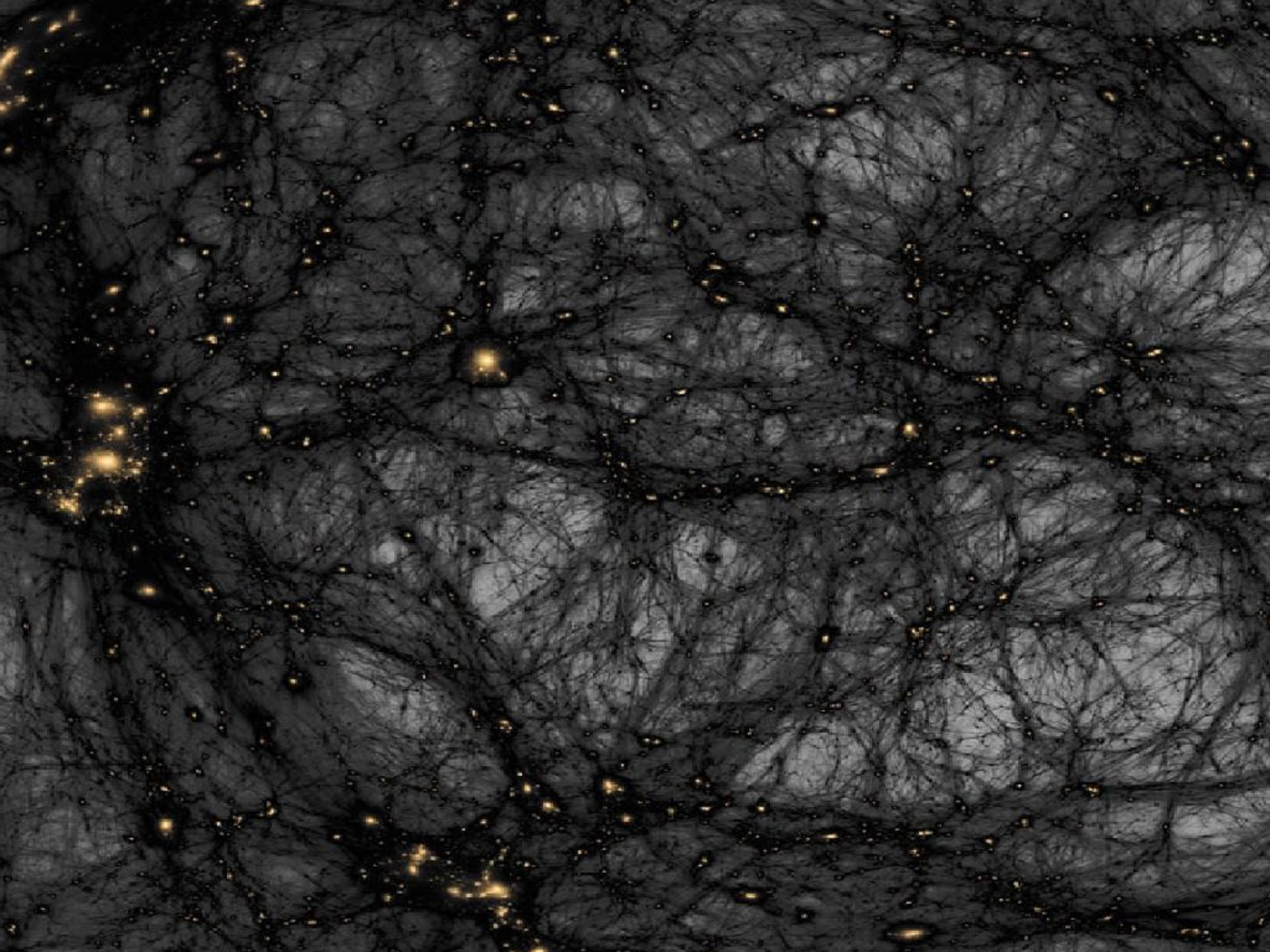

GGC
Grupo de Gravitação e Cosmologia
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LISHEP2018 - Sessão A
Salvador, 04.09.2018

Matéria Escura

Cassio Pigozzo
Instituto de Física
Universidade Federal da Bahia

- **Evidências observacionais**
  - **Astrofísica**
  - **Cosmologia**
- **Candidatos**
- **Experimentos/Sondas**

Qual a estrutura interna da matéria?

Quais interações regem os fenômenos na natureza?

$< 10^{-18}$ metros

$> 10^{26}$ metros

< 10^{-18} metros

$$\frac{1}{1\ 000\ 000\ 000\ 000\ 000\ 000}$$

1 metro

100 000 000 000 000 000 000 000 000

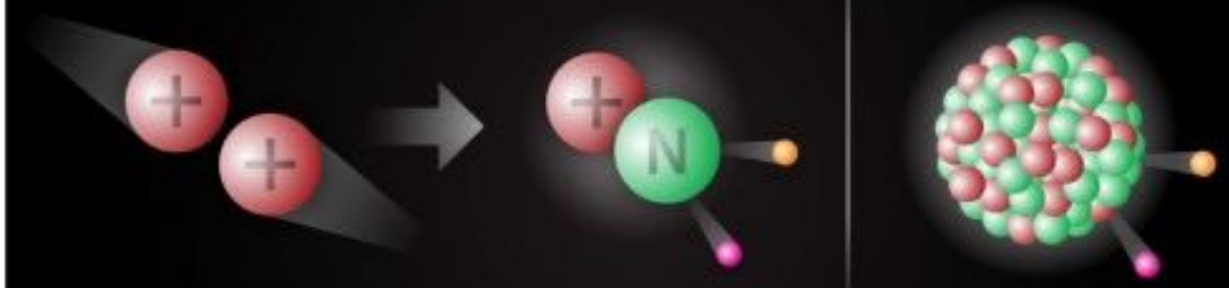
> 10^{26} metros

1 H Hydrogen																	2 He Helium
3 Li Lithium	4 Be Beryllium											5 B Boron	6 C Carbon	7 N Nitrogen	8 O Oxygen	9 F Fluorine	10 Ne Neon
11 Na Sodium	12 Mg Magnesium											13 Al Aluminum	14 Si Silicon	15 P Phosphorus	16 S Sulfur	17 Cl Chlorine	18 Ar Argon
19 K Potassium	20 Ca Calcium	21 Sc Scandium	22 Ti Titanium	23 V Vanadium	24 Cr Chromium	25 Mn Manganese	26 Fe Iron	27 Co Cobalt	28 Ni Nickel	29 Cu Copper	30 Zn Zinc	31 Ga Gallium	32 Ge Germanium	33 As Arsenic	34 Se Selenium	35 Br Bromine	36 Kr Krypton
37 Rb Rubidium	38 Sr Strontium	39 Y Yttrium	40 Zr Zirconium	41 Nb Niobium	42 Mo Molybdenum	43 Tc Technetium	44 Ru Ruthenium	45 Rh Rhodium	46 Pd Palladium	47 Ag Silver	48 Cd Cadmium	49 In Indium	50 Sn Tin	51 Sb Antimony	52 Te Tellurium	53 I Iodine	54 Xe Xenon
55 Cs Cesium	56 Ba Barium	57–71 Lanthanides	72 Hf Hafnium	73 Ta Tantalum	74 W Tungsten	75 Re Rhenium	76 Os Osmium	77 Ir Iridium	78 Pt Platinum	79 Au Gold	80 Hg Mercury	81 Tl Thallium	82 Pb Lead	83 Bi Bismuth	84 Po Polonium	85 At Astatine	86 Rn Radon
87 Fr Francium	88 Ra Radium	89–103 Actinides	104 Rf Rutherfordium	105 Db Dubnium	106 Sg Seaborgium	107 Bh Bohrium	108 Hs Hassium	109 Mt Meitnerium	110 Ds Darmstadtium	111 Rg Roentgenium	112 Cn Copernicium	113 Nh Nihonium	114 Fl Flerovium	115 Mc Moscovium	116 Lv Livermorium	117 Ts Tennessine	118 Og Oganesson

57 La Lanthanum	58 Ce Cerium	59 Pr Praseodymium	60 Nd Neodymium	61 Pm Promethium	62 Sm Samarium	63 Eu Europium	64 Gd Gadolinium	65 Tb Terbium	66 Dy Dysprosium	67 Ho Holmium	68 Er Erbium	69 Tm Thulium	70 Yb Ytterbium	71 Lu Lutetium
89 Ac Actinium	90 Th Thorium	91 Pa Protactinium	92 U Uranium	93 Np Neptunium	94 Pu Plutonium	95 Am Americium	96 Cm Curium	97 Bk Berkelium	98 Cf Californium	99 Es Einsteinium	100 Fm Fermium	101 Md Mendelevium	102 No Nobelium	103 Lr Lawrencium

4 Interações Fundamentais

Weak Nuclear Force



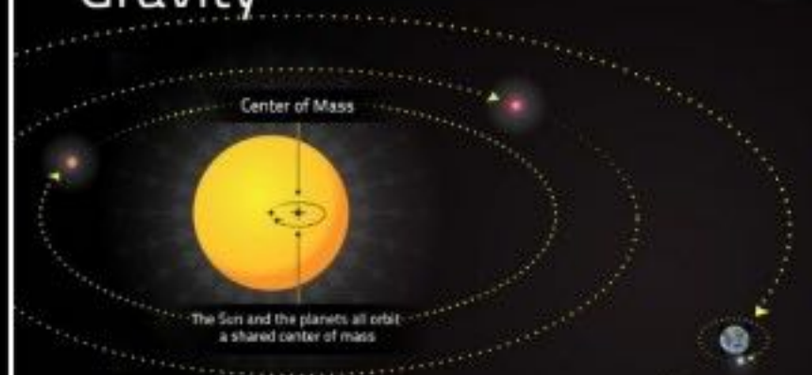
Converting protons into neutrons

When two protons collide and fuse, a disruption in the weak nuclear force emits a positron and neutrino, which converts one of the positively charged proton to a neutrally charged Nuetron. Without the weak nuclear force converting protons into nuetrons, certain complex nuclei cannot form.

Releasing radiation

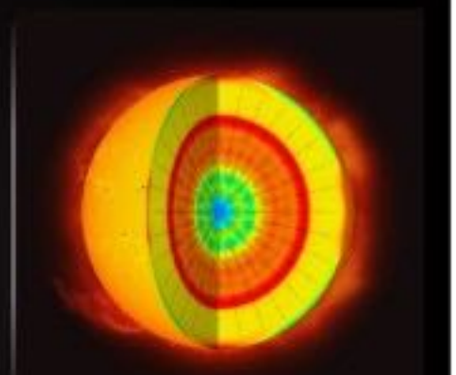
Heavy atoms have an imbalance of protons and nuetrons, so the weak nuclear force converts protons to nuetrons releasing radiation.

Gravity



Adding motion to the Universe

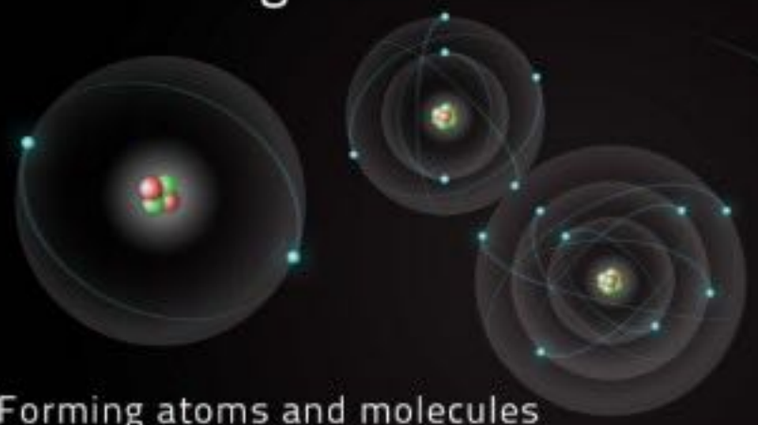
Gravity forms stars, planets, and moons, and forces these objects to spin on an axis and move along an orbital path. The planets appear to be orbiting the center of the Sun, but the Sun and planets all orbit a shared center of mass. Planets with enough mass can develop orbiting moons or rings of debris.



Creating energy

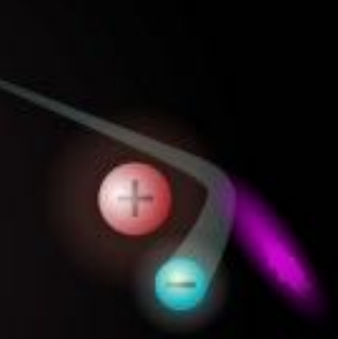
Gravity is the force that creates pressure and fusion energy in the core of stars allowing them to burn for millions of years.

Electromagnetic Force



Forming atoms and molecules

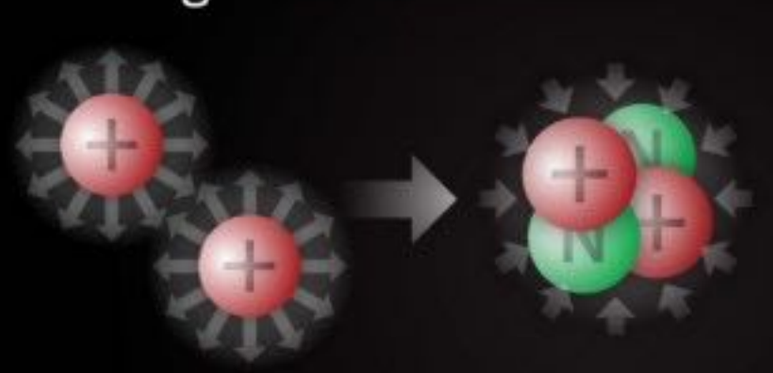
The electromagnetic force pulls negatively charged electrons into bound orbits around positively charged nuclei to form atoms and molecules. As a gas cools, electrons will find their way into the presence of atomic nuclei. Larger nuclei with a greater positve charge pull in more electrons until atoms and molecules have a balance of charges.



Generating light

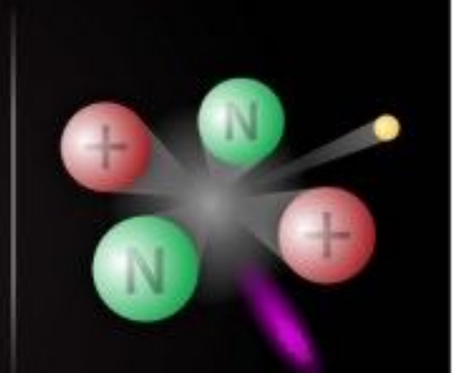
When a negative electron interacts with a positive proton, the electromagnetic force adds energy to the electron generating a photon.

Strong Nuclear Force



Binding protons in atomic nuclei

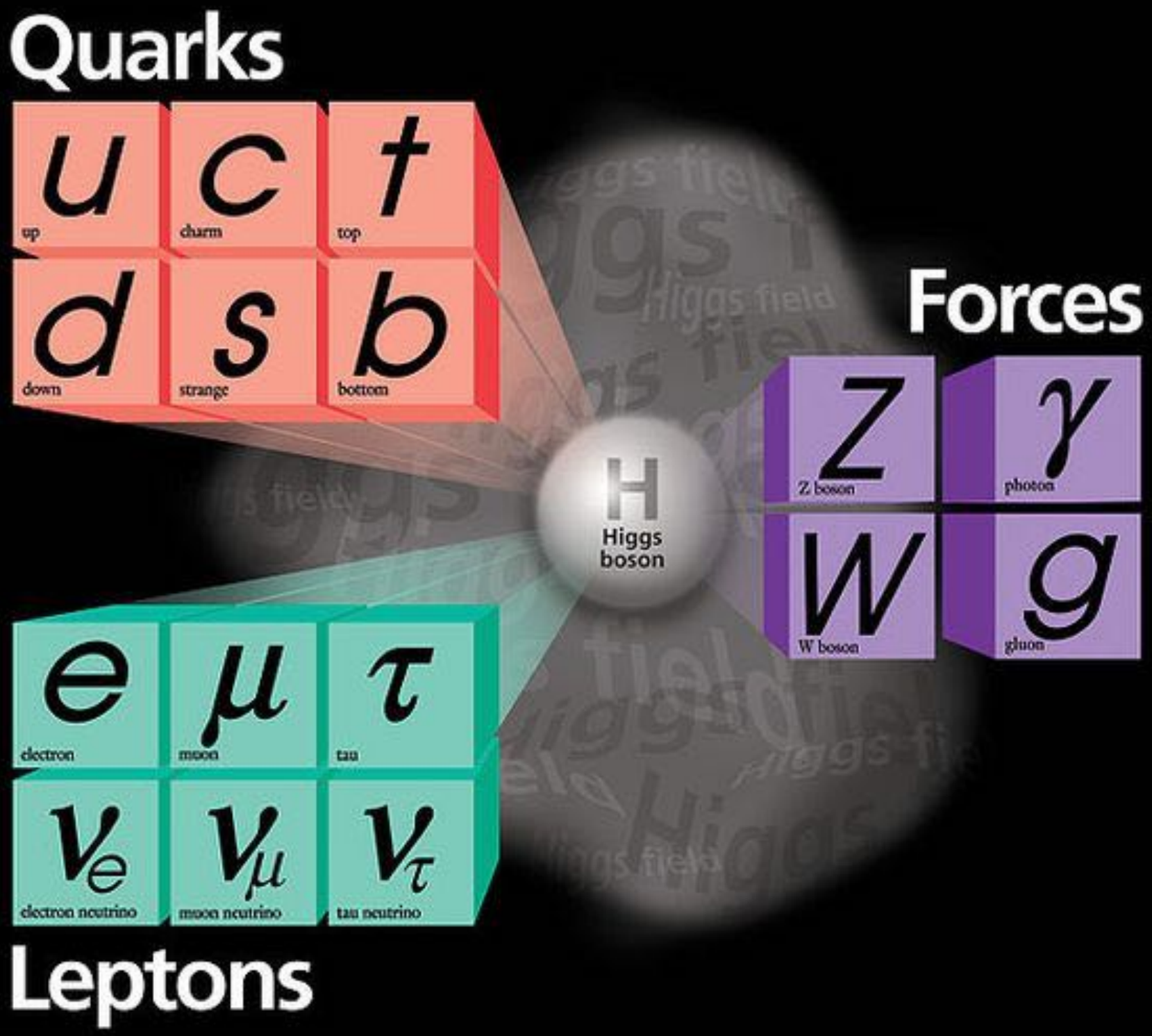
Positively charged particles naturally repel each other, it takes an extreme amount of force to hold protons together. The strong nuclear force overcomes the repulsion between protons to hold together atomic nuclei. Without the strong nuclear force, complex nuclei cannot form.



Breaking the bond

Enormous energy is released as gamma rays and nuetrinos when the strong nuclear force is broken between protons and neutrons.

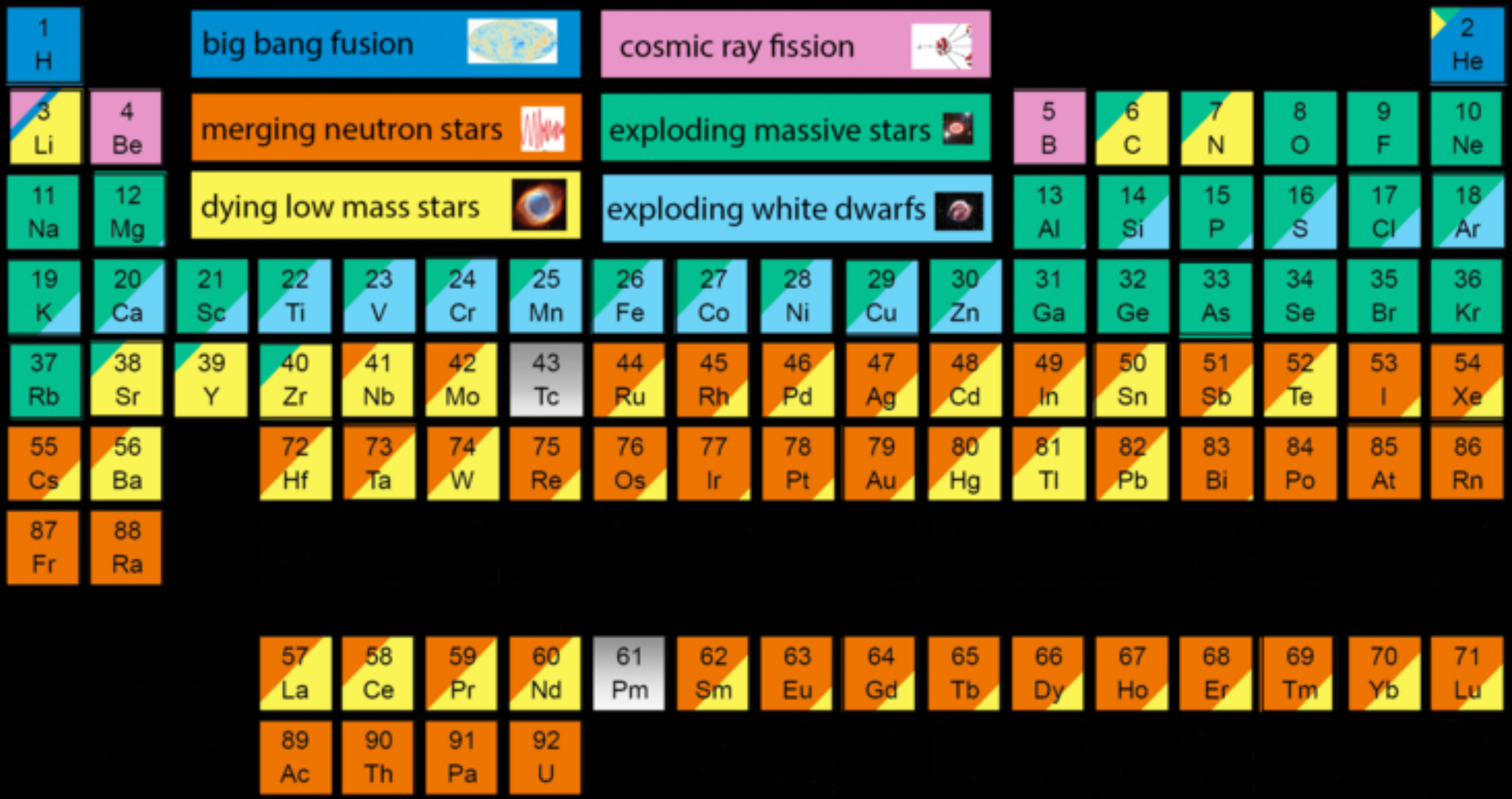
Modelo Padrão da Física de Partículas



Zoom até o aglomerado de galáxias Abell 315

Crédito: ESO/ Digitized Sky Survey 2

The Origin of the Solar System Elements



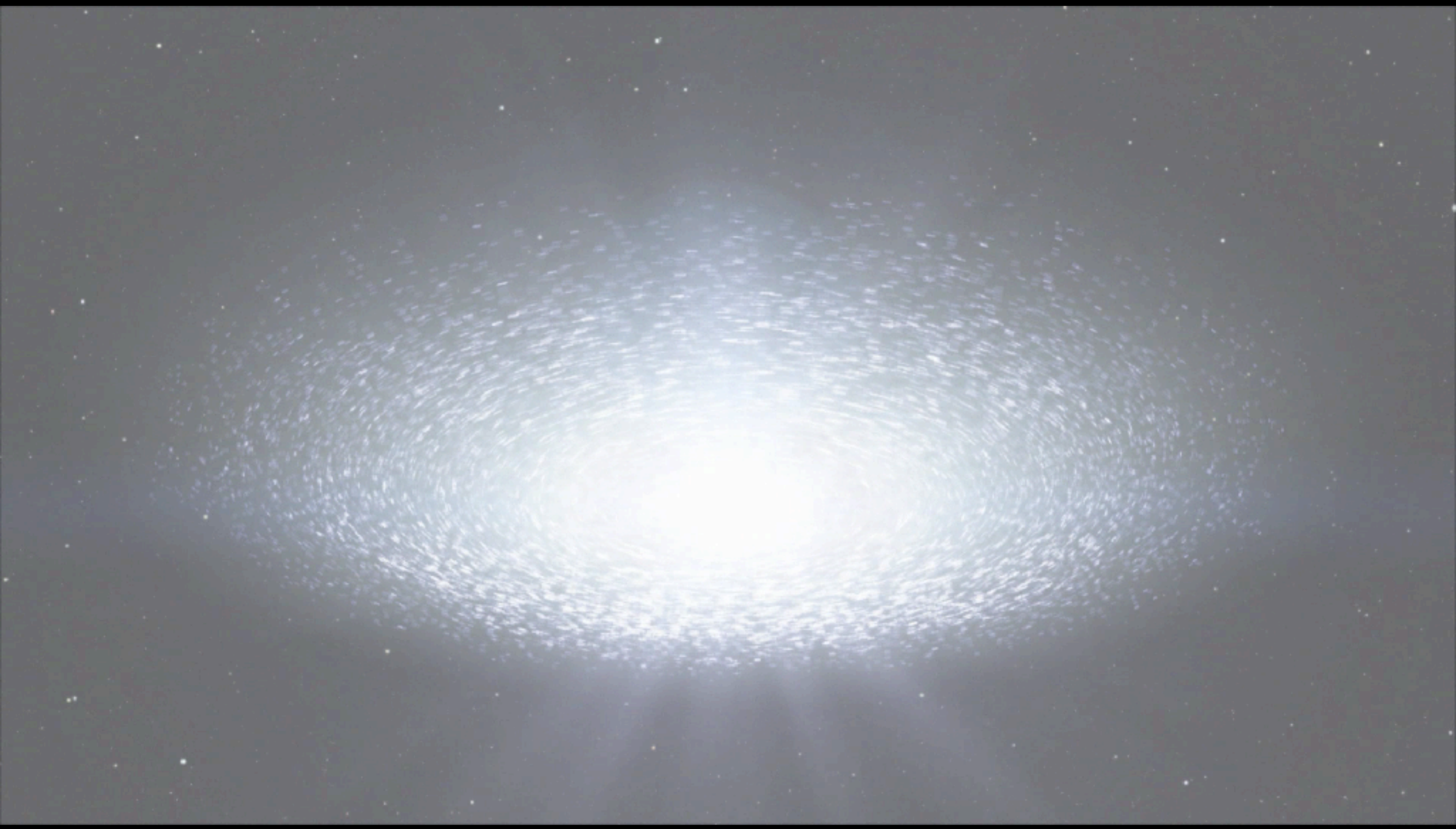
Crédito: Jennifer A. Johnson/The Ohio State University; NASA; ESA

Evidências Observacionais de Matéria Escura

Evidências Observacionais de Matéria Escura:

As galáxias espirais e suas rotações

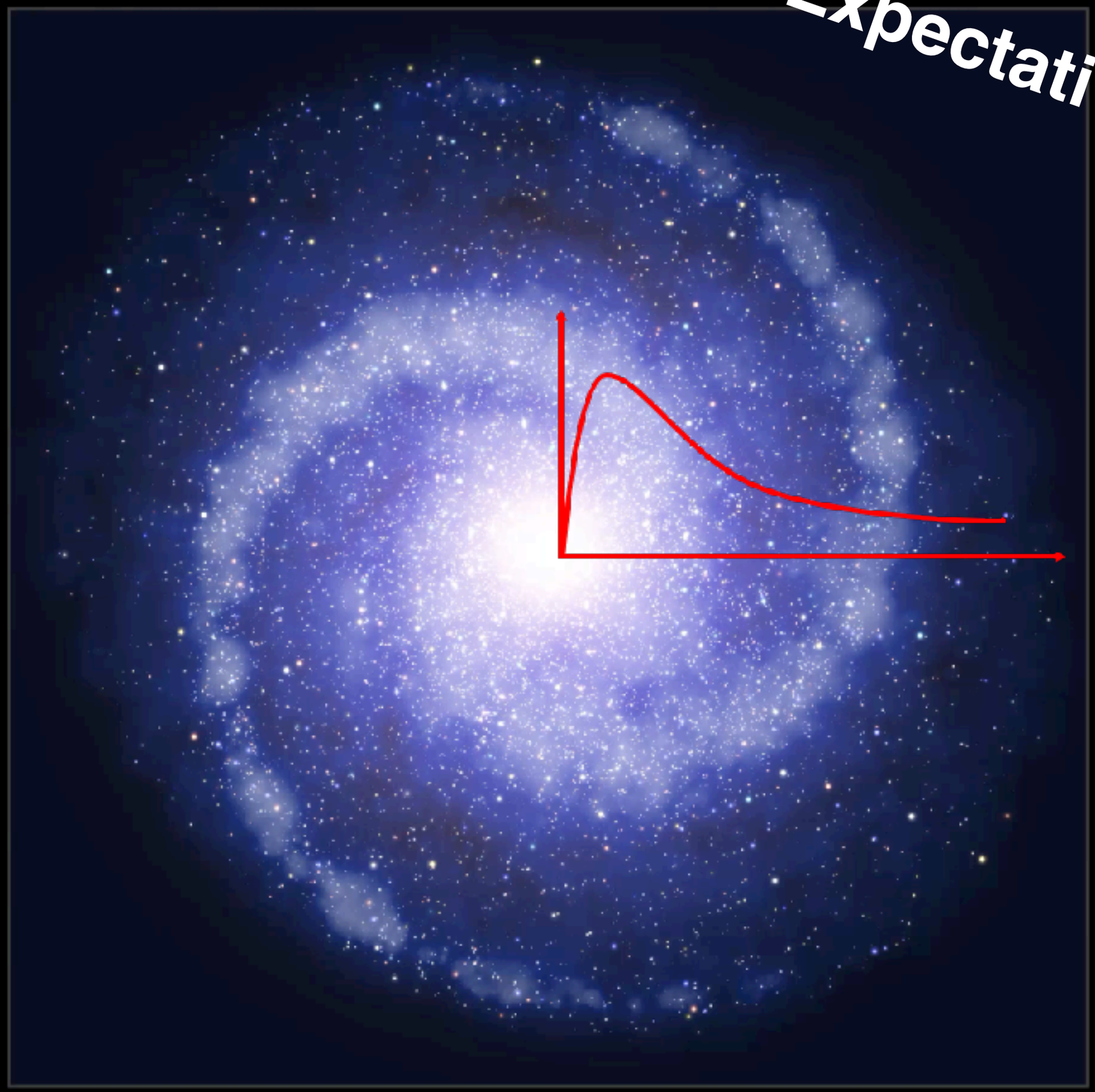
Crédito: ESO/L. Calçada



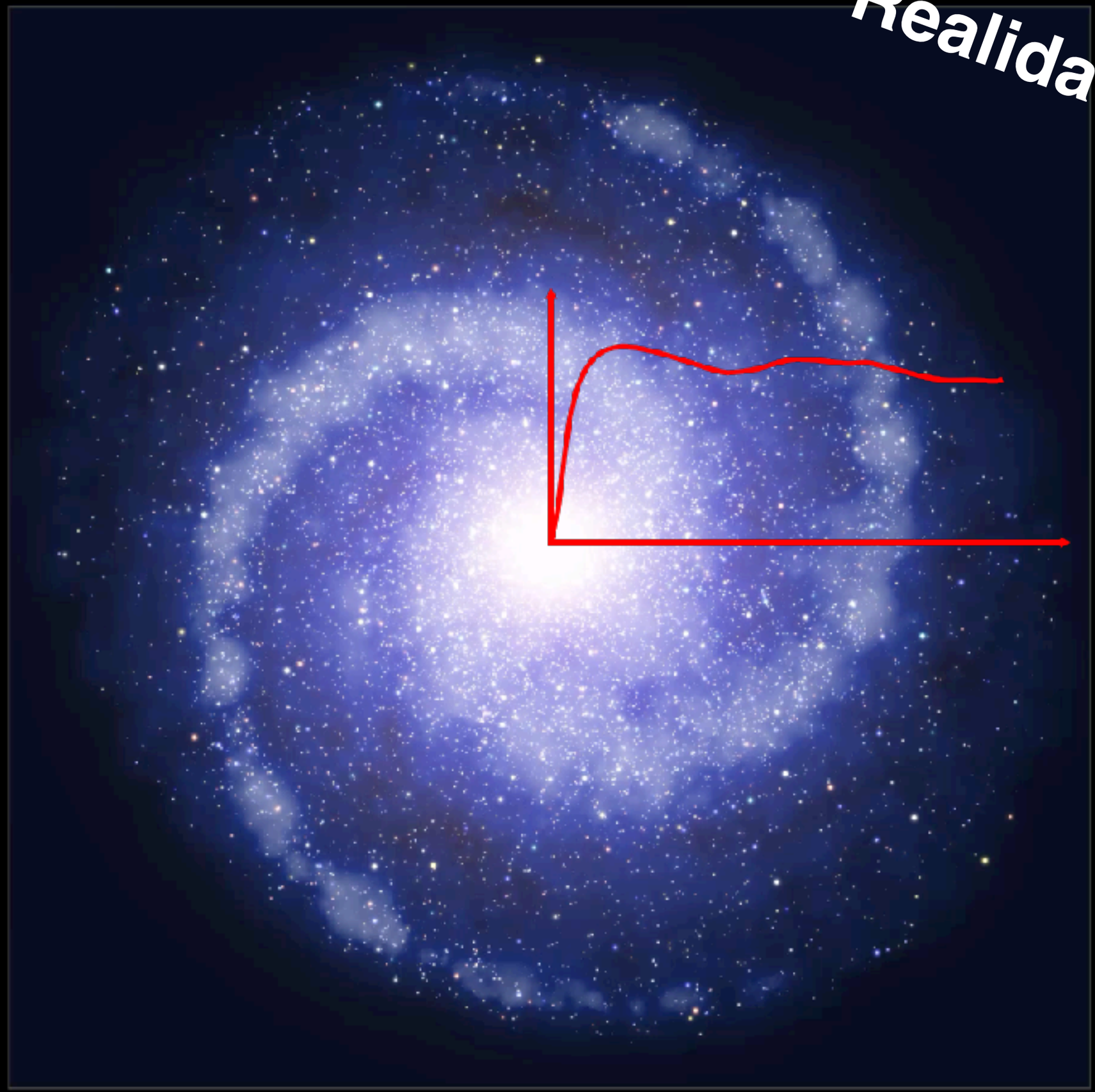
Década de 1970

Vera Rubin
Astrônoma norte-americana

Crédito: ESO/L. Calçada



Crédito: ESO/L. Calçada

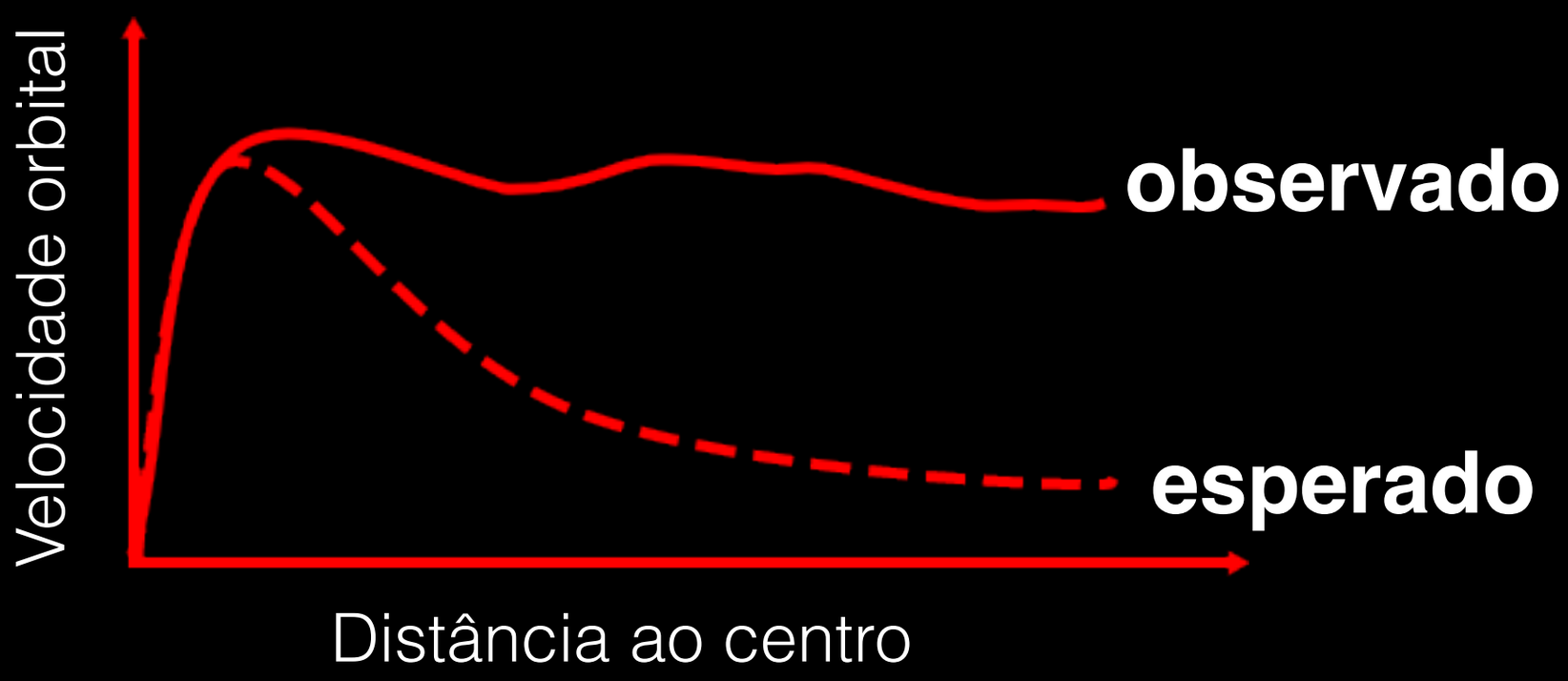


Crédito: ESO/L. Calçada

Realidade

Expectativa

$$v = \sqrt{\frac{GM(R)}{R}}$$



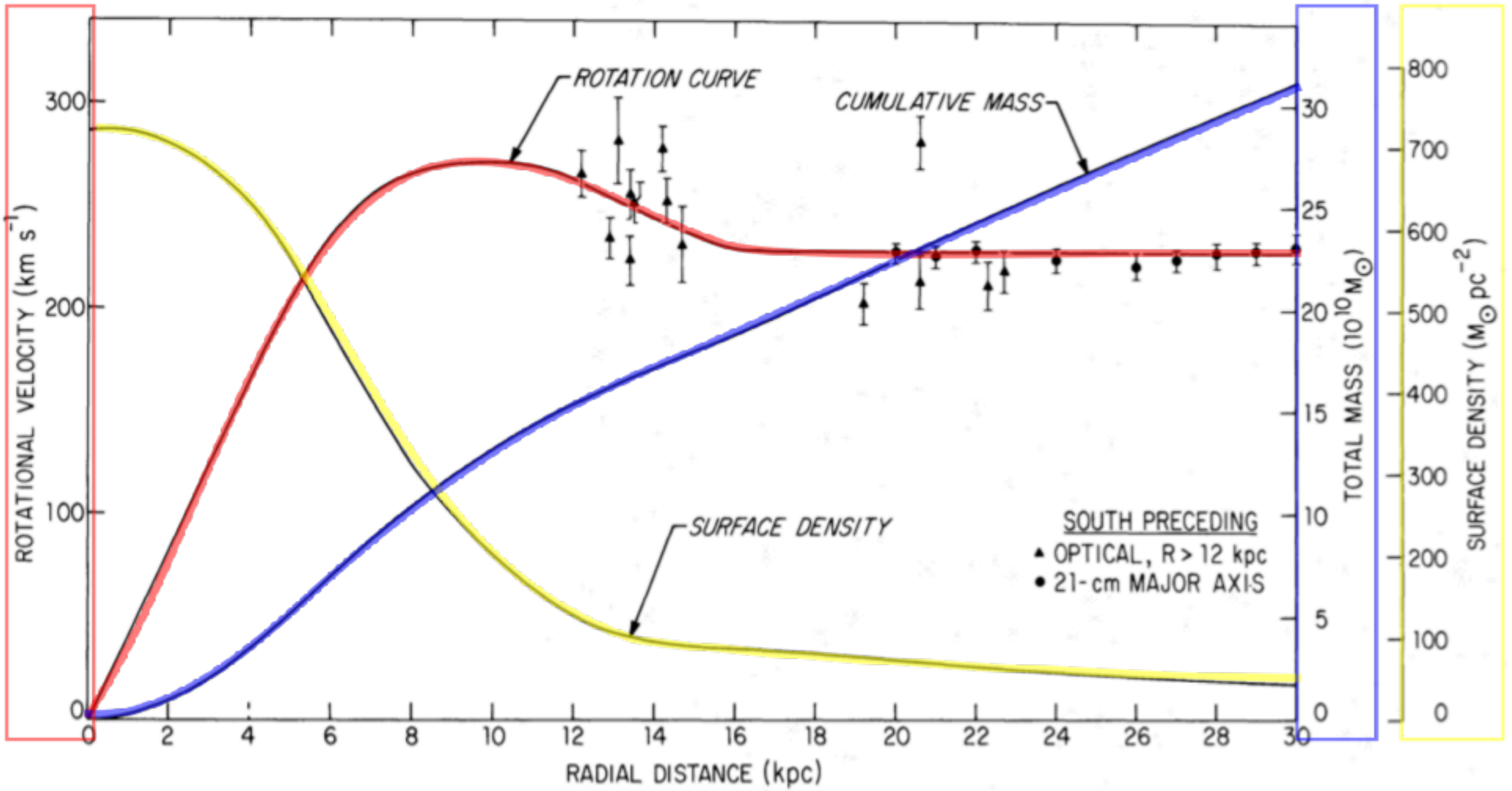
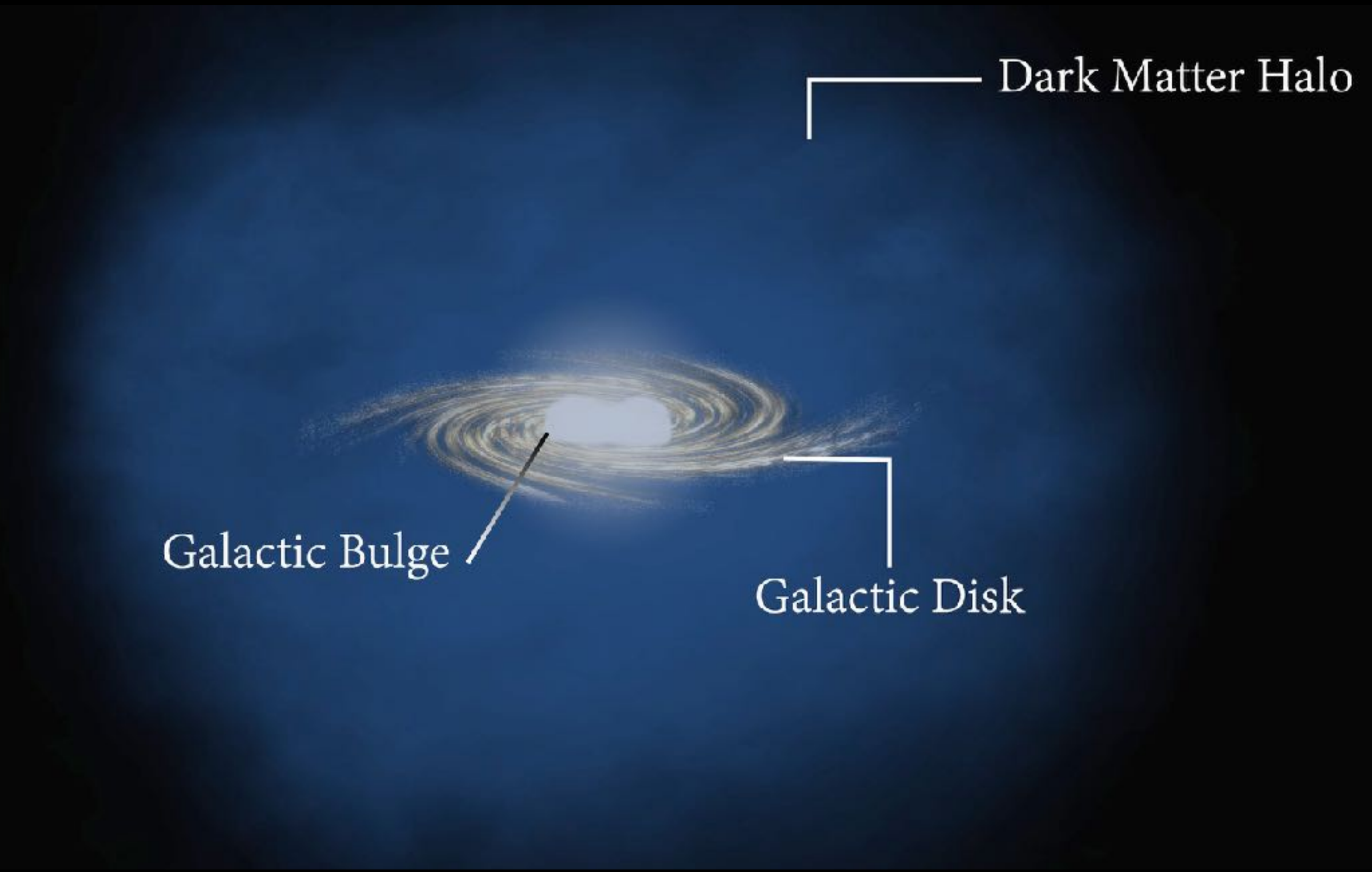


FIG. 16.—The adopted rotation curve, a composite of optical (Rubin and Ford 1970) data and 21-cm major axis measurements. The surface density and cumulative mass curves are for a highly flattened model.

The rotation curve and geometry of M31 at large galactocentric distances.
Roberts, M. S.; Whitehurst, R. N. Astrophysical Journal, Vol. 201, p.327 - 10/1975


Dark Matter Halo
Galactic Bulge
Galactic Disk

Evidências Observacionais de Matéria Escura:

Aglomerados de galáxias

Aglomerado de galáxias Coma

Cerca de 10 000 galáxias,
cada uma com bilhões de estrelas

Crédito: NASA / JPL-Caltech / L. Jenkins (GSFC)

Teorema de Virial: estado estacionário

$$2E_K + E_U = 0$$

$$M_{Coma} = \frac{< v^2 > r_h}{\alpha G}$$

~300 vezes mais massa que o observado

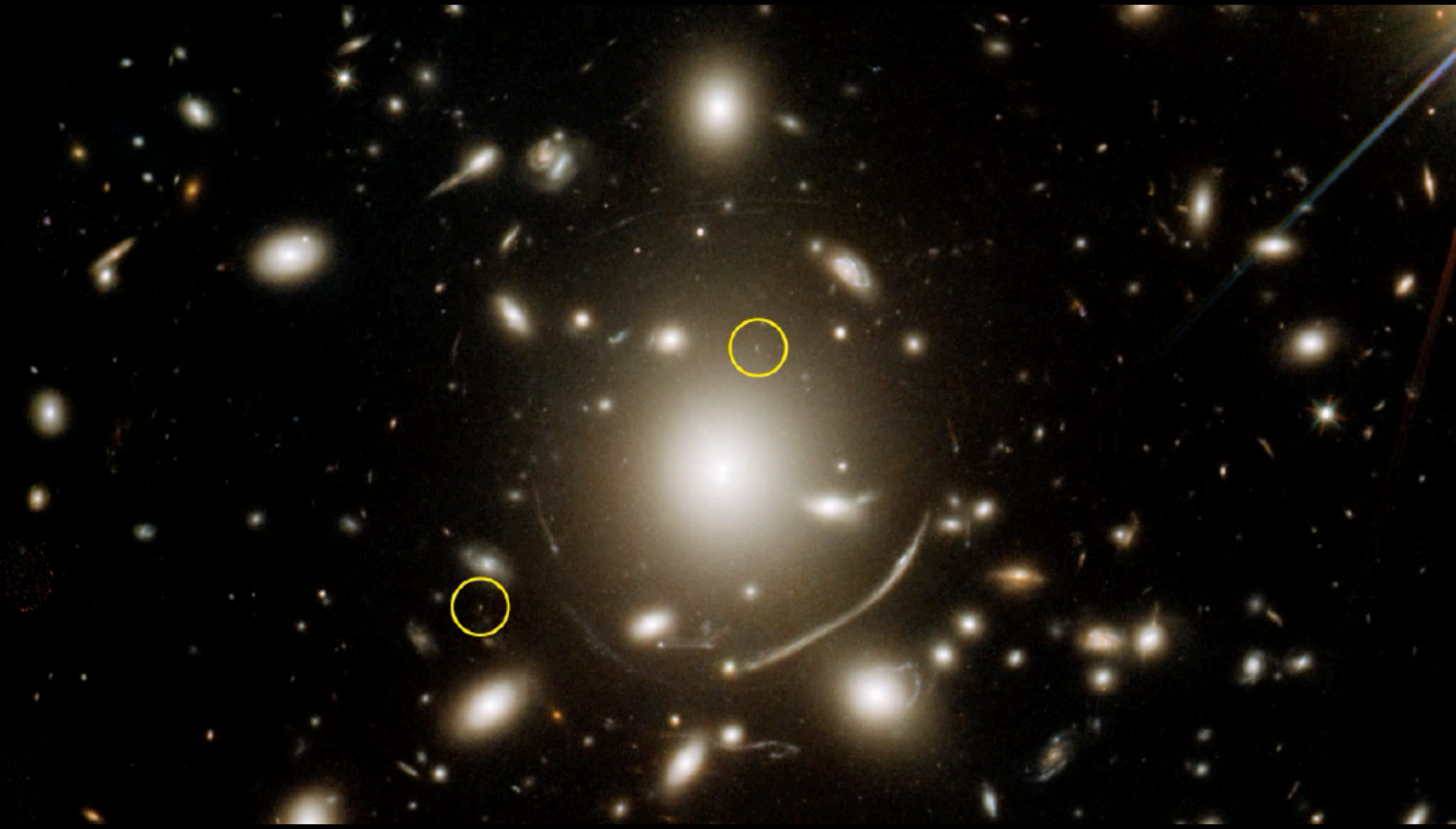
Fritz Zwick (1898 - 1974).

Fritz Zwick

1933: calculou a massa total do aglomerado de galáxias Coma baseado no movimento das galáxias que se situavam próximas à sua borda.

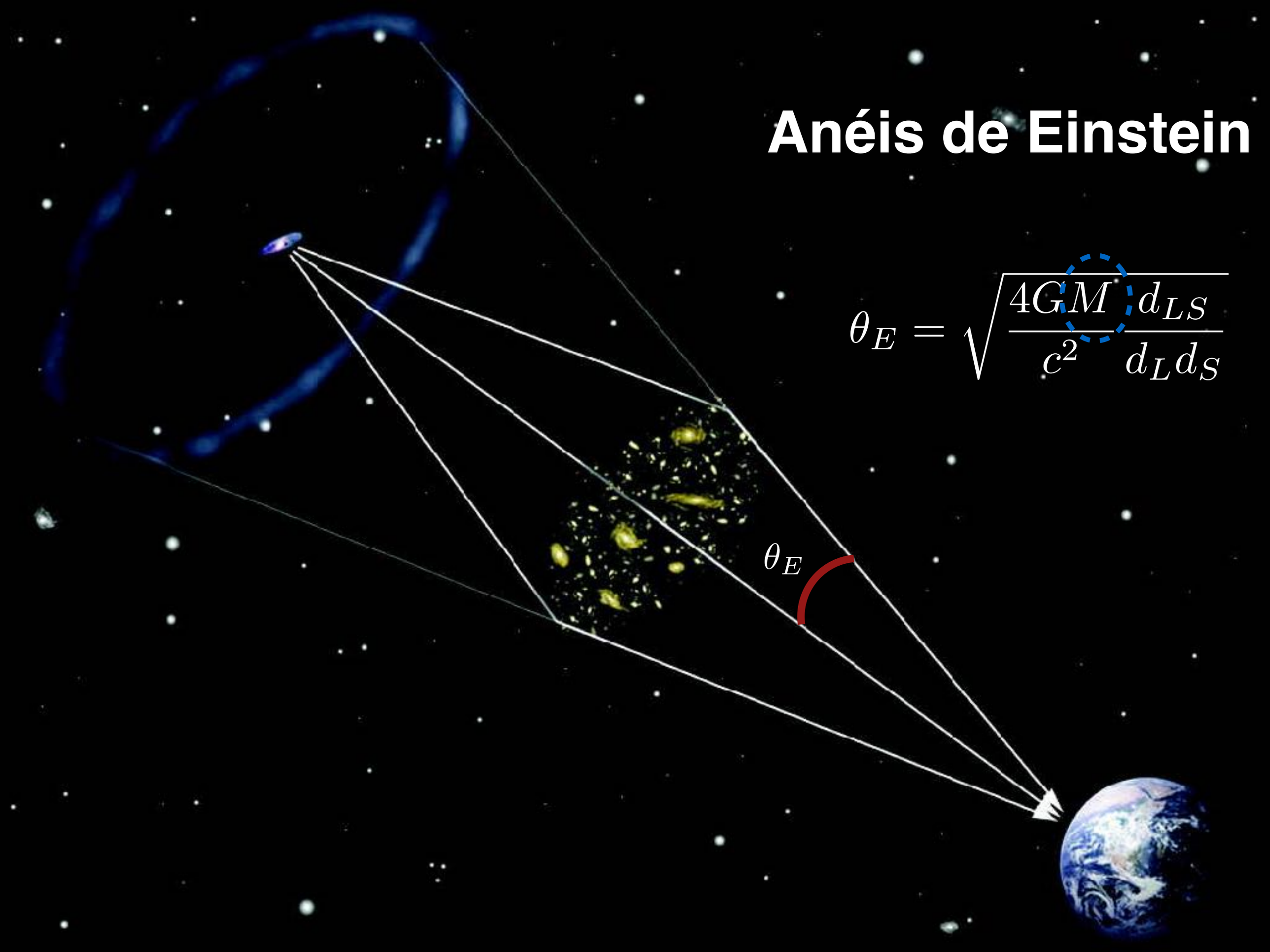
Evidências Observacionais de Matéria Escura:

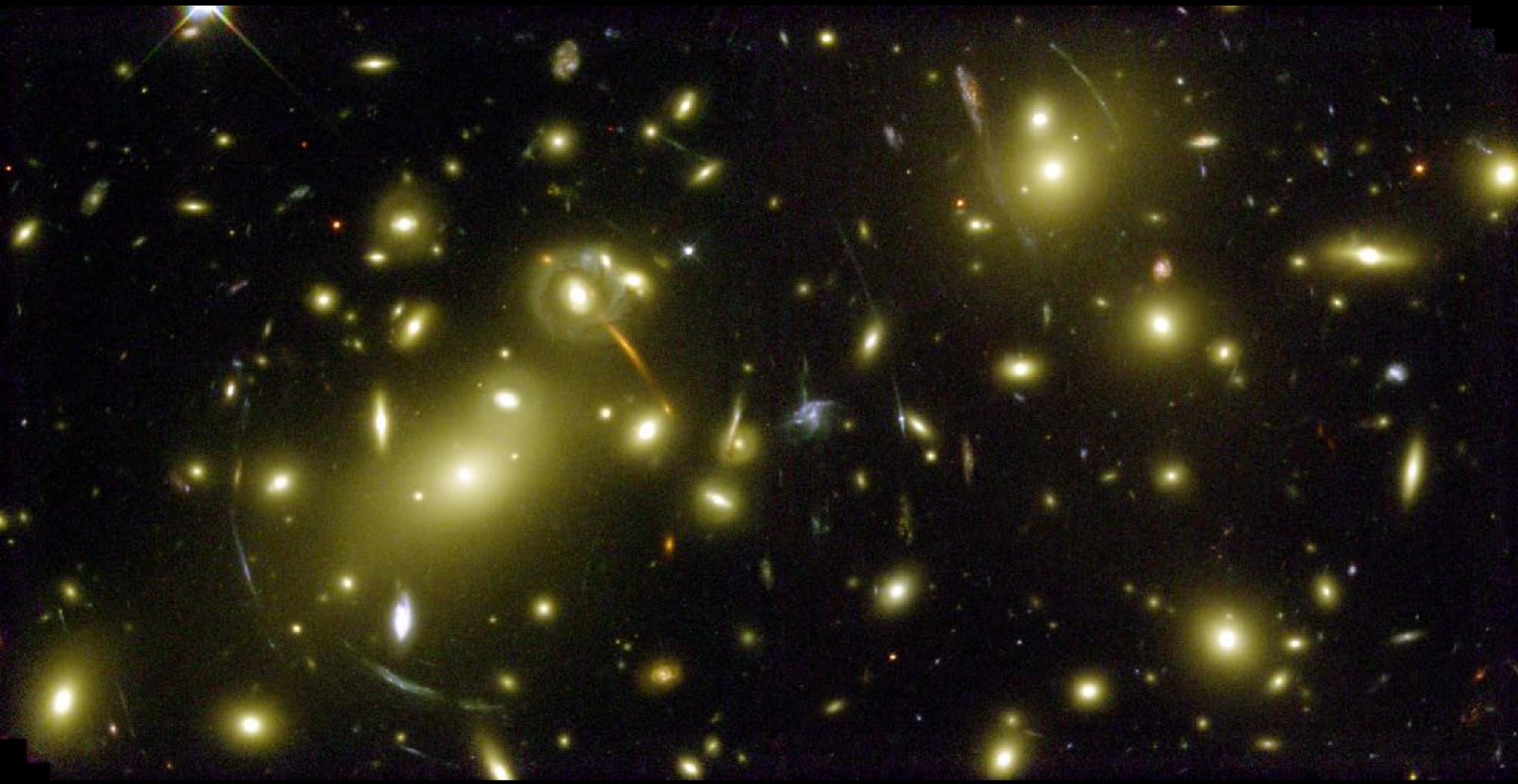
Lentes gravitacionais



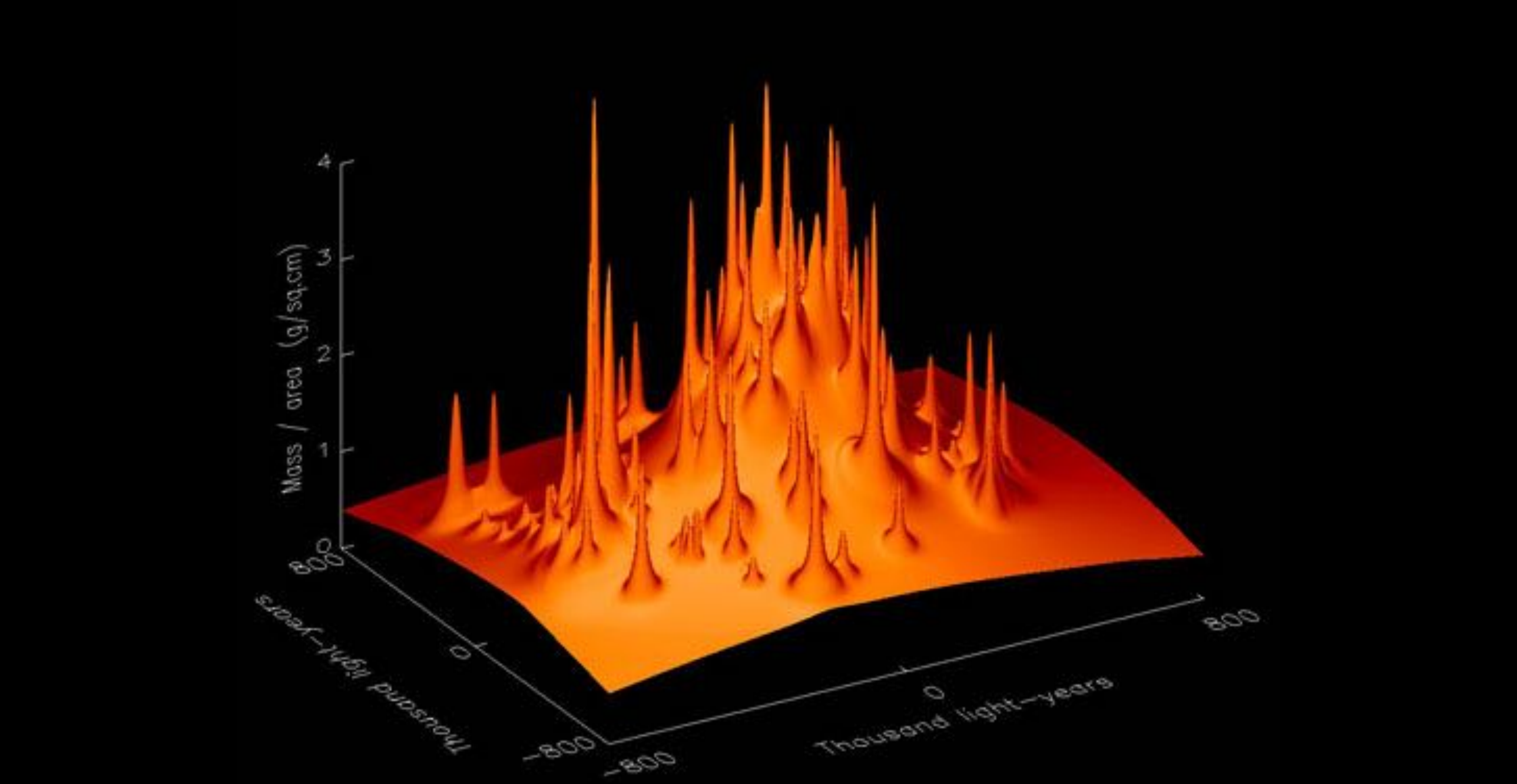
Anéis de Einstein

$$\theta_E = \sqrt{\frac{4GM}{c^2}\frac{d_{LS}}{d_L d_S}}$$





Crédito: NASA, Andrew Fruchter and the ERO Team

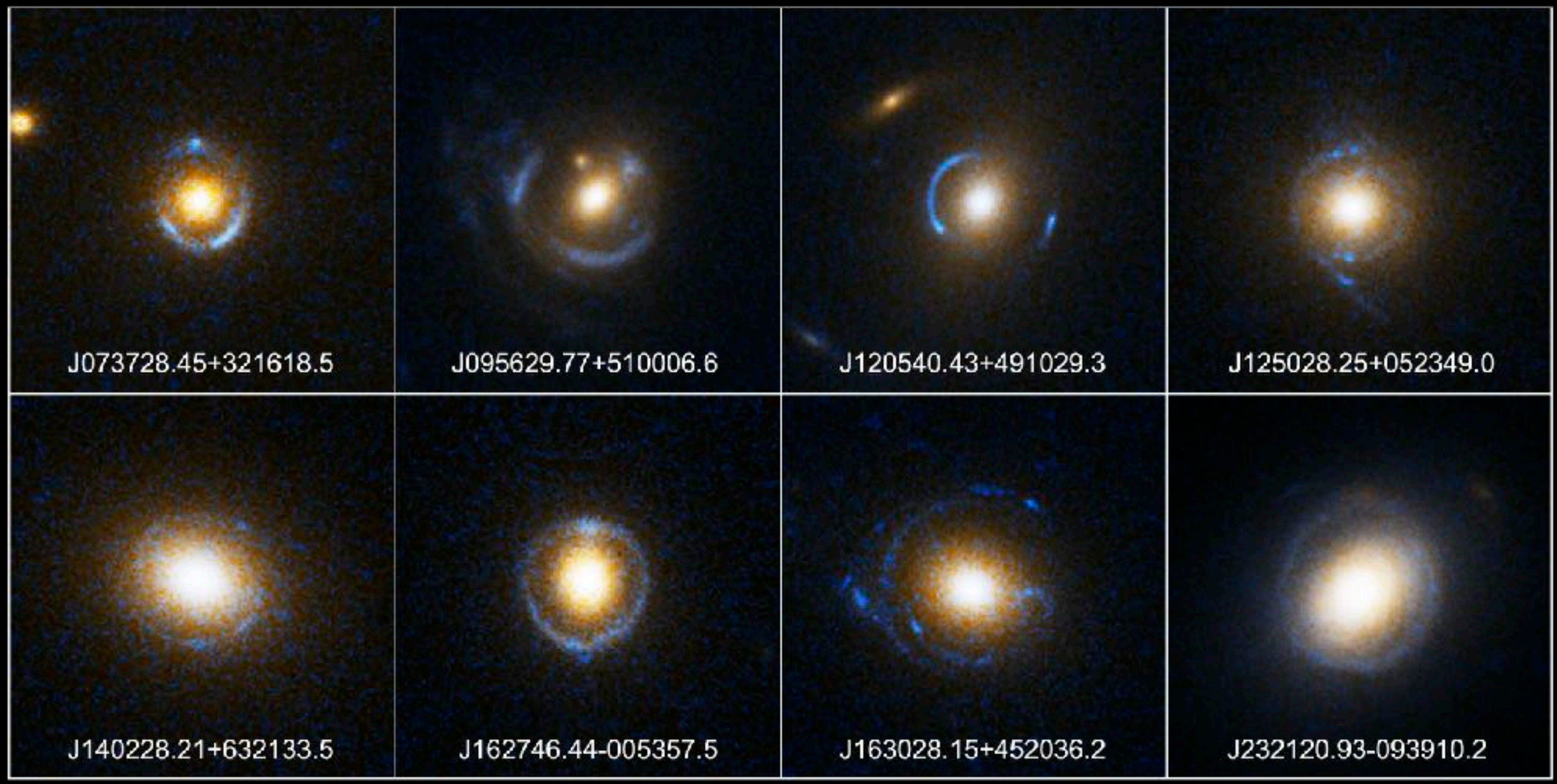


Mapeamento de distribuição de massa em aglomerado de galáxias via lentes gravitacionais.

Mapas de matéria escura em aglomerados de galáxias.

Credit: NASA, ESA, D. Harvey, R. Massey

Lenteamento gravitacional por Matéria Escura em Galáxias Elípticas



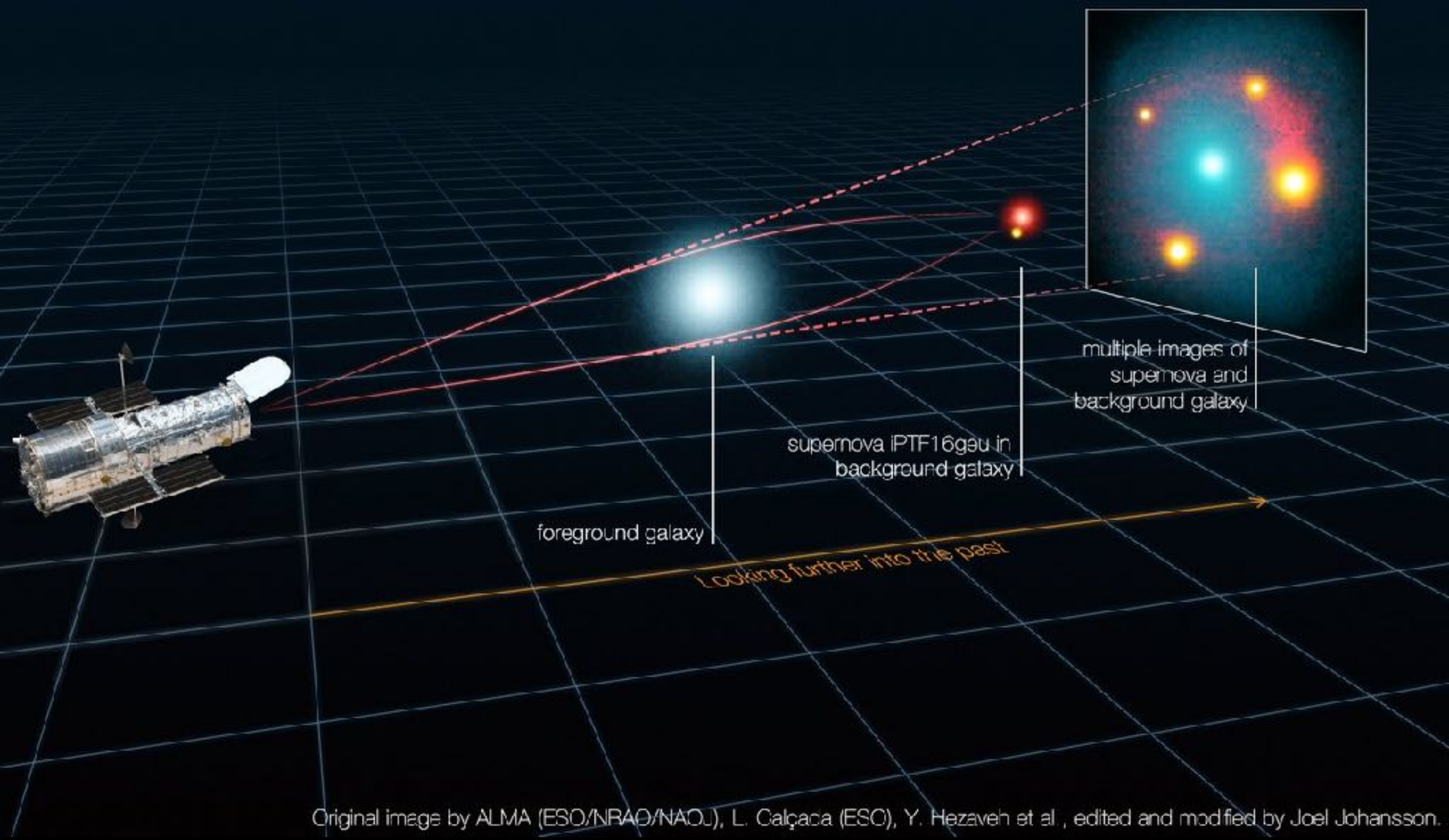
Einstein Ring Gravitational Lenses

Hubble Space Telescope • Advanced Camera for Surveys

NASA, ESA, A. Bolton (Harvard-Smithsonian CfA), and the SLACS Team

STScI-PRC05-32

Imagem da Supernova sob efeito de lente gravitacional



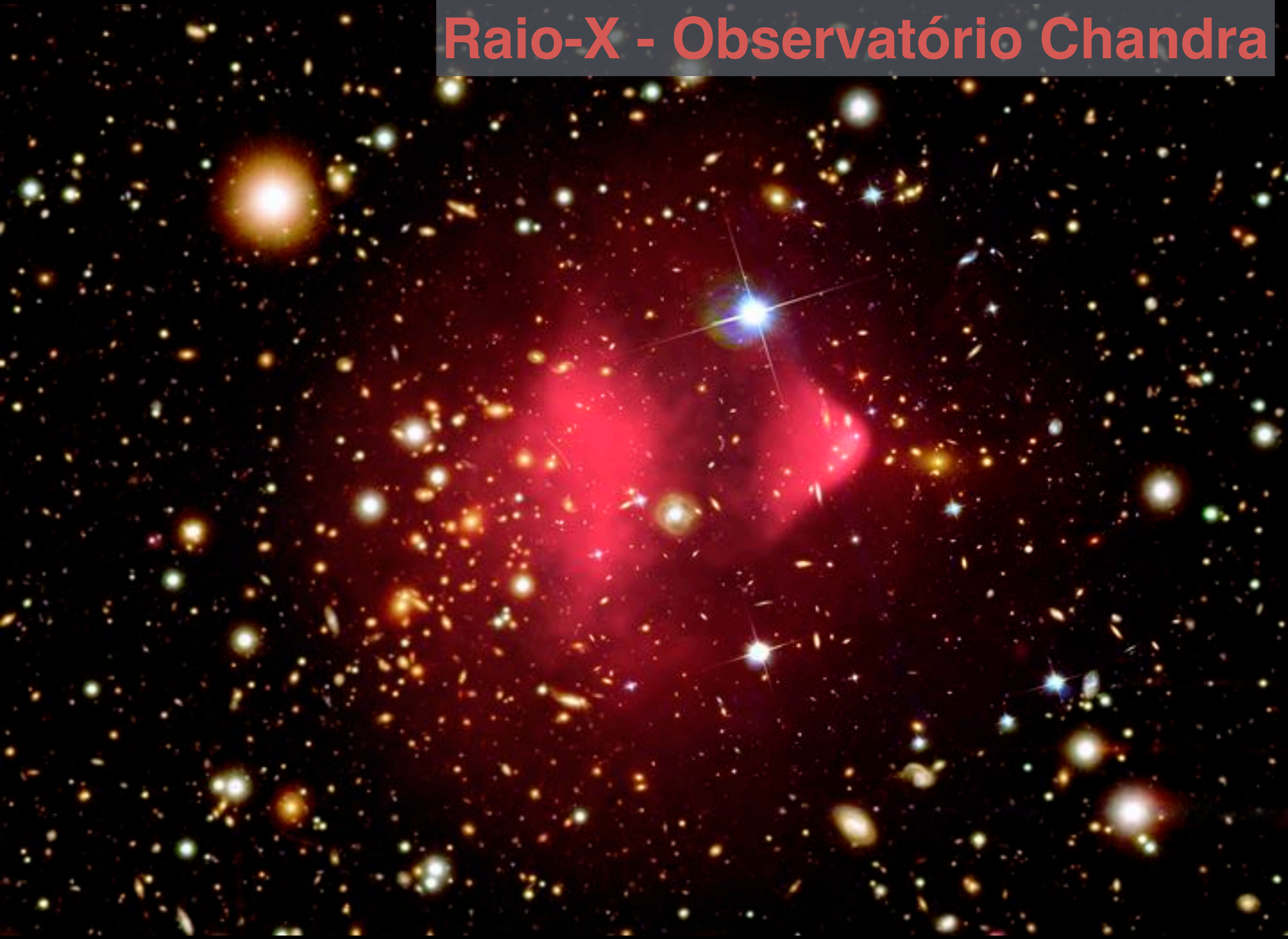
Original image by ALMA (ESO/NRAO/NAOJ), L. Calçada (ESO), Y. Hezaveh et al., edited and modified by Joel Johansson.

Evidências Observacionais de Matéria Escura:

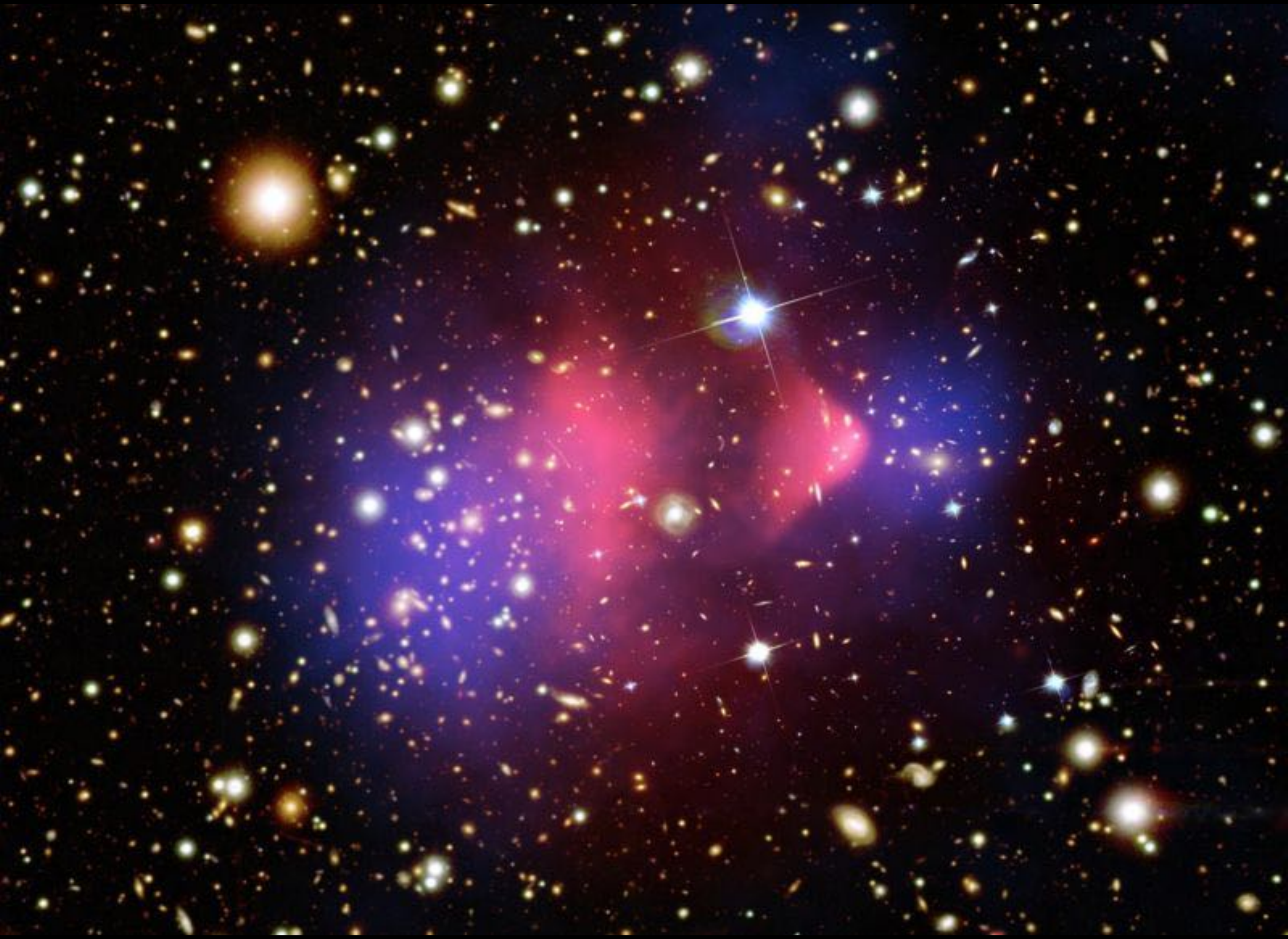
Aglomerado da Bala (Bullet Cluster)

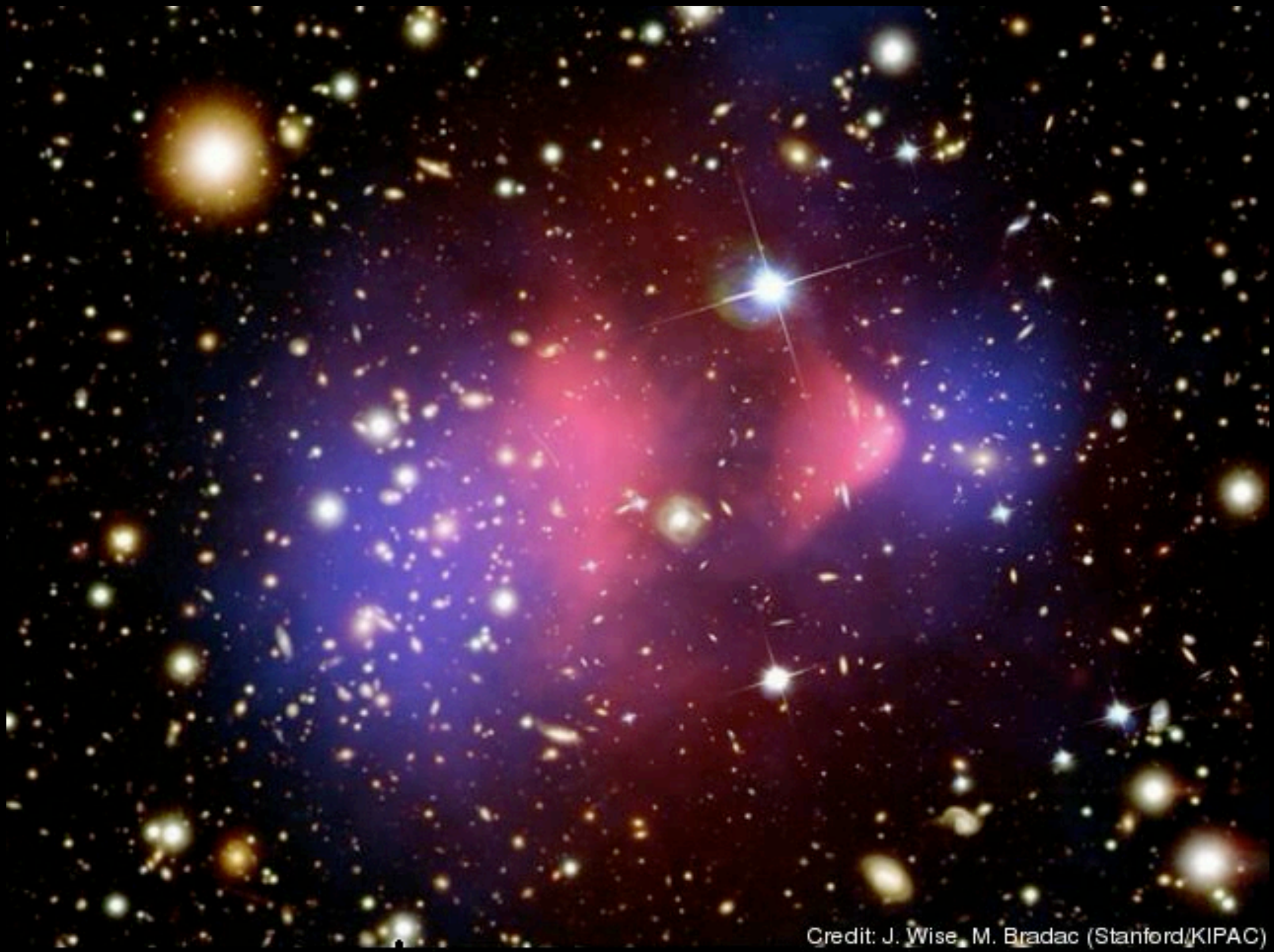
Luz visível - HST

Raio-X - Observatório Chandra



Mapeamento de matéria escura: Lentes Gravitacionais




Credit: J. Wise, M. Bradac (Stanford/KIPAC)

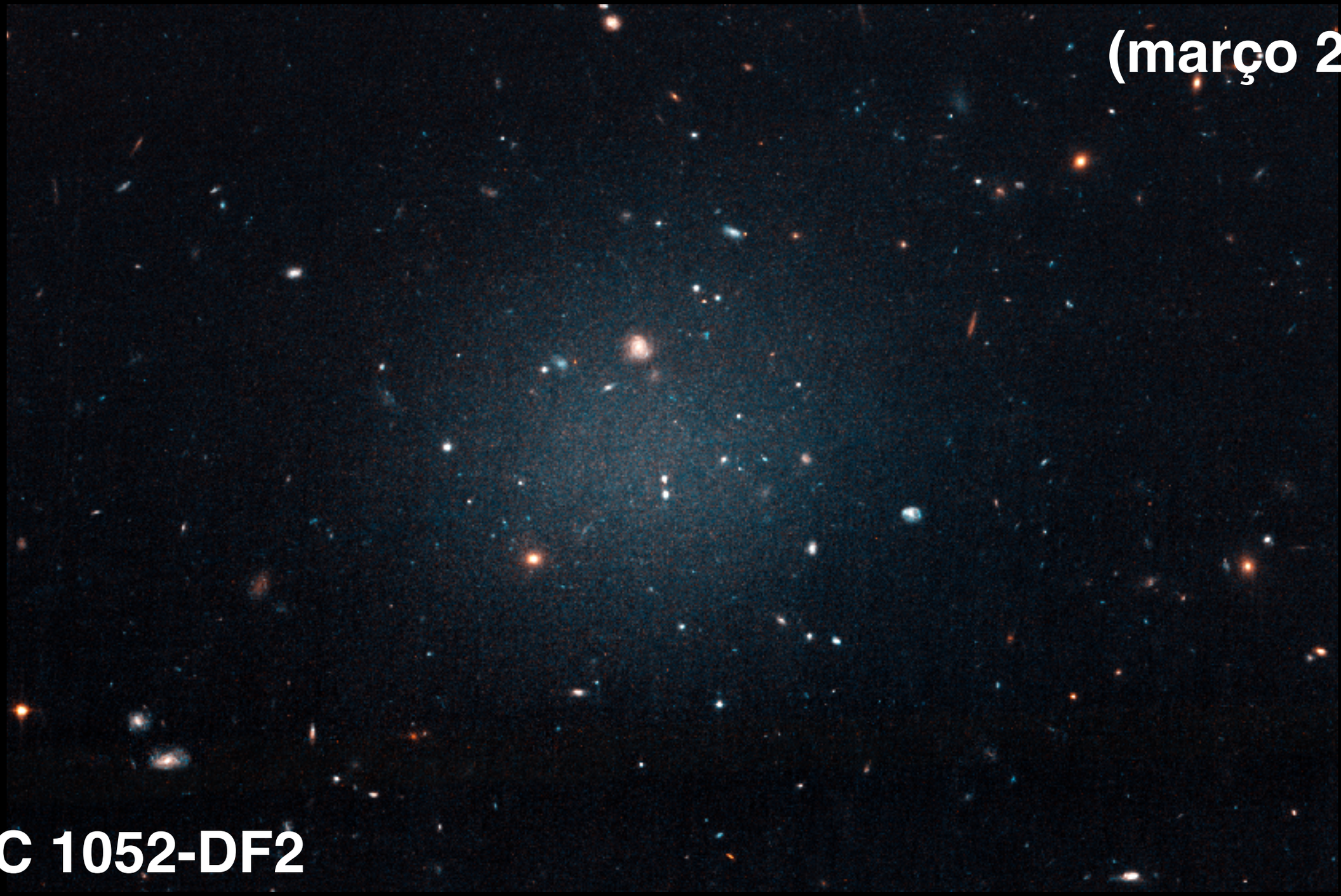
Evidências Observacionais de Matéria Escura:

Galáxia ultra difusa NGC 1052-DF2

Zoom através da constelação Cetus (Baleia) até observação da galáxia ultra difusa NGC 1052-DF2.

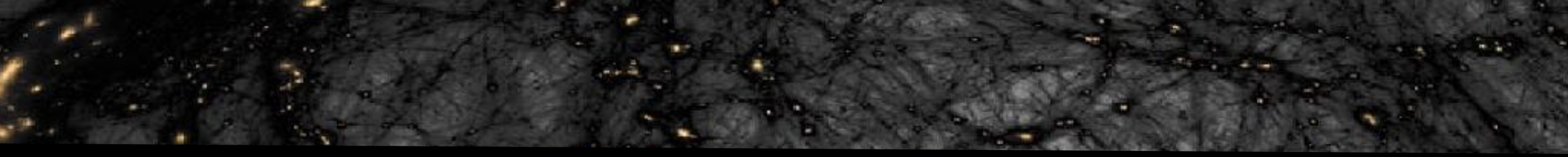
Crédito: ESA/Hubble, Digitized Sky Survey, Nick Risinger

(março 2018)



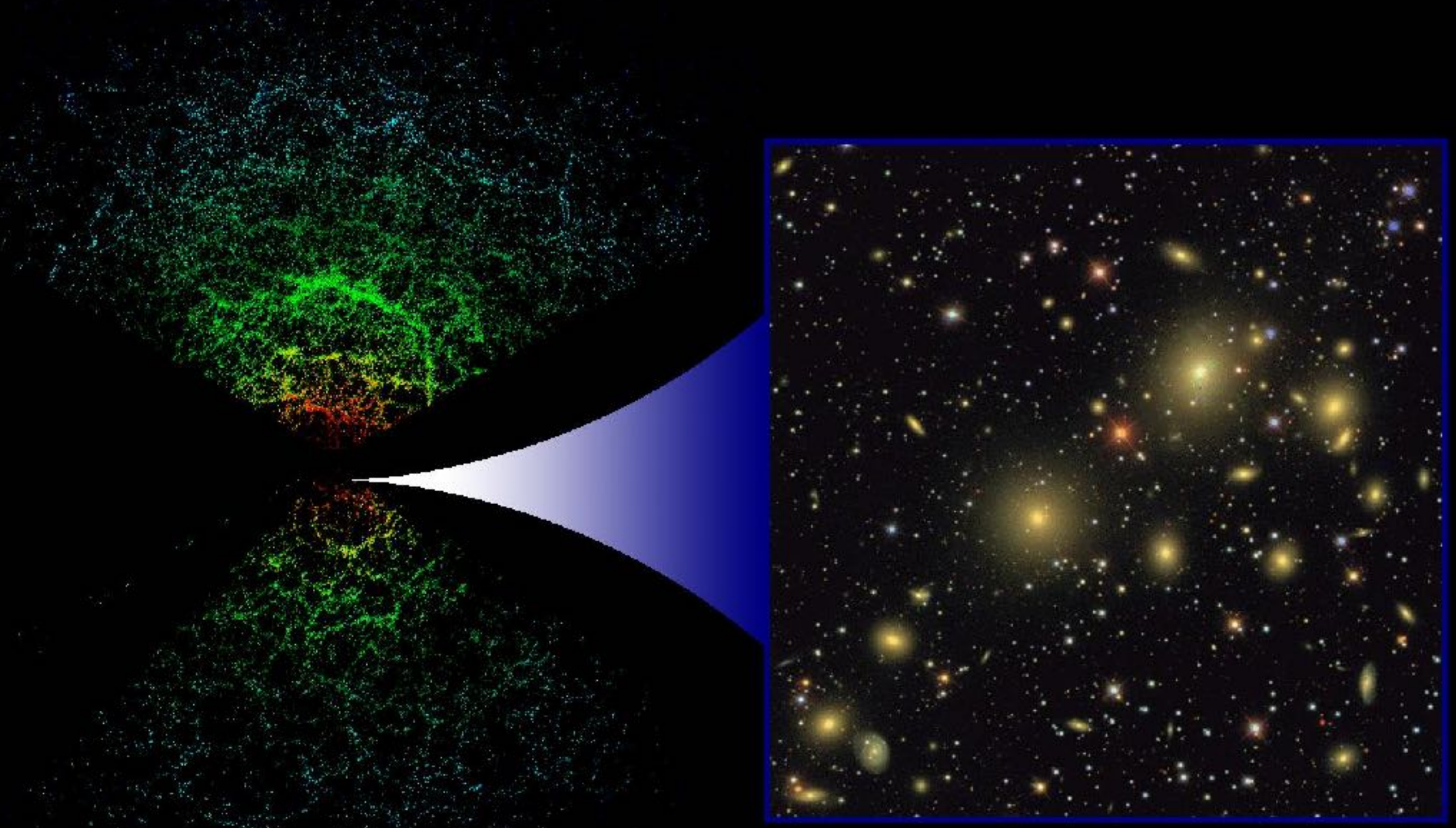
NGC 1052-DF2
~ tamanho da Via Láctea
0,5% do número de estrelas da Via Láctea

1/400 da quantidade de matéria escura esperada!!



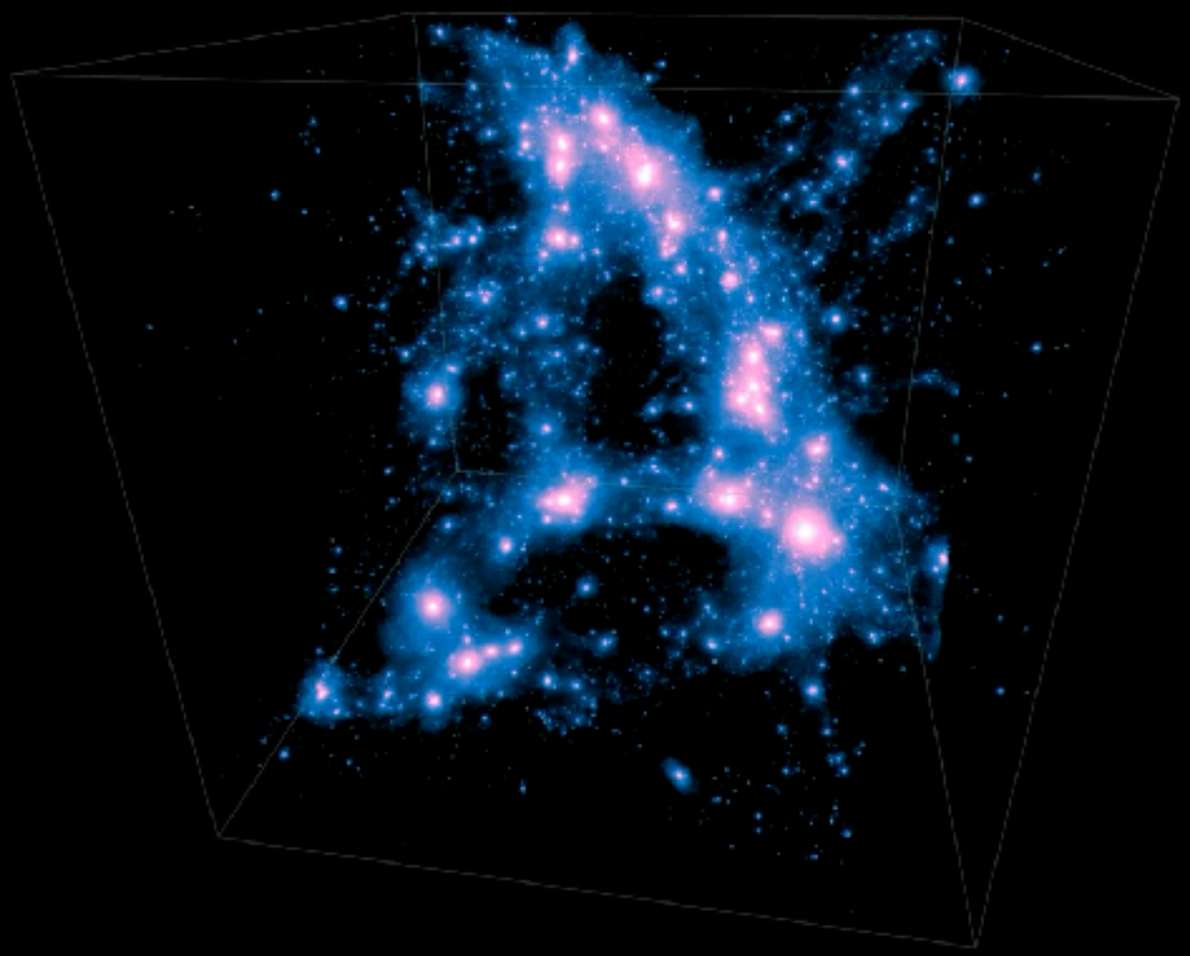
Evidências Observacionais De Matéria Escura:

Formação de estruturas em larga escala

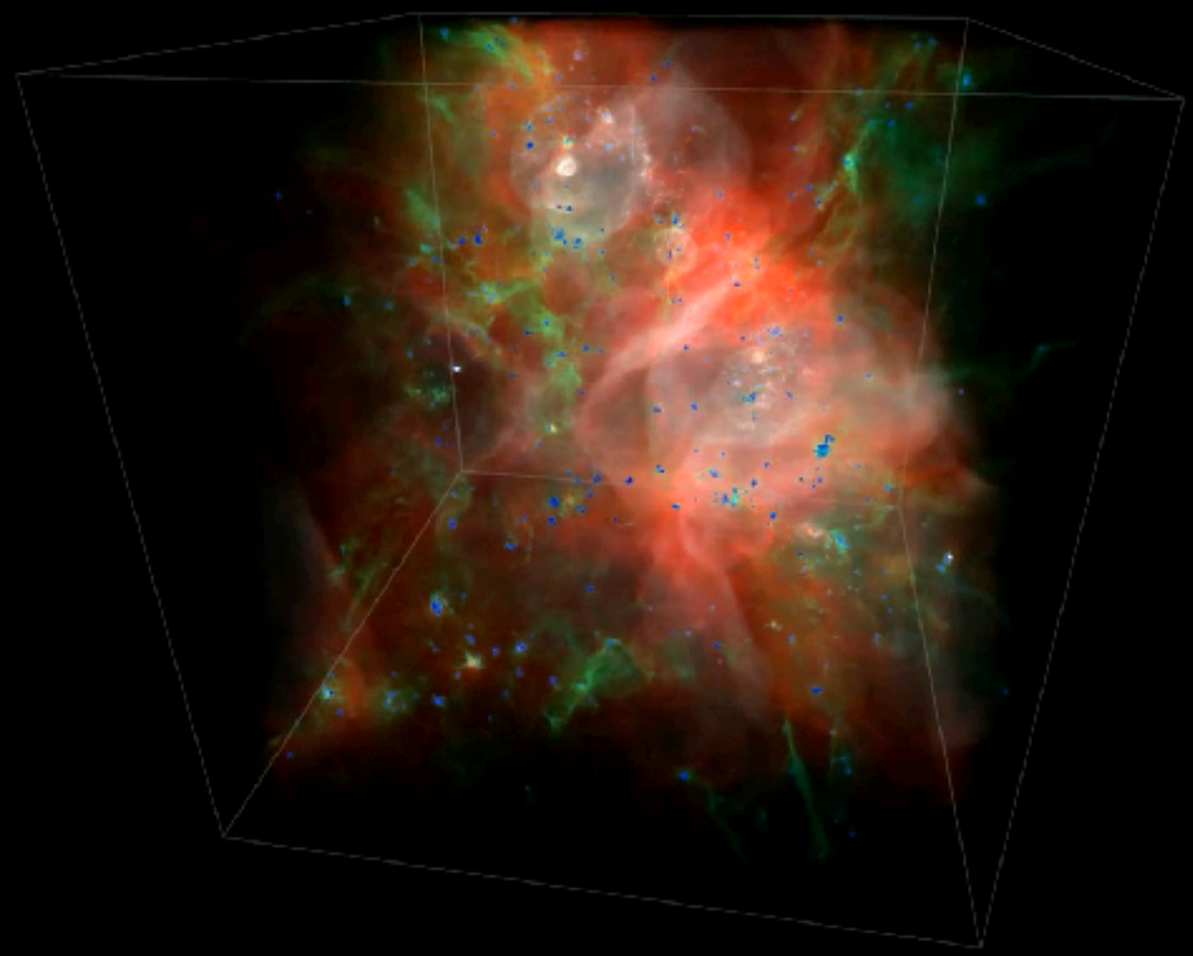


66 976 galáxias do SDSS

Dark Matter



Gas Temperature



redshift	: 0.30	stellar mass	: 72.4	billion solar masses	
Time since the Big Bang:	10.4 billion years				

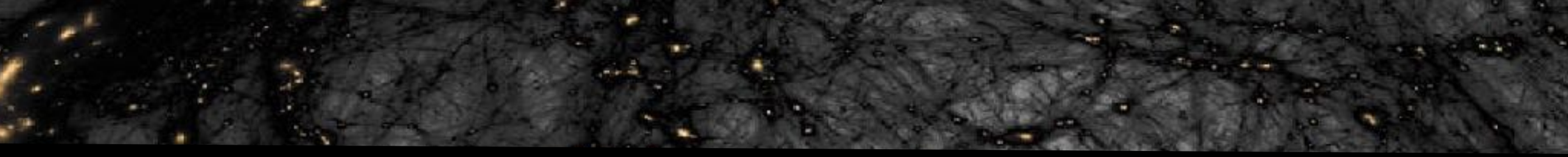
ILLUSTRIS

http://www.illustris-project.org/media/

Foto do Telescópio Hubble

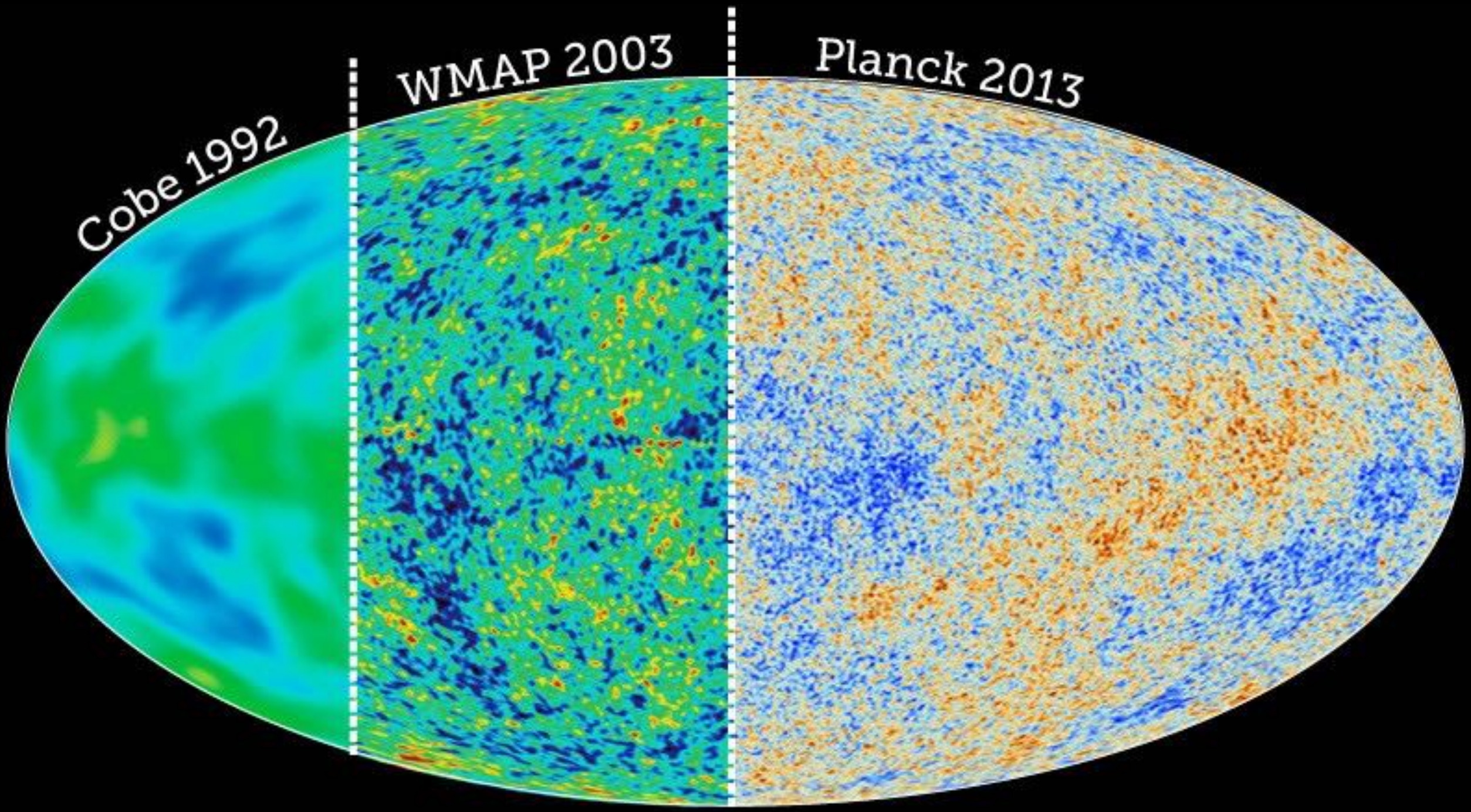
Simulação do Illustris

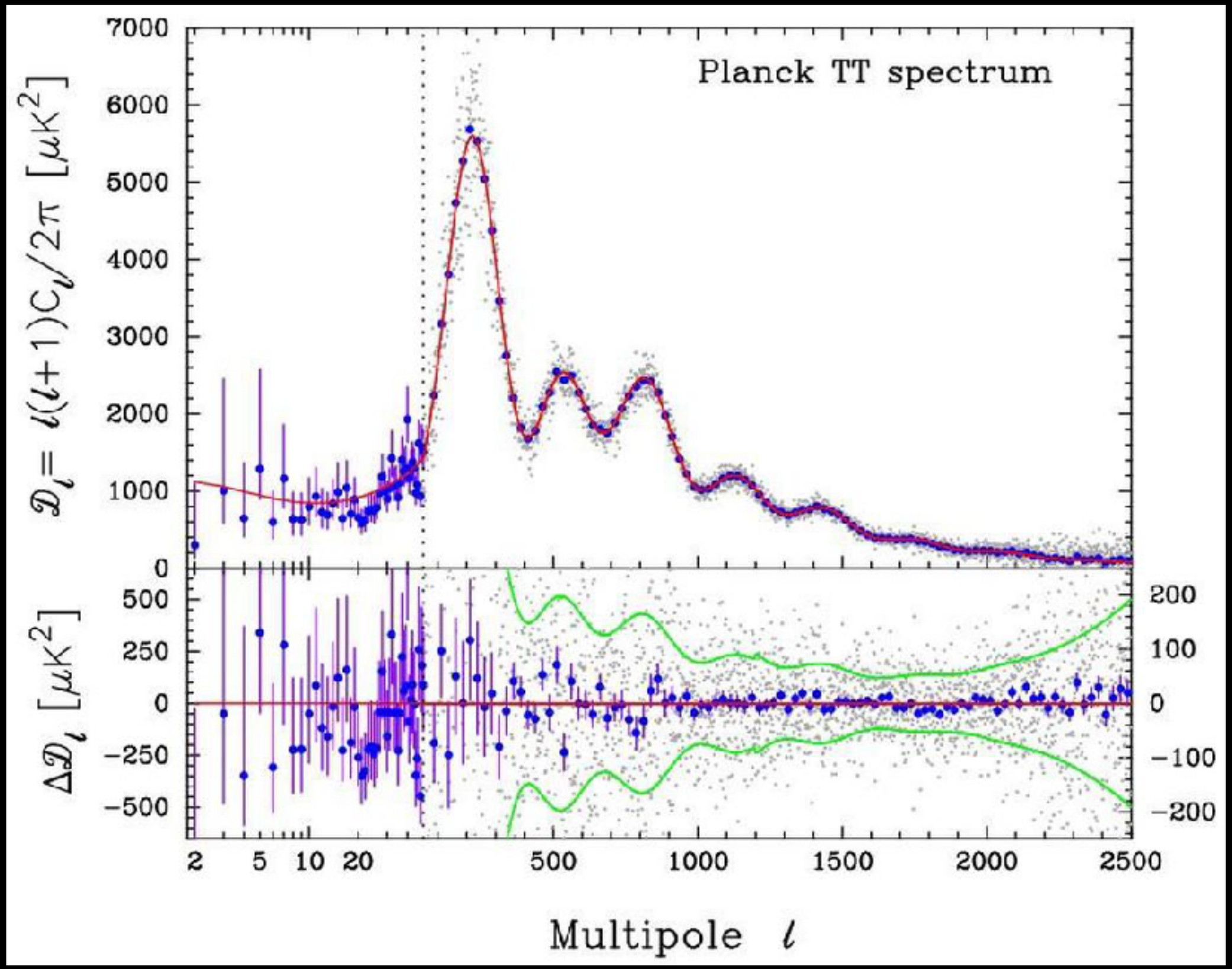
http://www.illustris-project.org/media/



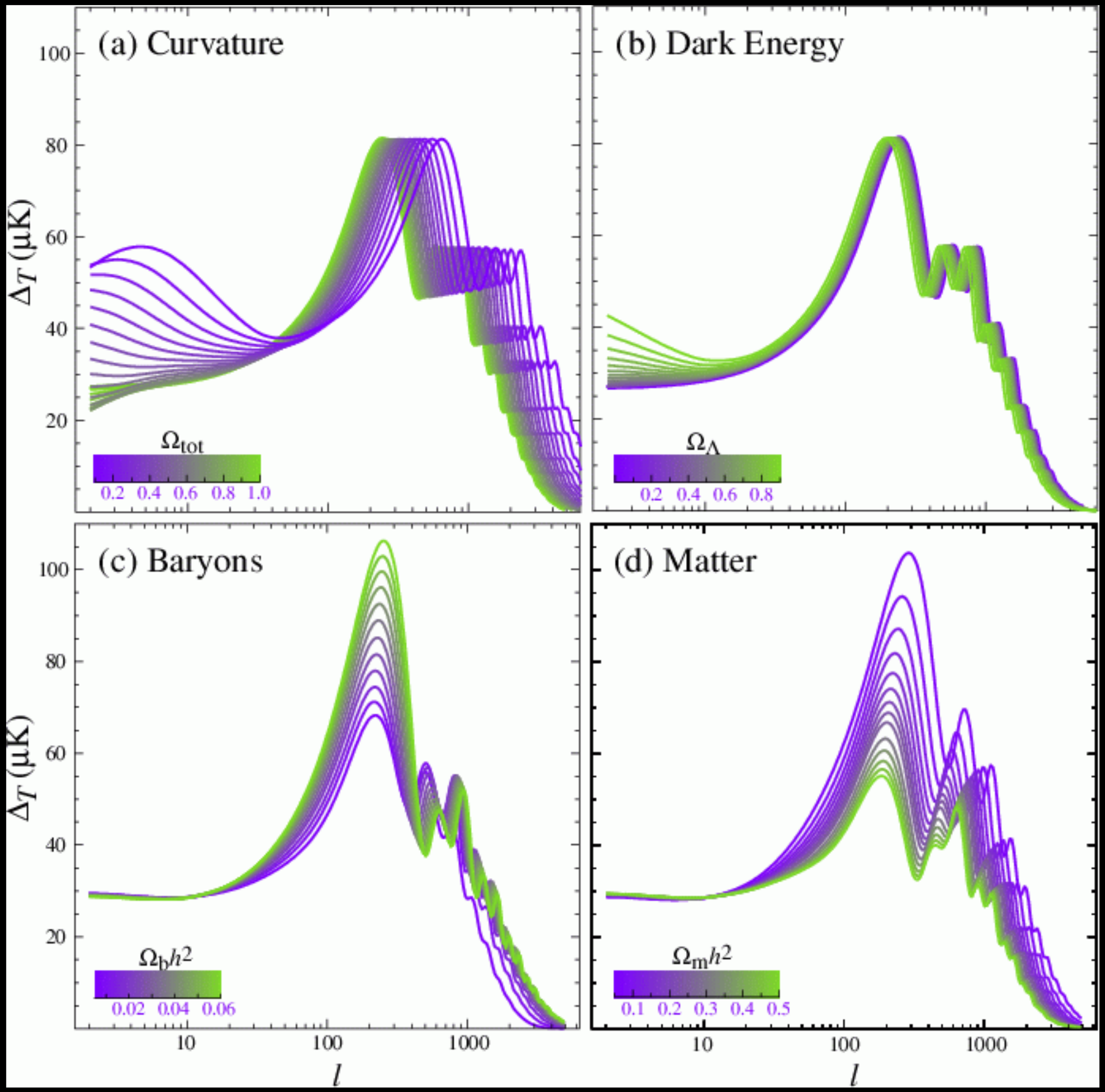
Evidências Observacionais De Matéria Escura:

Radiação Cósmica de Fundo em Microondas

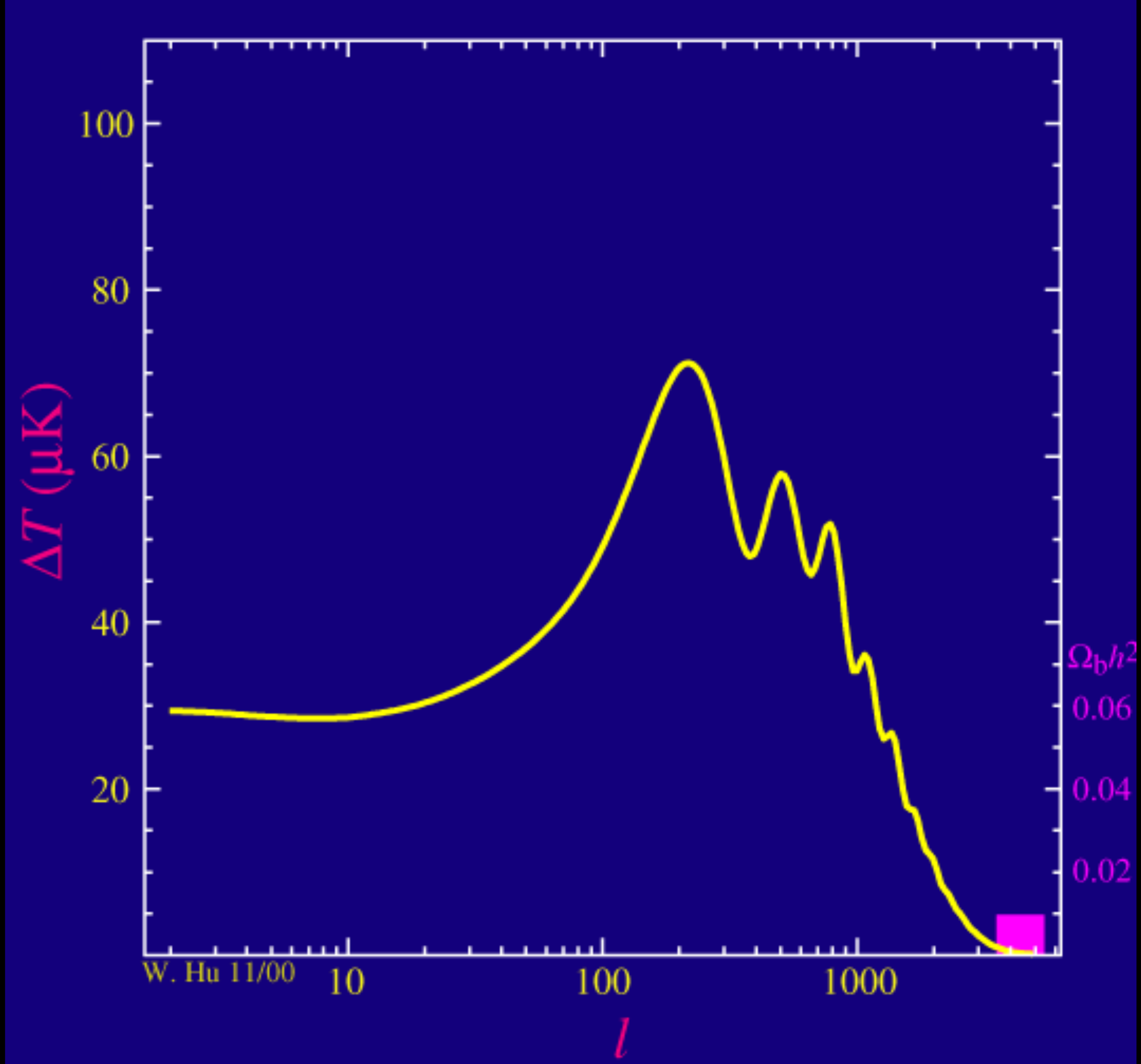

Cobe 1992
WMAP 2003
Planck 2013



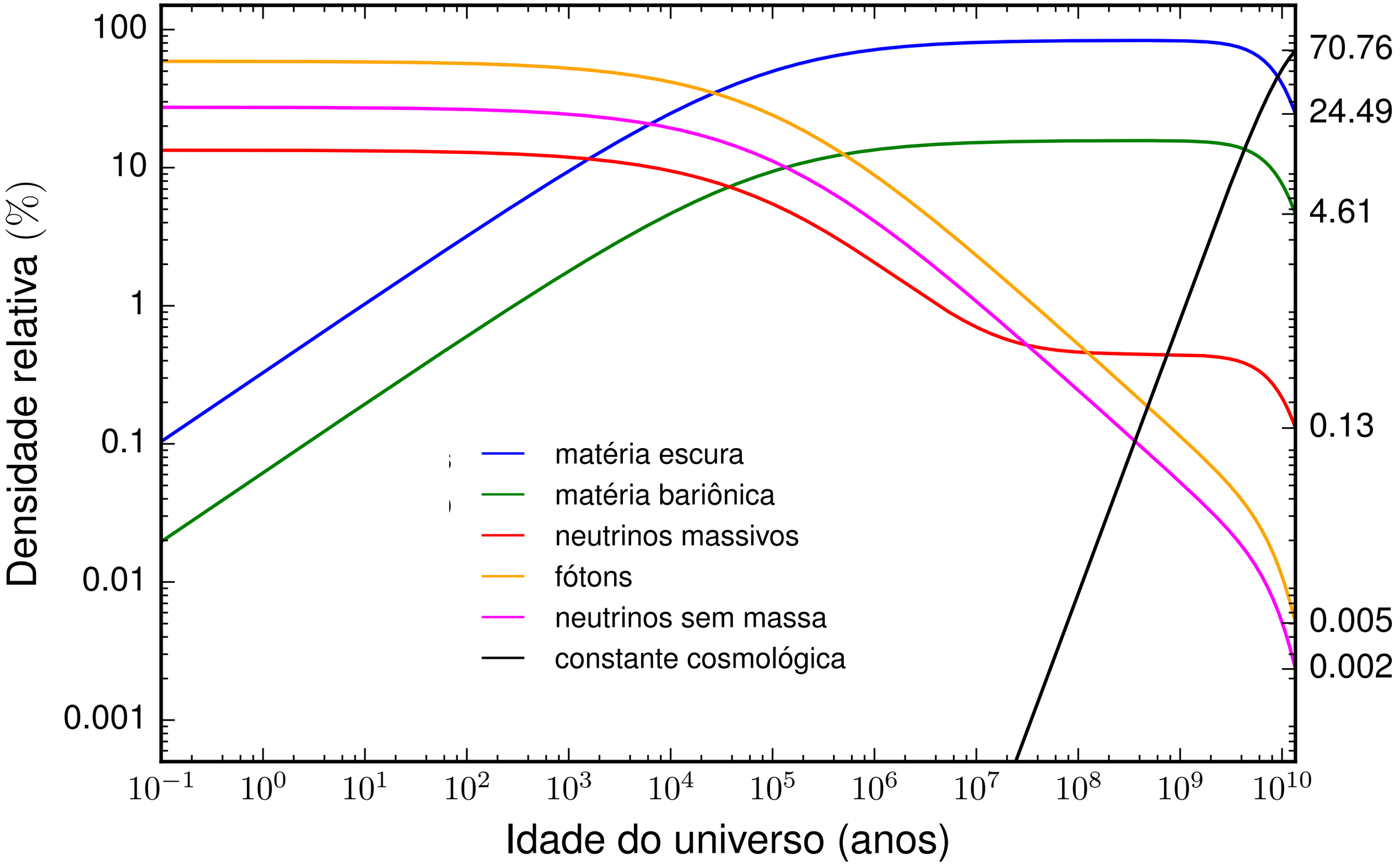
Crédito: Planck Collaboration: P. A. R. Ade et al., 2014, A&A.



Crédito: W. Hu and S. Dodelson, Ann.Rev.Astron.Astrophys.40:171-216,2002

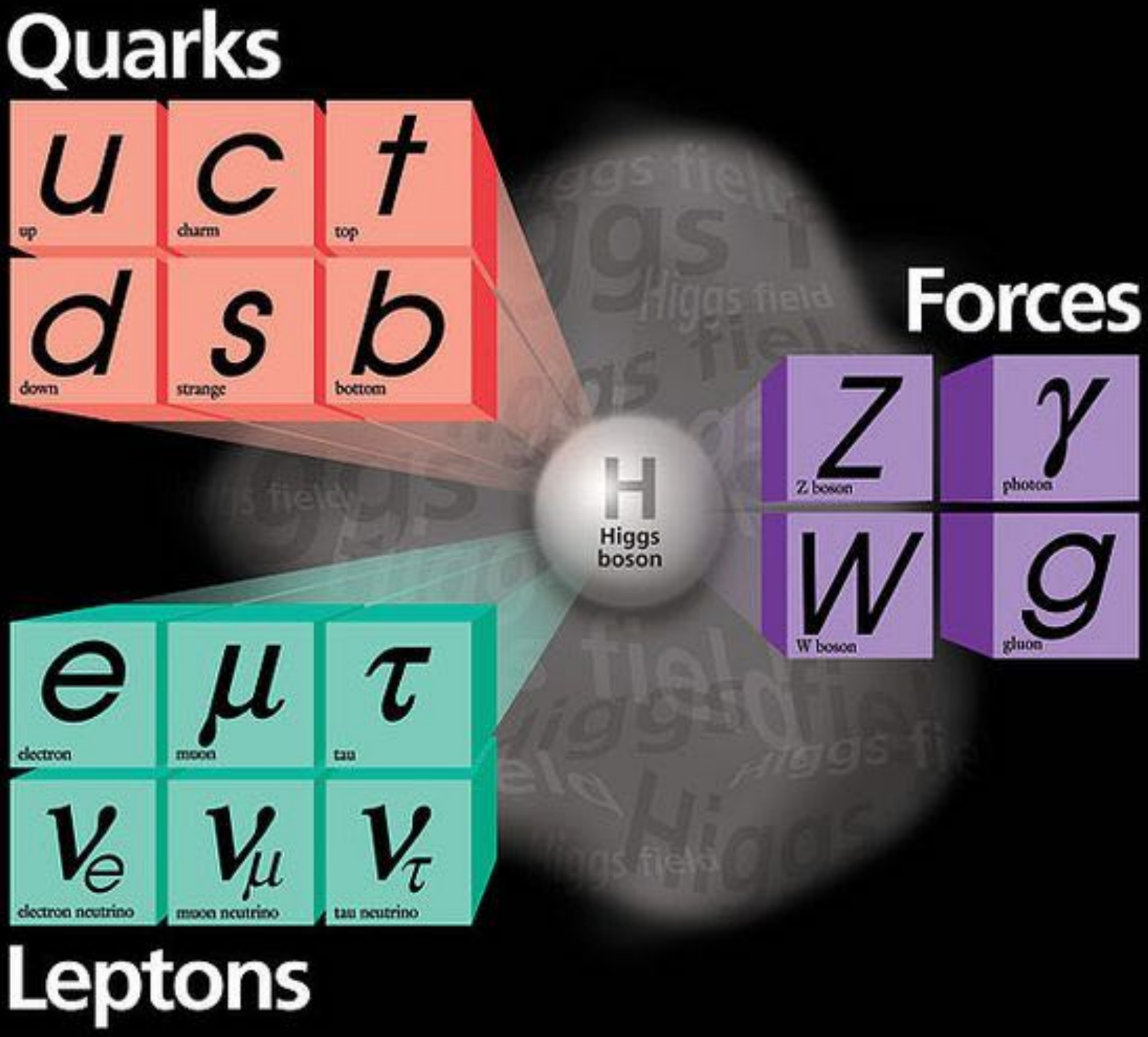

100
80
60
40
20
ΔT (μK)
$\Omega_b h^2$
0.06
0.04
0.02
W. Hu 11/00
10
100
1000
l

Evolução das densidades de energia no Modelo Padrão

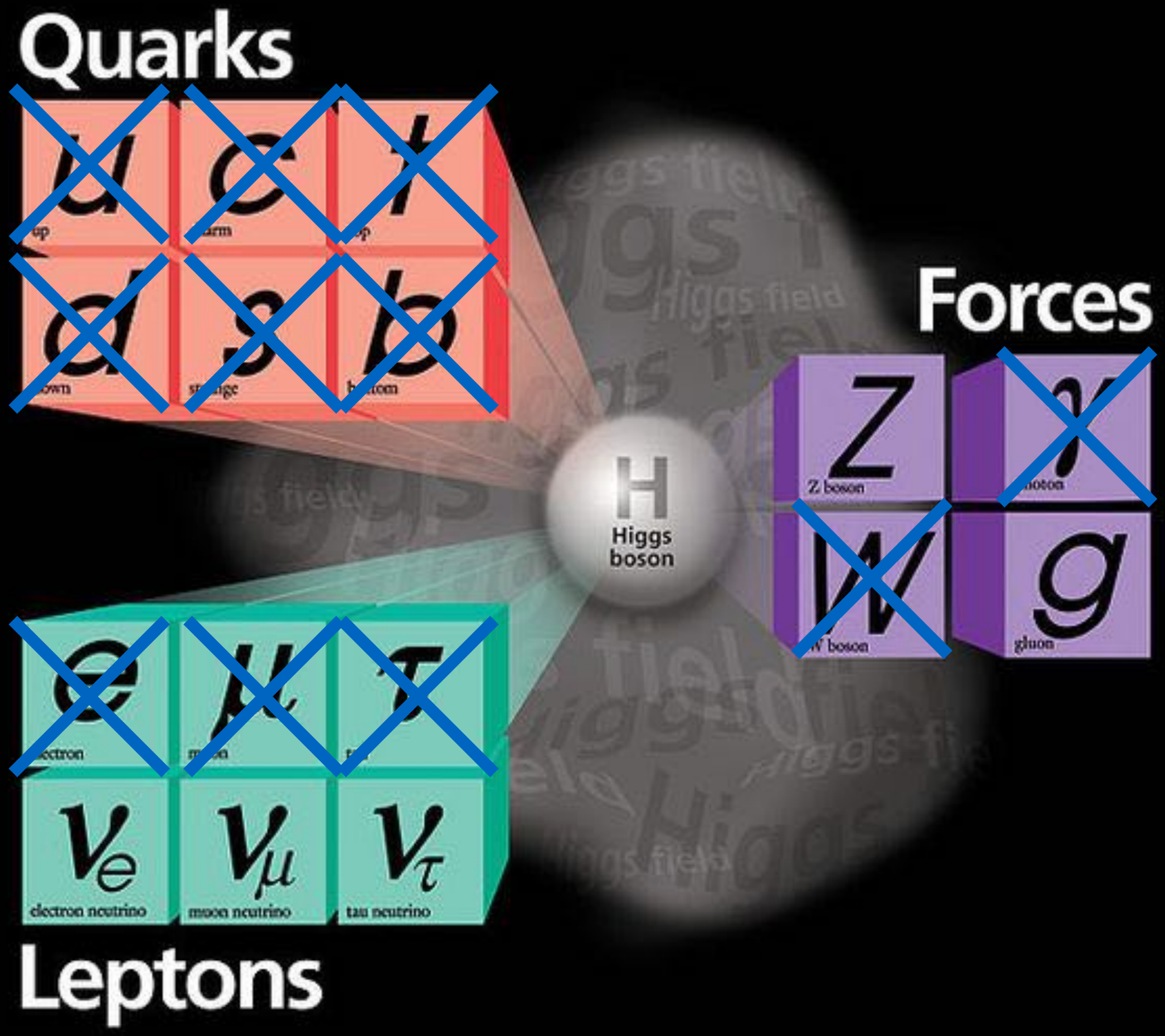


Natureza da Matéria Escura

É composta pela matéria ordinária?



Força eletromagnética



Força eletromagnética

Força forte

Quarks

Forces

Higgs boson

electron neutrino

muon neutrino

tau neutrino

Leptons

Força eletromagnética

Força forte

Instável

Quarks

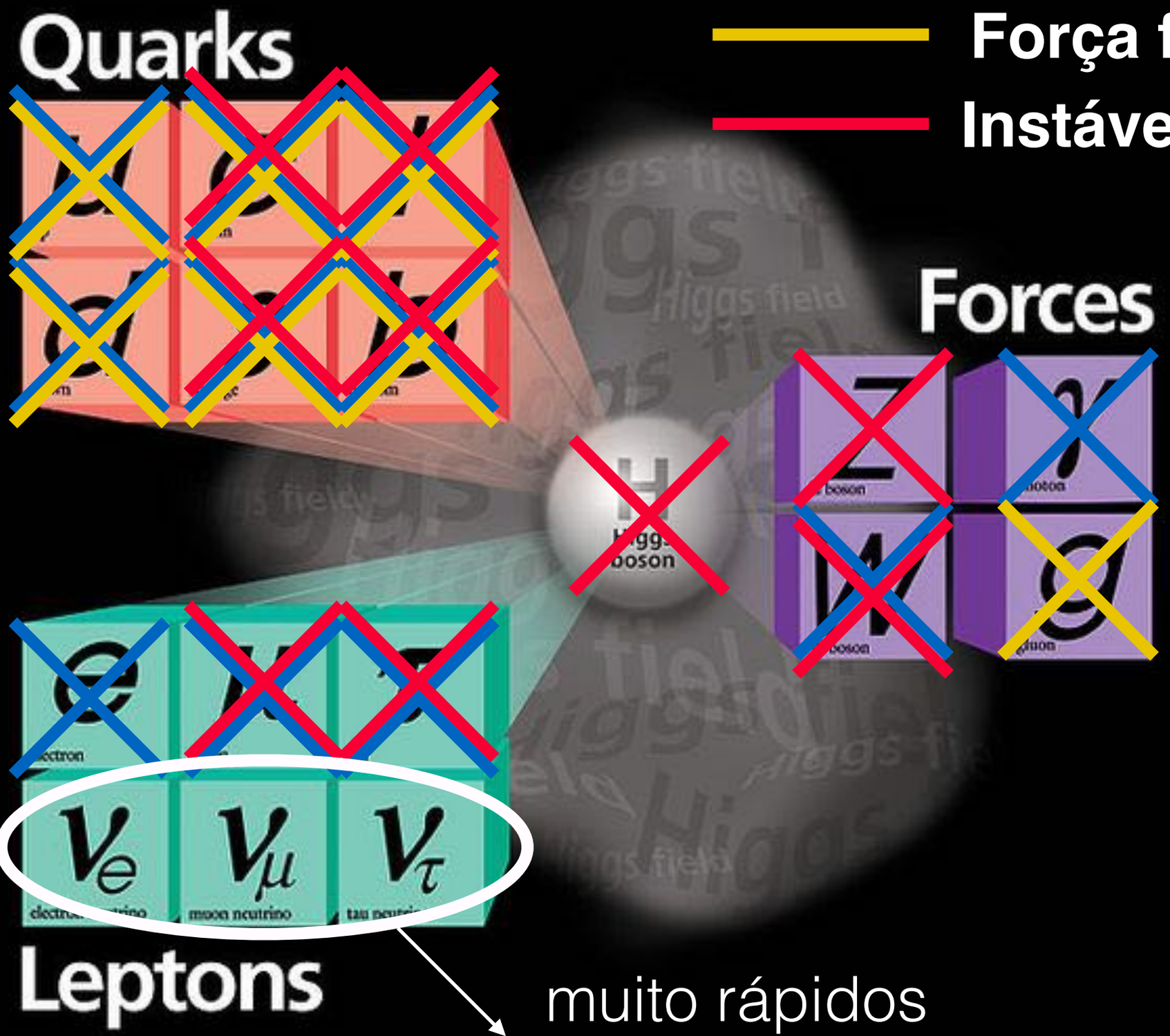
Forces

Leptons

Força eletromagnética

Força forte

Instável



Antimatéria

Neutrinos

Gás

MACHOs

“MAssive Compact Halo Objects”

Anãs marrons, anãs brancas,
estrelas de neutrôns e buracos negros.

Áxions

m_{ax} ~$2x10^{-41}$ kg
50 bilhões de áxions teriam
massa equivalente a 1 elétron

Buracos negros primordiais

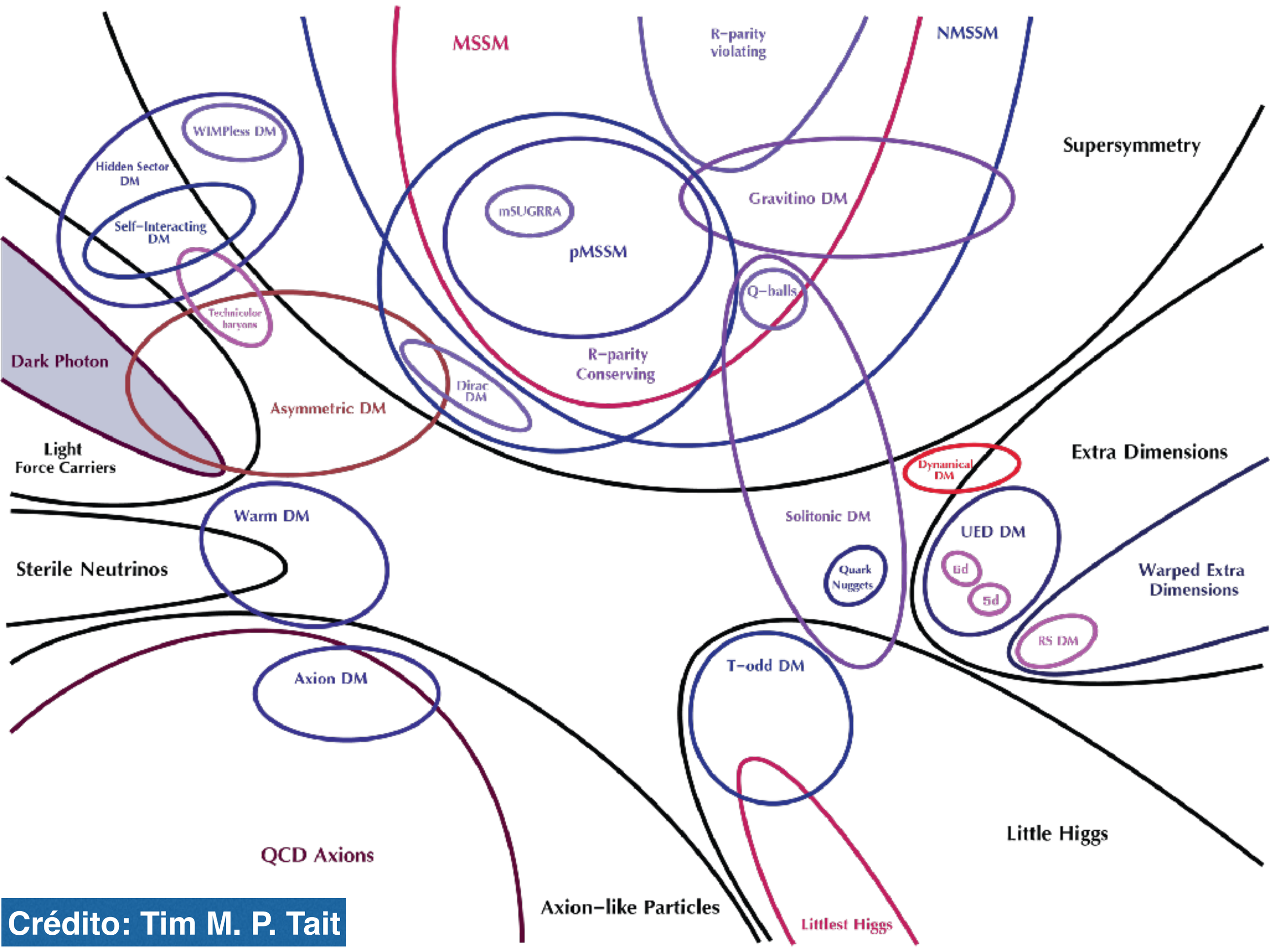
m_{ax} ~$2x10^{+35}$ kg
30 bilhões de Terras teriam
massa equivalente a 1 BH primordial

Partículas Supersimétricas

photinos, gravitinos, axinos, sneutrinos, gluinos…

WIMPs

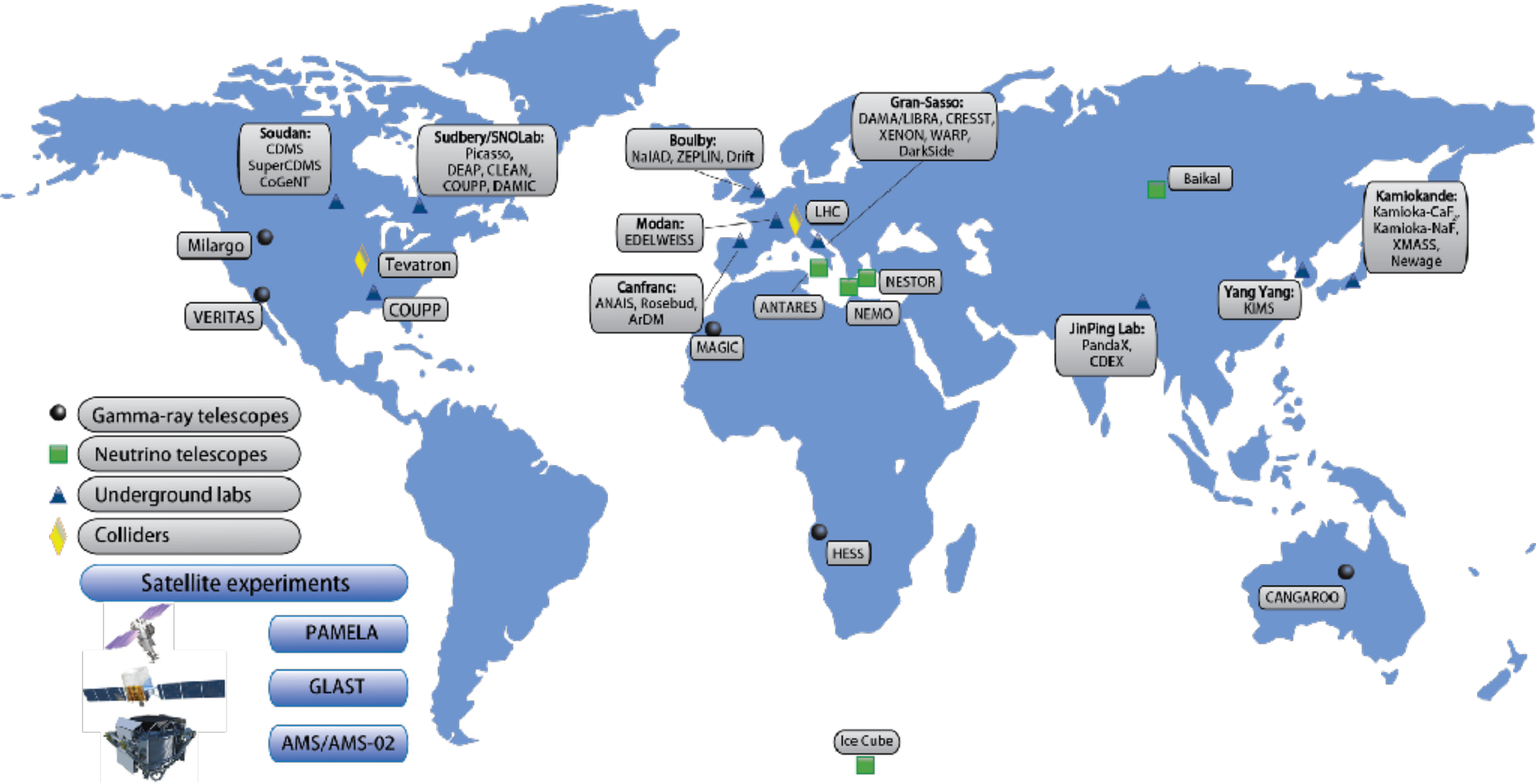
“Weakly Interacting Massive Particles”



Crédito: Tim M. P. Tait

Gravidade Escura?

Esforços para encontrar a partícula de Matéria Escura



Recent Progress in Search for Dark Sector Signatures
M.A. Deliyergiyev. Open Phys. 14 (2016) no.1, 281-303

Cryogenic Dark Matter Search

Large Hadron Collider

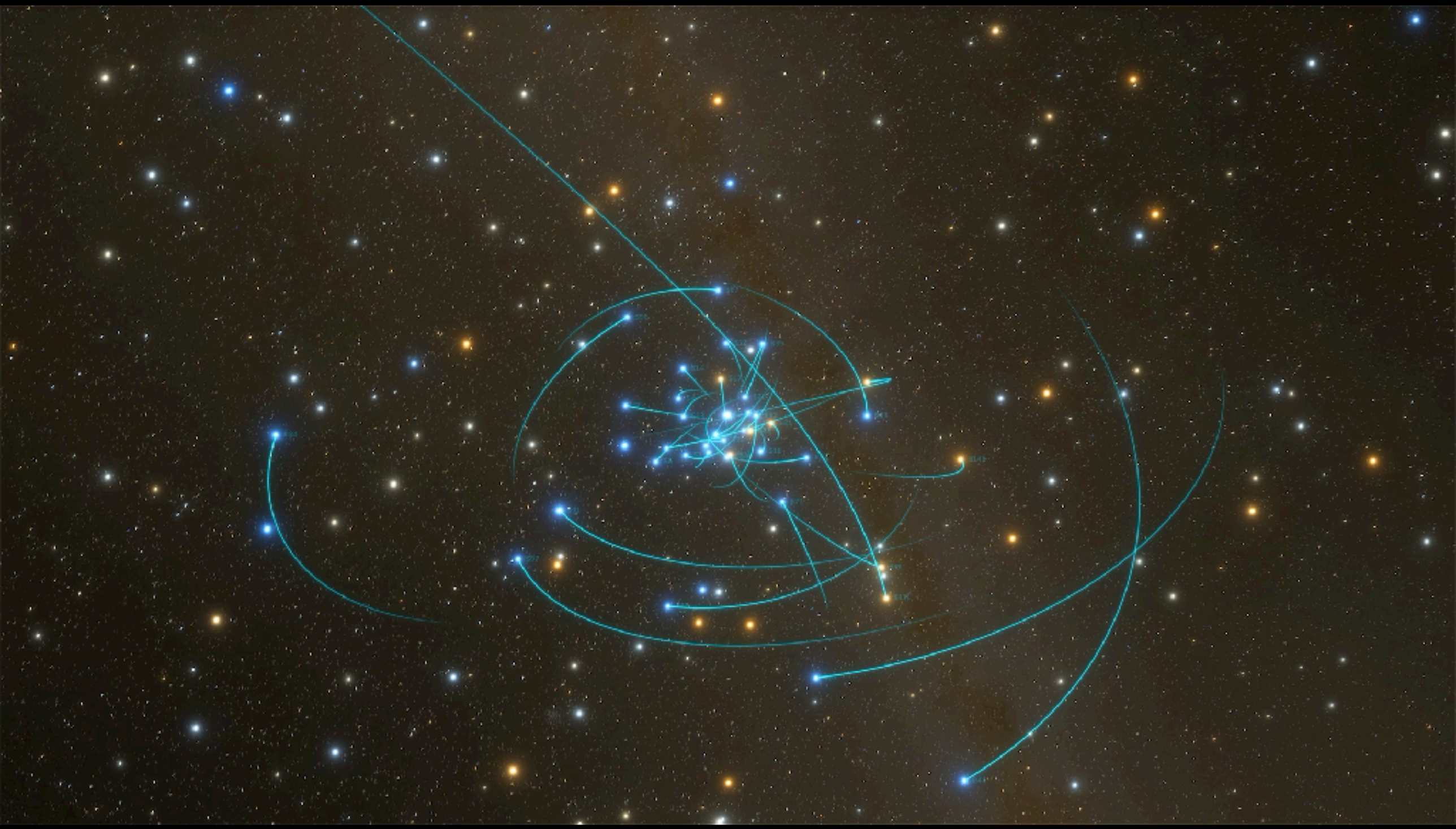
FermiLab
CoGeNT / XENON / DAMA/LIBRA

NASA's Fermi gamma-ray Satellite

Gamma Ray Large Array Space Telescope

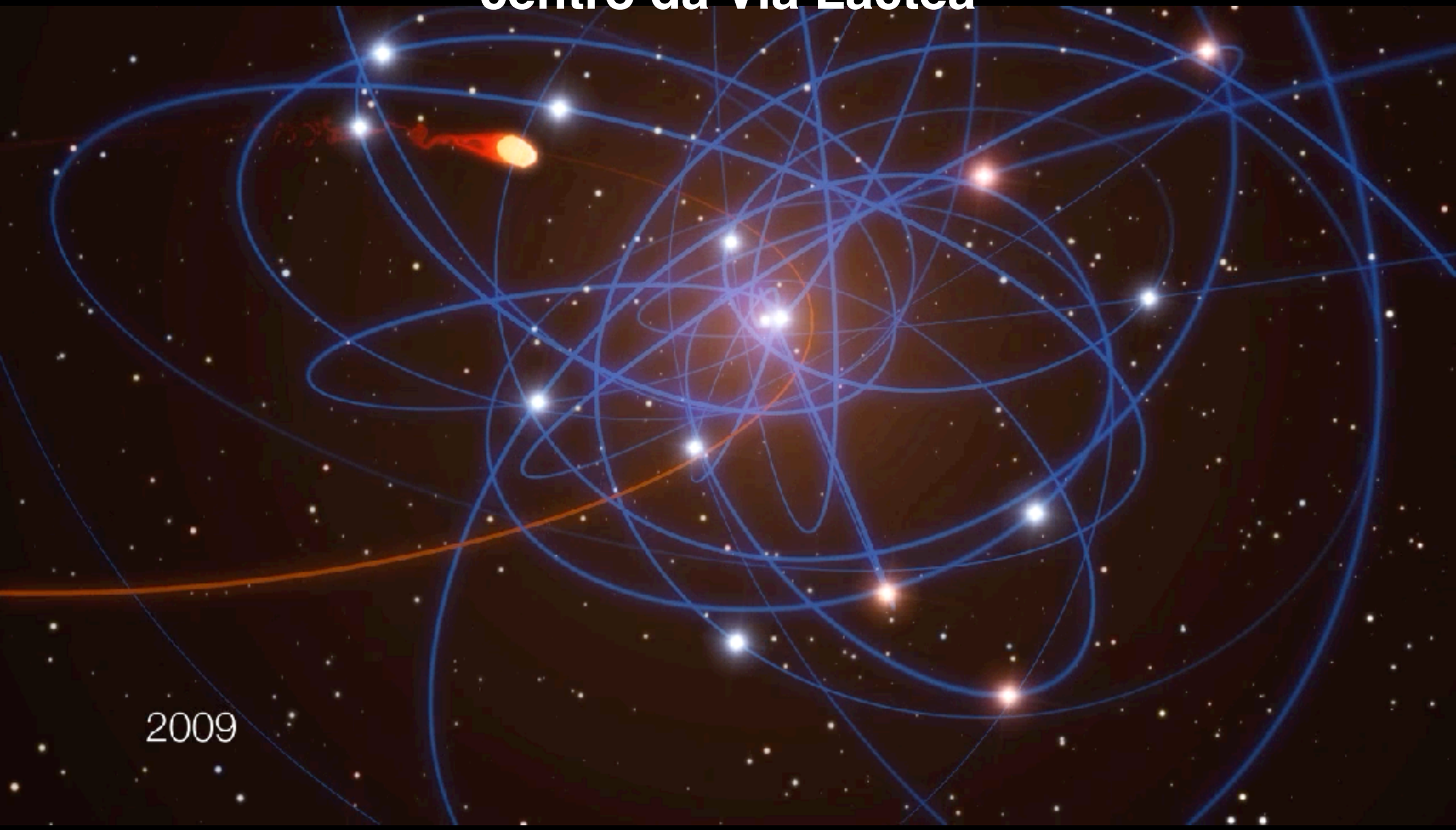
LZ Dark Matter Experiment

(...)

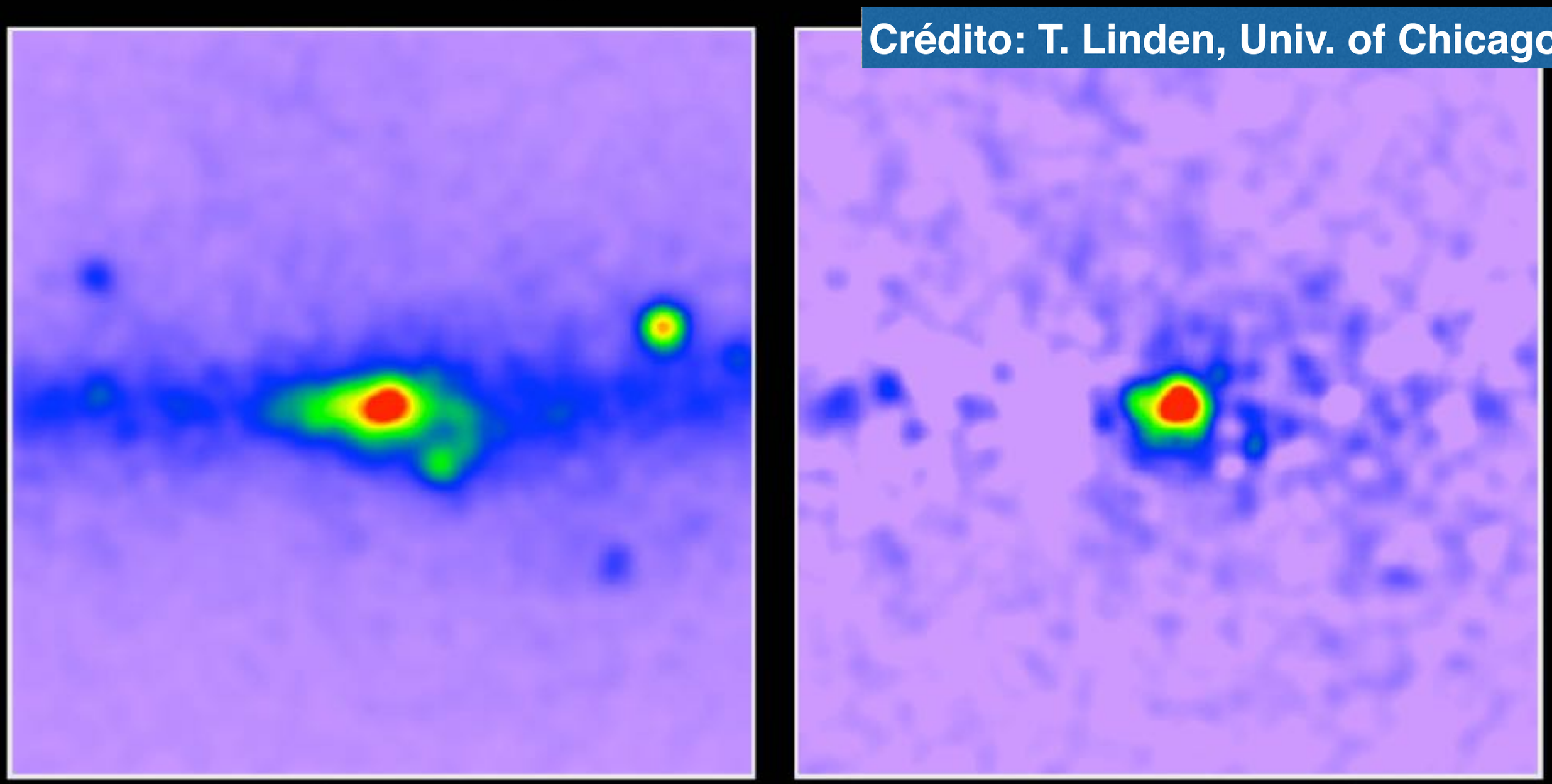


Crédito: ESO/GRAVITY Collaboration

Comportamento de estrelas próximas ao buraco negro no centro da Via Láctea



Crédito: ESO/MPE/M. Schartmann/L. Calçada



Mapa de raios gama detectados no centro galáctico pelo LAT/Fermi. À direita, raios gama após remoção de fontes conhecidas, podendo ter como fonte a aniquilação de matéria escura.

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Salvador, 04.09.2018

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