The X-ray source in the SNR RCW 103: a Young Magnetar in a Binary System?

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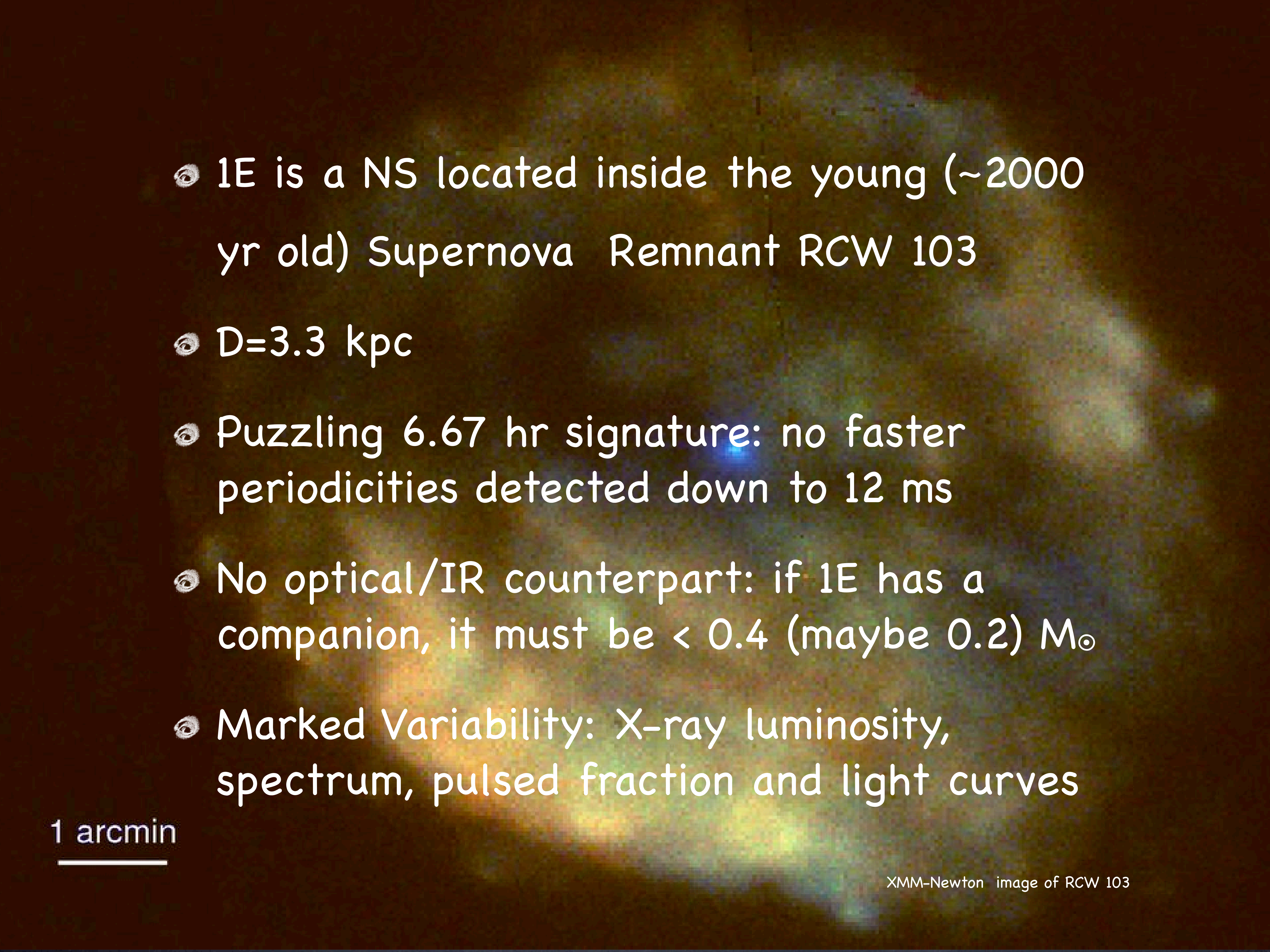
Outline

- Summary of the Observations of the X-ray source 1E 161348-5055
- Modelling 1E: Isolated vs. Binary Star
- Problems and Perspectives

Summary of the Observations



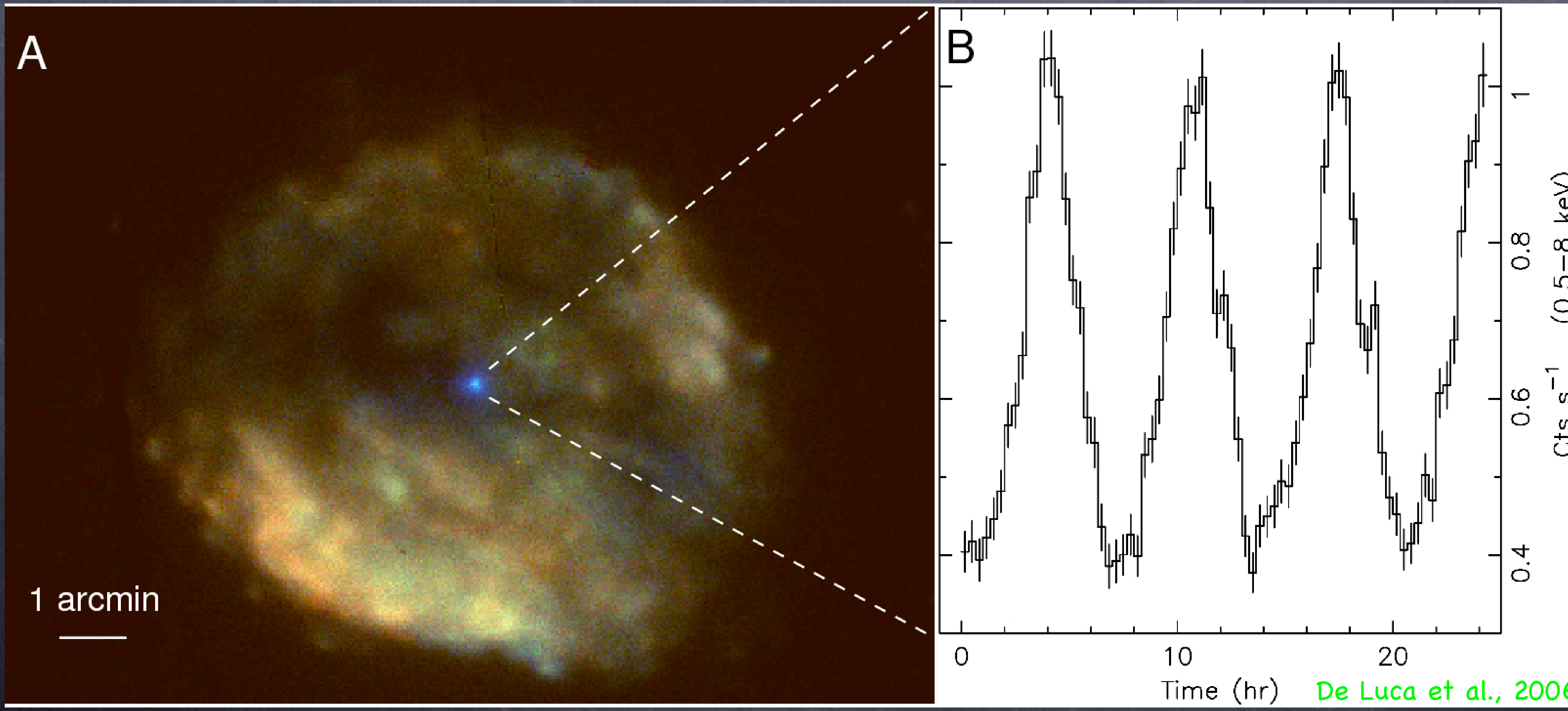
- 1E is a NS located inside the young (~2000 yr old) Supernova Remnant RCW 103
- D=3.3 kpc
- Puzzling 6.67 hr signature: no faster periodicities detected down to 12 ms
- No optical/IR counterpart: if 1E has a companion, it must be < 0.4 (maybe 0.2) $M_{\odot}$
- Marked Variability: X-ray luminosity, spectrum, pulsed fraction and light curves

XMM-Newton image of RCW 103

Period of 6.67 hr (!)

This period is much, much longer

than the period of any known young NS



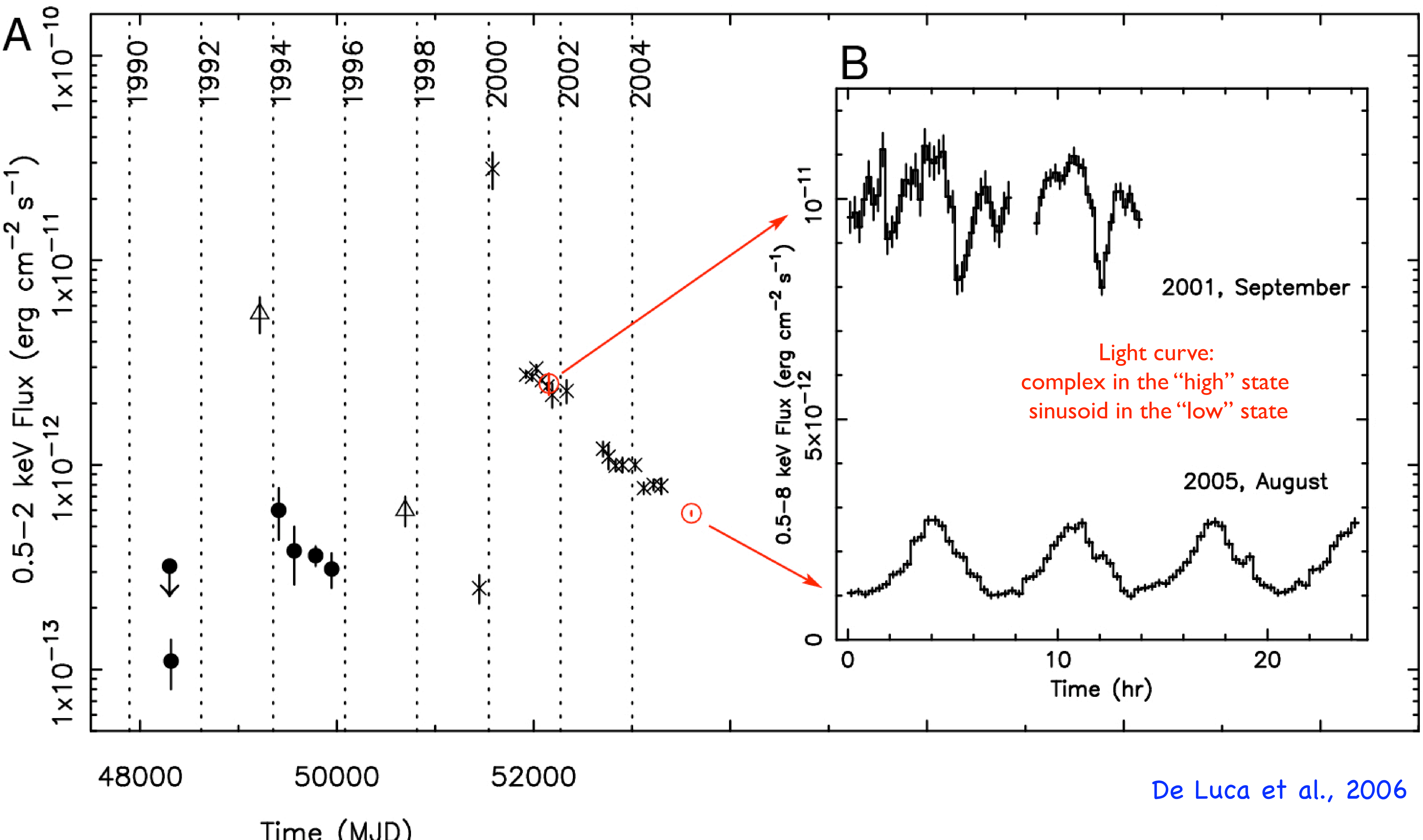
De Luca et al., 2006

1E's spectrum is adequately modelled by:

Black body (T_1~0.5 keV) + black body (T_2~1.4 keV)

Black body (T~0.5 keV) + steep power law (Γ~3)

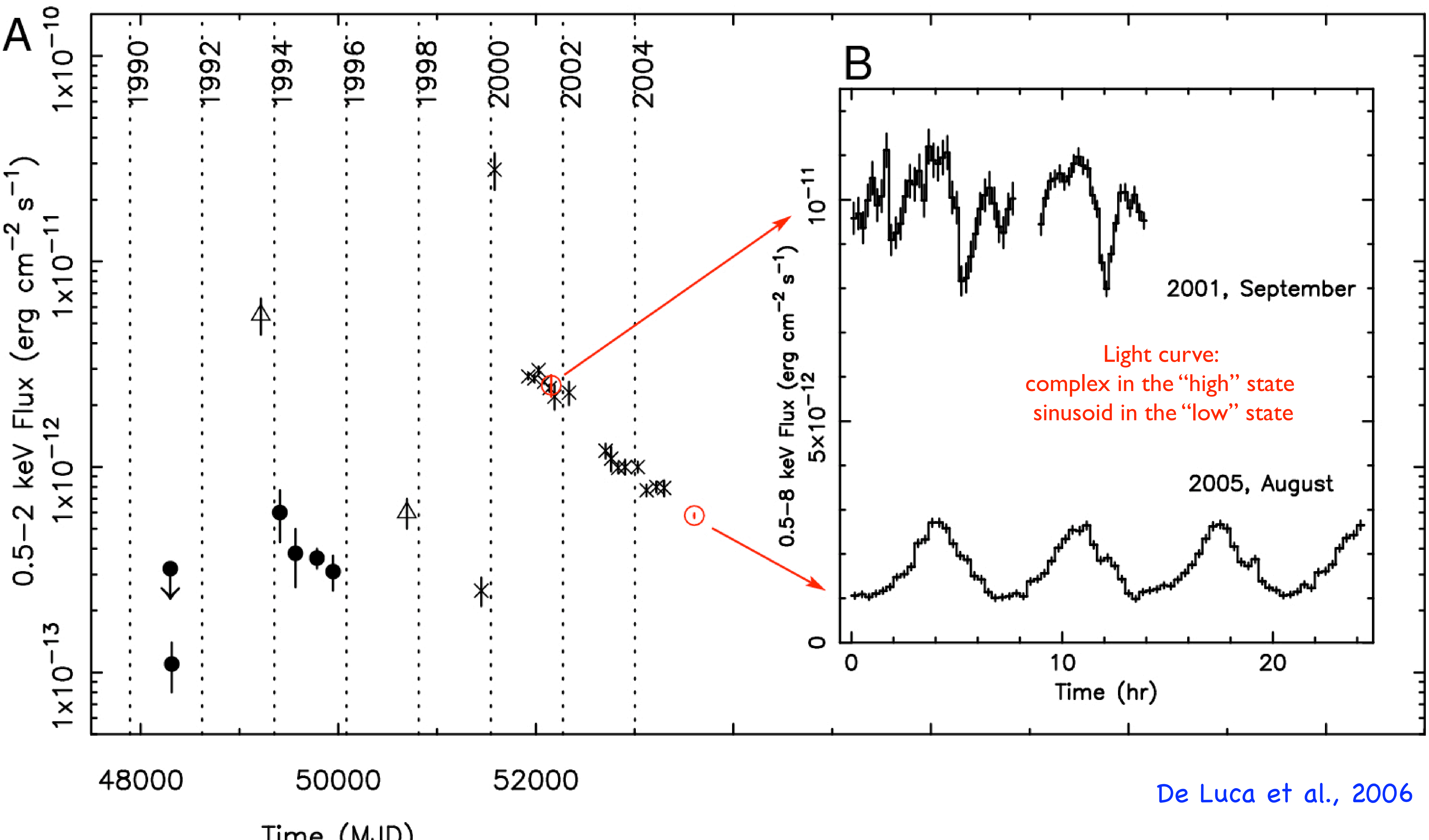
The long-term variability



De Luca et al., 2006

The long-term variability

In 1999 the X-ray luminosity jumped from 10^{33} to 10^{35} erg/s



De Luca et al., 2006

… in addition…

- The spectrum is significantly harder in the “high” state (-> normalisation of the hot BB)
- The absorption increases in the “high” state
- The Pulsed Fraction is larger (~43%) in the “high” and smaller (~12%) in the”low” state

Many questions,
we focus on this:
what is the 6.67 hr
signature?

The Isolated NS Model

- The 6.67 hr signature must be (almost by definition) the NS spin period
- Much longer than any known young NS' period: what could brake it that slow?
- Magneto-dipole losses written off : the implied magnetic field ($B \sim 10^{18}$ G) would be a wee bit too strong...
- Interaction of a magnetar ($B \sim 10^{15}$ G) with a relic disc more reliable (De Luca et al., 2006; Li, 2007)

The SN explosion left a debris disk, which now is accreting on the NS

If the star rotates too fast, i.e.

$$\omega_{NS} > \omega_{Kepler}(R_M)$$

the magnetosphere boundary lifts the incoming flow above its escape velocity, and no accretion is possible ("propeller" effect)

This extracts angular momentum from the NS, which is braked until a final equlibrium is reached when

$$\omega_{NS} \sim \omega_{Kepler}(R_M)$$

This leads to the "equilibrium period"

$$P_{\rm eq} \approx 6\ {\rm hr}\ \left(\frac{\mu_{\rm NS}}{10^{33}\ {\rm G\ cm^3}}\right)^{6/7} \left(\frac{\dot{\rm M}}{3\times10^{13}{\rm g\ s^{-1}}}\right)^{-3/7} \left(\frac{\rm M_{NS}}{1.4\ {\rm M_\odot}}\right)^{-5/3}$$

If 6.67 hr is interpreted as an equilibrium period btw the accretion and propeller torques of the disc, the NS <u>must</u> be endowed with a magnetar-like B field of 10^{15}-10^{16} G!

Problems of the Isolated Star Model

There is some evidence of a relic disc around the AXP 4U0142+61 (a magnetar candidate), yet this NS spins at 8.4s: why 1E is ~3000 times slower, then?

Initial slow rotation may be required to avoid the initial "ejector" phase, in which the e.m. output from the NS would destroy the fallback disc

With a slow rotation, magnetar-like field build-up may be problematic (inefficient dynamo)

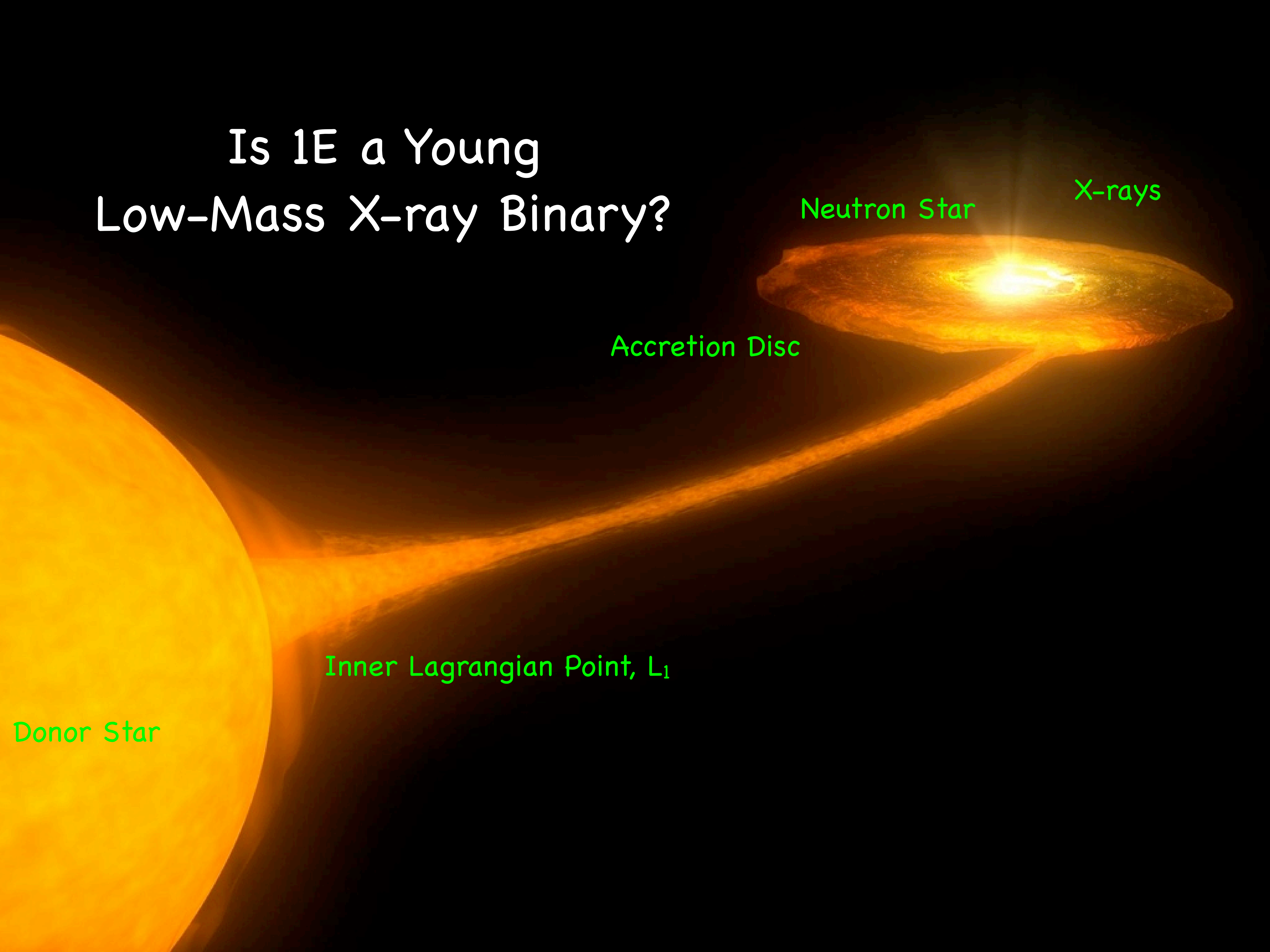
The Binary Star Model

1E is a binary system, made up by a NS and a lower main sequence star, which thus far has escaped detection

The signature at 6.67 hr is the spin period, equal to (or slightly shorter than) the orbital period

Is 1E some kind of Low-Mass X-ray binary?

Is 1E a Young Low-Mass X-ray Binary?



A Young LMXB? Sure?

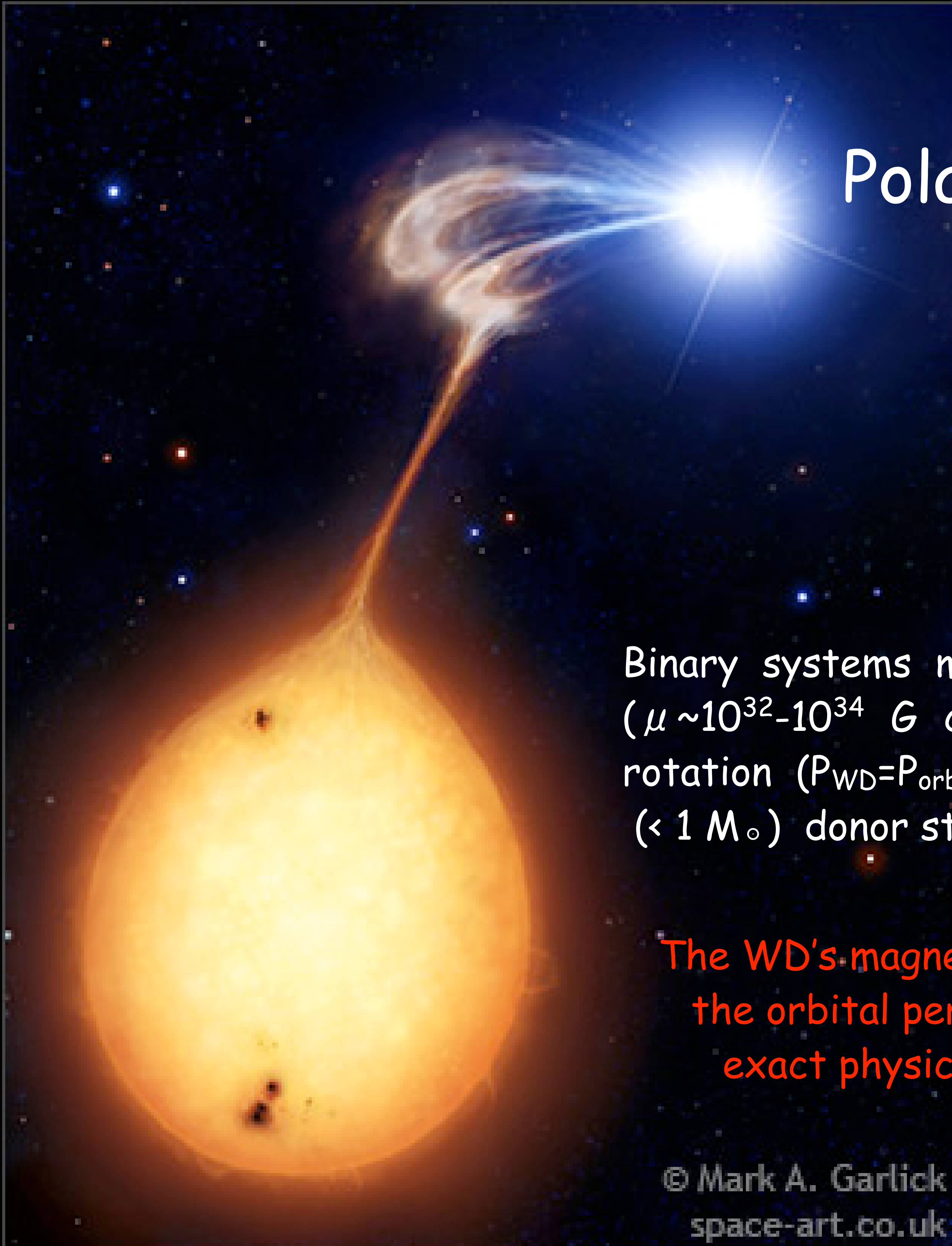
- 1E is much younger (2000 yr) than any LMXB
- 1E is 2-3 orders of magnitude dimmer than a LMXB
- Luminosity, light curve and spectral variability are difficult to reconcile with a LMXB!
- The complex light curve in the "high" state has no like in the LMXB class...

...taken at face value, the binary model has several problems...

The "Polar" Model

This model is motivated by some (loose!) analogies btw the X-ray light curve of 1E and the Polar (a.k.a. AM Herculis) Cataclysmic Variables (Pizzolato et al., 2008)

Polar (AM Herculis) CV



Binary systems made by a strongly magnetised ($\mu \sim 10^{32}$-10^{34} G cm^3) white dwarf in synchronous rotation ($P_{WD}=P_{orb}$) with a low main sequence (< 1 $M_\odot$) donor star

The WD's magnetic field is strong enough to lock the orbital period and the WD's rotation (the exact physical mechanism is still debated)

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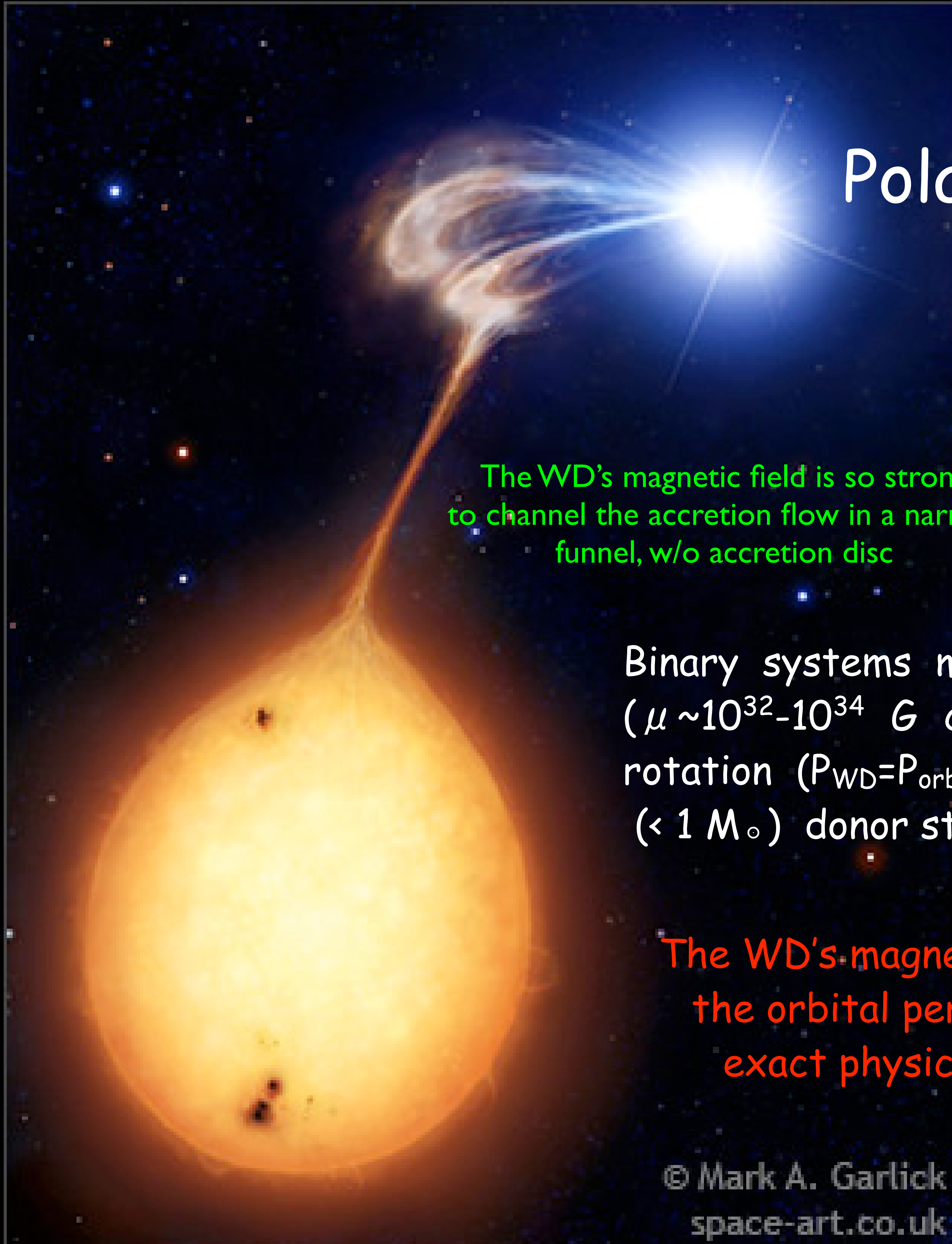

The WD's magnetic field is so strong to channel the accretion flow in a narrow funnel, w/o accretion disc

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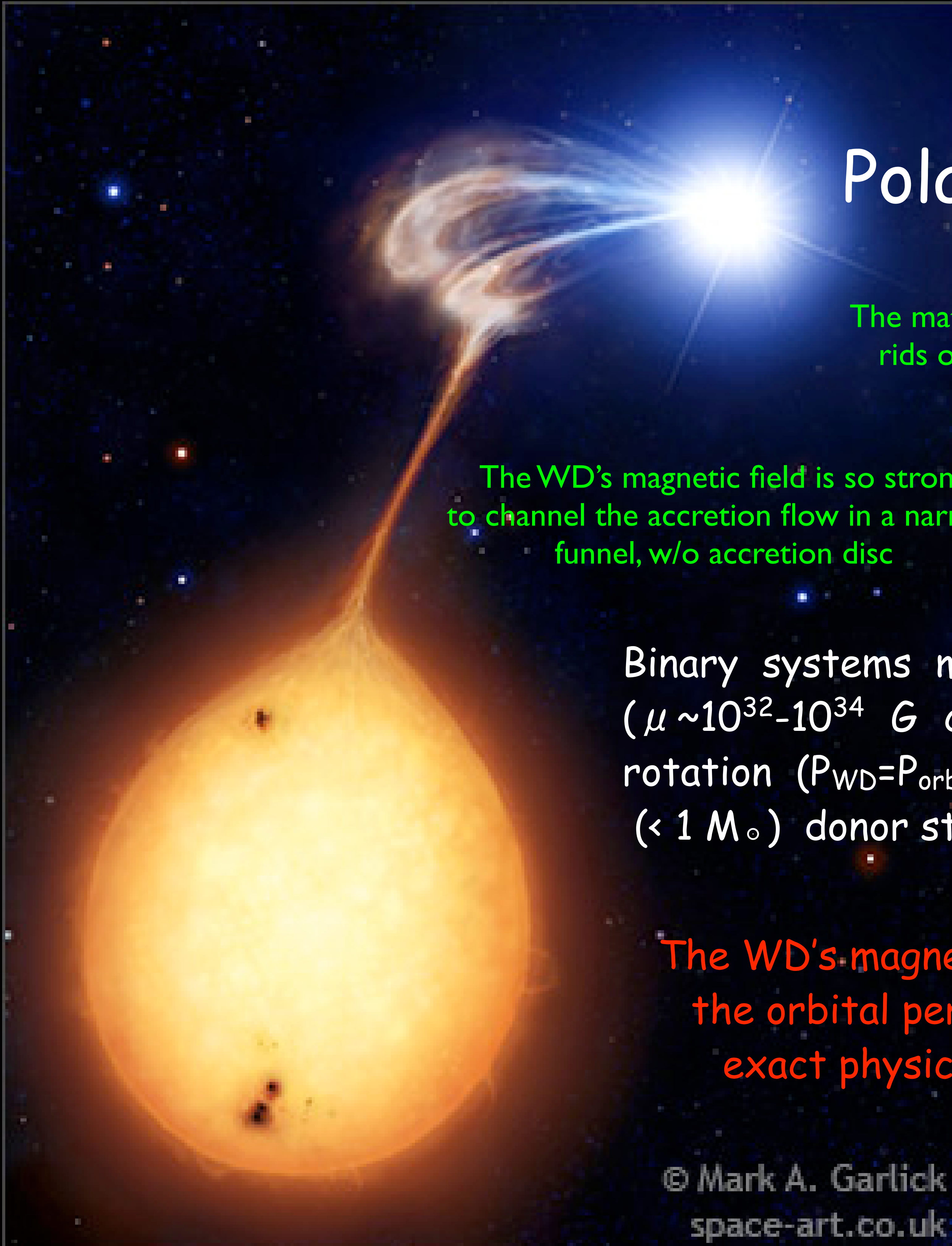

The matter impinging on the WD's magnetic pole(s) rids of its mechanical energy, emitted as X-rays

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The "Polar-like" Model

(Pizzolato et al., 2008)

- The system is made by a strongly magnetised NS and a lower main sequence star (-> optical/IR constraints)
- No faster period detected because the orbital and the NS spin period coincide, similar to what occurs in Polar Cataclysmic Variables
- A strong magnetic field is necessary: $\mu_{WD} \sim \mu_{NS}$ ⇨ $B_{NS} \sim B_{WD} (R_{WD}/R_{NS})^3 \sim 10^9 B_{WD}$ ⇨ $B_{NS} \sim 10^{15}$-10^{16} G
- The NS's magnetosphere (over)fills its Roche lobe and channels the accretion flow from L_1 to the NS magnetic poles
- Therefore, either there is no disc, or it is "intermittent": it may form after a mass ejection from the companion star, but it is unstable (1E in outburst)

Purely magnetic interaction btw the stars

If the magnetic torque is dominant, the NS spin period of 6.67 hr is coincident with the orbital period: $P_{orb}=P_{spin}$

A magnetar-like field of the NS is required for an efficient synchronism at ~6.67 hr within ~2000 yr

The Accretion Torque

- If mass transfer from the secondary has been important (i.e., comparable to the magnetic coupling), over a significant fraction of 1E's lifetime, the initial spin-down propeller brakes the NS; later on, however, the accretion spin-up torque would counteract the magnetic drag: no synchronism can be achieved

- The inclusion of the accretion torque fixes the NS equilibrium spin frequency at $\Omega_{Kepler}(L_1)$, i.e. P_{orb}= 1.4- 2 P_{spin} . This is similar to what observed in some Intermediate Polar CVs

In summary...

- According to the "Polar" model, 1E is a young magnetar in synchronous or almost synchronous orbit with a low main sequence star (0.2-0.4 $M_\odot$)

- The magnetic locking requires a high magnetic field (10^{15}-10^{16} G)

- Part of the X-ray emission may be accretion-powered, but part may also come from the intrinsic magnetar emission (e.g.Woods & Thompson 2006).

- Both the magnetic and the accretion-powered mechanism may explain the X-ray variability

Problems and Perspectives

- Experimental
  - Deeper observations in search of the optical/IR counterpart
- Theoretical
  - Synthetic formation models (birth rate of magnetars in binary systems)
  - Spectrum: can we predict it within the Polar model f/w?
  - Explanation of the different shape of the light curve in high/low states
  - X-ray luminosity: accretion-powered or magnetar? (Work) in progress

The End