Looking for MBH binary through its impact on the iron Kα emission line

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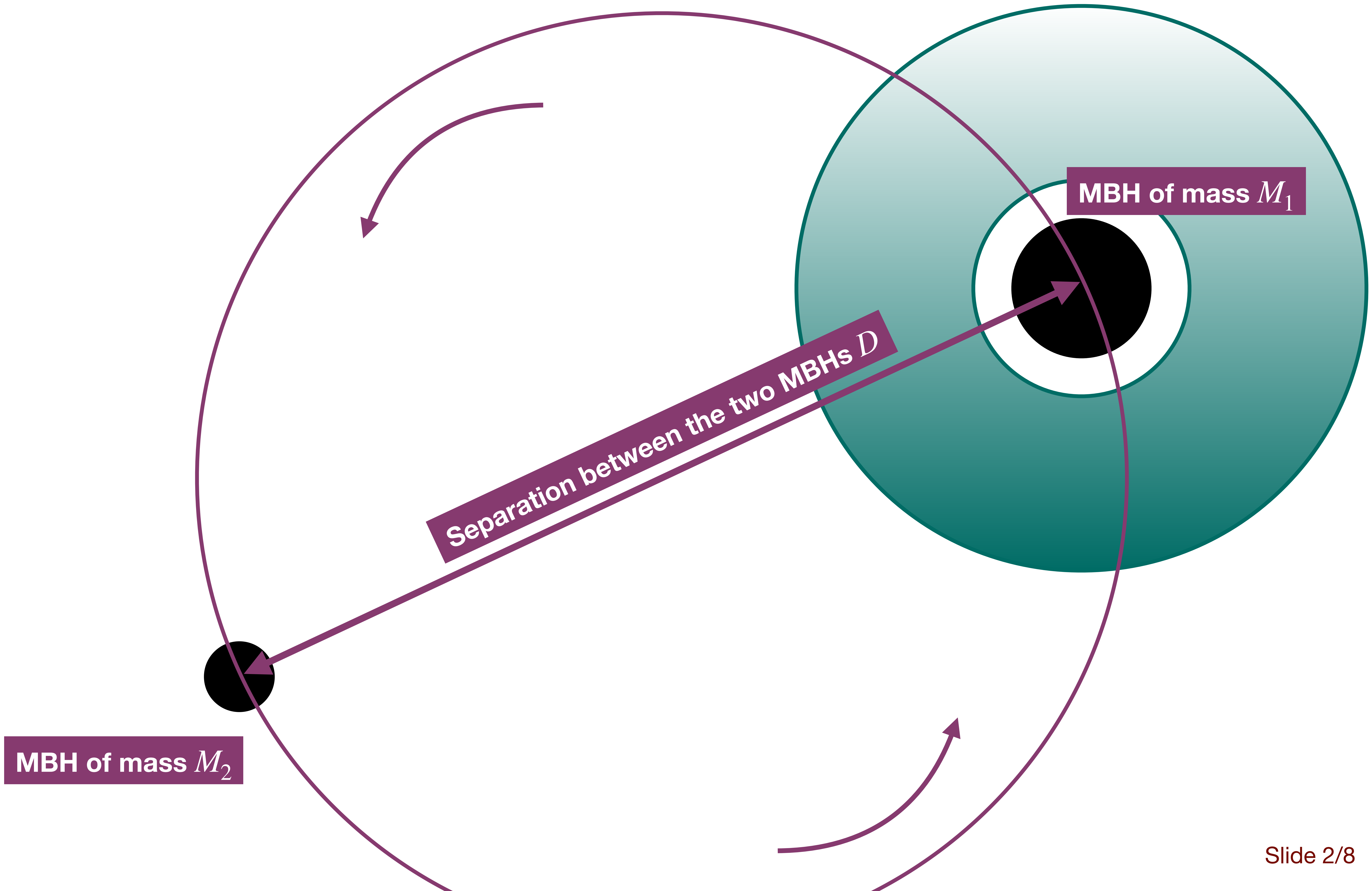
Gravitationally bound massive black hole binaries in the early stages of the merger



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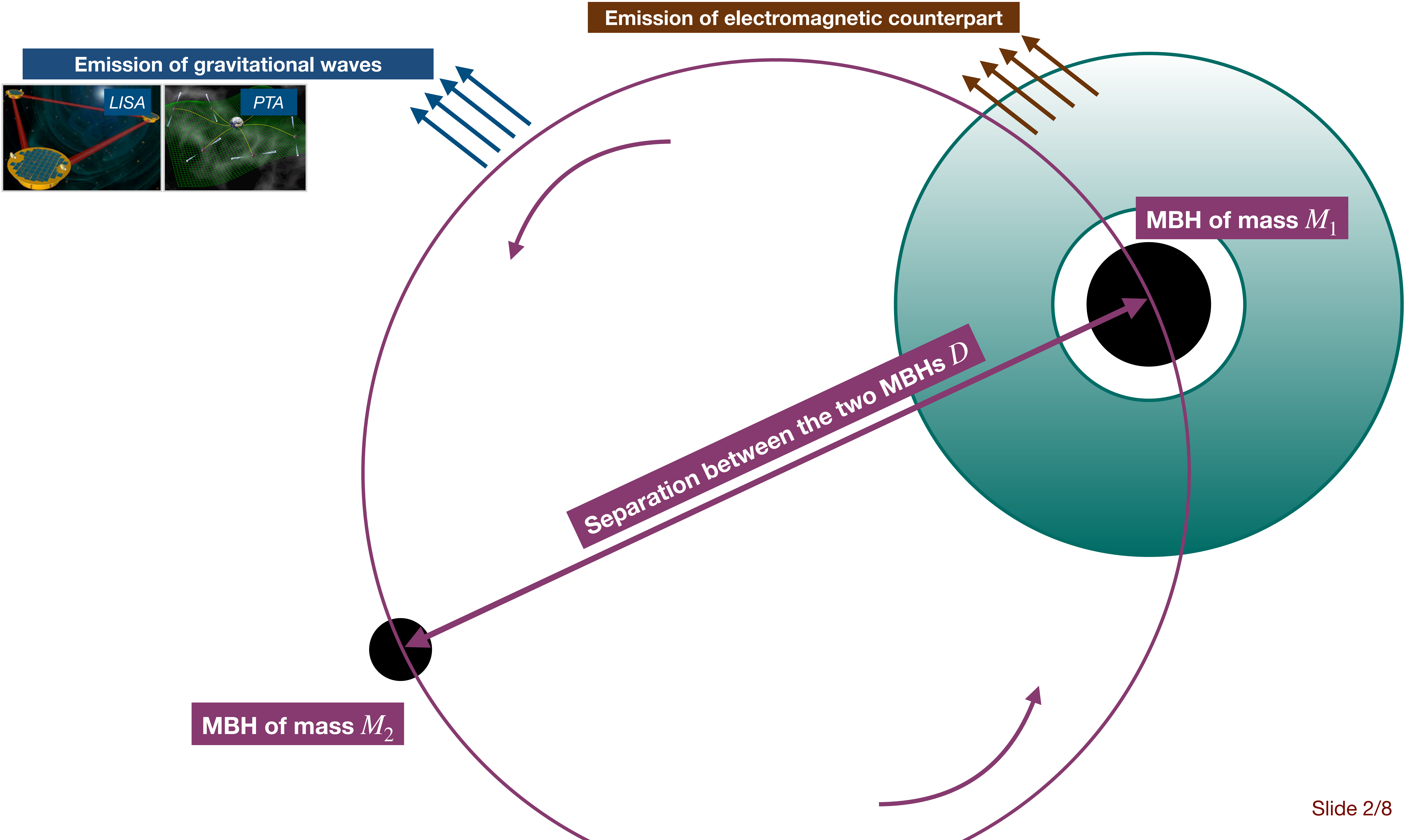


Gravitationally bound massive black hole binaries in the early stages of the merger

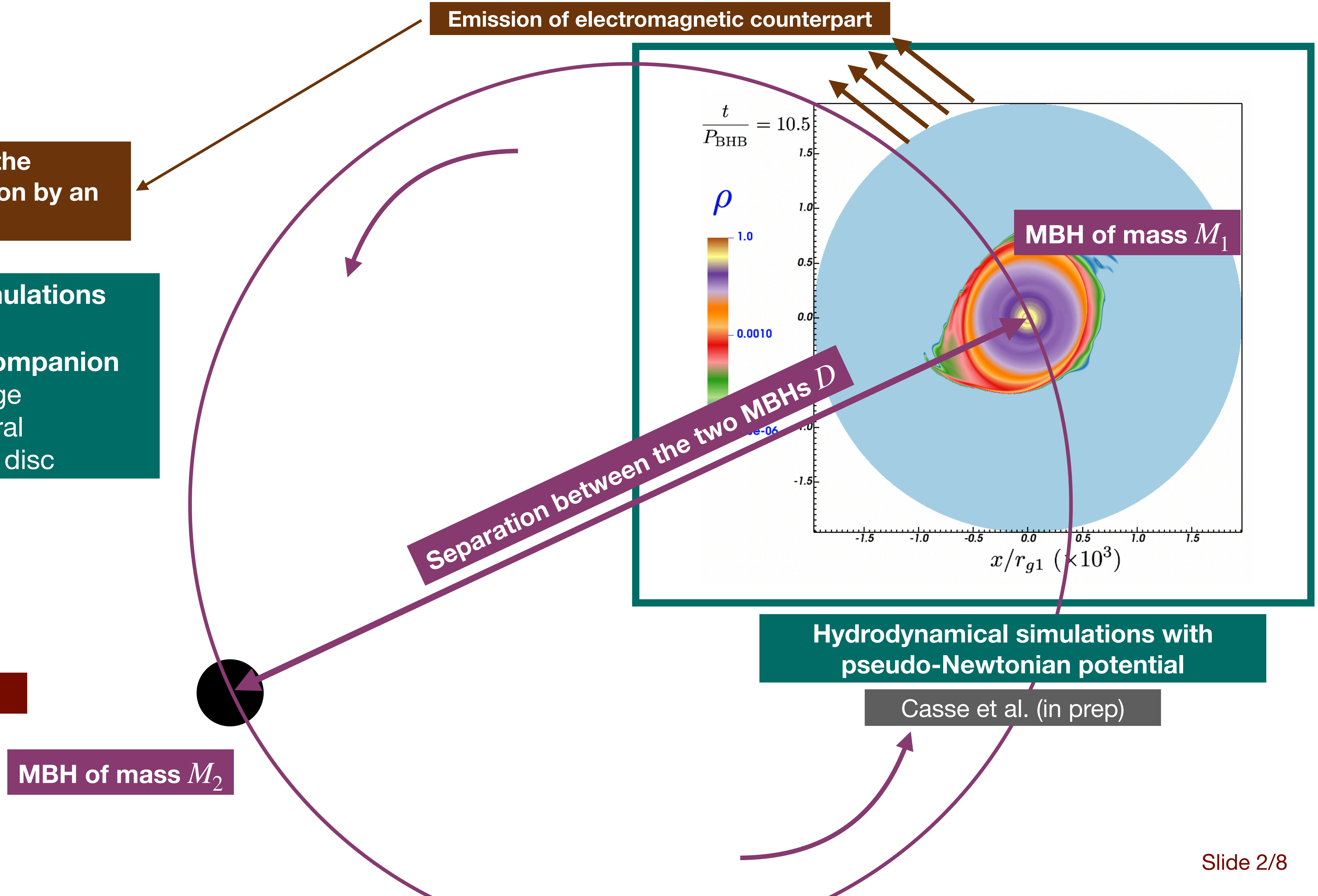
Gravitationally bound massive black hole binaries in the early stages of the merger

Is it distinct from the electromagnetic emission by an isolated AGN ?

Conclusions of the simulations

Influence of the MBH companion
Smaller outer edge
Density wave spiral
Elliptic shape of the disc

Detectability ?



Gravitationally bound massive black hole binaries in the early stages of the merger

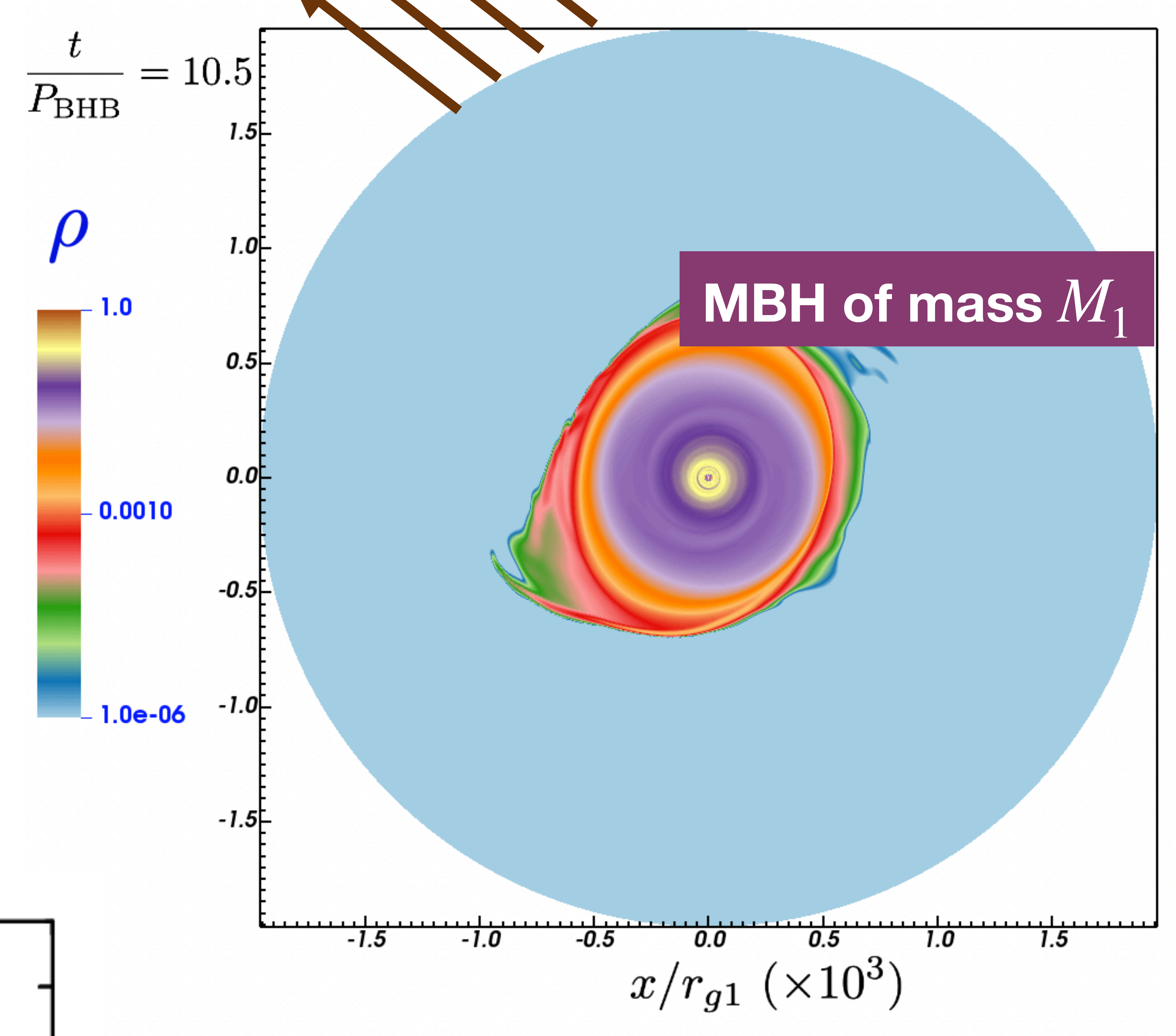
Emission of electromagnetic counterpart

Is it distinct from the electromagnetic emission by an isolated AGN ?

Conclusions of the simulations

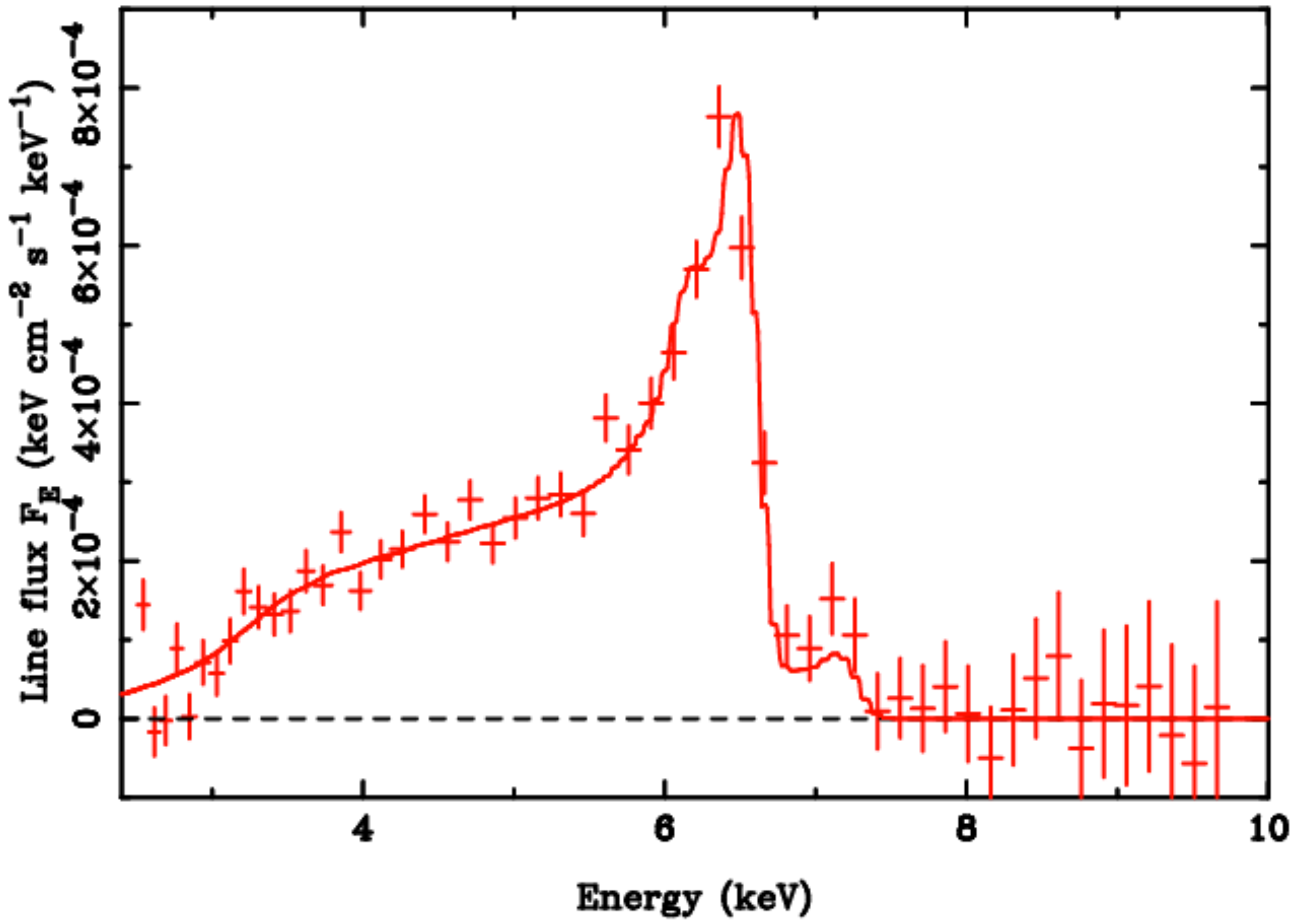
Influence of the MBH companion
Smaller outer edge

Detectability ?
→ Profile of the broad Kα emission line at 6.4 keV



Hydrodynamical simulations with pseudo-Newtonian potential

Casse et al. (in prep)



Broad iron line
XMM-Newton observation of MCG-6-30-15

Model of the iron Kα emission line profile as seen by an observer at infinity

Hartnoll & Blackman 2000, 2001 and 2002

Interest of this method

Non-axisymetries in the disc can be taken into account

→ *Impact of the spiral wave and the ellipticity*

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Hypothesis and approximations of the model

- Lamppost model to describe the hard X-rays emitting regions (*corona*)

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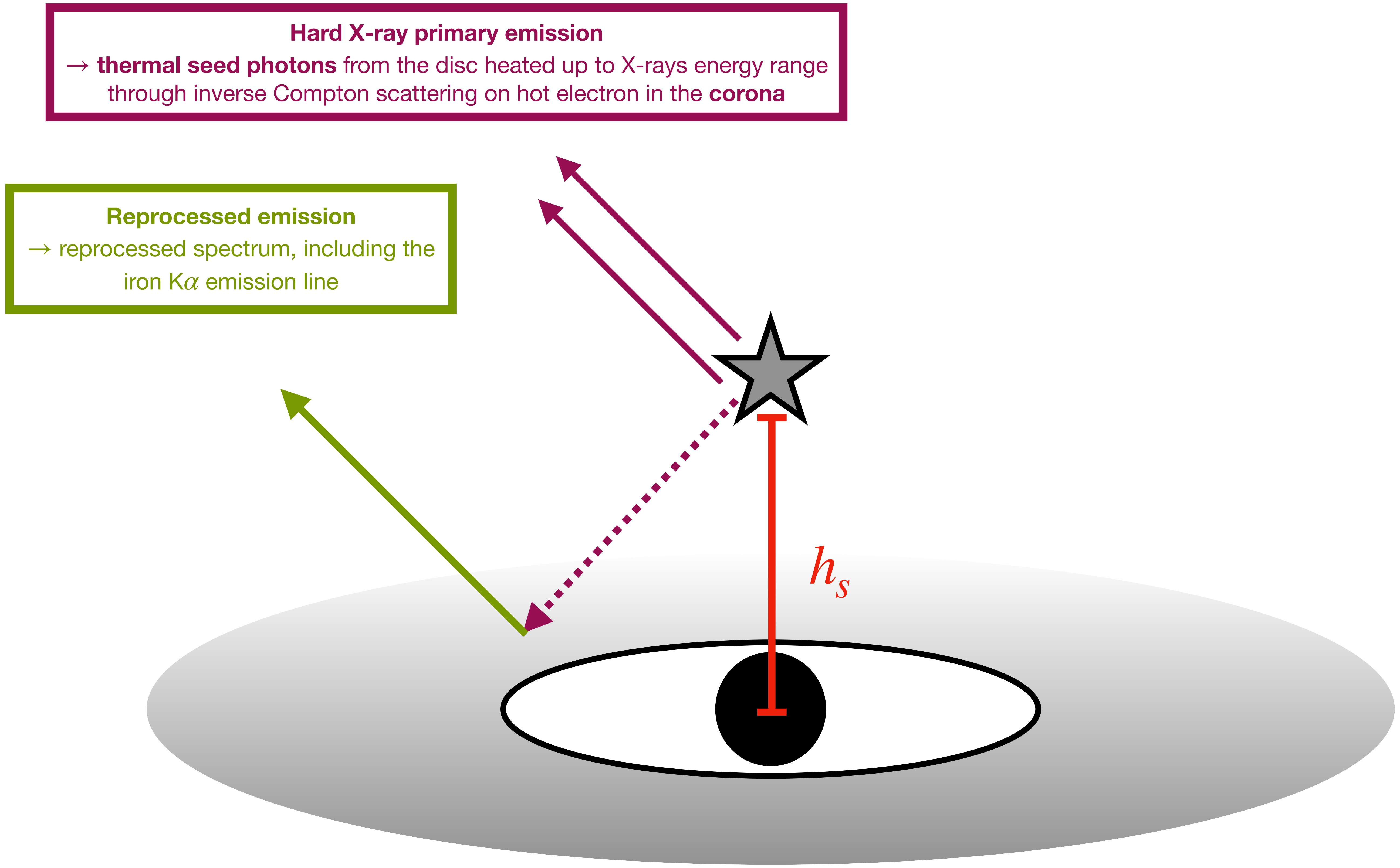
Hard X-ray illumination from the corona



Model of the iron Kα emission line profile as seen by an observer at infinity

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- Lamppost model to describe the hard X-rays emitting regions (*corona*)
- Schwarzschild metric to describe the space time around BH_1
- 1st order expansion of the photons geodesic equations

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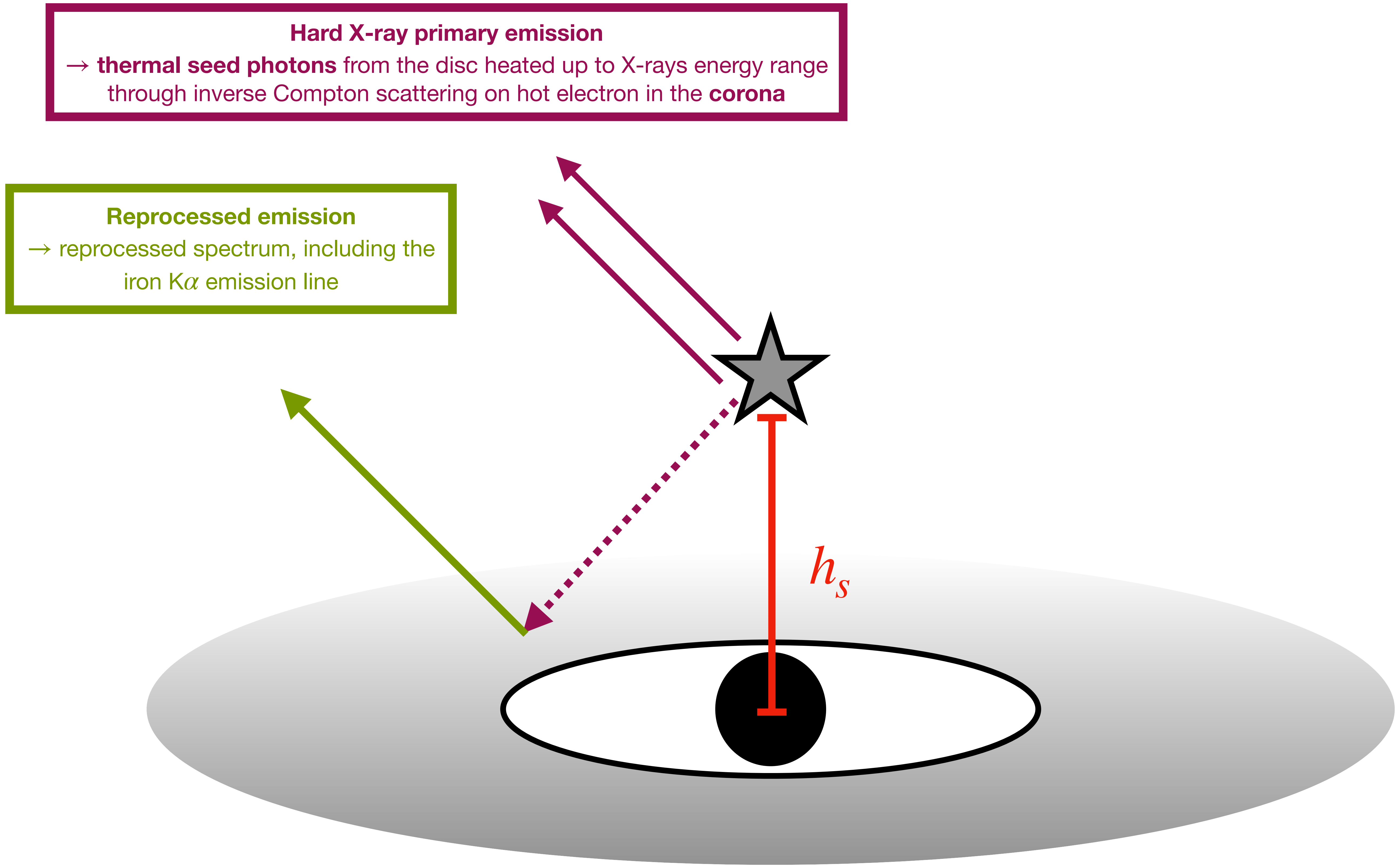
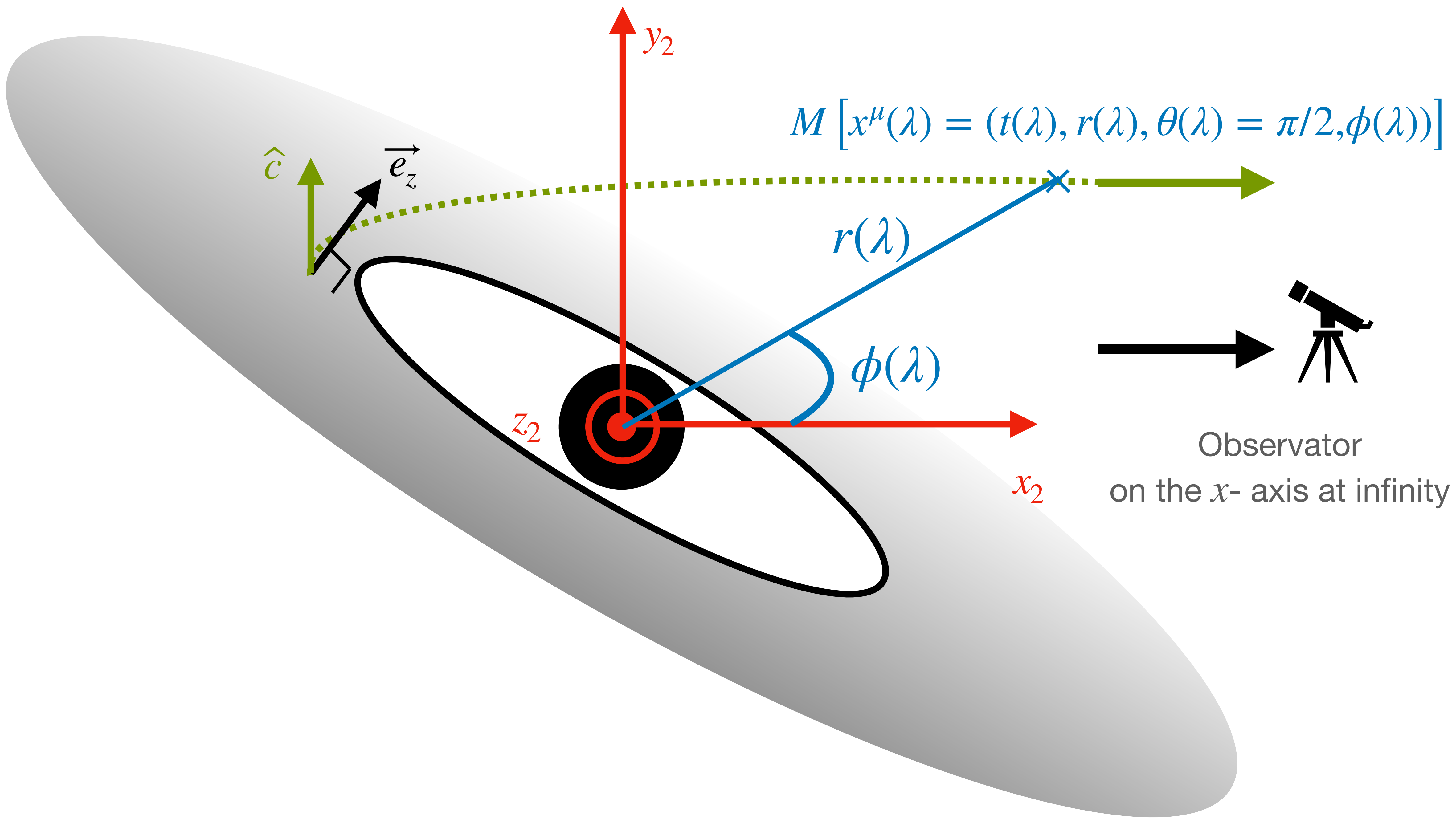


Line photons trajectory towards the observer



Model of the iron Kα emission line profile as seen by an observer at infinity

Hypothesis and approximations of the model

Hartnoll & Blackman 2000, 2001 and 2002

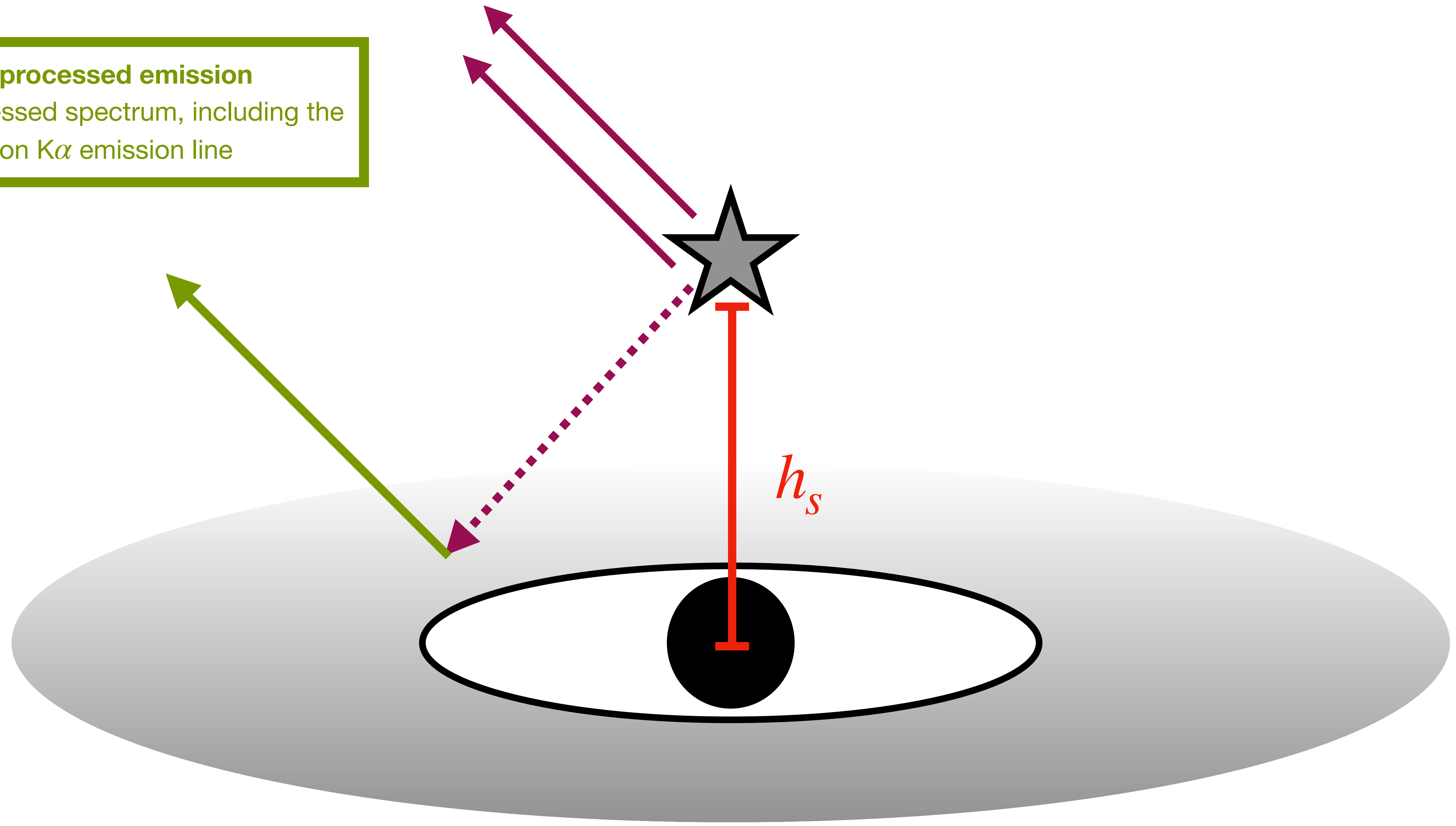
- Lamppost model to describe the hard X-rays emitting regions (*corona*)
- Schwarzschild metric to describe the space time around BH_1
- 1st order expansion of the photons geodesic equations
- The emitting region of the disc extends down to the last stable circular orbit

Interest of this method
Non-axisymetries in the disc can be taken into account
→ *Impact of the spiral wave and the ellipticity*

Hard X-ray illumination from the corona

Hard X-ray primary emission
→ **thermal seed photons** from the disc heated up to X-rays energy range through inverse Compton scattering on hot electron in the **corona**

Reprocessed emission
→ reprocessed spectrum, including the iron Kα emission line



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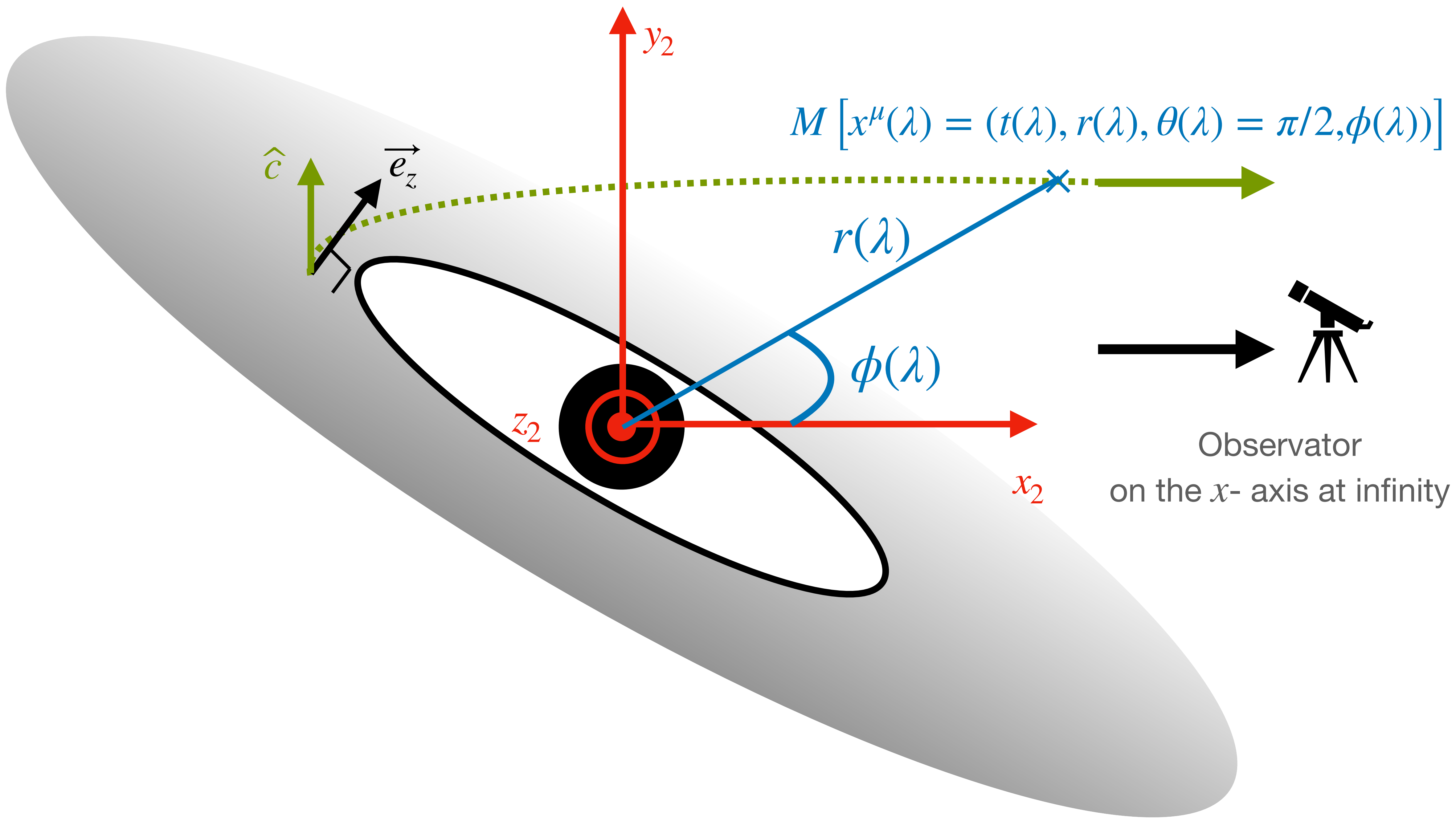
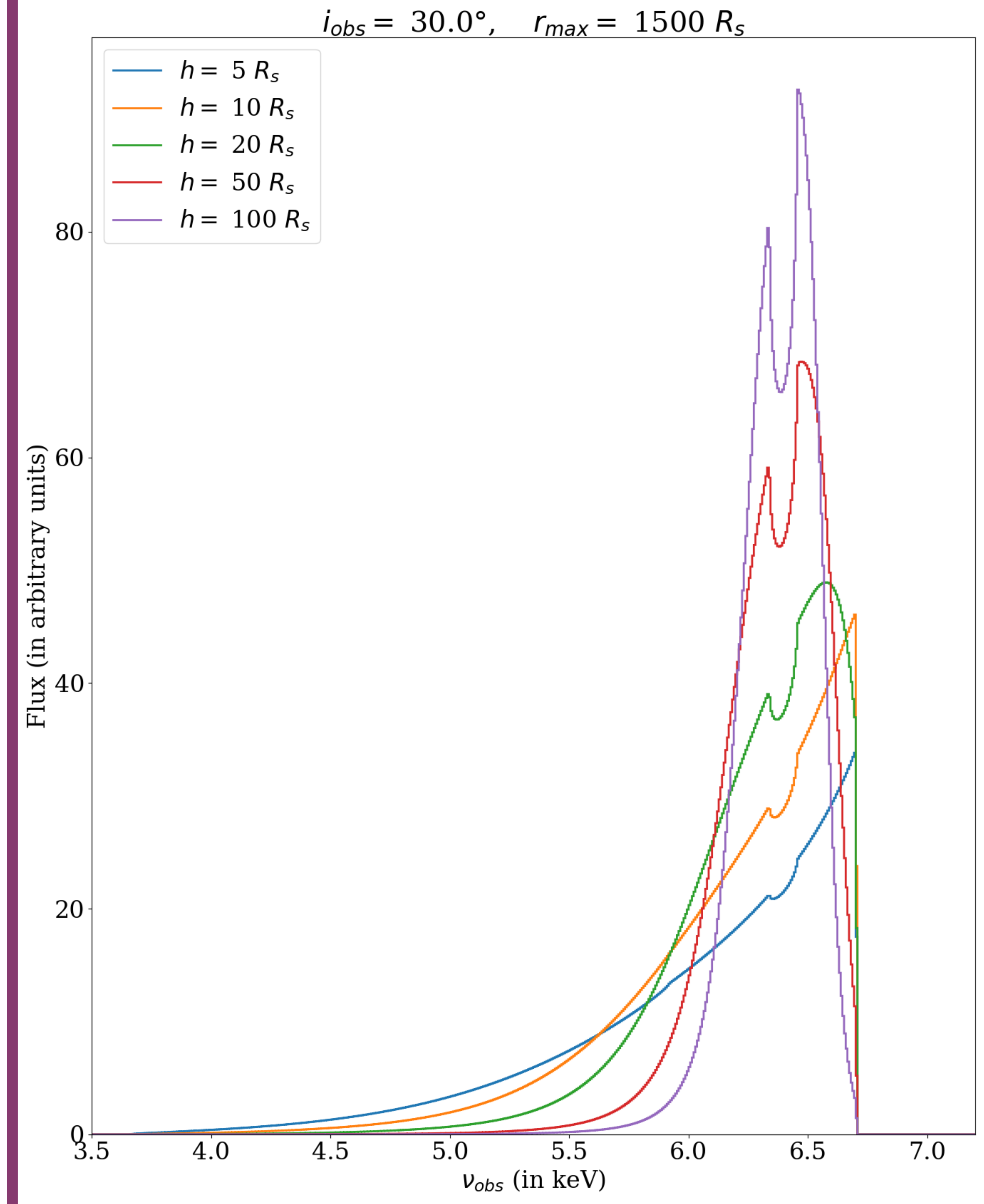


Iron Kα emission line profile

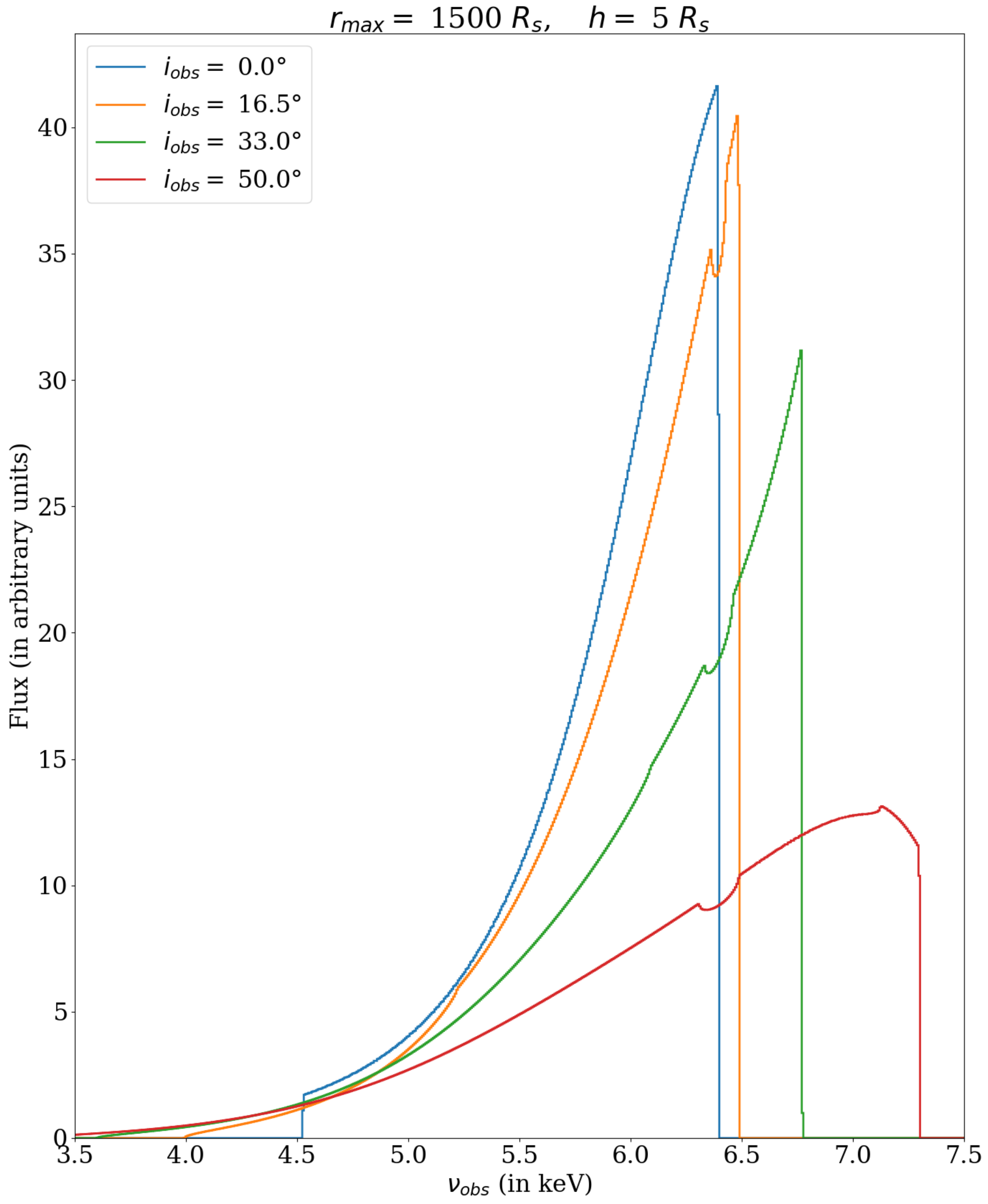
Parameters in the model

Isolated AGN

Inclination of the disc with respect to the observer line of sight
i_{obs}

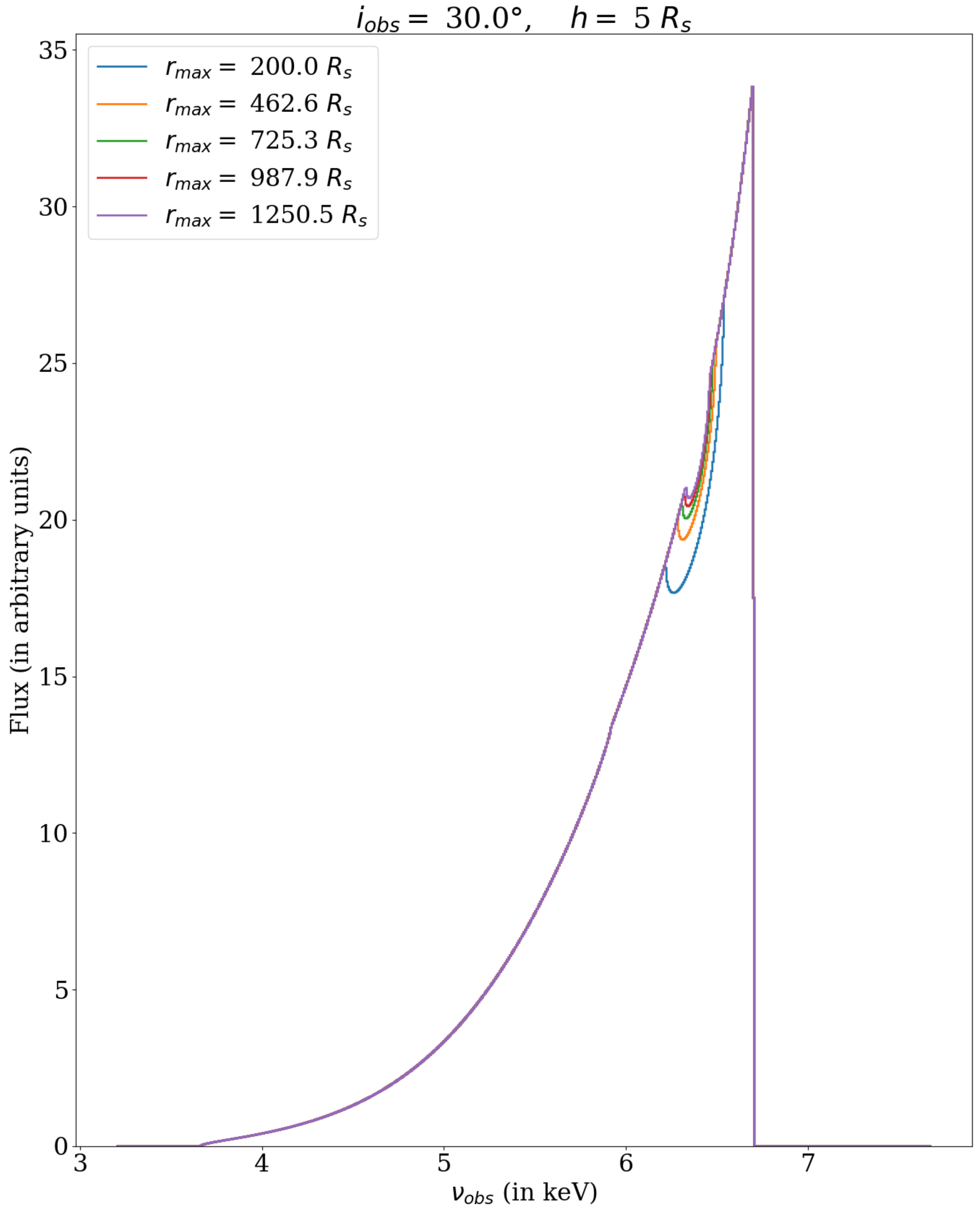


Value of the distance of the lamppost model to the central BH
h_s



Truncation of the outer edge

Outre edge of the disc
r_{max}



Iron Kα emission line profile

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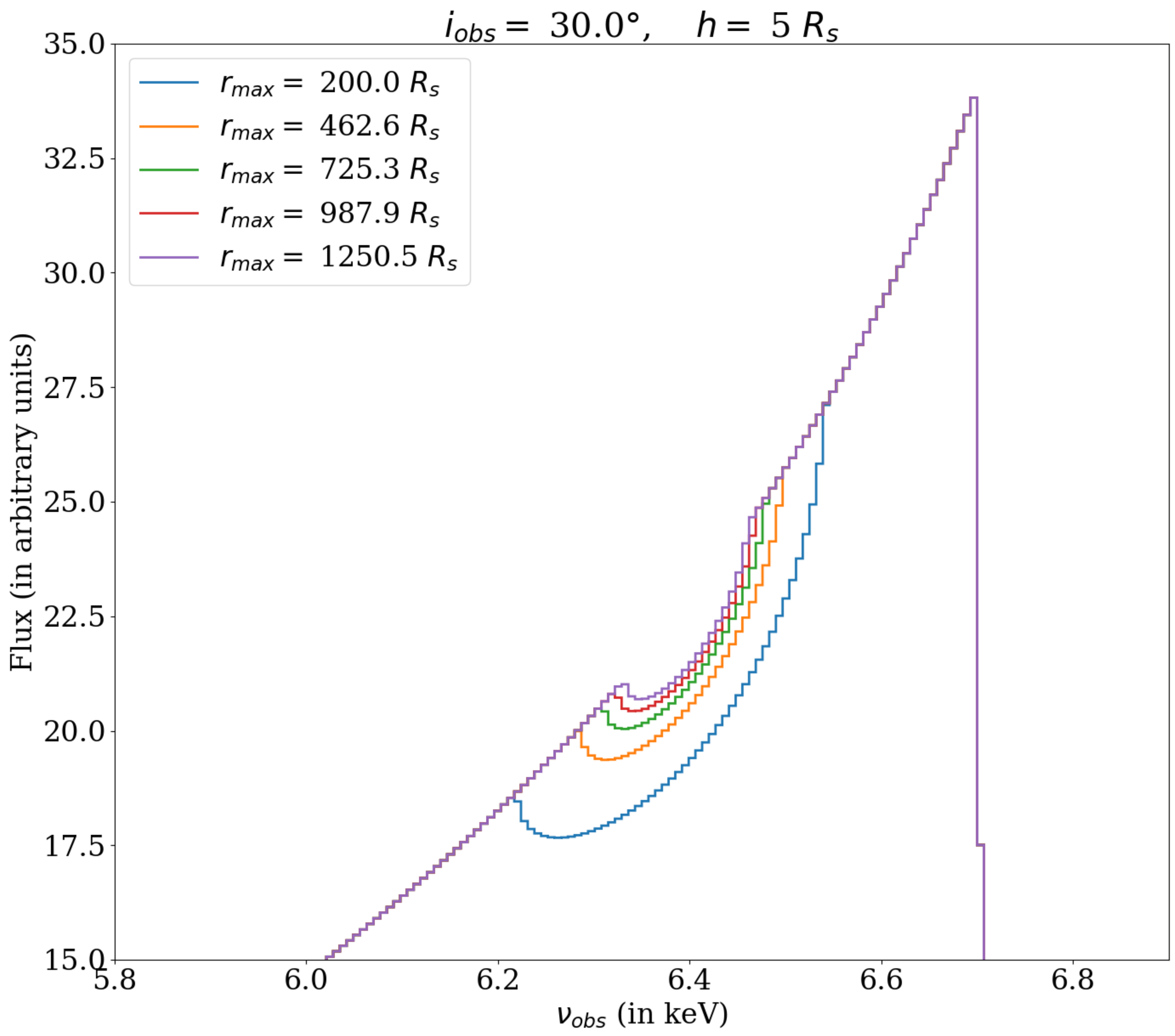

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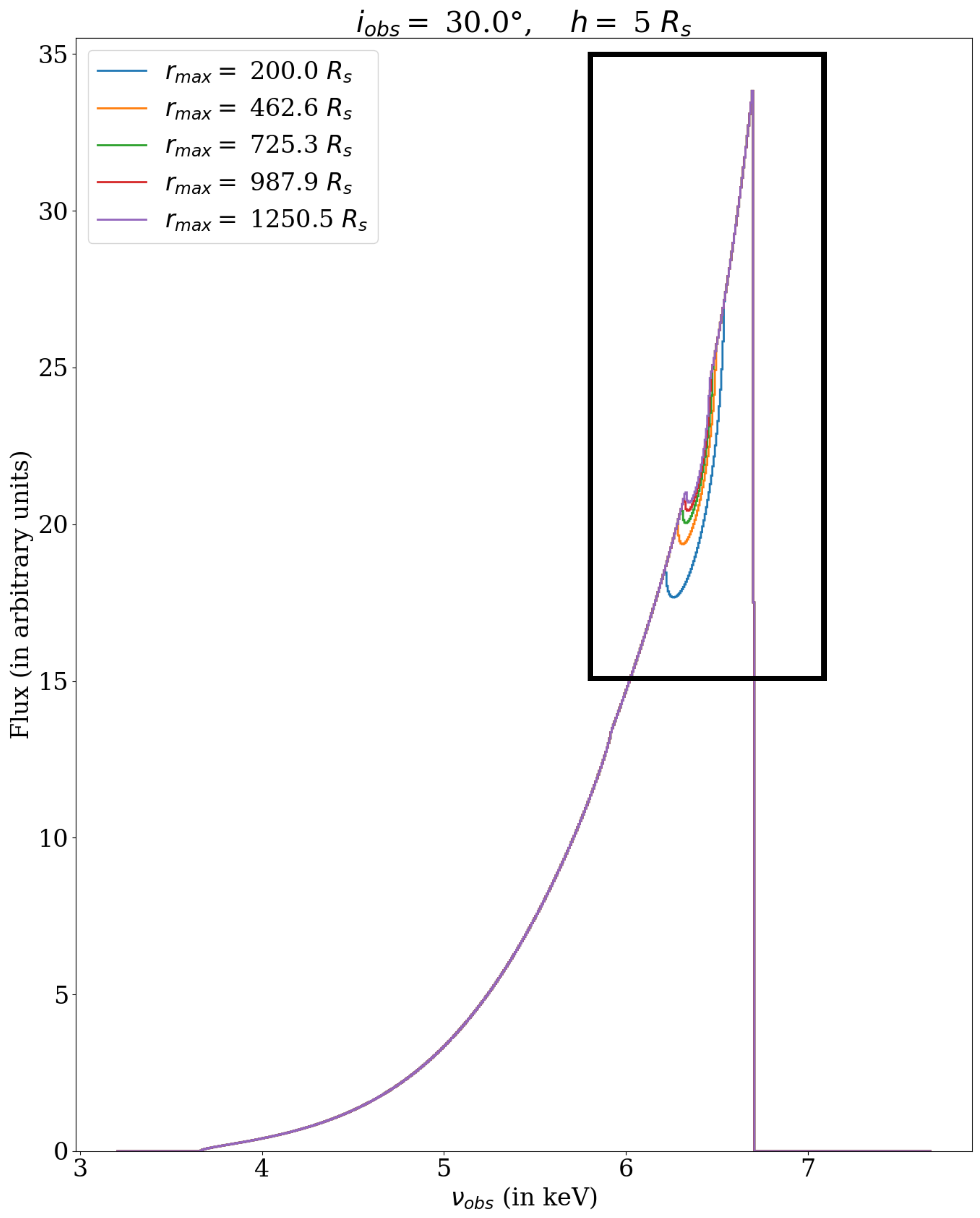
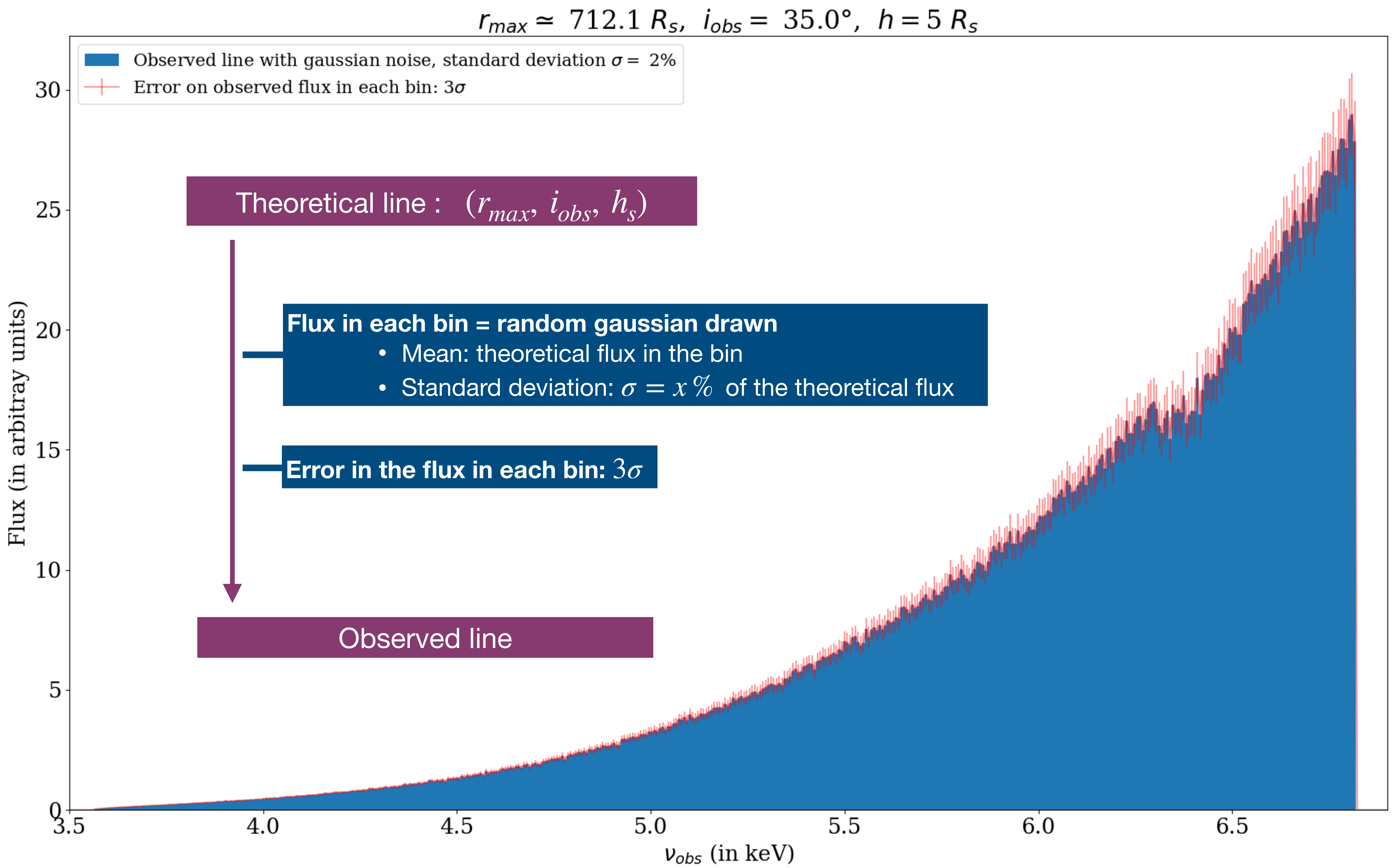


Can we estimate the radius of the disc outer edge ?

Generate an observed line



Can we estimate the radius of the disc outer edge ?

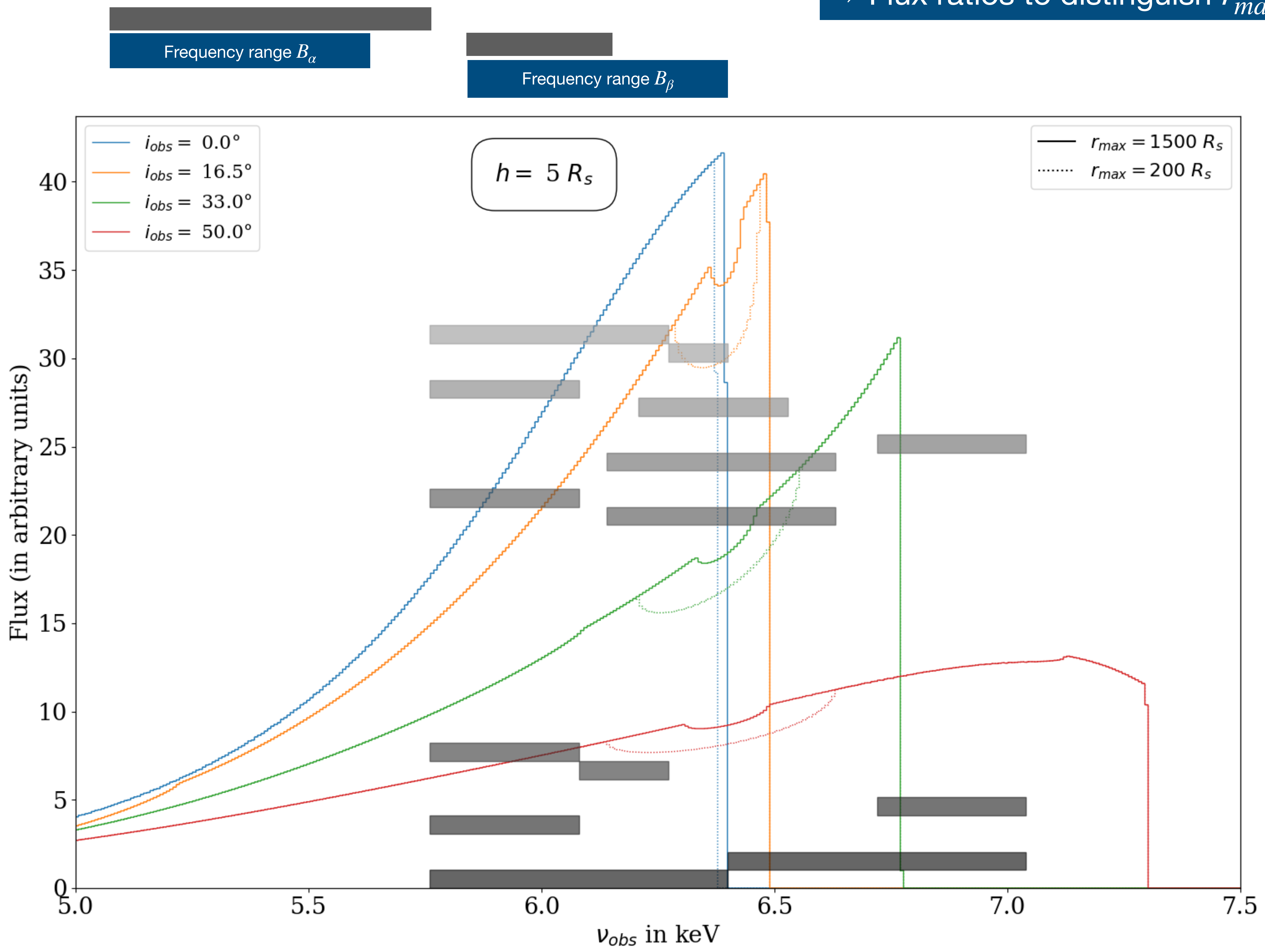
Presentation of the method

For an observed line : compute the flux ratio $\frac{F_{B_\alpha}}{F_{B_\beta}}$

Definition of the frequency ranges :

→ Flux ratios to distinguish i_{obs}

→ Flux ratios to distinguish r_{max}



Flux ratio i for the observed line: $\left(r_i \pm \Delta r_i\right)_{obs}$

↓

Compared to the theoretical value of $\left(r_i\right)_{theo}$

→ For a catalog based on a large number of lines $\left[r_{max},\ i_{obs},\ h\right]$

↓

Space of compatible values $\left\{\left[r_{max},\ i_{obs},\ h\right]\right\}$

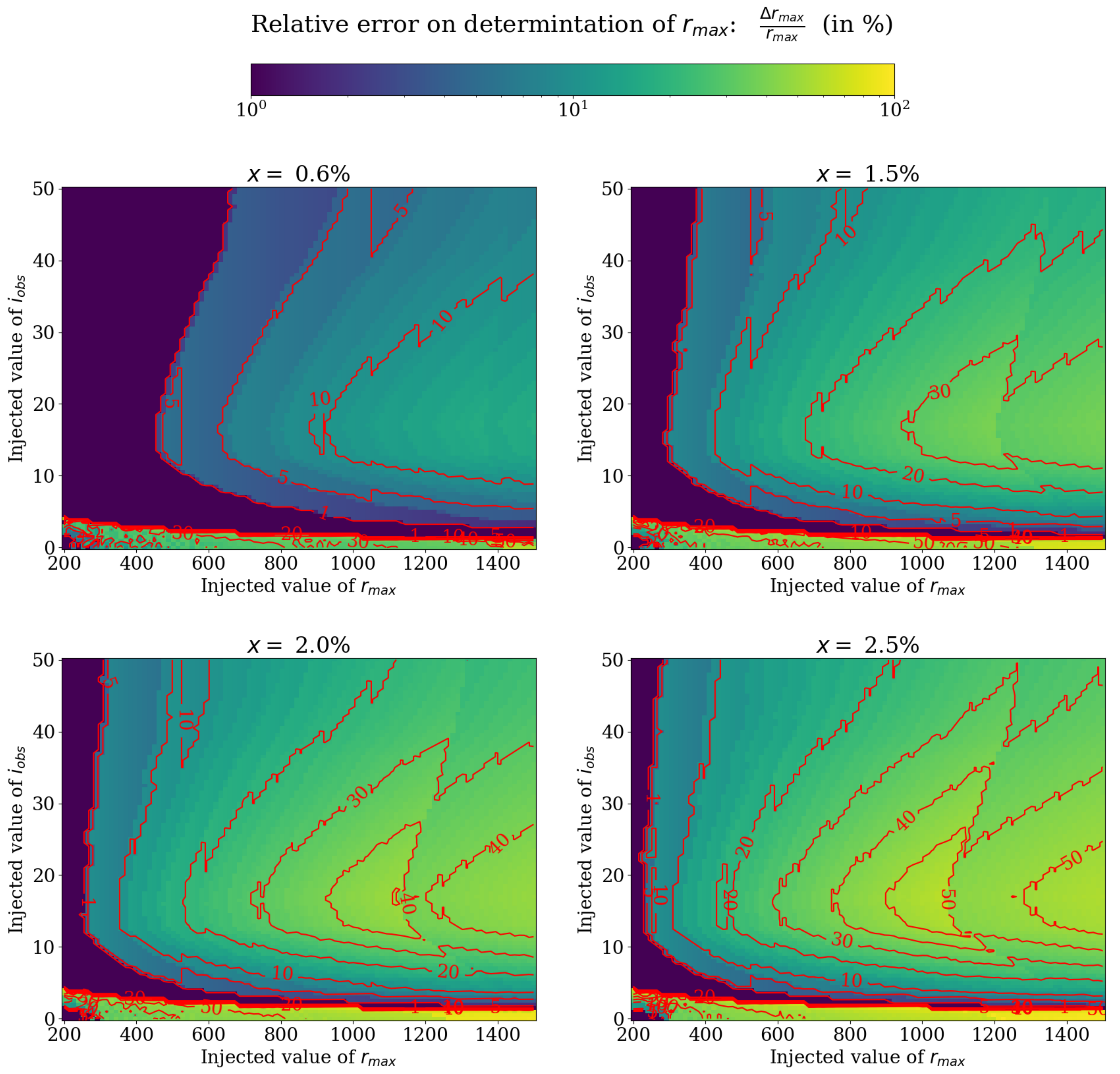
Intersection of all spaces $\left\{\left[r_{max},\ i_{obs},\ h\right]\right\}$ for all 7 flux ratio

⇒ **Final compatible values of r_{max}**

Can we estimate the radius of the disc outer edge ?

Gaussian standard deviation: $\sigma = x\, f_{theo}$

Uncertainty on the flux: 3σ



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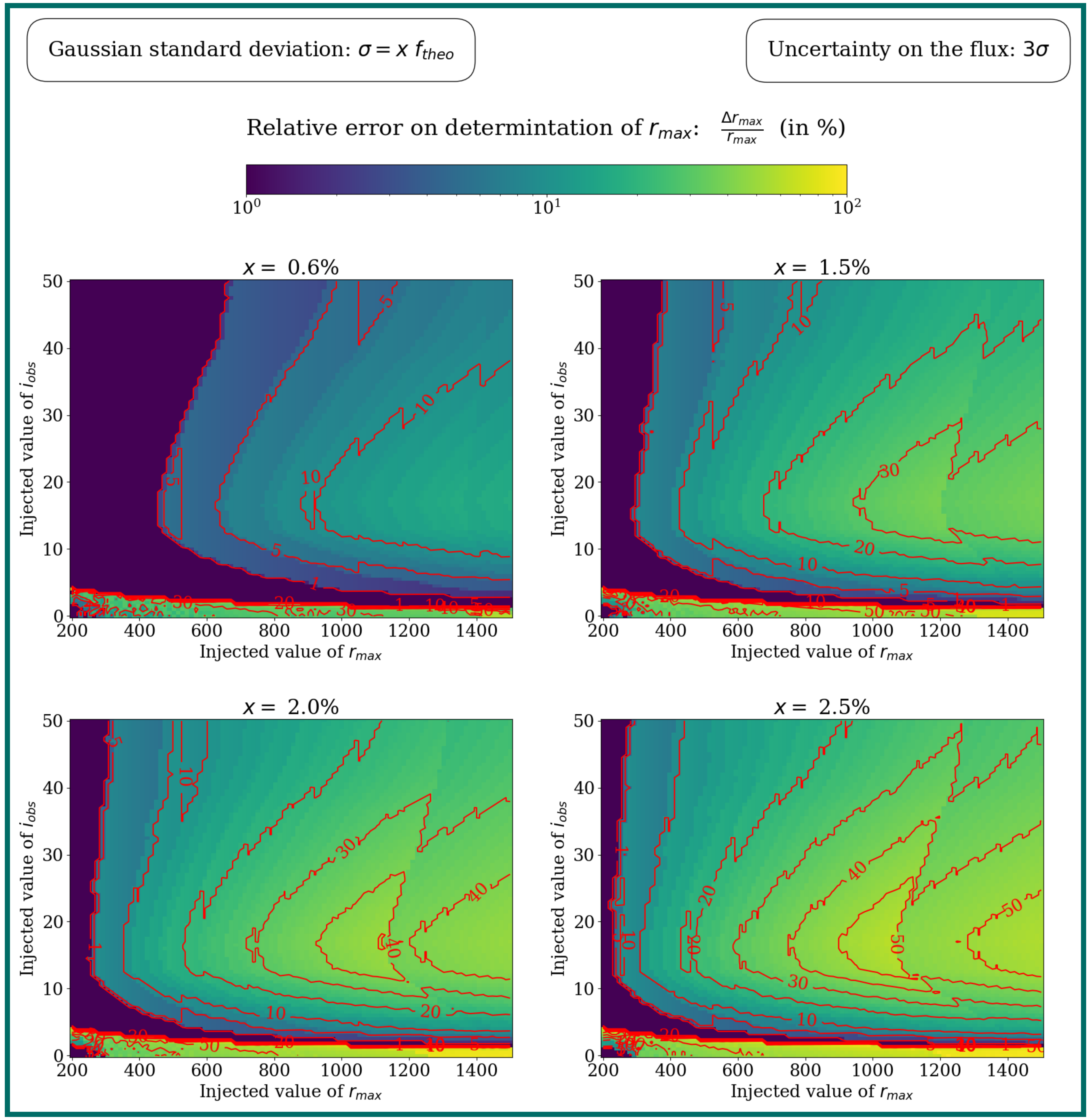

$$\frac{\Delta r_{max}}{r_{max}} < 50\,\%$$

→ Error on the flux in each bin of width $\Delta E = 7$ eV: Below $2\,\%$ of the flux

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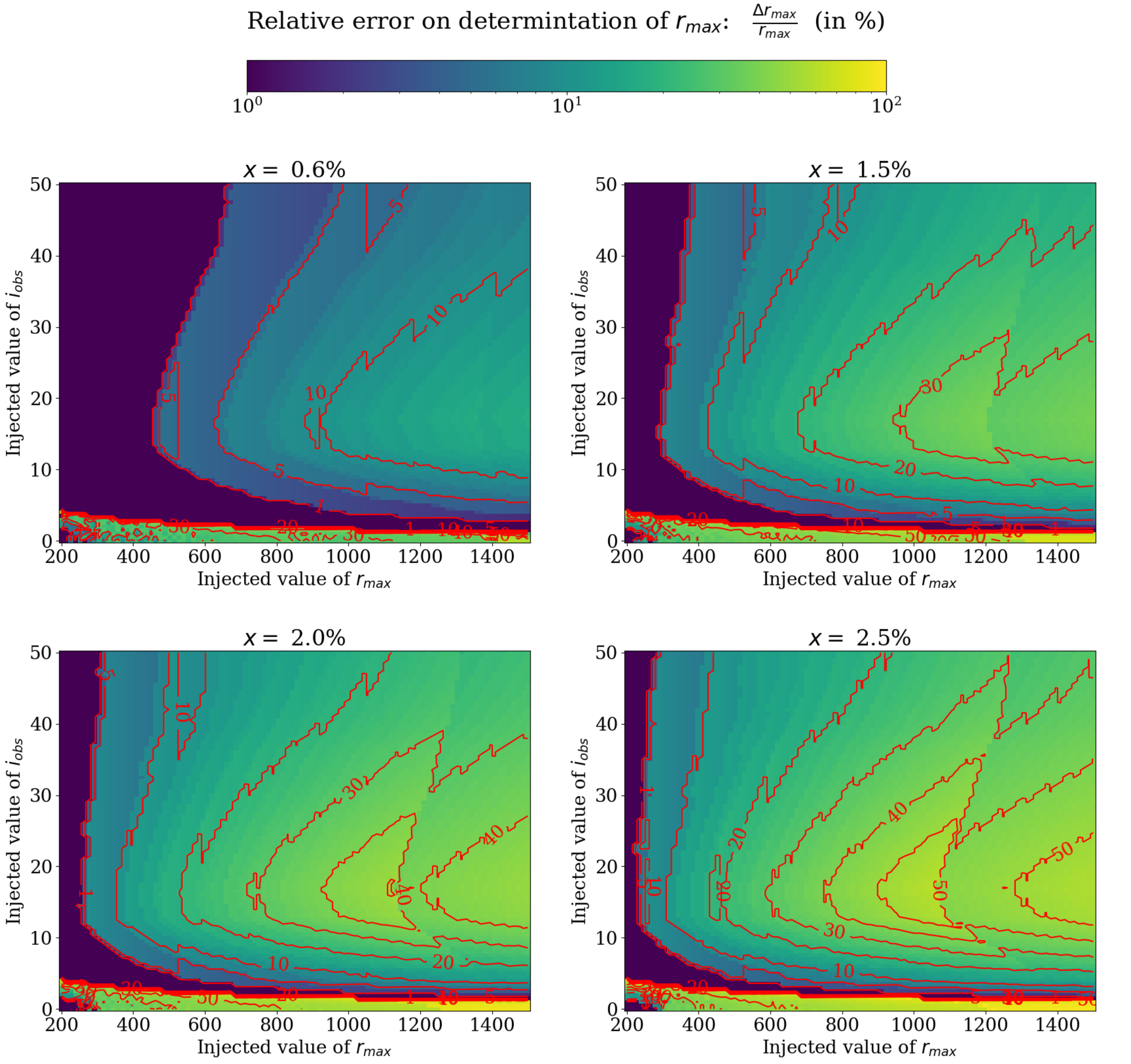
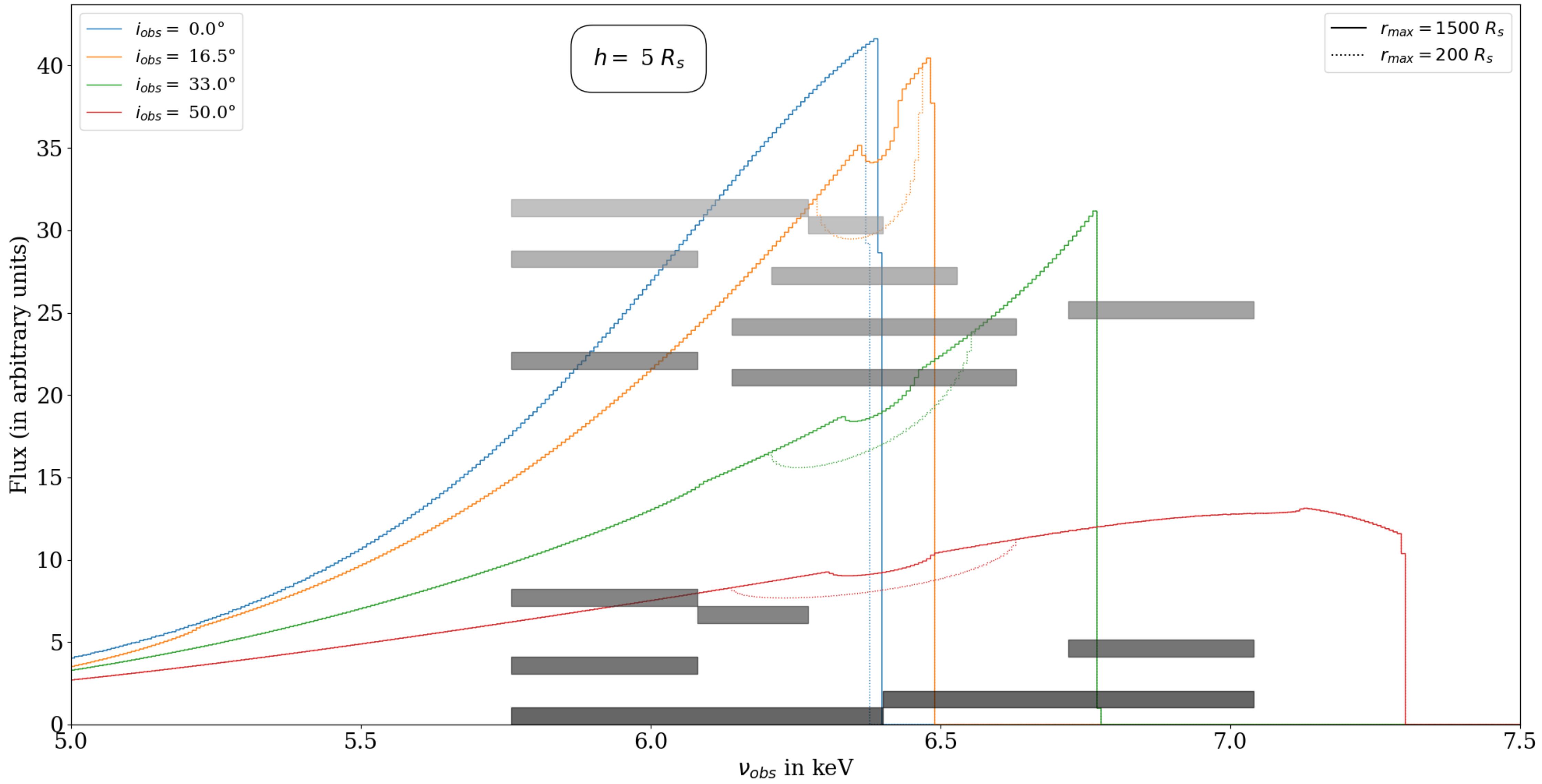
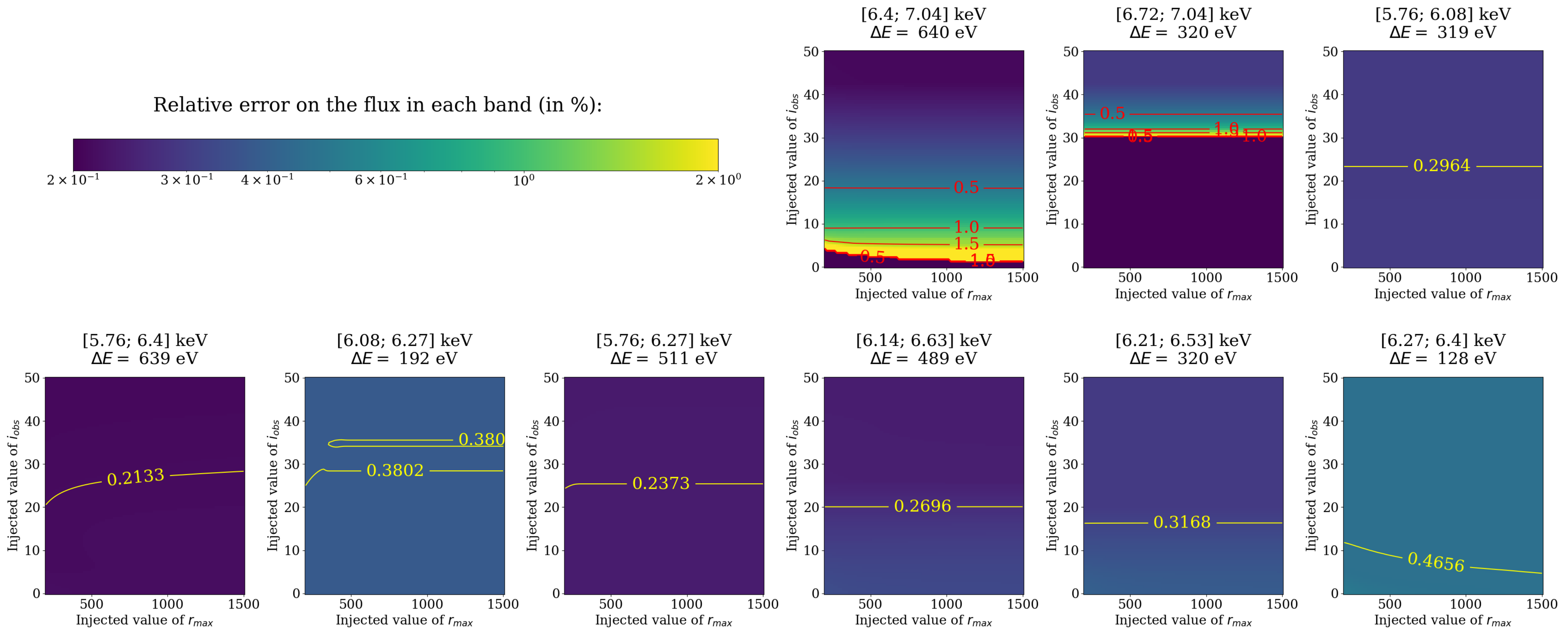






$$\frac{\Delta r_{max}}{r_{max}} < 50\,\%$$

$\rightarrow$ Error on the flux in each bin of width $\Delta E = 7$ eV: Below $2\,\%$ of the flux

Could the presence of a massive black hole companion impact the shape of the iron Kα emission line at a detectable level ?

CONLUSIONS

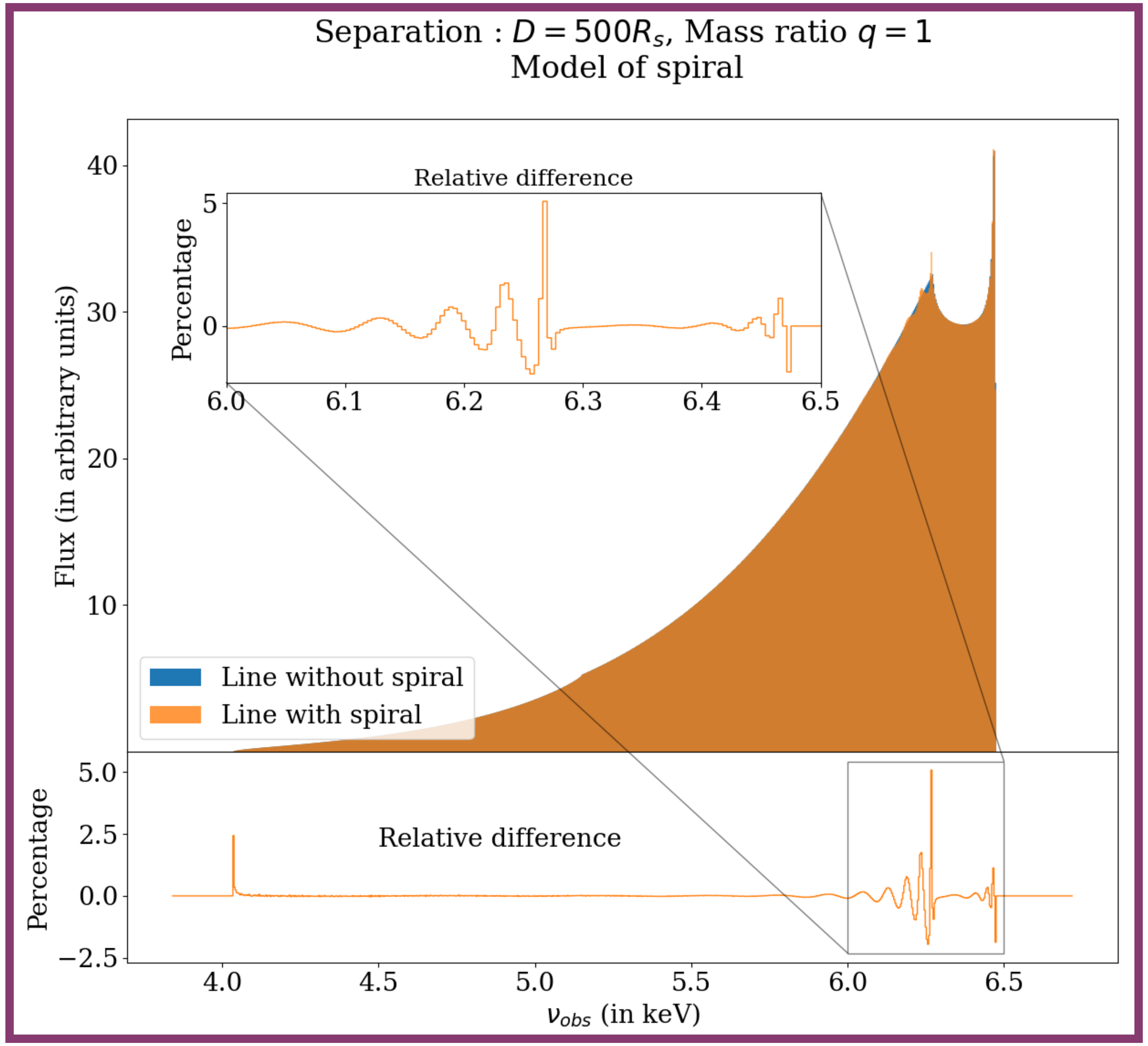
Influence of the MBH companion on the radius of the disc outer edge
$\Rightarrow$ Change the profile of the iron line

- With the 7 flux ratios that we chose
- To determine r_{max} at a precision of $50\,\%$:
  - $\rightarrow$ The error on the flux in bins of width 7 eV must me below $2\,\%$
  - $\rightarrow$ The correspondance for the precision on the flux in each band which define the flux ratios are given

$\Rightarrow$ for $M = 10^8 M_\odot$: $r_{max} + \Delta r_{max} \leq 1\ 200\ R_s$ when
$T_{orb} = 94$ days
$T_{merger} = 5 \times 10^6$ years

/!\ It is not a final diagnostic for the presence of MBH binary
$\rightarrow$ **BUT** it could be used **within a body of corroborating evidence** to distinguish between a MBH binary merging and isolated AGNs

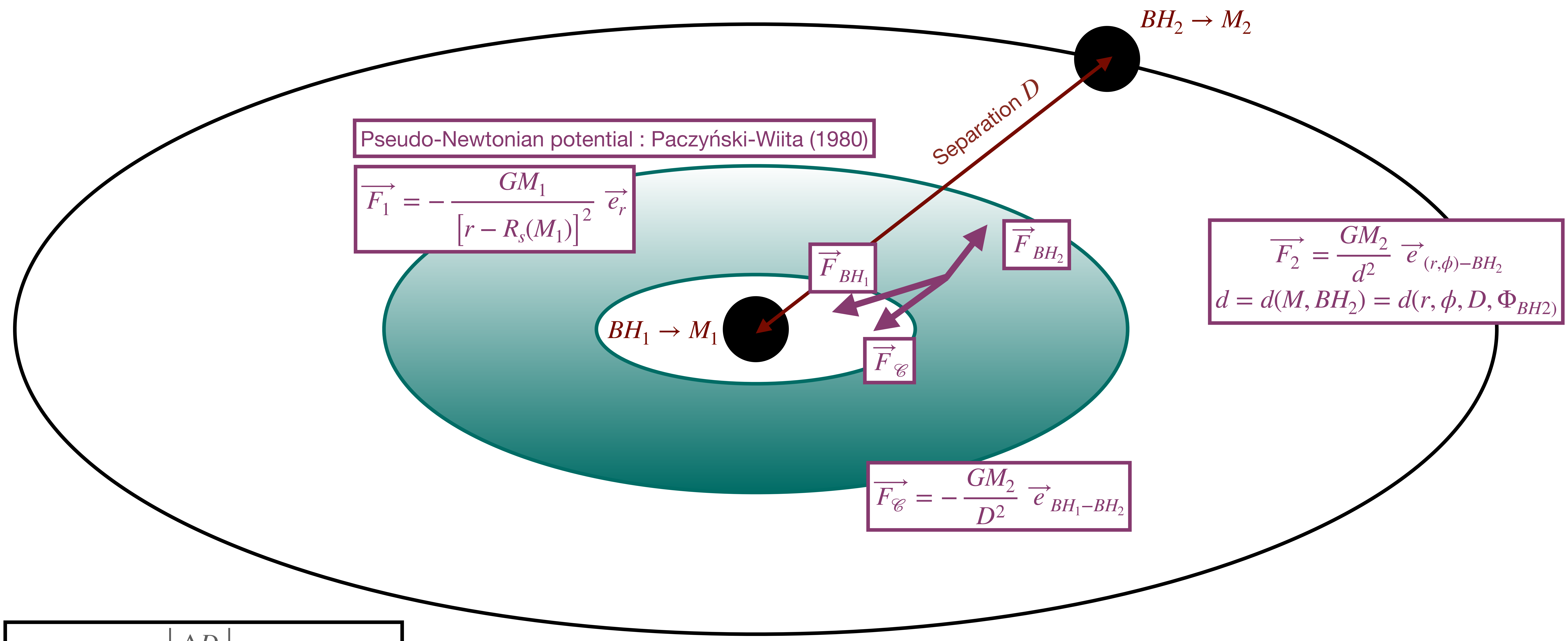
PERSPECTIVES



Gravitationally bound massive black hole binaries in the early stages of the merger

Influence of a MBH companion on the accretion disc of a primary MBH

Hydrodynamical simulations with pseudo-Newtonian potential



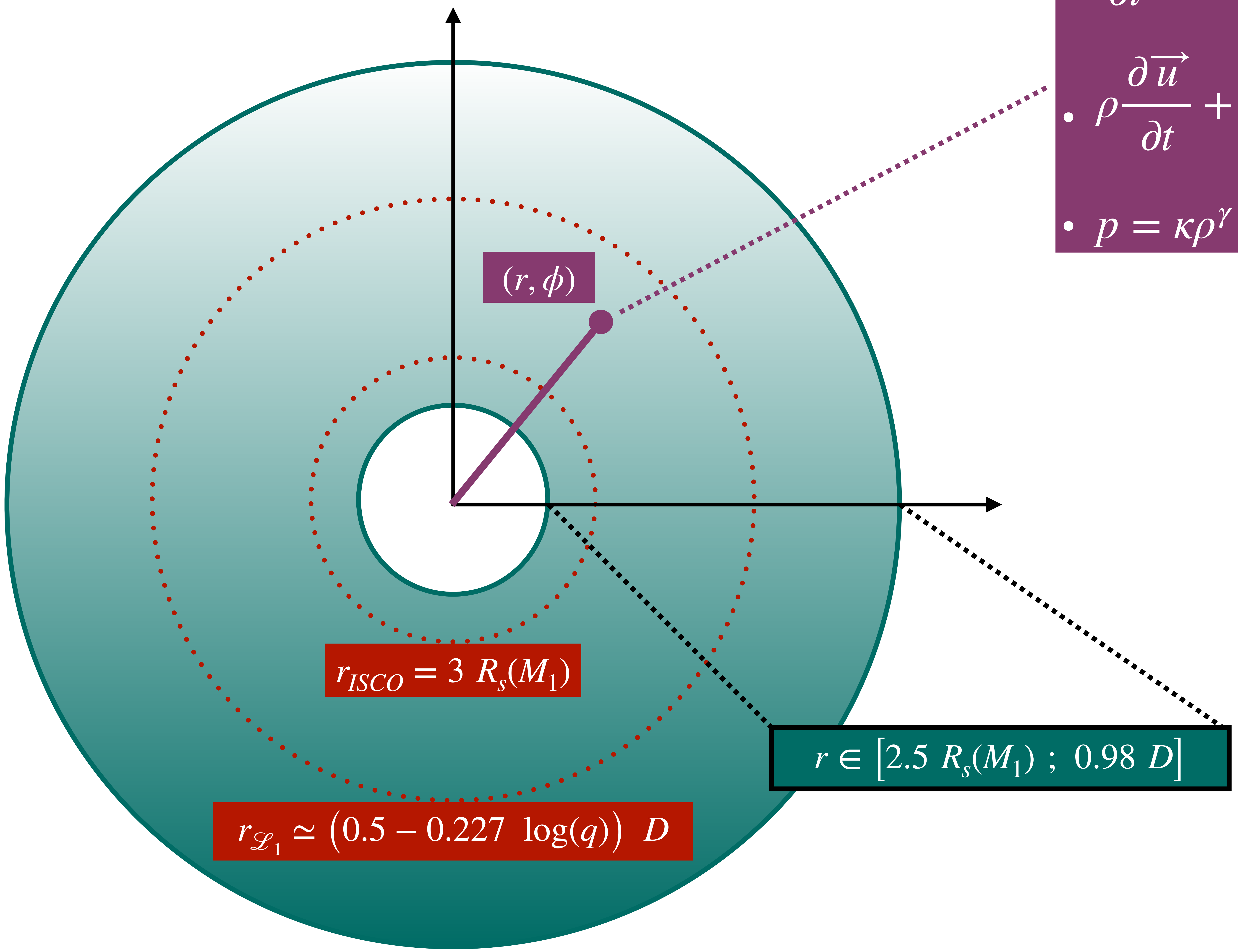
Circular orbit : $\left|\frac{\Delta D}{D}\right|_{t \rightarrow t+T_{orb}} < 0.1\ \%$

Influence of a MBH companion on the accretion disc of a primary MBH

Hydrodynamical simulations with pseudo-Newtonian potential

Code : MPI-AMRVAC (Keppens et al. 2012)

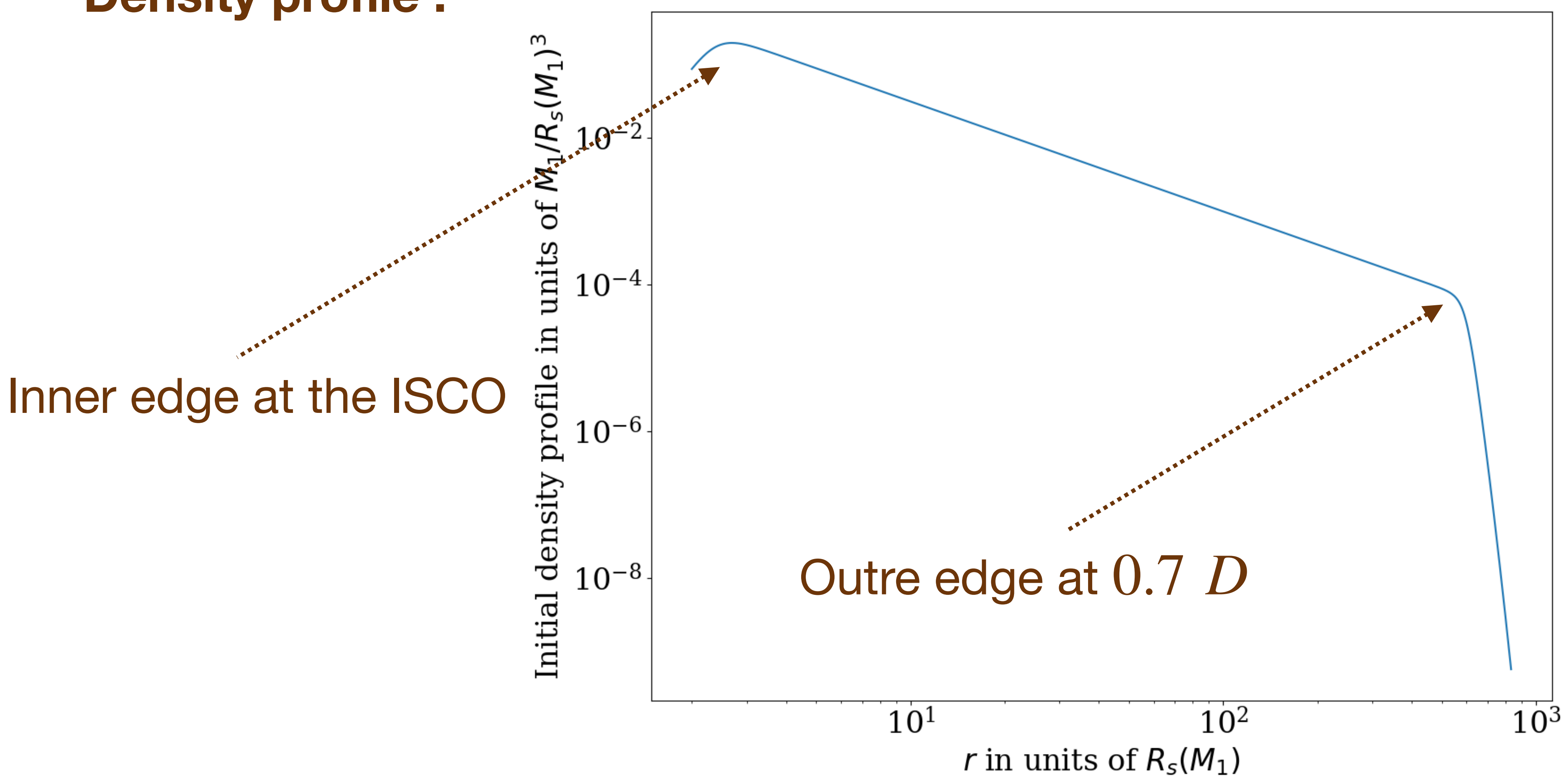
- $\frac{\partial \rho}{\partial t} + \vec{\nabla} \cdot \left(\rho \vec{u} \right) = 0$
- $\rho \frac{\partial \vec{u}}{\partial t} + \rho \left(\vec{u} \cdot \vec{\nabla} \right) \vec{u} = - \vec{\nabla} p + \vec{F}_{\mathscr{C}} + \vec{F}_{BH_1} + \vec{F}_{BH_2}$
- $p = \kappa \rho^{\gamma}$



Initial condition

Velocity field : equilibrium of the disc around an isolated BH_1

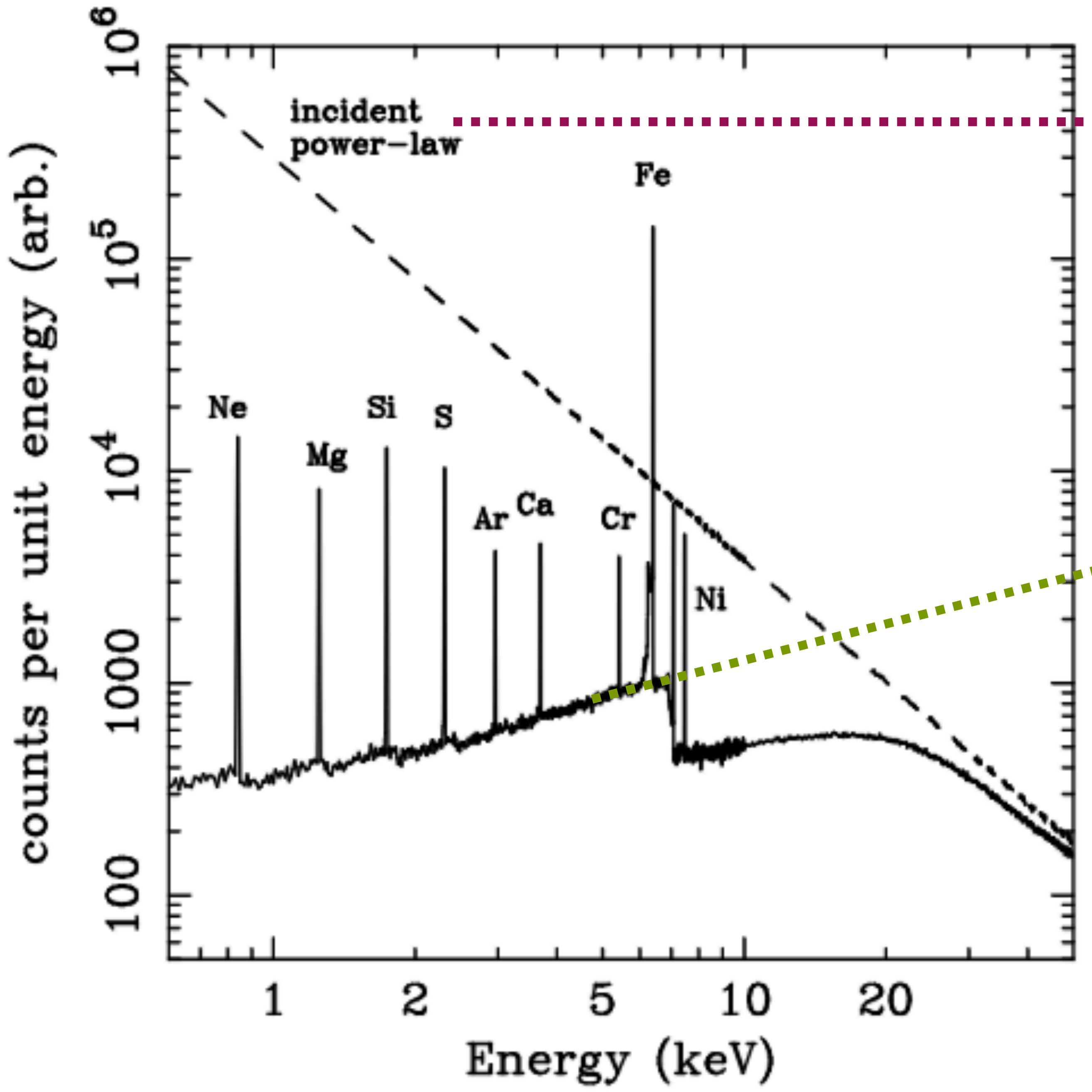
Density profile :



Iron Kα emission line

Monte Carlo simulation

Reynolds 1996; based on similar calculations by George & Fabian 1991



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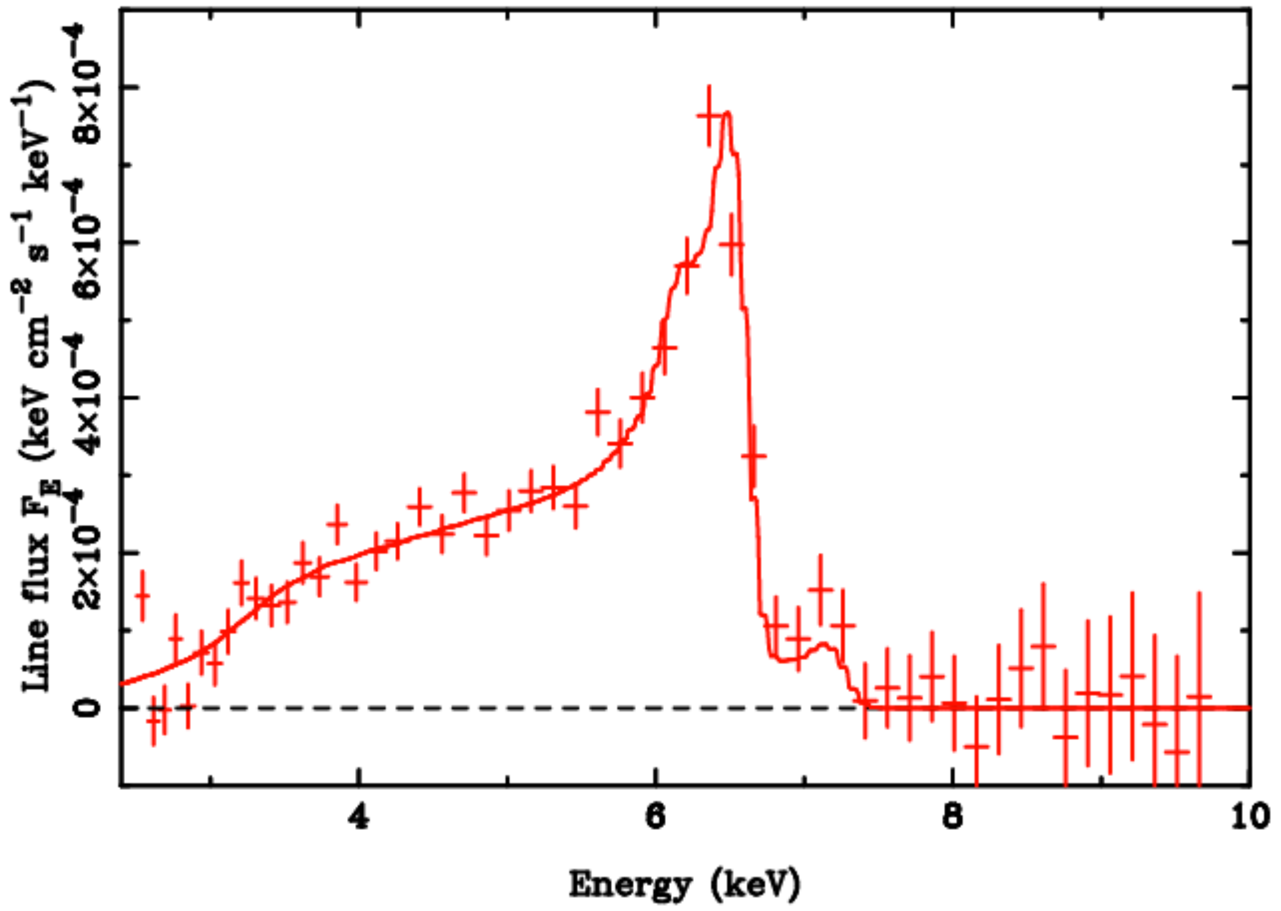
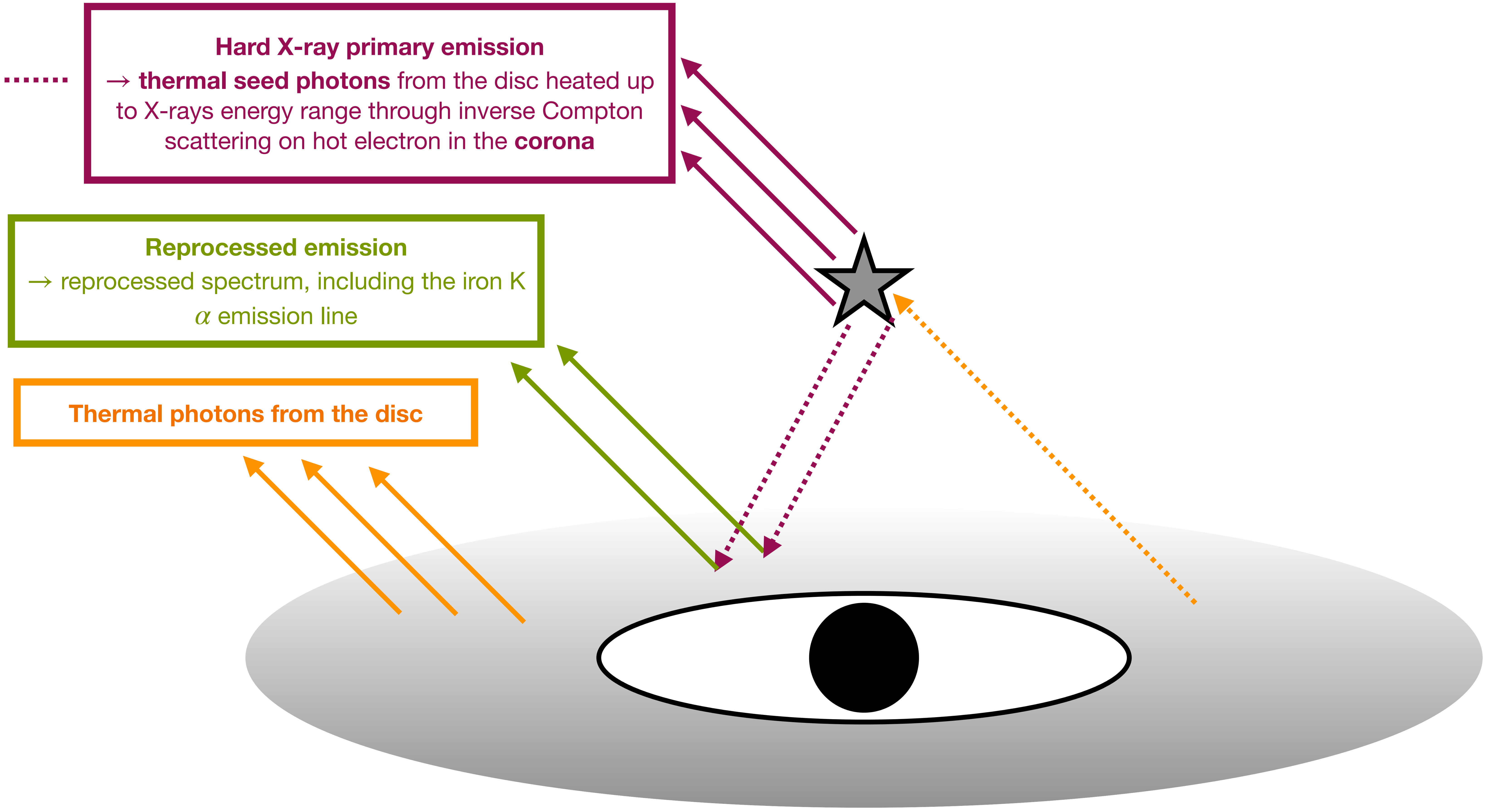
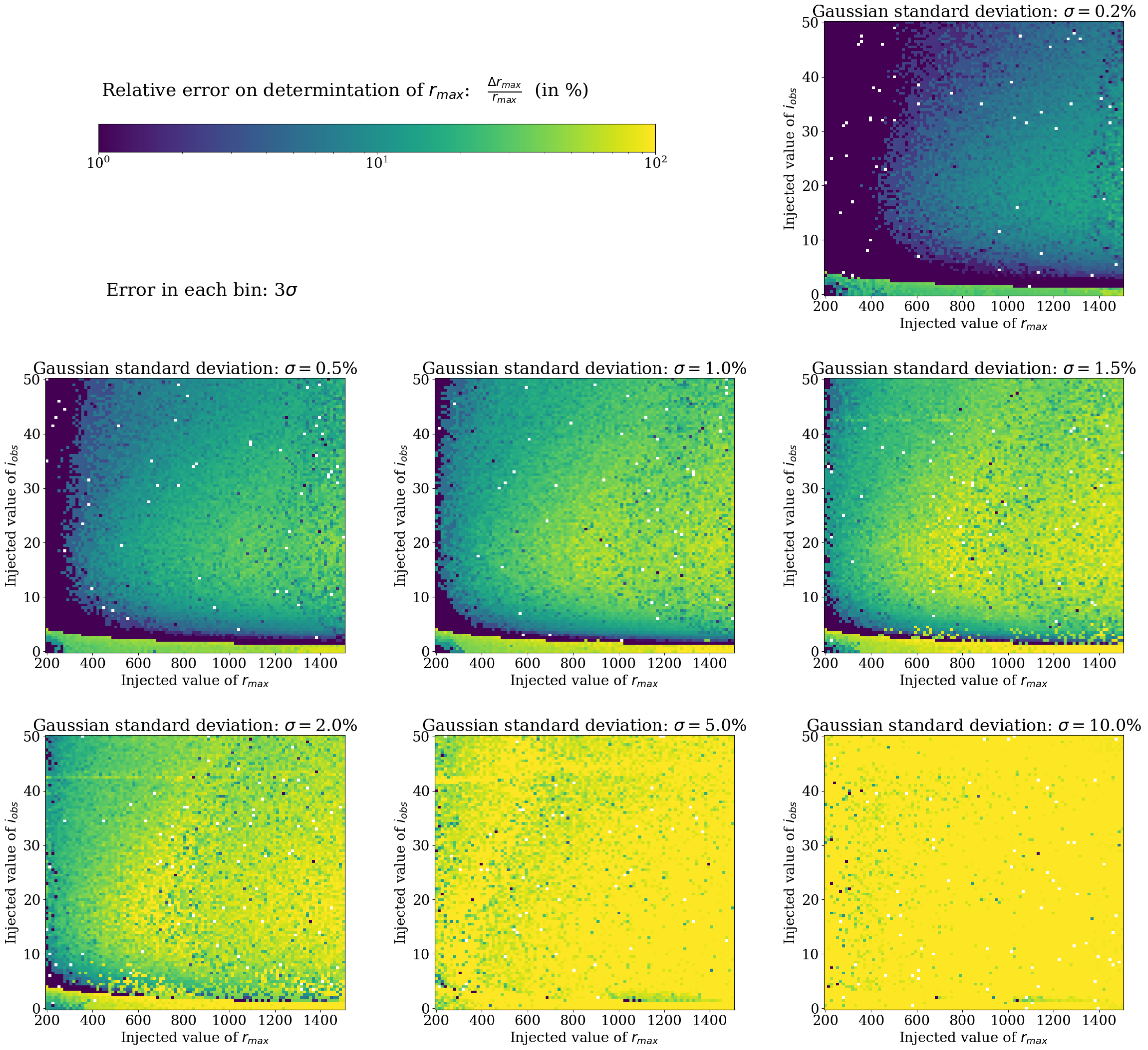




Relativistic broadening due to the presence of the central BH

Doppler shift ; Gravitational red-shift ; Light bending

Can we estimate the radius of the disc outer edge ?



Theoretical line : injected values r_{max}, i_{obs}, h_s

Flux in each bin = random gaussian drawn

- Mean: theoretical flux in the bin
- Standard deviation: $\sigma = x\,\%$ of the theoretical flux

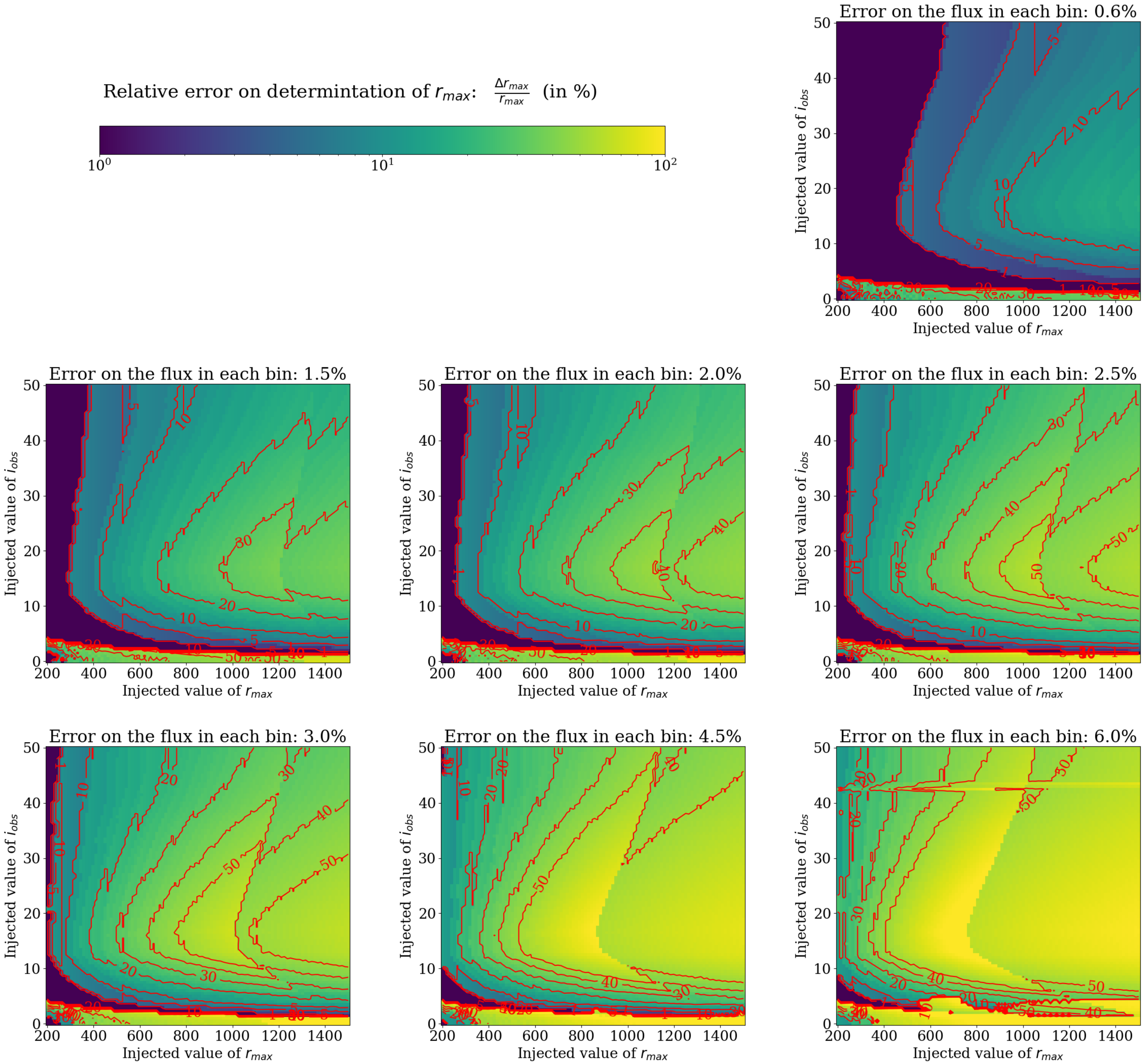
Error in the flux in each bin: 3σ

Observed line

Intersection of all spaces $\left\{ \left[r_{max},\ i_{obs},\ h \right] \right\}$ for all 7 flux ratio

$\Rightarrow$ **Final compatible values of** r_{max}

Can we estimate the radius of the disc outer edge ?



$$\frac{\Delta r_{max}}{r_{max}} < 50\,\%$$

→ Error on the flux in each bin of width $\Delta E = 7$ eV:
Below $2\,\%$ of the flux

Can we estimate the radius of the disc outer edge ?

Low inclination angles