Astronomy 405
Solar System and ISM

Lecture 16
Meteorites & Extrasolar Planets

February 20, 2013

The most famous meteorite hit Earth on Feb 8, 1969.
Bright blue-white light seen streaking across the sky in Chihuahua City, Mexico.
It broke into two pieces, then exploded into fireworks…
Rocks rain down over 50 km by 10 km (strewnfield).

The next day the first meteorite was discovered in Pueblito de Allende. Allende Meteorites.

Many rocks were collected and taken to the NASA Lunar Receiving Lab in Houston, TX for study.

The bright light was produced by frictional heating of the meteorite surfaces by Earth's atmosphere.
The fusion crusts on the surface flake off easily and the interiors of meteorites are not affected at all.

Radioactive dating - measure two isotopes of Pb.

Allende meteorites are 4.566±0.002 Gyr old, close to the solar model age of the Sun, 4.57 Gyr.

The meteorite's composition is similar to solar, except

- H, He, C, N, O, Ne, and Ar (volatiles) are under-abundant

-Li is over-abundant

Stars destroy their Li during their lifetime.

Radioactive Parent	Stable Product	Half-Life (10^9 yr)
$^{129}_{53}I$	$^{129}_{54}Xe$	0.016
$^{235}_{92}U$	$^{207}_{82}Pb$	0.704
$^{40}_{19}K$	$^{40}_{18}Ar$	1.280
$^{238}_{92}U$	$^{206}_{82}Pb$	4.468
$^{232}_{90}Th$	$^{208}_{82}Pb$	14.01
$^{176}_{71}Lu$	$^{176}_{72}Hf$	37.8
$^{87}_{37}Rb$	$^{87}_{38}Sr$	47.5
$^{147}_{62}Sm$	$^{143}_{60}Nd$	106.0

Allende Meteorite

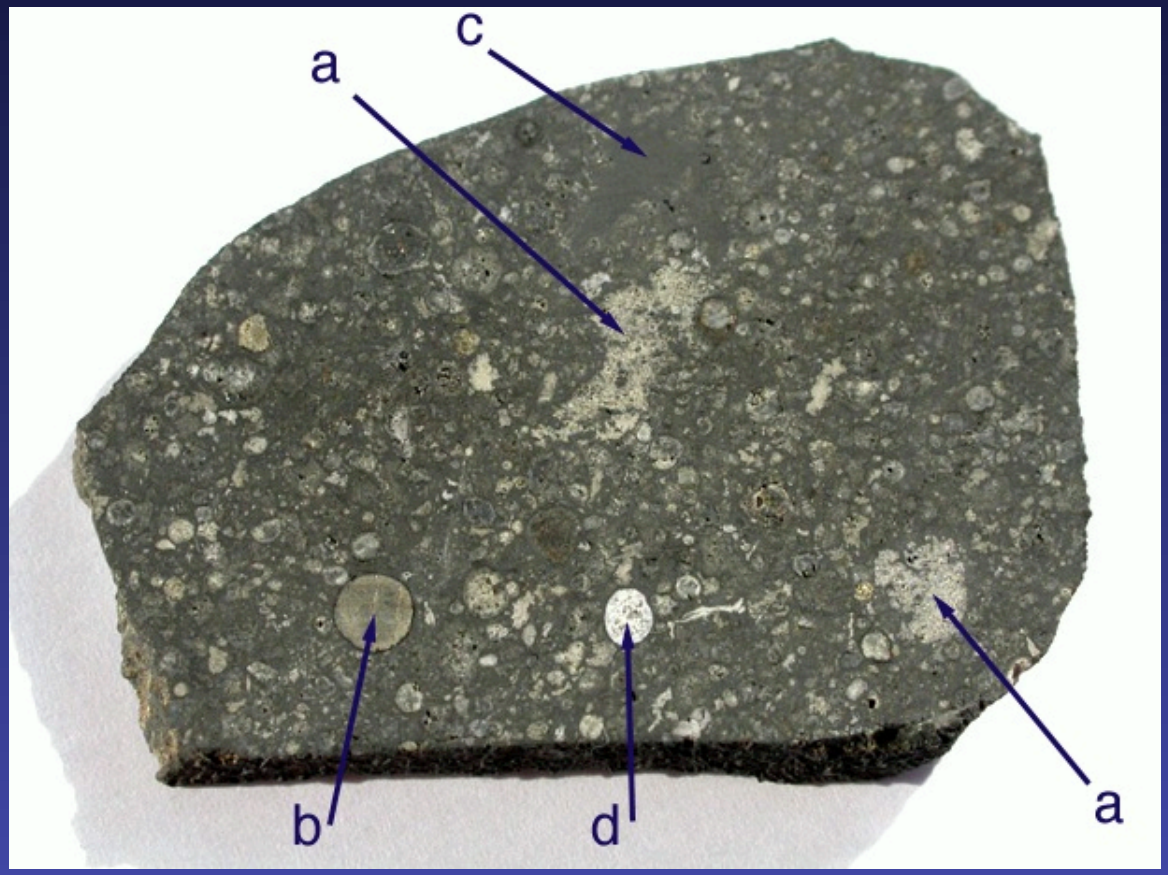
Olivine:
Mg, Fe silicate

Two types of nodules embedded in a matrix of dark silicate material.

Calcium-, Aluminuum-rich inclusions (CAIs), or refractory inclusions Up to 10 cm diameter. Ca, Al, Ti overabundant. Repeated episode of Evaporation and condensation

Chondrules. Spherical, 1-5 mm across, contain SiO_2, MgO, FeO. Rapidly cooled from a molten state.

(a) shows amoeboid olivine aggregates,
(b) anorthopyroxene rich chondrule,
(c) might be a CM inclusion,
(d) a melilite-fassaite-anorthite chondrule.

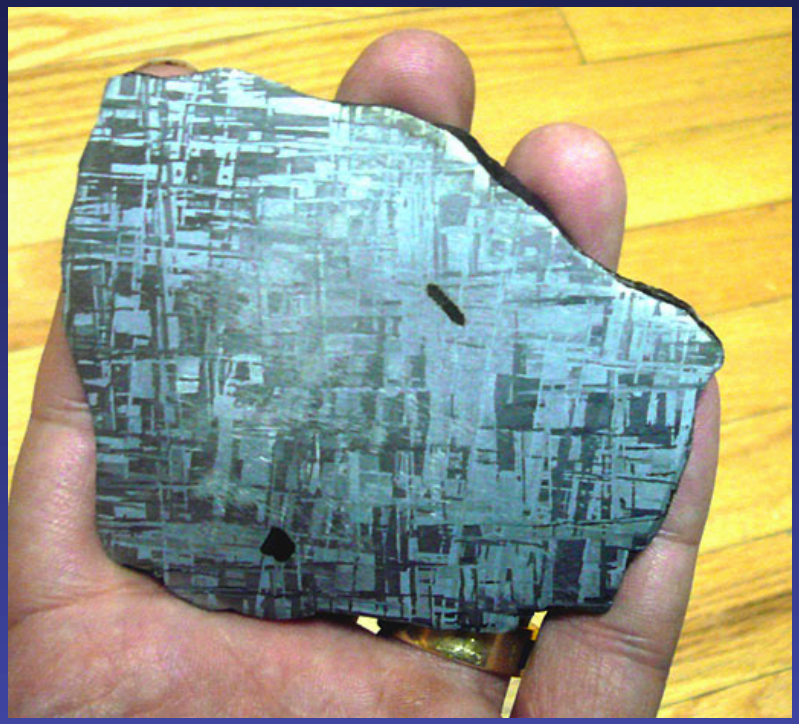


Different Types of Meteorites

Stones (96%)	Carbonaceous Chondrites	6	Silicates + H_2O, C	Primitive, rich in organic compound, chondrules
	Ordinary Chondrites	100	Silicates	Fewer volatile materials, formed in warmer temp
	Achondrites	10	Silicates	Formed from molten rock (igneous r
Stony Irons (1%)			50% Fe, Ni 50% silicate	Chemically differentiated
Irons (3%)			80-90% Fe up to 20% Ni No silicate	Chemically differentiated

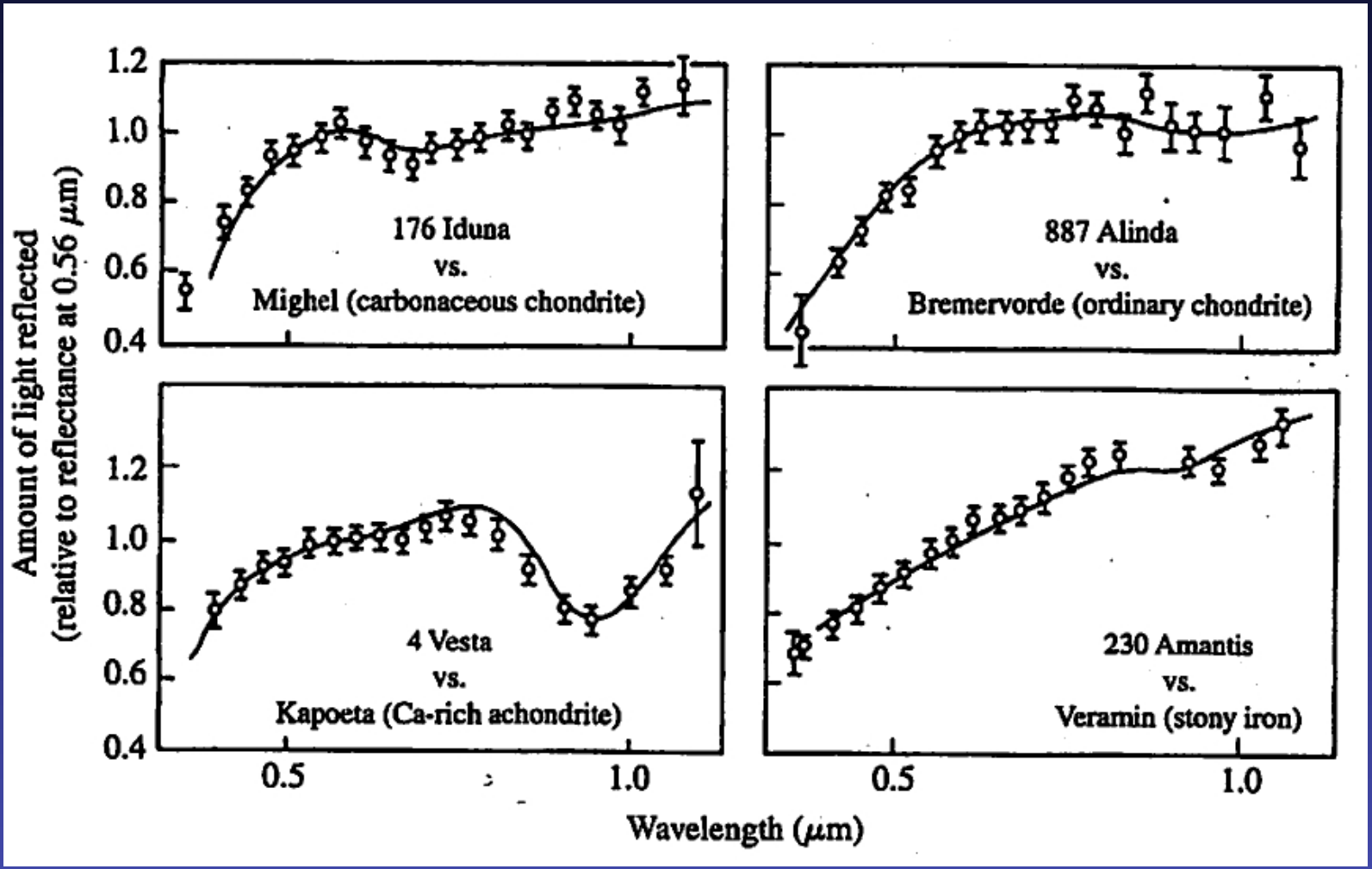
About 3/4 of all iron meteorites have long iron-nickle crystalline structures, up to several cm long - Widmansträtten patterns.

This could have developed only if the crystal cooled very slowly over millions of years.



Sources of Meteorites

The vast majority of asteroids originate from asteroids, either chipped off their parents or liberated form collisions.
metallic cores of large asteroids => irons
Small asteroids => chondrites (stones)

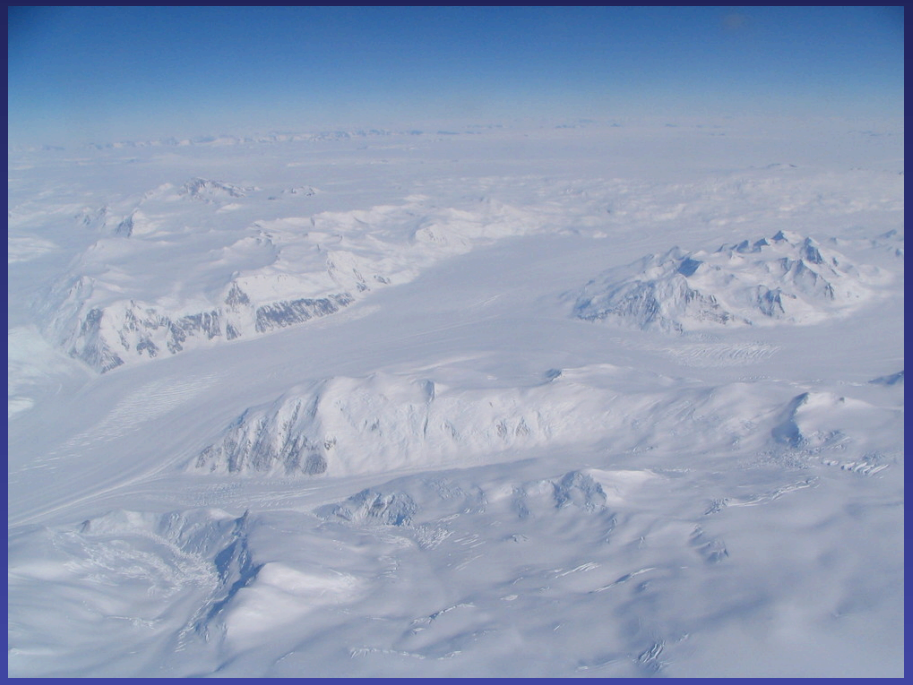


Sources of Meteorites

Some meteorites come from the Moon or Mars.

On the icy cap of Antarctica, an unusual achondrite was found and it has the chemical makeup of Moon rocks. It is 1.3 Gyr old.

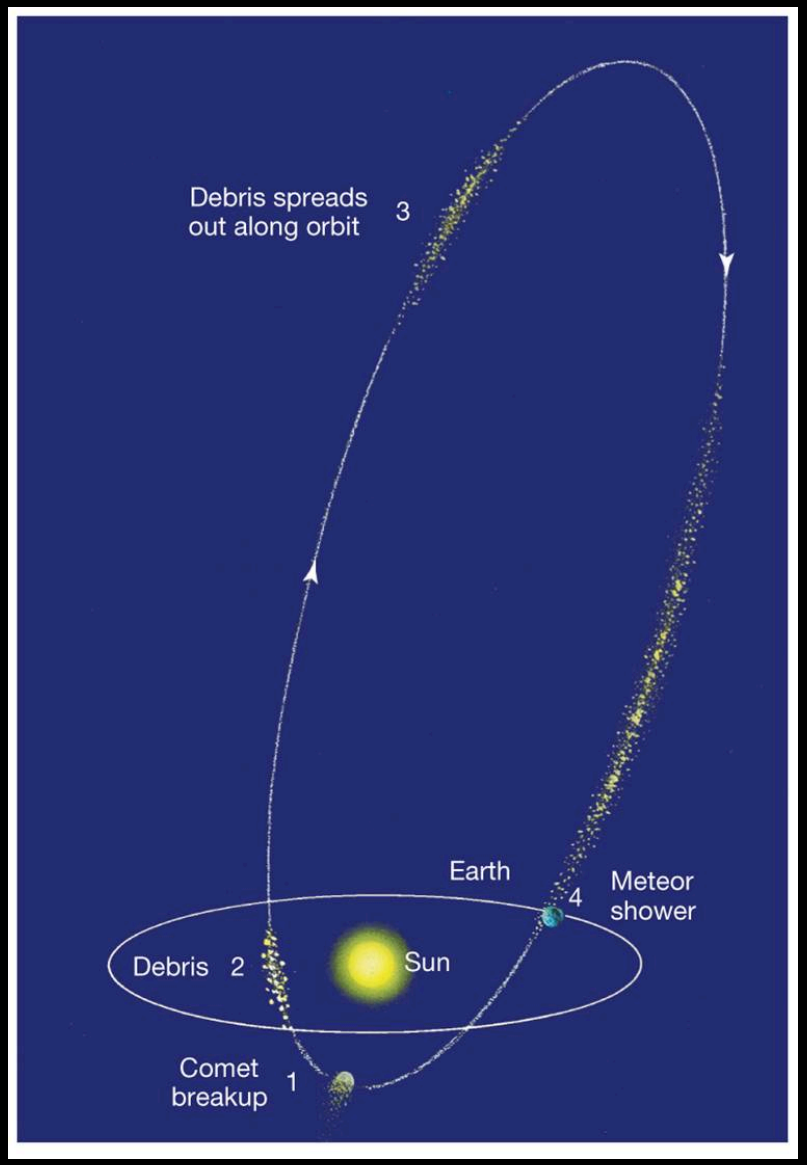
Remember the Martian meteorite?



Meteor showers occur when Earth crosses a comet's orbital path. Comet dust enters and burns in Earth's atmosphere causes meteor shower.

Radiant - constellation - name

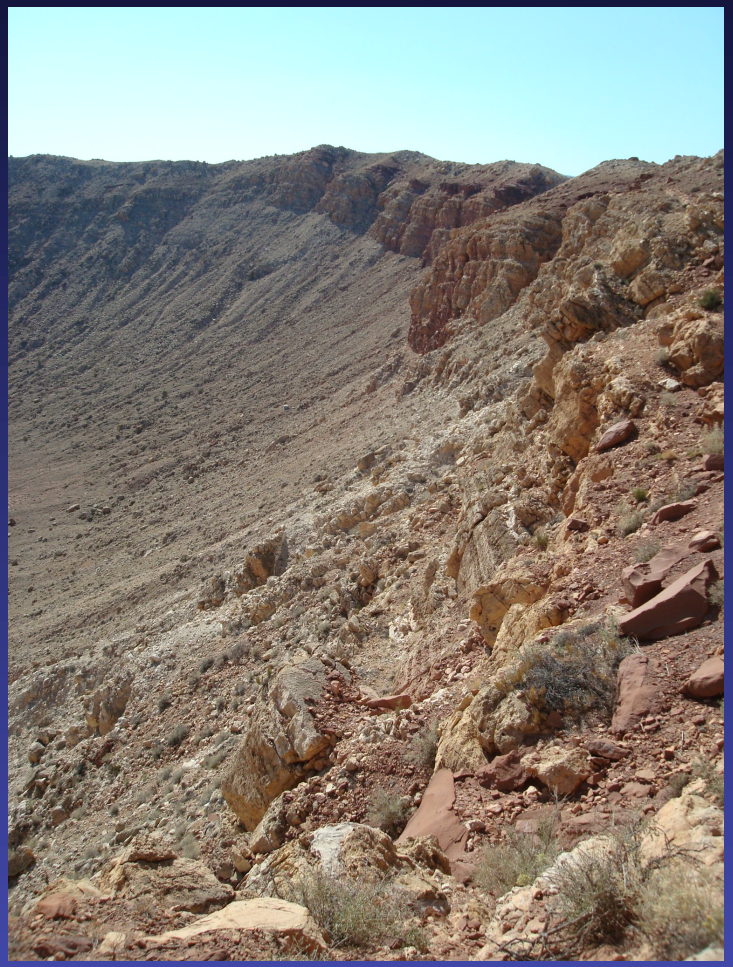
Perseid Meteor shower



Barringer Crater

50,000 yr ago, iron meteorite, 50 m diameter.

1.2 km wide, 200 m deep crater in Arizona.



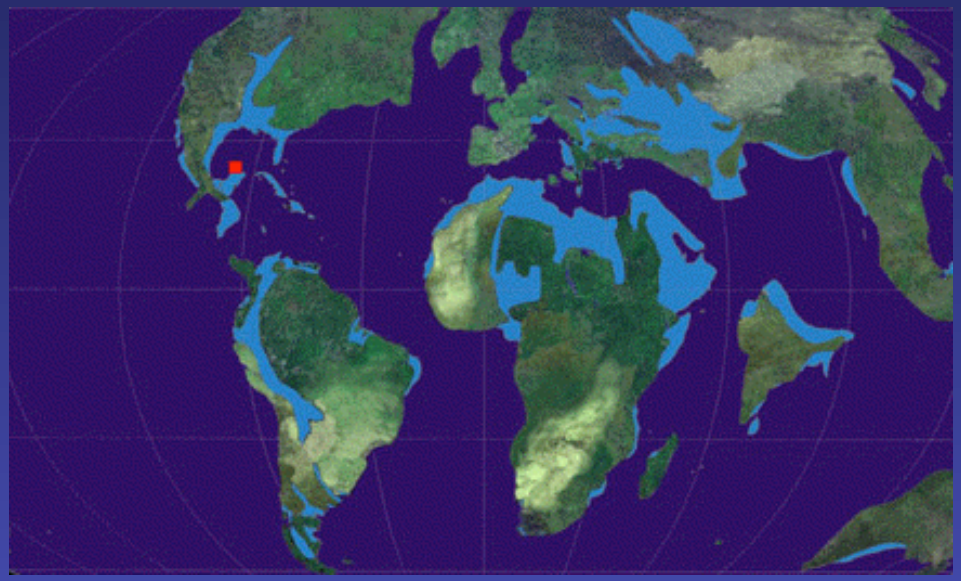
Could meteoritic impacts be responsible for the mass extinctions of many species in the paleontological record?

In 1979, Walter Alvarez and his father Luis Alvarez announced the discovery of high abundance of iridium in the Cretaceous-Tertiary boundary (K-T boundary), corresponding to the time of extinction 65 Myr ago. 70% of the species were wiped out, including dinosaurs.

Iridium is fairly common in iron-rich meteorites.

Impact of a stony asteroid 6 to 10 km across, which could produce a crater some 100 to 100 km in diameter.

Most likely impact site is along the northern coast of the Yucatan penisula, near Chicxulub.



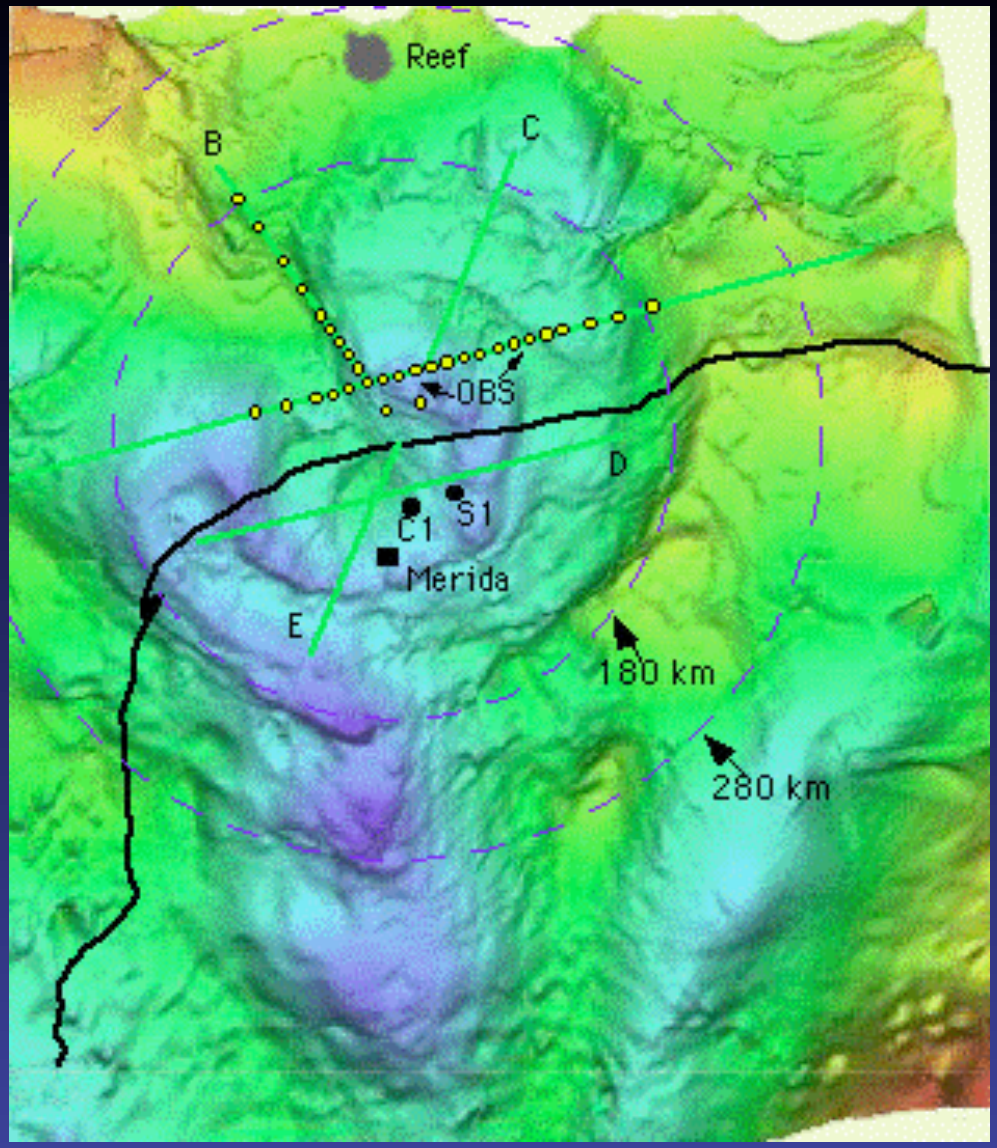
LPI gravitational anomaly image

4×10^{22} J of energy
$= 10^{13}$ tons of TNT

Tsunami traveled all the way to central Texas.

Vaporize water, wash out airborne dust, increase greenhouse effect, global and water temperature rose ~ 10 K.

Fires, nitrogen oxide, nitric acid => acid rain killed vegetation…

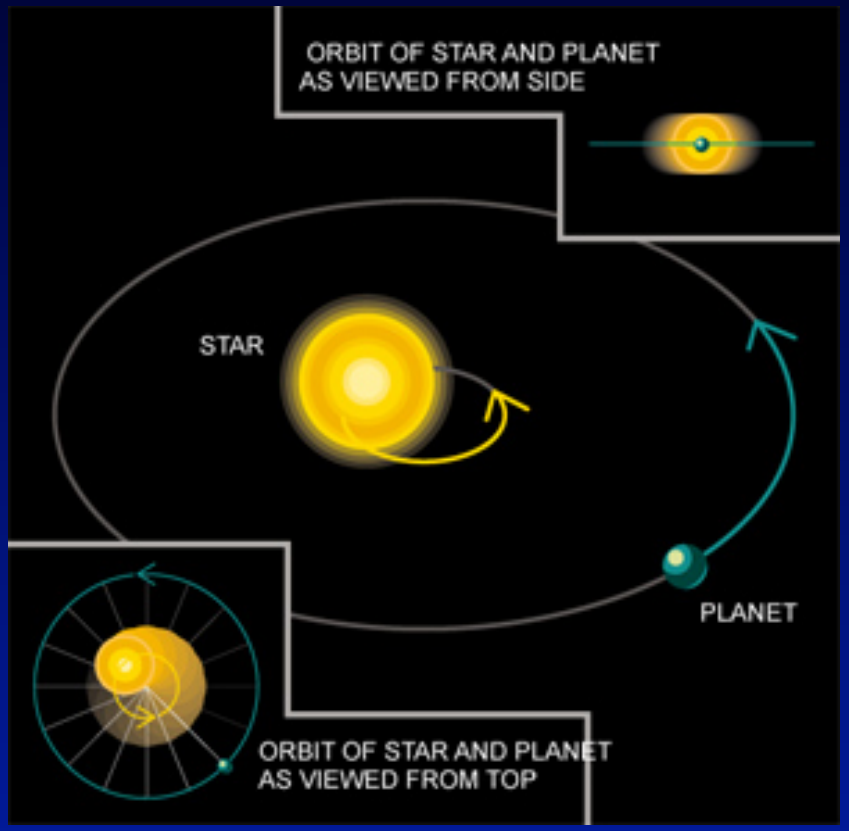


Some carbonaceous chondrites contains amino acids, basic building blocks for life!

Planet and Star

- **Direct Imaging**
- **Photometric Monitoring For transits**

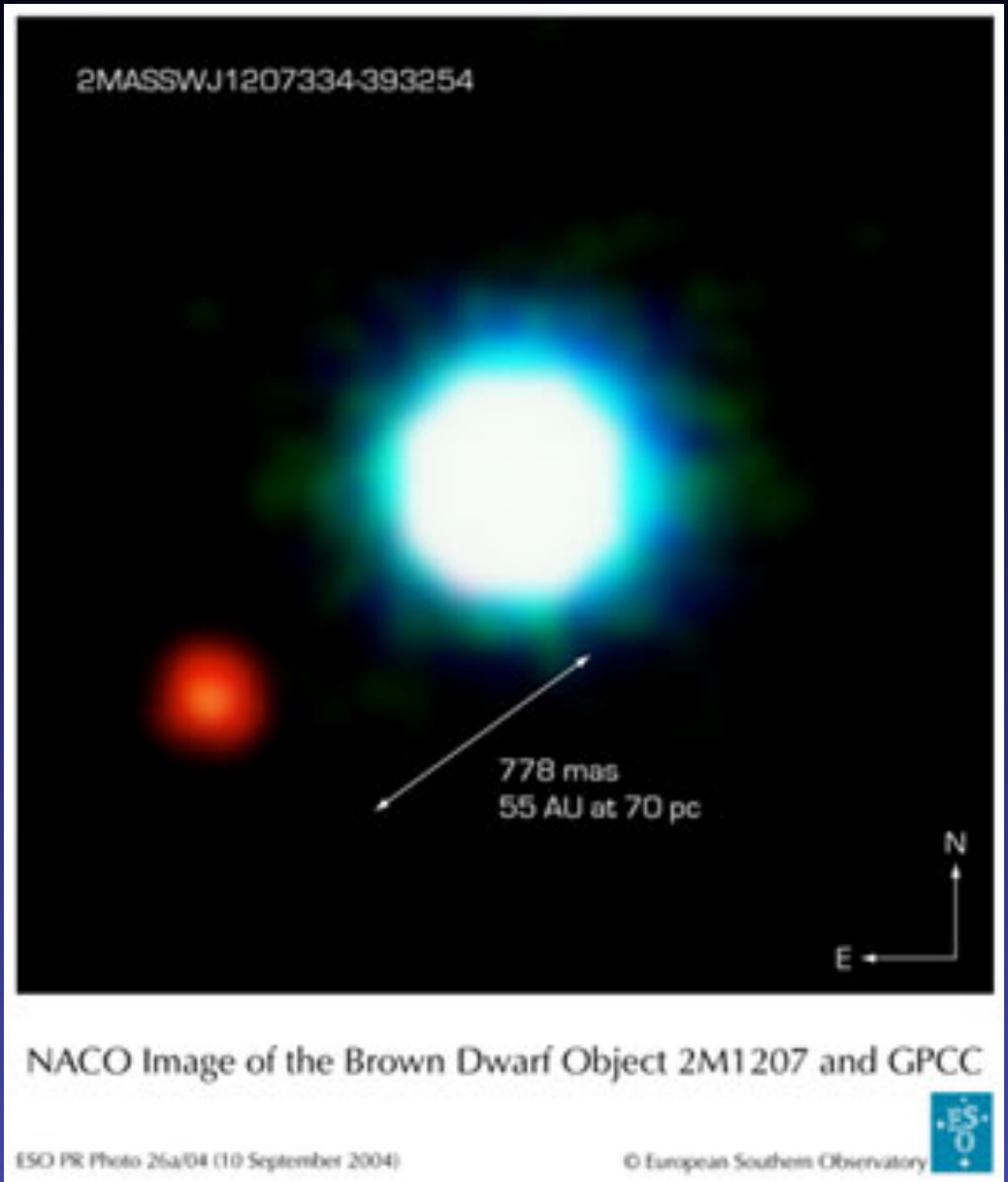
Star: emits light, reflex motion



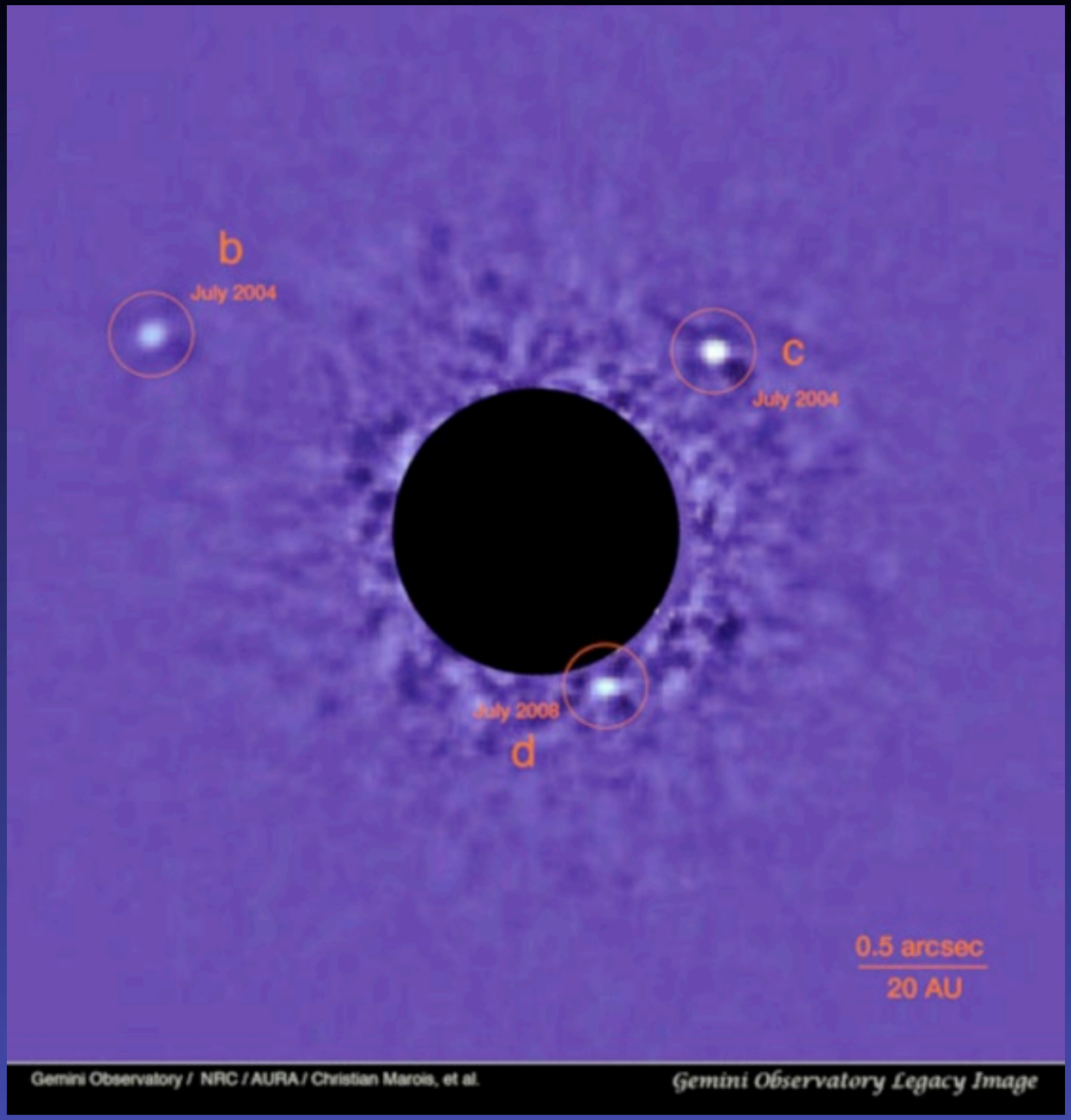
Planet: reflects light, orbital motion

- **Astrometry of the star**
- **Doppler Shift of the star**

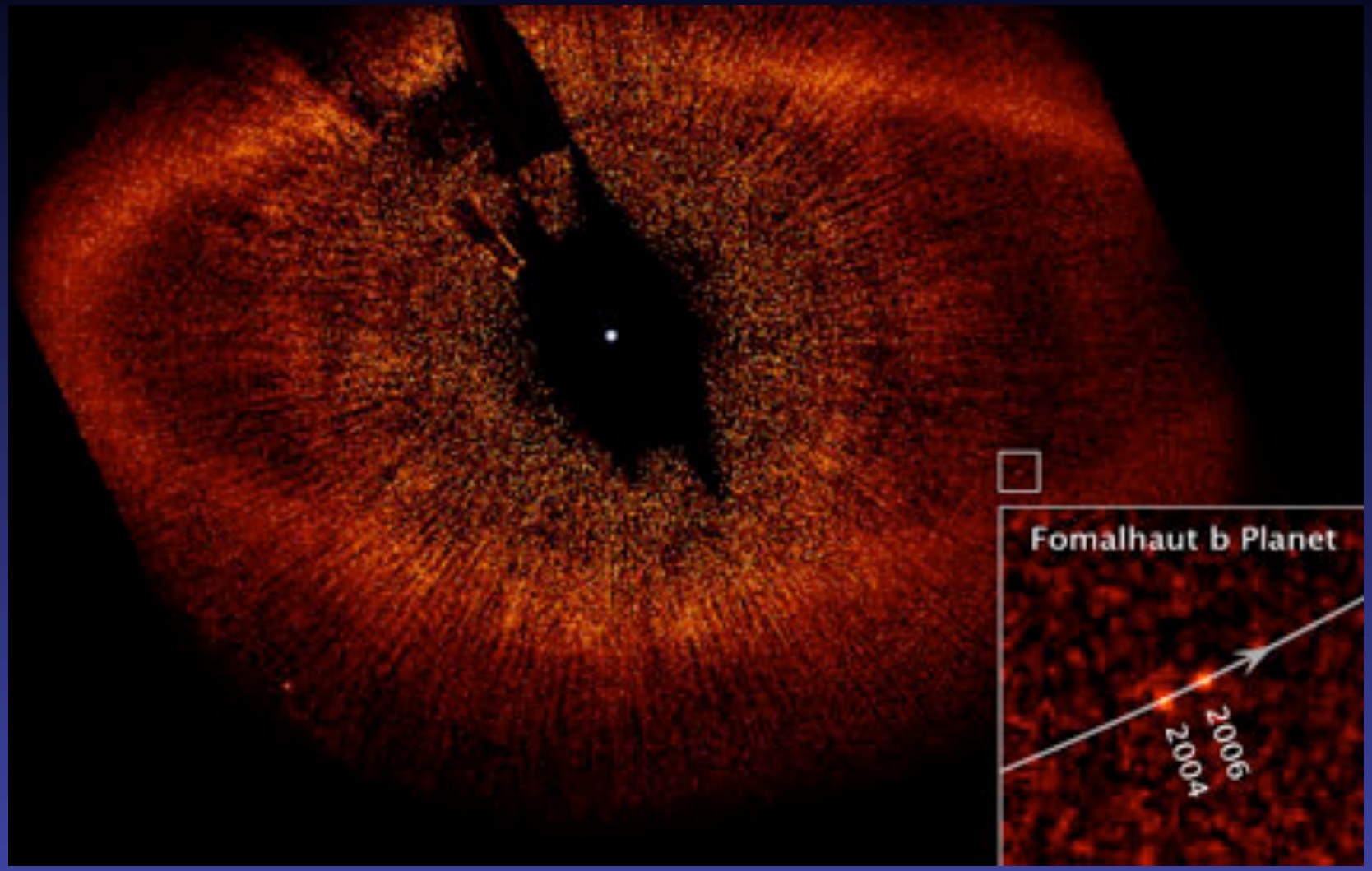
Direct Image of an Exoplanet around a brown dwarf

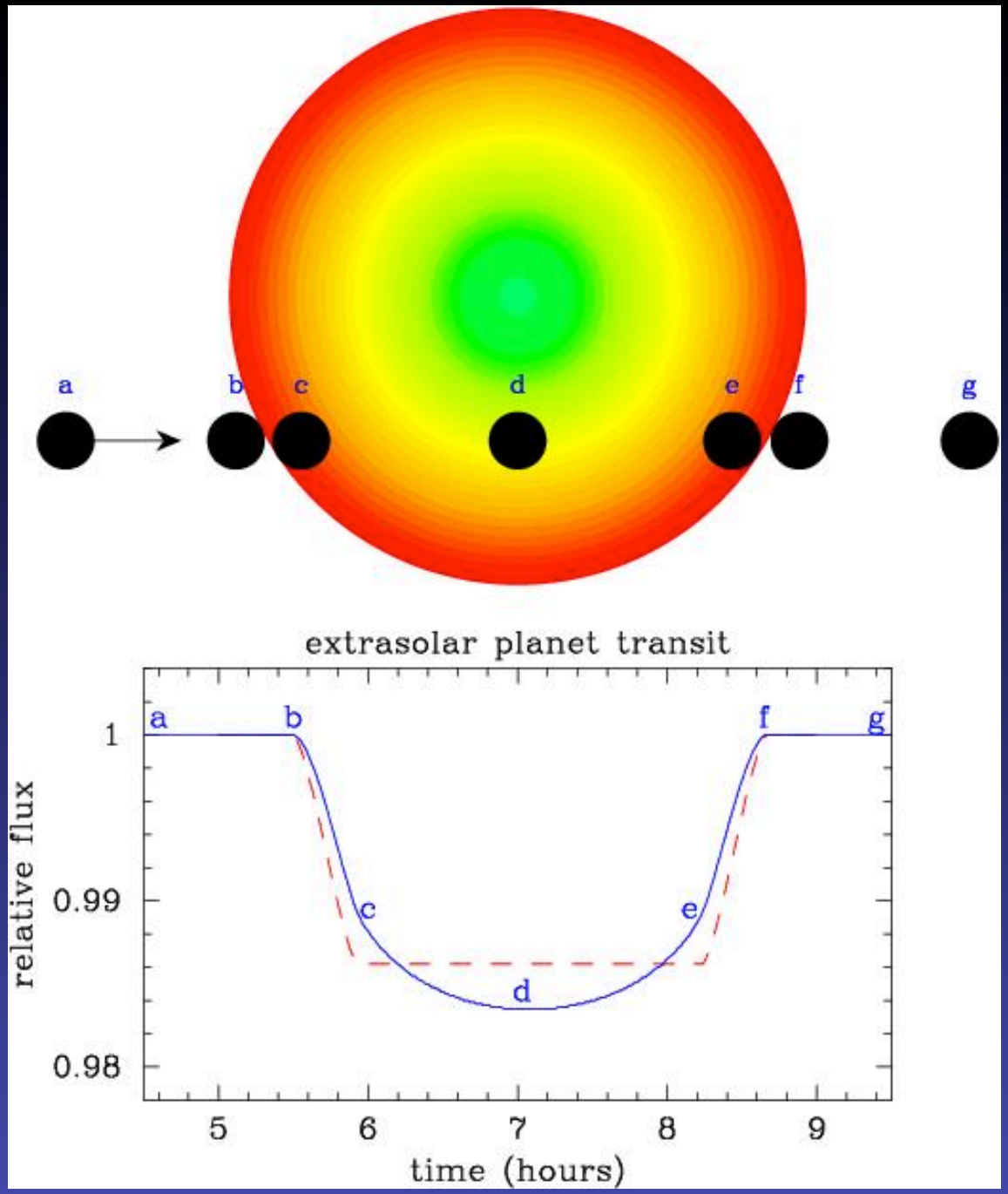


HR 8799 and its planets (Gemini Obs)



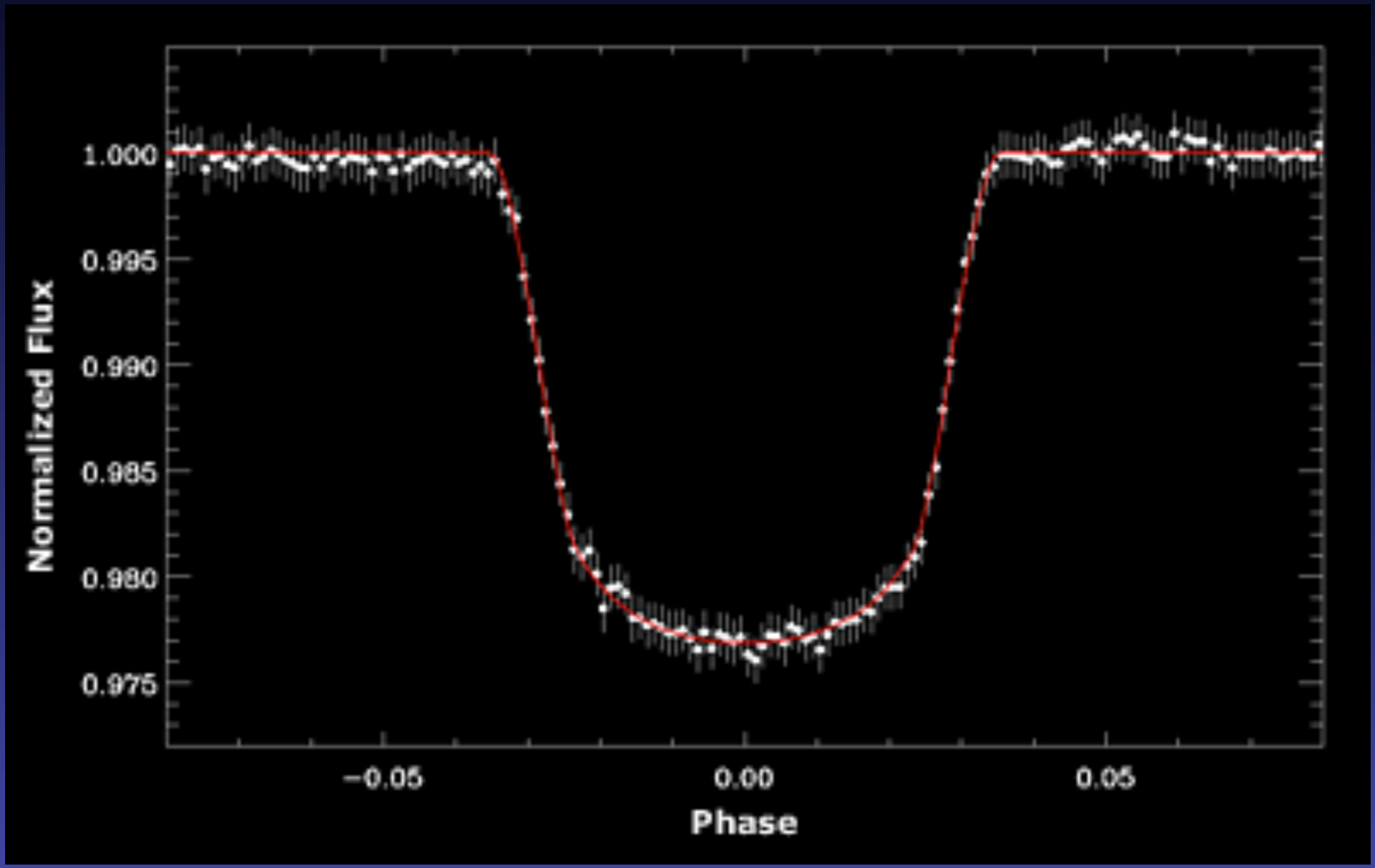
Fomalhaut's debris disk and planets




a
b
c
d
e
f
g
extrasolar planet transit
relative flux
1
0.99
0.98
5
6
7
8
9
time (hours)

COROT-Exo-1b Radius 1.78 R_J, Mass = 1.3 M_J

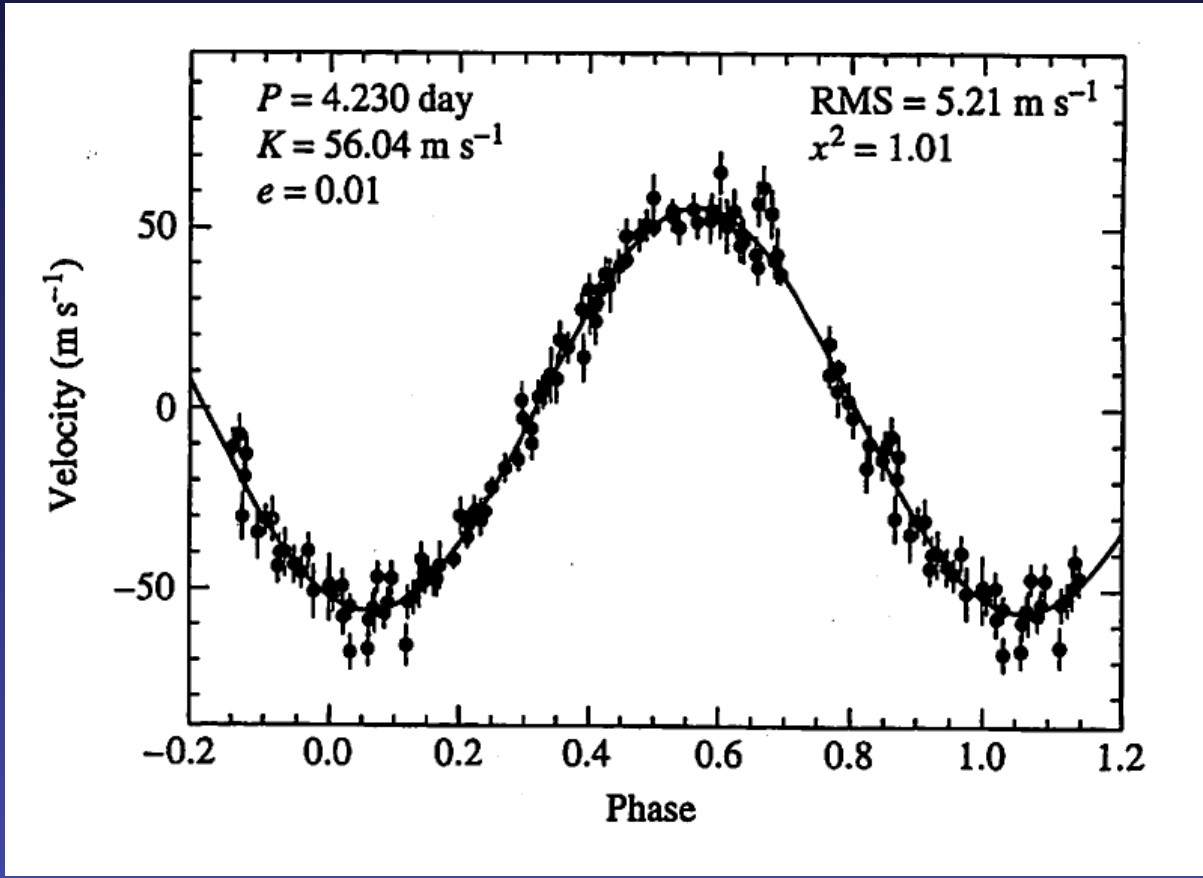
It orbits around a star similar to the Sun with *P* = 1.6 d.



Detection of Exoplanets through reflex radial Velocities

Star and planet orbits around the center of mass.
If the reflex motion of the star is detected, we get information on the planet's mass.

The first exoplanet was found around 51 Peg (G2V) by Michel Mayor and Didier Queloz in 1995.



Kepler's third law: $P^2 = \frac{4\pi^2}{G(m_1+m_2)}a^3$

$m_1 = 1\ M_\odot$ for 51 Peg; $m_2 =$ planet's mass.

$a = [\frac{GP^2(m_1+m_2)}{4\pi^2}]^{1/3}$, with $m_1 + m_2 \sim m_1$

For a period of 4.23 days, $a = 0.051$ AU.

The planet's orbital velocity is $v_2 = 2\pi a/P$=131 km/s.

The amplitude of the star's observed radial velocity is $v_{r,\max} = v_1 \sin i = 56.04$ m/s.

$m_1 v_1 = m_2 v_2$, thus $m_2 = \frac{m_1}{v_2}\frac{v_{r,\max}}{\sin i}$,

or $m_2 \sin i = \frac{m_1}{v_2} v_{r,\max} = 0.45\ M_J$. $\leftarrow$ at least

Sometimes the star's motion is more complicated than a sinusoidal curve => multiple planets.