Topics in Astrophysics

Dr Emma Whelan

Lecture 1: Our Solar System, Comets
Lecture 2:Star Formation, Searching for extra-solar planets
Lecture 3: Exobiology, The Drake Equation
Lecture 4:Supernova Remnants
Lecture 5: Black Holes
Lecture 6: Dark Matter

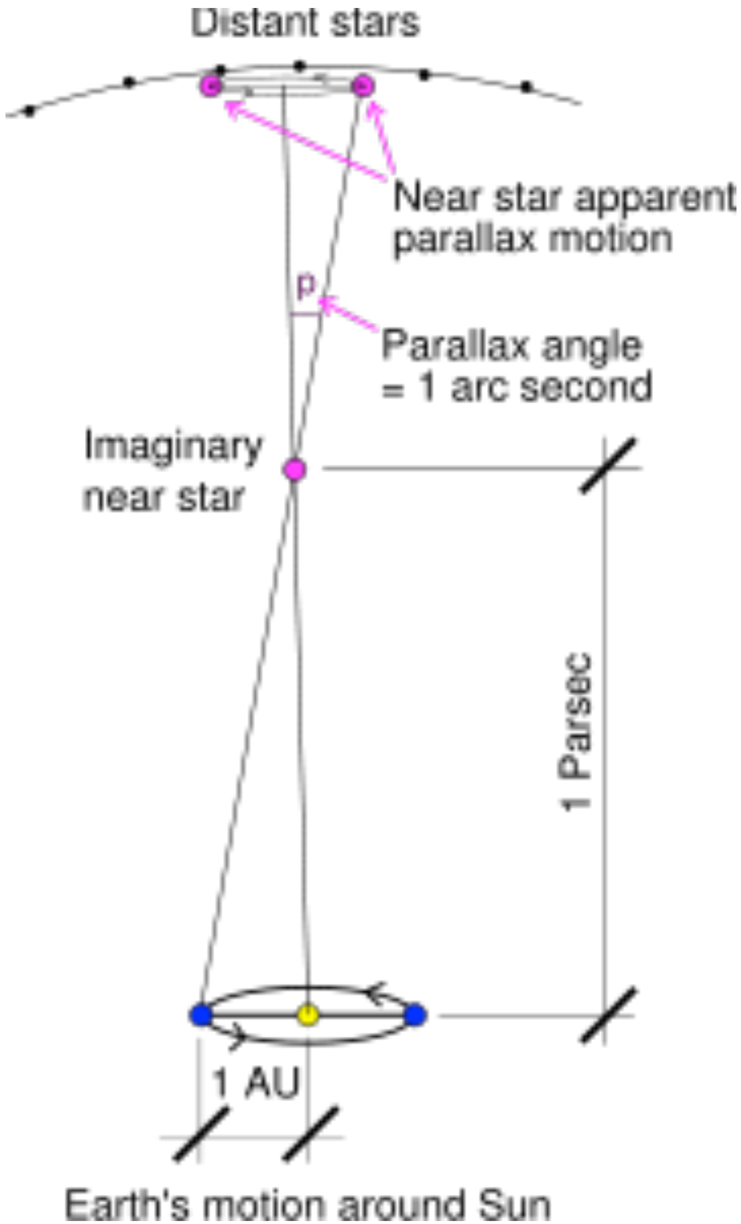
Some numbers explained

1 AU (Astronomical Unit) is approximately the distance from the Sun to the Earth and equals 1.49598×10^8 km

1 ly (Light Year) = The distance light travels in a vacuum in 1 year = 9.46×10^{12} km or 63,240 AU

1 Parsec =3.08×10^{13} km or 2.06265 x 105 AU

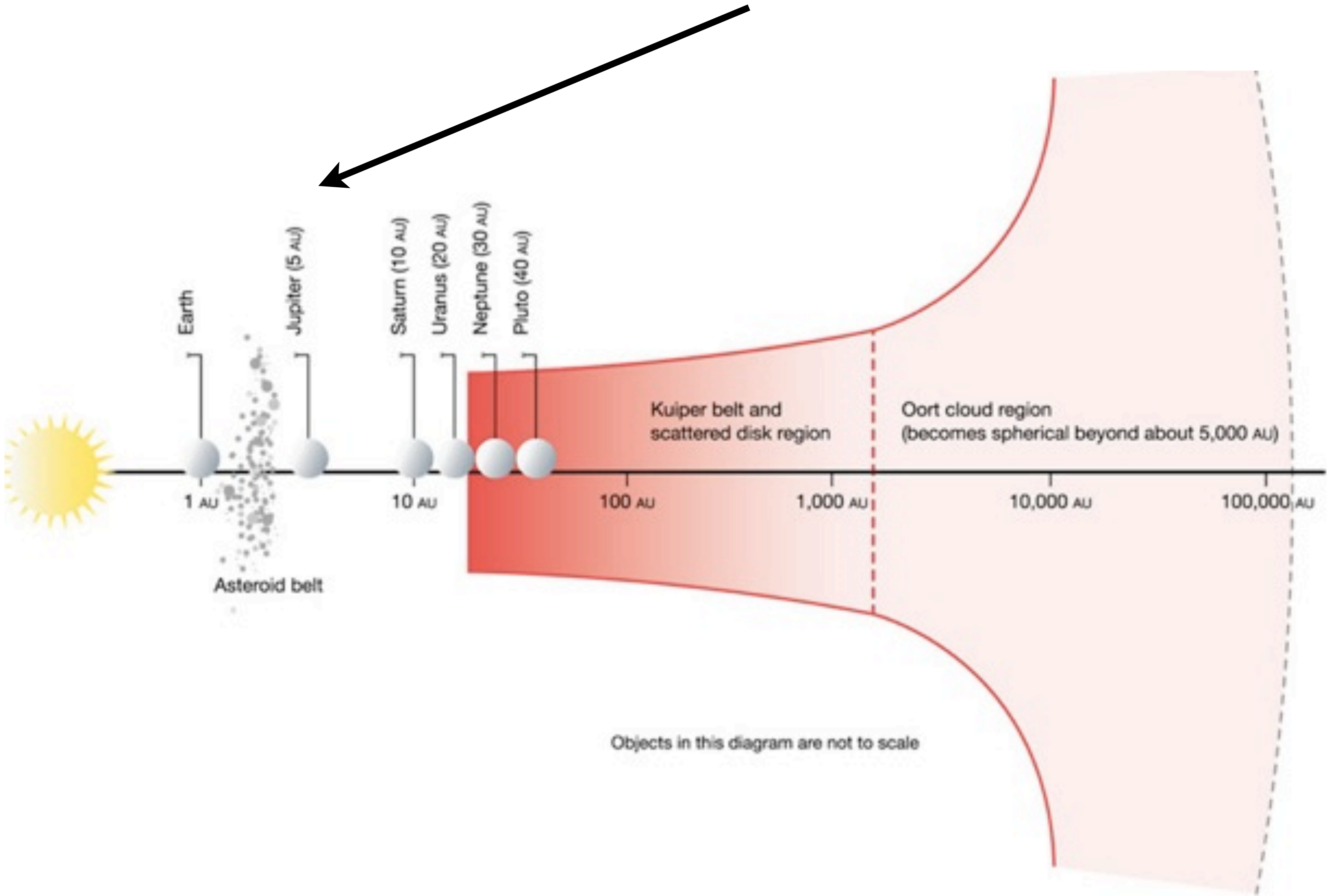
Parsec = Parallax second



Parallax in astronomical terms is the apparent shift of an astronomical object due to the motion of the earth it is measured in arcseconds

A parsec is the distance at which the semi-major axis of the Earths orbit would sub-tend an angle of 1 arcsecond

The Inner Solar System



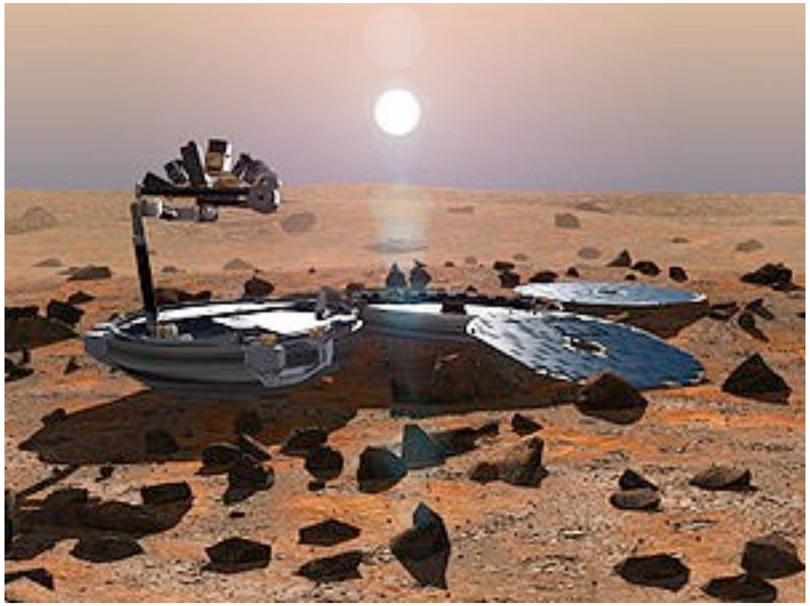
PHOENIX MARS MISSION

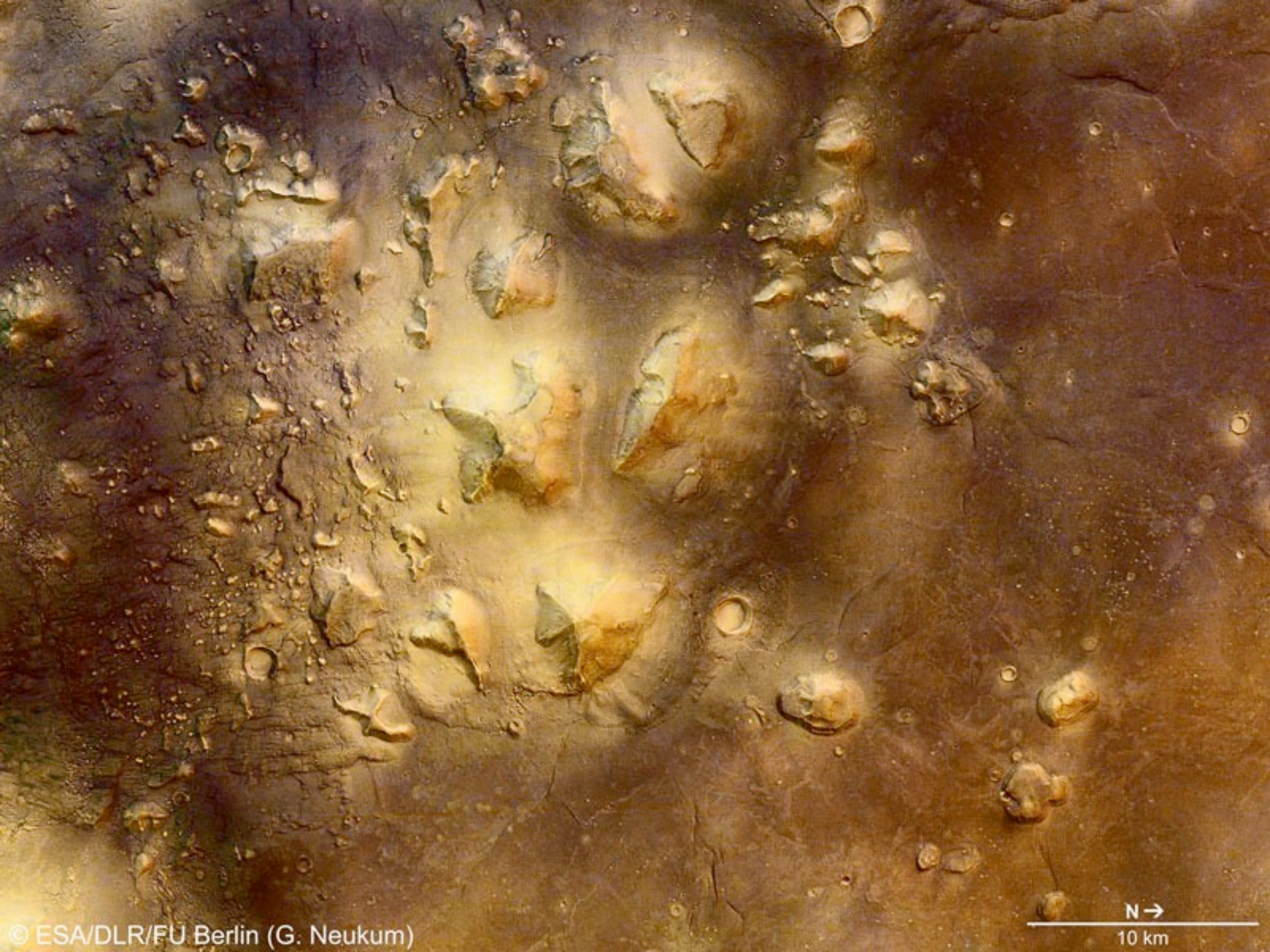
NASA

Some important missions to study planets

Mars Express — global view of the Red Planet, launched 2003, in orbit around Mars taking pictures of the atmosphere

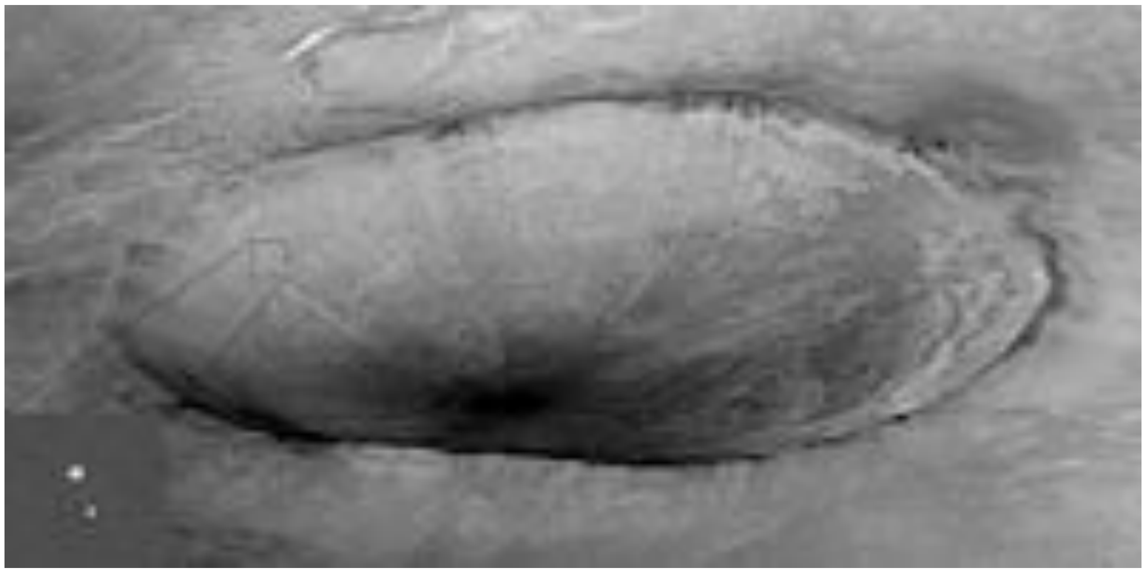
Mars Express consists of two parts, the *Mars Express Orbiter* and the *Beagle 2*, a lander designed to perform exobiology and geochemistry research. Although the lander failed to land safely on the Martian surface, the Orbiter has been successfully performing scientific measurements since early 2004, namely, high-resolution imaging and mineralogical mapping of the surface, radar sounding of the subsurface structure down to the permafrost, precise determination of the atmospheric circulation and composition, and study of the interaction of the atmosphere with the interplanetary medium.

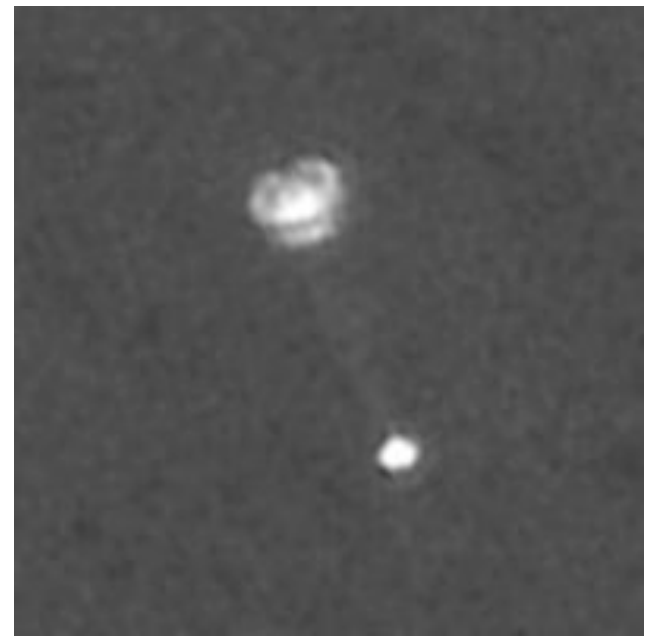



© ESA/DLR/FU Berlin (G. Neukum)
N →
10 km

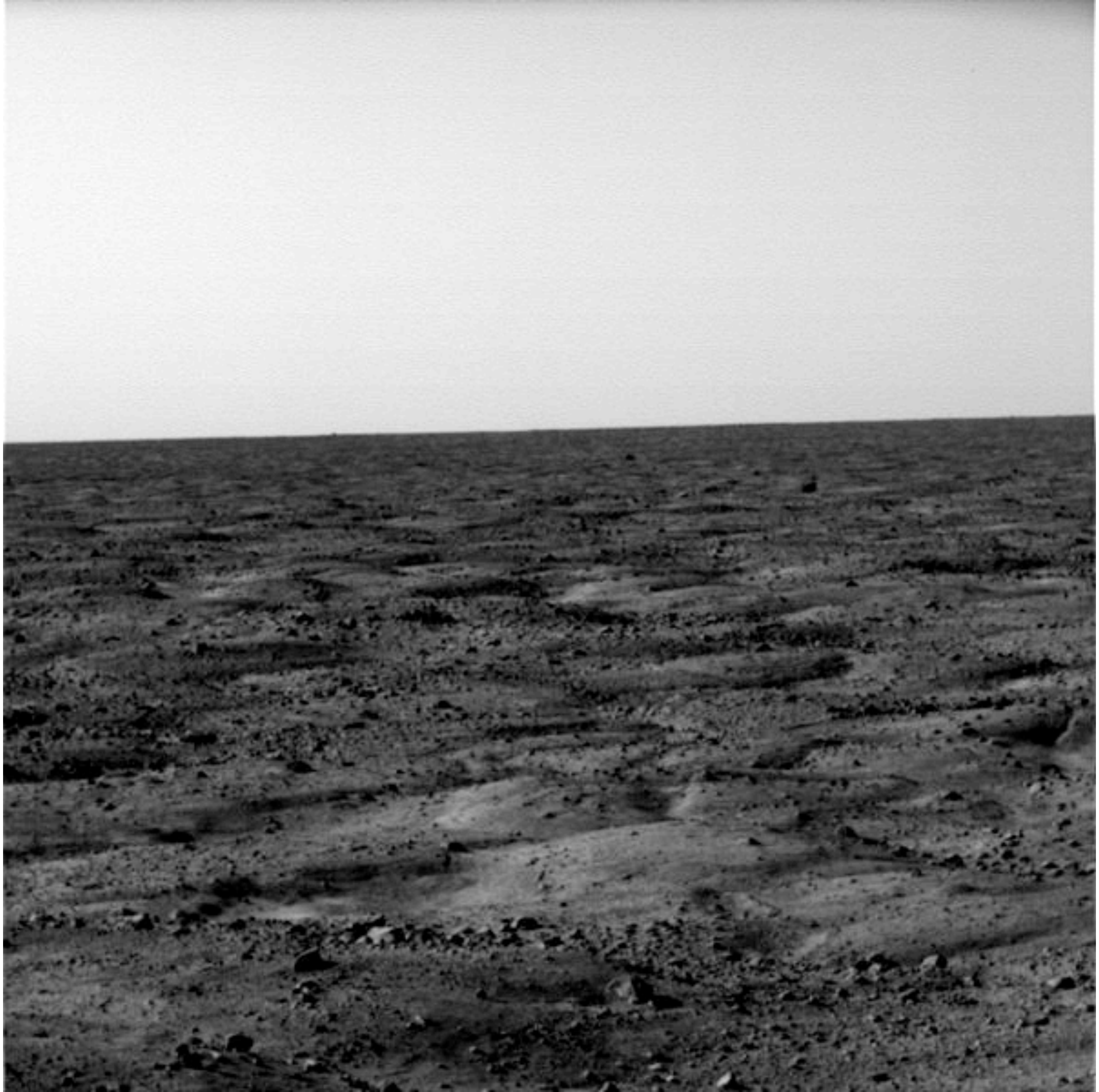
Phoenix Mars Mission

Phoenix was a robotic spacecraft on a space exploration mission on Mars under the Mars Scout Program. The *Phoenix* lander descended on Mars on May 25, 2008. Mission scientists used instruments aboard the lander to search for environments suitable for microbial life on Mars, and to research the history of water there.



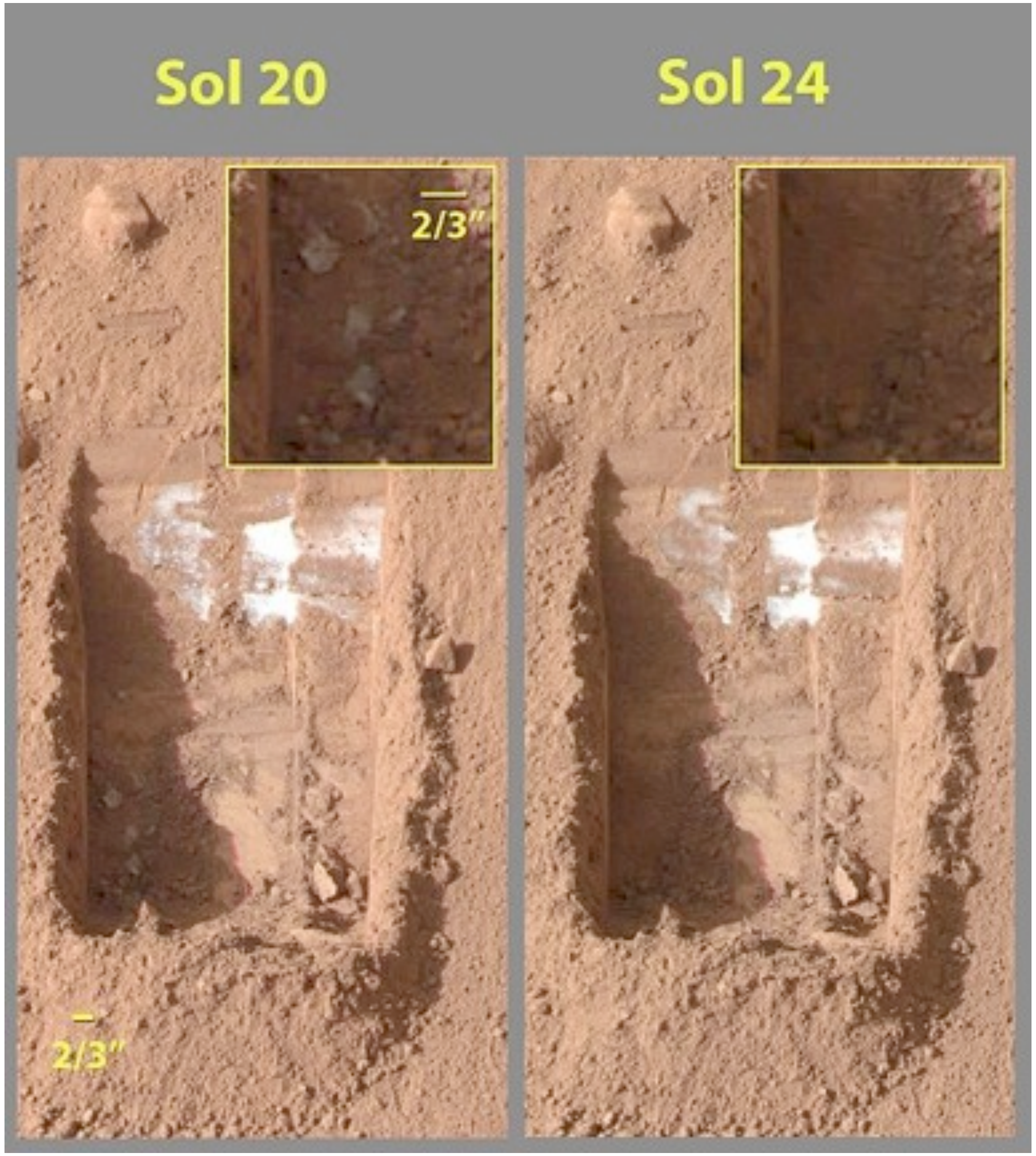


Mars Reconnaissance Orbiter (MRO) imaged *Phoenix* (lower left corner) in the line of sight to the 10-km-wide Heimdall Crater (the craft is actually 20 km in front of it).



On June 19, 2008, NASA announced that dice-sized clumps of bright material in the "Dodo-Goldilocks" trench dug by the robotic arm had vaporized over the course of four days, strongly implying that they were composed of water ice which sublimated following exposure. While dry ice also sublimates, under the conditions present it would do so at a rate much faster than observed.

On July 31, 2008, NASA announced that *Phoenix* confirmed the presence of water ice on Mars, as predicted on 2002 by the Mars Odyssey orbiter. During the initial heating cycle of a new sample, TEGA's mass spectrometer detected water vapor when the sample temperature reached 0 °C. Liquid water cannot exist on the surface of Mars with its present low atmospheric pressure, except at the lowest elevations for short periods.

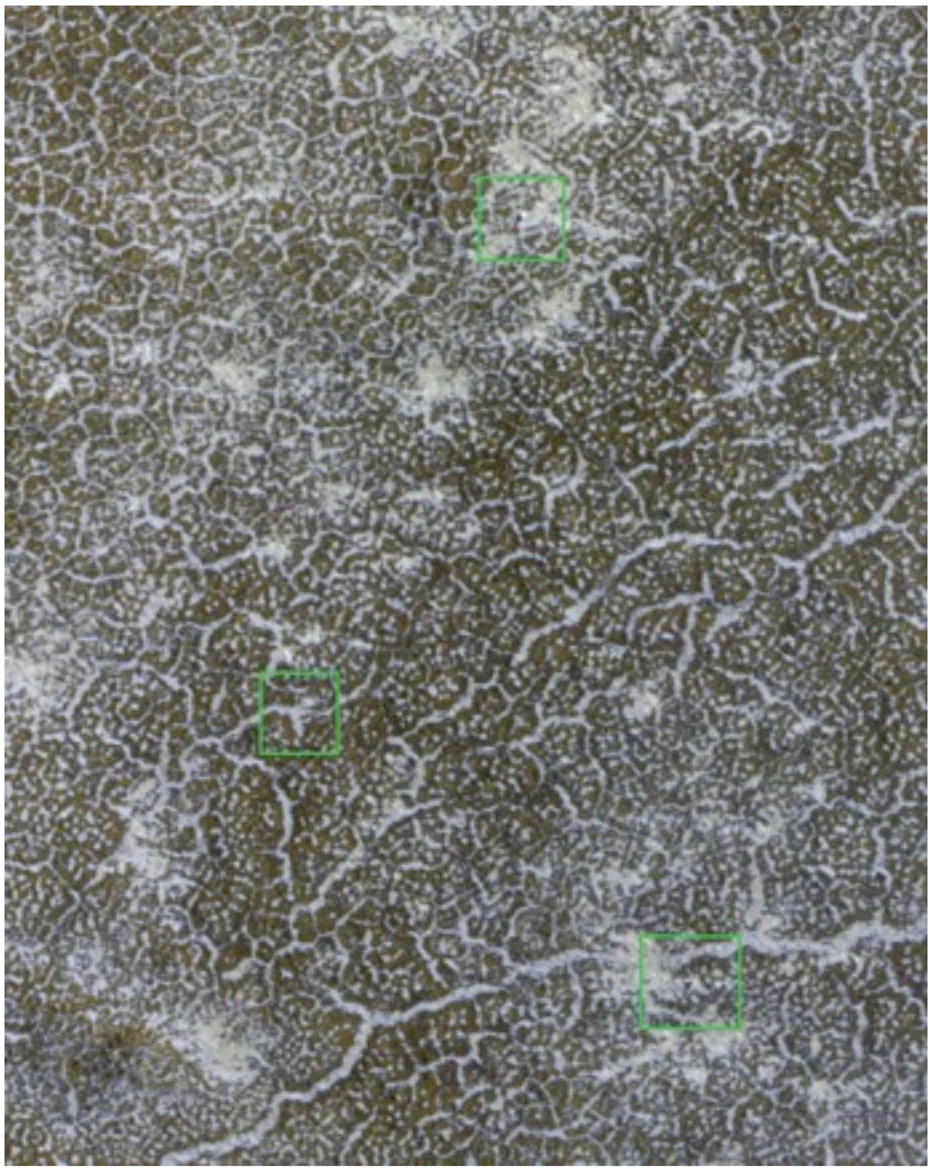


On November 10, Phoenix Mission Control reported the loss of contact with the Phoenix lander (the last signal was received on November 2). Immediately prior, Phoenix sent its final message: "Triumph" in binary.The demise of the craft occurred three weeks earlier than expected, as a result of a dust storm that reduced power generation even further.

While the spacecraft's work has ended, the analysis of data from the instruments is in its earliest stages.

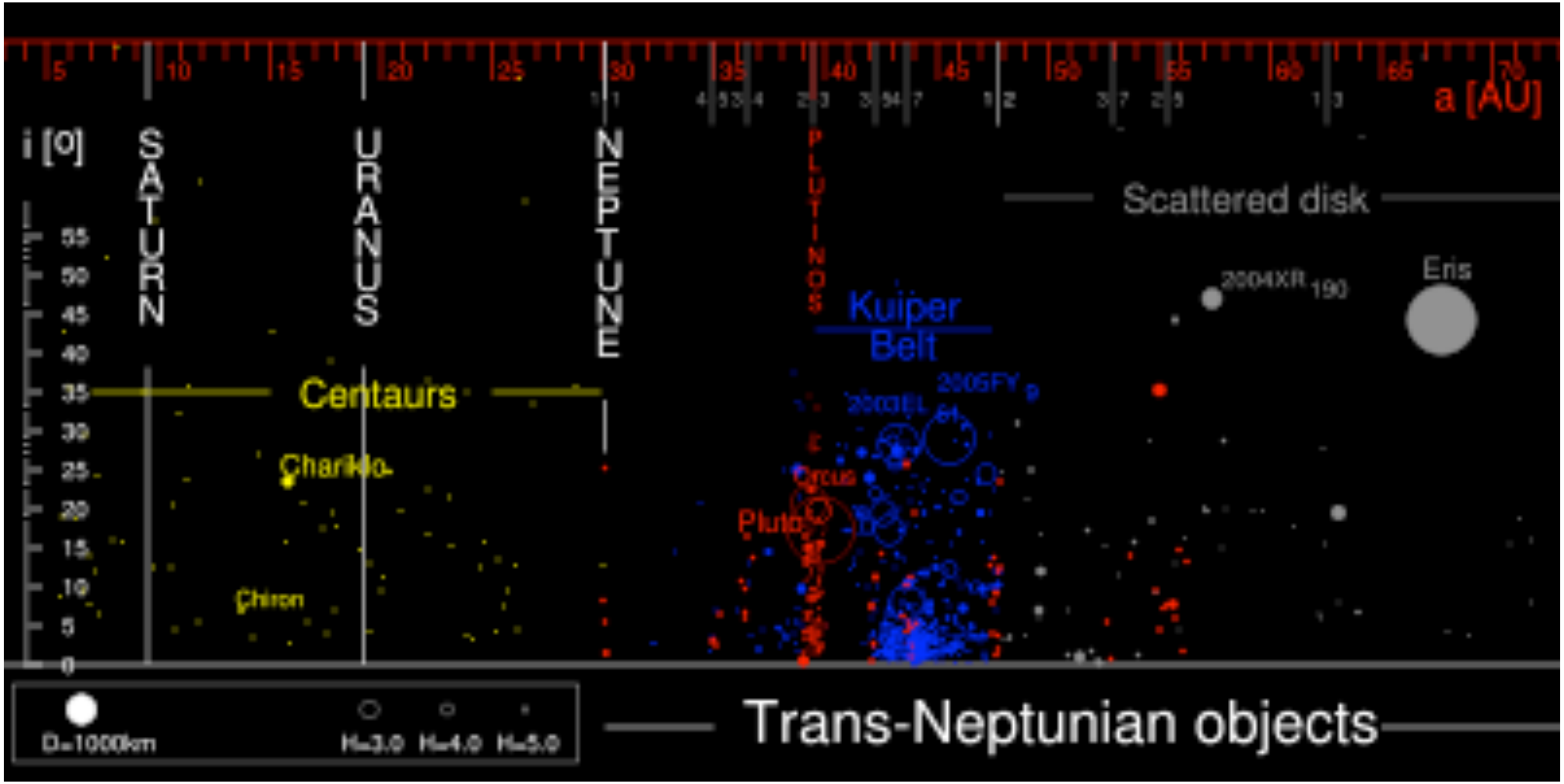
The spacecraft's computer has a safe mode that, theoretically, will attempt to reestablish communications when/if the lander can recharge its batteries next spring. However, its landing location is in an area that is usually part of the north polar ice cap during the Martian winter, meaning the spacecraft will likely be encased in dry ice. It is considered unlikely that the spacecraft will survive this condition.

Currently Odyssey is trying to make contact with Phoenix to see if it survived the winter



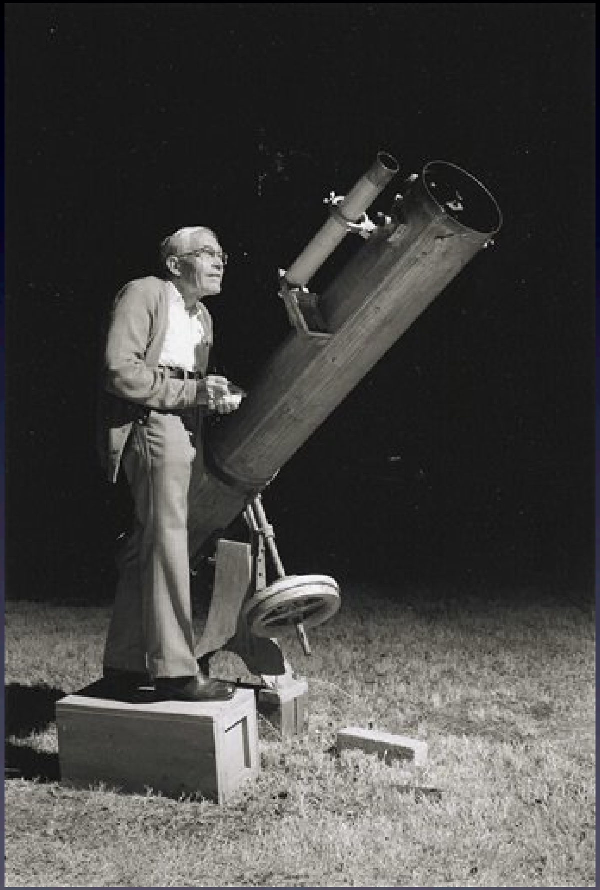
Trans-Neptunian Objects

Trans-Neptunian Objects are the name given collectively to any object in the solar system that orbits at a greater distance on average than Neptune. The Edge-worth Kuiper belt, Scattered disk and Oort cloud are the names for the three divisions of this volume of space.



Pluto

Clyde Tombaugh discovered Pluto in Feb 1930



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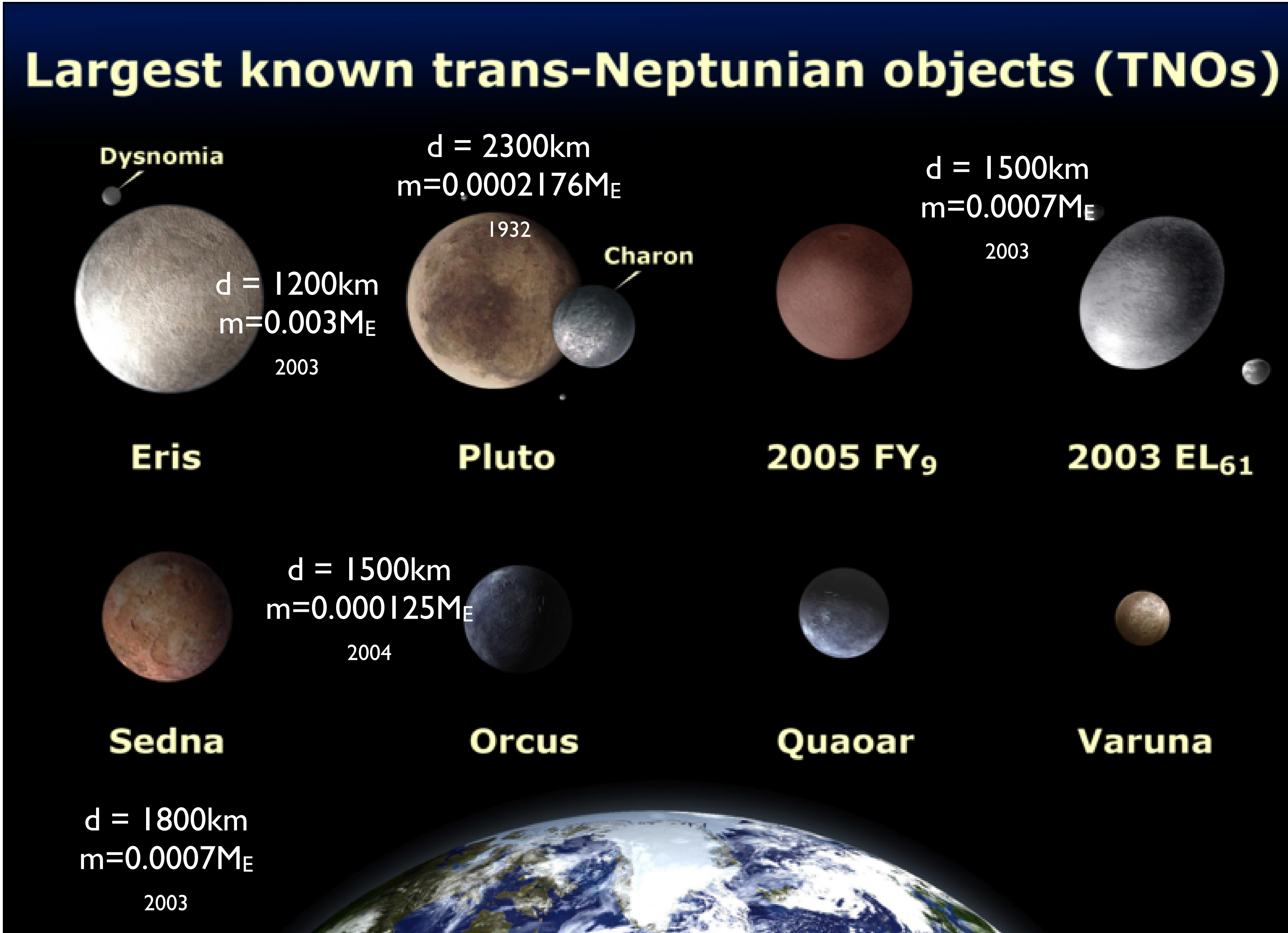
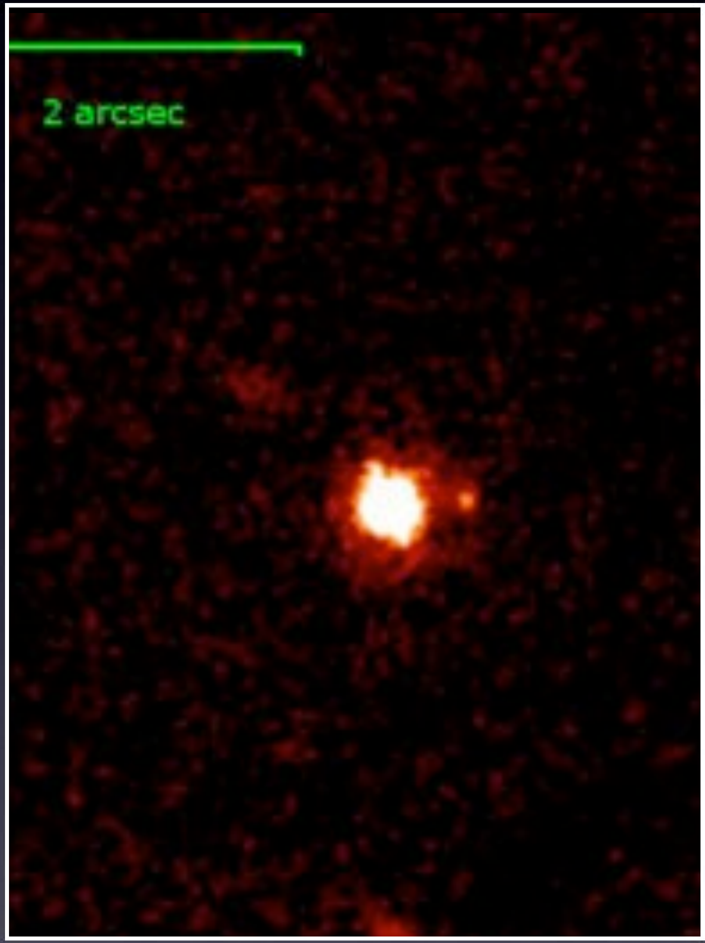

Largest known trans-Neptunian objects (TNOs)
Dysnomia
d = 1200km
$m=0.003M_E$
2003
d = 2300km
$m=0.0002176M_E$
1932
Charon
d = 1500km
$m=0.0007M_E$
2003
Eris
Pluto
2005 FY_9
2003 EL_{61}
d = 1500km
$m=0.000125M_E$
2004
Sedna
Orcus
Quaoar
Varuna
d = 1800km
$m=0.0007M_E$
2003

Eris and Dysnomia

- Crisis heats up with discovery of Eris by Mike Brown, Caltech in 2003
- Eris is bigger than Pluto and has a moon
- If Pluto is/is not a planet, then Eris should have same status



Aftermath

"I guess I'll be remembered as the guy who killed Pluto"

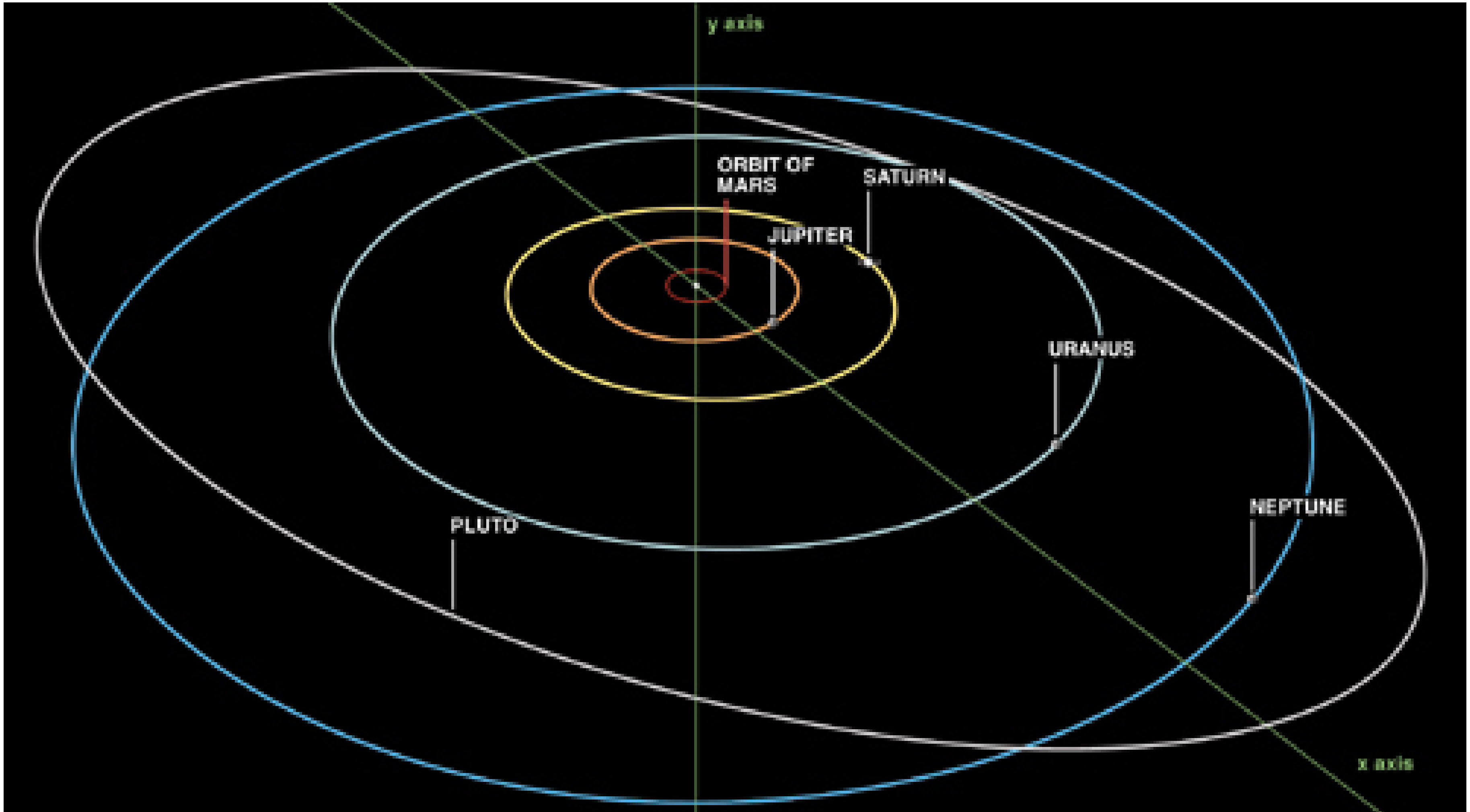
Mike Brown, discover of Eris

The Down-sizing of Pluto

The New Planet Definition

- A planet has sufficient mass to be round
- A planet is in its own orbit around the Sun but is not a star (Mass < 0.013 Msun)
- A planet has cleared the neighbourhood around its orbit.

The orbit of pluto is highly elliptical while the planets have a circular orbit. During its journey around the Sun the orbit of Pluto crosses the path of Neptune and as a result for approximately 13 to 20 years out of the every 248 (Pluto's orbital period), Neptune lies farther from the Sun than Pluto.



Pluto is now a Dwarf Planet

Definition introduce by the IAU in 2006

A **dwarf planet**, as defined by the IAU, is a celestial body orbiting the Sun that is massive enough to be rounded by its own gravity but has not cleared its neighbouring region of planetesimals and is not a satellite (moon).

Pluto

Our Solar System

Jocelyn Bell-Burnell announces the result: ‘8 planets’ win Pluto is no longer a planet

Aftermath

- New Horizons probe to Pluto was launced earlier this year
- Will arrive in 2012
- Principal Investigator is most prominent critic of decision

Aftermath

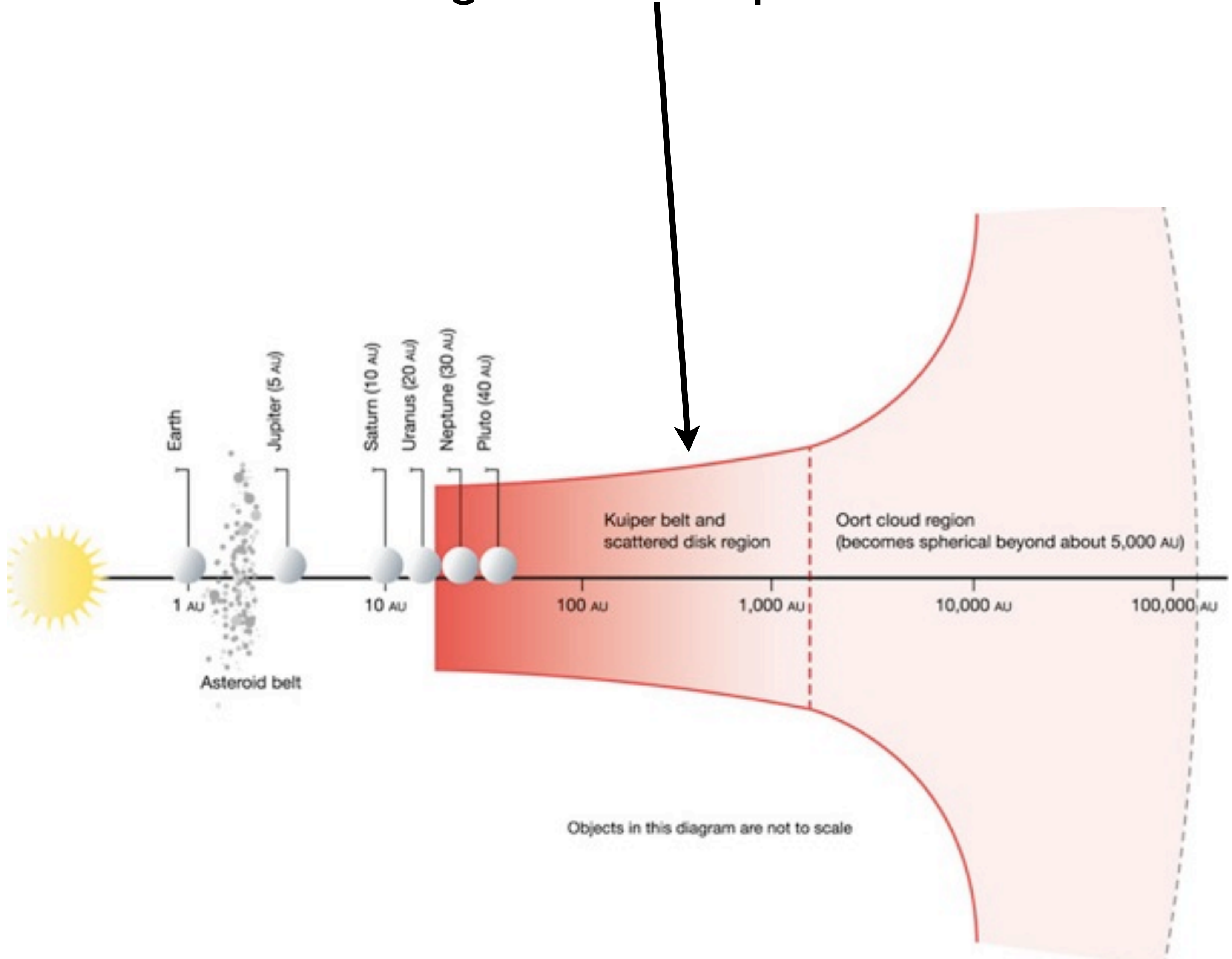
"The New Horizons project will not recognize the IAU's planet definition resolution"

Alan Stern, P.I. New Horizons mission

Aftermath

- New Horizons reaches Pluto in 2012
- Three more General Assembly meetings before then
- Could decision yet be reversed?

The Edge-worth Kuiper Belt

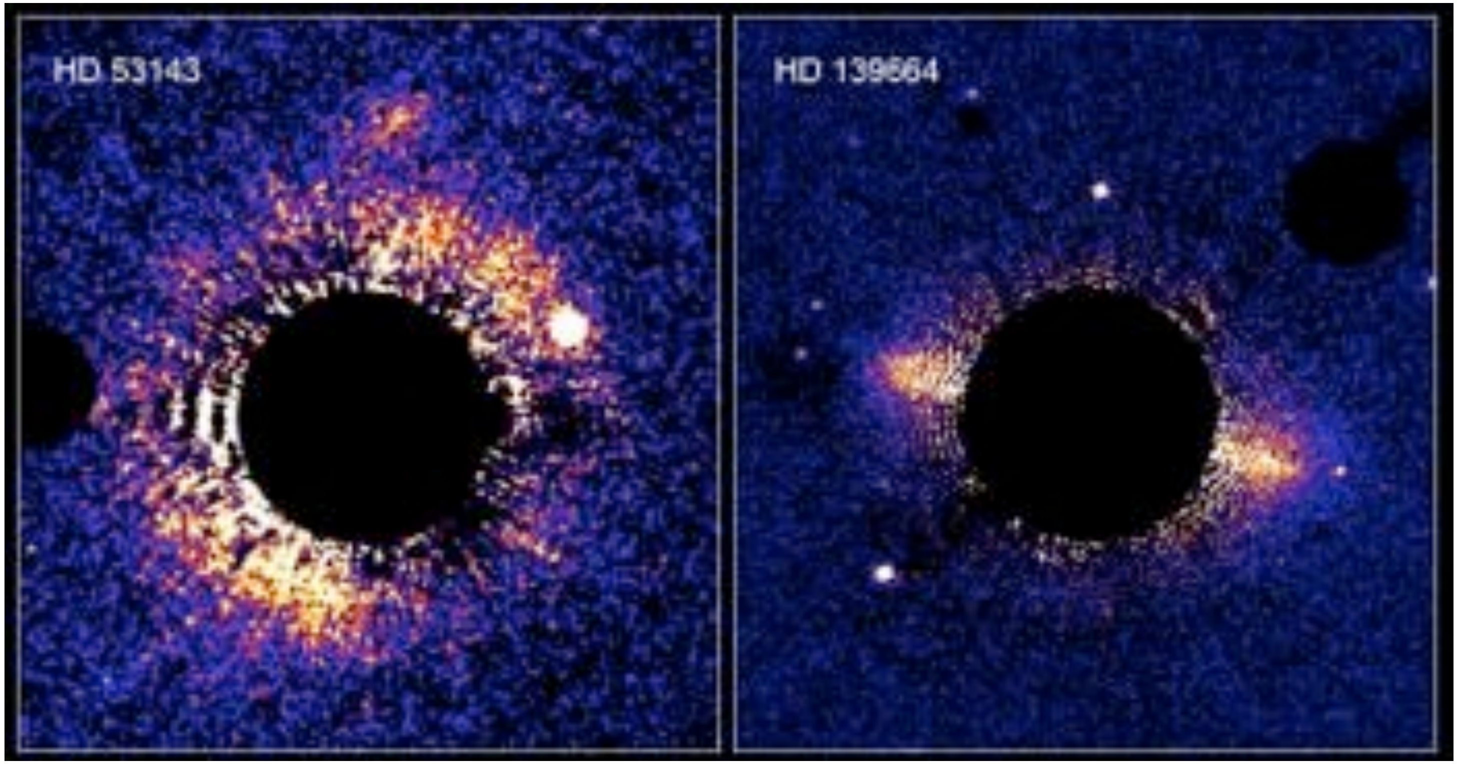


1943 Irish astronomer Kenneth E. Edgeworth and Gerard Kuiper 1951 suggested the existence of a belt of objects beyond Neptune that might be source of short period comets. Gerard Kuiper is generally credited with its discovery.

The E-Kuiper belt is an area of the solar system that extends beyond Neptune (at 30 AU) to 50 AU from the Sun. It is a vast resevoir of icy bodies.

Objects in the E-Kuiper belt are a sub-set of the **trans-Neptunian objects.**

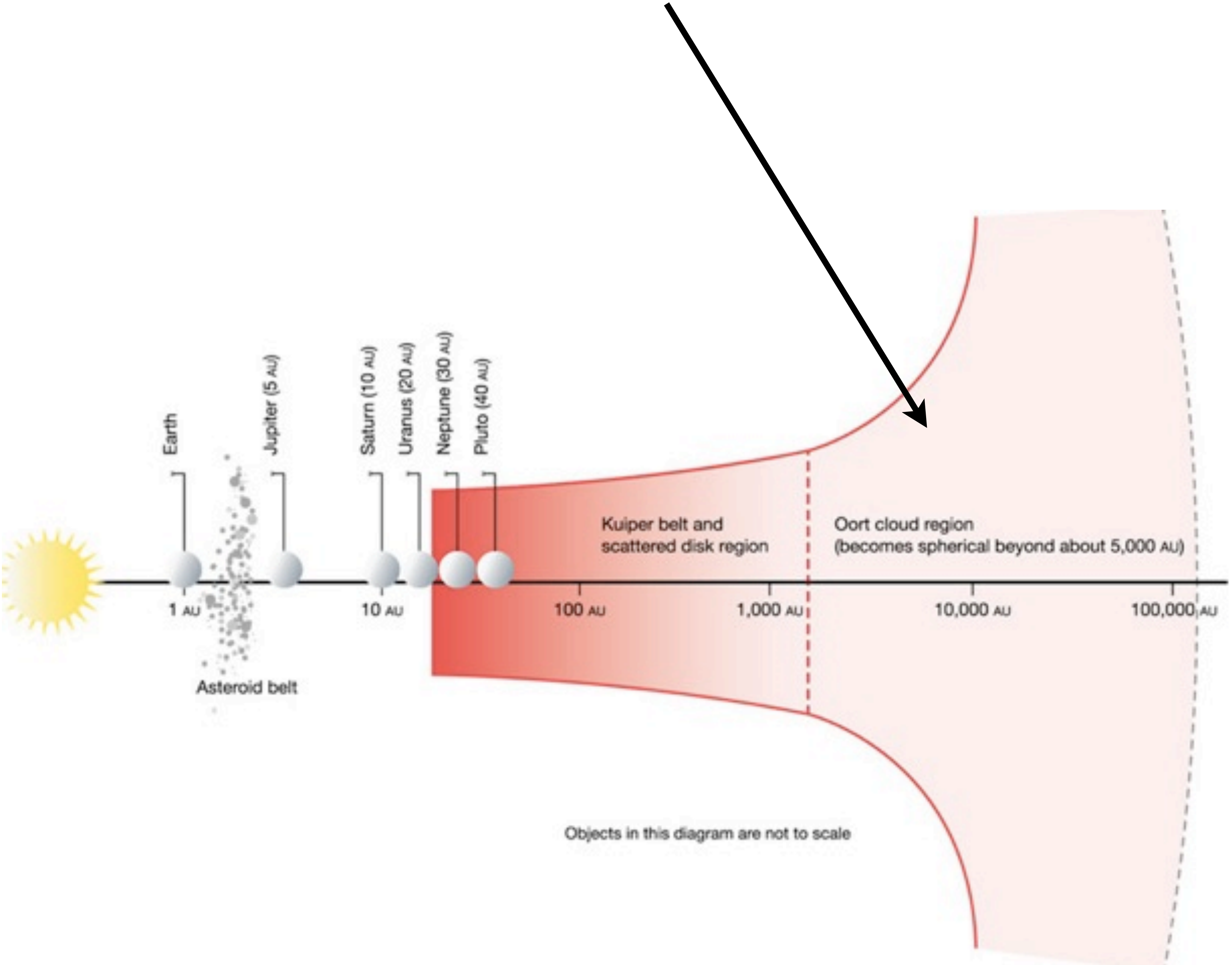
Over 800 Kuiper belt objects have been discovered to date. The first was found in 1992



Origin of E-Kuiper Belt

The E-Kuiper belt and scattered disk region represent the edge of the Sun's accretion disk. The disk became much less dense towards the edges and accretion progressed very slowly. Hence planets did not form and a ring of debris material or small objects remained. As these objects were located far beyond the Giant planets they escaped being ejected from the solar system.

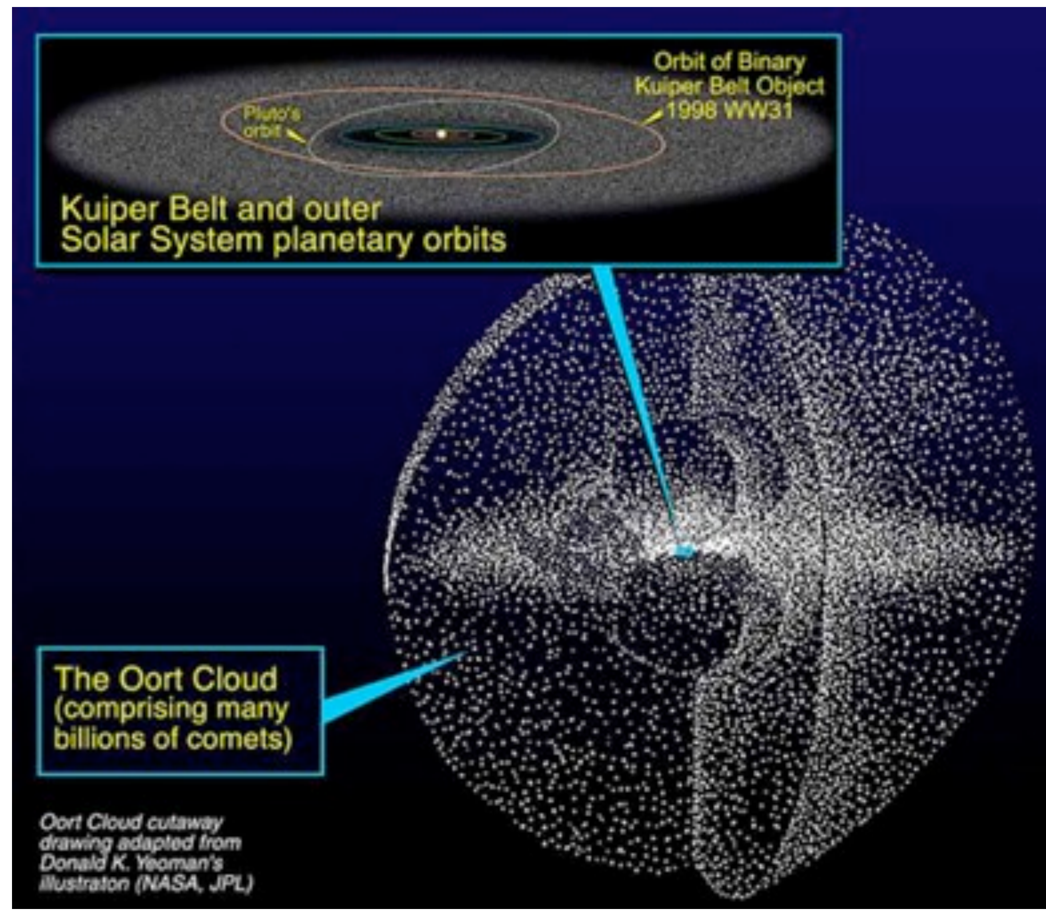
The Oort Cloud



The Oort Cloud is a spherical cloud of billions of comets at a distance of 50,000 to 100,000 AU from the Sun and with a predicted mass of 5-100 times the mass of the Earth. It is a resevoir for long-period comets

Its existence was first predicted by Jans Oort

The Oort cloud is a remnant of the original molecular core that collapsed to form the solar system. It is made up of left over fossil material. Some of the material formed in situ while some originated closer in but was ejected from the inner solar system and scattered out of the ecliptic plane due to gravitational interactions with the giants gas planets.

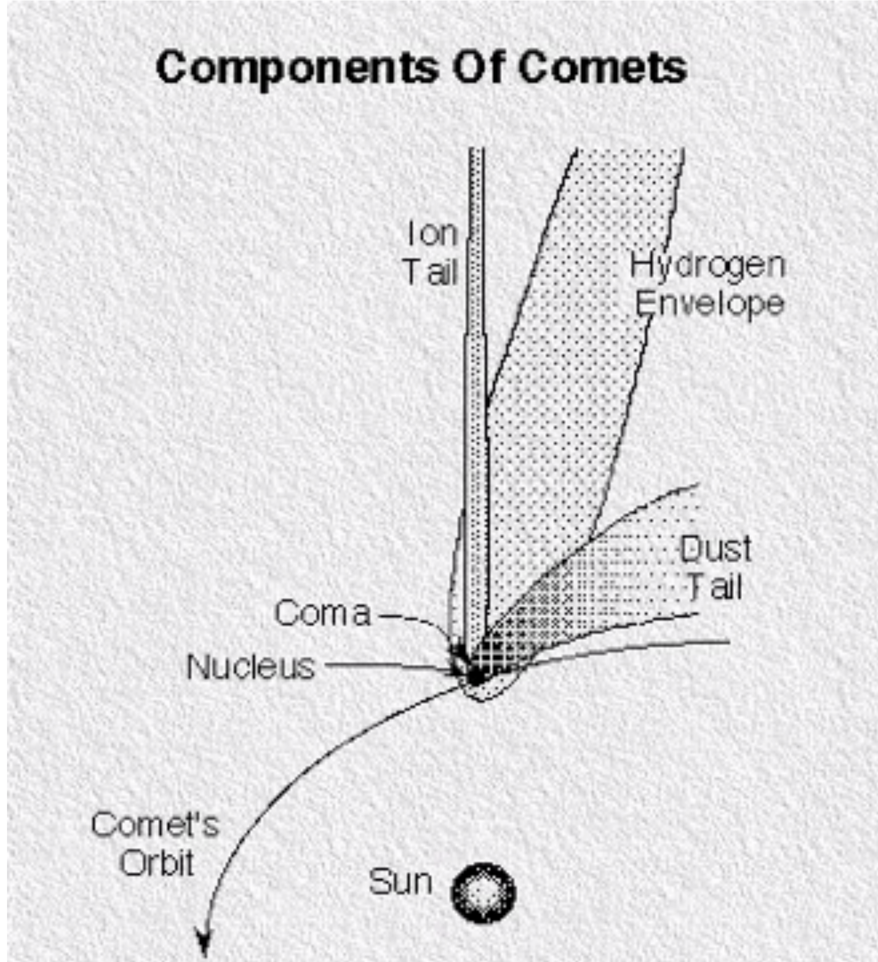


Comets

A comet is a small icy rocky body that has a highly elliptical orbit around the sun. If the orbit of this object is perturbed it can be forced into the inner solar system where it is theorised that the Sun's radiation causes the outer layers to melt and evaporate (Whipples Dirty Snowball Model). The streams of dust and gas thus released form a very large, extremely tenuous atmosphere around the comet called the *coma*, and the force exerted on the coma by the Sun's radiation pressure and solar wind cause an enormous *tail* to form, which points away from the sun.

Comet Hale-Bopp

Comet Mc Naught



When they are near the Sun and active, comets have several distinct parts:

- **nucleus**: relatively solid and stable, mostly ice and gas with a small amount of dust and other solids;
- **coma**: dense cloud of water, carbon dioxide and other neutral gases sublimed from the nucleus;
- **hydrogen cloud**: huge (millions of km in diameter) but very sparse envelope of neutral hydrogen;
- **dust tail**: up to 10 million km long composed of smoke-sized dust particles driven off the nucleus by escaping gases; this is the most prominent part of a comet to the unaided eye;
- **ion tail**: as much as several hundred million km long composed of plasma and laced with rays and streamers caused by interactions with the solar wind.

Short Period and Long Period

Comets are classified according to their orbital periods. *Short-period comets*, also called *periodic comets*, have orbits of less than 200 years, while *long-period comets* have longer orbits but remain gravitationally bound to the Sun

Short-period comets are thought to originate in the E-Kuiper belt whereas the source of long-period comets is thought to be the Oort Cloud.

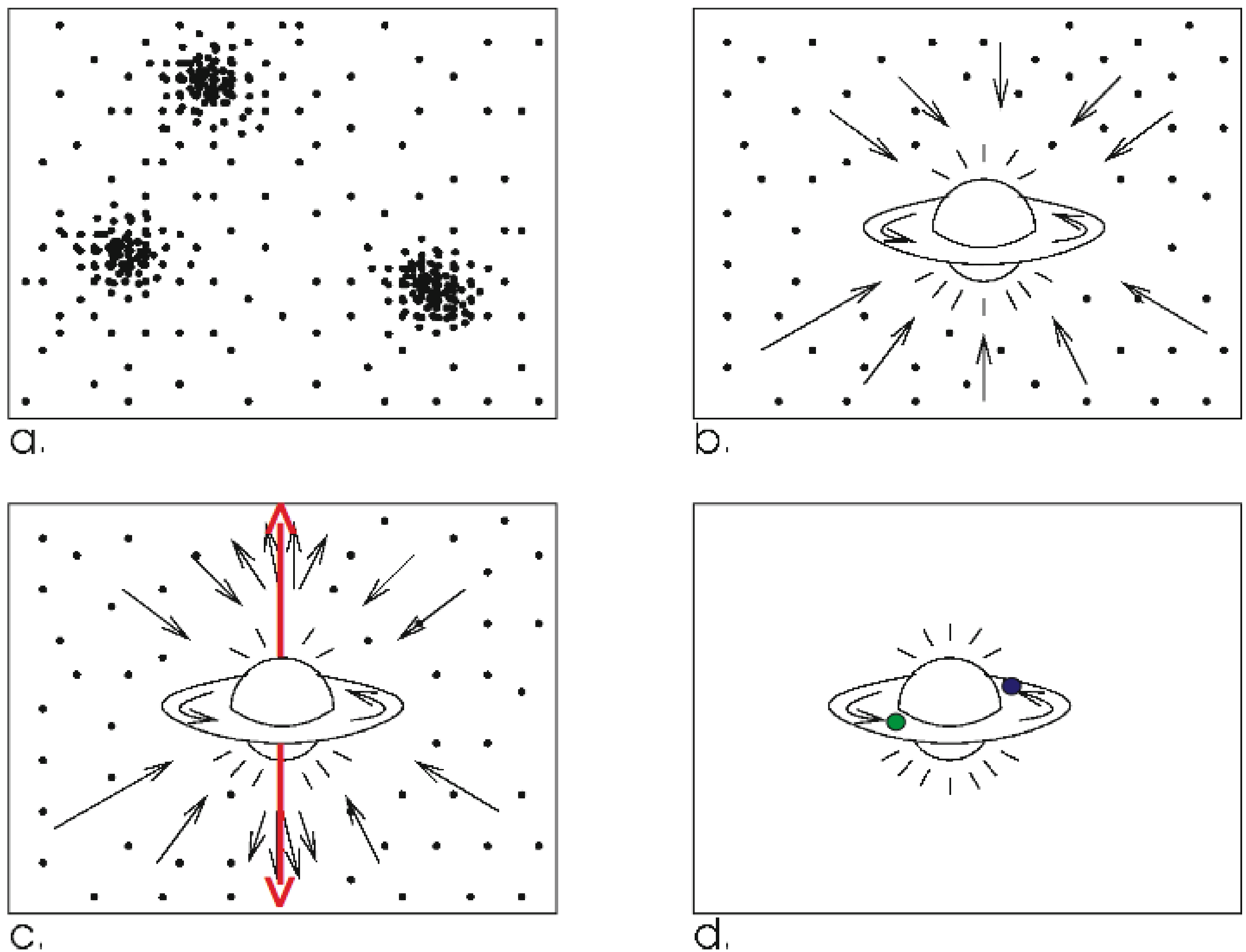
Halley's Comet

The most famous and the first comet shown to be periodic. Edmund Halley observed the comet of 1682 and recognised thats its characteristics were the same as comets that had been observed in 1531 and 1607. He predicted its return in 1758. Last time it was observed was 1986. The next perihelion is July 2061.

Discovery	
Discovered by:	prehistoric; Named after Edmond Halley
Discovery date:	1758 (first predicted perihelion)
Alternate designations:	Halley's Comet, 1P (see Designation below)
Orbital characteristics A	
Epoch:	2449400.5 (February 17, 1994)
Aphelion distance:	35.1 AU
Perihelion distance:	0.586 AU
Semi-major axis:	17.8 AU
Eccentricity:	0.967
Orbital period:	75.3 a
Inclination:	162.3°
Last perihelion:	February 9, 1986
Next perihelion (predicted):	July 28, 2061 [1]

Lecture 1 Monday March 3rd

Star Formation

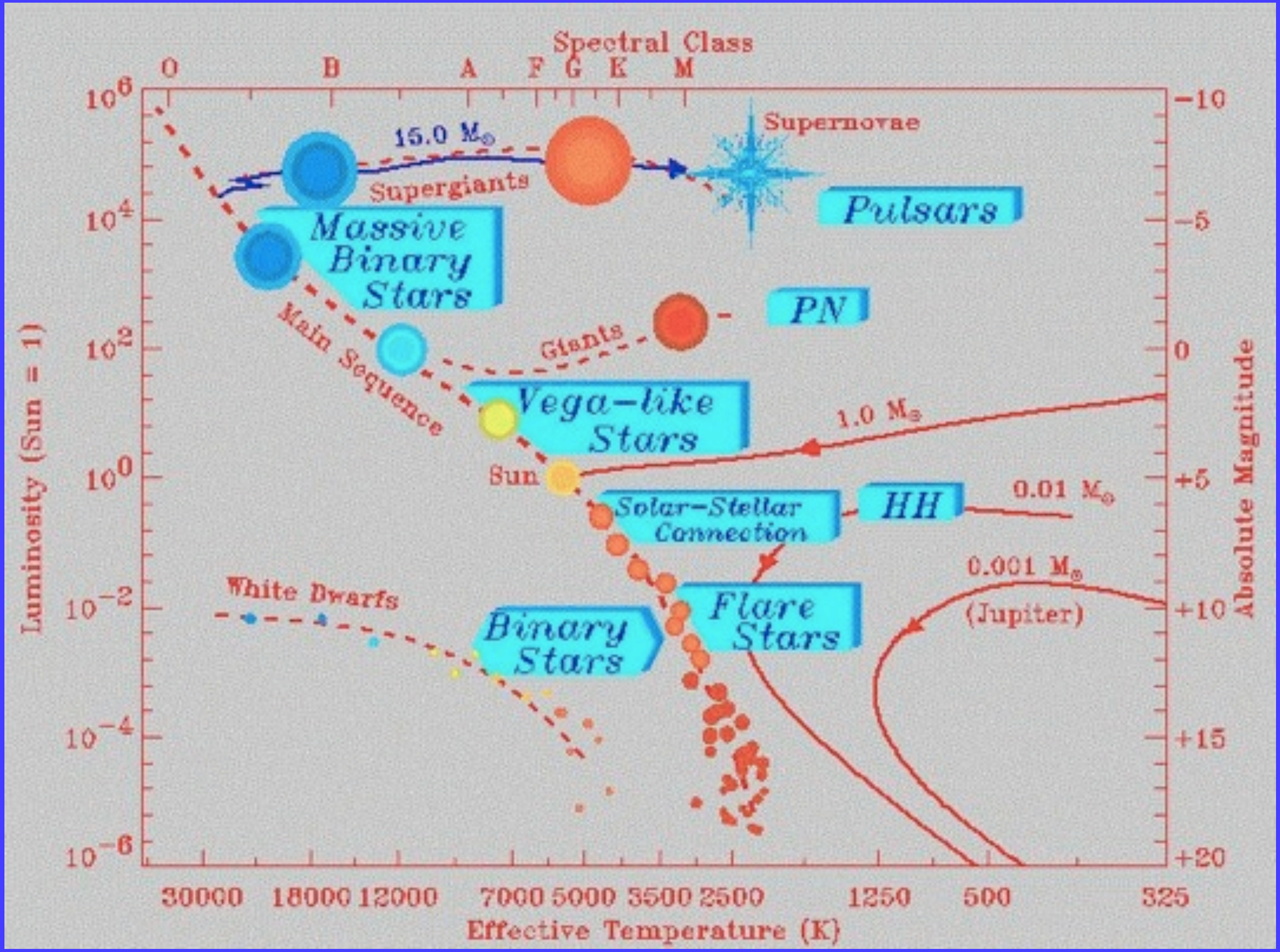


So What is a Star???

A collapsing cloud of cloud of interstellar matter becomes a star when the P and T at it centre become so high that nuclear reactions start

A star converts H into He releasing E that escapes through the stars's body and radiates out into space.

Named after the Danish and American astronomers Ejinar Hertzprung and Henry Russell the HR diagram illustrates the relationship between the Luminosity (total energy it radiates per second) surface temperature (colour) and radius

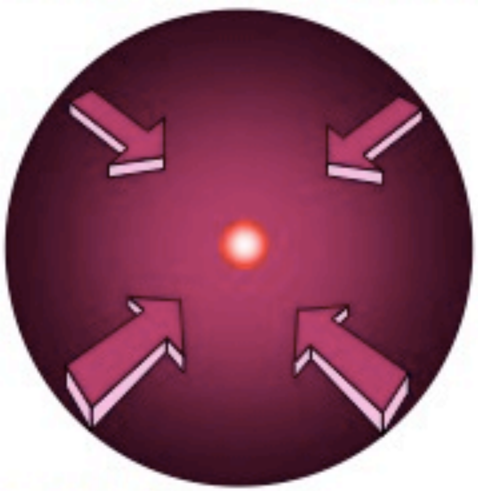


Stellar Spectral Types

Type	Prominent spectral lines	colour	average temp	Examples
O	He, H,O,N,C,Si	Blue	45,000 C	regor
B	He, H,O,N,Fe,Mg	bluish white	30,000 C	Rigel
A	H, ionised metals	white	12,000 C	Sirius
F	H, Ca, Ti,Fe	yellowish white	8,000 C	Procyon
G	Ca, Fe, Ti,Mg, H some molecular bands	yellowish	6,500 C	The Sun
K	Ca,H,molecular bands	orange	5,000 C	Aldebaran
M	TiO,Ca, molecular bands	red	3,5000 c	Betelgeuse

Searching for Extra-Solar Planets
How Do Planets Form?

Clouds of gas & dust collapse under gravity

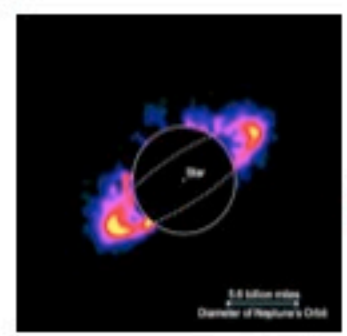


10^4 Years

Disk of gas and dust left over around new star.

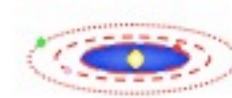
10^5 Years

Comets & Asteroids form



10^7 Years

Planets



Few x 10^7 Years

Molecular Clouds: Star Making Material

The Molecular Clouds (some Giant!) which make up a substantial fraction of the interstellar medium are the birth places of the stars. They are the Stellar Nurseries of The Universe

Molecular Clouds are the most massive (10,000,000 times the mass of The Sun), largest (50-100 pc) and coldest (on average 50 K) objects in The Universe.

Molecular Clouds are composed of a cocktail of molecules (H2, CO, NH3, ethanol) and DUST a vital component

Molecular Clouds are divided into 2 types. Small molecular clouds (SMCs) are colder and are distributed throughout the galaxy. There are some 4,000 giant molecular clouds (GMCs) in the Milky Way. They are confined to the spiral arms have average temperatures closer to 100 K.

1 pc = 200,000 times the distance of The Earth to The Sun or 31,000,000,000,000 km's

1 K = -272.15 Celsius

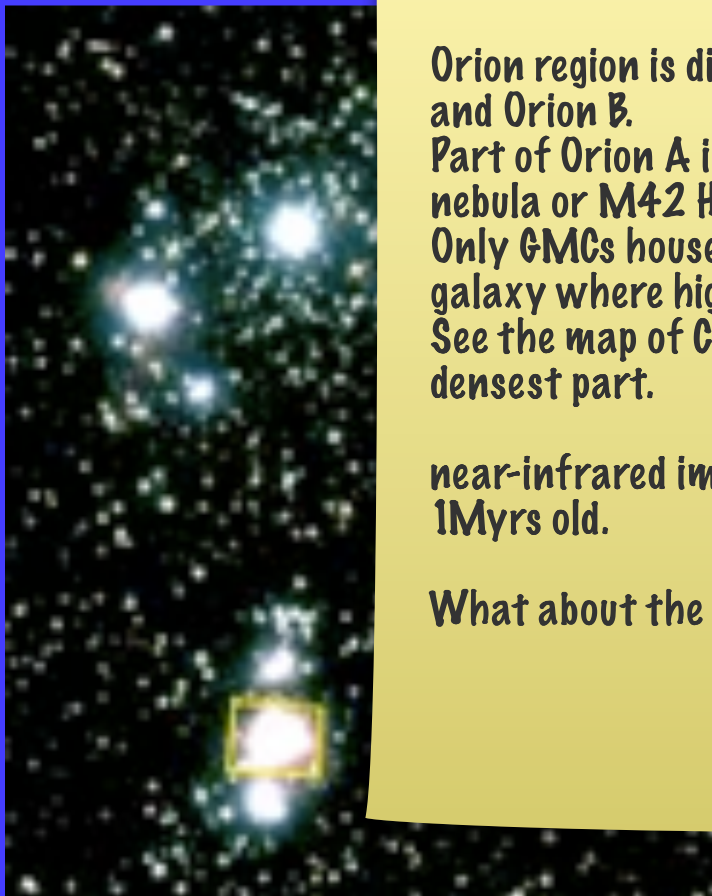
rion

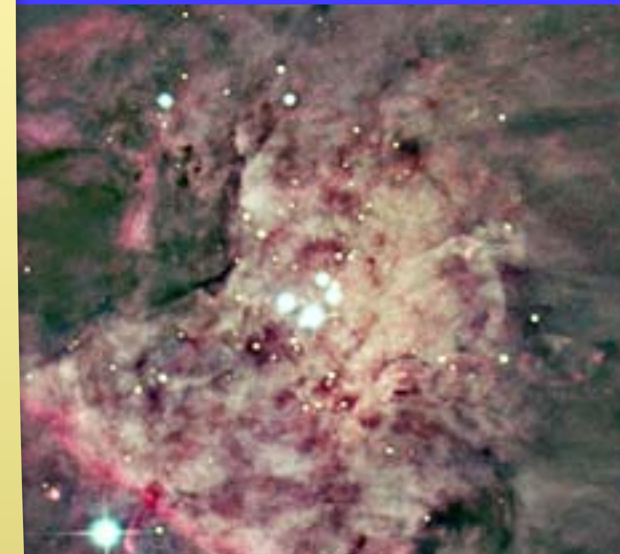
Orion is a well known constellation to all of us. Watch out for it at about ? 2nte.

Orion region is divided into two MC complexes Orion A and Orion B.
Part of Orion A in Orions sword is the famous Orion nebula or M42 Home to the massive trapezium stars.
Only GMCs house massive stars. Nearest place in our galaxy where high mass stars are being formed.
See the map of CO in the complex M42 is located in the densest part.

near-infrared image bottom right. 1,000 young stars ~ 1Myrs old.

What about the horsehead nebula

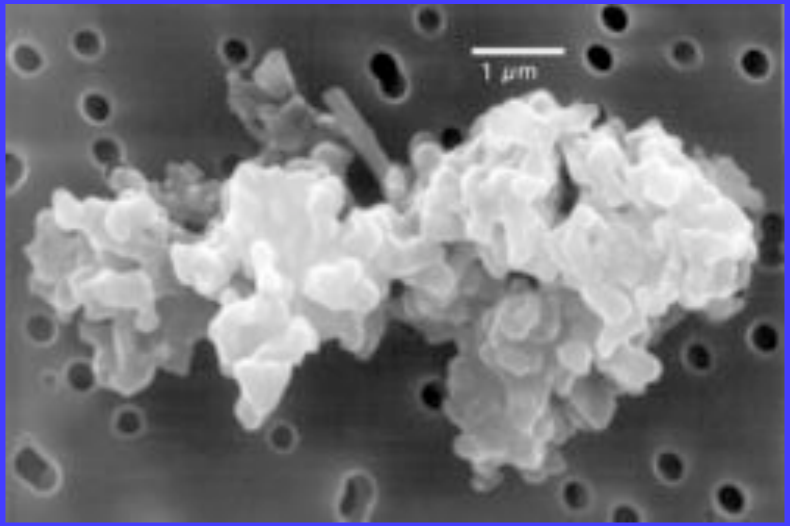


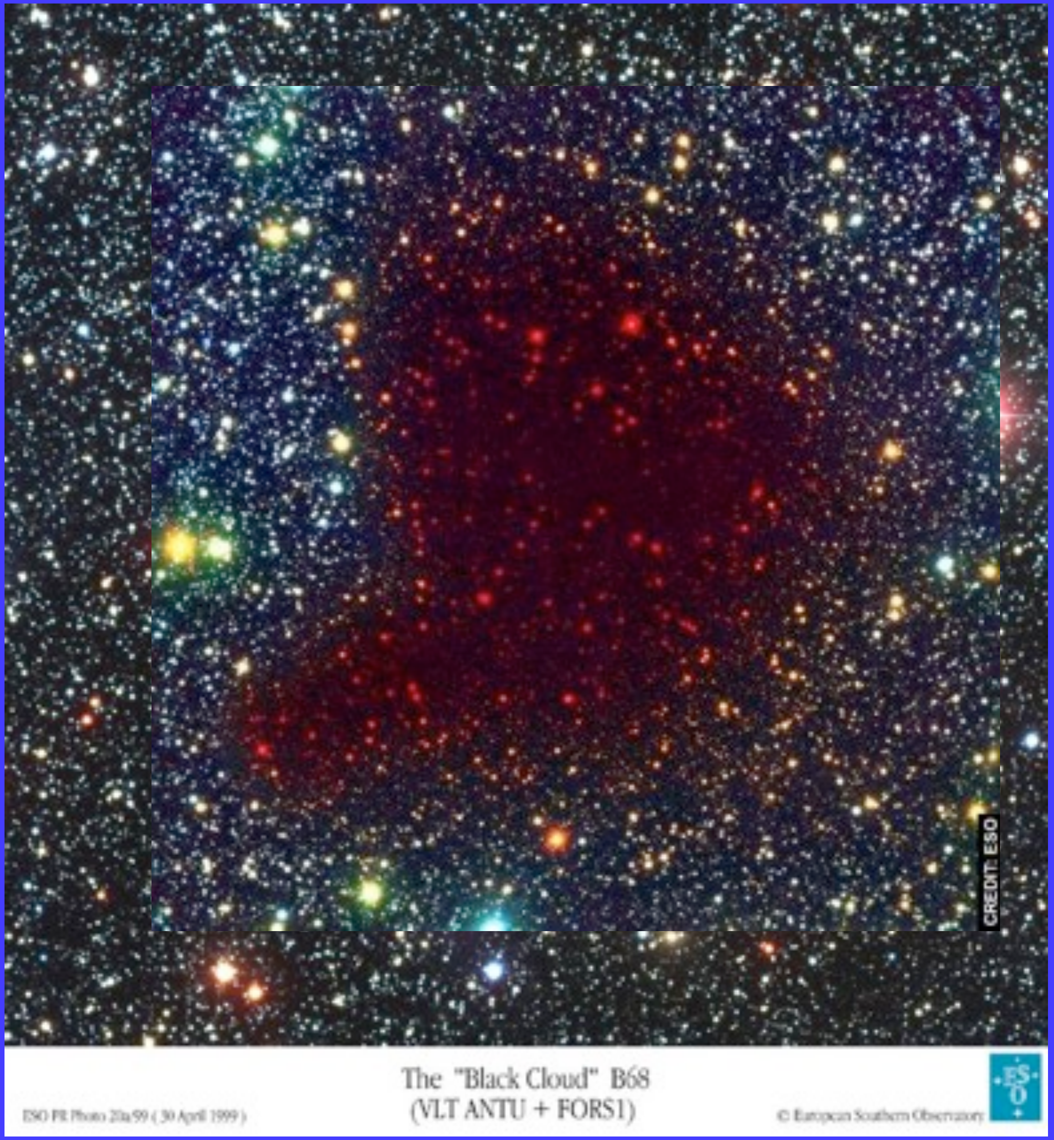


The Orion nebula is an intense region of Star Formation. Most of first protostars were discovered here aswell as many interstellar molecules



Dust


1 μm


CREDIT: ESO
The "Black Cloud" B68
(VLT ANTU + FORS1)
ESO PR Photo 20a/99 (30 April 1999)
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ESO

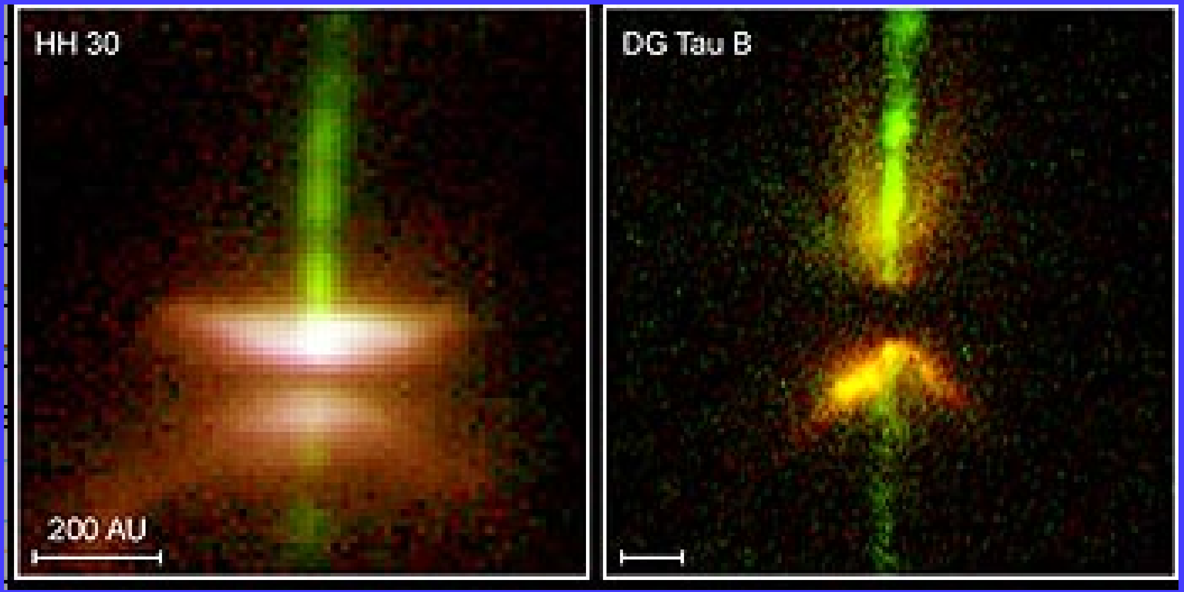
Core Accretion and protostars

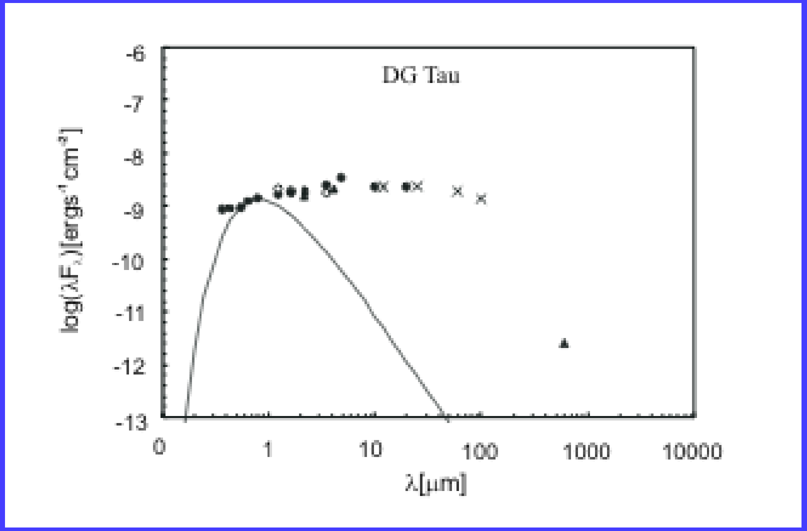
Protostars

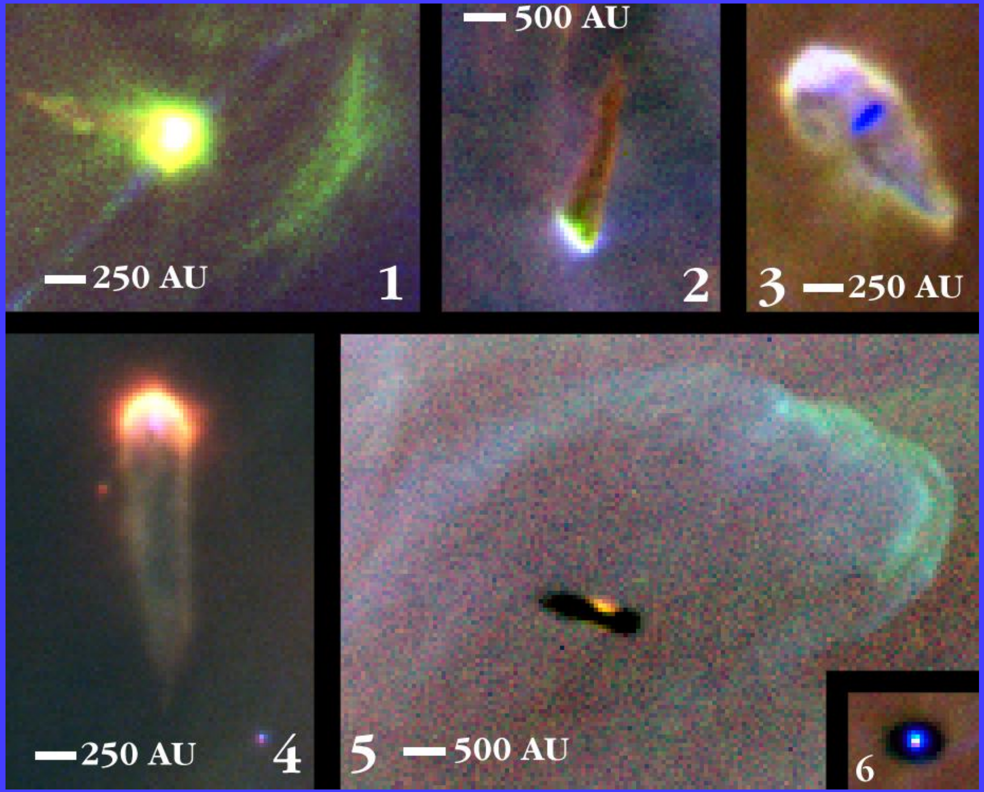
- Herbig Ae/Be stars, intermediate mass $3M_\odot \leq M_* \leq 10_\odot$
- Low mass Class I YSOs $M_* \leq 3M_\odot$
- Classical T-Tauris also low mass
- Very low mass stars $M_* \leq 0.2M_\odot$
- Brown Dwarfs $0.013M_\odot \leq M_{BD} \geq 0.075M_\odot$

Disks and Jets

Circumstellar Disks

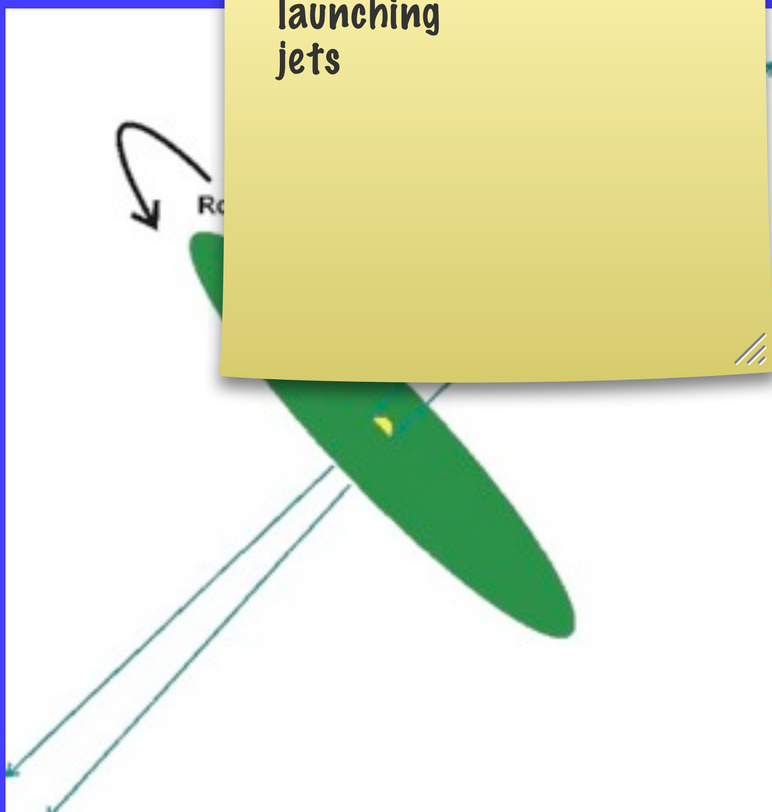


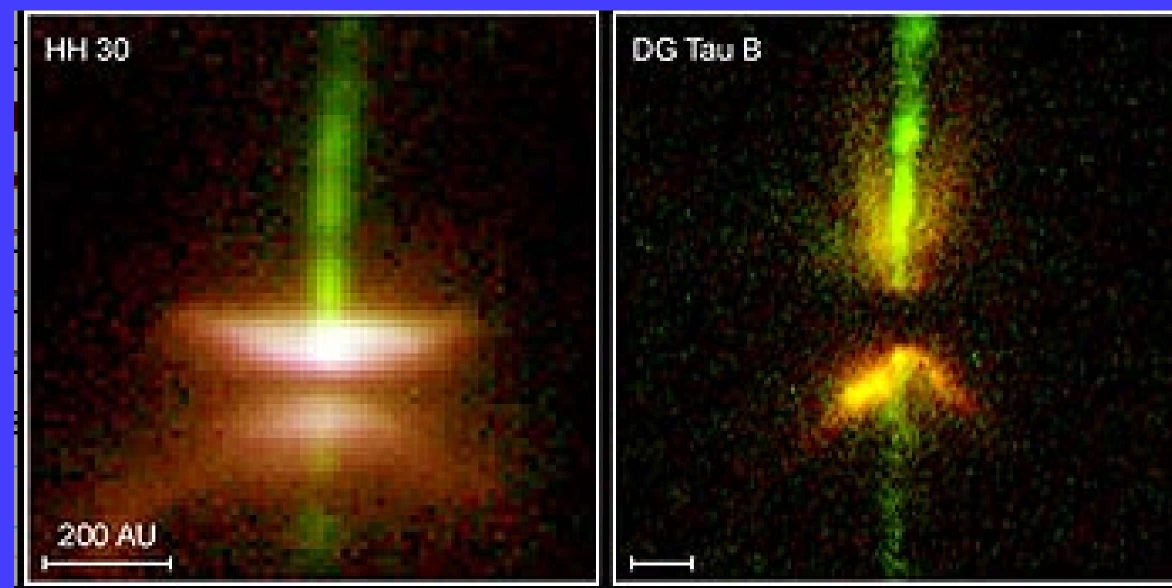


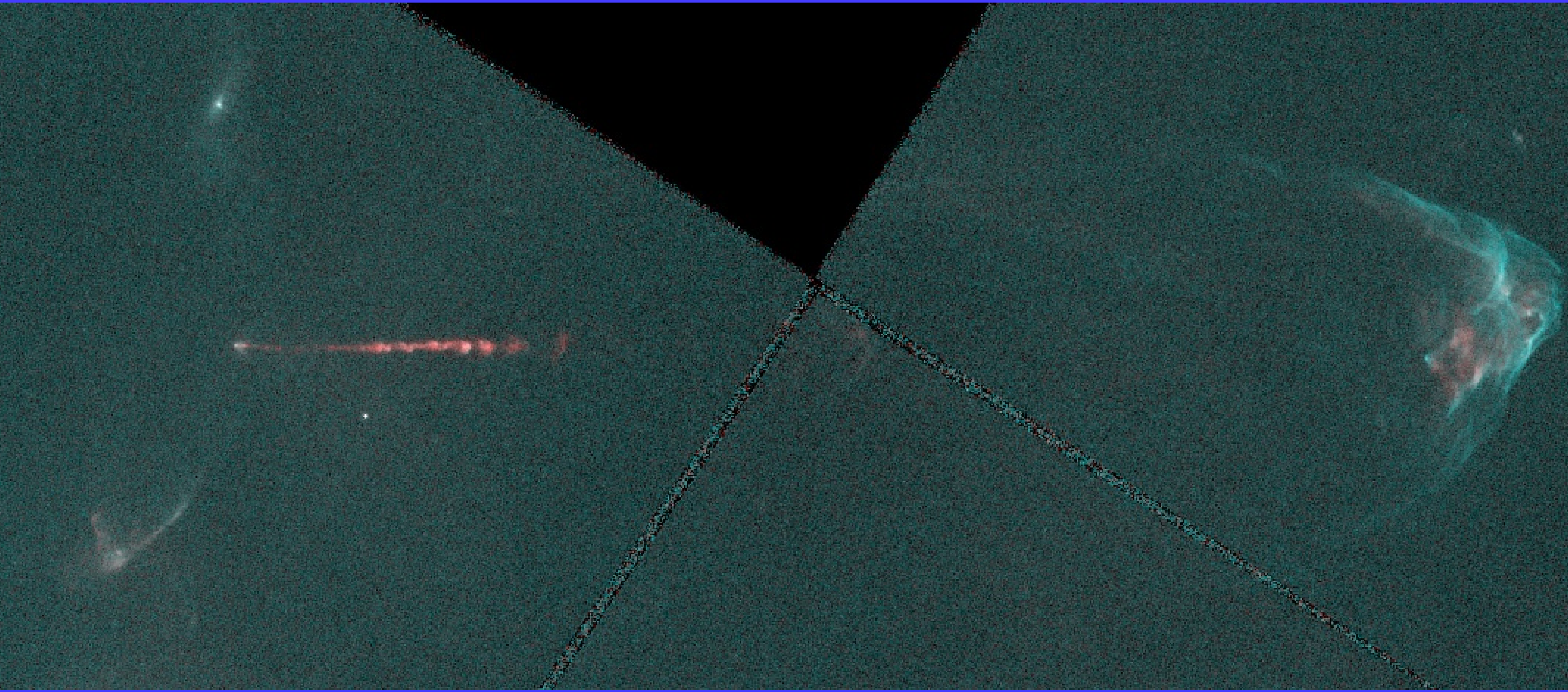


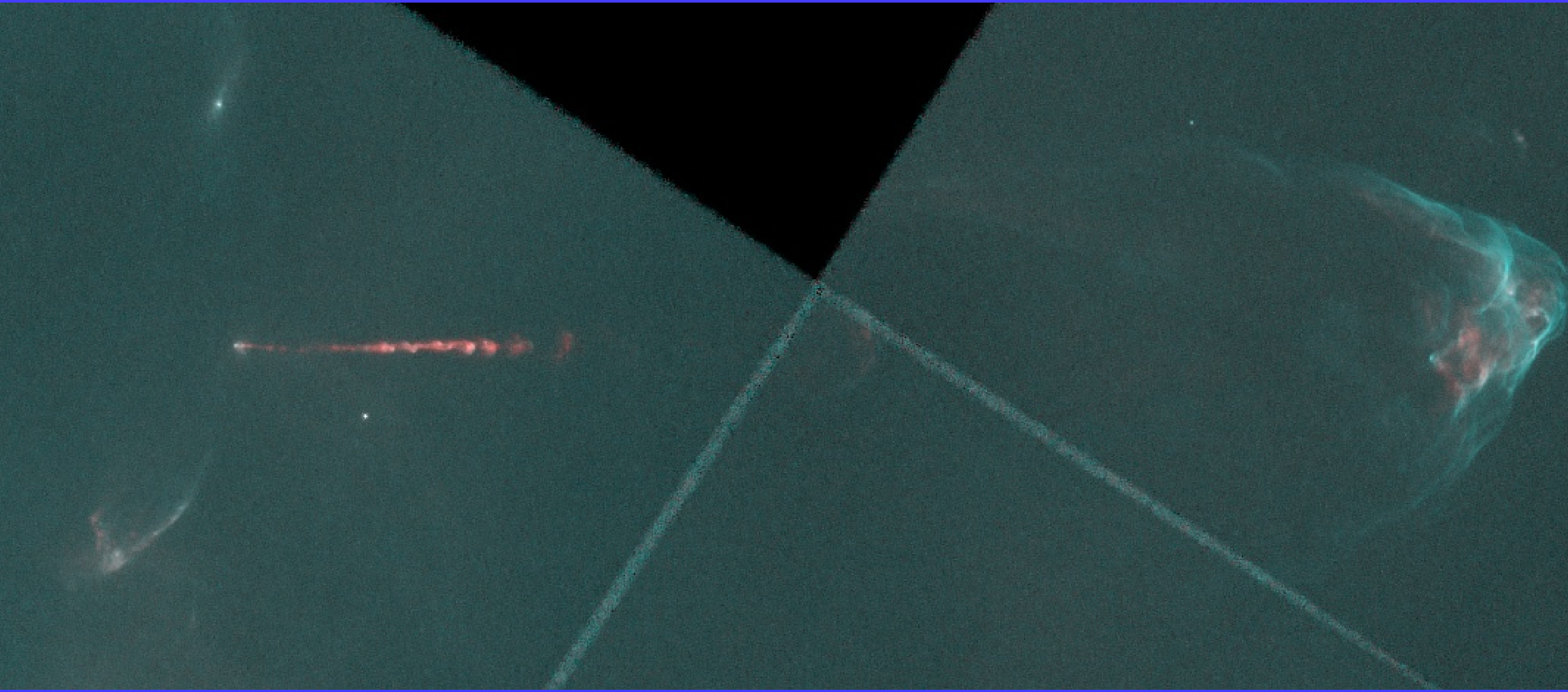
Protostellar Jets the Most Spectactular Manifestation of the Star Formation Process

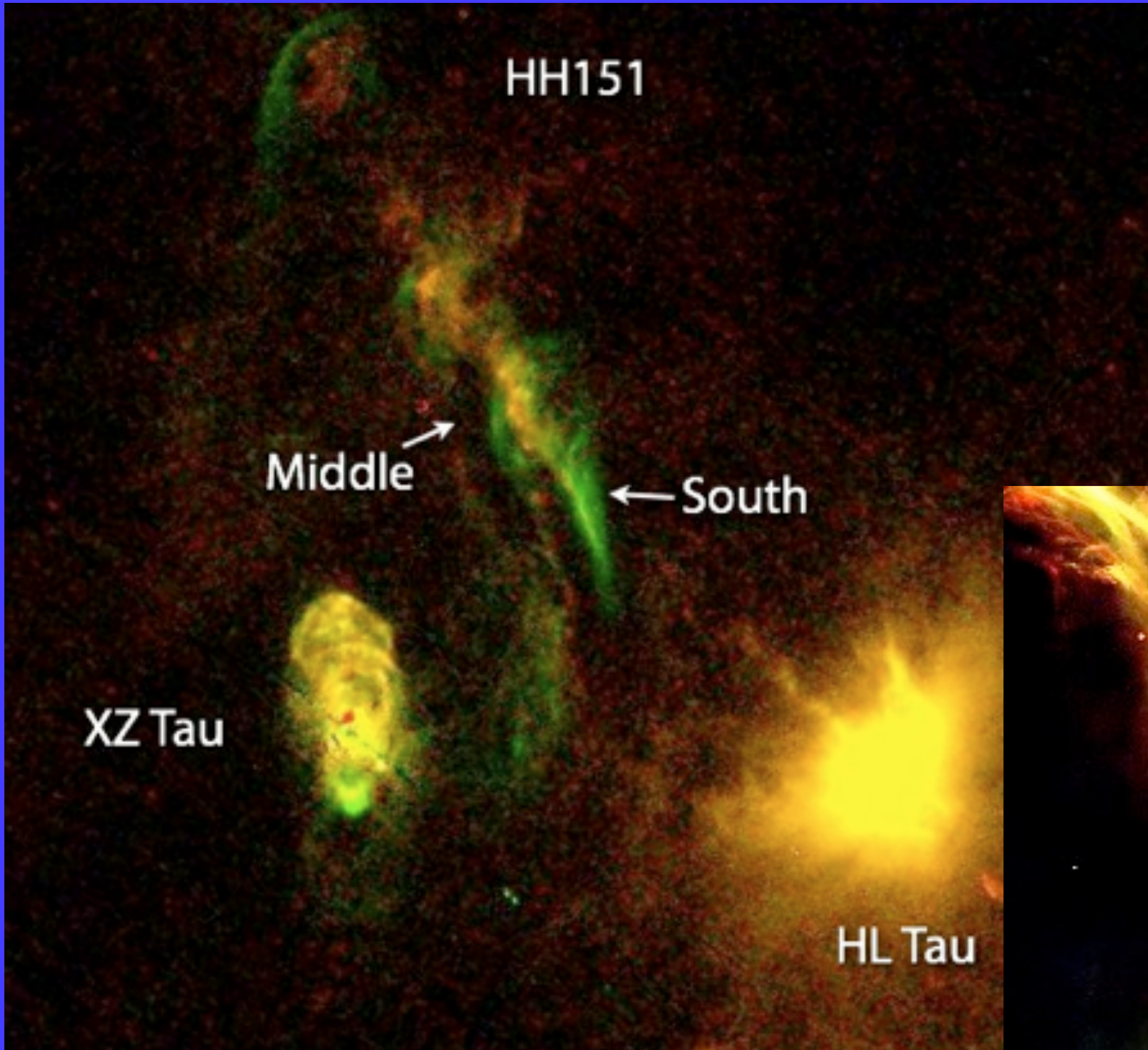
The mechanism for launching jets

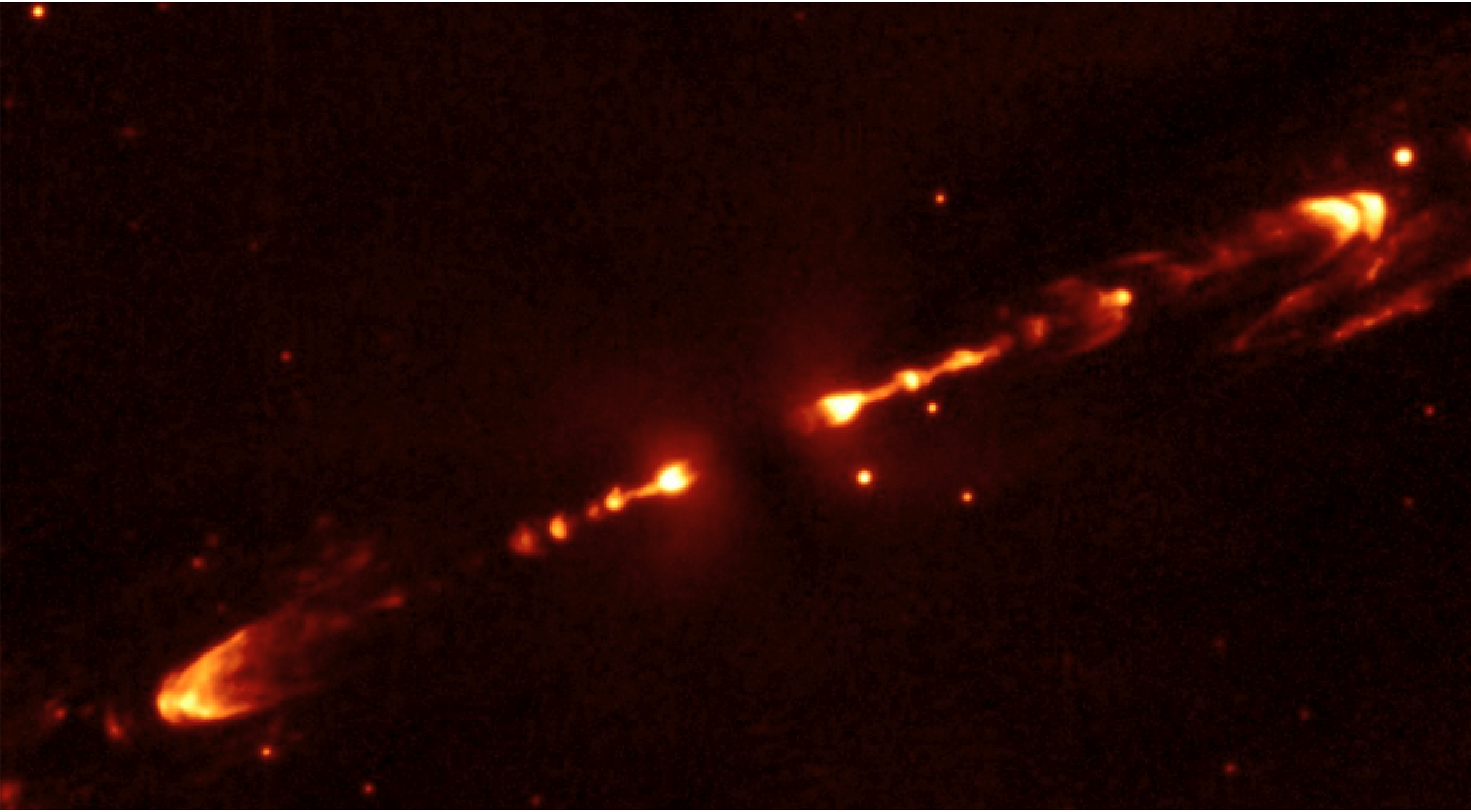


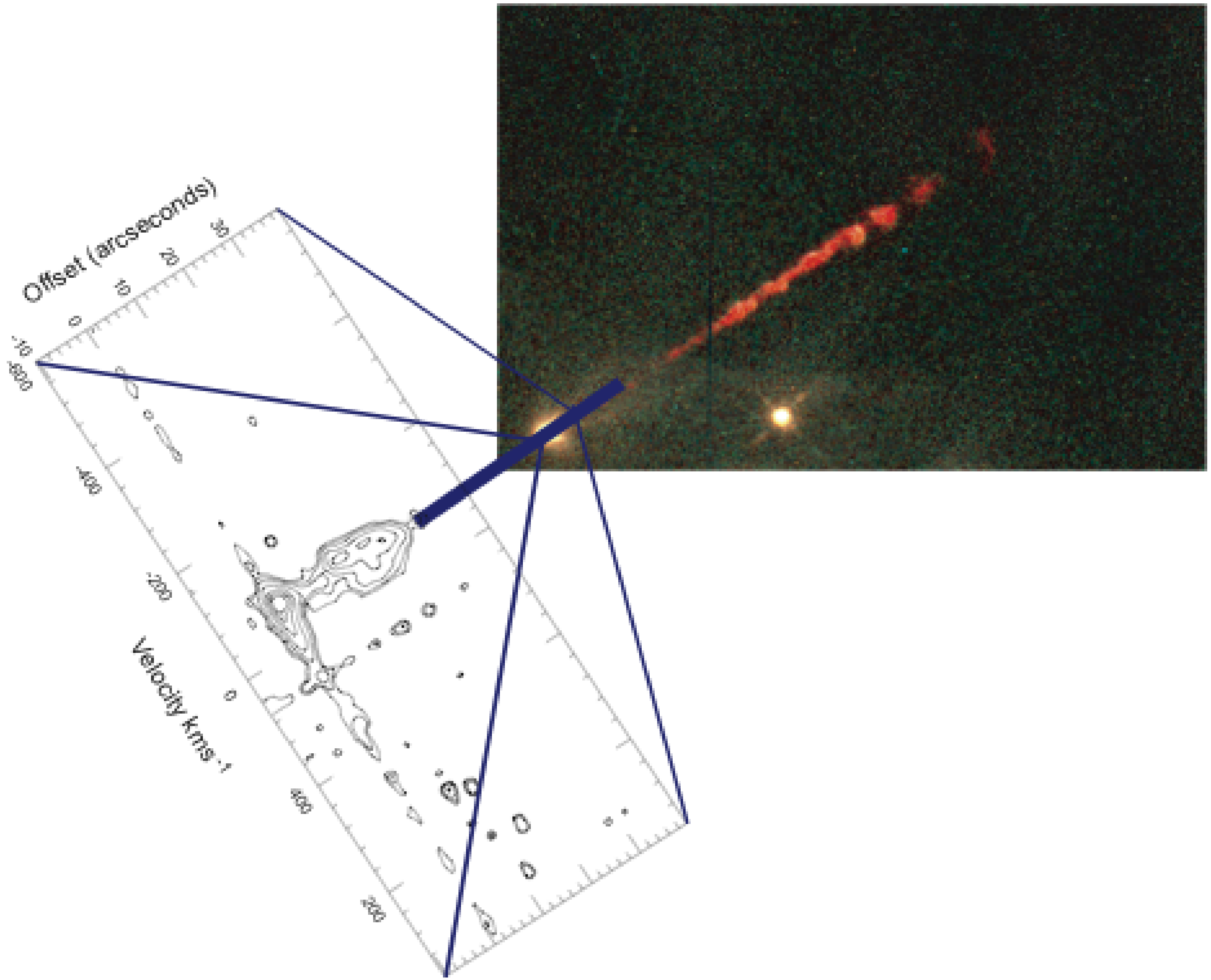






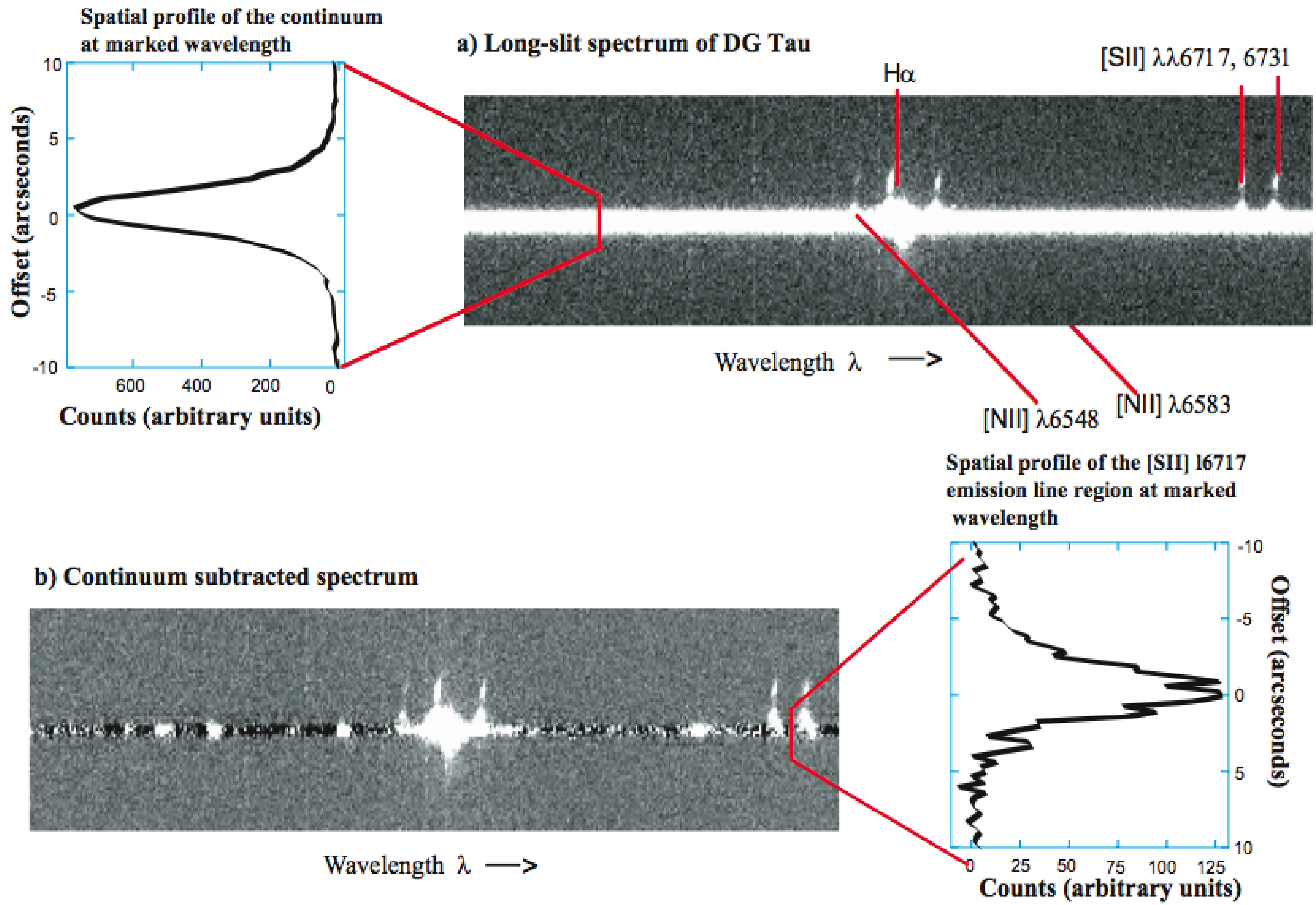

HH151
Middle
South
XZ Tau
HL Tau



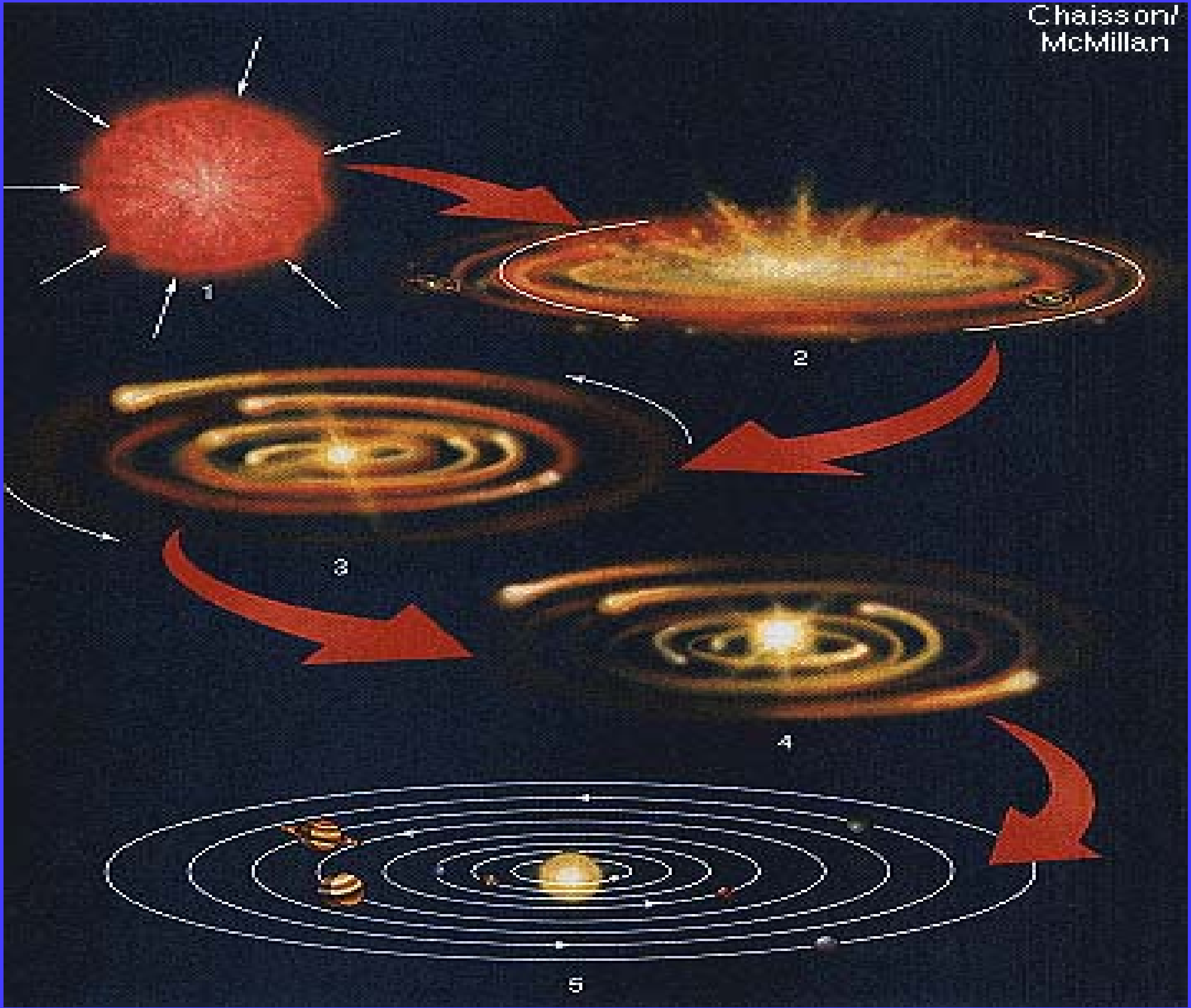


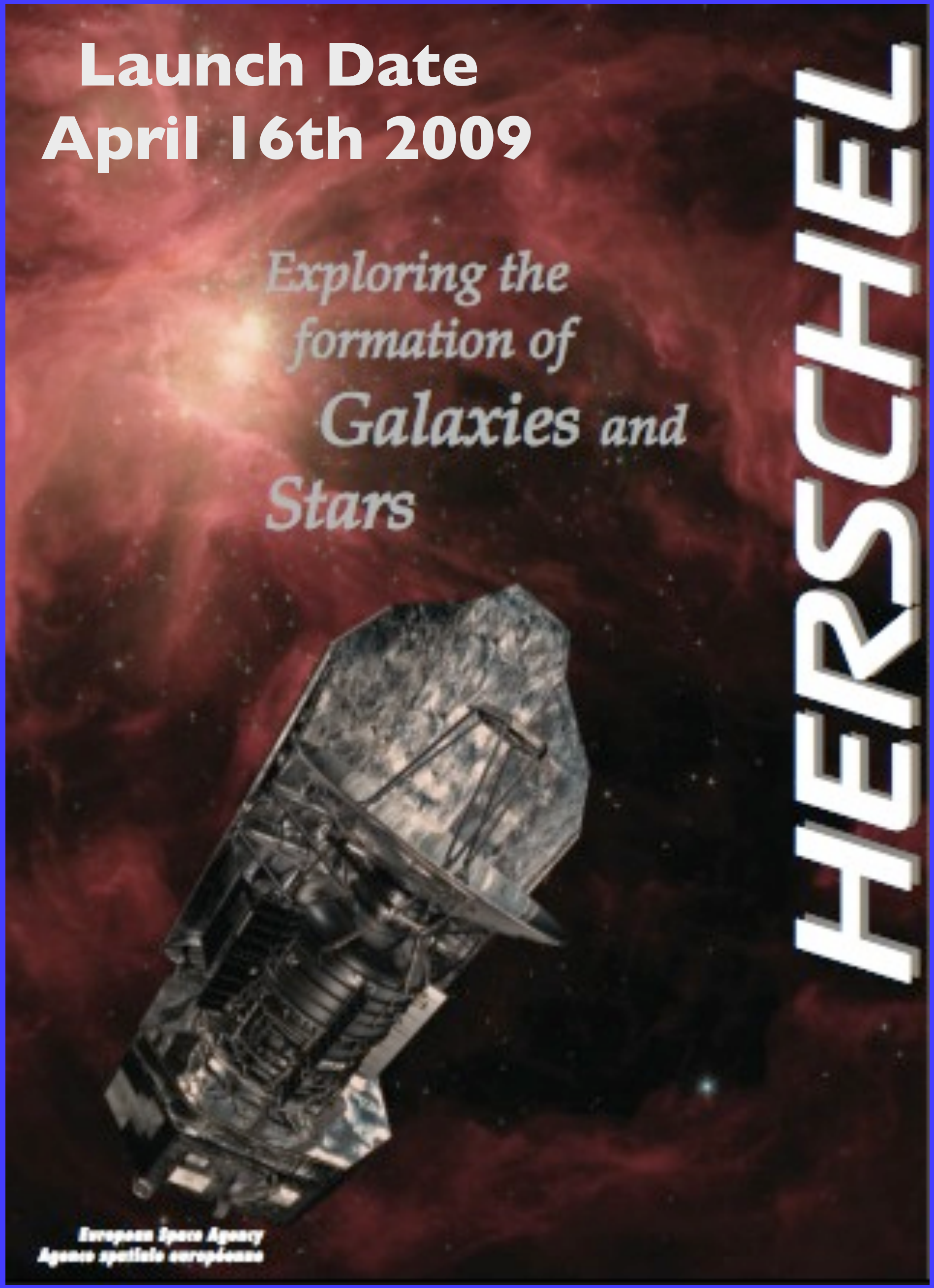
Offset (arcseconds)
-10
0
10
20
30
-600
-400
-200
0
200
400
Velocity kms -1

Forbidden Emission Lines are Important



Proto-Planetary Disks

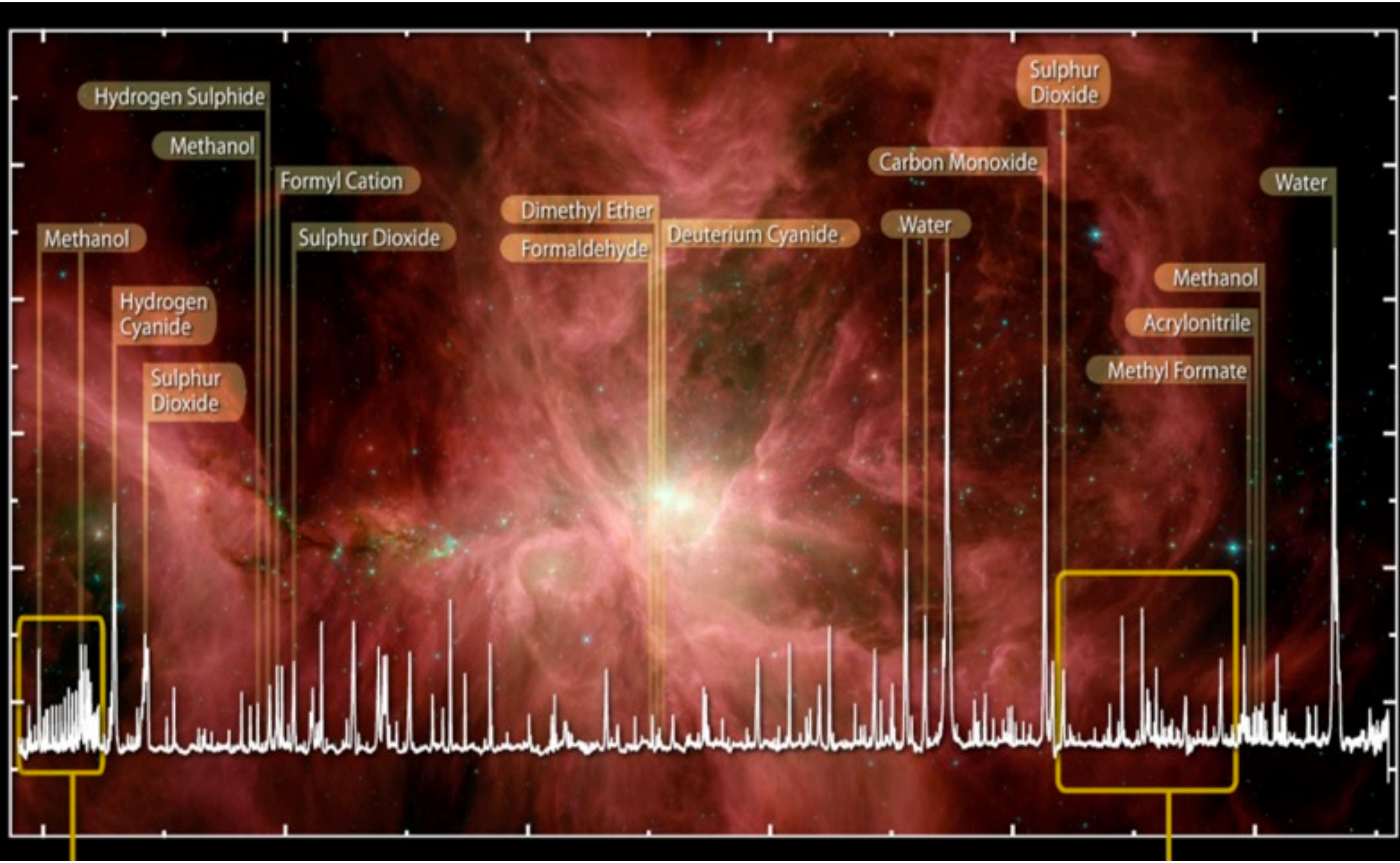

Chaisson/
McMillan
1
2
3
4
5



It will perform imaging photometry and spectroscopy in the far infrared and submillimetre part of the spectrum,

Herschel is the only space facility dedicated to the submillimetre and far infrared part of the spectrum.

Herschel will study the origins of the solar system and star birth. The sub-mm and FIR probes the coldest places in the universe and therefore is perfect for studying molecular clouds where stars in their earliest stages exist

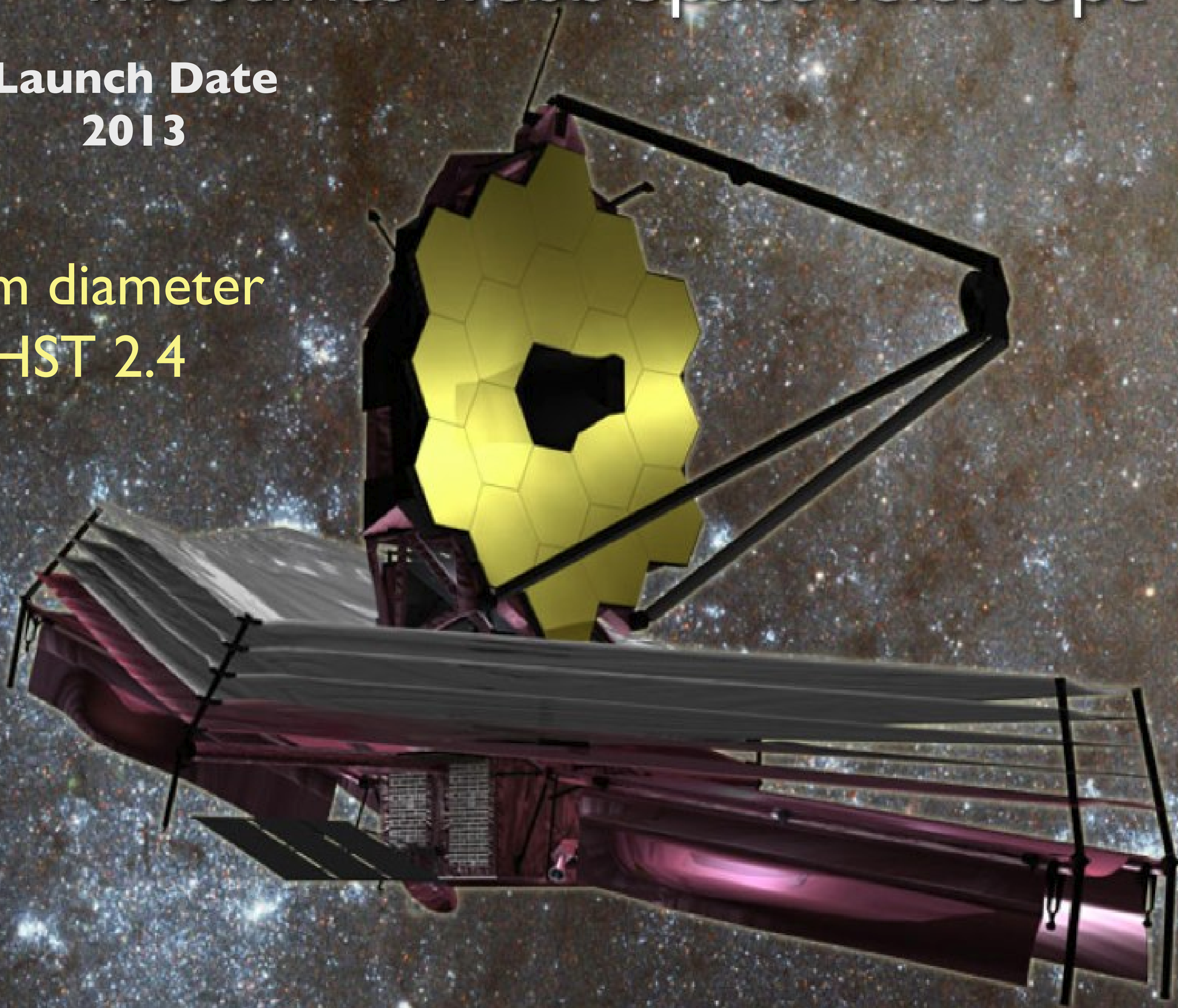


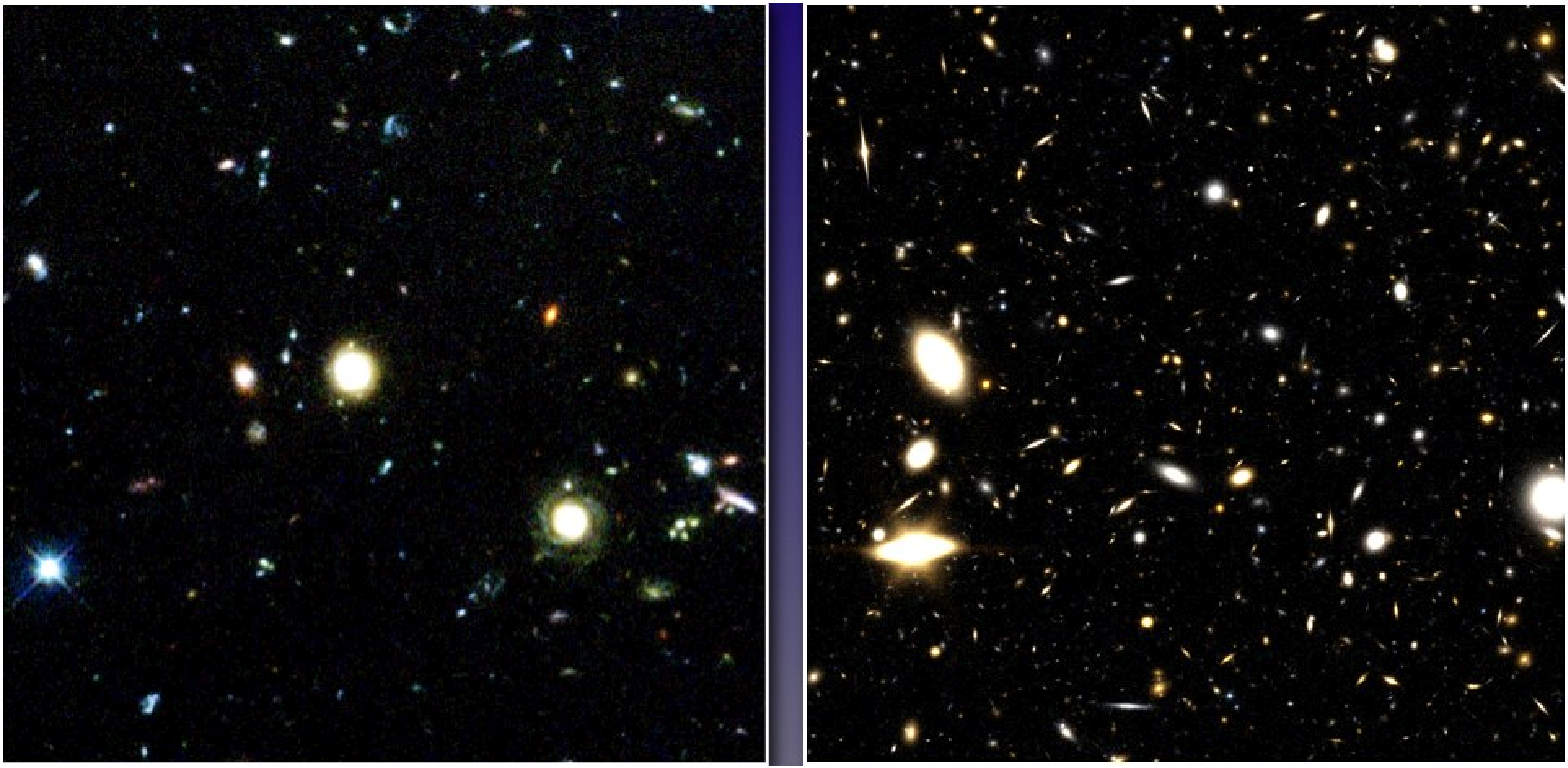
Hydrogen Sulphide
Methanol
Formyl Cation
Methanol
Sulphur Dioxide
Hydrogen Cyanide
Sulphur Dioxide
Dimethyl Ether
Formaldehyde
Deuterium Cyanide
Carbon Monoxide
Water
Sulphur Dioxide
Water
Methanol
Acrylonitrile
Methyl Formate

The James Webb Space Telescope

Launch Date
2013

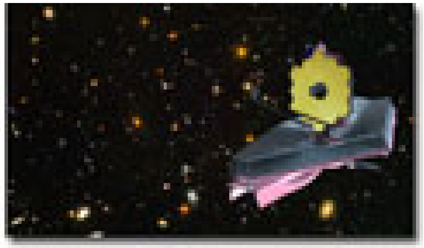
6.5m diameter
HST 2.4



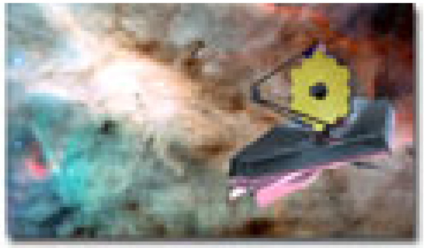


JWST Science

The James Webb Space Telescope (JWST) will be a giant leap forward in our quest to understand the Universe and our origins. The JWST will examine every phase of cosmic history: from the first luminous glows after the Big Bang to the formation of galaxies, stars, and planets to the evolution of our own solar system. The science goals for the JWST can be grouped into four themes:

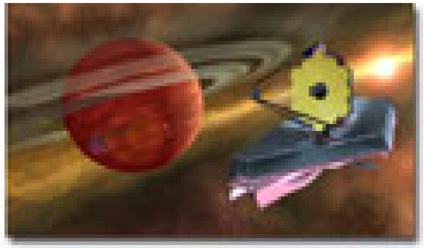


The End of the Dark Ages: First Light and Reionization seeks to identify the first bright objects that formed in the early Universe, and follow the ionization history.



Assembly of Galaxies will determine how galaxies and dark matter, including gas, stars, metals, physical structures (like spiral arms) and active nuclei evolved to the present day.

The Birth of Stars and Protoplanetary Systems focuses on the birth and early development of stars and the formation of planets.



Planetary Systems and the Origins of Life studies the physical and chemical properties of solar systems (including our own) and where the building blocks of life may be present.

How do Planets Form?

Initially grain size < 1mu to a few mm

Growth of ice mantles and grains to interstellar gravel, max size a few cm's

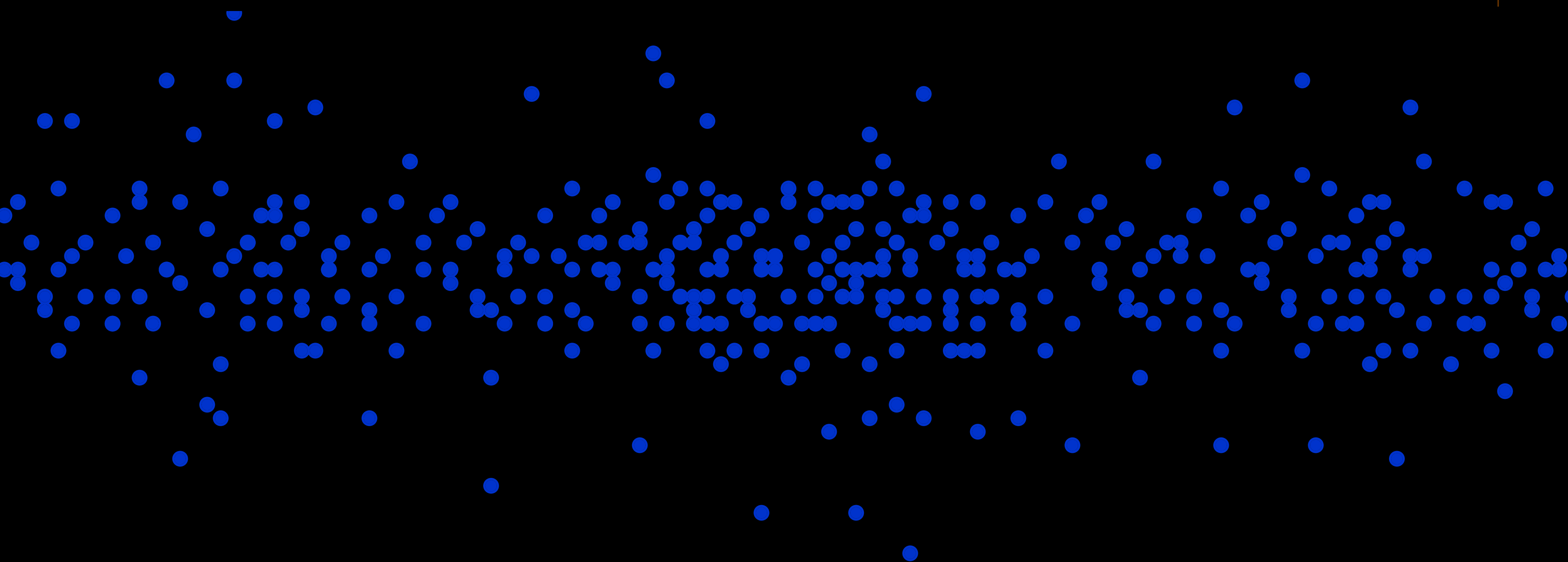
Growth of ice balls, rocks, max size a few m's

Planetisimal Formation km's in size

Planetisimal's accelerated by each others gravity, 10-1000 km's protoplanets formed

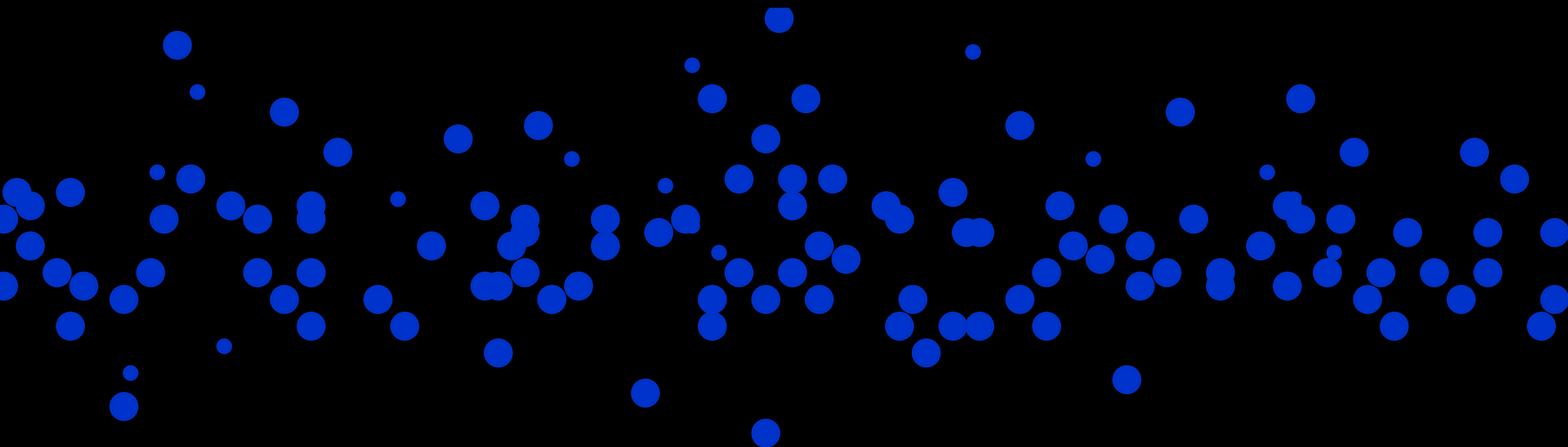
timescale of millions of years

A cross-section through a circumstellar disk



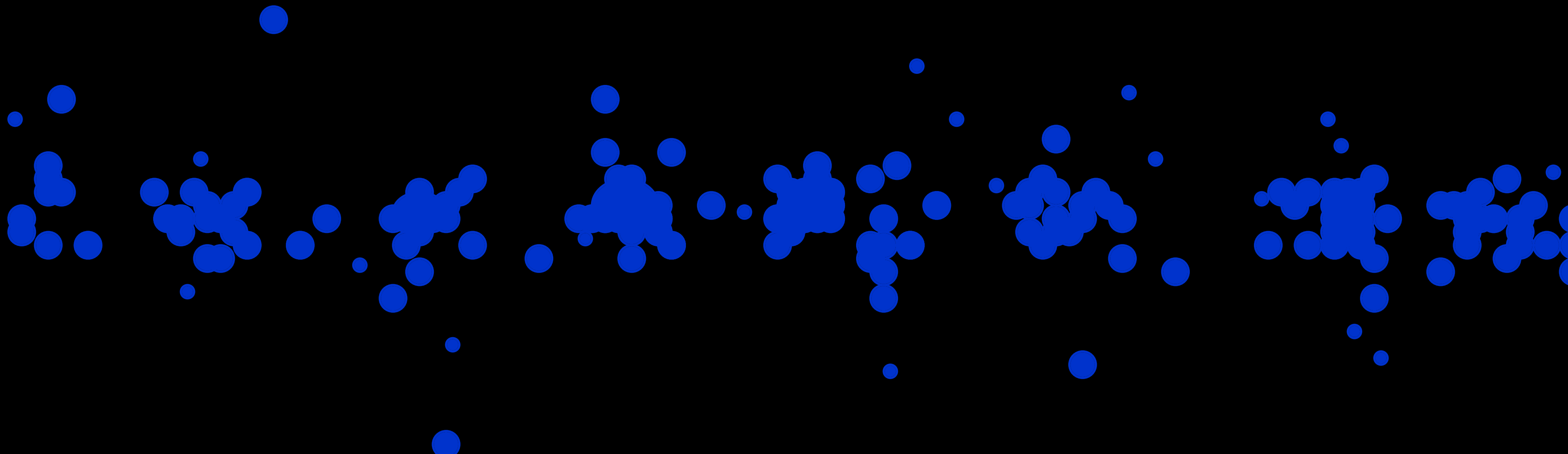
Grain size < 1mu to a few mm

Growth of ice mantles and grains to interstellar gravel



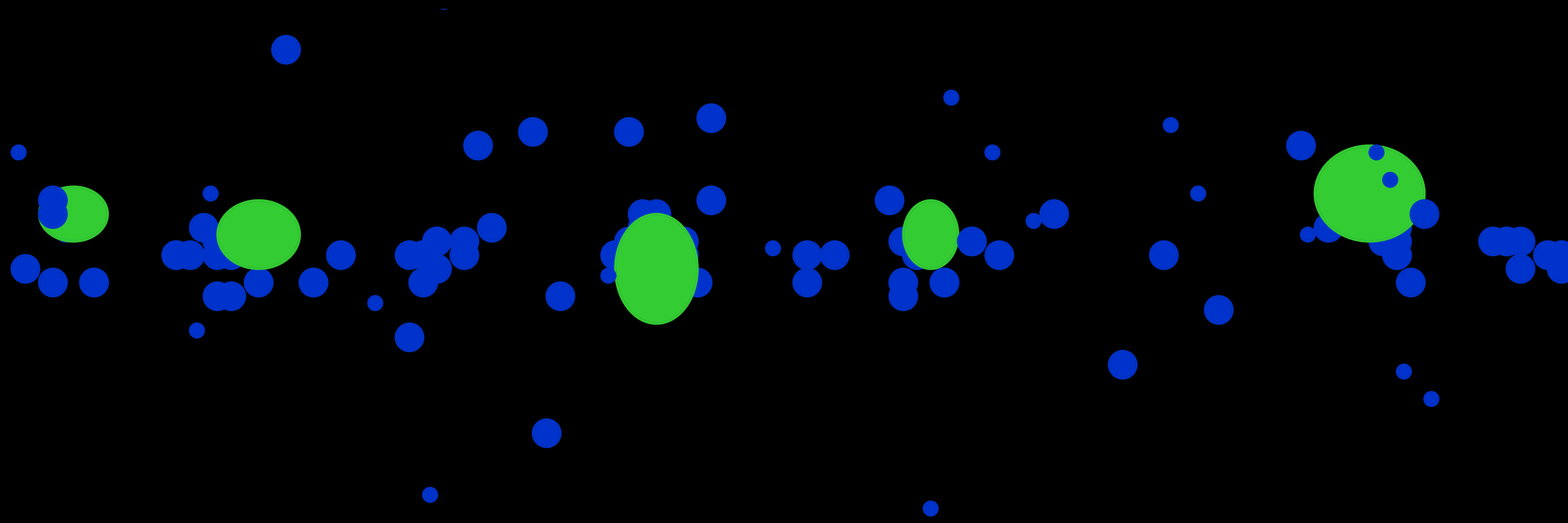
Maximum size: few centimeters

Growth of ice balls, rocks



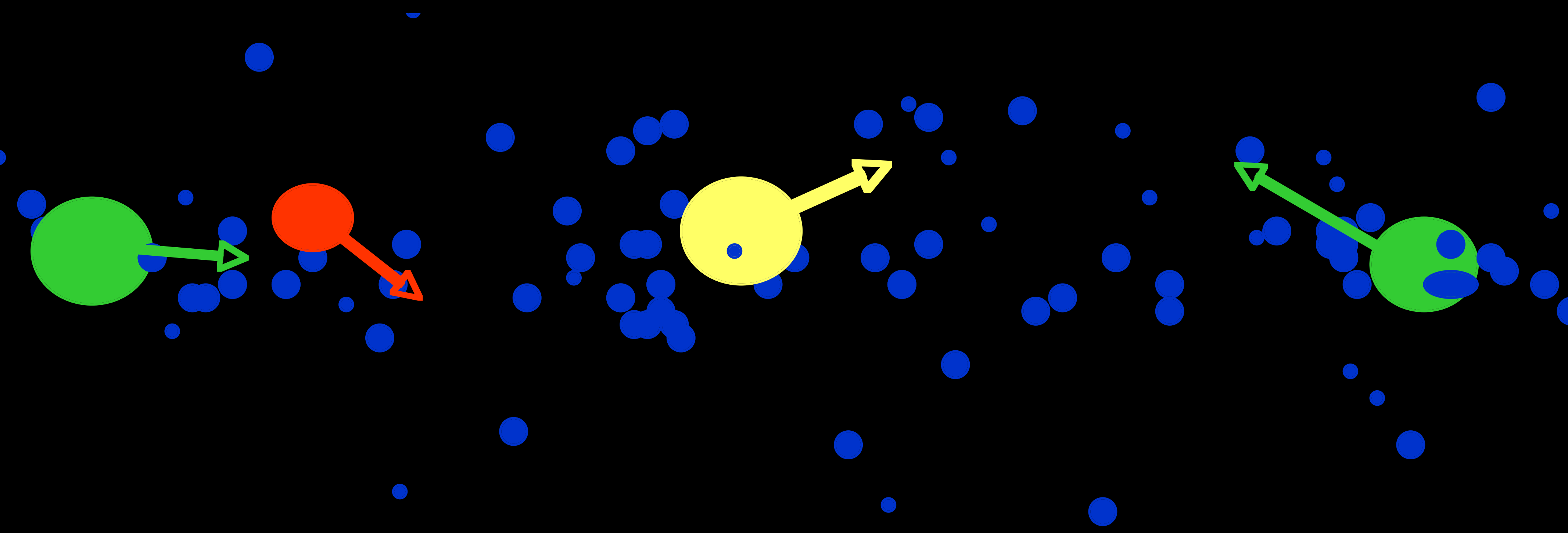
Maximum size: few meters

Planetisimal Formation



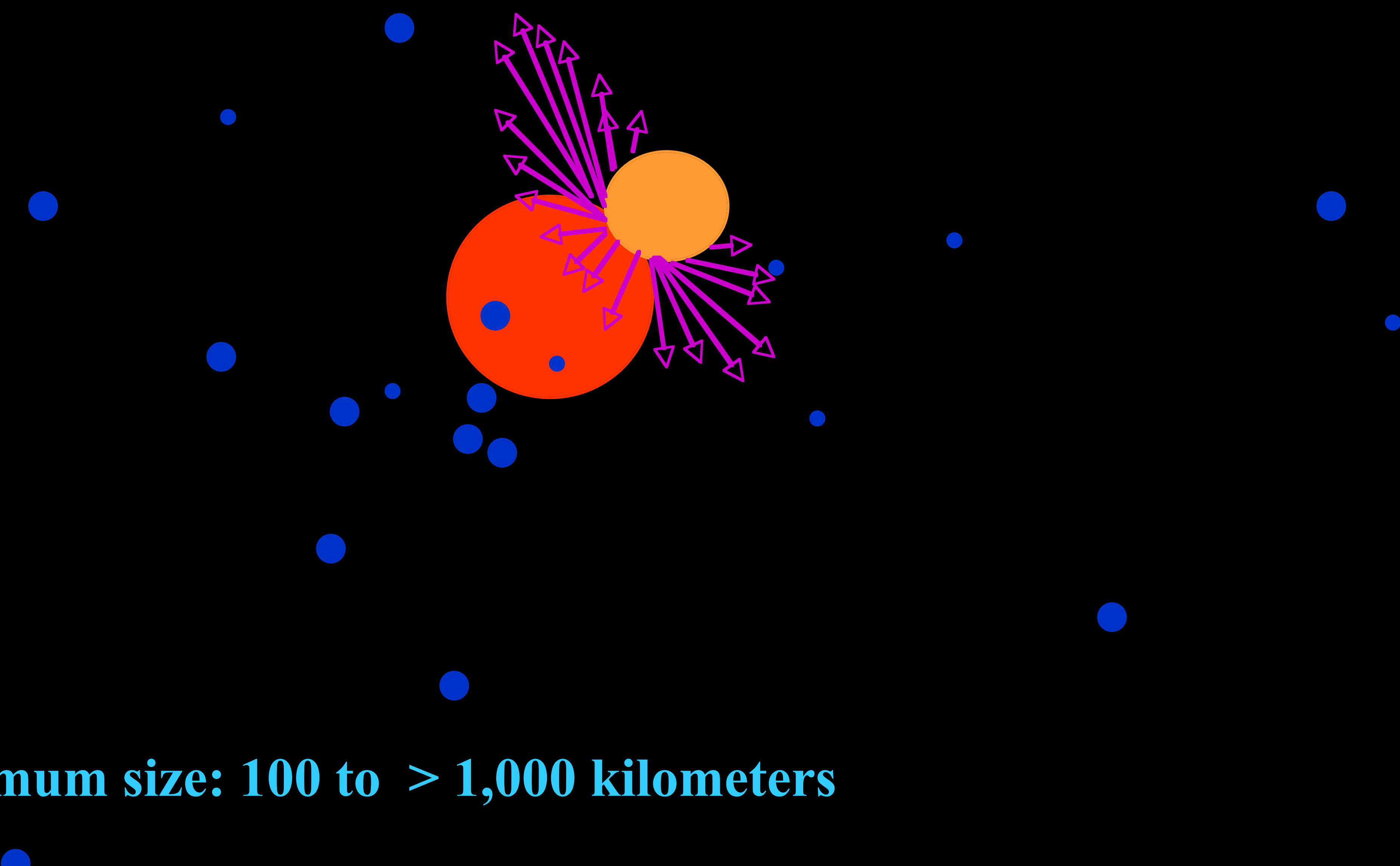
Maximum grain size: few kilometers

Planetisimal's accelerated by each others gravity

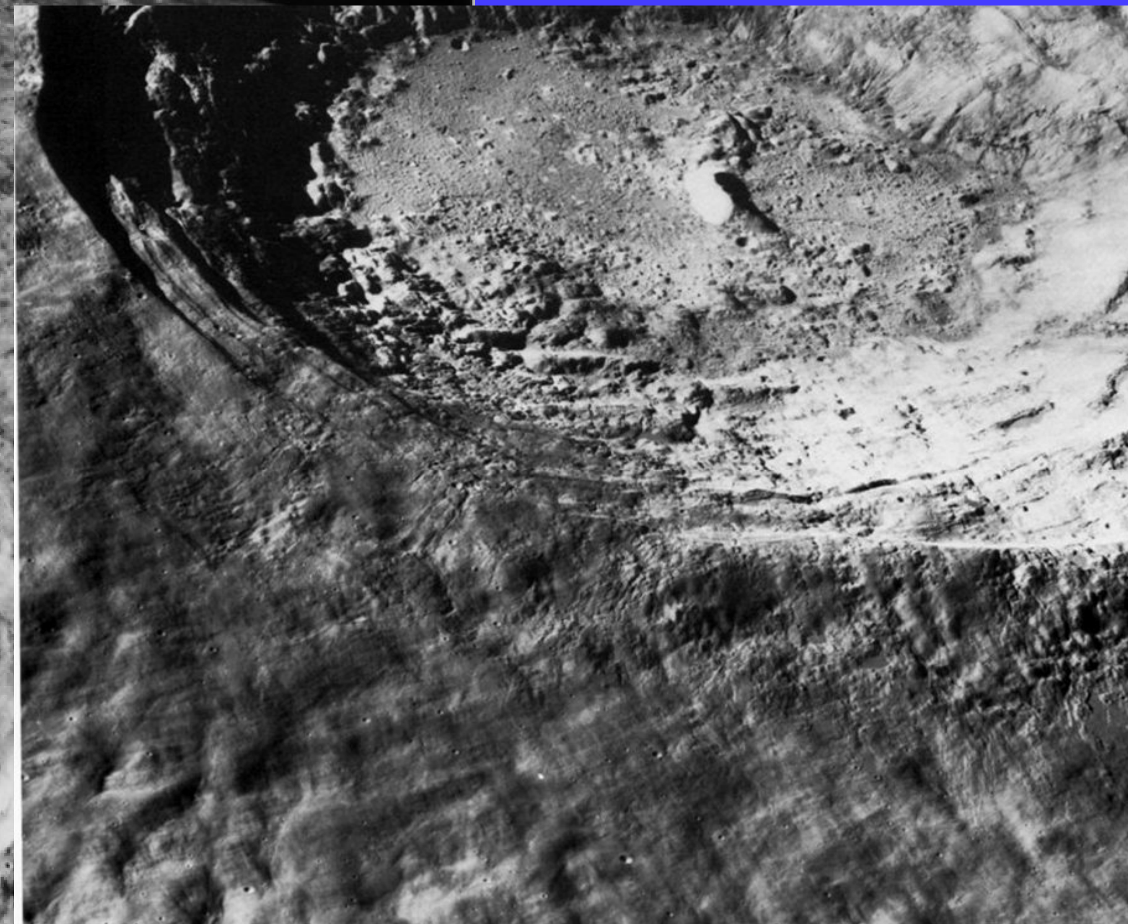


Maximum size: 10 to 1,000 kilometers

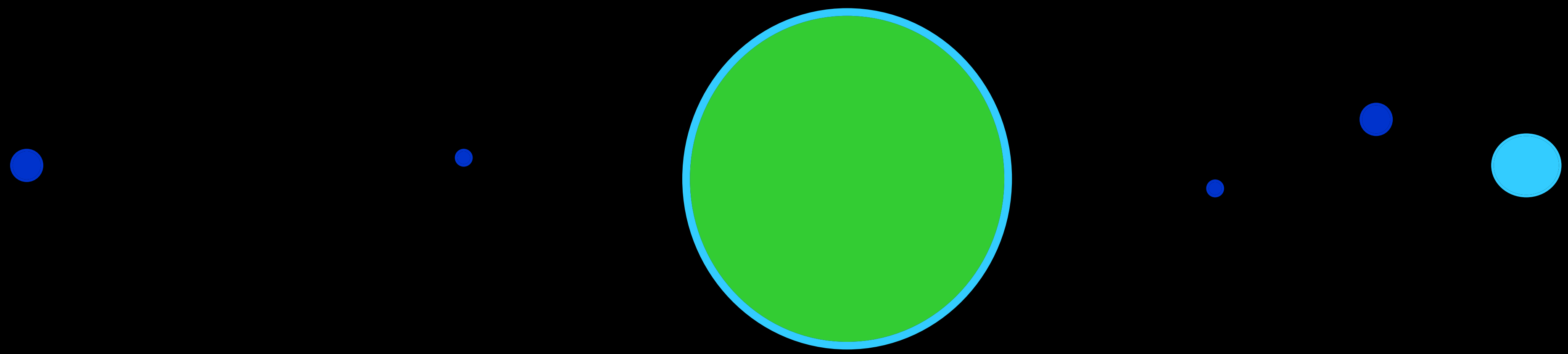
Protoplanet collisions



Maximum size: 100 to > 1,000 kilometers

A Young Planet!



Maximum size: > 10,000 kilometers

Methods for Finding Planets

As of February 2009, 342 exoplanets are listed in the Extrasolar Planets Encyclopaedia.

1. Direct Detection
2. Astrometry
3. Radial Velocity of Doppler Method
4. The Transit Method

Initially grain size < 1mu to a few mm

Growth of ice mantles and grains to interstellar gravel, max size a few cm's

Growth of ice balls, rocks, max size a few m's

Planetisimal Formation km's in size

Planetisimal's accelerated by each others gravity, 10-1000 km's protoplanets formed

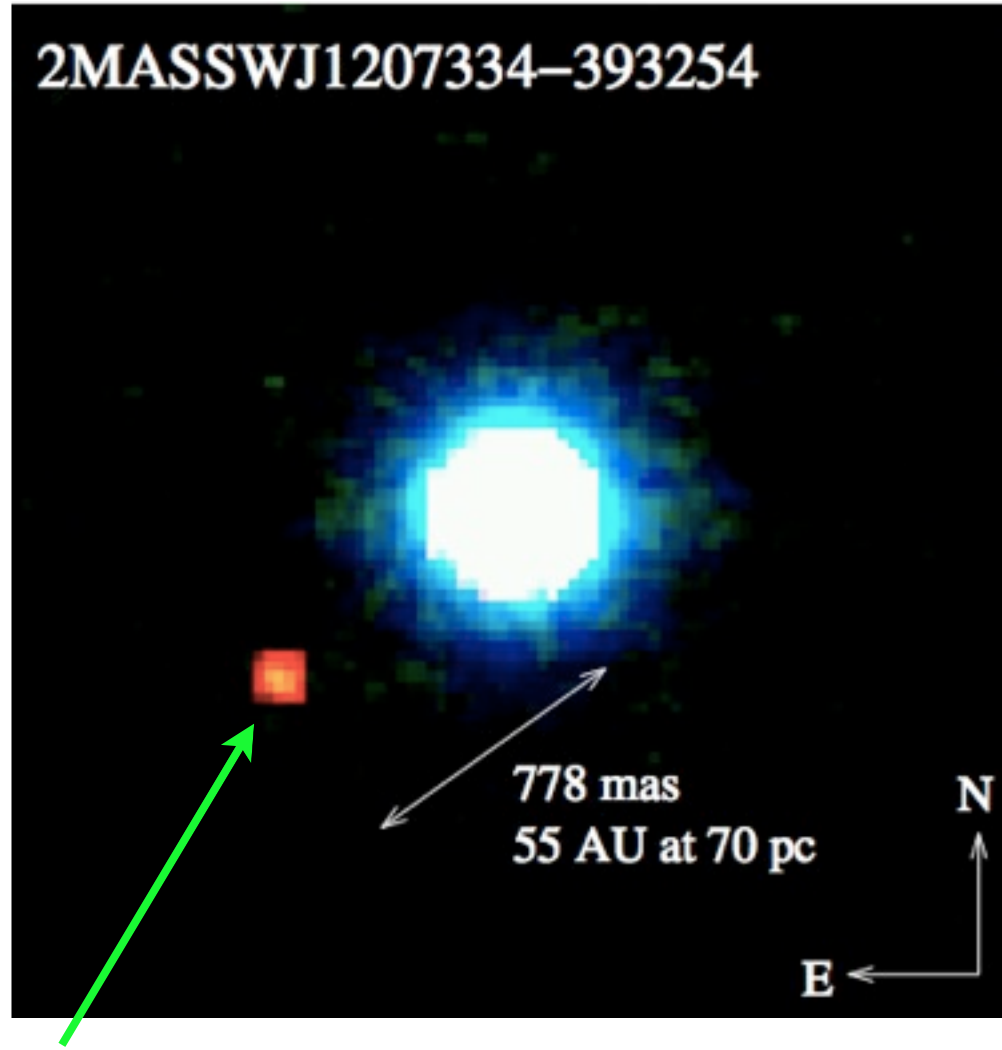
timescale of millions of years

Direct Detection

Planets are extremely faint light sources compared to their parent stars. At visible wavelengths, they usually have less than a millionth of their parent star's brightness. In addition to the intrinsic difficulty of detecting such a faint light source, the parent star causes a glare that washes it out.

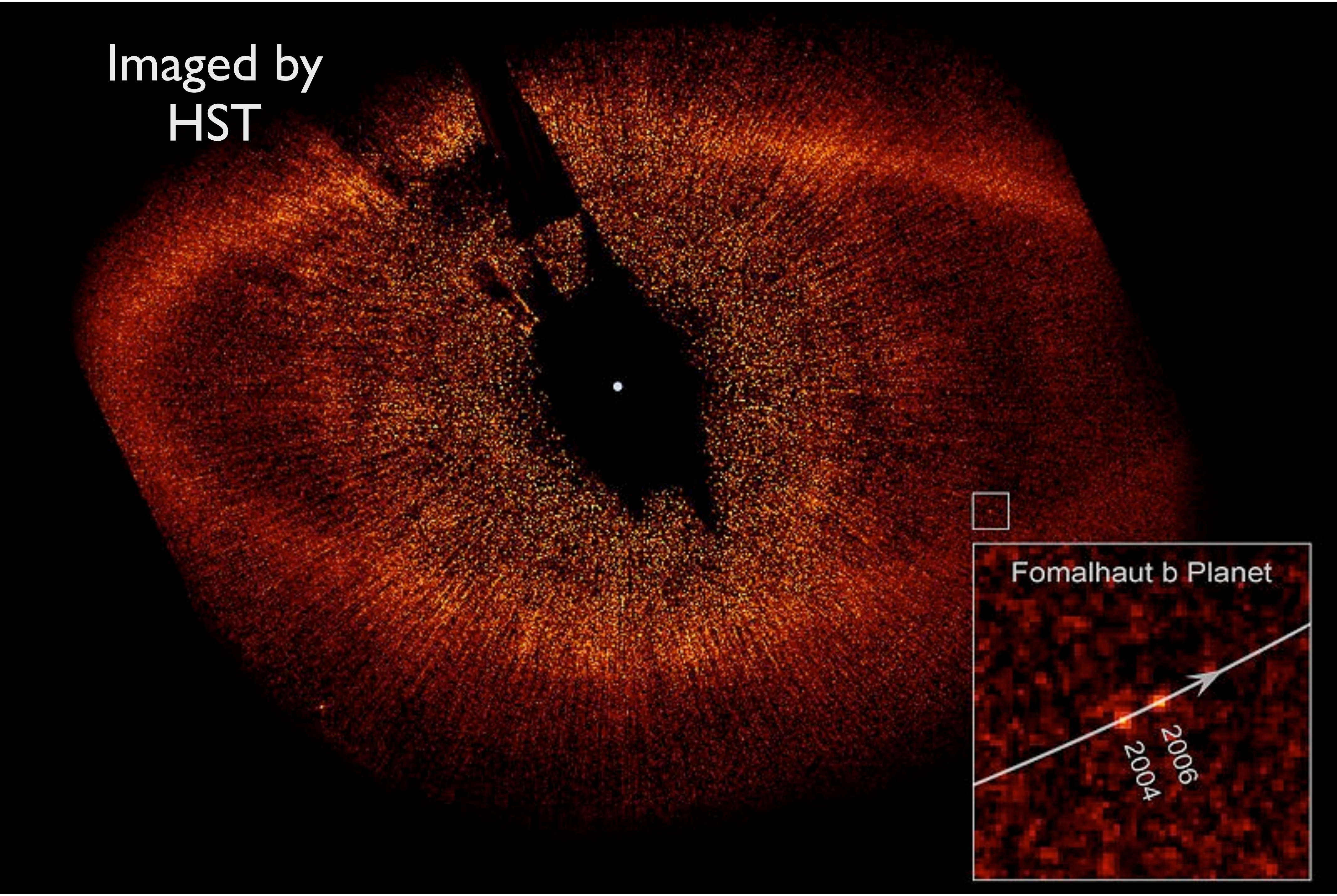
For those reasons, current telescopes can only directly image exoplanets under exceptional circumstances. Specifically, it may be possible when the planet is especially large (considerably larger than Jupiter, widely separated from its parent star, and young (so that it is hot and emits intense infrared radiation).

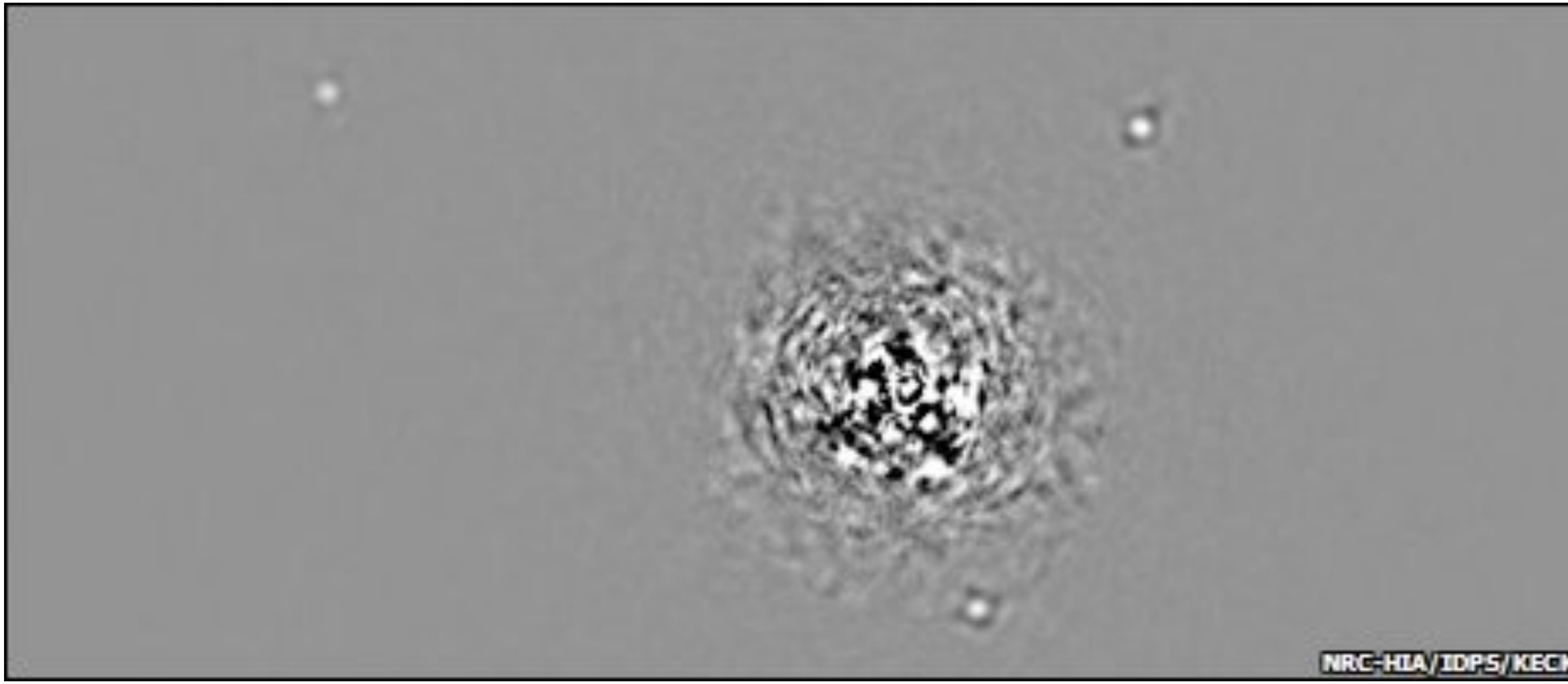
The vast majority of known extrasolar planets have been discovered through indirect methods.

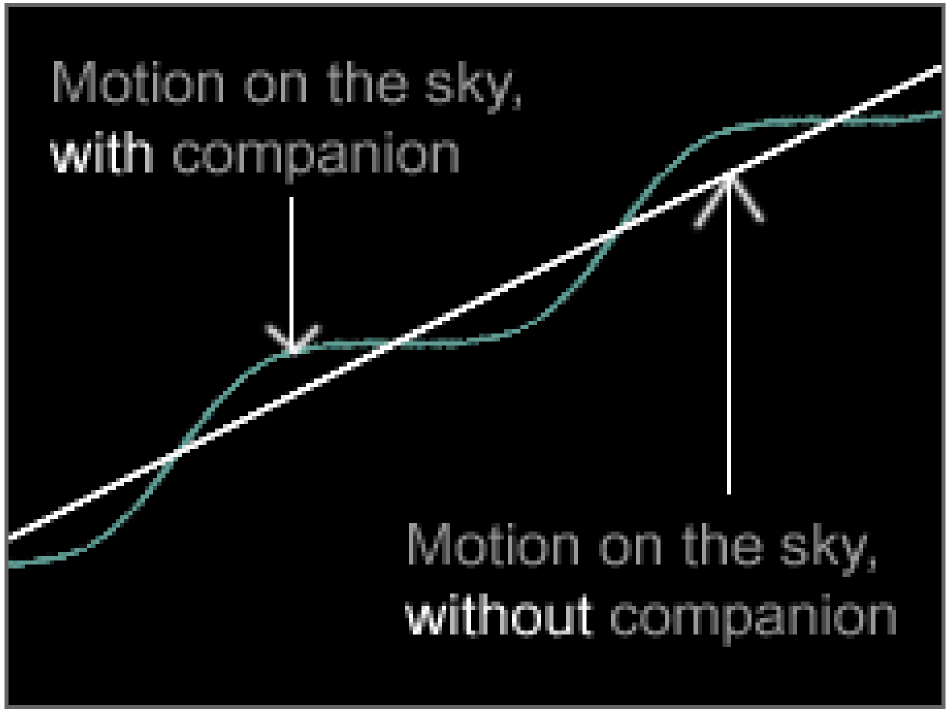


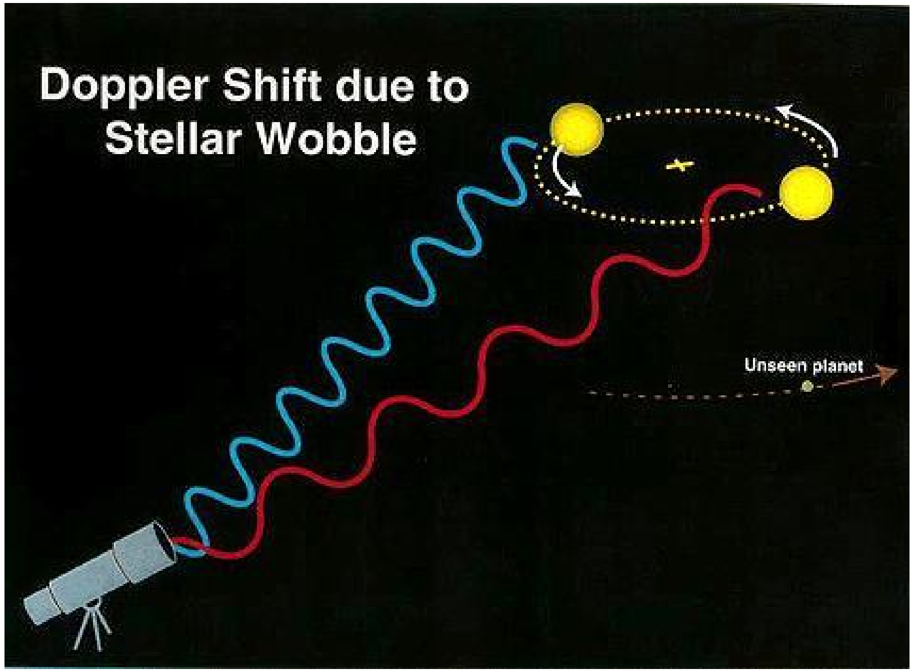
2M1207b up until Nov '08 the only exoplanet to be directly imaged its mass is 7 Mjup

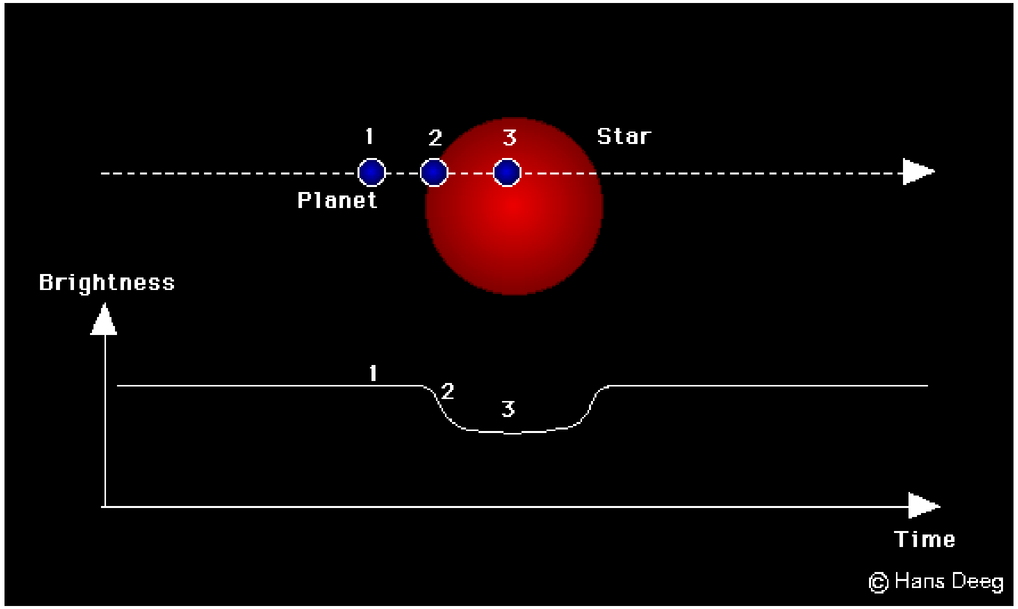
Imaged by HST




NRC-HIA/IDPS/KECK


Motion on the sky,
with companion
Motion on the sky,
without companion


Doppler Shift due to
Stellar Wobble
Unseen planet

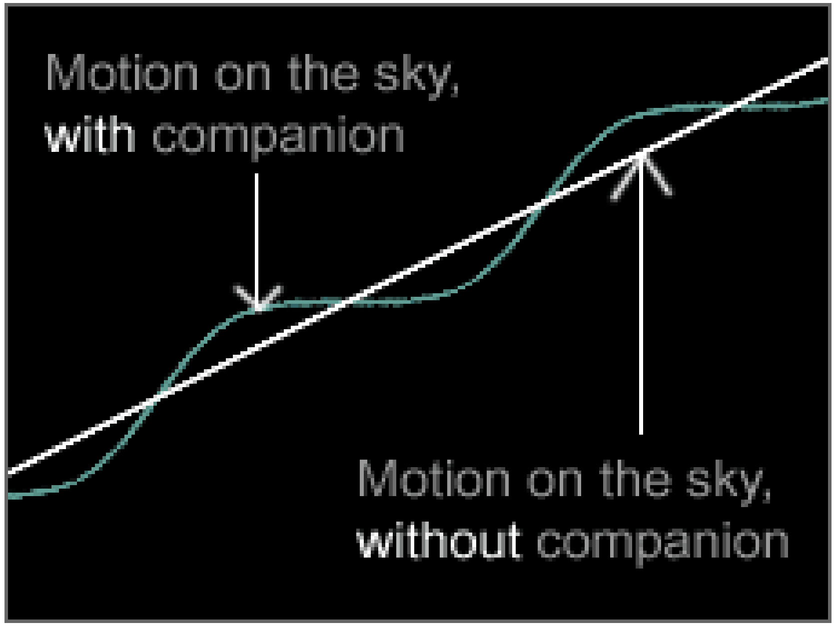

1
2
3
Star
Planet
Brightness
1
2
3
Time
© Hans Deeg

Astrometry

* Astrometry consists of precisely measuring a star's position in the sky and observing the ways in which that position changes over time.

*If the star has a planet, then the gravitational influence of the planet will cause the star itself to move in a tiny circular or elliptical orbit about their common center of mass.

*The astrometric method is most sensitive to planets with large orbits. However, very long observation times will be required — years, and possibly decades, as planets with larger orbits take a longer time to complete its orbit.

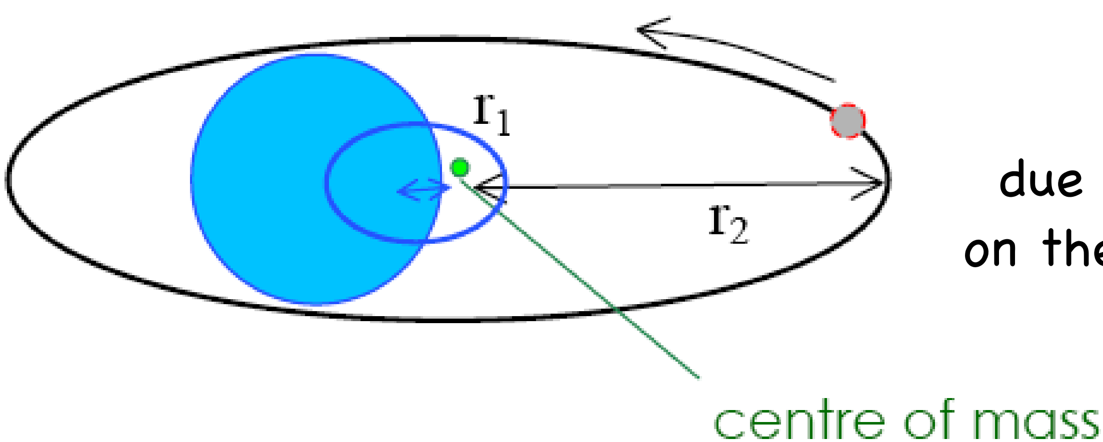


Radial Velocity

* Like the astrometric method, the radial-velocity method uses the fact that a star with a planet will move in its own small orbit in response to the planet's gravity.

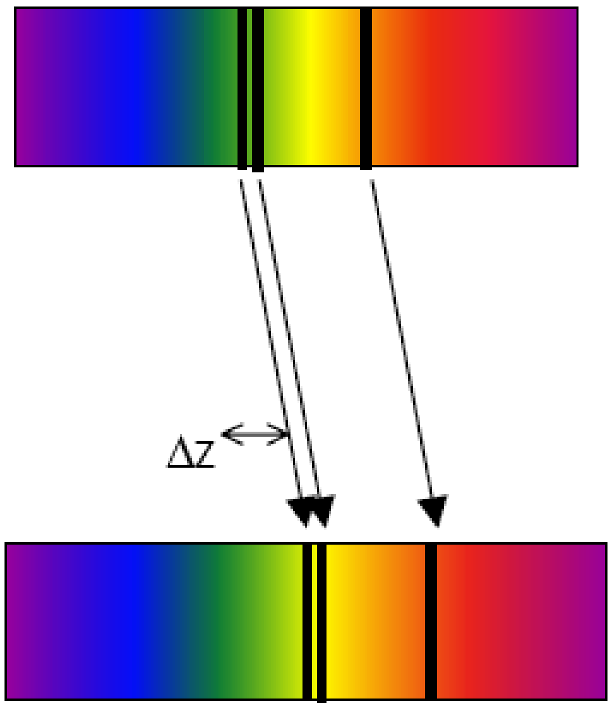
*The goal now is to measure variations in the speed with which the star moves toward or away from Earth.

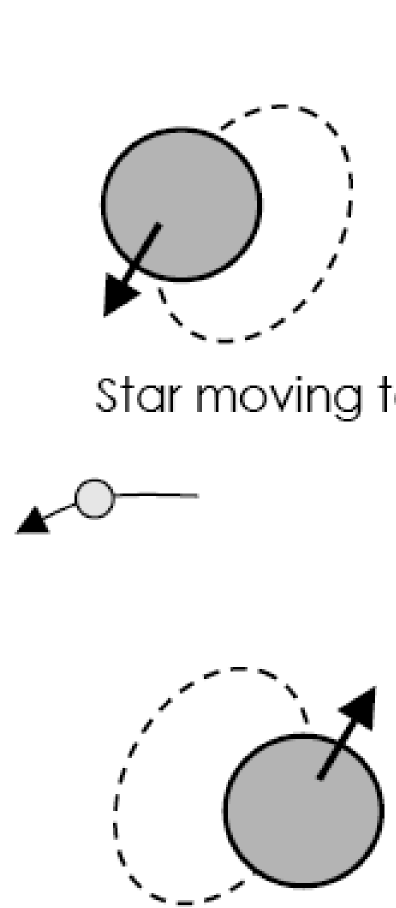
*The radial velocity can be deduced from the displacement in the parent star's spectral lines due to the Doppler Effect. Velocity variations down to 1 m/s can be detected with modern spectrometers



The star appears to wobble due to an unseen mass. Most methods rely on the doppler effect to measure the wobble

Measuring Doppler shift:





e.g. for Jupiter, the effect is only 12.5 metres per second over a 12-year period. Resolution of 10 meters per second needed to detect giant planets.

The radial velocity method also known as "Doppler method" or "wobble method" has been the most effective method to date for finding exoplanets.

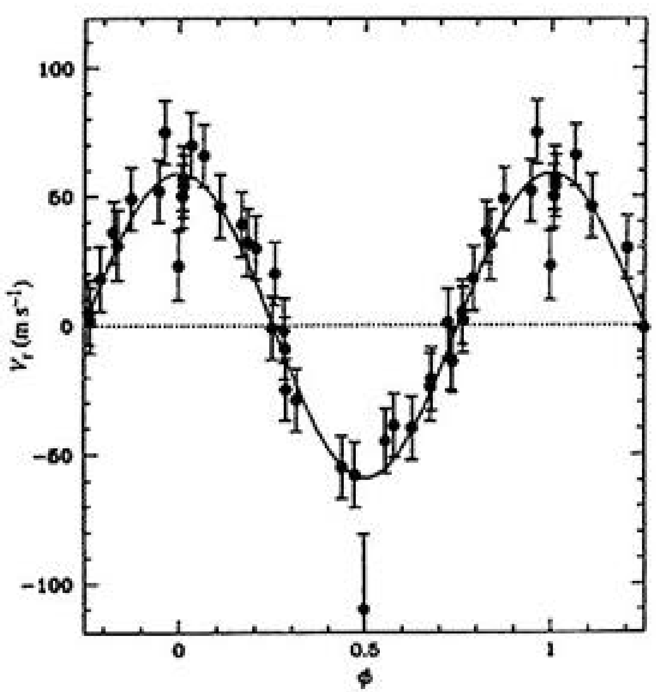
The method requires high signal to noise ratios to achieve high precision, and so is generally only used for relatively nearby stars out to about 160 light-years from Earth.

It easily finds massive planets that are close to stars, but detection of those orbiting at great distances requires many years of observation.

The radial-velocity method can be used to confirm findings made by using the transit method. When both methods are used in combination, then the planet's true mass can be estimated.

51 Pegasi b (the first exoplanet):

In October 1995, Michel Mayor and Didier Queloz announced the discovery of a exoplanet of 0.5 M_{jup} orbiting a solar type star called 51 Peg.



The variations in velocity has an amplitude of 59 m/s and a period of 4.2293 ± 0.0011 days. These observations were taken in Sep. 1994 and Sep. 1995.

The Transit Method

* If a planet crosses (transits) in front of its parent star's disk, then the observed visual brightness of the star drops a small amount. The amount the star dims depends on its size and on the size of the planet. For example, in the case of HD 209458, the star dims 1.7%.

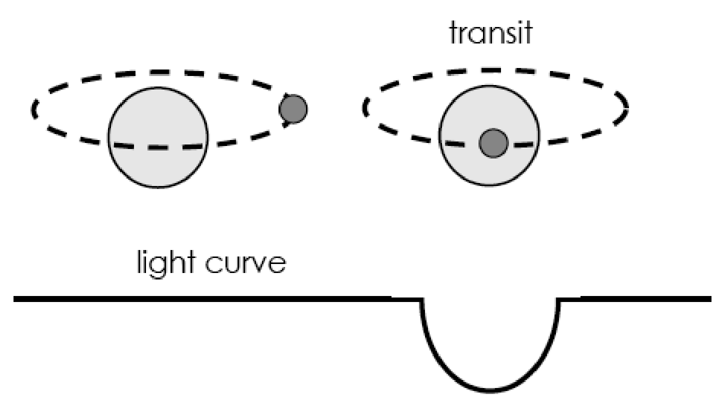
* This method has two major disadvantages. First of all, planetary transits are only observable for planets whose orbits happen to be perfectly aligned from astronomers' vantage point.

* Secondly, the method suffers from a high rate of false detections. A transit detection requires additional confirmation, typically from the radial-velocity method.

* The main advantage of the transit method is that the size of the planet can be determined from the lightcurve. When combined with the radial velocity method (which determines the planet's mass) one can determine the density of the planet, and hence learn something about the planet's physical structure.

Transit method:

Can observe a dip in the brightness of a star caused by a planet moving in front of it (a transit). E.g. recent (2005) observation: star (XO –1) was dimmed by 1.8% for 3 hours by a $1.3M_{jupiter}$ planet (XO-1b).



For this method to work the planet's orbit must be tilted nearly edge-on.

Known Properties of Extra-solar Planets

1. Most known exoplanets orbit stars roughly similar to our own Sun, that is, main-sequence stars of spectral categories F, G, or K. One reason is simply that planet search programs have tended to concentrate on such stars.

2. The vast majority of exoplanets found so far have high masses. All but two of them have more than ten times the mass of Earth. Many are considerably more massive than Jupiter. However, these high masses are in large part an observational selection effect: all detection methods are much more likely to discover massive planets.

3. Many exoplanets orbit much closer around their parent star than any planet in our own Solar System orbits around the Sun. Again, that is mainly an observational selection effect. The radial-velocity method is most sensitive to planets with such small orbits.

4. The eccentricity of an orbit is a measure of how elliptical (elongated) it is. Most known exoplanets have quite eccentric orbits. This is not an observational selection effect, since a planet can be detected about a star equally well regardless of the eccentricity of its orbit. The prevalence of elliptical orbits is a major puzzle, since current theories of planetary formation strongly suggest planets should form with circular (that is, non-eccentric) orbits. One possible theory is that small companions such as T dwarfs (methane-bearing brown dwarfs) can hide in such solar systems and can cause the orbits of planets to be extreme. This is also an indication that our own Solar System may be unusual, since all of its planets do follow basically circular orbits.

Exobiology

The study of how life originated on Earth and the search for it elsewhere.

Circumstellar Habitable Zone

Where can we look for life in our own solar system?

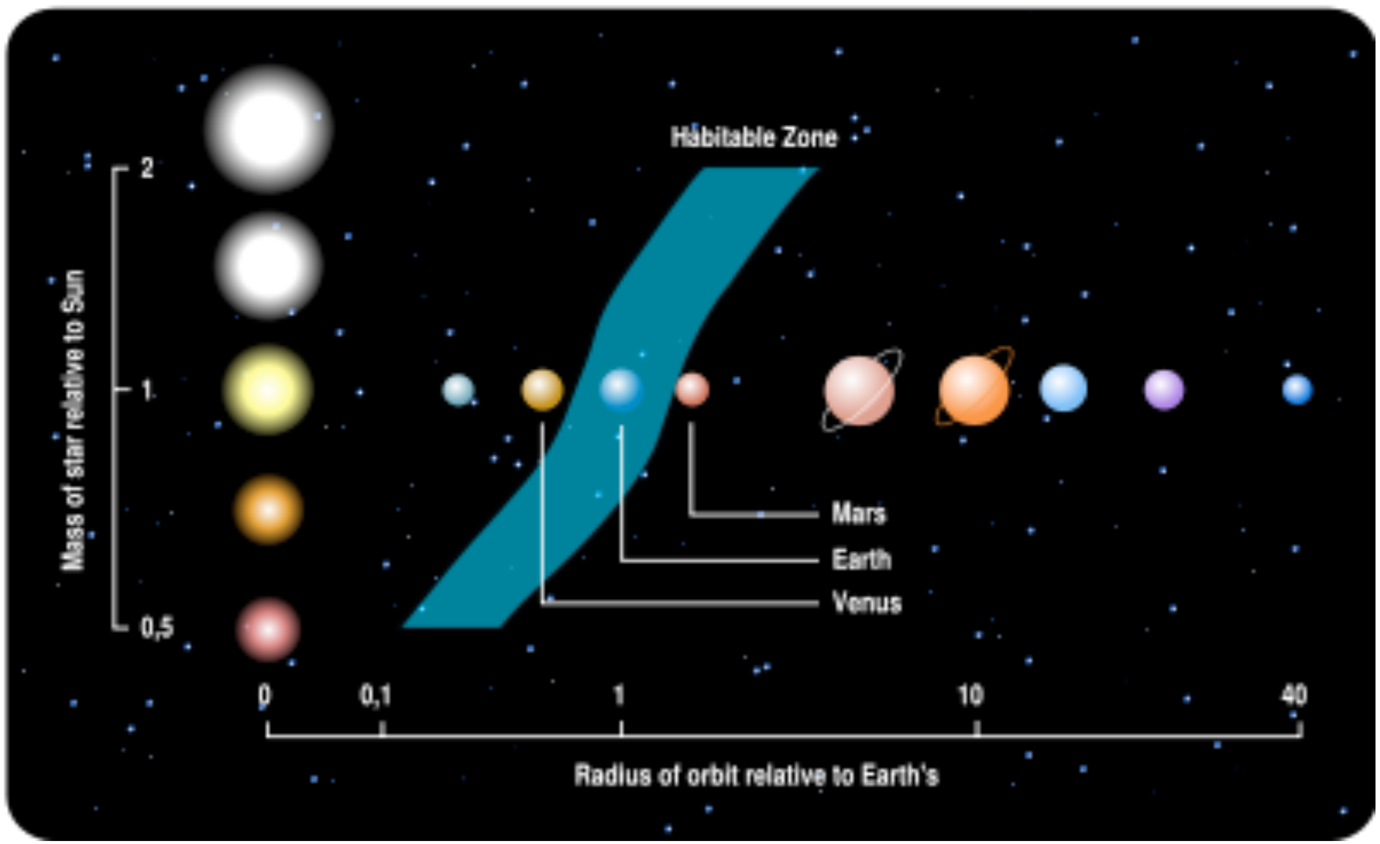
* In astronomy, **habitable zone** (**HZ**) is a region of space where conditions are favorable for the creation of life.

* The **Circumstellar HZ** (CHZ) is a ring-shaped zone around solar mass stars where we can reasonably expect life to exist.

* Within the CHZ conditions are not too hot or cold and it is possible for liquid water to survive. Also referred to as the "life zone", "Green Belt" or the "Goldilocks Zone" (because it's neither too hot nor too cold, but "just right").

Low mass stars more likely to have life supporting planets

low mass stars (our sun) longer lived (5-10 byrs), solar winds and UV radiation not strong, High mass stars excessive UV radiation, strong winds and short-lived



The distance from a star where this can take place can be calculated from star size and luminosity. The CHZ of a particular star is "centered" on a distance determined by the equation:

$$d_{AU} = \sqrt{L_{star}/L_{sun}}$$

where

d_{AU} is the mean radius of the HZ in astronomical units,

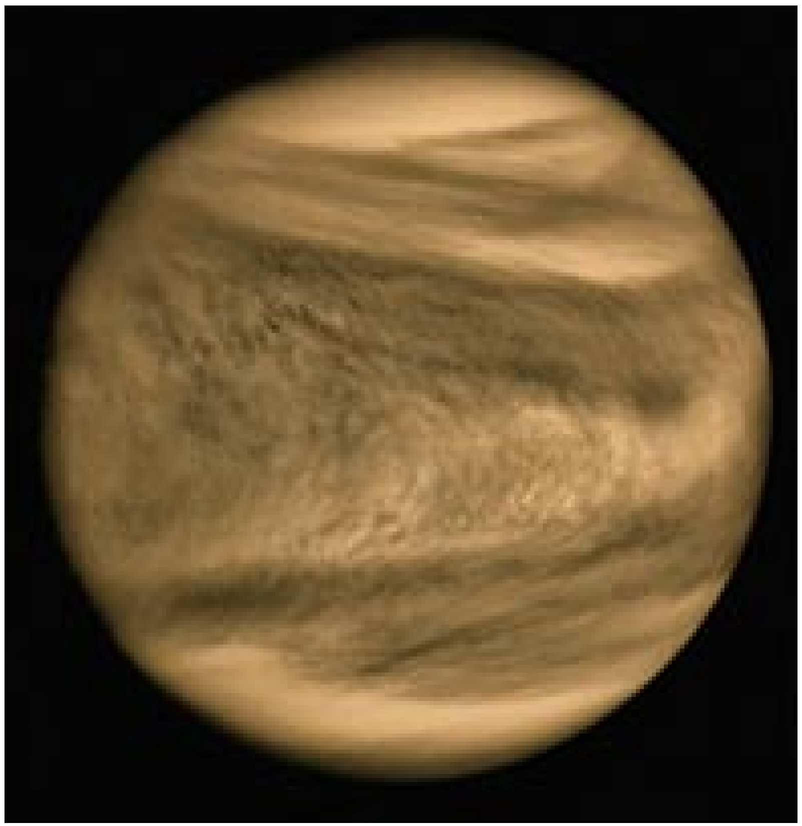
L_{star} is the bolometric luminosity of the star, and

L_{sun} is the bolometric luminosity of the Sun.

Changes in the core nuclear reactions of the central star can cause it to become hotter over time. Thus the CHZ will move outwards. Also inward migration of giant planets in some young solar systems will disrupt the orbits of the inner planets and effect the CHZ. The so-called Killer Jupiters

At present the Earth and Mars lie within our solar systems CHZ but Venus for doesn't. Too Hot!!

Venus Earths Evil Twin ??

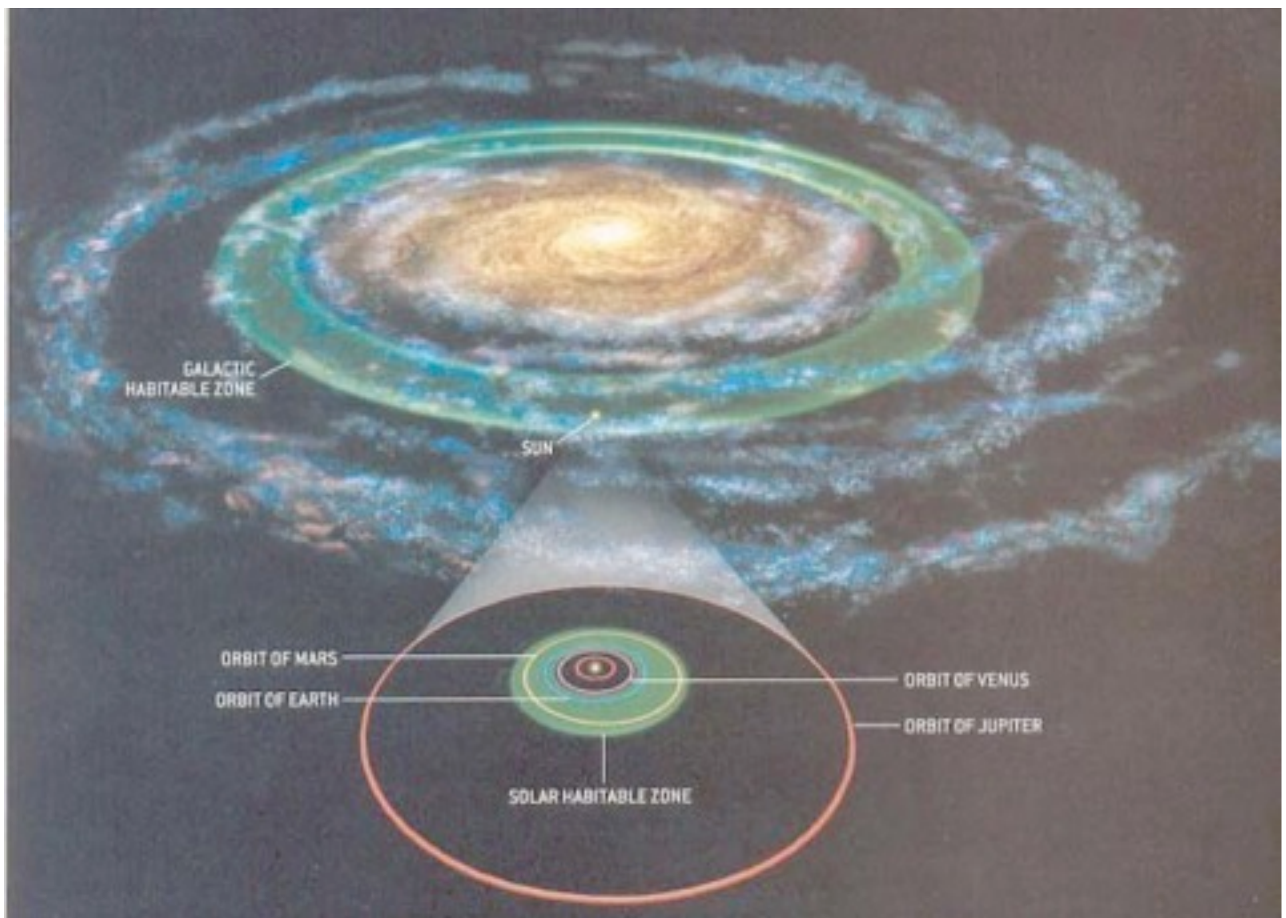


- Diameter: 12,100 km
- Mass: 4.869x10^{24} kg
- 95% diameter of Earth; 80% of the mass. Superficially very similar but in reality very different.
- Venus has a runaway greenhouse effect making it incompatible to life as we know it on Earth. Its atmosphere is 95% CO_2. Temperatures are over 740K, hot enough to melt lead!
- Sulphuric acid clouds!
- Atmospheric pressure on surface is 91 times the Earths.

We can also ask where we can reasonably expect life to exist in the Milky Way or another galaxy like it

The Galactic Habitable Zone

The size of GHZ is determined by availability of material to make a habitable planet and adequate seclusion from cosmic threats list some threats.



What determines the size and location of the GHZ

To harbor life a solar system

* must be close enough to the galactic center that a sufficiently high level of heavy elements exist to favor the formation of rocky planets. Heavier elements must be present, since they form complex molecules of life.

* must be far enough from the galaxy center to avoid hazards such as impacts from comets and asteroids, close encounters with passing stars, and outbursts of radiation from supernovae and from the black hole at the center of the galaxy.

* In our galaxy (the Milky Way), the GHZ is currently believed to be a slowly expanding region approximately 25,000 lyrs (8 kiloparsecs) from the galactic core, containing stars roughly 4 billion to 8 billion years old. It is approximately 6 Kpc wide. Other galaxies differ in their compositions, and may have a larger or smaller GHZ – or none at all.

The GHZ will change as the Galaxy evolves just like the CHZ

The Drake Equation

Estimates the number of technological civilisations that might exist in Our galaxy.

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

N = the number of communicative civilisations (radio emissions are Detectable)
R_* = The number of stars in the milky way galaxy
f_p = fraction of those stars with planets
n_e = number of "earths" per planetary system. Mass of planet in the Habitable zone is constrained if it is to allow liquid water.
f_l = fraction of the planets in n_e where life develops
f_i = fraction of f_l where intelligence develops
f_c = fraction of f_i where technology develops (releases detectable Sings of their existance into space)
L = the lifetime of communicating civilisations

Typical values:

$R_* = \sim 100$ billion
$f_p = 20 – 50\%$
$n_e = 1 - 5$
$f_l = 100\%$ (where life can evolve it will) - ~0%
$f_i = 100\%$ (intelligence is advantageous to survival so it will certainly evolve) - ~0%
$f_c = 10 – 20\%$
L = ? For Earth: the lifetime of the Sun and Earth is ~ 10 billion years. We have been communicating using radio waves for < 100 years. How long will our civilisation survive?
If we were destroyed tomorrow L = 1/100,000,000; if we survive for another 10,000 years L = 1/1000,000.

Estimate N:

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

$N = ?$

$R_* = 100$ billion

$f_p = 50\%$

$n_e = 1$

$f_l = 50\%$

$f_i = 20\%$

$f_c = 20\%$

$L = (10{,}000 \text{ years})\ 1/1000{,}000.$

$\Rightarrow N = 1000$

The Fermi Paradox

The **Fermi paradox** is the apparent contradiction between high estimates of the probability of the existence of extraterrestrial civilisations and the lack of evidence of contact with such civilisations.

The extreme age of the universe and its vast number of stars suggest that extraterrestrial life should be common. Considering this with colleagues over lunch in 1950, the physicist Enrico Fermi is said to have asked: "Where are they?" Fermi questioned why, if a multitude of advanced extraterrestrial civilisations exist in the Milky Way galaxy, evidence such as probes, spacecraft or radio transmissions has not been found. By asking the simple question *"Where are they?"* (alternatively, *"Where is everybody?"*) Fermi is widely credited with simplifying and clarifying the problem of the probability of extraterrestrial life.

The scale of the GHZ perhaps offers one solution to the Fermi Paradox. As the GHZ is a narrow ring in the galaxy communication would be very difficult.