

Title: Jocelyn Bell Burnell: University of Oxford

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Abstract: <p>ocelyn Bell Burnell, winner of the 2018 Special Breakthrough Prize in Fundamental Physics, is an accomplished scientist and champion for women in physics. As a graduate student in 1967, she co-discovered pulsars, a breakthrough widely considered one of the most important scientific advances of the 20th century. When the discovery of pulsars was recognized with the 1974 Nobel Prize in Physics, the award went to her graduate advisor. Undaunted, she persevered and became one of the most prominent researchers in her field and an advocate for women and other under-represented groups in physics.</p>

<p>She plans to use the \$3 million Breakthrough Prize to fund women and other under-represented groups pursuing physics to bring greater diversity to the field.</p>

# What is that? The discovery of pulsars - a graduate student's story

Jocelyn Bell Burnell

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Astrophysics  
and  
Mansfield College



# Topics

- Introduction to radio astronomy
- Quasars
- Cambridge (UK) and the discovery of pulsars
- What are pulsars?



# The electromagnetic spectrum



NB Gravitational radiation is a separate spectrum

# Radio astronomy



# Radio astronomy – quasars (QSR)

- Radio astronomy developed post WWII
- Developed by ex-radar ‘boffins’; using the radar receivers (not transmitting).
- Found an undreamt-of richness of radio emitting objects in the sky .
- Some starlike-ish – quasi-stellar
- Strong sources but VERY far (?)
- Called ‘quasars’.

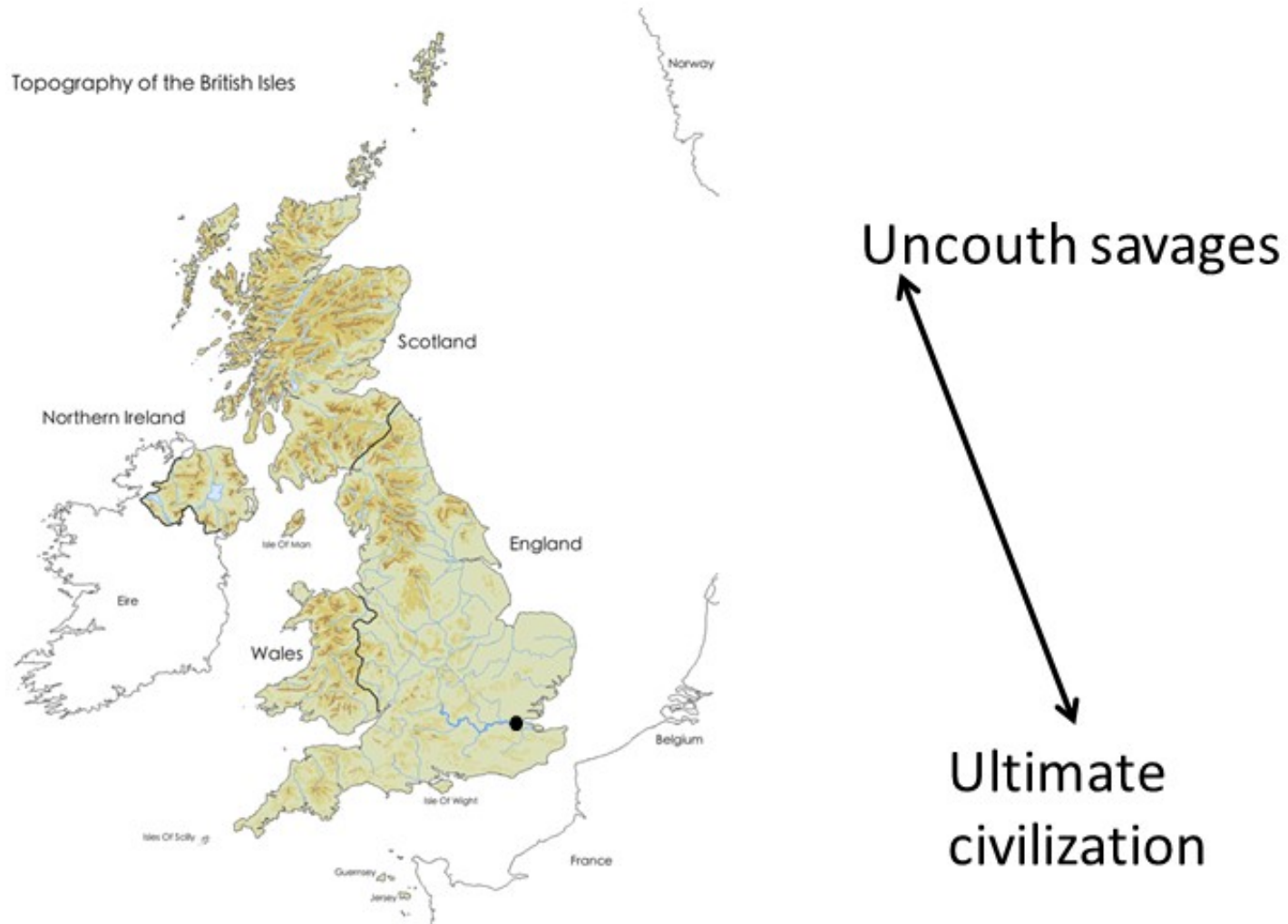




# My path - some British geography...



# Some British geography 2





# Imposter Syndrome

- Everyone here is *very* clever!
- I'm not.....
- They've made a mistake admitting me.....
- They're going to discover their mistake....
- And throw me out.....
- (I'd better leave before they throw me out)



# Yakov Zeldovich (1914 – 87)

- (Said of cosmologists.....!)
- ‘Frequently in error, but never in doubt.’



# On arrival in Cambridge 1965



- All new radio astronomy graduate students were given a set of tools.....

# First build your radio telescope (through hail, rain and sunshine)



Early 1967  
Don Rolph + JBB  
Checking impedance  
of air-spaced cables

**Area = 57 tennis courts. Grant £12k. 6 people worked for 2 years to build it.**



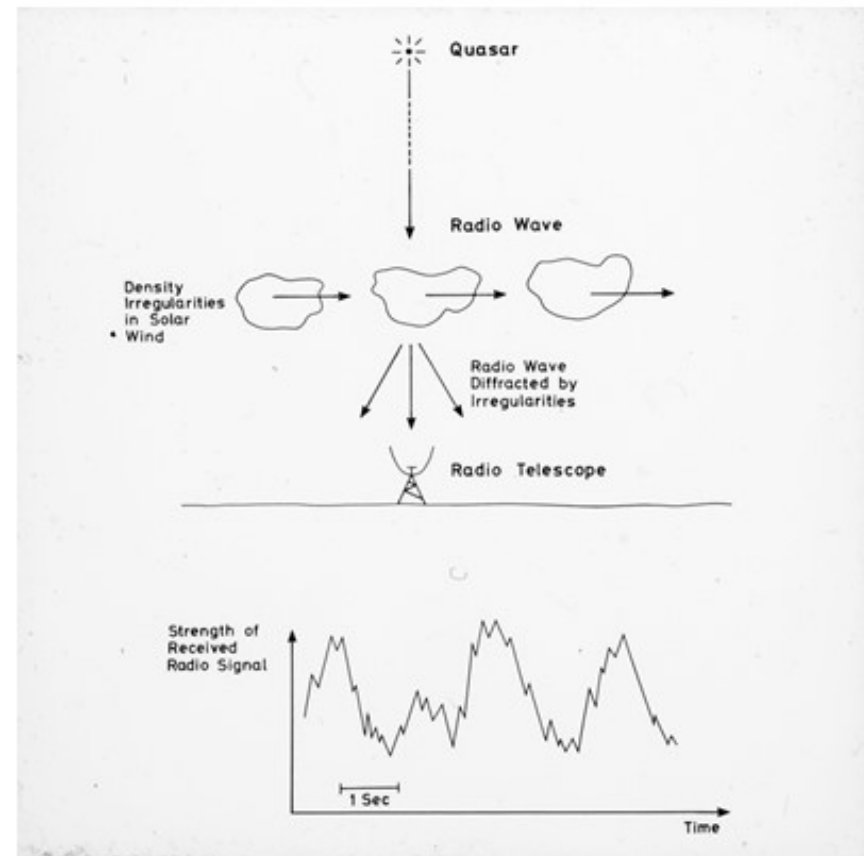
# The 4.5 acre\* radio telescope (\*1.8 hectares), looking West



**2048 81.5MHz  $\lambda/2$  antennae (16 E-W rows of 64 + 64),  
1000+ wooden posts, 192 km wire and cable. Phased  
interferometric array. Valve receiver!**

# Interplanetary scintillation

- Compact radio source scintillates, extended does not.
- Quasars (quasi-stellar radio sources) are compact; other radio sources are not





# Scintillation – a rough analogy



Swimming pool

- Swimming pool – patterns of light
- Caustic network produced by ripples
- Pattern moves as wind blows ripples

# Quasar Hunt!

- Only about 20 quasars known. Project was to find more, and measure their size, by repeated mapping of the sky.
- Pick quasars out by their rapid ‘twinkling’ - interplanetary scintillation; use short time constant /short integration time.  $\tau = 0.1$  s.
- 6 months’ observing
- Found c 180 more quasars



# Data analysis

No computer!

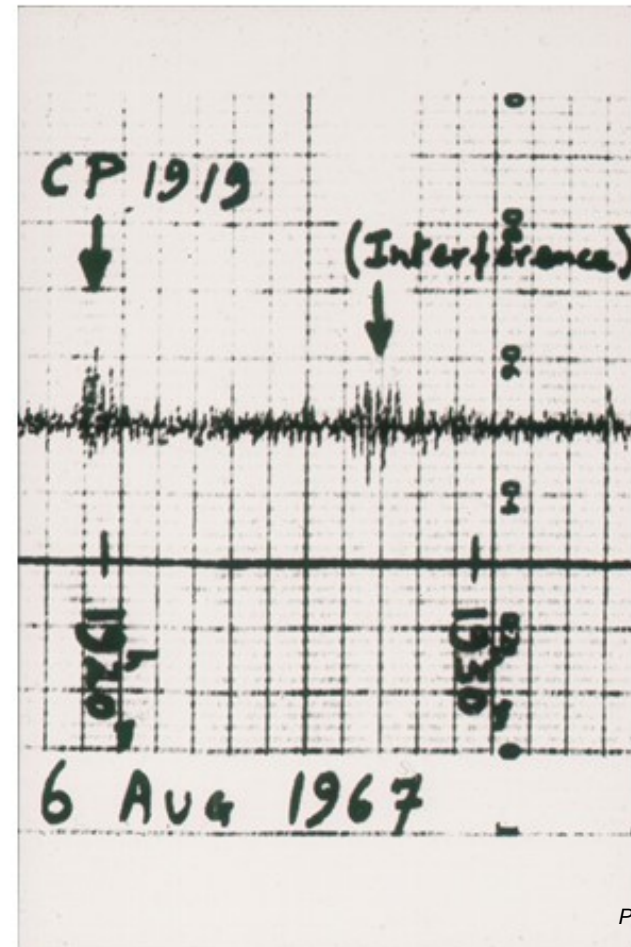
3-pen chart paper

- 30m / day
- 120m/sky scan
- 5.3km total

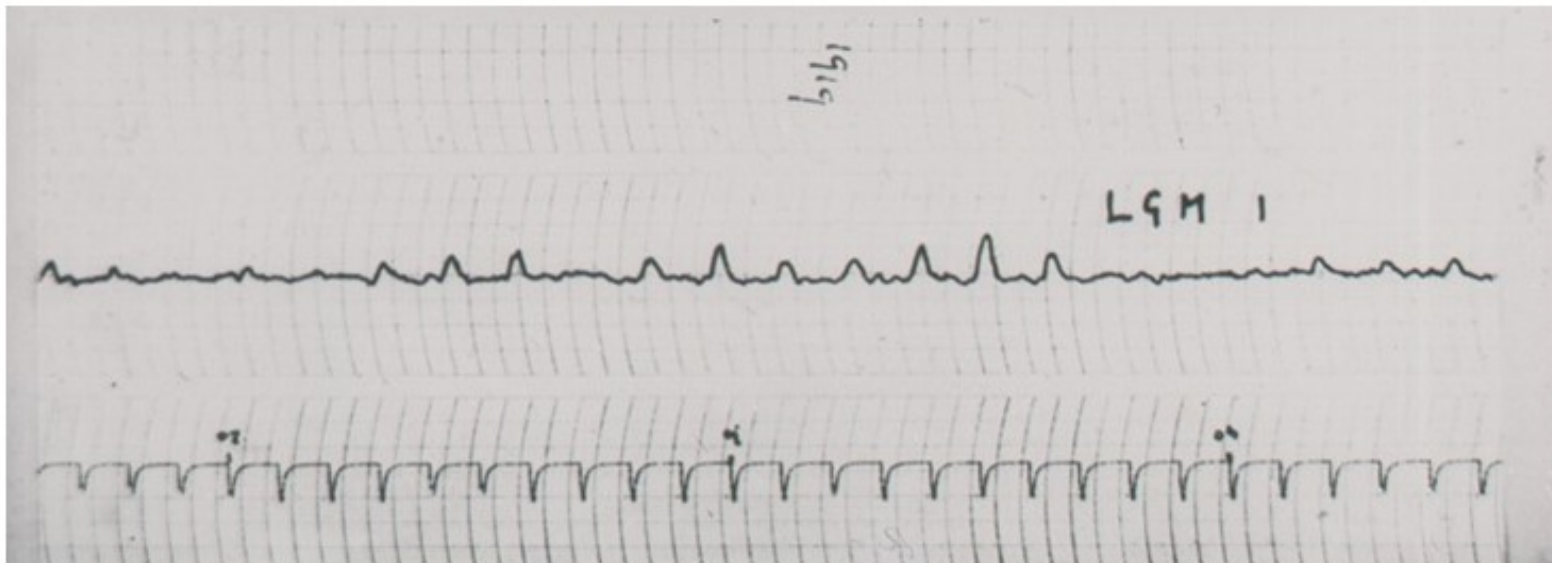


# Discovery of pulsars

- Occasionally 0.5 cm in the 120 m showed an unusual signal.
- 'Occasionally' = 20% of the occasions that part of sky observed
- This signal occupied approx 10 parts in a million of the chart paper!



# High-speed recording



Top line - pulsed emission detected  
Bottom line – one second time pulses



# What is it?

- Local radio interference? *No – keeps sidereal time.*
- Faulty equipment? *No – seen by a separate telescope and receiver.*
- Small (short pulses) and big (keeps accurate pulse period). ????????





# What is it (contd)?

- Dispersion measurement showed it was 200 light years away (i.e. beyond the Solar System, but nearby in the Milky Way)
- Little Green Men? They'd be on a planet orbiting their Sun; *no Doppler effect*
- Finding second, third and fourth (1133, 0833, 0950)



# The naming of pulsars

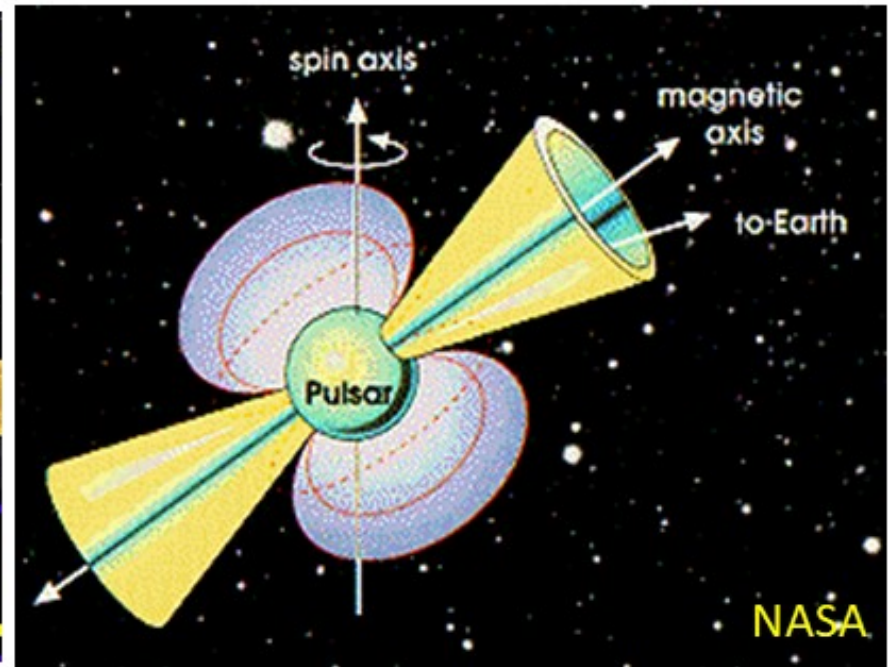
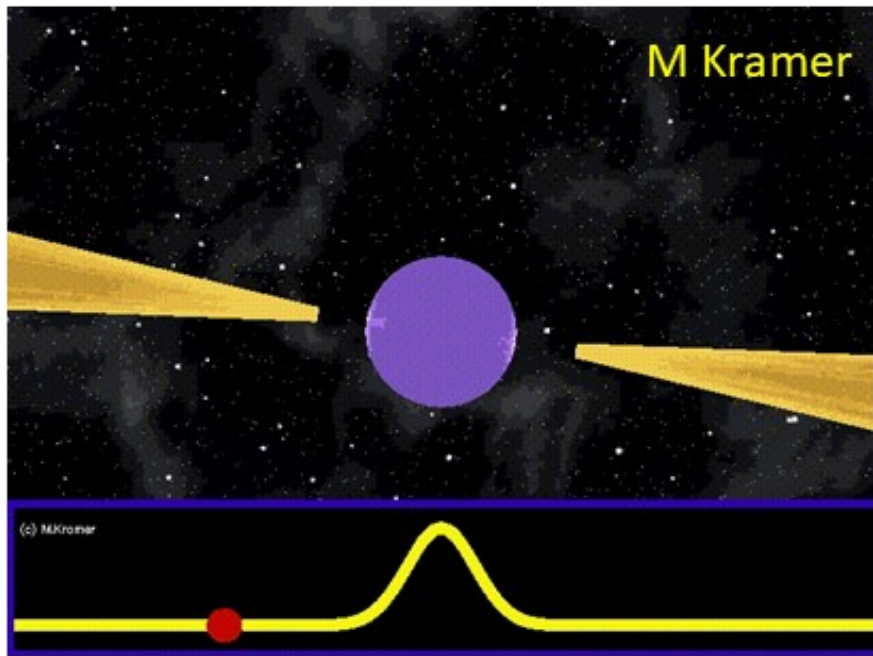
- Interviewed by Science Correspondent of The Daily Telegraph – Anthony Michaelis – shortly after the discovery
- What were we going to call them?
- He suggested *pulsar* – cf quasar

**The Daily Telegraph**

# What are pulsars?

## Overview

# Pulsars (pulsating radio stars) model



- Star spins like a lighthouse, sweeping radio beam around the sky.
- We see a pulse each time beam sweeps across us.

# Overview

- Pulsars are small, very dense neutron-rich stars (neutron stars).
- Strong gravitational fields; very strong E and M fields); rapidly spinning.
- Probably formed in the explosion (supernova) that ends the life of a massive ( $>10M_{\text{Sun}}$ ) star
- Primarily observed as pulsed, radio-emitting objects





# Pulsar population

- Seen in **RADIO**, (visible), X-rays and gamma rays
- About 2700 known; ~20 visible; ~100 X-ray; ~200 gamma ray
- Of the 2700; ~10% in binaries (one PSR-PSR); 1 triple system; a few with planets
- About  $10^5$  in the Galaxy (maybe)



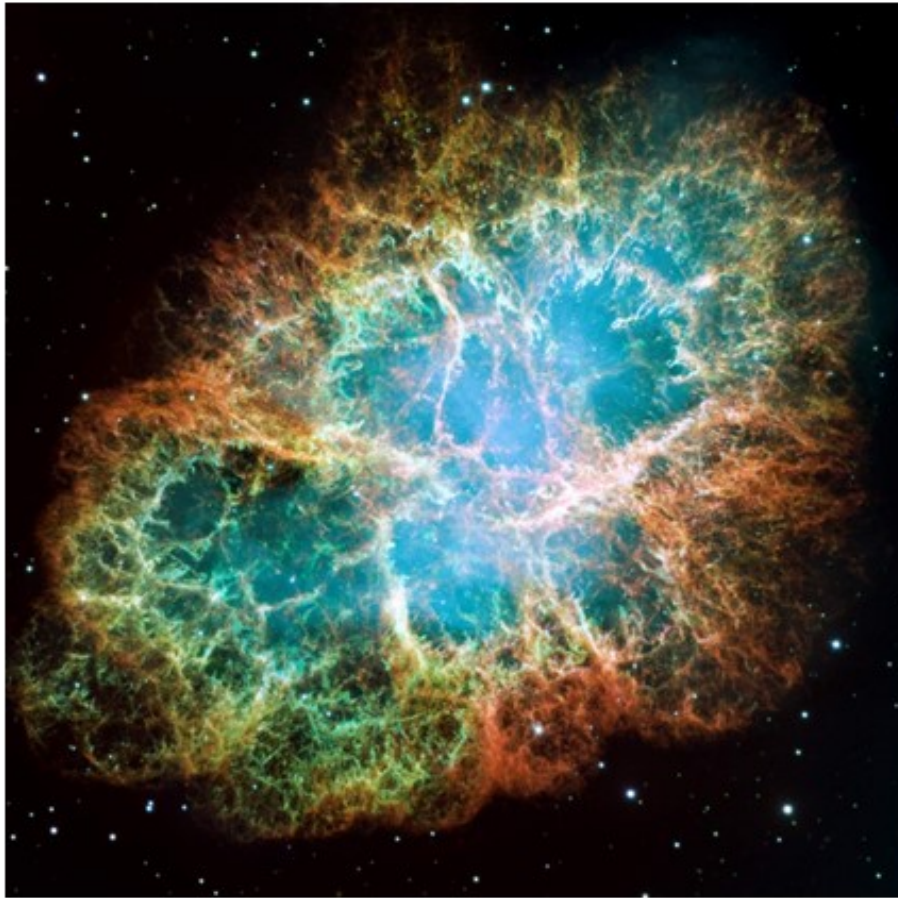


# Large Magellanic Cloud – SN1987a

When a large star (e.g. 10x bigger than the Sun) runs out of fuel the core of star collapses and becomes a neutron star. The outer 90 – 95% of star ejected giving a spectacular ‘supernova’ explosion



# Crab Nebula ~ 1000 yrs after SN



- Collapsed core is a neutron star or pulsar
- This nebula emits synchrotron radiation – kept energised by **pulsar** in its centre

# PROPERTIES OF PULSARS

In more detail

# Properties of Pulsars 1

- Mass  $\approx$  few  $\times 10^{27}$  tonnes, i.e. few thousand million million million tonnes (1.3 – 2 times mass of Sun)
- Radius  $\sim 10$  km
- $\therefore$  *average* density comparable with density of nucleus of an atom
- Rich in neutrons: 'neutron star'





# Properties of Pulsars - density



- A thimble-full of pulsar material has the same mass as the population of the Earth
- Strong surface gravity
- Tidal effects
- *Very* condensed matter physics

# Properties of Pulsars 2

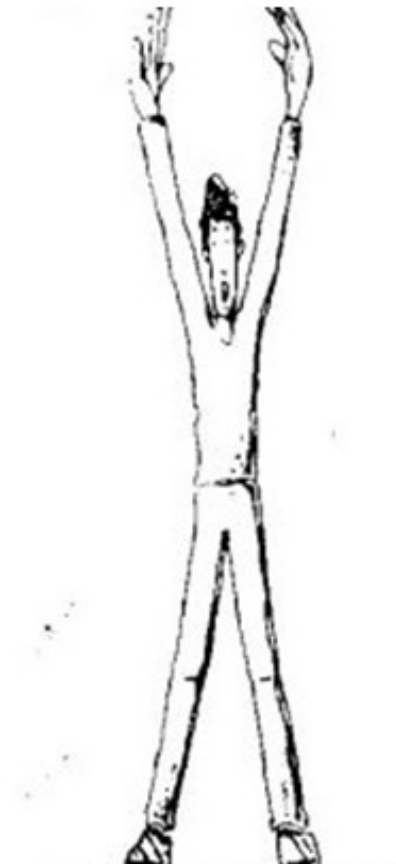
- Gravity bends light – one can see  $20^\circ$  –  $30^\circ$  over the horizon on a neutron star
- Gravity red shifts light
- Gravity affects clocks – clocks tick two times slower than here on Earth





# Properties of Pulsars 3

- The gradient of the gravitational force is strong – tidal disruption of bodies approaching pulsar



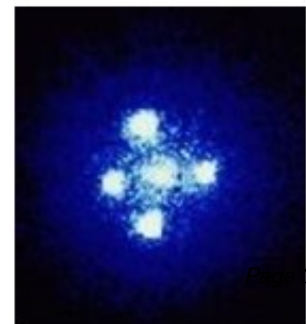
# Properties of Pulsars 3

- The gradient of the gravitational force is strong – tidal disruption of bodies approaching pulsar
- **Warning! Visiting a pulsar can seriously damage your health!**



# Properties of Pulsars 4

- Magnetic field of pulsar  $\sim 100$  million Tesla
- (Frig magnet  $\sim 0.01\text{T}$ , strong lab magnet  $\sim 10\text{T}$ .)
- Voltage drops of up to 10 billion Volt/cm
- **So electromagnetic forces are 100 billion times stronger than gravitational!**



# Properties of Pulsars 5

- Accurate timekeepers - good to 1 part in 10000 million million ( $10^{16}$ ); the period of a typical pulsar has increased by about 1 second since the age of the dinosaurs!
- This means they can be used as clocks to test Einstein's theory of Relativity.



# Things to watch over the next few years



FAST radio telescope – 500 m diameter, in S China.  
Now being commissioned – the world's largest.  
As of mid-August 2018, about 70 new PSRs.  
And some interesting/weird sources. (!?)



# CHIME – Canada's new radio telescope



Photo:



- In British Columbia
- Just starting operation
- Will be good for studying pulsars

# SOME PULSAR RECORDS



# Pulsars – some amazing facts 2

- The fastest known pulsar is  
**PSR1937+21**  
with a period of  
 **$P = 1.557806472448817 \pm 0.000000000000000003$**   
**milliseconds**



# Pulsars – some amazing facts 3

- The first planets discovered beyond the Solar System are three planets around the pulsar PSR1257+12. There is also a tiny fourth planet or asteroid in the system.





## Pulsars – some amazing facts 4

- **The roundest known thing in the universe is the orbit of the pulsar PSRJ1909- 3744 around another star. It is round to  $5 \mu\text{m}$  (one tenth the width of a human hair) in 567000km. (Eccentricity  $e = 1.30 \times 10^{-7}$ )**

# Pulsars – some amazing facts 5

- **If something falls on to the surface of a pulsar, it will hit the surface with a speed of  $0.5c$**

# The End

