Quantum Communication, Sensing and Measurement in Space

June 25 – 29, Pasadena, CA

Introductions and Provocative Questions session

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Outline

- Introductions
- Objectives of the workshop and study program
- Scope
- Structure of workshop and suggestions for productive interaction
- Provocative questions!

Introductions

- Rana Adhikari - Caltech
- Markus Aspelmeyer - University of Vienna
- Lukas Baumgartel - University of Southern California
- Kevin Birnbaum - JPL
- Don Boroson - MIT Lincoln Laboratory
- Carlton Caves - University of New Mexico
- Yanbei Chen - Caltech
- Joshua Combes - University of New Mexico
- Ben Dixon - MIT
- Sam Dolinar - JPL
- Gabriel Durkin - NASA Ames
- Baris Erkmen - JPL
- Vittorio Giovannetti - Scuola Normale Superiore
- Saikat Guha - Raytheon BBN
- Richard Hughes - Los Alamos National Laboratory
- Rainer Kaltenbaek - University of Vienna
- Prem Kumar - Northwestern University
- Paul Kwiat - University of Illinois at Urbana Champaign
- Jane Nordholt - Los Alamos National Laboratory
- Timothy Rambo - Northwestern University
- Keith Schwab - Caltech
- Jeffrey Shapiro - MIT
- Robert Spero - JPL
- Mankei Tsang - National University of Singapore
- Slava Turyshev - JPL
- Michelé Vallisneri - JPL
- Franco Wong - MIT
- Nan Yu - JPL

Objectives

- We want to investigate/discuss…
  - …communication to/from/in space
  - …precision measurements and fundamental quantum in space
  - …remote sensing and imaging in/from space

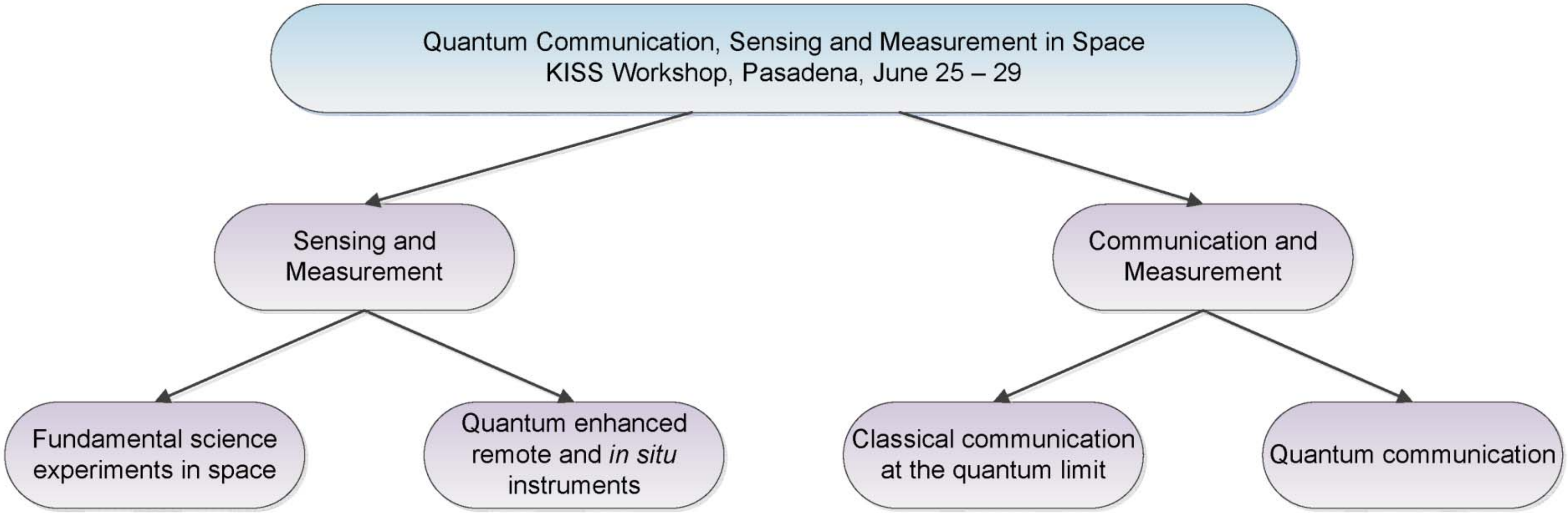
- Our goals are to…
  - …identify applications that could benefit from quantum-enhanced techniques
  - …identify key performance requirements to realize the promised gains
  - …determine the research and development avenues needed to achieve these requirements

Objectives - continued

- A successful outcome at the end of the workshop:
  - we will have identified several promising concepts
  - we will have defined sub-teams and task leaders to further refine these concepts
  - we will have defined a tentative schedule to reconvene and discuss these concepts and the final report content

- End of study program:
  - will have defined comprehensive requirements for realizing gains for several promising concepts.
  - will have identified technology development areas needed.
  - will have written a report that can serve as a road map towards successful infusion of ‘quantum technologies’ into space applications
  - will have written a report that represents broad consensus amongst our participants, which can be used as a reference by community and agencies

Workshop scope



Some topics of interest:

- Quantum-enhanced optical interferometry (e.g., gravity-wave detection)
- Testing quantum mechanics in space

Some topics of interest:

- Quantum-enhanced object detection, feature estimation and imaging
- Quantum-enhanced metrology and spectroscopy

Some topics of interest:

- Receiver and modulation architectures for quantum-limited communication
- High-energy photons in communication (e.g., X-Ray)

Some topics of interest:

- Entanglement distribution over long distances
- Space applications for transfer of quantum information

A note on ‘quantum’ vs. ‘classical’

- High-sensitivity photodetection is…
  - *always* quantum, because light is quantum mechanical and photodetection is a quantum measurement
- High-sensitivity photodetection performance may often be…
  - *calculated* semiclassically, by assuming light is classical and the electron charge is discrete, so that the noise behavior is Poisson shot noise plus classical-light excess noise
- Semiclassical theory is quantitatively correct…
  - when light is in a coherent state or a mixture thereof and standard photodetection (direct, homodyne, or heterodyne) is employed
- When we refer to “quantum-enhanced” performance, we imply enhancements that cannot be explained by semiclassical theory

Structure of workshop

- Discussion sessions are structured to have a lead-in talk, followed by a moderated discussion session
  - we plan to begin by formulating relevant questions then proceeding to discuss them in detail
  - we can form breakout sessions if needed

- We have volunteers (*thank you!*) to take notes in each discussion session

- We have room to make adjustments in our agenda, expand or change discussion topics

Guidelines/suggestions

- Productive discussion is key to our success
- Please share what you know (and don't fear to speak up if you don't know something)
- Help formulate the relevant questions and discussion topics
- Do not be dismissive; if we are discussing a moot point, help us understand it too (then help us form the right question)
- Postdocs/students: you are part of our core group. Ask questions, participate in discussions

Provocative questions

- Precision measurement
  - what are fundamental tests of quantum physics that are better done in space? what technologies are needed to perform them?
  - can we envision instruments sent to space that can generate/use nonclassical sources to study samples (e.g., spectroscopy/metrology)
  - what science would Heisenberg-limited optical interferometry in space enable?
  - what fundamental physics tests can be conducted with opto-mechanically coupled microdevices?
  - can we build better clocks?

Provocative questions – continued

- Communication
  - can we increase communication rates (say, for fixed transmitted power) an order of magnitude, by pursuing quantum-limited receivers?
  - can meaningful and valuable deep-space communication be done in x-ray frequencies?
  - if we do not have quantum computers flying on our spacecraft, would we still want to transfer quantum information to/from/in space? What quantum information would we want to transfer?
  - can our deep-space classical communication rates benefit from using entanglement as a resource? Does the answer change if we include the cost of distributing the entanglement as well?

Provocative questions – continued

- Sensing and imaging:
  - can we use entanglement to improve the resolution/sensitivity of imaging devices?
  - can we improve our estimation performance of doppler shifts, carrier phase etc. beyond the standard quantum limit? Is it still possible with high loss?
  - can we track stars/space objects/beacons with higher precision than we can now?
  - can we build instruments to measure accelerations, orientation etc. with higher sensitivity?

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