

# Exploring the circumnuclear environment of SMBHs using ray-tracing simulations in the X-ray band

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**George Dimopoulos**

**Advisor: Claudio Ricci | Collaborator: Stéphane Paltani**



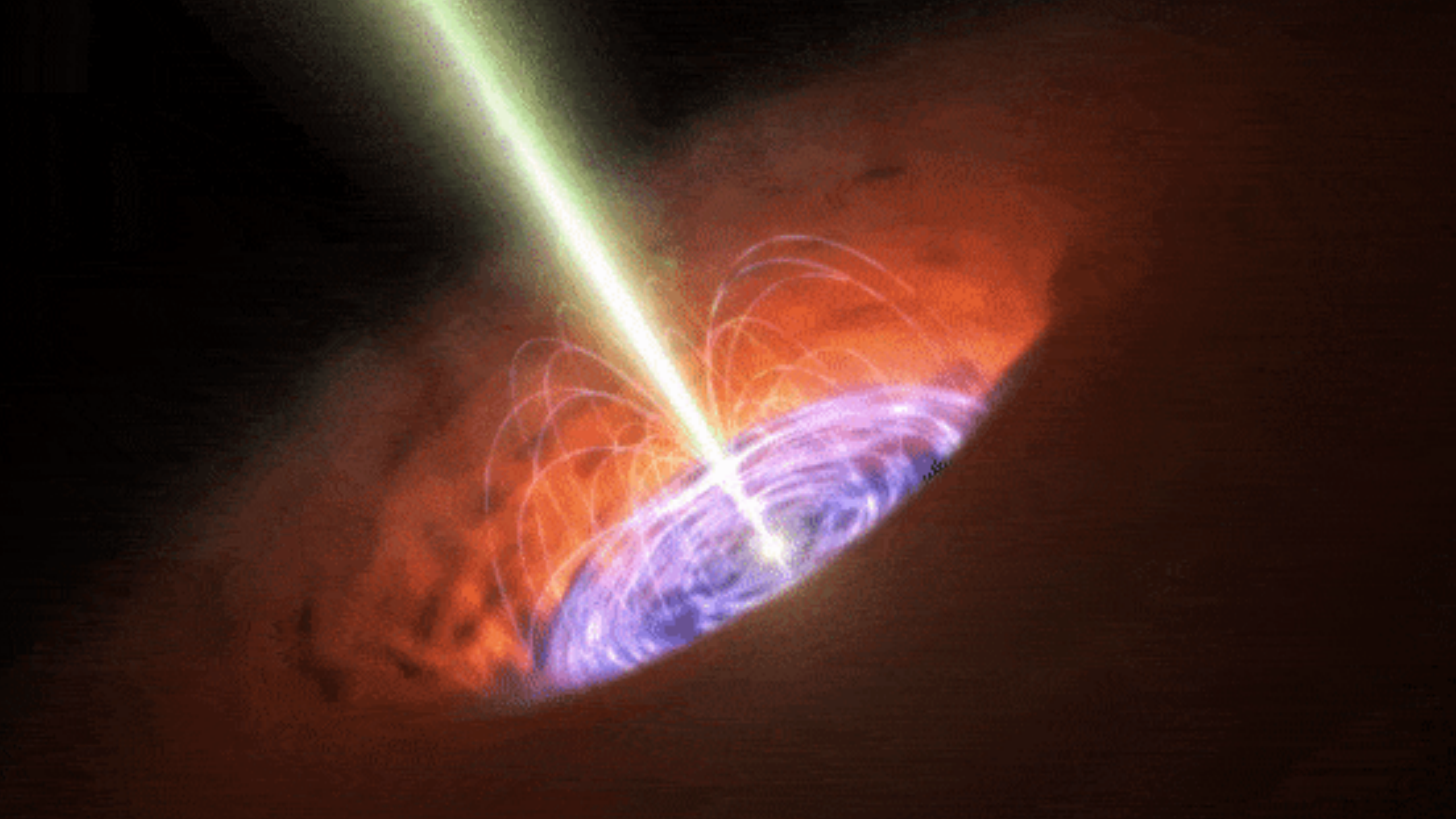
# Reinventing the X-ray spectral models for AGN

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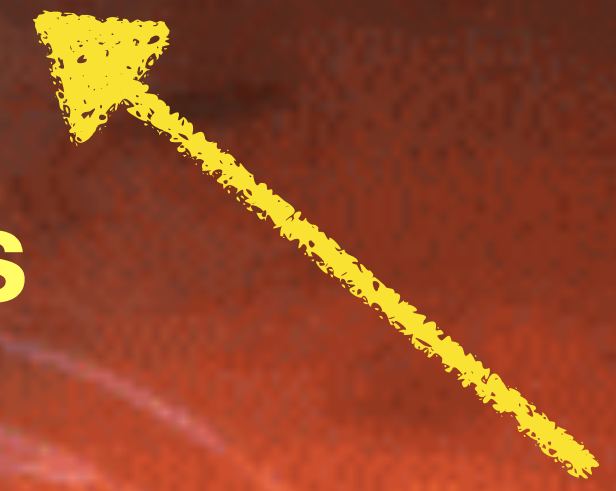




Radio



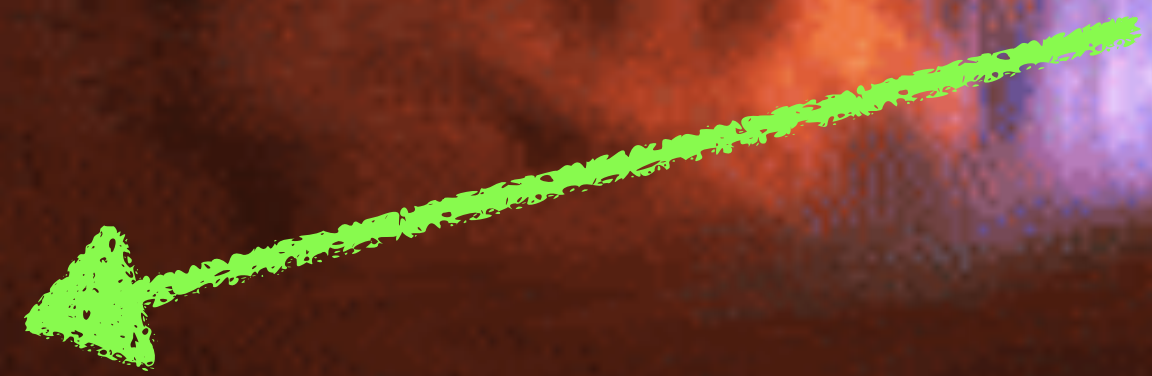
X-rays



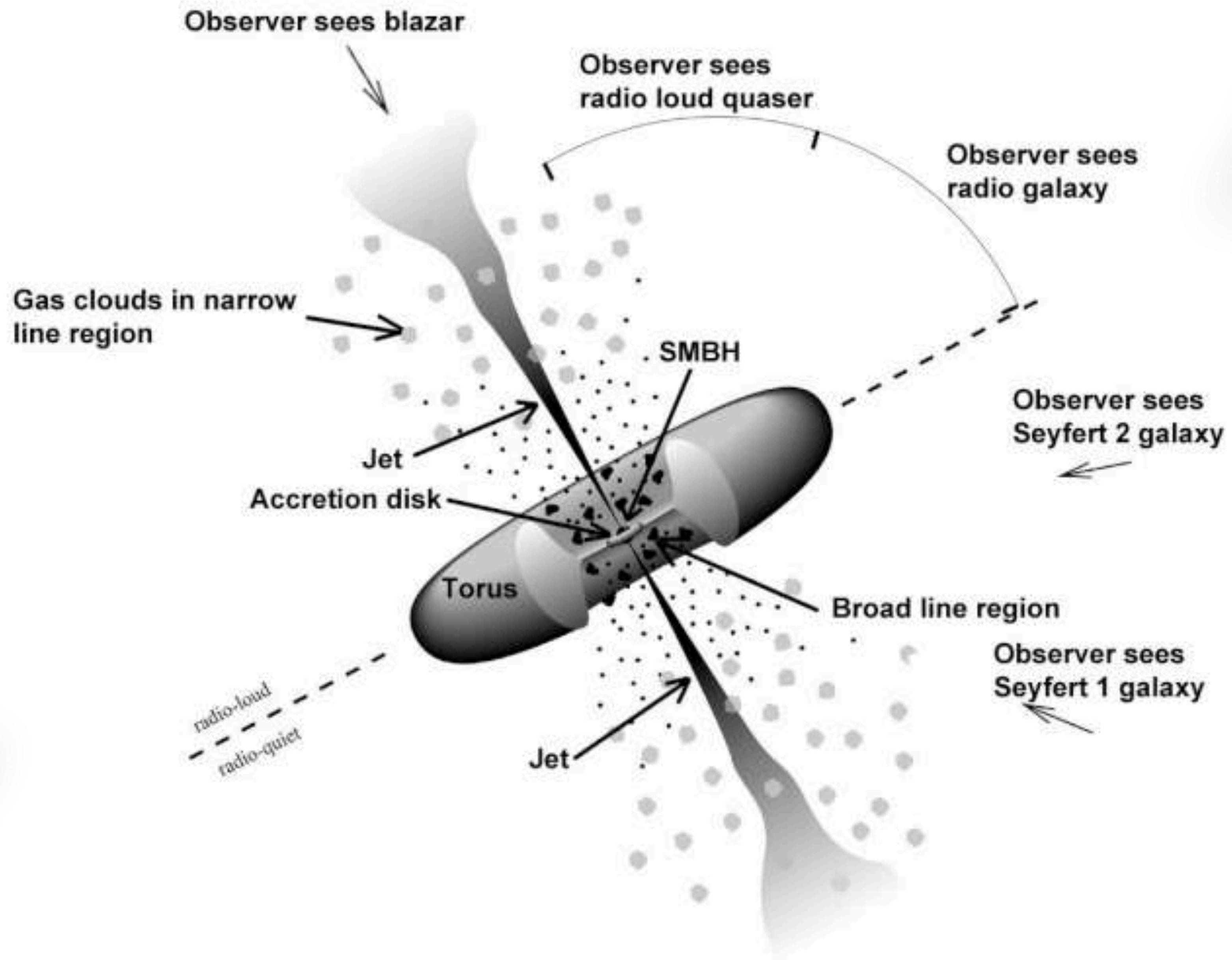
IR



Opt/UV

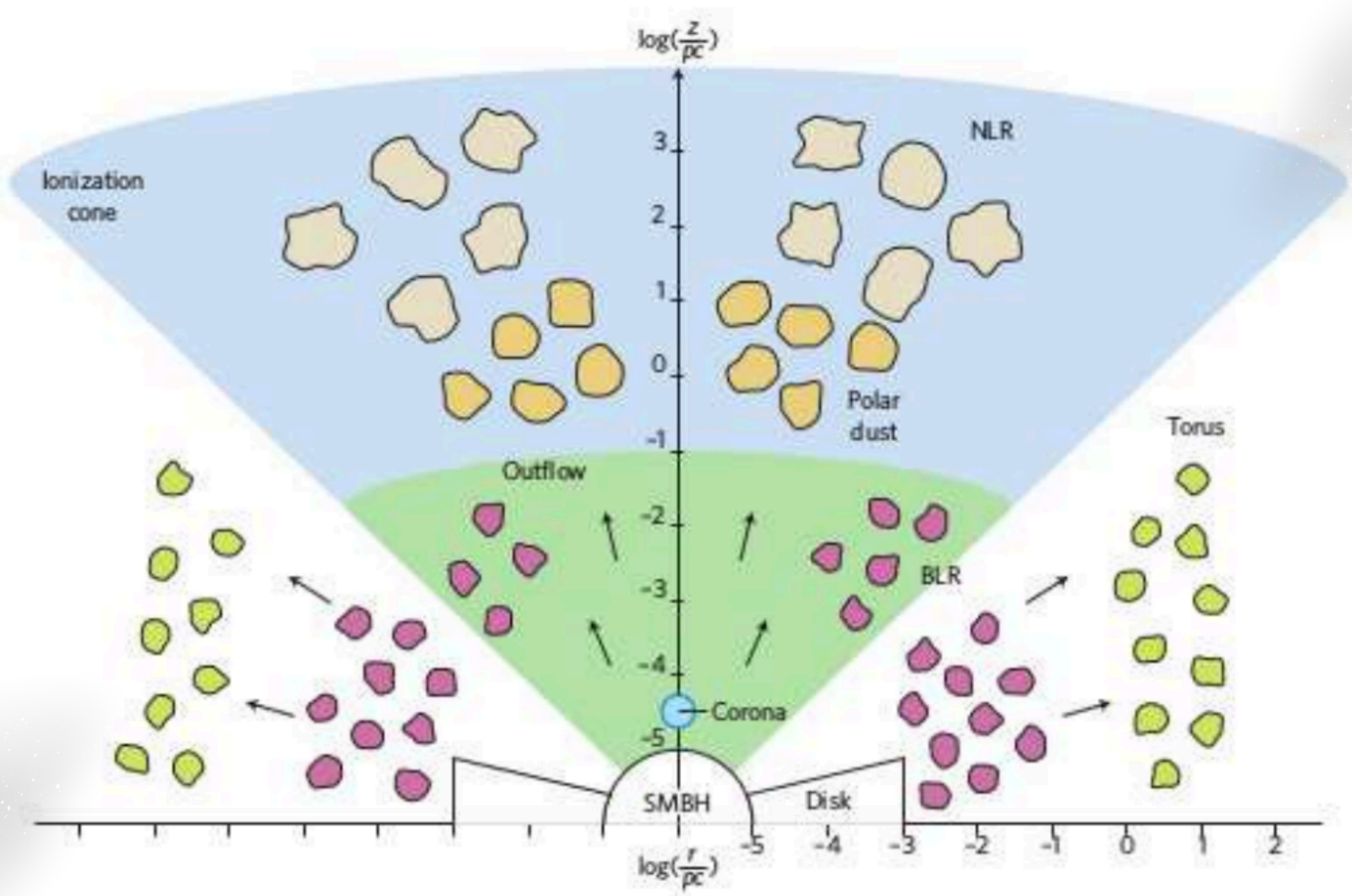
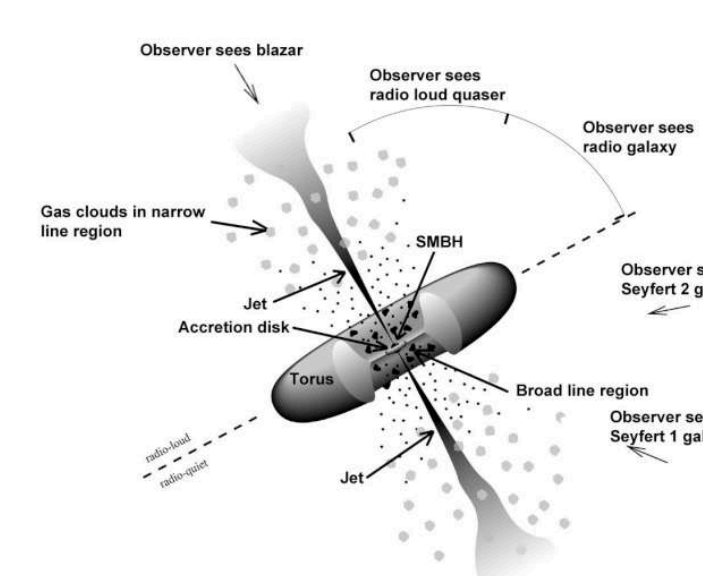






Unification model (e.g., Antonucci 1993)

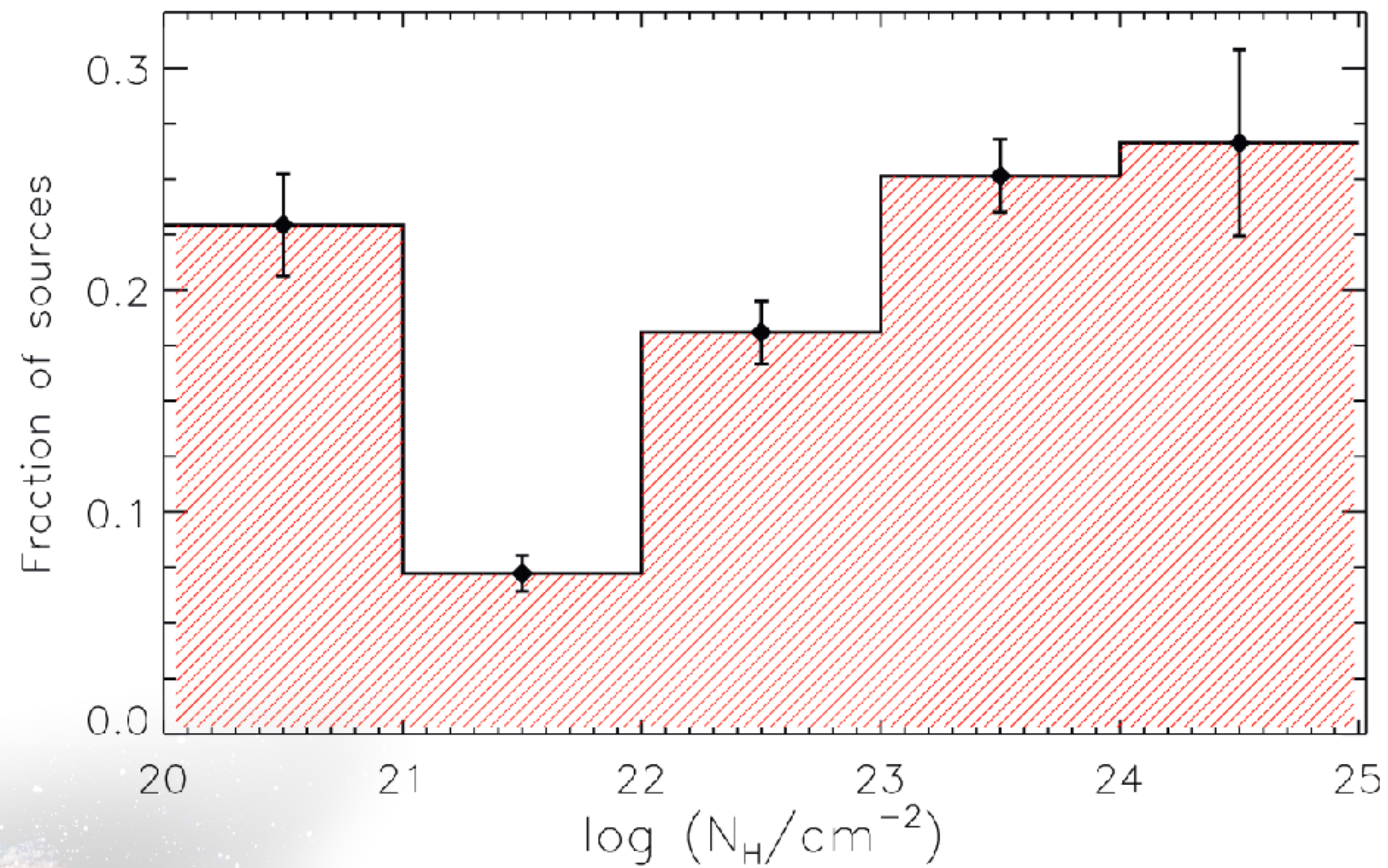




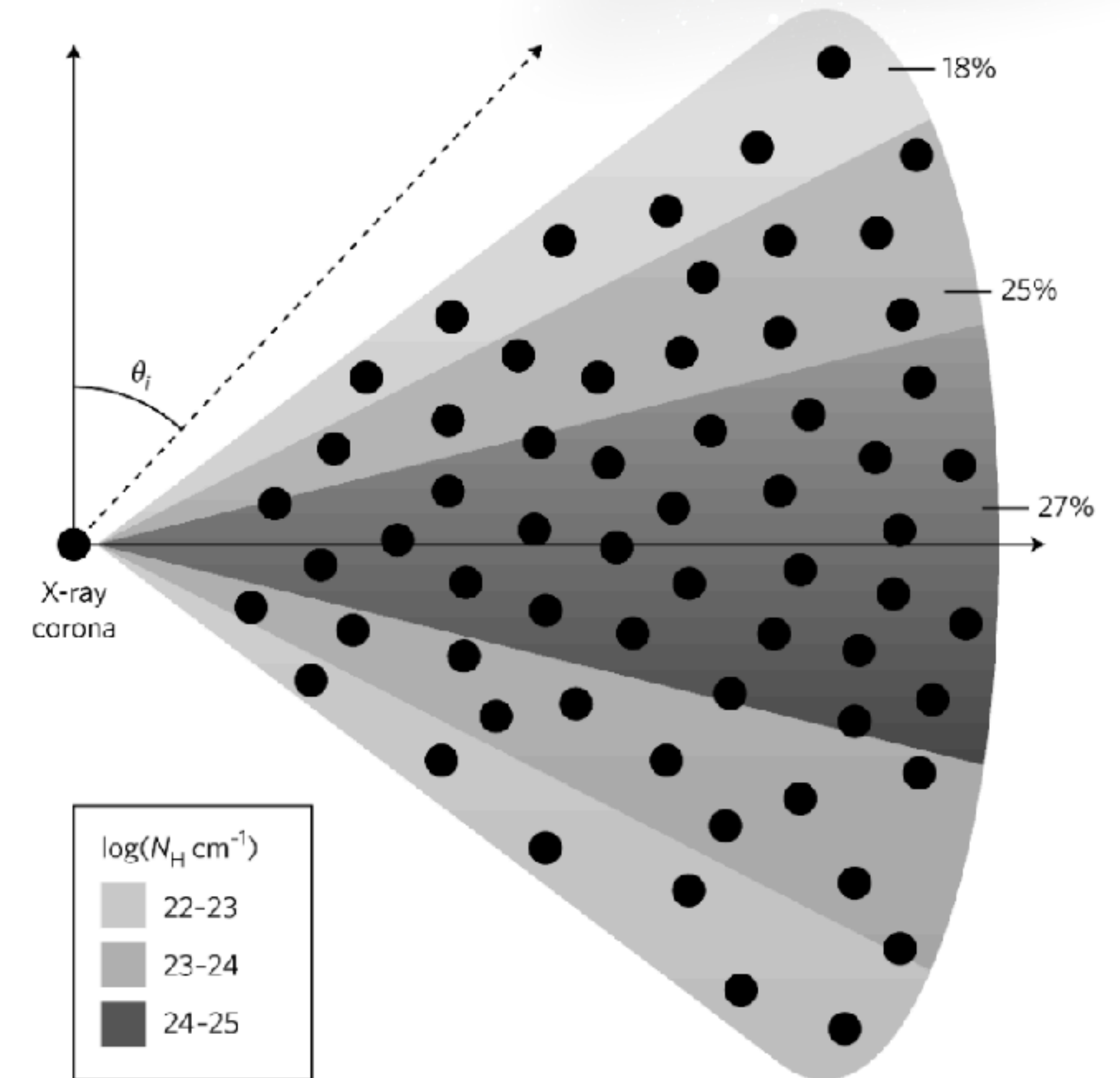
- Hot gas
- Cold gas
- Dust



# Supermassive black holes are surrounded by material



(a)



(b)

# Models for X-ray spectral fitting

## Slab models

**PEXRAV** (Magdziarz & Zdziarski, 1995)

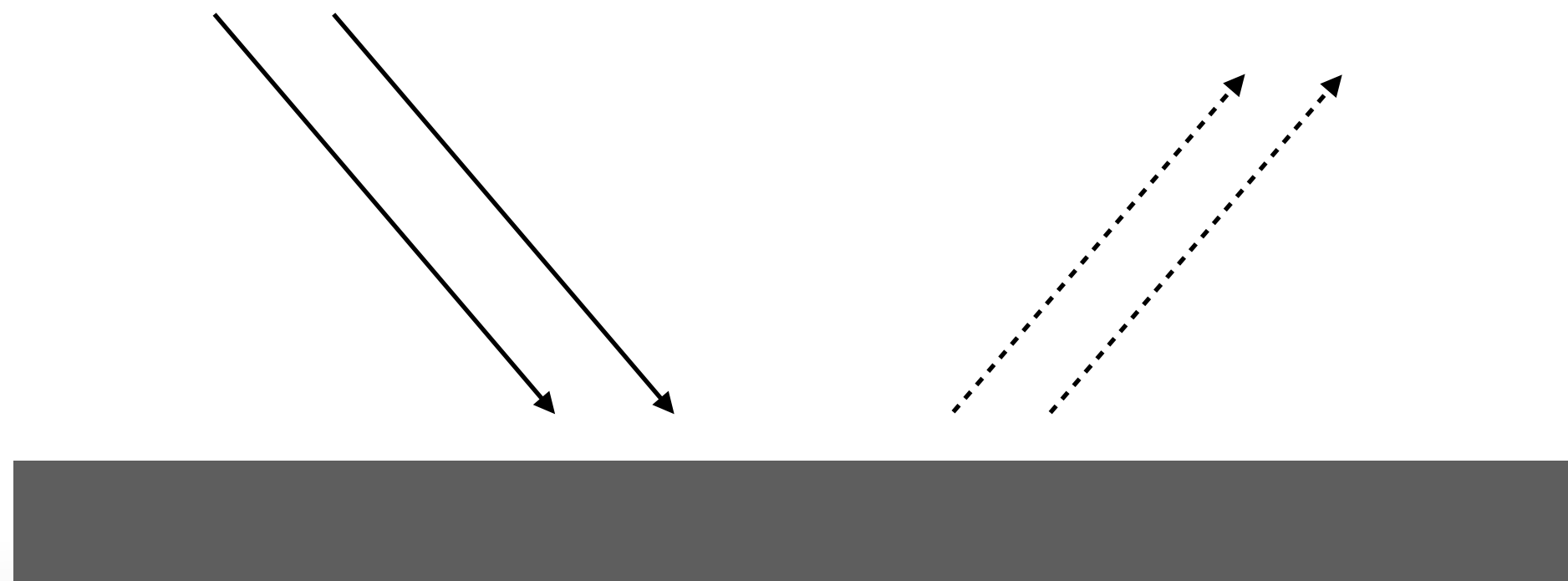
**XILVER** (García et al, 2010/13)

+

+

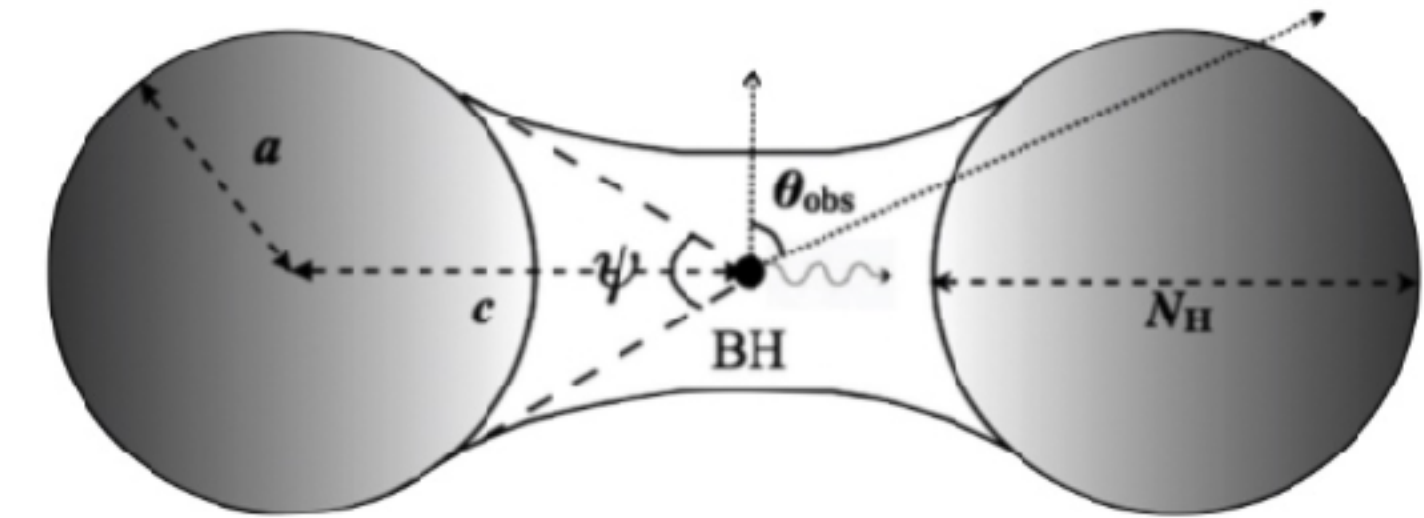
**PEXMON** (Nandra et al, 2007)

**RELLXIL** (García et al, 2014)

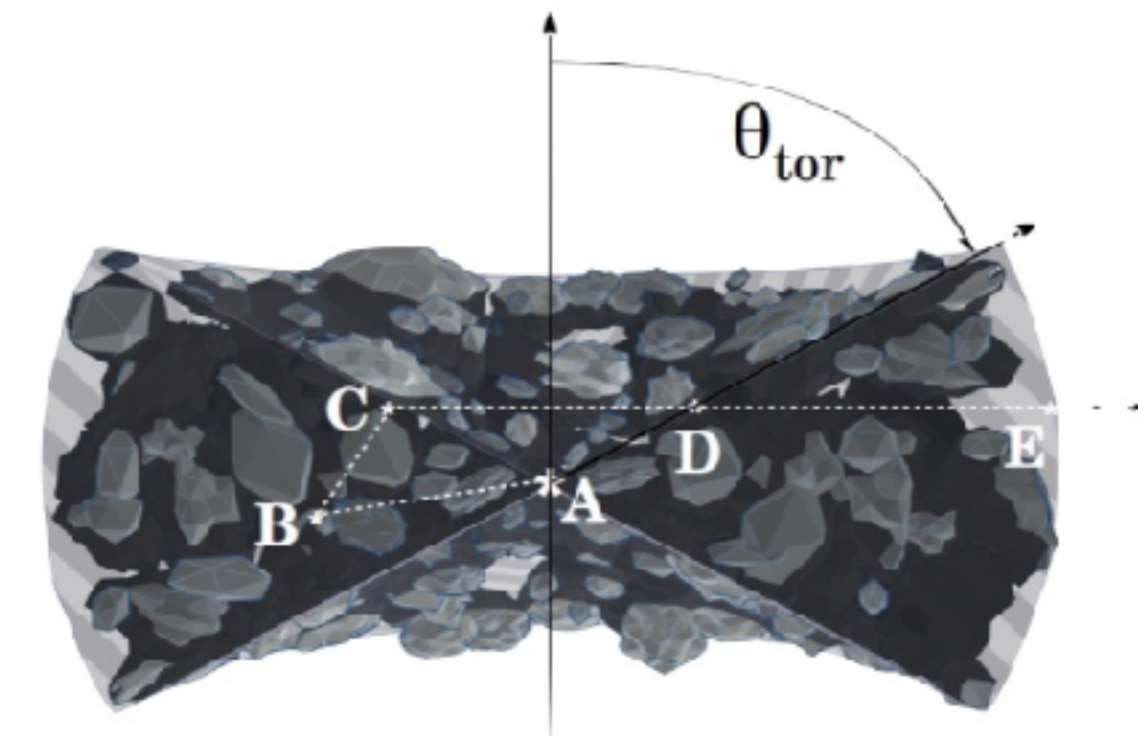


## Torus models

**MYTORUS** (Murphy & Yaqoob, 2009)



**borus02** (Balokovic 2018)



Some torus models : **e-TORUS** (Ikeda +09), **BNTORUS** (Brightman & Nandra 11), **CTORUS** (Liu & Li 14), **RefleX/RXTORUS(D)** (Paltani & Ricci 17) **XARS/UXCLUMPY** (Buchner +19,21), **SKIRT** (Vander Meulen +23)

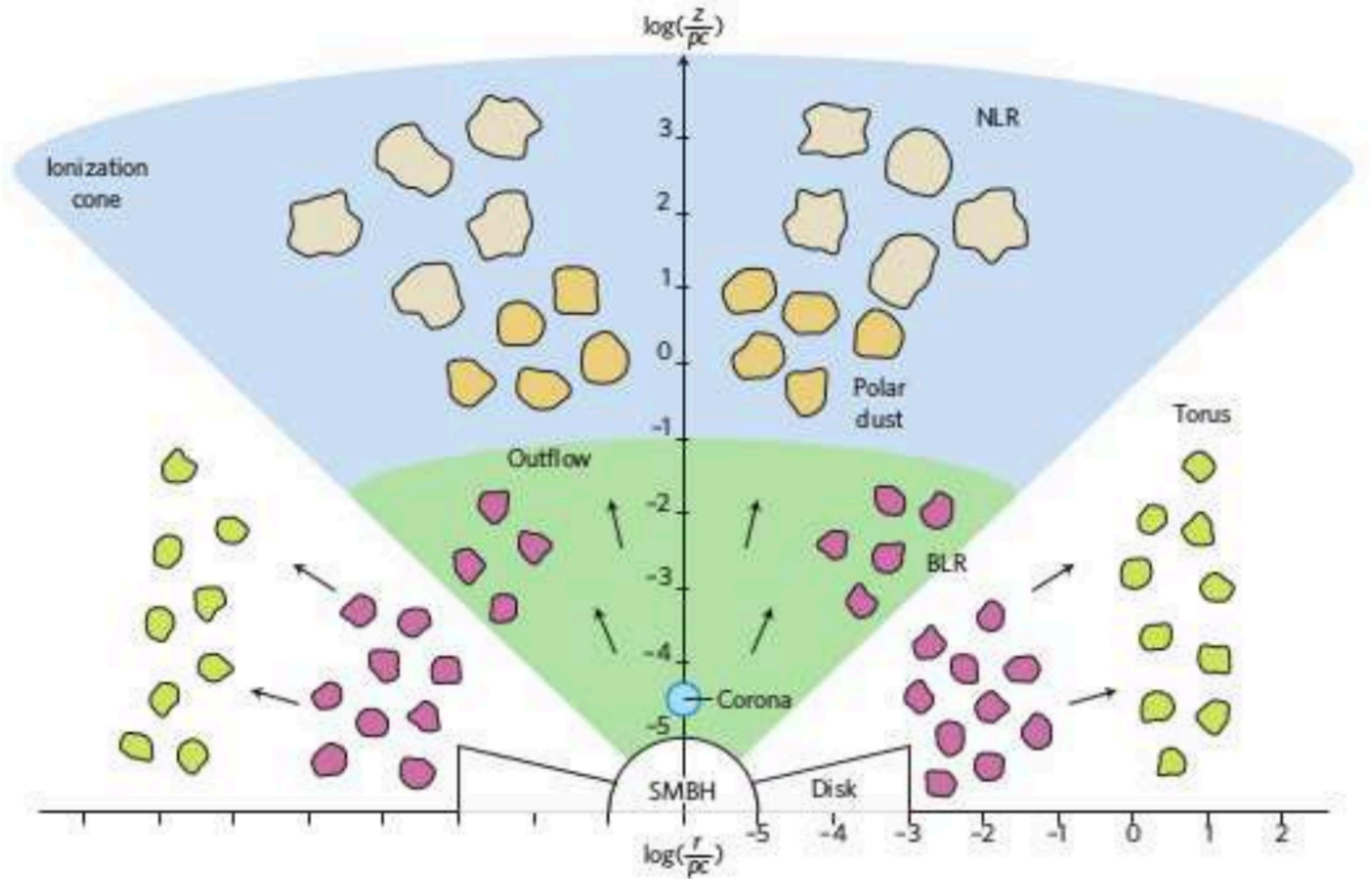


# Models for X-ray spectral fitting

PEXRAV (Mag



PEXMON (Na



Some torus models : **e-TORUS** (Ikeda +09), **BNTORUS** (Brightman & Nandra 11), **CTORUS** (Liu & Li 14), **RefleX/RXTORUS(D)** (Paltani & Ricci 17) **XARS/UXCLUMPY** (Buchner +19,21), **SKIRT** (Vander Meulen +23)



# RefleX (Paltani & Ricci 2017)

**Ray-tracing simulation code of X-ray photons**

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**Geometry  
Building Blocks**



**Set the physical  
conditions**







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# Model I

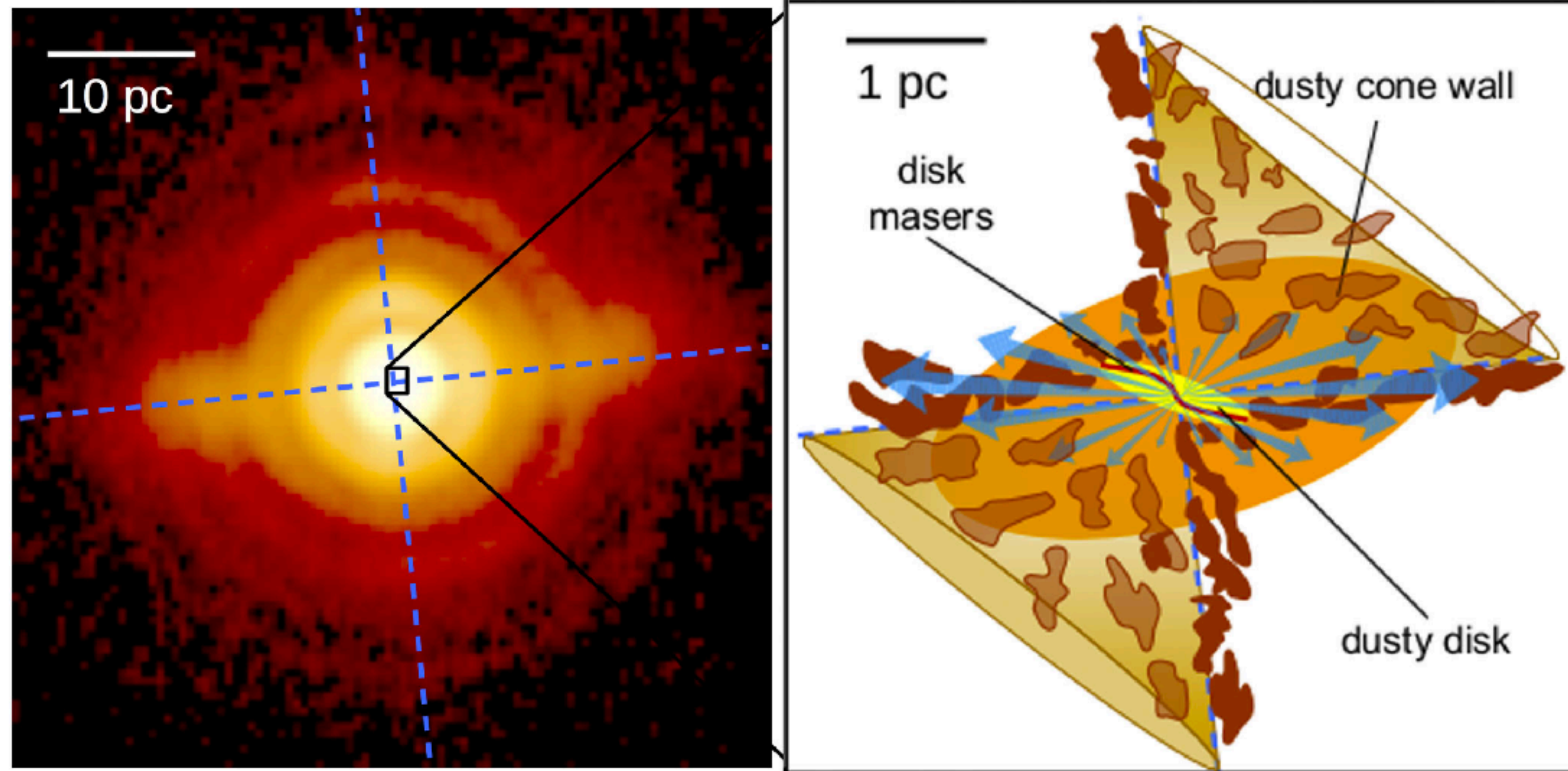
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# Model I

MIDI observations of the Circinus galaxy



Stalevski+2017

See also: Asmus 2019



# Model I

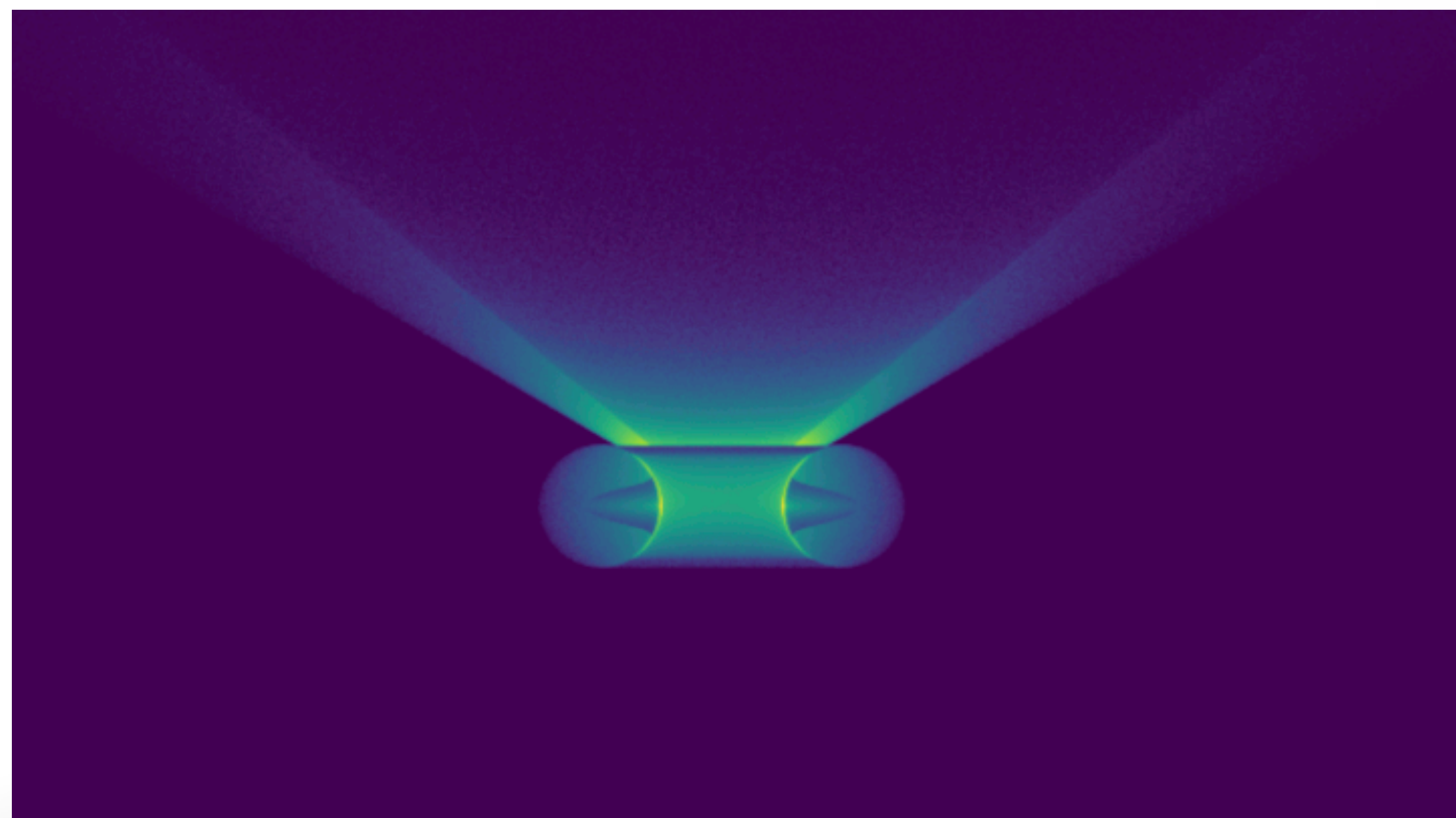
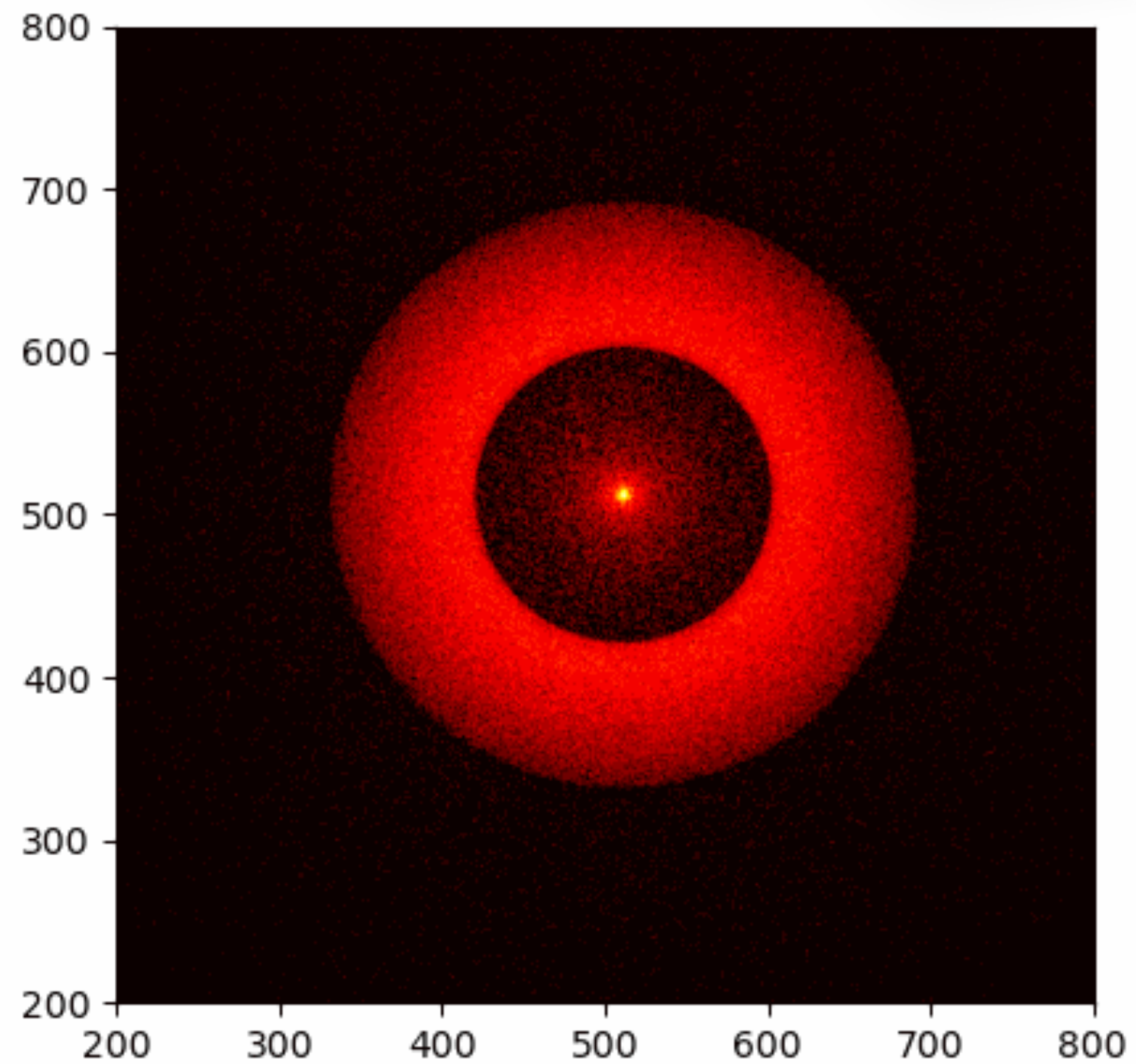


Image with RefleX



RefleX image; credits: Johanne Maëlle Girard (Uni. Geneva)

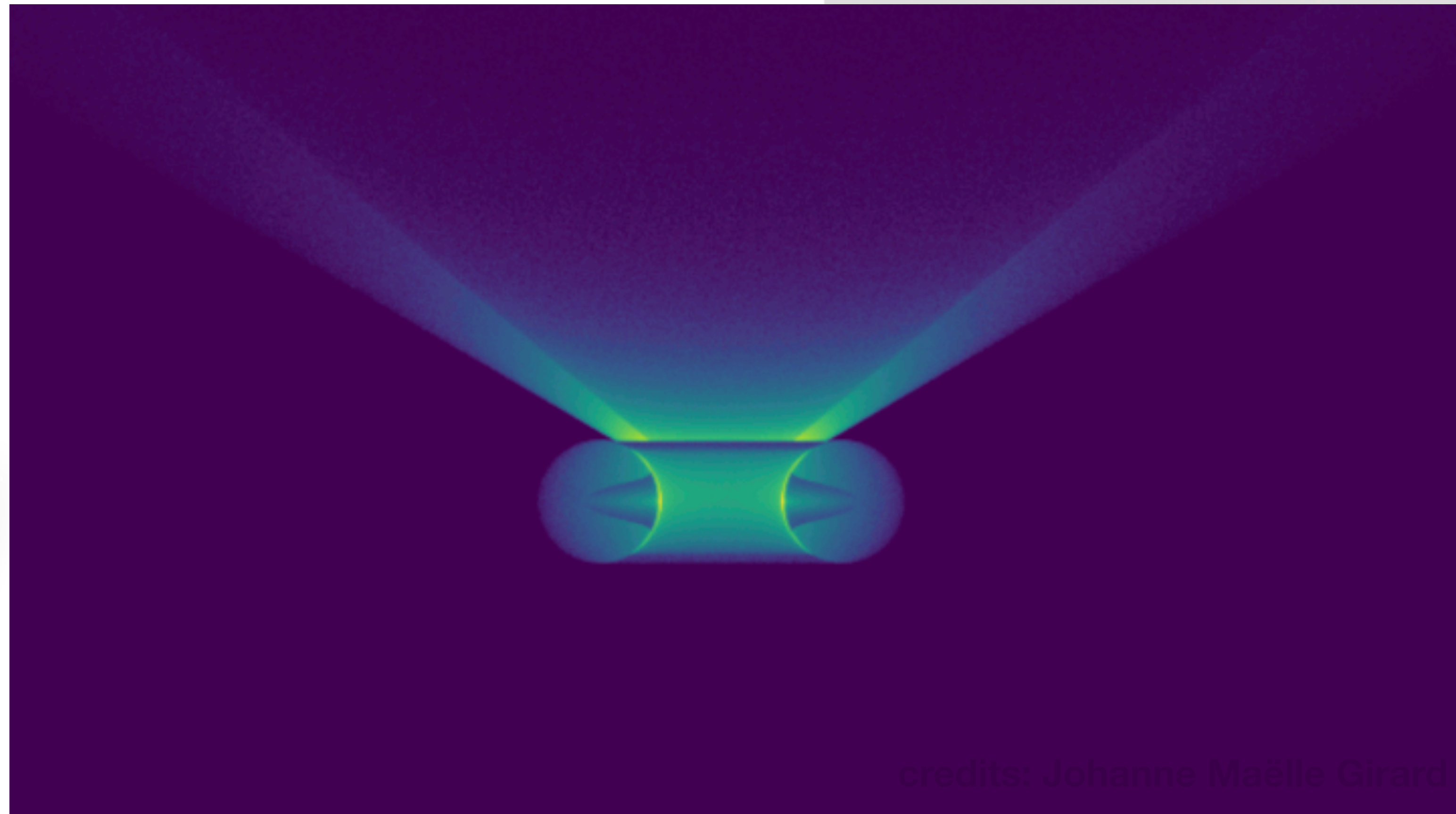


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# Model I

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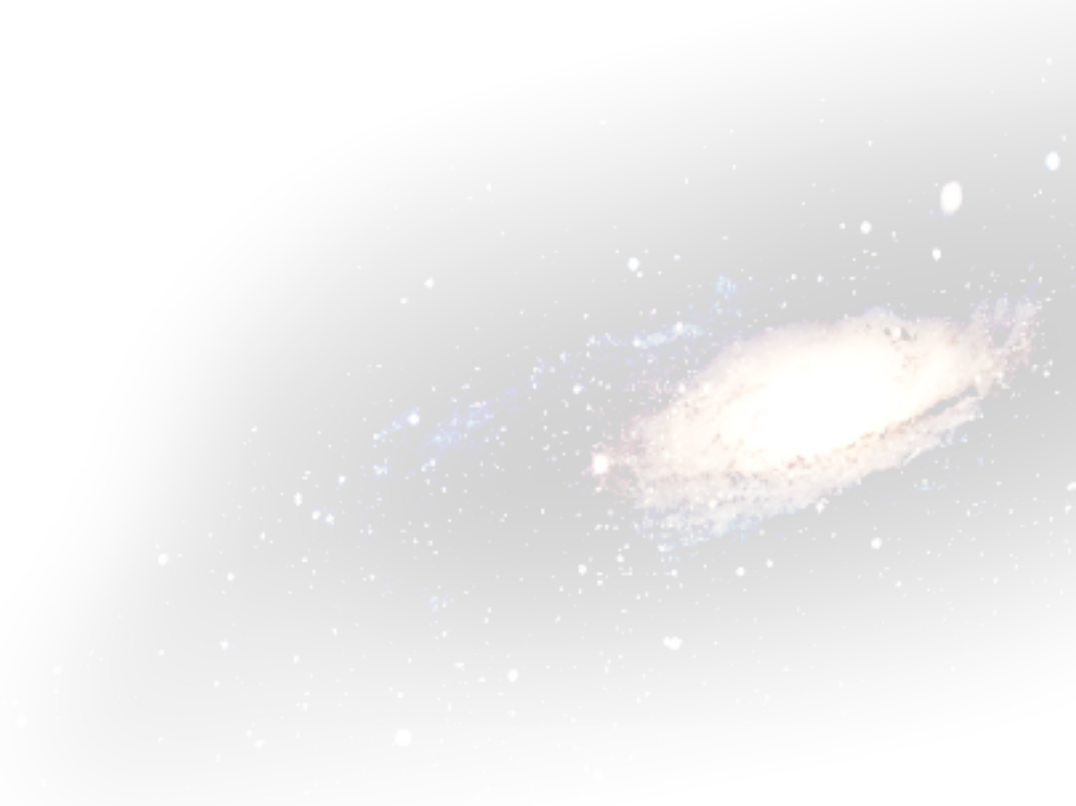
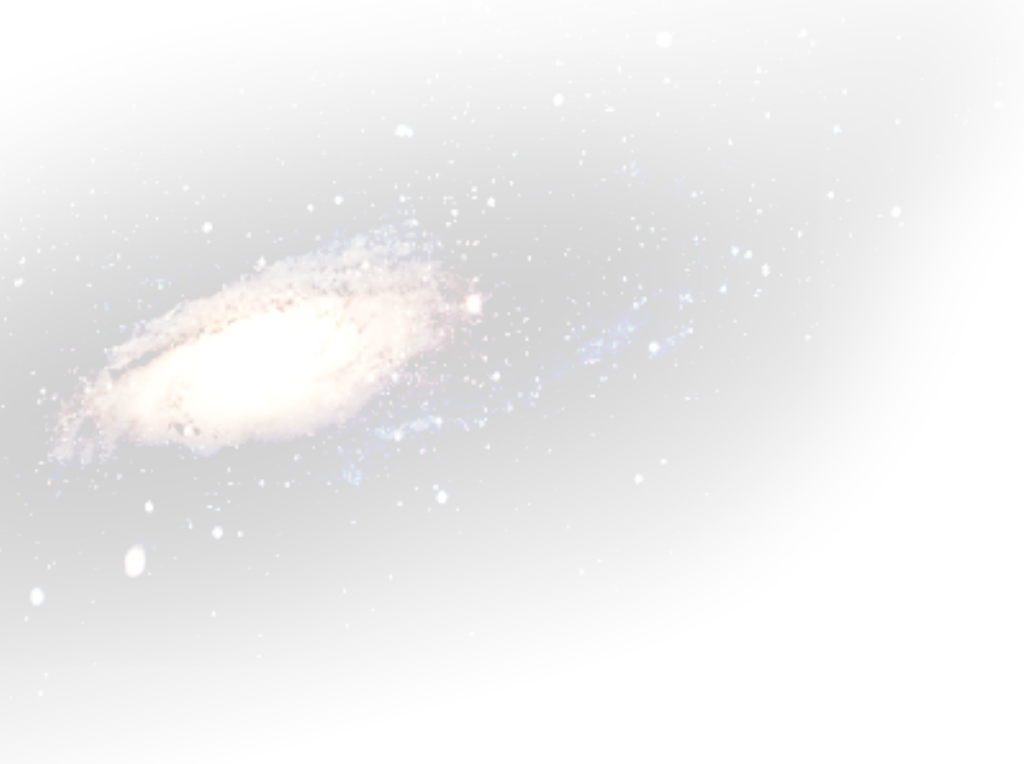
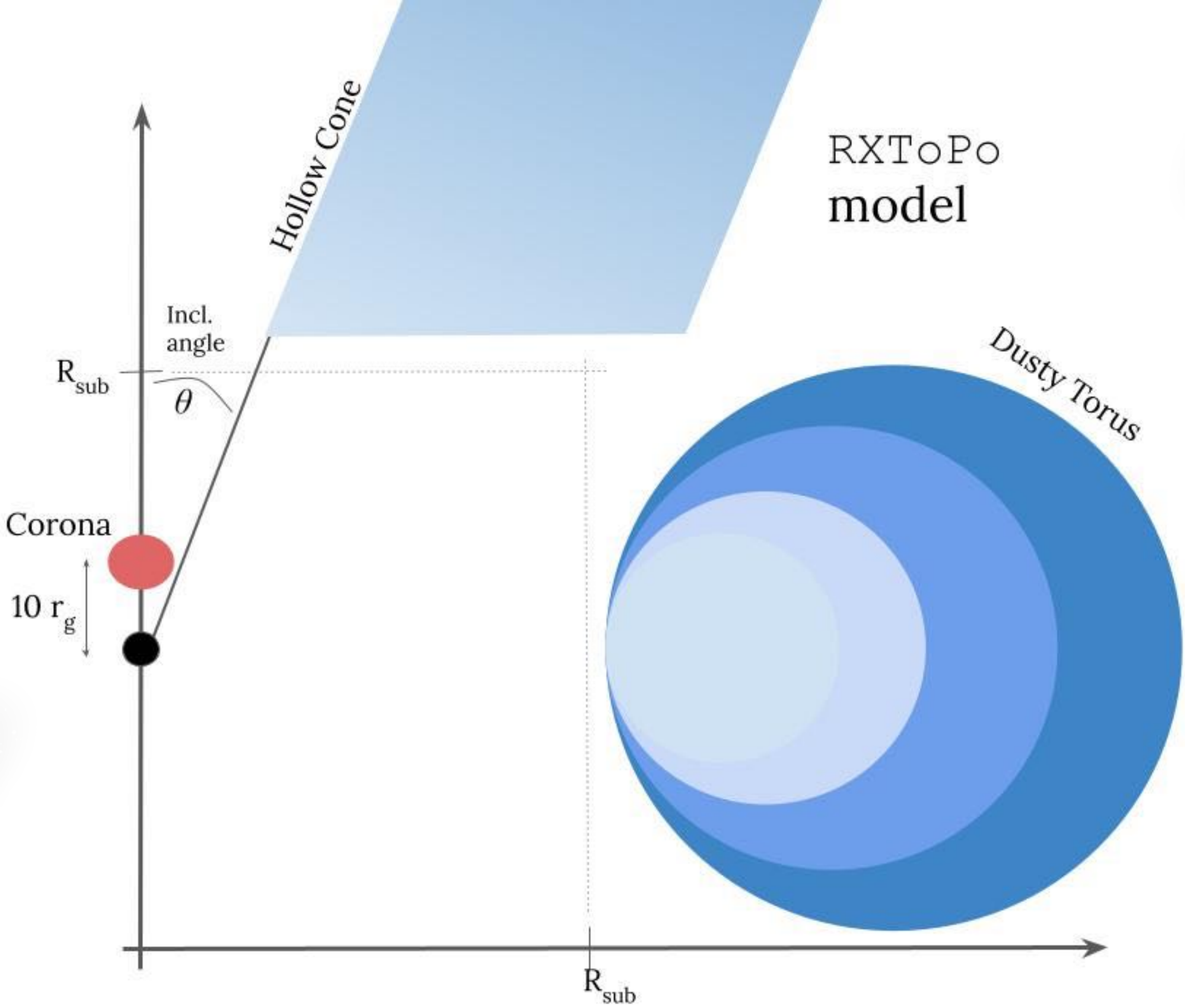
## RXToPo



credits: Johanne Maëlle Girard (Uni. Geneva)



# RXToPo



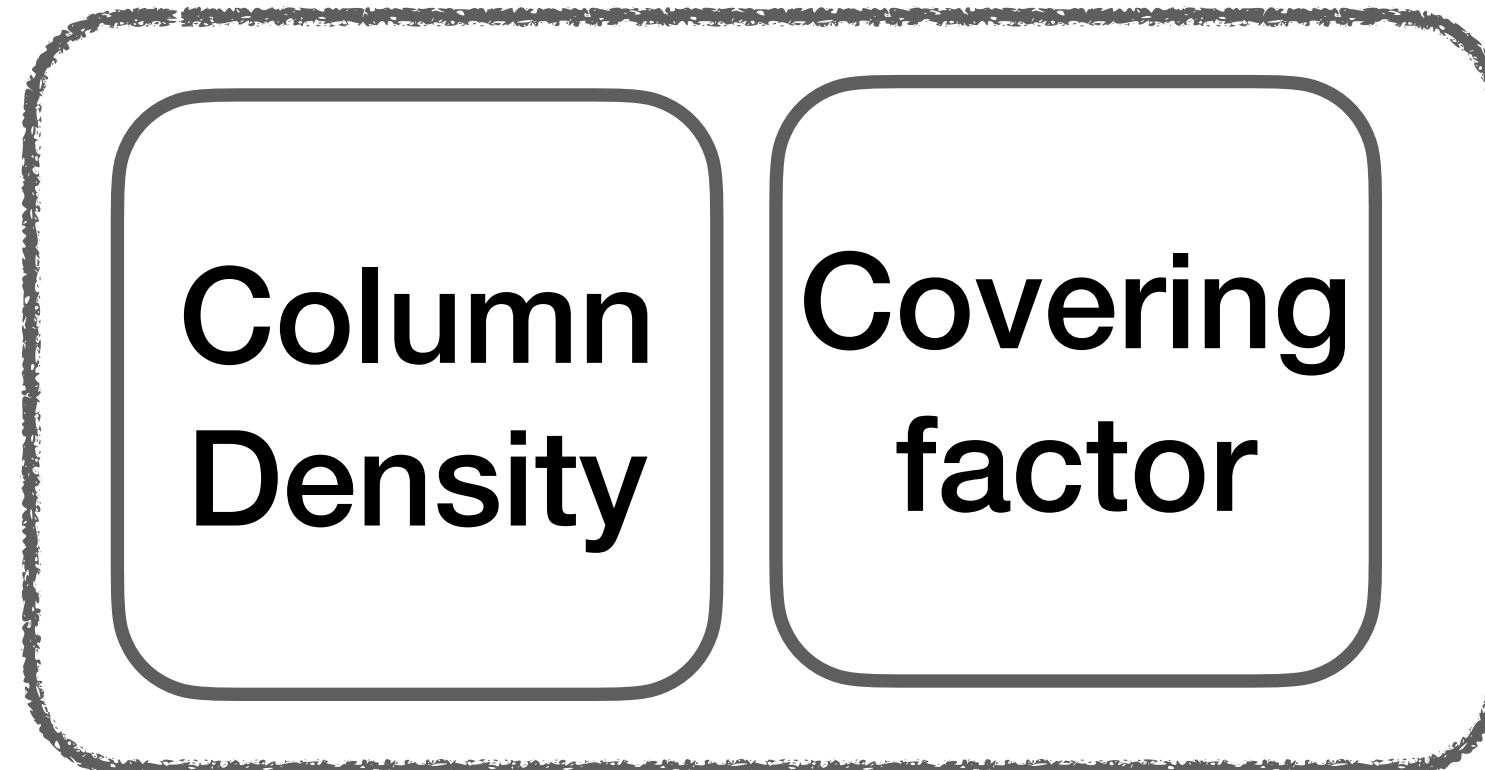


# The free parameters

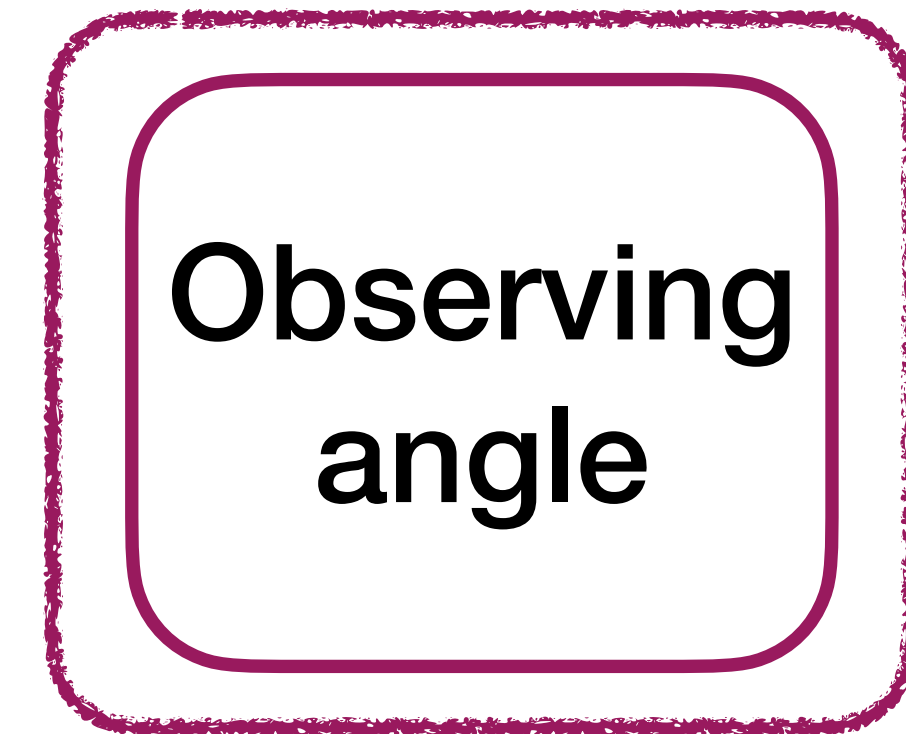
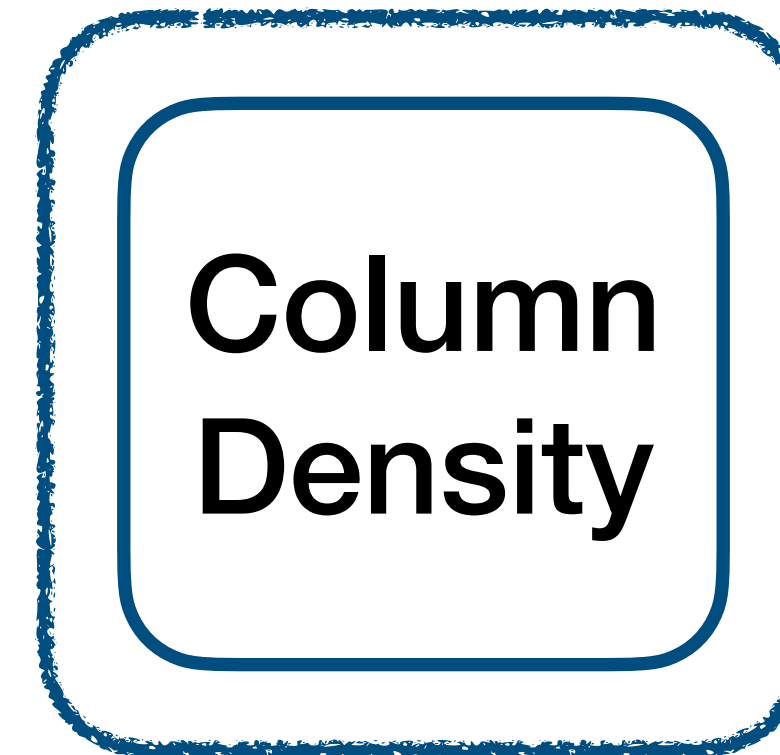
**Source**



**Dusty Torus**



**Polar medium**



The energy cutoff is fixed to 200 keV (e.g. Ricci+2017)



# The free parameters

## Source

Photon  
Index

1.6 - 2.4  
(0.1)

## Dusty Torus

Column  
Density

23.0 - 25.0  
(0.2)

Covering  
factor

0.1 - 0.9  
(0.1)

## Polar medium

Column  
Density


22.0 - 24.0  
(0.2)

Observing  
angle

0° - 90°

The energy cutoff is fixed to 200 keV (e.g. Ricci+2017)

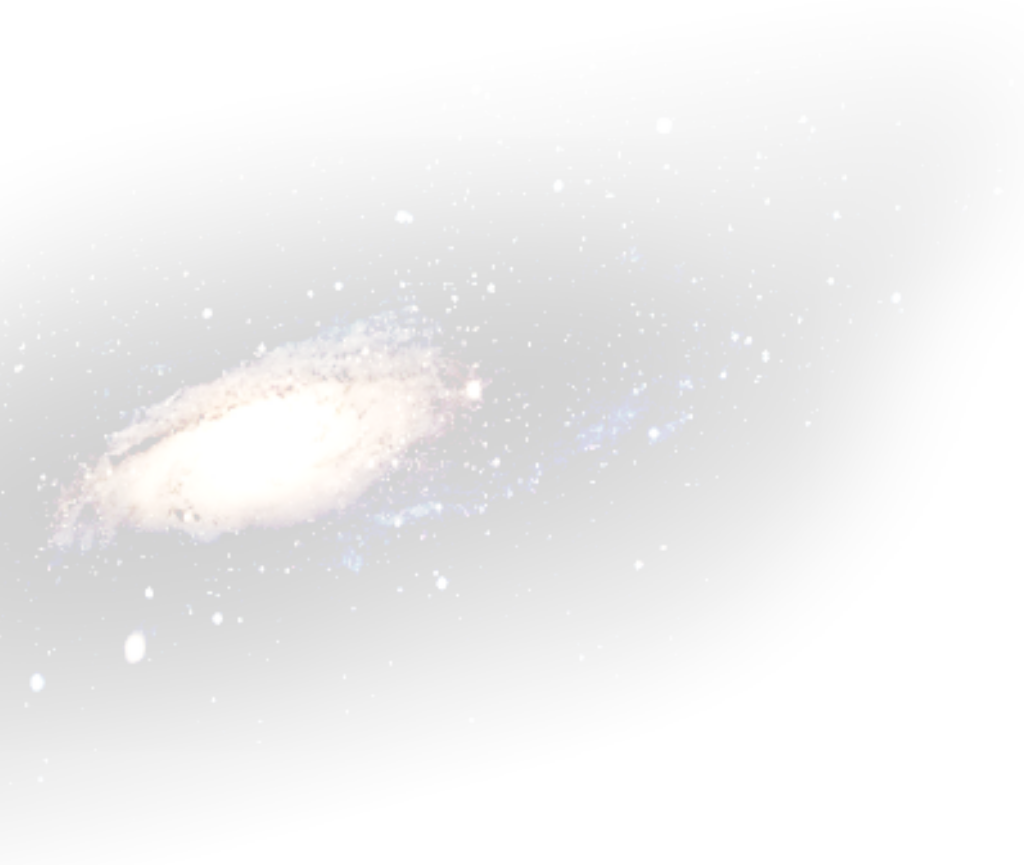




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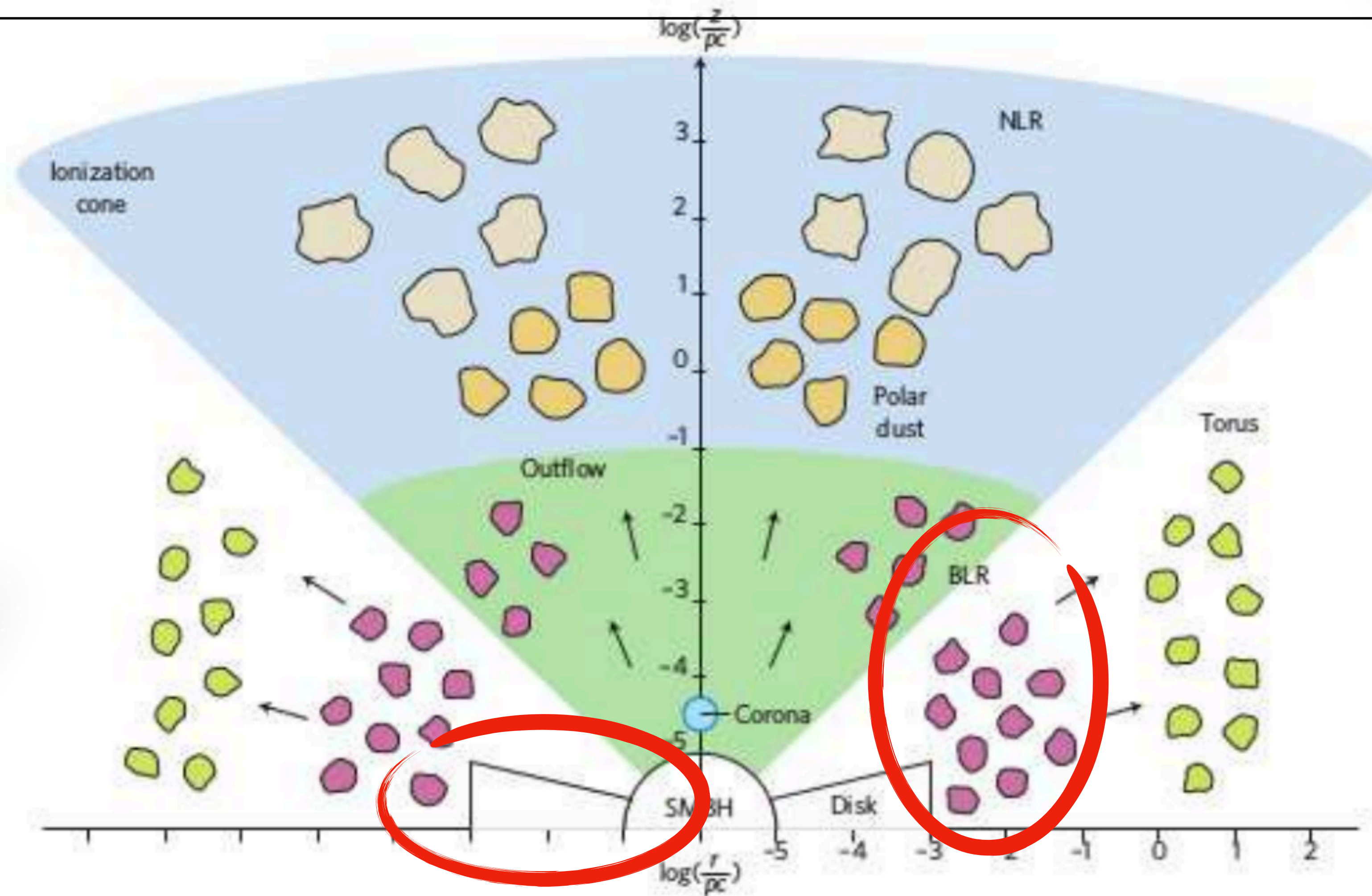
# Model II

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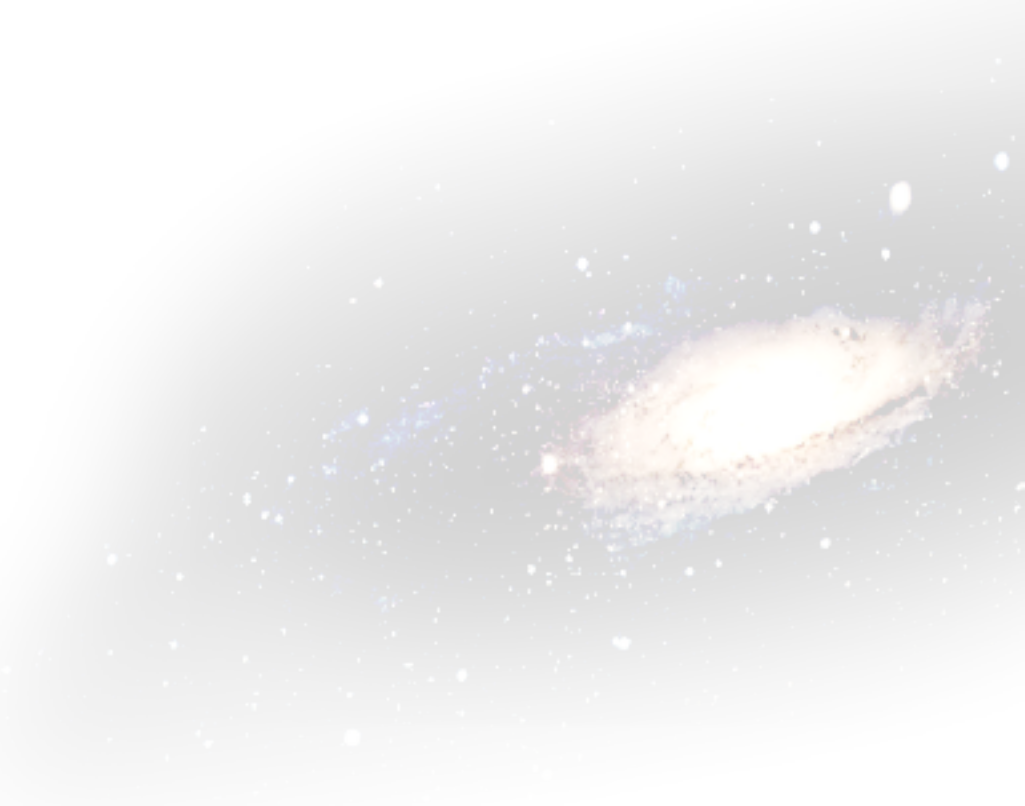
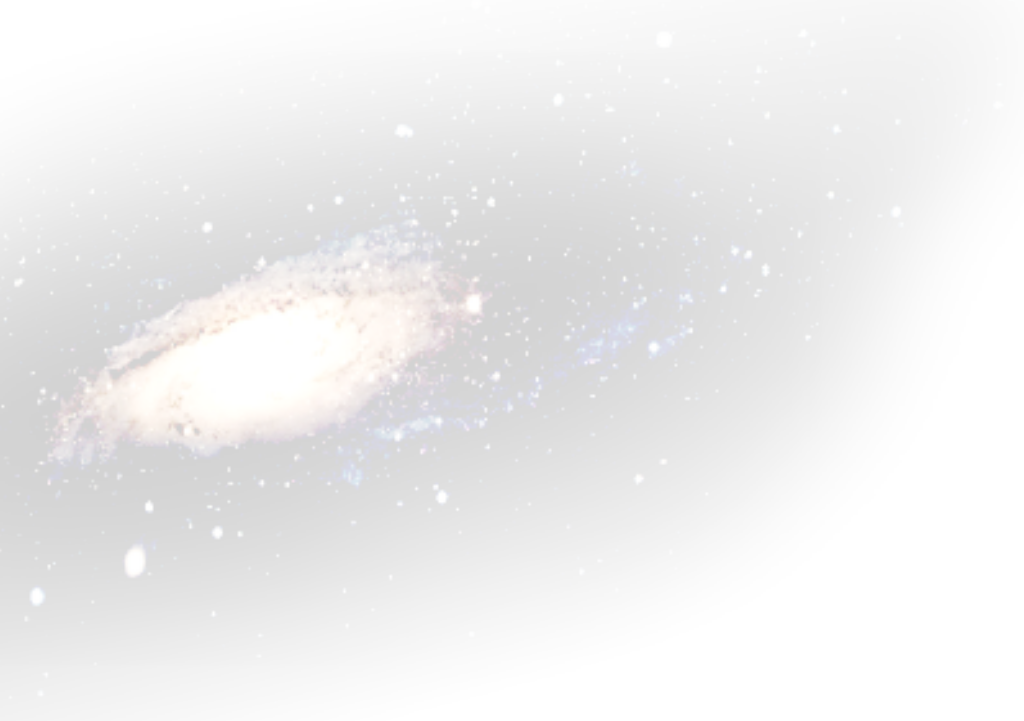
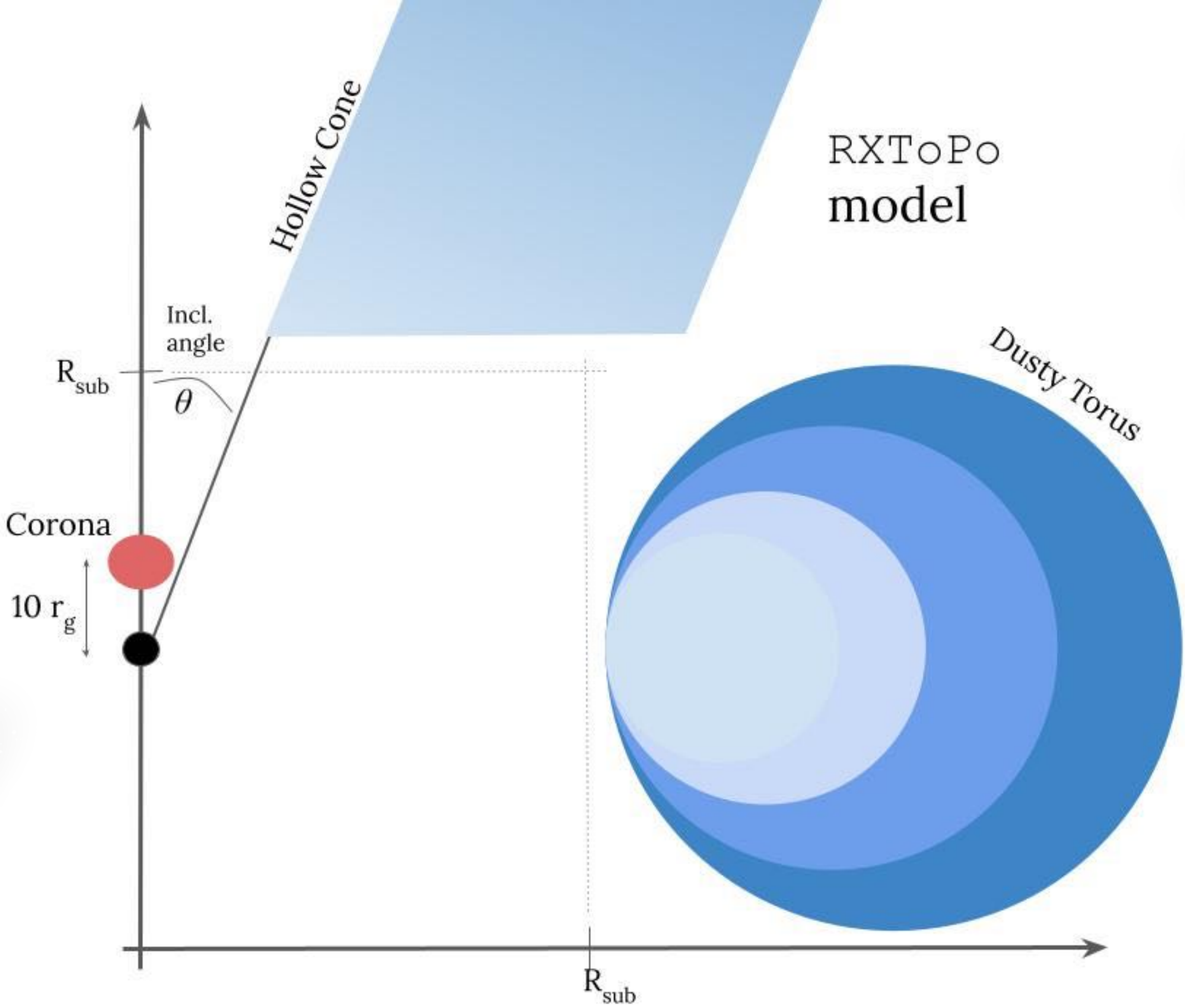


# Model II



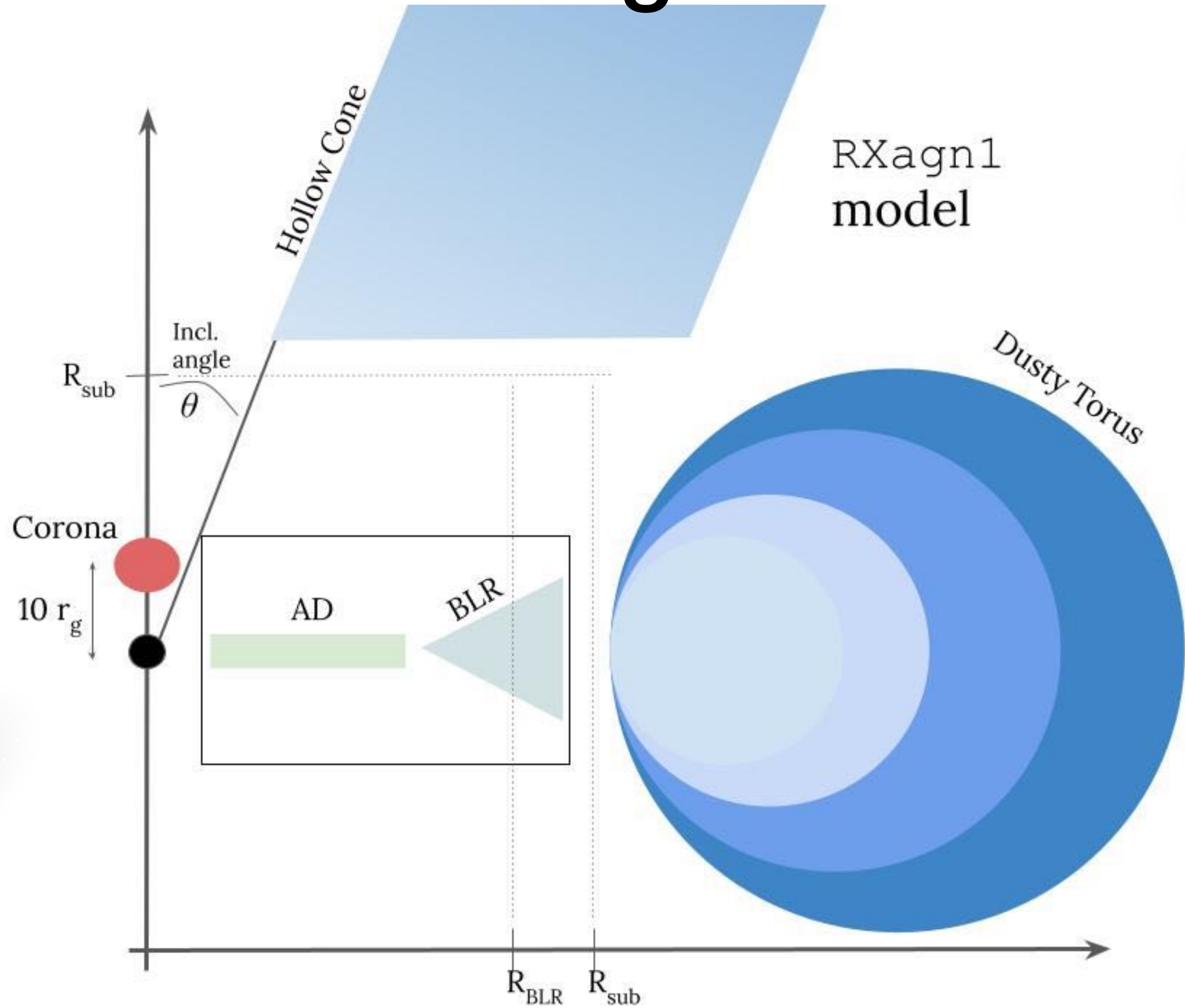


# RXToPo





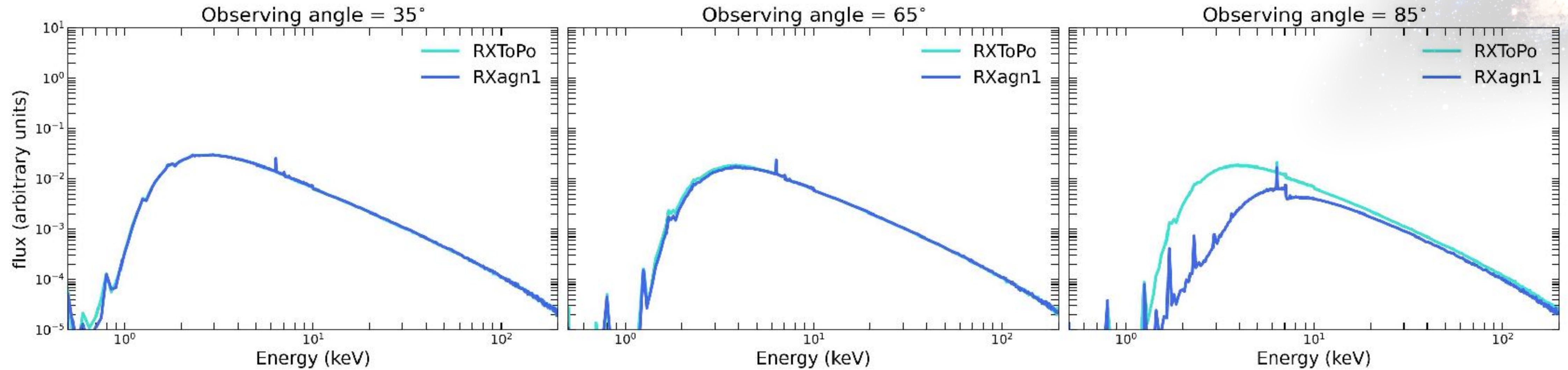
# RXagn1



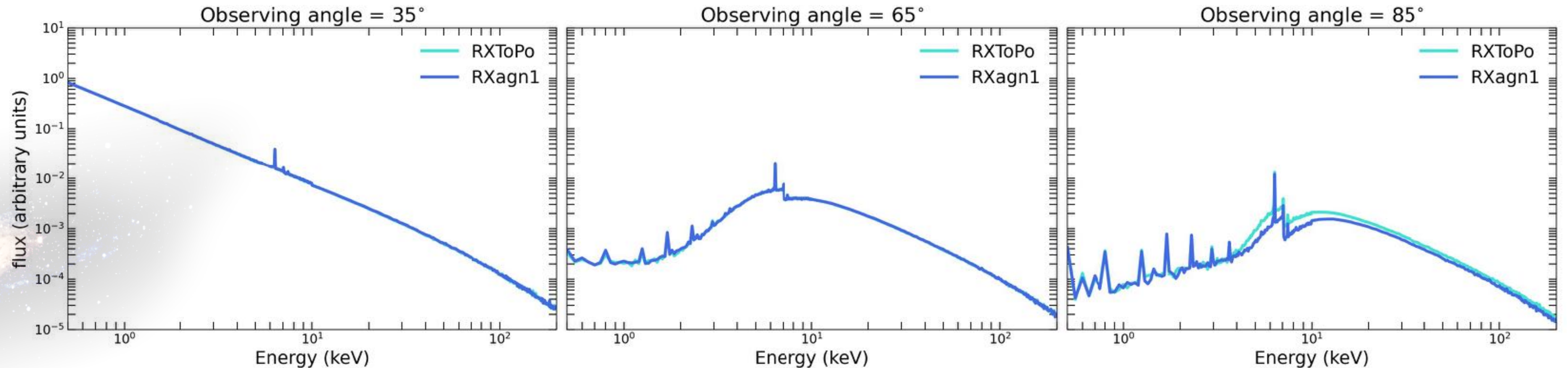


# RXToPo vs RXagn1

$\Gamma = 1.6$  |  $E_c = 140\text{keV}$  |  $\log(N_H/cm^{-2})_{tor} = 23.0$  |  $CF_{tor} = 0.9$  |  $\log(N_H/cm^{-2})_{cone} = 24.0$

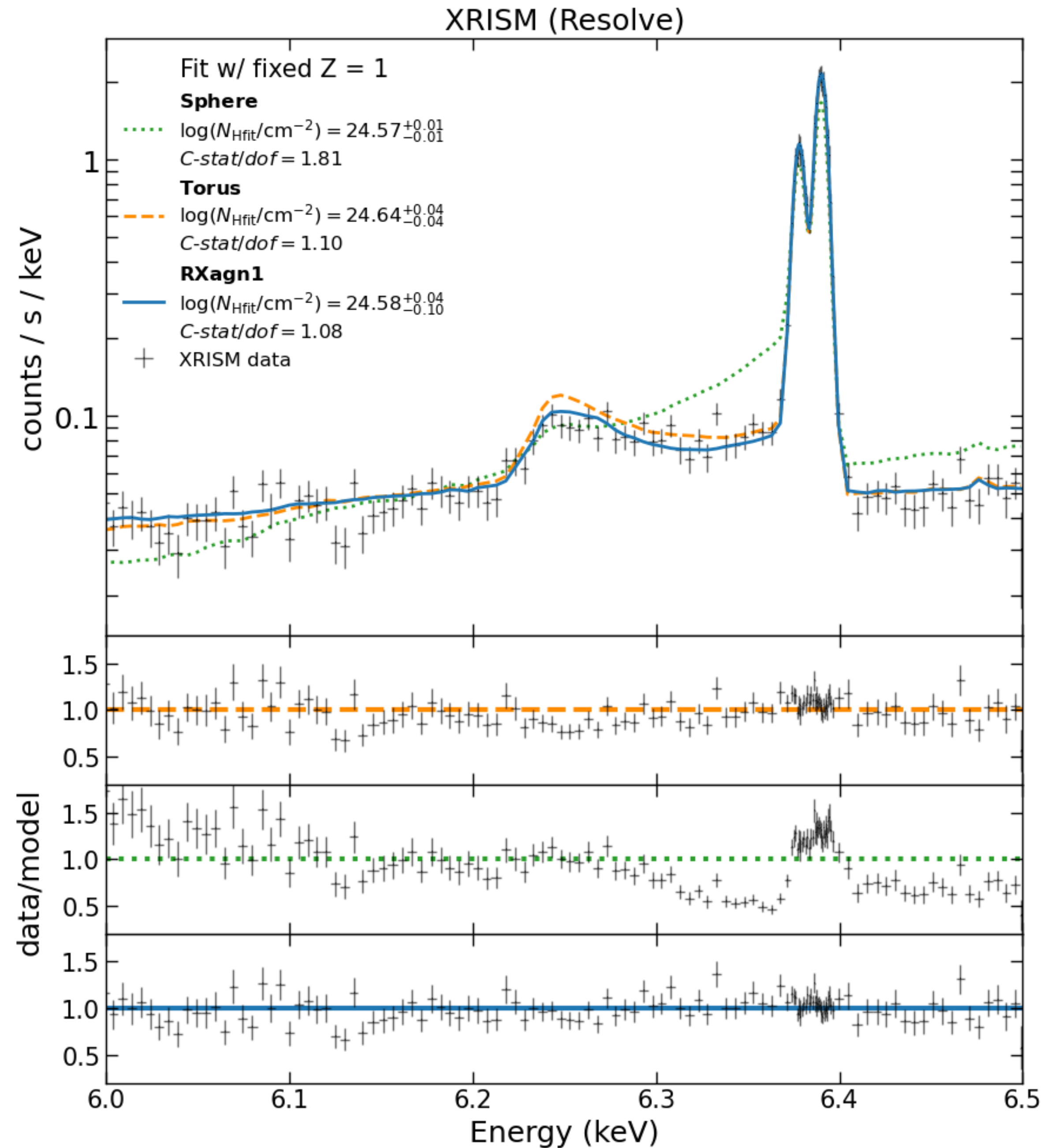


$\Gamma = 1.6$  |  $E_c = 140\text{keV}$  |  $\log(N_H/cm^{-2})_{tor} = 24.0$  |  $CF_{tor} = 0.5$  |  $\log(N_H/cm^{-2})_{cone} = 24.0$





# New models are needed...new telescopes are coming!



Chandra HETG @ Circinus:  
Hikitani+2018

Dimopoulos+ submitted



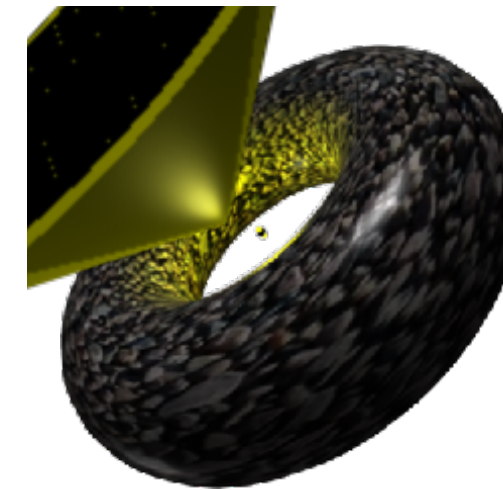
# RX spectral models family

RXTorus

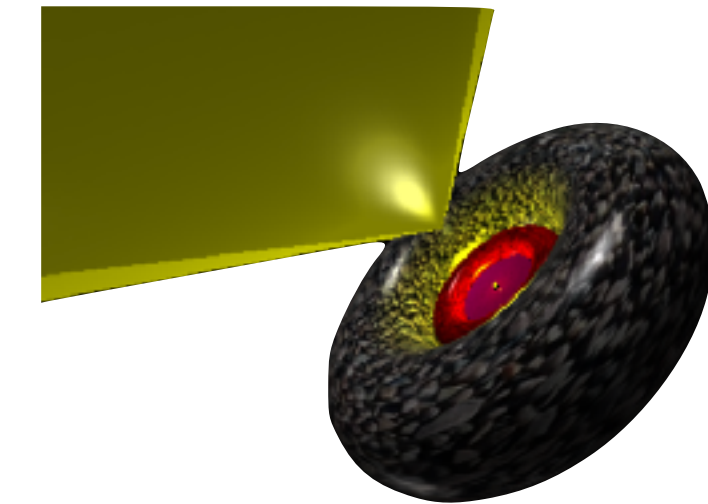


RXTorusD

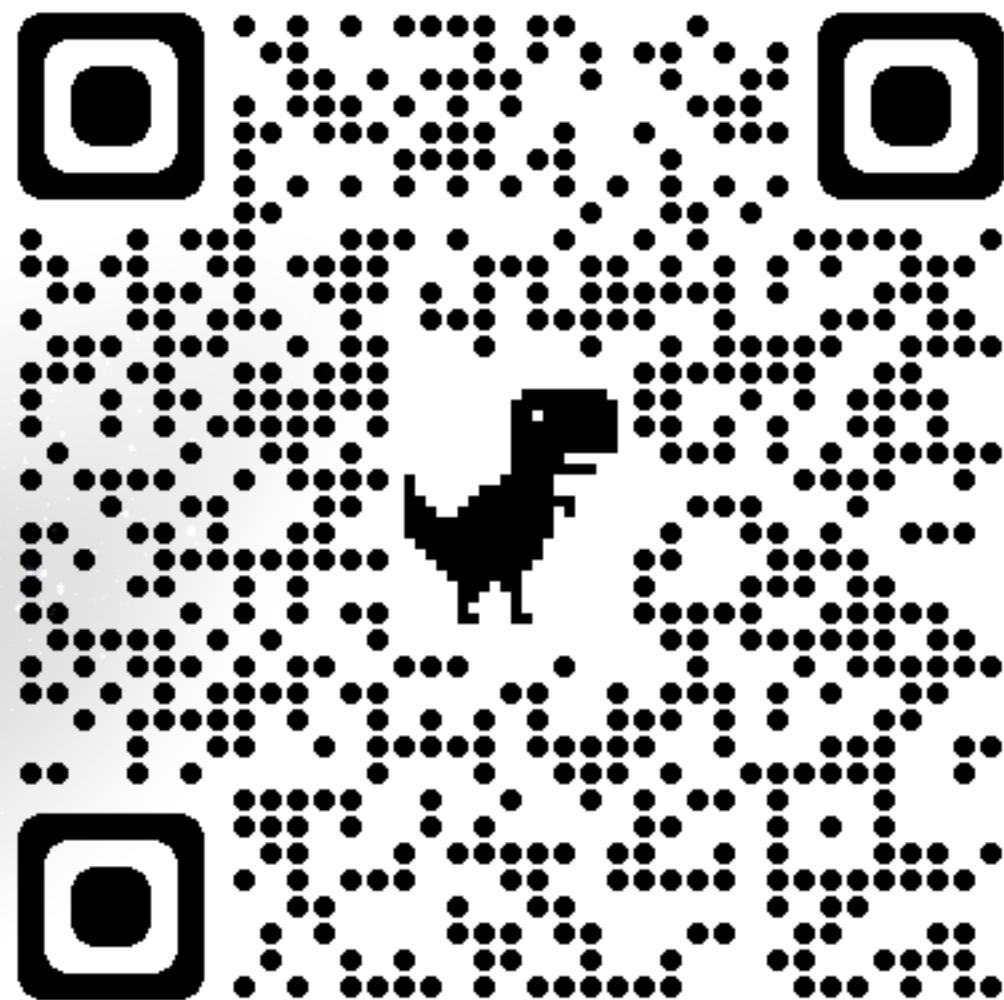
RXToPo



RXagn1

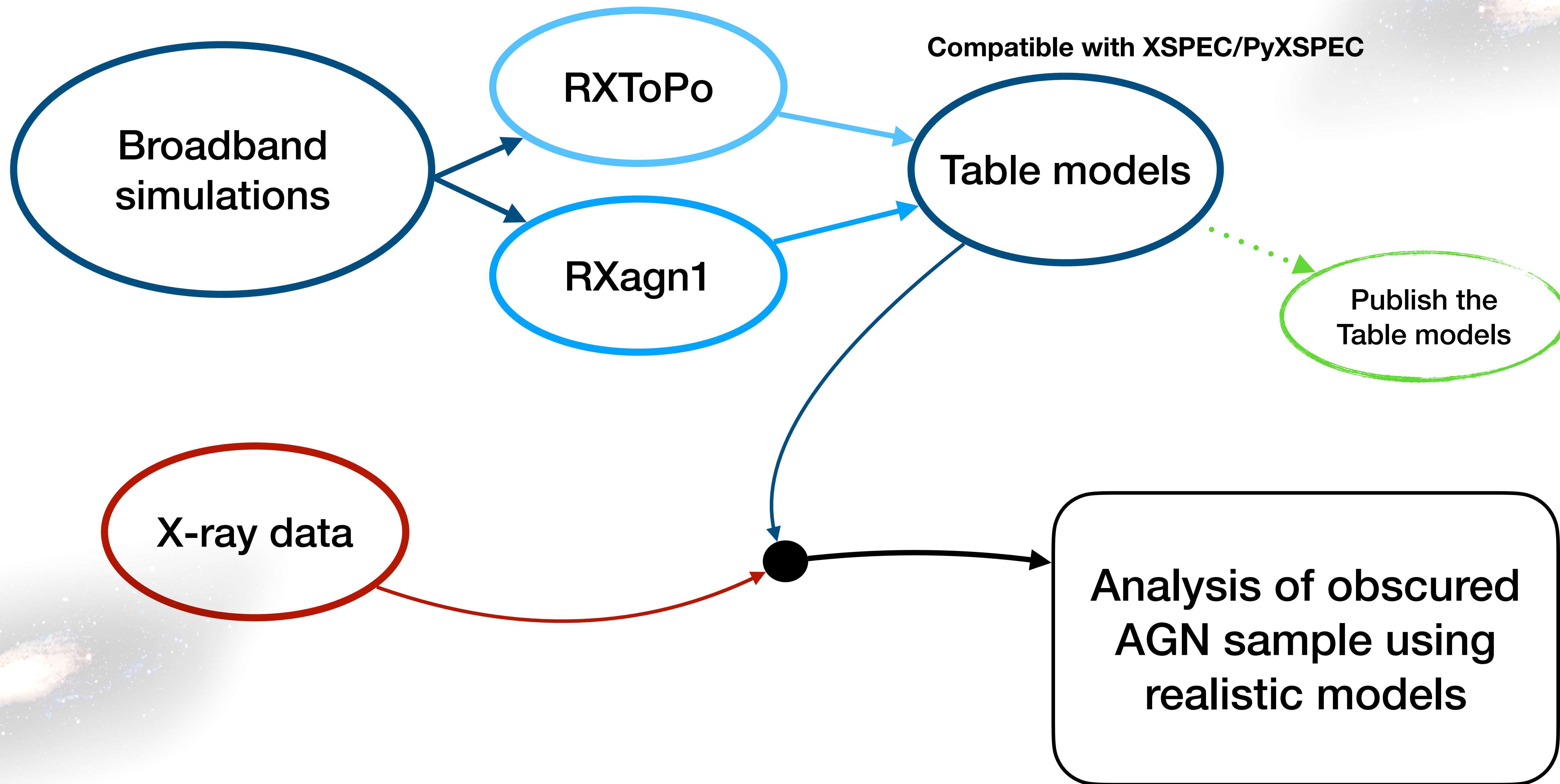


*Ready to use!*



**UNDER  
CONSTRUCTION**







# Thank you for your attention

- **The circumnuclear material shapes the X-ray spectrum**
- **X-ray spectral models focus on simple geometries**
- **We build models featuring more realistic configurations**
- **Two new models for the RX family**
  - **RXToPo**
  - **RXagn1**
- **Apply those models on real data:**
  - **Swift/BAT (BASS) + NuSTAR + Chandra + XMM**



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**RefleX**

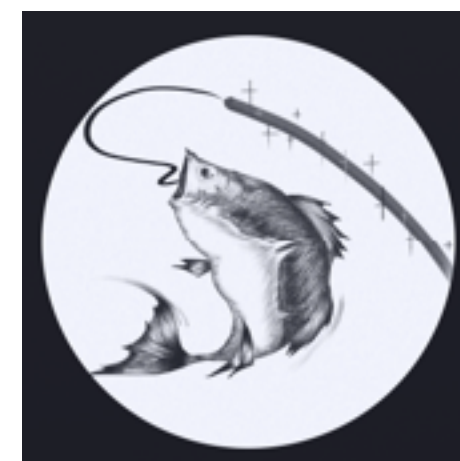
Ray-tracing of X-ray photons  
for arbitrary geometries



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[georgios.dimopoulos@mail.udp.cl](mailto:georgios.dimopoulos@mail.udp.cl)



**BASS**  
The BAT AGN  
Spectroscopic  
Survey



# Thank you for your attention

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RefleX

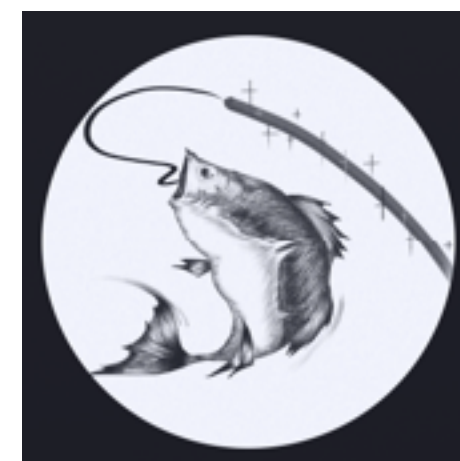
Ray-tracing of X-ray photons  
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**BASS**  
The BAT AGN  
Spectroscopic  
Survey



# Thank you for your attention

- The **city**
- X-ray s
- We bu
- Two ne
  - **RXT**
  - **RXa**
- Apply



**Simulations**



**Real data**

**spectrum**  
**etries**  
**figurations**



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**RefleX**

Ray-tracing of X-ray photons  
for arbitrary geometries



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Spectroscopic  
Survey