Report of Referee A -- LC16484/Gilmore  
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The manuscript by Gilmore et al. describes a measurement scheme for  
sensing mechanical motion of an ion crystal via the collective spin  
state of the ions. In my own words, the authors describe a scheme,  
where a 2D ion crystal is subject to a traveling optical wave that  
gives rise to a position dependent spin precession. If the ion crystal  
now oscillates in space at a frequency close to the effective  
frequency of the spin dependent dipole potential, the atoms will show  
a precession that can be measured subsequently. The measurement scheme  
makes use of a number of pulses similar to a Ramsey experiment. The  
motion of the ion crystal is driven by a calibrated externally applied  
electric field and amplitudes as small as 0.5nm can be sensed. The  
authors provide a model that nicely describes the data and provide  
arguments how this scheme could in principle be used to measure at the  
limits of quantum mechanics.  
  
I am not an expert in ion trapping, which made it initially **hard to  
understand the scheme itself**. The authors **could elaborate more on the  
measurement principle in general**, and **specifically on the coupling  
between the spin and the position of the atoms**. From the perspective  
of developing schemes to measure at the quantum limit I however was  
impressed by the work. I therefore support publication of this  
manuscript in PRL, but would like the authors to address the following  
points:  
  
1. As explained above, please provide **more information about the  
scheme itself.**

* We acknowledge the terseness of our general description of the measurement technique. We have made changes to the manuscript to better elucidate. In particular:

2. The spins couple to the position of the ions, not to their motion,  
correct?

- Yes, the spins are coupled to the position of the ions. We refer to this as coupling to ‘the motional state’ of the ions in the manuscript.

3. Why do you stress in the abstract that the scheme enables a  
**“discrete” measurement of one quadrature**?

- Contrast with continuous measurement characteristic of cavity-optomechanics style experiments. Not really projective?

4. When talking about “single measurements” and “measurement trials”  
it is unclear what is meant. Consecutive measurements of the same  
system, or applying once the experimental CPMG-sequence?

* Applying the entire sequence. Each iteration of the sequence is a new measurement of the system. The ODF interaction periods accumulate phase, but we only perform a measurement of the spins at the end of the sequence.  
    
  5. Measurement schemes operating close to quantum limits should show  
  **the transition from being dominated by imprecision to being dominated  
  by back action noise**. As the stated aim of this work is approach  
  quantum limits, I was missing the corresponding discussion in the  
  manuscript (except for the one sentence hinting at reference 31).  
  Which **processes lead to the imprecision**, where is the **current  
  measurement positioned when comparing imprecision, back action and  
  technical noise as a function of measurement strength**?

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Report of Referee B -- LC16484/Gilmore  
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This report by Authors K.A. Gilmore et al, is the latest in a long  
series of works by members of the NIST Boulder group that have  
described the development of exquisite methodologies for the trapping,  
cooling, interrogating collections of many identical particles (in  
this case Be+ ions) that form strongly coupled planar ion crystals.  
This work will be of high interest to specialists, but, unfortunately  
**is difficult to read by a general member of the prl audience**. (This  
is, of course, common to many works that appear in prl). The work is  
dense, but well presented and likely follow-able by those working in  
the field. The attachment of supplemental material is especially  
valuable, however, the general reader will only take away the result  
that sub zero point amplitude measurements are possible of the center  
of mass motion of an ion crystal containing about 100 ions. The  
authors refer to the possible utility of their methods to questions of  
fundamental interest (e.g. physics beyond the standard model) but the  
report is about the methodology and results of their measurement  
advances. I recommend that this work be published in prl, primarily  
because of its relevance to its sub-field and its advancement in the  
metrology of trapped ion many body systems.  
  
The authors may want to include in the supplemental material (or  
perhaps in the main body of the report) **reference to work that they or  
others may have produced that would act as introductory material** that  
would help the non-specialist "get up to speed" on their work. For the  
current manuscript, I found that a conference proceeding report  
(**Non-Neutral Plasma Physics VIII, AIP Conf. Proc. 1521, 200-209 (2013)**  
by some of the authors to be helpful; this report did not appear in  
the submitted references.