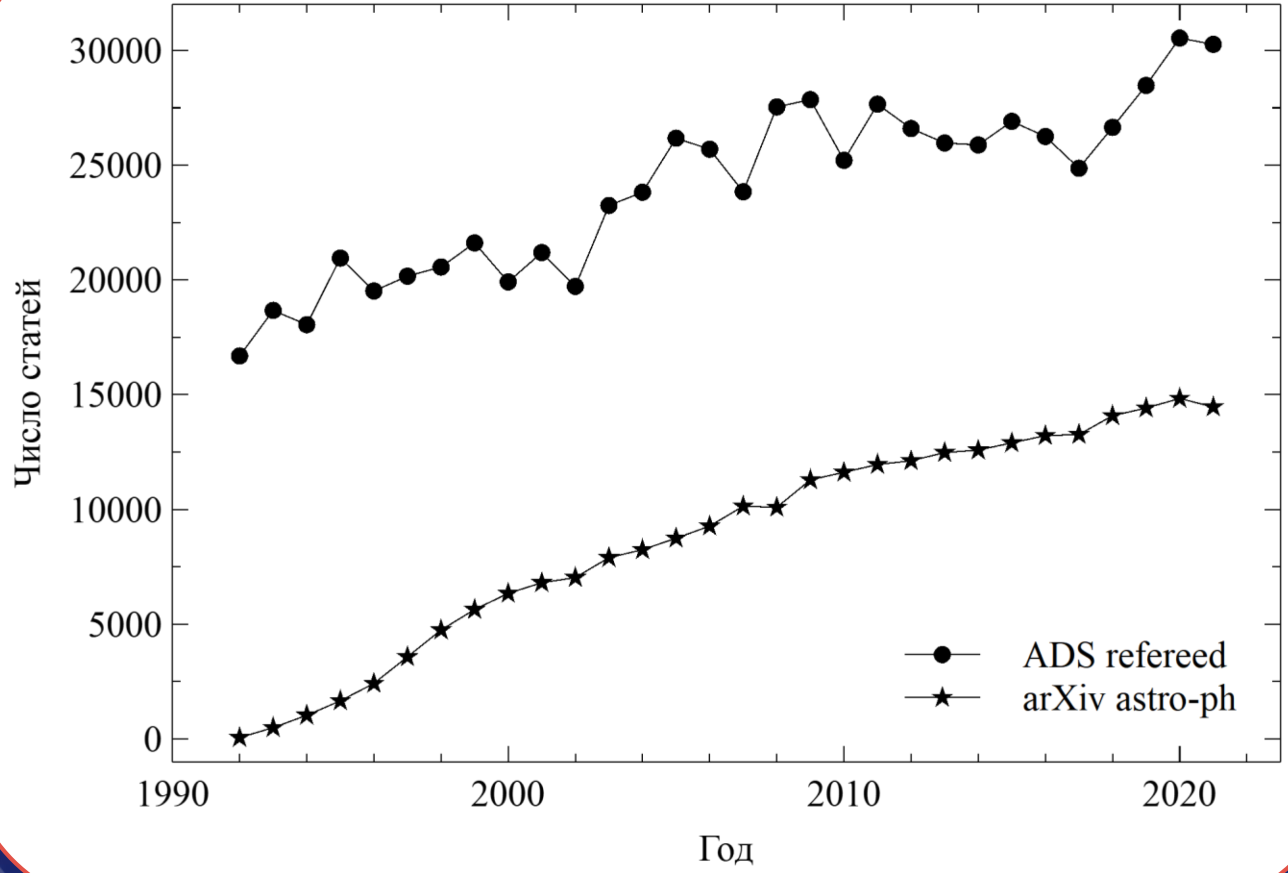
СОВРЕМЕННАЯ АСТРОФИЗИЧЕСКАЯ КАРТИНА МИРА

(ЛЕКЦИЯ 1. ВВЕДЕНИЕ В АСТРОФИЗИКУ. ВЕСНА 2022. ВШЭ)

АНТОН БИРЮКОВ, К.Ф.-М.Н.

АСТРОФИЗИКА И АСТРОФИЗИКИ



Cornell University

arXiv.org > astro-ph

Astrophysics

https://arxiv.org/list/astro-ph/new

astrophysics data system

https://ui.adsabs.harvard.edu/

Только ~60 тыс. из ~340 тыс. реферируемых работ по астрономии/астрофизике, опубликованные за последние 10 лет ни разу не цитировались.

ИСТОРИЯ ВСЕЛЕННОЙ

масштабный фактор

$$ds^2 = c^2dt^2 - a^2(t)dl^2$$

$$dl^2 = \frac{dr^2}{1-kr^2} + r^2(d\theta^2 + \sin^2\theta d\phi^2)$$

Метрика Фридмана-Робертсона-Уокера (FRW)

$$\left(\frac{\dot{a}}{a}\right)^2 + k\left(\frac{c}{a}\right)^2 = \frac{8\pi}{3}G\rho + \frac{\Lambda}{3}c^2$$

Уравнение Фридмана

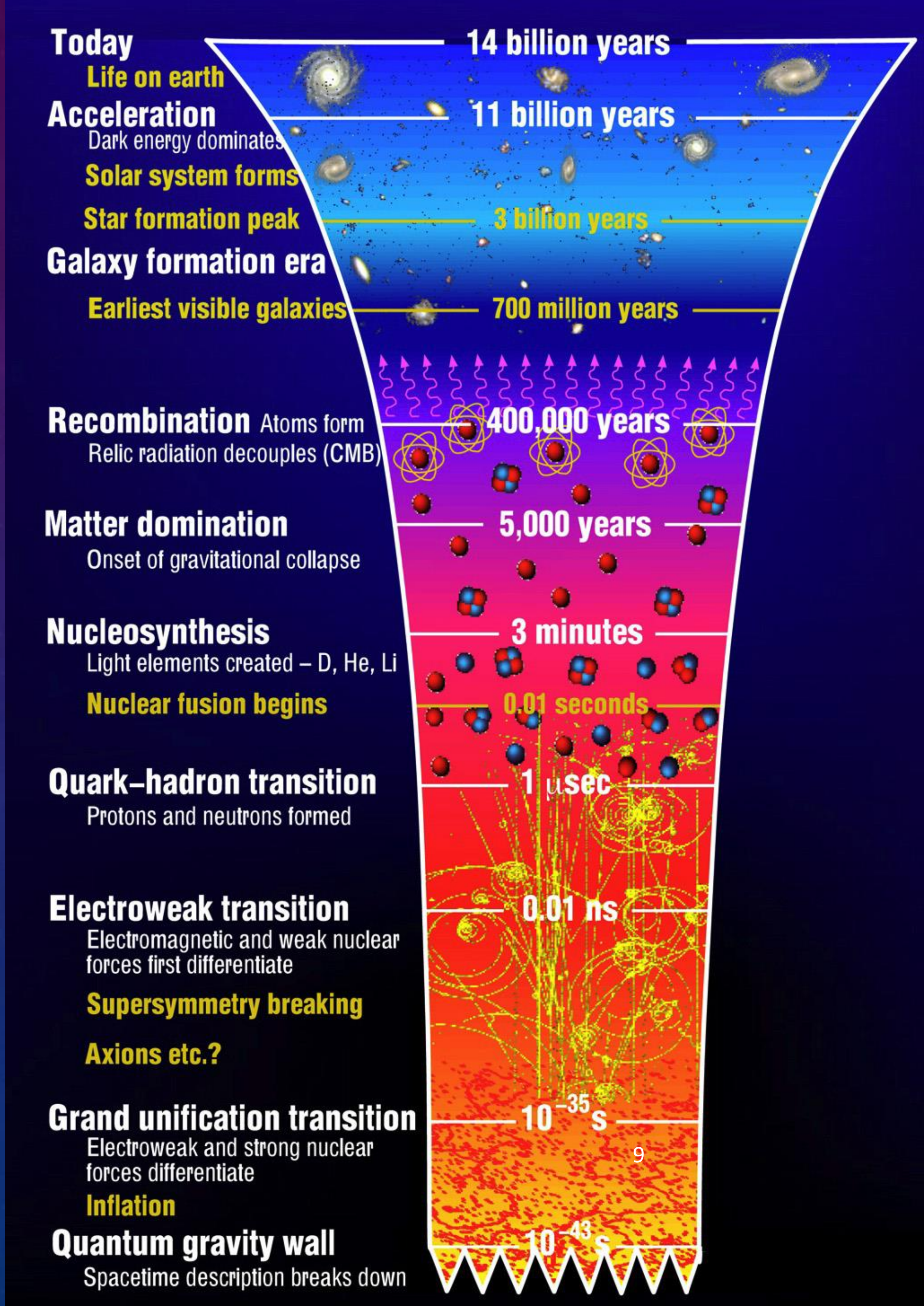
$$\rho_c = \frac{3H^2}{8\pi G} \approx 2\cdot 10^{-29}h^2 \text{ г см}^{-3}$$

Критическая плотность

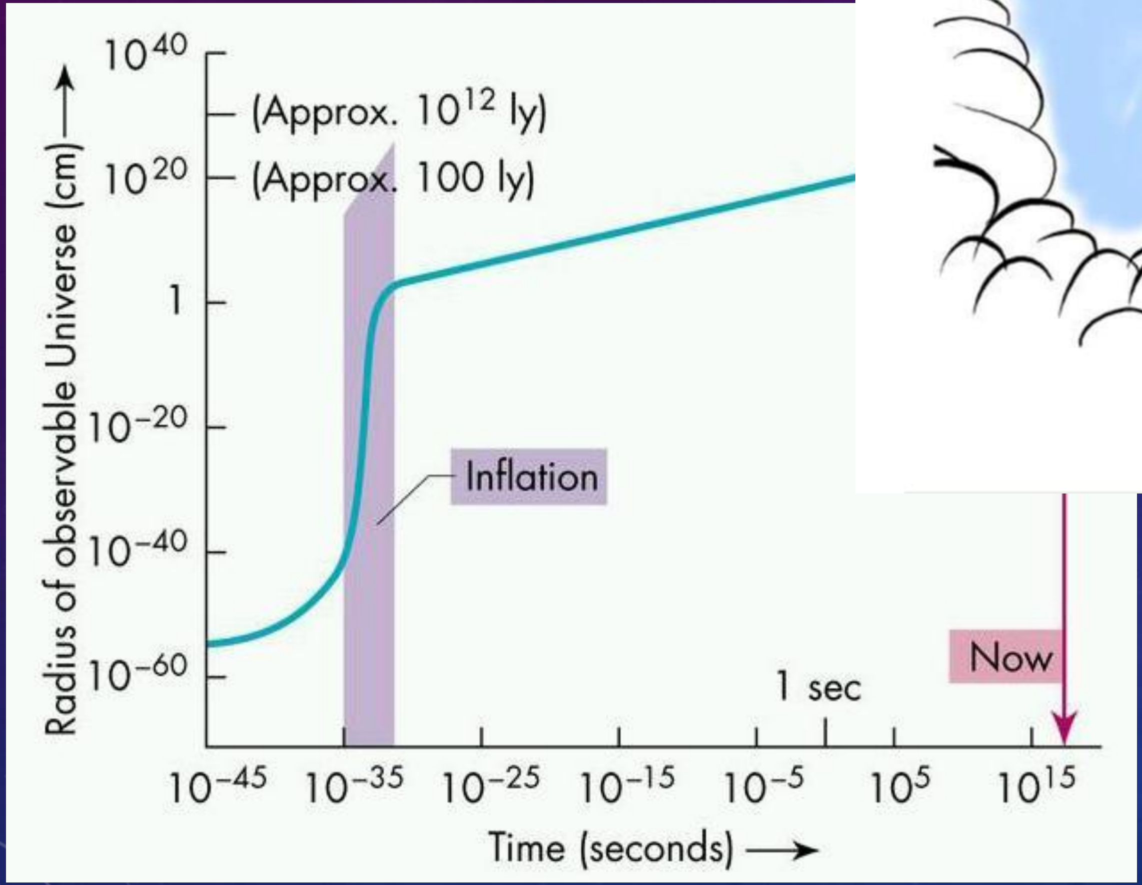
$$\tau = -\frac{1}{H_0}\int_0^\infty \frac{dz}{\sqrt{\Omega_m(1+z)^5 + \Omega_c(1+z)^3 + \Omega_\Lambda(1+z)^2}}$$

Возраст Вселенной

http://www.ctc.cam.ac.uk/outreach/origins/big_bang_three.php



ВСЕЛЕННАЯ



4. $\tau = 13.7 \cdot 10^9$ лет

5. $D = 92 \cdot 10^9$ св. лет

$6 \cdot 10^{-35}\, m.$

$5 \cdot 10^{-44}\, c.$

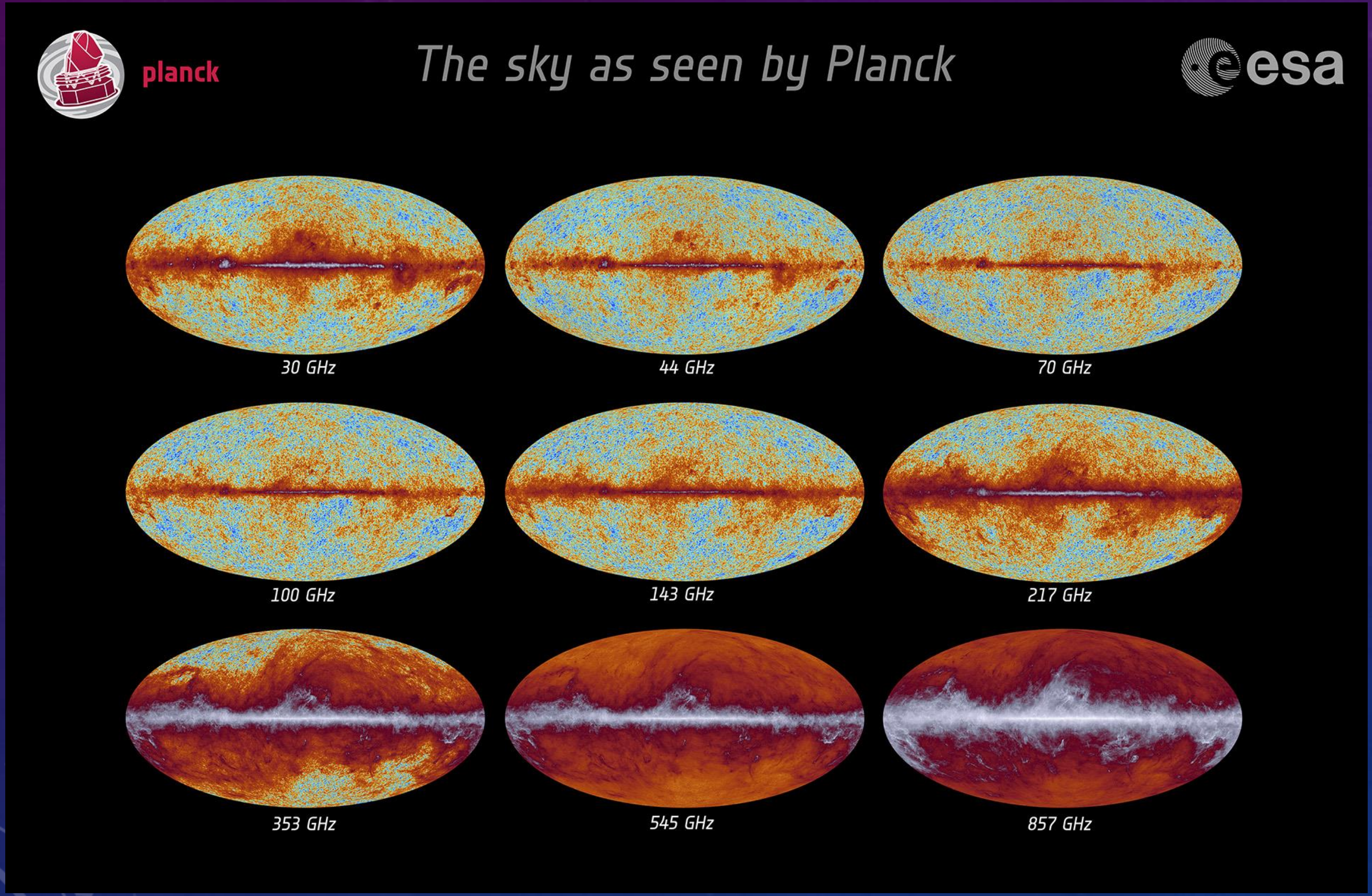
$2 \cdot 10^{-8}$ кг.

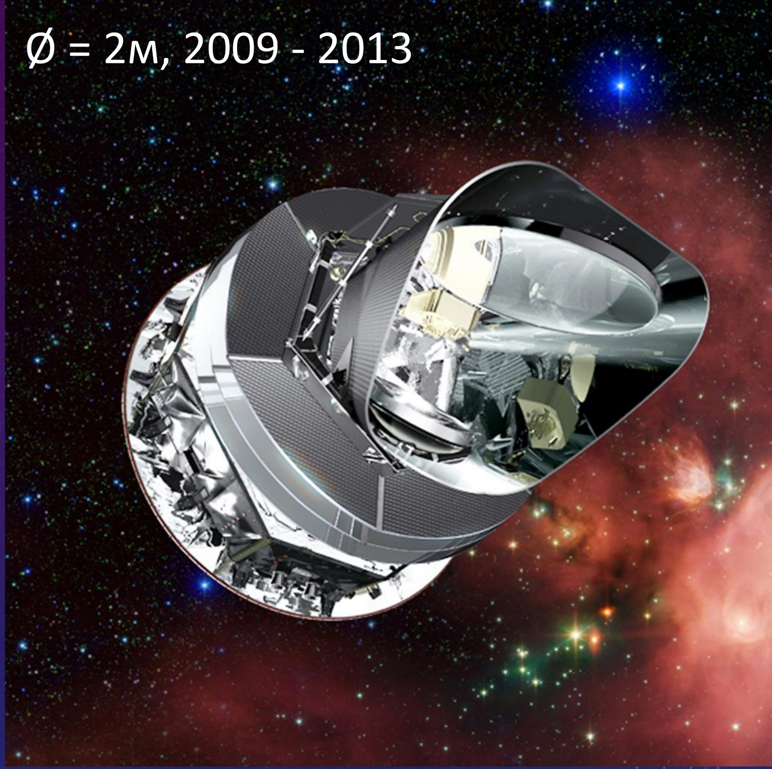
$E_п = m_p \cdot c^2 \approx 10^{19}$ ГэВ.

$T_п = \dfrac{m_\pi c^2}{k} \approx 1{,}4 \cdot 10^{32}$ K.

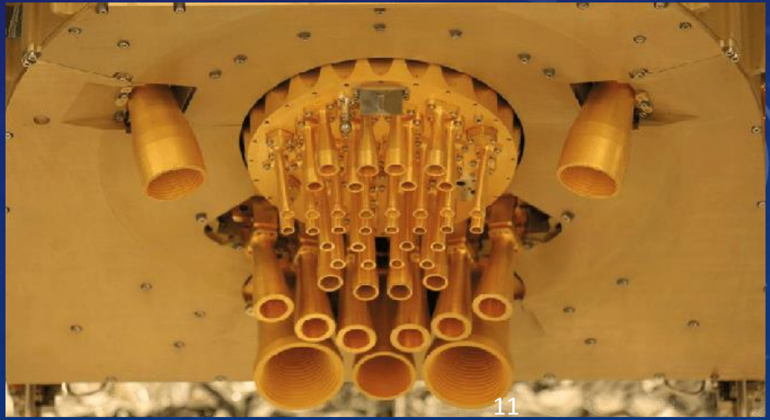
Планковские величины

PLANCK



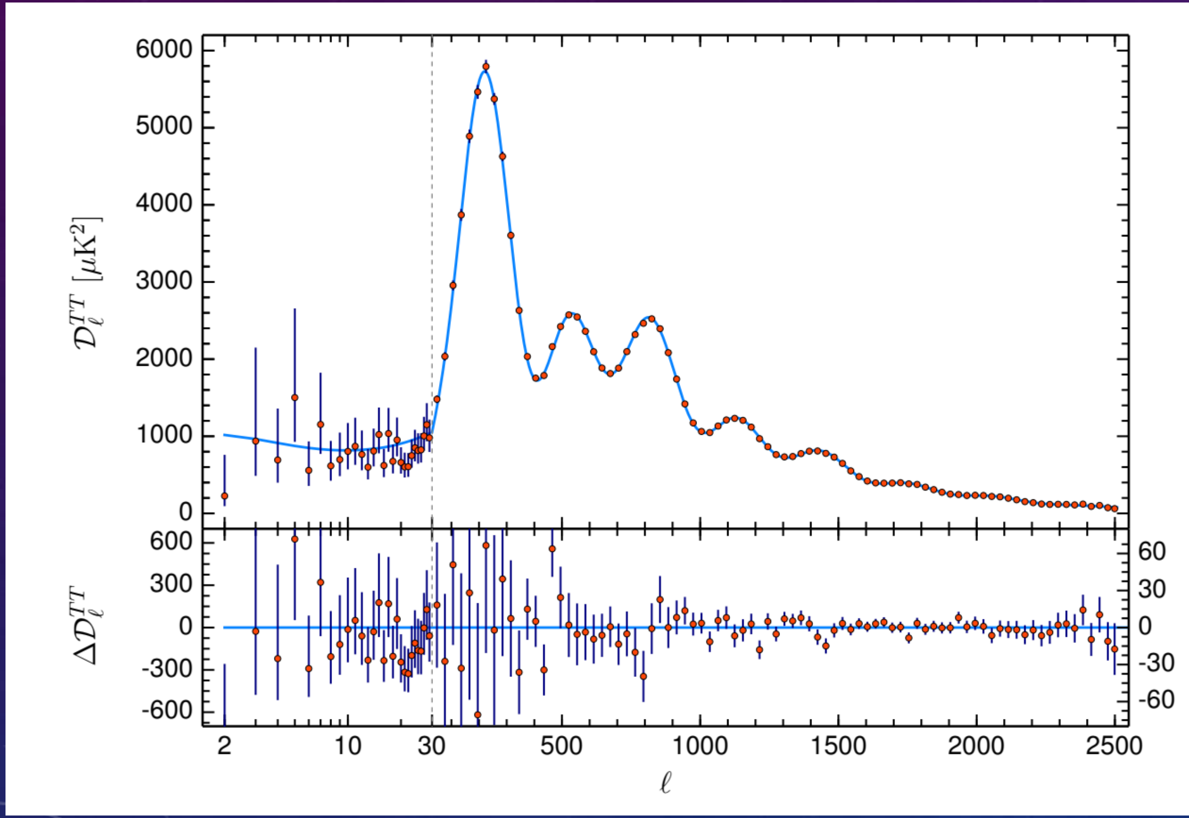


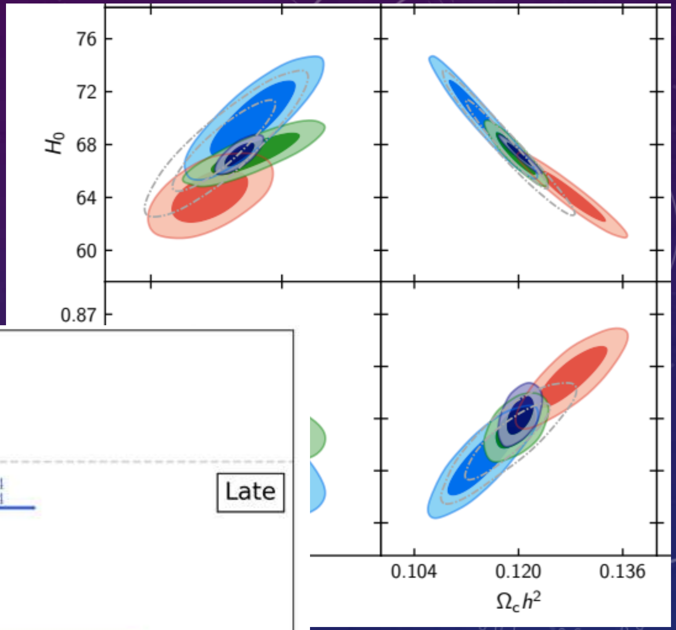
https://www.nasa.gov/mission_pages/planck/

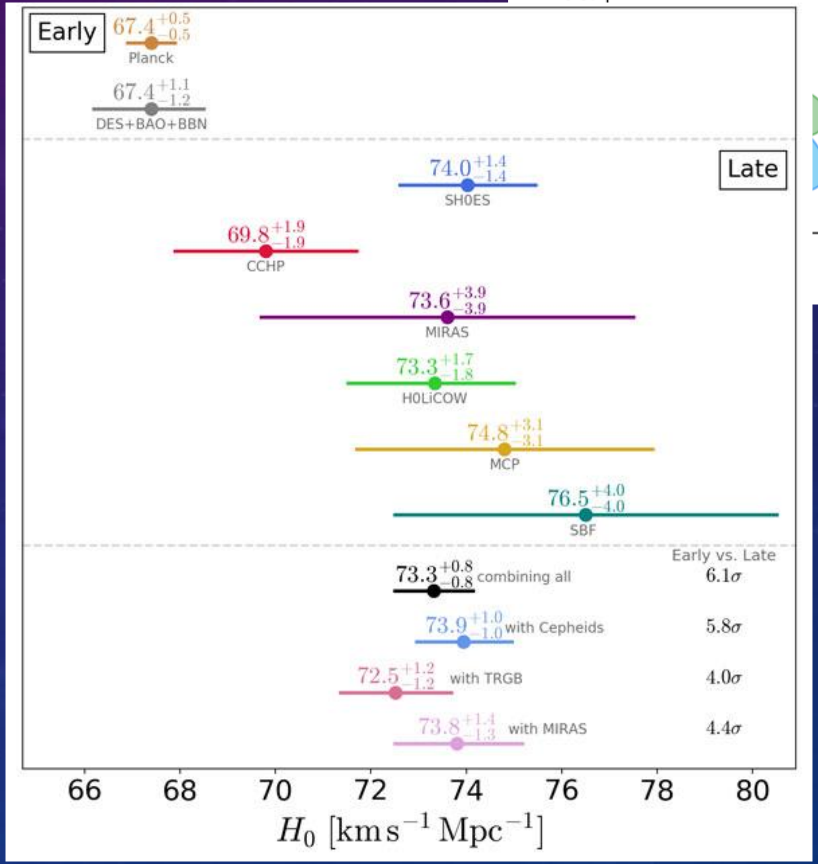


Tauber et al. 2010, A&A, 520, A2

РЕЛИКТОВЫЙ ФОН

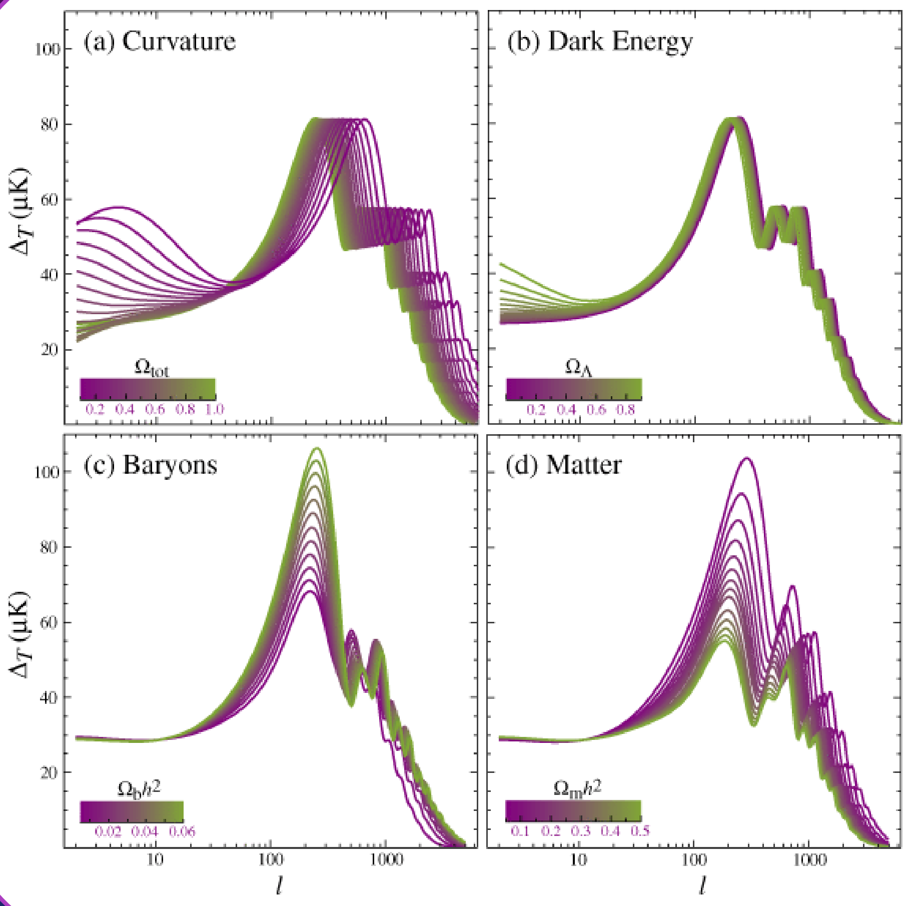


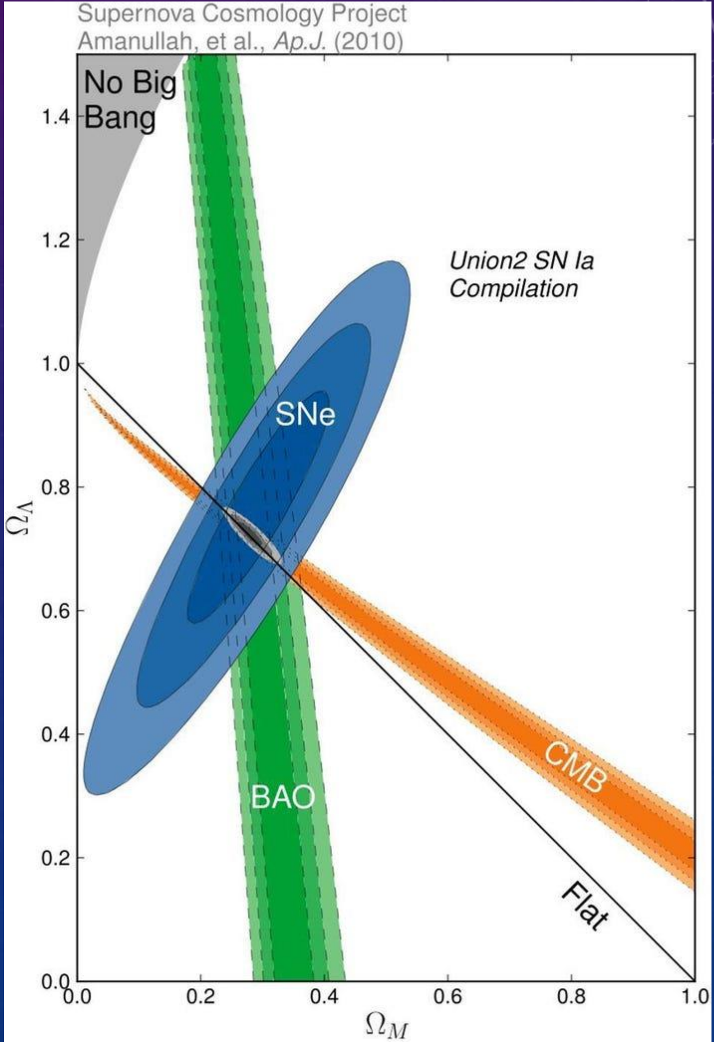




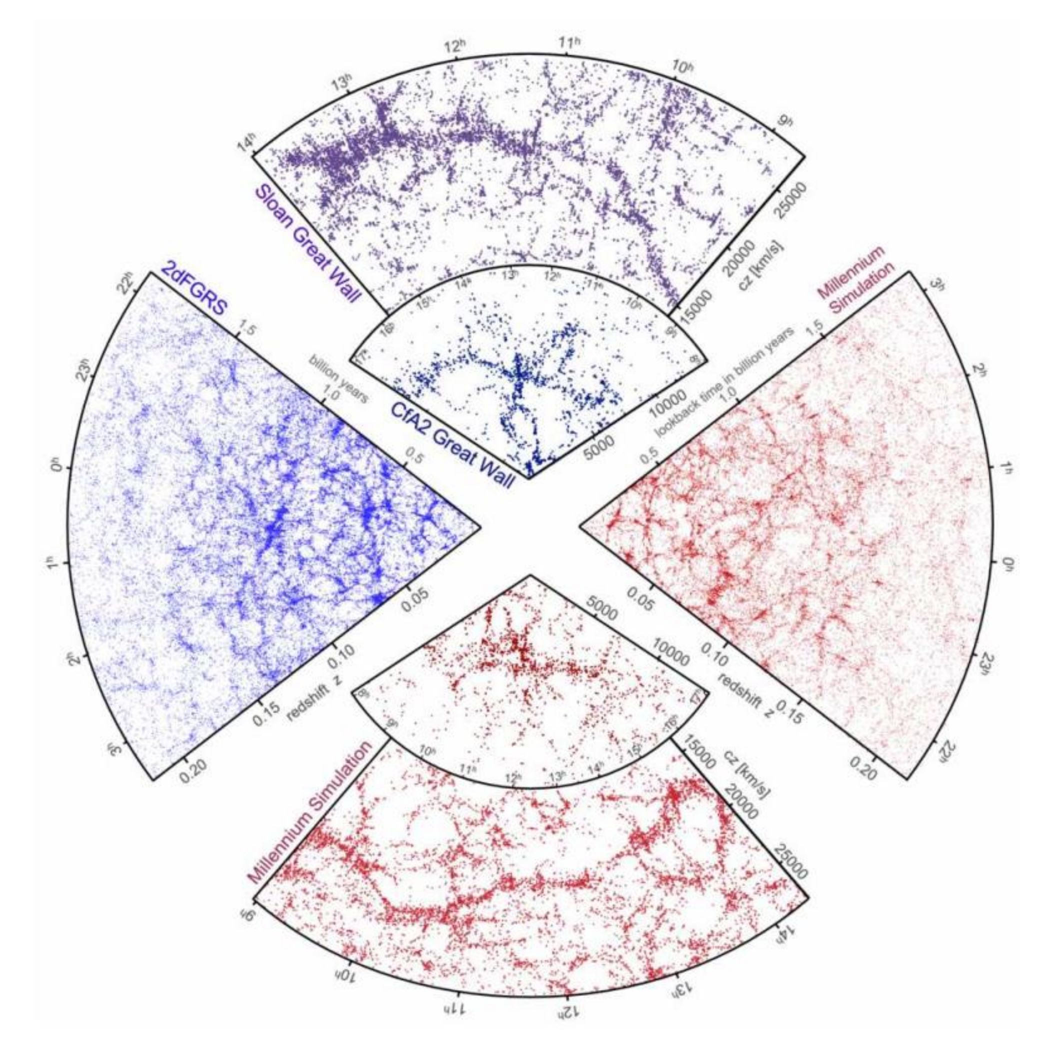
РЕЛИКТОВЫЙ ФОН

Parameter	TT+lowE 68% limits	TE+lowE 68% limits	EE+lowE 68% limits	TT,TE,EE+lowE 68% limits	TT,TE,EE+lowE+lensing 68% limits	TT,TE,EE+lowE+lensing+BAO 68% limits
$\Omega_b h^2$	0.02212 ± 0.00022	0.02249 ± 0.00025	0.0240 ± 0.0012	0.02236 ± 0.00015	0.02237 ± 0.00015	0.02242 ± 0.00014
$\Omega_c h^2$	0.1206 ± 0.0021	0.1177 ± 0.0020	0.1158 ± 0.0046	0.1202 ± 0.0014	0.1200 ± 0.0012	0.11933 ± 0.00091
$100\theta_{MC}$	1.04077 ± 0.00047	1.04139 ± 0.00049	1.03999 ± 0.00089	1.04090 ± 0.00031	1.04092 ± 0.00031	1.04101 ± 0.00029
τ	0.0522 ± 0.0080	0.0496 ± 0.0085	0.0527 ± 0.0090	$0.0544^{+0.0070}_{-0.0081}$	0.0544 ± 0.0073	0.0561 ± 0.0071
$\ln(10^{10} A_s)$	3.040 ± 0.016	$3.018^{+0.020}_{-0.018}$	3.052 ± 0.022	3.045 ± 0.016	3.044 ± 0.014	3.047 ± 0.014
n_s	0.9626 ± 0.0057	0.967 ± 0.011	0.980 ± 0.015	0.9649 ± 0.0044	0.9649 ± 0.0042	0.9665 ± 0.0038

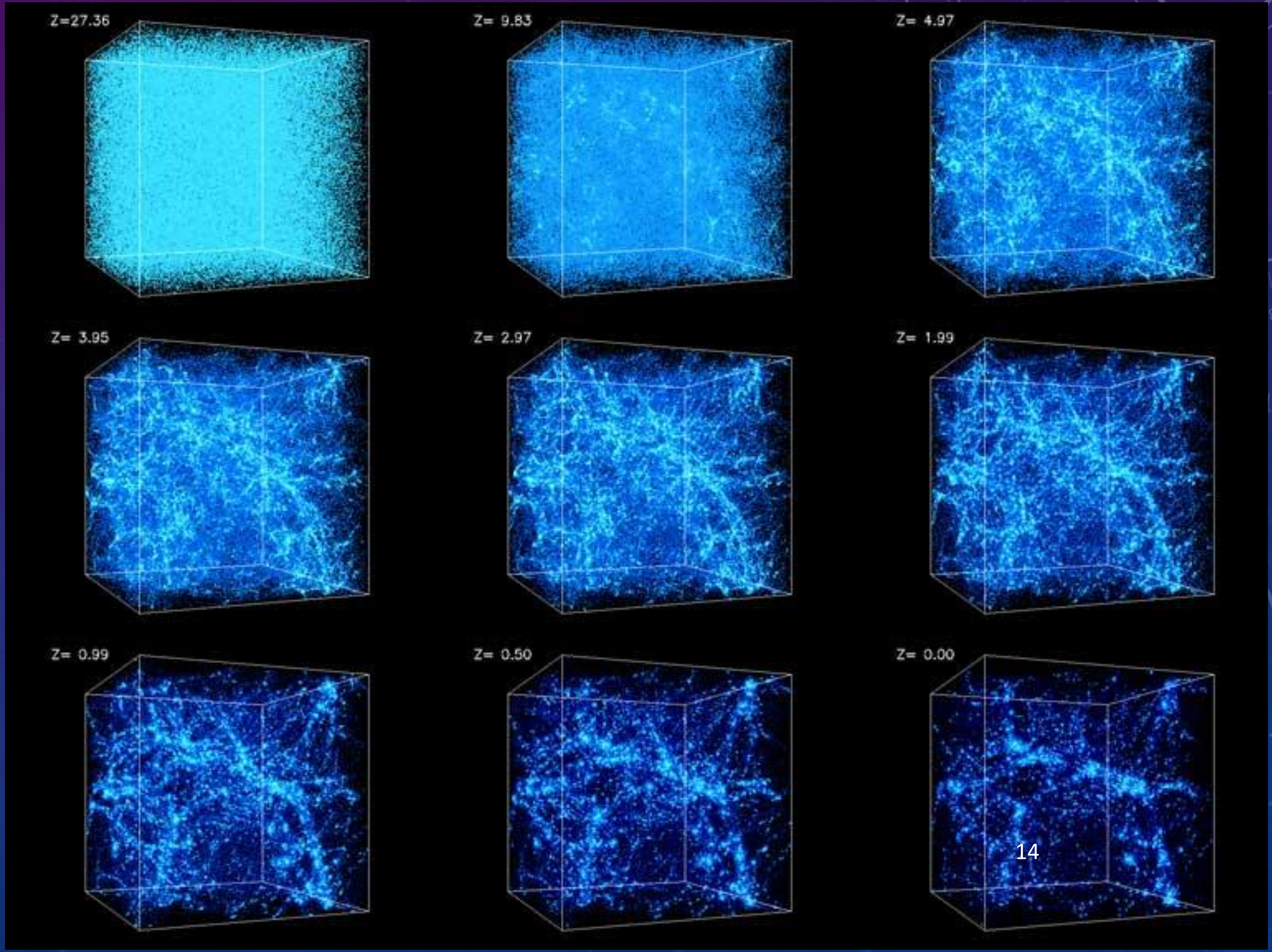




КРУПНОМАСШТАБНАЯ СТРУКТУРА

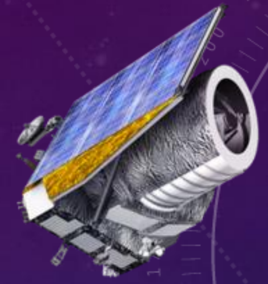


arXiv:astro-ph/0604561



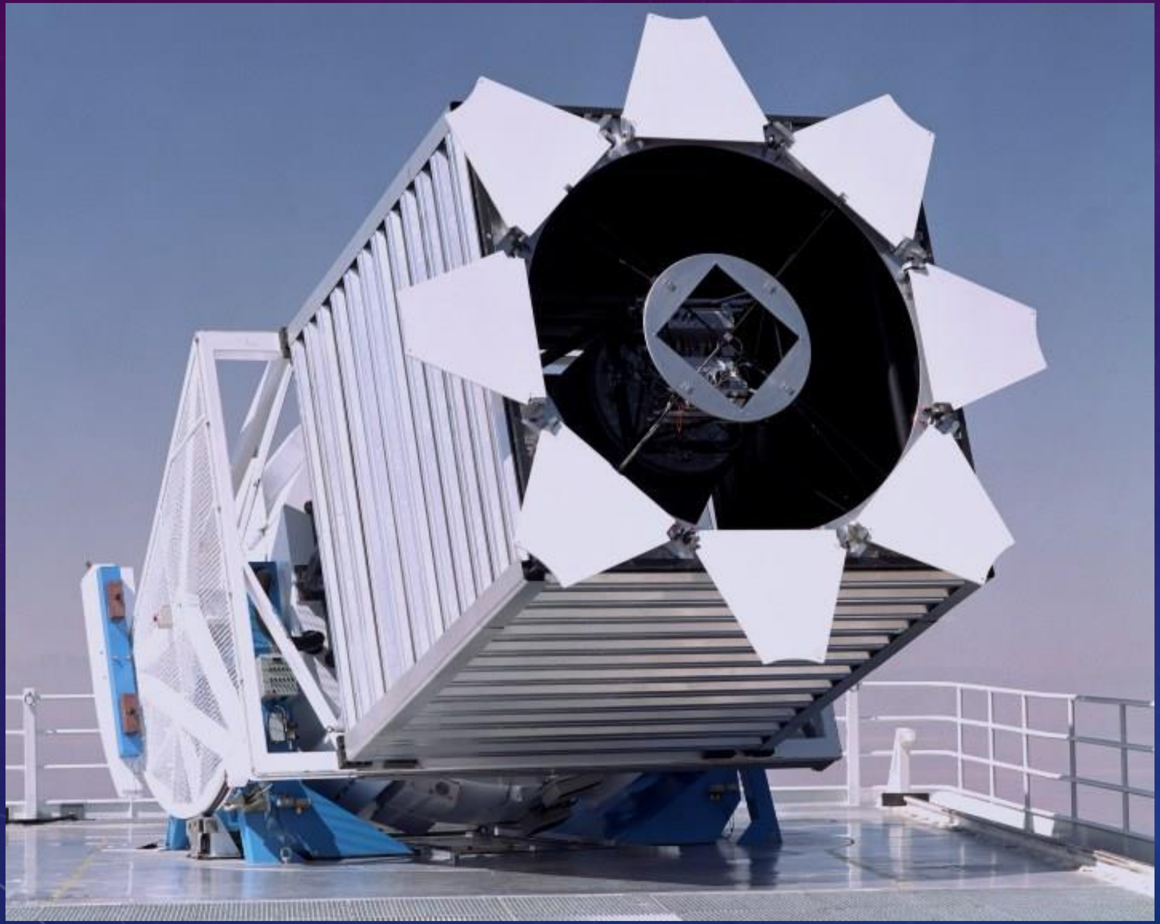
A. Kravtsov / http://cosmicweb.uchicago.edu/filaments.html

ОБЗОРЫ

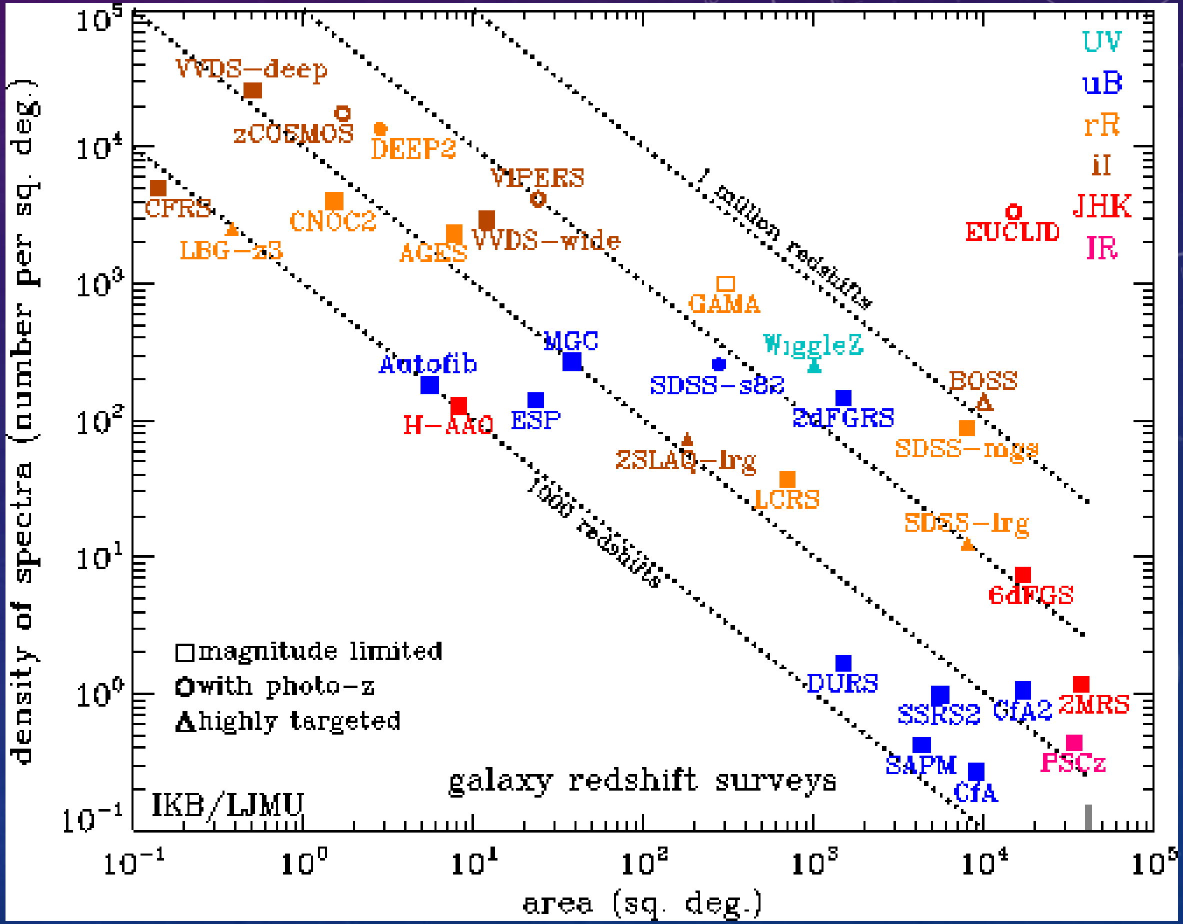


Euclid (ESA)

Старт: октябрь 2022?

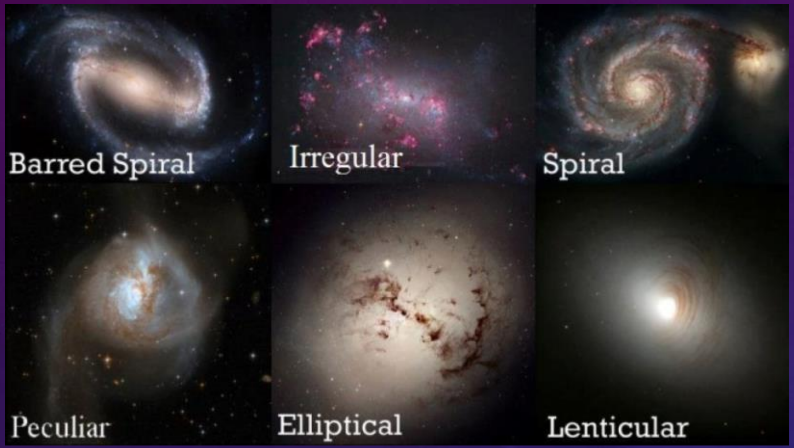


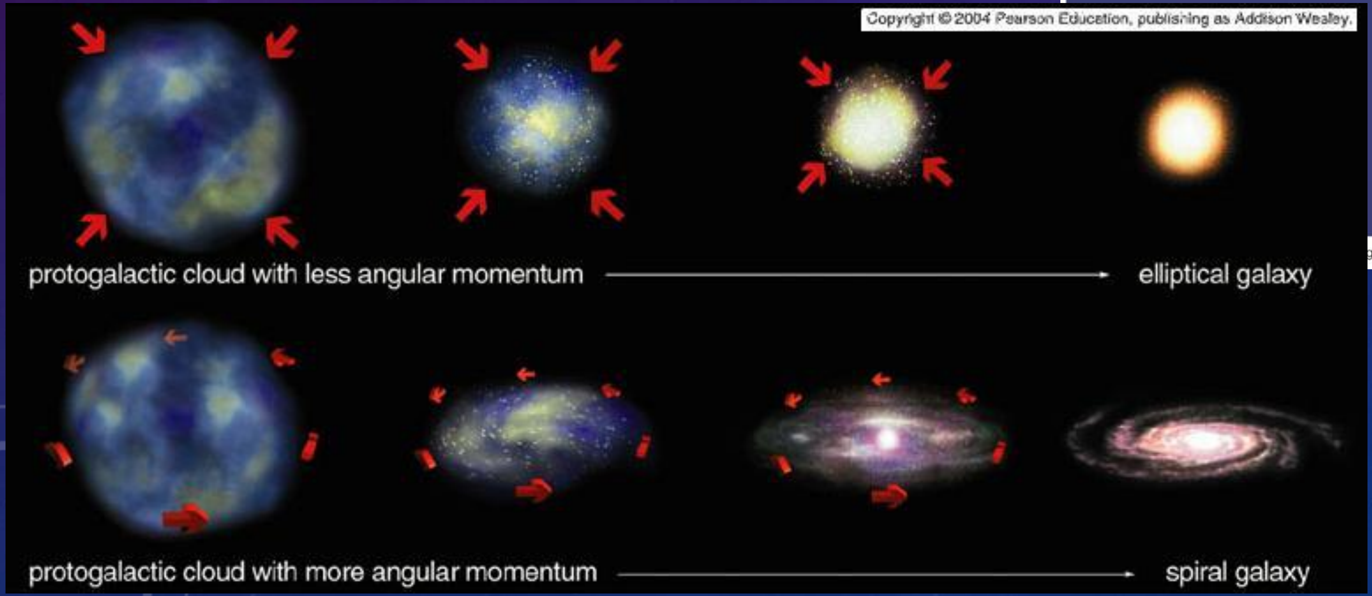
sdss.org

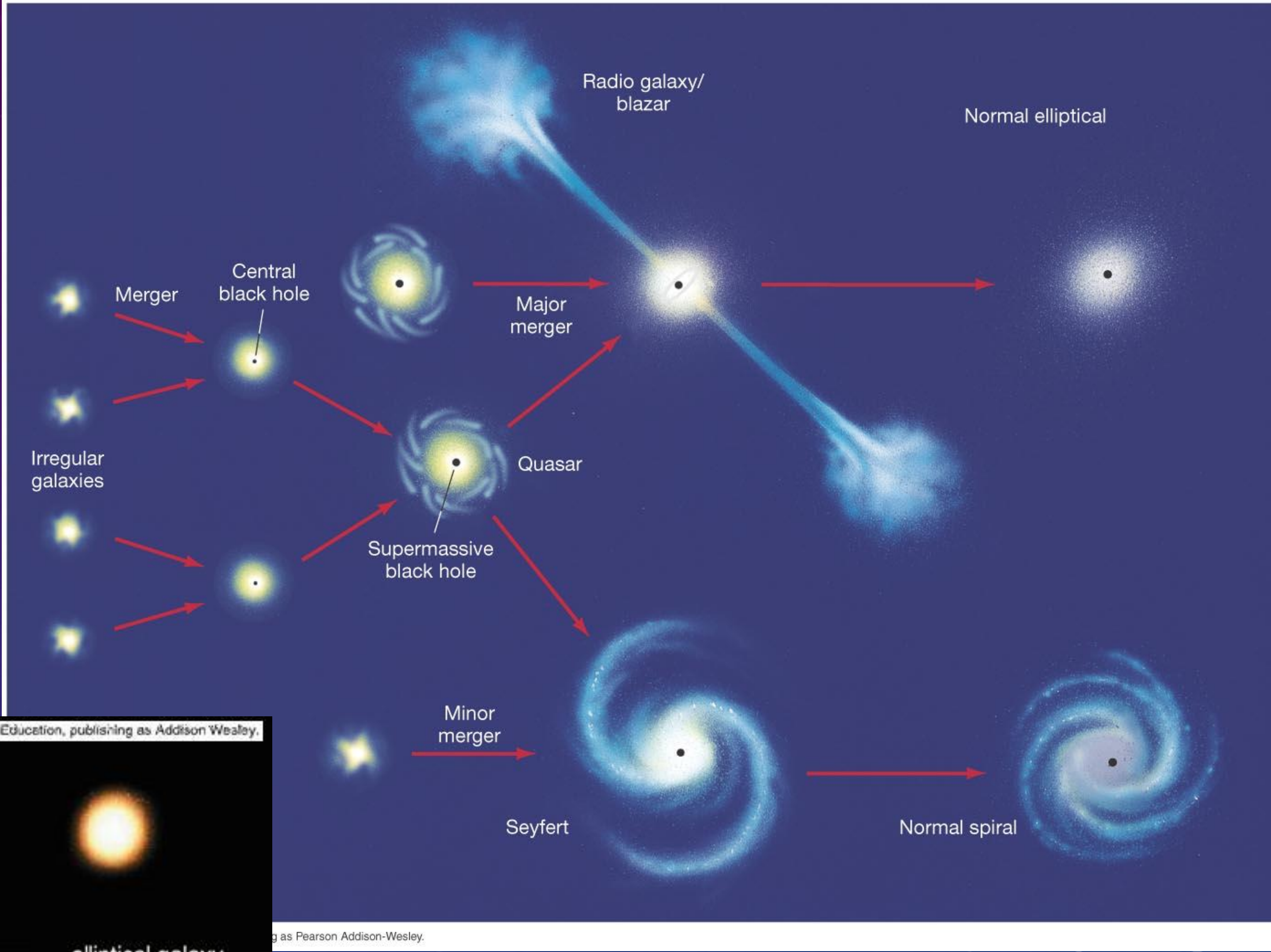


https://www.astro.ljmu.ac.uk/~ikb/research/galaxy-redshift-surveys.html

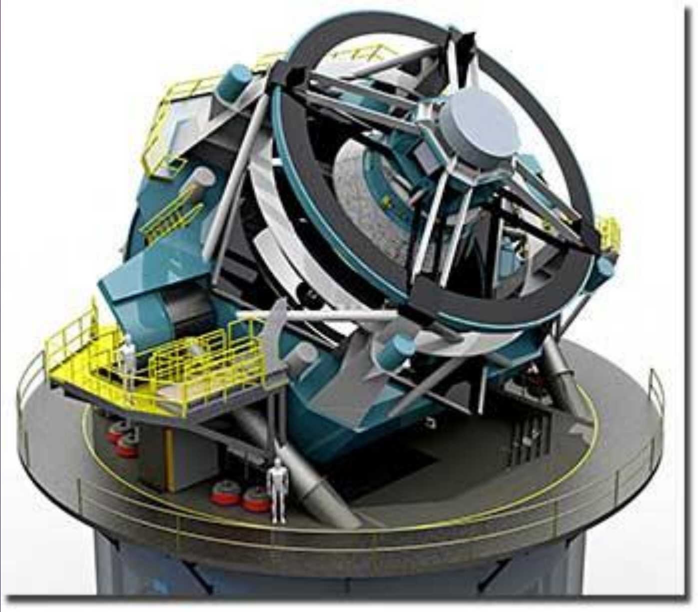
ЭВОЛЮЦИЯ ГАЛАКТИК







SYNOPTIC SURVEY TELESCOPE

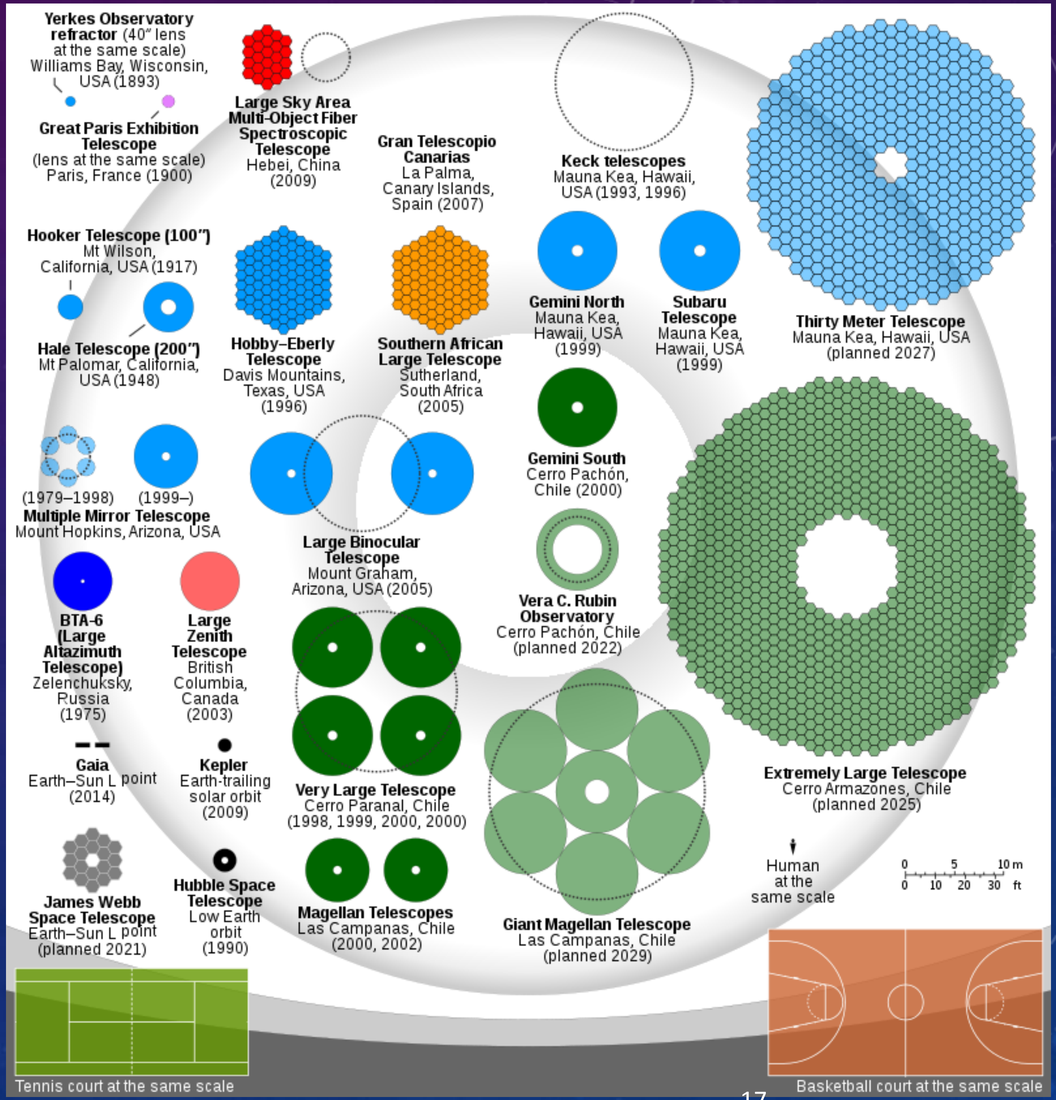


Phys.org

LSST (Vera Rubin Observatory), Ø8.5m, FOV = 9.5 sq. deg
3.2 Gpix, 30 Tb/ночь

https://www.lsst.org/

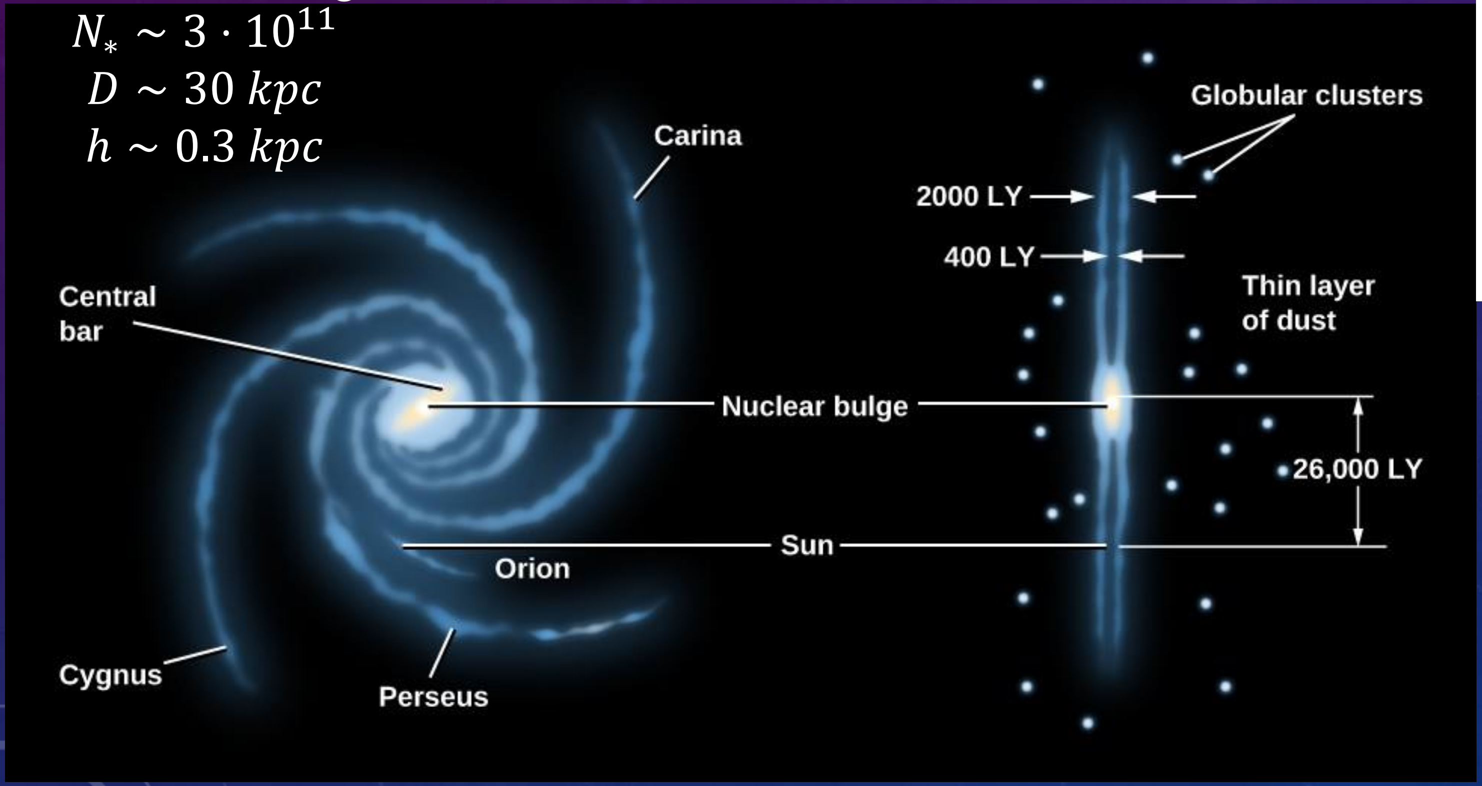
Первый свет:
октябрь 2022?



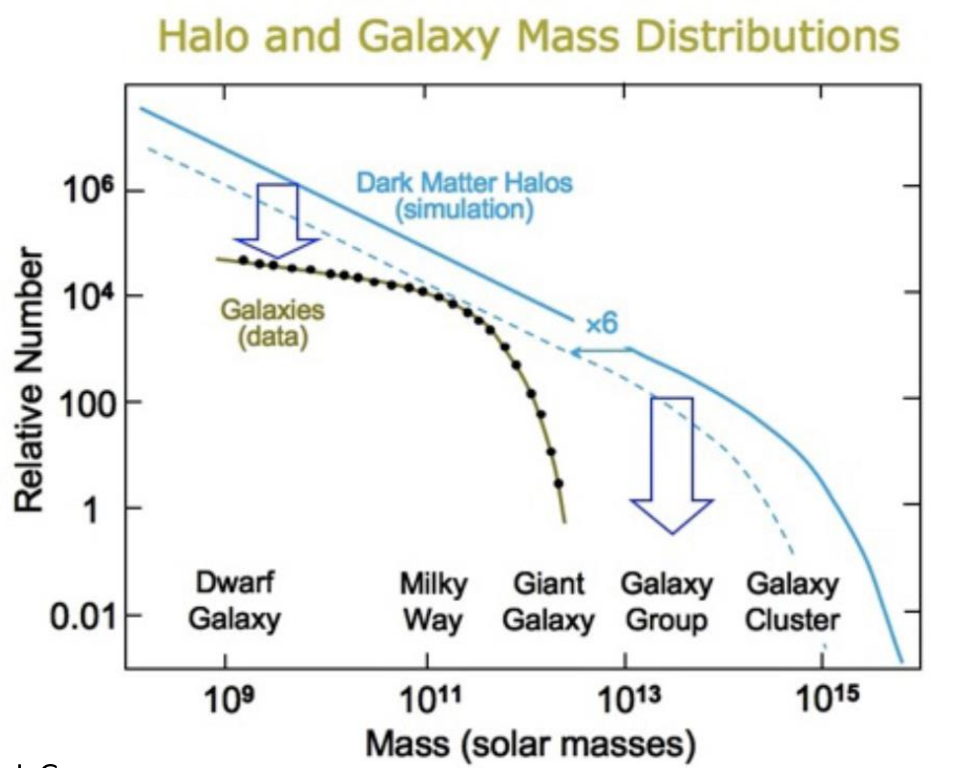
Wikipedia.org

ГАЛАКТИКА

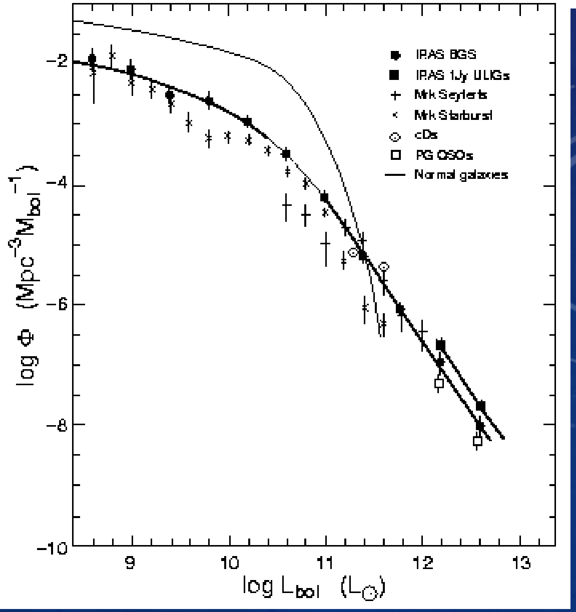
$M \sim 5 \cdot 10^{11}\ M_{\odot}$
$L \sim 2 \cdot 10^{10}\ L_{\odot}$
$N_{*} \sim 3 \cdot 10^{11}$
$D \sim 30\ kpc$
$h \sim 0.3\ kpc$



https://courses.lumenlearning.com/astronomy/chapter/the-architecture-of-the-galaxy/

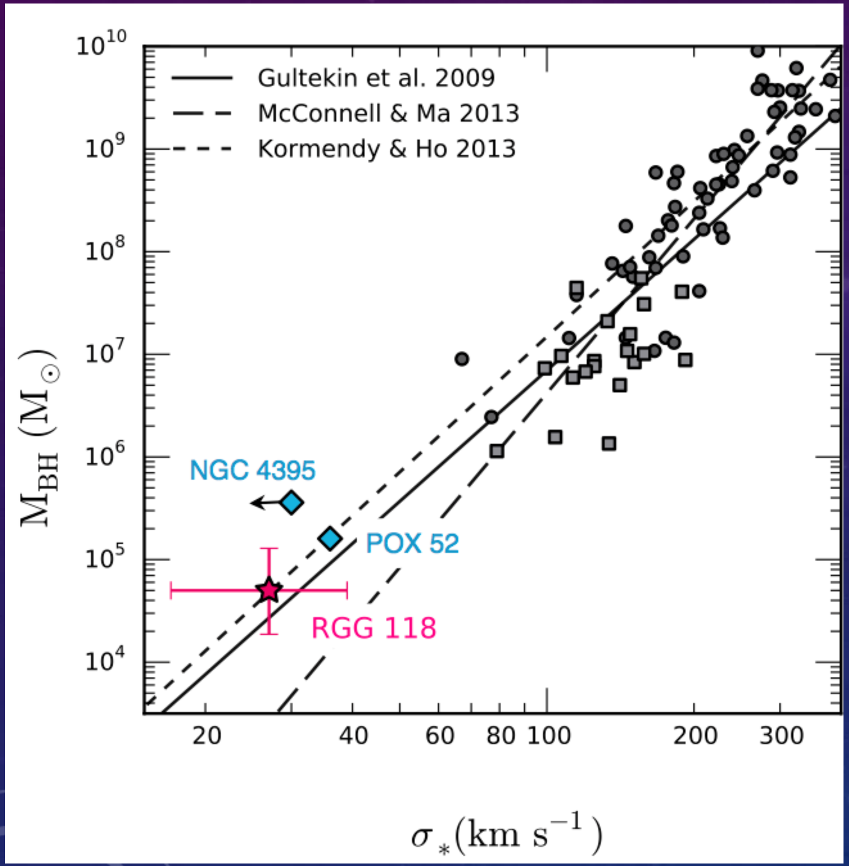


by J. Green

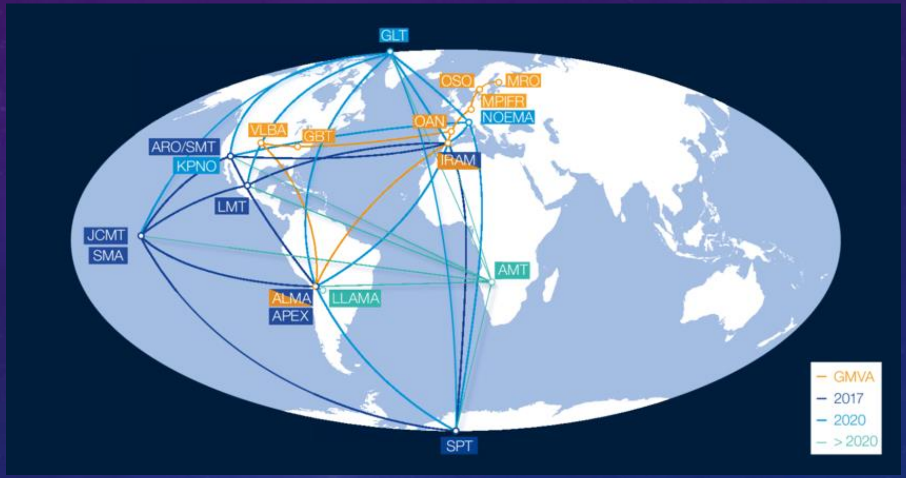


Sanders & Mirabel 1996

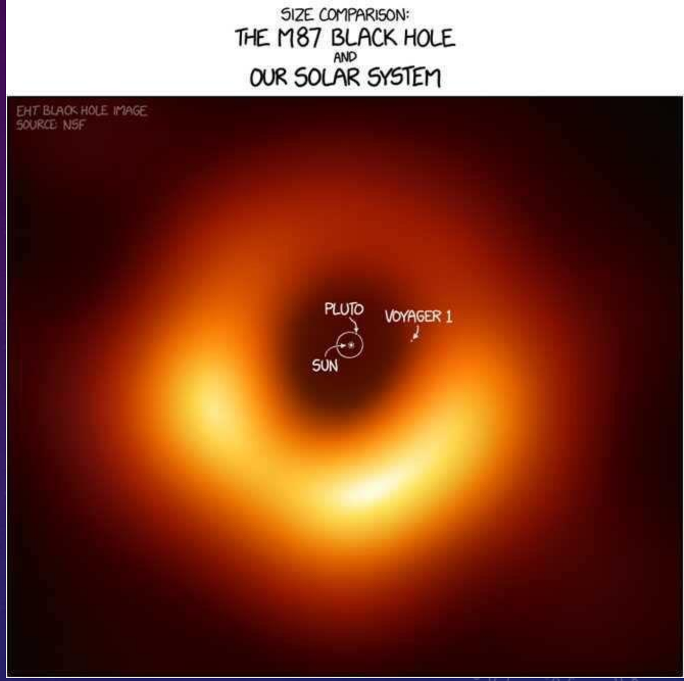
СВЕРХМАССИВНЫЕ ЧЕРНЫЕ ДЫРЫ

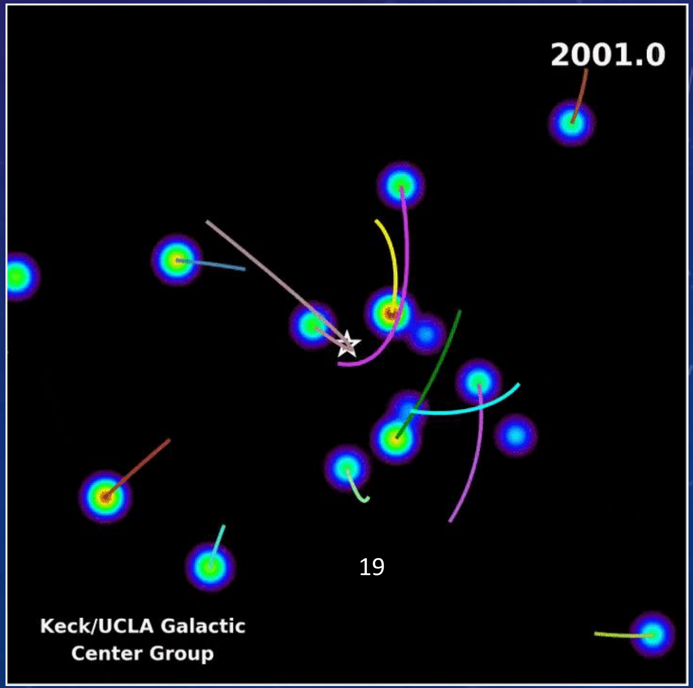


Baldassare et al. 2015

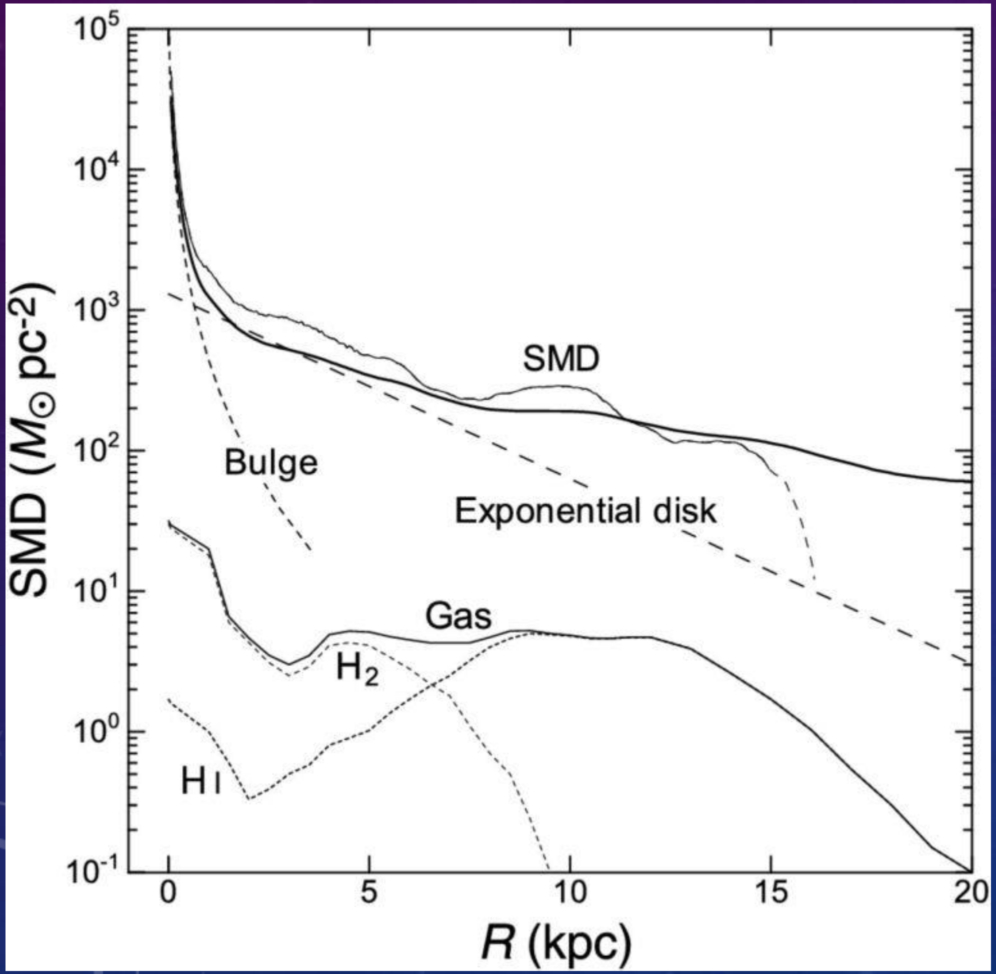


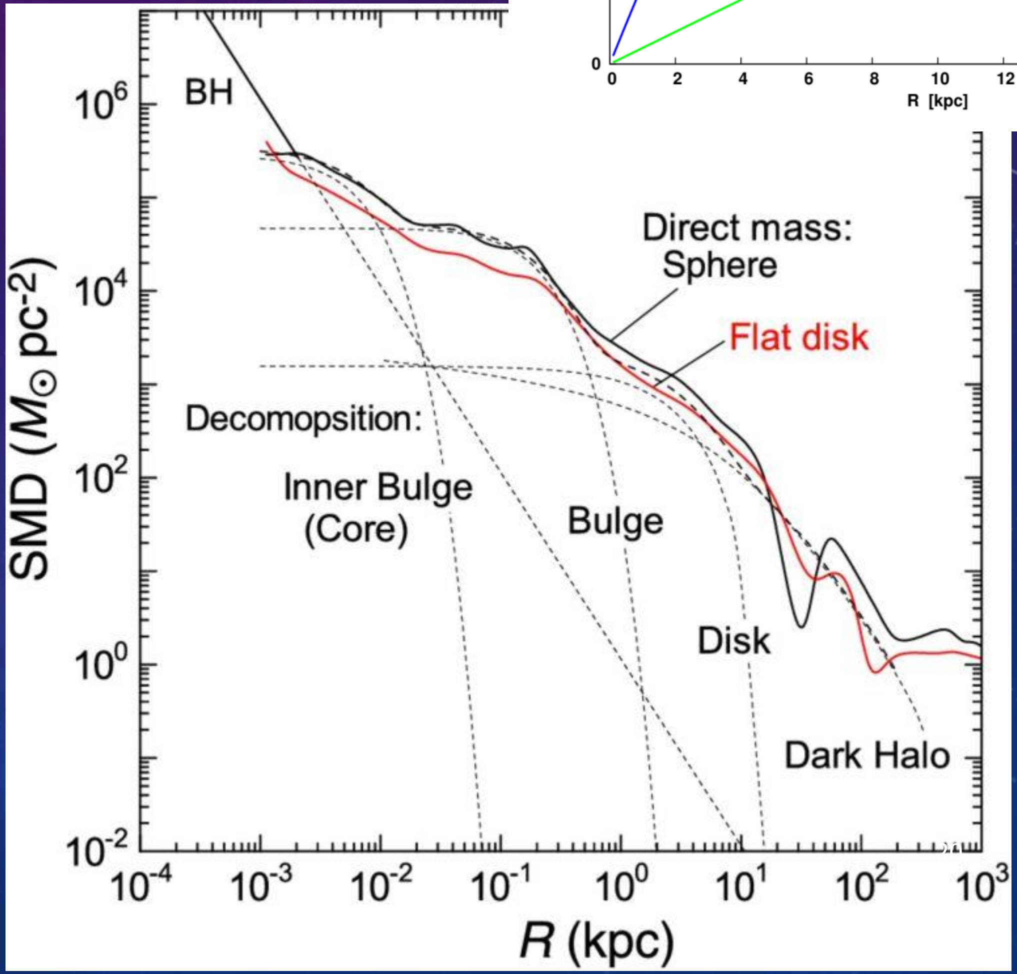
https://eventhorizontelescope.org/

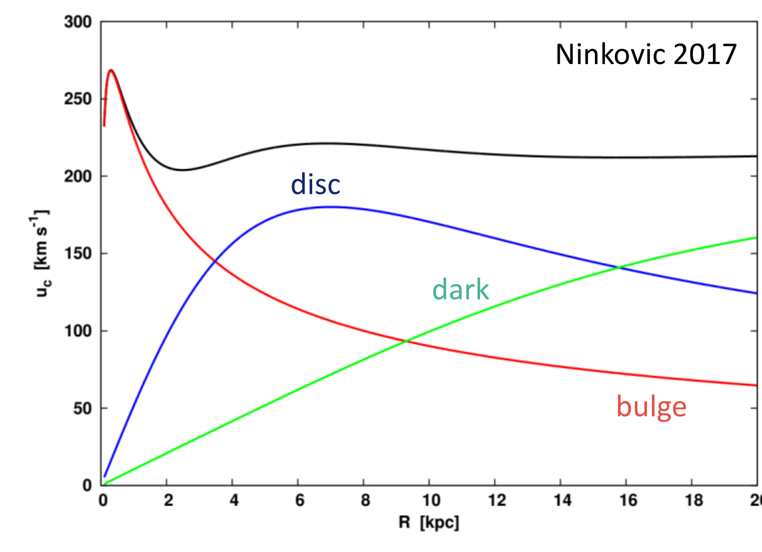




ГАЗ И ЗВЕЗДЫ

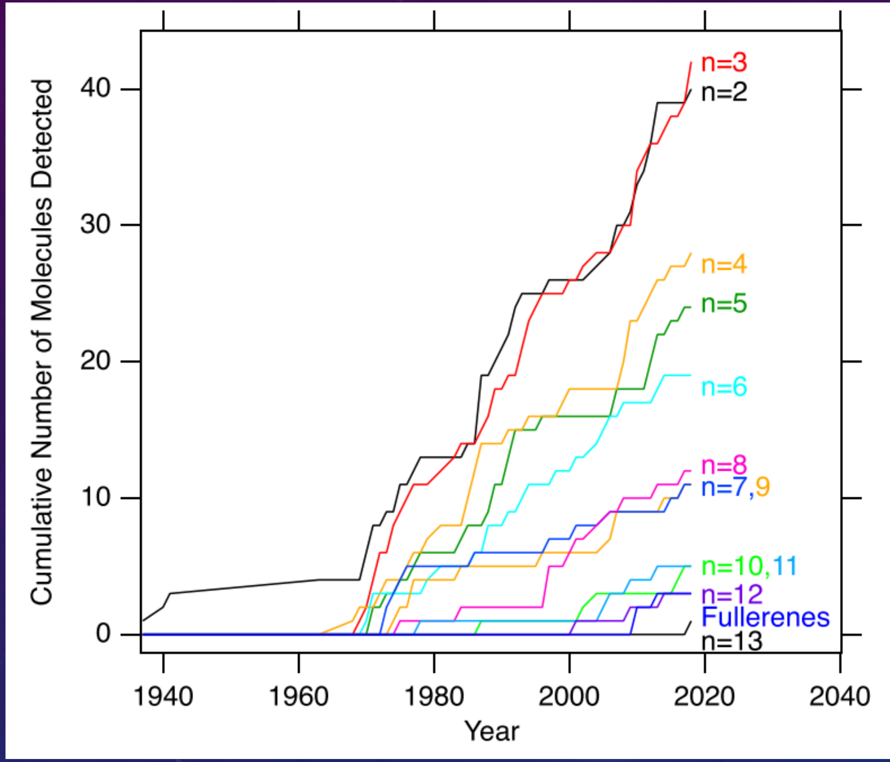




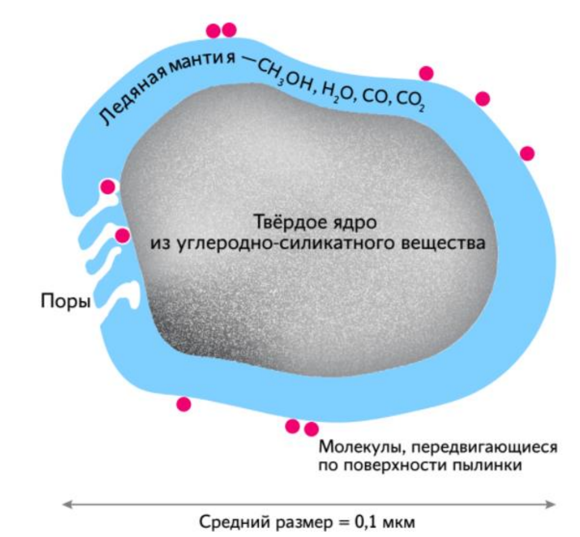


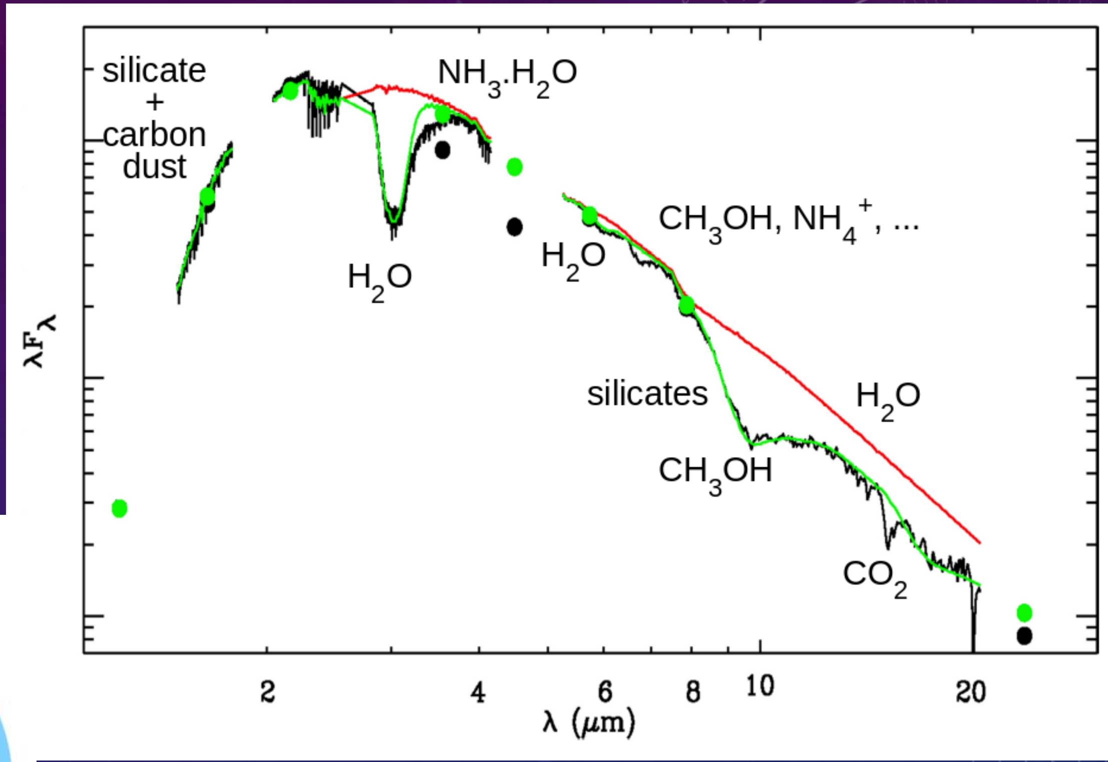
https://ned.ipac.caltech.edu/level5/Sept16/Sofue/Sofue4.html

МЕЖЗВЁЗДНАЯ СРЕДА

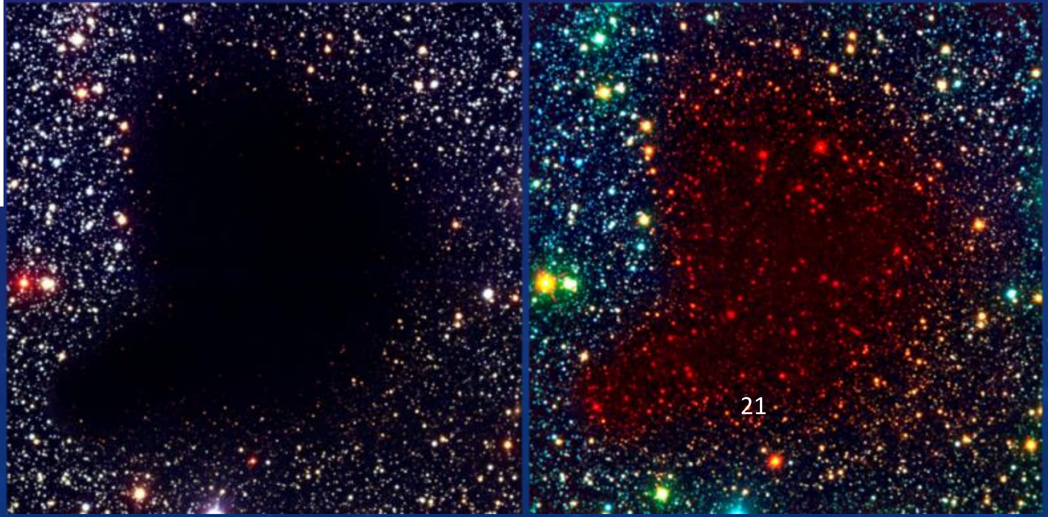


McGuire 2018, ApJS, 239, 17

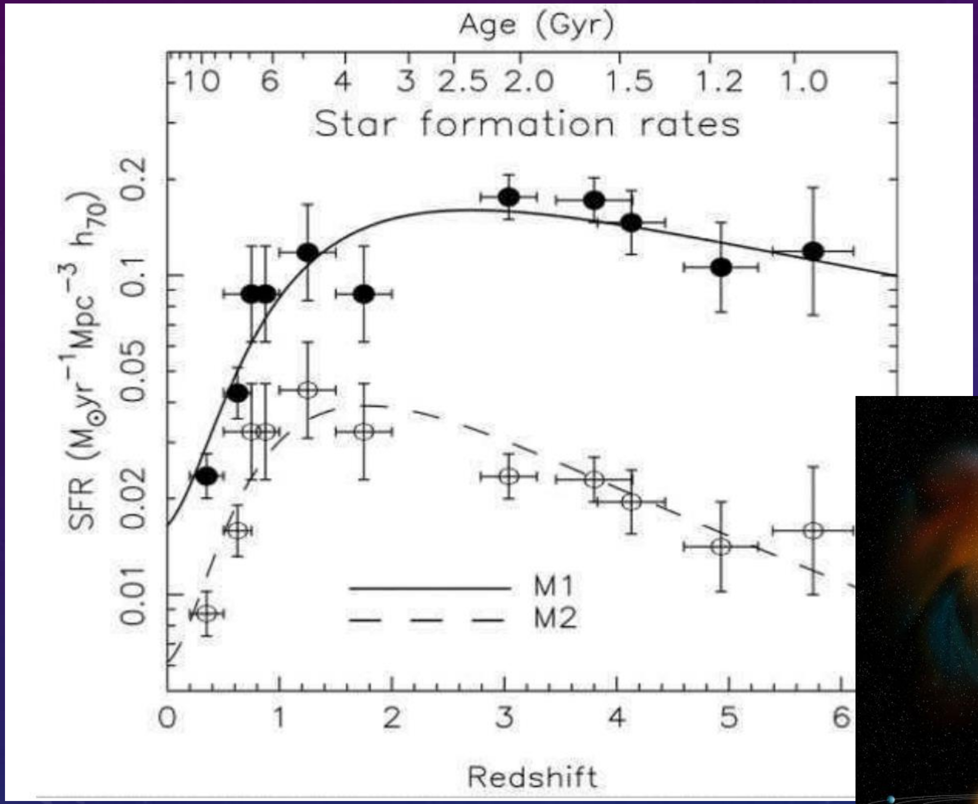




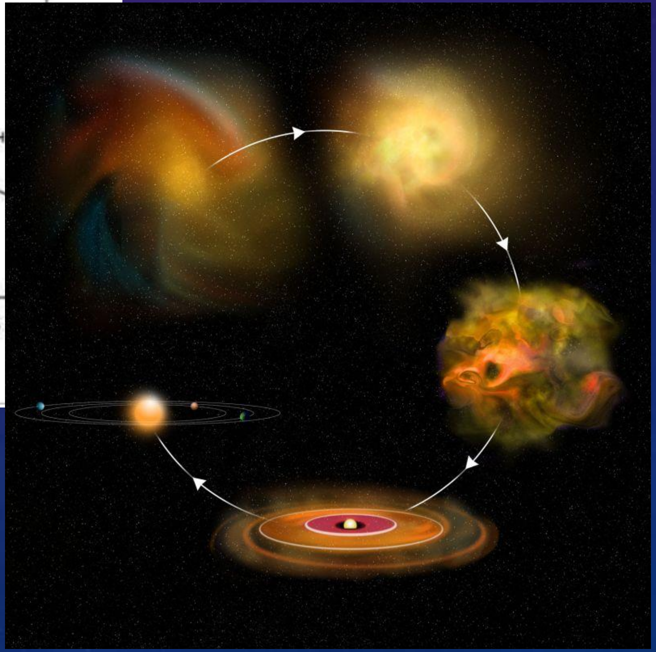
https://www.ifa.hawaii.edu/research/ISM.shtml

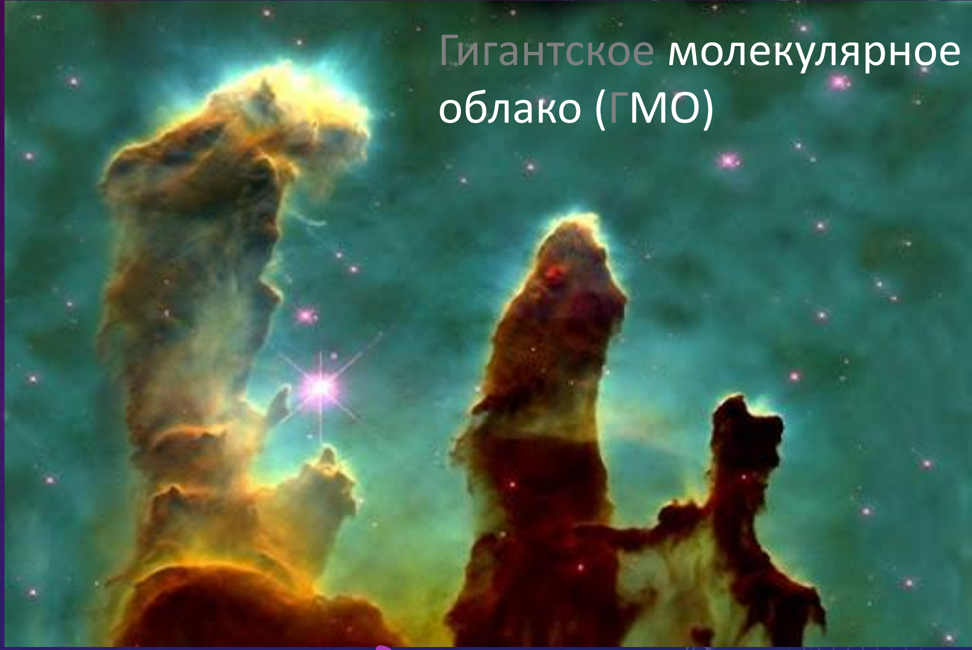


ЗВЁЗДООБРАЗОВАНИЕ



arXiv:astro-ph/0406546





$$\left.\begin{aligned} n &\sim 100\ \text{см}^{-3} \\ \rho_0 &\sim 10^{-22}\ \text{г см}^{-3} \end{aligned}\right\} \quad t_{ff} \sim \frac{1}{\sqrt{G\rho_0}} \approx 10^7\ \text{лет}$$

Джинсовская длина:

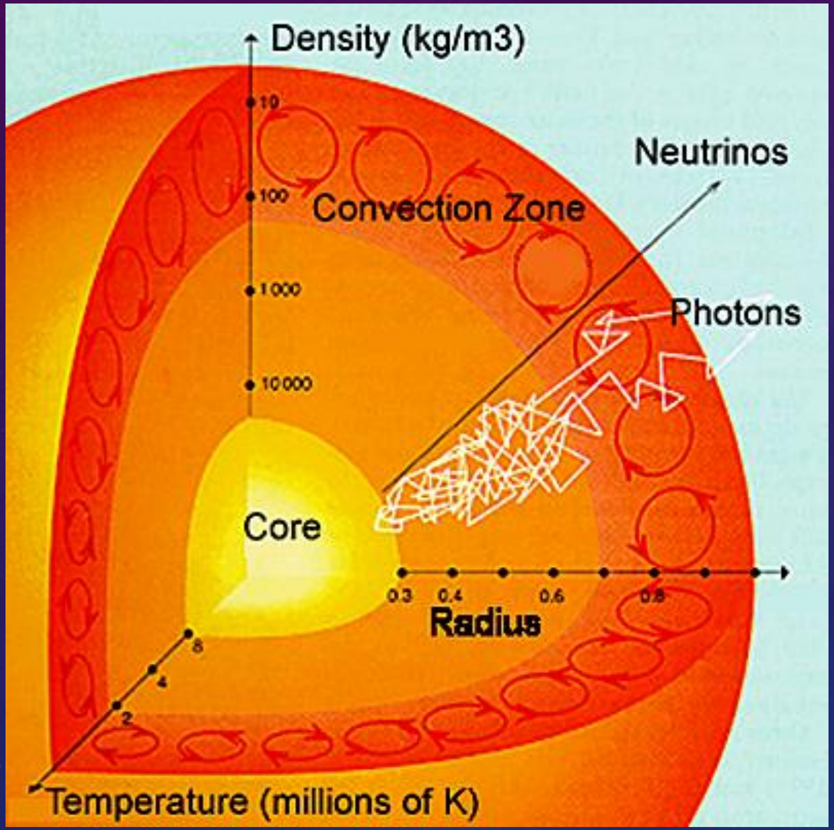
$$\lambda_J = c_s \left(\frac{\pi}{G\rho_0}\right)^{-\frac{1}{2}} \sim 100\ \text{пк}$$

Джинсовская масса:

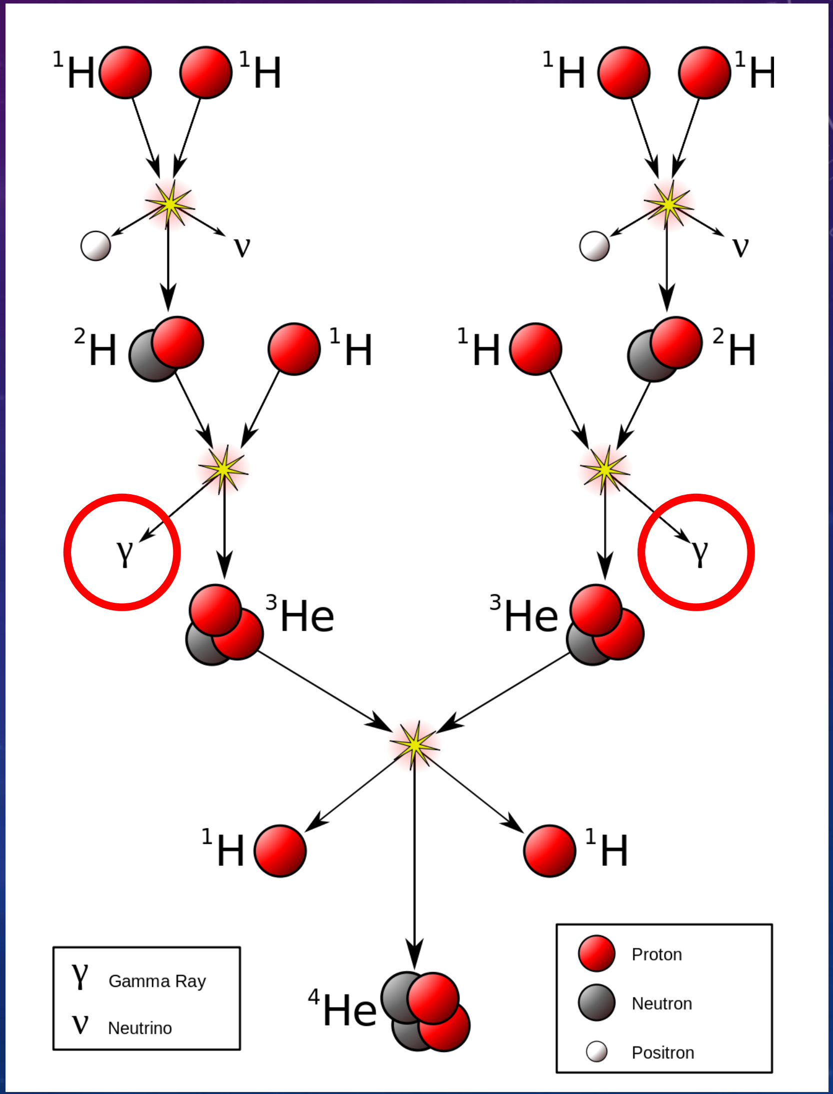
$$M_J = \rho_0 \lambda_J^3 \sim 5^{22} \cdot 10^4 M_\odot$$

В 90% звёзд Вселенной прямо сейчас горит водород.

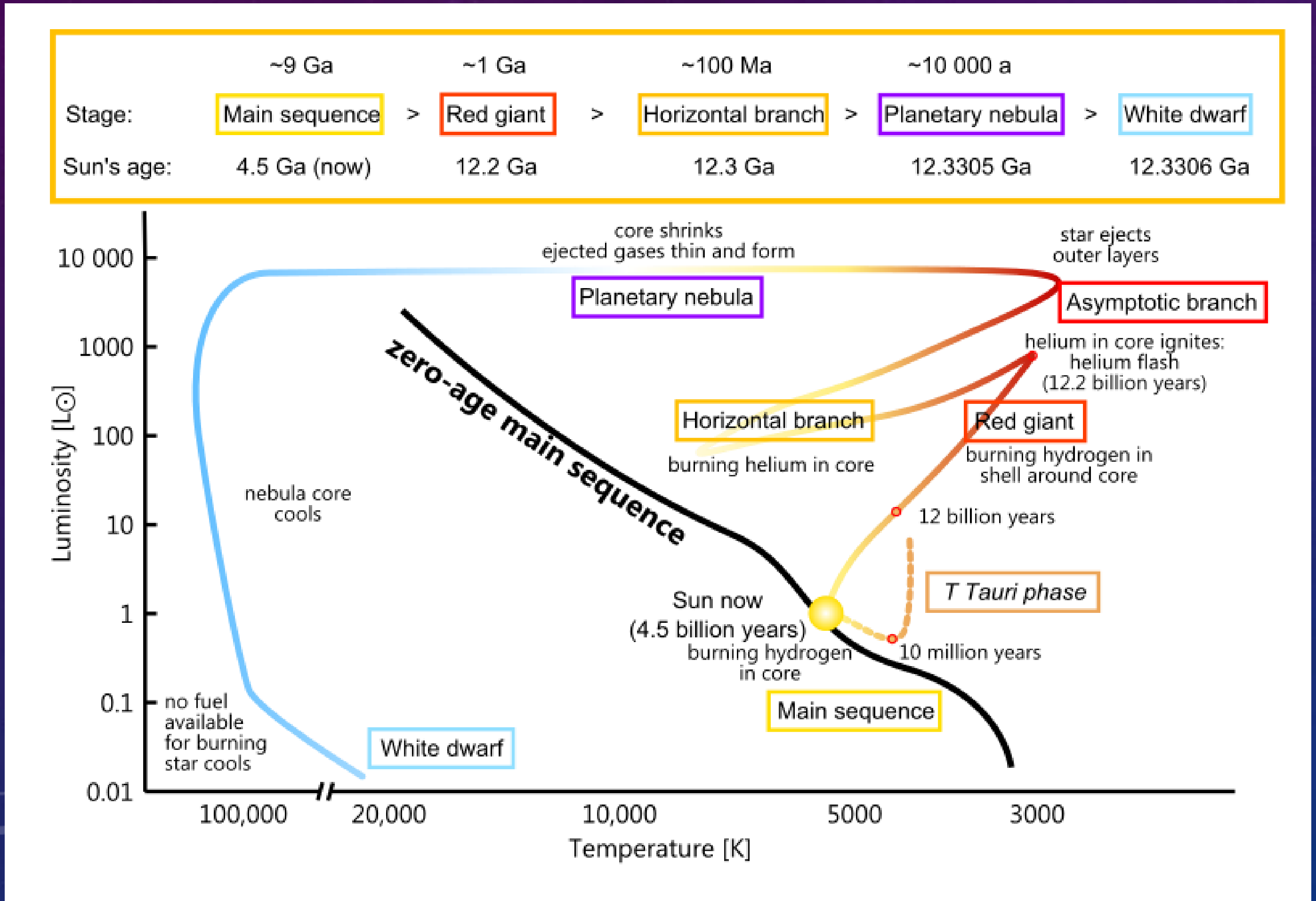
Термоядерный синтез

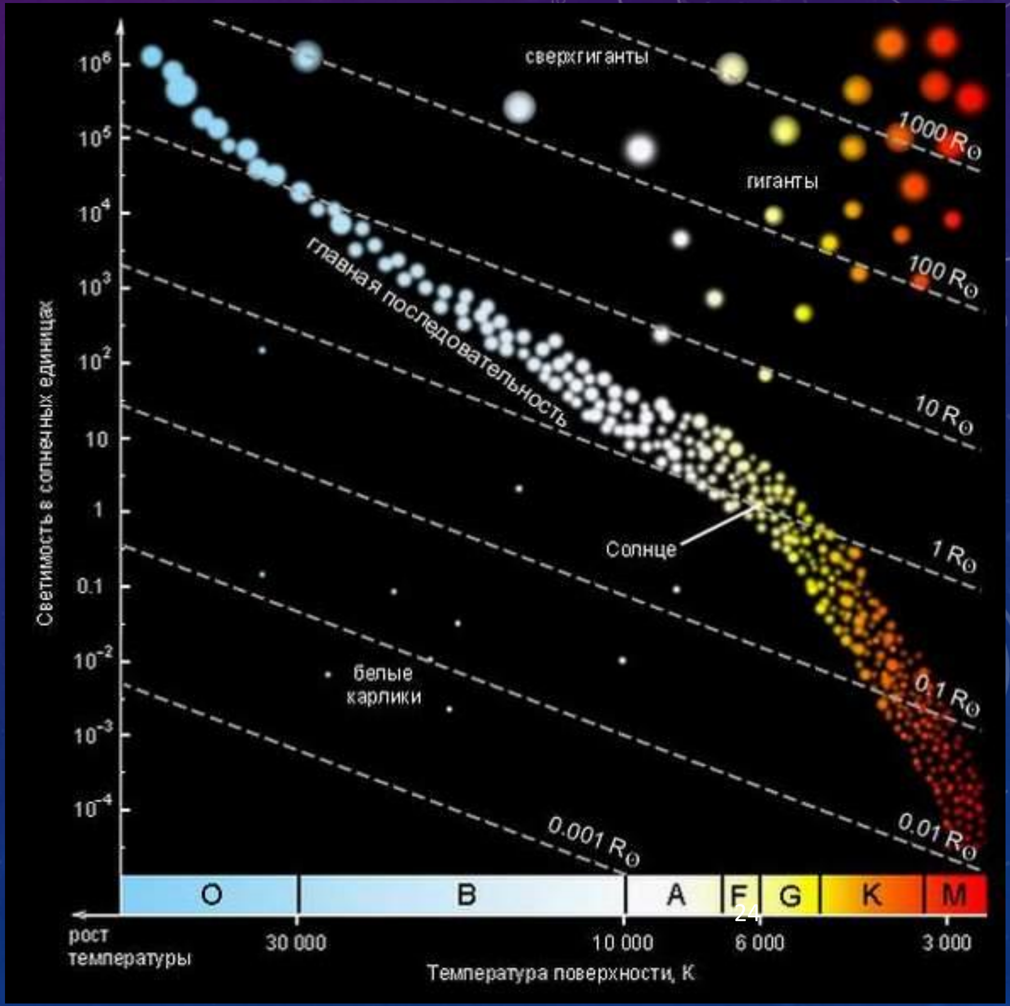


Состав: водород (¾), гелий (почти ¼), углерод, кислород и т. д. (менее 1%)



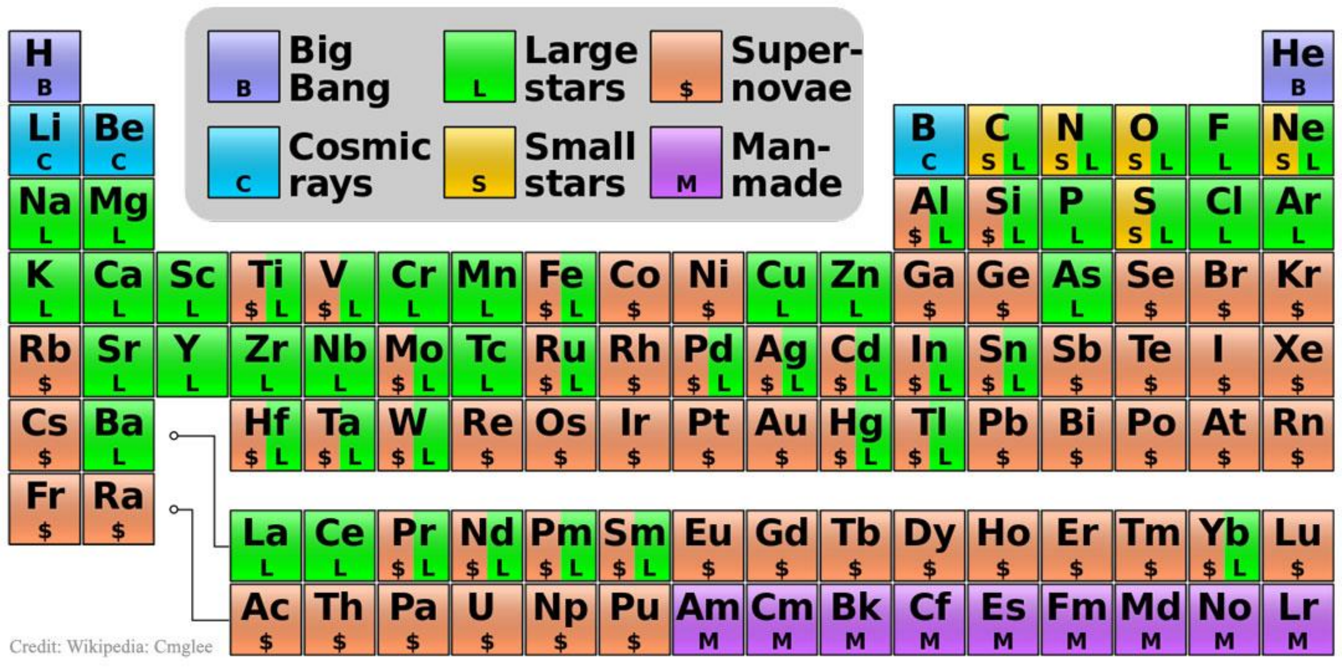
ЗВЁЗДЫ

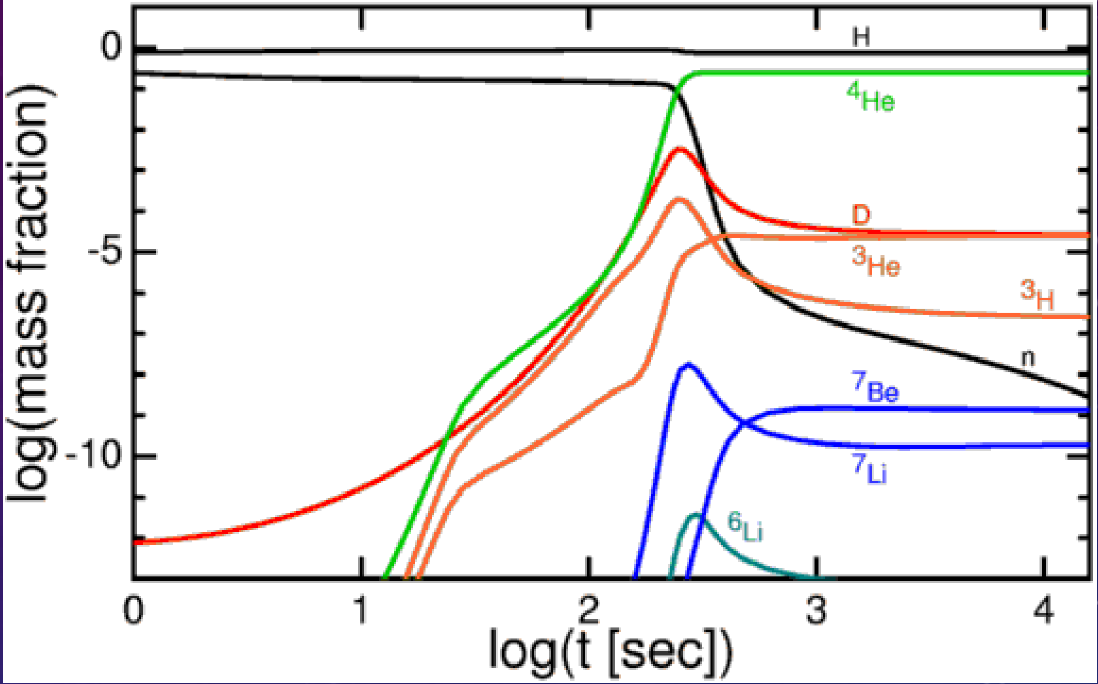




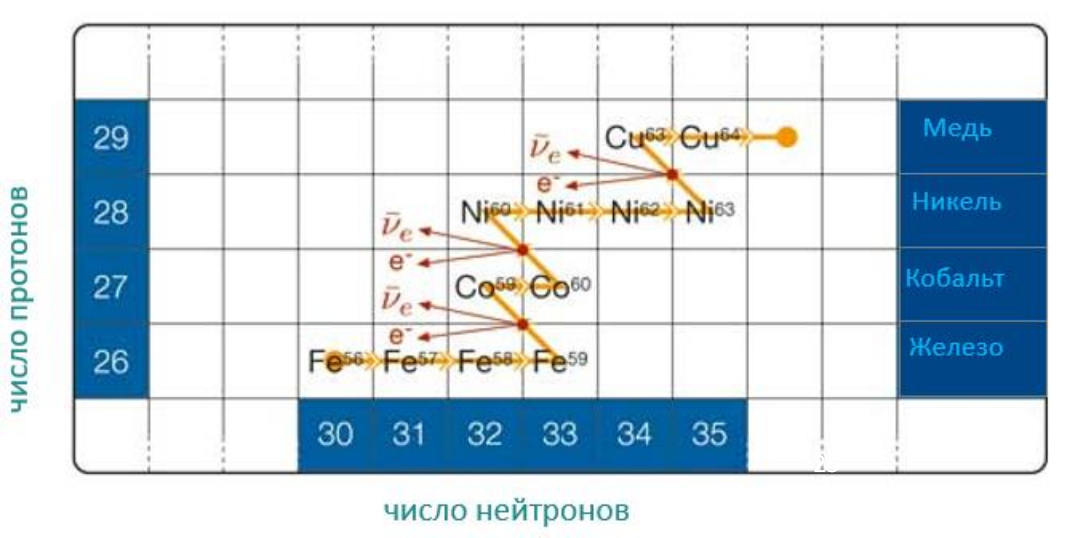
Wikimedia.org

НУКЛЕОСИНТЕЗ

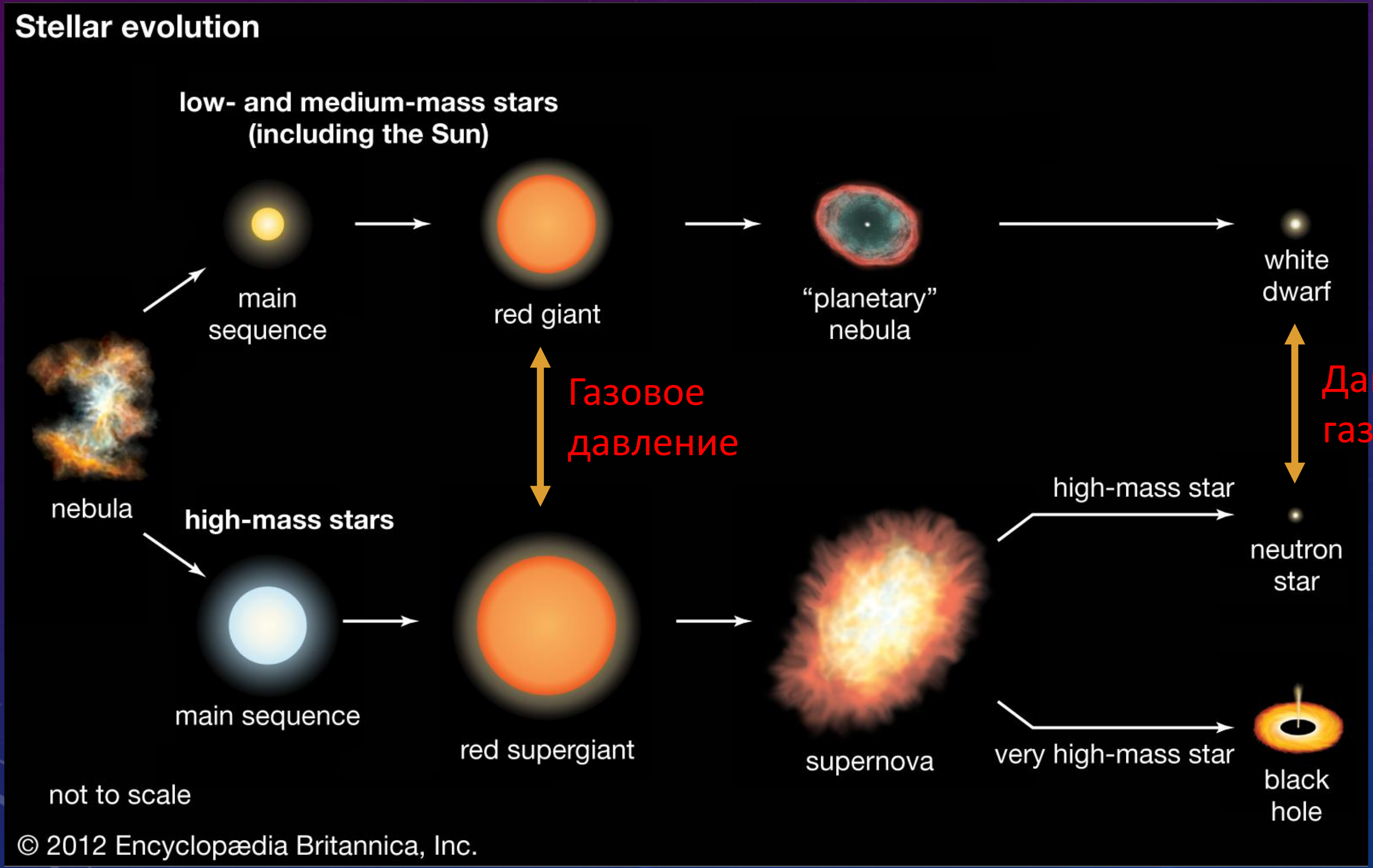




http://www.astro.ucla.edu/~wright/BBNS.html



ЗВЁЗДНАЯ ЭВОЛЮЦИЯ

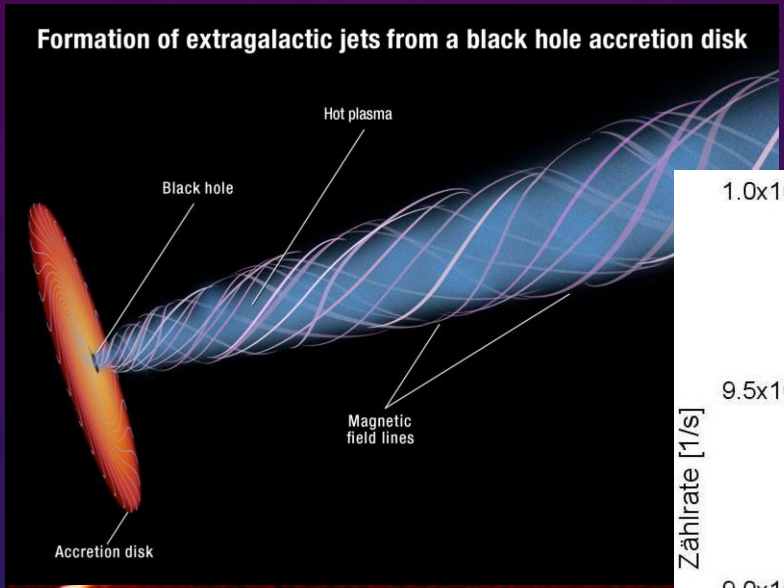


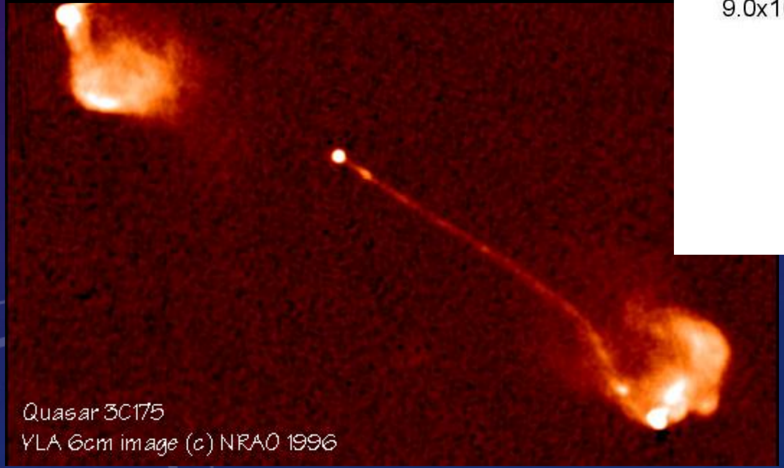
Газовое
давление

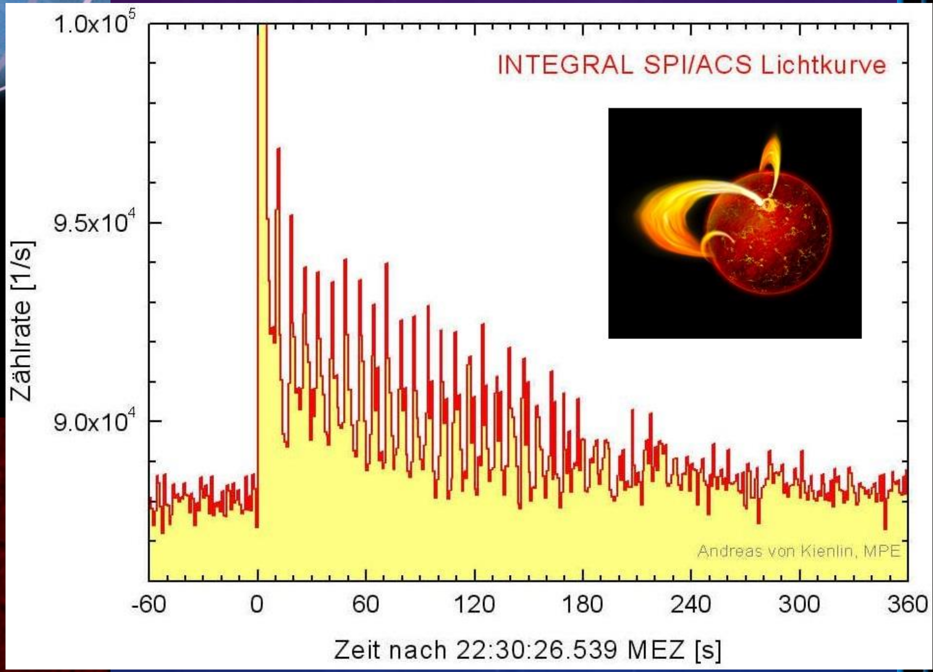
Давление вырожденного
газа

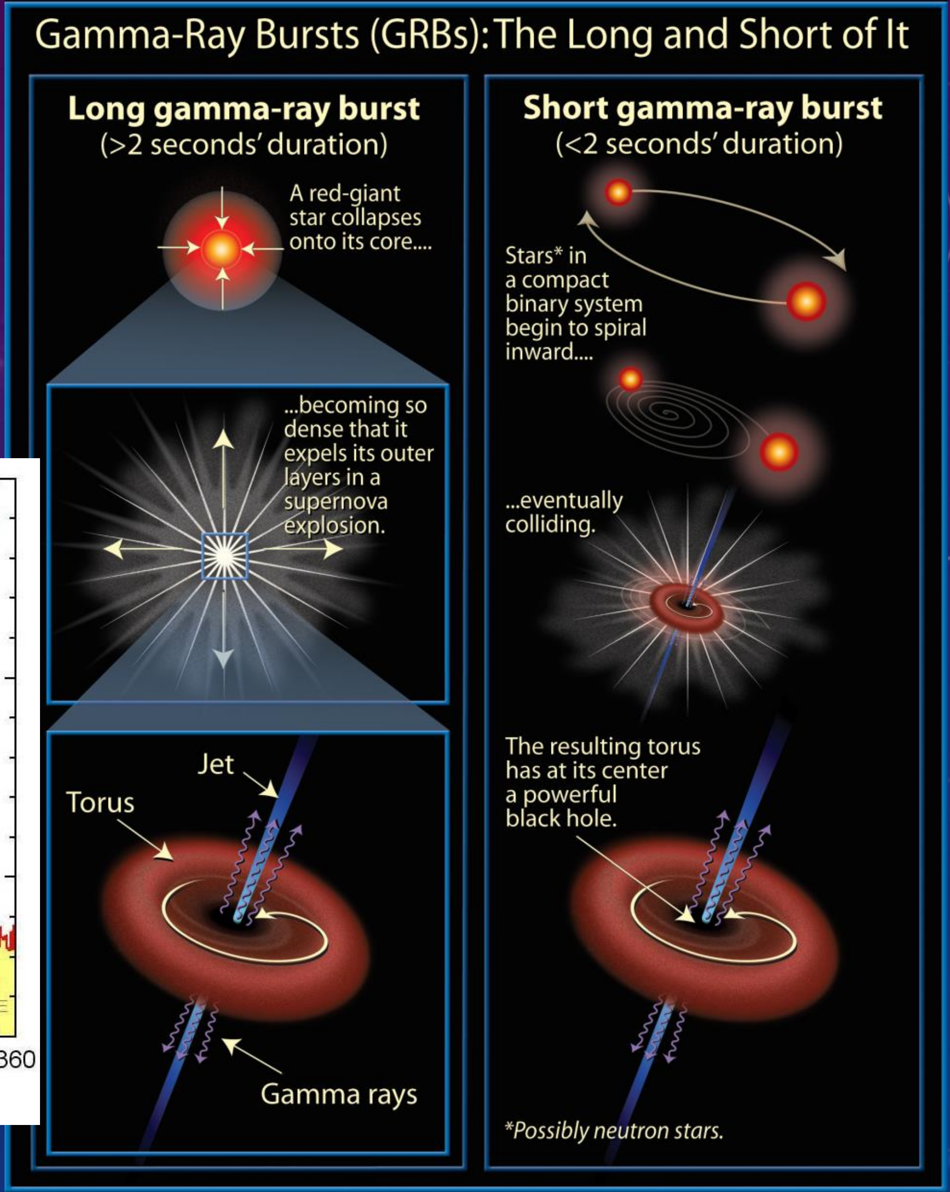
$$t_{MS} \approx 10^{10}\left(\frac{M}{M_\odot}\right)^{-2} \text{ лет}$$

КОМПАКТНЫЕ ОБЪЕКТЫ





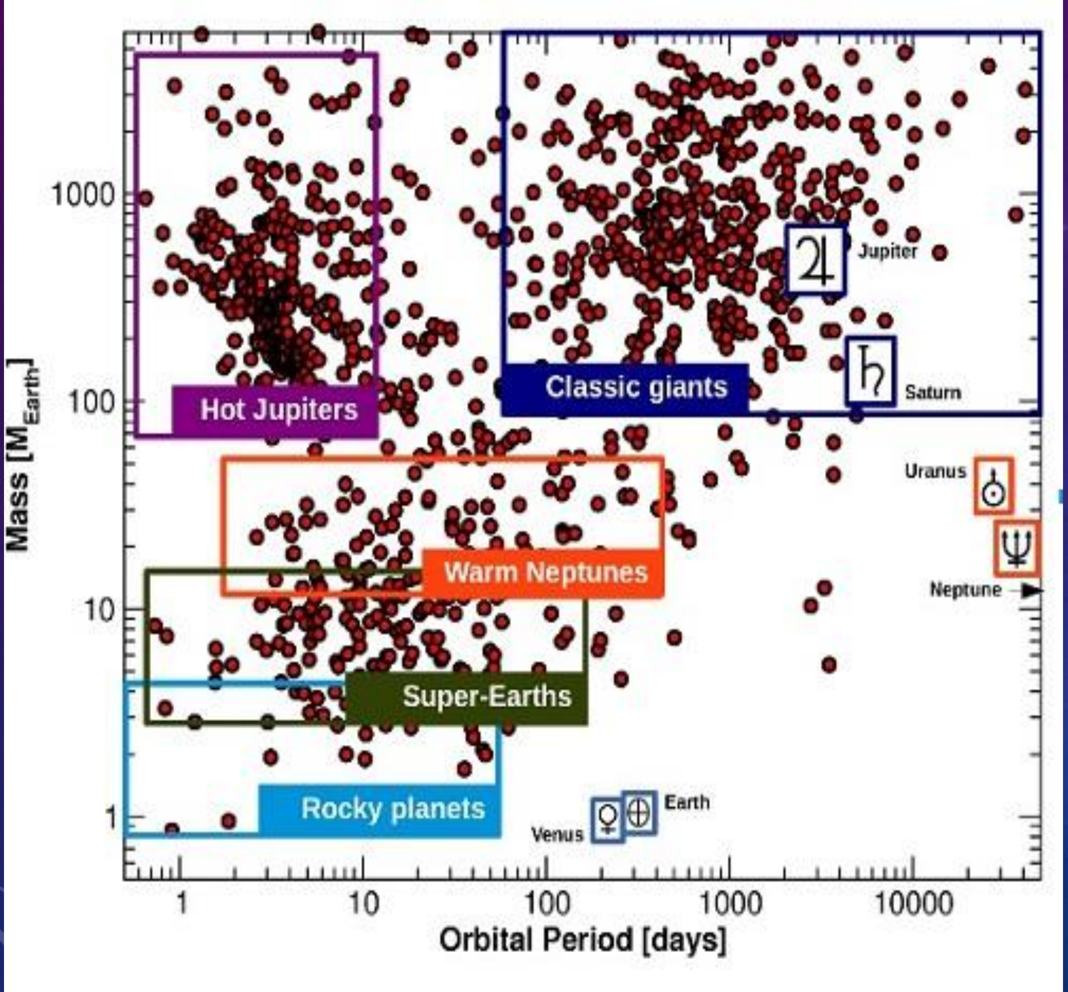


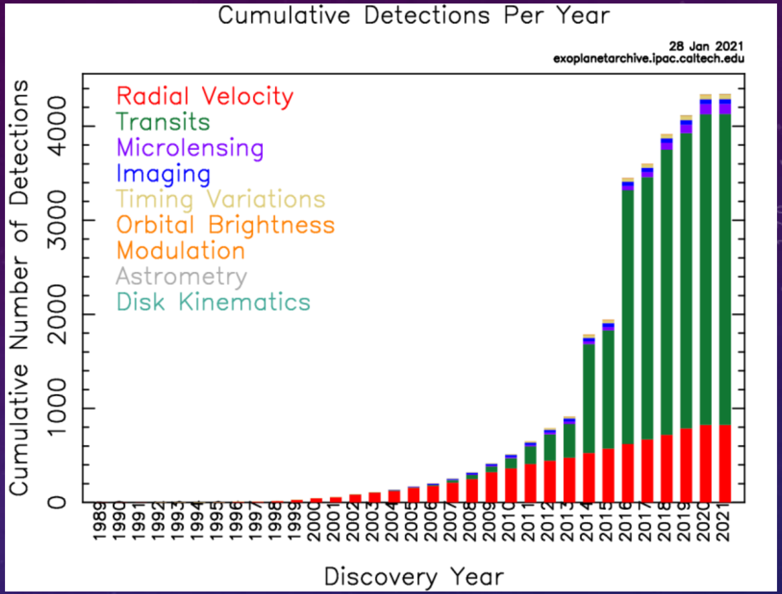


Hubblesite.org

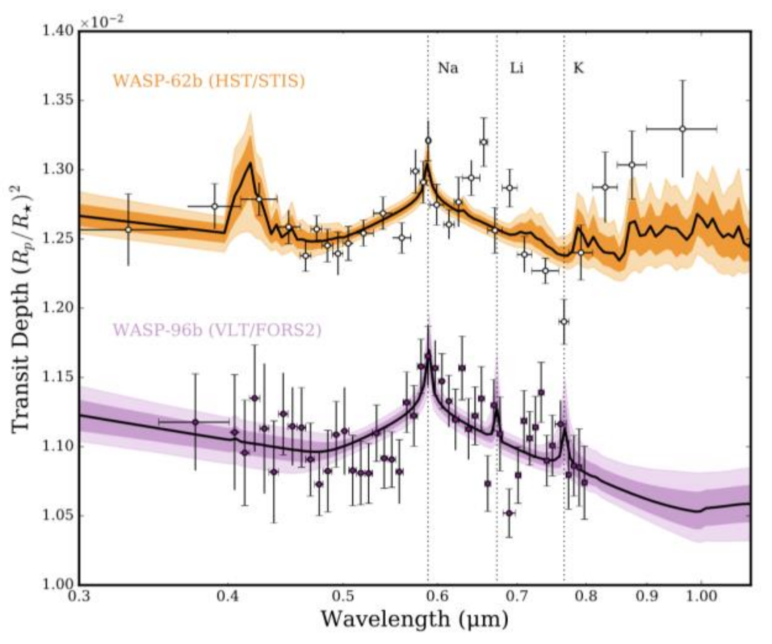
http://exoplanets.org/

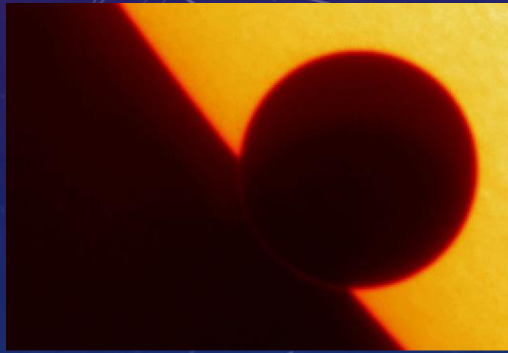
ПЛАНЕТЫ





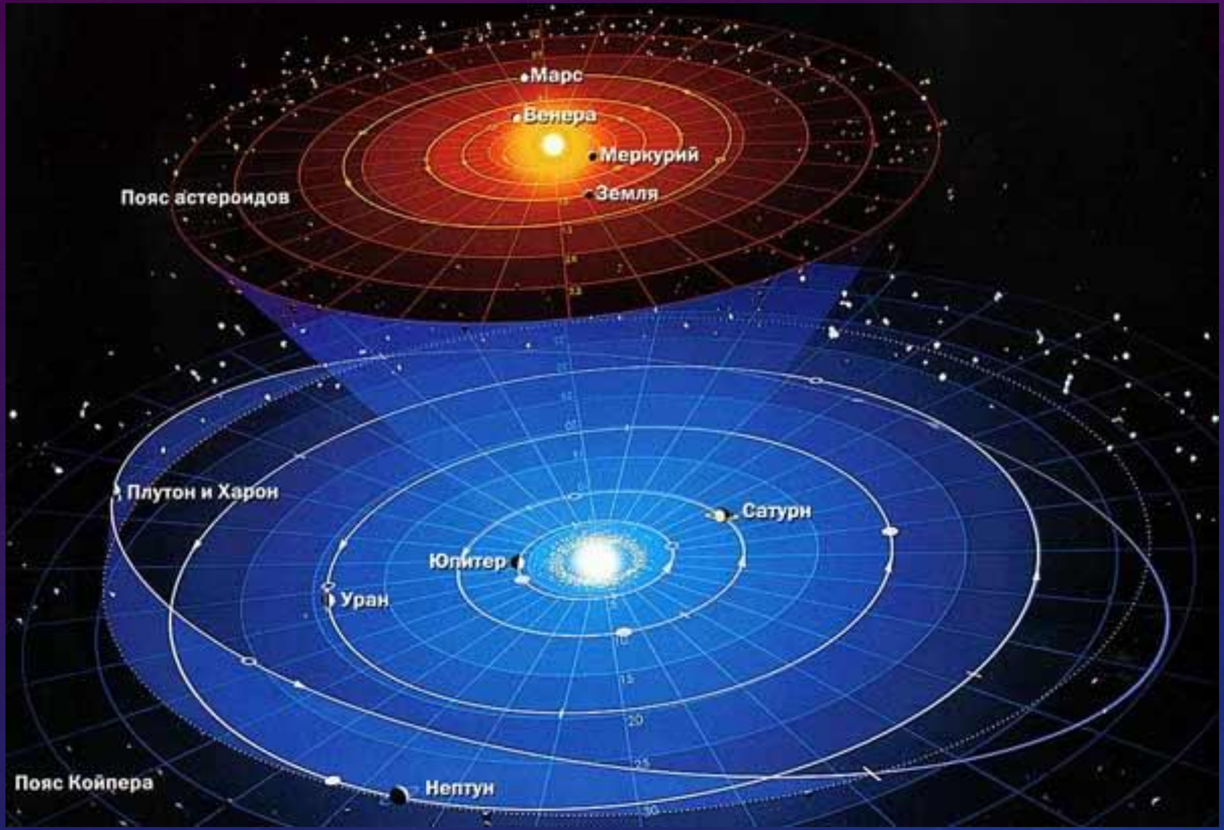
https://exoplanetarchive.ipac.caltech.edu/





https://wasp-planets.net/2020/11/13/wasp-62b-in-james-webbs-continuous-viewing-zone-has-a-clear-atmosphere/

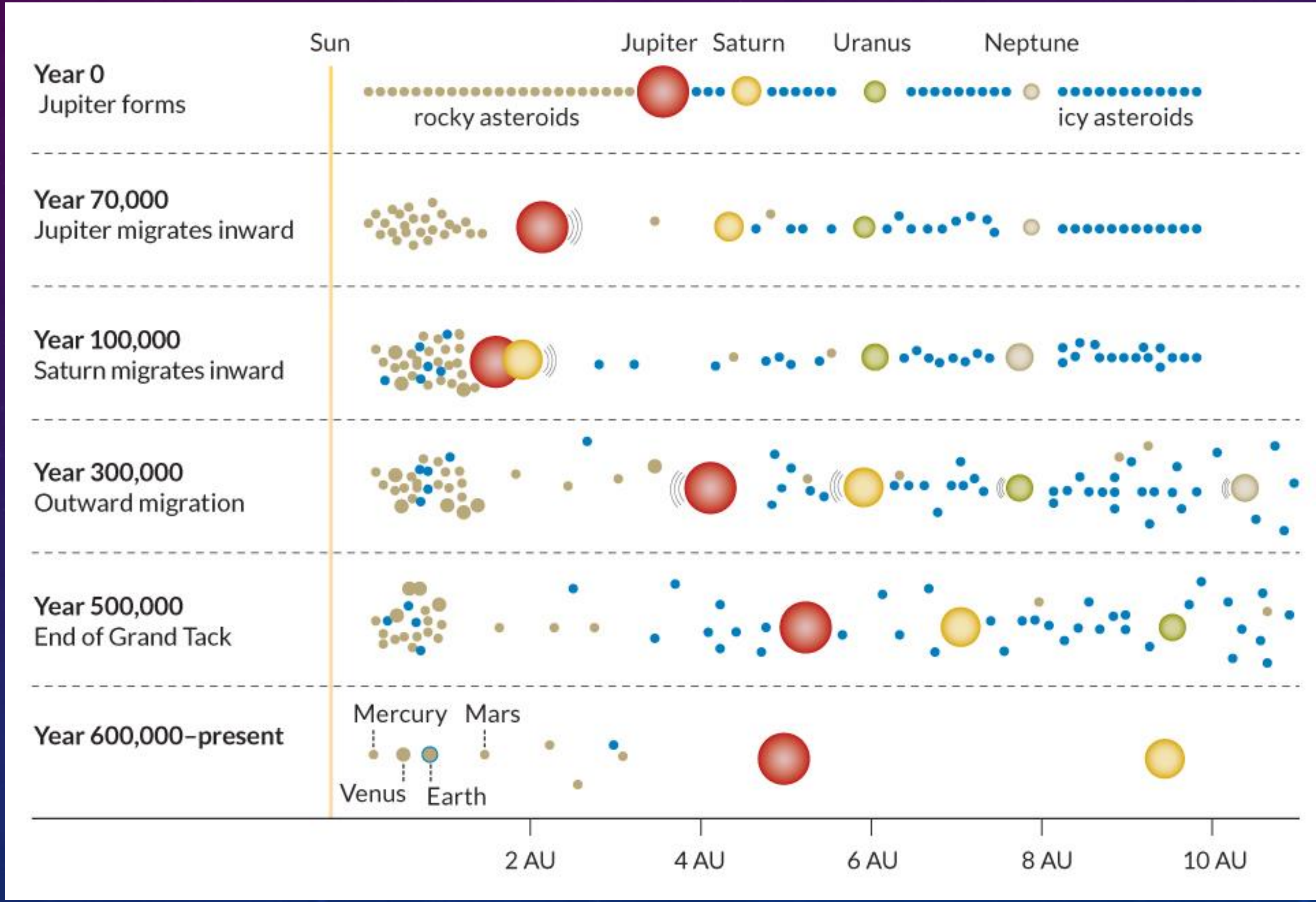
СОЛНЕЧНАЯ СИСТЕМА



Планеты СС:

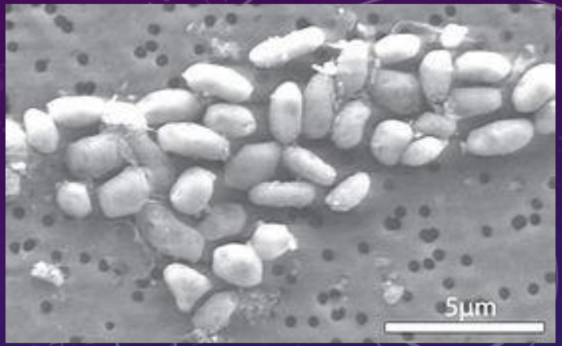
- 8 больших (M: 0.055 — 318; R: 0.38 — 11.2)
- 5+ карликовых
- 600 тыс. малых (астероидов)
- 20 тыс. с именами
- 100 млн. всего «замеченных»

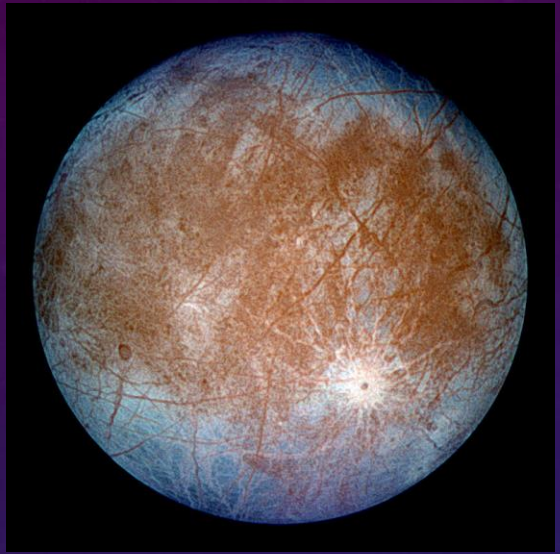
СОЛНЕЧНАЯ СИСТЕМА: ФОРМИРОВАНИЕ



НАДЕЖДЫ НА ЖИЗНЬ

GFAJ-1: А как хорошо начиналось… :-\



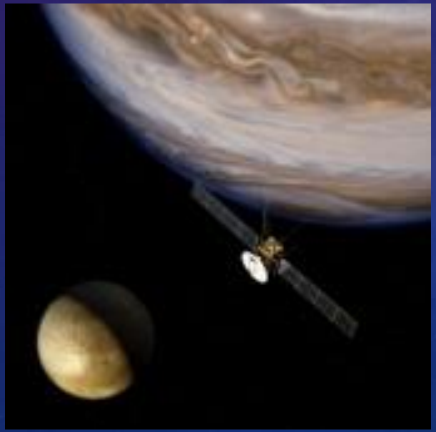


Спутники больших планет.

Поверхность – лед.

Разогреваются приливными взаимодействиями?

Европа: под слоем льда (10-30 км) находится жидкий водяной океан (глубиной до ~ 100 км)?

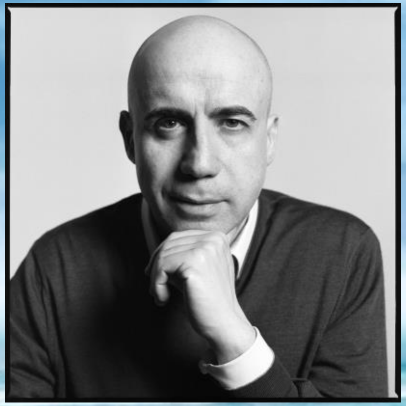


JUICE (ESA) – старт в июне 2022 г.?

Спасибо! ☺

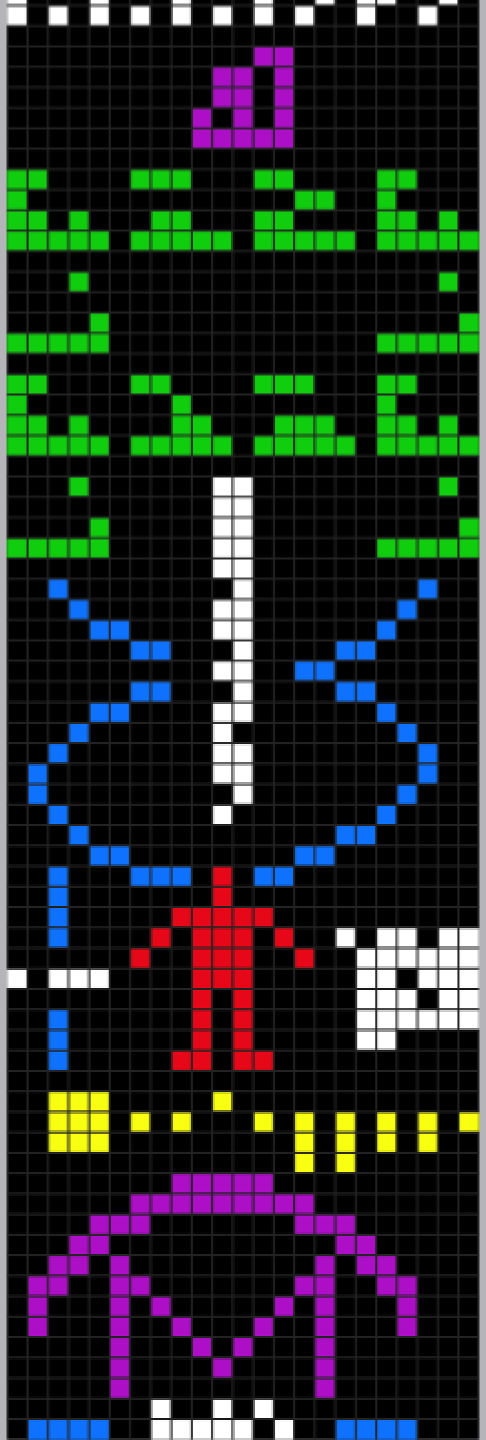
РАЗУМНАЯ ЖИЗНЬ?

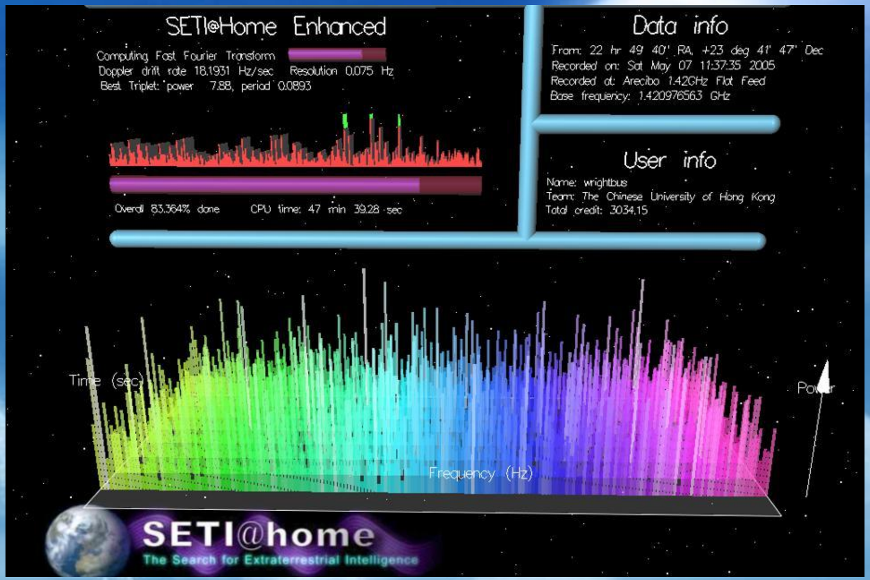
https://breakthroughinitiatives.org/



$$N = R \times f_s \times f_p \times n_e \times f_l \times f_i \times f_c \times L$$

- R average rate of star formation
- f_s fraction of good stars that have planetary systems
- n_e number of planets aound these stars within an "ecoshell"
- f_l fraction of those planets where life develops
- f_i fraction of living species that develop intelligence
- f_c fraction of intelligent species with communications technology





https://boinc.berkeley.edu/projects.php

https://www.seti.org/