Impact of sub-keV Soft Excess on Warm Absorbers

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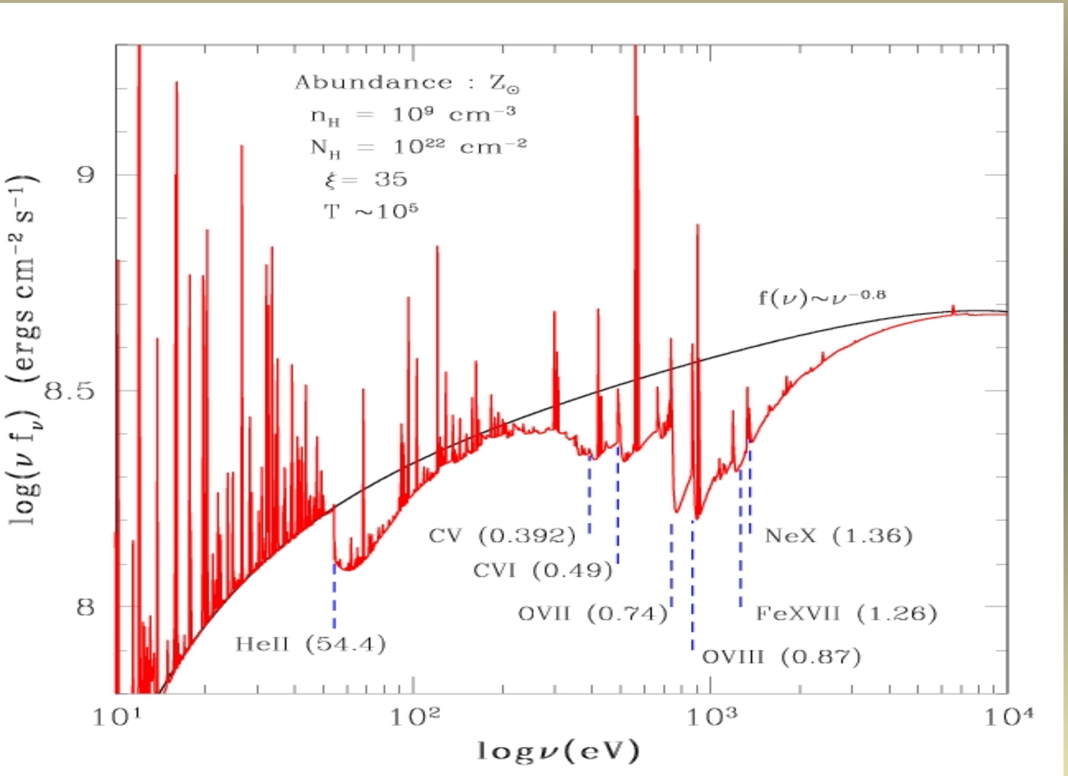

Ajit Kembhavi
Martin Elvis
Gary Ferland
N. R. Badnell

High Resolution Spectroscopy Workshop
MSSL, UCL
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Warm Absorber

➢ Absorption Edges in Soft X-ray Spectra

CV	CVI	OVII	OVIII	FeXVII	NeX	
392	490	740	870	1260	1360	(eV)

- C (V & VI) O (V - VIII) Fe (XVII - XXII)
- Ne (IX & X) Mg (XI & XII) Si (XIII - XVI)

➢ Properties

- Partially ionized gas in our line of sight to AGN
- Distance from the source ~ 0.01 – 1 pc
- Column Density (N_H) ~ $10^{22\pm1}$ cm^{-2}
- Density (n_H) ~ 10^9 cm^{-3}
- Ionization Parameter ξ ~ 10 – 100 erg cm s^{-1}
- Temperature ~ 10^5 K – 10^7 K

➢ Current Issues

- Absorption features are blue shifted relative to optical emission lines, indicating outflow
- Mass loss rate is a substantial fraction of the accretion rate, or exceeds it.
- The X-ray warm absorber could coexist with a UV absorber, but it is still difficult to connect them.

- **Is the Warm Absorber in thermodynamic equilibrium?**
- **If so, does the gas have multiphase nature?**

CLOUDY

"Photoionisation Simulation for the discriminating astrophysicist since 1978"

http://www.nublado/org/

Inputs

Radiation Field

Geometry

Neutral Composition

Density

Thickness

Process

Basic Assumption

Atomic processes reached time-steady state

$$n(X^{+i})\Gamma(X^{+i}) = n(X^{+i+1})n_e\alpha_G(X^{+i+1}, T)$$

Thermal balance achieved

$$\Lambda_{Coll} + \Lambda_{IC} = (\Gamma_{Ph} + \Gamma_C) / n$$

Working principle

$$\frac{\partial n_i}{\partial t} = \sum_{j\neq i} n_j R_{ji} + \text{Source} - n_i\left(\sum_{j\neq i} R_{ij} + \text{Sink}\right) = 0$$

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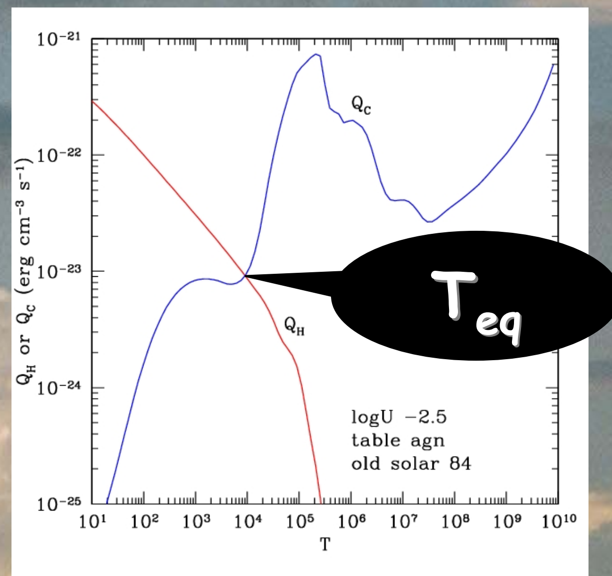
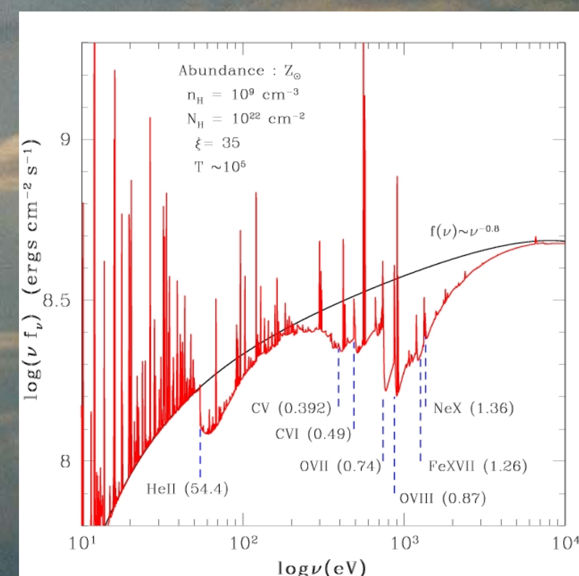
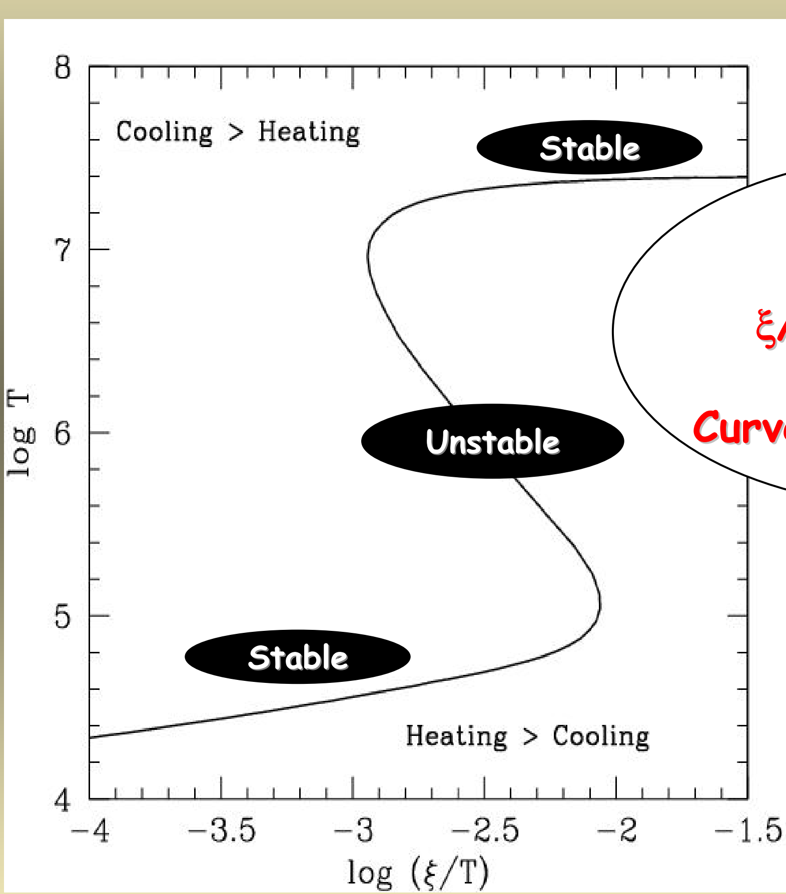




Output → Thermal state & Ionic composition of cloud

Stability Curve

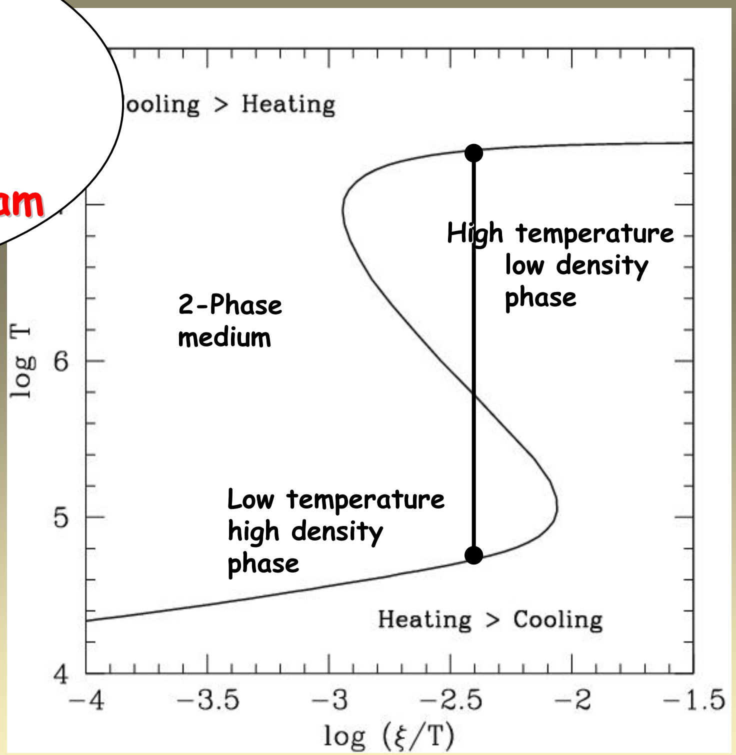
Each point in the curve have thermal and ionic composition information



$\xi = L/nR^2$

$\xi/T \sim (p_{rad})_{ion}/p$

Curve – phase diagram



Literature Survey

Krolik etal. (1981) : Obtained the stability curve for cold gas and hot gas in AGN.

Reynolds and Fabian (1995) : Warm absorber stability conditions as a function of ionizing continuum and gas density.

Hess et al. (1997) : Causes of instability in Warm gas as a function of ionizing continuum and abundance for low-mass X-ray binaries and Seyfert galaxies

Komossa & Meerschweinchen (2000) and Komossa & Mathur (2001) : Stability curve for Warm absorber as a function of ionizing continuum and chemical composition of the absorber

Netzer 1994, 1996

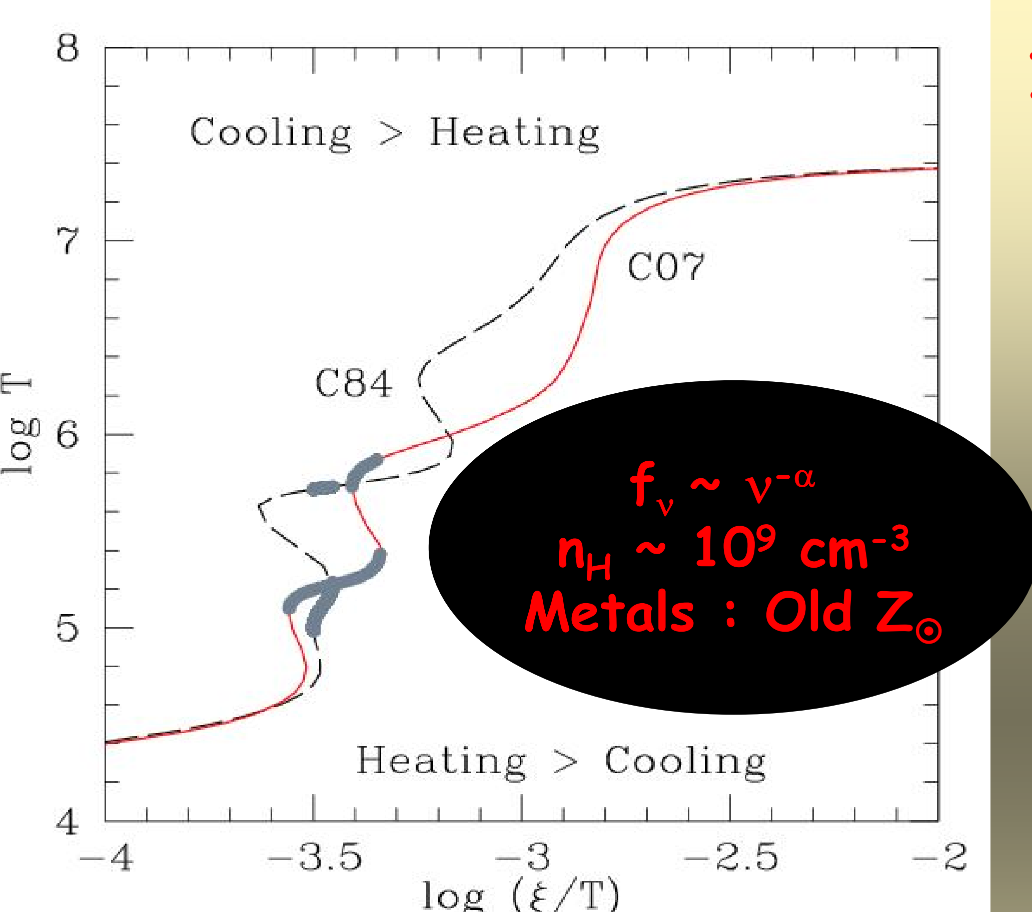
Krolik & Kriss, 2001

Chelouche & Netzer, 2005

Influence of Atomic Physics

Susmita Chakravorty et. al,

2008 MNRAS, 384L, 24



C07, 2007
&
C84 1993 to 1996
(Reynolds – Fabian, '95)

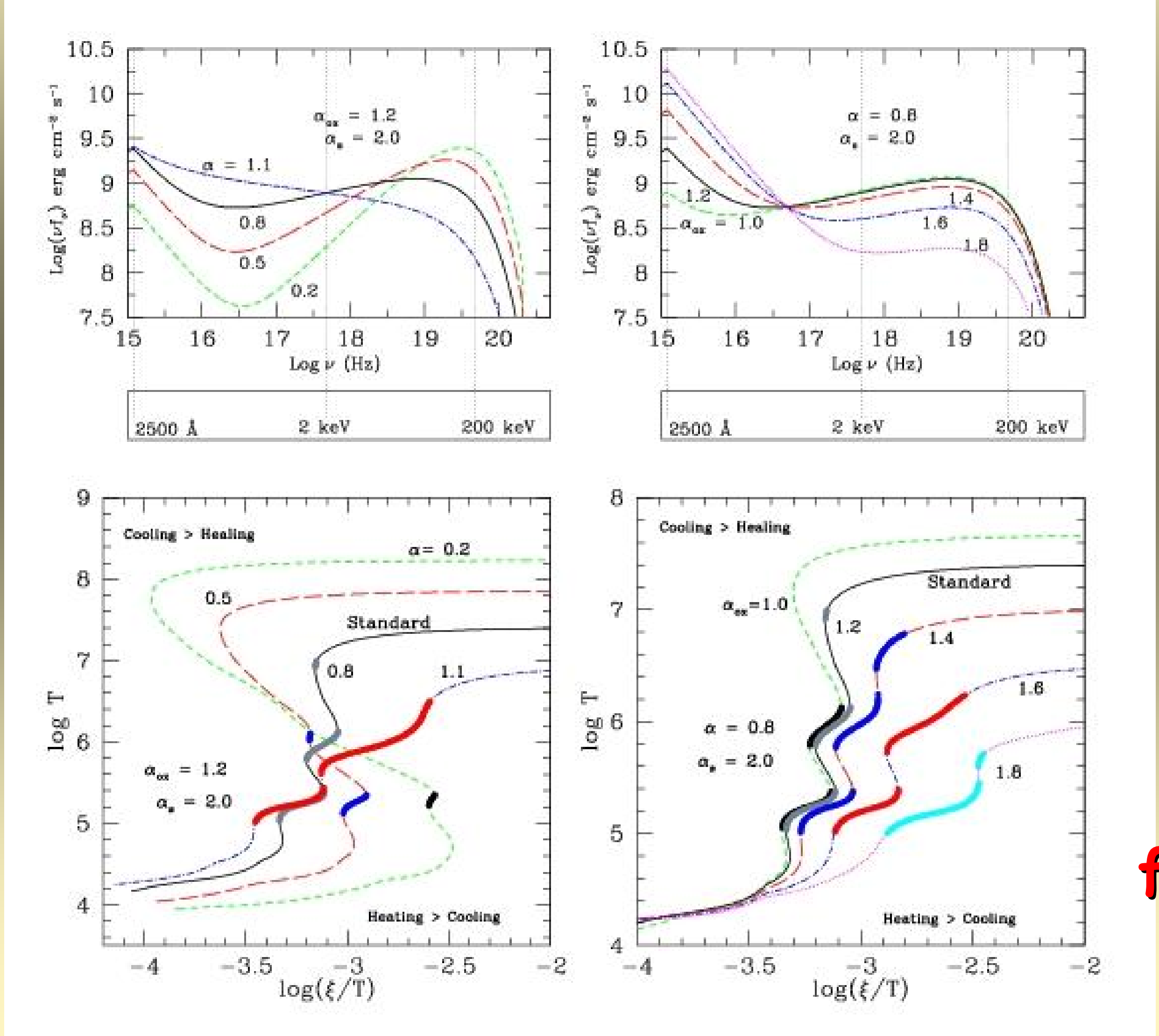
Version	ξ_5	N_{phases}	$\Delta\log(\xi/T)$ ~10^5K	$\Delta\log(\xi/T)$ ~10^6K	$\Delta_M\log(\xi/T)$
C84	45	2	0.05	0.47	0.05
C07	74	2	0.22	0.46	0.07

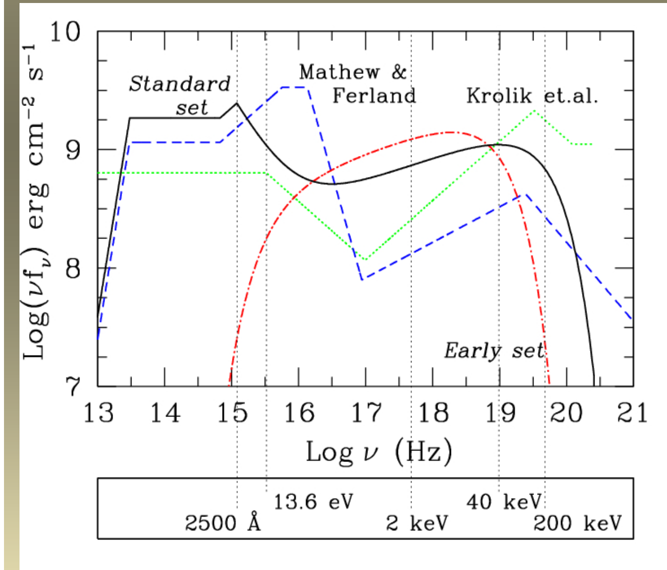
Systematic analysis of S-curves

Susmita Chakravorty et. al. 2009 MNRAS, 393, 83

The ionizing continuum

- No stable states if $\alpha < 0.2$
- Multiphase WA if $\alpha \sim 0.8$
- For $\alpha > 1.1$, no unstable states

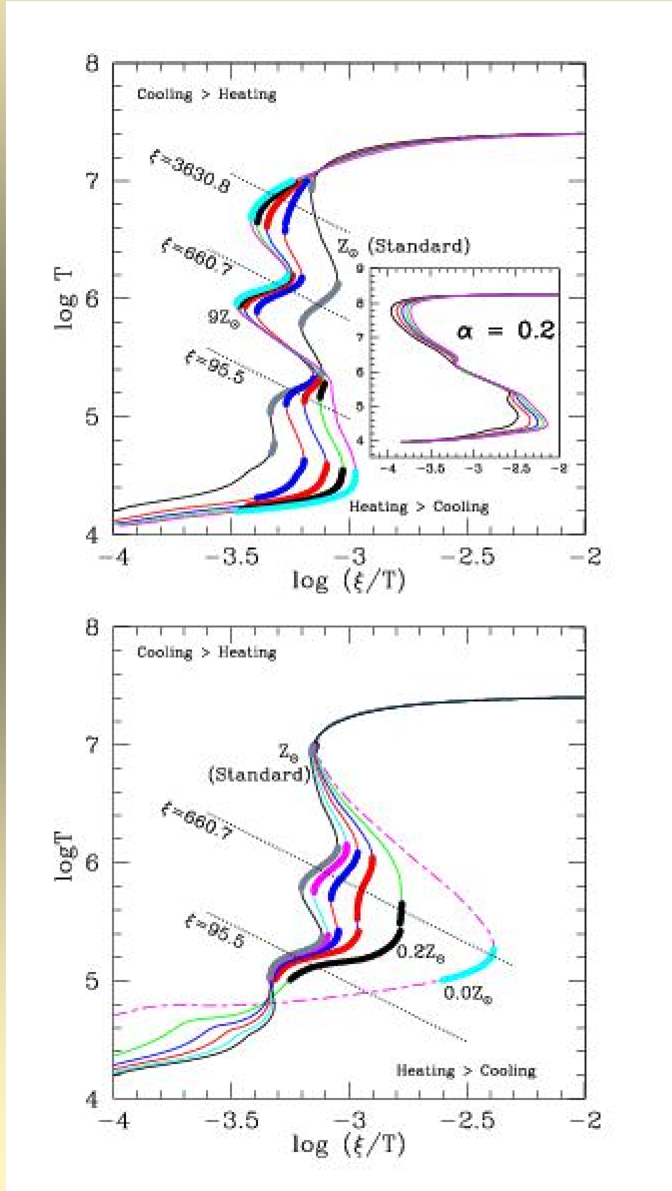




$$f_\nu \sim [\nu^{-\alpha} + \eta\nu^{-\alpha_s}]e^{-\nu/\nu_{max}}$$

Systematic analysis of S-curves

Abundance



- No stable states if $\alpha < 0.2$
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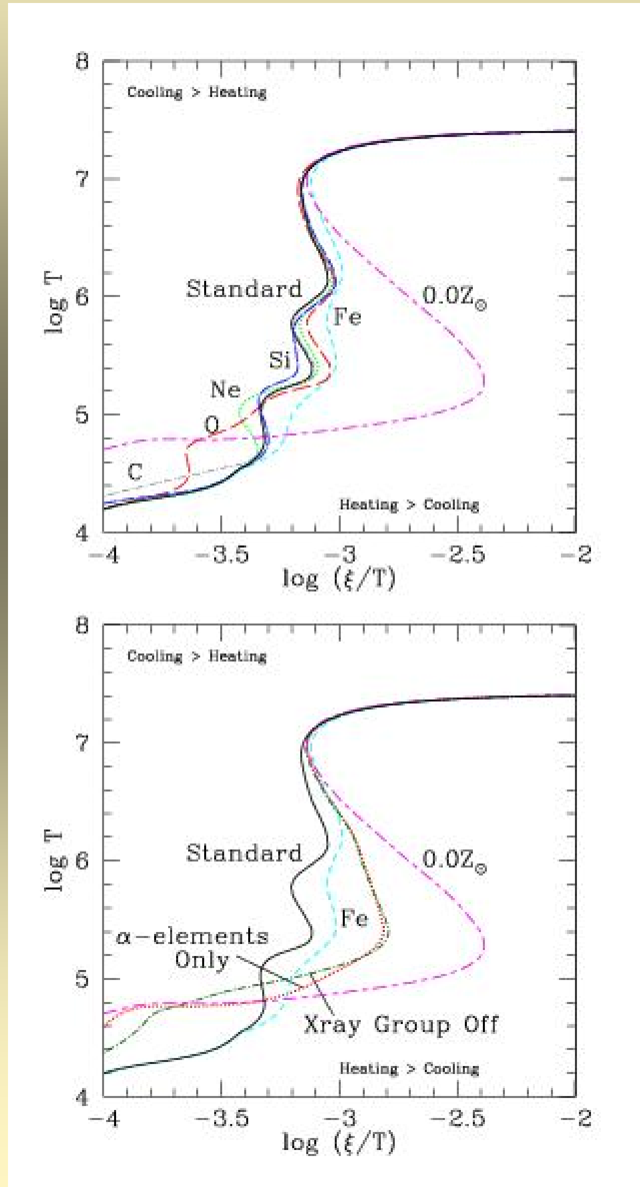
- For $\alpha > 1.1$, no unstable states
- Z_0 : Classical S-curve
- $Z > Z_{sol}$ enhances multiphase
  extended stable state at 10^6 K
- $Z < Z_{sol}$ reduces multiphase

Komossa & Mathur (2001)

Systematic analysis of S-curves

Abundance



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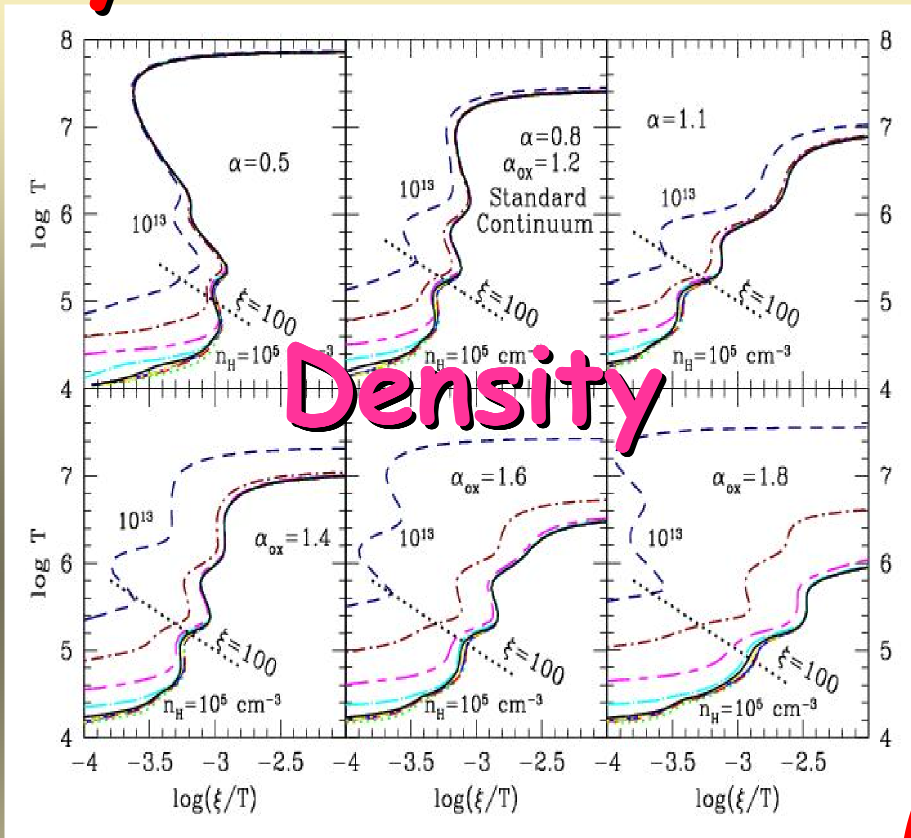
- Z_0 : Classical S-curve
- $Z > Z_{sol}$ enhances multiphase
- $Z < Z_{sol}$ reduces multiphase
- X-ray Group : Most effective group (C, O, Fe, Ne)
- Oxygen : Most effective element at 10^5 K. Needed for WA.
- Iron : Most effective element needed at 10^6 K. Iron was formed when T_{UNIV} = 1 Gyrs. WA before that different.
- α-elements only gas : WA unlikely

Systematic analysis of S-curves



High density gas exposed to steep α_{OX} continuum shows effect

Hydrogen free free absorption becomes a dominant heating agent

Can this become a tool for direct determination of density?

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Soft Excess & Warm Absorber

- ✓ Soft X-ray spectra fit with powerlaw.
- ✓ Fits high energy ~ 1 – 10 keV.
- ✓ Leaves excess at lower energies ~ 0.5 keV.
- ✓ Is likely to influence X-ray Group of elements & hence influence WA.

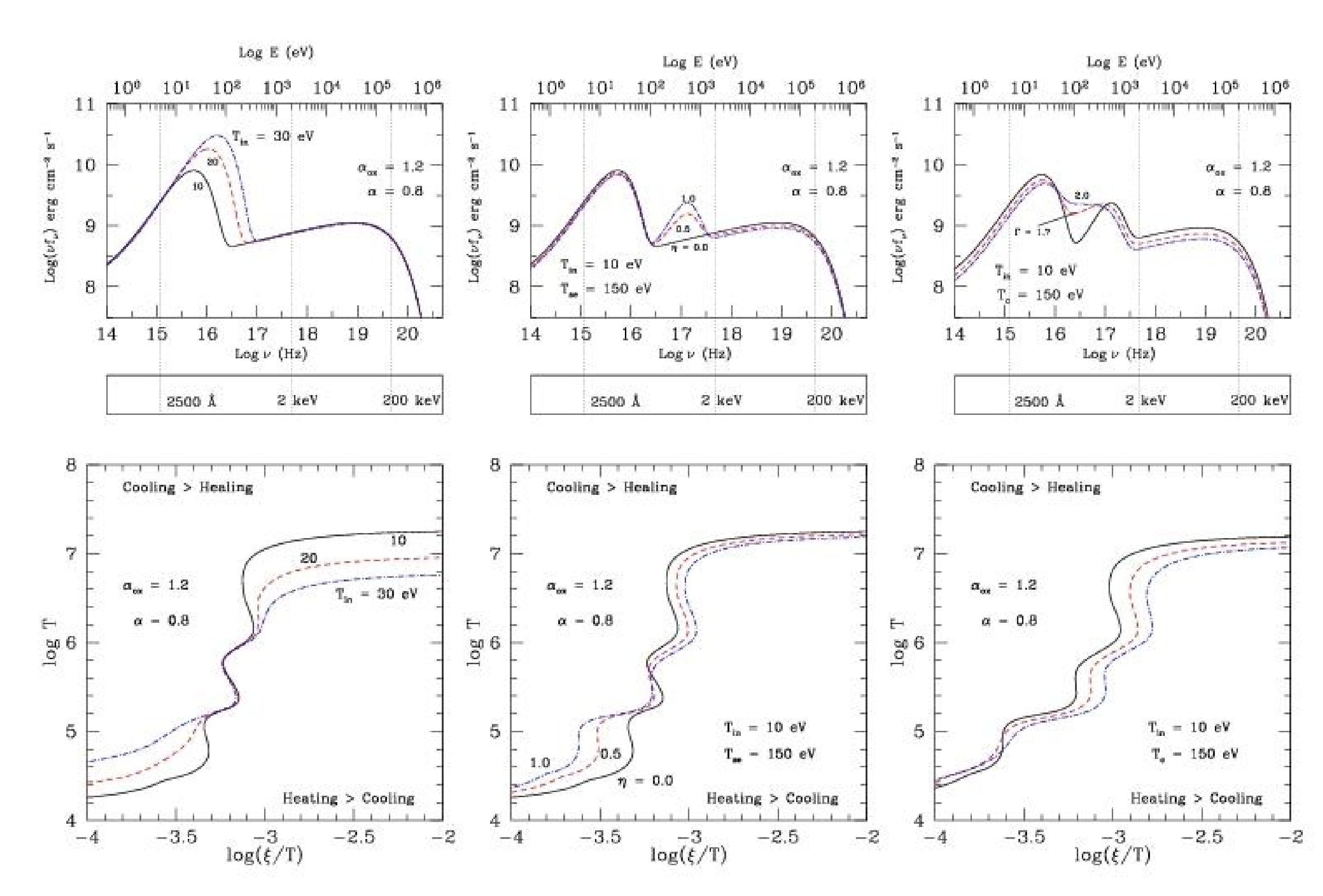
What & Why?

$$f(\nu) \sim [\{\nu^{-\alpha} + \eta' \frac{2\pi h}{c^2} \frac{\nu^3}{\exp(h\nu / KT_{se}) - 1}\} + \eta'' f_{dbb}(\nu, T_{in})]\, e^{-\frac{\nu}{\nu_{\max}}}$$

Blackbody as 'Soft excess'

- ✓ Can be fit with blackbody – T_{se} ~ 0.15 keV.
- ✓ Normalisation wrt. powerlaw – variable parameter.

Fabian and co-authors
Late 90's and earlier this decade

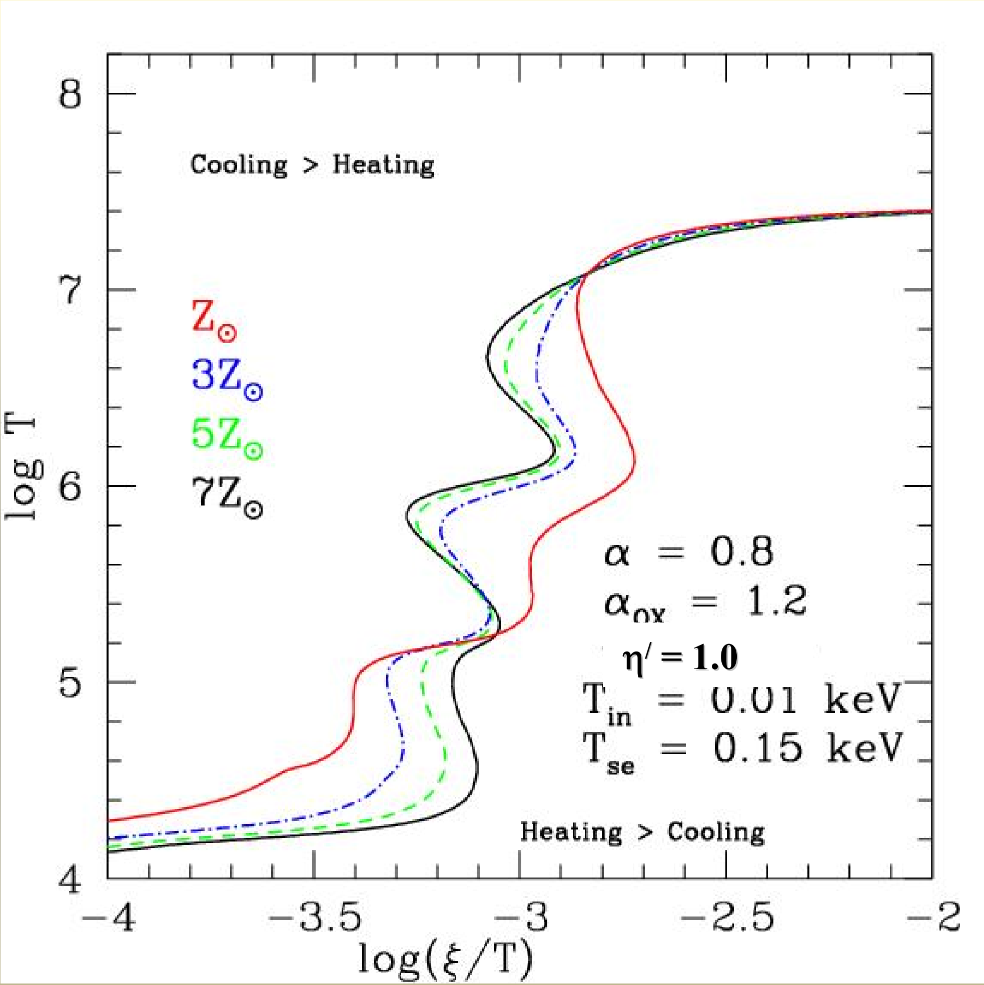


✓ Disk Blackbody has no effect

✓ Soft excess : 10^5 K phase. Remarkable stability. Solid support for gas in thermal equilibrium

✓ 10^6 K phase : Unaffected

✓ T_{se} : No qualitative difference



A combination of Soft Excess and Super Solar metallicity accounts for :

- Increased stability at 10^5 K
- Multiphase scenario with 10^5 K & 10^6 K in pressure equilibrium

Summary

Thank you

- $Z > Z_{sol}$ enhances multiphase
  extended stable state at 10^6 K
- X-ray Group (C, O, Fe, Ne) : Most effective group
- Oxygen : Most effective element at 10^5 K. Needed for WA.
- Iron : Most effective element needed at 10^6 K. Iron formed T_{UNIV} = 1 Gyrs. WA before and after that will be different.
- Continuum having significant "Soft Excess" enhances WA at 10^5 K.
- A combination of Soft Excess and Super Solar metallicity gives the best description of WA as gas in thermal equilibrium : Enhanced stability at 10^5 K and multiphase scenario with 10^5 K & 10^6 K in pressure equilibrium