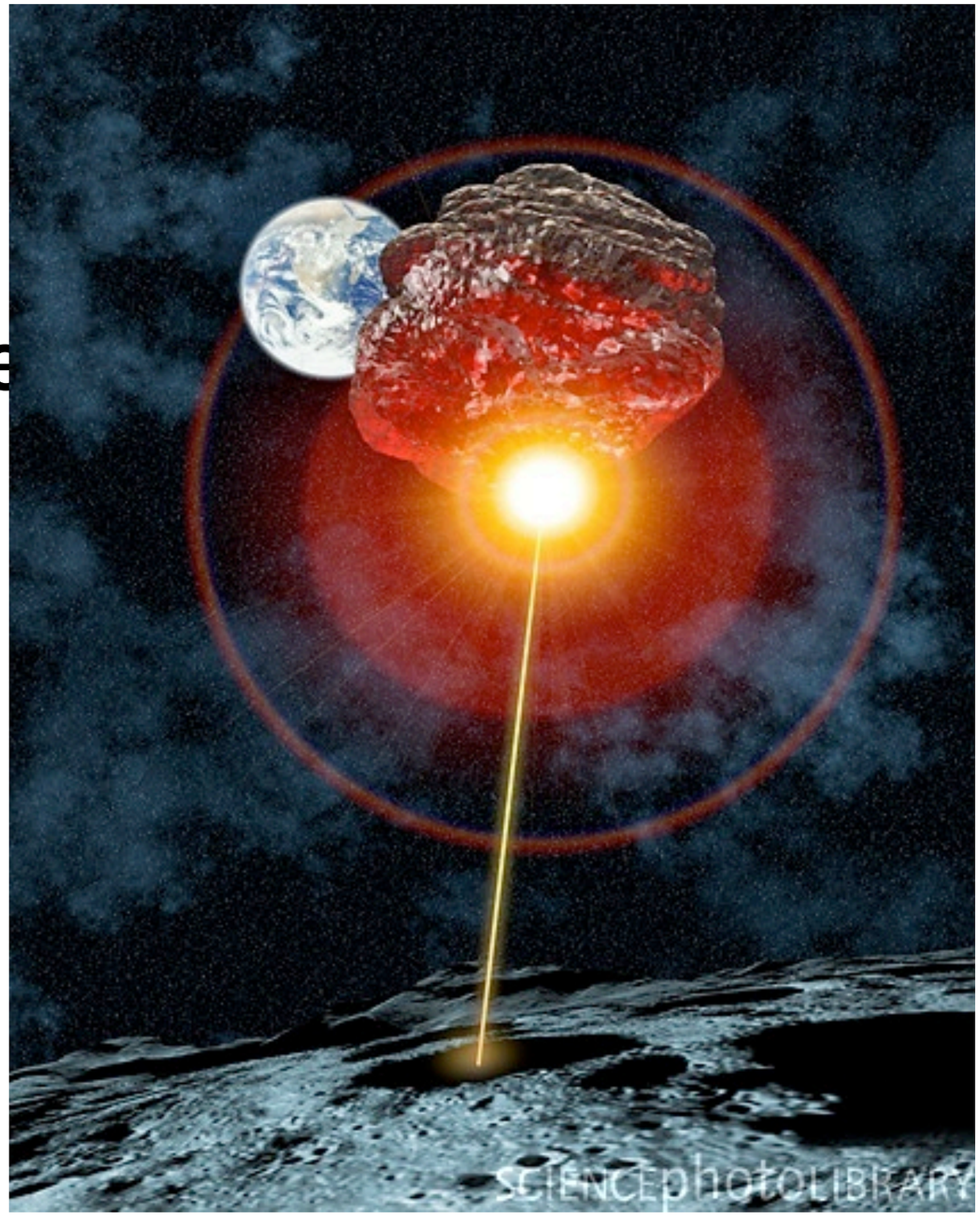
Lasers/Particle Beams

Use a laser to heat the surface of an asteroid or comet

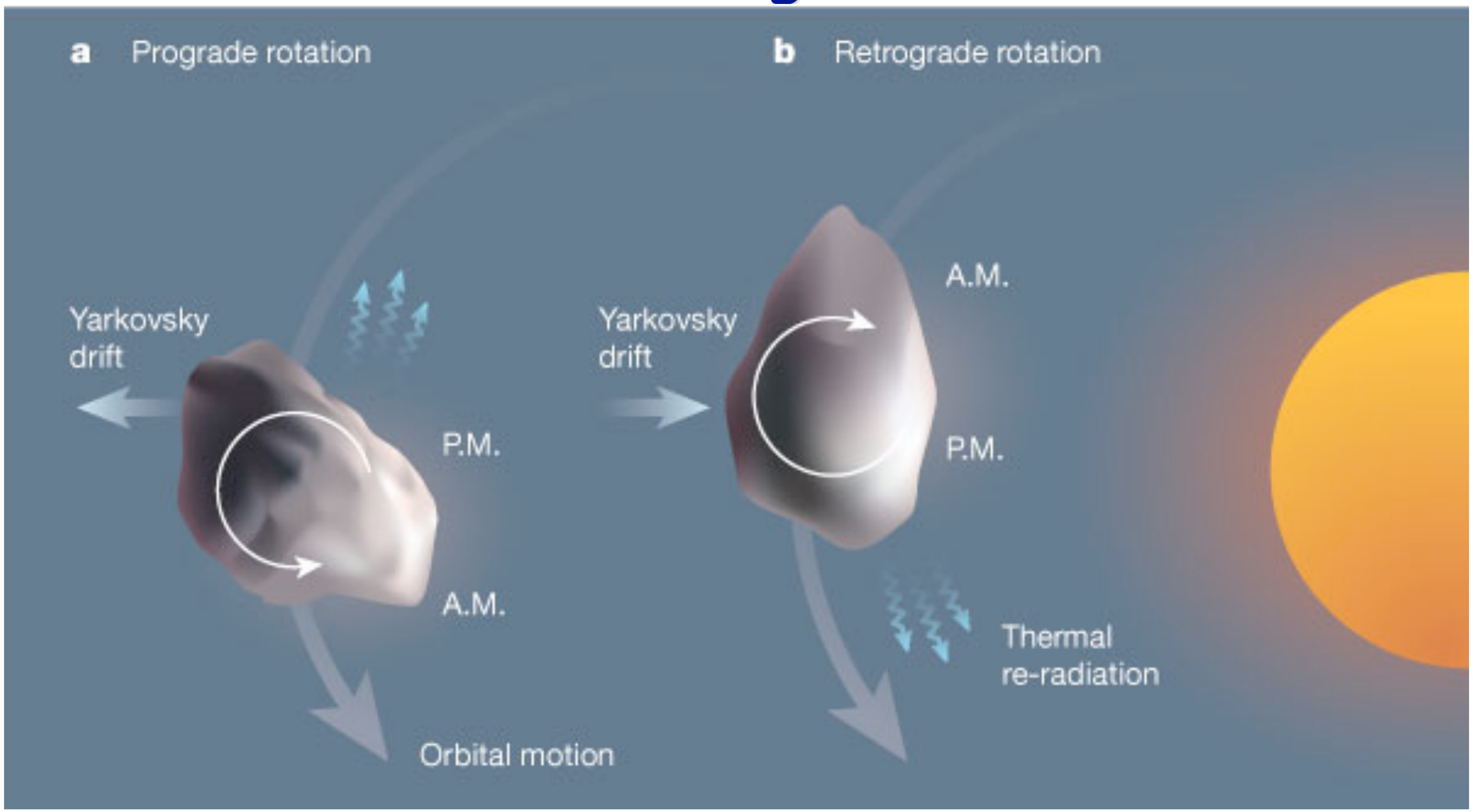
Gas jets are emitted

Jets act as rockets to prope the object off its impact course

Works best on comets or water-bearing asteroids



Yarkovsky Effect



- A spinning body is hottest on its afternoon side including the Earth!
- The release of infrared heat radiation slightly pushes on the asteroid, changing its orbit

Using the Yarkovsky Effect

If we change the asteroid's reflectivity (color)

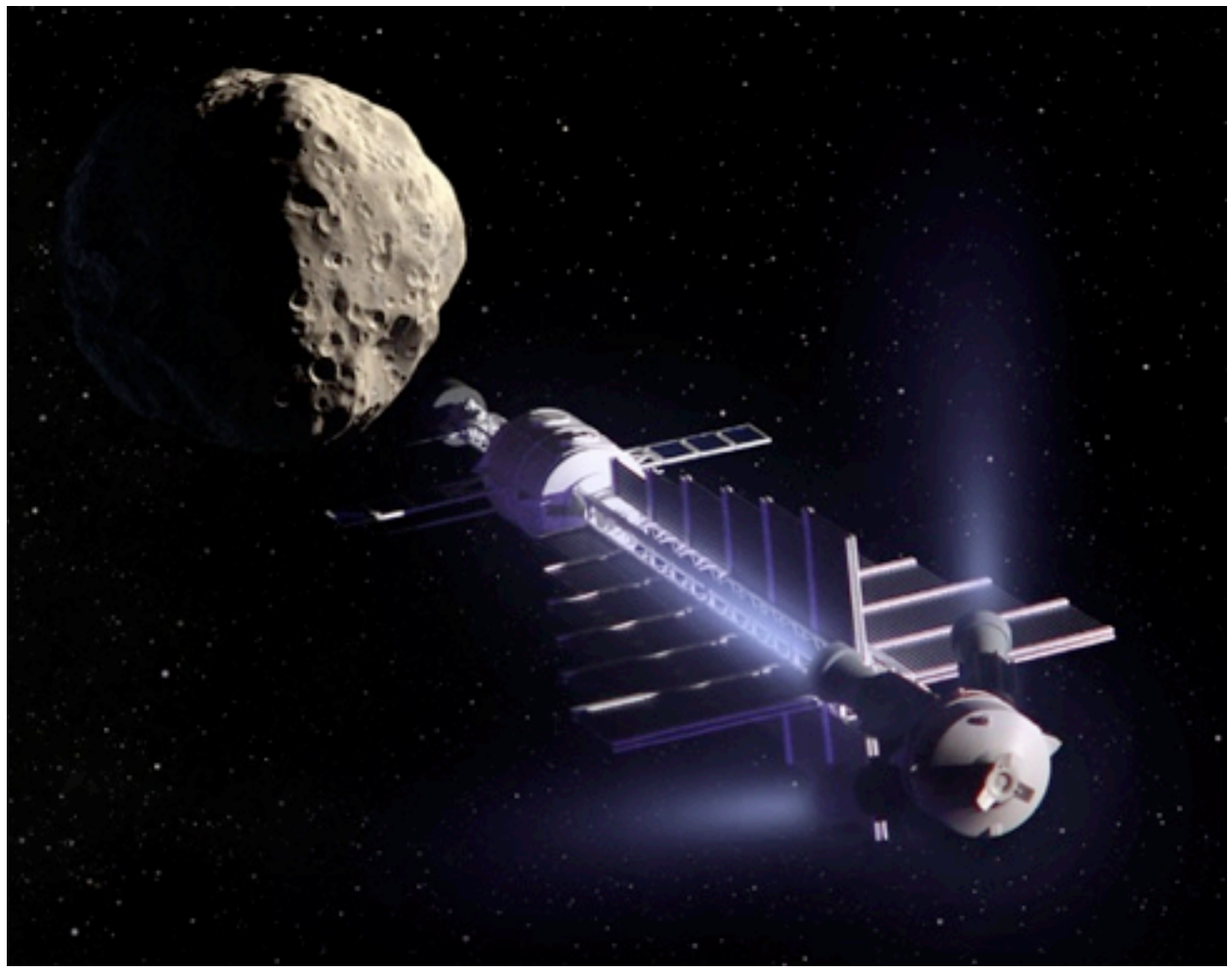
- then we change its ability to absorb heat
- and so we change its Yarkovsky drift

Change reflectivity by

- Deep Impact-type mission excavates brighter ejecta to the surface
- Paint the surface white!

Spraying white paint onto the side of an asteroid can alter its trajectory!

Gravity Tractor

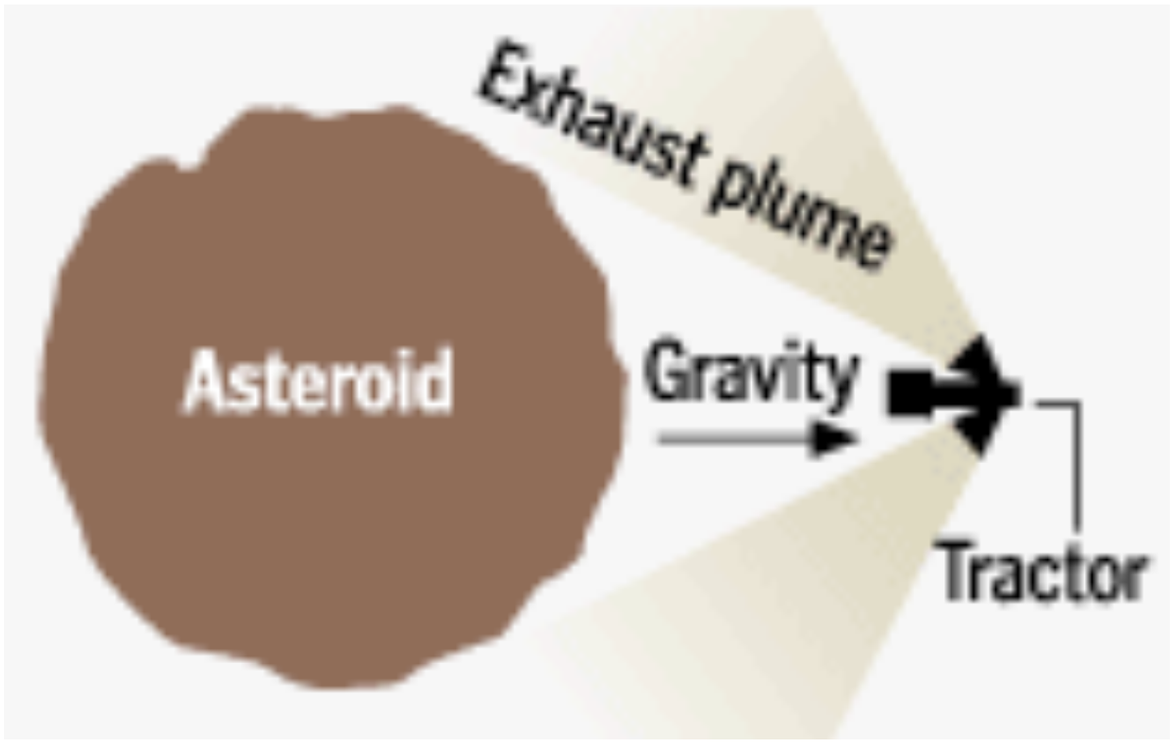


Park a large spacecraft close to the asteroid

- each object exerts equal and opposite gravity force on the other

Fire spacecraft engines for months (or more) - long continuous thrust

Aim engines so thrust doesn't hit the asteroid!



Gravity Tractor: The most elegant technique

Gravity acts as a towline connecting the asteroid/ comet and spacecraft

The method is slow

But unaffected by object composition or spin rate

Also allows precise control of object trajectory

i>clicker question

We do know of an asteroid that has a 1 in 300 chance of hitting us in 2880. What should we do?

A. Blow it up into smaller pieces that will dissipate over the next 800 years.
B. Send a Deep Impact-style spacecraft to impact the asteroid.
C. Coat it in white paint as soon as possible.
D. Construct a giant laser on the Moon (e.g. Alan Parsons Project) to deflect the asteroid.
E. Nothing; we can't reliably predict asteroid orbits more than ~20 years in advance.

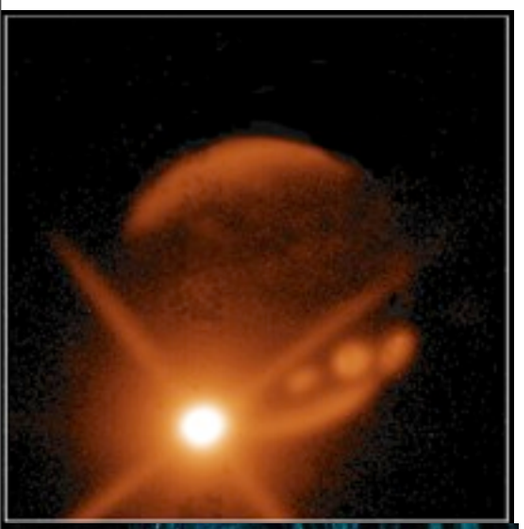
Early Detection is Key

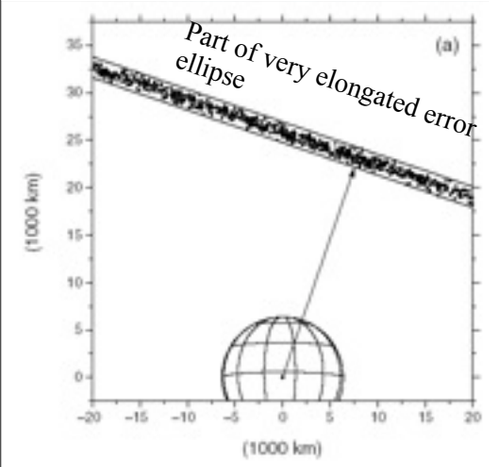
The earlier we can detect a threat, the easier it is to mitigate the danger

A very small change in an object's velocity can make a huge difference over long periods of time

An example of detecting the impactor too late!

Common Misperceptions





- Long waiting time until next impact
  - Instead, we should think of <u>chances</u> 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 <u>all</u> 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: <u>not intuitive</u>!

Asteroids are Not Likely to Destroy our World…


Alabama, 1954

…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 <u>are</u> 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!


(Pat Rawlings, SAIC)


Asteroid Itokawa


Arecibo radar

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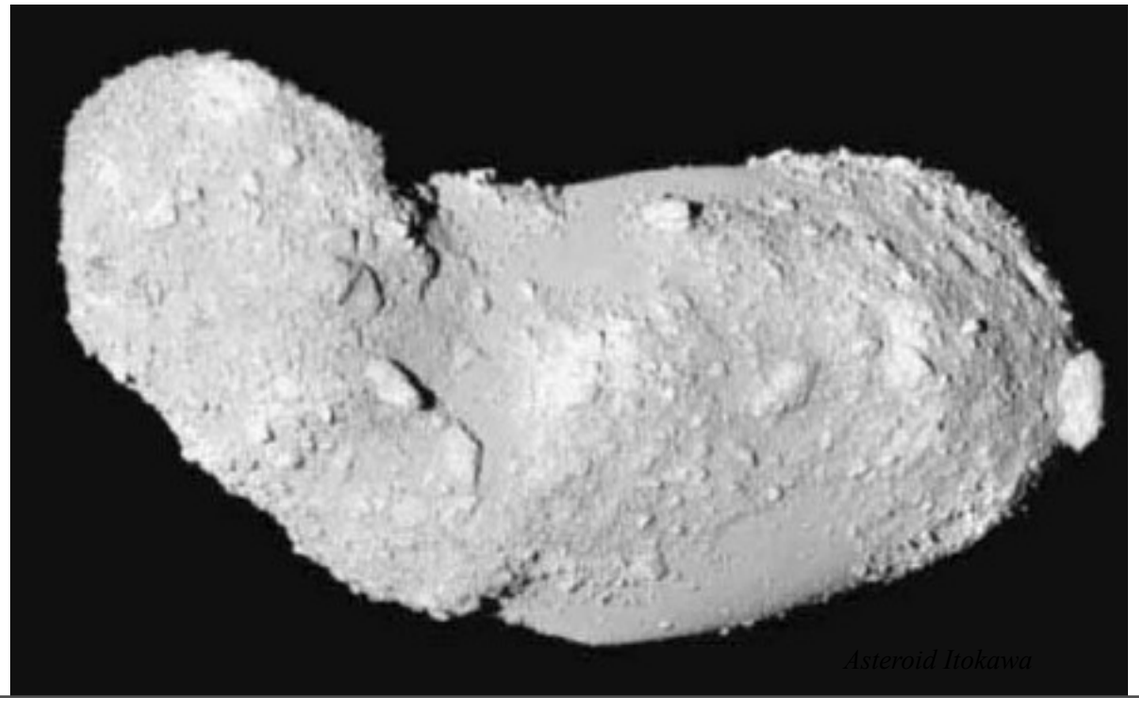
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Arecibo radar

Imagine

Imagine

Walking to class next week, you notice that you suddenly have two shadows.

You turn quickly, and it looks like there are two Suns, but one of them is moving toward the horizon!

Very Fast!

As it meets the horizon, there is a incredible bright flash, and you can feel the heat!


Imagine

Imagine

An earthquake throws you to the ground, and you get a little worried as you notice that the trees in the distance have burst into flames.

A sound wave bears down on you at 700 mph!

Like a mighty thunderclap, it sweeps over you, pulverizing all the nearby buildings…

As your body disintegrates, you wonder what Brian was going to lecture on today.

Asteroids are the number one astronomical threat, but not the only one!

Imagine

Imagine

After being dropped into suspended animation in a Pizza accident a billion years ago, you awake to a crazy new world.

Disregarding the signs warning people to stay underground, you wander outside and see that the Sun is only about 10% more luminous, but it is crazy hot and the oceans are nearly gone.

As you quickly succumb to heat stroke, you wonder what Brian said about Solar Evolution so many years ago.

Imagine

After being transported forward in time after a freak cellphone accident six billion years ago, you awake to a crazy new world.

The Sun is Red? And super hot.

The entire Earth's surface is molten rock during the day, slightly cooling at night.

As you burn in pain, you wonder what Brian said about Solar Evolution so many years ago.

Top 10 Ways Astronomy Can Kill you or your Descendents

2. Solar Evolution!

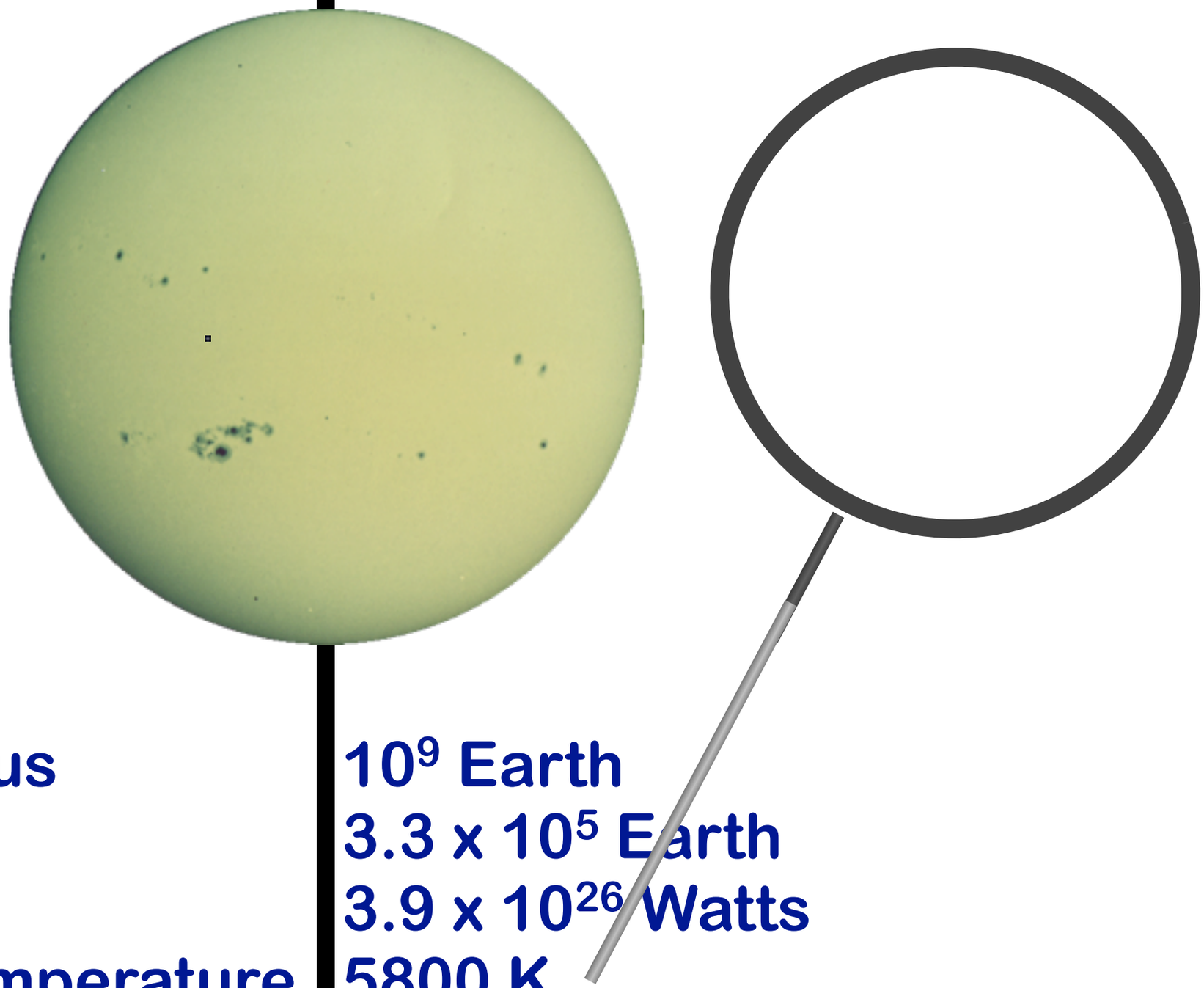
The Sun seems eternal, but it is changing. It has already changed quite a bit, and it will end!

I mean rock impact may never happen, but this is going to happen.

The Sun will become a Red Giant, then a White Dwarf, and the party stops!

http://www.youtube.com/watch?v=Q-jsJF09AHA

Earth-Sun Comparison



Visual radius	10^9 Earth
Mass	3.3×10^5 Earth
Luminosity	3.9×10^{26} Watts
Surface temperature	5800 K
Central temperature	1.5×10^7 K
Rotation period	25 days

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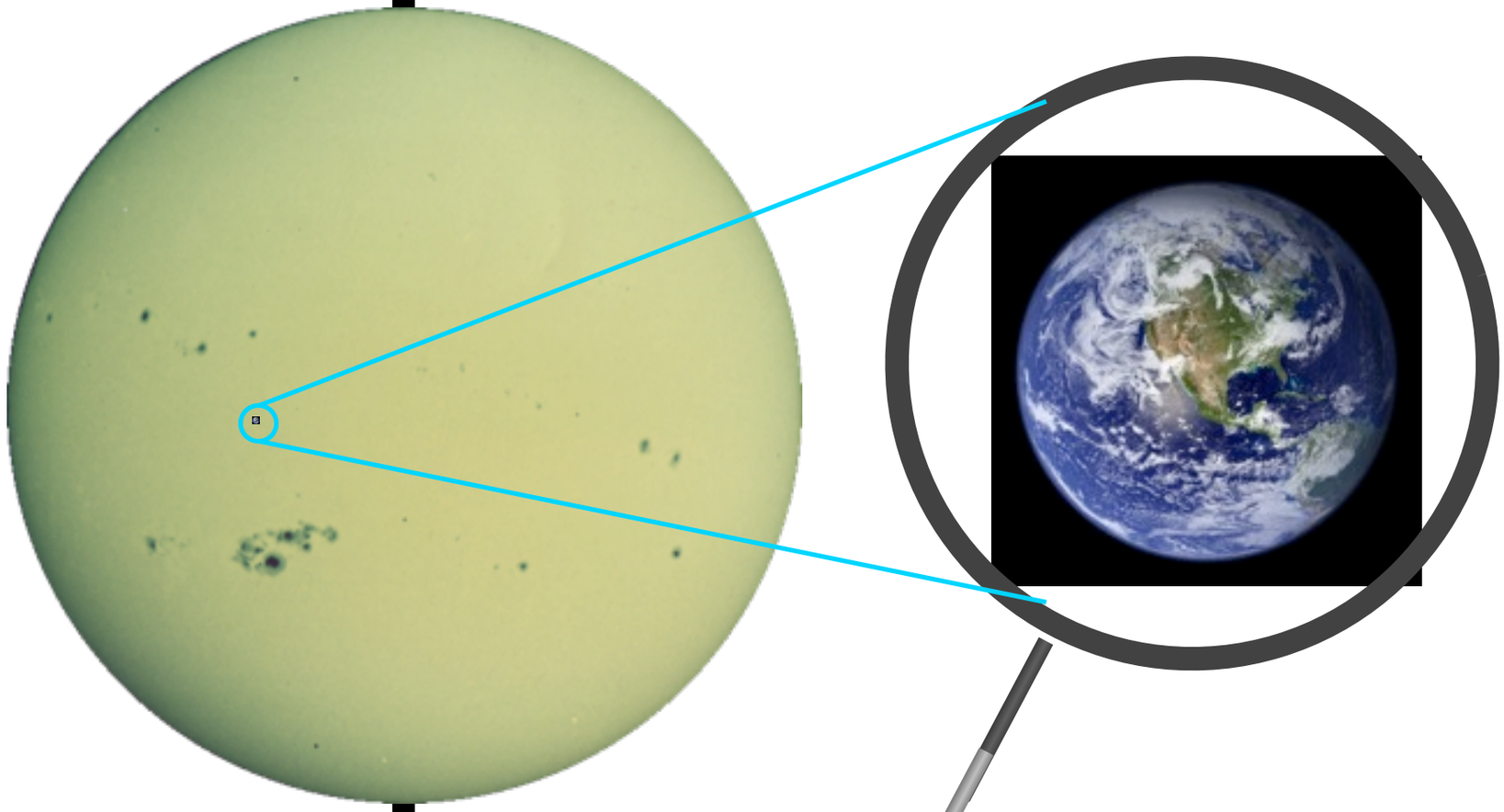

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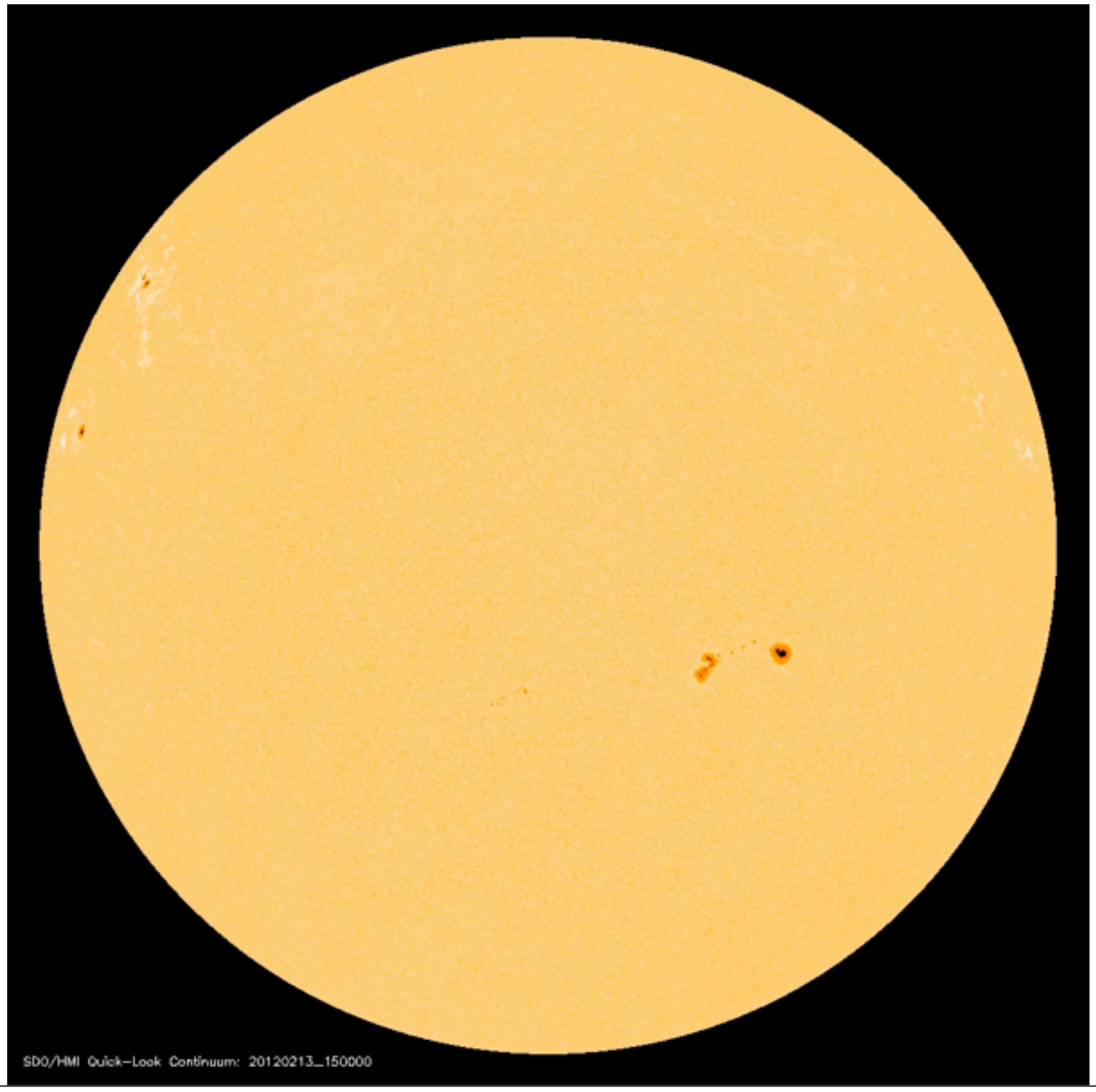
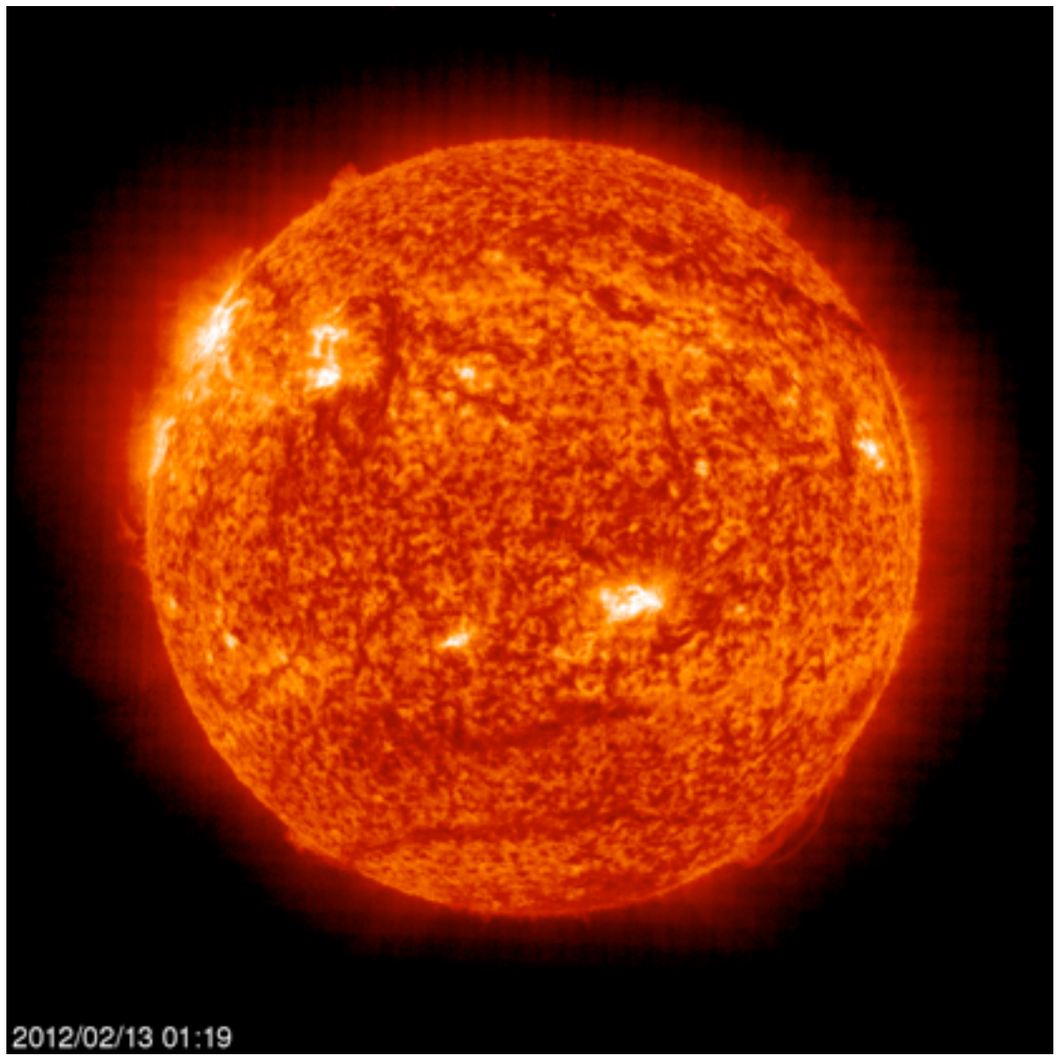
LIVE from the Sun

http://sohowww.nascom.nasa.gov/data/realtime/



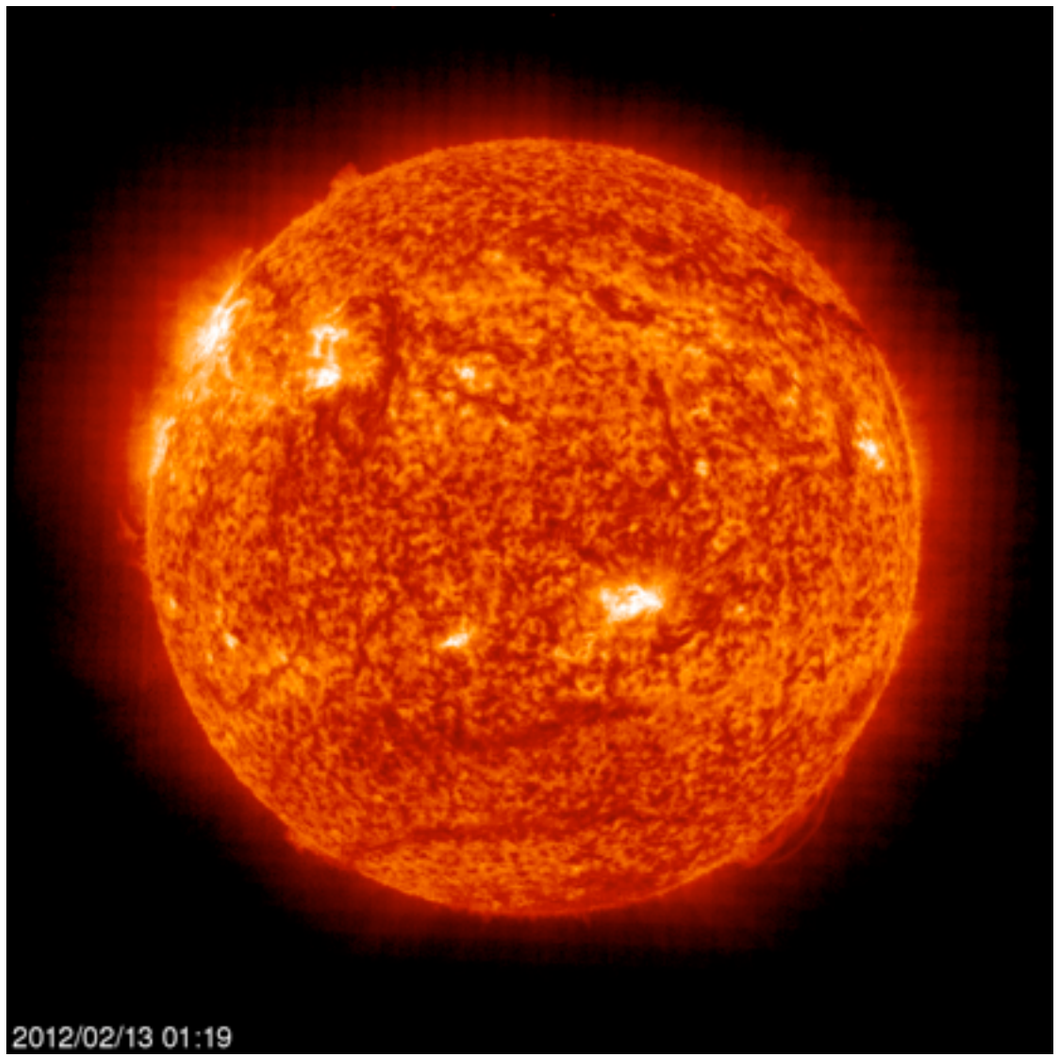
Question of Stability



http://sohowww.nascom.nasa.gov/data/realtime/eit_304/512/

Question of Stability

The Sun's size is constant.



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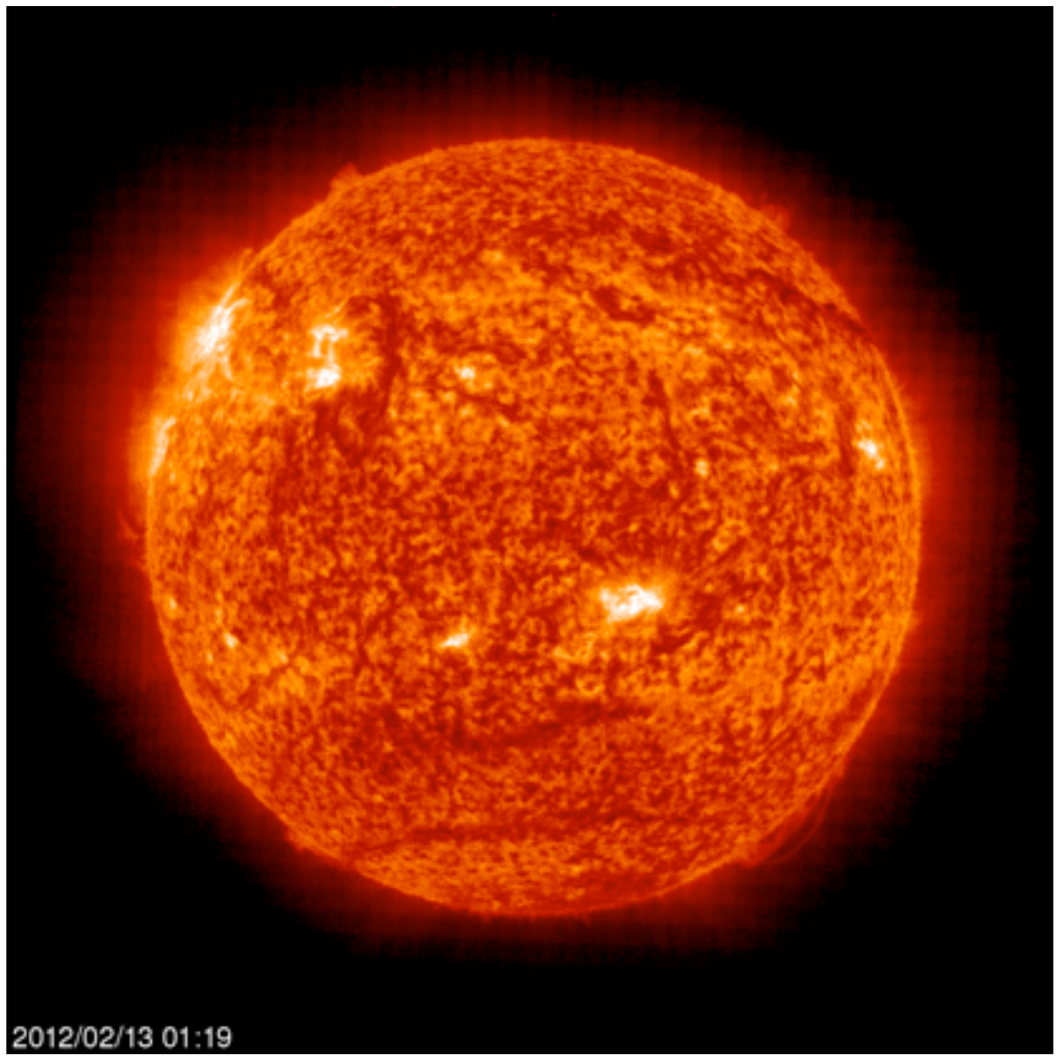
No weatherman says it will be especially hot tomorrow as the Sun's size will be increasing.



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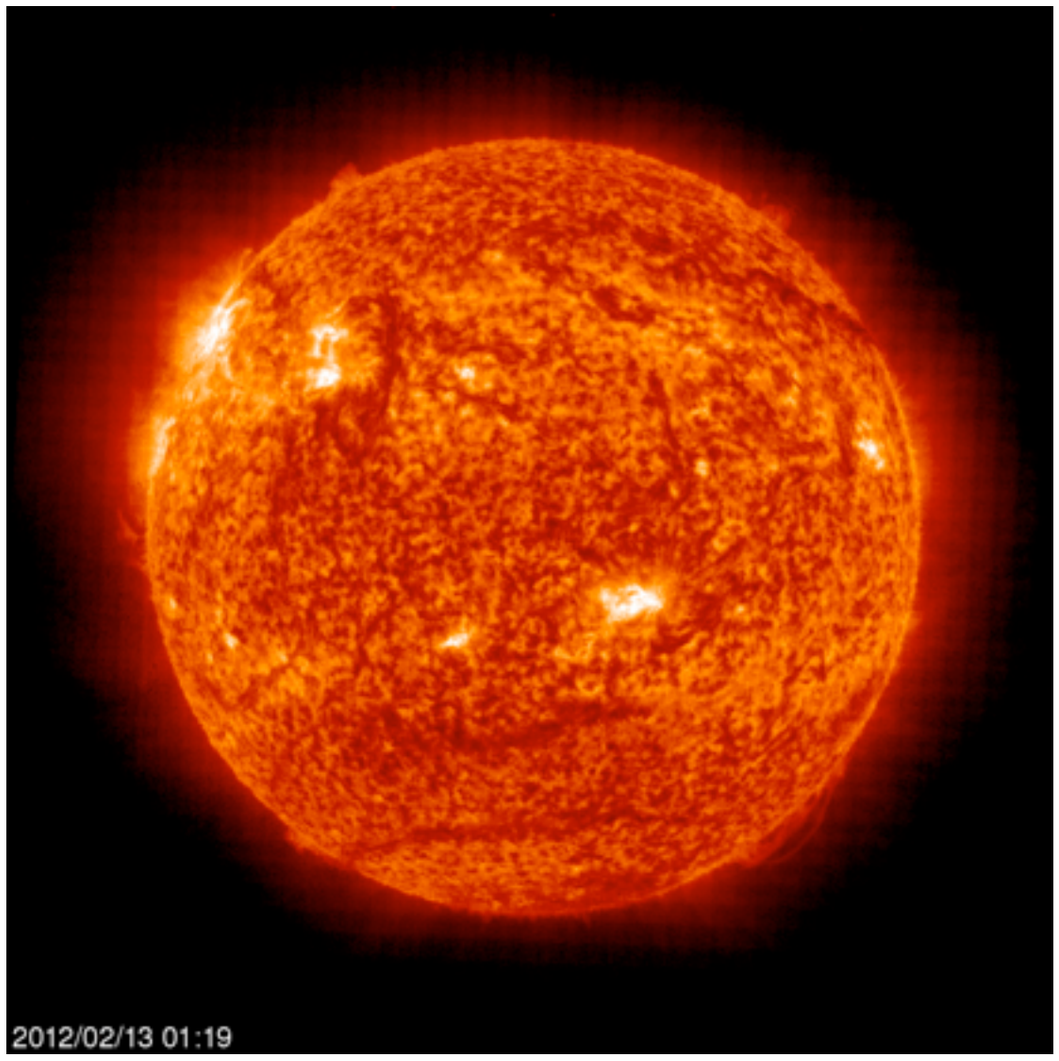

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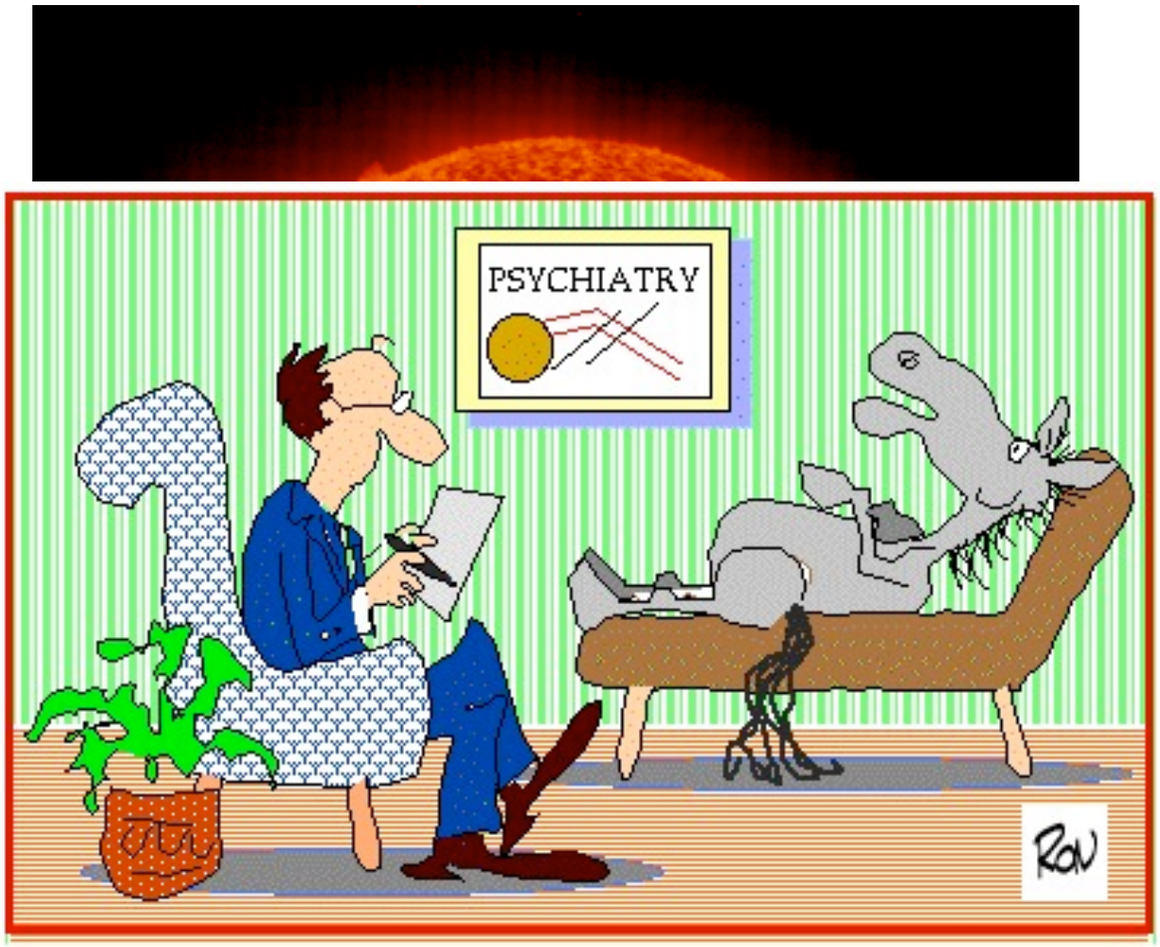
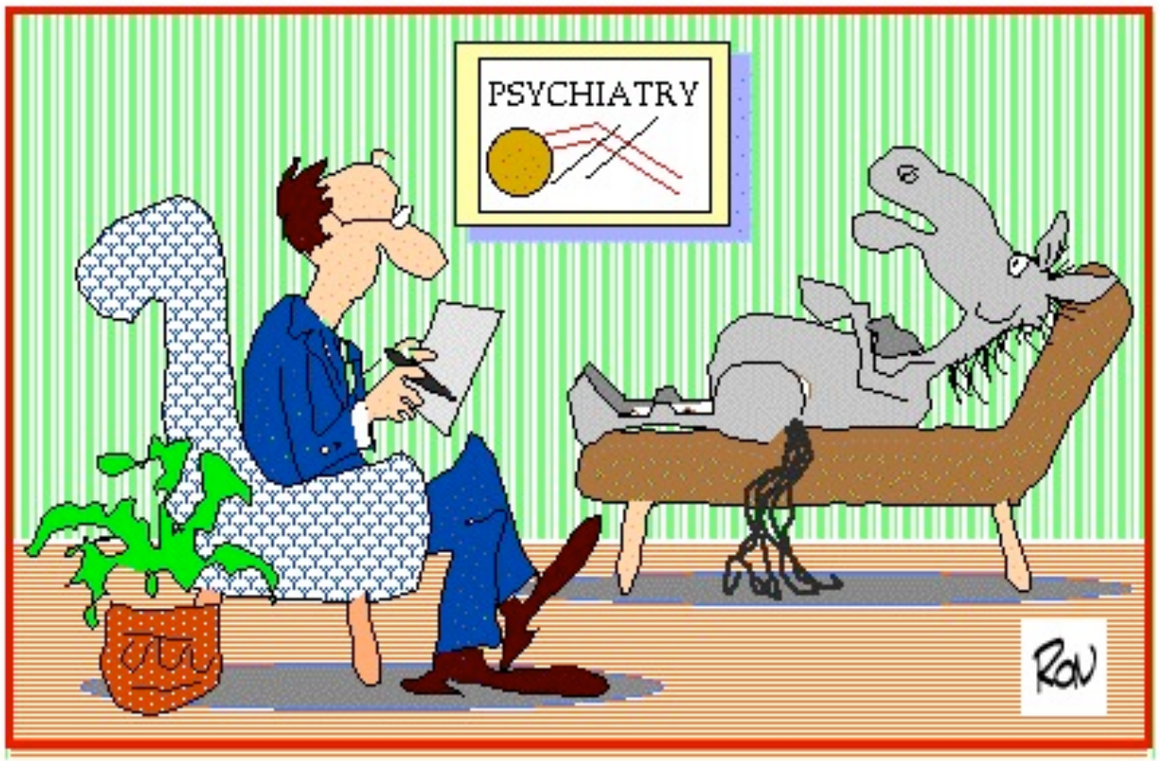
The Sun is stable! Why?



"I just don't feel stable."

http://www.londonstimes.us/toons/index_medical.html

Question of Stability



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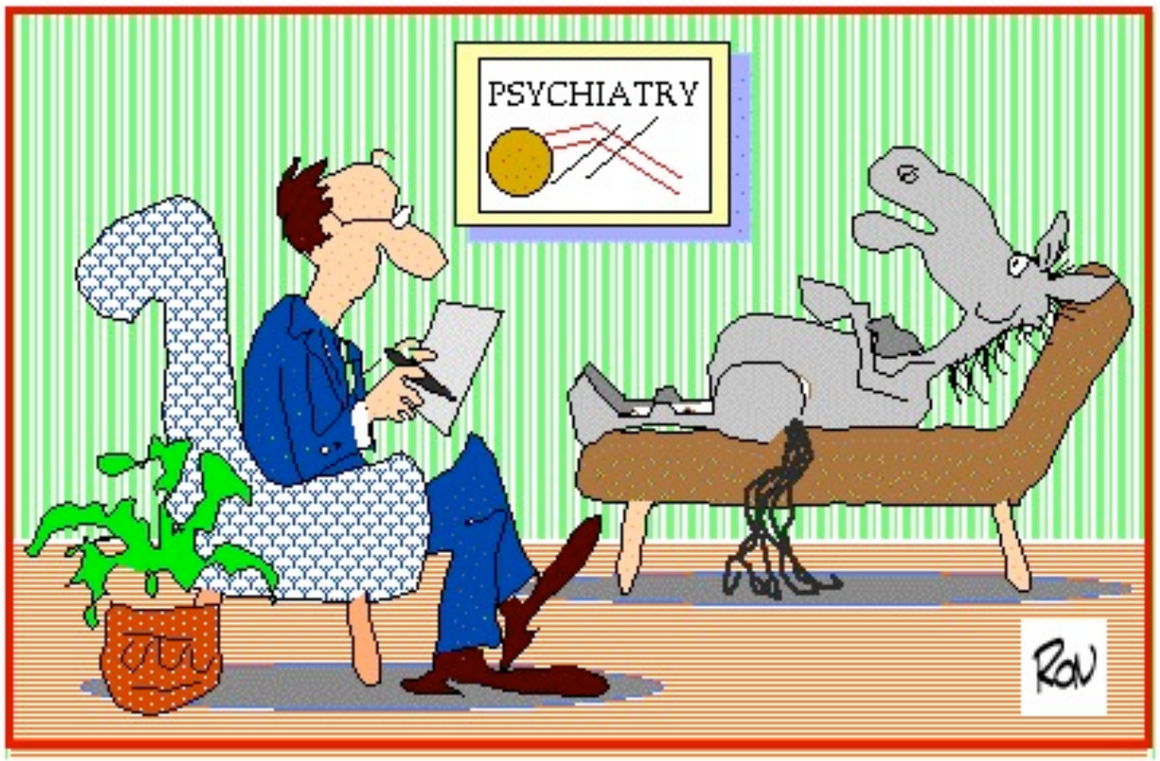
Question of Stability

Not trivial, could have gone the other way



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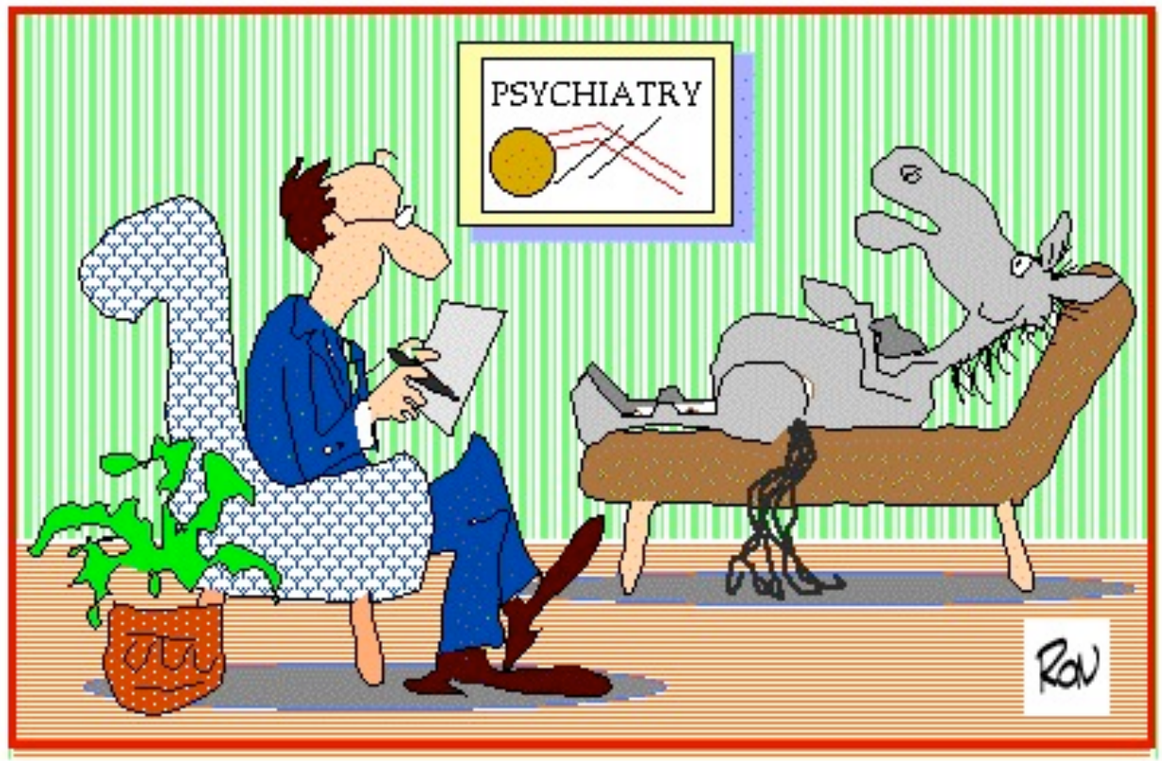
Think: Sun is made of gas, yet not like a cloud, for example, which is made of gas but size, shape changes all of the time



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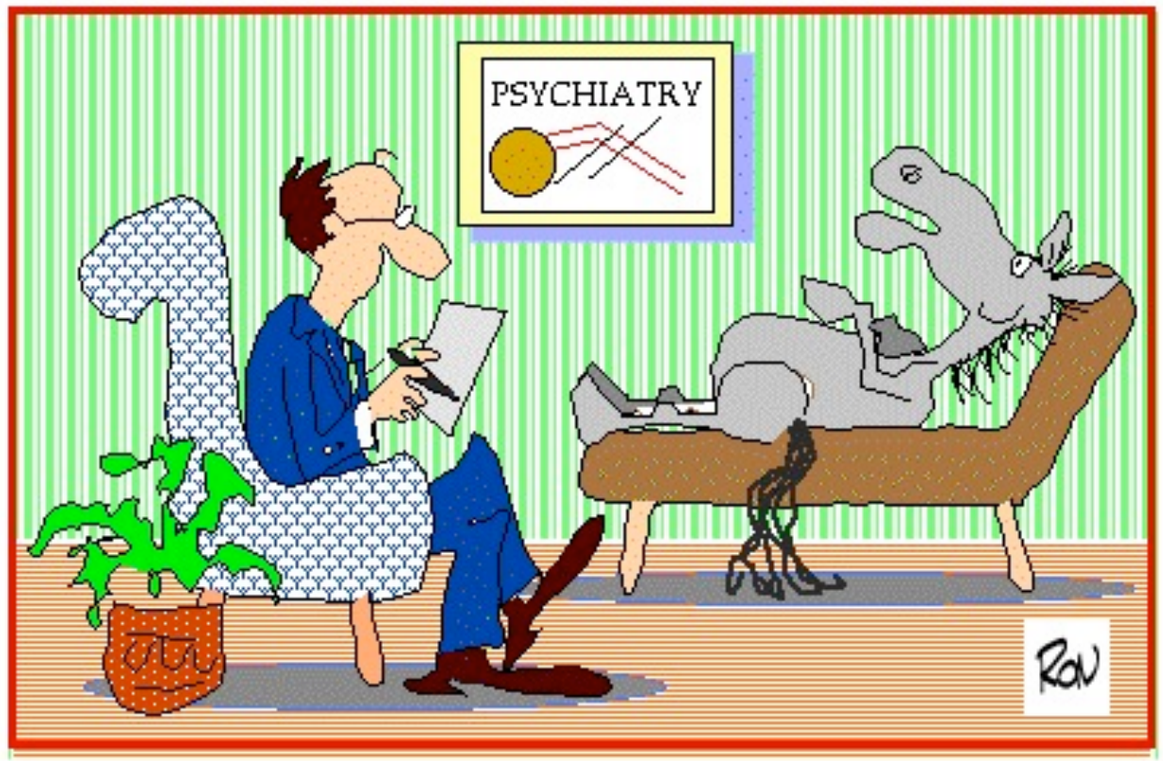
Not a coincidence: really good reason



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Why is the Sun Stable?

What keeps gravity from collapsing the Sun?

What keeps the Sun from exploding?