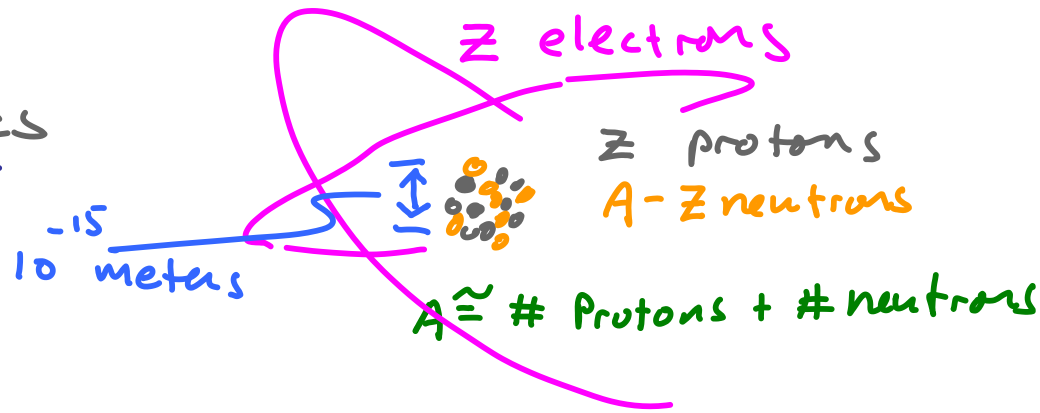
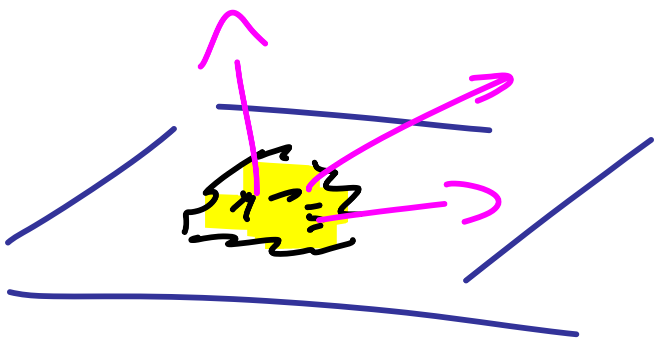
Physics 102 - March 21, 2011

nuclear physics





Some types of nuclei are naturally unstable "radioactive"

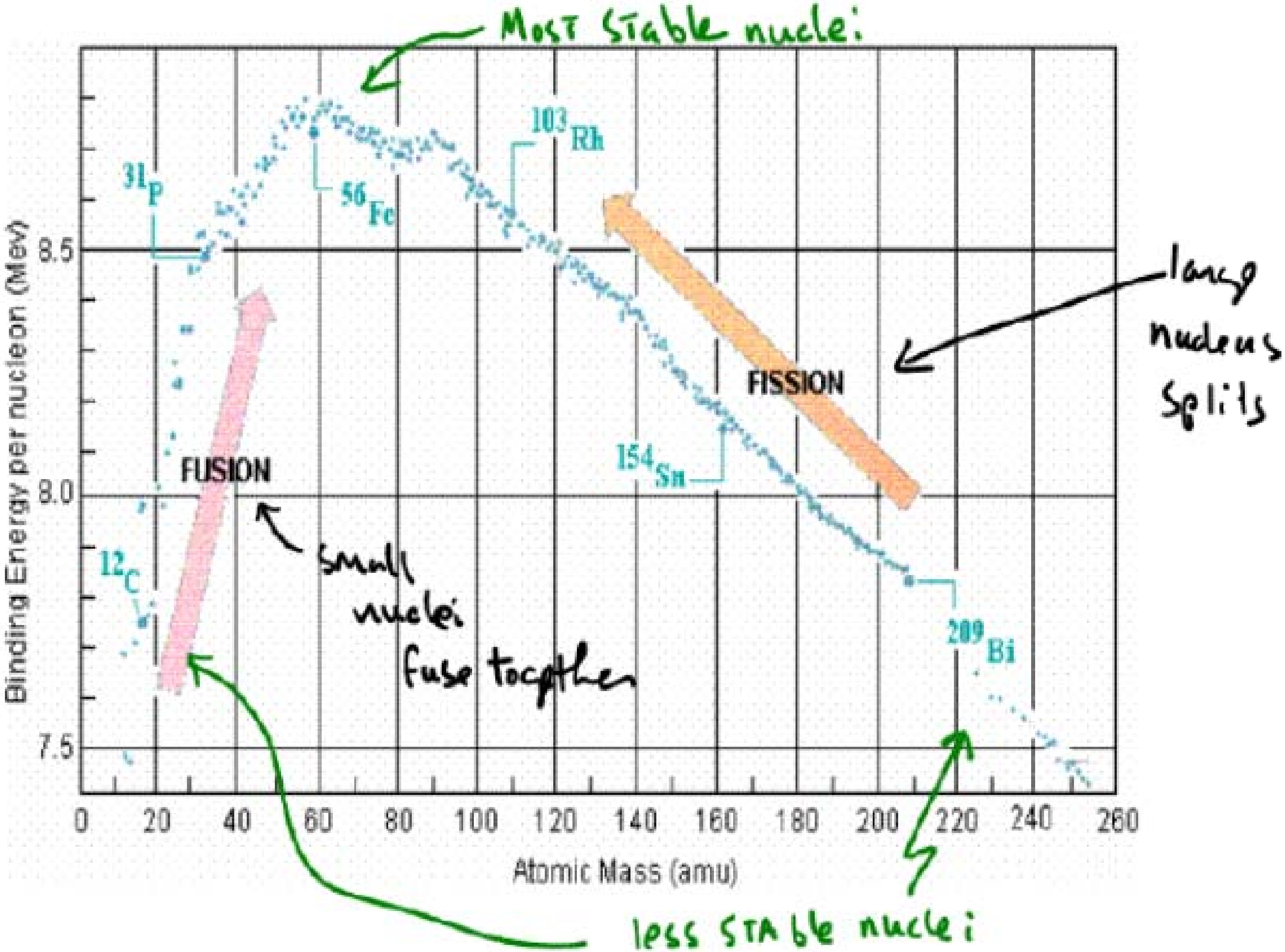
might emit:

- γ ≡ photon (Gamma)
- α ≡ 2p + 2n
- $\beta^{+/-}$ ≡ electron

characteristic ← what emitted, energy emitted, half life

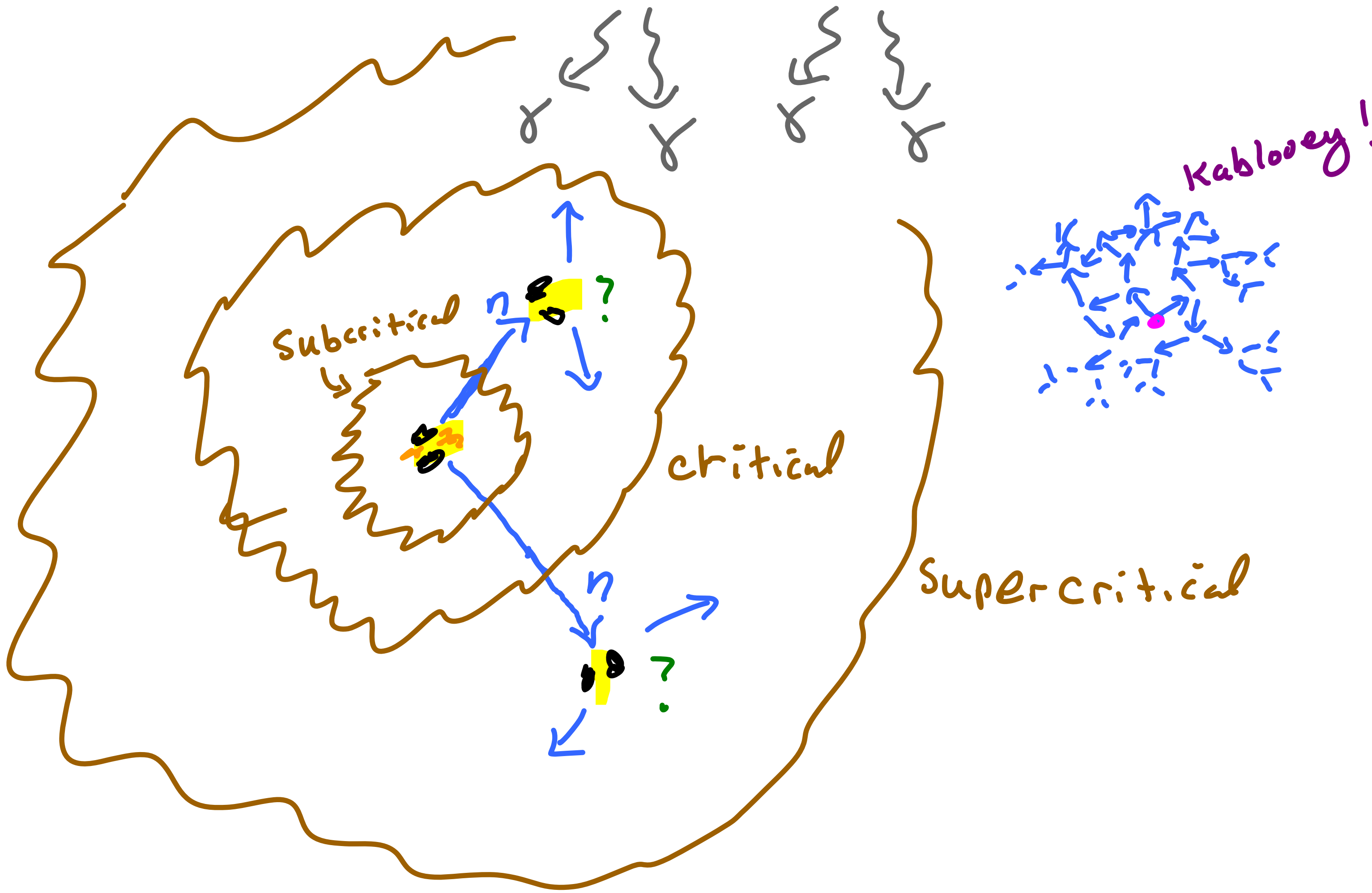
The secret of nuclear power ...

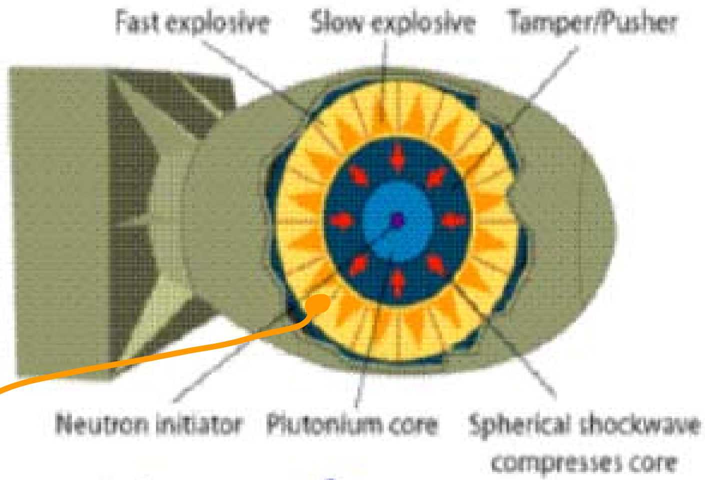
measure of how difficult it is to remove a nucleon (p or n) from the nucleus



a particularly useful nuclear reaction

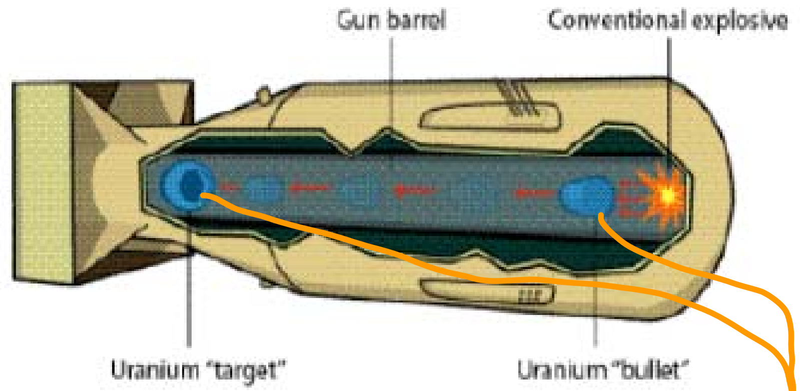
$$ {}^{235}_{92}U + n \longrightarrow {}^{93}_{37}Rb + {}^{141}_{58}Cs + 2n $$





Similar to Fat Man
used on Nagasaki
Aug. 9, 1945

Similar to "little Boy"
used on Hiroshima
August 6, 1945

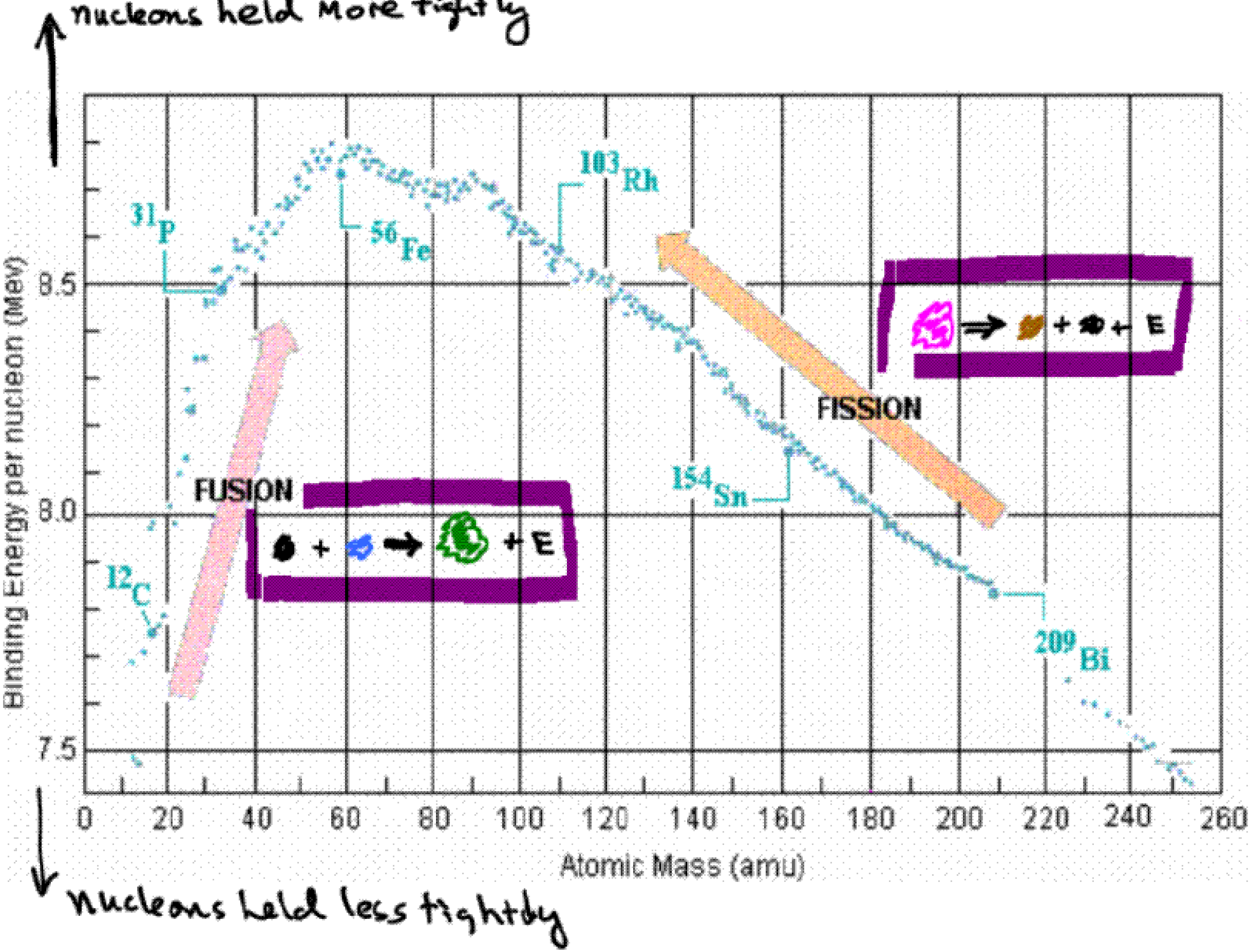


Diagrams from Wikipedia

Plutonium → Timing

uranium → enrichment

Inherent Nuclear stability as function of nuclear size



The life cycle of Stars

Gas in the interstellar medium

1 atom per ~ 20 cubic centimeters

89% H

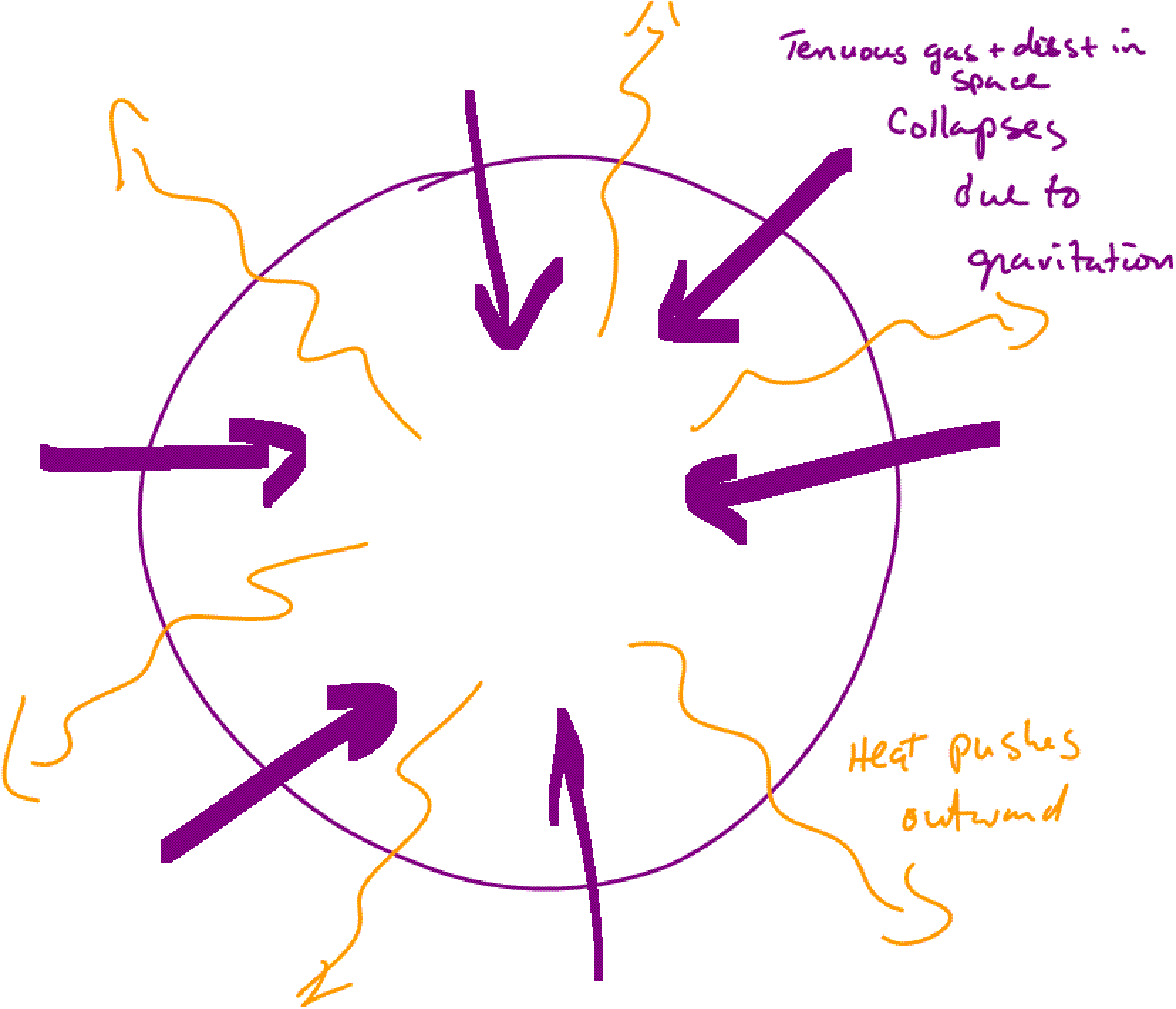
9% He

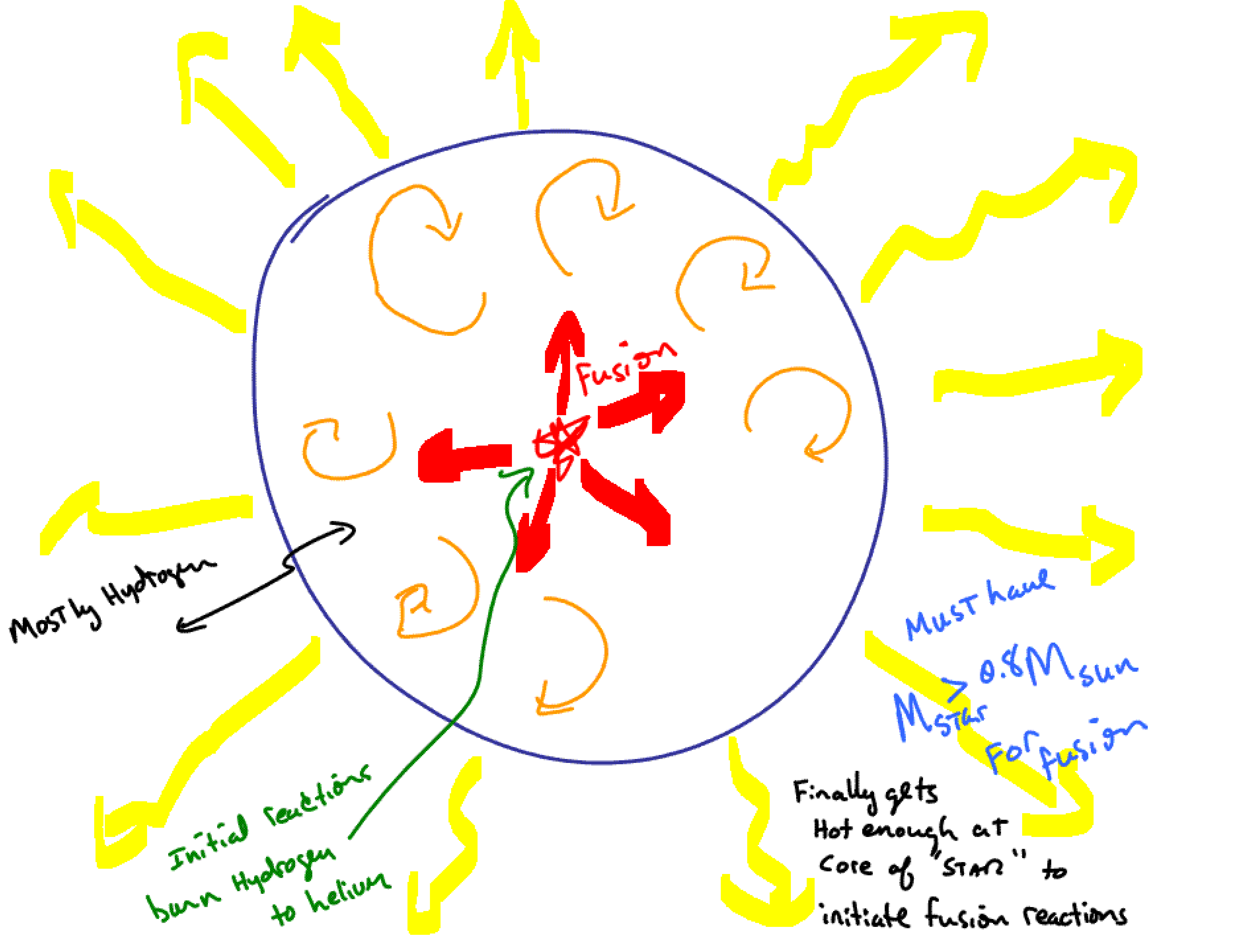
2% elements w/ $Z > 2$

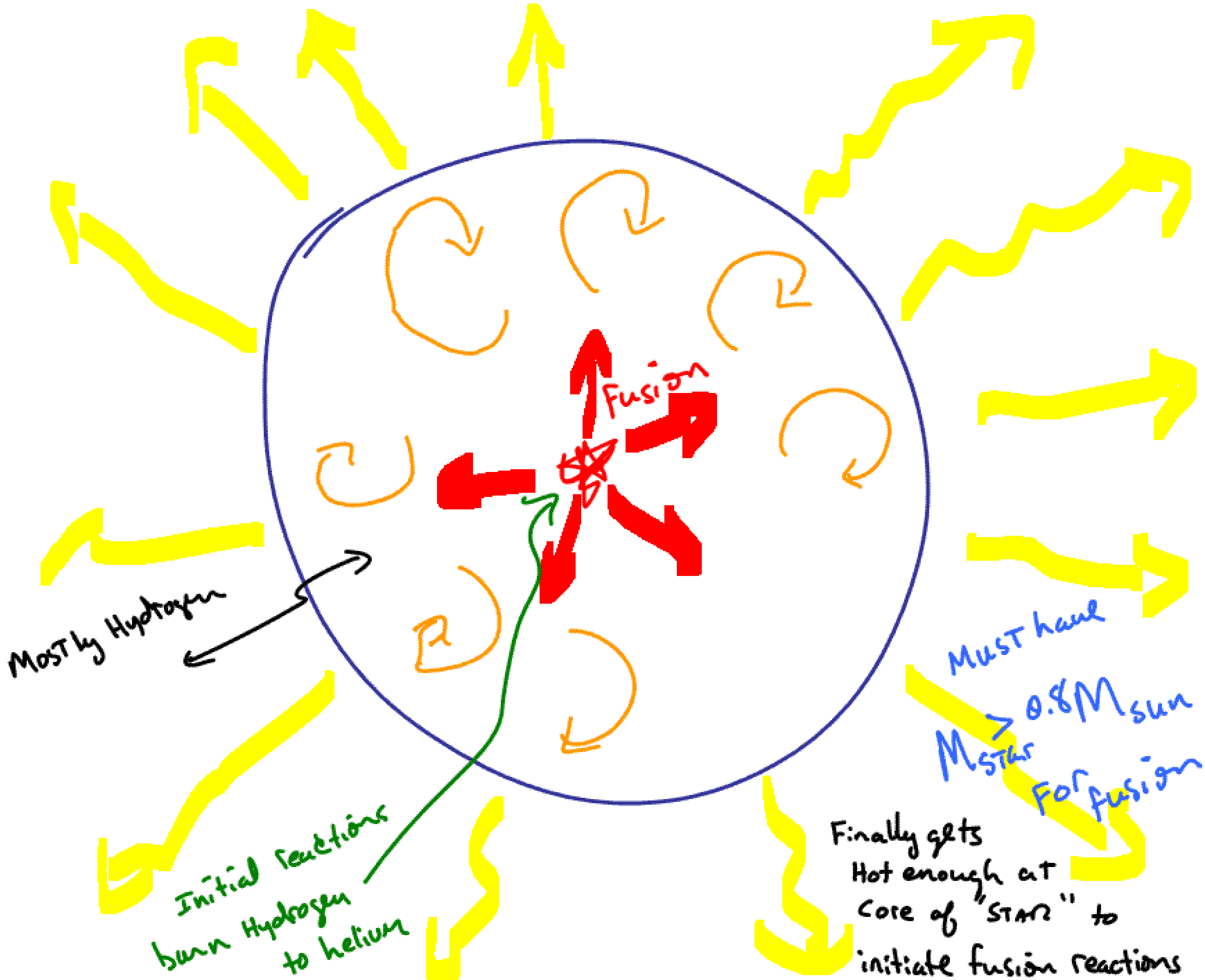
Light elements mostly Big Bang nucleosynthesis with contribution from fusion in stars

Heavy-ish elements from stellar fusion + Novas + supernovae

Much more on this later


Tenuous gas + dust in space
Collapses due to gravitation
Heat pushes outward


Fusion
Mostly Hydrogen
Must have
$M_{star} > 0.8 M_{sun}$
For fusion
Initial reactions
burn Hydrogen
to helium
Finally gets
Hot enough at
Core of "STAR" to
initiate fusion reactions


Fusion
Mostly Hydrogen
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Hot enough at
Core of "STAR" to
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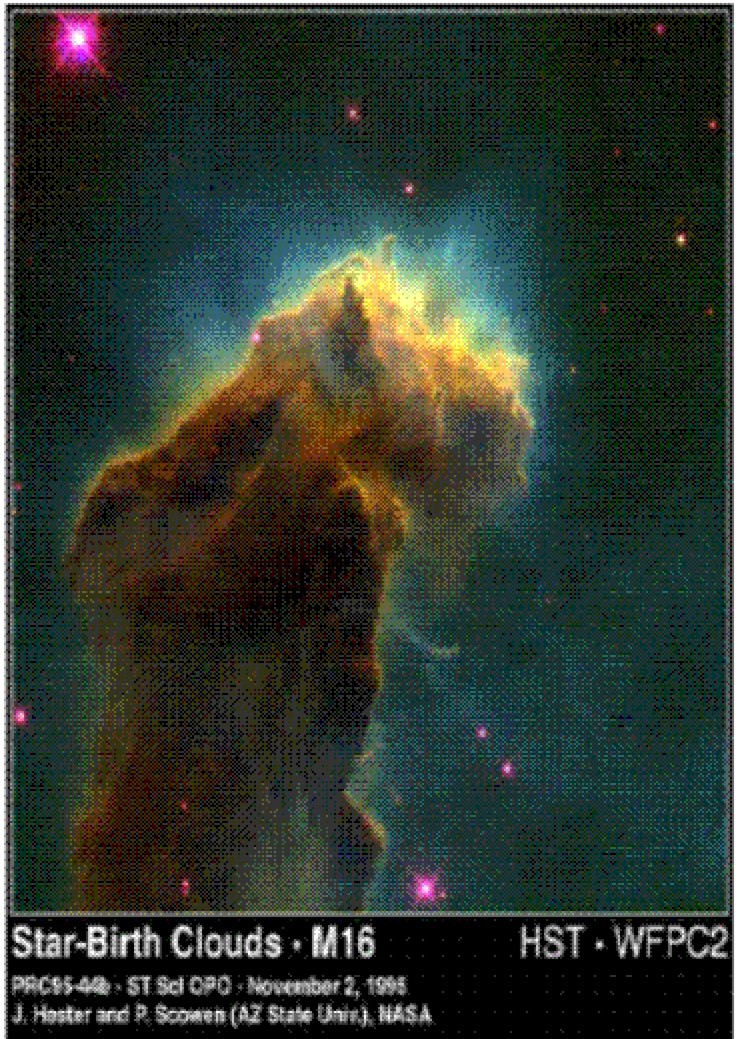
Stars - from dust to dust

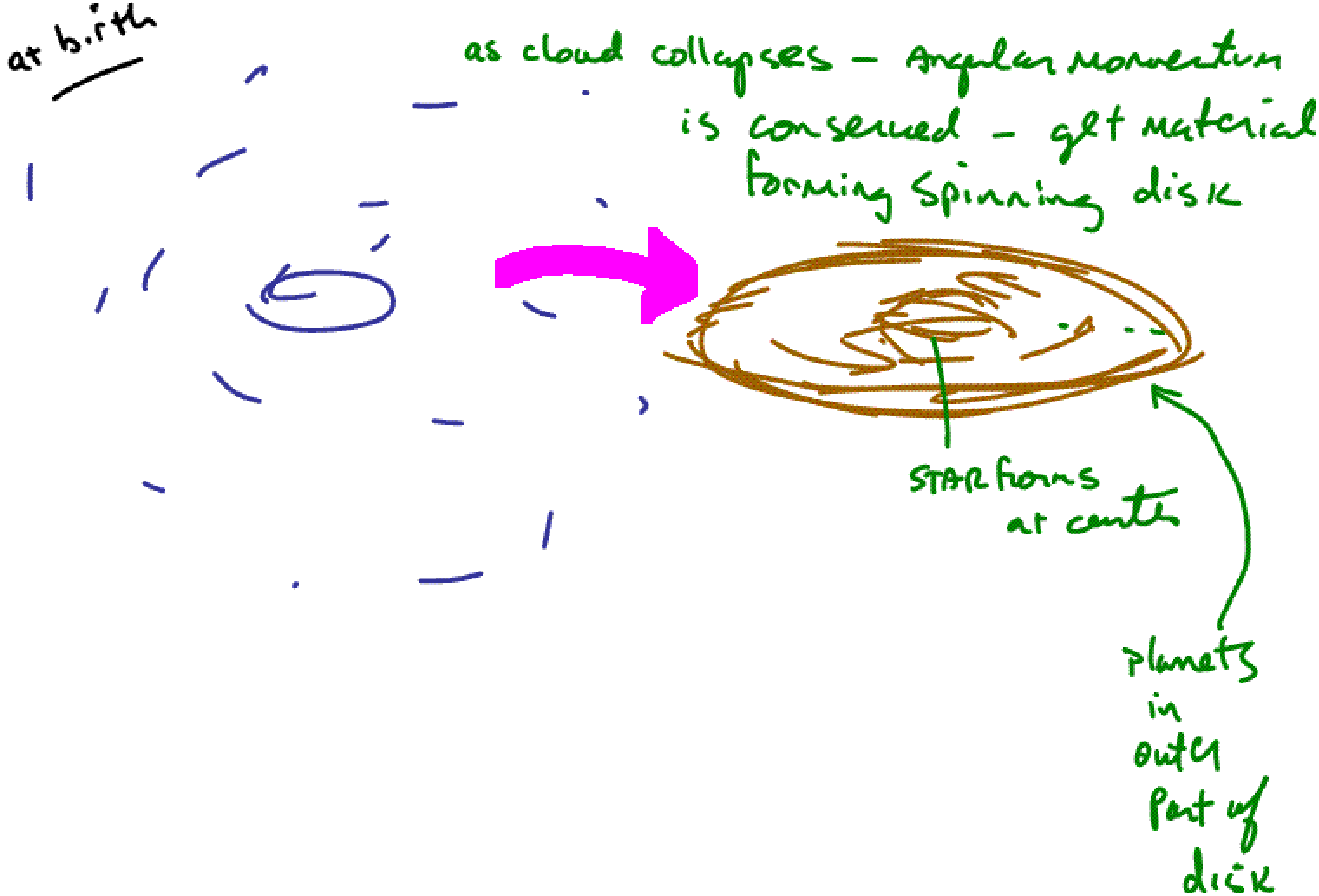
Stars form from
condensation of gas/dust
due to gravitation

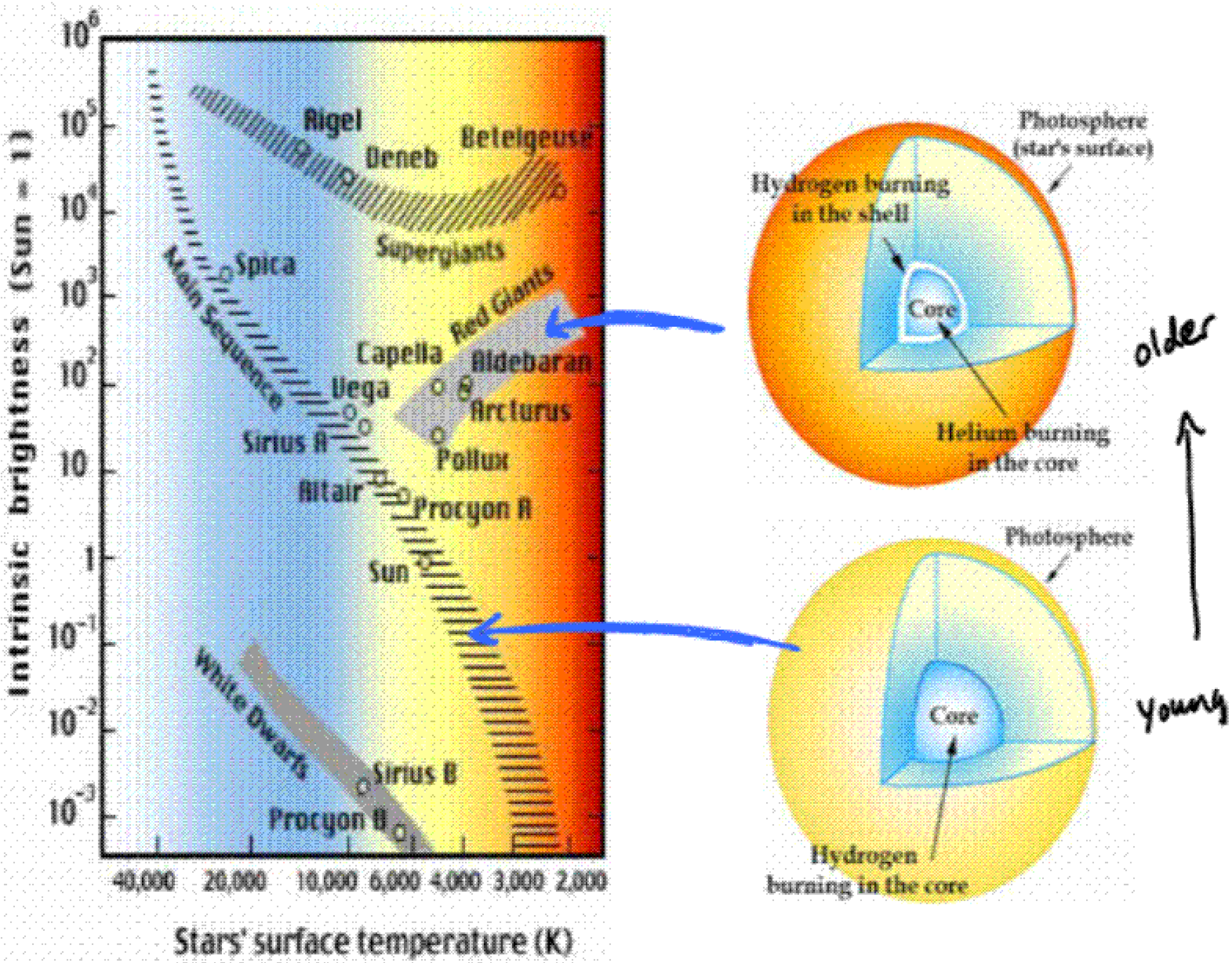
Mostly hydrogen gas



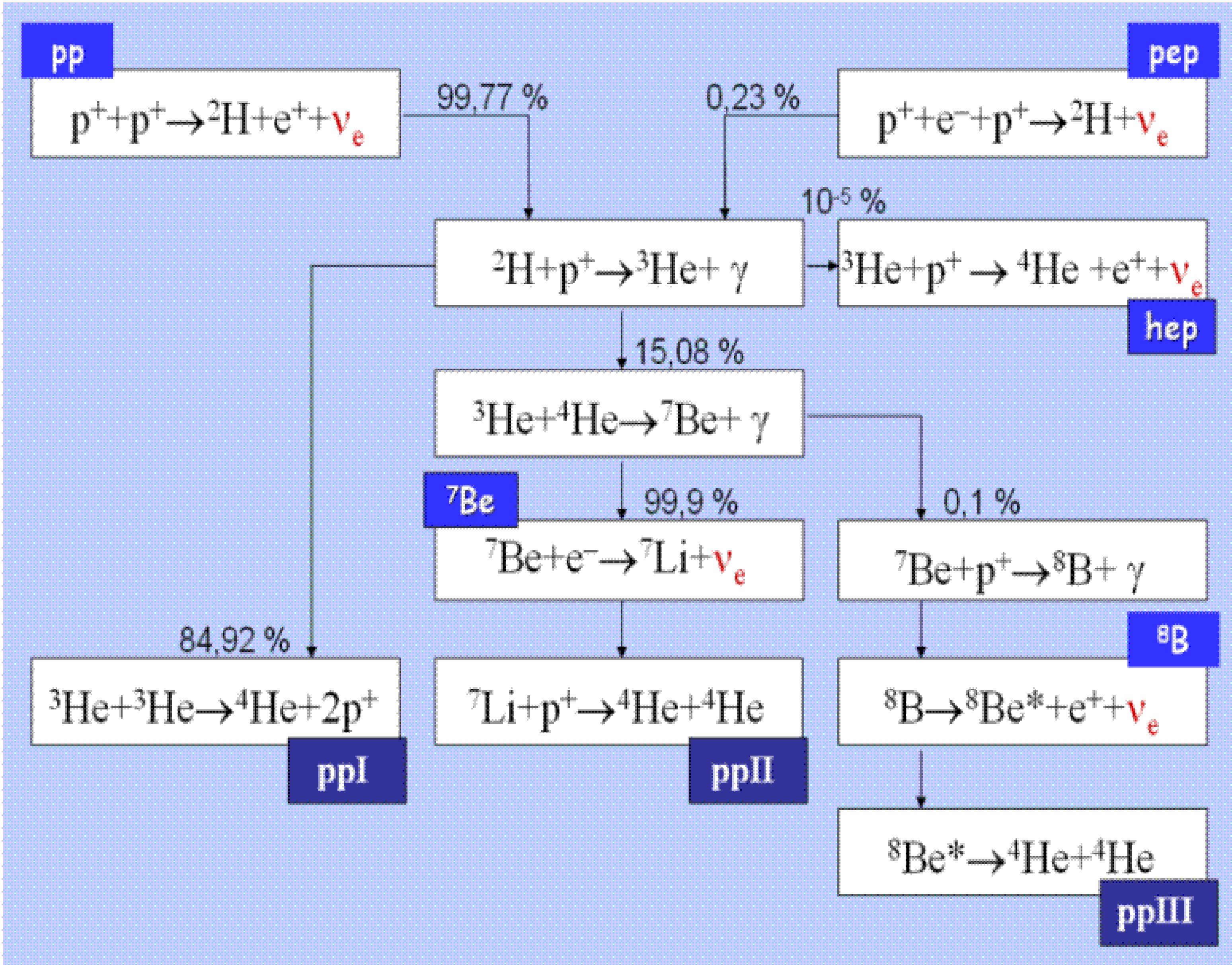
The Pleiades

Young stars residual dust
surrounding them

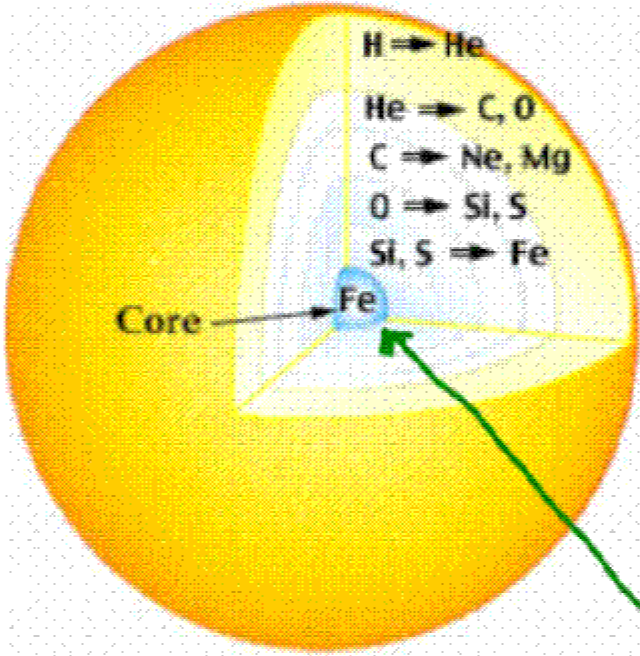

at birth
as cloud collapses - Angular momentum is conserved - get material forming spinning disk
STAR forms at center
planets in outer part of disk


Intrinsic brightness (Sun = 1)
10^6
10^5
10^4
10^3
10^2
10
1
10^-1
10^-2
10^-3
Rigel
Deneb
Betelgeuse
Supergiants
Spica
Main Sequence
Red Giants
Capella
Aldebaran
Vega
Arcturus
Sirius A
Pollux
Altair
Procyon A
Sun
White Dwarfs
Sirius B
Procyon B
40,000
20,000
10,000
6,000
4,000
3,000
2,000
Stars' surface temperature (K)
Photosphere
(star's surface)
Hydrogen burning
in the shell
Core
Helium burning
in the core
older
Photosphere
Core
Hydrogen
burning in the core
young

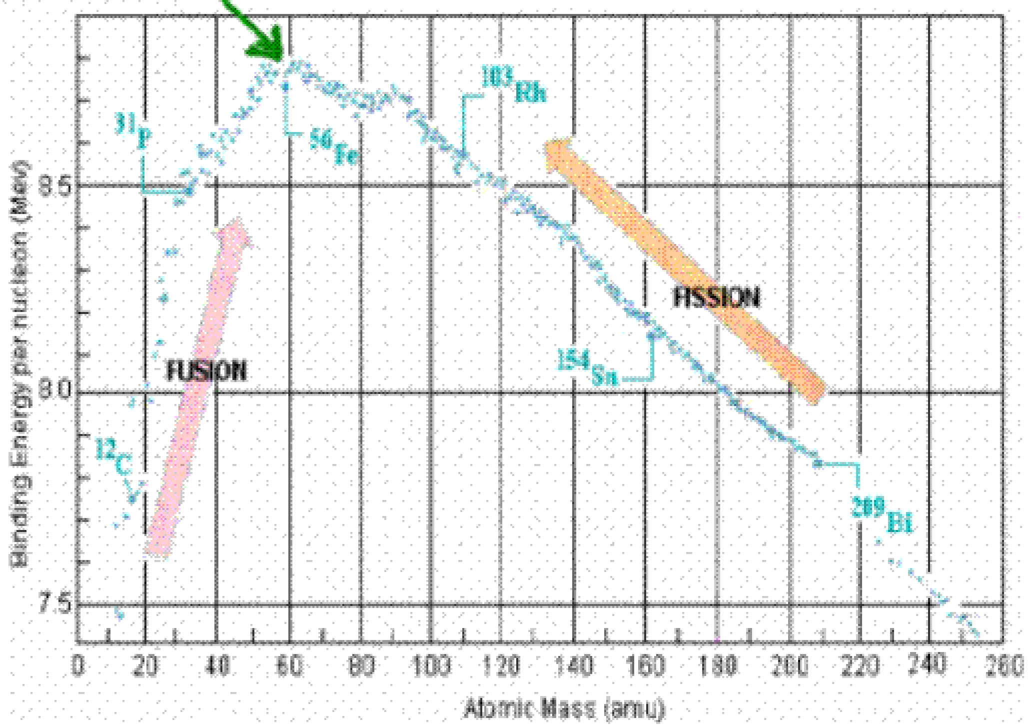
Primary Fusion Processes in the Sun

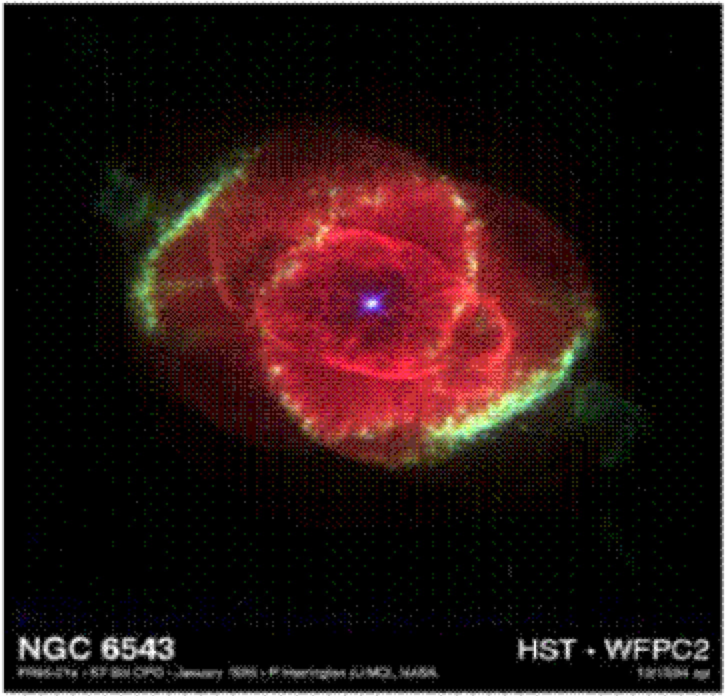


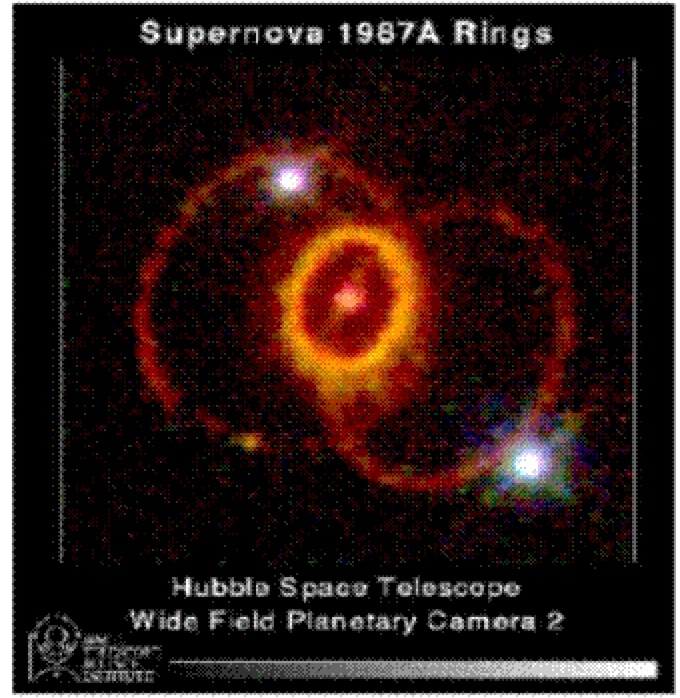
late life massive star



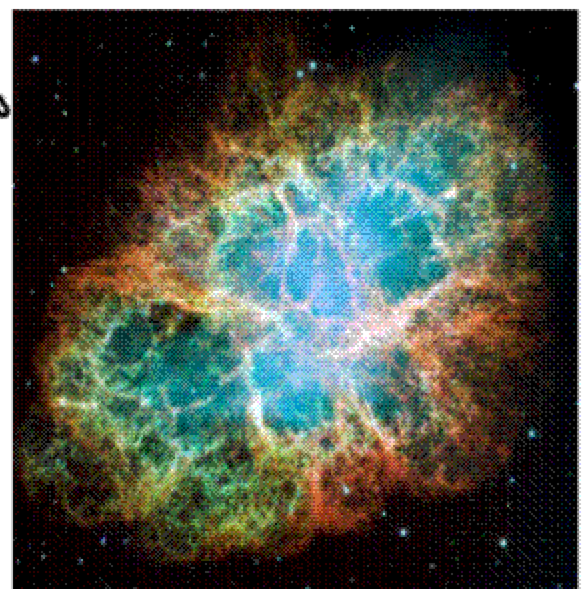
fusion process into nuclei larger than ^{56}Fe takes energy rather than releasing energy







STAR went supernova in 1054 — observed during day by Chinese and Arab Astronomers



Crab Nebula

star went Super Nova in 1054

A = 57

Elements with Atomic mass < that for iron can be made in Stars via fusion

How do we get elements with A > 57?

And how do these materials get dispersed into space to become part of other stars + planets?

Nova
+
Supernova

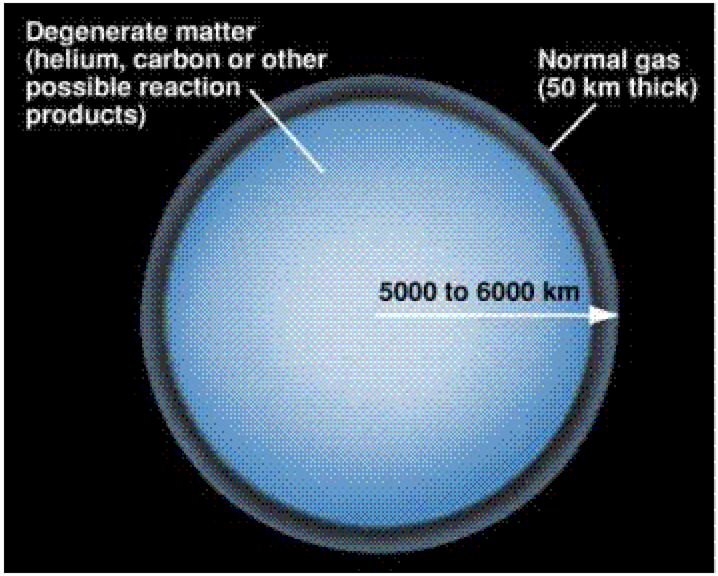
several types
still active area of research

→ as core of massive star cools down can have instability — core can collapse due to gravity and then slow or rebound as reach the point where "held up by particles".
Shockwave can propagate and ignite the outer layers of STAR
→ Massive explosion
→ Produces heavy elements + disperses material in space

Death of a Star

White dwarf

$0.8 M_\odot < M_{star} < 1.4 M_\odot$



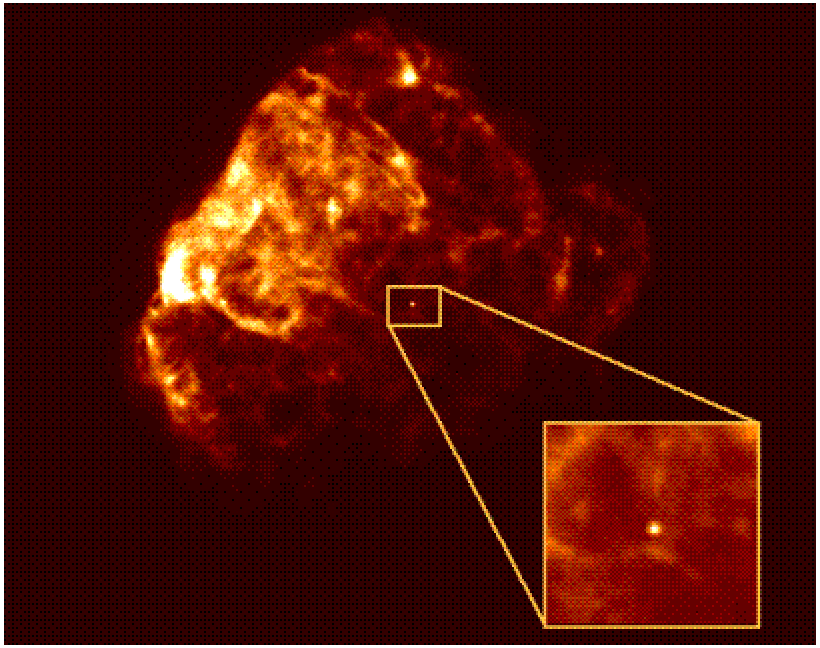
Star runs out of fusion fuel at temp reached + slowly cools

gravity "wins" – held up by electron degeneracy pressure

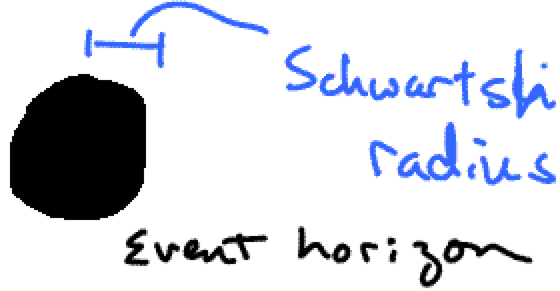
Neutron Star

$1.4\,M_\odot < M_{star} \lesssim 2.5\,M_\odot$

held up by neutron degeneracy pressure



Black hole



$M_{STAR} \gtrsim 2.5\, M_\odot$

gravitation so strong that even light cannot escape

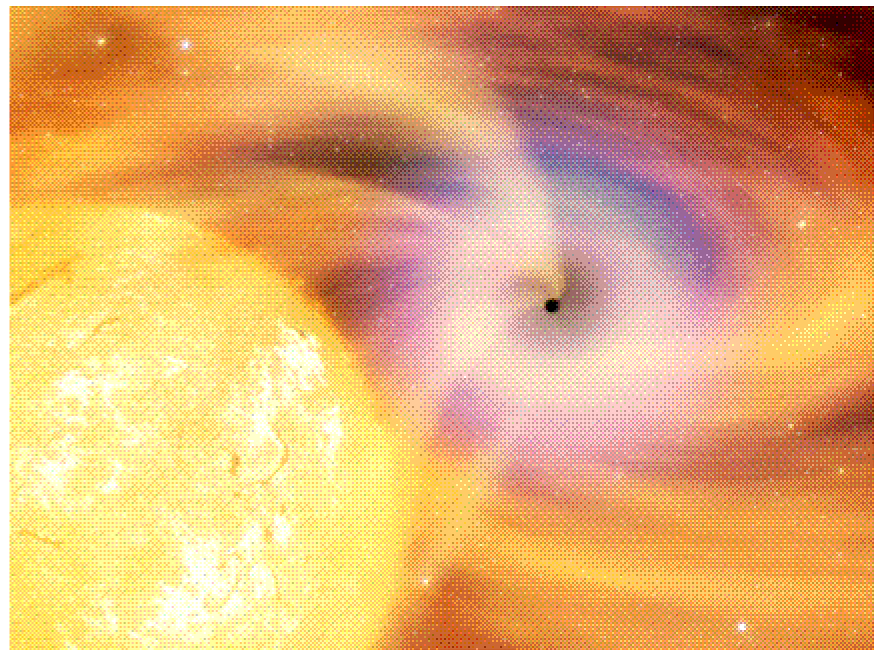


photo from http://orbitingfrog.com/blog/2008/07/10/can-light-orbit-a-black-hole/

Time appears to stop at event horizon (to outside observer)

Tidal effects ... Not a trip you want to take

Places to learn more: Particle and nuclear physics links

http://pdg.lbl.gov

http://particleadventure.org

http://www.slac.stanford.edu/gen/edu/aboutslac.html

http://www.bnl.gov/bnlweb/sciindex.html

http://www.bnl.gov/rhic/

http://public.web.cern.ch/public/

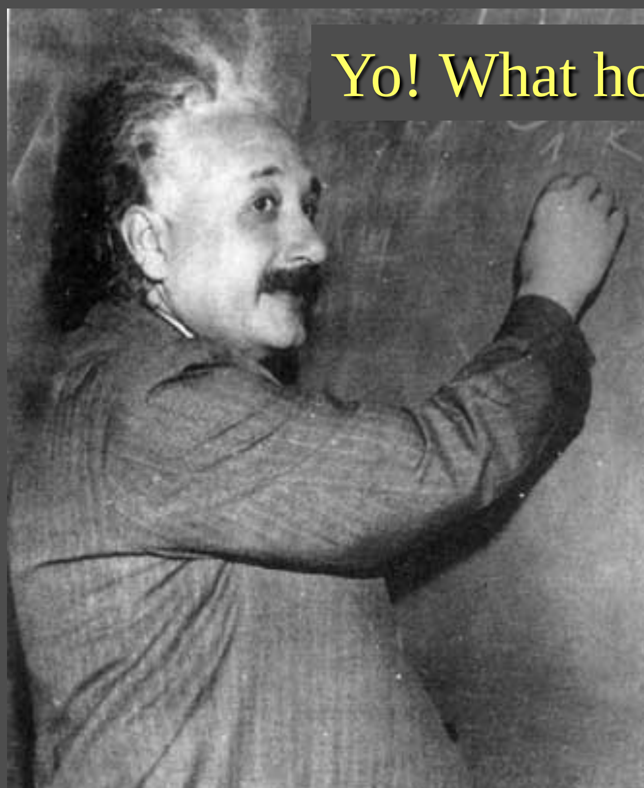
http://www.fnal.gov/

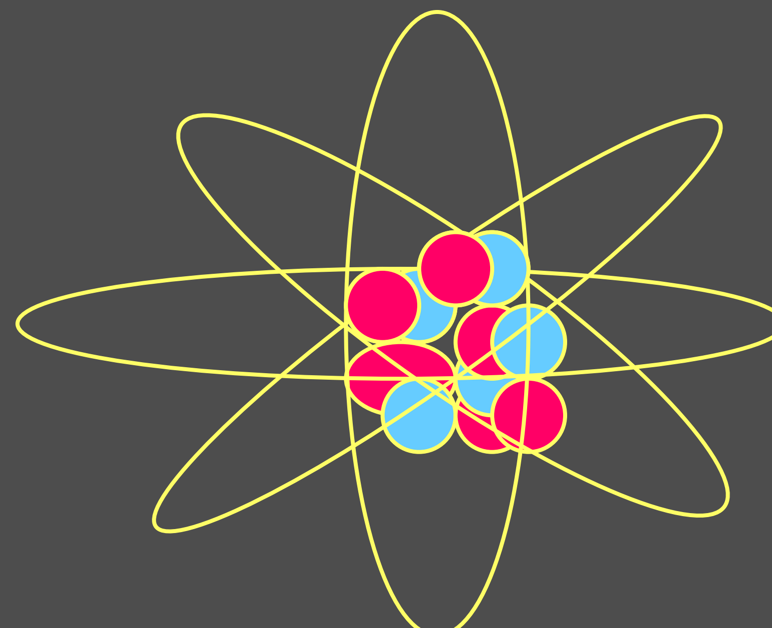
http://www.er.doe.gov/production/henp/np/index.html

http://www.science.doe.gov/hep/index.shtm

Inquiring minds want to know ...

Yo! What holds it together?






52
46
ACXIOM
27
HASTINGS

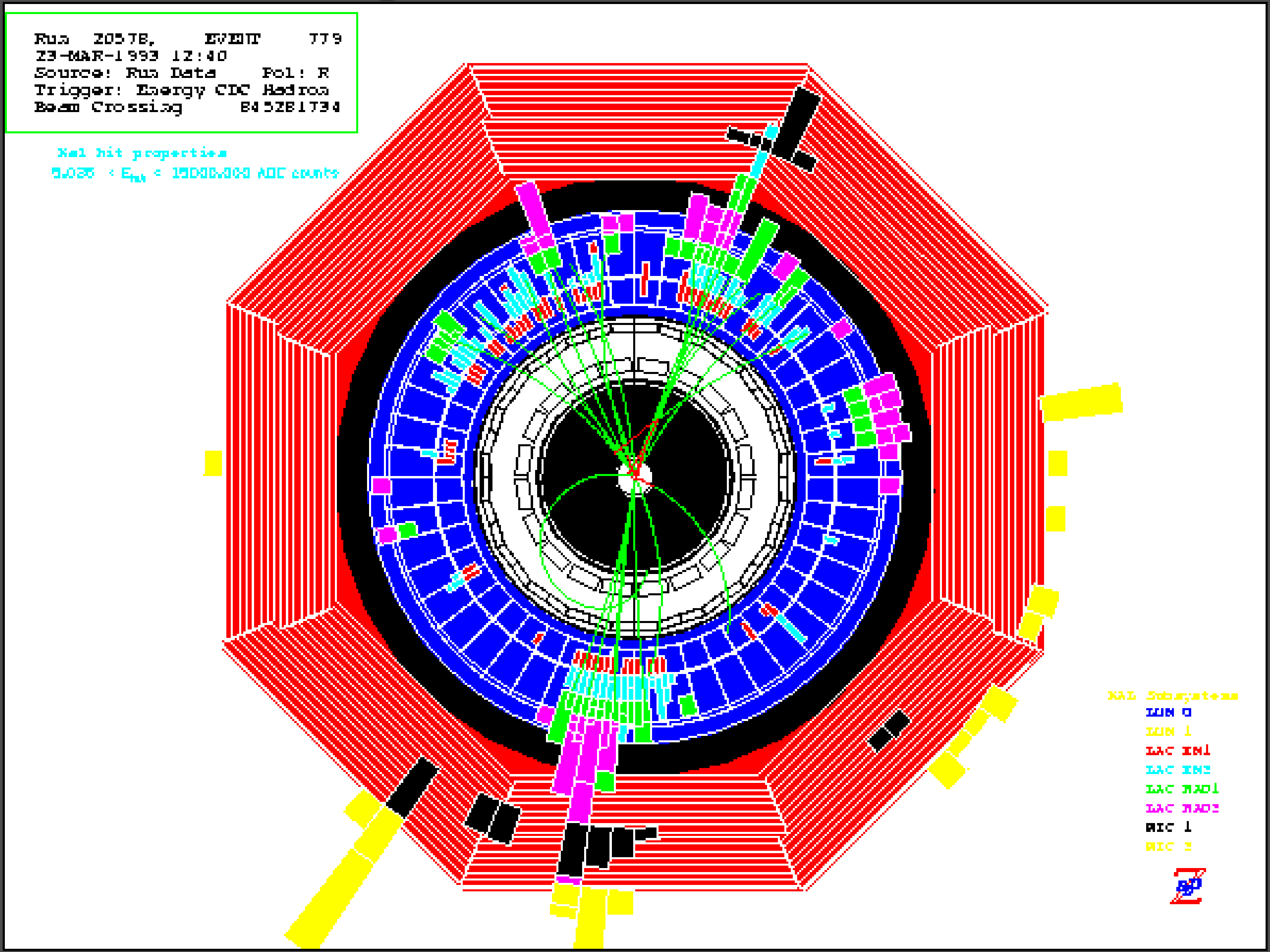
Fermi National Accelerator Laboratory (near Chicago)

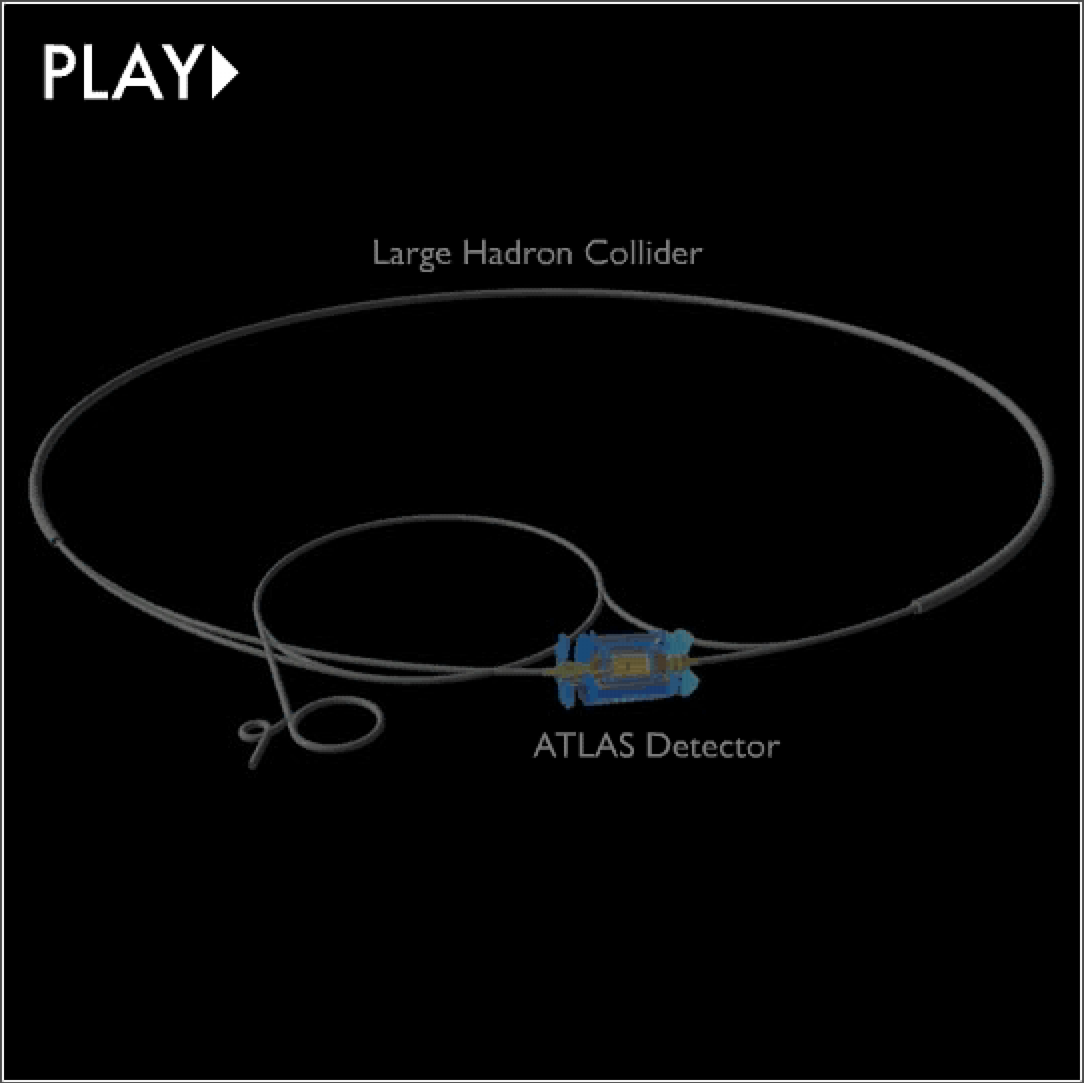
CDF

Minos

Stanford Linear Accelerator Center

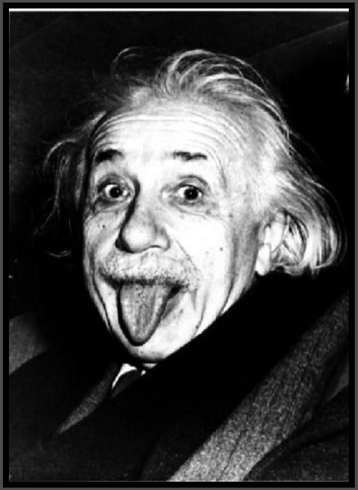
Event display from the SLD experiment at SLAC




PLAY
Large Hadron Collider
ATLAS Detector

What forces exist in nature?

What is a force?



How do they interact?

How do forces change with energy or temperature?

How has the universe evolved?

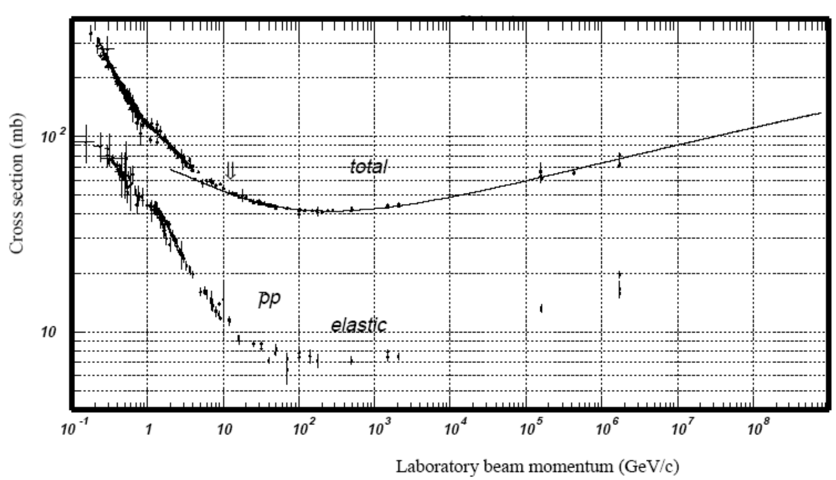
π^0 $I^G(J^{PC}) = 1^-(0^{-+})$

Mass $m = 134.9766 \pm 0.0006$ MeV (S = 1.1)
$m_{\pi^\pm} - m_{\pi^0} = 4.5936 \pm 0.0005$ MeV
Mean life $\tau = (8.4 \pm 0.6) \times 10^{-17}$ s (S = 3.0)
$c\tau = 25.1$ nm

For decay limits to particles which are not established, see the appropriate Search sections (A^0 (axion), and Other Light Boson (X^0) Searches, etc.).

π^0 DECAY MODES		Fraction (Γ_i/Γ)	Scale factor/ Confidence level	p (MeV/c)
2γ		(98.798 ± 0.032) %	S=1.1	67
$e^+e^-\gamma$		(1.198 ± 0.032) %	S=1.1	67
γ positronium		$(1.82 \pm 0.29) \times 10^{-9}$		67
$e^+e^+e^-e^-$		$(3.14 \pm 0.30) \times 10^{-5}$		67
e^+e^-		$(6.2 \pm 0.5) \times 10^{-8}$		67
4γ		$< 2 \times 10^{-8}$	CL=90%	67
$\nu\overline{\nu}$	[a]	$< 8.3 \times 10^{-7}$	CL=90%	67
$\nu_e\overline{\nu}_e$		$< 1.7 \times 10^{-6}$	CL=90%	67
$\nu_\mu\overline{\nu}_\mu$		$< 3.1 \times 10^{-6}$	CL=90%	67
$\nu_\tau\overline{\nu}_\tau$		$< 2.1 \times 10^{-6}$	CL=90%	67
$\gamma\nu\overline{\nu}$		$< 6 \times 10^{-4}$	CL=90%	–
Charge conjugation (*C*) or Lepton Family number (*LF*) violating modes				
3γ	C	$< 3.1 \times 10^{-8}$	CL=90%	67
μ^+e^-	LF	$< 3.8 \times 10^{-10}$	CL=90%	26
μ^-e^+	LF	$< 3.4 \times 10^{-9}$	CL=90%	–
$\mu^+e^- + \mu^-e^+$	LF	$< 1.72 \times 10^{-8}$	CL=90%	26

Cross section (mb)



week ending
4 JUNE 2004

$\rightarrow \omega\Upsilon(1S)$

E. Coan,[2] Y. S. Gao,[2] F. Liu,[2]
Dorjkhaidav,[3] R. Mountain,[3]
. Mahmood,[4] S. E. Csorna,[5]
pas,[7] A. Shapiro,[7] W. M. Sun,[7]

.S 30 MARCH 1998

ass

mendolia,[27] D. Amidei,[20] J. Antos,[33]
[8] M. Atac,[7] P. Azzi-Bacchetta,[25]

1 MARCH 1999

ne Measurement
miokande

Itow,[1] T. Kajita,[1] J. Kameda,[1]

26 MAY 1975

e $\psi(3095)$†

ischer, D. Fryberger, G. Hanson,
, D. Lyon, C. C. Morehouse,
R. F. Schwitters,

ford, California 94305

G. Golhaber, J. A. Kadyk,
Trilling, J. S. Whitaker,

lifornia, Berkeley, California 94720

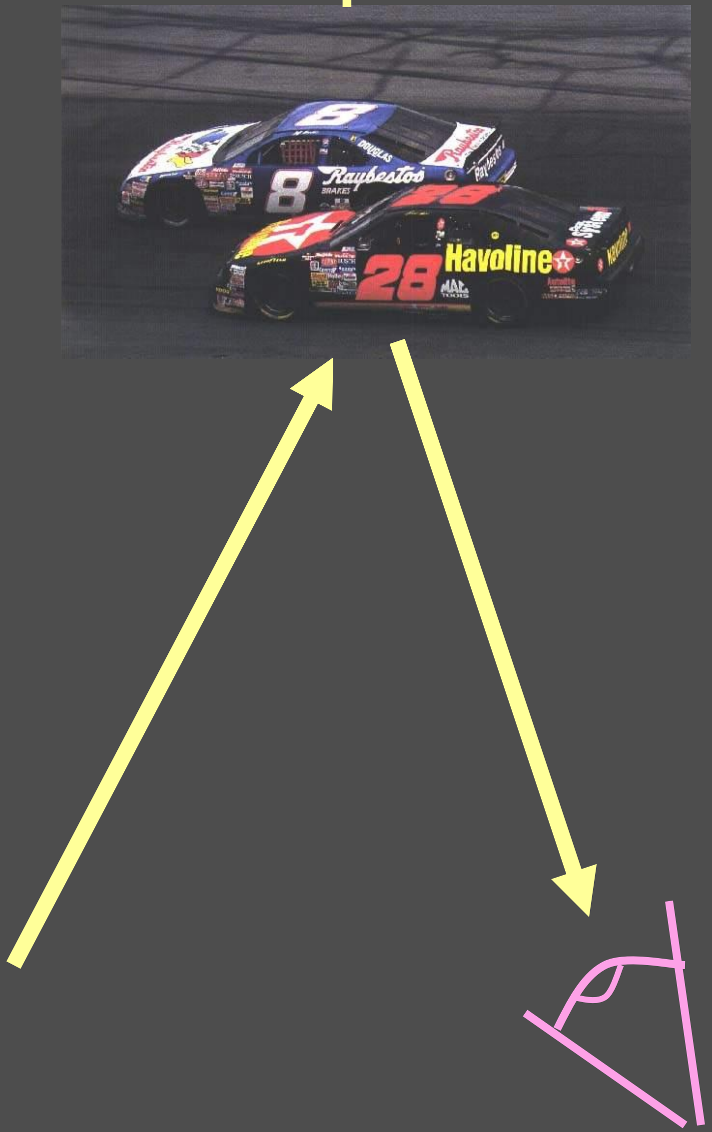
near 3095 MeV. The

Mini-Ph.D. – Quantum Mechanics 101

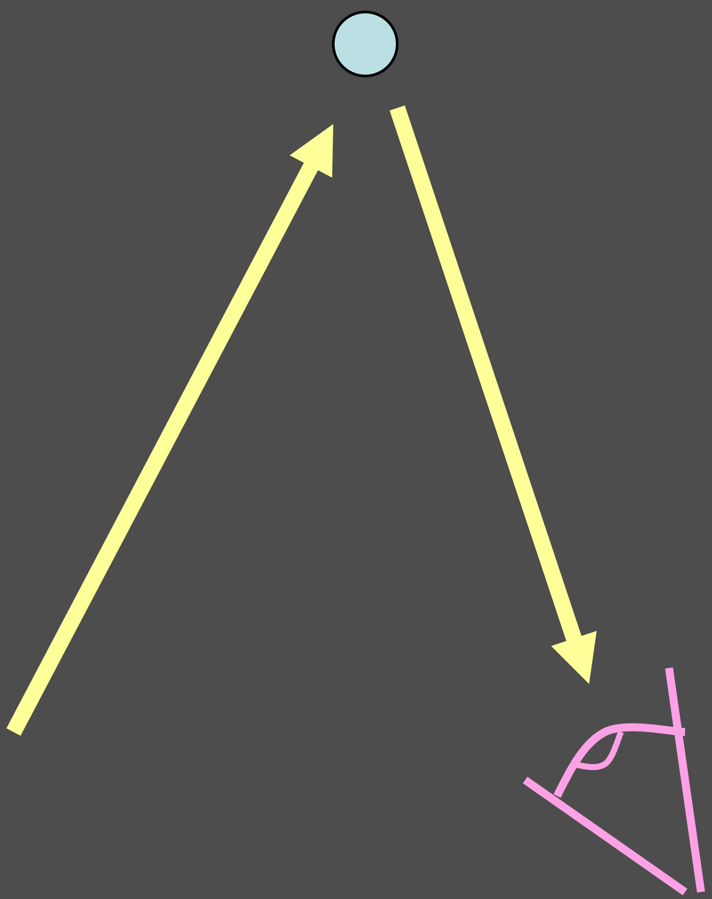
Lesson 1:

Size actually does matter.

Determine the postion and velocity of a car … no problem

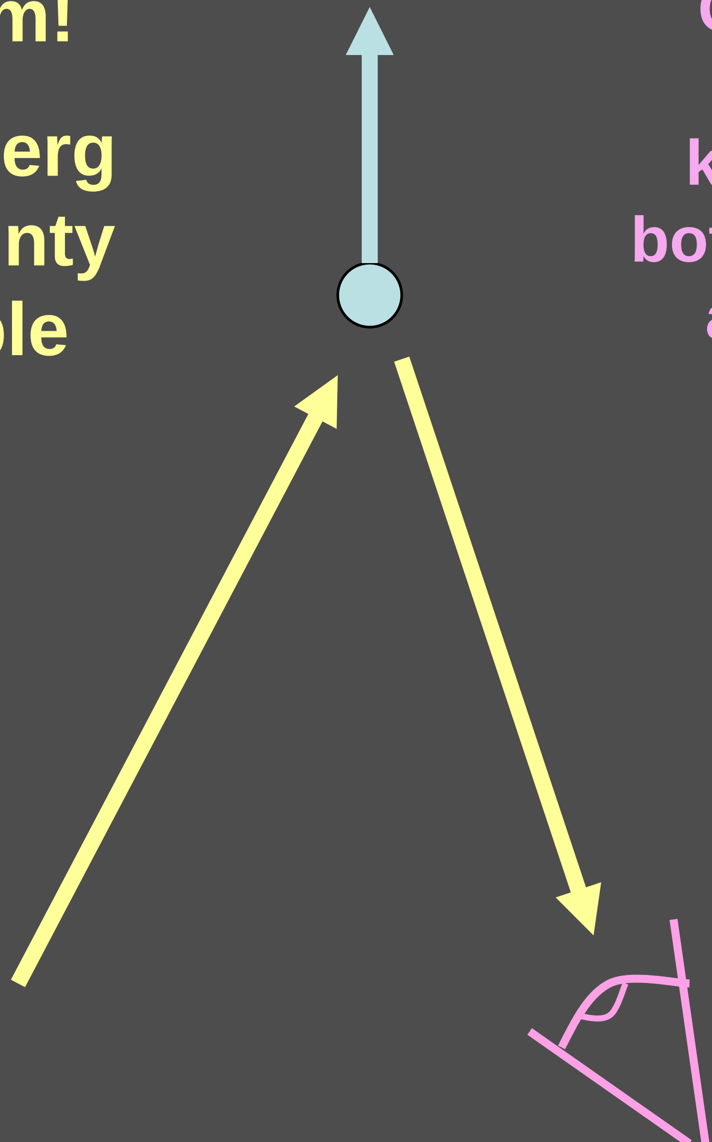


Determine the postion and velocity of a small particle … no problem



Problem!

Heisenberg uncertainty principle



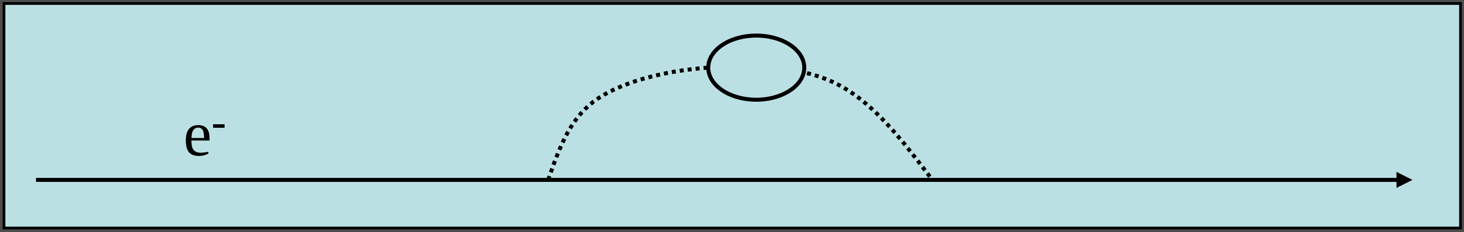
Cannot have perfect knowledge of both the position and velocity

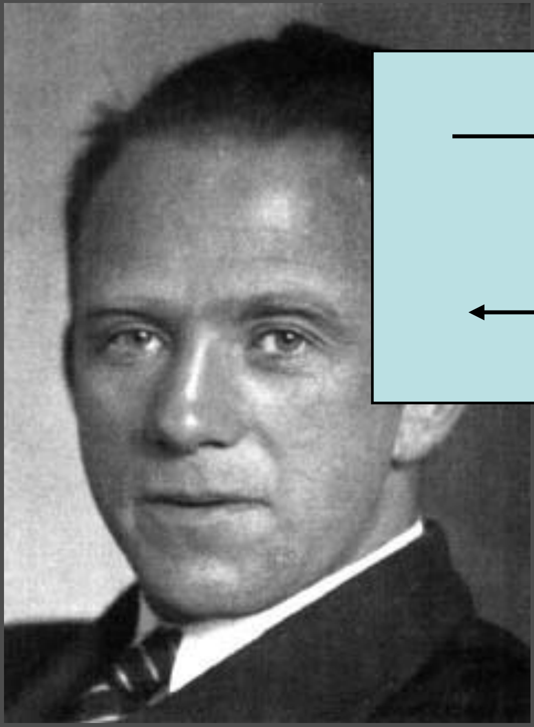
Heisenberg

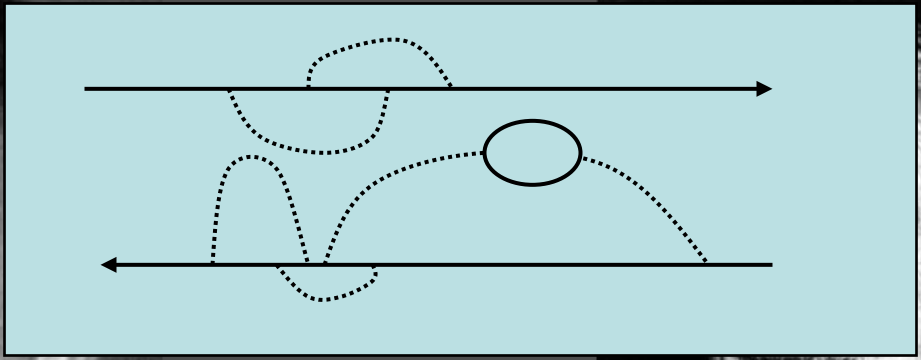
The fundamental nature of forces: virtual particles

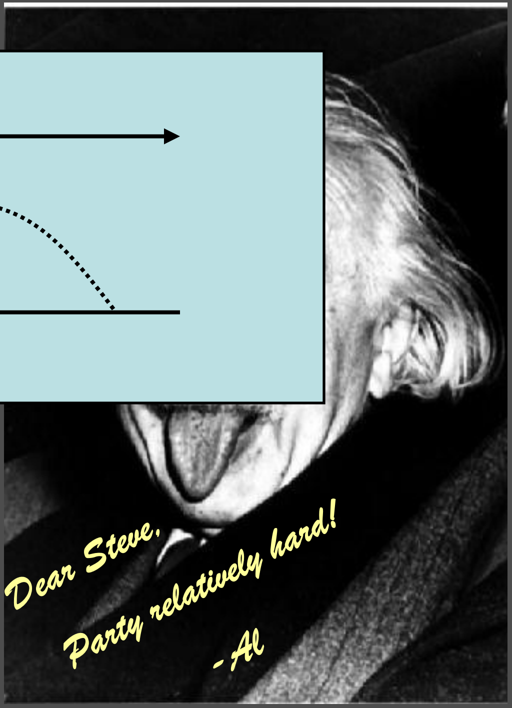
$\Delta E \Delta t \approx h$ Heisenberg

$E = mc^2$ Einstein









Quantum Field Theory → Exchange force

Force	*Source*	*Range*	*Strength*
Gravitation	mass	infinite	10^{-39}
Electromagnetism	Electric charge	infinite	10^{-2}
Strong nuclear	Color charge	10^{-15} m	1
Weak nuclear	Weak charge	10^{-18} m	10^{-5}