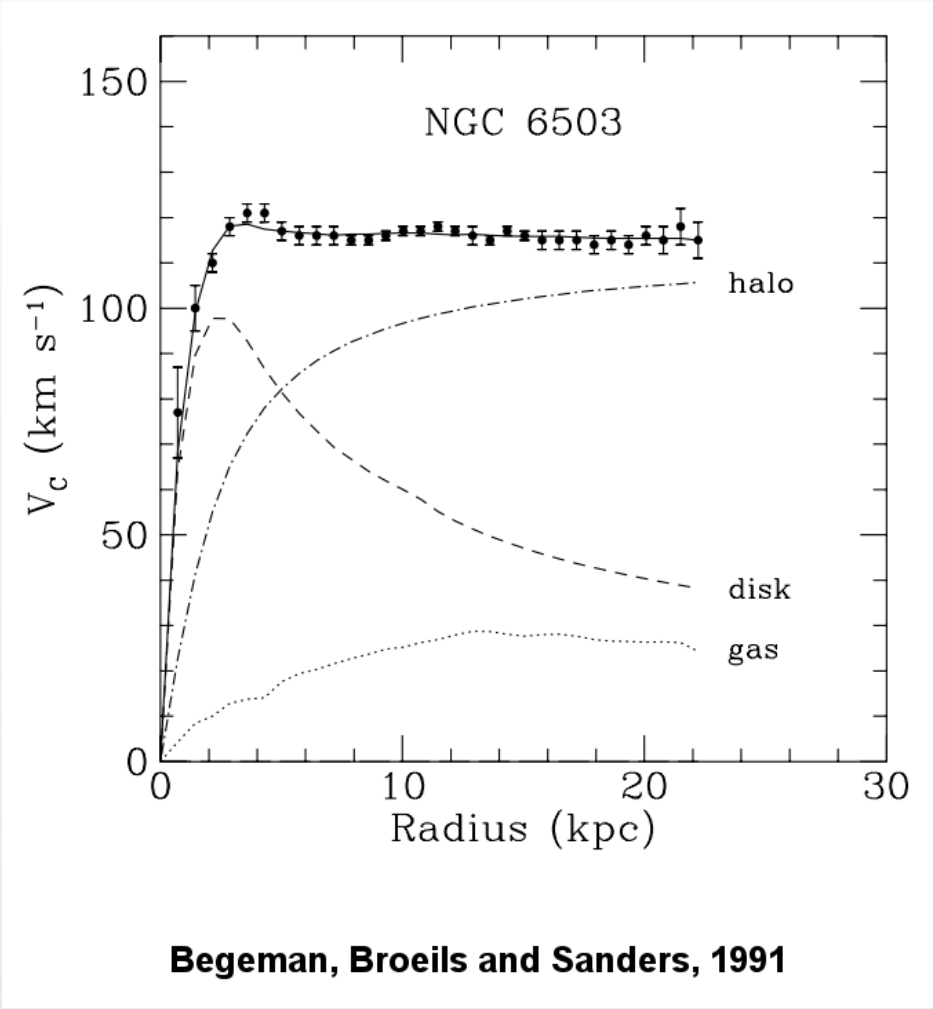
Indirect Dark Matter Search with VERITAS

Ryan Dickherber*
for the VERITAS collaboration

*Washington University in St. Louis
& McDonnell Center for the Space Sciences

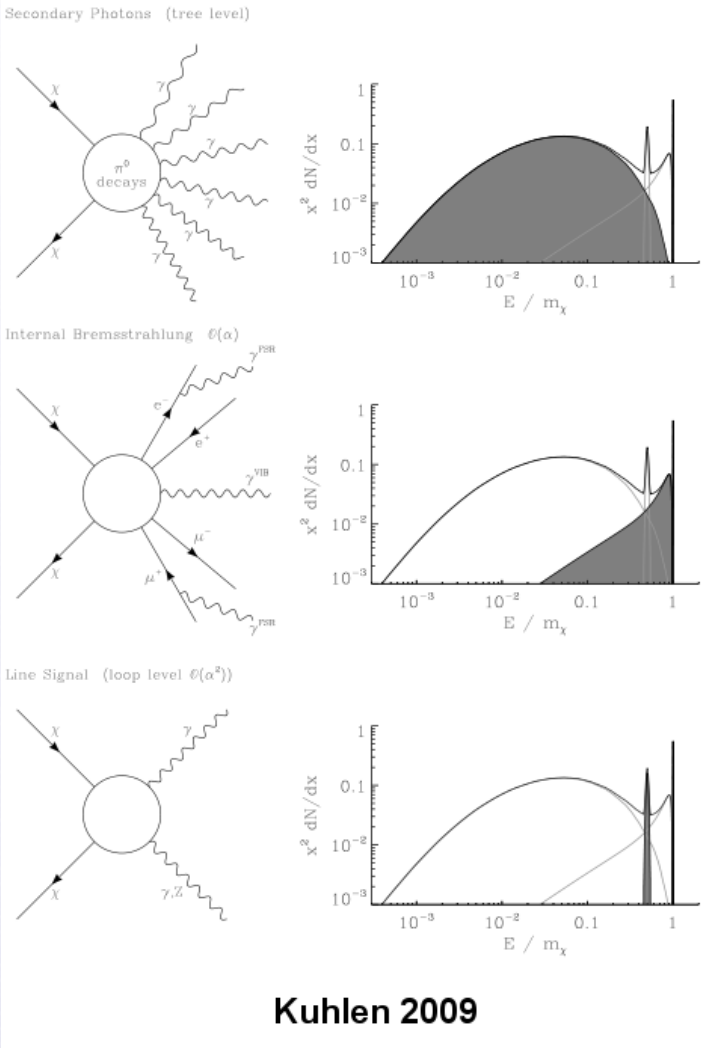
Evidence for Dark Matter



Begeman, Broeils and Sanders, 1991

- Galactic:
  - Rotation Curves
  - Velocity Dispersion
  - Colliding Clusters
- Universal
  - CMB (WMAP)
  - Distribution of Galaxies (SDSS)
- ...and more
- But what is it?

Gamma-Ray Annihilation

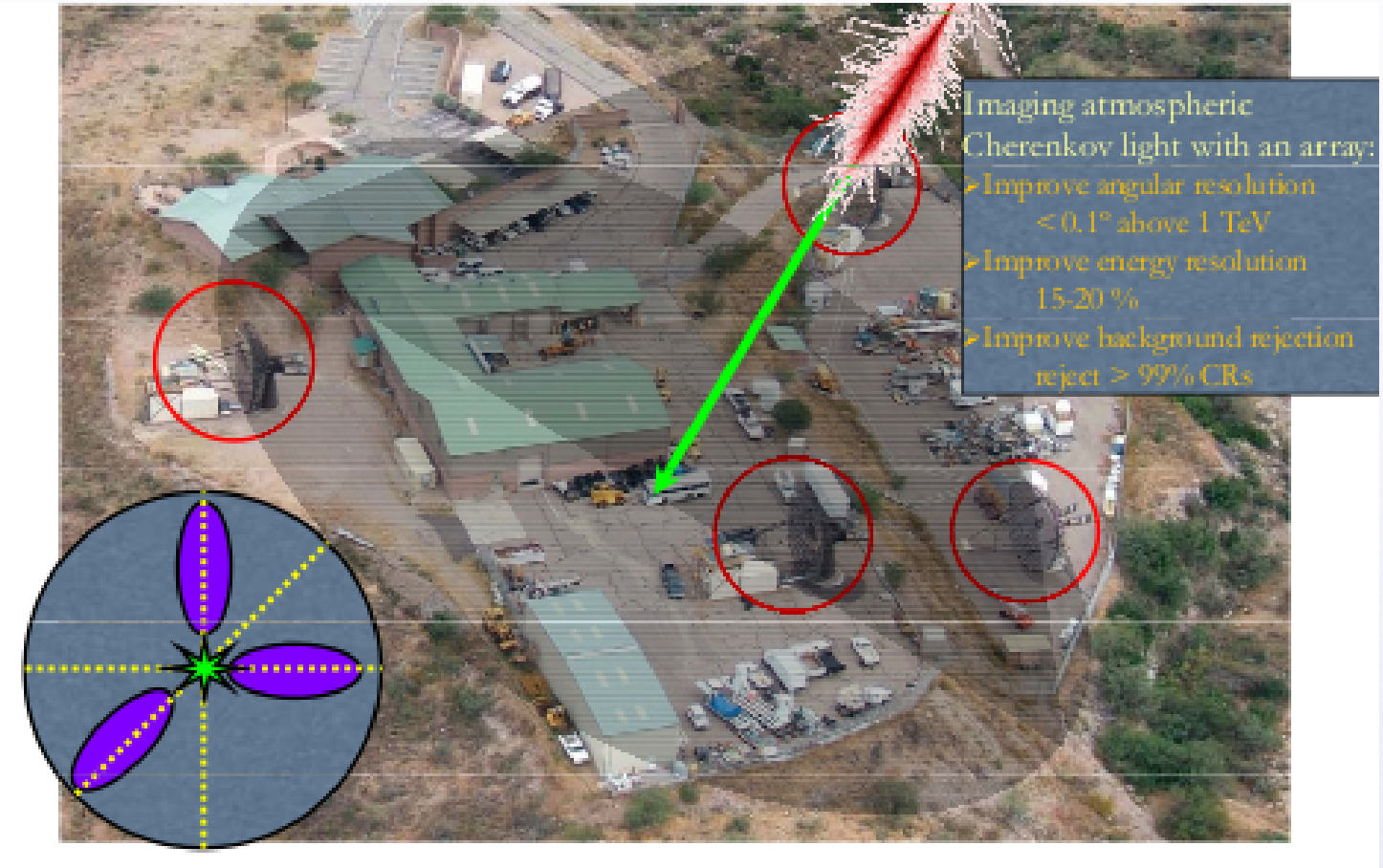


- WIMPs
  - LSP (supersymmetry)
  - LKP (extra dimensions)
- DM+DM->gamma-rays
  - Pions decay
  - Internal bremsstrahlung
  - Line emission
- DM decay -> gamma-rays
- Experiments
  - Fermi (space)
  - HESS
  - MAGIC
  - VERITAS
  - And others

VERITAS

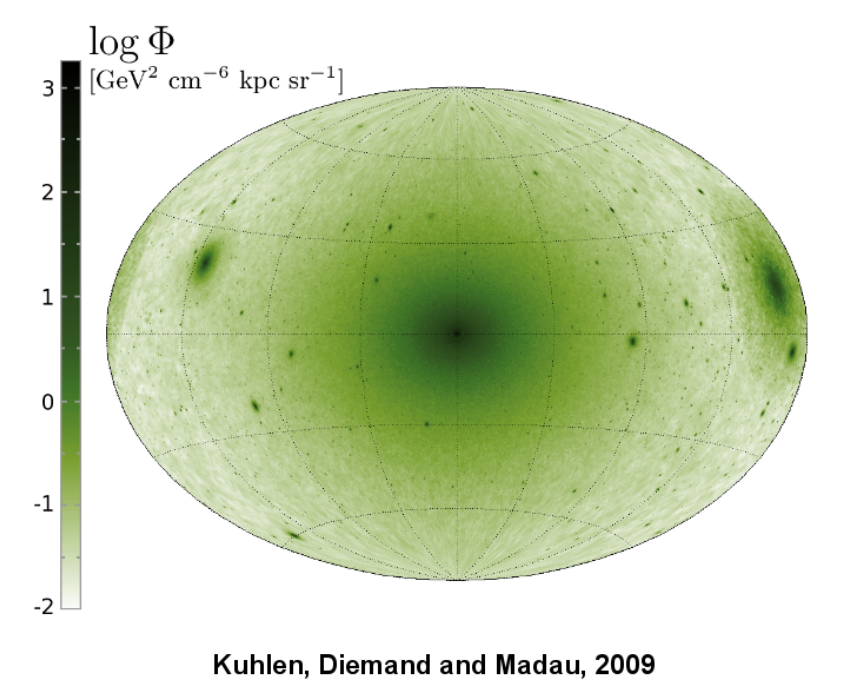
- 4 IACTs see Cherenkov light from gamma-ray (and cosmic-ray) air showers
- Sensitive to ~100GeV-30TeV
  - Energy resolution ~15%
  - Good for neutralinos, e.g., constrained ~50GeV-100TeV
- 3.5° field of view
  - Cannot search the whole sky. What are well-motivated sources?
- Location: Southern Arizona

How VERITAS Works



Graphic taken from Brian Humensky. For more information on VERITAS, see Brian Humensky's excellent talk from yesterday.

Lambda-CDM



Kuhlen, Diemand and Madau, 2009

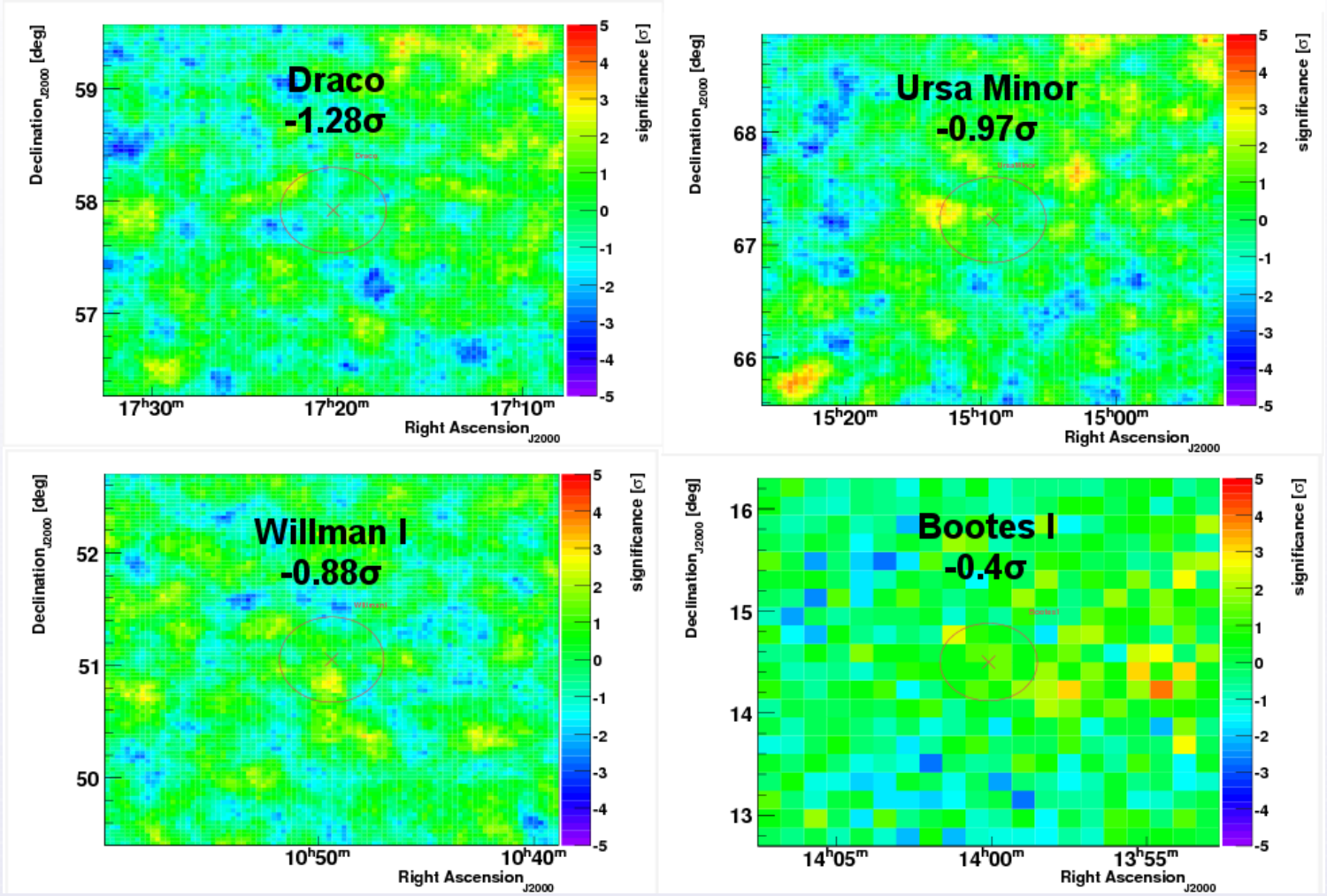
- Hierarchical structure formation
- DM halos have subhalos
- More dwarfs predicted than observed
  - DM-only dwarfs with no visible component?

Target: Dwarf Galaxies

- Dwarf Spheroidals
  - Draco
  - **Ursa Minor ->**
  - Willman I
  - Bootes I
- Motivation
  - High mass/light ~200
    - DM dominated
  - No typical gamma-ray sources
    - Clean DM signal

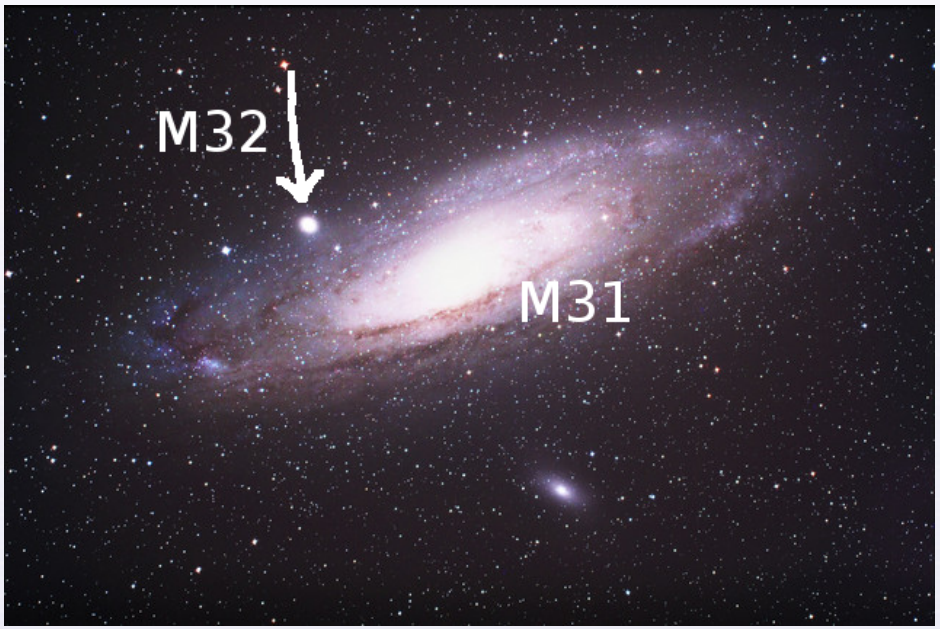
Credit: DSS Image

Observations: Dwarf Galaxies



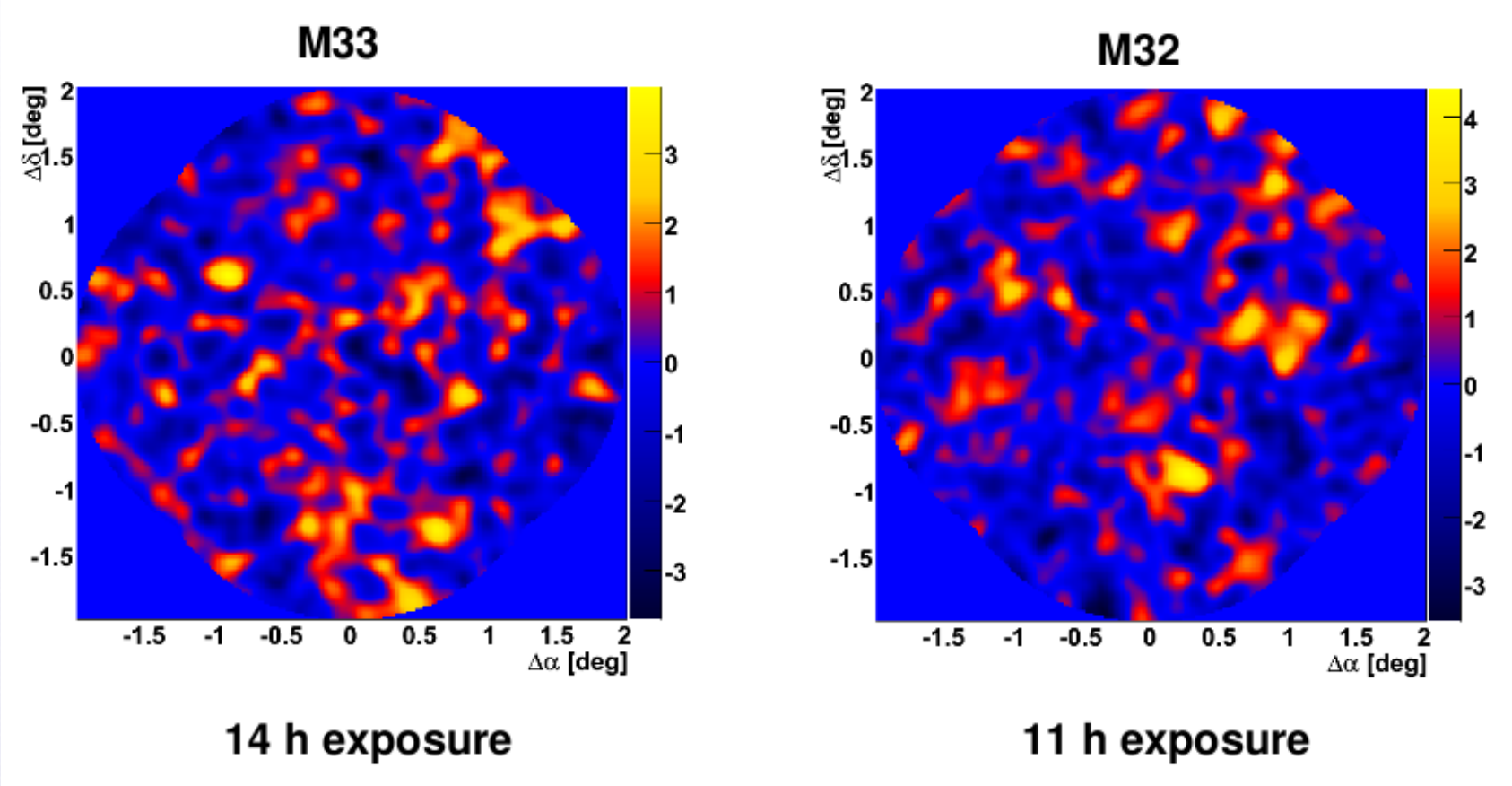
~10-15 hours exposure each

Target: Local Group Galaxies



- M32 and M33
  - High central stellar density may enhance concentration of DM subhalos or increase density of DM
- (not M31)

Observations: Local Group Galaxies



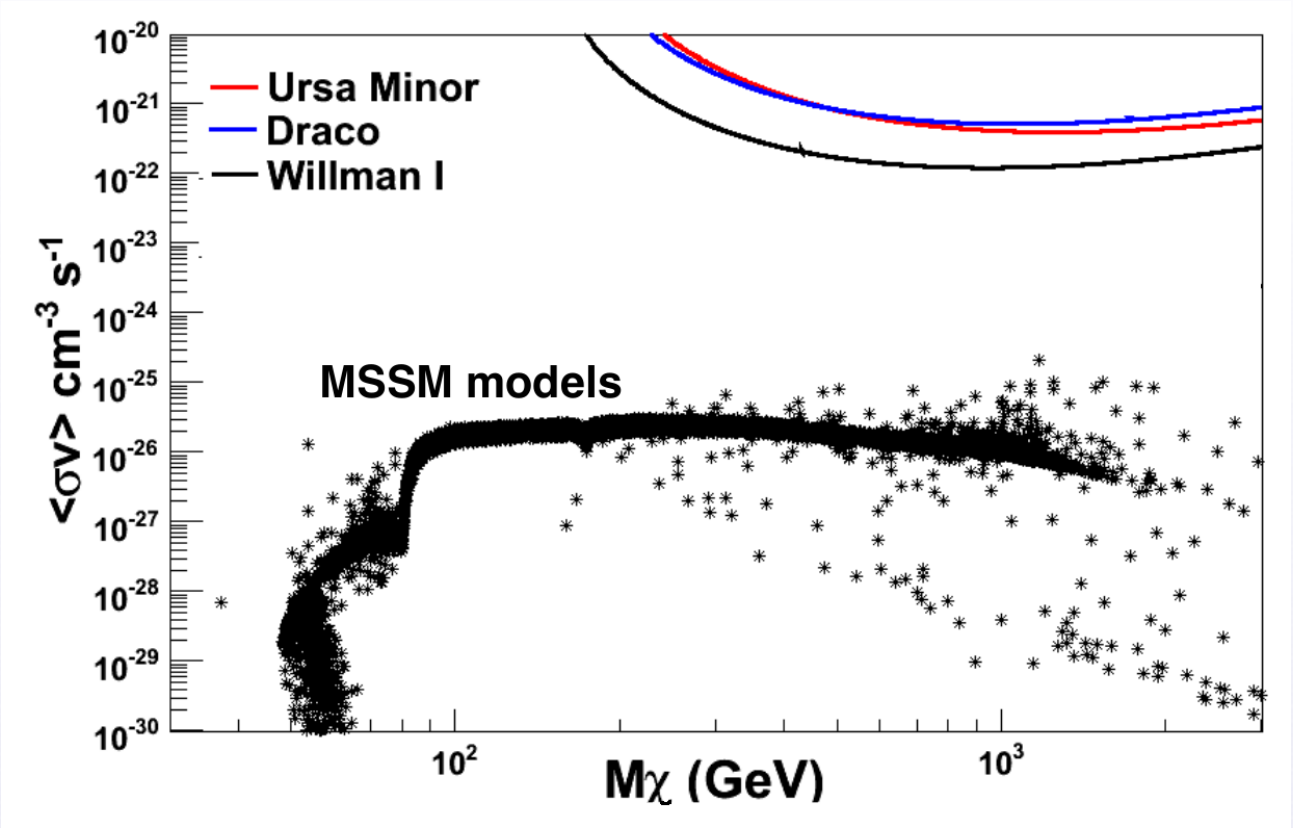
- M33: -0.3σ
- M32: 0.59σ

Gamma-ray Flux Equation

Particle Physics Astrophysics

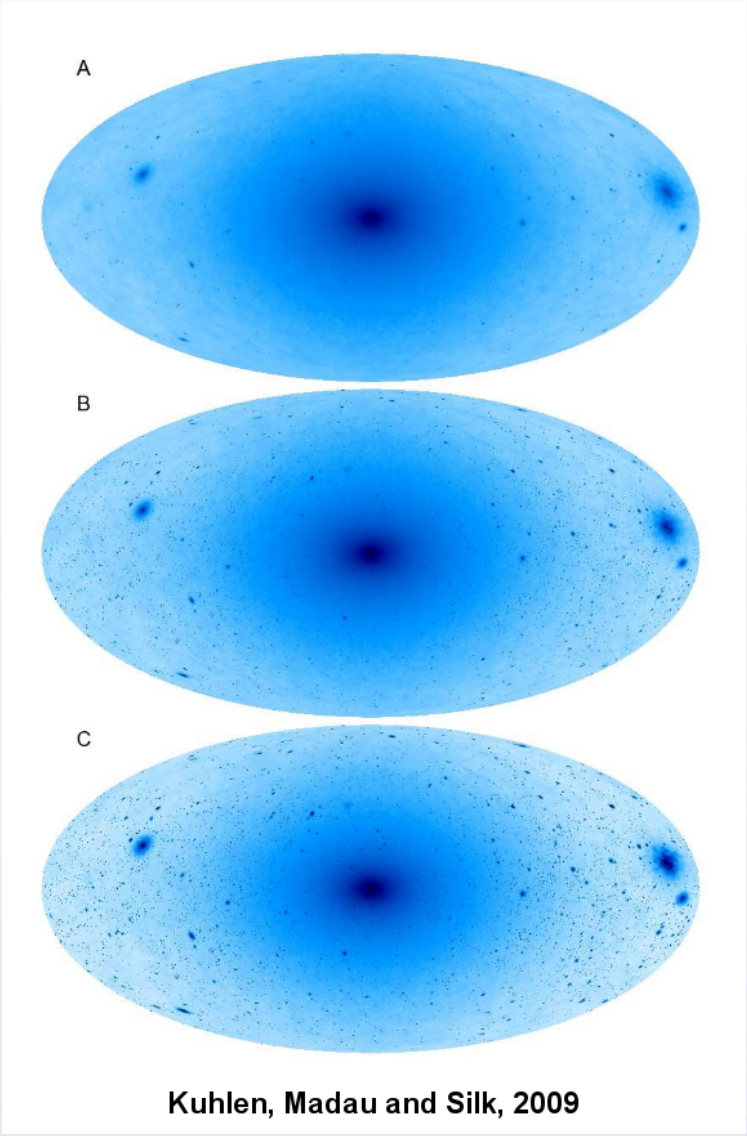
$$\frac{d\phi(E,\vec{\psi},\Delta\Omega)}{dE} = \left[\frac{\langle\sigma v\rangle}{8\pi m_\chi^2}\frac{dN(E,m_\chi)}{dE}\right] J(\vec{\psi},\Delta\Omega)$$

Cross Section Upper Limits



- Given flux and assuming NFW mass profile, solve for cross section
- MSSM models within 3 std deviations from WMAP relic density
- 95% confidence upper limits; ring background model analysis and Rolke zero-bounded profile likelihood

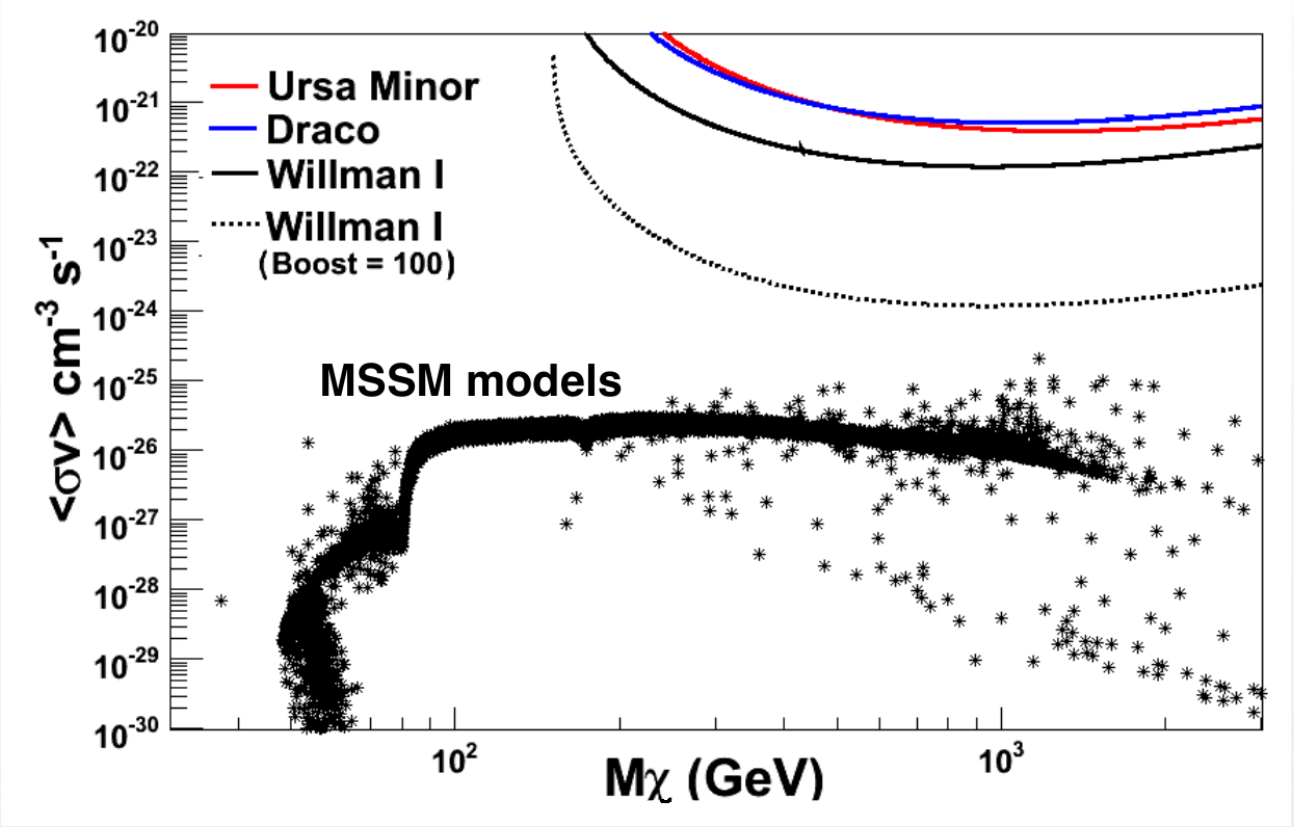
Boosts



Kuhlen, Madau and Silk, 2009

- Substructure
  - Flux goes as ρ^2
  - boost=amount over NFW flux
  - N-body sims: boost minimum of ~3
  - Boost could be ~100
- Sommerfeld Enhancement
  - DM particles go ~270km/s; not relativistic
  - Slow moving particles suffer Sommerfeld Enhancement
  - Goes as $1/v^2$

Upper Limits with Boost



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Conclusion

- Gamma-ray observations are the most direct technique to map the distribution of dark matter in the sky
- Gamma-ray observations cover regions of parameter space uncovered by other techniques
- Status of VERITAS search for dark matter:
  - Upper limits placed on several well-motivated sources
  - Search will continue with more sources and longer observations
  - Follow-up on Fermi unidentified sources?
  - Annulus around galactic center?
- Next-generation gamma-ray experiments will dig deeper into parameter space