Title: PHYS 781 - Lecture 25

Date: Nov 28, 2014 12:00 PM

URL: http://pirsa.org/14110060

Abstract:

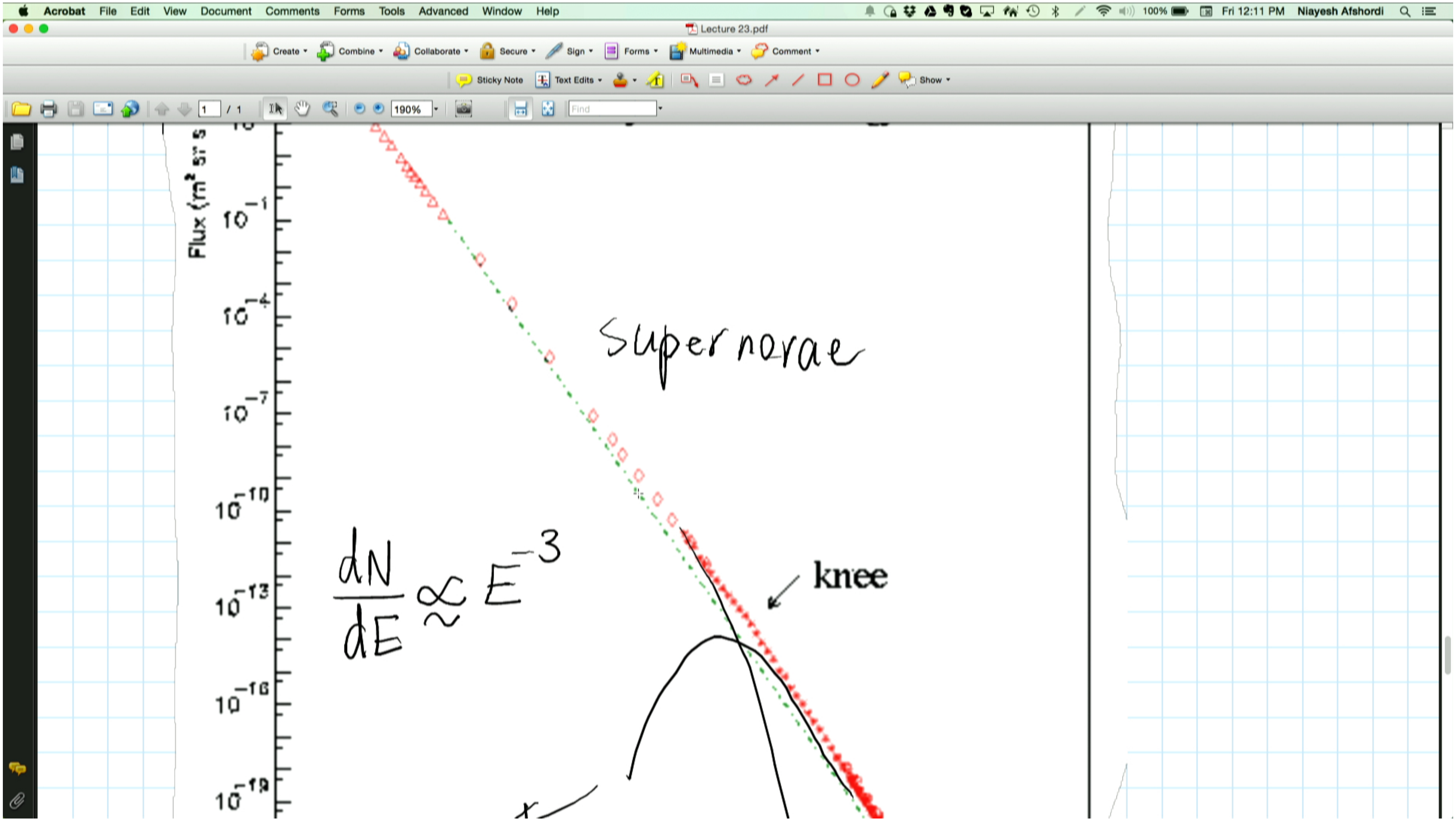
$$\alpha^2 = \frac{t_{ref.}}{t_{esc.}\langle \Delta h \varepsilon^2 \rangle} \sim \frac{c^2 t_{ref.}^2}{L^2 \left(V_{mirror}^2 / c^2\right)}$$

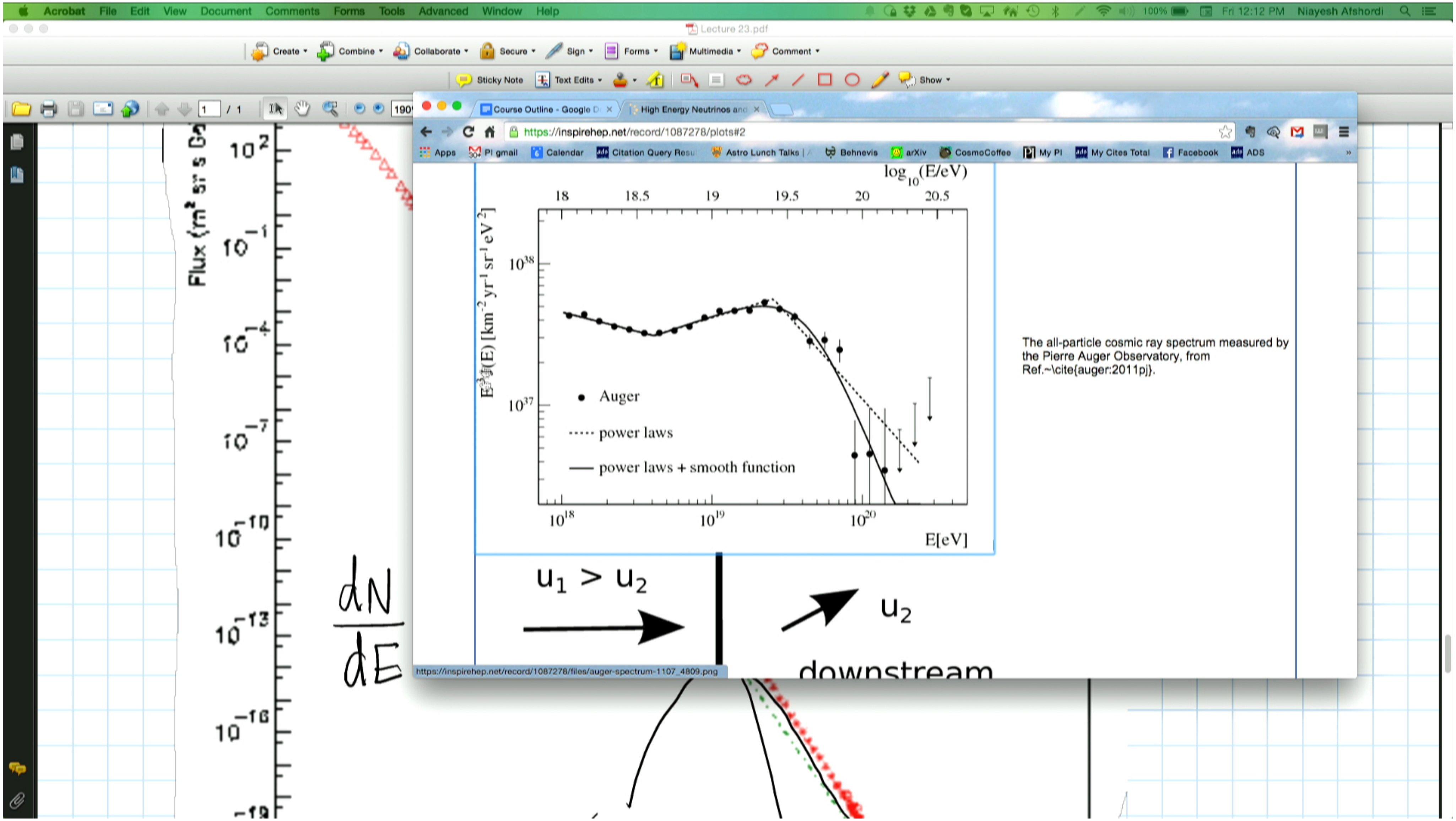
$$\Rightarrow \alpha^{-1} \sim \left(\frac{L}{L_{ref.}}\right)\left(\frac{V_{mirror}}{c}\right)$$

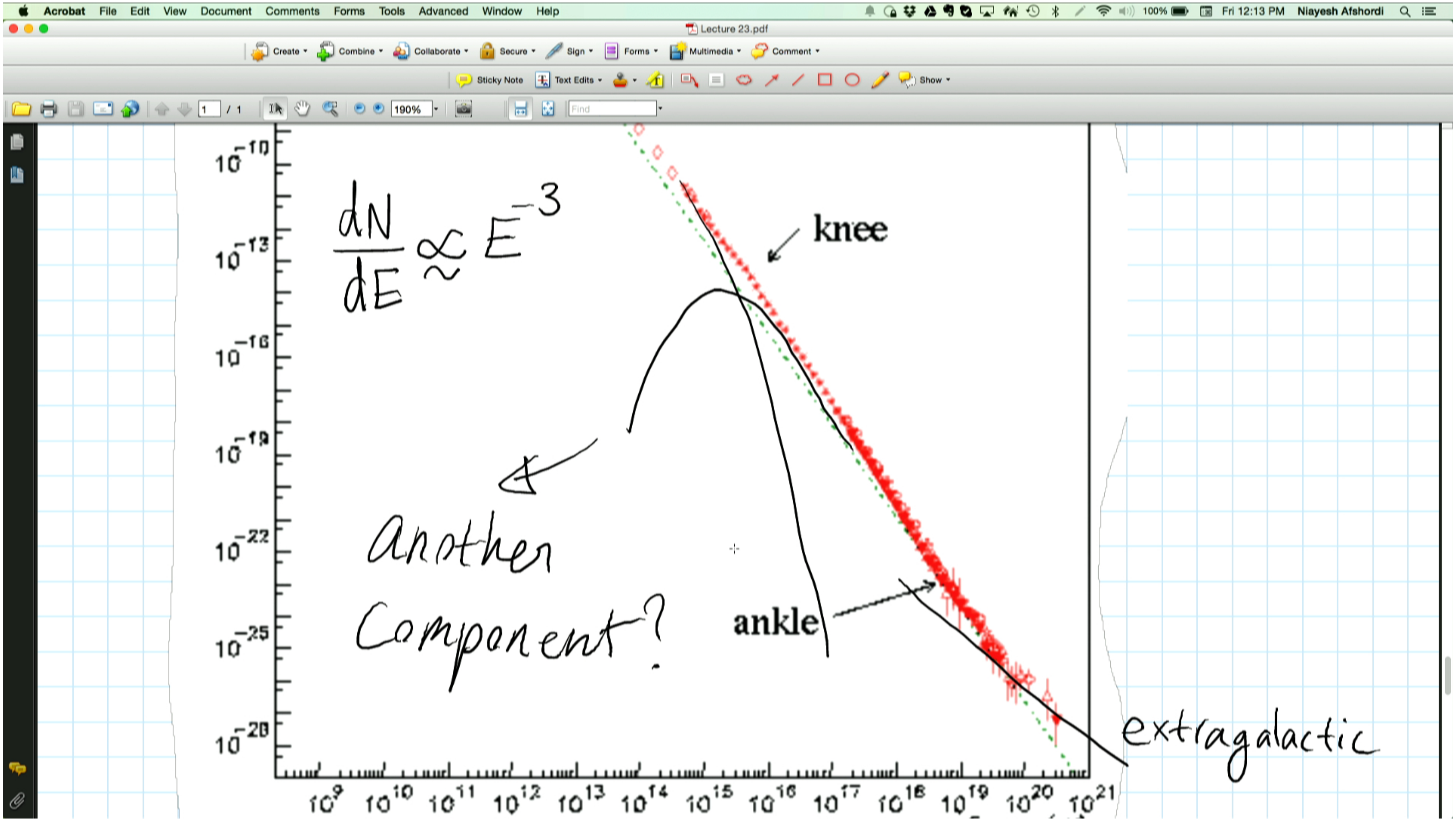
Size of the system

plasma velocity

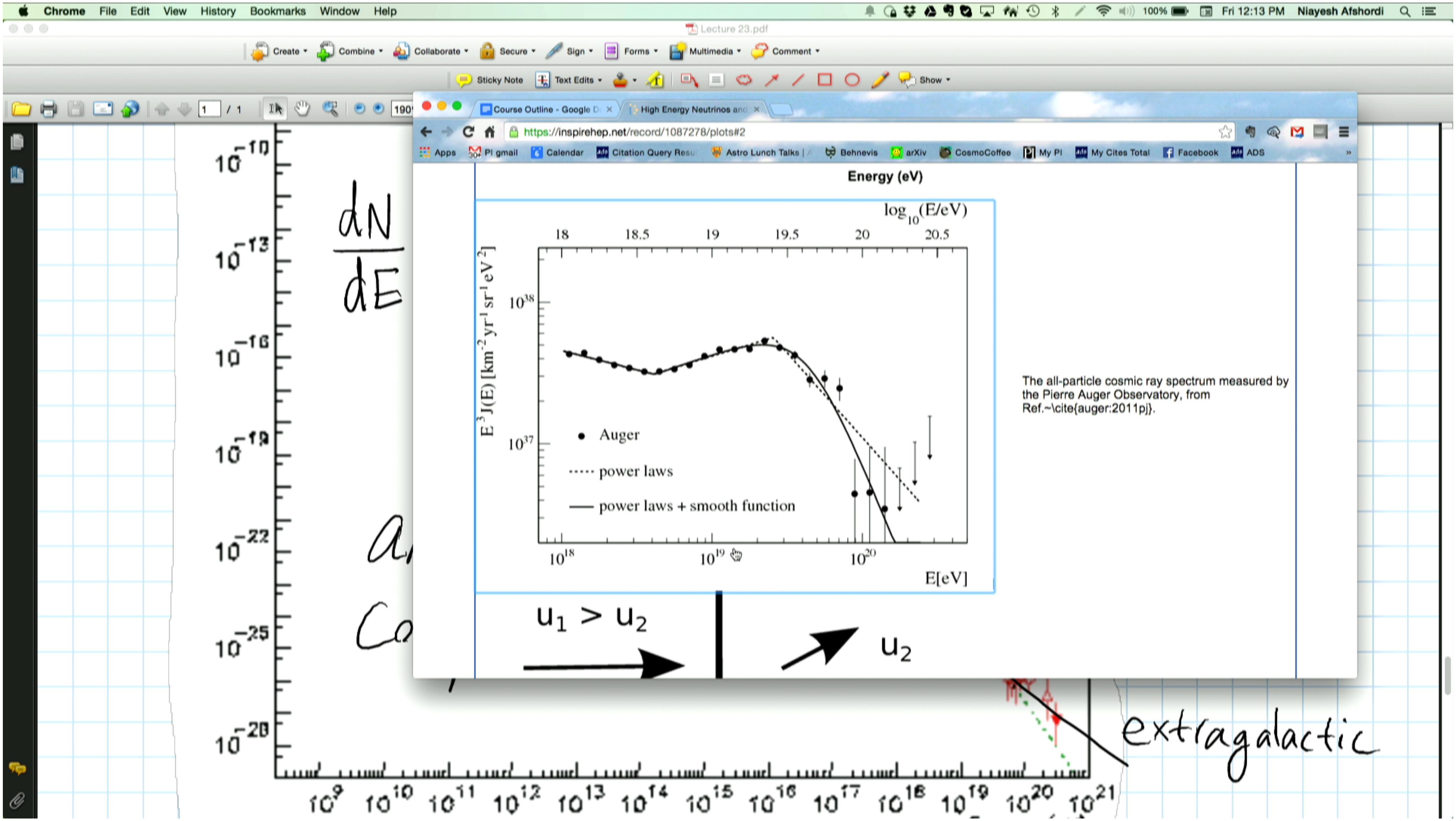
Coherence length of B-field


Lecture 23.pdf
Flux (m² sr s
10⁻¹
10⁻⁴
10⁻⁷
10⁻¹⁰
10⁻¹³
10⁻¹⁶
10⁻¹⁹
Supernovae
dN/dE ∝ E⁻³
knee


Lecture 23.pdf
https://inspirehep.net/record/1087278/plots#2
log10(E/eV)
E[eV]
Auger
power laws
power laws + smooth function
The all-particle cosmic ray spectrum measured by the Pierre Auger Observatory, from Ref.~\cite{auger:2011pj}.
Flux
dN/dE
u1 > u2
u2
downstream



Lecture 23.pdf
dN/dE ∝~ E^-3
knee
another Component?
ankle
extragalactic
10^-10
10^-13
10^-16
10^-19
10^-22
10^-25
10^-28
10^9 10^10 10^11 10^12 10^13 10^14 10^15 10^16 10^17 10^18 10^19 10^20 10^21


Energy (eV)
$\log_{10}(E/eV)$
18 18.5 19 19.5 20 20.5
$E^3 J(E)$ [km^{-2} yr^{-1} sr^{-1} eV^2]
10^{38}
10^{37}
Auger
power laws
power laws + smooth function
10^{18} 10^{19} 10^{20}
E[eV]
The all-particle cosmic ray spectrum measured by the Pierre Auger Observatory, from Ref.~\cite{auger:2011pj}.
$u_1 > u_2$
u_2
$\frac{dN}{dE}$
extragalactic
10^{-10} 10^{-13} 10^{-16} 10^{-19} 10^{-22} 10^{-25} 10^{-28}
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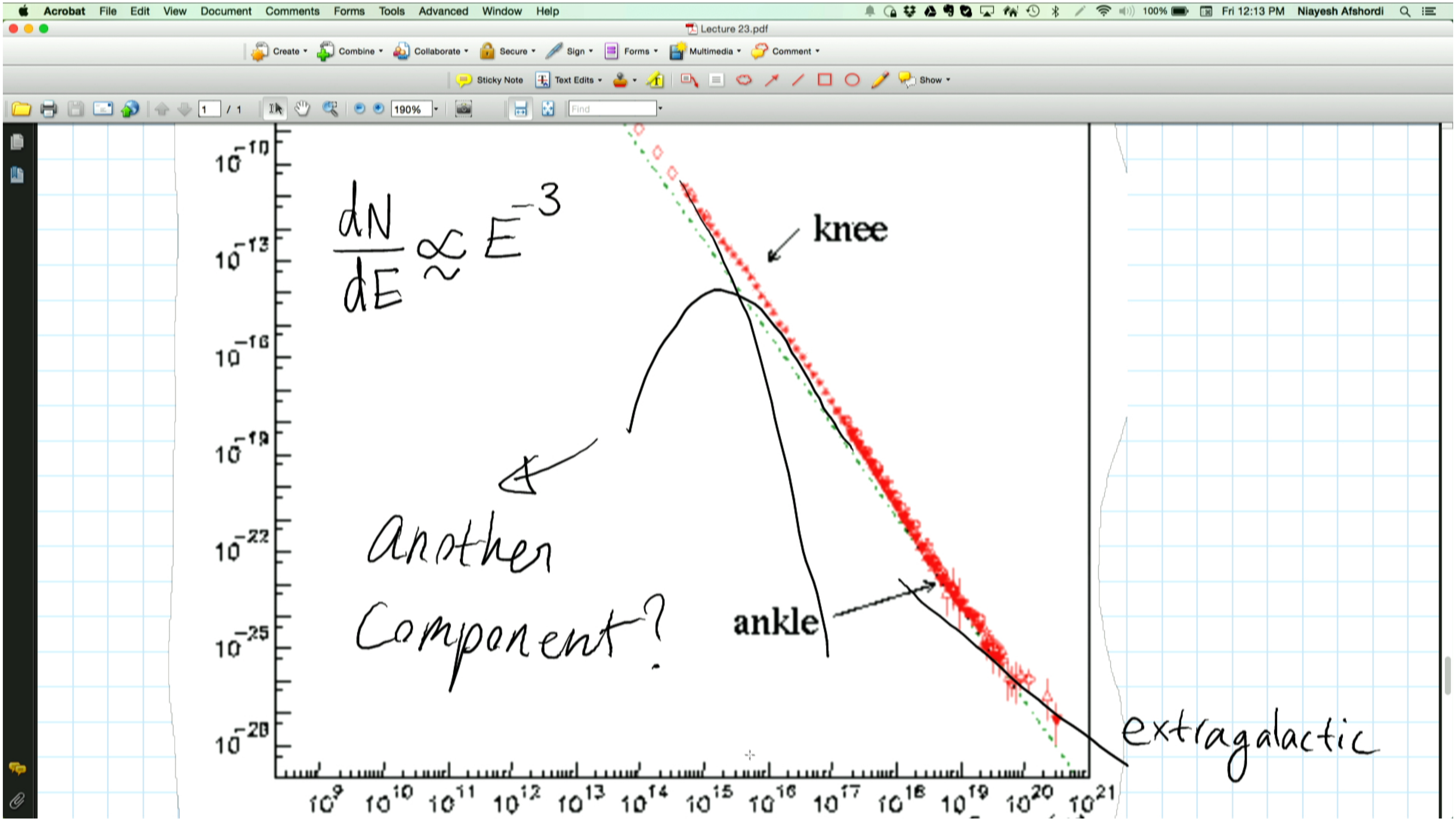
Lecture 23.pdf
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another Component?
ankle
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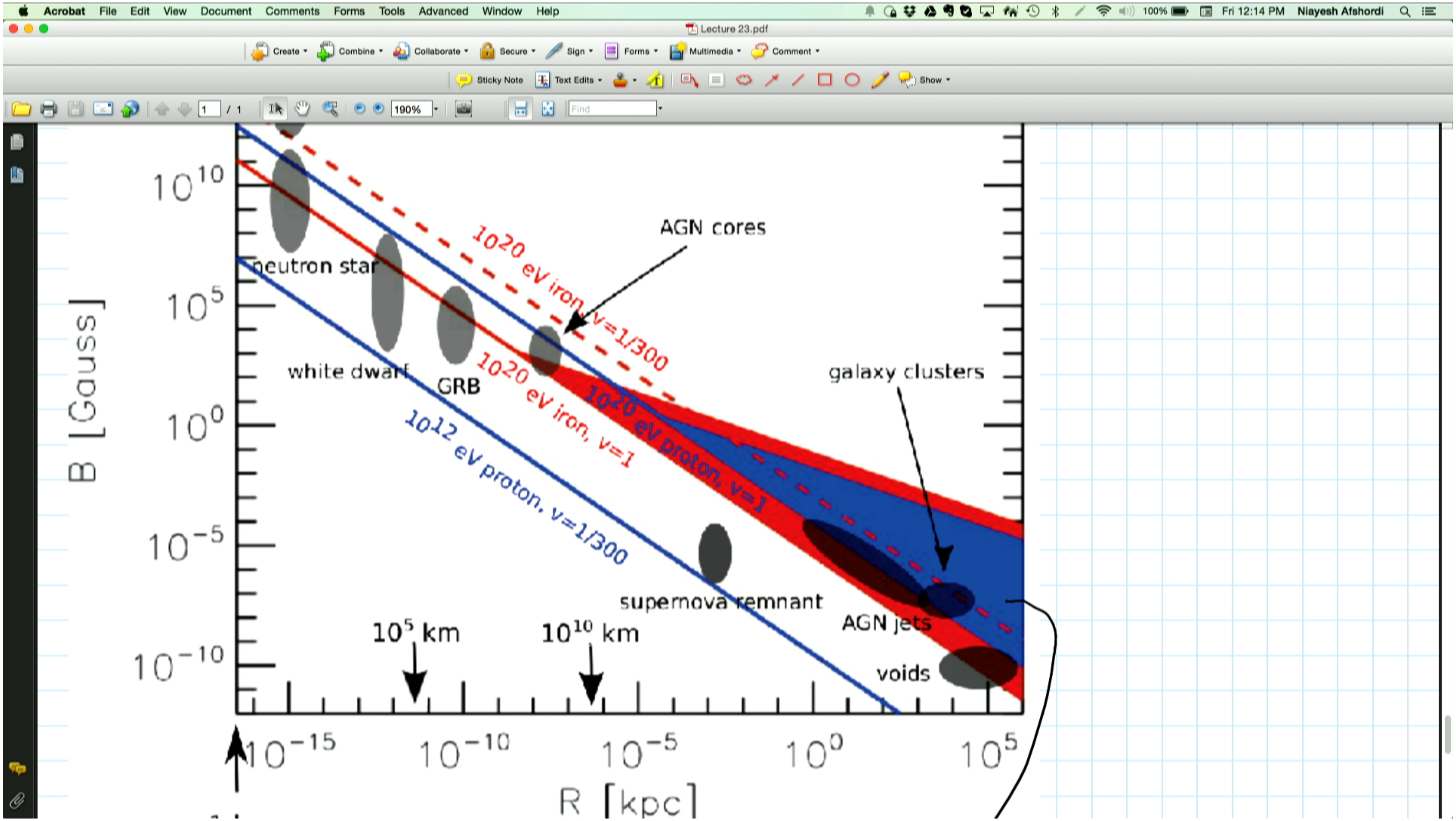
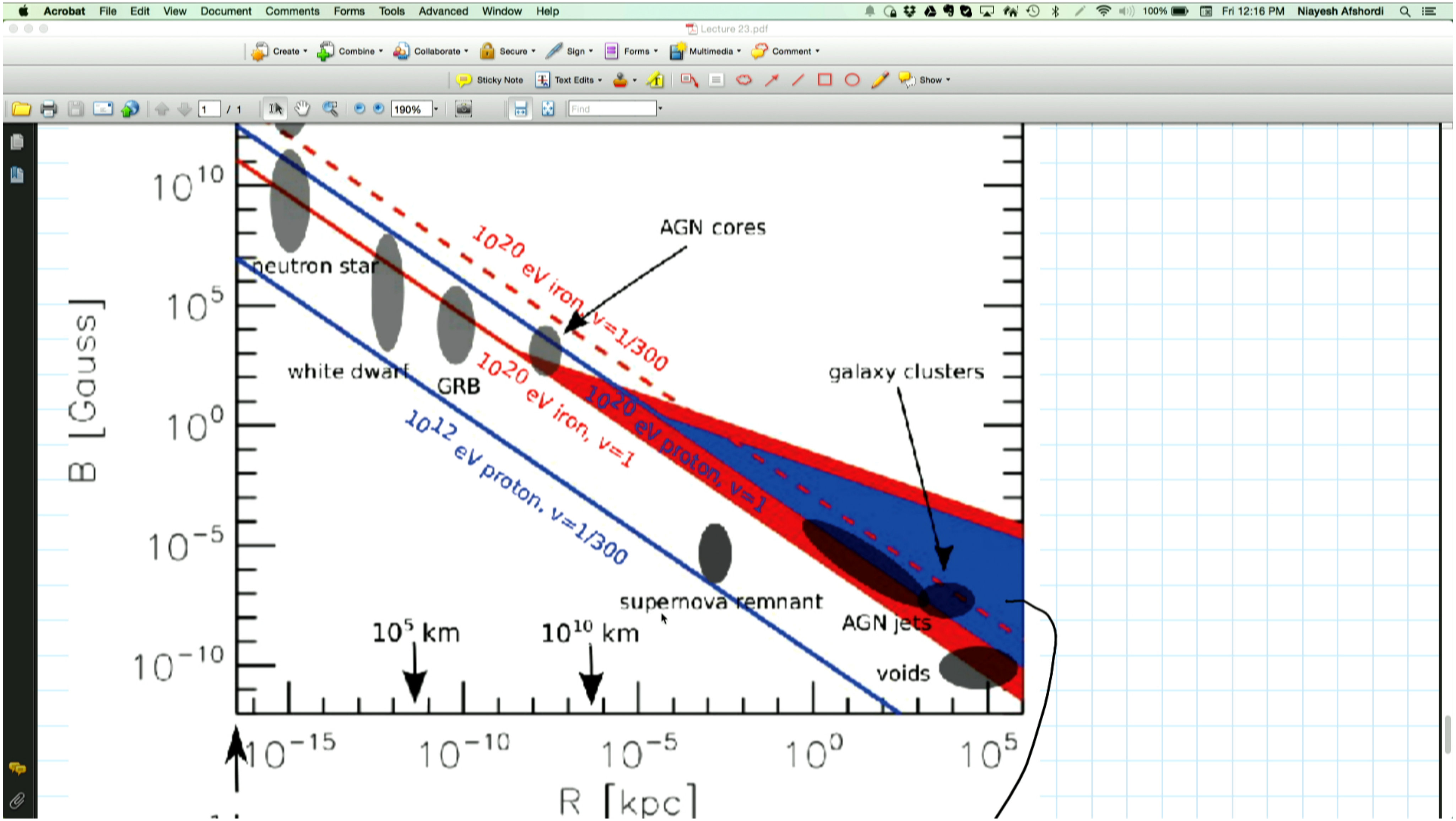

Lecture 23.pdf
AGN cores
neutron star
white dwarf
GRB
10^{20} eV iron, v=1/300
10^{20} eV iron, v=1
10^{20} eV proton, v=1
10^{12} eV proton, v=1/300
galaxy clusters
supernova remnant
AGN jets
voids
10^5 km
10^{10} km
B [Gauss]
10^{10}
10^5
10^0
10^{-5}
10^{-10}
10^{-15}
10^{-10}
10^{-5}
10^0
10^5
R [kpc]

$$\omega P_\perp = eB$$

$$\omega = \frac{v_\perp}{r} \qquad \frac{P_\perp v_\perp}{r} = eB$$

$$\sin^2\theta \; \frac{E}{r} = eB$$


AGN cores
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10^{20} eV iron, v=1/300
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10^5 km
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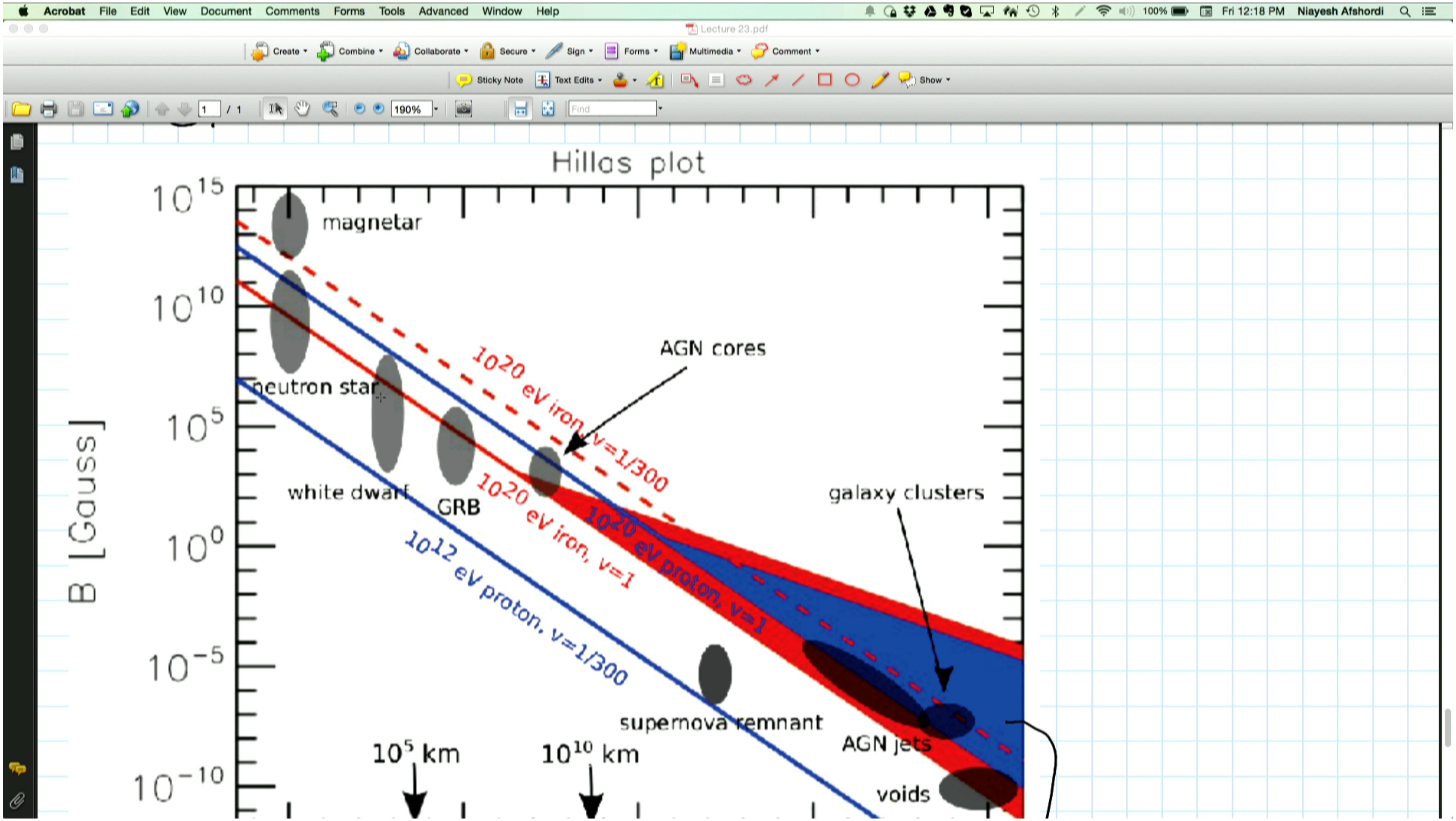
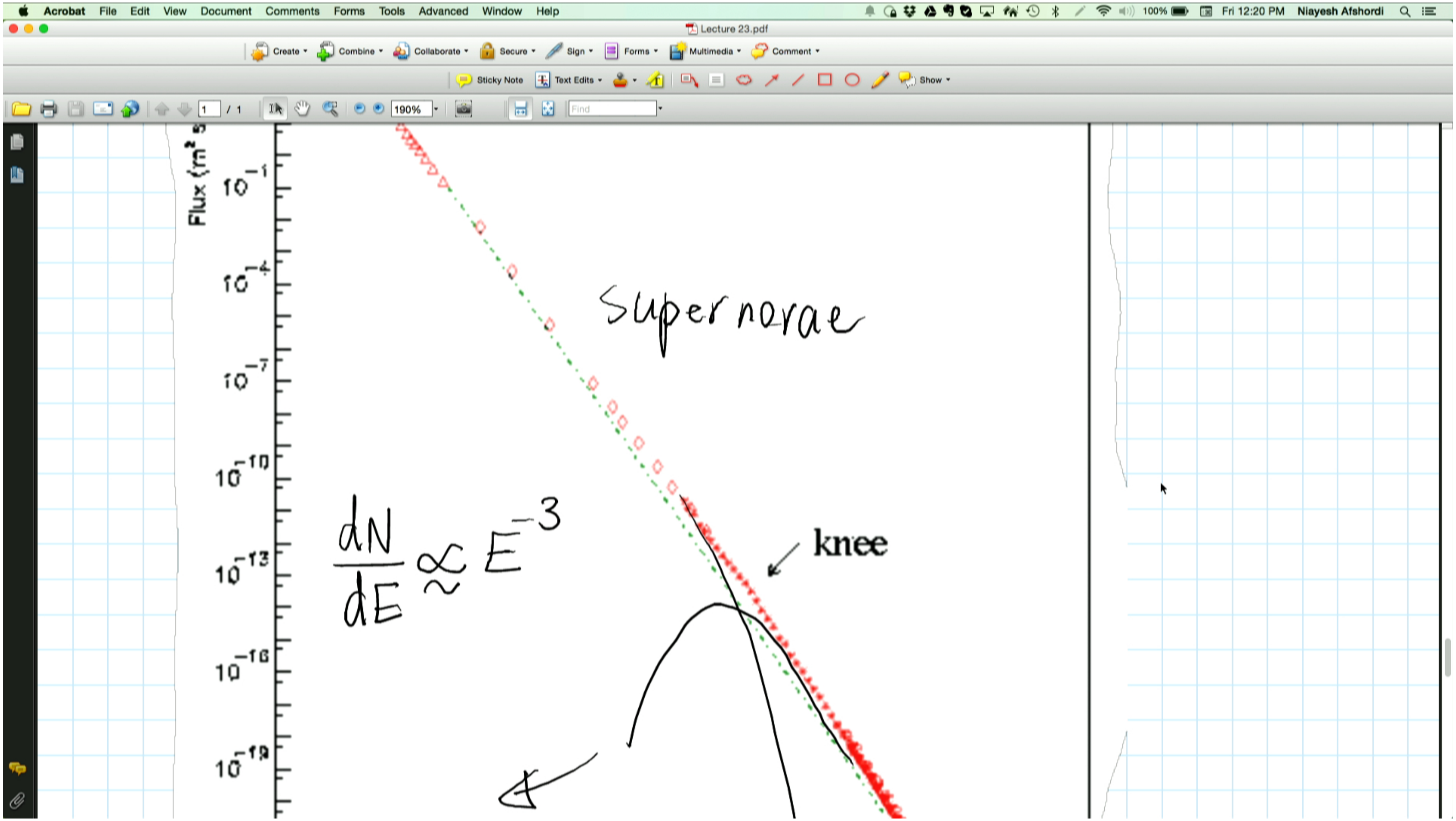
B [Gauss]
R [kpc]


Lecture 23.pdf
Hillas plot
B [Gauss]
10^15
10^10
10^5
10^0
10^-5
10^-10
magnetar
neutron star
white dwarf
GRB
AGN cores
1020 eV iron, v=1/300
1020 eV iron, v=1
1020 eV proton, v=1
1012 eV proton, v=1/300
galaxy clusters
supernova remnant
AGN jets
voids
10^5 km
10^10 km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Lecture 23.pdf
Create Combine Collaborate Secure Sign Forms Multimedia Comment
Sticky Note Text Edits Show
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Flux (m²
10⁻¹
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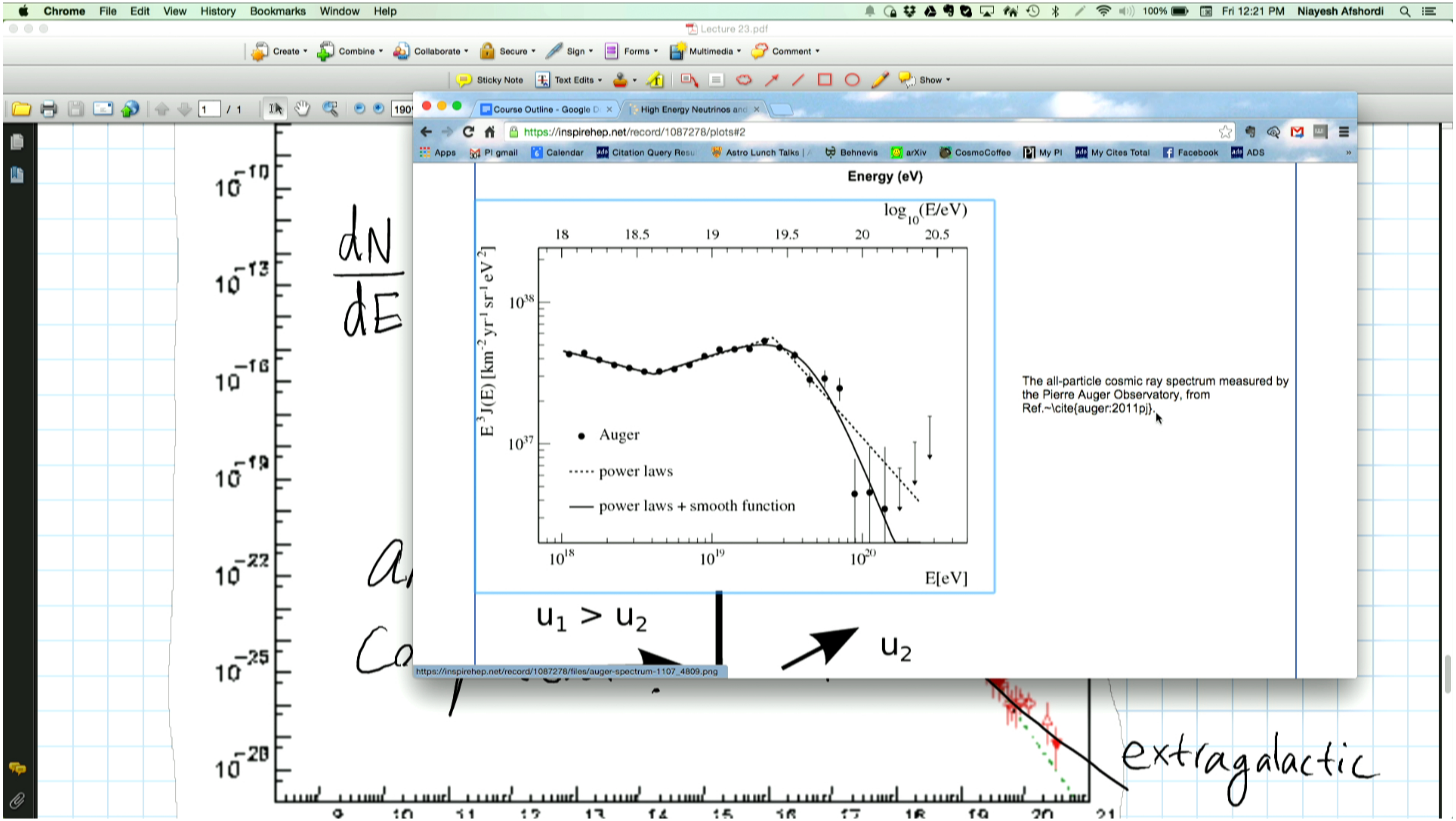

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dE
u1 > u2
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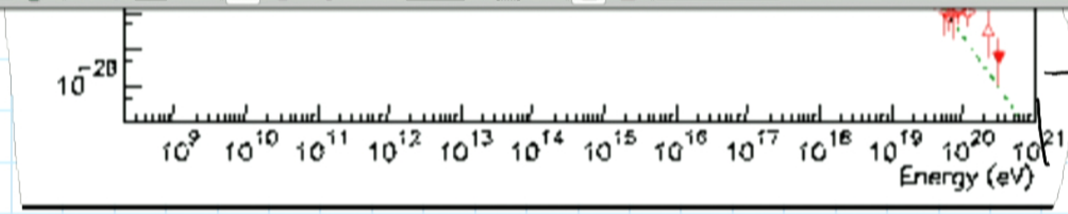
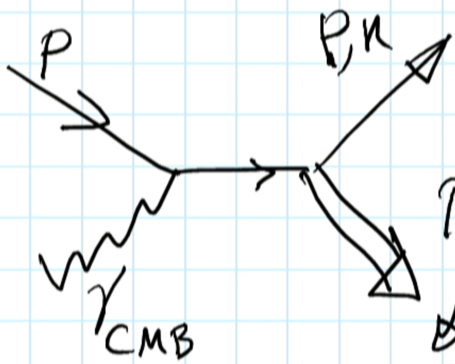


$\to$ GZK cut-off



$\pi^0, \pi^+ \to u\bar{d}$

$\pi^0 \to \frac{u\bar{u} - d\bar{d}}{\sqrt{2}}$

$m_\pi \sim 140$ MeV

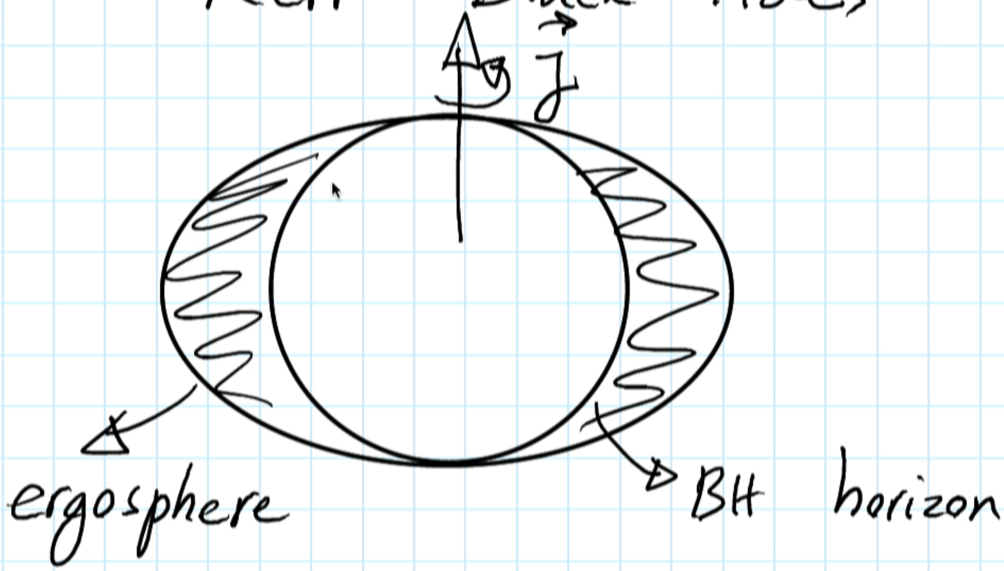
$$E_{CMB}\, E_p \gtrsim m_\pi^2 \Rightarrow 10^{-4}\,\text{eV} \times E_p \gtrsim 10^{16}\,\text{eV} \Rightarrow E_p \gtrsim 10^{20}\,\text{eV}$$

possibly seen by Pierre Auger observatory ergosphere BH horizon

particles that don't rotate fast enough have negative energies

Penrose process: a particle can gain energy by emitting a negative-E particle (not very efficient)

Kerr Black Holes

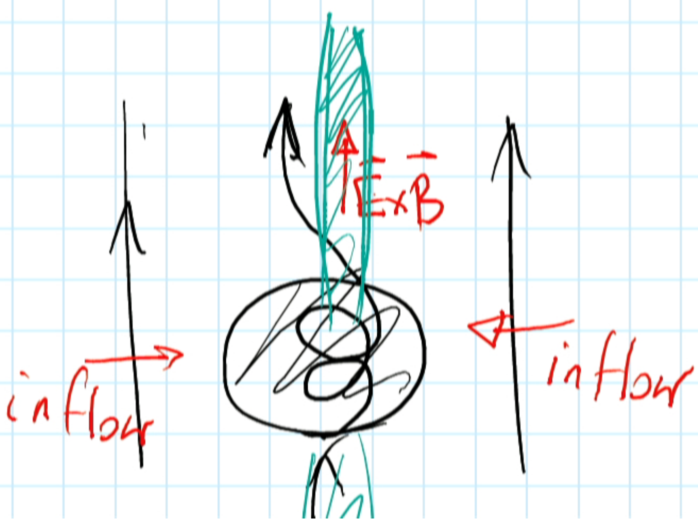


particles that don't rotate

fast enough have negative energies

Blanford–Znajek Process:

Extraction of energy by twisting polar B-field lines



$$\frac{v\times B_z}{c}, \quad \frac{v}{c}B_z$$

$$\text{Power} \simeq (E \times B_\phi) \times \pi r^2$$

$$\simeq \left(\frac{\omega r}{c}\right)^2 B_z^2 \times \pi r^2$$

$$L = \frac{G M \dot{M}}{R} \qquad \dot{M} = \frac{R L}{G M}\eta = \frac{4\pi c\, m_H R_s}{\sigma_T}$$

$$\dot{M} = \frac{4\pi\, m_H\, 2 G M}{\sigma_T c} \qquad L_{edd} = \frac{4\pi c\, G M m_H}{\sigma_T}$$

$$\int_{M}^{2M} \frac{dM'}{M'} = \int_0^t \frac{80\pi\, G M_H\, dt'}{\sigma_T c} \Rightarrow t = \frac{c\,\sigma_T \ln(2)}{8\pi G m_H} \sim 1.56 \times 10^{7}\ \text{years}$$

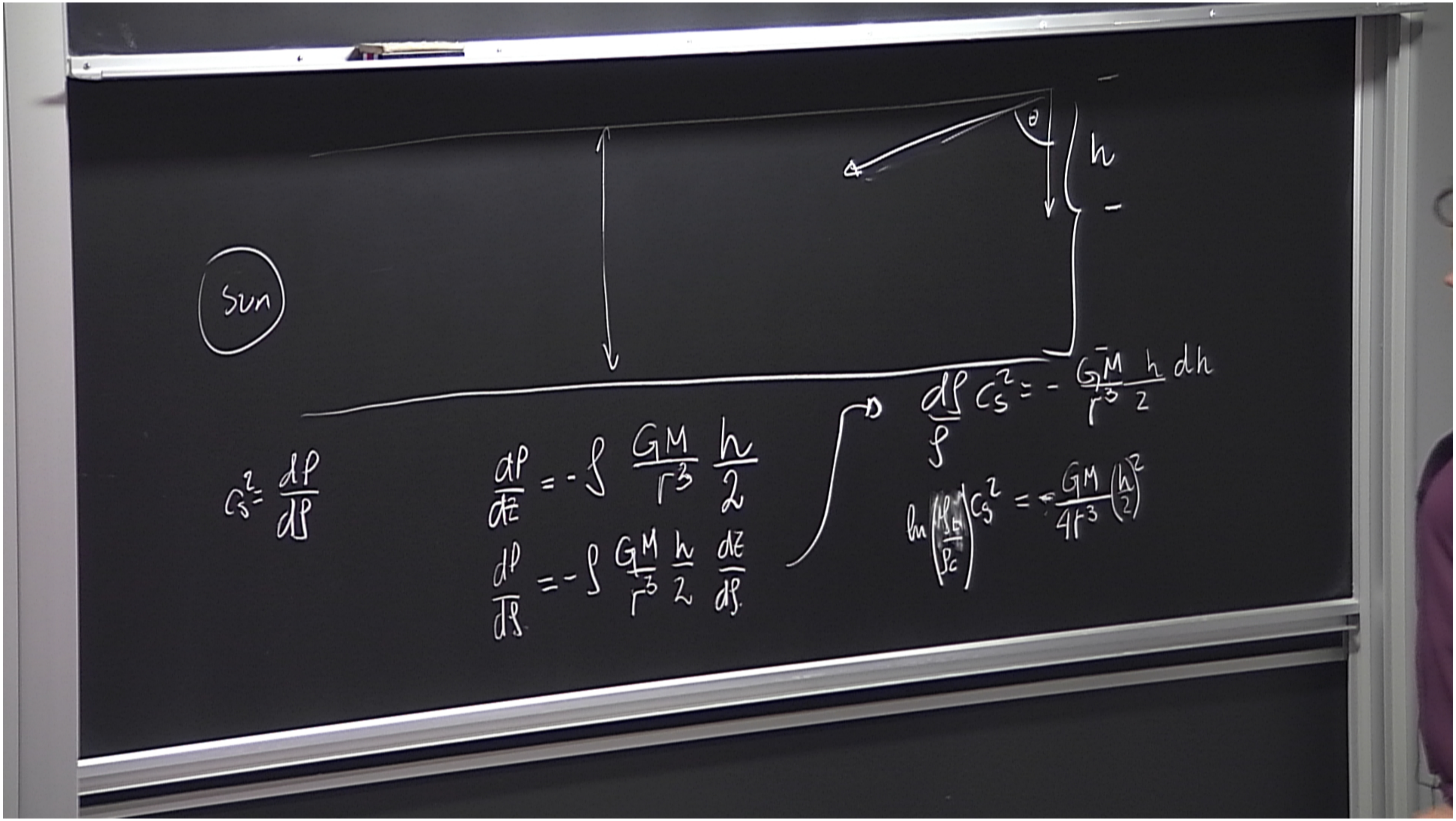
$$4.9 \times 10^{14}\ \text{s}$$

$$\dot{M} = 1.6 \cdot 10^{26}\ g/s$$

$$\dot{V} = v A = \frac{c}{10}(2\pi r)\, h = \frac{2\pi r^2 c}{10^2} \approx 1.7 \times 10^{36}\ cm^3/s$$

$$\rho = \frac{\dot{M}}{\dot{V}} = 8.2 \times 10^{-11}\ g/cm^3$$

$$\frac{1}{8\pi} B^2 = \frac{1}{2}(v_T)^2 \rho \Rightarrow B = \left(\frac{c}{10}\right)(4\pi\rho)^{1/2} = 3 \times 10^4 \text{ Gauss}$$


Sun
h
θ
$c_s^2 = \frac{dP}{d\rho}$
$\frac{dP}{dz} = -\rho \frac{GM}{r^3} \frac{h}{2}$
$\frac{dP}{d\rho} = -\rho \frac{GM}{r^3} \frac{h}{2} \frac{dz}{d\rho}$
$\frac{d\rho}{\rho} c_s^2 = -\frac{GM}{r^3} \frac{h}{2} dh$
$\ln\left(\frac{\rho_s}{\rho_c}\right) c_s^2 = -\frac{GM}{4r^3}\left(\frac{h}{2}\right)^2$

$$t_s^2 = \left(\frac{h}{c_s}\right)^2 = -\ln\left(\frac{\rho_t}{\rho_c}\right)\frac{4 r^3}{GM} \sim \frac{T^2}{4\pi^2}$$