Studying the thermal state of molecular gas with JCMT

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outline

• Why kinetic temperature?
• how to derive kinetic temperature?
• examples
• summary
How important is the kinetic temperature of molecular gas?

- A fundamental parameter in all physical and chemical processes:
  - Balance result between cooling and heating processes
  - Directly affect chemical reaction rates
  - Sound speed: \( \sqrt{\frac{\gamma k T_{\text{kin}}}{\mu m_H}} \)
  - Mach number: shocks
- Jean Mass: \( \approx (2 \, M_\odot) \left( \frac{c_s}{0.2 \, \text{km s}^{-1}} \right)^3 \left( \frac{n}{10^3 \, \text{cm}^{-3}} \right)^{-1/2} \)

And so on ........
How can we measure the kinetic temperature?
CO LTE

the most abundant molecule after $H_2$

- method
  - CO optically thick
  - Tex from RT equation
  - populations fully thermalised: $Tex = T_{kin}$

- shortcoming:
  - not LTE, populations not fully thermalised
CO LTE

the most abundant molecule after $\text{H}_2$

• method

• CO optically thick

Any other more accurate method?

Yes, non-LTE radiative transfer

• shortcoming:

• not LTE, populations not fully thermalised
CO non-LTE

- method

- multiple-J CO lines J=1-0, 2-1, 3-2

- solve the statistical equilibrium equation (non-LTE RT): gives us kinetic temperature and density

- possible: JCMT (2-1, 3-2) data in combination with the MWISP (1-0) data can be used to do the method

\[ T_{\text{kin}} \]

\[ \log[n \ (\text{cm}^{-3})] \]
• MWISP: the *Milky Way Imaging Scroll Painting* project

• simultaneous observations of $^{12}\text{CO}$ $^{13}\text{CO}$ C$^{18}\text{O}$ (1-0) with the PMO-13.7 m telescope

• large-scale: targets the northern Galactic plane and several other regions of interests

• information website: [http://www.radioast.nsdc.cn/mwisp.php](http://www.radioast.nsdc.cn/mwisp.php)
A MWISP example
This is a large area mapping toward MC in outer arms

Background: 12CO
countours: 13CO

resolved for the first time

Gong et al. (2016), A&A, 588, 104
A MWISP example
This is a large area mapping toward MC in outer arms

So, if we have supplementary JCMT data in combination with the MWISP data, we can study physical properties of molecular gas

Background: 12CO contours: 13CO

resolved for the first time
However

- shortcomings of multi-J CO lines
- different beam sizes
- usually cannot be obtained with only one telescope
- different calibrations, different pointing accuracy
However

Any other method to overcome these shortcomings?

- usually cannot be obtained with only one telescope
  
  Yes, use H$_2$CO

- different calibrations, different pointing accuracy
H$_2$CO

- p-H$_2$CO 218 GHz lines, close in frequency, $\Delta K_a = 2$
- Fall in JCMT RxA band
- Can be obtained simultaneously
- The ratios free of pointing accuracy, calibration errors, different beam sizes
- Abundance changes little ($10^{-10} \sim 10^{-9}$)

Wilson et al. (2009)
sensitive to temperature
independent of density
So the ratios can be used
to derive kinetic temperature

RADEX: H$_2$CO

$\frac{[\text{para-H}_2\text{CO}]}{1.0 \times 10^{-9}, \text{dv/dr} = 5 \text{km/s}}$

$T_{\text{kin}} (\text{K})$

$\log_{10} n \ (\text{cm}^{-3})$

the ratio
$p$-H$_2$CO $(3_{22}-2_{21})/(3_{03}-2_{02})$

sensitive to temperature
independent of density
So the ratios can be used

See also Ao et al. (2013)
examples of 218 GHz H$_2$CO line observations

3 minute APEX single-point observation

$\sim$70 K

H$_2$CO (3$_{03}$-2$_{02}$)

H$_2$CO (3$_{22}$-2$_{21}$)
IRAM 30m mapping observations of a dust clump

Another example

IRAM 30m mapping observations of a dust clump

$\frac{3_{2,2}-2_{1,2}}{3_{0,3}-2_{0,2}}$

Higher than the kinetic temperature ($\sim 30$ K) derived from NH$_3$

A temperature gradient across the clump not radial profile ($r \sim T^{-a}$)

Heating mechanisms? outflows?
The NH$_3$ thermometer has a more limited temperature range with only (1,1) and (2,2) lines.

Ginsburg et al. (2015): warm gas by turbulent heating
summary

• JCMT data + the MWISP data: multiple-J rotational transitions of CO lines can be used to study the properties of molecular gas

• JCMT observations of 218 GHz H$_2$CO lines can be used to study the temperature of dense clumps

Hope that I can obtain the JCMT data in the future
Thanks for your attention!

Herschel

Sorry man, your telescope is already dead,
but my telescope still survives

Maxwell
• a symmetry top molecule

• A widely used thermometer

• inversion lines: (1,1), (2,2) close in frequency (23.7 GHz)

Inversion splitting: excellent probe of kinetic temperature

Wilson, T. et al. (2009)

NH$_3$