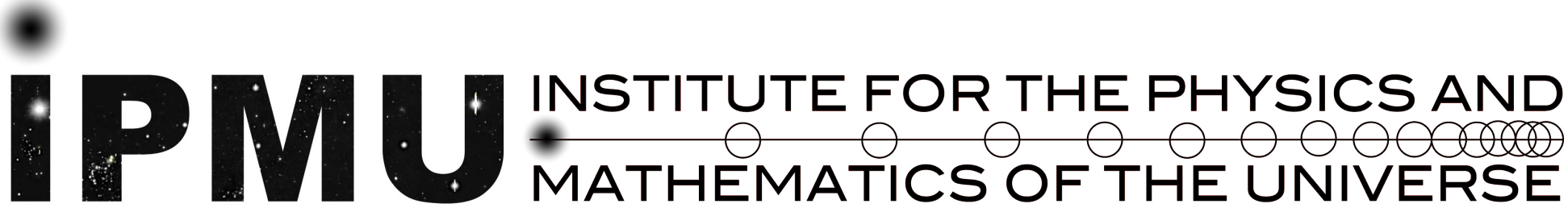
Neutrino and proton decay what can we learn FOR FUNDAMENTAL PHYSICS AND COSMOLOGY

Hitoshi Murayama

(IPMU Tokyo & Berkeley)

NNN '08, Sep 13, 2008





INSTITUTE FO
MATHEMATIC

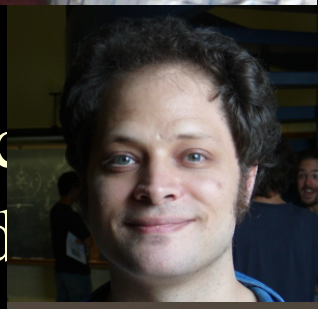

New intl research institute in Japan
- astrophysics
- particle theory
- particle expt
- mathematics


official language: English


>30% non-Japanese

$14M/yr for 10 years

- launched O
- ≈25 now, >40 in
- excellent new fac hires, young and dynamic!
- will hire about 3(scientists
- new bui
- intl gue
- wkshp ~

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Science

For the committee:

- What is the Universe made of?
- How did it start?
- What is its fate?
- What are its fundamental laws?
- Why do we exist?

translation for scientists:

- nature of dark matter
- resolving space-like singularity
- *w* of dark energy
- unified theory, *p*-decay
- origin of baryon asymmetry, neutrinos

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Also photo detector development
for future experiments

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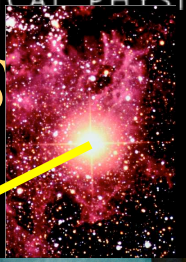
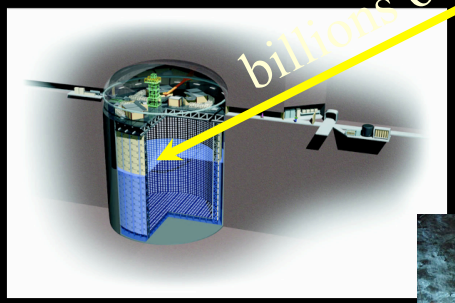
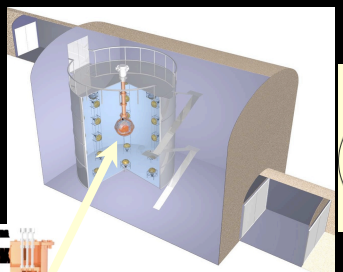
IPMU initiatives in experiments

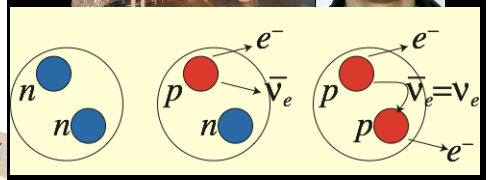
- Vagins: let SuperK detect relic supernova with Gd
- Kozlov: use KamLAND to see if $\nu=\bar{\nu}$ with Xe
- Suzuki/Nakahata /Martens: XMASS to detect dark matter
- Aihara/Takada/Yoshida: HyperSuprimeCam at Subaru and data analysis to study dark energy

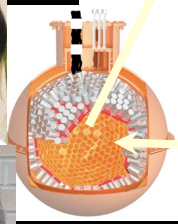


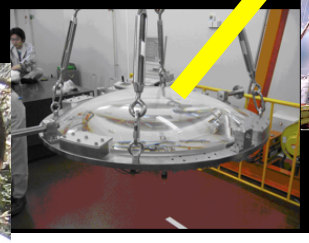
billions of years











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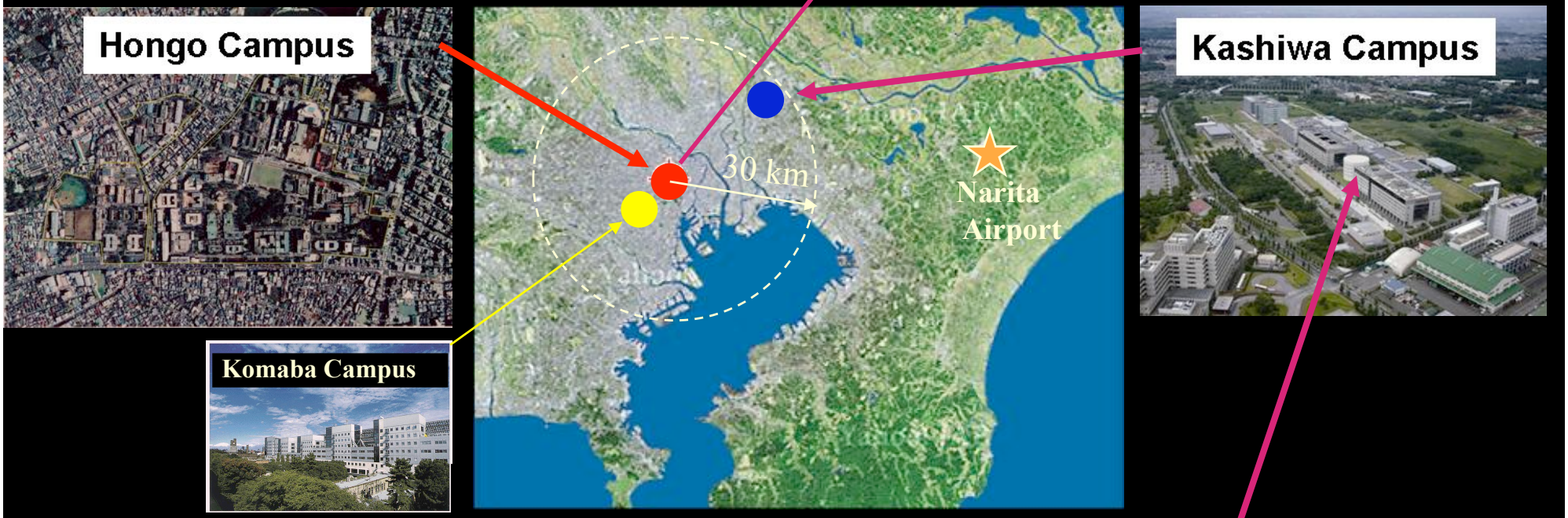
Where it is



~one hour from much of Tokyo
Also a satellite in Kamioka

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K. Nomoto	H. Ooguri (Caltech)	Y. Suzuki (Tokyo)
K. Saito	D. Spergel (Princeton)	M. Nakahata (Tokyo)
	M. Nojiri (KEK)	

Mathematician, Theoretical Physicists, Experimental Physicist, Astronomer


Winter 2009 occupancy
~5900m2
Murayama, NNN '08, Paris


emphasis on large interaction area
"like a European town square" ~400 m^2
Murayama, NNN '08, Paris

Full-time Scientists

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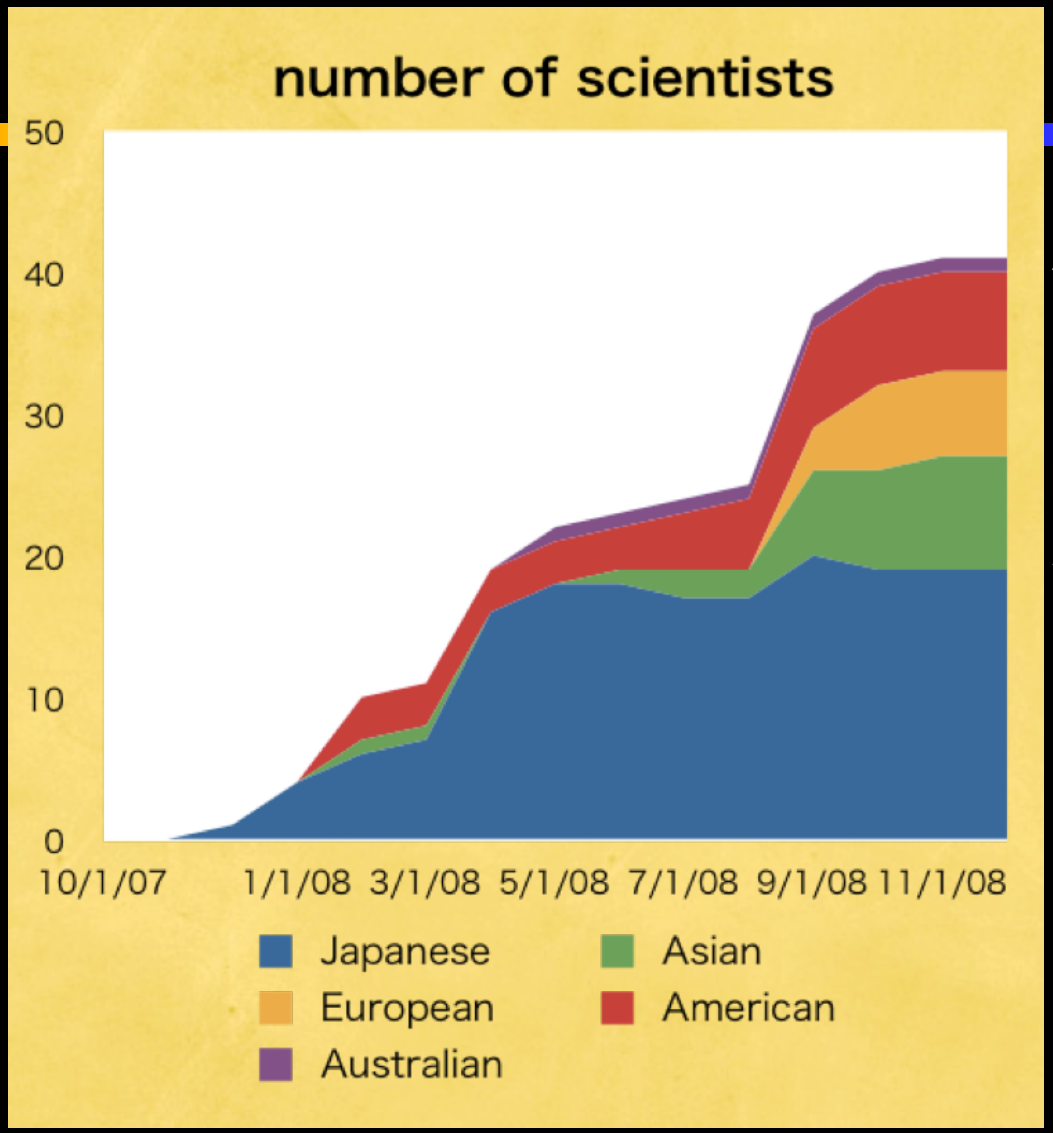
Expect ~15 positions this year

Check out www.ipmu.jp



non-Japanese 50%

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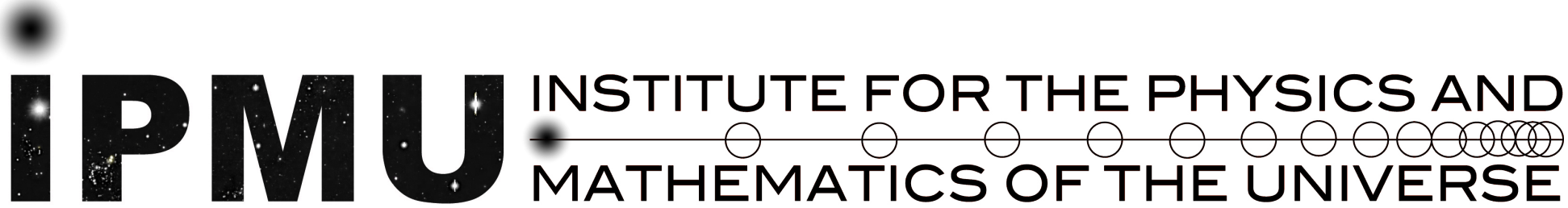
NNN '08, Sep 13, 2008



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東京大学 THE UNIVERSITY OF TOKYO

How do we test Seesaw & Leptogenesis?

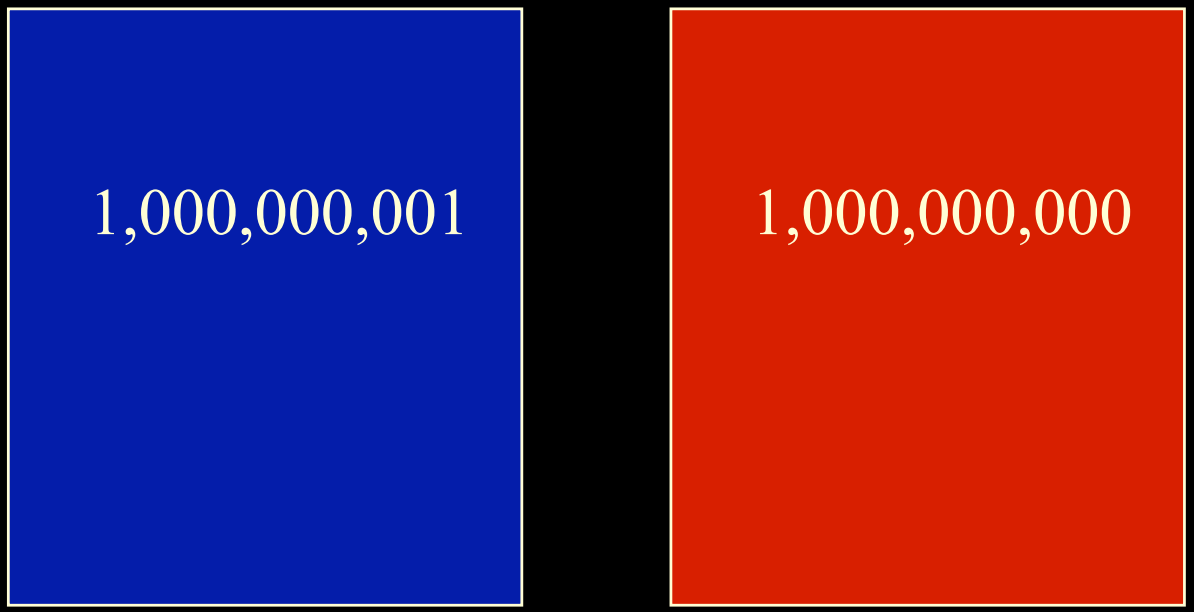
Hitoshi Murayama

(IPMU Tokyo & Berkeley)

NNN '08, Sep 13, 2008

with Matt Buckley

Matter and Anti-Matter Early Universe



Matter and Anti-Matter Current Universe

us

1

Matter Anti-matter

The Great Annihilation

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Dream

- Neutrinos have mass!
- If *Majorana*, neutrinos can turn into anti-neutrinos and vice versa
- Can reshuffle matter & anti-matter, create the asymmetry of the universe, and hence leads to our existence
- *Can we test if we are born from neutrinos?*
- At the same time, *can we learn where the neutrino mass comes from?*

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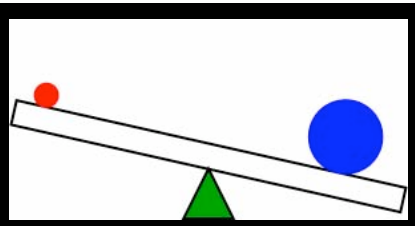
Seesaw Mechanism

- Why is neutrino mass so small?
- Need right-handed neutrinos to generate neutrino mass, but ν_R SM neutral

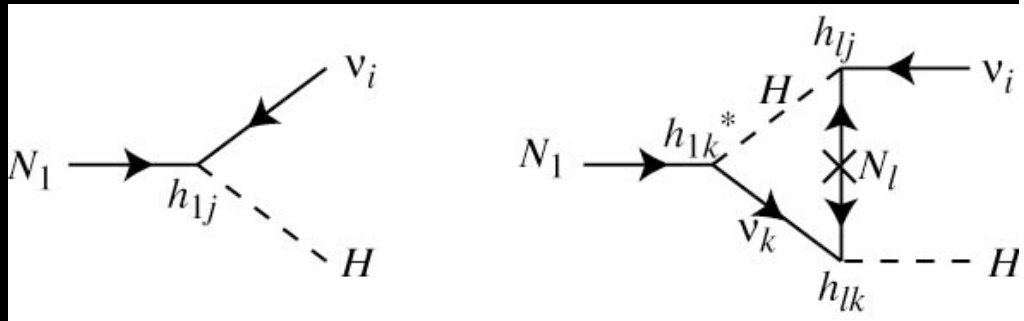
$$(\nu_L \quad \nu_R)\begin{pmatrix} & m_D \\ m_D & M \end{pmatrix}\begin{pmatrix} \nu_L \\ \nu_R \end{pmatrix} \qquad m_\nu = \frac{m_D^2}{M} << m_D$$



To obtain $m_3 \sim (\Delta m^2_{\rm atm})^{1/2}$, $m_D \sim m_t$, $M_3 \sim 10^{14}$GeV (GUT?)

Leptogenesis

- You generate *Lepton Asymmetry* first.
- Generate *L* from the direct CP violation in right -handed neutrino decay
- *Like ε'/ε!*



$$\Gamma(N_1 \to \nu_i H) - \Gamma(N_1 \to \bar{\nu}_i H) \propto \mathrm{Im}(h_{1j} h_{1k} h_{lk}^* h_{lj}^*)$$

- *L* gets converted to *B* via EW anomaly

$\Rightarrow$ More matter than anti-matter

$\Rightarrow$ *We have survived "The Great Annihilation"*

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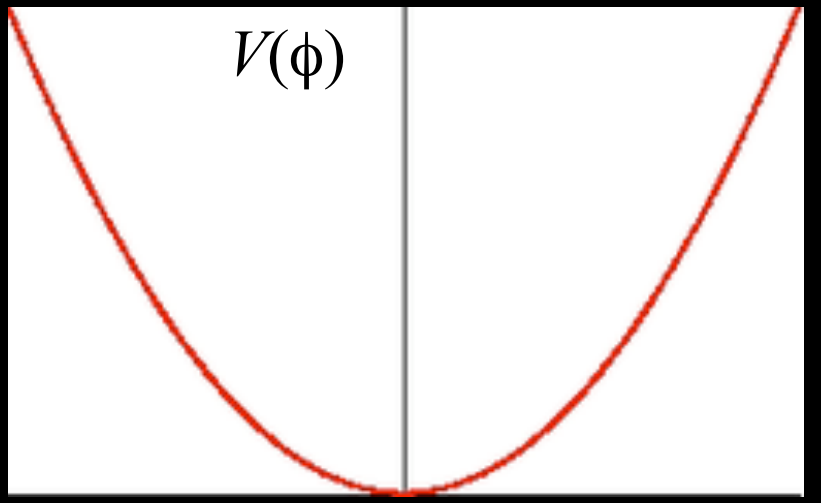
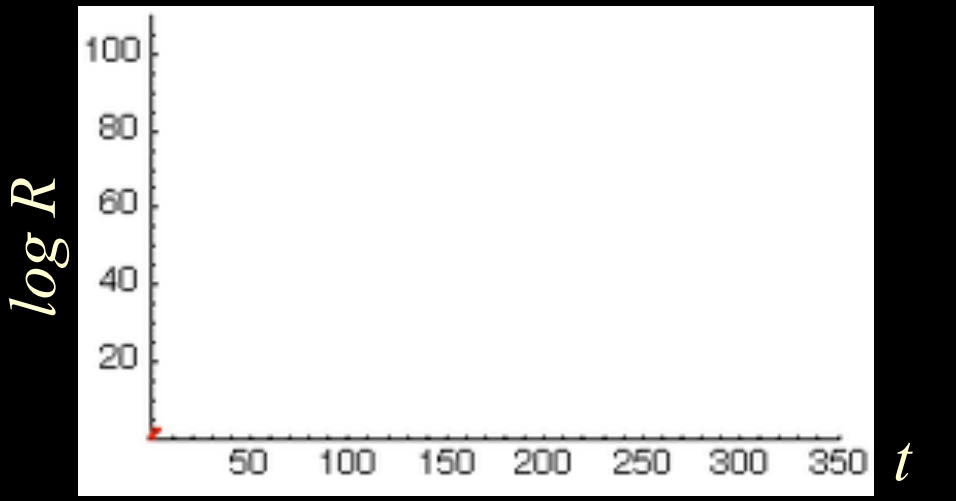
Origin of Universe

- Good evidence that inflation kicked-off the Universe
- Need a spinless field that
  - slowly rolls down the potential
  - oscillates around it minimum
  - decays to produce a thermal bath
- *The superpartner of right -handed neutrino fits the bill*
- Inflation requires 10^{13}GeV, just right for seesaw!
- Reheating produces the lepton asymmetry at the same time

(HM, Suzuki, Yanagida, Yokoyama)

Neutrino is mother of the Universe?





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How can it be possible at all?

- We can (hope to) do good measurements on observables at low energies (meV–TeV)
- If we know something about the boundary conditions GUT-scale, we can say something non-trivial about physics at seesaw/inflation scale
- We have to be very lucky to be able to do this

Need the whole planets lined up!

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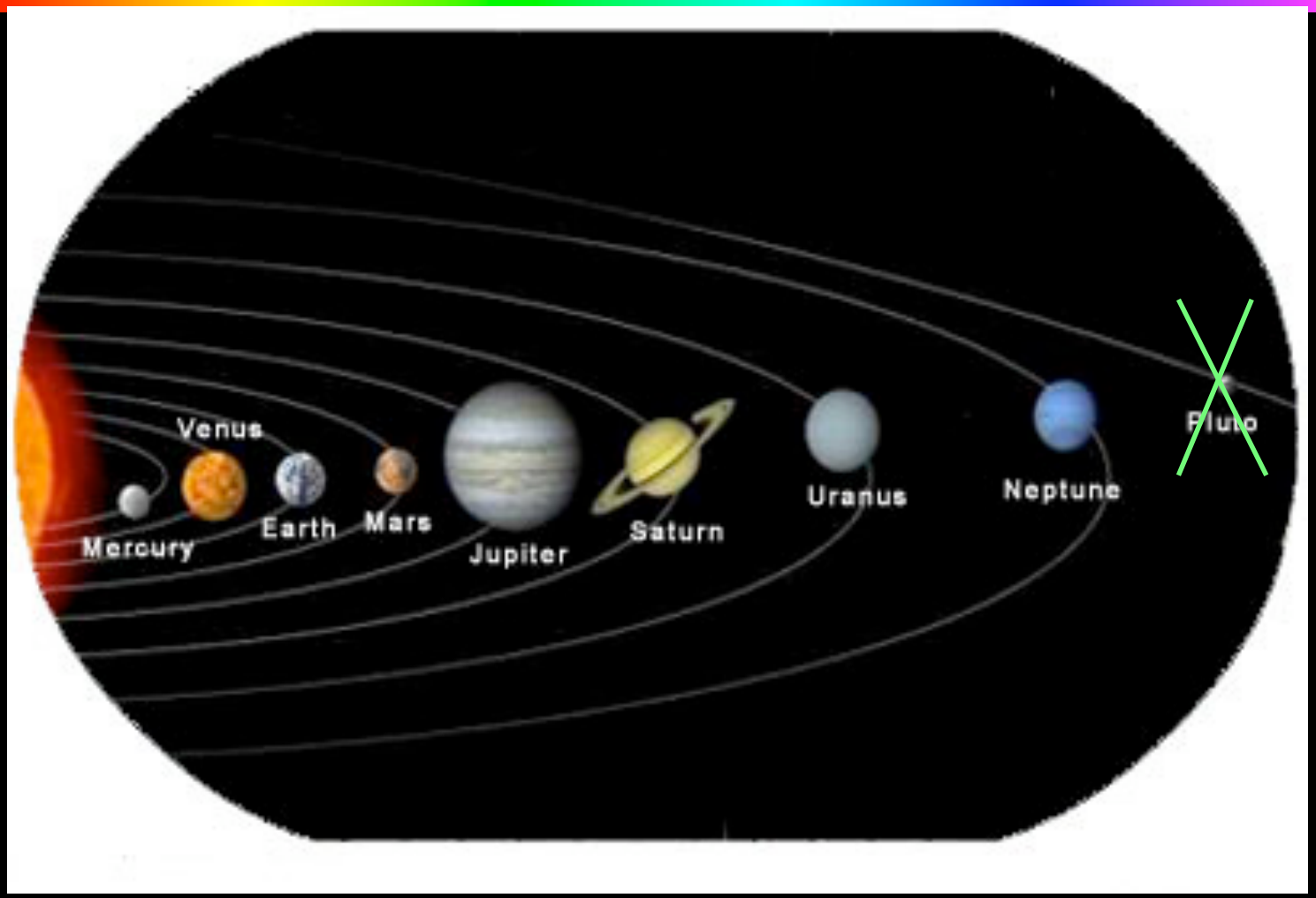
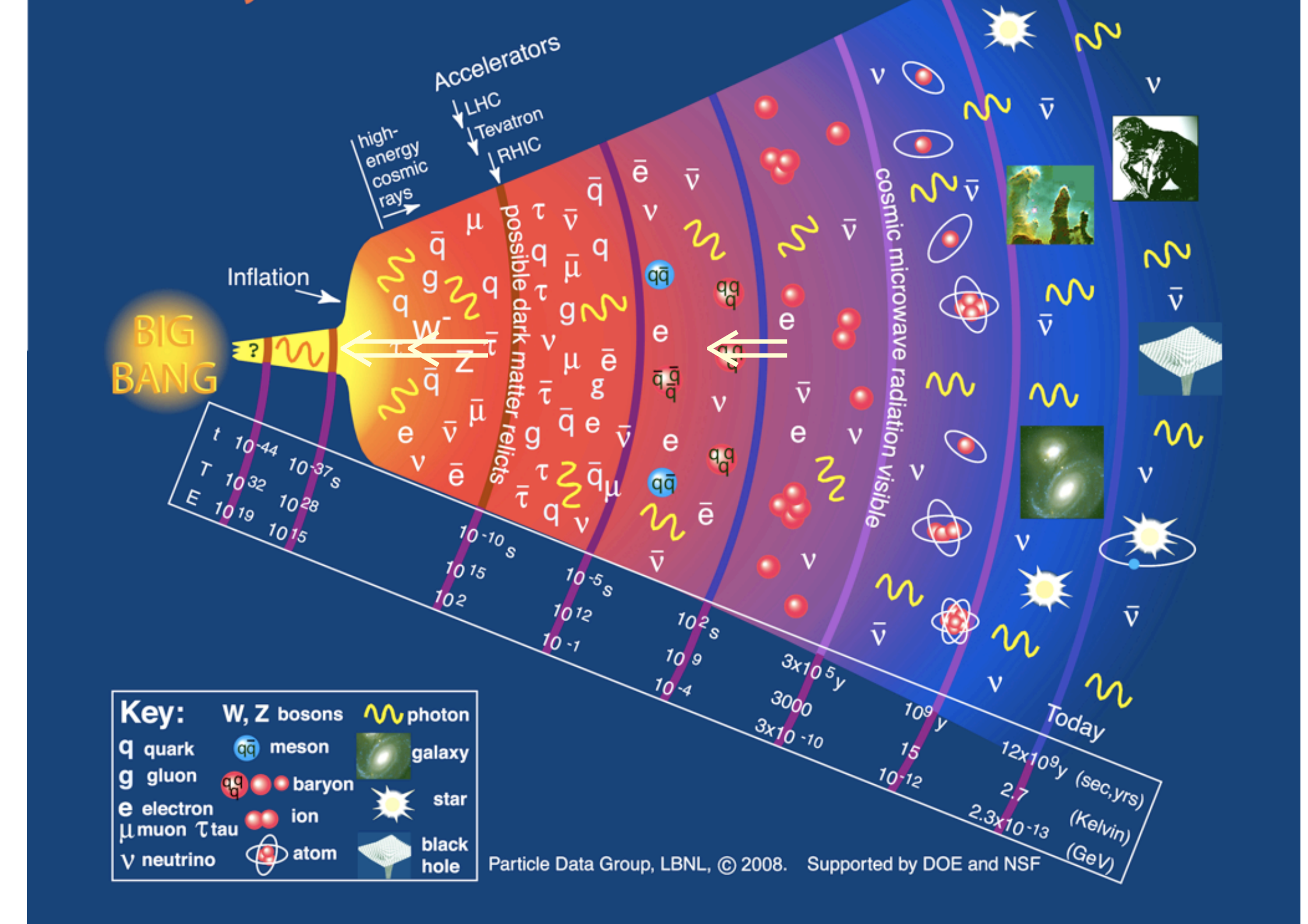
Alignment of the Planets




Accelerators
LHC
Tevatron
RHIC
high-energy cosmic rays
Inflation
BIG BANG
possible dark matter relicts
cosmic microwave radiation visible
t 10-44 10-37 s
T 10 32 10 28
E 10 19 10 15
10-10 s
10 15
10 2
10-5 s
10 12
10 -1
10 2 s
10 9
10 -4
3x10 5 y
3000
3x10 -10
10 9 y
15
10-12
12x10 9 y (sec,yrs)
2.7 (Kelvin)
2.3x10 -13 (GeV)
Today
Key:
q quark
g gluon
e electron
μ muon τ tau
ν neutrino
W, Z bosons
meson
baryon
ion
atom
photon
galaxy
star
black hole
Particle Data Group, LBNL, © 2008. Supported by DOE and NSF

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Can we prove it experimentally?

- Short answer: no. We can't access physics at $>10^{10}$ GeV with accelerators directly
- But: we will probably believe it if the following scenario happens

  Archeological evidences

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We should push this

- U_{e3} is not too small
  - At least makes it plausible that CP asymmetry in right-handed neutrino decay is not unnaturally suppressed
- CP violation in neutrino oscillation
  - At least proves that CP is violated in the lepton sector
- But need more *fossils* to fill *missing links*

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LHC is here

Google Search I'm Feeling Lucky

Advanced Search
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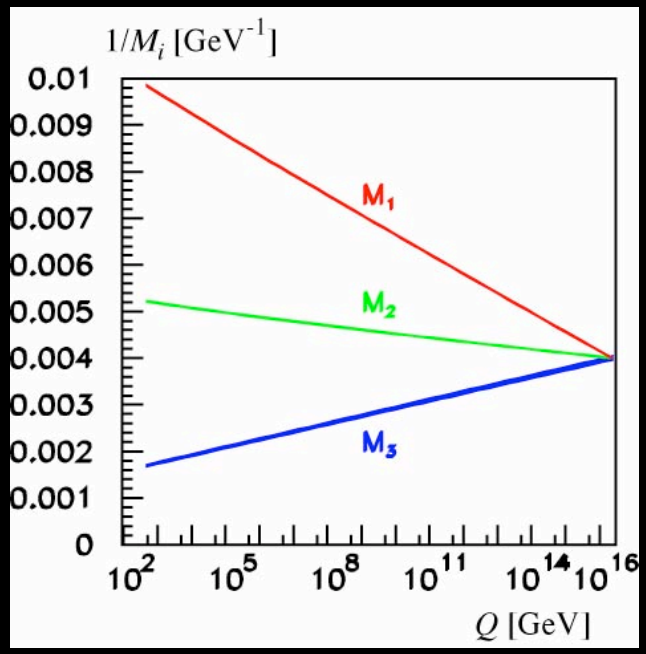
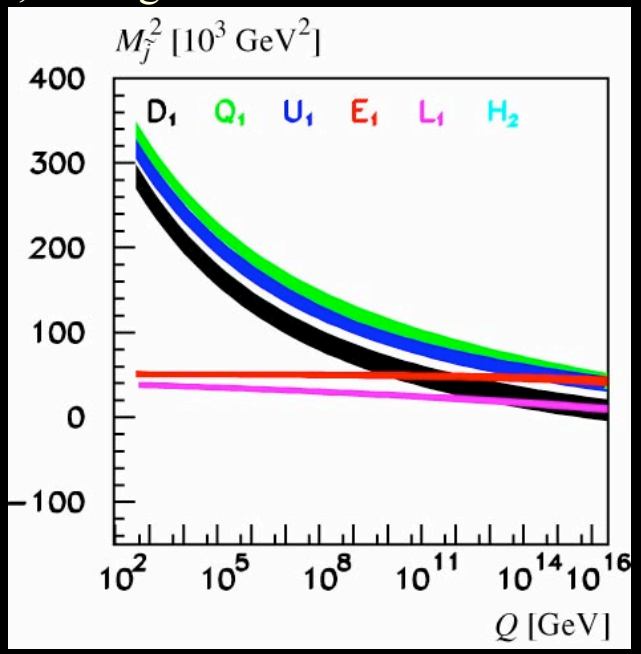
Language Tools

If SUSY discovered

- Gaugino masses test unification itself independent of intermediate scales and extra complete SU(5) multiplets
- Scalar masses test beta functions at all scales, depend on the particle content

Kawamura, HM, Yamaguchi

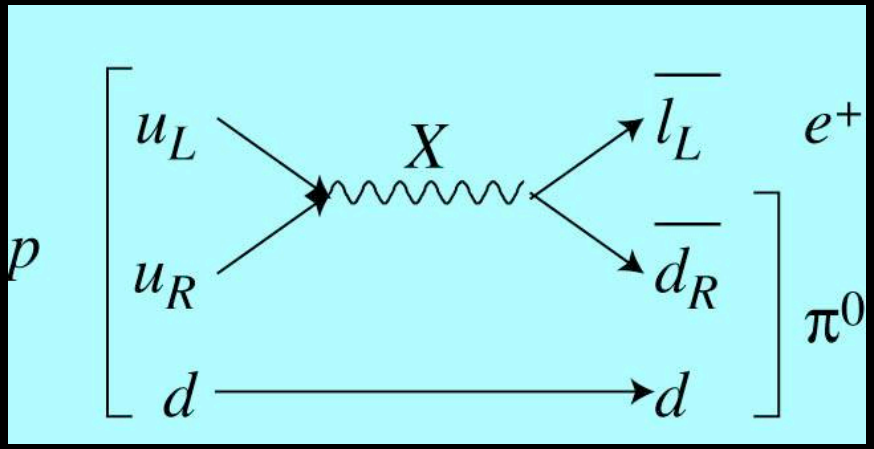




Murayama, NNN '08, Paris

Proton Decay

- *Very strong case for large p-decay detector(s)!*
- SUSY GUT predicts $\tau(p \to e^+\pi^0) \approx 10^{35\pm1}$ years
- Combination with collider data "proves" GUT
- Also $K^+\nu$ mode even more interesting



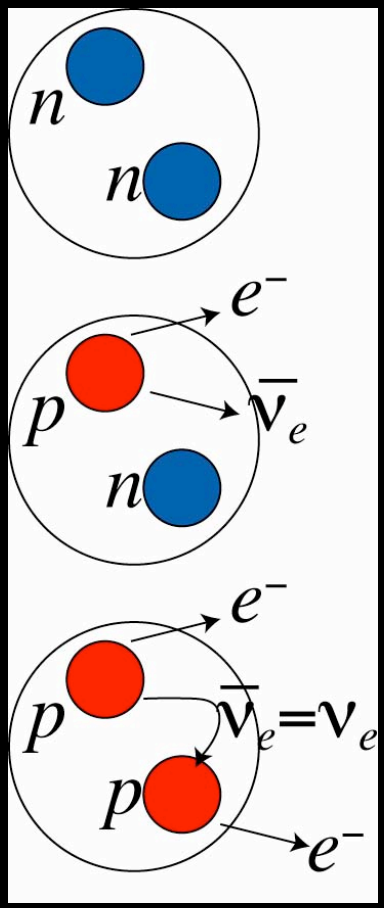
$$\Gamma \propto \left(\frac{g^2}{M_X^2}\right)^2 m_p^5$$

Majorana

- Next generation experiments discover neutrinoless double beta decay
- Say, $\langle m_\nu \rangle_{ee}$~0.01-0.1eV
- There must be new physics below $\Lambda \sim 10^{14}$GeV that generates the Majorana neutrino mass

$$\mathcal{L}_5 = (LH)(LH) \to \frac{1}{\Lambda}(L\langle H\rangle)(L\langle H\rangle) = m_\nu \nu\nu$$

- well below the GUT scale!



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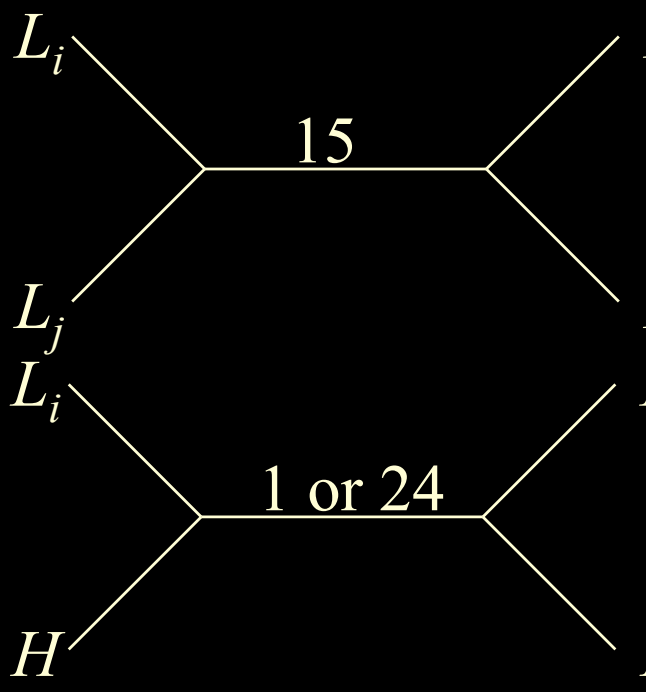
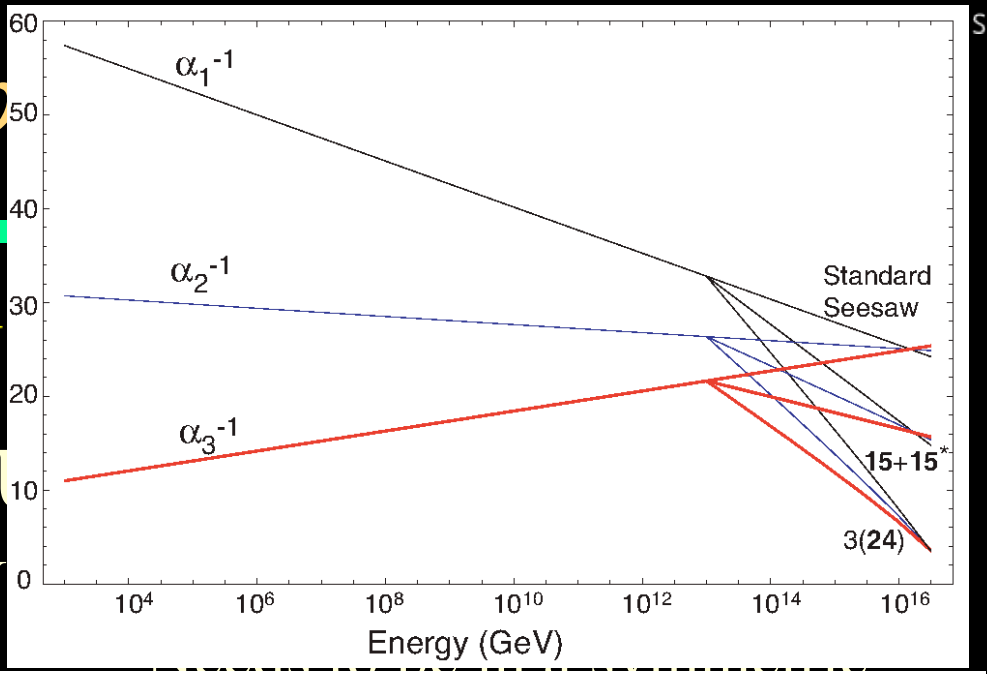
Possib

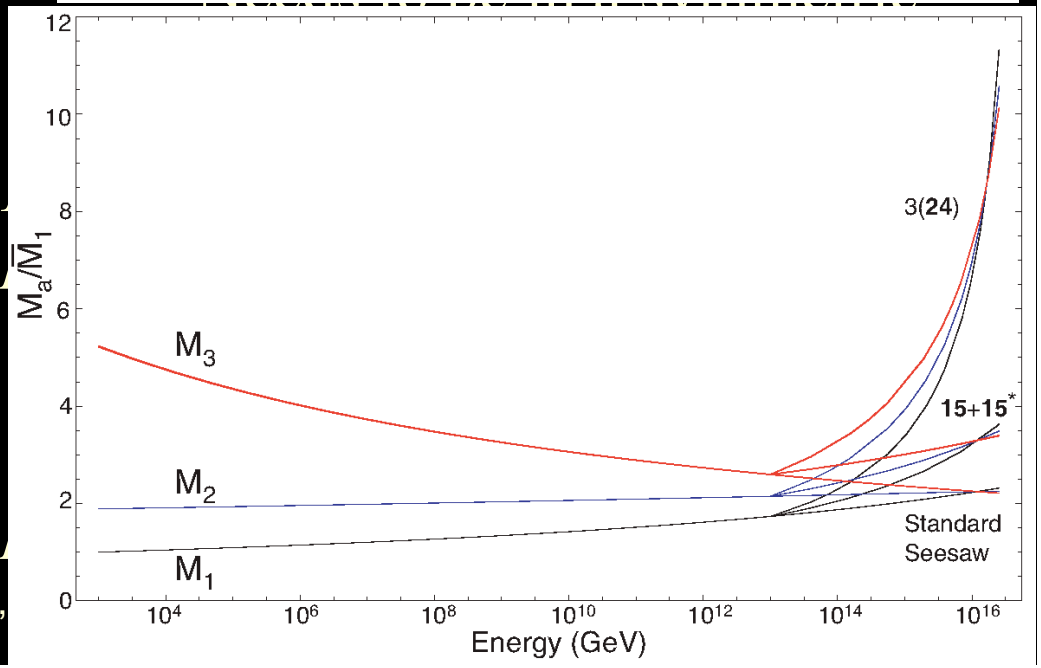
$$\mathcal{L}_5 = (LH)(LH) \to \frac{1}{\Lambda}(L\langle H$$

- L is in 5^*, H in 5 of SU



Murayama,





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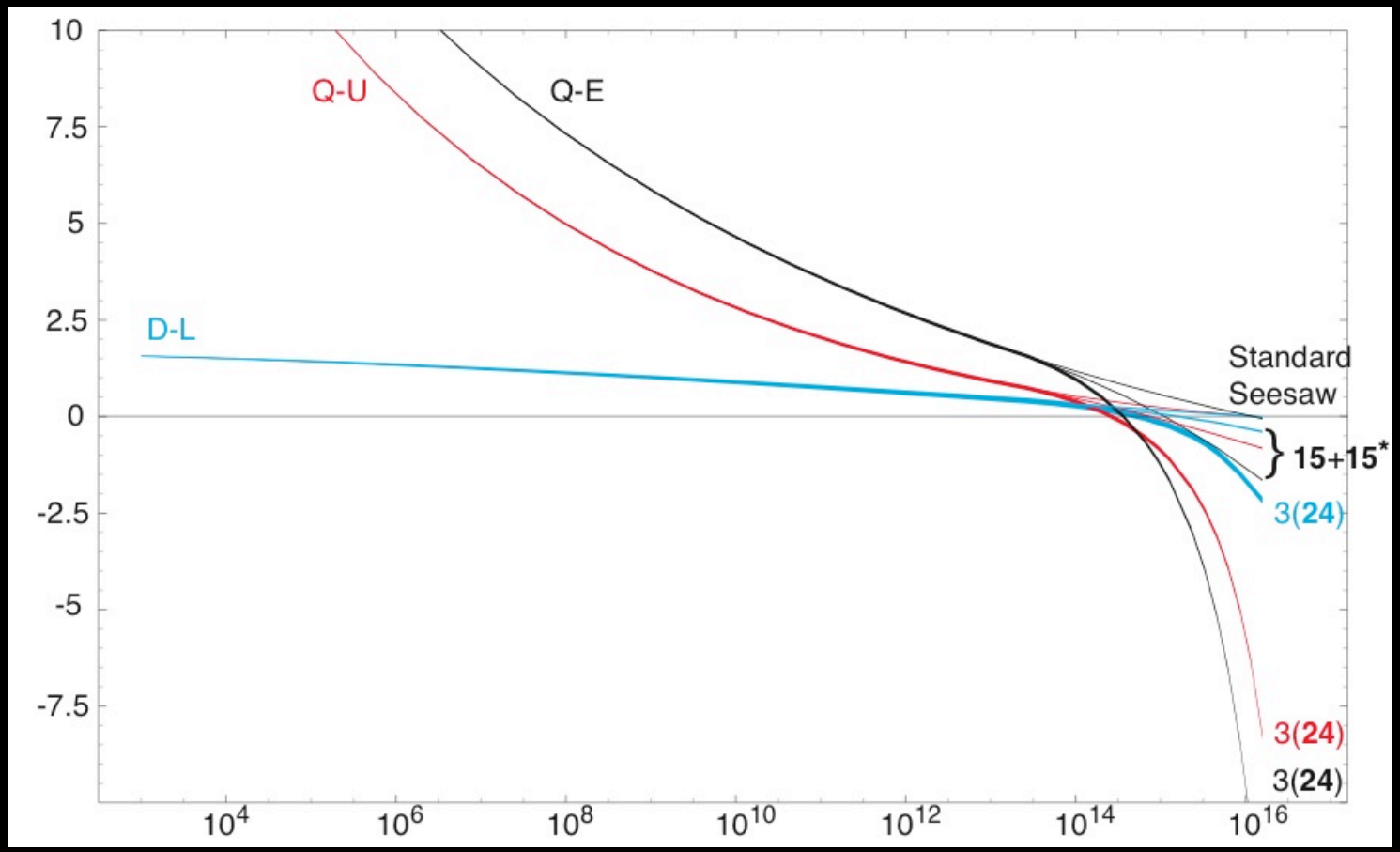
Scalar Masses



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If this works out

- Evidence for SU(5)-like unification hard to ignore
- Only three possible origins of Majorana neutrino mass < 10^{14} GeV consistent with gauge coupling and gaugino unification
- Only one consistent with scalar mass unification
- Origin of neutrino mass is heavy singlet particles
- The standard seesaw mechanism "established"!

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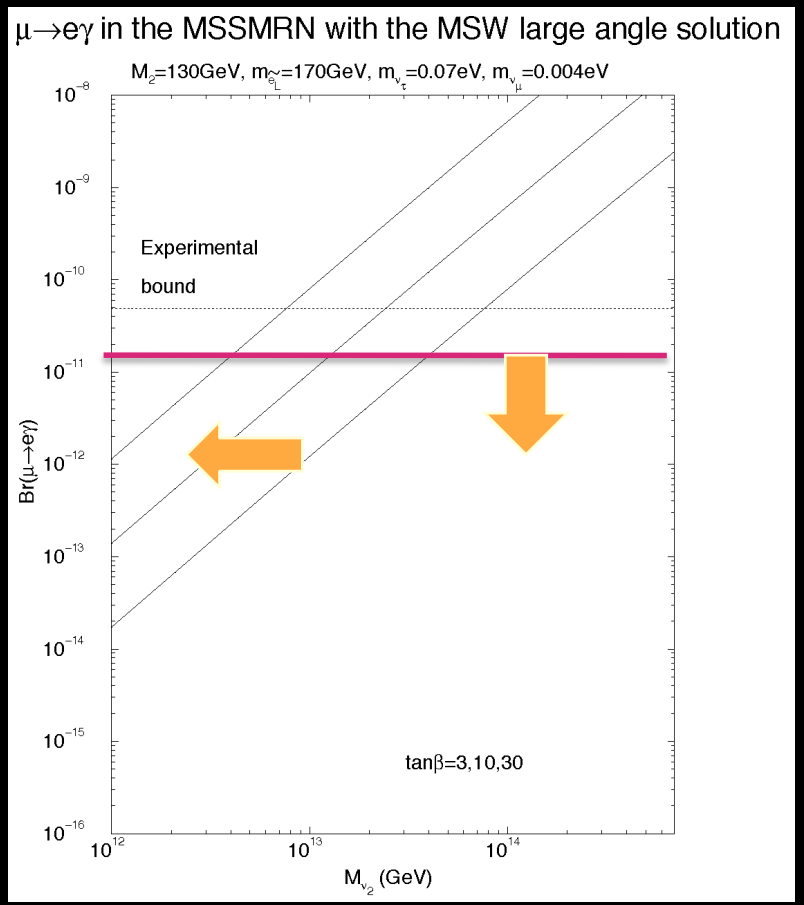
What about the seesaw scale?

- Yukawa couplings can in principle also modify the running of scalar masses
- We may well have an empirical evidence against large neutrino Yukawa coupling and large *M* by the lack of lepton-flavor violation



Hisano&Nomura, hep-ph/9810479

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Leptogenesis?

- No new gauge non-singlets below M_{GUT}
- Either
  - Baryogenesis due to particles we know at TeV scale, *i.e.*, electroweak baryogenesis
  - Baryogenesis due to gauge-singlets well above TeV, *i.e.*, leptogenesis by ν_R
- The former can be excluded by colliders & EDM
- The latter gets support from Dark Matter concordance, *B* -mode CMB fluctuation that point to "normal" cosmology after inflation

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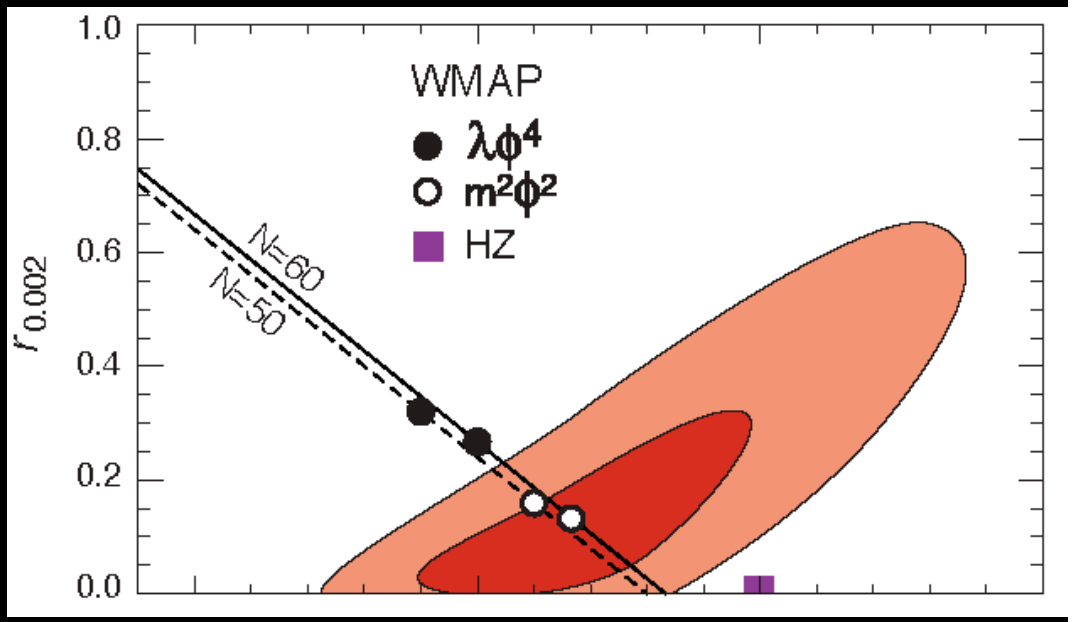
Origin of the Universe

- Right-handed scalar neutrino: $V=m^2\phi^2$
- n_s~0.96
- r~0.16
- Need m~10^{13}GeV
- Still consistent with latest WMAP
- But $V=\lambda\phi^4$ is excluded
- Verification possible in the near future



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Conclusions

- Neutrinos and proton decay: very important clues to early universe, fundamental physics
  - *Are neutrinos mother of our existence?*
  - *Are they mother of the Universe?*
  - *Do their mass come from unified theory?*
- We have a shot at answering these questions
- Need to pull every single stop in our field


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MISSION: POSSIBLE
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THE MISSION BEGINS MAY 5