4.5 / 15 P

Klausur I: Grundkonzepte der Astro- und Teilchenphysik WS2014/15 26.2.2015

Name: Matr. Nr.: Stud.Kzl.:

Bitte die Heftung nicht öffnen !
Bitte um **kurze prägnante Antworten** und achten Sie etwas auf Schriftbild und Form!
Please do not open the stitching!
We are kindly asking for short, concise and readable answers!

1) Which particle acceleration process is the ***more efficient*** one – Fermi 1st or Fermi 2nd order process? Justify by discussing the respective energy gain ΔE/E!
(no explicit derivation required) [2P]

statistical distribution of ΔE/E ~ ?
random walk

Shock Front
↳ ΔE/E ~ const ✓

↳ 1st order p. more efficient why?

½ P

2 a) What was the so-called "Solar neutrino problem"? What explanation addressed the problem?
b) Which particle reactions allowed to experimentally confirm this explanation? Why could it be proven this way?

a) measured flux was lower than expected → Detector only sensitive to ν_e ✓ ✓ 2P
↳ expl.: Neutrino Oscillations
↳ not all ν_e „arrive" at earth as ν_e

b) ~~Ket~~ use detector, that is sensitive to all neutrino flavours ✓
↳ as heavy water reaction formulae?
Neutrinos interact with Deuteron
→ 2 processes ~~D + p + ν~~ : one is sensitive to all flavour ✓
: one only to ν_e ✓ ½ P

3) What is the connection between the short time flux variability and the size of an emission region in distant astronomical objects?

... and then?

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4 a) Cosmic Rays: Why can we approximate *electromagnetic* shower development and propagation with a simple mathematical prescription. Why can't we do that in case of shower development of the *nucleonic* component? [2P]

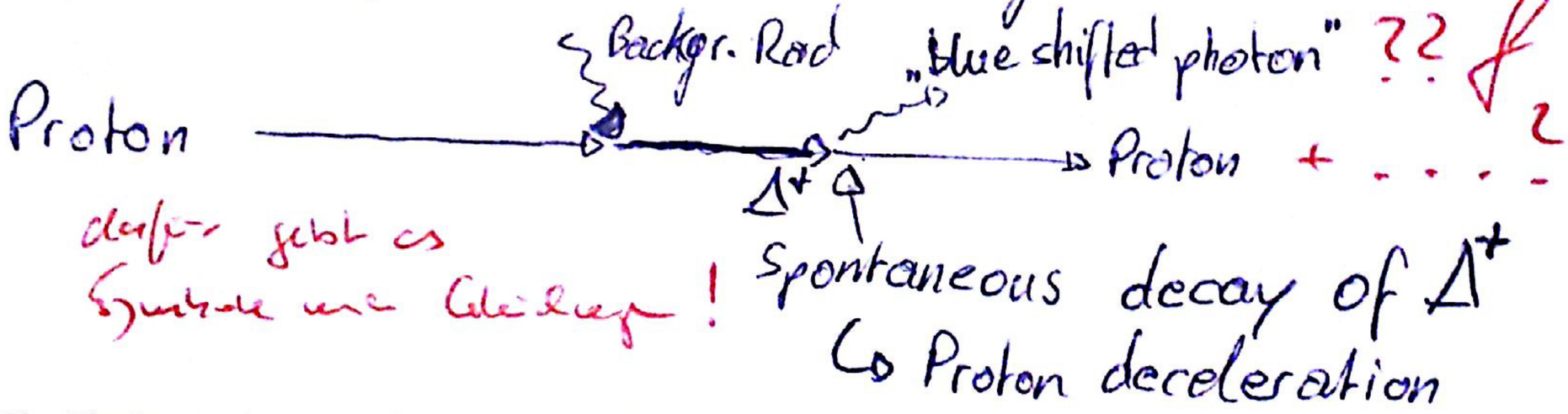
EM waves ~~propagation~~ werden weniger Stark gestreut als Massive Teilchen.

der ist nicht der Grund für die mögliche mathematische Beschreibbarkeit

4 b) Cosmic Rays: Write down the particle interaction that limits the accessible volume of our Universe to UHECRs! What is the role of the $\Delta^+(1232)$ resonance thereby? How many Mpc we can approximately look out for UHECRs?

$L_0 \sim 100$ Mpc

1/2 P interaction of UHECR with Photons of Background radiation. (c)



dafür gibt es Synchrotron und Gleichgewicht!

6) Trajectories of charged particle bend in magnet spectrometers, and the sagitta is a measure for the distance from the center of the curved particle path to that traversing unaffected. Which physical parameters determine the sagitta for high energy particles?

B-Field strength (and homogenity)
mass of particle
Energy of particle
charge of particle
→ A/2!

1P

--- Berg res Sagitta?

J.S / 15 r

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2

6a) **Cyclotron**: Derive the classical formula for the cyclotron frequency ω_C and argue how it changes due to relativistic effects? [1.5P]

$\vec{F} = q(\vec{E} + \vec{v} \times \vec{B})$

$\vec{F} = m\omega^2 r$

$\omega_c = \sqrt{\frac{q(\vec{v} \times B)}{mr}}$

$\gamma = \frac{1}{\sqrt{1 - \frac{v^2}{c^2}}}$

$\omega_c = \sqrt{\frac{q(\vec{v} \times B)}{m\gamma r}}$

γ steckt ω !

1P

ω_c wird annähernd Konstant, weil $|\vec{v}|$ begrenzt auf c zum indest beim LHC c_0 $\vec{B}$ wird

b) **Higgs events**: Calculate the number of $H \to \gamma + \gamma$ events one expects in 25 fb^{-1} of data of the ATLAS experiment, which is the complete data sample of LHC run 1. Assume that the efficiency for detecting a photon is 90%. [1.5P]

dort aber auch verände damit r=con

The cross section for the process $p + p \to H$ is 15 pb. (p = proton, H = Higgs)
The probability for the decay $H \to \gamma + \gamma$ is 0.23%.
pb = picobarn, fb^{-1} = inverse femtobarn (~ integrated luminosity), 1 barn = 10^{-28} m^2

$N_{events} = L \cdot \sigma = 25\,fb^{-1} \cdot 15\,pb \cdot 0{,}9 \cdot 0{,}0023 =$

0,9 det. efficiency ← zum Quadrad

$= 25 \cdot 15 \cdot 10^3 \cdot 0{,}9 \cdot 0{,}0023 = 776{,}25$ Events

1P

2.5

7) A proton beam is directed towards a hydrogen target at rest. **Derive the threshold kinetic energy** of the incident proton beam for the additional production of three pions using the concept of invariant mass: $p + p \to p + p + \pi^+ + \pi^- + \pi^0$.
$m_{\pi 0} = 135\ MeV/c^2$, $m_{\pi \pm} = 140\ MeV/c^2$, $m_p = 938\ MeV/c^2$. [3P]

$$\begin{pmatrix} E_p \\ \vec{p} \end{pmatrix} + \begin{pmatrix} m_p \\ 0 \end{pmatrix} = \begin{pmatrix} m_p \\ 0 \end{pmatrix} + \begin{pmatrix} m_p \\ 0 \end{pmatrix} + \begin{pmatrix} m_{\pi^+} \\ 0 \end{pmatrix} + \begin{pmatrix} m_{\pi^-} \\ 0 \end{pmatrix} + \begin{pmatrix} m_{\pi^0} \\ 0 \end{pmatrix}$$

$(E_p + m_p)^2 - \vec{p}^2 = (m_p + m_p + m_{\pi^+} + m_{\pi^-} + m_{\pi^0})^2$

$= p^2 + 2E_p m_p + m_p^2 - \vec{p}^2 =$ ⁰/₀

$2E_p m_p + 2m_p^2 =$ ⁰/₀

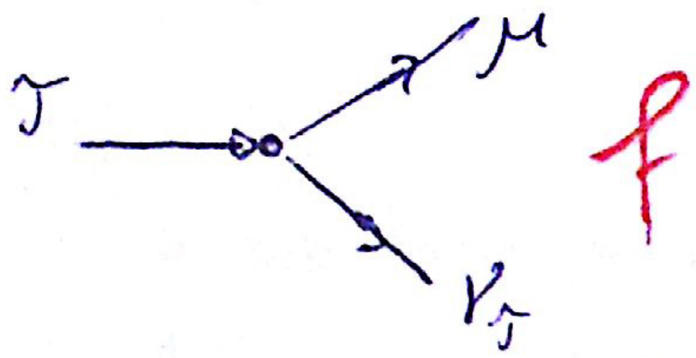
$E_p = \frac{⁰/₀ - 2m_p^2}{2m_p} = \frac{(2 \cdot 938 + 135 + 2 \cdot 140)^2 - 2 \cdot 938^2}{2 \cdot 938}$

$E_p = 1859{,}8 \frac{MeV}{c^2}$ ✓

✓ $E_{KIN} = E_p - m_p$

2

8) Draw one possible **Feynman diagram for the decay of the tau-lepton** and show how the corresponding matrix element can be written down by **naming the different elements** that are needed.
(Don't write down the matrix element explicitly, but rather symbolically).



M = incoming particle · coupling · outgoing particles ✓

M = inc. part · coupling · virt. part · coupling · outgoing pa ✓

Propagator

1.5

9a) What is a (Dirac) spinor and what does it describe? [1P]

mathematical object, which describes a relativistic spin $\frac{1}{2}$-partic ✓

b) List two properties of a spinor. [1P] 0

has only two Eigenstates

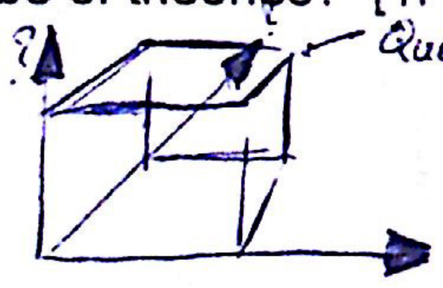
c) What kind of objects does the Klein-Gordon equation describe? [0.5P] 0

aus QRT →

d) How is the ultimate theory that includes all forces of nature called? [0.5P]

Quantum Gravitation or GUT or theory of everything ✓

e) Which three properties does this ultimate theory have according to Bronshtein's cube of theories? [1P] 0



→ valid on large and small scale
→ combines all interactions

1.5

10) The neutron and the myon decay through the same interaction, but their lifetimes τ_n and τ_μ differ by a factor of about 10^{10}. Explain why there is such a big difference, or even better, give the approximate theoretical expression for the factor τ_n/τ_μ. [2P]

Lebensdauer durch die selbe Formel beschrieben
↳ nur andere Massen einsetzen ✓

Bin mir nicht mehr ganz sicher wie die Formel wär. Vermutung: $\tau_n = \tau_\mu$. Faktor für Anzahl der Zerfallskanäle

$\mu \ldots \tau \approx 2{,}2 \cdot 10^{-6}\,s$
$n \ldots \tau \approx 20\,min \approx 1600\,s$ } 10^9 ✓

$m_n - m_p$

$\cdot \left(\frac{m_e}{m_\mu}\right)^5$

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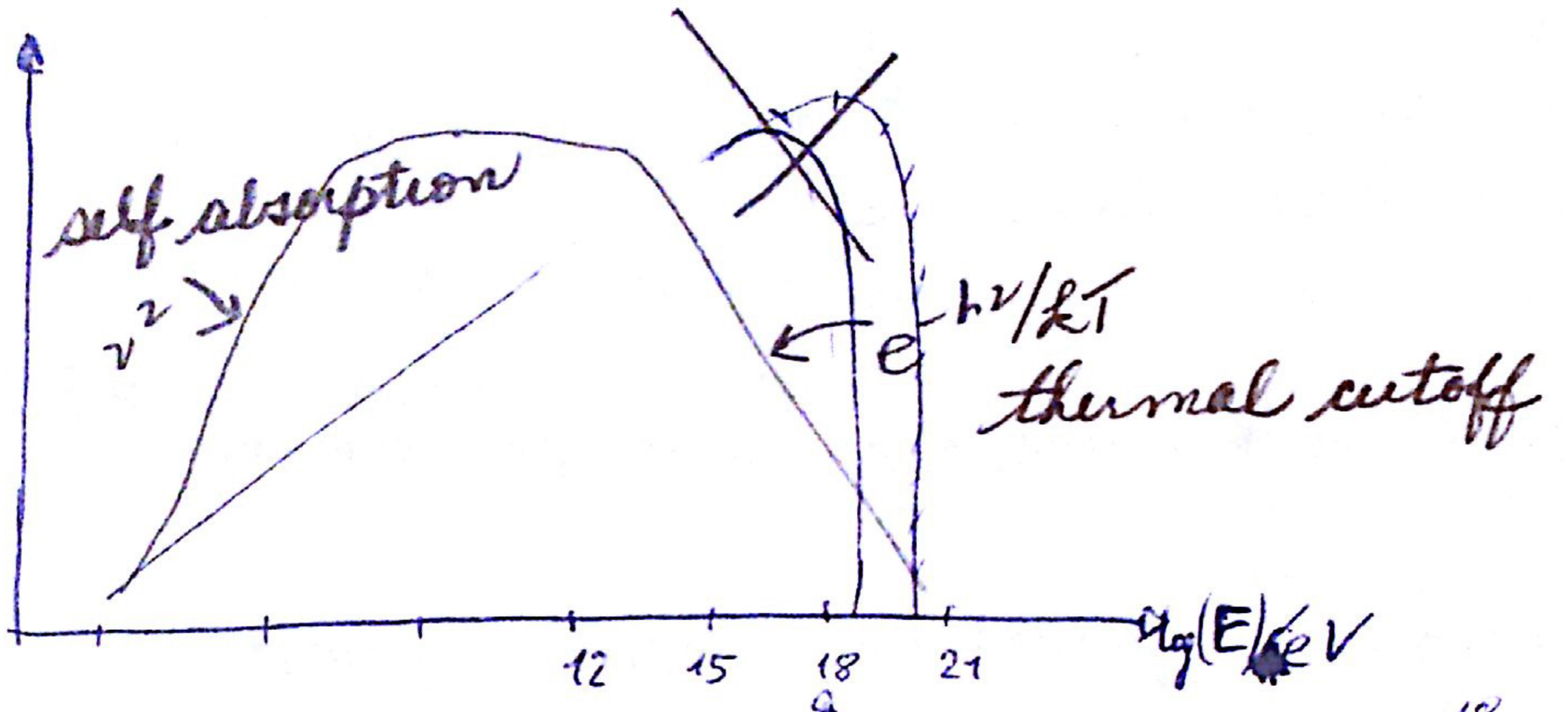
5,6/15

11) Radiation Processes

a) Sketch the thermal bremsstrahlung spectrum of an HII region. Why does it turn over at high frequency? Indicate the actual frequency dependencies on your diagram in the low and high frequency limits. [1P]

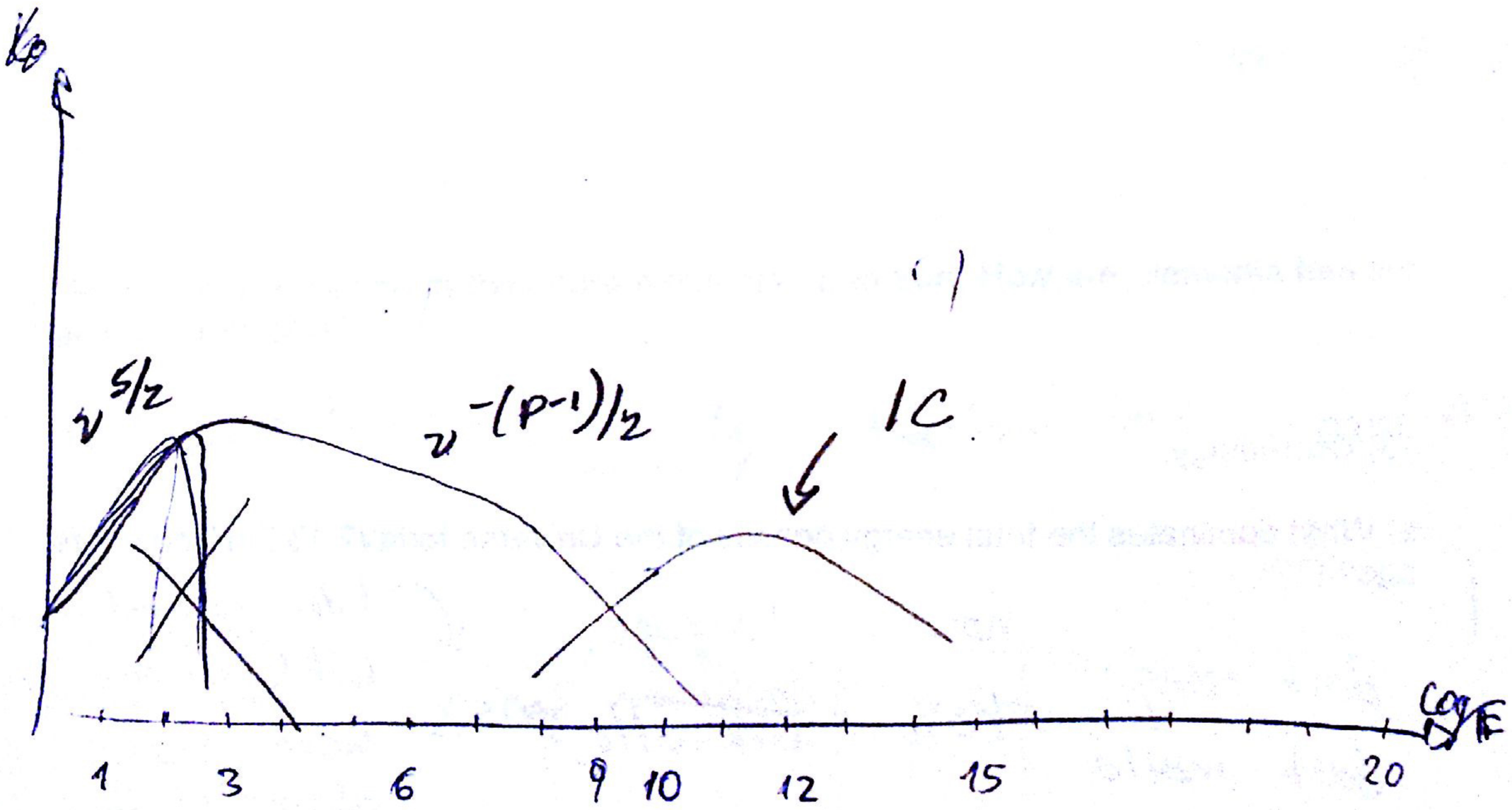
0



I dont remember the energy, but i suppose 10^{18} eV is too high.

b) Sketch the synchrotron radiation spectrum of the Crab Nebula. What is the functional form of the synchrotron radiation spectrum at low frequencies? At high frequencies? At very high energies (greater than 100MeV), the Crab Nebula spectral energy distribution shows another peak at TeV energies. What is the radiation process responsible for this peak? [2P]

0



12) Instrumentation

0.8 a) What defines the best possible spatial resolution of a telescope? Describe and write down its functional form. How can this be achieved from the ground? [1P]

2 points must be distinguish_able
↳ smeared out → airy discs

depends on wavelength and ✓ telescope diameter

resolution can be improved by adaptive Optics ✓

1,1 b) The goal of instrumentation is to discern the signal of an astrophysical source from a sea of noise within a reasonable amount of time. What are the most efficient detectors today in optical astronomy? For an astronomical source observed with these detectors, what are the main sources of noise? [2P]

CCDs ✓ are most efficient

temperature and ~~the~~ athmosphere

13) Cosmology.

a) What dominates the total energy density of the Universe today? 13.7 billion years ago? [2P]

now	
dark energy	≈ 76%
dark matter	
matter (Stars, protons, He, ...)	≈ 4%

Long ago	
~~dark energy~~ dark matter	≈ 75%
protons ~~He~~	≈ 25%
gravitons	10^{-5}

I don't remember exactly, but (dark energy) and ~~matter~~ were significantly less abundant than today

b) What evidence is there that our Milky Way Galaxy hosts a supermassive black hole? What is its estimated mass? [2P]

seriously? since when is it necessary to learn constants to get points in an exam? If I'd like to study constants, I would NOT be interested in physics

motion of stars in the galatic center observed over long period of time
↳ stars are moving around a point, where no star is visible
↳ BH evidence

the mass of a SMBH is not a constant and you should know roughly what SM means.

15) Stellar Physics

0.5 a) What source of pressure dominates in the Solar core? How is the energy transported from the core to the surface? [2P]

gas pressure
Gleichgewicht zwischen radiation pressure and gravitational pressure
(balance between)

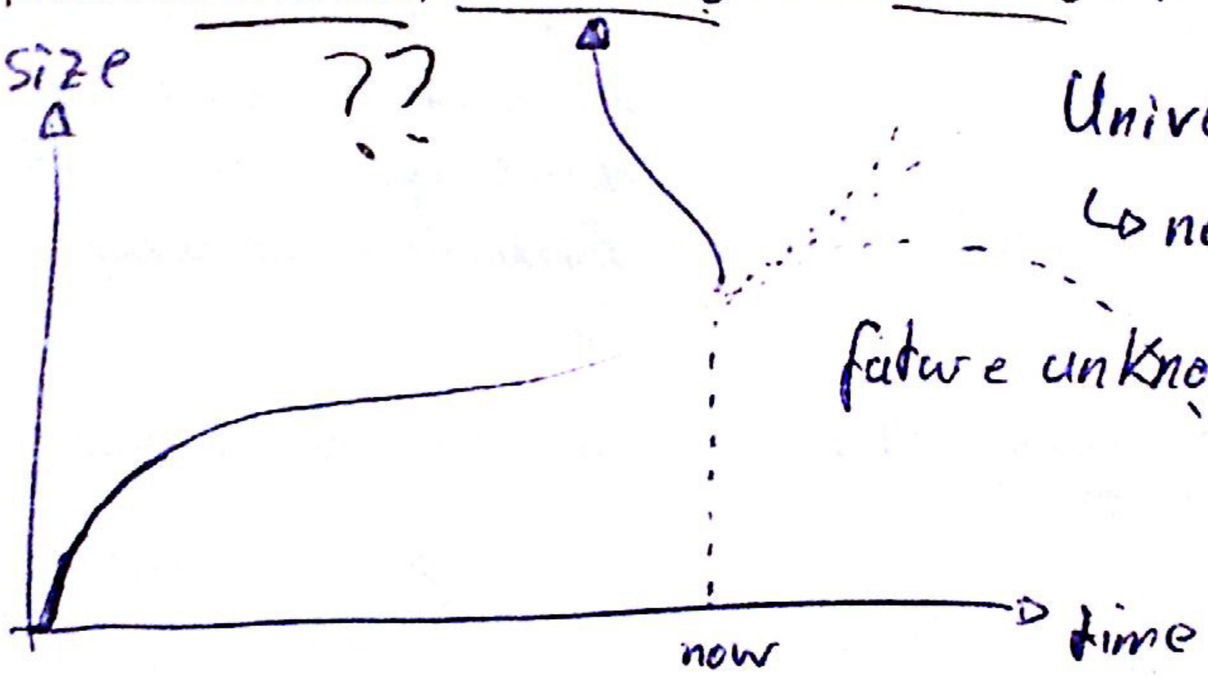
depending on size of star transport via • radiation ?
Sun? • convection
• mix of both

0.8 b) Stars can synthesize in their core elements up to iron. How are elements heavier than iron produced? [1P]

in Super Novae ? or by Neutron capture and β-decay

b) Describe and sketch the evolution of the size (scale factor) of the Universe as a function of time, from the Big Bang to the present time. Is the Universe currently in a phase of constant, accelerating or decelerating expansion? [1P]

0.3



Universe expanded since Big Bang.
↳ now described by Hubble constant
↳ actually not a const

future unknown

$H_0 \approx 70 \frac{km}{s\,Mpc}$

14) Galaxies.

a) Describe the properties of elliptical and spiral galaxies. What are the characteristic features (both lines and continuum) in their spectra? [1P]

0.1

less rotation than spiral galaxy, or young galaxy, that will form arms later

~~old~~ → arms come from rotation of the whole galaxy