Astroparticle Physics

Autumn 2022, Tata Institute of Fundamental Research

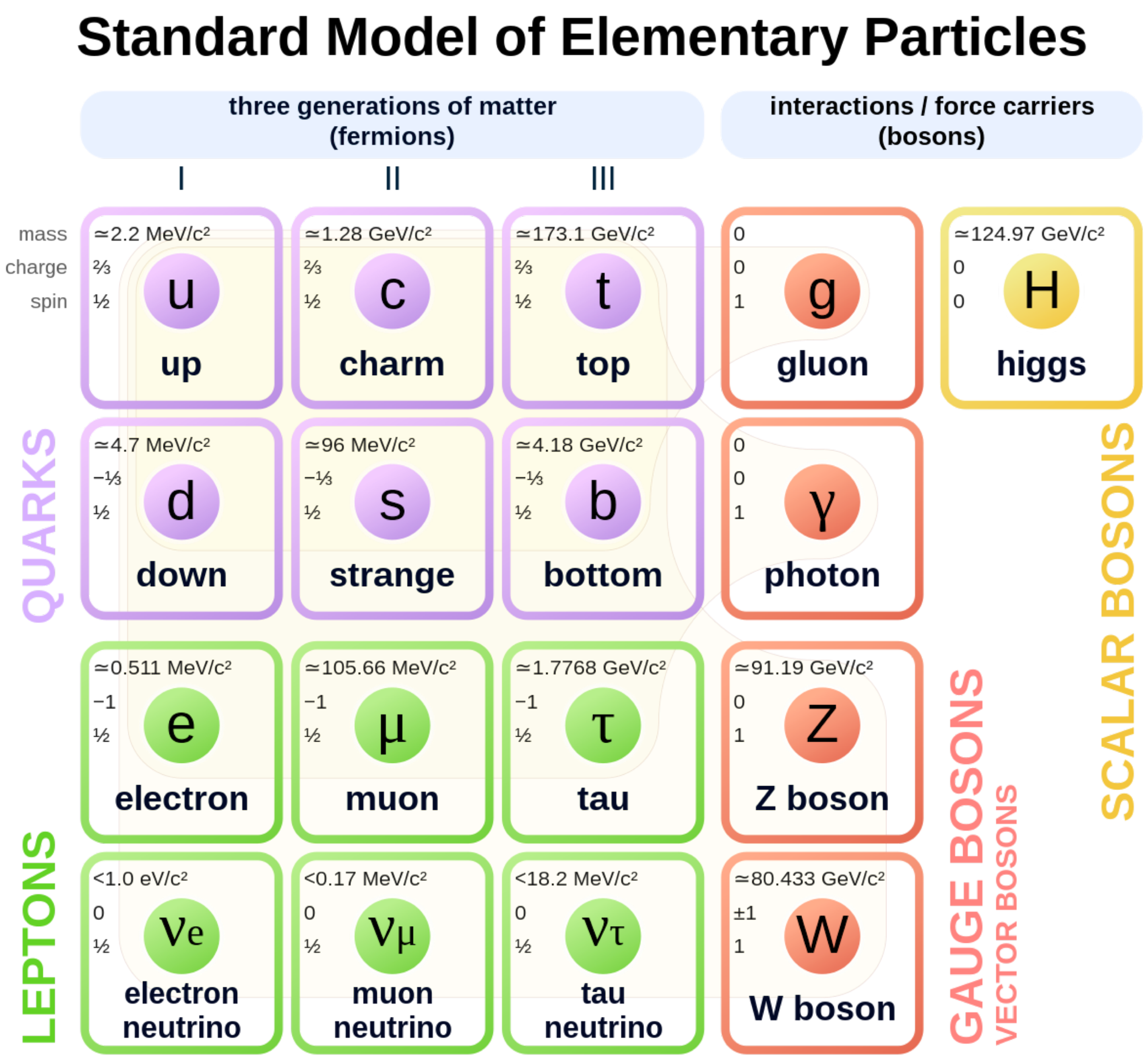
Introductory Lecture and lesson plan

Mohamed Rameez

DHEP

Room : C119

Course Consultation hours : 1100 to 1200, Wednesdays



One of the most remarkable achievements of the last 70 years.

Repeatable experiments

Yang mills theory with Local SU(3) X SU(2) X U(1) gauge symmetry

19 parameters

Ultraviolet complete and renormalizable without Neutrino masses (or does not explain neutrino oscillations)

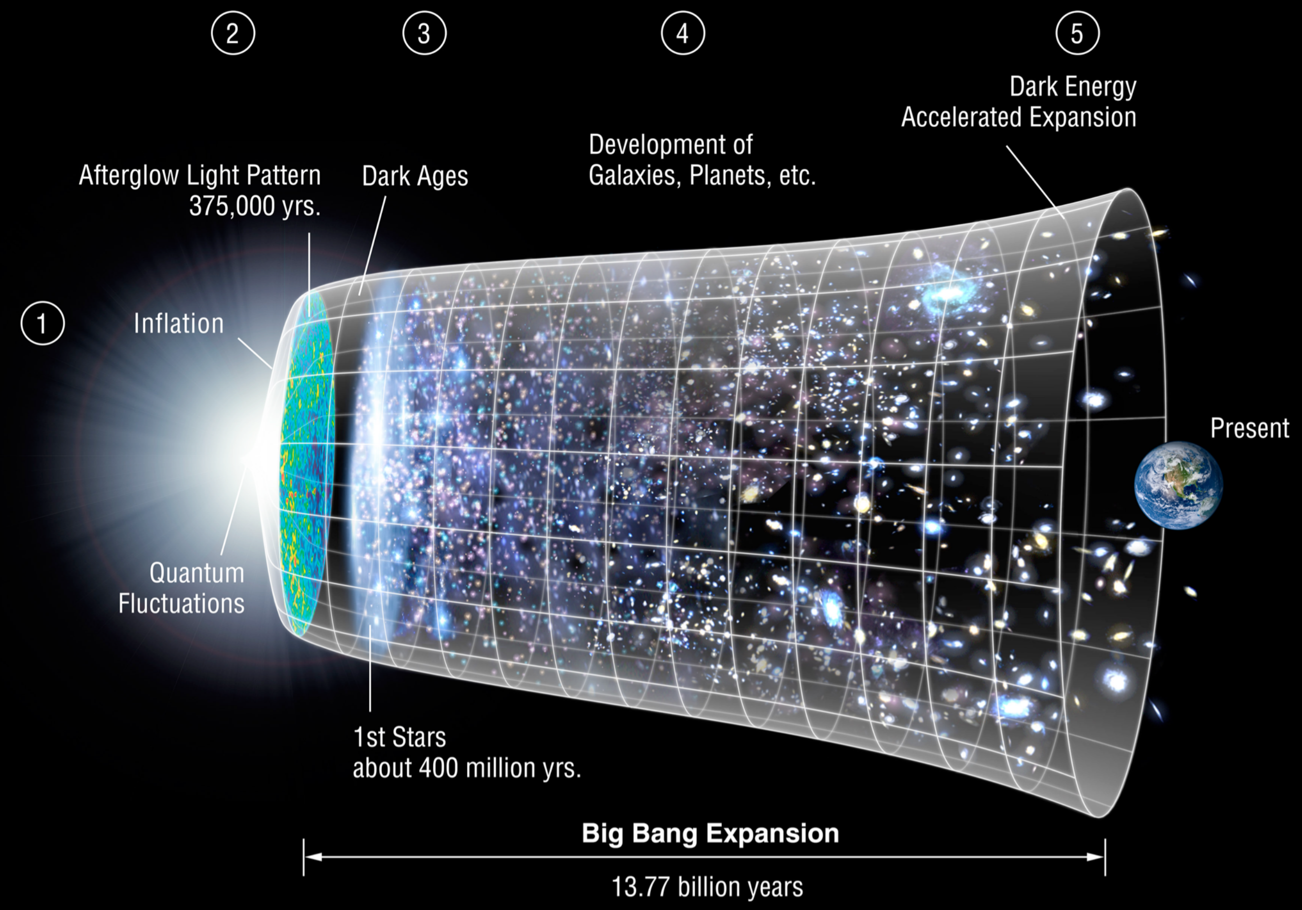
No explanation for baryon asymmetry

No connection to our best theory of Gravity

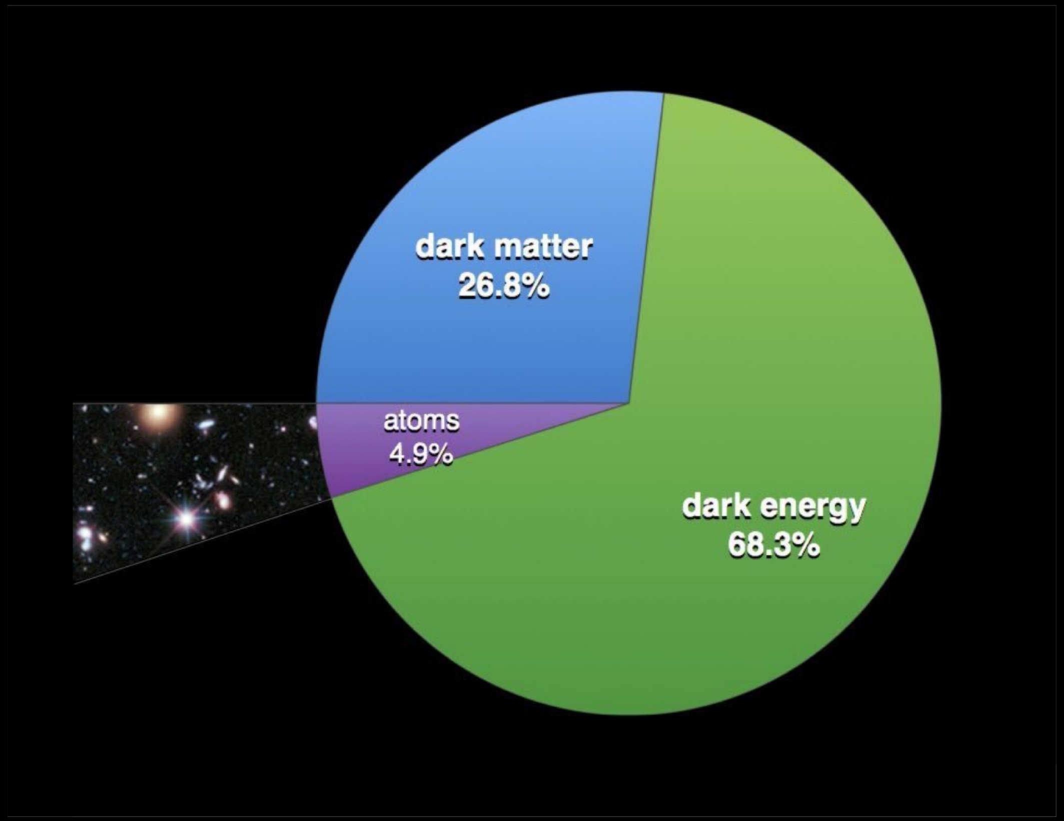
Some argue it has inelegant features.

Not axiomatized

Cosmology : concordance model



NASA/WMAP Science Team



Based on observations (not repeatable)

Based on general relativity, Friedmann equations
Assumed isotropy and homogeneity

Astroparticle physics

Is a collection of scientific endeavors at the interface of the two.

- Questions:
  - The nature of Dark Matter and Energy
  - The origin of high energy cosmic rays and the mechanism by which they are accelerated
  - Neutrino oscillations, origin of mass.
  - Origin of Baryon asymmetry in the Universe
- • The methods:
  - Observing the Universe using multiple wavelengths and messengers.
  - Modelling the dynamics (gravitational and otherwise).
- The tools:
  - Observatories:
    - γ-ray, radio, optical, infrared, x-ray, neutrinos, cosmic rays

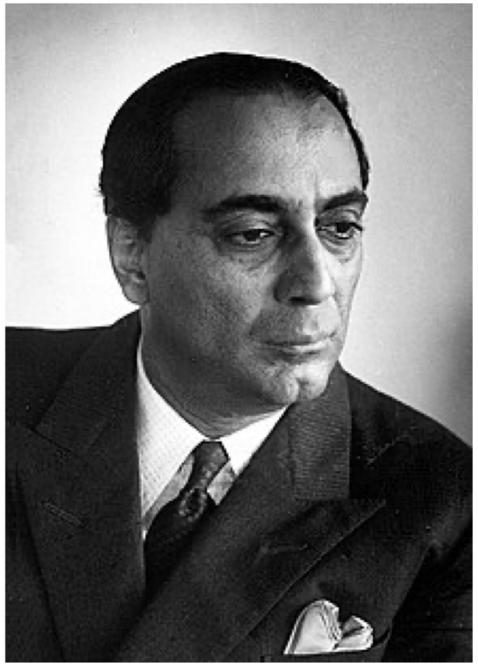
This course

- 29 lectures [Mon/Thu] 22-08-2022 to 15-12-2022
- Objective:
    - Tell you the present consensus as a story
    - Build the empirical and logical foundations
    - Enable you to work with me as your PhD advisor
- Today:
    - Broad overview
    - Course plan and schedule (lecture wise breakup)
    - Prerequisites. How much do you already know?
- Evaluation?

Lecture 2.0 : Historical Introduction

Victor Hess, balloon borne cosmic ray experiments

Fritz Zwicky

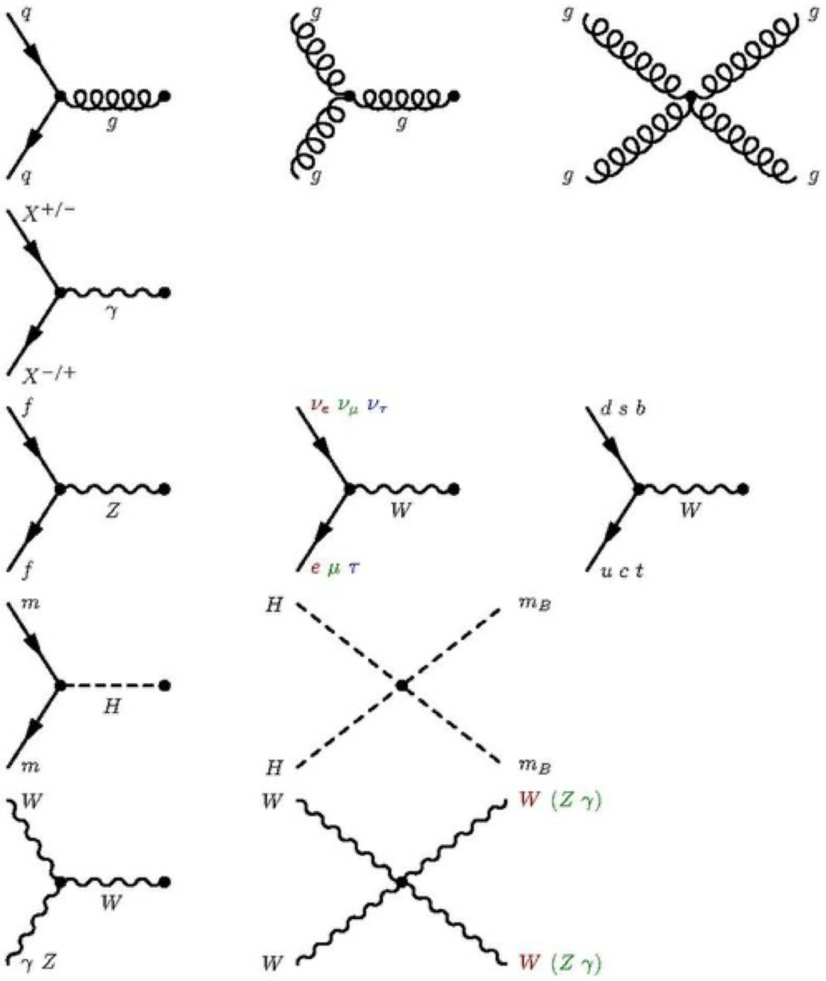


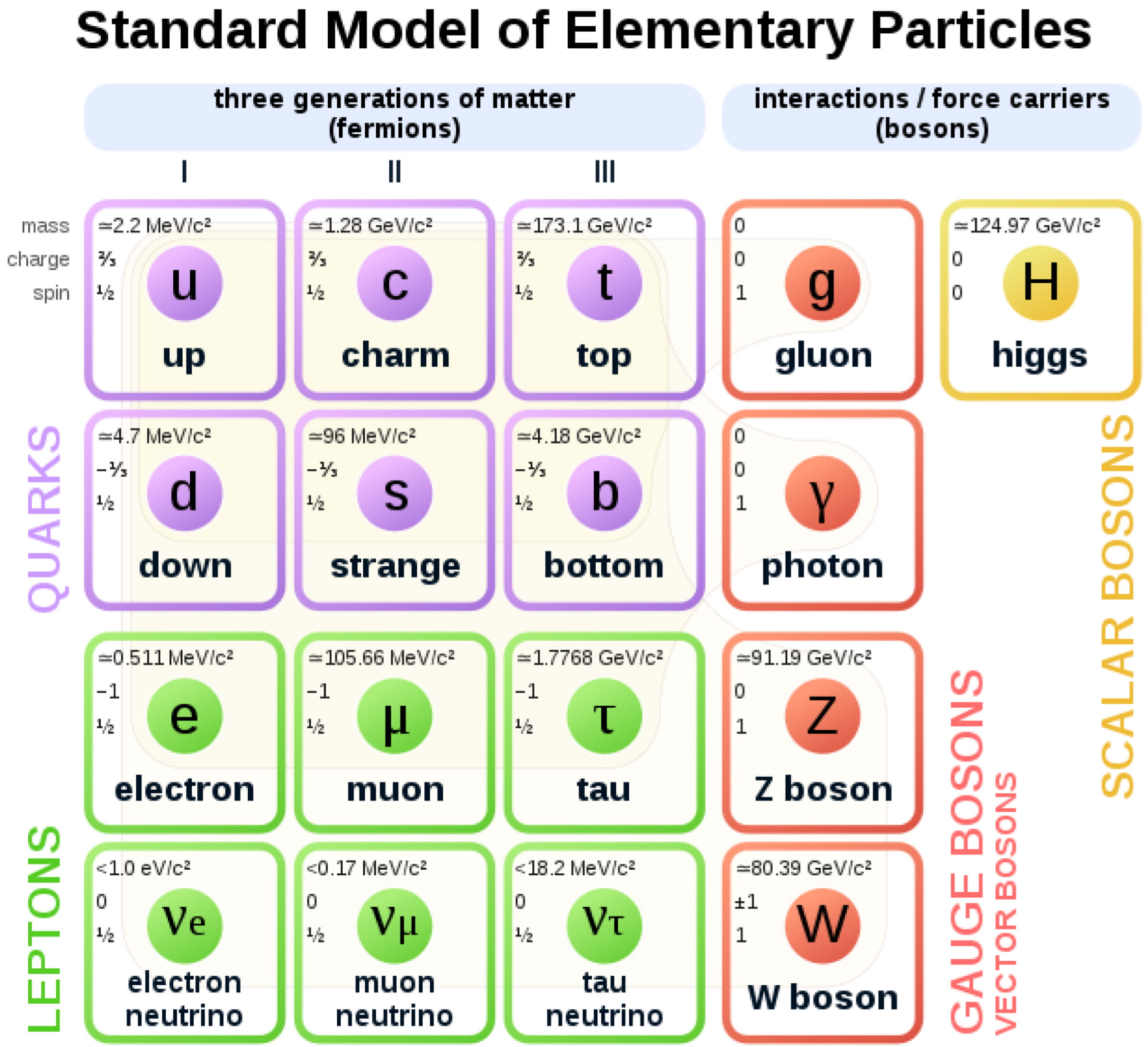
Homi Bhabha and cosmic ray research in India

Cirkel-Bartelt : Living Rev Relativ. 2008; 11(1): 2.
https://dx.doi.org/10.12942%2Flrr-2008-2

As well as more recent developments

Lecture 3,4 : Basic Particle Physics



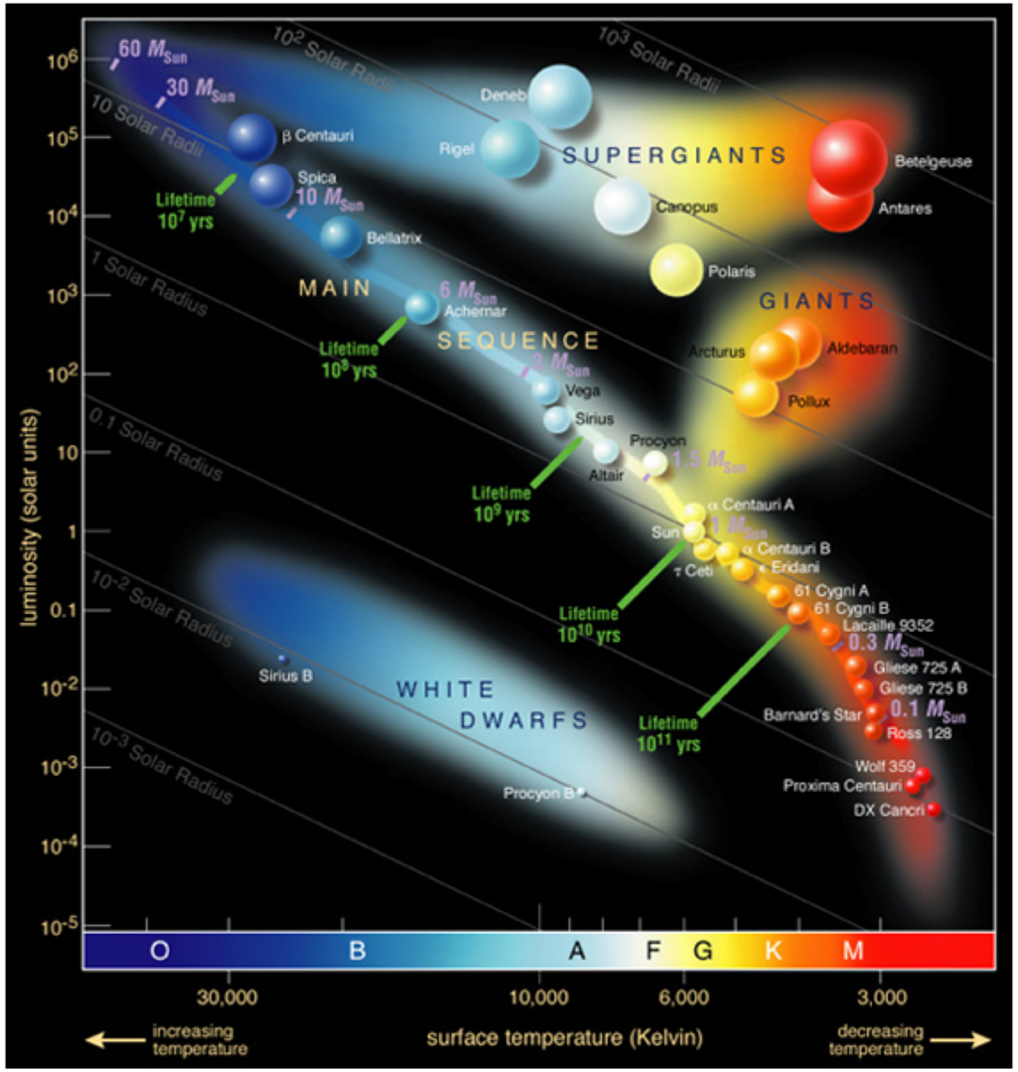


Also : EFT, Units used

Halzen & Martin chapters 1- 3, 6, 12, 14

No classes from 2^{nd} to 10^{th} September

Lecture 5, 6 : Basic Astronomy/Astrophysics



Through this, stellar evolution: Longair chapter 2

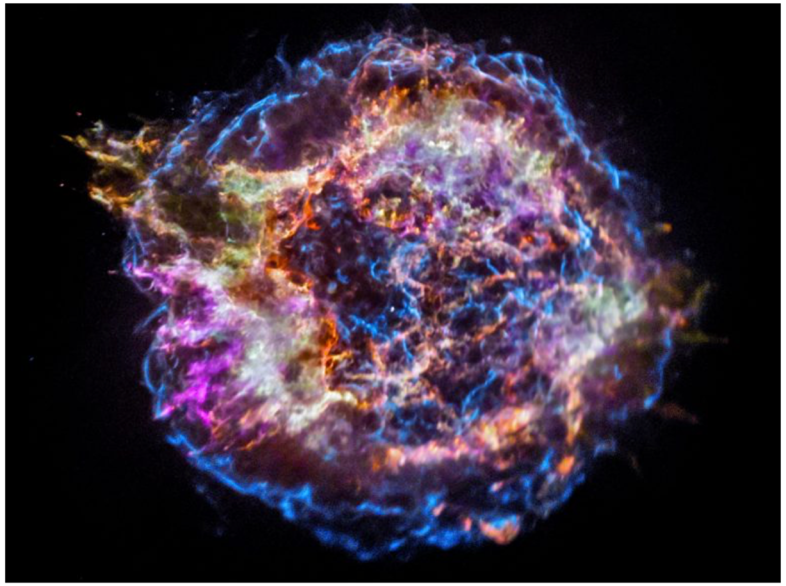
Units

The Hubble sequence : Longair chapter 3

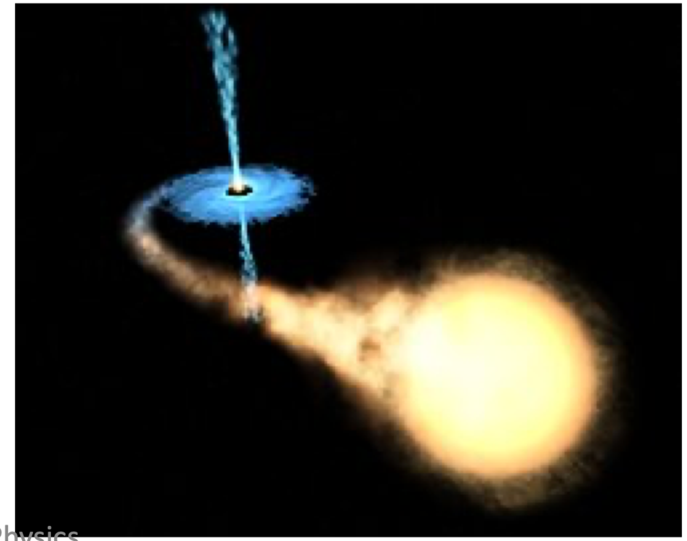
Also, bands, definitions, colour filters, basics of telescope optics, angular resolution, photometry, astrometry, frames of reference.

Lecture 7: High Energy Astrophysics

- Supernovae (Longair 13)



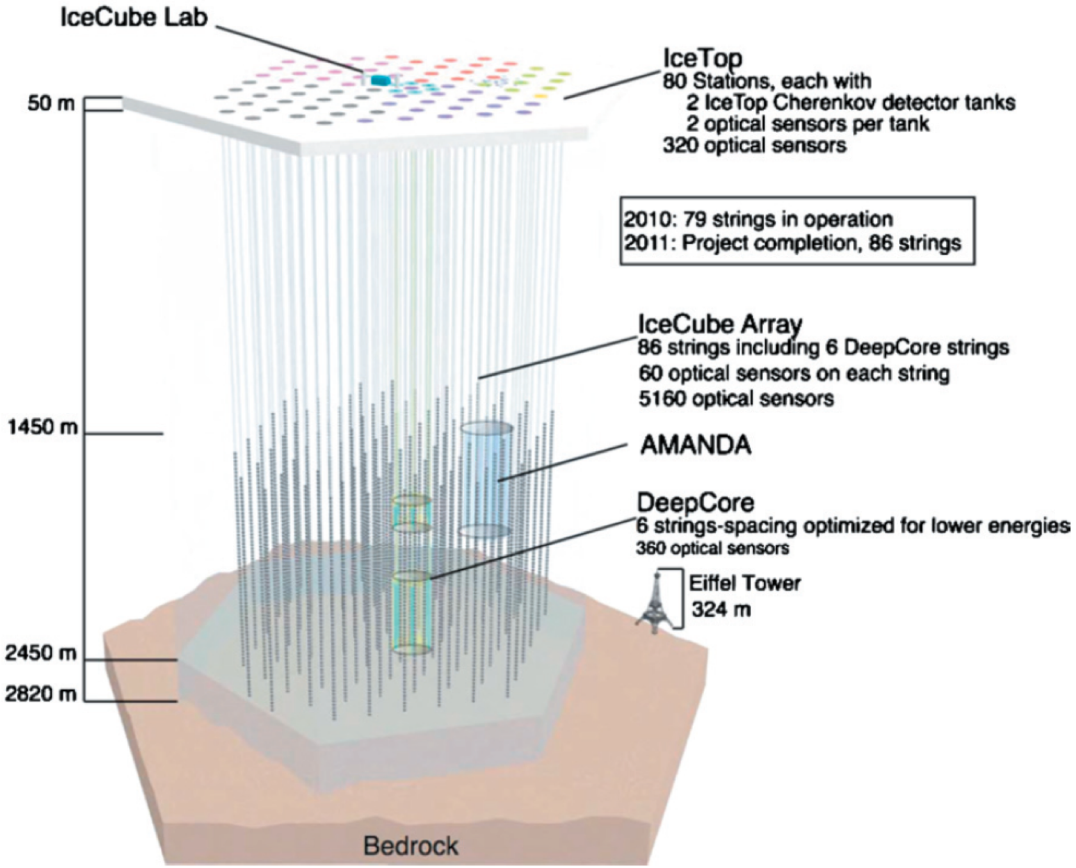
- Accretion Power (Longair 14)



Lecture 8-12 : Particle detectors

GRAPES-3 air shower array at Ooty

Guest lectures (2) by Dr. PK Mohanty



IceCube neutrino observatory

But also, Fermi, Auger, AMS, IACTs
Understand terms like effective area, grammage, exposure, event rates, triggering, readout, reconstruction

Guest lecture : IACTs

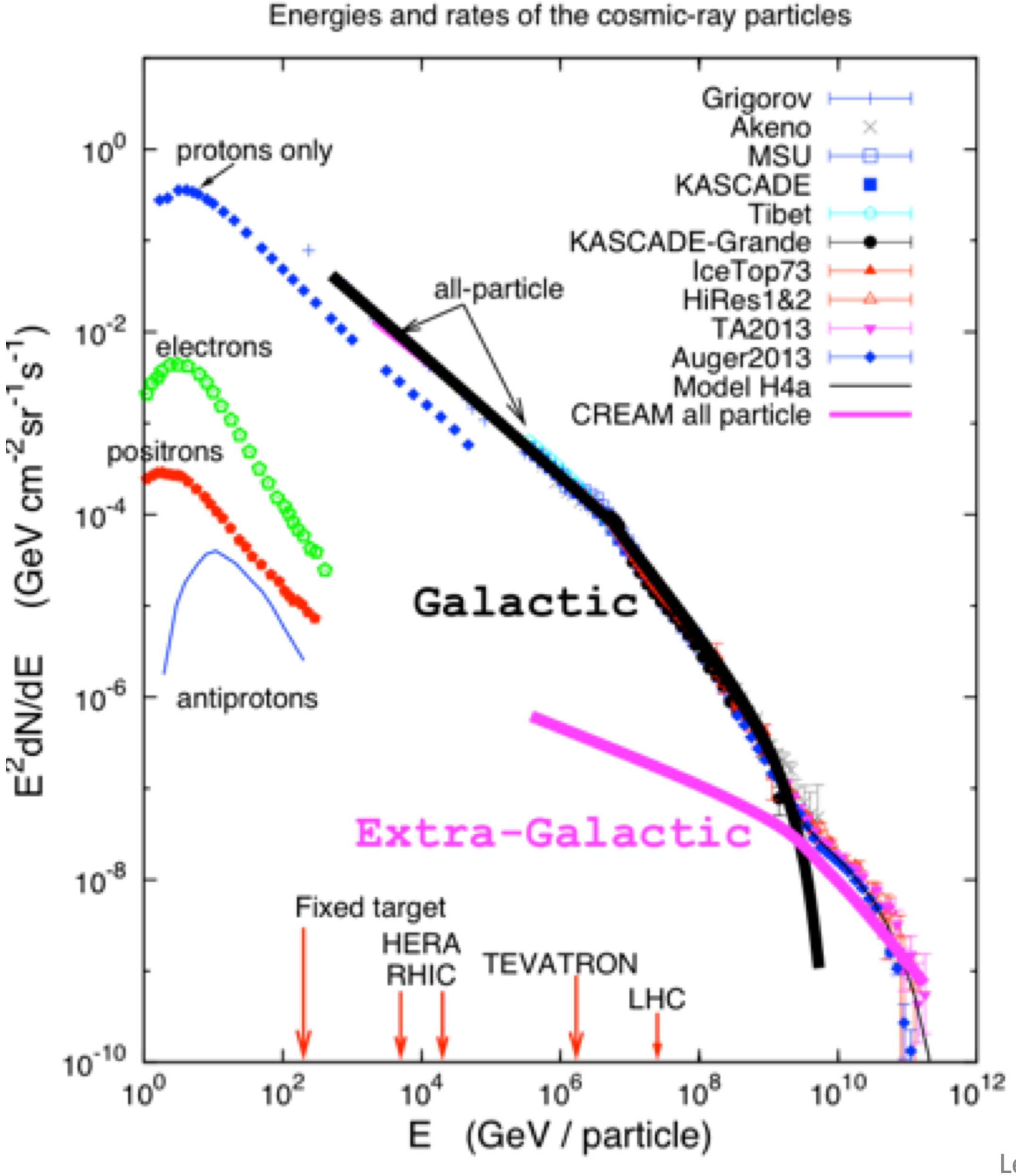
Prof. Varsha Chitnis

Imaging atmospheric Cherenkov telescopes, such as MACE, CTA

Lecture 13, 14: Some statistics

- Point estimation, interval estimation, Chapters 8, 9 of Fred James
- Confidence levels, coverage
- Maximum Likelihood Estimators, Chapter 10, 11
- Statistical Significance
- Frequentists? Bayesians? Likelihoodists? Chapter 2, Fred James

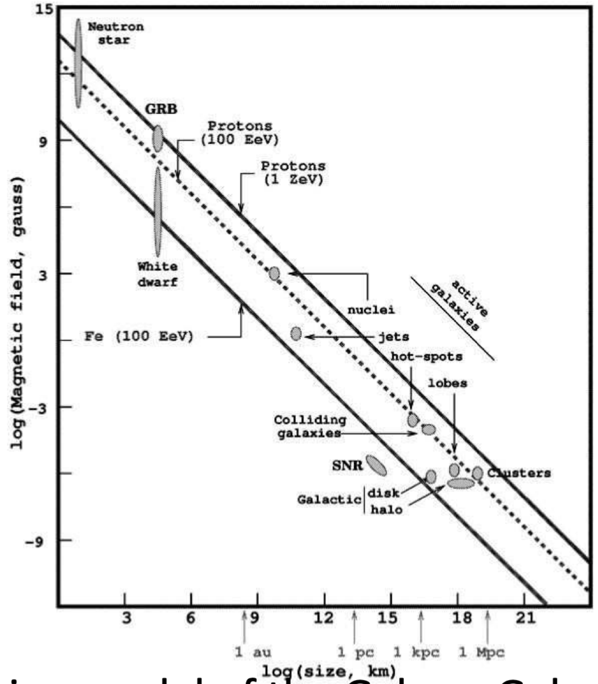
Lecture 15-16: Cosmic Rays



CRs, where do they come from? What accelerates them?

- Galactic: SNRs, microquasars?
- Extragalactic : AGNs, galaxy clusters, starburst galaxies, GRBs?

How are they accelerated? fermi acceleration – predicts parent proton spectrum of power law E^{-2} for an ideal shock.



CR diffusion, CR diffusion model of the Galaxy: Galprop

Chapters 15, 16, 17 Longair

Lecture 17

Evaluation

Lecture 18-19

History, detection of atmospheric neutrinos at KGF

Osciillations, role in stars, in cosmology

Mass Ordering, sterile neutrinos

Overview of current and future experimental facilities and goals

Problems

Kuo & Pantaleone chapters 1 to 6

Lecture 21-24 Multi messenger Astronomy

Photons

>1 cm ~1 mm ~10 μm ~1 nm <0.1 nm

10^{-6} eV 10^{-4} eV 10^{-1} eV ~1 KeV > 100 KeV

Pulsars, quasars, radio galaxies The Big Bang (CMB) Non thermal processes

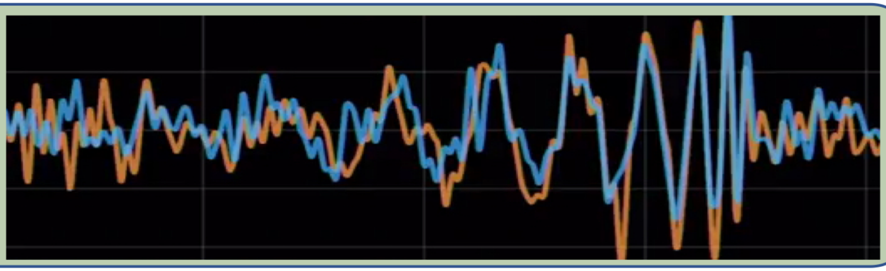
Cosmic Rays

Electrons, protons, heavy nuclei : 10^8 - 10^{20} eV – Origins unknown.

Gravitational Waves

Predicted by General relativity – Observed first in 2015
BH-BH merger ~410 MPc away.
Phys. Rev. Lett. 116 (6): 061102

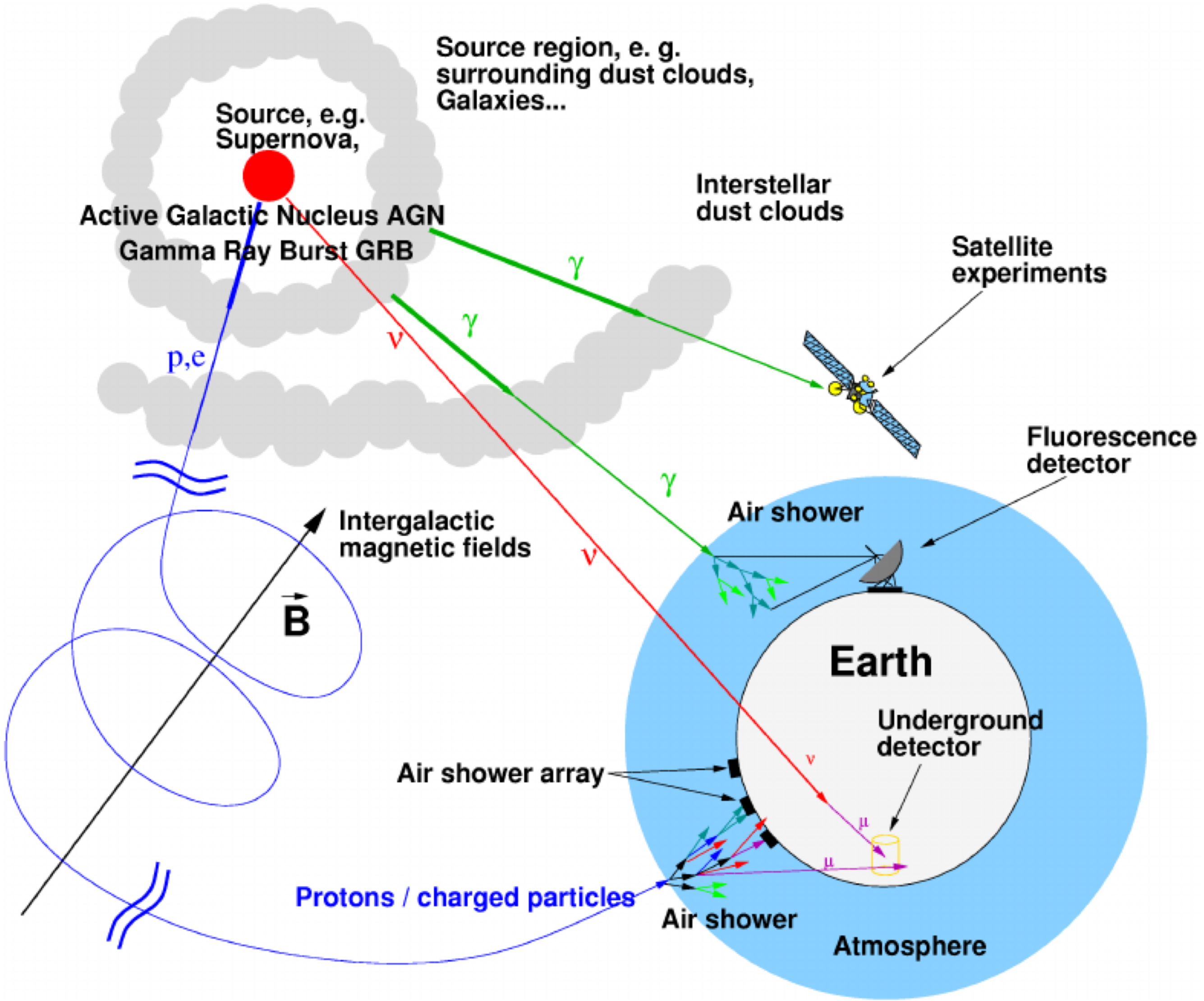
New



Neutrinos

Proposed by Pauli in 1930, detected by Reines and Cowans in 1959, neutral, weakly interacting.
The Sun, SN1987 A – 10 MeV
Diffuse astrophysical flux >50 TeV

Lecture 21-24 : Multimessenger astronomy



An examination of the two recent breakthroughs

IC170922 : Alert and followup campaign, archival data. Leptohadronic models

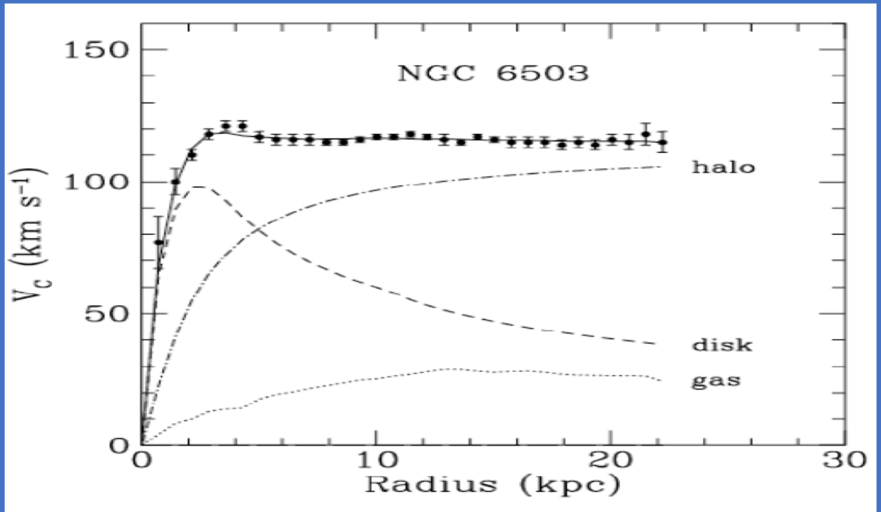
GW170817 + GRB 170817

Lecture 25-28 : Dark Matter

We think DM exists from

- **Galactic Rotation Curves :**

$$\Omega_{dm} \geq 0.1$$

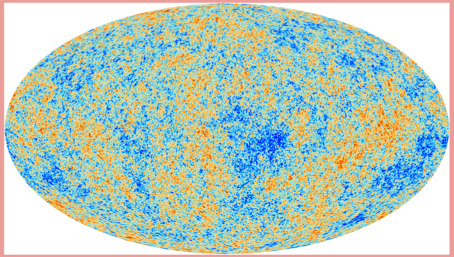


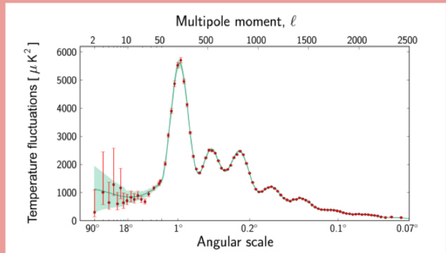
- **Gravitational Lensing** due to galaxy Clusters
  Bullet Cluster :
  astro-ph/0608247

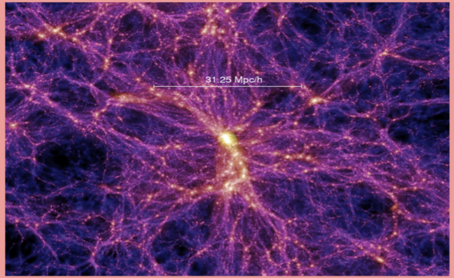
$$\Omega_{dm} \sim 0.2 - 0.4$$

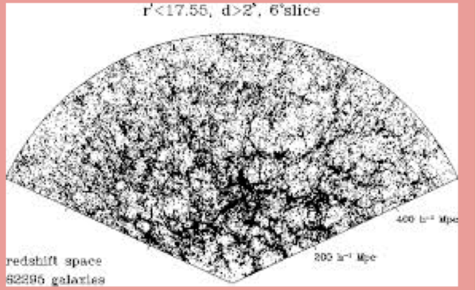
- **Precision Cosmology**
  - Planck CMB Measurements
  - CDM simulations such as Millenium reproduce observed LSS

$$\Omega_{dm} = 0.268 \pm 0.02$$

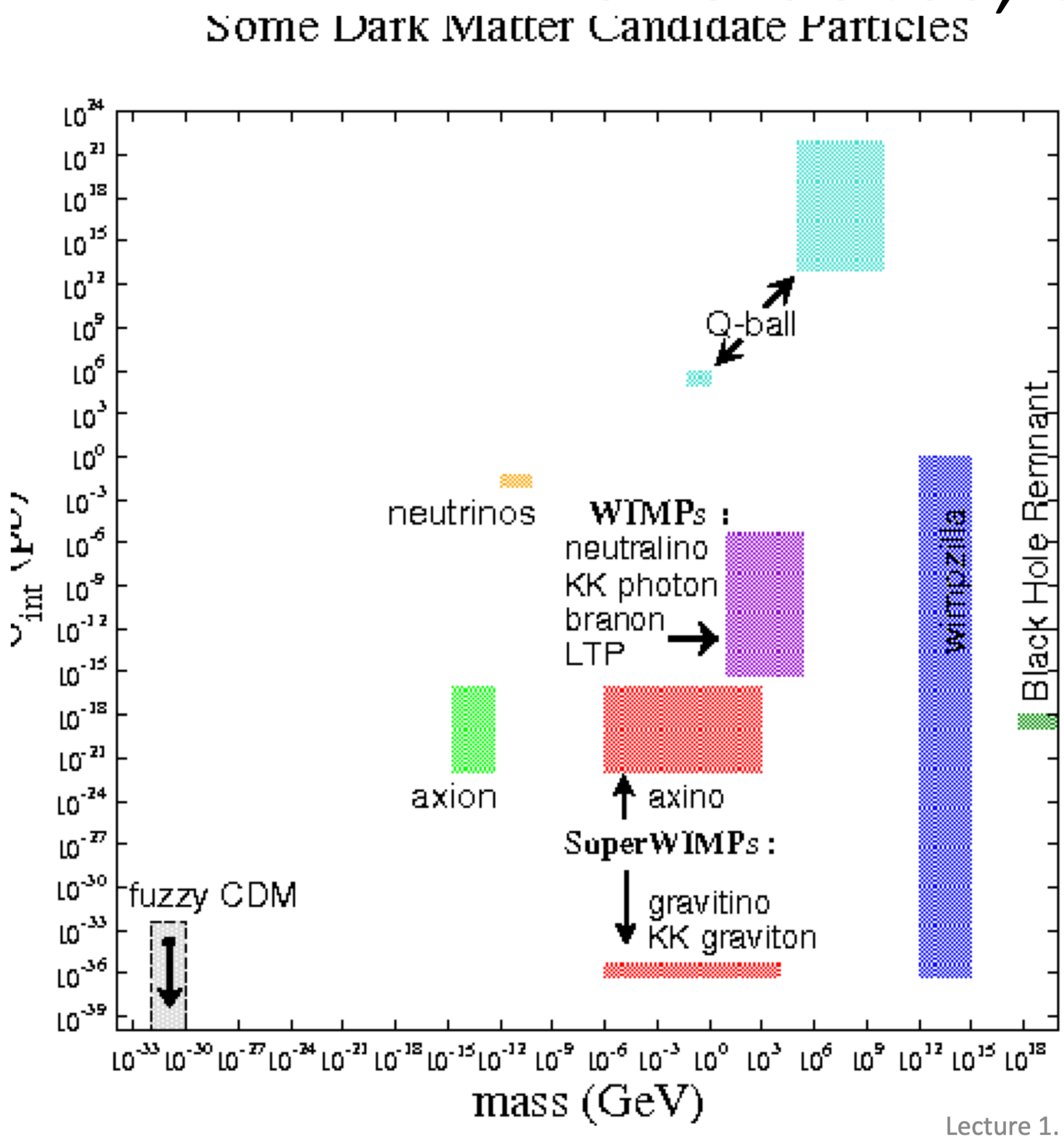






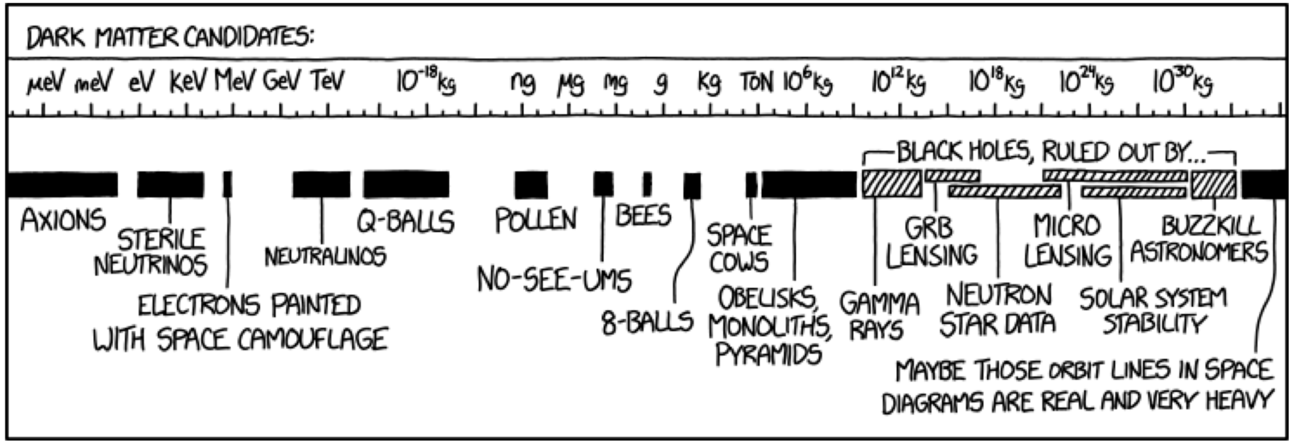


Candidates, also alternatives



MOND : history, successes, challenges

The MOND acceleration scale as an emergent property
(Rodrigues et al 2019)



Complementarity and DM Models

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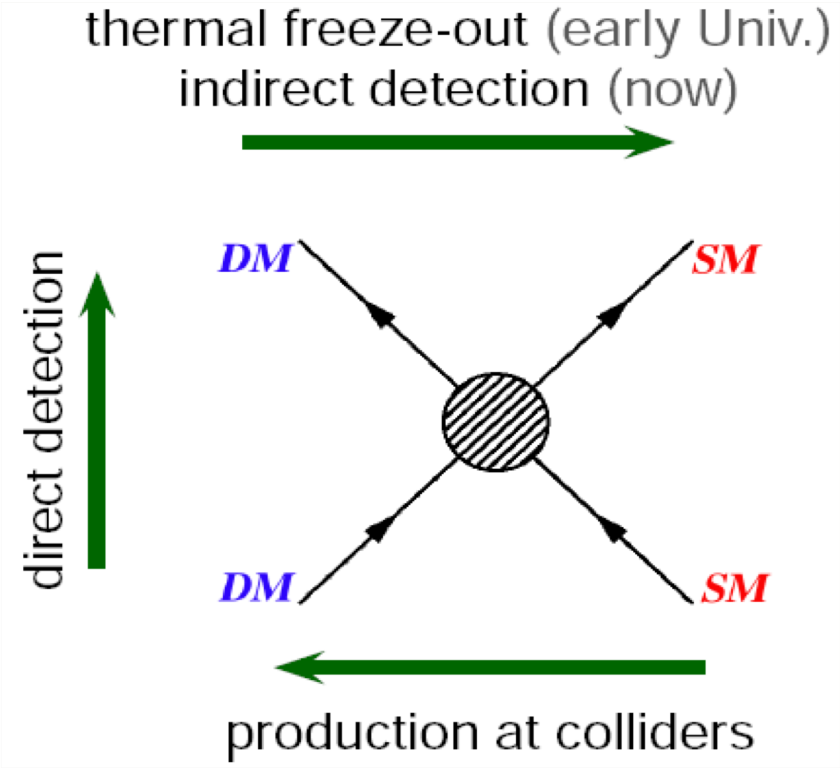
$\sigma_{\chi-P}$



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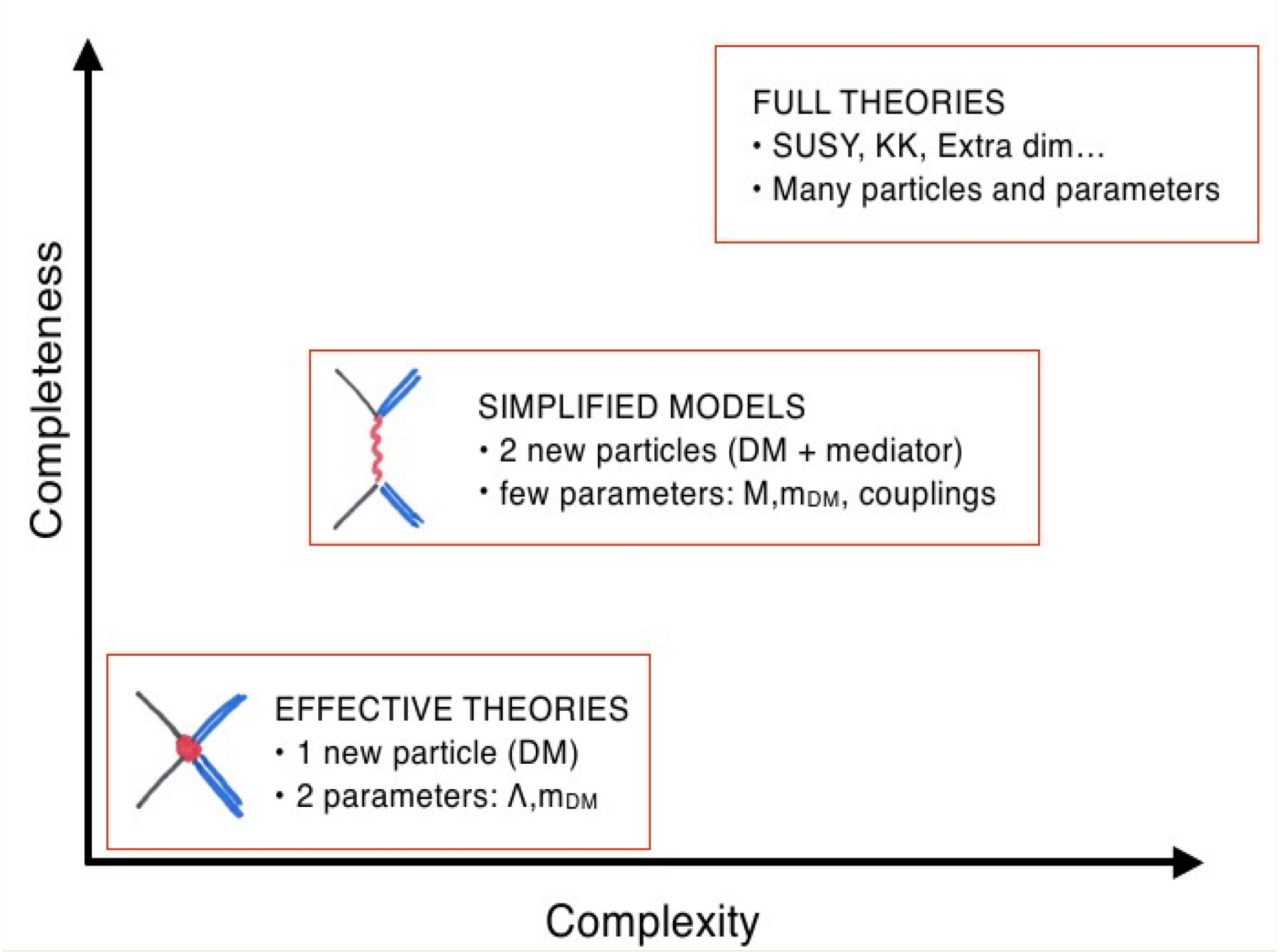

Lecture 29

Evaluation

Additional Lectures (optional)

- Cosmology : Friedmann Equations, the concordance model. Inhomogeneous cosmology? Statistical mechanics and 3d gravity

- Gravitational waves?
- Big bang nucleosynthesis?

- Some philosophy of physics : If you really want to understand Dark Matter and Dark energy.

I need information

- Your names, backgrounds (departments, courses taken so far), whether you are auditing or crediting this course.
- If and how you would like the curriculum to be modified.
- How you would like to be evaluated.
- Please sign up on moodle.
- Also email me: mohamed.rameez@tifr.res.in