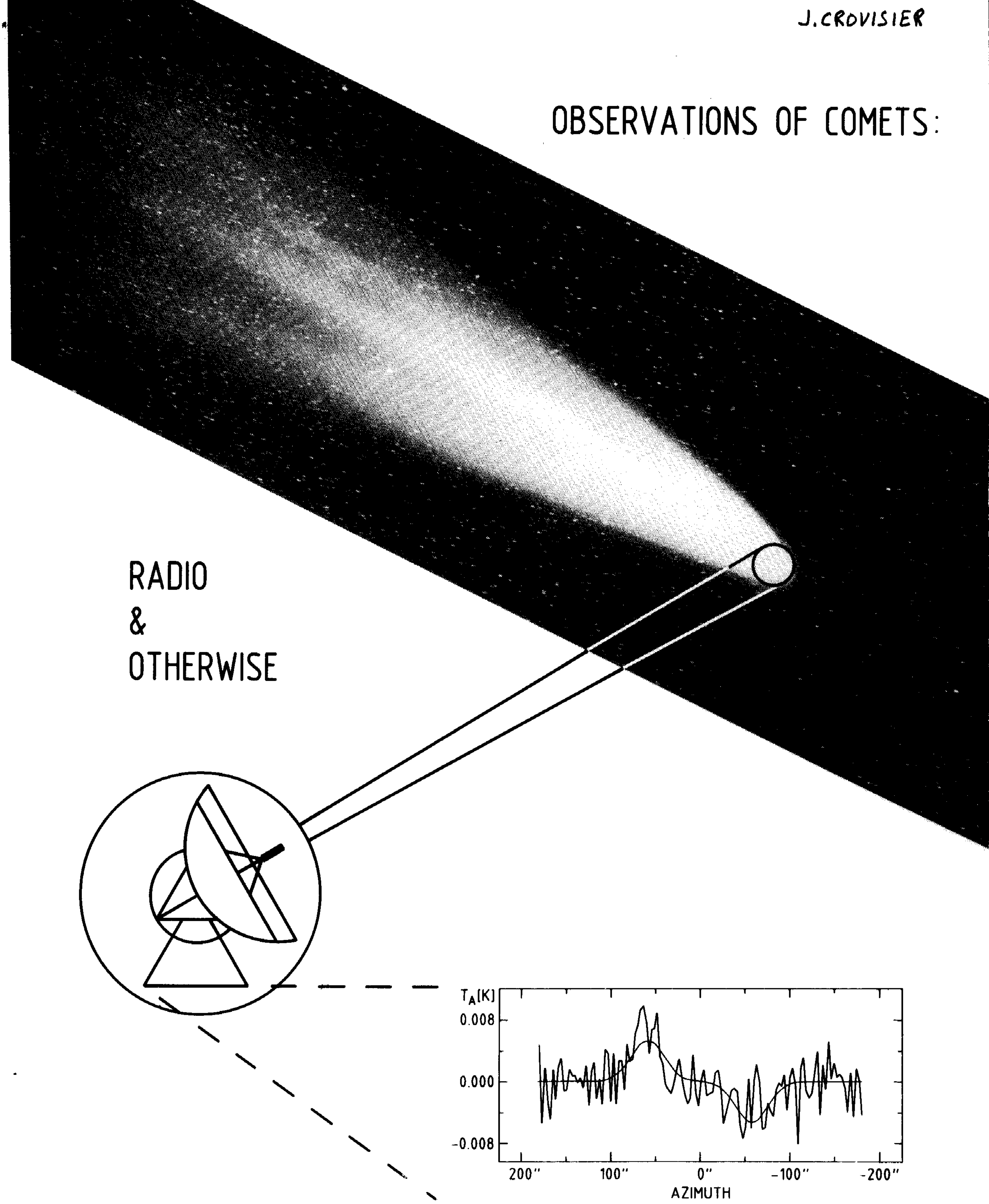
J. CROVISIER

OBSERVATIONS OF COMETS:

RADIO & OTHERWISE



Max-Planck-Institut für Radioastronomie

TECHNISCHER BERICHT

Nr. 64

OBSERVATIONS OF COMETS: RADIO AND OTHERWISE

A collection of extended abstracts of the papers presented at a workshop held at the Max-Planck-Institut für Radioastronomie in Bonn on 4 June 1984.

Edited by
M.K. Bird

August 1984

Max-Planck-Institut für Radioastronomie
Auf dem Hügel 69, 5300 Bonn 1, F.R.G.

THEORETICAL ASPECTS OF COMETARY RADIO LINE EXCITATION: OH, H_2O AND OTHERS

J. Crovisier
Observatoire de Meudon
92195 Meudon / France

Models of radio and infrared molecular emissions in comets must account for the various processes listed in the first illustration (Fig. 7-1). The solar UV is the principle destructive agent for most cometary molecules via photodissociation, thus regulating the size of the emission region. The well-known Swings effect in the OH-molecules is also governed by the fine structure of the solar UV spectrum. Electronic transitions are less frequent for other important molecules (e.g. CO, H_2O), which are more easily excited to higher vibrational states by the solar infrared radiation. Collisional excitation and secondary radiation sources (nucleus and dust grains) need to be included in models of the inner coma. It has become apparent over the past few years that: (a) LTE conditions are invalid and cannot explain the distribution of rotational energy levels, and (b) specific calculations must be performed for each individual species ("simplest" assumption: fluorescence equilibrium).

Since each molecular type more or less "does its own thing", it is appropriate to comment briefly on some of the more widely-sought constituents of cometary comae:

OH : The excitation and fluorescence of the hydroxyl maser in comets is one of the very few processes in this field that could be classified as well known. Some minor discrepancies from the refined theory (Depois *et al.*, 1981), such as the (as yet unconfirmed) post-perihelion emission predicted by Schleicher and A'Hearn (1982), still need to be resolved.

CO : Carbon monoxide, having a relatively long photodissociation lifetime, is expected to be in a state of fluorescence equilibrium in the outer coma with detectable emissions in the infrared (1-0 band) and microwave (mostly submillimeter) ranges (Crovisier and Le Bourlot, 1983). Typical excitation rates (s^{-1}) at 1 AU and the expected relative populations of the rotational levels of CO are displayed in Fig. 7-2.

H_2O : The water molecule is expected to show profuse fluorescence emission at IR and submillimeter wavelengths which cannot be observed at ground level due to absorption by telluric water. The radio line at λ1.35-cm cannot be explained by fluorescence models (Crovisier, 1984). A recent maser model by Strelnitskii (1983) is outlined in Fig. 7-3. The model has a compact emission region some 100 km in diameter which can account for the line width (thermal) and blue shift (optically thick) of the line observed in Comet Bradfield (1974 III). It fails to explain the detection in Comet IRAS-Araki-Alcock.

NH_3 : Ammonia is a more fragile molecule in the solar radiation field (level diagram: Fig. 7-4), so its coma size may not be too much larger than the collision-dominated regime about the cometary nucleus ($r \approx 5\text{-}8 \times 10^3$ km). Near-Earth approaches are thus quite favorable for its detection. The molecule is expected to assume primarily the metastable (J=K) states, so that a determination of the relative intensities of the K-band inversion lines could be used to derive the kinetic temperature of the coma.

Bibliography

Biermann, L., Giguere, P.T. and Huebner, W.F., A model of a comet coma with interstellar molecules in the nucleus, Astron. Astrophys. **108**, 221, 1982.

Bockelée-Morvan, D. and Gérard, E., Radio observations of the hydroxyl radical in comets with high spectral resolution. Kinematics and asymmetries of the OH coma in C/Meier (1978 XXI), C/Bradfield (1979 X), and C/Austin (1982g), Astron. Astrophys. **131**, 111, 1984.

Chin, G. and Weaver, H.A., Vibrational and rotational excitation of CO in comets: Nonequilibrium calculations, Astrophys. J. (in press), 1984.

Combes, M., Infrared observations of Comet Halley, in *The Need for Coordinated Ground-based Observations of Halley's Comet*, P. Véron *et al.* (eds.), ESO Publication, 83, 1982.

Crovisier, J., Fluorescence of water molecules in comets, in *The Need for Coordinated Ground-based Observations of Halley's Comet*, P. Veron *et al.* (eds.), ESO Publ., 149, 1982.

Crovisier, J., The water molecule in comets: fluorescence mechanisms and thermodynamics of the inner coma, Astron. Astrophys. **130**, 361, 1984. (Erratum: Astron. Astrophys. **135**, 197, 1984).

Crovisier, J., Combes, M., Encrenaz, T. and Le Bourlot, J., Infrared and microwave fluorescence of molecules in comets, in Cometary Exploration, T.I. Gambosi (ed.), Hungarian Acad. Sci., Budapest, 197, 1983.

Crovisier, J. and Encrenaz, T., Infrared fluorescence of molecules in comets: the general synthetic spectrum, Astron. Astrophys. 126, 1983.

Crovisier, J. and Le Bourlot, J., Infrared and microwave fluorescence of carbon monoxide in comets, Astron. Astrophys. 123, 61, 1983.

Depois, D., Gêrard, E., Crovisier, J. and Kazès, I., The OH radical in comets: Observation and analysis of the hyperfine microwave transitions at 1667 MHz and 1665 MHz, Astron. Astrophys. 99, 320, 1981.

Elitzur, M., On pumping of the OH ground state in comets, Astrophys. J. 246, 354, 1981.

Huebner, W.F., Einige Mikrowellenübergänge für in Kometen und im interstellaren Raum vermutete Moleküle, Astron. Astrophys. 7, 359, 1970.

Jackson, W.M., The lifetime of the OH radical in comets at 1 AU, Icarus 41, 147, 1980.

Mies, F.H., Ultraviolet fluorescent pumping of OH 18-centimeter radiation in comets, Astrophys. J. 191, L145, 1974.

Potter, A.E. and Del Duca, B., Lifetime in space of possible parent molecules of cometary radicals, Icarus 3, 103, 1964.

Schleicher, D.G. and A'Hearn, M.F., OH fluorescence in comets: fluorescence efficiency of the ultraviolet bands, Astrophys. J. 258, 864, 1982.

Strelnitskii, V.S., The water maser emission from Comet Bradfield (1974 III), Sov. Astron. Lett. 9, 99, 1983.

Weaver, H.A. and Mumma, M.J., Infrared molecular emissions from comets, Astrophys. J. 276, 782, 1984.

Yamamoto, T., Evaluation of infrared line emission from constituent molecules of cometary nuclei, Astron. Astrophys. 109, 326, 1982.

Modelling radio and IR molecular emission in comets.

Excitation mechanisms -

- Solar UV
  - → mainly photodissociation $(10^{-3} - 10^{-6} s^{-1})$
- Solar IR
  - prevailing mechanism - excites fundamental bands of vibration - $g \sim 10^{-4} s^{-1}$.
- cometary dust IR
  - in the inner coma - dust models needed.
- collisions
  - in the inner coma - collision cross-sections needed.
  - temperature law needed = very cold (~ 15K) at r ~ 50 - 100 km !

Dynamical evolution of the rotational population distribution :

- from thermal distribution (nucleus region)
- to fluorescence equilibrium (outer coma)

⇒ thermal emission (200 K) not valid.

⇒ Specific calculations necessary for each molecule.

Fig. 7-1. Some aspects to be considered in modelling radio and infrared line emission from comets

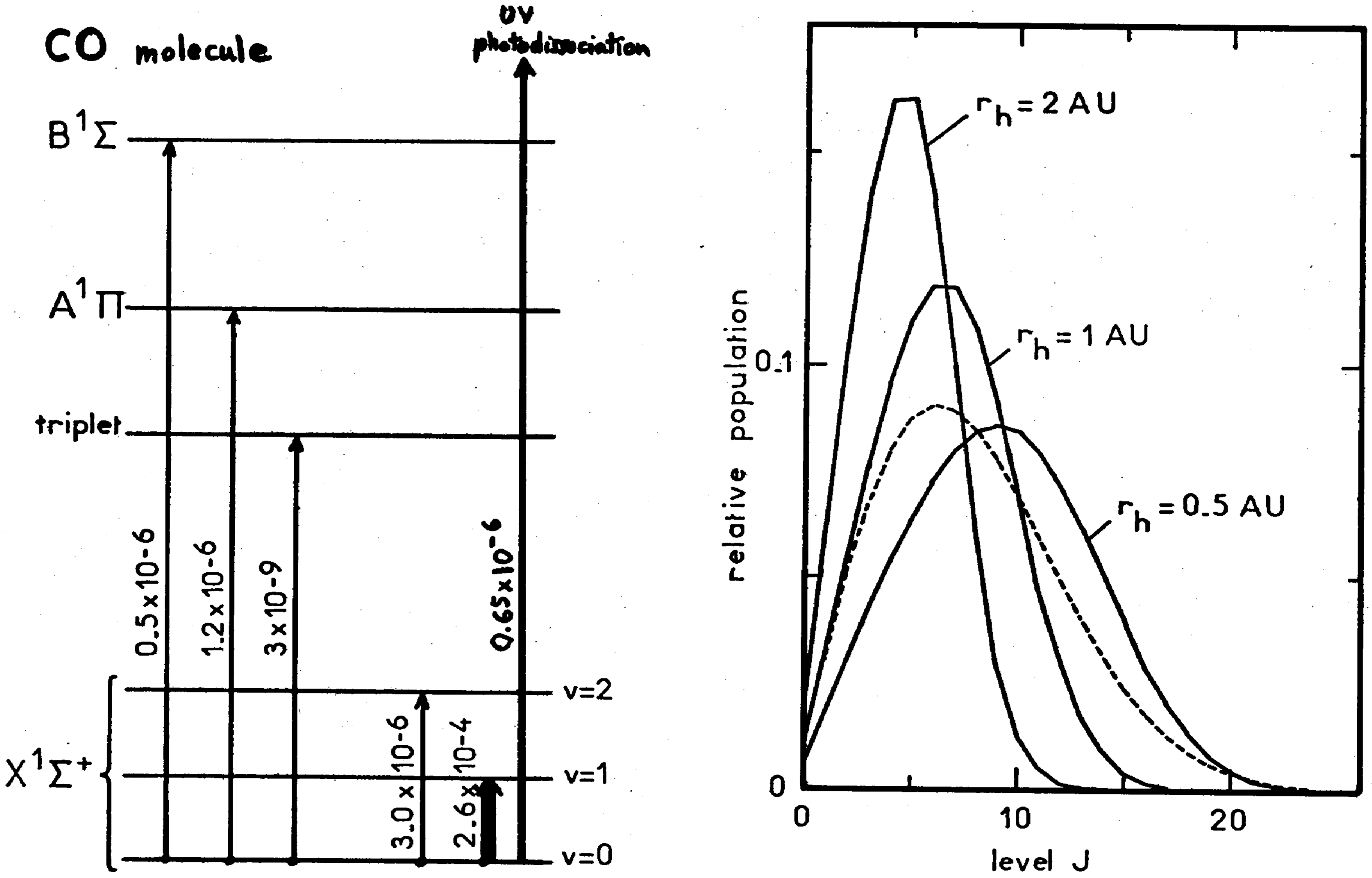
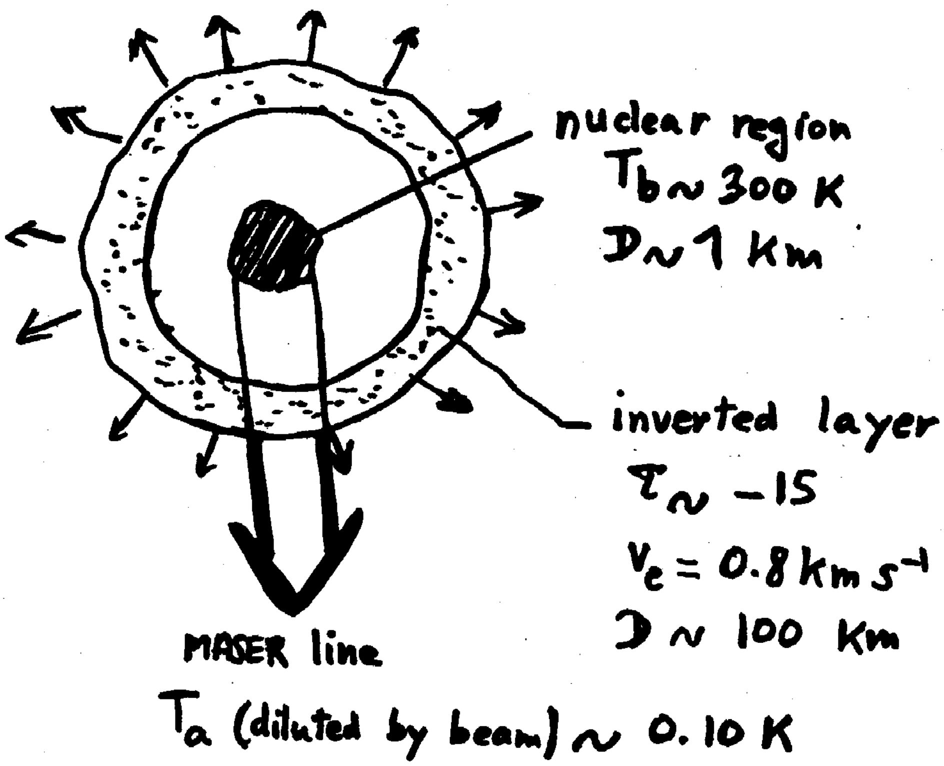
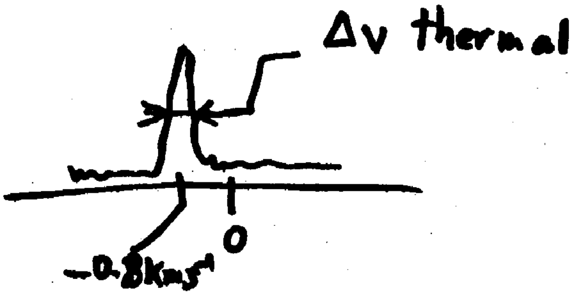


Fig. 7-2. Schematic excitation diagram (left) and relative population of rotational energy levels (right) for cometary CO (from Crovisier and Le Bourlot, 1983).

H_2O maser models for comets

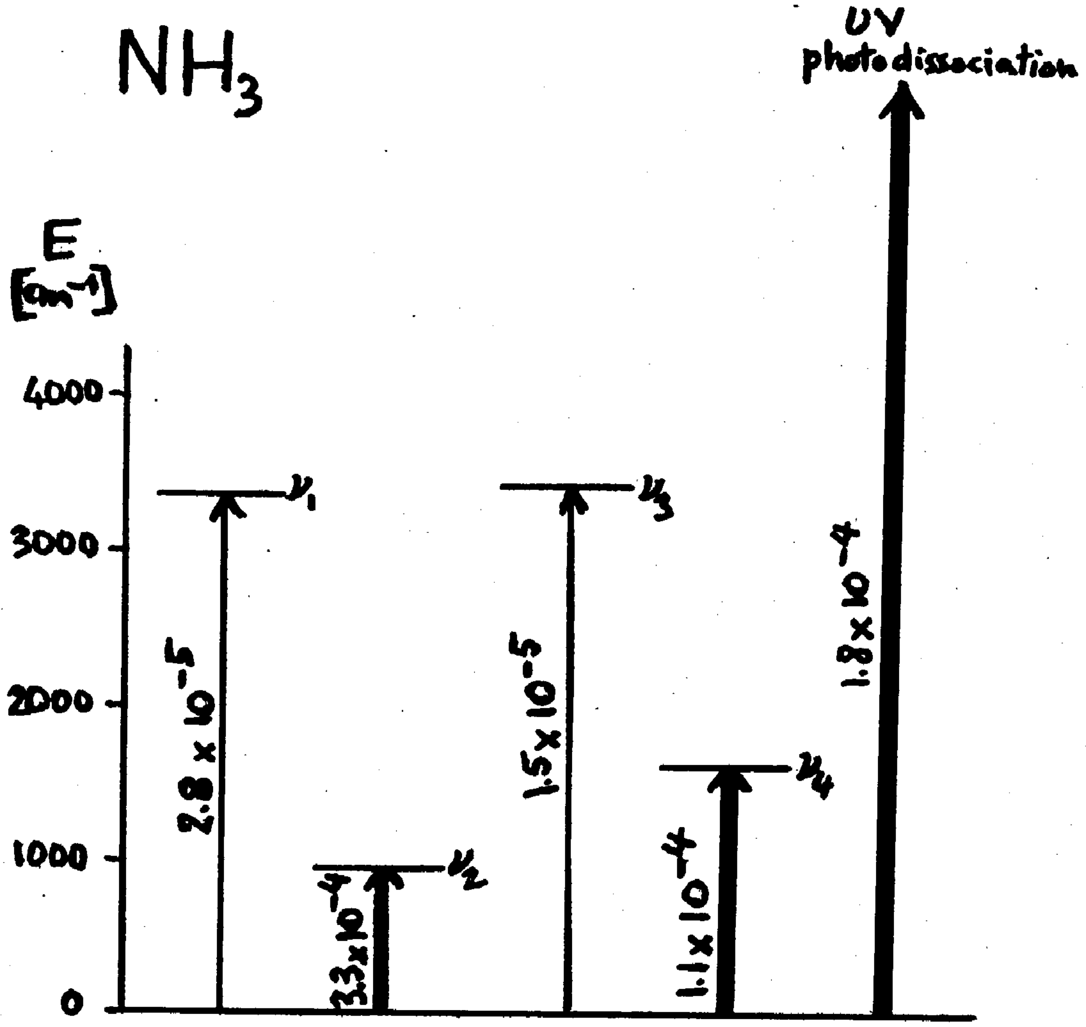


[from Strel'nitskii, 1983]



- explains Bradfield 1974 III.
- does not explain I.-A.-A. 1983d.
- requires high $Q(H_2O) = 10^{29}-10^{30}$ molec. s^{-1}.
- the pumping mechanism must be figured out.

Fig. 7-3. A maser model for cometary H_2O (Strelnitskii, 1983)



life time $\sim 5.5 \times 10^3$ s

A_{ij} (vib). $\sim 10\ s^{-1}$

A_{ij} (rot) $\sim 10^{-2}\ s^{-1}$

Fig. 7-4. Excitation rates for ammonia at 1 AU.