Searching for Dark Matter with HAWC

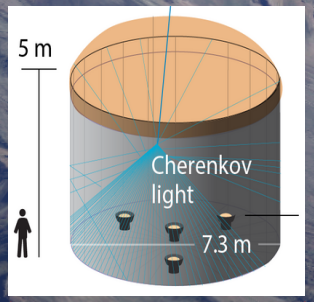
- J. Patrick Harding

- 8/1/17

The High Altitude Water Cherenkov Observatory

- **22,000 m^2** air shower array
- **300 Water Cherenkov detectors** (WCD)
- **200,000 liters** of purified water **per WCD**
- **4 sensors (photo-multiplier tubes) per WCD**
- **Completed March 2015**

Citlaltepetl
Pico de Orizaba
5160m a.s.l.

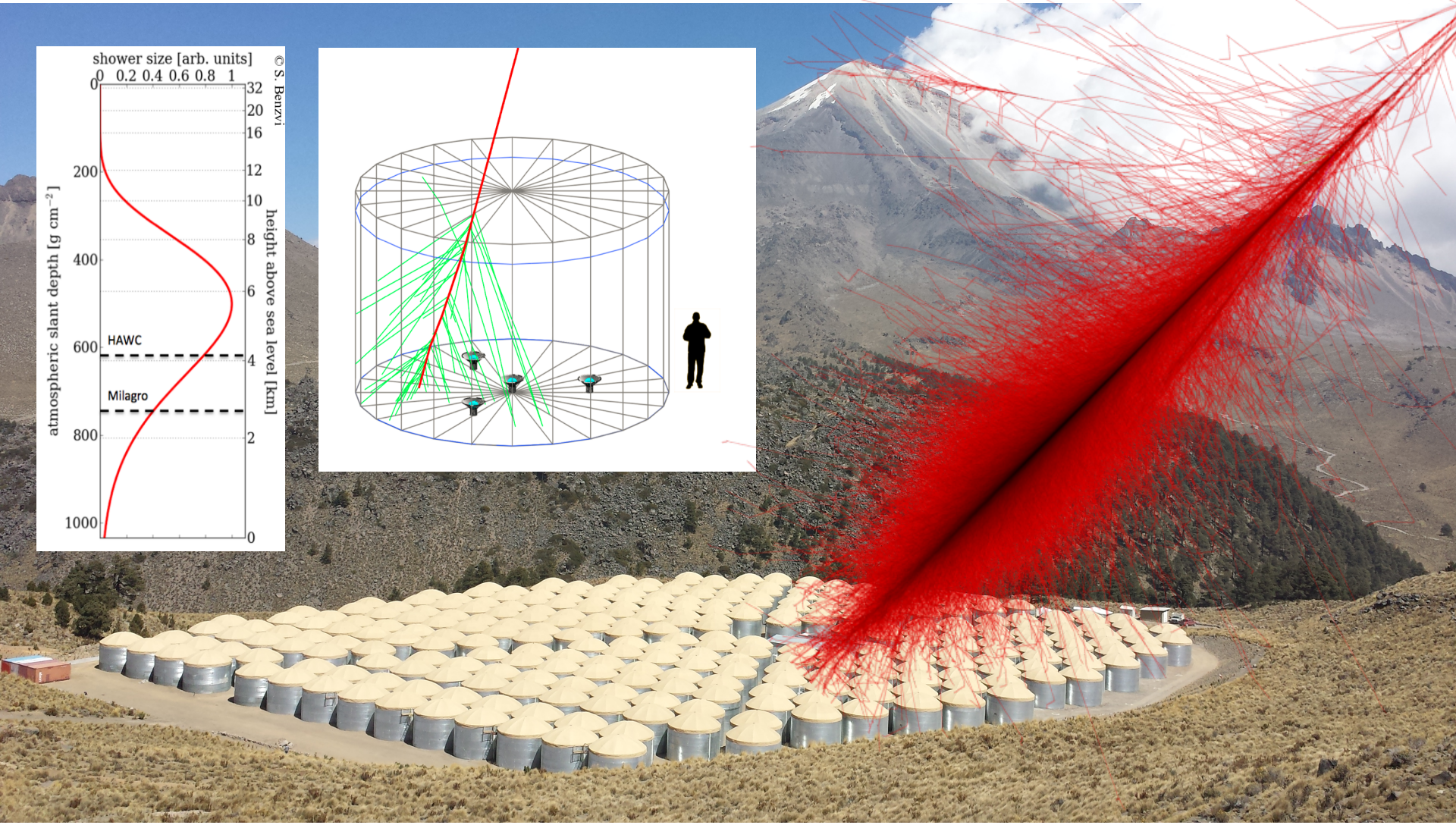


Large
Millimeter
Telescope

HAWC
4100 m

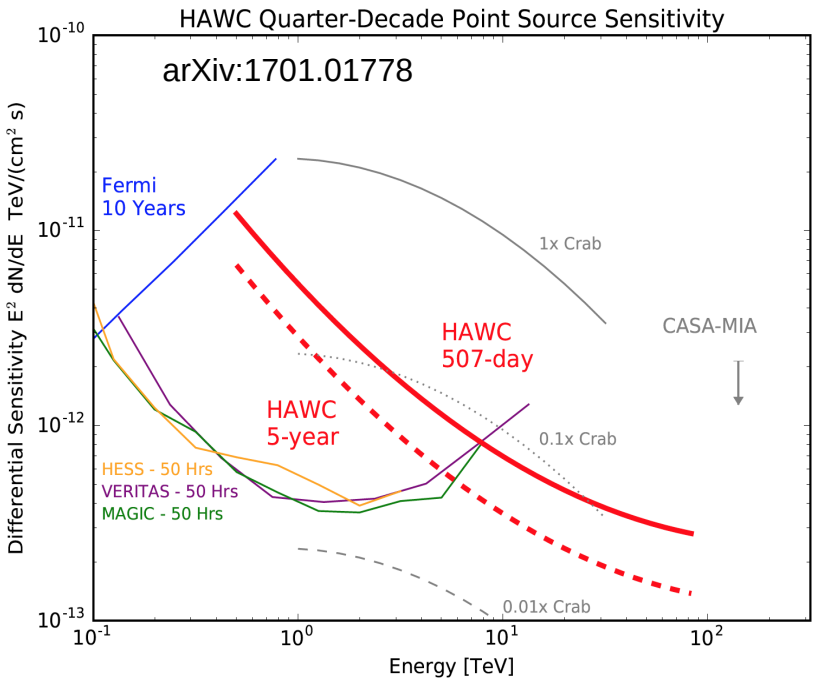
Tliltepetl
Sierra Negra
4582m a.s.l.

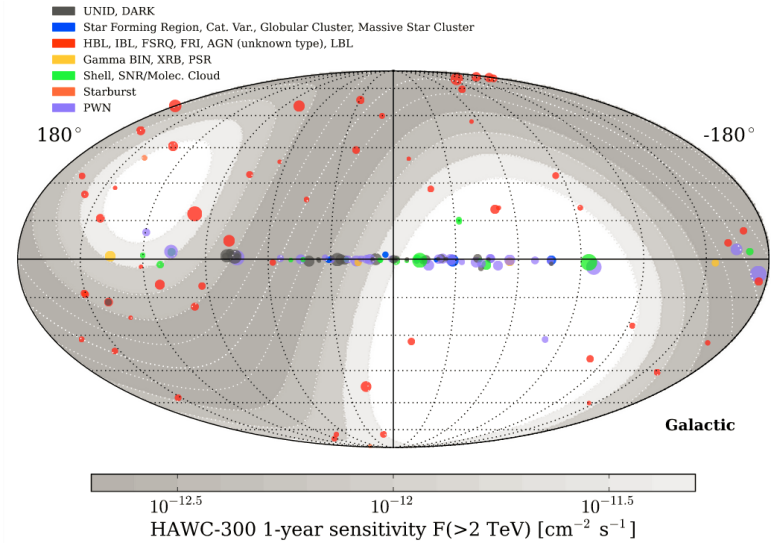
Extensive Air Shower Arrays



HAWC is the most sensitive observatory to the highest-energy gamma rays

- HAWC has ~2.4 sr field of view and observes ~2/3 of the sky each day





- Long integration times give sensitivity to the highest energy gamma rays
- Angular resolution and field of view are similar to Fermi LAT

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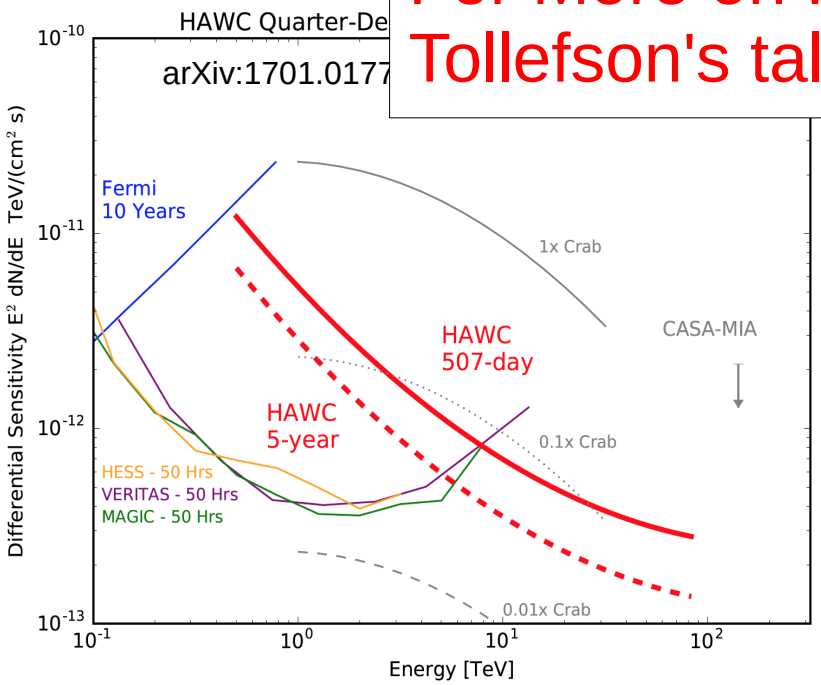
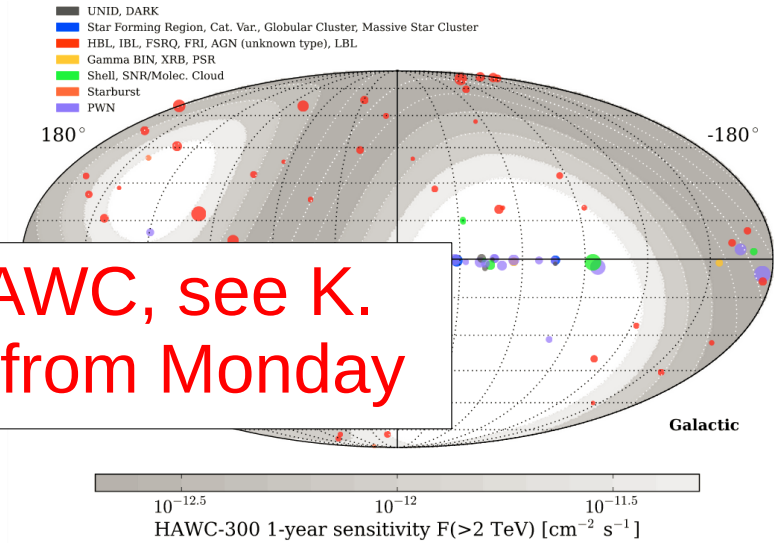
- HAWC has ~2.4 sr field of view and observes ~2/3 of the sky each d

For More on HAWC, see K. Tollefson's talk from Monday





- Long integration times give sensitivity to the highest energy gamma rays
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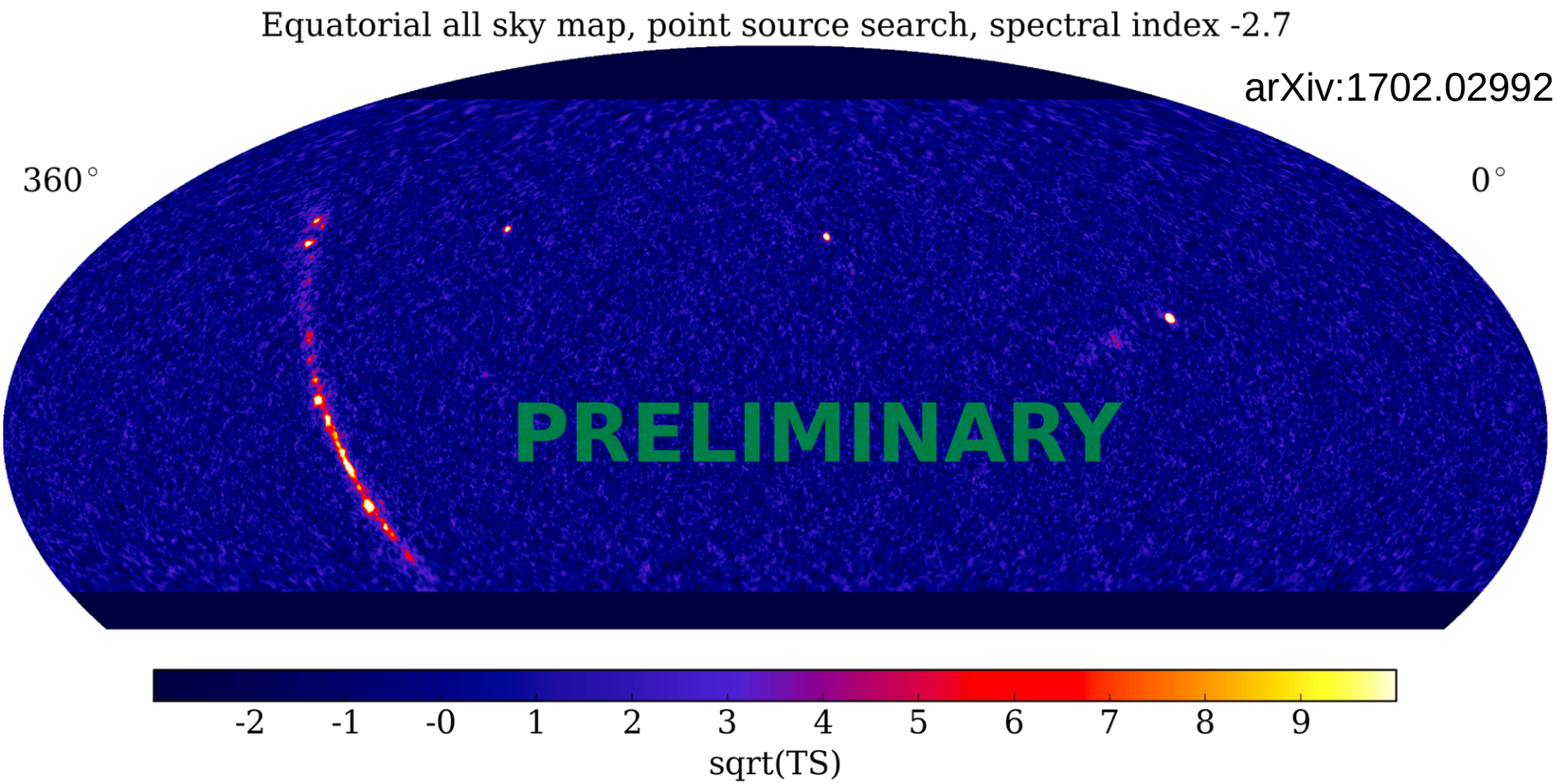
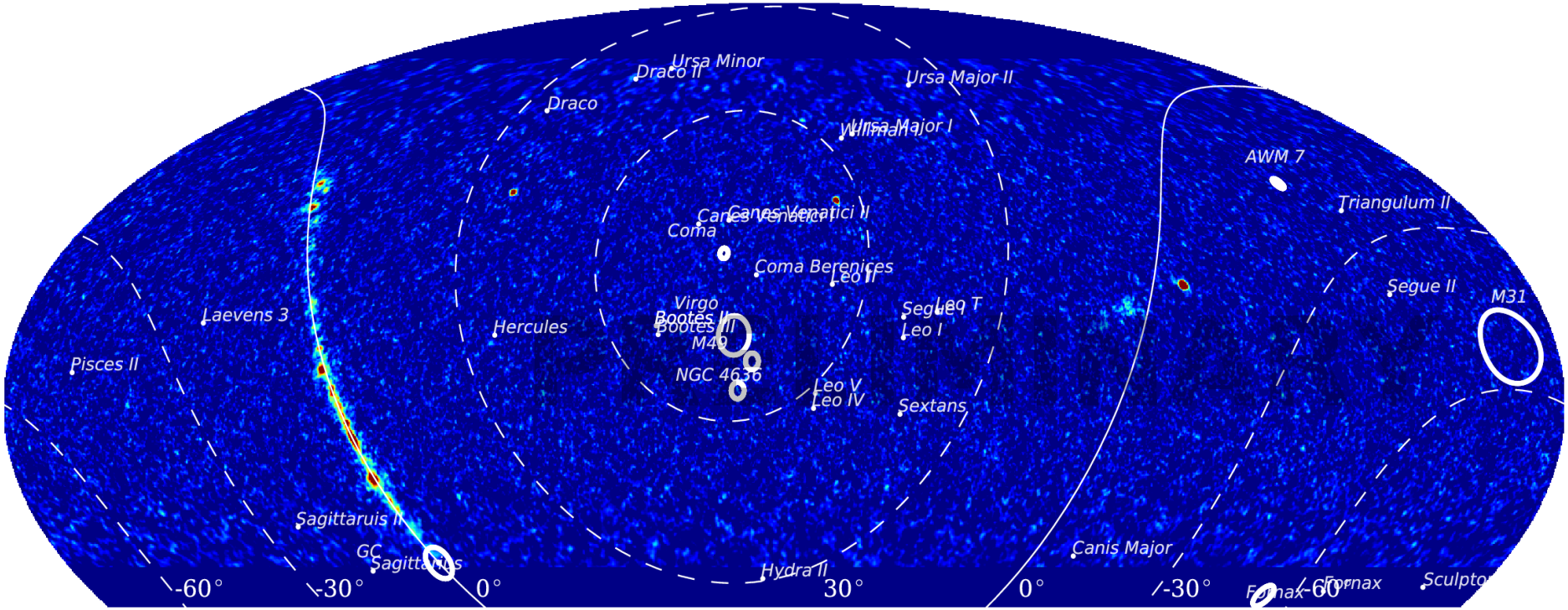
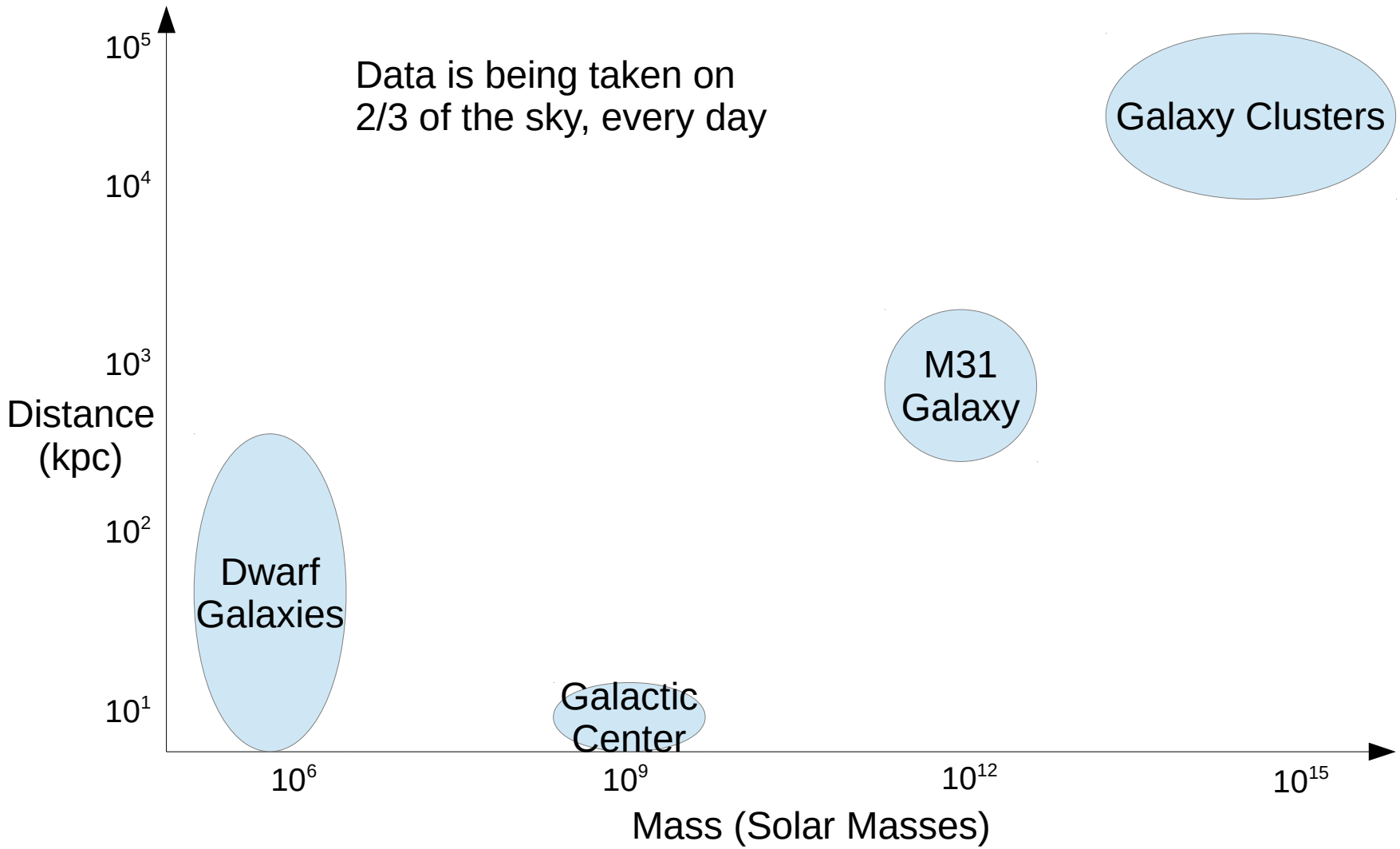
Over 20 Months of HAWC Data



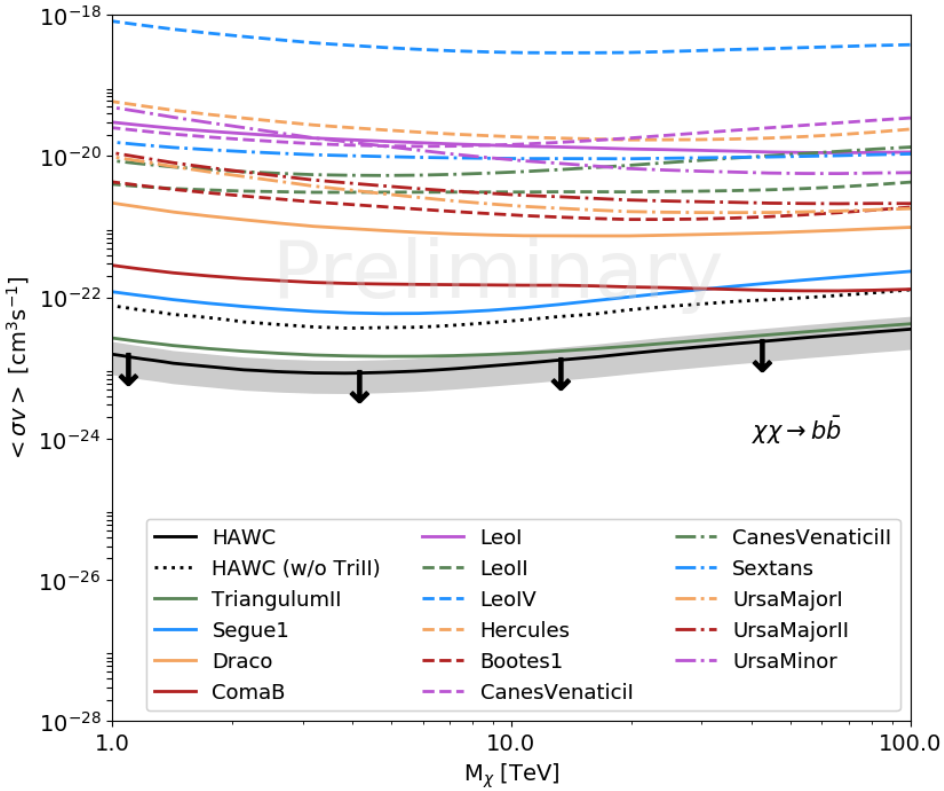
Dark Matter Sources in the HAWC Sky

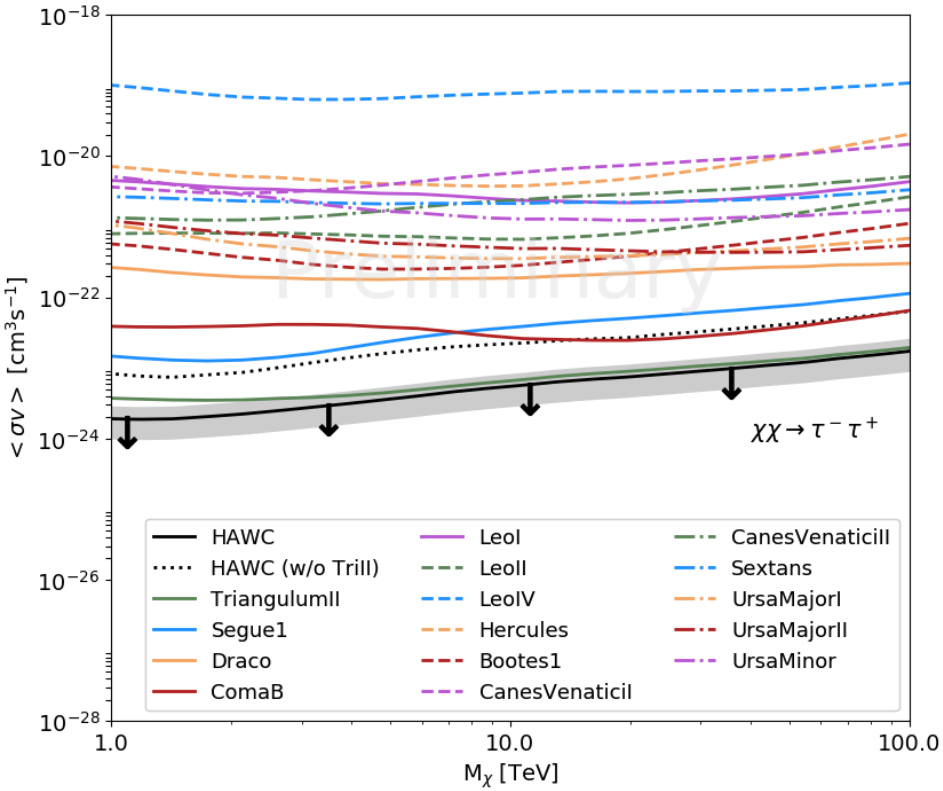


Where HAWC is Looking for Dark Matter



HAWC Dark Matter Annihilation Limits from Dwarf Galaxies





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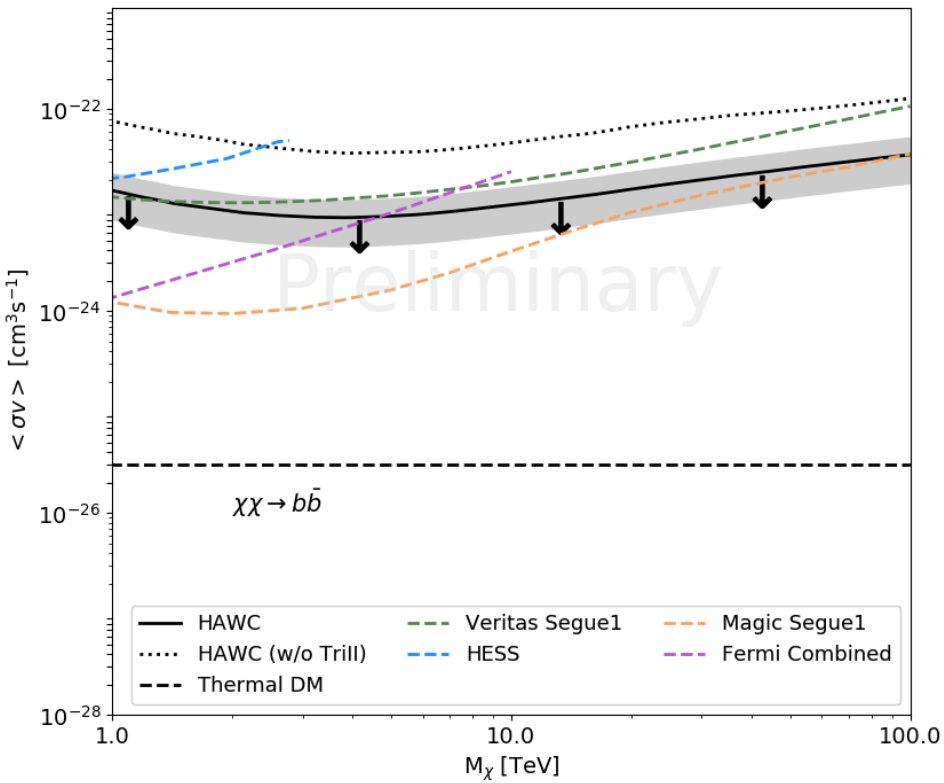
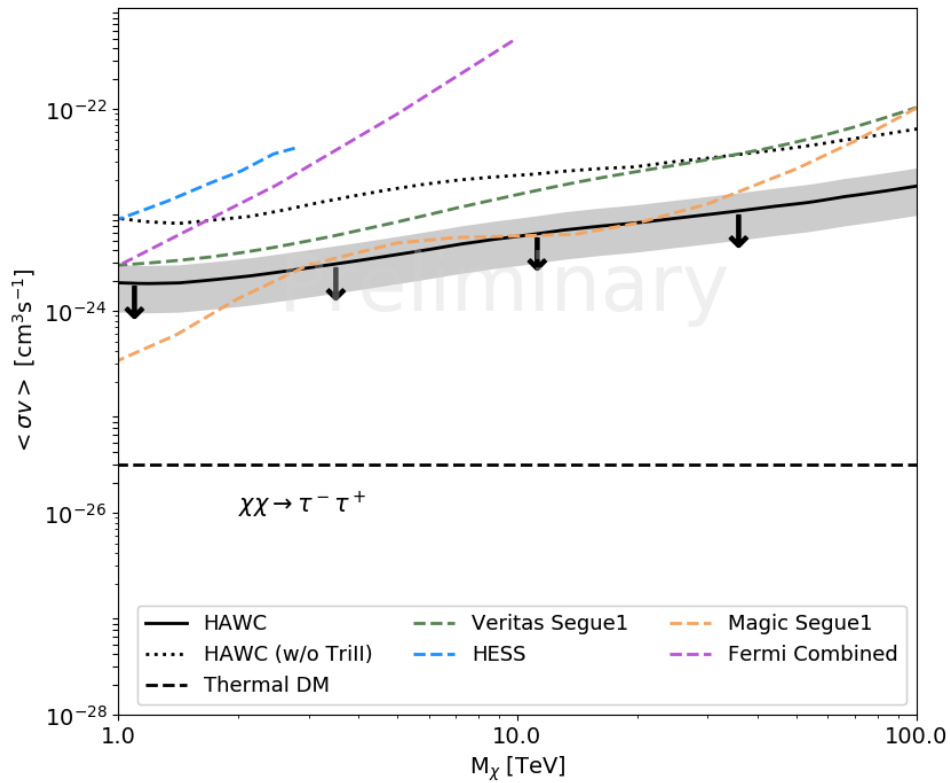
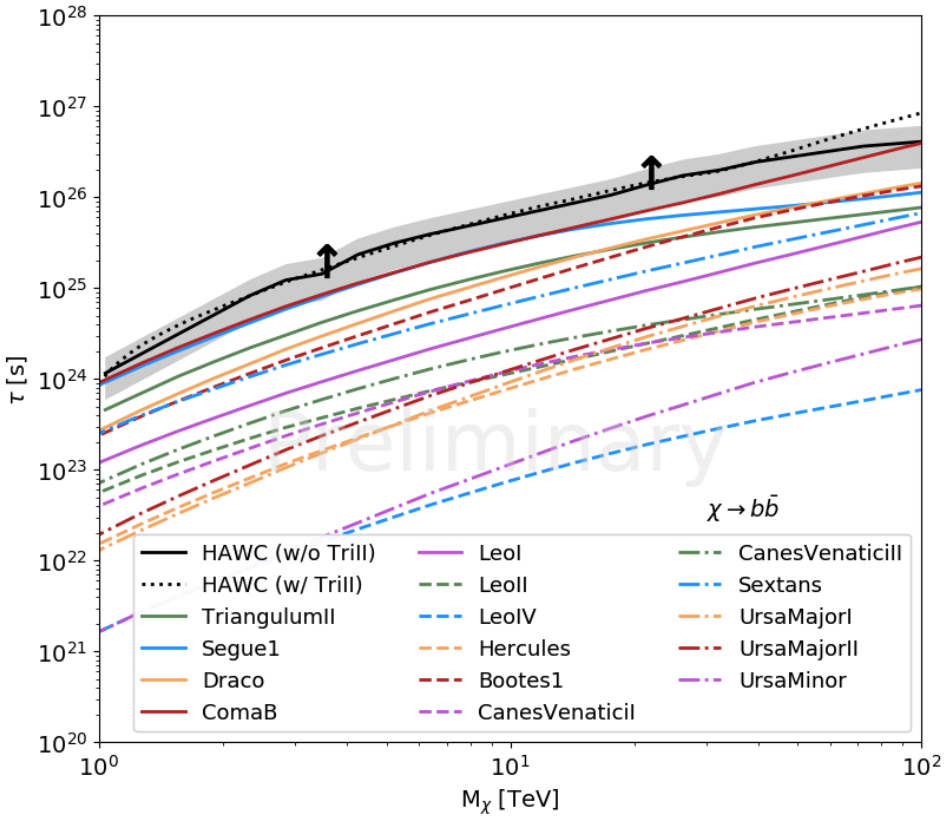
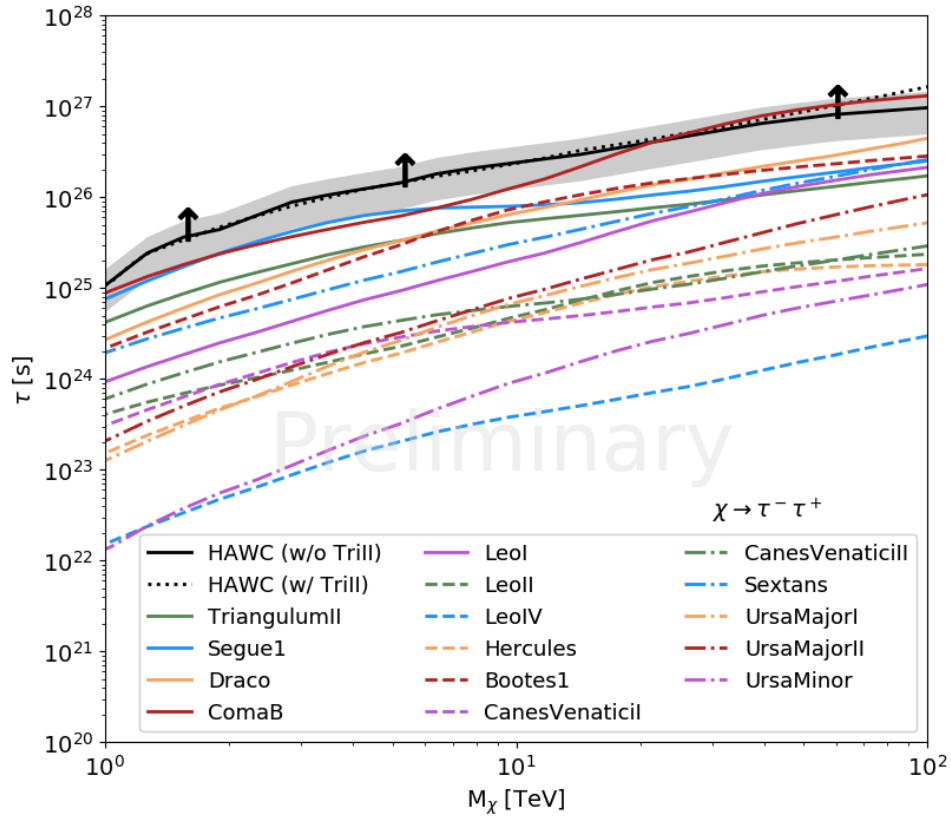




HAWC Dark Matter Decay Limits from Dwarf Galaxies





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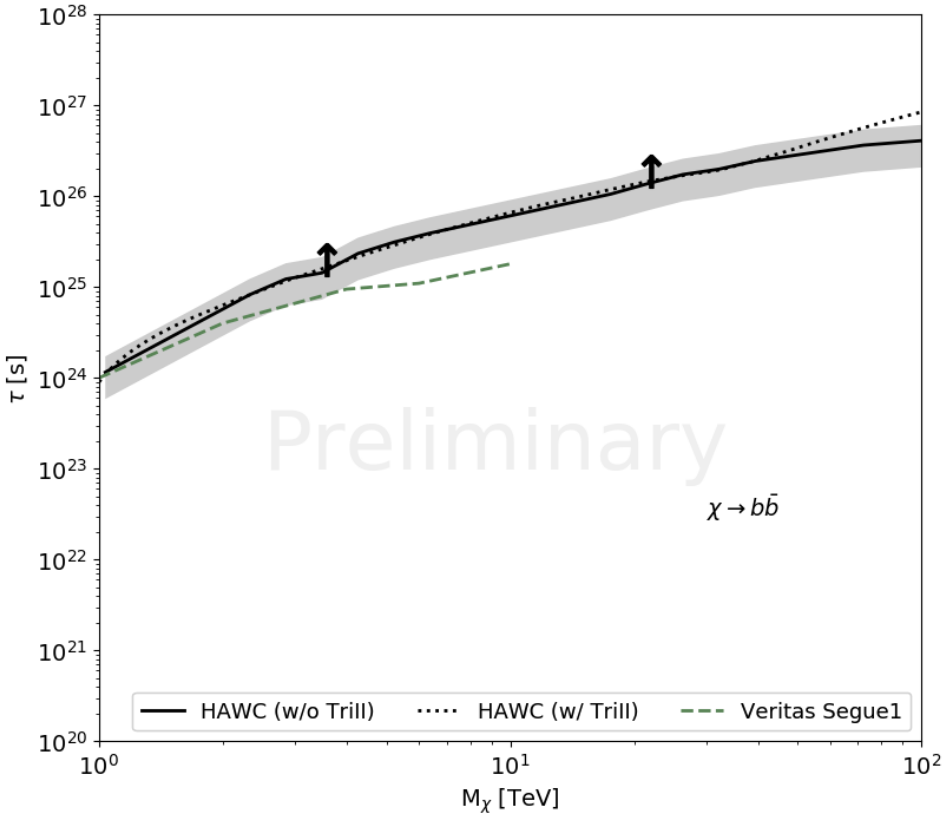
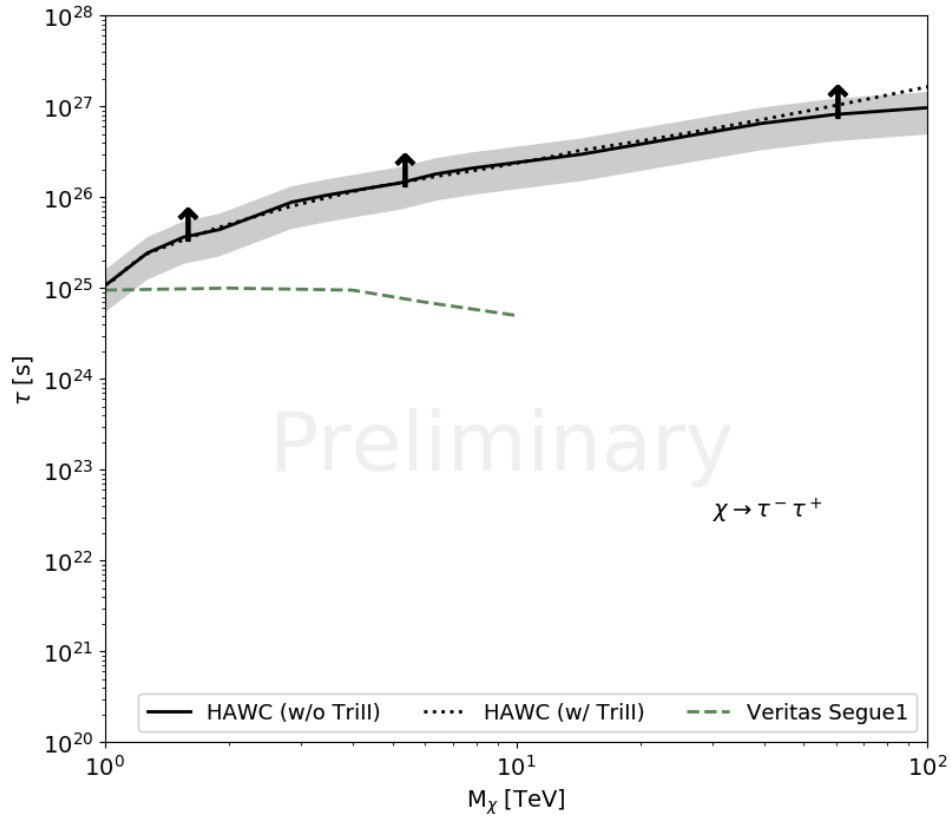
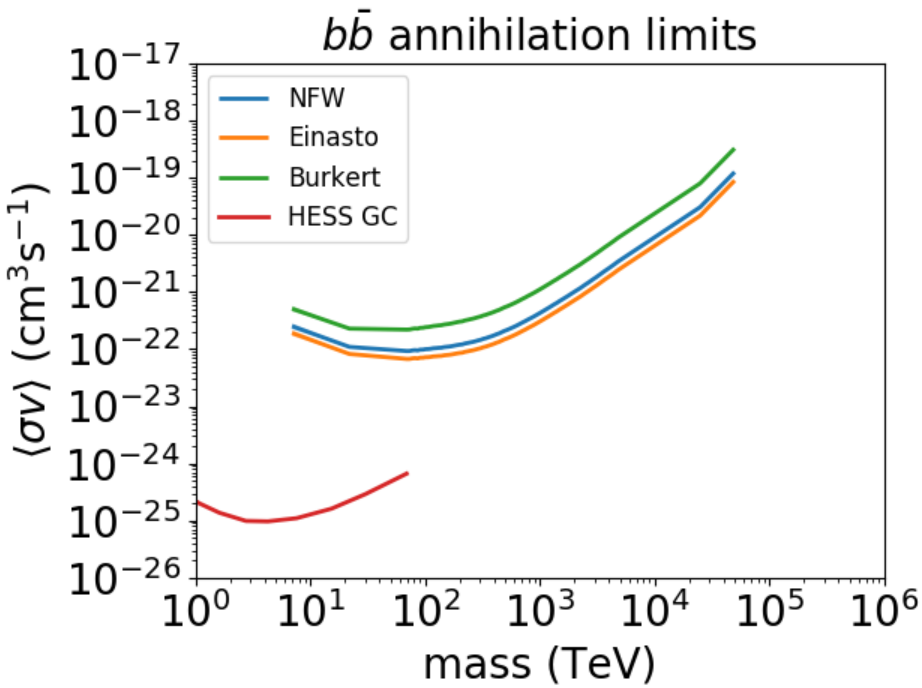
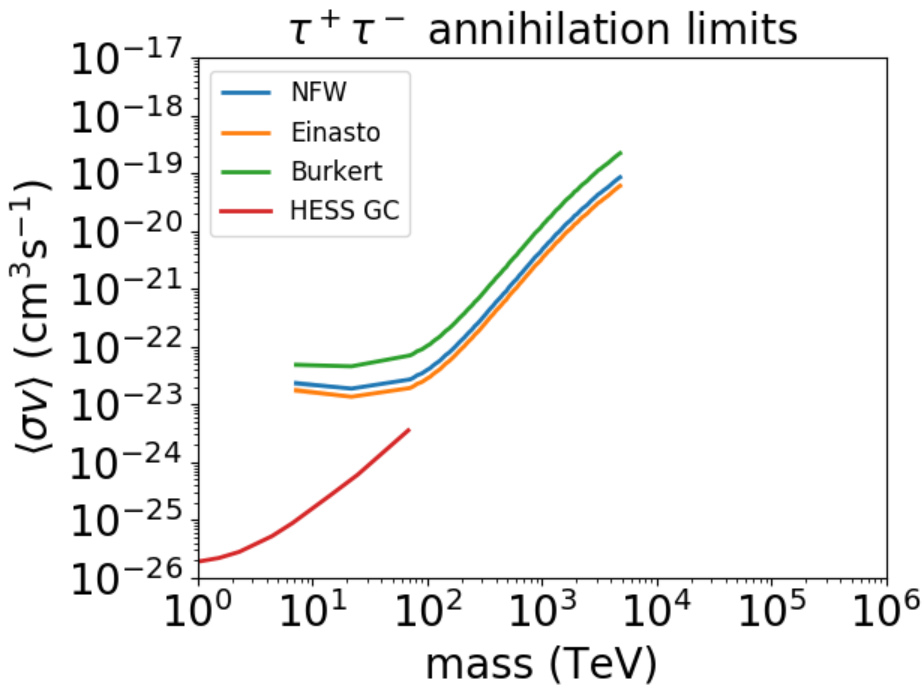




HAWC Dark Matter Annihilation Limits from the Galactic Halo





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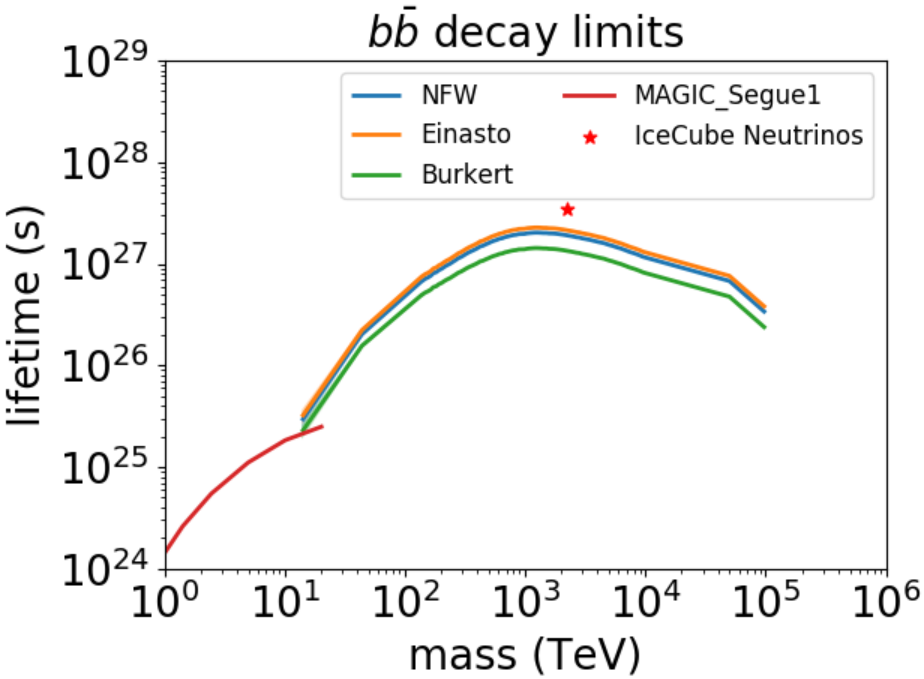
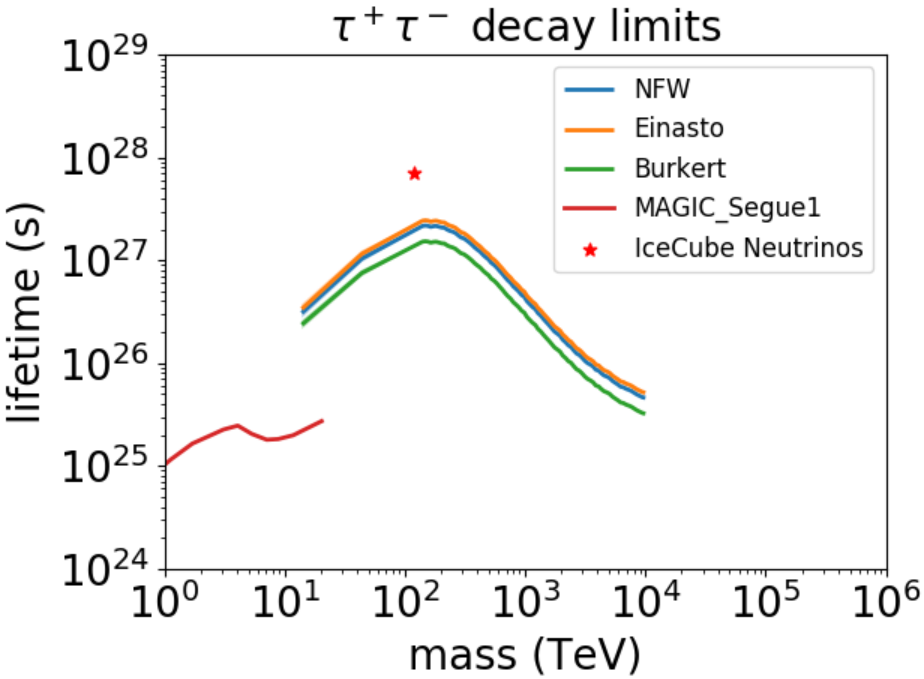
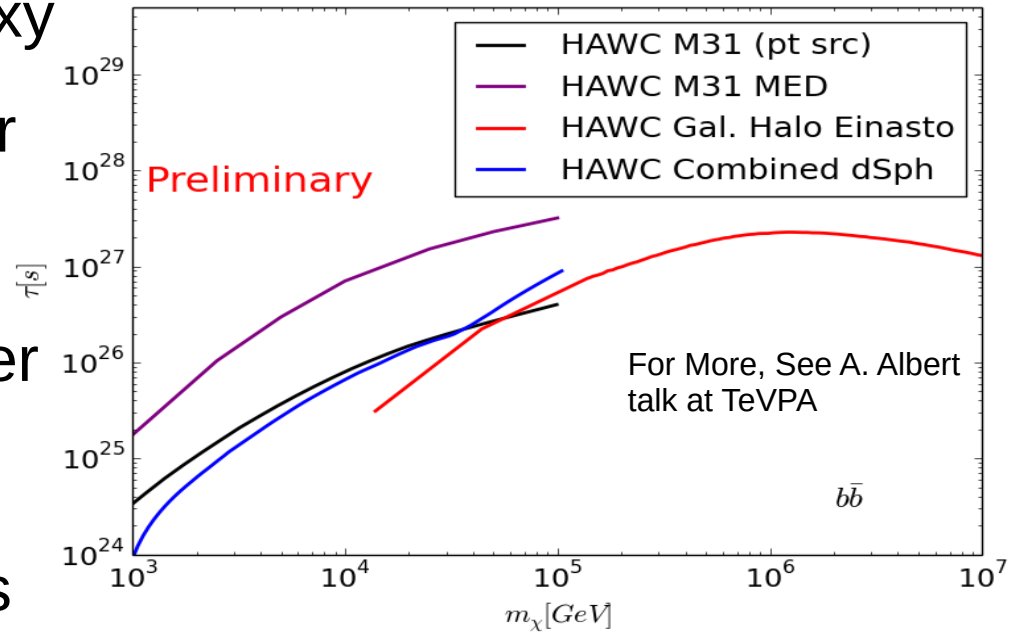




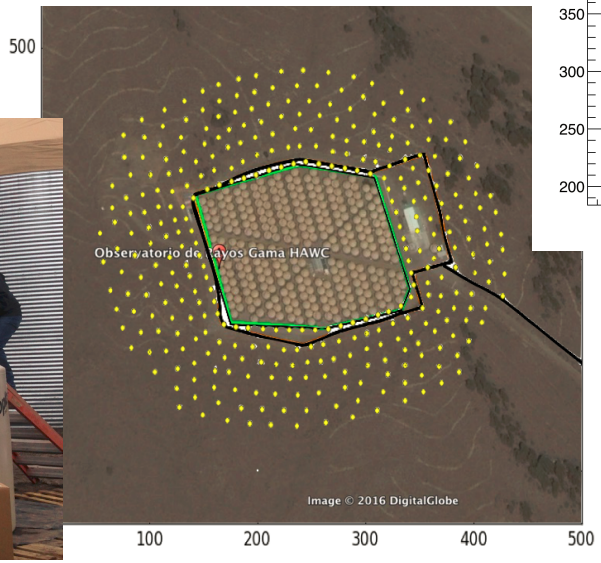
Upcoming Dark Matter Analyses with HAWC

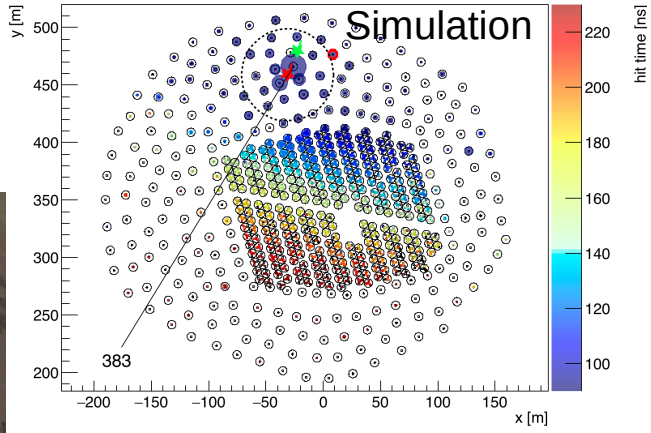
- M31 (Andromeda) Galaxy
  - Nearby, large J-factor
- Virgo Cluster
  - Nearest galaxy cluster
  - Large D-factor
- Dwarf Irregular Galaxies
  - Similar Analysis Method to Dwarf Spheroidal Galaxies
- Stacked Galaxy Clusters
  - Thousands of low-J, low-D sources combine to give strong dark matter search



Looking Forward: HAWC Outriggers

- 350 small WCD outrigger detectors
  - Cover an area 4x HAWC
- Sensitivity increase by 3-4x above 50 TeV
- Deployment in progress



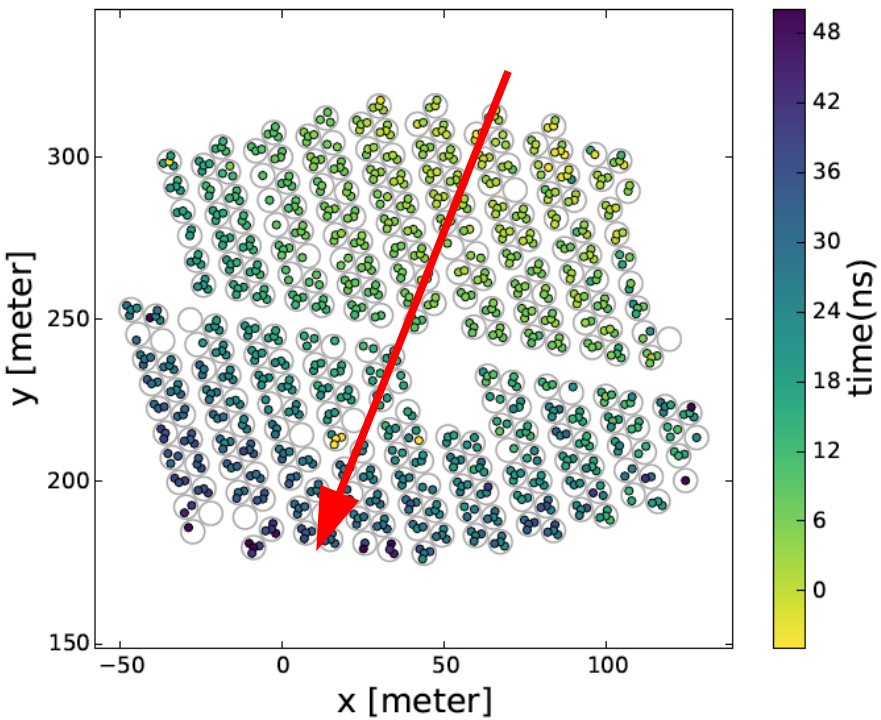


Backups

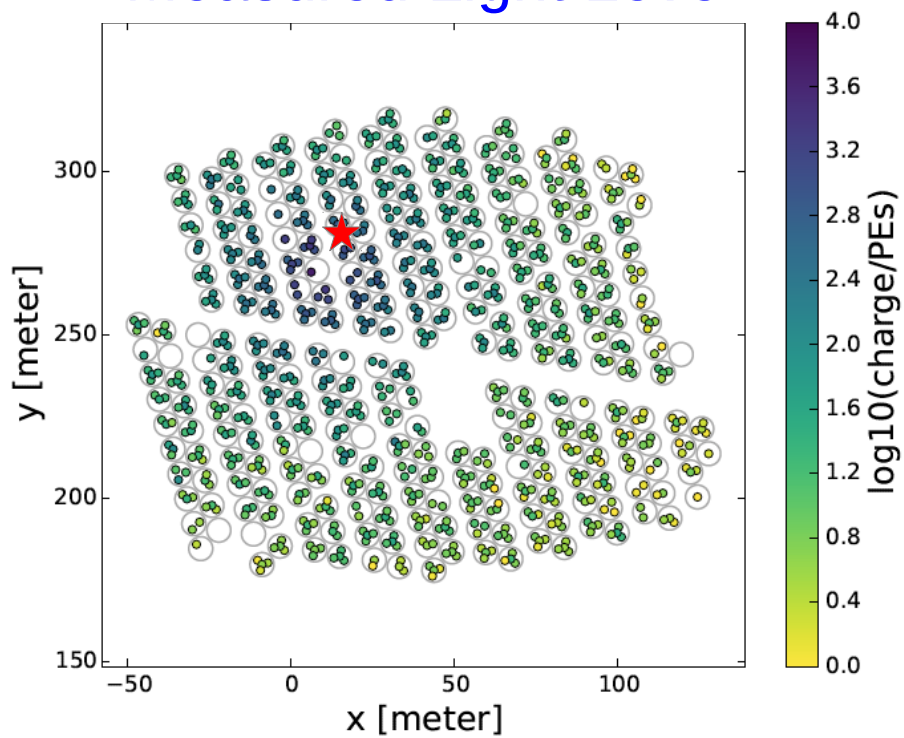
Shower Reconstruction

- Measure: time and light level in each of our detectors
- Estimate: direction, location, energy, and background rejection

Measured Time



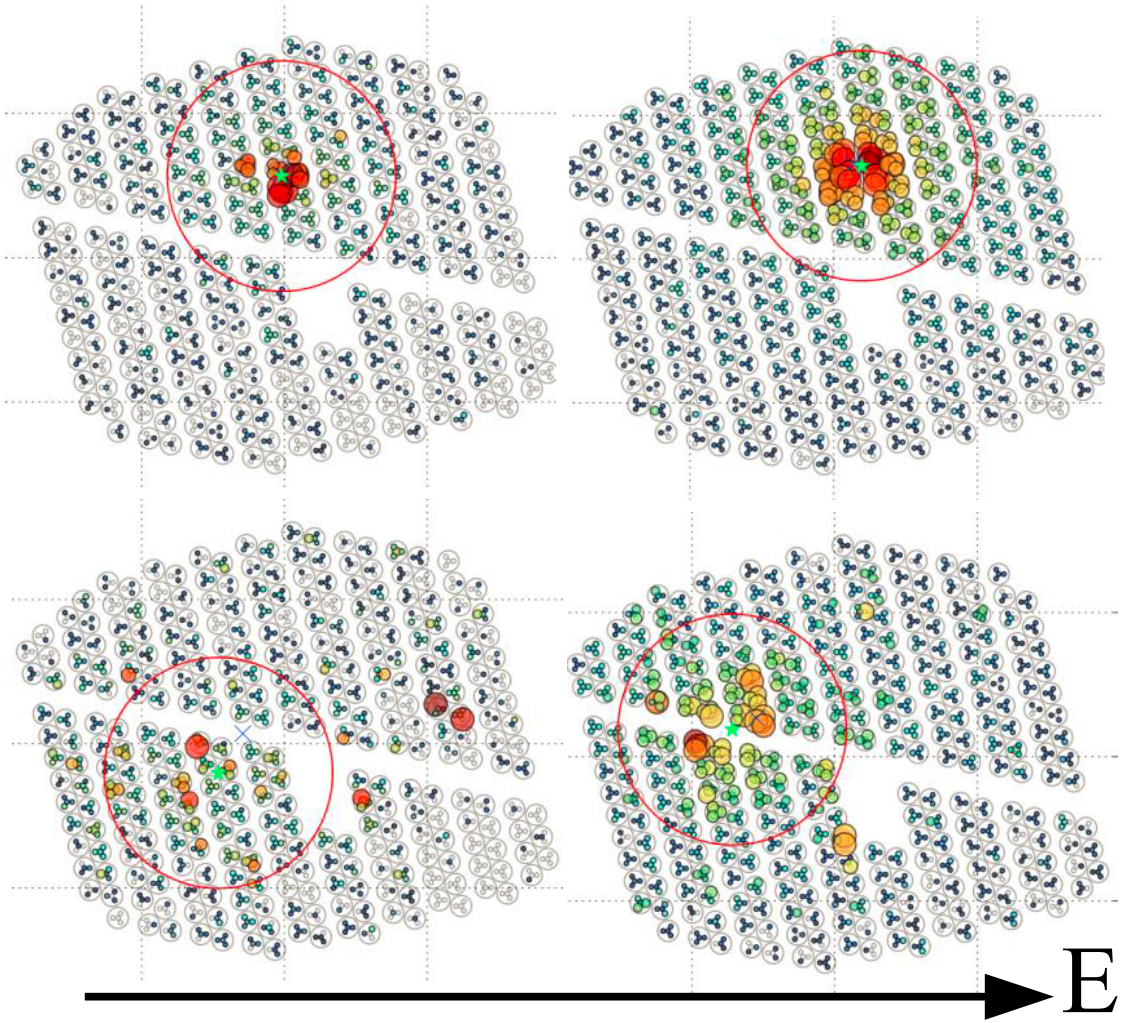
Measured Light Level



Gamma/Hadron Separation

γ ray

Hadron

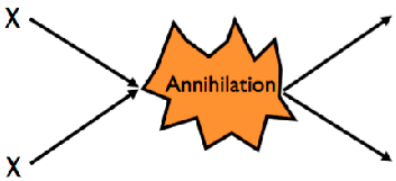


Dark Matter Annihilation and Decay

Particle Physics | Astrophysics

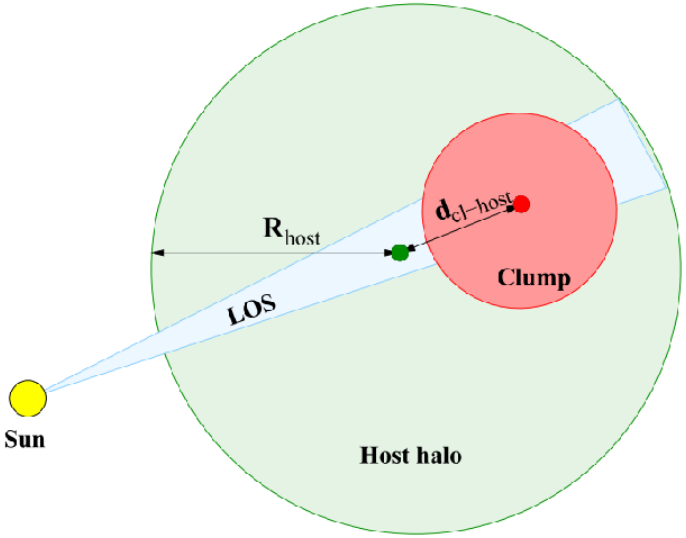
$$\frac{d\phi}{dE}_{annihilation} \propto \frac{<\sigma v>}{M_\chi^2} \frac{dN}{dE} \int d\Omega \int_{l.o.s.} \rho^2 dx$$

$$\frac{d\phi}{dE}_{decay} \propto \frac{1}{\tau M_\chi} \frac{dN}{dE} \int d\Omega \int_{l.o.s.} \rho dx$$



$b, t, W^+, \tau^+, \mu^+, ... \rightarrow e^+, e^-, p, \nu, \gamma$

$\bar{b}, \bar{t}, W^-, \tau^-, \mu^-, ... \rightarrow e^+, e^-, p, \nu, \gamma$



from T. Yapici

J-factors and D-factors

Source	RA (deg)	Dec (deg)	log10[J(θ)] (GeV^{2}cm^{-5}sr)	log10[D(θ)] (GeV^{2}cm^{-2}sr)	θ_{max} (deg)
Bootes 1	210.05	14.49	18.47	18.45	0.47
CanesVenatici I	202.04	33.57	17.62	17.55	0.53
CanesVenatici II	194.29	34.32	17.95	17.69	0.13
Coma Berenices	186.74	23.90	19.32	18.71	0.31
Draco	260.05	57.07	19.37	19.15	1.30
Hercules	247.72	12.75	16.93	16.89	0.28
Leo I	152.11	12.29	17.57	18.05	0.45
Leo II	168.34	22.13	18.11	17.36	0.23
Leo IV	173.21	-0.53	16.37	16.48	0.16
Segue 1	151.75	16.06	19.66	18.64	0.35
Sextans	153.28	-1.59	17.96	18.48	1.70
Triangulum II[10]	33.33	36.18	20.44	18.42	0.12
Ursa Major I	158.72	51.94	19.67	19.04	0.53
Ursa Major II	132.77	63.11	18.66	17.78	0.43
Ursa Minor	227.24	67.24	19.24	18.13	1.37
M31	10.68	41.27	20.86	19.10	-
Virgo Cluster	186.75	12.38	19.50	19.44	-

From different realizations of profile parameters, mean values were calculated. (from Geringer-Sameth et al., 2015 for dSph, Tamm et al., 2012 for M31 and Sanchez-Conde et al., 2014 for Virgo Cluster)
NFW profile was used as Dark Matter density profile.
Sources are considered as point sources. The contribution of substructure is only important at the extent of the source.

from T. Yapici

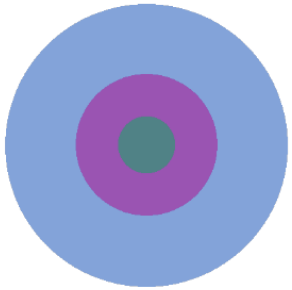
Systematic Uncertainties

HAWC Systematics

- Signal passing rate
- Measured number of photo-electrons (PEs) based on simulations
- Simulated PMT charge and the charge from actual data
- Uncertainty associated with the angular resolution

~50% uncertainty [arxiv:1701.01778]

Astrophysical systematics



outer blue: 1.0° HAWC PSF
inner green: 0.2° HAWC PSF
J(D) factor integration angle: ~0.5° [purple]

J and D factor Integration angles kept constant, but HAWC PSF changes with energy.
Physical constraint by DM profile yields **one sided uncertainty**
42% uncertainty for annihilation cross-section limits
38% uncertainty for decay lifetime limits

from T. Yapici