Dedication of the Symposium: This symposium is dedicated to the memory of Charles Malcolm Walmsley

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Astrophysical Masers:
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Malcolm Walmsley's Maser Science

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Charles Malcolm Walmsley passed away on 1 May 2017. Over a long and highly productive career, Malcolm made numerous and fundamental contributions to the science of the interstellar medium and star formation. These have recently been summarized elsewhere (Menten & Cesaroni 2017). Here I would like to describe some of his work related to masers.

Malcolm became strongly engaged in astronomical maser research in the mid-1980s, when a relatively strong and narrow spectral line from the methanol molecule (CH_3OH) at 23.1 GHz was serendipitously discovered with the Effelsberg 100 meter radio telescope of the Max-Planck-Institut für Radioastronomie (MPIfR). At that time, the only known methanol *maser* lines were the series of $J_{k=2} - J_{k=1}$ transitions of E-type CH_3OH ($J = 2, 3, 4, \ldots$) near 25 GHz that had *only* been found in the Orion Kleinmann-Low nebula in 1971 by Barrett *et al.* (1971) and nowhere else, despite extensive searches.. It became clear that toward Orion-KL, the newly detected 23.1 GHz line was *not* masing, although it was detected there. The title of the article, by Wilson *et al.* (1984), reporting this line, *Detection of a new type of methanol maser*, gave the first hint at the class I/class II methanol maser dichotomy – the 23.1 GHz $9_2 - 10_1$ A^+ being the first class II line, to which soon the even stronger 19.9 GHz $2_1 - 3_0$ E line was added (Wilson *et al.* 1985). In contrast, the 25 GHz lines belong to class I.

These discoveries triggered Malcolm's interest in methanol masers, which became a major portion of my dissertation that he had started supervising. With the great sensitivity of Effelsberg, more 25 GHz maser sources were detected in regions much farther away than Orion (Menten *et al.* 1986). Malcolm also became curious about the excitation of methanol masers. At that time, collisional rate coefficients didn't exist for CH_3OH, so he used what published (experimental) information he could find in the literature and conducted statistical equilibrium calculations that indeed predicted maser action in the class I maser lines newly discovered by Morimoto *et al.* (1985) with the Nobeyama 45 meter telescope. Most interestingly, these calculations also predicted enhanced absorption against the cosmic microwave background ("over-cooling") in the 12.1 GHz $2_0 - 3_{-1}$ E transition toward cold dark clouds. This he indeed discovered toward two objects, a result he particularly cherished (Walmsley *et al.* 1988). Toward high-mass star forming regions with strong far infrared (FIR) radiation he and his collaborators had found this line to be the (then) strongest class II methanol maser line (Batrla *et al.* 1987).

At that time, Malcolm also was studying hyperfine structure (hfs) lines from rotationally excited levels of the hydroxyl radical (OH) at multiple radio frequencies, also with the Effelsberg telescope and with the VLA and VLBI (e.g., Walmsley *et al.* 1986). A conclusion of this work is a comprehensive study of OH excitation (with R. Cesaroni) that consisted of innovative statistical equilibrium calculations (considering FIR line overlaps; Cesaroni & Walmsley 1991). It was aimed at reproducing the observed pattern of maser emission in some hfs lines and absorption in others and constrained the physical conditions in the OH-bearing regions, i.e, the warm, dense molecular envelopes of ultracompact HII regions, which also harbor class II CH_3OH masers.

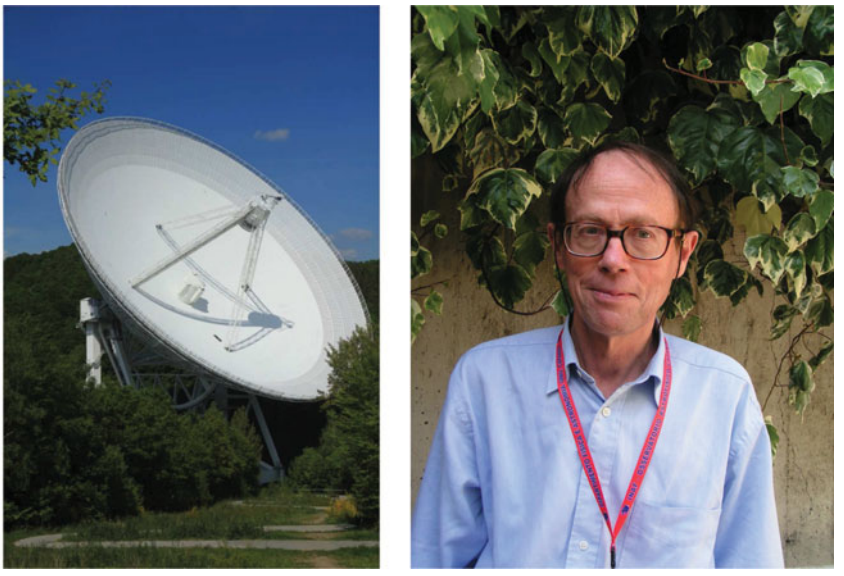

Figure 1. The MPIfR 100 meter radio telescope at Effelsberg, Germany. It started operations in 1972 and was extensively used by Malcolm Walmsley, his collaborators and students for a wide range of studies on interstellar radio recombinations lines and molecules. The picture of Malcolm was taken in 2005 in Acireale on Sicily at the IAU Symposium 227 *Massive star birth: A Crossroads of Astrophysics*, a conference he co-organized. Credits: MPIfR/N. Junkes and Cambridge University Press

The above work was done while Malcolm was a staff member of the MPIfR in Bonn, where he worked from 1969–1994. During the second part of his career, at Arcetri Observatory, he collaborated in numerous projects on high mass star forming regions, many of which involved masers. Finally, in one of his last papers, he returned to the topic of class I methanol masers and made major contributions to a comprehensive study of their excitation. It was published 30 years after his first paper on the subject (Leurini *et al.* 2016, see also the contribution by Leurini & Menten to these proceedings).

Malcolm Walmsley was invited to give the summary talk at this conference, a task he sadly could not perform. This meeting has been dedicated to his memory.

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