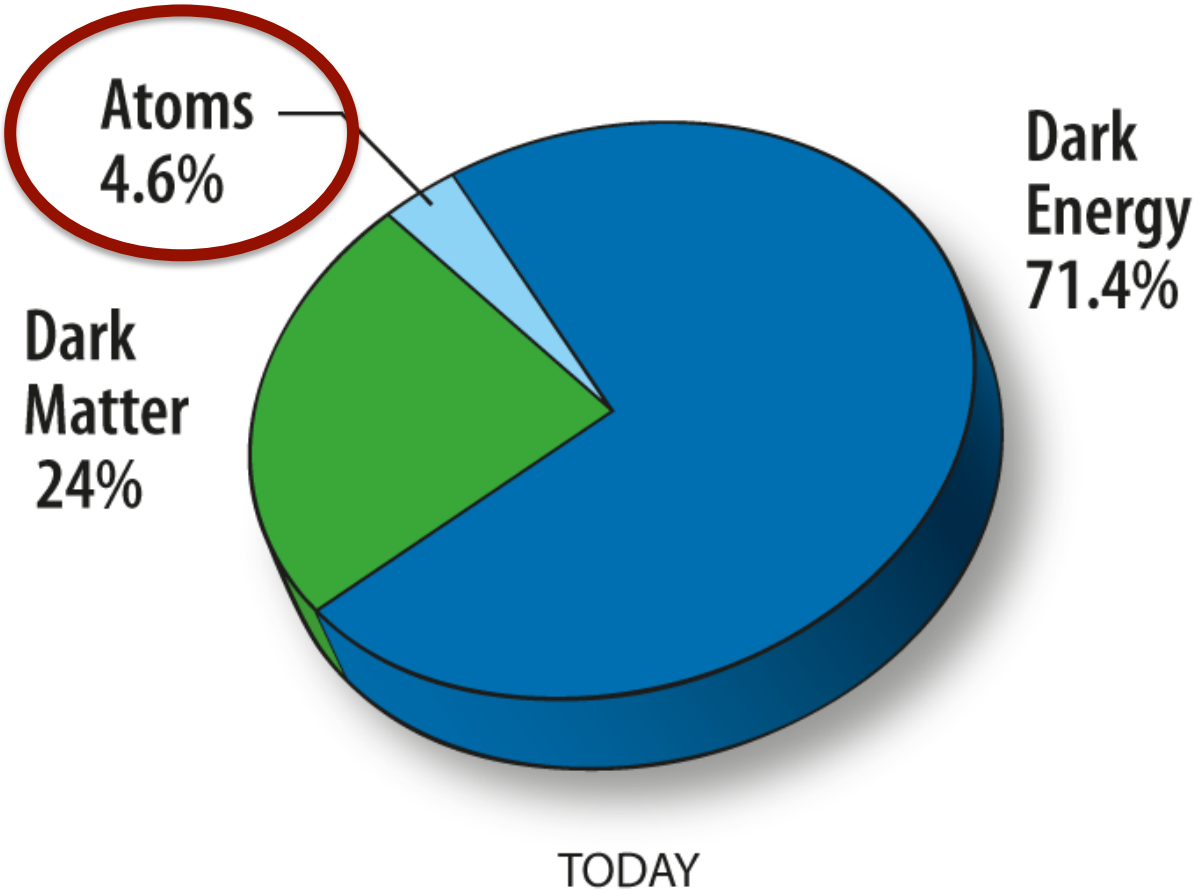
# CF6: Cosmic Particles & Fundamental Physics

J. Beatty, A. Nelson, A. Olinto, G. Sinnis



Busy Atoms!!!!

# CF6: Cosmic Particles & Fundamental Physics

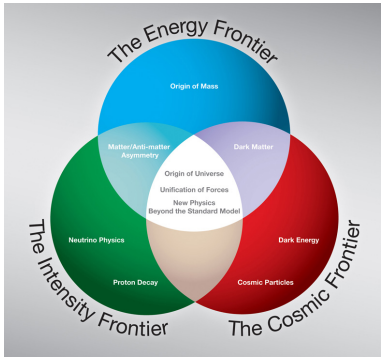
J. Beatty, A. Nelson, A. Olinto, G. Sinnis

**CF6-A Cosmic Rays, Gamma Rays and Neutrinos** (conveners: **Gus Sinnis**, Tom Weiler)

**CF6-B The Matter of the Cosmological Asymmetry** (convener: **Ann Nelson**)

**CF6-C Exploring the Basic Nature of Space and Time**

(conveners: Aaron Chou, **Craig Hogan**)




**Overlaps with**

**CF1,2,3,4,5 +**

**Intensity Frontier: IF3: Neutrinos;**

**(Nu6) Astrophysical and Cosmological Neutrinos**

**Instrumentation Frontier**

# Cosmic Frontier CF6-A
# Cosmic Probes of Fundamental Physics

Conveners:

A. Olinto, J. Beatty, A. Nelson

T. Weiler, G. Sinnis

# Cosmic Probes of Fundamental Physics

1. Physics of Interactions Beyond Laboratory Energies
2. Cosmic Particle Acceleration
3. Cosmic Particles as Probes of Fundamental Physics
4. New Particles
5. Neutrino Physics from Astrophysics

- New Facilities

- 31 Talks in 6 sessions all very well attended
- Thanks to all the speakers!

# CF6A: Conclusions

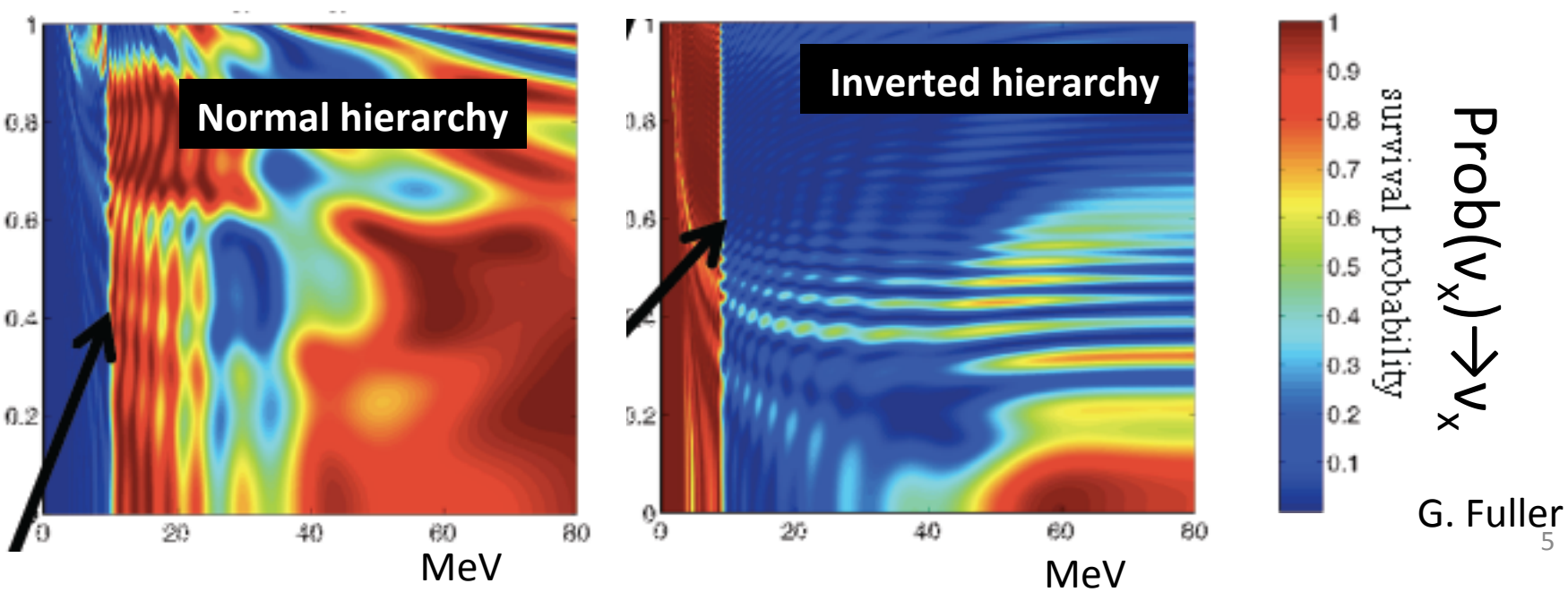
- The Universe will tell us a lot if we know how to listen
  - Encoding can be complicated
  - Multiplexing is common
- Neutrinos, gamma rays, and cosmic rays (including anti-particles) carry a lot if information
- To get at physics beyond the standard model we need to understand the astrophysics
- Existing and planned instruments have a broad physics program.
  - Some high risk/high reward physics may be within reach
- Interface to Instrumentation Frontier (IF2)
- Need to fund theorists in this area

# Fundamental Physics from Cosmic Messengers

- Neutrino mass hierarchy
  - Supernova burst neutrinos (LBNE underground)
  - Atmospheric neutrinos (PINGU at South Pole)
- Probing physics at the Plank scale
  - Sensitivity to violations of Lorentz invariance (Fermi, HESS, VERITAS, CTA, HAWC)
- Probing scale of extra dimensions
  - Neutrino cross sections at high energies (IceCube, ARA, ARIANNA, EVA, JEM-EUSO)
- Measure particle interactions at 60 (300) TeV Auger (JEM-EUSO)

# Neutrino Properties from Astrophysics

- Supernova burst neutrinos
  - Neutrino mass hierarchy (G. Fuller)
  - Supernova physics (JJ Cherry)
- Collective oscillations of $\nu_x$ leads to a "spectral swap"
  - Normal hierarchy $\nu_x$ oscillate to other flavor states below ~10 MeV
  - Inverted hierarchy $\nu_x$ oscillate to other flavor states above ~10 MeV
- A large (~10 kT) liquid Argon detector sensitive mostly to $\nu_x$ could detect swap (need to go underground!)



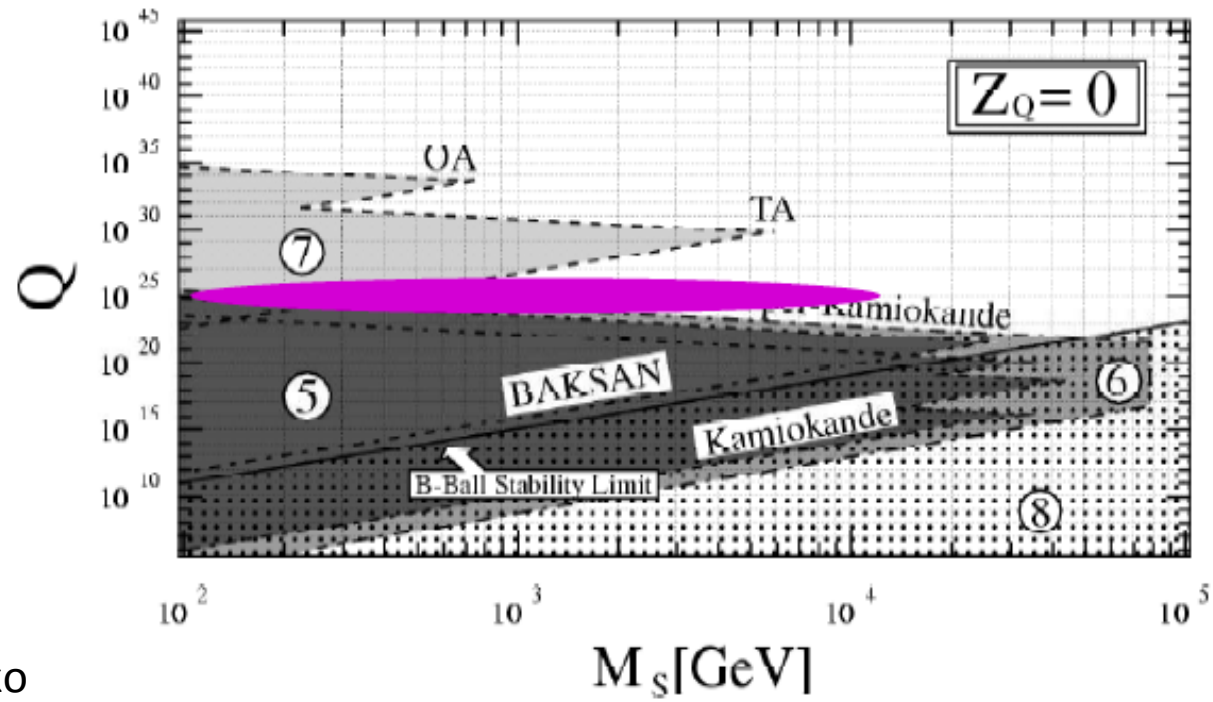

G. Fuller

# New Particles

- Primordial black holes (HAWC)
  - Probe density fluctuations at very small scales
  - Time evolution of evaporation sensitive to beyond standard model physics
- Q-Balls (scalar condensate of squark fields) (HAWC, IceCube, JEM-EUSO?)
  - Prediction of SUSY in early universe (carry baryon # $10^{\sim 26}$)
  - Explains baryon asymmetry & dark matter
  - High cross section >100 mbarn, very low flux $<10^{-15} cm^{-2} sr^{-1} s^{-1}$
    - SuperK, HAWC, IceCube become direct dark matter detectors
- Anti-nuggets (antimatter color superconductor)
  - Hold all the anti-matter
  - Similar to Q-balls in flux and baryon number
  - Cross section much greater than Q-balls (energy loss mechanism quite different)
- SUSY Particles (relativistic heavy particles)
- Axion-like particles

# Q-Balls

- Prediction of inflation and SUSY
- Explains Baryon asymmetry and dark matter (is baryonic!)
- Large mass: $10^{\sim 18}$ GeV
- Low flux: $<10^{-15} cm^{-2} sr^{-1} s^{-1}$
- Spectacular signal (~100 GeV/cm in pions)
- Large detectors needed: SuperK, HAWC

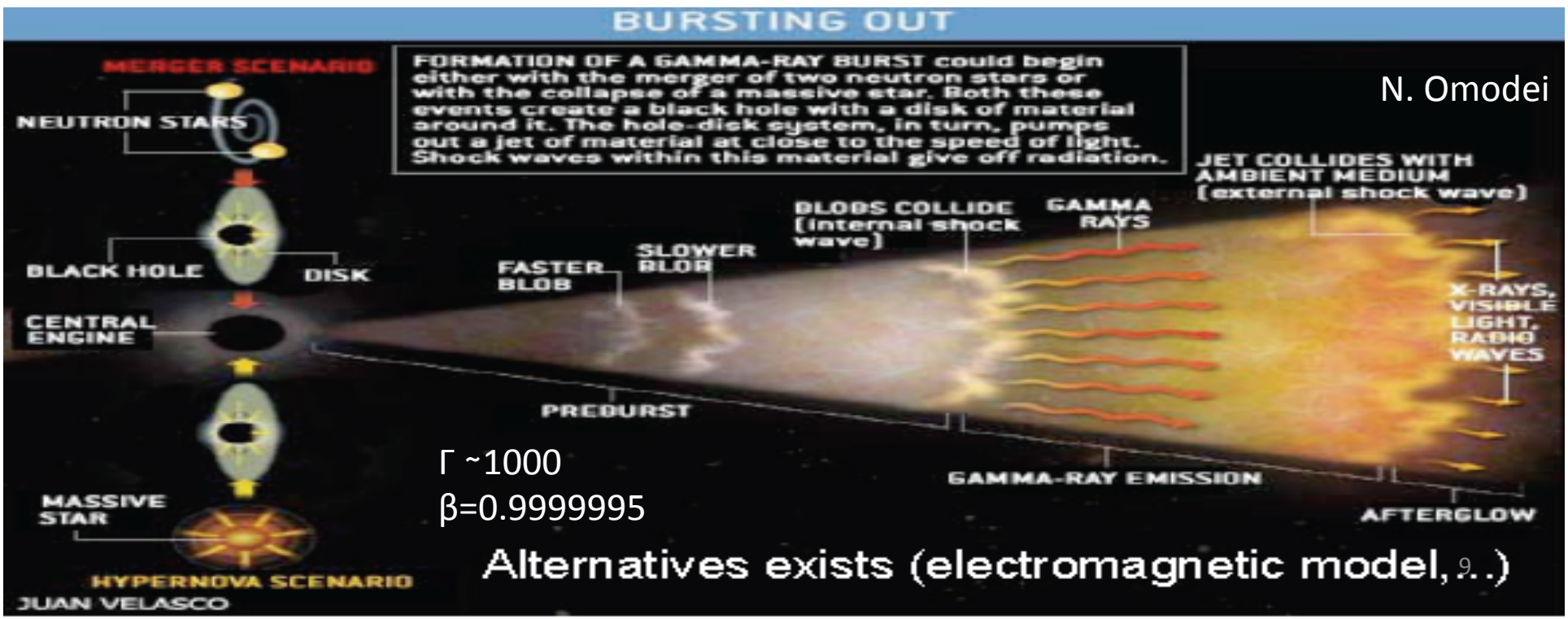


# Gamma-Ray Astrophysics

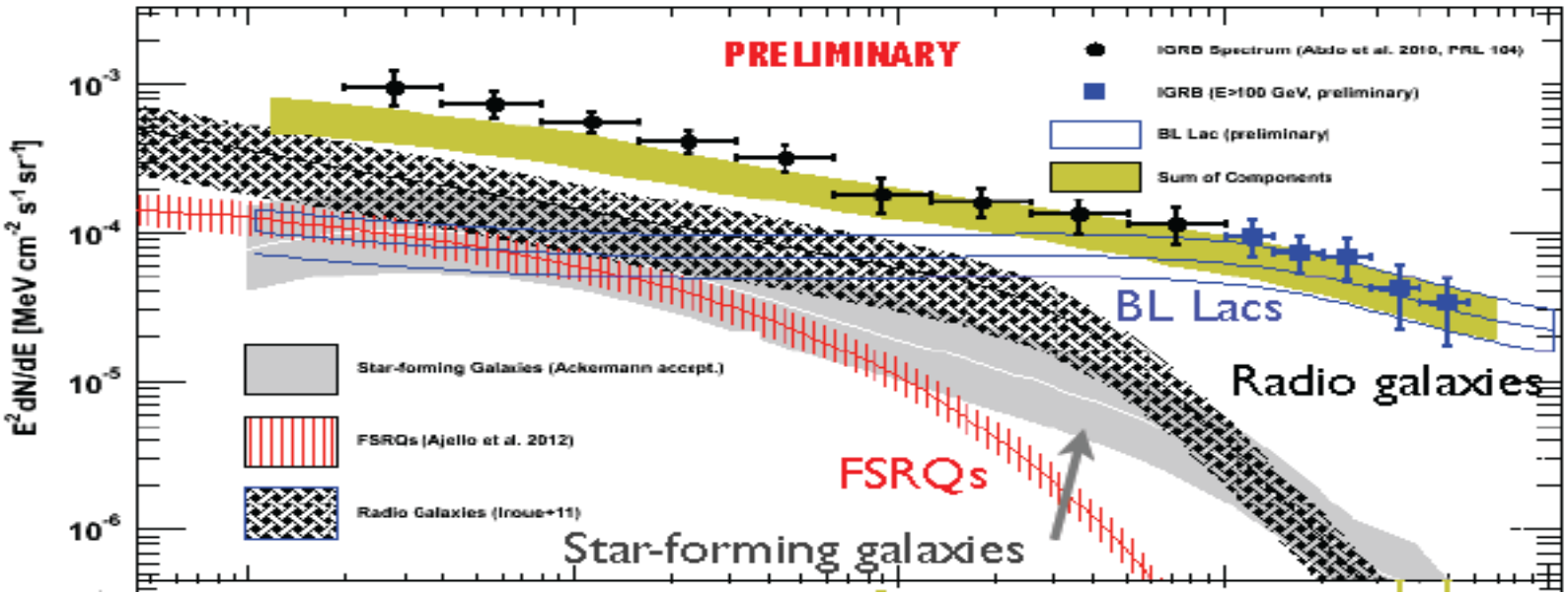
- Astrophysical sources can mask or mimic dark matter signatures
  - Isotropic diffuse gamma-ray background shows excess above sum of known sources
  - Positron excess may be explained by pulsar wind nebulae
- Particle Acceleration is of Fundamental interest
  - Gamma-Ray Bursts
    - Merging neutron stars ejecting solar masses of matter at Lorentz factors of 1000
  - Active Galactic Nuclei
    - Supermassive black holes: probe physics near event horizon

# Cosmic Particle Acceleration

- Particle acceleration to extreme energies is of fundamental interest
  - How does nature create particles with $10^{20}$ eV?
- Gamma-Ray Bursts provide a short pulse (~1sec) of gamma rays that light up the universe
  - Use to probe Lorentz Invariance violation



# Isotropic Diffuse Gamma-Ray Backgrounds




- What is the origin of the diffuse excess?
- Examine angular power spectrum
- AGN account for all of the observed angular power but only 20% of the required intensity
- Dark matter? Star forming galaxies?

J. Siegal-Gaskins

# New Instruments

- Many creative ideas presented at meeting
- EHE Cosmic Rays
  - JEM-EUSO, Radio Detection, Radar Detection
- Anti-Particles
  - AMS (current), GAPS (new technique: background free)
- Neutrinos
  - LBNE (10 kT liquid Argon)
    - Need to go underground for Cosmic Frontier
  - PINGU, MICA (optical detectors)
  - ARA, ARIANNA, EVA (radio detection) – 500 GT detector!
- Gamma Rays
  - CTA – pointed instrument
  - HAWC, Fermi, - all-sky: what's next?

# Path Forward

- We are calling for white papers (~1 pages)
  - Scientific ideas: what physics is important to pursue?
  - New instruments: physics scope, rough cost, rough time line (near term <5 yrs, ~10 years, ~20 years)
- We have an email list: SNOWMASS-CF6A@fnal.gov
  - Look to webpage for instructions to sign up (coming soon)
  - Uses of the list:
    - Communication to the community on the process
    - To facilitate communication between people in the community (looking for people to work on a white paper).
    - Mail is archived at FermiLab
- See everyone in Minneapolis (July 29 – August 6)!

# CF6-B

Cosmological asymmetries

Ann Nelson

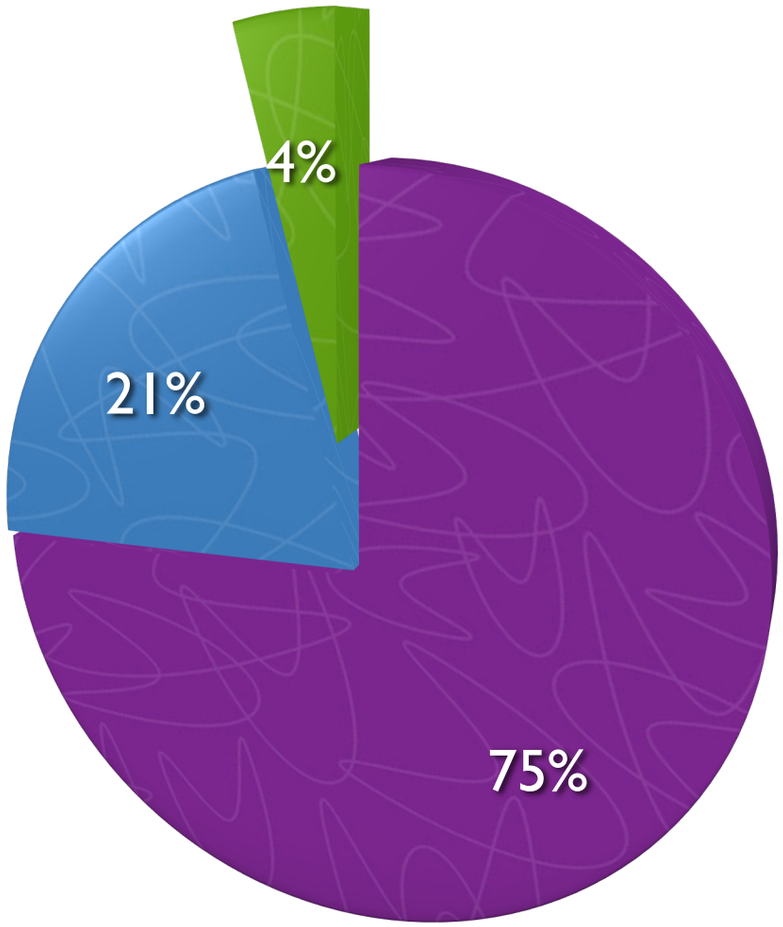
March 8, 2013

Cosmic Frontier Pre-Snowmass Workshop

SLAC

# non-dark BSM cosmology

- *Dark Energy*
- *dark matter*
- *atoms .....*

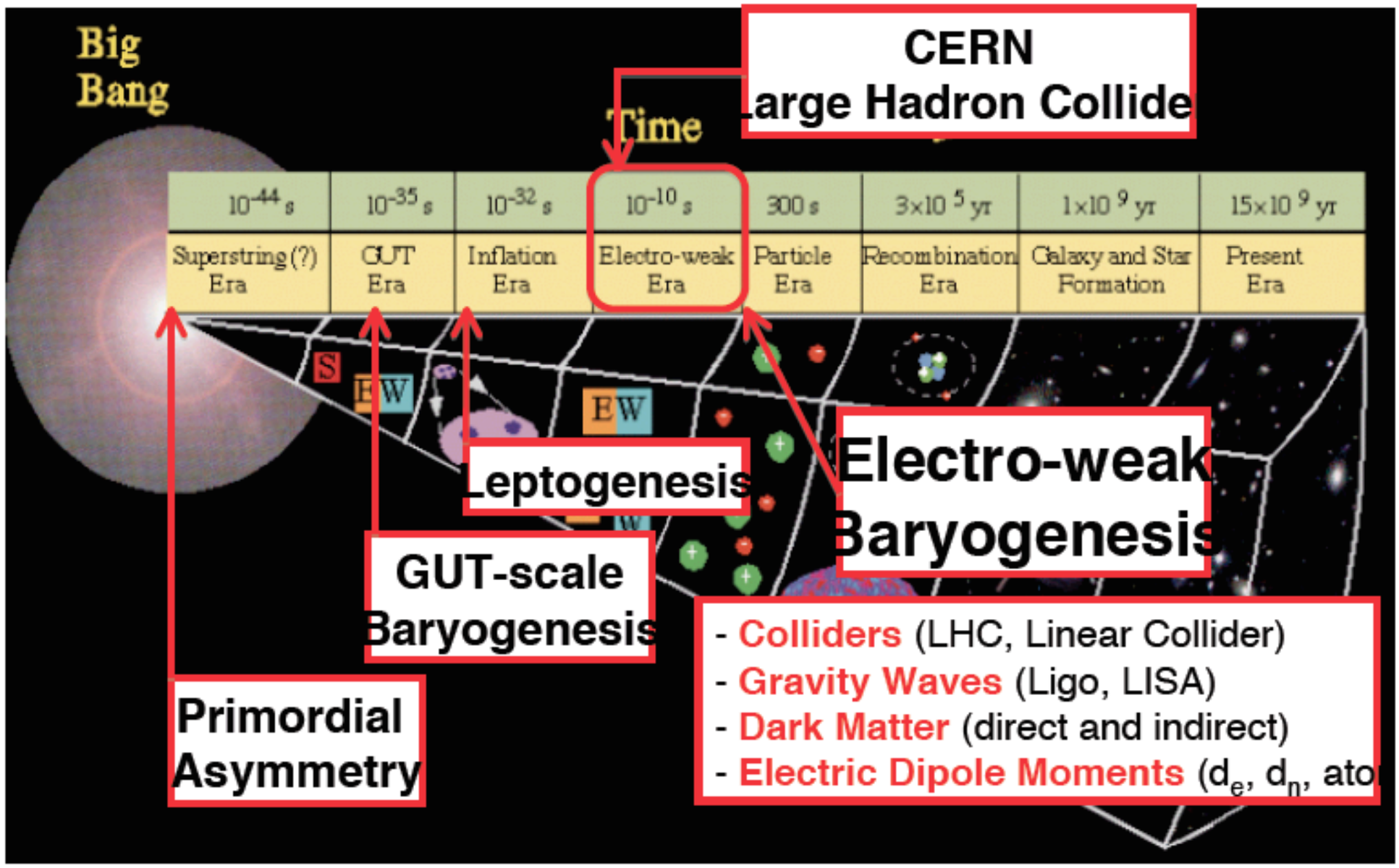



- CF6-B: cosmological asymmetries:

  Why $n_B/n_\gamma \sim 10^{-10}$

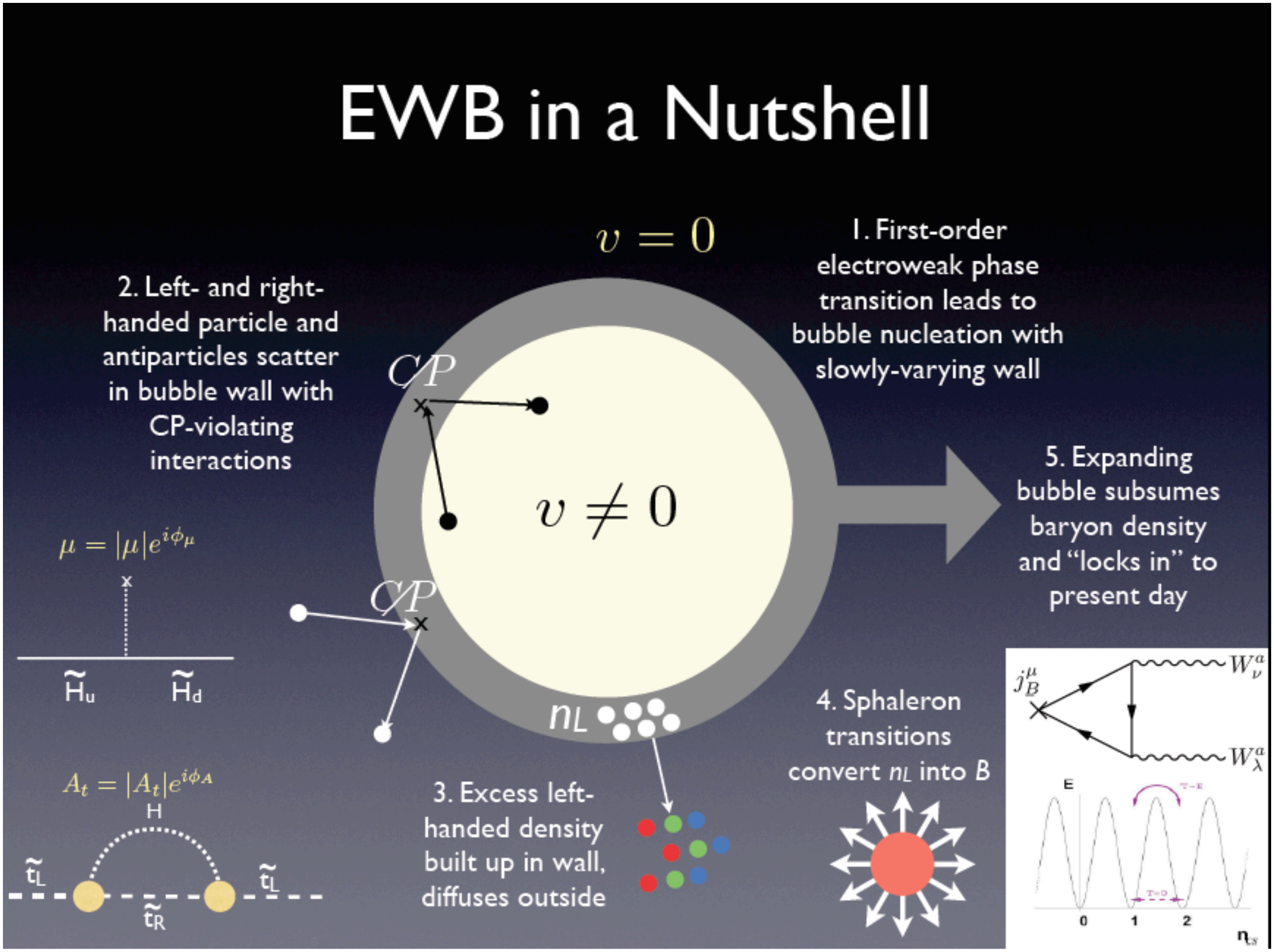
  - BSM CPV (?)
  - BSM B-L violation (?)
  - cosmological departure from thermal equilibrium due to BSM physics (?)

# No "Standard Model" of Baryogenesis!

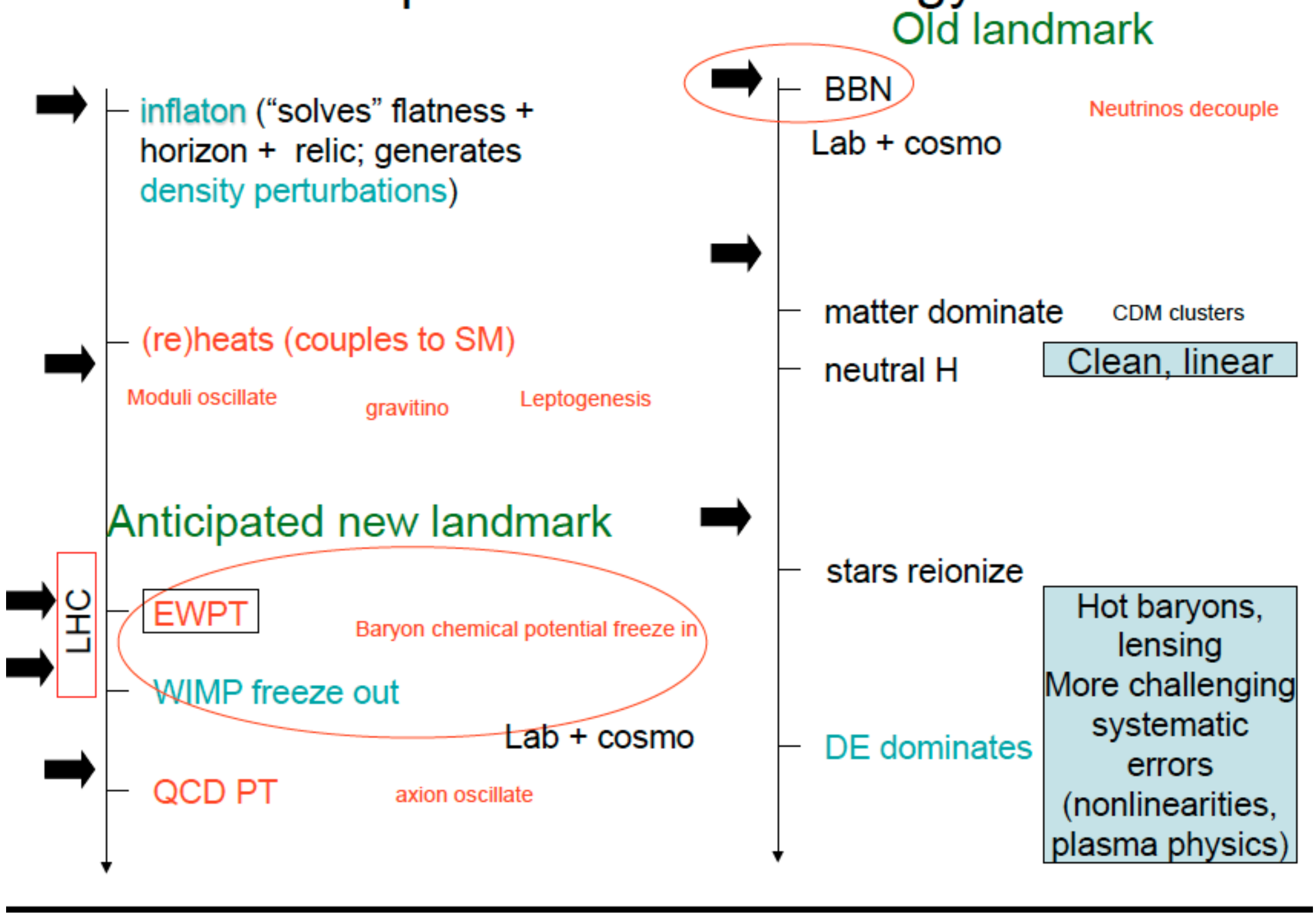


# Electroweak Baryogenesis

Stefano Profumo, Chris Lee, Daniel Chung, Andrew Long


EWB in a Nutshell
$v = 0$
1. First-order electroweak phase transition leads to bubble nucleation with slowly-varying wall
2. Left- and right-handed particle and antiparticles scatter in bubble wall with CP-violating interactions
$\not{C}\not{P}$
$v \neq 0$
5. Expanding bubble subsumes baryon density and "locks in" to present day
$\mu = |\mu| e^{i\phi_\mu}$
$\not{C}\not{P}$
$\tilde{H}_u$
$\tilde{H}_d$
$n_L$
4. Sphaleron transitions convert $n_L$ into $B$
$A_t = |A_t| e^{i\phi_A}$
H
$\tilde{t}_L$
$\tilde{t}_L$
$\tilde{t}_R$
3. Excess left-handed density built up in wall, diffuses outside
$j_B^\mu$
$W_\nu^a$
$W_\lambda^a$
E
0
1
2
$\eta_{cs}$

# Important for Cosmology



# Baryogenesis and dark matter

- Sigurdson: dark matter carries anti baryon number and catalyzes unusual “proton decay” events
- Zhitnitsky: semi-Exotic quark and antiquark nugget dark matter
- Fan: some dark matter is asymmetric, self interacting via a dark photon, and collapsed into a dark disk parallel (?) to ours

# Leptogenesis

Mu-Chun Chen

## Conclusions

- origin of matter: one of the great mysteries in particle physics and cosmology
- leptogenesis: appealing mechanism connected to neutrino physics
- various leptogenesis realizations:
  - standard leptogenesis: gravitino problem, incompatible with SUSY
  - Low scale alternatives:
    - resonance leptogenesis
    - Dirac leptogenesis
    - Soft leptogenesis (CP phases in soft SUSY sector; decouple from neutrino physics; require small B term)

# Future Plans for CF6B

- before Snowmass: draft 5-10 pages on opportunities in theory and experiment to elucidate origin of cosmological asymmetries
- some highlights
  - impact of LHC on EWB
  - EWB CPV calculations <=> EDM predictions
  - connection with dark matter
  - testable leptogenesis models
- Send your 1 page white papers by April 5

# Basic Nature of Space and Time

# Basic Nature of Space and Time

- Lenny Susskind: Field theory and string theory do not predict detectable Planck scale effects on laboratory scales
- Craig Hogan: In some forms of quantum geometry, Planckian information density is detectable as transverse position uncertainty
- Aaron Chou: The Fermilab Holometer is in commissioning, and will achieve Planck spectral density sensitivity within ~2 years

# Conclusions

- Depending on the results, there may either be a sub-Planckian limit on quantum geometry, or a clear path forward for experiments that probe Planck scale physics
- Other types of experiments may be possible