Leibniz Universität Hannover

Emmy Noether-Programm

DFG Deutsche Forschungsgemeinschaft

Primordial black holes and cosmic gravitational waves

La-CoNGA physics

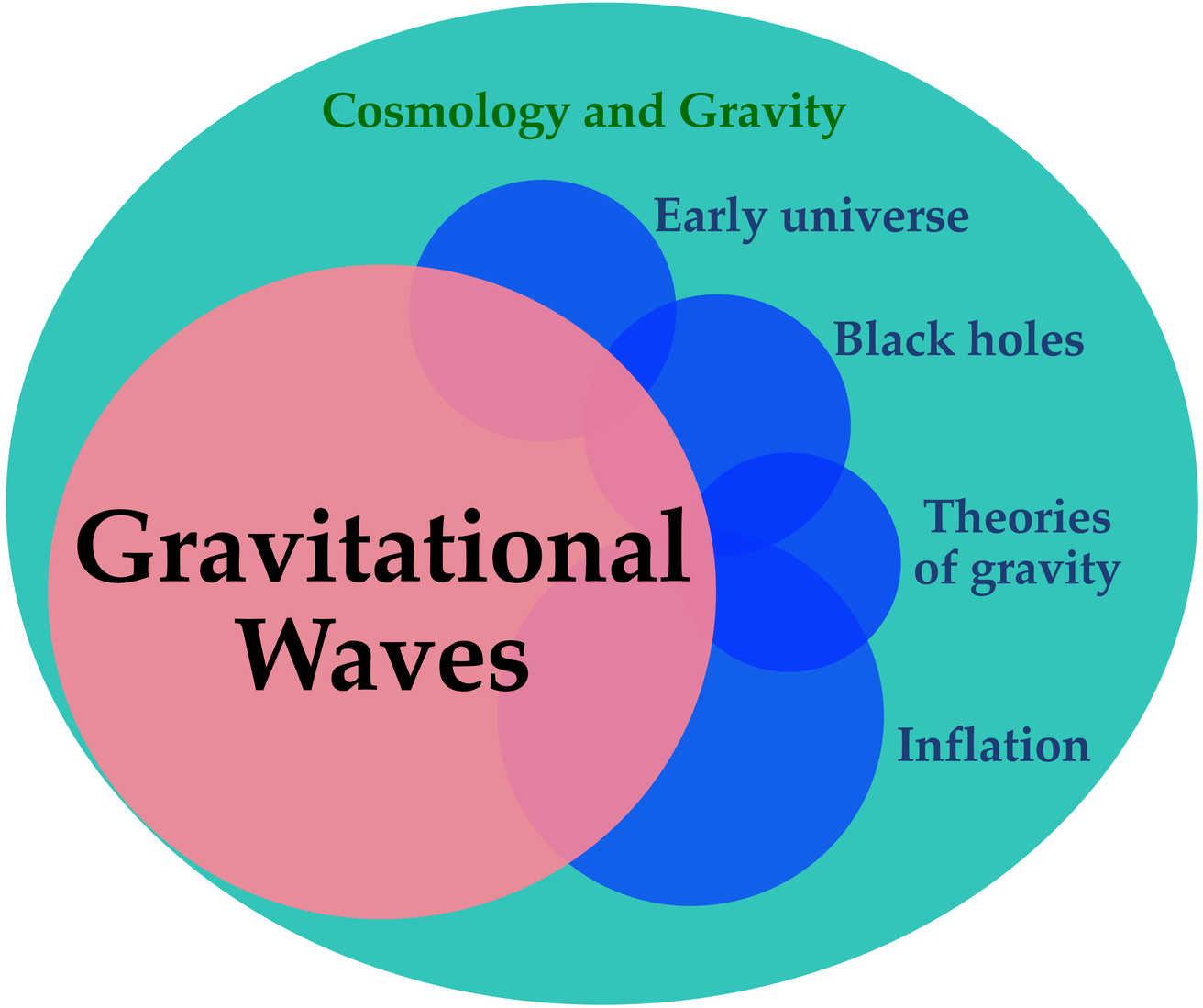
Latin American alliance for Capacity buildiNG in Advanced physics

LA-CoNGA physics

Guillem Domenech — 08/10/24 & 10/10/24

About me

- 2023-2029
  JUNIOR, Leibniz U., Hannover
- 2022-2023
  VISITOR, Garching, Max Planck Inst.
- 2020-2023
  POSTDOC, INFN, Padua
- 2017-2020
  POSTDOC, U. Heidelberg, ITP
- 2014-2017
  PHD, Kyoto U., Yukawa Inst., Kyoto
- 2012-2013
  MASTER, Barcelona U.



Studying in Germany

- Master’s or PhD in Germany with the DAAD and the StipendiumPlus scholarships.
- Very good PhD programs in the Max Planck Society in Germany.
- Master's and PhD in Japan with the Monbukagakusho scholarships.
- In physics, master level and above are mainly in English.

Suggested additional lectures

- Introduction to cosmology, Barbara Ryden (Book + YouTube Lectures)
- Fundamentals of cosmology, James Rich (Springer book)
- Cosmology, Daniel Bauman (Book + YouTube Lectures)
- Oxford master course in cosmology, Subir Sarkar, (Online recoded lectures)
- Lectures on PBHs: https://arxiv.org/pdf/2110.02821 and https://arxiv.org/pdf/2112.05716
- Lectures on GWs associated with PBHs: https://arxiv.org/abs/2307.06964

Astrophysical constants

Quantity	Symbol, equation.	Value	Reference,footnote
Newtonian constant of gravitation	G_N	$6.674\,30(15) \times 10^{-11}\,\mathrm{m^3\,kg^{-1}\,s^{-2}}$	[1]
Planck mass	$M_P = \sqrt{\hbar c/G_N}$	$1.220\,890(14) \times 10^{19}\ \mathrm{GeV}/c^2 = 2.176\,434(24) \times 10^{-8}\ \mathrm{kg}$	[1]
Planck length	$l_P = \sqrt{\hbar G_N/c^3}$	$1.616\,255(18) \times 10^{-35}\ \mathrm{m}$	[1]
tropical year (equinox to equinox, 2020)	yr	$31\,556\,925.1\ \mathrm{s} = 365.242\,189\ \mathrm{days}$	[4]
sidereal year (period of Earth around Sun relative to stars)		$31\,558\,149.8\ \mathrm{s} \approx \pi \times 10^7\ \mathrm{s}$	[4]
mean sidereal day (Earth rotation period relative to stars)		$23^{\mathrm{h}}\,56^{\mathrm{m}}\,04\overset{\mathrm{s}}{.}090\,53$	[4]
astronomical unit	au	$149\,597\,870\,700\ \mathrm{m}$ exact	[5]
parsec (1 au/1 arc sec)	pc	$3.085\,677\,581\,49 \times 10^{16}\ \mathrm{m} = 3.261\,56\ldots\ \mathrm{ly}$ exact	[6]
light year (deprecated unit)	ly	$0.306\,601\ldots\ \mathrm{pc} = 0.946\,073\ldots \times 10^{16}\ \mathrm{m}$	[7]
present-day CMB temperature	T_0	$2.7255(6)\ \mathrm{K}$	[27,28]
present-day CMB dipole amplitude	d	$3.3621(10)\ \mathrm{mK}$	[27,29]
Solar velocity with respect to CMB	$v_\odot$	$369.82(11)\ \mathrm{km\,s^{-1}}$ towards $(l,b) = (264.021(11)^\circ, 48.253(5)^\circ)$	[29]
Local Group velocity with respect to CMB	v_{LG}	$620(15)\ \mathrm{km\,s^{-1}}$ towards $(l,b) = (271.9(20)^\circ, 29.6(14)^\circ)$	[29]
number density of CMB photons	n_γ	$410.7(3)\,(T/2.7255)^3\ \mathrm{cm^{-3}}$	[30]
density of CMB photons	ρ_γ	$4.645(4)\,(T/2.7255)^4 \times 10^{-34}\,\mathrm{g\,cm^{-3}} \approx 0.260\ \mathrm{eV\ cm^{-3}}$	[30]
entropy density/Boltzmann constant	s/k	$2\,891.2\,(T/2.7255)^3\ \mathrm{cm^{-3}}$	[30]
present-day Hubble expansion rate	H_0	$100\,h\ \mathrm{km\,s^{-1}\,Mpc^{-1}} = h \times (9.777\,752\ \mathrm{Gyr})^{-1}$	[31]
scaling factor for Hubble expansion rate	h	$0.674(5)$	[2,32]
Hubble length	c/H_0	$0.925\,0629 \times 10^{26}\,h^{-1}\ \mathrm{m} = 1.372(10) \times 10^{26}\ \mathrm{m}$	
scaling for cosmological constant	$c^2/3H_0^2$	$2.85247 \times 10^{51}\,h^{-2}\ \mathrm{m^2} = 6.21(9) \times 10^{51}\,\mathrm{m^2}$	
critical density of the Universe	$\rho_{\mathrm{crit}} = 3H_0^2/8\pi G_N$	$1.878\,34(4) \times 10^{-29}\,h^2\ \mathrm{g\ cm^{-3}}$ $= 1.053\,672(24) \times 10^{-5}\,h^2\ (\mathrm{GeV}/c^2)\ \mathrm{cm^{-3}}$ $= 2.77536627 \times 10^{11}\,h^2\ M_\odot \mathrm{Mpc^{-3}}$	
baryon-to-photon ratio (from BBN)	$\eta = n_{\mathrm{b}}/n_\gamma$	$5.8 \times 10^{-10} \leq \eta \leq 6.5 \times 10^{-10}$ (95% CL)	[33]
number density of baryons	n_{b}	$2.515(17) \times 10^{-7}\,\mathrm{cm^{-3}}$ $(2.4 \times 10^{-7} < n_{\mathrm{b}} < 2.7 \times 10^{-7})\,\mathrm{cm^{-3}}$ (95% CL, $\eta \times n_\gamma$)	[2,3,34,35]
CMB radiation density of the Universe	$\Omega_\gamma = \rho_\gamma/\rho_{\mathrm{crit}}$	$2.473 \times 10^{-5}(T/2.7255)^4\,h^{-2} = 5.38(15) \times 10^{-5}$	[30]
- - - *Planck* 2018 6-parameter fit to flat ΛCDM cosmology - - -			
baryon density of the Universe	$\Omega_{\mathrm{b}} = \rho_{\mathrm{b}}/\rho_{\mathrm{crit}}$	$^\ddagger 0.02237(15)\,h^{-2}\ = {}^\dagger 0.0493(6)$	[2,3,27]
cold dark matter density of the Universe	$\Omega_{\mathrm{c}} = \rho_{\mathrm{c}}/\rho_{\mathrm{crit}}$	$^\ddagger 0.1200(12)\,h^{-2}\ = {}^\dagger 0.265(7)$	[2,3,27]
$100 \times$ approx to r_*/D_{A}	$100 \times \theta_{\mathrm{MC}}$	$^\ddagger 1.04092(31)$	[2,3,27]
reionization optical depth	τ	$^\ddagger 0.054(7)$	[2,3,27]
ln(power prim. curv. pert.) $(k_0 = 0.05\,\mathrm{Mpc^{-1}})$	$\ln(10^{10}\Delta^2_{\mathcal{R}})$	$^\ddagger 3.044(14)$	[2,3,27]
scalar spectral index	n_{s}	$^\ddagger 0.965(4)$	[2,3,27]

Outline of the lectures

- Lecture 1:
  - Recap of early universe cosmology
  - Primordial black holes
- Lecture 2:
  - Gravitational waves in Cosmology
  - GW background associated with PBHs