Evidence for radiation pressure compression in the X-ray narrow-line region of Seyfert galaxies

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DMF

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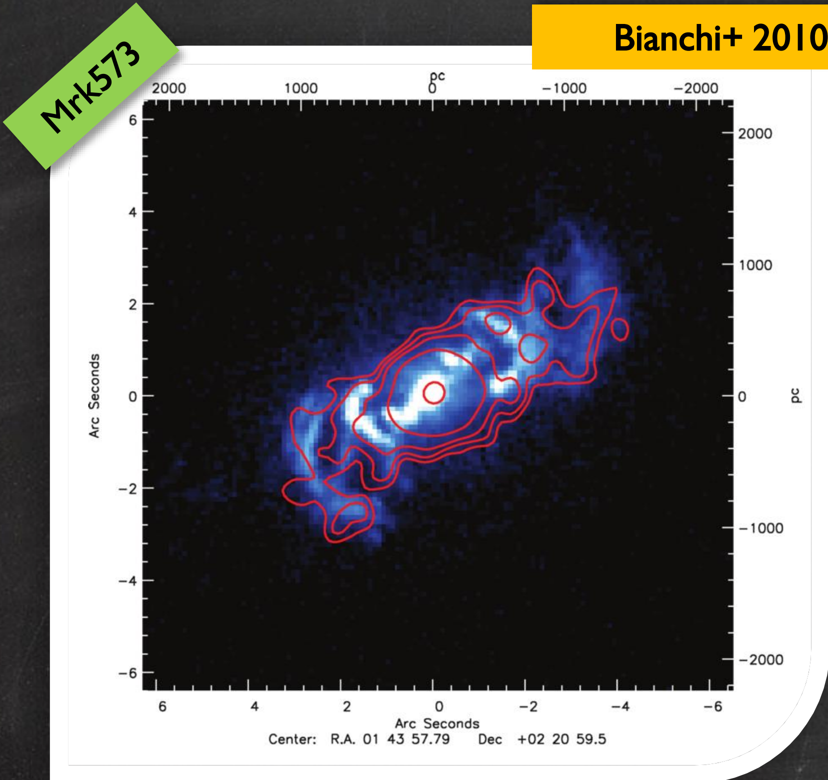


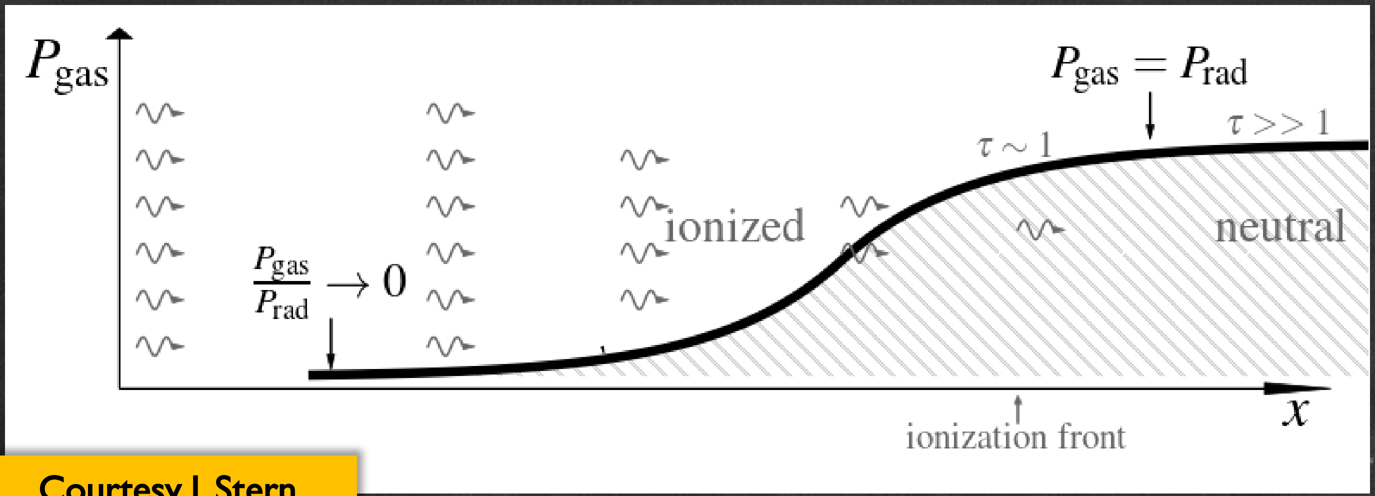
The coincidence between the soft X-ray and [O III] emission is striking in most obscured AGN observed by *Chandra* and *HST*, both in extension and in morphology (e.g. Bianchi+, 2006)

The same gas, photoionized by the AGN continuum, and extended on $\sim 100s$ pc, produces both the soft X-ray emission lines and the NLR optical emission

- Inconsistent with a single-U model → requires high-U and low-U phases
    - The [O III]/soft X-ray ratio is spatially constant → $n \propto r^{-2}$
    - The [O III]/soft X-ray ratio is fairly universal among the sources

Radiation Pressure Compression

Mathews 67; Pier&Voit 95; Dopita+02; Różańska+06; Pellegrini+07,09; Draine 11; Yeh&Matzner 12;Stern+14a,b; Baskin+14a,b



Courtesy J. Stern

Assumptions

✓ Radiation is the dominant force acting on the gas

✓ The ambient pressure is much lower than radiation pressure

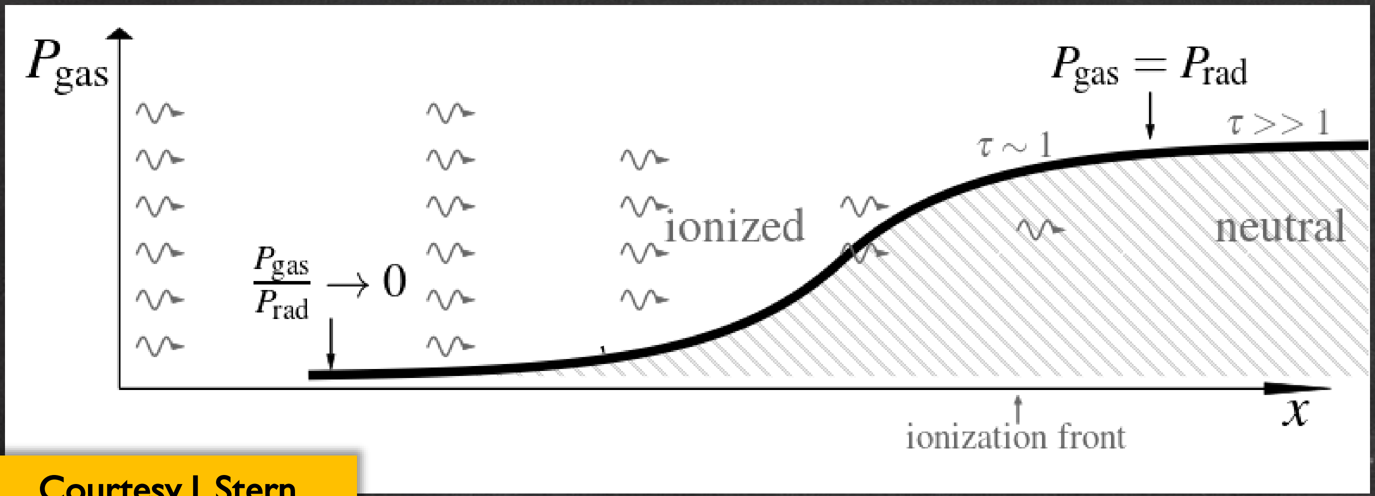
Consequences

The radiation is absorbed in the surface layer of the gas, both ionizing it and compressing it, thus increasing its pressure

The pressure of the incident radiation itself can confine the ionized layer of the illuminated gas: **the gas is Radiation Pressure Compressed**

Radiation Pressure Compression

Mathews 67; Pier&Voit 95; Dopita+02; Różańska+06; Pellegrini+07,09; Draine 11; Yeh&Matzner 12;Stern+14a,b; Baskin+14a,b



Courtesy J. Stern

At $\tau \gg 1$, all the radiation is absorbed, and there is a transition to neutral gas

At $\tau \sim 1$, the gas pressure roughly equals the radiation pressure: this layer is called the **ionization front**

Near the ionization front, at the boundary between the H II and H I layers, the temperature is always $T_f \sim 10^4\ K$, and the equality of gas pressure and radiation pressure implies that the ionization parameter is always ~ 0.03

Radiation Pressure Compression

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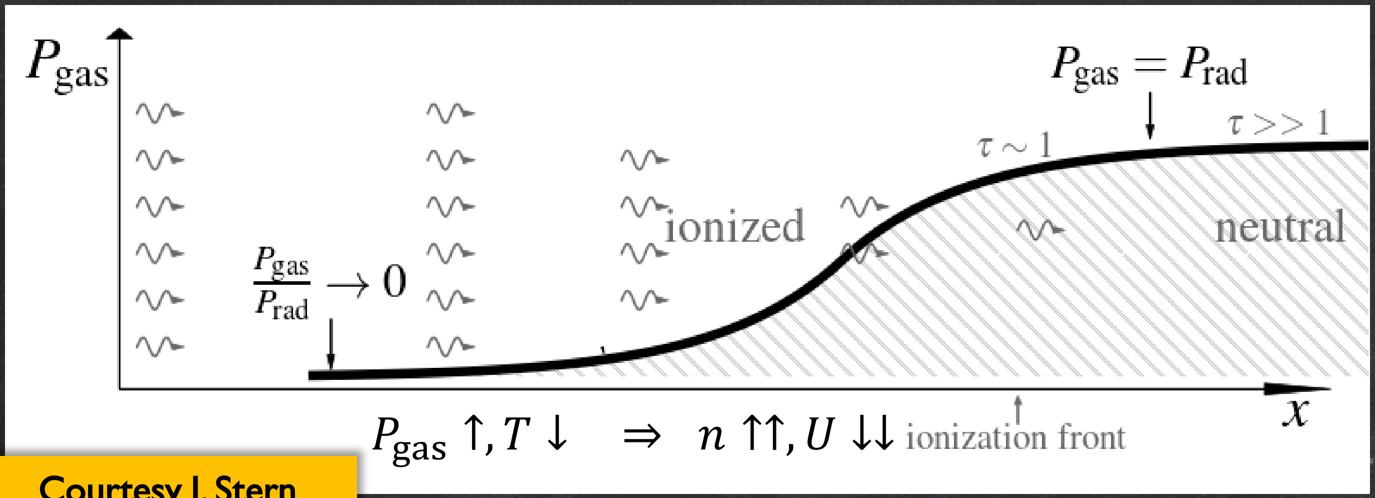
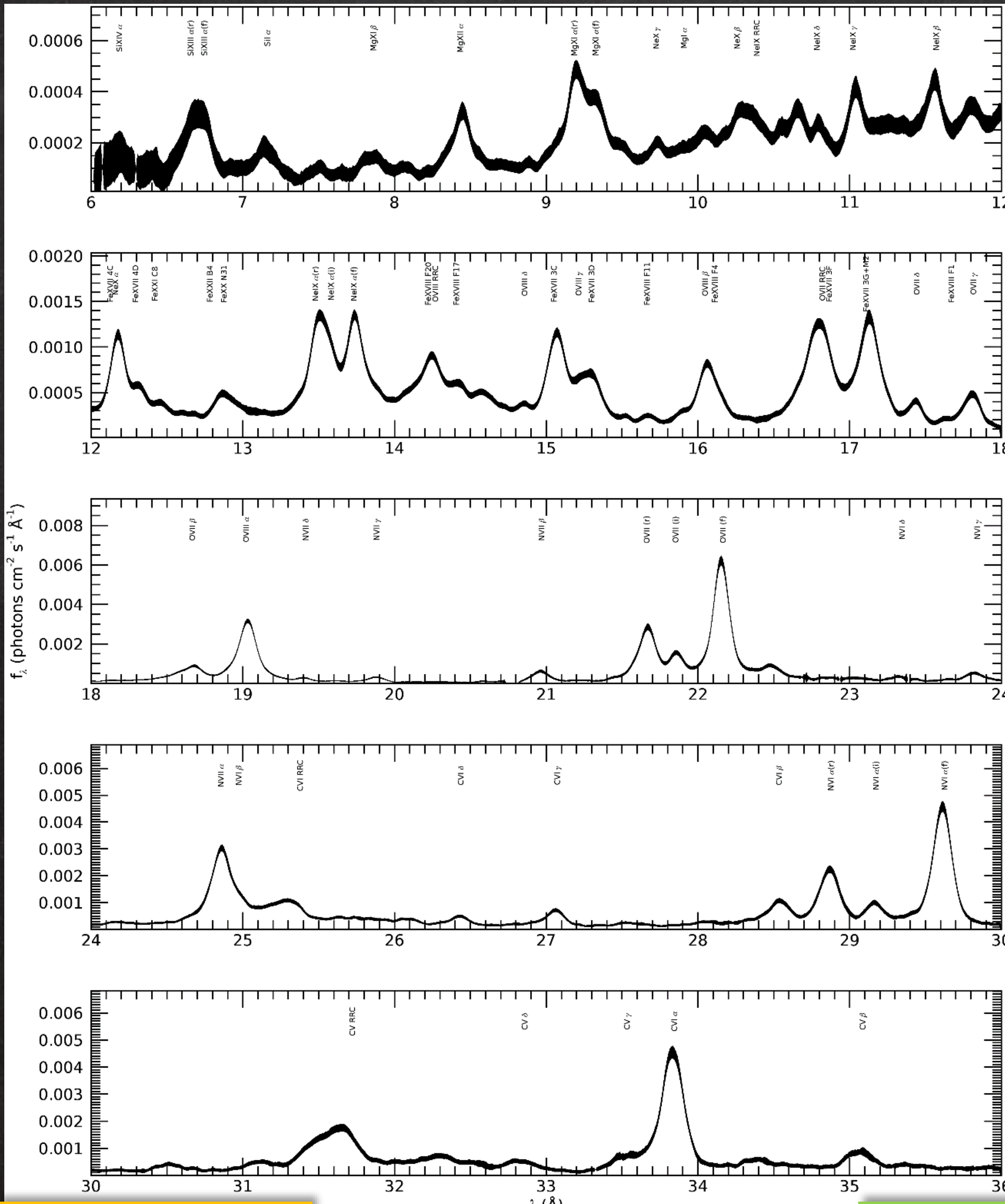


Courtesy J. Stern

- ✓ A large range of n and U in a single slab: the same gas which emits the low-ionization emission lines has a highly ionized surface which emits X-ray lines
- ✓ At the ionization front, the temperature is universal and $P_{gas} = P_{rad}$: since the latter is $\propto r^{-2}$, then $n \propto r^{-2}$
- ✓ The hydrostatic solution of RPC gas is independent of the boundary values at the illuminated surface $(U_0, n_0, P_{gas,0})$: RPC models are universal and have essentially zero free parameters

Soft X-ray Emission in Obscured AGN



Bianchi+ prep.

NGC1068

Dominated by strong emission lines with low or no continuum

Most of the 'soft excess' is concentrated in very strong lines easily detected even in very low SNR spectra

(e.g. Guainazzi & Bianchi, 2007)

Diagnostic ratios on triplets and higher order series lines point to photoionization, with an important role of photoexcitation

(e.g. Kinkhabwala+ 2002, Guainazzi & Bianchi, 2007)

The Emission Measure Distribution

Emission line luminosity

$$L = \int_V j_{ul}(\xi) dV$$

Emissivity

$$j_{ul}(\xi)$$

Ionization Parameter

$$\xi = L_{ion}/n_e r^2$$

Emission Measure

$$\mathrm{EM} = \int_V n_e^2 dV$$

Line Power

$$P_{ul}(\xi) = j_{ul}/n_e^2$$

$$L = \int_\xi d\log\xi \left[\frac{d\,(\mathrm{EM})}{d\log\xi}\right] P_{ul}(\xi)$$

The bracketed quantity above represents the **differential emission measure (DEM) distribution** (e.g. Liedahl 1999; Sako+ 1999)

In practice, the DEM distribution is the ensemble of weighting factors that determine the contributions of each ionization zone to the total line flux

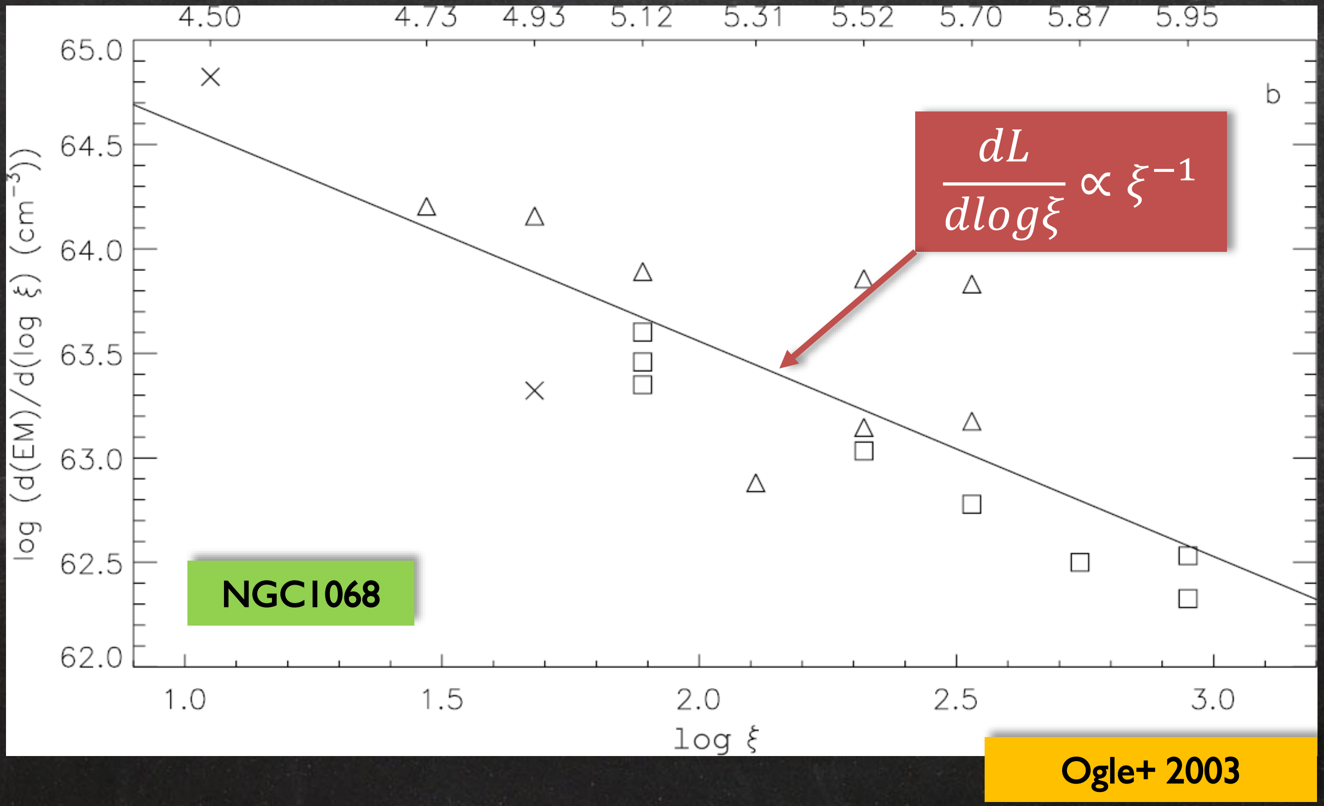
The usefulness of the DEM is that it can be derived theoretically for a given scenario, and readily compared to what is measured experimentally

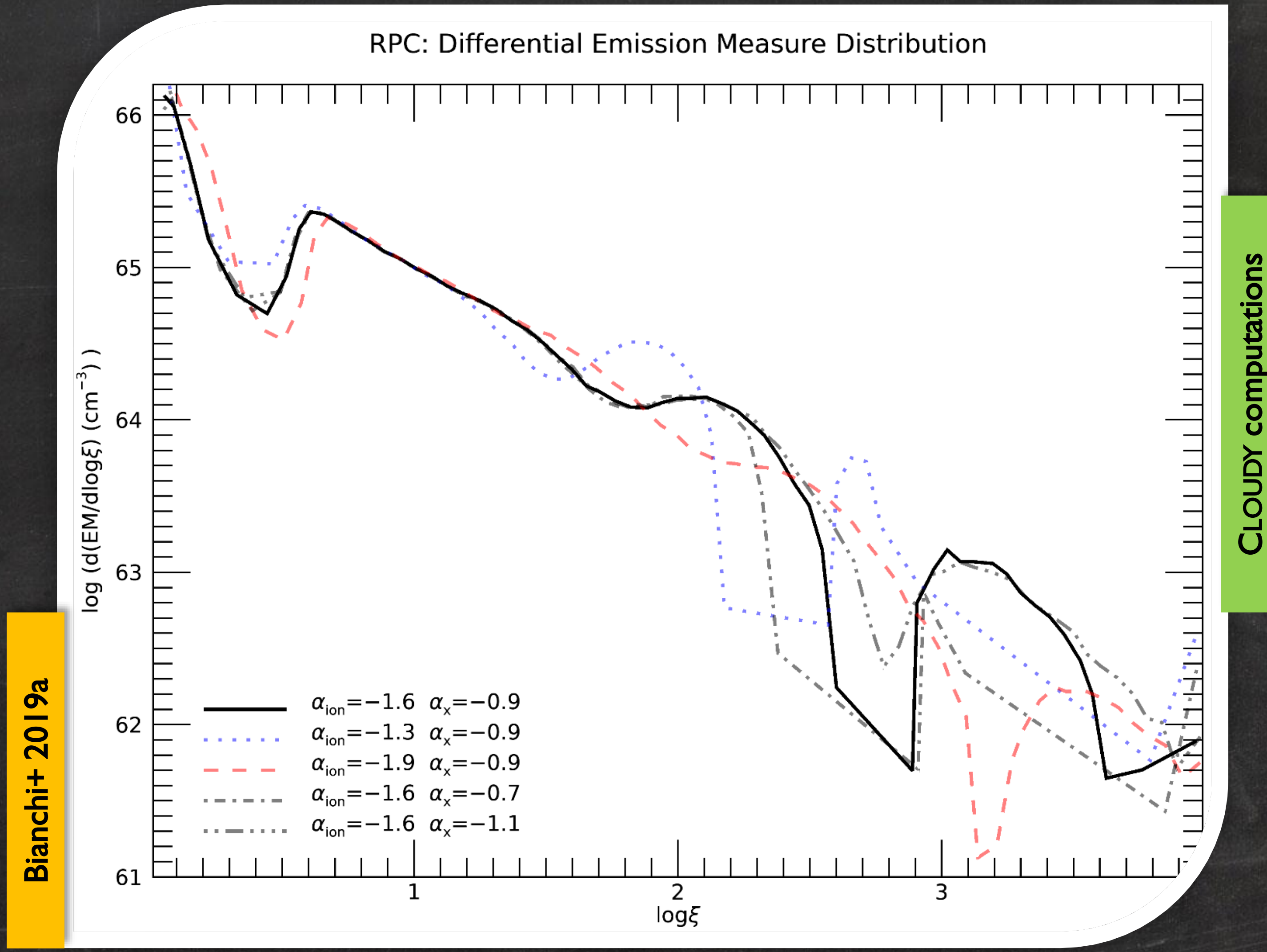
Constant Density (Liedahl 1999)

$$d\,(\mathrm{EM})\,/d\log\xi \;\propto\; \xi^{-3/2}$$

RPC (Stern+14, Bianchi 2019a)

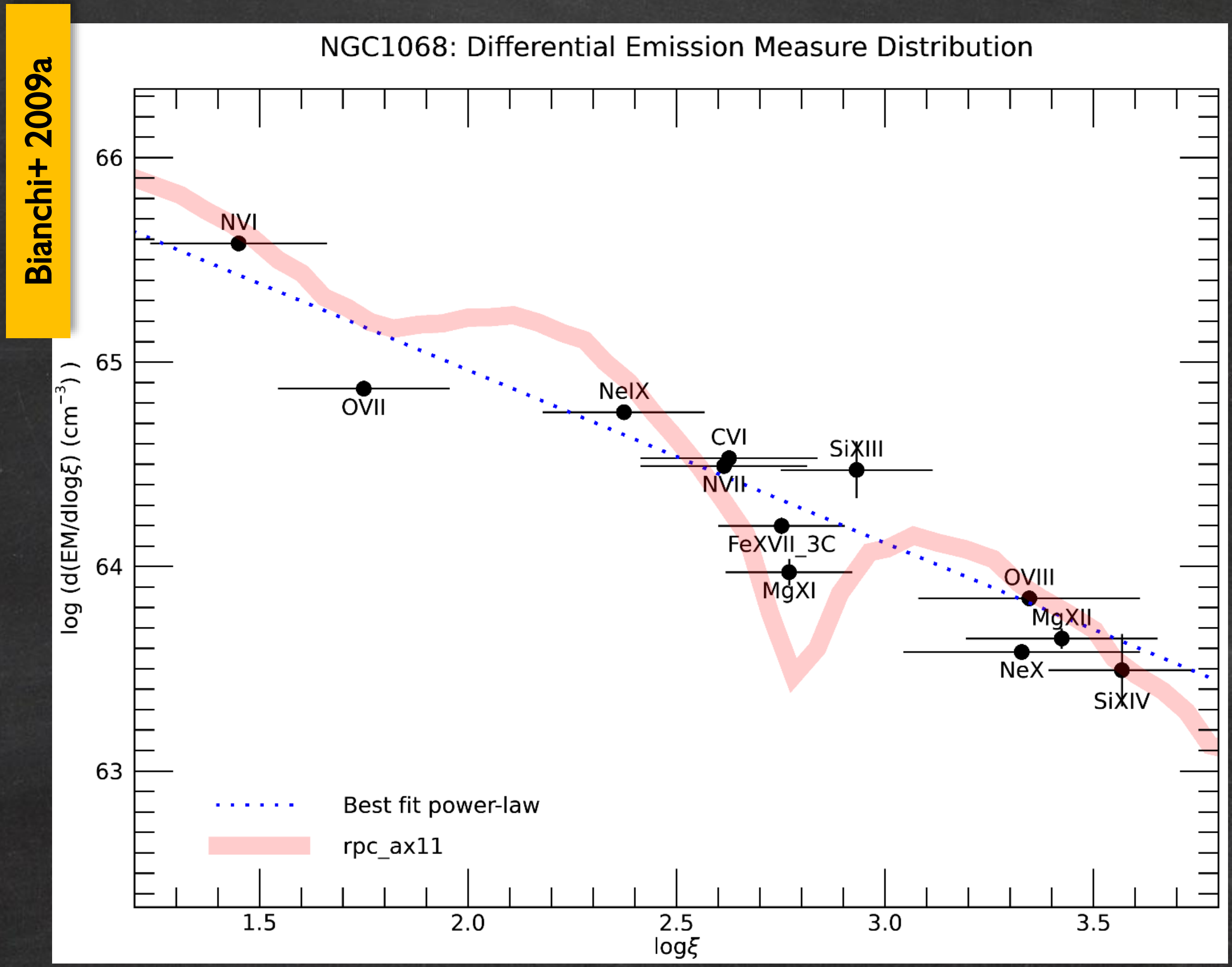
$$\frac{d}{d\log\xi}\mathrm{EM} = 2.2\cdot 10^{68}\,\Omega_{4\pi}L_{45}\xi^{-0.9}\,\mathrm{cm}^{-3}$$





The derived DEM in the case of RPC gas is very characteristic and robust against the specific gas parameters and illuminating SEDs

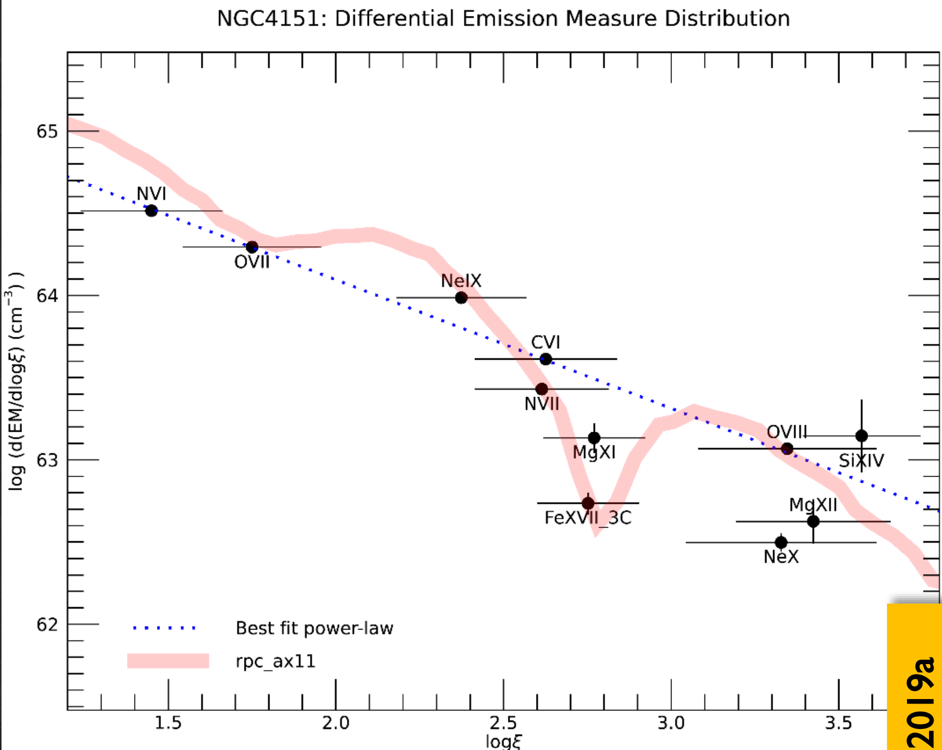
In practice, the DEM is basically set by the hydro-static equilibrium which the gas must obey in case of RPC, and does not depend on the other details



The observed DEM in NGC1068 evidently appears as a power-law distribution: a linear regression gives a slope of ~ -0.85

The correspondence between the observed DEM and the distribution predicted for a RPC gas is impressive

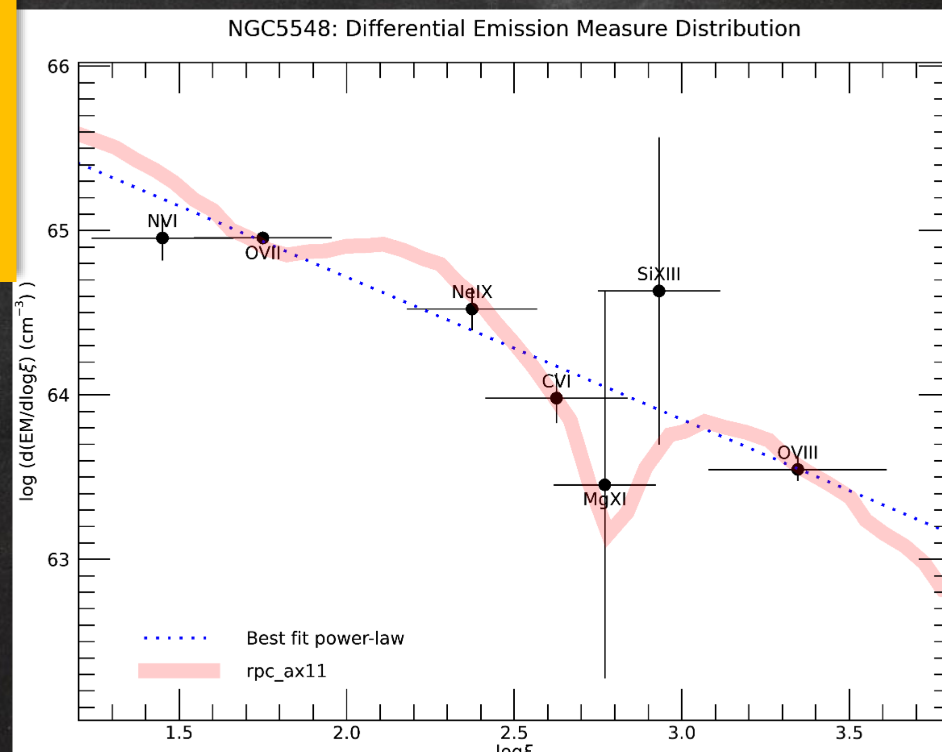
It is important to stress that there are no free parameters in this comparison, apart from the average normalization of the two curves



The observed DEM distribution of NGC 4151 is very similar to that of NGC 1068, again in extremely good agreement with the RPC predictions (slope ~ − 0.78)

Bianchi+ 2019a

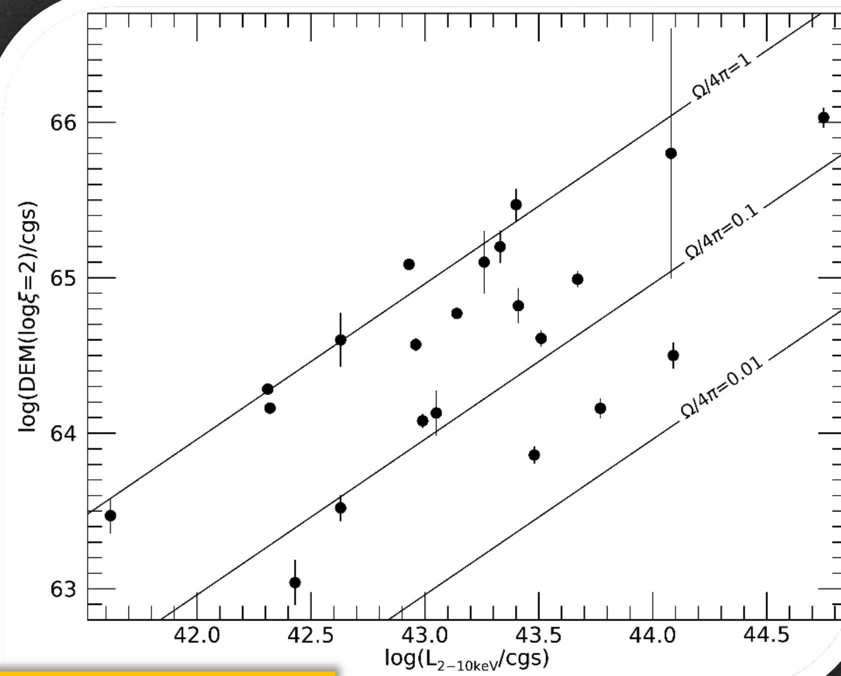
Very interesting case of NGC 5548: the archetypal Seyfert 1 is in an obscured state since (at least) 2012 Its soft X-ray emission is now the same as in Seyfert 2s (slope ~ − 0.87)



The DEM in CHRESOS

Catalogue of High REsolution Spectra of Obscured Sources: 239 XMM-Newton RGS observations of 100 X-ray obscured AGN

Source (1)	$\log L_{2-10}$ (2)	Lines (3)	Best fit (4)	DEM ($\log\xi = 2$) (5)	DEM Slope (6)	$\Omega/4\pi$ (7)
NGC 1068	42.93	12	ax11	65.086 ± 0.004	-0.846 ± 0.006	1.567 ± 0.014
NGC 4151	42.31	11	ax11	64.284 ± 0.005	-0.782 ± 0.006	1.030 ± 0.012
NGC 1365	42.32	8	ax11	64.162 ± 0.019	-0.53 ± 0.04	0.76 ± 0.03
NGC 5548	43.14	7	ax11	64.77 ± 0.03	-0.87 ± 0.05	0.47 ± 0.03
Circinus	42.63	7	ax07	63.52 ± 0.08	-0.2 ± 0.2	$0.085^{+0.017}_{-0.014}$
NGC 7582	43.48	7	ax11	63.86 ± 0.05	-0.45 ± 0.09	0.026 ± 0.003
ESO362-G018	42.96	6	ax11	64.57 ± 0.04	-0.71 ± 0.06	0.45 ± 0.04
MRK 3	43.67	6	ax11	64.99 ± 0.05	-0.58 ± 0.07	$0.23^{+0.03}_{-0.02}$
NGC 4507	43.51	6	ax11	64.61 ± 0.05	-0.84 ± 0.08	$0.138^{+0.017}_{-0.015}$
NGC 5506	42.99	6	ax11	64.08 ± 0.04	-0.49 ± 0.09	$0.135^{+0.013}_{-0.012}$
IRAS05189-2524	43.40	5	ax11	65.47 ± 0.10	-0.6 ± 0.2	1.3 ± 0.3
NGC 424	43.77	5	aion16	64.16 ± 0.06	-0.91 ± 0.09	$0.027^{+0.004}_{-0.003}$
ESO138-G01	44.09	4	ax11	64.50 ± 0.08	-0.65 ± 0.12	$0.028^{+0.006}_{-0.005}$
MRK 477	43.26	4	ax11	65.1 ± 0.2	-0.9 ± 0.3	$0.8^{+0.4}_{-0.3}$
NGC 777	–	4	aion19	66.05 ± 0.04	-1.84 ± 0.13	–
NGC 1052	41.62	4	ax11	63.47 ± 0.11	-0.43 ± 0.19	$0.77^{+0.22}_{-0.17}$
NGC 5643	42.43	4	ax11	63.04 ± 0.14	-0.72 ± 0.18	$0.045^{+0.017}_{-0.012}$
NGC 6240	44.75	4	aion19	66.03 ± 0.06	-2.1 ± 0.2	0.21 ± 0.03
H0557-385	44.08	3	ax11	65.8 ± 0.8	0.30 ± 0.13	$0.6^{+3.0}_{-0.5}$
IRAS13197-1627	43.41	3	aion13	64.82 ± 0.11	-0.63 ± 0.18	$0.28^{+0.08}_{-0.06}$
MRK 231	–	3	ax07	65.46 ± 0.19	-0.2 ± 0.6	–
MRK 704	43.33	3	ax11	65.20 ± 0.10	-0.8 ± 0.3	$0.81^{+0.21}_{-0.17}$
NGC 1320	–	3	aion19	64.09 ± 0.17	-0.4 ± 0.4	–
NGC 3393	42.63	3	aion13	64.60 ± 0.17	-0.7 ± 0.2	$1.0^{+0.5}_{-0.3}$
NGC 4388	43.05	3	metals3	64.13 ± 0.14	-0.68 ± 0.18	$0.13^{+0.05}_{-0.04}$
UGC 1214	–	3	metals3	64.80 ± 0.16	-0.7 ± 0.2	–



Bianchi 2019a

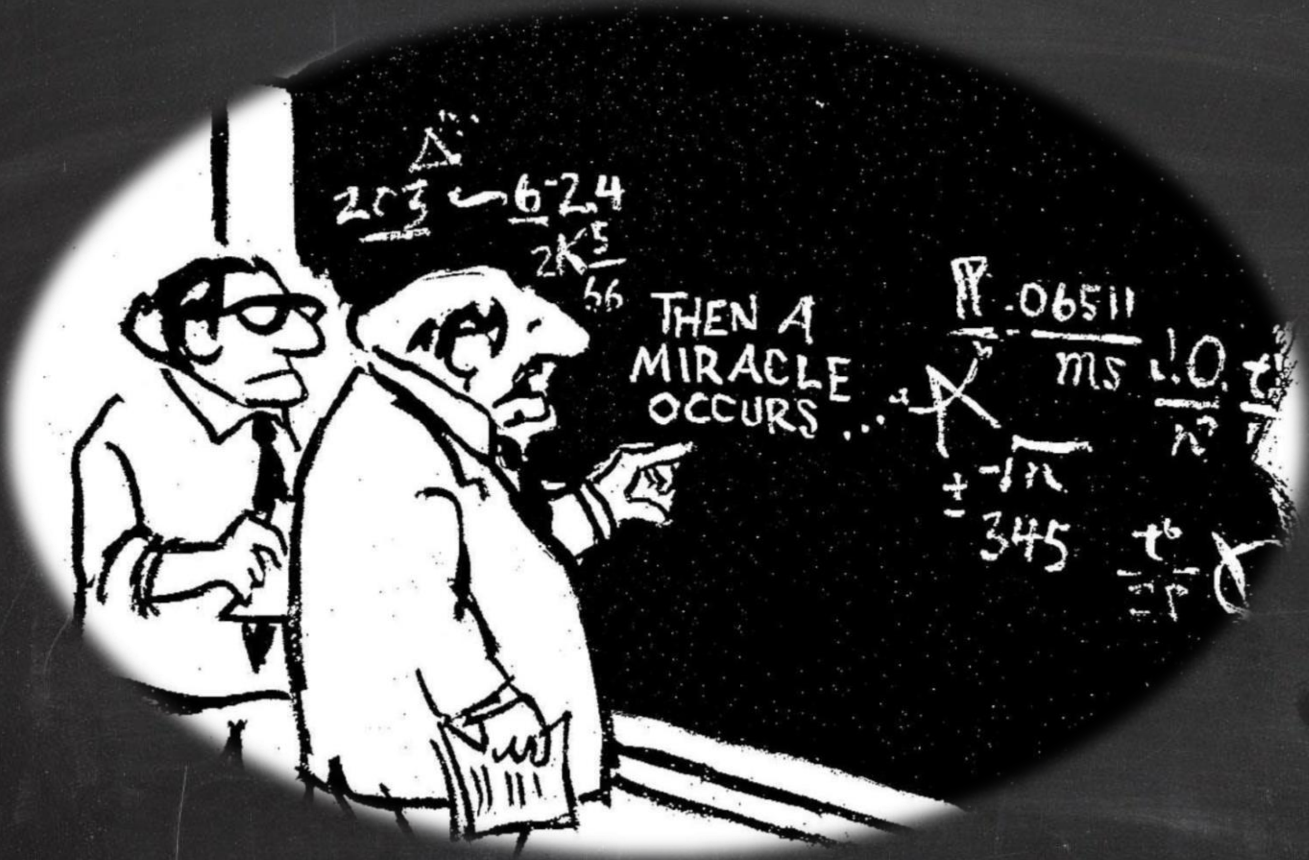
No steeper DEMs than RPC:

- Lower N_H clouds can only flatten it (you must have the ionized layer!)
- No other gas compressing mechanism (i.e. magnetic), which can produce only dense photoionized gas

No apparent correlation between covering factor and luminosity

Take Me Home

- ✓ In an optically thick cloud illuminated by a source of photons, a gas pressure gradient must arise to counteract the incident ionizing radiation pressure.
- ✓ The observed soft X-ray DEMs of obscured AGN are in remarkable agreement with the predicted universal DEM for RPC
- ✓ A constant gas pressure multiphase medium is not ruled out, but it is based on the assumption that radiation pressure is negligible, which is not true, and the universal slope of the observed DEMs is not a natural consequence as in RPC.
- ✓ RPC predicts an increasing gas pressure with decreasing ionization: this can be tested with future high-throughput and high-resolution X-ray microcalorimeters, using density diagnostics.



“You put a cloud of gas at some distance from the AGN, and the rest is set by nature.”

(Ari Laor)

BASIC REFERENCE

Bianchi, Guainazzi, Laor, Stern, Behar, 2019, MNRAS, 485, 1