Journal club 11/21: "Discovery of a new Galactic Center excess consistent with upscattered starlight"

"Galactic center excess" (GCE) / "GeV excess" observed with Fermi gamma-ray telescope

(N.B. *NOT* the same excess referred to in title!)

interesting to particle physicists because...

(1) <u>spatial</u> morphology is consistent with NFW radial profile:

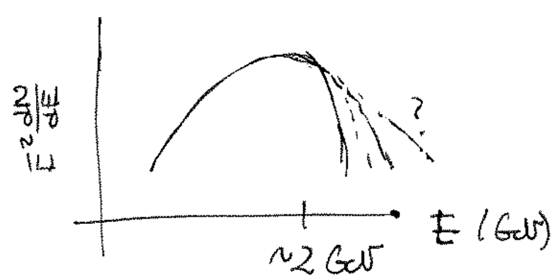
$$\rho(r) = \rho_0 \cdot \frac{(r/r_s)^{-\gamma}}{(1 + r/r_s)^{3-\gamma}}$$

where $\rho_0$ = normalization such that local DM density $\sim 0.3$ GeV cm$^{-3}$

$\gamma$ = inner profile slope, $\approx 1$

$r_s$ = scale radius, $\approx 20$ kpc

(2) <u>spectral</u> morphology is consistent with WIMP annihilation




(log - log)

spectrum best fit w/ $\chi\chi \to b\bar{b}$ ($m_{DM} \sim 35$ GeV)

$\chi\chi \to \tau^+\tau^-$ ($m_{DM} \sim 10$ GeV)

(3) spectrum normalization gives annihilation cross-section that is close to $\sim 2 \times 10^{-26}$ cm$^3$s$^{-1}$ required for DM relic density!

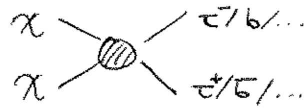
but there are also alternative astrophysical sources for excess:

millisecond pulsars

cosmic ray bursts

photons from WIMP annihilations

"prompt" :




primary products decay, hadronize ⇒ $e^\pm$, $\nu$'s, ($\gamma$'s)

all of the above happens @ site of DM annihilation,
so <u>prompt $\gamma$'s DIRECTLY trace DM halo distribution</u>

"secondary" – resultant $e^\pm$'s interact w/ environment

- inverse Compton – upscatter ~~dust~~ interstellar radiation field (ISRF)
- Bremsstrahlung – $e^\pm$ interactions with gas
- spatial morphology of these signals depends on:
  - diffusion + energy losses of $e^\pm$
  - ISRF / gas distributions

⇒ IC and/or Brems. signals can have DISTINCT spectial morphologies from GCE; if so, Fermi should be able to detect as individual sources!

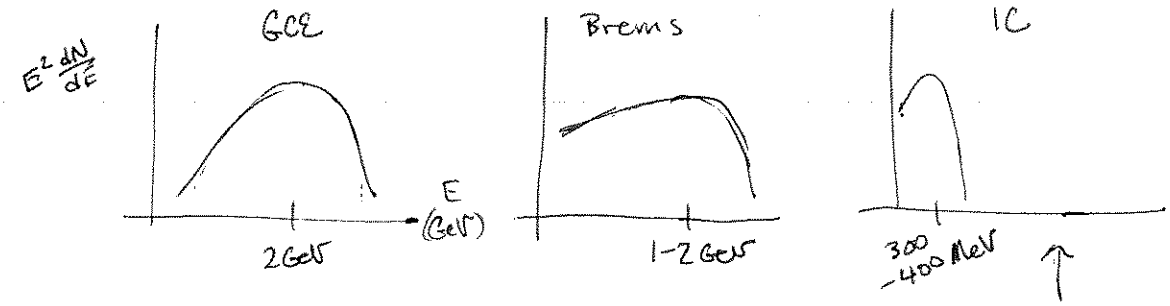
how are extended sources detected?

template maximum likelihood fitting ⇒ norm. + spectrum for each of:

- Fermi galactic diffuse model – dominant source @ GC
- " extragalactic isotropic background
- " point source catalog
- NFW halo profile template
- IC template: infrared map, traces background starlight
- Brems template: 20 cm radio map, traces gas thru synchrotron radiation

results: prompt + secondary emission templates all detected at high significance ($2\Delta \ln \mathcal{L} \gtrsim 100$)

sketches of spectra:




new detection of this source! hence the title

notice cutoff's in IC + brems spectra...
imply ~~break~~ cutoff in electron spectrum, which you can get quite naturally if $e^-$s that produce IC + brems spectra are coming from DM annihilations

very roughly:

IC upscattering $\propto \gamma^2$ of $e^-$

$\nu_{IC} \approx \gamma_e^2 \nu_0$, or $E_{IC\,photon} \approx \left(\frac{E_e}{m_e}\right)^2 hc \cdot \frac{1}{\lambda_0}$

($hc \to \sim 10^{-9}$ GeV·μm; $m_e \to .5$ MeV)

ISRF peaks @ 1 μm : $\lambda_0 = 1$ μm

if assuming DM annihilations to all leptons is producing the prompt spectrum (GCE), $M_{DM} \sim 10$ GeV

$\Rightarrow E_e = 10$ GeV

$E_{IC\,photons} \approx 0.4$ GeV for above values

hey, that's where our actual observed IC template spectrum cuts off...

DM → leptons Interpretation of the GCE:

(1) get best-fit mass & cross section from prompt spectrum
(2) use $m_{DM}$, $\langle\sigma v\rangle$, annihilation channel to predict $e^{\pm}$ spectrum produced by annihilations
(3) use $e^{\pm}$ spectrum, solve diffusion eqn to predict resulting IC + brems spectra

1) assume democratic annihilation, $\frac{1}{3}$ each $\mu^{\pm}/e^{\pm}/\tau^{\pm}$'s

need $\tau$'s to produce prompt gamma-rays
need $e$'s to produce secondary gamma-rays

$\Rightarrow$ $M_{DM} \approx 8$ GeV, $\langle\sigma v\rangle \approx 3.6 \times 10^{-26}$ cm$^3$s$^{-1}$

* $\langle\sigma v\rangle$ for this mass + channel is in conflict w/ AMS + LEP limits!! will go into more details later *

2) just used PPPC4DMID

3) diffusion + energy losses governed by

$$q(\vec{x},E) + K(E)\,\nabla^2\psi(\vec{x},E) + \frac{\partial}{\partial E}\left(b_{tot}(\vec{x},E)\,\psi\right) = 0$$

$q$: source term; $K(E)$: diffusion coeff.; $\psi$: electron spectrum; $b_{tot}$: energy losses; $= 0$: assuming steady state

$$q(\vec{x},E) = \frac{\langle\sigma v\rangle}{2}\,\frac{dN}{dE}(E)\,\frac{1}{M_{DM}^2}\,\rho_{NFW}^2(\vec{x})$$

$$K(E) = K_0 \cdot \left(\frac{E}{1\,\text{GeV}}\right)^{\delta}$$

$$b_{tot} = b_{sync} + b_{brems} + b_{IC}$$

$b_{sync} \propto B^2$, $b_{brems} \propto n_{gas}$, $b_{IC} \propto E_{ISRF}$

using middle-of-the-road values for $K_0$, $\delta$, $B$, $n_{gas}$,
resultant IC + brems spectra are consistent w/ data points!

BUT there is a wide range of uncertainties
in the diffusion parameters

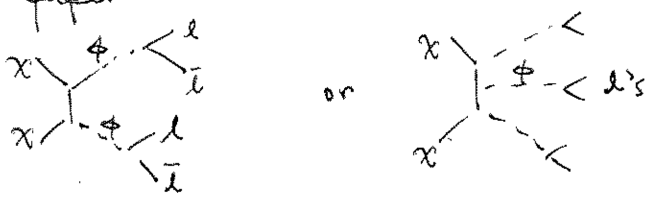
back to constraints on $\chi\chi \to e^+e^-$ from other experiments

1) AMS-02: strong limits on direct annihilation to $e^\pm$ — $\sim 0.5\text{e-}28$ @ 8 GeV
   no lines observed in $e^\pm$ spectrum

2) LEP monophoton search — no missing energy — $10^{-28}$ – $\sim$ few $\times 10^{-27}$

constraints can be loosened:

(Mo's paper 1404.6528) DM annihilation thru on-shell mediators:




light mediator produced on shell in DM annihilation
$\langle\sigma v\rangle$ only depends on DM-mediator coupling, mediator-lepton coupling can be small
$\Rightarrow$ wouldn't see collider production, dodge LEP bounds

resultant lepton spectra is smeared:

box instead of line

$\Rightarrow$ loosen tension w/ AMS's lack of $e^\pm$ lines observed

but, competing effect from increased DM $(\text{mass})^2$:

$$\frac{d\Phi_\gamma}{dE} = \frac{1}{8\pi}\frac{\langle\sigma v\rangle}{m_{DM}^2}\frac{dN_\gamma}{dE}\int_{l.o.s} \rho^2\, dx$$

required $\langle\sigma v\rangle$ also increases largest uncertainty on $\langle \sigma v \rangle$ comes from DM profile:

again, $\rho_{NFW}(r) = \rho_0 \frac{(r/r_s)^{-\gamma}}{(1 + r/r_s)^{3-\gamma}}$ and $\Phi_\gamma \propto \langle \sigma v \rangle \cdot \int_{l.o.s} \rho^2 dx$ (squared!)

local DM density $\rho_\odot = 0.3$ GeV cm$^{-3}$ $\pm$ 0.1 "

uncertainty on $\gamma$ (inner slope) can greatly affect $\langle \sigma v \rangle$!

adiabatic contraction - center of MW is baryon-dominated → deepens grav. potential → increases DM density

uncertainty up to ~10 downwards!

* these uncertainties aren't included usually when people publish their $\langle \sigma v \rangle$ from GCE analyses, so take their limits figures w/ a grain of salt. *