Title: Dark Sector Theory

Speakers:

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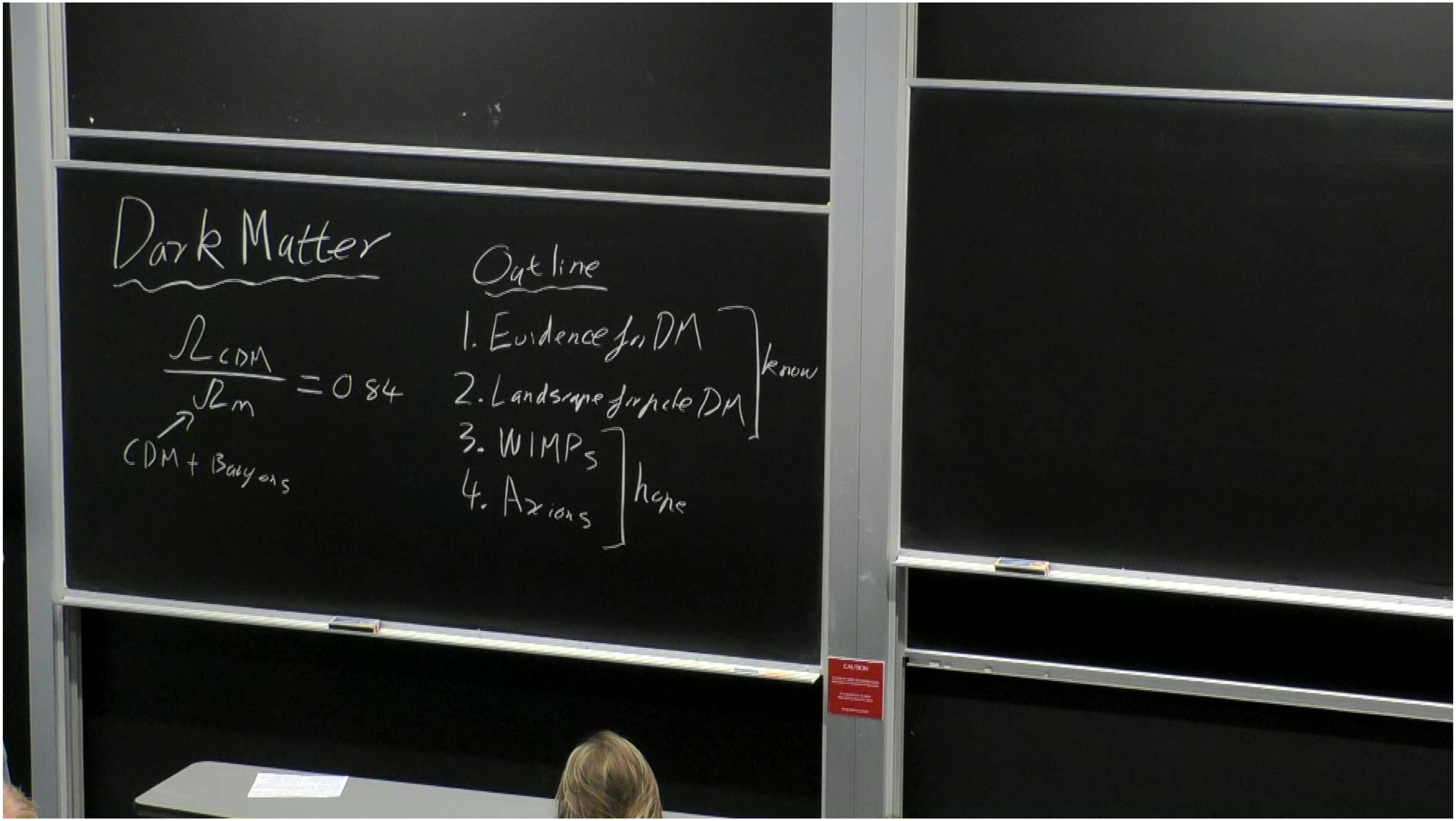
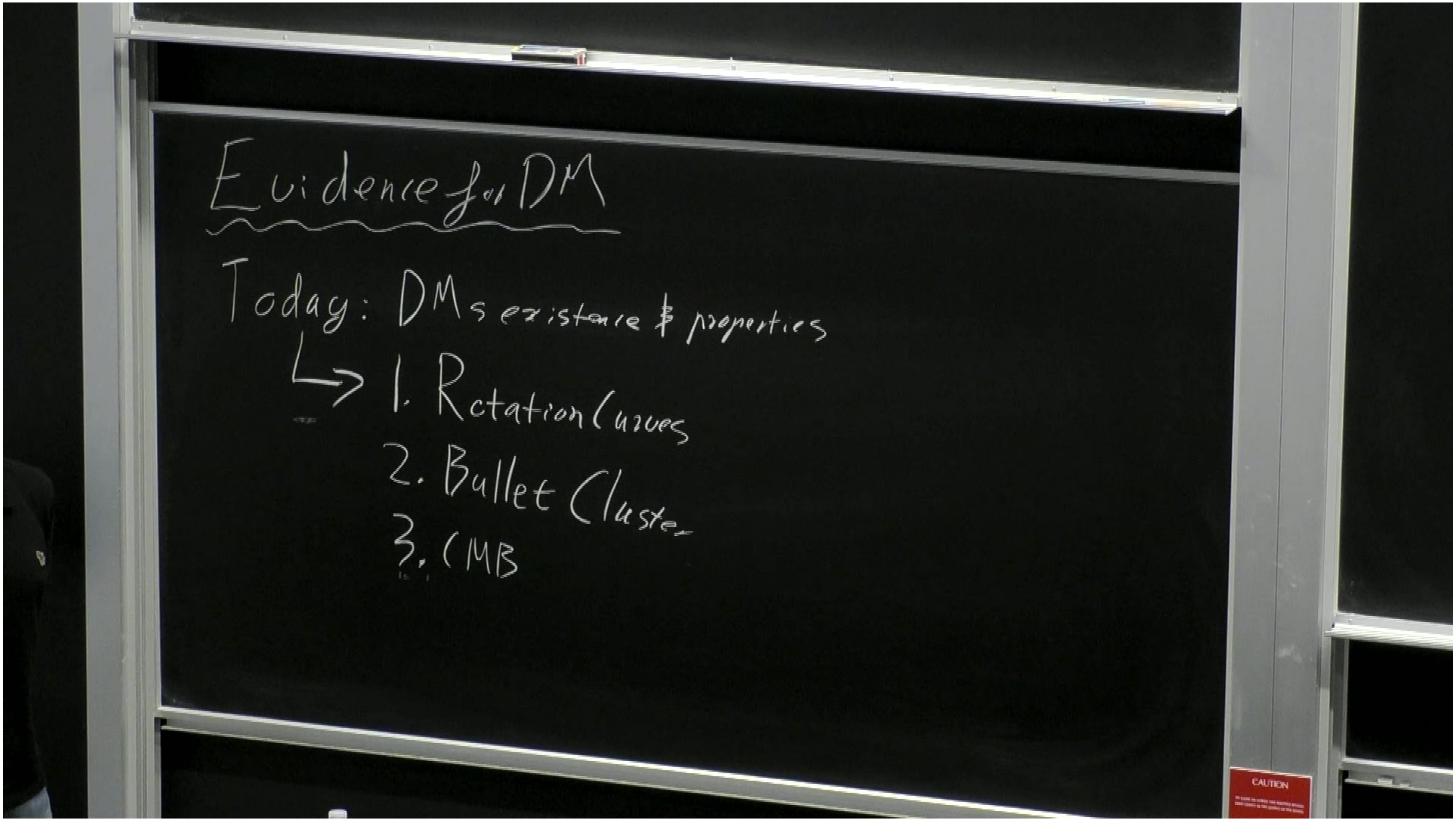
URL: https://pirsa.org/23060067


Dark Matter
$\frac{\Omega_{CDM}}{\Omega_m} = 0.84$
CDM + Baryons
Outline
1. Evidence for DM
2. Landscape for particle DM
know
3. WIMPs
4. Axions
hope


Evidence for DM
Today: DMs existence & properties
1. Rotation Curves
2. Bullet Cluster
3. CMB
CAUTION

Prehistory

Zwicky (1930s): virial th^{m} to Coma cluster

$$2\langle K\rangle + \langle U\rangle = 0 \implies \langle v^2\rangle = \frac{GM}{R}$$

$$\langle K\rangle = \left\langle \frac{1}{2}\sum_i m_i v_i^2 \right\rangle = \frac{1}{2} N m \langle v^2\rangle$$

$$\langle U\rangle = -GmMN\left\langle \frac{1}{r}\right\rangle = -\frac{GmMN}{R}$$

$$\implies M \gg M_*$$

Rotation Curves

Warmup: planets

$$\frac{m v^2}{r} = \frac{G m M_\odot}{r^2}$$

$$v = \sqrt{\frac{G M_\odot}{r}}$$

Determine with

$$G = 4.30091851 \times 10^{-6} \, (\mathrm{km/s})^2 \, M_\odot^{-1} \, \mathrm{kpc}$$

$$\simeq (30 \, \mathrm{km/s})^2 \, M_\odot^{-1} \, \mathrm{AU} \Rightarrow v_\oplus \simeq 30 \, \mathrm{km/s}$$

Units

$1\,AU \simeq 8$ light minutes

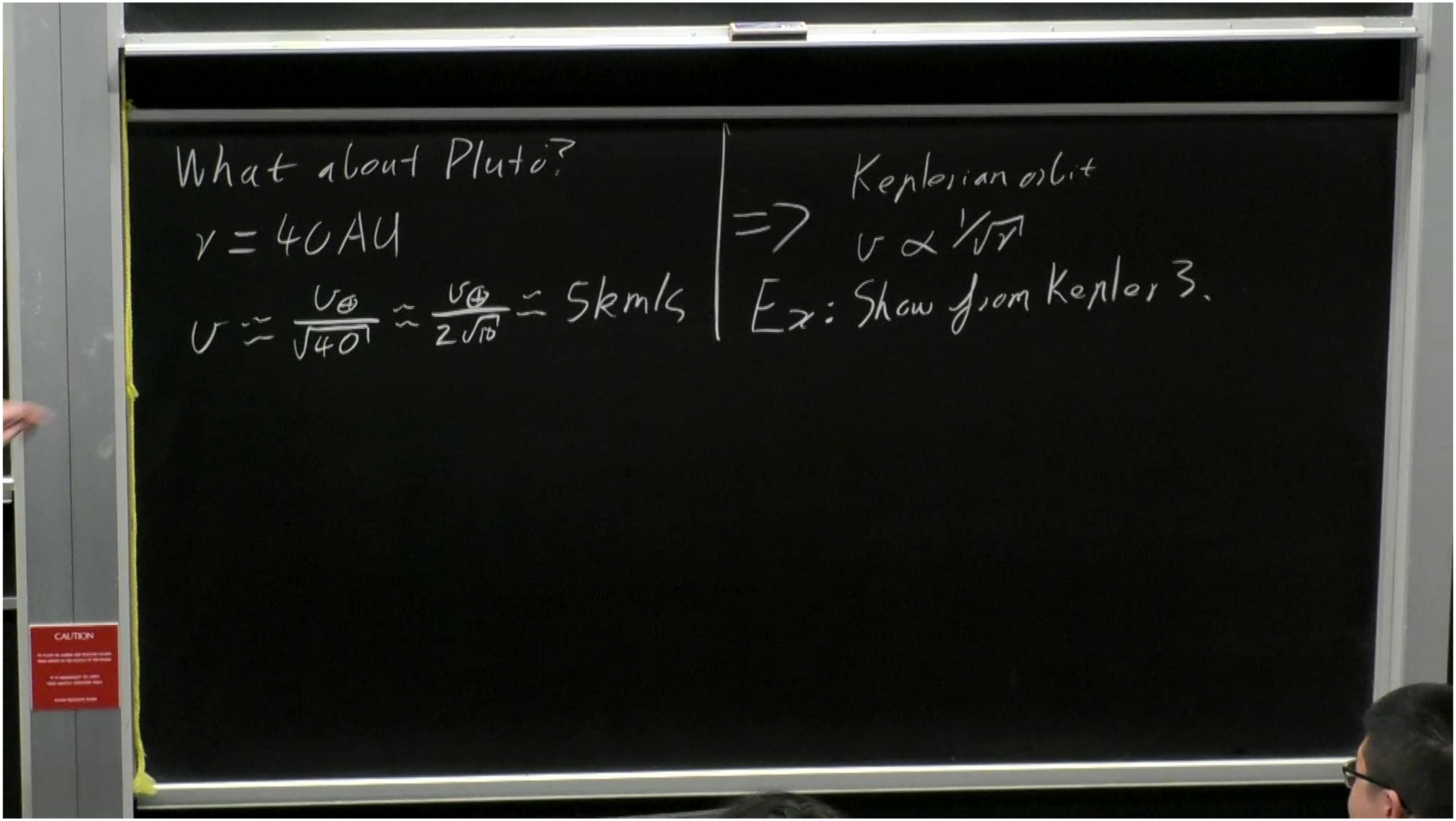
$= 8 \times 60\,s \times (3 \times 10^{10}\,cm/s)$

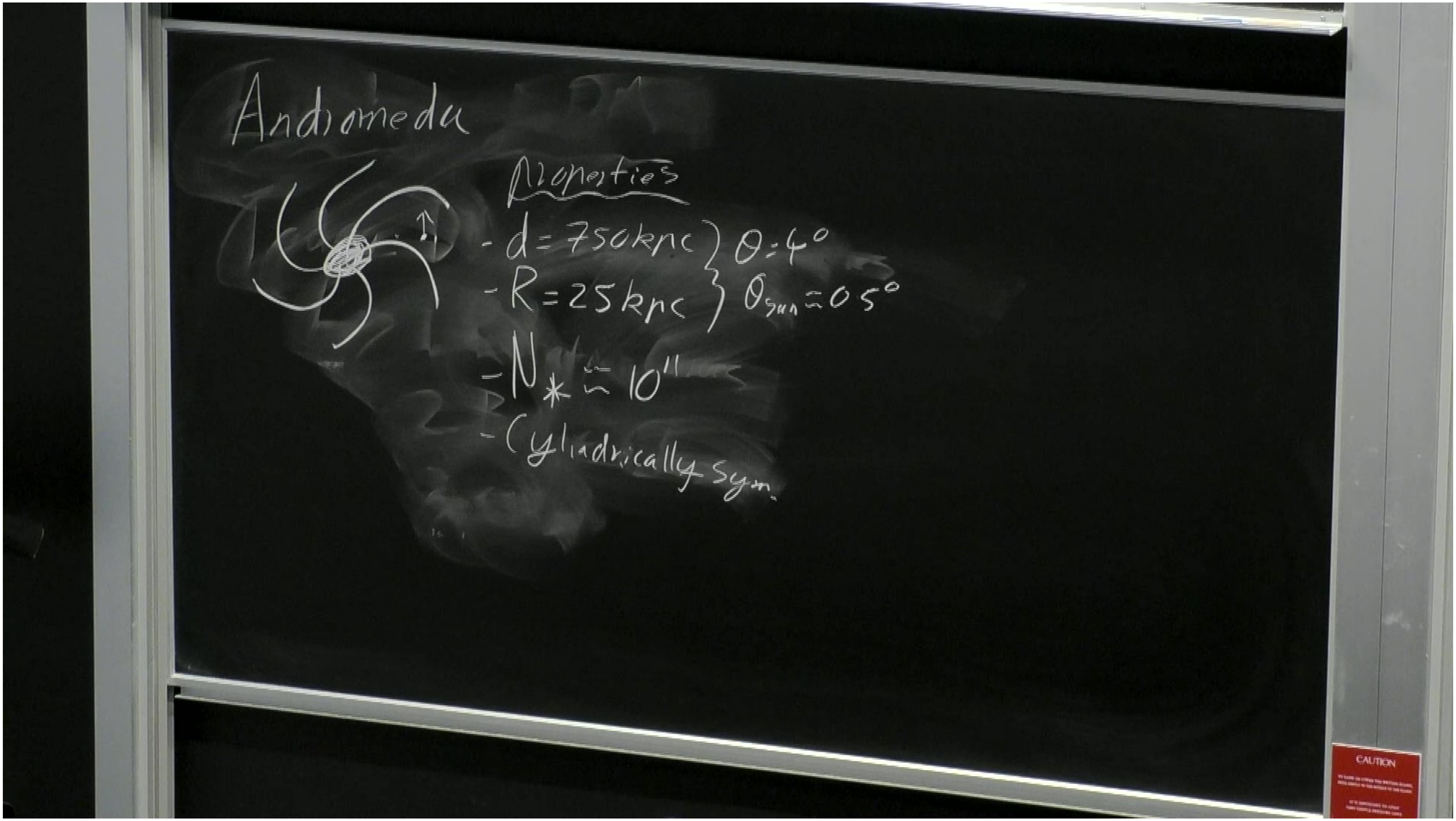
$\simeq 1.5 \times 10^{13}\,cm$

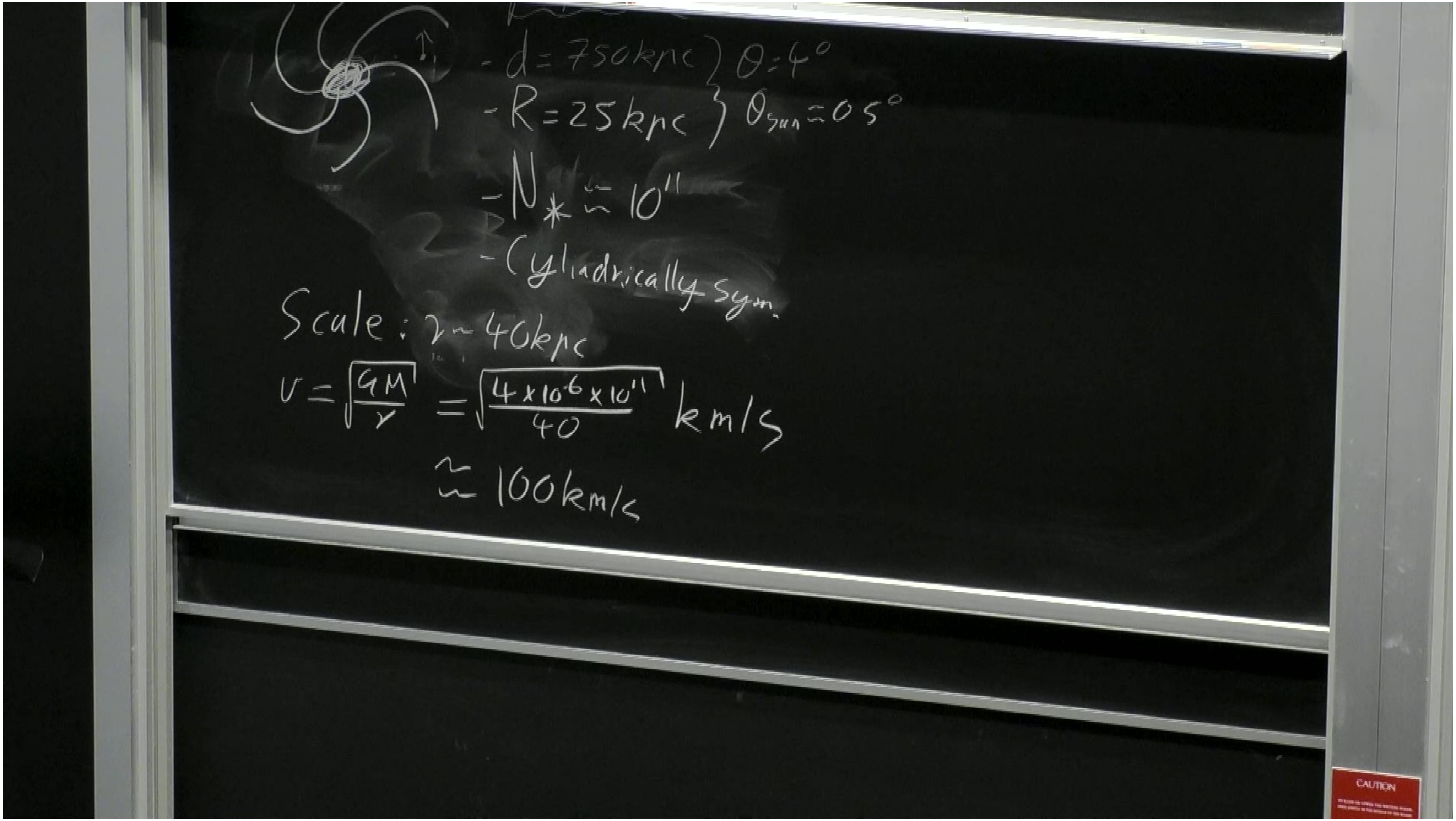
$1\,pc \simeq 3$ light years

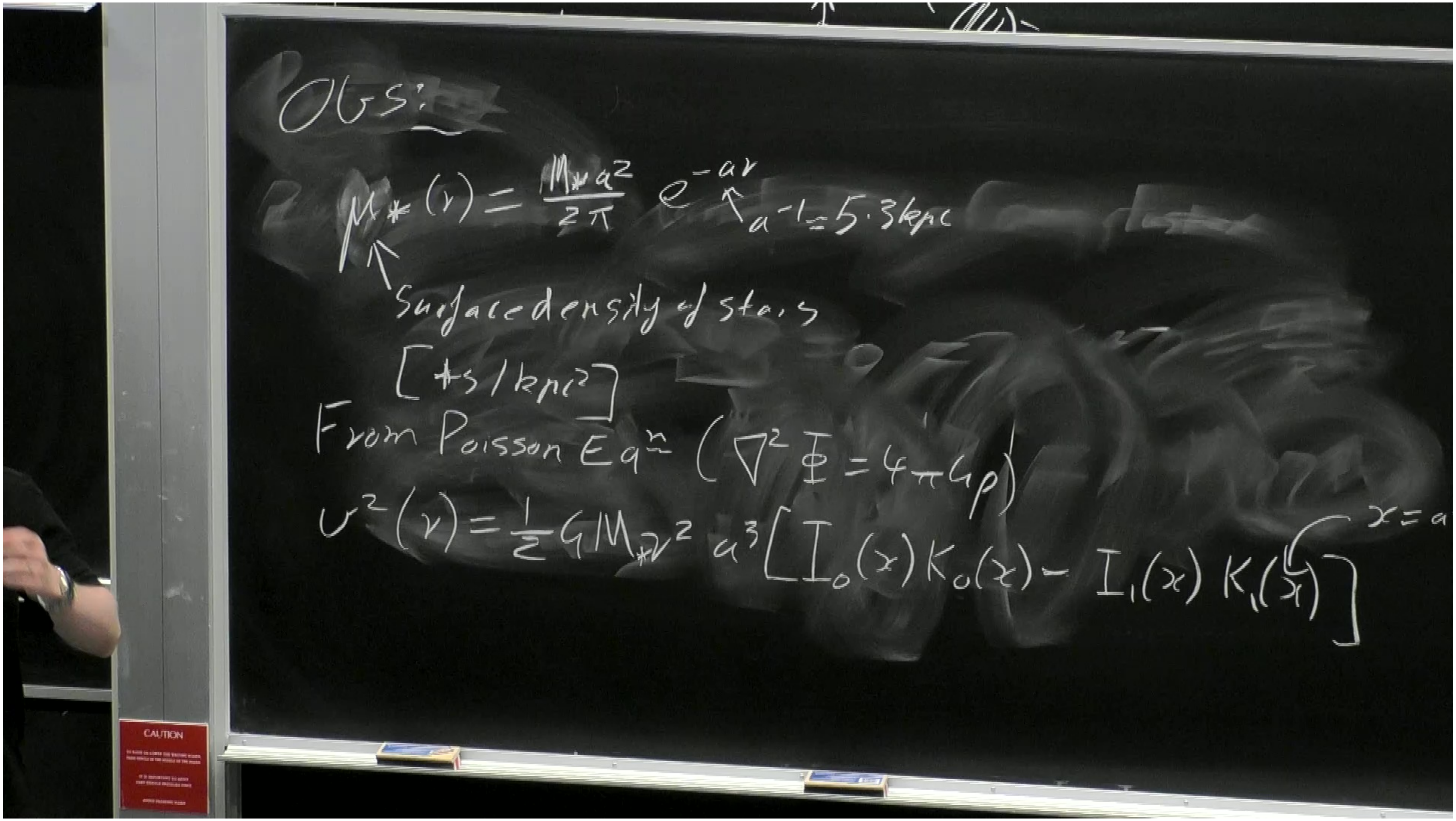
$\simeq 3 \times (\pi \times 10^{7}\,s)(3 \times 10^{10}\,cm/s)$

$\simeq 3 \times 10^{18}\,cm$


What about Pluto?
r = 40AU
v ≃ v⊕/√40 ≃ v⊕/2√10 ≃ 5km/s
=> Keplerian orbit
v ∝ 1/√r
Ex: Show from Kepler 3.


Andromeda
Properties
- d = 750 kpc
θ ≈ 4°
- R = 25 kpc
θ_sun ≈ 0.5°
- N_* ≈ 10^11
- Cylindrically sym.
CAUTION


- d = 750 kpc } θ ≈ 4°
- R = 25 kpc } θ_sun ≈ 0.5°
- N_* ≈ 10^11
- Cylindrically sym.
Scale: r ~ 40 kpc
v = √(GM/r) = √(4 x 10^-6 x 10^11 / 40) km/s
≈ 100 km/s


Obs:
$\mu_*(r) = \frac{M_* a^2}{2\pi} e^{-ar}$
$a^{-1} = 5.3\,kpc$
Surface density of stars
[#s / kpc^2]
From Poisson Eq^n ($\nabla^2 \Phi = 4\pi G\rho$)
$v^2(r) = \frac{1}{2} G M_* r^2 a^3 [I_0(x)K_0(x) - I_1(x)K_1(x)]$
$x = a$
CAUTION

$\mu_*(r) = \frac{[illegible]}{2\pi}$ [illegible] $a^{-1} = 5.5$ kpc

↑ Surface density of stars

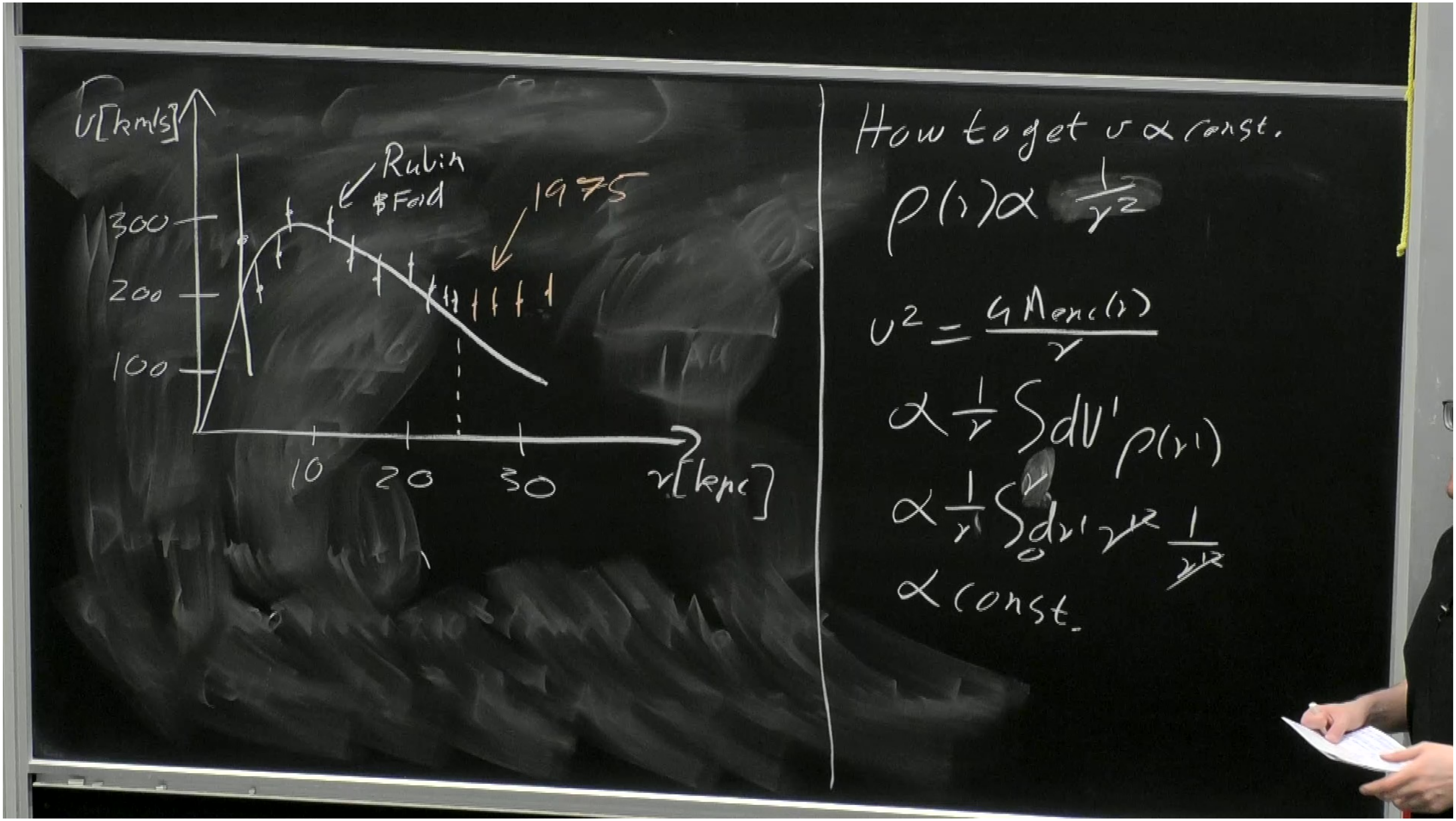
[*s / kpc^2]

From Poisson Eq^n ($\nabla^2 \Phi = 4\pi G \rho$)

$$v^2(r) = \frac{1}{2} G M_* r^2 a^3 \left[I_0(x) K_0(x) - I_1(x) K_1(x) \right], \quad x = ar/2$$

Ex: Show that ↑ becomes

$v^2 = \frac{GM}{r}$ @ $r \gg a^{-1}$. At what radius is that a good approx

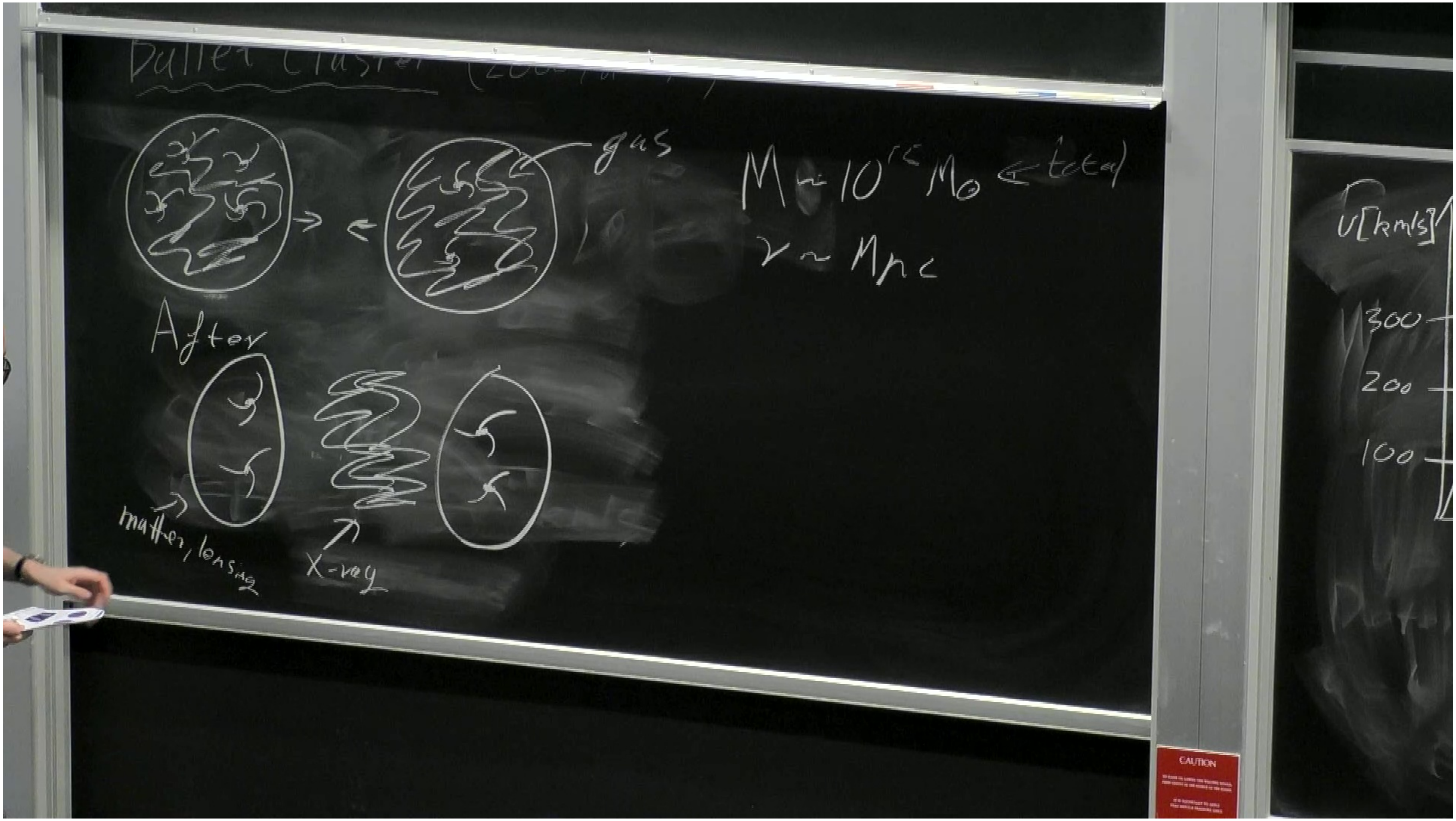

v[km/s]
Rubin
& Ford
1975
300
200
100
10
20
30
r[kpc]
How to get v ∝ const.
ρ(r) ∝ 1/r²
v² = G M_enc(r) / r
∝ 1/r ∫ dV′ ρ(r′)
∝ 1/r ∫₀ dr′ r′² 1/r′²
∝ const.

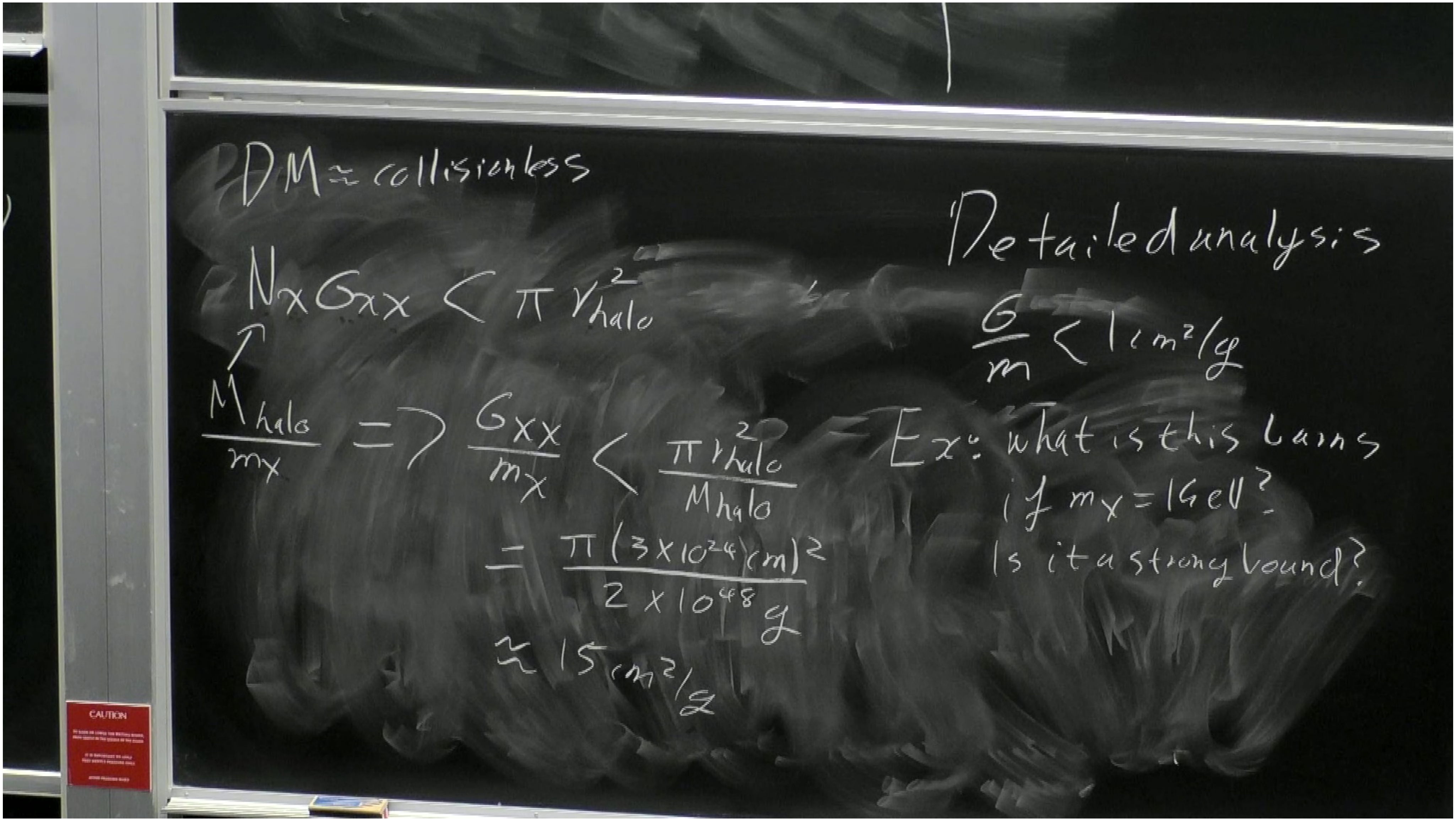
$$\rho(r) = \frac{\rho_0}{(r/r_s)(1+r/r_s)^2}$$

Ex: $M_{DM} = 10^{12} M_\odot$ & $r_s = 35$ kpc what is $v^2_{DM}(r)$ out to 200 kpc

If $M_* = 10^{11} M_\odot$ & $a^{-1} = 5.3$ kpc, what is v^2 from disk + DM?

Which dominates @ 8 kpc?


gas
M ~ 10^15 M⊙ ← total
r ~ Mpc
After
matter, lensing
X-ray
v[km/s]
300
200
100
CAUTION


DM ≈ collisionless
$N_\chi \sigma_{\chi\chi} < \pi r_{halo}^2$
M_{halo}/m_χ
$\Rightarrow \frac{\sigma_{\chi\chi}}{m_\chi} < \frac{\pi r_{halo}^2}{M_{halo}}$
$= \frac{\pi (3\times10^{24} cm)^2}{2\times10^{48} g}$
$\approx 15 \, cm^2/g$
Detailed analysis
$\frac{\sigma}{m} < 1 \, cm^2/g$
Ex: what is this bound
if $m_\chi = 1$ GeV?
Is it a strong bound?