“Tension” in Fundamental/Partcle Physics.

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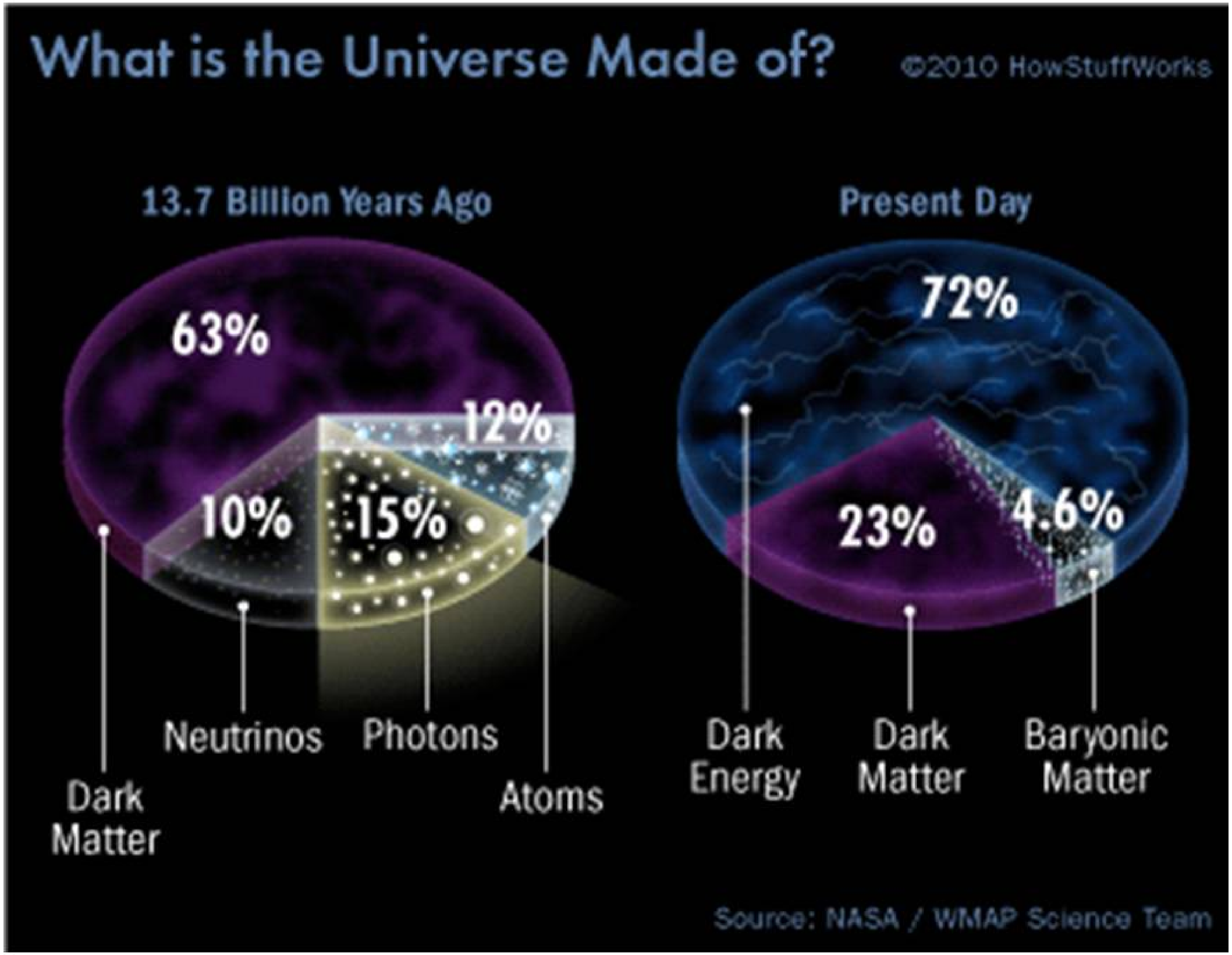
Disclaimer: There are a Lot of Big and Little Mysteries in Science/Physics

- Wikipedia "List of unsolved problems in physics"
  https://en.wikipedia.org/wiki/List_of_unsolved_problems_in_physics
- Biggest Unsolved Mysteries in Physics, 2017
  https://www.livescience.com/34052-unsolved-mysteries-physics.html
- The 7 Biggest unanswered Questions in Physics (NBC News)
  https://www.nbcnews.com/mach/science/7-biggest-unanswered-questions-physics-ncna789666

Disclaimer: Nope Not Talking about Dark Energy nor Dark Matter



Inconsistencies in Physical Measurements that Persist (and maybe grow)

- The measurement of the **Hubble Constant** by different methods yields incompatible results.
- **Neutrino physics** (the light but not massless counterpart to the electron, muon, and tau) shows some discrepancy with the Standard Model (SM) of particle physics.
- In **B-meson** decays there is odd excess of electron-positron pairs over muon-antimuon pairs.

The Hubble Constant

- Definition: *As we look further and further away (back in time) and we average over local motion, we find galaxies and clusters are receding at a radial velocity proportional to distance.*

$$v_{rec} = H_0\, d$$

- usually H_0=*68-72* km/s / Mpc and often the "little h" notation is used, H_0=*h*100 km/s/Mpc*, so *h=0.68-0.72*.
- Hubble's 1929 work not so pretty...

Edwin Hubble 1929 Graph

- 1929 graph of distances and “effective” velocities (from redshift), he thought these were super-giant stars but turned out to be giant HII (gas) regions, so he erred on the distance---actual distance much further.

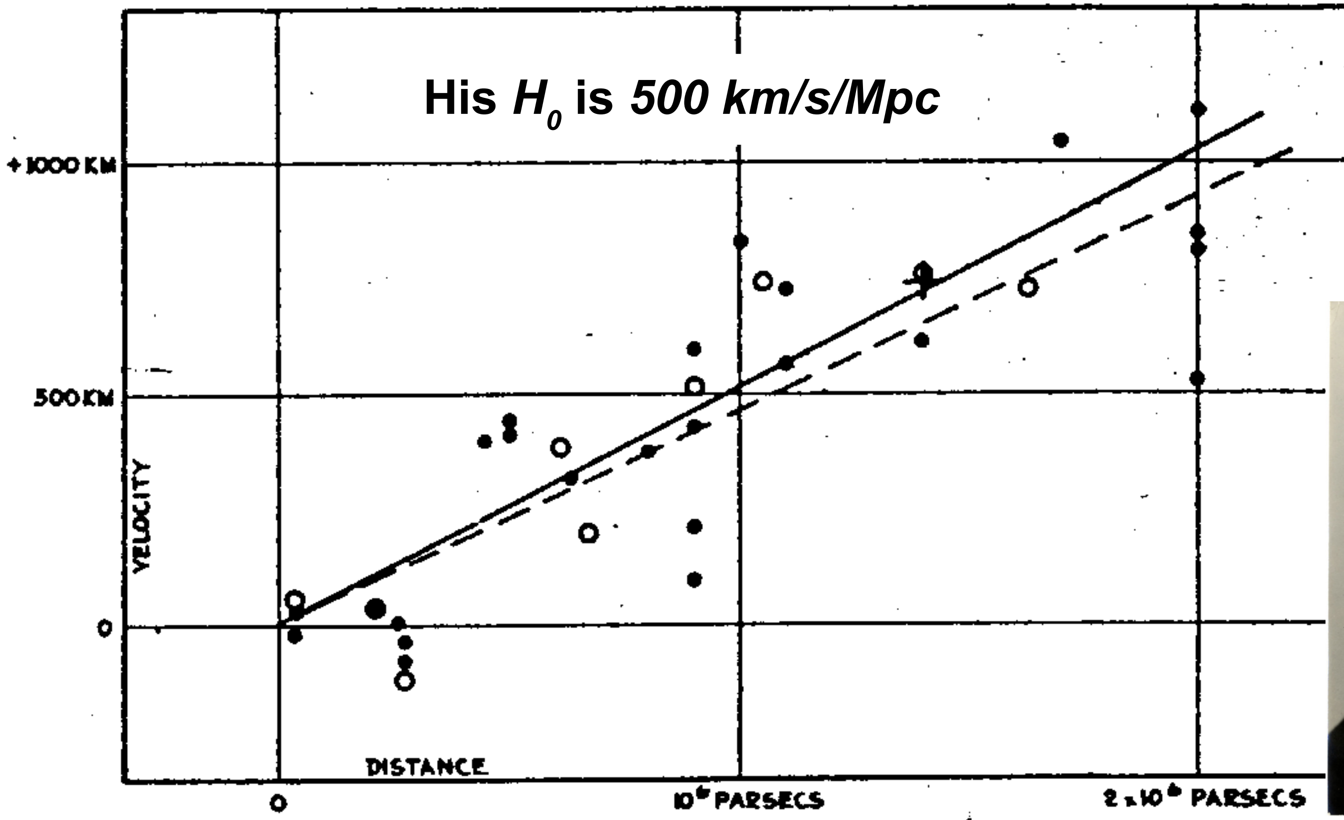
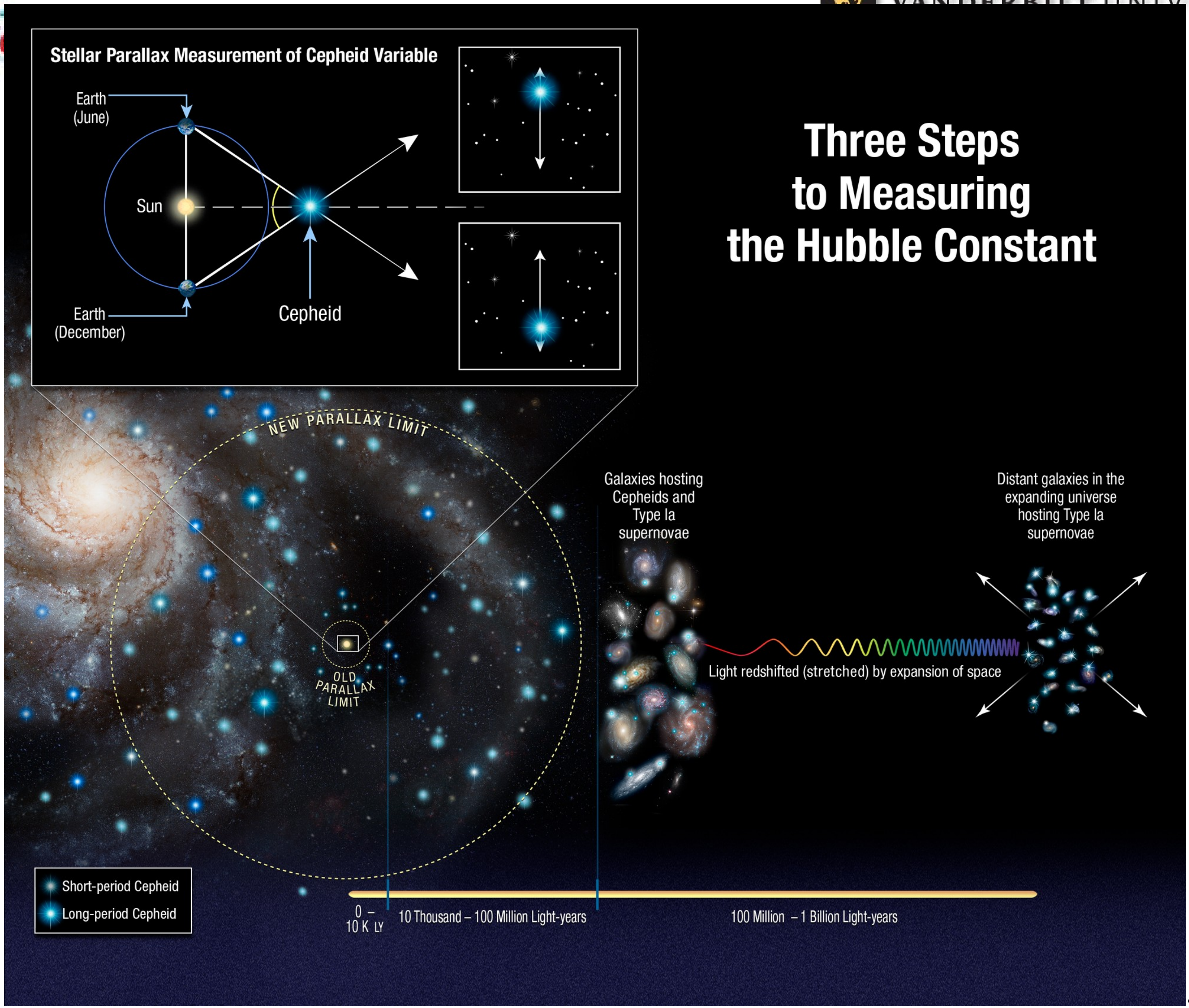


FIGURE 1

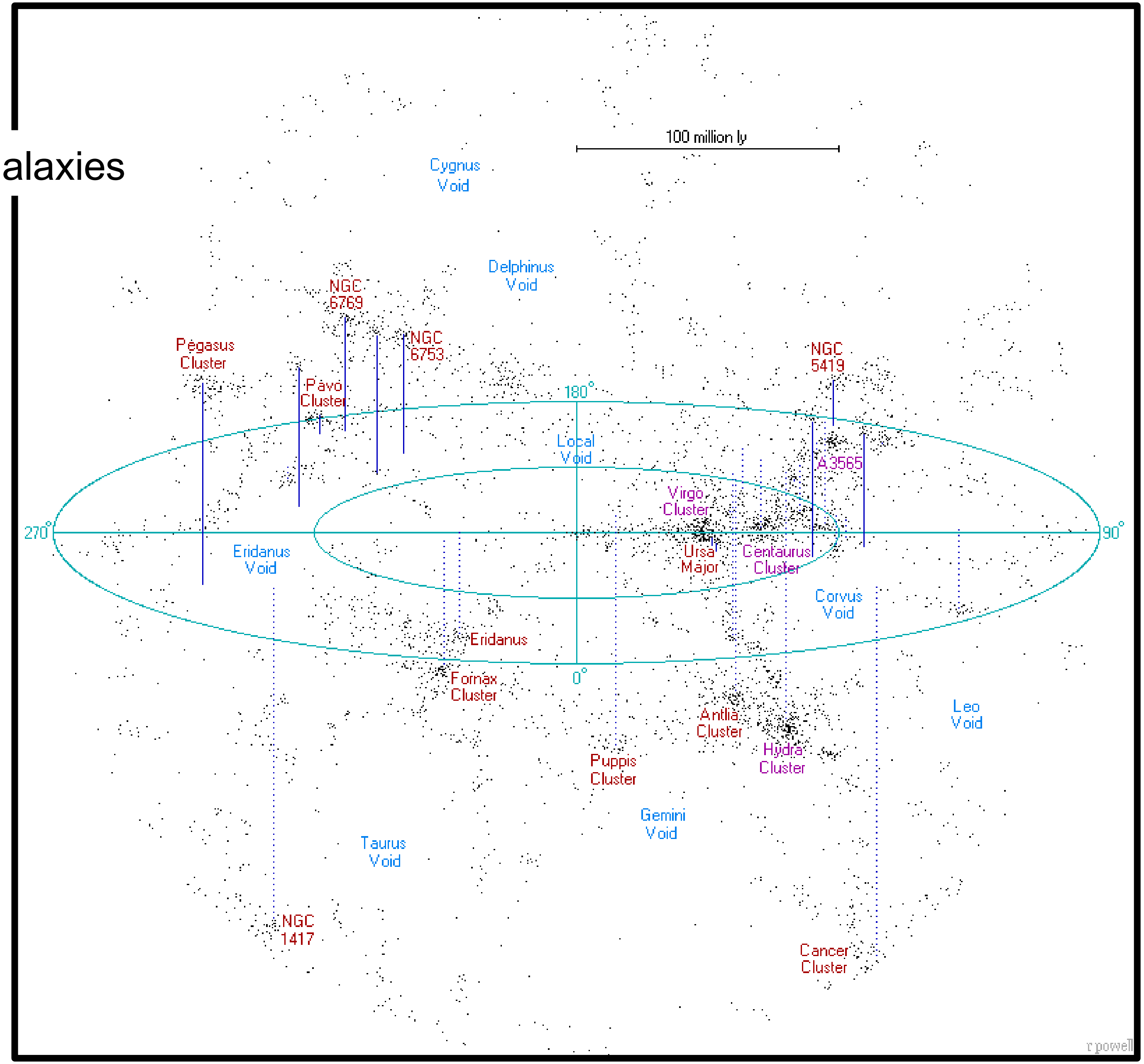
Improved Measurements in the last 90 years

- From the NASA link, the "Yardstick" and how we measure distances:
  - *Nearby*, **parallax**, the angle change relative to much more distant stars as the earth goes from one side to the other of its orbit;
  - *Middle*, calibrate **Cepheid variable stars** that pulsate in a way related to their absolute brightness in the "Nearby" and use for further out.
  - *Distant*, use supernovae Type Ia which have light curves (rise and fall) which you can relate to their absolute brightness.
- These "yardsticks" overlap, so you can check one against the other. Looks like we can get to 1 billion light-years.
- aa galaxies within 200 million light years.


Stellar Parallax Measurement of Cepheid Variable
Earth (June)
Sun
Earth (December)
Cepheid
Three Steps to Measuring the Hubble Constant
NEW PARALLAX LIMIT
OLD PARALLAX LIMIT
Galaxies hosting Cepheids and Type Ia supernovae
Distant galaxies in the expanding universe hosting Type Ia supernovae
Light redshifted (stretched) by expansion of space
Short-period Cepheid
Long-period Cepheid
0 – 10 K LY
10 Thousand – 100 Million Light-years
100 Million – 1 Billion Light-years

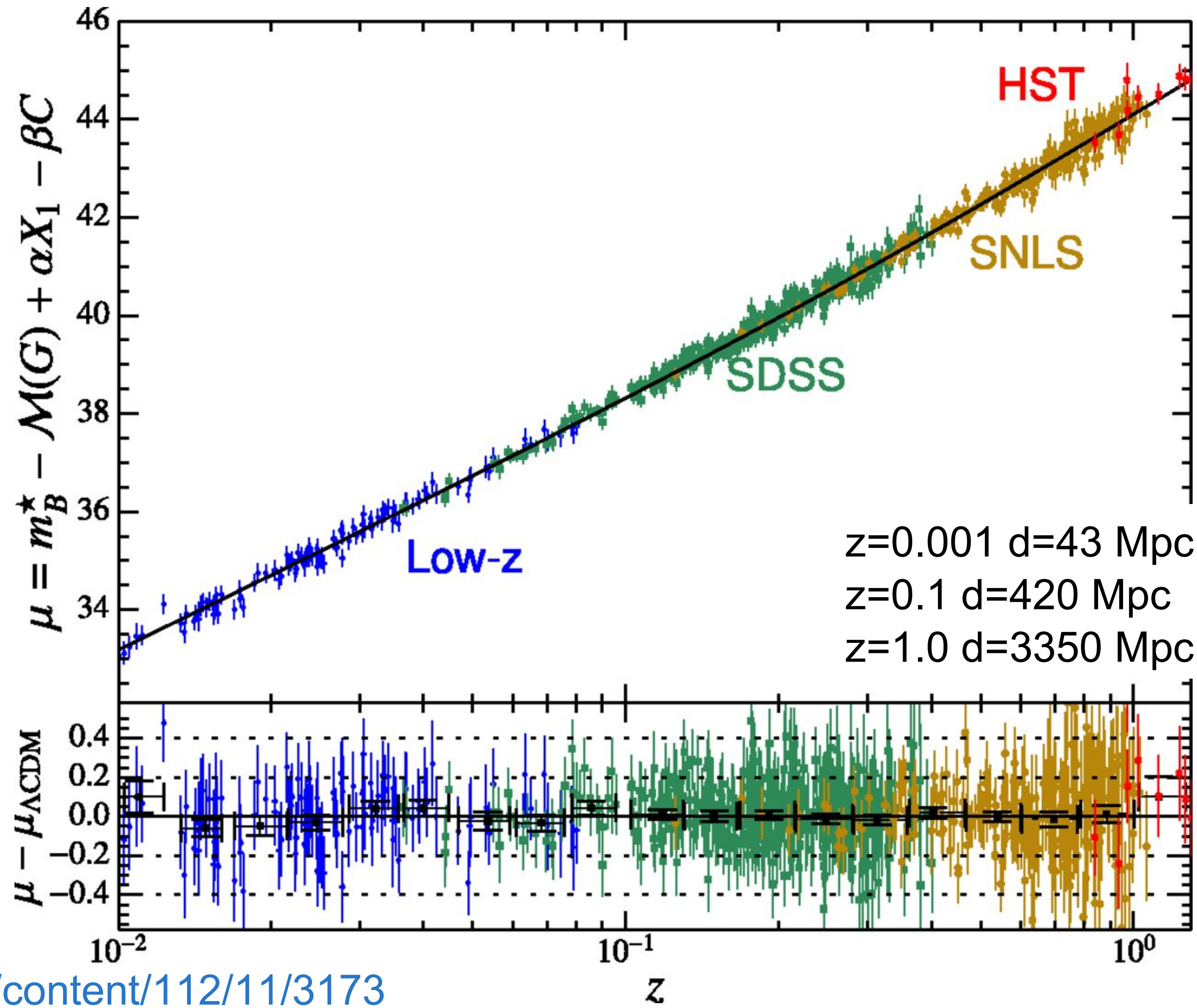
Uni within 200 million light years

About 990 Galaxies



Updated Hubble Graph, just SNe Type 1

- Hubble Constant H0 = 73.45+/-1.66 km/s/Mpc



z=0.001 d=43 Mpc
z=0.1 d=420 Mpc
z=1.0 d=3350 Mpc

Ref: http://www.pnas.org/content/112/11/3173
http://www.astro.ucla.edu/~wright/CosmoCalc.html
https://ned.ipac.caltech.edu/help/cosmology_calc.html

Updated Hubble Graph---Caption

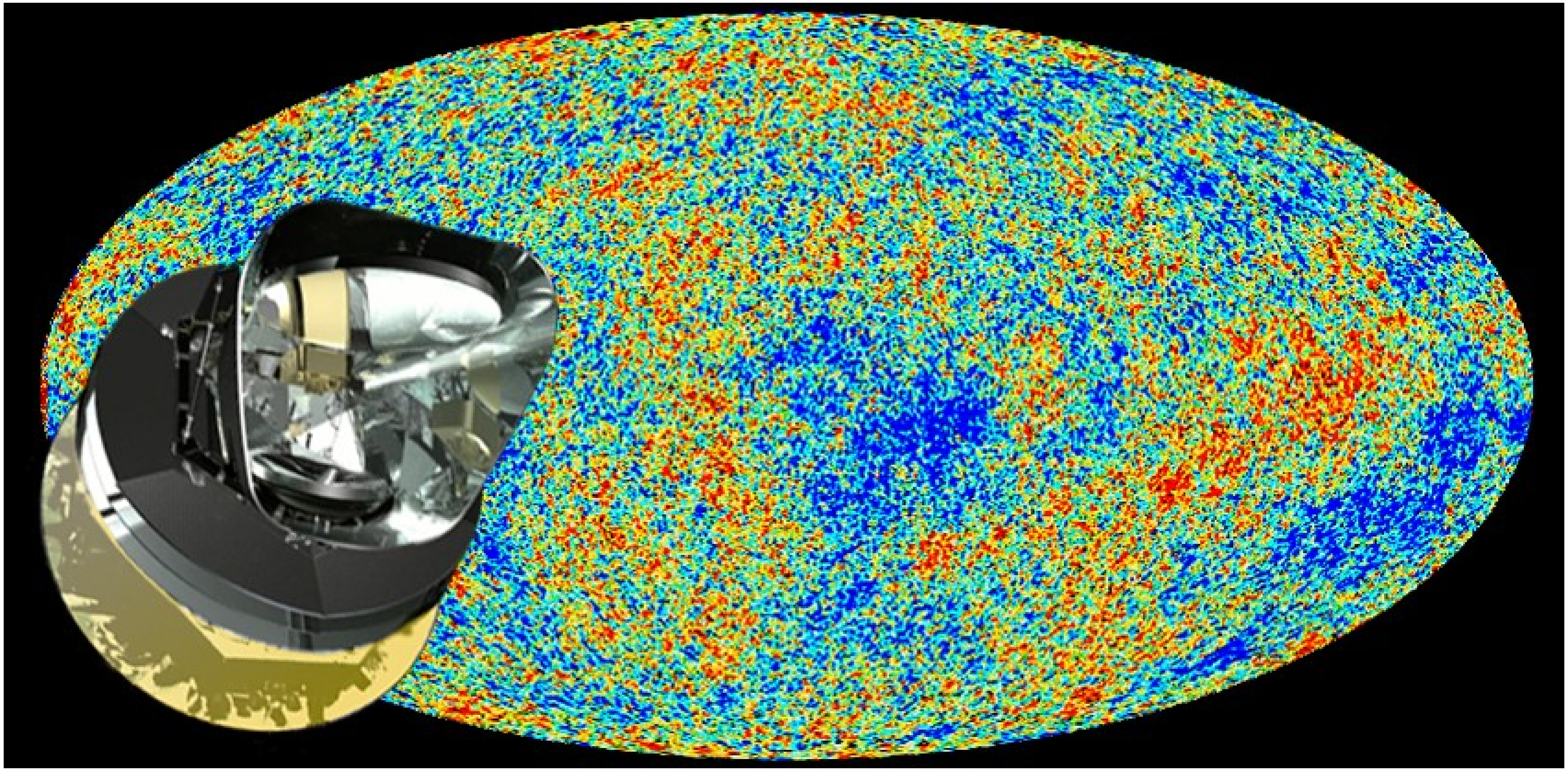
Fig. 2. The Hubble diagram of galaxies [distance vs. redshift (velocity)] from a large combined SNIa distance-indicator sample [reproduced with permission from ref. 14 (©) ESO]. A recent Hubble diagram of a large combined sample of galaxies using SNIa as standard candles for distance measurement. The graph presents distance (as distance modulus; proportional to log of distance) vs. redshift z (Doppler shift, proportional to velocity for small redshift: $v/c \sim z$). The different SNIa samples are denoted by different colors and are listed by name [low-z sample; Sloan SDSS sample; SN legacy survey, SNLS; and Hubble Space Telescope SNIa, HST; for detail and references, see Betoule et al.(14)]. The black line (that fits the data so well) represents the $d(z)$ relation expected for the current cosmology (a flat universe with mass density 30% and cosmological constant 70%) and a Hubble Constant of H_o = 70 km/s/Mpc. The slight deviation in shape at large distances is the evidence for acceleration. Hubble's 1929 graph (Fig. 1, plotted with reverse axes, v vs. d) will fit in a tiny spot near/below the origin of this diagram.

Planck CMB Fit

- The Planck satellite fits to the temperature fluctuations in the Cosmic Microwave Background gives a measure of the Hubble Constant H0.
- Key points, the light decoupled from matter at z~1100 or d~

Planck & CMB

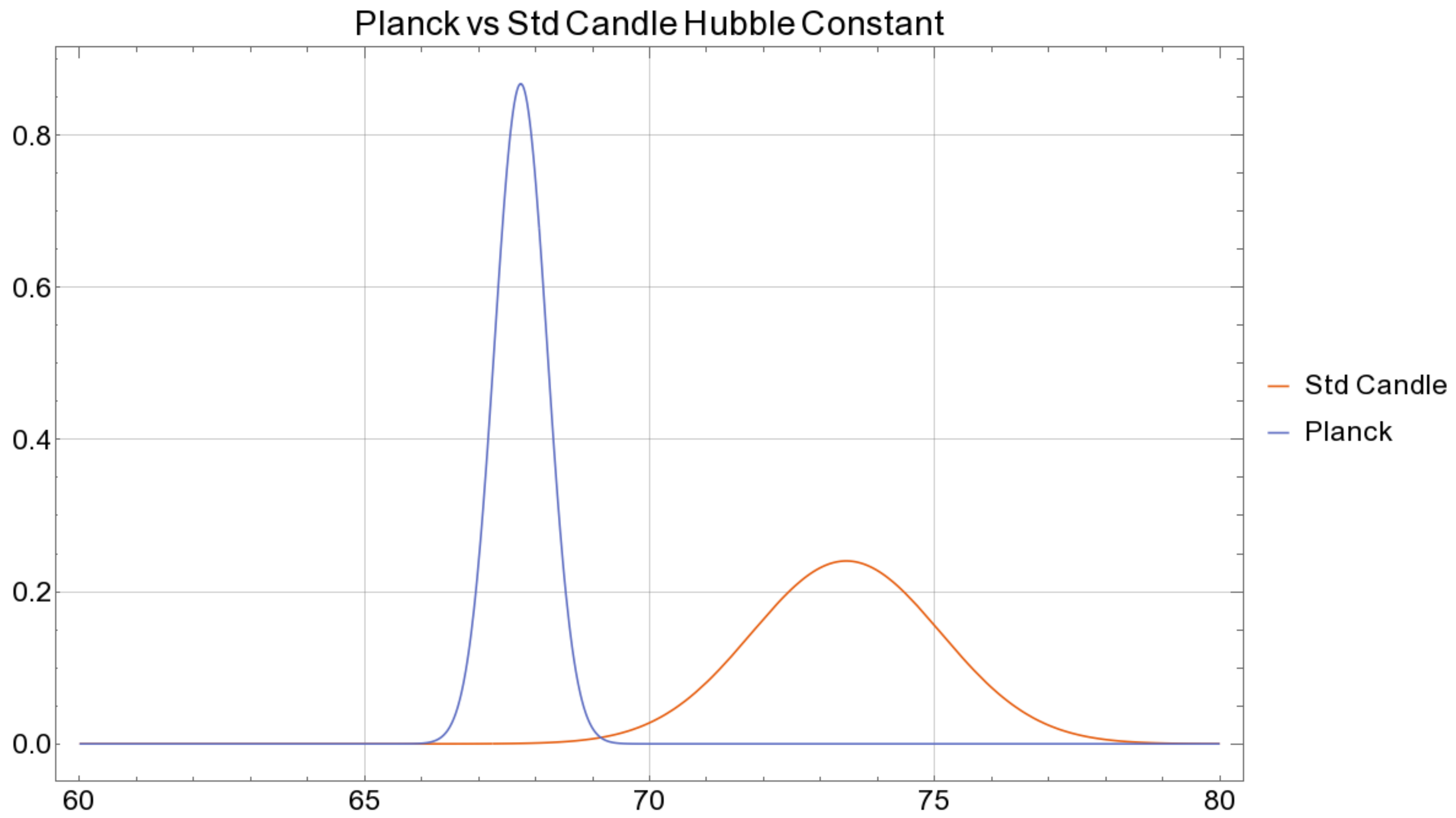
- The Planck satellite
- Measures fluctuations in the CMB around T=2.73 deg K, ΔT~few micro K



Ref: http://newscenter.lbl.gov/2013/03/21/planck-results/
https://arxiv.org/abs/1502.01589

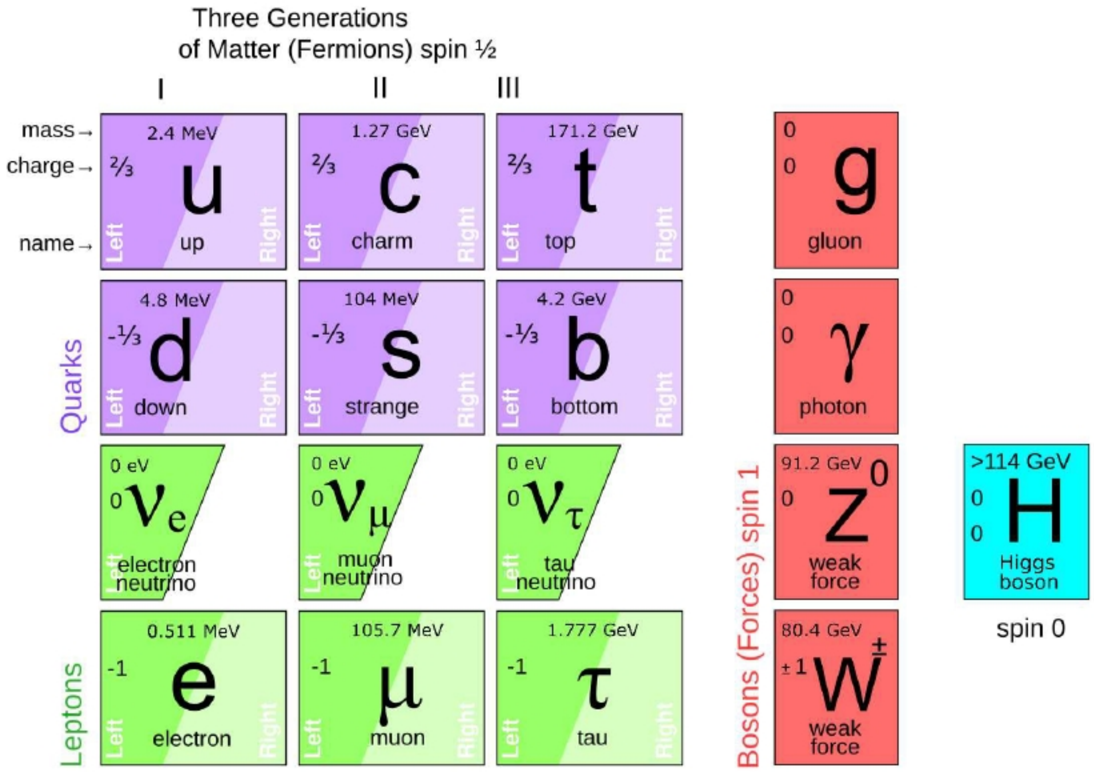
Planck & CMB

- The Standard Candle H0 = 73.45+/-1.66 km/s/Mpc
- The Planck satellite & ΛCDM model give H0 = 67.74+/-0.46 km/s/Mpc
- Estimate 3.7 sigma difference between the two



Neutrino Physics

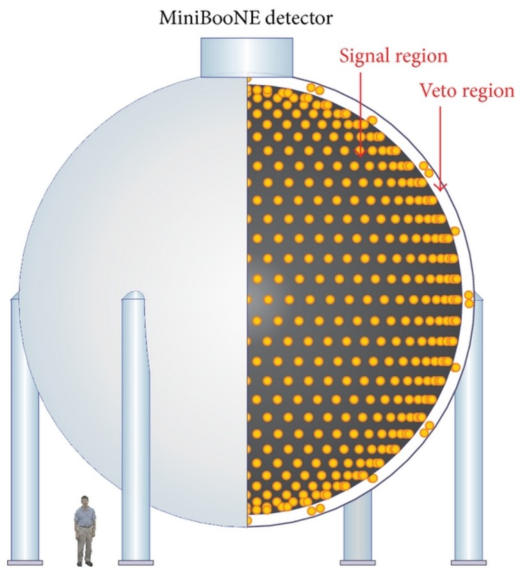
- MiniBooNE at Fermilab sees too many electron neutrinos coming from protons hitting Be target, to the level of 4.5 sigma.
- Consistent with observations at Los Alamos on the Liquid Scintillator Neutrino Detector.
- Consistent with other excesses seen by MiniBooNE.
- Can be explained by a "sterile" neutrino (meaning not like the ones in the particle grid). Only interact with the Higgs and gravity.

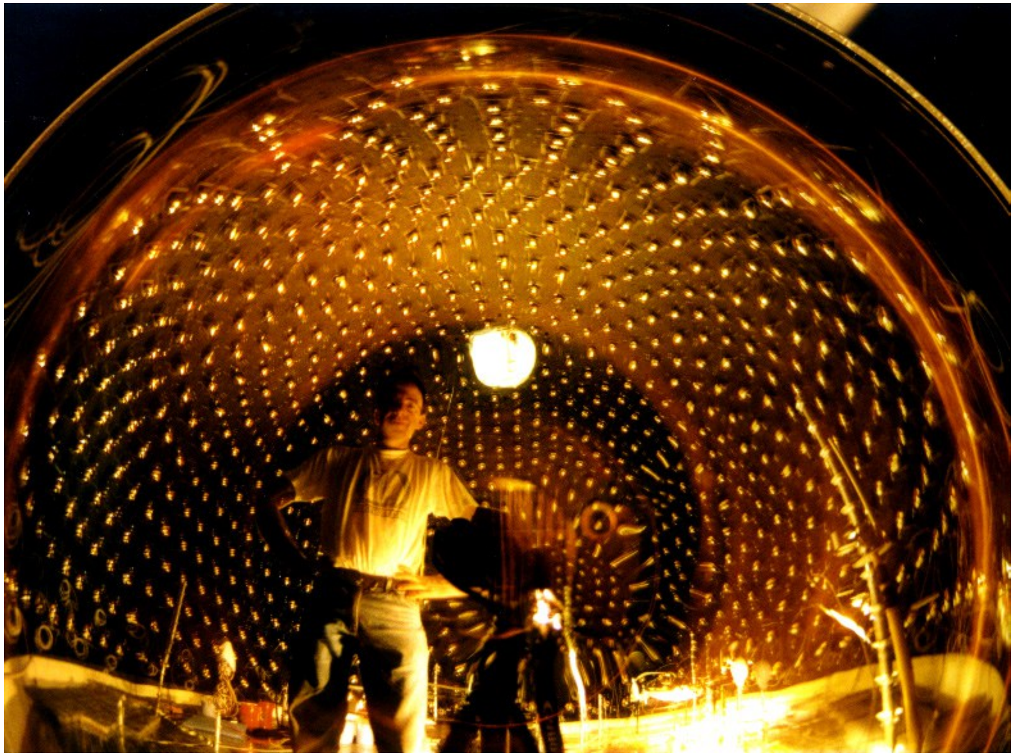


Ref: https://www.sciencenews.org/article/mysterious-neutrino-surplus-hints-existence-new-particles
https://arxiv.org/abs/1805.12028

MiniBooNE

- Protons at 8 GeV hit a Be target, Kaons and Pions decay into muons and muon neutrinos, they measure electron neutrinos.
- 12m Sphere filled with 800 tons of mineral oil
- PMTs look for Cerenkov light of neutrino interactions.





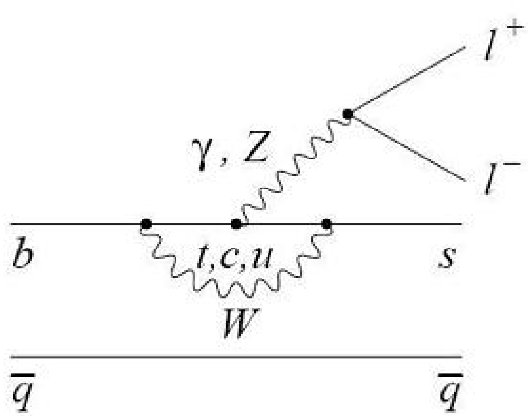
Ref: https://www.sciencenews.org/article/mysterious-neutrino-surplus-hints-existence-new-particles
https://arxiv.org/abs/1805.12028
https://dorigo.wordpress.com/2007/04/11/live-feed-of-miniboone-results-seminar-today/

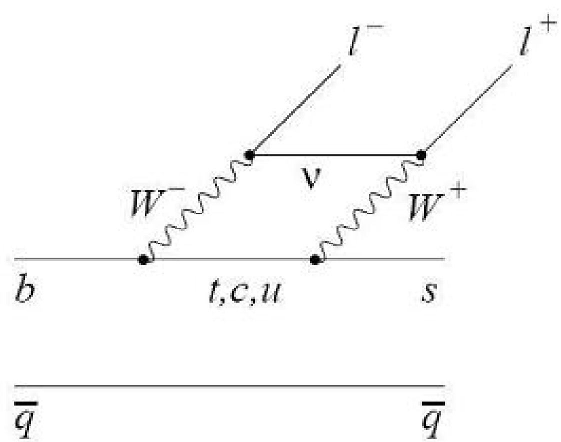
B-Physics makes too many muons

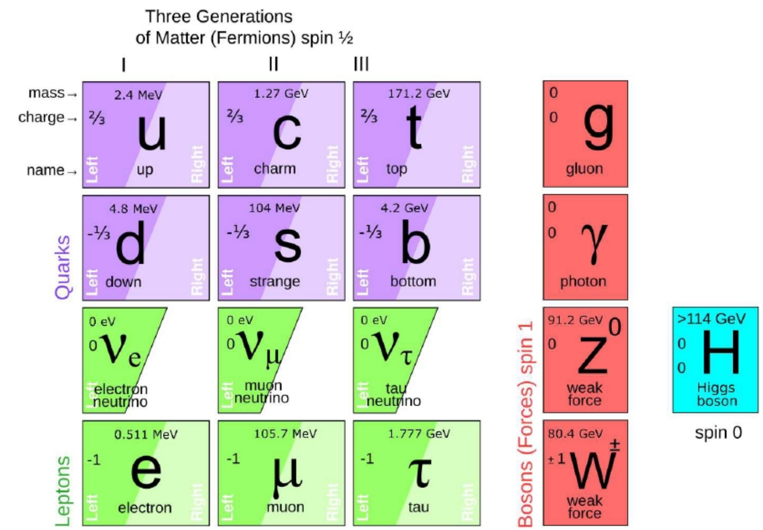
- For many years, different b (quark) or B (meson) decays have shown anomalies...excesses when non are expected. Some measurements are difficult due to QCD (strong nuclear force) effects.
- Recently, too many electron-positron pairs observed in

$$R(K^{(*)}) = \mathcal{B}(B \to K^{(*)}\mu^+\mu^-)/\mathcal{B}(B \to K^{(*)}e^+e^-)$$

- Considered a “clean” measurement.
- B-meson is   u+b-bar or d+b-bar and antiparticles.
- Kaons are   u+s-bar or d+s-bar , etc.







Ref: https://arxiv.org/abs/1705.05802
http://ppewww.physics.gla.ac.uk/LHCb/New_LHCb_webpage/B2Kstmumu_intro.htm

Links

- Hubble Constant
  - “...call for new physics?” https://arxiv.org/abs/1801.07260
  - physics lab http://community.dur.ac.uk/ian.smail/hdfSize/hdfSize_intro.html
  - NASA Improved Hubble... https://www.nasa.gov/feature/goddard/2018/improved-hubble-yardstick-gives-fresh-evidence-for-new-physics-in-the-universe
  - Science Alert https://www.sciencealert.com/lowest-uncertainty-hubble-constant-record-parallax-cepheid-brightness
  - aa
- Neutrino deficit
  - Ars Technica 2018 https://arstechnica.com/science/2018/06/weird-neutrino-excess-wont-go-away-hints-at-new-physics/
  - Mortsell et al. arXiv https://arxiv.org/abs/1801.07260
- b-physics

Backup