Pulsar Planet - How do such systems form ?

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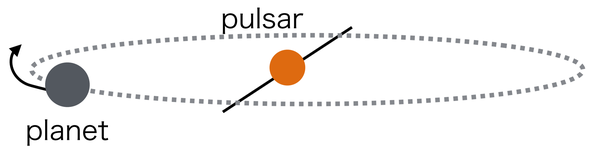
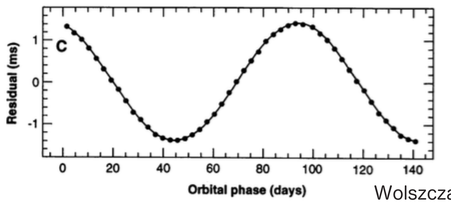
What is a pulsar planet ?

- Planets orbiting around pulsars.
- First detected extrasolar planets.
- Three systems have been discovered since 1992 by using pulsar timing method.
  - (PSR B1257+12, PSR B1620-26, PSR J1719-1438)



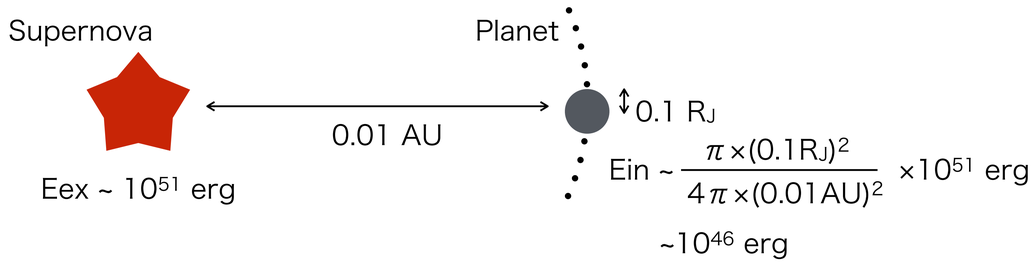


Wolszczan & Frail (1992) [1]

How do planets form ?

- Pulsars are generated as result of supernovae explosions of massive stars.
- When do planets form ? before explosions ? after explosions ?

- **Before explosion ?**
  - A massive star having planets explodes and becomes a pulsar with planets.
  - Explosion energy is injected from supernovae to planets. If the star has a jupiter-like planet, about 10^{46} erg is injected to the planet. This energy is enough to strip the atmosphere from the planet. Therefore only a core without atmosphere of pre-existing planets can survive in this scenario.



- **After explosion ?**
  - Protoplanetary disks are formed by using supernovae ejecta.
  - It has been observed that the magnetar 4U 0142+61 has a debris disk which is composed of heavier metals[3].
  - However, radiation from a pulsar to a surrounding disk is larger than other planetary systems(fig. 1)[5] and makes to form of planets difficult.

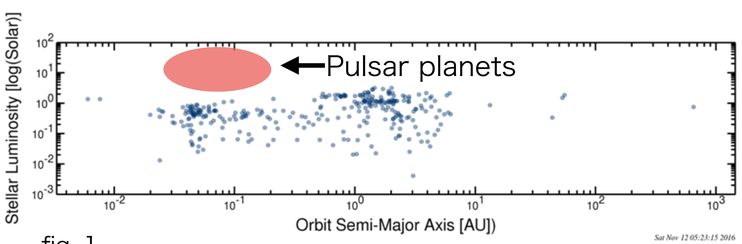


fig. 1

NASA Exoplanet Archive [5]

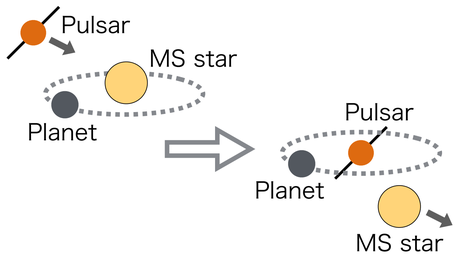
- **Several scenarios**
  - There are some scenarios about formation of pulsar planets(tab. 1),
  - However it is difficult to conclude because detected systems are only three.

	Description	Frequency	ms Pulsar?	Tests
Planet Survival Model	pre-existing planets which survived evolution and supernova	very low	no	third planet very unlikely
Planet Capture Model	neutron star collides with solar system and replaces central star	low	no?	outer planets in eccentric, oblique orbits
Massive Binary Model	circumbinary planets dragged in during Thorne-Żytkow phase	common?	no?	outer planets in eccentric, coplanar orbits
Fall-Back Model	planets formed out of fall-back material after supernova	common?	no	outer planets unlikely
WD+WD or NS+WD Merger	(lighter) WD disrupted to form planetary disk	relatively common?	yes	outer planets in circular orbits, planets out of WD material
Be Binary Model	massive disk accreted from massive companion	relatively common?	?	all planets in circular orbits, WD companion possible
TŻO Deflation Model	TŻO envelope deflates after fuel exhaustion to form massive disk	moderately common?	?	planets (low-mass stars) in circular orbits
Evaporation Model	"planet" is remnant of (almost completely) evaporated low-mass star	rare	yes	only one planet possible
Disrupted Companion Model	low-mass companion is dynamically disrupted and forms massive disk	moderately common?	yes	all planets in circular orbits
Circumbinary Disk Model	evaporated wind forms circumbinary, planet-forming disk	moderately common?	yes	all planets in circular orbits
Ablation Scenario	planetary disk formed out of material ablated from close binary companion during supernova	rare	no	all planets in circular orbits
Disk-Capture Scenario	ms pulsar captures protostellar disk	low?	no	all planets in circular orbits
Overmassive WD Scenario	planets survive around overmassive WD	impossible?	no	

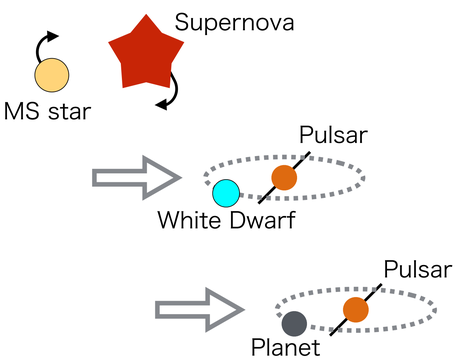
tab. 1

P. Phillipp (1992) [2]

- Planet Capture



- Evolved from White Dwarf [4]



References

[1] A. Wolszczan, D. A. Frail, Nature 355, 145 (1992)

[2] P. Phillipp, In: Planets around pulsars; Proceedings of the Conference, 1992(A93-36426 14-90), p. 149-165

[3] Z. Wang, D. Chakrabarty, D. L. Kaplan, Nature 440 (2006)

[4] M. Bailes et al., Science 333, 6050 (2011)

[5] NASA Exoplanet Archive