Co-evolution of massive stars and neutron stars in wind-fed HMXBs

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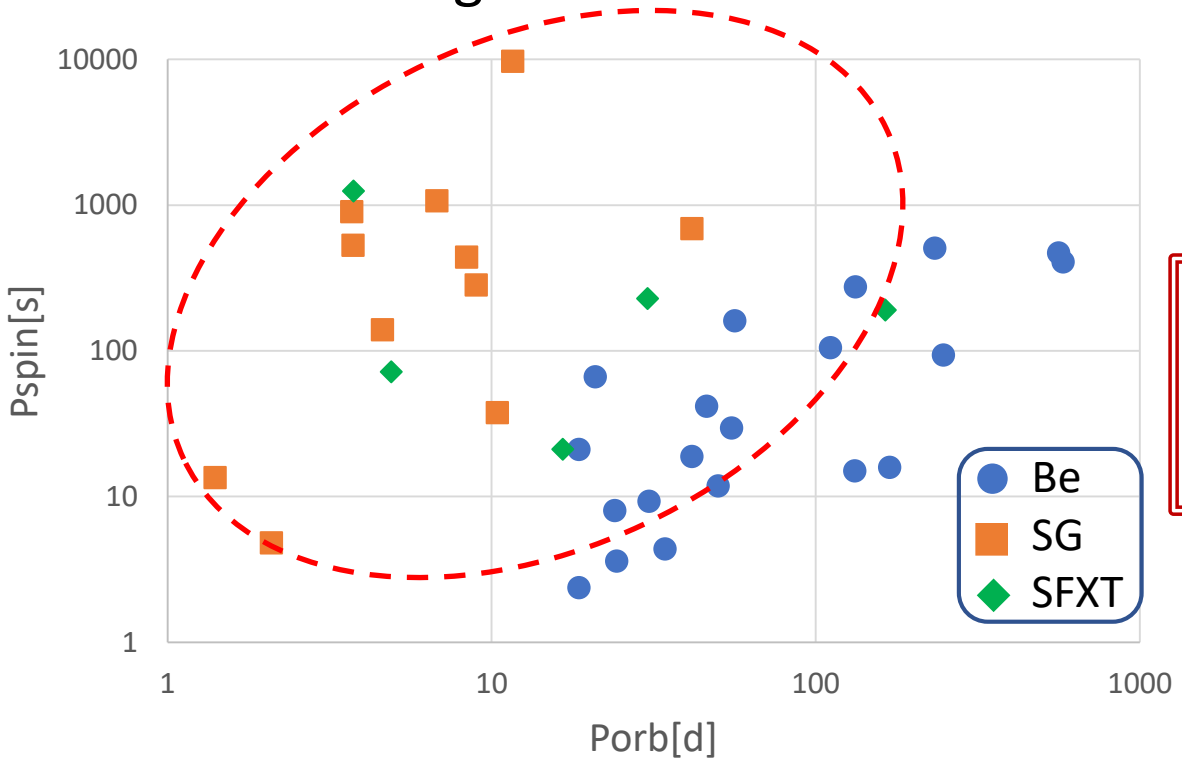
The Evolution of Massive Stars and Formation of Compact Stars: from the Cradle to the Grave

26 Feb. 2020 @ Waseda Univ.

Corbet diagram

- HMXBs~ categorized into Be-type and SG-type
- The position of WIND-fed HMXBs with SG donor
  - Broad distribution of SPIN up to extremely slow rotation
  - Their magnetic-fields are similar: B~10^{12}G



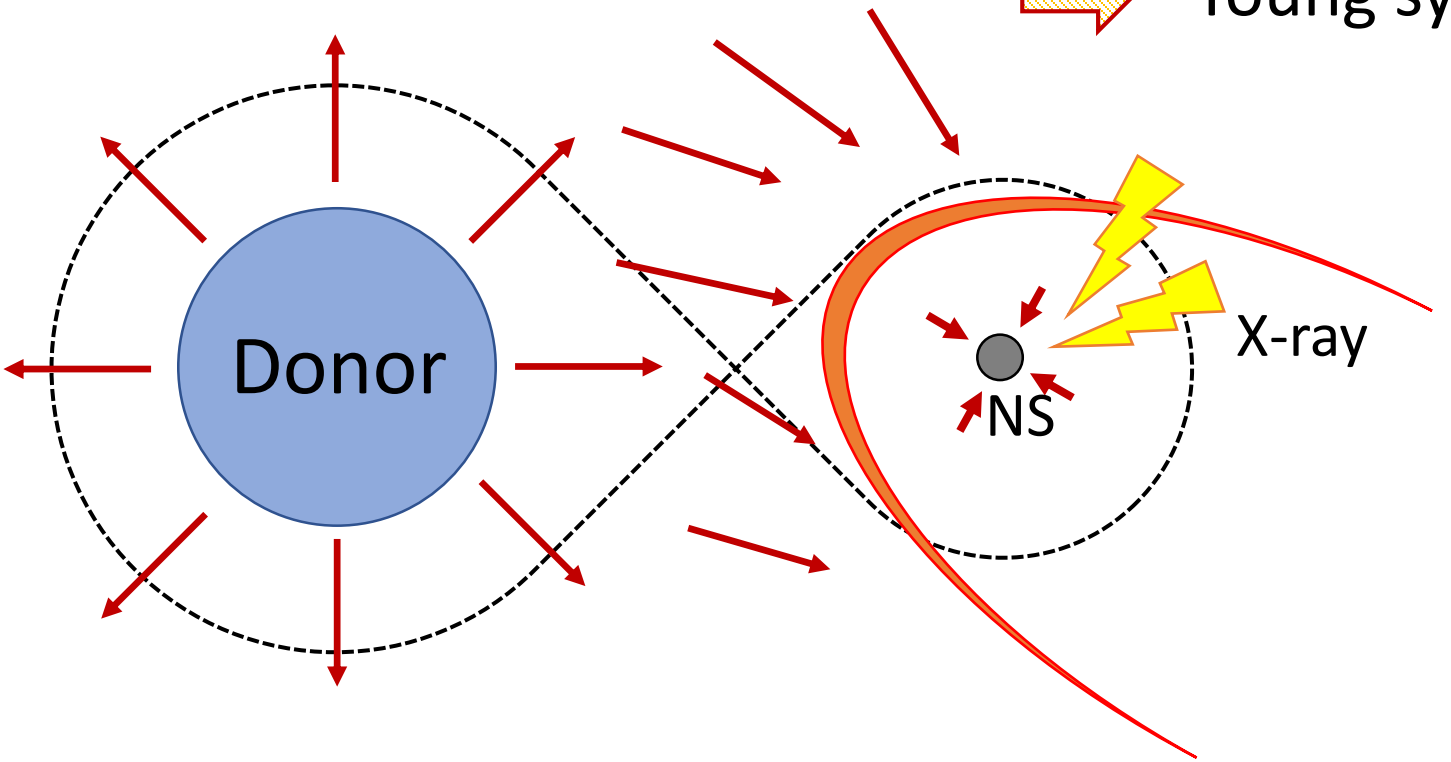
What is the origin of the broad distribution of NS spins?

Binary configuration

- Wind-fed HMXBs

Donor evolves within ~10Myr

Young system

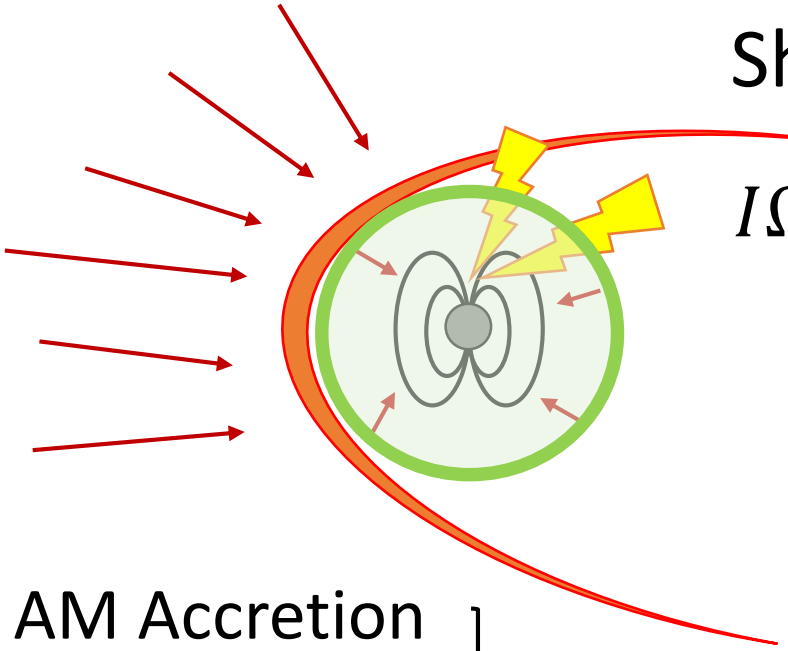


Line-accelerated wind from
Roche lobe under-filling donor

Magnetized NS

Binary configuration

- NS Spin Evolution



Shell Formation

$$I\dot{\Omega} = A\dot{M}^{7/11} - B\dot{M}^{3/11}$$

$$A = A(v_{\rm w}, P_{\rm orb})$$

$$B = B\left(B_{\rm NS}, P_{\rm spin}\right)$$

Shakura et al. 2012

Mass / AM Accretion

Dipole Radiation

Propeller Effect

Accretion Shell

⇒ Spin Evolution

⇒ Magnetic Field Evolution

Example: SXP1062

- NS HMXB associated with a SN Remnant
  - Age: ~10000-25000 yr
  - Be donor
  - P_{orb} = 300 d
  - P_{spin} = 1062 s
  - Rapid spin-down

Young NS!

Not typical Be-HMXB;
Persistent, wind-fed system?

Very slow!



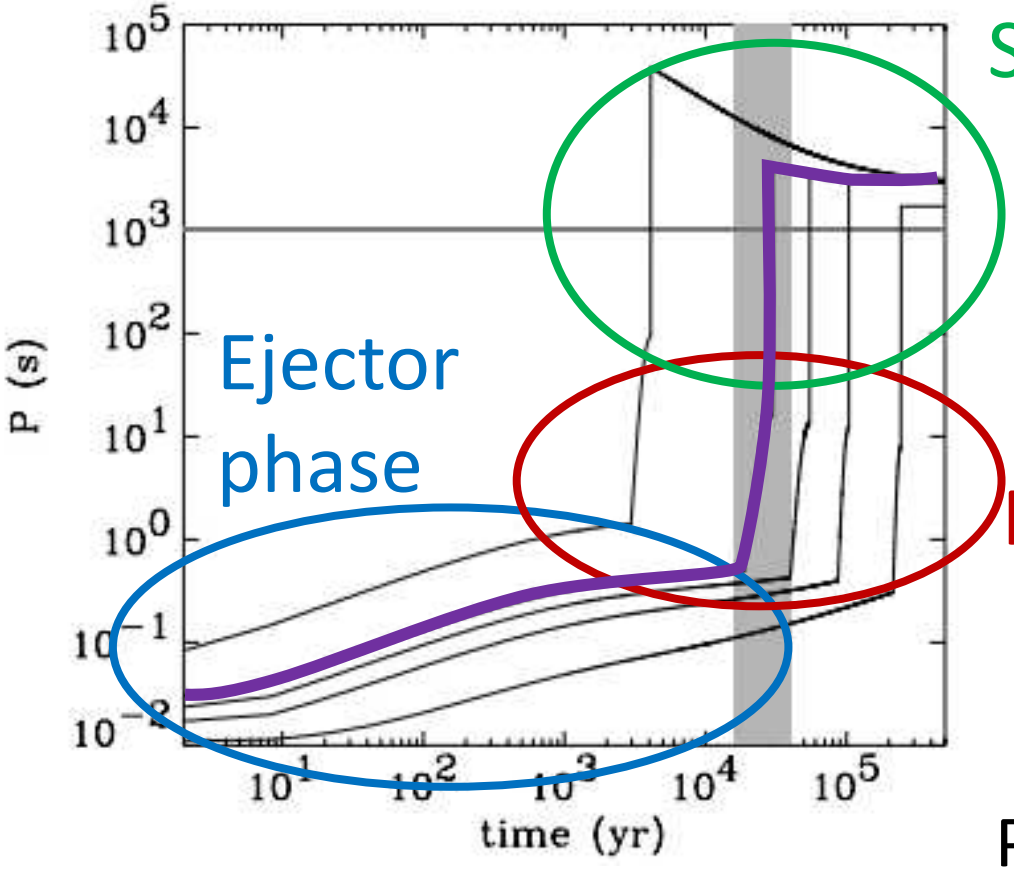
©Chandra/NASA

Assuming rotational equilibrium, strong magnetic fiel

$B \sim 10^{15}$ G ???

NS spin evolution with shell formation

- In ejector stage, slowly spins down
- After that, rapid spin down due to propeller + shell



$B_{ini} = 10^{14}$G model fits the observation well

Popov & Turolla 2012

Example: MC SNR J0513-6724

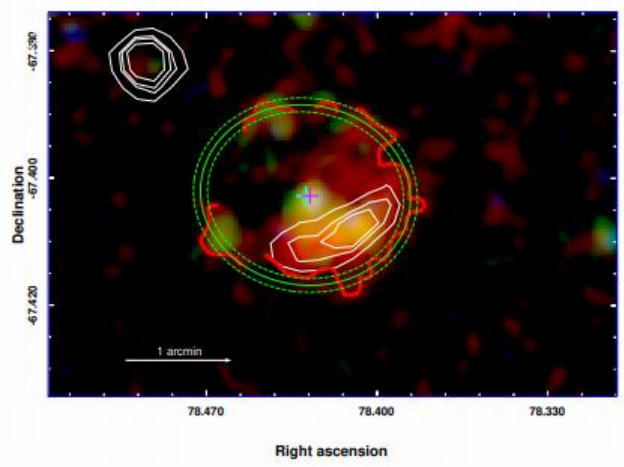
- NS HMXB associated with a SN Remnant
  - Age: 3000-6000 yr
  - B-type donor
  - P_{orb} = 2.23 d
  - P_{spin} = 4.4 s
  - Lx = 7 x 10^{33} erg/s

Very young!

Tight system, but RL is not filled

Fast rotation!

Smaller than typical HMXBs



Assuming the same model, weak B-field is required

Maitra et al. 2019

B = 10^{11} G ???

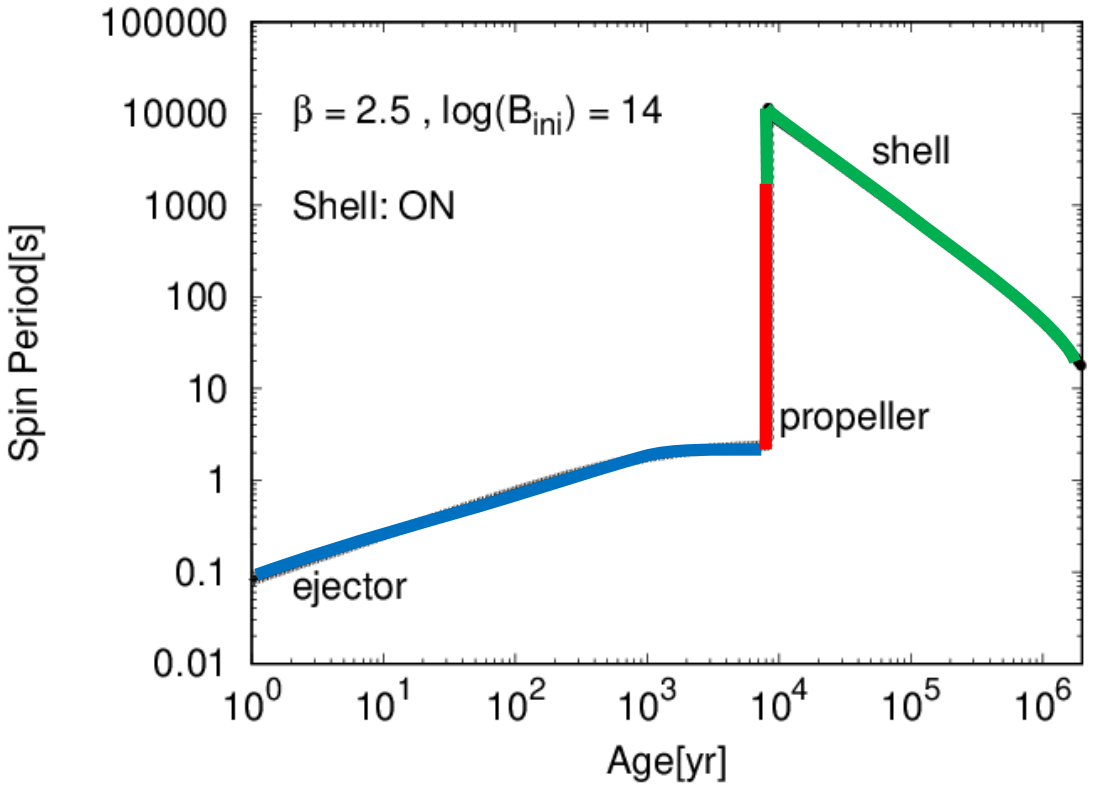
Binary evolution model

- Based on BSE code [1]
- Implemented modifications
  - Wind accretion: modified Hoyle-Littleton model [2][3]
    - Considering CAK wind acceleration / orbital motion
  - Mass loss model for massive stars [4]
  - Spin evolution of NS [5][6]
    - Propeller spin down
    - Dipole radiation
    - Interaction with settling shell
  - Evolution of NS magnetic field [7][8][9]
    - Hall / Ohmic diffusion
    - Accretion induced field decay
  - Short time-stepping to cover spin evolutions

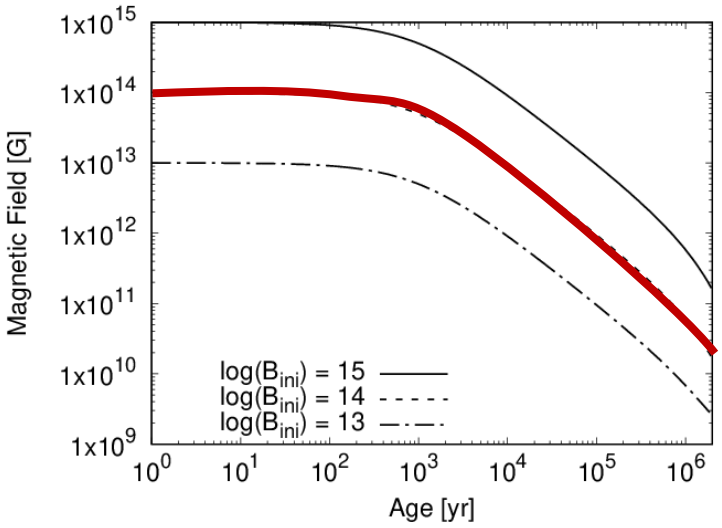
[1] Hurley et al.2002
[2] Wang et al.1981
[3] Karino et al. 2019
[4] Vink et al. 2001
[5] Ghosh 2007
[6] Shakura et al. 2012,2014
[7] Aguilera et al. 2008
[8] Popov & Turolla 2012
[9] Zhang & Kojima 2006

Example of binary evolution

- Spin evolution of typical wind-fed HMXB
  - Slow wind velocity + initially strong B-field
  - Magnetic field decays in 1kyr



Magnetic field



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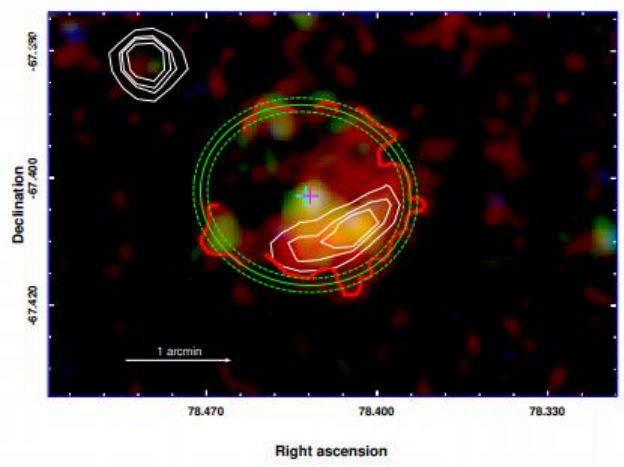

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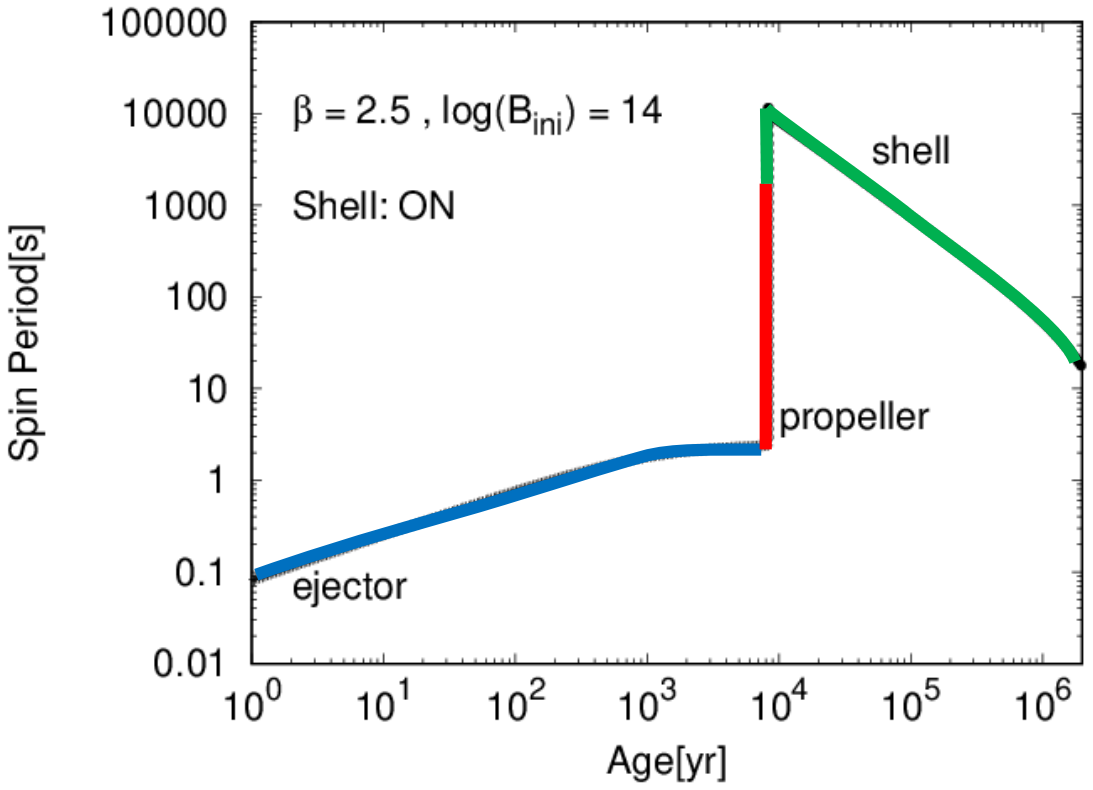
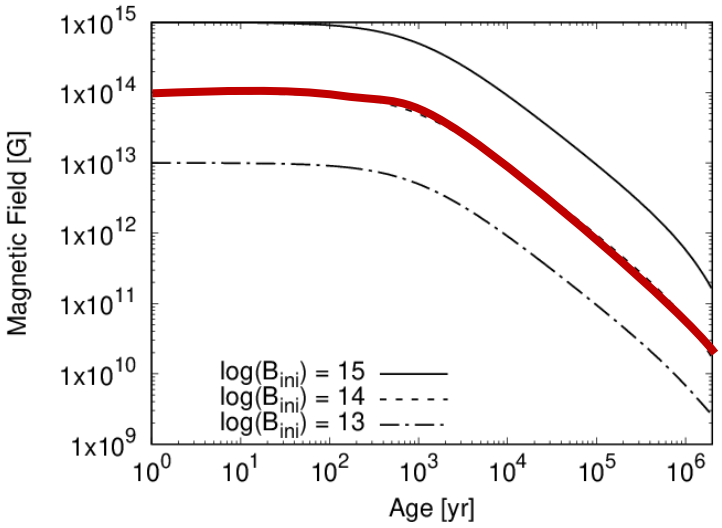


Magnetic field



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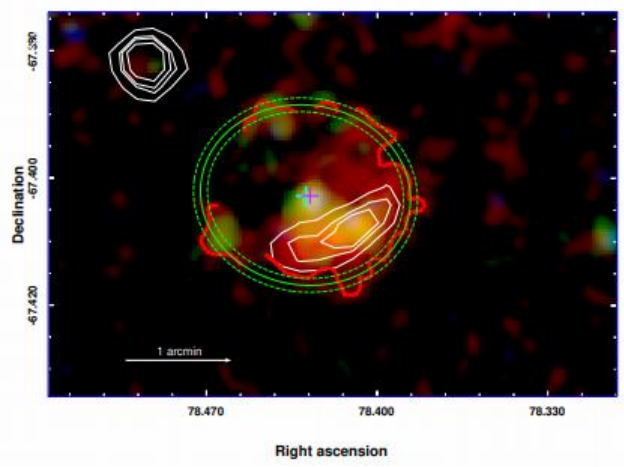

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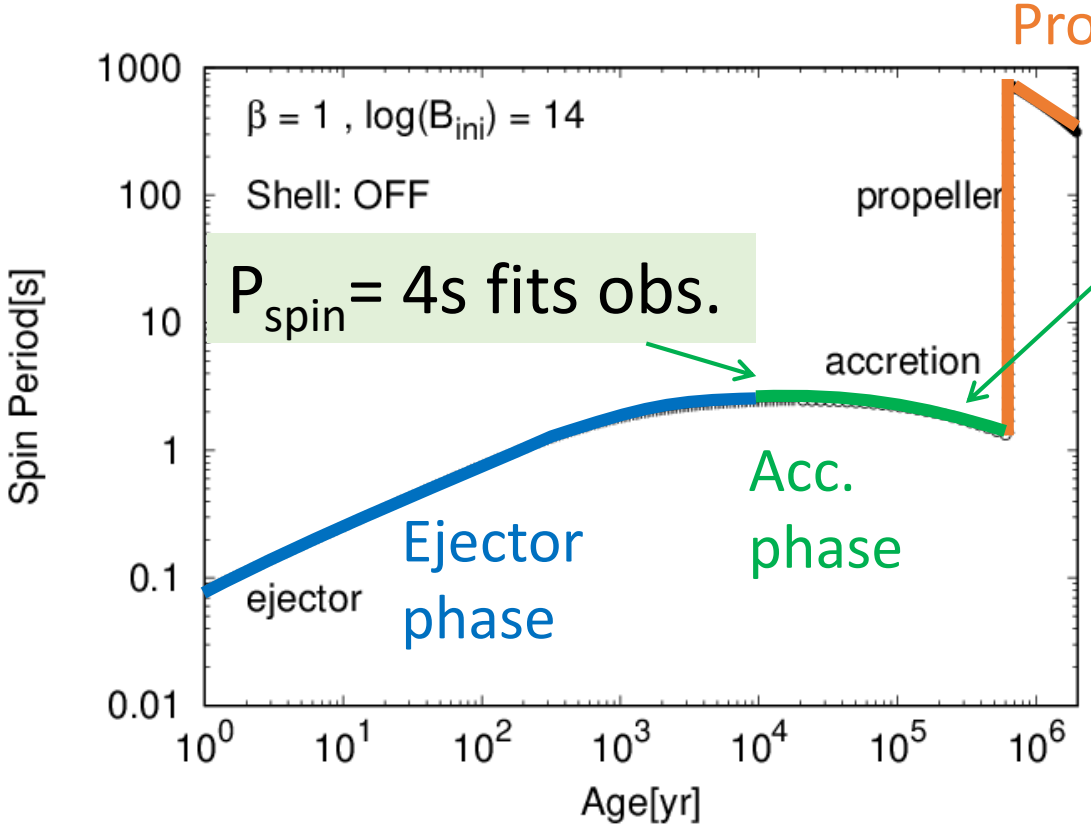
Application: MC SNR J0513-6724

- Fast wind velocity?
  - X-ray luminosity is low in this system
  - Accretion rate is low
  - Under standard mass loss rate, wind velocity should be fast
- Subsonic accretion shell really form?
  - Orbital separation is narrow in this system
  - Accretion geometry could be highly spherically asymmetric
  - Disk-like acc. flow reduces its thermal pressure and thick shell formation could be avoided

Application: MC SNR J0513-6724

- Shell formation is switched OFF
  - Strong field + fast wind model fits the obs.

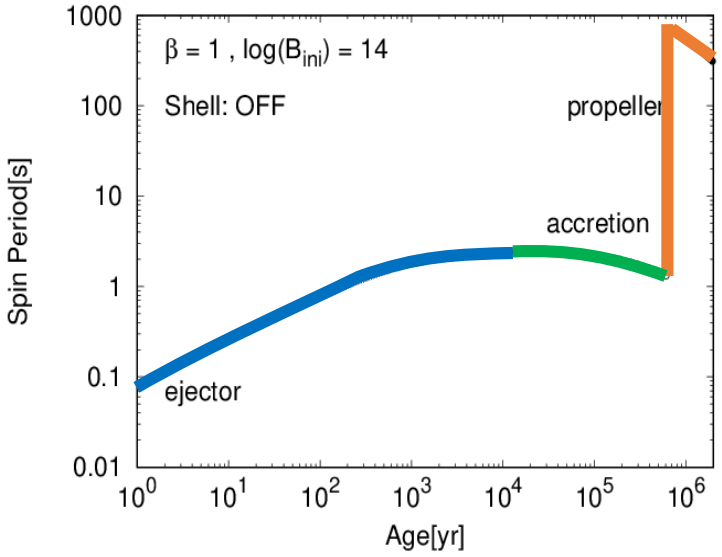


L_X=9x10^{33} erg/s also fits the obs.

New Accretion regime appears before spin-down

Discussion

- No shell + Strong field
  + Fast wind model fits obs.
- “New Accretion Regime”



Strong field
~ rapid energy loss

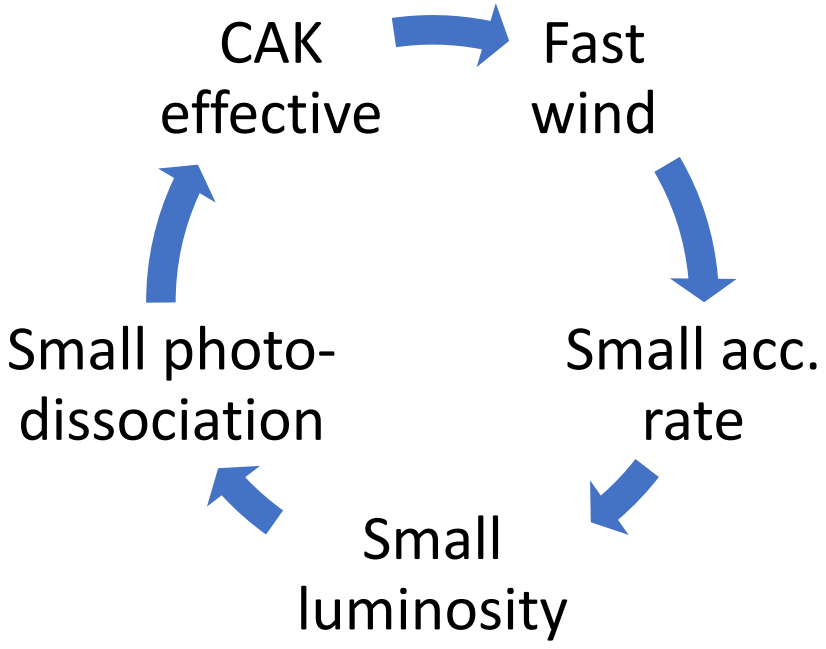
→ Ejector phase finished in short time-scale

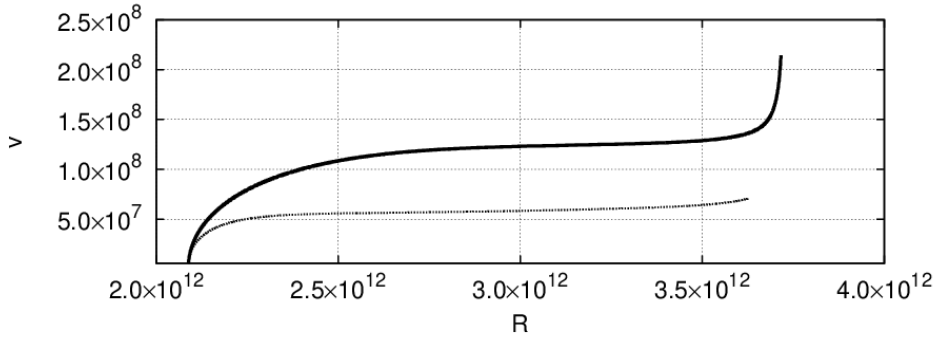
Strong field ~ large R_M
Fast wind ~ small R_{acc}

→ Propeller effects start working after magnetic field decays

Discussion

- Fast wind – low L_X consistency
- Bimodal wind?
  - Fast wind – Low luminosity
  - Slow wind – High luminosity





1D numerical study gives TWO solutions of wind velocity, in acc. flow from donor to NS (Karino 2014)

Conclusion

- The evolution tracks of wind-fed HMXBs involving NSs are considered
  - Including NS spin and magnetic-field evolutions
- After ejection regime, propeller / shell formation spin-down dominates the spin of NS
- New accretion window is opened !!
  - Fast-wind, strong B-field, no shell formation
  - Spin-age relation in MC SNR J0513-6724 could be well fit
- X-rays from compact companion affects the mass loss feature of massive donor
  - Wind velocity could change the mass loss rate