ALMA Synergy with ATHENA

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ALMA & Athena: common issues

Galaxy formation and evolution, clustering
Surveys of galaxies at high and intermediate redshifts
Mass assembly and star formation, mergers, cold accretion
Co-evolution of galaxies and black holes

AGN, fueling and feedback
Early galaxies and black holes $z=10-6$
Nearby galaxies, entrained molecular flows
Ultra-Fast Outflows (UFO) stirring the ISM

Multi-phase gas in cool core clusters
Bubbles, cavities, cold gas buoyantly up-lifted
Cold gas filaments, fueling the central AGN
SDP.81, at $z=3.042$

Large Baselines $\rightarrow$ **30mas resolution**
Corresponds to 50-100pc on the $z=3$ galaxy (gain x 3-4 due to lensing)

Mass within 1.5kpc, $3 \times 10^{10} \, M_{\odot}$, almost entirely gas!
5 different groups have published on this object! 9 papers
ALMA Partnership 2015
Black hole in the lens (z=0.3)?

The remote galaxy is composed of tens of <100pc SF clumps, in a 2kpc disk.

Ratio between the central image, and the others Scent/Stot

\[ \text{MBH} > 3 \times 10^8 \text{M}_\odot \] to suppress the central image of SDP.81

CO, Dust, UV

**Tamura et al 2015**

**Rybalk et al 2015**
PHIBSS: 52 galaxies
Molecular gas at IRAM, z~2.3 & z~1.2

« Normal » massive Star Forming Galaxies (SFG)
Quiescent SF, in the main sequence
Gas content ~34% and 44% in average at z=1.2 and 2.3 resp.
Star formation efficiency SFE increases in (1+z)

Tacconi et al 2010, 2013
Grey-scale NIR from HST, VLT, SOAR
Vieira et al 2013 (23/26 detected)
10 z > 4
Red=ALMA 870 μm contours, 2min, 0.5"
ALMA-obtained spectro redshift
Source counts

Source counts for submm galaxies cut off at S(850μ) ~7 mJy (Simpson et al 2015)

+ Multiplicity (interactions)
Galaxies during the EoR

CII line in LBG galaxies at $z=6.8-7.1$, with ALMA
SFR = 5-15 M$\odot$/yr

CII Contours Offset from the optical Ly$\alpha$/UV by 4kpc
Feedback? No FIR dust Low Z?

Maiolino et al 2015
QSO at $z=7.1$: J1120+0641

Venemans et al 2012
PdB observations,
Unresolved point source

SFR~160-440 Mo/yr
CII line 4 times lower than in J1148+5251
AGN, SM black holes, MBH/Mbulge

QSO at $z=6$

$\Rightarrow$ An order of magnitude higher MBH than expected

Wang et al 2010

But:

Unknown inclination

Could be a bias in CO width too small due to a detection bias?

$\Rightarrow$ ALMA needed to resolve the morphology, and find actual inclinations

First CII obs with ALMA of 6 QSO-hosts (Wang et al 2013)
AGN feedback

Molecular outflow in Mrk 231
AGN and also nuclear Starburst, $10^7$-$10^8$ Mo
Outflow 700 Mo/yr

IRAM Ferruglio et al 2010

4C12.50 Outflow ~130 Mo/yr

H2 rotational lines and CO in mm (IRAM-PdB)

Dasyra & Combes 2011, 2012
**Fueling in low-luminosity AGN**

**NGC 1433:** Sy 2 barred spiral, the « Lord of the Rings »

*The smallest molecular AGN-driven outflow*

**CO(3-2) with ALMA (Cycle 0)**

- Beam = 0.5” = 24pc
- Flow of 60pc size

*Combes et al 13*
Off-center AGN and outflow in N1068

Outflow of 63M⊙/yr
About 10 times the SFR in this CMD region

Black V= -50 km/s
White V= 50 km/s

ALMA, Garcia-Burillo et al 2014
Are black holes co-evolving with galaxies?

Over massive BH: N1277 (van den Bosch et al 2012)

\[ \frac{M_{BH}}{M_{bulge}} \approx 50\% \]
\[ M_{BH} = 1.5 \times 10^{10} \text{Mo} \]

Controversial (Emsellem 2013)

The molecular gas can help to trace the potential

At 320pc from the center

Under the sphere of influence of the BH

Scharwaechter et al 2015
Clusters in X-rays, Radio

Large number of low-z clusters
Discovered with Planck-SZ

Followed up with XMM
Unrelaxed clusters
With radio halos
Perseus cool core cluster

Salomé et al 2006

Perseus A, Fabian et al 2003
Cold CO in filaments

Inflow and outflow coexist

The molecular gas coming from previous cooling is dragged out by the AGN feedback

The bubbles create inhomogeneities and further cooling

The cooled gas fuels the AGN

Velocity much lower than free-fall

Salome et al 2008
ALMA: cold gas in cool core clusters

$H_2$ mass $1.1 \times 10^{10}$M$\odot$ in a $-250->250 \text{km/s}$ component around $V_{\text{sys}}$ and a HVS at $-570 \text{km/s}$ (an outflow if in front of the BCG?)

A1664 BCG: CO(3-2) in systemic and HVS

Russell et al 2014
ALMA: molecular gas in A1835

$\text{MH}_2 = 5 \times 10^{10} \text{ Mo within 10kpc of the BCG Abell 1835}$

Narrow (130km/s) profile: face-on disk?

$+ \text{High-V components}$

Outflows?

McNamara et al 2014
ALMA, cold gas in X-ray groups

CO molecular clouds (blue & red-shifted), on the Chandra image

HST image

Masses of the clumps, or GMA, $3 \times 10^5$ to $10^7$ Mo, 10-50 km/s

No rotating disk, but clumps also in absorption

David et al 2014
X-ray and molecular tails

Ram pressure in clusters: **in general slow gas stripping** but **can be fast** in exceptional cases: ESO137-001

*Jachym et al 2014*
Ram-pressure quenching SF

Tail of 80 kpc in X-ray gas, 40 kpc in CO
$M(\text{H}_2)$ in $C = 1.5 \times 10^8 M_\odot$

Jachym et al 2014
Synergies Athena and ALMA for galaxies

Galaxy formation, mass assembly
Physics of high redshift galaxies, BH

Co-evolution of SMBH and galaxies
AGN feedback and fueling

Galaxy clusters, Cooling flows
Ram-pressure gas stripping (X-ray and molecular tails)

⇒ Both will observe AGN and galaxy clusters