Need astronomical, compact mass to generate detectable GW (exercise 1.1)

↳ Astrophysics of compact bodies

~~what the~~ stars → not so compact, hot due to nuclear burning
what happens when a star burns its fuel?

no thermal pressure to counter gravity
↳ collapse, with mass ejection (sometimes: explosions, supernovae)
... until degeneracy pressure takes over
(Fermions ⇒ Pauli principle + Compton-wavelength $\sim \hbar/m$)
dominant pressure from lightest particle (longest wavelength) ⇝ electrons!
⇝ **white dwarfs**

but: they have a maximum mass $\sim 1.5 M_\odot$! ← $\hat{=}$ initial mass ca $8 M_\odot$, rest is ejected
(Chandrasekhar mass)
more mass ⇝ further collapse!
⇝ very high pressure
⇝ inverse β-decay becomes energetically favorable

$$p^+ + e^- \longrightarrow n + \nu_e$$

⇝ degeneracy pressure from neutrons
⇝ **neutron stars**

again: have a max. mass $\gtrsim 2 M_\odot$ $\hat{=}$ initial mass 20-$30 M_\odot$
more mass ⇝ further collapse
⇝ **black holes**

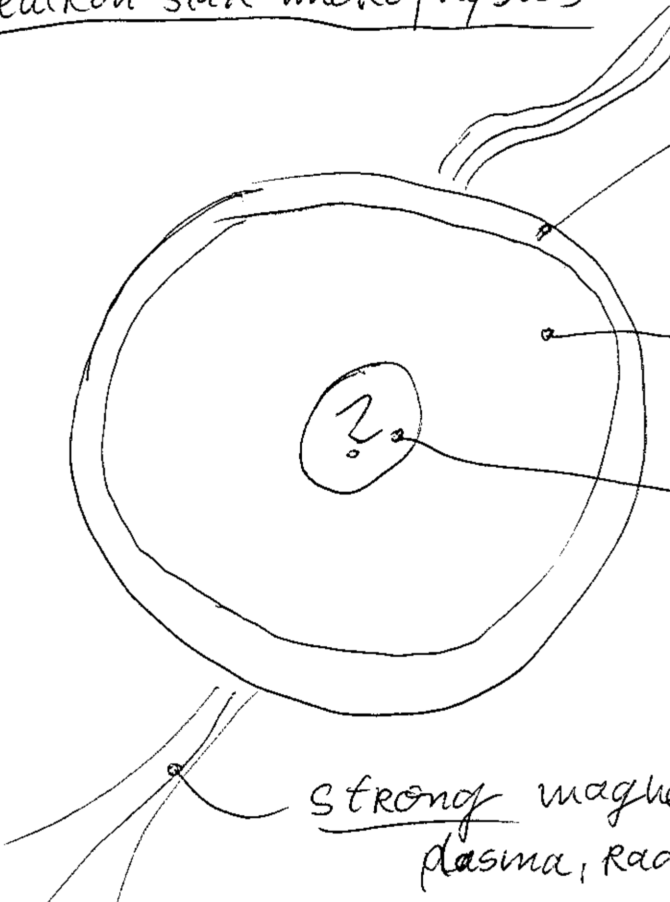
most interesting for GW: black holes & neutron stars

black holes → lectures by Maria Rodriguez

modeling neutron stars:
Einstein equations + hydrodynamics + equation of state
(+ symmetries) (ideal fluid) ↳ microphysics

neutron star microphysics

Ehlers 2018 L4P2



CRUST: nulei in a lattice
"nuclear pasta" with
neutron superfluid

outer core: neutron superfluid
proton superconductor

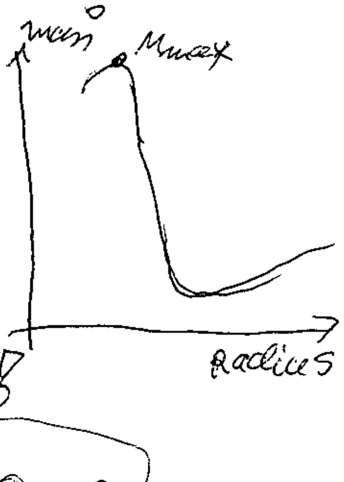
? ? ?
inner core: condensation of
hyperons, kaons, pions, ..., ?
deconfined quarks ?
? ?

strong magnetic field 10^{8}-10^{11} tesla
plasma, radio emission (→ pulsars)

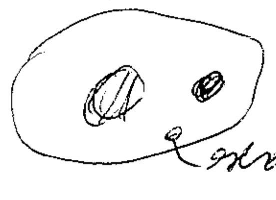
other properties: 10 km < neutron star radius < 15 km
mass 1-2 $M_{\odot}$
↝ the sun compressed to the size of a city
↝ a teaspoon of neutron star matter ~10^{13} kg ~ a mountain

open problem: eg. observed 2 $M_{\odot}$ neutron star
incompatible with predicted condensation
of hyperons ↝ hyperon problem

How can one solve these problems? ↝ observations!
- mass-radius relation, max mass
- "mountains" on neutron stars }
- tidal deformation in binaries } GW astronomy!



Another question for GW astro:
how do compact binaries form?
(from binary stars)
↳ challenges:
- asymmetric supernova
↝ recoil ("kick") ↝ binary could disrupt
- star towards death expands
↝ common envelope phase → might be eaten by companion



Good sources of GW:
- binaries with black holes, neutron stars
- mountains on rotating neutron stars
- supernova (asymmetric)
- big bang
- surprises?

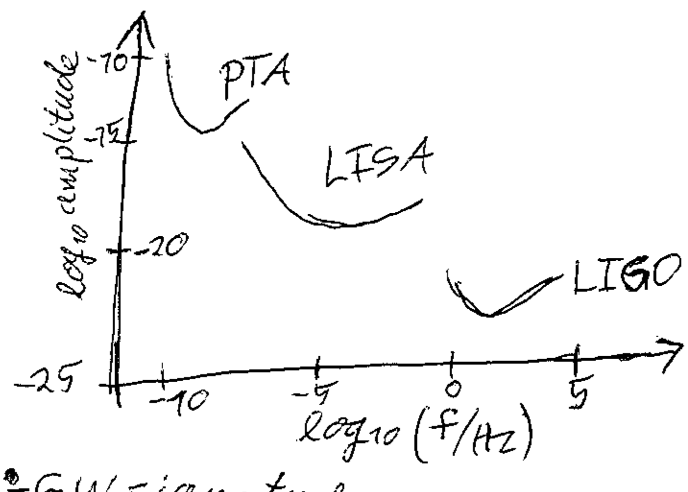
GW astonomy ⇝ precisiscion physics

↳ since GW basically ~~dont~~ don't get disturbed on their way to detector!

important exceptions: - cosmological redshift
- gravitational lensing
⇝ (de-) magnification, phase perturbations or same signal arrives multiple times!

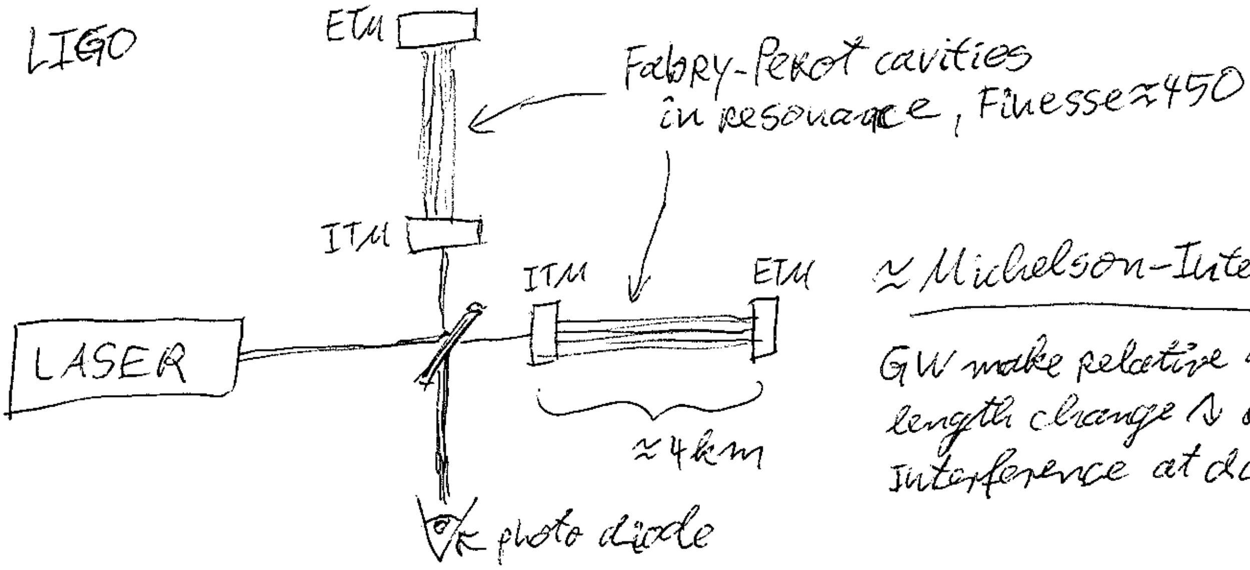
GW Detectors

- ground-based detectors (interferometers)
  LIGO (USA), Virgo (Italy) } "2nd generation"
  future: Kagra (Japan), LIGO India } ~4 km
  3rd generation? ~ 10-30 km
- pulsar timing arrays (PTA) 2020's
  ↳ including the Square Kilometre Array (SKA)
- LISA space mission 2034



also: GW signatures in the cosmic microwave background ⇝ Planck, Bicep2 ⇝ nothing found
- bar detectors "Weber bars"

Ground-based detectors (Interferometers)



≈ Michelson-Interferometer

GW make relative arm length change ⇝ changed interference at diode

4 test-masses: 2 x ITM, input test mass
2 x ETM, end test mass } 34 x 20 cm fused silica 40 kg

test-masses are "free falling" in horizontal direction
↳ approximately valid for frequencies > 10 Hz due to ~~[illegible]~~ suspension ⇝ seismic isolation, damps forces by 10 orders of magnitude

complicated instrument: hundreds of feedback control loops keep interferometer in "lock" (eg. Fabry-Perot in resonance)

sensitivity: $h \sim 10^{-21}$ ⇝ $\Delta L = 10^{-18}$ ~~[illegible]~~ m $\sim \frac{1}{1000}$ proton radius !

incredible experimental achievement!