HTC for Shedding Light on the Dark Matter

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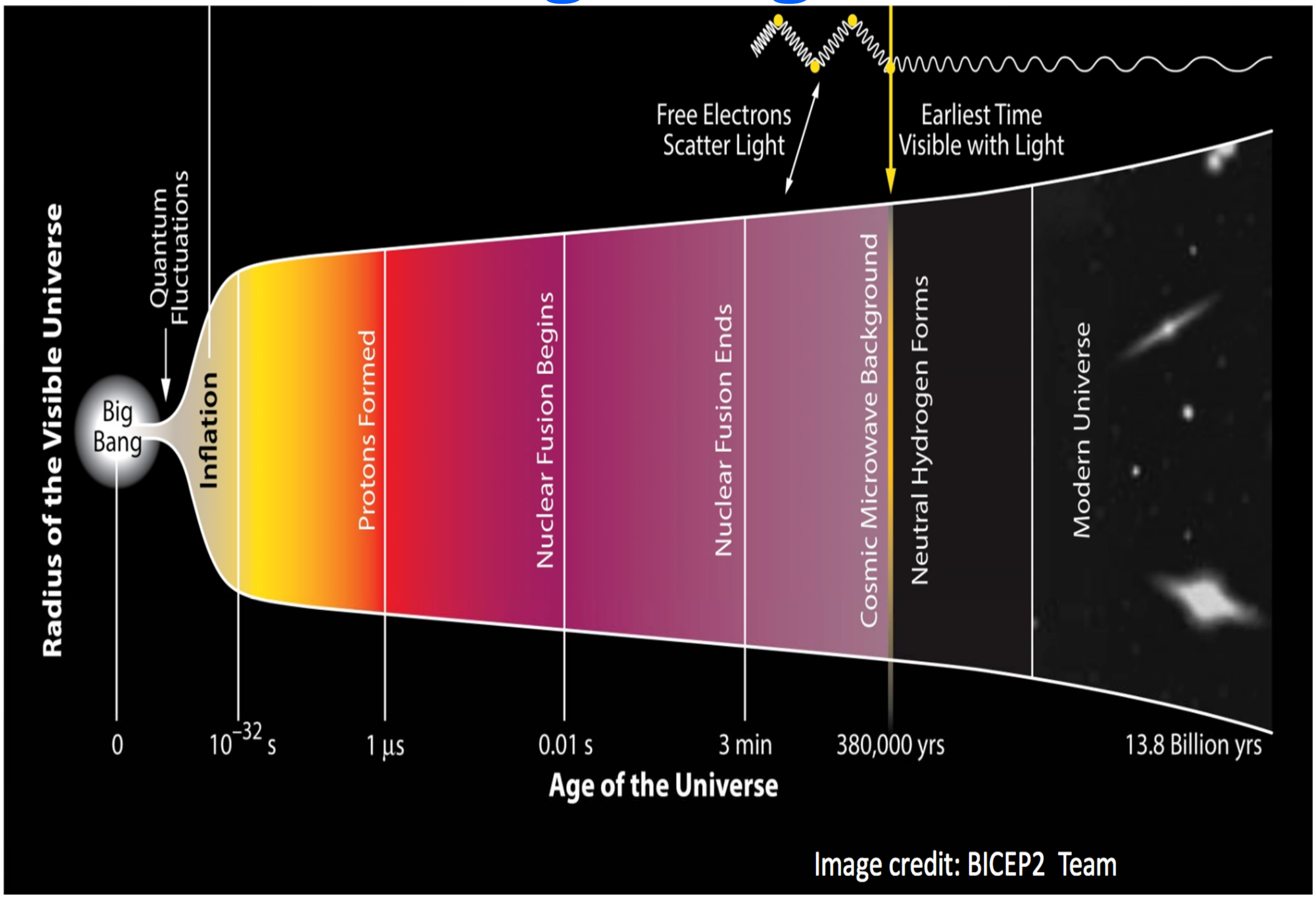
Cosmology

Basic Principles:

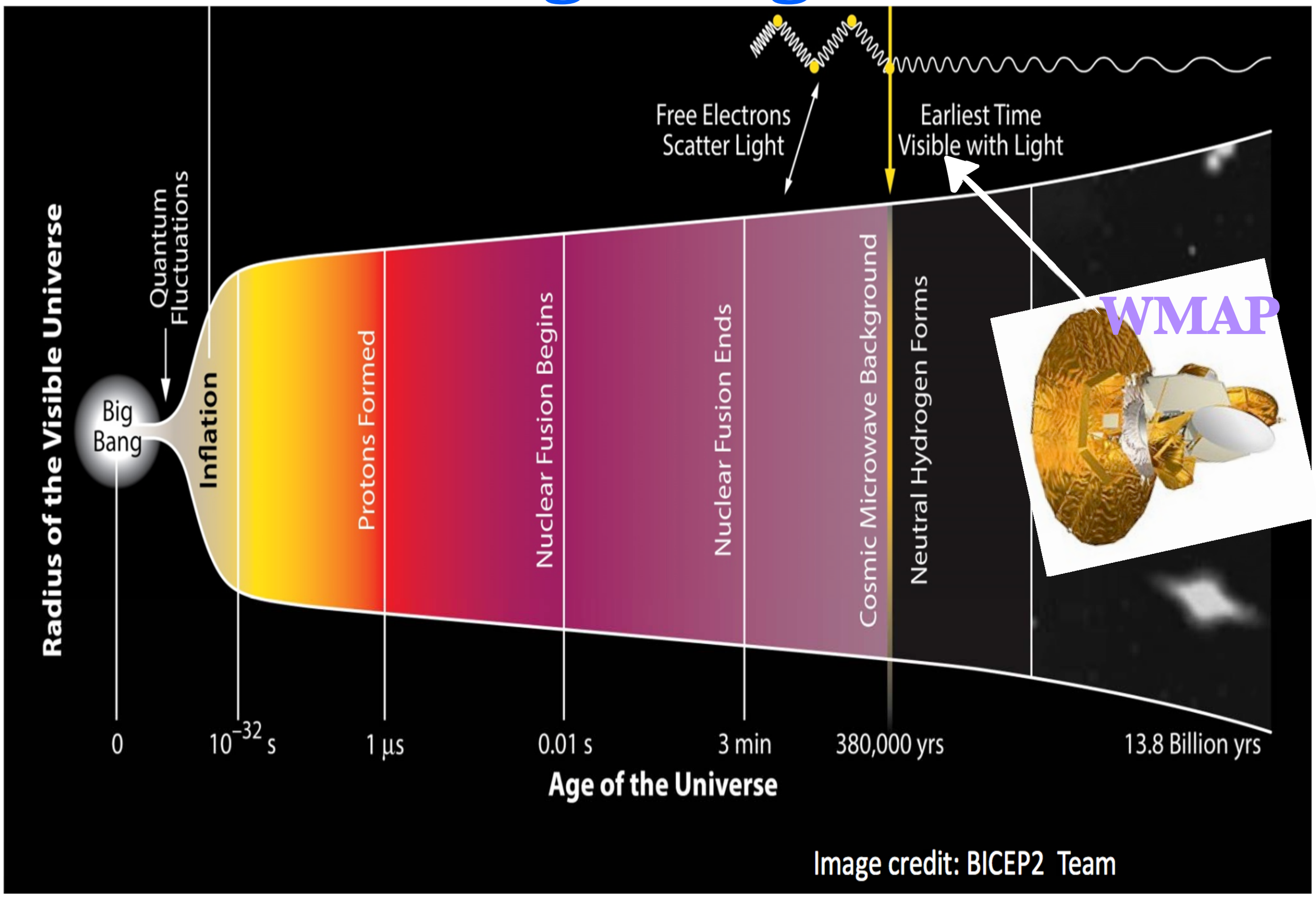
- **Big Bang model:**
  - Expansion of the universe
    - Universe started off hot and dense
    - Since then cooling and expanding

- **Gravitational Attraction brings mass together:**
  - Large/Small mass attracts, leading to formation of galaxy and stars as we see today

Big Bang !


Free Electrons
Scatter Light
Earliest Time
Visible with Light
Radius of the Visible Universe
Quantum
Fluctuations
Big
Bang
Inflation
Protons Form
Nuclear Fusion Begins
Nuclear Fusion Ends
Cosmic Microwave Background
Neutral Hydrogen Forms
Modern Universe
0
10^{-32} s
1 μs
0.01 s
3 min
380,000 yrs
13.8 Billion yrs
Age of the Universe
Image credit: BICEP2 Team

Big Bang !


Free Electrons
Scatter Light
Earliest Time
Visible with Light
WMAP
Radius of the Visible Universe
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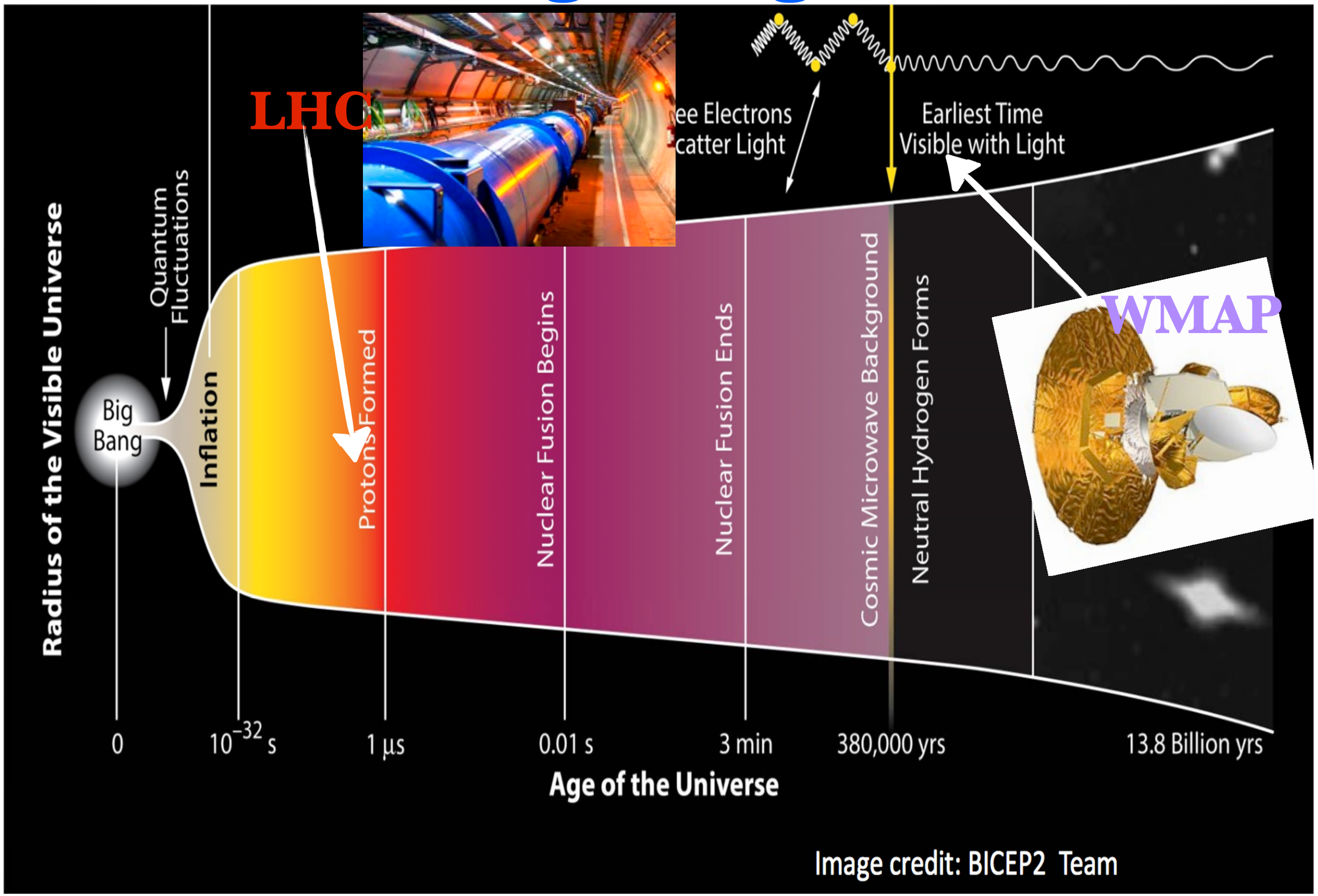
Big Bang !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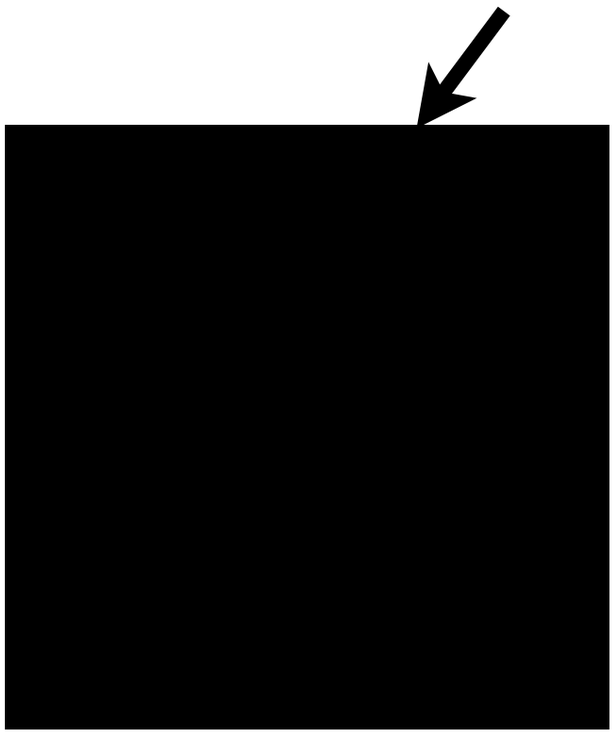
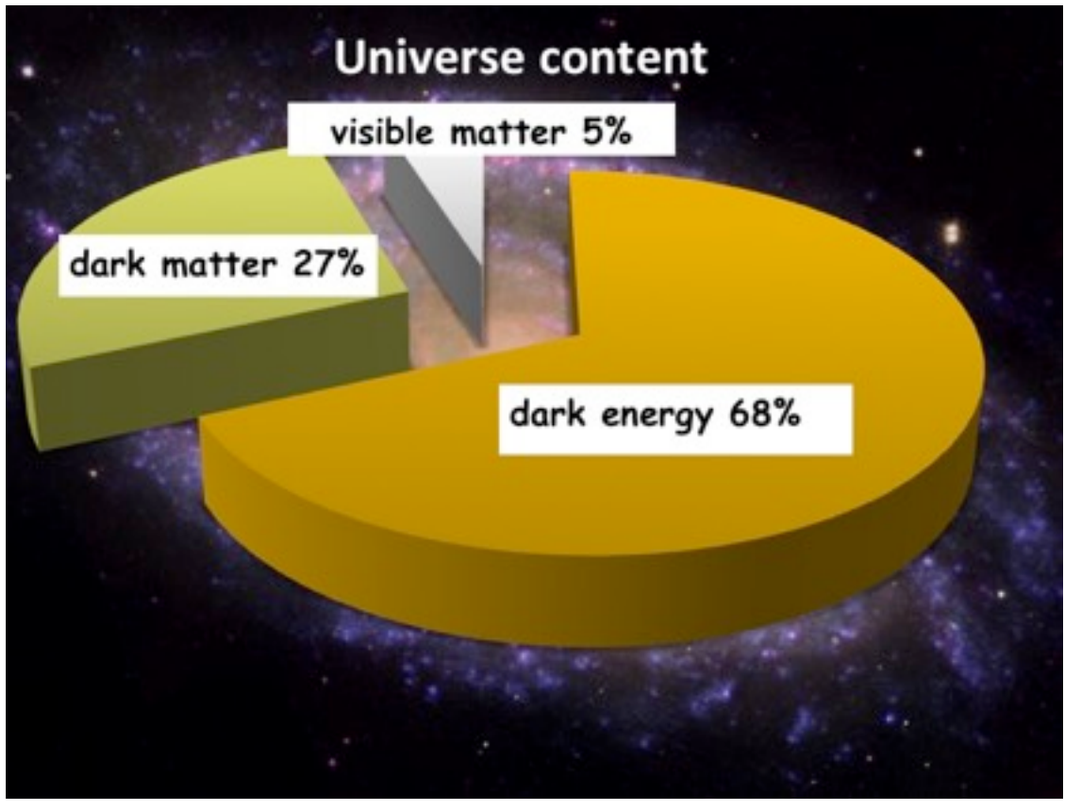
Dark Matter



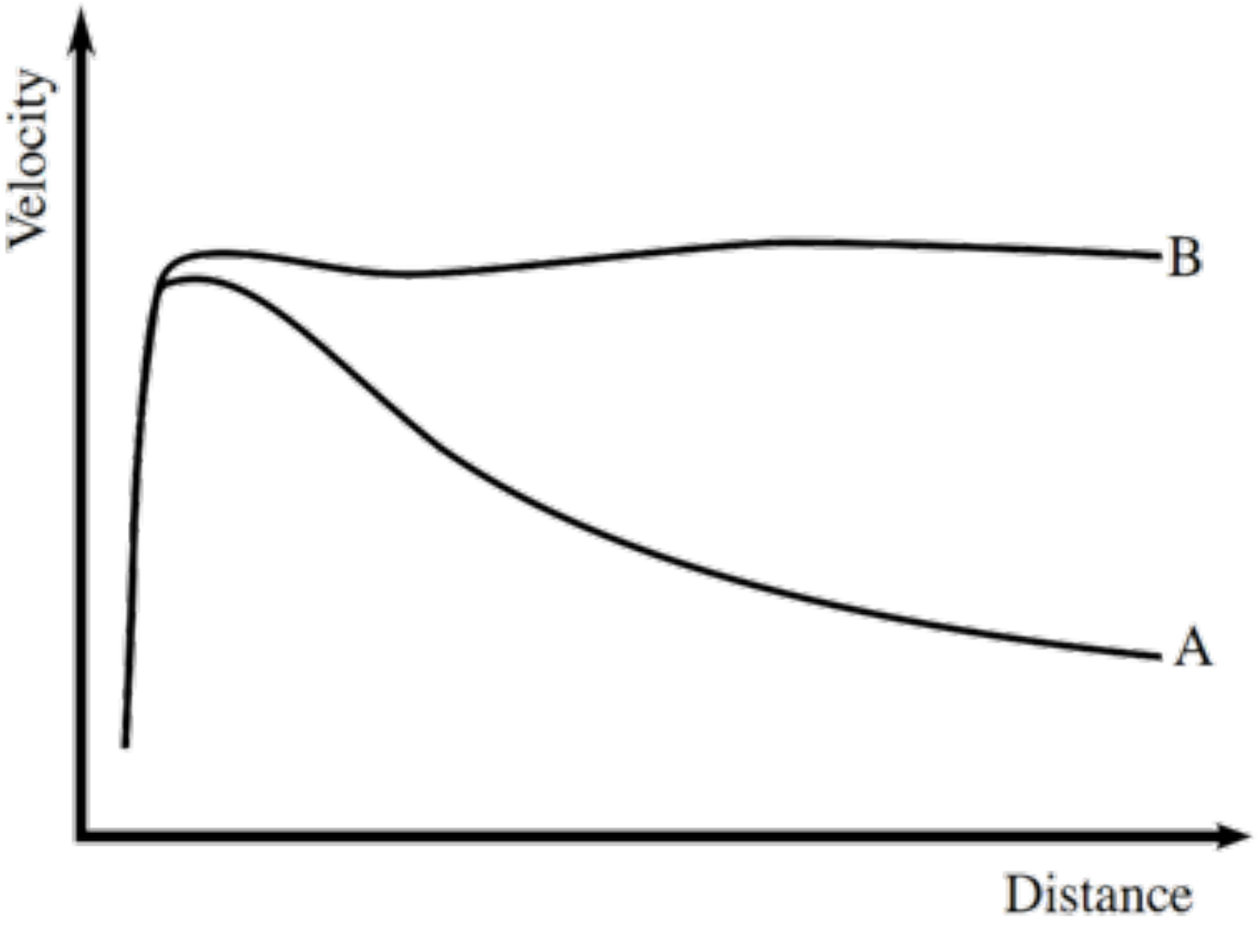
Visible Matter

- Most of the matter in the universe is Dark

- How do we know Dark Matter exist at all ?



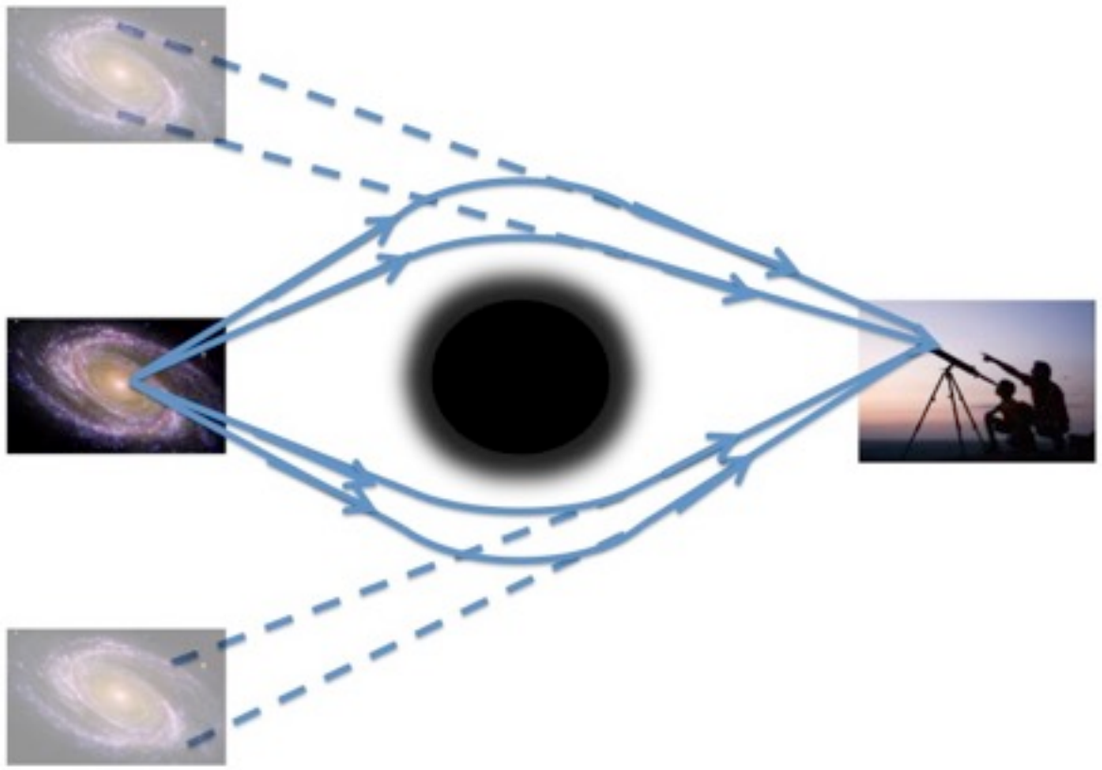
Velocity Curves of Spinning Galaxies

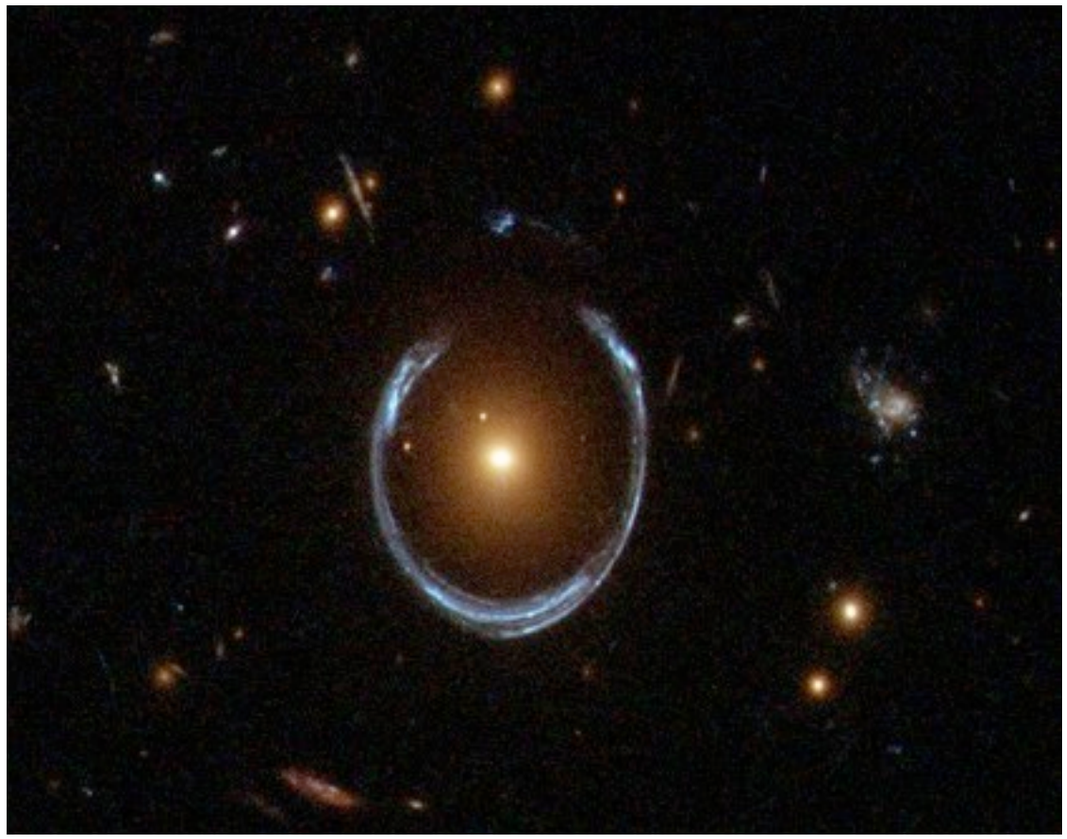


(A) is how it should be if objects in the galactic disk follow Kepler's laws of planetary motion

(B) is how it is observed: implying there is more mass in the galaxy than meets the eye !

Gravitational Lensing



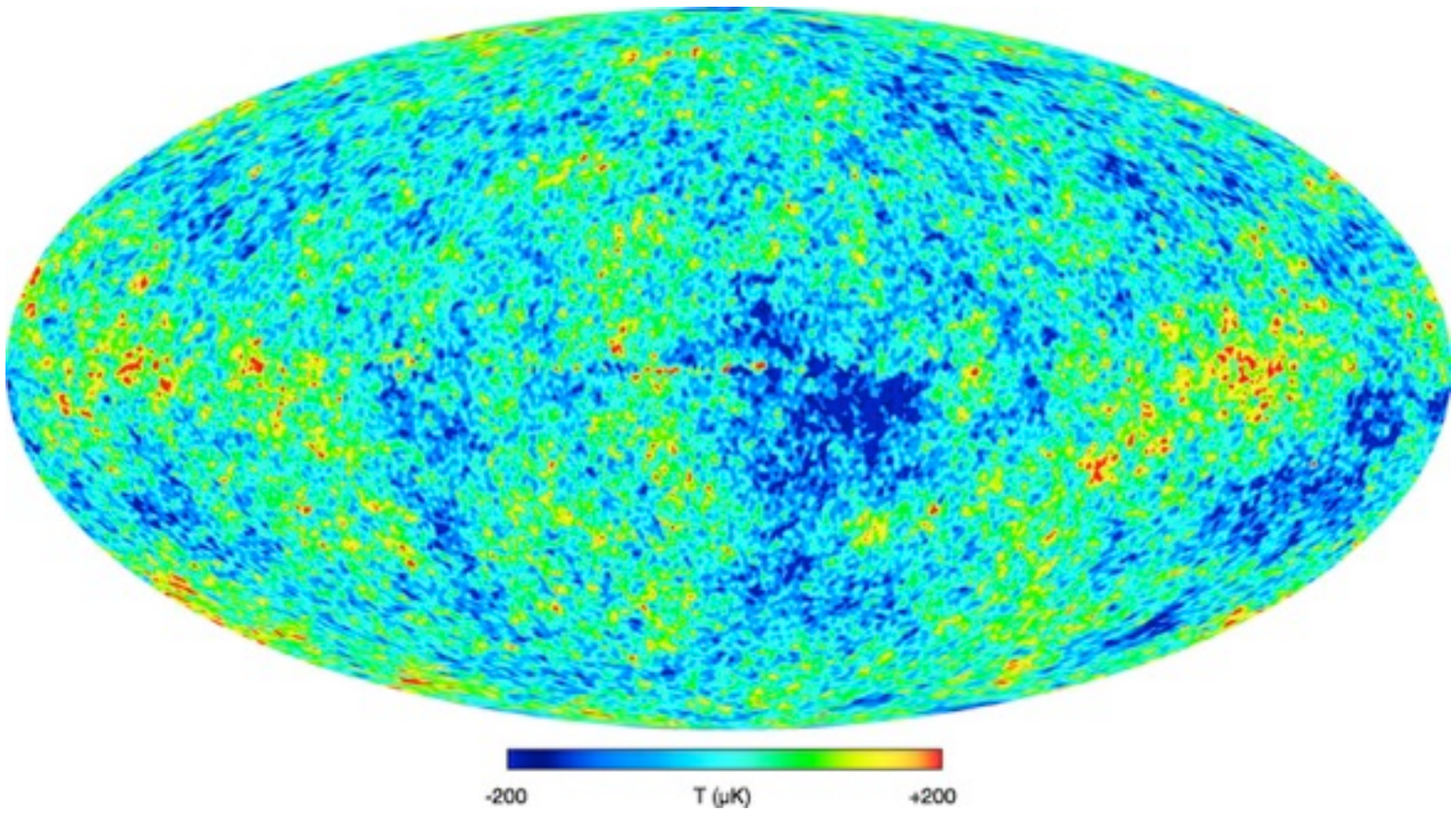


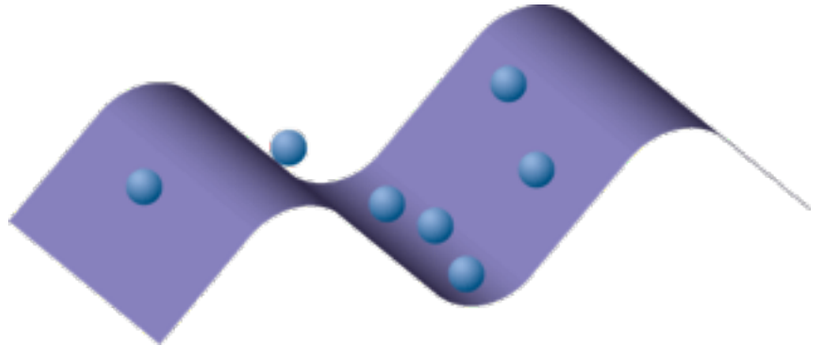
Hubble image of a Einstein-Chwolson Ring

- Gravity bends light
- Light coming from a distant galaxy appears to be shifted when passes near a ginormous clump of Dark Matter (same galaxy appears in different locations)

First Light a.k.a Cosmic Microwave Background

- As our universe cooled and expanded the first light waves stretched into microwave spectrum
  - WMAP found **anisotropy** in the microwave radiation from the Big Bang ; 1 part in 100,000
  - These small ripples in density of matter resulted in galaxies as we see today because of gravity





Structure Formation and Dark Matter

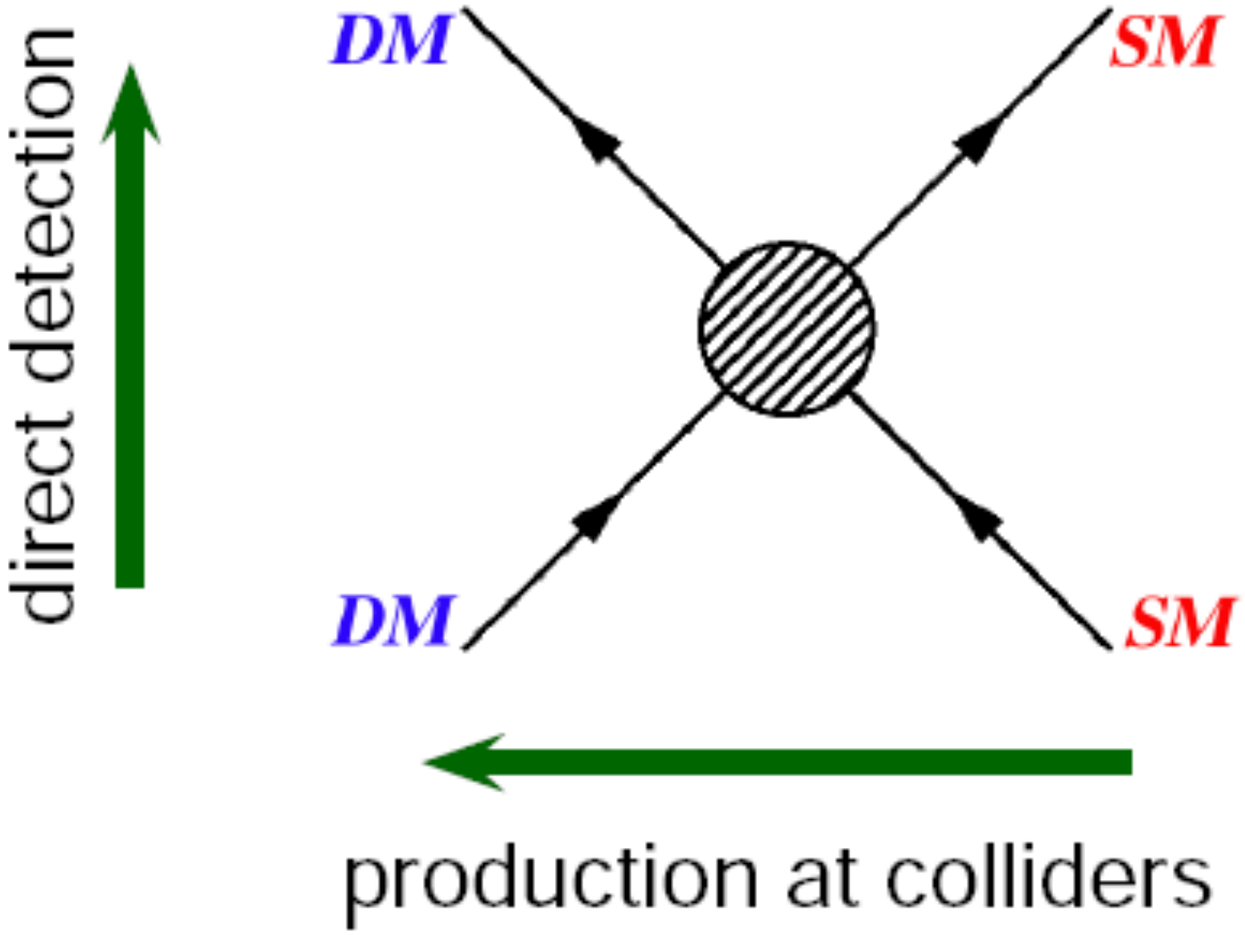
- Dark Matter is required in order to enable gravity to amplify the small fluctuation in the Cosmic Microwave Background enough to form the large-scale structure we see in the universe today
  - These models depend on the amount and type of dark matter present
- Most of these models predict a Dark Matter (DM) is necessary to simulate the growth of the universe since Big Bang !

- We know DM exists; from the observation of its gravitational effect on galactic disks
- Is it made of 'a' fundamental particle ?
- How does it interacts with the visible matter ?

Shedding Light on Dark Matter

thermal freeze-out (early Univ.)

indirect detection (now)



direct detection

Underground Experiments: LZ

production at colliders

Large Hadron Collider

Detection Signature at LHC

Indirect detection of DM

- By colliding protons at very high energy, the Large Hadron Collider produces conditions equivalent to about 10^{-25} seconds after the Big Bang

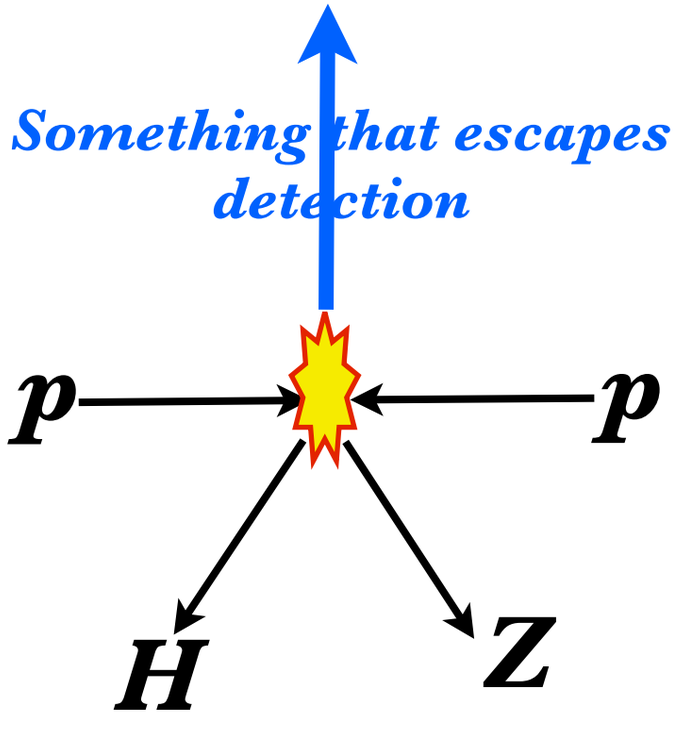
- These conditions should give rise to DM production through the interactions of visible matter

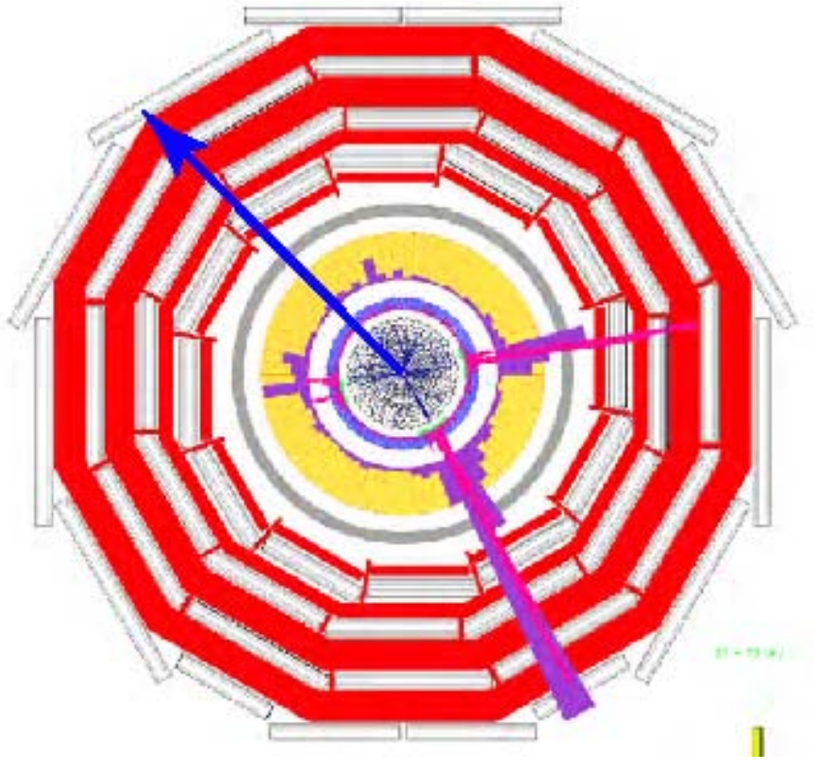
- An ideal candidate will be a stable and weakly interacting particle

- DM are assumed to be primordial, it barely interacts with visible matter; thus escapes the detection almost all the time

★How do you detect something that escapes detection ?

Momentum conservation





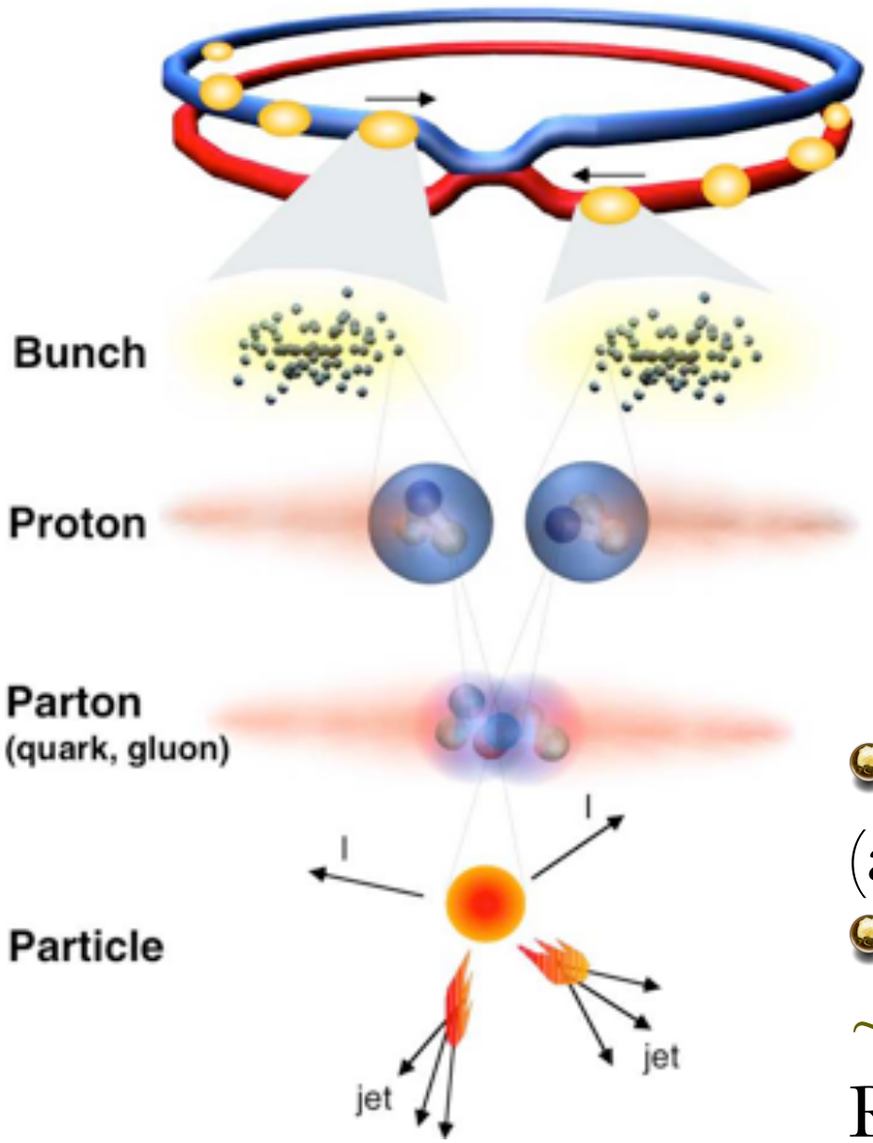
- **Fundamental physics:**
  - Total momentum before a collision between two objects is equal to the total momentum after the collision

  - In case of LHC experiments (CMS and ATLAS):

    If anything is unaccounted for in the total momentum after the collision of two protons, it can be considered as a smoking gun for Dark Matter

  - This missing transverse momentum is denoted by **ET_{Miss}**

Proton-Proton collision at the LHC

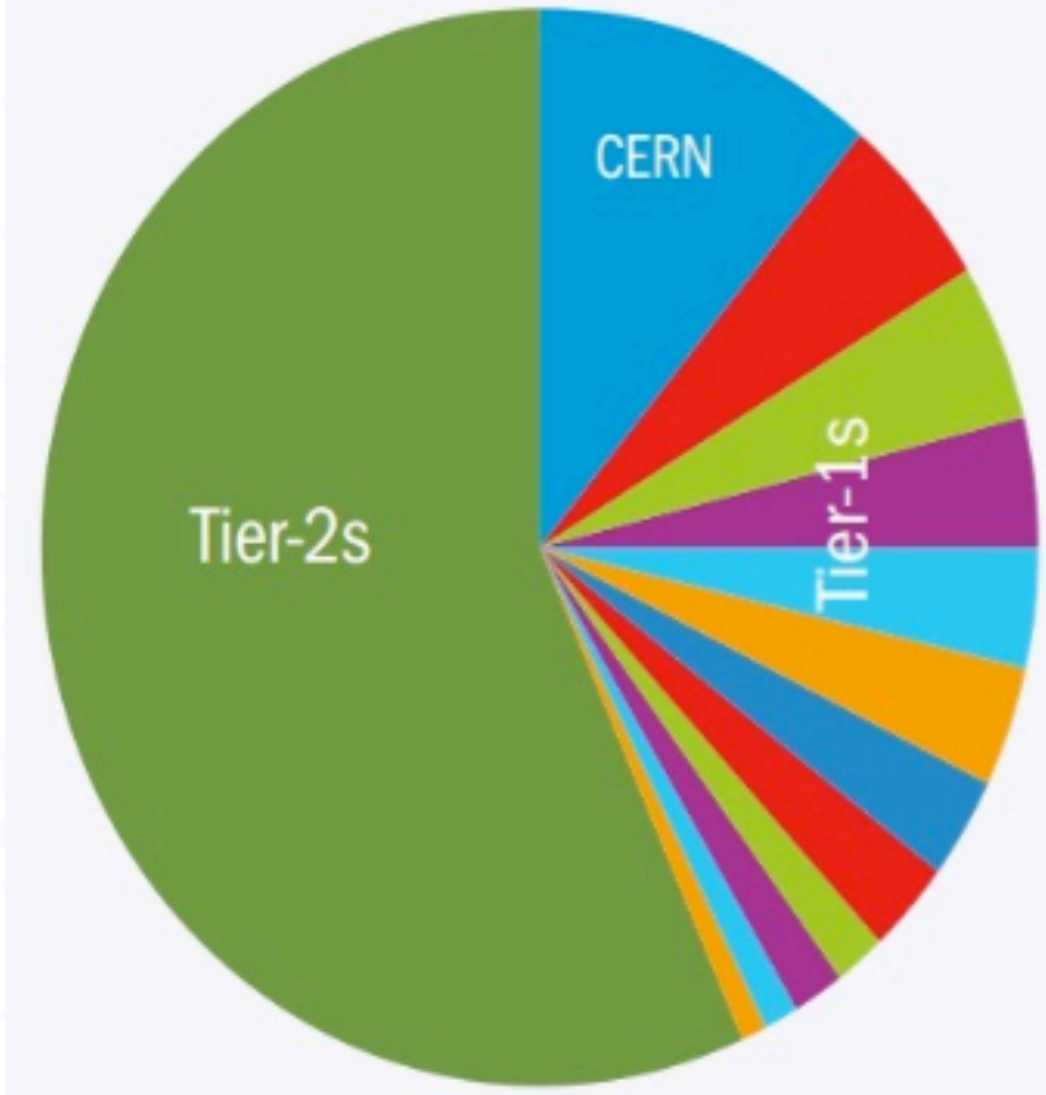


	Run-2 2015-17	2011	2012
Beam energy	7 TeV	3.5 TeV	4.0 TeV
Bunches/ beam	2835	1380	1380
Protons/ bunch	1.15×10^{11}	1.5×10^{11}	2.2×10^{11}
N Collisions Created	1×10^{16}	2.5×10^{14}	3.5×10^{14}
N Higgs Events	Thousands	Few hundred	Few hundred

- LHC produces about 1 billion collisions (also called events) per second
- LHC would require ~100,000 cores of CPU and ~100 Petabyte of Disk space in 2015(~ 3 times for Run-2)
- A gigantic amount of data gets stored, waiting for analysis by physicists

★This is where HTC enters into the game

Grid Computing @ LHC



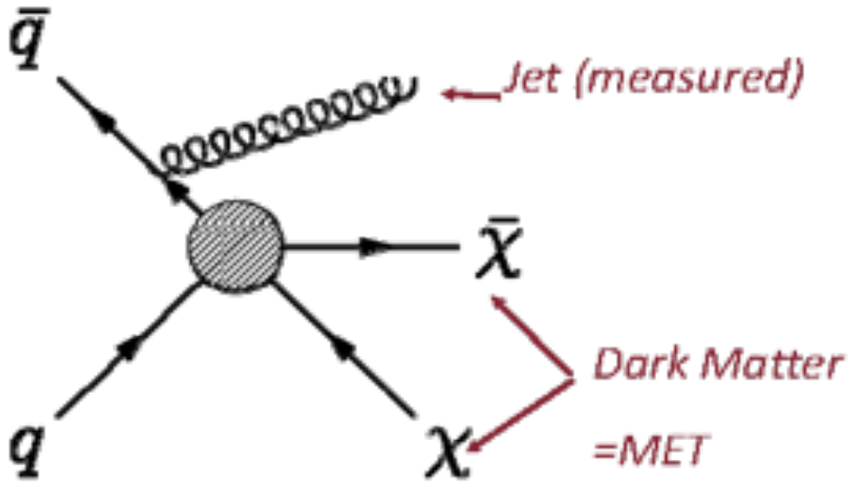
Delivered resources

More than 50% from Tier-2

data centers around the world

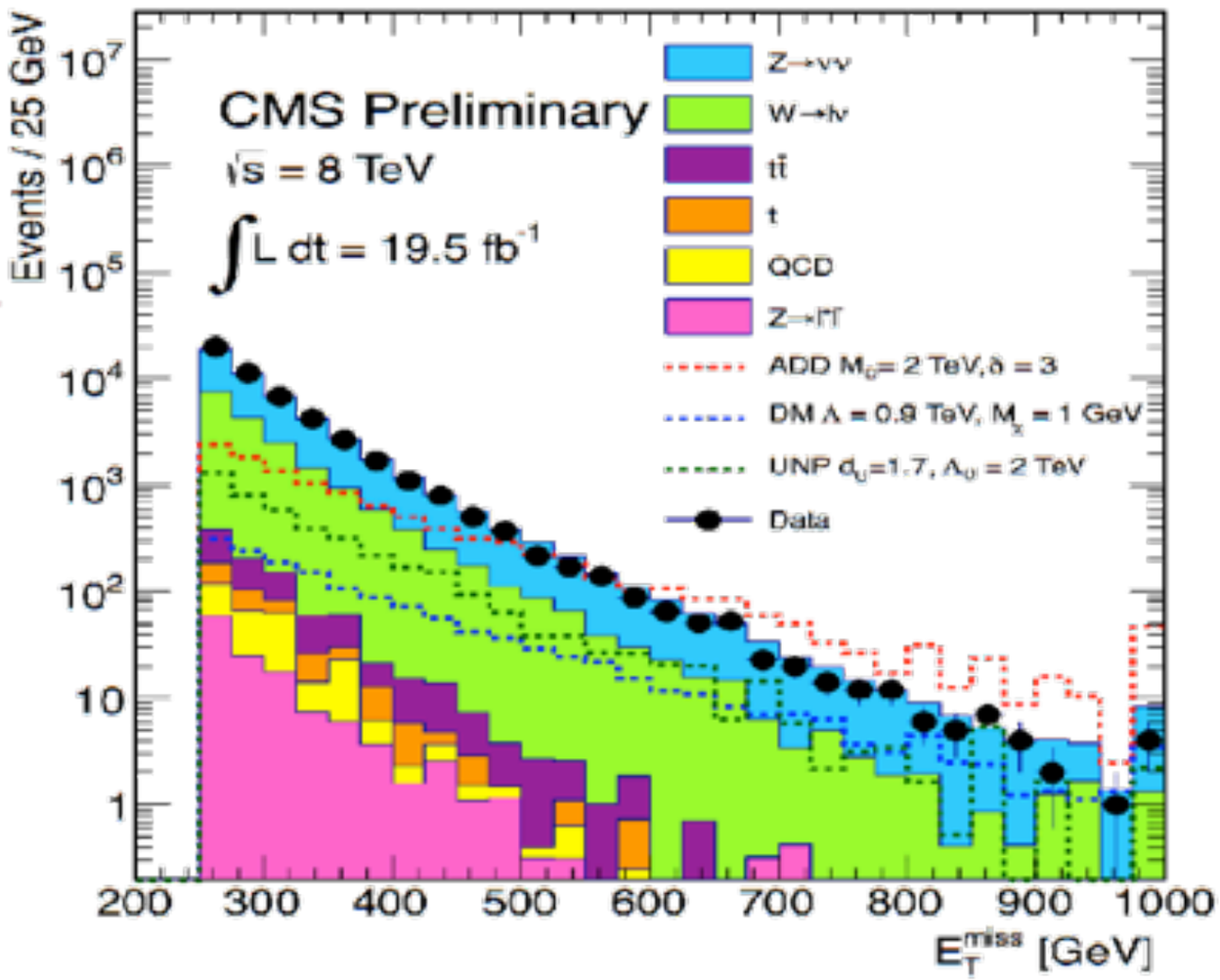
- 4-Tier model; Tier-0 is the CERN data center
- 11 Tier-1 and 140 Tier-2 centers
- About 10K physicists using the Grid
- On average 250K jobs run concurrently on the Grid
- 260K available CPU cores
- 180 PB disk storage
- 10-Gigabit optical fibre links connect CERN to each 11 Tier-1 centers (Fermilab is one of them)
- More than 70 Petabytes of stored data at CERN from the LHC

DM Search is ON! @ LHC (Run-2)



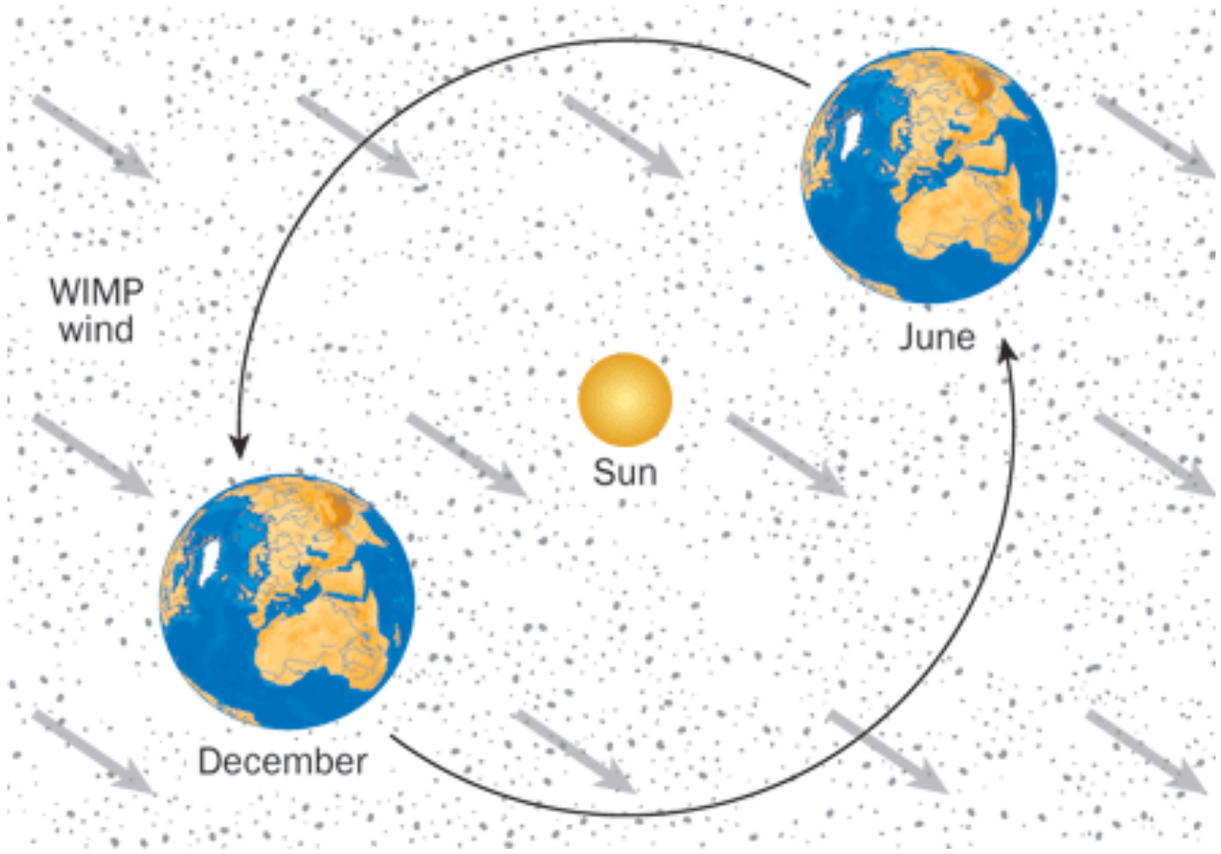
Best limits expected with

E_T^{miss} > 350–400 GeV



Any excess in the E_T^{miss} that can't be accounted for would be a tantalizing hint of Dark Matter

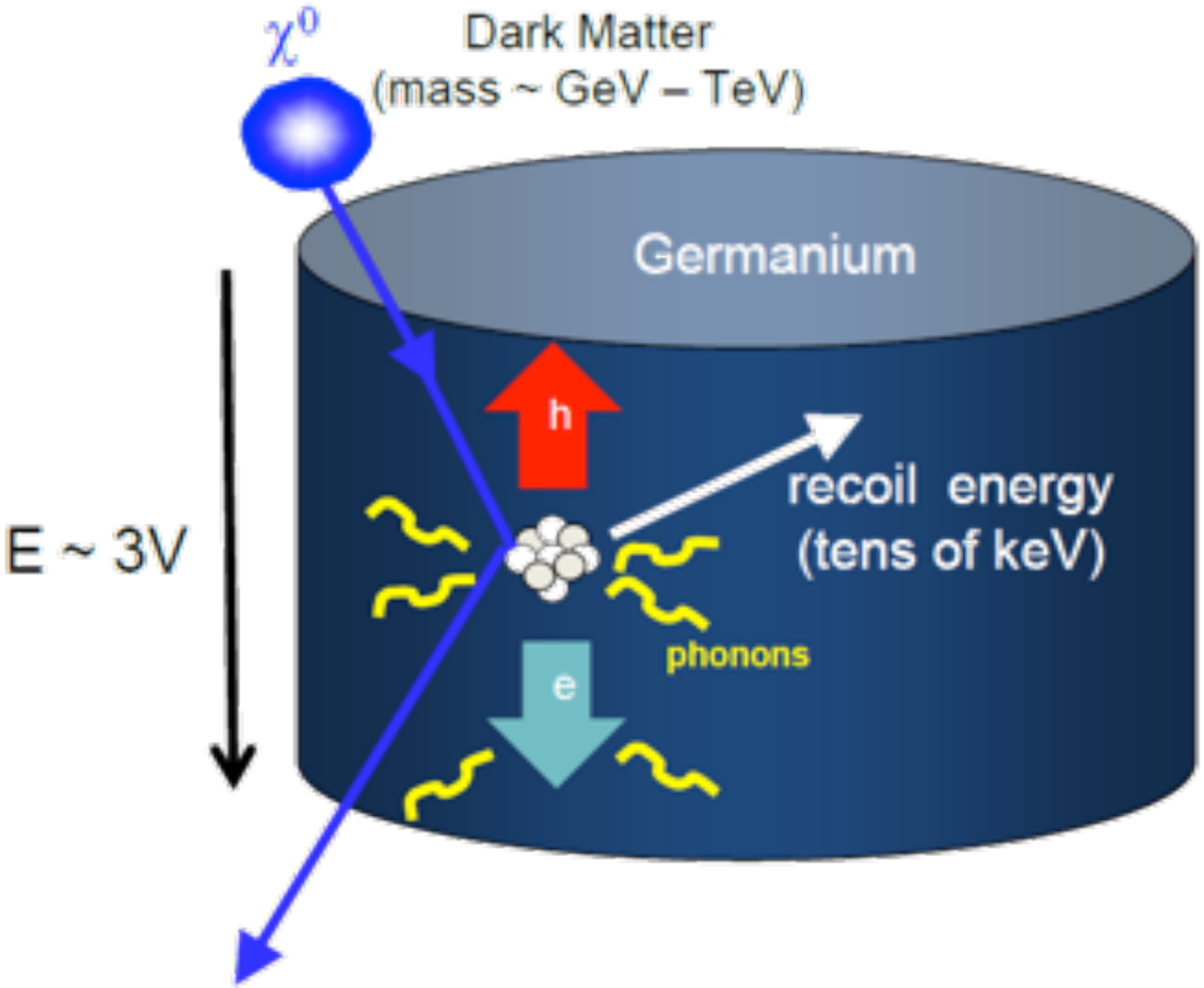
Direct Detection Searches



★Interaction of DM with visible matter inside a detector may reveal its presence

★The detection mechanism has to be extremely sharp because such interactions are extremely weak in nature

Direct Detection Techniques



Basic Principles:

- Put a detector deep underground (like South Dakota mines) to suppress unnecessary collisions

- DM collides with one of the nucleuses of the fluid, excites it and the collision produces photons

- These photons run towards a PMT which as the name suggests amplifies the signal and read out by computer

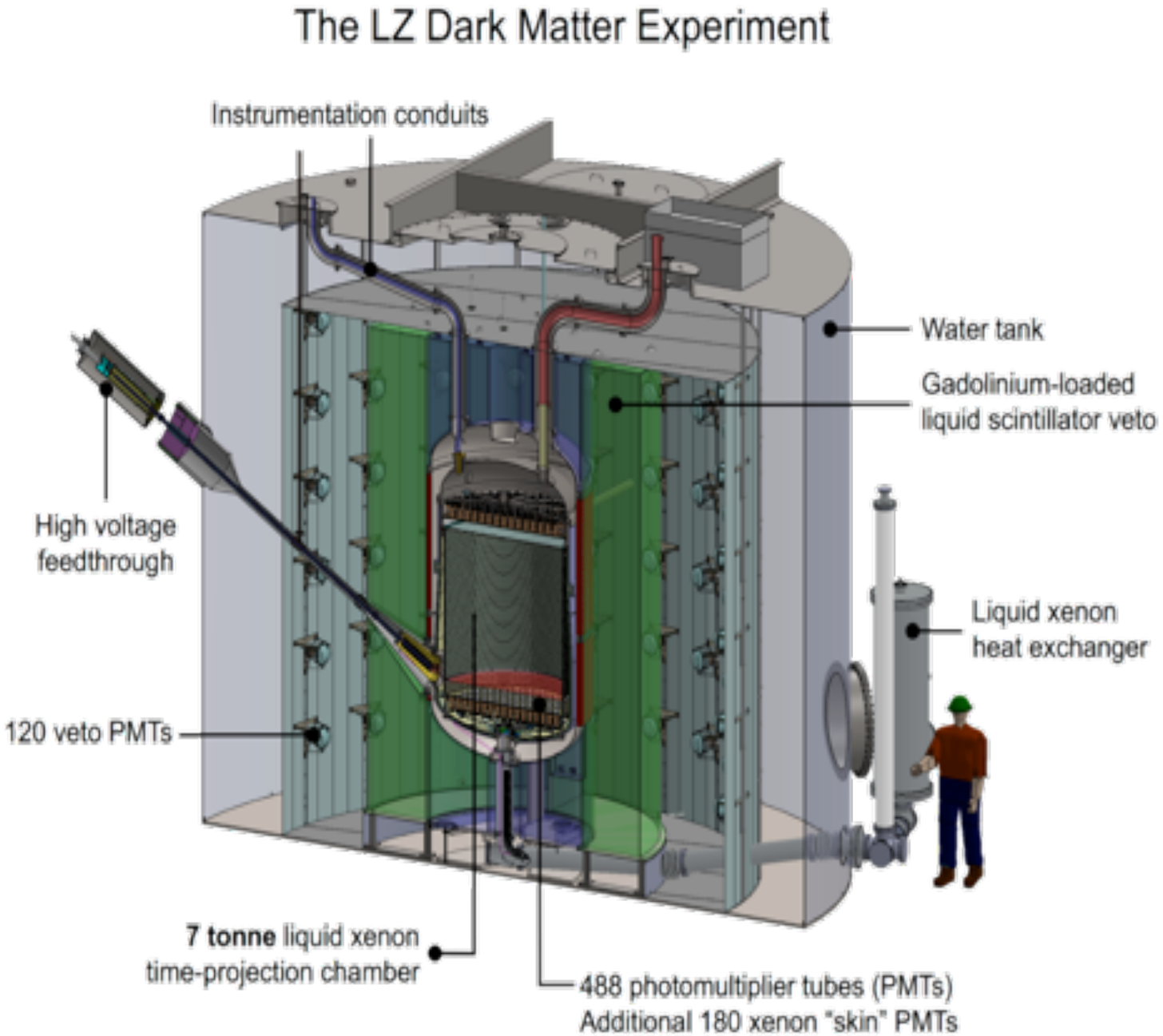
LZ Dark Matter experiment in South Dakota

- Recently approved LZ experiment contains a record-sized 7 ton liquid xenon time projection chamber designed to push limits on direct dark matter detection.

- Deep underground to filter out cosmic rays.

- Careful material selection to reduce radioactivity

- U.Wisconsin is helping build this experiment



Summary

- Dark Matter remains as one of the mysterious questions in modern science !

- Plausible explanations and cosmological observations suggest that they should be weakly interacting and stable in nature

- Searches at the LHC has been resumed since this spring !

- Advancement in our knowledge of Dark Matter from LHC searches will happen soon and are essential for future and other searches

- Direct detection searches like the LZ experiment will start taking data by the end of this decade

- **Even though it may not be obvious from these slides, HTC is an inseparable part of all these efforts without which these experiments will take decades(may be a century) to analyze all the physics data**