Exploring Torus geometries

with

NuSTAR Compton humps

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http://astrost.at/istics/

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Goals

- Test geometries
  - Toroids
  - Clumpy
  - Warped disks
  - Hydro-radiative sims
  - …

Constraints:

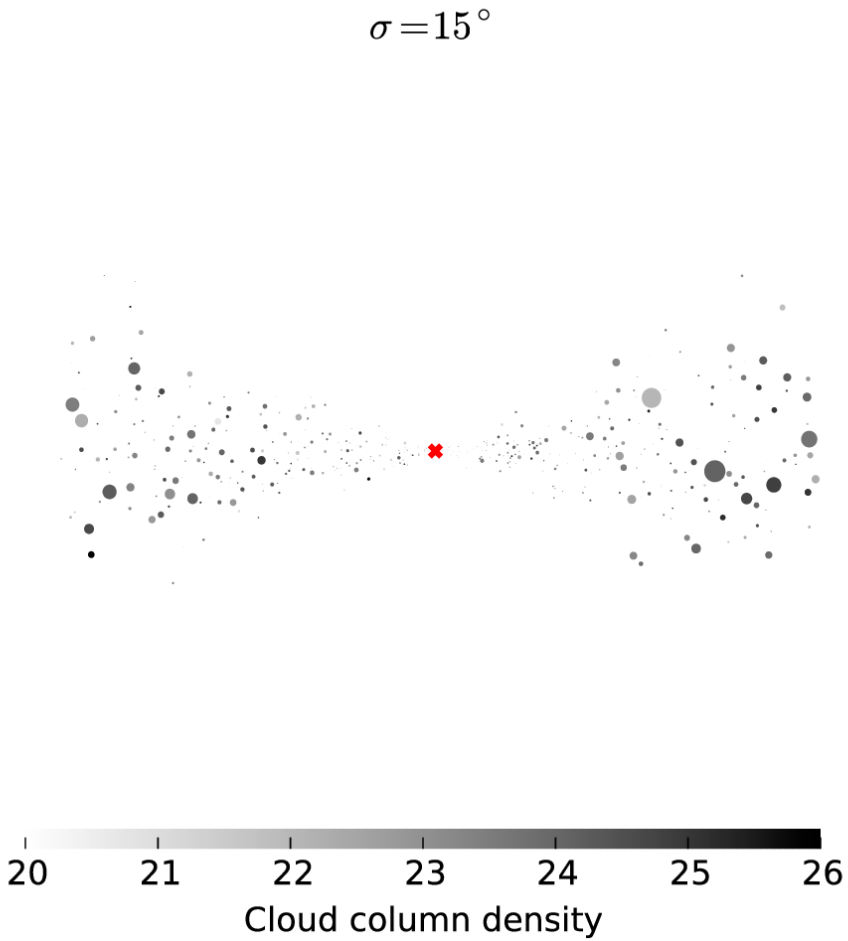
- Spectral diversity
- Unification
- Eclipse events

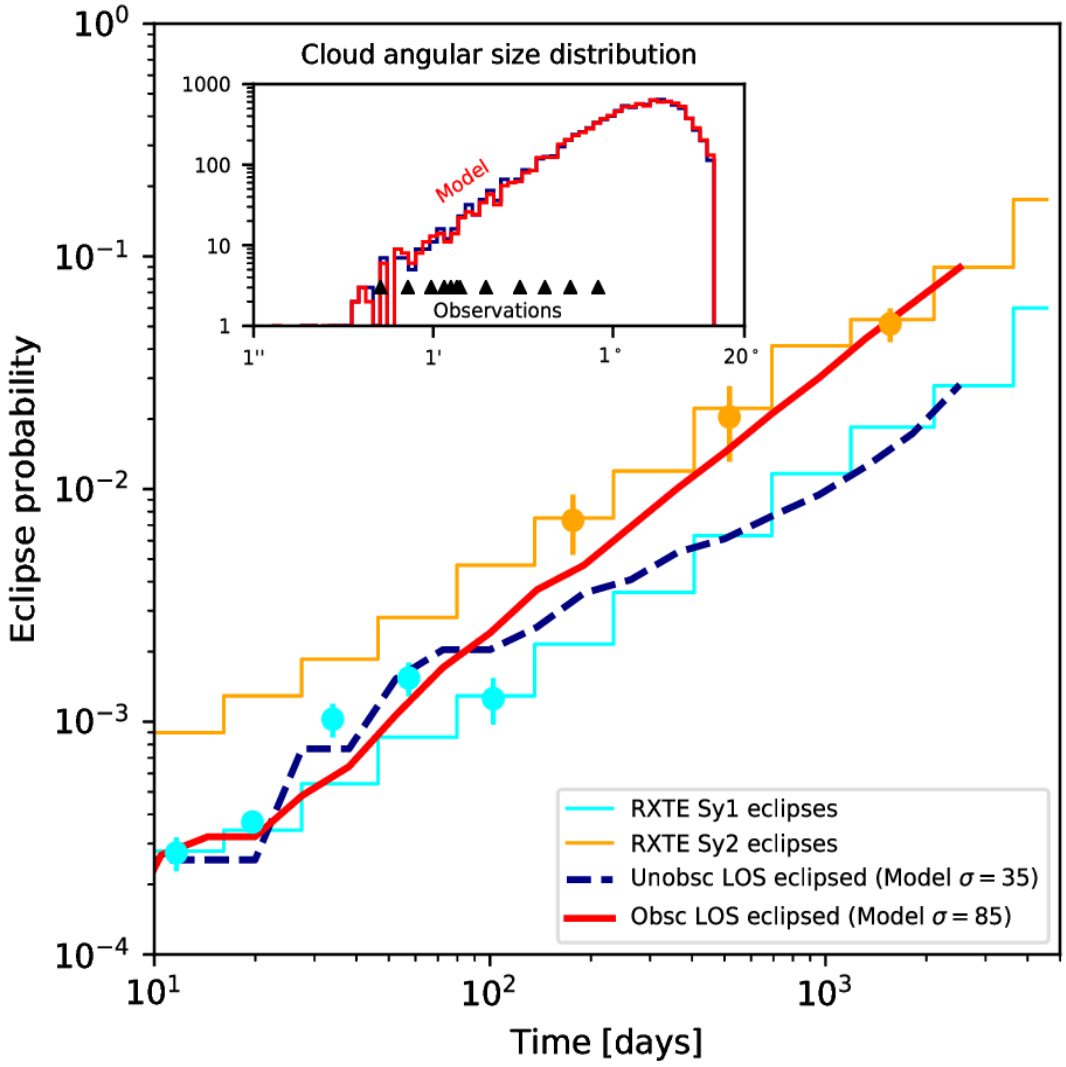
+ ultimately: IR+X

Buchner et al. (submitted)

UXCLUMPY

- Eclipse events (Markowitz+14, Nikutta in prep.)
- Unification





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- Eclipse events
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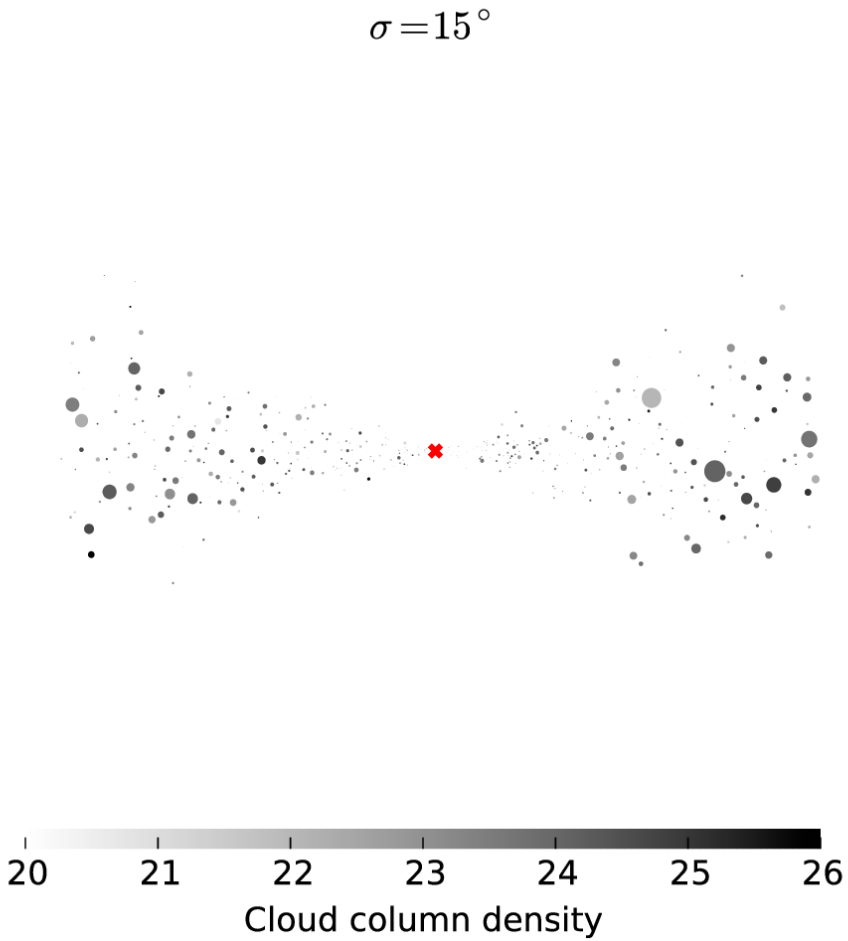
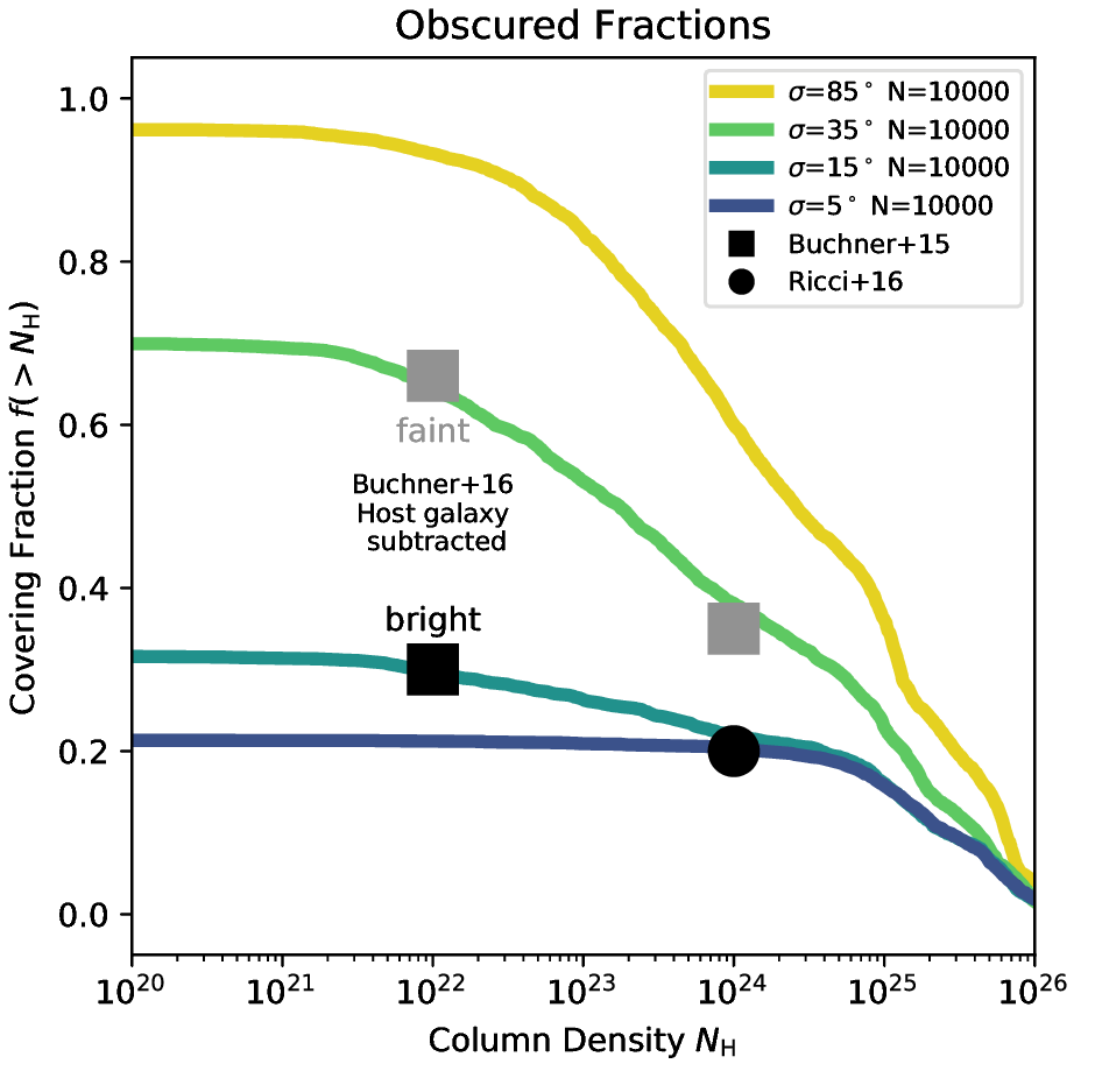


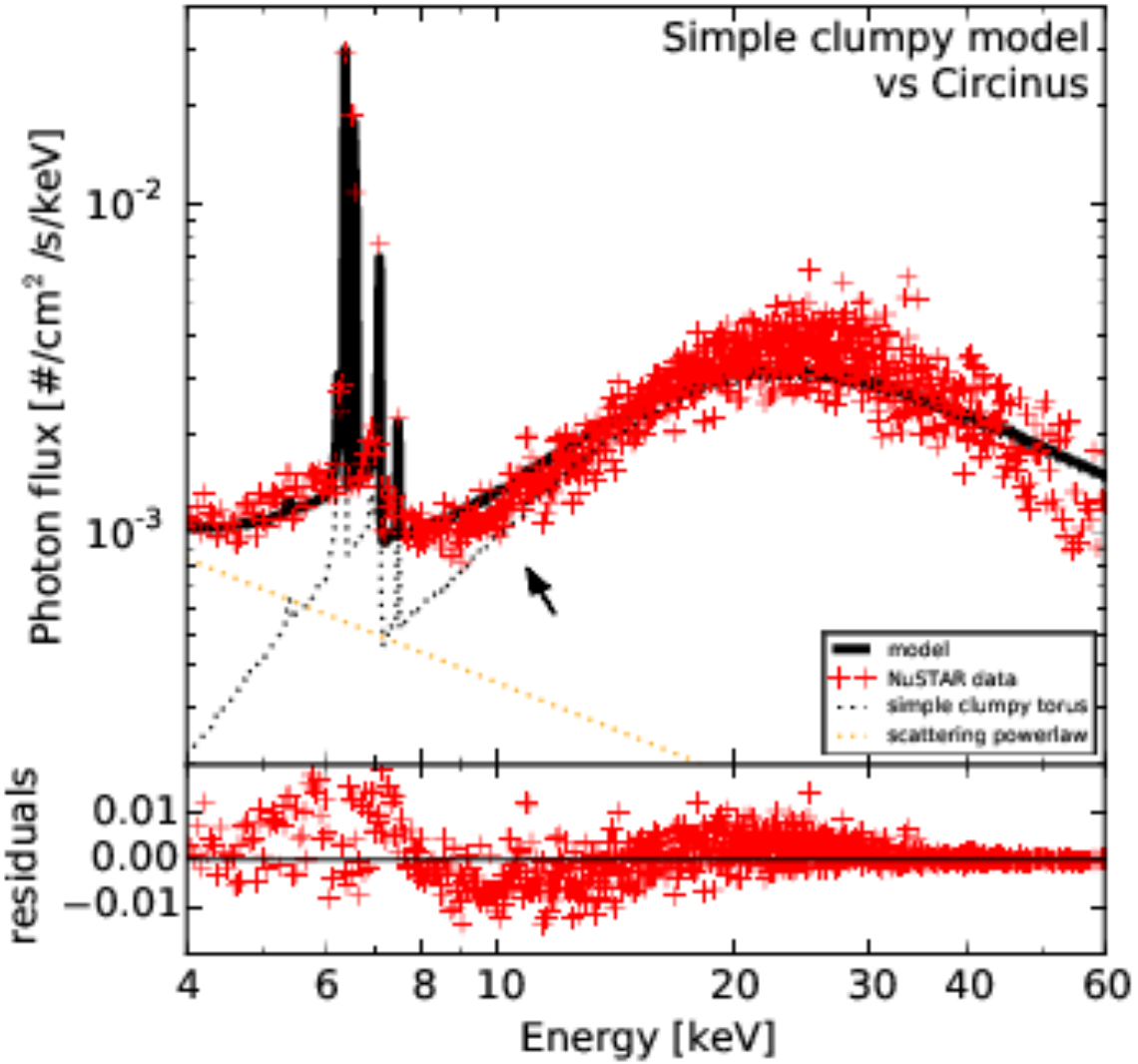


XARS

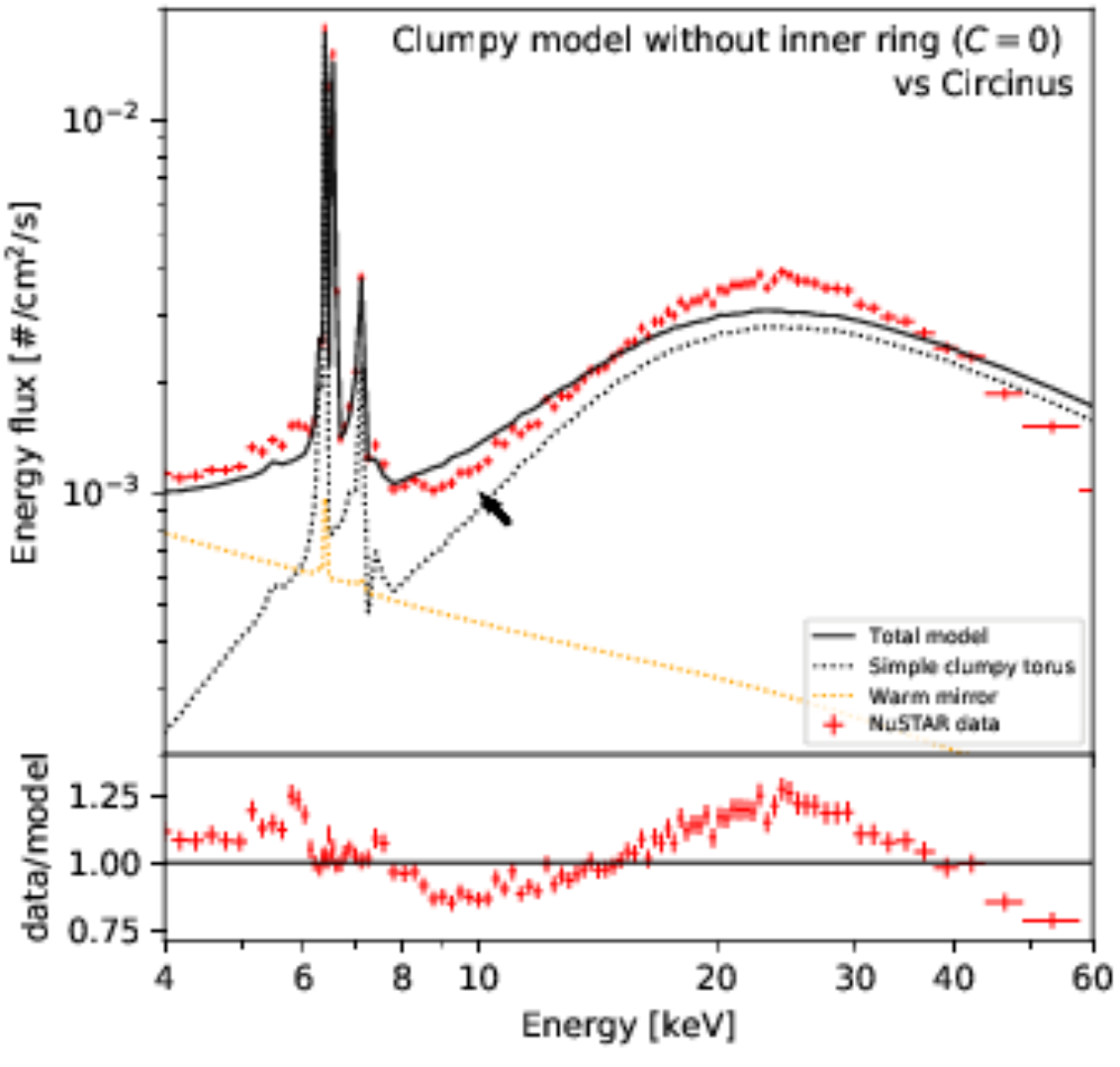
- X-ray Absorption Re-emission Scattering
- Ray-tracing code for X-rays
- Open source, Python
- Arbitrary geometries:
  - Torus, Sphere,
  - Millions of spheres
  - Grids (like from hydrodynamic simulations)

http://github.com/JohannesBuchner/xars

The problem


Simple clumpy model
vs Circinus
Photon flux [#/cm² /s/keV]
10⁻²
10⁻³
model
NuSTAR data
simple clumpy torus
scattering powerlaw
residuals
0.01
0.00
−0.01
4
6
8
10
20
30
40
60
Energy [keV]

The problem



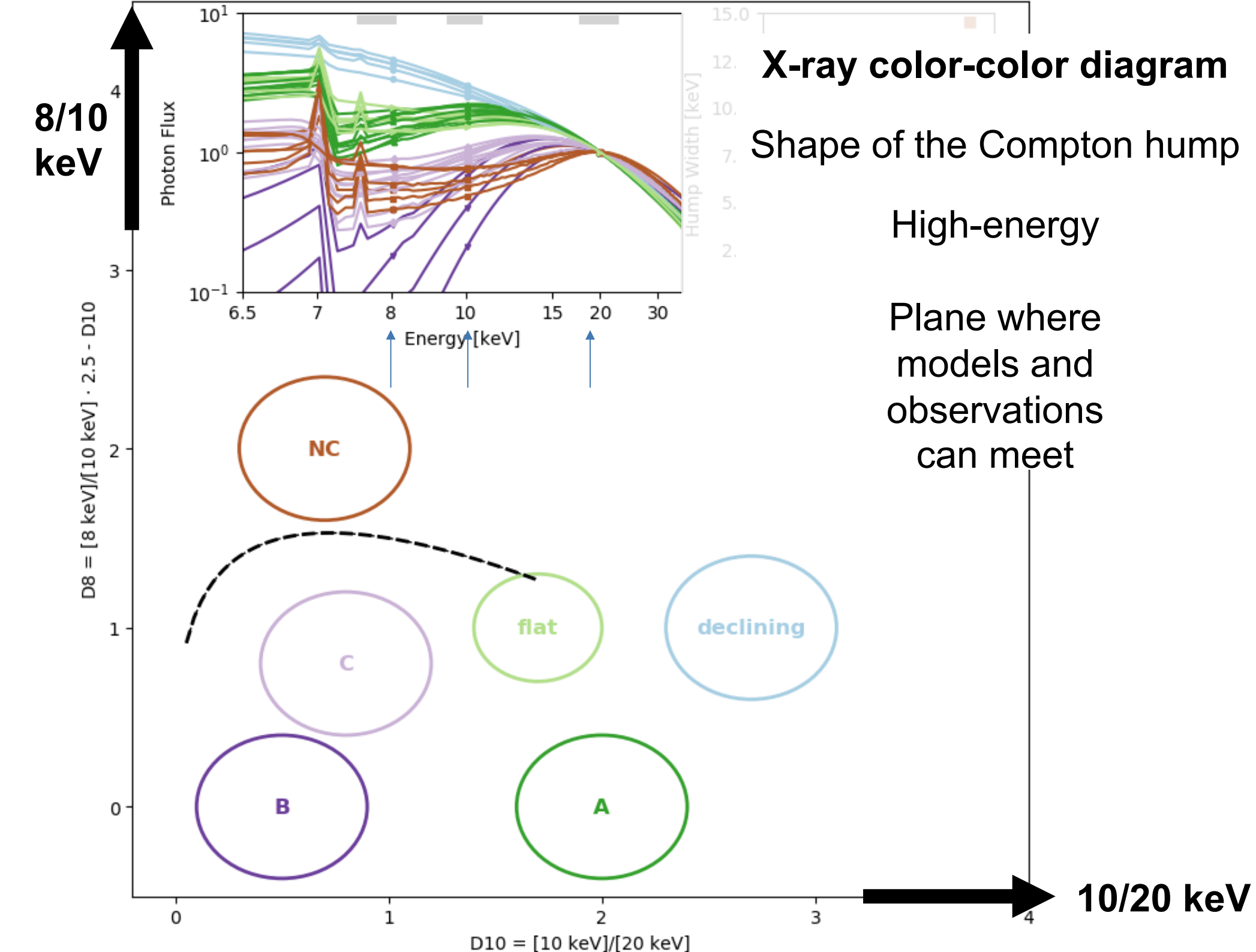
(nuclear contamination already modelled out)

Circinus

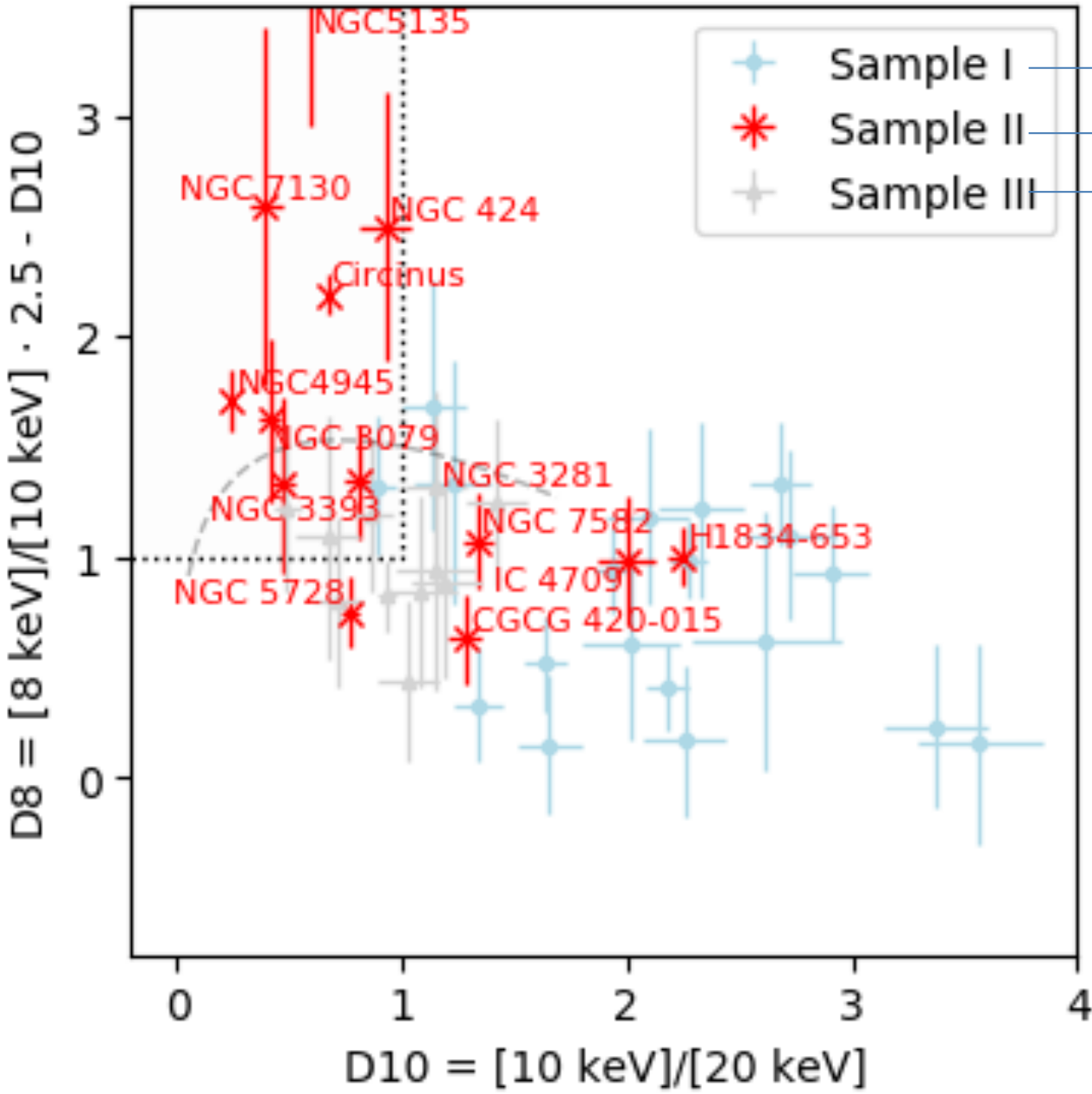
- Has a weird shape,
  explained with complex models
- Physics is simple at >8keV

- Geometry models don’t fit
- so there is constraining power here!
- Search for geometries matching the data

- Simplify problem: 3 flux measurements


X-ray color-color diagram
Shape of the Compton hump
High-energy
Plane where models and observations can meet
8/10 keV
10/20 keV
Photon Flux
Energy [keV]
Hump Width [keV]
D8 = [8 keV]/[10 keV] · 2.5 - D10
D10 = [10 keV]/[20 keV]
NC
C
flat
declining
B
A

NuSTAR Observations

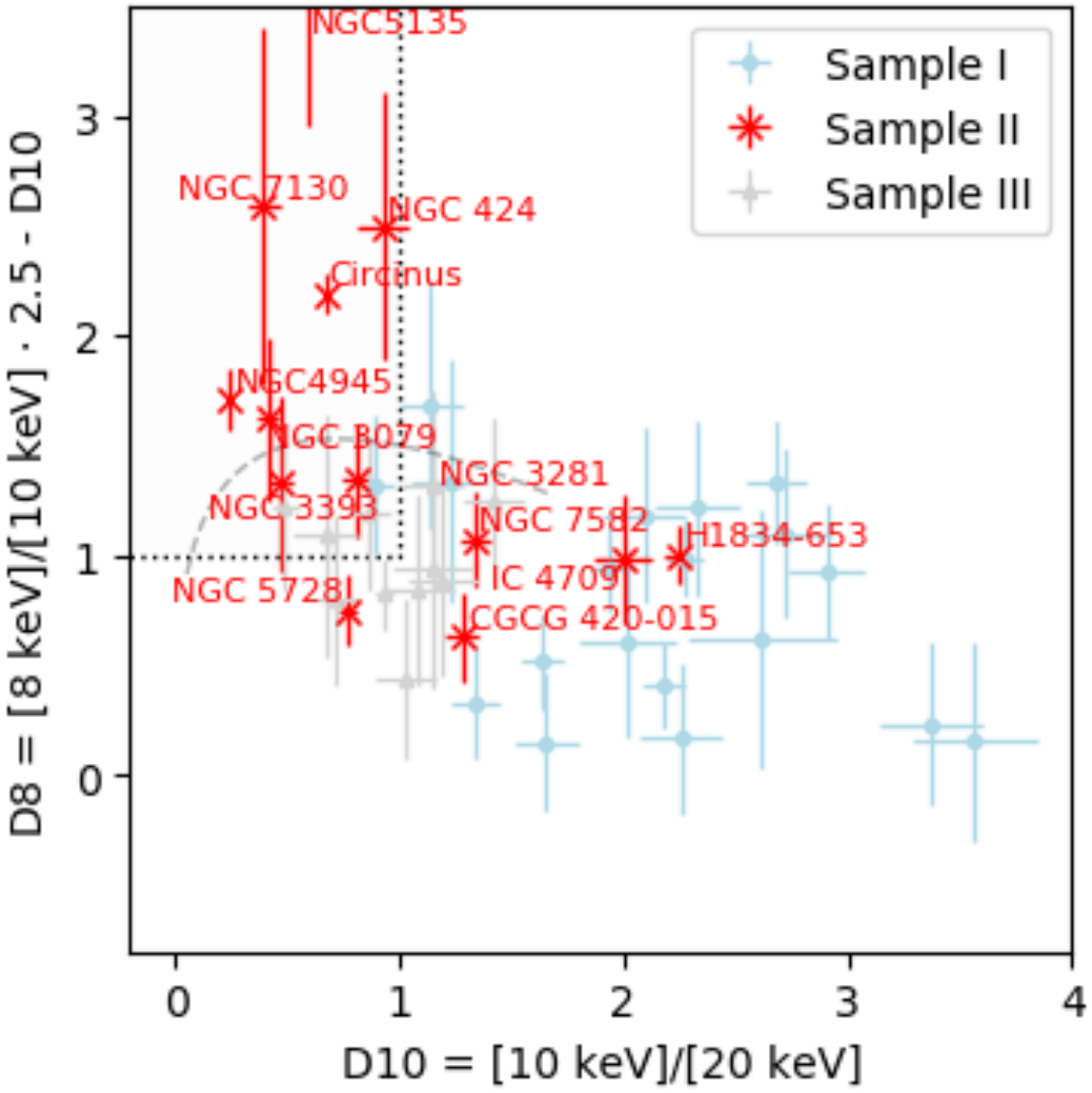


Below X-MIR correlation

Some interesting sources

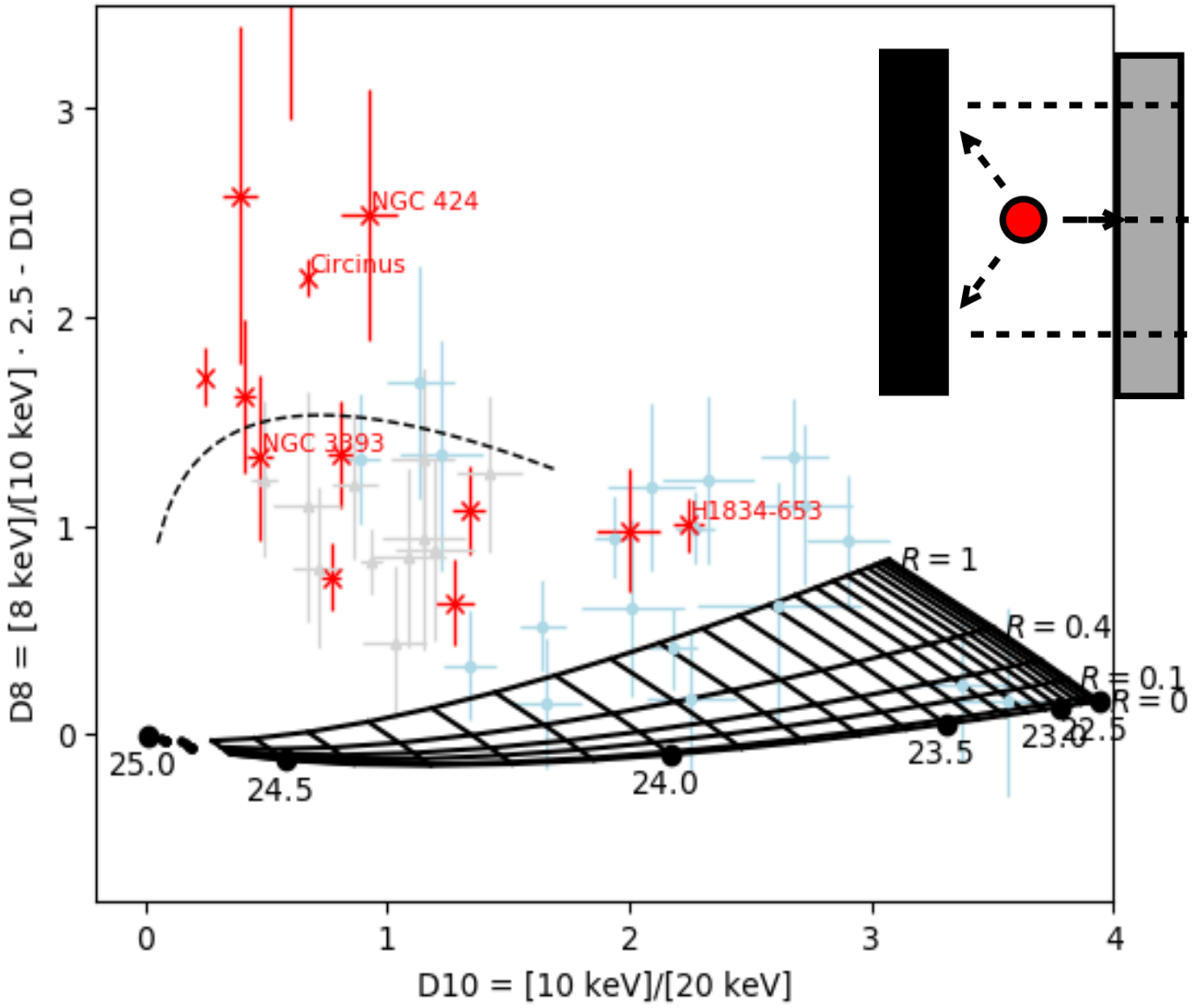
Compton-thick candidates from previous studies (Swift/BAT sample, Balokovic et al., in prep.)

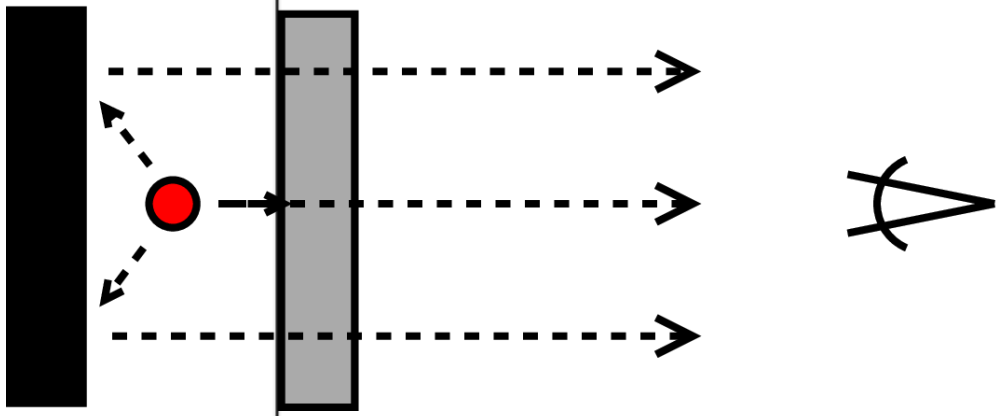
What is the point?



- Can we find a model geometry for each? 3pts!
- Can a single geometry explain most? (Unification)
- Any model space not used by nature?
- Quick way to check new models
- Model-independent characterisation of sources

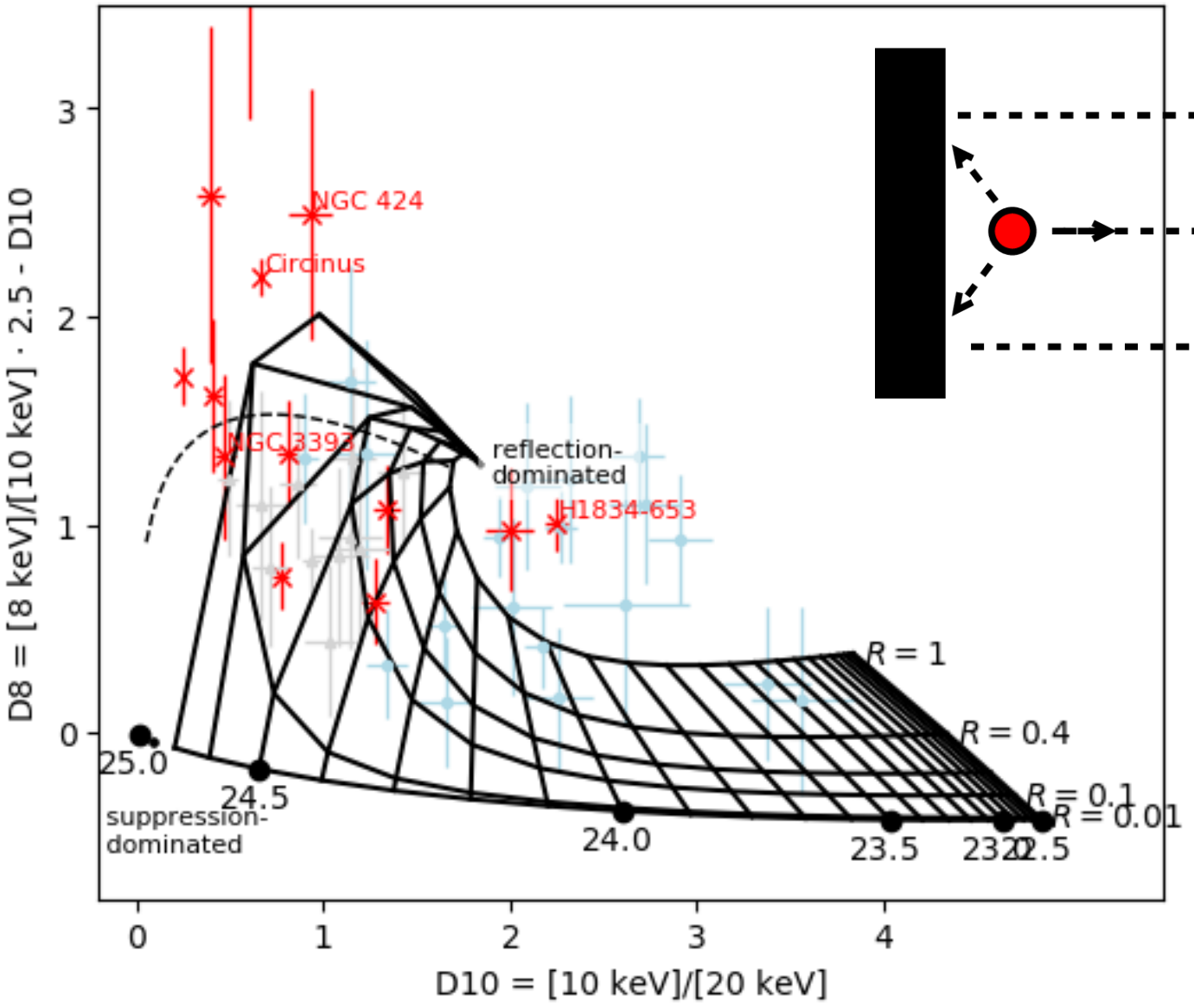
Absorbed system

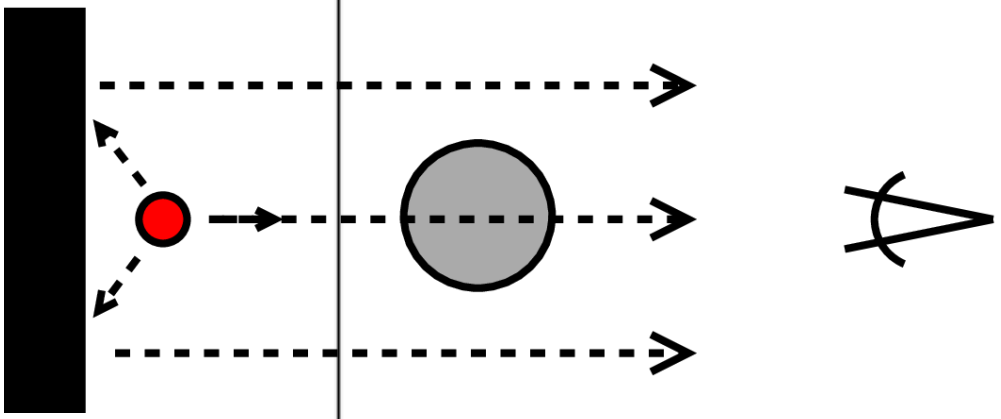




- Lessons learned:
- No 4pi obscured sources?

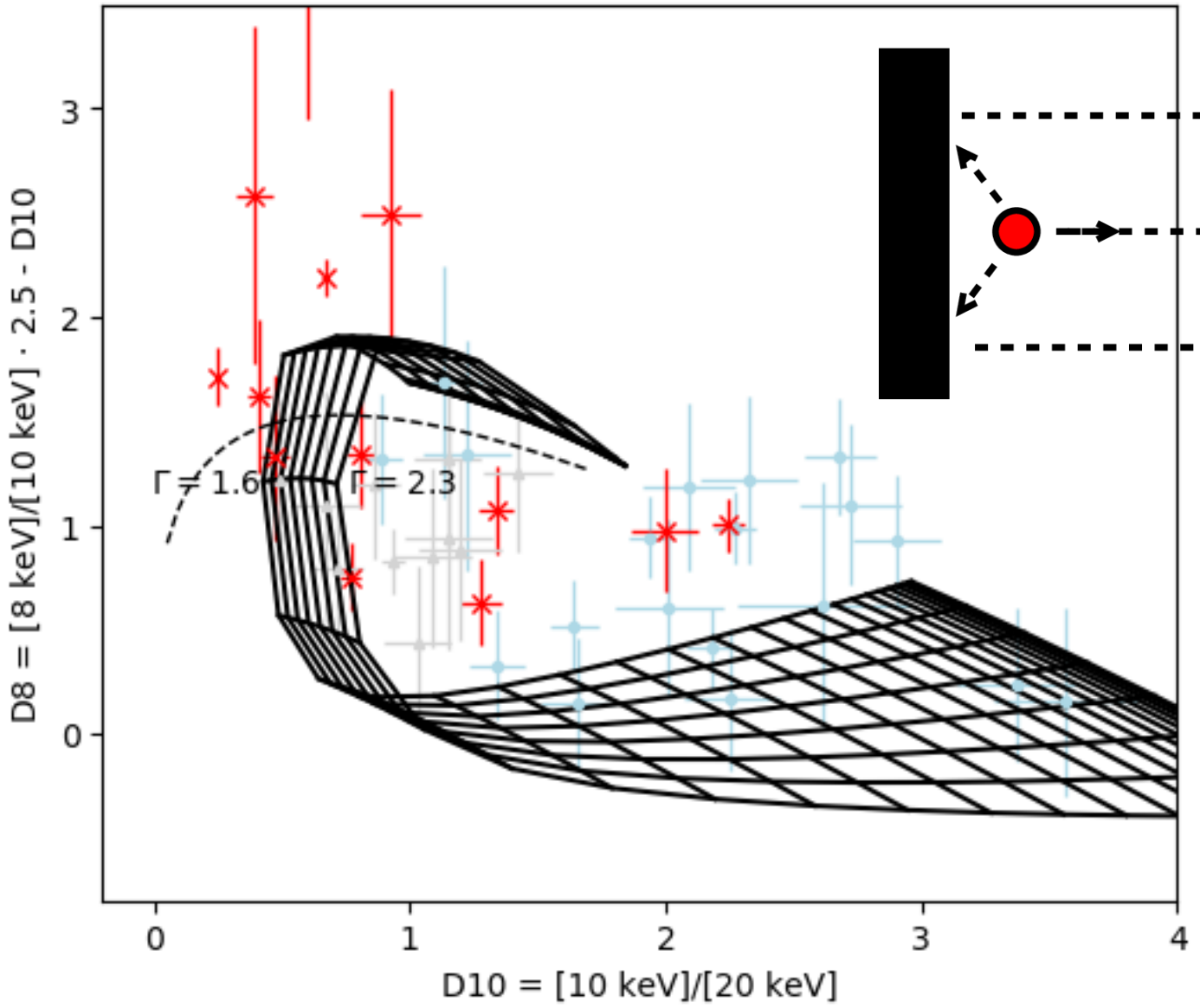
Unobstructed view to cold mirror

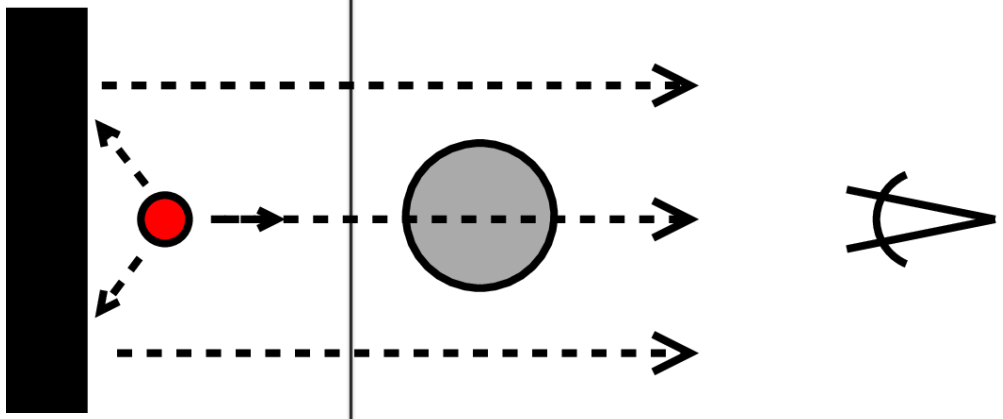




- Lessons learned:
- Reflection dominated sources
- Fair overlap

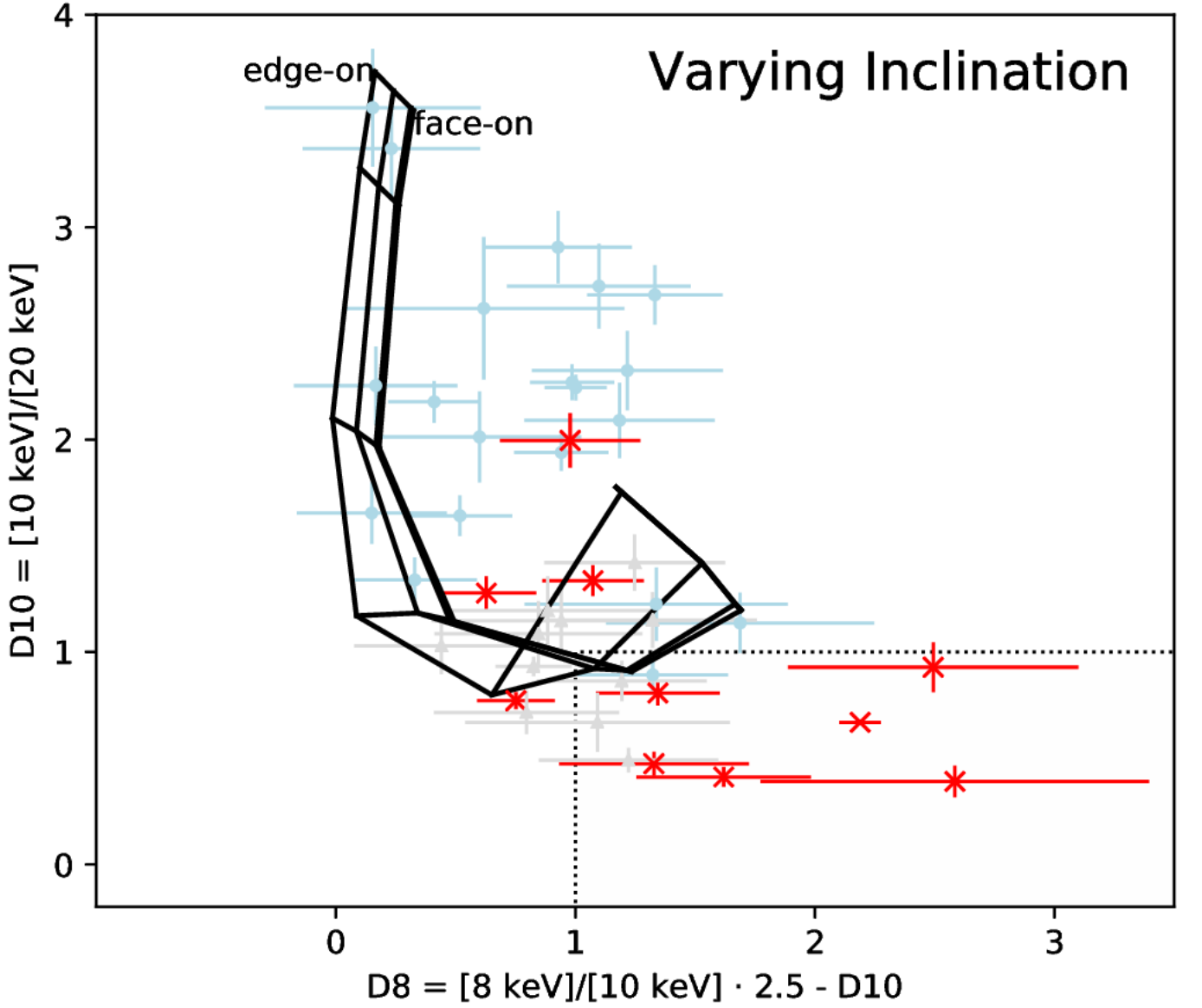
Impact of Photon Index

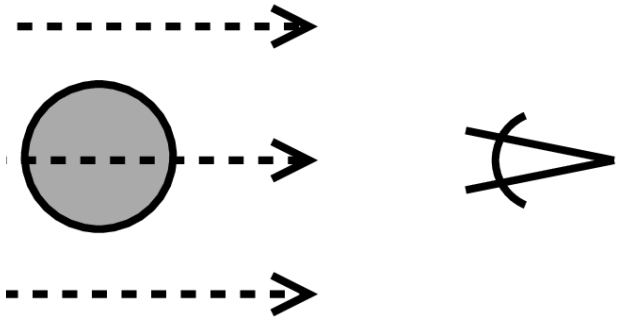




- Lessons learned:
- Small impact

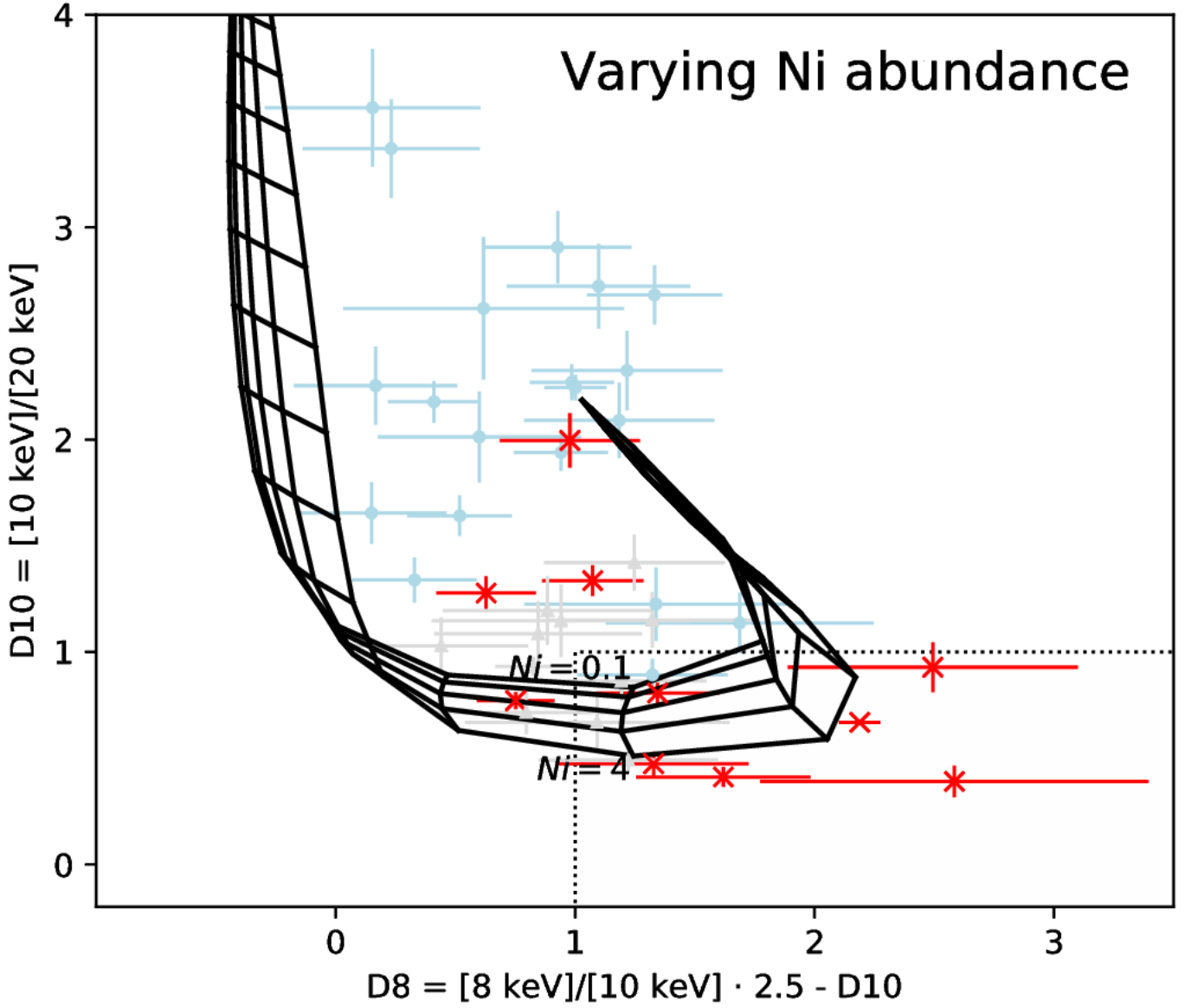
Impact of Inclination

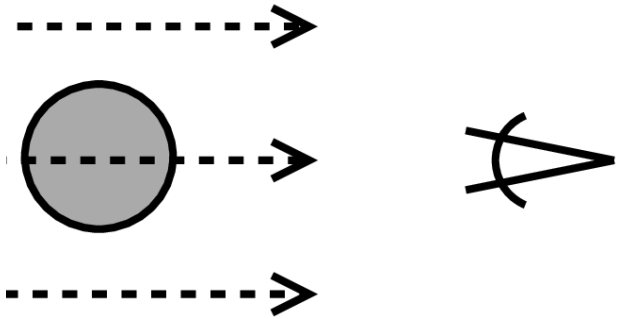




- Lessons learned:
- Small impact

Impact of Ni/Fe ratio

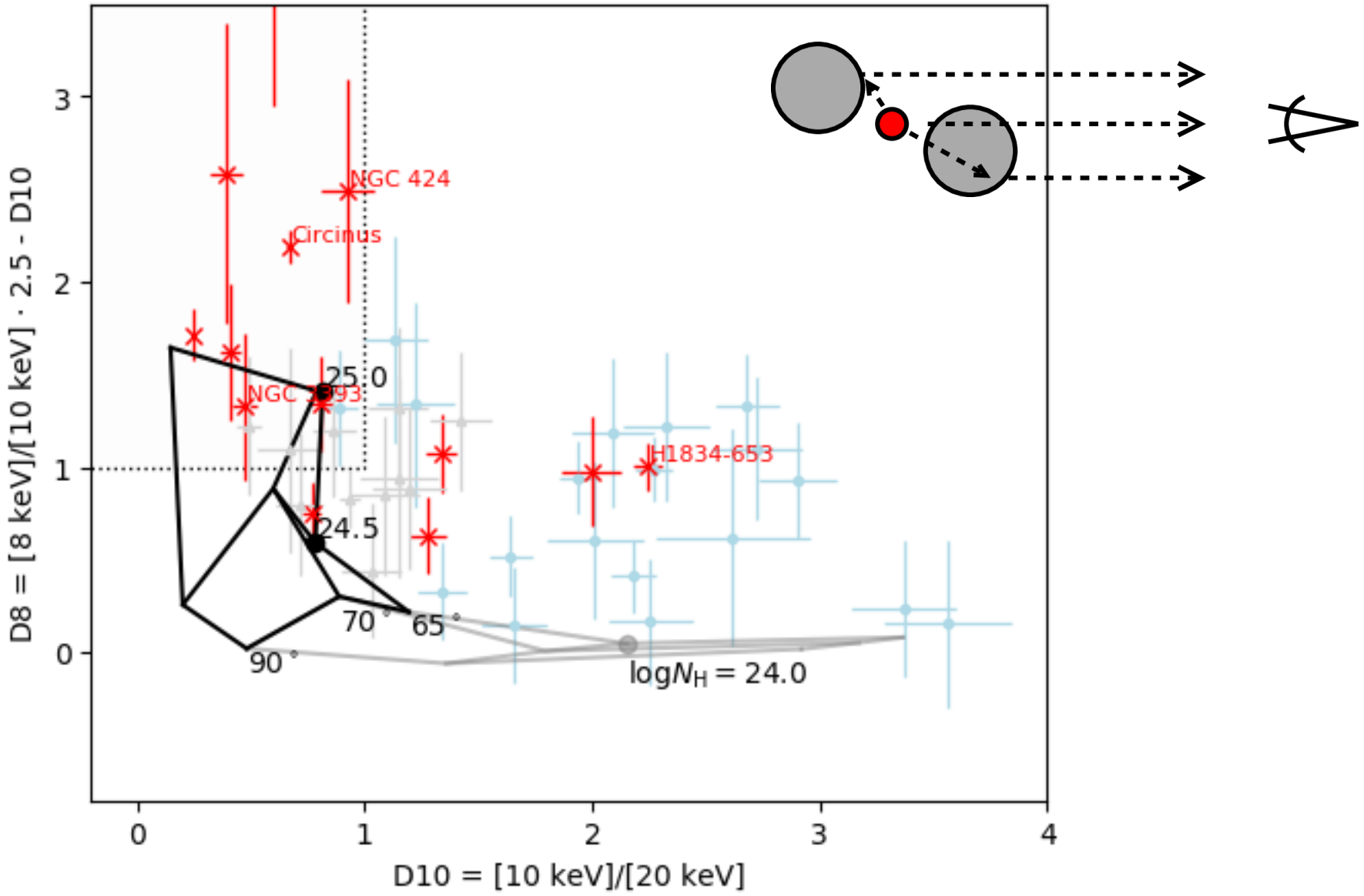




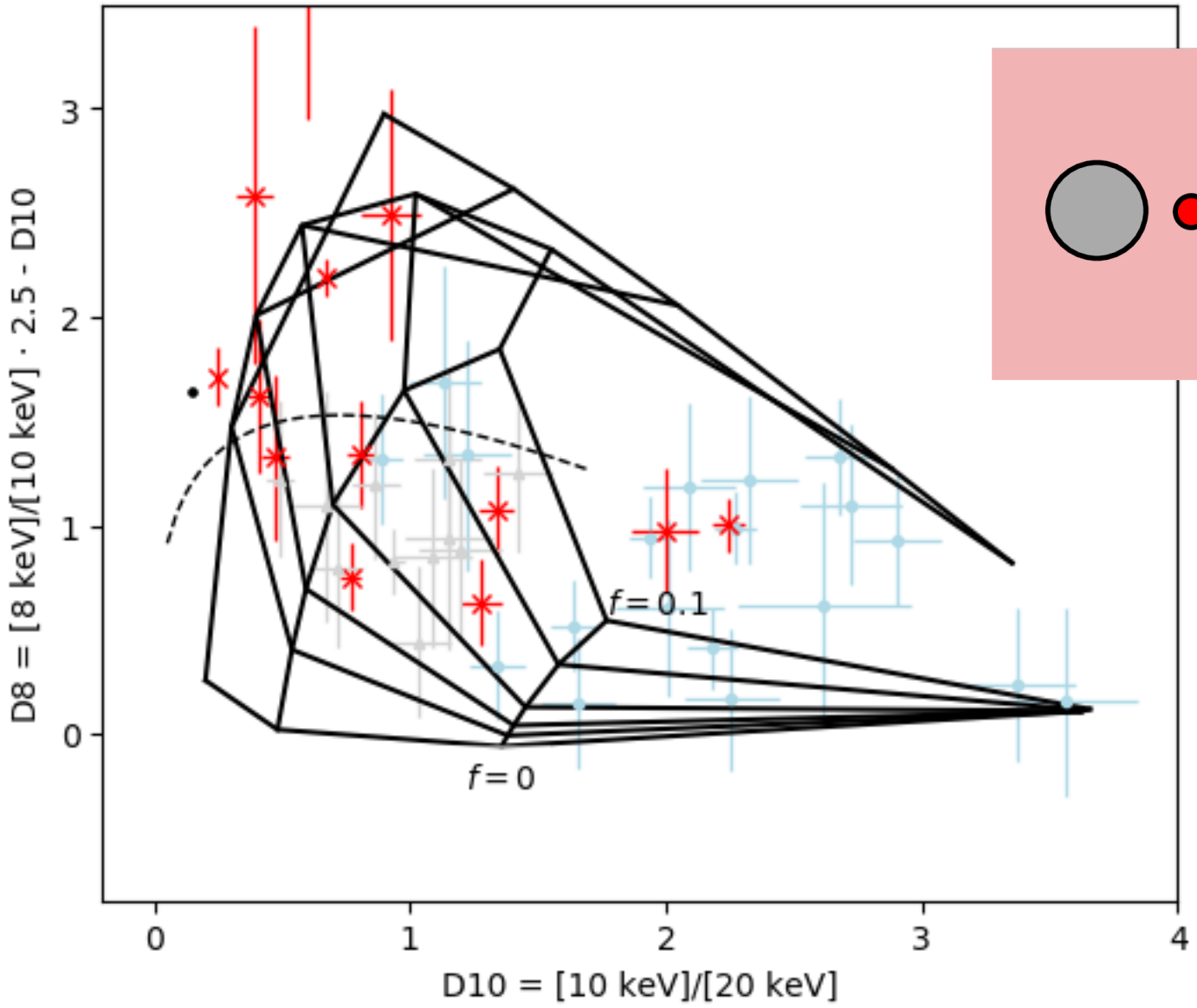
- Lessons learned:
- Small impact

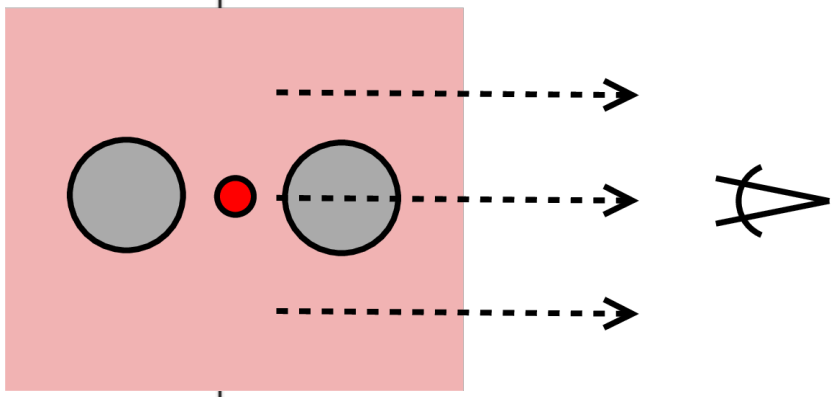
Smooth torus

Murphy & Yaqoob (2009)



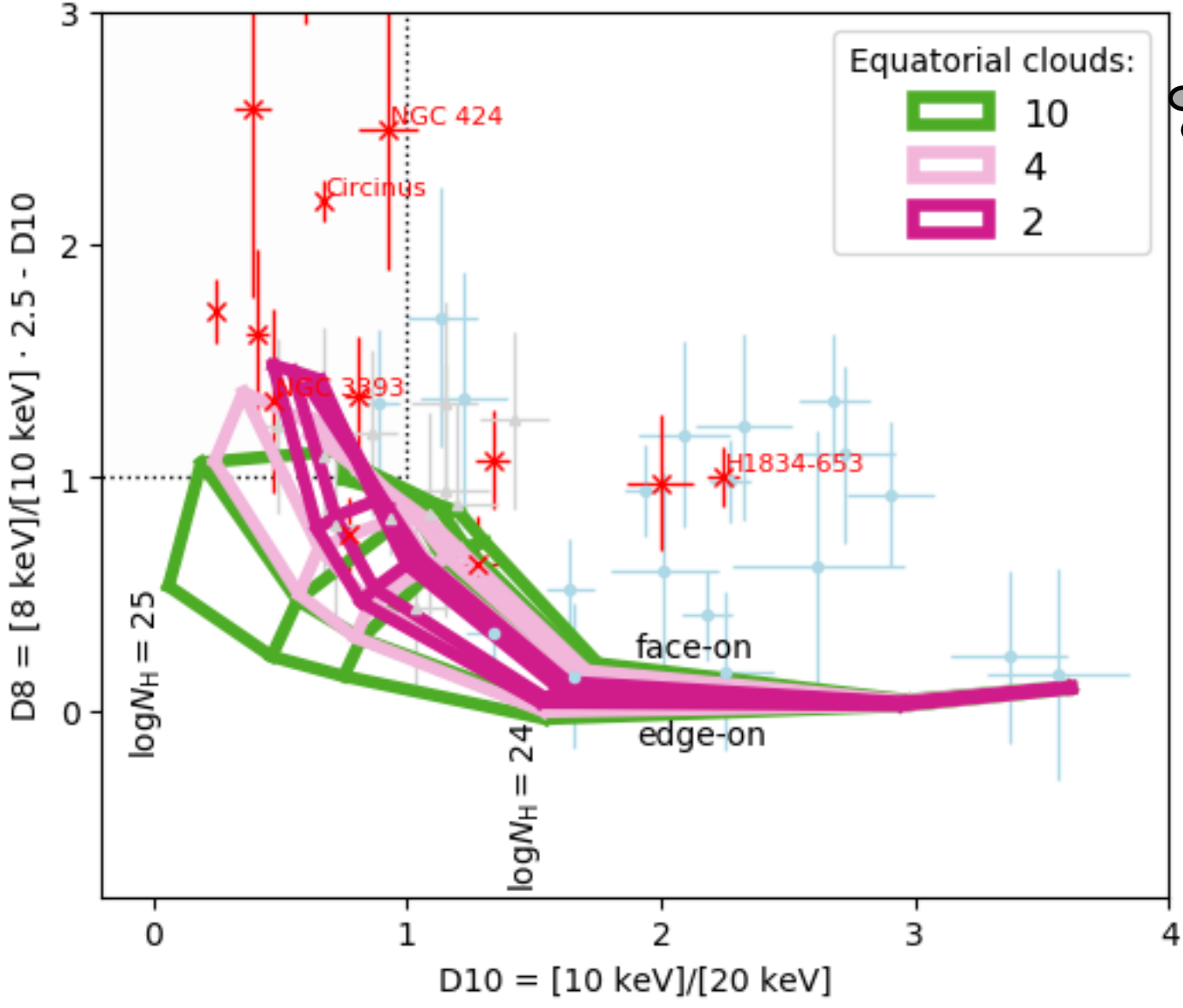
Smooth torus + warm mirror

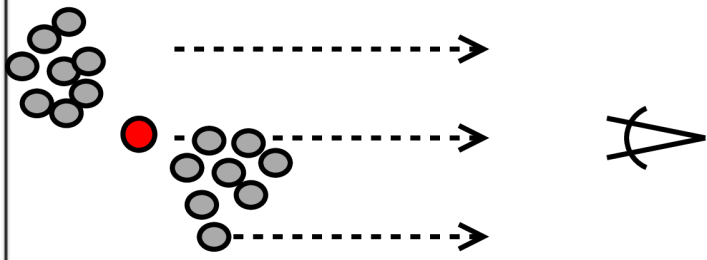




Clumpy torus

Liu&Li (2014)

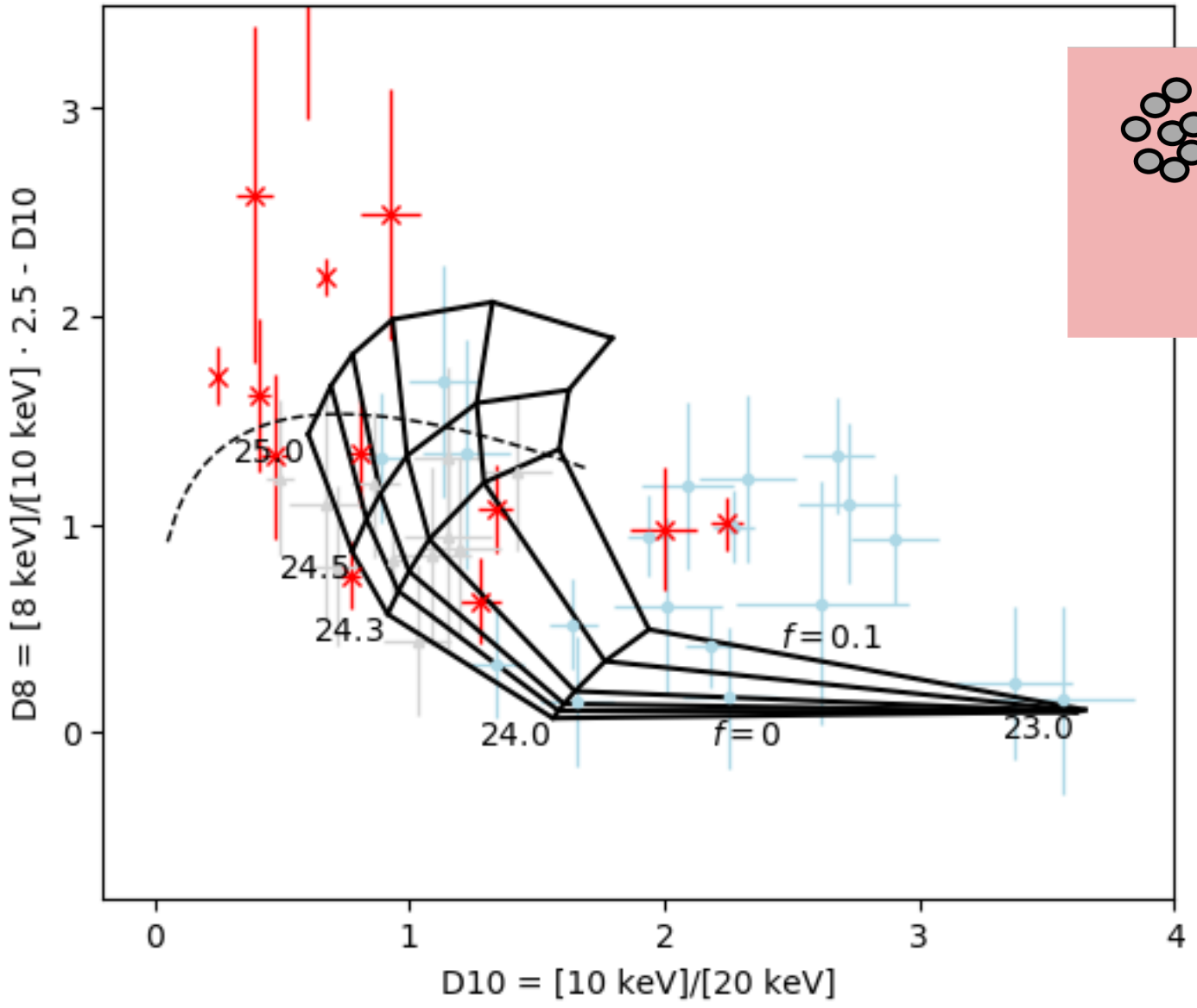


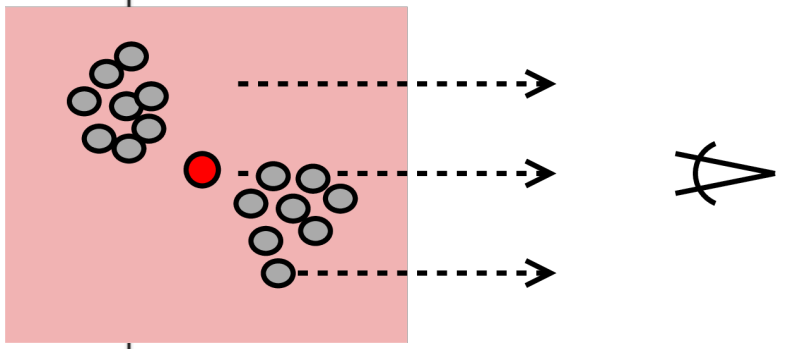


- Lessons learned:
- Low number of clouds preferred
- $\log N_H > 25$ reflectors needed (!)

Clumpy torus

Liu&Li (2014)

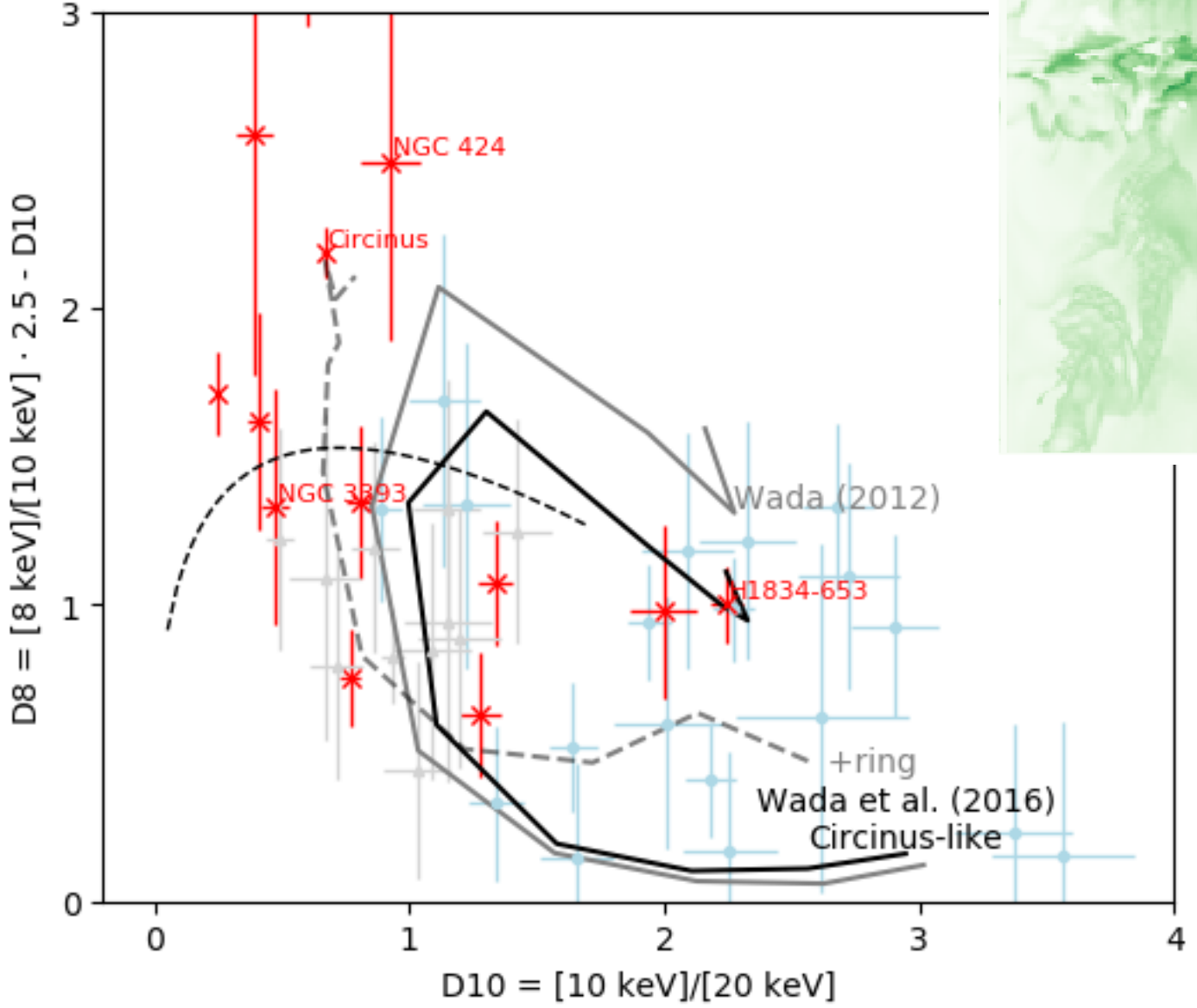


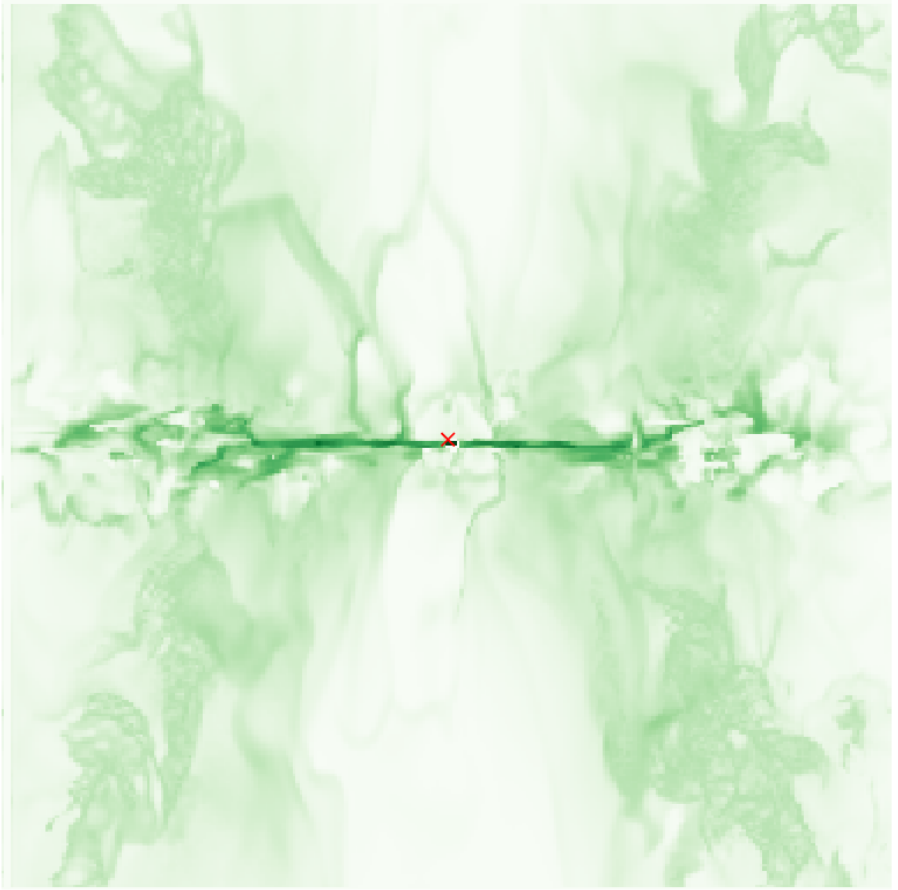


- Lessons learned:
- Low number of clouds preferred
- $\log N_H$>25 reflectors needed (!)

Radiative fountain

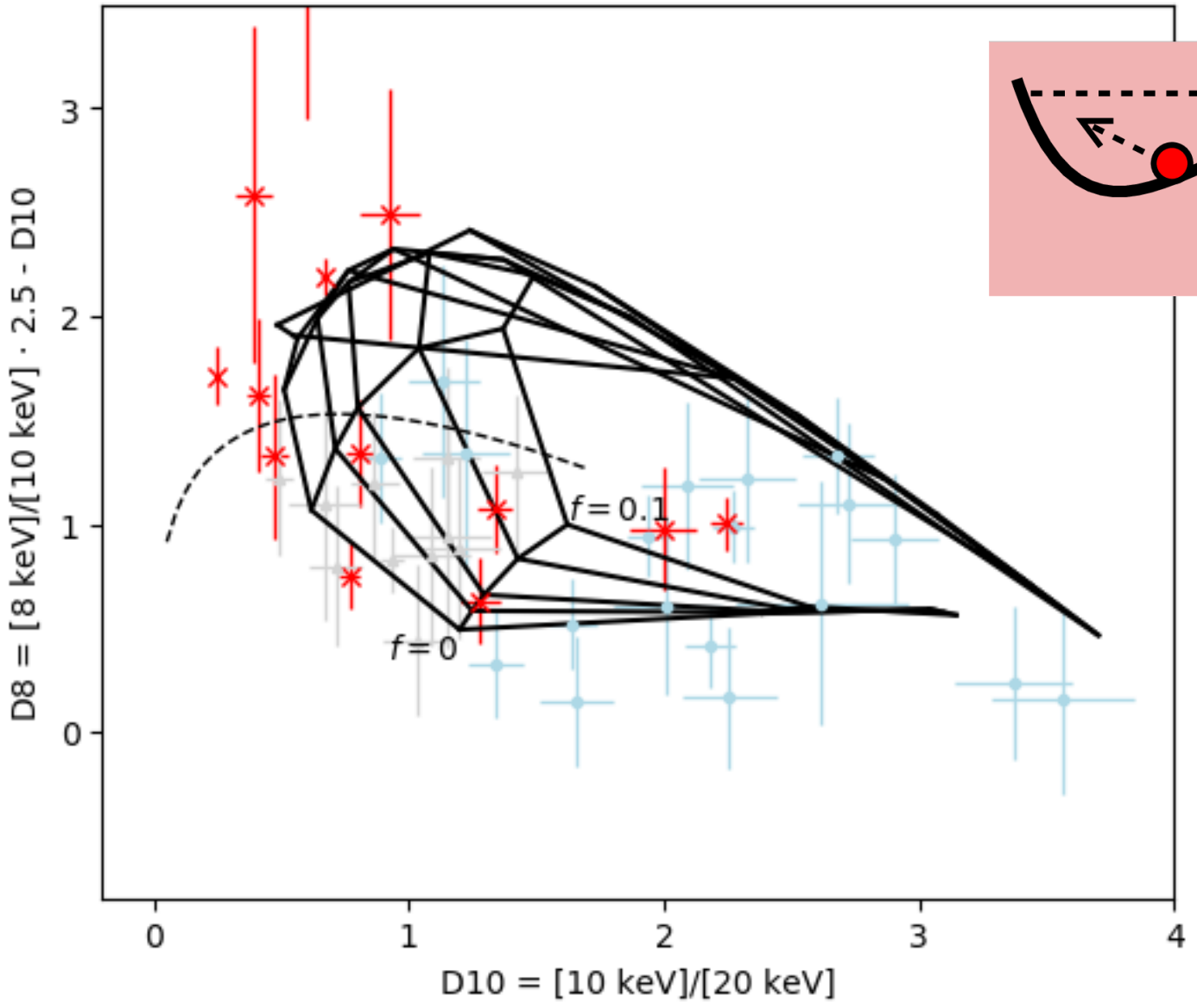
Wada12, Wada+15

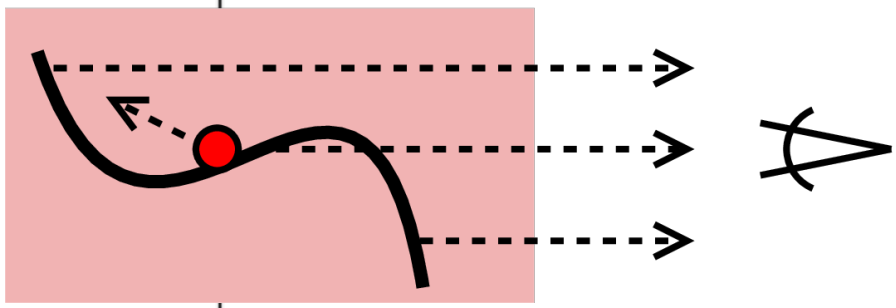




- Lessons learned:
- Physically motivated
- Polar Compton-thin gas contaminates

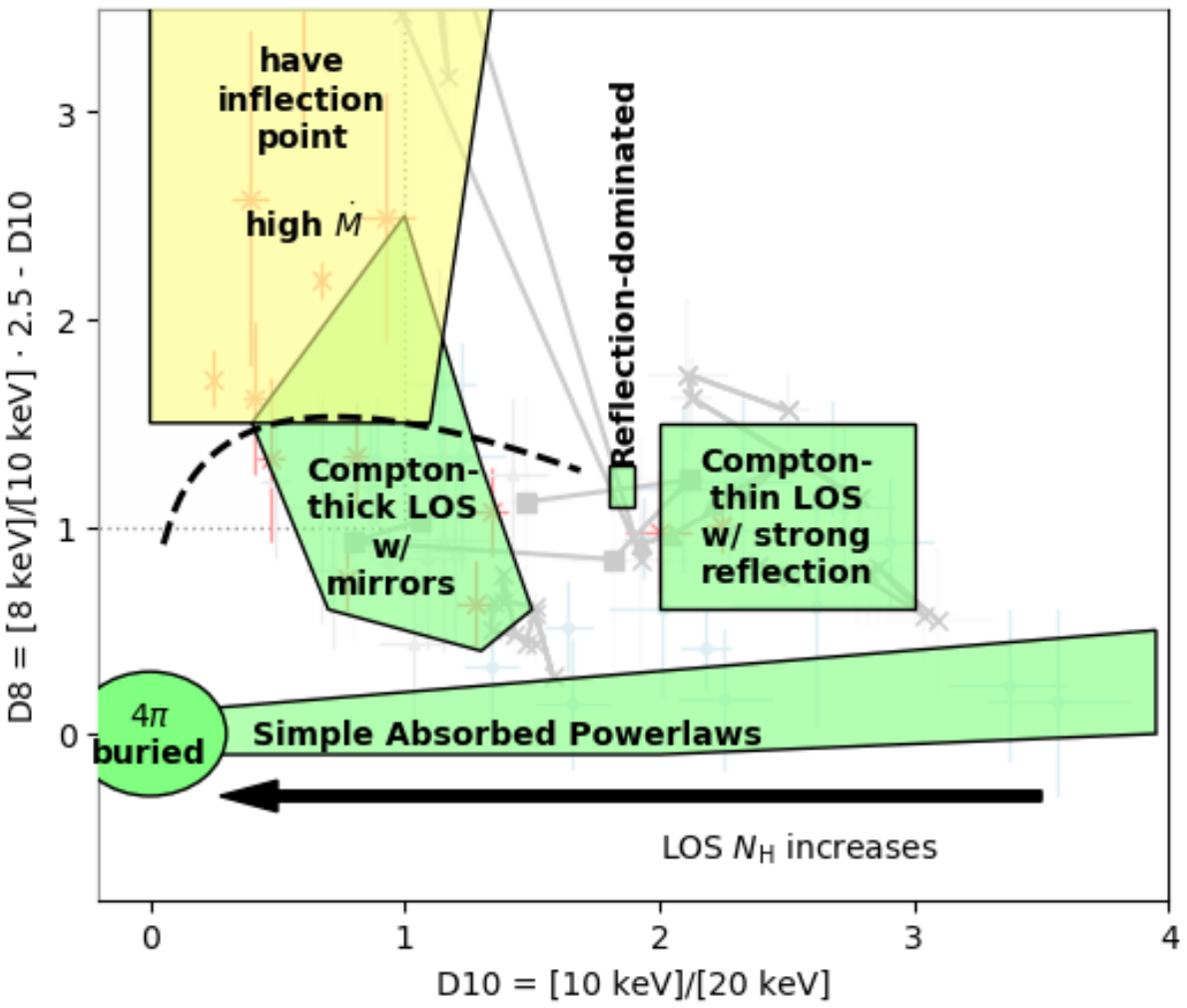
Warped disk + warm mirror





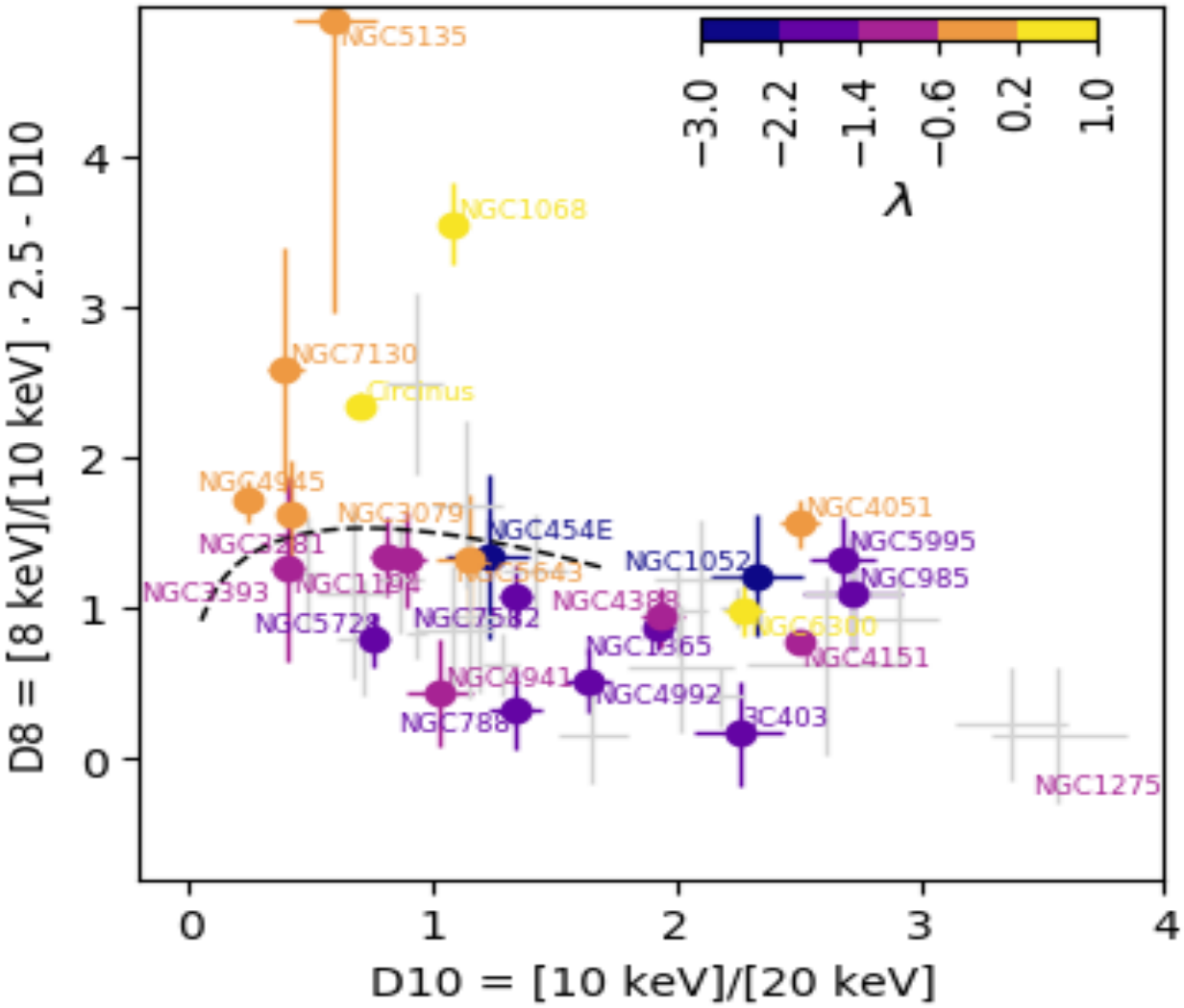
- Lessons learned:
- Reproduces left outline
- Physically motivated
- Best spectral fit to Circinus

Properties of the diagram



- Hard X-ray color-color diagram
- Observations:
  - Mission-independent
  - Model-independent classification
- Geometries:
  - Quick check if covers observations
  - Need more models at top left

Eddington rate

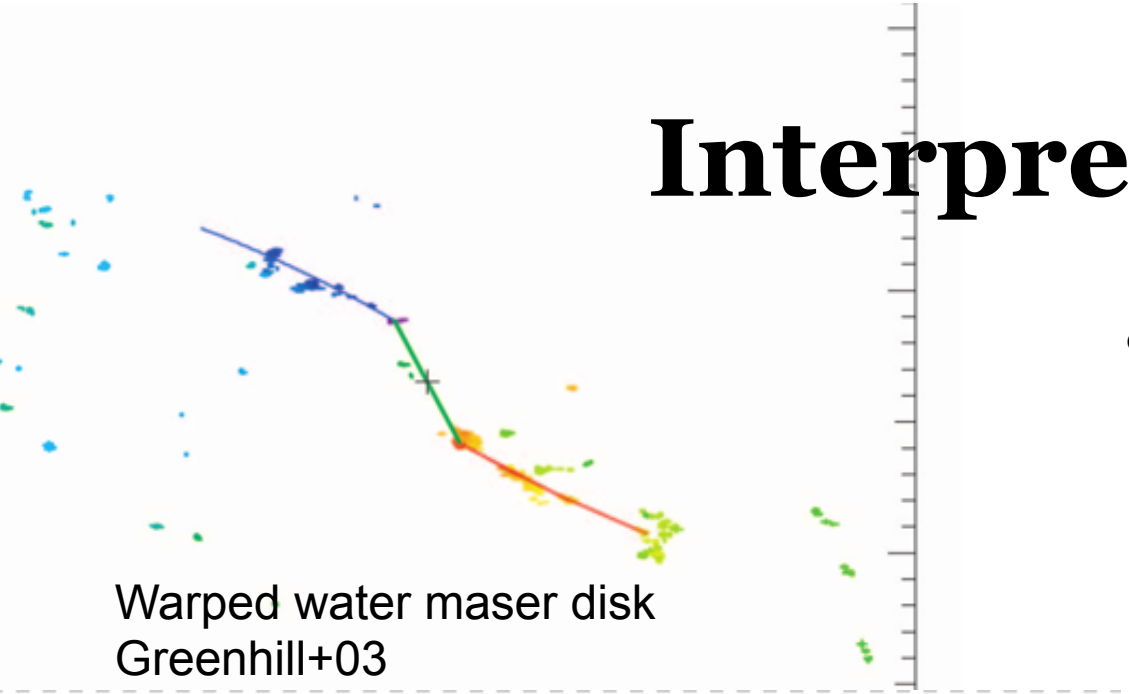


- Rapid accretors
- <-> inflection point
- Something happens at $\sim 25\% \dot{M}/\dot{M}_{\rm Edd}$

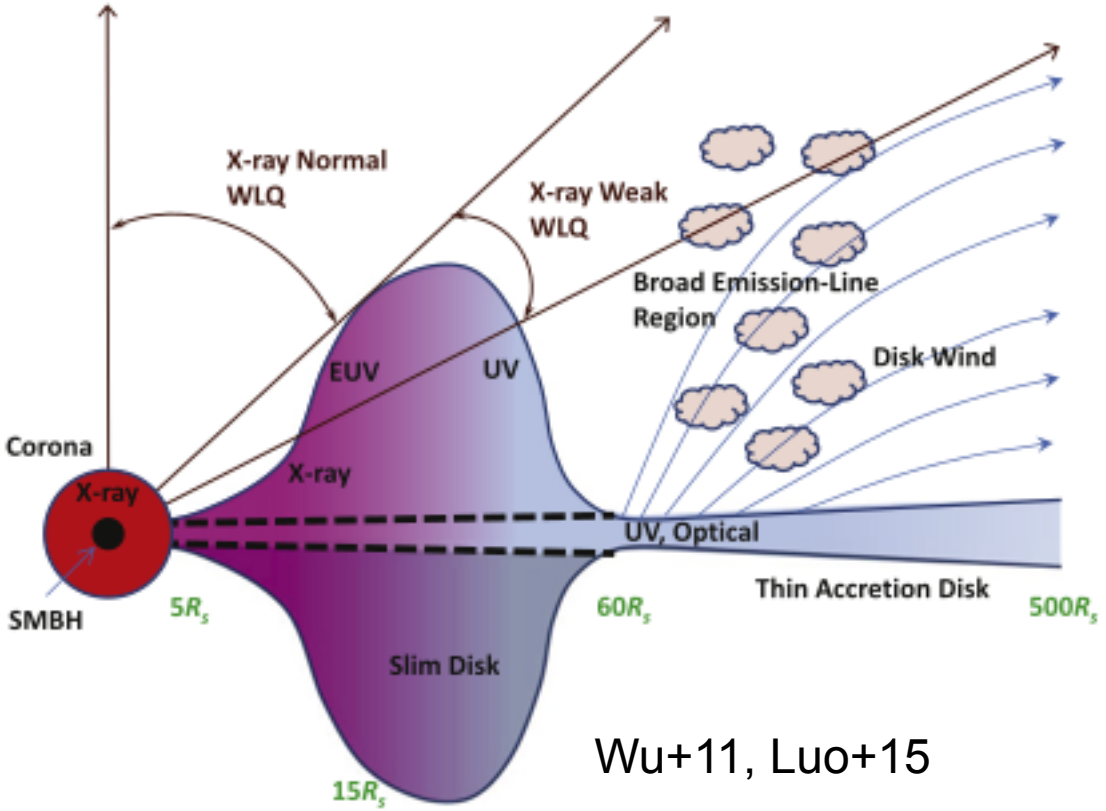
Side-note: changing-look sources

BHM: Gao+15, Koss+15, Bian&Gu07, Beckmann+09 | Lbol: VLT/VLTI 12μm Asmus+15

Interpretation

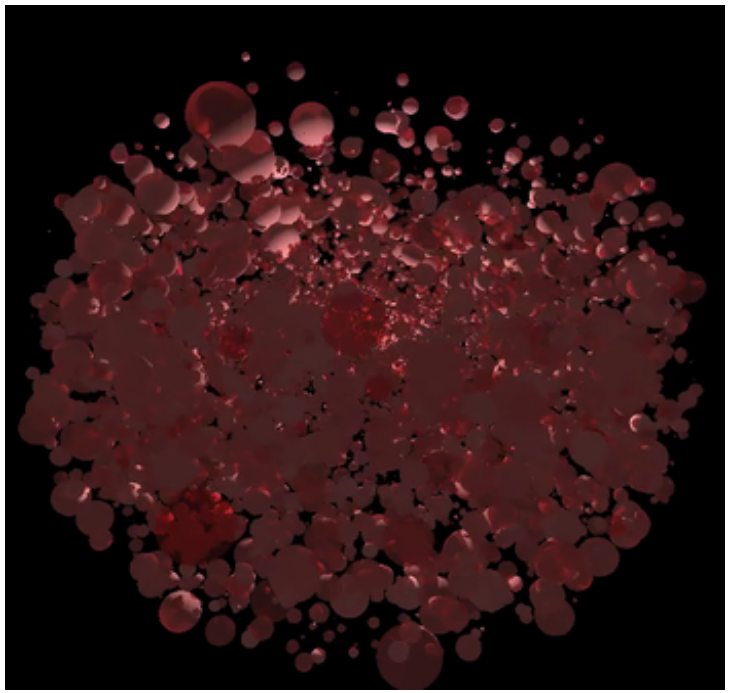


Warped water maser disk
Greenhill+03

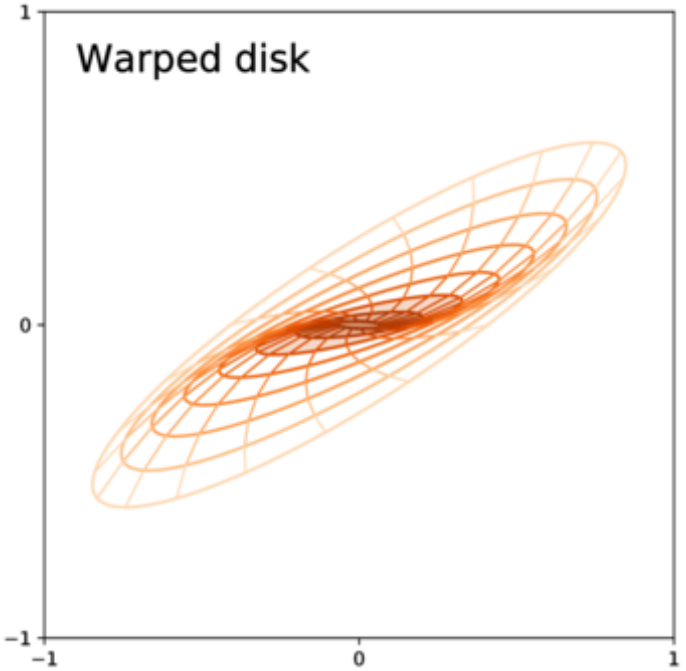


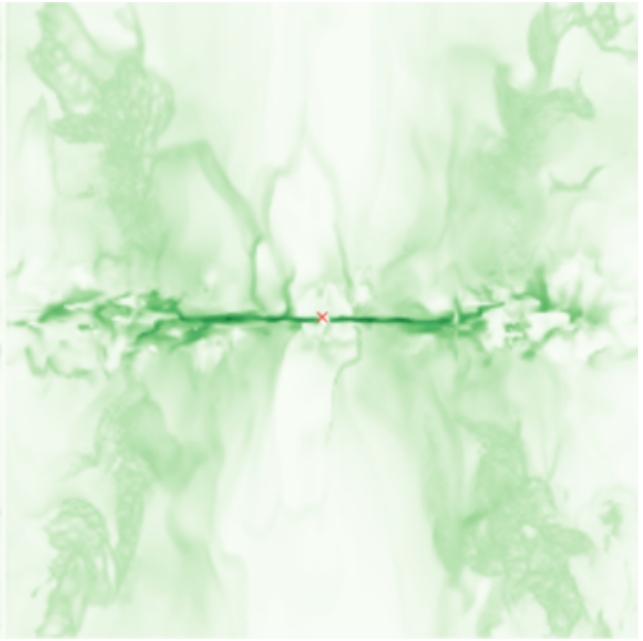
Wu+11, Luo+15

- Seeing a reflector
  - $\log N_H > 25$
  - With large area
  - Unobscured to our LOS
  - When accretion is rapid
- Geometries:
  - Warped disk?
  - Puffed-up/Slim disk?
  - Shielding gas?



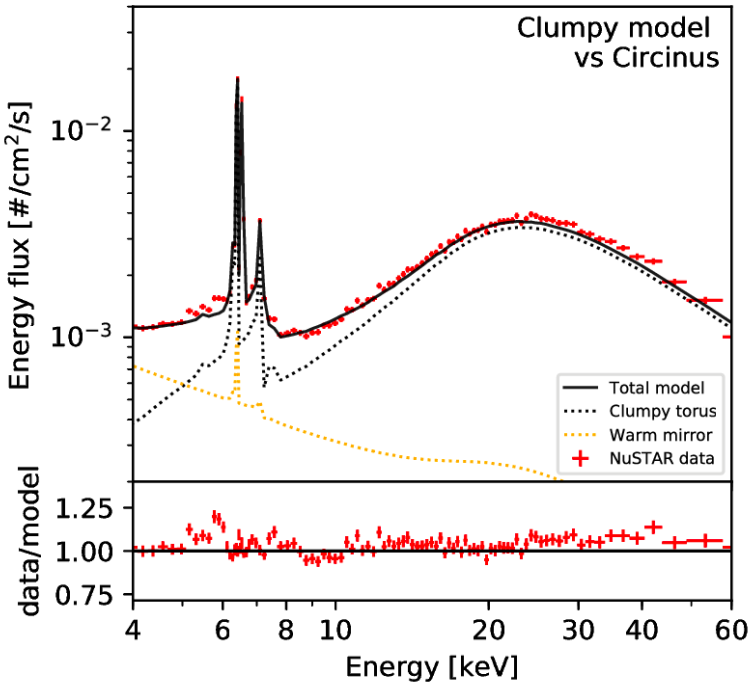
UXCLUMPY





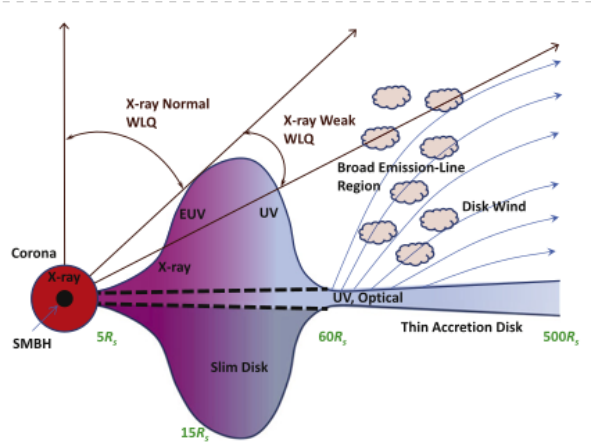
Radiative fountain

Outcomes



UXCLUMPY

- Eclipse events
- Unification
- CLUMPY-compatible



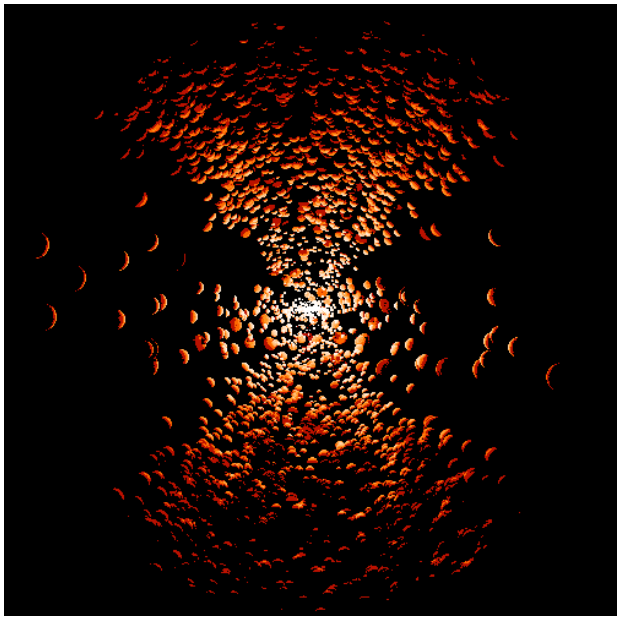
http://github.com/JohannesBuchner/xars/

Wada 2012, Wada+2016 Pringle96,Maloney+96,Nixon+12

Outcomes

http://github.com/JohannesBuchner/xars

UXCLUMPY



CAT3D+WIND