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Prospects for AGN studies with ALMA

R. Maiolino

INAF – Astronomical Observatory of Rome, Via di Frascati, 33, 00040 Monte Porzio Catone, Italy

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ABSTRACT

These lecture notes provide an introduction to mm/submm extragalactic astronomy, focused on AGN studies, with the final goal of preparing students to their future exploitation of the ALMA capabilities. I first provide an overview of the current results obtained through mm/submm observations of galaxies and AGNs, both local and at high redshift. Then I summarize the main mm/submm facilities that are currently available. ALMA is then presented with a general description and by providing some details on its observing capabilities. Finally, I discuss some of the scientific goals that will be achievable with ALMA in extragalactic astronomy, and for AGN studies in particular.

1. Introduction

The Atacama Large Millimeter Array (ALMA) is one of the largest ground-based astronomy projects of the next decade, which will revolutionize several fields of astronomy. A large community of scientists is expected to use ALMA to tackle several outstanding questions in astrophysics. However, mm/submm astronomy is often considered a field restricted to experts. In the case of students and young scientists in particular, the limited familiarity with mm/submm facilities and observations may prevent them to fully exploit the ALMA capabilities in the future. These lecture notes are aimed at providing students and young researches some background on mm/submm extragalactic astronomy, with a focus on the investigation of AGNs. I will first provide a quick overview of the current results obtained through extragalactic mm/submm observations, by focusing on AGNs (Section 2). I will then summarize the currently available (and forthcoming) mm–submm facilities (Section 3). Then I will shortly describe ALMA and summarize its observing capabilities (Section 4). Finally, I will discuss some of the ALMA prospects for extragalactic studies, and in particular for AGNs, both in the local universe and at cosmological distances (Section 5). These lecture notes are far from being exhaustive; several scientific cases will not be discussed at all; the main goal of these notes is only to provide an introduction to mm/submm extragalactic astronomy and to highlight some scientific cases that ALMA will be able to tackle.

2. Millimetric and submillimetric extragalactic astronomy

This branch of astronomy includes observations at wavelengths between ~10 mm and ~300 μm. Longer wavelengths are traditionally identified as radio-astronomy domain. Shorter wavelengths, out to mid-IR wavelengths, are unobservable from ground because of the nearly complete atmospheric absorption (although some sites, under exceptional conditions, allow observations out to

E-mail address: maiolino@oa-roma.inaf.it

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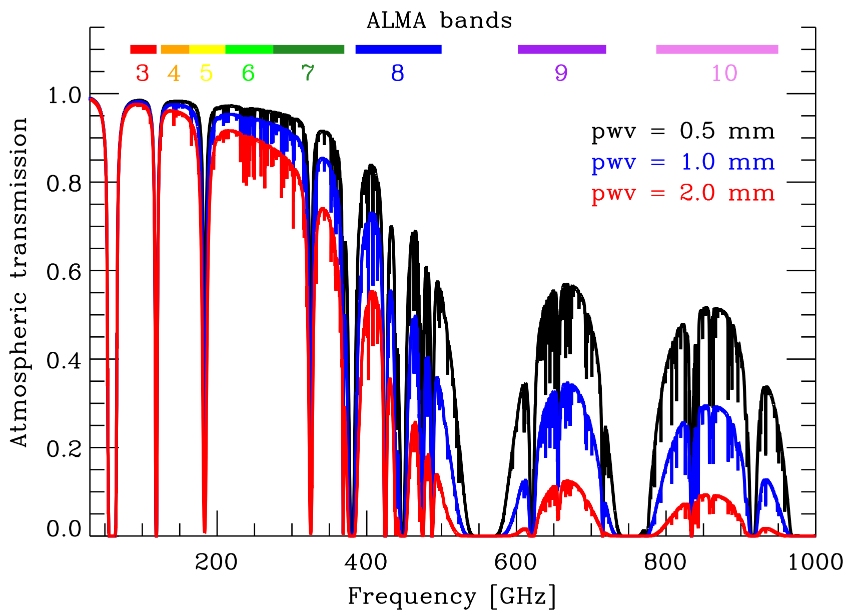

Fig. 1. Atmospheric transmission at Chajnantor Plateau, the ALMA site, with different amounts of precipitable water vapor. The horizontal colored bars indicate the frequency ranges of the ALMA bands.

~200 μm.). Even within the mm–submm range not all wavelengths are equally easy to observe, since the sky transparency on average decreases rapidly at shorter wavelengths. At $\lambda < 700$ μm only a few atmospheric windows are accessible, and only under optimal weather conditions. This issue is clearly illustrated in Fig. 1, which shows the atmospheric transmission at the ALMA site.

The main source of opacity at these wavelengths is the water vapor. This is the reason for locating mm–submm observatories at dry and high altitude sites, where the amount of water vapor is much reduced. However, even at these optimal sites there are strong variations of the the water vapor, which make the atmospheric transmission change strongly (Fig. 1) both on long (seasonal) and short (day/night) time scales.

Given the difficulties of observing at these wavelengths one may wonder why international agencies are investing so much effort to develop facilities with enhanced observing capabilities in these bands. The mm–submm band contains a wealth of information that cannot be inferred from any other band. Most of the ~150 molecules known so far in the cold interstellar medium (see http://astrochemistry.net for an updated list) emit their rotational transitions in the mm–submm bands, with a density of about 70 lines/GHz. All of these transitions are important diagnostics of the chemistry, of the physics and of the dynamics of the inter stellar medium (ISM) from which stars form. Some of these lines are so strong (e.g. the CO transitions) to be powerful tools to trace the dynamics and the gas physics even in distant galaxies. Furthermore, some of the strongest lines emitted by the ISM of any galaxy, such as the [CII]158 μm and the [OI]63 μm fine structure lines (the two main coolants of the ISM), are redshifted into the mm–submm bands at $z > 2$–4.

Within the context of the continuum emission, the mm–submm bands encompass the Rayleigh–Jeans region of the warm dust thermal emission (which traces star formation and the dust mass), the high frequency tail of the synchrotron emission (dominating the radio emission in most galaxies) and of the free–free emission (tracing HII regions). At high redshift the prominent IR dust thermal bump (which dominates the spectral energy distribution – SED – in starburst galaxies) is shifted into the submm band, therefore making this one of the best spectral regions to search and characterize high-z star forming galaxies.

This was just a very quick glance at the scientific motivations behind the development of mm–submm facilities, and mostly limited to the extragalactic field. Young stellar objects, protostars and proto-planetary systems are, for instance, additional fields where the mm–submm range is crucial for a thorough investigation.

The importance of the mm–submm band within the extragalactic context will become more obvious in the following sections, where I will provide some (shallow) background on what we currently know of external galaxies based on mm–submm observations, and where some extragalactic ALMA science cases will be discussed.

On the technical side, it is important to mention that the (sub)mm is currently the shortest wavelength where sensitive, many-elements coherent detection interferometers are feasible from the ground. These can simultaneously provide high angular resolution, sensitivity, and image reconstruction fidelity. Direct detection interferometers at shorter wavelengths (e.g. mid/near-IR) can achieve similar angular resolution, but are more severely constrained in terms of sensitivity and image fidelity.

2.1. Local normal and starburst galaxies

The warm dust emitting at far-IR wavelengths is mostly heated by the UV radiation field of young massive stars in star forming regions. As a consequence, the far infrared luminosity L_{FIR} and its submm Rayleigh–Jeans part are considered good tracers of star formation in galaxies. In particular, these bands are useful to trace obscured star formation, since they are virtually unaffected by dust extinction. This is evident in Fig. 2, where the 350 μm map of the interacting galaxies "Antennae" (obtained at the CSO telescope, C. Dowell, priv. comm.) is compared with the optical HST image: the region of most vigorous star formation traced by the submm emission is actually the most obscured and less visible at optical wavelengths. The main problems of the current instrumentation (bolometer arrays on single dish telescopes) in tracing star formation in external galaxies are their limited sensitivity and their poor angular resolution (10–20″). Both these issues will no longer be a problem with ALMA, which will have sensitivities orders of magnitude better and an angular resolution similar to HST.

As already mentioned, also most of the gas phase of the cold ISM emits in the mm–submm range. More specifically, it is in this