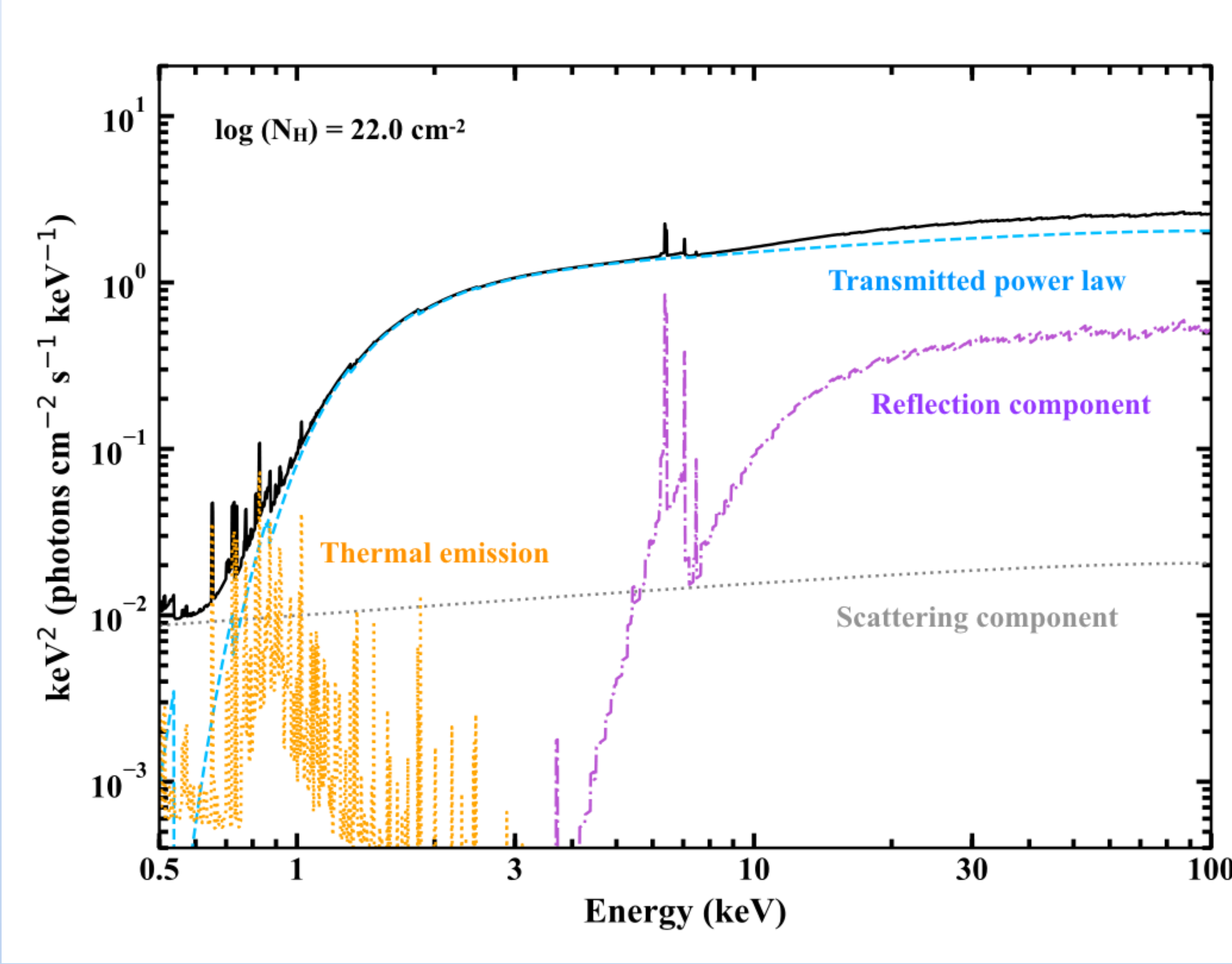
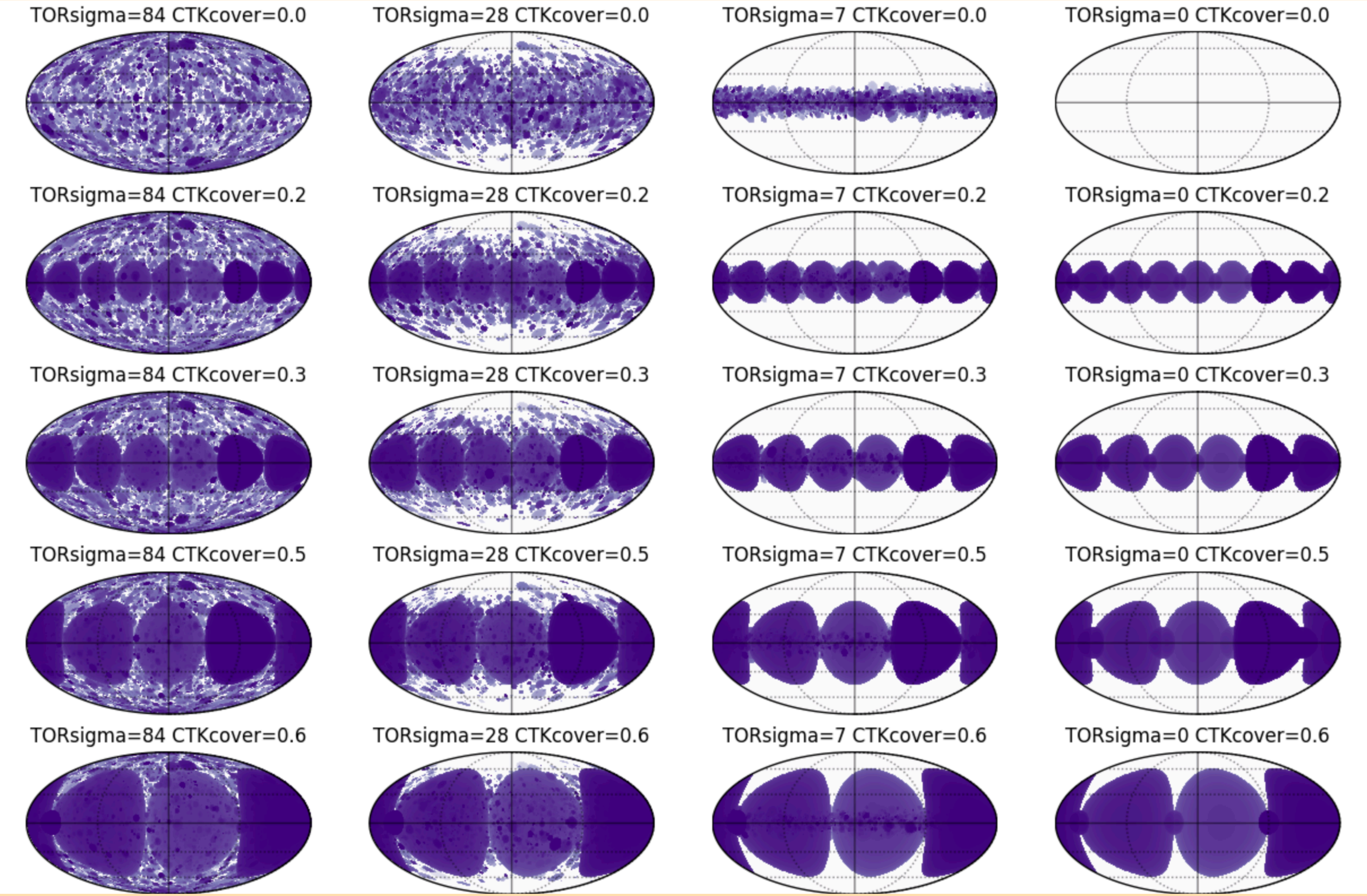
AGN obscuration: the X-ray spectral prospective

- AGN emission from accretion disk and the corona, surrounded by a dense torus of gas and dust.
- Depending on our viewing angle with respect to the central engine, part of the emission can be suppressed (absorption by metals).
- The shape of the X-ray spectrum changes depending on the column density of hydrogen (NH) in the line of sight: higher energy photons can be absorbed/ scattered away from the line of sight at larger NH values.
- Compton thick (CT-) AGN: $NH>10^{24}$ cm^{-2} ($\tau>1$), most of the emission suppressed <10 keV.



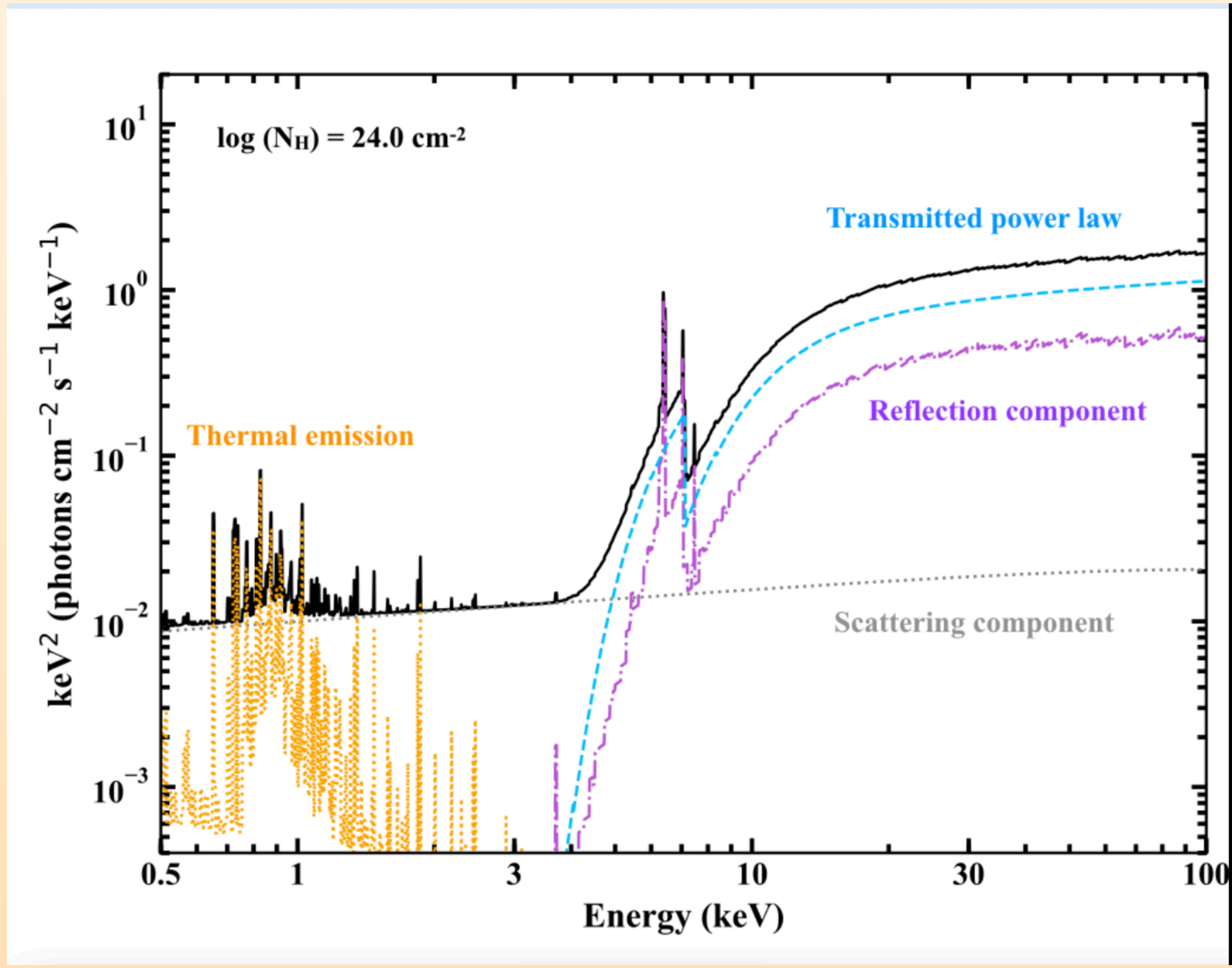
Courtesy of X. Zhao

Modelling X-ray emission in heavily obscured AGN

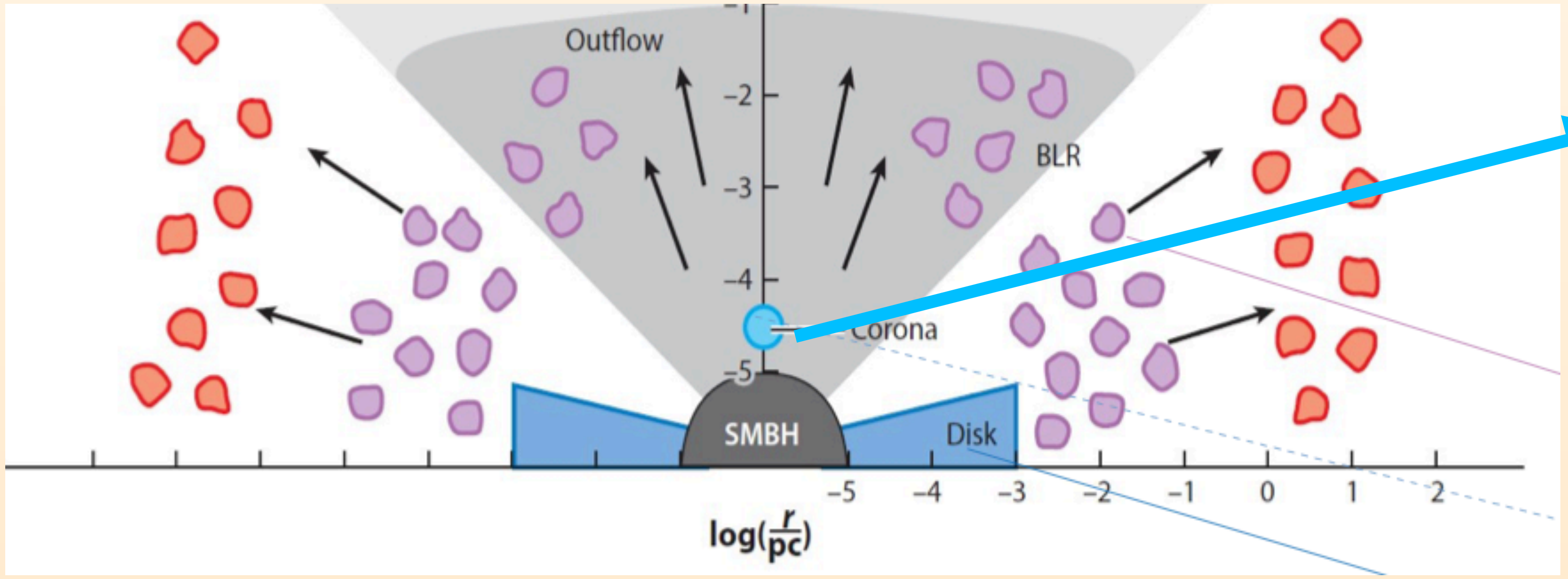


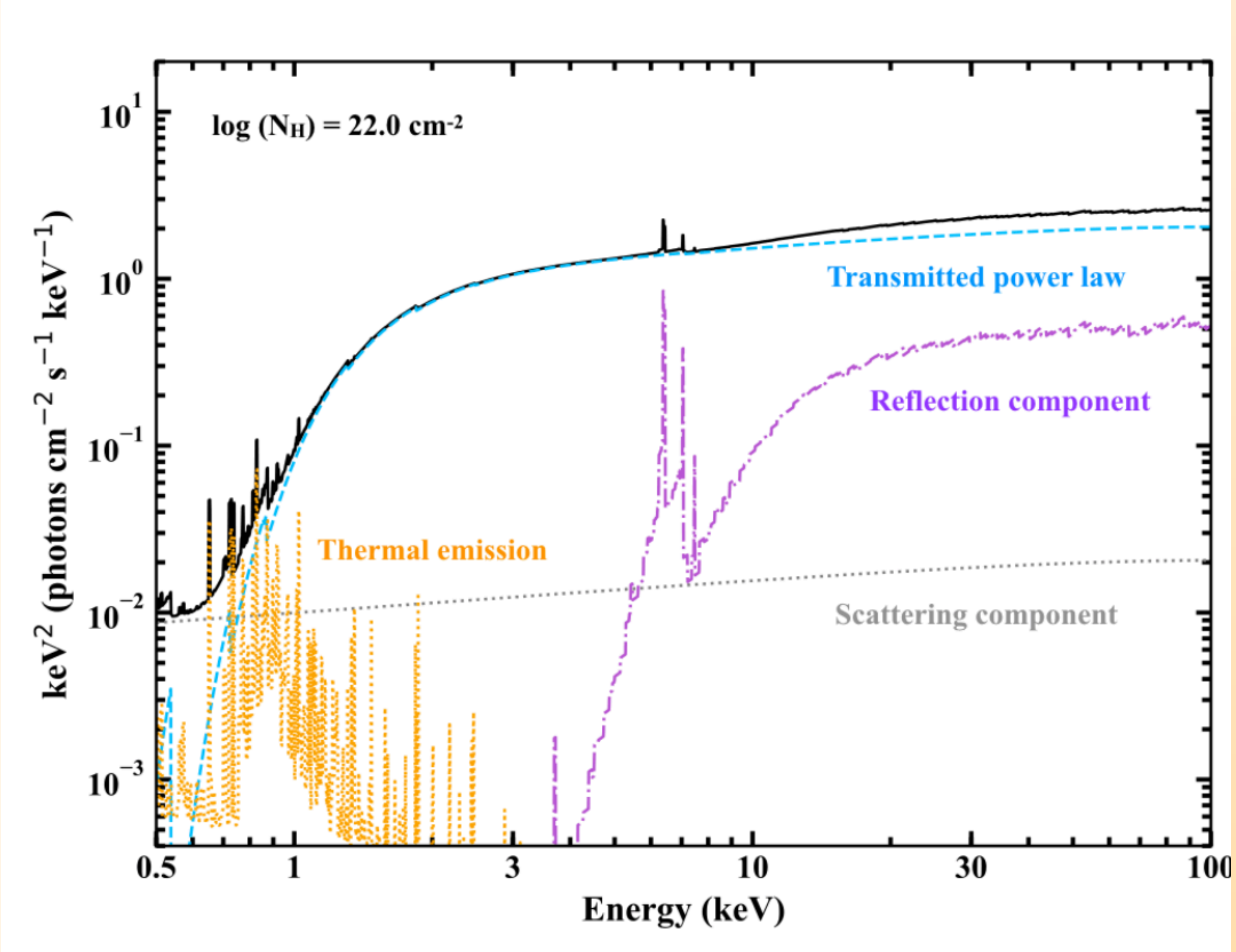
The accurate characterization of X-ray emission in heavily obscured AGN

- From a purely phenomenological perspective, obscured AGN X-ray spectrum is a combination of three components.
- From a physical standpoint, each component gives us a different information on AGN and obscuring material surrounding it.



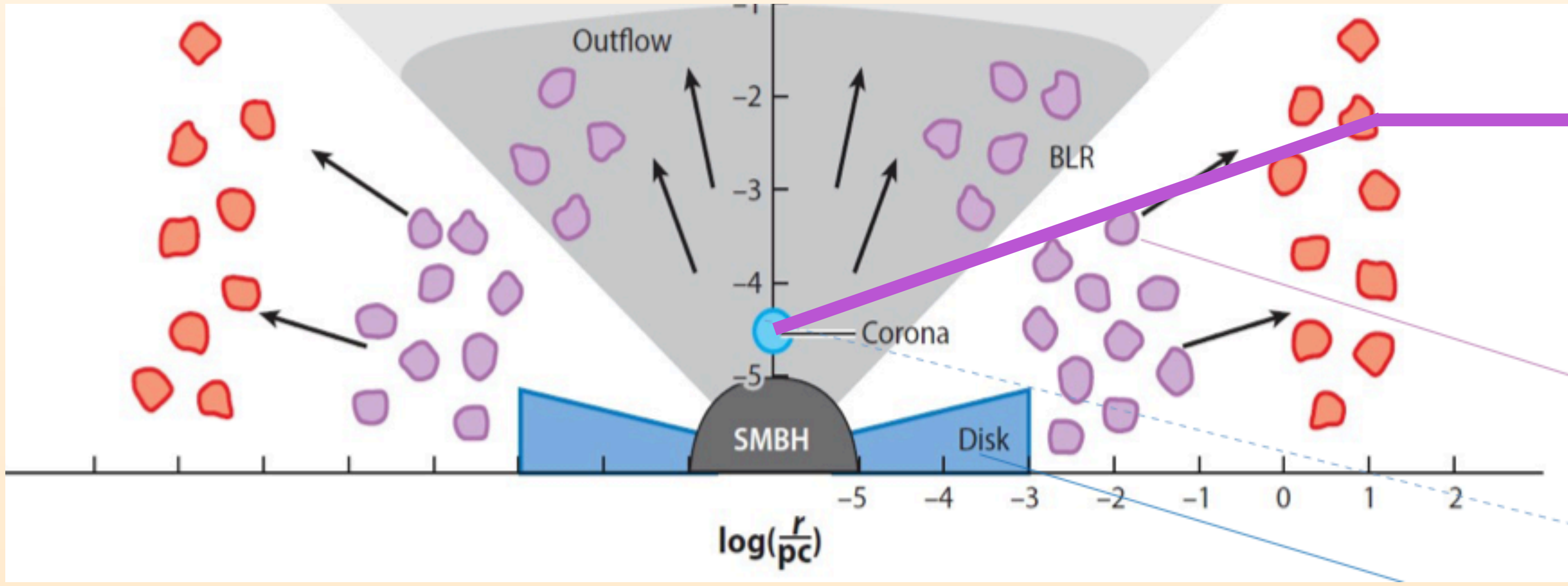
Transmitted power law - line-of-sight column density

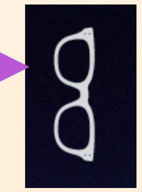




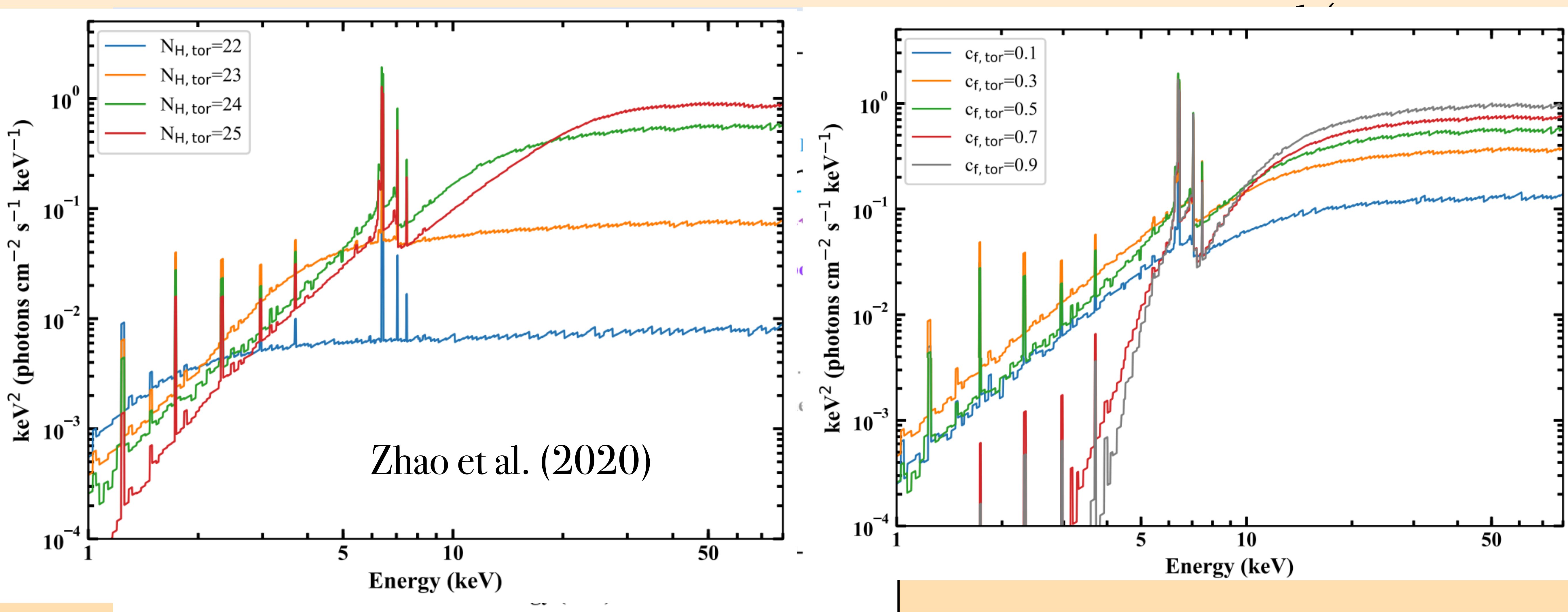
- Corona photons absorbed by obscuring material between SMBH and observer
- Energy-dependent effect: low E, soft photons are more easily absorbed, even by low NH clouds.
- Main parameters: power law photon index; l.o.s. column density

Reprocessed power law - average column density / torus covering factor

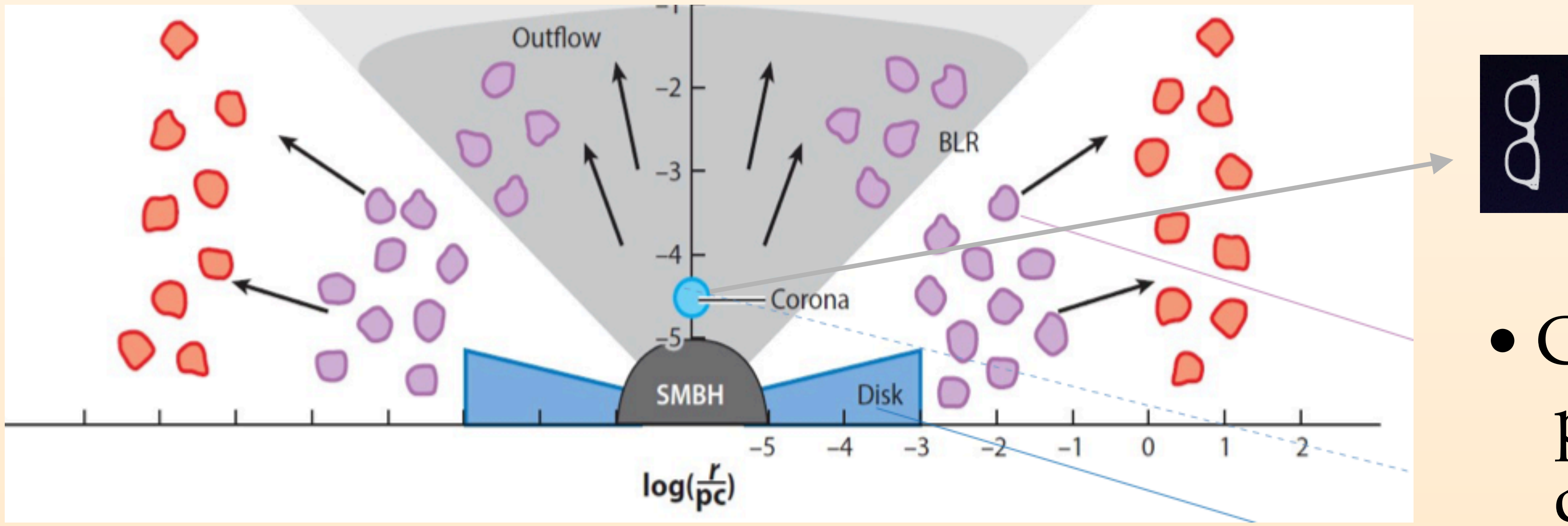


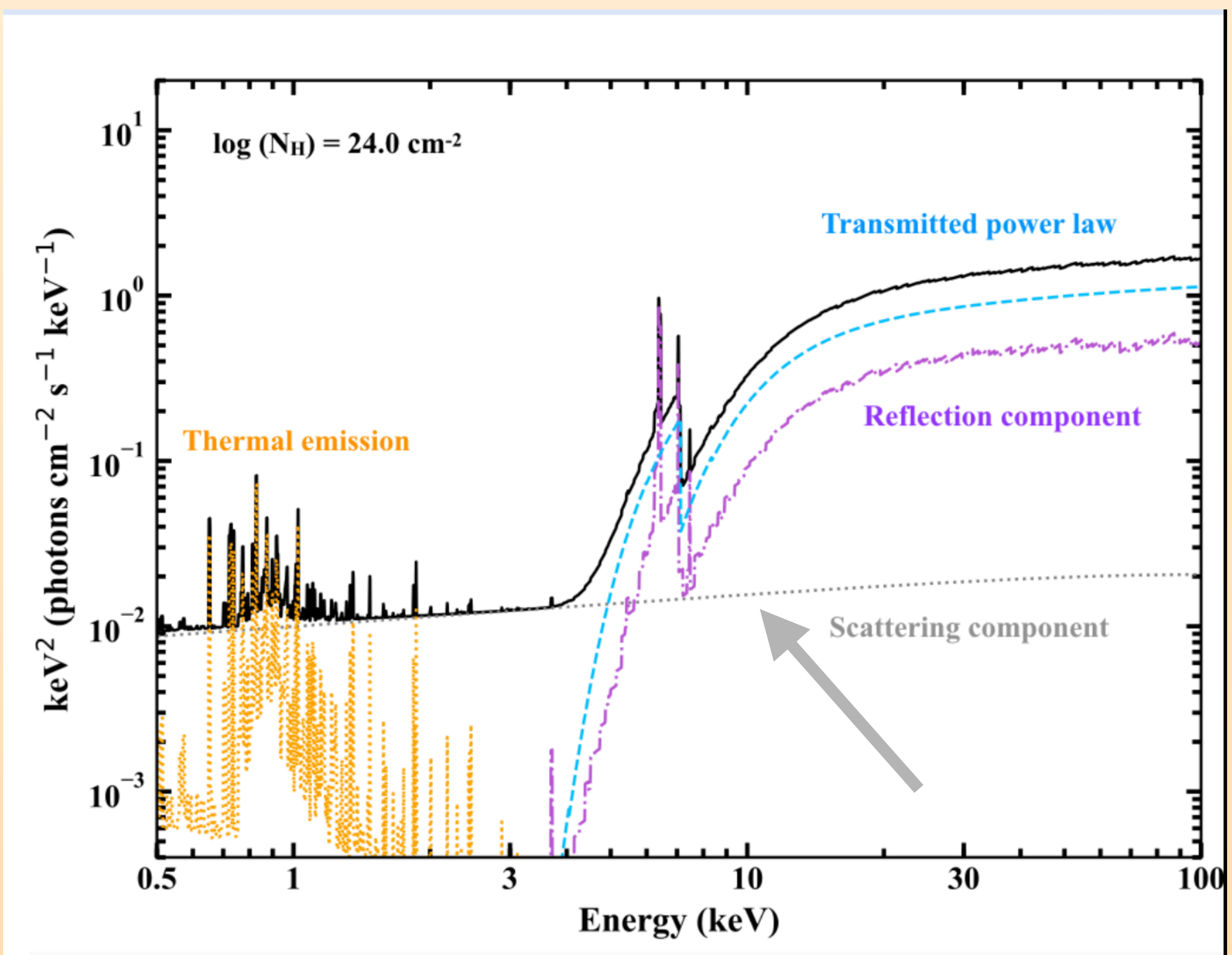


- Corona photons interacting with the obscuring material and



Scattered power law - torus covering factor

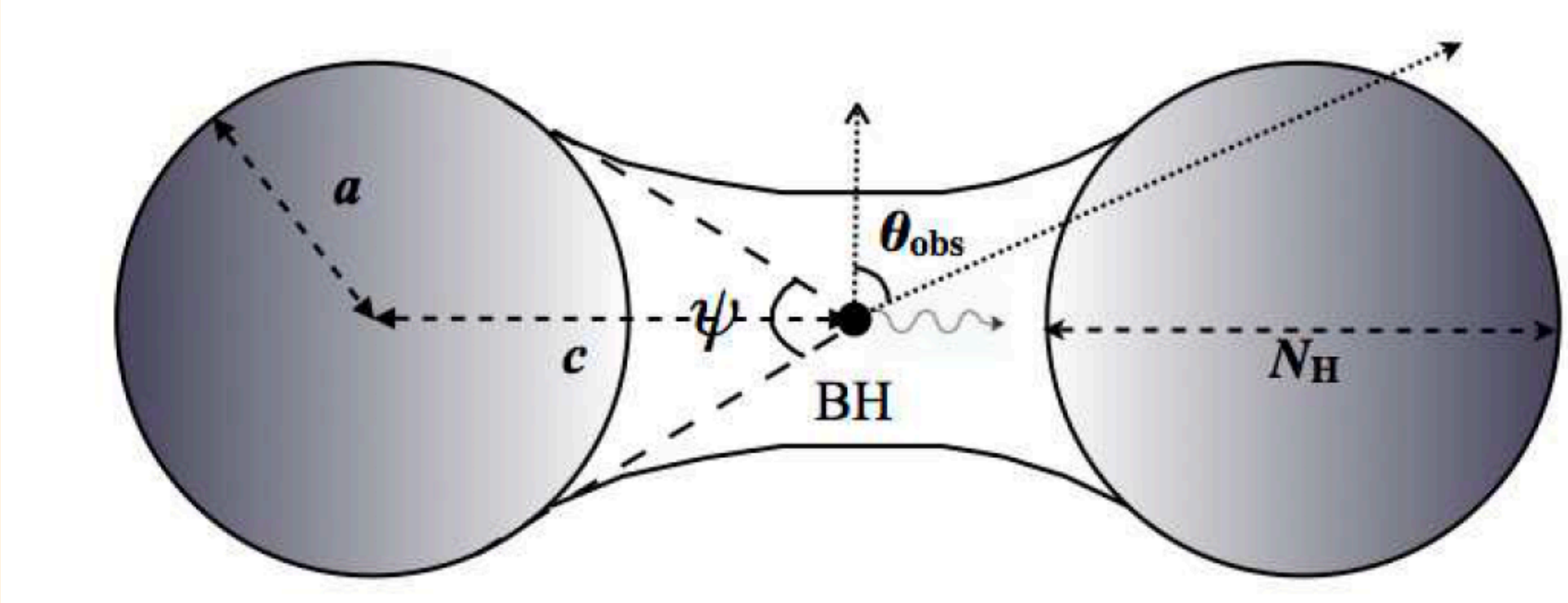




- Corona photons passing through the clouds without interacting or being absorbed
- Usually a fraction 1-10% of the emitted photons
- Main parameters: torus covering factor (although less accurate than reprocessed component)

MyTorus coupled: self-consistently characterizing an uniform torus

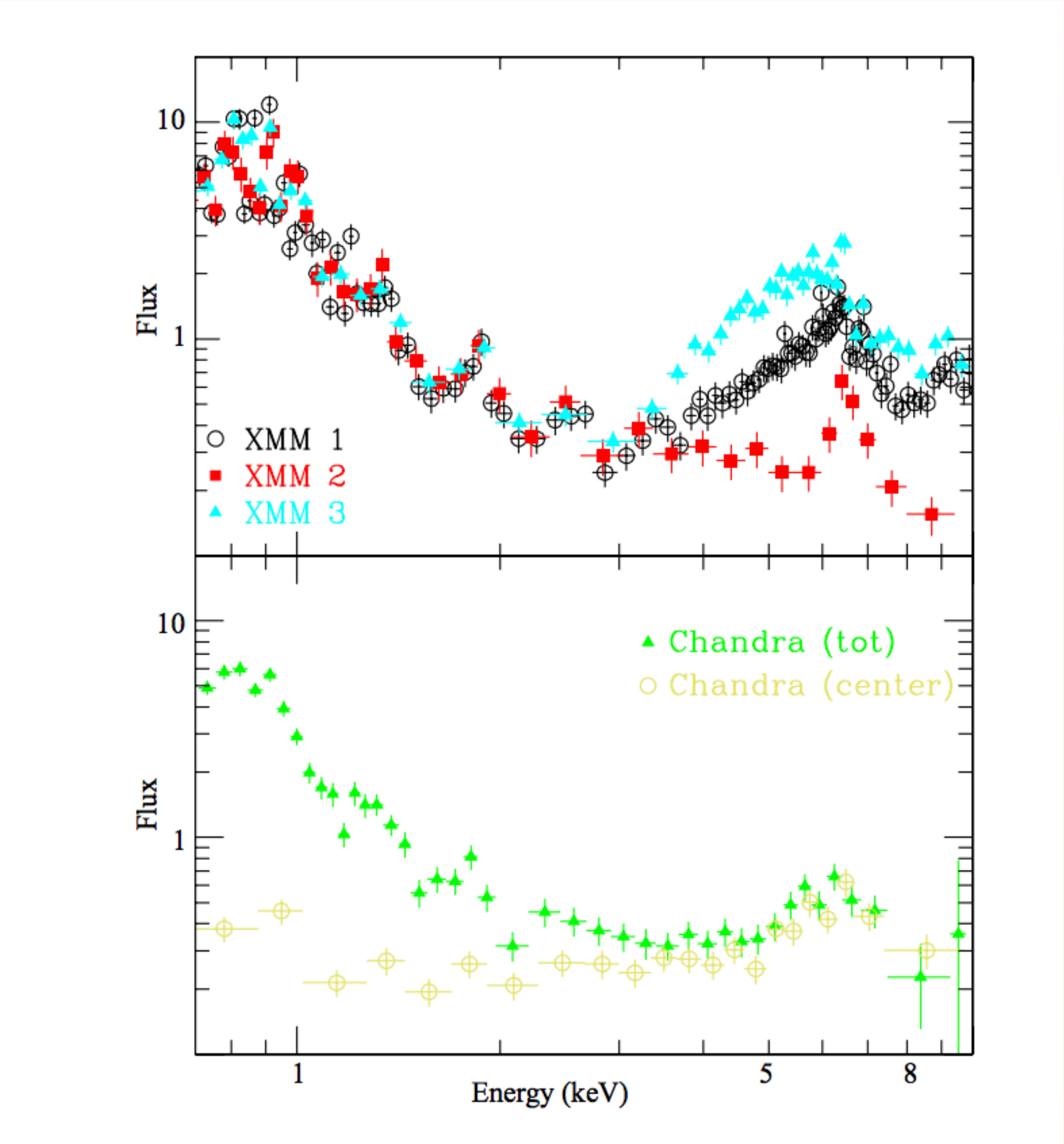
- Murphy & Yaqoob (2009): among the first models to self-consistently characterize X-ray spectra of heavily obscured AGN.
- Three components: absorbed main power law; reprocessed component; fluorescent lines (Fe K alpha and beta; Ni K alpha)
- Uniform torus: cannot decouple l.o.s. and average NH.
- Inclination angle as a free parameter.
- Covering factor fixed to 0.5 (i.e., torus opening angle fixed to 60 deg).



Murphy and Yaqoob (2009)

Limits of a uniform torus

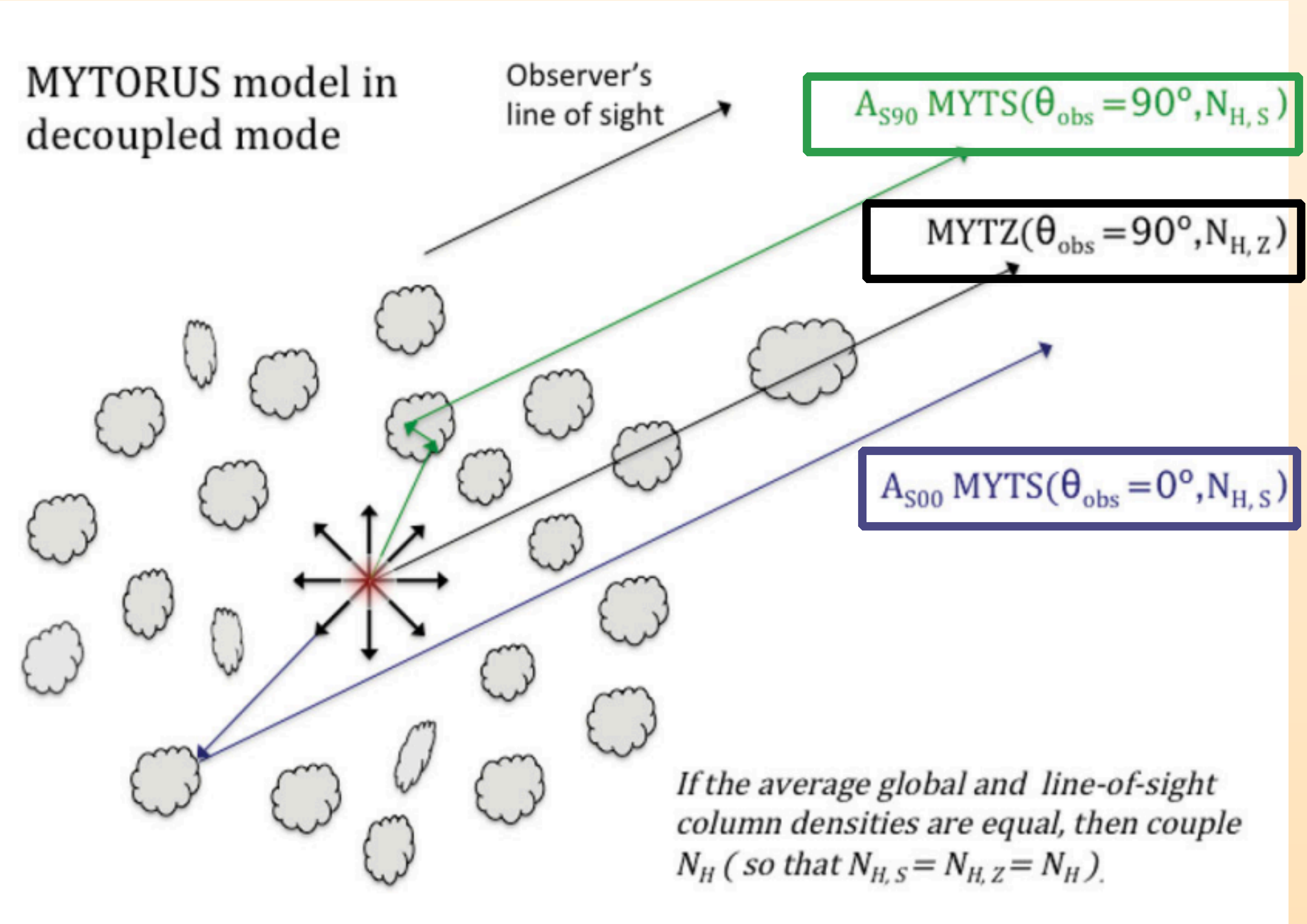
- Observational evidence, both in X-rays and in IR, points towards a "clumpy torus" scenario
- Variability in NH l.o.s. observed on time-scales of days, weeks -> Obscuring material needs to move very close to SMBH
- Models need to be updated to take into account this observational evidence.



Risaliti+05 (see also Bianchi+09, Guainazzi+12, Miniutti+14, Ricci+16...)

MyTorus decoupled: a first clumpy torus modelling

- Yaqoob (2012) and Yaqoob et al. (2015)
- L.o.s. component (MYTZ) untied from reprocessed one
- Reprocessed (and lines): proxy of torus average NH
- Two reprocessed components
- theta_obs=90 -> Material between SMBH and observer.
- theta_obs=0 -> material behind the SMBH
- Ratio between two components can give information on torus covering factor



Yaqoob (2012)

MyTorus decoupled in XSpec

MyTZ l.o.s. NH

average NH

Scattered emission

Thermal emission

Data group: 1

1	1	constant	factor		1.00000	frozen
2	2	phabs	nH	10^22	3.83000E-02	frozen
3	3	MYtorusZ	NH	10^24	0.935362	+/- 4.83159E-02
4	3	MYtorusZ	IncAng	Degrees	90.0000	frozen
5	3	MYtorusZ	z		1.34360E-02	frozen
6	4	zpowerlw	PhoIndex		1.59957	= p12
7	4	zpowerlw	Redshift		1.34360E-02	= p5
8	4	zpowerlw	norm		5.62266E-03	+/- 1.32837E-03
9	5	constant	factor		0.401144	+/- 7.55201E-02
10	6	MYtorusS	NH	10^24	0.372699	+/- 7.27184E-02
11	6	MYtorusS	IncAng	Degrees	90.0000	frozen
12	6	MYtorusS	PhoIndx		1.59957	+/- 5.98016E-02
15	7	constant	factor		0.401144	= p9
16	8	MYTorusL	NH	10^24	0.372699	= p10
17	8	MYTorusL	IncAng	Degrees	90.0000	= p11
18	8	MYTorusL	PhoIndx		1.59957	= p12
19	8	MYTorusL	z		1.34360E-02	= p13
20	8	MYTorusL	norm		5.62266E-03	= p14
21	9	constant	factor		1.62872E-03	+/- 4.39518E-04
22	10	zpowerlw	PhoIndex		1.59957	= p12
23	10	zpowerlw	Redshift		1.34360E-02	= p5
24	10	zpowerlw	norm		5.62266E-03	= p8
25	11	mekal	kT	keV	0.584302	+/- 3.51773E-02
26	11	mekal	nH	cm-3	1.00000	frozen
27	11	mekal	Abundanc		0.448132	+/- 0.879008
28	11	mekal	Redshift		1.34360E-02	= p5
29	11	mekal	switch		1	frozen
30	11	mekal	norm		2.21229E-05	+/- 4.01863E-05

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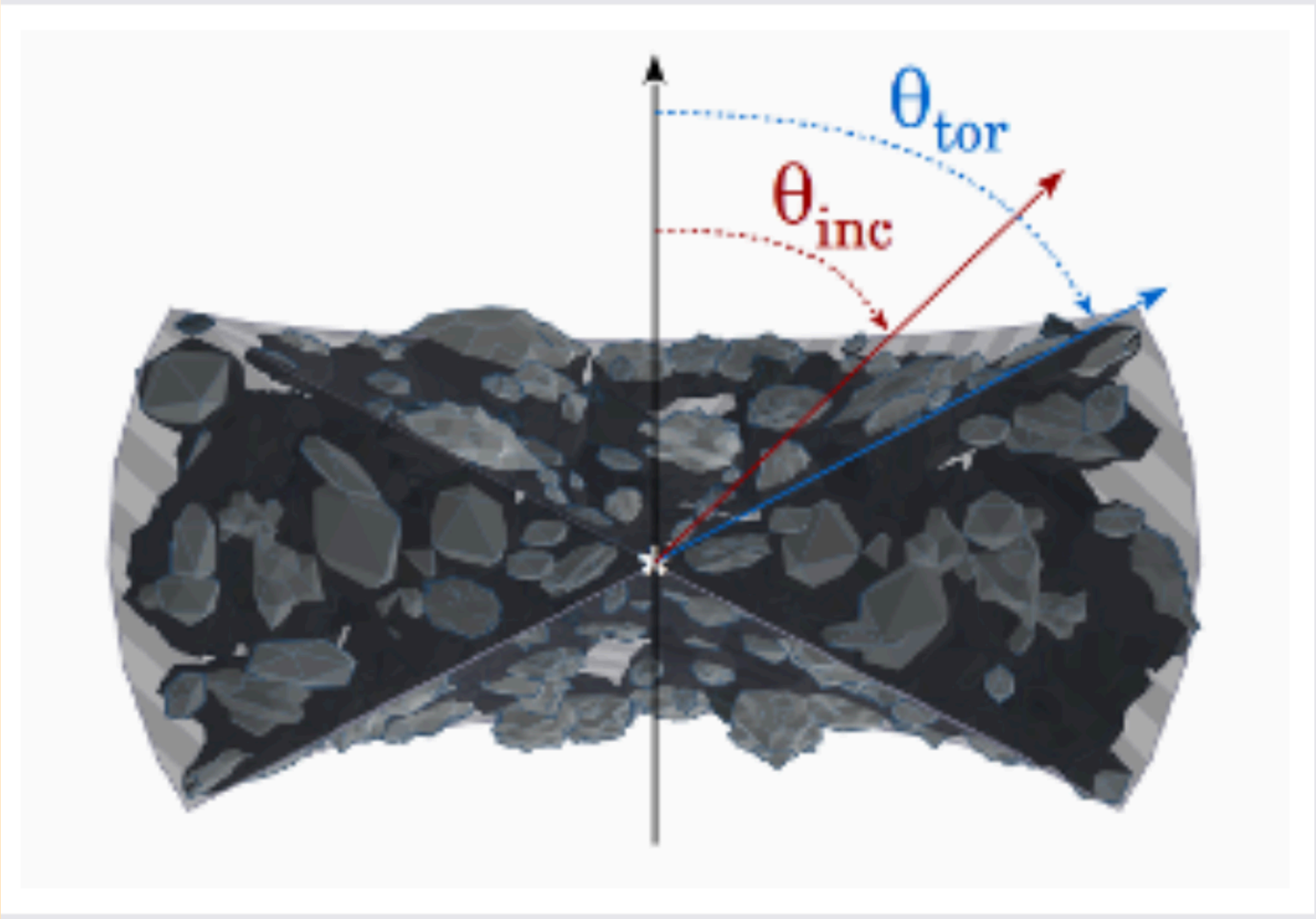
```

Borus02: measuring the covering factor

- Balokovic et al. (2018)
- borus02 models only the reprocessed component: l.o.s. absorption treated by an additional parameter
- Average torus NH and covering factor are both free parameters
- Torus still assumed to be uniform, but NH torus can be different from NH los -> Indirect indication of clumpiness



Balokovic et al. (2018)

borus02 in XSpec

borus02
average NH
covering factor

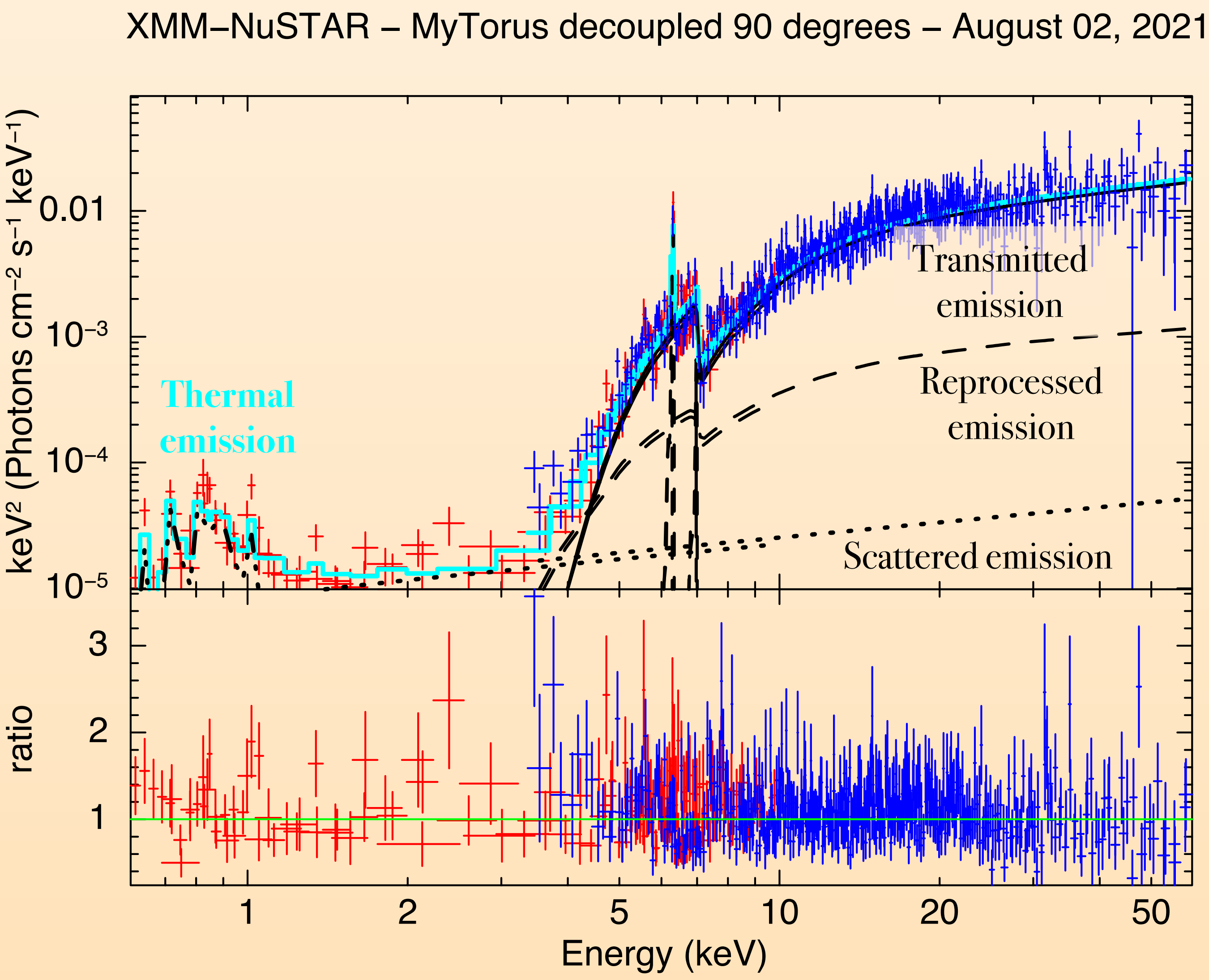
l.o.s. NH

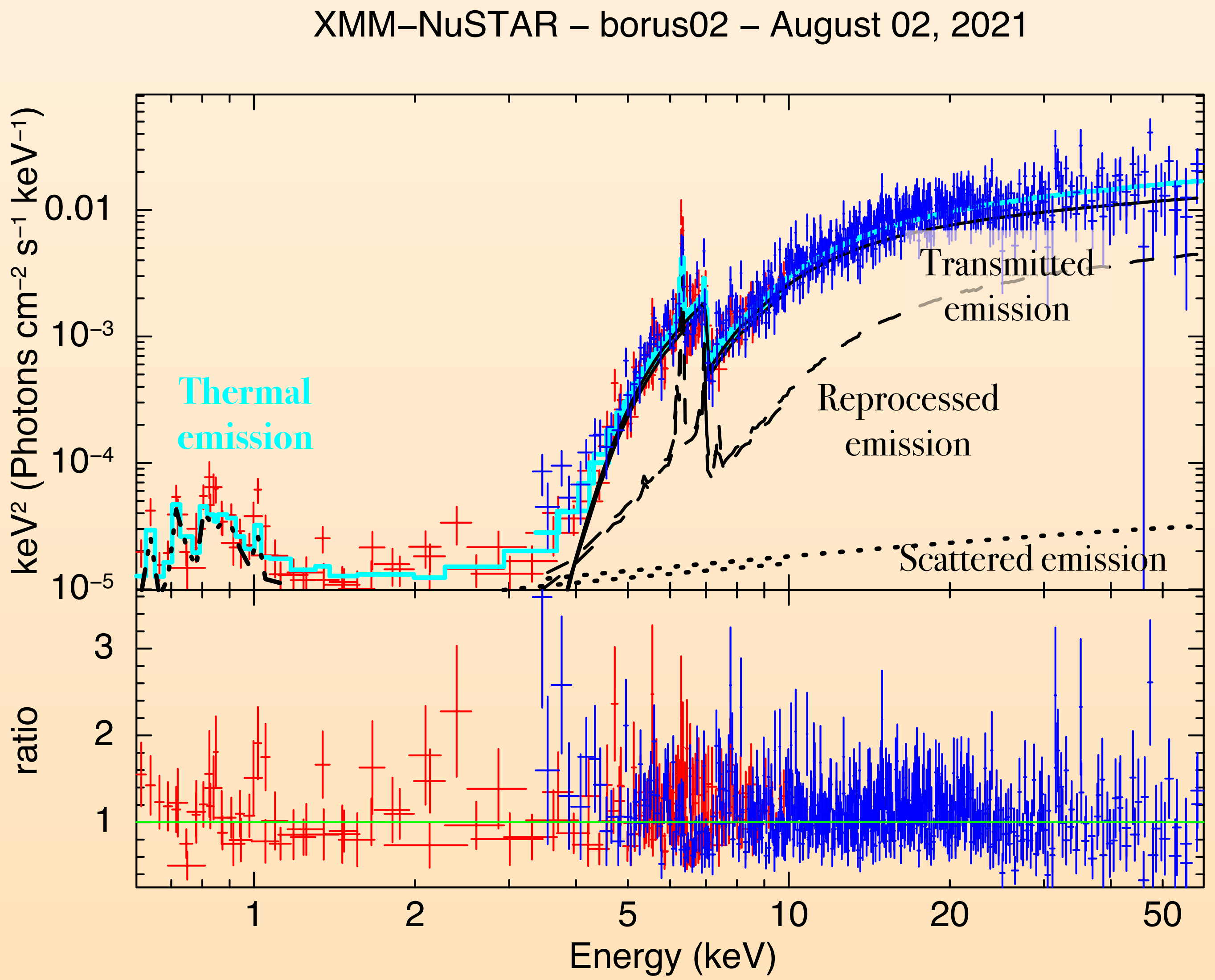
Scattered
emission

Thermal
emission

```
                              Data group: 1
  1    1   constant   factor                  1.00000      frozen
  2    2   phabs      nH         10^22        3.83000E-02  frozen
  3    3   constant   factor                  1.00000      frozen
  4    4   borus02    PhoIndex                1.59599      +/-  0.0
  5    4   borus02    Ecut       keV          300.000      frozen
  6    4   borus02    logNHtor                24.2394      +/-  0.0
  7    4   borus02    CFtor                   0.278200     +/-  0.0
  8    4   borus02    cos(thInc)              0.194618     +/-  0.0
  9    4   borus02    A_Fe       A_Sun        1.00000      frozen
 10    4   borus02    z                       1.34360E-02  frozen
 11    4   borus02    norm                    1.00000      +/-  0.0
Model constant<1>*phabs<2>(constant<3>*atable{/Users/stefano/Documents/work/clemson/nustar_ctagn/test_borus/borus02_v170323a.fits}<4> + zphabs<5>*cabs<6>*
cutoffpl<7> + constant<8>*cutoffpl<9>) + mekal<10> Source No.: 1   Active/On
 13    5   zphabs     Redshift                1.34360E-02  = p10
 14    6   cabs       nH         10^22        83.4422      = p12
 15    7   cutoffpl   PhoIndex                1.59599      = p4
 16    7   cutoffpl   HighECut   keV          300.000      = p5
 17    7   cutoffpl   norm                    4.51593E-03  +/-  0.0
 18    8   constant   factor                  1.49725E-03  +/-  0.0
 19    9   cutoffpl   PhoIndex                1.59599      = p4
 20    9   cutoffpl   HighECut   keV          300.000      = p5
 21    9   cutoffpl   norm                    4.51593E-03  = p17
 22   10   mekal      kT         keV          0.600535     +/-  0.0
 23   10   mekal      nH         cm-3         1.00000      frozen
 24   10   mekal      Abundanc                0.136573     +/-  0.0
 25   10   mekal      Redshift                1.34360E-02  = p10
 26   10   mekal      switch                  1            frozen
 27   10   mekal      norm                    5.63755E-05  +/-  0.0
```

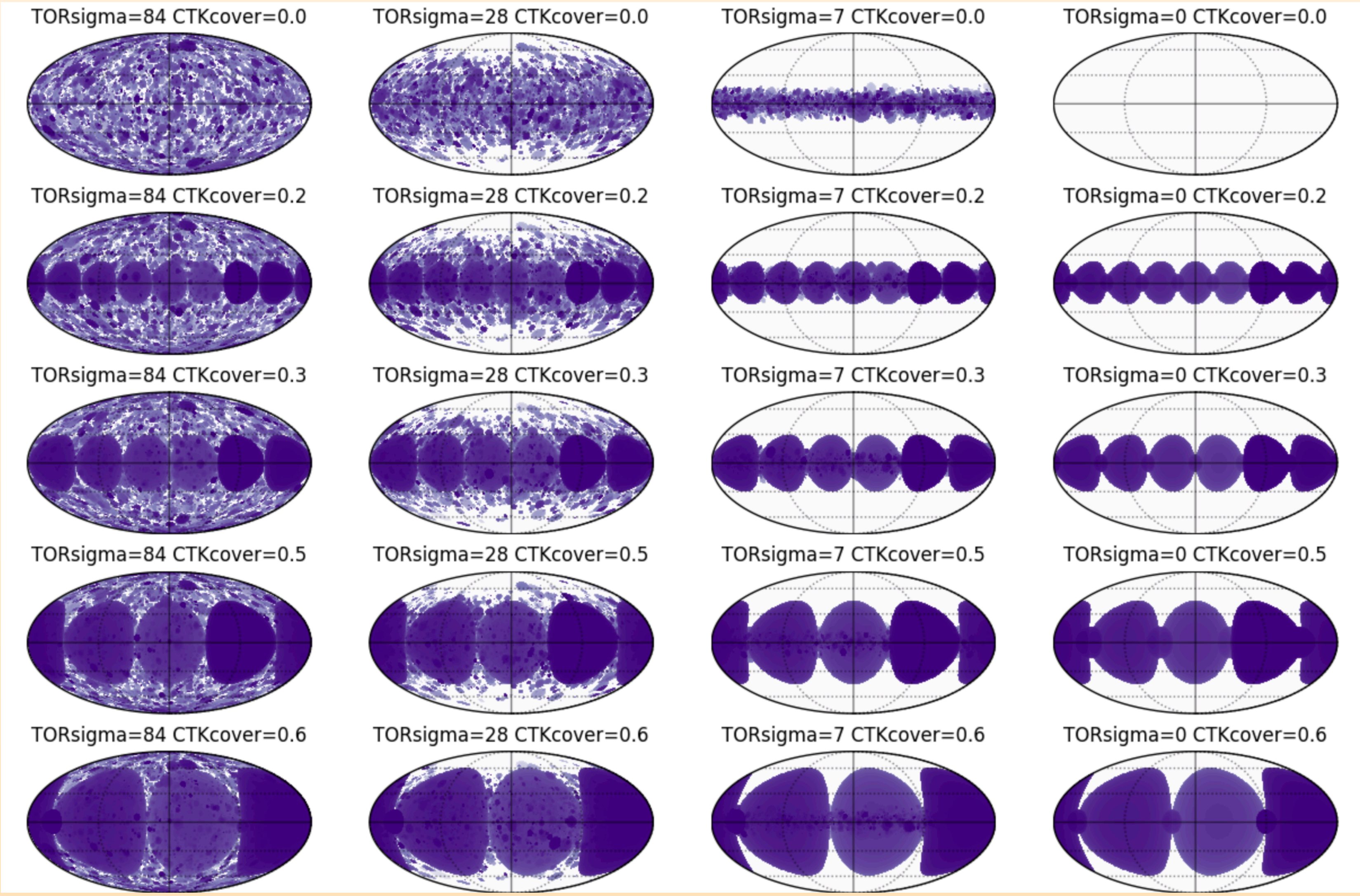
MyTorus - borus02 comparison





UXClumpy: parameterizing the clumpiness

- Buchner et al. (2019)
- No more uniform distribution, but clouds orbiting around the accreting SMBH
- New free parameter: TORsigma (vertical height of clouds around the SMBH).
- Observational evidence: some sources require extra reprocessed component -> Possible inner ring of clouds, parameterized with CTKcover
- Large CTKcover: few large clouds; small CTKcover: many small clouds.



UXClumpy in XSpec

Torus absorbed and reprocessed emission

Scattered emission

Thermal emission

Data group: 1

1	1	constant	factor		1.00000	frozen	
2	2	phabs	nH	10^22	3.83000E-02	frozen	
3	3	torus	nH		91.2953	+/-	6.36989
4	3	torus	PhoIndex		1.63035	+/-	0.143057
5	3	torus	Ecut		300.000	frozen	
6	3	torus	TORsigma		10.2774	+/-	6.24846
7	3	torus	CTKcover		1.41449E-07	+/-	0.276019
8	3	torus	Theta_inc		87.8574	+/-	7.95276
9	3	torus	z		1.34360E-02	frozen	
10	3	torus	norm		6.78988E-03	+/-	2.36278E-03

```
Model constant<1>*phabs<2>*atable{/Users/stefano/Documents/work/clemson/UXClumpy/uxclumpy-cutoff.fits}<3> + constant<4>*atable{/Users/stefano/Documents/wo
rk/clemson/UXClumpy/uxclumpy-cutoff-omni.fits}<5> + mekal<6> Source No.: 1   Active/On
```

12	5	scat	nH		91.2953	= p3	
13	5	scat	PhoIndex		1.63035	= p4	
14	5	scat	Ecut		300.000	= p5	
15	5	scat	TORsigma		10.2774	= p6	
16	5	scat	CTKcover		1.41449E-07	= p7	
17	5	scat	Theta_inc		87.8574	= p8	
18	5	scat	z		1.34360E-02	= p9	
19	5	scat	norm		6.78988E-03	= p10	
20	6	mekal	kT	keV	0.616787	+/-	4.12811E-02
21	6	mekal	nH	cm-3	1.00000	frozen	
22	6	mekal	Abundanc		8.80642E-02	+/-	5.96450E-02
23	6	mekal	Redshift		1.34360E-02	= p9	
24	6	mekal	switch		1	frozen	
25	6	mekal	norm		7.99735E-05	+/-	3.99139E-05

Not only X-rays: the IR perspective

- Esparza-Arredondo et al. (2019, 2021)
- IR emission comes from optical photons absorbed and reprocessed by torus -> Excellent proxy of torus properties
- X-ray/IR synergy to best understand gas and dust properties and distribution
- First results: no clear agreement between IR and X-ray covering factor, but result could be biased by Seyfert 1 galaxies.