Spin period evolution of GX 1+4

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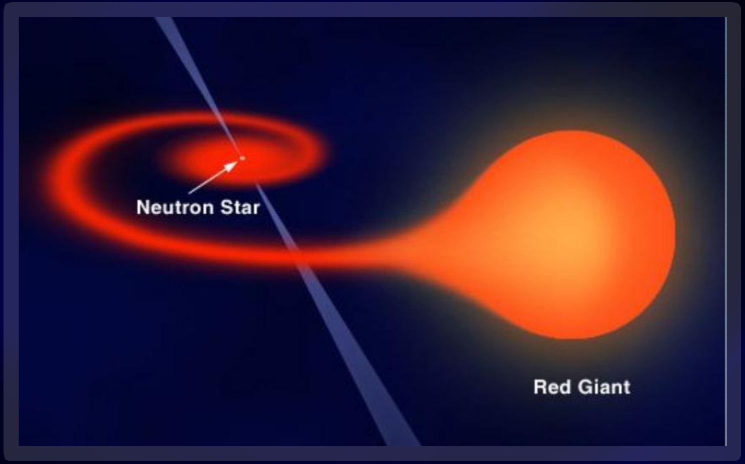
GX 1+4

Symbiotic accreting X-ray pulsar

M (V2116 Oph) ~ 1.2 M⊙ (Hinkle et al. 2006) **LMXB**



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Some properties of LMXB:

- Roche lobe overflow.
- Old systems with low magnetic field.
- Porb ~ from few minutos to hundred of days.

Some properties of GX +4:

- Wind fed system (Hinkle et al. 2006).
- High magnetic field (~10^{13} G (Cui & Smith 2004), ~ 10^{12} G (Ferrigno et al. 2007)).
- Porb ~ 1161 days (Hinkle et al. 2006).

GX 1+4

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GX 1+4

Symbiotic accreting X-ray pulsar

Lewin et al. 1971:

- Discovery of GX 1+4 in 1970
- X-ray pulses with **P** ~ **2 min**

Davidsen et al. 1977: **SyXB**

The optical companion is an M giant

GX 1+4

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- Compact object = White dwarf.

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GX 1+4 is the first LMXB with an M giant companion.
GX 1+4 is the first SyXB with a NS.

Only 4 SyXB with NS have already been confirmed.

GX 1+4

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Only 4 SyXB with NS have already been confirmed.

Some properties of SyXB with NS:

- Porb ~ 500 days or even more (GX 1+4 Porb ~ 1161 days).
- X-ray light curves dominated by irregular flaring type behavior.
- NS are slow rotators (GX 1+4 Pspin ~160 s).

Satellites & Instruments

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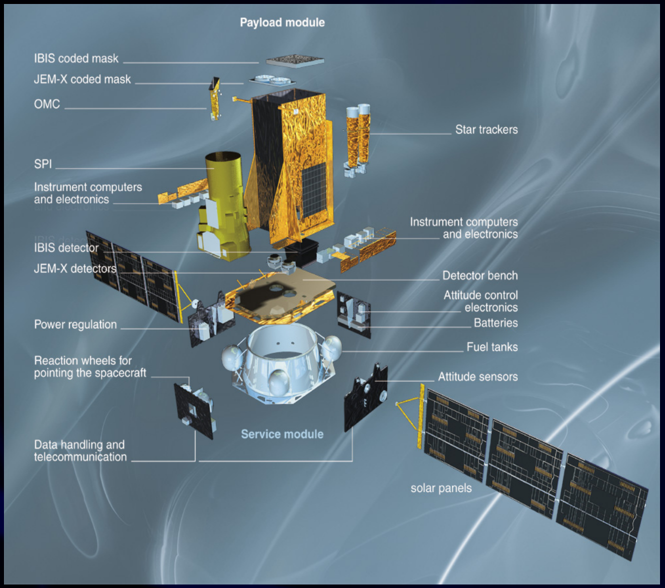

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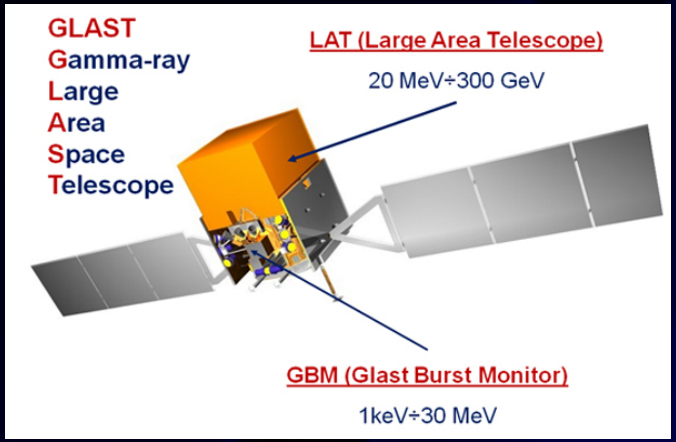

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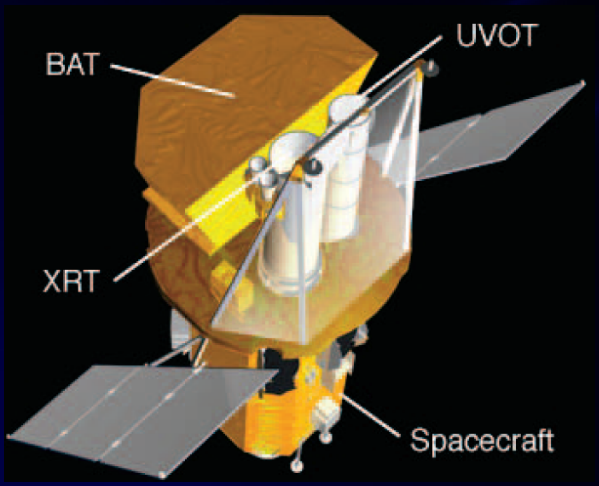
Swift/BAT



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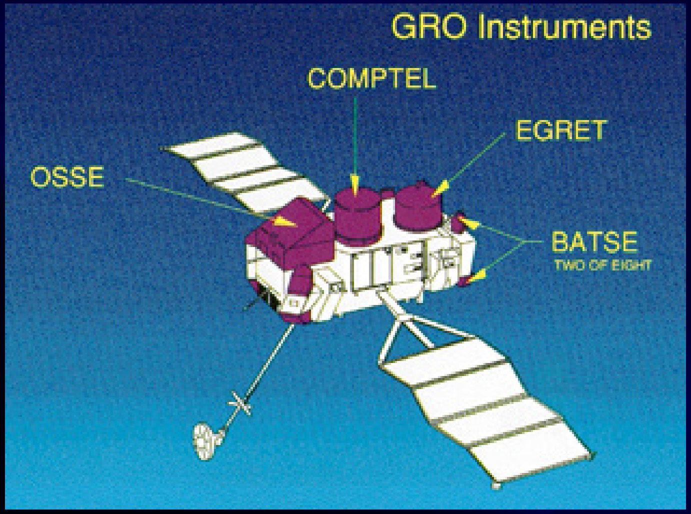
CGRO/BATSE



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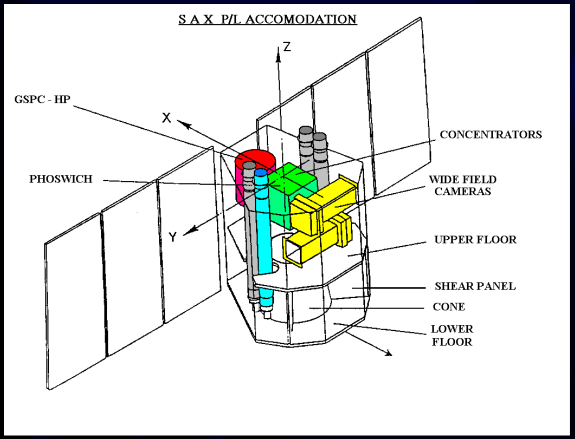

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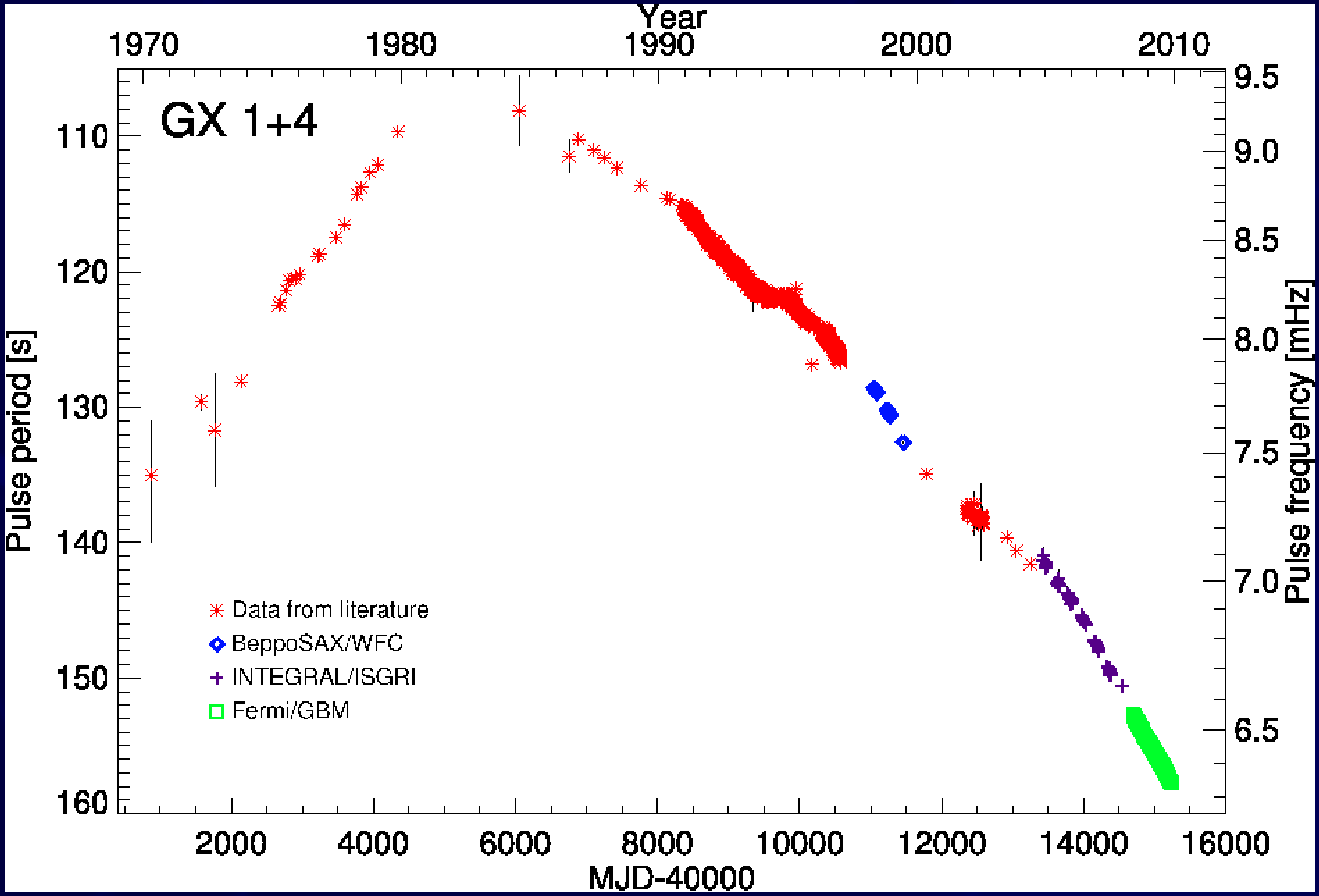
Results: Long-term spin period history



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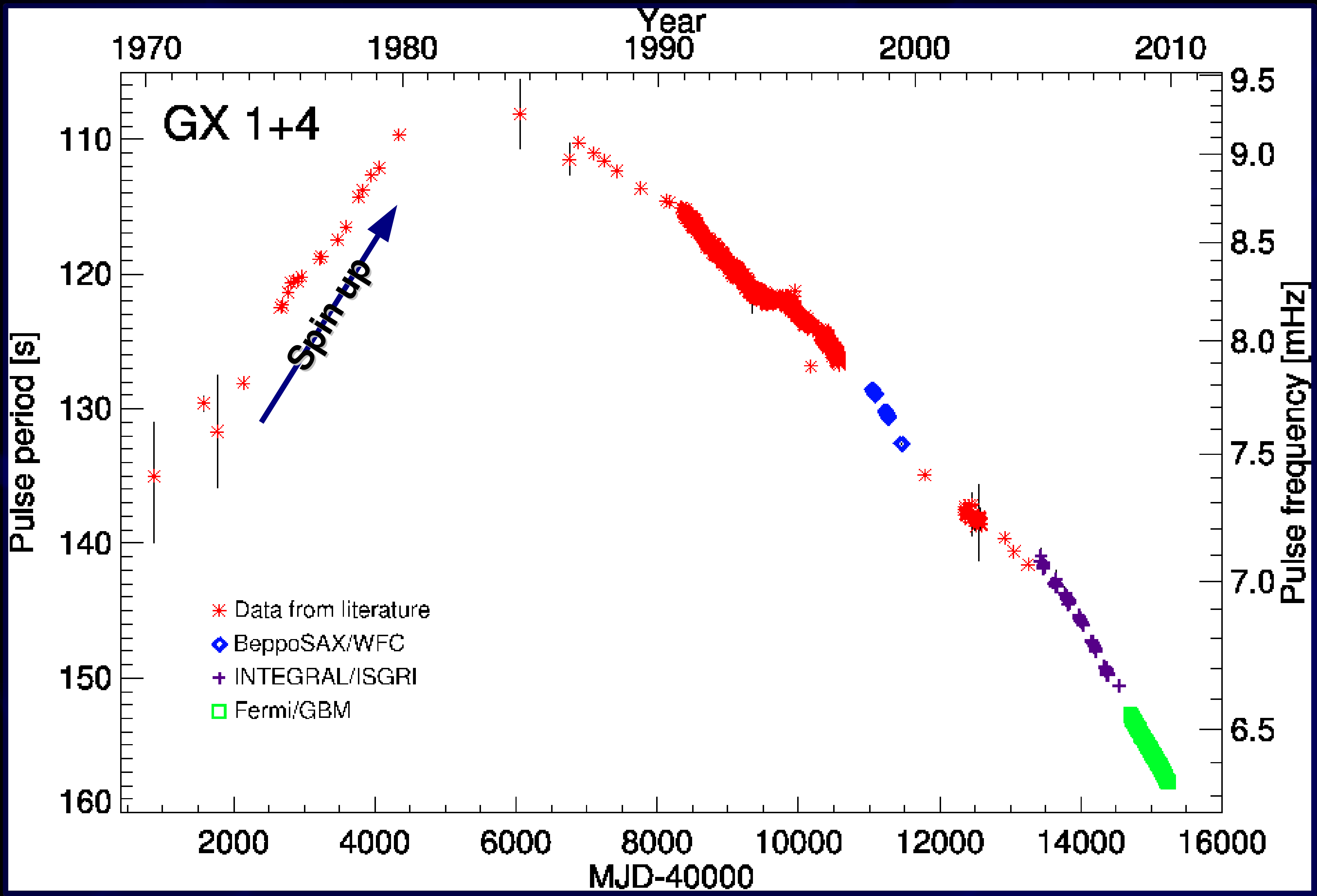

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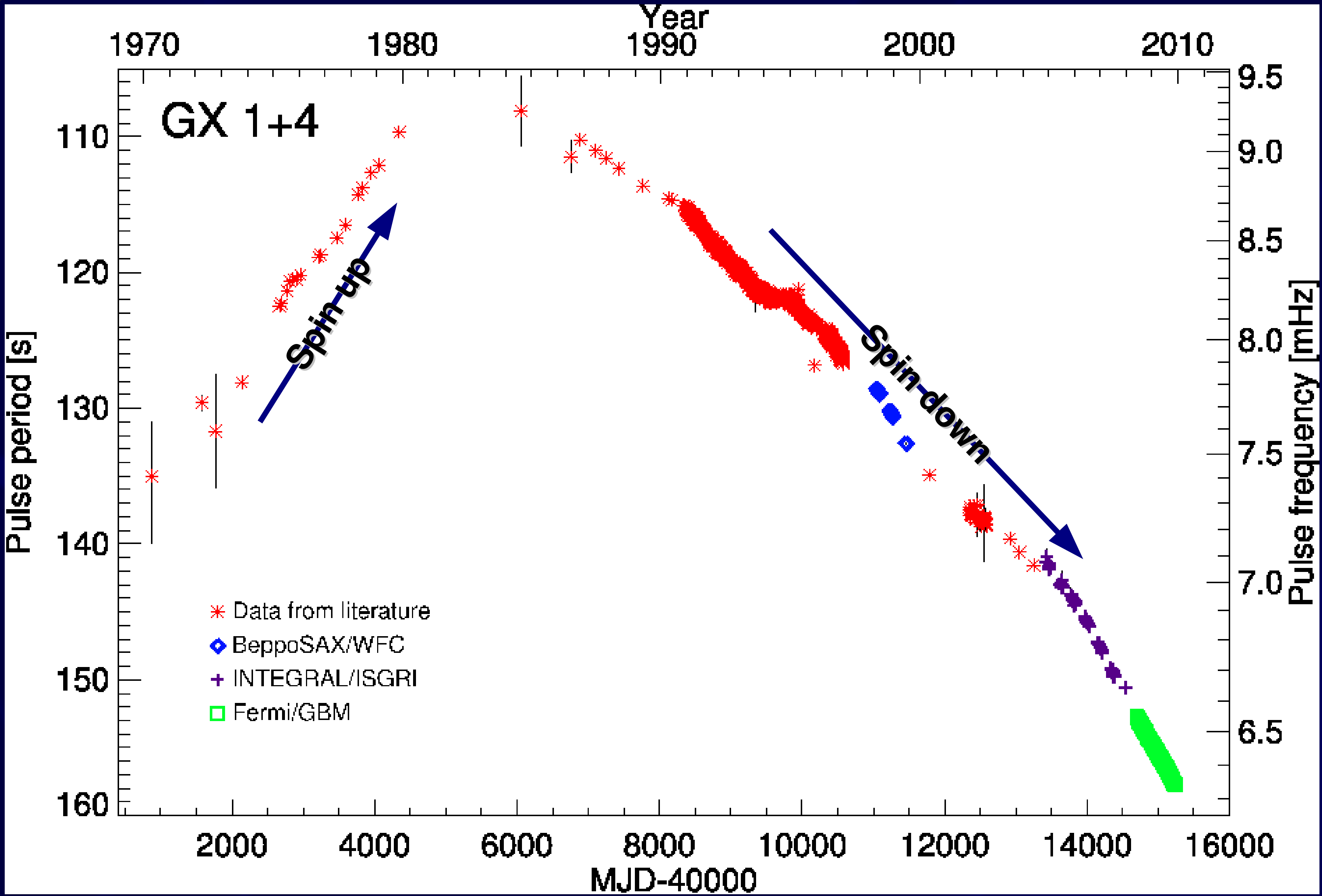

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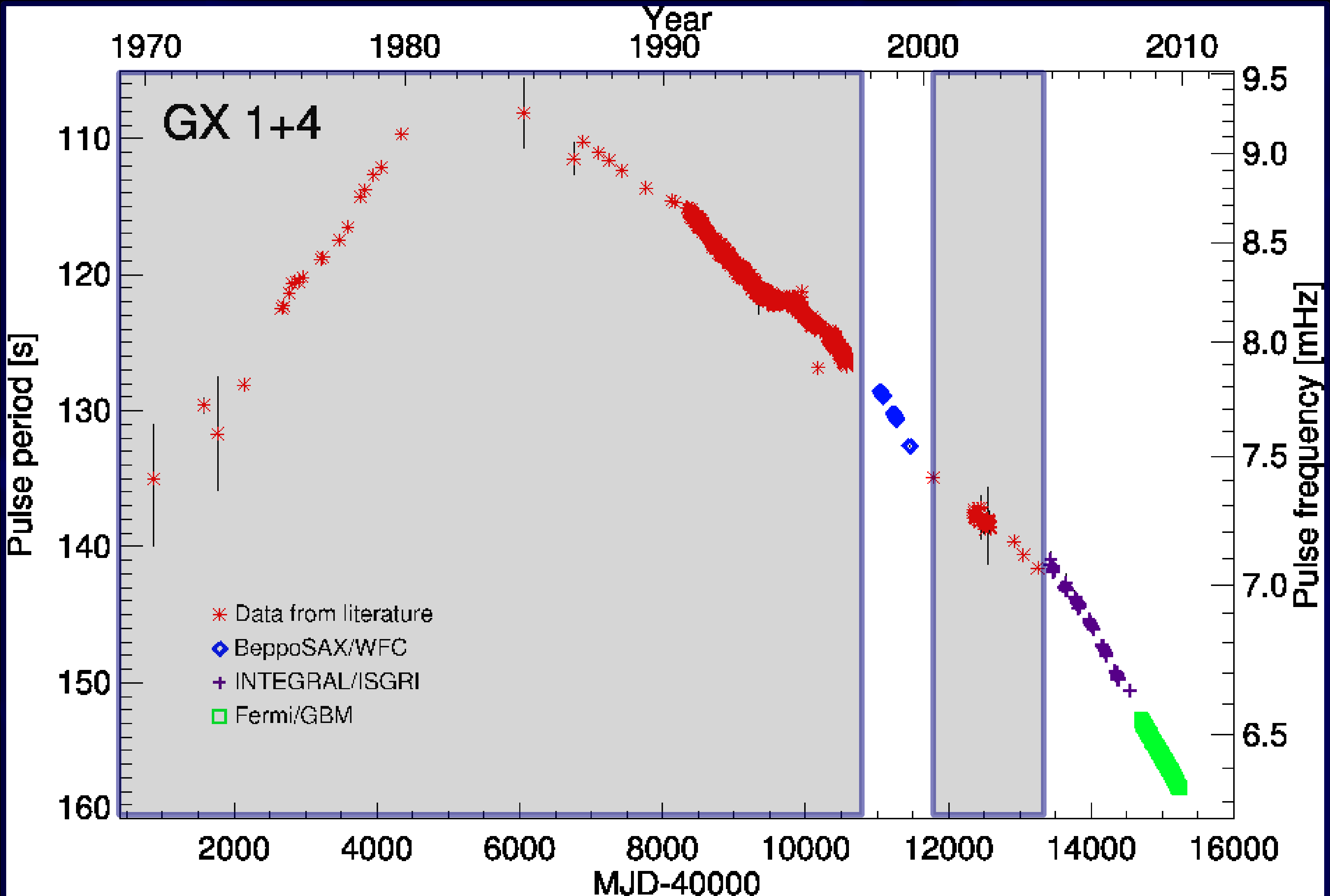

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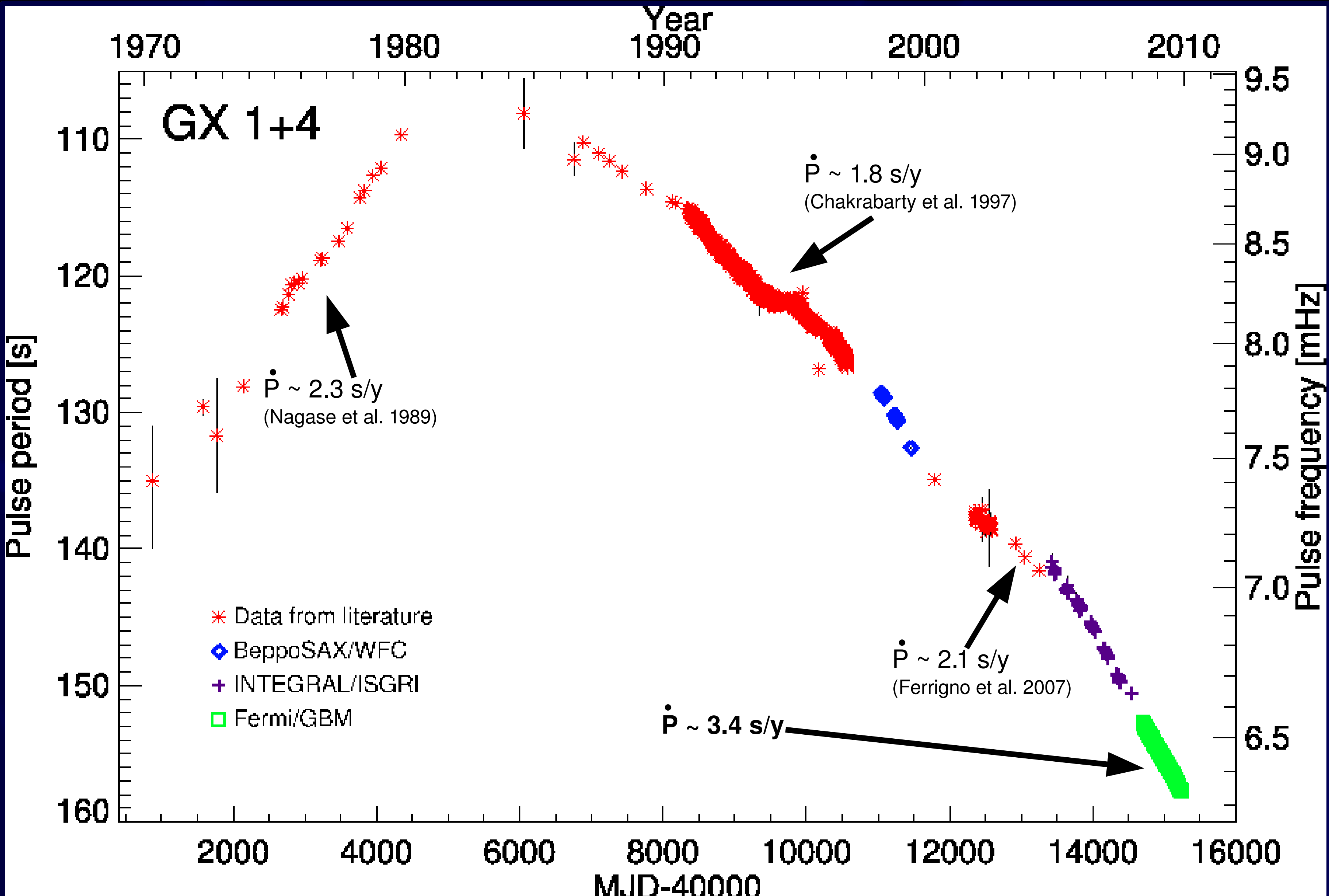

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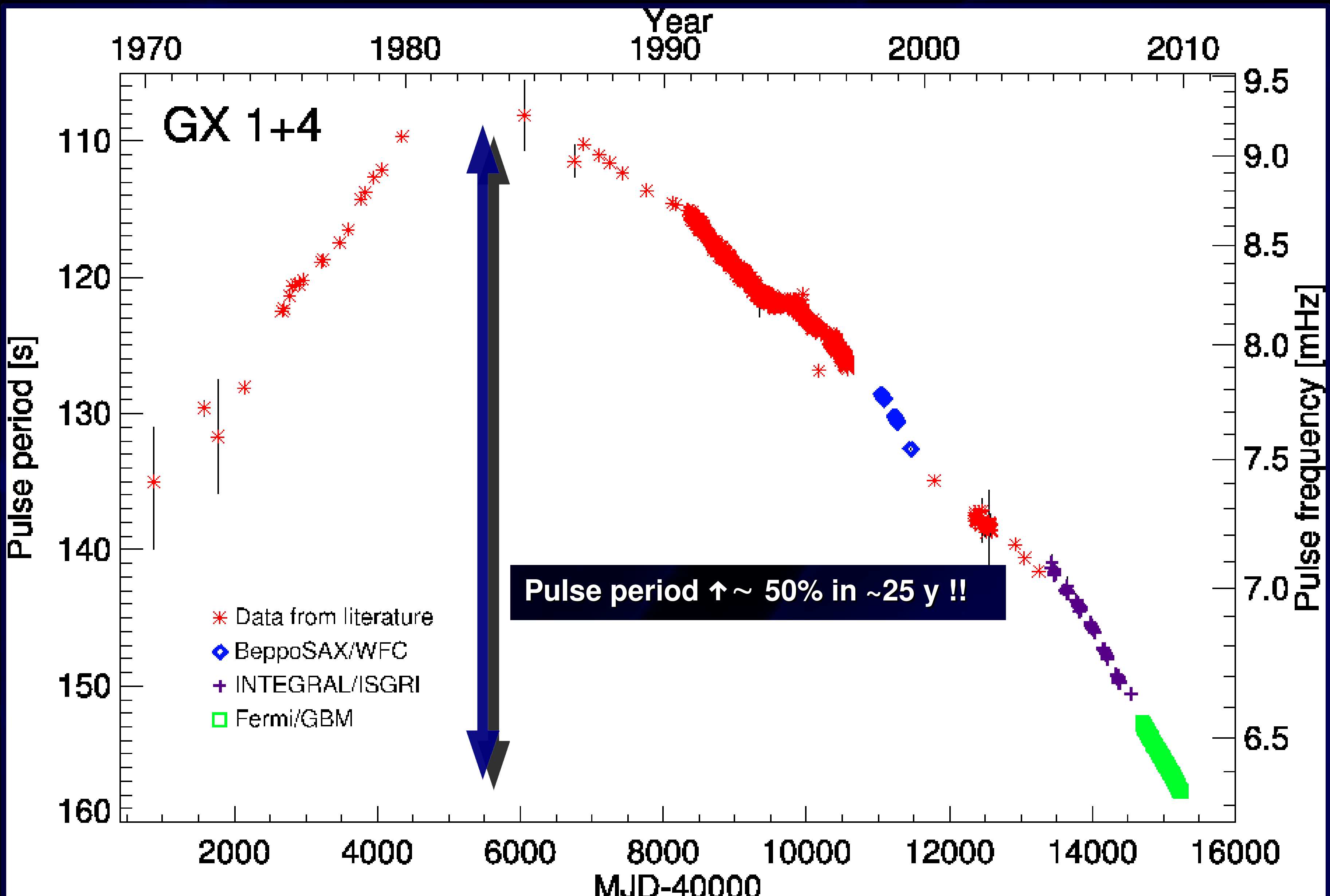

Results: Pulse periods and fluxes

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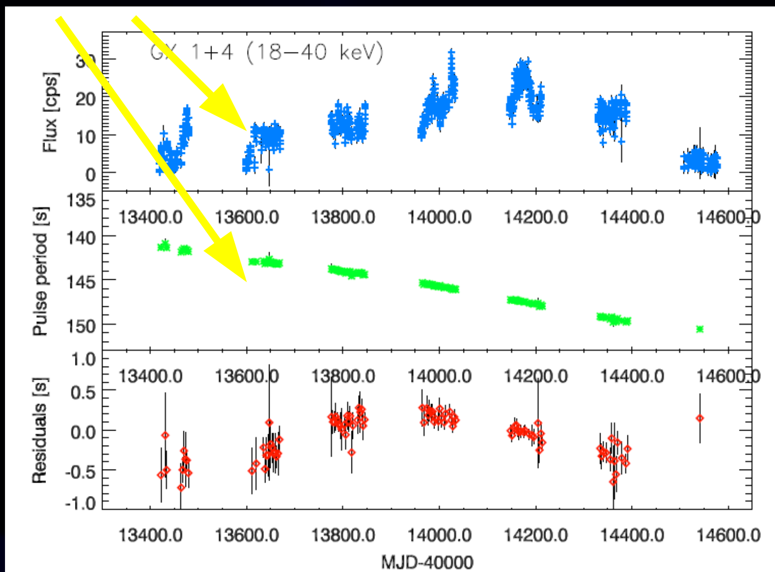

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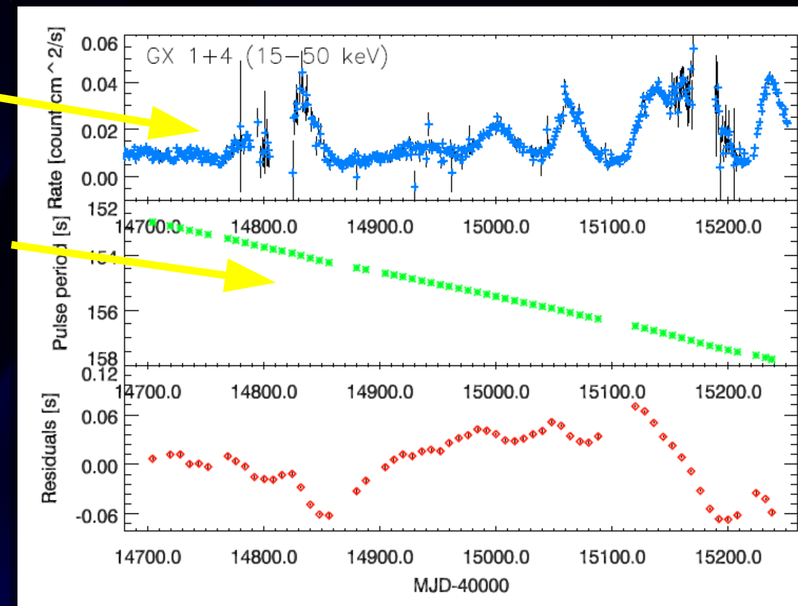

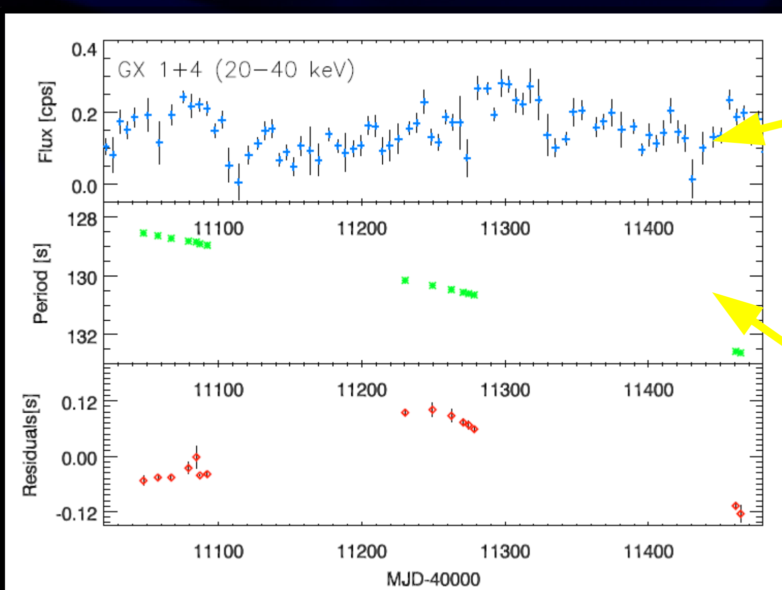

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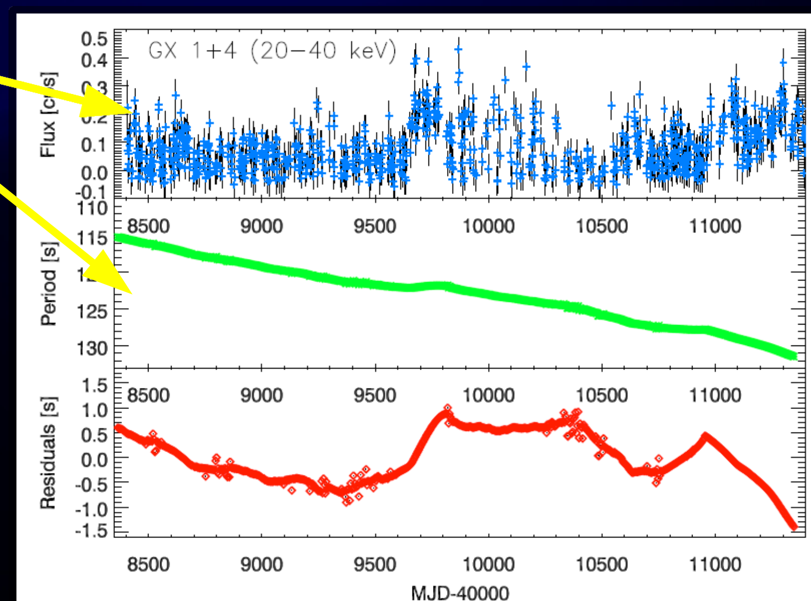
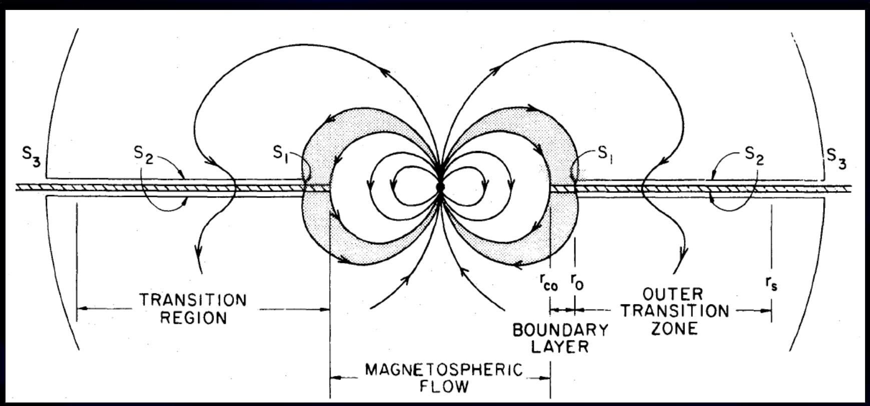
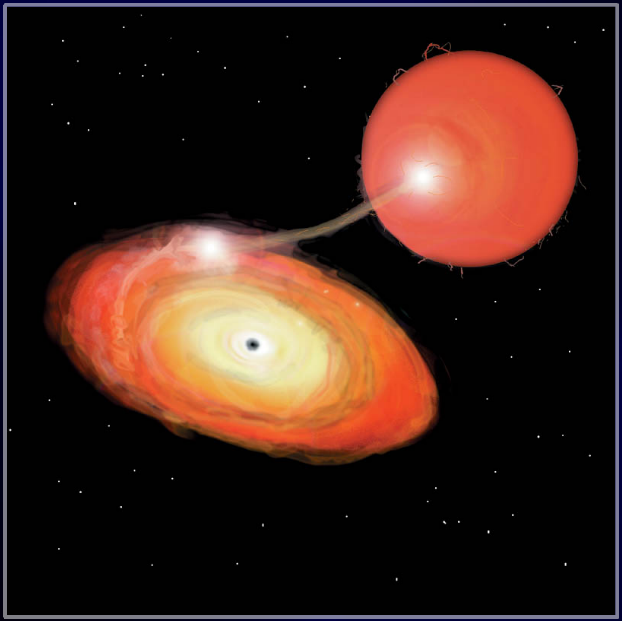


Theoretical models

1. Standard disk accretion → NS rotating in the same direction as the disk

Ghosh & Lamb (1979)





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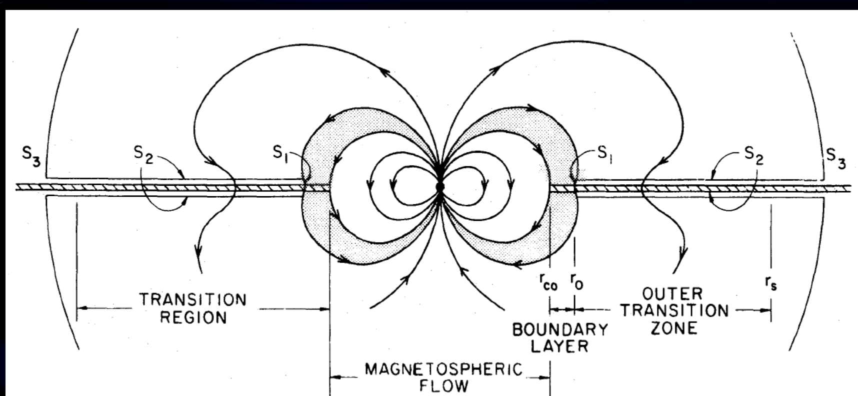
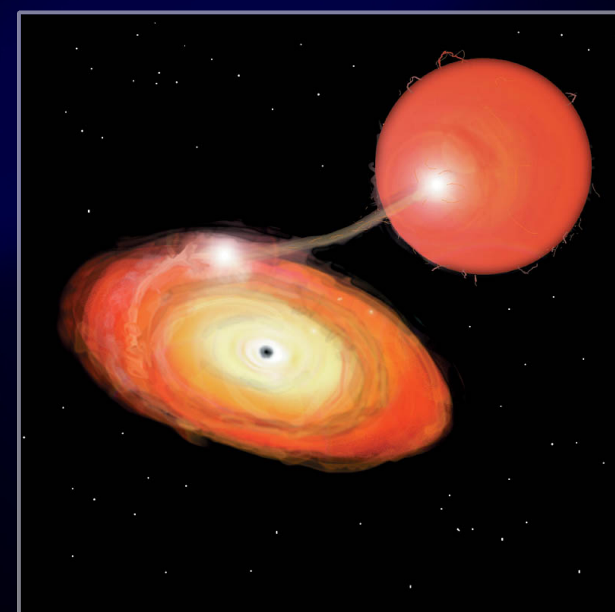


$$\dot{M}\uparrow \Rightarrow P\downarrow \Rightarrow \dot{P}<0\,\&-\dot{P}\uparrow$$
$$\dot{M}\downarrow \Rightarrow P\downarrow \& -\dot{P}\downarrow$$
$$\dot{M}=\dot{M}_C \Rightarrow P\uparrow \Rightarrow \dot{P}>0\,\&\,\dot{P}\uparrow \rightarrow \dot{M}_{MIN} \Rightarrow \dot{P}=0$$



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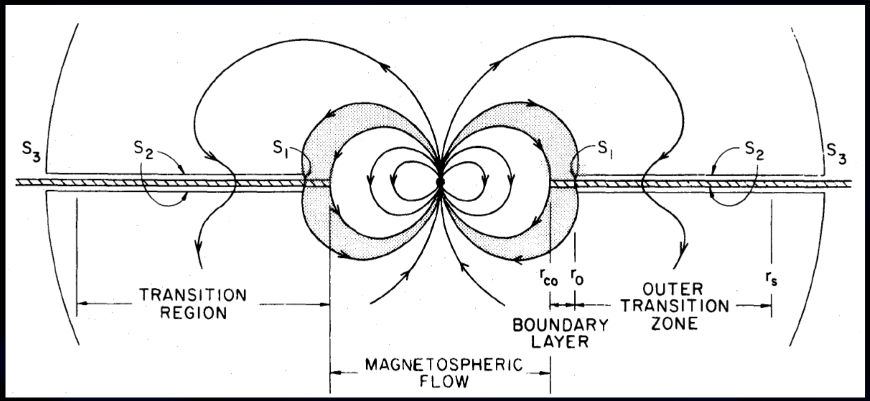
→ NS rotating in the same direction as the disk

↘ Spin-down ⇒ NS near its equilibrium period

↘ $r_m \simeq r_{co} \Rightarrow B \sim 10^{13}\,G$



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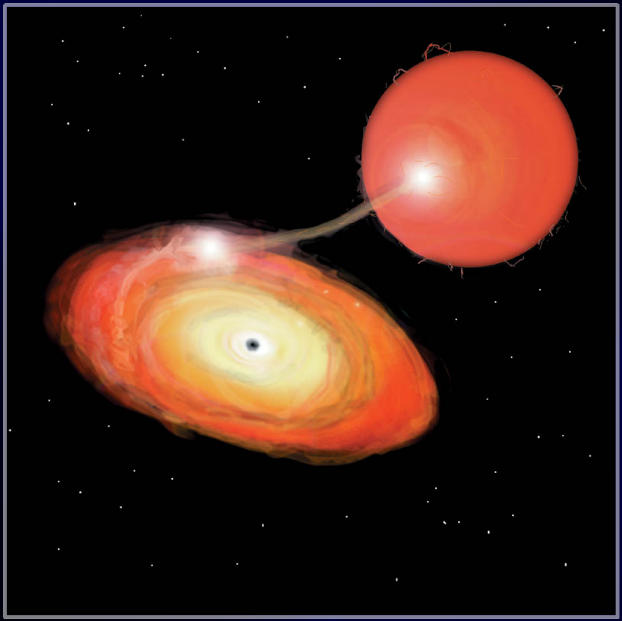
$$\dot{M} \propto F_X$$



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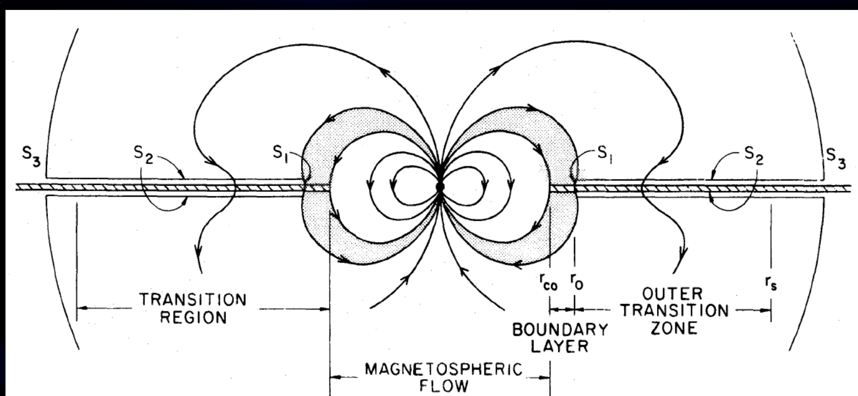

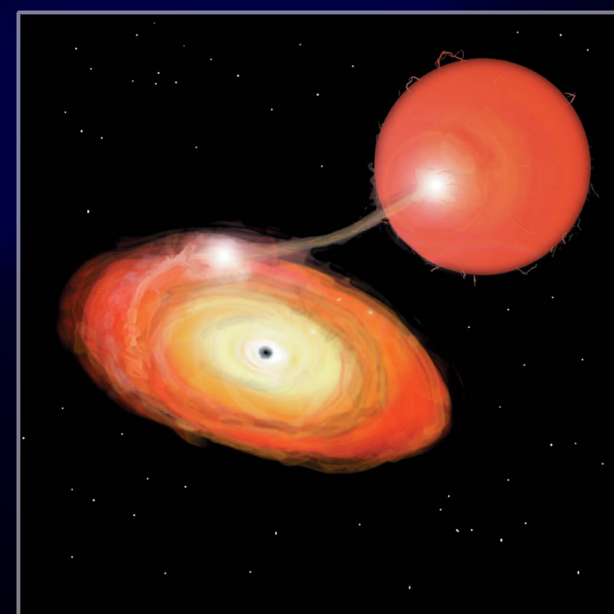

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Equations:

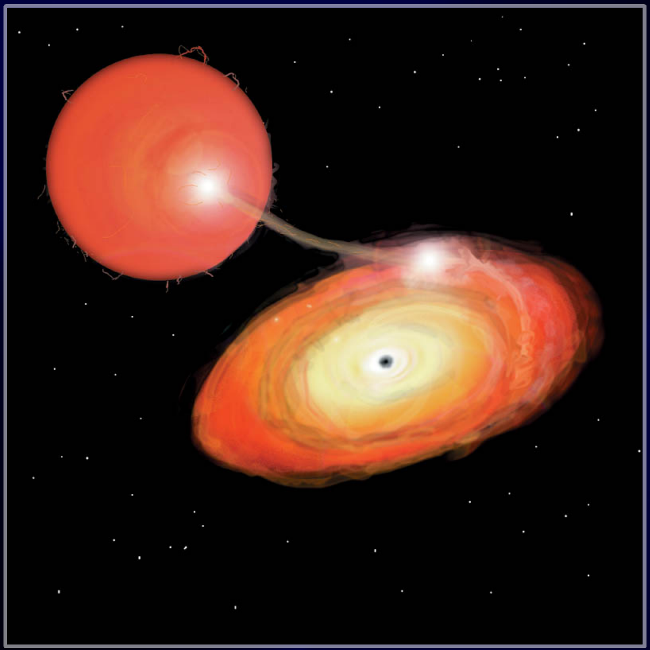
$$\frac{dI\,\omega}{dt} = \dot{M}\sqrt{G\,M\,R_A} = A\,\dot{M}^{6/7}$$

$$-\dot{P} \propto \dot{M}^{6/7} \Rightarrow \dot{\nu} \propto F_X^{6/7}$$

$$L_X \sim ct \Rightarrow P(t) = P(t_0) - B(t - t_0)$$

Theoretical models

2. Retrograde disk accretion
Makishima et al. (1988) → NS rotating in the opposite direction to the disk



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Theoretical models

2. Retrograde disk accretion

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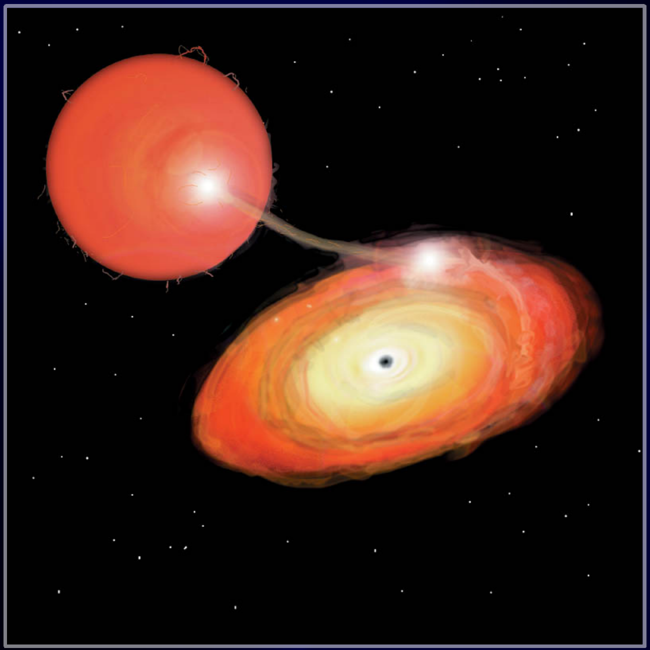
Transient disks with an alternating sense of rotation are known to form in numerical simulations in binary systems fed from stellar wind. (Fryxel & Taam 1988)



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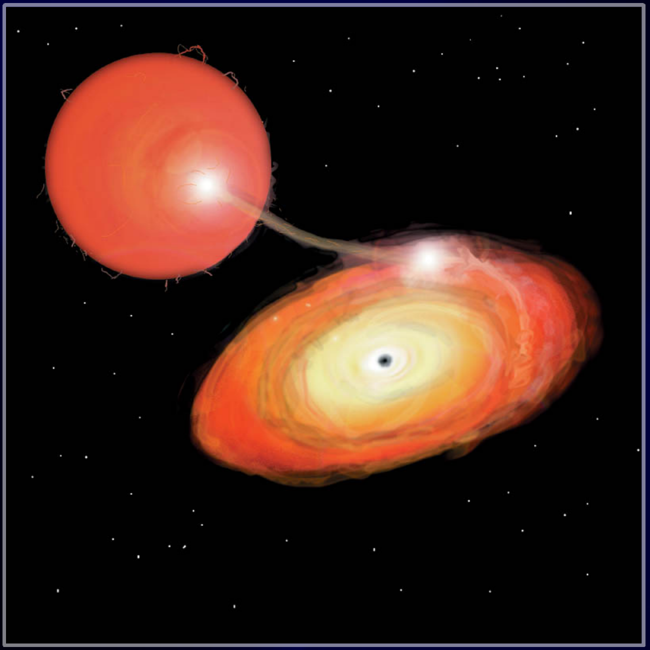
Spin-down $\not\Rightarrow$ NS near its equilibrium period

$$r_m \not\approx r_{co} \Rightarrow B \sim 10^{12}\, G$$



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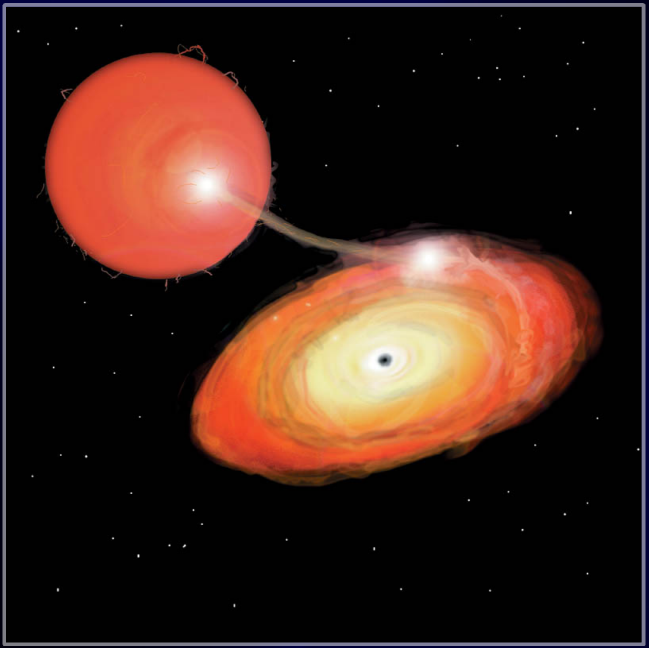
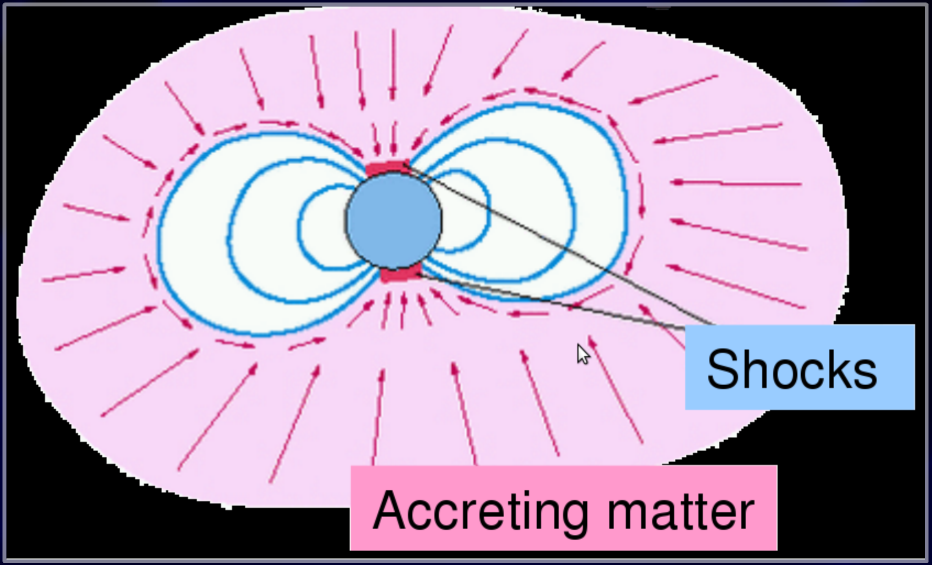


Theoretical models

3. Quasi-spherical accretion

González-Galán et al. in prep.

No accretion disk formation around the NS



Theoretical models

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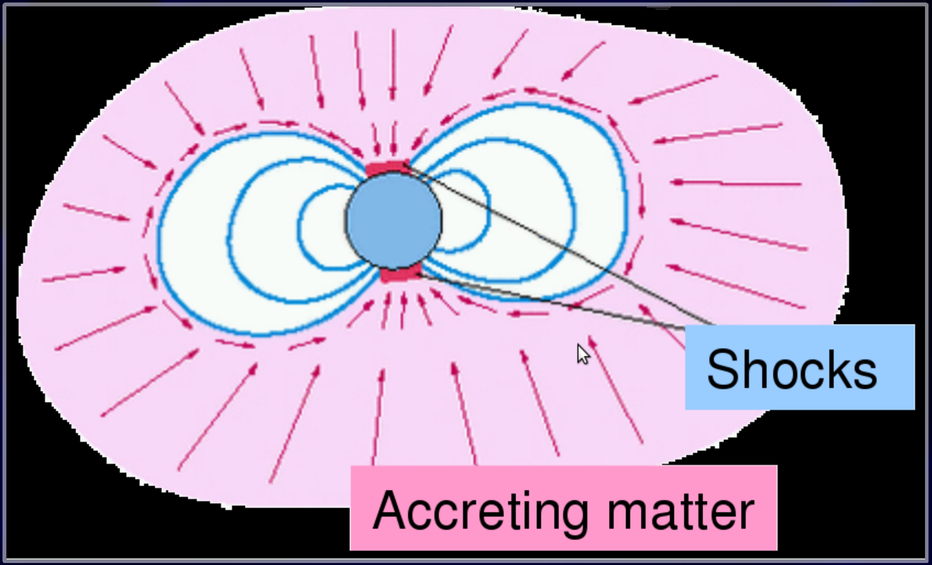
“Atmosphere” around the NS.

Spin-down ⇏ NS near its equilibrium period

↓

$B \sim 10^{13}$ not required but not discarded



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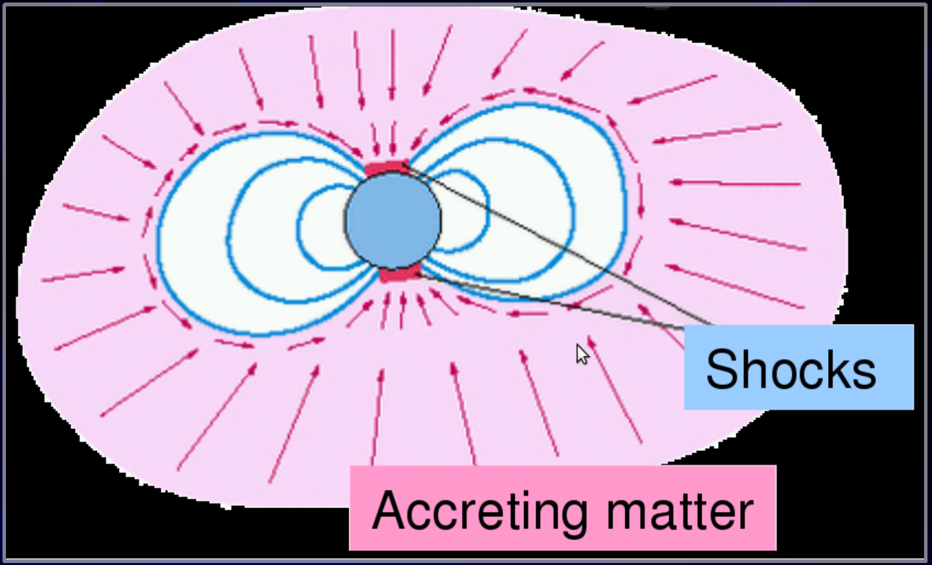


Equations (spin-down dominates)

(Shakura et al. in prep):

$$\frac{dI\,\omega}{dt} = -\kappa_{sd}\,\dot{M}\,\omega\,R_A^2$$

$$\dot{P} \propto \dot{M}^{3/7} \Rightarrow -\dot{\nu} \propto F_X^{3/7}$$

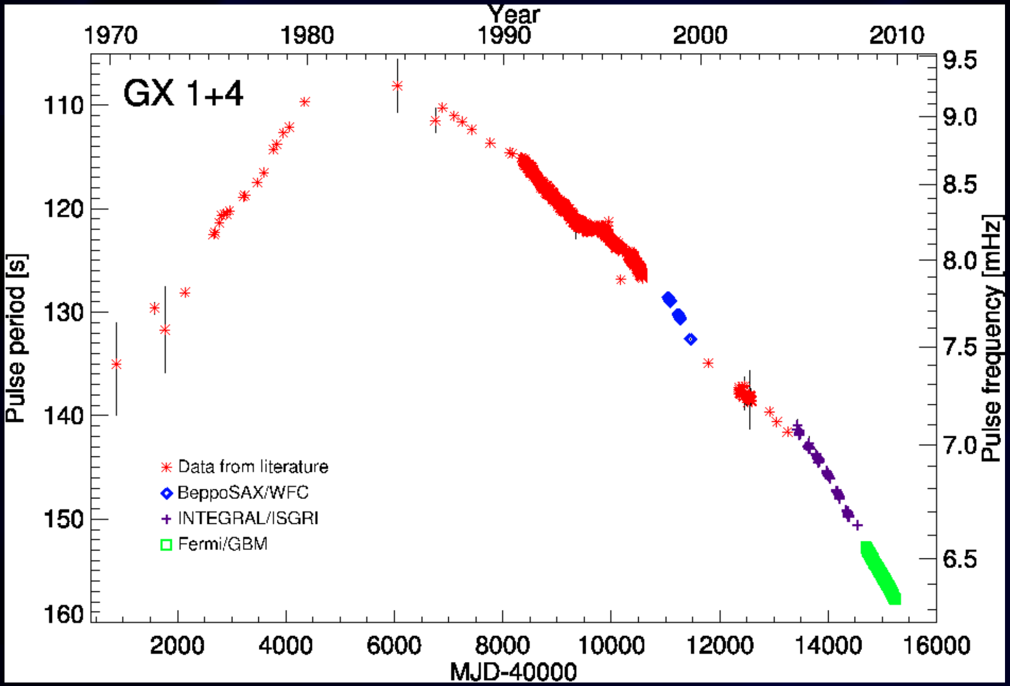
$$L_X \sim ct \Rightarrow P(t) = P(t_0)\,e^{t/\tau}$$

Discussion

Standard disk accretion

Retrograde disk accretion

Quasi-spherical accretion



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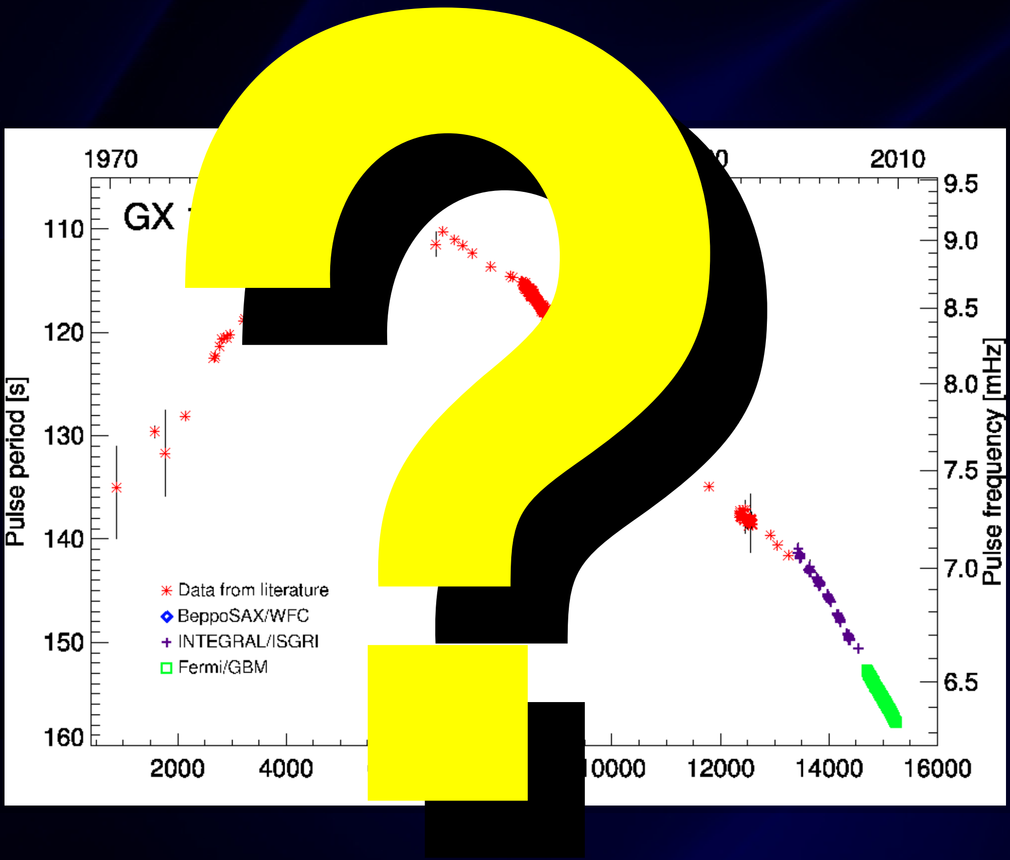
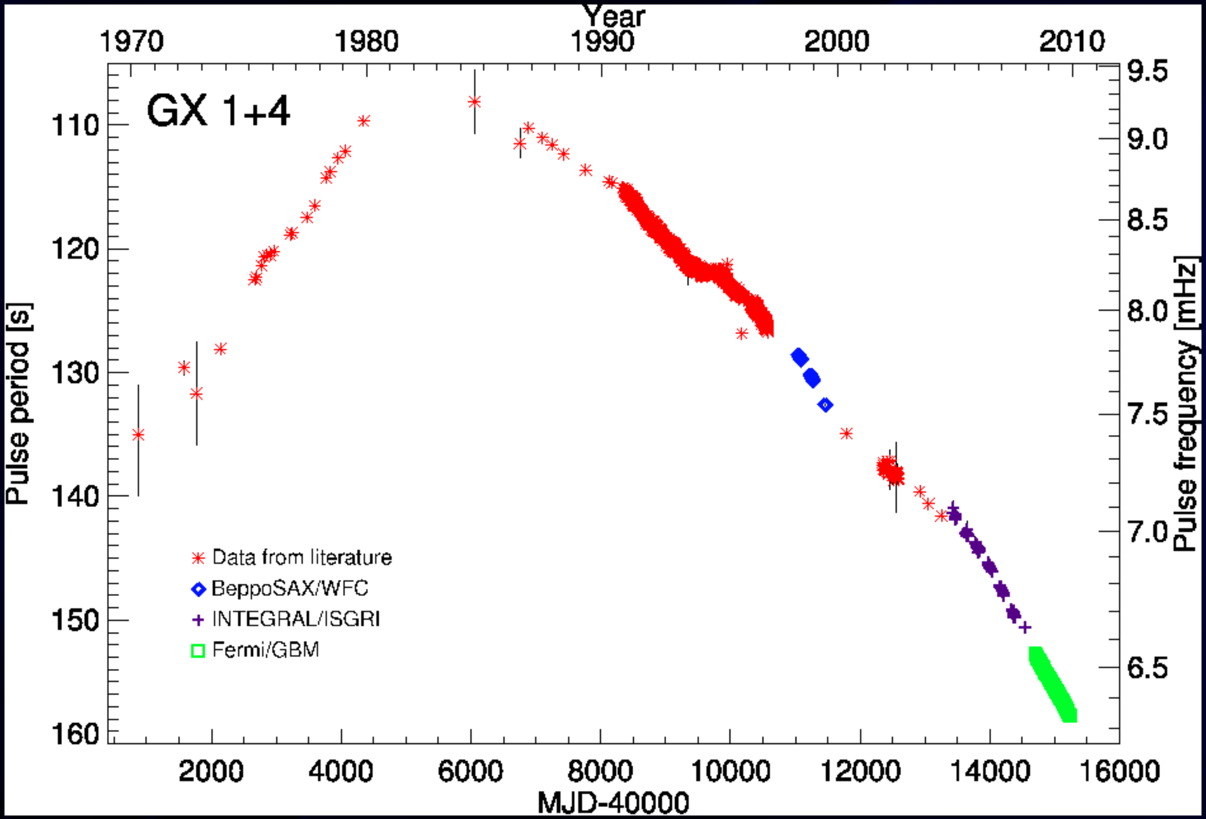


Discussion

Standard disk accretion during spin-up



Discussion

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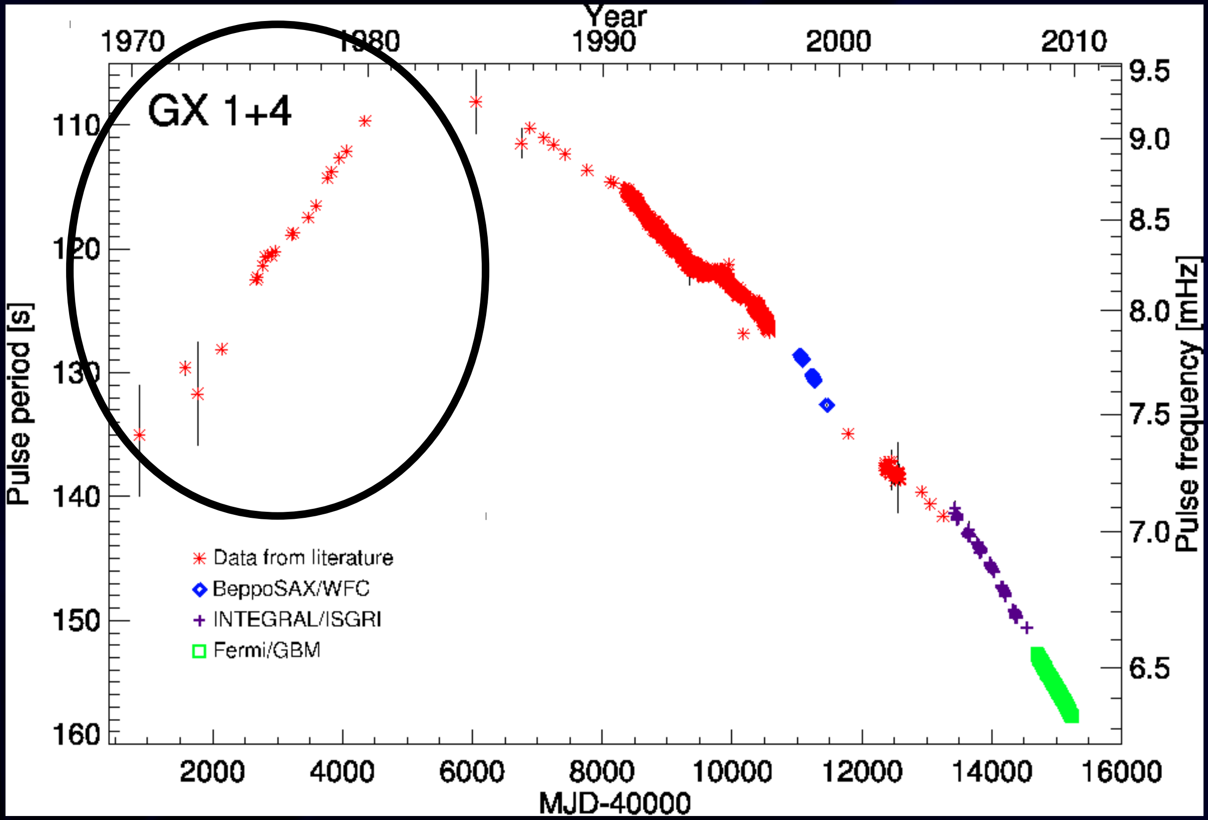

Discussion

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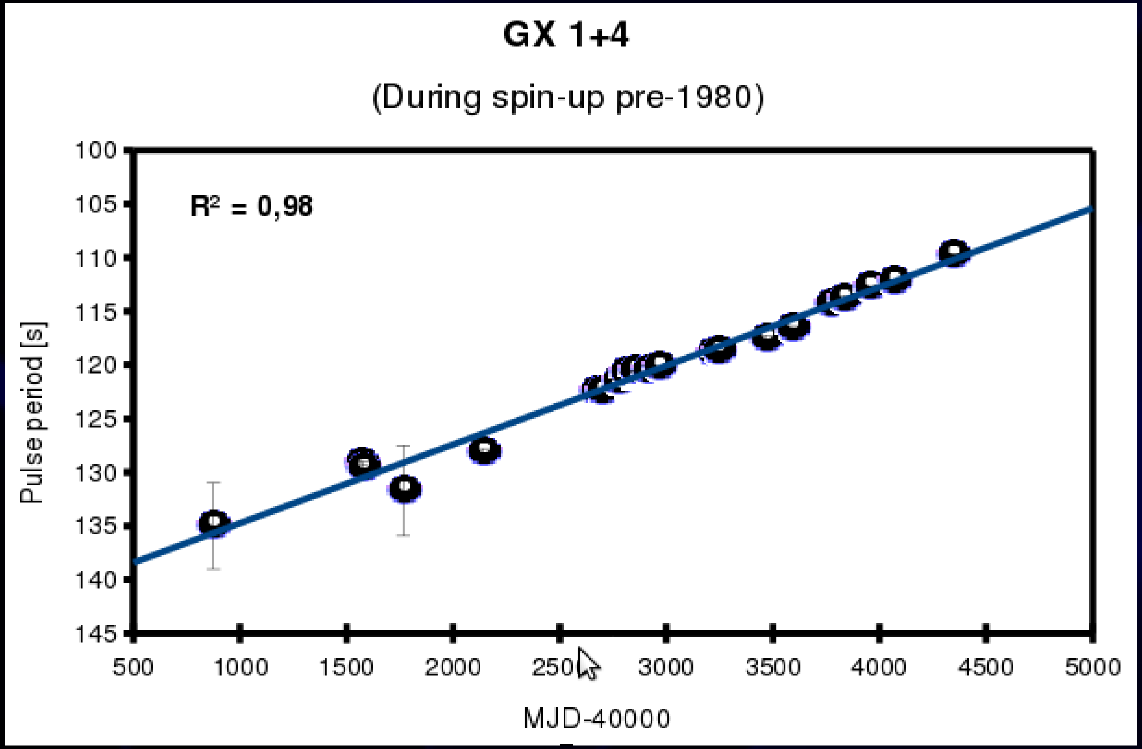


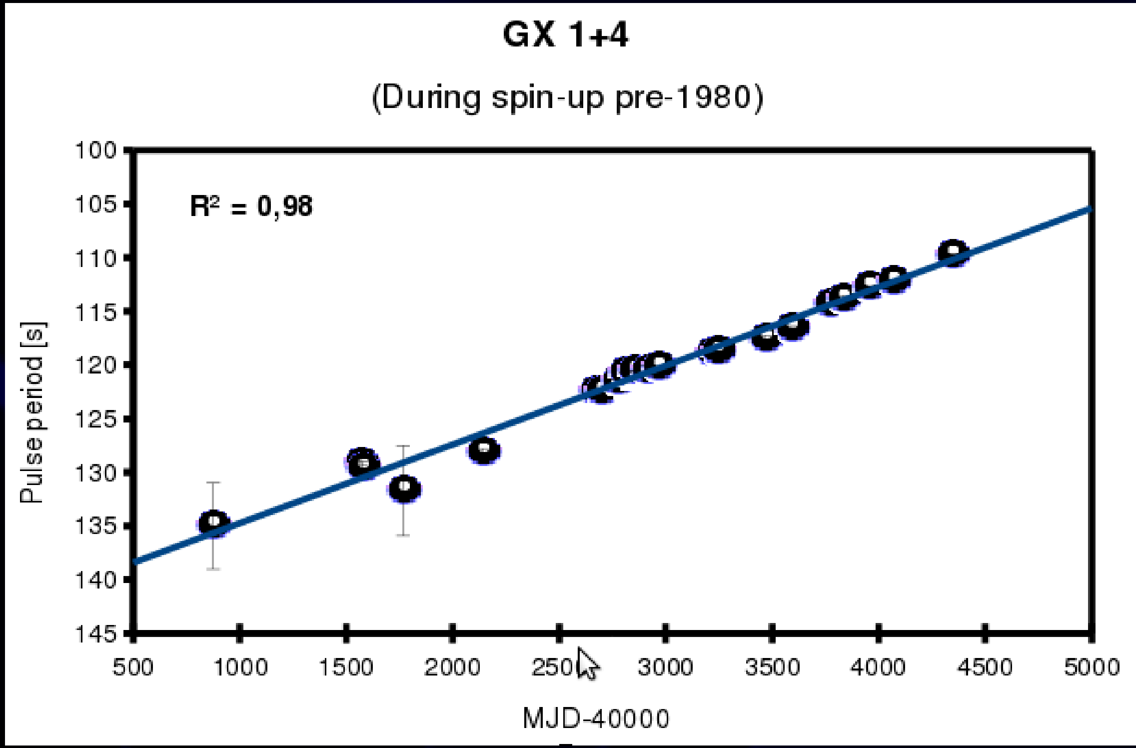
Linear trend:

Accretion disk spinning-up the NS

$$\dot{P} < 0 \;\&\; \dot{P} \sim ct \Rightarrow \dot{M} \sim ct \Rightarrow \boldsymbol{L_X \sim ct}$$

Discussion

Standard disk accretion during spin-up ✔



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$$\dot{P} < 0 \;\&\; \dot{P} \sim ct \Rightarrow \dot{M} \sim ct \Rightarrow L_X \boldsymbol{\sim ct}$$

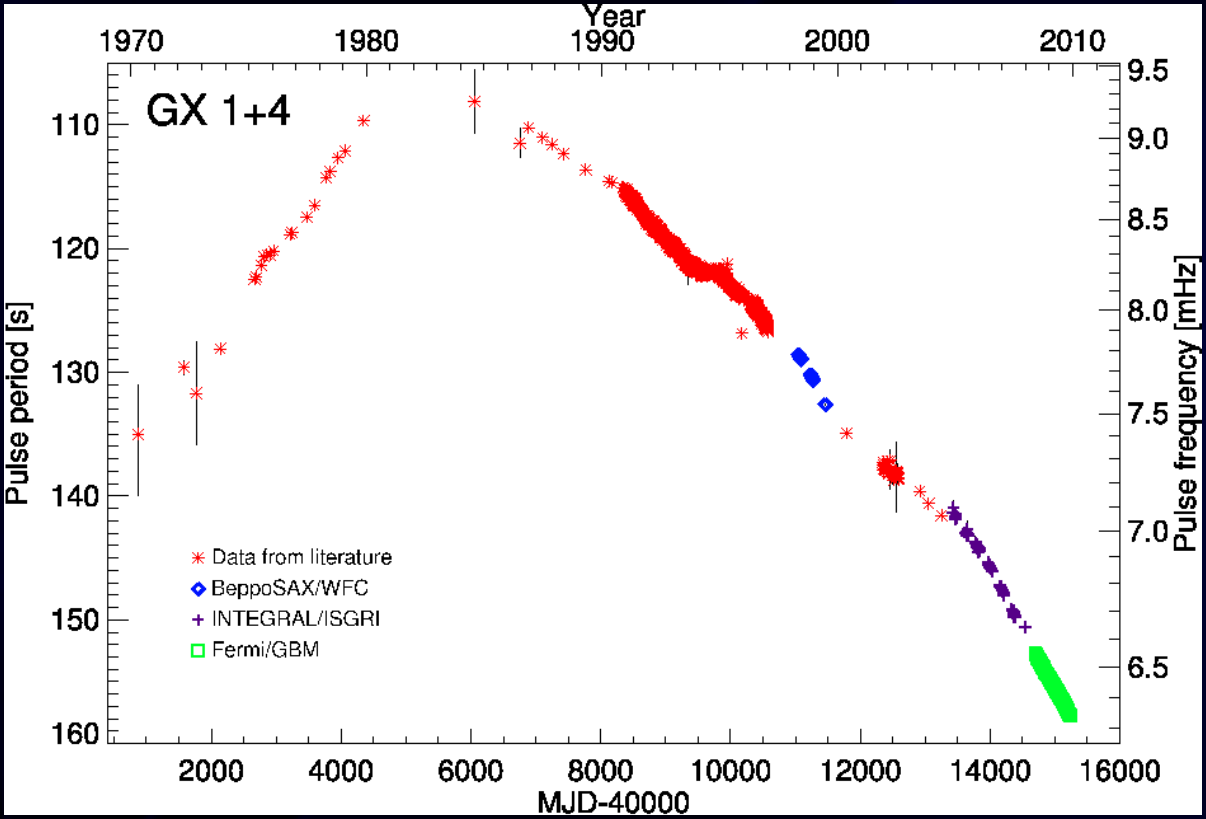
$$L_X(1970\text{s}) \sim 100\, mCrab$$

(e.g. Doty et al. 1981, White et al. 1983, Nagase 1989)

GX 1+4 might have a standard accretion disk before ~1980

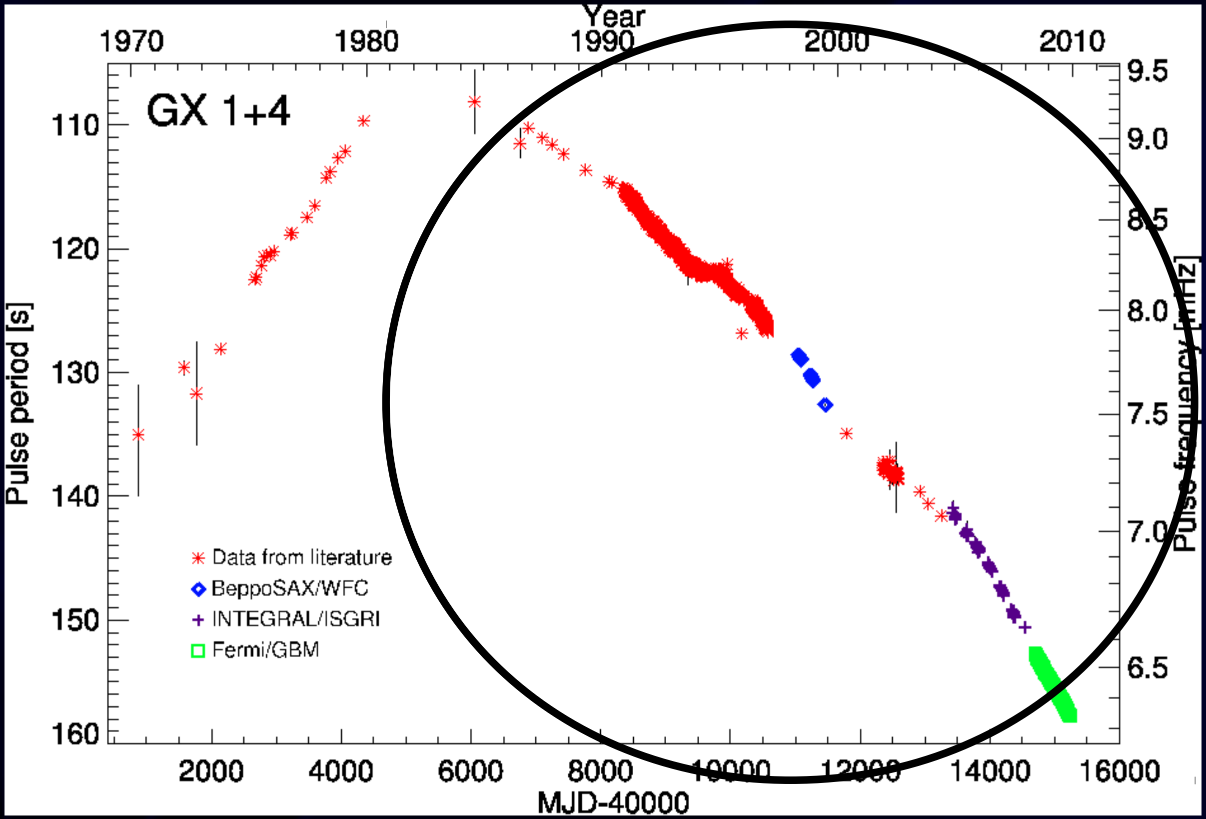
Discussion

Standard disk accretion during spin-down



Discussion

Standard disk accretion during spin-down



Discussion

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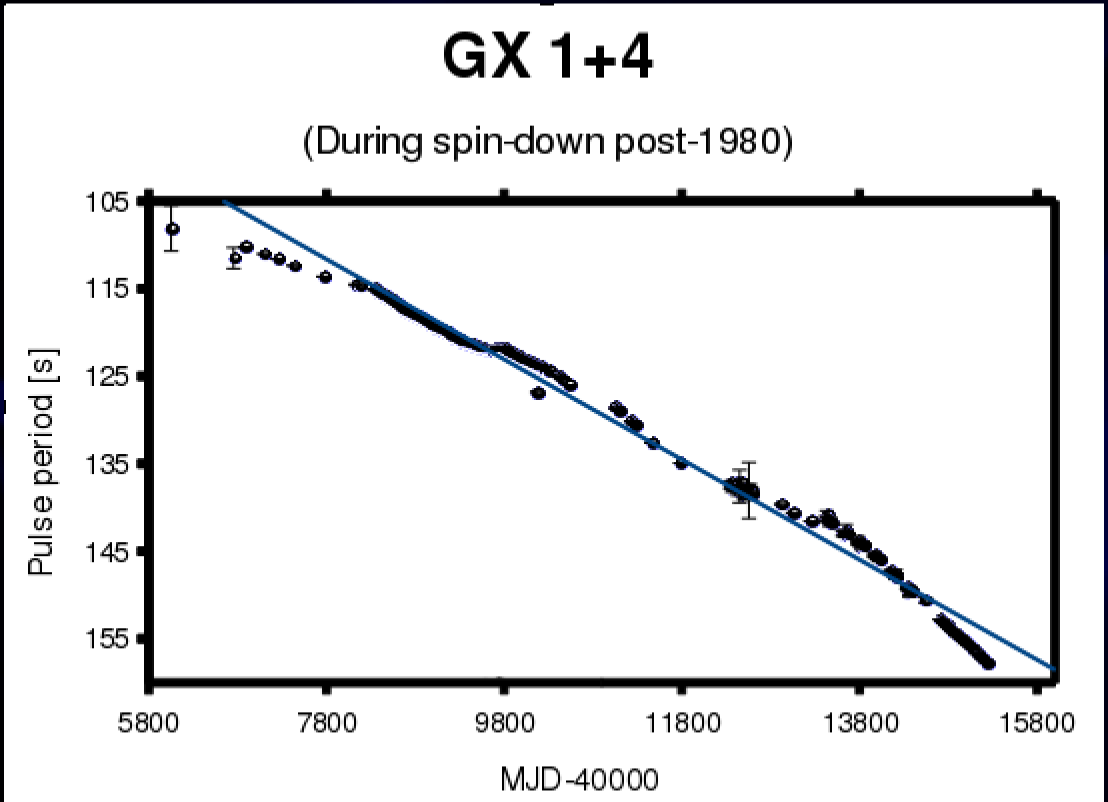


Linear trend??? (I have my doubts on it...)

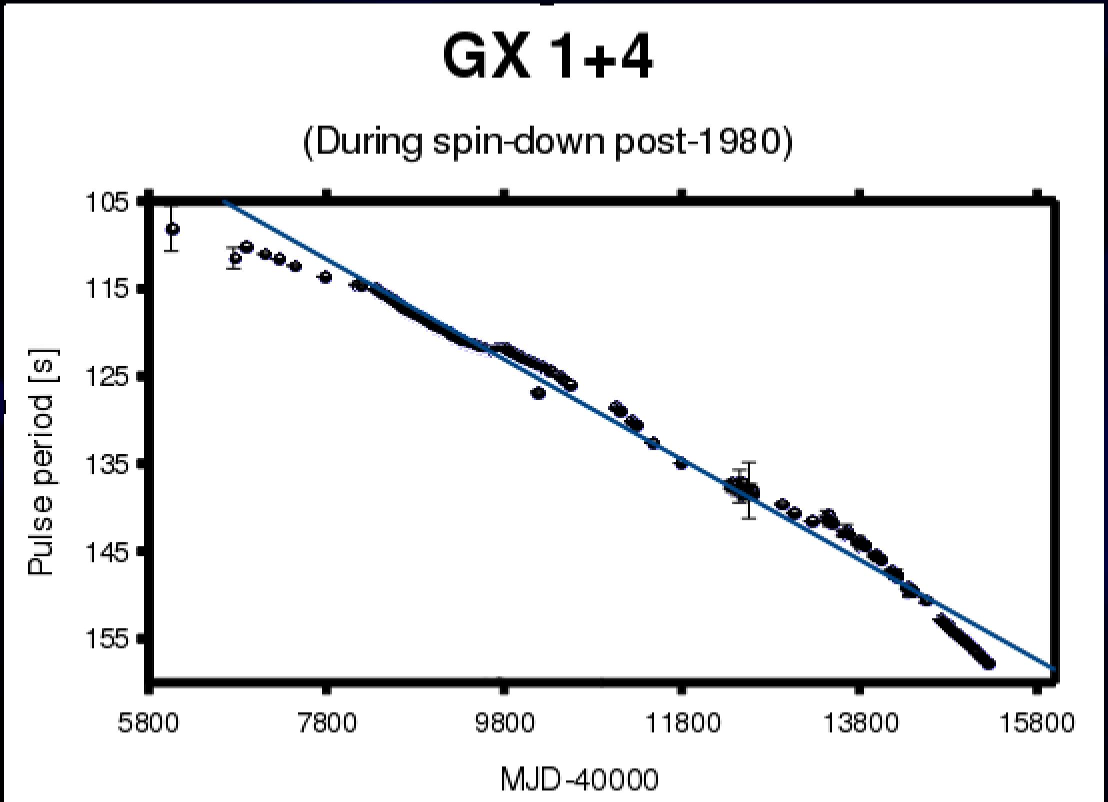
Accretion disk spinning-down the NS:

$\dot{M}\downarrow \Rightarrow L_X \downarrow$ It could explain the lack of detections (~1980-1987)

L_X (1987) ~ 3 mCrab (Makishima 1987)
L_X (1988) ~ 15 mCrab (Nagase 1989)

Discussion

Standard disk accretion during spin-down



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L_X (1988) ~ 15 mCrab (Nagase 1989)

$L_X(1970s) \sim 100\, mCrab$ ✔??

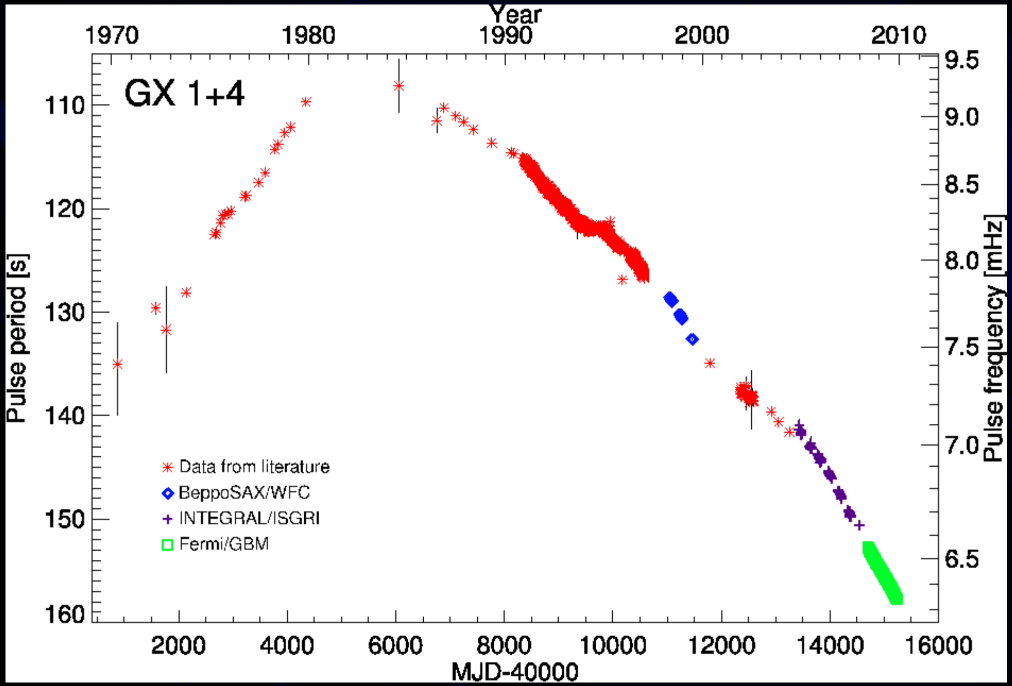
Next step: $\dot{\nu} \propto F_X^{6/7}$ **??**

Discussion

Standard disk accretion during spin-down

Next step: $\dot{\nu} \propto F_X^{0.86}$ **??**

A very regular sequence of periods and fluxes is required to look for this correlation!!



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Standard disk accretion during spin-down

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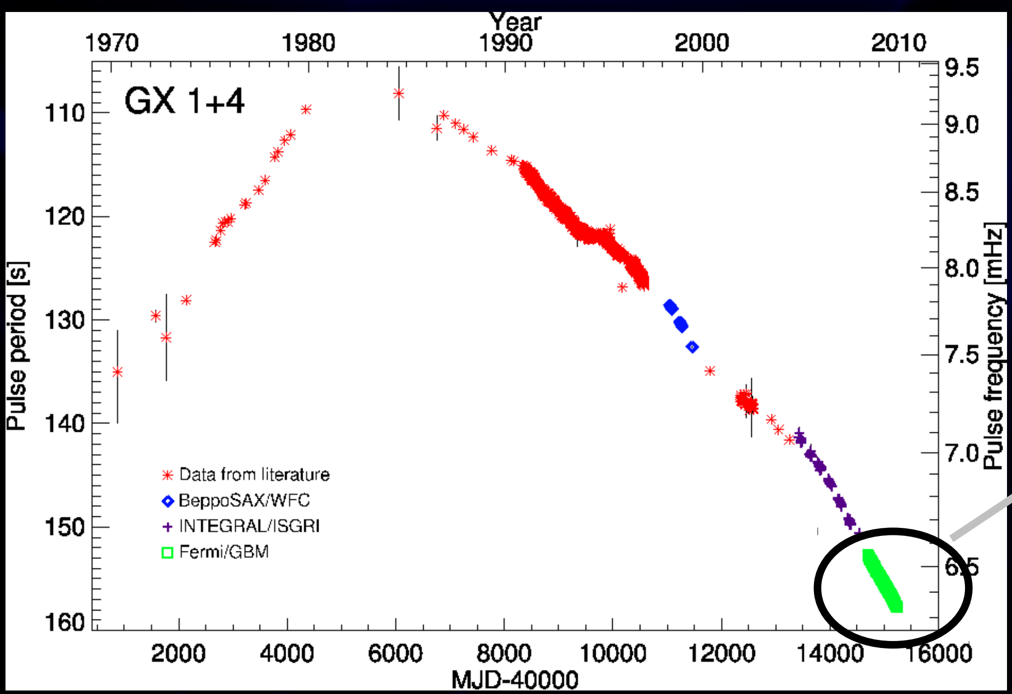

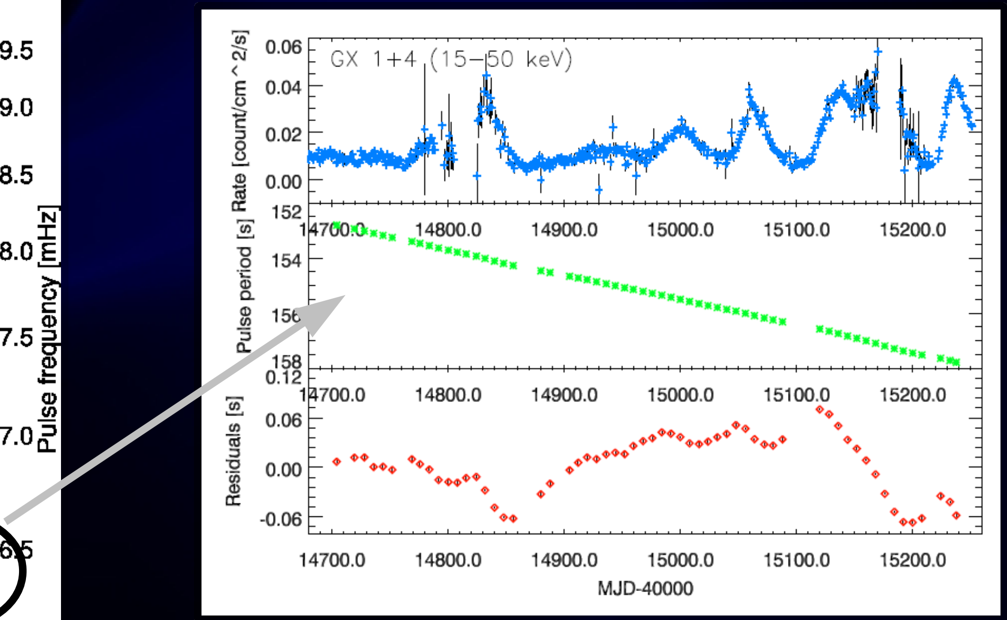

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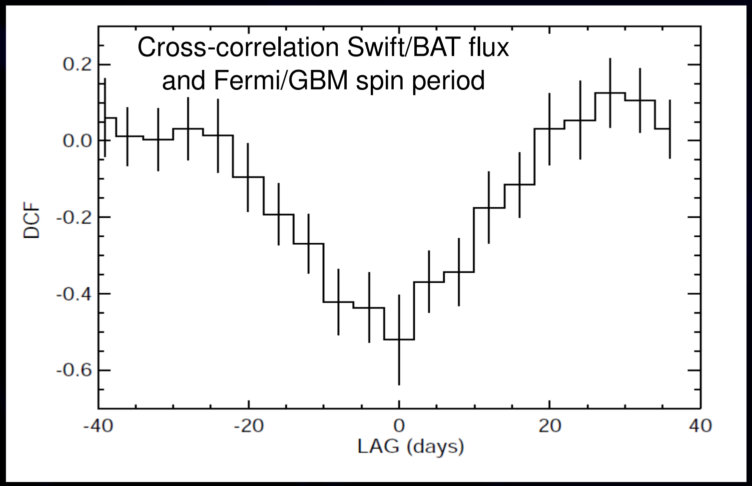

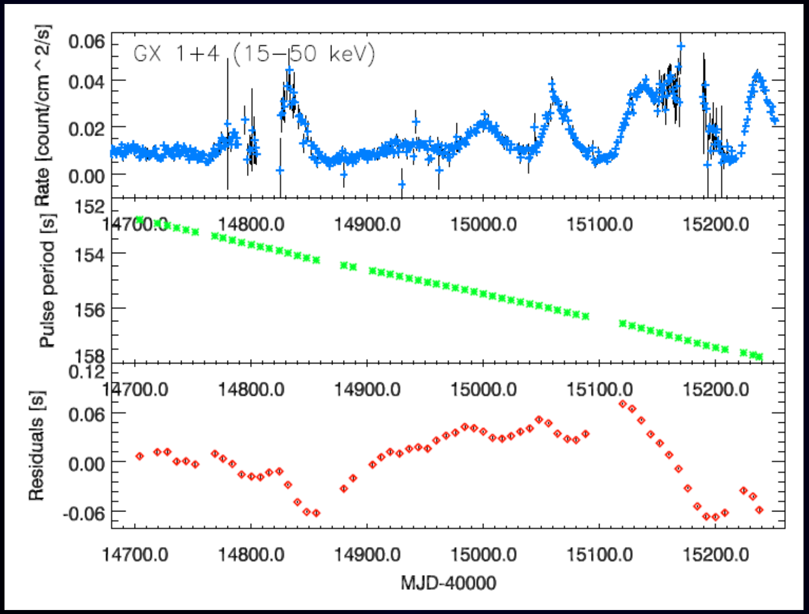

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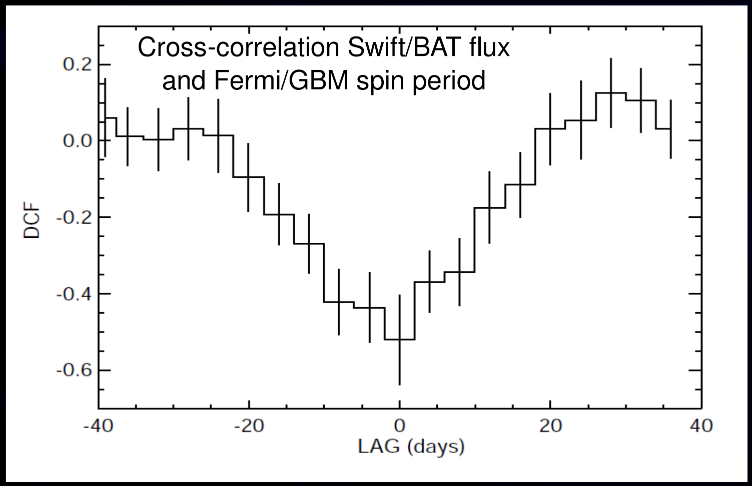
Standard disk accretion during spin-down

Next step: $\dot{\nu} \propto F_X^{0.86}$ **??**

A very regular sequence of periods and fluxes is required to look for this correlation!!



$$-\dot{\nu} \propto F_X^{\sim 0.30}$$

This negative correlation has been previously found

Chakrabarty et al. 1997 : $-\dot{\nu} \propto F_X^{\sim 0.48}$

Discussion

Standard disk accretion during spin-down

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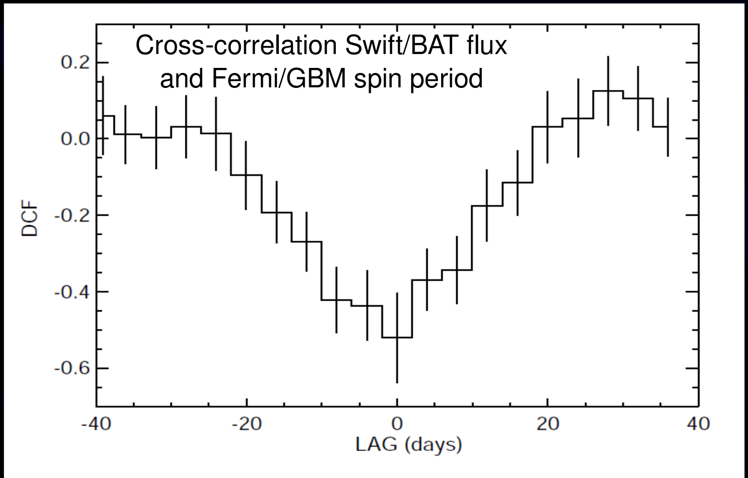

$-\dot{\nu} \propto F_X^{\sim 0.30}$ ✗

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GX 1+4 cannot have a standard accretion disk after ~1980

Discussion

Standard disk accretion during spin-up ✔

Standard disk accretion during spin-down ✗

↓

Retrograde disk accretion ???

(Makishima et al. 1988, Dotani et al. 1989, Chakrabarty et al. 1997, Nelson et al. 1997, Ferrigno et al. 2007, etc.)

Reminder: Transient disks with an alternating sense of rotation are known to form in numerical simulations in binary systems fed from stellar wind. (Fryxel & Taam 1988)

Discussion

Standard disk accretion during spin-up ✔

Standard disk accretion during spin-down ✗

↓

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Reminder: Transient disks with an alternating sense of rotation are known to form in numerical simulations in binary systems fed from stellar wind. (Fryxel & Taam 1988)

→ **GX 1+4 is a wind fed system**
(Hinkle et al. 2006) ✔

Discussion

Retrograde disk accretion during spin-down

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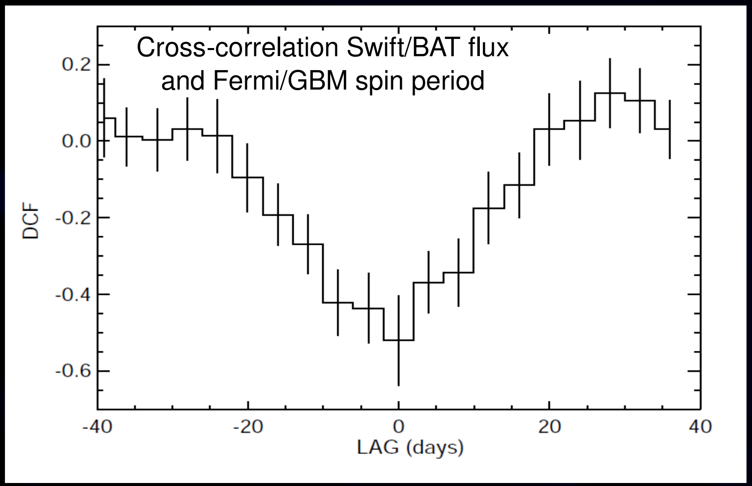

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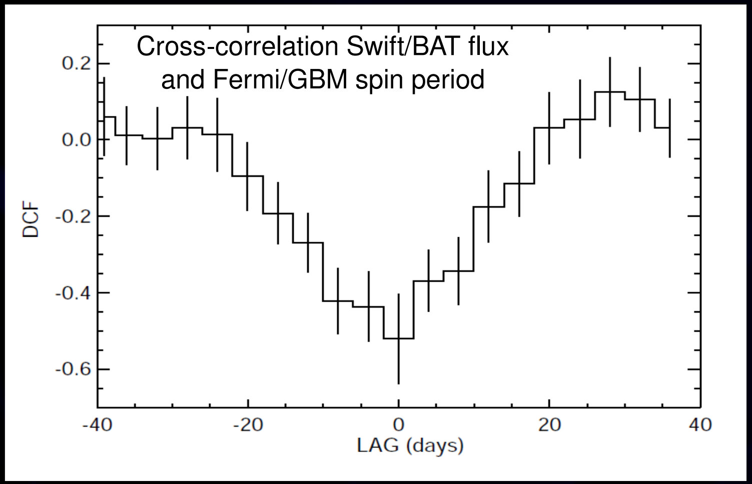

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Correlation: Correct sign ☑

Predicted is much stronger than observed ☒

?

Discussion

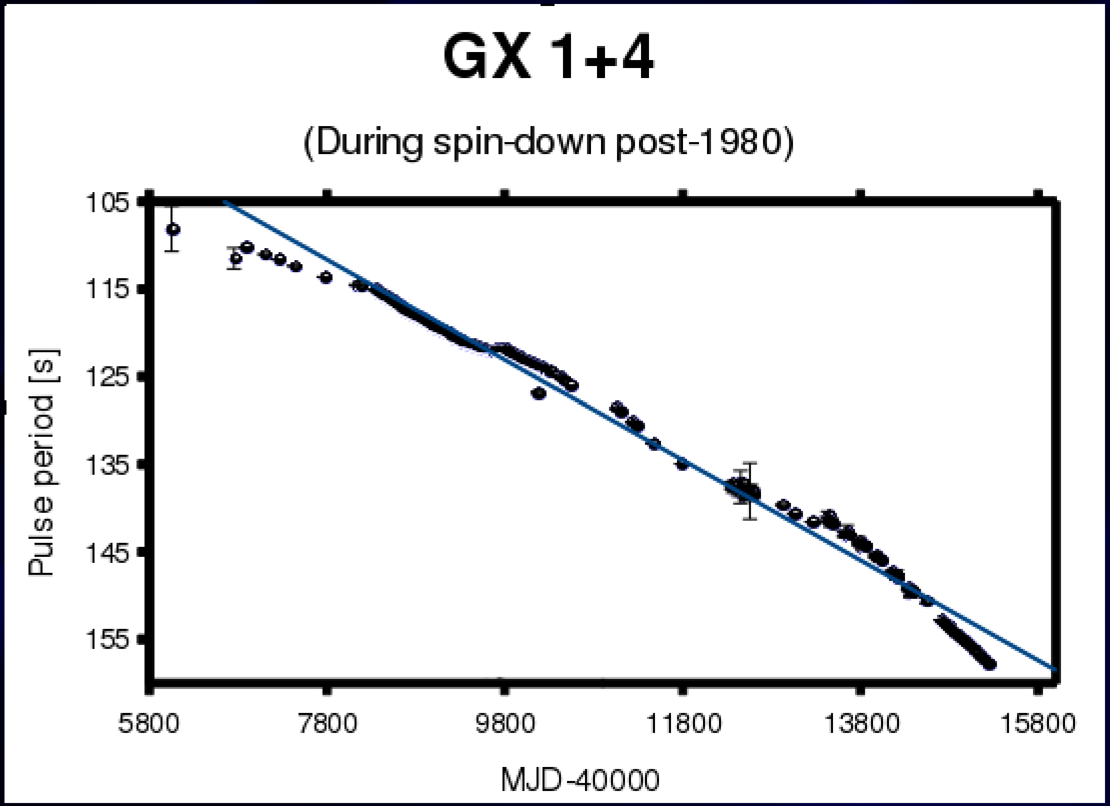
Retrograde disk accretion during spin-down

Linear trend???

I have my doubts on it...

$\dot{P} \sim 1.8\, s/y$ (Chakrabarty et al. 1997)

$\dot{P} \sim 3.4\, s/y$ (González-Galán et al. in prep)



Discussion

Retrograde disk accretion during spin-down

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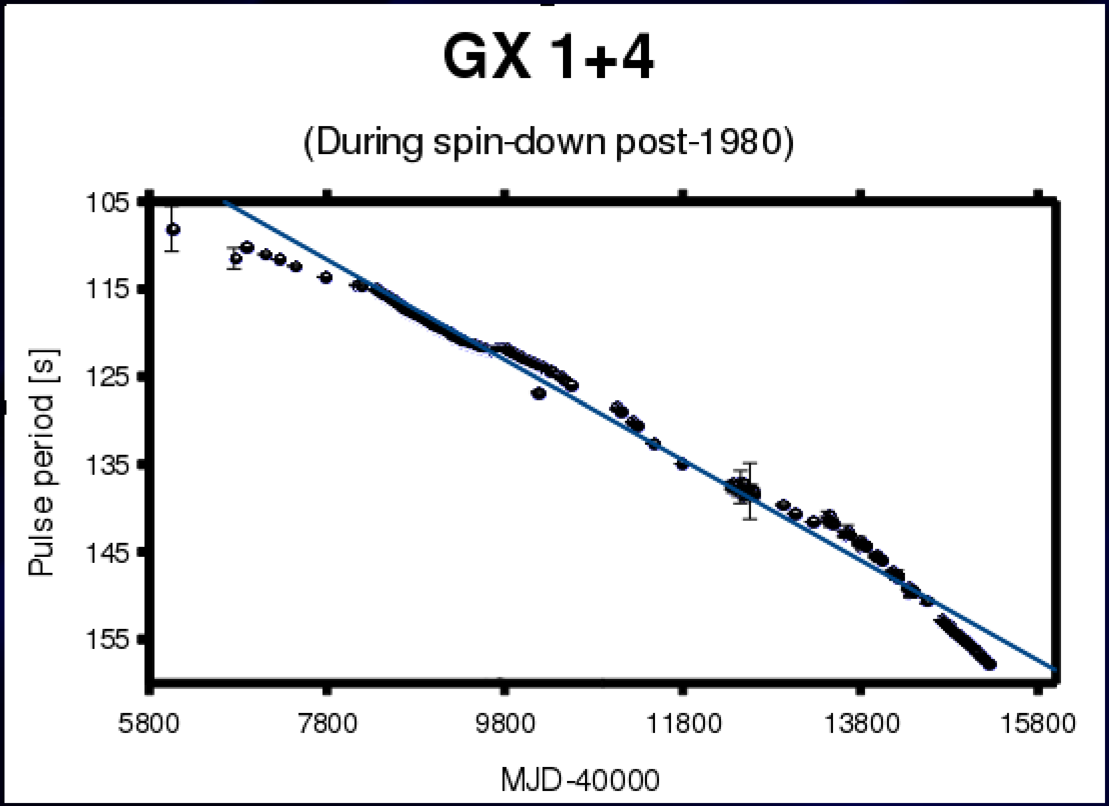
The spin-down rate is increasing!!

It's not linear $\dot{P} \neq ct \Rightarrow L_X \neq ct$

$$\dot{P} \uparrow \Rightarrow L_X \uparrow$$



Discussion

Retrograde disk accretion during spin-down ✗

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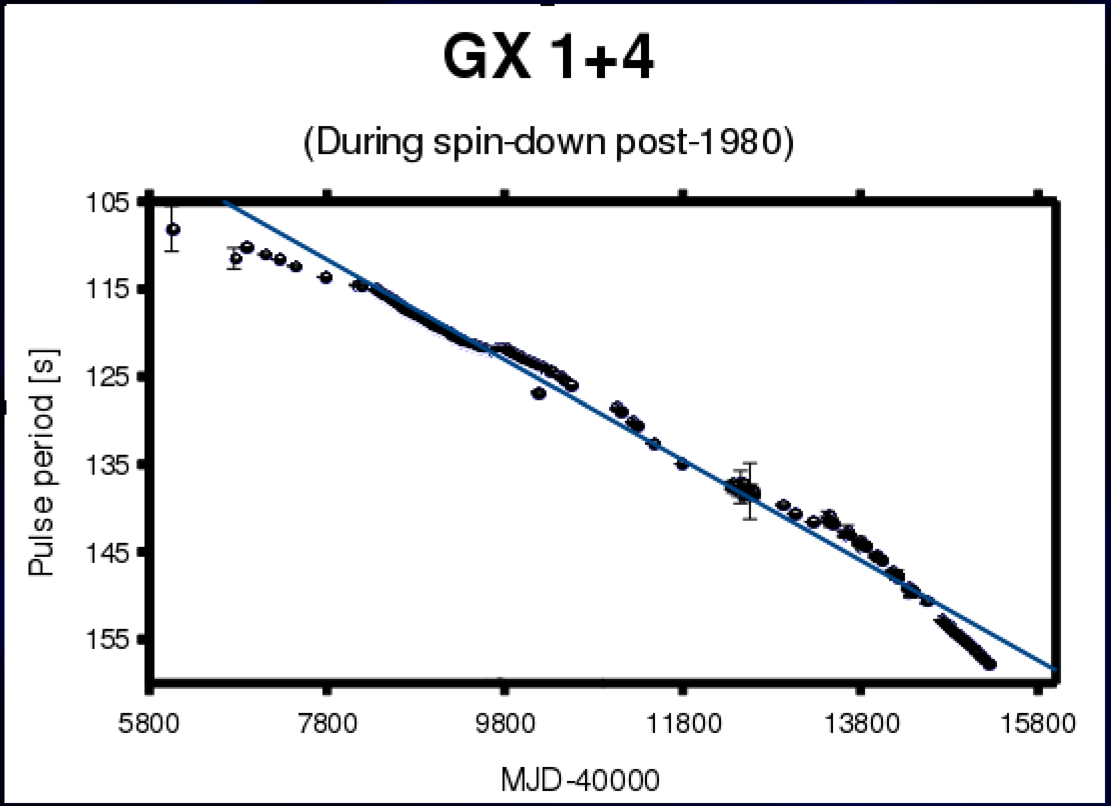
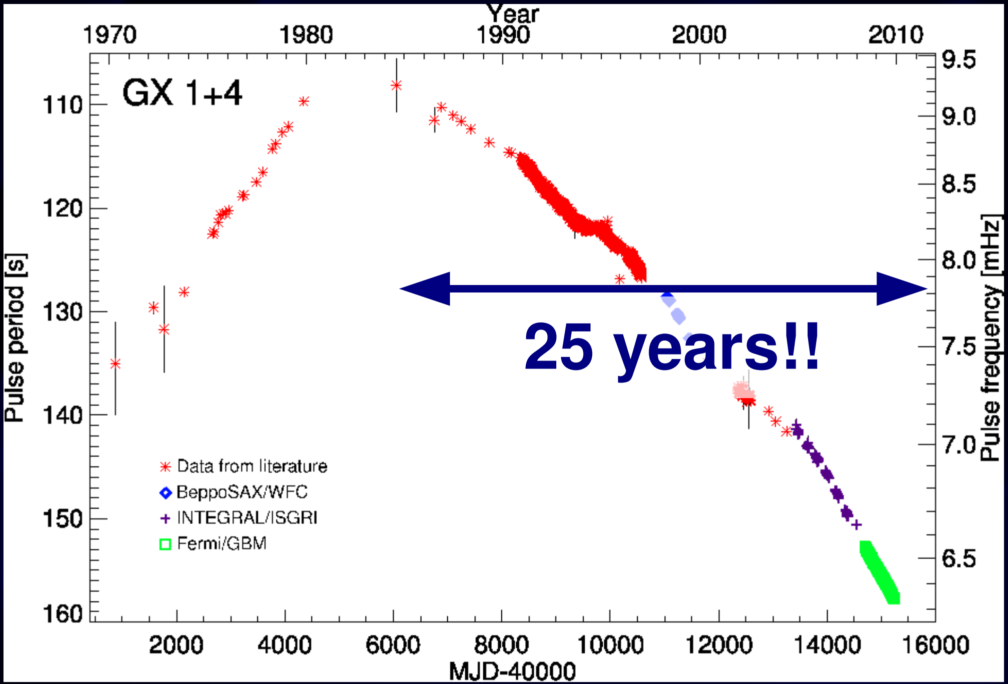


But L_X is **constant in average**:

L_X (1988) ~ 15 mCrab (Nagase 1989)
L_X (1997) ~ 15 mCrab (Chakrabarty 1997)
"The source is still maintaining a much lower luminosity than in the 1970s" (Ferrigno et al. 2007)

Discussion

Retrograde disk accretion during spin-down ✗

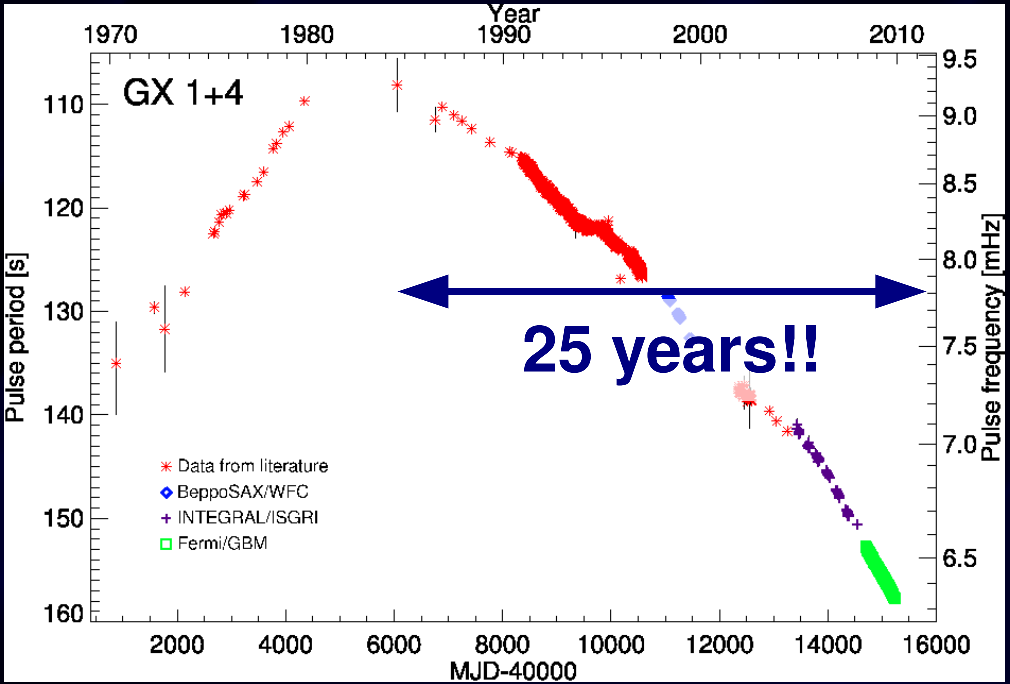


Which mechanism could produce a long-term stable retrograde disk??

Discussion

Retrograde disk accretion during spin-down ✗

Predicted	Observed
$-\dot{\nu} \propto F_X^{0.86}$	$-\dot{\nu} \propto F_X^{0.40}$
$L_X \uparrow\uparrow$	$L_X \sim ct$



Which mechanism could produce a long-term stable retrograde disk??

Discussion

Standard disk accretion during spin-up ✔

Standard disk accretion during spin-down ✗

Retrograde disk accretion during spin-down ✗

⬇

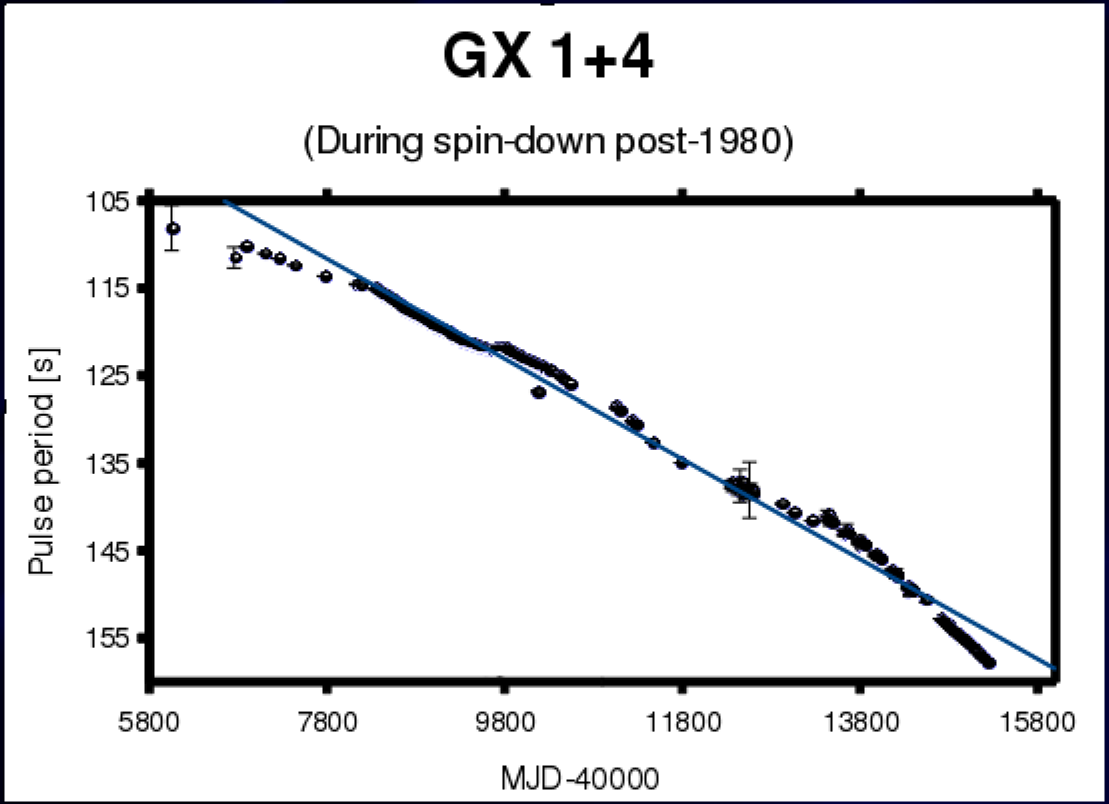
Quasi-spherical accretion during spin-down

Systems fed by stellar winds → GX 1+4 ☑

Discussion

Quasi-spherical accretion during spin-down

Linear trend???



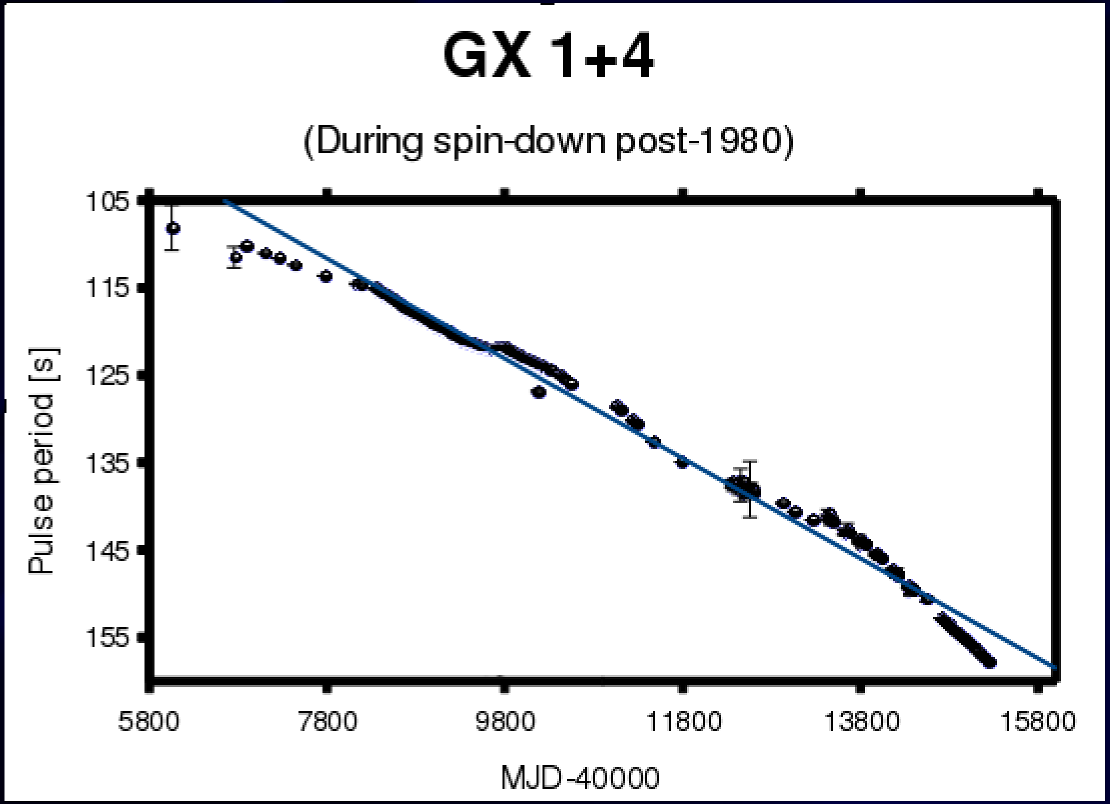
Discussion

Quasi-spherical accretion during spin-down

~~Linear trend???~~

Quasi-spherical accretion:

$$\dot{M} \sim ct \Rightarrow L_X \sim ct \Rightarrow P(t) = P(t_0)\, e^{t/\tau}$$



Discussion

Quasi-spherical accretion during spin-down ✔

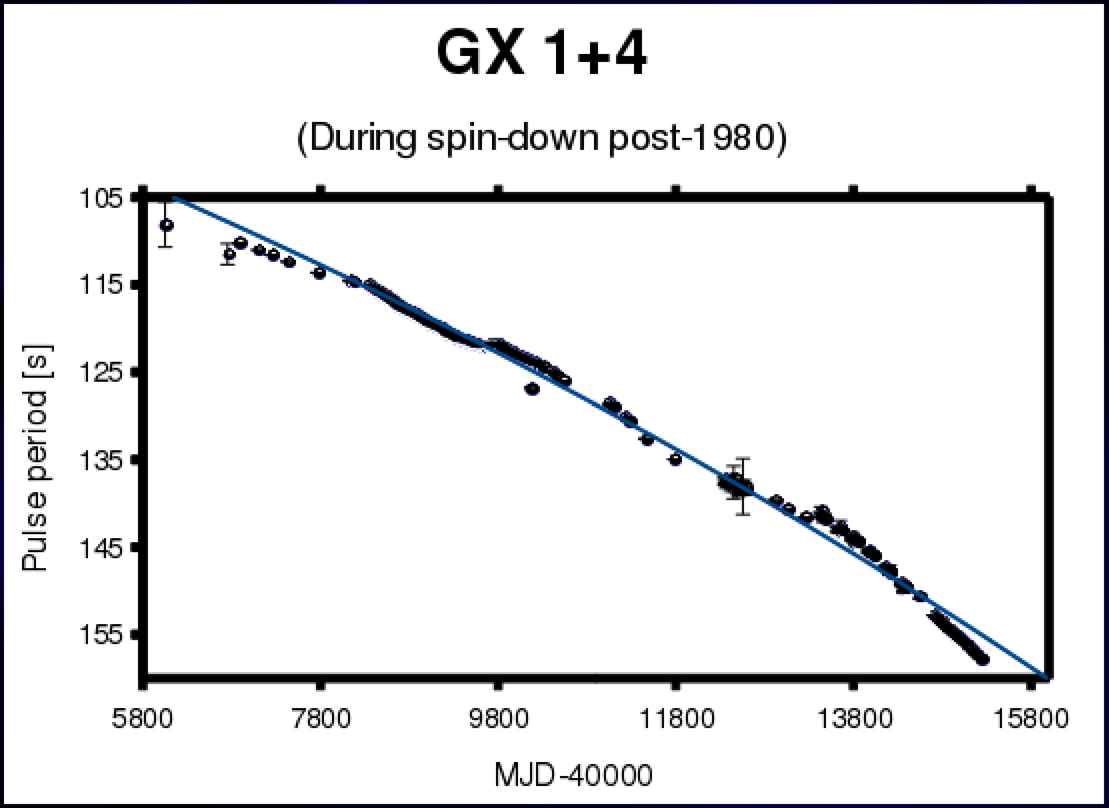
~~Linear trend???~~

Exponential trend

Quasi-spherical accretion:

$$\dot{M} \sim ct \Rightarrow L_X \sim ct \Rightarrow P(t) = P(t_0)\, e^{t/\tau}$$ ✔

Predicted	**Observed**
$-\dot{\nu} \propto F_X^{0.43}$	$-\dot{\nu} \propto F_X^{0.40}$
$L_X \sim ct$	$L_X \sim ct$



Conclusions

- ✔ The spin-down rate observed with Fermi/GBM is stronger than ever.
- ✔ P_{SPIN} ↑ ~ 50% in the last ~25 years.
- ✔ The spin-up pre-1980s is well described by standard accretion disk theory, but this model does not explain the long-term spin-down observed in GX 1+4.
- ✔ The retrograde disk is discarded as a possible explanation for the long-term spin-down observed in this binary system.
- ✔ Currently, the most likely explanation for the long-term spin-down observed in GX 1+4 is the quasi-spherical accretion model.
- ✔ Source continues to be monitored ⇒ new data and new ideas to come!