Calculation of the Hubble Constant assuming the Gravitational Red Shift model

Detailed Response to the caught zomb from *poly*
As described at www.zombal.com
Report by *dragozzine*
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Zomb Statement:

Because all particles in the Universe are subject to mutual gravitational attraction, this "background" gravitation can be thought of as a type of viscosity.

Solar systems and galaxies rotate against this background according to gravitational laws as set down by Newton. That is, the individual bodies involved, such as the Sun and its planets, move in accordance with Newtonian laws of gravity.

In smaller systems, such as a solar system, the effect of this "background gravitation" may be completely negligible. With larger celestial assemblies, such as galactic clusters, the outer parts of these assemblies must be subject to drag from the background gravitation which increases with their peripheral velocity with respect to the centre of gravity of the assembly.

A framework is sought by which this background gravitation may be quantized[1]. It might be treated as a sort of viscosity, as with a paddle-wheel rotating in a liquid, or as a type of field. Bids are invited for a framework concept. Offers for further development by mathematical modelling or otherwise would be welcome. (ZBL148).

Response

Abstract: I summarize the current scientific understanding of background gravitation in a few different regimes and when it is important to include for a correct understanding of motion. For the most part, background gravitation is very unimportant. The primary reason is that the universe is far more sparse than we usually imagine it to be and nearly isotropic mass distributions have forces that cancel on average. There are some cases where background gravitation is important. The most common situations in astrophysics are "tides" from an external mass distribution and "dynamical friction". As suggested by the names, these often act like a source of viscosity that can be quantified. I review the existing framework and understanding of background gravitation in the context of tides and dynamical friction as applied to a few specific cases. This response provides a clear initial understanding of the topic for further investigation.

Introduction: Scientific Philosophy

In general, Einstein's Theory of General Relativity describes the motion of objects due to the influence of other masses. This theory superseded Newton's Law of Universal Gravitation (NLUG) and is needed for either strong gravitational fields (e.g., compact black hole binaries or supermassive black holes) or for very precise measurements (e.g., the extra perihelion precession rate of Mercury or the motion of GPS satellites). Since this Zomb is focused on interactions with distant masses, Newtonian mechanics is completely sufficient. Newton's Law of Universal Gravitation is

1 For this Zomb, I am going to assume that the author meant "quantified" instead of "quantized", the latter has a specific meaning in quantum mechanics that does not apply here.

$$\vec{F} = \frac{GM_1M_2}{r^2}\hat{r}$$

where F is a vector describing the amount of the force and its direction, G is the universal gravitational constant, M1 and M2 are the masses of the two objects between which the force is calculated, r is the distance between the two masses and “r hat” is a unit vector pointing from one mass to the other, showing that this is the direction along which the force is pointed. In accordance with Newton's Third Law, there are two forces acting, one pulling M1 toward M2 and the other pulling M2 toward M1.

Technically, this force needs to be calculated between every individual massive particle (i.e., between every atom) and then added up to see what happens on a macroscopic scale. Thankfully, an extremely good approximation in most cases is to consider each object as a single point of mass, located at the center of mass, and with a mass constituting the total mass of the object. For perfectly spherical mass distributions, this is an exact approximation as can be shown mathematically. The deviation from this approximation is called the “tidal” component of the gravitational field, about which I have written elsewhere. I will come back to this later, but in this sense, this is unimportant and we can consider everything as a “point mass”.

When there are only two bodies, the time evolution of their trajectories due to their mutual gravitation is called an “orbit”. Even in the case where two objects are not bound and do not forever circle one another, we refer to the trajectories of motion as hyperbolic orbits. With some guidance from Kepler's Law, Newton developed the calculations that turn his law of gravitation into orbital trajectories that follow conic shapes: circles, ellipses, parabolae, and hyperbolae. In the pure Newtonian two-body problem without tides, the motion is completely known for all time.

Adding a small change, like a third mass, changes things significantly. Even in the case where the third object has negligible mass compared to the other massive objects (in which case it is called a “test particle”) it's motion due to gravitational forces of the other two objects is not able to be written down in basic equations: there is no “closed form” to the three-body problem. The motion can easily be highly non-linear and chaotic, in the celestial mechanics sense that the exact future motion is not reliably predictable, regardless of the precision with which the present state is known.

Even when the gravitationally important number of objects is very small, many times of interesting motion and orbital evolution occur. The study of these more complicated motions makes up the field of orbital dynamics, with which I am very familiar. This doesn't mean that studying motions in the universe is fruitless, since it practically always turns out that a two or three body interactions are the most important component, with the rest of the N-bodies not contributing much in importance.

Throughout this document, we'll consider a few of the more common gravitationally interacting situations: planets orbiting a star, stars in a single galaxy, and a cluster of galaxies.

The General Unimportance of Distant Masses

There are several arguments that show why distant masses have minimal importance. Before we can address these, we must ask, “minimally important compared to what?” Here, we mean generally unimportant compared to the normal interactions within the system. For example, in a planetary system, the dominant motion is the orbit of the planets around the Sun, of secondary importance is the interactions of planets amongst themselves, and much less important is the influence of the galaxy on the motion of the planetary system.

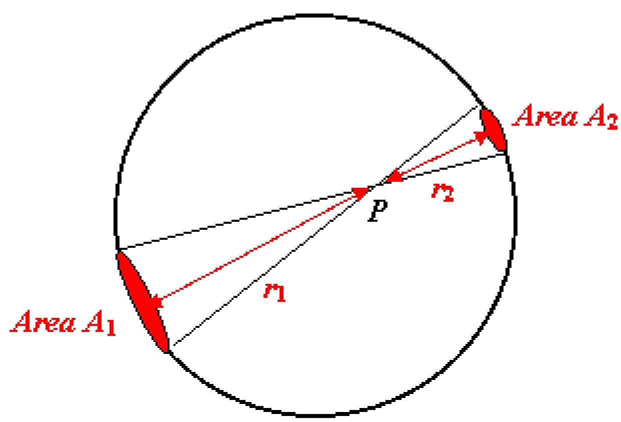
Here's an argument, appealing to our sense. Note that stars and planets have roughly similar densities, around 0.1-10 g/cc in most cases. Take two objects of the same or similar densities and place them at different distances. Then, from Newton's Law above, the gravitational force from the object is inversely proportional to the distance squared. Similarly, the solid angle, i.e., the fraction of sky covered by the object, is also proportional to the distance squared. Therefore, in some sense, you can tell the relative importance of different gravitational effects just by looking and seeing what seems largest!

On Earth, clearly the Earth covering one entire half of our field of view means that it completely dominates the motion of people on its surface. The gravitational field of the Sun and Moon come next and these do have some influence over the oceans in the form of tidal waves, but this is much weaker. With binoculars, once can make out the disks of Jupiter and Saturn; they don't affect motion on the Earth's surface, but they do subtly change the orbit and spin direction of our planet over 10000-100000 year timescales.

These relative importance scales can be easily confirmed by calculating the Forces based on the NLUG equation above. For example, the ratio of the importance of the closest star compared to the Earth for me on the surface is about 1 part in 100000000000000. Alpha Centauri is about 1000000 times more massive than the Earth, but it is 5,000,000,000 times further away, and this component is squared!

For stars, in a similar way, the brightness of a star falls over inversely proportional to the distance squared. Therefore, the gravitational effect of a star is proportional to its brightness. The fact that the Sun ridiculously outshines all other stars in the sky by a factor of well over 10 billion is a clear indication that it is by far the most important star for determining our gravitational trajectory.

But it's even worse than that! Recall that the force of gravity has not just a magnitude (amount), but also a direction. If two distant galaxies exert equal and opposite gravitational forces on the Milky Way, then these forces cancel and these contribute no overall force.



Usually, any background gravitation is due to a collection of distant objects that is roughly isotropic. There is a well-known proof that the gravitational field due to a spherical shell is zero inside the shell. This can be seen by picking any point inside and drawing two cones of any size as in the diagram on the right. Then, the ratio of areas, and therefore the mass in the thin shell approximation, is proportional to the inverse square of the distance. Then when plugging these into NLUG, the forces exactly cancel and there is no force inside the sphere. A more careful and sophisticated calculation confirms this specifically. In the exact same way, isotropic distributions of matter exterior to the system have most of their already small forces cancel almost entirely, leading to very very small background gravitational forces in most systems. Of course, the external mass distribution may not be entirely isotropic, in which case not all the forces cancel.

Empirically, it must be the case that for planetary systems, at least, external gravitational interactions are not always devastating. Our own solar system has survived for 5 billion years apparently without any major influence from outside sources. The low eccentricity of Neptune and the dynamical coherence of the likely ancient Haumea collisional family (Ragozzine & Brown 2007), suggest that our solar system has been mostly calm for billions of years. However, there are some planetary systems that may have been significantly affected by the accumulation of small external forces (Veras et al. 2012, Kaib et al. 2012).

So, the combination of the sparseness of matter and that the effect from many distant objects mostly cancels with other distant objects, lead to the usually negligible importance of background gravitation. A good illustration is our own asteroid belt. Science fiction shows to the contrary, the asteroid belt is extremely sparse: standing on the surface of an asteroid, you would not be able to see any other asteroid on average. However, with hundreds of thousands of known objects, in a few cases we can predict and very precisely measure the encounters between two asteroids that allow us to estimate their masses based on nanoscopic orbit changes due to gravitational interactions. The influence of all the other masses in the asteroid belt, like a "background gravitation" there, is of minimal importance. In fact, there are not even any great measurements of the mass of the asteroid belt as a whole, it's mass is uncertain to within 10%. And this despite a wealth of precise data and observations spanning hundreds of years.

Cases where Background Gravitation can be important: Tidal Fields

Even very weak forces can eventually become important. A clear example of this case is the gravitational influence of the galaxy and passing stars on the orbits of comets. Comets are thought to originate in a structure called the Oort cloud with huge orbits extending out tens of thousands times further than the Earth's orbit. At these large distances, the gravitational field of the Sun is reduced by a factor of several million and therefore background forces can become important.

At this distance, there are two ways of significantly modifying the orbits that could be termed as due to "background gravitation" (e.g., Oort 1950, Brown et al. 2006, Collins et al. 2008, Kaib et al. 2010). First, as part of regular life within a Galaxy, occasionally a star will pass close enough to the Sun, to provide a small acceleration to some of these comets, significantly modifying their orbits. The other mechanism, known as the "galactic tide" is simply the influence of the gravitational field of the Galaxy as a whole; in part because only the non-isotropic component significantly contributes, it is called a "tidal" force.

In both cases, the change in orbital trajectory sometimes causes these comets to leave their large circular orbits and embark on highly elliptical orbits that allow them to interact with the planets (especially Jupiter) or to come into the inner solar system. Such comets are readily recognizable by their orbits and are called Oort cloud comets. Probably the most famous example is recent history is Comet Hale-Bopp (pictured at left).

A similar phenomenon can happen when two galaxies collide. First, it's important to remember the sparseness of your typical galaxy: if stars are the size of grains of sand, then the typical distance between stars in a galaxy is a few miles. Thus, it is not surprising, that when two galaxies collide, the frequency of actual stellar collisions is extremely small. Still, there are significant gravitational interactions that significantly distort the galaxies. This can sometimes result in a “tidal tail” a long thin wisp of gas where star formation can occur. Possibly the most famous example is the Antennae Galaxies with two tidal tails, as seen at the right. This isn't strictly an example of background gravitational per se, but is an intermediate phase between direct gravitational interactions of the stars orbiting the center of the galaxy and how this changes when another major mass enters the scene.

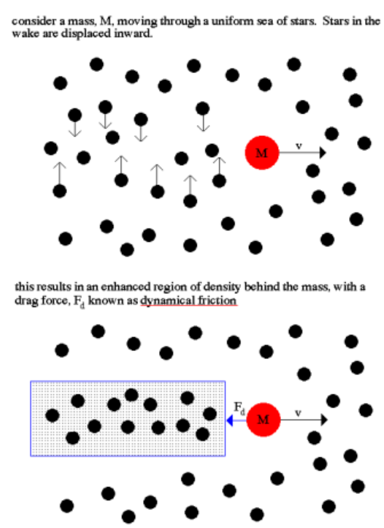
<u>Cases where Background Gravitation can be important: Dynamical Friction</u>

The above cases considered the motion of a small objects when large objects came nearby. Another case to consider is a large object surrounded by a large “sea” of small objects. In many astrophysical cases, the sea of small objects overall actually has more mass than the large object, but most of force of this mass cancels.

However, if the larger mass is moving with respect to the sea of smaller masses, the background gravitation can create a “dynamical friction” effect. Consider a galaxy with a central supermassive black hole, a sea of stars, and a second supermassive black hole that is orbiting within the sea of small stars. This situation can readily occur during galaxy collisions like the one shown above.

As the large mass moves through the sea of smaller masses, it perturbs their orbits, often scattering them to more energtic states. By conservation of energy, this naturally drains a small amount of energy out of the larger mass.

Similarly, these new orbits increase the amount of mass behind the large object by creating a gravitational wake. The increased mass behind the object creates a non-isotropic distribution and allows for a net effect of pulling back on the large mass.



igure: http://abyss.uoregon.edu/~js/lectures/
annibalism/cannibalism_7.html

There are no direct drag forces, but since this effect slows down the mass of the object, it is called “friction” and is considered to act like a “viscous” force. It has been studied analytically and numerically for several decades. Although it depends on the exact setup and assumptions, a few results are known. More massive companions feel a greater dynamical friction, which makes sense as these would create larger wakes. Dynamical friction is stronger when the density of small objects is higher, also a reasonable expectation. Both of these follow the intuition from actual frictional forces, like pushing a box across the floor: heavier objects have larger frictional forces and some floors are harder to push across than others. As with, e.g., air resistance, there are also different velocity regimes. As long as the large object has time to interact with the smaller objects (i.e., it's not moving too fast), the dynamical friction force is proportional to velocity, with faster objects experiencing more drag.
In the case of supermassive black holes, the influence of the stars in the galaxy acts to remove energy from the orbit. This eventually allows the supermassive black holes to merge, although astronomers are still searching for clear evidence of such mergers.

Another regime where dynamical friction is thought to be important is during planet formation. Early in the history of planetary systems, the cloud of gas and dust from which the star formed has contracted significantly. By conservation of angular momentum (like an ice skater pulling her arms in), this spins up the material into a disk shape, called the circumstellar or protoplanetary disk. At one phase in a dominant planet formation theory (“core accretion”), there are many large protoplanetary “embryos” embedded in a sea of small planetesimals (embryos are ~1000 km size and planetesimals ~1 km size, but this is not known exactly). Dynamical friction has been proposed as a critical component of this stage of planet formation, slowing down the large bodies and, in some cases, allowing large Kuiper belt binaries to form, for example (Goldreich, Lithwick & Sari 2002).

One of the strongest theories of galaxy formation is now emerging with the following observation: clusters of galaxies, influenced by dynamical friction and other effects, end up coalescing into larger galaxies. We have seen dwarf galaxies orbiting the Milky Way, tidal tails from past destroyed (“eaten”) galaxies are also present.

Conclusions

For the most part, gravitational dynamics is completely dominated by interactions with one or a few other objects (e.g., the central star in the case of a planetary system). We have shown heuristically, analytically, and empirically that most systems are hardly affected by the presence of background gravitation.

There are, of course, exceptions. We have seen that there are some cases when the average gravitational influence of large numbers of “background” objects can affect orbital trajectories: cometary orbits are sculpted by galactic tides, tidal tails show dynamical interactions between colliding galaxies, supermassive black hole mergers, planet formation, and galaxy growth.

We have not delved into the detailed mathematical methods, analytical equations, or numerical results for understanding and dealing with background gravitation, but the background provided herein can provide a clear starting place for a study of many extant resources on the matter.

I believe that the above answers the questions posed in this Zomb, along with given significant explanation. Please let me know if any of the above arguments are unclear or if you have any other questions or zombs. Doing a Google or Wikipedia search on most of the above concepts will provide helpful insights and references. Other bibliographic citations are available upon request.

Thank you for this opportunity.

Dr. Ragozzine is a Postdoctoral Researcher in the Astronomy Department at the University of Florida. He is currently funded by the United States National Aeronautics and Space Administration (NASA) to work on the NASA Kepler Space Mission. This document is his personal composition and reflects his personal opinion, not that of the University of Florida, NASA, or any other party. He has many years of research experience in the orbital dynamics of planetary systems, the Kuiper belt within our own solar system, and extra-solar planets observed around other stars.