Sub-millisecond radio pulsars

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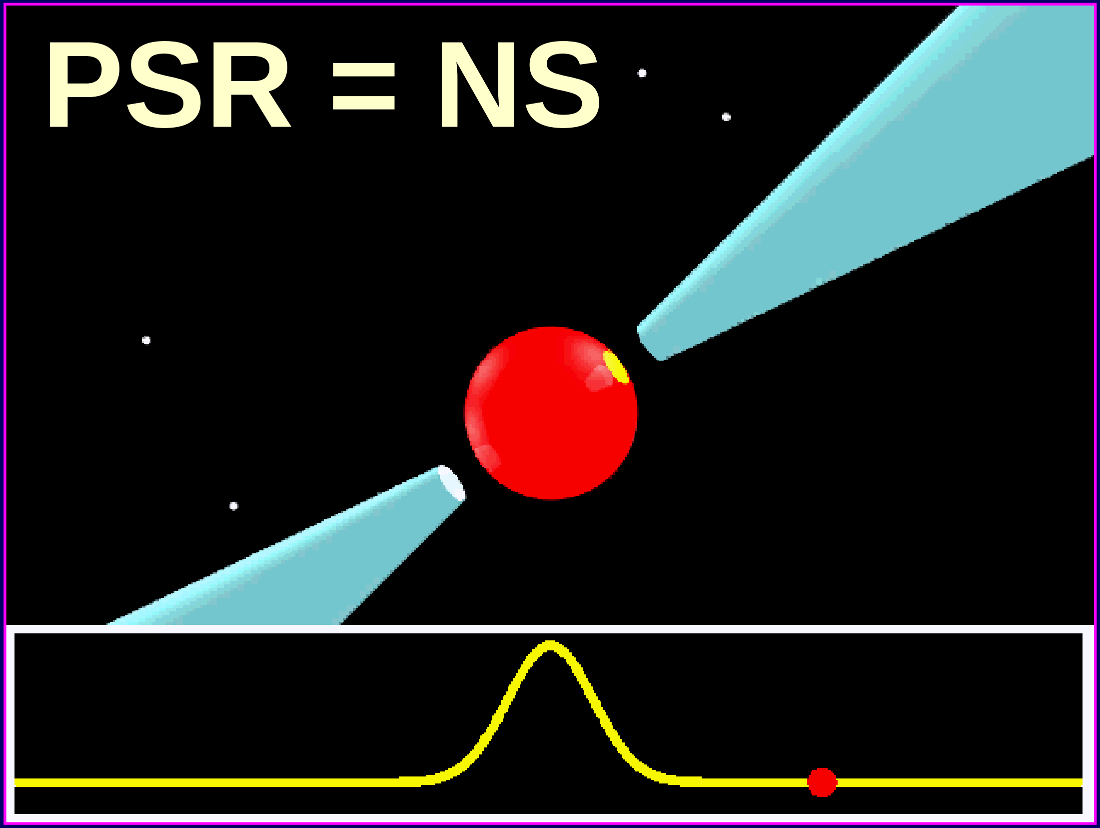
Summary

- ✓ *Introduction: PSRs & Spin*
- Activity of subms-PSRs
- To find a subms-PSR
- Conclusions

Why to focus on pulsars?

Important object!

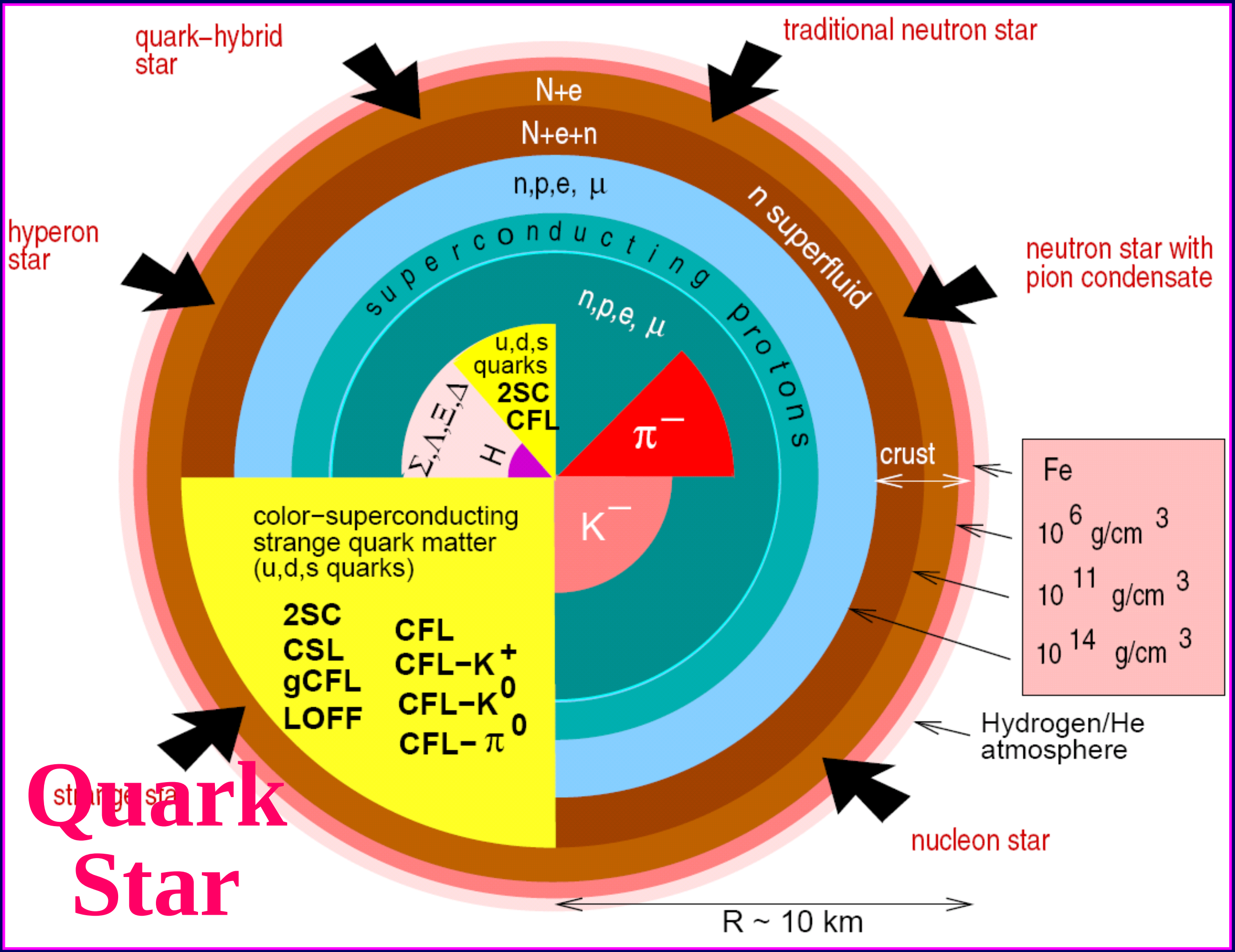


PSRs are spinning NSs

- **Peculiar astro-lab for *testing phy-law***
  - **Strong gravity**
  - **Strong EM force**
  - **Supranuclear ρ**
- **Precision clocks to be *very useful***
  - **Measure GW, M, …**
  - **Time standard**
  - **Navigation …**

What's the nature of pulsars?

Speculations v.s. *The truth*



F. Weber: Prog.Part.Nucl.Phys. 54 (2005) 193

NSs

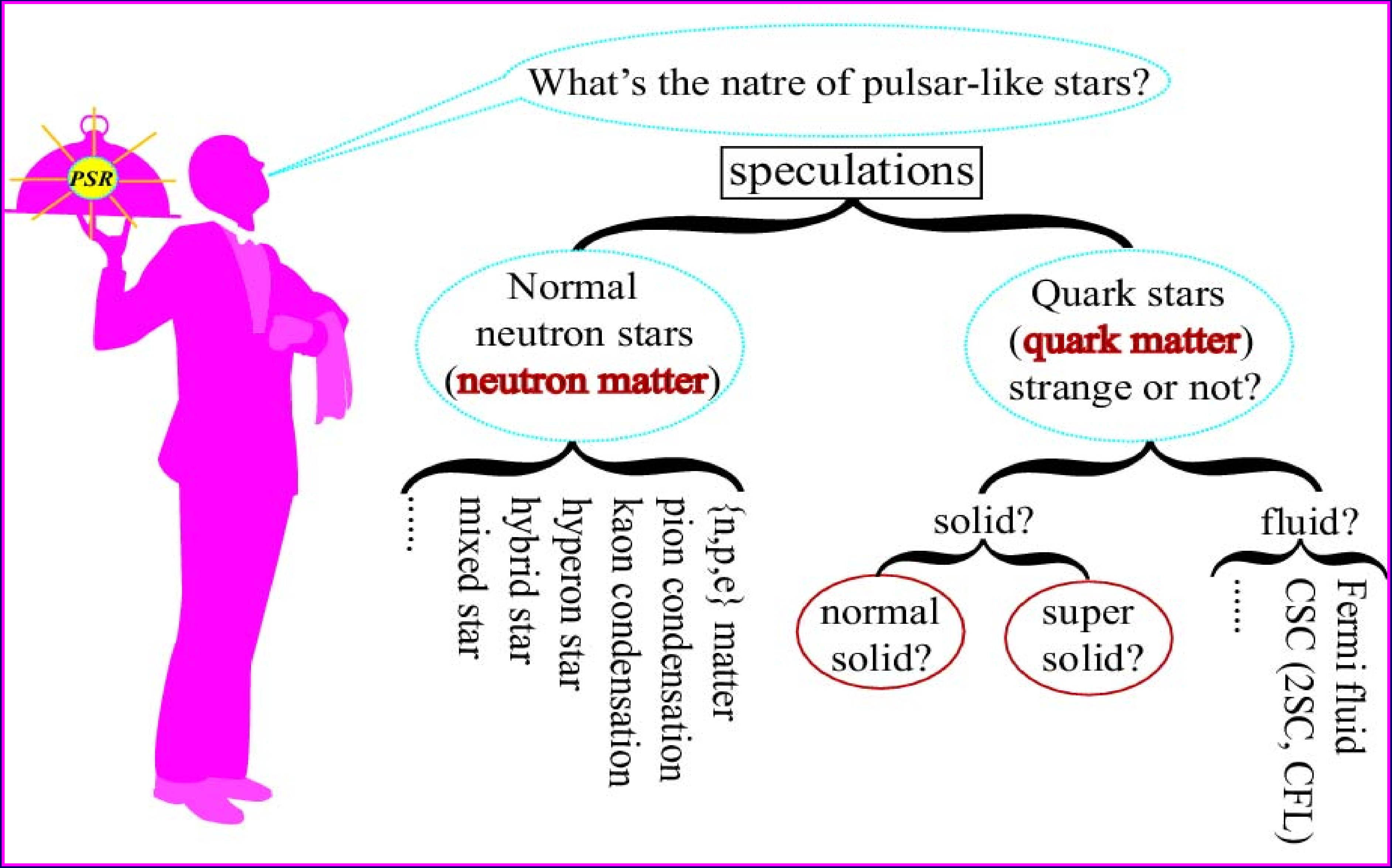
=

(normal) NSs

+

Quark stars

The nature of pulsars depends on physics of matter at *supranuclear density* which is still uncertain!



Observational *Evidence for* NSs or QSs?

To explain observational features in these two kinds of models

	Phenomena observed	Normal neutron stars	(Solid) quark stars	Note
Radio pulsars:	magnetospheric emission	ok?	ok?	$e^{\pm}$ plasma
	glitch	vortex (un)pinning	star-quake	to be checked
	slow glitch	???	in low-mass QS	no NS model
	drifting subpulses	binding?	binding!	surface condition
	(free) precession	damped?	no damping!	rigid or not
	timing noise	high in msPSR?	low-mass QS	random torque
AXPs/SGRs*:	energy	B-field	gravity & strain	magnetar?
	burst with glitch $\sim 10^{-6}$	?	AISq*	sometimes
	super-flare	high-B magnetar?	giant-quake?	
CCOs*:	age discrepancy	?	QS with fossil disk	
	erratic timing	?	torqued by disk	
DTNs*:	non-atomic feature	high B & Z?	bare QS!	
Thermal radius	why small?	polar cap?	low-mass QS	
APXPs*:	ADmsXPs*	ok?	low-mass QS?	spin down & up
XRBs*:	burst	nuclear power	crusted QS?	
Sub-msPSRs*:	super-Kepler spin	no!	possible	prediction (QS)
Others:	supernova	ν-driven??	γ-driven?	not successful
	MACHOs*?	?	(low-mass) QS?	
	UHECRs*?	?	strangelets?	

*AXPs/SGRs: anomalous X-ray pulsars/soft γ-ray repeaters, CCOs: compact central objects, DTNs: dim thermal "neutron stars", APXPs: accretion-powered X-ray pulsars, XRBs: X-ray bursts, Sub-msPSRs: sub-millisecond pulsars, MACHOs: massive compact halo objects, UHECRs: ultra-high energy cosmic rays, AISq: accretion-induced star-quake.

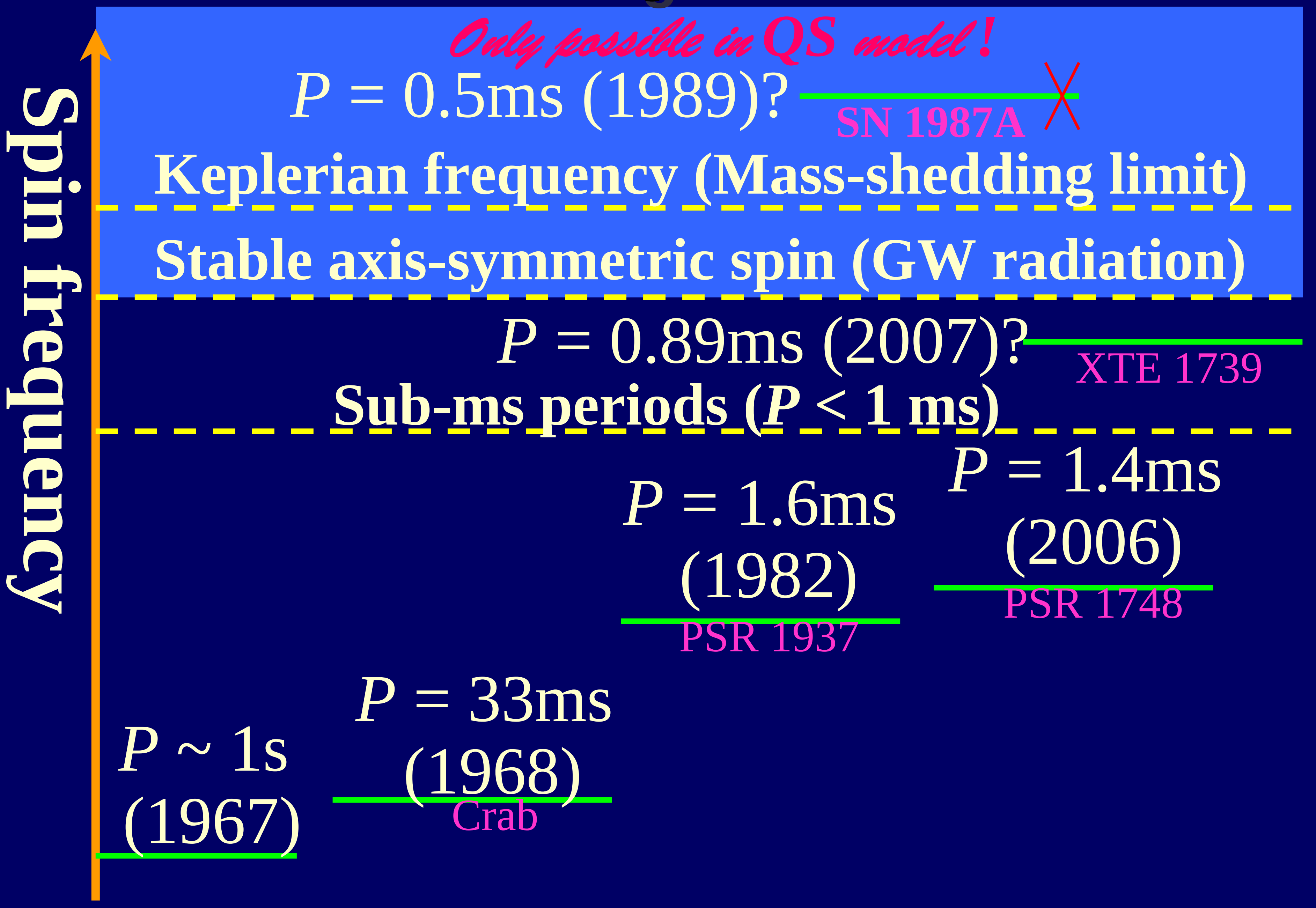
How to find clear feature to distinguish NSs and QSs?

Whether or not PSRs could rotate at sub-millisecond periods?

subms-PSRs …

Subms-PSR would be *solid* evidence for quark stars!

Milestones in detecting PSRs faster and faster



•**Minimum period of stable uniform rotating for *causal* EoSs, with good precision, is given by an empirical formula:**

Haensel et al. (1995)

$$P_{\rm min}({\rm EoS}) \approx 0.82{\rm ms}\left(\frac{M_\odot}{M_{\rm max}^{\rm stat}({\rm EoS})}\right)^{1/2}\left(\frac{R_{M_{\rm max}}^{\rm stat}({\rm EoS})}{10{\rm km}}\right)^{3/2}$$

A QS with $P < P_{\rm min}$ is possible because of low *M* and *R*!

•**Could *super*-Kepler spin be possible for QSs?**

$$P_{\rm Kepler} = 0.5\, M_1^{-1/2} R_6^{3/2}\,{\rm ms} \sim 0.6{\rm ms}$$

for *gravitationally* confined NSs!

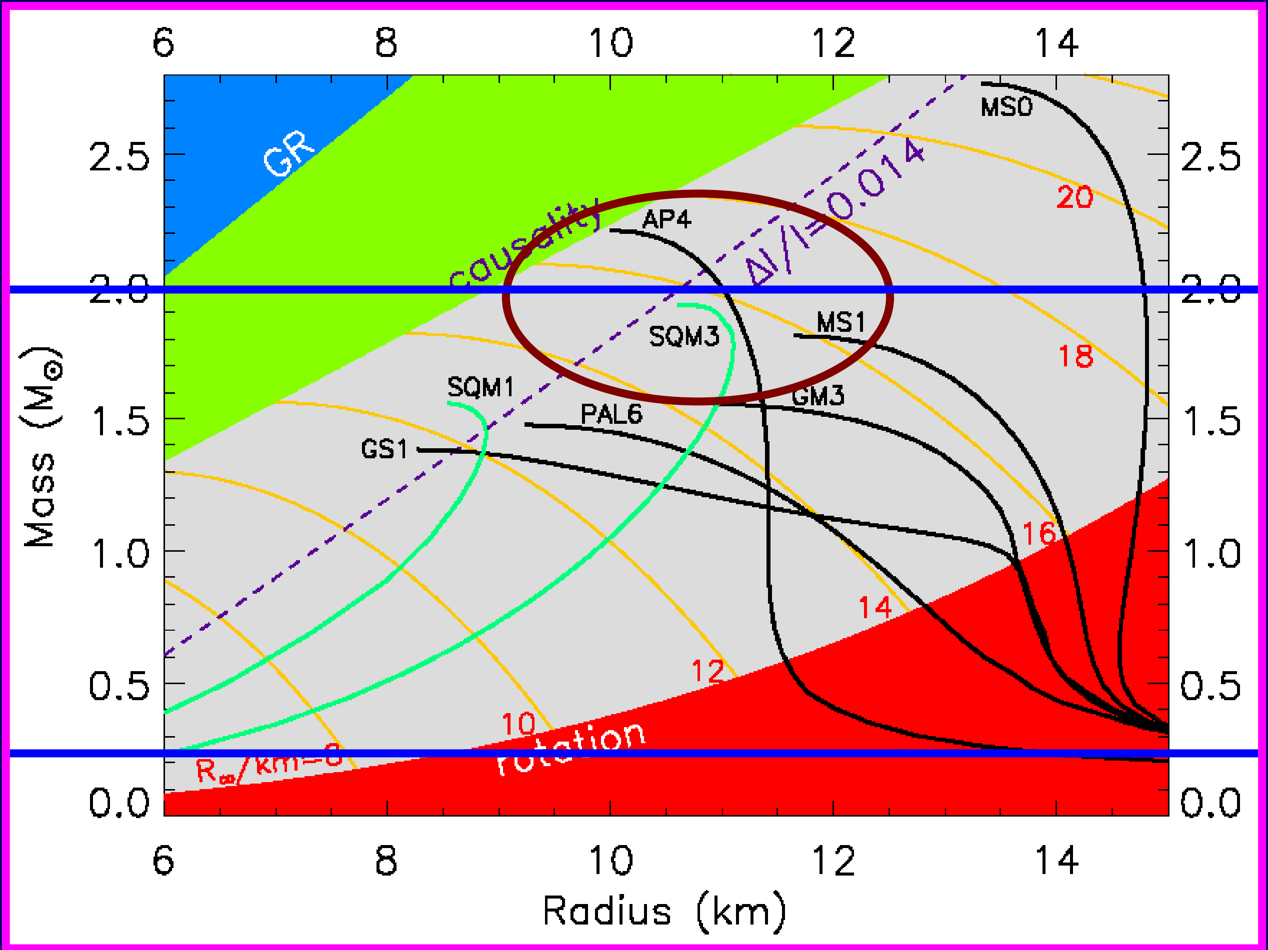
For *self*-binding QSs … High-T QGP in terrestrial experiment

RHIC → sQGP (2004) → super-Kepler?

Mass-Radius relation and spin limit

- QSs *can be* very light & small, while NSs *can not*.

⇒To *identify* a quark star in reality?



Lattimer & Prakash (2004)

~2$M_\odot$ ~10km

0.2 $M_\odot$

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Rotation powered subms-PSRs: low activity

- **Total *spindown* power:**

$$\frac{\mathrm{d}}{\mathrm{d}t}\left(\frac{1}{2}I\Omega^2\right) = I\Omega\dot{\Omega} \sim MR^2\Omega\dot{\Omega} \sim R^5\Omega\dot{\Omega}$$

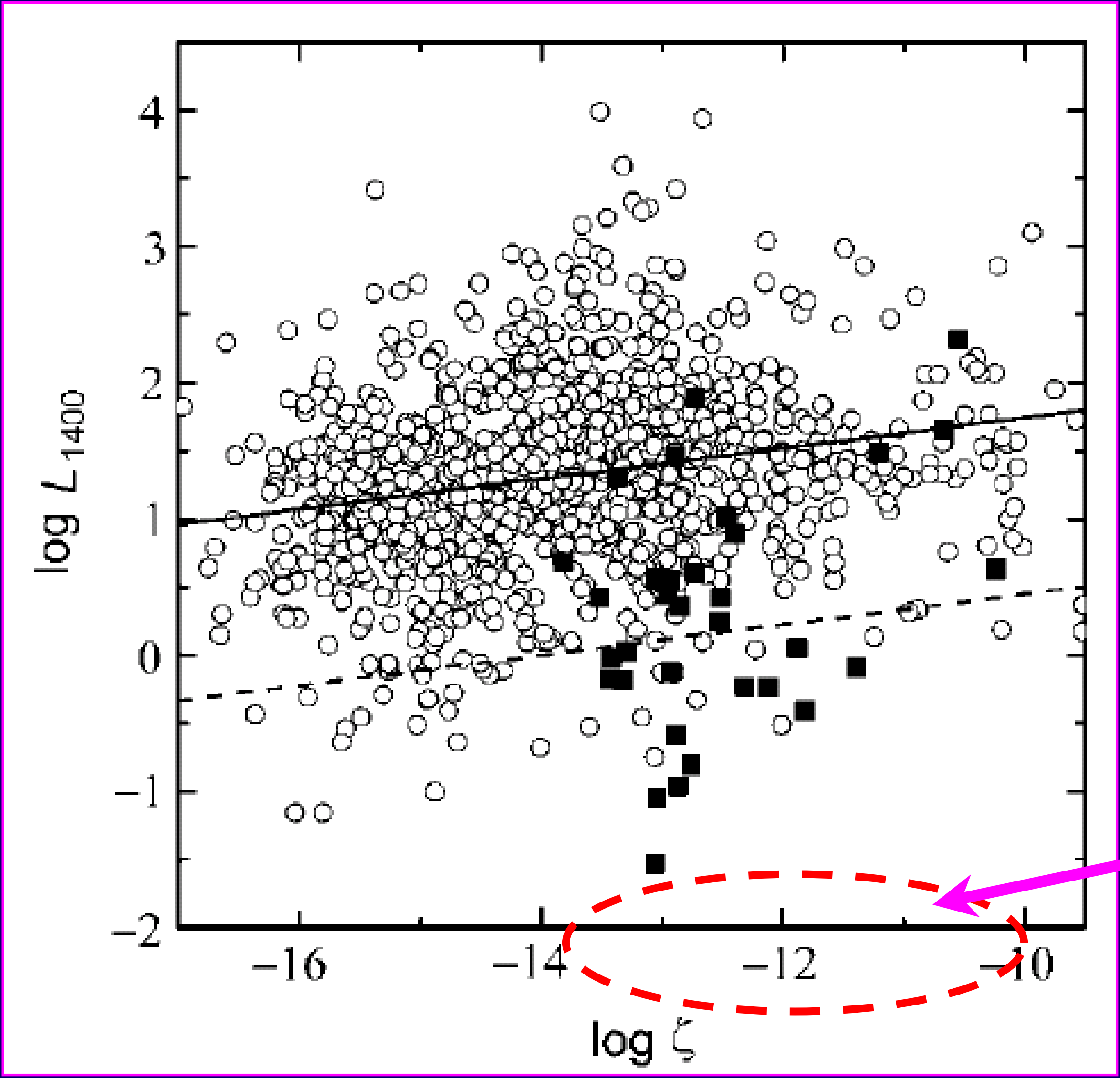
subms-PSRs with same $\mathrm{d}\Omega/\mathrm{d}t$ could be $\sim 10^{-4}$ that of msPSRs, if $R \sim 1$ km ($M \sim 10^{-3}$ Msun).

- **Subms-PSRs are very low active in their magnetosphere.**

- **Their *radio luminosity would be much lower* than that of msPSRs if the η-coefficient is the same.**

→ *More sensitive radio telescope is necessary!*

Radio luminosity: normal-PSRs vs. ms-PSRs



Xu et al. (2006)

L_{1400}: L at 1400 Hz

$\zeta \equiv (dP/dt)/P^3$

relevant to charge

○: normal PSRs

■: msPSRs, P<15ms

Subms-PSRs?

The reason that we have still not detected radio sub-msPSRs?

$$-I\Omega\dot{\Omega} = \frac{32G\Omega^6 I^2 \epsilon_e^2}{5c^5} + \frac{2}{3c^3}\mu_m^2 M^2 \Omega^4$$

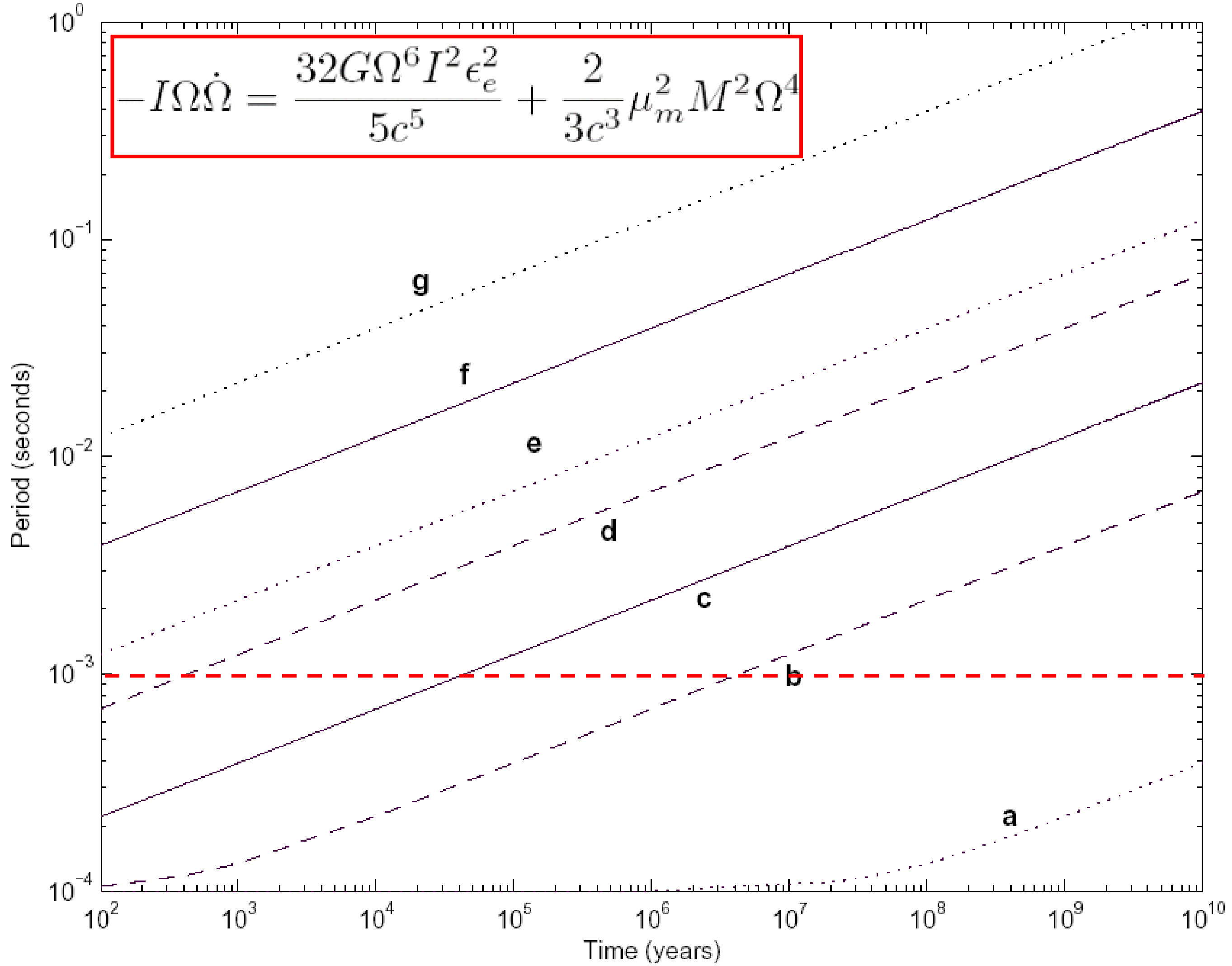


Figure 1. Gravitational-wave-radiation-induced period evolution of sub-millisecond pulsars with an initial period $P_i = 0.1$ ms for different parameters of equatorial ellipticity, ϵ_e, and effective radius, $R_{\rm eff}$, but a fixed density $\rho = 4 \times 10^{14}$ g/cm^3. The lines are labelled from "**a**" to "**g**". "a": $\epsilon_e = 10^{-3}$, $R_{\rm eff} = 0.01$ km; "b": $\epsilon_e = 10^{-3}$, $R_{\rm eff} = 0.1$ km; "c": $\epsilon_e = 0.01$, $R_{\rm eff} = 0.1$ km; "d": $\epsilon_e = 0.1$, $R_{\rm eff} = 0.1$ km; "e": $\epsilon_e = 10^{-3}$, $R_{\rm eff} = 1$ km; "f": $\epsilon_e = 0.01$, $R_{\rm eff} = 1$ km; "g": $\epsilon_e = 0.1$, $R_{\rm eff} = 1$ km.

Magnetospheric activity of submsPSRs

3. Magnetospheric activity of sub-millisecond pulsars

The potential drop in the open-field-line region is essential for the magnetospheric activity of sub-millisecond pulsars. In case of approximately constant $\mu_{\rm m}$, the potential drop between the center and the edge of a polar cap can be expressed as[8],

$$\phi = \frac{64\pi^3}{3c^2}\bar{B}\mu_m R_{\rm eff}^3 P^{-2} \simeq 2.2\times 10^{13}(\text{volts})\ \mu_{m-6} R_{\rm effkm}^3 P_{\rm ms}^{-2}, \qquad (8)$$

where the bag constant $\bar{B} = 60$ MeV/fm$^3 \simeq 10^{14}$ g/cm^3 (i.e., $\rho/4$). It is well known that pair production mechanism is a key ingredient for pulsar radio emission. A pulsar is called to be "death" if the pair production condition can not be satisfied. Although a real deathline depends upon the dynamics of detail pair and photon production, the deathline can also be conventionally taken as a line of constant potential drop ϕ. Assuming a critical drop $\phi_c = 10^{12}$ volts, a sub-millisecond pulsar with $P = 0.1$ ms could still be active even its radius is only 0.08 km, in case of $\mu_{m-6} = 1$.

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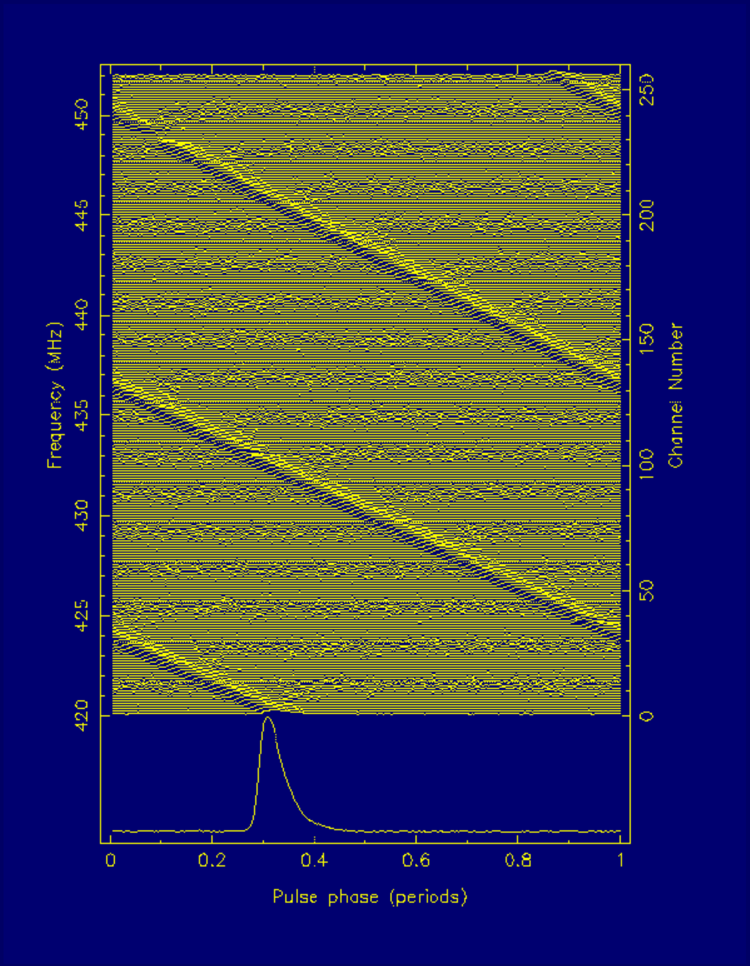
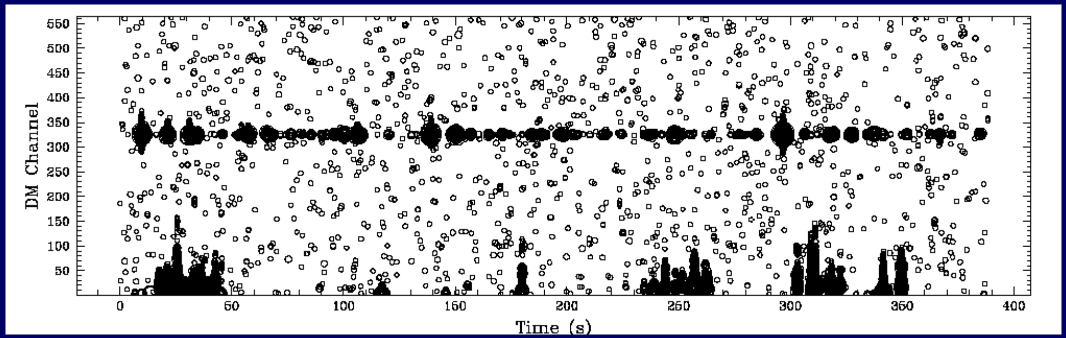
Observation of radio pulsars



$$dt = 4\times10^{6}\left(\nu_{\rm low}^{-2} - \nu_{\rm high}^{-2}\right)\cdot \rm DM$$

De-dispersion

FFT ⇒ P-search
DM-search
} **P-DM**



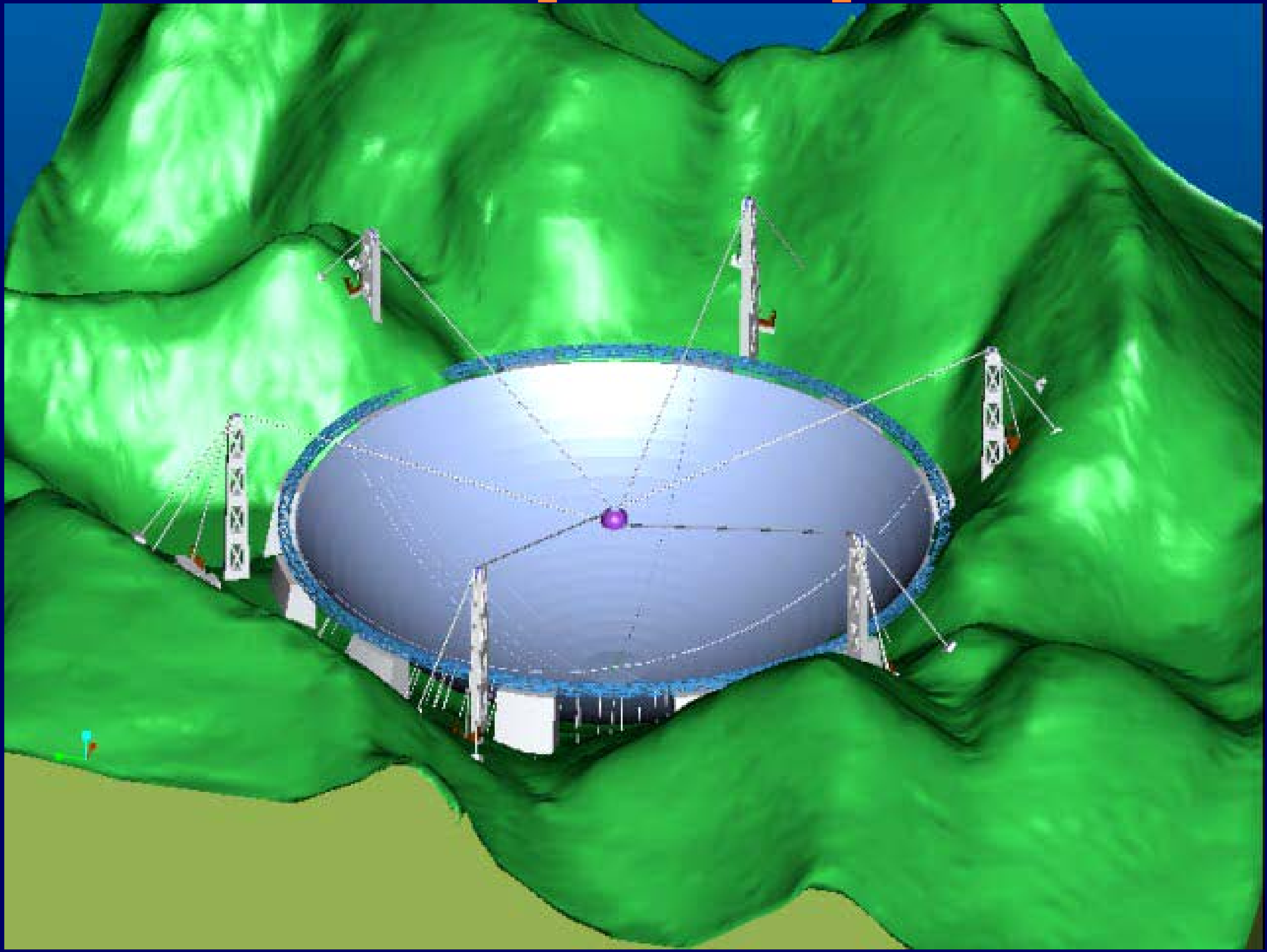
Sensitivity:

$$S_{\rm min} = \frac{C(T_{\rm sys}+T_{\rm sky})}{G\sqrt{N_{\rm p} t_{\rm int}\Delta\nu}}\sqrt{\frac{W}{P-W}}$$

Data: *Huge*

To find submsPSRs by FAST?

Five hundred meter Aperture Spherical Telescope



What if a subms PSR is found?

- ***Pulsars*** **should be a special kind of NSs (QSs!) if discovering** $P < 0.8$ **ms.**
- **Understand more about Nature:**

  formation-origin, cosmic evolution
- **Higher precision of PSR timing:**

$$\sigma_{\mathrm{TOA}} \propto \frac{T_{\mathrm{sys}}}{\sqrt{t_{\mathrm{int}}\Delta\nu}} \frac{P(W/P)^{3/2}}{S_{\mathrm{mean}}}$$

⇒ **GWR background detection**

⇒ **Time standard based on PSR timing**

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Conclusion

- To find a submillisend PSR is *clear* evidence for quark stars. If successful, it will certainly improve our understanding of the elementary strong interaction between quarks.
- Because of low masses, the radio luminosity of subms-PSRs should be low, but X-ray pulsation may be significant for detection.
- To search submsPSRs is supposed to be one of the key projects in the future FAST program.

Thanks a lot

and

hope to receive your comment-suggestion

Any time

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