

## Why is Fundamental Physics important to Space Research?

- Physics technologies, such as atomic clocks and atom interferometers, have important benefits for space inertial navigation and resource detection.
- Without proper relativistic corrections the Global Positioning System would be grossly inaccurate.
- Use of quantum entanglement may allow quantum communications safe from Cyber security threats.

## Why is Space Research important to Fundamental Physics?

- The force of gravity limits the precision of fundamental physics investigations achievable on the ground
- Space allows access to different gravitational potentials and relative motions.
- A free fall environment allows vastly longer interrogation times for studies of atoms, molecules, and other samples
- Space enables physics research in quiet drag-free satellites

## Why is Fundamental Physics Space Research important to Society?

- Better technologies are developed to enable space science experiments that take full advantage of the environment. These find applications on the Earth to benefit society.
- Research in fundamental physics lays the foundation for tomorrow's breakthrough technologies. Examples are MRI, superconductivity, lasers, clocks, atom interferometers.
- Enlighten humanity's view of the Universe in which we live.

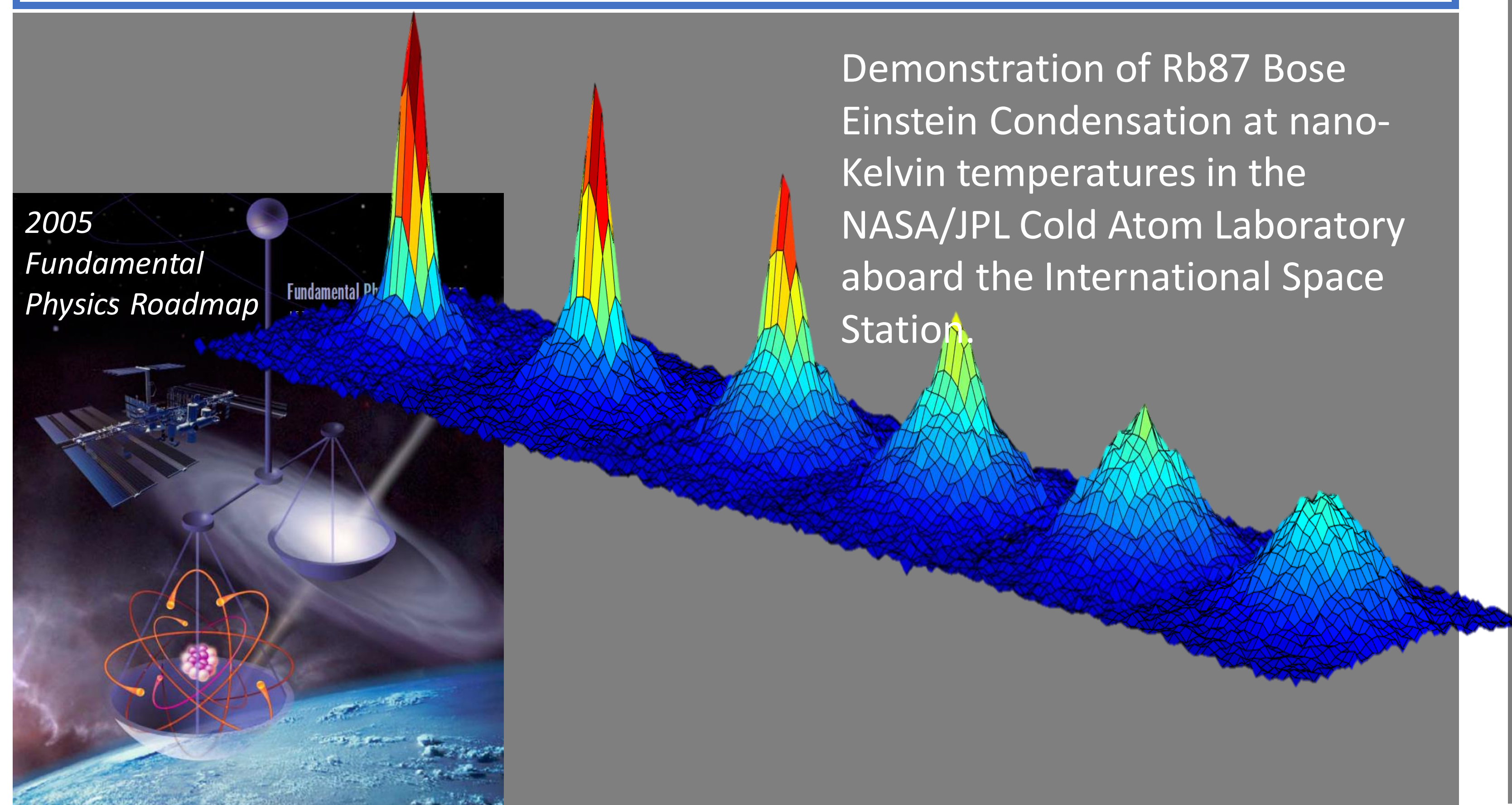
## Important Questions – what do we need to know about Fundamental Physics to support space exploration?

**Communication**– What is the fundamental quantum limit to classical communication links, and what are the quantum properties of light that can increase communication rates, efficiency, and security.

**Navigation** – How can optical clocks in space be used to enable advanced navigation in the Solar System?

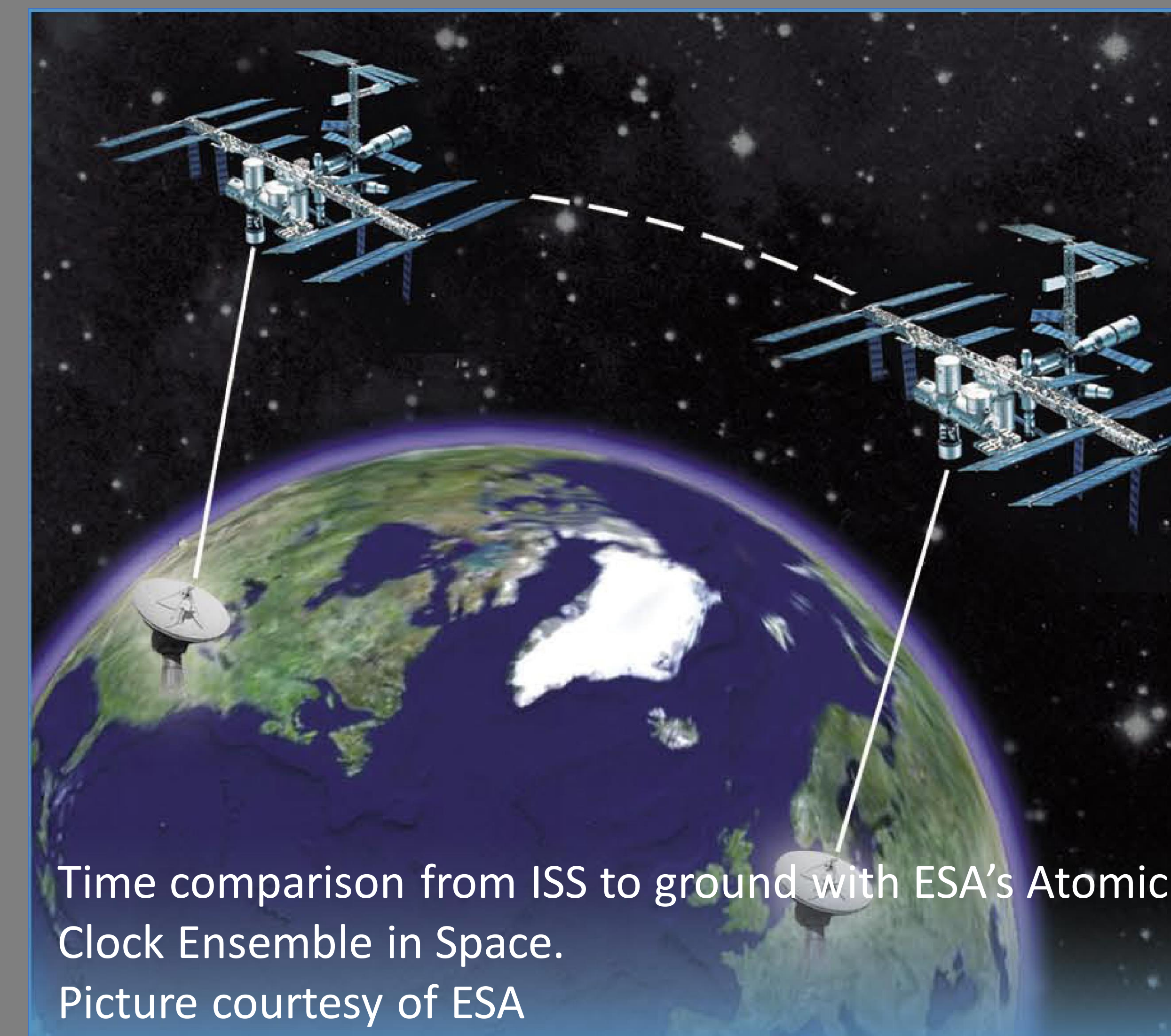
**Dust Mitigation** – How can dusty plasma technology mitigate the risk to Astronauts and their equipment from dust on Moon and Mars?

**Resource Location** – How can advanced atom interferometers and gradiometers be used for planetary terrestrial gravity surveys and to efficiently locate important resources on the Moon and Mars?



## An interesting Fundamental Physics fact relevant to spaceflight: *Time moves slower the faster you move, or the closer you are to a large mass, like the Earth.*

Time on a GPS satellite runs 38 micro seconds faster per day than time on Earth. This leads to a 10 km daily GPS location error if uncorrected.



Clocks at NIST in Boulder, CO and at JPL in Pasadena, CA will be compared with the ACES signal via microwave links.

## Selected Important Answers – what have we learned that could only be revealed in space?

**Critical Phenomena** – Critical phase transitions remain sharp all the way to one billionth of a degree of the transition, and agree with theory.

**Finite Size Effects** – Properties of materials depend on the size of the system and the scaling behavior can be predicted from basic principles.

**General Relativity** – Einstein's general theory of relativity accurately predicts how time depends on the gravitational potential.

**Cold Atom Research** – A Bose Einstein Condensate can be created and studied in the ISS environment providing long interrogation times and temperatures below one billionth of a degree above absolute zero.

**Dusty Plasma Research** – Experiments using ESA's PK4 instrument have revealed the gravity obscured, three dimensional nature of forces between charged dust particles and plasma environment.



**American Society for Gravitational and Space Research**

Biological and Physical Sciences  
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<https://asgrs.org/SpaceScience101>

<p><b>1</b> CHAPTER</p> <p>Fundamental Laws</p> <p>"The important thing is not to stop questioning. Curiosity has its own reason for existing." ALBERT EINSTEIN</p> <p>GOAL: To Discover and Explore Fundamental Physical Laws Governing Matter, Space, and Time</p>	<p><b>2</b> CHAPTER</p> <p>Organizing Principles</p> <p>"Nature uses only the longest threads to weave her patterns, so each small piece of her fabric reveals the organization of the universe." RICHARD FENMAN</p> <p>GOAL: To Discover and Understand Organizing Principles of Nature from which Structure and Complexity Emerge</p>	<p><b>3</b> CHAPTER</p> <p>Physics to Enable Human Space Exploration</p> <p>"Exploration is really the essence of the human spirit." FRANK FORTNEY</p> <p>GOAL: To Apply physics results to enable technologies that allow human space exploration far beyond what is possible today.</p>	<p><b>4</b> CHAPTER</p> <p>Space Research Facilities and Flight Experiments</p> <p>"Nothing has such power to broaden the mind as the ability to investigate systematically and truly all that comes under the observation in life." MARCO AURELIUS</p>	<p><b>5</b> CHAPTER</p> <p>Enabling Technologies</p> <p>"We are the music makers, the dreamers of dreams." ARTHUR W. SHAGHNESSY</p> <p>GOAL: To Apply physics insights to enable Earth-based applications that promote industrial prowess and enhance national security.</p>	<p><b>6</b> CHAPTER</p> <p>Research and Analysis</p> <p>"When you have eliminated the impossible, whatever remains, however improbable, must be the truth." SIR ARTHUR CONAN DOYLE</p>	<p><b>7</b> CHAPTER</p> <p>Physics and Earth-Based Applications</p> <p>"Not only will atoms prove to be related, but someday we will harness the rise and fall of the tides and imprison the rays of the sun." THOMAS ALVA EDISON</p>	<p><b>8</b> CHAPTER</p> <p>Physics Education and Outreach</p> <p>"A generation that ignores history has no past — and no future." ROBERT A. HEINLEIN</p>
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