Testing a quantitative model for dark energy

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Integral BH mass fct starts at $\sim 3\,10^6\,M_\odot$

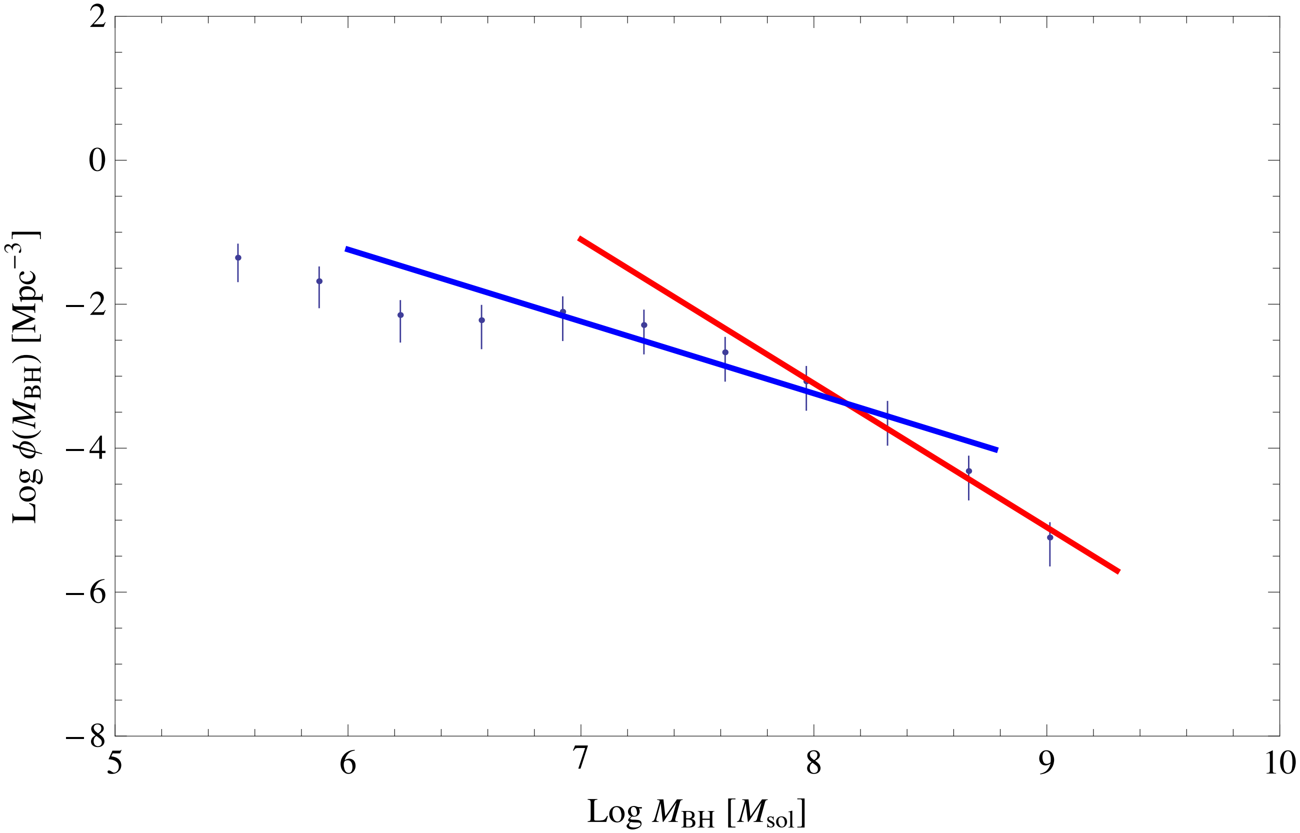

Figure 1 Integral mass function corrected for Hubble type sampling, 2928 objects, the slope of the lines is: red -2.0 fitting $>\ 10^8\,M_\odot$, and blue -1.0 fitting between $10^7\,M_\odot$ and $10^8\,M_\odot$. See Caramete & PLB, 2010 AA. This mass function suggests that black holes start near $3\ 10^6\ M_\odot$, possibly at redshift of order $\lesssim 50$, and grow by merging (see PLB & Kusenko 2006 PRL). Lower mass objects included here are probably nuclear star clusters.

Bekenstein and consequences?

Bekenstein (1973 PRD) writes: Black hole entropy must be a property of the universe. Entropy is information, and information needs a carrier. Gravitational waves?

$$\frac{S}{k_B} = N_{GW} = 4\pi \left(\frac{M_{BH}}{m_{Pl}} \right)^2 \text{ , zero spin}$$

$$\text{With} \quad E_{GW} = \frac{1}{8\pi} \frac{\hbar c^3}{G_N M_{BH}} = \frac{c^2}{8\pi} \frac{m_{Pl}^2}{M_{BH}}$$

$$N_{GW} \, E_{GW} = \frac{1}{2} M_{BH} \, c^2$$

Can black holes match dark energy?

- $N_{BH,0} \; = \; 10^{-2.2}$ Mpc^{-3} to 1 Mpc^{-3}
  Systematic errors, statistical errors, merging dominant?

- $M_{BH} \; = \; 10^{6}$ M$_{\odot}$ to 10^{7} M$_{\odot}$
  From cut in mass function, instability, and Galactic Center black hole (Caramete & PLB 2010 AA)

- $z_{\star} \; = \;$ 25 to 70 (PLB & Kusenko 2006 PRL)
  Very early massive star formation? Black holes?

$$\frac{1}{2} \, N_{BH,0} \, M_{BH} \, c^{2} \, (1 + z_{\star})^{3} \; \simeq \; 10^{-8.1} \, \mathrm{erg \, cm^{-3}} \; = \; \mathrm{DE}$$

From $3 \cdot 10^{6}$ M$_{\odot}$ with $z_{\star} \; = \;$ 50 to $1 \cdot 10^{7}$ M$_{\odot}$ with $z_{\star} \; = \;$ 30 at the same density 1 Mpc^{-3}

Three questions - three answers?

Requirement: $E_{BH} = \frac{1}{2} M_{BH} c^2 \left(\frac{1+z_\star}{1+z}\right)^3$

- Initial shell of gravitational waves, thought of as coherent burst (soliton).
- Question: Gravitons as a soliton shell? What frame of reference possible?

- It grows from itself, so like stimulated emission.
- Question: What is the phase space density in this case?

- The energy comes from a background. Inspired by Randall & Sundrum (1999), but variable in time
- Question: What exactly is the nature of the background? Energy density?

Boltzmann equation derivation

The distribution function $\mathcal{N}(k,t)$ for coherent production of gravitons in a Friedman-Robertson-Walker (FRW) universe, frequency of the wave at emission ν_0

$$\frac{\partial}{\partial t}\mathcal{N}(\nu_0,t) = \kappa_0\, R(t)\, \frac{c\, k_B\, T_{g0}}{h\, \nu_0} \frac{\partial}{\partial \nu_0}\mathcal{N}(\nu_0,t)\,,$$

$$\kappa_0 = \frac{1}{2\pi}\int \frac{d^3p}{(2\,\pi)^3}\frac{|M|^2}{E(p)^2}$$

$$\text{Adopt } |M|^2 \;\simeq\; \frac{energy}{mass}\left(\frac{1+z}{1+z_\star}\right)\frac{1}{R^3}\,\frac{1}{\tau_H}$$

where R^{-3} for quadrupoles, $R = \left(\frac{1+z_\star}{1+z}\right)$. With conditions for coherence and some numerical simplifications

$$\frac{1}{2}\,M_{BH}\,c^2\left(\frac{1+z_\star}{1+z}\right)^3$$

Heuristic derivation

Four steps: 1) Reference frame $\Gamma \;=\; \frac{1}{2}\,\frac{r(z,z_\star)}{l_{Pl}}\,\{H(z)\tau_{Pl}\}^{1/2}$,

2) occupation number first bracket $\left(N_{GW}\,\frac{\sigma_{Pl}}{4\pi R_s^2}\,\Gamma\right)$,

3) coherence patch $\pi\lambda_{BH}^2$,

4) one per coherence patch per Planck time in comoving frame (interaction probability unity with resonant 3D momentum phase space).

For stimulated emission familiar non-linear form (Kompaneets 1957):

$$\frac{dE}{d\tau} \;=\; \left(N_{GW}\,\frac{\sigma_{Pl}}{4\pi R_s^2}\,\Gamma\right)^2 \left(\frac{4\pi R_s^2}{\pi\lambda_{BH}^2}\Gamma\right)\frac{E_{GW}\Gamma}{\tau_{Pl}}$$

In observer frame we obtain again

$$\frac{1}{2}\,M_{BH}\,c^2\left(\frac{1+z_\star}{1+z}\right)^3$$

Summary

- Dark energy drives universe apart with acceleration.
- We propose: Dark energy is ensemble of coherent bursts (soliton-like) gravitational waves originally produced when first generation of super-massive back holes was formed.
- These solitons get their initial energy as well as keep up their energy density throughout evolution of universe by stimulating emission from background.
- Key tests involve pulsar timing, clock jitter, the radio, X-ray, γ-ray and neutrino background, early formation of pure-disk galaxies, and magnetization of IGM.
- First steps are in (PLB & Harms) arXiv:1205.4016, and in arXiv:1302.0040.

Abstract

Dark energy drives the universe apart with acceleration. We propose to develop quantitative tests of a concept for dark energy, and to evolve it further to a full theory. The concept is that dark energy is the ensemble of coherent bursts of (soliton-like) gravitational waves originally produced when the first generation of super-massive back holes were formed. These solitons get their initial energy as well as keep up their energy density throughout the evolution of the universe by stimulating emission from a background. Key tests involve pulsar timing, clock jitter, the radio-, X-ray, gamma- and neutrino-background, and the early formation of pure-disk galaxies. First steps are in arXiv:1205.4016, and arXiv:1302.0040 (PLB & Harms).

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