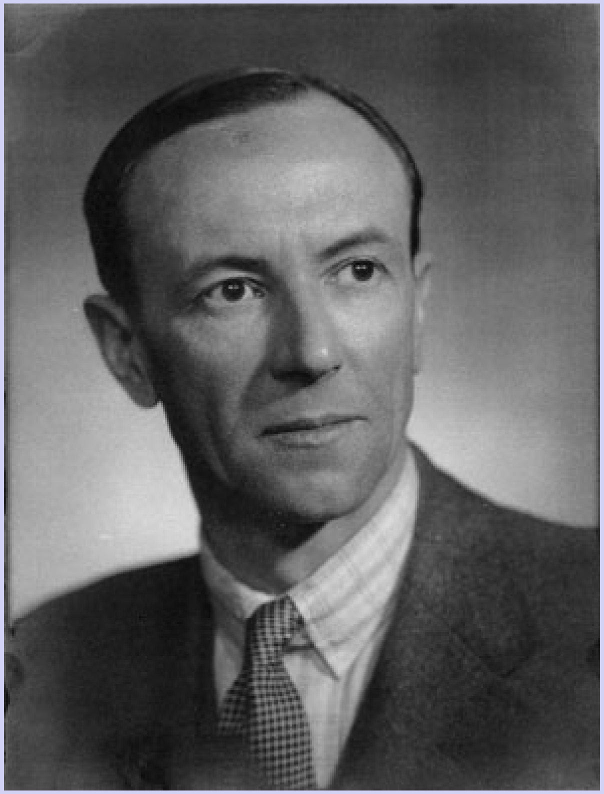
Neutron Stars: Introduction

Stephen Eikenberry

16 Jan 2018

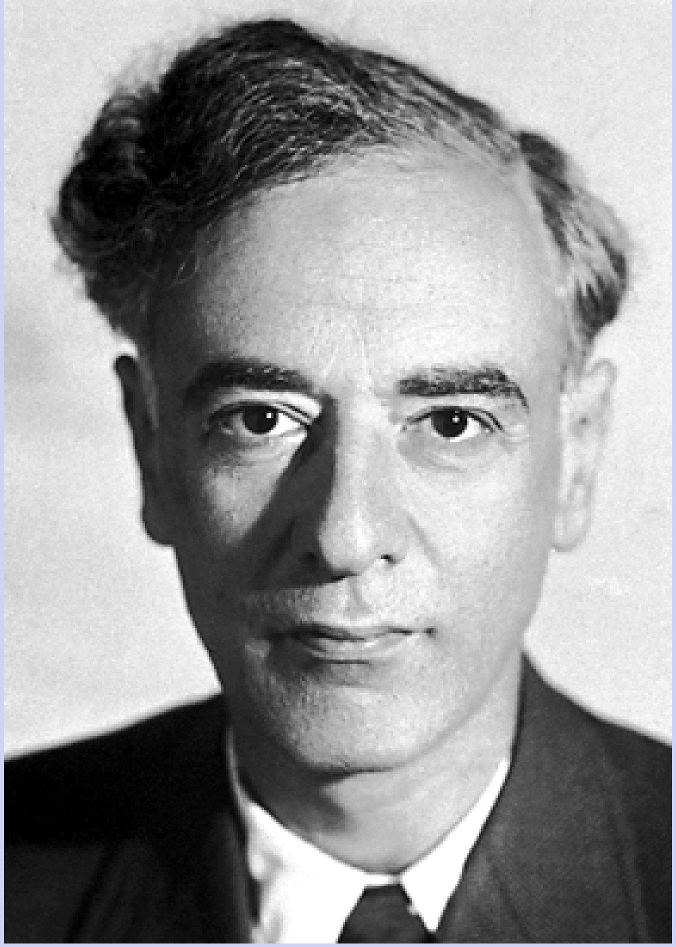
Original Ideas - I



- May 1932: James Chadwick discovers the neutron
- People knew that nuclei were not protons only (nuclear mass >> mass of protons)
- Rutherford coined the name “neutron” to describe them (thought to be p+ e- pairs)
- Chadwick identifies discrete particle and shows mass is greater than p+ (by 0.1%)
- Heisenberg shows that neutrons are not p+ e- pairs

Original Ideas - II

- **Lev Landau supposedly suggested the existence of neutron stars the night he heard of neutrons**
- **Yakovlev et al (2012) show that he in fact discussed dense stars similar to a giant nucleus BEFORE neutron discovery; this was immediately adapted to "neutron stars"**

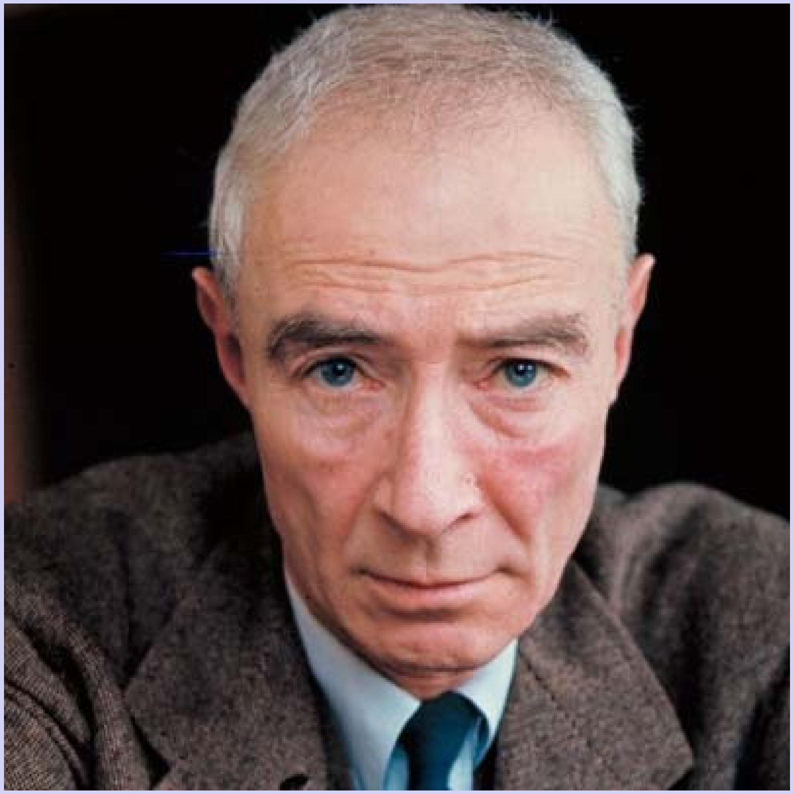


Original Ideas - III

- 1934: Walter Baade and Fritz Zwicky suggest that supernova events may create neutron stars
- Why?
- Supernovae have huge (but measured) energies
- If NS form from normal stars, then the gravitational binding energy gets released
- $E_{SN} \sim \Phi_{star}$ …

Original Ideas - IV

- Late 1930s: Oppenheimer & Volkoff develop first theoretical models and calculations of neutron star structure
- Would have continued, but WWII intervened (and Oppenheimer was busy with other things)
- And that is how things stood for about 30 years …

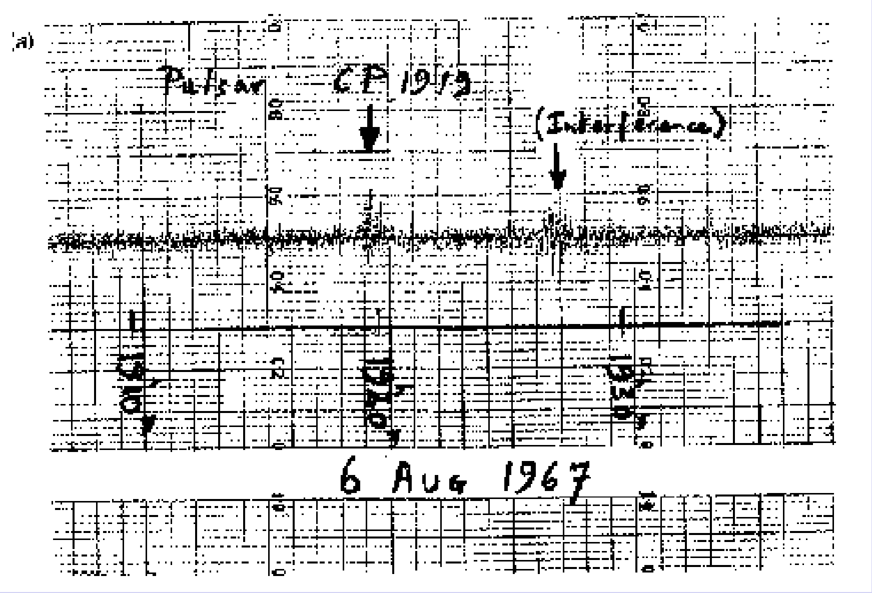


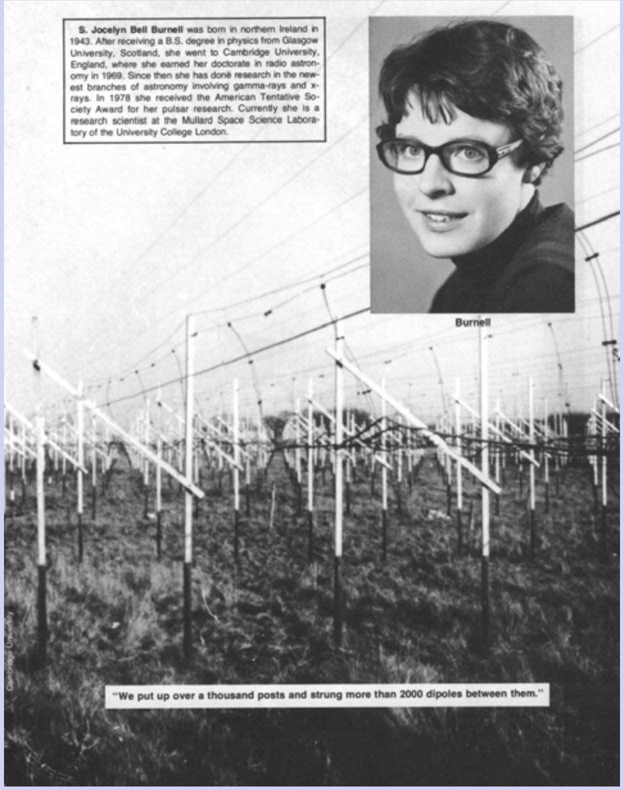
Little Green Men - I

- **Cambridge experiment with dipole antennae to map cosmic radio sources**
- **PI: Anthony Hewish; grad students included Jocelyn Bell**

Little Green Men - II

- August 1967: CP 1919 discovered in the radio survey
- November 1967: Bell notices pulsations at P =1.337s
- Source rises and sets sidereally ⇒ “It’s not local”





Little Green Men - III

- **Nobody knows what to make of this at first**
- **Cambridge group dubs them "LGM" for Little Green Men**
- **Whimsical name, but this actually had some serious scientific consideration (as it should)**
- **Several more "pulsars" discovered subsequently; all seen to be slowly increasing in pulse period (so probably natural?)**
- **Can they be white dwarfs? [Derive]**

Little Green Men - IV

- **Could the "pulsars" be near-maximal rotating white dwarfs?**
- **In theory, yes**
- **But, why are so many so close to maximum rotation, yet showing evidence of slowdown? (With an inferred age of P/(dP/dt) ~ 10^6 years – implying much faster original periods?)**

The Crab

- **Crab Nebula = Messier 1 (First object in Messier's old/famous catalog of things that are NOT stars)**
- **Identified with a bright "guest star" in the sky in 1054 AD**
- **Known to be expanding; theory is that the "guest star" was a Galactic supernova, and the Crab Nebula is the remnant**
- **Bright star at the center of the nebula $\Rightarrow$ could this be a neutron star?**

WIRC-2K
Commissioning Image

The Crab Nebula supernova remnant observed in J (blue - 2 min.); H (green - 1.5 min.); K-narrow (red-6 min.) at Palomar Observatory on Sep 2, 2002. Image size is approx 8.5x8.5 arcmin (one WIRC-2K FOV) with 0.6-arcsec FWHM.

Image credits: S.S. Eikenberry, J.C. Wilson, C.P. Henderson, J. Carson, T.L. Hayward, B.R. Brandl, B. Pirger, D.J. Barry, J. Schoenwald, J.R. Houck, R. Smith, M. Bonati, D. Guzman, K. Matthews, N. Robinson, K. Bundy

Zoom subimage: Central region of the Crab Nebula. The pulsar is the star at the center. The wispy features to the lower-left and upper-right of the pulsar are shocks where the pulsar's relativistic particle wind collides with the gas in the supernova remnant. Image size is approximately 1x1 arcminutes.

The Crab - II

- **Reifenstein & Staelin (fall 1968) discover pulsar in the Crab with period P = 0.033s (NB: Staelin was my undergraduate thesis advisor)**
- **WAY too fast for a white dwarf ⇒ seems to indicate NS (!)**
- **Previously: Crab nebula is very luminous with L = a few $\times 10^{38}$ ergs/s ($\sim 10^{5}\ L_{sun}$) ⇒ what powers this?**
- **Crab pulsar is slowing down (Pdot = -3×10^{-12} s/s), as are all the other known pulsars at this point**
- **Loss of rotational energy from the pulsar, must show up somewhere!**
- **Tommy Gold (and Franco Pacini, who was visiting Cornell at the time, and published first) calculate the energy loss if the "pulsar" is indeed a neutron star**
- **[derivation]**

The Crab - III

- **Previously: Crab Nebula is very luminous with L = a few $x10^{38}$ ergs/s ($\sim 10^5 L_{sun}$) $\Rightarrow$ what powers this?**
- **Crab pulsar spindown implies a luminosity of $4x10^{38}$ ergs/s**
- **Conclusions:**
  - **Crab Nebula is powered by the spindown luminosity of the Crab pulsar**
  - **Pulsars are neutron stars (!)**
  - **NS are created in SNe (as Baade/Zwicky predicted)**
  - **Zwicky vindicated (after decades of mockery $\Rightarrow$ see the intro to his 3rd Catalog of Galaxies)**
  - **Anthony Hewish wins the Nobel Prize!**
  - **Jocelyn Bell does NOT win the Nobel Prize (one of several great oversights in the history of the Prize, leading to one of the worst "makeup calls" in history)**