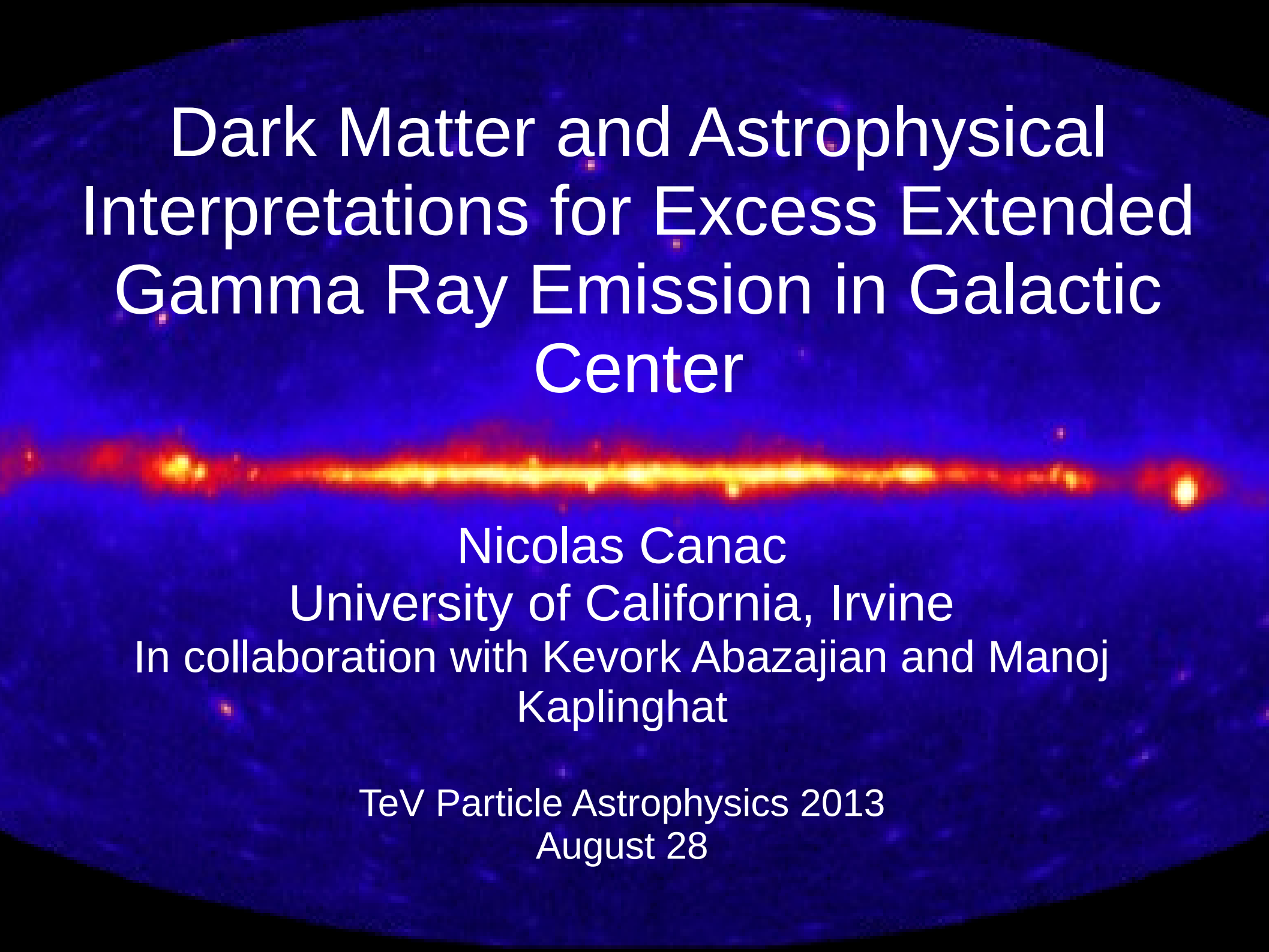
Dark Matter and Astrophysical Interpretations for Excess Extended Gamma Ray Emission in Galactic Center



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TeV Particle Astrophysics 2013
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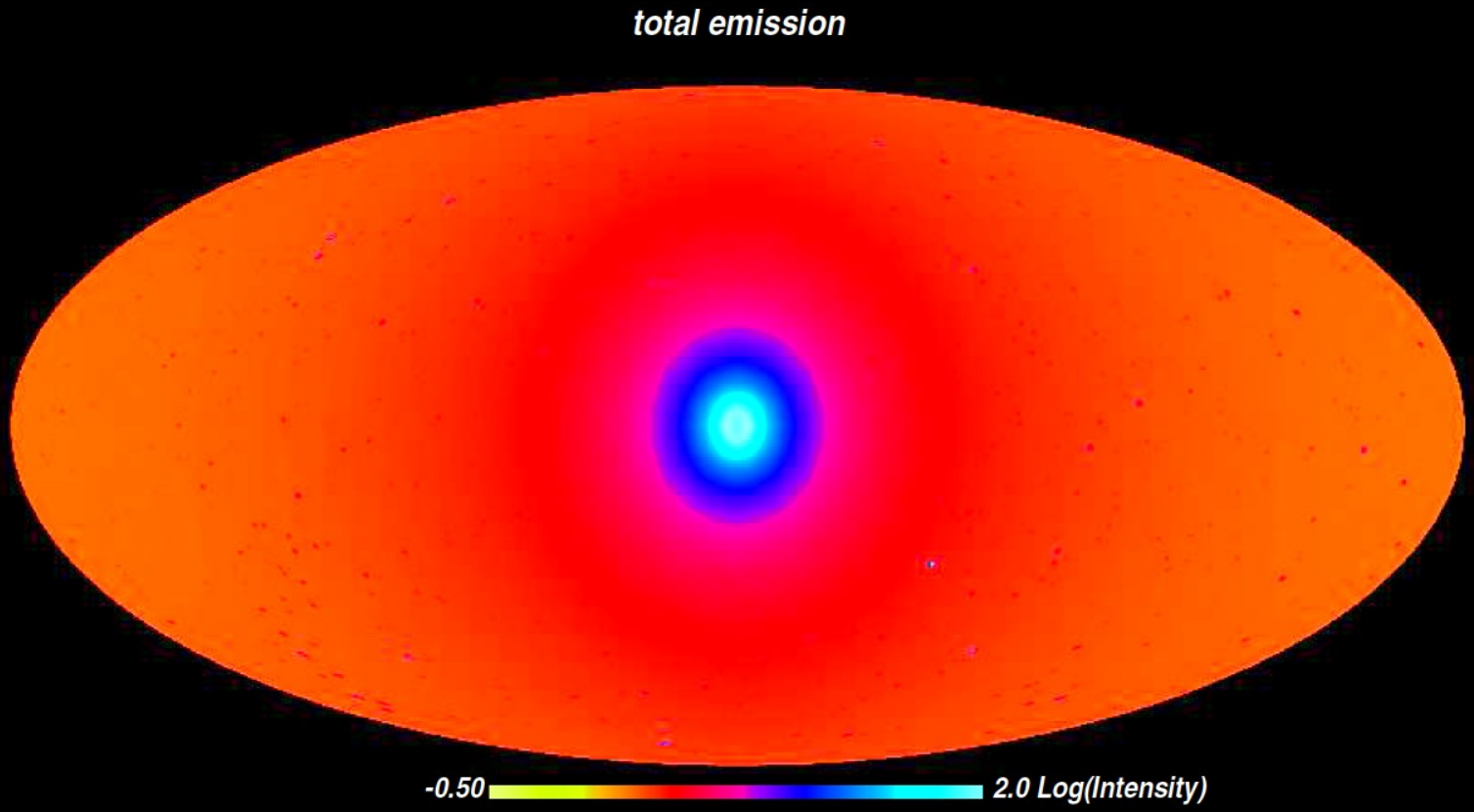
Galactic Center is the Brightest DM Source

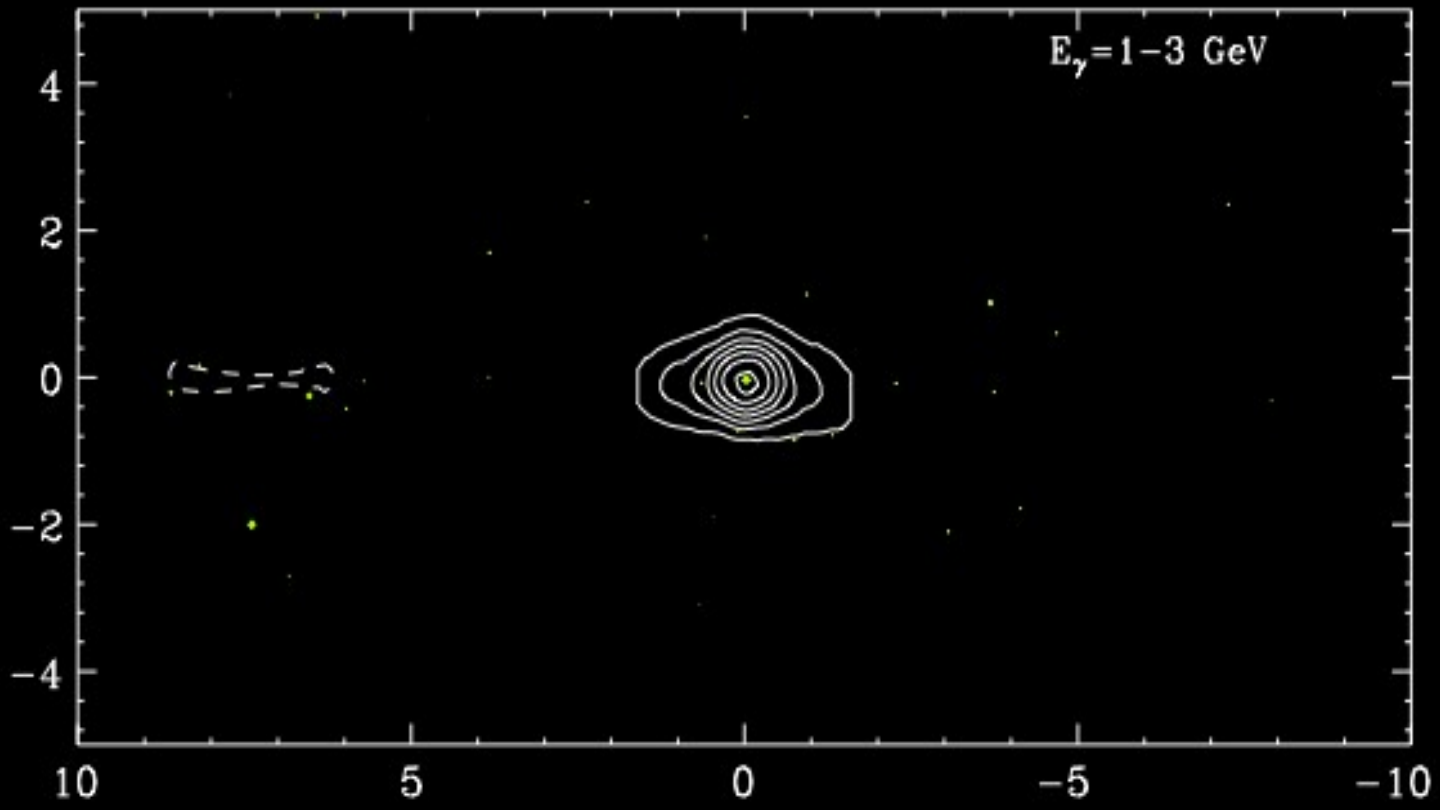
$$\frac{d\Phi_\gamma}{dE} = \frac{\langle \sigma_A v \rangle}{2} \frac{\mathcal{J}_{\Delta\Omega}}{J_0} \frac{1}{4\pi m_\chi^2} \frac{dN_\gamma}{dE}$$

$$\mathcal{J}(b,\ell) = \mathrm{J}_0 \int_{x_{\min}}^{x_{\max}} \rho^2 \left(r_{\mathrm{gal}}(b,\ell,x) \right) dx$$



Springel et al 2008

Extended Source in the Galactic Center?

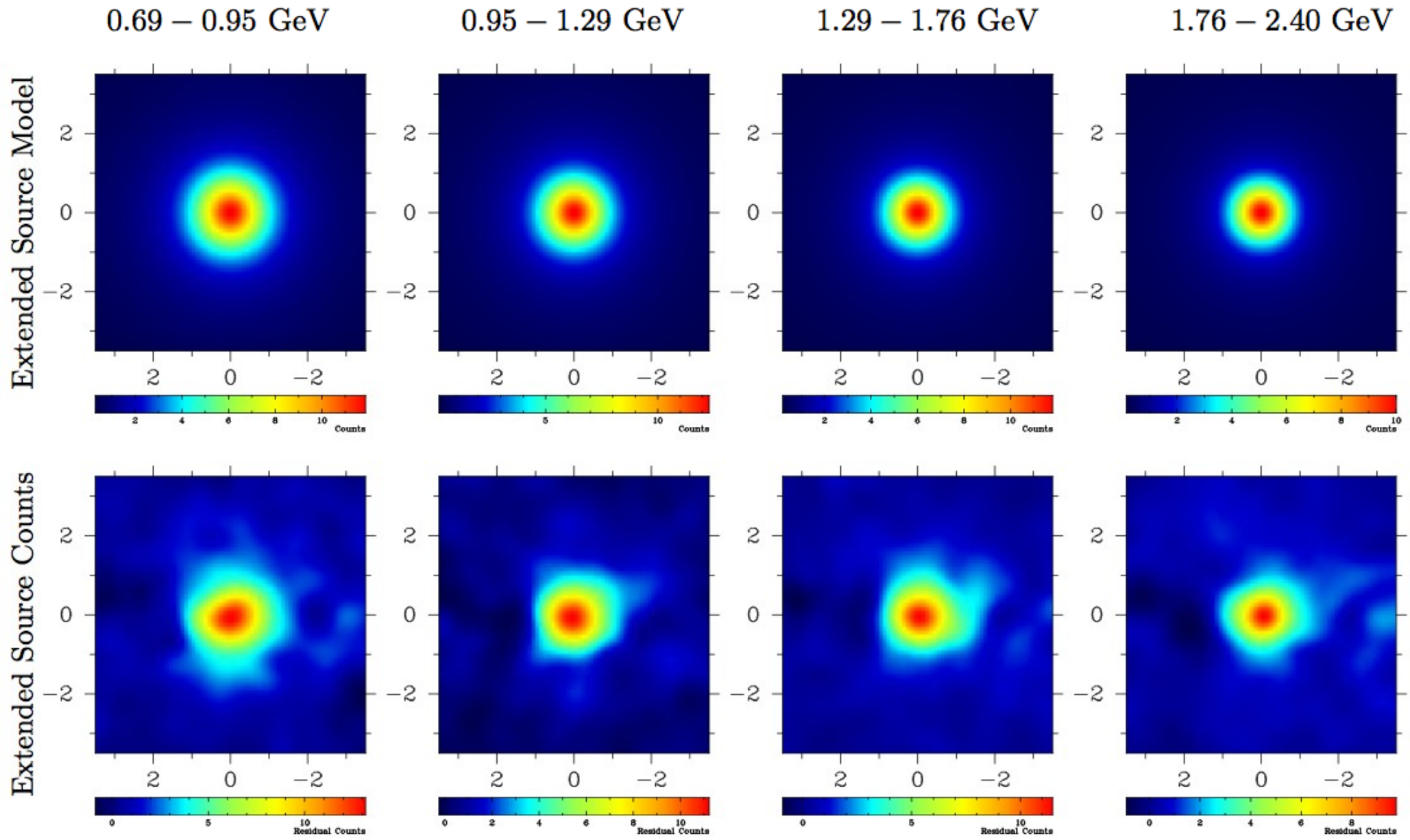


Hooper & Linden, 2011
Boyarsky et al., 2011
Abazajian & Kaplinghat, 2012
Gordon & Macias, 2013

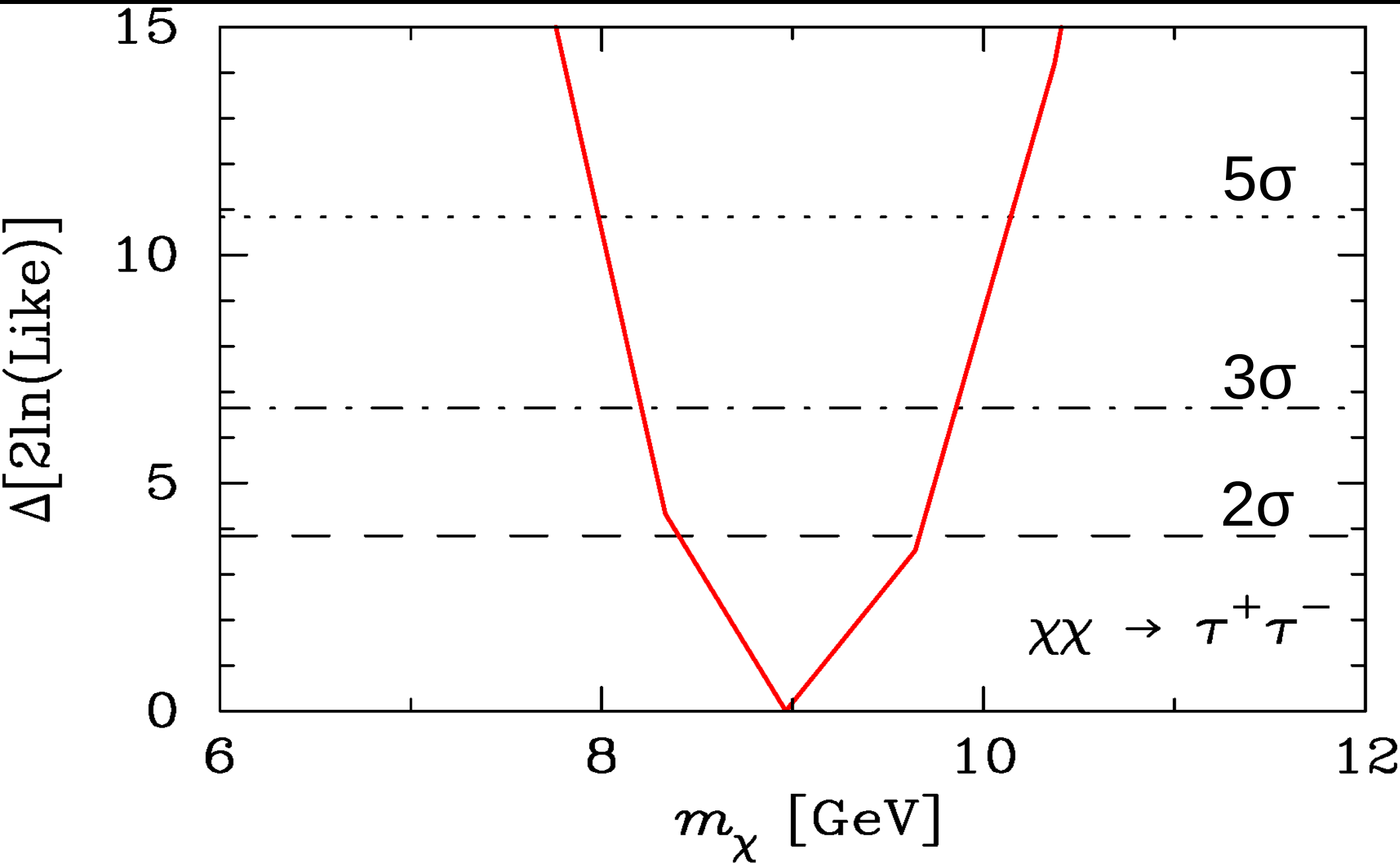
Dark Matter in the Galactic Center?

$m_\chi = 30$ GeV

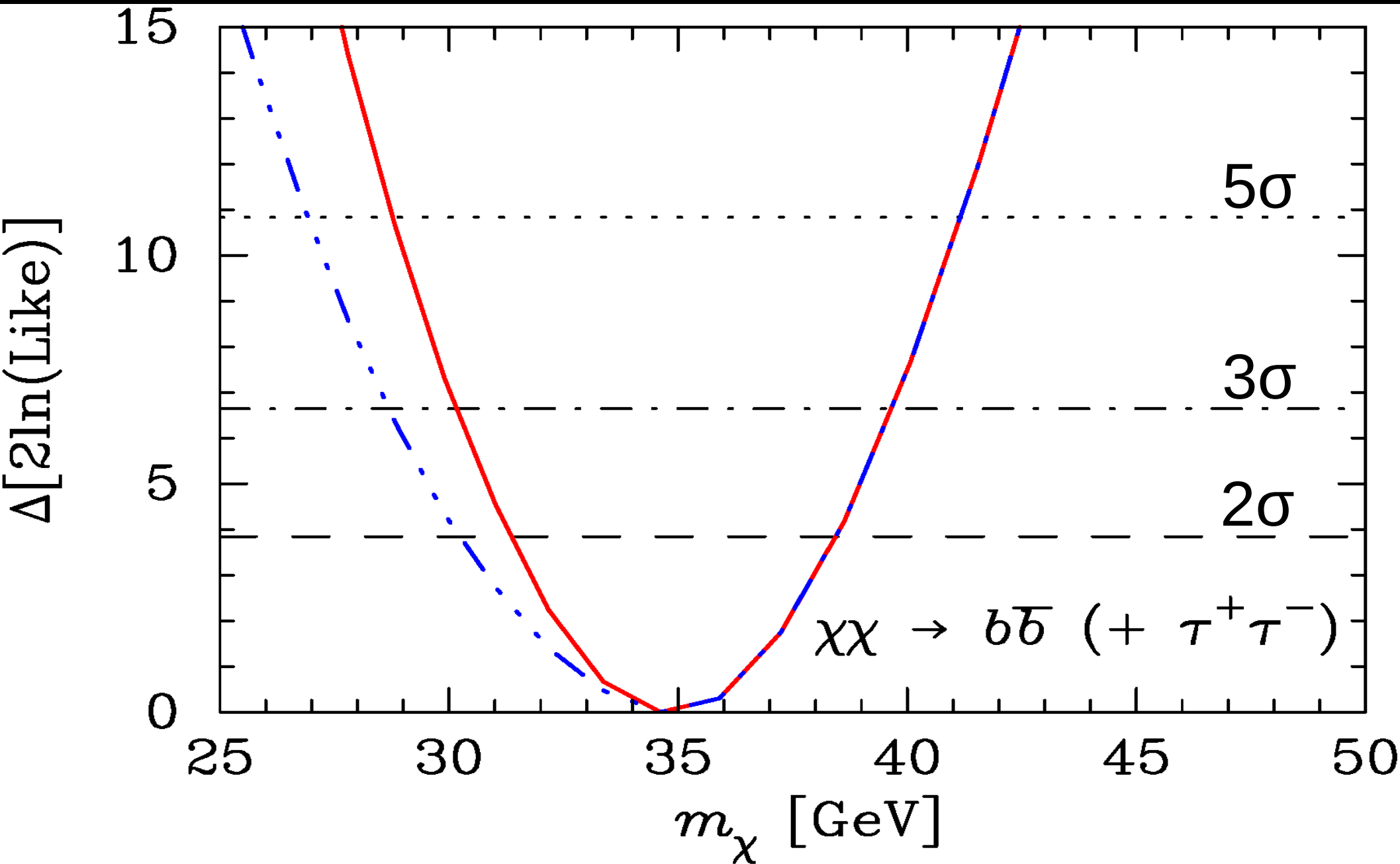
NFW $\gamma = 1.2$ $\quad \mathrm{TS}_{\mathrm{true}} = 2\Delta \ln \mathcal{L} = 824,\ 28.7\sigma,\ p = 4 \times 10^{-181}$



Dark Matter Interpretation: Taus



Dark Matter Interpretation: b quarks



Notes on Dark Matter Interpretation

- Consistency between GC signal and DM morphology (generalized NFW profile), spectrum, and rate
- Best fit for annihilation to b quarks ~ 35±3 GeV
- Best fit for annihilation to tau leptons ~ 9±0.5 GeV (not including bremsstrahlung effect, Cirelli et al. 2013)
- Bottom channel strongly preferred, $\Delta \ln(L)=87.8$
- No evidence for branching to taus

Astrophysical Interpretation

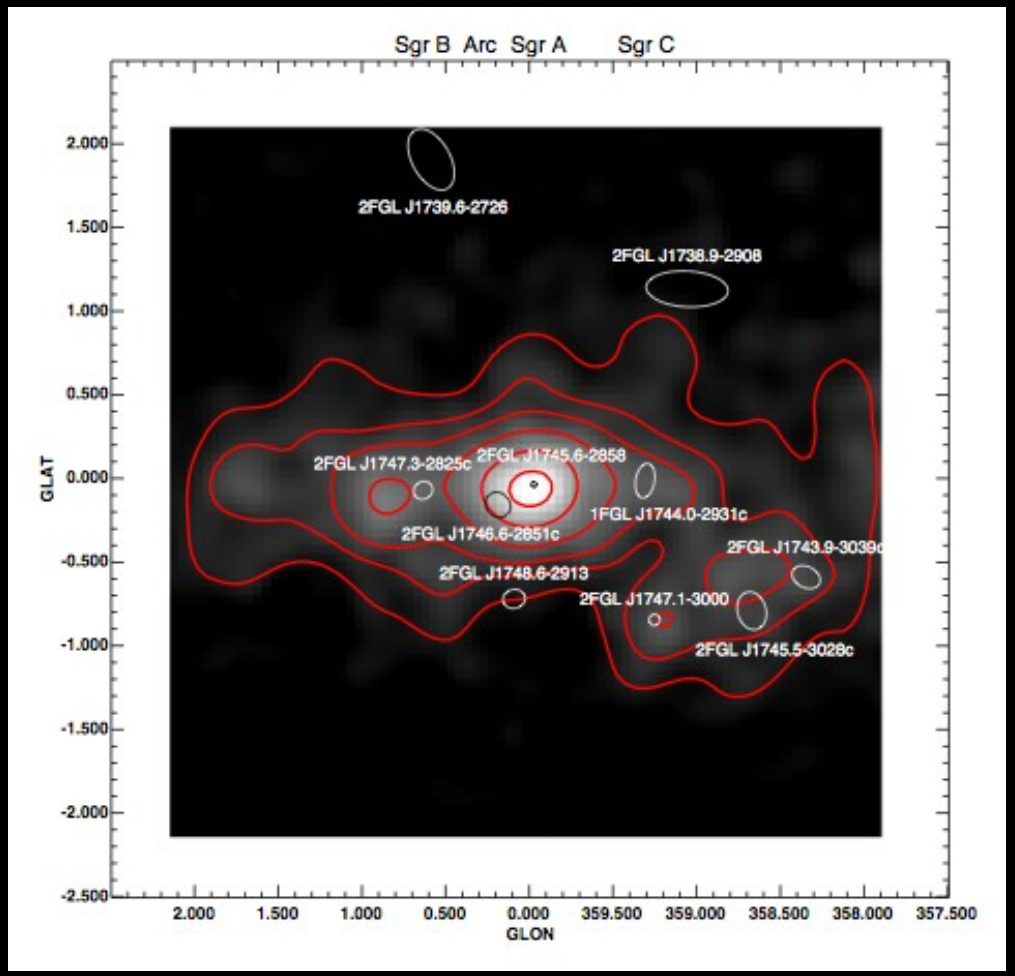
Alternatively, a number of astrophysical sources could account for the extended emission, e.g. an unresolved population of millisecond pulsars (MSPs), cosmic ray e^- bremsstrahlung on molecular gas (BMG), and uncertainty in the Galactic diffuse background.

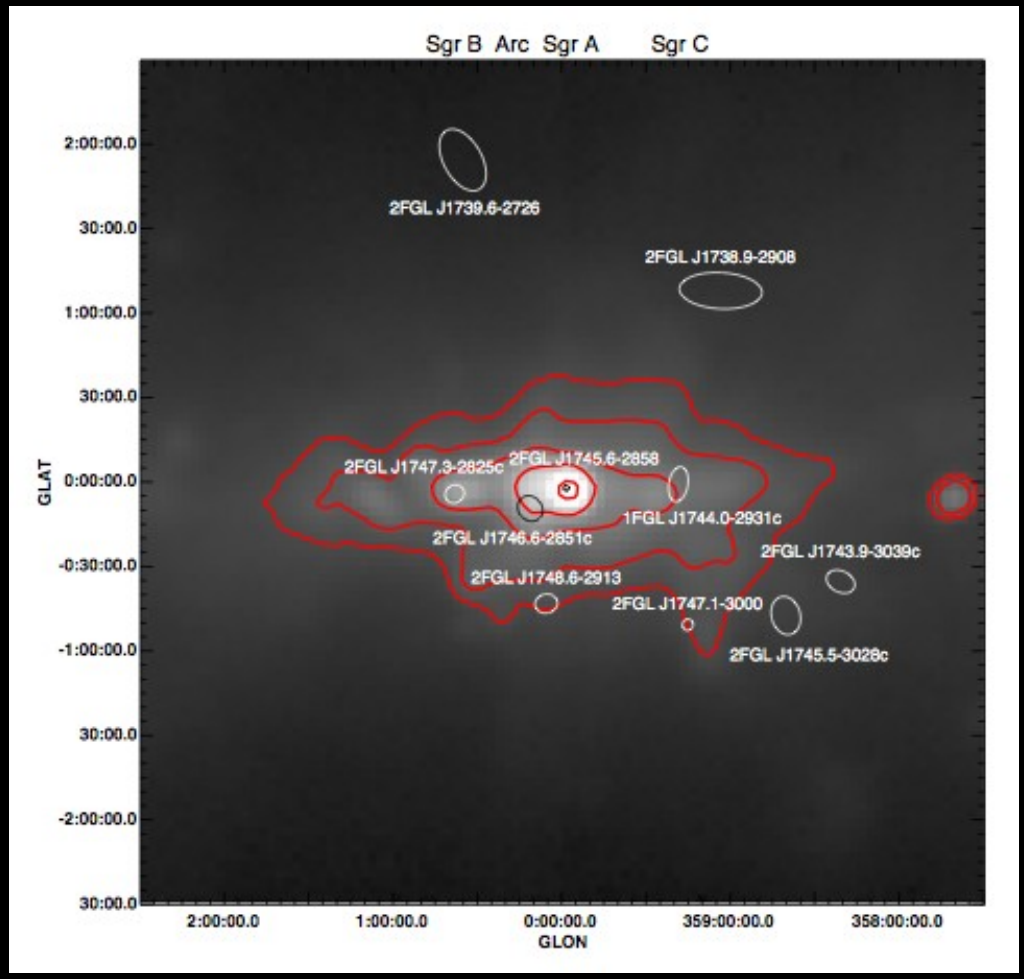
MSP population: $\rho(r) \propto r^{-2\gamma}$

New diffuse component: $\rho_{projected}(R) \propto R^{-\Gamma}$

Astrophysical Interpretation

Cosmic ray e^- bremsstrahlung on molecular gas (BMG):
Yusef-Zadeh et al., 2012





Gamma-Ray

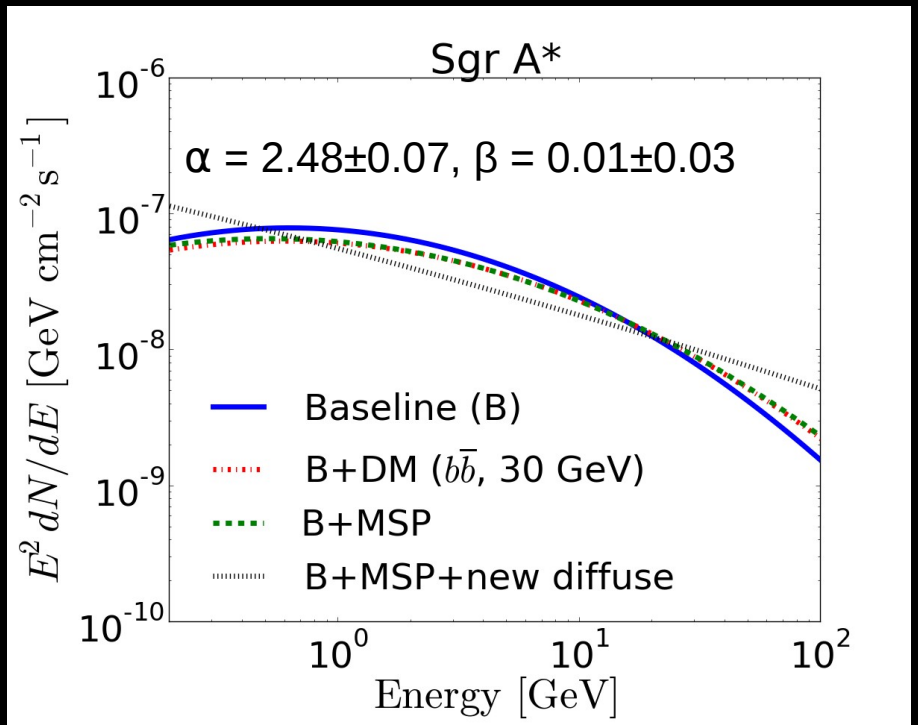
1.4 GHz Radio

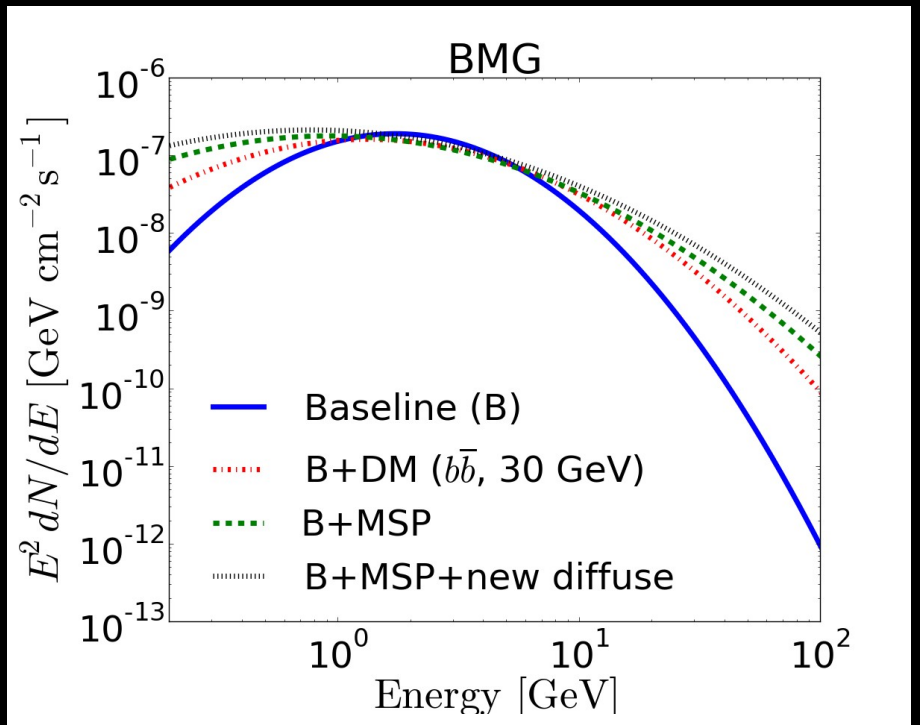
Method & Results

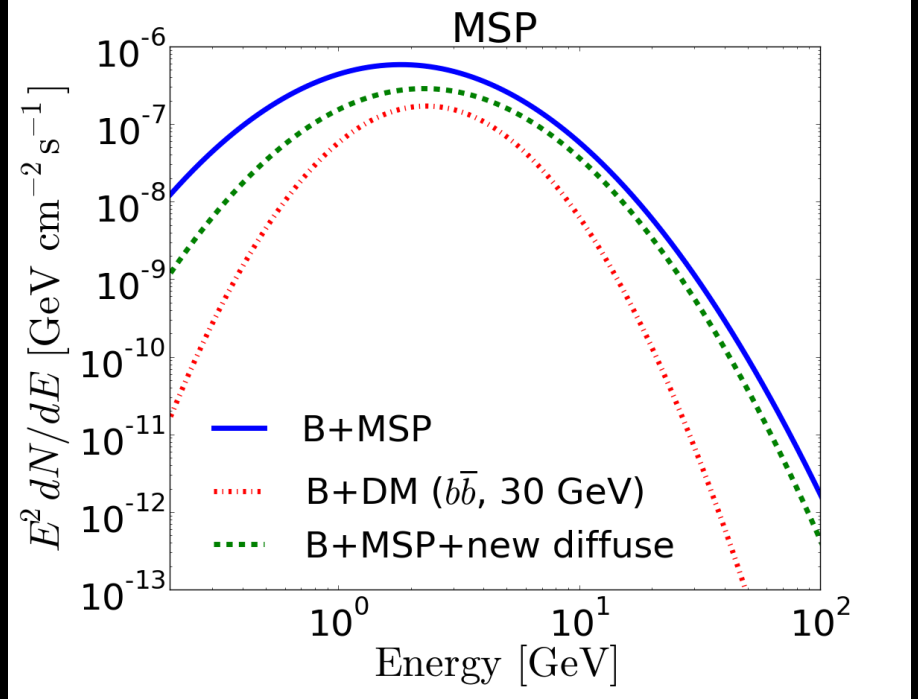
- Fit all 20 point sources in the 7x7 degree region around GC, along with Galactic & Isotropic Diffuse Backgrounds (2FGL sources)
- Add extended astrophysical sources: BMG, MSP population, additional galactic diffuse component and refit sources in first step

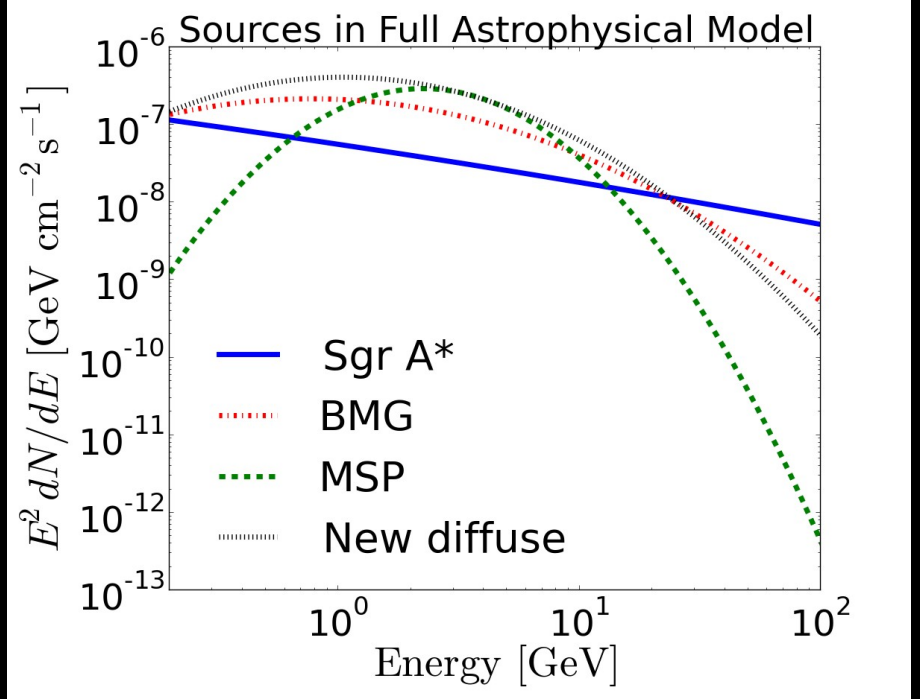
Source	-ln(L)	Δln(L)
Baseline	1080571.2	--
BMG	1080738.1	166.9
BMG + γ=1.0	1081039.5	468.3
BMG + Γ=1.0	1081047.8	476.6
BMG + γ=1.2 + Γ=-0.6	1081080.3	509.1

Spectra


Sgr A*
α = 2.48±0.07, β = 0.01±0.03
Baseline (B)
B+DM ($b\bar{b}$, 30 GeV)
B+MSP
B+MSP+new diffuse
$E^2\,dN/dE$ [GeV cm^{-2} s^{-1}]
Energy [GeV]


BMG
Baseline (B)
B+DM ($b\bar{b}$, 30 GeV)
B+MSP
B+MSP+new diffuse
$E^2\,dN/dE$ [GeV cm^{-2} s^{-1}]
Energy [GeV]


MSP
B+MSP
B+DM ($b\bar{b}$, 30 GeV)
B+MSP+new diffuse
$E^2\,dN/dE$ [GeV cm^{-2} s^{-1}]
Energy [GeV]

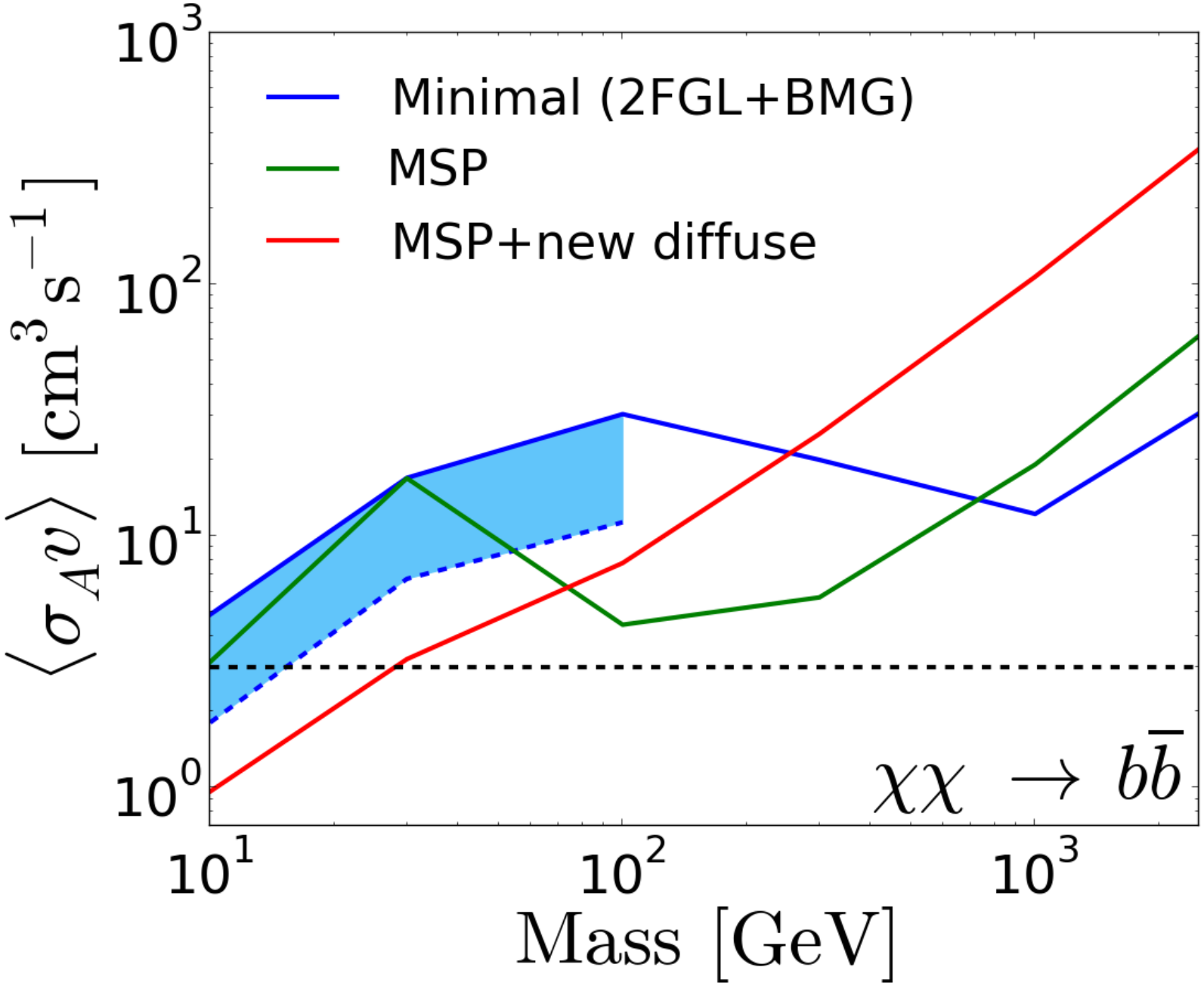

Sources in Full Astrophysical Model
Sgr A*
BMG
MSP
New diffuse
$E^2\,dN/dE$ [GeV cm^{-2} s^{-1}]
Energy [GeV]

Notes on Astrophysical Interpretation

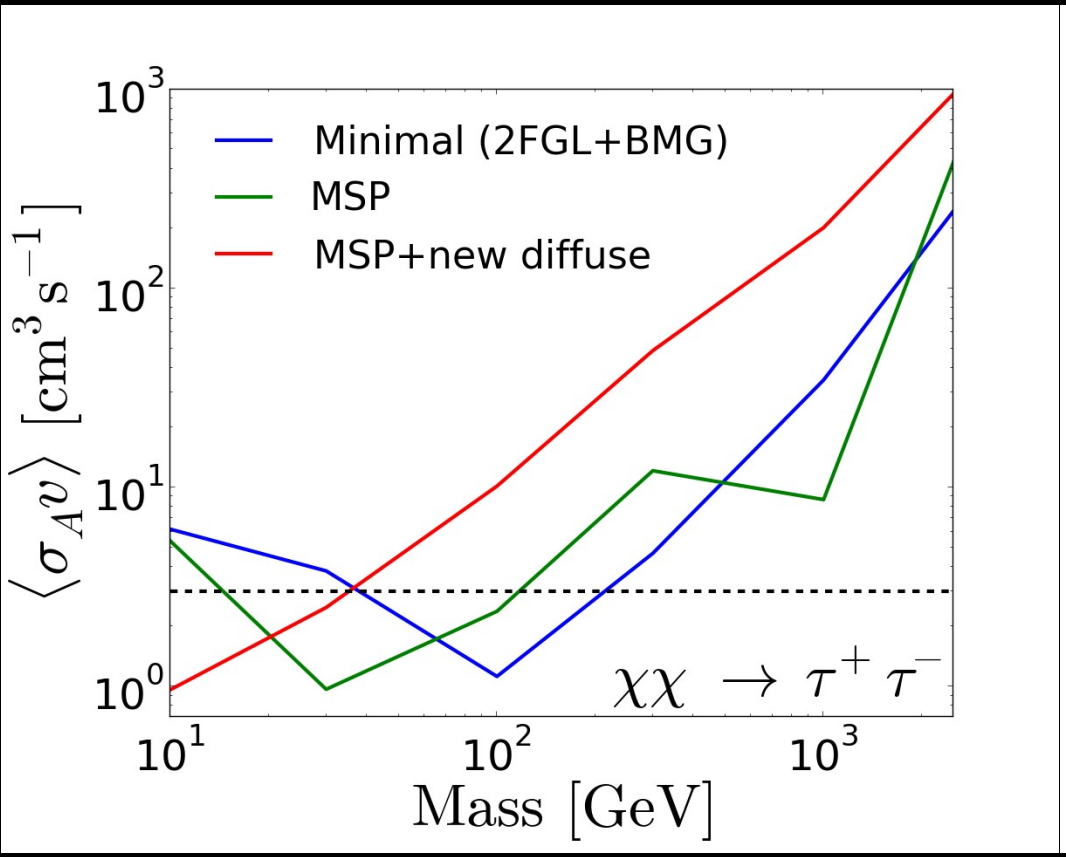
- Number of MSPs required is 1000-2000 for 2FGL model
- Adding the BMG reduces this number to 450-900
- Adding the new diffuse component further reduces this to 150-300
- Spectrum of Sgr A* is highly dependent on the model we use for the extended emission, and becomes a power law when our full astrophysical model is taken into account: implications for Chernyakova et al. (Crocker) Sgr A* analysis
- BMG spectrum wants to fit best fit MSP spectrum, and becomes more power law-like when MSP is added
- No DM detections in full astrophysical model – not surprising as MSP is basically like DM

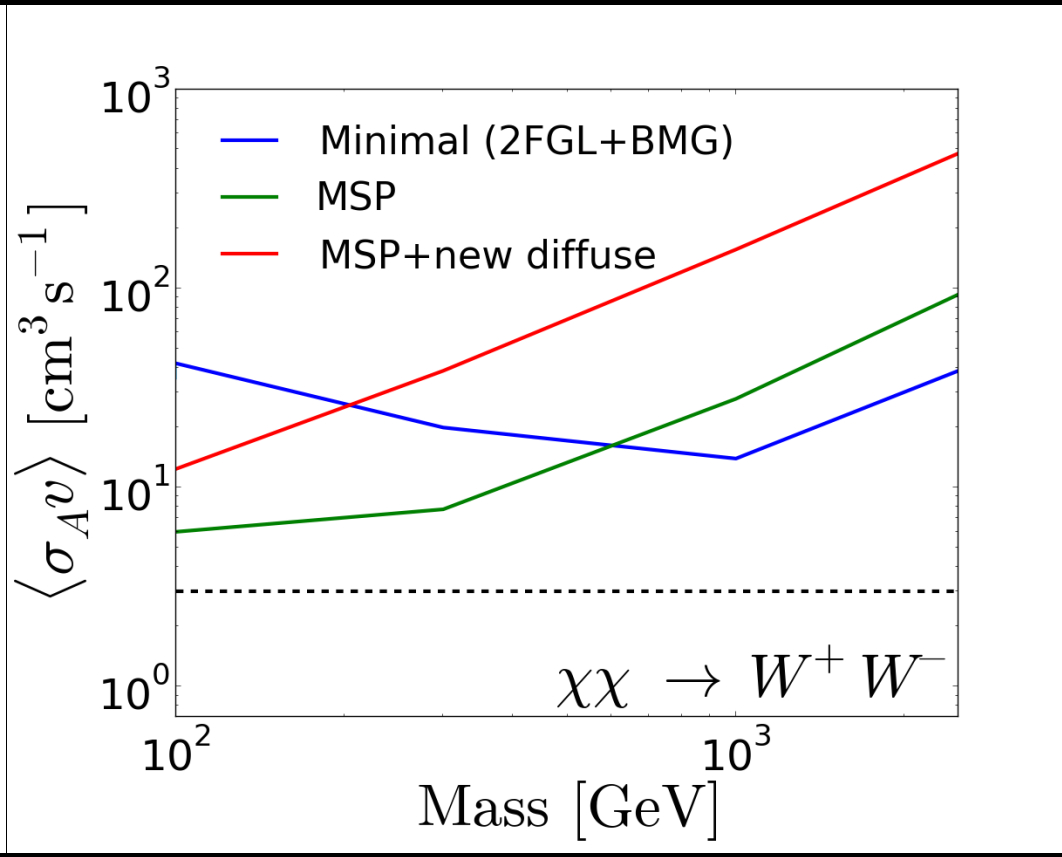
Given an astrophysical interpretation for the extended emission, what limits can we place on the presence of dark matter in the Galactic center?

Limits


Minimal (2FGL+BMG)
MSP
MSP+new diffuse
$\chi\chi \rightarrow b\bar{b}$
$\langle \sigma_A v \rangle$ [cm^3 s^{-1}]
Mass [GeV]
10^0
10^1
10^2
10^3
10^1
10^2
10^3

Limits


Minimal (2FGL+BMG)
MSP
MSP+new diffuse
$\chi\chi \rightarrow \tau^+ \tau^-$
$\langle \sigma_A v \rangle$ [cm^3 s^{-1}]
Mass [GeV]


Minimal (2FGL+BMG)
MSP
MSP+new diffuse
$\chi\chi \rightarrow W^+ W^-$
$\langle \sigma_A v \rangle$ [cm^3 s^{-1}]
Mass [GeV]

Summary

- Galactic center is a good place to look for annihilating dark matter
- Extended source emission is consistent with either a dark matter or an astrophysical interpretation
- If dark matter, 35±3 GeV annihilating to b quarks is preferred, and is robustly detected even with inclusion of molecular gas diffuse emission
- If MSPs, need between 150-2000, depending on model
- Strong detection of bremsstrahlung emission from molecular gas detected in radio even with MSP source
- Spectrum of point source associated with Sgr A* changes considerably with addition of new detected extended sources, and is a power law in best fit model: implications for Chernyakova et al. (Crocker) Sgr A* analysis
- With pure astrophysical interpretation, DM limits inferred from GC highly dependent on model and are not as stringent as stacked dwarf galaxy limits because of astrophysical uncertainties