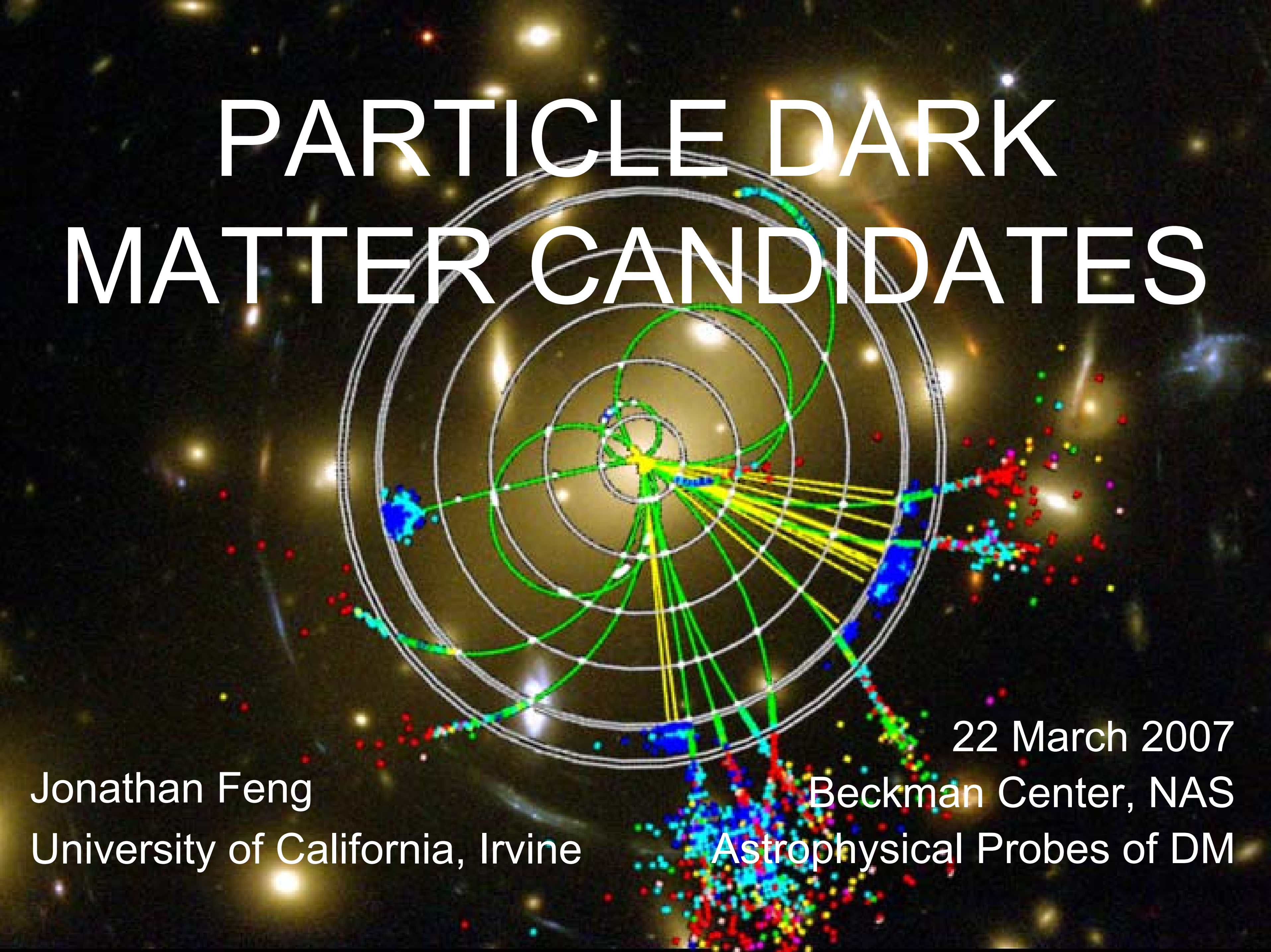
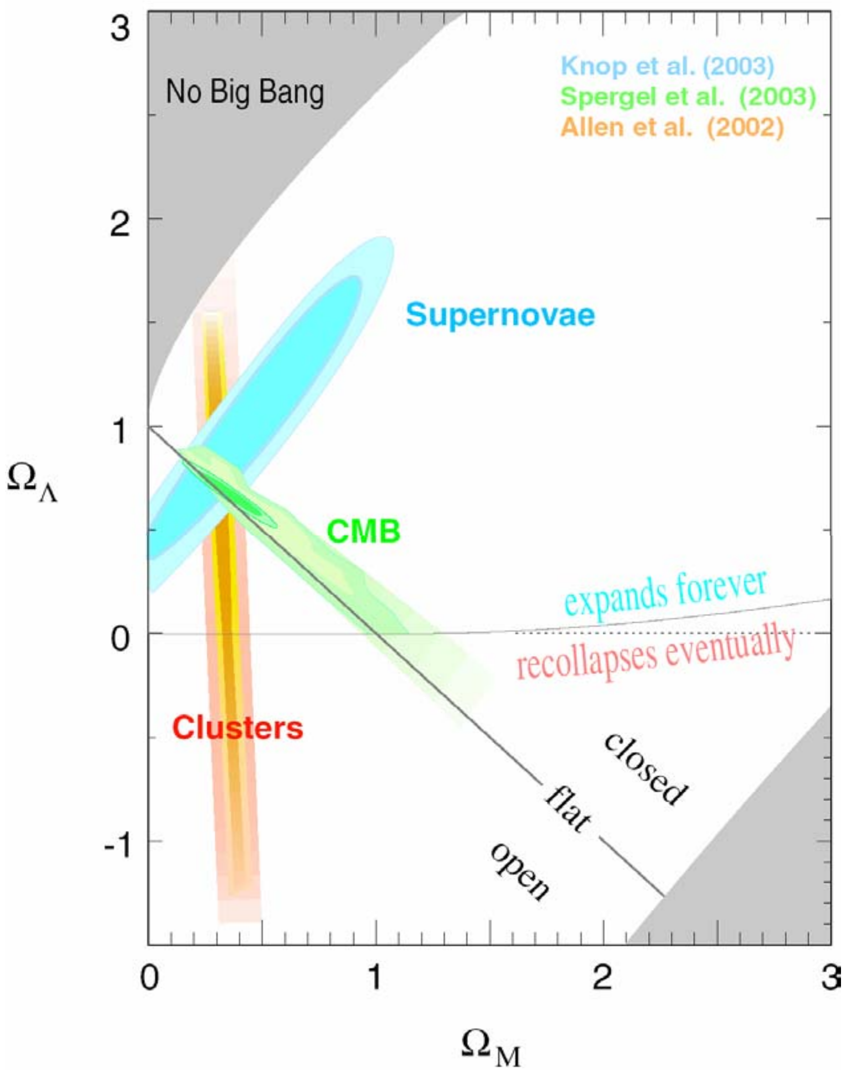


PARTICLE DARK MATTER CANDIDATES

Jonathan Feng
University of California, Irvine

22 March 2007
Beckman Center, NAS
Astrophysical Probes of DM

Dark Matter



- Tremendous recent progress:

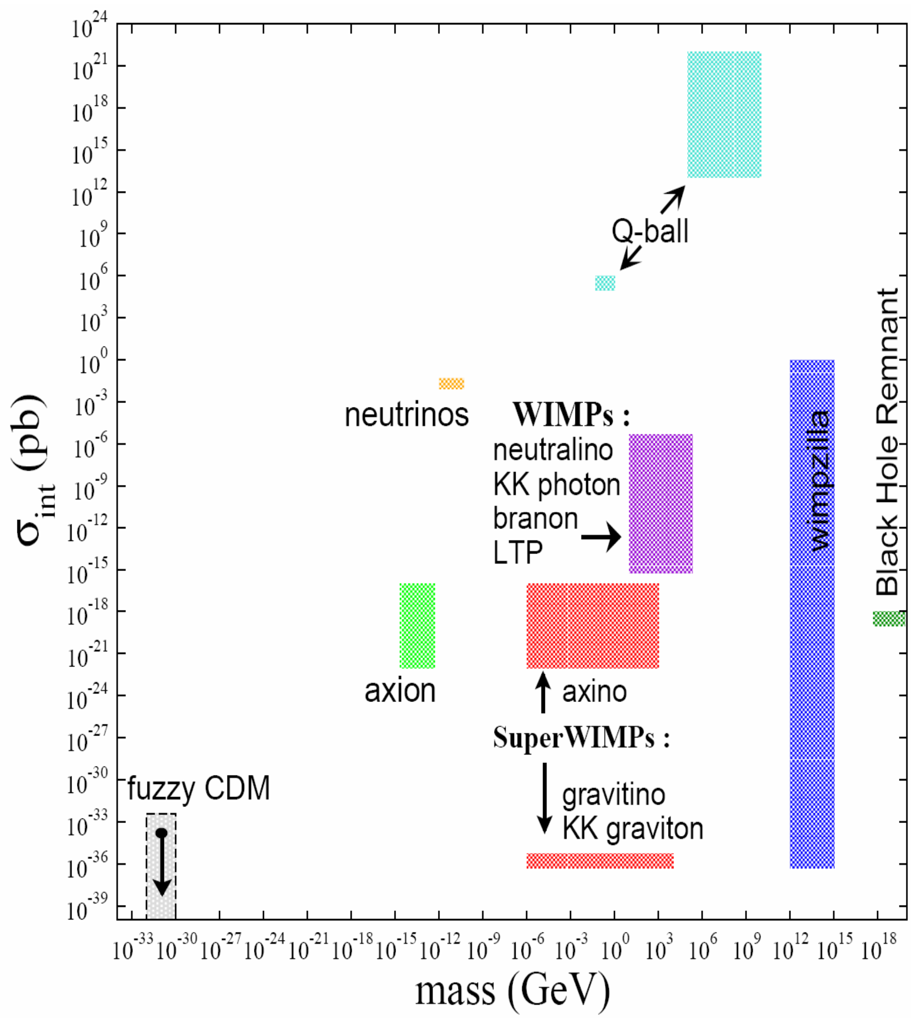
  $\Omega_{DM}h^2 = 0.113 \pm 0.009$

- Unambiguous evidence for new particles

- What is it?
  - Not baryonic
  - Not hot
  - Not short-lived

- Here review recent progress:
  - Proliferation of candidates
  - Many as well-motivated as neutralino dark matter, but with completely different implications for structure formation, etc.

Candidates

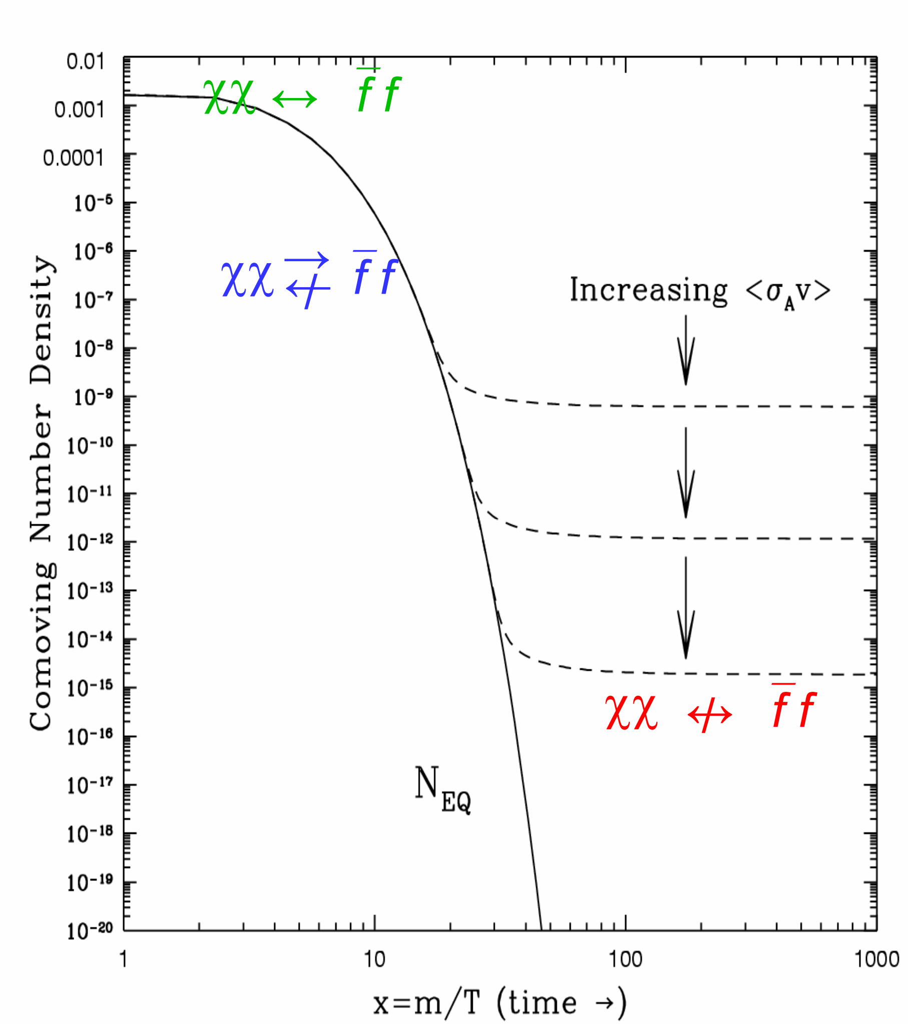


HEPAP/AAAC DMSAG Subpanel (2007)

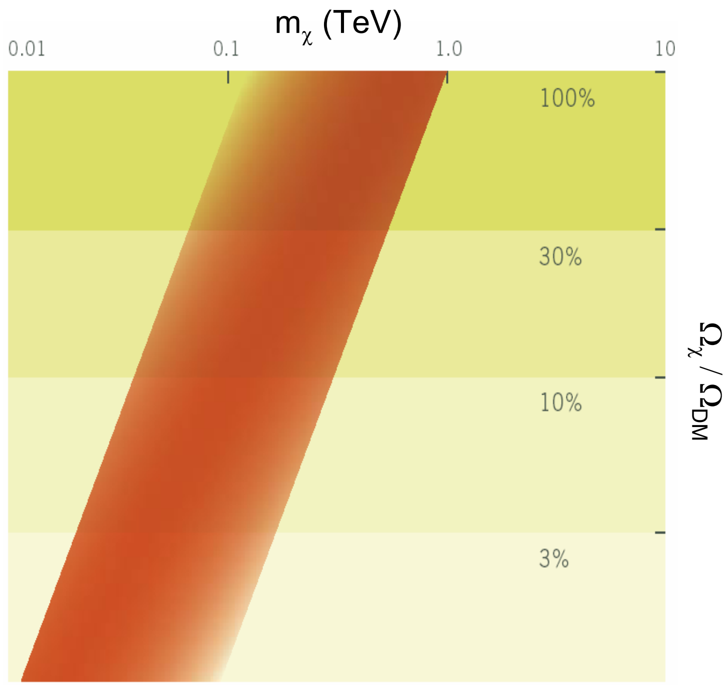
- Masses and interaction strengths span many, many orders of magnitude
- Diverse motivations
  - DAMA
  - HEAT
  - HESS
  - Small scale structure
  - 511 keV photon line

  …

The WIMP "Miracle"



$$\Omega_\chi \sim <\sigma_A v>^{-1} \sim m_\chi^{2}/(k\alpha^2)$$



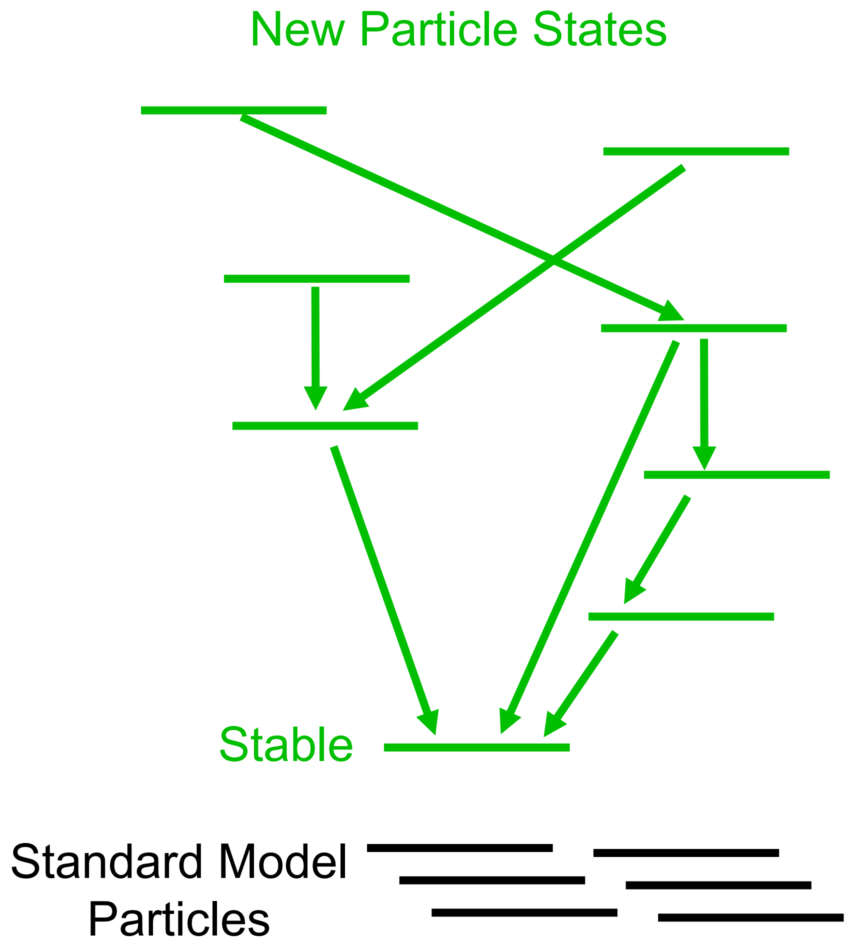
HEPAP LHC/ILC Subpanel (2005)

[k = 0.5 – 2, S- and P-wave]

Remarkable "coincidence": particles required for electroweak symmetry breaking ~100 GeV → right amount of dark matter!

STABILITY

- This all assumes the WIMP is stable
- How natural is this?

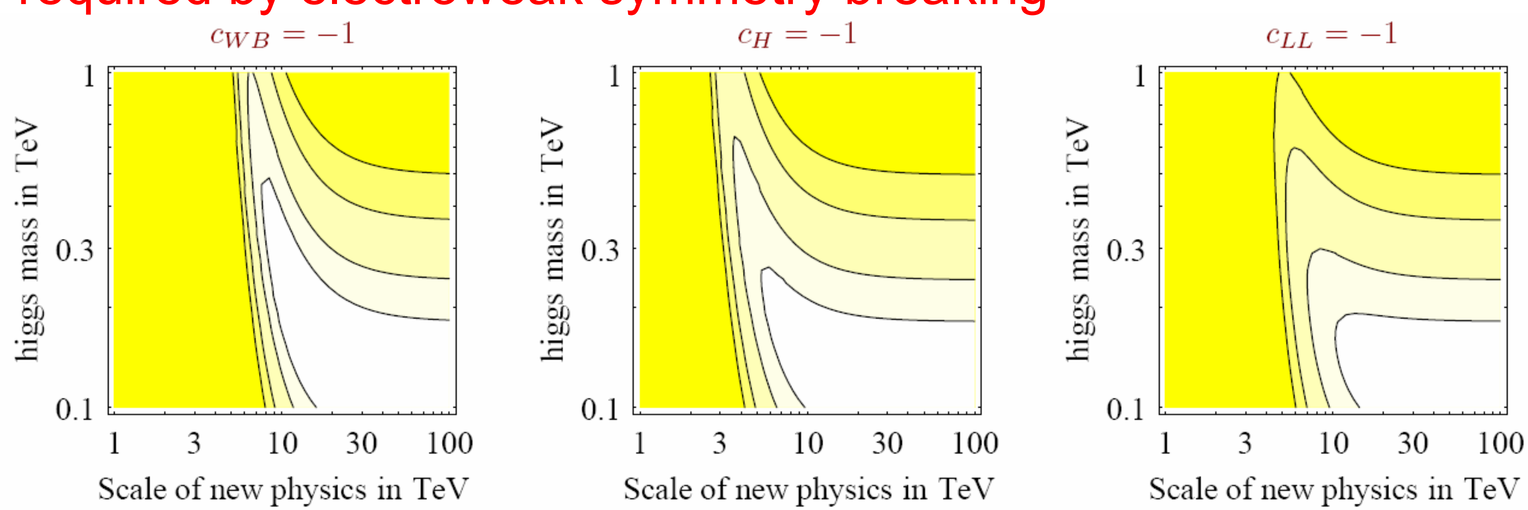


LEP

- Large Electron Positron Collider at CERN, 1989-2000

- Confirmed the standard model, stringently constrained effects of new particles

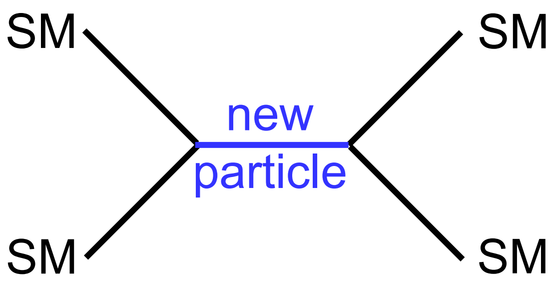
- Problem: new particles should be above ~ 3 TeV, far heavier than ~100 GeV required by electroweak symmetry breaking



Barbieri, Strumia (1999)

SOLUTION

- This assumes new particles mediate interactions at tree-level.
- Simple solution: impose a discrete parity, so all interactions require pairs of new particles.
- This also makes the lightest new particle stable.



Cheng, Low (2003); Wudka (2003)

- The Cosmological Legacy of LEP:

LEP constraints ↔ Discrete symmetry ↔ Stability

- The WIMP paradigm is more natural than ever before
- Dark matter is easier to explain than no dark matter, and with the proliferation of EWSB models has come a proliferation of WIMP possibilities

EXAMPLES

- Supersymmetry
  - Superpartners
  - R-parity
  - Neutralino χ with significant Ω_{DM}

Goldberg (1983); Ellis et al. (1984)

- Universal Extra Dimensions
  - Kaluza-Klein partners
  - KK-parity
  - B^1 ("heavy photon") with significant Ω_{DM}

Appelquist, Cheng, Dobrescu (2000)

Servant, Tait (2002)

Cheng, Feng, Matchev (2002)

- Branes
  - Brane fluctuations
  - Brane-parity
  - Branons with significant Ω_{DM}

Cembranos, Dobado, Maroto (2003)

WIMPS FROM SUSY

The classic WIMP: neutralinos predicted by supersymmetry

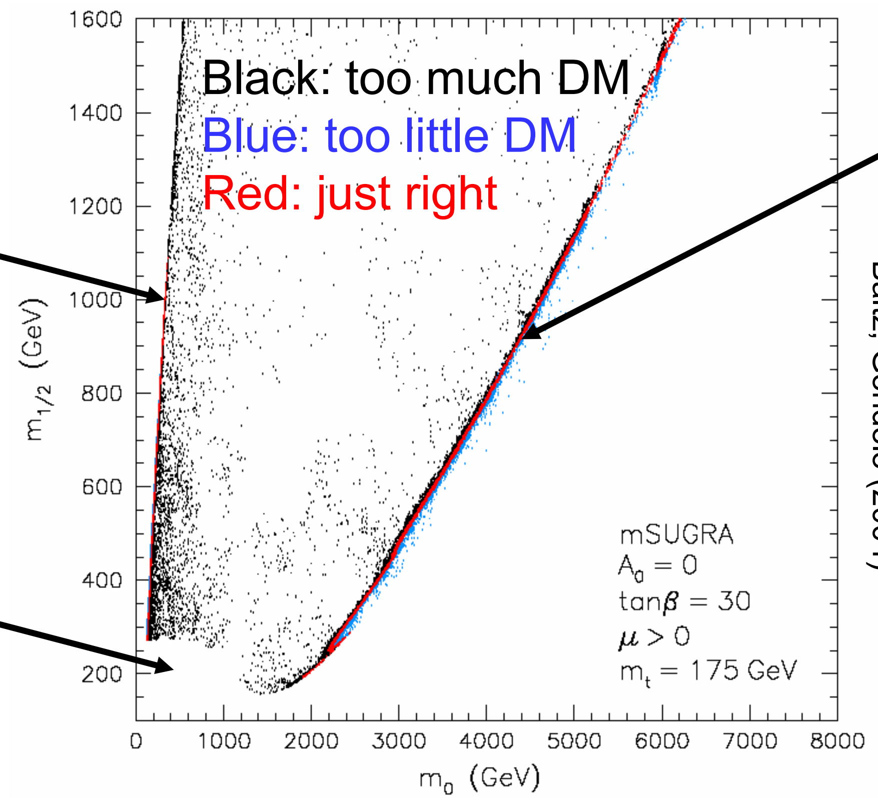
Goldberg (1983), Ellis et al. (1983)

- Supersymmetry: For every known particle X, predicts a partner particle $\tilde{X}$. Stabilizes weak scale if masses are ~ 100 GeV.

- Neutralino $\chi \in (\tilde{\gamma}, \tilde{Z}, \tilde{H}_u, \tilde{H}_d)$: neutral, weakly-interacting.

- In many models, χ is the lightest supersymmetric particle and stable. All the right properties for dark matter!

Minimal Supergravity



Co-annihilation region

Bulk region

Focus point region

Baltz, Gondolo (2004)

$\Omega_{DM}h^2 = 0.113 \pm 0.009$ excludes many possibilities, favors certain models

WIMPS FROM EXTRA DIMENSIONS

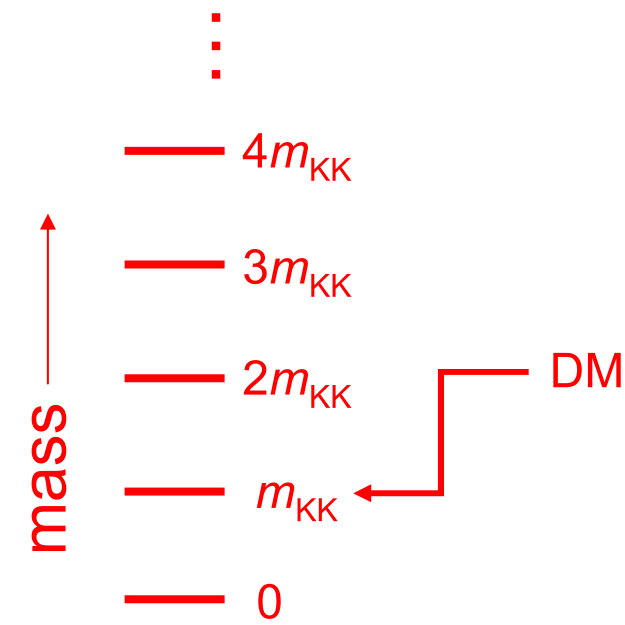
Servant, Tait (2002); Cheng, Feng, Matchev (2002)

- Extra spatial dimensions could be curled up into small circles of radius *R*

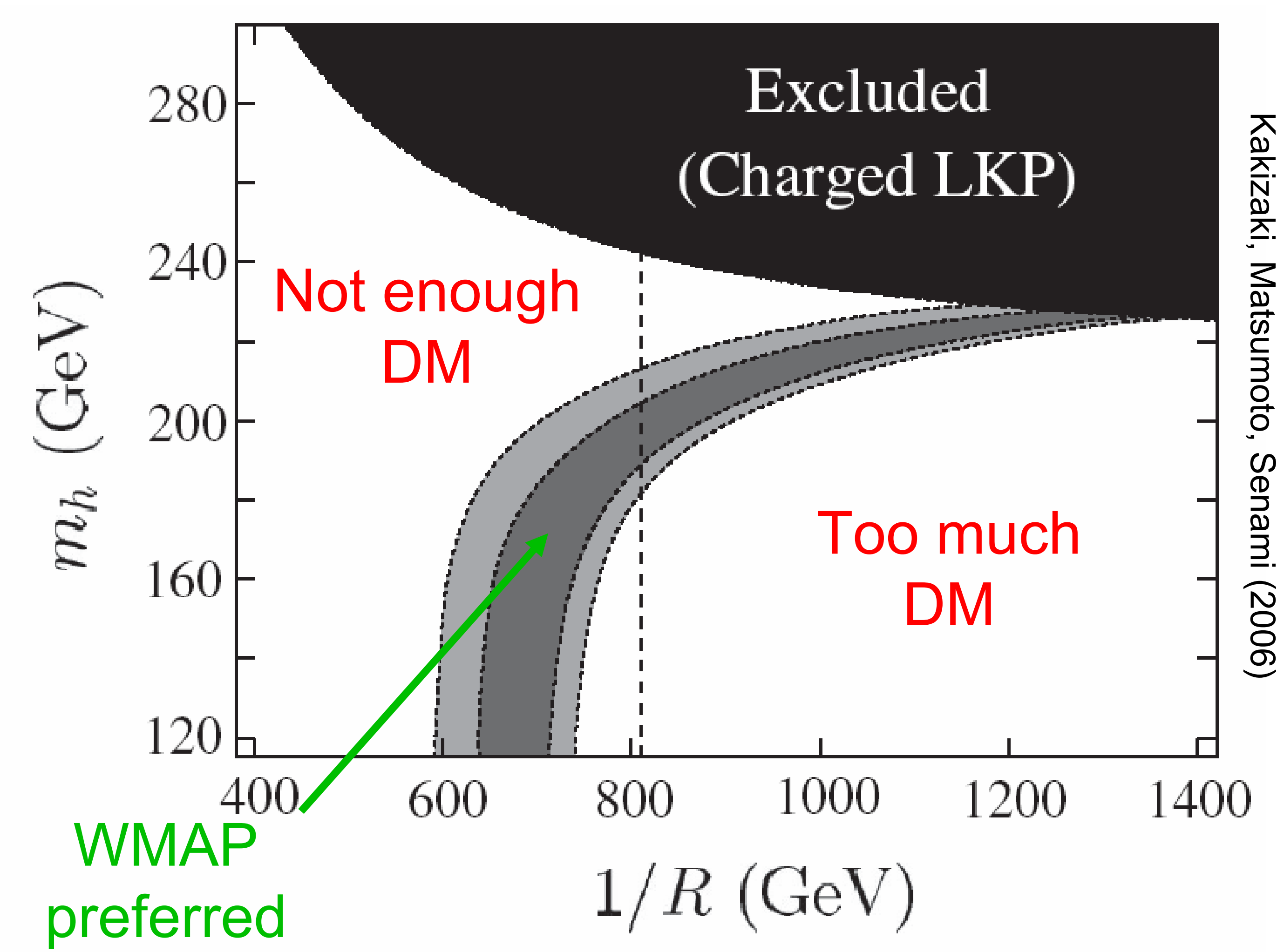
- Particles moving in extra dimensions appear as a set of copies of SM particles

- New particle masses are integer multiples of

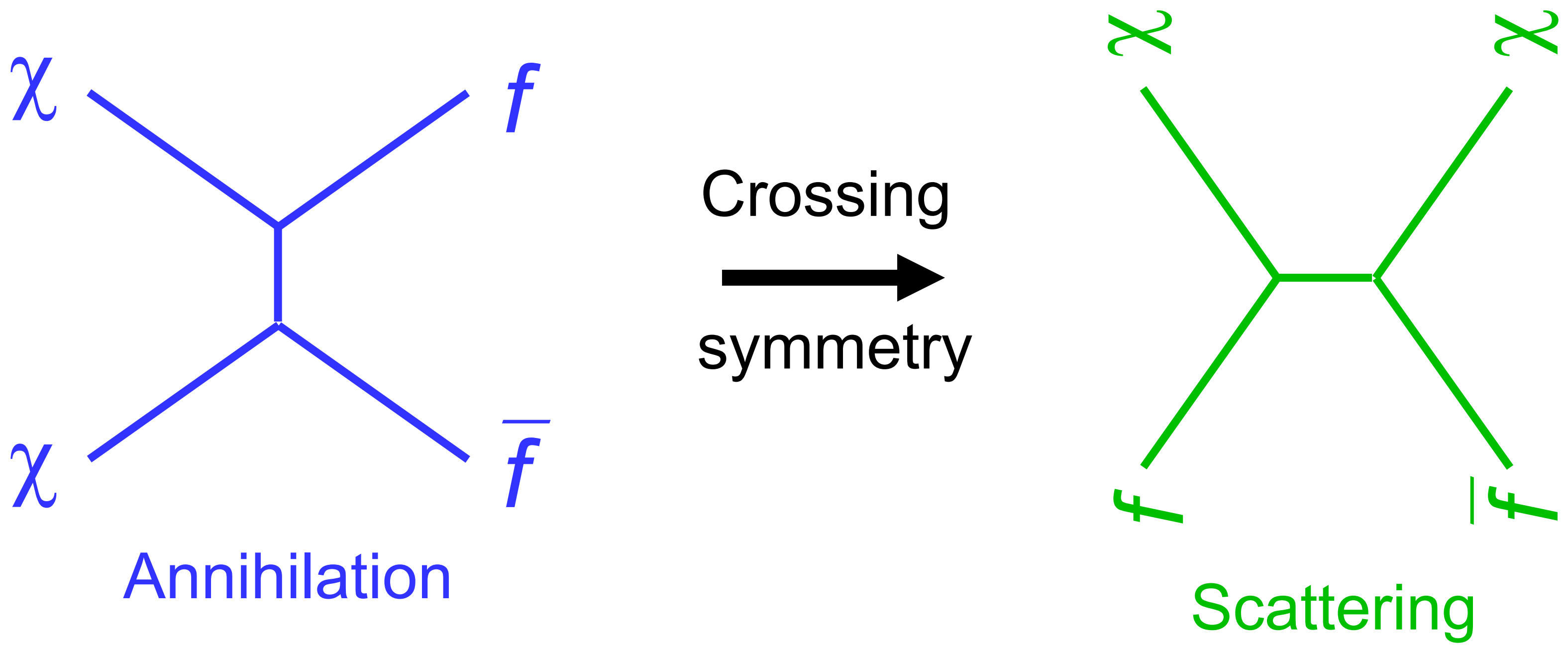
$$m_{KK} = R^{-1}$$



Minimal Universal Extra Dimensions



WIMP DETECTION



Correct relic density → Efficient annihilation then

→ Efficient annihilation now (indirect detection)

→ Efficient scattering now (direct detection)

ALTERNATIVES TO WIMPS

- Must DM have weak force interactions?
- Strictly speaking, no – the only required DM interactions are gravitational (much weaker than weak)
- But the relic density “coincidence” strongly prefers weak interactions

Is there an exception to this rule?

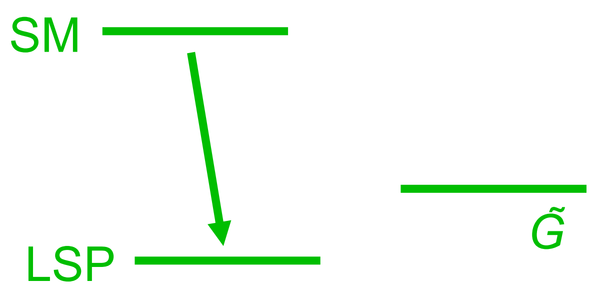
SuperWIMPs: The Basic Idea

- Supersymmetry also predicts gravitinos

Pagels, Primack (1982); Weinberg (1982)

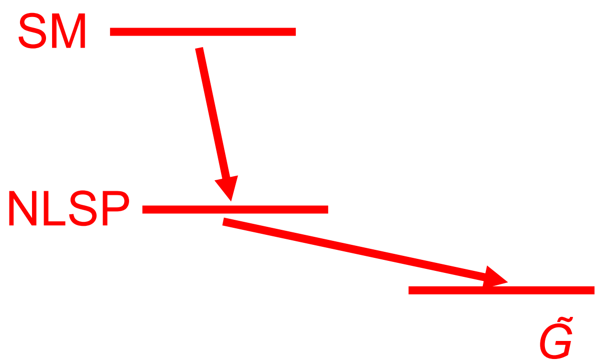
Most typically: mass ~ 100 GeV, couplings ~ M_W/M_{Pl} ~ 10^{-16}

- $\tilde{G}$ not LSP



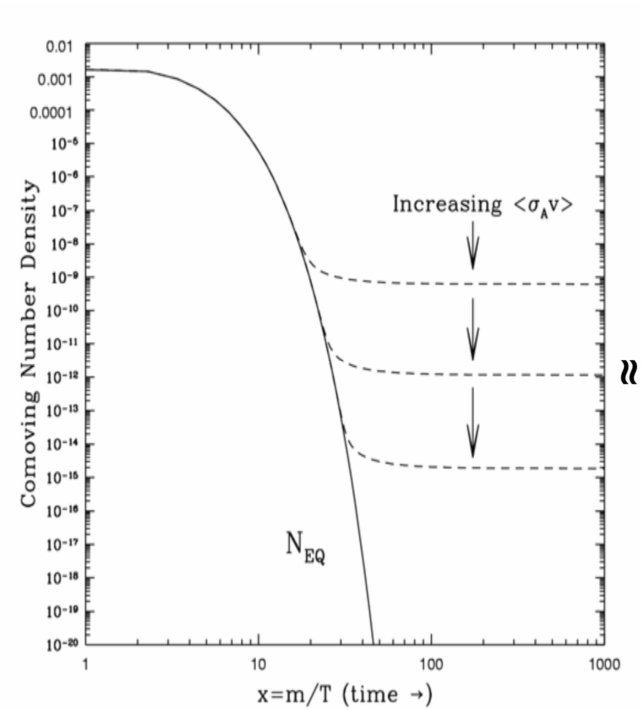
- Assumption of most of literature

- $\tilde{G}$ LSP

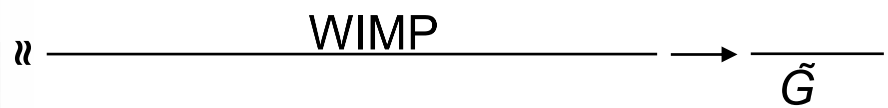


- Completely different cosmology and particle physics

SUPERWIMP RELICS



- Suppose gravitinos $\tilde{G}$ are the LSP
- WIMPs freeze out as usual



- But then all WIMPs decay to gravitinos after

  M_{Pl}^2/M_W^3 ~ hours to month

Gravitinos naturally inherit the right density, but interact only gravitationally – they are superWIMPs (also axinos, KK gravitons, quintessinos, etc.)

Feng, Rajaraman, Takayama (2003); Bi, Li, Zhang (2003); Ellis, Olive, Santoso, Spanos (2003); Wang, Yang (2004); Roszkowski et al. (2004); …

SuperWIMP Detection

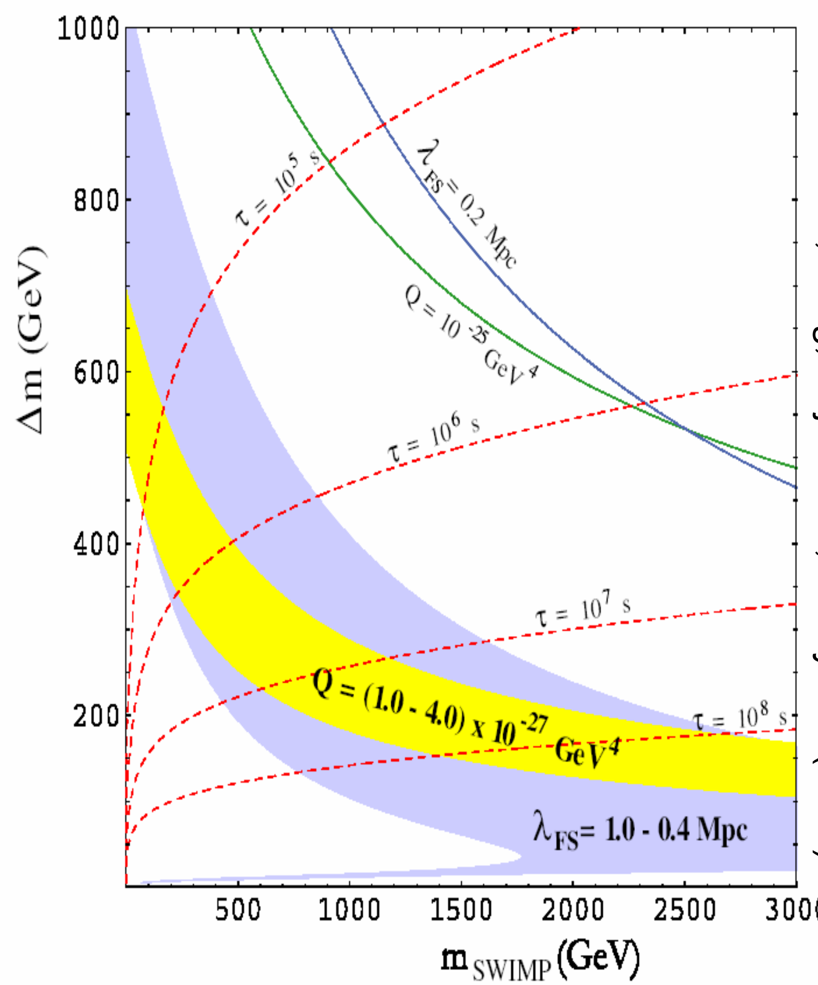
- SuperWIMPs evade all conventional dark matter searches
  - Direct detection
  - Indirect detection

- But superweak interactions → very late decays $\tilde{l} \to \tilde{G} l$, $\tilde{\gamma} \to \tilde{G}\gamma$ → observable consequences
  - Small scale structure
  - Big Bang nucleosynthesis
  - CMB μ distortions

STRUCTURE FORMATION

- SuperWIMPs are produced in late decays with large velocity (0.1c – c)
- Suppresses small scale structure while preserving WIMP motivations: warm!
- Typical decay times are 10^5 – 10^6 s, but can be arbitrarily long by adjusting $m_{\tilde{G}}$ (metaCDM)

Dalcanton, Hogan (2000)
Lin, Huang, Zhang, Brandenberger (2001)
Sigurdson, Kamionkowski (2003)
Profumo, Sigurdson, Ullio, Kamionkowski (2004)
Kaplinghat (2005)
Cembranos, Feng, Rajaraman, Takayama (2005)
Strigari, Kaplinghat, Bullock (2006)
Bringmann, Borzumati, Ullio (2006)



Cembranos, Feng, Rajaraman, Takayama (2005)

CONCLUSIONS

- Many interesting, well-motivated new candidates for particle dark matter
- Cosmological legacy of LEP: stability of a new particle is common feature of many viable particle models
- WIMPs: many new candidates; excellent prospects for direct and indirect dark matter searches, colliders
- SuperWIMPs: warm DM with all the virtues of WIMPs