Photoionisation Modelling of the Emission Line Regions and Warm Absorbers in AGN

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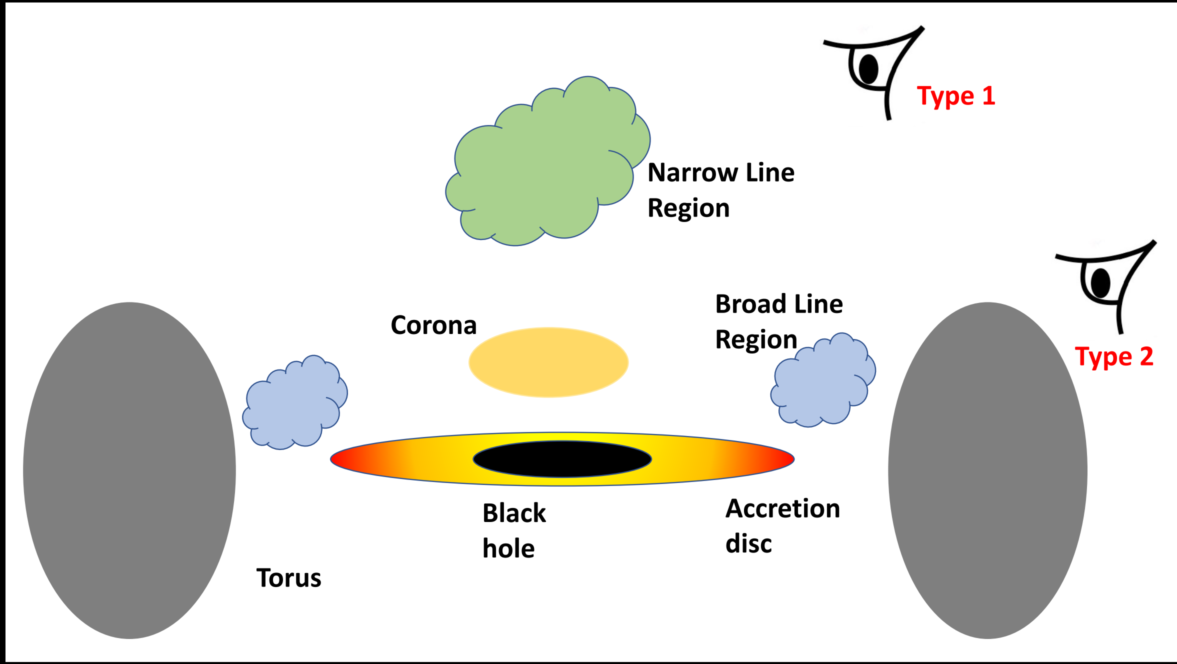
What are AGN and why should we care?

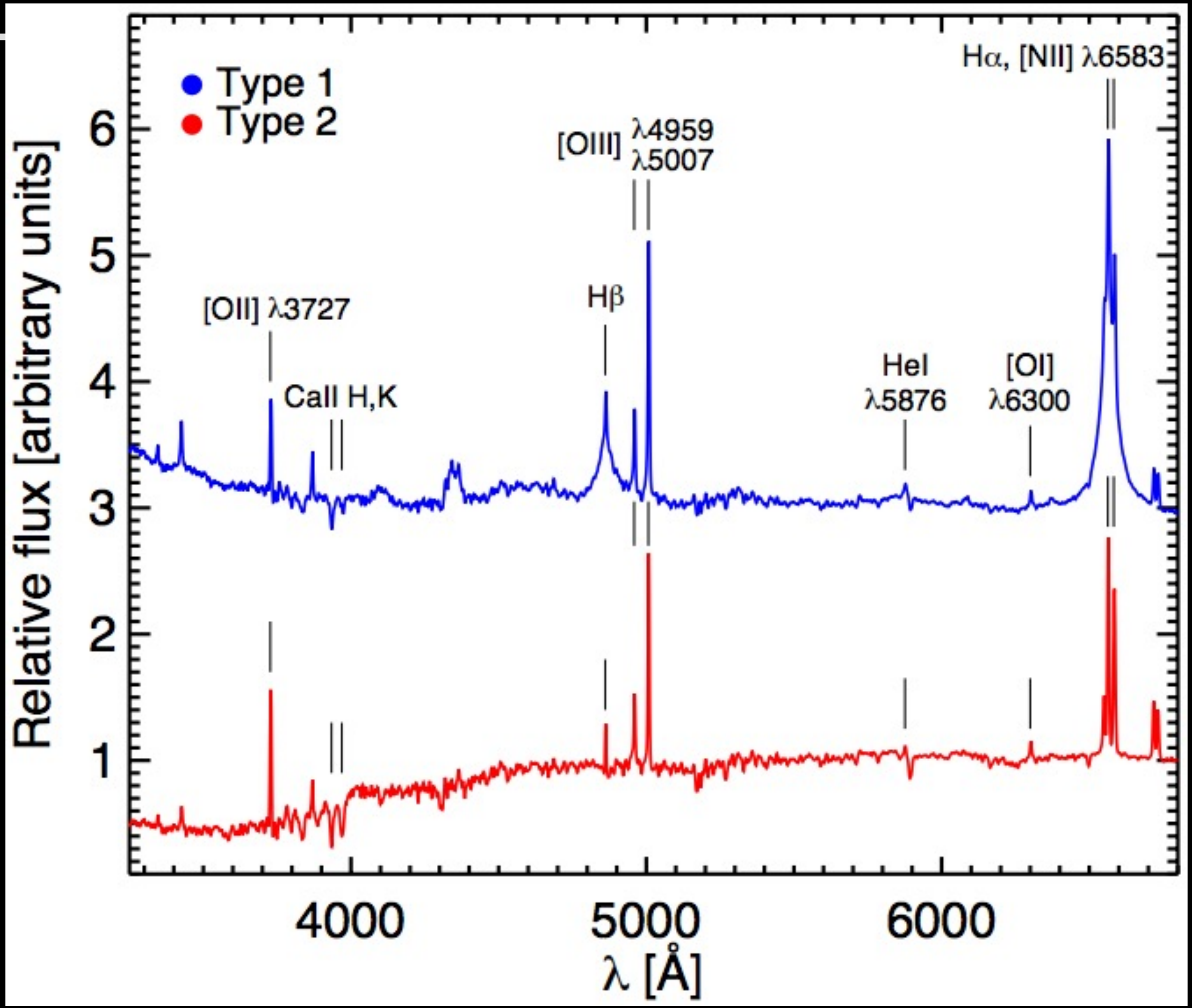
AGN – in a Nutshell

- $M_{BH} = 10^5 - 10^{10}\, M_{\odot}$
- $L_{bol} = 10^{34} - 10^{41}\, W$
- Powered via accretion
- Matter also ejected into galaxy
  - Disk winds (UFO; $v_{out} \sim 0.1 - 0.4\, c$; e.g. Tombesi et al. 2010,12,13)
  - Torus Winds (WA; $v_{out} \sim 100 - 1000\ km\ s^{-1}$; e.g. Blustin et al. 2005)

Image courtesy: MIT Kavli Institute for Astrophysics and Space Research

AGN Unification



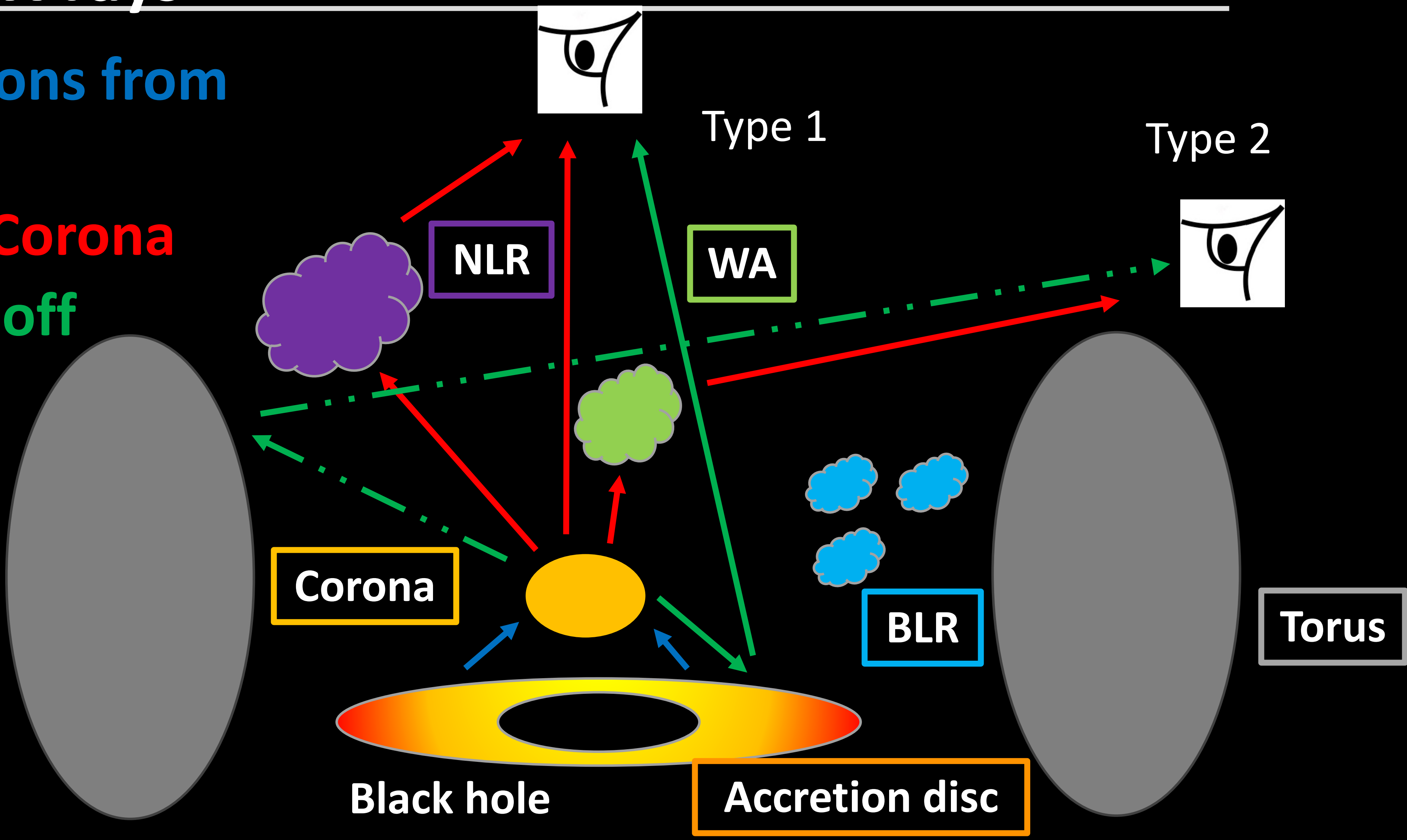


Adapted from DiPompeo et al. 2018 by Hickox & Alexander 2018

Unification Theory of AGN: Miller & Antonucci 1983; Antonucci & Miller 1985

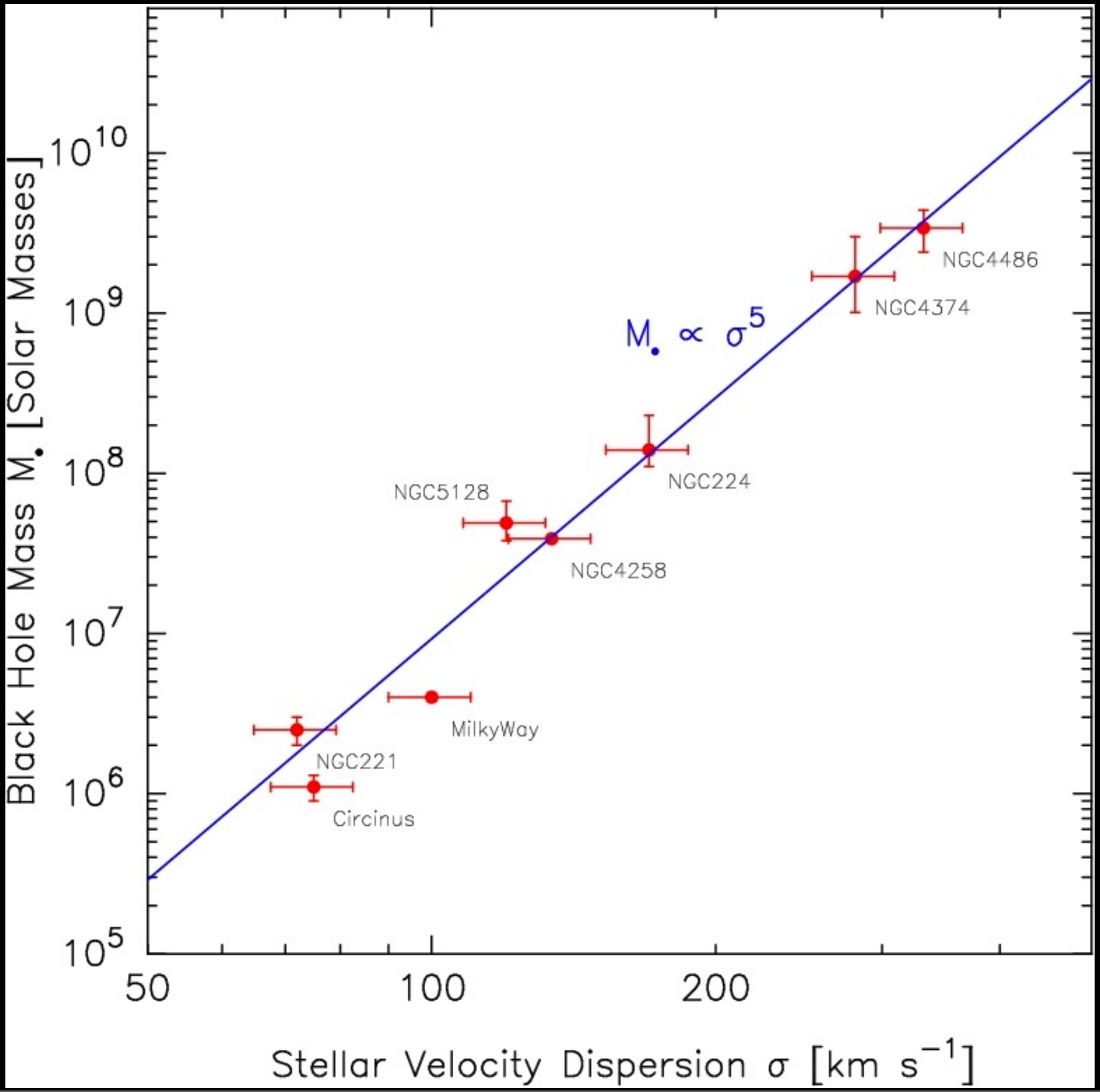
Origin of X-rays

- UV/Optical photons from accretion disc
- X-rays from hot Corona
- Reflected X-rays off the disc or torus



Motivation for studying AGN winds

- Main questions:
  - Origin of winds
  - Launching Mechanism
  - Location and Geometry
- M-σ relation
  - Galaxy impact
  - Co-evolution



Talk outline

1. Photoionisation modelling
- ➢ Photoionised Plasma properties
- ➢ Model: PION

2. Results from X-ray analysis on AGN
- ➢ NGC 5548
- ➢ NGC 3783

3. NGC 7469
- ➢ My Analysis from Multiwavelength Campaign
- ➢ Distance Measurements

4. Current work: NGC 1068
- ➢ Spectral analysis

5. Future: ATHENA

Photoionisation Modelling

PION model in SPEX

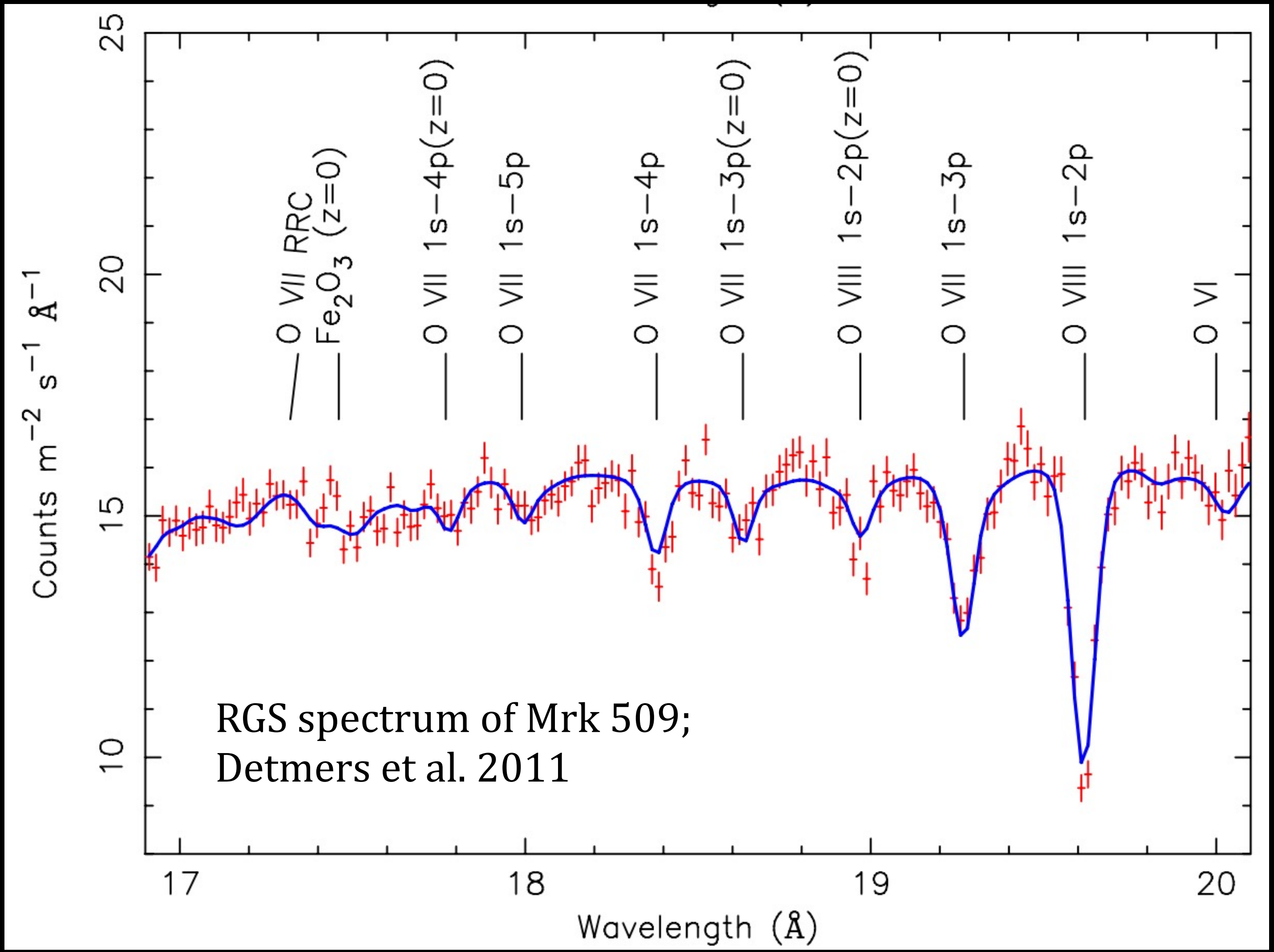
- Assume photoionisation equilibrium
  - Rate of ionisation = Rate of recombination
- State of the photoionised gas depends on the ionisation parameter ξ

$$\xi \equiv \frac{L_{ion}}{nr^2}$$

PION

- Self consistent model (M. Mehdipour et al. 2016)
- Simultaneously models the continuum and ionised plasma
  - Requires SED of AGN
- Computes both the photoionisation solution and X-ray spectrum

Plasma Properties

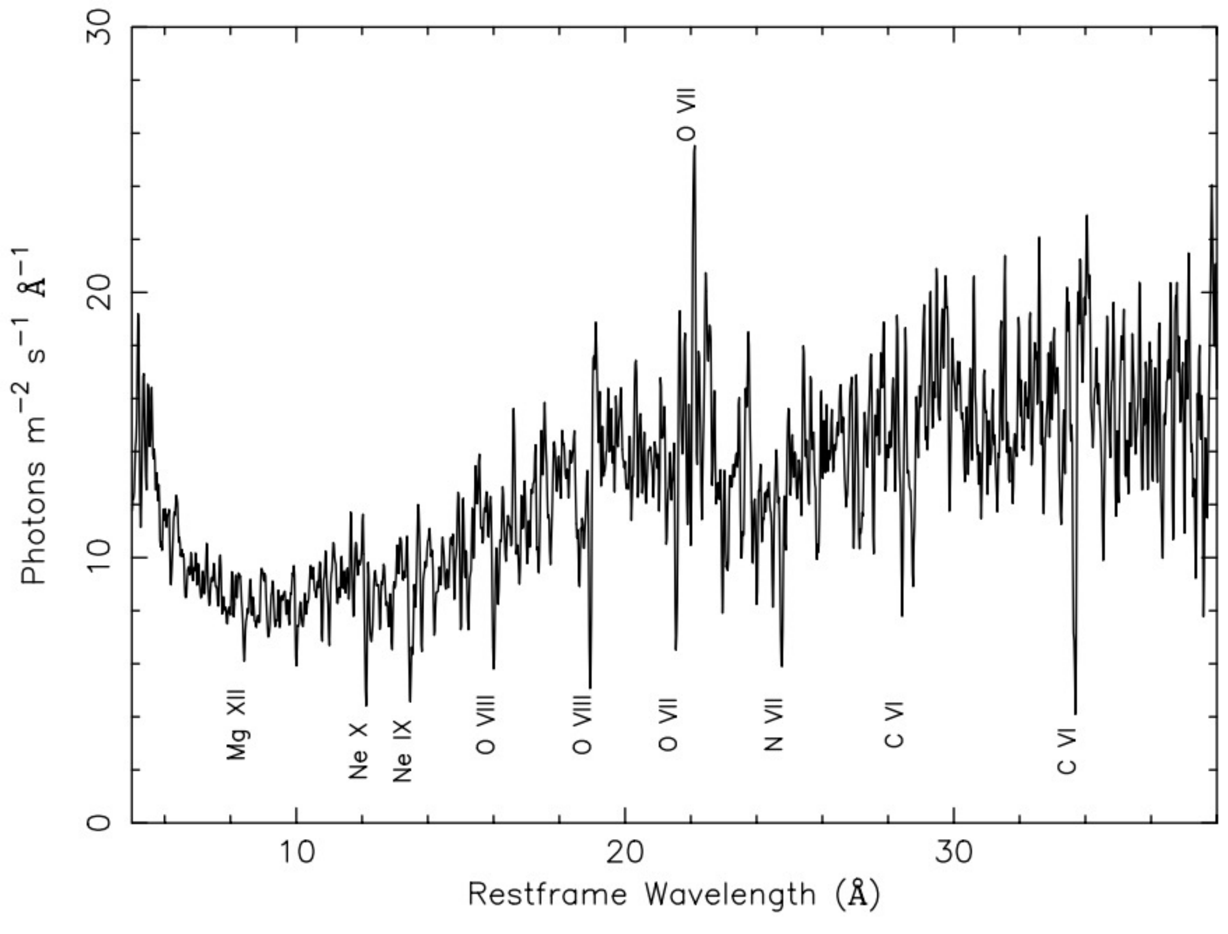


- N_H - the line depth
  - $10^{24} – 10^{28}$ m^{-2}
- $\xi \equiv \frac{L_{ion}}{nr^2}$ - ionisation
  - log ξ = 0 - 3
- v_{turb} - line broadening
  - ~ $10^1 – 10^2$ km s^{-1}
- v_{out} - line centring
  - > $10^2 – 10^3$ km s^{-1}
  - Blueshifted
- **Multiple components to fit all the emission/ absorption lines**

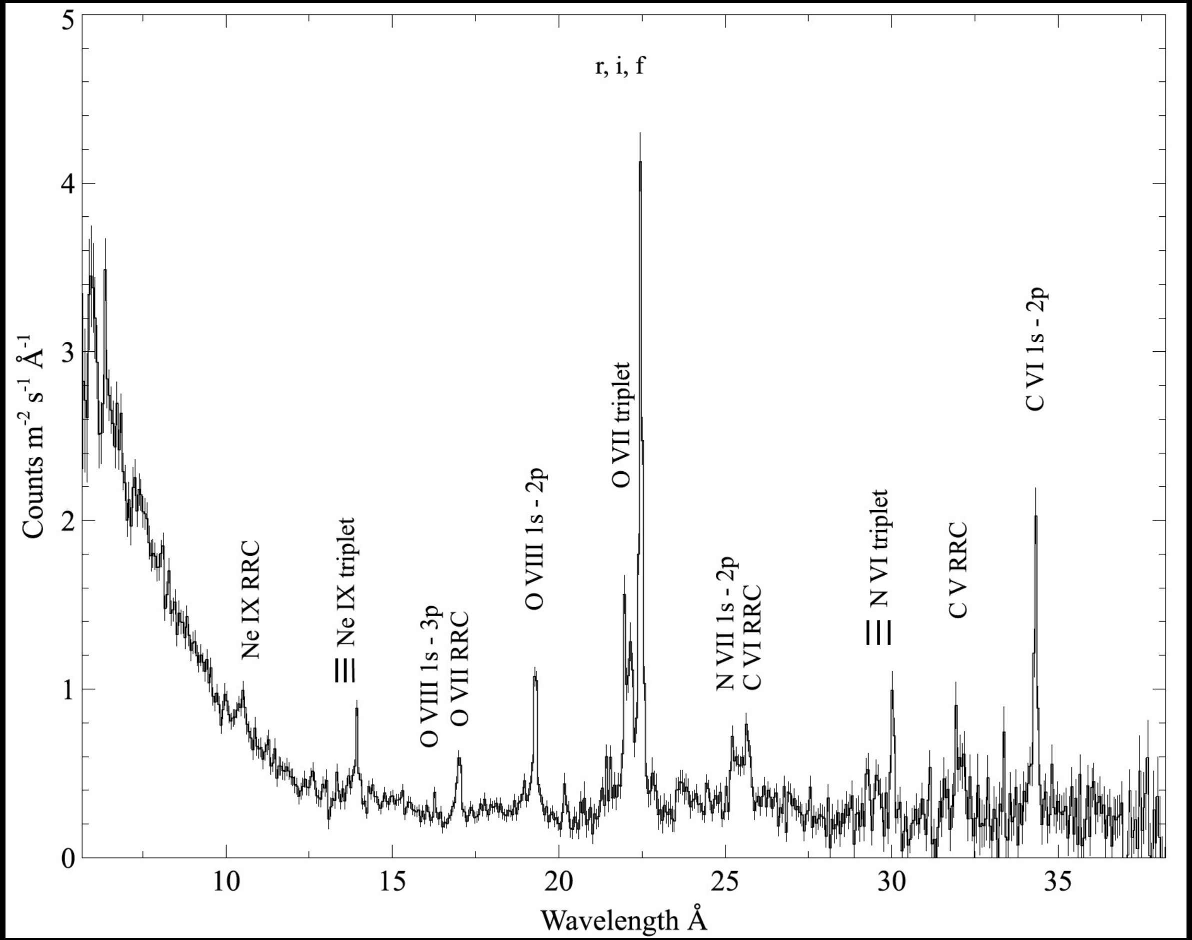
NGC 5548

ESA/Hubble

Spectral Features

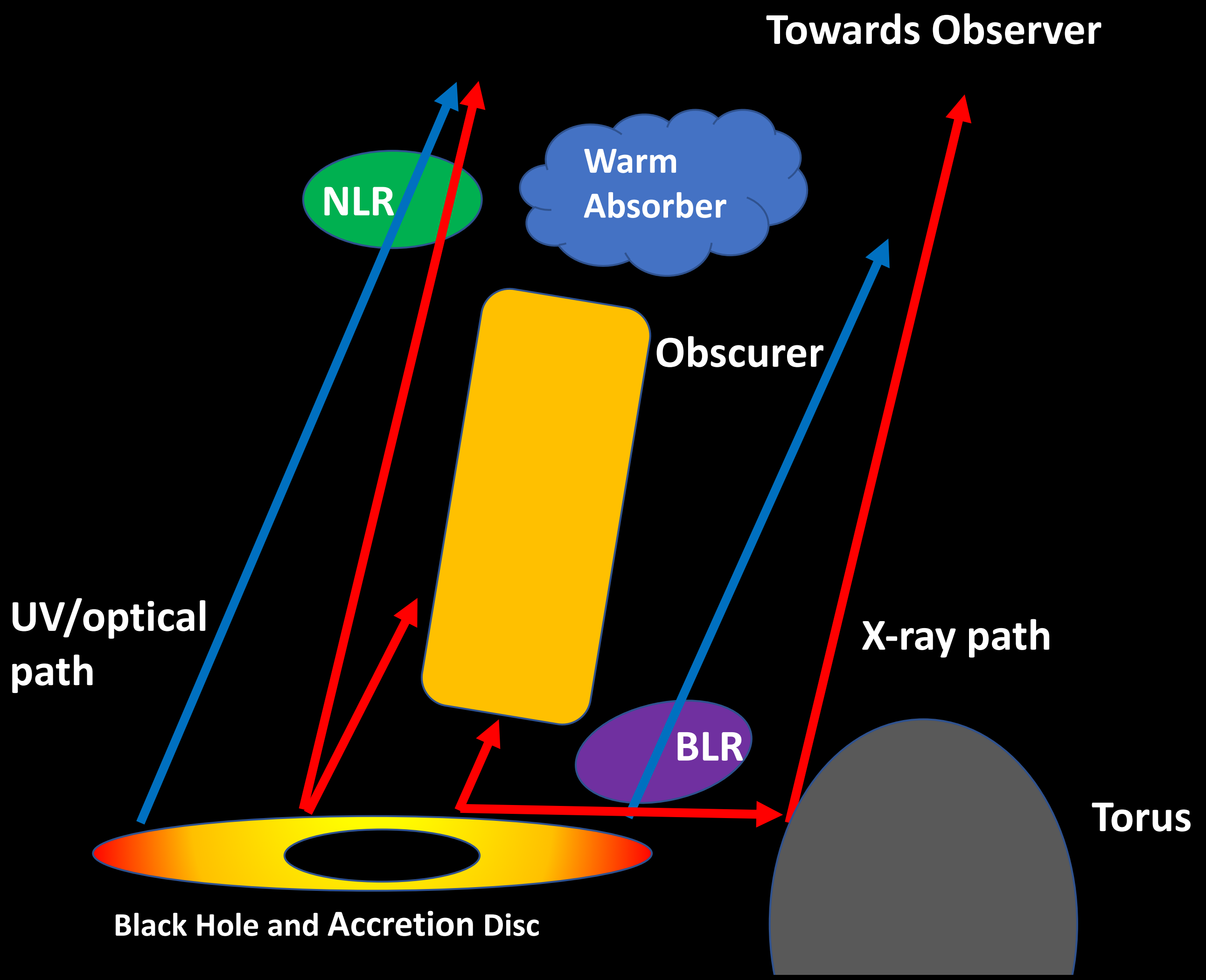


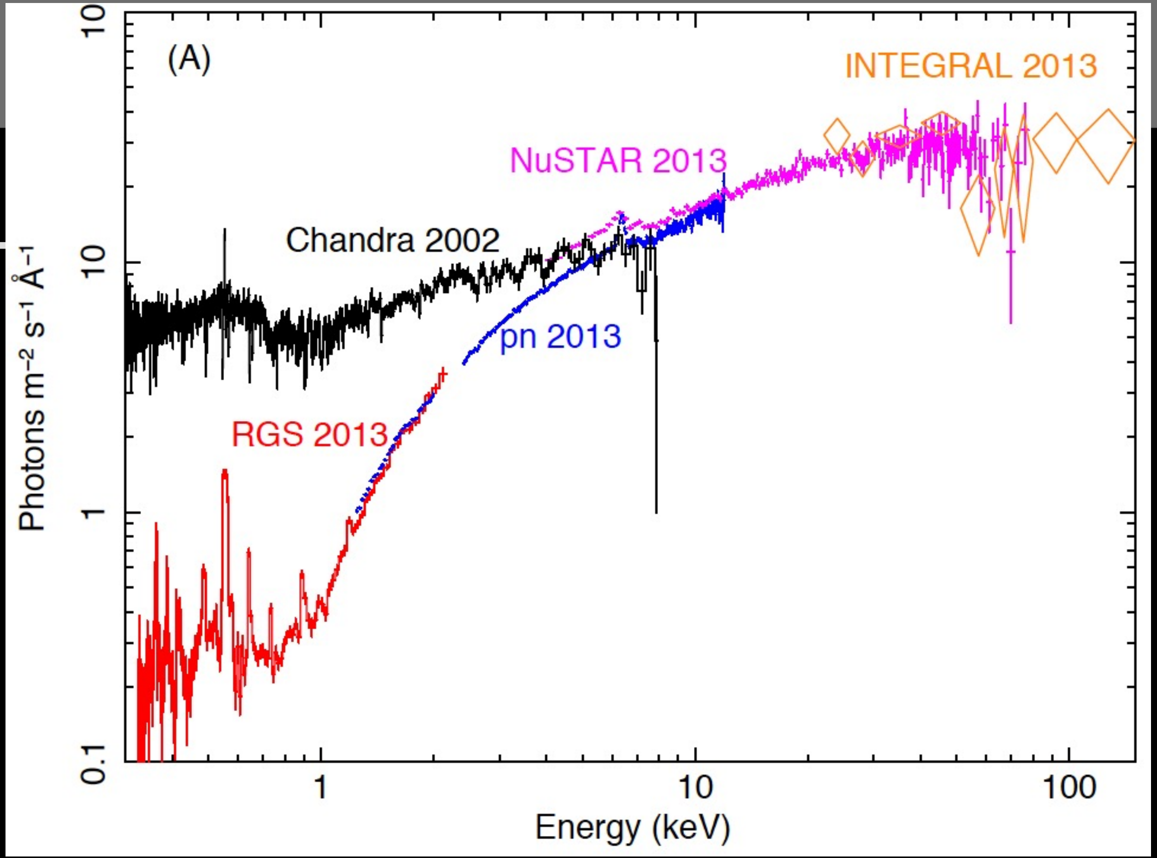
Chandra Spectrum 2000;
J. Kaastra et al 2000



RGS Spectrum 2013;
M. Whewell et al. 2015

The Obscurer



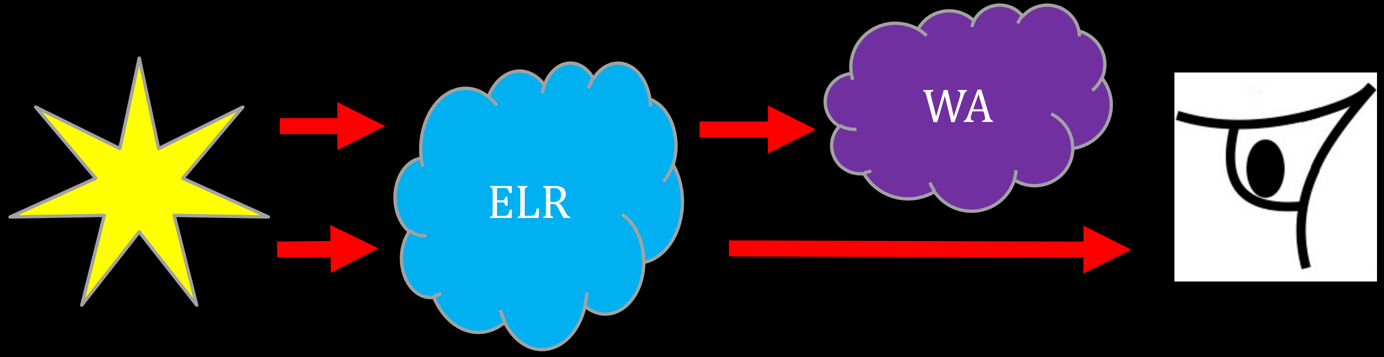


J. Kaastra et al. 2014

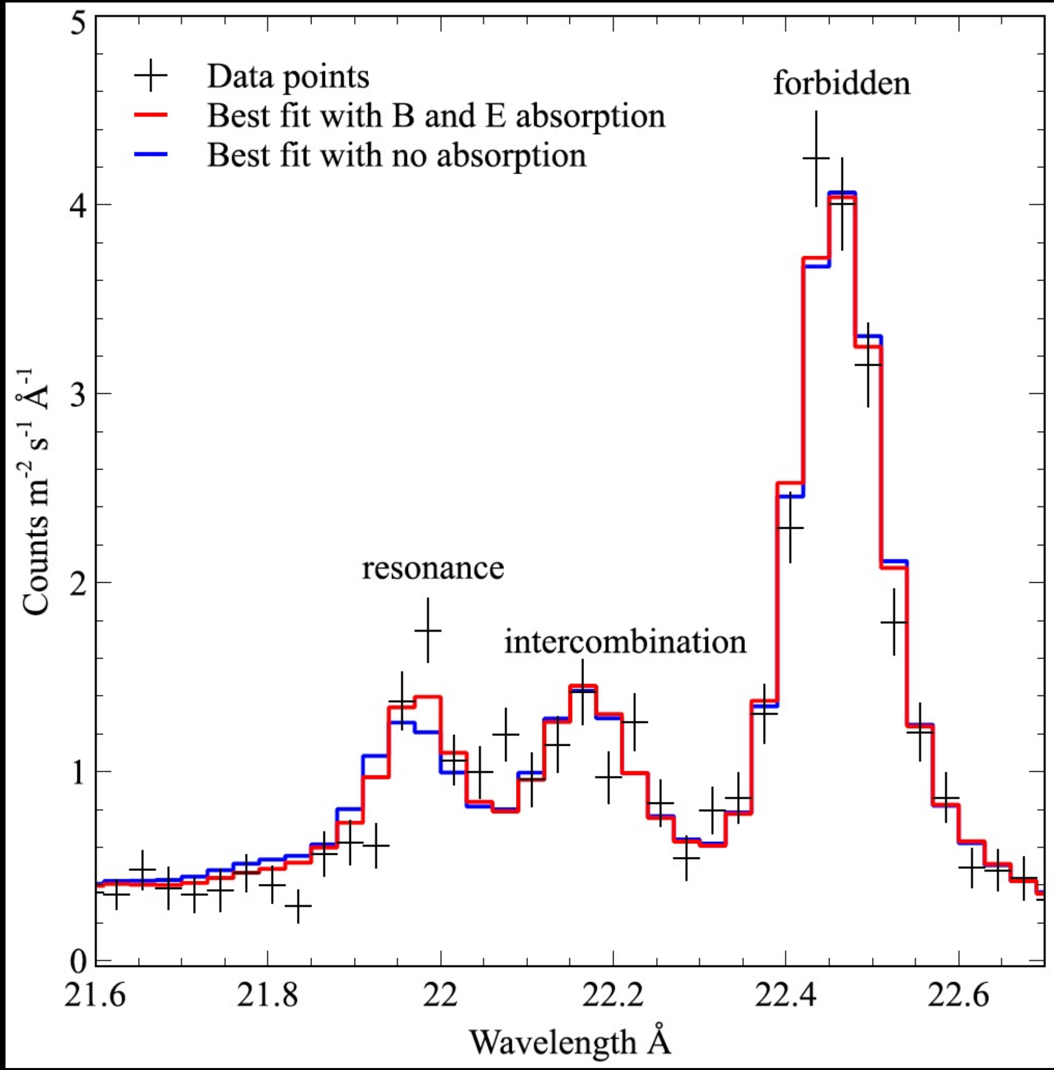
- 2 components
- v_{out} ~ 5000 km/s
- Covers 80% of X-ray flux
- r = few light days
- Obscuration event 7+ years long

O VII Discrepancy

Line [a]	Rest λ (Å)	Measured λ [b c] (Å)	Flow velocity (km s^{-1})
O VIIr	21.602	21.601±0.004	−20 ± 50
O VIIi	21.807	21.772±0.020	−480 ± 160
O VIIf	22.101	22.077±0.002	−320 ± 40



M. Whewell et al. 2015



Multi-Component Model

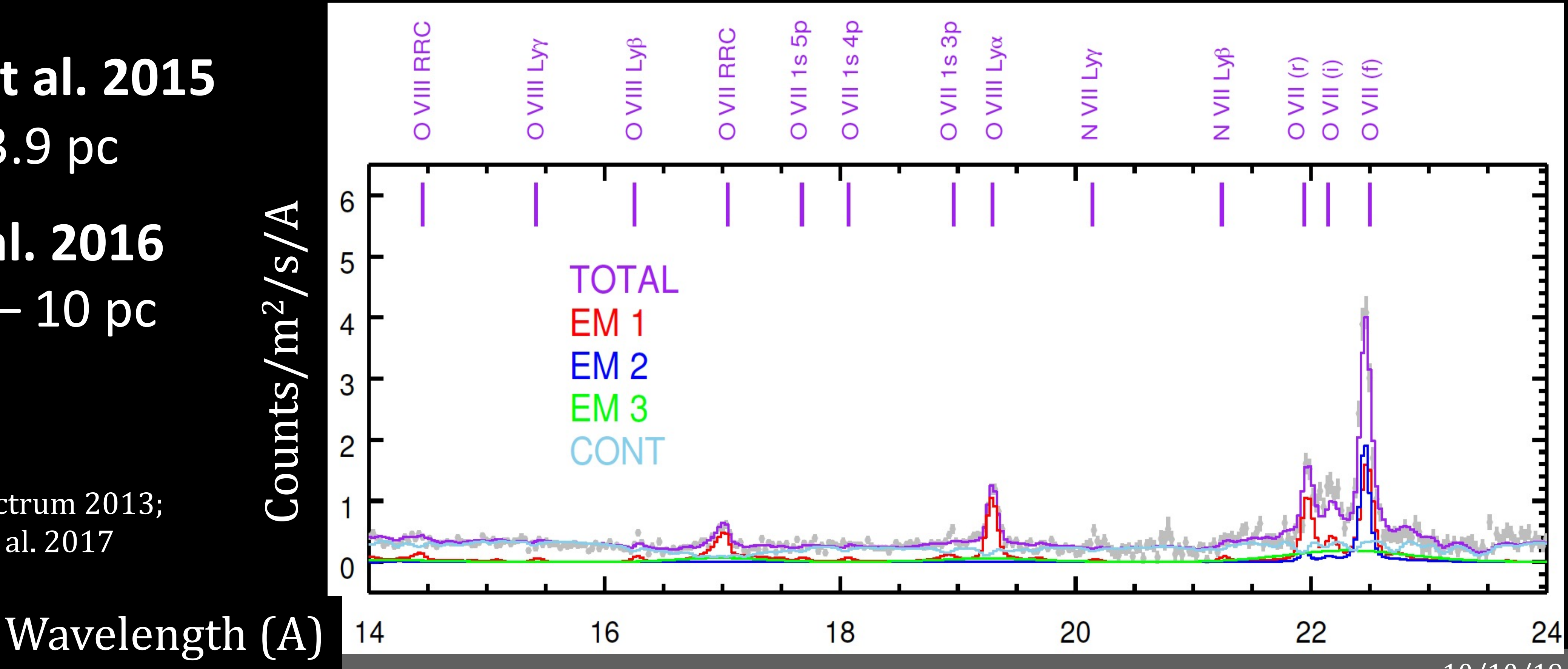
Comp.	N_H (10^{25} m^{-2})	log (ξ) (10^{-9} W m)	v_{mic} (km s^{-1})	v_{out} (km s^{-1})
EM 1	14.7 ± 0.1	1.30 ± 0.02	520 ± 40	−49 ± 6
EM 2	19.3 ± 1.3	0.14 ± 0.04	250 ± 60	−410 ± 50
EM 1	9.7 ± 1.3	1.31 ± 0.02	400 ± 30	−47 ± 4
EM 2	30 ± 7	0.13 ± 0.05	< 280	−420 ± 30
EM 3	23 ± 6	1.24 ± 0.07	100 (f)	0 (f)

Whewell et al. 2015

- r_{ELR} = 13.9 pc

Ebrero et al. 2016

- r_{WA} = 5 – 10 pc

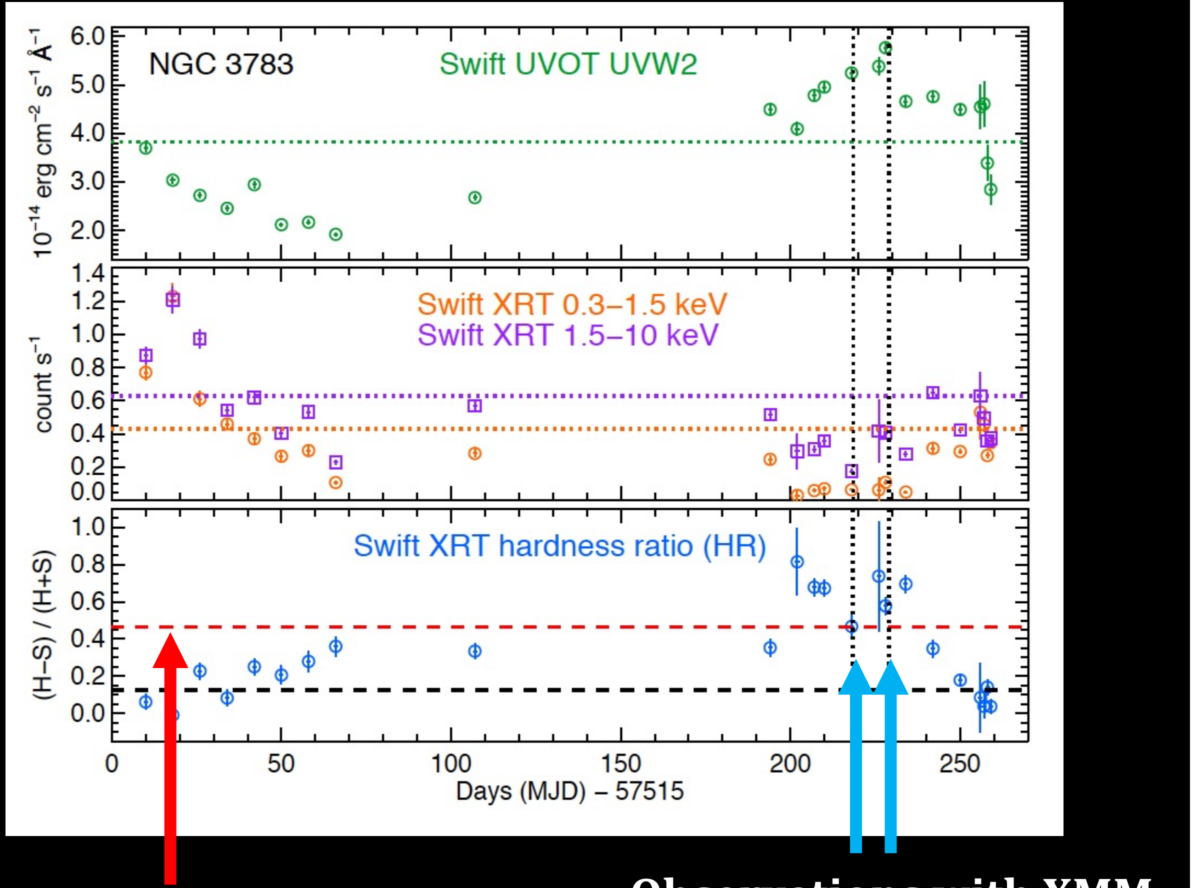


RGS Spectrum 2013;
J. Mao et al. 2017

NGC 3783

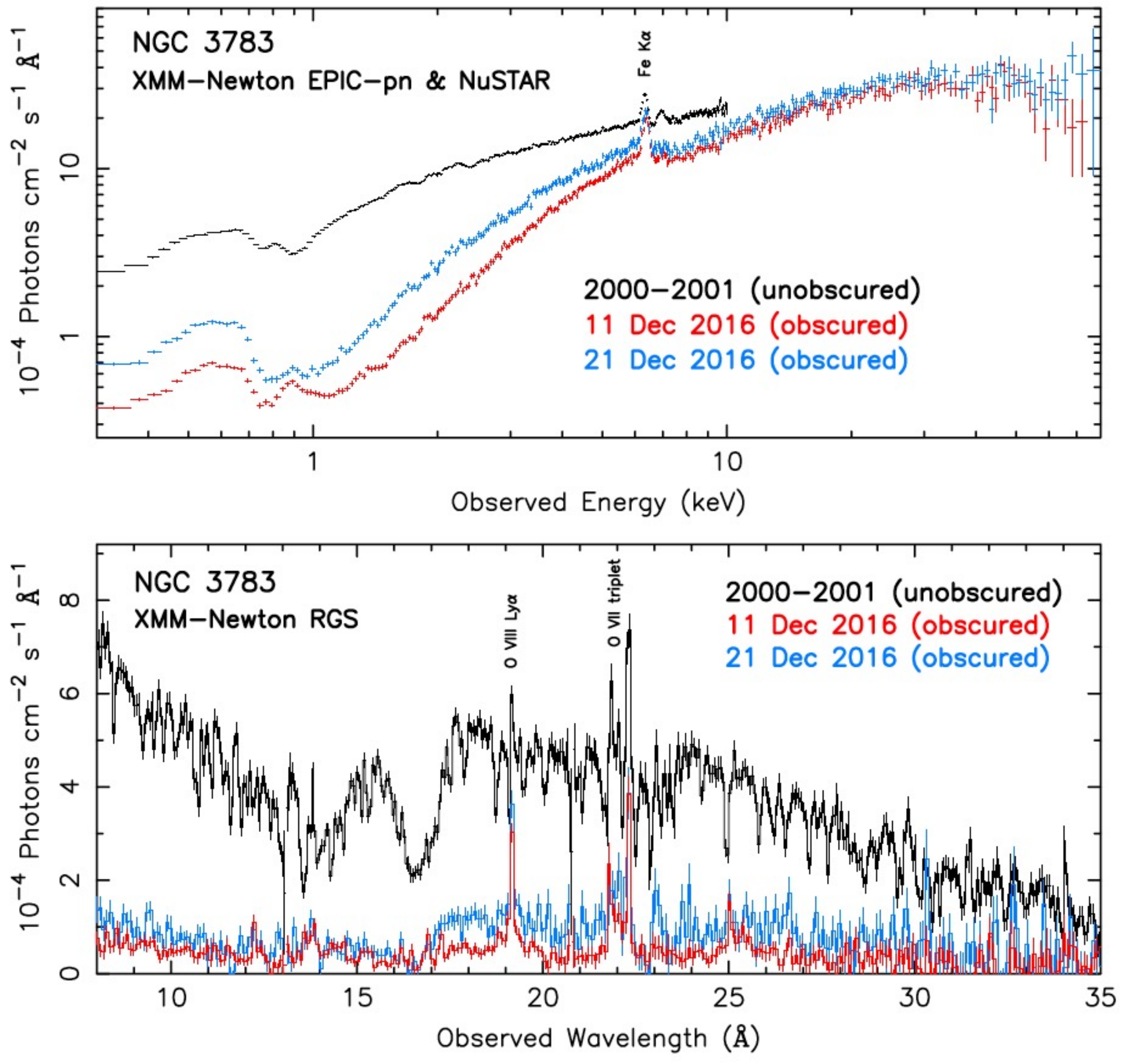
DSS; Simbad

Swift Triggering



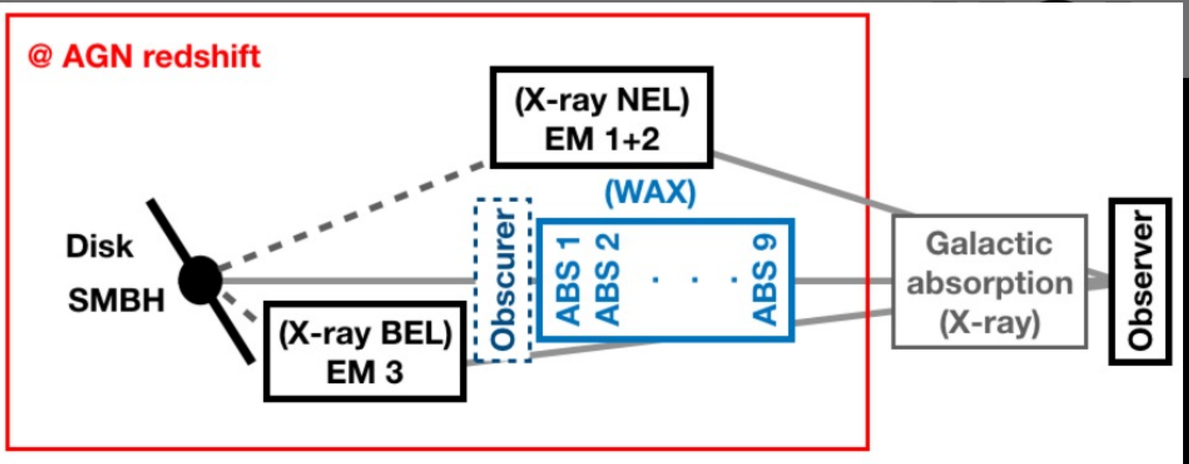
Hardness ratio triggering limit

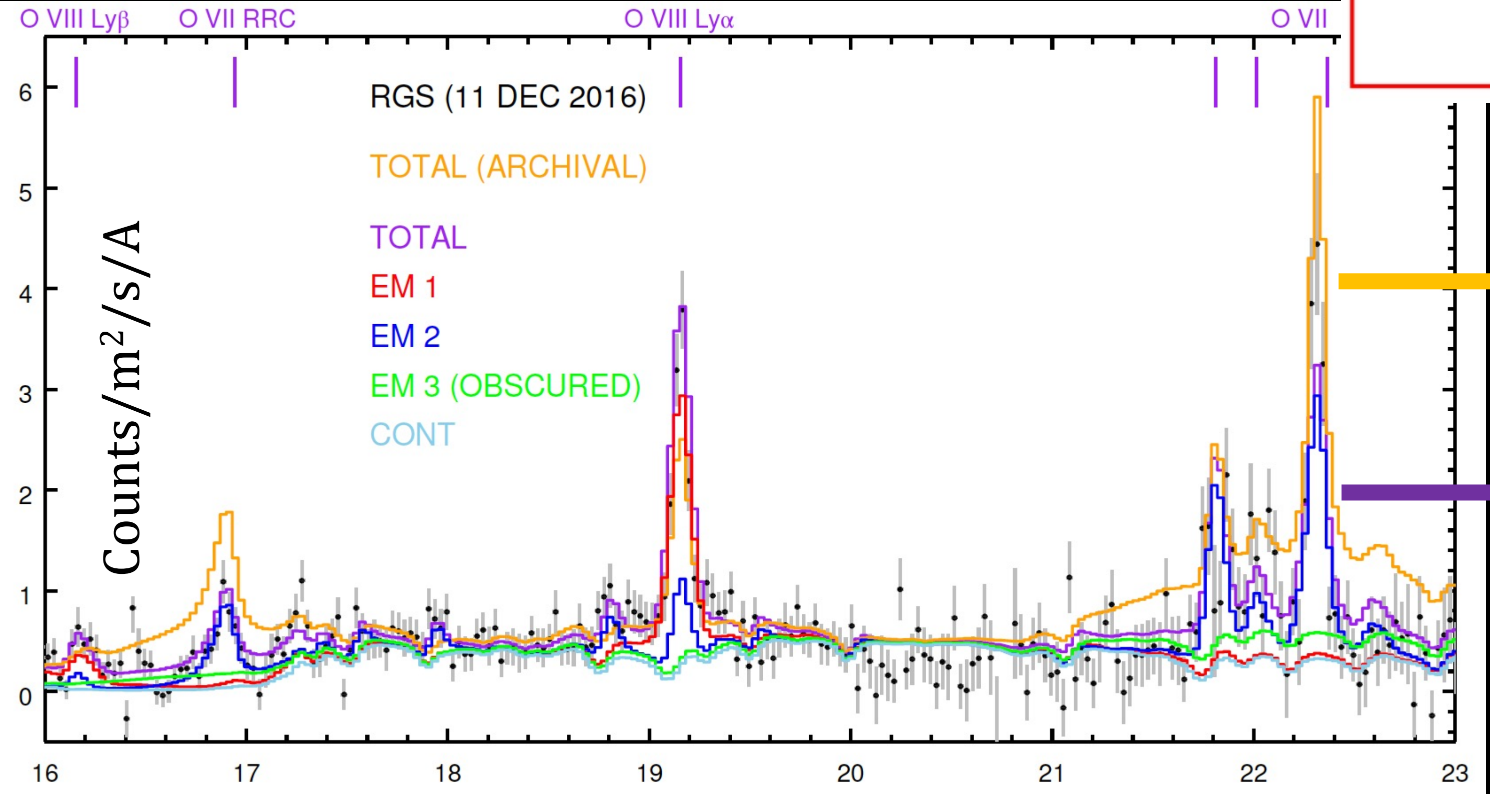
Observations with XMM, NuSTAR and HST



M. Mehdipour et al. 2017

Multiple Emission Components





Wavelength (A)

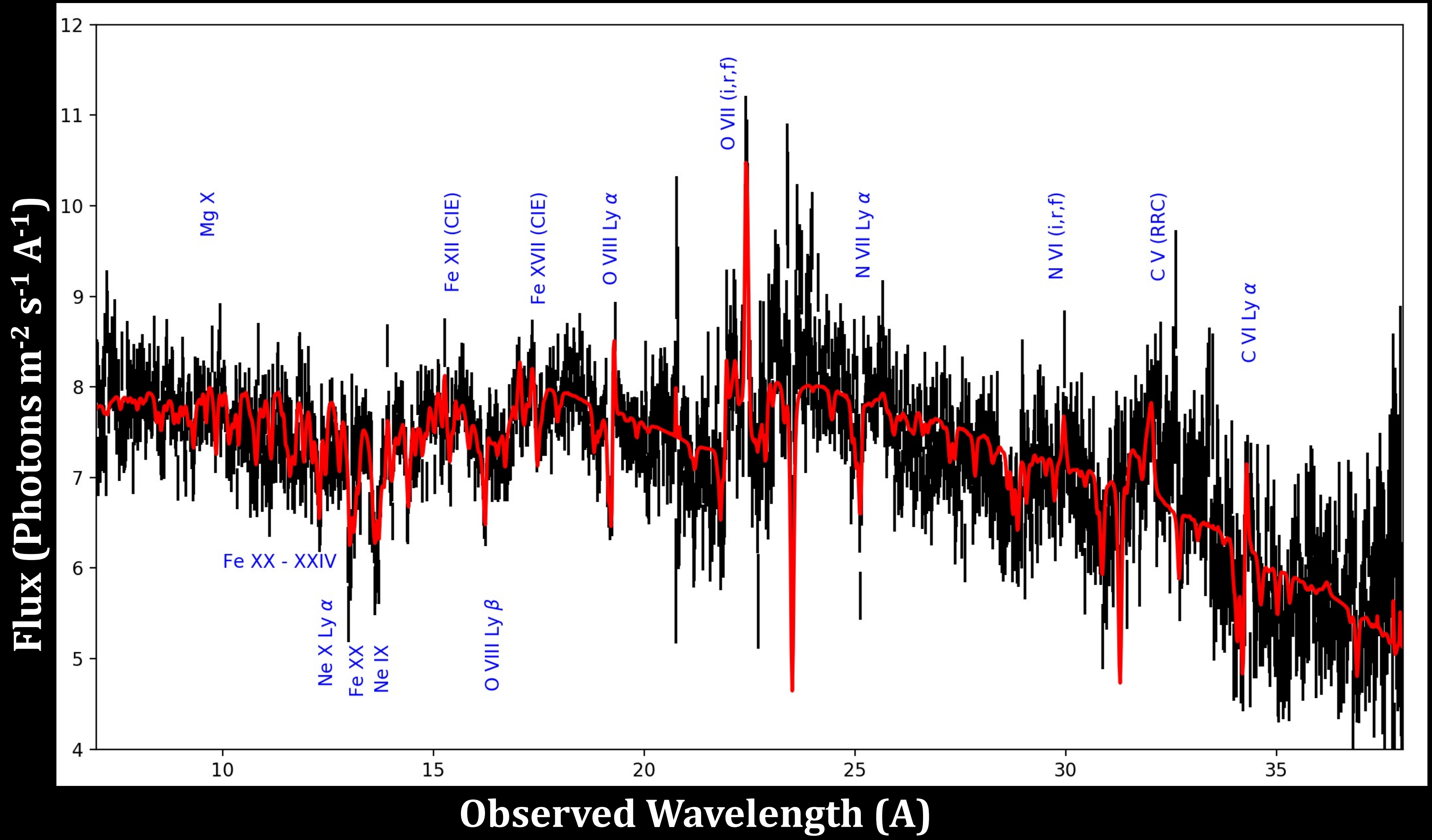
Comp.	N_H 10^{26} m^{-2}	$\log_{10}(\xi)$ 10^{-9} W m	v_{mic} km s^{-1}	C_{em} %	E.M. 10^{70} m^{-3}
			2000–2001		
1	60 ± 37	2.60 ± 0.07	600 ± 100	0.29 ± 0.12	$0.5^{+0.8}_{-0.4}$
2	$5.2^{+5.4}_{-2.3}$	1.35 ± 0.05	140^{+50}_{-100}	$0.6^{+0.4}_{-0.2}$	$1.5^{+4.1}_{-1.0}$
3	28^{+72}_{-5}	0.82 ± 0.02	100 (f)	$0.3^{+0.1}_{-0.2}$	13^{+53}_{-10}
			11 DEC 2016		
1	25 ± 6	2.58 ± 0.05	590 ± 90	0.98 ± 0.13	$1.0^{+0.6}_{-0.4}$
2	3.0 ± 0.7	1.03 ± 0.05	350 ± 70	7.0 ± 1.3	30^{+19}_{-13}
3	28 (f)	1.00 (f)	100 (f)	0.3 (f)	13 (f)

J. Mao et al. 2018

NGC 7469

NASA/ESA/Hubble

RGS Analysis – Our Contribution



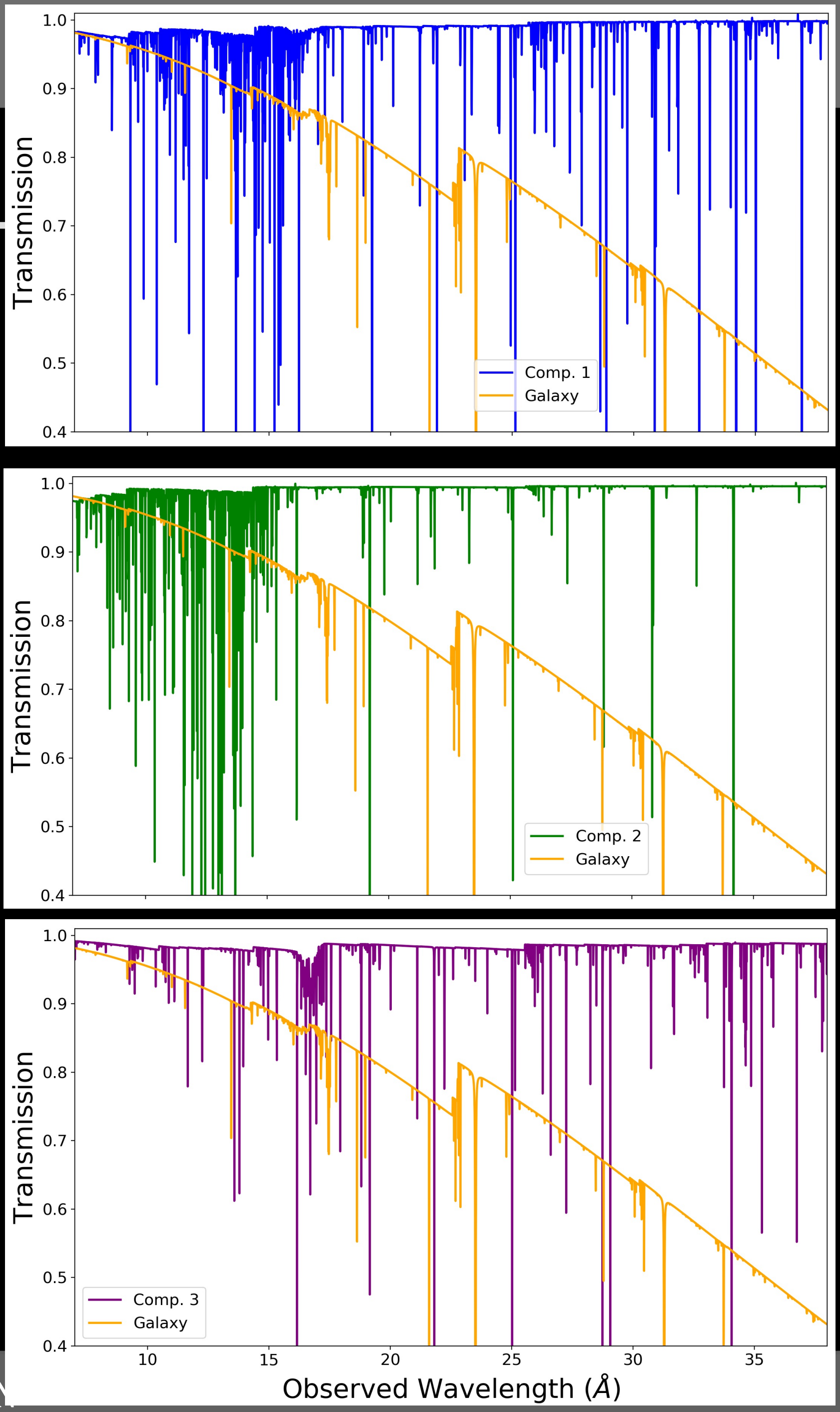
The Warm Absorber

Absorption Component	N_H (10^{24} m^{-2})	log ξ (10^{-9} Wm)	v_{turb} (km s^{-1})	v_{out} (km s^{-1})
1	$10.0^{+0.5}_{-0.4}$	2.32 ± 0.01	35 ± 2	-630 ± 20
2	52.0 ± 2.2	3.00 (f)	[a] -	-910^{+50}_{-30}
3	2.3 ± 0.1	1.57 ± 0.04	11 ± 3	-1960 ± 20

SGW et al. 2019

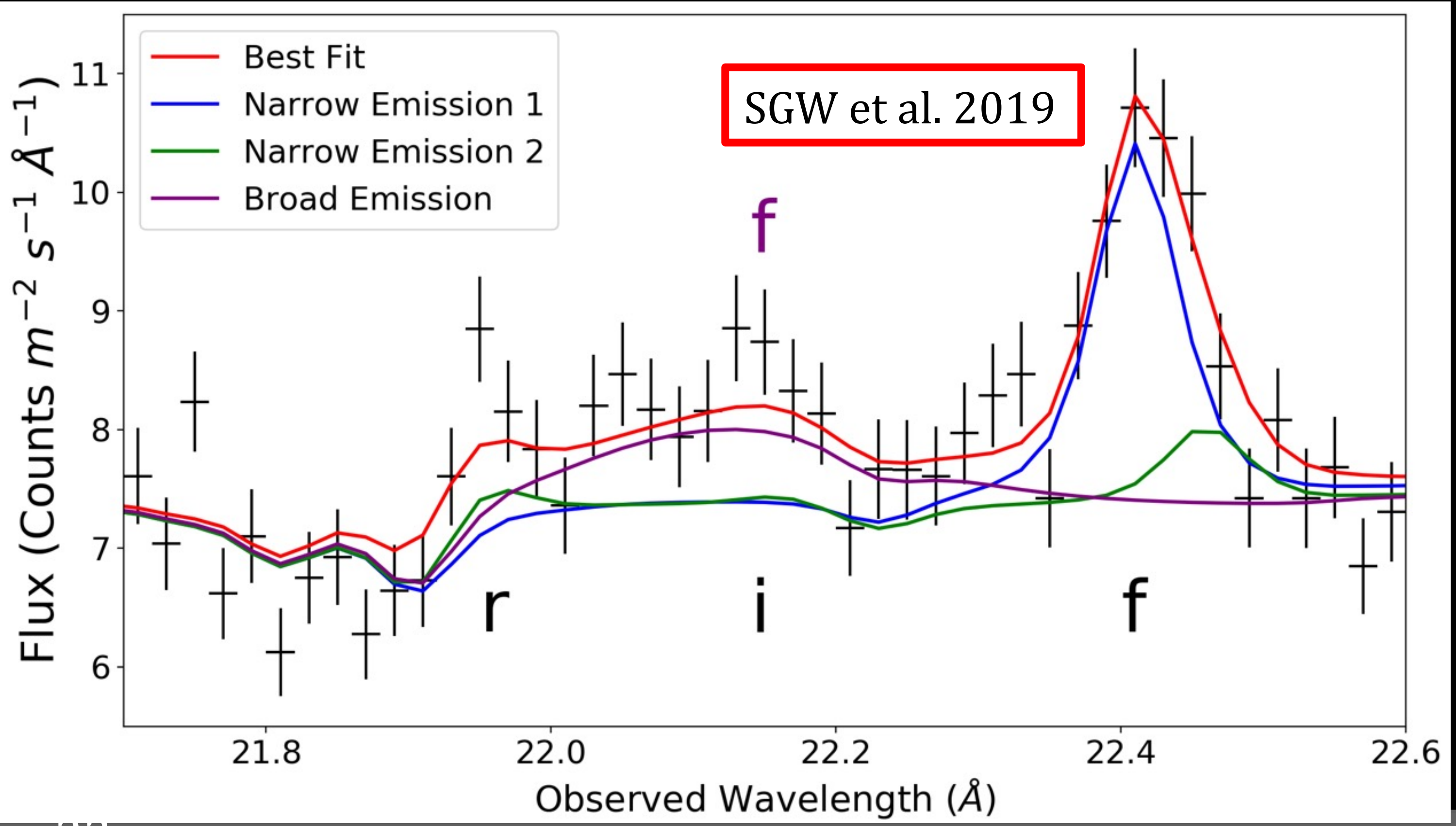
Comp. #	v_{out}[a] (km s^{-1})	v_{turb} (km s^{-1})	log ξ (erg s^{-1} cm)	N_H (10^{20} cm^{-2})	ΔC
1	-650 ± 50	70 ± 10	-0.6 ± 0.2	0.2 ± 0.1	33
2	...	70 ± 10	1.4 ± 0.1	1.0 ± 0.3	221
3	...	70 ± 10	2.0 ± 0.1	5.5 ± 1.0	1027
4	-950^{+50}_{-100}	35 ± 20	2.7 ± 0.2	22 ± 10	383
5	-2050^{+50}_{-160}	60 ± 30	2.0 ± 0.3	1.1 ± 0.3	82
6	...	60 ± 30	0.3 ± 0.2	0.1 ± 0.1	48

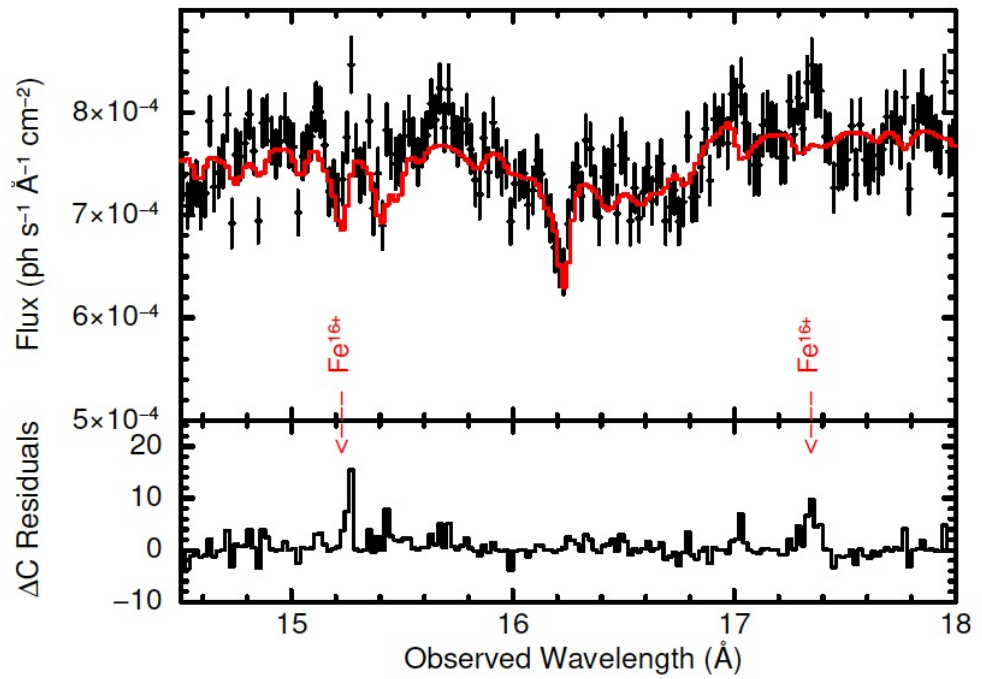
E. Behar et al. 2017



Emission Line Regions

Emission Component	N_H (10^{25} m^{-2})	log ξ (10^{-9} Wm)	v_{turb} (km s^{-1})	v_{out} (km s^{-1})	$C_{cov} = \Omega/4\pi$
EM1	641 ± 50	$0.35^{+0.09}_{-0.01}$	50^{+140}_{-50}	-660^{+110}_{-20}	$2.1 \pm 0.2 \times 10^{-4}$
EM2	42^{+7}_{-6}	1.55 ± 0.08	50^{+180}_{-30}	0 (f)	$2.1 \pm 0.3 \times 10^{-3}$
EM3	787^{+130}_{-110}	$0.18^{+0.01}_{-0.07}$	^{a} 1360^{+340}_{-270}	-4460^{+200}_{-110}	$1.4 \pm 0.2 \times 10^{-4}$

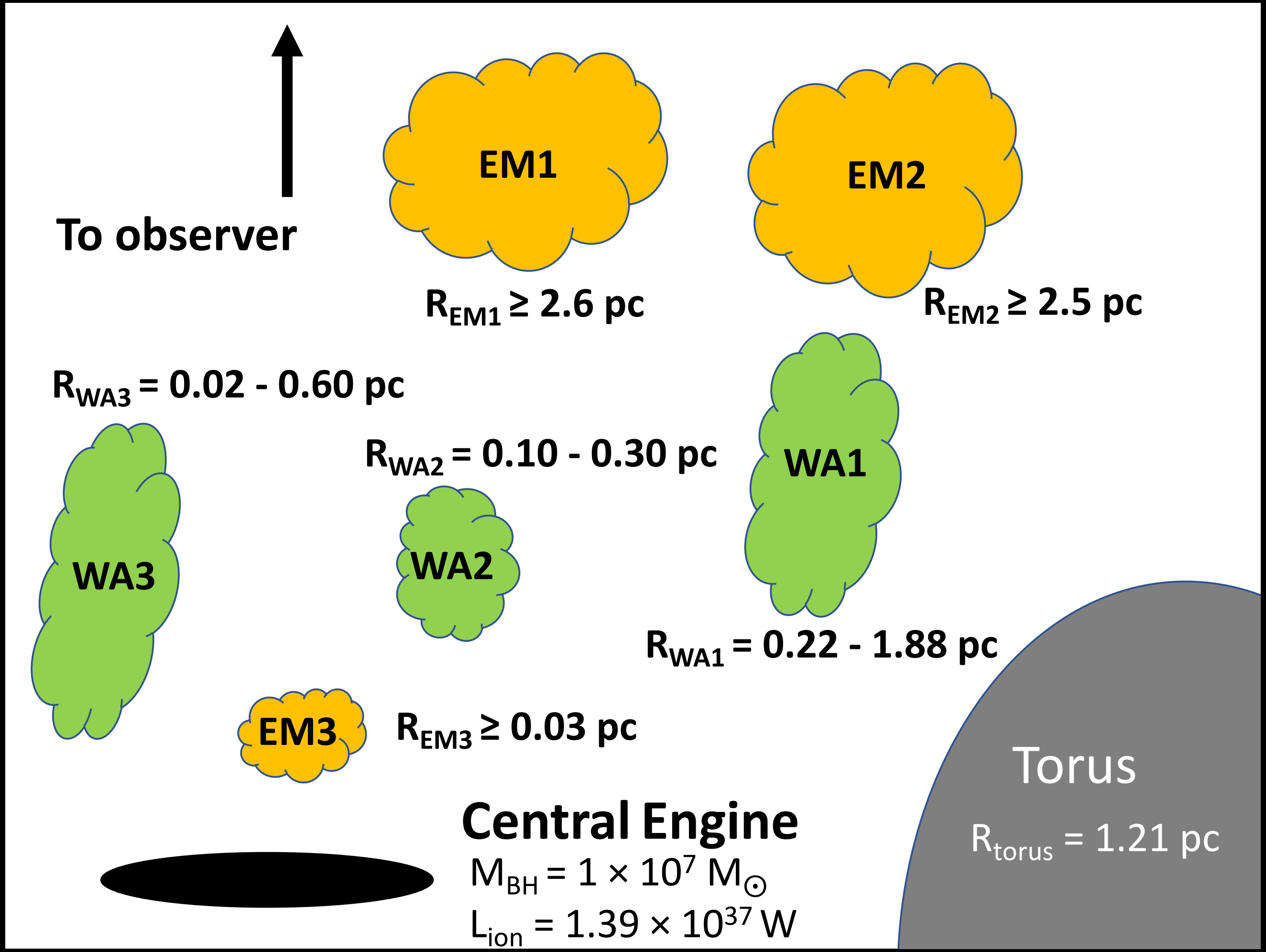




E. Behar et al. 2017

Location of ELR

f = volume filling factor



$$r_{min} = \frac{L_{ion} f}{N_H \xi}$$

$$N_H = \int_{r_{min}}^{r_{max}} nf\, dr$$

$$\xi \equiv \frac{L_{ion}}{nr^2}$$

Assume:

- Extended regions
- No further absorption by WA

Values for f

- Require f value < 1
  - $f \sim 0.01$ for most nebulae (e.g. Osterbrock 1991).
  - $f \sim 0.001$ for BLR (e.g. Sneddon & Gaskell 1999).
- For EM1 and EM2 we assume $f = 0.1$
- For EM3 $f = 0.001$

Emission Comp.	R (pc)
EM1	$2.62^{+0.31}_{-0.73}$
EM2	$2.52^{+1.05}_{-0.81}$
EM3	0.03 ± 0.01

$$r_{min} = \frac{L_{ion} f}{N_H \xi}$$

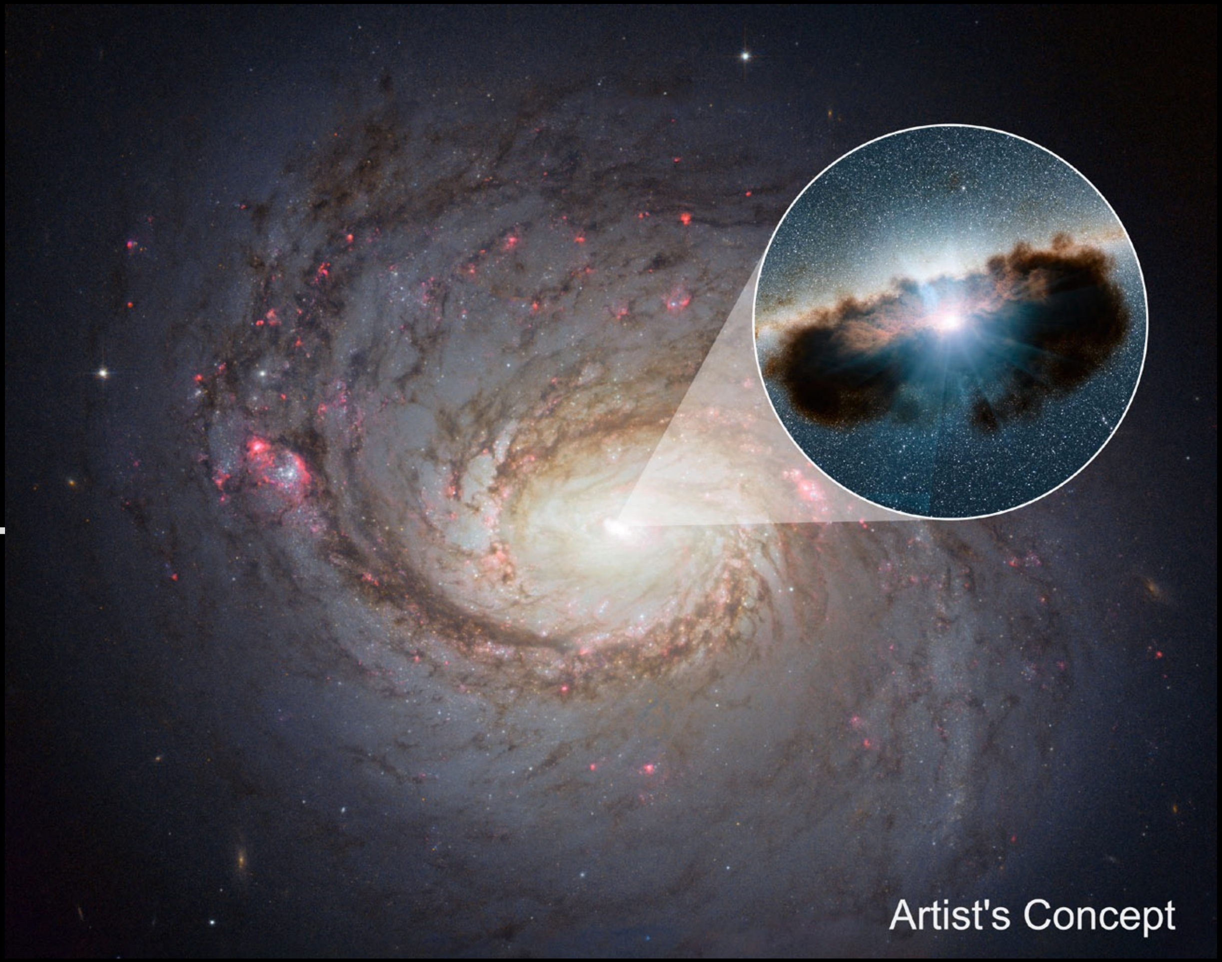
However …

- Optical BLR r_{BLR} = 0.004 pc (Kollatschny & Zetzl 2013).
- Kinematics: $v_{esc} = v_{out} \sim -4500$ kms^{-1} $\left(R = \frac{2GM_{BH}}{v_{out}^2}\right)$
  - $r_{EM3} \simeq 0.004$ pc.
- Possible solution: $f_{EM3} < 0.001$
- But most likely due to ξ of EM3

Conclusions for NGC 7469

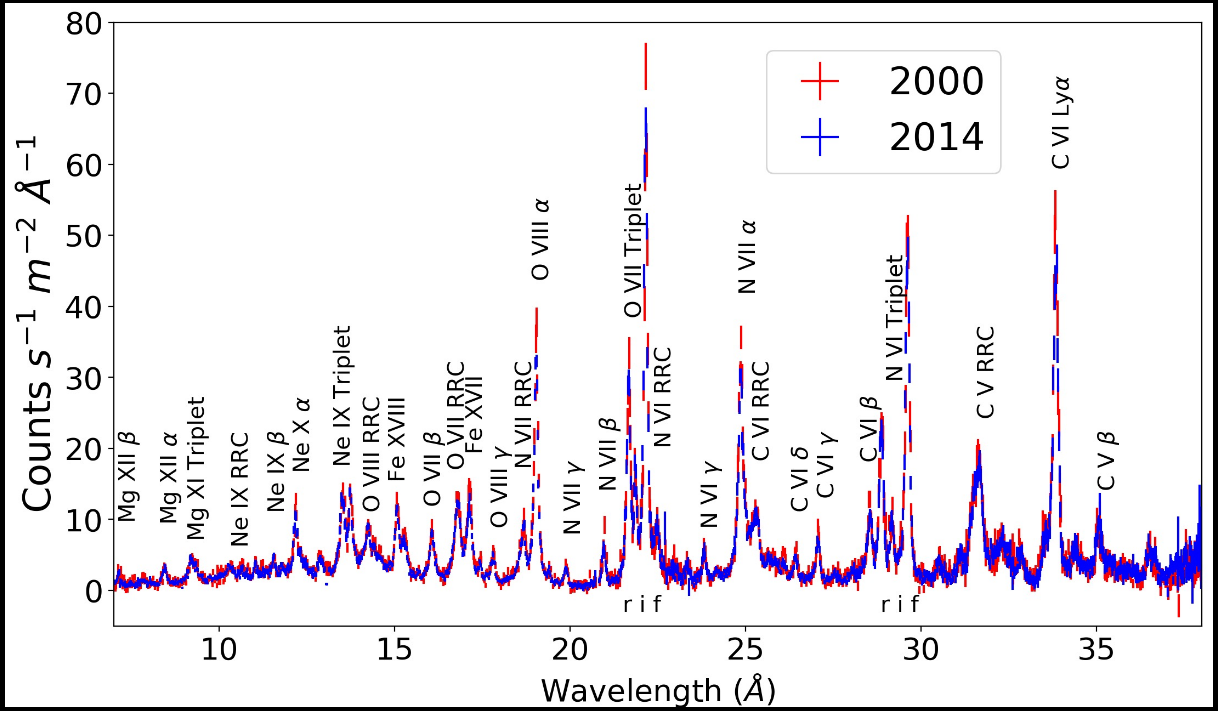
- WA can be explained by 3 components – different N_H, v_{out}, ξ
- Most emission lines are fitted with 2 narrow emission components
- Able to measure the distances of the Narrow Line Region
  - Assuming no further absorption by the WA
- Some lines require a broad component
  - Uncertain if it is a physical component

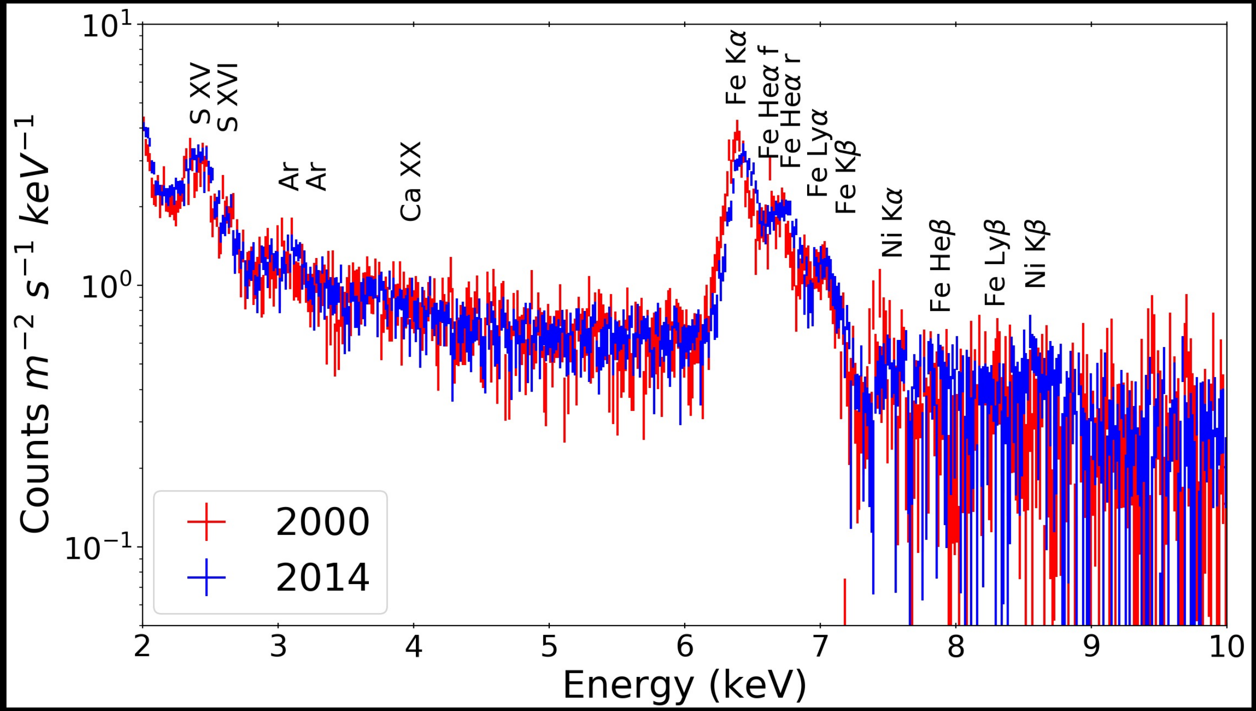
NGC 1068



NASA/JPL-Caltech

XMM-Newton Spectra of NGC 1068





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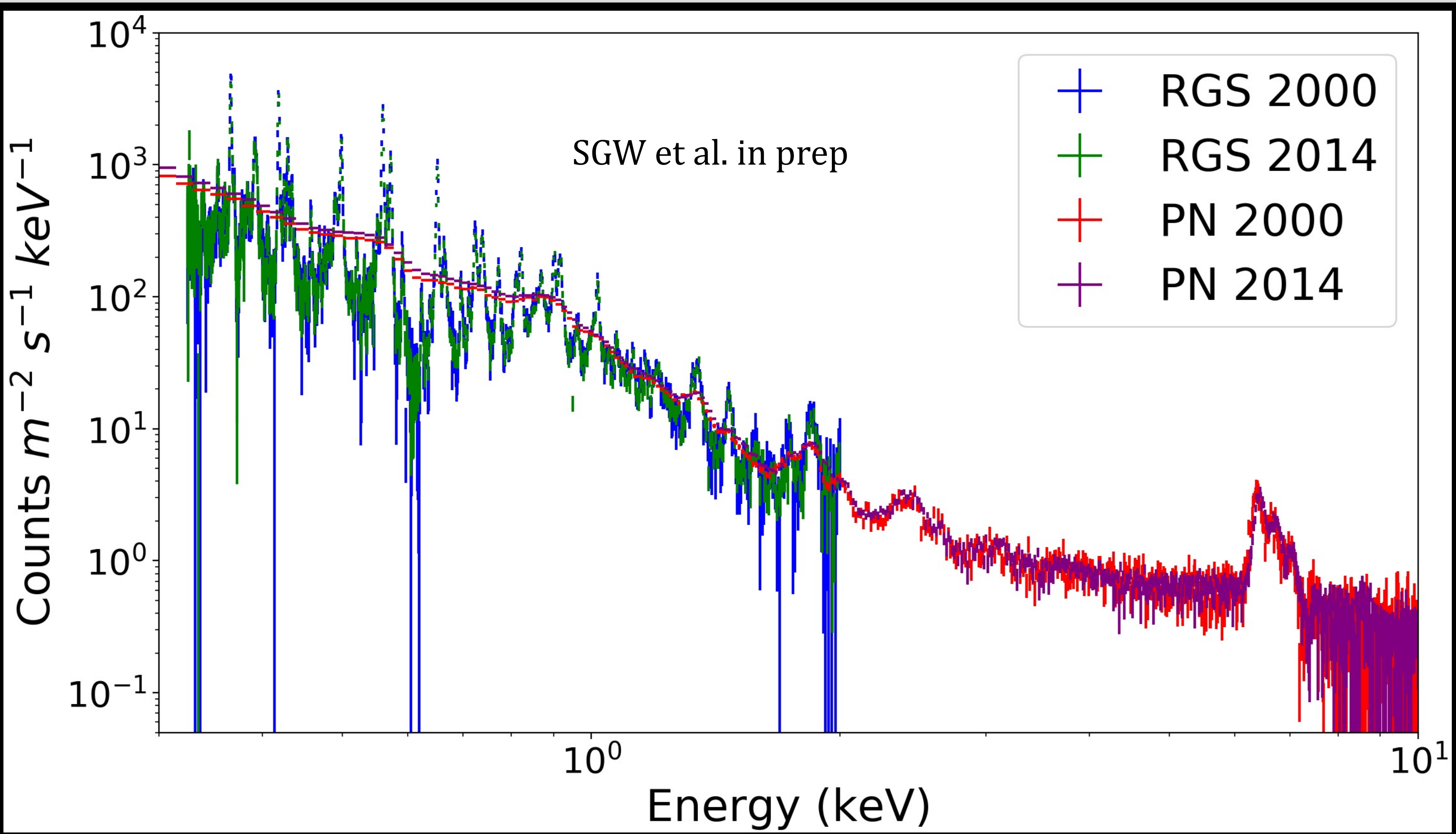
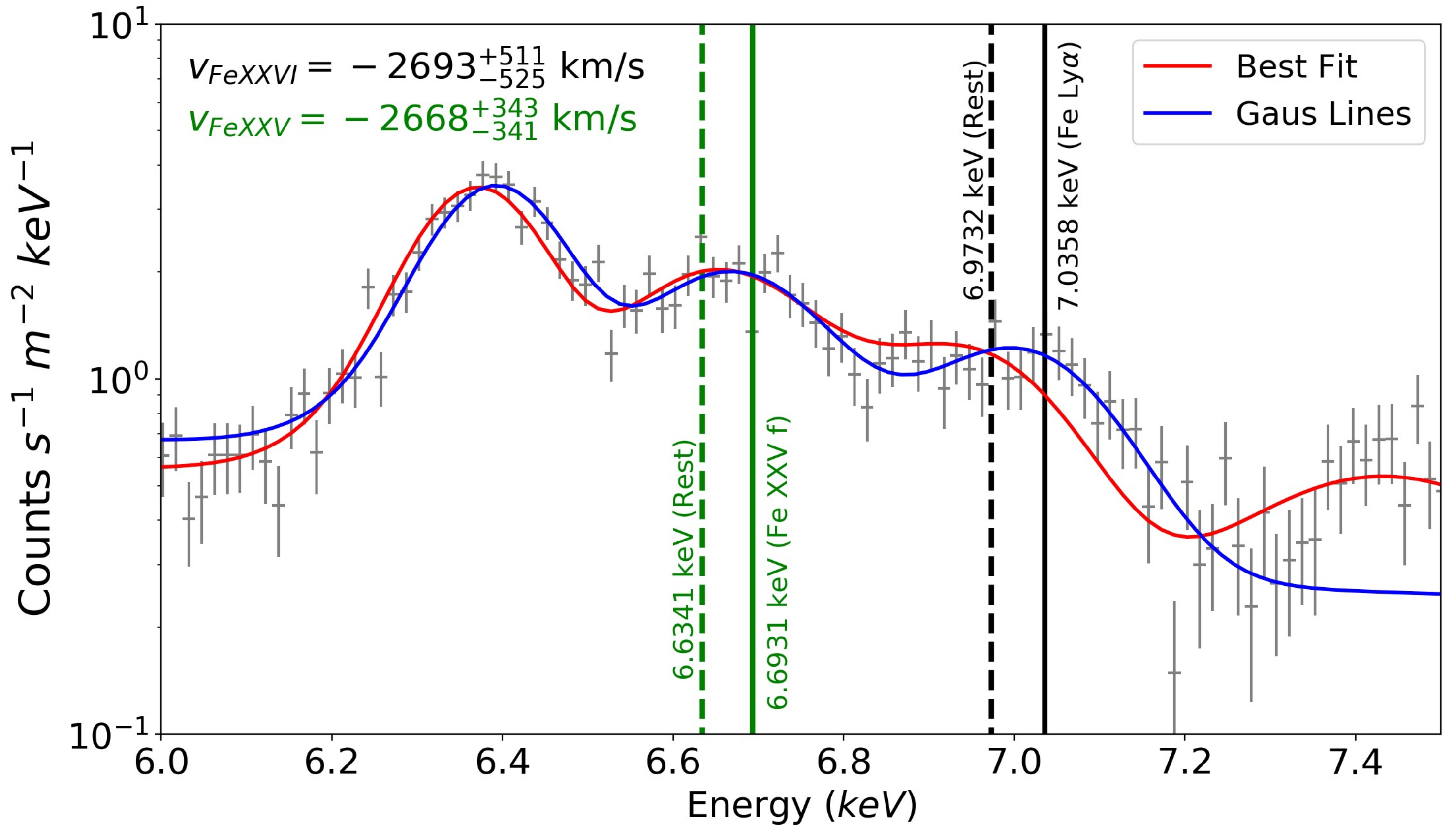
Simultaneous Fitting



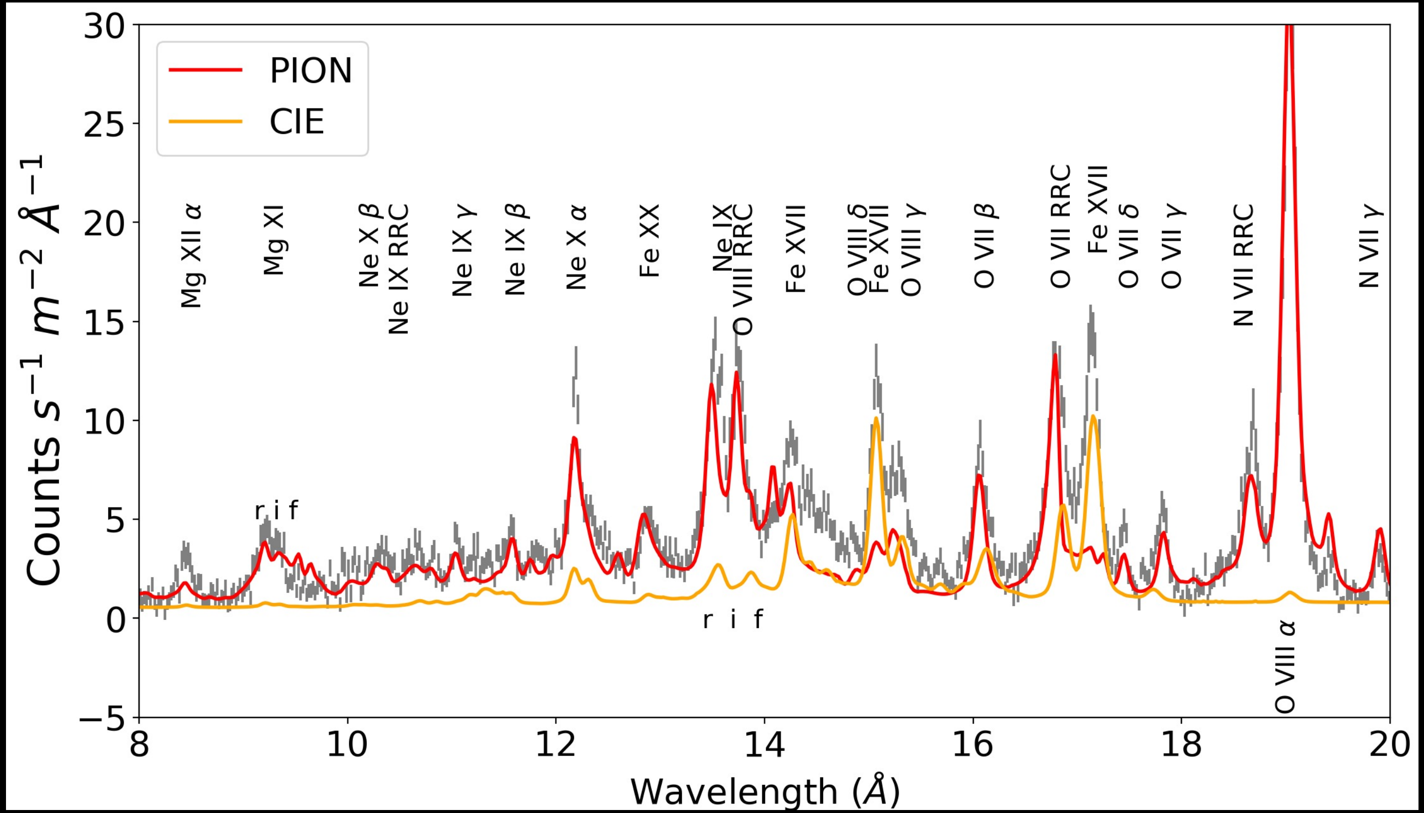
High Energy Lines

- Expect high energy component to be moving faster than lower two
- Find (with Gaussian components) that lines are blueshifted ~ 2680 km/s
- Therefore fix PION at this velocity
- Find a fourth component is required to solve this problem



Obs.	PION Component	N_H (10^{25} m^{-2})	$\log\xi$ (10^{-9} W m)	v (km s^{-1})	v_{out} (km s^{-1})	$C_{cov} = \Omega/4\pi$
2000	EM1	130 ± 30	$3.82^{+0.01}_{-0.02}$	3600^{+330}_{-240} ^{a}	-75^{+86}_{-216}	$0.13^{+0.07}_{-0.06}$
	EM2	37^{+1}_{-4}	0.69 ± 0.01	400 ± 10 ^{b}	-260 ± 10	$3.77 \pm 0.10 \times 10^{-2}$
	EM3	21 ± 2	$1.97^{+0.03}_{-0.01}$	888 ± 20 ^{b}	-150^{+50}_{-5}	$5.64^{+0.92}_{-0.31} \times 10^{-2}$

Collisionally Ionised Plasma



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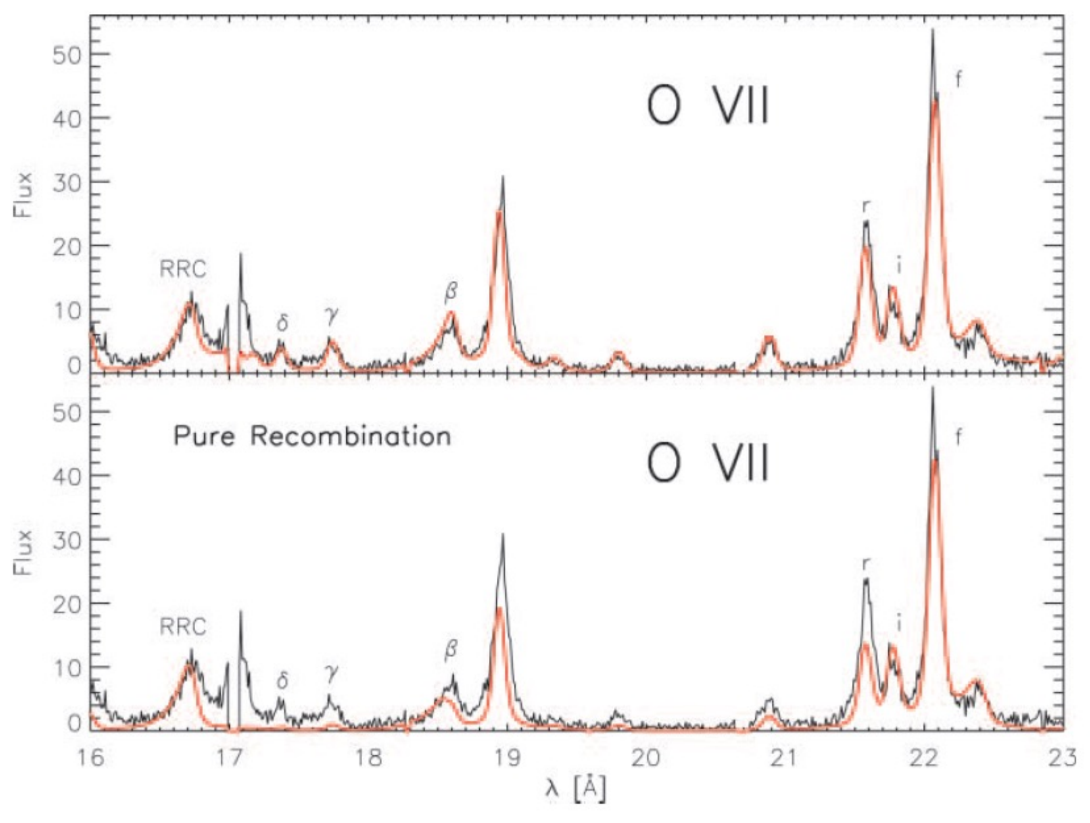
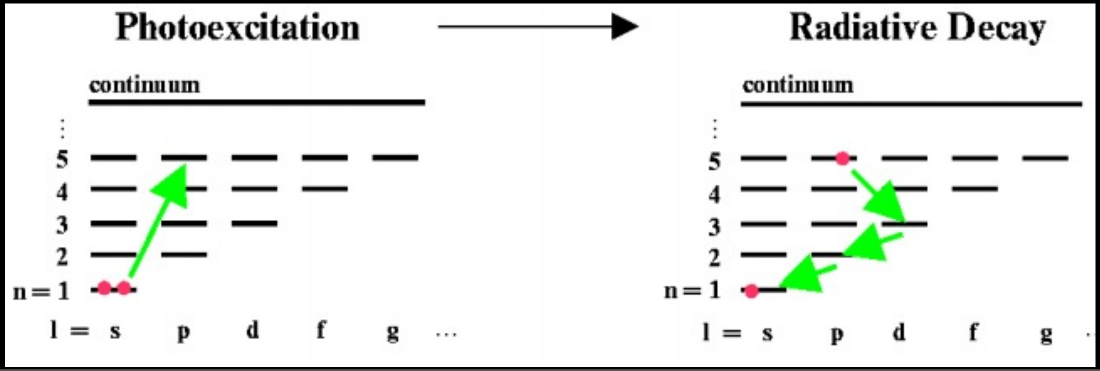
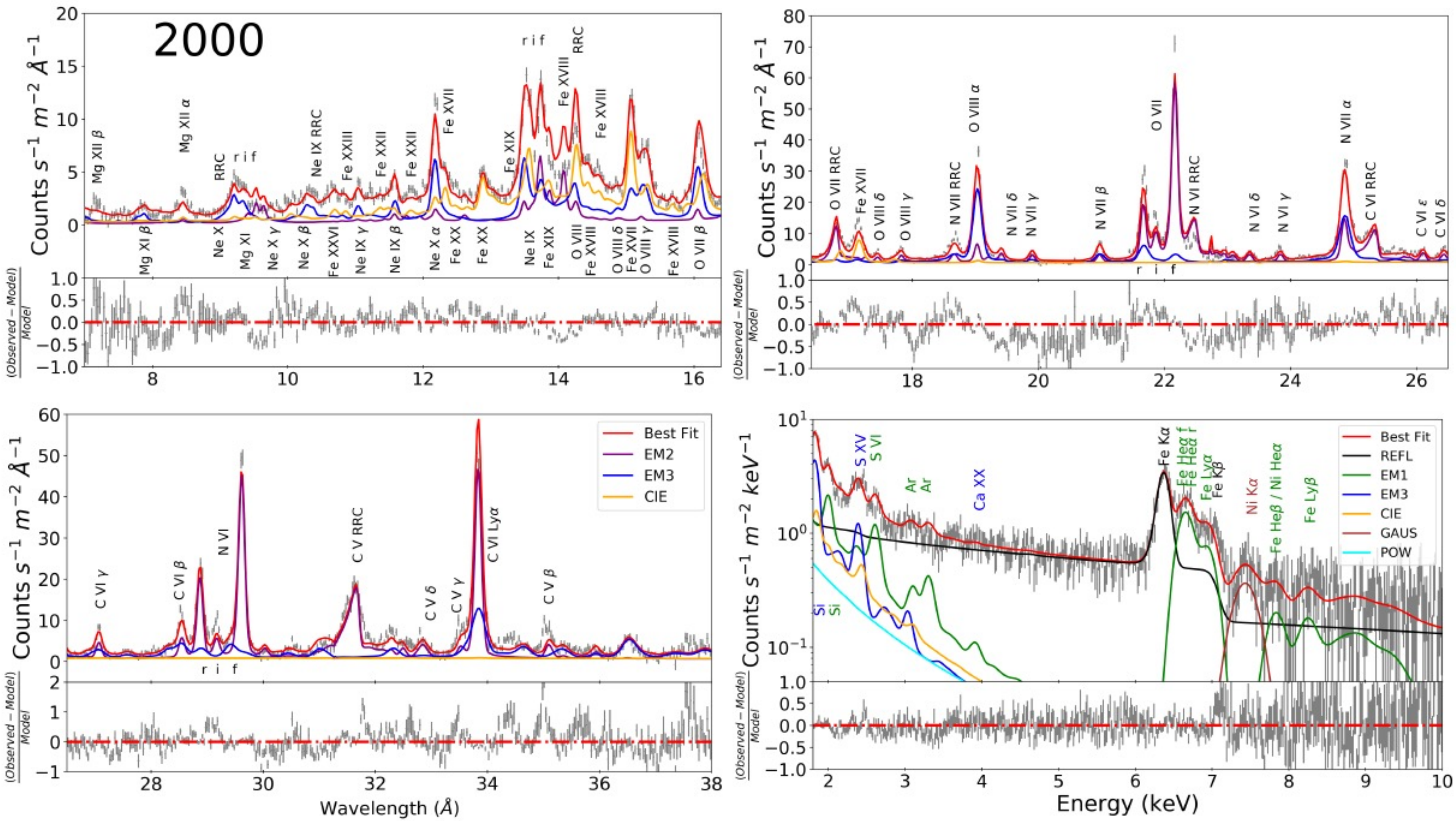


A. Kinkhabwala et al. 2002





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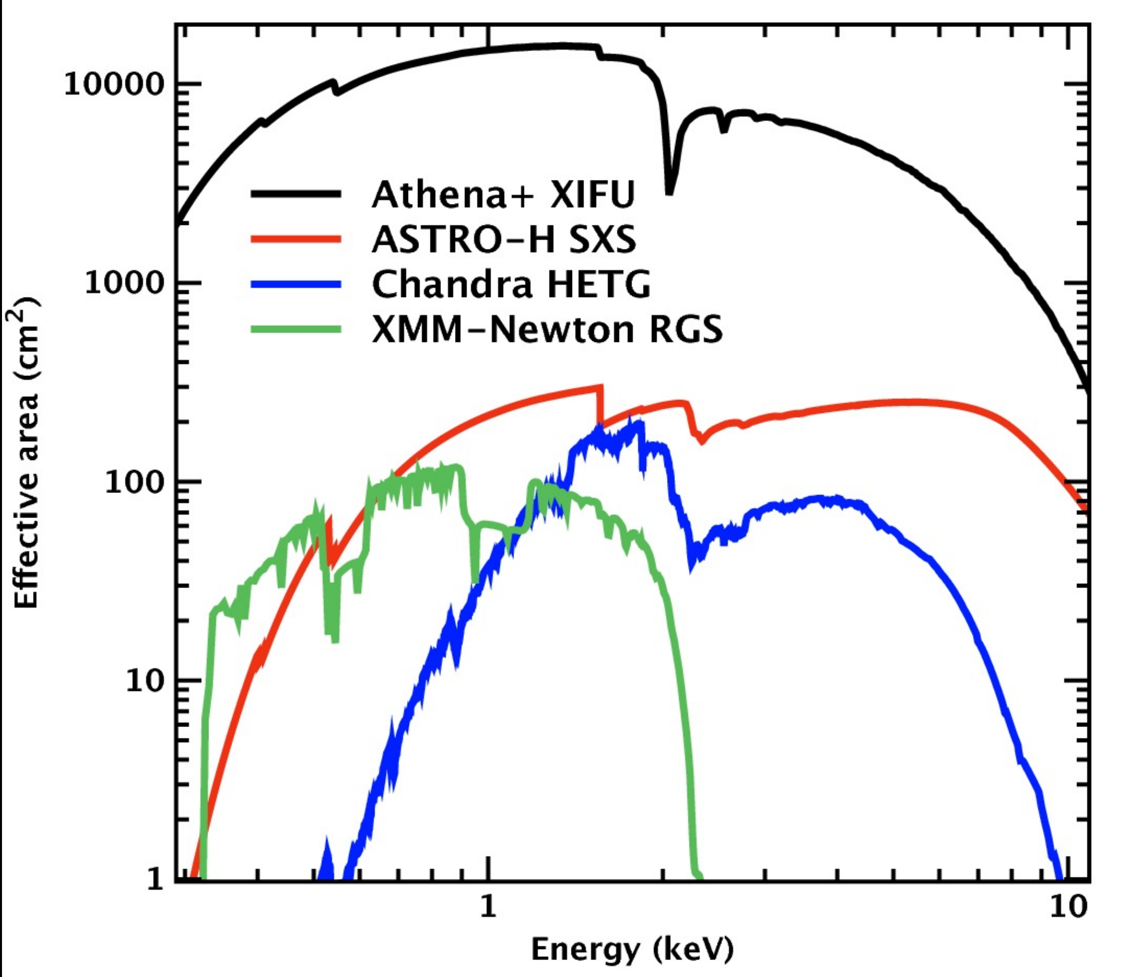
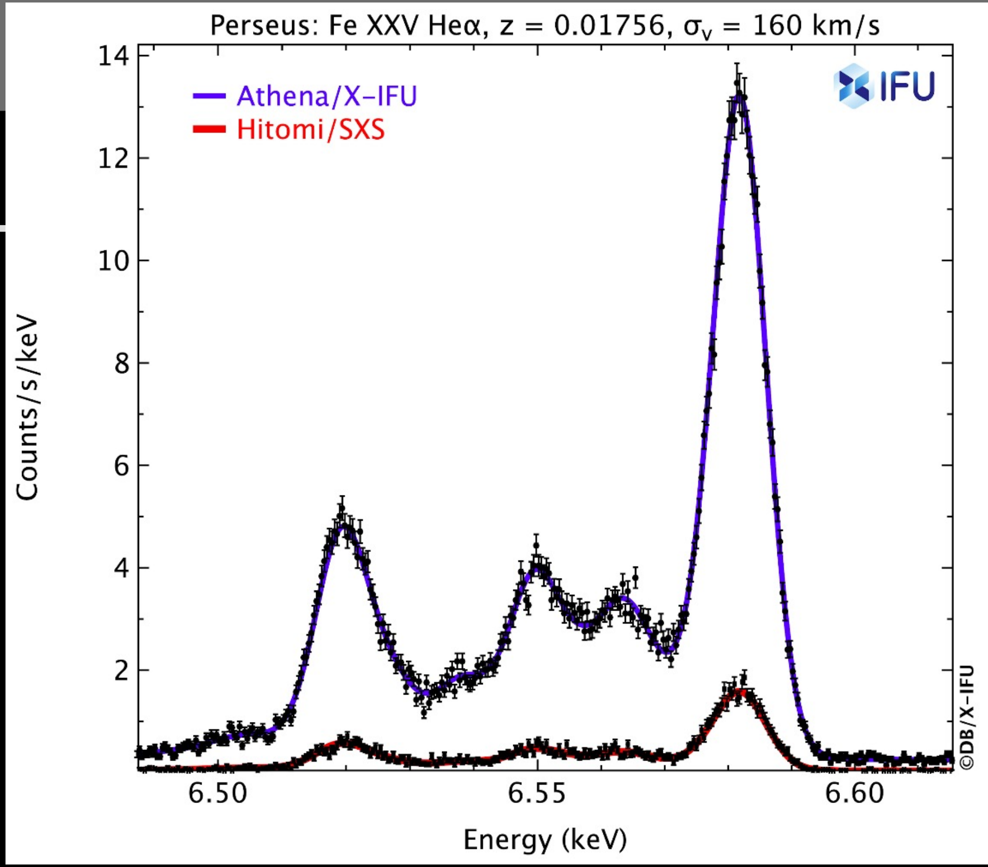
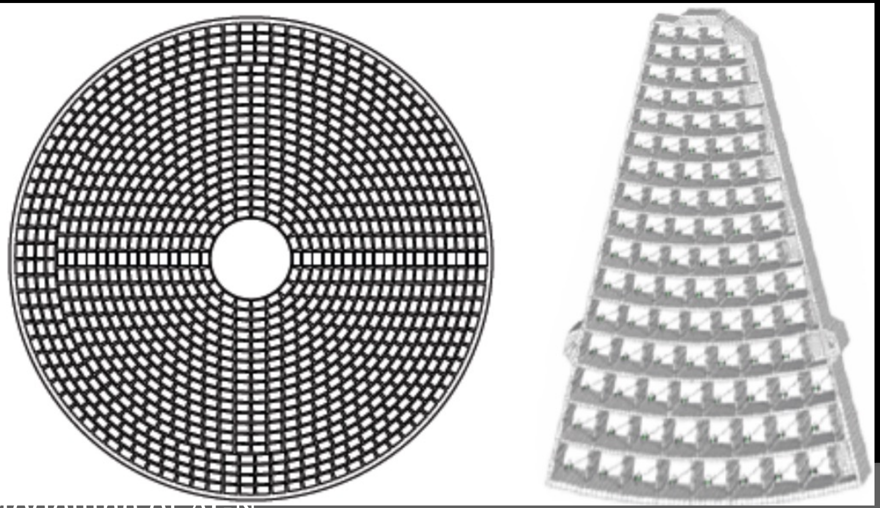
Looking into the Future

ATHENA

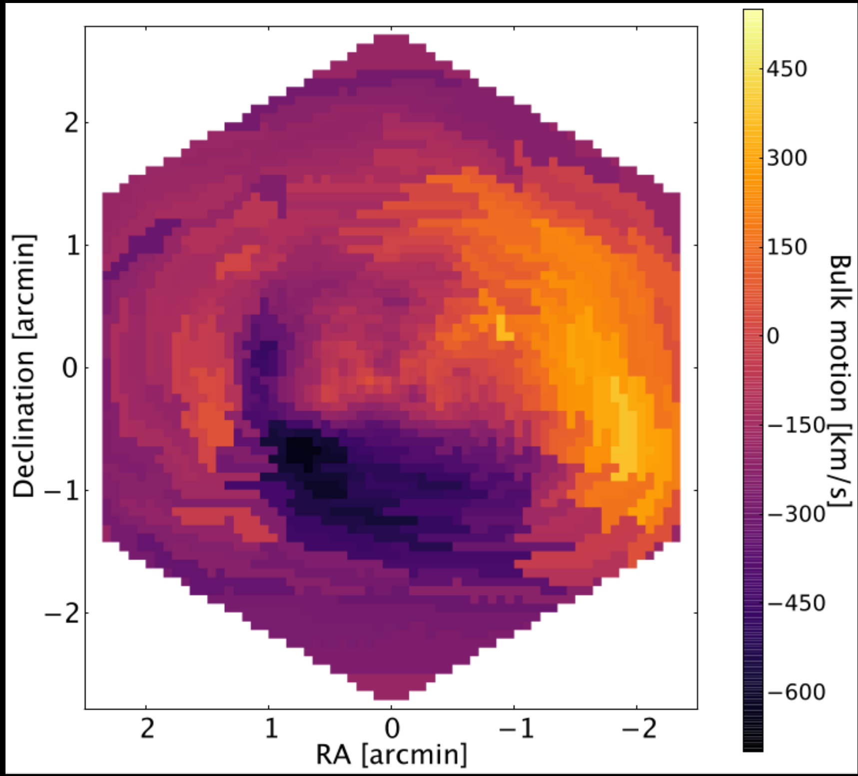






X-IFU consortium: Barrett et al. 2013; Nandra et al. 2013; Willingale et al. 2013

X-IFU (X-ray integral field unit)



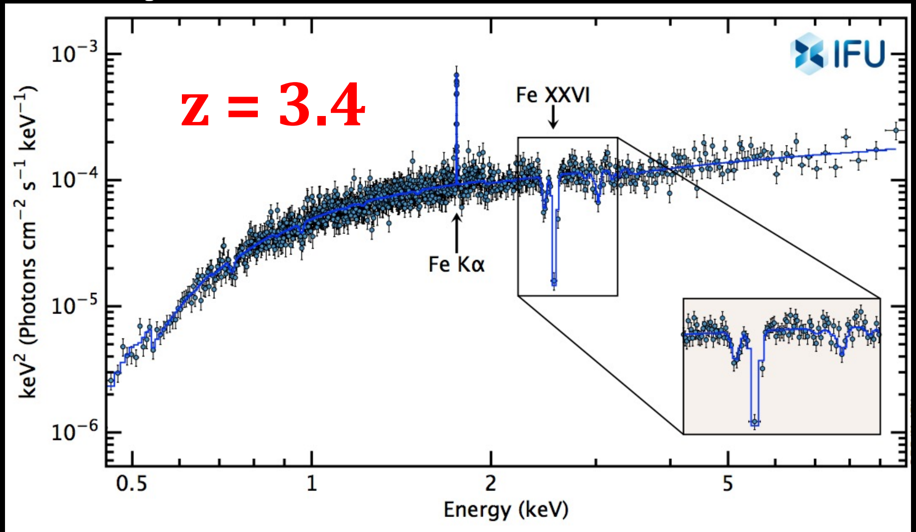
X-IFU team (E. Cucchetti, IRAP)

Hyper-luminous quasar
50 ks spectrum

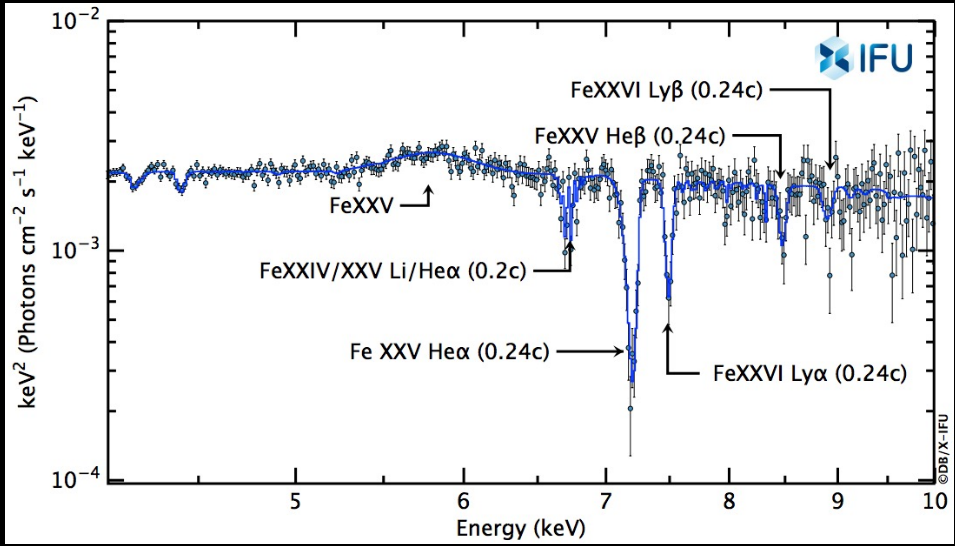
UFO:

- $v_{out} = 0.15\,c$

$$\Delta T \propto E_{Xray}$$



X-IFU team (Barrett 2019)



PDS456 (z = 0.184)
Simulated 100 ks

UFO:

- $\log \xi = 3.1, 3.6$

	RGS	X-IFU
Energy Range (keV)	0.3 – 2.5	0.2 - 12
Resolution (eV)	2 - 6	2.5 (@ 7 keV)

Summary

- High resolution X-ray spectroscopy and photoionisation modelling are tools to study highly ionised plasma regions within AGN
- Obtaining distances and parameter measurements of the ELR help to relate it to the WA and outflowing winds
- Recent obscuring events in Seyfert 1 AGN require further investigation
- Outflowing plasma regions will aid us in understanding how AGN and the host galaxy co-evolve through feedback
- Athena will allow for more accurate high resolution X-ray spectra across the full energy band