A NEW APPROACH TO FUSION POWER

– **STABLE COLLAPSE OF PLASMA SPHERE UNDER ELECTRO-MAGNETIC FIELDS SYMMETRICAL IN 3D SPACE**

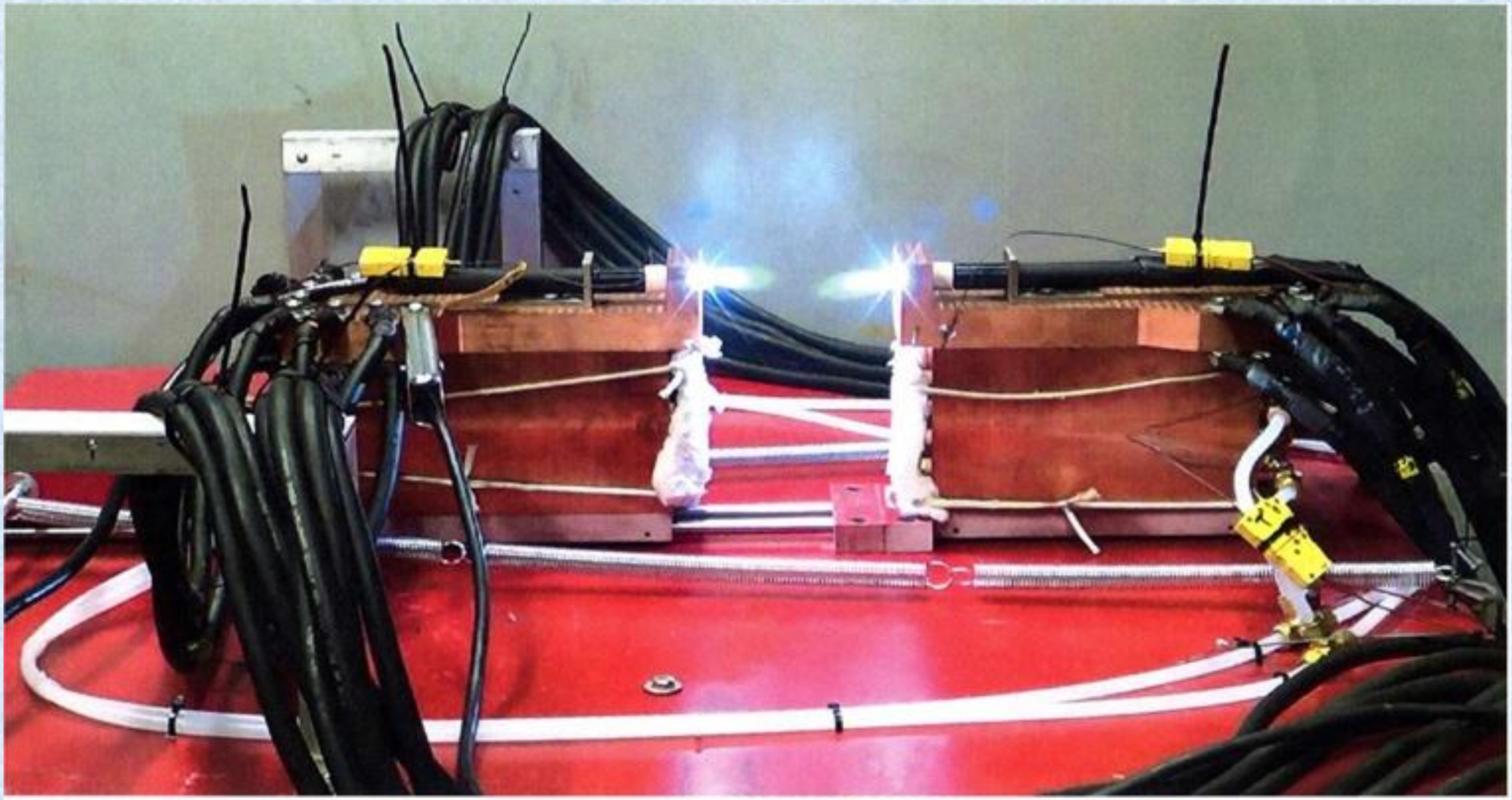
PRESENTATION OUTLINE

1. Observations from Stern Labs tests
2. New interpretation of 1957 Harwell Zeta tests
3. World-wide achievements and technical challenge
4. Stable collapse of plasma – a new approach
5. D-D Fusion as a clean, “neutron-free” solution
6. Development Plan

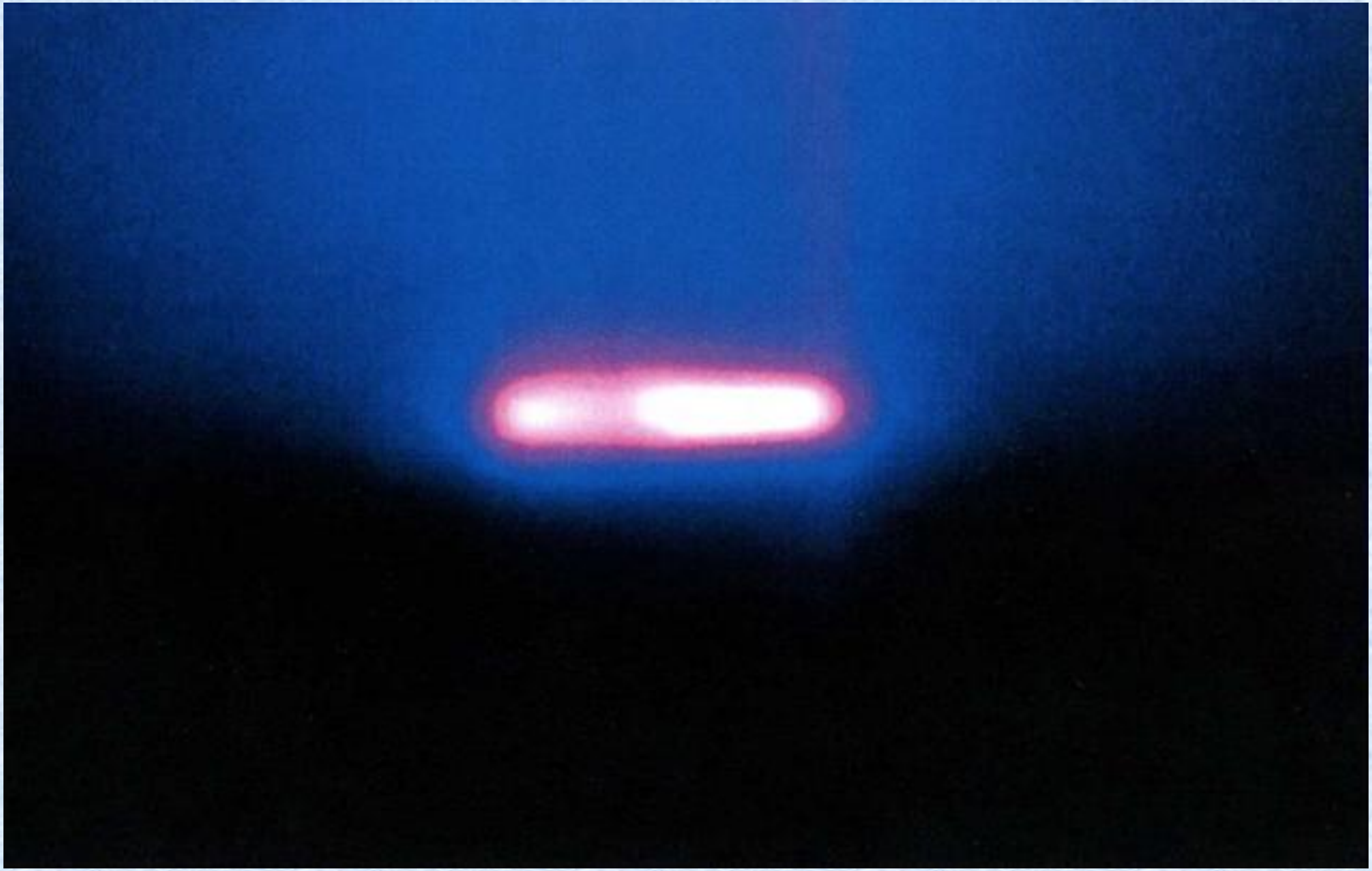
INVESTIGATIVE TESTS AT STERN LABS

- Plasma sources were ignited / sustained
- Two plasma sources were connected by an independent electrical power source to establish a plasma beam
- Observations:
  - Connection center shifted by moving electrons
  - Switch plasma source generators – no change
  - Increase pressure on other side – no change

STERN LABS — PLASMA SOURCES/GENERATOR



STERN LABS — PLASMA BEAMS ESTABLISHED



POSTULATED PHYSICAL MECHANISM

- Electrons flow in electric field
- Electrons interact with adjacent plasma nuclei
  - Nuclei attracted to electrons by opposite charges
  - Nuclei / electrons move together
    - plasma's collective movement - a "glue" effect
  - Relative velocity required by constant current
  - Electrons accelerated ➔ nuclei followed

POSTULATED PHYSICAL MECHANISM

- Final observations:
  - Steady state equilibrium reached
  - Shifting connection center is interpreted as evidence that plasma nuclei follow the electrons
  - Infer enhanced plasma velocity

Z-PINCH TESTS WITH NEUTRONS

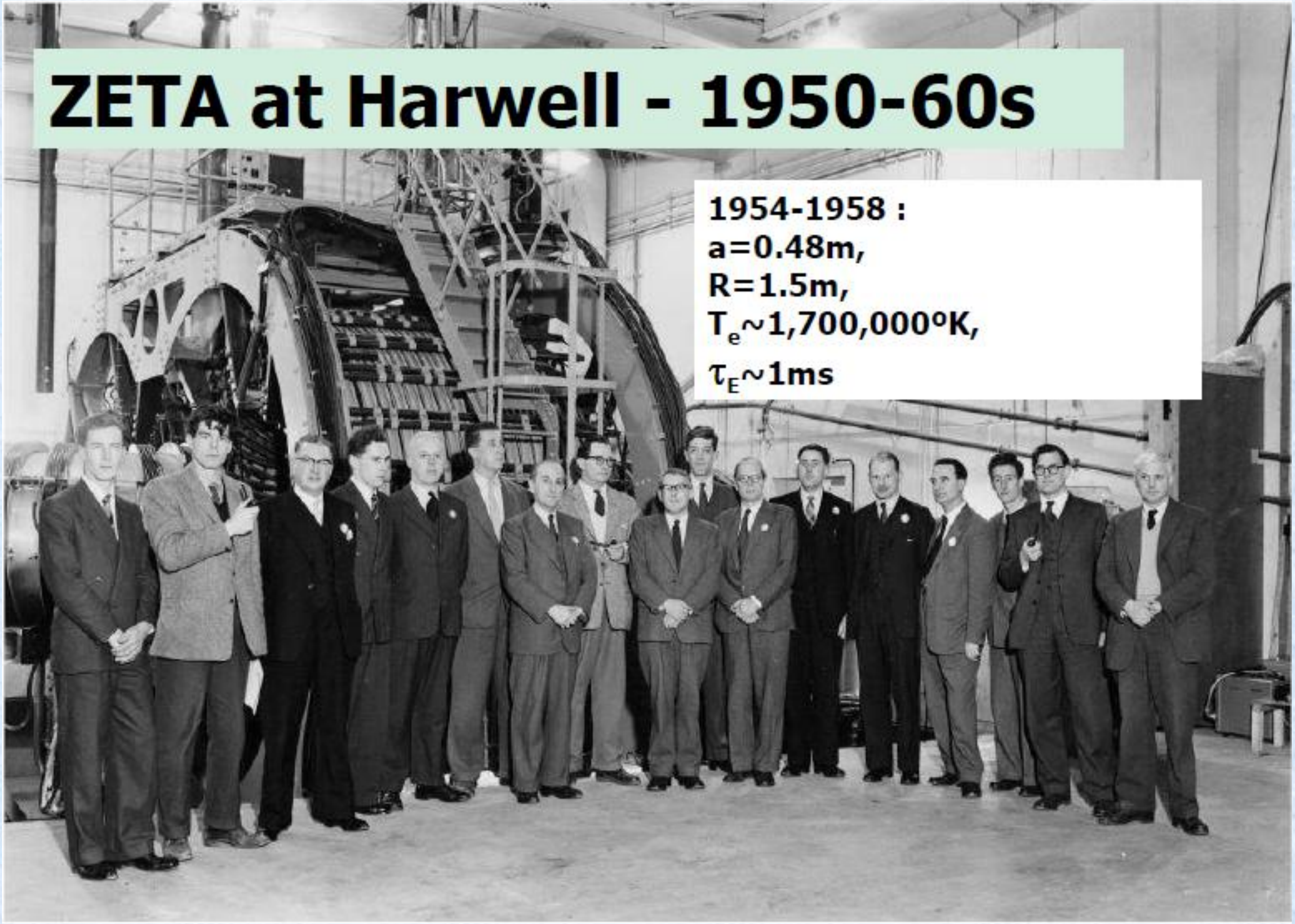
- ZETA at Harwell – 1957 in UK
  - Aluminum vacuum chamber – torus shape
  - 3 meters diameter / 1 meter bore – deuterium gas
  - Specification 100,000 A, increased to 900,000A

P.C. Thonemann, et al., “Controlled Release of Thermonuclear Energy – Production of High Temperatures and Nuclear Reactions in a Gas Discharge”, Nature, Vol. 181, pp. 217-220, January 25, 1958.

Z-PINCH TESTS WITH NEUTRONS

- Burst of neutrons at 200,000 A
  - Up to 1 million neutrons / pulse
  - Results published in Nature – Jan. 1958
  - "90% certain" neutrons thermonuclear - John Cockcroft
  - Later measurements – neutrons not thermonuclear
- Neutron source still unclear

Z-PINCH TESTS WITH NEUTRONS



PHYSICAL MECHANISMS

- Deuterium plasma pinched by applied current
- Magnetic force resisted by pressure in plasma
  - Current ↑ ➔ Magnetic Force ↑
  - Balanced by Temperature ↑ ➔ Pressure ↑
  - Density ↑ ➔ Magnetic Force / Pressure ↑, Proportionally

POSTULATED PHYSICAL MECHANISMS

- Electrons split deuterons into neutrons and protons
  - Deuteron bonding energy ~ 1-2 MeV (>10 billion K)
  - Assuming 1 MeV:
  - Dissociation of deuterons when electron energy = 1 MeV
  - Deuteron kinetic energy = electron kinetic energy

POSTULATED PHYSICAL MECHANISMS

- Deuteron velocity exceeded 10,000 km/s
  - Faster than protons at solar center, 600 km/s

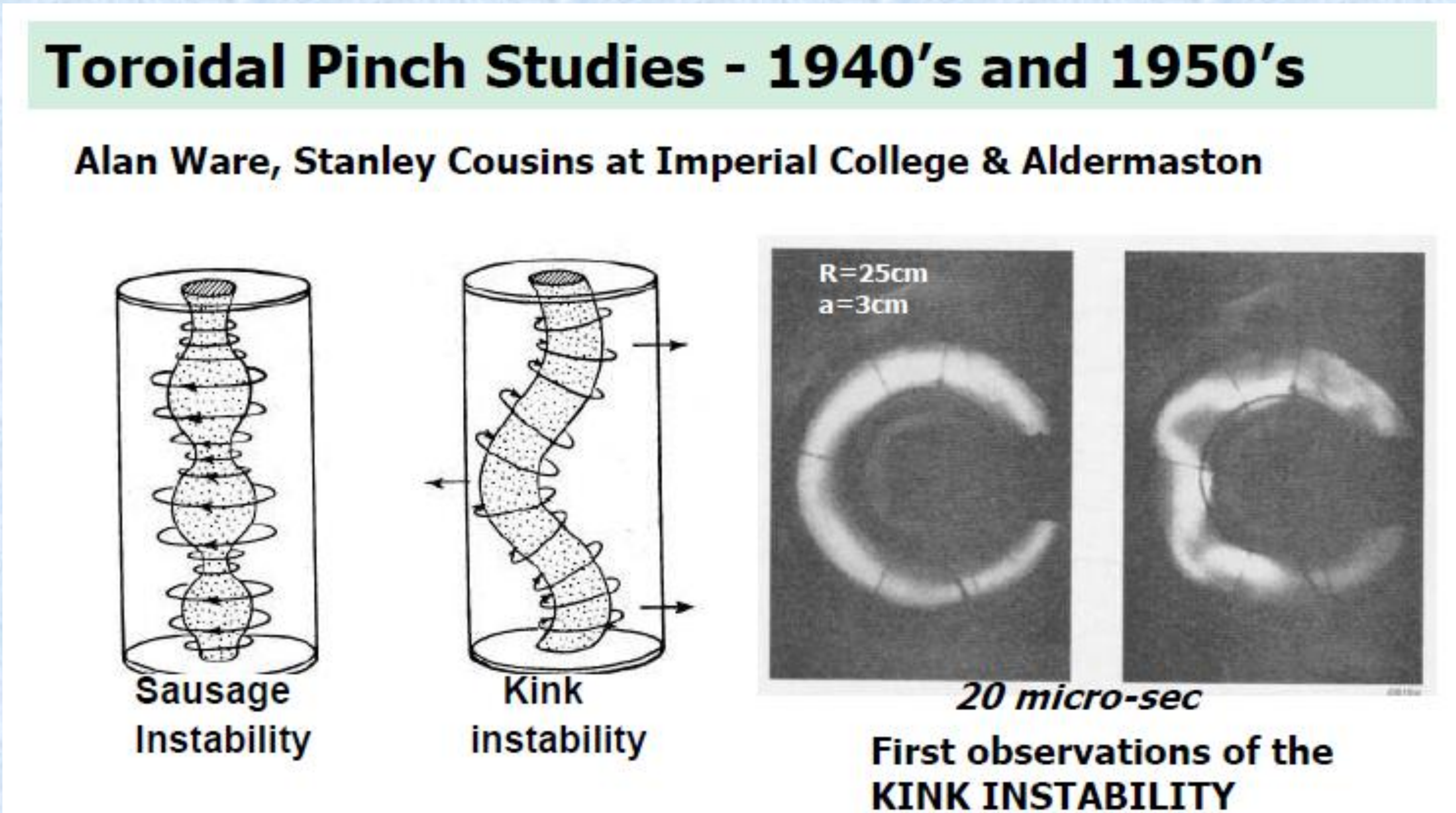
$$V_f = \sqrt{\frac{3kT_{eq}}{m_D}} = \sqrt{\frac{3 \times 1.38 \times 10^{-23} \times 10 \times 10^{9}}{3.32 \times 10^{-27}}} = 1.12 \times 10^{7} \ (m/s)$$

ENERGY OF DEUTERONS

- Z-pinch tests at Harwell, UK in 1957
  - About 1 MeV, in order of 10,000 km/s
- USSR tests, 1958, cylinders with electrodes
  - About 0.2 MeV, or 5,000 km/s
  - Smaller than UK apparatus (~ 0.5 m x 1.0 m)

A.M. Andrianov, et al, "High-current Pulse Discharges", the 2nd United Nations International Conference on the Peaceful Uses of Atomic Energy, Volume 31, pp. 348-364, September 1-13, 1958, Geneva.

Z-PINCH INSTABILITIES



TOKAMAK

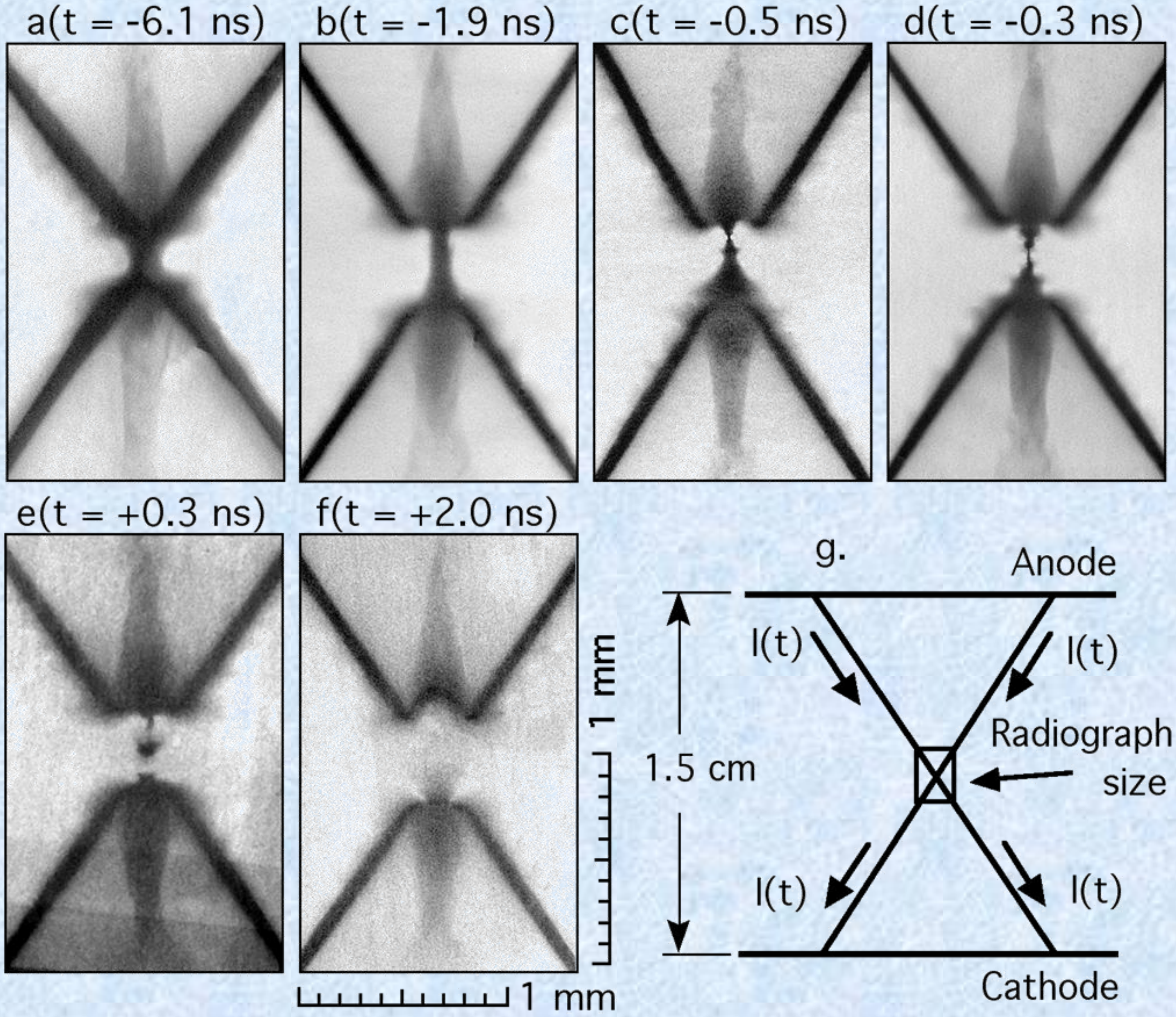
- Improving stability:
  - ZETA improved stability (added a toroidal field)
  - Apply a stronger toroidal field ➔ Tokamak
  - Pinch concept abandoned ➔ low plasma density
    - Economic reasons + technical difficulties
  - Hotter temperature + longer confinement time
- Mainstream approach world-wide

TOKAMAK - CHALLENGES

- Technical challenges:
  - Low plasma density, e.g., 1 millionth of air
  - Reduced fusion reaction rate
  - Micro-level instabilities, e.g., turbulence
  - D-T reaction requires handling of tritium

J.A. Snipes, “Plasma Operation in ITER”, Joint ITER/IAEA/ICTP Advanced Workshop on Fusion and Plasma Physics, Trieste, Italy, October 3-14, 2011.

X-PINCH AT CORNELL, 2003



Z-PINCH AS X-RAY SOURCE

- Arrange wires into an X-shape, i.e., X-pinch
  - Experiments at Cornell University
  - Micro-pinch formed at intersection of metal wires
  - Achieved a record near solid density, 10 MK

D.B. Sinars, et al., "Time-resolved spectroscopy of AL, Ti, and Mo X pinch radiation using an X-ray streak camera", Journal of Quantitative Spectroscopy & Radiative Transfer, 2003

Z-PINCH AS X-RAY SOURCE

- Similar experiments conducted at Sandia Labs, USA, utilizing parallel wires
  - Measured 1-2 MK using tungsten wires
  - Achieved 2 GK using steel wires in 2005

M.D. Haines, et al, "Ion Viscous Heating in a Magnetohydrodynamically Unstable Z Pinch at Over 2×10^9 Kelvin", Physical Review Letters – 24 February 2006, Volume 96, Issue 7

POWERFUL LASER BEAMS

- Livermore Lab, USA, 2011:
  - Applied 192 laser beams
  - D-T plasma peaked at record density, i.e., 600 g/cc
  - Neutron emissions = 10^{15}

S.H. Glenzer, "Cryogenic thermonuclear fuel implosions on the National Ignition Facility", Physics of Plasma, Vol. 19, Issue 5, 2012.

SUMMARY OF ACHIEVEMENTS

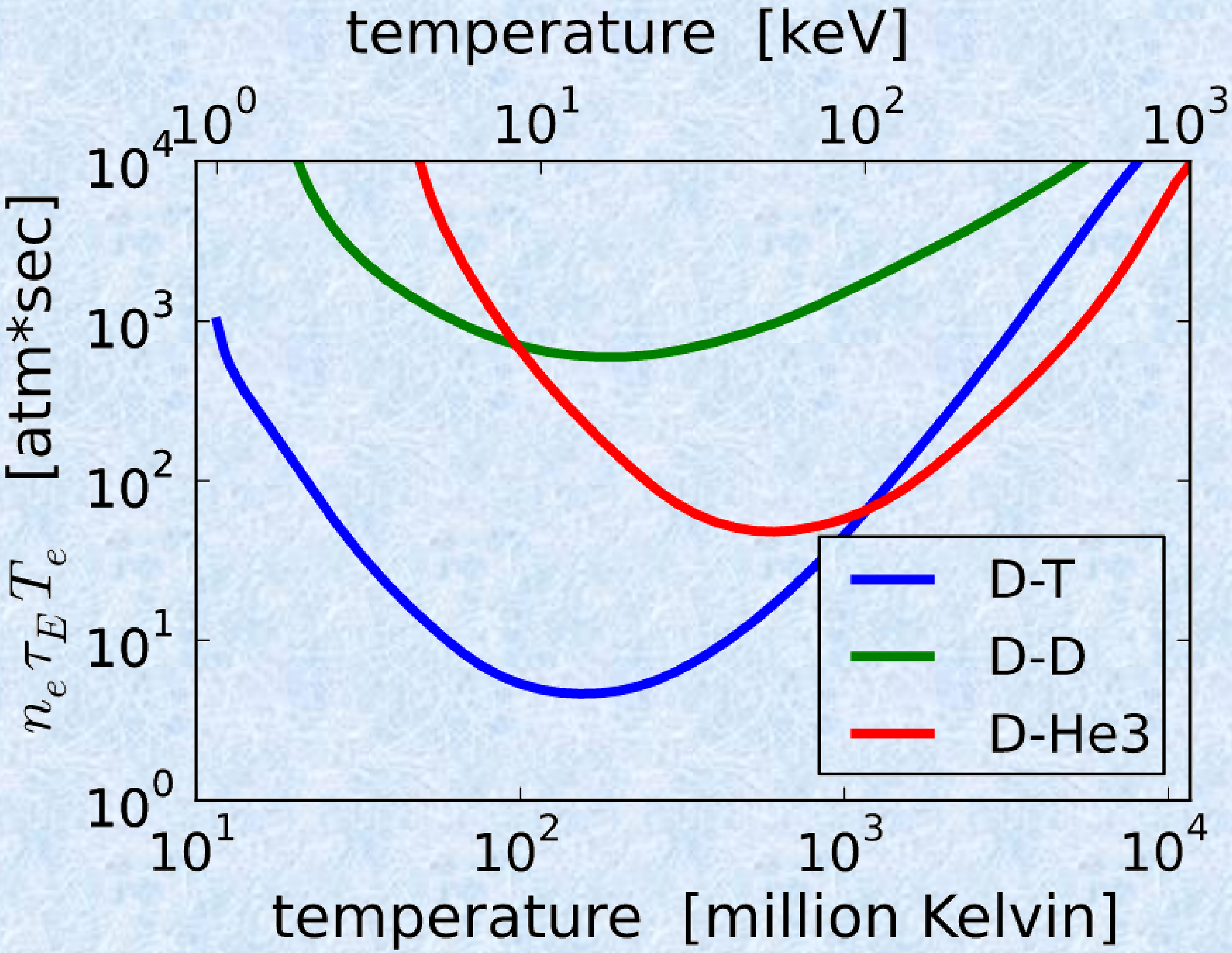
- Z-Pinch Approaches:
  - Deuteron velocity : 5,000-10,000 km/s - USSR/UK
  - Plasma temperature > 2 GK - Sandia Labs, USA
- Joint European Torus – Tokamak in UK
  - Confinement time > 0.5 second
- Powerful Laser Beams – Livermore, USA
  - D-T plasma density peaked at 600 g/cc

TECHNICAL CHALLENGE

- Lawson criterion:
  - ρ x *T* x Δ*t* > minimum requirement
- Confinement time: *Δt* is not sufficient
  - Tokamak – micro-level turbulence
  - Laser beams – Rayleigh–Taylor instability
  - Z-pinches – sausage / kink instabilities

J. D. Lawson, "Some Criteria for a Power Producing Thermonuclear Reactor", Proceedings of the Physical Society B, Volume 70 (1957), p. 6

LAWSON CRITERION

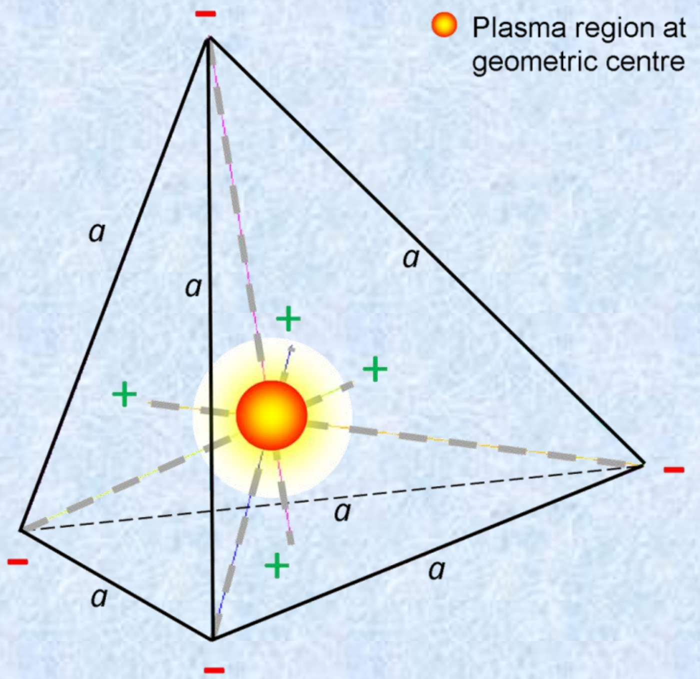


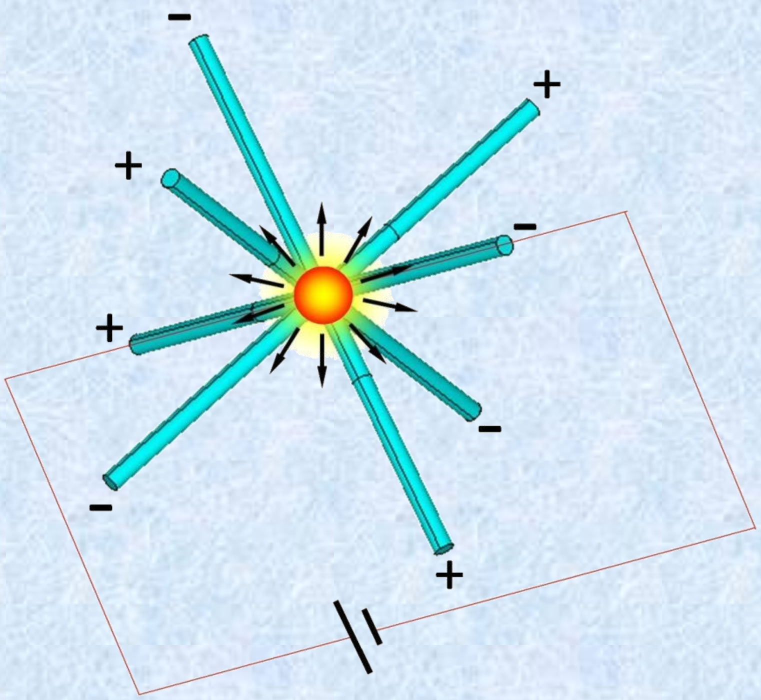
SOLUTION – HOPE INNOVATIONS

- A four beam configuration:
  - Each beam pinched by current
  - Pass through a single region, i.e., focusing effects
  - Symmetrical in three dimensional space:
    - Geometry + electro-magnetic fields

X.J. Zheng, “Continuous Fusion due to Energy Concentration Through Focusing of Converging Particle Beams”, New United States Provisional Patent Application No. 61/495,481, Filing Date, June 10, 2011

A FOUR BEAM CONFIGURATION





X.J. Zheng, "Continuous Fusion in Common Focal Region of Converging Fuel Lightning Bolts"， 受控核聚变反应系统，Chinese Patent Office, 中国国家知识产权局，Application # 201210211552.8, June 21, 2012

STABILITY ASSURED BY MINIMIZATION OF MAGNETIC POTENTIAL ENERGY

- Stable collapse of plasma ball to ignite and sustain fusion
  - If plasma region is higher in one direction, radial magnetic force brings it down
  - Magnetic force does work to minimize its potential energy
  - Stability achieved + round shape maintained
- Analogous to gravitational potential energy:
  - Minimization principle ensures stable collapse:
    - Hydrogen clouds ➔ stars ➔ black holes
    - Spherical shape maintained
  - If one surface region is higher, gravity brings it down
    - Gravity does work to minimize its potential energy

STABILITY ISSUES ADDRESSED

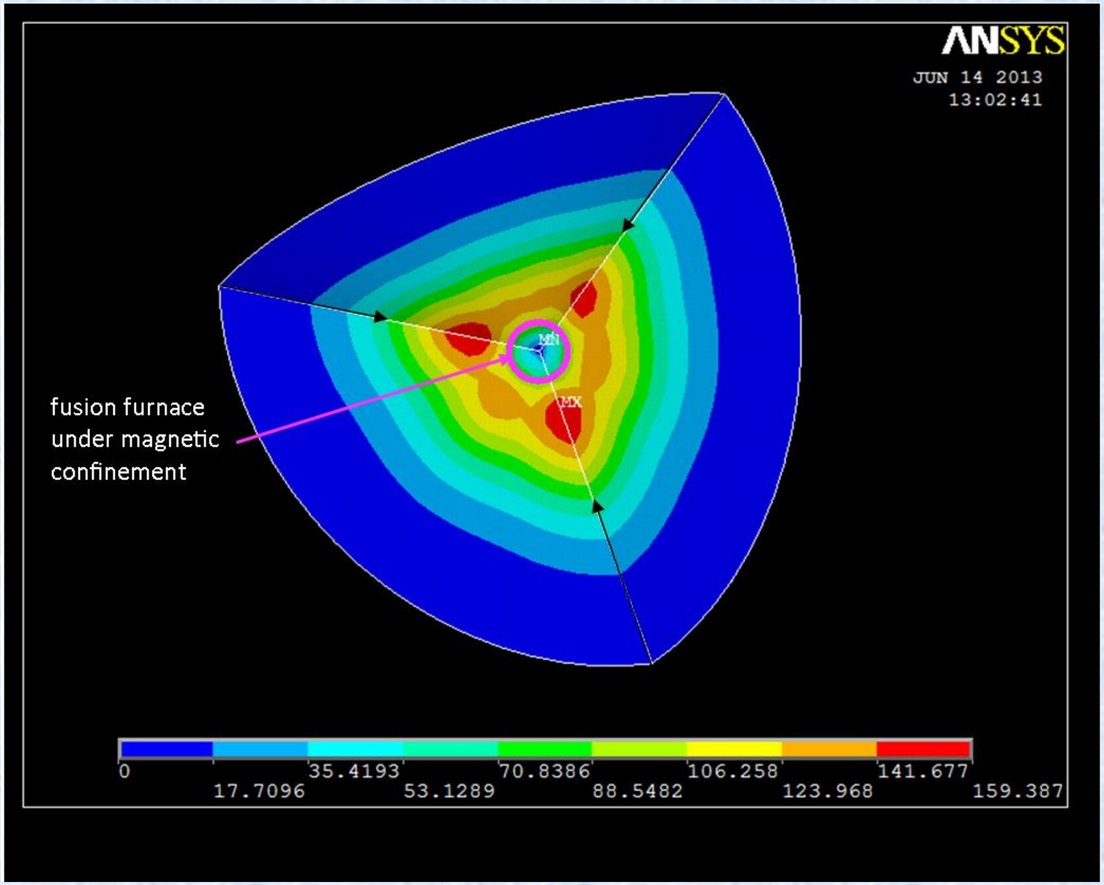
- Sausage + kink instabilities
  - Incompatible with spherical geometry
- Rayleigh-Taylor instability
  - Control / extend period of pulses in, e.g., A/C currents
  - Minimize particle acceleration into plasma sphere
- X-pinch: micro-pinch instability
  - Region of intersection collapsed first
    - Dynamic effects of plasma flow with currents
    - <u>Individual beams: stability maintained</u>
  - <u>Avoid micro-pinch: sum of our four currents = zero</u>

FUSION POWER – FOUR BEAMS

- Region of intersection:
  - Consider a sphere of radius: 1.23 μm
  - Plasma density = 4 x 2.337 = 9.35 g/cc
- Gross power: 215 GW – deuterium plasma
  - Input power = 4 x 150 MW = 600 MW

X.J. Zheng and B.Q. Deng, “Nuclear Fusion Within Dense Plasma Enhanced by Quantum Particle Waves”, Report # HOPE-RP-002, July 28, 2013 (Abstract Accepted for Technical Presentation at ICONE21, July 29-August 2, 2013).

FUSION POWER – WORKING PRINCIPLE



X.J. Zheng and B.Q. Deng, “Fusion Power Based on a Symmetrical Plasma Beam Configuration”, June 28, 2013. To be submitted for publication in Nature.

APPROACHING SOLAR CONDITIONS

- Plasma beams pinched by currents:
  - One beam (**Z-pinch**), 1-2 MK, air density
  - Two beam (**X-pinch**), 10 MK, near solid density
  - Four beam (**Star-pinch**), <u>solar conditions</u>
- Conditions at solar center:
  - Temperature at <u>15.7 MK</u>, exceeded by Sandia Labs
  - Density at <u>150 g/cc</u>, exceeded by Livermore Lab

CONTINUOUS OPERATION

- Confinement time must exceed pulse time
- Confinement time:
  - Target: $\Delta t > 10$ ms, exceeded by Tokamak through improvement in stability
  - Star-pinch stability expected to be better than Tokamak
- Pulse time:
  - Example, A/C currents with 60 Hz, each pulse in 8 ms
  - Practically, 10 ms ensures years of continuous operation

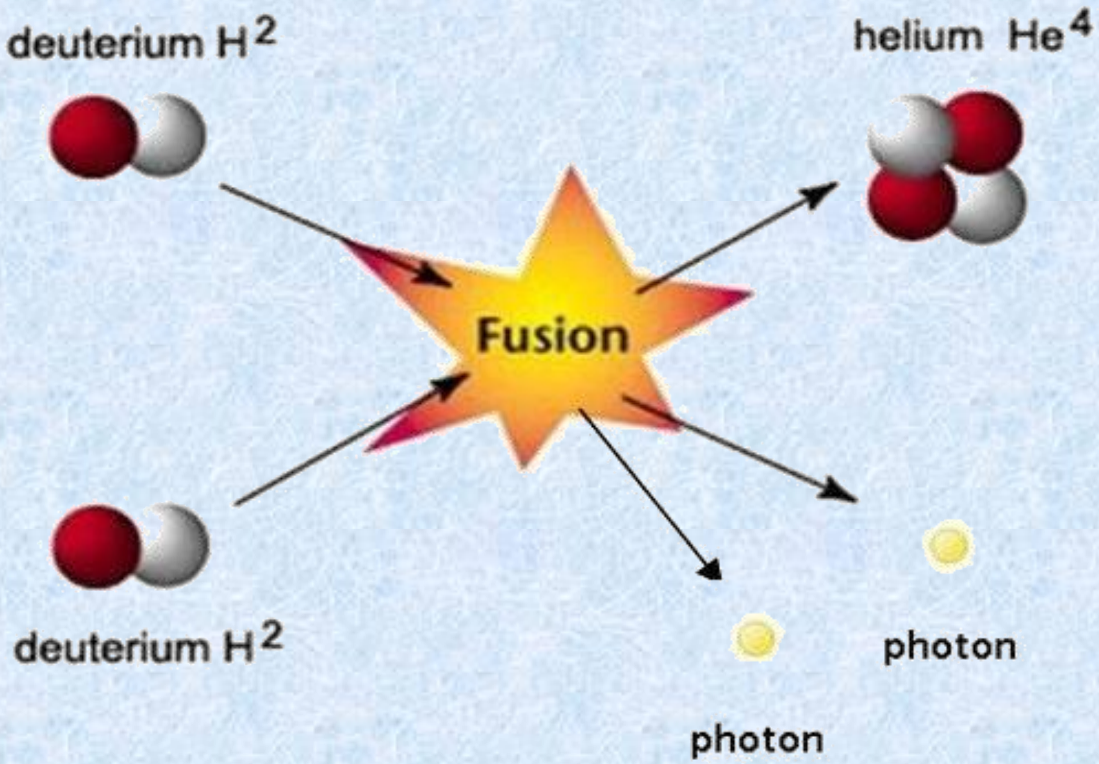
WHY THIS WILL WORK?

- Achieve necessary density and temperature at intersection
  - Solar conditions (already achieved by other researchers)
- Confinement by converging magnetic forces will provide stability
  - >10ms, already achieved by Tokamak
  - Similar to gravitational forces in stars
- Duplicates natural phenomena:
  - Lightning beams to transport fuel
  - Solar core furnace – spherical in shape

FUSION AS IN SOLAR CENTER

- Water as fuel, regular / heavy water mixture
- Dilute deuterium concentration:
  - Reduce fusion power output
  - Promote hydrogen-deuterium reactions, as in the Sun
- Achieve 100% green solar solution:
  - 2p + 2D ➔ 2He-3
  - He-3 + He-3 ➔ He-4 + 2p + 2γ

CLEAN FUSION ENERGY



SUMMARY

- Electron / nucleus interactions
  - Shifted connection center at Stern Labs
  - Hit / split deuterons at Harwell, neutrons released
- Z-pinch tests at Harwell - 1957
  - 1.7 MK, 2 x water, 10^4 km/s, 1 μm radius
- World-wide achievements:
  - 600 g/cc, 2 GK, 10^4 km/s, 0.5 sec

SUMMARY

- Star-pinch, 4 beams, symmetrical in 3D space :
  - Magnetic forces ensure stability
    - No: kink / sausage instabilities – Z-pinch
    - No: Rayleigh – Taylor instability – Laser beams
    - No: micro-pinch instability – X-pinch
  - Approaches conditions at solar center
    - Fusion power as in solar center, 100% green

HOPE DEVELOPMENT PLAN

- Simulations/modelling to define experimental parameters
- Metal/carbon filament/wire experiments (3Y):
  - To demonstrate stability
  - Metal hydride wires to demonstrate fusion
- Fluids as plasma media (5Y)
  - Argon / air to demonstrate connection
  - Deuterium / water to demonstrate fusion
  - Experimental pilot for fusion with positive energy gain

HOPE INNOVATIONS