

Co jsme věděli (a nevěděli) před 100 lety



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Astronomický ústav MFF UK



1916: Karl Schwarzschild

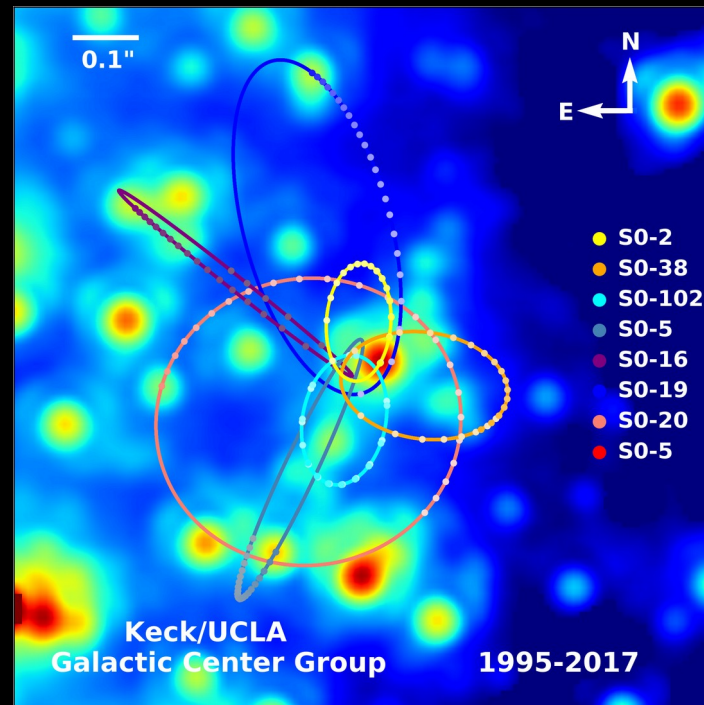
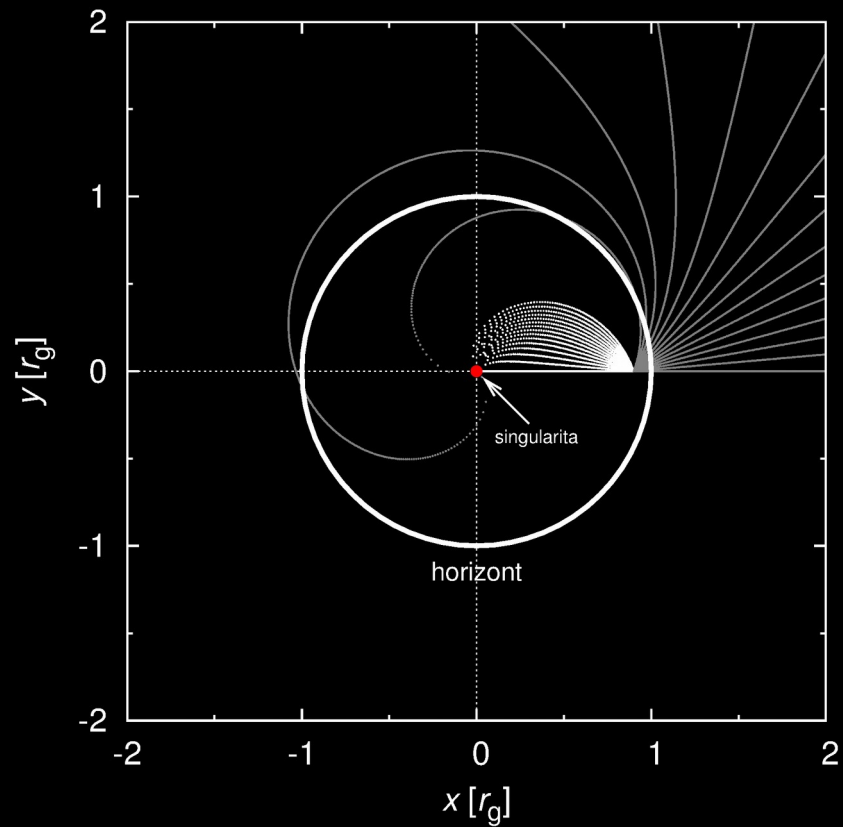
- * 1873 Frankfurt † 1916 Postupim
- Göttingen; invalida z 1. světové války
- přesné sférické řešení EFE, Schwarzschildova metrika a poloměr:

$$g_{ik} = \begin{pmatrix} 1 - r_S/r & 0 & 0 & 0 \\ 0 & -(1 - r_S/r)^{-1} & 0 & 0 \\ 0 & 0 & -r^2 & 0 \\ 0 & 0 & 0 & -r^2 \sin^2 \vartheta \end{pmatrix}$$

$$r_S = \frac{2GM}{c^2}$$



Černé díry



Ghez et al. (2017), Abuter et al. (2018); * S0-2: $0.0255 c$, GR

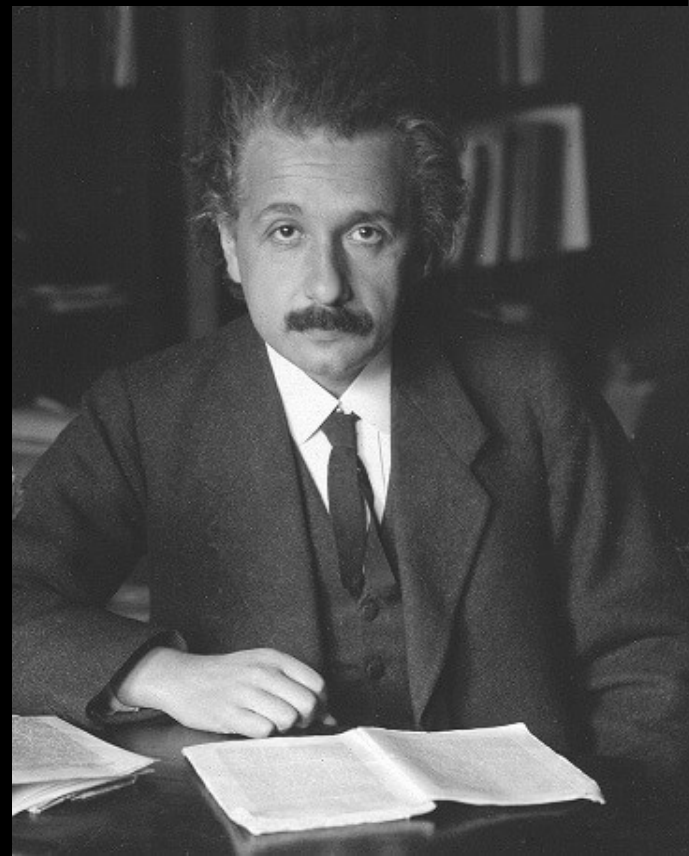
1917: Albert Einstein

- * 1879 Ulm † 1955 Princeton
- Bern, Zürich, Praha, Berlín, ...
- objev stimulované emise, Phys. Zeit. **18**, 121-128
- Light Amplification by Stimulated Emission of Radiation = LASER; konstrukce až Maiman (1960)

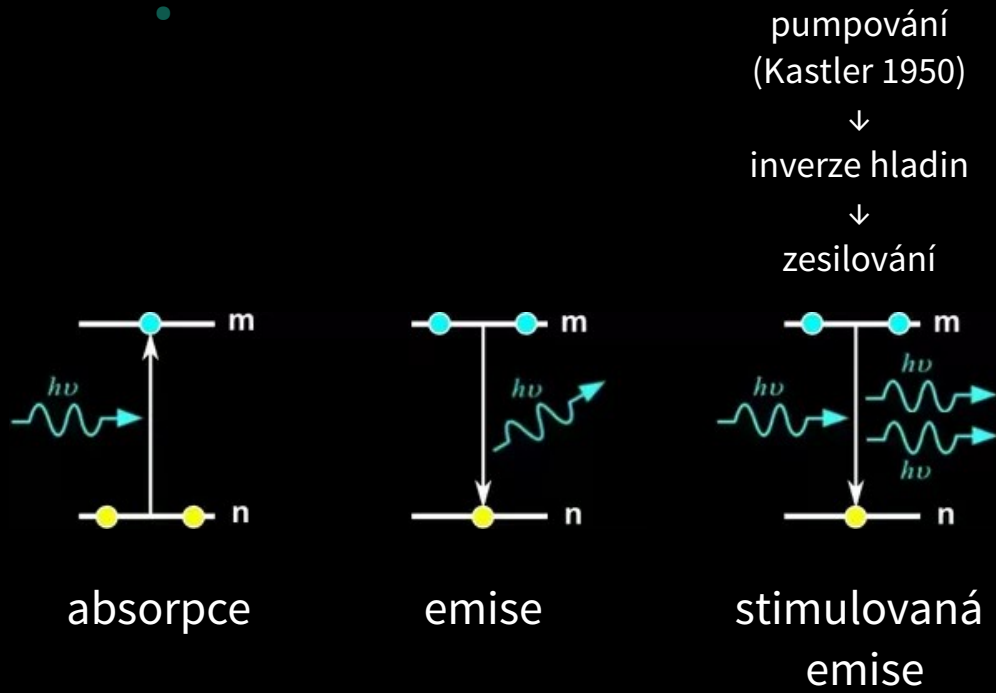
$$j_{\nu\rho} = \frac{h\nu_{12}}{4\pi} n_2 A_{21} \phi_{12}(\nu)$$

$$\kappa_{\nu\rho} = \frac{h\nu_{12}}{4\pi} (n_1 B_{12} - n_2 \underline{B_{21}}) \phi_{12}(\nu)$$

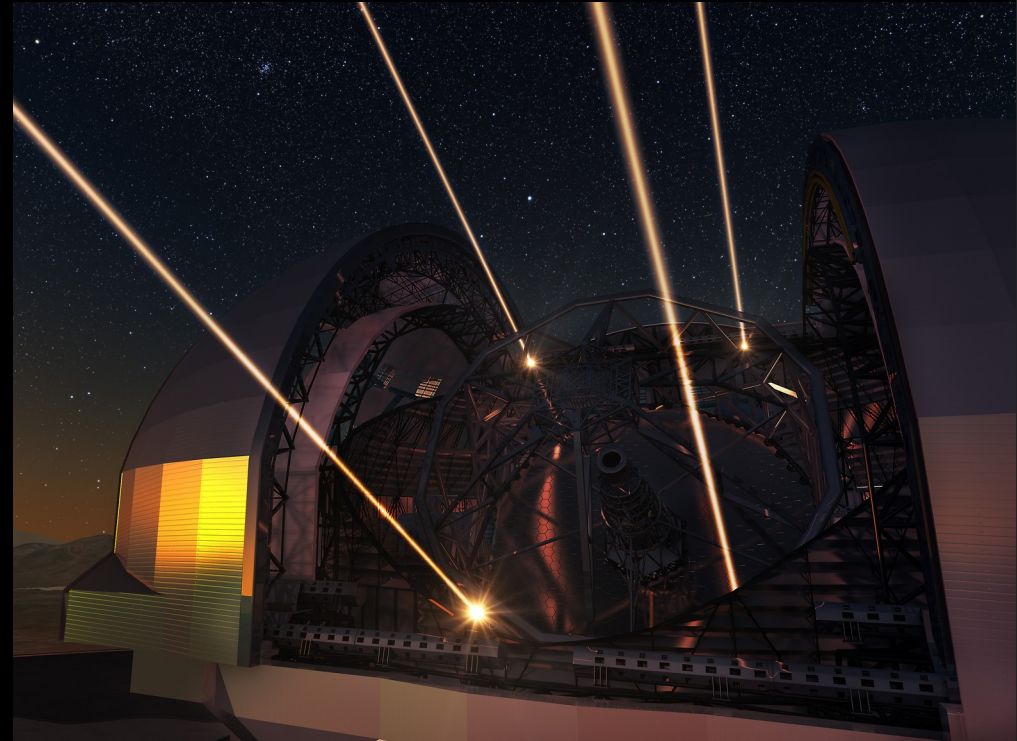
A, B ... Einsteinovy koeficienty



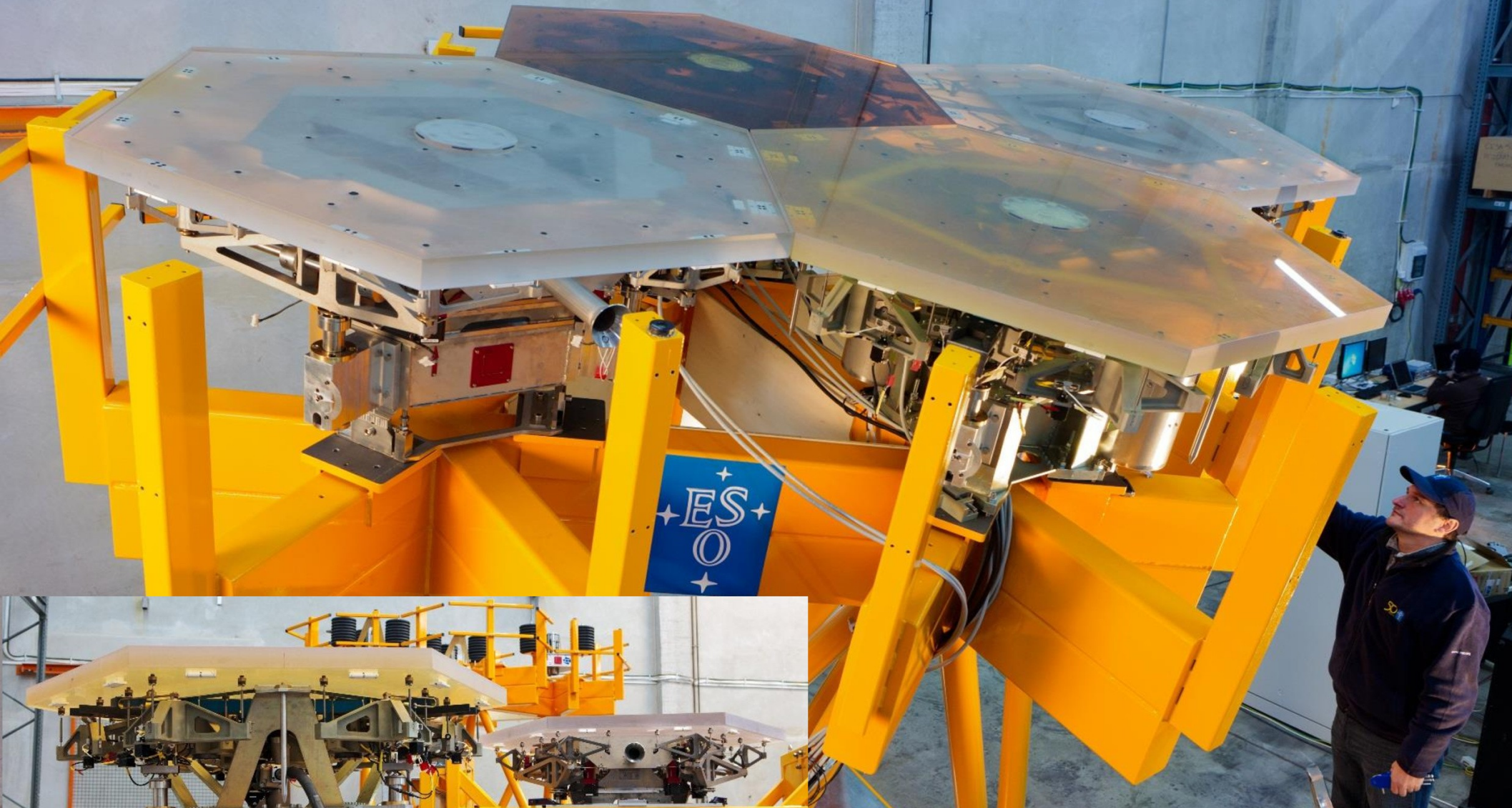
ELT



pumpování
(Kastler 1950)
↓
inverze hladin
↓
zesilování

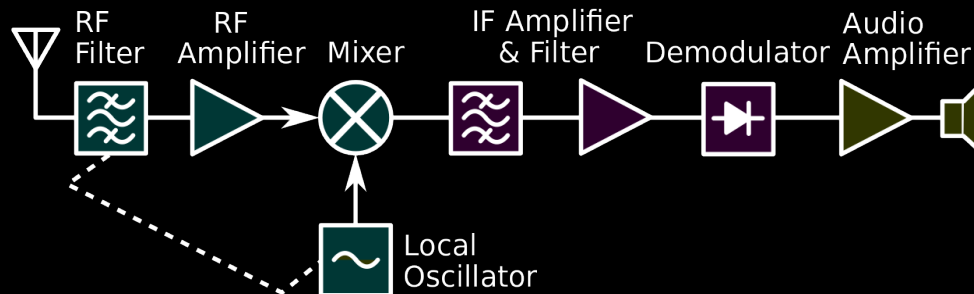


LGS, Hartmannův-Shackův senzor, metrologie, technika PDH (Drever et al. 1983)

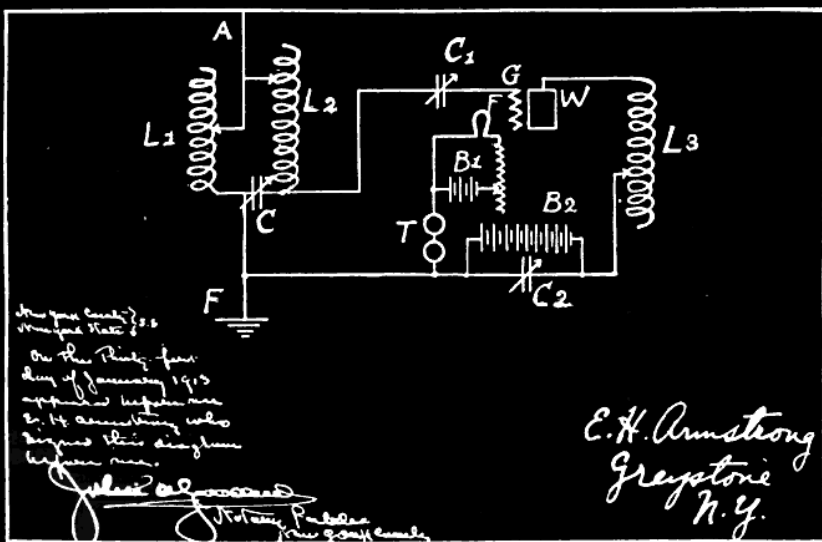


1918: Edwin Armstrong

- * 1890 New York † 1954 dtto
- patent na super-heterodynní obvod (Westinghouse)
← spor s Lucienem Lévyem (AT&T)
- anténa → vlnovod → VF předzesilovač → směšovač + lokální oscilátor → NF zesilovač → diodový detektor → A/D převodník

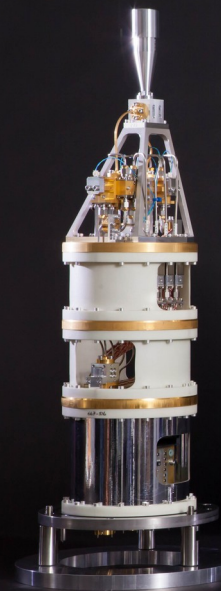


ALMA

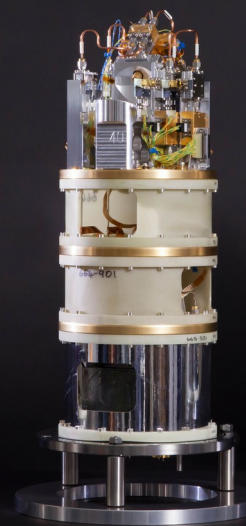


regenerační obvod

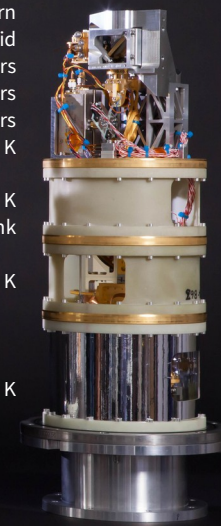
Band 4



8



10 (787- 950 GHz)



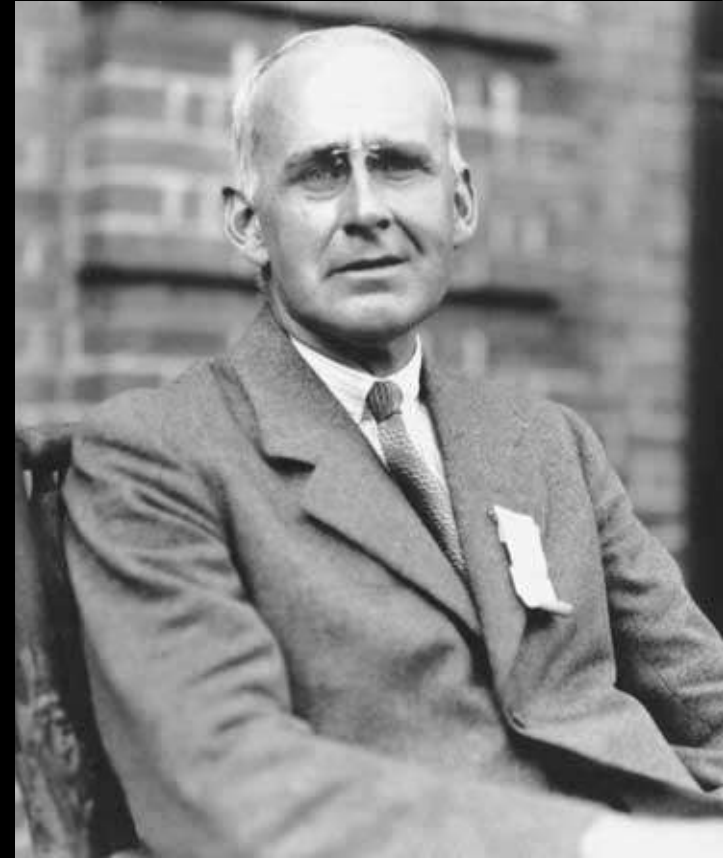
M1, M2
 horn
 wire grid
 isolators
 SIS mixers
 amplifiers
 4 K
 15 K
 heat sink
 115 K
 300 K

1919: Arthur Eddington

- * 1882 Kendall † 1944 Cambridge
- vnitřní stavba hvězd: rovnice kontinuity, hydrostatické rovnováhy, polytropy $P = K\rho^\gamma$
→ Laneova-Emdenova rovnice
- vyvrátil teorii KH kontrakce, předpověděl termonukleární reakce, ...

$$\frac{d^2\varphi}{dz^2} + \frac{2}{z} \frac{d\varphi}{dz} + \varphi^n = 0$$

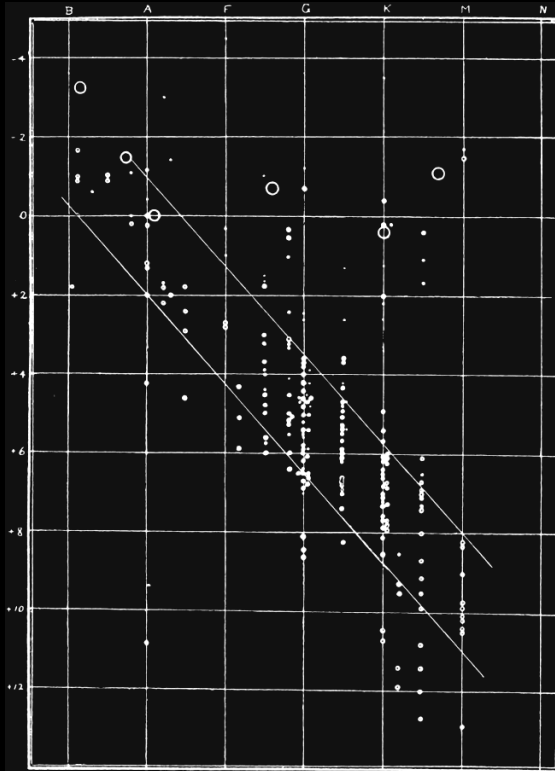
φ ... škálovaný gravitační potenciál



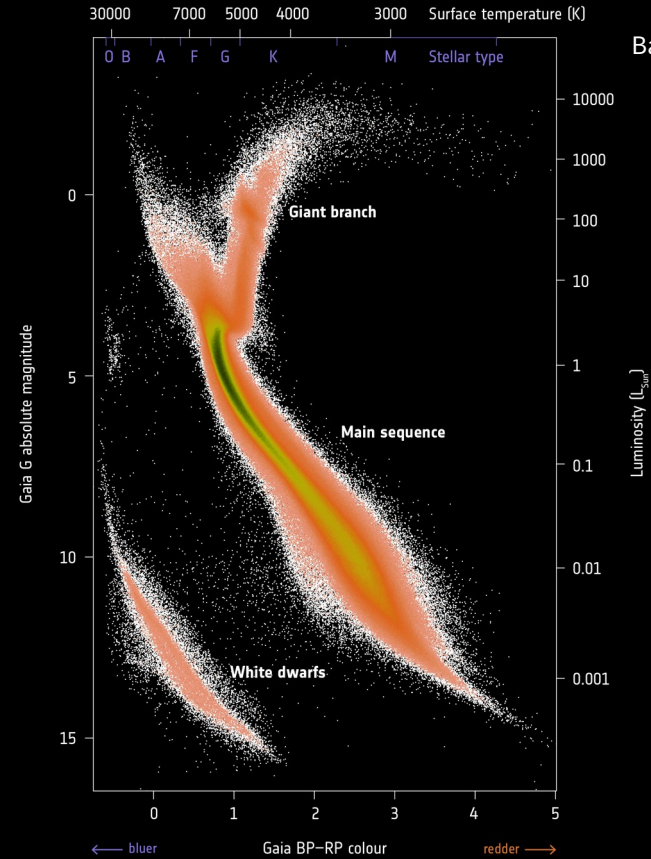
HR diagram

Russell (1914)

zářivý výkon
 $\log L/L_{\odot}$



spektrální typ



Babusiaux et al. (2018)

1919: James H. Jeans

- * 1877 Ormskirk † 1946 Dorking
- Cambridge, Princeton, Mt Wilson
- Jeansova délka, hmotnost, nestabilita, únik, teorém, atd. (Phil. Trans. R. Astron. Soc. **199**, 1-53)

$$\lambda_J = \frac{c_s}{\sqrt{G\rho}}, \quad c_s = \sqrt{\frac{\gamma kT}{\mu m_u}}$$

- hypotéza stacionárního vesmíru, tvoření hmoty
- hypotéza nebulární vs rotační vs slapová



Vznik planetárních systémů

Jeans (1919)

195–197]

The Tidal Problem

127

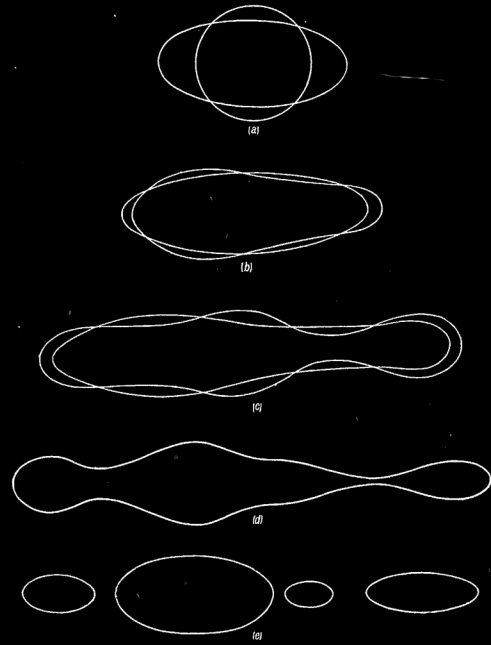
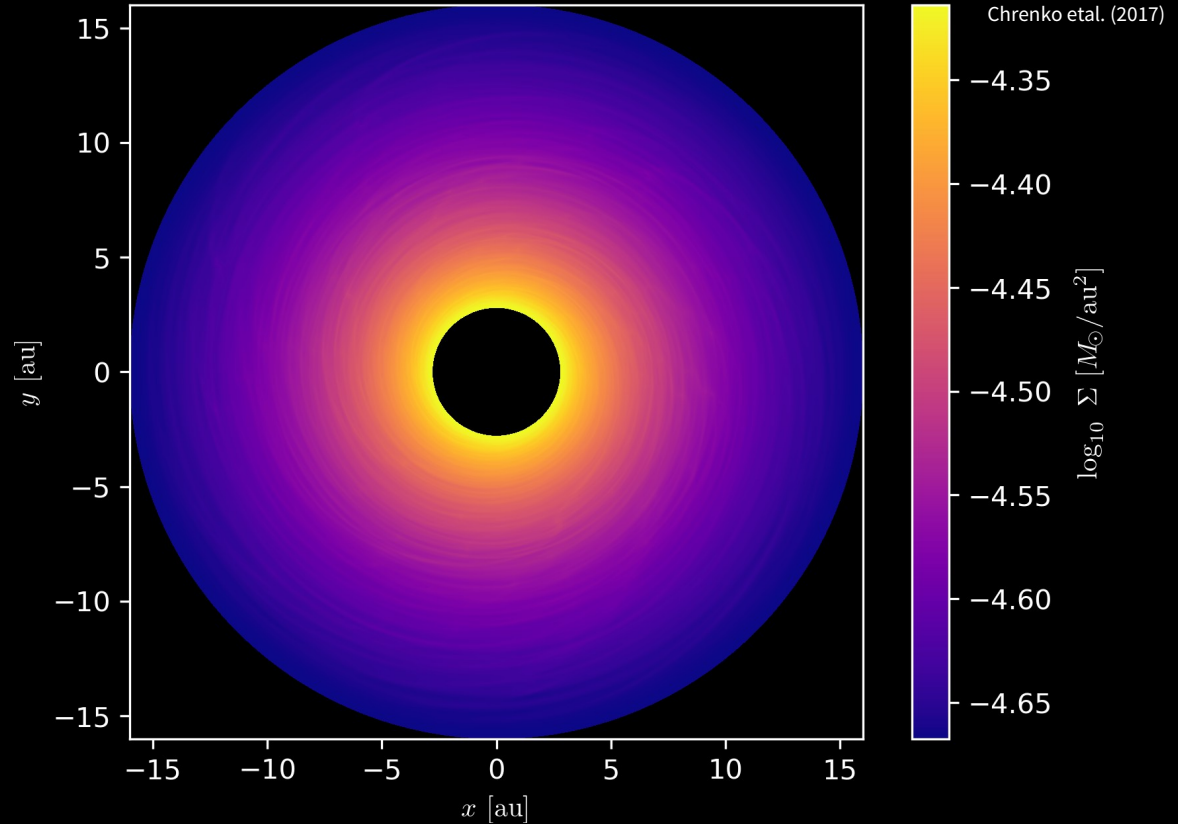


Fig. 23.

EXPLANATION.

- (a) Undistorted sphere, and longest spheroid which is statically stable.
- (b) Longest spheroid which is dynamically stable, and pear-shaped figure derived by third harmonic displacement.
- (c) More elongated pear-shaped figure, and figure derived by fourth harmonic displacement.
- (d) The last figure more elongated, and with fifth harmonic displacement superposed.
- (e) Conjectural drawing of subsequent configuration.



1921: Albert A. Michelson

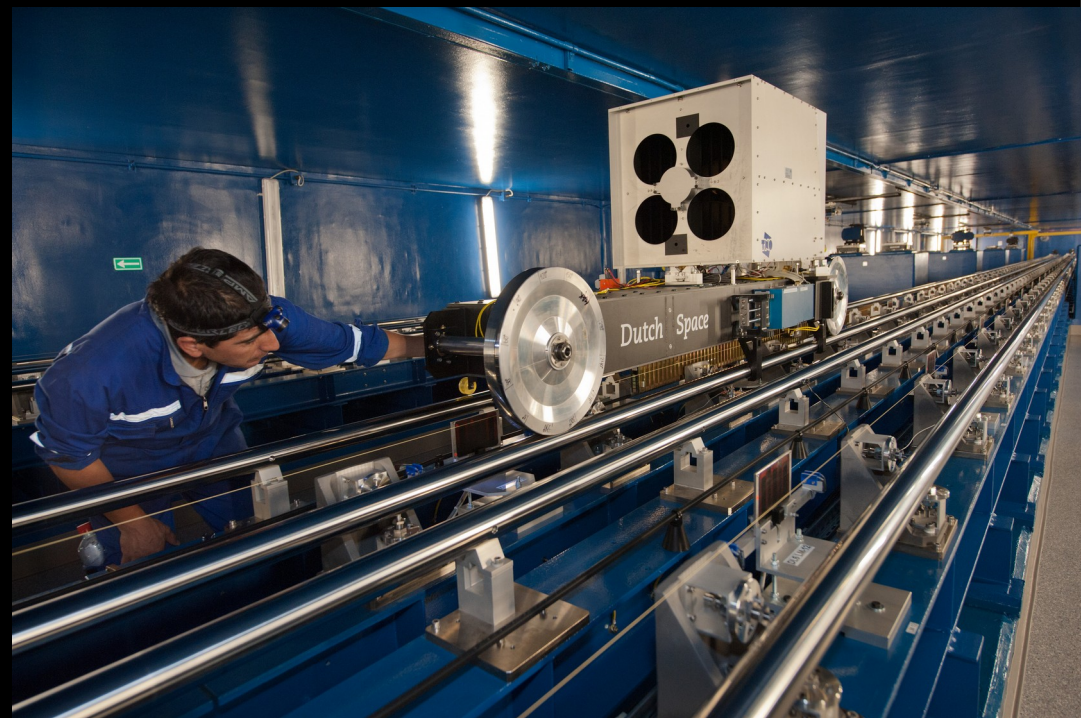
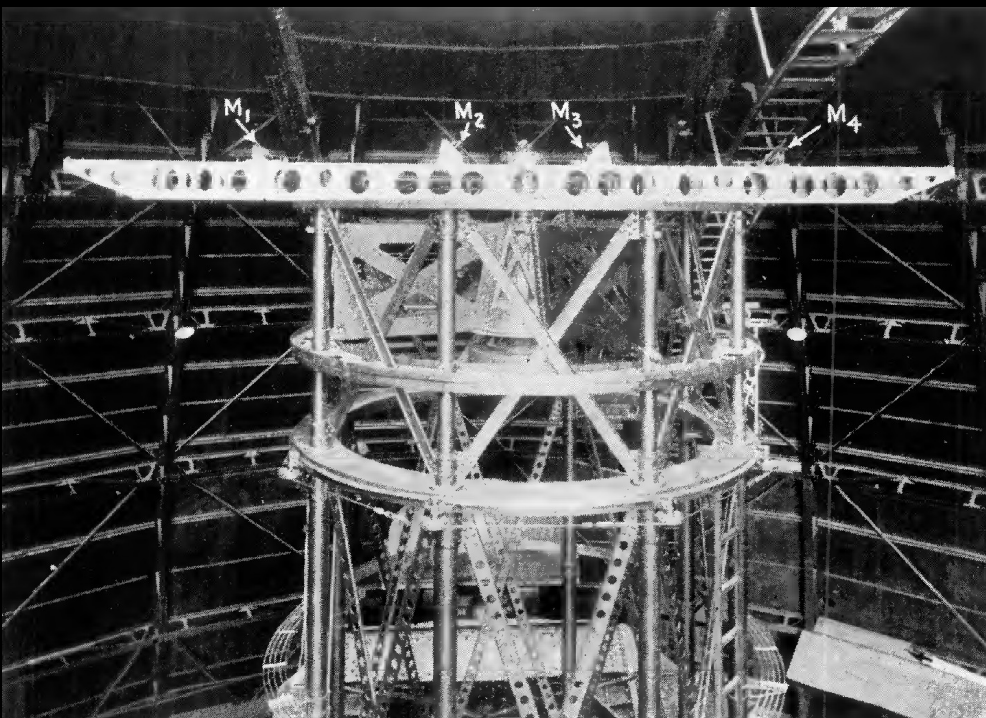
- * 1852 Strzelno † 1931 Pasadena
- Nobelova cena 1907 (měření c)
- optická interferometrie, pozorování proužků, kontrast \rightarrow průměr hvězdy (α Ori)
- teorém van Citterta & Zernikeho (1934-8):

$$\mu(\vec{B}) \equiv \frac{\int I(\vec{\alpha}') e^{-ik\vec{\alpha}' \cdot \vec{B}} d\alpha'}{I_0}$$

μ ... komplexní funkce viditelnosti

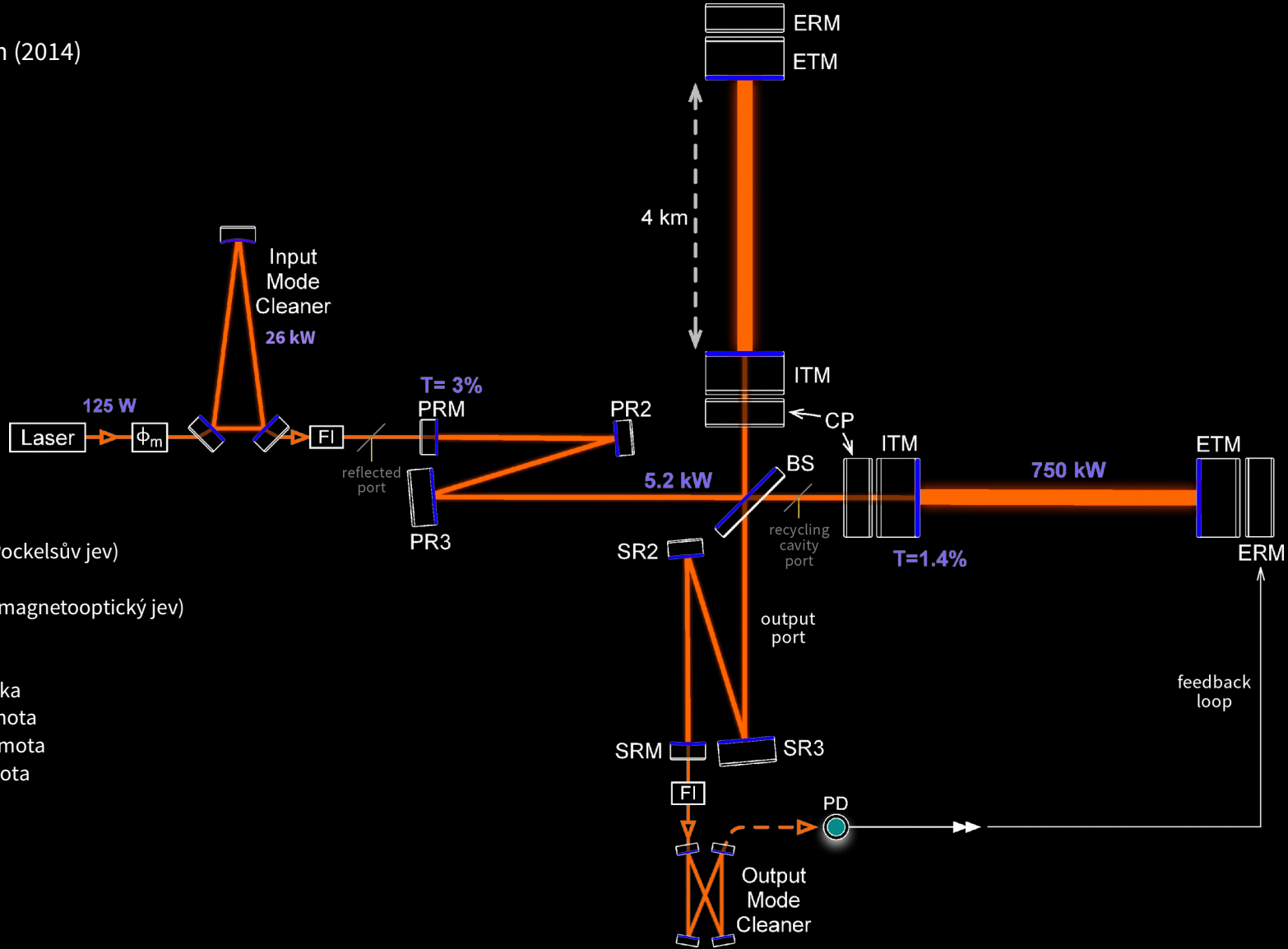


VLTI



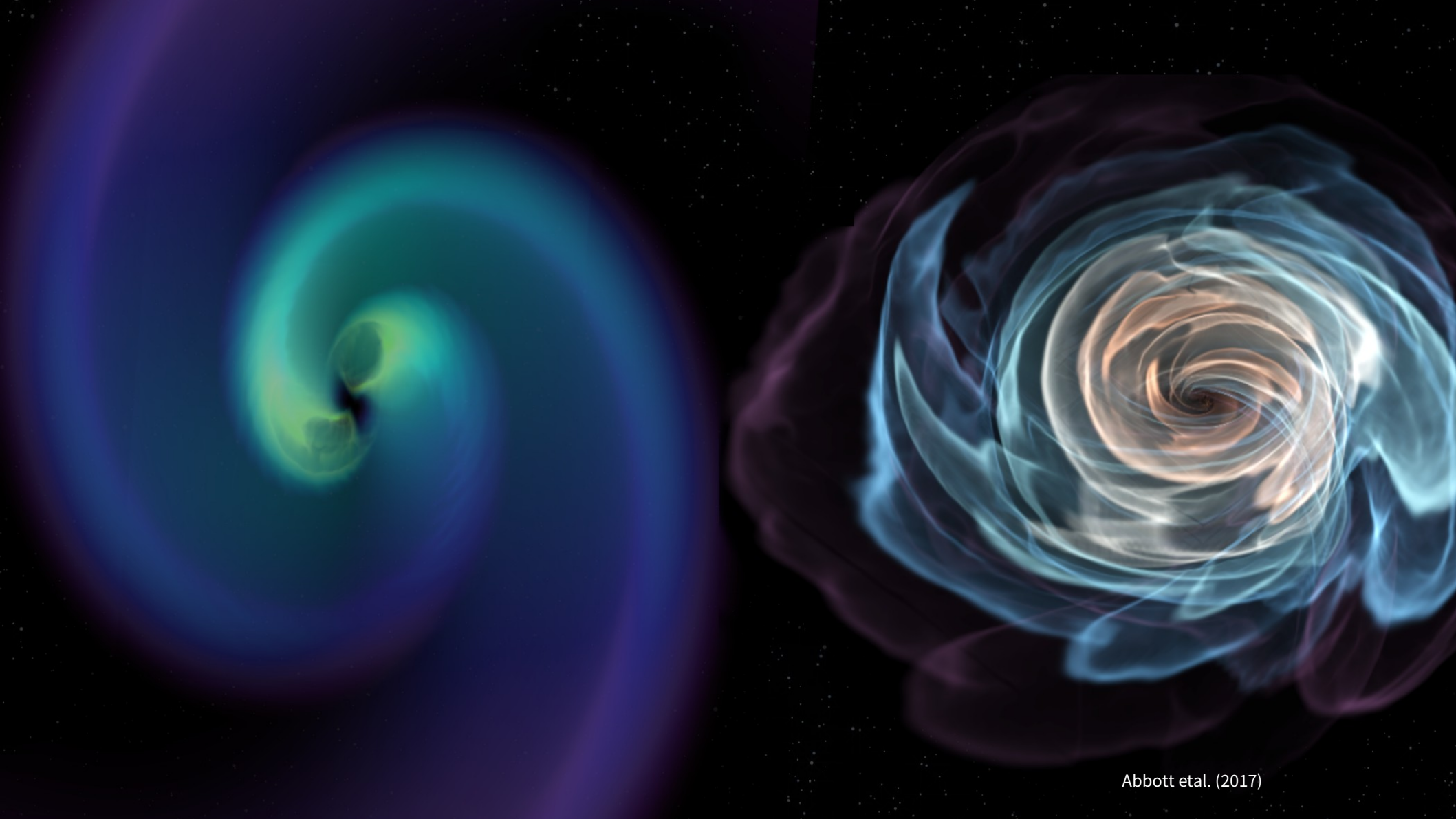
Labeyrie (1975), Merkle (1982)

LIGO collaboration (2014)



stabilizovaný laser

- fázový modulátor (Pockelsův jev)
- optický filtr
- Faradayův izolátor (magnetooptický jev)
- recyklační zrcadla
- dělič svazků 50/50
- kompenzační destička
- vstupní testovací hmota
- koncová testovací hmota
- koncová reakční hmota
- recyklační zrcadla
- Faradayův izolátor
- optický filtr
- fotodioda
- zpětná vazba



1922: Alexandr Fridman

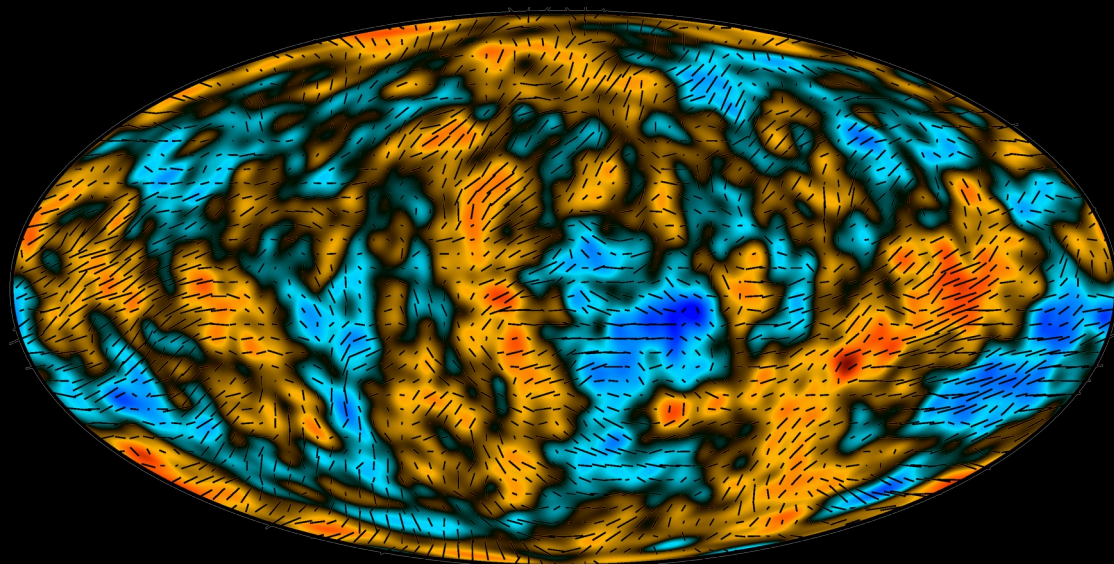
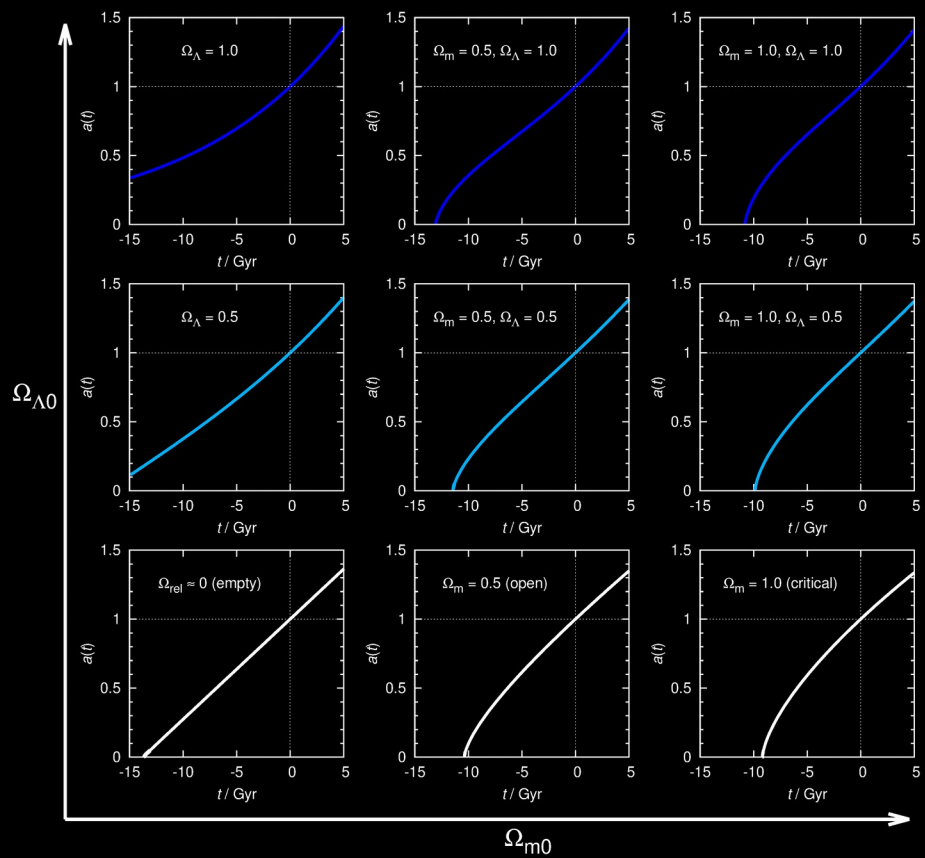
- * 1888 Petrohrad † 1925 (po letu balónem?)
- nestatické řešení EFE, Zeit. Phys. **21**, 326-332
- rozpínání vesmíru popsané fci $a(t)$ a křivostí K , bez Λ
- metrika FLRW:

$$g_{ik} = \begin{pmatrix} -c^2 & 0 & 0 & 0 \\ 0 & \frac{a(t)^2}{1-Kr^2} & 0 & 0 \\ 0 & 0 & a(t)^2 r^2 d\theta^2 & 0 \\ 0 & 0 & 0 & a(t)^2 r^2 \sin^2 \theta d\phi^2 \end{pmatrix}$$

- CMB až Penzias & Wilson (1965)



Kosmologie Λ -CDM



0.41 μK

-160 160 μK

Aghanim et al. (2018)

Kosmologické parametry

- $\Omega_b h^2 = 0,0224 \pm 0,0001$... relativní hustota baryonické látky (dnes)
- $\Omega_c h^2 = 0,1193 \pm 0,0009$... relativní hustota temné látky
- $100 \theta_{MC} = (1,0410 \pm 0,0003)$ rad ... akustická úhlová škála CMB, $0,5^\circ$
- $\tau = 0,056 \pm 0,007$... optická hloubka reionizace, první *
- $\ln(10^{10} A_s) = 3,05 \pm 0,01$... amplituda fluktuací křivosti (počáteční)
- $n_s = 0,967 \pm 0,004$... spektrální index fluktuací

- stáří vesmíru $t_0 = (13,79 \pm 0,02)$ Gyr
- Hubblův parametr $H_0 = (67,4 \pm 0,5)$ km s⁻¹ Mpc⁻¹ ← cf. $(73,5 \pm 1,6)$ km s⁻¹ Mpc⁻¹ (Riess et al. 2018)

Aghanim et al. (2018)

1923: Arthur H. Compton

- * 1892 Wooster † 1962 Berkeley
- 1. bratr MIT, 2. bratr U. Washington
- Comptonův rozptyl RTG paprsků, dvojí povaha záření (vlny, částice):

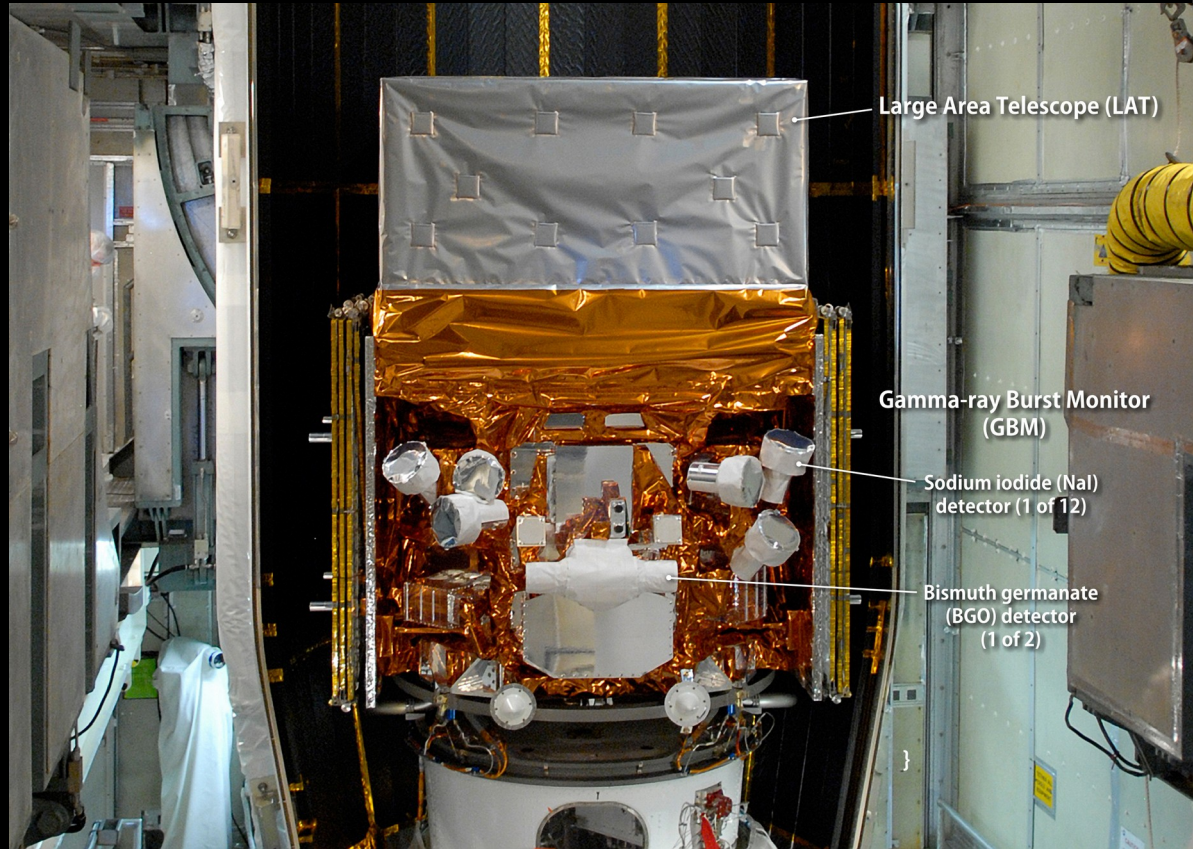
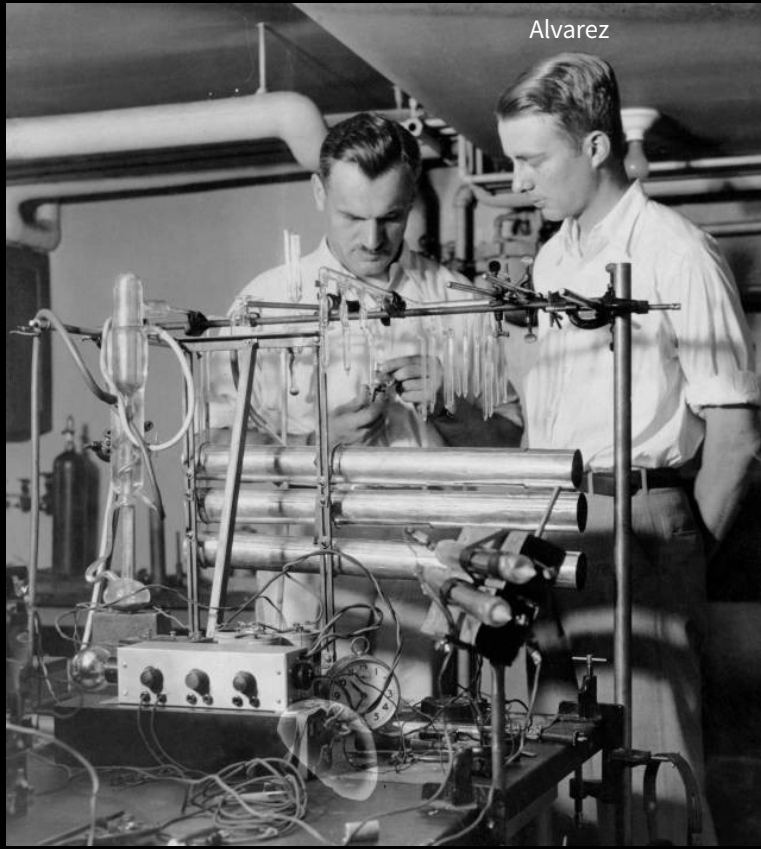
$$\lambda' - \lambda = \frac{h}{m_e c} (1 - \cos \vartheta)$$

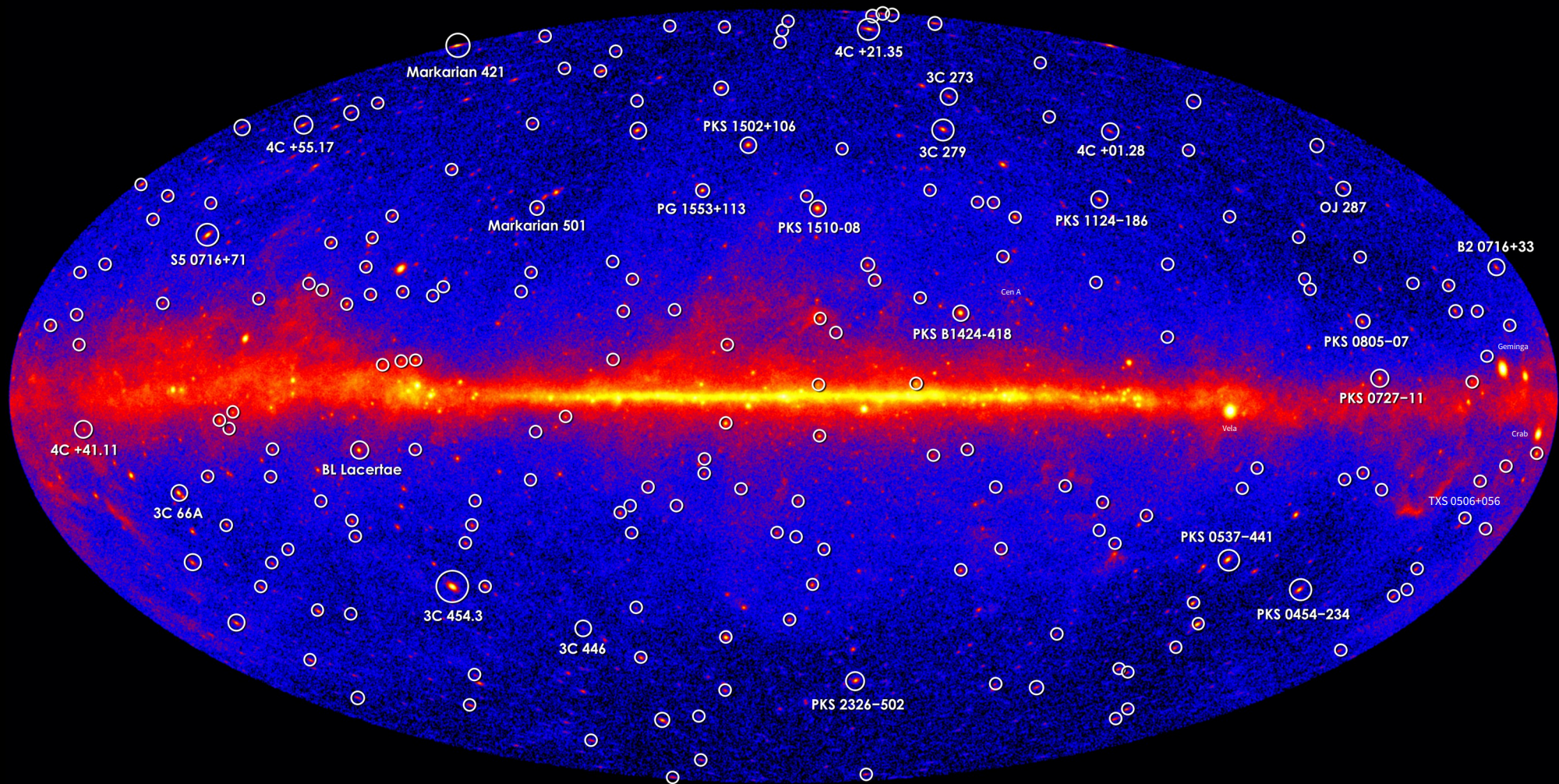
- studium kosmického záření (původ?)
- NC 1927, projekt Manhattan (Pu)



FERMI

20 MeV-300 GeV, pair-production, $\gamma + W \rightarrow W + e^+ + e^-$, kalorimetr, scintilátor CsI, autokoincidenční scintilátor (pozadí 10^5)

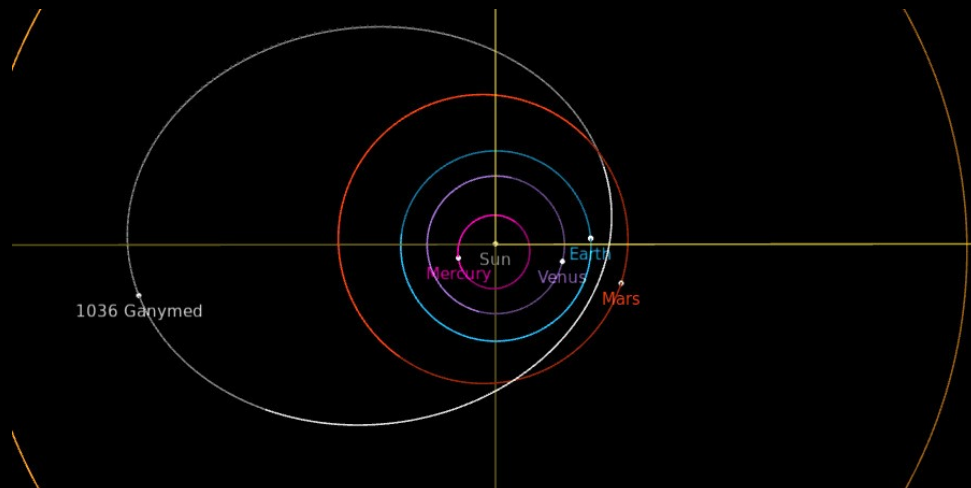




Icecube coll. et al. (2018): blazar TXS 0506+056, $\nu + \gamma$, 290 TeV!

1924: Walter Baade

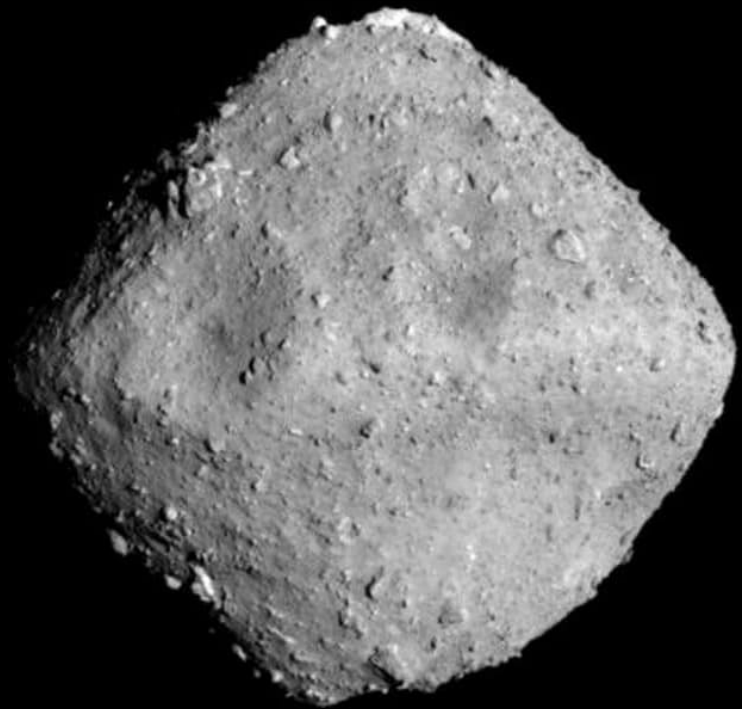
- * 1893 Schröttinghausen † 1960 Göttingen
- objevil planetku (1036) Ganymed, $D = 35$ km



- rozpoznal supernovy (& F. Zwicky 1934), * v M1, „okno“ s výhledem na výduť Galaxie (Baade 1946), 2 populace * → 2 typy Cefeid (Baade 1956)

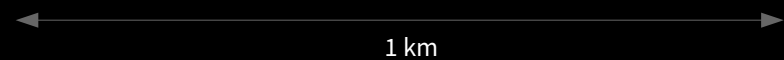


(162173) Ryugu



© JAXA

cf. interstelární asteroid 1I/'Oumuamua (Weryk et al. 2017; Jewitt et al. 2017)



1925: Edwin Hubble

- * 1889 Marshfield † 1953 San Marino
- Mt Wilson, 100-in Hooker telescope (& V. Slipher)
- extragalaktické cefeidy, vzdalování galaxií

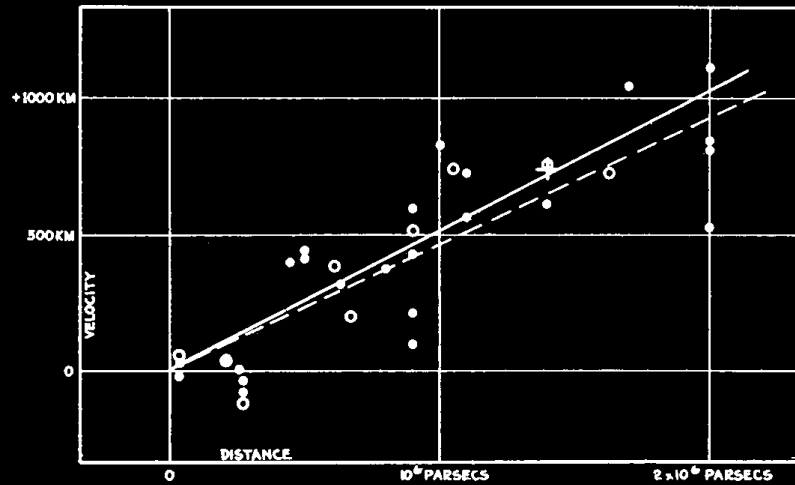
$$v_{\text{rad}} = Hd$$

- $H = 500 \text{ km s}^{-1} \text{ Mpc}^{-1}$, dnes $(67,4 \pm 0,5) \text{ km s}^{-1} \text{ Mpc}^{-1}$
- nedůvěřoval kosmologii?
- ~~NG~~, rezoluce IAU 2018 B4 Hubble-Lemâitre

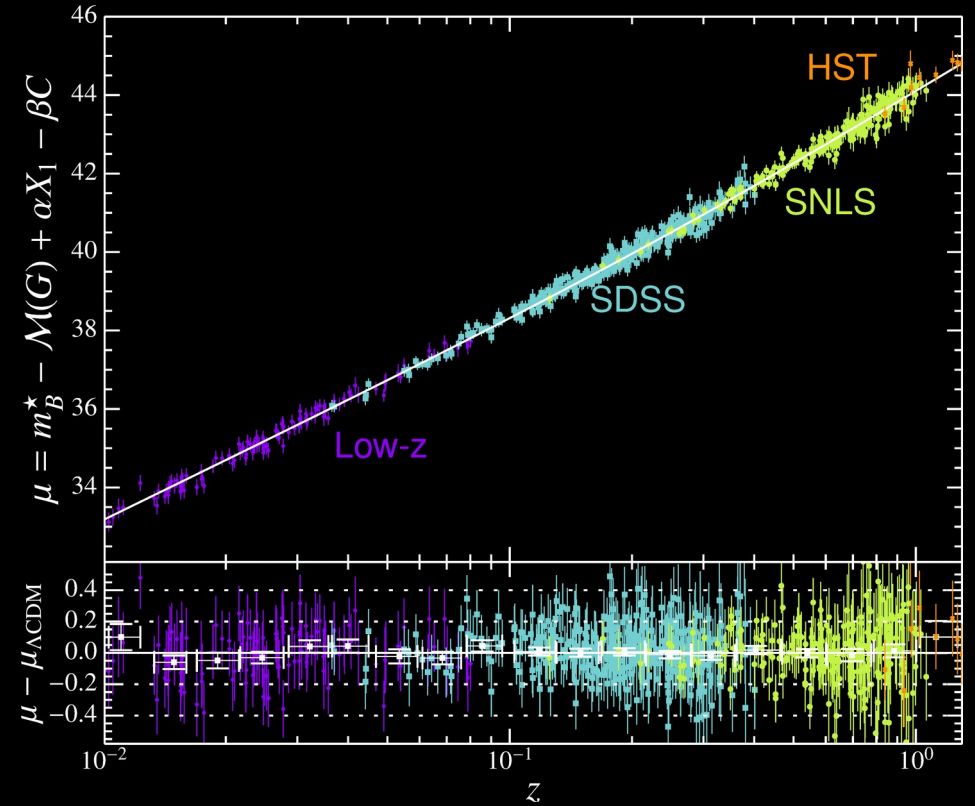


Supernovy typu Ia

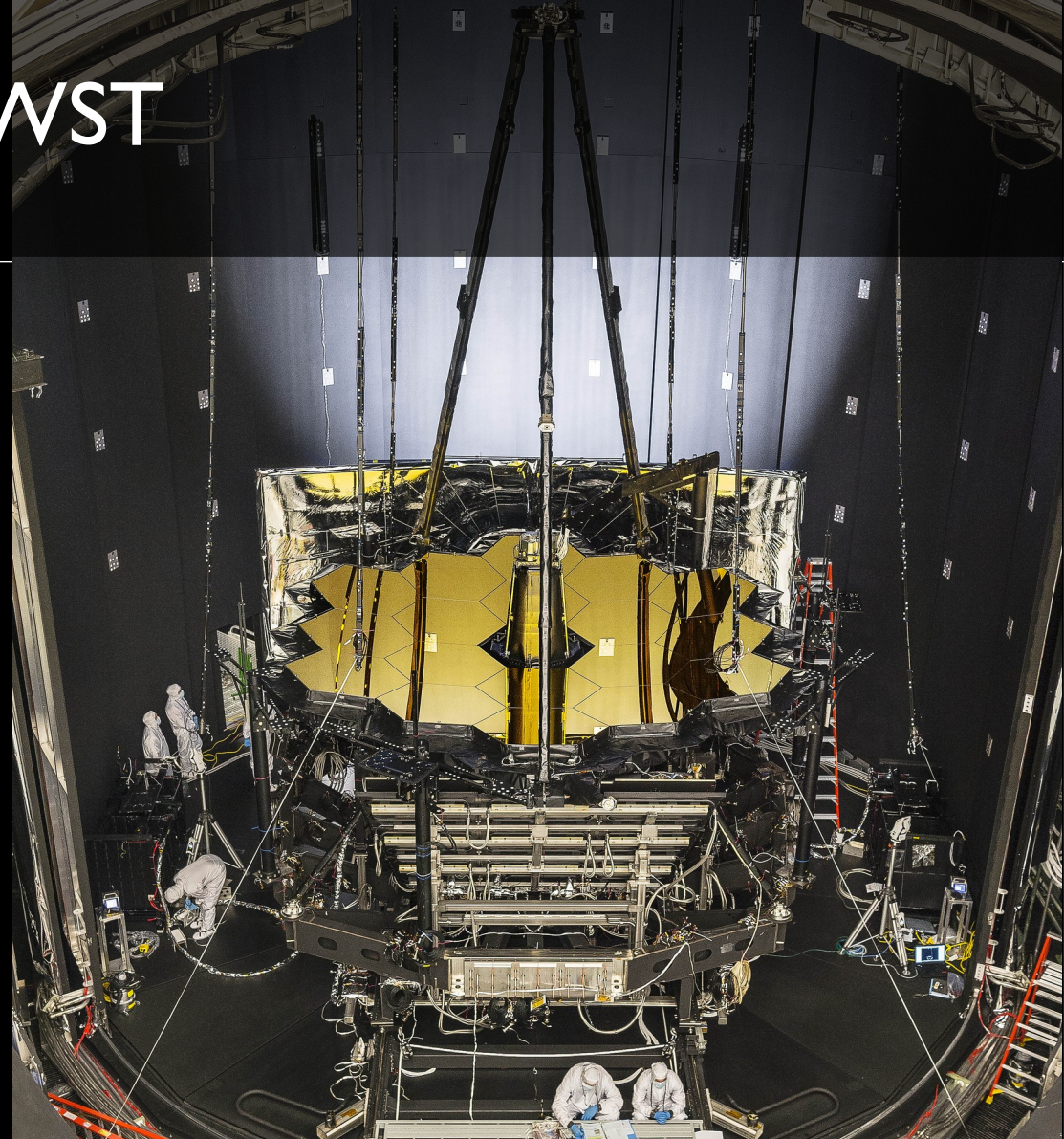
Hubble & Humason (1929)



Betoule et al. (2014), 740 SN



JWST

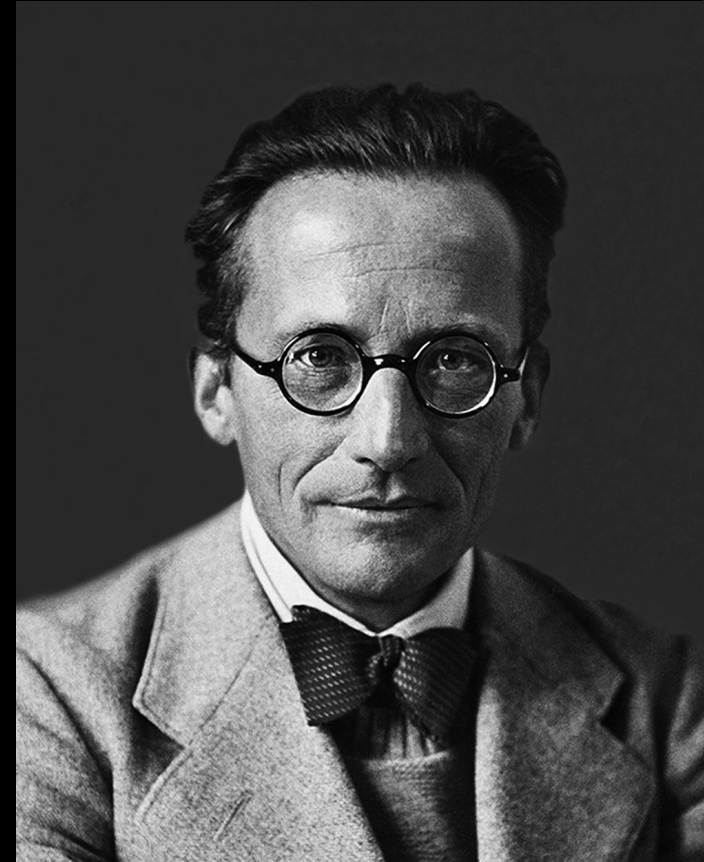


1926: Erwin Schrödinger

- * 1887 Wien † 1961 dtto
- Breslau, Zürich, Berlin, Dublin
- Schrödingerova rovnice, vlnová funkce Ψ :

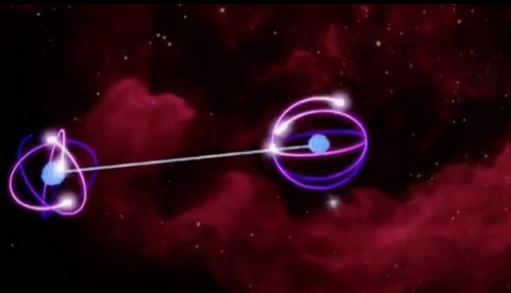
$$i\hbar \frac{\partial \Psi(\mathbf{r}, t)}{\partial t} = -\frac{\hbar^2}{2m_e} \nabla^2 \Psi(\mathbf{r}, t) + V(\mathbf{r}) \Psi(\mathbf{r}, t)$$

- paradox Schrödingerovy kočky
- NC 1933, *What is life?* → DNA? (Watson, Crick, Franklin 1953)

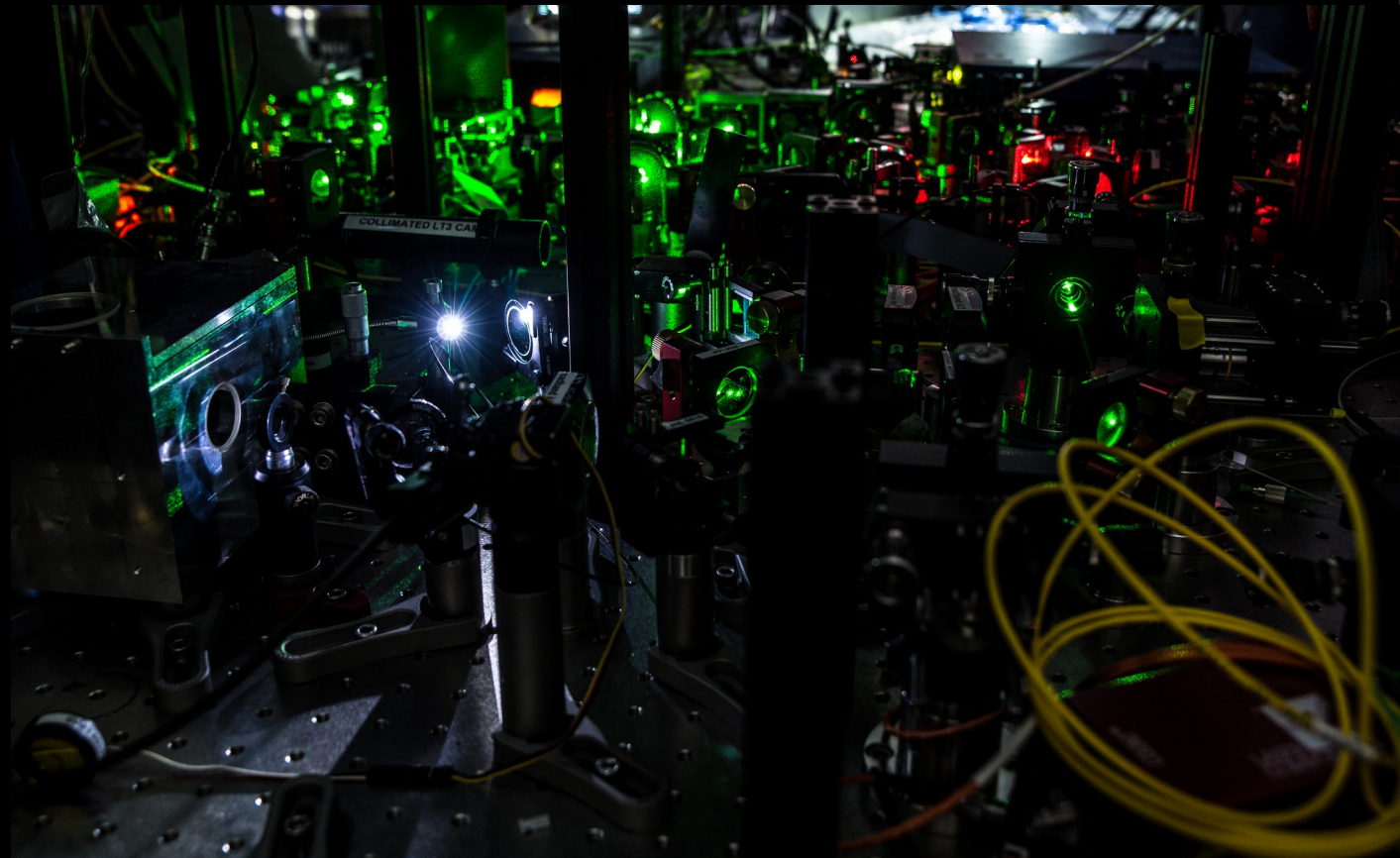


Kvantové provázání

[angl. entanglement]



Hensen et al. (2014)
Bellova nerovnost



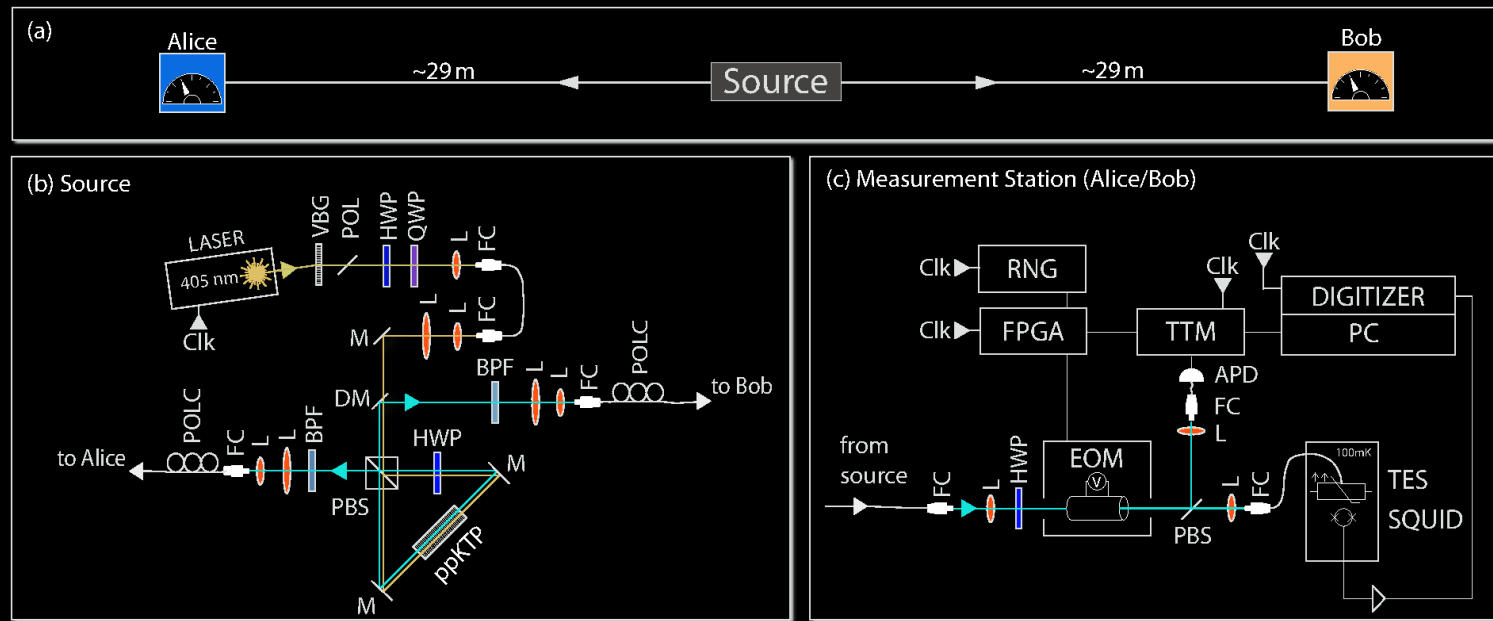


Figure 1. (a) Schematic of the setup. (b) Source: The source distributed two polarization-entangled photons between the two identically constructed and spatially separated measurement stations *Alice* and *Bob* (distance ≈ 58 m), where the polarization was analyzed. It employed type-II spontaneous parametric down-conversion in a periodically poled crystal (ppKTP), pumped with a 405 nm pulsed diode laser (pulse length: 12 ns FWHM) at 1 MHz repetition rate. The laser light was filtered spectrally by a volume Bragg grating (VBG) (FWHM: 0.3 nm) and spatially by a single-mode fiber. The ppKTP crystal was pumped from both sides in a Sagnac configuration to create polarization entanglement. Each pair was split at the polarizing beam splitter (PBS) and collected into two different single-mode fibers leading to the measurement stations. (c) Measurement stations: In each measurement station, one of two linear polarization directions was selected for measurement, as controlled by an electro-optical modulator (EOM), which acted as a switchable polarization rotator in front of a plate PBS. Customized electronics (FPGA) sampled the output of a random number generator (RNG) to trigger the switching of the EOM. The transmitted output of the plate PBS was coupled into a fiber and delivered to the TES. The signal of the TES was amplified by a SQUID and additional electronics, digitized, and recorded together with the setting choices on a local hard drive. The laser and all electronics related to switching/recording were synchronized with clock inputs (Clk). Abbreviations: APD: avalanche photodiode (see Fig. 2); BPF: band-pass filter; DM: dichroic mirror; FC: fiber connector; HWP: half-wave plate; L: lens, POL: polarizer; M: mirror; POLC: manual polarization controller; QWP: quarter-wave plate; SQUID: superconducting quantum interference device; TES: transition-edge sensor; TTM: time-tagging module.

1927: Warren Marrison

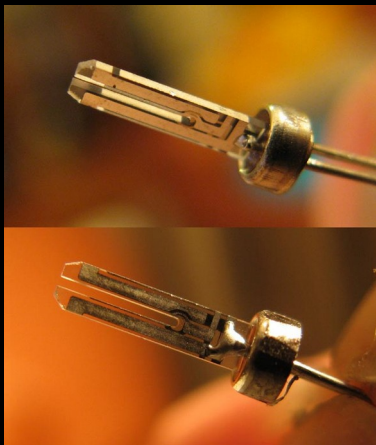
- * 1896 Invenary, CA † 1980 New York
- hodiny řízené elektro-mechanickými oscilacemi krystalu SiO_2 (J. W. Horton, Bell Laboratories),
 $f = 32768 \text{ Hz} = 2^{15} \text{ Hz} \rightarrow$ dělič $\rightarrow 1 \text{ Hz}$

$$f = \frac{1,875^2}{2\pi} \frac{a}{l^2} \sqrt{\frac{E}{12\rho}}$$

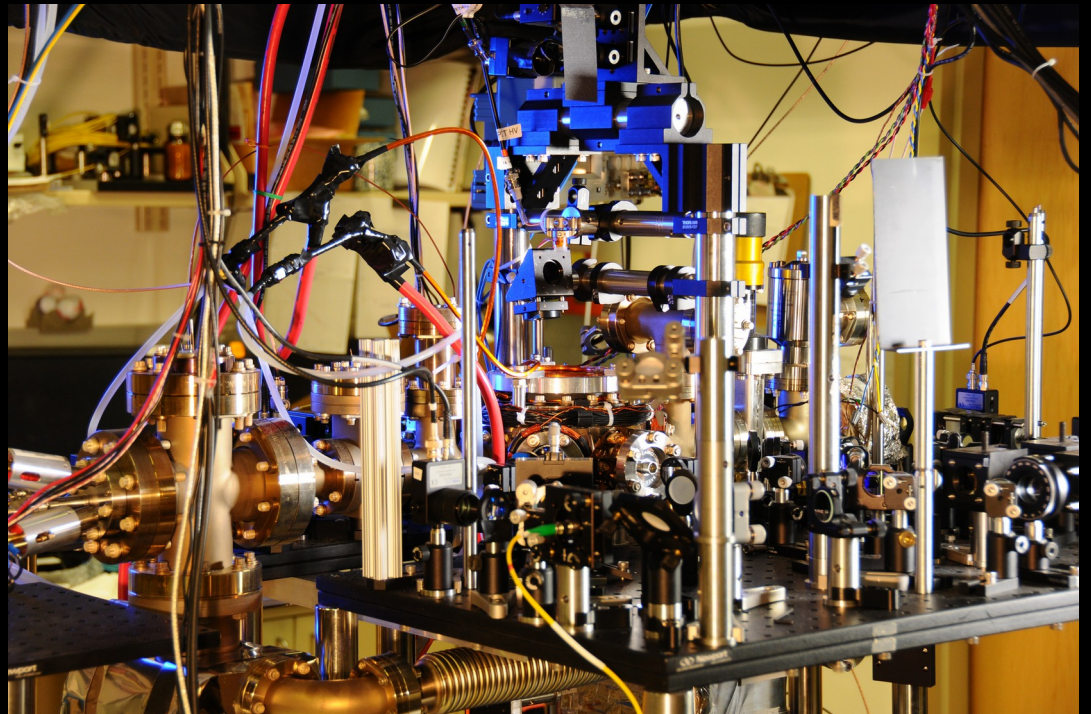
f ... základní frekvence nosníku



Kvantové # hodiny



$1 \text{ s} / 10^5 \text{ s} \doteq 1 \text{ den}$



$1 \text{ s} / 10^{18} \text{ s} \sim$ stáří vesmíru, 10000 atomů Yt, $T = 10 \mu\text{K}$, optická mřížka (past), laser 518 THz, středování 1 s (Hinkley etal. 2013)

1928: Paul Dirac

- *1902 Bristol † 1984 Tallahassee, FL
- nespolečenský podivín; 1 di = 1 s./h
- maticová formulace kvantové mechaniky
- Diracova rovnice, spin, předpověď *pozitronu*:

$$E = \sqrt{(mc^2)^2 + (pc)^2}$$
$$i\hbar \frac{\partial \Psi(\mathbf{r}, t)}{\partial t} = \left(\beta mc^2 + c \sum_{n=1}^3 \alpha_n p_n \right) \Psi(\mathbf{r}, t)$$

- NC 1933 (E. Schrödinger), 1927 W. Heisenberg



Standardní model částic

FERMIONS

matter constituents
spin = 1/2, 3/2, 5/2, ...

Leptons spin = 1/2		
Flavor	Mass GeV/c ²	Electric charge
ν_e electron neutrino	$<1 \times 10^{-8}$	0
e electron	0.000511	-1
ν_μ muon neutrino	<0.0002	0
μ muon	0.106	-1
ν_τ tau neutrino	<0.02	0
τ tau	1.7771	-1

Quarks spin = 1/2		
Flavor	Approx. Mass GeV/c ²	Electric charge
u up	0.003	2/3
d down	0.006	-1/3
c charm	1.3	2/3
s strange	0.1	-1/3
t top	175	2/3
b bottom	4.3	-1/3

BOSONS

force carriers
spin = 0, 1, 2, ...

Unified Electroweak spin = 1		
Name	Mass GeV/c ²	Electric charge
γ photon	0	0
W^-	80.4	-1
W^+	80.4	+1
Z^0	91.187	0

Strong (color) spin = 1		
Name	Mass GeV/c ²	Electric charge
g gluon	0	0
H Higgs	126	0

$e^-, \gamma, p, e^+, \dots$

Glashow (1961)
Higgs (1964)
Gell-Mann (1964)
Zweig (1964)
Weinberg (1967)
Salam (1968)
Gross & Wilczek (1973)
Kobayashi & Maskawa (1973)

Bloom et al. (1968)
Aubert et al. (1974)
Hasert et al. (1973)
Herb et al. (1977)
Abe et al. (1995)

PROPERTIES OF THE INTERACTIONS

Property	Interaction				
	Gravitational	Weak (Electroweak)			Strong
		Flavor	Electric Charge	Fundamental	Residual
Acts on:	Mass – Energy	Flavor	Electric Charge	Color Charge	See Residual Strong Interaction Note
Particles experiencing:	All	Quarks, Leptons	Electrically charged	Quarks, Gluons	Hadrons
Particles mediating:	Graviton (not yet observed)	$W^+ W^- Z^0$	γ	Gluons	Mesons
Strength relative to electromag for two u quarks at:	10^{-41}	0.8	1	25	Not applicable to quarks
for two protons in nucleus	10^{-41}	10^{-4}	1	60	
	10^{-36}	10^{-7}	1	Not applicable to hadrons	20

DM?
DE?!

Konec