Astro 596/496 NPA
Lecture 23
Oct. 16, 2009

Announcements:
- Preflight 4 was due today
- Problem Set 4 out, due in class next Friday

Lingering issues from Last time: Supersymmetry

★ key point: $m(\tilde{x}) > m(x)$ always–spartners heavier
so $\tilde{x} \rightarrow x +$ junk if allowed by R-parity
Why? otherwise SUSY trivially dead–no spartners found (yet!)
How? *not* automatic–SUSY symmetry "breaking" required
many schemes exist; least elegant SUSY aspect (in my view)

★ SUSY decays: obey normal conservation laws + R-parity
e.g., squark $\tilde{q} \rightarrow q + \tilde{\gamma}$
check electric charge, baryon #, angular momentum

Q: WIMP detection methods?

The Particle Dark Matter Trifecta

Create in Accelerators

Tevatron/LHC creates TeV WIMP

or more likely: detects new physics implying WIMPS (e.g., SUSY)

Directly Detect in Underground Experiments

see signal WIMP-nucleus scattering

note: DAMA experiment claims signal at high confidence!

`www: DAMA signal`

...but nobody else sees it...

Indirectly Detect Annihilation Products

- locally: see products as anomalous cosmic rays
  2009: e^+ excess seen! ...but could have astrophysical origin
- at Galactic center
  Q: why is this an interesting region?

Indirect Detection: Galactic Center Annihilation

Galactic center is $\rho_{\rm DM}$ peak $\rightarrow$ annihilation goldmine!?!

Direct Photon Production

★ $\psi\bar{\psi} \rightarrow \gamma\gamma$ line: $E_\gamma = m_\psi$, and

★ $\psi\bar{\psi} \rightarrow q\bar{q} \rightarrow \pi^0 \rightarrow \gamma\gamma$ continuum $E_\gamma < m_\psi$

Galactic center seen in GeV range (1990's: EGRET)
with poorly understood "GeV excess"!?!

But new γ-ray observatory `www: Fermi`
launched last year, finds no GeV excess

Galactic center seen in TeV range

`www: HESS`

but point source too localized(?), energy spectrum a power-law

Synchrotron Radiation

if $\psi\bar{\psi}\to e^+e^-$: source of high-energy e^+

move in strong Galactic B field*:

accelerated (spiral path) $\to$ synchrotron radiation

emission from radio bands, possibly up to X-ray

$\to$ recent claim: radio & sub-mm observations currently *strongest astronomical DM constraint!*

beat out γs! (but less clean, no direction info)

Neutrino Production

from $\psi\bar{\psi}\to\nu\bar{\nu}$, but more from $\psi\bar{\psi}\to q\bar{q}\to \pi^\pm\to \nu_e\nu_\mu\bar{\nu}_\mu$

`www: http://icecube.wisc.edu`ICECUBE

use South Pole ice as target

monitor with array of buried photomultipliers

observe e^- Čerenkov light from elastic $\nu e\to\nu e$

* no relation to instructor

Supersymmetric Dark Matter: Where Do We stand?

Obviously, no clear detections thus far

Current status:
accelerator and astrophysical constraints are:
competitive: both place strong constraints
on allowed MSSM SUSY parameters $(m_0, m_{3/2}, \mu, A, \tan\beta)$
complementary: different methods strong in different parts
of parameter space

Upgrades coming soon on all fronts
$\longrightarrow$ the race is on!
$\longrightarrow$ an answer will emerge in the non-distant future!

If confirmed WIMP detection:

- DM found
- need particle physics beyond Standard Model

$\star$ payoff big!

If no WIMP signature

- SUSY much less attractive
- dark matter not a cold relic $\rightarrow$ what is it?
  an asymmetric relic? but why asymmetrical?
  modified gravity?
  hidden in braneworld?

Baryogenesis: Origin of Matter/Antimatter Asymmetry

Observed Matter (Baryon) Asymmetry of Univ.

As far as we are able to observe,
a cosmic asymmetry exists:
baryons and leptons dominate over
antibaryons and antileptons.

`www: schematic of scenarios`

Q: What is evidence for different scales? Solar Sytem, solar neighborhood, MW Galaxy, galaxy clusters, Hubble volume?

Evidence for Baryon Excess

Matter-only System	Asymmetry Evidence
Solar system	landings, solar wind, proto-$\odot$ neb
Cosmic rays	consistent with in-flight orign, e.g., $p_{\rm cr}p_{\rm ism}\to ppp\bar{p}$
MW Galaxy	cosmic rays, no annihilation γs
Galaxy clusters	no γ from galaxy-intracluster gas interface nor in colliding clusters $\Rightarrow$ all matter or all antimatter
Hubble volume	too few 1–10 MeV γ, no CMB distortion

no evidence for animatter "domains" anywhere

strictly: if animatter domains exist
segregated from matter on scales $\gtrsim 10^{14} M_\odot$
and probably $> d_H = 2$ Gpc

Conclude:

cosmi baryon asymmetry exists

$Y_B = n_B/s \simeq n_B/7n_\gamma = \eta/7 \sim 10^{-10}$

at $T \gtrsim \Lambda_{\rm QCD} \simeq 200$ MeV, $q\bar{q}$ pairs abundant,

$n_q \simeq n_{\bar{q}} \sim n_\gamma$, so asymm was

$$\frac{n_q - n_{\bar{q}}}{n_q + n_{\bar{q}}} \sim \frac{n_B}{n_\gamma} \sim 6 \times 10^{-10} \qquad (1)$$

for every 1,000,000,000 antiquarks

there were 1,000,000,001 quarks

a tiny but crucial excess!

but on theoretical grounds, expect particle creation in pairs

so how did this happen?