

Astro 507
Lecture 28
April 2, 2014

Announcements:

- **PF 5 due Friday**
- **No class next Monday April 7**

time off for good behavior! BDF @ APS talking BBN

Last time: Particle Dark Matter

Q: why do we think dark matter is a particle? what's it like?

Q: what's a WIMP in the WIMP miracle? why miraculous?

Q: how can we test these ideas?

WIMP Searches: Accelerators

if WIMPs exist in nature

...and especially if they are supersymmetric particles

likely to be found in \sim *few* yrs

at CERN Large Hadron Collider www: CERN, LHC

SUSY/WIMP discovery would revolutionize particle physics

and all but guarantee dark matter = cold relics

Q: what would the signature be at a collider?

What are challenges to digging it out?

Even if nature is not supersymmetric

↳ many particle theories predict new physics at \sim 1 TeV

WIMP Searches: Direct Detection

if WIMPs are DM \rightarrow dark halo full of them

local density $\rho = mn \sim 0.3 \text{ GeV cm}^{-3}$

virial velocities $v_0^2 \sim GM_{\text{halo}}/R_{\text{halo}} \sim (400 \text{ km/s})^2$

\Rightarrow WIMP flux $F_{\text{WIMP}} = nv_0$

\Rightarrow Look for *WIMP-nucleus elastic scattering* – challenging!

Search using sensitive detectors: cryogenic, underground

interaction: *WIMP collision \rightarrow nuclear recoil*

measure: effects of recoiling ($E_{\text{kin}} \sim 1 - 100 \text{ keV}$) nucleus

Q: for example?

WIMP-nucleus recoil signatures

- ▶ *energy injection*: recoil heats detector
crystal specific heat $C = dE/dT \sim T^3$
 $\Delta T = \Delta E/C \propto T^{-3}$
if supercold, can detect ΔT rise
- ▶ *momentum transfer*: detector lattice (phonons) excited
- ▶ *scintillation, ionization*: charged recoil nucleus excites medium
relax via γ, e , phonon emission \rightarrow detect these

Hints at WIMPS?

several direct detection experiments see...*anomalies*

- DAMA (≥ 1998): 250 kg NaI, Gran Sasso, Italy
annual modulation seen ! very high significance

Q: why is $P = 1$ yr modulation interesting?

- CRESST (2011): CaWO₄ crystals, 730 kg days, Gran Sasso
excess of events in signal region

- CoGENT (2011, 2013): 100 g Ge, Soudan, Minnesota
annual modulation announced

- ⁵ ● CDMS Si (2013): silicon, low-background, 124 kg days, Soudan
excess of events in signal region

what if anomalies are dark matter?

www: plots of $\sigma_{\chi N \rightarrow \chi N}$ vs m_χ

- recoils are low-energy \rightarrow suggest “light” dark matter
 $m_\chi \sim 10m_{\text{nucleon}} \sim 10 \text{ GeV}$: weak nuclear recoil
- curse: low-energy recoils more difficult to dig from noise
- note: not all anomalies are consistent with each other

But: *many other experiments see nothing*, especially

- LUX: 370 kg liquid Xe, Sanford Laboratory, South Dakota
- SuperCDMS: SNOLab, Canada

at face value, LUX rules out other signals

though alternatives remain (DM-nucleon spin dependence, DM bound states)

clearly: situation messy and confused!

that's still not all...

Q: astrophysical means infer WIMP existence and properties?

WIMP Searches: Indirect Detection

if WIMPs are DM \rightarrow Galactic dark halo full of them
but Galactic halo density \gg cosmic mean
 \rightarrow annihilation rate $q \propto \langle \sigma_{\text{ann}} v \rangle \rho_{\text{wimp}}^2$ can be large
 \rightarrow annihilation products potentially observable

Local annihilations

Q: how see if $\chi\bar{\chi} \rightarrow \gamma\gamma$ only?

Q: how see if $\chi\bar{\chi} \rightarrow$ other Standard Model particles?

e.g., $\chi\bar{\chi} \rightarrow e^+e^-$ or $q\bar{q}$?

Galactic center annihilations

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Indirect Detection: Local Annihilation Signatures

if $\chi\bar{\chi} \rightarrow \gamma\gamma$ only: line emission $E_\gamma \sim m_\chi$

\Rightarrow local contribution to diffuse γ signature

but: two-photon annihilation $\chi\bar{\chi} \rightarrow \gamma\gamma$ must be *suppressed*

else χ has direct EM coupling \rightarrow electric charge \rightarrow DM not dark!

but *can and often do* have things like $\chi\bar{\chi} \rightarrow \pi's \rightarrow \gamma's$

if $\chi\bar{\chi} \rightarrow q\bar{q}$: hadronize, sometimes to nucleons $N\bar{N}$

source of \bar{n}, \bar{p} , and $\bar{d} = \boxed{\bar{n}\bar{p}}$

\Rightarrow can look for these in *cosmic rays!*

but “foreground”: “normal” antimatter

from cosmic ray propagation

e.g., $p_{\text{cr}} + p_{\text{ISM}} \rightarrow ppp\bar{p}$

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if $\chi\bar{\chi} \rightarrow e^+e^-$: local source of *high-energy* e^+

Indirect Detection: Galactic Center Annihilation

Galactic center is ρ_{DM} peak \rightarrow annihilation goldmine!?!

Direct Photon Production

- ★ $\chi\bar{\chi} \rightarrow \gamma\gamma$ line: $E_\gamma = m_\chi$, and
- ★ $\chi\bar{\chi} \rightarrow q\bar{q} \rightarrow \pi^0 \rightarrow \gamma\gamma$ continuum $E_\gamma < m_\chi$

Galactic center seen in TeV range

www: HESS

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

Galactic center in GeV range

www: Fermi sky

astrophysical foregrounds large:

- cosmic-ray interactions with ISM
- in Galactic plane $p_{cr} + p_{ism} \rightarrow \pi^0 \rightarrow \gamma\gamma$

Daylan+ (2014): strongest claims of non-astrophysical signal
centered on Galactic center, axisymmetric geometry
energy spectrum $\rightarrow \chi\chi \rightarrow b\bar{b}$, $m_\chi \sim 30$ GeV

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 particle models for WIMPS

complementary: different methods strong in different parts
of parameter space

Upgrades coming soon on all fronts

→ the race is on!

→ an answer will emerge in the non-distant future!

If confirmed WIMP detection:

- DM found
- need particle physics beyond Standard Model
- ★ payoff big!

If no WIMP signature

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