FUNDAMENTOS PARA O ENSINO DE ASTRONOMIA

Semana 6
(Aulas 19 a 22)

Mecânica Celeste

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I. A cinemática celeste pré-newtoniana

Da cinemática à mecânica: da descrição observacional à busca pelas causas e leis gerais.

Modelo aristotélico-ptolomaico (~150 d.C.): descrição matemática muito precisa da esfera celeste.

Muhammad al-Khwarizmi (~820): álgebra e a questão da prova como determinação para regras gerais científicas. Ideia de Leis Gerais.

Nicolau Copérnico (~1543) e a proposta de modelagem heliocêntrica.

Tycho Brahe (~1590), geocentrista, e as observações detalhadas e categorizadas.

Johannes Kepler (~1610), heliocentrista, e a publicação das Leis do Movimento.

I. A cinemática celeste pré-newtoniana

Leis de Kepler:

- 1ª: Lei das órbitas elípticas: os planetas se movem em elipses focadas no Sol;

- 2ª: Lei das áreas: os planetas se movem com velocidade areolar (momento angular) heliocêntrica constante;

- 3ª: Lei harmônica: a relação entre os cubos dos eixos maiores das elipses e os quadrados dos períodos dos movimentos planetários é igual para todos os planetas ($a^3/T^2 = k$).

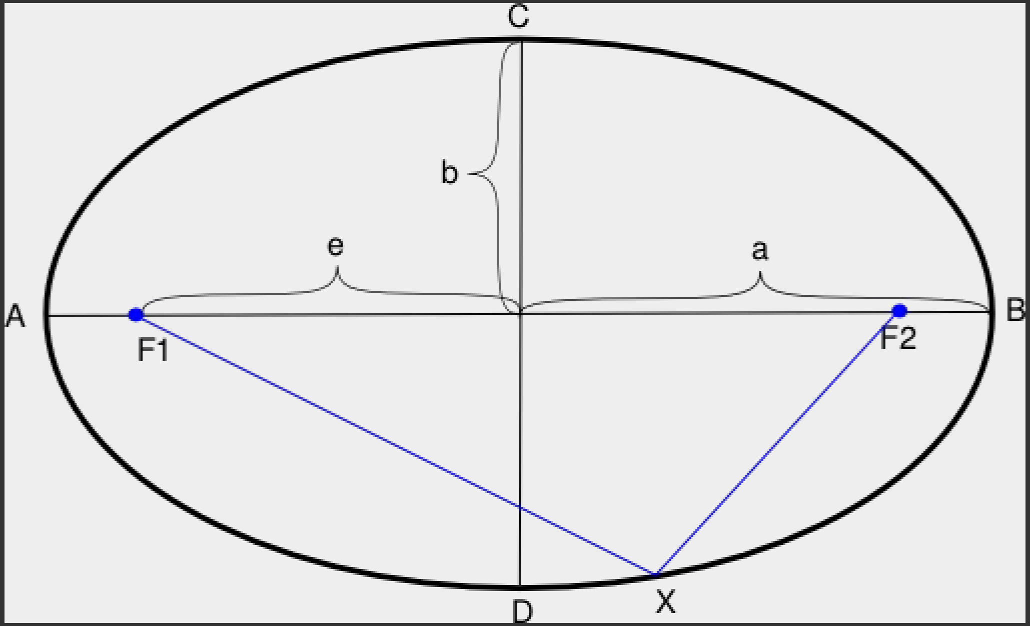


Fig. 1:
Elipse

http://matematecnologia.blogspot.com.br/2010/10/elipse-para-ensino-medio.html

Abrir applet: Leis de Kepler

Disponível em: https://phet.colorado.edu/en/contributions/view/3874

II. A mecânica celeste newtoniana

Galileu (~1630): Diálogo sobre dois máximos sistemas de mundo / Discurso sobre duas novas ciências: céu e terra como um só mundo.

Newton (~1680): Lei da Gravitação Universal: matéria atrai matéria na razão direta das massas e inversa do quadrado das distâncias ($F_G = G.m_1.m_2/r^2$).

Cavendish (~1800): $G = 6,672.10^{-8}$ $cm^3.g^{-1}.s^{-2}$ (válida para quaisquer corpos no Universo).

Applet: Lei da Gravitação Universal

Disponível em:
https://phet.colorado.edu/en/simulation/legacy/gravity-and-orbits

II. A mecânica celeste newtoniana

Mecânica celeste (Laplace, ~1810): Leis do movimento e Lei da Gravitação Universal newtonianas.

Conservação do momento angular ($L = m.r.v.\text{sen}\theta$): plano orbital constante e lei das áreas obedecida.

Conservação da energia ($E_C + E_P = \text{const.}$): movimento cônico (elipse, parábola, hipérbole ou circunferência); lei harmônica revisitada ($a^3/T^2 = \mu/4.\pi^2$, onde $\mu = G.(M + m)$).

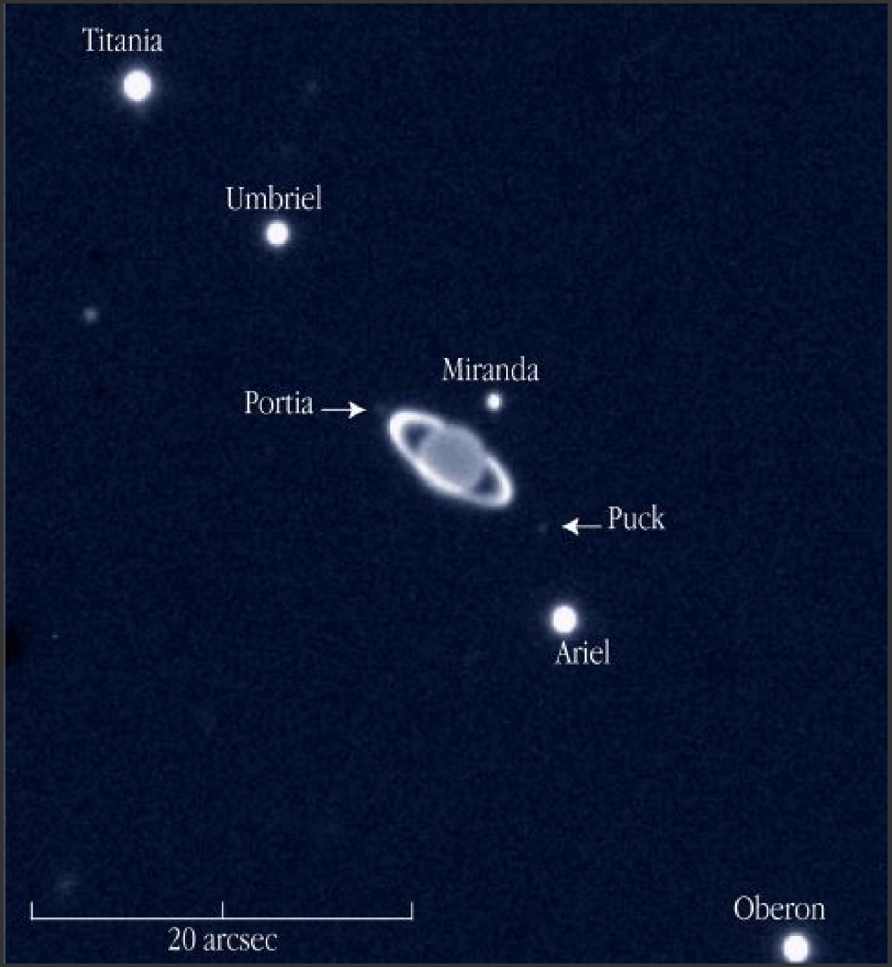
Previsão de Newton da passagem do cometa Halley em 1758 (após percepção das passagens de 1531, 1607 e 1682 na literatura).

Demônio de Laplace: determinismo!

Descoberta de Urano (1781) e sua órbita não newtoniana.
Descoberta/confirmação de Netuno (1845) como perturbador da órbita de Urano.
Mercúrio, suas anomalias orbitais e o planeta Vulcano.

II. A mecânica celeste newtoniana

Fig. 2: Urano com anéis.



2003 January 15
Ringed Planet Uranus
Credit: E. Lellouch, T. Encrenaz (Obs. Paris), J. Cuby , A. Jaunsen (ESO-Chile), VLT Antu, ESO

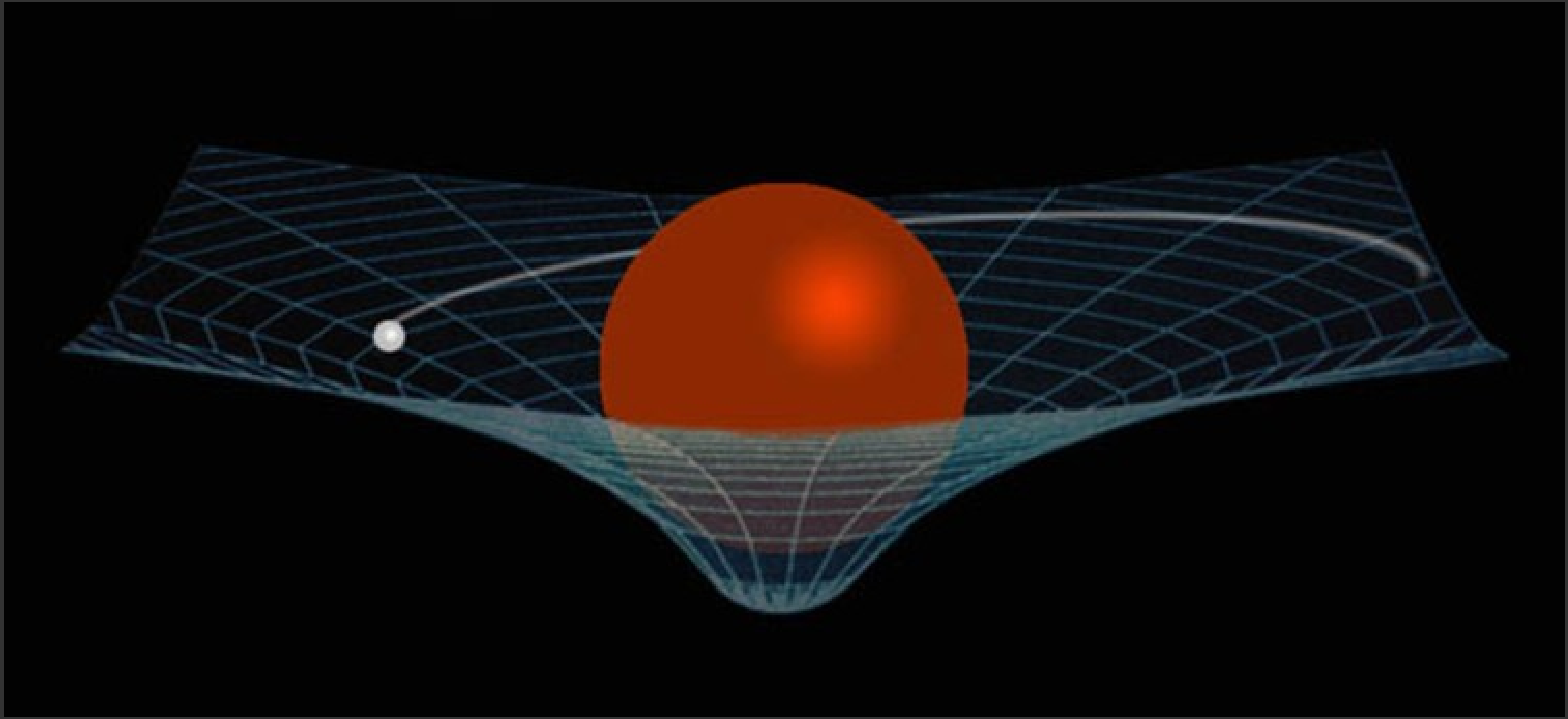
Explanation: Yes it does look like Saturn, but Saturn is only one of four giant ringed planets in our Solar System. And while Saturn has the brightest rings, this system of rings and moons actually belongs to planet Uranus, imaged here in near-infrared light by the Antu telescope at the ESO Paranal Observatory in Chile. Since gas giant Uranus' methane-laced atmosphere absorbs sunlight at near-infrared wavelengths the planet appears substantially darkened, improving the contrast between the otherwise relatively bright planet and the normally faint rings. In fact, the narrow Uranian rings are all but impossible to see in visible light with earthbound telescopes and were discovered only in 1977 as careful astronomers noticed the then unknown rings blocking light from background stars. The rings are thought to be younger than 100 million years and may be formed of debris from the collision of a small moon with a passing comet or asteroid-like object. With moons named for characters in Shakespeare's plays, the distant ringed world Uranus was last visited in 1986 by the Voyager 2 spacecraft.

III. A mecânica celeste depois de Einstein

Einstein (~1915) e a Teoria da Relatividade Geral: movimento e campo como uma só lei. Geodésicas do espaço-tempo.

Anomalias nas órbitas (periélio) previstas pela teoria einsteiniana (ex.: Mercúrio → 43''/século).

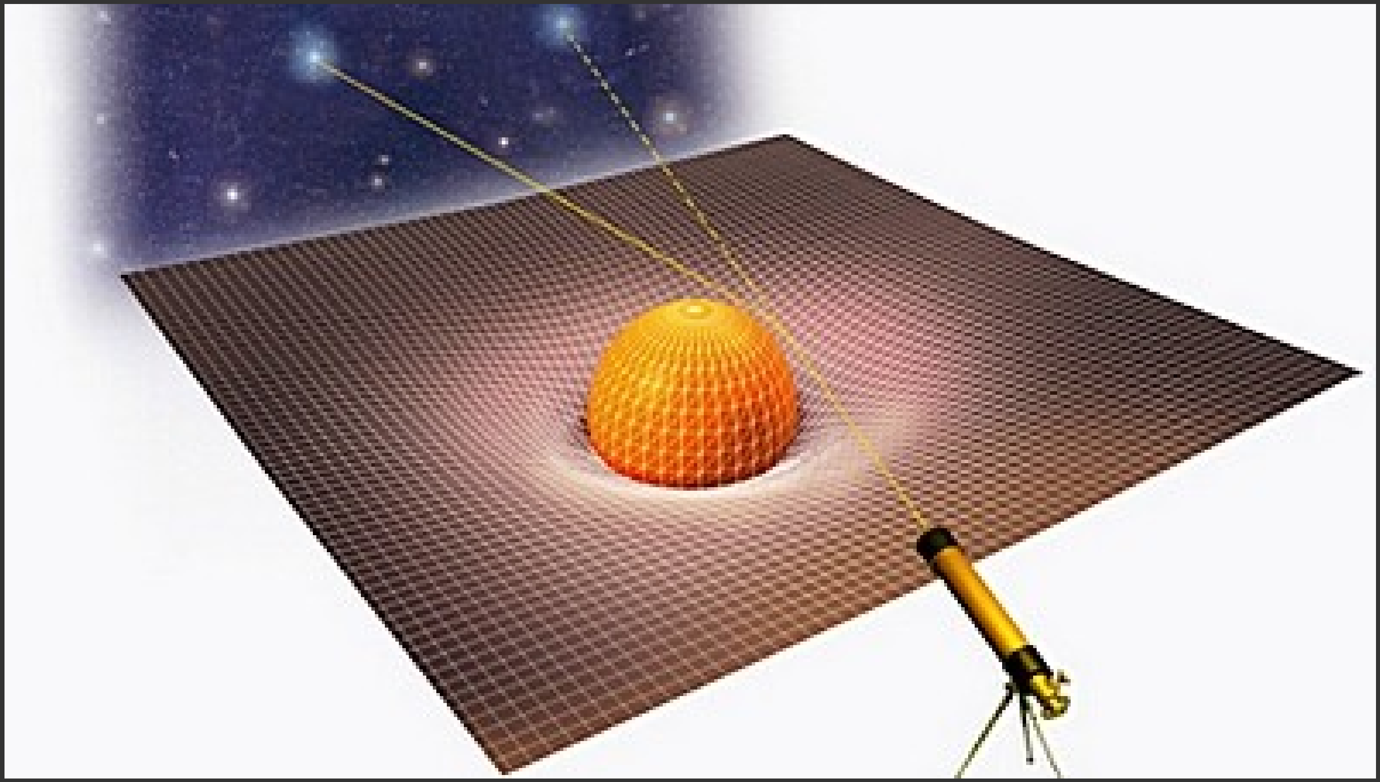
Fig. 3: Modelo de espaço-tempo curvo.



http://theconversation.com/rippling-space-time-how-to-catch-einsteins-gravitational-waves-7058

III. A mecânica celeste depois de Einstein

Fig. 4: Modelo de espaço-tempo curvo.



http://blogs.proquest.com/elibrary/einsteins-general-theory-of-relativity-published/

IV. A mecânica do Sistema Solar

O que temos no Sistema Solar?

Matéria: Sol, planetas, planetas-anões, luas, asteroides, cometas, meteoroides, poeira...

Energia: Ondas, campos eletromagnéticos e gravitacionais...

Planetas

Movimento (e suas variáveis) bem conhecido.

Órbitas elípticas (rosáceas), movimento de precessão do plano, excentricidades e inclinações variáveis no tempo, segundo atração mútua entre planetas, principalmente.

IV. A mecânica do Sistema Solar

Fig. 5: Movimento das órbitas (Fig. 4.4, p. 61)

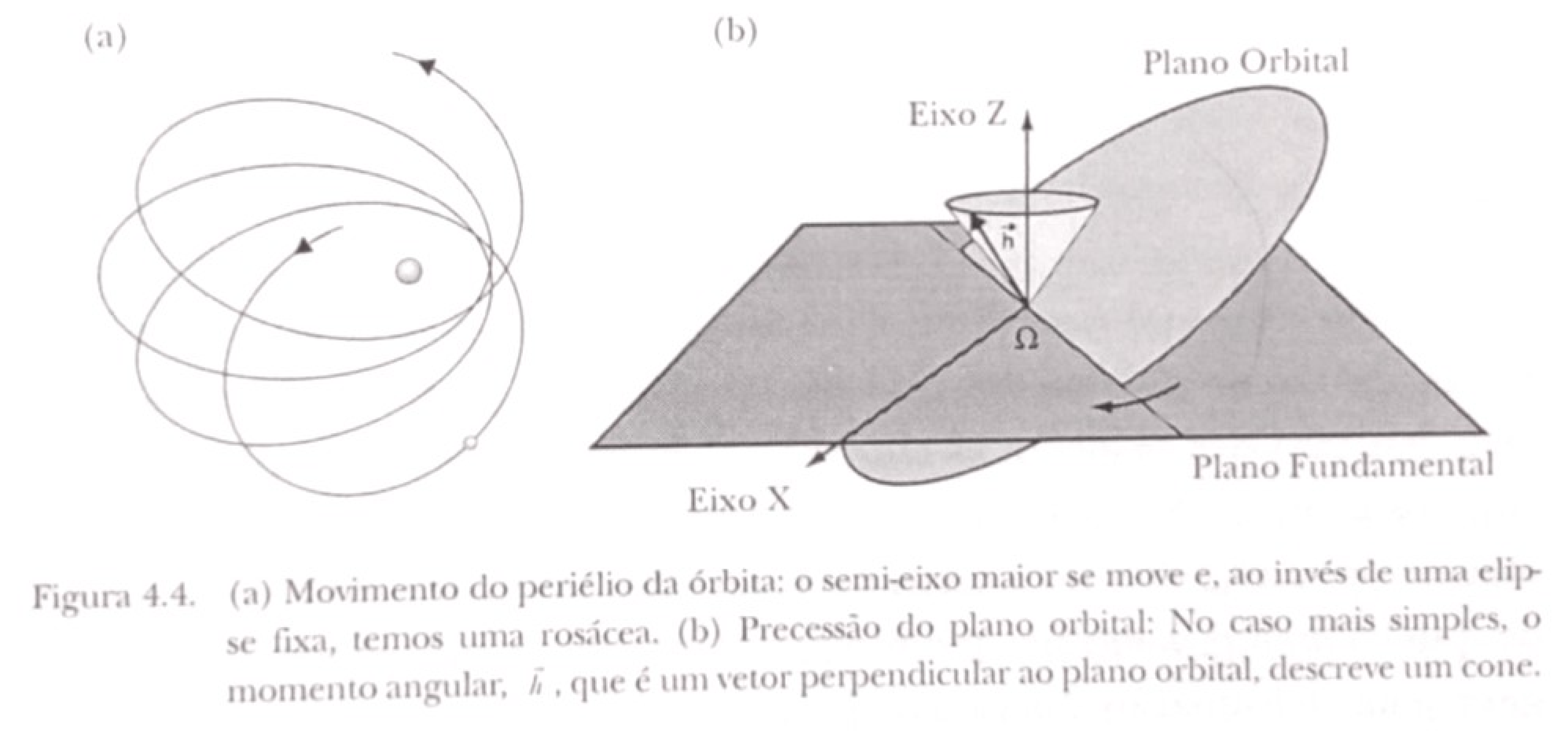


Figura 4.4. (a) Movimento do periélio da órbita: o semi-eixo maior se move e, ao invés de uma elipse fixa, temos uma rosácea. (b) Precessão do plano orbital: No caso mais simples, o momento angular, $\vec{h}$, que é um vetor perpendicular ao plano orbital, descreve um cone.

IV. A mecânica do Sistema Solar

Fig. 6: Órbitas de Netuno e Plutão (Fig. 4.6, p. 62)

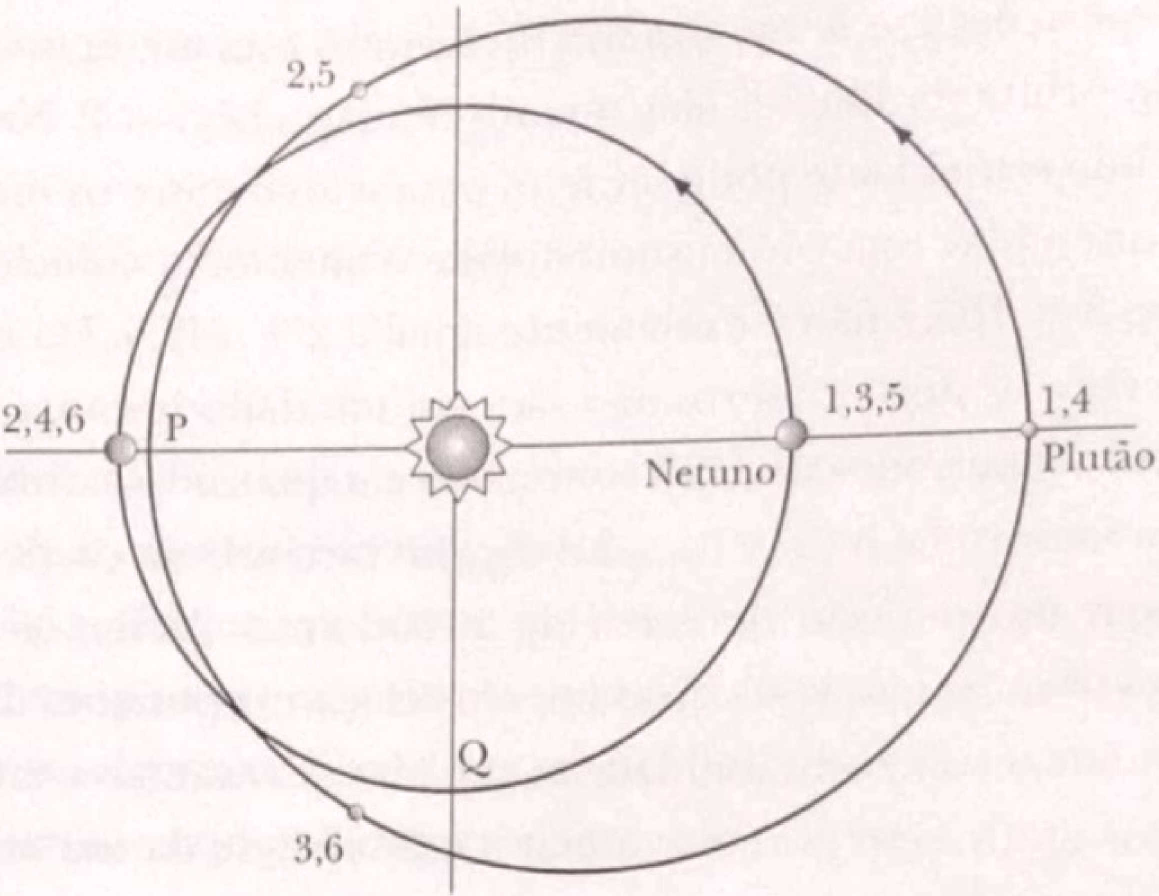
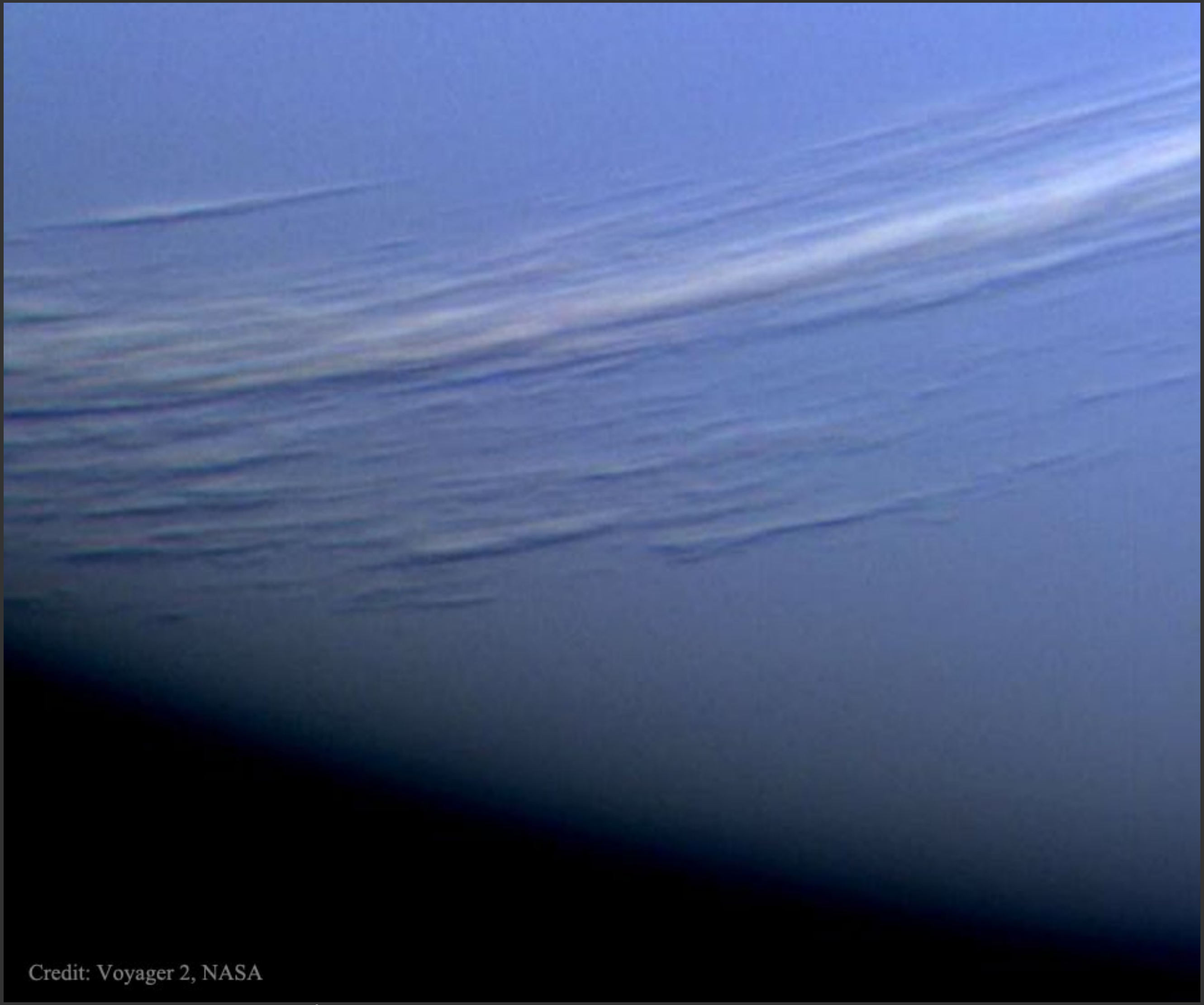


Figura 4.6. Posição relativa das órbitas de Netuno e Plutão. Os números 1, 2, 3, 4, 5 e 6 indicam posições simultâneas de Netuno e Plutão. Repetindo-se ciclicamente, elas mostram porque Netuno e Plutão não podem jamais colidir.

IV. A mecânica do Sistema Solar

Fig. 7: Netuno pela Voyager 2



2015 February 15
Two Hours Before Neptune
Image Credit: Voyager 2, NASA

Explanation: Two hours before closest approach to Neptune in 1989, the Voyager 2 robot spacecraft snapped this picture. Clearly visible for the first time were long light-colored cirrus-type clouds floating high in Neptune's atmosphere. Shadows of these clouds can even be seen on lower cloud decks. Most of Neptune's atmosphere is made of hydrogen and helium, which is invisible. Neptune's blue color therefore comes from smaller amounts of atmospheric methane, which preferentially absorbs red light. Neptune has the fastest winds in the Solar System, with gusts reaching 2000 kilometers per hour. Speculation holds that diamonds may be created in the dense hot conditions that exist under the cloud tops of Uranus and Neptune. Twenty-six years later, NASA's New Horizons is poised to be the first spacecraft to zoom past Pluto this July.

IV. A mecânica do Sistema Solar

Satélites

Movimentos seguindo Leis de Kepler (e suas correções relativísticas).

Órbitas, planos e perigeo variáveis (em nodo, não em inclinação) segundo achatamento planetário.

Ex. 1: Lua: período do movimento do plano: 18,6 anos.

Ex. 2: Satélite artificial: com inclinação de 20 º sobre equador, a 900 km de altitude: 2 meses.

Interação Satélite-Planeta: há 2.10^9 anos, a Lua devia estar a 20.10^3 km da Terra e a rotação do planeta devia durar 5 h. Ao afastarem-se (ganho de energia potencial), reduzem-se as velocidades angulares (energia cinética). Sincronicidade de movimentos de rotação e translação dos satélites.

IV. A mecânica do Sistema Solar

Fig. 8: Lançamento de satélite artificial do Japão

2016 February 18
Hitomi Launches
Image Credit & Copyright: F. Scott Porter (NASA, Goddard Space Flight Center)

Explanation: On February 17 at 5:45pm JST this H-IIA rocket blasted skyward from JAXA's Tanegashima Space Center located off the southern coast of Japan, planet Earth. Onboard was the ASTRO-H X-ray astronomy satellite, now in orbit. Designed to explore the extreme cosmos from black holes to massive galaxy clusters, the satellite observatory is equipped with four cutting-edge X-ray telescopes and instruments sensitive to photon energies from 300 to 600,000 electron volts. By comparison, visible light photon energies are 2 to 3 electron volts. Following a tradition of renaming satellites after their successful launch, ASTRO-H has been newly dubbed "Hitomi", inspired by an ancient legend of dragons. Hitomi means "the pupil of the eye".

IV. A mecânica do Sistema Solar

Fig. 9: O astronauta que capturou um satélite

2010 January 11
The Astronaut Who Captured a Satellite
Credit: STS-51A, NASA

Explanation: In 1984, high above the Earth's surface, an astronaut captured a satellite. It was the second satellite captured that mission. Pictured above, astronaut Dale A. Gardner flies free using the Manned Maneuvering Unit and begins to attach a control device dubbed the Stinger to the rotating Westar 6 satellite. Communications satellite Westar 6 had suffered a rocket malfunction that left it unable to reach its intended high geosynchronous orbit. Both the previously caught Palapa B-2 satellite and the Westar 6 satellite were guided into the cargo bay of the Space Shuttle Discovery and returned to Earth. Westar 6 was subsequently refurbished and sold.

IV. A mecânica do Sistema Solar

Asteroides/ Planetas anões

Órbitas semelhantes às dos planetas.

Mais de 50000 bem conhecidos, a grande maioria entre Marte e Júpiter.

Inclinações (de até 60º) e excentricidades (de até 0,9) bastante diversificadas.

Asteroides Hildas (~60) , com períodos menores e ressonantes com Júpiter.

Asteroides Troianos (~1000), com períodos iguais ao de Júpiter.

Agrupamentos (famílias: Koronis, Themis, Eos...) de pontos na análise estatística de energia própria e inclinações do momento angular.

IV. A mecânica do Sistema Solar

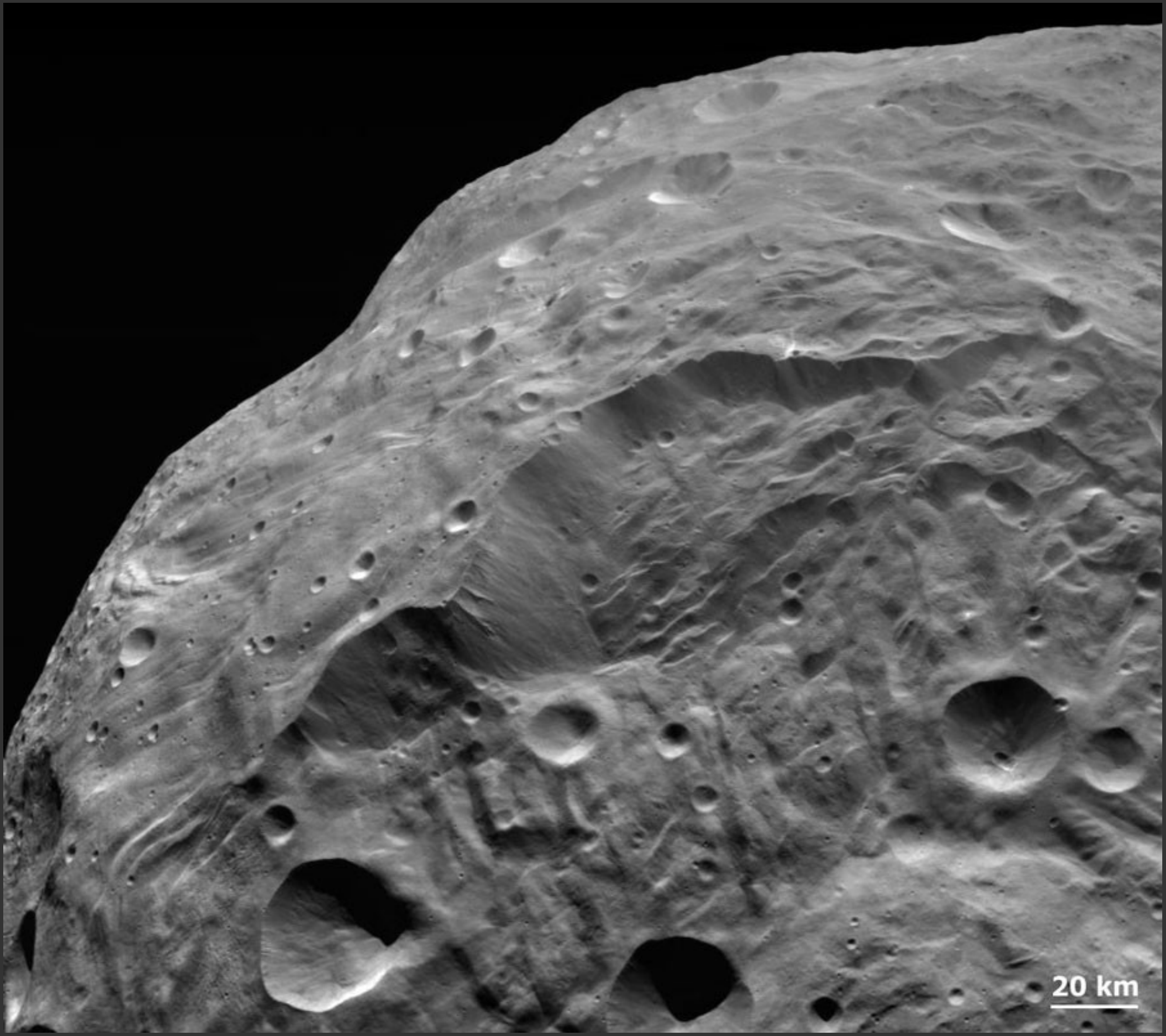
Fig. 10: Aproximando-se do asteroide Ceres

2015 January 20
Approaching Asteroid Ceres
Image Credit: NASA, JPL-Caltech, UCLA, MPS/DLR/IDA/PSI

Explanation: It is the largest asteroid in the asteroid belt -- what secrets does it hold? To find out, NASA has sent the robotic Dawn spacecraft to explore and map this cryptic 1,000-kilometer wide world: Ceres. Orbiting between Mars and Jupiter, Ceres is officially categorized as a dwarf planet but has never been imaged in detail. Featured here is a 20-frame video taken a week ago of Dawn's approach that now rivals even the best images of Ceres ever taken by the Hubble Space Telescope. The video shows enough surface definition to discern its 9-hour rotation period. On target to reach Ceres in early March, Dawn will match speeds and attempt to orbit this previously unexplored body, taking images and data that may help humanity better understand not only the nature and history of Ceres but also the early history of our entire Solar System.

IV. A mecânica do Sistema Solar

Fig. 11: Paisagem no asteroide Vesta



2011 November 28
A Landslide on Asteroid Vesta
Image Credit: NASA, JPL-Caltech, UCLA, MPS, DLR, IDA

Explanation: Asteroid Vesta is home to some of the most impressive cliffs in the Solar System. Pictured above near the image center is a very deep cliff running about 20 kilometers from top to bottom. The image was taken by the robotic Dawn spacecraft that began orbiting the 500-kilometer space rock earlier this year. The topography of the scarp and its surroundings indicates that huge landslides may have occurred down this slope. The scarp's origin remains unknown, but parts of the cliff face itself must be quite old as several craters have appeared in it since it was created. Dawn has now finished up its high altitude mapping survey and will spiral down to a lower altitude orbit to better explore the asteroid's gravitational field. During 2012, Dawn is scheduled to blast away from Vesta and begin a long journey to the only asteroid belt object known to be larger: Ceres.

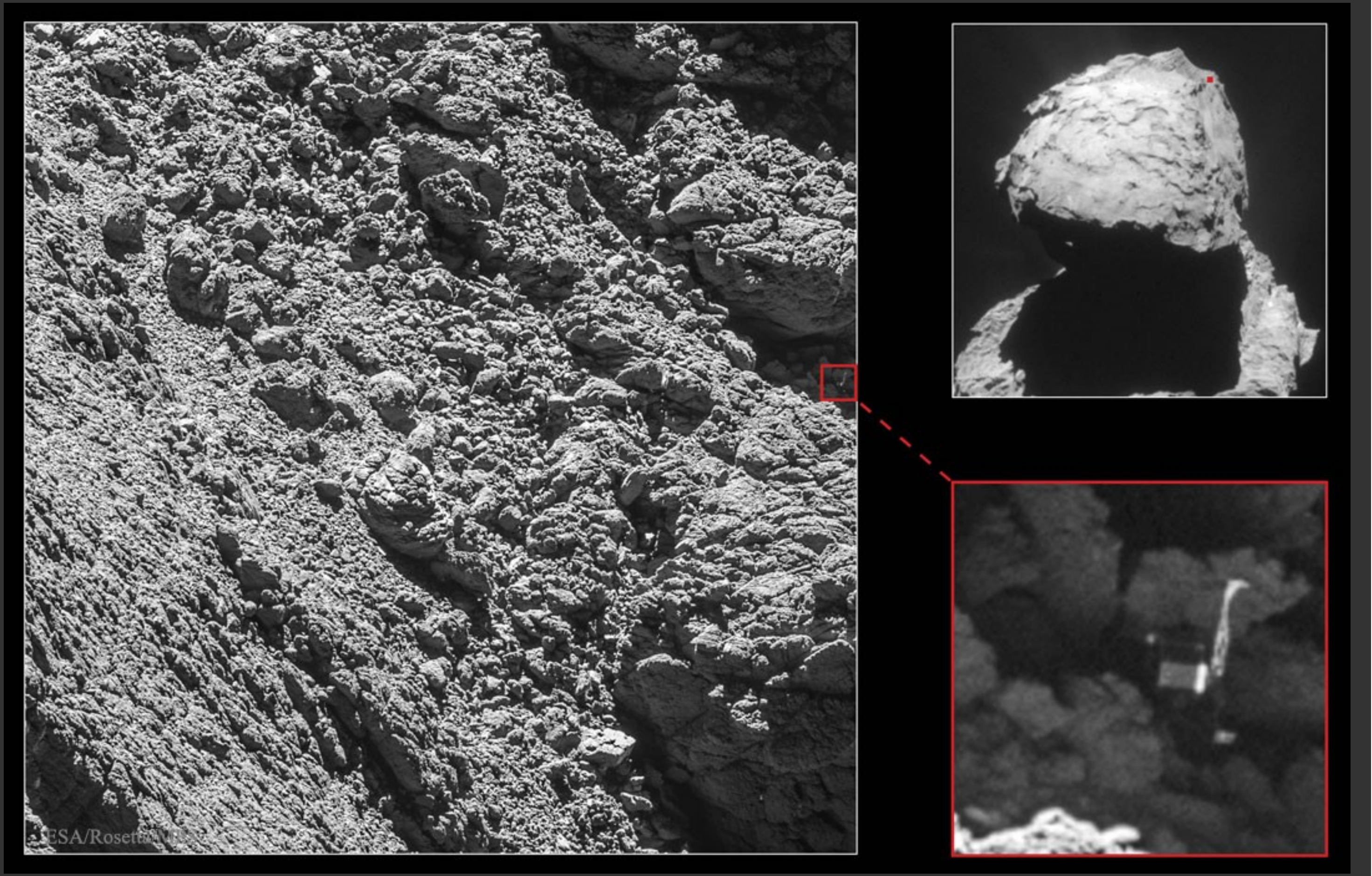
IV. A mecânica do Sistema Solar

Cometas

Órbitas elípticas, hiperbólicas ou parabólicas, mantendo-se ou afastando-se do Sistema Solar.

Cônicas [desenhar]

Fig. 12: Philae Lander encontrada no cometa 67P



2016 September 12
Philae Lander Found on Comet 67P
Image Credit & Copyright: ESA, Rosetta, MPS, OSIRIS; UPD/LAM/IAA/SSO/INTA/UPM/DASP/IDA/Navcam

Explanation: A little spacecraft that was presumed lost has now been found. In 2014, the Philae lander slowly descended from its parent Rosetta spacecraft to the nucleus of Comet C67/P Churyumov-Gerasimenko. At the surface, after a harpoon malfunction, the lander bounced softly twice and eventually sent back images from an unknown location. Earlier this month, though, Rosetta swooped low enough to spot its cub. The meter-sized Philae is seen on the far right of the main image, with inset images showing both a zoom out and a zoom in. At the end of this month, Rosetta itself will be directed to land on 67P, but Rosetta's landing will be harder and, although taking unique images and data, will bring the mission to an end.

V. Outros mundos

Estrelas duplas, triplas e sistemas galácticos: uso de disciplina própria, a saber, Dinâmica Estelar.

Detecção de planetas extrassolares por variações da linha espectral e movimentação do baricentro.

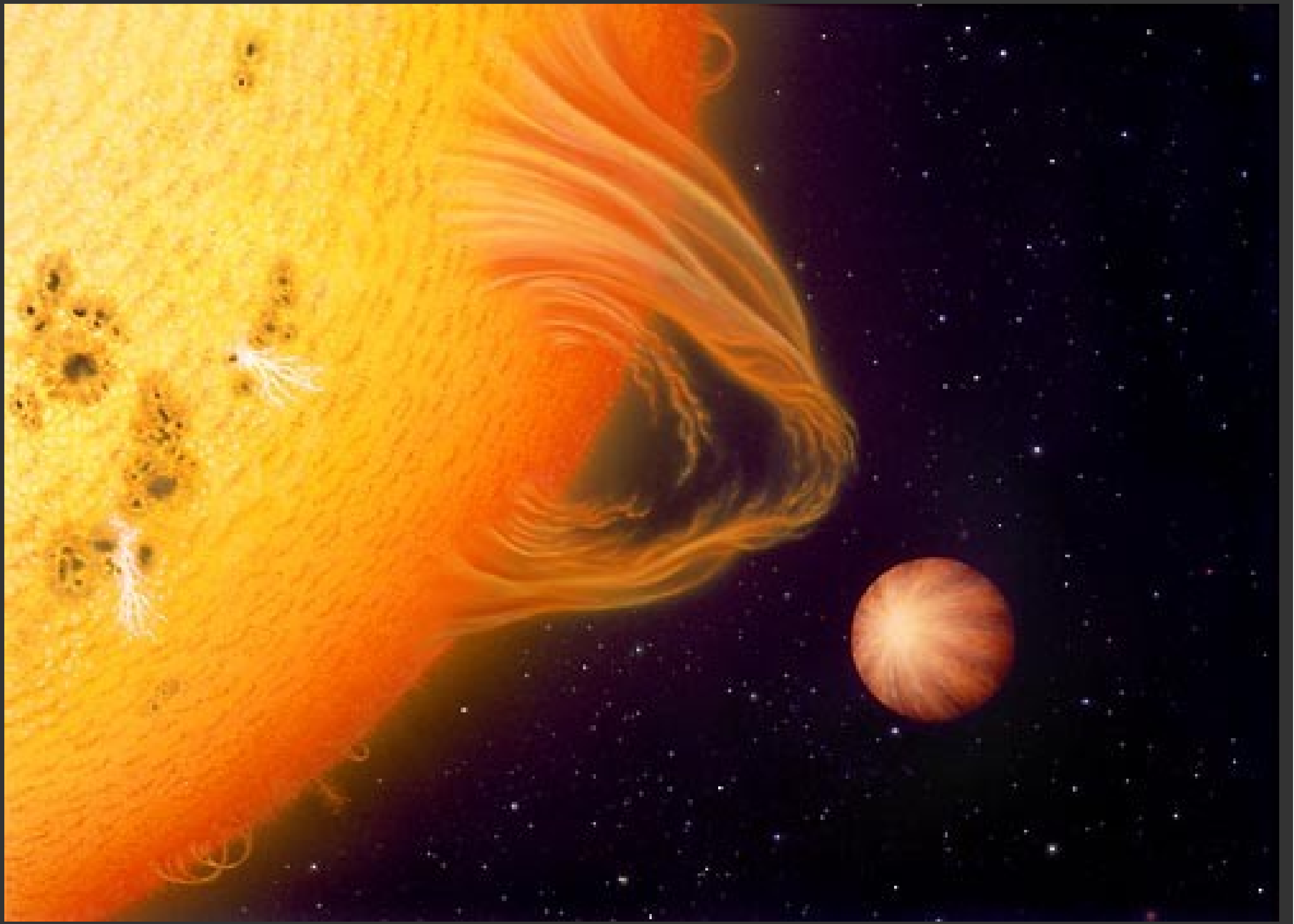


Fig. 13: Upsilon de Andrômeda: um sistema extrassolar

April 16, 1999
Upsilon Andromedae: An Extra-Solar System
Drawing Credit & Copyright: Lynette Cook

Explanation: Yesterday, astronomers announced the discovery of the first system of planets around a normal star other than our Sun. Previously, only single planet star systems had been found. Subtle changes in the wobble of Upsilon Andromedae, a Sun-like star in the constellation of Andromeda, allowed astronomers led by R. Paul Butler (AAO) and Geoffrey W. Marcy (SFSU /UCB) to make the breakthrough. This star system is quite different from our own Solar System, however. All three detected planets have masses near or above Jupiter. The discovery implies that multiple-planet systems are quite common, increasing speculation that life-bearing planets similar to Earth may one day be found. The drawing above is an artist's depiction of the Upsilon Andromedae system and its innermost planet. This planet orbits unexpectedly close to its parent star.

V. Outros mundos

Pulsares (ex.: estrelas de nêutrons girantes)

Fig. 14: M1: a nebulosa do caranguejo

2014 November 21
M1: The Crab Nebula
Image Credit & Copyright: Martin Pugh

Explanation: The Crab Nebula is cataloged as M1, the first object on Charles Messier's famous 18th century list of things which are not comets. In fact, the Crab is now known to be a supernova remnant, debris from the death explosion of a massive star, witnessed by astronomers in the year 1054. This sharp, ground-based telescopic view uses narrowband data to track emission from ionized oxygen and hydrogen atoms (in blue and red) and explore the tangled filaments within the still expanding cloud. One of the most exotic objects known to modern astronomers, the Crab Pulsar, a neutron star spinning 30 times a second, is visible as a bright spot near the nebula's center. Like a cosmic dynamo, this collapsed remnant of the stellar core powers the Crab's emission across the electromagnetic spectrum. Spanning about 12 light-years, the Crab Nebula is a mere 6,500 light-years away in the constellation Taurus.

VI. Caos

Muitos problemas da Mecânica Celeste são resolvidos de modo puramente gravitacional (energia e momento angular conservados por milhões ou bilhões de anos).

Caos: diferenças mínimas na origem levam a condições absurdamente diferentes na evolução: imprevisibilidade.
Caso das duas Terras (p. 76, § 1º).

Todo movimento celeste é caótico.
Asteroides desviados em direção ao Sol e os meteoritos.
Lua e outros satélites como possíveis resultados de alterações caóticas em órbitas de Asteroides.

VI. Caos

Fig. 15: Via Láctea condenada: colisão com Andrômeda pendente.

2012 June 4
Milky Way Galaxy Doomed: Collision with Andromeda Pending
Illustration Credit: NASA, ESA, Z. Levay and R. van der Marel (STScI), and A. Mellinger

Explanation: Will our Milky Way Galaxy collide one day with its larger neighbor, the Andromeda Galaxy? Most likely, yes. Careful plotting of slight displacements of M31's stars relative to background galaxies on recent Hubble Space Telescope images indicate that the center of M31 could be on a direct collision course with the center of our home galaxy. Still, the errors in sideways velocity appear sufficiently large to admit a good chance that the central parts of the two galaxies will miss, slightly, but will become close enough for their outer halos to become gravitationally entangled. Once that happens, the two galaxies will become bound, dance around, and eventually merge to become one large elliptical galaxy -- over the next few billion years. Pictured above is an artist's illustration of the sky of a world in the distant future when the central parts of each galaxy begin to destroy each other. The exact future of our Milky Way and the entire surrounding Local Group of Galaxies is likely to remain an active topic of research for years to come.

VIII. Atividade

Durante e após a aula:

- Relembrar da atividade de fotografia.

- Ler capítulos 5 e 6 do texto base.