Fourier transform spectroscopy at the James Clerk Maxwell Telescope

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Abstract: Over the last decade we have used a Fourier transform spectrometer at the James Clerk Maxwell telescope in a variety of astronomical programs. Results from these programs will be reviewed, and future plans for an imaging submillimetre FTS at the JCMT discussed.

OCIS codes: (300.6300) Imaging Fourier transform spectroscopy; (350.1270) Submillimetre astronomy

Introduction Submillimetre astronomy has experienced rapid growth over the last decade primarily as a result of the development of sensitive array detector systems and efficient spectrometers. Heterodyne receivers, with their high spectral resolution but limited spectral range, are ideally suited to the study of narrow line emission from, for example, cold molecular clouds. By comparison, Fourier transform spectrometers (FTS), with their inherently broad spectral coverage at intermediate resolution, are well suited to the study of tropospheric lines in planetary atmospheres, bright extragalactic objects and to unbiased spectral line searches. In these cases the required instantaneous bandwidth exceeds that of heterodyne receivers.

In 1990 an existing Michelson interferometer [1], modified to operate at submillimetre wavelengths, was used to measure the atmospheric transmission above Mauna Kea [2] in order to determine the feasibility of conducting broadband spectroscopic observations from the James Clerk Maxwell Telescope (JCMT). These encouraging results provided the impetus for developing a polarizing FTS [3]. Initially this FTS used the JCMT facility bolometer UKT14 [4] as the detecting element. In more recent years a dual-polarization bolometer detector system [5] has been developed for use with the polarizing FTS. This system employs a fully differential electronic design which virtually eliminates common mode electrical noise from the often hostile telescope environment. In addition, the optical design minimizes the background radiant loading on the bolometer elements and the occurrence of resonant optical cavities.

Results The atmospheric transmission above Mauna Kea for 0.5 mm precipitable water vapour, corresponding to relatively dry conditions, is shown in Fig. 1. In this paper we will review some of the results from observing programs conducted with the FTS at the JCMT over the last decade. These include measurements of the atmospheric transmission throughout the submillimetre spectral region [6], the search for HCN, NH_3 and PH_3 in the troposphere of Jupiter [7], the detection of CO in the troposphere of Neptune [8], the detection of high-n HI Rydberg transitions in the submillimetre spectrum of the sun [9, 10] and measurements of line emission from the Orion molecular cloud.

Future directions The rapid growth in the field of astronomical imaging Fourier transform spectrometers (IFTS) is a direct result of the recent development of array detectors and extends upon the pioneering work of Maillard [11] at near infrared wavelengths with the CFHT's FTS. We are currently developing an IFTS for use with the JCMT. The design is similar to that of the SPIRE project [12] (Spectral and Photometric Imaging REceiver) of ESA's Far Infrared and Submillimetre Telescope (FIRST). It is based on the Mach-Zehnder interferometer [13, 14], which allows access to the two input and two output ports, and is shown schematically in Fig. 2. This configuration uses two broadband intensity beamsplitters in place of the conventional polarising beamsplitters. The spatial separation of the two input ports allows differential measurements with one port viewing the astronomical source while the other views an adjacent background

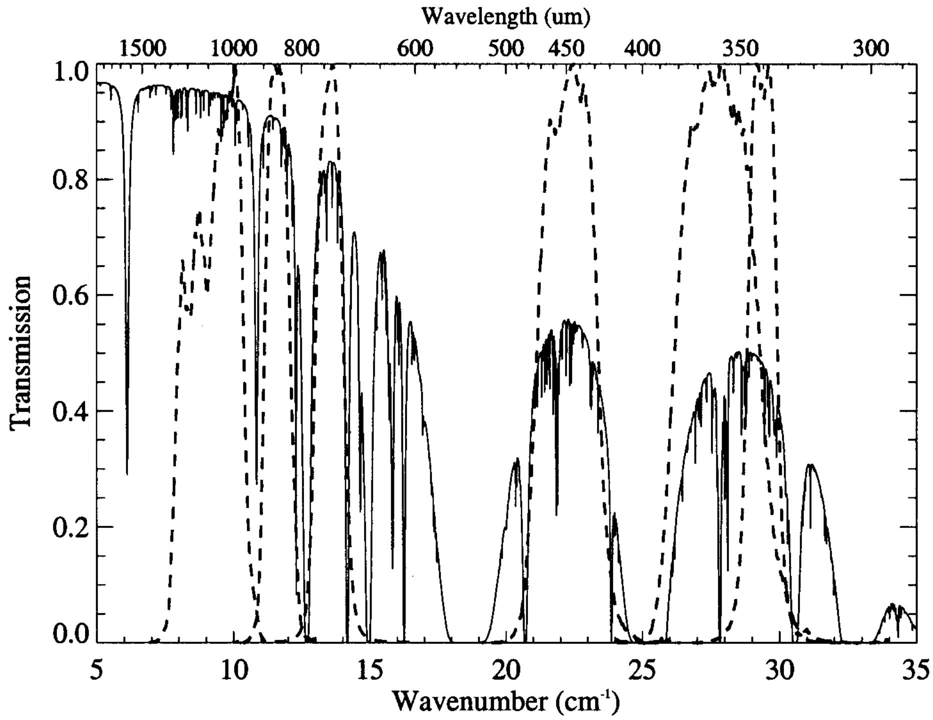

Fig. 1. Theoretical atmospheric transmission spectrum modeled for Mauna Kea with 0.5 mm precipitable water vapour. Some of the available filter bands are also shown.

position. This differential measurement is critical for submillimetre astronomical observations without which variations in atmospheric emission during an interferogram scan can severely distort both the baseline and line shape of the resulting spectrum. While both output ports are available, and could in principle be used to observe two different wavelength ranges, in the initial design only one output port will be used.

Although the SCUBA array detector [15] has revolutionised submillimetre astronomy in the two years that it has been at the JCMT, it uses bolometer technology that is now well out of date. Today it is possible to make larger arrays and to meet more stringent sensitivity requirements at higher operating temperatures. The successor to SCUBA (SCUBA-2) is intended to have a wide field of view (~ 10' x 10'), sky background limited sensitivity, simultaneous 850 and 450μm imaging and instantaneous full spatial sampling of the image. The favoured detector technology for SCUBA-2 is the superconducting Transition-Edge Sensor (TES) bolometer with multiplexed SQUID readout. In parallel with the SCUBA-2 development program we are planning to interface a detector array with the IFTS at the JCMT. This will provide valuable feedback to both the SCUBA-2 and SPIRE projects. The detailed design of the IFTS, which is currently under development, will be presented.

One promising application of the proposed IFTS is the redshift measurement of distant young galaxies. Submillimetre and FIR surveys by SCUBA, SIRTF, FIRST and ALMA should be able to detect large numbers of primeval galaxies, but will not easily be able to measure their redshifts. In many cases there will be no optical counterparts, and one of the promising methods of determining z is to measure two redshifted high-J CO lines, a task well suited to a broadband IFTS. Band-limitation by means of a grating post-disperser would remove one dimension of the array for imaging but allow deep spectroscopic measurements.

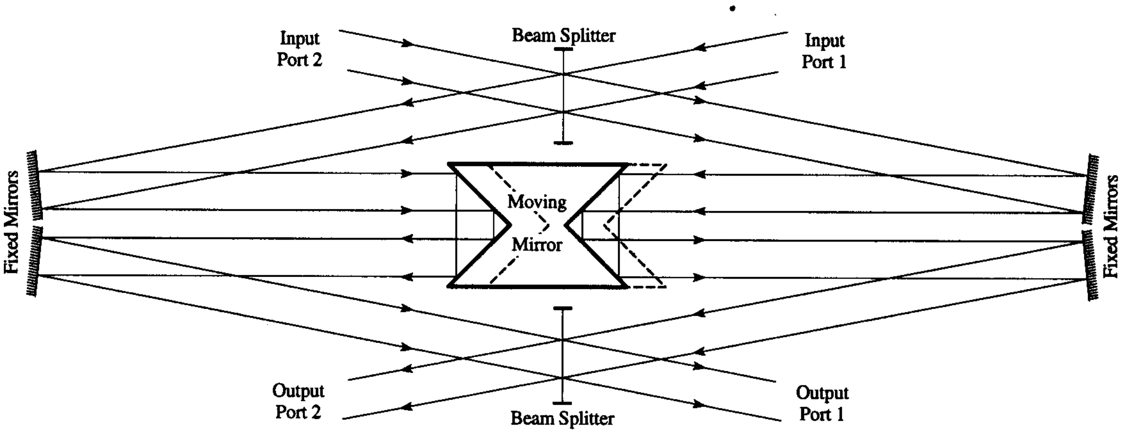

Fig. 2. A schematic of the Mach-Zehnder imaging Fourier transform spectrometer.

References

1. Naylor D.A. & Clark T.A., "A mid-infrared astronomical Fourier transform spectrometer" in ***Instrumentation in Astronomy VI***, Crawford D.L., ed(s)., Proc. SPIE 627, 482-490 (1986)
2. Naylor D.A., Clark T.A., Schultz A.A. & Davis G.R., "Atmospheric transmission at submillimetre wavelengths from Mauna Kea" MNRAS, **251**, 199-202 (1991)
3. Naylor D.A., Clark T.A. & Davis G.R.,"A polarizing Fourier transform spectrometer at submillimetre and mid-infrared wavelengths" in ***Astronomical Telescopes and Instrumentation for the 21st Century***, Crawford D.L. & Craine E.R., ed(s)., Proc. SPIE 2198, 703-714 (1994)
4. Duncan W.D., Robson E.I., Ade P.A.R., Griffin M.J. & Sandell G., "A millimetre/submillimetre common user photometer for the James Clerk Maxwell Telescope" , MNRAS, **243**, 126-132 (1990)
5. Naylor D.A., Gom B.G., Ade P.A.R. & Davis J.E., 1999, "Design and performance of a dual polarizing detector system for broadband astronomical spectroscopy at submillimetre wavelengths", Rev. Sci. Inst., **70**, 4097–4109 (1999)
6. Naylor D.A., Davis G.R., Gom B.G., Clark T.A. & Griffin M.J., "Atmospheric transmission at submillimetre wavelengths from Mauna Kea" MNRAS, **315**, 622-628 (2000)
7. Davis G.R., Naylor D.A., Griffin M.J., Clark T.A. & Holland W.S., "Broadband submillimetre spectroscopy of HCN, NH_3 and PH_3 in the troposphere of Jupiter" Icarus, **130**, 387-403 (1997)
8. Naylor D.A., Davis G.R., Griffin M.J., Clark T.A., Gautier D. & Martin A., "Broadband spectroscopic detection of the CO J=3-2 tropspheric absoprtion line in the atmosphere of Neptune" A & A , **291**, L51-L53 (1994)
9. Clark T.A., Naylor D.A. & Davis G.R., "Detection and limb brightening of the HI n=20-19 Rydberg line in the submillimetre spectrum of the Sun" A & A, **357**, 757-762 (2000)
10. Clark T.A., Naylor D.A. & Davis G.R., "Detection and of the HI n=22-21 Rydberg line in emission at the submillimetre limb" A & A, (In press)
11. Maillard J.P., "3D-Spectroscopy with a Fourier Transform Spectrometer" in ***Tridimensional Optical Spectroscopic Methods in Astrophysics. Proceedings of I.A.U. Colloquium 149***, Comte G. & Marcelin M., ed(s)., **71**, 316+ (1995)
12. Griffin M.J., Swinyard B.M. & Vigroux L., "The SPIRE Instrument for FIRST" Proc. SPIE 4013, 184+ (2000)
13. Ade P.A.R., Hamilton P.A. & Naylor D.A.,"An absolute dual beam emission spectrometer", in ***Fourier Transform Spectroscopy: New Methods and Applications***, OSA **90** (1999)
14. Swinyard B.M., Ade P.A.R., Griffin M.J., Dohlen K., Baluteau J-P, Pouliquen D., Ferand D., Dargent P., Michel G., Martignac J., Rodriguez L., Jennings D.E., Caldwell M.E., Richards A.G., Hamilton P.A. & Naylor D.A., "The FIRST SPIRE spectrometer: a novel imaging FTS for the submillimeter" Proc. SPIE 4013, 196+ (2000)
15. Holland W.S., Robson E.I., Gear W.K., Cunningham C.R., Lightfoot J.F., Jenness T., Ivison R.J., Stevens J.A., Ade P.A.R., Griffin M.J., Duncan W.D., Murphy J.A. & Naylor D.A., "SCUBA: a common-user submillimetre camera operating on the James Clerk Maxwell Telescope", MNRAS, **303**, 659-672 (1999)