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LHC and Cosmology

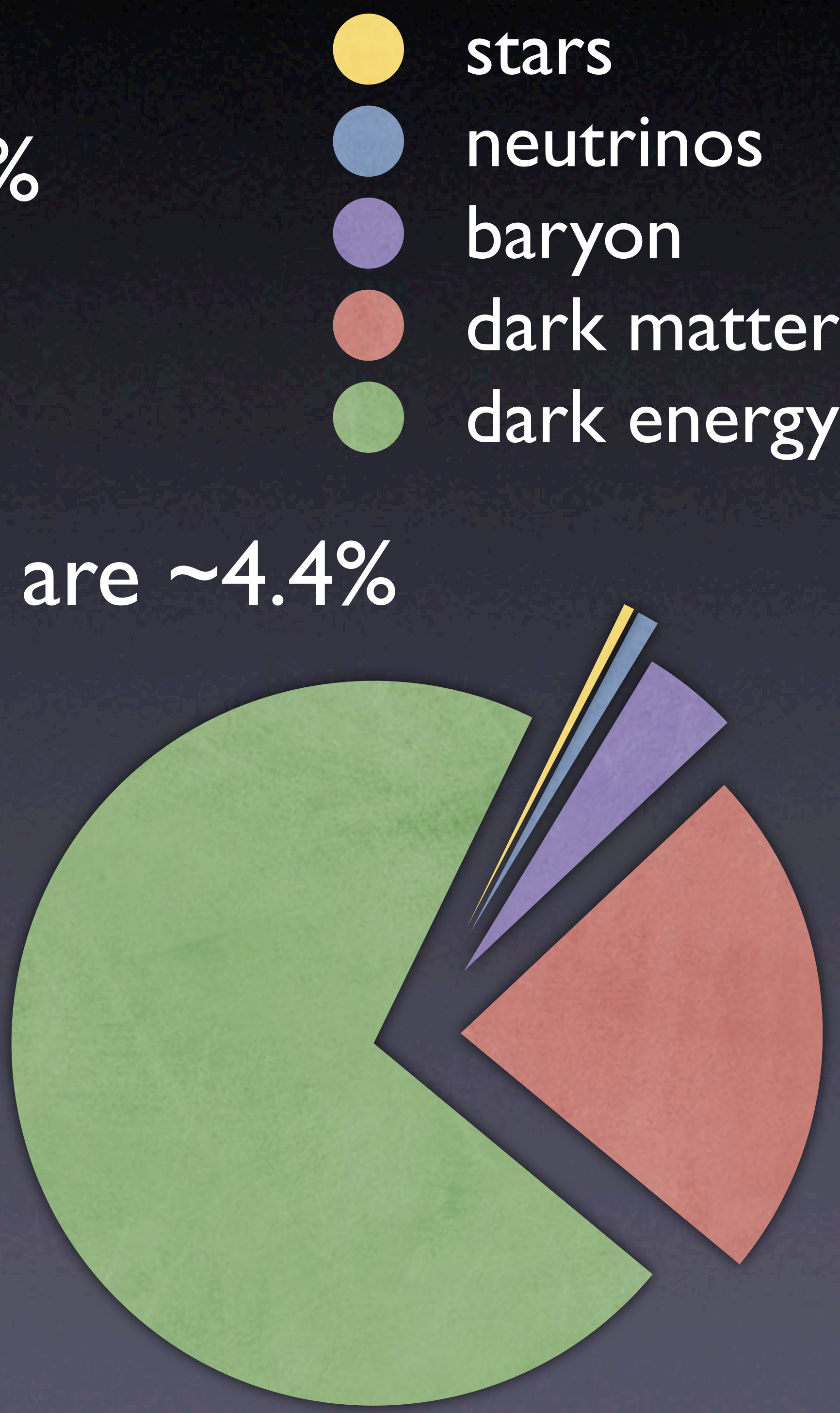
Hitoshi Murayama (IPMU Tokyo, Berkeley)

APS Meeting@Denver, May 3, 2009

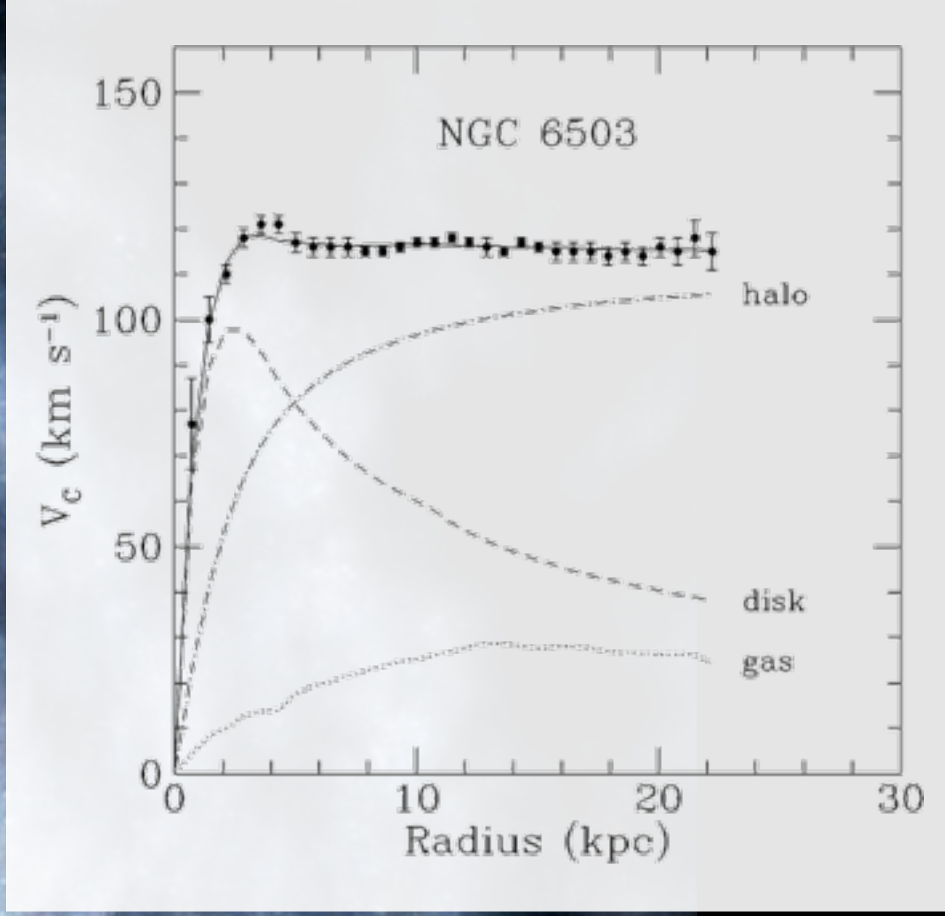

There are many things we don't see

Energy Budget of the Universe

- Stars and galaxies are only ~0.5%
- Neutrinos are ~0.1–1.5%
- Rest of ordinary matter (electrons, protons & neutrons) are ~4.4%
- Dark Matter ~23%
- Dark Energy ~73%
- Anti-Matter 0%
- Dark Field (Higgs) ~10^{62}%??



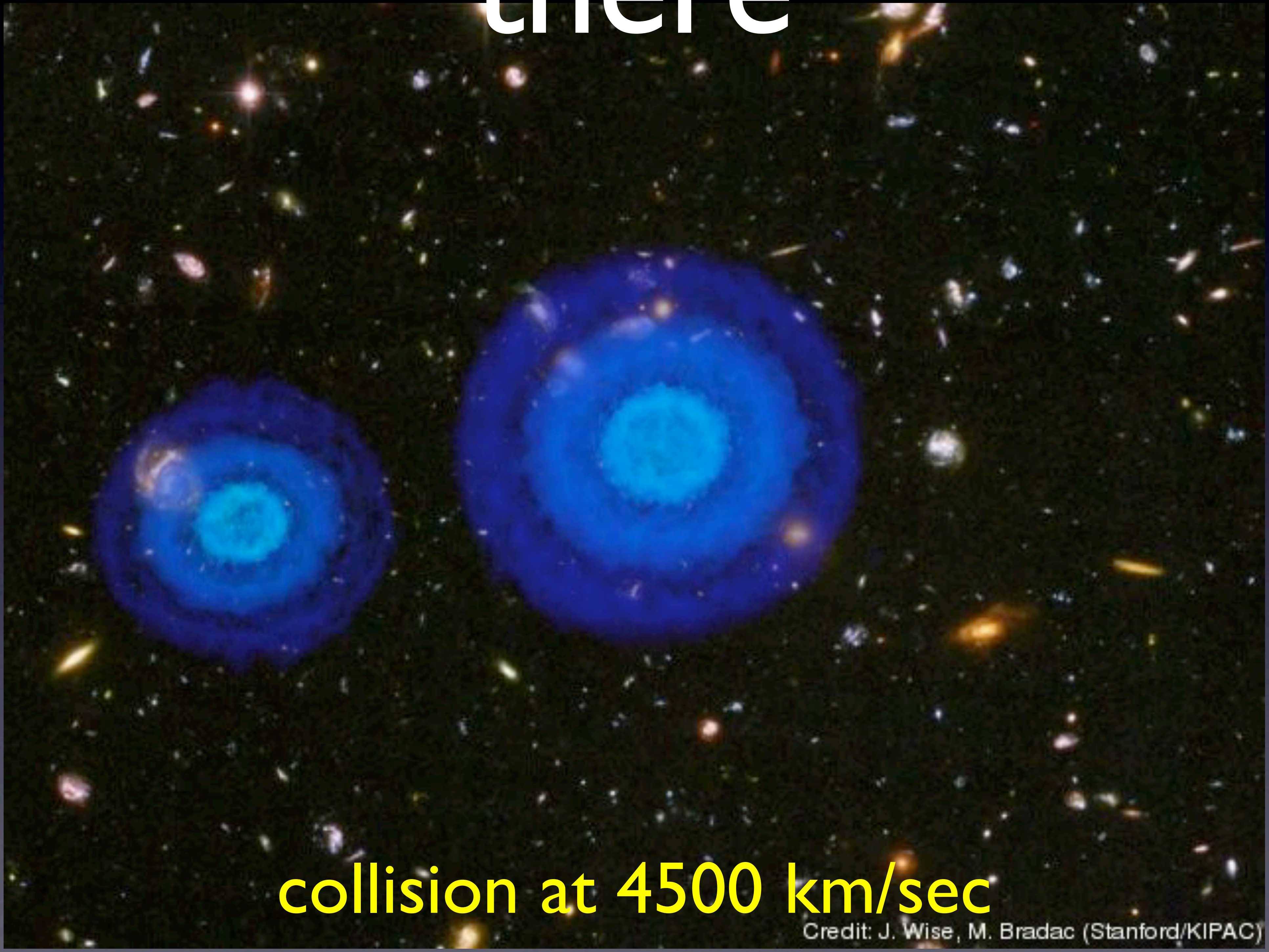
Dark Matter



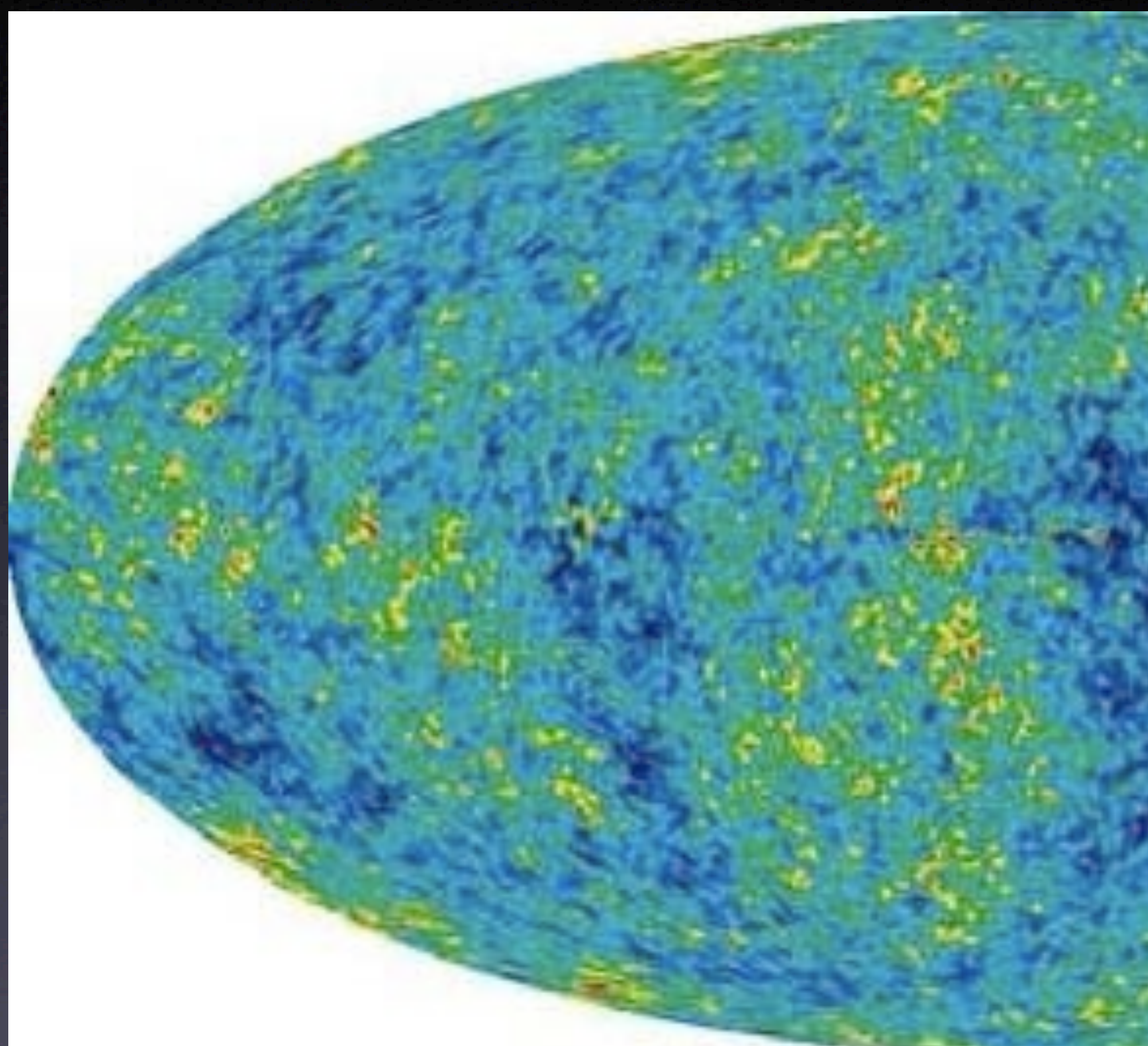
Solar system revolves at 220km/s

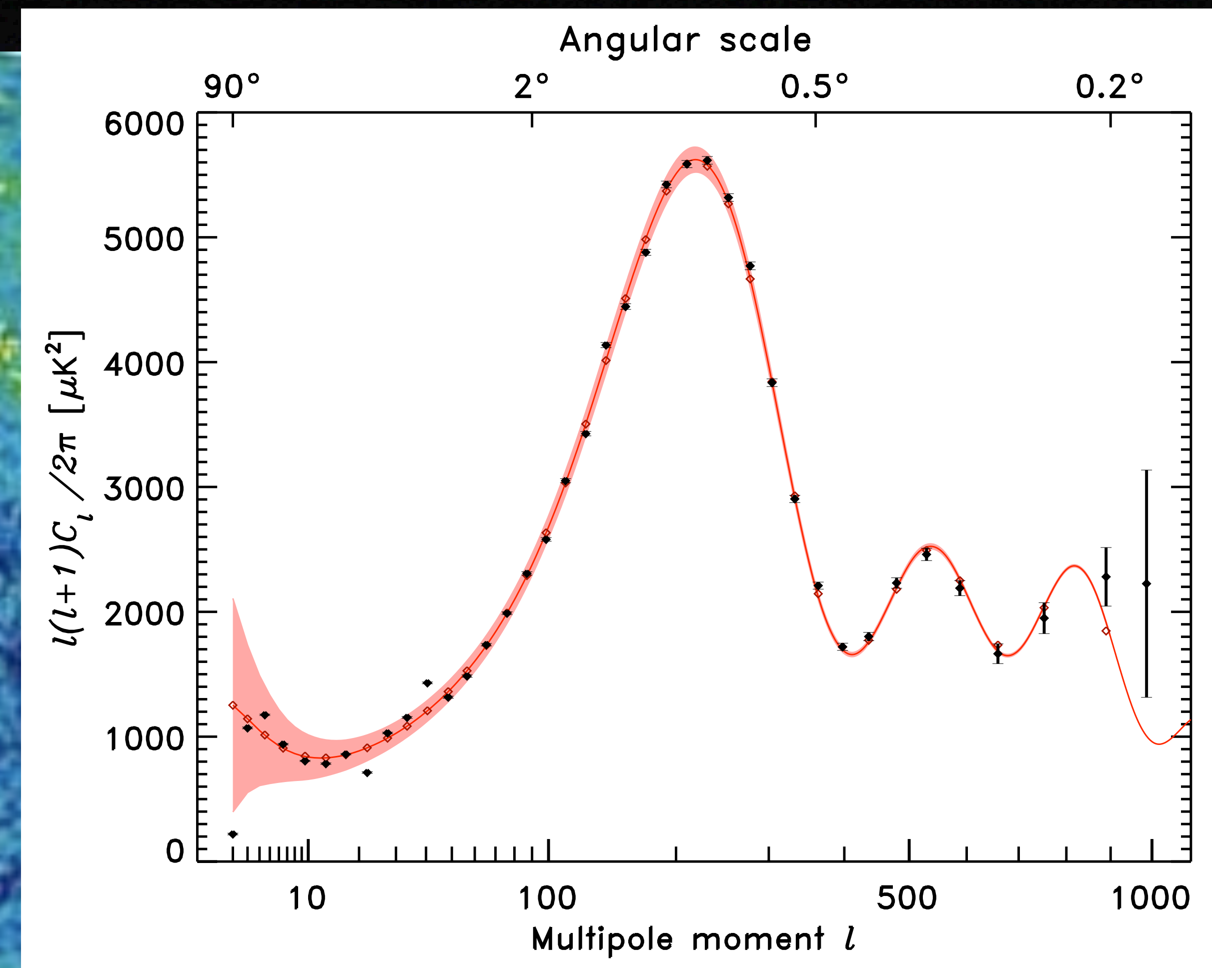
requires a lot of mass to keep it inside Milky Way

You don't want to be there



Cosmological scales





$$\frac{\text{matter}}{\text{all atoms}} = 5.70^{+0.39}_{-0.61}$$

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What do we know?

- Cold and Neutral
  - dark matter must be non-relativistic and clump together by gravitational attraction
  - must be electrically neutral
- lifetime longer than age of the Universe
- beyond that, rather little

Mass Limits

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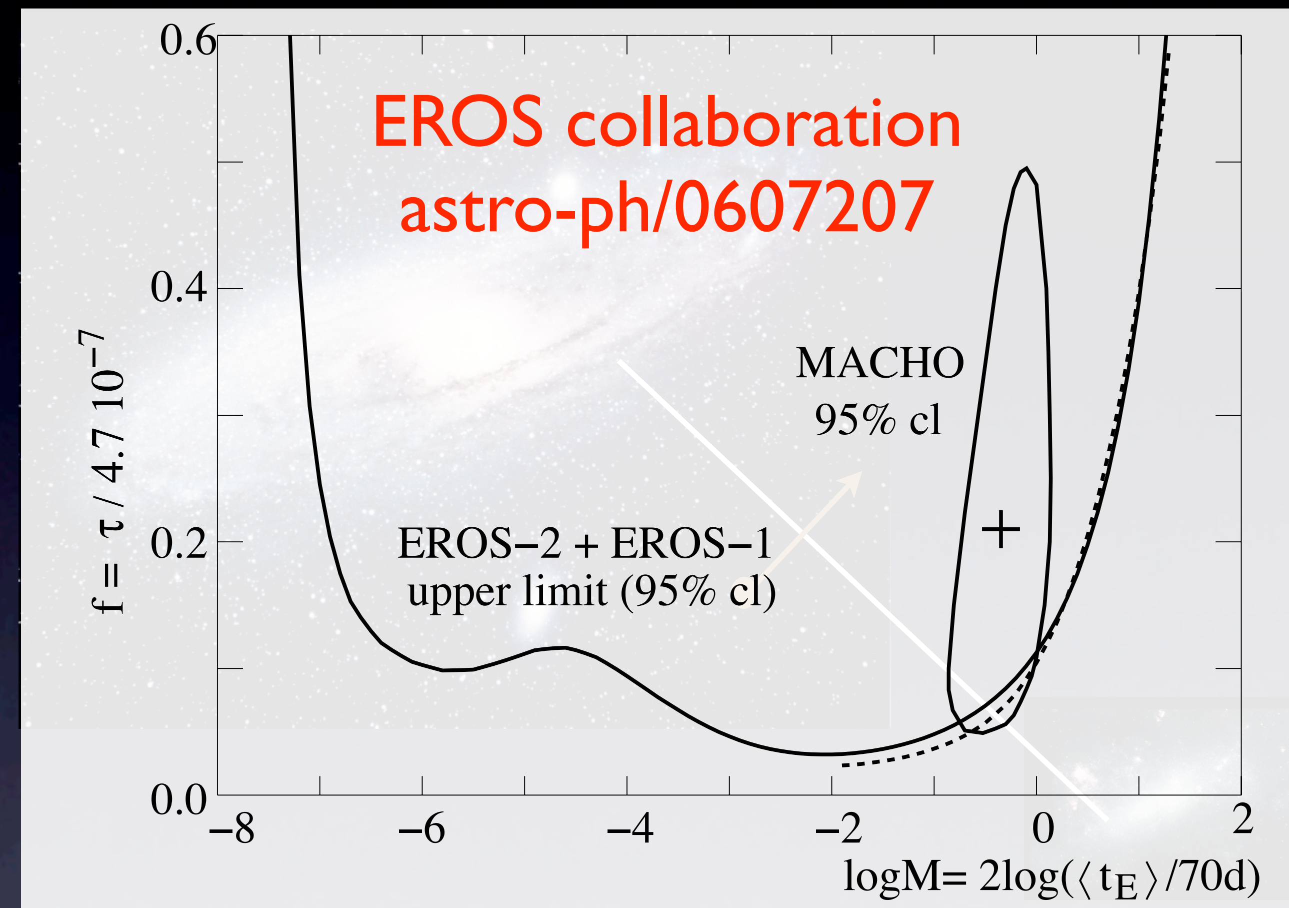
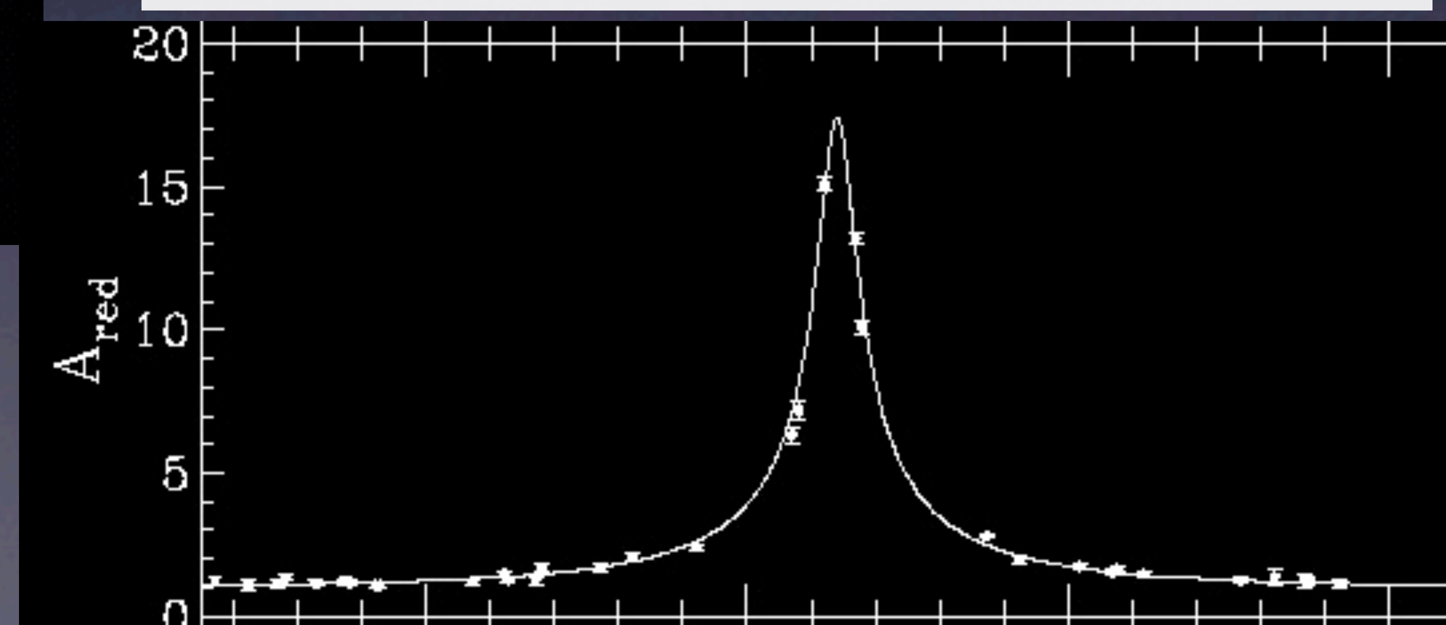
"Uncertainty Principle"

- must clump to form galaxies, clusters
- imagine $V = G_N \frac{Mm}{r}$
- "Bohr radius": $r_B = \frac{\hbar^2}{G_N M m^2}$
- too small m ⇒ won't *fit* in a galaxy!
- m >10^{-22} eV "uncertainty principle" bound
  (modified from Hu, Barkana, Gruzinov, astro-ph/0003365)

Dim Stars?

Search for MACHOs
(Massive Compact Halo Objects)

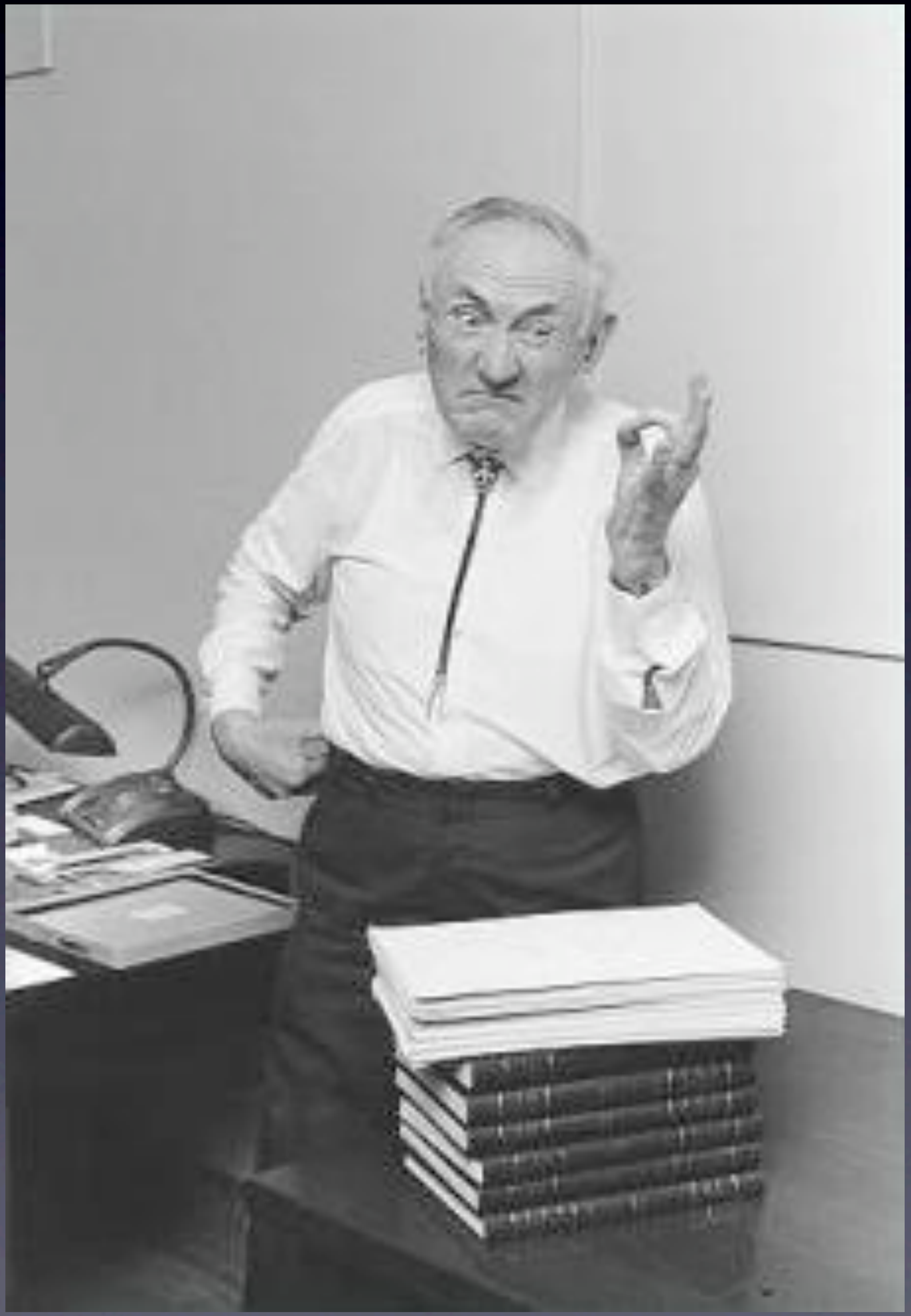




Not enough of them!

Summary
Mass Limits

- 10^{-31} GeV to 10^{50} GeV
- narrowed it down to within 81 orders of magnitude
- a *big* progress in 75 years since Zwicky



Self-Coupl

- if self-coupling too big, will “smooth out” cuspy profile at the galactic center
- some people wanted it

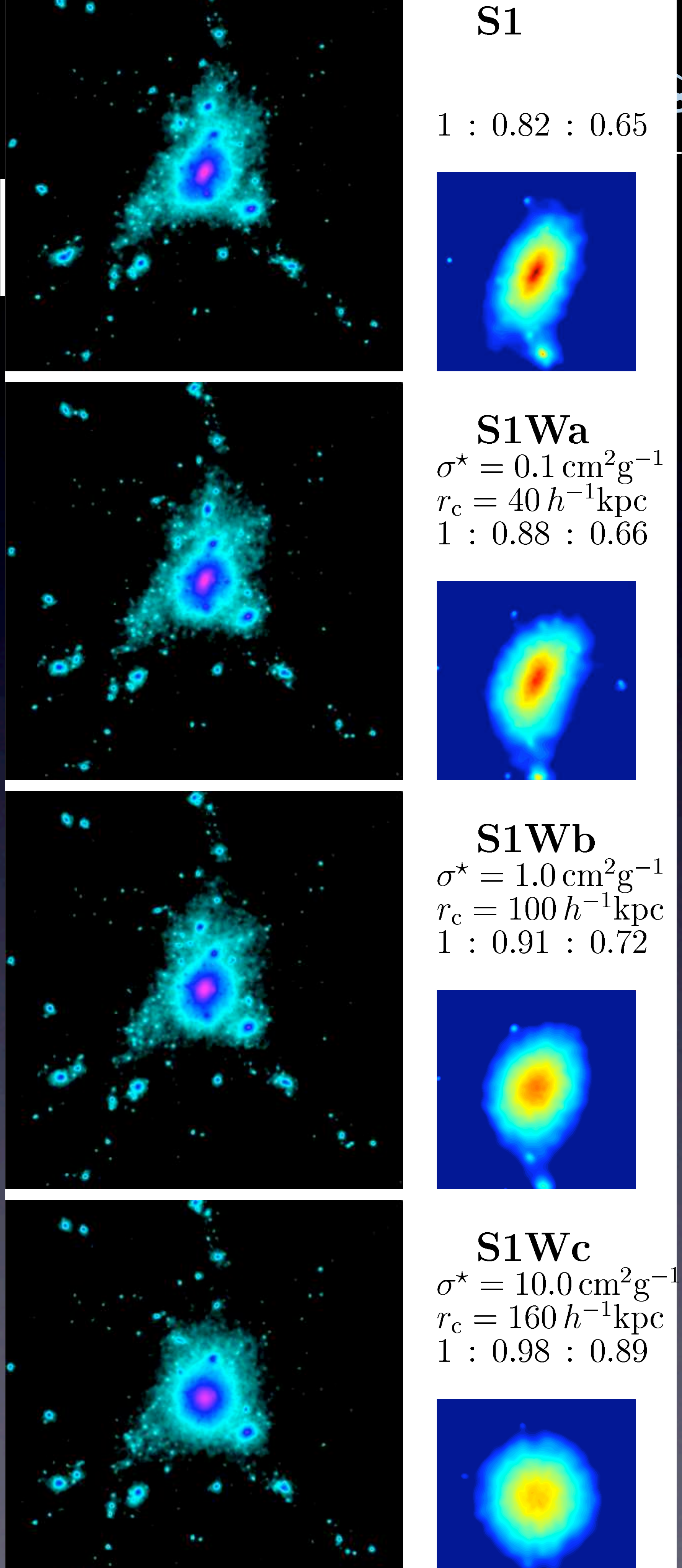
  (Spergel and Steinhardt, astro-ph/9909386)
- need core < 35 kpc/h from data

  σ < 1.7 x 10^{-25} cm^2 (m/GeV)

  (Yoshida, Springel, White, astro-ph/0006134)
- bullet cluster:

  σ < 1.7x10^{-24} cm^2 (m/GeV)

  (Markevitch et al, astro-ph/0309303)



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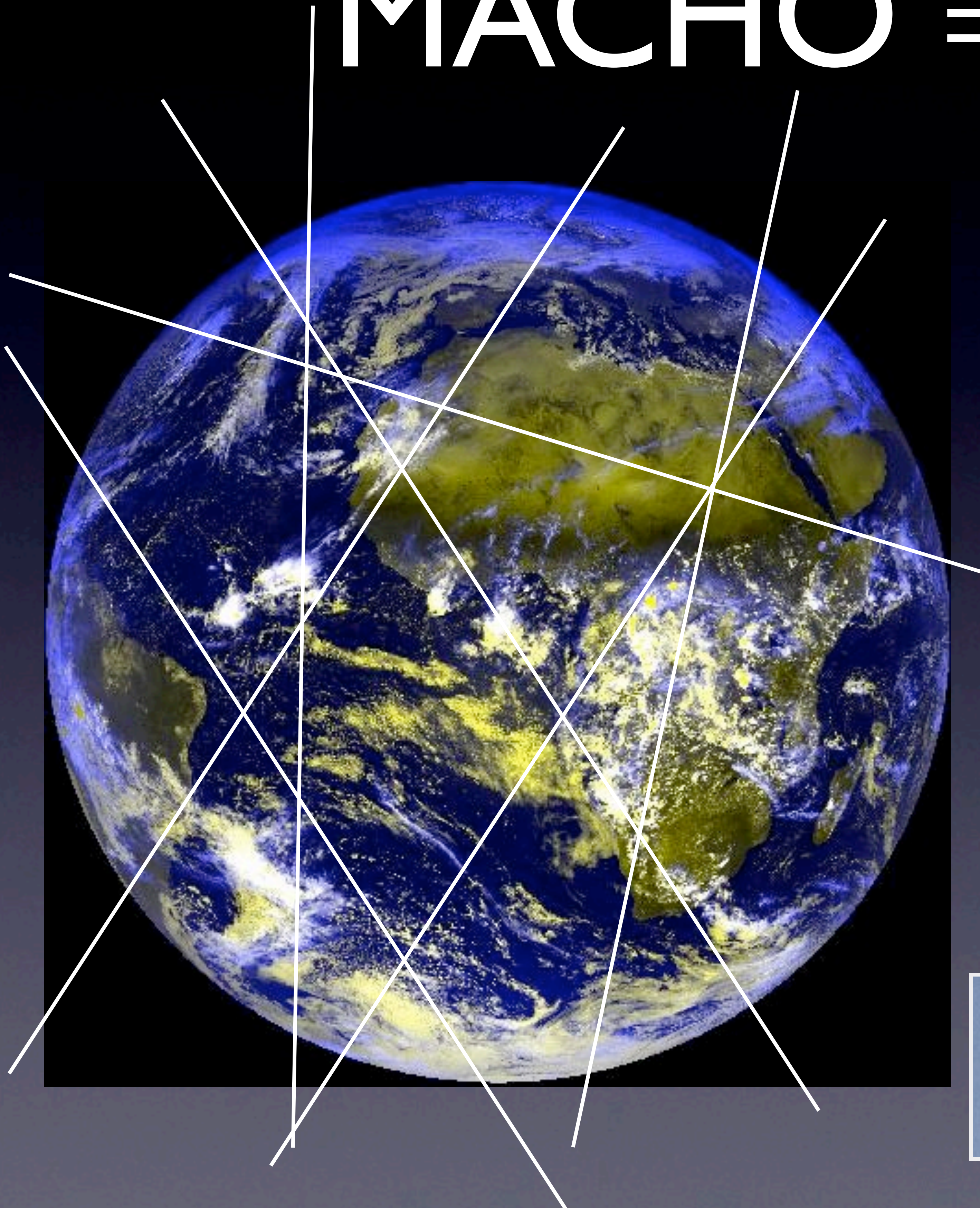
MACHO ⇒ WIMP



- dominant paradigm: WIMP *(Weakly Interacting Massive Particle)*
- *Stable heavy particle produced in early* Universe, *left-over from near-complete annihilation*

$$\Omega_M = \frac{0.756(n+1)x_f^{n+1}}{g^{1/2}\sigma_{ann}M_{Pl}^{3}}\frac{3s_0}{8\pi H_0^2} \approx \frac{\alpha^2/(TeV)^2}{\sigma_{ann}}$$

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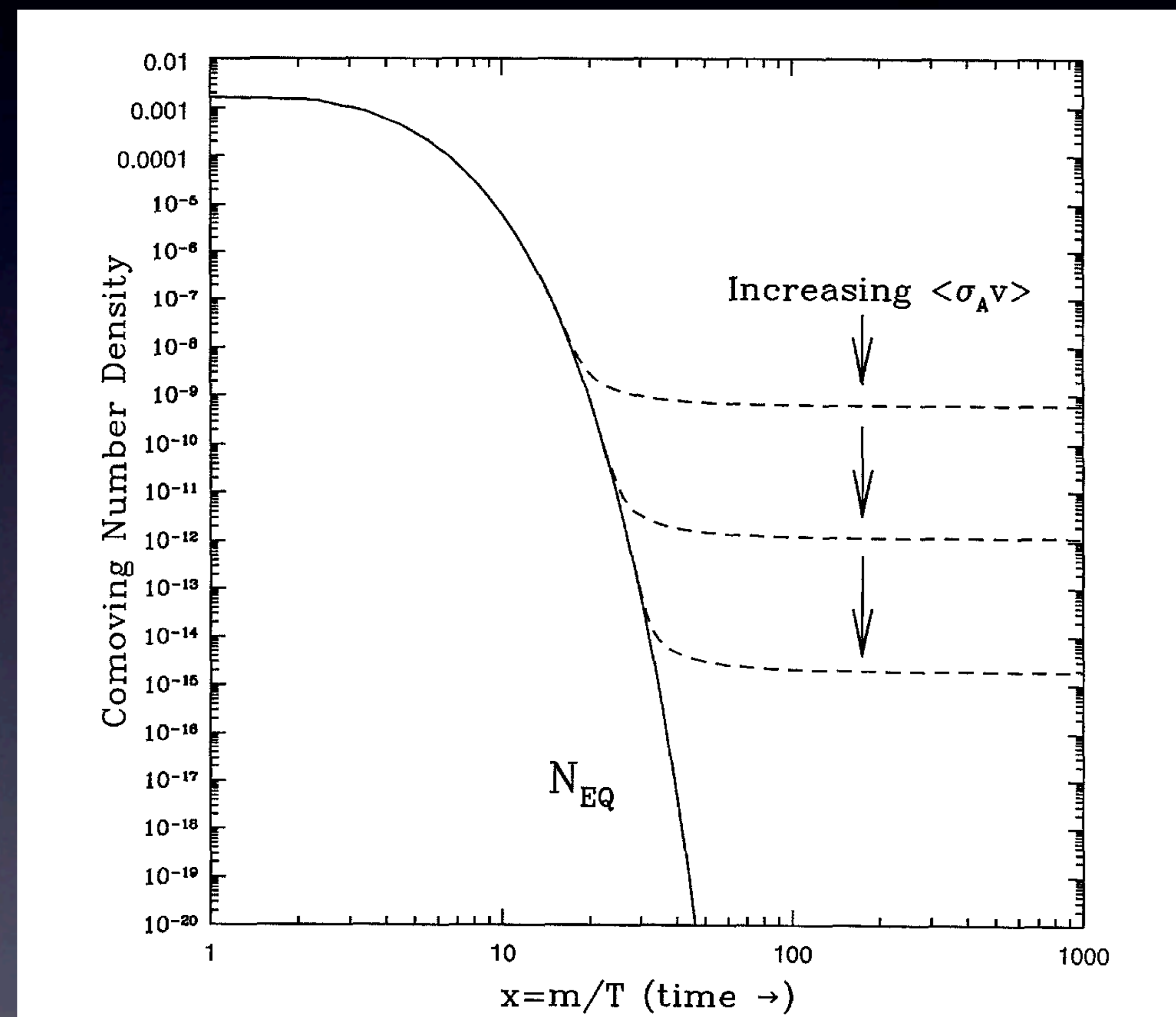
thermal relic

- thermal equilibrium when $T>m_\chi$
- Once $T<m_\chi$, no more χ created
- if stable, only way to lose them is annihilation
- but universe expands and χ get dilute
- at some point *they can't find each other*
- their number in comoving volume "frozen"



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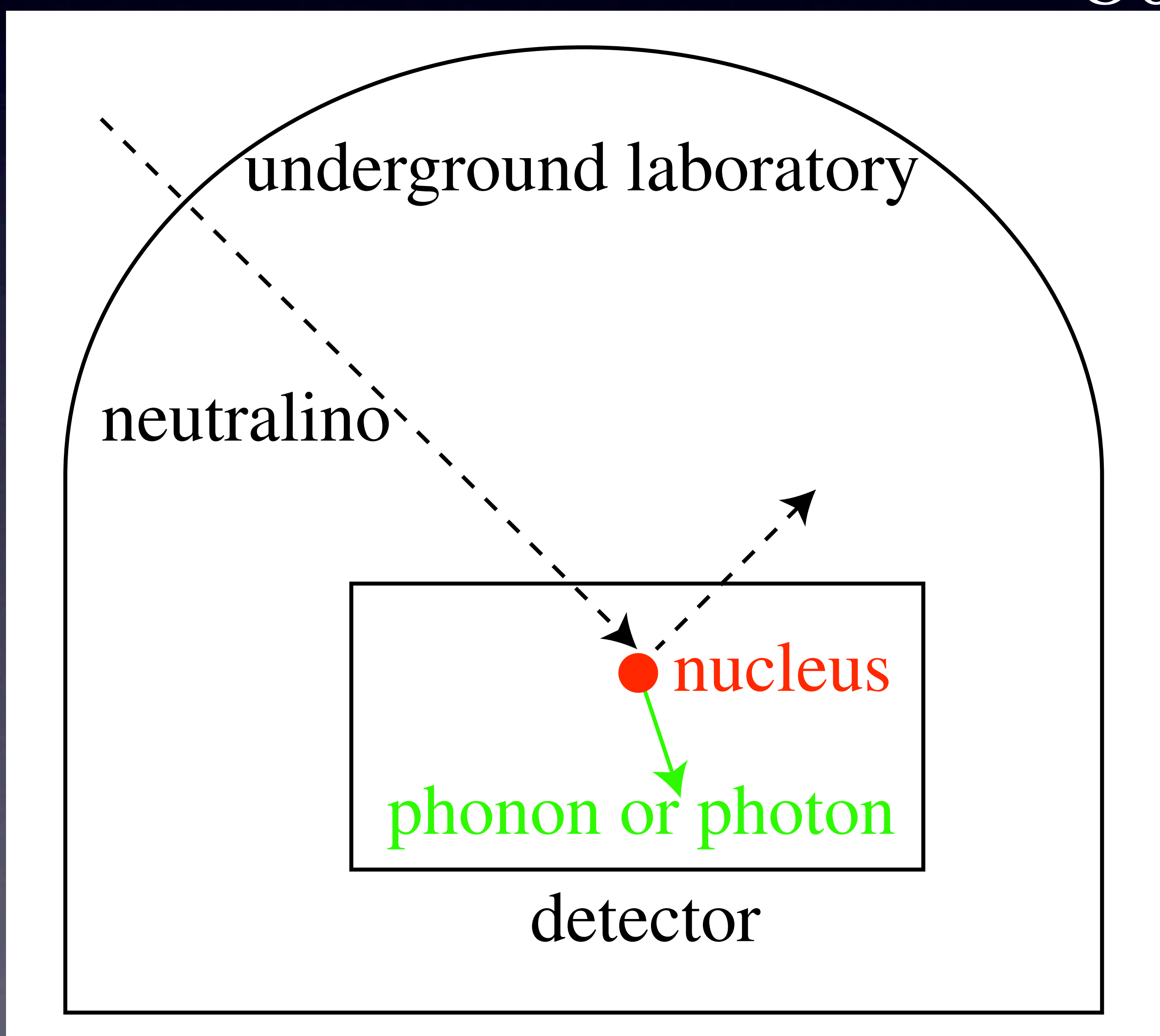
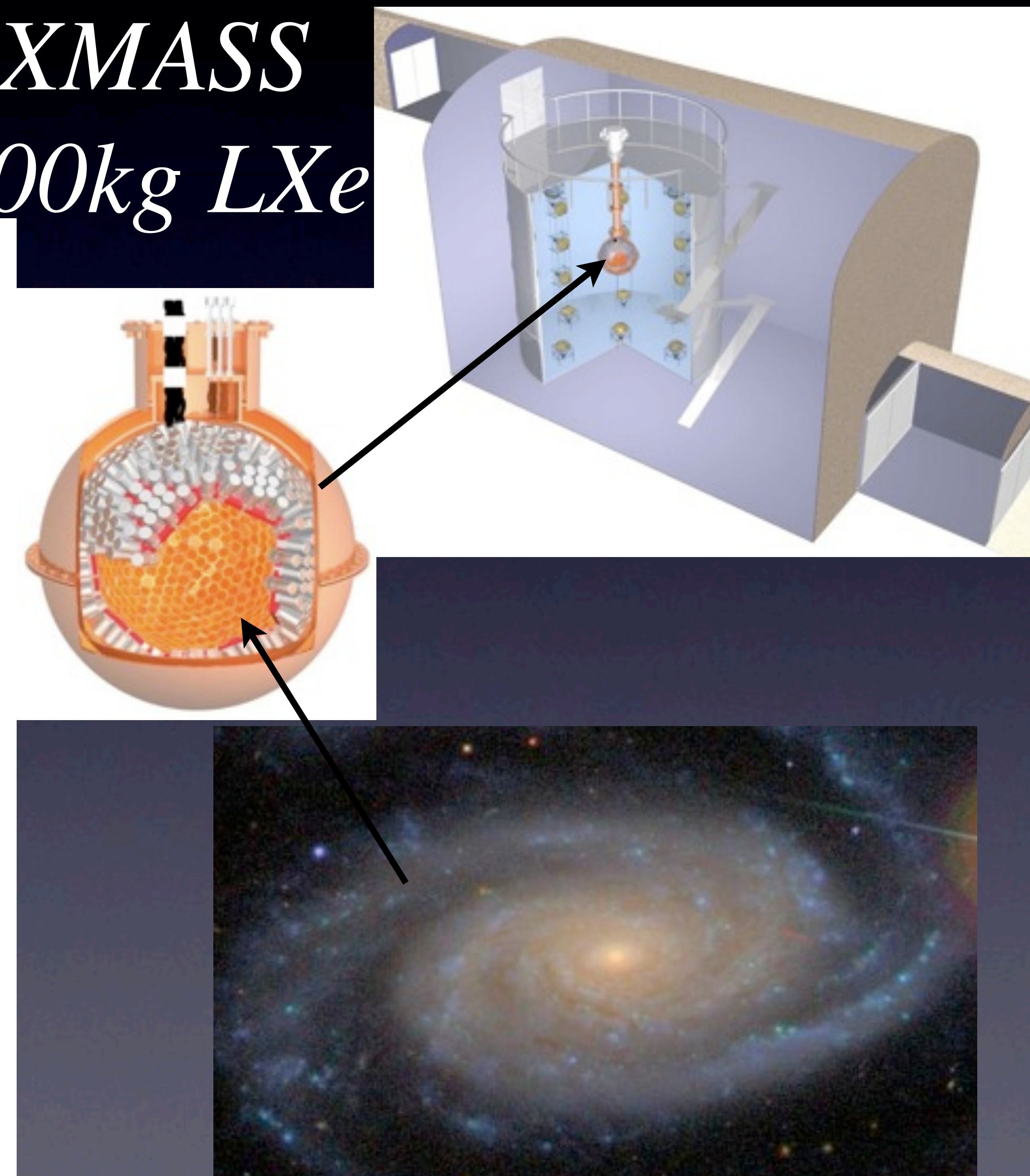
Finding Dark Matter

Direct detection

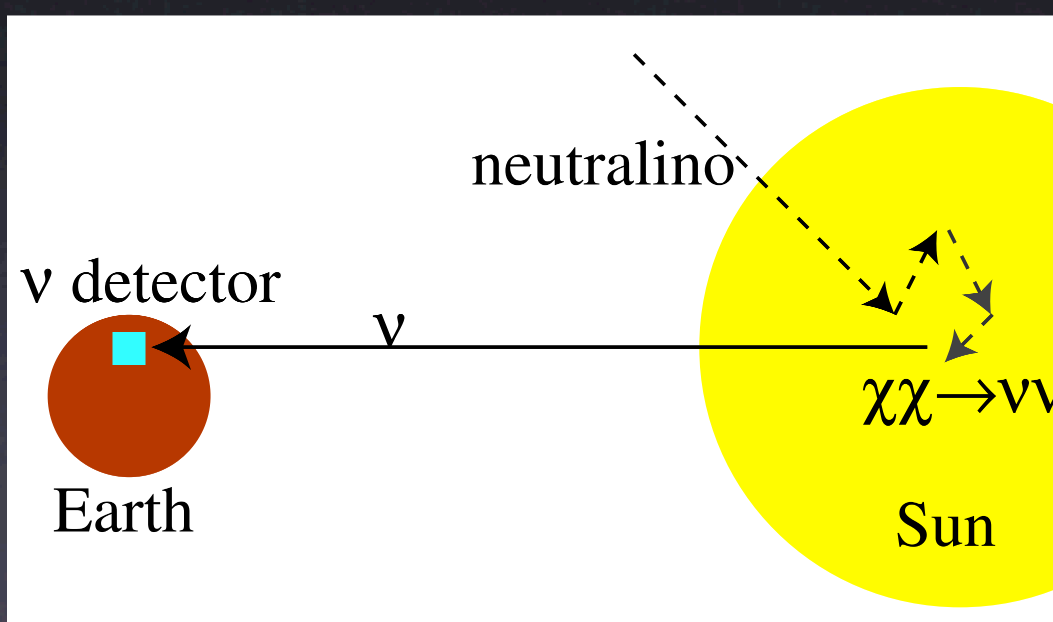
XMASS
800kg LXe



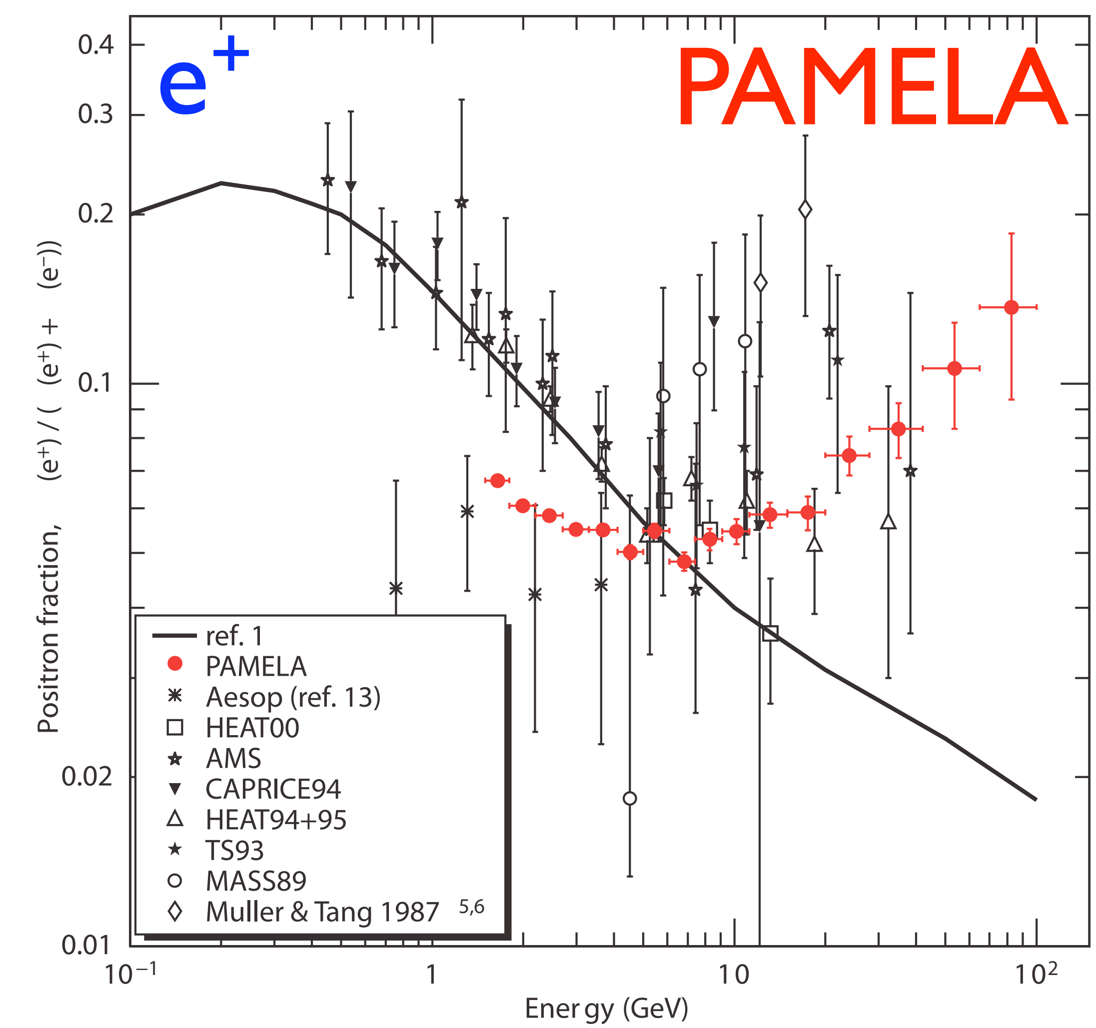


Finding Dark Matter

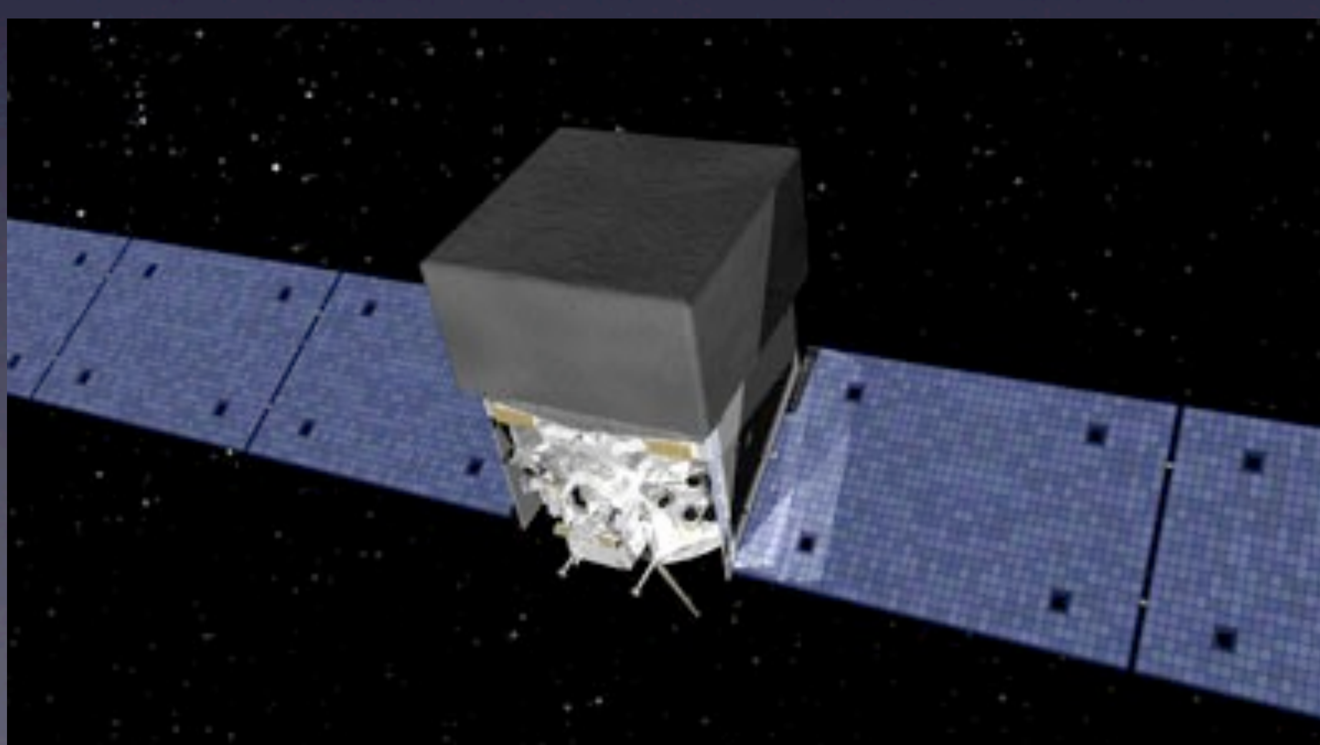
Indirect method

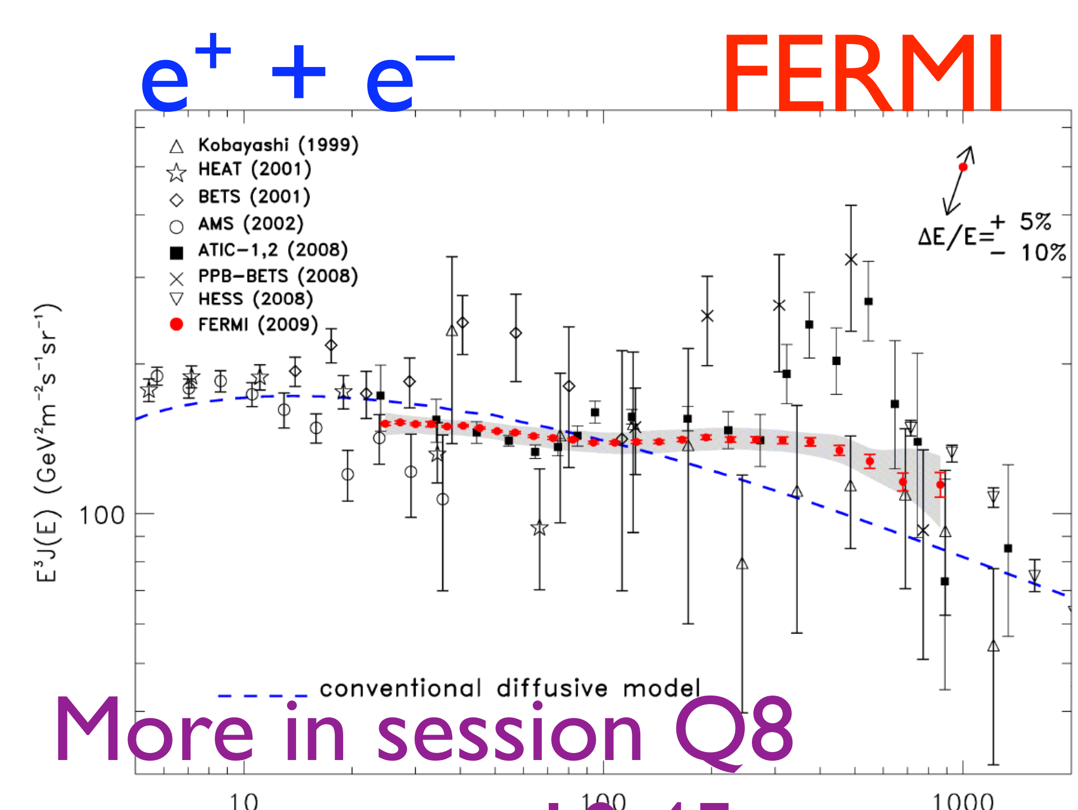


PAMELA



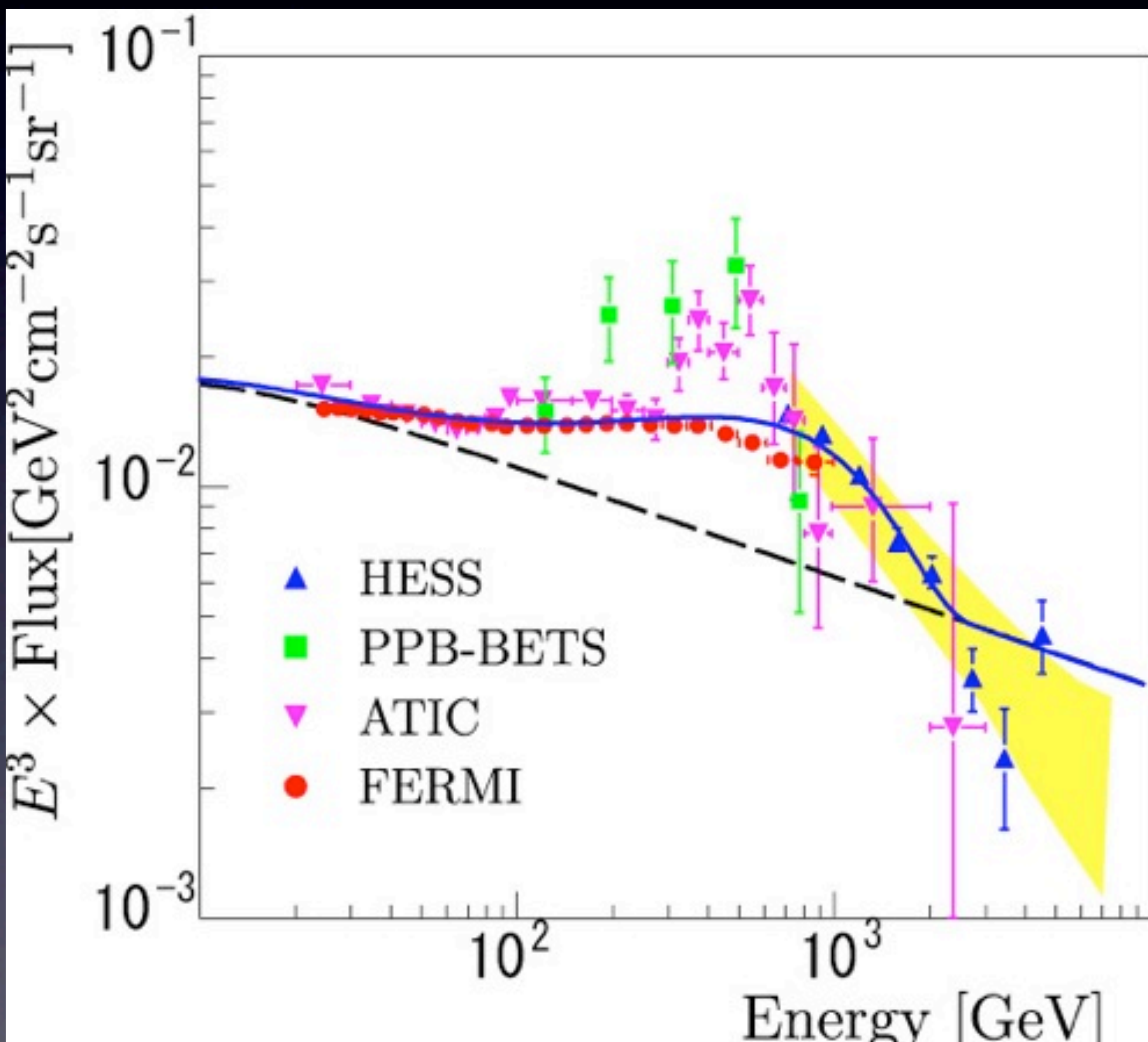
FERMI

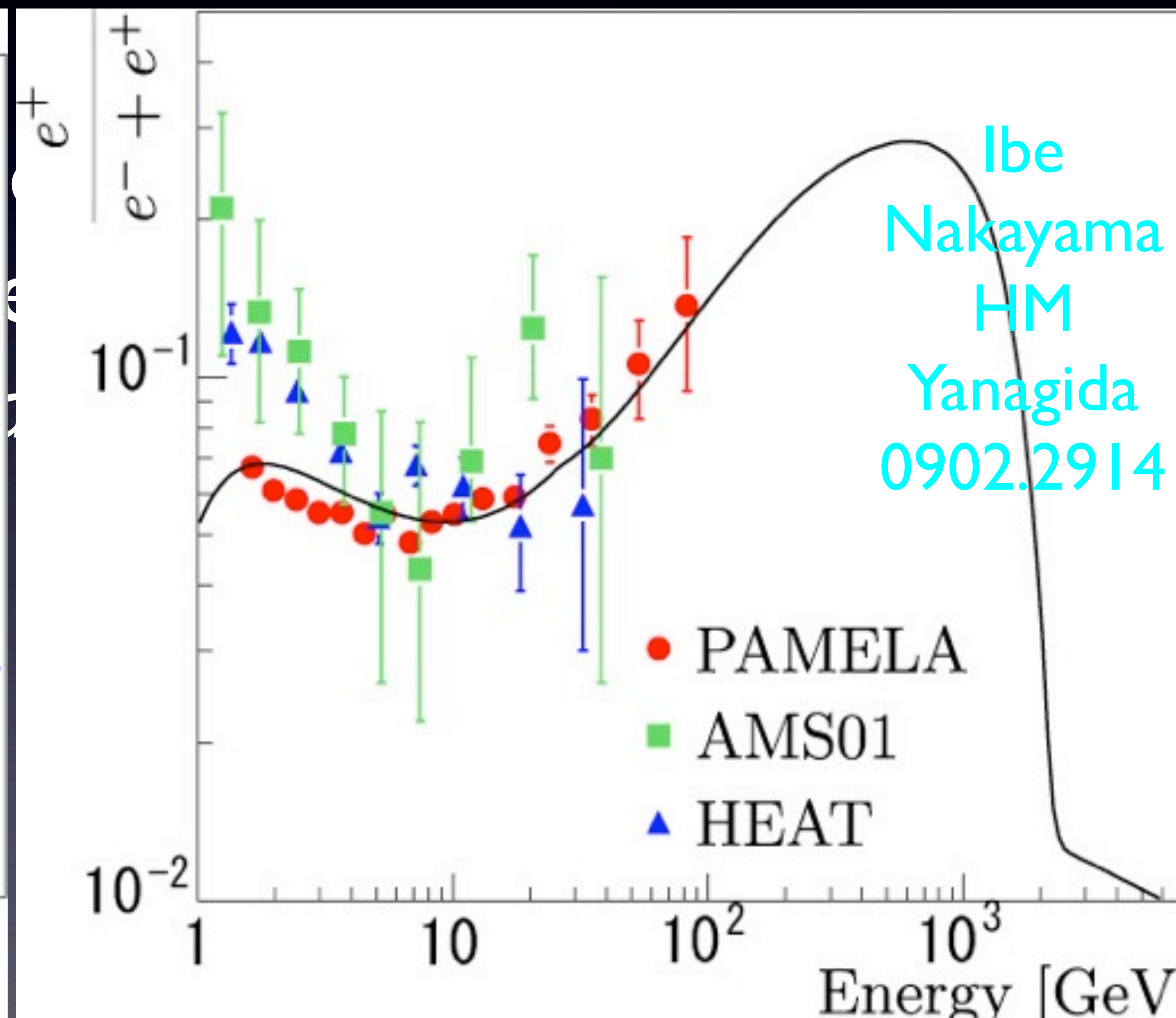




More in session Q8 tomorrow 10:45

Nambu-Goldstone Dark Matter





Ibe
Nakayama
HM
Yanagida
0902.2914

BF=2500=overdensity×Breit-Wigner

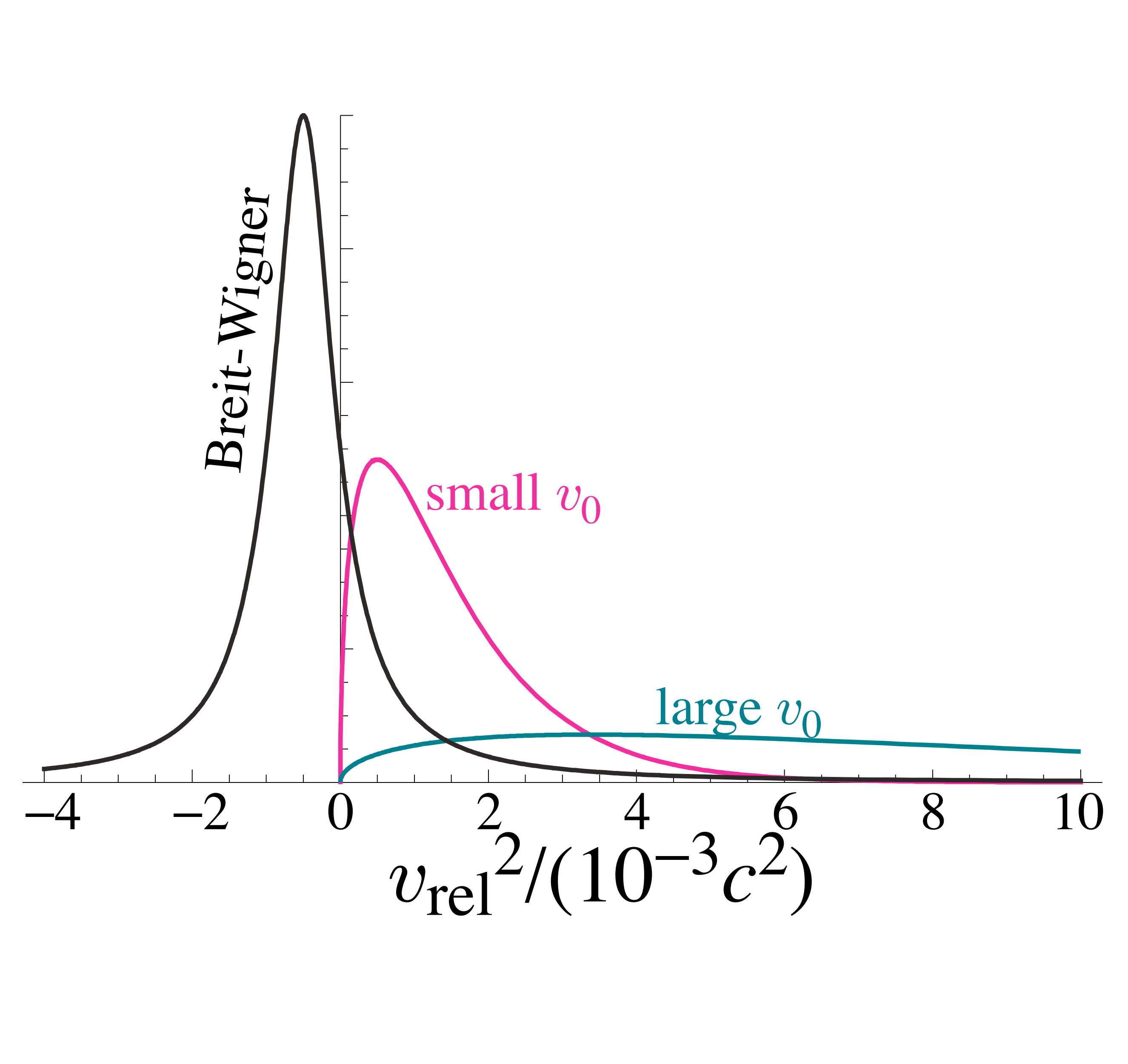
Ibe, HM, Shirai, Yanagida, in preparation

need for enhancement

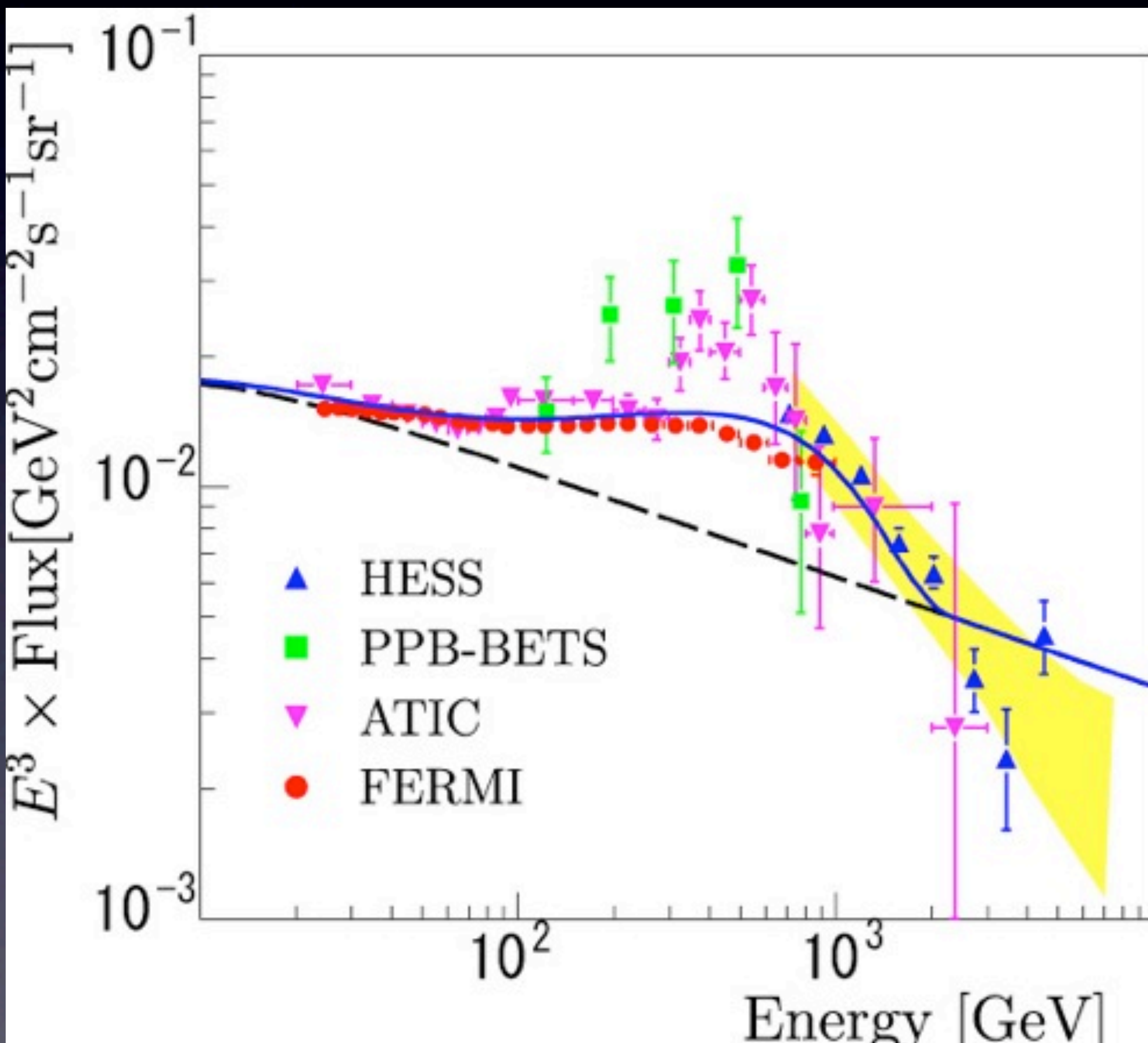
- At the freezeout, we need $\langle\sigma v\rangle \sim 10^{-9}\text{GeV}^{-2}$
- In the galactic halo, we need $\langle\sigma v\rangle \text{BR} \sim 10^{-7}\text{GeV}^{-2}$
- How do we reconcile them?
  - non-thermal relics
  - enhancement in the (halo density)^2
  - attractive force between dark matter particles (Sommerfeld enhancement)
  - Our proposal: s-channel resonance just below threshold (Breit-Wigner enhancement)

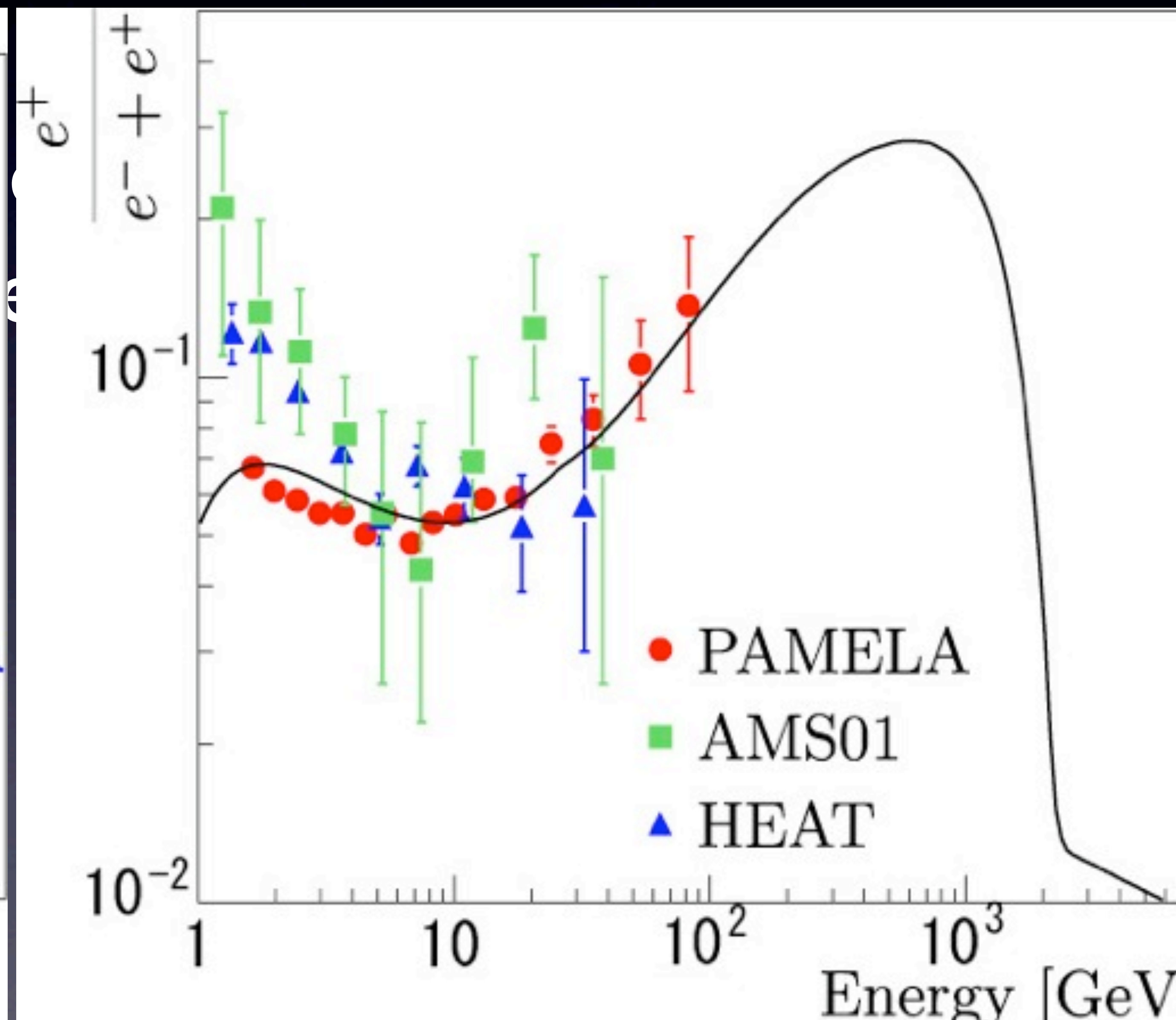
Breit-Wigner enhancement

- $s=4m^2+v_{rel}^2$
- If resonance M is below threshold $4m^2$, not accessible $v_{rel}^2<0$
- early universe, does not see the BW tail very much
- in halo, dark matter does see the tail
- called “ghost” in nuclear physics



Nambu-Goldstone Dark Matter



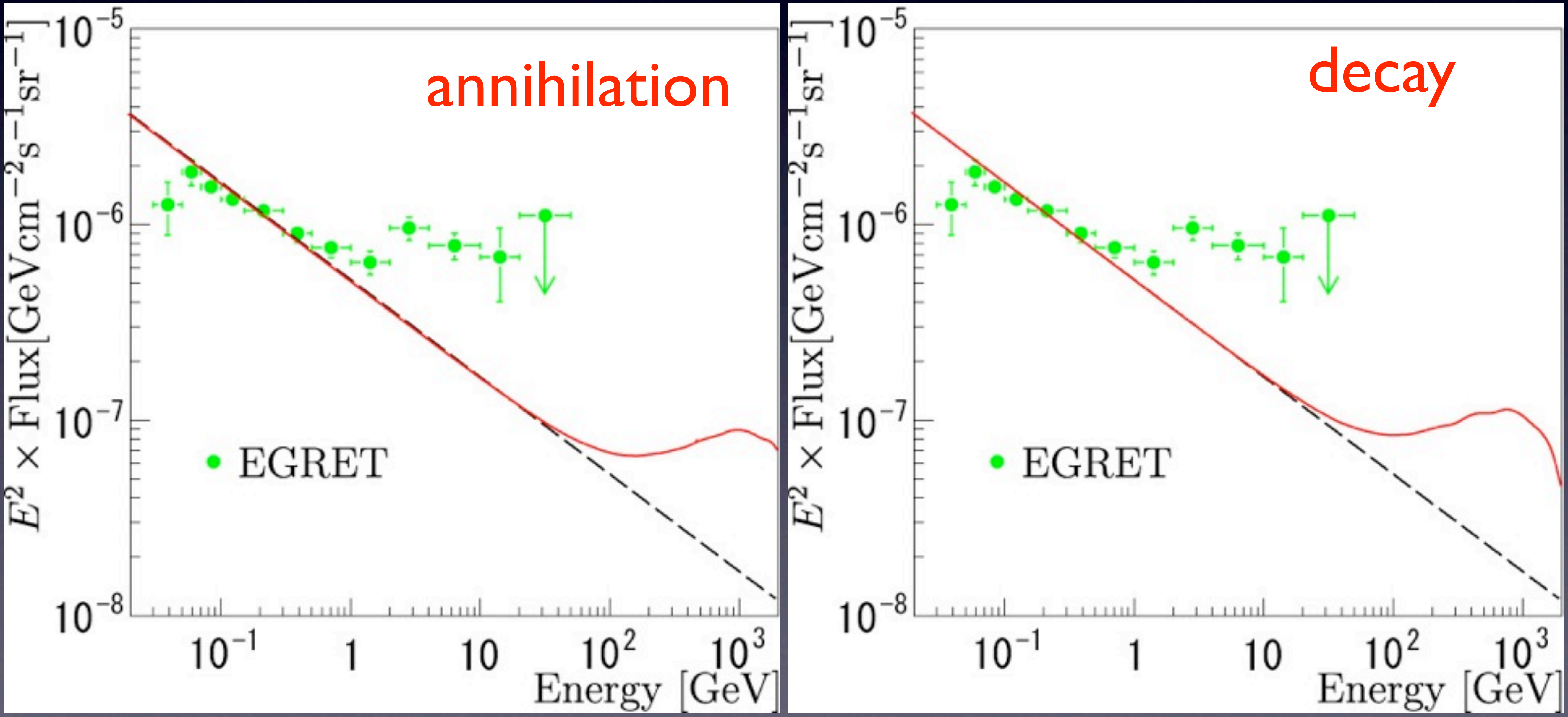


$\tau = 1.3 \times 10^{26}$ sec

Ibe, HM, Shirai, Yanagida, in preparation

prediction

- bumps in diffuse gamma



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SUSY spectrum

- no dark matter (3-5 TeV) at LHC, but associated SUSY particles within LHC
- The model predicts light gauginos
  - gluino < 1 TeV, wino < 300 GeV
- very light gravitino $m_{3/2}$<16eV with no cosmological problem
- a lot to learn from LHC!

Large Hadron Collider (LHC)

Recreating Big Bang

Standard WIMP

- SUSY, Universal Extra Dimensions, Little Higgs with T-parity, Warped Extra Dimension, ...
- Can produce dark matter directly at LHC
- missing $\not{E}_T$ signature
- details depend on models, parameters

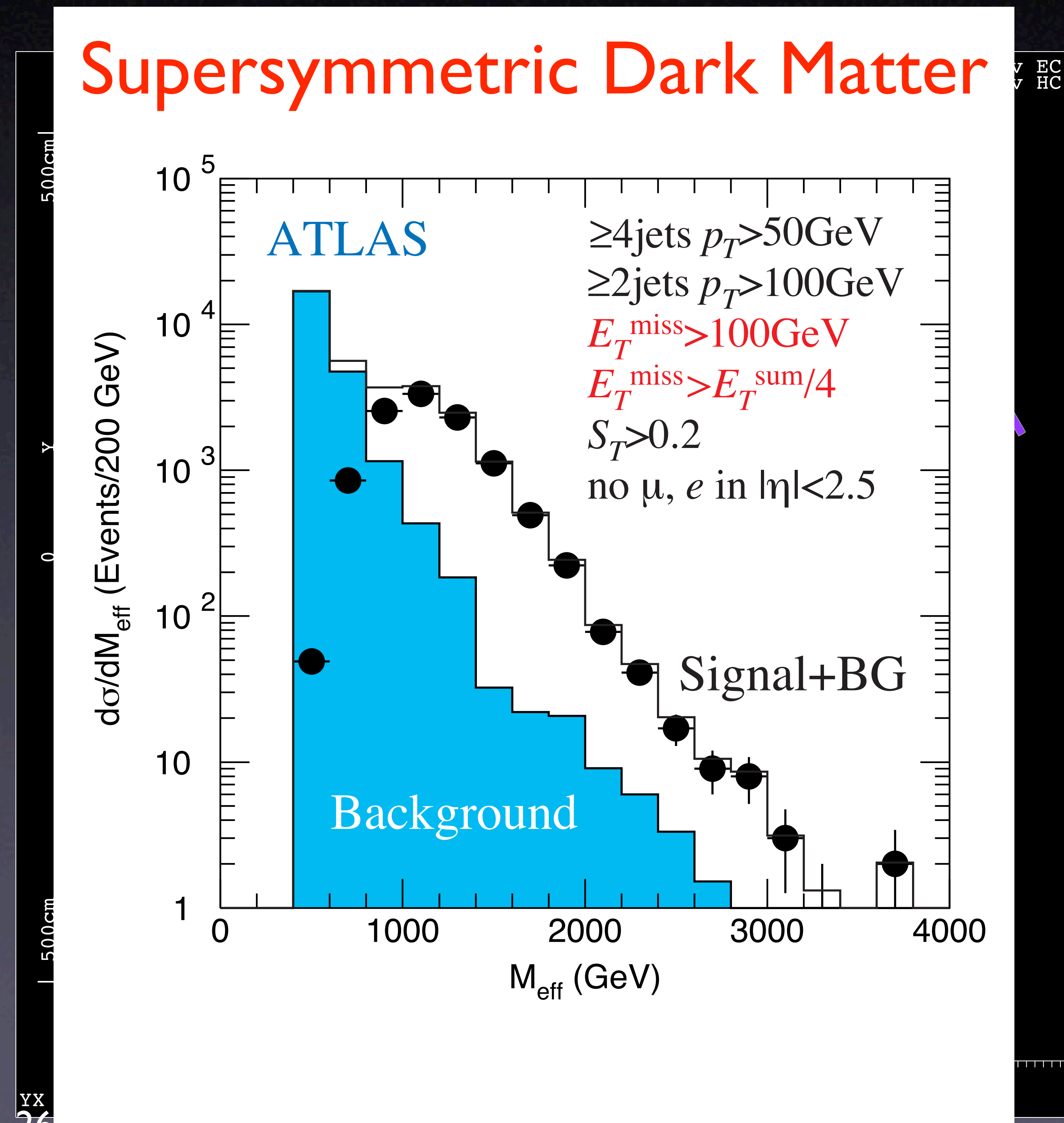
Producing Dark Matter in the laboratory

- Mimic Big Bang in the lab
- Hope to create invisible Dark Matter particles
- Look for events where energy and momenta are unbalanced

“missing energy” E_{miss}

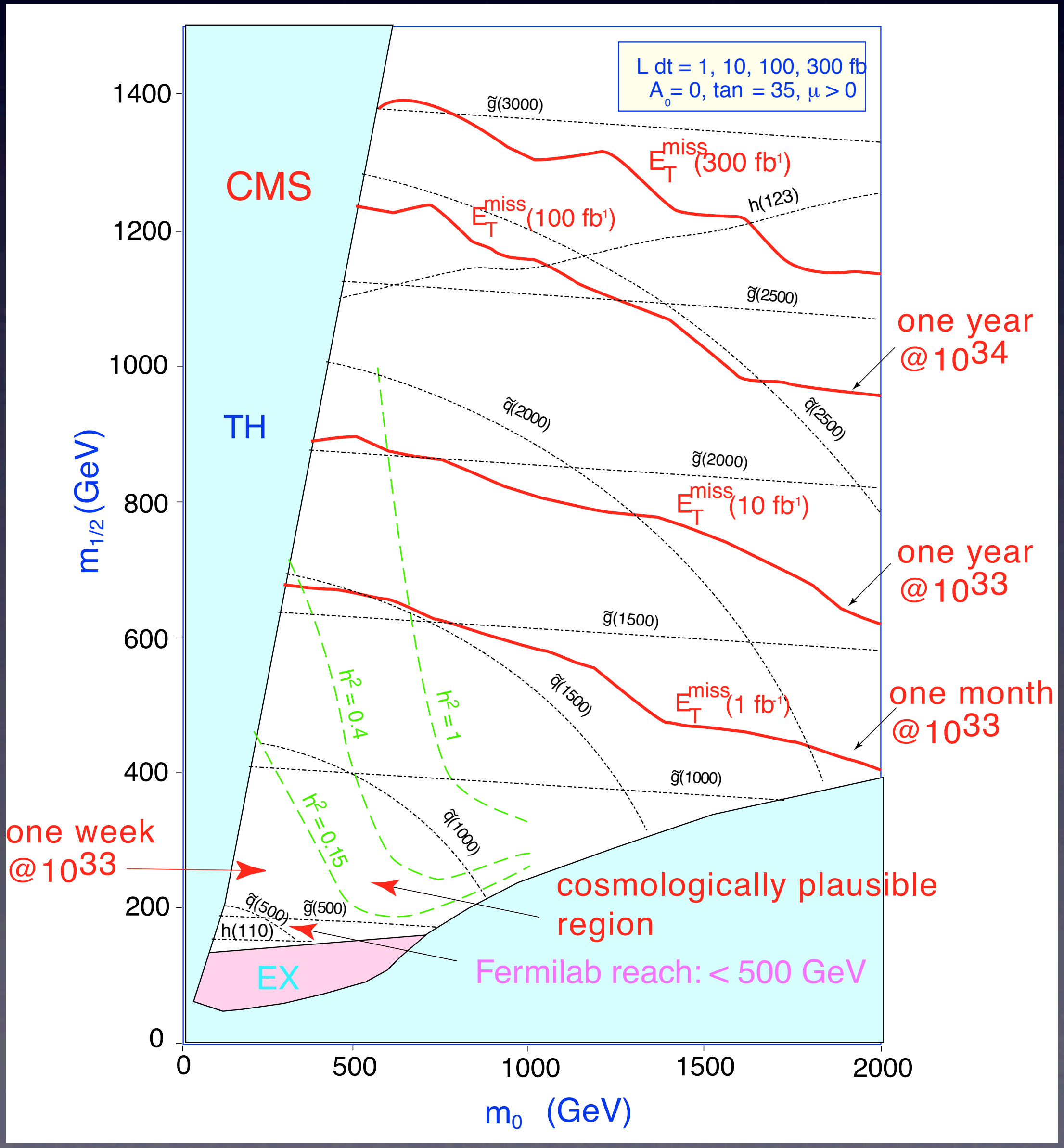
- Something is escaping the detector

⇒Dark Matter!?

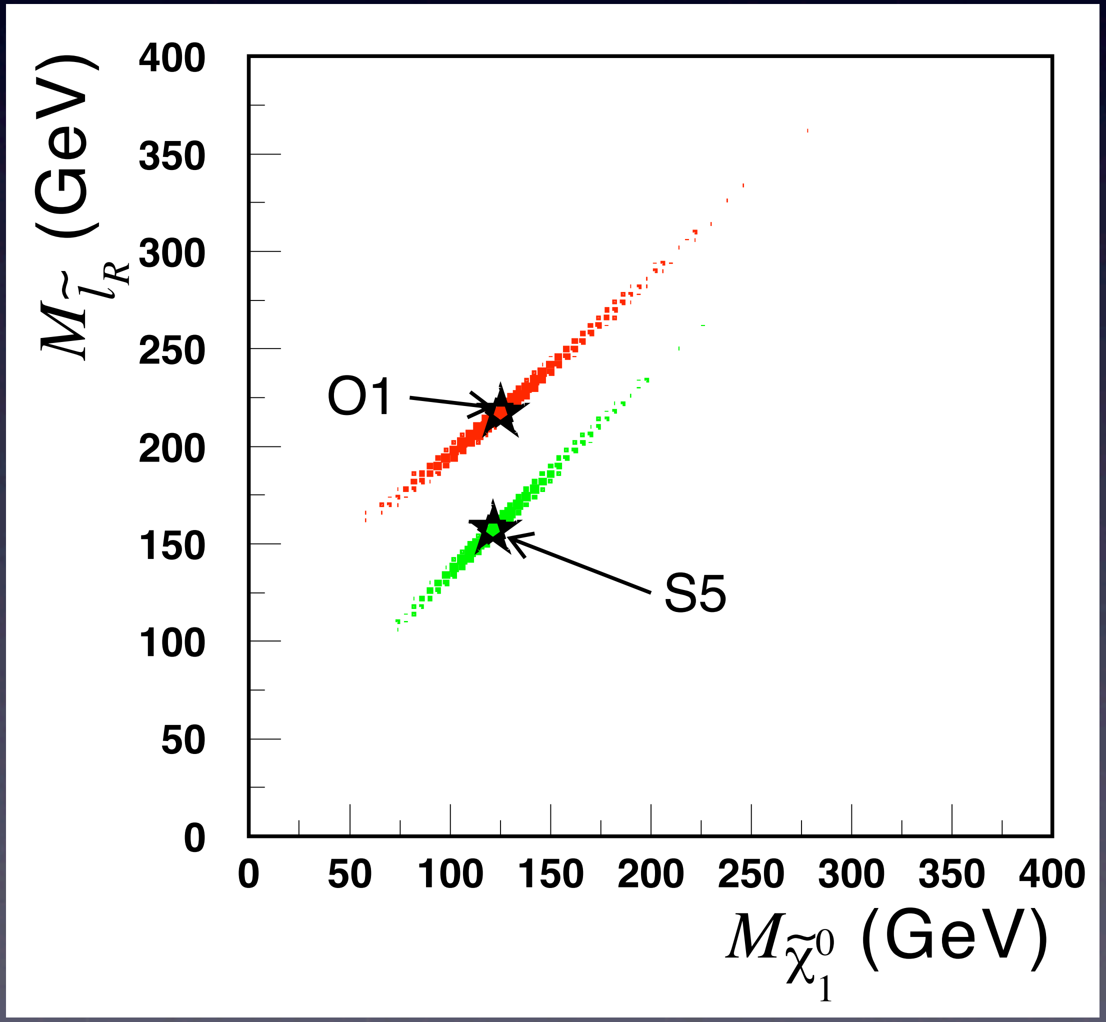


Supersymmetry

amazing reach

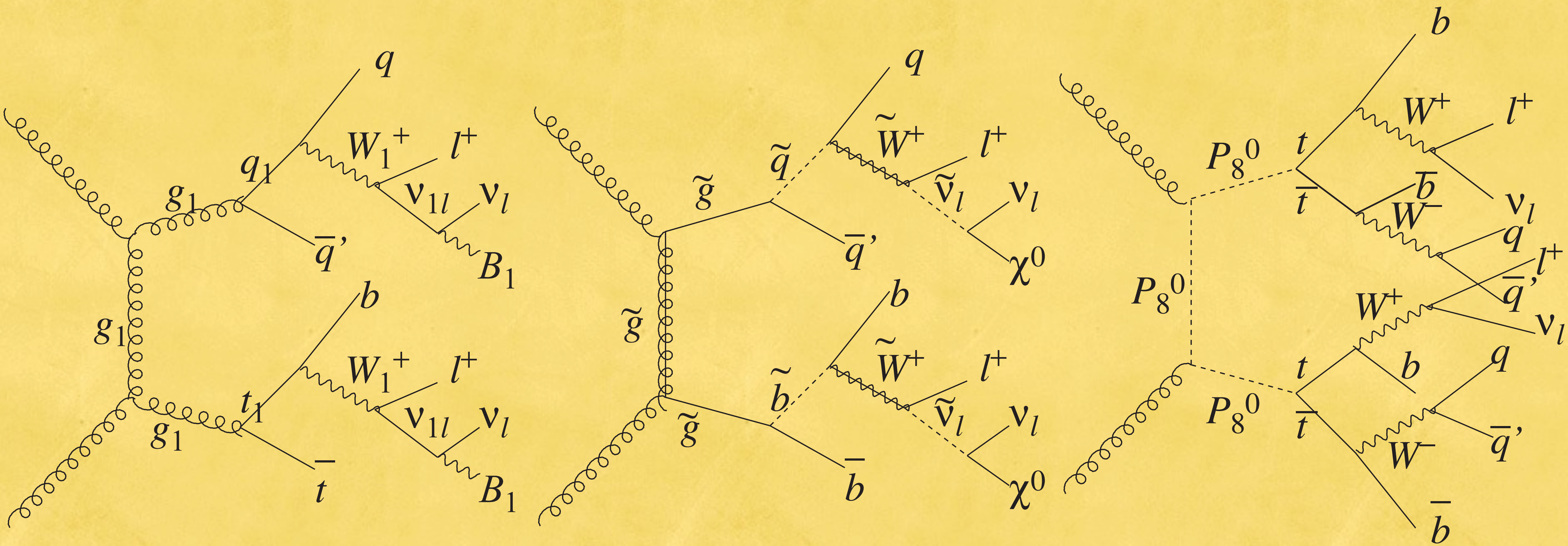


Can do many precision measurements at LHC



New physics looks alike

missing E_T, multiple jets, b-jets, (like-sign) di-leptons



UED
spin 1

SUSY
spin 1/2

technicolor
spin 0

+little Higgs with T-parity, warped ED with Z_3 baryon

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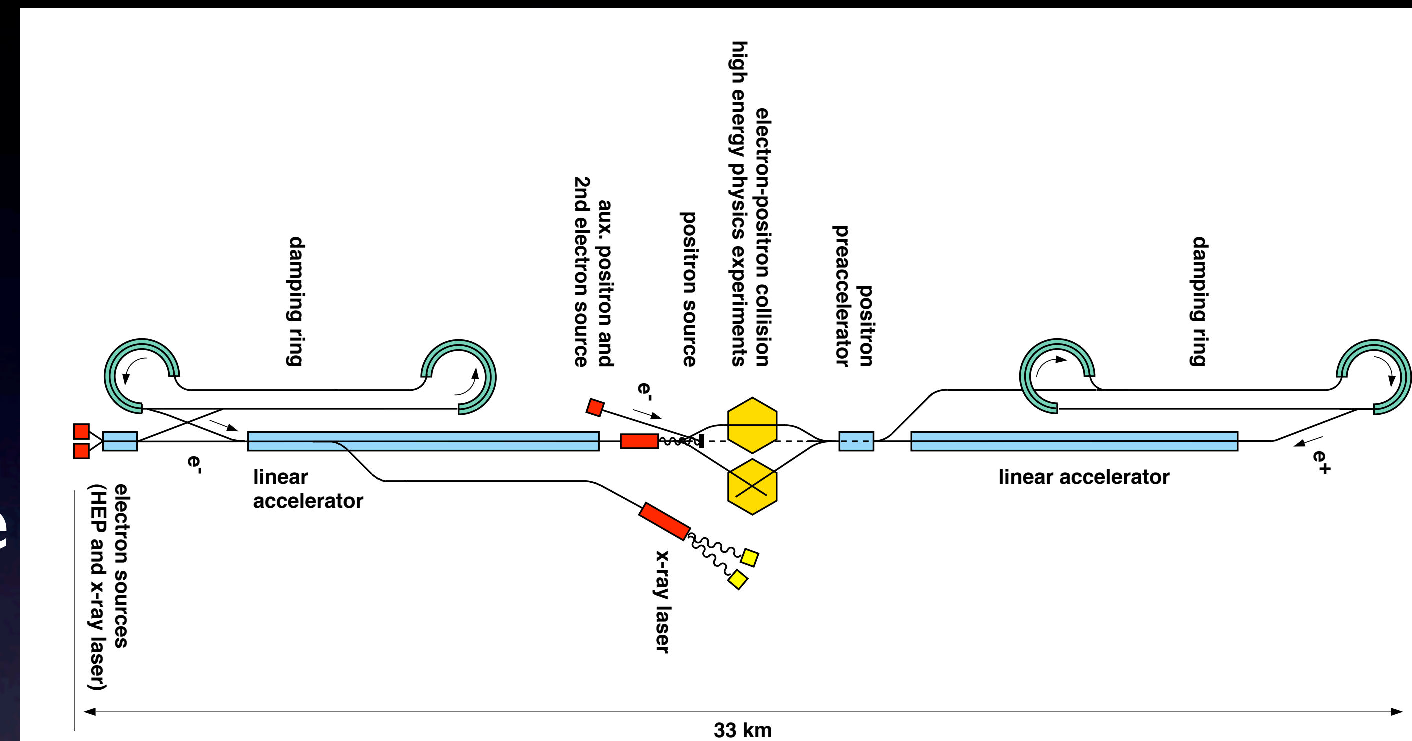
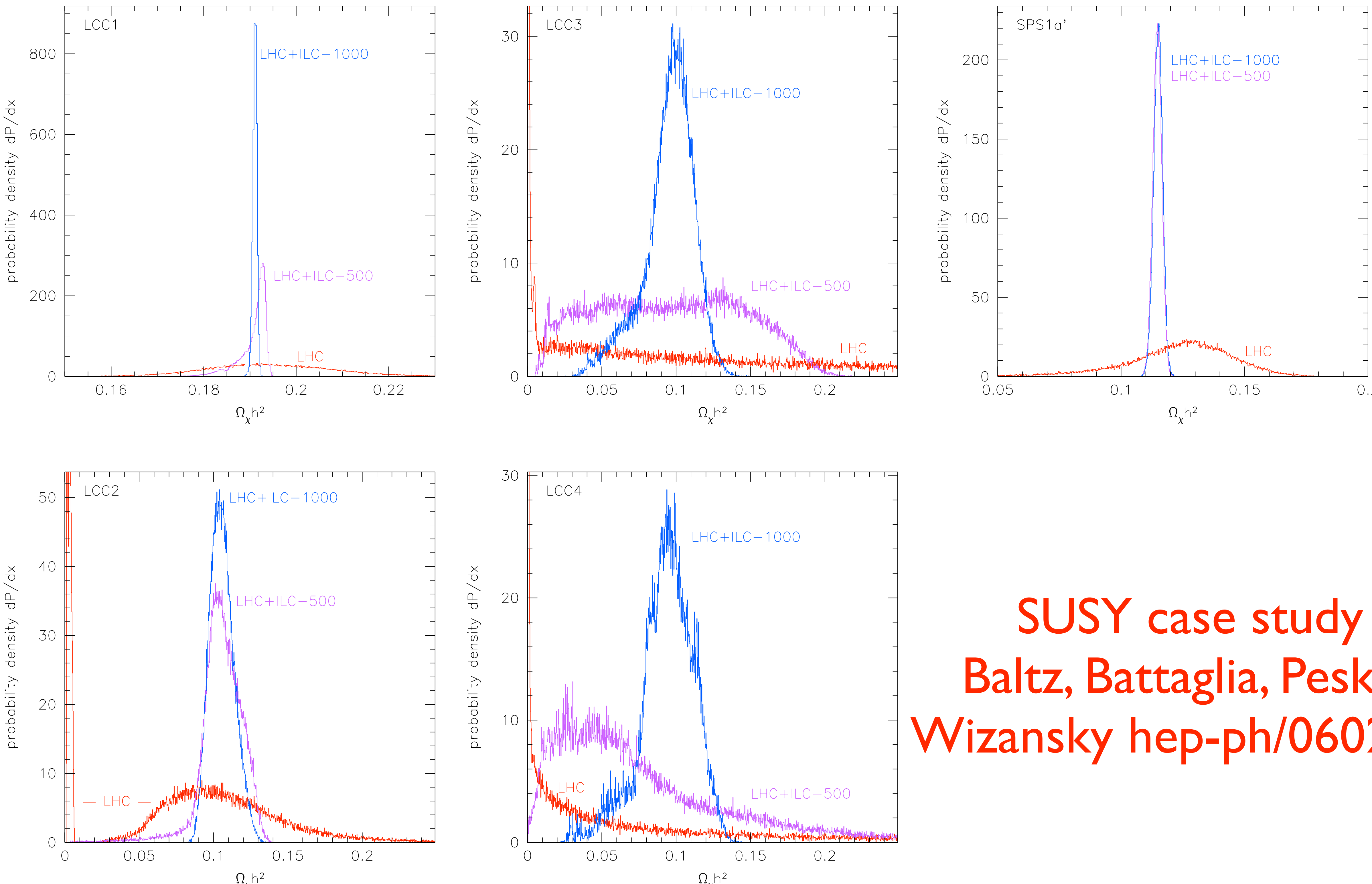
Linear Collider

- Electron-positron collider
- Super-high-tech machine
- Accelerate the beam over ten miles
- Focus beam down to a few nanometers and make them collide
- Precisely measure the dark matter properties



International Linear Collider (ILC)

Omega from colliders



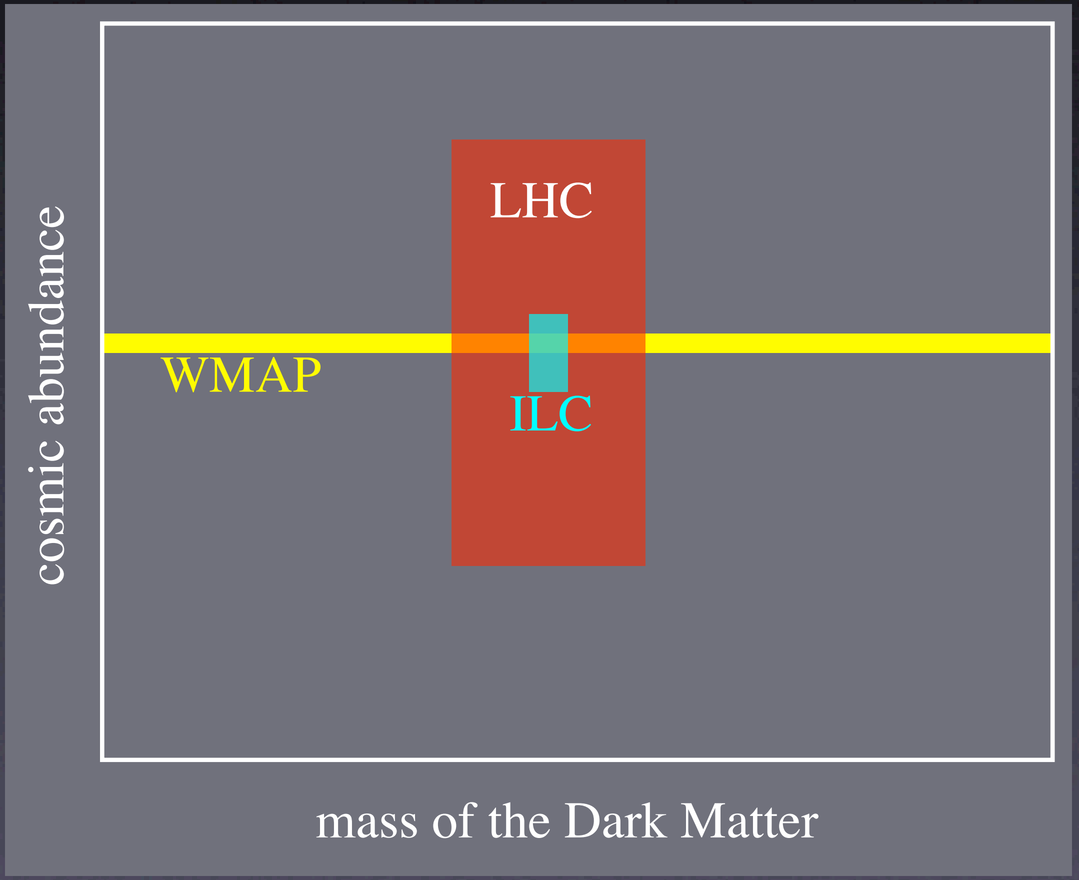
SUSY case study
Baltz, Battaglia, Peskin, Wizansky hep-ph/0602187

How do we know what Dark Matter *is*?

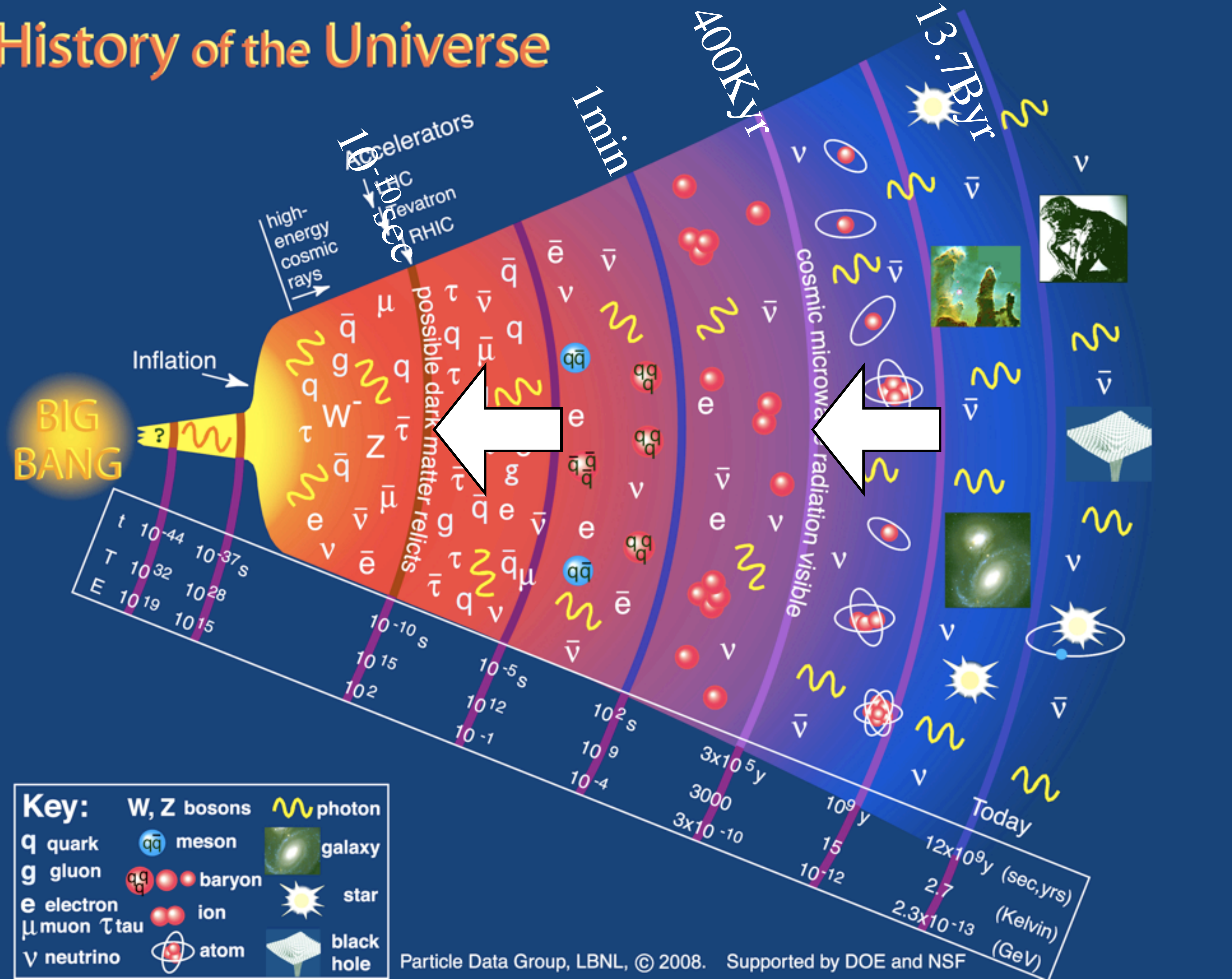
- cosmological measurement of dark matter
  - abundance $\propto \sigma_{ann}^{-1}$
- detection experiments
  - scattering cross section
- production at colliders
  - mass, couplings
  - can calculate cross sections
- If they agree with each other:

$\Longrightarrow$ Will know *what Dark Matter is*

$\Longrightarrow$ Will understand universe back to t~10^{-10} sec



History of the Universe



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Conclusion

- Major puzzles at the intersection of particle physics and cosmology
- TeV energy scale appears relevant
  - Dark Matter, Dark Field
- Possibly also origin of baryon asymmetry
- We are finally getting there with LHC!
- combine LHC with underground, astro, cosmic ray, CMB, followed by LC


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