LECTURE # 4

(1) ν-TELESCOPES

SPECIFICS OF 3 INDIR. DET. METHODS: (3) CR ANTIMATTER, (2) γ RAYS

(1): ν's: POINT-SOURCE DETECTION HARD
(IN FACT ONLY 2 ν ASTRO SOURCES OBSERVED)
SN1987A, SUN)

BUT! CAN BE
- CAPTURED IN SUN/EARTH
- SINK IN
- PAIR ANNIHILATE
- PRODUCE DISTINCTIVE SIGNAL (VIRT. NO BCKG)

MOST PROMISING CASE: SUN

LET'S ESTIMATE THIS PROCESS: $\frac{dN(t)}{dt} = C^{\odot} - A^{\odot}\left(N(t)\right)^2 - E^{\odot}N(t)$ ($N(t)$ = # OF DM PARTICLES IN SUN)

($E^{\odot}N(t)$: ONLY RELEVANT IF $m_\chi \lesssim$ GeV)

CAPTURE RATE: $C^{\odot} \sim \phi_\chi \left(\frac{M_\odot}{m_p}\right) \sigma_{\chi p}$

- ϕ_χ: FLUX OF DM
- $\frac{M_\odot}{m_p}$: # OF TARGETS
- $\sigma_{\chi p}$: RELEVANT CROSS SECTION

- $\phi_\chi \sim n_\chi \cdot v_\chi = \frac{\rho_{DM}}{m_\chi} \cdot v_{DM}$
- $M_\odot \sim 10^{30}\,kg \sim 10^{57}\,GeV$
- $\sigma_{\chi p}$ { SPIN DEP $\lesssim 10^{-39}\,cm^2$ ← MOST RELEVANT FOR SUN (>90% H, 70% MASS); SPIN INDEP $\lesssim 10^{-44}\,cm^2$

So $C^\odot \sim \frac{10^{23}}{5}\left(\frac{\rho_{DM}}{0.3\ GeV/cm^3}\right)\left(\frac{v_{DM}}{300\ km/s}\right)\left(\frac{100\ GeV}{m_\chi}\right)\left(\frac{\sigma_{\chi p}}{10^{-39}\ cm^2}\right)$ 1/2

$A^\odot \simeq \frac{\langle\sigma v\rangle}{V_{eff}} \longrightarrow 10^{28}\ cm^3 \left(\frac{m_\chi}{100\ GeV}\right)^{3/2}$

"WIMP-SPHERE" $n(r) = n_0 \exp\left(-\frac{m_\chi \phi_{grav}}{T^\odot}\right)$

$N(t)$ WITHOUT EVAPORATION CAN BE SOLVED EXACTLY

$$N(t) = \sqrt{\frac{C^\odot}{A^\odot}} \tanh\left(\underbrace{\sqrt{C^\odot A^\odot}\, t}_{\frac{1}{t^{EQ}}}\right)$$

IF $t^{EQ} \ll t^\odot$

THEN THE ANNIHILATION RATE $\Gamma_A = \frac{1}{2} A^\odot (N(t))^2$

REDUCES TO $\Gamma_A \simeq \frac{C^\odot}{2}$

DO WE REACH CAPTURE-ANN. EQUILIBRIUM? IF SO $\begin{cases} \cdot \text{MAX SIGNAL} \\ \cdot \text{INDEP OF } \sigma \end{cases}$

$C^\odot \sim 10^{+23}\ s^{-1}\left(\frac{\sigma_{\chi p}}{10^{-39}\ cm^2}\right)$ $\qquad A^\odot \sim \underbrace{1}_{\text{VANILLA WIMP}} \left(\frac{\langle\sigma v\rangle}{3\cdot 10^{-26}\ cm^3/s}\right) \frac{3\cdot 10^{-26}}{10^{28}}\ s^{-1}$

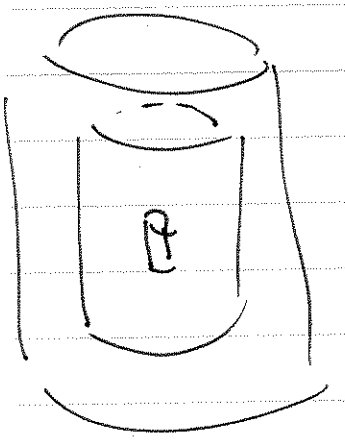
$\sim 3\cdot 10^{-54}\ s^{-1}$

WE WANT $C^\odot A^\odot \gg \frac{1}{(t^\odot)^2}$ $\qquad \frac{\sigma_{\chi p}}{10^{-39}\ cm^2} \gg \frac{10^{-34}}{3\cdot 10^{-54}\cdot 10^{23}} 10^{-3}$

$4.5\ Gyr \sim 10^{17}\ s$ $\qquad$ so $\sigma_{\chi p} > 10^{-41}$ ok

SHOULD THEN SEE STREAM OF HE ν's (esp FROM WW, ZZ
$\to \mu\nu_\mu$ $\to \nu_\mu\bar{\nu}_\mu$ ... BUT CURRENTLY, NO EVENTS!

PROBLEM: ENERGY THRESHOLD IS HIGH!



MATRIOSKA

ICECUBE $\gtrsim$ 100 GeV FOR CC-CONVERT. MUONS

DEEPCORE $\gtrsim$ 10 GeV

PINGU $\gtrsim$ a/c GeV

(SO EVEN HIGHER FOR ν'S!)

GAMMA RAYS

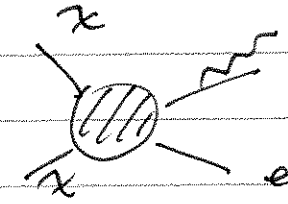
GAMMA RAYS

LIGHT FROM DM { (i) PROMPT (@ ANNIHILATION EVENT)
(ii) SECONDARY (FROM RADIATIVE PROCESSES ASSOCIATED WITH STABLE, CHARGED PARTICLES FROM ANN.)

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

NOTE: $\frac{dN_\gamma^{\pi^0}}{dE_\gamma}$ SYMMETRIC AROUND $\frac{m_\pi}{2}$ ON LOG SCALE! (HW)

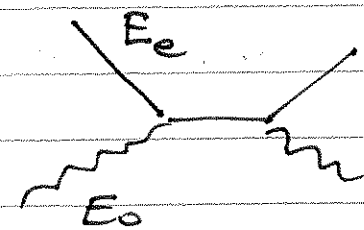
• PHOTONS FROM "INTERNAL BREMSSTRAHLUNG"



(TYPICALLY HIGHER ENERGY, "HARDER" CONTRIBUTION)

(ii) KEY ENERGY LOSSES FOR $e^\pm$: (a) INVERSE COMPTON (b) SYNCHROTRON

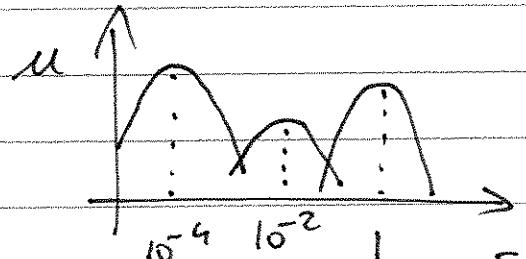
(a) IC



$\langle E_0' \rangle \sim \frac{4}{3}\gamma_e^2 E_0$

AMBIENT PHOTON

→ CMB: $E_0 \sim 2\times10^{-4}$ eV
→ STARLIGHT: $E_0 \sim 1$ eV
→ DUST: $E_0 \sim 0.01$ eV



SO FOR $E_e \sim \frac{m_x}{10}$, $\gamma_e = \frac{m_x}{10 \cdot \underbrace{0.5 \cdot 10^{-3}}_{m_e}} = \left(\frac{m_x}{100\,\text{GeV}}\right) \cdot 2 \cdot 10^6$

SO $E'_{CMB} \sim \frac{4}{3} \cdot \underbrace{4 \cdot 10^8}_{\gamma_e^2} \left(\frac{m_x}{100\,\text{GeV}}\right)^2 \cdot \underbrace{2 \cdot 10^{-4}\,\text{eV}}_{E_0} \sim 10^5\,\text{eV} \left(\frac{m_x}{100\,\text{GeV}}\right)^2$

SO IC PRODUCES HARD X-RAY PHOTONS $\sim 100\,\text{keV}$

[GREAT NEWS: NUSTAR JUST LAUNCHED!]

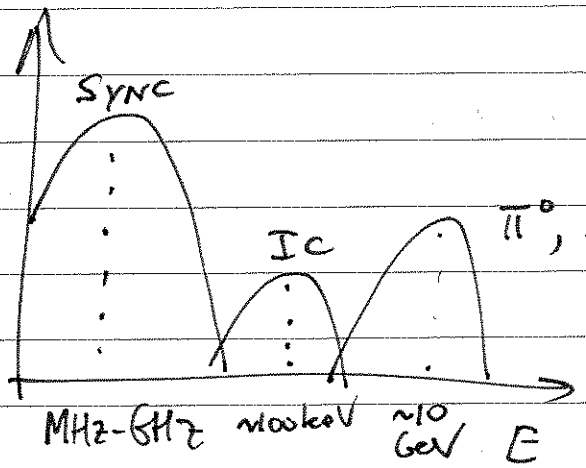
STARLIGHT $\sim 10\,\text{GeV}$
DUST $\sim 0.1\,\text{GeV}$
} γ-RAY REGIME

(b)

SYNCHROTRON, IN MONOCHROMATIC APPROXIMATION

$$\frac{\nu_{\text{Sync}}}{\text{MHz}} \simeq 2 \cdot \left(\frac{E_e}{\text{GeV}}\right) \left(\frac{B}{\mu\text{G}}\right)^{1/2}$$

AND SYNCHROTRON POWER $\sim B^2$



⇒ SLIDE FIG. 1

OPTIMAL TARGETS AND RATES

$$\phi_\gamma = \frac{\Delta\Omega}{4\pi}\left\{\frac{1}{\Delta\Omega}\int d\Omega \int dl(\psi)\left(\rho_{DM}\right)^2\right\}\frac{\langle\sigma v\rangle}{2m_\chi^2}\frac{dN_\gamma}{dE_\gamma}$$

ϕ_γ: FLUX

$\left\{\frac{1}{\Delta\Omega}\int d\Omega \int dl(\psi)\left(\rho_{DM}\right)^2\right\} = J(\Delta\Omega, \psi)$

UNITS: $\frac{GeV^2}{cm^5}$

$\frac{dN_\gamma}{dE_\gamma} = \sum_f \frac{dN_f^\gamma}{dE_\gamma}$ PER ANNIHILATION

$\Delta\Omega$: ANGULAR REGION, OPTIMIZED FOR $\frac{\text{SIGNAL}}{\text{NOISE}}$ FOR GIVEN DETECTOR, TARGET, FIELD OF VIEW, ANG. RES...

TYPICALLY, $\Delta\Omega \sim 1$ obj $\rightarrow 10^{-3}$ sr (FERMI @ 1 GeV)

~ 0.1 obj $\rightarrow 10^{-5}$ sr (ACT, FERMI @ 10 GeV)

LAUNDRY LIST OF POTENTIAL TARGETS

(UNITS: $\frac{GeV^2}{cm^5}$)

- DWARF GALAXIES
  - cl Sph
    - Draco $\sim 10^{19} \pm$ factor 1.5
    - UMi $\sim 10^{19} \pm$ "
    - Segue $\sim 10^{20} \pm$ factor 3
- M31-LIKE GALAXIES
  - M31 $\sim 10^{20}$
- CLUSTERS AND GROUPS
  - Fornax Cluster $\sim 10^{18}$
  - Coma $\sim 10^{17}$
  - Bullet $\sim 10^{14}$
- GALACTIC CENTER
  - $0.1°$: $10^{22} \div 10^{25}$
  - $1°$: $10^{22} \div 10^{24}$

CURRENT BEST LIMIT: cl Sph $\gamma\gamma$: $\langle\sigma v\rangle \sim 3\times10^{-26}\ \frac{cm^3}{s}$ (30 GeV)

COSMIC RAYS

$\bar{p}, \bar{D}$: KEY IDEA: MOSTLY PRODUCED IN SPALLATION PROCESSES: (SUPPRESSED COMPARED TO PRIMARIES ESP AT LOW ENERGY)

$$p + p \longrightarrow p + p + p + \bar{p}$$

(p: INTERSTELLAR H^+; CONS OF B)

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

$$E^2 + 2 m_p c^2 + m_p^2 - E^2 \simeq 16\, m_p^2$$

$$E \sim 7.5\, m_p$$

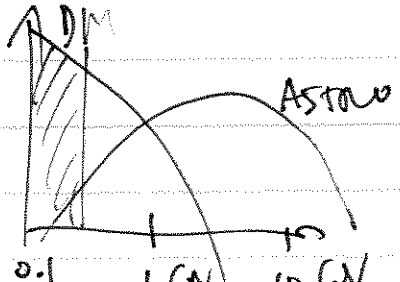
$\longrightarrow \langle E \rangle \sim$ few GeV

$\longrightarrow \frac{dN_p}{dE} \sim E^{-2.7}$ STEEPLY FALLING $\longrightarrow$ COMPARED TO CR FLUX AT 0.1 GeV

$$\left(\frac{0.1}{7.5}\right)^{2.7} \sim 10^{-5}$$ SUPPRESSION OF $\bar{p}$ FLUX

$\bar{D}$: EVEN MORE EXTREME: $p + p \longrightarrow p + p + p + \bar{p} + n + \bar{n}$

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



CHARGED SPECIES UNDERGO "RANDOM-WALK" (i.e. DIFFUSIVE) PROPAGATION, DESCRIBED BY A DIFF. EQ LIKE

$$(1)\quad \frac{\partial}{\partial t}\psi = \underbrace{D(E)\,\Delta\psi}_{\text{DIFFUSION}} + \underbrace{\frac{\partial}{\partial E}\left(b(E)\psi\right)}_{\text{ENERGY LOSS}} + \underbrace{Q(\vec{x}, E, t)}_{\text{SOURCE}}$$

(PLUS: CONVECTION, DIFFUSIVE REACC., FRAGMENTATION, DECAY...)

$$D(E) \sim D_0 \left(\frac{E}{E_0}\right)^{\delta}$$ ← FROM "LARMOR RADIUS"

$$D_0 \sim \text{few} \times 10^{28}\ \frac{\text{cm}^2}{\text{s}}$$

IN STEADY STATE (1) REDUCES TO

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

RELEVANT TIME SCALES:

$$\tau_{diff} \sim \frac{R^2}{D_0} E^{-\delta}$$ (DIFF. REGION)

$$\tau_{loss} \sim \frac{E}{b(E)} \longrightarrow b(E) \sim 10^{-16} \left(\frac{E}{\text{GeV}}\right)^2 \frac{\text{GeV}}{\text{s}}$$

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

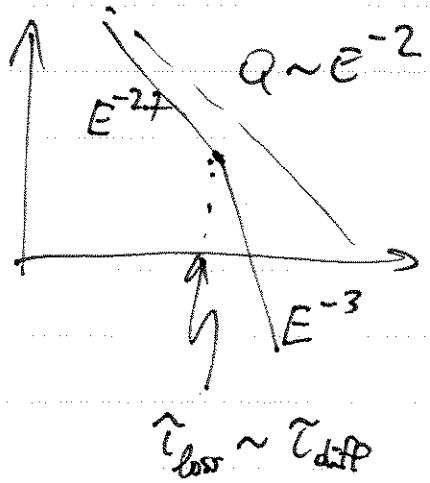
... APPLY THIS TO SEC. TO PRIM. RATIO

- PROTONS: PRIMARY SOURCE: SNR, $Q \sim E^{-2}$ (FERMI ACCEL.)

$$\phi \sim E^{-2} \cdot E^{-\delta} = E^{-2.7}$$ ✓

$\tau_{diff} \ll \tau_{loss}$

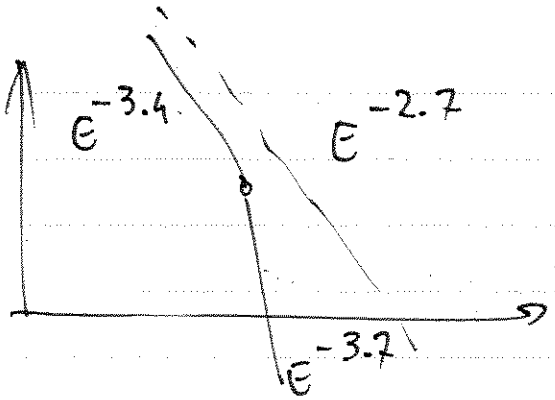
- PRIMARY ELECTRONS:



$\tau_{loss} \sim \tau_{diff}$

- SECONDARY (e^+): $Q \sim$ PRIMARY PROTONS, $E^{-2.7}$

SO



SO GENERICALLY $\frac{\phi_{e^+}}{\phi_-} \sim E^{-\delta} \sim E^{-0.7}$ ... NOT OBSERVED!

WHAT COULD PRODUCE $E \sim 100$ GeV POSITRONS?

TIMESCALE: $t_{\text{loss}} \sim \frac{E}{b(E)} \sim \frac{100\ \text{GeV}}{10^{-16} \cdot 100^2\ \frac{\text{GeV}}{\text{s}}} \sim 10^{14}\ \text{s}$

100 GeV e^+ LOSE ENERGY IN ABOUT $\underbrace{1\ \text{Myr}}_{\text{PSR AGE}}$

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

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

SO $\begin{cases} \text{MATURE, LOCAL PSR} & (\text{Myr}, \sim \text{kpc}) \\ \underbrace{\text{LOCAL } (< 3\ \text{kpc}) \text{ DM}}_{\text{MANY ISSUES... SEE MY TALK ON MONDAY!}} \end{cases}$