

# SUSY DARK MATTER AND QUINTESSENCE

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Based on

- SP and Piero Ullio, JCAP 11(2003)006 and *work in progress*
- SP and Carlos E. Yaguna, hep-ph/0402208 and *work in progress*

# WHY, AND HOW MUCH, *DARK MATTER* ?

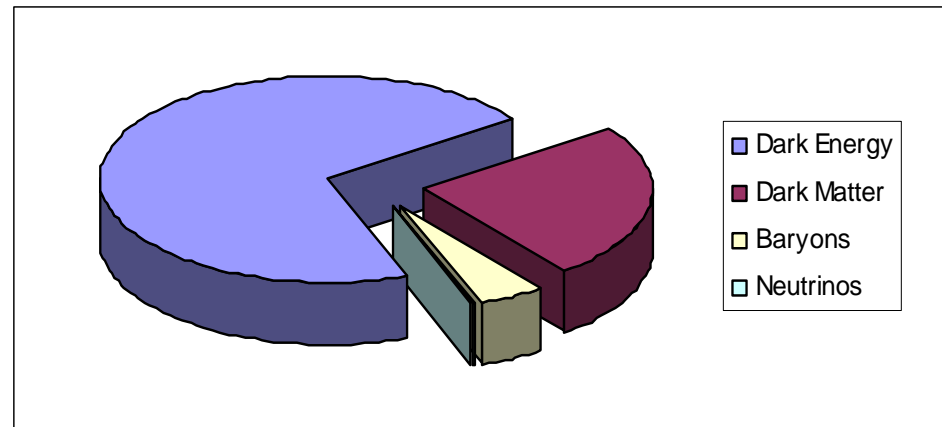
## EVIDENCES

- DYNAMICAL AND PHYSICAL OBSERVATIONS
- COSMOLOGICAL (CROSSED) OBSERVATIONS
- STRUCTURE FORMATION

**WMAP** (CMB + Sn Ia + Lyman Alpha) → **Energy Density Budget of the Universe**

$$0.09 < \Omega_{CDM} h^2 < 0.13$$

$$\left[ \begin{array}{ll} \dots \text{before 2003} & 0.1 < \Omega_{CDM} h^2 < 0.3 \\ \dots \text{before 1998} & \Omega_{CDM} h^2 < 0.7 \end{array} \right]$$



**CDM** → *Evidence for Particle Physics Beyond the Standard Model !*

# WHY SUPERSYMMETRIC DARK MATTER ?

**IS SUSY SO ATTRACTIVE?**

- Hierarchy problem
- Gauge Coupling Unification
- Radiative EWSB
- Needed by Superstrings and SUGRA
- Provides Ideal CDM candidates

**SUSY DM CANDIDATES**

MSSM

**Neutralino**

$$\chi_i = \underbrace{\alpha_{i1} B^0}_{\text{Bino}} + \underbrace{\alpha_{i2} W^0}_{\text{Wino}} + \underbrace{\alpha_{i3} H_u^0 + \alpha_{i4} H_d^0}_{\text{Higgsino}}$$

ext-MSSM

**Gravitino, Axino, Sneutrino (?)**

$$\Omega_\chi h^2 \approx \frac{3 \times 10^{-27} \text{ cm}^3 \cdot \text{s}^{-1}}{\langle \sigma_{\text{ann}} v \rangle_{T_{f.o.}}}$$

...for WIMPs

$$\langle \sigma_{\text{ann}} v \rangle \approx 10^{-26} \text{ cm}^3 \cdot \text{s}^{-1}$$

...for NEUTRALINOs

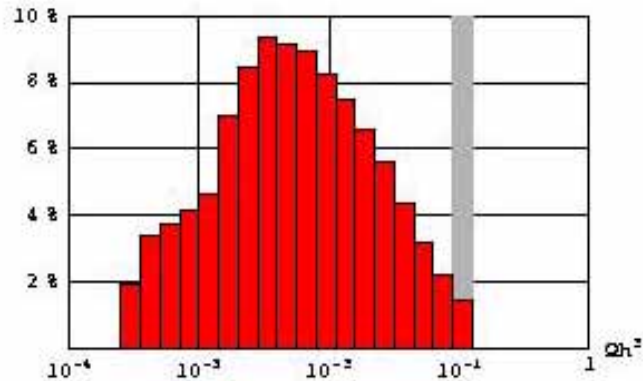
# NEUTRALINO DARK MATTER

- $\Omega_\chi h^2$  depends on
- **Neutralino Mass**
  - **Neutralino Composition** ( $B, W$  and  $H$  fractions)
  - **SUSY Spectrum** *Relic Density Suppression Mechanisms (Co-Annihilations, Resonances)*

- BINOS**
- ✓ *Low* Annihilation Rates  $\rightarrow$  Large  $\Omega_\chi h^2$
  - ✓ Need for Relic Density **SUPPRESSION**
  - ✓ *Low* Detection Rates

- WINOS, HIGGSINOS**
- ✓ *Large* Annihilation Rates  $\rightarrow$  Low  $\Omega_\chi h^2$
  - ✓ Need for Relic Density **ENHANCEMENT**
  - ✓ *Large* Detection Rates

# LOW RELIC DENSITY MODELS



MSSM scan for SUSY masses  $50 \text{ GeV} < m < 5 \text{ TeV}$

Light Higgsinos & Winos *underproduce* DM!

Boltzmann Equation: 
$$\frac{dn}{dt} = -3Hn - \langle \sigma_{\text{eff}} v \rangle (n^2 - n_{\text{eq}}^2)$$

**Freeze-out** (=decoupling) **condition:**

$$n \langle \sigma_{\text{eff}} v \rangle \approx H$$

We accurately know  $H(T)$  for  $T < T_{\text{BBN}} \approx 1 \text{ MeV}$

...but **freeze-out** takes place at  $T_{\text{f.o.}} \approx m_\chi / 20 \approx 10 \text{ GeV}$

$$n_{\text{eq}} \propto \exp(-m/T)$$

**Raise  $H(T)$   $\longrightarrow$  increase  $\Omega_\chi h^2$**

# QUINTESENTIAL RELIC DENSITY ENHANCEMENT

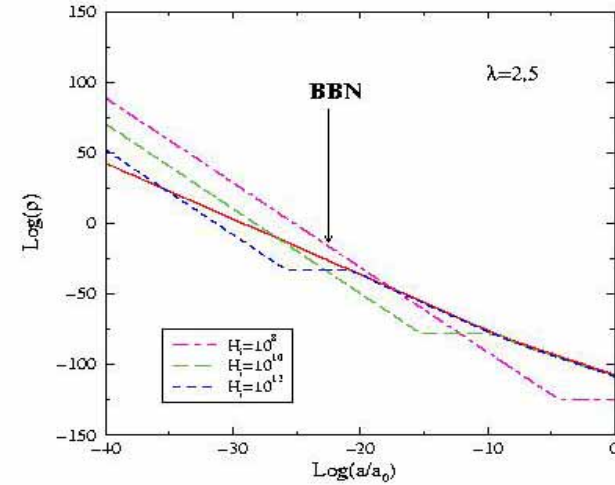
$$H \propto \sqrt{\rho_{rad} + \rho_{mat} + \rho_{other}}$$

If **DARK ENERGY = QUINTESENCE**

$$\rho_{other} \rightarrow \rho_{\phi}$$

$$\rho_{\phi} \propto a^{-6}$$

- ✓ *Joyce-Ferreira Model*
- ✓ *possible tracking solutions*
- ✓ *compatible with BBN bounds*

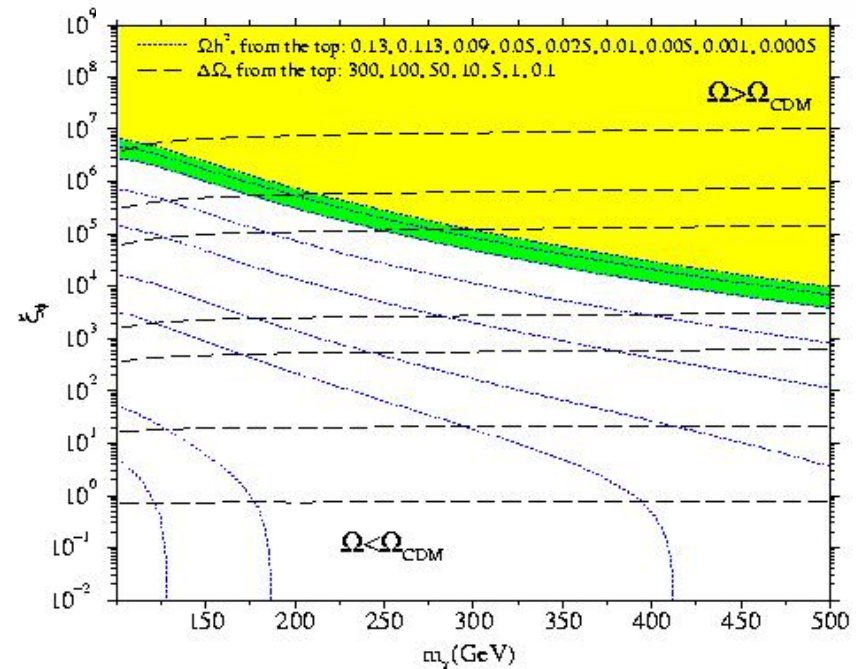


A **parameter** to quantify the enhancement:

$$\xi_{\phi} \equiv \frac{\rho_{\phi}}{\rho_{rad}} (T_{f.o.})$$

e.g. for WINO DM (mAMSB) →

**Example of (*minimal*) non-trivial Dark Sector Interaction!**

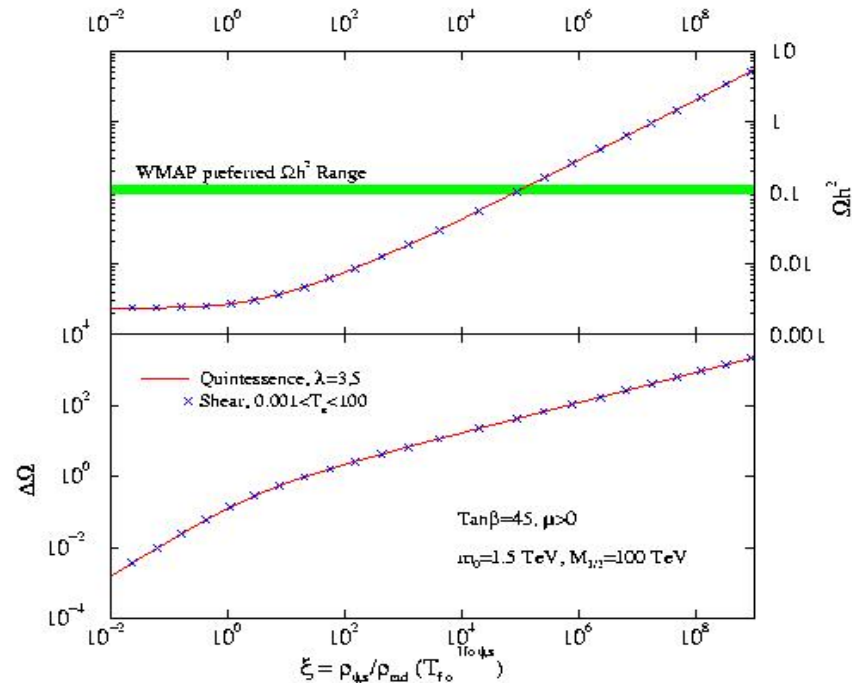


# OTHER COSMOLOGICAL RELIC DENSITY ENHANCEMENT SCENARIOS

- **Anisotropic Cosmologies** e.g. Bianchi I type  $\rho_{shear} \propto a^{-6}$
- **Brans-Dicke-Jordan Cosmologies** or other scalar-tensor theories  $\rho_{\Phi} \propto a^{-6}$
- **Extra Dimensional Theories**  $D$ -compact dim  $G = G_0 \left( \frac{R}{R_0} \right)^D$
- **Other Theories with varying  $G$**   $H \propto G^{1/2}$

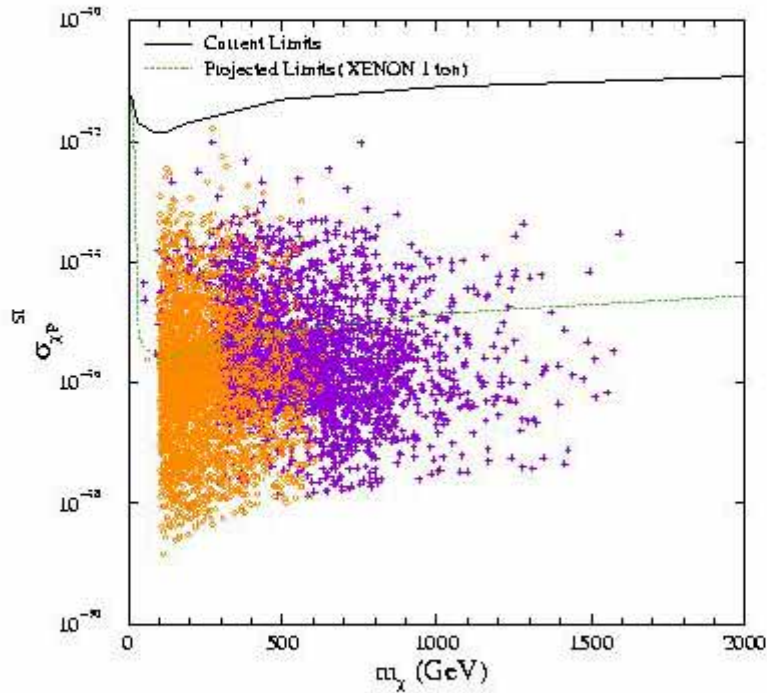
*...comparing Anisotropic and quintessential cosmological relic density enhancements*

**$\xi$  is a (universally) good parameter!**

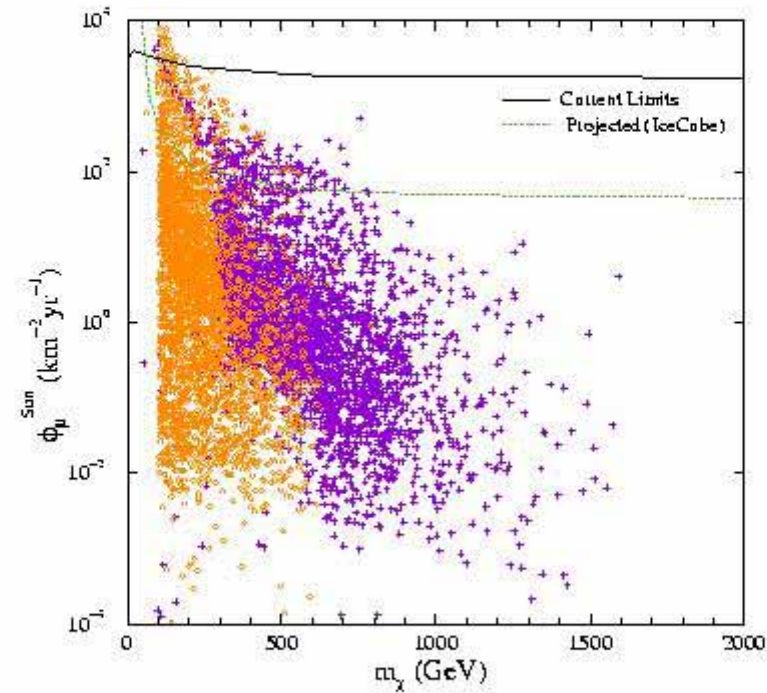


# DARK MATTER IN LOW RELIC DENSITY MODELS

Direct Detection



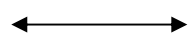
Indirect Detection



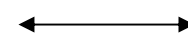
Violet plus:  $0.01 < \Omega h^2 < 0.09$ , Orange diamonds:  $0.001 < \Omega h^2 < 0.01$

*Typical LHC Reach below 500 GeV !*

**Large  
Detection  
Rates**



**Large  
Annihilation  
X-sections**



**Low  
Relic  
Density**



# CONCLUSIONS

- **SUSY** provides ideal *DM candidates*
- Neutralinos within the WMAP Relic density **range** will be *hard to detect* in DM searches
- **Low relic density** models with *Quintessence* may be WMAP-compatible
- Low relic density models have *promising SUSY DM Detection Rates*