IRAS 00183-7111: ALMA and X-ray view of an Ultra Luminous Infrared Galaxy

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Introduction

IRAS 00183-7111 (I00183) is an Ultra Luminous Infrared Galaxy (ULIRG) at z=0.327; most of the ULIRGs are known to host a heavily obscured AGN in their nuclear regions. The detection of the most heavily obscured sources is crucial to shed light on the obscured accretion phase in black hole growth, the AGN/host-galaxies co-evolution issues, and eventually estimate the contribution of these sources to the X-ray cosmic background. We present a study of the multi-frequency properties of I00183, connecting ALMA mm/sub-mm observations with those at high energies (Ruffa *et al.* in prep.); one of the purposes consists in verifying at what level the gas, traced by the CO, may be responsible for the obscuration observed in X-rays ($N_H \approx 2 \times 10^{23}$ cm^{-2}, Nandra & Iwasawa 2007).

The case of IRAS 00183-7111

I00183 was selected from the top-left region of the so-called Spoon diagnostic diagram (Spoon *et al.* 2007, black circle in fig. 1); it compares the strength of the 9.7 μm silicate absorption feature and the equivalent width of the 6.2 μm PAH emission feature to investigate about the AGN/starburst components in ULIRGs: the top-left region is populated by the absorption-dominated sources.

I00183 is one of the most powerful ULIRGs known: $L_{bol} = 9 \times 10^{12}$ L_{sun}, mostly in the far-IR (Spoon *et al.* 2009). Its K-band image (Rigopoulou *et al.* 1999) shows a disturbed morpology and a single nucleus, interpreted as signs of a recent merger. This property is typical of ULIRGs: their high IR luminosity is attributed to the merger of two gas-rich spirals which triggers both AGN activity and a powerful nuclear starburst. The high amount of dust accompanying the vigorous starburst activity in I00183 ($\approx$ 220 M_{sun} yr^{-1}, Mao *et al.* 2014) causes significant extinction to its nucleus ($A_V \geq 90$, Spoon *et al.* 2009); for this reason, I00183 mid-IR spectrum lacks the typical AGN tracers (e.g. the 7.65 μm [Ne IV], and the 14.3 and 24.3 μm [Ne V]). However, the presence of a powerful AGN source in its nucleus was already established by the X-ray study presented by Nandra & Iwasawa (2007).

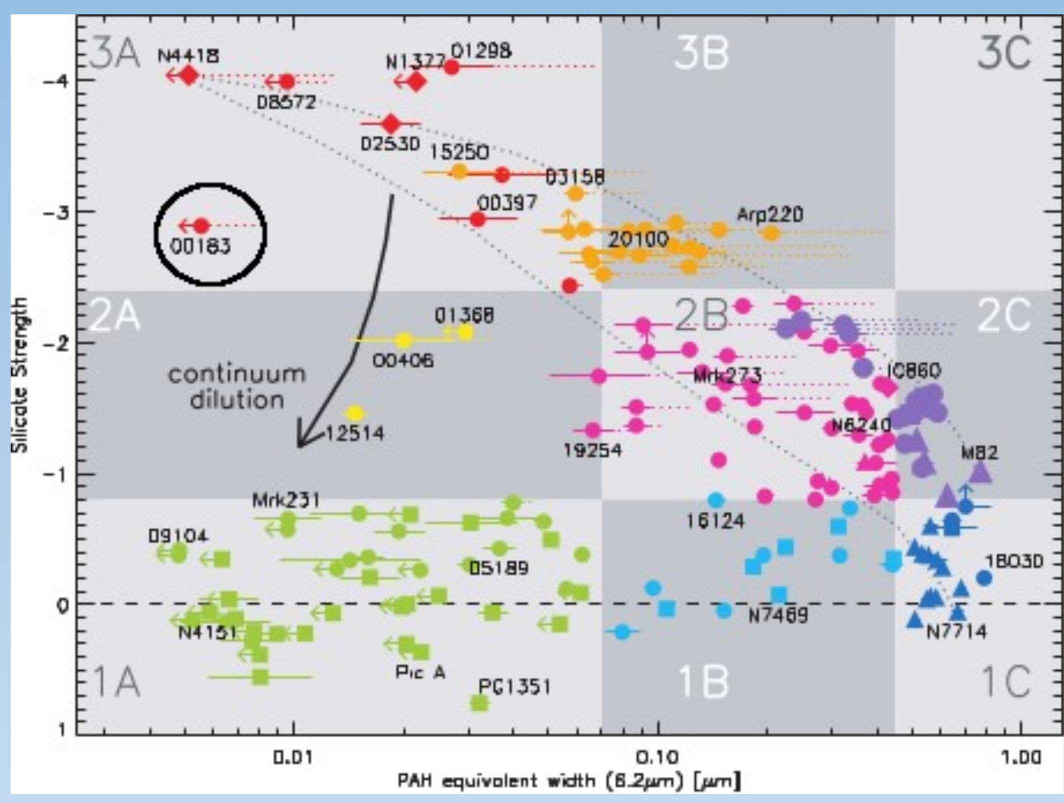


Fig. 1: Spoon diagnostic plot of the equivalent width of the 6.2 μm PAH emission feature versus the 9.7 μm silicate absorption feature, adapted from Spoon *et al.* (2007). The galaxy spectra are classified into nine classes, identified by the gray rectangles. Different colors of the plotting symbols are used to distinguish between the nine classes: filled circles, trinagles, squares, and diamonds refer to ULIRGs and HyLIRGs, starburst galaxies, Seyfert galaxies and QSOs, and other infrared galaxies, respectively. The black circle highlights the position of the target, I00183.

Data

To link the sub-mm to the X-ray properties of I00183, ALMA archival Cycle 0 data in Band 3 and Band 6 were calibrated and analyzed.

The X-ray analysis was carried out using *Chandra*, XMM-*Newton*, and *NuSTAR* (courtesy of the PI, K. Iwasawa) data, allowing a broad-band coverage of the X-ray spectrum (0.5 – 30 keV).

The multi-frequency observation properties are summarized in table 1.

ALMA observation properties				
	ν_{obs} (GHz)	Time on target	Angular resolution	Spectral resolution
Band 3	87	79 min	1.8”	90 km/s
Band 6	270	118 min	0.8”	2 km/s
	260	98 min	0.8”	2 km/s
X-ray observation properties				
	Exp. time	**Obs. date**	**Instrument**	
Chandra	22 ks	13/02/2013	ACIS-S	
XMM-Newton	22.2 ks	16/04/2003	EPIC PN - MOS 1/2	
NuSTAR	115 ks	21/12/2015-26/04/2016	FPMA - FPMB	

Table 1: Summary of the multi-frequency observation properties.

ALMA results

$CO_{(1-0)}$ line successfully (32σ) detected in ALMA Band 3 (87 GHz):

- ⇒ **Integrated flux density**: (2.56±0.11) Jy km s^{-1}
- ⇒ **M(H_2)=(1.14±0.10)×10^{10} M_{sun}** (α≈0.8, Downes & Solomon 1998)
- ⇒ **SFR≈180 M_{sun} yr^{-1}** (CO and FIR luminosity correlation, Carilli & Walter 2013)

Others results:

- ⇒ **Three continuum maps** (at 87, 260, 260 GHz) with decreasing flux densities (α=−0.24) : possible origin from the tail of the radio synchrotron emission, rather than from thermal dust emission.
- ⇒ **Offset of ≈ 2.5 kpc** between the CO and the continuum emission (Band 3): probably due to a “newborn” radio-loud source in I00183 nucleus, detected by VLBI observation (Norris *et al.* 2012, fig. 2).
- ⇒ **Outflow hint** from the molecular gas region; too low spectral resolution to do a kinematic study: future ALMA Cycle 5 observations are in planning.

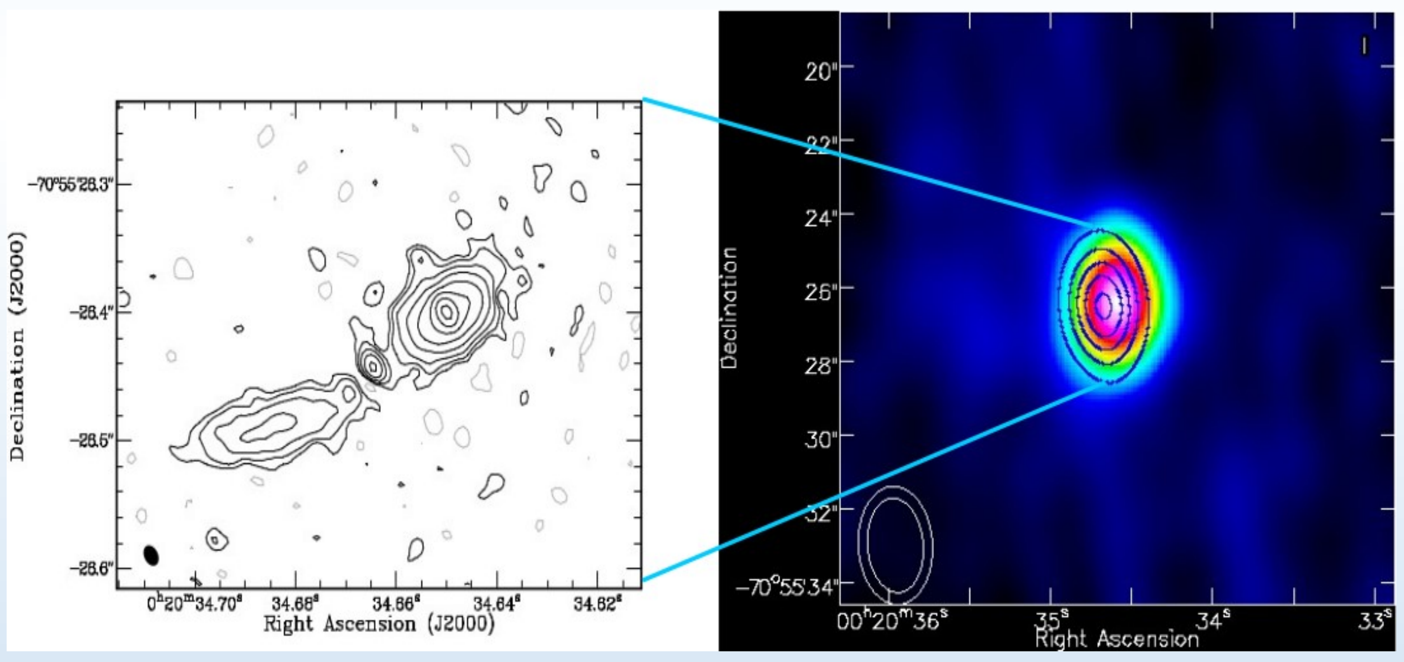


Fig. 2 (above): VLBI map of I00183 (left panel) adapted from Norris et al. (2012) and ALMA CO line moment 0 with the continuum contours superimposed. Contours are drawn at 3,6,9...times the 1σ rms noise level. The jet length (1.7 kpc) and orientation of the radio source detected by the VLBI are consistent with the observed offset (2.5 kpc).

Fig. 3 (on the right): I00183 XMM and NuSTAR spectra (folded through the instrumental response) with XILLVER plus a neutral absorbed model superimposed. Observed energy frame: 0.5—30 keV. The bottom panel shows the residuals between the data and the model in terms of σ. Black and red colors refer to XMM data, while the others to NuSTAR detectors.

X-ray results

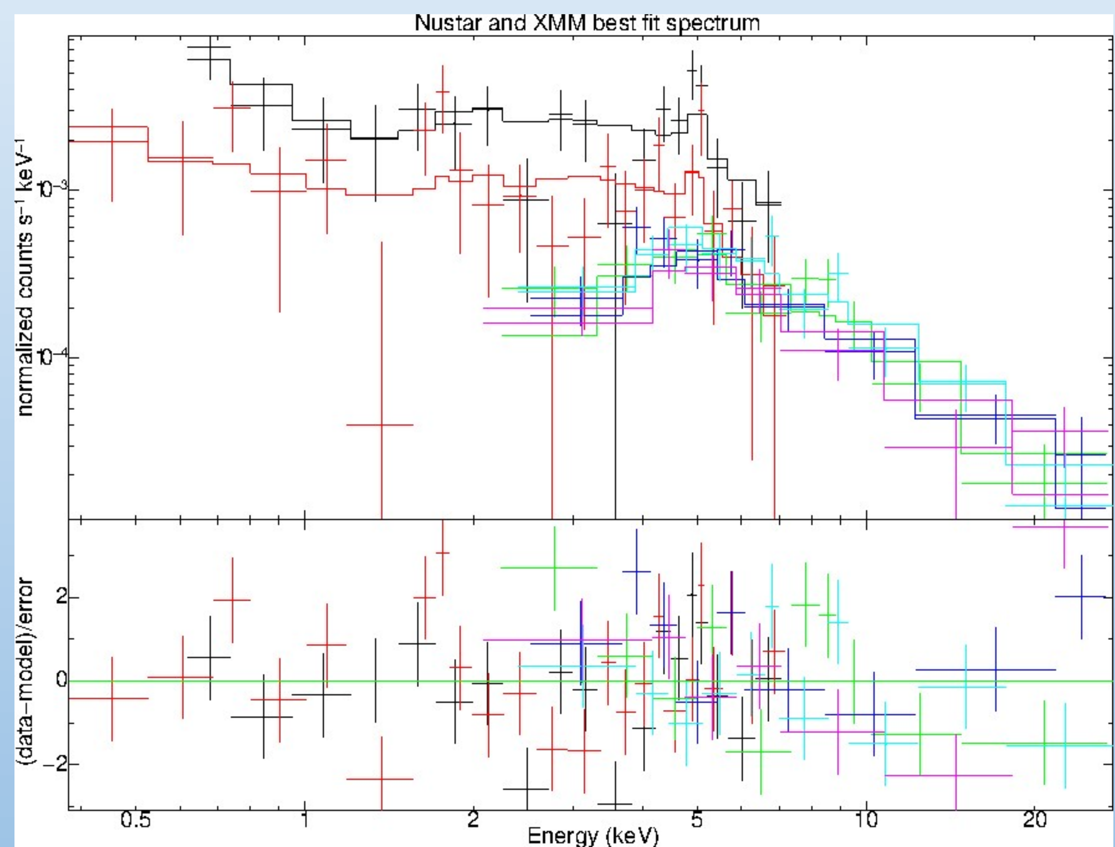
At first, X-ray spectra analyzed individually; XMM and NuSTAR used then for the broad-band spectral fitting.

MyTORUS model (Murphy & Yaqoob 2009):

- ⇒ $N_h \approx (1.70 \pm 0.04) \times 10^{23}$ cm^{-2}
- ⇒ He-like iron line (6.7 keV) with large EW (~ 1 keV): **ionized reflection**.

XILLVER model (Garcia *et al.* 2010, 2013) plus neutral absorber (fig. 3):

- ⇒ Logξ = 2.8±0.2: **highly ionized medium**
- ⇒ $L_{2-10\ keV}$= 6.1 × 10^{43} erg s^{-1}: **higher than usual for ULIRGs**



The gas column density: ALMA vs X-ray

ALMA

- Spherical simmetry of the CO line emitting region; median radius: 6.4 kpc
- The HI mass is unknown

Following Gilli *et al.* (2014)

N_h = (8.0 ± 0.9) × 10^{21} cm^{-2}

X-RAY

- Flat observed photon index: intrinsic neutral absorber

Using a simple, phenomenological model:

N_h = (8.3 ± 2.0) × 10^{22} cm^{-2}

The molecular gas (traced by the CO) may contribute only for a fraction to the obscuration observed in X-ray (given the assumptions adopted here)

REFERENCES: Carilli & Walter 2013, ARA&A, 51, 105; Downes & Solomon 1998, ApJ, 507, 615; Garcia et al. 2010, ApJ, 718, 695; Garcia et al. 2013, ApJ, 768, 146; Gilli et al. 2014, A&A, 562, 67; Mao et al. 2014, MNRAS, 440, L31; Murphy & Yaqoob 2009, MNRAS, 397, 1549; Norris et al. 2012, MNRAS, 422, 1453; Rigopoulou et al. 1999, AJ, 118, 2625; Spoon et al. 2007, ApJ, 654, L49; Spoon et al. 2009, ApJ 693, 1223