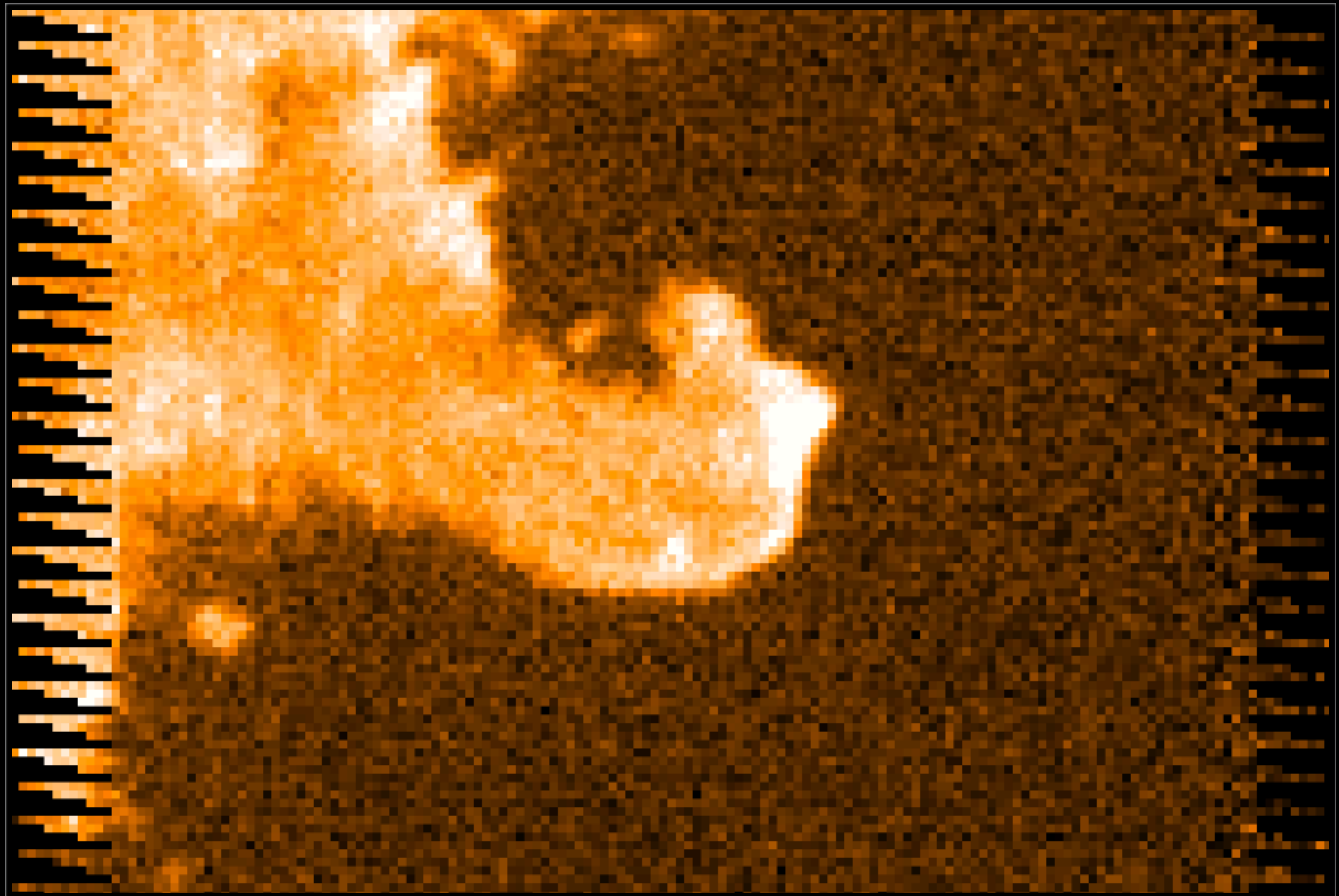


Image Cubes

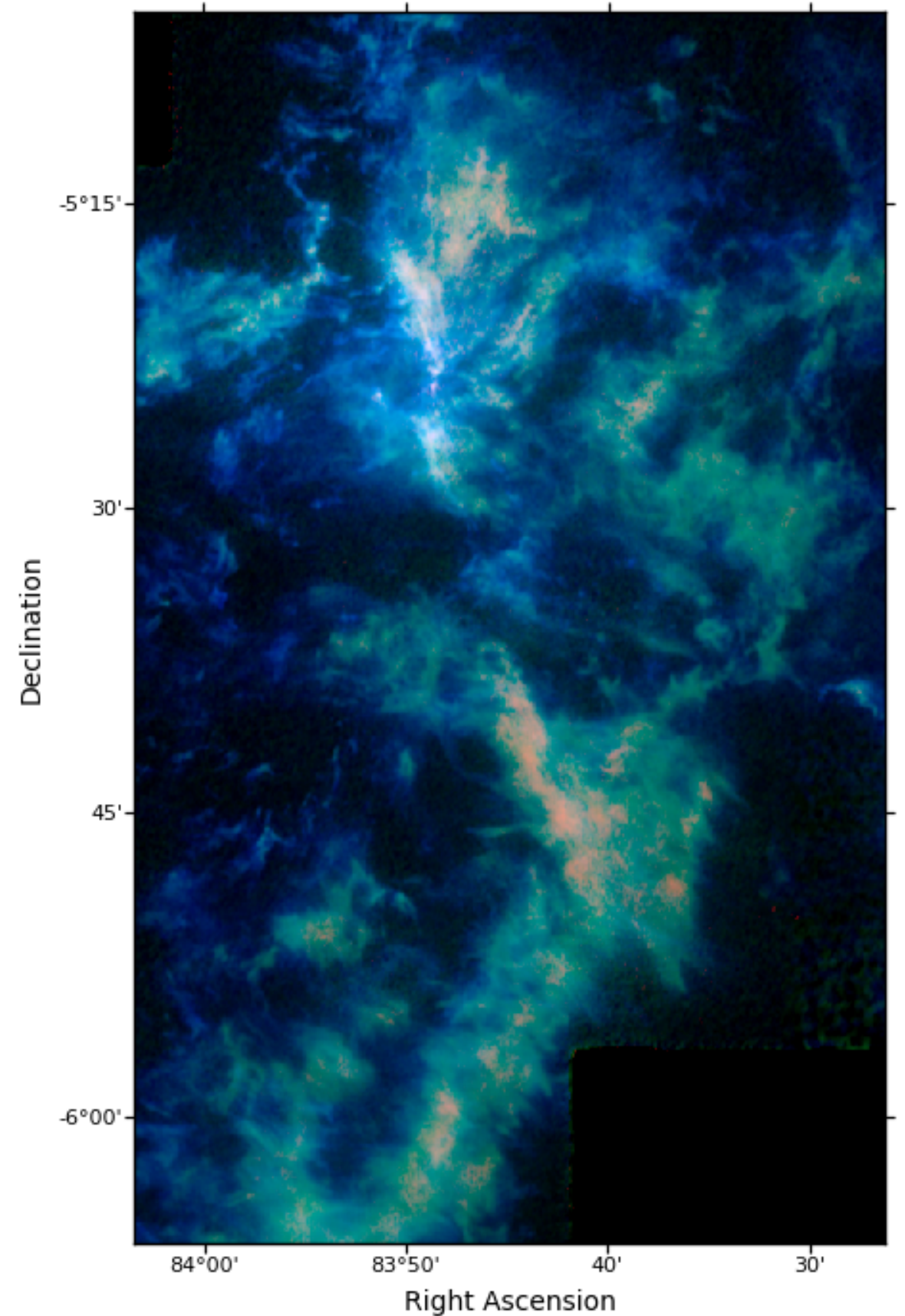
And Space Horses



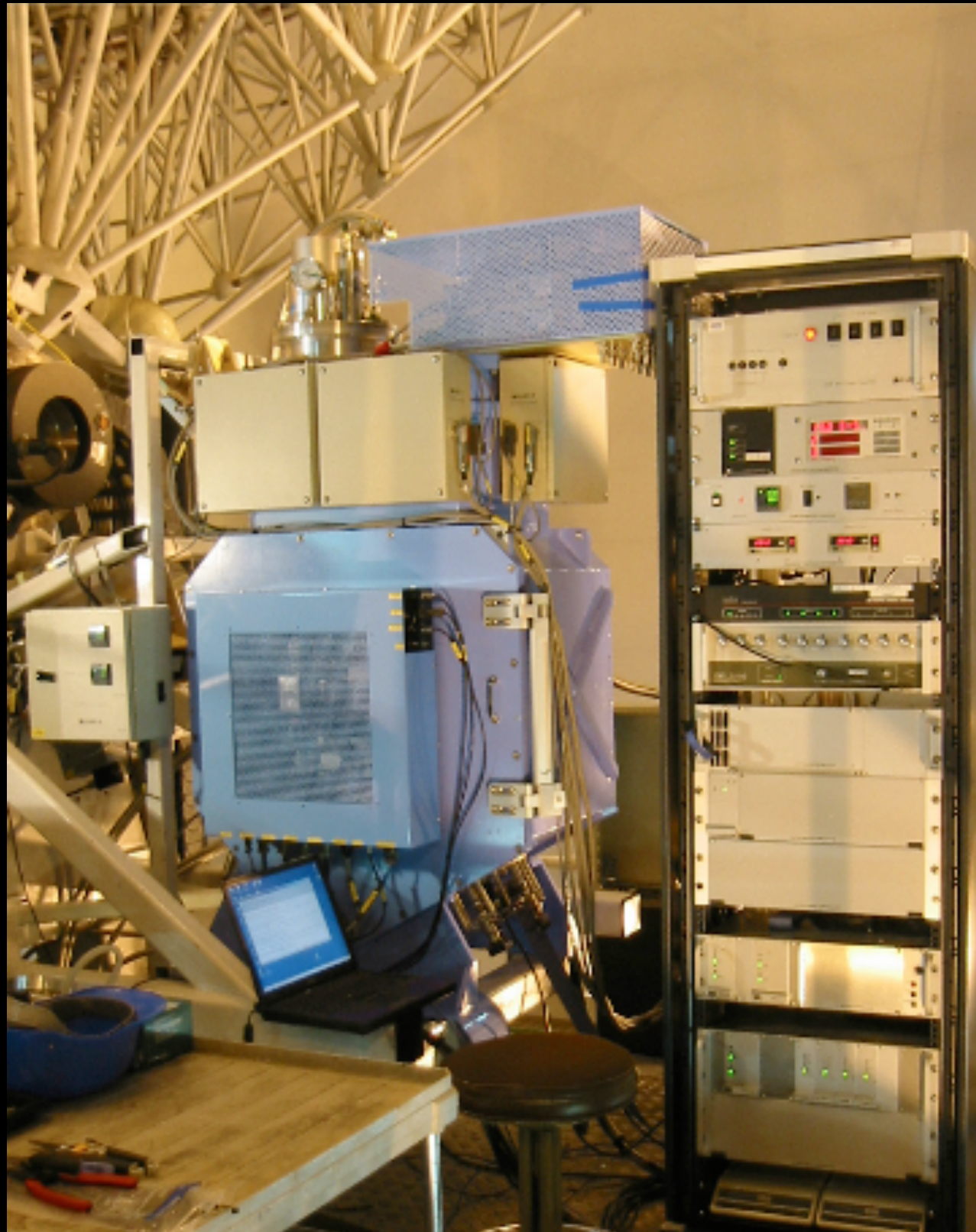
Dr. Steve Mairs (ASTR351L Spring 2019)

Overview

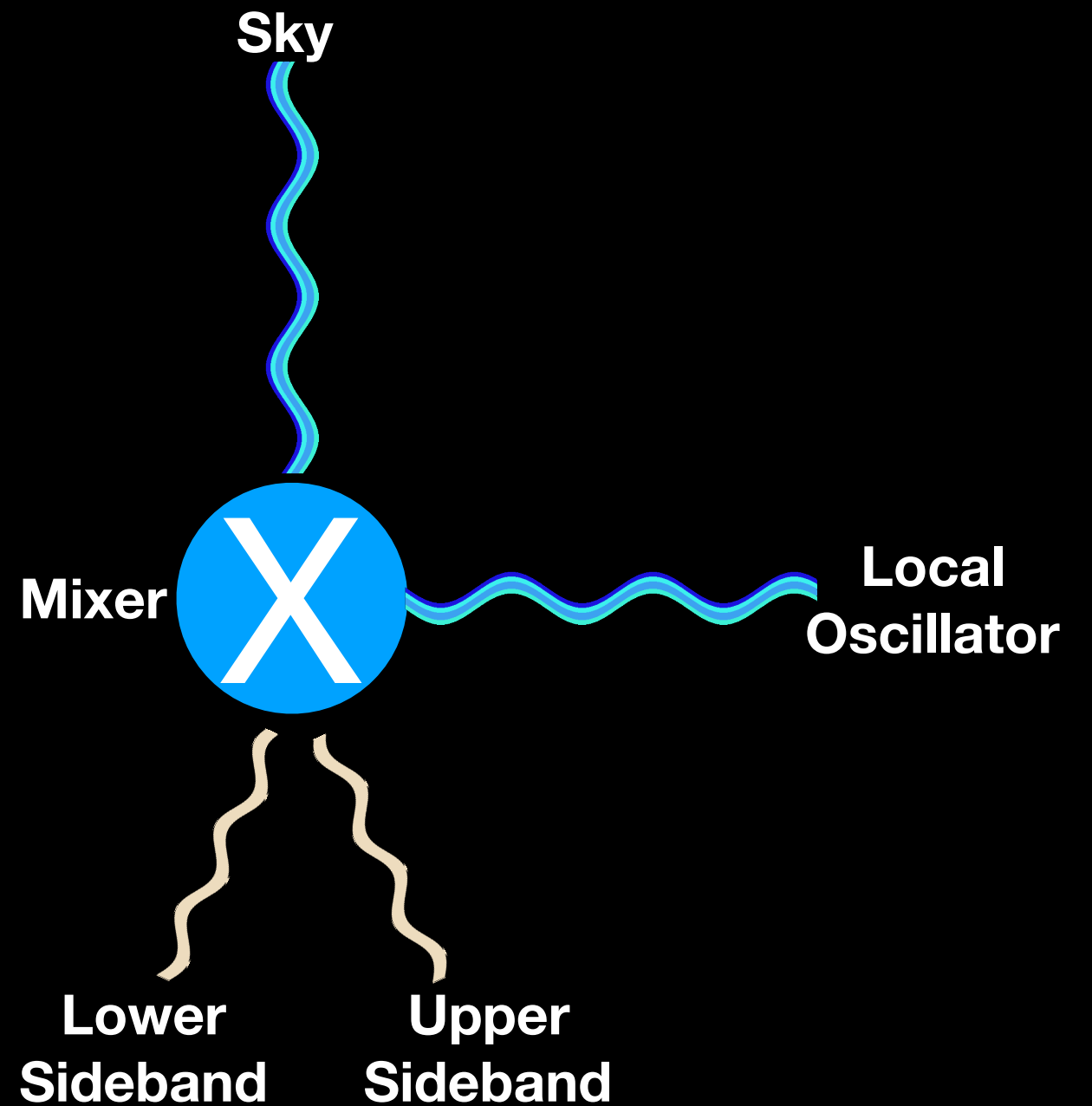
1. **HARP and Heterodyne Instruments**
2. **Image Cubes**
3. **Line widths**
4. **Dust Fractions**



HARP: A Heterodyne Receiver



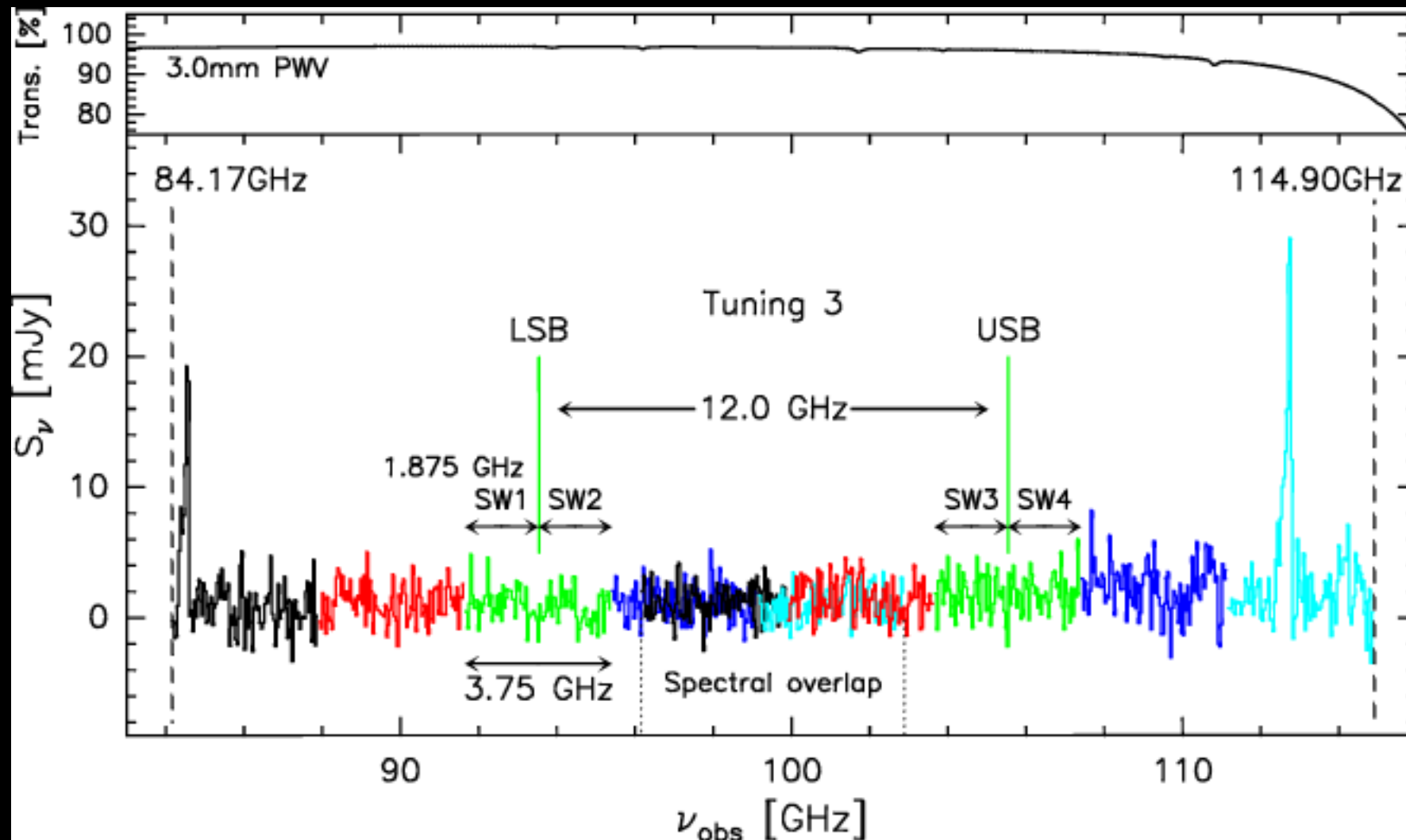
Heterodyne = Different Frequencies



$$\sin\theta_1\sin\theta_2 = \frac{1}{2}\cos(\theta_1 - \theta_2) - \frac{1}{2}\cos(\theta_1 + \theta_2)$$

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

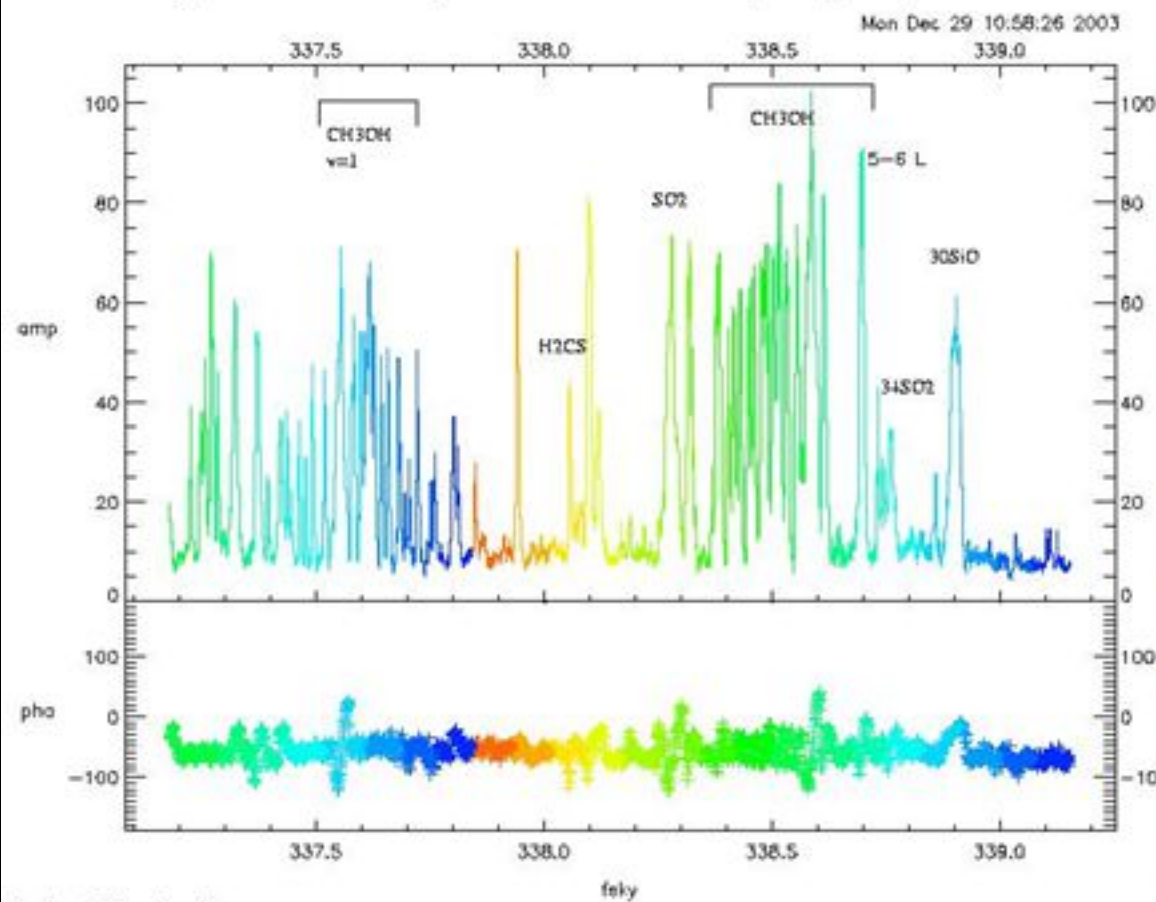
An Example from our Friends at ALMA

LSB: 2 GHz = 24x82 MHz

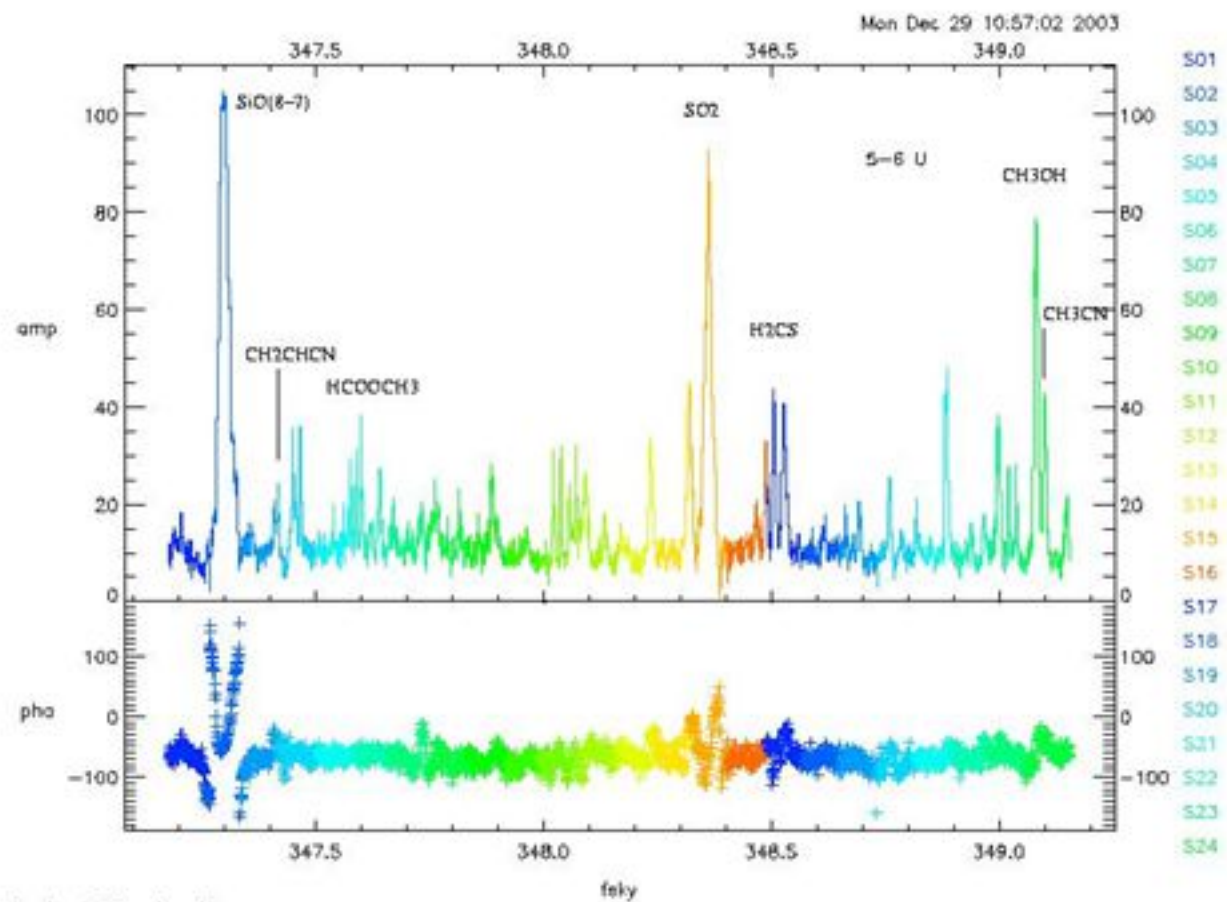
USB: 2 GHz = 24x82 MHz



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



track : 3496 orion-kl

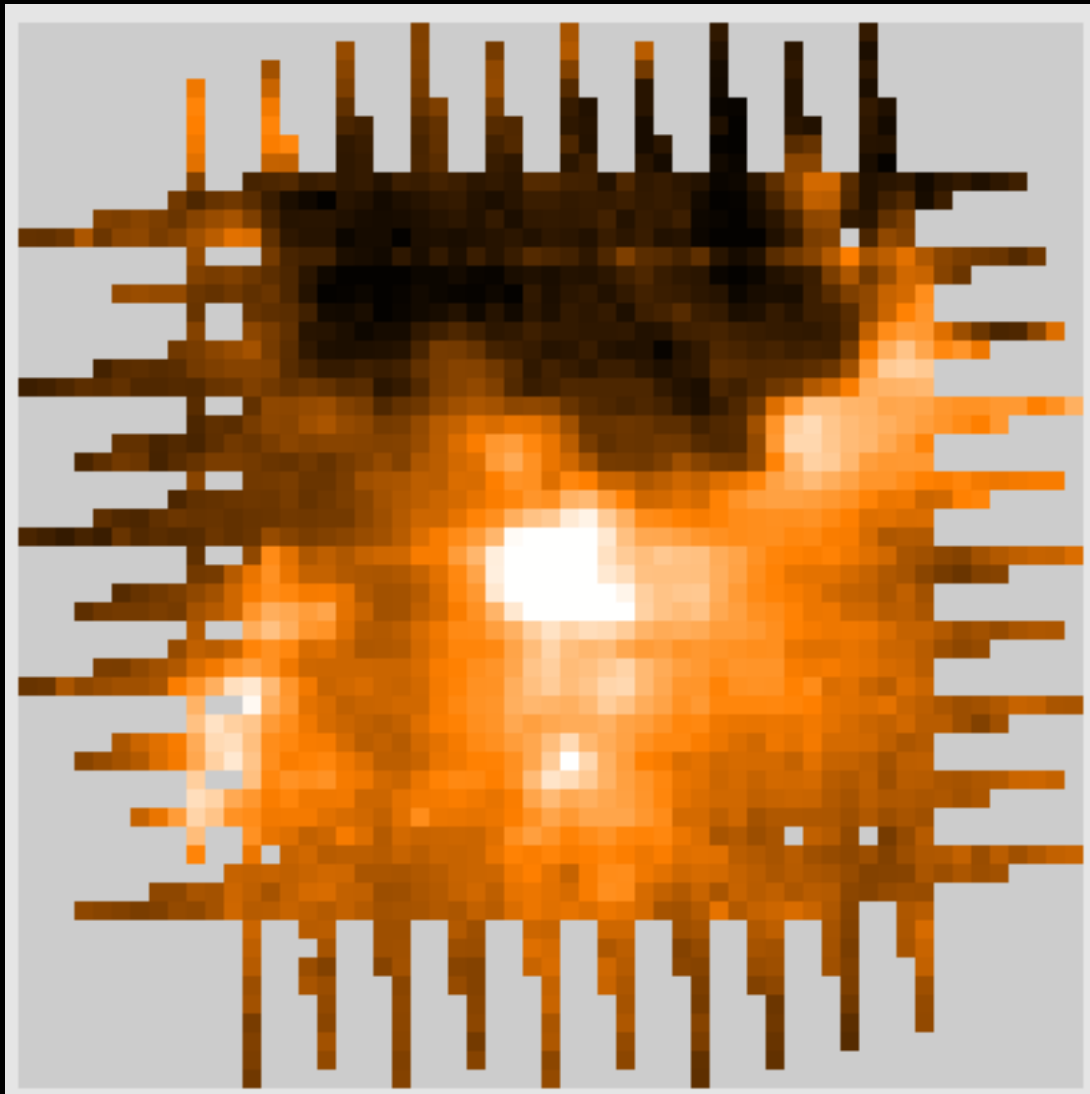


track : 3496 orion-kl

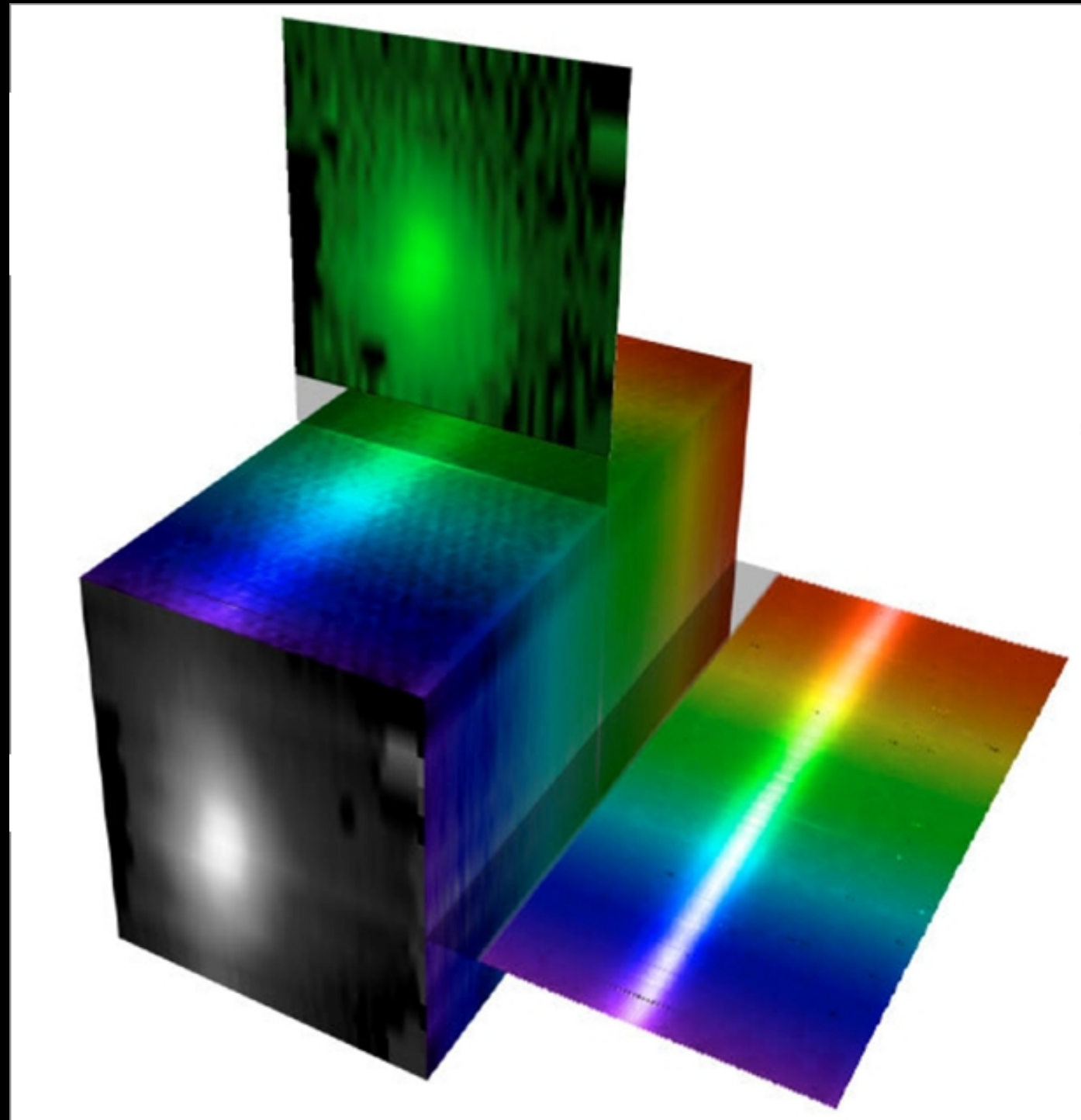
HARP: Tunes from 325-375 GHz (799-922 μ m)

Generates Image Cubes
With Velocity Information

For nearly 70 different molecules
(CO, HCN, Formaldehyde...)

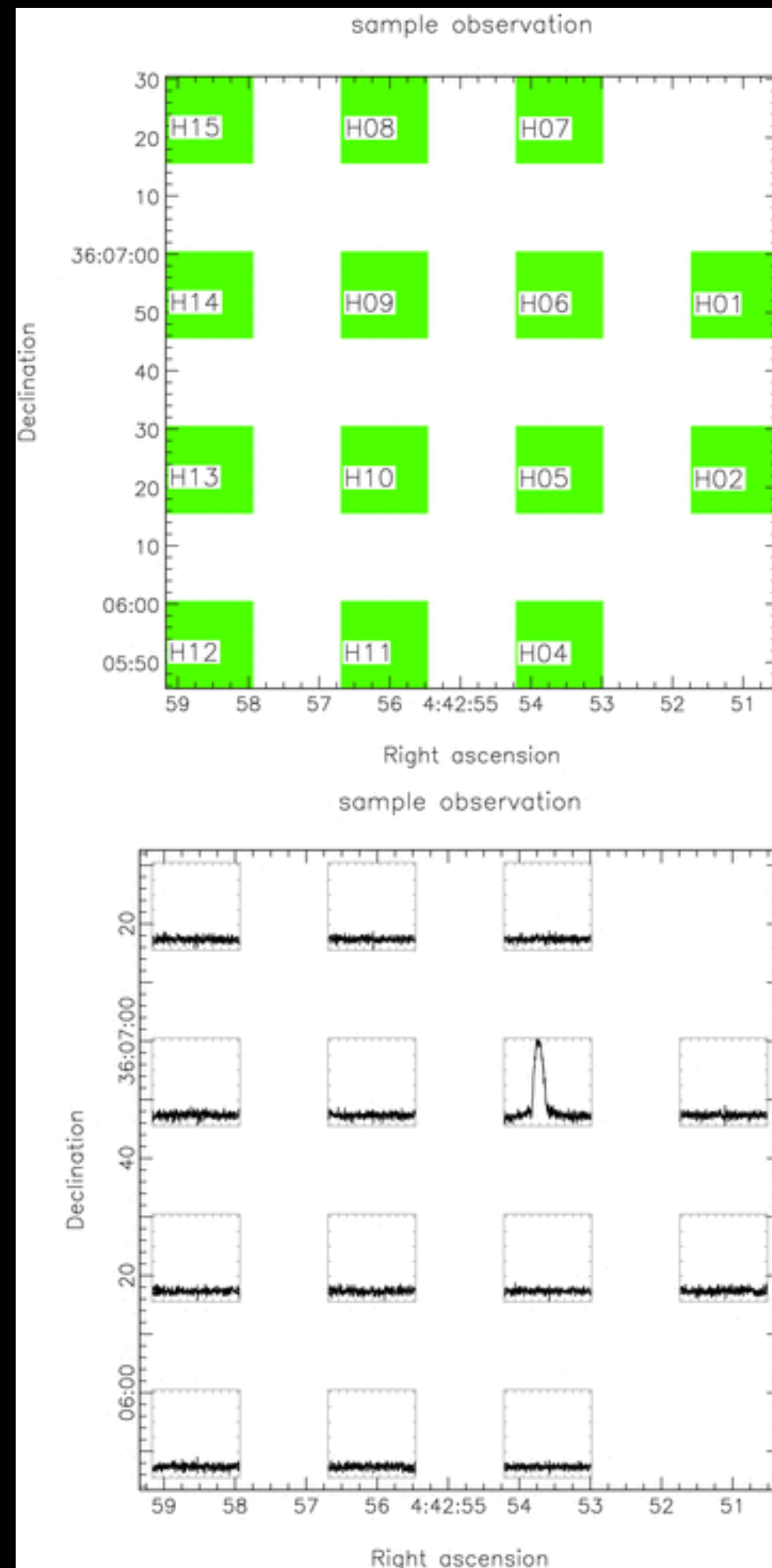
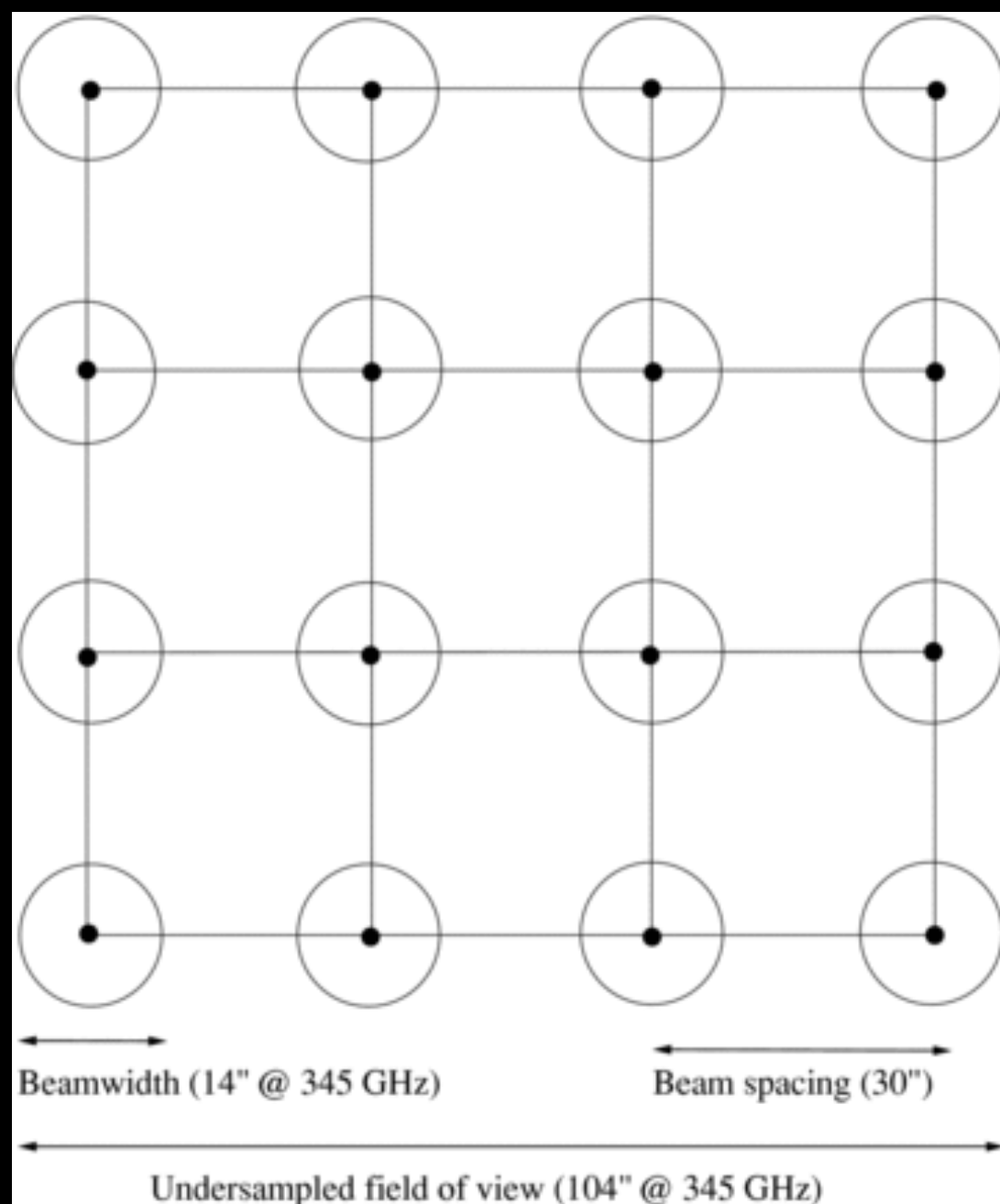


**HARP is sensitive to a range of
Each “channel” corresponds to a different
frequency/wavelength/doppler velocity**

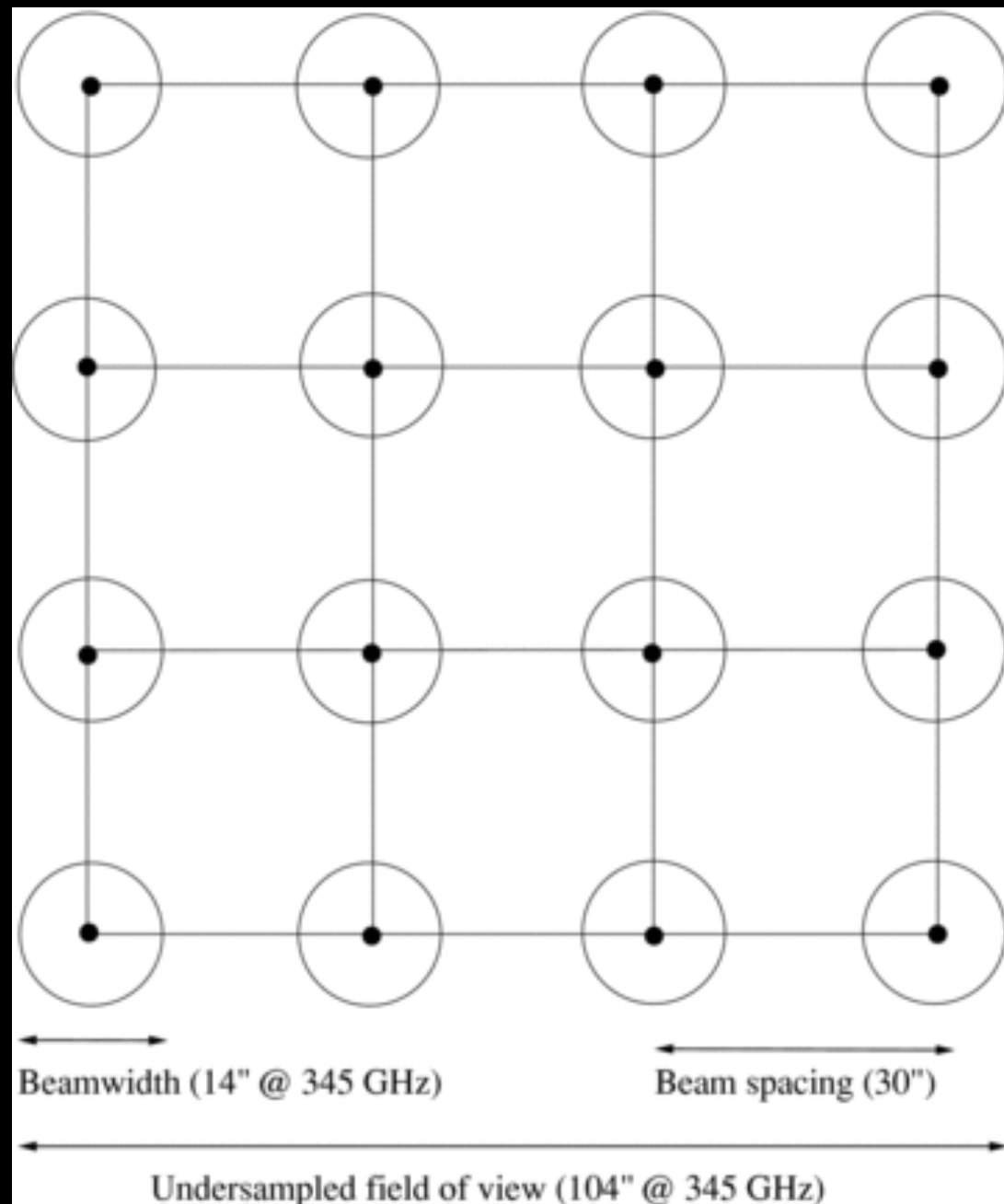


HARP: 325-375 GHz Stare Mode (Point Sources)

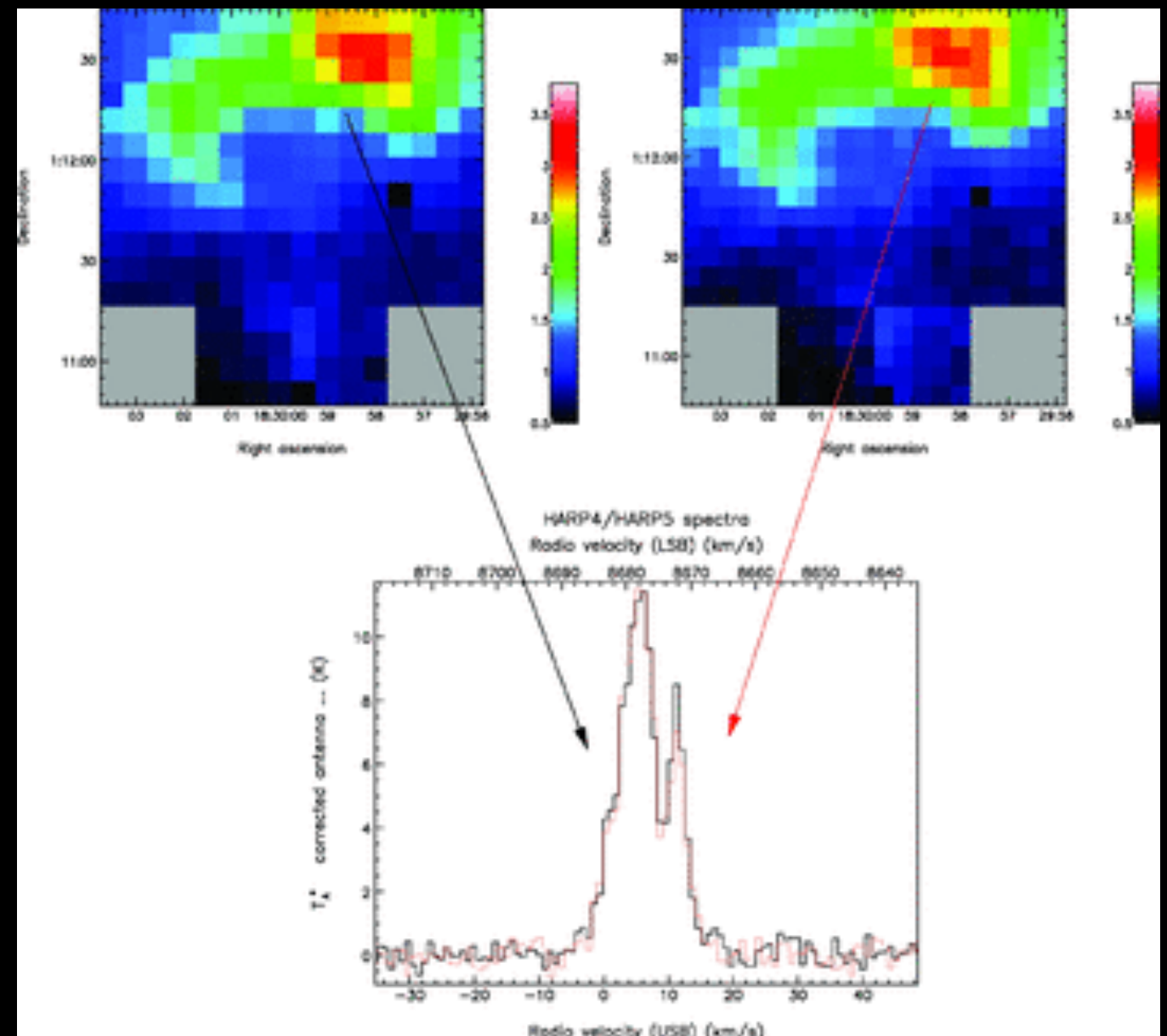
**16 Receptors that each
produce a spectrum!**



HARP: 325-375 GHz — Jiggle Mode (<2')

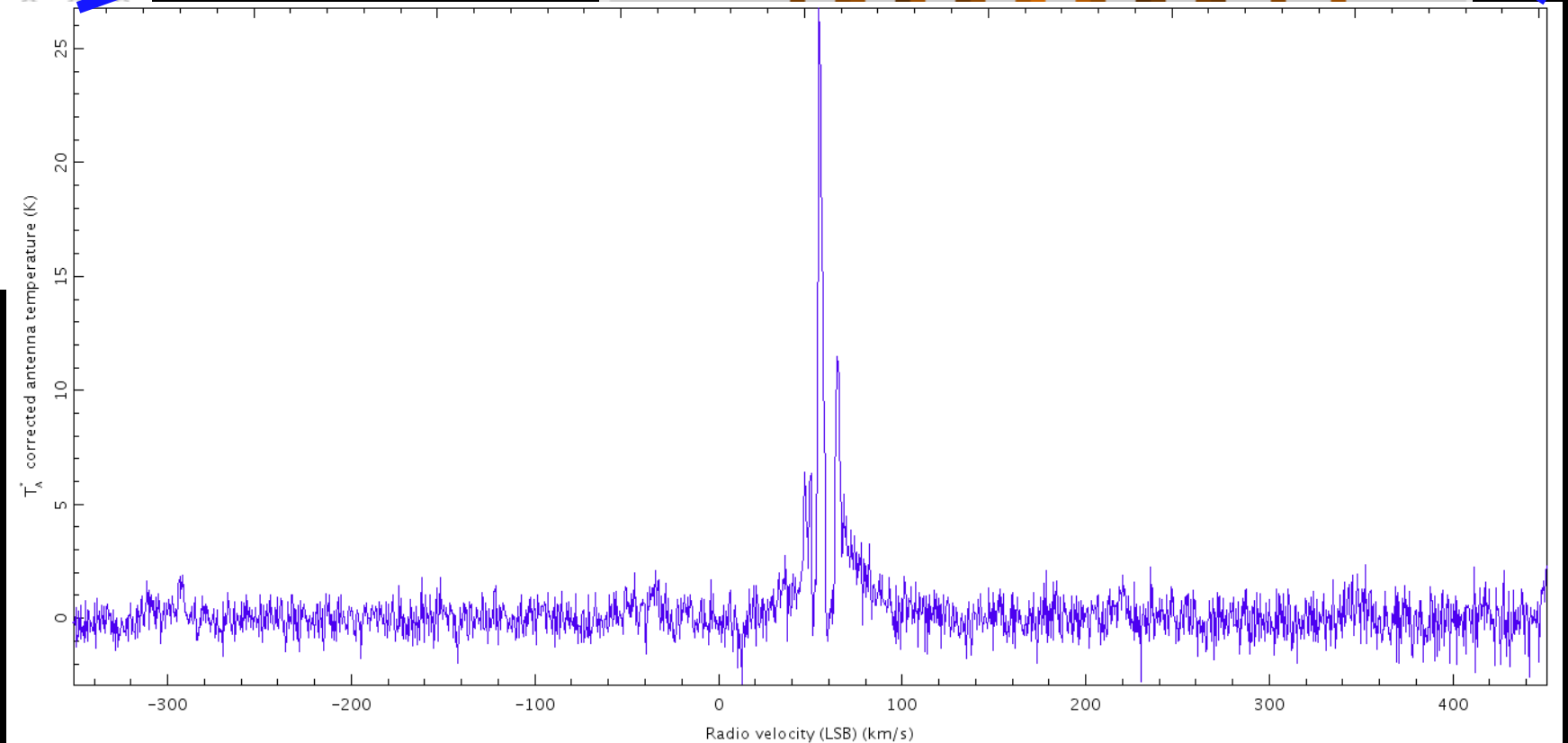
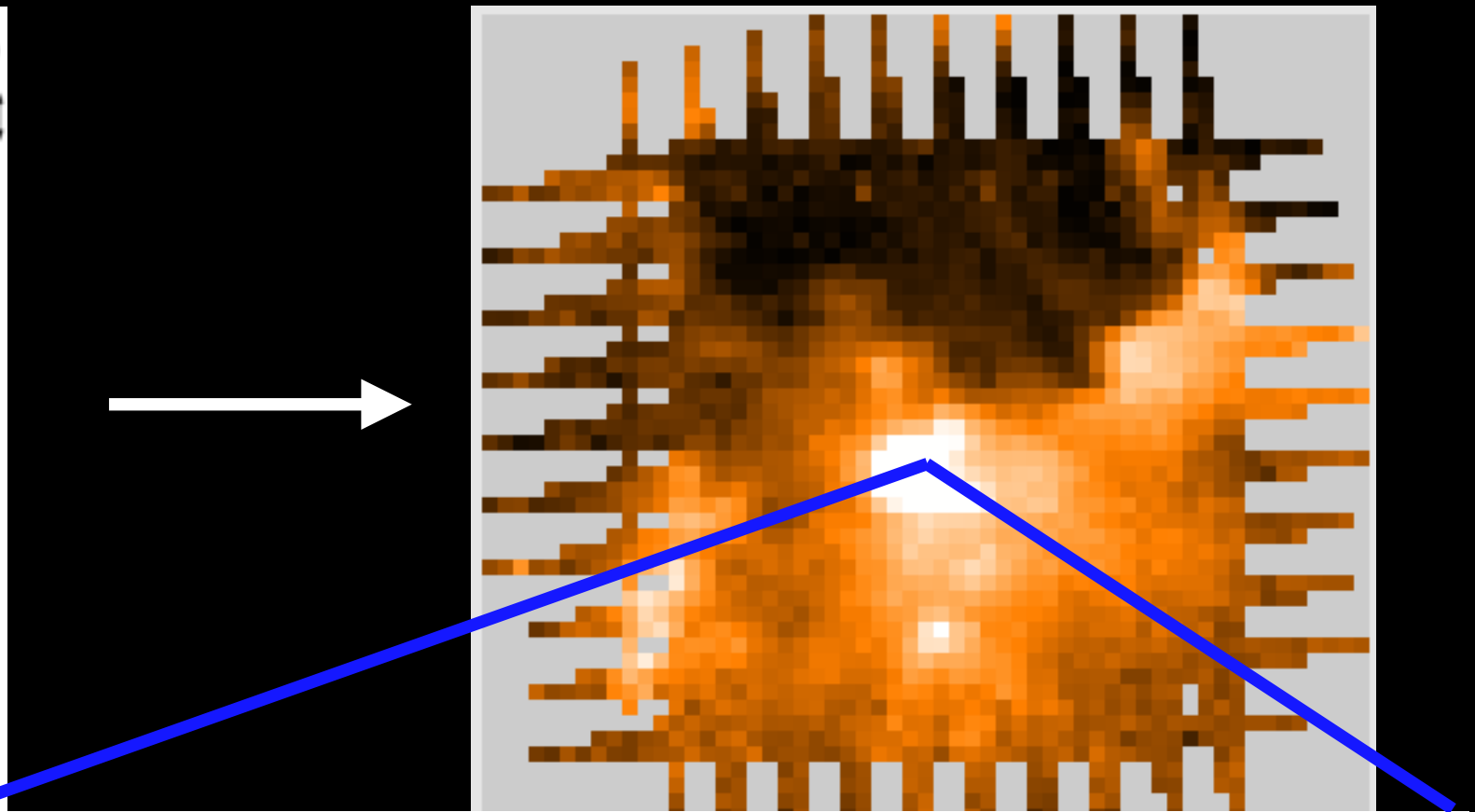
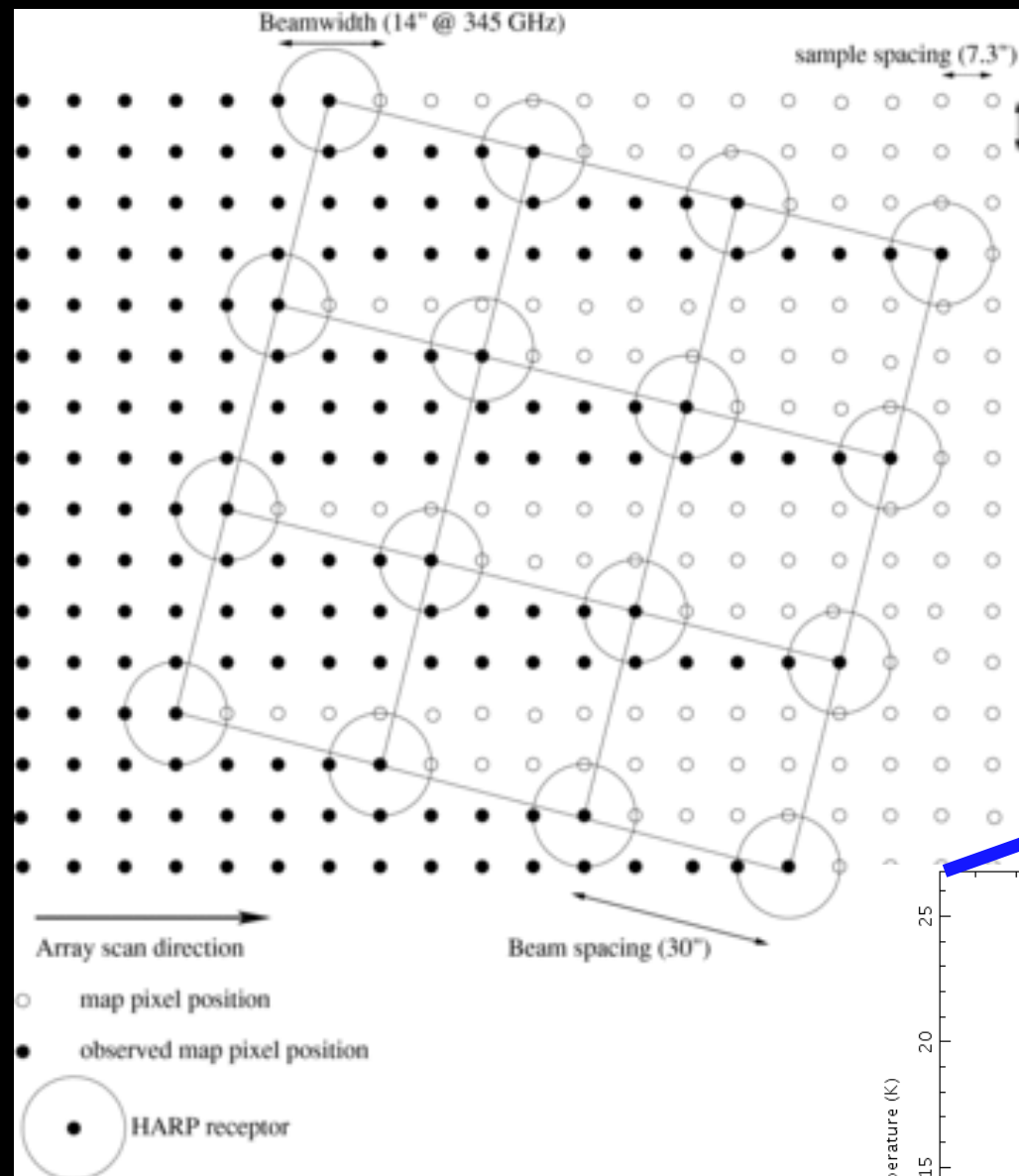


**Jiggle those 16 Receptors
that each produce a spectrum
around the sky in a grid
to get a map!**



***Jiggles are efficient for
small maps**

HARP: 235-275 GHz — Raster Mode ($>2'$)



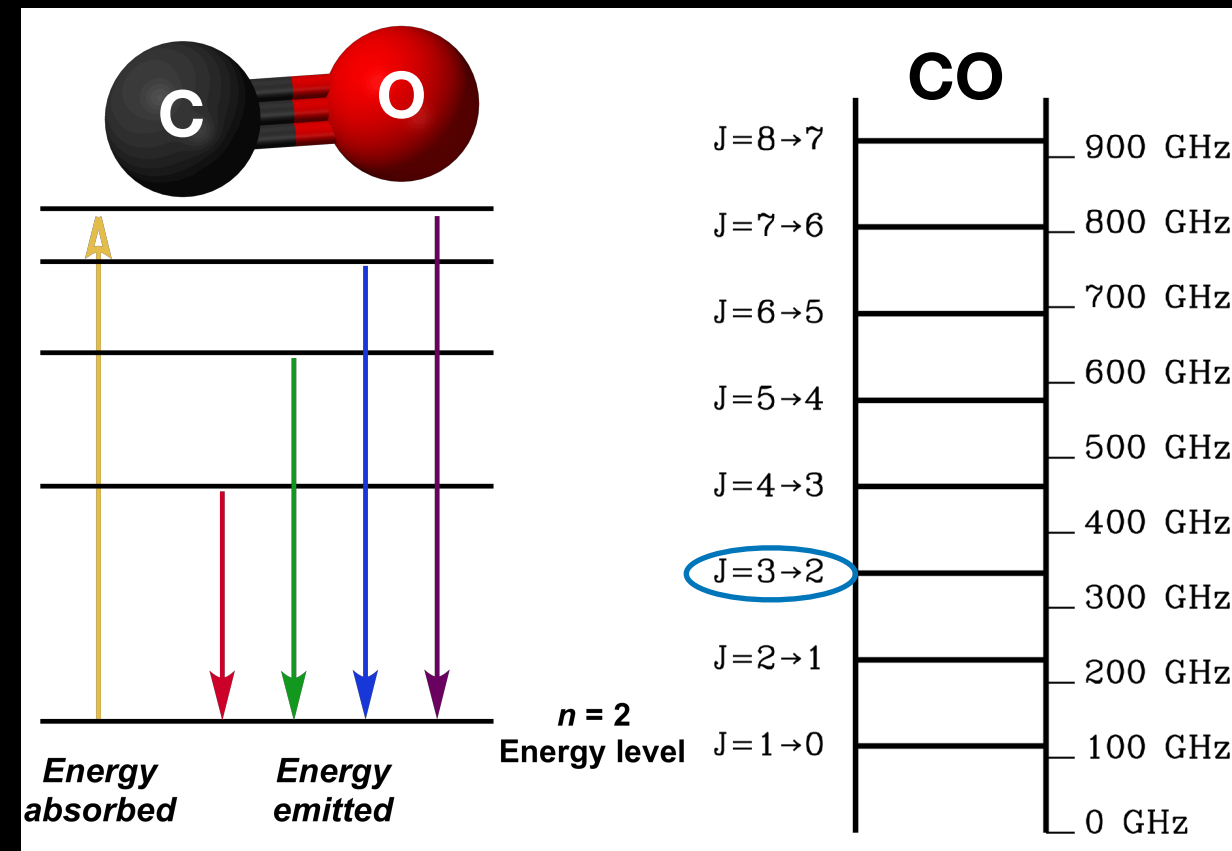
In this way, we measure
kinematic information
over large areas

Carbon Monoxide

JCMT / HARP
 ^{12}CO (3-2)

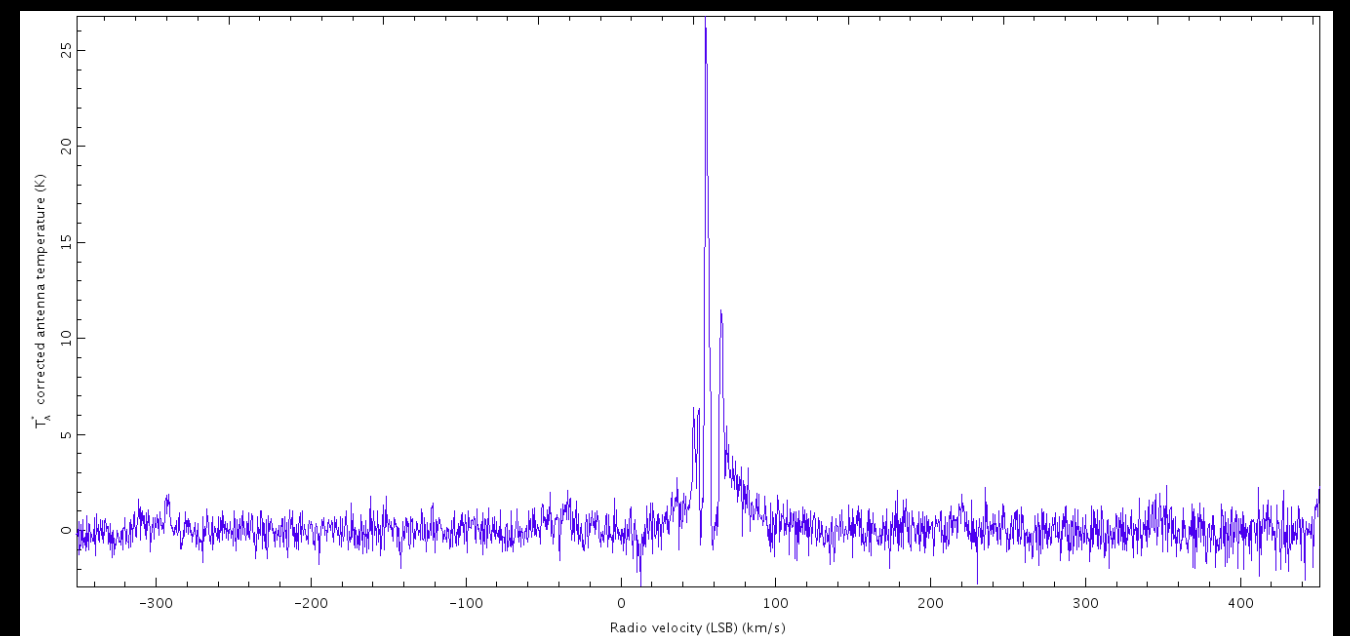
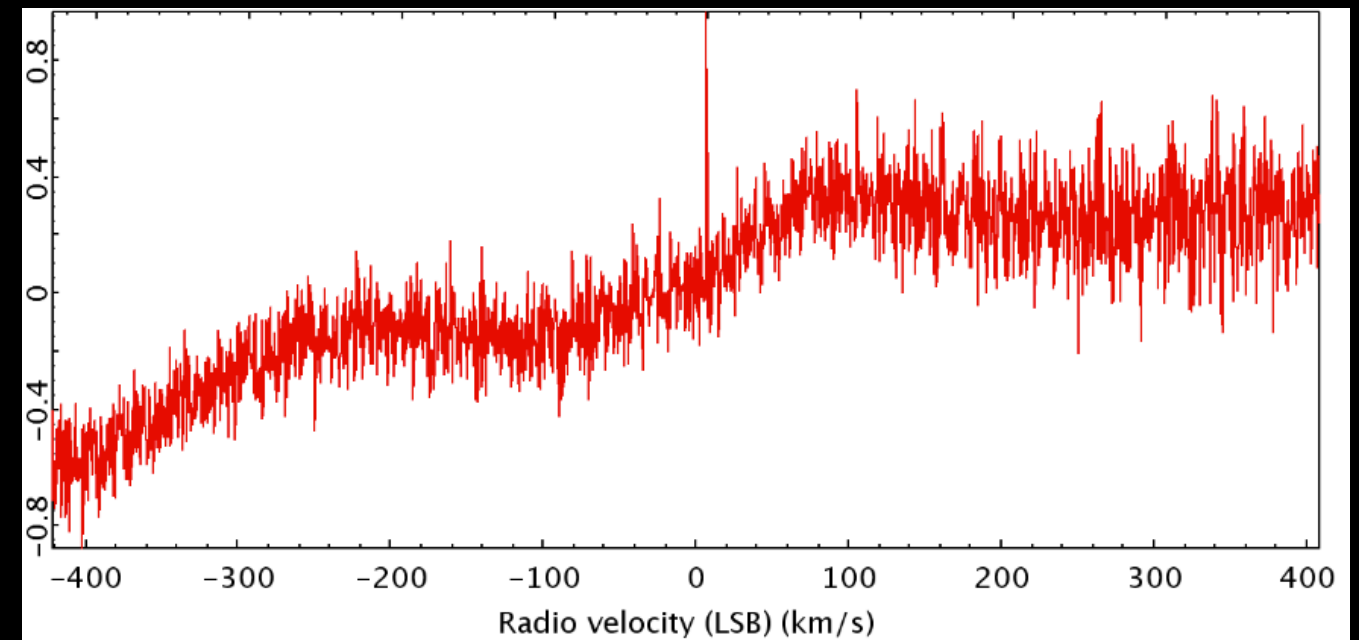
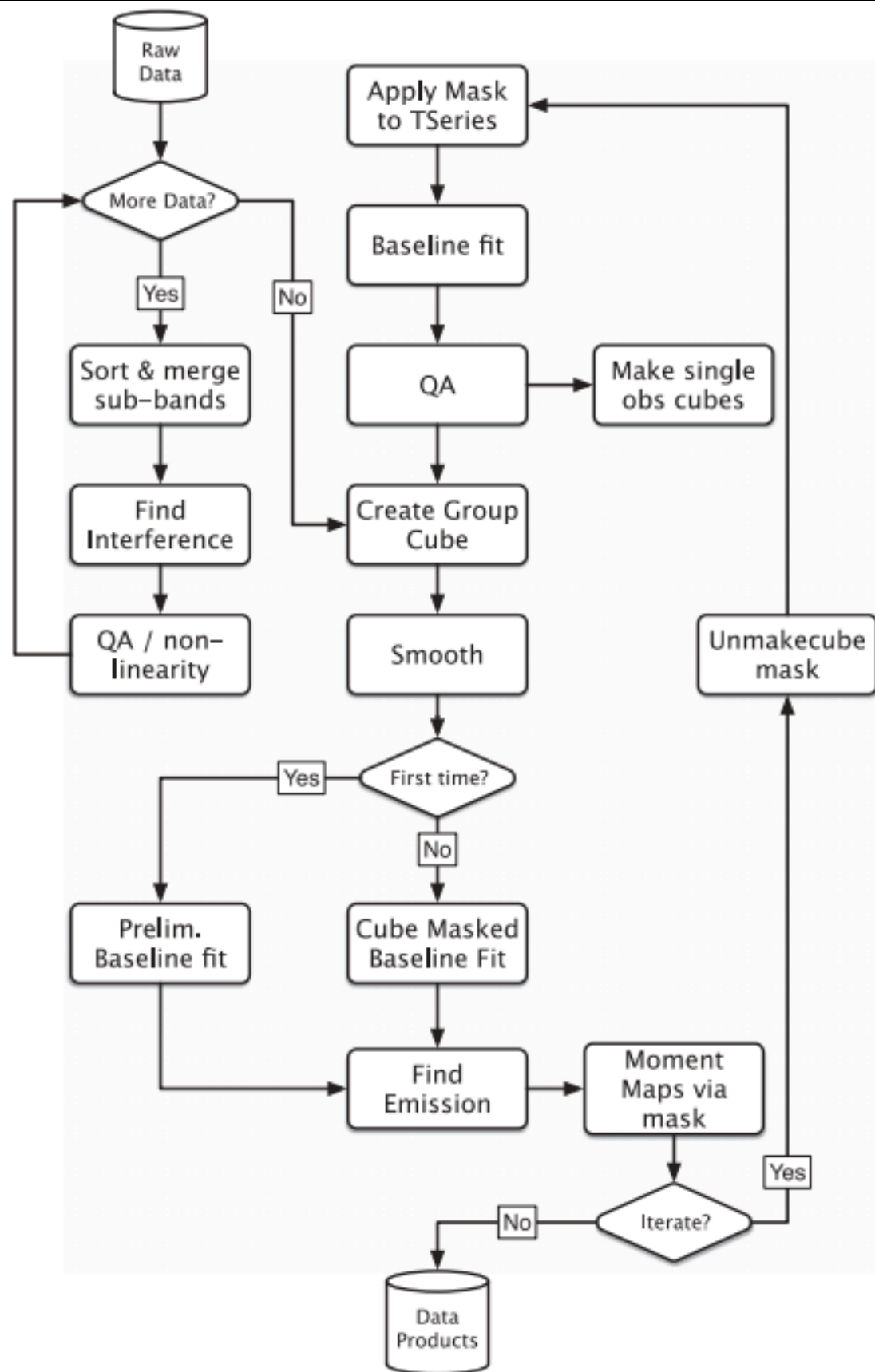
J ↗

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

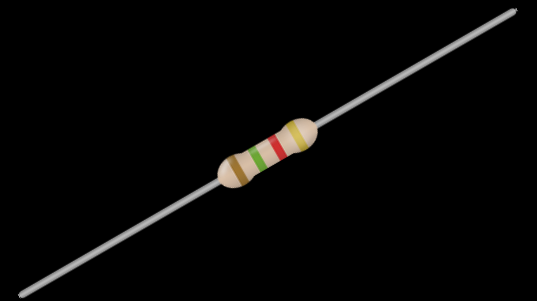


Units: Antenna Temperature

(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:

$$P_{noise} = k_B T$$



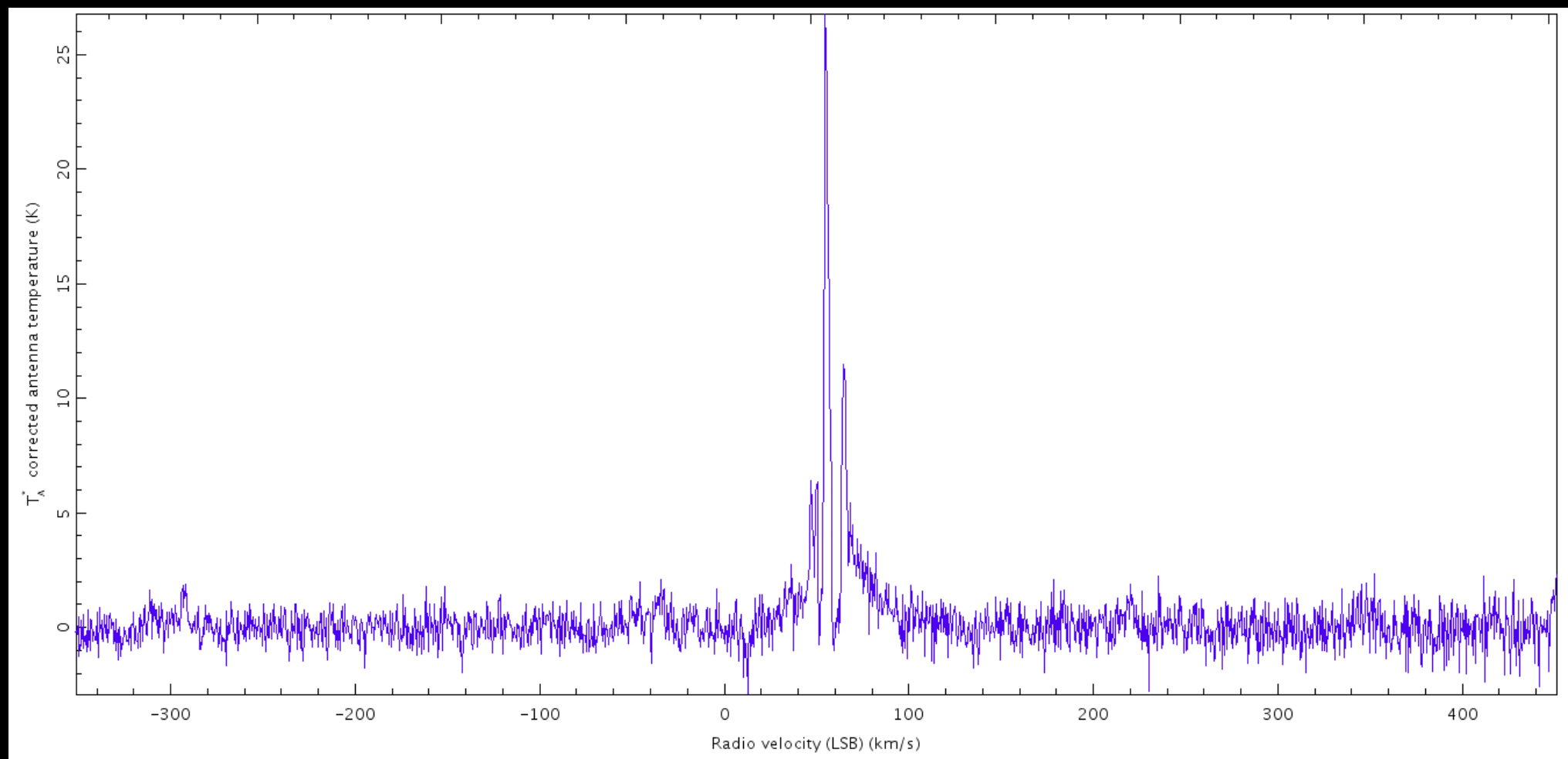
We define the **antenna temperature (T_A^*)** as the temperature of a perfect blackbody that gives the same amount of power as the received signal

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

This is **not a physical temperature relating to the source in space, just a way to characterise the signal-to-noise ratio!**

Antenna Temperature

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



These are the units of HARP data when you first reduce it!

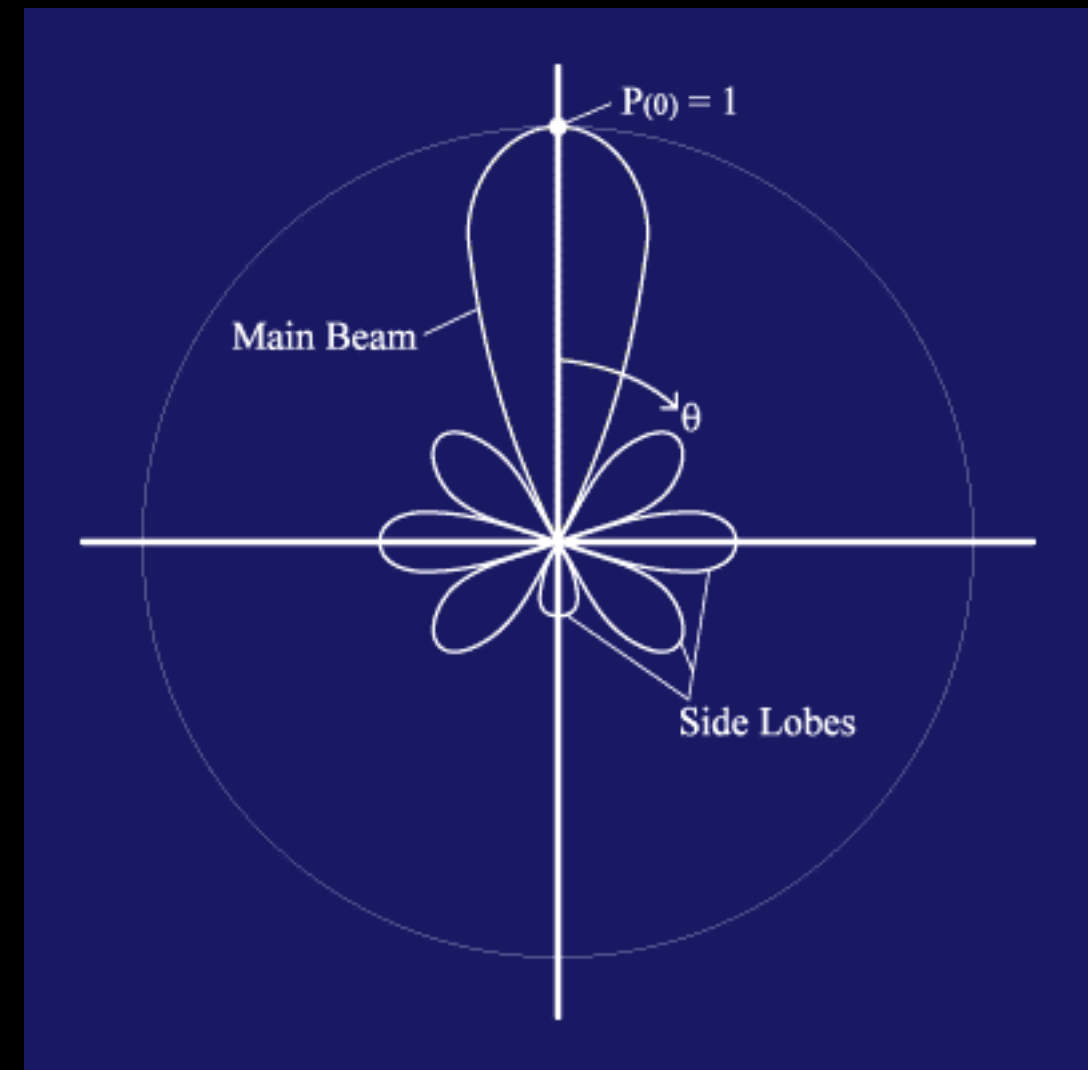
What About Physical Temperatures?

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, η_{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)

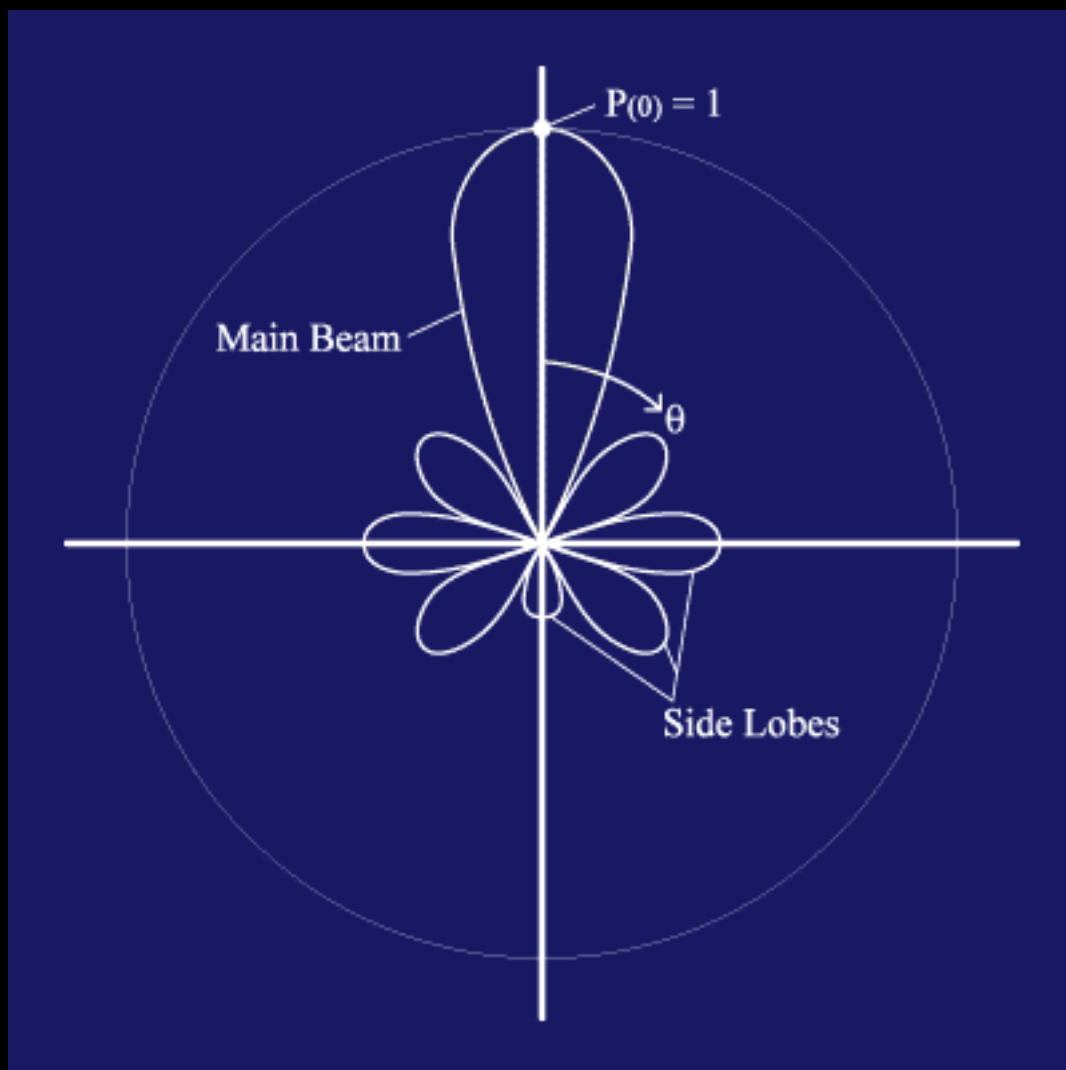


For the JCMT, we find that $\eta_{\text{MB}} = 0.64$

Main Beam Temperature

Main Beam Temperature: T_{MB}

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:

$$T_{MB} = \frac{T_A^*}{\eta_{MB}}$$

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

Radiation Temperature

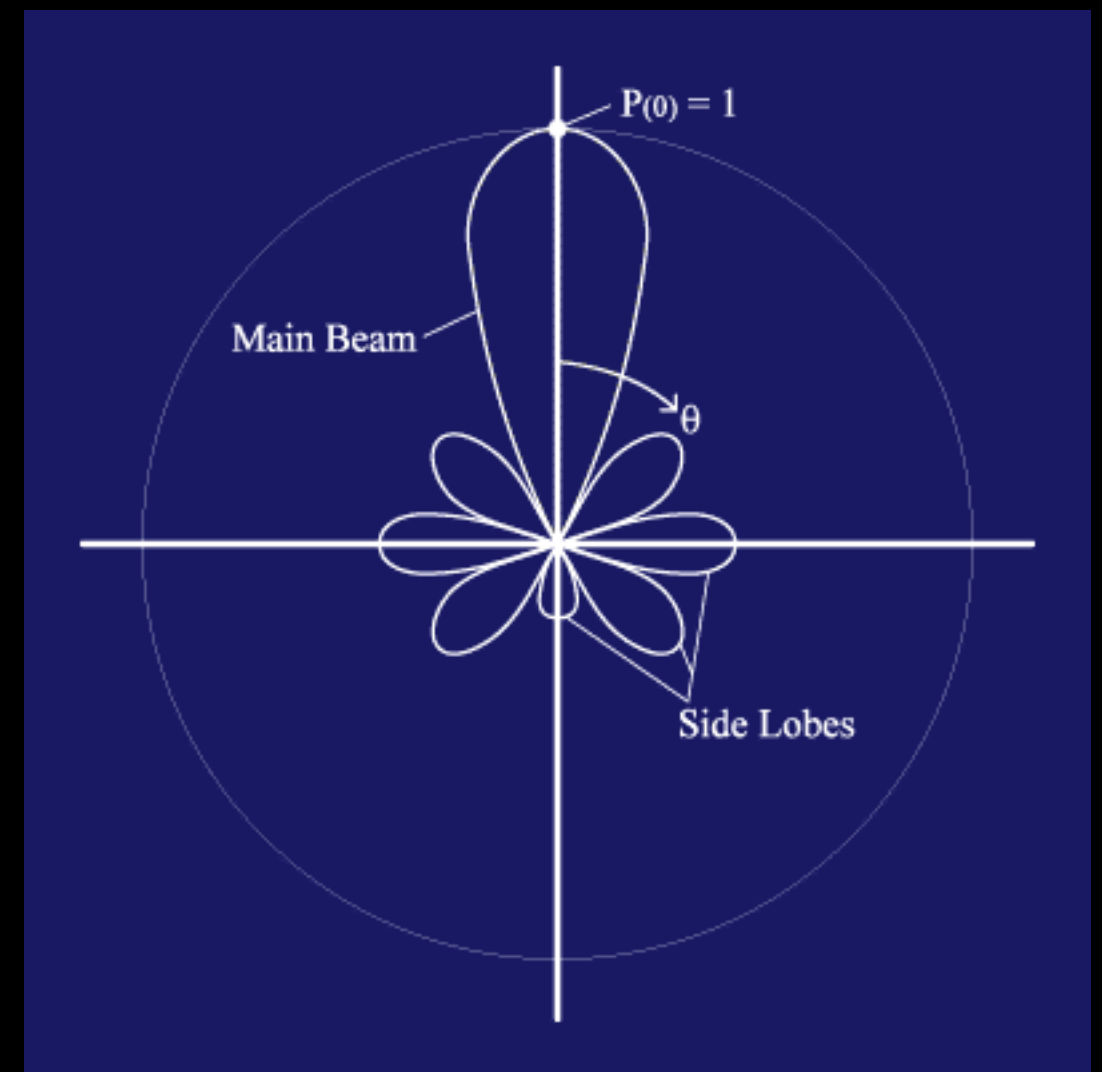
Radiation Temperature: T_R

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:

$$T_R = \frac{T_A^*}{\eta_{full}}$$

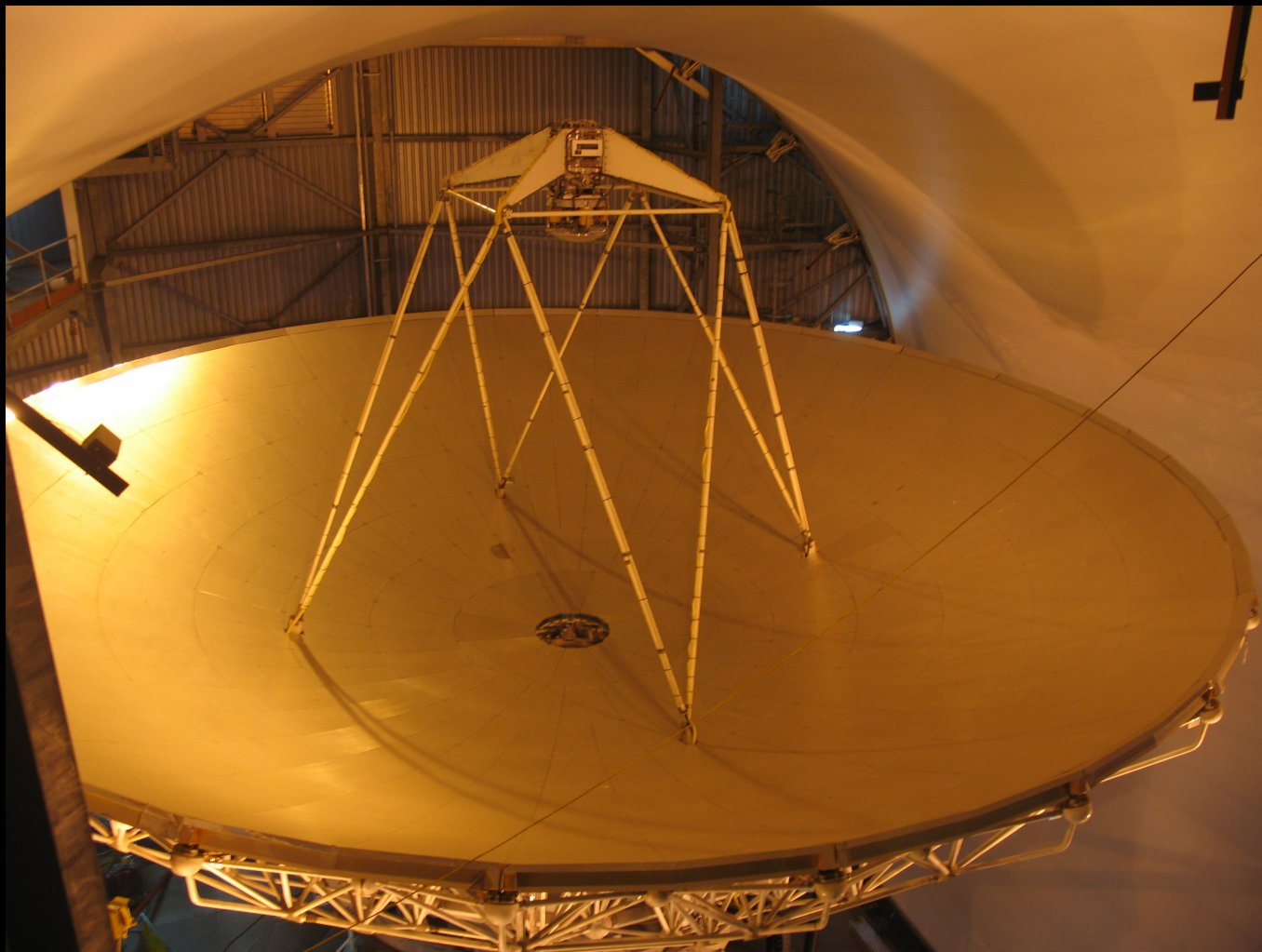
This works for extended sources that span angular sizes beyond the main beam



Converting to Flux Density

Aperture Efficiency

Aperture efficiency, η_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

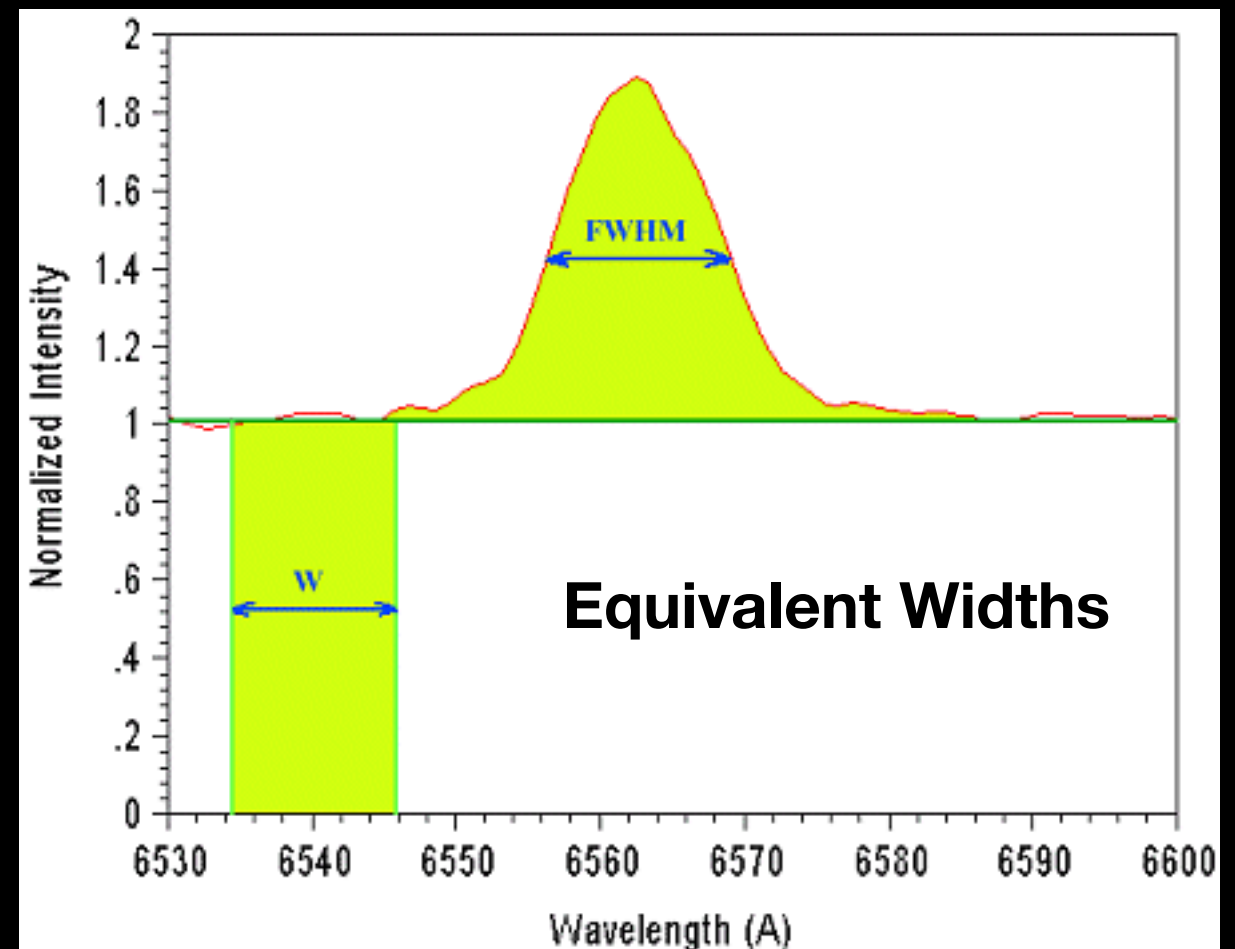
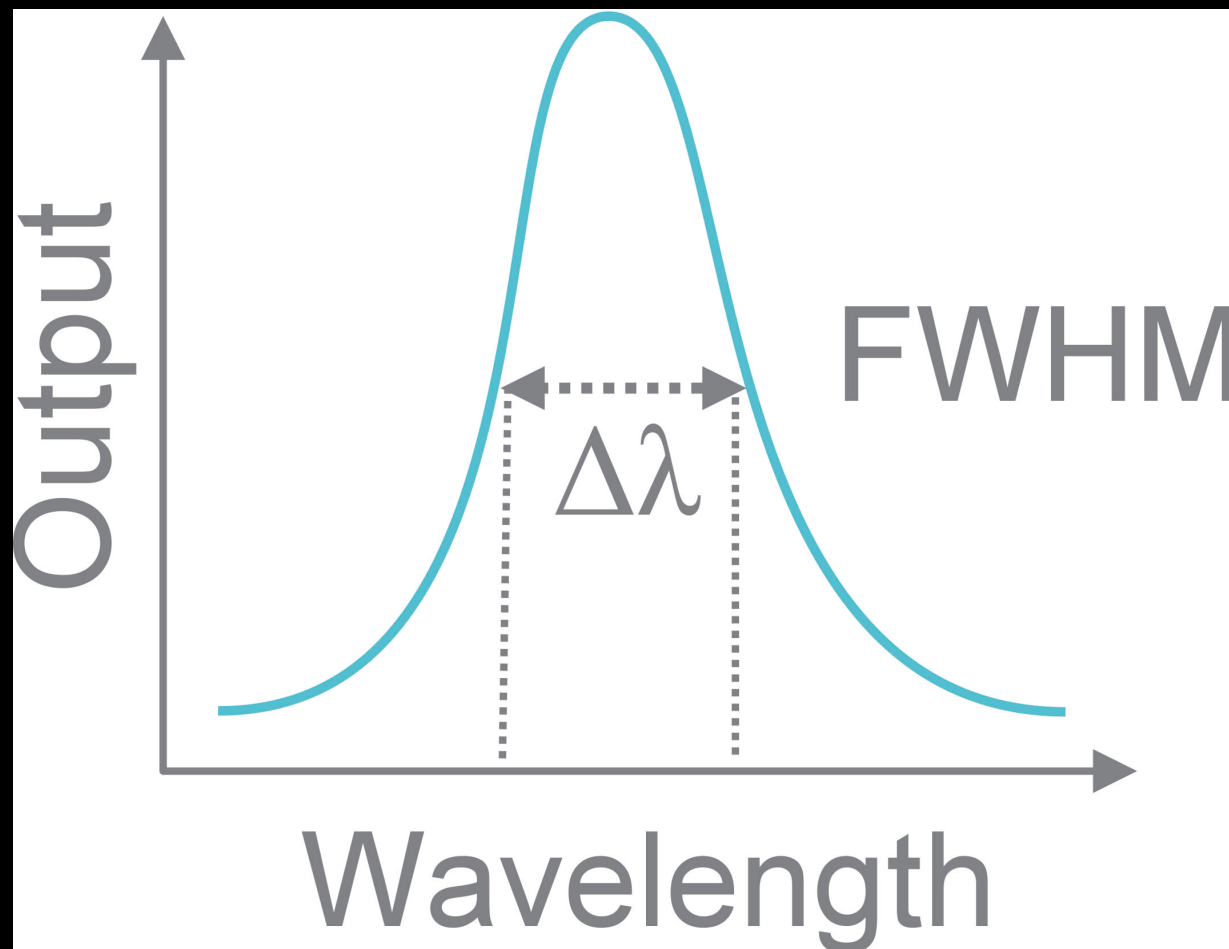


$$\eta_A = 0.52$$

$$S \text{ (Jy)} = \frac{15.6 T_A^*}{\eta_A}$$

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

Turbulence

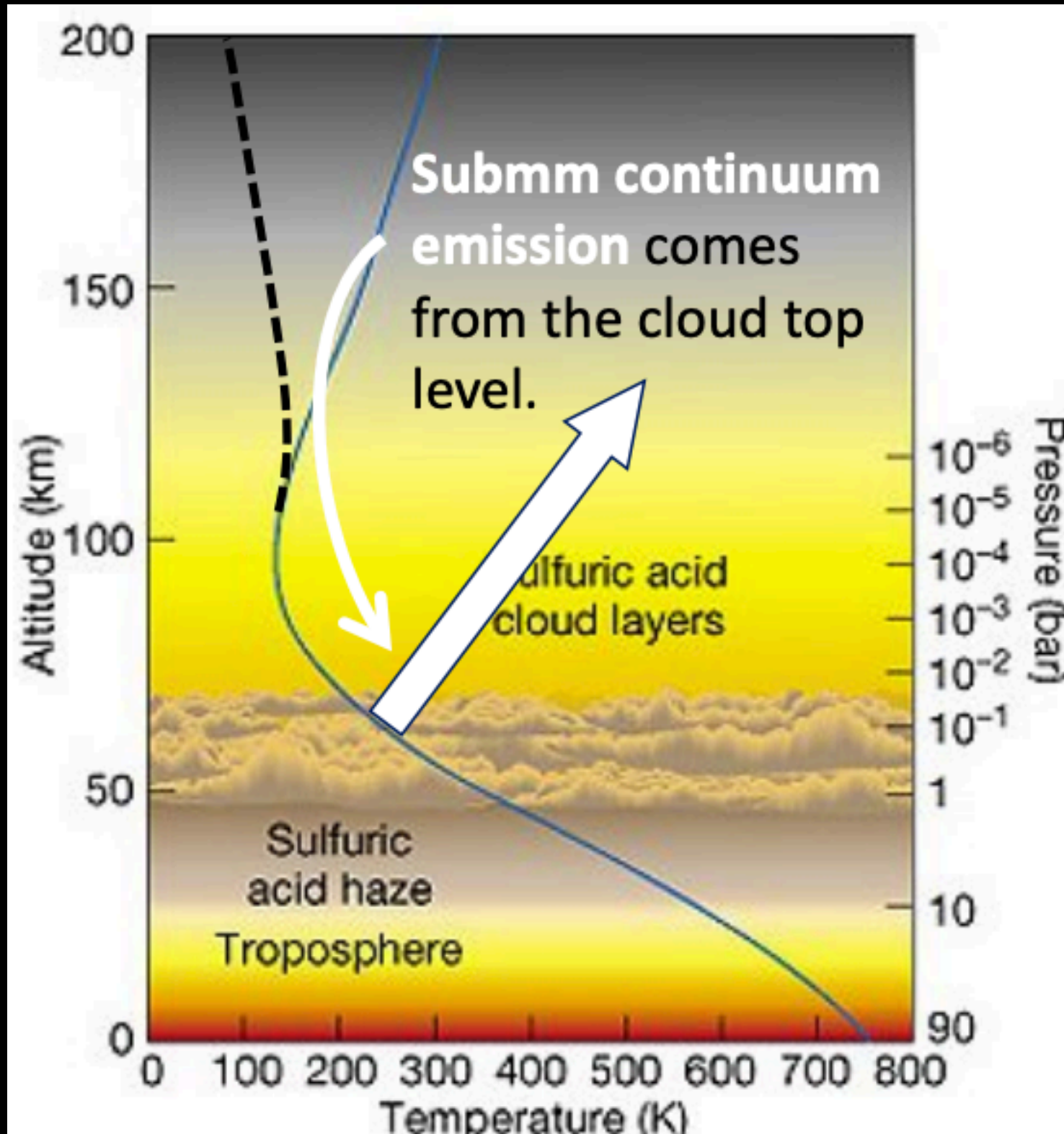
Relative Energy States

Organised Bulk Motion

Interesting Chemistry

Physical Temperatures

An Example of JCMT Heterodyne Science



Led by Dr. Hideo Sagawa
(Kyoto Sangyo University)

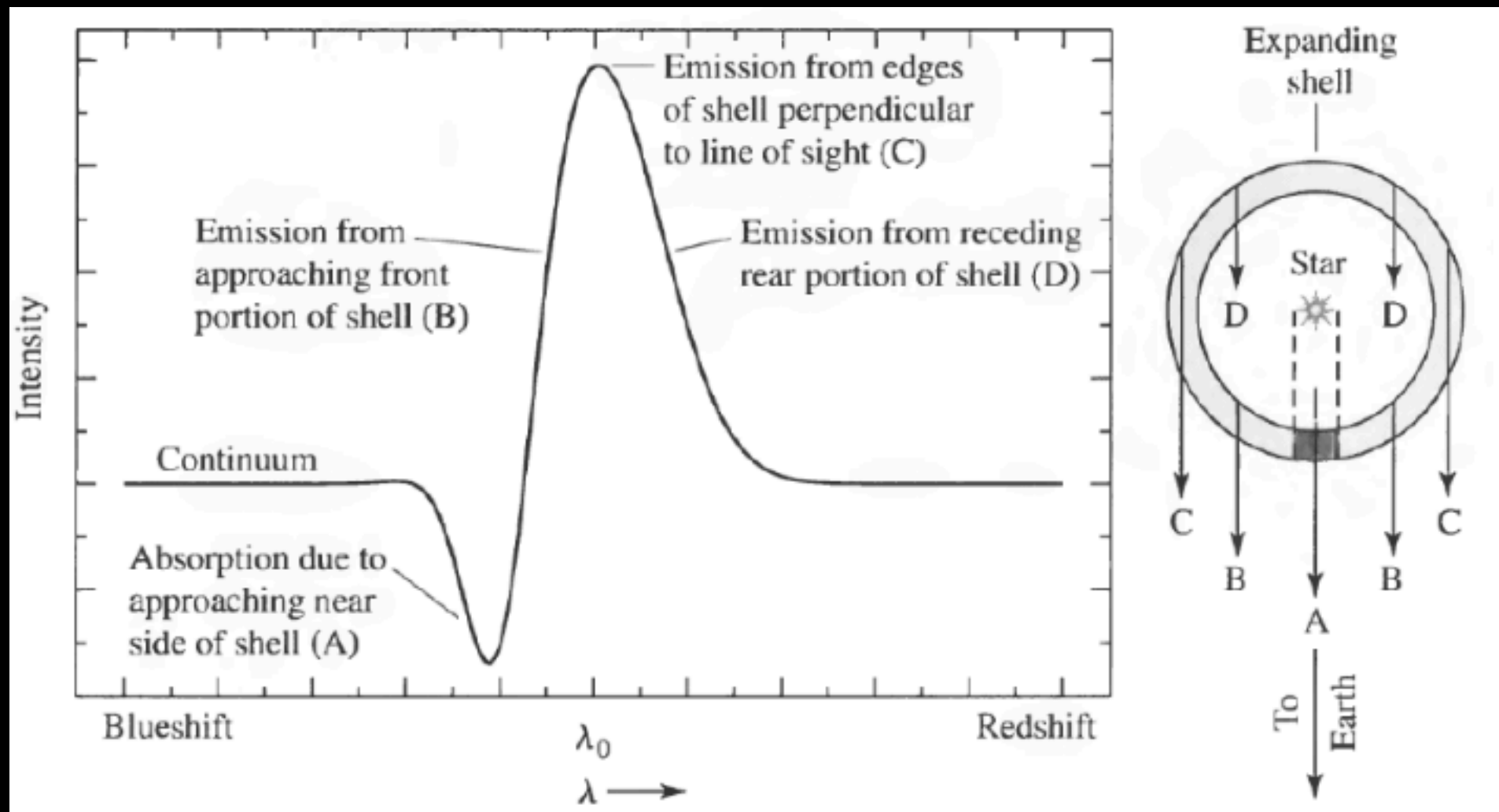
Studying the photochemistry and
dynamics of Venus' atmosphere
at an altitude of 70-100 Km

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

All observations performed
in the light of day!

Line shapes: P Cygni Profile as an Example

The **shapes** of molecular profiles can also tell us a lot!



From: Carroll, B. W. & Ostlie, D. A. 2006, An introduction to modern astrophysics, Second edn.

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!

