Dark Matter All-sky Searches and Limits

Joe Lundeen

Why All-sky?

- No need to assume a profile
  - Can compute limits even without astrophysical data for each point
  - Lets us do the “hard” work all at once
- Can compute limits on detectibility of dark dwarfs
  - How many can we expect to find?

Our Search Method

- Four unassociated sources in the 2HWC catalog
- We test these for dark matter
  - Compare test statistic (TS) for power laws and dark matter spectra
  - Dark matter is “detected” if TS is much better for dark matter
- No assumptions make about profile, fitting spectral shape only
- Allows us to generalize technique to any point in the sky

Power Laws

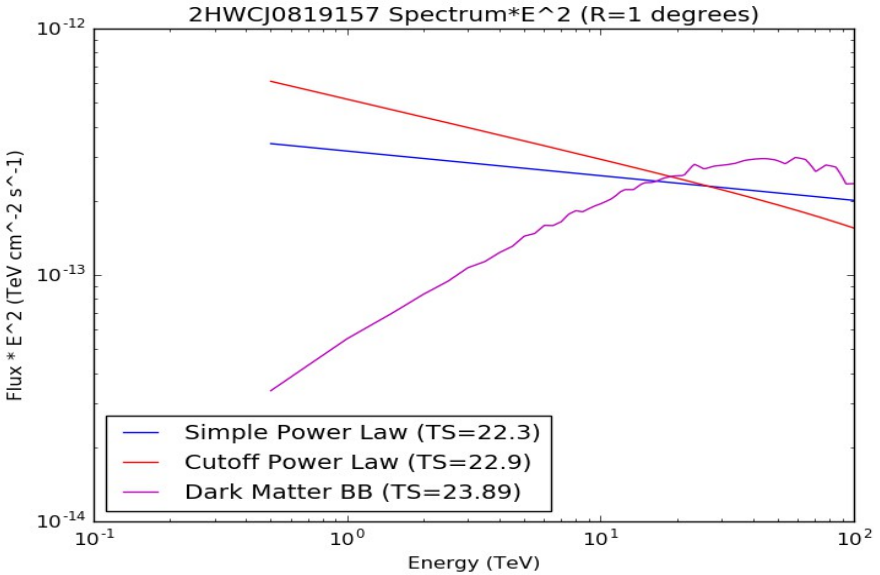
$$\frac{d\Phi}{dE} = \Phi_0 (E/E_0)^{-n}$$

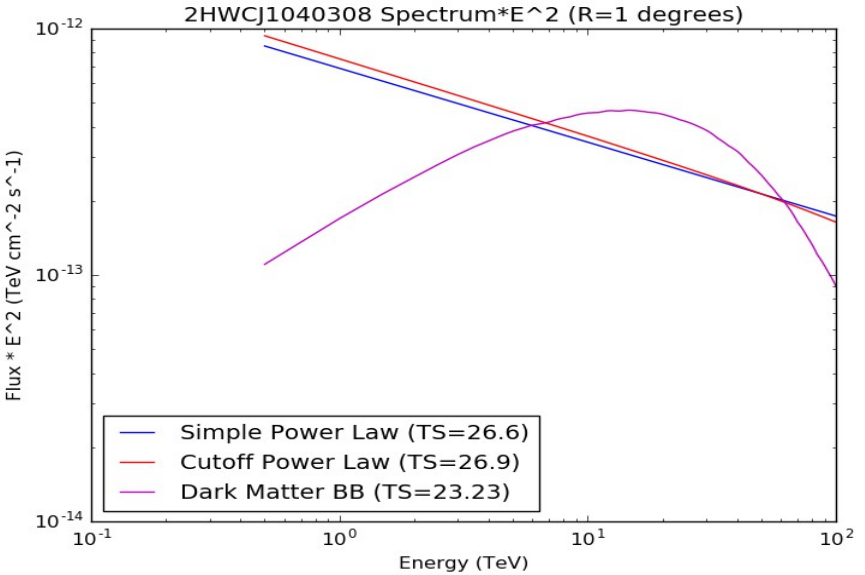
$$\frac{d\Phi}{dE} = \Phi_0 (E/E_0)^{-n} e^{-E/X}$$

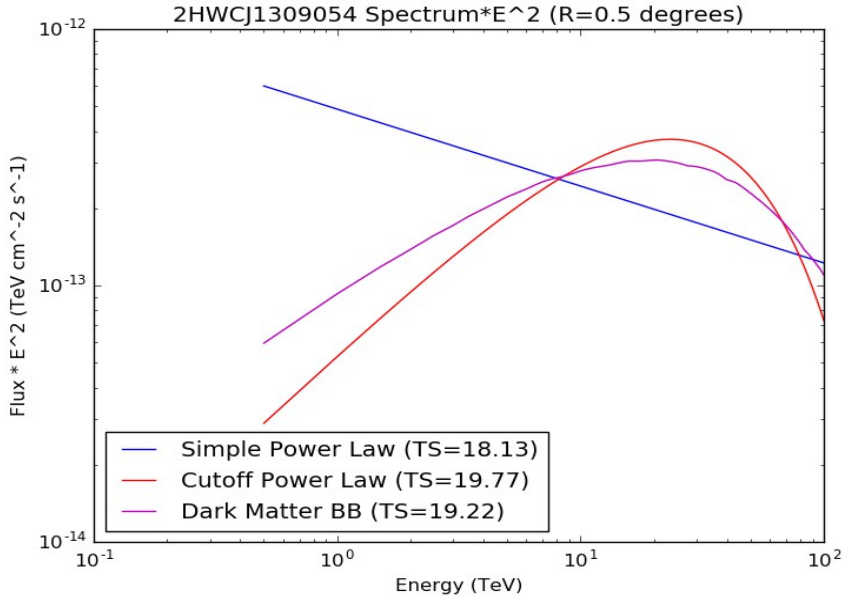
Dark Matter

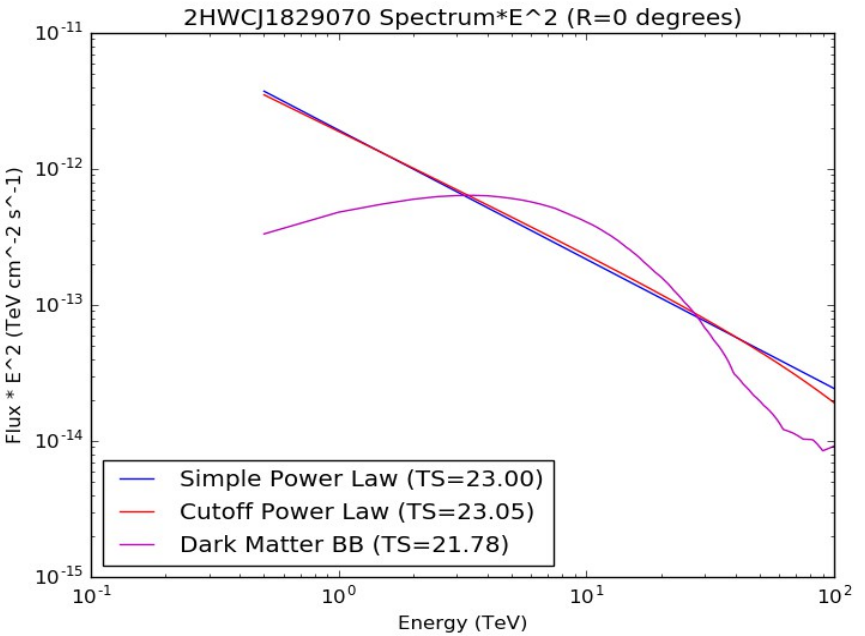
$$\frac{d\Phi}{dE} = \frac{\sigma v J}{8\pi M^2} \frac{dN(M,channel)}{dE}$$

$$J = \int \int \rho_{dm}^2 (l,\Omega) dl d\Omega$$


2HWCJ0819157 Spectrum*E^2 (R=1 degrees)
Flux * E^2 (TeV cm^-2 s^-1)
Energy (TeV)
Simple Power Law (TS=22.3)
Cutoff Power Law (TS=22.9)
Dark Matter BB (TS=23.89)


2HWCJ1040308 Spectrum*E^2 (R=1 degrees)
Flux * E^2 (TeV cm^-2 s^-1)
Energy (TeV)
Simple Power Law (TS=26.6)
Cutoff Power Law (TS=26.9)
Dark Matter BB (TS=23.23)


2HWCJ1309054 Spectrum*E^2 (R=0.5 degrees)
Flux * E^2 (TeV cm^-2 s^-1)
Energy (TeV)
Simple Power Law (TS=18.13)
Cutoff Power Law (TS=19.77)
Dark Matter BB (TS=19.22)


2HWCJ1829070 Spectrum*E^2 (R=0 degrees)
Flux * E^2 (TeV cm^-2 s^-1)
Energy (TeV)
Simple Power Law (TS=23.00)
Cutoff Power Law (TS=23.05)
Dark Matter BB (TS=21.78)

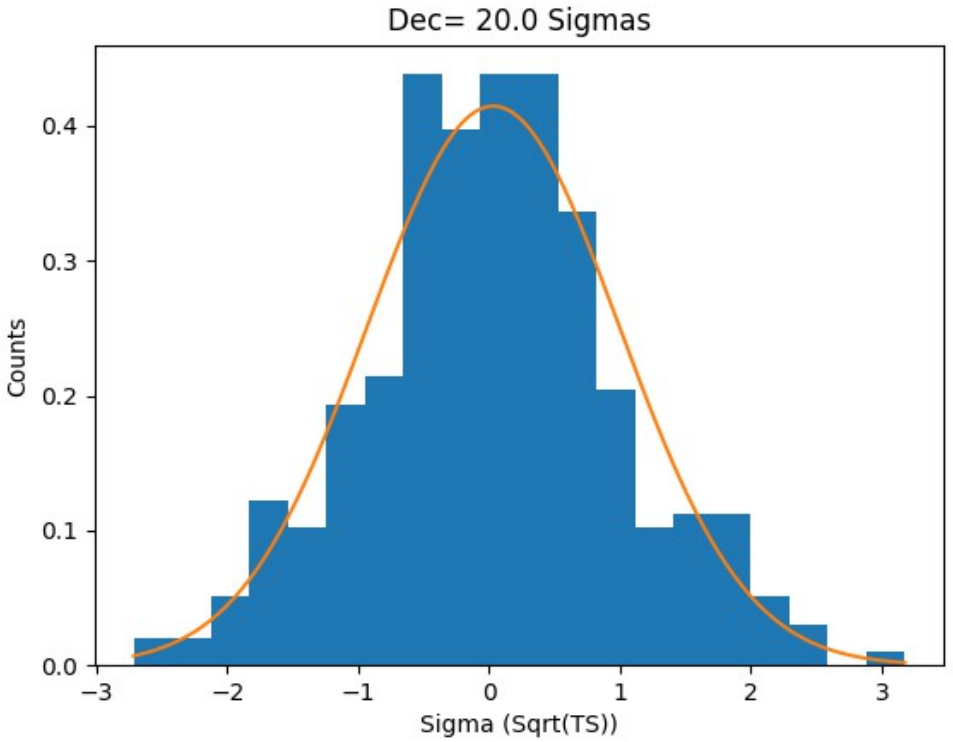
Fit Discussion

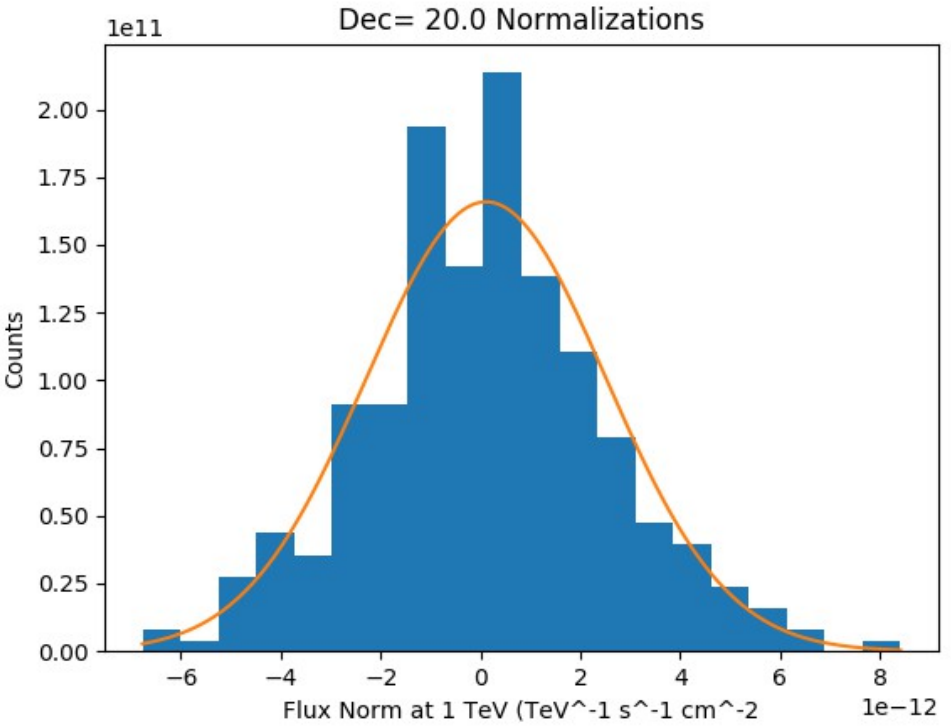
- 2HWCJ1309054 is consistent with dark matter
  - Definitely has a cutoff
- However, power laws fit equally well in each case
- Cannot distinguish a “better” fit
- Dark matter is not ruled out, but isn't unambiguously confirmed either

Limit Technique

- Generate b bbar spectra for a series of masses
- Mask out known sources from sky
- Fit a spectrum at each point of the sky in 5-degree dec bands and 1 degree RA bins
  - Use liff to obtain flux, flux error and sigma
- Histogram each dec bin flux norm and use Sqrt(2.7)*sigma for 95% containment (sanity check)
  - Will use actual 95% containment for published limits

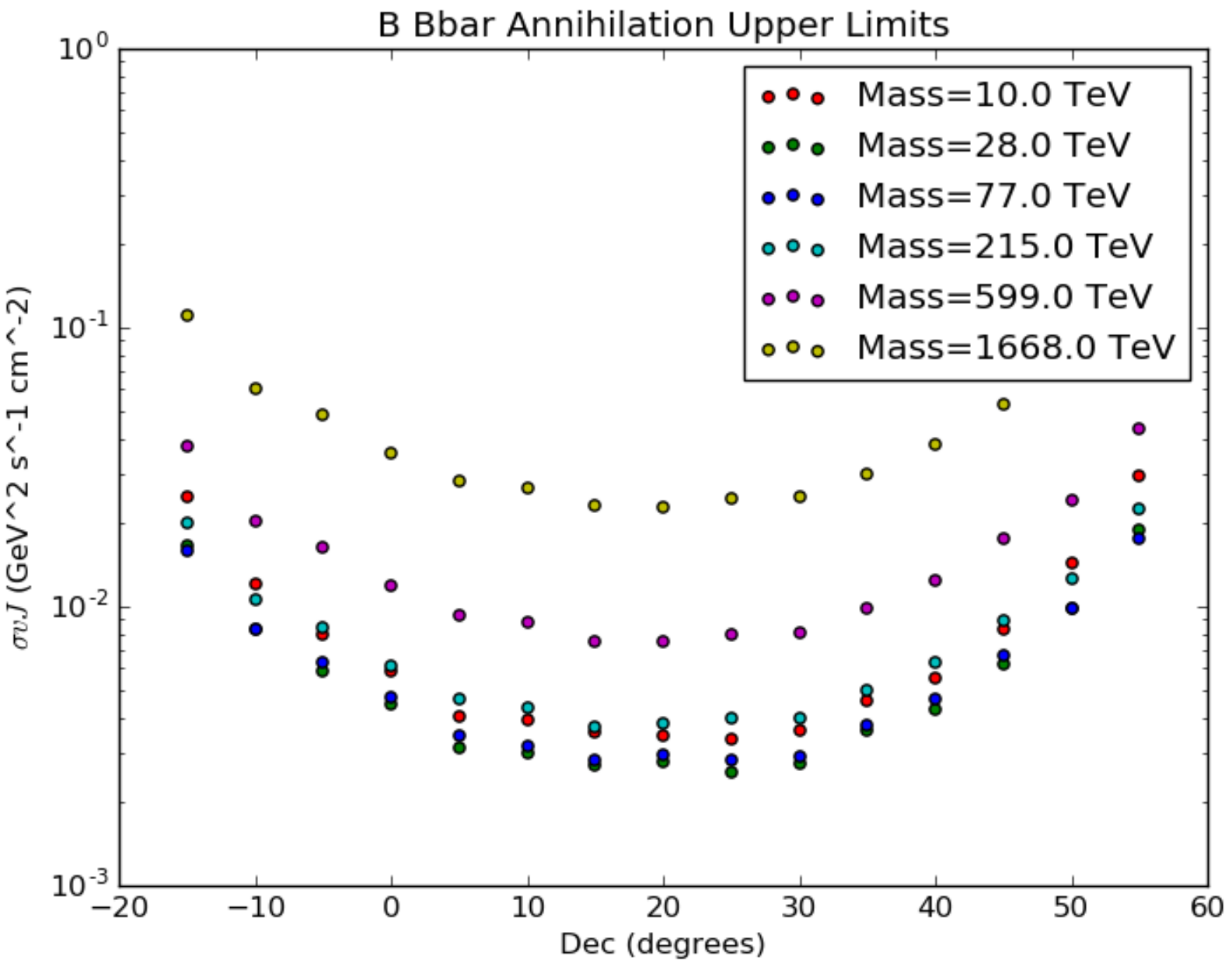
Checking Things are Gaussian





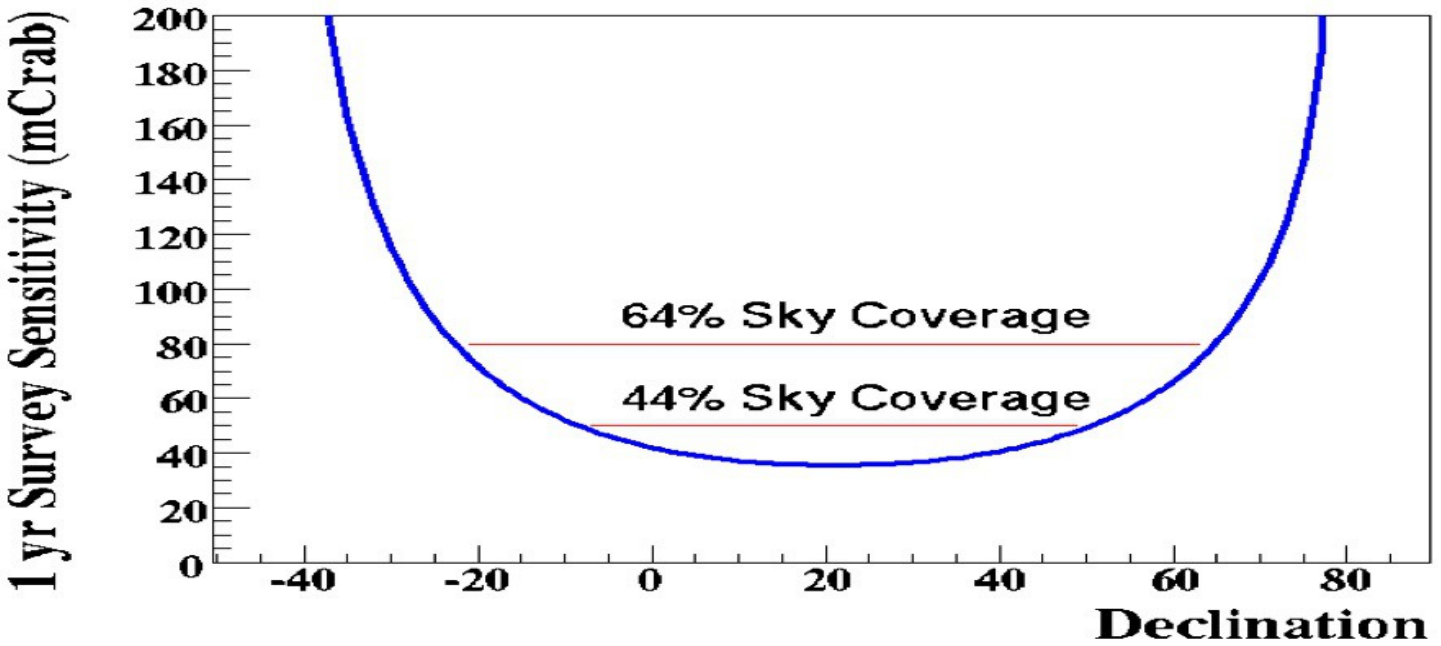
Mean:.03
Sigma: .96

Mean: 1.13e-13 1/(TeV s cm^2)
Sigma: 2.4e-12 1/(TeV s cm^2)


B Bbar Annihilation Upper Limits
Mass=10.0 TeV
Mass=28.0 TeV
Mass=77.0 TeV
Mass=215.0 TeV
Mass=599.0 TeV
Mass=1668.0 TeV
$\sigma v J$ (GeV^2 s^-1 cm^-2)
Dec (degrees)
10^0
10^{-1}
10^{-2}
10^{-3}
−20
−10
0
10
20
30
40
50
60

Discussion and Sanity Checks

- Results are (roughly) consistent with the dwarf paper
- For example Leo IV:
  - Dwarf paper (dec=-.53) : 0.90 GeV^2 cm^-2 s^-1
  - Us (dec=0): 0.98 GeV^2 cm^-2 s^-1
- Limits match our sensitivity curve



Summary and Next Steps

- Obtained all-sky limits on dark matter annihilation
- If a profile is assumed, we can easily convert these into cross section limits
- Dark dwarf limits
  - Involves simulations of DM structure formation and expected flux
  - Can then use our flux upper limits to compute upper limits on dark dwarfs
- Code used can be found at:
  - https://private.hawc-observatory.org/svn/hawc/sandbox/lundeenj/dark_matter/