Co je nového v kosmologii

2019

Jan Novotný

Osnova

O čem je vědecká kosmologie. Kosmologický princip. Einsteinův vesmír.

První revoluce v kosmologii. Červený posuv a rozpínání vesmíru. Základní rovnice. FLRW metrika.

Druhá revoluce. Reliktní záření. Fluktuace. Rané fáze vývoje vesmíru.

Třetí revoluce. Zrychlené rozpínání. Lambda CDM vesmír. Temná hmota a temná energie.

Pochybnosti o temné hmotě a temné energii.

První hvězdy. Nové poznatky.

Gravitační vlny. Historie, objev, současný stav.

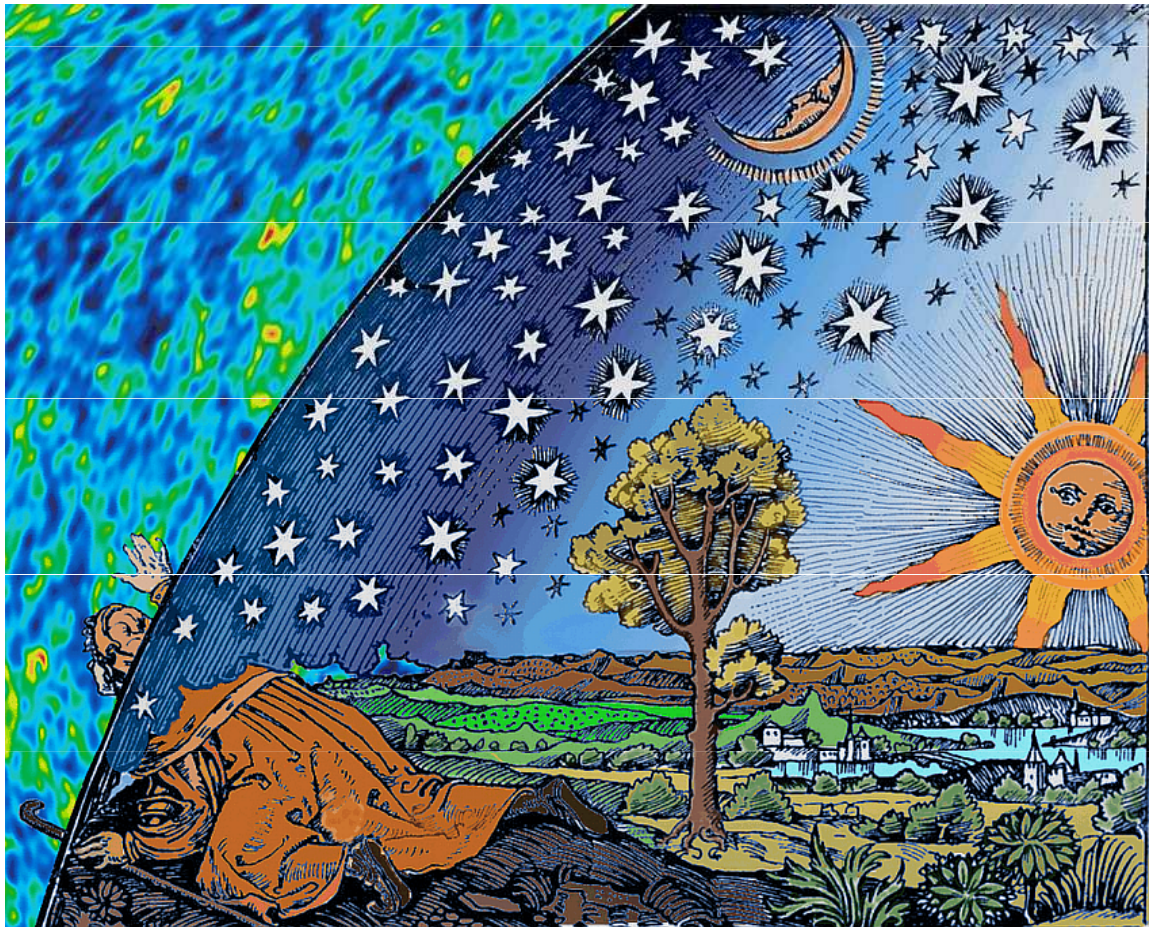
O čem je vědecká kosmologie.

K. R. Popper: Každá věda je kosmologie.

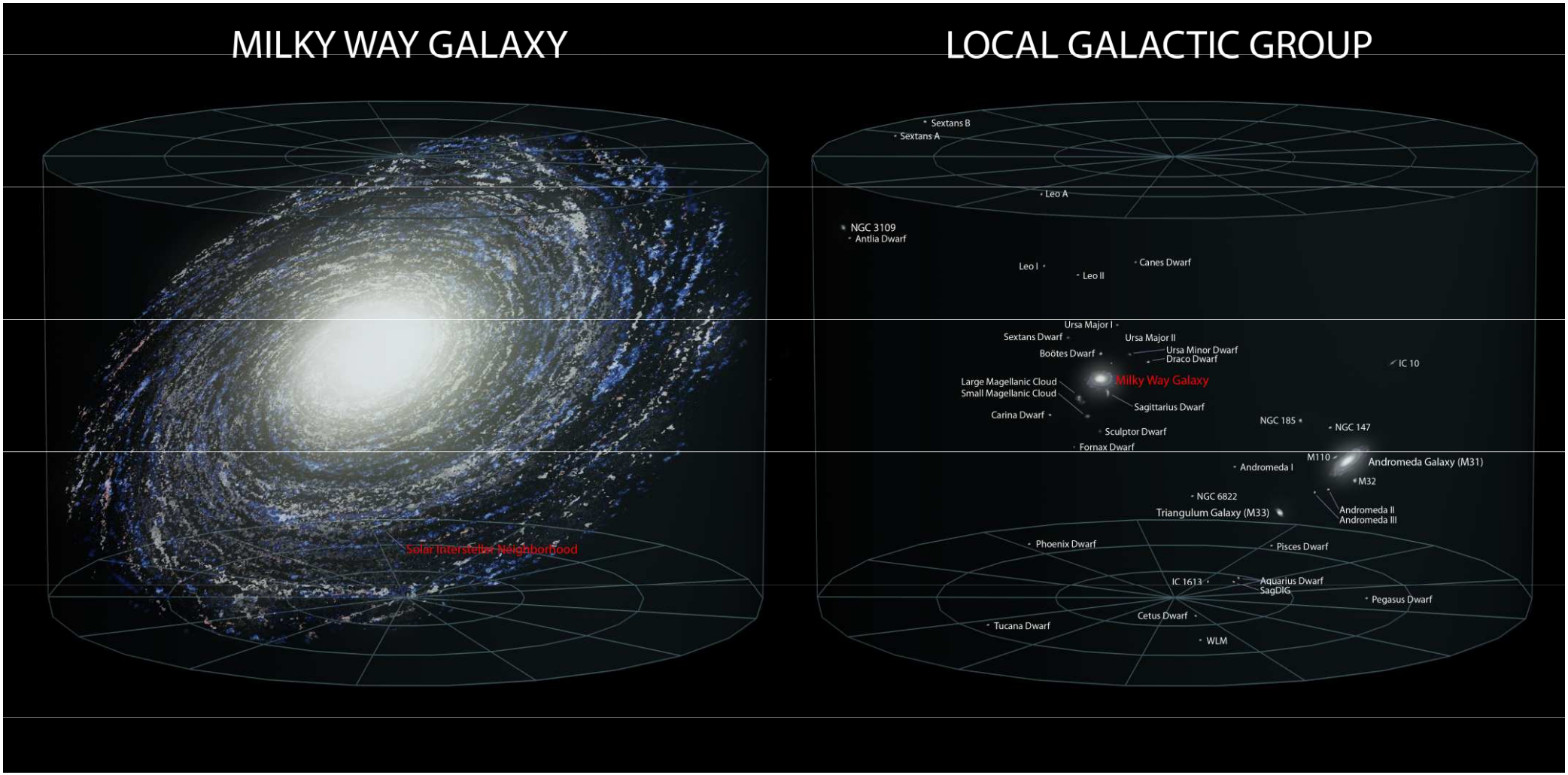
Kosmologie: věda o vesmíru. Vesmír: Největší soubor „věcí“, dostupných našemu poznání. Ale jakému? Teorii či empirii?

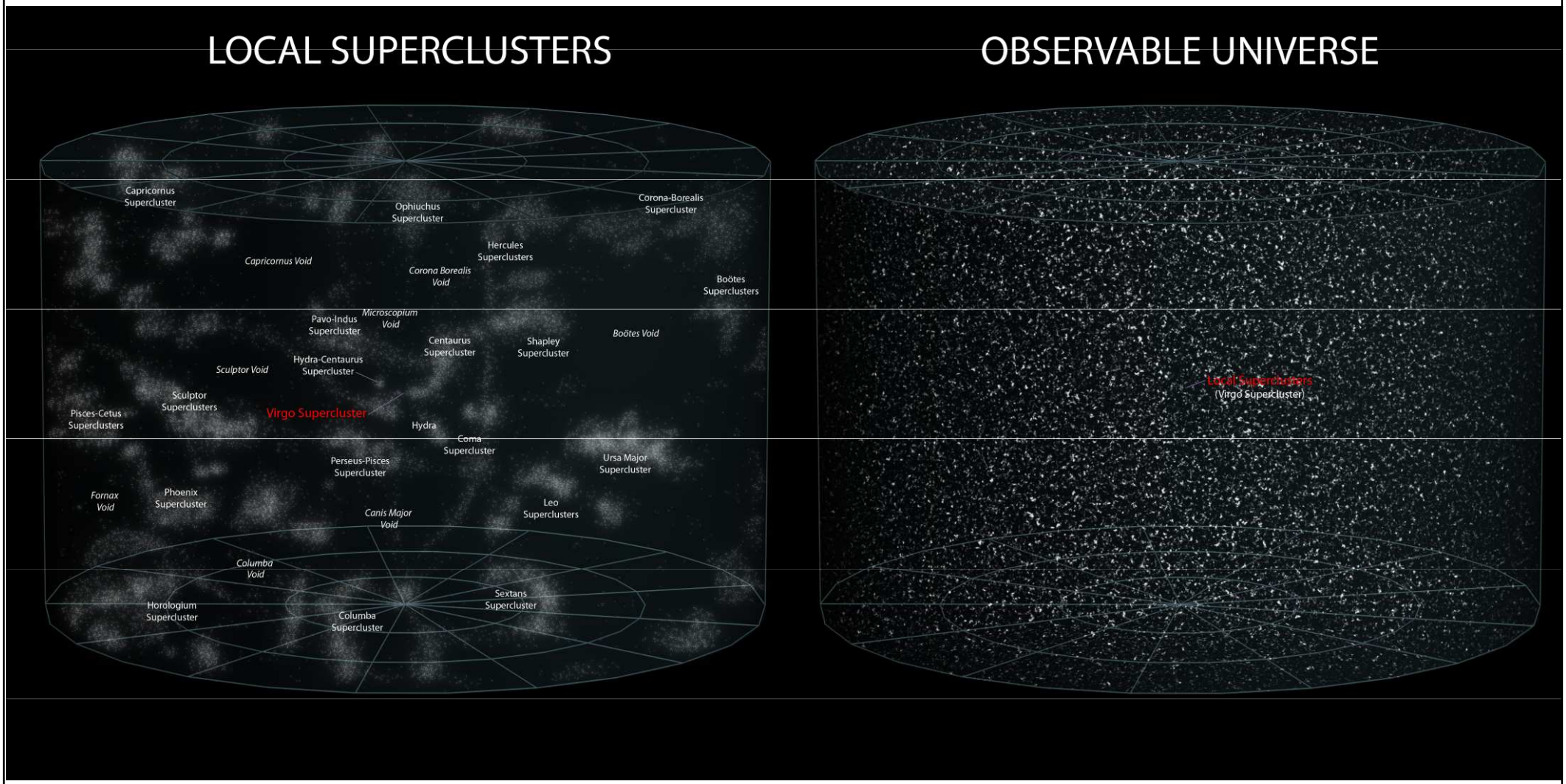
Kosmologický princip: Vesmír je ve velkém měřítku homogenní a izotropní.

Zrod vskutku vědecké kosmologie: 1917, Einsteinův statický vesmír



https://en.wikipedia.org/wiki/Flammarion_engraving


MILKY WAY GALAXY
Solar Interstellar Neighborhood
LOCAL GALACTIC GROUP
Sextans B
Sextans A
Leo A
NGC 3109
Antlia Dwarf
Leo I
Leo II
Canes Dwarf
Ursa Major I
Sextans Dwarf
Ursa Major II
Boötes Dwarf
Ursa Minor Dwarf
Draco Dwarf
IC 10
Large Magellanic Cloud
Small Magellanic Cloud
Milky Way Galaxy
Sagittarius Dwarf
Carina Dwarf
NGC 185
NGC 147
Sculptor Dwarf
Fornax Dwarf
M110
Andromeda Galaxy (M31)
Andromeda I
M32
NGC 6822
Triangulum Galaxy (M33)
Andromeda II
Andromeda III
Phoenix Dwarf
Pisces Dwarf
IC 1613
Aquarius Dwarf
SagDIG
Pegasus Dwarf
Cetus Dwarf
Tucana Dwarf
WLM


LOCAL SUPERCLUSTERS
OBSERVABLE UNIVERSE
Capricornus Supercluster
Ophiuchus Supercluster
Corona-Borealis Supercluster
Hercules Superclusters
Capricornus Void
Corona Borealis Void
Boötes Superclusters
Microscopium Void
Pavo-Indus Supercluster
Centaurus Supercluster
Shapley Supercluster
Boötes Void
Hydra-Centaurus Supercluster
Sculptor Void
Sculptor Superclusters
Pisces-Cetus Superclusters
Virgo Supercluster
Hydra
Coma Supercluster
Perseus-Pisces Supercluster
Ursa Major Supercluster
Fornax Void
Phoenix Supercluster
Canis Major Void
Leo Superclusters
Columba Void
Sextans Supercluster
Horologium Supercluster
Columba Supercluster
Local Supercluster
(Virgo Supercluster)

První revoluce v kosmologii.

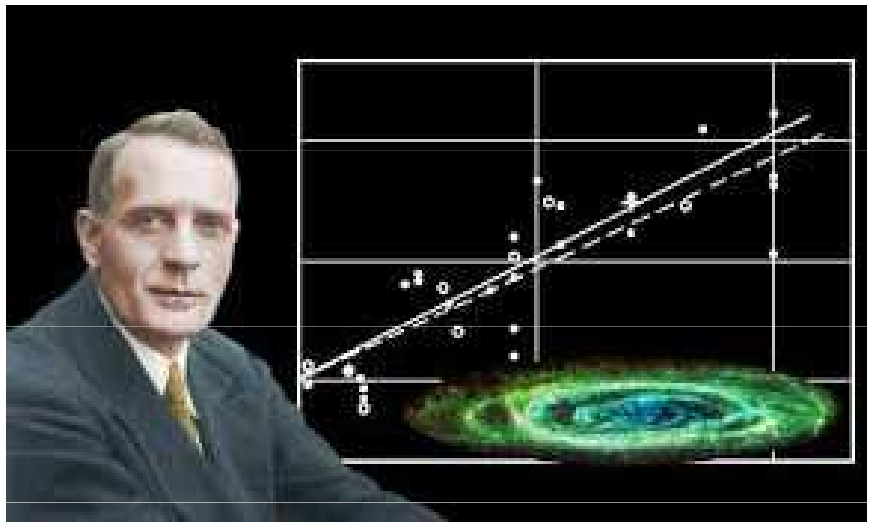
Objev rudého posuvu, rozpínání vesmíru

$$ds^2 = c^2dt^2 - R^2(t)\left[\frac{dr^2}{1-\varepsilon r^2} + r^2\left(d\vartheta^2 + \sin^2\vartheta d\varphi^2\right)\right] \qquad \varepsilon = \begin{cases} -1 \\ 0 \\ 1 \end{cases}$$

FLRW metrika homogenního a izotropního vesmíru

$$\ddot{R} = -\frac{4}{3}\pi\rho_o G\frac{1}{R^2} + \frac{1}{3}\Lambda R \qquad \dot{R} = \frac{dR}{dt},\ \ddot{R} = \frac{d^2R}{dt^2}$$

vývoj vesmíru podle Einsteinových rovnic



rudý posuv a pozorovatelné veličiny

$$z = \frac{\lambda - \lambda_o}{\lambda_o} = \frac{f_o - f}{f_o}$$

$$1 + z = \frac{R}{R_o} \qquad z \approx \frac{r}{c}H = \frac{v}{c}$$

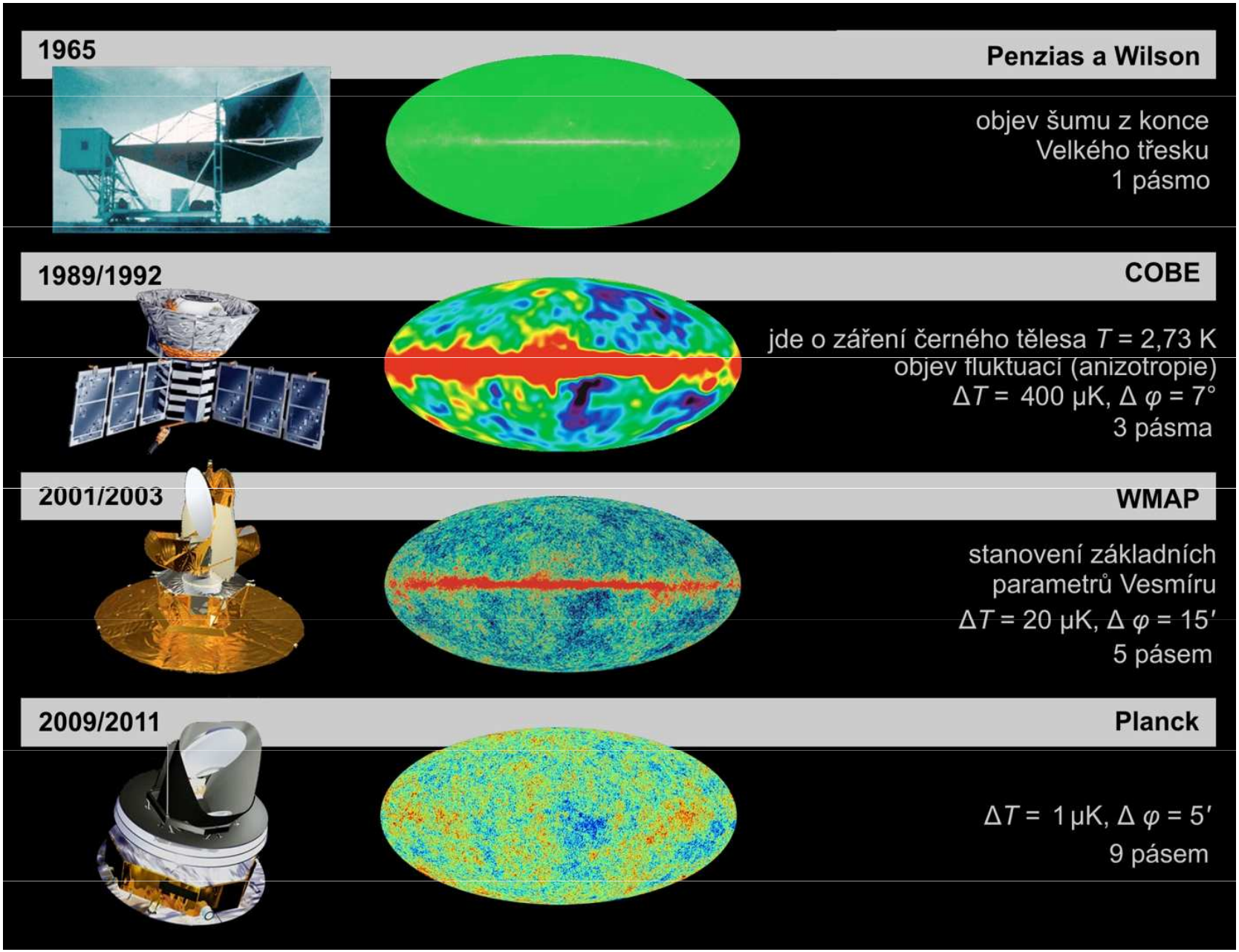
$$H = \frac{\dot{R}}{R}$$ Hubbleova konstanta

$$q = \frac{-R\ddot{R}}{\dot{R}^2}$$ decelerační parametr

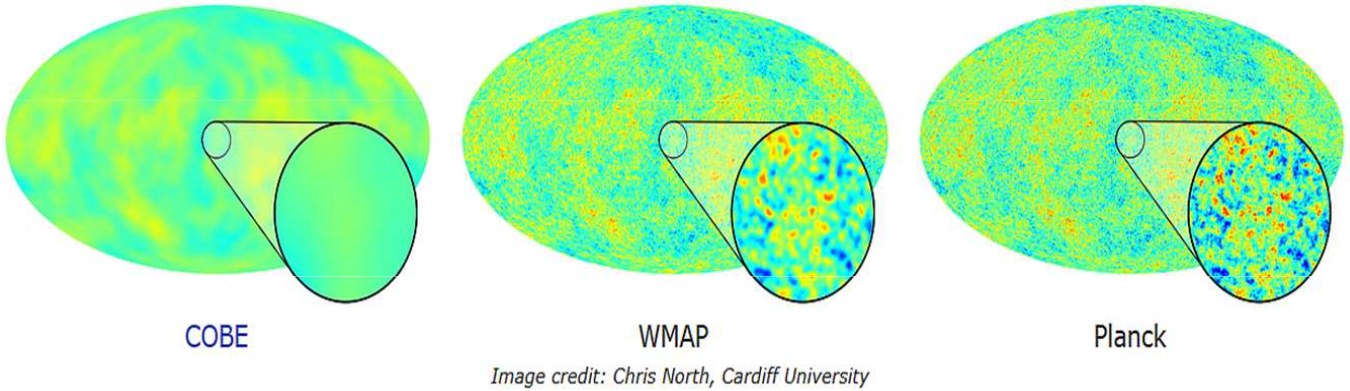
https://en.wikipedia.org/wiki/Redshift#History

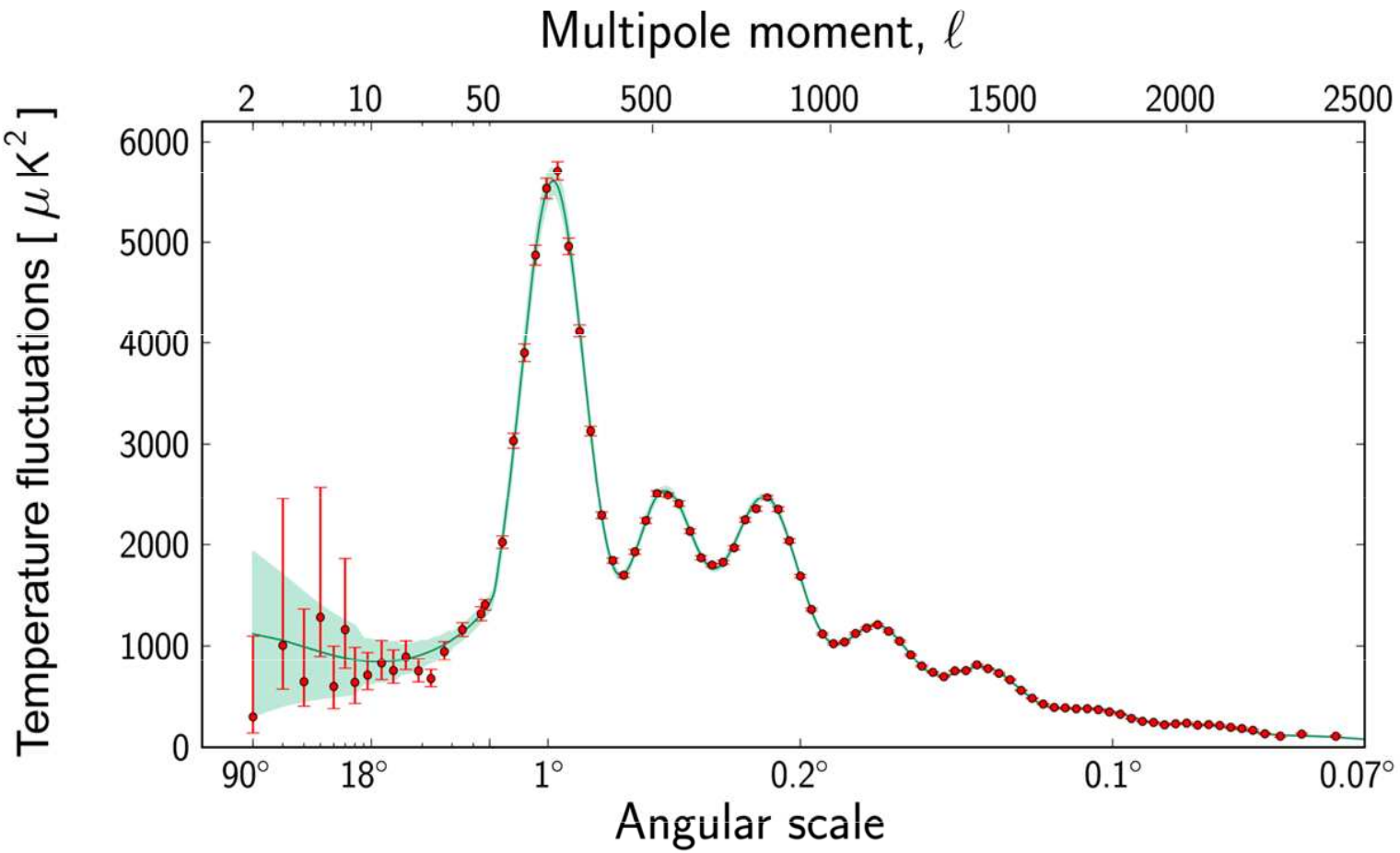
Druhá revoluce.

1978 Arno A. Penzias, Robert W. Wilson
Nobel.cena za objev kosmického mikrovlnného reliktního záření



Druhá revoluce.

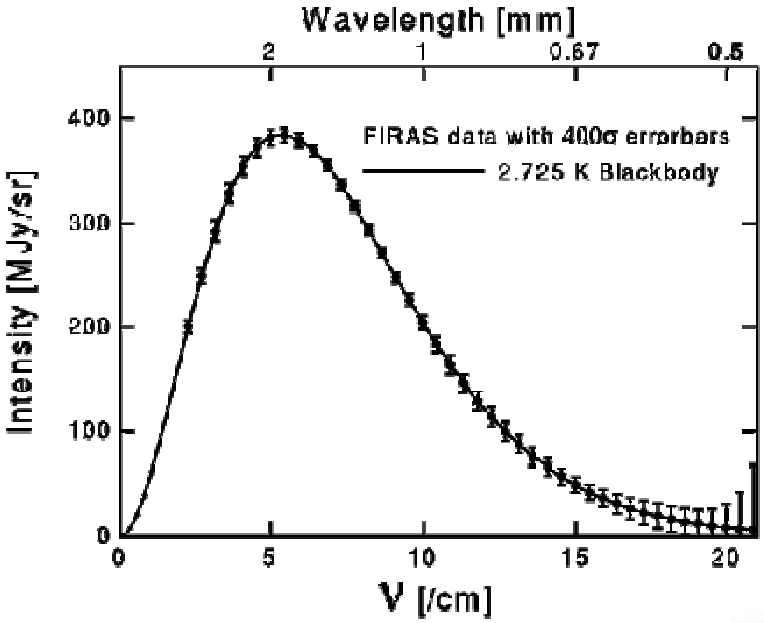


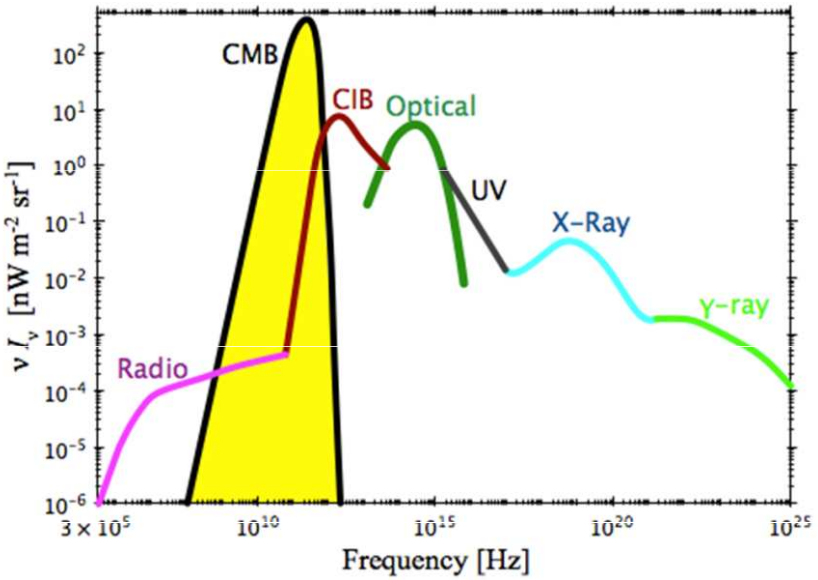


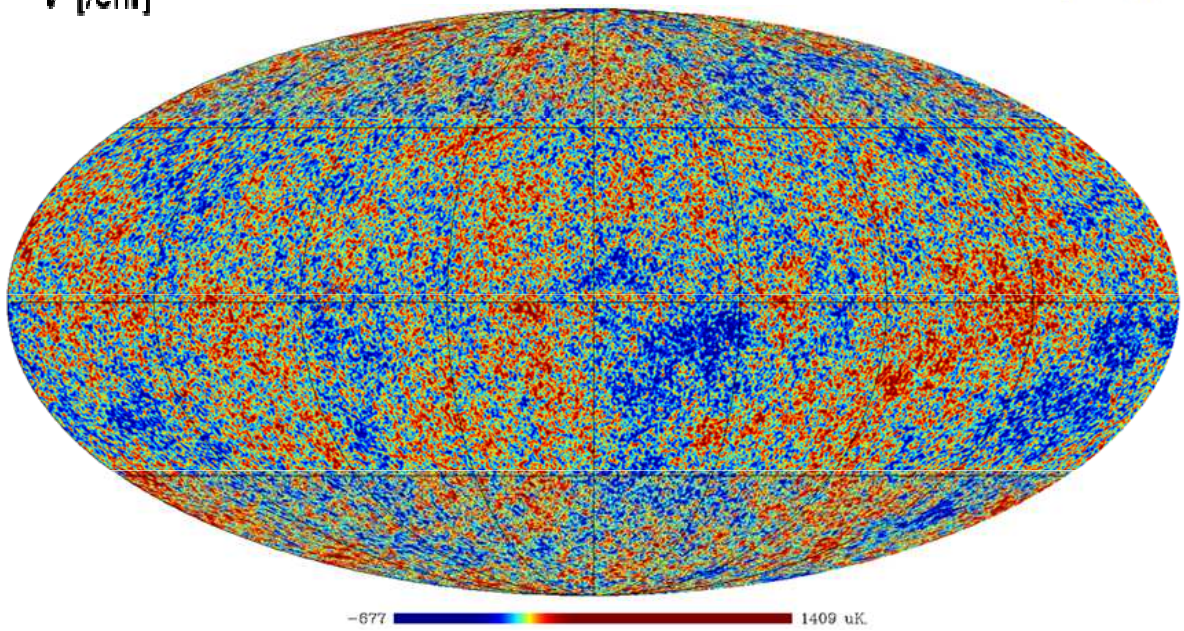
http://map.gsfc.nasa.gov/resources/camb_tool/index.html

Druhá revoluce

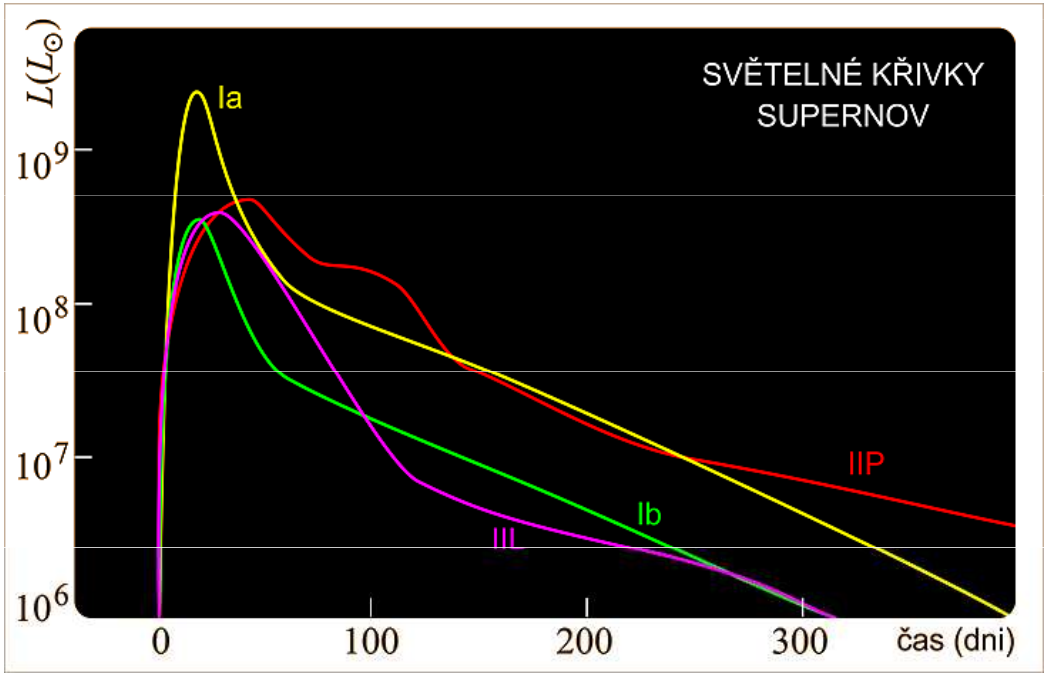
2006 John C. Mather, George F. Smoot
Nobel.cena za objev černotělesové povahy a anizotropie reliktního záření





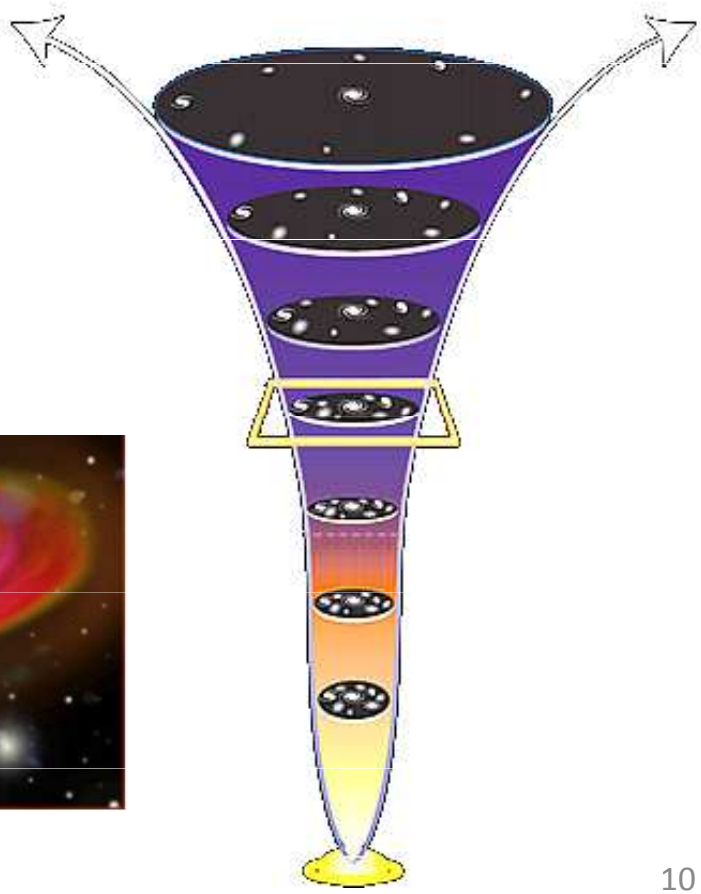


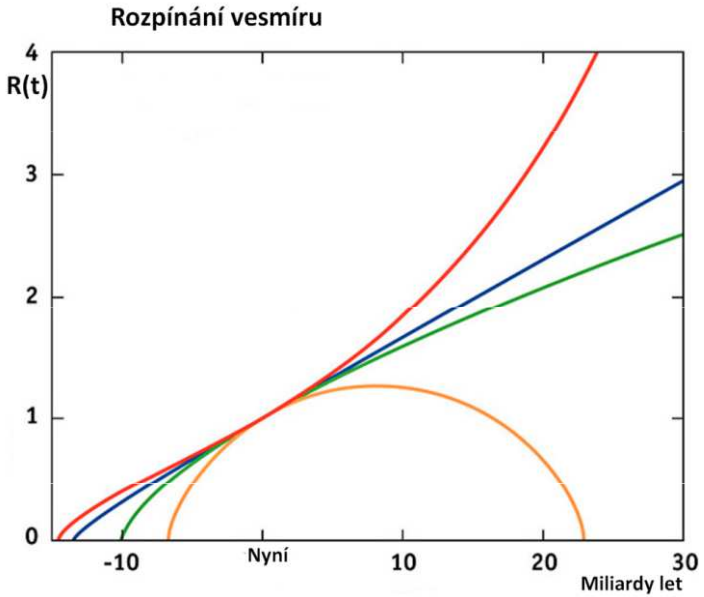
Třetí revoluce.

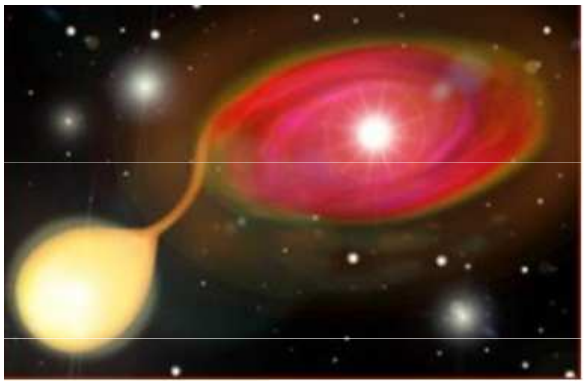


2011 Saul Pearlmutter, Brian P. Schmidt
Adam C.Riess
Nobelova cena za objev zrychlujícího se rozpínání vesmíru odhalený pozorováním vzdálených supernov

Zrychlené rozpínání.

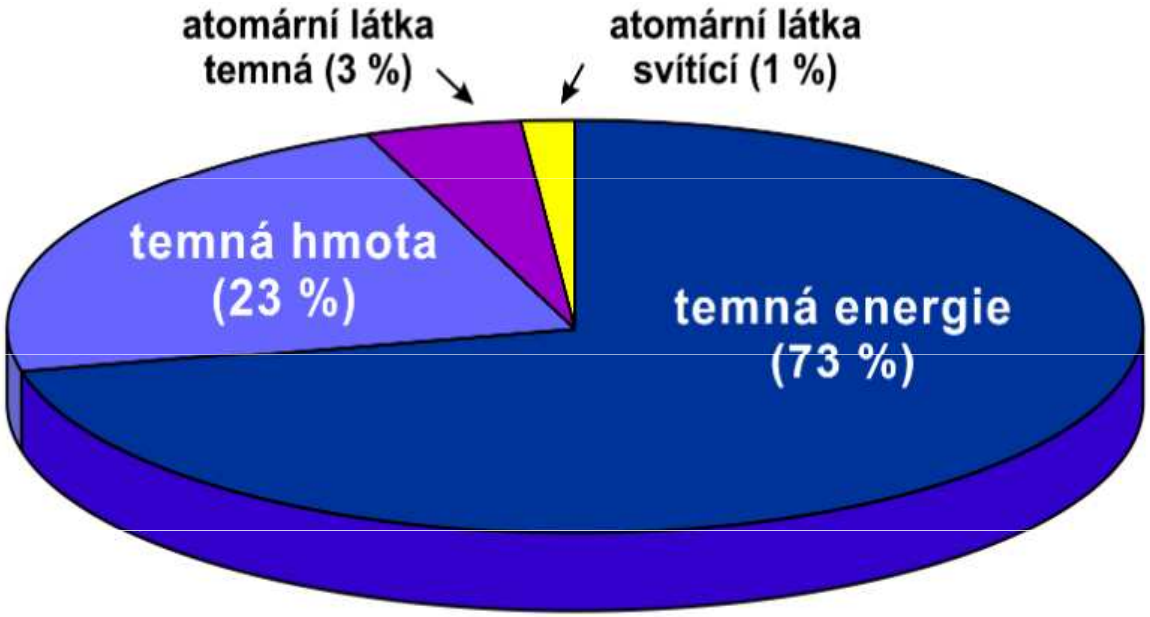






Třetí revoluce

Lambda CDM vesmír.

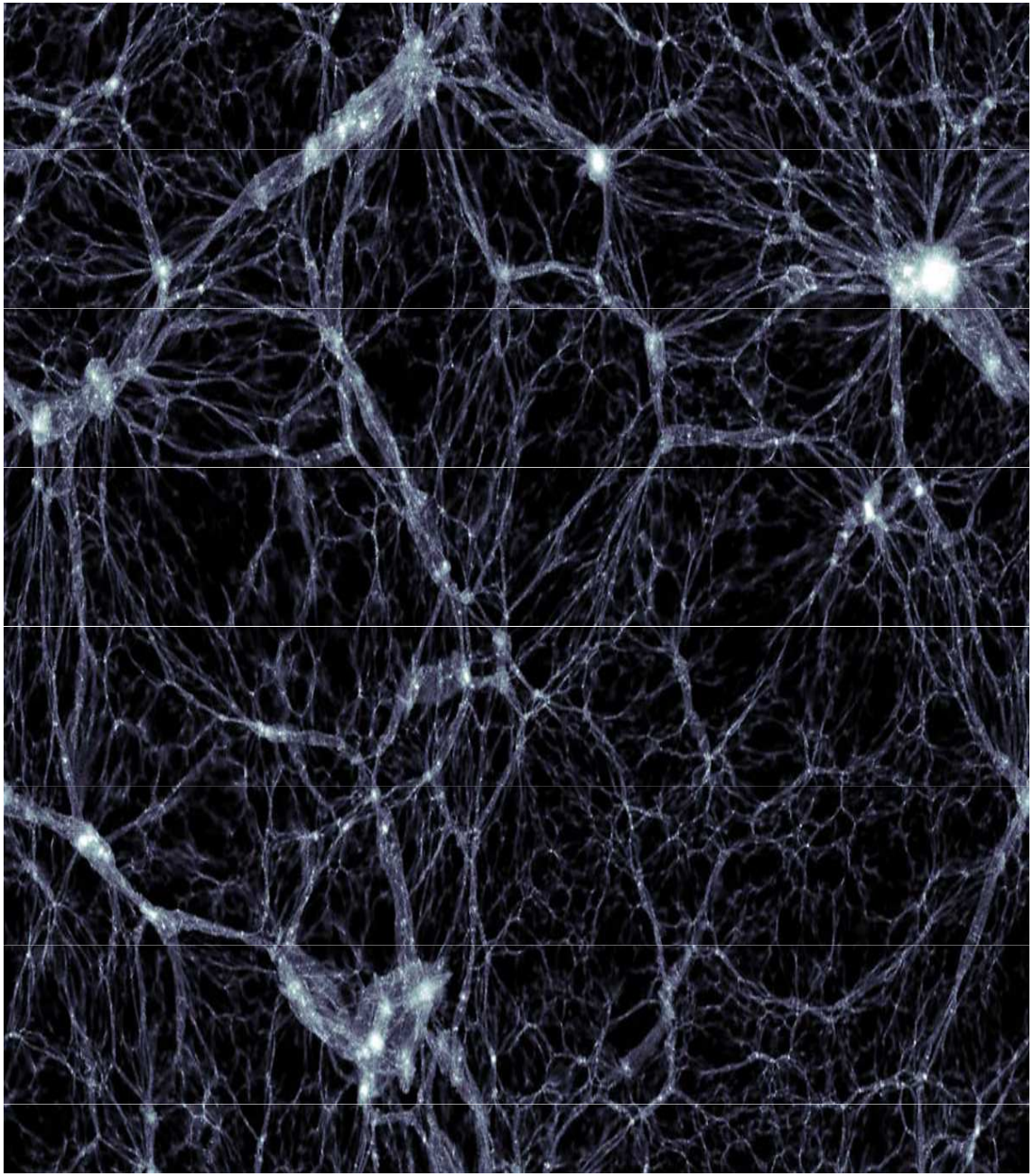


Temná hmota a temná energie.

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

http://www.osel.cz/index.php?obsah=36

Pochybnosti o temné hmotě a temné energii.



(Courtesy: Markus Haider/Illustris Collaboration)

Problém:

- Struktury
- Horizontu
- Plochosti
- Expanze

Speciální počáteční podmínky, nebo inflace?

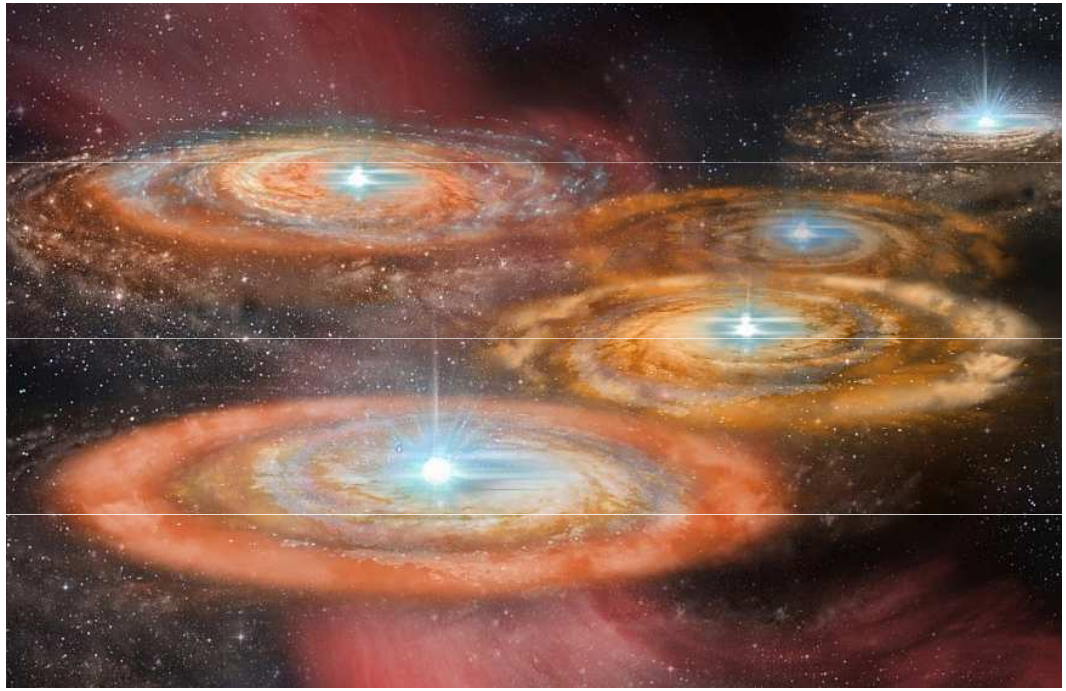
Rozpíná se vesmír opravdu zrychleně?
Je tím dokázána existence temné energie?

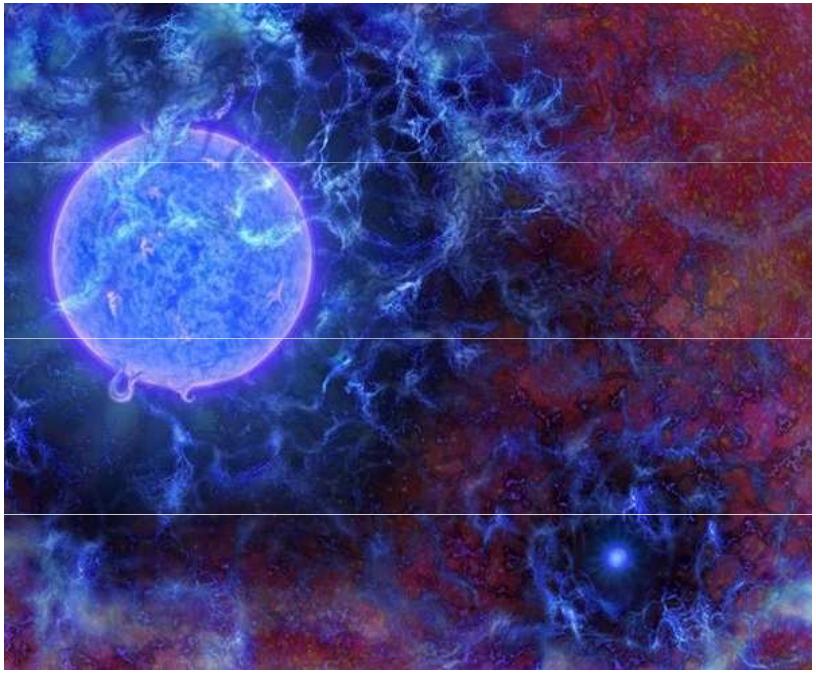
Nejstarší fosilie
Největší a nejmenší pozorované objekty

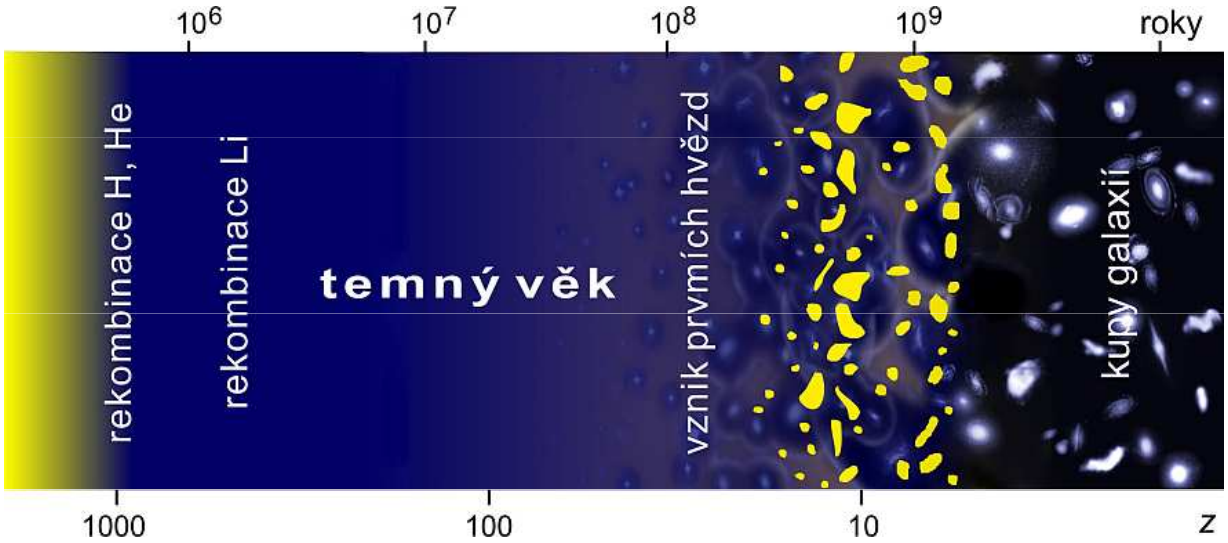
https://physicsworld.com/a/the-dark-energy-deniers/

První hvězdy.

první hvězdy nulté generace

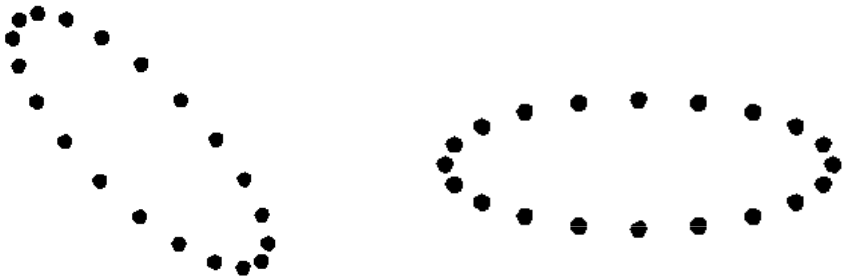


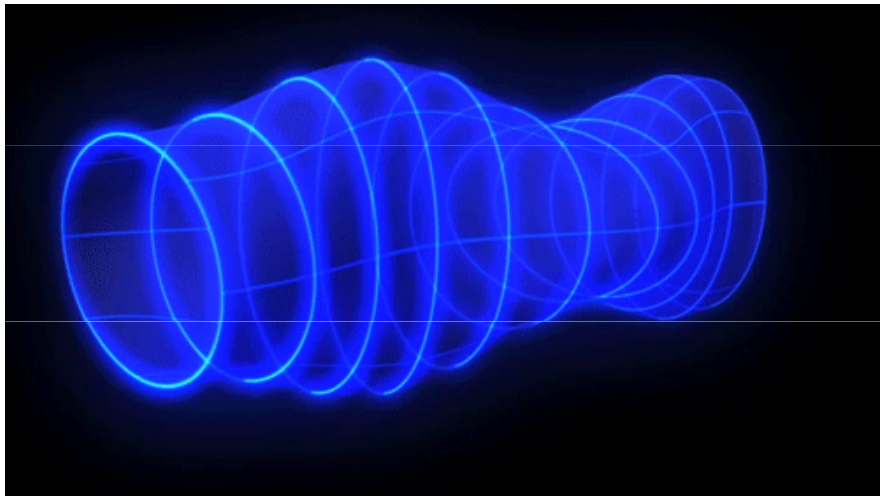




http://www.astronomy.com/news/2018/03/fingerprinting-the-very-first-stars

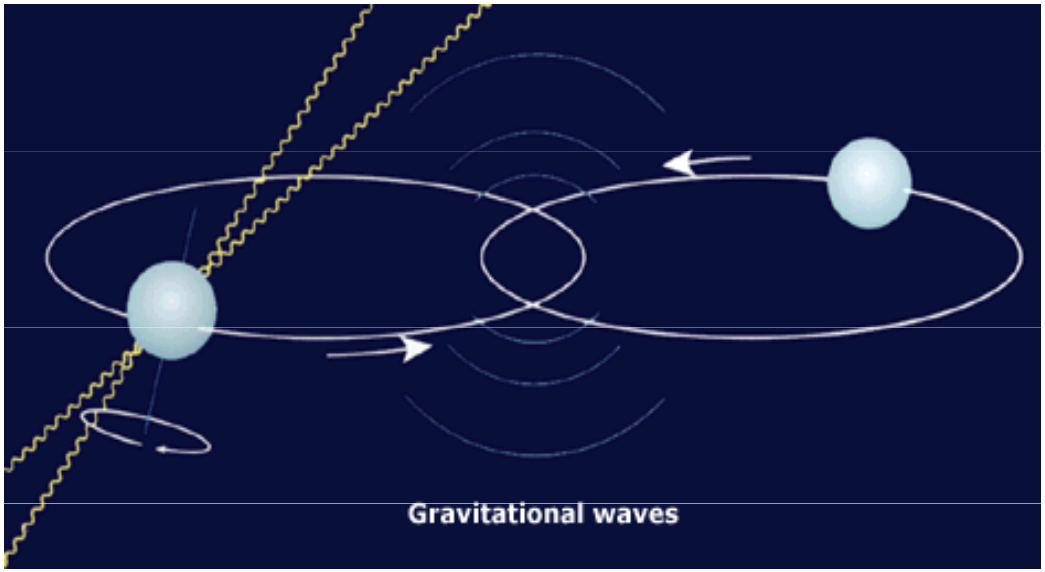
Gravitační vlny.

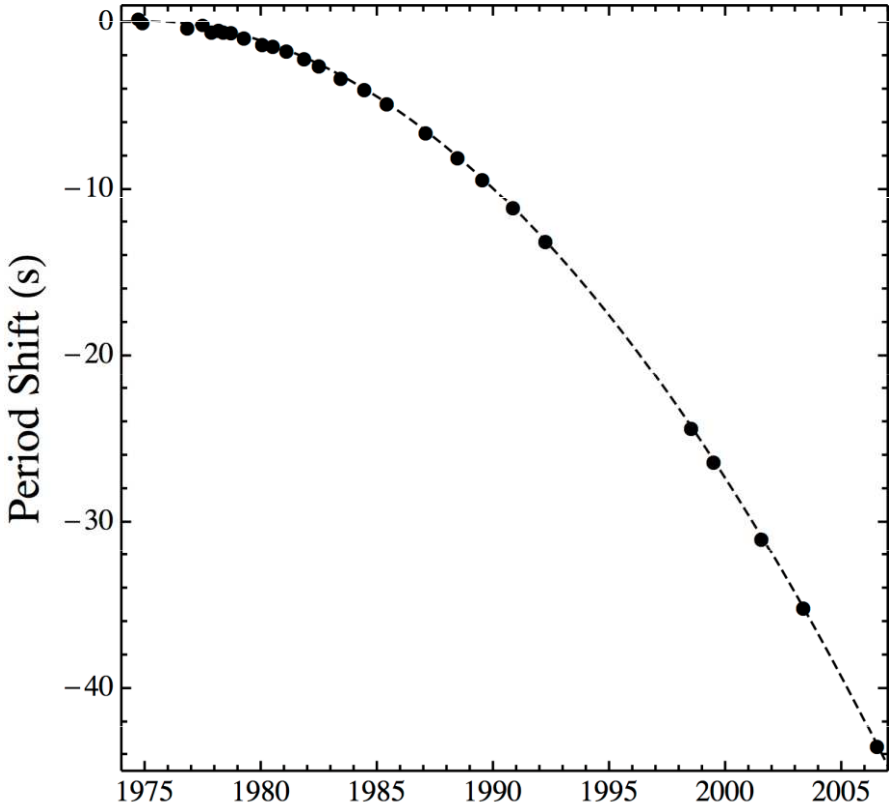


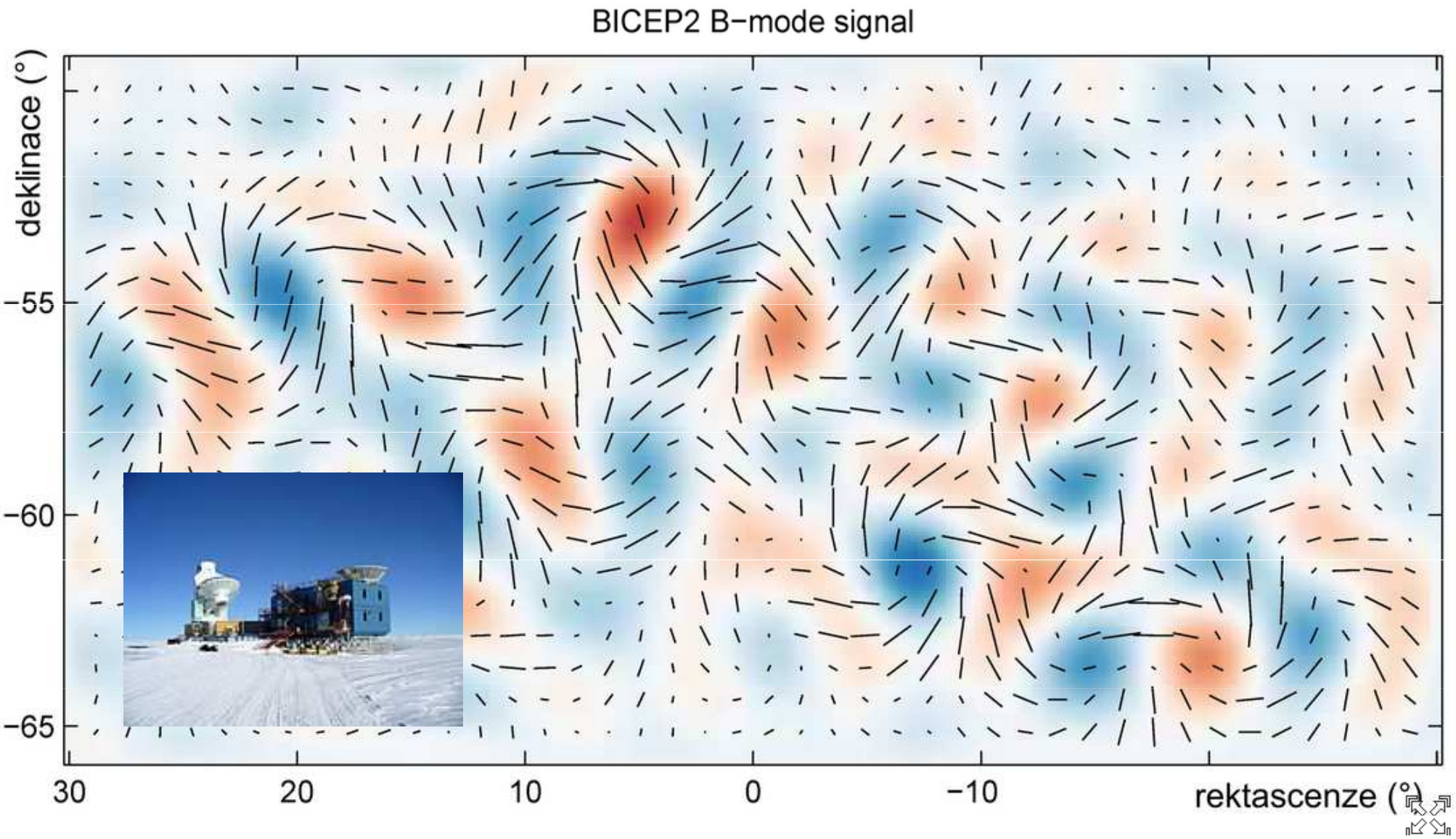


1993 Russell Alan Hulse a Joseph Hooton Taylor
Nobelova cena za objev nového typu pulsaru, který otevřel nové možnosti pro studium gravitace

Možný zdroj gravitačních vln

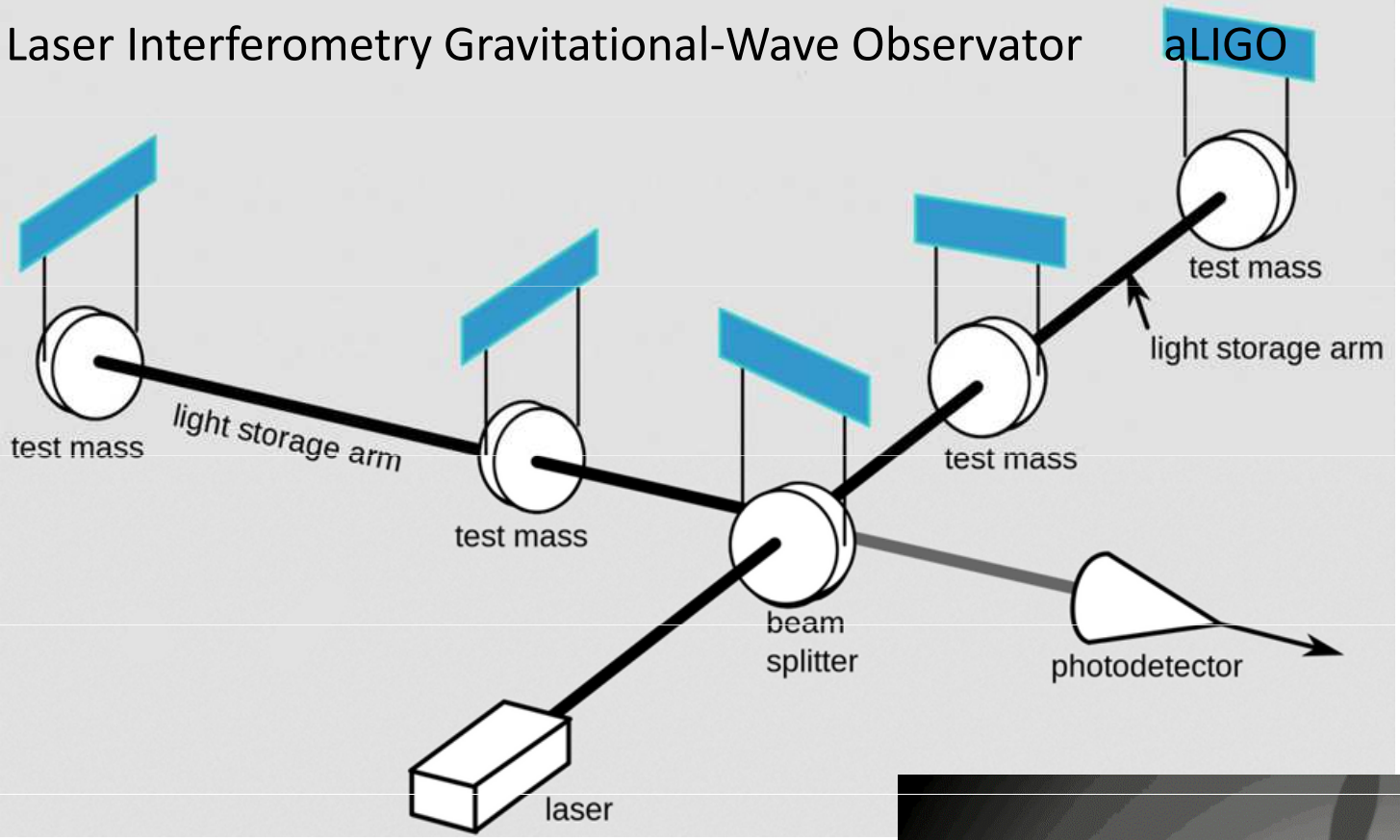






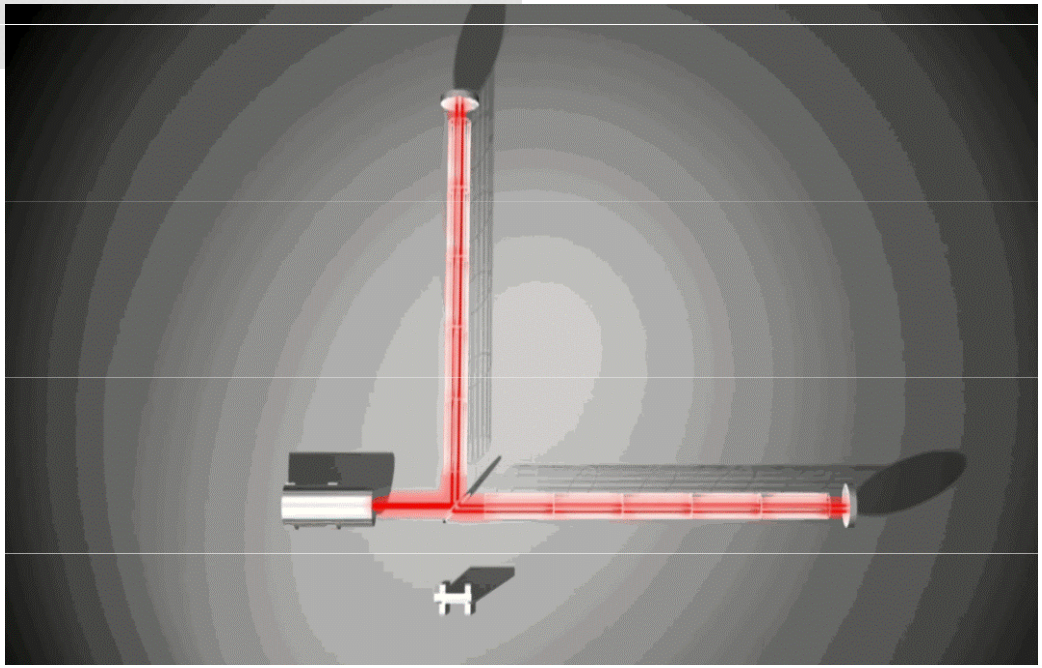
Snaha o nepřímou detekci reliktních gravitačních vln observatoř BICEP (2014) na Jižní pólu
- srovnání s měřením sondy Planck výsledky nepotvrdilo

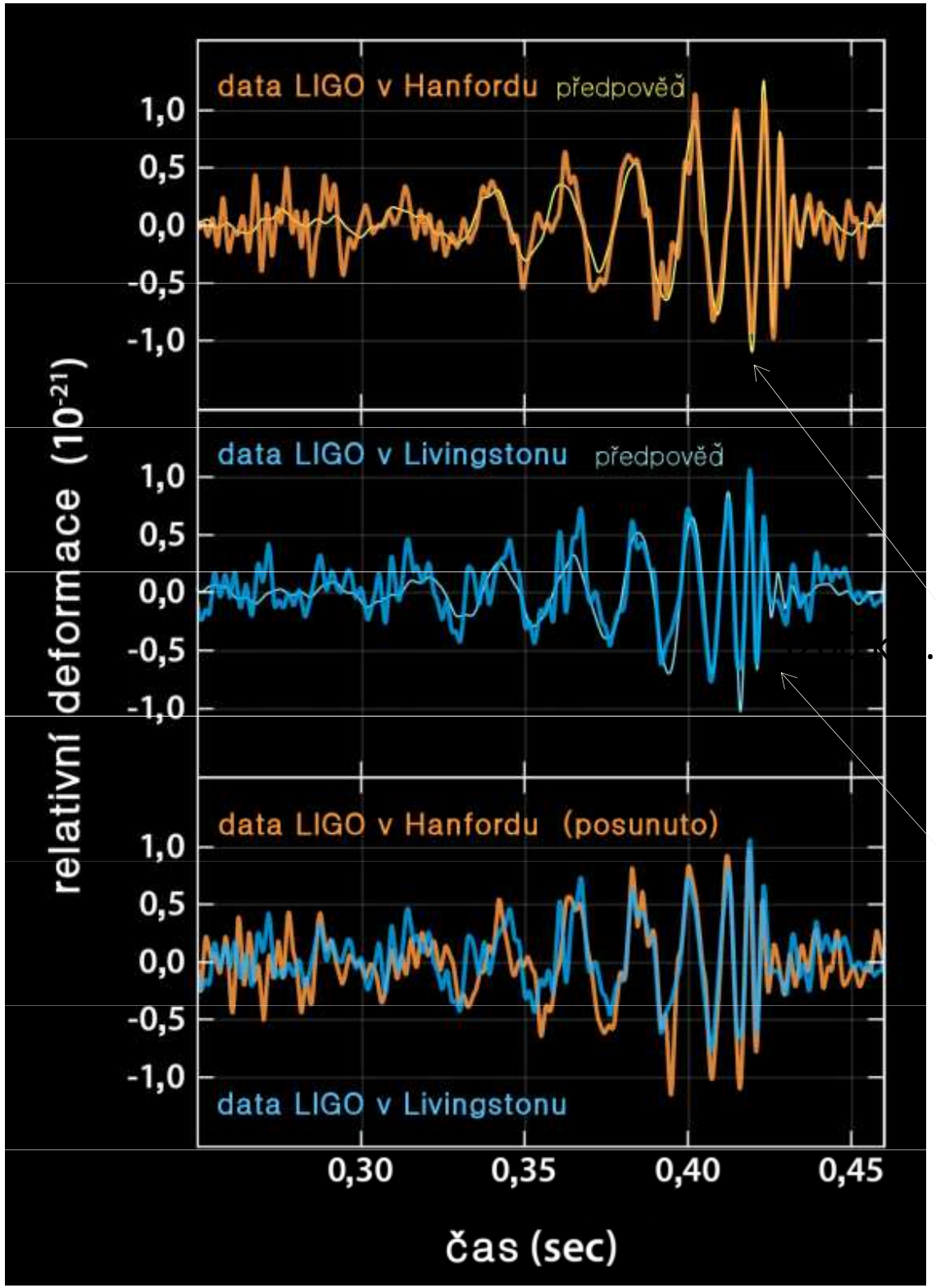
Laser Interferometry Gravitational-Wave Observator aLIGO



4 km dlouhá ramena

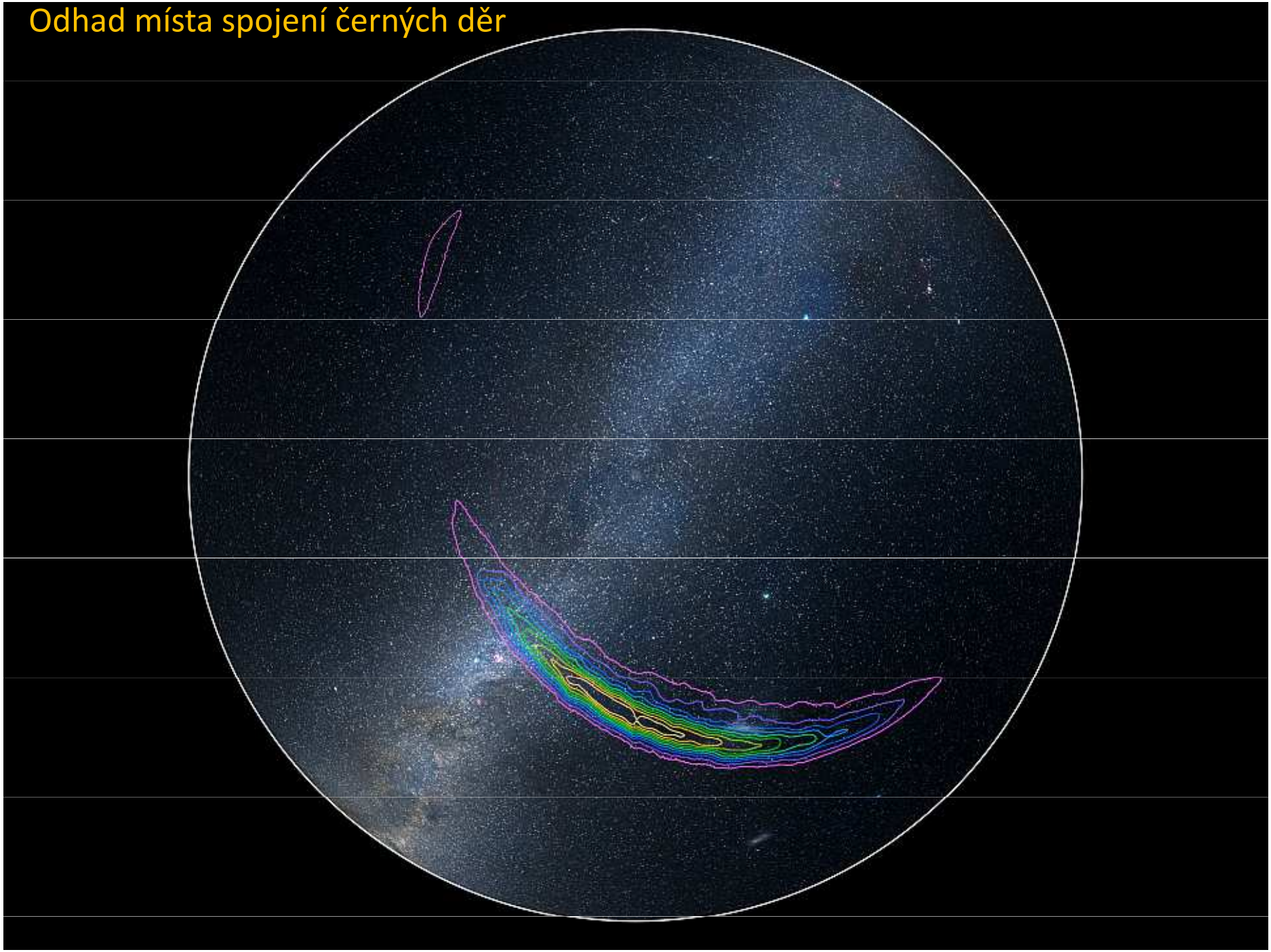
$$\frac{\Delta L}{L} \sim 10^{-23}$$





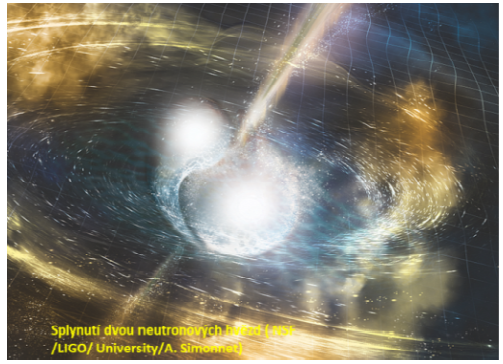
14.9.2015 11. února 2016

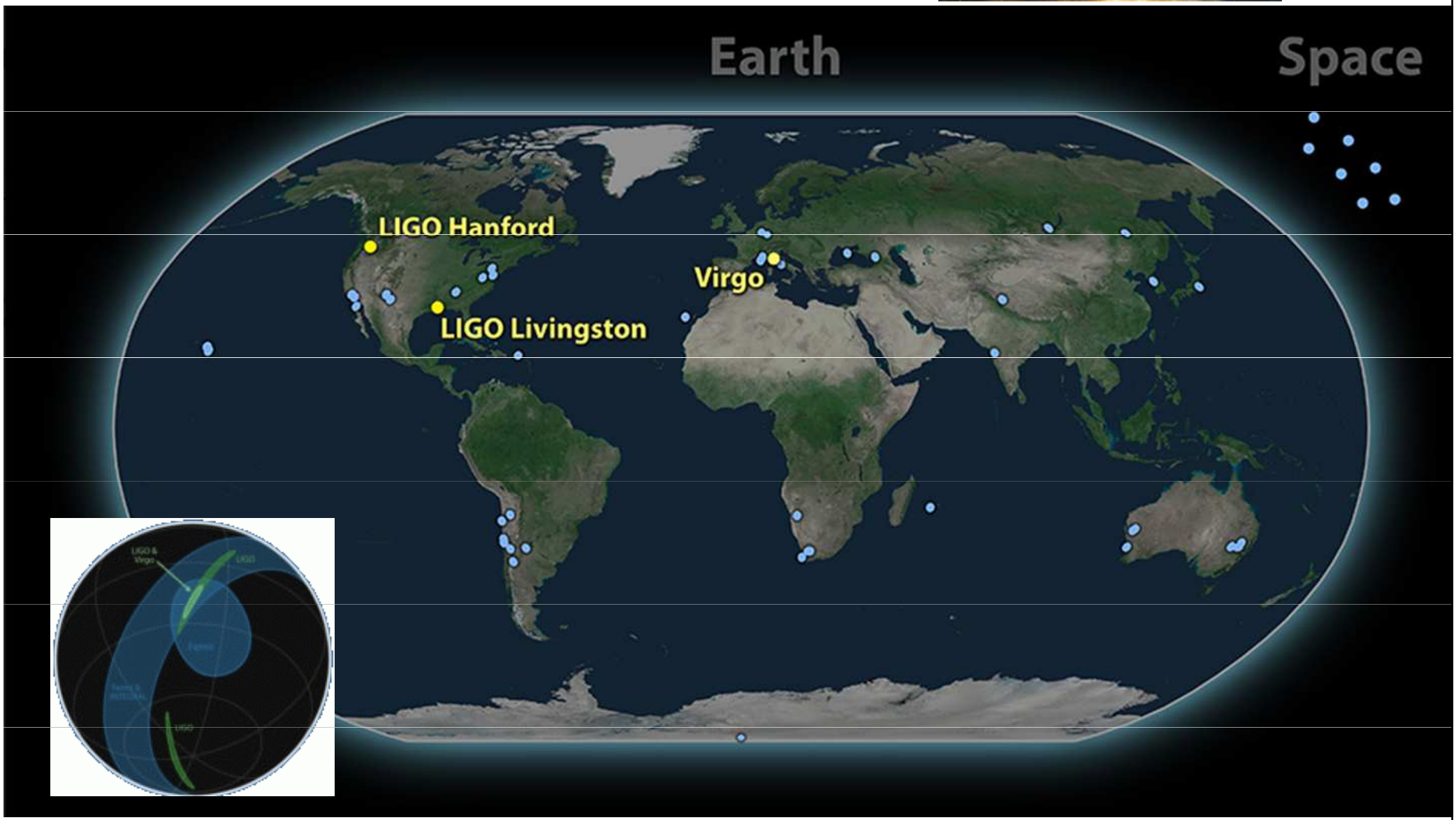
Odhad místa spojení černých děr



Aldebaran Bulletin, únor 2016 Petr Kulhánek: http://www.aldebaran.cz/bulletin/2016_06_gra.php

Detekce gravitační vlny spolu s gama zářením vzniklým při splývání 2 neutronových hvězd.





Dosavadní záchyty

https://en.wikipedia.org/wiki/List_of_gravitational_wave_observations

List of binary merger events[2][3]

GW event	Detection time (UTC)	Date published	Location area[n 2] (deg^2)	Luminosity distance (Mpc)[n 3]	Energy radiated ($c^2M_\odot$)[n 4]	Chirp mass ($M_\odot$)[n 5]	Effective spin[n 6]	Primary		Secondary		Remnant		
								Type	Mass ($M_\odot$)	Type	Mass ($M_\odot$)	Type	Mass ($M_\odot$)	Spin[n 7]
GW150914	2015-09-14 09:50:45	2016-02-11	179; mostly to the south	430^{+150}_{-170}	$3.1^{+0.4}_{-0.4}$	$28.6^{+1.6}_{-1.5}$	$-0.01^{+0.12}_{-0.13}$	BH [n 8]	$35.6^{+4.8}_{-3.0}$	BH [n 9]	$30.6^{+3.0}_{-4.4}$	BH	$63.1^{+3.3}_{-3.0}$	$0.69^{+0.05}_{-0.04}$
GW151012 [fr]	2015-10-12 09:54:43	2016-06-15	1555	1060^{+540}_{-480}	$1.5^{+0.5}_{-0.5}$	$15.2^{+2.0}_{-1.1}$	$0.04^{+0.28}_{-0.19}$	BH	$23.3^{+14.0}_{-5.5}$	BH	$13.6^{+4.1}_{-4.8}$	BH	$35.7^{+9.9}_{-3.8}$	$0.67^{+0.13}_{-0.11}$
GW151226	2015-12-26 03:38:53	2016-06-15	1033	440^{+180}_{-190}	$1.0^{+0.1}_{-0.2}$	$8.9^{+0.3}_{-0.3}$	$0.18^{+0.20}_{-0.12}$	BH	$13.7^{+8.8}_{-3.2}$	BH	$7.7^{+2.2}_{-2.6}$	BH	$20.5^{+6.4}_{-1.5}$	$0.74^{+0.07}_{-0.05}$
GW170104	2017-01-04 10:11:58	2017-06-01	924	960^{+430}_{-410}	$2.2^{+0.5}_{-0.5}$	$21.5^{+2.1}_{-1.7}$	$-0.04^{+0.17}_{-0.20}$	BH	$31.0^{+7.2}_{-5.6}$	BH	$20.1^{+4.9}_{-4.5}$	BH	$49.1^{+5.2}_{-3.5}$	$0.66^{+0.08}_{-0.10}$
GW170608	2017-06-08 02:01:16	2017-11-16	396; to the north	320^{+120}_{-110}	$0.9^{+0.0}_{-0.1}$	$7.9^{+0.2}_{-0.2}$	$0.03^{+0.19}_{-0.07}$	BH	$10.9^{+5.3}_{-1.7}$	BH	$7.6^{+1.3}_{-2.1}$	BH	$17.8^{+3.2}_{-0.7}$	$0.69^{+0.04}_{-0.04}$
GW170729	2017-07-29 18:56:29	2018-11-30	1033	2750^{+1350}_{-1320}	$4.8^{+1.7}_{-1.7}$	$35.7^{+6.5}_{-4.7}$	$0.36^{+0.21}_{-0.25}$	BH	$50.6^{+16.6}_{-10.2}$	BH	$34.3^{+9.1}_{-10.1}$	BH	$80.3^{+14.6}_{-10.2}$	$0.81^{+0.07}_{-0.13}$
GW170809	2017-08-09 08:28:21	2018-11-30	340	990^{+320}_{-380}	$2.7^{+0.6}_{-0.6}$	$25.0^{+2.1}_{-1.6}$	$0.07^{+0.16}_{-0.16}$	BH	$35.2^{+8.3}_{-6.0}$	BH	$23.8^{+5.2}_{-5.1}$	BH	$56.4^{+5.2}_{-3.7}$	$0.70^{+0.08}_{-0.09}$
GW170814	2017-08-14 10:30:43	2017-09-27	87; towards Eridanus	580^{+160}_{-210}	$2.7^{+0.4}_{-0.3}$	$24.2^{+1.4}_{-1.1}$	$0.07^{+0.12}_{-0.11}$	BH	$30.7^{+5.7}_{-3.0}$	BH	$25.3^{+2.9}_{-4.1}$	BH	$53.4^{+3.2}_{-2.4}$	$0.72^{+0.07}_{-0.05}$
GW170817	2017-08-17 12:41:04	2017-10-16	16; NGC 4993	40^{+10}_{-10}	≥ 0.04	$1.186^{+0.001}_{-0.001}$	$0.00^{+0.02}_{-0.01}$	NS	$1.46^{+0.12}_{-0.10}$	NS	$1.27^{+0.09}_{-0.09}$	NS [n 10]	≤ 2.8[n 11]	≤ 0.89
GW170818	2017-08-18 02:25:09	2018-11-30	39	1020^{+430}_{-360}	$2.7^{+0.5}_{-0.5}$	$26.7^{+2.1}_{-1.7}$	$-0.09^{+0.18}_{-0.21}$	BH	$35.5^{+7.5}_{-4.7}$	BH	$26.8^{+4.3}_{-5.2}$	BH	$59.8^{+4.8}_{-3.8}$	$0.67^{+0.07}_{-0.08}$
GW170823	2017-08-23 13:13:58	2018-11-30	1651	1850^{+840}_{-840}	$3.3^{+0.9}_{-0.8}$	$29.3^{+4.2}_{-3.2}$	$0.08^{+0.20}_{-0.22}$	BH	$39.6^{+10.0}_{-6.6}$	BH	$29.4^{+6.3}_{-7.1}$	BH	$65.6^{+9.4}_{-6.6}$	$0.71^{+0.08}_{-0.10}$

B. P. Abbott,[1] R. Abbott,[1] T. D. Abb
R. X. Adhikari,[1] V. B. Adya,[8] C.
A. Ain,[14] P. Ajith,[15] B. Allen,[8,16,17]
M. C. Araya,[1] C. C. Arceneaux,[21]
S. M. Aston,[6] P. Astone,[28] P.
F. Baldaccini,[32,33] G. Ballardin,[34] S.
B. Barr,[36] L. Barsotti,[10] M. Barsug
J. C. Batch,[37] C. Baune,[8] V. Bav
C. J. Bell,[36] B. K. Berger,[1] J. Bergn
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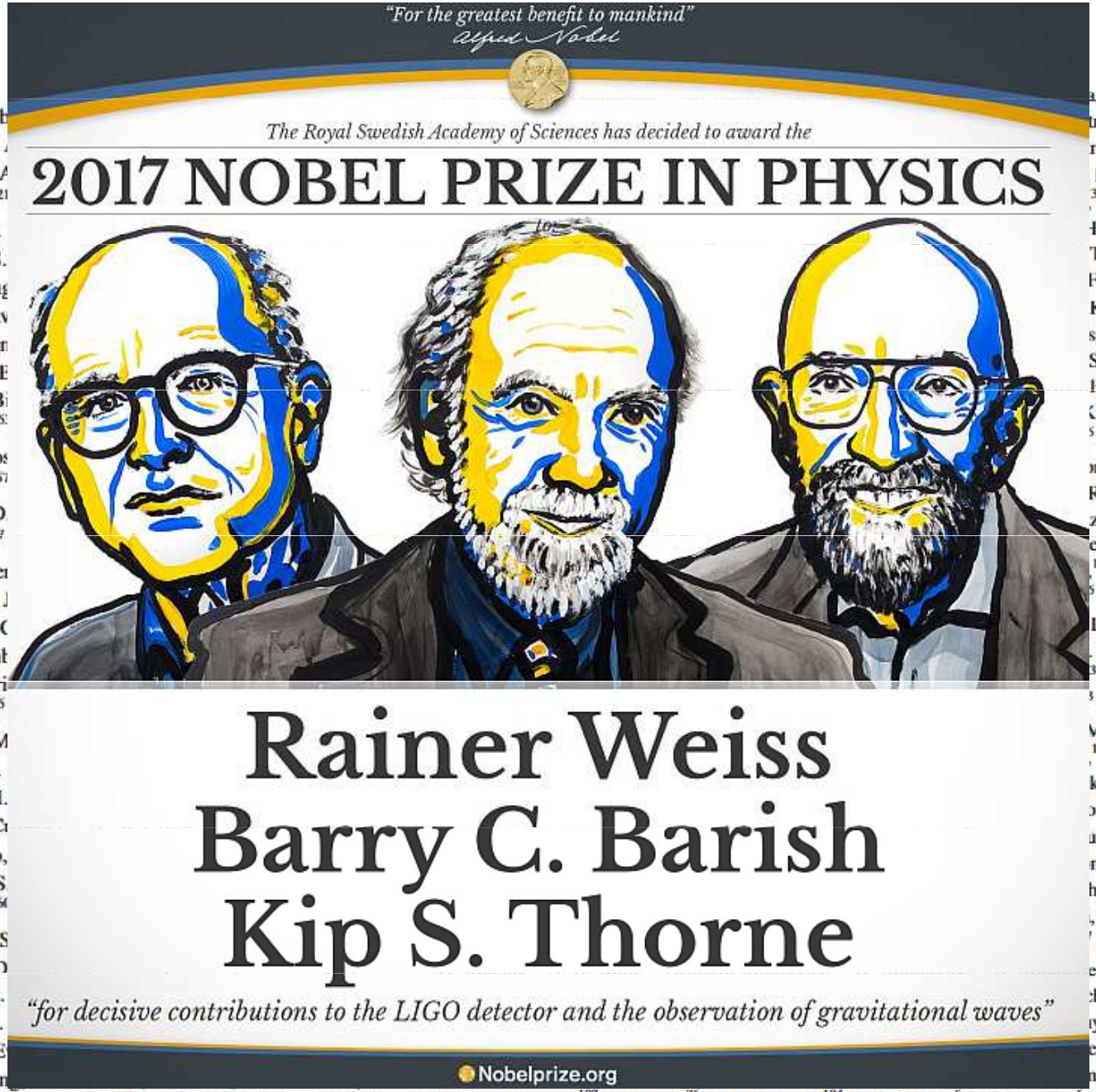
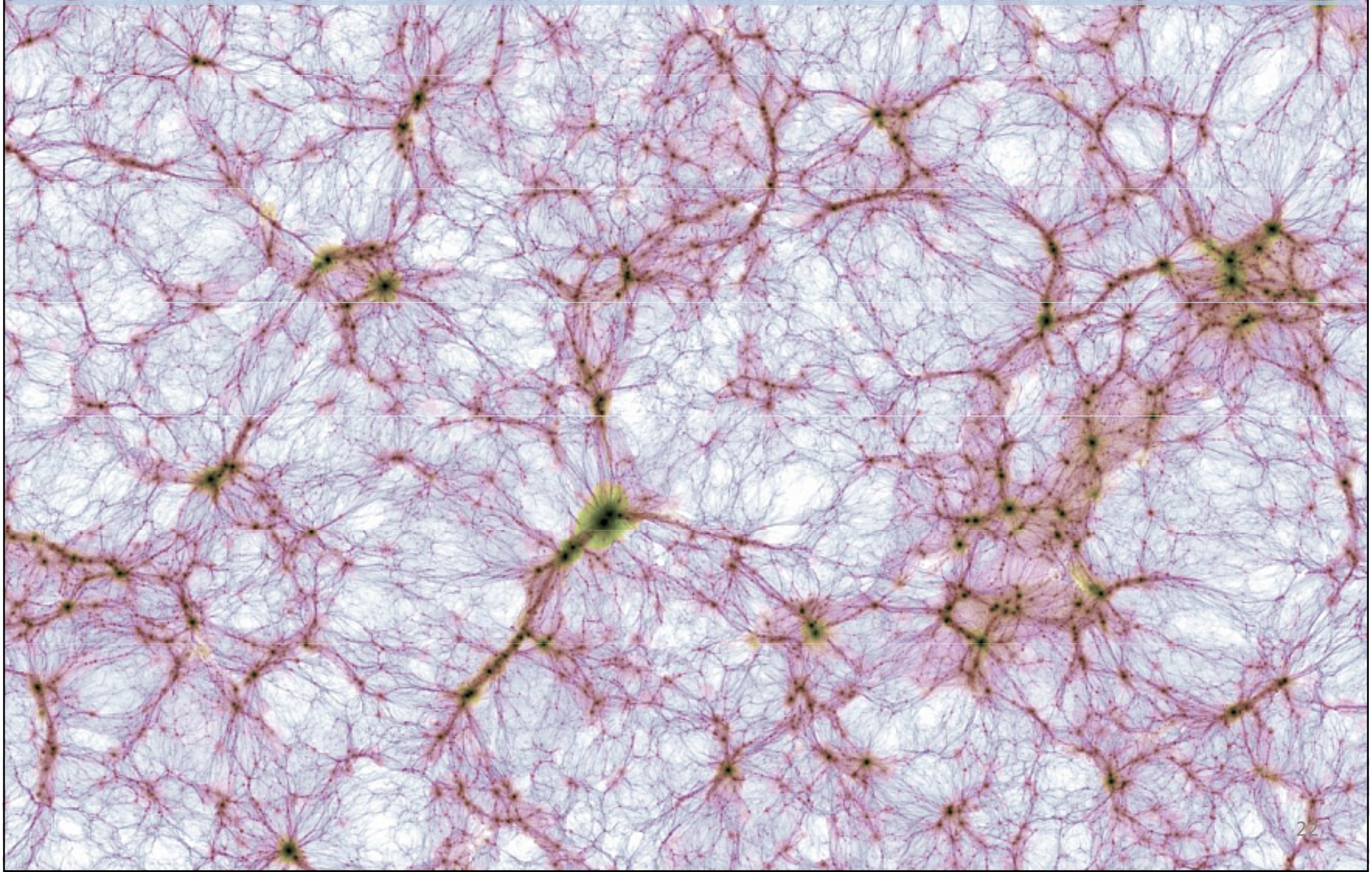


Řez kosmickou velkoplošnou strukturou v simulaci projektu Illustris. (2014)
Jas udává hmotnostní hustotu a barva zobrazuje teplotu plynu obyčejné ("baryonické") hmoty.
Zobrazená oblast -1,2 miliardy světelných let.



Zdroje:
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