Overview

1. HARP and Heterodyne Instruments
2. Image Cubes
3. Line widths
4. Dust Fractions
HARP: A Heterodyne Receiver

Heterodyne = Different Frequencies

\[
\sin \theta_1 \sin \theta_2 = \frac{1}{2} \cos (\theta_1 - \theta_2) - \frac{1}{2} \cos (\theta_1 + \theta_2)
\]
HARP: A Heterodyne Receiver

There are tons of interesting molecular lines to observe in space... Everything from Carbon Monoxide and Formaldehyde to Water and Complex Sugars!

Heterodyne setups allow us to sample across different frequency ranges where interesting lines live. HARP observes 1 sideband at a time.
An Example form our Friends at ALMA

LSB: 2 GHz = 24x82 MHz          USB: 2 GHz = 24x82 MHz

10 GHz

e.g. Orion-KL, Beuther et al., in prep

September 24, 2004
ESO ALMA Community Day
HARP: Tunes from 325-375 GHz (799-922μm)

Generates Image Cubes With Velocity Information
For nearly 70 different molecules (CO, HCN, Formaldehyde…)

HARP is sensitive to a range of Each “channel” corresponds to a different frequency/wavelength/doppler velocity
HARP: 325-375 GHz
Stare Mode (Point Sources)

16 Receptors that each produce a spectrum!
HARP: 325-375 GHz — Jiggle Mode (<2')

Jiggle those 16 Receptors that each produce a spectrum around the sky in a grid to get a map!

*Jiggles are efficient for small maps*
In this way, we measure kinematic information over large areas.
Next to Molecular Hydrogen, Carbon Monoxide is the most abundant molecule in Molecular Clouds.

We observe emission from rotational states which we label “J”.
A Note About Data Reduction
Units: Antenna Temperature

(from: http://astro.u-strasbg.fr/~koppen/10GHz/basics.html):

With our receiver, we measure the power density, $P$, picked up by the antenna. This power density can be compared with the thermal noise produced by a resistor of a given temperature $T$, which is:

$$P_{\text{noise}} = k_B T$$

We define the **antenna temperature** ($T_A^*$) as the temperature of a perfect blackbody that gives the same amount of power as the received signal

$$P_{\text{noise}} = k_B \times T_A^*$$

This is not a physical temperature relating to the source in space, just a way to characterise the signal-to-noise ratio!
We define the \textbf{antenna temperature (T}_A^*) as the temperature of a perfect blackbody that gives the same amount of power as the received signal.

These are the units of HARP data when you first reduce it!
What About Physical Temperatures?

If the antenna temperature doesn’t describe anything physical about the source, how do we relate it to the real temperature of the object?

The power pattern is the response of the telescope to a point source (function of angle).

The main beam efficiency, $\eta_{\text{MB}}$, is the ratio of the power received in the main beam to the total power emitted.

We observe planets with well known power outputs (Like Uranus, Jupiter, and Mars).

For the JCMT, we find that $\eta_{\text{MB}} = 0.64$.
Main Beam Temperature

If the source was a perfect blackbody, this would be the temperature it would have to be in order to generate the received signal by the main diffraction beam of the telescope.

So, we just take the antenna temperature (the temperature of a resistor would be to produce the observed signal) and correct for the efficiency of the beam:

\[
T_{MB} = \frac{T_A \ast}{\eta_{MB}}
\]

This works for point sources (they are small enough to fit completely inside the main beam).
Radiation Temperature

**Radiation Temperature:** $T_R$

If the source was a **perfect blackbody**, this would be the **temperature** it would have to be in order to **generate** the received signal by the entire beam (including all those pesky sidelobes!)

We take the **antenna temperature** and correct it for the **efficiency** of entire beam:

$$T_R = \frac{T_A \ast}{\eta_{full}}$$

This works for **extended sources** that span angular sizes beyond the main beam.
Converting to Flux Density

Aperture Efficiency

Aperture efficiency, $\eta_A$, is the ratio of the effective aperture of a radio telescope divided by the true aperture. The true aperture is defined as the collecting area of the telescope surface. The effective aperture is the collecting area after losses due to blockage of the surface by the secondary mirror/supports and other factors such as surface irregularities.

$$\eta_A = 0.52$$

$$S \text{ (Jy)} = \frac{15.6 T_A}{\eta_A}$$
Line Widths

Line widths can tell us a lot about the physical characteristics of systems.

Degree of broadening and relative strengths of lines gives us information about:

- Internal Thermal Pressure
- Organised Bulk Motion
- Relative Energy States
- Turbulence
- Interesting Chemistry
- Physical Temperatures
An Example of JCMT Heterodyne Science

Led by Dr. Hideo Sagawa
(Kyoto Sangyo University)

Studying the photochemistry and dynamics of Venus’ atmosphere at an altitude of 70-100 Km

Finding correlations in variations among many chemical species (temperature, wind, day/night)

All observations performed in the light of day!
The shapes of molecular profiles can also tell us a lot!

HARP can tune to the frequencies of transitions associated with nearly 70 different molecules including CO, HCN, Formaldehyde...
Gas Subtraction

SCUBA-2 observes the continuum around 450 and 850 μm - the Dust!

But! There are Carbon Monoxide transition lines at these wavebands that contribute some flux from the CO Gas

We can measure the amount of CO flux contributing to a region with HARP

We convert the HARP map into SCUBA-2 units, multiply by -1, and “add” the result to the raw SCUBA-2 data

When we reduce the SCUBA-2 data, it subtracts out the gas contribution and we can make dust/gas ratio maps!