Brief Notes for AAS meeting 9th October, 2017 : Black Holes & Dark Matter

Various Definitions:-

1) Black Holes (BH) : A BH is a region of space where the gravitational field is so strong that nothing, including light, can escape from it.

The boundary of a BH is known as the event horizon, beyond which point matter and radiation is trapped.

At the centre of a BH is a singularity. This is a point at which an infinitely large mass is contained in an infinitely small space.

As Kip Thorn, the physicist who shared the 2017 Nobel prize as part of the LIGO team, is quoted as saying "...a singularity: a location where the laws of physics break down and measurements of gravity go to infinity". He also defined a BH as being made up from warped space and time.

2) Dark Matter (DM) : DM is a hypothetical type of matter that is different to ordinary matter, ie everything we can see. It does not emit or interact with light or any other type of electromagnetic radiation. The only interaction there appears to be is gravitational.

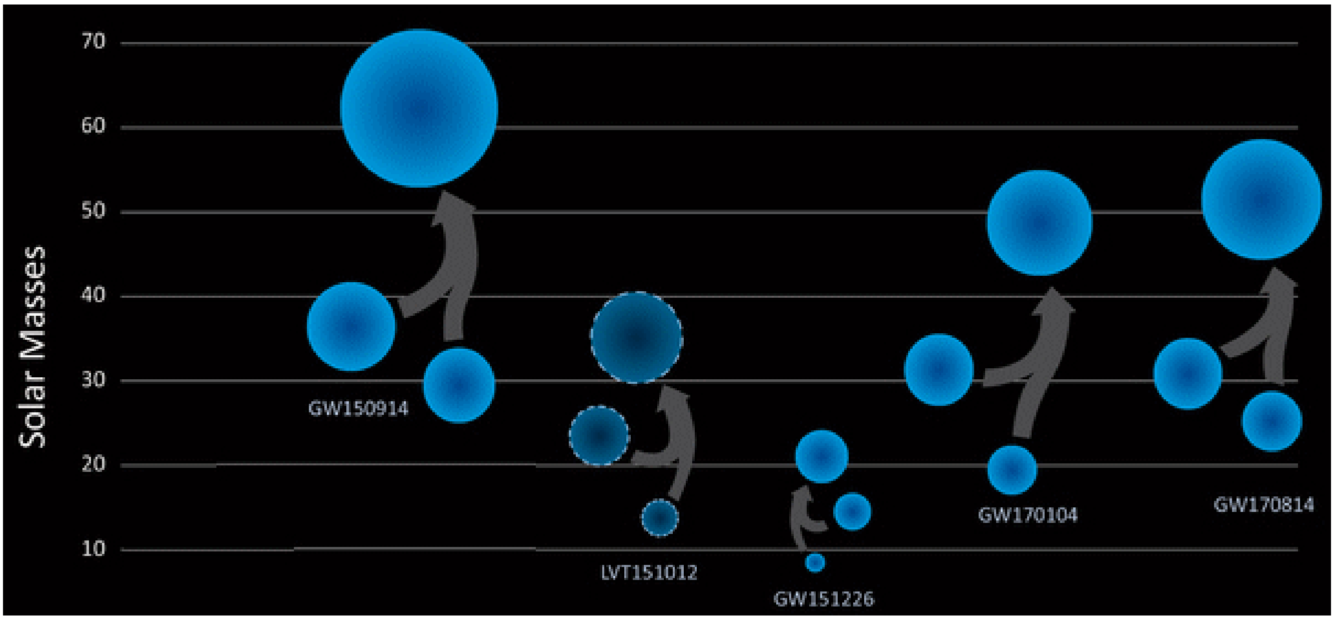
The term *"dunkie materie"* (dark matter) was conjured up by Zwicky in 1933 to explain the fact that the Coma group of galaxies, which he was studying, held together even though there was insufficient visible mass to do so.

It is currently estimated that the portion of the universe we can see is 5% of the total with 25% being DM. The other 70% is Dark Energy, even more enigmatic than DM!

3) Gravitational Waves (GW) : These were predicted in Einstein's Theory of General Relativity. They are ripples in space-time caused by enormous gravitational fields, for example 2 black holes orbiting each other and merging.

They were first detected by the LIGO observatories (Laser Interferometer Gravitational Wave Observatory) in 2015. To date 4 GW events have been detected, 14/09/15, 26/12/15, 04/01/17 and 14/08/17 with another possible on the 12/10/15, see diagram below.

It is estimated that the 14/09/15 event resulted in 2 solar mass equivalents being converted into a Gravitational Wave.



Contenders for Dark Matter

- The current favoured theory for what constitutes DM are WIMPs (weakly interacting massive particles). WIMPs are an, as yet, undiscovered elementary particle. They only react via gravity and the weak nuclear force – the force that acts on the scale of atomic nuclei and mediates ·-decay. They also emerge from the super-symmetry extension of the standard model. Unfortunately, despite many years of searching, including the LHC, nothing has been found as yet.

- A previous contender for DM were MACHOs (massive compact halo objects). MACHOs include black holes but also other "normal" matter that emits little or no radiation like neutron stars, faint white dwarfs, brown dwarfs, red dwarfs and exo-planets. They are proposed to form halos around galaxies and be detectable by gravitational

lensing. But again, as with WIMPs, no evidence has been found for sufficient mass that would account for the fact that there appears to be 5 times as much DM as ordinary matter.
The investigations ruled out MACHOs up to 10 solar masses.

- In the 1970's Carr and Hawking proposed primordial BHs. They were only looking at small sizes which would have evaporated by now and they concluded that these objects would only have a marginal contribution to DM.

- It was proposed by Guth in the 1979 that a solution to the question of homogeneity and flatness of the universe could be solved by the theory of rapid inflation. In this theory the universe expanded rapidly immediately after the big bang so that in 10^{-35} seconds (that's 0.00000000000000000000000000000000001 secs) two points that were less than an atomic radius apart would have been separated by 4 light years.
During this inflation quantum fluctuations were magnified to large scale sufficient to provide the density variations that formed the initial structure of the universe that we see today. To date this theory is the best available and has made predictions that have proved correct.

- In the article in Scientific American, Garcia-Bellido & Clesse, work is described which suggests that these quantum fluctuations could be magnified by inflation and produce, very dense regions which would, within a second after inflation, collapse into a large population of BHs. These density fluctuations could produce BHs that would vary in size from 0.01 to 10,000 solar masses.

If this proposal is correct then it would answer a number of questions:-

1) The chances of very large black holes forming and then approaching each other close enough to orbit and merge are low. If the LIGO results, as they seem to at the moment, show that there are many BH mergers this would suggest mergers are much more frequent and provide evidence for the primordial black hole theory.

2) Current simulations of the universe predict that there should be many satellite galaxies around the Milky Way system, but we don't see them. If they were dominated by DM then star formation would be suppressed and these galaxies would be very faint.

3) Also we haven't been able to find the population of galaxies between dwarf and massive galaxies predicted by simulations. Again they may be ultra faint.

4) There is uncertainty as to the evolution of Super Massive Black Holes, those that are millions of solar masses and are at the centre of large galaxies and quasars. These appeared very early on in the history of the universe, too early, on current models, to have grown from the collapse of the first population of stars. Massive primordial BHs is one solution.

Observations over the next few years may help to answer some of these questions and confirm or rule out this particular theory or throw up new ideas. These observations could include:-
1) More GW wave detections. As new instruments come on line and upgrades are made we will also be able to indentify were in the sky these mergers are.
2) Finding ultra faint dwarf galaxies. Proposed space based projects would be expected to find these objects.
3) The current GAIA mission is measuring the position and speed of 1 billion stars. If there are isolated BHs the results should be able to identify them from the effect on stars.
4) The ground based Square Kilometre Array project, which looks as though it is being scaled back, will map the 21cm line of neutral hydrogen. If primordial black holes exist then the accretion of matter by them will produce x-rays which will imprint a signature on the 21cm map.
5) NASA's proposed Primordial Inflation Explorer, not yet confirmed, would look at inflation, primordial density perturbations and dark matter decay along with other subjects.

This also shows how GW observations are opening a new window on our universe.

SOME LINKS:-

Dark Matter	:	Top 5 candidates for Dark Matter
Black Holes & Dark Matter	:	NASA : AAAS : The Guardian