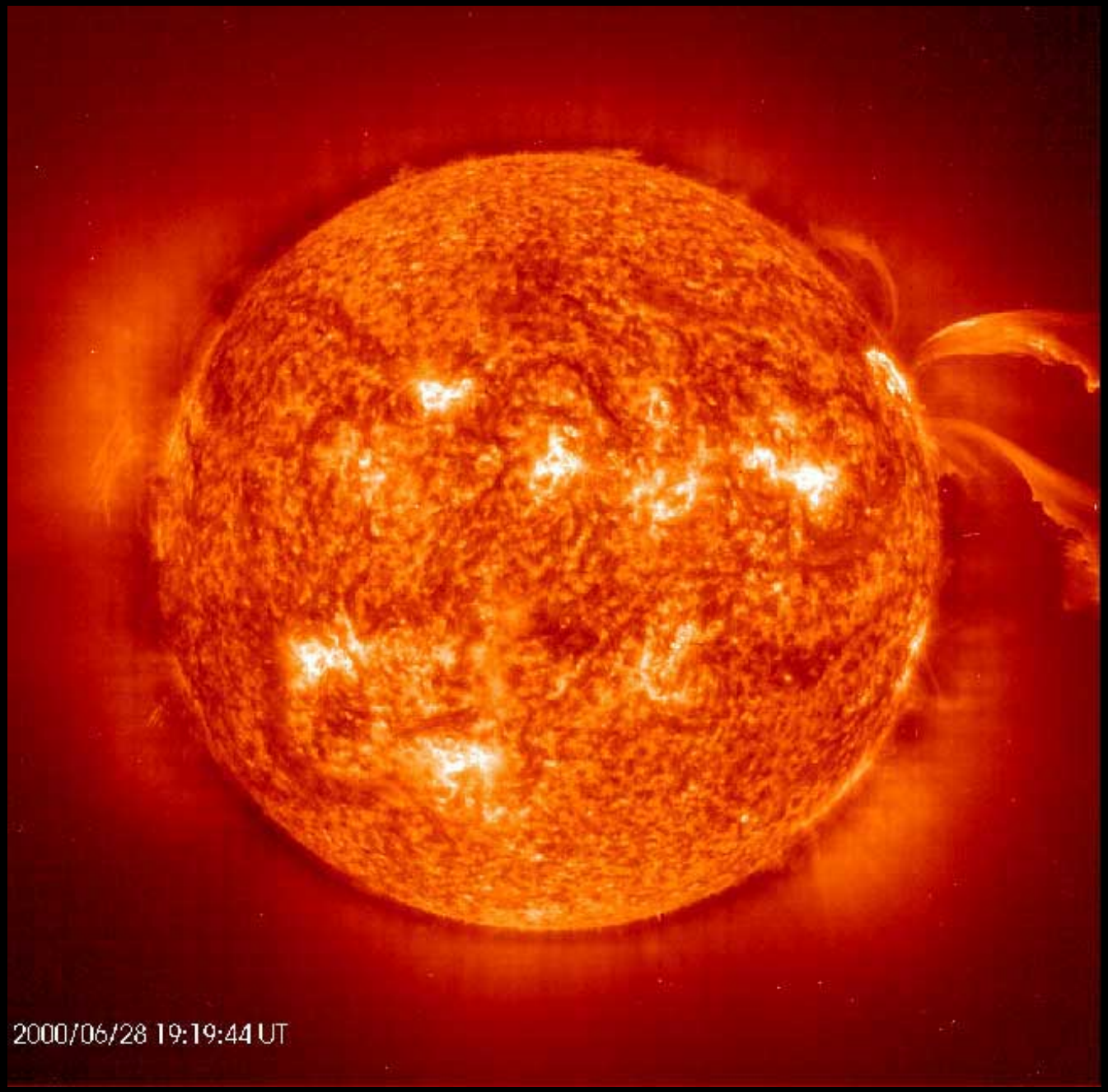


Paul Sedita

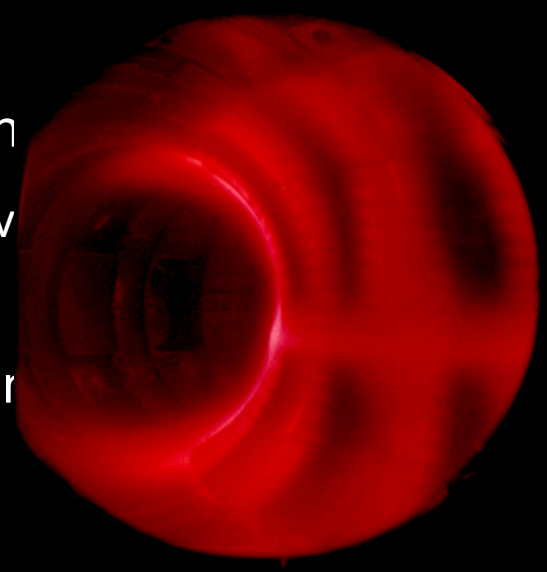
DOE-ACTS 2009

Princeton Plasma
Physics Lab

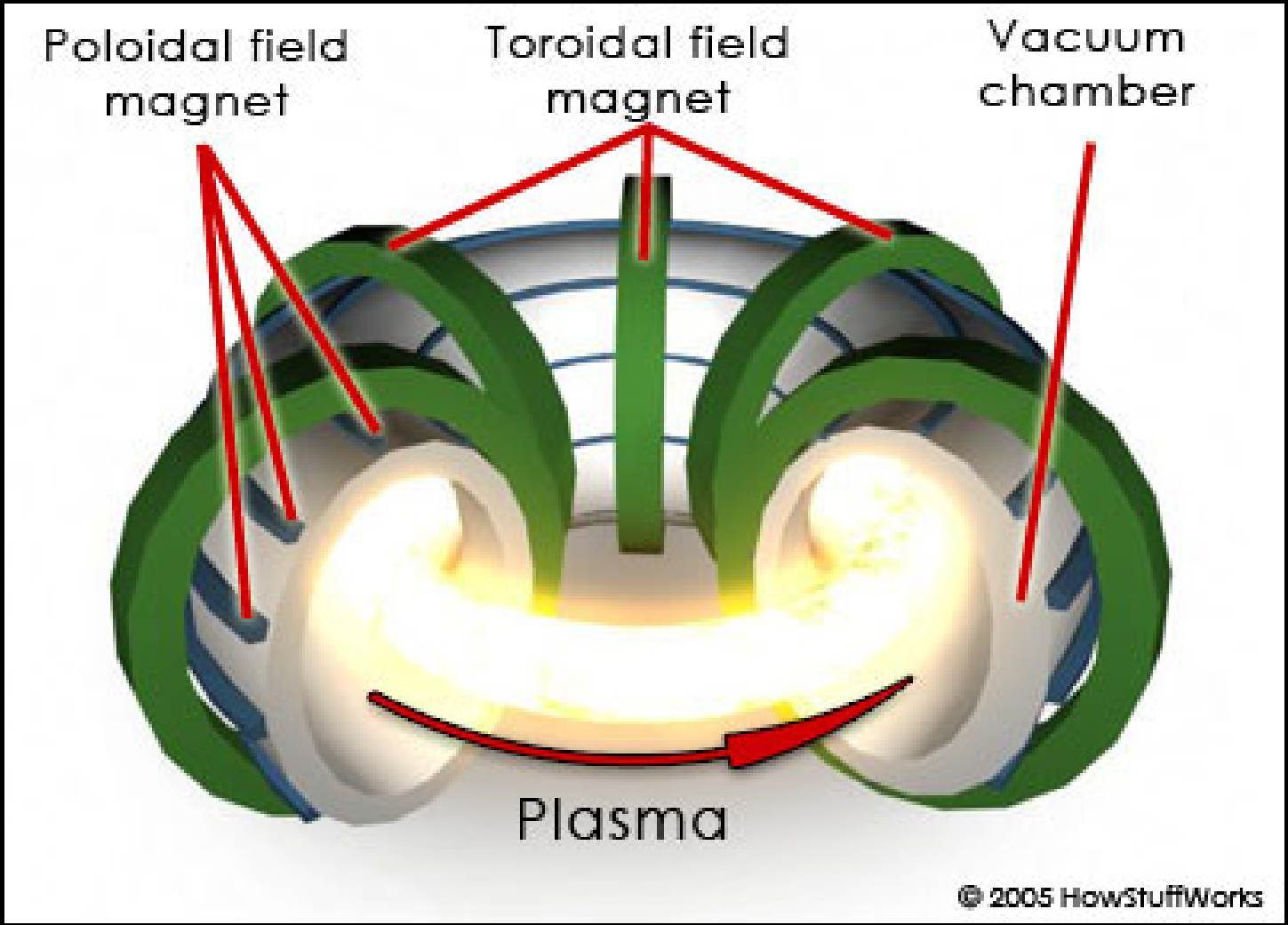
Creating Power Using FUSION On EARTH

FUSION REACTORS

- Most common fuel is combo of Deuterium (^2H) & Tritium (^3H)
- Must be energized to ~ 100 million K in order to overcome Coulomb repulsion
- High temperatures create a quasi-neutral PLASMA (electrons + D-T ions)
- Plasma must be confin netic fields (~ 5 T)
  - ➔ otherwise would sev s
- Most successful desig it shaped vessel)



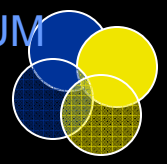
TOKAMAK DESIGN



D-T FUSION REACTION

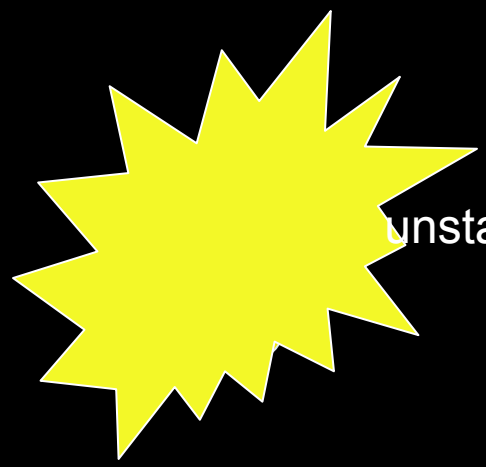
DEUTERIUM

DEUTERIUM



TRITIUM

TRITIUM



unstable ^{5}He nucleus

^{4}He nucleus

NEUTRON

+ 17.6 MeV of

EXTRA ENERGY

D-T FUSION REACTION

^{2}H		^{3}H		^{4}He		^{1}n		17.6 MeV
Deuterium	+	Tritium	→	Helium	+	neutron	+	KE

- Where does this extra energy come from?
  - ➔ Mass was converted into (kinetic) energy !!

$$E = \Delta m c^2$$

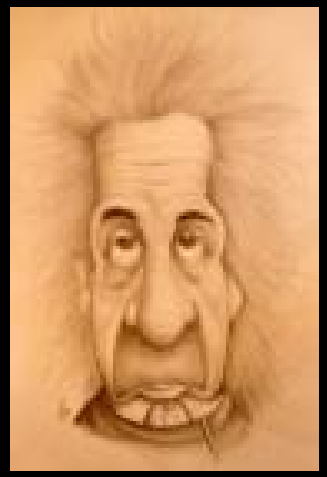
c → SPEED OF LIGHT (huge)

Δm → MASS DEFECT (tiny)

Calculating energy from D-T fusion

- All masses measured in AMU's (u)
  - ➔ 1 u = 1/12 mass of carbon-12 nucleus = 1.6605 E -27 kg
- Energy equivalent of 1 u of mass
  - ➔ $E = \Delta mc^2$ = 1.6605 E -27 kg $(3\ E\ 8\ m/s)^2$

    = 1.4944 E -10 J



- Convert to electronvolts (eV)
  - ➔ 1 eV = 1.6 E -19 J
  - ➔ E = 1.4944 E -10 J / (1.6 E -19 J/eV) = 9.31 E 8 eV

Δm of 1 u = 931 MeV of energy

Calculating energy from D-T fusion

$$D + T \rightarrow {}^{4}He + {}^{1}n + KE$$

Determine mass defect (Δm): mass reactants – mass products

nucleus	mass (u)
D	2.0141
T	3.0160
He	4.0026
n	1.0086

$\Delta m = (2.0141 + 3.0160)u – (4.0026 + 1.0086)u$

$= 5.0311\ u – 5.0112\ u$

$\Delta m = .0189\ u$

RECALL

1 u (of mass) = 931 MeV (of KE)

Calculating energy from D-T fusion

$$D + T \rightarrow {}^{4}He + {}^{1}n + KE$$

Determine mass defect (Δm): mass reactants – mass products

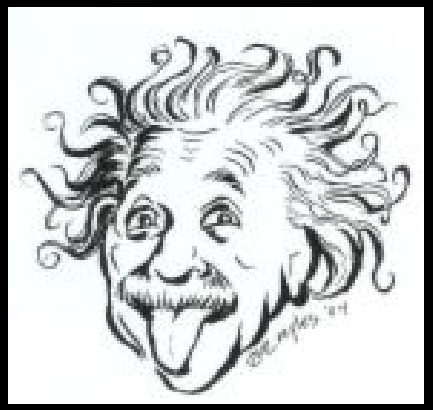
nucleus	mass (u)
D	2.0141
T	3.0160
He	4.0026
n	1.0086

$\Delta m = (2.0141 + 3.0160)u – (4.0026 + 1.0086)u$

$= 5.0311\ u – 5.0112\ u$

$\Delta m = .0189\ u$

KE = .0189 u (931 MeV/u) = 17.6 MeV



Predicted Power from D-T fusion

- According to Charlie @ PPPL …

… D-T is "burned" @ a rate of ~ 15 curie/second

➔ 1 curie = 1/9700 gram… so burn rate ~ 1.5 E -3 g/s

➔ recall … 17.6 MeV of energy per D-T reax

- Using dimensional analysis, let's derive POWER OUTPUT

$$P\ (J/s) \sim \frac{1.5\ E\ -3\ g}{s} \quad \frac{1\ mol}{2.5\ g} \quad \frac{6\ E\ 23\ D\text{-}T}{mol} \quad \frac{17.6\ MeV}{D\text{-}T} \quad \frac{1.6\ E\ -13\ J}{MeV}$$

Predicted Power from D-T fusion

$$P\ (J/s) \sim \frac{1.5\ E\ -3\ g}{s} \quad \frac{1\ mol}{2.5\ g} \quad \frac{6\ E\ 23\ D\text{-}T}{mol} \quad \frac{17.6\ MeV}{D\text{-}T} \quad \frac{1.6\ E\ -13\ J}{MeV}$$

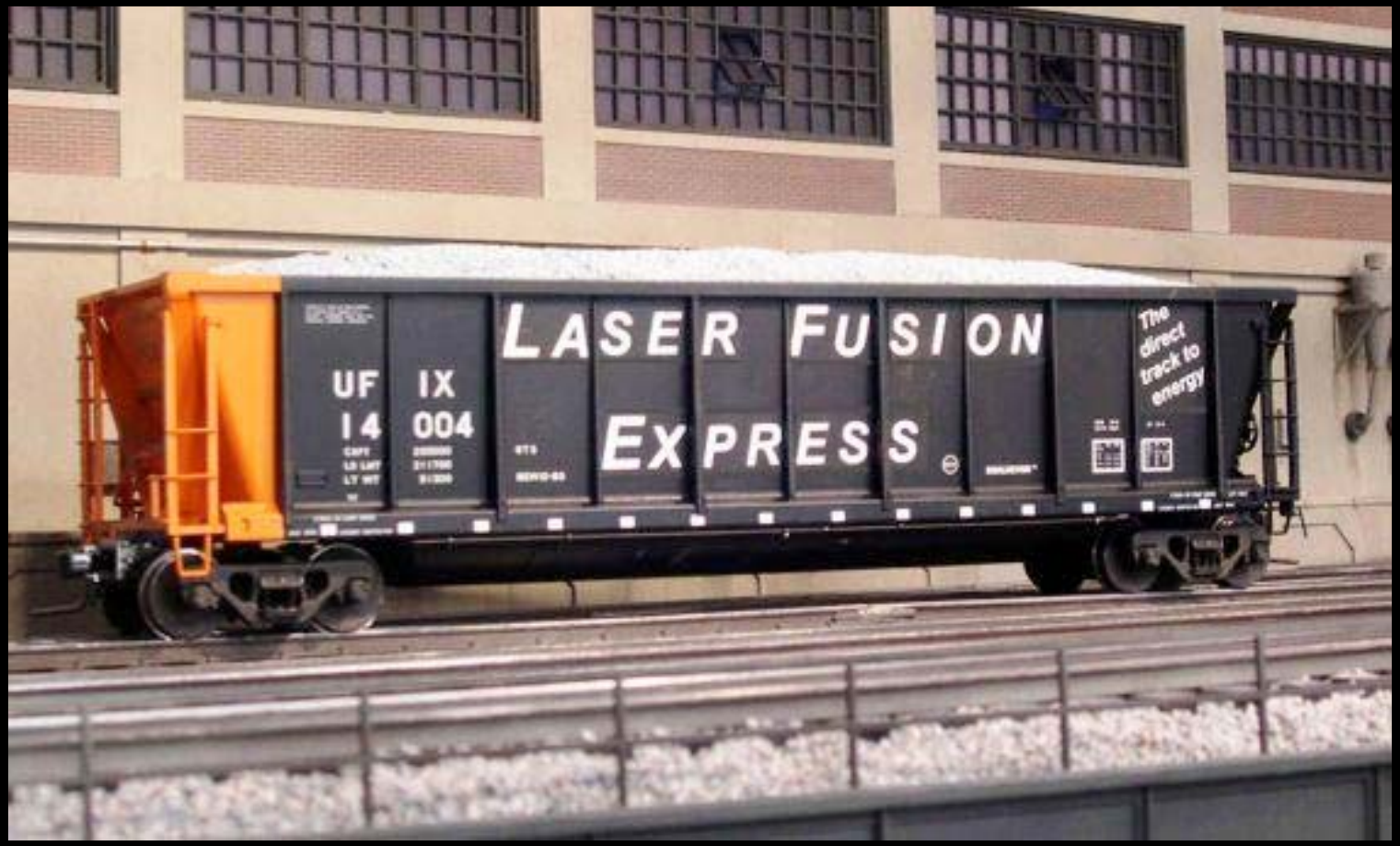
Fusion Power ~ 1 GW

↳ @ ~ 40% efficiency ➔ 400 MW of electricity

This is @ a "burn" rate of .0015 g/s

For coal it would be ~ 40,000 g/s

Put another way …



Filled w/ COAL this hopper would run a 1 GW plant for 10 min.

Filled w/ D-T targets hopper would run a 1 GW plant for 7 years