FUNDAMENTOS PARA O ENSINO DE ASTRONOMIA

Semanas 8 e 9
Aulas 27 a 32

Estrelas e objetos estelares

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IFSP/Pirituba
2017

I. Introdução

Fig. 1: Trífida, Lagoa e Marte

2016 October 6
Trifid, Lagoon, and Mars
Image Credit & Copyright: Mohammad Nouroozi

Explanation: Bright nebulae and star clusters along this 5 degree wide field of view are popular stops on telescopic tours of the constellation Sagittarius and the crowded starfields of the central Milky Way. Cataloged by 18th century French astronomer Charles Messier, M20, the colorful Trifid Nebula, and M8, the expansive Lagoon Nebula, are at upper left and center. Both are well-known star forming regions about 5,000 light-years distant. Just passing through the same field of view on September 29, the yellowish star lined up with M8 and M20 at the lower right is actually Mars, close to 8.8 light-minutes from Earth on that date. That distance is nearly equivalent to 1 astronomical unit or the distance from Earth to Sun. Mars is overexposed in the image, with visible diffraction spikes created by the telescope mirror supports. Of course, Mars has long been known to wander through planet Earth's night skies.

I. Introdução

Como surgiu a ideia de que as estrelas são outros sóis?

- Cálculo da distância (paralaxe, ~1840)

- Medida do brilho aparente (~1850)

Conclusão: pela distância e pelo brilho as estrelas são semelhantes ao Sol.

E mais...
- Determinação de massa em sistemas duplos/triplos (~1860)
- Espectroscopia (~1860)
- Relatividade (~1920)

Teoria da evolução estelar!
(em desenvolvimento)

II. O Sol: uma estrela modelo

Princípio de conservação de energia (Meyer, ~1840; Helmholtz, ~1850)

Qual a fonte energética do Sol?

- Carvão? TNT?

Modelo com fonte gravitacional (newtoniano): vida solar de 30 milhões de anos.

Obs.: A datação da Terra, via calor de fossas profundas, era estimada em 40 milhões de anos.

Teoria da Relatividade (Einstein, ~1916; Eddington, ~1920)
$E = m.c^2$

Modelo com fonte nuclear (relativístico/quântico): vida solar de 100 bilhões de anos.

II. O Sol: uma estrela modelo

Possíveis reações nucleares em sistemas estelares (altas energias):

- Próton-próton (P-P) → Reações proporcionais a T^4 (temperatura até 20.10^6 K):
[H → He + energia].

- Carbono-Nitrogênio-Oxigênio (CNO) → T^{16} (20.10^6 a 100.10^6 K):
[C + H → C + He + energia]

- Triplo-alfa → T^{30} (acima de 100.10^6 K):
[He → C + energia]

Fig. 2: Fig. 7.1, p. 143.

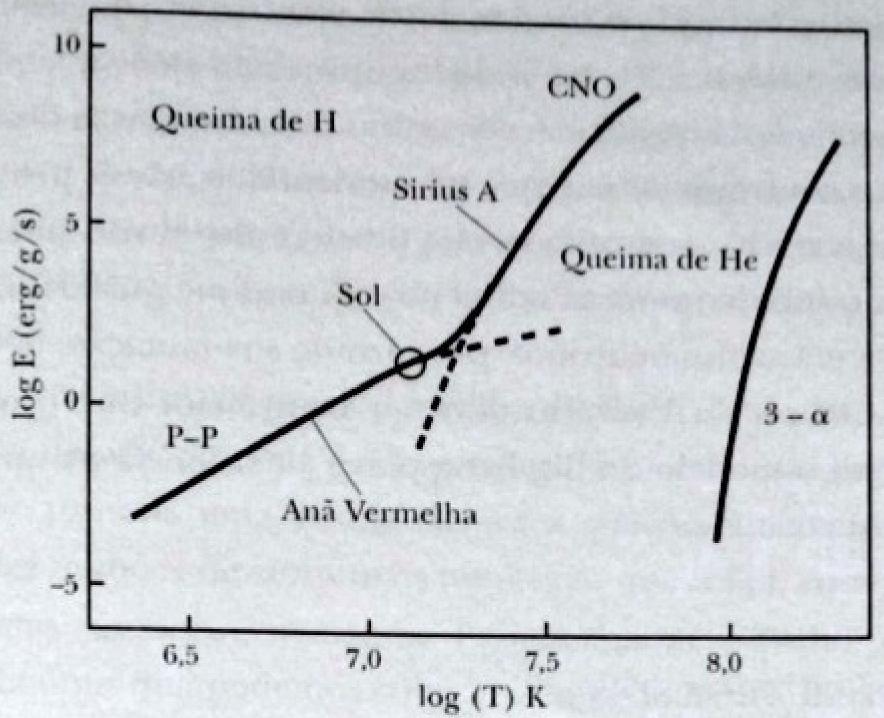


Figura 7.1. Energia por grama de matéria produzida pelos ciclos PP, CNO e triplo-α.

II. O Sol: uma estrela modelo

Da Luminosidade, Raio e Temperatura superficial do Sol:

- T(núcleo) = 15.10^6 K

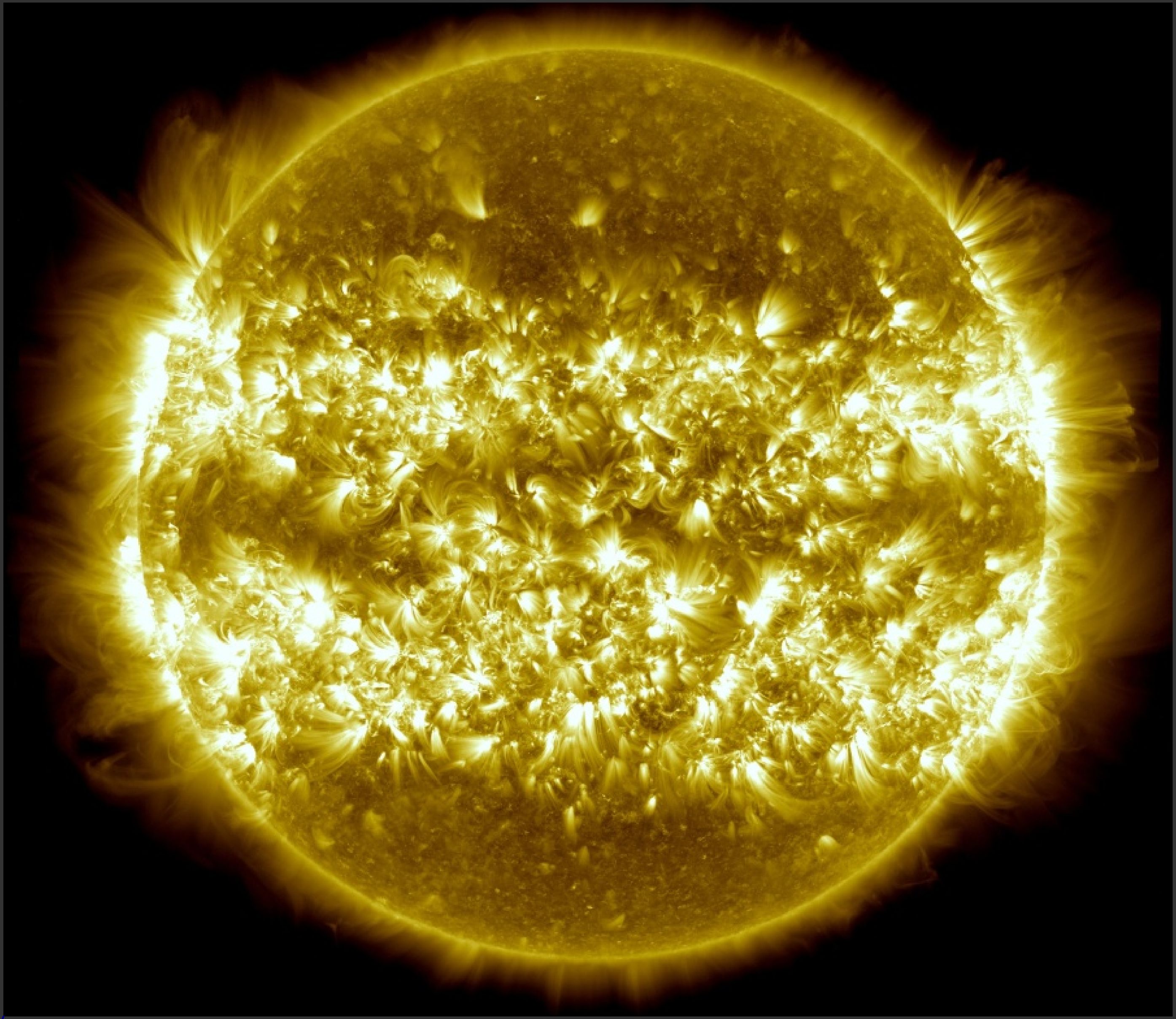
Se fosse cadeia PP, teríamos 66.10^9 neutrinos/cm².s

Só conseguimos detectar 17.10^9 neutrinos/cm².s → Isso daria T(núcleo) = $14{,}25.10^6$ K, raio, luminosidade e T(superfície) menores.

Problema do paradigma atual (neutrinos): Modelo atômico? Massa? Mutação? …

II. O Sol: uma estrela modelo

Fig. 3: Um ano no Sol



2013 April 26
A Year on the Sun
Image Credit: NASA,
Solar Dynamics Observatory

Explanation: Our solar system's miasma of incandescent plasma, the Sun may look a little scary here. The picture is a composite of 25 images recorded in extreme ultraviolet light by the orbiting Solar Dynamics Observatory between April 16, 2012 and April 15, 2013. The particular wavelength of light, 171 angstroms, shows emission from highly ionized iron atoms in the solar corona at a characteristic temperatures of about 600,000 kelvins (about 1 million degrees F). Girdling both sides of the equator during approach to maximum in the 11-year solar cycle, the solar active regions are laced with bright loops and arcs along magnetic field lines. Of course, a more familiar visible light view would show the bright active regions as groups of dark sunspots. Three years of Solar Dynamics Observatory images are compressed into this short video.

III. As estrelas: outros sóis

Como explorar?

- Brilho aparente (em magnitudes por exposição)

Relação de Pogson (~1850) – **Magnitudes aparentes** (visuais - V)

Ex.:

Vega (alfa Lira): m_V = 0;
Sol: m_V = - 26,74;
Sírius (alfa Cão Maior): m_V = - 1,45;
Rígel (beta Órion): m_V = 0,12;

Margem: - 26,74 (Sol) até + 6 (as mais fracas)

Magnitudes absolutas (A)
(considerando uma distância igual [10 pc] entre observador e qualquer estrela)

Ex.:
Vega (alfa Lira): m_A = + 0,65;
Sol: m_A = + 4,83;
Sírius (alfa Cão Maior): m_A = + 1,4;
Rígel (beta Órion): m_A = - 6,7;

Margem: - 10 (as mais brilhantes) até + 17 (as mais fracas)

PS: Limites estelares.

III. As estrelas: outros sóis

Fig. 4: Noite estrelada, Van Gogh, 1889.

2009 October 11
Starry Night by Vincent van Gogh
Credit: Vincent van Gogh; Digital image courtesy of Wikipedia

Explanation: The painting Starry Night is one of the most famous icons of the night sky ever created. The scene was painted by Vincent van Gogh in southern France in 1889. The swirling style of Starry Night appears, to many, to make the night sky come alive. Although van Gogh frequently portrayed real settings in his paintings, art historians do not agree on precisely what stars and planets are being depicted in Starry Night. The style of Starry Night is post-impressionism, a popular painting style at the end of the nineteenth century. The original Starry Night painting hangs in the Museum of Modern Art in New York City, New York, USA.

III. As estrelas: outros sóis

Espectros de diferentes estrelas
(Secchi, ~1870)

Sistema UBV
U = 3600 Å (ultravioleta);
B = 4400 Å (ultravioleta);
V = 5500 Å (amarelo/visível).

Fig 5: Fig. 7.4, p. 148.

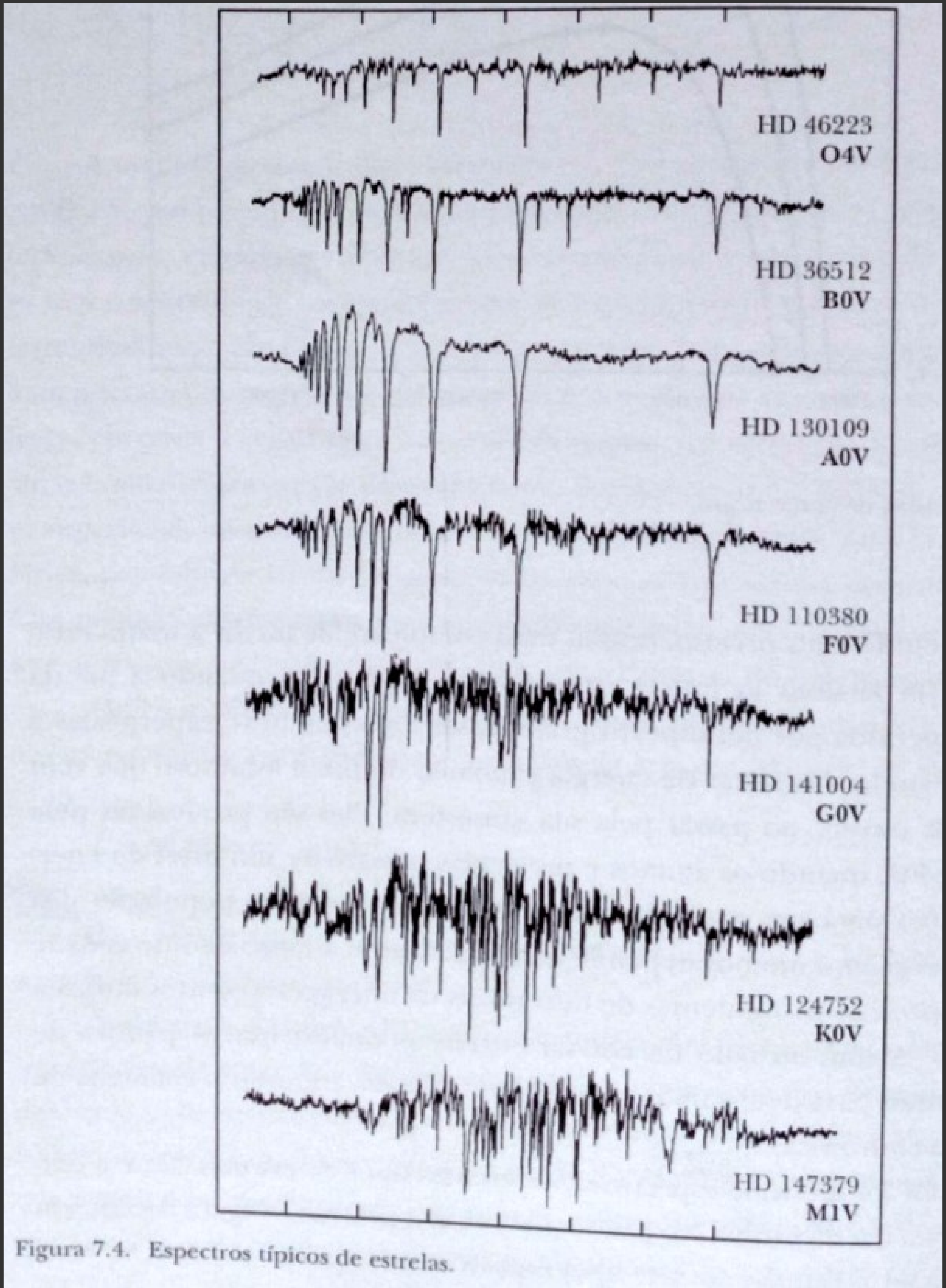


Figura 7.4. Espectros típicos de estrelas.

III. As estrelas: outros sóis

Análise comparativa do espectro do ultravioleta (B) e do visível (V).

Fig. 6: Tab. 7.1, p. 149.

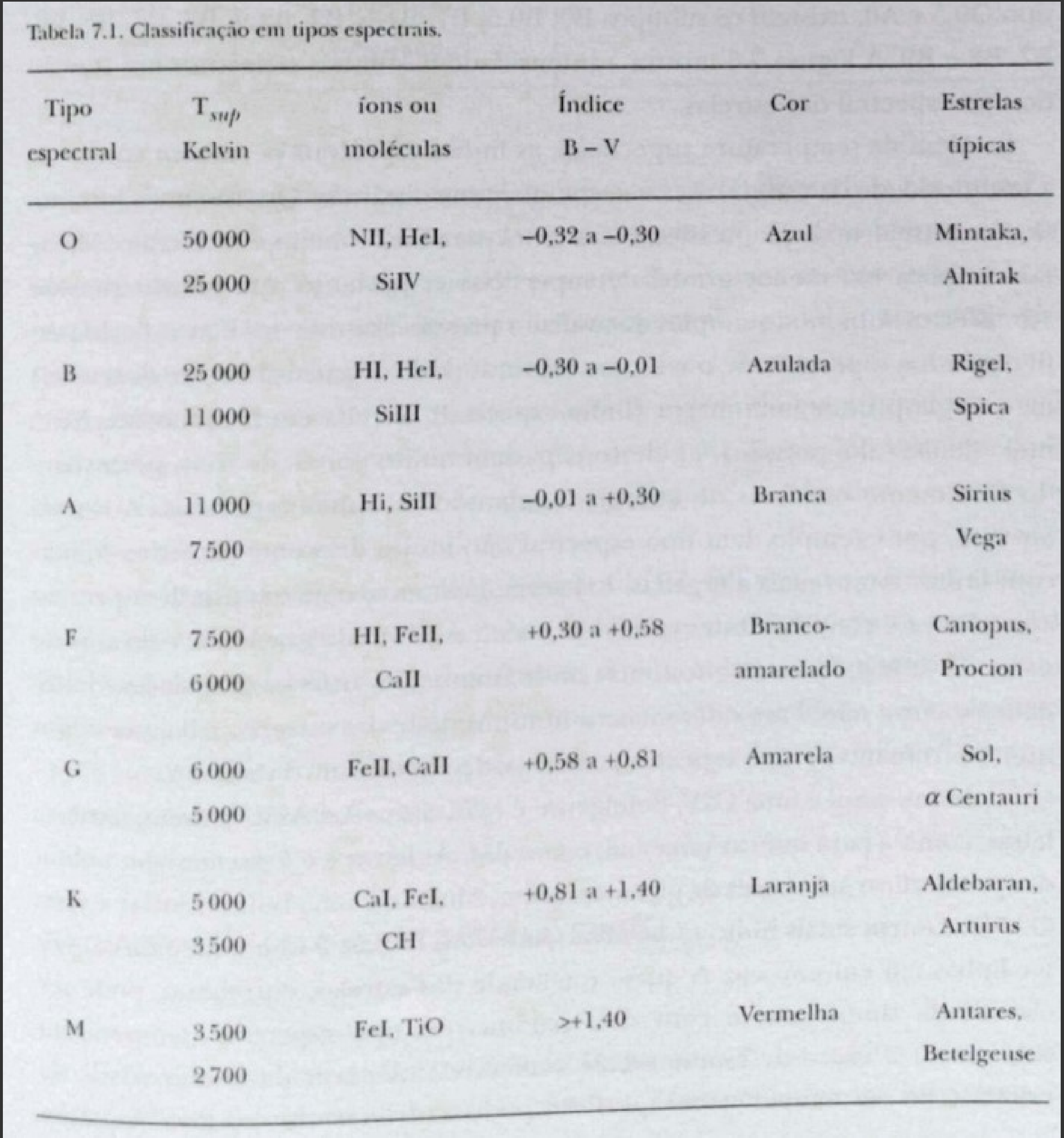


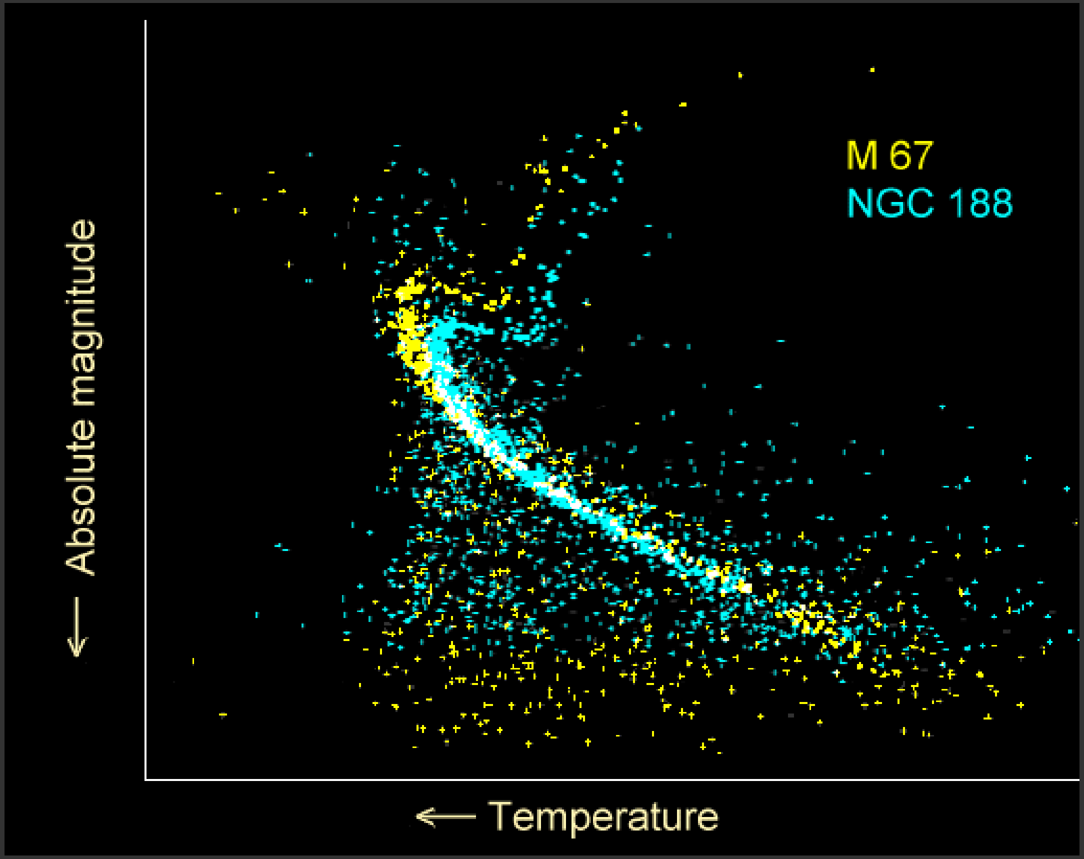
Tabela 7.1. Classificação em tipos espectrais.

Tipo espectral	T_{sup} Kelvin	íons ou moléculas	Índice B – V	Cor	Estrelas típicas
O	50 000 25 000	NII, HeI, SiIV	–0,32 a –0,30	Azul	Mintaka, Alnitak
B	25 000 11 000	HI, HeI, SiIII	–0,30 a –0,01	Azulada	Rigel, Spica
A	11 000 7 500	Hi, SiII	–0,01 a +0,30	Branca	Sirius Vega
F	7 500 6 000	HI, FeII, CaII	+0,30 a +0,58	Branco-amarelado	Canopus, Procion
G	6 000 5 000	FeII, CaII	+0,58 a +0,81	Amarela	Sol, α Centauri
K	5 000 3 500	CaI, FeI, CH	+0,81 a +1,40	Laranja	Aldebaran, Arturus
M	3 500 2 700	FeI, TiO	>+1,40	Vermelha	Antares, Betelgeuse

IV. O diagrama HR: um retrato de família

Ejnar Hertzsprung e Henry Russel: Diagrama H-R (~1910).

Relação entre Temperatura (Tipo Espectral) e Luminosidade (Magnitude) de estrelas.



Agrupamentos característicos:

1. Sequência principal
   cerca de 90% das estrelas;
2. Sequências superiores
   gigantes e supergigantes azuis e vermelhas;
3. Sequências inferiores
   pouco luminosas e pequenas;

Fig. 7: Diagrama HR (https://pt.wikipedia.org/wiki/Diagrama_de_Hertzsprung-Russell)

IV. O diagrama HR: um retrato de família

Fig. 8: Diagrama HR (Fig. 7.6, p. 152)

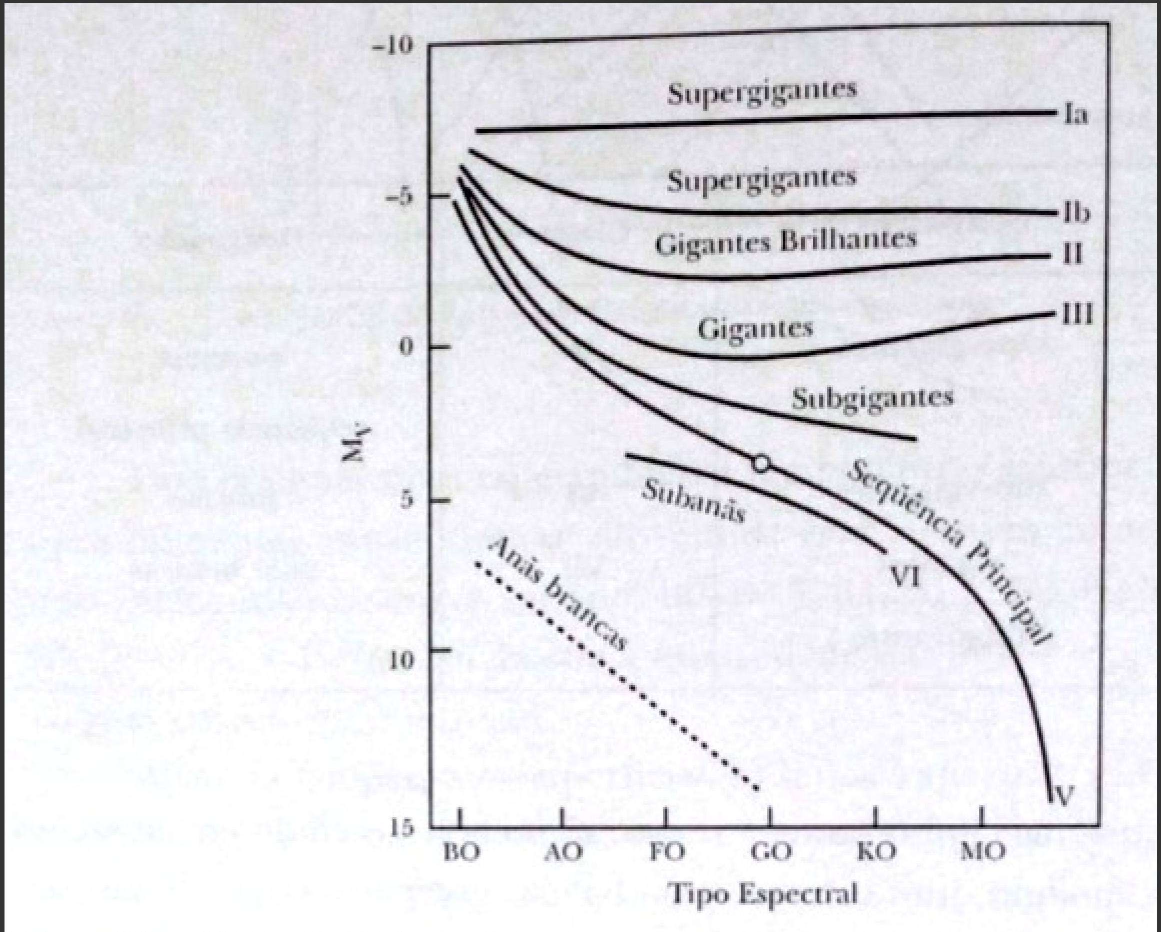


Figura 7.6. Diagrama H-R.

Conclusões da análise do Diagrama HR:

Estrelas estáveis ao longo dos séculos → Equilíbrio Hidrostático;

Massa x Luminosidade → a massa como parâmetro fundamental, acima de magnetismo, rotação e composição;

Modelo nuclear → Justifica forma, brilho, tamanho, aparência, energia...

IV. O diagrama HR: um retrato de família

Fig. 9: Aglomerado de estrelas M67

2007 August 9
Star Cluster Messier 67
Credit & Copyright: Processing - Noel Carboni, Imaging - Greg Parker

Explanation: Gathered at the center of this sharp skyview are the stars of Messier 67, one of the oldest known open star clusters. In fact, though open star clusters are usually much younger, the stars of M67 are likely around 4 billion years old, about the same age and with about the same elemental abundances as the Sun. Open clusters are almost always younger because they are dispersed over time as they encounter other stars, interstellar clouds, and experience gravitational tides while orbiting the center of our galaxy. Still, M67 contains over 500 stars or so and lies some 2,800 light-years away in the constellation Cancer. At that estimated distance, M67 would be about 12 light-years across.

V. A vida na Sequência Principal

Tempo de vida da estrela: relação entre massa (combustível) e luminosidade (gasto).

Se 90% das estrelas estão na Sequência Principal, elas passam nessa situação 90% de sua vida (inclusive o Sol).

Modelagem com esferas gasosas parecidas com o Sol combinam com a Sequência Principal.

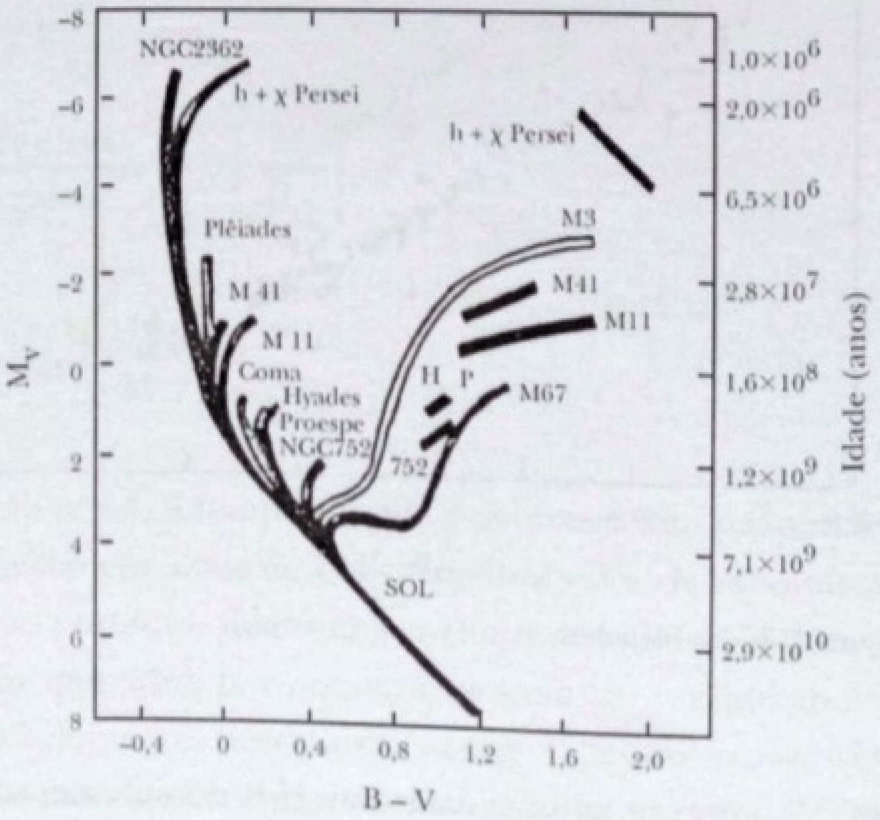


Figura 7.10. Diagrama H-R com aglomerados estelares de diversas idades.

Fig. 10: Diagrama HR – Ponto de saída (Fig. 7.10, p. 156)

O ponto de saída determina a idade do aglomerado estelar.

A maior parte da energia liberada está na etapa H → He.

VI. O nascimento de uma estrela

Fig. 11: Nuvens escuras na Águia

2012 June 29
Dark Clouds in Aquila
Image Credit & Copyright: Adam Block, Mt. Lemmon SkyCenter, University of Arizona

Explanation: Part of a dark expanse that splits the crowded plane of our Milky Way galaxy, the Aquila Rift arcs through the northern hemisphere's summer skies near bright star Altair and the Summer Triangle. In silhouette against the Milky Way's faint starlight, its dusty molecular clouds likely contain raw material to form hundreds of thousands of stars and astronomers eagerly search the clouds for telltale signs of star birth. This telescopic close-up looks toward the region at a fragmented Aquila dark cloud complex identified as LDN 673, stretching across a field of view slightly wider than the full moon. In the scene, visible indications of energetic outflows associated with young stars include the small red tinted nebulosity RNO 109 at top left and Herbig-Haro object HH32 above and right of center. The dark clouds in Aquila are estimated to be some 600 light-years away. At that distance, this field of view spans about 7 light-years.

VI. O nascimento de uma estrela

Teoria da Evolução Estelar

Nascem de nuvens frias (escuras) de gás e poeira em contração gravitacional.

Energia gravitacional se converte em energia térmica: ET = - EG/2 (equilíbrio hidrostático e emissão de radiação)

Se M < 0,08.MS → Planetas e outros corpos frios

Se M > 0,08.MS → Nasce uma estrela (protoestrela)

Se M > 200.MS → Sistema instável (deve se eclodir em várias protoestrelas)

Encontramos estrelas entre 0,1 e 60.MS, sendo que a maioria está entre 0,1 e 10.MS.

VII. Evolução Pós Sequência Principal

Fig. 12: O brilho sobre o Chile

2014 January 14
The Gegenschein Over Chile
Image Credit & Copyright: Yuri Beletsky
(Las Campanas Observatory,
Carnegie Institution)

Explanation: Is the night sky darkest in the direction opposite the Sun? No. In fact, a rarely discernable faint glow known as the gegenschein (German for "counter glow") can be seen 180 degrees around from the Sun in an extremely dark sky. The gegenschein is sunlight back-scattered off small interplanetary dust particles. These dust particles are millimeter sized splinters from asteroids and orbit in the ecliptic plane of the planets. Pictured above from last year is one of the more spectacular pictures of the gegenschein yet taken. Here a deep exposure of an extremely dark sky over Las Campanas Observatory in Chile shows the gegenschein so clearly that even a surrounding glow is visible. Notable background objects include the Andromeda galaxy, the Pleiades star cluster, the California Nebula, the belt of Orion just below the Orion Nebula and inside Barnard's Loop, and bright stars Rigel and Betelgeuse. The gegenschein is distinguished from zodiacal light near the Sun by the high angle of reflection. During the day, a phenomenon similar to the gegenschein called the glory can be seen in reflecting air or clouds opposite the Sun from an airplane.

VII. Evolução Pós Sequência Principal

"A História da Ciência é mais fascinante que um romance policial. O mistério de um romance policial sempre se esclarece no fim, mas o da Ciência nunca se esclarece. Apesar dos avanços no conhecimento científico, os mistérios talvez se tornem cada vez maiores" (Schenberg, 2001, p. 38).

Critério Schenberg-Shandrashekar: crise no caroço nuclear após queima de 10% das reservas de H no ciclo P-P (durante 10 bilhões de anos).

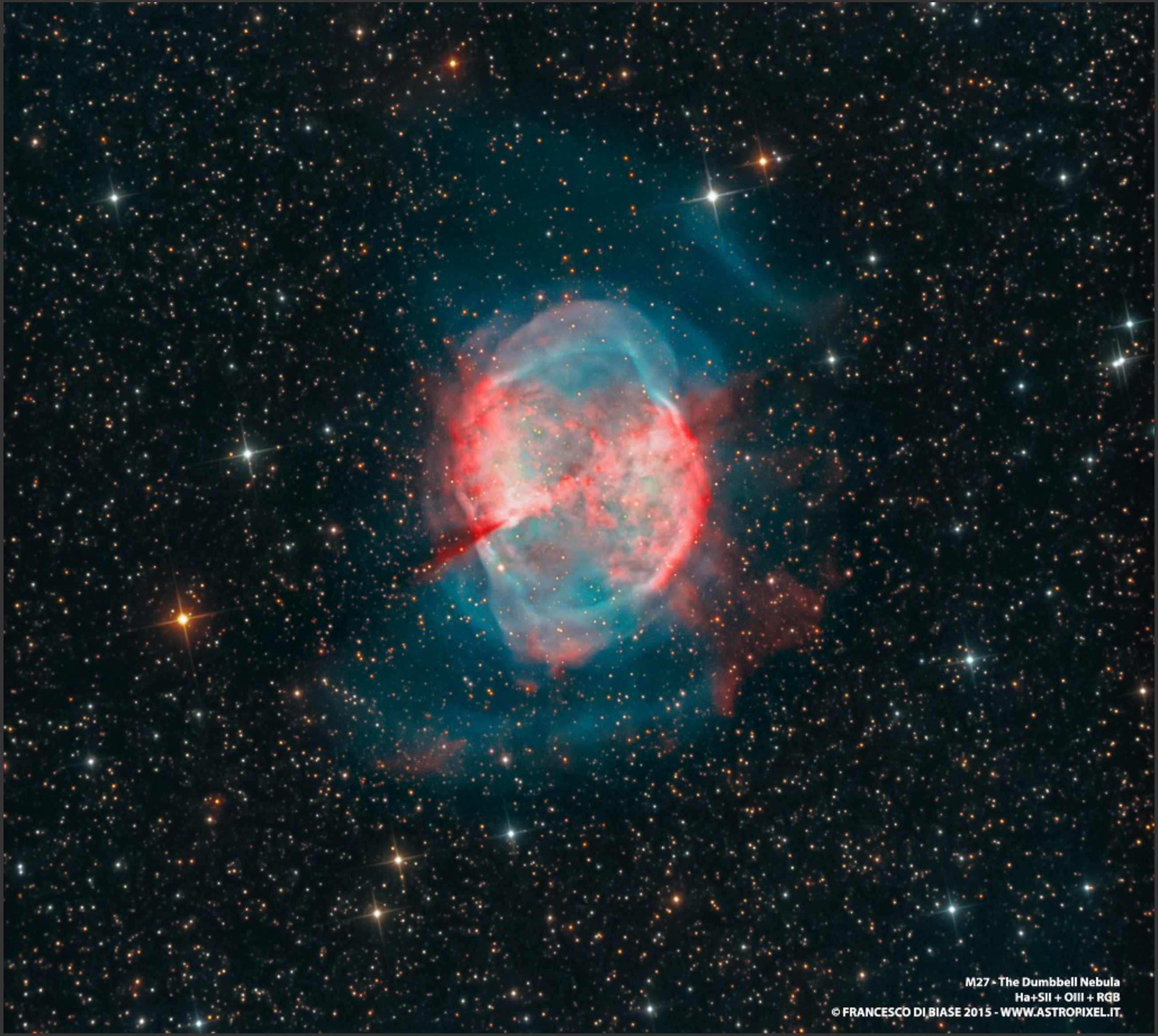
Queima de H pelo ciclo CNO (por 800 milhões de anos), se transformando em uma Gigante Vermelha → 100 vezes maior e 1000 vezes mais luminoso. Início do ciclo Triplo-alfa.

H → He → C (O Sol não terá massa e temperatura suficientes para fundir C)

Formação de nebulosa planetária e contração do núcleo (Para M < 8.MS)

VII. Evolução Pós Sequência Principal

Fig. 13: M27: Não é um cometa



2015 August 20
M27: Not a Comet
Image Credit & Copyright: Francesco di Biase

Explanation: While hunting for comets in the skies above 18th century France, astronomer Charles Messier diligently kept a list of the things he encountered that were definitely not comets. This is number 27 on his now famous not-a-comet list. In fact, 21st century astronomers would identify it as a planetary nebula, but it's not a planet either, even though it may appear round and planet-like in a small telescope. Messier 27 (M27) is an excellent example of a gaseous emission nebula created as a sun-like star runs out of nuclear fuel in its core. The nebula forms as the star's outer layers are expelled into space, with a visible glow generated by atoms excited by the dying star's intense but invisible ultraviolet light. Known by the popular name of the Dumbbell Nebula, the beautifully symmetric interstellar gas cloud is over 2.5 light-years across and about 1,200 light-years away in the constellation Vulpecula. This impressive color composite highlights details within the well-studied central region and fainter, seldom imaged features in the nebula's outer halo. It incorporates broad and narrowband images recorded using filters sensitive to emission from sulfur, hydrogen and oxygen atoms.

VII. Evolução Pós Sequência Principal

E as estrelas mais massivas?

C + He → O + Ne (acima de 300.10^6 K)
C + He → O + Ne + Na (acima de 500.10^6 K)
O → F + Si + Mg (acima de 1.10^9 K)
Ne → O + Mg (acima de $1{,}5.10^9$ K)
Si → Fe (5.10^9 K)

Os átomos de Fe se fundem em processo endotérmico, colapsando a estrela.

E os outros elementos mais pesados que o Fe?

Fig. 14: Tabela periódica (http://www.tabelaperiodicacompleta.com/)

Formam-se por absorção de nêutrons/prótons e em explosões de alta energia.

VIII. Os dois tipos de morte das estrelas

M < 8.MS

Formação de nebulosa planetária (com até 5.MS) e contração do núcleo

Resultado inicial: Anã Branca

Pequena, muito densa e luminosa (M < 1,4.MS)

Resultado final 1: Anã Negra

Ao se resfriar e apagar, devido à não reposição energética.

Resultado final 2: Supernova (Tipo Ia)

Se houver enriquecimento por nêutrons ou outros corpos, tornando-se instável.

VIII. Os dois tipos de morte das estrelas

Fig. 15: O caso da companheira da Supernova perdida

2012 January 12
The Case of the Missing Supernova Companion
Image Credit: X-ray: NASA/CXC/SAO/J. Hughes et al., Optical: NASA/ESA/Hubble Heritage Team (STScI /AURA)

Explanation: Where's the other star? At the center of this supernova remnant should be the companion star to the star that blew up. Identifying this star is important for understanding just how Type Ia supernova detonate, which in turn could lead to a better understanding of why the brightness of such explosions are so predictable, which in turn is key to calibrating the entire nature of our universe. The trouble is that even a careful inspection of the center of SNR 0509-67.5 has not found any star at all. This indicates that the companion is intrinsically very faint -- much more faint that many types of bright giant stars that had been previous candidates. In fact, the implication is that the companion star might have to be a faint white dwarf, similar to -- but less massive than -- the star that detonated. SNR 0509-67.5 is shown above in both visible light, shining in red as imaged by the Hubble Space Telescope, and X-ray light, shown in false-color green as imaged by the Chandra X-ray Observatory. Putting your cursor over the picture will highlight the central required location for the missing companion star.

VIII. Os dois tipos de morte das estrelas

M > 10.MS

(poucas têm mais do que 40.MS, a maior já encontrada tem 60.MS)

Fusão do Fe em He no caroço central, absorvendo energia.

Fusão de elétrons e prótons (Schenberg-Gamow, 1940) em nêutrons e neutrinos (expelidos).

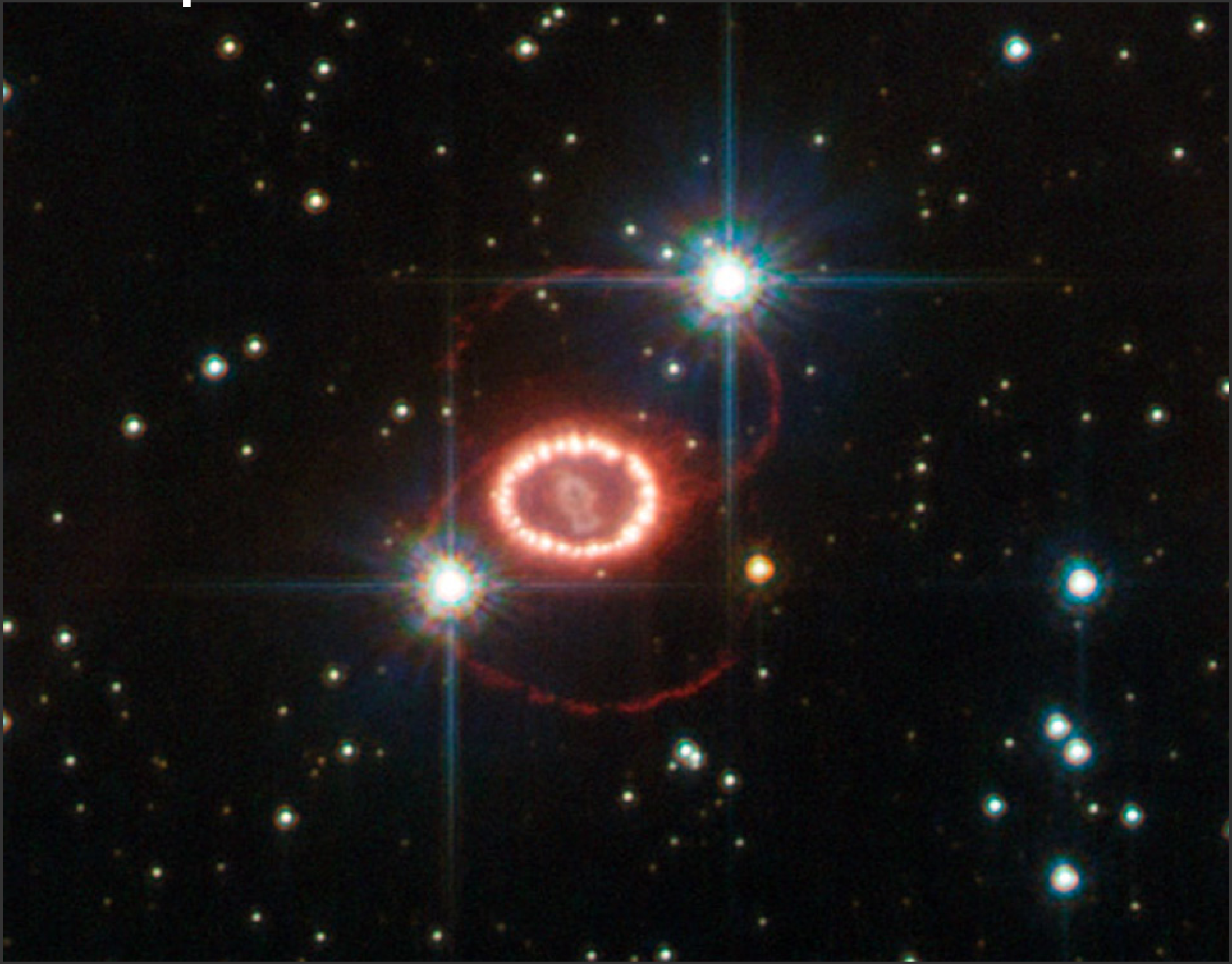
Se 10 < M < 15.MS

Resultado inicial: Supernova (expulsões) e Estrela de Nêutrons (caroço).

Volkoff e Openheimer (1938), Landau (~1935), Pr. Exclusão de Pauli (1925) e Pr. Incerteza de Heisenberg (1927).

VIII. Os dois tipos de morte das estrelas

Fig. 16:
Os misteriosos anéis
da Supernova 1987a



2012 February 26
The Mysterious Rings of Supernova 1987A
Image Credit: ESA/Hubble, NASA

Explanation: What's causing those odd rings in supernova 1987A? Twenty five years ago, in 1987, the brightest supernova in recent history was seen in the Large Magellanic Cloud. At the center of the above picture is an object central to the remains of the violent stellar explosion. Surrounding the center are curious outer rings appearing as a flattened figure 8. Although large telescopes including the Hubble Space Telescope monitor the curious rings every few years, their origin remains a mystery. Pictured above is a Hubble image of the SN1987A remnant taken last year. Speculation into the cause of the rings includes beamed jets emanating from an otherwise hidden neutron star left over from the supernova, and the interaction of the wind from the progenitor star with gas released before the explosion.

VIII. Os dois tipos de morte das estrelas

Se M > 15.MS

Resultado inicial:
Supernova (expulsão) e
Buraco Negro (caroço).

Raio de Schwarzschild (1916):

Ex.: Terra: R = 9 mm.

Denominação (Wheeler, 1968)

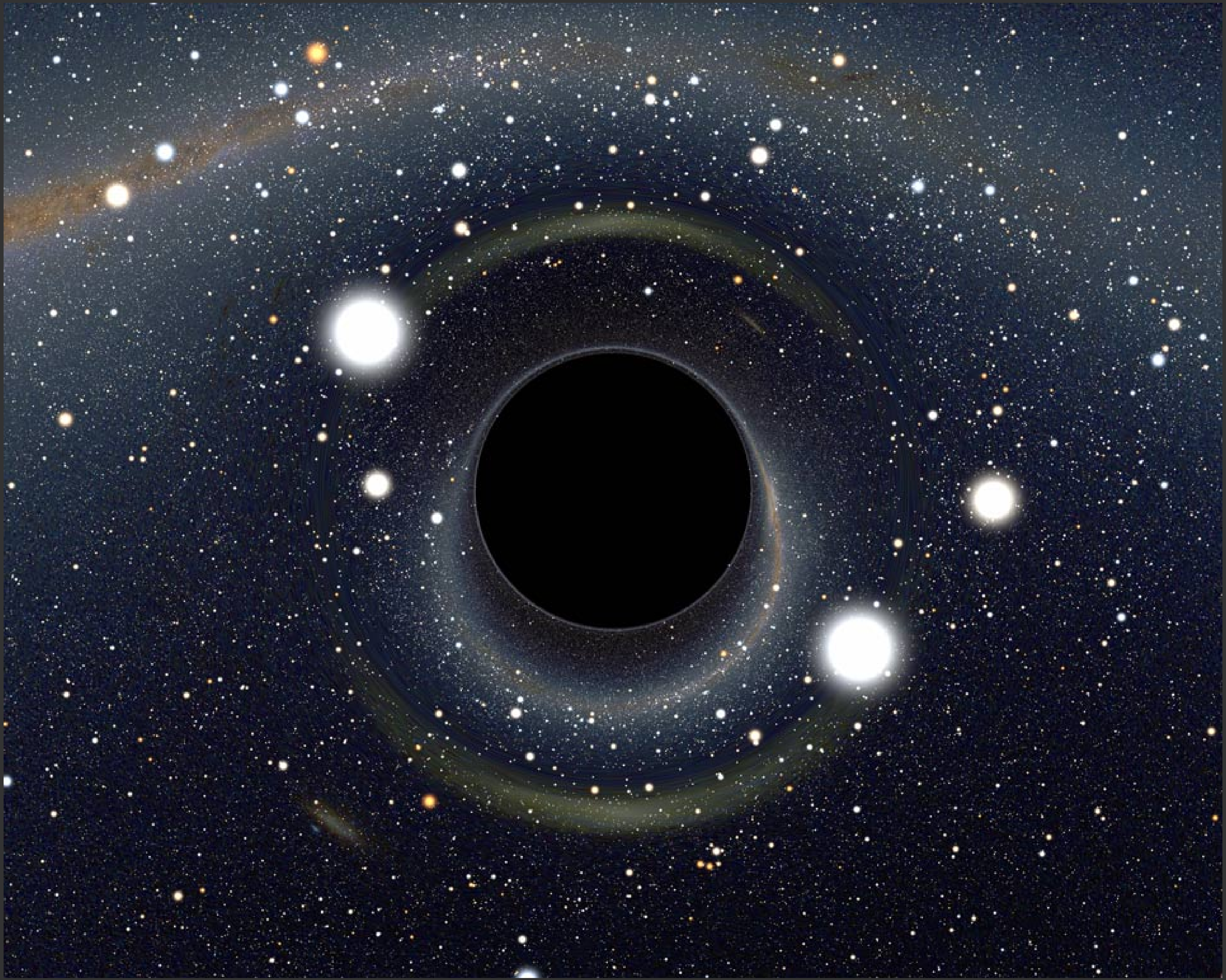
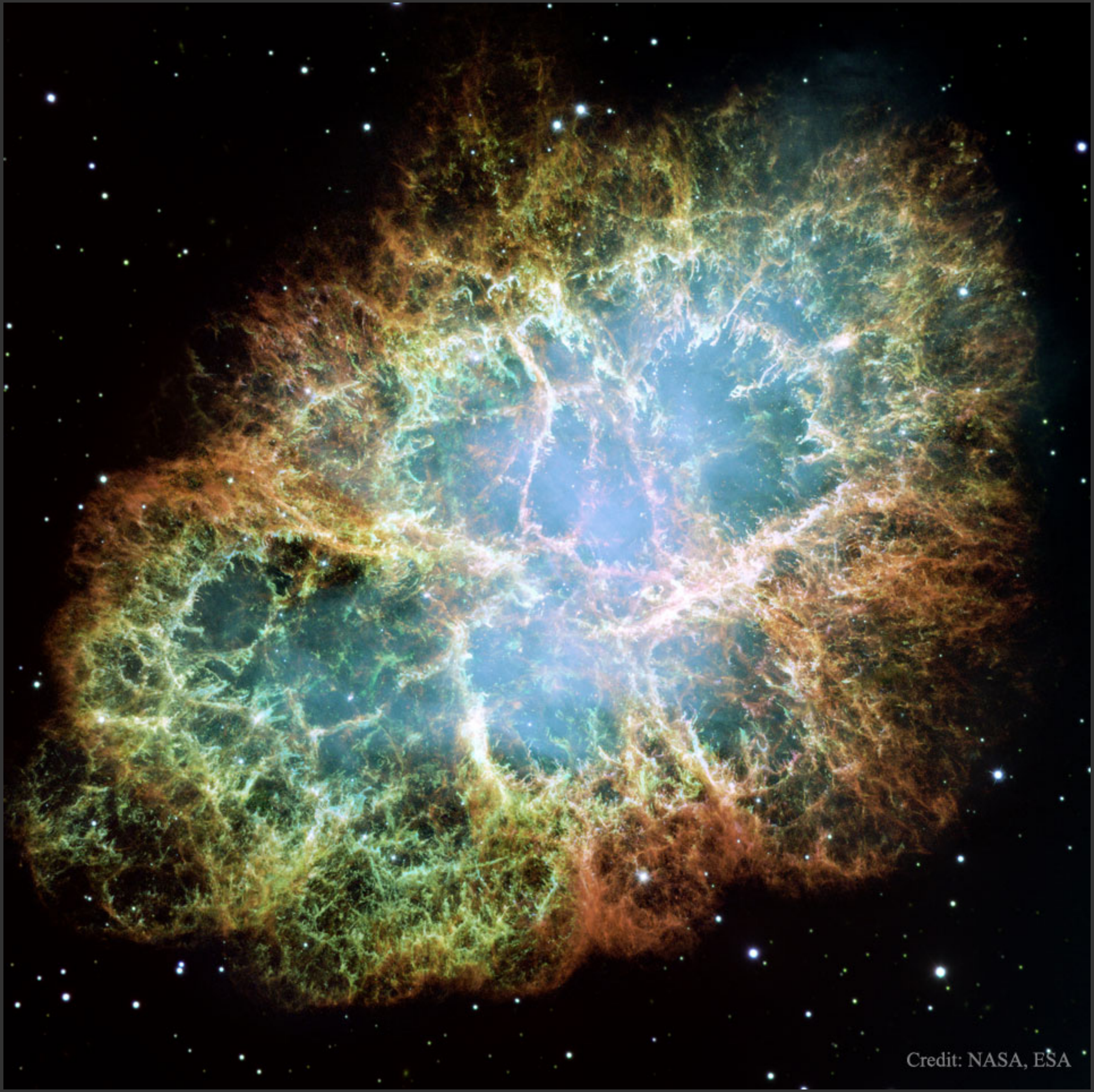


Fig. 17: Muito próximo de um Buraco Negro

2014 October 26
Too Close to a Black Hole
Image Credit & Copyright: Alain Riazuelo

Explanation: What would you see if you went right up to a black hole? Featured is a computer generated image highlighting how strange things would look. The black hole has such strong gravity that light is noticeably bent towards it - causing some very unusual visual distortions. Every star in the normal frame has at least two bright images - one on each side of the black hole. Near the black hole, you can see the whole sky - light from every direction is bent around and comes back to you. The original background map was taken from the 2MASS infrared sky survey, with stars from the Henry Draper catalog superposed. Black holes are thought to be the densest state of matter, and there is indirect evidence for their presence in stellar binary systems and the centers of globular clusters, galaxies, and quasars.

IX. Pulsares


Credit: NASA, ESA

Previsão (Baade; Zwicky, 1934);
Matematização (Hoyle, 1946);
Detecção de pulsos de rádio
(Bell; Gold; Pacini; ~1967)

Sinais de vida extraterrestre ou estrelas de nêutrons em rotação?

Mais de 100 pulsares encontrados.

Fig. 18: M1: A nebulosa do Caranguejo pelo Hubble

2015 August 16
M1: The Crab Nebula from Hubble
Image Credit: NASA, ESA, J. Hester, A. Loll (ASU)

Explanation: This is the mess that is left when a star explodes. The Crab Nebula, the result of a supernova seen in 1054 AD, is filled with mysterious filaments. The filaments are not only tremendously complex, but appear to have less mass than expelled in the original supernova and a higher speed than expected from a free explosion. The featured image, taken by the Hubble Space Telescope, is presented in three colors chosen for scientific interest. The Crab Nebula spans about 10 light-years. In the nebula's very center lies a pulsar: a neutron star as massive as the Sun but with only the size of a small town. The Crab Pulsar rotates about 30 times each second.

X. Atividade

Durante a aula:

- Apresentar atividade final do curso – planejamento de atividade didática.

Após a aula:

- Ler capítulos 9 e 10 do texto base.