Cosmology

April 11, 2020

Lecture: Cosmology Cosmology

Questions:

Christian: As I understand it, baryonic acoustic oscillation [cosmology slide 22] relates the spacing of clustering (like galaxies) with the wavelength of densities in the primordial plasma. But how could we know what this wavelength was? I mean, such wavelengths would depend on density, the amount of dark matter and charged matter, and maybe the curvature of space.

JW I'm guessing the predictions are model-dependent, but we actually know quite a lot about how much matter and charge there is. We can estimate the amount of dark matter by a combination of what it takes to get the orbital speeds we need within galaxies and in galactic clusters and superclusters. We know the amount of charged matter because it's visible; there are estimates of the number of unseen black holes, neutrinos, and other hard to see material.

The densities are also constrained by the Eddington instability. In a uniform gas, fluctuations will arise at predictable scales, and these have to give rise to stars and galaxies. We can work backward from the observed galaxies.

Christian: Regarding the cosmological constant, I don't quite understand the concept of negative pressure. That sounds like the constant would pull things together, but instead we see an accelerated expansion.

JW Hmm, you have a point. Maybe we need the other sign in that equation. The cosmological constant can come in with either sign, so whichever works is the one that's right.

That said, there's an important difference between normal dust and the cosmological constant. The energy tensor for dust is

$$T_{dust} = \begin{pmatrix} \rho & & & \\ & p & & \\ & & p & \\ & & & p \end{pmatrix}$$

where ρ is the density and p the pressure. But for a cosmological constant the effective energy tensor is

$$T_{cosmo} = \pm \begin{pmatrix} -\Lambda & & & \\ & \Lambda & & \\ & & \Lambda & \\ & & & \Lambda \end{pmatrix}$$

where Lambda can have either sign. It's the difference between ++++ and -+++ that lets you get expansion. If we take the positive sign, then the energy density is negative, giving, perhaps, a sort of antigravity, and the pressure is positive. There's another difference between T_{cosmo} and a normal energy tensor. We generally require the energy density to be greater than the sum of the pressures, but that's not the case for a cosmological constant.

There are different conventions for signs in the Einstein equation, so depending on which you choose, you might need either sign for Lambda to get the expansion. You sort that all out when you solve the equation. If you solve the Einstein equation for a cosmological model with a constant Λ, you find that the scale factor is exponential,

$$a\left(t\right) = \exp\left(\left(\frac{\Lambda}{3}\right)^{\frac{1}{2}} t\right)$$

Also, it depends which side of the equation you put the cosmological constant on. In field equations, I always put the field terms on one side and the sources (usually from other fields) on the other side. A cosmological constant is really part of the gravity theory, so I write it with the Einstein tensor. It changes sign if you move it to the other side.

Christian On cosmology slide 36, you have a term, "cold non-baryonic dark matter". What is meant by "cold?" Does it not even have measurable black body radiation? And why can't it be made of baryons? Why couldn't dark matter just be neutral baryonic matter that wouldn't be affected by radiation pressure? (Like a neutron, but more stable).

JW Cold dark matter is in contrast to hot dark matter. The distinction is just one of how much initial kinetic energy you give the dark matter. It'll still have some temperature, but the point (I think) is that it's energy is dominated by its mass - it's non-relativistic.

It can't be made of baryons because then it would interact strongly with other baryons and we'd see the effect. Also, baryons (or at least their constituent quarks) are charged, so they'd also interact electromagnetically. Either way, we'd see them.

An example of this is the bullet galaxy. Slide 33 is a picture of it. This is a collision of two galaxies showing the resultant bending of light from a distant source behind the colliding galaxies. The point is that baryonic matter interacts strongly with other baryonic matter, so the two galaxies have crunched together and slowed down. Nonetheless, we see gravitational lensing to the sides in the direction the galaxies were originally moving. This is thought to be due to dark matter that has passed through the collision with little interaction.