FUNDAMENTOS PARA O ENSINO DE ASTRONOMIA

Semana 11
(Aulas 33 a 36)

Galáxias

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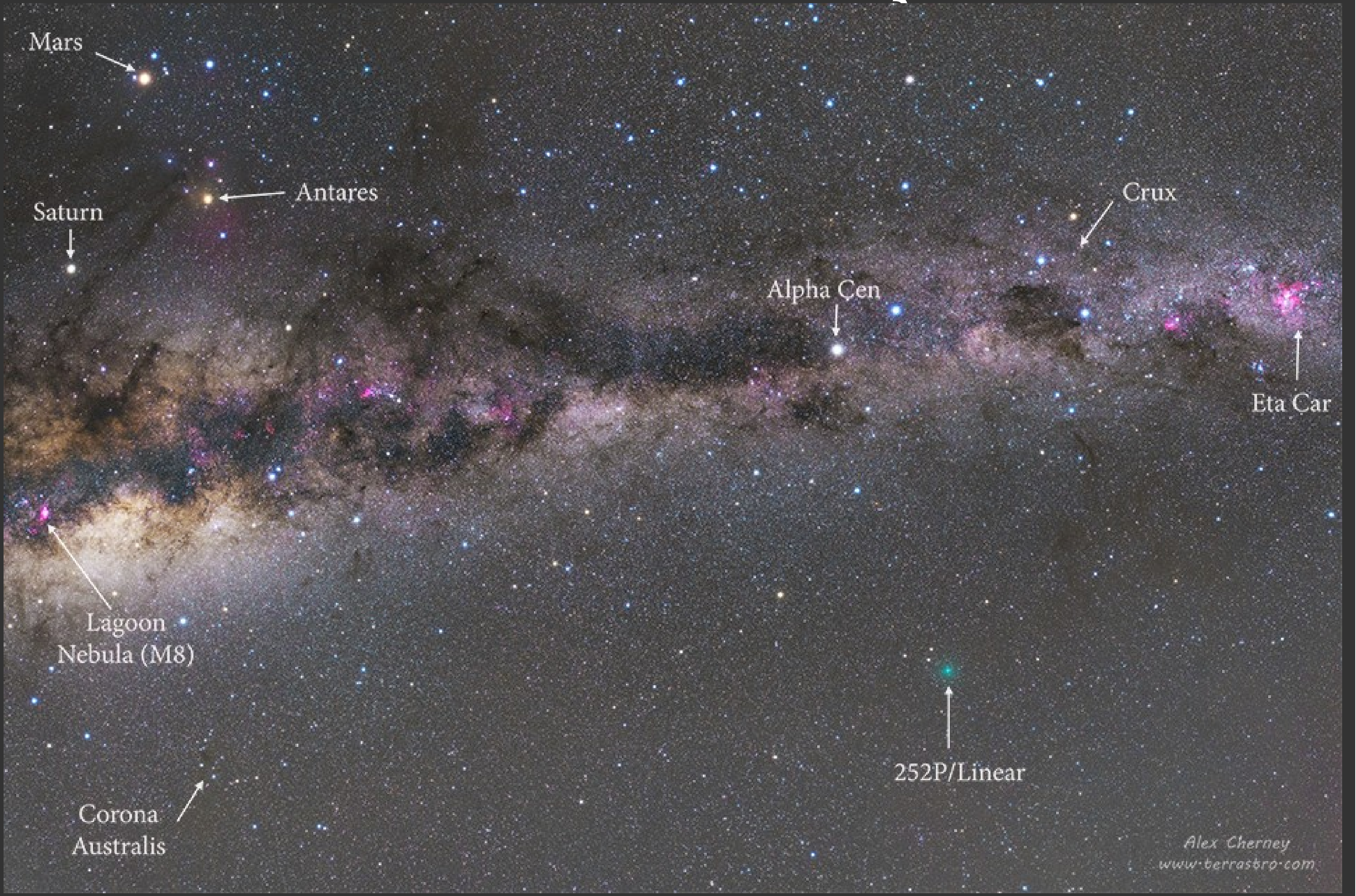
2017

I. A Galáxia – Introdução

Fig. 1: Cometa próximo e a Via Láctea



2016 March 25
Close Comet and the Milky Way
Image Credit & Copyright: Alex Cherney (Terrastro, TWAN)

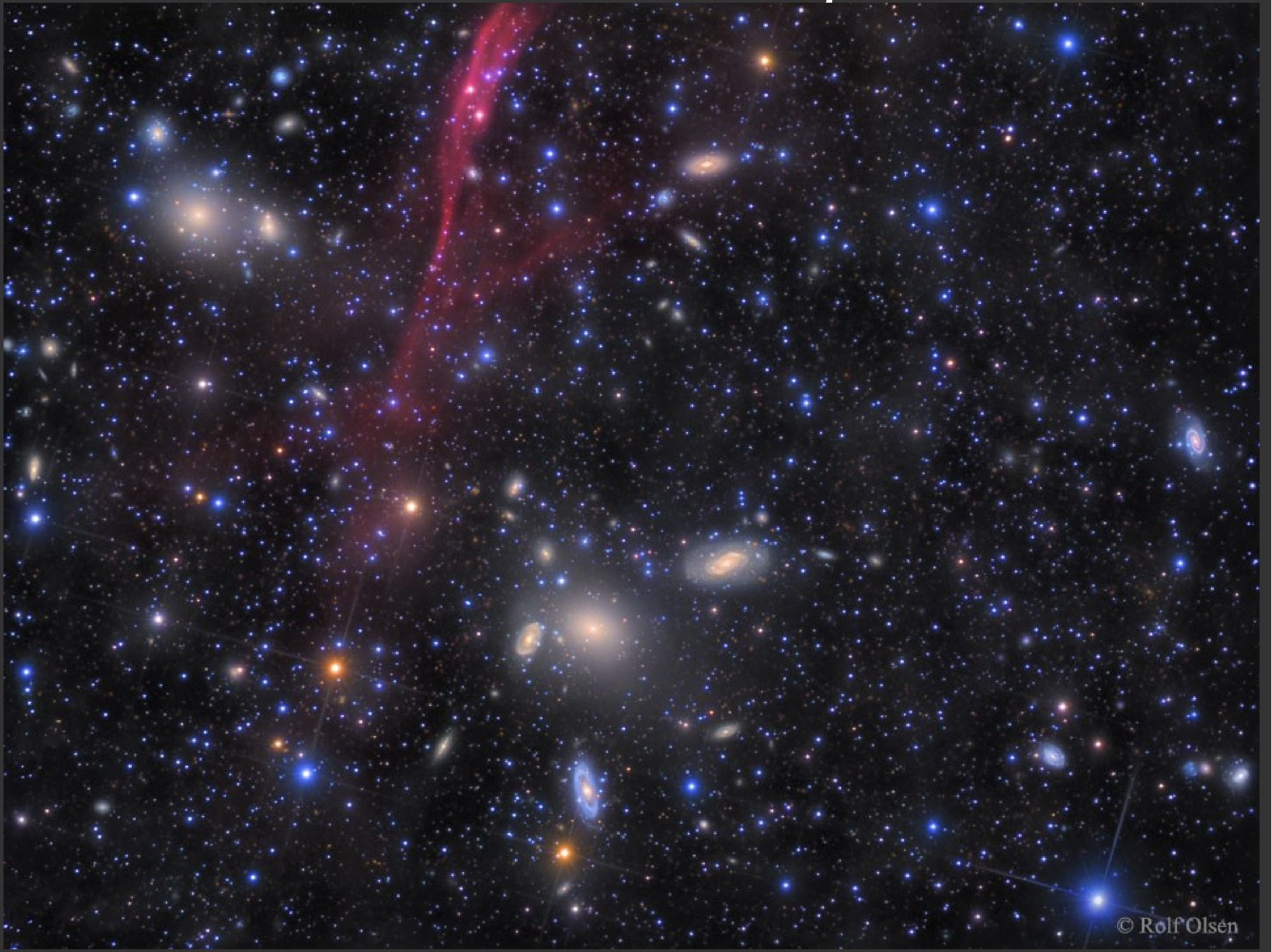
Explanation: Comet 252P/Linear's lovely greenish coma is easy to spot in this expansive southern skyscape. Visible to the naked eye from the dark site near Flinders, Victoria, Australia, the comet appears tailless. Still, its surprisingly bright coma spans about 1 degree, posed here below the nebulae, stars, and dark rifts of the Milky Way. The five panels used in the wide-field mosaic were captured after moonset and before morning twilight on March 21. That was less than 24 hours from the comet's closest approach, a mere 5.3 million kilometers from our fair planet. Sweeping quickly across the sky because it is so close to Earth, the comet should be spotted in the coming days by northern hemisphere comet watchers. In predawn but moonlit skies it will move through Sagittarius and Scorpius seen toward the southern horizon. That's near the triangle formed by bright, yellowish, Mars, Saturn, and Antares at the upper left of this frame.

I. A Galáxia – Introdução

- Distribuição não uniforme das estrelas no céu;
- Via Láctea e a nossa Galáxia;
- Distribuição das estrelas não uniforme na Via Láctea;
- Como mapear a nossa galáxia? Observando outras galáxias e avaliando dados.

I. A Galáxia – Introdução

Fig. 2: O aglomerado de galáxias da Bomba de Ar (constelação moderna)



2016 October 18
The Antlia Cluster of Galaxies
Image Credit & Copyright: Rolf Olsen

Explanation: Galaxies dot the sky in this impressively wide and deep image of the Antlia Cluster. The third closest cluster of galaxies to Earth after Virgo and Fornax, the Antlia cluster is known for its compactness and its high fraction of elliptical galaxies over (spirals. Antlia, cataloged as Abell S0636, spans about 2 million light years and lies about 130 million light years away toward the constellation of the Air Pump (Antlia). The cluster has two prominent galaxy groups - bottom center and upper left -- among its over 200 galactic members, but no single central dominant galaxy. The vertical red ribbon of gas on the left is thought related to the foreground Antlia supernova remnant and not associated with the cluster. The featured image composite, taken from New Zealand, resulted from 150+ hours of exposures taken over six months.

II. A Galáxia – Histórico

Via Láctea: leite derramado pela deusa Hera (na mitologia grega)

Modelo galáctico:

Wright (~1760) → Sistema achatado com concentração central de estrelas

Kant (~1780) → Sistema estelar isolado de outros sistemas estelares (universos-ilha)

Messier (~1780) → Observação de galáxias como objetos do nosso sistema estelar

Parsons (~1850) → Grandes telescópios e observação de galáxias

Kapteyn (~1910) → Modelo com aglomerados globulares

Shapley (~1940) → Modelo com diâmetro de 60 kpc, com o Sol a 15 kpc do centro.

Atualmente → Modelo com diâmetro de 30 a 40 kpc, com o Sol a 7,5 kpc do centro.

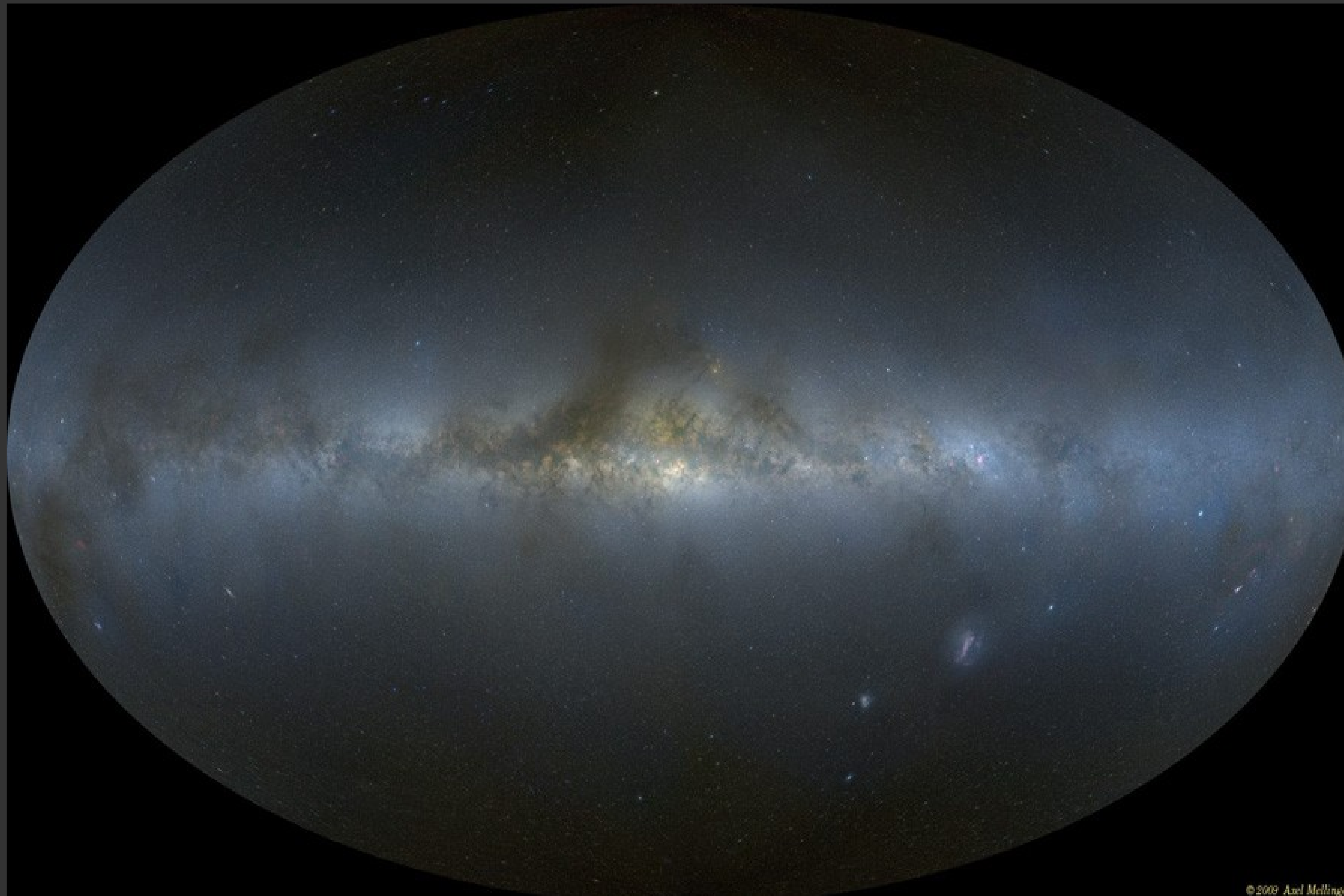
Obs.: Parsec (pc): unidade de medida de distância associada a paralaxe estelar anual de 1 segundo de arco. Paralaxe (paralax) + Segundo (second) = Parsec. 1 pc = 3,26156 anos-luz.

Ex.: Andrômeda (M31) está a 600 kpc da Via Láctea.

Fig. 3: Planificação da Galáxia (desenhar)

II. A Galáxia – Histórico

Fig. 4: Panorama da Via Láctea no céu inteiro



2009 November 25
All-Sky Milky Way Panorama
Credit & Copyright: Axel Mellinger (Central Mich. U)

Explanation: If you could go far away from the Earth and look around the entire sky -- what would you see? Such was the goal of the All-Sky Milky Way Panorama 2.0 project of Axel Mellinger. Presented above is the result: a digital compilation of over 3,000 images comprising the highest resolution digital panorama of the entire night sky yet created. An interactive zoom version, featuring over 500 million pixels, can be found here. Every fixed astronomical object visible to the unaided eye has been imaged, including every constellation, every nebula, and every star cluster. Moreover, millions of individual stars are also visible, all in our Milky Way Galaxy, and many a thousand times fainter than a human can see. Dark filaments of dust lace the central band of our Milky Way Galaxy, visible across the image center. The satellite galaxies Large and Small Magellanic Clouds are visible on the lower right. This was not the first time Dr. Mellinger has embarked on such a project: the results of his first All-Sky Milky Way Panorama Project, taken using photographic film, are visible here.

III. Estrutura e Constituintes

Fig. 5: Via Láctea e ALMA

2014 July 24
ALMA Milky Way
Image Credit & Copyright: Yuri Beletsky (Las Campanas Observatory, Carnegie Institution)

Explanation: This alluring all-skyscape was taken 5,100 meters above sea level, from the Chajnantor Plateau in the Chilean Andes. Viewed through the site's rarefied atmosphere at about 50% sea level pressure, the gorgeous Milky Way stretches through the scene. Its cosmic rifts of dust, stars, and nebulae are joined by Venus, a brilliant morning star immersed in a strong band of predawn Zodiacal light. Still not completely dark even at this high altitude, the night sky's greenish cast is due to airglow emission from oxygen atoms. Around the horizon the dish antenna units of the Atacama Large Millimeter/submillimeter Array, ALMA, explore the universe at wavelengths over 1,000 times longer than visible light.

III. Estrutura e Constituintes

Componentes principais: Bojo, Disco e Halo.

Bojo: parte central, com núcleo e nuvens de gás e poeira, melhor estudadas com rádio e infravermelho, pode conter um aglomerado compacto de estrelas ou um Buraco Negro;

Disco: região dos braços espirais, estrelas azuis e mais jovens, contendo o Sol.

Halo: esfera galáctica, com aglomerados globulares, estrelas vermelhas e velhas. Estende-se até as galáxias mais próximas, como as Nuvens de Magalhães.

Fig. 6: Estrutura da Galáxia
(Fig. 9.4, p. 184)

Sol: 7,5 kpc (24000 anos-luz) do centro

Constituição: Estrelas, campo de radiação estelar, meio interestelar, campo magnético galáctico e raios cósmicos.

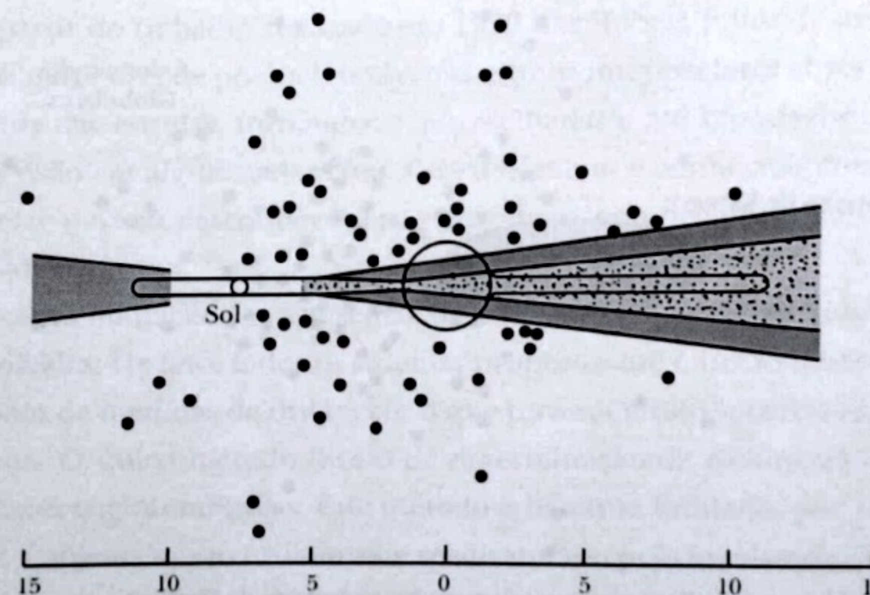


Figura 9.4. Estrutura da Galáxia, com os aglomerados globulares da Figura 9.3. A escala embaixo da figura está em kpc.

IV. A Galáxia – A Rotação

Objetos jovens, no disco, possuem órbitas circulares.

Objetos mais velhos, no disco espesso (mais distantes do centro), possuem órbitas mais excêntricas, isto é, com velocidades menos tangenciais e mais perpendiculares ao plano.

Objetos globulares, no Halo, possuem velocidades muito perpendiculares ao plano, praticamente fora da rotação galáctica.

(Lindblad; Charlier; James Jeans; Oort. 1930-1960)

Se fosse um corpo rígido:
$v = \omega.R$

Se tiver rotação diferencial kepleriana:
$v = \sqrt{(G.M/R)}$

O Efeito Doppler (em rádio, visível ou outras frequências) permite calcular velocidades radiais das estrelas e aglomerados.

Modelos recentes indicam que a velocidade linear não cai após o raio (círculo) solar.

Fig. 7: Rotação de galáxias (Fig. 9.6, p. 192)

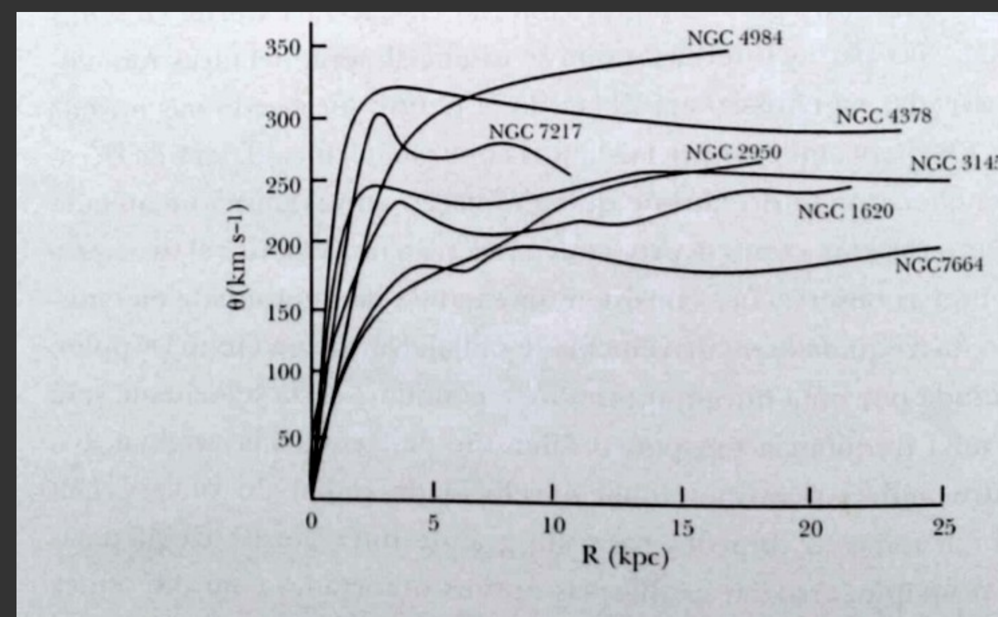


Figura 9.6. Exemplos de curvas de rotação para algumas galáxias espirais.

V. A natureza espiral da Via Láctea

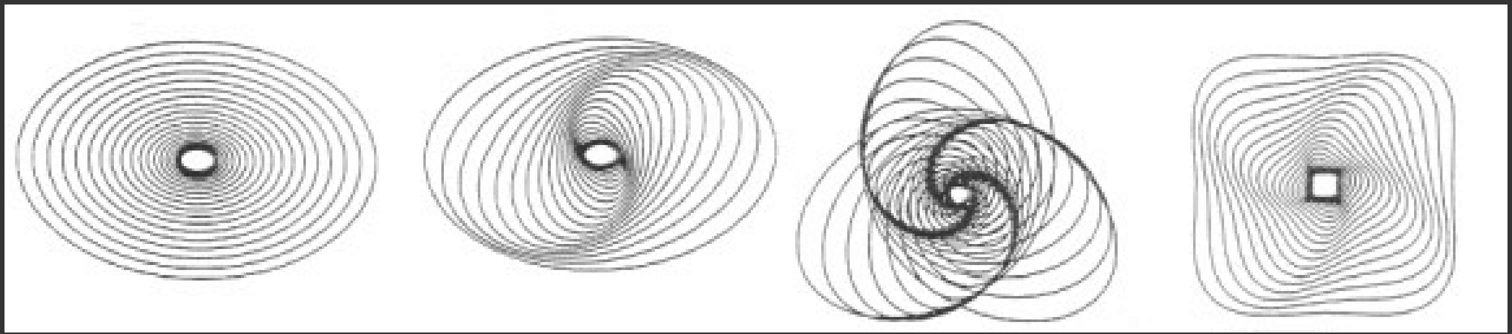
Aparentemente a Galáxia está organizada em braços (quantidade e localização em discussão), com estrelas jovens e azuis.

Estrelas velhas e avermelhadas mais concentradas no disco e no halo.

Problema: modelo kepleriano e diferencial não justifica a manutenção dos braços espirais com a idade do Sol e sua velocidade (220 km/s e 5 bilhões de anos). Isso leva a 5 voltas e um emaranhamento dos braços.

Modelo novo: Teoria das ondas de densidade (Lin; Shu; 1965) – Ondas gravitacionais que orientam a acumulação e dispersão de estrelas e aglomerados no plano galáctico.

Fig. 8: Ondas de densidade (http://astro.if.ufrgs.br/vialac/node3.htm)



VI. Outras galáxias

Hubble (~1920) verifica que algumas nebulosas são sistemas estelares (galáxias) mais distantes do que qualquer estrela individual (da nossa galáxia), ou seja, extragalácticos.

Novo ramo da ciência: Astronomia Extragaláctica!

Galáxias Elípticas (E) ou Espirais (S), devido sua evolução, sua massa e sua rotação (momento e energia).

Fig. 9: Classificação das galáxias (Fig. 10.1, p. 198)

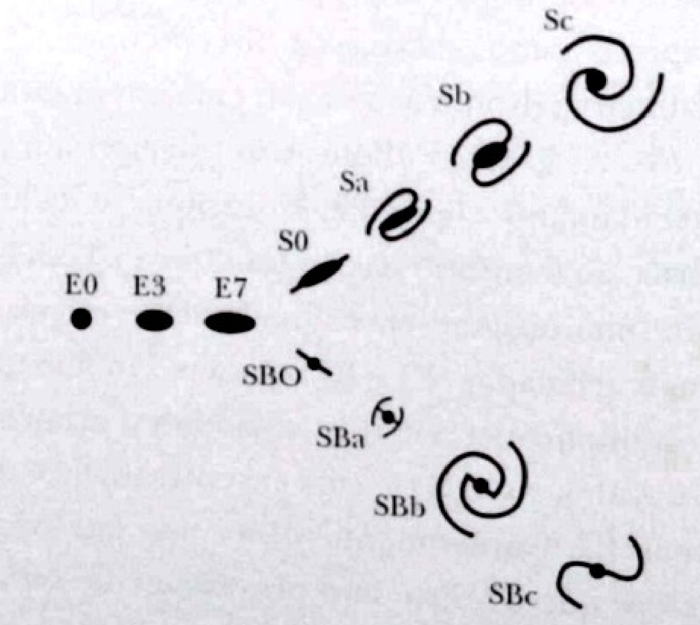


Figura 10.1. Ilustração do esquema de classificação proposto por Hubble. Da esquerda para a direita, a seqüência corresponde inicialmente a galáxias elípticas (E), de elipticidade crescente. A seqüência divide-se, então, em dois ramos, o das galáxias *normais* (S0, Sa, Sb, Sc) e o das *com barras* (SB0, SBa, SBb, SBc).

VI. Outras galáxias

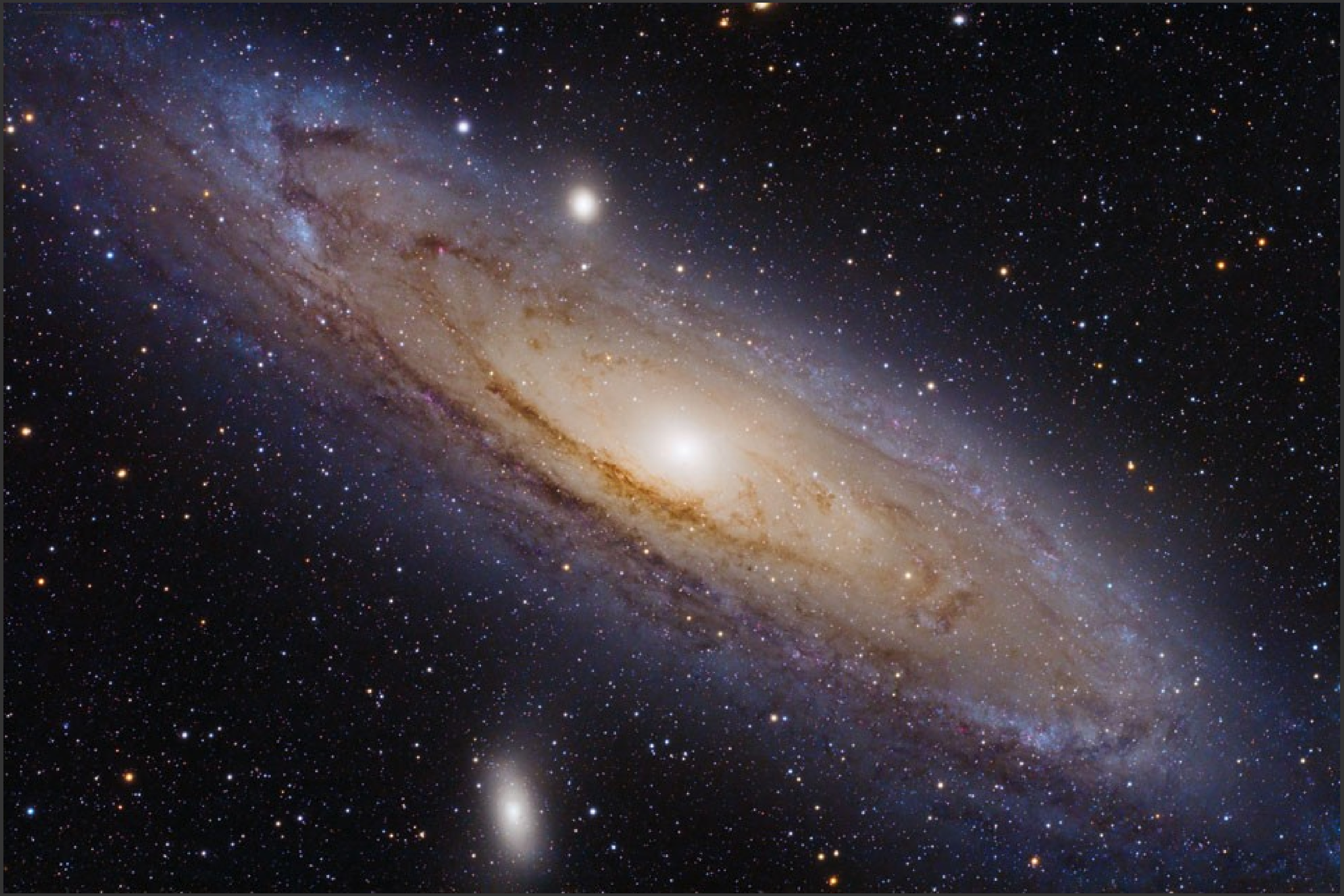
Fig. 10:
A Grande Nuvem de Magalhães
(Large Cloud of Magellians - LCM)

2013 May 28
The Large Cloud of Magellan
Image Credit & Copyright: L. Comolli, L. Fontana, G. Ghioldi & E. Sordini

Explanation: The 16th century Portuguese navigator Ferdinand Magellan and his crew had plenty of time to study the southern sky during the first circumnavigation of planet Earth. As a result, two fuzzy cloud-like objects easily visible to southern hemisphere skygazers are known as the Clouds of Magellan, now understood to be satellite galaxies of our much larger, spiral Milky Way galaxy. About 160,000 light-years distant in the constellation Dorado, the Large Magellanic Cloud (LMC) is seen here in a remarkably deep, colorful, and annotated composite image. Spanning about 15,000 light-years or so, it is the most massive of the Milky Way's satellite galaxies and is the home of the closest supernova in moder times, SN 1987A. The prominent patch just left of center is 30 Doradus, also known as the magnificent Tarantula Nebula, is a giant star-forming region about 1,000 light-years across.

VI. Outras galáxias

Fig. 11: M31: A Galáxia de Andrômeda

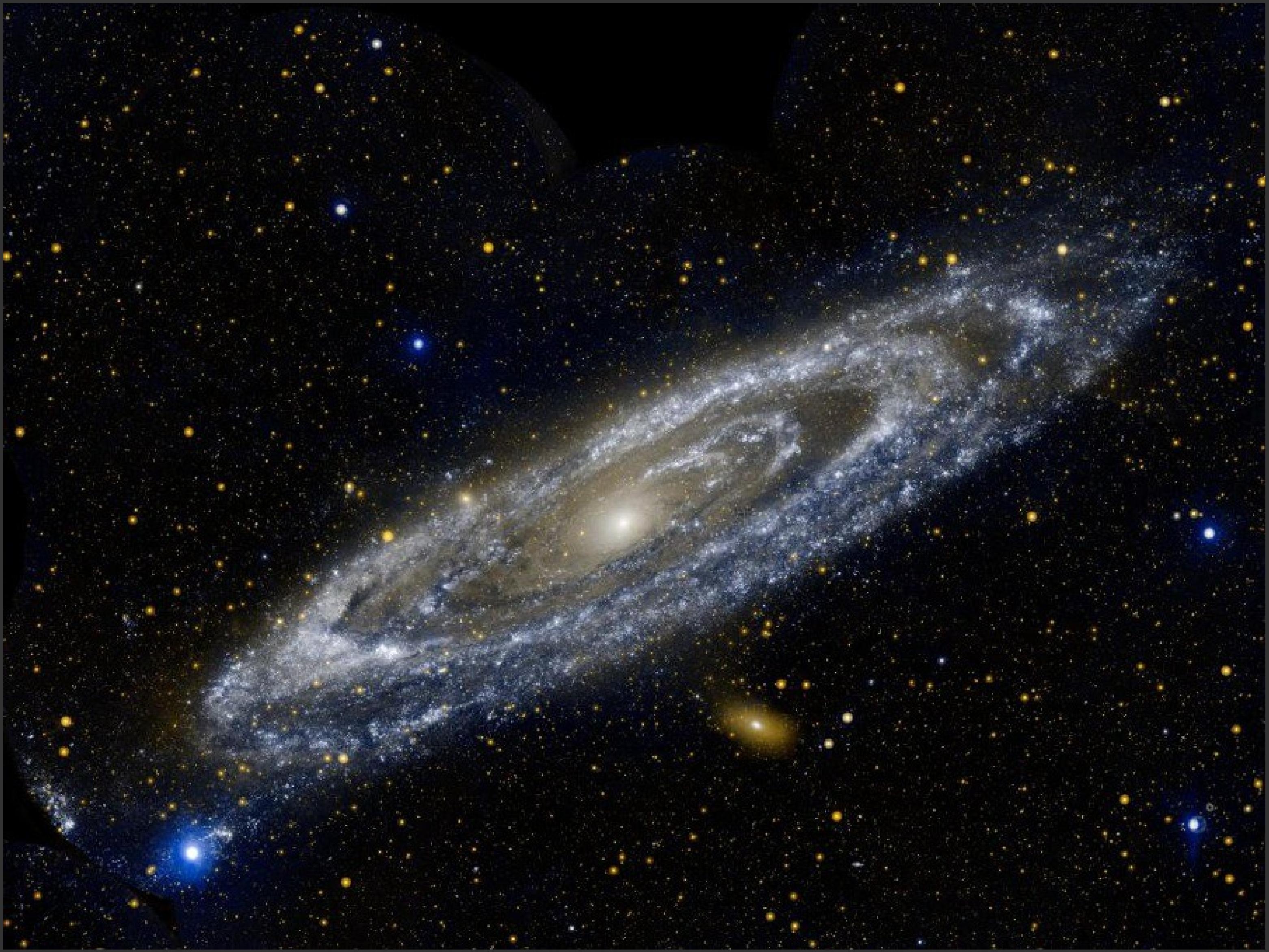


2013 June 26
M31: The Andromeda Galaxy
Image Credit & Copyright: Lorenzo Comolli

Explanation: Andromeda is the nearest major galaxy to our own Milky Way Galaxy. Our Galaxy is thought to look much like Andromeda. Together these two galaxies dominate the Local Group of galaxies. The diffuse light from Andromeda is caused by the hundreds of billions of stars that compose it. The several distinct stars that surround Andromeda's image are actually stars in our Galaxy that are well in front of the background object. Andromeda is frequently referred to as M31 since it is the 31st object on Messier's list of diffuse sky objects. M31 is so distant it takes about two million years for light to reach us from there. Although visible without aid, the above image of M31 was taken with a small telescope. Much about M31 remains unknown, including how it acquired its unusual double-peaked center.

VI. Outras galáxias

Fig. 12: Anéis ultravioletas da M31



2015 July 24
Ultraviolet Rings of M31
Image Credit: GALEX, JPL-Caltech, NASA

Explanation: A mere 2.5 million light-years away the Andromeda Galaxy, also known as M31, really is just next door as large galaxies go. So close and spanning some 260,000 light-years, it took 11 different image fields from the Galaxy Evolution Explorer (GALEX) satellite's telescope to produce this gorgeous portrait of the spiral galaxy in ultraviolet light. While its spiral arms stand out in visible light images of Andromeda, the arms look more like rings in the GALEX ultraviolet view, a view dominated by the energetic light from hot, young, massive stars. As sites of intense star formation, the rings have been interpreted as evidence Andromeda collided with its smaller neighboring elliptical galaxy M32 more than 200 million years ago. The large Andromeda galaxy and our own Milky Way are the most massive members of the local galaxy group.

VII. Galáxias Ativas (NAG) e Quasares

Galáxias normais: radiação térmica (luz estelar, emissão radiotérmica de gás, emissão infravermelho de poeira);

Galáxias ativas: radiação não-térmica (emissão síncroton [elétrons com v ~ c] ou processos de altas energias), emitidas por núcleos pequenos mas com enorme atividade, possíveis Buracos Negros: Núcleos Ativos de Galáxias (NAG).

Divididas em grupos, como as Seyfert, BL Lacertae e Radiogaláxias, são encontradas a distâncias de até 400 Mpc.

Trabalhos de Seyfert, Jansky, Baade, Minkowski (entre 1930 e 1960)

VII. Galáxias Ativas (NAG) e Quasares

Fig. 13:
NGC 1672:
Galáxia Espiral
com barras
pelo Hubble

2016 September 13
NGC 1672: Barred Spiral Galaxy from Hubble
Image Credit: Hubble Legacy Archive, NASA, ESA; Processing & Copyright: Steve Cooper

Explanation: Many spiral galaxies have bars across their centers. Even our own Milky Way Galaxy is thought to have a modest central bar. Prominently barred spiral galaxy NGC 1672, featured here, was captured in spectacular detail in an image taken by the orbiting Hubble Space Telescope. Visible are dark filamentary dust lanes, young clusters of bright blue stars, red emission nebulas of glowing hydrogen gas, a long bright bar of stars across the center, and a bright active nucleus that likely houses a supermassive black hole. Light takes about 60 million years to reach us from NGC 1672, which spans about 75,000 light years across. NGC 1672, which appears toward the constellation of the Dolphinfish (Dorado), is being studied to find out how a spiral bar contributes to star formation in a galaxy's central regions.

VII. Galáxias Ativas (NAG) e Quasares

Fig. 14: NGC 6814: Galáxia Espiral do tipo Bem Desenhada (Grand Design) pelo Hubble.

2016 June 21
NGC 6814: Grand Design Spiral Galaxy from Hubble
Image Credit: ESA/Hubble & NASA; Acknowledgement: Judy Schmidt (Geckzilla)

Explanation: In the center of this serene stellar swirl is likely a harrowing black-hole beast. The surrounding swirl sweeps around billions of stars which are highlighted by the brightest and bluest. The breadth and beauty of the display give the swirl the designation of a grand design spiral galaxy. The central beast shows evidence that it is a supermassive black hole about 10 million times the mass of our Sun. This ferocious creature devours stars and gas and is surrounded by a spinning moat of hot plasma that emits blasts of X-rays. The central violent activity gives it the designation of a Seyfert galaxy. Together, this beauty and beast are cataloged as NGC 6814 and have been appearing together toward the constellation of the Eagle (Aquila) for roughly the past billion years.

VII. Galáxias Ativas (NAG) e Quasares

Fig. 15: M87: Galáxia Elíptica com Jato

2010 May 20
M87: Elliptical Galaxy with Jet
Image Credit & Copyright: Adam Block, Mt. Lemmon SkyCenter, U. Arizona

Explanation: In spiral galaxies, majestic winding arms of young stars, gas, and dust rotate in a flat disk around a bulging galactic nucleus. But elliptical galaxies seem to be simpler. Lacking gas and dust to form new stars, their randomly swarming older stars, give them an ellipsoidal (egg-like) shape. Still, elliptical galaxies can be very large. Centered in this telescopic view and over 120,000 light-years in diameter, larger than our own Milky Way, elliptical galaxy M87 (NGC 4486) is the dominant galaxy of the Virgo Galaxy Cluster. Some 50 million light-years away, M87 is likely home to a supermassive black hole responsible for a high-energy jet of particles emerging from the giant galaxy's central region. In this well-processed image, M87's jet is near the one o'clock position. Other galaxies are also in the field of view, including large Virgo Cluster ellipticals NGC 4478 right of center and NGC 4476 near the right edge.

VII. Galáxias Ativas (NAG) e Quasares

Quasares (quasi-stellar radio sources): possíveis núcleos extremamente luminosos com corpo (disco, halo, bojo) não visível e muito distantes. Emissão não-térmica intensa na faixa do ultravioleta, infravermelho, rádio e raio X.

Radiofontes não visíveis, identificadas inicialmente entre 1960 e 1970.

Alguns emitem luz visível, assemelhando-se a estrelas. Contudo, emitem muita radiação não-térmica e sincrotrônica.

Objetos mais distantes já encontrados, alguns a 15 bilhões de anos-luz, sendo os objetos com maiores desvios para o vermelho (redshifts).

Problema atual: qual a fonte de energia desses quasares? Parece ser muito superior aos modelos nucleares.

VII. Galáxias Ativas (NAG) e Quasares

Fig. 16: A Lente Gravitacional em Cruz de Einstein

2010 February 7
The Einstein Cross Gravitational Lens
Credit & Copyright: J. Rhoads (ASU) et al., WIYN, AURA, NOAO, NSF

Explanation: Most galaxies have a single nucleus -- does this galaxy have four? The strange answer leads astronomers to conclude that the nucleus of the surrounding galaxy is not even visible in this image. The central cloverleaf is rather light emitted from a background quasar. The gravitational field of the visible foreground galaxy breaks light from this distant quasar into four distinct images. The quasar must be properly aligned behind the center of a massive galaxy for a mirage like this to be evident. The general effect is known as gravitational lensing, and this specific case is known as the Einstein Cross. Stranger still, the images of the Einstein Cross vary in relative brightness, enhanced occasionally by the additional gravitational microlensing effect of specific stars in the foreground galaxy.

VII. Galáxias Ativas (NAG) e Quasares

Fig. 17: Túnel do tempo

2007 September 6
Time Tunnel
Credit & Copyright: Johannes Schedler (Panther Observatory)
Additional Image Data: Ken Crawford (Rancho Del Sol Observatory)

Explanation: Spiky stars are nearby, but fuzzy galaxies are strewn far across the Universe in this cosmic view. Spanning about 1/2 degree on the sky, the pretty picture is the result of astronomer Johannes Schedler's project to look back in time, toward a quasar 12.7 billion light-years away. The quasar is just visible in the full resolution image at the position marked by short vertical lines (center). The intrinsically bright nucleus of a young, active galaxy powered by a supermassive black hole, the quasar was recently identified as one of the most distant objects known. Since light travels at a finite speed, the galaxies receding into the distance are seen as they were in the increasingly remote past. The quasar appears as it did about 12.7 billion years ago, when the Universe was just 7 percent of its present age. Of course, the expansion of the Universe has redshifted the light. Schedler added image data extending to the near-infrared, acquired by collaborator Ken Crawford, to detect the distant quasar, with a measured redshift of 6.04.

VIII. Grupos e aglomerados de galáxias

Galáxias são encontradas em conjunto, geralmente em grupos de 1 Mpc, aglomerados de alguns Mpc e superaglomerados de até 50 Mpc.

A Via Láctea possui algumas galáxias satélites, como a SMC e a LMC (facilmente visíveis a olho nu).

A galáxia de Andrômeda forma um sistema binário com a Via Láctea.

Grupo Local: Via Láctea, Andrômeda e mais algumas dezenas.

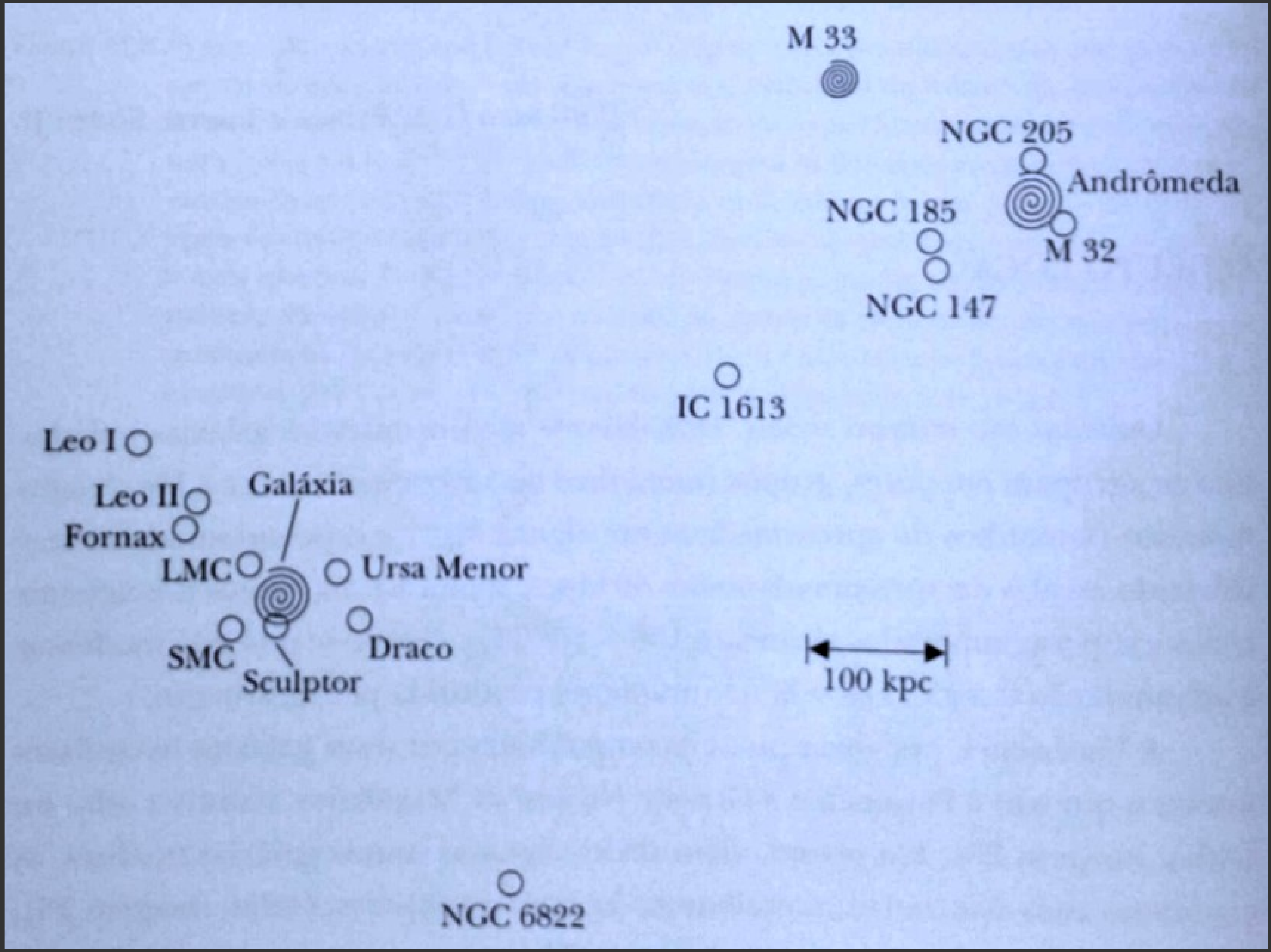


Fig. 18: Grupo Local
(fig. 12.1, p. 220)

VIII. Grupos e aglomerados de galáxias

Superaglomerado Local: centrado no aglomerado de Virgem, com diâmetro de 40 Mpc.

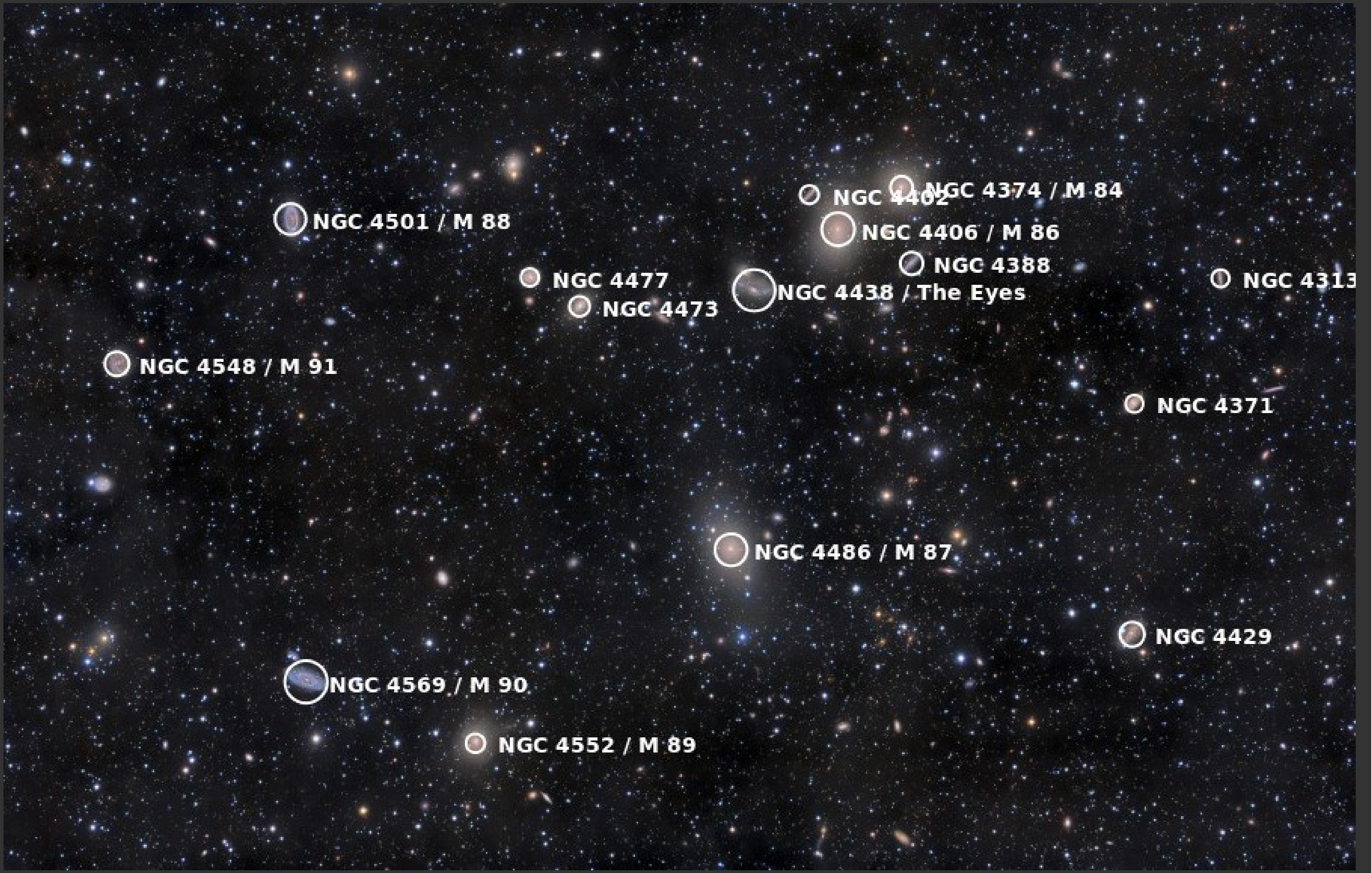
Aglomerado de Virgem possui cerca de 250 galáxias, enquanto o Grupo Local tem cerca de 20.

Alguns aglomerados são regulares (núcleo com galáxia gigante) ou irregulares (distribuição difusa).

Trabalhos de Abell, Dressler, Corwin, Olowin e outros (entre 1960 e 1990).

VIII. Grupos e aglomerados de galáxias

Fig. 19:
O aglomerado de galáxias de Virgem



2011 April 22
Virgo Cluster Galaxies
Image Credit & Copyright: Rogelio Bernal Andreo

Explanation: Well over a thousand galaxies are known members of the Virgo Cluster, the closest large cluster of galaxies to our own local group. In fact, the galaxy cluster is difficult to appreciate all at once because it covers such a large area on the sky. Spanning about 5x3 degrees, this careful mosaic of telescopic images clearly records the central region of the Virgo Cluster through faint foreground dust clouds lingering above the plane of our own Milky Way galaxy. The cluster's dominant giant elliptical galaxy M87, is just below center in the frame. Above M87 is the famous interacting galaxy pair NGC 4438, also known as The Eyes. A closer examination of the image will reveal many Virgo cluster member galaxies as small fuzzy patches. Sliding your cursor over the image will label the larger galaxies using NGC catalog designations. Galaxies are also shown with Messier catalog numbers, including M84, M86, and prominent colorful spirals M88, M90, and M91. On average, Virgo Cluster galaxies are measured to be about 48 million light-years away. The Virgo Cluster distance has been used to give an important determination of the Hubble Constant and the scale of the Universe. (Editor's Note: Labels courtesy of Astrometry.net.)

VIII. Grupos e aglomerados de galáxias

Fig. 20: Abell 370: Lente gravitacional em aglomerado de galáxias

2016 August 28
Abell 370: Galaxy Cluster Gravitational Lens
Image Credit: NASA, ESA, and the Hubble SM4 ERO Team & ST-ECF

Explanation: What is that strange arc? While imaging the cluster of galaxies Abell 370, astronomers had noted an unusual arc to the right of many cluster galaxies. Although curious, one initial response was to avoid commenting on the arc because nothing like it had ever been noted before. In the mid-1980s, however, better images allowed astronomers to identify the arc as a prototype of a new kind of astrophysical phenomenon -- the gravitational lens effect of entire cluster of galaxies on background galaxies. Today, we know that this arc actually consists of two distorted images of a fairly normal galaxy that happened to lie far behind the huge cluster. Abell 370's gravity caused the background galaxies' light -- and others -- to spread out and come to the observer along multiple paths, not unlike a distant light appears through the stem of a wine glass. In mid-July of 2009, astronomers used the then just-upgraded Hubble Space Telescope to image Abell 370 and its gravitational lens images in unprecedented detail. Almost all of the yellow images featured here are galaxies in the Abell 370 cluster. An astute eye can pick up many strange arcs and distorted arclets, however, that are actually images of more distant galaxies. Studying Abell 370 and its images gives astronomers a unique window into the distribution of normal and dark matter in galaxy clusters and the universe.

VIII. Grupos e aglomerados de galáxias

Fig. 21: Aglomerado de galáxias Abell S1063 e além.

2016 July 22
Galaxy Cluster Abell S1063 and Beyond
Image Credit: NASA, ESA, Jennifer Lotz (STScI)

Explanation: Some 4 billion light-years away, galaxies of massive Abell S1063 cluster near the center of this sharp Hubble Space Telescope snapshot. But the fainter bluish arcs are magnified images of galaxies that lie far beyond Abell S1063. About twice as distant, their otherwise undetected light is magnified and distorted by the cluster's largely unseen gravitational mass, approximately 100 trillion times the mass of the Sun. Providing a tantalizing glimpse of galaxies in the early universe, the effect is known as gravitational lensing. A consequence of warped spacetime it was first predicted by Einstein a century ago. The Hubble image is part of the Frontier Fields program to explore the Final Frontier.

IX. As Radiações de Fundo

Radiação presente no espaço para além das radiações dos corpos observáveis.

Fig. 22: Radiações de fundo (tab. 12.2, p. 225)

Tabela 12.2. Radiações de fundo

Tipo de Radiação	Comprimento de onda λ Freqüência ν Energia E	Densidade de Energia ($erg\,cm^{-3}$)
Rádio	$\nu \leq 4\,080$ MHz	$\leq 10^{-18}$
Microondas	λ entre 80cm e 1mm	$\approx 4 \times 10^{-13}$
Óptico	λ de 4 000 Å a 8 000 Å	$\approx 3{,}5 \times 10^{-15}$
Raios X	E entre 1 e 40 keV	$\approx 10^{-16}$
Raios γ	$E \geq 100$ MeV	$\leq 2 \times 10^{-17}$

X. Atividade

Durante a aula:

- Confirmar visita ao Observatório (local e horário);

- Apresentar forma do trabalho final.

Após a aula:

- Ler capítulo 13 do texto-base.