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Modeling Hubble Behavior Using the Petit Bang Model

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Abstract

We extend the Petit Bang Model of Feix, Minneau and Muriel, a one-dimensional gravitational system, to calculate the Hubble parameter and introduce a possible explanation for the origin of rapid inflation.

Keywords: Petit Bang Model; Hubble Parameter; Variable Values of Hubble Constant; Cosmological Inflation; Zero-Point Energy

Introduction

There is some controversy about multiple measurements of the Hubble constant [1]. There does not seem to be a unique value for the Hubble constant, hence there is a need to find out how the Hubble constant arises. The one dimensional model described here shows how a non-unique Hubble "constant" may arise. We show how different Hubble constants could arise using the highly simplified Petit Bang model, a one-dimensional system introduced by Minneau, et al. [2]. In the original model we explain how structure formation could arise from a primordial explosion [3]. In that model, it was suggested that structure formation could arise without invoking primordial fluctuations. In this work, we show how the Hubble parameter arises. This pedagogical model introduces the idea that rapid inflation may be due to an application of the zero-point energy or momentum of quantum mechanics as explained in Section 5.

Review of Time Evolution of the Single Particle Distribution Function

We start in three dimensions. Let f (r, p, t) be the single-particle distribution function of a many-body system. It represents the probability that at a particle in location r possesses the momentum p at time t. We use the phase space variables r=(x, y, z), p = (p_x.p_y, p_z.) in keeping with kinetic theory. Using factored initial distributions for the initial data, that is, f_2 (r, r') = f_1 (r)f_1(r'), etc., we start with the equation derived in [4,5]:

$$f(r,p,t) = f\left(r - \frac{pt}{m}, 0\right)\varphi(p)$$

$$+n_o\int_0^t ds_1 e^{-s_1 L_o}\int dr'\left[V(r-r')\frac{\partial}{\partial r'_j}f(r',0)\right]\frac{\partial}{\partial p_j}\left(\frac{p_i}{m}\frac{\partial}{\partial r_i}f(r,0)\varphi(p)\right)$$

$$+n_o\int_0^t ds_1\int_0^{s_1} ds_2 e^{-s_2 L_o}\int dr'\left[V(r-r')\frac{\partial}{\partial r'_j}f(r',0)\right]\frac{\partial}{\partial p_j}\left(\frac{p_i}{m}\frac{\partial}{\partial r_i}f(r,0)\varphi(p)\right)$$

$$-n_o\int_0^t ds_1\int_0^{s_1} ds_2 e^{-s_2 L_o}\int dr' V(r-r')\frac{\partial}{\partial r'_j}f(r',0)\left(\frac{\partial}{\partial r_i}f(r,0)\frac{\partial}{\partial p_j}\varphi(p,0)\right)\int dp'\frac{p'_i}{m}\varphi(p')$$

$$-\frac{n_o^2}{2}\int_0^t ds_1\int_0^{s_1} ds_2 e^{-s_2 L_o} f(r)\int dr' V(r-r')\frac{\partial f(r')}{\partial r'_j}\int dr'' V(r-r'')\frac{\partial f(r'')}{\partial r'_j}\left(\frac{\partial}{\partial p_j}\frac{\partial}{\partial p_i}\varphi(p)\right)$$

$$+\sum_{n=3}^{\infty} Order\left(g^n\frac{\partial^n}{\partial p^n}\right) \quad (1)$$

The distribution function evolves from initial data on the right hand side. By the nature of the infinite series, each term in the series comes to the order of $g^n\left(\frac{\partial}{\partial p}\right)^n, n = 0..\infty$ Equation. (1) drops an infinite number of terms of order $\left(\frac{\partial}{\partial p}\right)^n, n = 3..\infty$ for the following reason: we will calculate averages of (1,p,p2). Using integration by parts, the contribution of an infinite number of terms in addition to above is zero, effectively truncating the series to six terms due to the vanishing of the momentum distribution at the boundary of momentum space. We use the operator $L_o = \frac{p}{m}\frac{\partial}{\partial r}$. n_o is the average particle density. $V\left(r - r''\right)$ is a general form of the pair-potential of two particles located at r, r. The existence of this pair-potential distinguishes this approach from the usual continuum model of hydrodynamics. We use Cartesian coordinates and the convention of repeated indices. e^{-tL_o} is the shift operator $e^{-\left[\left(x-\frac{p_x t}{m}\right)+\left(y-\frac{p_y t}{m}\right)+\left(z-\frac{p_z t}{m}\right)\right]}$.

The first term of Equation (1) describes an ideal gas.

We note that the third, fourth and fifth terms of Equation (1) contain the integral

$$\int dr' \left[V\left(r - r'\right)\frac{\partial}{\partial r'_j} f\left(r', 0\right)\right]$$

For an initially uniform system, or a system symmetric with respect to the origin at r = 0, the integral is zero and Equation (1) reduces to

$$f(r, p, t) = f(r - pt/m, 0)f(p)$$

$$+\frac{n_o^2}{2}\int_0^t ds_1\int_0^{s_1} ds_2 e^{-s_2 L_o} f\left(r\right)\int dr' \left(V\left(r - r'\right)\right)^2 \frac{\partial}{\partial r'_j}\frac{\partial}{\partial r'_i} f\left(r'\right)\frac{\partial}{\partial p_j}\frac{\partial}{\partial p_i}\varphi\left(p\right) \quad (2)$$

Now we reintroduce our 1990 model. The Petit Bang Model is one-dimensional; Equation (2) reduces to an exact time evolution equation below:

$$f\left(x, p, t\right) = f\left(x - pt/m\right)\varphi\left(p\right) +$$

$$+\frac{n_o^2}{2}\int_0^t ds_1\int_0^{s_1} ds_2 e^{-s_2 L_o} f\left(x\right)\int dr' \left(V\left(x - x'\right)\right)^2 \frac{\partial^2 f\left(x'\right)}{\partial x'^2}\frac{\partial^2\varphi\left(p\right)}{\partial p^2} \quad (3)$$

The field velocities of hydrodynamics are calculated from Equation (1) or its simplifications like Equation (3). From earlier works [4, 5] but taking only the ballistic or first term of the time evolution equation,

$$f(x, p, t) = f(x - pt/m, p, t = 0) \quad (4)$$

Our variables of interest in our model are:

$$\rho\left(x, t\right) = \int_{-\infty}^{\infty} dp f\left(x - \frac{pt}{m}, p, t = 0\right) \quad (5)$$

$$\mathrm{v}\left(x,t\right)=\frac{1}{m}\int_{-\infty}^{\infty}\mathrm{dpp}f\left(x-\frac{\mathrm{pt}}{m},t=0\right)\quad(6)$$

In contrast to conventional continuum mechanics, the particle mass is important.

We analyze each of the two terms in Equation (3). Two terms remain:

$$\mathrm{f1}=\mathrm{f}\left(\mathrm{x}-\frac{\mathrm{pt}}{\mathrm{m}}\right)\varphi\left(\mathrm{p}\right)\qquad(7)$$

$$\mathrm{f2}=\frac{\mathrm{n}_{\mathrm{o}}^{2}}{2}\int_{0}^{\mathrm{t}}\mathrm{ds}_{1}\int_{0}^{\mathrm{s}_{1}}\mathrm{ds}_{2}\mathrm{e}^{-\mathrm{s}_{2}\mathrm{L}_{\mathrm{o}}}\mathrm{f}\left(\mathrm{r}\right)\int^{\mathrm{dx}'}\left(\mathrm{V}\left(\mathrm{x}-\mathrm{x}'\right)\right)^{2}\frac{\partial^{2}\mathrm{f}\left(\mathrm{x}'\right)}{\partial x'^{2}}\frac{\partial^{2}\varphi\left(\mathrm{p}\right)}{\partial p^{2}}\quad(8)$$

Now we use the pair potential for a one dimensional gravitational gas

$$V=g*abs(x-x')\quad(9)$$

Equations (7, 8) may be evaluated with the following initial data

$$f(x)=no*exp(-a*x^{2})$$

$$(p)=Dirac(p-po)+Dirac(p+po)\qquad(10)$$

Representing an initial explosion with momentum po. When $P_0=0$, the system collapses from its Gaussian spatial distribution, a feature that we will discuss in Section 4.

The equations may be evaluated quickly:

$$f1=no*e^{(-a(x-pt/m))}(Dirac(p-po)+Dirac(p+po))\quad(11)$$

$$f2=-2\frac{g^{2}no^{2}L}{p^{2}}\left(Dirac\left(2,p-p_{o}\right)+Dirac\left(2,p+p_{o}\right)\right)e^{-a\left(L^{2}+x^{2}\right)}$$

$$\left(e^{(-apt(pt-2x))}\right)+\sqrt{\pi a}\left(pt-x\right)e^{ax^{2}}erf\left(\sqrt{a}\left(pt-x\right)\right)-1+\sqrt{\pi a}*erf\left(\sqrt{a}\left(x\right)\right)e^{ax^{2}}(12)$$

To arrive at a closed analytic expression, we have integrated intermediate expressions in x' from $-L$ to $-L$ to represent a system with a size $2L$

The expressions for the density are obtained by integrating over p, yielding

$$\rho_{1}=n_{o}\left(e^{-\frac{(mx-p_{o}t)^{2}}{m^{2}}}+e^{-\frac{(mx+p_{o}t)^{2}}{m^{2}}}\right)\qquad(13)$$

$$\rho_2 = \frac{1}{p_o^4}\left\{24e^{-a\left(L^2+x^2\right)}\left(-\frac{at^2p_o^2}{6}-\frac{1}{2}\right)e^{-ap_ot(p_ot-2x)}+\left(-\frac{at^2p_o^2}{6}-\frac{1}{2}\right)e^{-ap_ot(p_ot+2x)}\right.$$

$$-\frac{\sqrt{\pi a}e^{x^2}\left(p_ot-3x\right)erf(\sqrt{a}\left(p_ot-x\right)}{6}-\frac{\sqrt{\pi a}e^{x^2}\left(p_ot+3x\right)erf(\sqrt{a}\left(p_ot+x\right)}{6}$$

$$\left.+\sqrt{\pi a}e^{ax^2}erf\left(\sqrt{a}x\right)x+1\right\}g^2Ln_o^2 \quad (14)$$

To check if the densities are properly normalized, integrate Equations (13, 14) over the momentum to yield the total mass contributions

$$m1 = 2n_o\sqrt{\frac{\pi}{a}}, \quad m2 = 0 \quad (15)$$

m2 is zero, even if plots may show negative and positive contributions to the total density

We show the density contributions of the two terms in Figures. (1, 2) using the parameters m=1,g = 4,b=2,c=1,no=1,a=4,L=1;T=1,po=4.

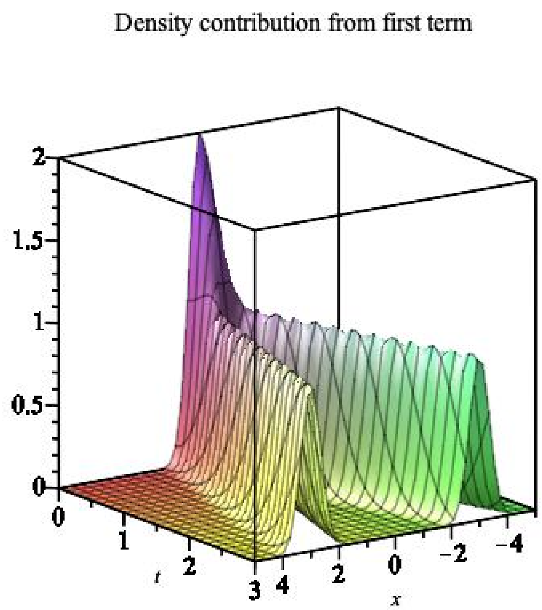


Figure 1: Density contribution from first term.

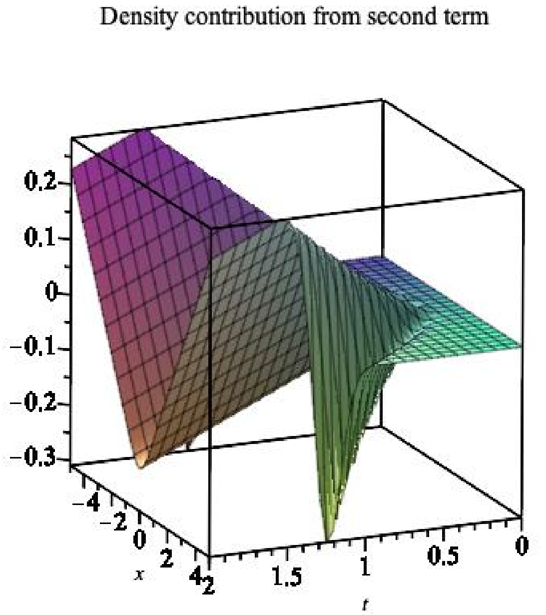


Figure 2: Density contribution from second term.

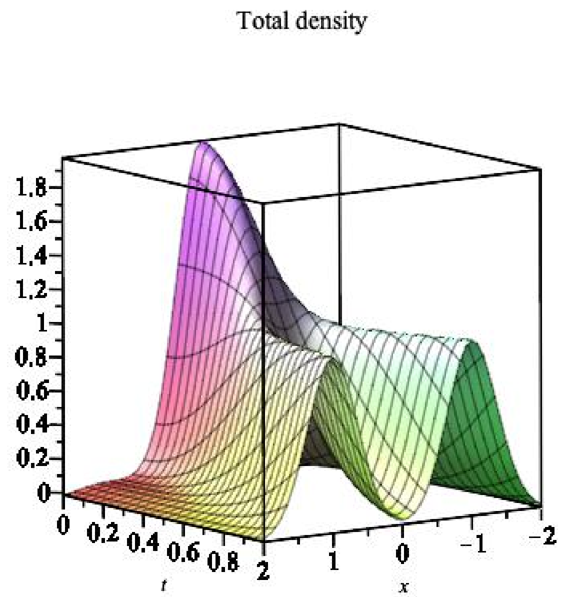


Figure 3: Total density.

We may integrate the density contributions over all x and find that the mass contribution from the first term is $2no\sqrt{(\pi/a)}$ and zero from the second term, reassuring us that the time evolution equations preserve normalization.

In Search of Hubble Behavior

We now calculate the velocity of "galaxies" in this exploding system as a function of time by averaging p/m using the distribution function. Integrating over all momentum,

$$v = \frac{n_o}{m}\left(e^{-\frac{(mx-p_o t)^2}{m^2}} + e^{-\frac{(mx+p_o t)^2}{m^2}}\right)$$

$$+\frac{4n_o^2 g^2}{mp_o^3}\left\{\left(\left(-\frac{at^2p_o^2}{6}-\frac{1}{2}\right)e^{-atp_o(p_o t-2x)}+\left(\frac{at^2p_o^2}{6}+\frac{1}{2}\right)e^{-atp_o(p_o t+2x)}\right)\right\}mp_o^3 s$$

$$\frac{4n_o^2 g^2\sqrt{\pi a}e^{ax^2}x\left(erf(\sqrt{a}\left(p_o t-x\right)+erf(\sqrt{a}\left(p_o t+x\right)\right)Le^{-a\left(L^2+x^2\right)}}{mp_o^3} \quad (16)$$

We display the velocity of the molecules, or "galaxies" as a function of the coordinate x and time or epoch in Figures. 4, 5, 6. The derivative of velocity with respect to x is the Hubble parameter. This parameter does not necessarily remain constant. But for our model, there is indeed a temporary Hubble behavior near the origin as shown in Figure 4.

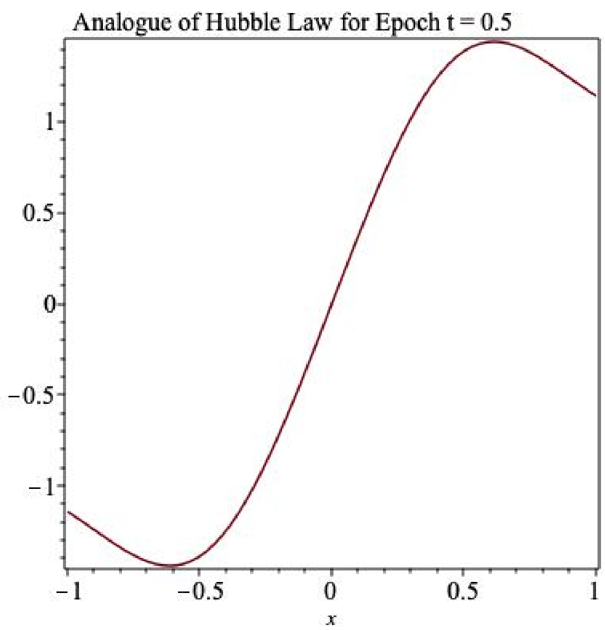


Figure 4: Appearance of Hubble behavior near the origin. Elsewhere, this behavior is not sustained.

In Figure 4, the vertical axis is the velocity as a function of location. Hubble expansion is indeed exhibited, but only near the origin.

Next, we calculate the derivative of velocity with respect to x to give

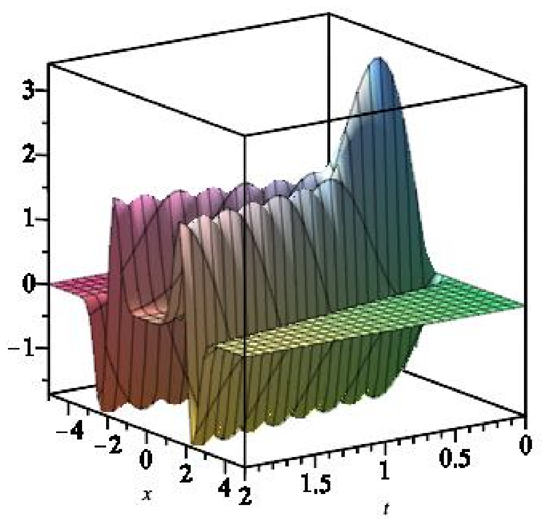
$$\frac{dv}{dx} = \frac{n_o}{m}\left(e^{-a\frac{(mx-t)^2}{m^2}} - e^{-a\frac{(mx+t)^2}{m^2}}\right) + \frac{4aLg^2mn_o^2t(ap_o^2t^2+1)}{m^2p_o^2}$$

$$\left\{e^{-a(p_o^2t^2+ap_otx-L^2+x^2)} - e^{-a(p_o^2t^2-ap_otx-L^2+x^2)}\right.$$

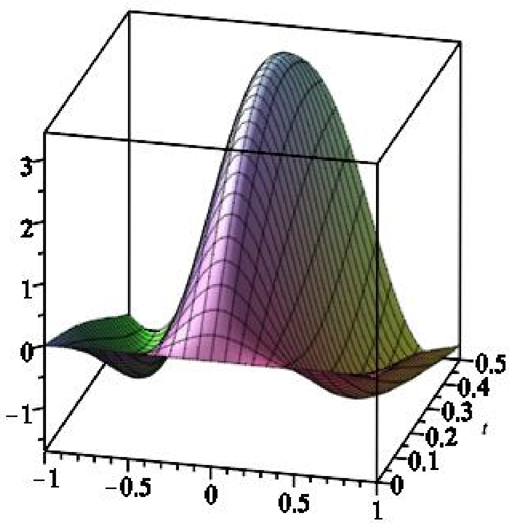
$$\left.+\sqrt{\pi a}e^{ax^2}x\left(erf\left(\sqrt{a}\left(p_ot-x\right)\right)+erf\left(\sqrt{a}\left(p_ot+x\right)\right)\right)\right\} \quad (17)$$

This Hubble parameter varies with time as shown in Figure 5. Hubble behavior occurs near the origin and only for short times. Acceleration occurs near the origin. Around the origin, acceleration or increase of the Hubble constant occurs without invoking dark energy, it is simply due to the initial condition using classical mechanics for non-zero p_o. We will comment on this later in Section 4.

Variable values of Hubble parameter



Rapid rise of Hubble parameter for po = 4



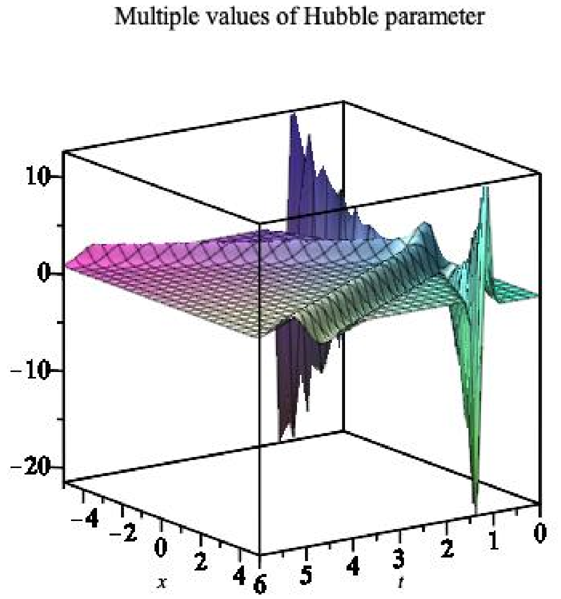


Figure 5: The Hubble parameter, in the vertical axis, for regions away from the origin. We assign the value *g =10* to highlight the nature of the plot. There is no single value of the Hubble parameter. Deceleration occurs eventually after a short period of expansion.

Petit Bang Version of Rapid Inflation

We magnify the plot of Figure. 5 near the origin, resulting in Figure. 6. Note the rapid increase of the Hubble parameter for any finite po. Next, we make an analogous plot for P_0=0 shown in Figure. 7. Figure.6 shows acceleration or rapid inflation for finite po. Figure 7 shows deceleration for po = 0.

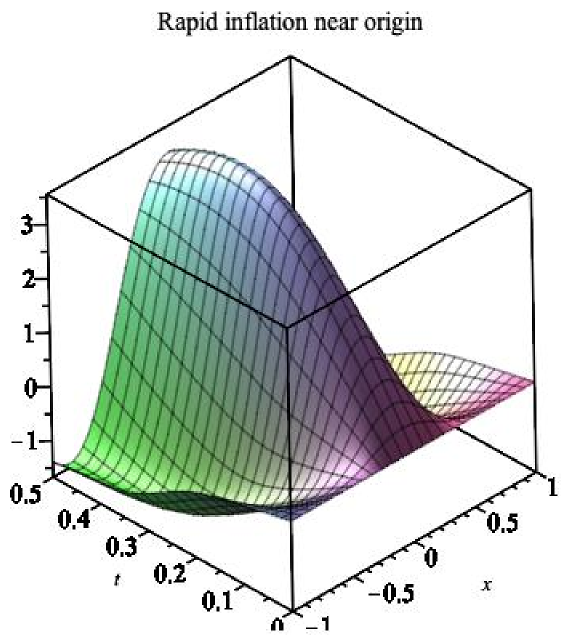


Figure 6: Rapid acceleration for po = 4.

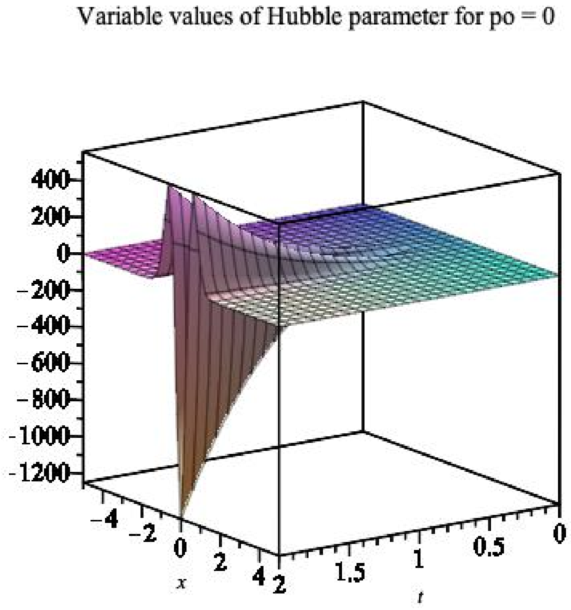


Figure 7: Deceleration for po = 0.

The qualitative behavior of rapid inflation or acceleration of the Hubble parameter in Figure 6, is attributable to the finite initial momentum or energy of explosion. The deceleration shown in Figures 7 is due to zero momentum, allowed in classical physics. Not so in quantum mechanics, where the zero point energy must be finite. Once an explosion at zero time occurs in a big or petit bang, quantum mechanics requires a finite value of momentum or energy – which then results in rapid acceleration. Extrapolating our reasoning to the real universe, we propose that rapid inflation originates from quantum mechanics. There is no other alternative, and we propose, for the first time, we think, that the origin of an inflationary universe is quantum mechanics. In the history of cosmology, it has been accepted that the origin of rapid inflation is unknown [5, 6]. From this study, we claim that quantum mechanics must lead to rapid inflation.

Conclusions from the Petit Bang Model

It is of course too much of an extrapolation to say that a simple classical one dimensional "universe" can say something about a 3d universe, a universe usually studied with general relativity. 3d behavior is usually lost when reduced to 1d. For example, there is no Schwardschild singularity in 1d, the metric is very simple. But perhaps the reverse is not true; extrapolating from 1d to 3d may be helpful in illustrating possible characteristics of the real universe. In our caricature of the universe, Hubble behavior with a unique Hubble constant is not accurate. We have to live long enough in the real universe to test its uniqueness.

By simply looking at an explosion with a finite momentum, it is possible to show rapid inflation, as shown in Figure. 6. Bringing the initial momentum to zero erases the rapid inflation as shown in Figure 7. But we are reminded from quantum mechanics that the zero-point energy of a system cannot be zero, or that po is non-zero. We thus conclude in our simple model that quantum mechanically, the model has no choice but to explode rapidly. It seems that no one has pointed out this possible origin of rapid inflation. We thus propose that quantum mechanics actually requires a rapid inflation of any petit or big bang.

Acknowledgment

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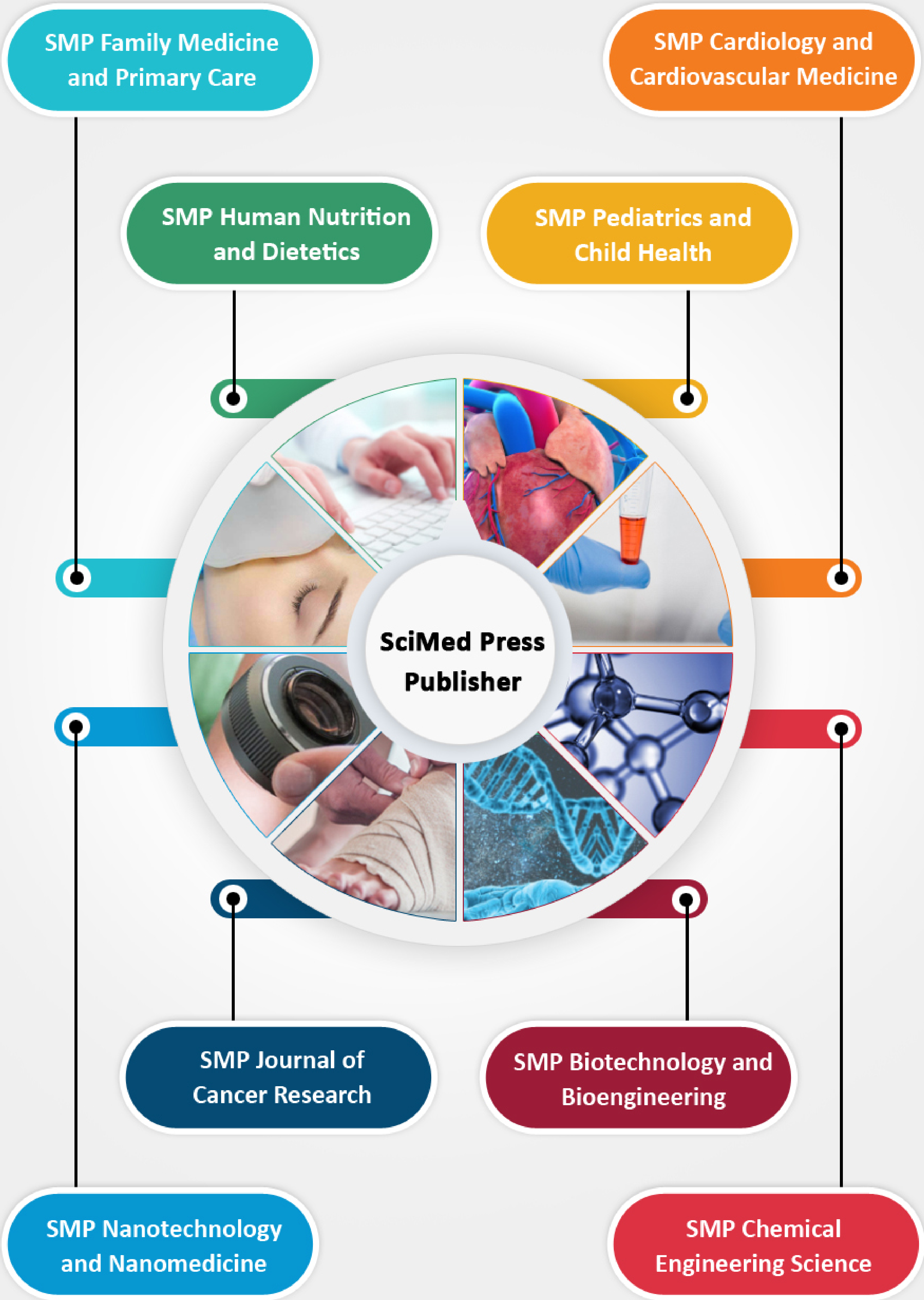
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