Answer to Questions/Criticisms raised by G. Felder, A. Frolov, L. Kofman and A. Linde

Felder *et al.* (hep-th/0202017) and Linde (hep-th/0205259) have claimed "many problems" with the cyclic model. The purpose of this note is to offer a response. The bottom line is that these papers offer no new issues to consider. All have already been raised or addressed directly or indirectly in the original papers proposing the cyclic model, (hep-th/0111098 and hep-th/011030).

The cyclic model is a recent idea and, as such, relies on certain plausible assumptions that ultimately have to be proven. (The latter can also be said for inflationary cosmology.) Foremost among these for the cyclic model is the hypothesis of a continuous transition from a big crunch to a big bang via a bounce. We have been open about this assumption and have explained our proposal for how this bounce may ultimately be understood as a simple collision between branes. In recent work by Tolley, Turok, and Steinhardt (hep-th/0306109) we have made significant strides in showing that this proposal is theoretically viable, and we continue to work along this direction. Another openly stated assumption is that there is an interbrane potential and warp factor with certain specific properties.

When Felder *et al.* and Linde point to these issues as "unresolved problems," we must certainly concur since they are simply restating what we ourselves have written. Those authors have added nothing new to the discussion of these issues either positively or negatively. Nor have they given any thoughtful consideration to the detailed roadmap we have suggested for addressing the issues. The interested reader should look to the original papers to find a discussion of the roadmap and to the important Tolley *et al.* paper cited above to learn about current progress along this direction.

The purpose of this note is to address the claim by Felder *et al.* and Linde that there are many additional problems, flaws that they have found that have not been considered before. This is, presumably, the purpose of their papers and, if true, could be a serious indictment of the cyclic proposal. However, as described below, this is not the case. These "additional problems" turn out to be easily addressed; in many cases, they are misunderstandings or misinterpretations of the the original cyclic papers (hep-th/0111098 and hep-th/011030). In some cases, a claimed problem is actually a useful feature that has been explicitly invoked in our papers.

Because there is no real new problem to consider, we opt for this informal note rather than a formal publication. This also gives us the opportunity to update the response if further feedback or similar types of questions are raised in the future.

Issues and Answers

1. *Criticism:* For a potential $V(\phi) = V_0(1 - \mathrm{e}^{-c\phi})F(\phi)$ with $F(\phi) = \mathrm{e}^{-\mathrm{e}^{-\gamma\phi}}$, the value of γ must be tuned to 1% accuracy to have density perturbations with a correct magnitude.

Answer: The particular model in question was introduced in our papers as a simple example to illustrate the various stages of the cyclic picture, not to study the tuning requirements for the cyclic scenario to work generally. The factor $F(\phi)$ does not have to be of this particular form. One could ask what is the tuning that is required generically. A fair approach would be to compare dimensionless ratios in the big bang/inflationary versus cyclic scenario. This has been done in astro-ph/0301395 (see also astro-ph/0302012), and the result is that two scenarios require essentially identical tuning.

Returning to this simple example, the criticism is deceptive. The density perturbations spectrum would change significantly if γ changed by 1% and no other changes are made. However, a shift of γ by 100% or more can be accommodated by appropriate changes in other parameters.

2. *Criticism:* As the field rolls downhill, from its present positive value, there are "fluctuations that are supposed to produce density perturbations after the singularity. Then the field reaches the regions with $V(\phi) < 0$ ..."

Answer: This description is incorrect and can lead to the erroneous conclusion that the fluctuations are generated in an expanding phase the same way as in inflation. Instead, fluctuations are produced when $V < 0$. This is important because $V < 0$ leads to a transition from expansion to contraction and a change in the effective equations of state w to a value much greater than unity, completely unlike inflation and precisely the novel conditions required to generate nearly scale-invariant fluctuations in the cyclic model.

3. *Criticism:* As the bounce approaches, "the kinetic energy of the field ϕ becomes $\sim 10^6 M_p^4$, *i.e.*. a million times greater than the Planck density!"

Answer: The scalar field kinetic energy is not simply large; it diverges as one approaches the bounce.

But, this is not a problem. It is a characteristic feature of our scenario that we emphasize and discuss in great detail. See hep-th/0111030 and Sections II.B and II.C of hep-th/0111098, our original papers, where we explain why this is not a problem.

Namely, the scale factor $a(t) \to 0$ and the scalar field $\phi(t) \to -\infty$ in the 4d theory as the bounce approaches, but that the effects just cancel one another. This is because they are singular combinations of more-fundamental, well- behaved fields that describe the scale-factors on the two branes, which remain finite at the bounce. Re-expressed in terms of those coordinates, all physically relevant (classical) energy densities are finite.

4. *Criticism:* It is assumed that "the value of kinetic energy of the scalar field *increases* after the bounce."

Answer: This is not a problem. The Appendix in hep- th/0111098 goes into explicit detail on how this naturally occurs when branes with positive and negative tension collide.

5. *Criticism:* The cyclic *scenario* is not an alternative to the inflation anymore. Rather it is very specific version of inflationary theory."

Answer: This boils down to a criticism about semantics. What is surely unambiguous is that the cyclic *scenario* is completely different from the "big bang/inflationary" cosmological *scenario*," where *scenario* refers to the whole cosmic history. The differences are stark. One has periodic evolution; the other does not. The key events that shape the large-scale structure of the universe in the cyclic scenario occur before the bang at completely different times and temperatures, and the mechanism for generating fluctuations is different. Fluctuations are generated in a slowly contracting phase with equation of state $w \gg 1$ rather than in a rapidly expanding phase with $w \approx -1$. What could be more different?

What the authors have in mind is the fact that the cyclic model includes a period of dark energy domination with (slow) accelerated expansion that aids in homogenizing and flattening the universe during each cycle. This part is like inflation. We have made that very point ourselves.

However, to conflate two wholly different scenarios for this one similarity serves only to make discourse confusing. See next criticism as an example. In particular, we note that Guth's original paper, which coined the term "inflation," had "scenario "scenario" in the title and referred specifically big bang/inflation picture. Furthermore, many cosmologists take the term inflation to include the generation of density perturbations during the exponentially expanding phase. But, the fluctuations are *not* generated in the dark energy dominated phase in the cyclic model.

6. *Criticism:* "One may wonder, however, whether this version of inflationary theory is good enough to solve all the major cosmological problems. If one considers a closed universe filled with matter and a scalar field with the potential used in the cyclic model, it will typically collapse within the Planck time, so it will not survive until the beginning of inflation."

Answer: This criticism is a perfect demonstration of the problem that arises by using the same term for two wholly different scenarios. It invites confusion.

Here, the author mistakenly ascribes an issue in the big bang/inflationary scenario to the cyclic model. In the big/bang inflationary scenario, the conditions under which the universe emerges from the big bang are uncertain, and it is conceivable that the universe could be closed. Then, it really does become an issue whether or not the universe avoids collapse before inflation takes hold.

But this is irrelevant for the cyclic model where we have shown the existence of stable, attractor cyclic solutions for which the universe is spatially flat throughout.

7. *Criticism:* "The violation of the equivalence principle [in the cyclic model] can be avoided if $(\ln\beta(\phi))_{,\phi} \ll 10^{-3}$. However, in the Kaluza- Klein limit, in which the 4d approximation used in [33] could be valid ... the equivalence would be strongly violated."

Answer: This issue was already raised and addressed in Section III.A of hep-th/0111098. We presented the condition on $\beta(\phi)$. But, as we e, the KK limit is only relevant when the branes are close. When the branes are many Planck lengths away, the warp factor can change substantially and cause $\beta(\phi)$ to be very different from its KK form ($\beta(\phi) \sim \mathrm{e}^{\phi/\sqrt{6}}$). In our simple example , $\beta(\phi) \to \cosh(\phi/sqrt6)$ on our brane, for which $(\ln\beta(\phi))_{,\phi} \to \tanh\phi/\sqrt{\phi}$ does satisfy condition above at large positive ϕ.

8. *Criticism:* "Are there cycles in the cyclic scenario?" Does the radiation produced at the bounce damp the scalar field so much that the field halts well before comes back to its initial position on the potential plateau?

Answer: This is not a problem. The damping effect due to radiation is a well-known effect and has already been included and accounted for in our calculations of the cyclic solution beginning with our very first paper. In fact, as described in Section IV of hep-th/0111098, we do not regard damping by radiation as a problem, but rather as a feature: the damping helps to bring the field (or branes) to halt to begin the next (radiation dominated) phase of the cycle. In their critique, the authors point out that the field only propagates a few times the Planck mass because of the damping. However, it is important to note that this only applies *after* radiation dominates the scalar field kinetic energy. What Section IV demonstrates is that this does not occur in our examples until after the field is within a few Planck masses of its initial position on the plateau.

Criticism: In a contracting backgrounding, quantum processes cause particle creation resulting in a radiation density that scales as $1/t^4$. This competes with the scalar field density.

Answer: First of all, this effect does not occur in the cyclic model. The reason is that the particle fields couple to the brane metric and the brane scale factor $a_\pm$ approaches a constant at the bounce. In the 4d effective theory, this is reflected in the coupling between matter and the scalar field $\beta(\phi)$. Second, even if there were such an this radiation density begins much smaller than the scalar field energy density and would only grow at the same rate (since the scalar field energy density also grows as $1/t^4$). So, its contribution to the equation of state remains small.