QUICK PRIMER ON IND. DET

- ν's
- γ's
- ANTIMATTER

1. NEUTRINOS

ν's: HARD TO DETECT!

ONLY 2 ASTRO SOURCES DETECTED SO FAR!

BUT: CAPTURE IN SUN / EARTH

$\downarrow$

SINK IN

$\downarrow$

PAIR ANNIHILATE

$\downarrow$

PRODUCE HE ν's (~ BKG FREE!)

MOST PROMISING CASE: <u>SUN</u>

KEY EQUATION: $N(t)$: # χ's IN SUN

$$\boxed{\frac{dN(t)}{dt} = C^{\odot} - A^{\odot}(N(t))^2 - \underbrace{E^{\odot}N(t)}}$$

EVAPORATION
→ NEGLECT
(ONLY RELEVANT FOR $m_\chi \lesssim$ few GeV)

$$C^{\odot} \sim \underbrace{\phi_\chi}_{\text{FLUX OF DM}} \underbrace{\left(\frac{M_\odot}{m_p}\right)}_{\text{\# OF TARGETS}} \underbrace{\sigma_{\chi p}}_{\text{CAPTURE X-SEC}}$$

- $\phi_\chi \sim n_\chi \cdot v_\chi$
- $M_\odot \sim 10^{30}\,\text{kg} \sim 10^{57}\,\text{GeV}$
- $\sigma_{\chi p} \begin{cases} \sigma_{SD} \lesssim 10^{-39}\,\text{cm}^2 \\ \sigma_{SI} \lesssim 10^{-44}\,\text{cm}^2 \end{cases}$

So, $C^{\odot} \sim \frac{10^{23}}{s} \left(\frac{\rho_{DM}}{0.3\ \frac{GeV}{cm^3}}\right)\left(\frac{v_{DM}}{300\ \frac{km}{s}}\right)\left(\frac{100\ GeV}{m_\chi}\right)\left(\frac{\sigma_{\chi p}}{10^{-39}\ cm^2}\right)$

$$A^{\odot} \simeq \frac{\langle \sigma v \rangle}{V_{eff}}$$

V_{eff} — "WIMP-SPHERE": $10^{28}\ cm^3 \left(\frac{m_\chi}{100\ GeV}\right)^{3/2}$

$$\boxed{N(t) = \sqrt{\frac{C^{\odot}}{A^{\odot}}}\tanh\Big(\underbrace{\sqrt{C^{\odot}A^{\odot}}}_{\frac{1}{t^{eq}}}\, t\Big)}$$

If $t^{eq} \ll t^{\odot} \longrightarrow$ $\boxed{\Gamma_A = \frac{1}{2}A^{\odot}N(t)^2 \simeq \frac{C^{\odot}}{2}}$

$$C^{\odot} \sim 10^{23}\, s^{-1} \left(\frac{\sigma_{ap}}{10^{-39}\, cm^2} \right) \qquad A^{\odot} \sim 3 \cdot 10^{-54}\, s^{-1} \left(\frac{\langle \sigma v \rangle}{3 \times 10^{-26}\, cm^3/s} \right)$$

$$C^{\odot} A^{\odot} \gg \frac{1}{\underbrace{(t^{\odot})^2}_{4.5\ \text{byr} \sim 10^{17} s}} \longrightarrow \boxed{\sigma_{ap} \gg 10^{-41}\, cm^2}$$

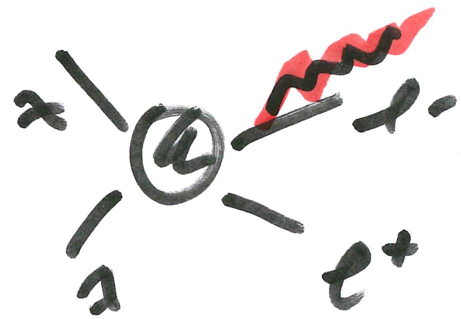
... THERE'S ROOM FOR EQUILIBRATION,
BUT DIR DET IS CLOSING IN!!

2. GAMMA RAYS

LIGHT FROM DM? $\begin{cases} \text{(i) PROMPT} \\ \text{(ii) SECONDARY} \end{cases}$

(i) • π^0 FROM HADRONIZATION, $\pi^0 \to \gamma\gamma$

• INTERNAL BREMS:



(ii) KEY <u>ENERGY</u> <u>LOSSES</u>:

– <u>INVERSE COMPTON</u>

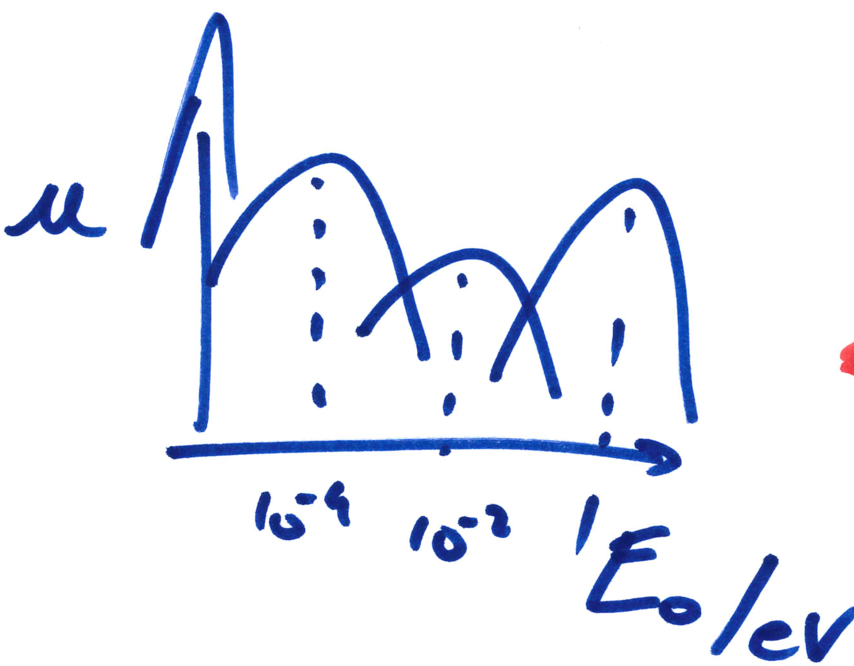
– <u>SYNCHROTRON</u>

- IC:

$$\langle E_0' \rangle \sim \gamma_e^2 E_0$$

AMBIENT PHOTON:

- CMB $E_0 \sim 10^{-4}$ eV
- STARLIGHT $E_0 \sim 1$ eV
- DUST $E_0 \sim 10^{-2}$ eV



BCKG PHOTONS ENERGY DENSITY DISTRIBUTION

SO, FOR $E_e \sim \frac{m_\chi}{10}$, $\gamma_e \sim \left(\frac{m_\chi}{100\ \text{GeV}}\right) \cdot 2 \cdot 10^4$

$E'_{CMB} \sim 100\ \text{keV} \left(\frac{m_\chi}{100\ \text{GeV}}\right)$] HARD X-RAY

$E'_{STARLIGHT} \sim 10\ \text{GeV}$

$E'_{DUST} \sim 0.1\ \text{GeV}$] γ-RAY

(b) <u>SYNCHROTRON:</u> $\frac{\nu_s}{\text{MHz}} \simeq \left(\frac{E_e}{\text{GeV}}\right)\left(\frac{B}{\mu G}\right)^{1/2}$

POWER $\sim B^2$

... OPTIMAL TARGETS & RATES:

- LARGE $\int d\ell(\psi)\, \rho_{DM}^2$ (A.K.A $J(\psi)$)
- LOW BCKG

⟶ dSph
CLUSTERS
GC
...

⟶ SEE JENNY'S TALK!

3. CHARGED COSMIC RAYS

$\bar{p}$, $\bar{D}$ (SOON: $\overline{{}^3He}$!)

KEY IDEA:

- DM PRODUCES LOW-ENERGY SOFT JET REMNANTS
- CR'S (BCKG) HAVE LARGE KINETIC ENERGIES

HOW DO YOU PRODUCE A $\bar{p}$?

$$p + \underbrace{H^+}_{\text{INTERST.}} \longrightarrow p + p + \bar{p} + p$$

THRESHOLD E FOR PRIMARY $\bar{p}$:

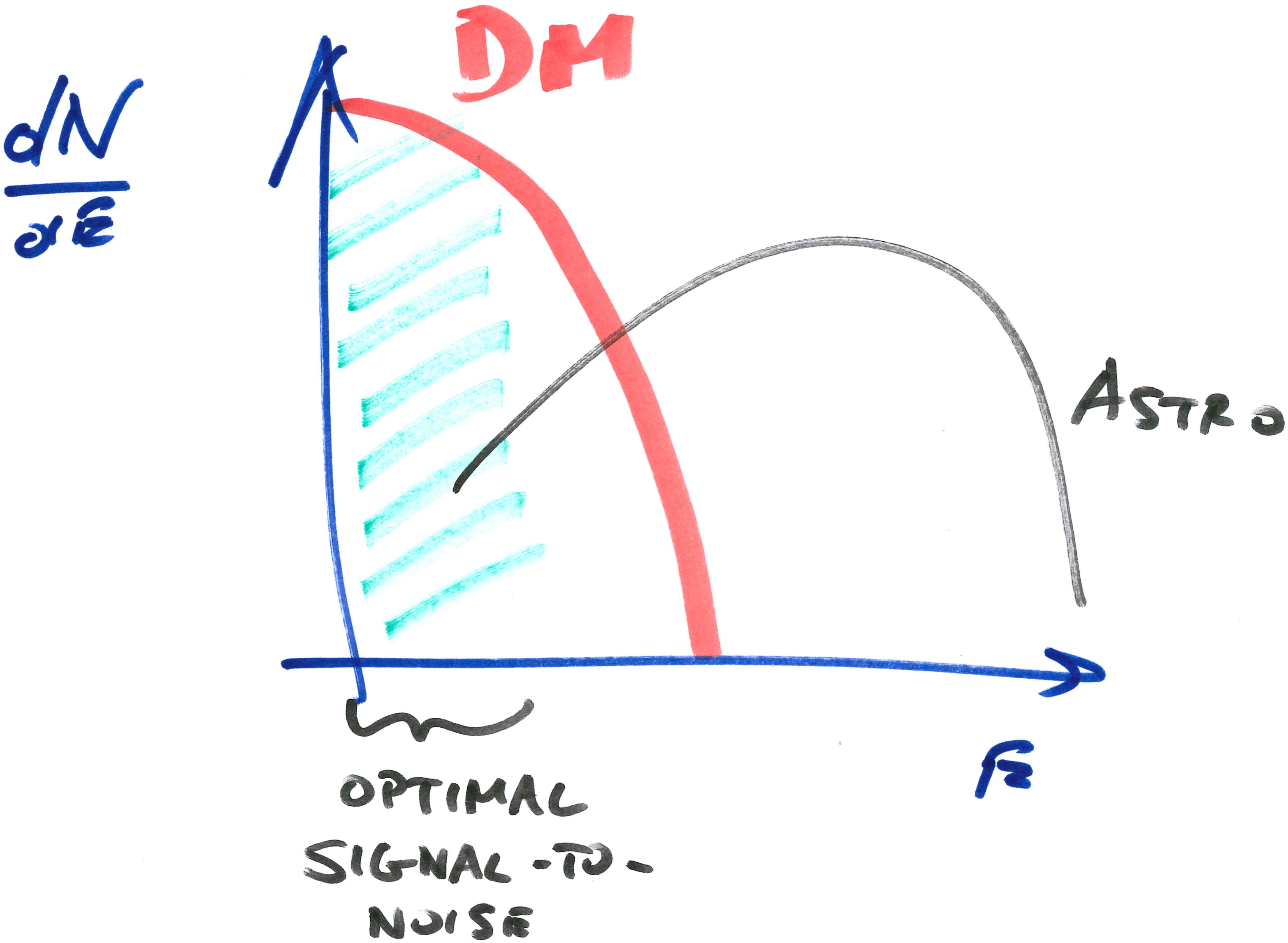
$$\left((E,p)+(m_p,0)\right)^2 \simeq (4m_p)^2$$

$$E^2+2m_pE+m_p^2-E^2 \simeq 16m_p^2$$

$$\boxed{E \sim 7.5\, m_p} \Rightarrow \boxed{\langle E\rangle \sim \text{few GeV}}$$

FOR $\bar{D}$: $p+p \longrightarrow p+p+\bar{p}+p+\bar{n}+n$

$$\boxed{E_{th} \sim 17.5 \text{ GeV}}$$



e.g. GAPS!

DETAILS OF CR FLUX CALCULATIONS:

DIFFUSION EQUATION

$$(1) \quad \underbrace{\frac{\partial}{\partial t}\psi}_{\substack{\text{CR} \\ \text{FLUX}}} = \underbrace{D(E)\,\Delta\psi}_{\text{DIFFUSION}} + \underbrace{\frac{\partial}{\partial E}\big(b(E)\,\psi\big)}_{\text{E-LOSSES}} + \underbrace{Q(\vec{x}, E, t)}_{\text{SOURCE}}$$

- $D(E) \sim D_0 \left(\frac{E}{E_0}\right)^{\delta}$ — "LARMOR RADIUS" $\delta \approx 0.2$
  $\longrightarrow$ few $\times\, 10^{28}\ \frac{cm^2}{s}$

- $b(E) \sim 10^{-16} \cdot \left(\frac{E}{(GeV)}\right)^2 \frac{GeV}{s}$

... IN STEADY STATE, (1) REDUCES TO:

$$0 = -\frac{\psi}{\tau_{diff}} - \frac{\psi}{\tau_{loss}} + Q$$

WHERE

$$\begin{cases} \tau_{diff} \sim \dfrac{R^2}{D_0} E^{-\delta} \\ \tau_{loss} \sim \dfrac{E}{b(E)} \end{cases}$$

... SO $\boxed{\psi \approx Q \cdot \min\left[\tau_{diff}, \tau_{loss}\right]}$

... APPLY THIS TO SECONDARY-TO-PRIMARY RATIOS:

① **PROTONS:** PRIMARY SOURCE: SNR

$Q \sim E^{-2}$ (FERMI 2nd ORD)

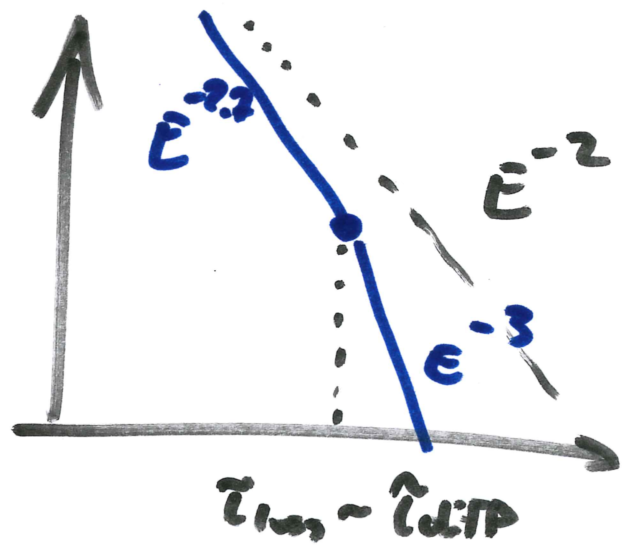
$$\psi \sim E^{-2} \cdot E^{-\delta} \sim E^{-2.7} \checkmark$$

$\tau_{diff} \lll \tau_{loss}$

② **PRIMARY ELECTRONS:**

PRIMARY SOURCE: AS PROTONS,

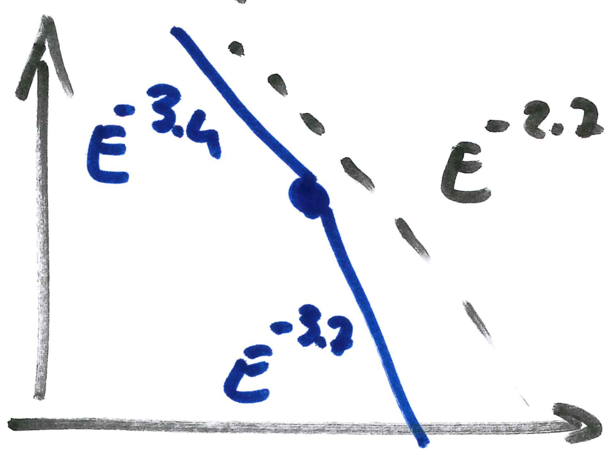
$Q \sim E^{-2}$



SECONDARY ELECTRONS / POSITRONS

PRIMARY SOURCE: PRIMARY **PROTONS**!

$$Q \sim \phi_p \sim E^{-2.7}$$



SO, GENERICALLY,

$$\boxed{\frac{\phi_{e^+}}{\phi_{e^-}} \sim E^{-\delta} \sim E^{-0.7}}$$

... **NOT OBSERVED**!

(ALTHOUGH PERFECTLY FINE WITH ALL OTHER C.P. SECONDARY-TO-PRIMARY RATIOS!)

WHAT COULD PRODUCE $E \sim 100\,\mathrm{GeV}$ e^{+}'s?

TIMESCALE FOR E-LOSSES:

$$\tau_{\mathrm{loss}} \sim \frac{E}{b(E)} \sim \frac{100\,\mathrm{GeV}}{10^{-16} \cdot 100^2\ \frac{\mathrm{GeV}}{\mathrm{s}}} \sim 10^{14}\,\mathrm{s}$$

SO 100 GeV $e^{\pm}$ LOOSE ENERGY IN $\sim \boxed{1\,\mathrm{Myr}}$

PSR AGE!

HOW FAR CAN THEY TRAVEL?

HOW FAR CAN 100 GeV $e^{\pm}$ TRAVEL ?

$$\text{DISTANCE} \ll \sqrt{D(E)\cdot t_{loss}} \sim \sqrt{10^{28}\cdot(10^{2})^{0.7}\cdot 10^{14}}\ \text{cm}$$

$$\sim 10^{22}\ \text{cm} \sim \boxed{3\ \text{kpc}}$$

... SO :

- MATURE, LOCAL PSR (Myr, ~kpc)
- LOCAL (< 3kpc) DM