Enabling Exploration of Deep Space:

High Density Storage of Antimatter

Dr. Steven D. Howe and Dr. Gerald A. Smith

Synergistic Technologies

NASA Institute for Advanced Concepts Annual Meeting

Washington, DC

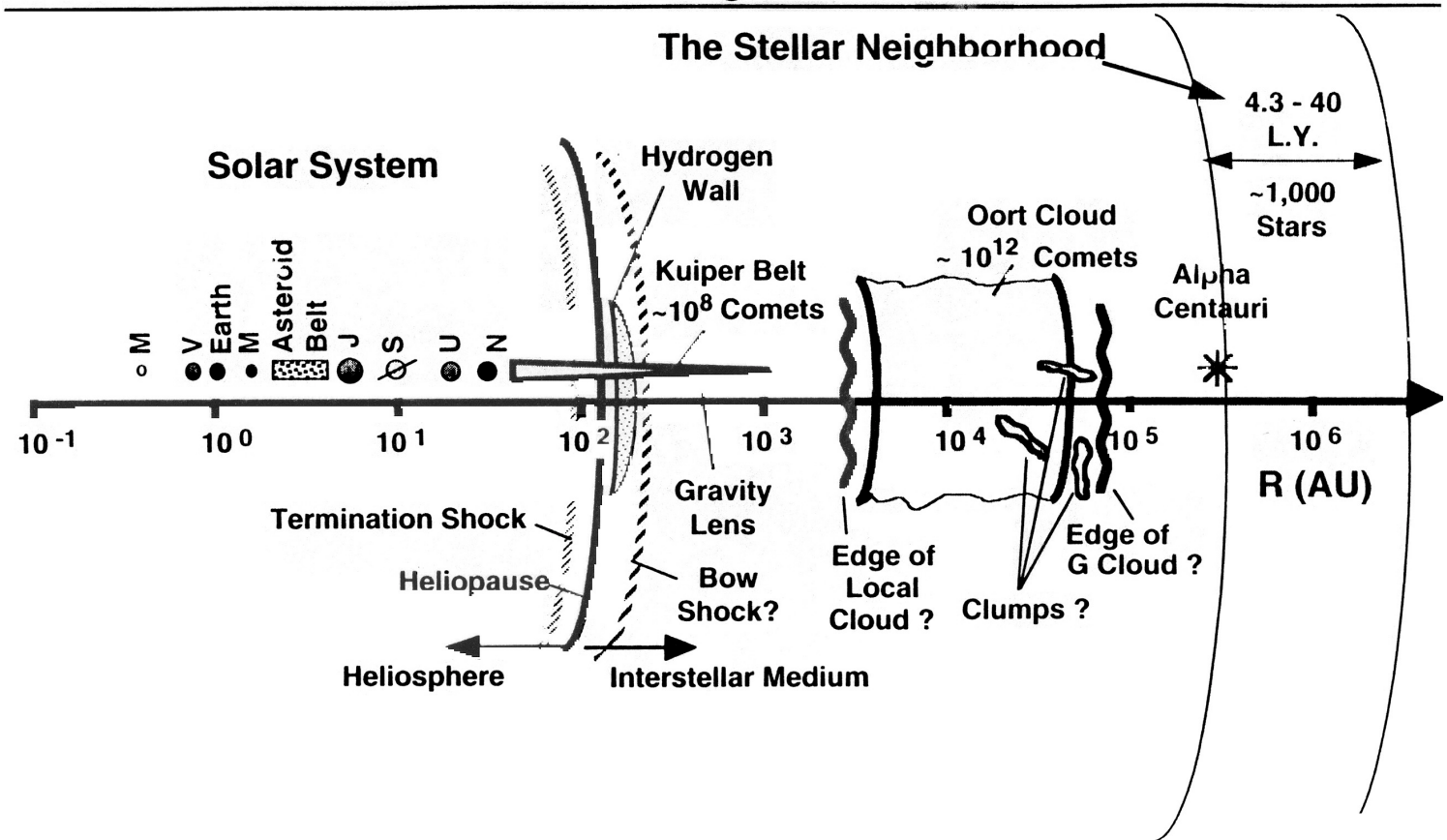
3/24/99

"A journey of a thousand miles begins with a single step."

Synergistic Technologies

INTERSTELLAR EXPLORATION

Stellar Neighborhood



Synergistic Technologies

Missions of the Future

Mission	Vc (characteristic velocity) km/sec	Specific Energy (J/kg)
250 AU in 10 years	60	1.8e09
10,000 A U in 40 years	1200	7.2e11
Alpha Centauri in 40 years	30,000	4.5e14

Synergistic Technologies

Energy Density

Reaction	Specific Energy Fuel(J/kg)	System alpha (kg/kw)	Specific Impulse (s)
chemical	1.5e07	?	470
fission	7.1e13	35	5,000-10,000
fusion	7.5e14	1	40k-60k
antimatter	9.0e16	.01-.1	40k-100k

Synergistic Technologies

Fusion and antimatter are the only candidates for trans-Oort Cloud missions.

Fusion might work if the mass of the system could be reduced.

Antimatter could work if the production and storage issues can be settled.

Synergistic Technologies

	Fusion		Pbars
Pro	+high energy density +high/variable Isp	Pro	+highest energy density +high/variable Isp +100% burn efficiency
Con	-low burn efficiency -Q>1 not yet achieved -massive engines	Con	-expensive -low storage energy density

Antimatter Initiated Fusion

*enables fusion microbursts

*reduces engine mass for fusion

*most energy comes from fusion

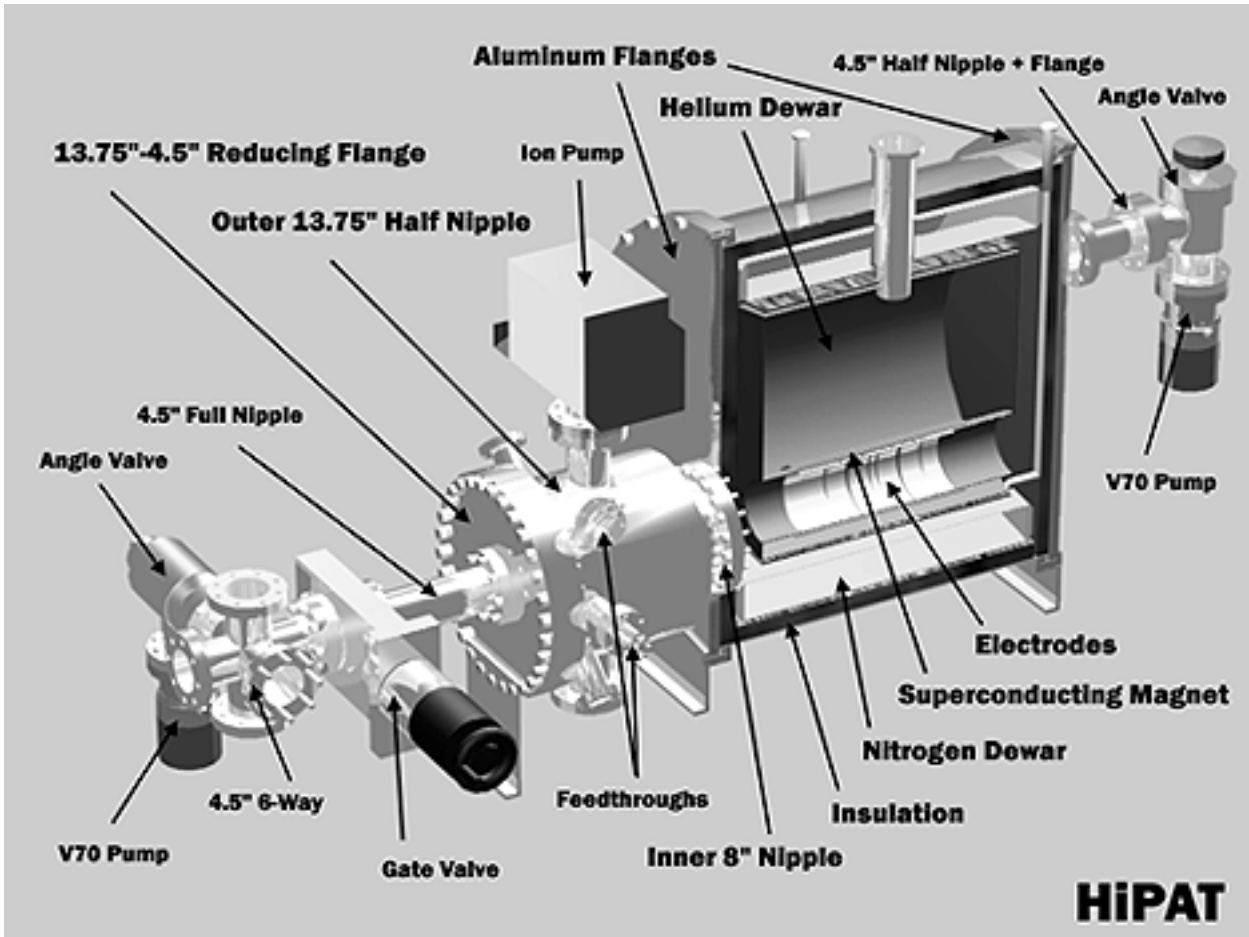
*reduces production requirement of pbars

Synergistic Technologies

The first critical path requirement is:

High Density Storage Of Antimatter

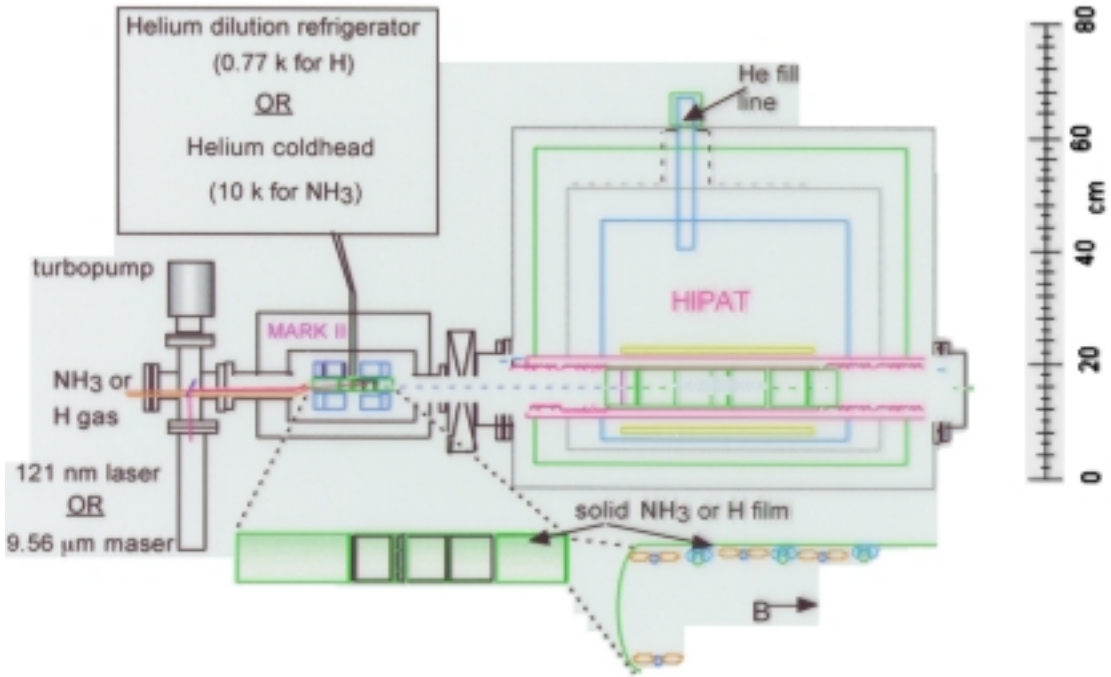
Synergistic Technologies



Synergistic Technologies

Mark II Antiproton Penning Trap

Test Brillouin Density Limit with Solid H or NH_3 Reflector[1,2]

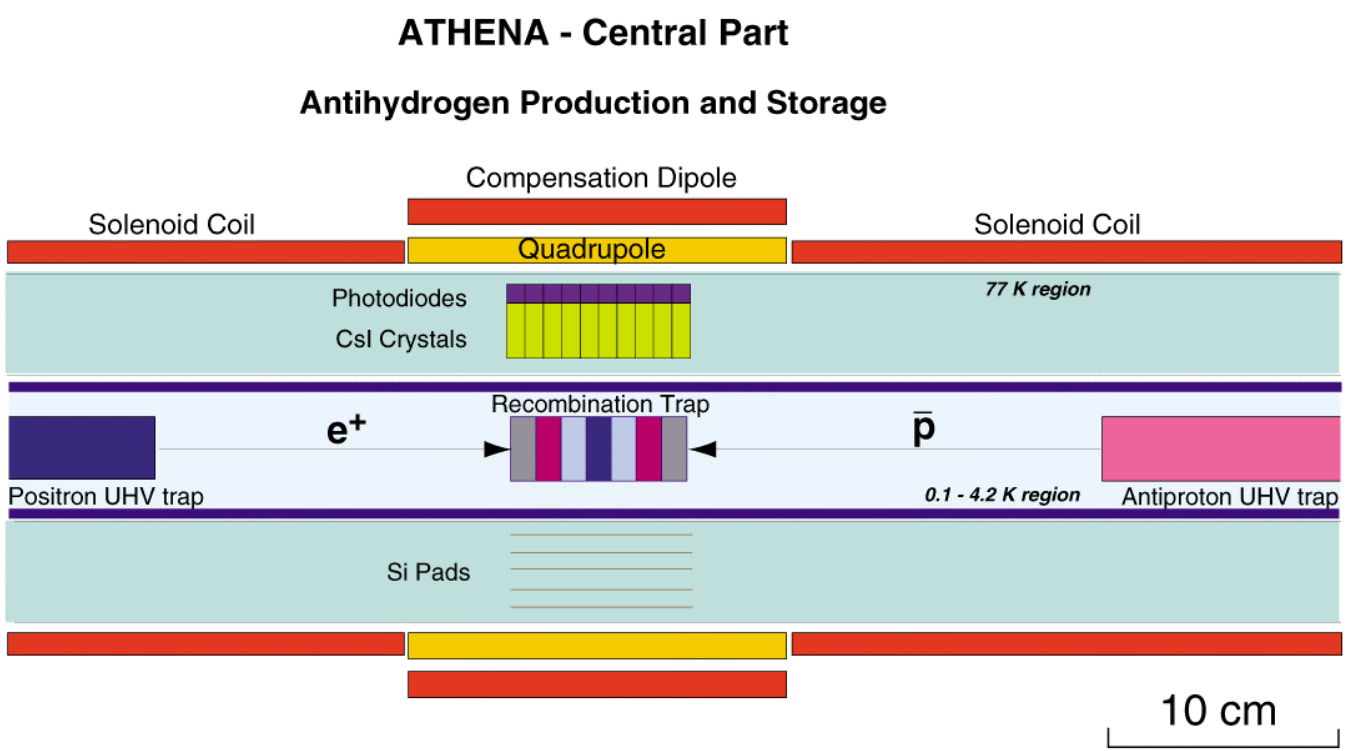


1. R.R. Zito, "The Cryogenic Confinement of Antiprotons for Space Propulsion Systems", J. Brit. Interplanetary Soc. 35, 414 (1982).

2. R.Y. Chiao and J. Boyce, "Superluminarity, Parelectricity and Earnshaw's Theorem in Media with Inverted Populations", Phys. Rev. Lett. 73, 3383 (1994).

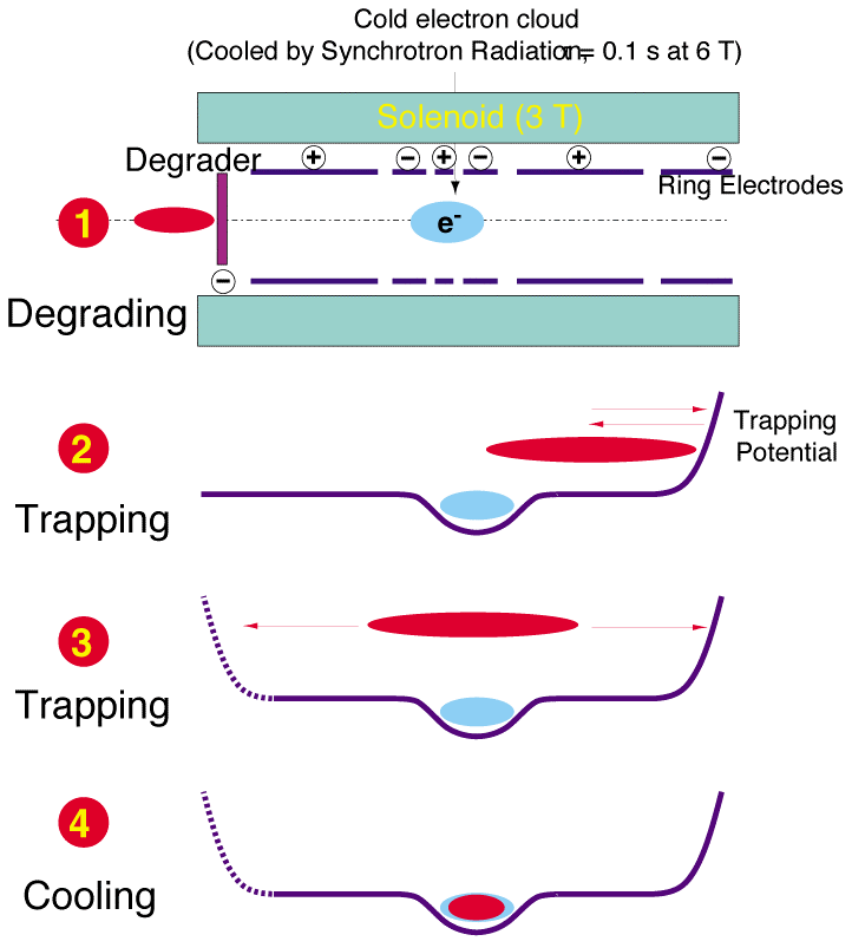
Synergistic Technologies

ATHENA Central Trap Arrangement



Synergistic Technologies

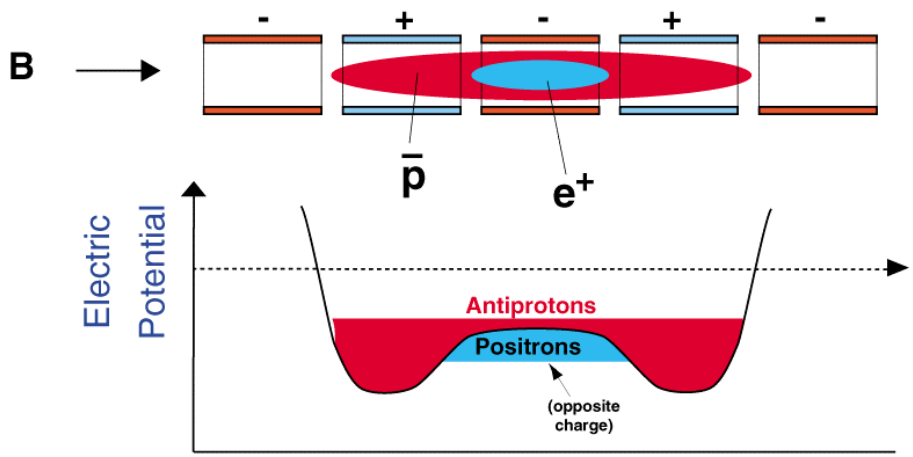
AntiprotonAccumulationandCooling



Synergistic Technologies

Antiproton-PositronRecombination

Recombination in Combined Penning Traps



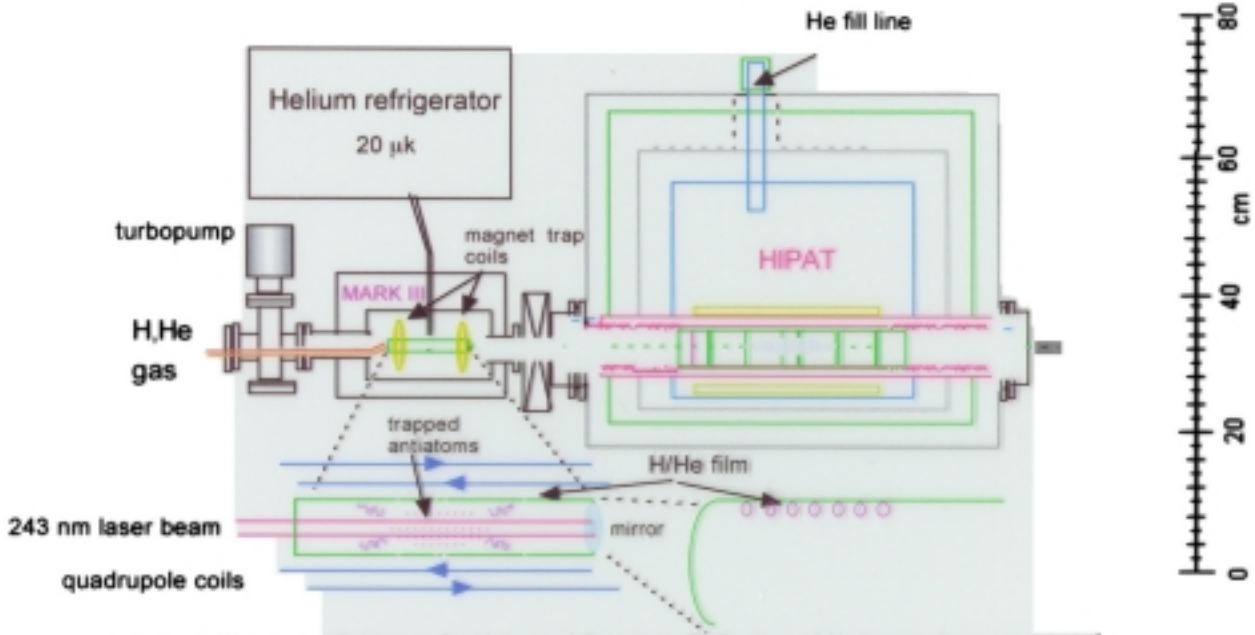
- Theoretical estimate for spontaneous radiative recombination (to low-n levels): 10^7 antiprotons, 10^8 positrons, 10 % overlap of plasma clouds, T = 1 K :

~ 9,000 antihydrogen atoms / second

Synergistic Technologies

Mark III Antihydrogen Ioffe-Pritchard Trap

Test Quantum Reflection[1,2] with H or He Reflector[3,4]



1. Ite A. Yu et al., "Evidence for Universal Quantum Reflection of Hydrogen from Liquid He^4," Phys. Rev. Lett .71, 1589 (1993).
2. C. Carraro and M. Cole, "Sticking Coefficient at Ultralow Energy: Quantum Reflection", Prog. Surface Sci. 57, 61 (1998).
3. D.G. Fried et al., "Bose-Einstein Condensation of Atomic Hydrogen", Phys. Rev. Lett. 81, 3811 (1998).
4. A.I. Safanov et al., "Observation of Quasicondensate in Two-dimensional Atomic Hydrogen", Phys. Rev. Lett. 81, 4545 (1998).

Synergistic Technologies

Antimatter Storage

First Step

➢ **Synergistic Technologies'** Phase II SBIR will provide low energy antiprotons trapped in the NASA-MSFC HiPAT in sufficient in numbers to experimentally test the potential use of Bose-Einstein Condensates (BEC), Parelectricity and Quantum Reflection.

Synergistic Technologies

Research Status

1. NASA SBIR Phase I NAS8-98110 ---- **completed**
   "Design of a High Efficiency Antiproton Degrader/Accumulator to Support Advanced Propulsion Research"

2. NASA SBIR Phase II NAS8-99091 ---- **awarded**
   "Construction of a High Efficiency Antiproton Degrader/Accumulator to Support Advanced Propulsion Research"

3. NASA STTR Phase I NAS8-99004 ----- **in progress**
   "Antimatter Plasma Gun for Advanced Thruster Research"

4. NIAC (NASA Institute of Advanced Concepts)Phase I--- **in progress**
   "Enabling Exploration of Deep Space: High Density Storage of Antimatter"

Synergistic Technologies

Antimatter Storage

➢ The next step is to use modern storage ring technologies that may enable the following goals in storage:

- The NASA-MSFC HiPAT Penning trap - 10^{12}
- HiPAT Penning trap enhanced with BEC or Paraelectric NH3 - $10^{15?}$
- Ioffe-Pritchard trap enhanced with He quantum reflection - $10^{18?}$

Synergistic Technologies

Conclusions

- **Only fusion and antimatter offer sufficient energy densities to launch a trans-Oort cloud mission within the next 50 years.**
- **Current studies indicate that fusion will require massive support structure while antimatter will need major production and storage development.**
- **By using the unique properties of antimatter to enable fusion, the mass of the fusion system can be reduced and the production requirement of antimatter is reduced.**
- **Thus, the immediate objective is high-density antimatter storage:**
  - Non-neutral plasmas - beyond Brillouin limit - parelectricity
  - Antihydrogen - ATHENA experiment
  - Beyond ATHENA - Quantum Reflection/Bose-Einstein Condensates

High energy-density storage of antimatter is the first step that could enable humanity to probe the stars.

Synergistic Technologies