Planets and exoplanets

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Goals

- Understand the meaning of the numerical values found in the data tables of the Solar System planets
- Understand the main characteristics of extra-solar planetary systems

Solar system

We look for models that provide information, not only arts and crafts.

According to the content

We want models with scientific content and those that display some concrete points

Activity 1: Distances from the Sun

Mercury	57 900 000 km	6 cm	0.4 AU
Venus	108 300 000 km	11 cm	0.7 AU
Earth	149 700 000 km	15 cm	1.0 AU
Mars	228 100 000 km	23 cm	1.5 AU
Jupiter	778 700 000 km	78 cm	5.2 AU
Saturn	1 430 100 000 km	143 cm	9.6 AU
Uranus	2 876 500 000 km	288 cm	19.2 AU
Neptune	4 506 600 000 km	450 cm	30.1 AU

Activity 2: Model of Diameters

Sun	1 392 000 km	→	139.0 cm
Mercury	4 878 km	→	0.5 cm
Venus	12 180 km	→	1.2 cm
Earth	12 756 km	→	1.3 cm
Mars	6 760 km	→	0.7 cm
Jupiter	142 800 km	→	14.3 cm
Saturn	120 000 km	→	12.0 cm
Uranus	50 000 km	→	5.0 cm
Neptune	45 000 km	→	4.5 cm

Activity 2: Model of Diameters

T-shirt with the diameters of the planets to scale

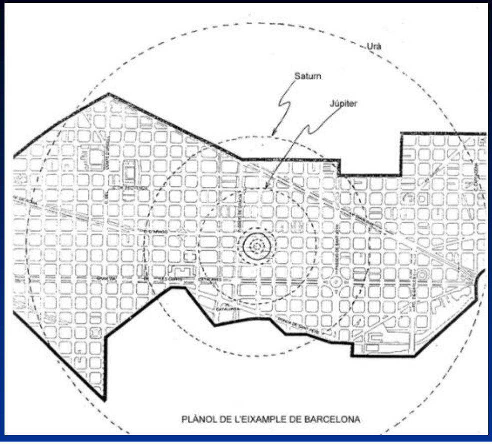
Activity 3: Diameters and distances from the Sun

Sun	1 392 000 km		⇒	25.0 cm	
Mercury	4 878 km	57 900 000 km	⇒	0.1 cm	10 m
Venus	12 180 km	108 300 000 km	⇒	0.2 cm	19 m
Earth	12 756 km	149 700 000 km	⇒	0.2 cm	27 m
Mars	6 760 km	228 100 000 km	⇒	0.1 cm	41 m
Jupiter	142 800 km	778 700 000 km	⇒	2.5 cm	140 m
Saturn	120 000 km	1 430 100 000 km	⇒	2.0 cm	250 m
Uranus	50 000 km	2 876 500 000 km	⇒	1.0 cm	500 m
Neptune	45 000 km	4 506 600 000 km	⇒	1.0 cm	800 m

Usually a school yard only reaches out to Mars

Activity 3: Model of diameters and distances in the playground ...

Activity 4: Model in the city *(Barcelona)*



Sun	Washing machine	*Puerta Instituto*
Mercury	Caviar egg	*Puerta Hotel Diplomatic*
Venus	Pea	*Pasaje Méndez Vigo*
Earth	Pea	*Entre Méndez Vigo y Bruc*
Mars	Pepper grain	*Paseo de Gracia*
Jupiter	Orange	*Calle Balmes*
Saturn	Tangerine	*Pasaje Valeri Serra*
Uranus	Chestnut	*Calle Entenza*
Neptune	Chestnut	*Estación de Sans*

Model in the city of Metz (France)

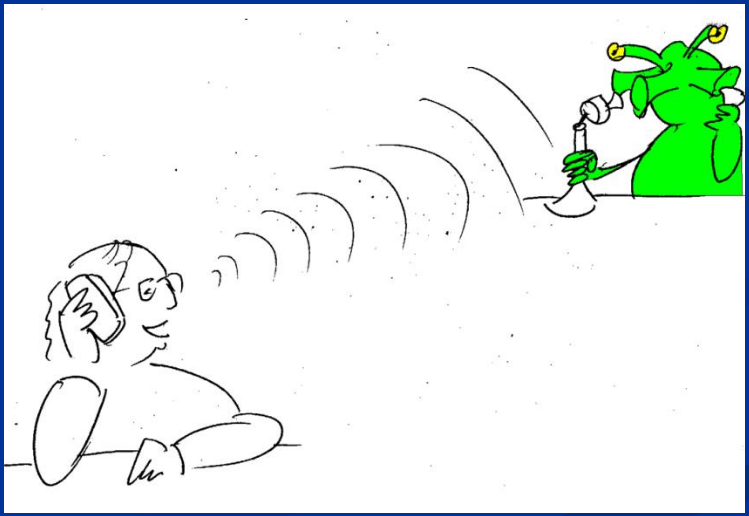
Activity 5: Model of times

- c = 300 000 km/s

The time it takes light to go from Earth to Moon is:

t = distance EM / c = 384 000 km / 300 000 = 1.3 s

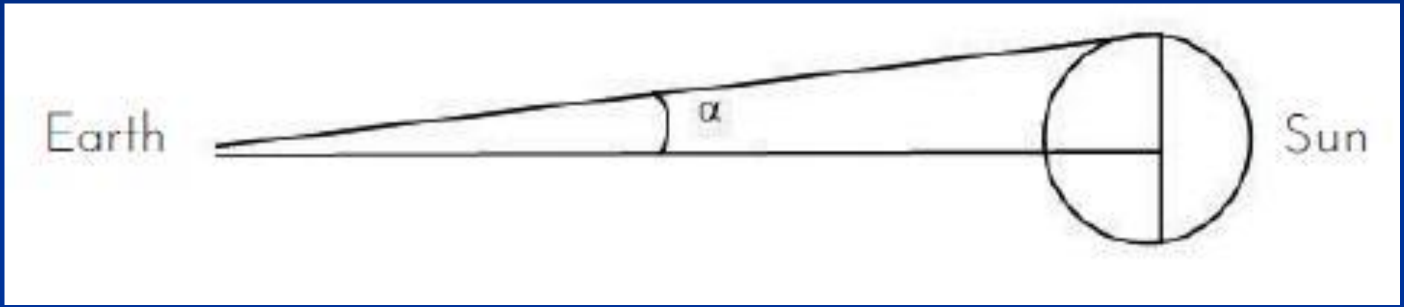
How would a conversation between planets by “video” be?



Sunlight takes to get to …

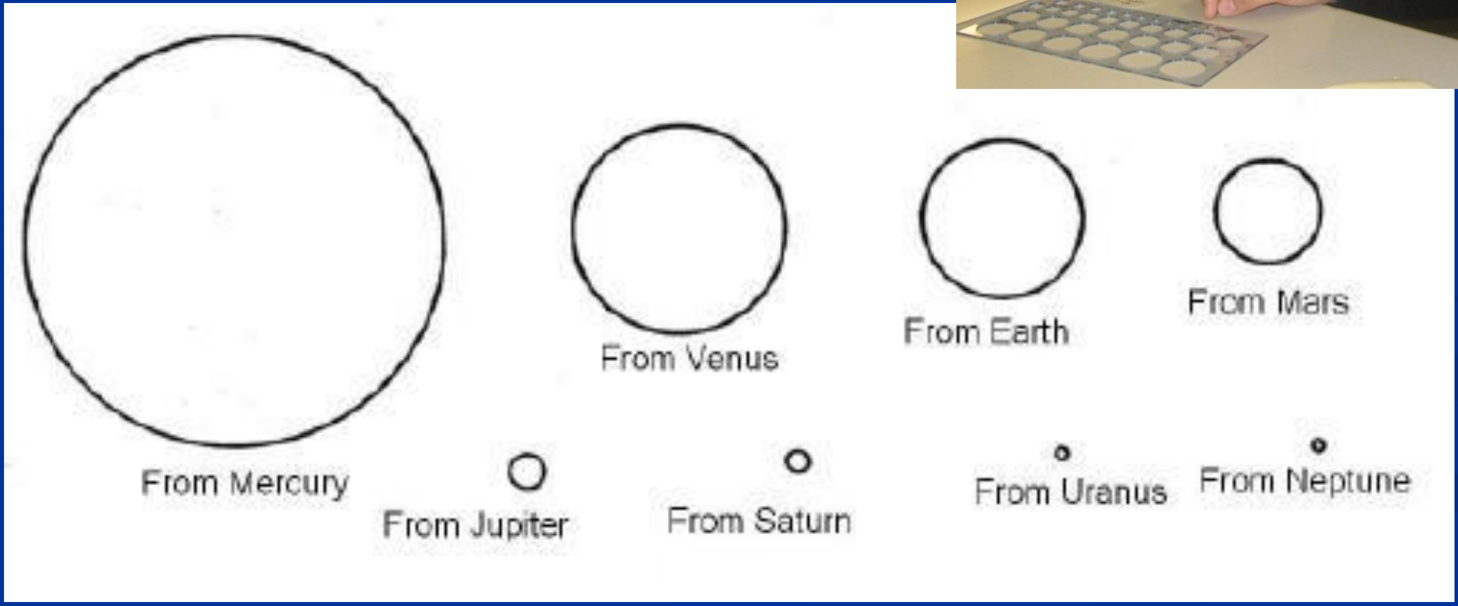
Mercury	57 900 000 km		3.3 minutes
Venus	108 300 000 km		6.0 minutes
Earth	149 700 000 km		8.3 minutes
Mars	228 100 000 km		12.7 minutes
Jupiter	778 700 000 km		43.2 minutes
Saturn	1 430 100 000 km		1.32 hours
Uranus	2 876 500 000 km		2.66 hours
Neptune	4 506 600 000 km		4.16 hours

Activity 6: The Sun as seen from the planets



- $\alpha = \tan \alpha =$ radius Sun / distance to Sun $= 700\,000/150\,000\,000 = 0.0045$ radian $= 0.255°$
- From the Earth, the Sun measures $2\,\alpha = 0.51\,°$

Activity 6: The Sun as seen from planets



Activity 7: Model of densities

Sun	1.41 g/cm^3		Sulfur (1.1-2.2)
Mercury	5.41 g/cm^3		Pyrite (5.2)
Venus	5.25 g/cm^3		Pyrite (5.2)
Earth	5.52 g/cm^3		Pyrite (5.2)
Mars	3.90 g/cm^3		Blende (4.0)
Jupiter	1.33 g/cm^3		Sulfur (1.1-2.2)
Saturn	0.71 g/cm^3		Pine wood (0.55)
Uranus	1.30 g/cm^3		Sulfur (1.1-2.2)
Neptune	1.70 g/cm^3		Clay (1.8-2.5)

Activity 8: Flattening Model

- Cut cardboard strips of 35 x 1 cm.
- Attach them to a cylindrical stick 50 cm long and 1 cm in diameter. Leave the lower end loose so that it can move along the stick.
- Rotate the stick in between your hands with quick rotations in one direction and the other. The centrifugal force deforms the cardboard bands as planets are deformed.

Activity 8: Flattening

Planets	(equatorial radius-polar radius)/ equatorial radius
Mercury	0.0
Venus	0.0
Earth	0.0034
Mars	0.005
Jupiter	0.064
Saturn	0.108
Uranus	0.03
Neptune	0.03

Activity 9: Orbital Periods model

- Attach a nut to one end of a rope and hold the rope opposite to it. Turn the rope over your head.
- As you release more rope, it takes longer to complete an orbital period
- If you remove some of the rope, it takes less time

Activity 9: Earth orbital data

The average orbital velocity $v = 2\pi R / T$

For the Earth

$v = 2\pi \times 150 \times 10^6/365$

$v = 2\ 582\ 100$ km/day $= 107\ 590$ km/h $= 29.9$ km/s

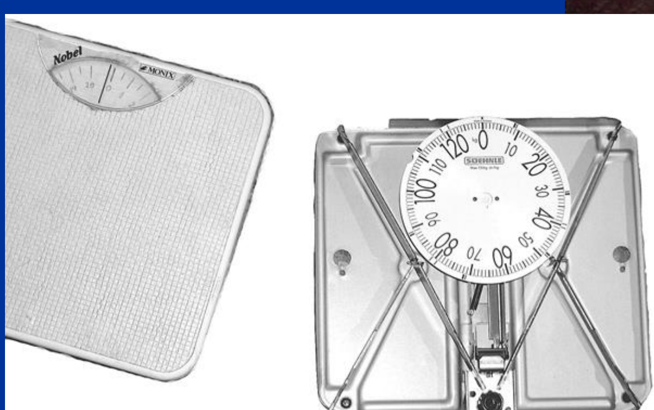
(The average orbital speed of Sun around the galactic centre is 220 km/s or 800 000 km/h.)

Activity 9: Orbital data

Planet	Orbital period (days)	Distance from the Sun (km)	Orbital average speed (km/s)	Orbital average speed (km/h)
Mercury	87.97	57.9×10^6	47.90	172 440
Venus	224.70	108.3×10^6	35.02	126 072
Earth	365.26	149.7×10^6	29.78	107 208
Mars	686.97	228.1×10^6	24.08	86 688
Jupiter	4331.57	778.7×10^6	13.07	47 052
Saturn	10759.22	$1\,430.1 \times 10^6$	9.69	34 884
Uranus	30.799.10	$2\,876.5 \times 10^6$	6.81	24 876
Neptune	60190.00	$4\,506.6 \times 10^6$	5.43	19 558

Activity 10: Model of surface gravitational accelerations

- Surface gravity, $F = G\,M\,m/d^2$, with $m = 1$, $d = R$. Thus $g = G\,M\,/\,R^2$, where $M = 4/3\,\pi\,R^3\,\rho$
- Replacing: $g = 4/3\,\pi\,G\,R\,\rho$



Activity 10: Surface gravitational accelerations

the mass is the same on every planet, only the weight (attraction force) is different

Planets	Eqt. Radius	Density		Calc. acc.	Real acc.	
Mercury	2 439 km	5.4 g/cm^3	⇨	0.378	3.70 m/s^2	0.37
Venus	6 052 km	5.3 g/cm^3	⇨	0.894	8.87 m/s^2	0.86
Earth	6 378 km	5.5 g/cm^3	⇨	1.000	9.80 m/s^2	1.00
Mars	3 397 km	3.9 g/cm^3	⇨	0.379	3.71 m/s^2	0.38
Jupiter	71 492 km	1.3 g/cm^3	⇨	2.540	23.12 m/s^2	2.36
Saturn	60 268 km	0.7 g/cm^3	⇨	1.070	8.96 m/s^2	0.91
Uranus	25 559 km	1.2 g/cm^3	⇨	0.800	8.69 m/s^2	0.88
Neptune	25 269 km	1.7 g/cm^3	⇨	1.200	11.00 m/s^2	1.12
Moon			⇨		1.62 m/s^2	0.16

Activity 11: Model of "impact craters”

- Cover the floor with newspapers to prevent a mess
- In a shallow box, set a layer of 1 or 2 cm of flour with a strainer to make the surface very smooth
- Sprinkle a layer of a few millimetres of cocoa powder over the flour with the strainer
- From about 2 m high, drop a tablespoon of cocoa powder to create marks like impact craters
- The used flour can be recycled for a new experiment

Activity 12: Escape velocity

- $E_{kin} = \frac{1}{2} mv^2$
- $E_{pot} = -GM_{planet} m / R_{planet}$
- $E_{mec} = E_{kin} + E_{pot} = 0$
- $g_{planet} = GM_{planet} / R^2_{planet}$

Then: $-GM_{planet} m / R_{Planet} + \frac{1}{2} mv^2 = 0$

$$\frac{1}{2} mv^2 = g_{planet} m R_{planet}$$

the scape velocity results:

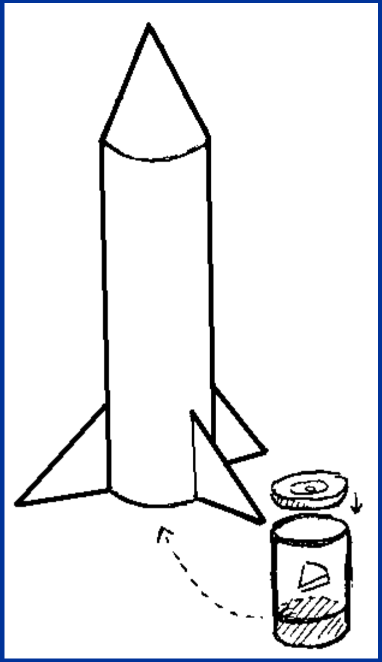
$$v = (2gR)^{1/2}$$

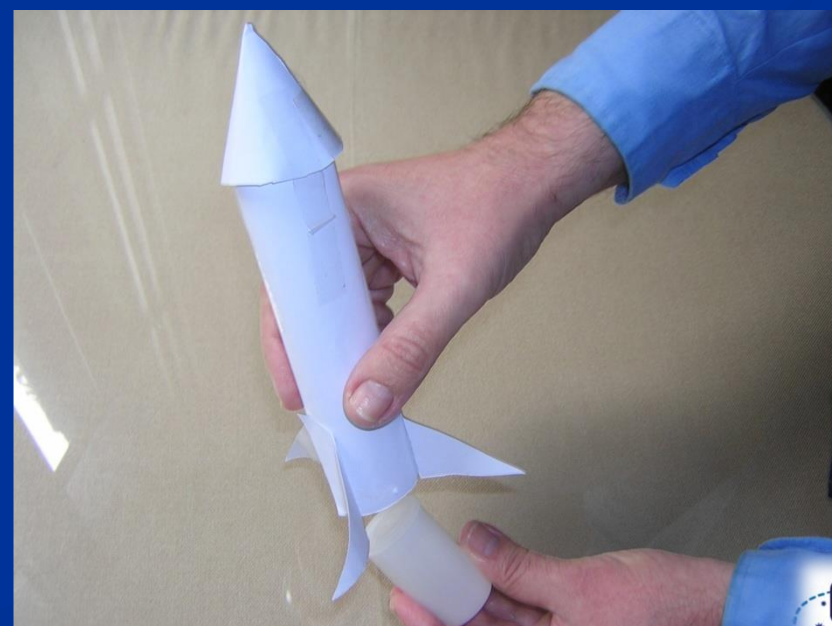
Activity 12: Escape velocity

Planets	Equatorial Radius	g_{Planet}/g_{Earth}		Escape Velocity
Mercury	2 439 km	0.378		4.3 km/s
Venus	6 052 km	0.894		10.3 km/s
Earth	6 378 km	1.000		11.2 km/s
Mars	3 397 km	0.379		5.0 km/s
Jupiter	71 492 km	2.540		59.5 km/s
Saturn	60 268 km	1.070		35.6 km/s
Uranus	25 559 km	0.800		21.2 km/s
Neptune	25 269 km	1.200		23.6 km/s

Activity 12: Rocket launch

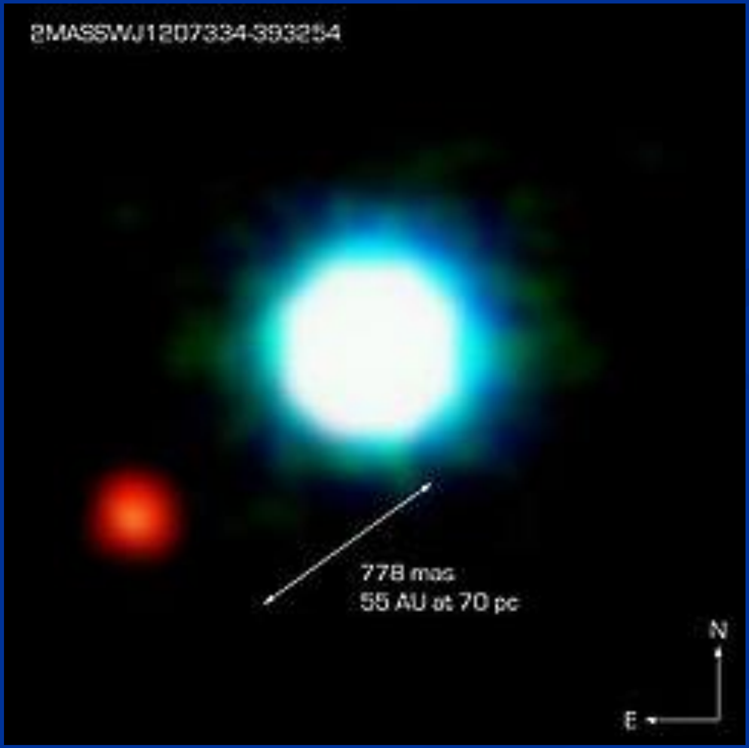
- Cardboard
- Film container
- ¼ Effervescent tablets





Extrasolar planetary systems

In 1995 Michael Mayor and Didier Queloz announced the detection of an exoplanet orbiting 51 Pegasi



2M1207b directly imaged (ESO)

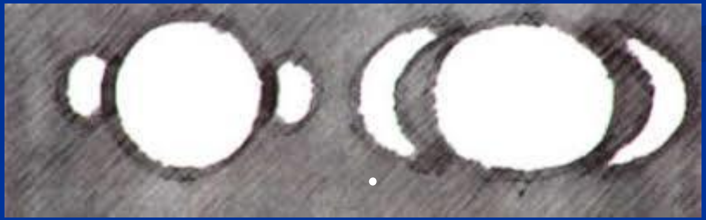
The first image of an exoplanet

2003 March 16th

We depend on the technology

Galilei observed Saturn with his telescope in 1610 for the first time. He did not see a fine ring but interpreted it as a star with three bodies.

You had to wait for Huygens (1659) with a better telescope to solve the ring. For this reason the painting of Rubens (1636-1638) symbolizes Saturn with three objects according to the discovery of Galilei.



Names for exoplanets

A letter is placed after the name of the central star starting with "b" for the first planet found in the system

(e.g. 51 Pegasi b).

The next planet is named with the next letter of the alphabet c, d, e, f, etc.

(51 Pegasi c, 51 Pegasi d, 51 Pegasi e or 51 Pegasi f).

Exoplanet detection methods

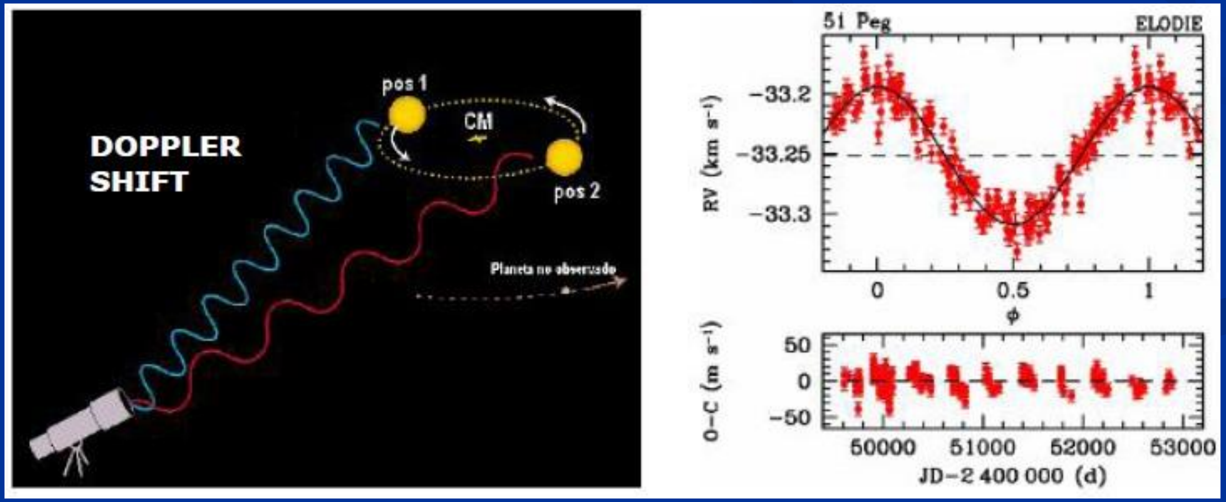
Many methods are used:

- Radial Velocity and Doppler Effect
- Transit Method
- Microlensing
- Others

Detection Method: Radial Velocity

The variation of the radial velocity of the star when orbiting the barycenter of the planet and star system is measured using the Doppler Effect.

It was with this method that the first exoplanet 51 Pegasus b was detected.

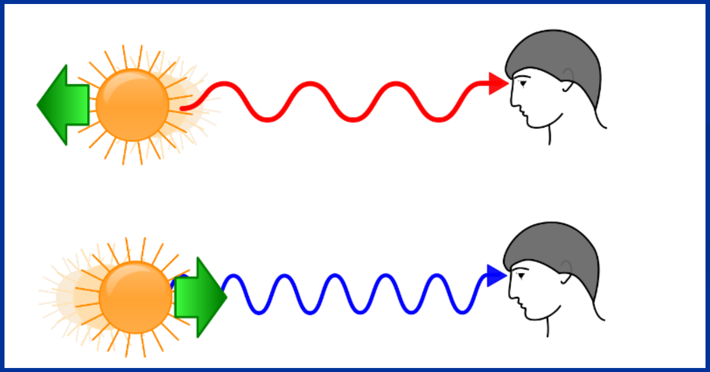


Activity 13: Doppler Effect

The Doppler effect is the change of the wavelength of the light when the source is in motion.

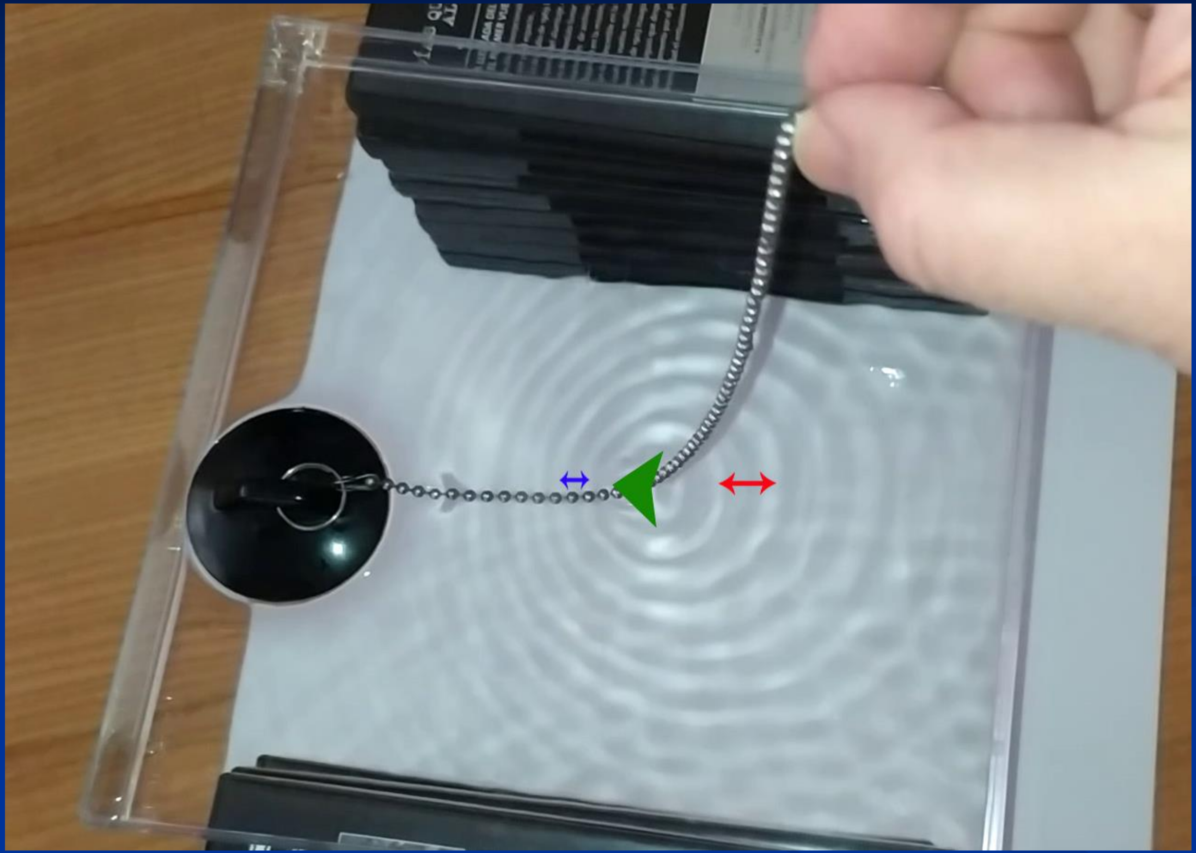
When the source approaches the wavelength is shortened and the observed light shifting to the blue part of the visible spectrum.

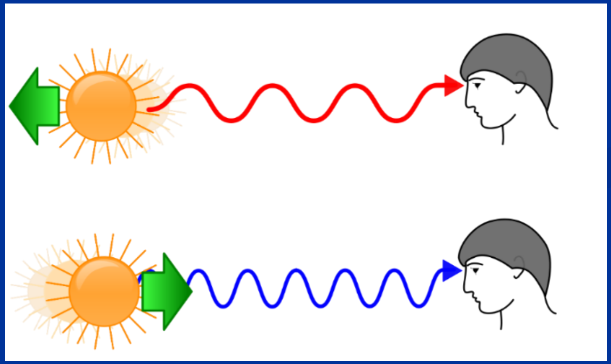
When it moves away, the wavelength lengthens and the observed light shifting to the red part of the visible spectrum.



Activity 13: Doppler Effect

It has been reproduced by reproduced with a bucket of water, a cap with chain and the mobile flash.

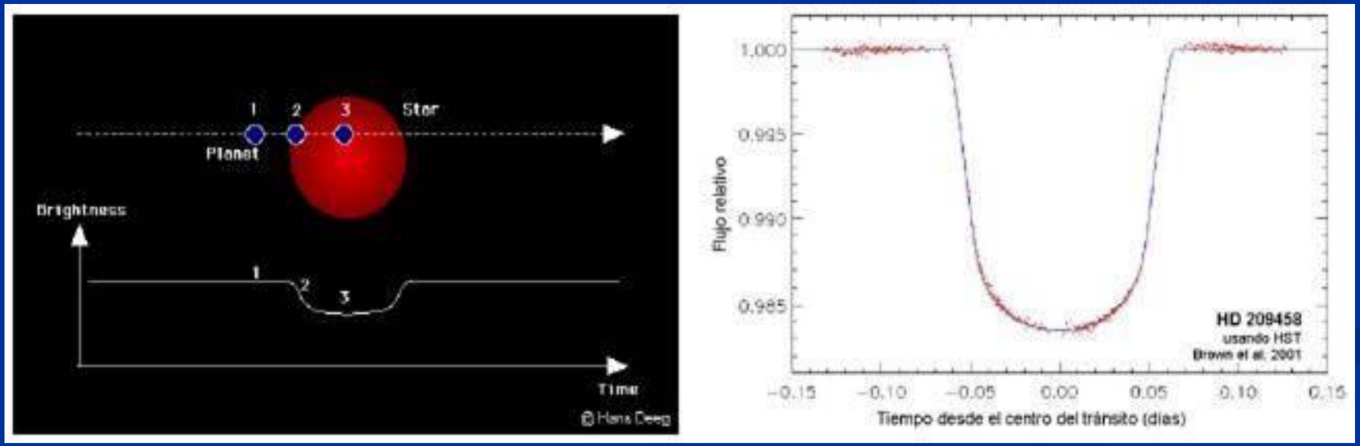




Detection Method: Transits

During the transit of an exoplanet, the brightness of the star undergoes a small decrease.

For solar-type stars and Jupiter-sized planets, the brightness decrease is approximately 1%, in the case of Earth-sized planets the decrease is around 0.03%.

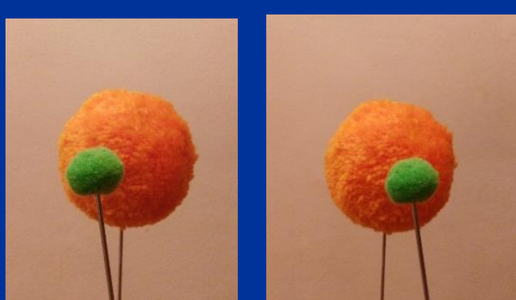


Activity 14: Transit simulation

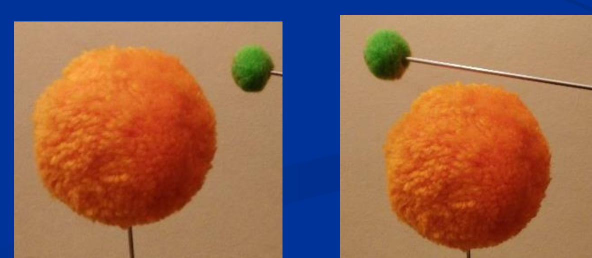
Using two balls: one large for the star and one small for the exoplanet orbiting the star.

With the observer in the same plane of the orbit and observing from that place, you will see the exoplanet passing in front of the star and the brightness of the star decreasing.

But if the observer is not in the same plane of orbit, no change in the brightness curve will be observed.



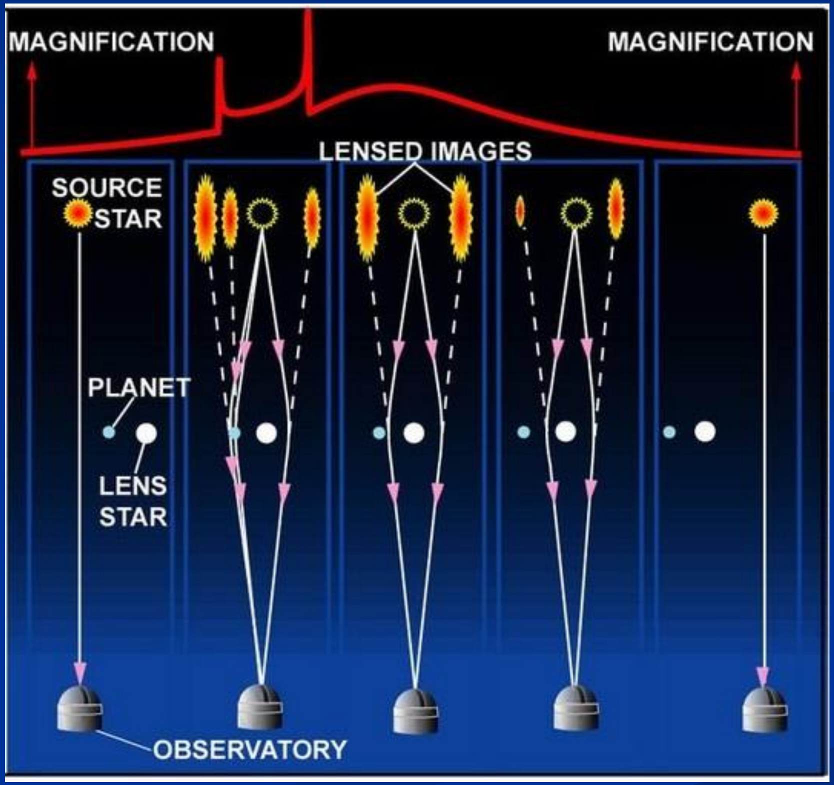
Observer in the plane of the orbit



Observer out of the plane of orbit

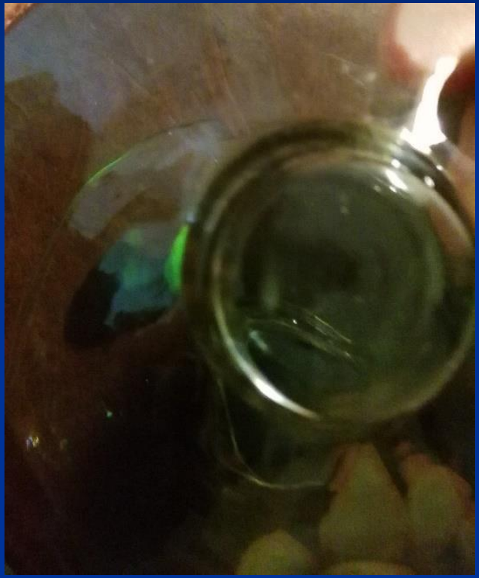
Detection Method: Micro Lensing

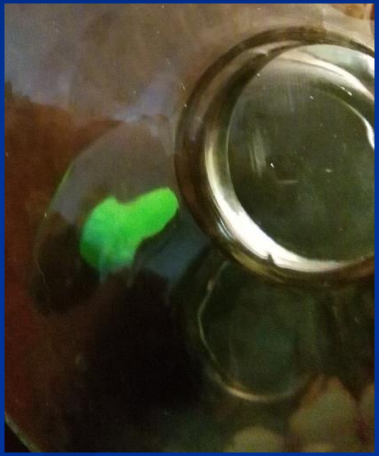
There is an enlargement or distortion that highlights the star-exoplanet system, due to the alignment of the system with a star or object that makes the gravitational lens.



There must be complete visual alignment between the three bodies (earth, object-lens and star-exoplanet).

Activity 15: Simulation of microlenses





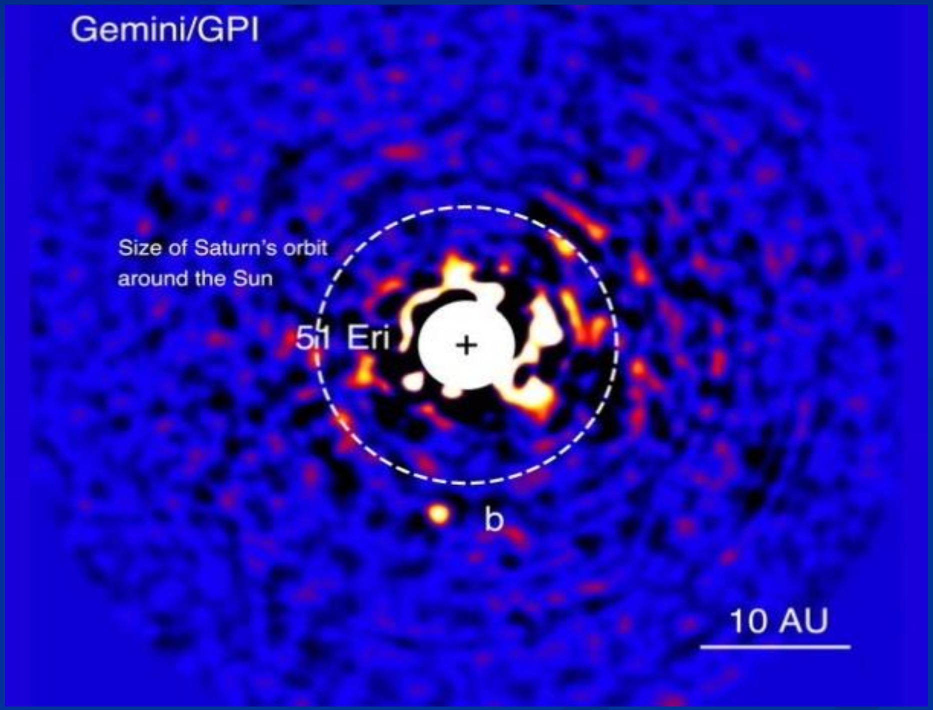
With only one wine glass foot, nothing is seen.

With a pair of wine glass feet

Then we pass one over the other and a point emerges and then even two.

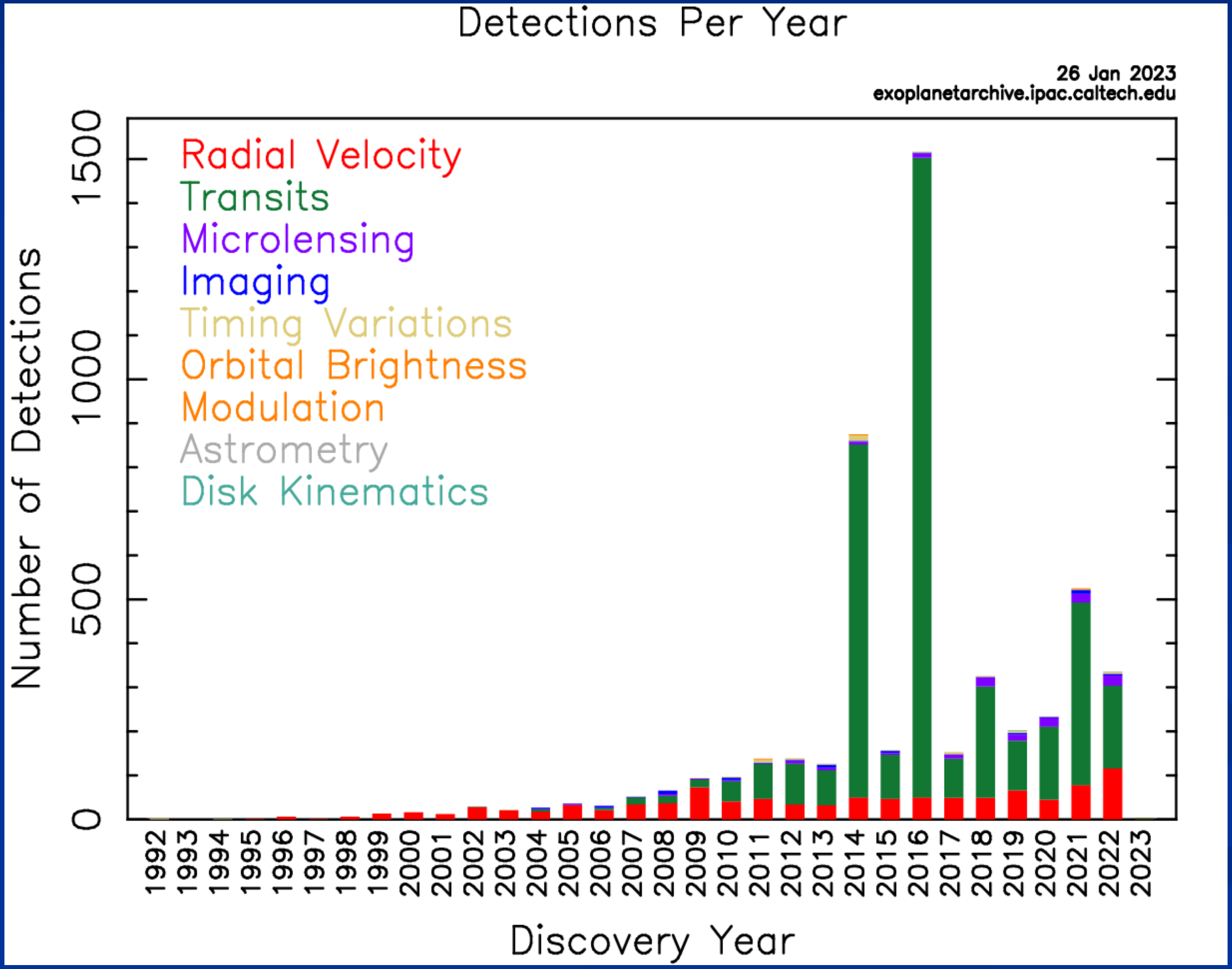
Detection Method: Direct

The image of the star is studied to determine the exoplanets around it.



Due to the amount of light emitted by the star, it is not easy to carry out.

2023 known exoplanets according to the different detection methods

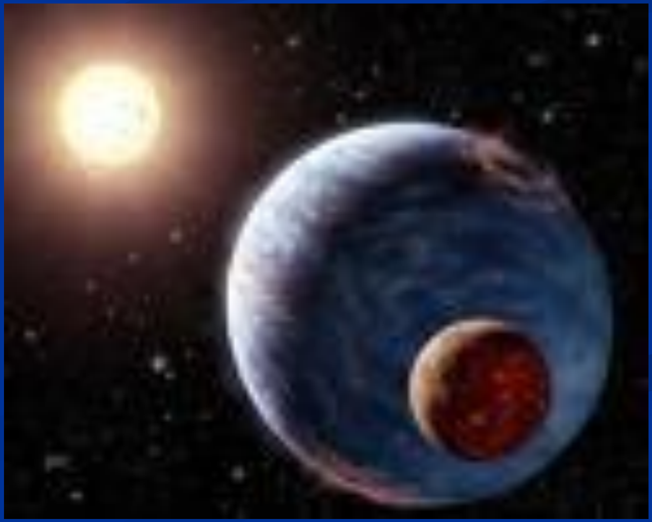


Models of exoplanet systems

To date, nearly 4,000 planetary systems and more than 5,300 exoplanets have been discovered, and nearly 10,000 observations have been made that may be planets

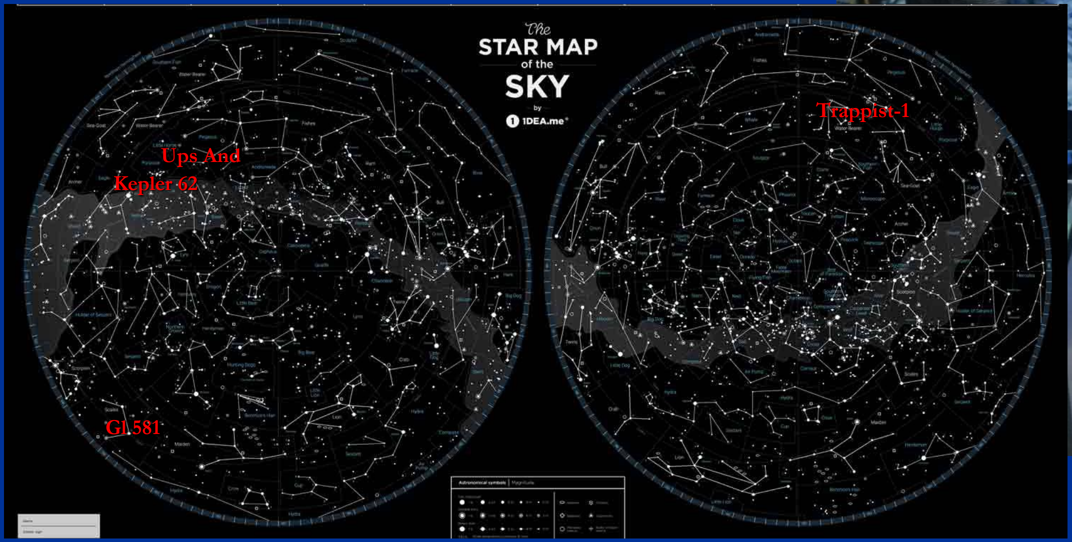
Jet Propulsion Laboratory (NASA; http://planetquest.jpl.nasa.gov/)

The masses are compared with Jupiter (1.9 x 10^{27} kg) or the Earth (5.97 $\times$ 10^{24} kg).



Technological limits are the cause.

Activity 16: Scale models of exoplanetary systems



Distance 1 AU = 1 m
Diameter 10000 km = 0.5 cm

Activity 16: Build Solar System:

Solar System	Distance AU	Diameter km	Model Distance	Model Diameter
Mercury	0.39	4879	40 cm	0.2 cm
Venus	0.72	12104	70 cm	0.6 cm
Earth	1	12756	1m	0.6 cm
Mars	1.52	6794	1.5 m	0.3 cm
Jupiter	5.2	142984	5 m	7 cm
Saturn	9.55	120536	10 m	6 cm
Uranus	19.22	51118	19 m	2.5 cm
Neptun	30.11	49528	30 m	2.5 cm

Host Star Sun G2V, Diameter of the Sun in the model is 35 cm

Distance 1 AU = 1 m

Diameter 10000 km = 0.5 cm

Activity 16: Build 1st exoplanetary system:

Upsilon Andromedae Titawin	**Discovery** year	Distance AU	Diameter km	Model Distance	Model Diameter
Ups And b/Saffar	1996	0.059	108 000	6 cm	5.5 cm
Ups And c/Samh	1999	0.830	200 000	83 cm	10 cm
Ups And d/Majriti	1999	2.510	188 000	2.5 m	9 cm
Ups And e/Titawin e	2010	5.240	140 000	5.2 m	7 cm

Host Star Ups Andromedae F8V is at 44 l.y. in And.,
Diameter 1.28 of the Sun in the model is 45 cm

Distance 1 AU = 1 m
Diameter 10000 km = 0.5 cm

Activity 16: Build "terrestrial" planets

Gliese 581	Discovery year	Distance AU	Diameter km	Model Distance	Model Diameter
Gl.581 e	2009	0.030	15 200	3 cm	0.8 cm
Gl.581 b	2005	0.041	32 000	4 cm	1.6 cm
Gl.581 c	2007	0.073	22 000	7 cm	1.1 cm

Host star Gliese 581 M2,5V is 20,5 l.y. in Libra, Diameter 0.29 of the Sun in the model is 10 cm

Distance 1 AU = 1 m

Diameter 10000 km = 0.5 cm

Activity 16: Build "habitable terrestrial"planets

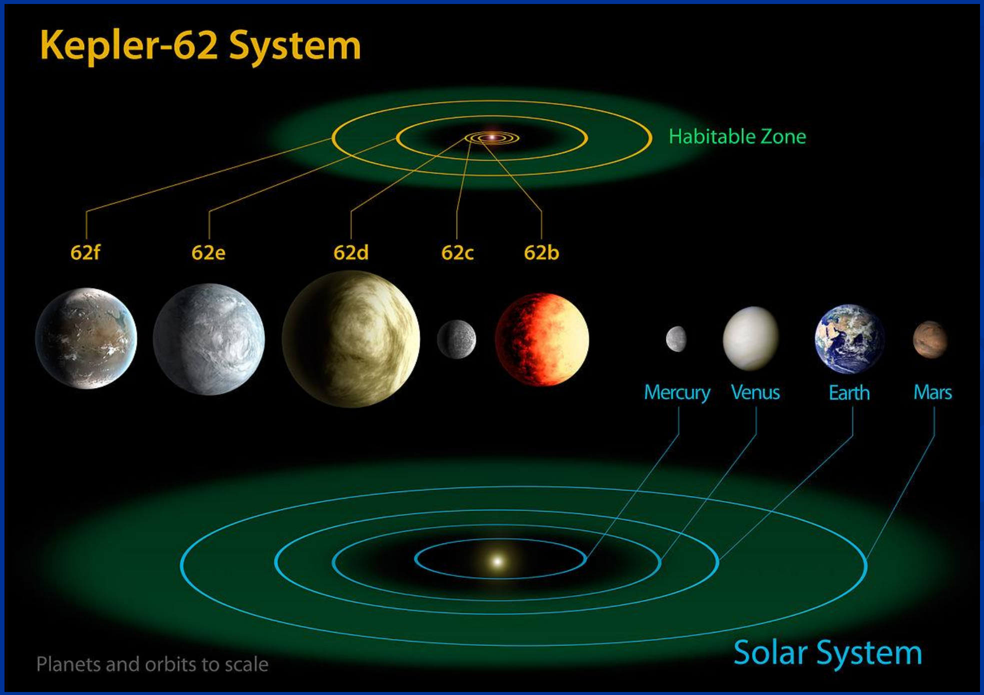
Kepler 62	Discovery year	Distance AU	Diameter km	Model Distance	Model Diameter
Kepler-62 b	2013	0.056	33 600	5.6 cm	1.7 cm
Kepler-62 c	2013	0.093	13 600	9 cm	0.7 cm
Kepler-62 d	2013	0.120	48 000	12 cm	2.4 cm
Kepler-62 e	2013	0.427	40 000	43 cm	2 cm
Kepler-62 f	2013	0.718	36 000	72 cm	1.8 cm

Host star Kepler 62 K2V is at 1200 l.y. in Lyr,. Diameter 0.64 of the Sun in the model is 22 cm

Distance 1 AU = 1 m
Diameter 10000 km = 0.5 cm

Possible habitability of exoplanets

- In the habitable zone of Kepler-62: the two exoplanets could have liquid water on their surfaces. For Kepler-62e, which is near the interior of the habitable zone, this would require coverage of reflective clouds that reduces the radiation that heats the surface. Kepler-62f, on the other hand, is in the outer zone of the habitable zone



Activity 16: Build “habitable terrestrial”planets

Trappist-1	**Discovery** year	Distance AU	Diameter km	Model Distance	Model Diameter
Trappist-1 b	2016	**0.012**	**28 400**	**1.2 cm**	**1.4 cm**
Trappist-1 c	2016	**0.016**	**28 000**	**1.6 cm**	**1.4 cm**
Trappist-1 d	2016	**0.022**	**20 000**	**2.2 cm**	**1.0 cm**
Trappist-1 e	2017	**0.030**	**23 200**	**3.0 cm**	**1.2 cm**
Trappist-1 f	2017	**0.039**	**26 800**	**3.9 cm**	**1.3 cm**
Trappist-1 g	2017	**0.047**	**29 200**	**4.7 cm**	**1.5 cm**
Trappist-1 h	2017	**0.062**	**19 600**	**6.2 cm**	**1.0 cm**

Host star Trappist 1 M8V is at 40 l.y. in Acuarius,

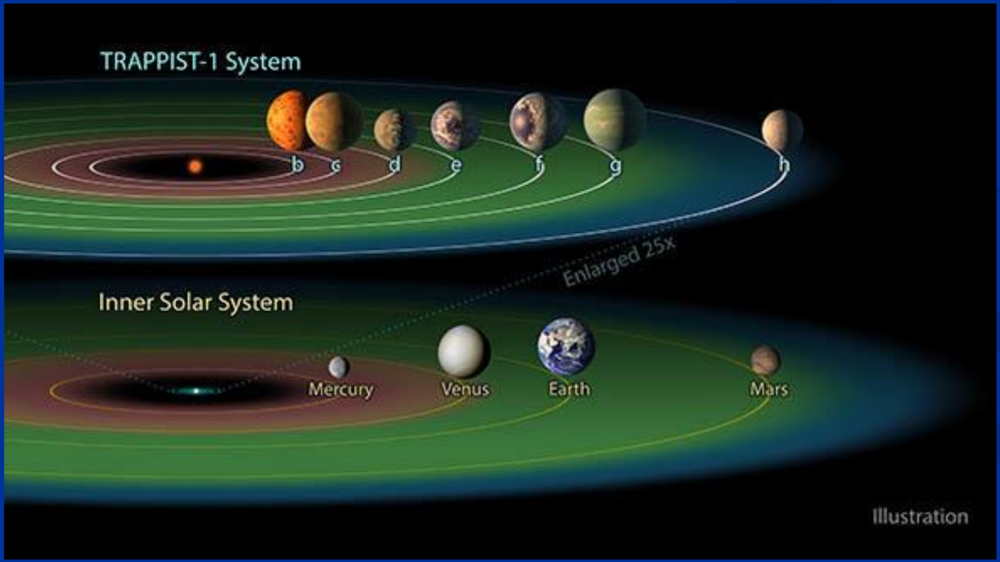
Diameter 0.1 of the Sun in the model is 4 cm

Distance 1 AU = 1 m

Diameter 10000 km = 0.5 cm

Possible habitability of exoplanets

- In the Trappist-1 system are rocky and could have large amounts of water on their surface, either liquid, in the form of steam, or as an ice crust. In the habitable zone of Trappist 1 is Trappist-1e which appears to have a dense nucleus, comparable to Earth which seems to indicate that of all the planets in this system, this is the most Earth-like and is likely to have a protective magnetosphere.



Conclusions

- Knowledge is more "concrete" of planets
- Relationships establish "parameters" that allow a better understanding of dimensions
- The solar system "is empty"
- Introduction of exoplanets. Recognize the methods for detection.

Thank you for your attention!