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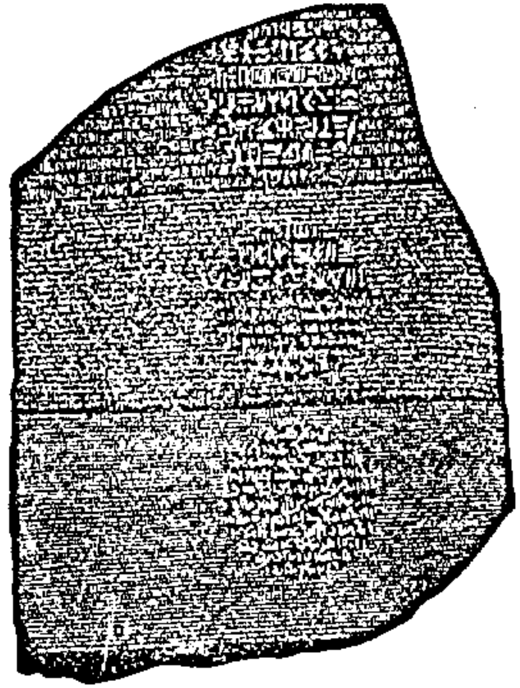
Grenoble, 1810

European Geophysical Society XIX General Assembly
Grenoble, 25-29 April 1994

How to decipher the Rosetta Stone ?



IN SITU MICROWAVE OBSERVATIONS OF A COMET

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Summary. We investigate the scientific capabilities of a small radio telescope with a millimetre-submillimetre spectrometer aboard a space probe orbiting a comet. A small antenna is sufficient to make such an instrument very sensitive for the study of molecules in the gas coma through their rotational lines. These lines could be observed in absorption against the nucleus continuum, or in emission near the limb or at various impact parameters. The most intense line should be the 557 GHz water line and its observation could probe very low levels of activity. Many minor constituents and isotopic species could be measured within the bands of a few receivers at selected wavelengths. The simultaneous observation of several rotational lines of the same species and the space mapping of strong lines could inform us on the physical conditions within the coma. The high spectral resolution of heterodyne techniques allows to resolve the lines and to investigate the kinematics of the gas jets. In addition, continuum channels could perform radiometric observations of the nucleus and study the thermal properties of its sub-surface. These radio observations should be complementary to other analyses of the composition of the cometary atmosphere, to an exploration of the nucleus surface, and to studies of the gas jets-nucleus interface and cometary activity.

Spectrometry

Spectrometer sensitivity

• The spectrometer is very sensitive for detecting lines in absorption against the nucleus continuum emission.

• The 557 GHz water line can be detected for production rates as low as 3 10^{21} molec. s^{-1} (isotropic outgassing approximation).

• For a production rate of 10^{27} molec. s^{-1}, polar species with relative abundances as low as 10^{-5} could be observed (for typical integration times of 10 min).

Note: The 557 GHz water line will be heavily thick even for moderate cometary activity. Then, unsaturated lines from minor species and isotopic species will be observed to measure column densities and line profiles.

The high spectral resolution of heterodyne techniques

Cometary lines have Doppler profiles. Their widths are of the order of 1 km s^{-1}.

• It allows unambiguous identification of the molecular species (which is not the case for medium-resolution IR spectroscopy).

• It allows a very good sensitivity for observations in absorption (lines are resolved).

• It allows to measure the line profiles and to investigate the kinematics of the coma.

The spectrometer scientific program

• Observation of the **onset of activity** by monitoring the 557 GHz water line, at large heliocentric distances (if the energy budget permits).

• Determination of the **origin of outgassing** by mapping the 557 GHz water line (and others):
- from discrete active regions;
- from the mantle (observations can be done even on the night side of the nucleus);
- from grains.

• A **spectral survey** of the frequency bands accessible to the instrument, for probing minor species and isotopic ratios.

• An investigation of the **hydrodynamics of the gas jets** by observing line profiles:
- interface nucleus surface - gas jets;
- evolution of the gas jet expansion velocity;
- collimation or isotropization of the jets;
- interaction with dust and gas-productive grains.

• An investigation of the **gas temperature** and **molecular excitation** by probing the molecular rotational distribution:
- saturated lines (e.g. 557 GHz water line) give directly the excitation (rotational) temperature;
- simultaneous observations of several rotational lines (e.g. methanol) give the rotational distribution.

Possible choice of molecular lines

	molecule	transition	frequency (GHz)
3-mm channel	HCN	1-0	88.6
	CH_3OH	several	96.7
1.3-mm channel	CO 2-1	230.5	
	HDO	2_{11}-2_{12}	241.6
	CH_3OH	several	241.8 & 251.8
0.5-mm channel	HCN	6-5	531.7
	$H_2{}^{18}O$	1_{10}-1_{01}	547.5
	$H_2{}^{17}O$	1_{10}-1_{01}	552.0
	H_2O	1_{10}-1_{01}	556.7
	CO	5-4	576.3

and many others:

H_2CO, H_2S, HCOOH, C_2H_5OH, CH_2NH... isotopic species...

Radiometry

Radiometry at mm wavelengths samples the nucleus sub-surface at 1-100 cm depth scales.

Cometary nucleus mapping

- Mapping of the nucleus brightness in the three channels;
- Determination of the active/inactive areas;
- Measurement of the thermal inertia of the nucleus;
- Measurement of the thickness of the crust covering ice.

⇒ *Complement to IR mapping and assistance in selecting sites for in situ analyses.*

Asteroid flyby:

The instrument could detect a 20-km size asteroid as far as 500 000 km:measurement of the average surface brightness as a function of rotation and phase angle.

Instrument characteristics:

- **small antenna** (30 cm: HPBW = 2.1 mrad at 557 GHz)

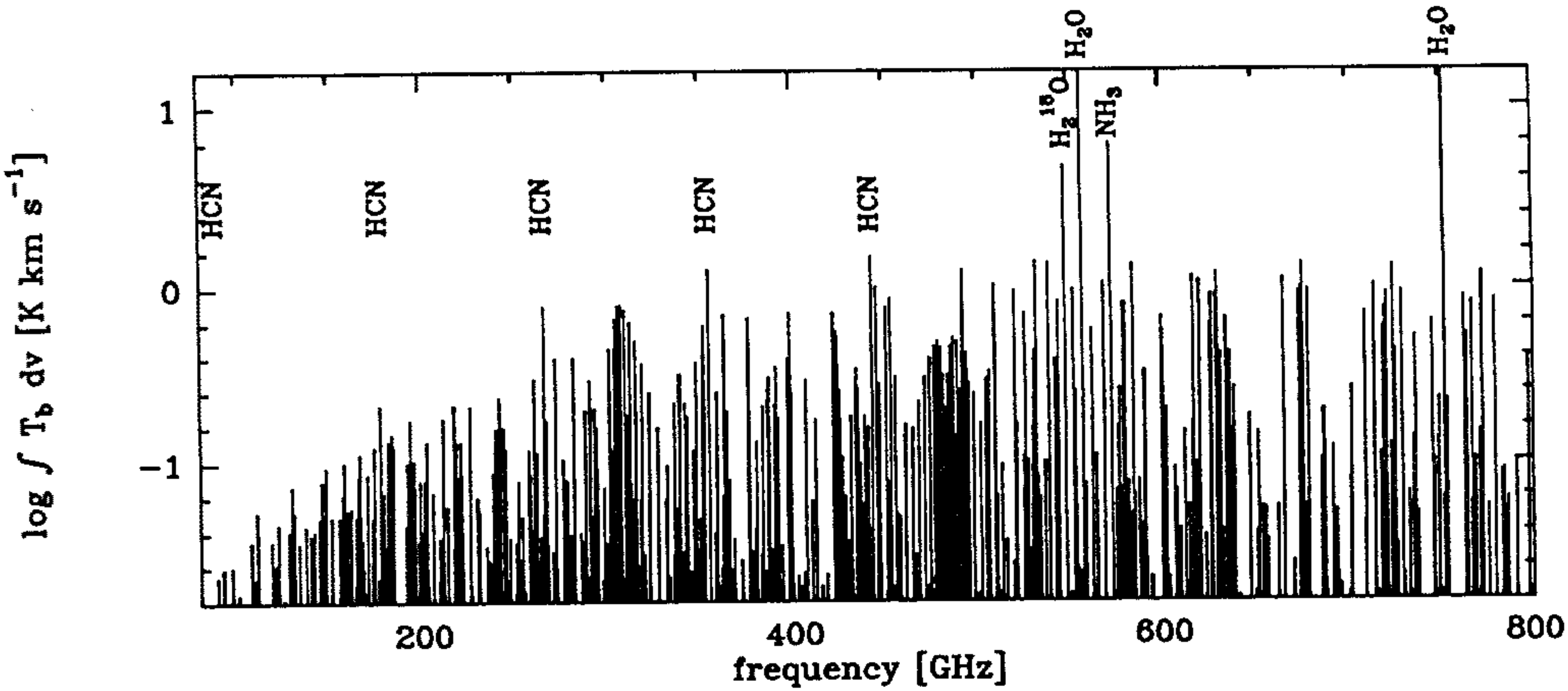
- **3 channel receivers**, bandwidths = 2-10 GHz

  ~ 3 mm, system noise ~ 300 K
  ~ 1.3 mm, system noise ~ 600 K
  0.5 mm (557 GHz water line), system noise ~ 2000 K

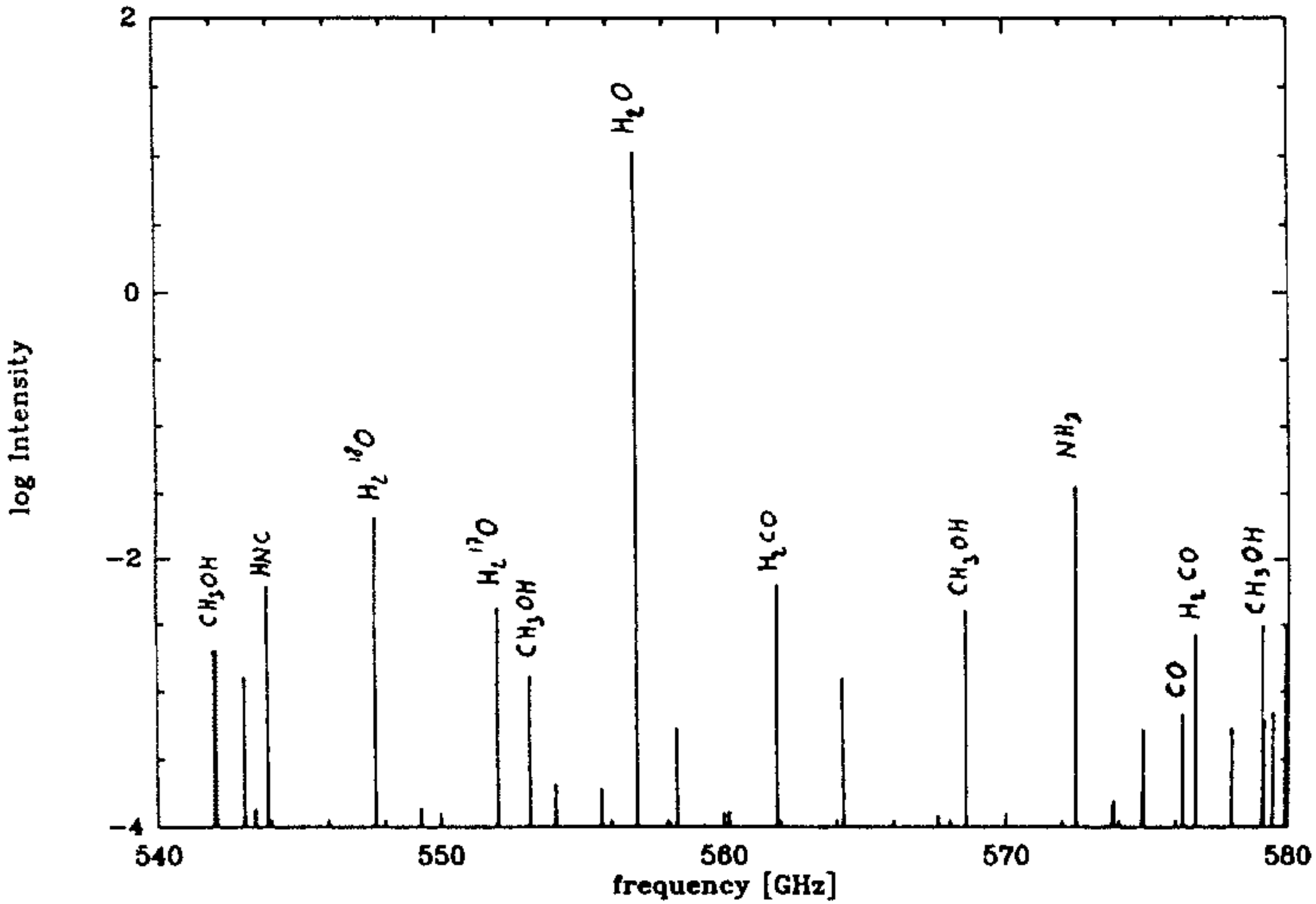
  (central frequencies, bandwidths and image band frequency separations are to be determined for optimal spectral coverage).

- **high-resolution, versatile spectrometer**:

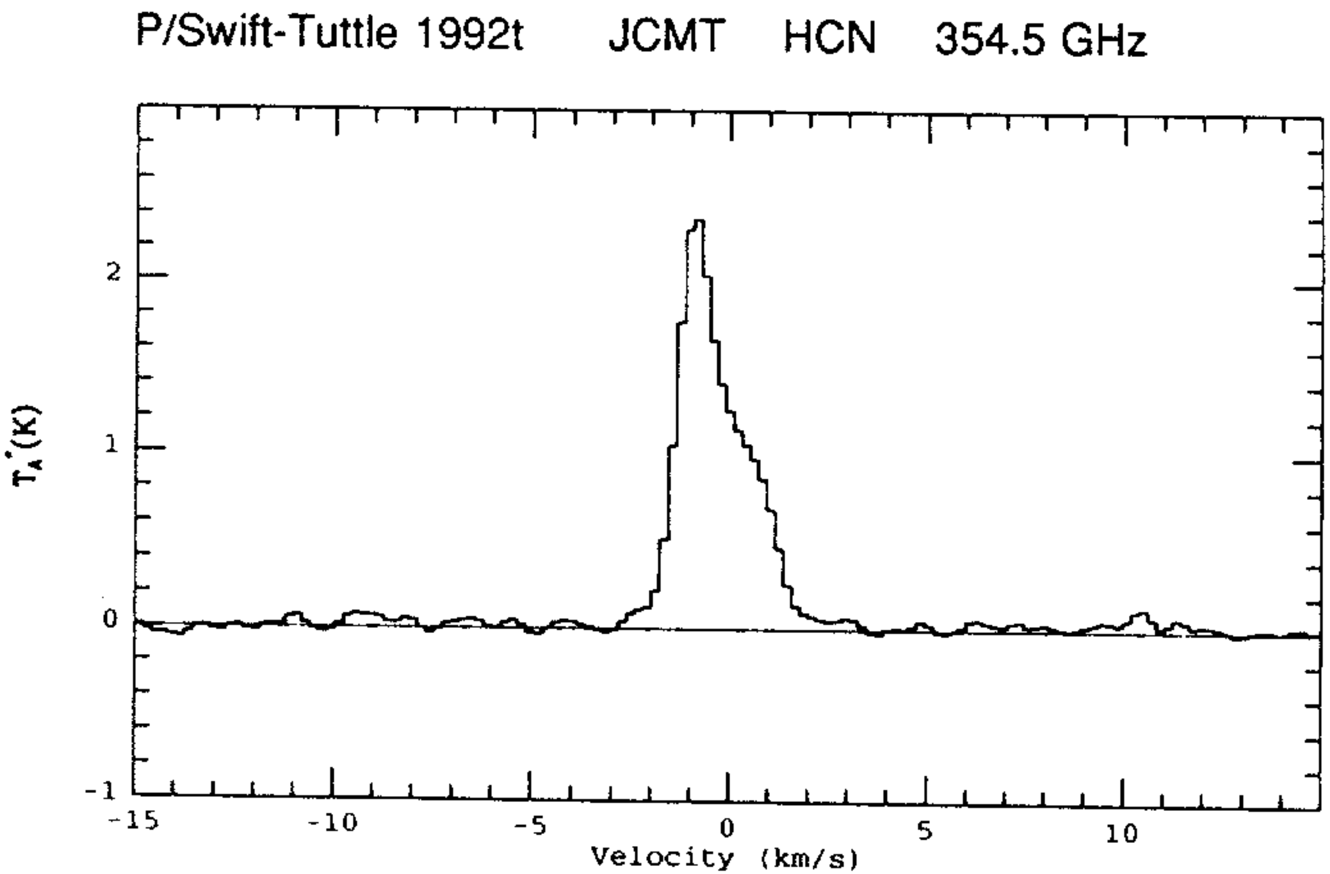
  1000 channels, total band = 100-200 MHz
  spectral resolution = 100 kHz (0.054 km s^{-1} at 557 GHz)



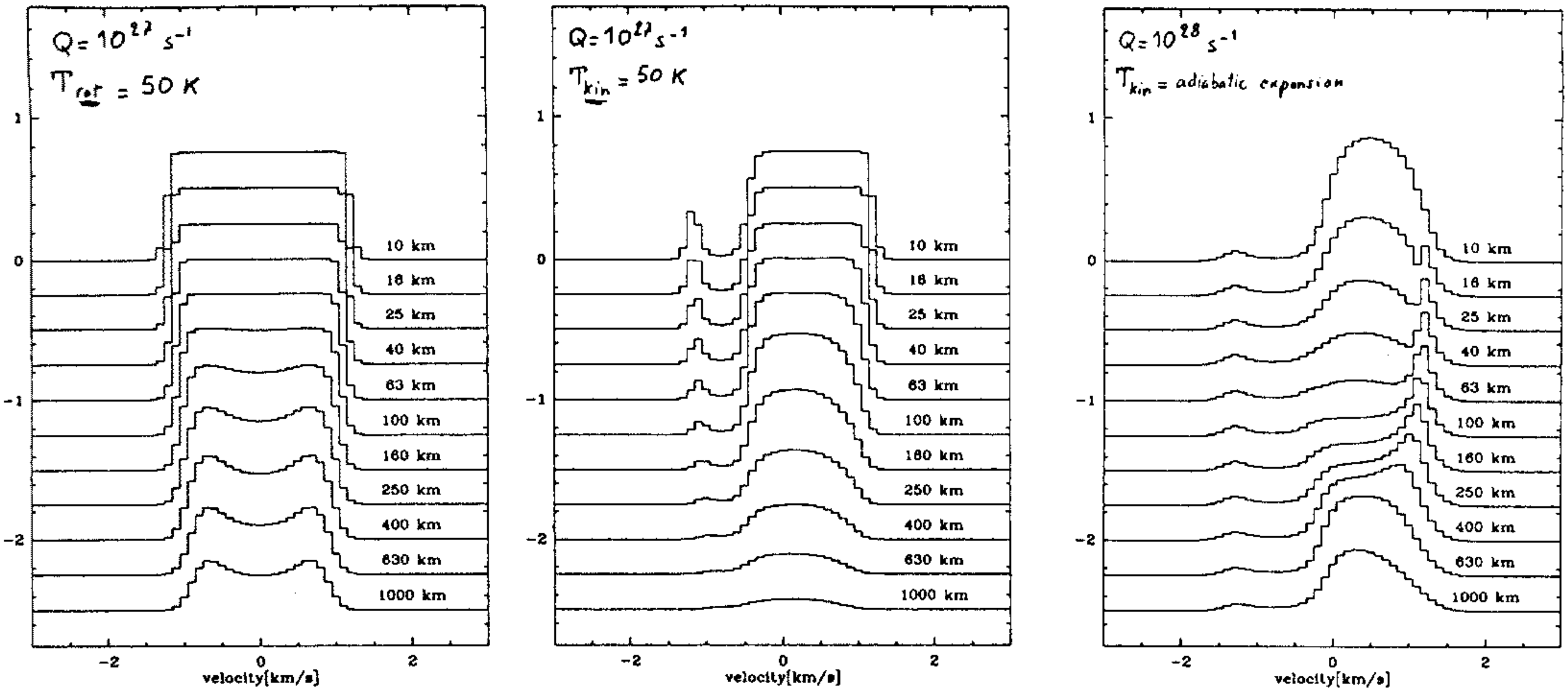
A synthetic spectrum of a comet in the submillimetre domain. A "standard" composition and a rotational temperature of 40 K are assumed. The comet is at $r_h = \Delta = 1$ AU with a water production rate of 10^{28} molec. s^{-1}, and is observed with a 15-m telescope. Most of the lines which are not tagged are from methanol.



A synthetic spectrum of a comet in the region of the 1_{10}-1_{01} fundamental water band. The intensity scale is arbitrary and optical depth is not taken into account.



The J(4-3) HCN line at 345 GHz observed in comet P/Swift-Tuttle at the JCMT. The line width (~3 km s^{-1}) is about twice the coma expansion velocity. The strong peak at negative velocities is due to strong jets towards the observer. Here, the field of view was 15 000 km at the comet. An *in situ* observation will resolve the jets and their velocity fields.



Examples of the 557 GHz water line shape evolution as a function of the impact parameter. This shape and its evolution critically depend upon the physical conditions.