# Comets: Links to the Origins of our Solar System

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**Comets are among the most spectacular of Astrophysical phenomena.**

- *Only the Sun and Moon are brighter than comets can be.*
- *They appear seemingly at random and change in shape and brightness.*
- *The move rapidly across the sky.*

# Scientifically, comets live up to their popular reputation.

*Comets are a remnant of the early solar system and its formation*

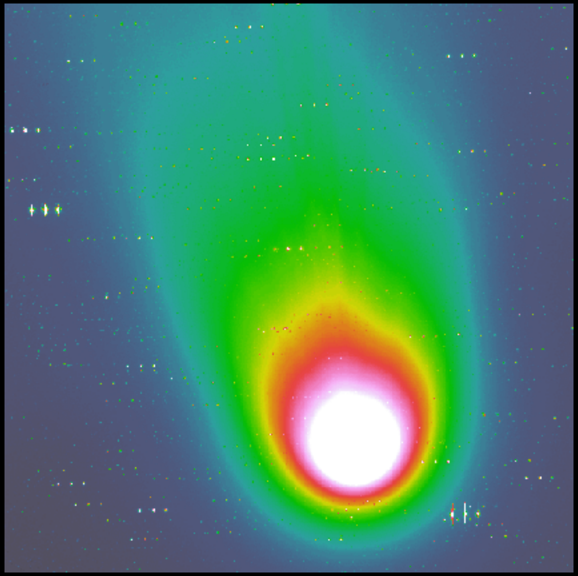
- *Comets are evolving astrophysical laboratories to study*
  - *The Galaxy*
  - *The Environment between the planets*
  - *The interaction of matter with sunlight*
- *Comets have played an important role in the development and evolution of life on Earth.*

**Today we are going to discuss some general questions about comets.**

*What are the different parts of a comet?*

- *Where do comets come from?*
- *How are comets important to our studies of the early solar system and galaxy?*
- *How are comets useful as astrophysical laboratories?*
- *What roles have comets played in popular culture?*

# What *ARE* Comets Anyway?



Most of use know the spectacular features we associate with the typical comet, including the large spherical gas cloud and the long sweeping tail.

***BUT***… That' s not the comet.

## Comets are really very small and very dark!

- A typical comet is a dark icy object only about 10 miles across.
- From our typical perspective on them, an object of that size would appear as large as a dime would on top of the capital building in Madison……if you were looking at it from *Downtown Milwaukee!!!!*
- So, if *that's* the comet, then what do we see?

The observable parts of a comet consist of 3 very different components that are defined by how comets are made and how evolve when they get close to the Sun.

## Question:

Why do we see comets as so much brighter than asteroids the same size?

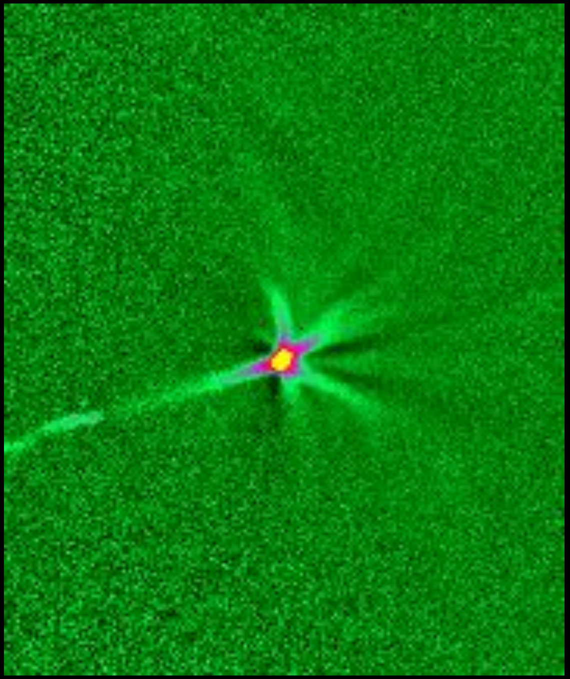
## Answer:

Because comets are made of *volatiles* (things that can evaporate)!

The most common volatile in comets is *water* (90%), but there are many other nasty compounds as well, including *carbon monoxide*, *cyanide*, *ammonia*, and *soot*. All of these melt off the *comet*, and *that's* what we see!

Outgassing from the nucleus can be diffuse across its surface.

Or tightly collimated into jets from active regions.



However it's produced, we call the cloud of neutral gas that surrounds the nucleus, *the coma*. (The first visible element of a comet)

How much gas is evaporated? A typical active comet will outgas 5000 gallons of water *every second!*

That's enough water to fill a small backyard swimming pool!

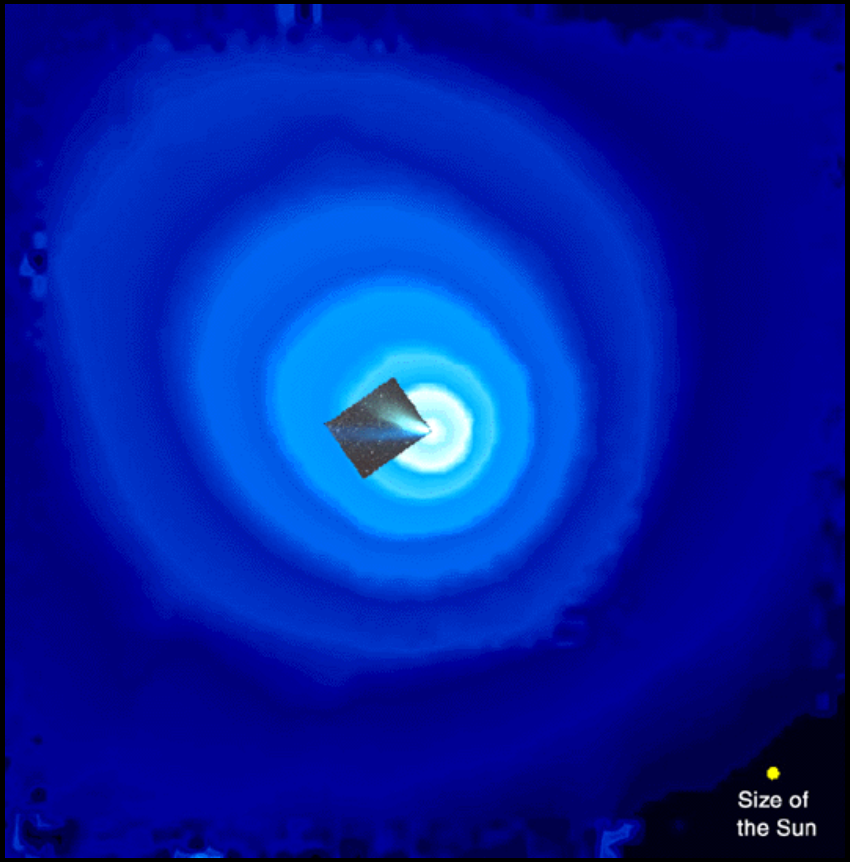
We are able to see the comet because the dust scatters sunlight and the gasses fluoresce in different colors.

This means that coma looks different, depending on what we look at.....

Dust CN + Dust CN

In some gas species the coma appears small, because they are destroyed by sunlight very quickly. Other species survive for a long time, and, when we look at them, the coma is *very* large.

Atomic Hydrogen is the most extended gas cloud in the coma. It can extend more than *10 million km* from the nucleus.



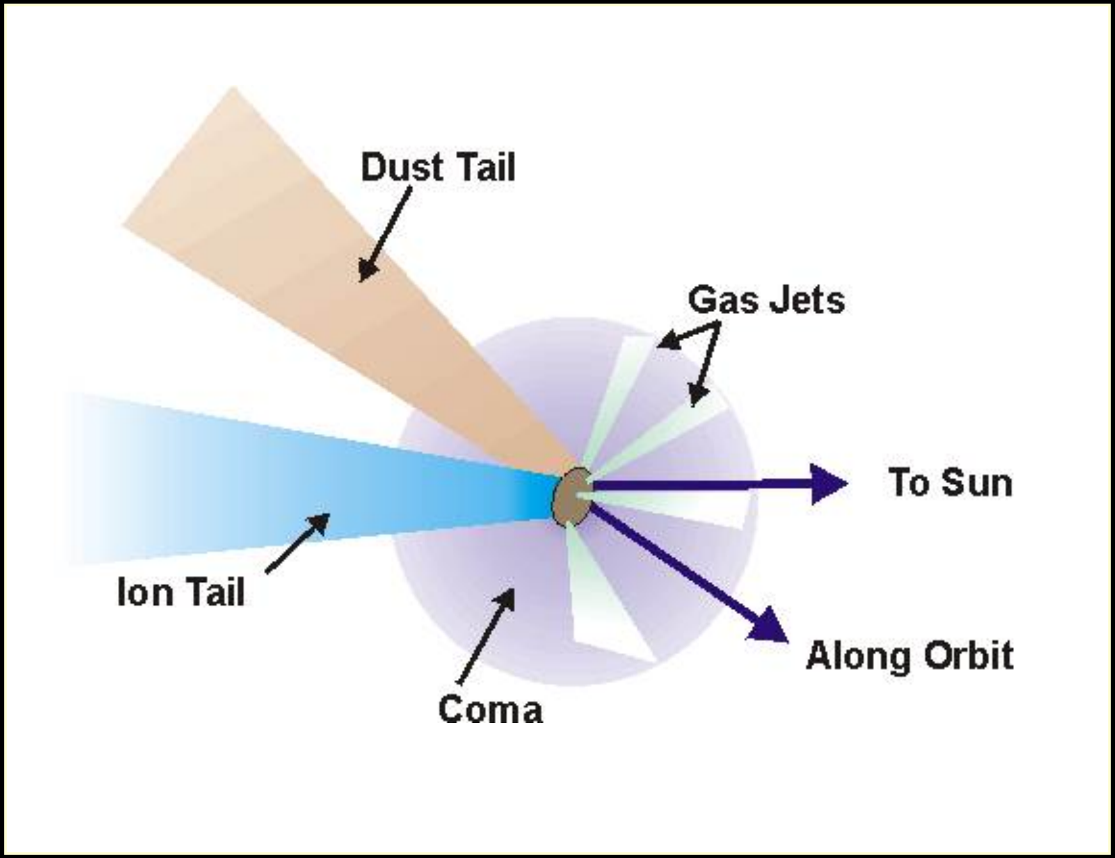
The *second visible element* of a comet is formed as a result of the interaction of sunlight and the gasses in the coma.

- Ultraviolet Sunlight will break apart molecules and in some cases strip electrons off to make ions.
- The ions are quickly attracted to a stream of charged particles from the Sun: *the Solar wind*.
- The solar wind and ions flow away to form the *ion tail*.

The final element of what we think of as a comet is formed from the trail of larger debris produced in the wake of the comet.

The larger pieces of the nucleus that break or are blown off tend to spread out along the line of the orbit. These pieces disintegrate and the small particles produced are blown backward by radiation pressure to form *the dust tail*.

The extent of the dust tail depends somewhat on the cohesiveness of the nucleus. Under certain conditions (age, gravity) the entire nucleus can be processed into an extended dust tail. This ‘Kills’ the comet, but makes a spectacular show for a short time.




So finally we have all the parts we are used to seeing.

# Where do comets come From?

GET-WISE

It's pretty clear that no object made of ice could have formed or survived long near the orbit of the Earth……

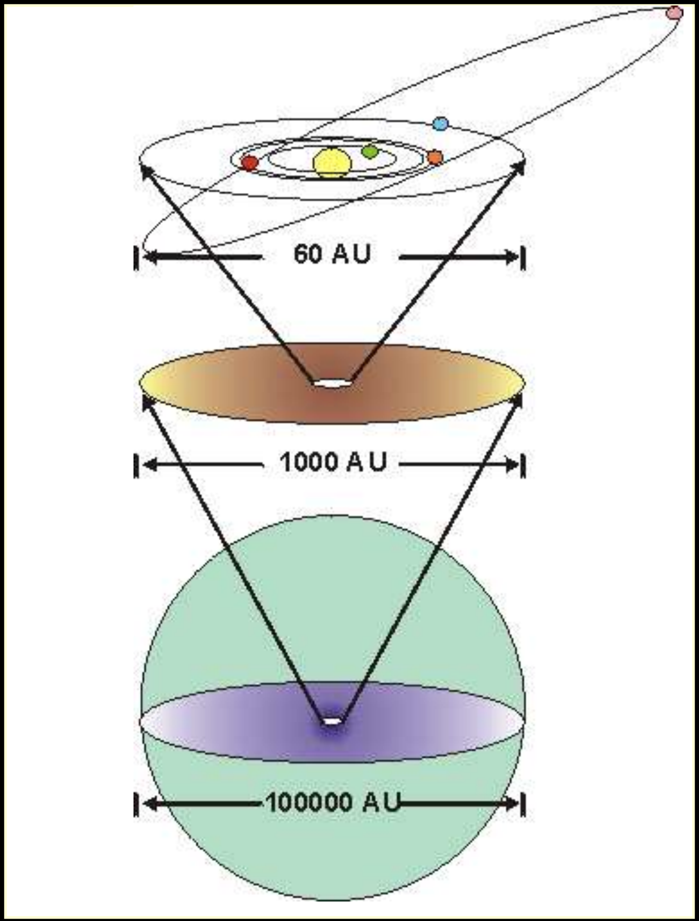
So where *did*

A quick inventory of the outer solar system shows us that comets have most in common with the moons of planets at or farther from the Sun than Jupiter.

**Planets**

**Kuiper Belt**

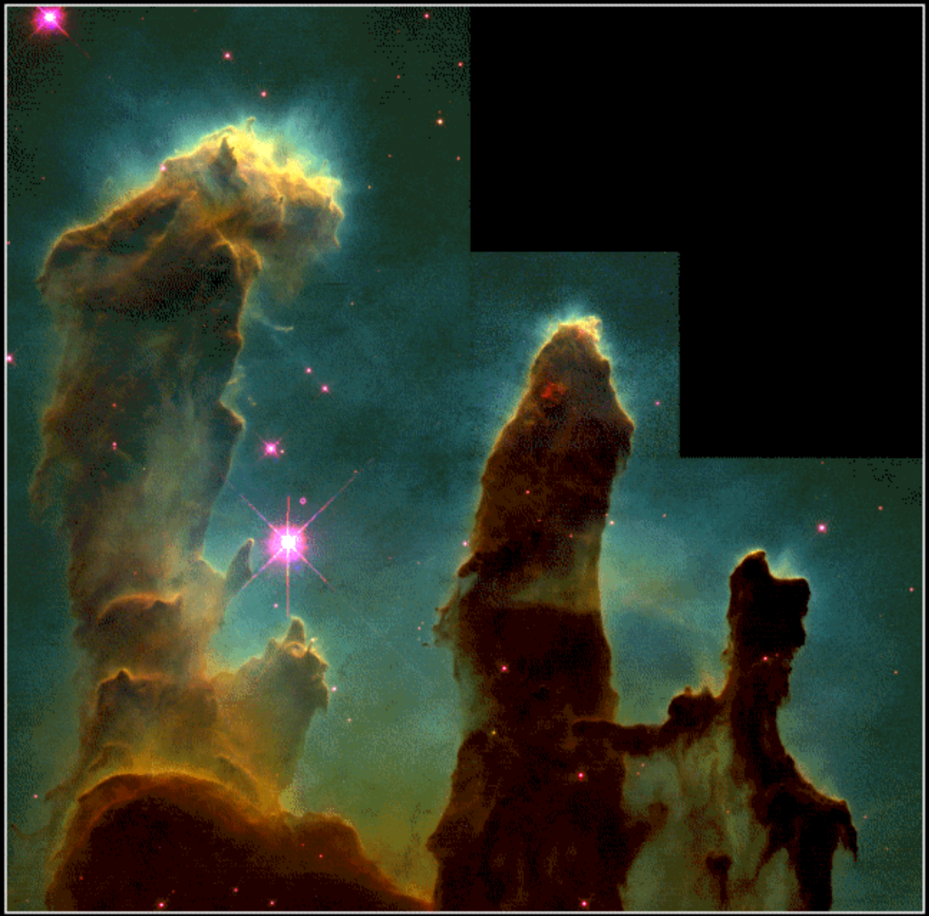
**Oort Cloud**




Actually we can do better than that.  We know that comets come from two areas, the Kuiper Belt and the Oort Cloud.

Of course, knowing where comets come from and knowing *how they got there* are two different things.

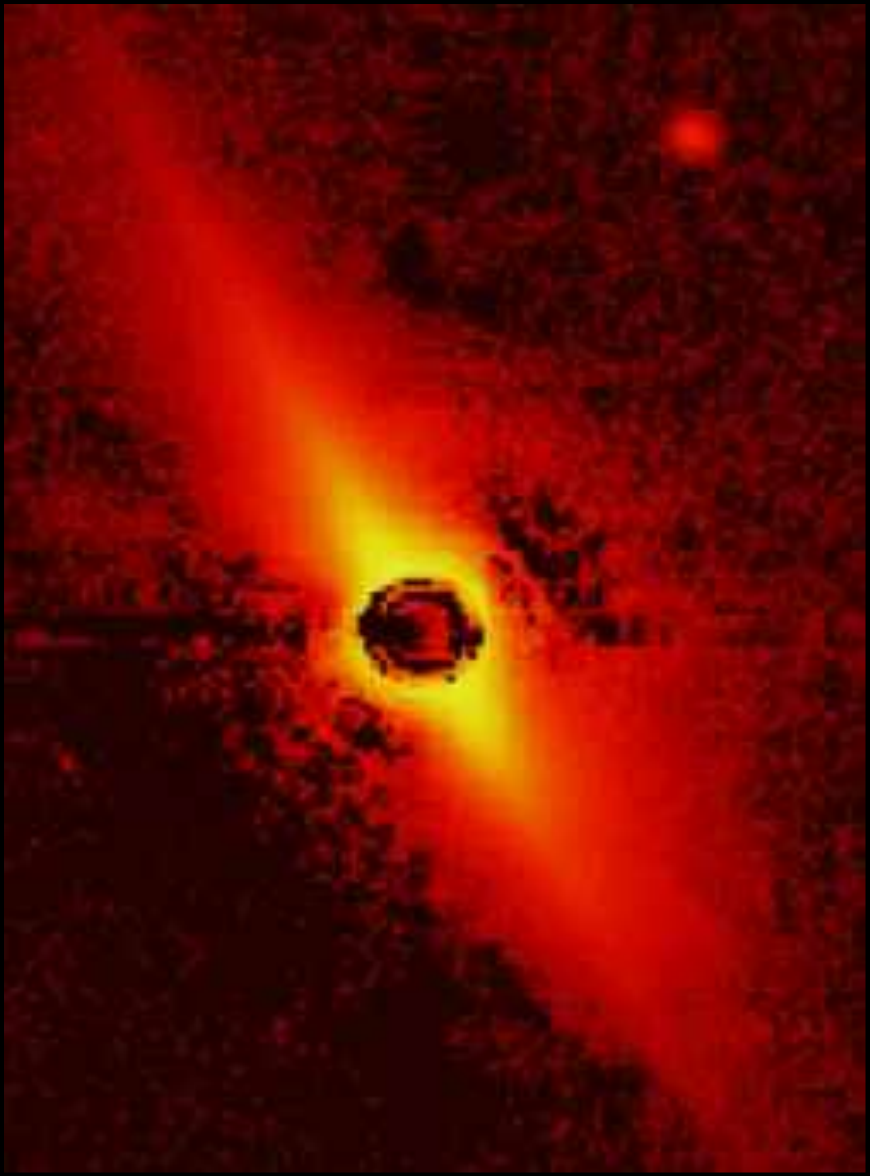
As it turns out, the answer is fundamental to how *everything* got here.  It has to do with the *formation of planetary systems*.



**Gaseous Pillars • M16** HST • WFPC2

PRC95-44a • ST ScI OPO • November 2, 1995
J. Hester and P. Scowen (AZ State Univ.), NASA

In the modern model of solar system formation, the Sun and planets all formed from a gigantic cloud of interstellar gas and dust.



Most of the material in the collapsing cloud went into the Sun, but a small amount of gas and dust collapsed down onto a *protoplanetary disk*.

Within the protoplanetary disk material begins to accumulate.

Like a snowball rolling downhill, small particles begin to increase in size as more material is accumulated.  Eventually, trillions of small bodies ranging in size from boulders to miniature planets have formed.

We call the smaller bodies *planetesimals*, and the larger ones *protoplanets*.

The Planetesimals took on different forms depending on how close to the early Sun they were produced.

- In the inner solar system, where conditions were too hot for ices to exist, the planetesimals are stony, solid, and contained relatively little mass.
- In the colder regions of the solar system, ices and gassed were abundant, and positively phenomenal numbers of planetesimals were produced.

Eventually, the planetesimals and protoplanets combined to make objects big enough to form their own accretion disks, and the major planets we know today were born.  The left over planetesimals are known today by more common terms.

- In the inner solar system there are *Asteroids* and *Minor Planets*.
- In the outer solar system there are the *Comets* and *Kuiper Belt Objects.*

But how did the comets and asteroids get to the specific places we find them today?

Once again, the planets are responsible.

As the planets became larger, they began to perturb the orbits of the remaining planetesimals. Some were in orbits that the planets did not affect, but others met one of *four fates*.

- **They were thrown in toward the Sun and lost.**
- **They were accreted onto the planets.**
- **They were deflected out of the solar system altogether.**
- **They were diverted to stable, but far more distant orbits.**

Following this ‘Dispersal Phase’, the small percentage of remaining planetesimals occupied only three regions of the solar system.

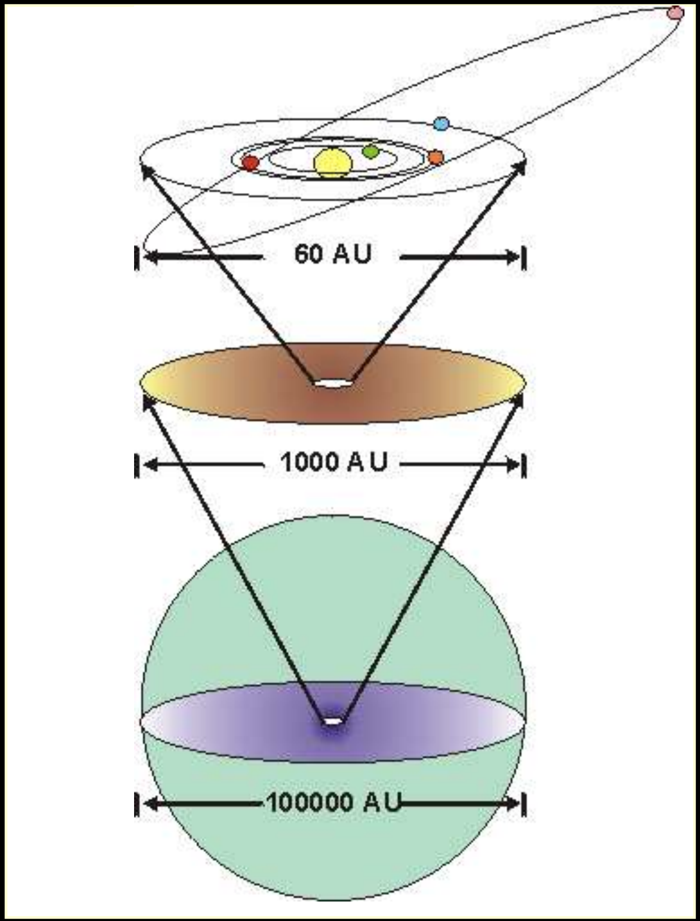
- The Asteroid Belt. (dynamically stable)
- The Kuiper Belt. (dynamically stable)
- The Oort Cloud. (deflected orbits)

This new information allows us to look at this earlier picture in a new light.  The Kuiper belt is really just the material that *never formed planets*. This region includes some very large members, including *Pluto*.

**Planets**

**Kuiper Belt**

**Oort Cloud**




The Oort cloud however consists of objects from the planet forming regions thrown into orbits so distant, that they are up to *20% of the way to the nearest star* away from the Sun!

An interesting irony of this is that the Oort cloud is actually made up of objects that originally formed *closer to the Sun* than the much nearer population of the Kuiper belt!

Question:

*"If all the remaining planetesimals are in stable orbits in the Oort cloud and Kuiper/Asteroid belts, then why do we still see comets in the inner solar system?"*

Well, in a relative sense, the answer is that we *don't* see them anymore.

Early in the solar system's history, there were far more comets in the inner solar system than there are today, perhaps *1000 Hale-Bopps* would have been present at any given time.

During this era, the Earth was struck by large objects roughly *once every century*, *100,000 times* more frequently than today.

Whereas comets *used* to be deflected into the inner solar system by the motion of the forming planets, today, they must do so via the *cosmic lottery*.

Even though comets are widely spaced, there are billions of them and occasionally 2 of them pass close by one another.

When this happens one gets flung out (this happens *a lot* doesn't it?), while another gets deflected in toward the Sun.

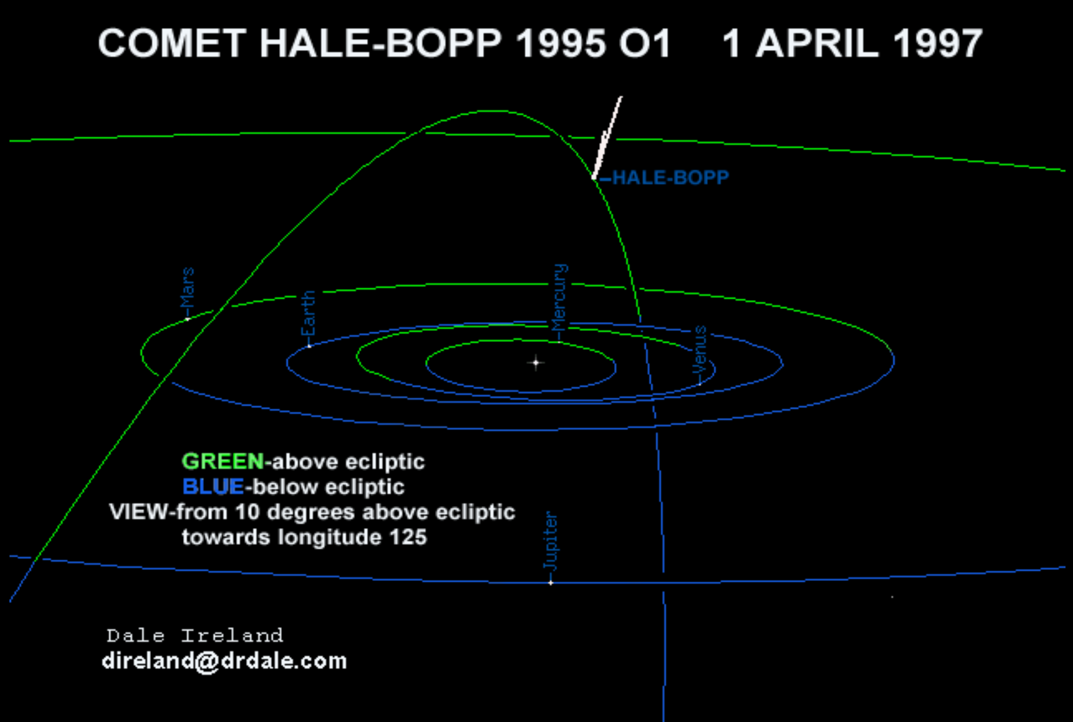
This second body becomes a visible comet.

Aside Question:

*"If so many comets are thrown out of forming star systems, how do we know if a new comet is from the Oort cloud or a passing visitor from another star system?"*

# Comet orbits:

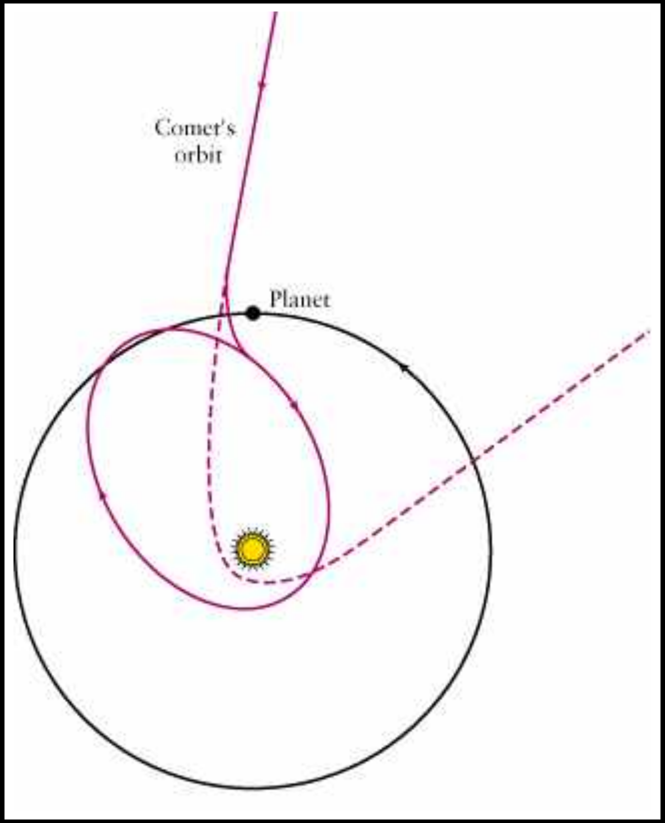
Once they are deflected into the solar system, comets follow a very distinctive elliptical orbit that takes it briefly near to the Sun followed by a long trek back out into the cold regions of the solar system, where it will spend nearly all of its time.




The comet orbit carries it across those of the planets, which increases the risk of a collision. Many times, however, the orbit is inclined to the ecliptic

# Orbit Evolution:

The longer a comet orbits the Sun, the more likely it is to interact with a planet that will perturb it again.




Comets affected this way are typically either lost (again!) or shunted to a smaller orbit. This accelerates their decay as they spend more time near the Sun. We call such comets *'Short' period*, and they include *1P/Halley*, the most famous comet of all.

There are more than 150 short period comets that we routinely track. Their periods range from several hundred years to as short as 3.3 years (*Comet Encke*). They are most important to us because *we can predict when they will appear*.

Short period comets will leave a well worn trail of dust in their orbit. Occasionally the Earth will pass through the tail of a short period comet, and we will be treated to a *"meteor shower"* of tiny dust grains. The *Leonid* and *Perseid* showers are the most famous of these.

# Why do we Study Comets?

By now we know

- The different parts of a comet
- Where they came from
- How they formed
- What their orbits and life cycles are like

So then, why do we need to continue studying them? In fact the reason is that they are among the most scientifically important objects, with many avenues of research to pursue.

# Comets are Time Machines:

Unlike every other object in the solar system (except the asteroids), comets retain a nearly *unmodified record* of the *composition*, *temperature*, and *density* of the cloud from which the planets formed.

By studying them we can gain insight into the processes that gave rise to the formation of the Sun and planets.

# Comets are Astrophysical Probes:

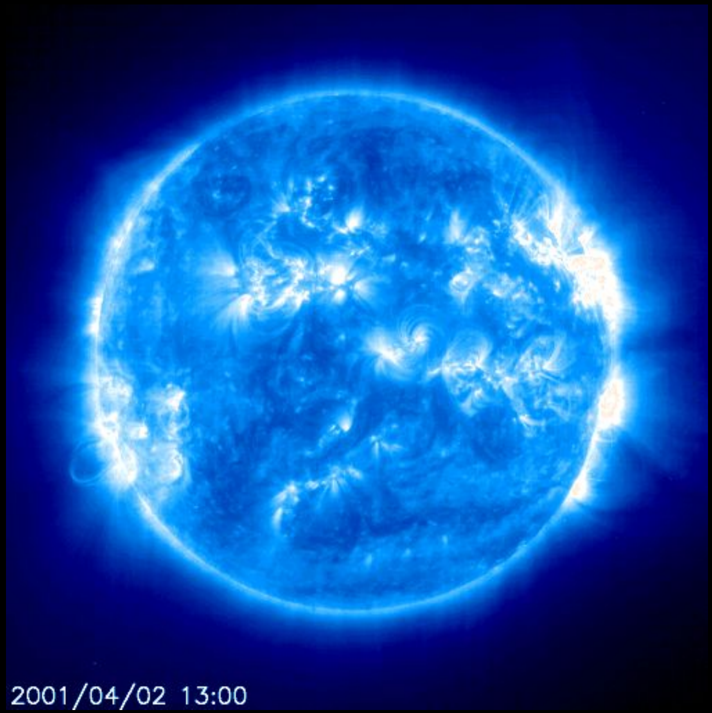
The solar system formed out of a part of the interstellar medium (ISM) that exits today in our galaxy and others.

As most astrophysical phenomena are, the ISM is remote and unchanging. This limits our perspective on it.

As a nearly unmodified remnant of an ancient ISM cloud, we attempt to use comets as a *proxy* for studies of the ISM. We are able to study dust and compositions under a range of changing circumstances. Missions like NASA's *Stardust* and *Contour* instruments seek to dissect the elements of a comet and unlock the secrets of the ISM.

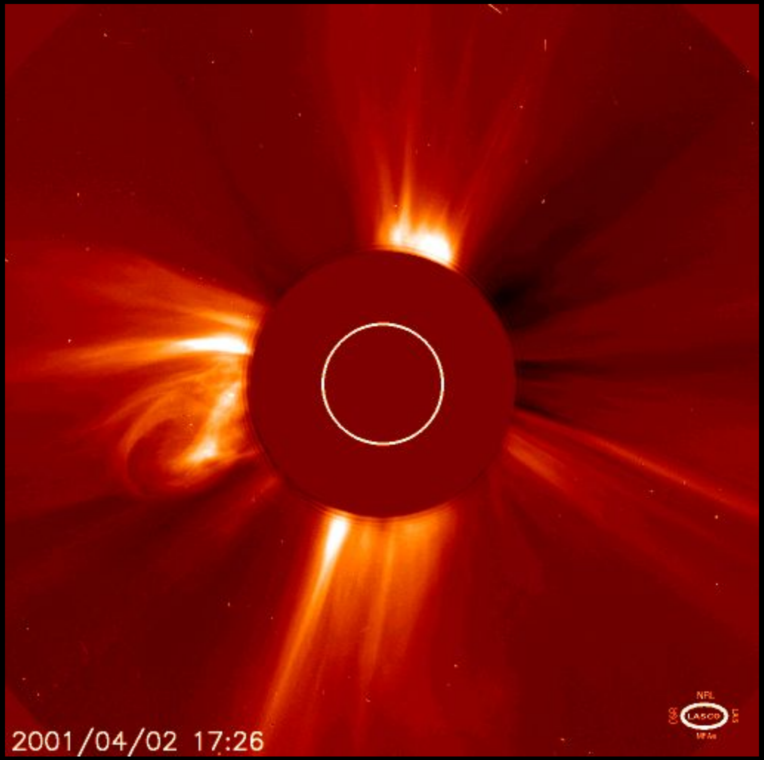
# Comets aid in the study of the Solar Wind and Radiation Field:

Observations of the neutral coma and ion tails of comets provides us with an opportunity to study the production of charged particles from the Sun and the energetic Solar radiation that is attenuated in the Earth's atmosphere.




Energetic UV and EUV photons from the Sun *drive chemistry* in our atmosphere and *pose a threat* to surface dwelling animals (especially in Ozone depleted areas).

From our basic knowledge of chemical processes, we are able to observe the photochemical evolution of the coma and *"back out"* the characteristics of the solar radiation field.




The characteristics of the solar wind have more to do with our lives than *just* providing the *Aurora Borealis* show.   In the are of advanced technology, the solar wind poses many potential problems.

In particular the Solar Wind:

- Heats and expands the atmosphere which drags on satellites.
- Causes particle storms that can damage spacecraft.
- Creates EM effects in the atmosphere that affect communications.


Through observations of the comet ion tail we can get information about the *density and velocity of the solar wind* that is hard to obtain with existing spacecraft.

Comets also move so quickly through the solar system. They can give us a perspective on many different parts of the solar wind in a short period of time

## Comets tell us about Ourselves:

While they didn't form near the orbit of the Earth and will be destroyed after a short period at our distance from the Sun, comets are nevertheless *an important part of why we are here today*.

Keeping in mind that the Earth formed out of rocky planetesimals, where did our oceans and atmosphere come from? *Comets?* Maybe…

During the dispersal period the Earth was perhaps impacted *more than 1,000,000 times* by large comets. That's enough water to have provided all the volatiles we needed for life to develop.

Scientists are divided about whether the evidence shows that comets provided the Earth with its oceans and atmosphere.  But there are some researches that attribute an even more expansive role to comets in the development of life.

Adherents of the concept of *"Panspermia"* hold that comets themselves *contain life*, and that they deliver that life to new environments.  Such a theory would suggest that life, if it exists elsewhere in the solar system, would be identical to ours, because they came from the *same source*.

# Comets Pose a Threat to us:

The history of our world is clear. Over its geologic time there have been periodic impacts that wiped out large fractions of the existing species and pushed evolution in a new direction.

The most famous of these was the impact that killed the dinosaurs 65 million years ago. It destroyed 70% of all species alive at that time.

# Catastrophe can come from many sources:

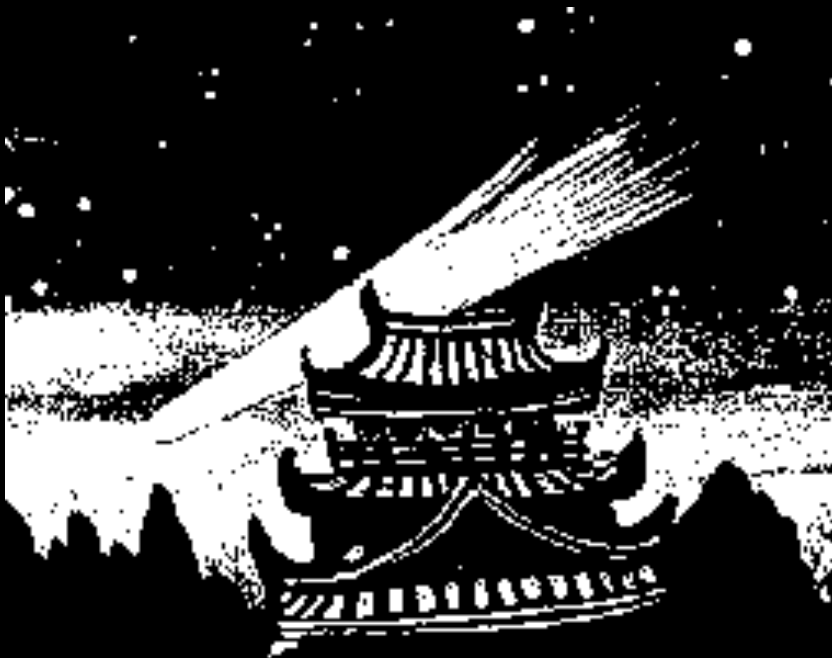
As terrifying as such impacts seem to be, we probably *owe our existence* to the dinosaur killer. It opened the door for mammals to become the dominant land animals.

It is likely that we will posses the technology to deflect a rogue comet within 100-200 years. This will make the world safe for *mankind*, but probably *not* save it from a comparable extinction event.

We are currently on a pace to wipe out as many species on our own over the next century as the dinosaur killing comet did. A chilling reminder of *the price of progress*.

# The Role of Comets in the Public Psyche:

Let's end on a somewhat lighter note by discussing the amusing history of how human civilization has responded to comets over its history.



Consider being a peasant living 1000 years ago and a comet appears in the sky… The justifiable concern you would feel is why comets have been up there with solar eclipses in importance over time.

Comets always seem to be present when something happens, is about to happen, or has just happened. That's why they get blamed for so many things.  Keep in mind though, civilization is a busy place.  On any given day there is ALWAYS something happening!

Comets have been “responsible” for everything from earthquakes to volcanic eruptions to plagues. Even the modern term describing the arrival of a comet, *“apparition”*, carries the paranormal history of these objects.

But we shouldn’t get too cocky about our modern scientifically governed approach to them. Despite knowing what we do about comets, we continue to make fools of ourselves when they appear.

# Recent Examples:

In 1910 the Earth passed through the tail of comet 1P/Halley. This was not long after the discovery of HCN (Cyanide) in the comet. Hysteria followed as people bought gas masks and "comet pills" to protect themselves.

In 1997 a group of religious fanatics committed suicide in the belief that comet Hale-Bopp was a divine sign.

Finally, we spend a great deal of time and effort worrying about impacts with comets, even though we are not paying attention to the fact that we are doing more environmental damage on our own than a comet impact would…..

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*Comments & Questions…*