Baryogenesis and Particle Physics

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Baryogenesis: One of the Large Questions in Our Field

Given the success of inflation, probably not an initial condition.
We have known for almost 50 years the basic conditions (Sakharov).
Several ideas to implement:

1. Electroweak baryogenesis
2. Leptogenesis
3. Affleck-Dine Baryogeneisis

Big question: Can we tell, through experiments or observations?

Electroweak Baryogenesis: most promising, Can't occur in minimal standard model. *Need new degrees of freedom at relatively low energy scales.* In MSSM and extensions, only possible in narrow regions of parameter space. Reheating after inflation at least to weak scale.

If discovered, spectacular. Could hope to infer baryogenesis mechanisms from (measured) parameters.

Exciting in that some states must be rather light, but only narrow slivers of parameter space left (Kozaczuk talk this session).

Leptogenesis: relies on facts we know about neutrinos (or almost know): lepton number violation. Readily implemented in models with heavy right handed neutrinos. No smoking gun. Can't measure all of the relevant parameters. Detailed cosmological picture. High reheat temperature after inflation probably required. No direct tie to supersymmetry or other possible new low energy phenomena.

Affleck-Dine baryogenesis

Supersymmetry intrinsic. But discovery of supersymmetry is not incompatible with electroweak baryogenesis or leptogenesis.

Relies on approximate flat directions of MSSM (or extensions).

But what would AD Baryogenesis say about the scale of supersymmetry breaking (or vice versa)?

If supersymmetry “natural" (= LHC discovery), then AD baryogenesis highly plausible. Experiment could discover the relevant degrees of freedom. Better than leptogenesis. But, as for leptogenesis, no “smoking gun". Establishing that AD baryogenesis operative requires knowledge of high dimensional couplings, initial conditions for fields in flat directions.

Q-Balls as dark matter are one possible piece of evidence.

Detection strategies not as straightforward as for WIMP dark matter. Depend on size. Much of parameter space ruled out.

Other possibilities? Higher dimension operators studied through baryon, lepton number violation? Connections to phenomenon in inflationary cosmology?

Some study of possible correlations recently by D. Marsh, and there are possibilities, e.g. for back reaction on inflation in particular inflationary scenarios.

Moduli and the Scale of Supersymmetry Breaking

Presence or absence of moduli controlling feature for scale of supersymmetry breaking: (Bose, Draper, M.D. building on work of Banks, Kaplan, Nelson, Randall and Moroi, others):

1. No moduli: conventional ideas of naturalness should be operative, thermal dark matter likely. Hard to reconcile with Higgs mass, LEP and LHC exclusions. Strong CP problem (no axion?) Leptogenesis, electroweak baryogenesis possible (universe once hot enough)
2. Supersymmetric moduli (only) ($F_M \ll m_{3/2} M_p$): constraints if LSP produced in decays. Still no axions. Conventional ideas about naturalness still hold. Leptogenesis, electroweak baryogenesis more problematic (universe may never have been hot enough).
3. Non-supersymmetric moduli: require large mass to reheat to temperatures above nucleosynthesis temperature (10's of TeV). Universe never hot enough for leptogenesis, electroweak baryogenesis.

The case of non-supersymmetric moduli would seem particularly generic and interesting. If stable dark matter, constraints on spectrum (moduli lighter than LSP, in general). Baryogenesis: require AD. AD readily implemented, even for such high scales of susy breaking.

For high scale susy breaking, first clues likely to be rare processes (Edm's, $\mu \to e + \gamma$, etc.)

Other ideas re moduli and AD baryogenesis explored recently by Garcia and Olive.

Conclusion: Two Possible Implementations of AD Baryogenesis

1. if low energy susy discovered, clearly AD baryogenesis interesting and potentially operative.
2. If evidence that susy at a higher scale (as suggested by Higgs mass), likely that universe was never terribly hot, and AD baryogenesis was quite likely relevant.