Molecular Spectroscopy & Masers

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Maser Molecules

H: atom
SiO, SiS: simple rotors
OH, CH: simple rotors with electronic spin
HCN: linear triatomic
NH$_3$: symmetric top
H$_2$O, H$_2$CO: asymmetric top
CH$_3$OH: asymmetric top & complications
Simple Rotor (SiO)

- Evenly-spaced vibrational levels
- Rotational levels with increased spacing
- Complications: Zeeman effect & 3 common isotopologues
Diatomic Radical (OH)

- Spin-orbit coupling
- Body rotation
- Lambda-doubling
- Hyperfine structure
- Zeeman effect
Linear triatomic (HCN)

3 v-modes, 2 stretch & 1 bend

In bent formation rotation about long axis

I-doubling: coupling of rotation to bending
Symmetric Top

3 good quantum numbers: J and 2 projections

Masers in rotation-inversion transitions

Transfer across K-ladders weak

2 Nuclear spin species
Asymmetric Top

\( \text{H}_2\text{O} \) has 3 v-modes;

\( \text{H}_2\text{CO} \) has 6 3 independent moments of inertia

2 hydrogen spin species

\( \text{o-H}_2\text{O} \) has hyperfine structure

Weak Zeeman effect
Methanol

9v-states, only need 1

Hindered internal rotation 3-fold symmetry

2 symmetry classes share $K=0$

Hyperfine & Zeeman
Why Masers?

• Interesting objects in their own right!!
• Astrophysical tools
• Very high brightness temperatures: easy to observe
• Information on smallest scales (relatively)
• Range of variability
VLBI

Angular resolution
\[ \theta = 1.22 \frac{\lambda}{D} : \text{m to } < 1\text{mm} \]

D up to 12000km
(Earth) or x10 with satellite (RadioAstron)

Q down to 10\(\mu\)as

Still see structure
Source Types ('Environments')

- Star-formation
- Evolved stars (AGB, RSG, pPN)
- SNRs
- Galactic nuclei ('megamasers')
- Hot stars
- Comets, planetary atmospheres
Massive Star-Forming Region

Shock

Molecular Outflow

v~10km s^{-1}

Class I CH₃OH
NH₃ metastable
H₂O

NH₃ non-metastable

Ambient molecular cloud gas

Shock

v~40km s^{-1}

DISC

10 000 AU

1000AU

North Offset (arcsec)

East Offset (arcsec)

Torus

N

NW

C

S

NE

SE

W

E

NE

5035

6030

1720

1667

1685

1813
Highly Evolved Stars

O-rich: 3 zones: SiO, H$_2$O & OH main, OH 1612MHz
Several H$_2$O lines mark zones of different conditions
C-rich: various lines of HCN
Megamasers

Various species: OH, H$_2$O, H$_2$CO

Water: 100pc torus orbits black hole

With model, construct feature accelerations

Get geometrical distance
SiO Shells
Supernova Remnants

1720MHz OH
Radiative phase
Interface of SNR and ISM
VLBI hotspots
W44 remnant
Masers as Tools

Magnetic fields: Zeeman effect and polarization

Kinematic tracers: proper motions

Distances: (1) phase lag; (2) parallax target; (3) Keplerian rotation model

Cosmological variation of fundamental constants: OH & CH lambda doubling & hyperfine

Parameters of turbulence: spectral monitoring
Variability

Model of SiO masers in AGB star
Parameters like o Cet
Pulsation periods ~1yr
Influence of shocks
Pumping mostly IR
Computer Modelling
Models of Flaring
Light Curves