Emerging Tools for the Future HEP Landscape
The Theoretical Perspective on the Future of Particle Physics
Hitoshi Murayama (Berkeley, Kavli IPMU)
The Last GRC on Particle Physics
HKUST, July 4, 2019
Beautiful data!

ATLAS-CONF-2016-067

ATLAS Preliminary

$\sqrt{s} = 13$ TeV, 13.3 fb$^{-1}$

$H \rightarrow \gamma \gamma$, $m_H = 125.09$ GeV

S/B weighted sum of event categories

CMS-HIG-16-041

CMS Preliminary

Jónatan Piedra
Higgs mass range

**SM** (valid up to $M_P$)

Supersymmetry
MSSM

Composite Higgs

preferred

preferred

GeV
Nima’s anguish

$m_H=125$ GeV seems almost maliciously designed to prolong the agony of BSM theorists....
Naturalness works!

- Why is the Universe big?
- Inflation
  - horizon problem
  - flatness problem
- large entropy
What is Higgs really?

Only one? (SM) 
has siblings? (2DHM) 
not elementary?

Lumi 1920 fb-1, sqrt(s) = 250 GeV 
Lumi 2670 fb-1, sqrt(s) = 500 GeV
Higgs as a portal

- having discovered the Higgs?
- Higgs boson may connect the Standard Model to other “sectors”

\[ \mathcal{L} = \mathcal{O}_{\text{hidden}} H^\dagger H \]
Higgs exotic decay

Complementary to hadron collider searches

Liantao Wang, GRC 2019
Five evidences for physics beyond SM

- Since 1998, it became clear that there are at least five missing pieces in the SM
  - non-baryonic dark matter
  - neutrino mass
  - dark energy
  - apparently acausal density fluctuations
  - baryon asymmetry

We don’t really know their energy scales...
Inconvenient Truth

- colliders are expensive
  - constant CERN budget ~1BCHF
  - construction 300-400MCHF/year
  - CLIC380 ~6BCHF, FCC-ee ~12BCHF
  - HE-LHC ~ 7BCHF, FCC-hh ~24BCHF???
  - 38.5 TeV (100km+6T) ~15BCHF

- Hope for e^+e^- & higher energy pp
- R&D on high-B magnets, plasma, μμ, ...
- we need more resources
- need interconnected approach
- non-accelerator projects important
- many new tools emerging
Seesaw & Leptogenesis

\[ \tilde{m}_1 = \frac{(m_D^\dagger m_D)_{11}}{M_1} \]

di Bari, Plüümacher, Buchmüller
How do we test it?

build a $10^{14}$ GeV collider
new symmetry breaking

- $10^9 < M_R < 10^{14} \text{ GeV} \ll M_{\text{GUT}}, M_{\text{Pl}}$
- need symmetry to forbid MR
- $<\varphi>v_R v_R$
- gravitational wave from
  - 1st order phase transition
  - topological defects
Future experiments DECIGO/BBO can probe $G\mu \sim 10^{-20}$

$v \sim \mu^{1/2} \sim (10^{-20})^{1/2} M_{Pl} \sim 10^9 \text{GeV}$

can probe the whole seesaw/leptogenesis range!

But particle production?  

Jose J. Blanco-Pillado, Ken D. Olum, Xavier Siemens arXiv:1709.02434
1st order Phase Transition

FIG. 2: The predicted GW spectrum for various values of $v$ for $g_{B-L} = 0.4$ and $\lambda_2 = 0.001$.

IV. SUMMARY

In this paper, we have calculated the spectrum of stochastic GW radiation generated by the cosmological phase transition of the minimal $U(1)_{B-L}$ model. We have found that a first-order phase transition strong enough to generate GWs with a detectable amplitude can be realized in the the minimal $U(1)_{B-L}$ model with a single $B-L$ Higgs field, while an additional Higgs field has been thought to be necessary for such a strong first-order phase transition through previous studies. The Higgs potential of the minimal gauged $U(1)_{B-L}$ model is quite simple, and only three parameters are involved in our analysis. We clarify a dependence of the resultant GWs spectrum on the three parameters: the peak amplitude is sensitive to the gauge coupling constant and the self-coupling constant, while the peak frequency is roughly proportional to the VEV of the $B-L$ Higgs field and the self-coupling constant.

The $B-L$ phase transition at an energy scale far beyond the LHC reach can be observed through GWs in the future. We have also found the existence of a lower bound on the Higgs self-coupling constant $\lambda_2 \gtrsim 10^{-4}$ in order not to realize an unwanted second inflation. We stress that, although our analysis has been done based on the $U(1)_{B-L}$ model, our results in this paper are general and applicable for any $U(1)$ gauge theory with $\lambda_2 \gtrsim 10^{-4}$.
Passed the Torch Oct 15, 2018
June 20, 2019

Toru Iijima

Tom Browder
downselect by JAXA 2018, expected launch 2025

Figure courtesy of Dr. Chinone
$r<0.001$ covers most of the large-field inflation models.

LiteBIRD

now downselected by JAXA 2019, expected launch 2027
Best limit on Black Hole dark matter

Niikura, Takada et al., Nature Astronomy

observe Andromeda for one night
read out CCDs every 2 min

No detection $\Rightarrow$ more stringent
upper bound, than 2yr Kepler data (Griest et al.)
SIMP: dark hadrons
$m \sim 0.3 \text{GeV, } \sigma \sim 10^{-24} \text{cm}^2$

QCD axion

moduli w/ vector mediation

gravitino

SIMP

asymmetric DM

WIMP

sterile neutrino

defects

preheating

Q-balls

mirolensing etc

to fluffy
SuperKEKB & Belle II

50 ab$^{-1}$!

\[ E_\gamma = \frac{\sqrt{s}}{2} \left( 1 - \frac{M_{\text{inv}}^2}{s} \right) \]
$SU(2), N_f = 2$

$\alpha_D = 1/4\pi$

$m_{\pi} = 300$ MeV
BES III projection

$\sqrt{s} = 4$ GeV, $100$ fb$^{-1}$

$\sigma_{E_{\gamma}}/E_{\gamma} = 2\%$

$m_{\gamma_d} = 3$ GeV, $\epsilon_{\gamma} = 8 \times 10^{-4}$
Belle II projection
\[ \sqrt{s} = 10 \text{ GeV}, \ 50 \text{ ab}^{-1} \]
\[ \sigma_{E\gamma}/E_{\gamma} = 1\% \]
\[ m_{\gamma_d} = 12 \text{ GeV}, \ \epsilon_{\gamma} = 10^{-2} \]
FIG. 4: Left: Observed rotation curve of dwarf galaxy DDO 154 (black data points) compared to models with an NFW profile (dotted blue) and cored profile (solid red). Stellar (gas) contributions indicated by pink (dot-)dashed lines. Right: Corresponding DM density profiles adopted in the fits. NFW halo parameters are $r_s \approx 3.4 \text{kpc}$ and $\rho_s \approx 1.5 \times 10^7 \text{M}_\odot/\text{kpc}^3$. While the cored density profile is generated using an analytical SIDM halo model developed in [116, 118].

Recent high-resolution surveys of nearby dwarf galaxies have given further weight to this discrepancy. The HI Near Galaxy Survey (THINGS) presented rotation curves for seven nearby dwarfs, finding a mean inner slope $\rho \approx 0.29 \pm 0.07$ [96], while a similar analysis by LITTLE THINGS for 26 dwarfs found $\rho \approx 0.32 \pm 0.24$ [167]. These results stand in contrast to $\rho \approx 1$ predicted for CDM.

However, this discrepancy may simply highlight the inadequacy of DM-only simulations to infer the properties of real galaxies containing both DM and baryons. One proposal along these lines is that supernova-driven outflows can potentially impact the DM halo gravitationally, softening cusps [78, 168], which we discuss in further detail in § II E. Alternatively, the inner mass density in dwarf galaxies may be systematically underestimated if gas pressure—due to turbulence in the interstellar medium—provides radial support to the disk [169, 170]. In this case, the observed circular velocity will be smaller than needed to balance the gravitational acceleration, as per Eq. (5), and purported cores may simply be an observational artifact.

In light of these uncertainties, LSB galaxies have become an attractive testing ground for DM halo structure. A variety of observables—low metallicities and star formation rates, high gas fractions and mass-to-light ratios, young stellar populations—all point to these galaxies being highly DM-dominated and having had a quiescent evolution [171]. Moreover, LSBs typically have larger circular velocities and therefore deeper potential wells compared to dwarfs. Hence, the effects of baryon feedback and pressure support are expected to be less pronounced.

Rotation curve studies find that cored DM profiles are a better fit for LSBs compared to cuspy profiles [54, 58, 59, 63, 64]. In some cases, NFW profiles can give reasonable fits, but the required halo concentrations are systematically lower than the mean value predicted cosmologically. Although early HI and long-slit HI observations carried concerns that systematic effects—limited resolution (beam-smearing), slit misalignment, halo triaxiality and noncircular motions—may create cores artificially, these issues have largely been put to rest with the advent of high-resolution HI and optical velocity fields (see Ref. [148] and references therein). Whether or not baryonic feedback can provide the solution remains actively debated [67, 172, 173, 174]. Cored DM profiles have been further inferred for more luminous spiral galaxies as well [65, 175, 176].
Diversity in stellar distribution

Similar outer circular velocity and stellar mass, but different stellar distribution

- compact → redistribute SIDM significantly
- extended → unchange SIDM distribution

Ngc 6503, \( c_{200}: \text{median}, M_{200}: 2.5 \times 10^{11} M_\odot \)

\[ M_* : 0.83 \times 10^{10} M_\odot \]

Ngc 2903, \( c_{200}: \text{median}, M_{200}: 1.2 \times 10^{12} M_\odot \)

\[ M_* : 0.83 \times 10^{10} M_\odot \]

UGC 128, \( c_{200}: \text{median}, M_{200}: 3.8 \times 10^{11} M_\odot \)

\[ M_* : 0.57 \times 10^{10} M_\odot \]

Ayuki Kamada

AK, Kaplinghat, Pace, and Yu, PRL, 2017
one of the largest telescopes: 8.2m
big field of view $\sim 1.5^\circ$
**Imaging** with Hyper Suprime-Cam (HSC)
- 870M pixels
- $\sim 300M$ galaxy images
- 2014–2019, 330 nights
**spectroscopy** with PrimeFocusSpectrograph (PFS)
- 2394 optical fibers, 280–1260nm
- $>1M$ redshifts
- 2022–2026 360 nights
PFS pointings for MW satellites
~ HSC imaging data are available for all samples ~

- Ursa Minor
- Draco
- Sextans
- Sculptor
- Fornax
- Bootes I

Tidal radius of stellar comp.
Conclusions

• SM is technically UV complete

• Matt Reece: No no-lose theorem

• Problems have sharpened

• Particle physics is as interesting as ever!

• facing resource problems

• interconnected approach with new tools
We’ll do whatever we can!
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Status of ILC in Japan
MEXT’s view in regard to the ILC project
Executive Summary

March 7, 2019
Research Promotion Bureau, MEXT

- Following the opinion of the SCJ, MEXT has not yet reached declaration for hosting the ILC in Japan at this moment. The ILC project requires further discussion in formal academic decision-making processes such as the SCJ Master Plan, where it has to be clarified whether the ILC project can gain understanding and support from the domestic academic community.

- MEXT will pay close attention to the progress of the discussions at the European Strategy for Particle Physics Update.

- The ILC project has certain scientific significance in particle physics particularly in the precision measurements of the Higgs boson, and also has possibility in the technological advancement and in its effect on the local community, although the SCJ pointed out some concerns with the ILC project. Therefore, considering the above points, MEXT will continue to discuss the ILC project with other governments while having an interest in the ILC project.
Given the statement this time, I hope discussions in the scientific community both in and outside Japan will continue, and we intend to continue exchange of opinions internationally at the governmental level. As for the timeline, as we outlined in the statement, we will keep our eyes on the Master Plan process of the Science Council of Japan domestically, as well as the European Strategy Update for Particle Physics. We will act based on the discussions in the scientific community in and outside Japan. The completion of the Master Plan will be around February 2020, and the European Strategy in May 2020, and we will follow up on them.
Proposed 500 GeV ILC in Japan

Request SCJ for assessment

Report with various study items

Fact-finding committee “wait till LHC Run2 results”

ILC as Higgs factory starting with 250 GeV

March MEXT statement

Master Plan

Release of Master Plan

International governmental discussions

MEXT Roadmap

4 years of prep

ILC construction ~9 years

Release of Master Plan

June Physics subcommittee September presentation

MEXT statement

European Strategy Update

European Strategy Update

ILC International WG

Report on 250 GeV ILC

MEXT Roadmap

ILC construction ~9 years
In the future, while paying close attention to the progress of discussions on the European Elementary Particle Physics Strategy, we would like to deepen discussions with France and Germany at the governmental level, by proposing, for instance, to establish a standing discussion group similar to the one with the US. (Mr.Isogai)

So, also for the ILC project, we expect there will be a working group set up in the High Energy Accelerator Research Organization, so-called KEK, and at its initiative, discussions within the community of domestic and foreign researchers will proceed regarding international cost sharing, etc. (Mr.Isogai)

As I mentioned earlier, I am also aware that this is a project of great significance both from the academic research point of view and from the perspective of regional revitalization. Therefore, I would like to continue our investigations, closely collaborating with related communities while keeping an eye on the international situation. (Minister Shibayama)
Official launch of the Japan-Germany and Japan-France discussion groups on ILC after consultation among congress people and relevant ministries in both countries. We also agreed to pursue trilateral cooperation.
Model of international cost-sharing for construction and operation
Organization and governance of the ILC Laboratory
International sharing of the remaining technical preparation

Report to MEXT this September