Wind Roche lobe overflow

Reporter: Kun Xu

Ref: El Mallah + 2019, AA, 622, L3

December 12, 2019

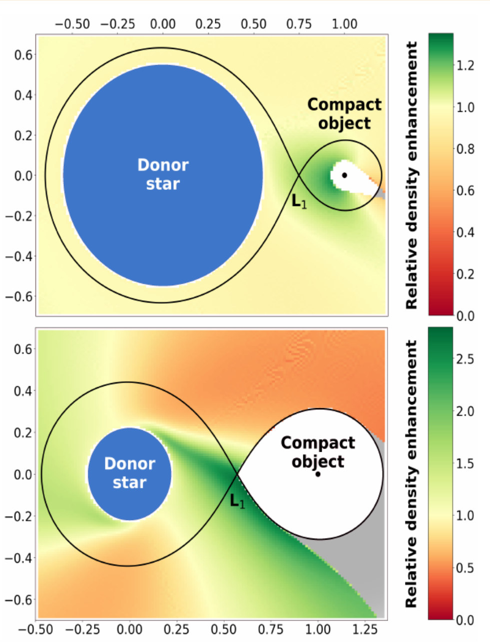
Why Read

- wind accretion code
- why beamed
- coding

NOTE: Maybe there are mistakes.

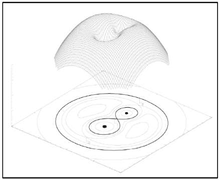
Vela X-1 – BHL model

M101 – wind-RLOF model

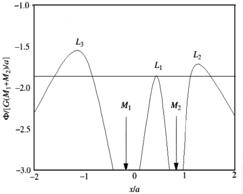


Why beamed

When the wind is slow enough compared to the orbital speed to see its dynamics significantly altered by the Roche potential, it is beamed towards to accretor.



3D representation of the Roche potential for a binary with $q = 2$. From van der Sluys (2006)



Variation of the Roche potential as a function of position on the line connecting the two stars.
A fitting formula is

$$\frac{-\Phi_L}{GM_{tot}/a} = \frac{3}{2} + \exp\{\frac{\ln(10)}{3} - [\frac{12}{5} + (\frac{4}{9}\ln^2(q))^{9/8}]^{7/16}\}$$

L_{X}

L_{X} depends on:

1. $\dot{M}_*$
   the stellar mass-loss rate;
2. μ
   the rate $\mu\dot{M}_*$ at which mass is transfered from the star into the domain of gravitational influence of the accretor;
3. ΔM_{acc}(?)
   the mass which actually ends up being accreted onto the compact object;
4. $\zeta \sim 10\%$
   the efficiency of the conversion of accreted mass to radiation.

Stellar winds in SgXBs

In an isotropic situation, radial-velocity profiles can be well approximated by a β-law (Puls + 2008)

$$v_\beta(r) = v_\infty(1 - R_*/r)^\beta$$

β is a positive exponent which represents the efficiency of the acceleration, that is, how fast the wind reaches the terminal speed: the lower β, the earlier v_∞ is matched.

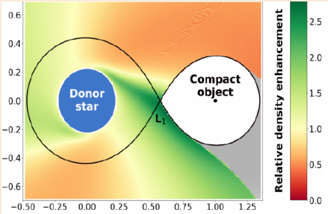
$R_{\rm ecs}$

The effective cross section of the accretor $R_{\rm ecs}$

- BHL model, $R_{\rm ecs} = R_{\rm acc}$

$$R_{\rm acc} = 2GM_{\bullet}/v_{\beta}^{2}(r = a)$$

- wind-RLOF model
  $R_{\rm ecs} = R_{\rm acc}$, if $R_{\rm acc} < R_{\rm RL}$;
  $R_{\rm ecs} = R_{\rm RL}$, if $R_{\rm acc} > R_{\rm RL}$;



NOTE: in wind-RLOF model, RL indicate the accretor's ($\times$).

Dimensionless form

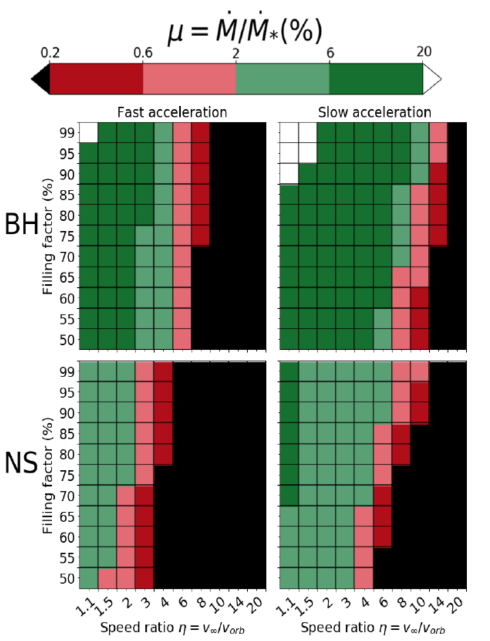
In dimensionless form, the solutions of the equation of motion depend only on

1. q
   the mass ratio;
2. f
   the falling factor (the ratio of the stellar radius to the Roche lobe radius);
3. β
   the exponent in the radial-velocity profiles;
4. η
   $\eta = v_\infty / v_{\rm orb}$, the ratio of the terminal wind speed to the orbital speed.

Mass transfer via wind-RLOF

$\beta = 1$ $q = 2$	$\beta = 2$ $q = 2$
$\beta = 1$ $q = 15$	$\beta = 2$ $q = 15$

$L_X \propto \mu$



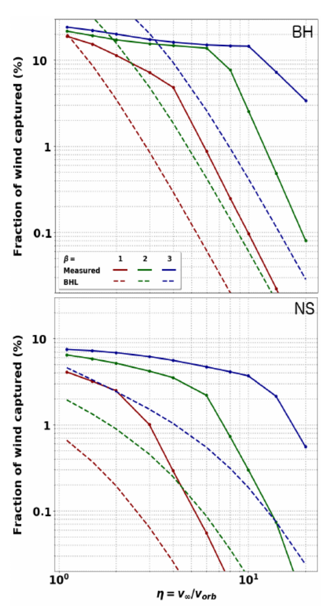
μ in BHL model

$$\mu_{\rm BHL} = \dot{M}_{\rm BHL}/\dot{M}_* = \frac{(1+q)/q^3}{\eta(1-f\varepsilon)^\beta[1+(\eta(1+q)(1-f\varepsilon)^\beta/q)]^{3/2}}$$

where ε is the ratio of the stellar Roche lobe radius by the orbital separation given by Egglenton (1983) which depends only on q.

μ

$f = 90\%$



BH
NS
Fraction of wind captured (%)
10
1
0.1
β =
1
2
3
Measured
BHL
10^0
10^1
$\eta = v_\infty / v_{orb}$

Accretion luminosity

$$L_{\rm acc} = (\zeta \mu \dot{M}_*) c^2$$

- P13
  $\dot{M}_* \sim 10^{-5} M_\odot\ \mathrm{yr}^{-1}$;
  $f > 90\%$, $q \sim 15$, $\eta = 1 - 3$;
  $\Rightarrow \mu = 6\%$ for $L_{\rm X} = 3 \times 10^{39}$ cgs ($\mu > 5\%$)
- M101
  $\dot{M}_* \sim 2 \times 10^{-5} M_\odot\ \mathrm{yr}^{-1}$;
  $f = 50\%$, $q \sim 2$, $\eta = 3 - 4$;
  $\Rightarrow \mu \gtrsim 6\%$ for $L_{\rm X} = 3 \times 10^{39}$ cgs ($\mu > 2.6\%$)
- Vela X-1
  $\dot{M}_* \sim 6.3 \times 10^{-7} M_\odot\ \mathrm{yr}^{-1}$;

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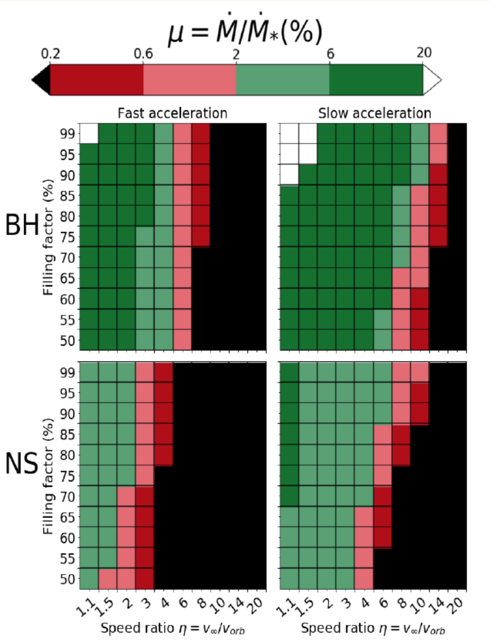


Disk ?

A disk can be form only if the wind is slow enough (Illarionov & Sunyaev 1975).

In the wind-fed X-ray binaries, the physical condition for the formation of an accretion disk is

$$j_{\rm a} > j_{\rm K}(R_{\rm A})$$

$j_{\rm a} = k_{\rm w}\Omega_{\rm b}R_{\rm G}^2 \propto v_{\rm w}^{-4}$ is the specific angular momentum of the captured stellar wind matter, $j_{\rm K}(R_{\rm A}) = \sqrt{GM_{\rm NS}R_{\rm A}}$ is the Keplerian angular momentum at the NS magnetosphere.

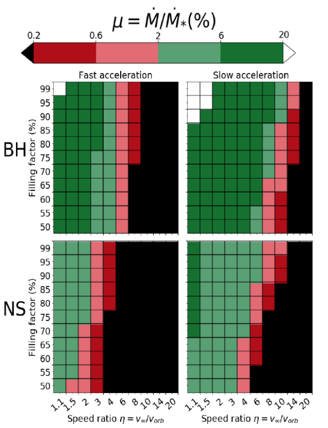
(Ref: Lü G.-L. +, 2012, MNRAS, 424, 2265.)

Coding

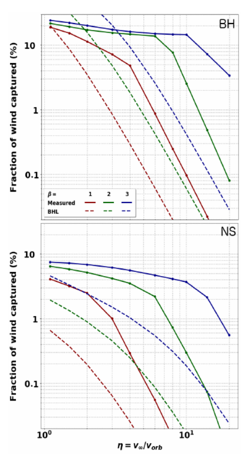
Unsolved...

Idea:

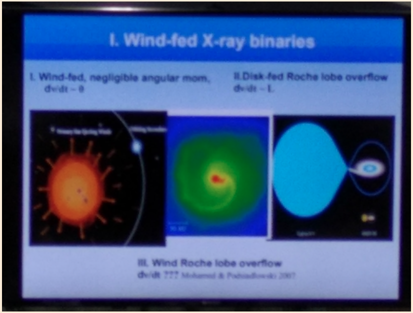
1,



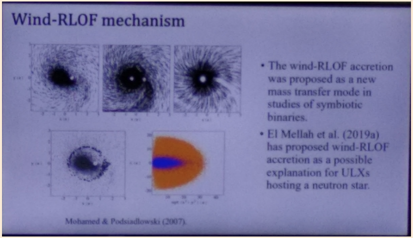
2,



The 2nd XRB meeting @ Xiamen



Jiren Liu



Zhenxuan Liao

Comments from collegues

- Jiren Liu
  Not clear about the torque
- Zhenxuan Liao
  What is the transition between the BHL model and the wind-RLOF model?
- Hao Tong
  Only simulation results, how to use it?
- Guoliang Lv
  Grid

Interesting points got from the meeting

- Liming Song
  evolution of cyclotron line
- Zhenxuan Liao
  disk in Vela X-1
- Hao Tong
  accreting magnetar


THANK YOU