Wind accretion onto compact objects

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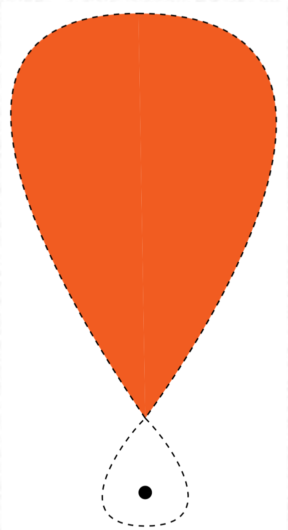
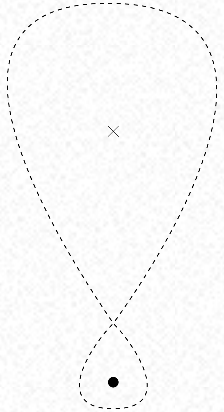
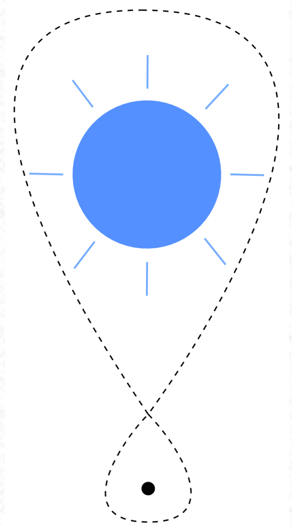
Introduction

X-ray binaries







Roche lobe overflow

Wind accretion

Low-mass stellar companion (**LMXB**)

Permanent accretion disc

↳ multi-color black body (Shakura & Sunyaev 73)

↳ support on top of which grows various instabilities

High-mass stellar companion (**HMXB**)

Intense radiatively driven **stellar winds** (CAK 75)

↳ terminal velocity ~ 1000 km/s

↳ mass outflows ~ 10^{-6} $M_\odot$/yr

↳ **clumpy**

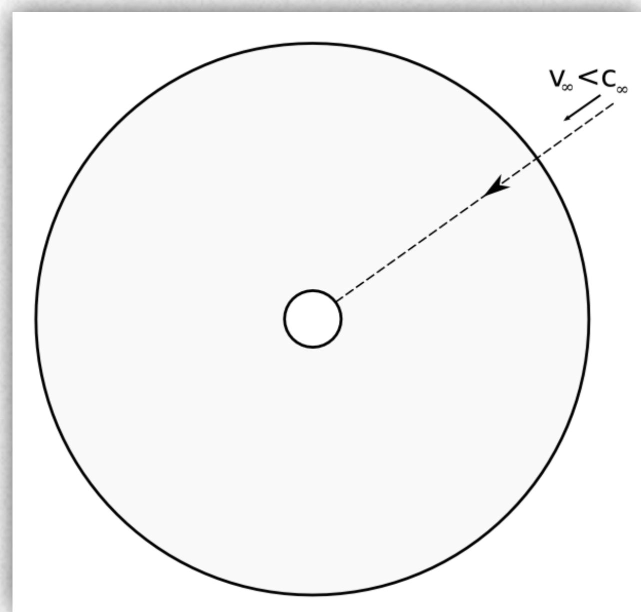
Low angular momentum flow => disc? permanent?

Contents

I. 1. Spherical flow VS planar flow

Spherical flow

BONDI 52



- ↳ spherical (1D)
- ↳ homogeneous flow at infinity
- ↳ **subsonic** incoming flow ($v_\infty<c_\infty$)
- ↳ thermal flow

Sonic radius

$$r_0 = \frac{5-3\gamma}{4}\frac{GM}{c_\infty^2 + \frac{\gamma-1}{2}v_\infty^2}$$

Planar flow

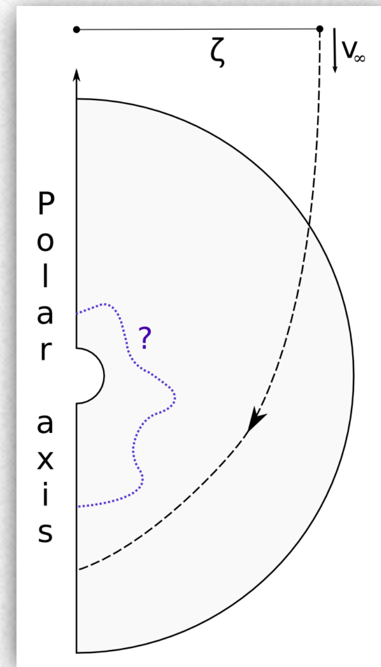
HOYLE & LYTTLETON 39
BONDI & HOYLE 44

$$\zeta < \zeta_{\rm HL} = \frac{2GM}{v_\infty^2}$$

B-H accretion condition

$$\Downarrow$$

$$\dot{M}_{\rm HL} = \pi\zeta_{\rm HL}^2\rho_\infty v_\infty$$



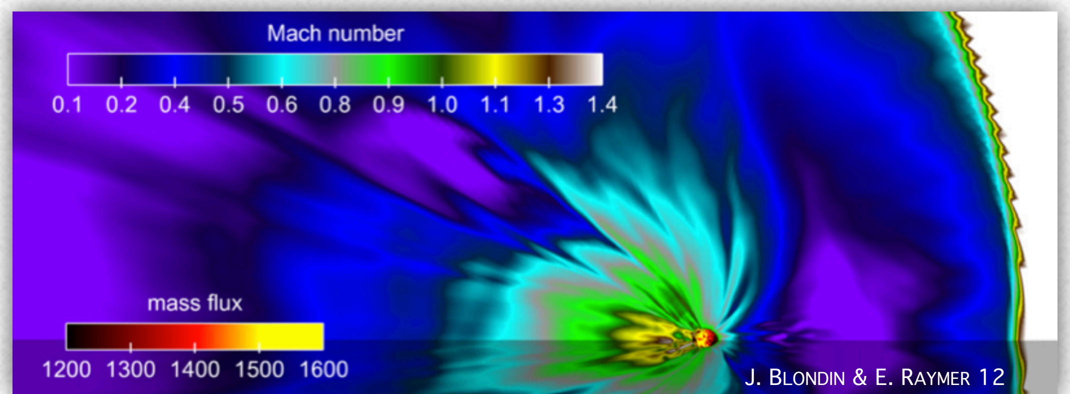
- ↳ axisymmetric (2D)
- ↳ homogeneous flow at infinity
- ↳ **supersonic** incoming flow ($v_\infty>c_\infty$)
- ↳ ballistic approximation (zero temperature flow)

Topological result by FOGLIZZO & RUFFERT (96) :
the B-H sonic surface intersects its spherical counterpart

=> a γ=5/3 gas admits a sonic surface anchored into the accretor

I. 2. Numerical simulations : state of the art

Large accretors



Full 3D simulations

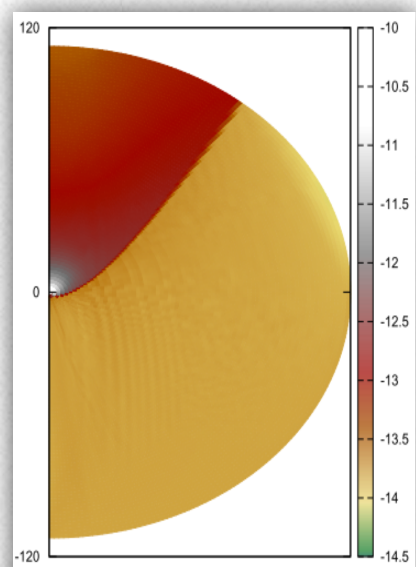
Influence of the accretor size (RUFFERT 94)

Inner boundary conditions

$r_{out}/r_{in} = 10^3$

$$\frac{\zeta_{HL}}{R_{Schw}} = \left(\frac{c}{v_\infty}\right)^2$$

Relativistic winds



F. S. LORA-CLAVIJO & F. D. GUZMÁN 12

GRHD simulations of B-H on to a black hole

Down to the event horizon

Wind velocity of **10,000 km/s**

$r_{out}/r_{in} = 10^3$

I. 3. Numerical setup

The code

MPI-AMRVAC
↳ solves the conservative equation of (M)HD
↳ mesh-based finite volumes
↳ openMPI parallelized
↳ highly customizable

$$\partial_t \rho + \boldsymbol{\nabla} \cdot (\rho \mathbf{v}) = 0$$

$$\partial_t (\rho \mathbf{v}) + \boldsymbol{\nabla} \cdot (\rho \mathbf{v} \otimes \mathbf{v} + P \mathbb{1}) = -\rho \boldsymbol{\nabla} \Phi$$

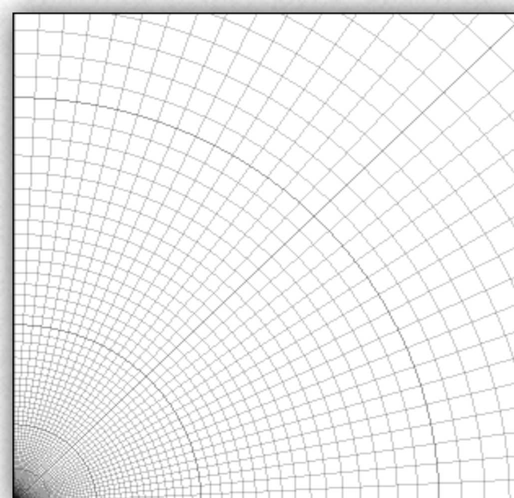
$$\partial_t e + \boldsymbol{\nabla} \cdot [(e+P)\,\mathbf{v}] = -\rho \mathbf{v} \cdot \boldsymbol{\nabla} \Phi$$

VERSATILE ADVECTION CODE

R. Keppens + 12
O. Porth + 14

The setup

Grid
↳ spherical 2.5D
↳ logarithmically stretched => cell uniform aspect ratio
↳ r_{out}/r_{in} up to 10^5



Boundary conditions
↳ outer : extension of Bisnovatyi-Kogan+79
↳ **inner** : continuous fluxes

Physical setup

Free input parameters
↳ mass & velocity
↳ **Mach number at infinity**
↳ adiabatic index
↳ inner boundary size

I. 4. Results

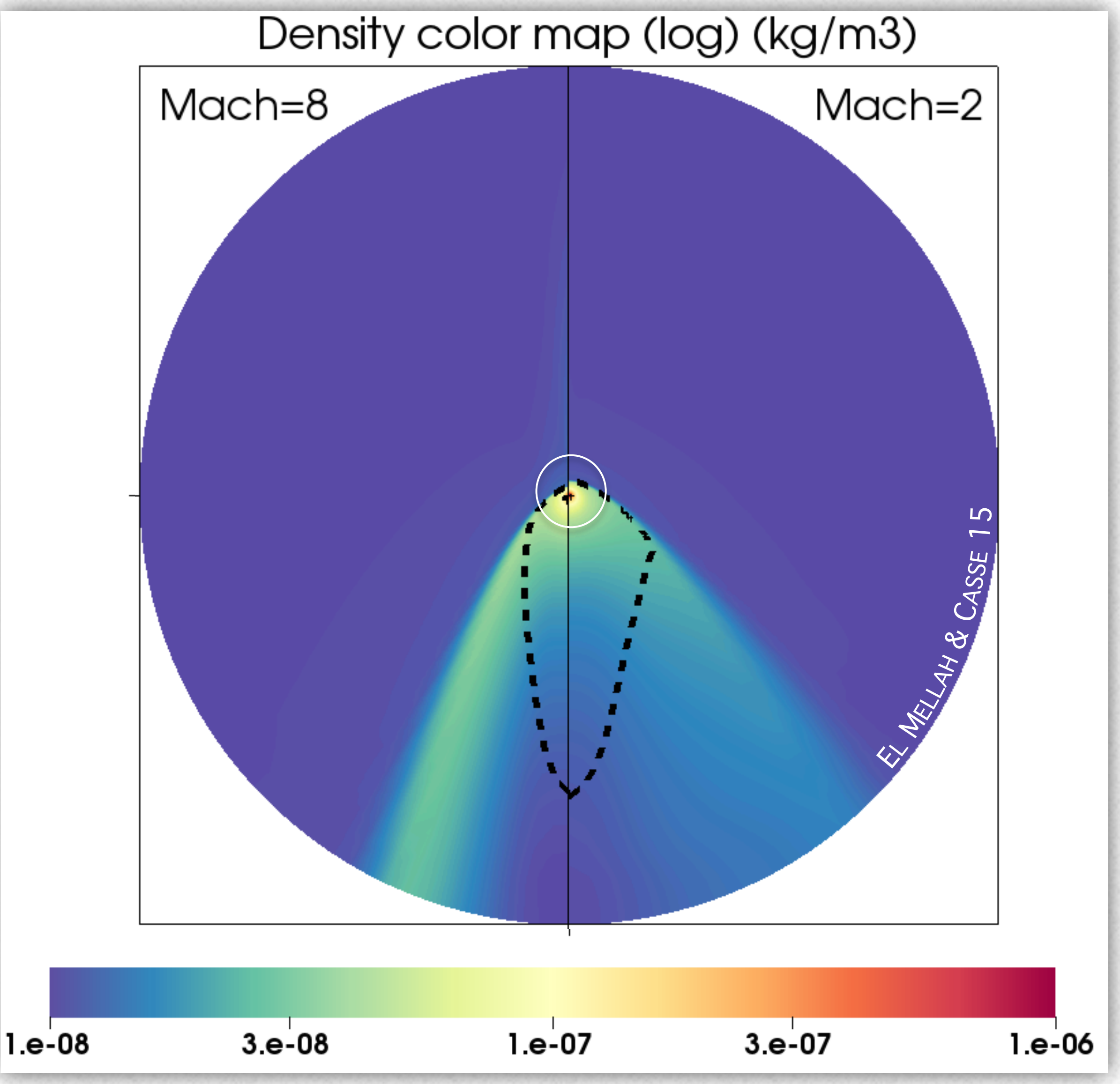
Relaxed configuration

Accretion radius ζ_{HL}

Stagnation point

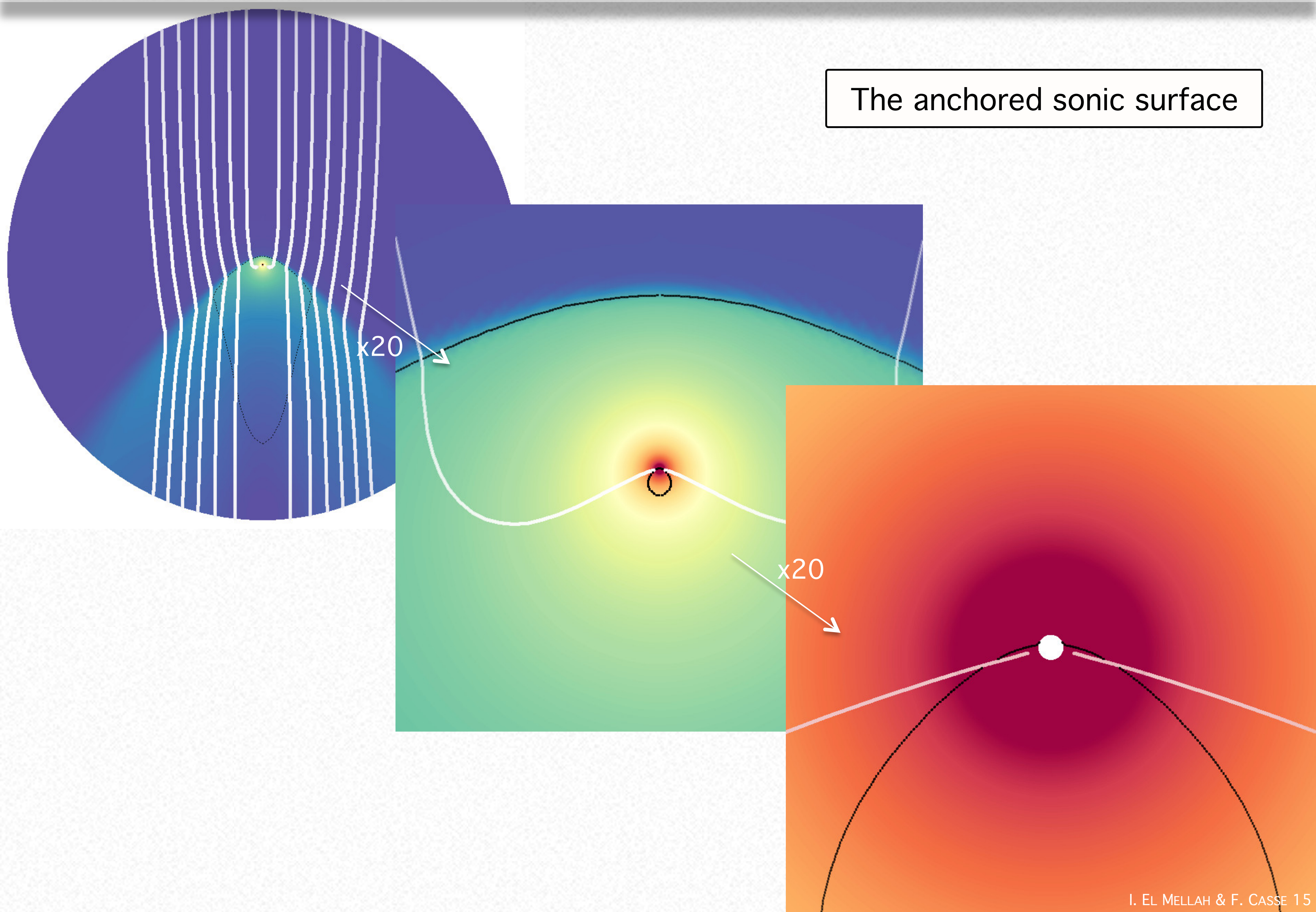
Bow shock

Steady-state (no instability)

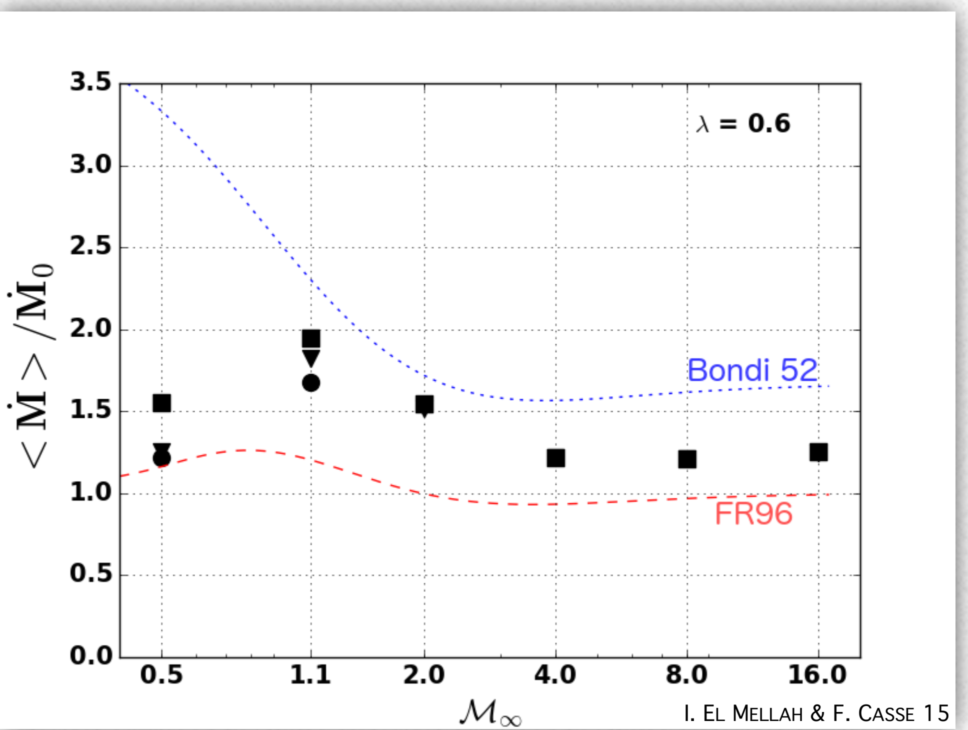


I. 4. Results

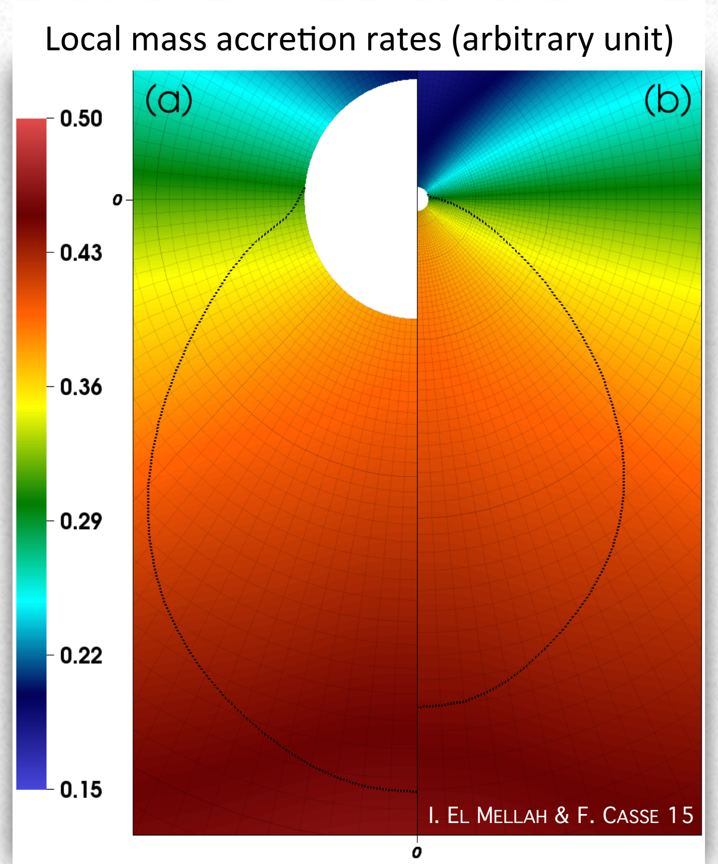
The anchored sonic surface



I. 4. Results



Mass accretion trends for B-H flows



Comparison w/ FR96 formula (in red)

Convergence (independent of r_{in})

Downstream amplified accretion

Contents

II. 1. Winds of hot isolated stars

Photons > eV absorbed by metals => **absorption line driven winds**

CAK acceleration

$$g_{\mathrm{CAK}} = \frac{Q}{1-\alpha} \cdot \frac{\kappa_e L_*}{4\pi r^2 c} \cdot \left(\frac{1}{\rho c \kappa_e Q} \frac{\mathrm{d}v}{\mathrm{d}r} \right)^{\alpha}$$

CASTOR, ABBOTT & KLEIN (73)
Reviews by KUDRITZKI & PULS (00) and PULS ET AL. (08)

$\Longrightarrow$

Beta-wind velocity profile

$$v(r) = v_\infty \left(1 - \frac{R_*}{r} \right)^{0.7} \quad \text{with} \quad v_\infty \sim 2.5 v_{\mathrm{esc}} \frac{\alpha}{1-\alpha}$$

Force multipliers **for B0-1 Ia :**

↳ α ~ 0.45 to 0.55 : acc. efficiency

↳ Q ~ 900 : mass-loss amplitude

Non-linear acceleration term

↳ ballistic assumption

↳ 4^{th} order Runge-Kutta integrator

Critical point

↳ **mass loss rate**

↳ **terminal speed**

↳ strong **coupling** between variables

II. 2. Radiatively-driven winds in a Roche potential

Aims

↳ to explicit the relevant parameters

SHAPE
- q : mass ratio (star/accretor)
- α : alpha force multiplier
- Γ : Eddington factor (~luminosity)
- f : filling factor (~radius)

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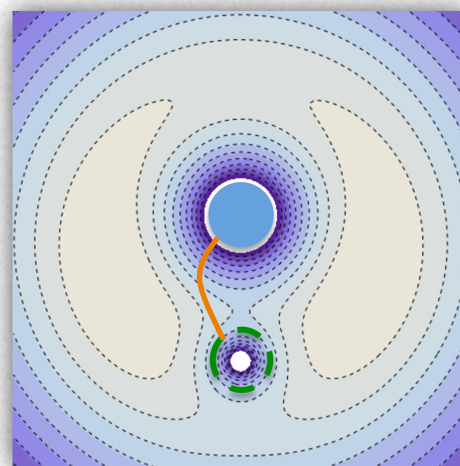
SCALE
- P : orbital period
- M_2 : mass of the compact object
- Q : Q force multiplier

↳ to produce physically motivated **outer boundary conditions**



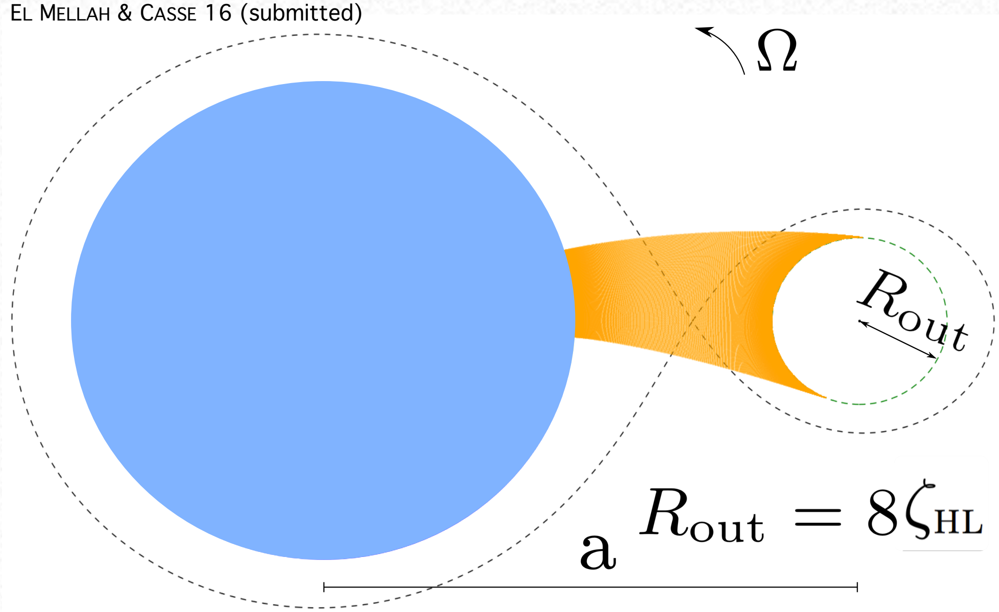
Methods

↳ sample the stellar surface

↳ integrate the trajectories (RK4,3D)

↳ refine those which enter the vicinity of the compact object

El Mellah & Casse 16 (submitted)



Results

Self-consistent parameters for :

↳ **orbit** (eg orbital velocity)

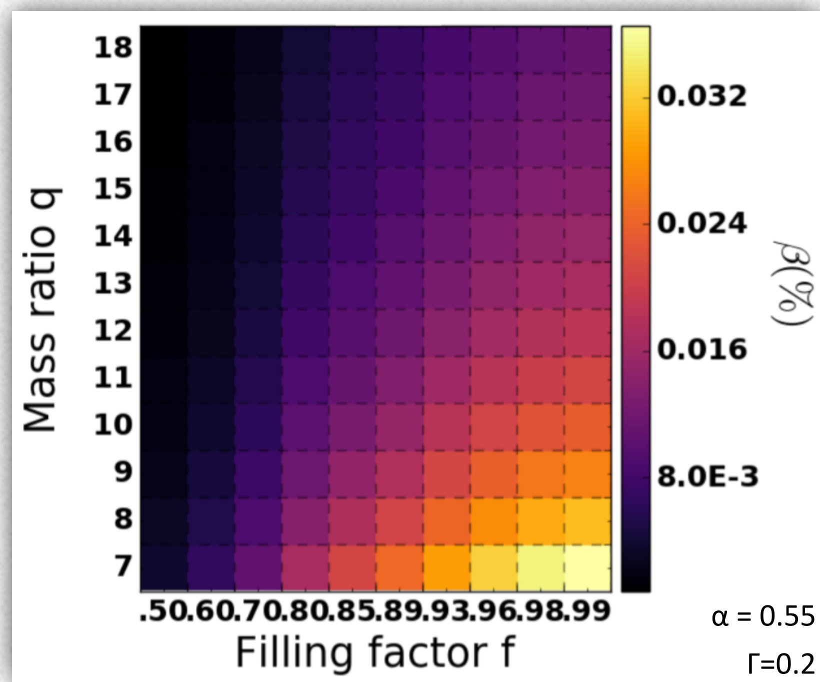
↳ **star** (eg effective temperature)

↳ **wind** (eg terminal speed)

↳ **accretion** (eg mass and angular momentum accretion rates)

Physically-motivated outer boundary conditions for full 3D hydro simulations

II. 3. The likelihood of a wind-capture disc



β : fraction of wind accreted onto the compact object

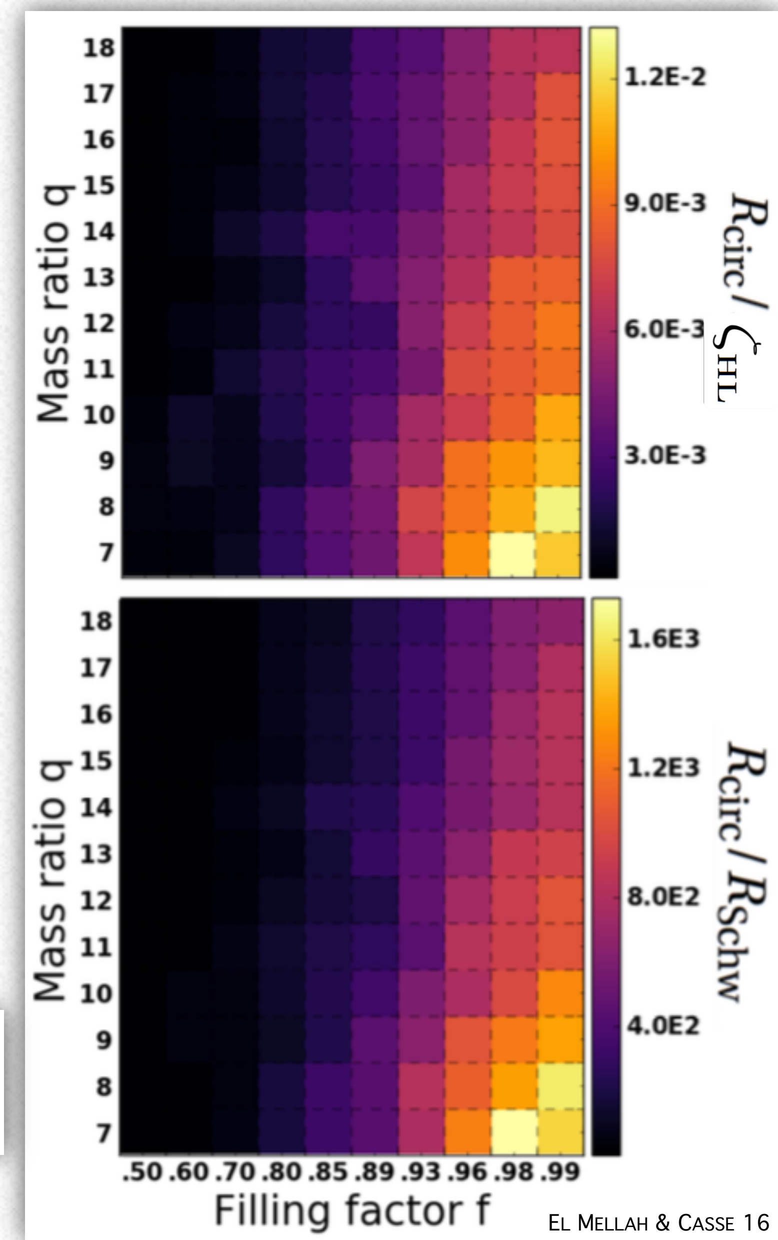
Circularization radius (~ size of the disc) midway between :

↳ the shock (HD and radiative instabilities)

↳ the NS (truncation at magnetosphere)

$$\frac{R_{\mathrm{mag}}}{R_{\mathrm{Schw}}} \sim 400 \left(\frac{0.2}{\Xi}\right)^{\frac{10}{7}} \left(\frac{B}{10^{11}\mathrm{G}}\right)^{\frac{4}{7}} \left(\frac{M}{1.5\mathrm{M}_{\odot}}\right)^{\frac{4}{7}} \left(\frac{L_{\mathrm{acc}}}{10^{36}\mathrm{erg}\cdot\mathrm{s}^{-1}}\right)^{-\frac{2}{7}}$$

Does it correspond to the X-ray bright configurations?



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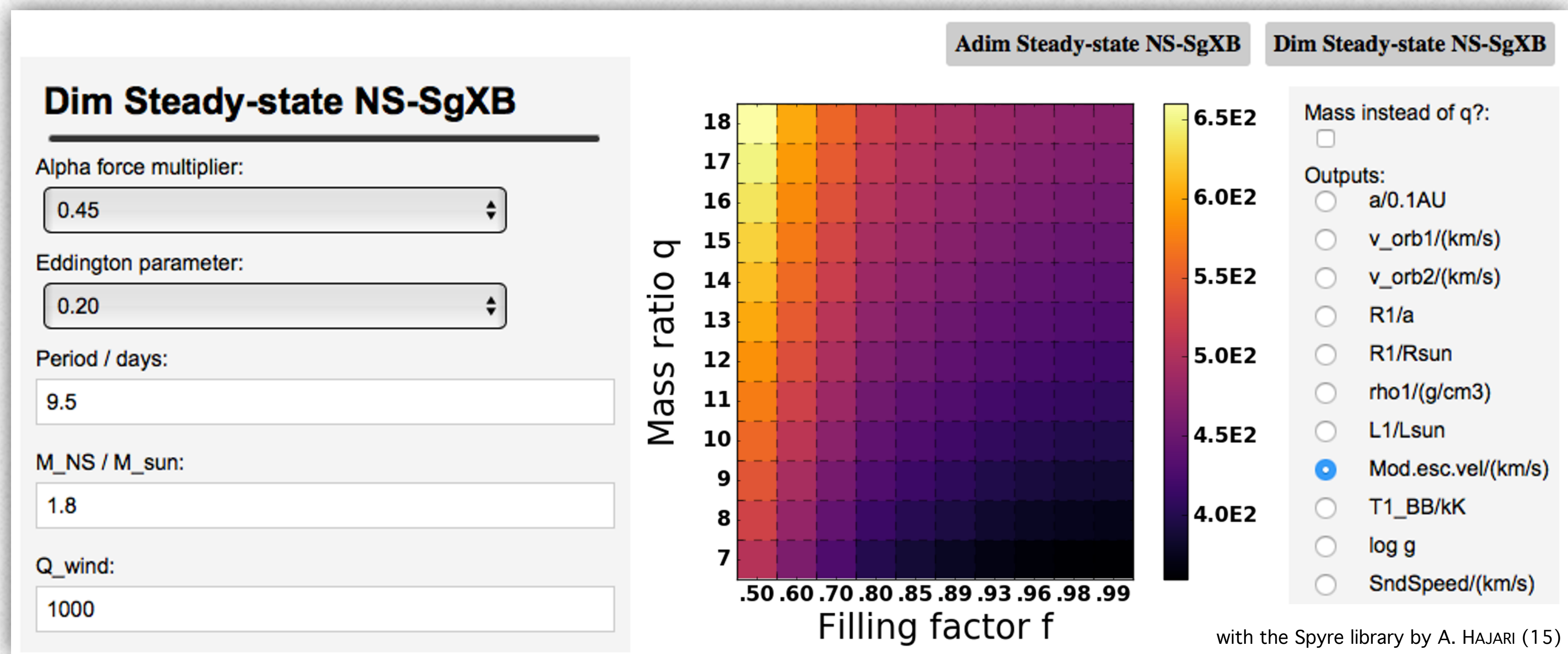
II. 3. Self-consistent sets of parameters



with the Spyre library by A. HAJARI (15)

Web data visualization tool : the WASO interface

Relates the observables to the physical parameters w/ :
- the orbital period
- the **mass of the compact object**
- the surface gravity
- the effective temperature
- the terminal speed
- the **X-ray luminosity**

II. 3. The X-ray luminosity

SHAPE

q

α

Γ

f

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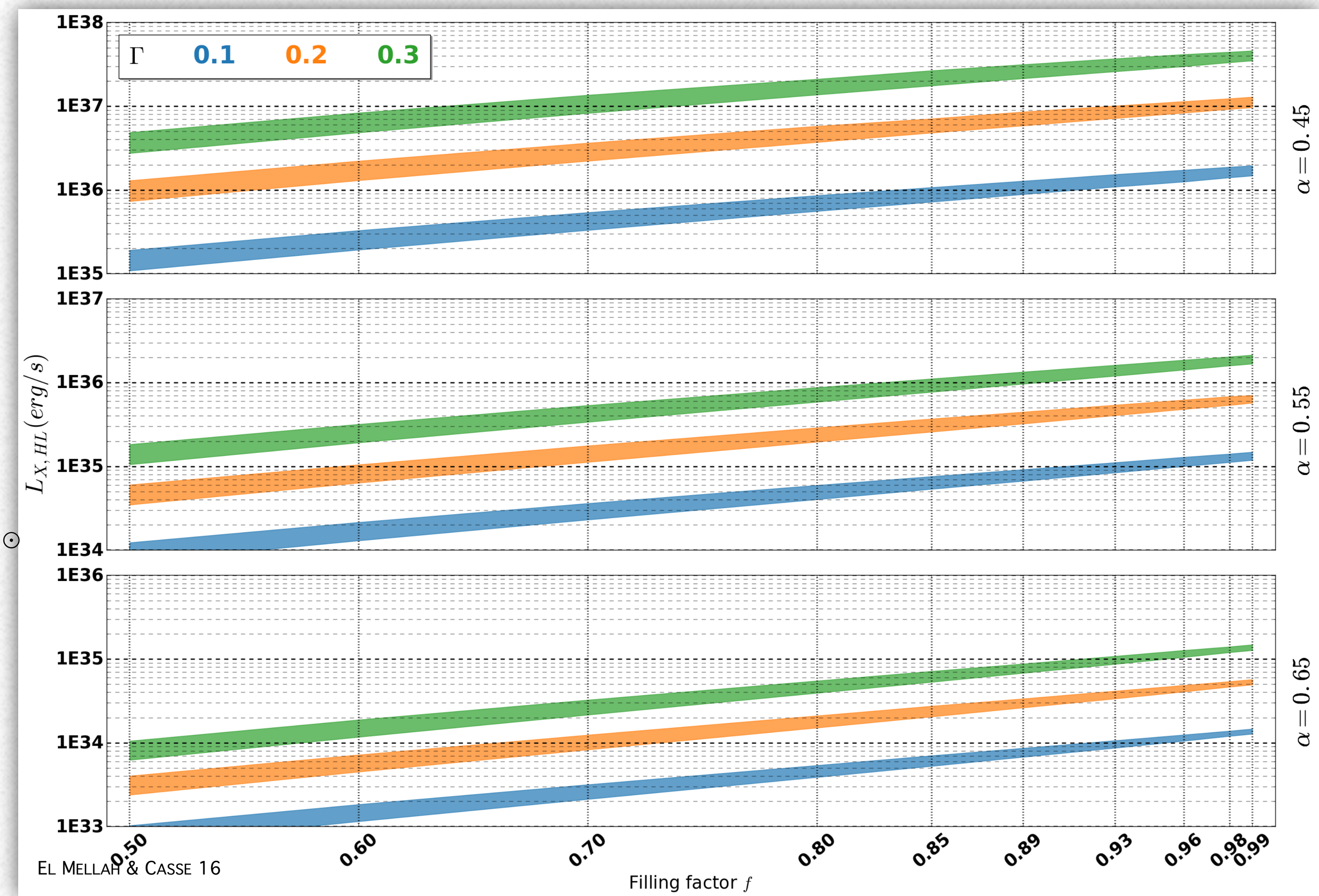
SCALE

~~R~~

M_2=1.8 $M_\odot$

Q = 900



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Explicits

↳ the **dependence strengths**

↳ the **degeneracies**

Terminal speed, mass outflow, etc **not forced**

Perspectives

Overview

Planar axisymmetric accretion flow (B-H)
↳ stable bow shock
↳ anchored sonic surface
↳ independence of the flow with the inner mask
↳ mass accretion rates

Wind accretion in Sg HMXB
↳ 4 shape parameters : q, α, Γ and f
↳ X-ray luminosity
↳ shearing of the inflow

Perspectives

↳ optically-thin cooling
↳ ionizing radiation feedback
↳ pulsar magnetosphere
↳ wind clumpiness
↳ pulsar spin and accretion
↳ stability of the wake?
Time variability : link Sg HMXB / SFXT?

↳ wind – Roche lobe overflow :
hybrid accretion regimes (Cen X-3, Cyg X-1)