What You See…

Introduction to MASERs

Before LASERs were made on Earth, astronomers discovered MASERs, **M**icrowave **A**mplification by **S**timulated **E**mission of **R**adiation. Here small molecules are stimulated to emit large pulses of coherent microwave radiation. MASERs are used as atomic frequency standards, an atomic clocks, for example in geodesy.

Molecules

Different types of atoms can combine in the coldest regions of space (around 10 K) to make molecules. The cold molecules are detected in the radio band. Most of the molecules are hydrogen molecules (H_2) and carbon monoxide (CO). Actually, molecular hydrogen does not emit radio energy but it is found with carbon monoxide, so the radio emission of CO is used to trace the H_2. Other small molecules include such familiar ones as H_2O (water), OH (hydroxide), NH_3 (ammonia), SiO (silicon monoxide), CO_2 (carbon dioxide) and over a hundred other molecules. Many carbon-containing molecules (organic molecules), water and ammonia molecules are used in biochemical reactions to create the building blocks of life: amino acids and nucleotides. The presence of these molecules in the interstellar medium shows that some of the ingredients for life exist throughout the Galaxy. Some carbonaceous meteorites have amino acids in them---amino acids can be created in conditions too harsh for normal biological processes.

Molecular Clouds

Based primarily on observations of the CO emission, astronomers find that the molecules in the interstellar medium are clumped together into clouds with masses anywhere from just a few solar masses to over a million solar masses with diameters ranging from several light years to over 600 light years. Since molecules need to have shielding from the high-energy light from stars which would destroy them, molecular clouds have dust in them. The dust grains may provide the shelter for molecules to form. Compared to the size of atoms, the dust grains are enormous and have many pits and recesses for atoms to congregate and combine.

Stars form in the molecular clouds. If the molecular cloud is cold and dense enough, it can collapse under its own gravity. Smaller fragments can form and produce stars. The Milky Way has about 2.5 billion solar masses of molecular gas with about 70% of it in a ring extending from 13,000 to 26,000 light years from the center. Not much molecular gas is located at 4,900 to 9,800 light years from center but about 15% of the total molecular gas mass is located close to galactic

center within 4,900 light years from the center. Most of the molecular clouds are clumped in the spiral arms of the disk and stay within 390 light years of the disk midplane.

Molecular Hydrogen and Carbon Monoxide Connection

Molecular hydrogen H_2 produces absorption lines in the ultraviolet but not radio emission. However, the gas and dust become so thick in a molecular cloud that the ultraviolet extinction is too large to accurately measure all of the H_2 in the interior of the cloud. Fortunately, there is evidence of a correlation between the amount of CO and H_2, so the easily detected *CO* radio emission lines (at 2.6 and 1.3 mm) are used to infer the amount of H_2 present. The CO emission is caused by H_2 molecules colliding with the CO molecules. An increase in the density of the H_2 gas results in more collisions with the CO molecules and an increase in the CO emission.

Another nice feature of the CO radio emission is that its wavelength is small enough (about 100 times smaller than 21-cm line radiation) that even medium-sized radio telescopes have sufficient resolution to map the distribution of the molecular clouds. The higher resolution of large radio telescopes can be used to probe the structure of individual molecular clouds. There is some controversy about how the molecules are clumped together in the clouds. Is one gas cloud actually made of many smaller gas clouds? There is some evidence that indicates that 90% of the *H_2* is locked up in 5000 giant molecular clouds with masses greater than 10^5 solar masses and diameters greater than 65 light years. The largest ones, with diameters greater than 160 light years, have more than a million solar masses and make up 50% of the total molecular mass. Other studies indicate that the giants are actually made of smaller clouds grouped together into larger complexes.
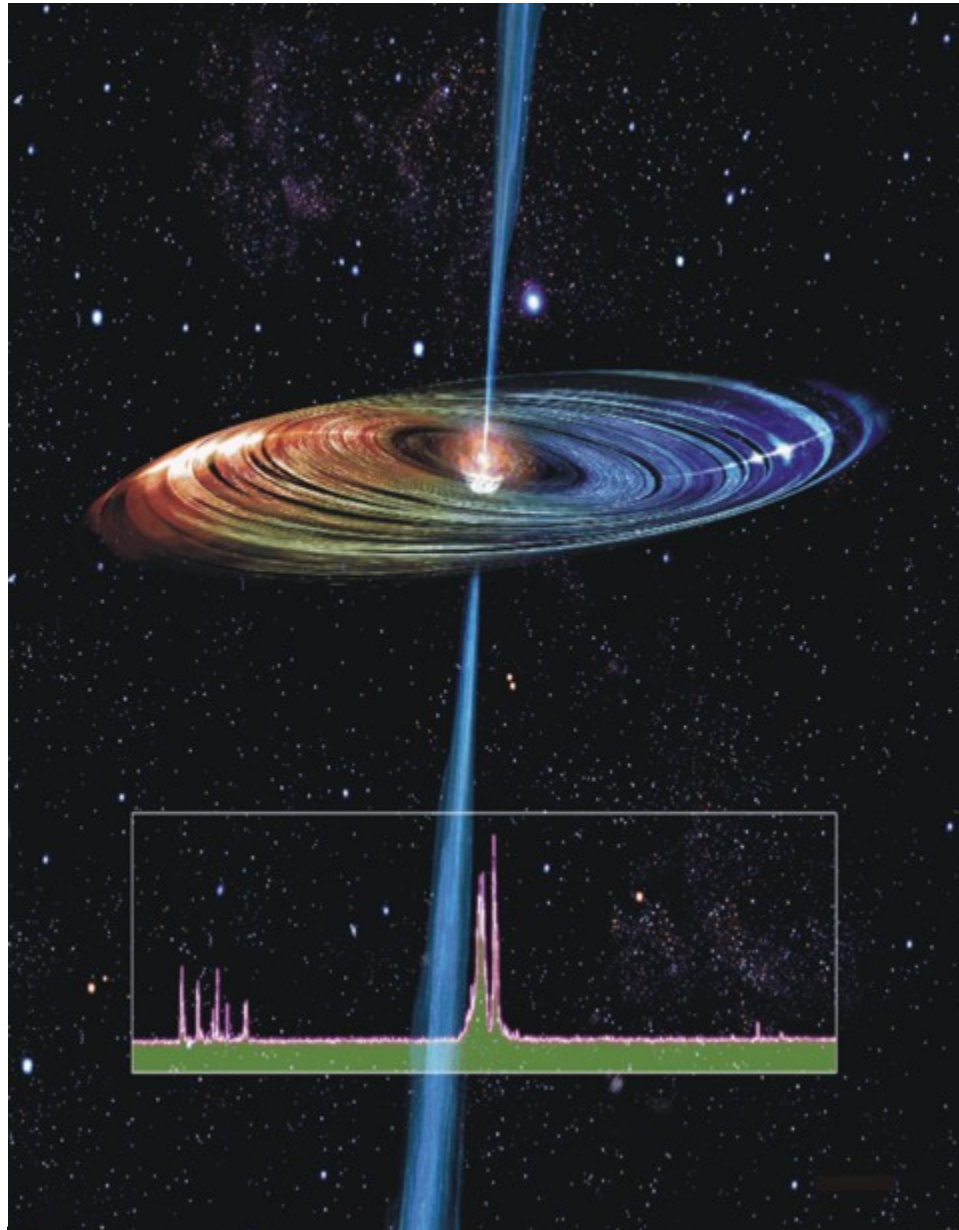
For more information, activities, and a worksheet on MASERs, visit the Haystack website:

http://www.haystack.mit.edu/edu/pcr/Astrochemistry/index.html

MASER Activity: What you see…

Examine the following three presentations of water MASERs. In particular, look the details of spectra for the H_2O MASERs.

1.

Artist's rendition of the accretion disk and radio jet around the black hole in the heart of the Seyfert galaxy NGC 4258. Image courtesy of NRAO/AUI and Artist: John Kagaya (Hoshi No Techou). "NRAO / AUI / NSF"
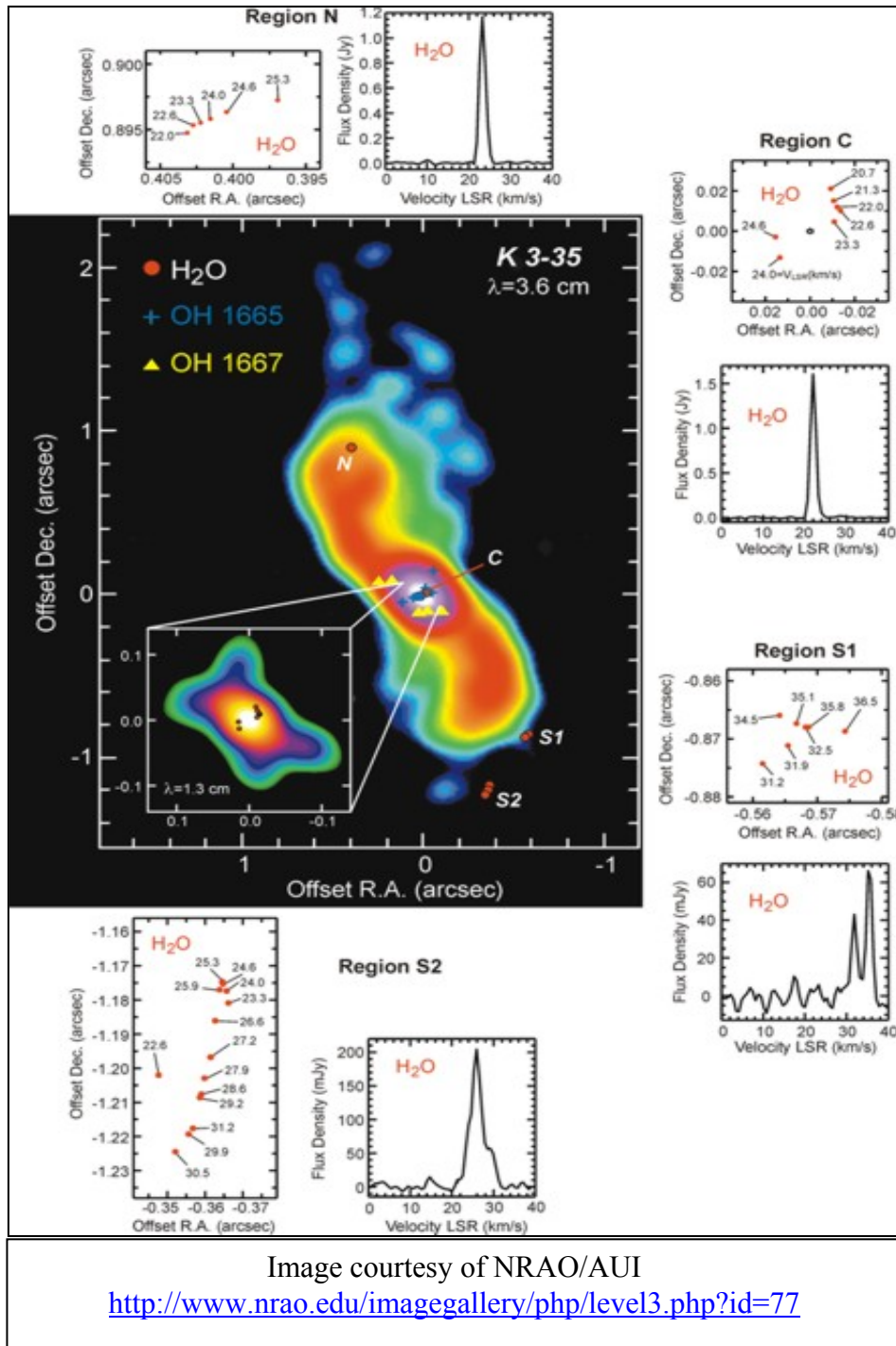
About this Image: NGC4258 contains one of the very few galactic nuclei for which astronomers can make images of accretion disk material that lies within a few tenths of a parsec from a supermassive black hole. The disk is "paper thin," warped, and rotating differentially.

In this artist's conception, the disk is color coded according to Doppler shift. The blue regions of the disk are moving toward us, while the red regions move away from us. The inset at the bottom of the graphic is a radio spectrum (intensity as a function of frequency or velocity) of the water MASER emission. It is the distribution of water emission on the sky that astronomers map as they trace the outlines of the disk. The white glints on the disk surface show the locations of regions where MASER emission has been detected.

From: http://www.nrao.edu/imagegallery/php/level3.php?id=347

2.

Image courtesy of NRAO/AUI
http://www.nrao.edu/imagegallery/php/level3.php?id=77

About this Image: Water MASER and OH MASER emission in the planetary nebula K3-35 (figure adapted from Miranda et al. 2001). The color images show the 3.6 cm and 1.3 cm (inset) continuum emission, which trace the ionized nebular material. A bright core, with incipient hour-glass morphology at 1.3 cm, and two bipolar lobes,

whose brightest parts correspond to the precessing bipolar jet, can be distinguished. Red dots in the figure represent the positions of the H20 MASER spots. The detailed spatio-kinematical structure and the spectra of the water MASER emission are shown in the panels for the four regions (N, C, S1 and S2) in which water emission is detected. The blue crosses mark the positions of the OH 1665 MHz MASER spots, and the yellow triangles mark the positions of the OH 1667 MHz MASER spots.

Investigator(s): Luis F. Miranda, Yolanda Gómez, Guillem Anglada, and José M. Torrelles

3. Image from the Literature.

A STUDY OF THE VARIABILITY OF WATER MASER EMISSION IN A SAMPLE OF YOUNG STELLAR OBJECTS

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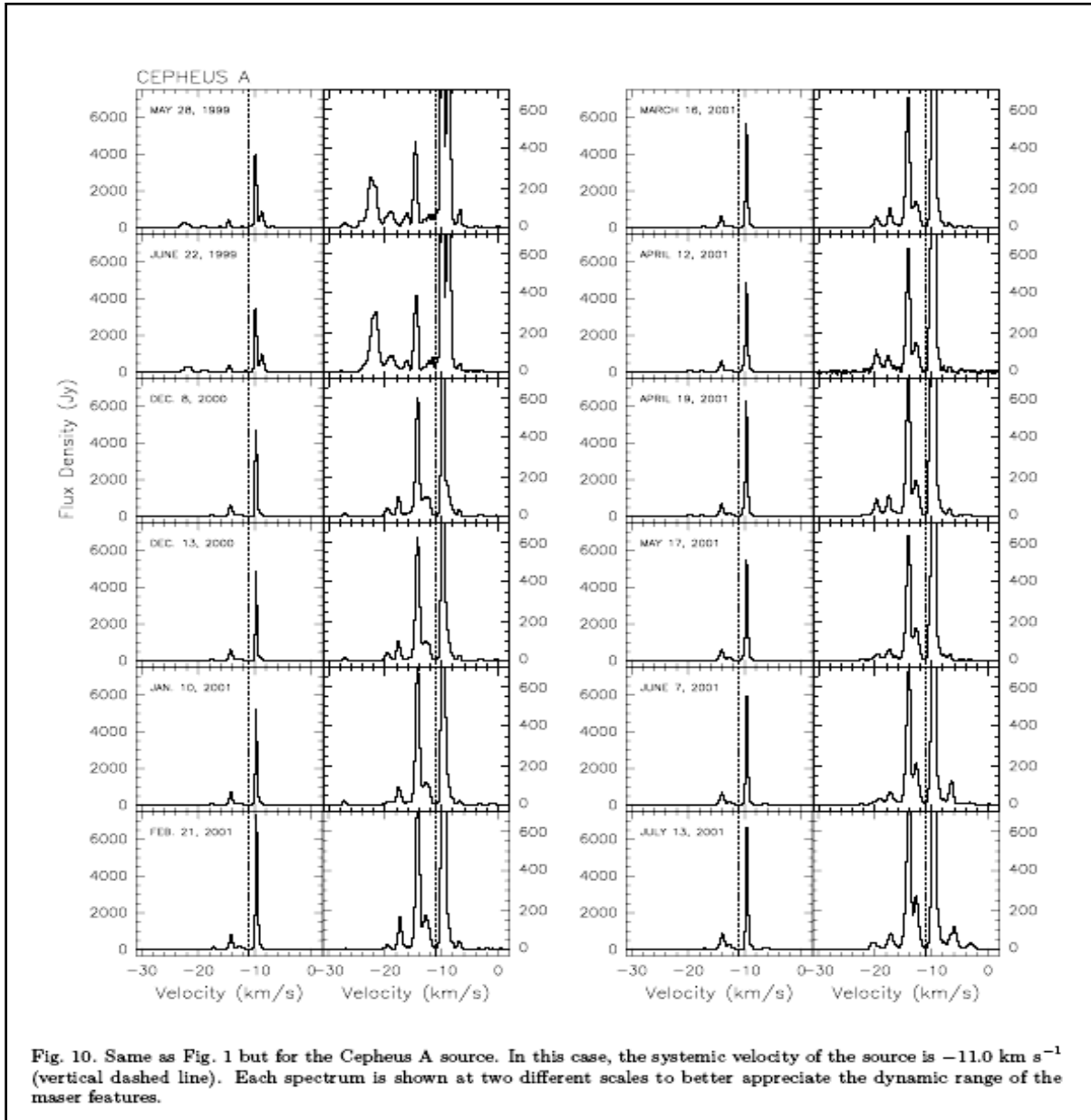

Fig. 10. Same as Fig. 1 but for the Cepheus A source. In this case, the systemic velocity of the source is −11.0 km s⁻¹ (vertical dashed line). Each spectrum is shown at two different scales to better appreciate the dynamic range of the maser features.

Name_____   Period _____   Date_____

MASER Activity 1: MASERs in Literature

Answer the following questions from the three pictures of MASERs
1. From the three spectra of water MASERs, where were these MASERs found?

2. Were the MASER water spectra similar? Why or why not.

3. What was the purpose of the MASER spectra? What were they used for?

Analyzing the Data

Now you will actually get some data that comes from a radio telescope and analyze it. The data can be accessed on the website,

http://www.haystack.mit.edu/edu/pcr/downloads/

Select "Water_MASER_Data.xls". You will need Excel to open the data.

Look at the data obtained from Haystack's 37 meter radio telescope.
Examine some typical data on the Excel spreadsheet "Water MASER Data." The velocity and intensity are given for three water MASERs: N2538m, N2538w, and Dr21n. The first two, N2538m, N2538w, come from different regions of the same area. Dr21n is a water MASER which is more distant.

Graph the intensity of each MASER as a function of velocity. If you are a bit short on time, select only N2538m and N2538w.

1. Click on the chart icon.
2. Click the graph at the second row left corner.
3. Click "Next ﹥".
4. Go to the series tab, not the data range tab.
5. Click "Add".
6. X values:
   - Click on the red icon to the right. This brings you back to the spread sheet.
   - Go to the "Velocity" column. Highlight the cell below and drag it all the way down the values in that column.
   - Click on the red icon again.
7. Y values:
   - Click on the red icon to the right.
   - Go to the "Intensity" column. Highlight the cell below and drag it all the way down the values in that column.
   - Click on the red icon again.
   - Click "Next ﹥".
8. Label the axes and title of the graph
   - Chart title: Intensity vs. Velocity
   - Value (x) axis: Velocity (km/s)
   - Value (y) axis: Intensity
   - Click "Next﹥".

9. Choose the location of your graph.
   - As object in: MASER Data
   - Click "Finish".
10. Customize your graph
    - **Scale.** Place the mouse on top of any number on the x axis. Double left click. Click on the "Scale" tab. Change the Minimum, Maximum, Major unit, and Minor unit to your desire.
      - ❖ Click "Ok".
      - ❖ Do the same thing for the y axis.
    - Draw **gridlines.** Right click on any empty space of your chart. Go to Chart Options… go to the Gridlines tab.
    - Add **color.** You can add color to the line connecting the dots and to the background if you would like.
11. Repeat this process to graph the rest of the data. You will now have 3 graphs that should look similar to the graph below.
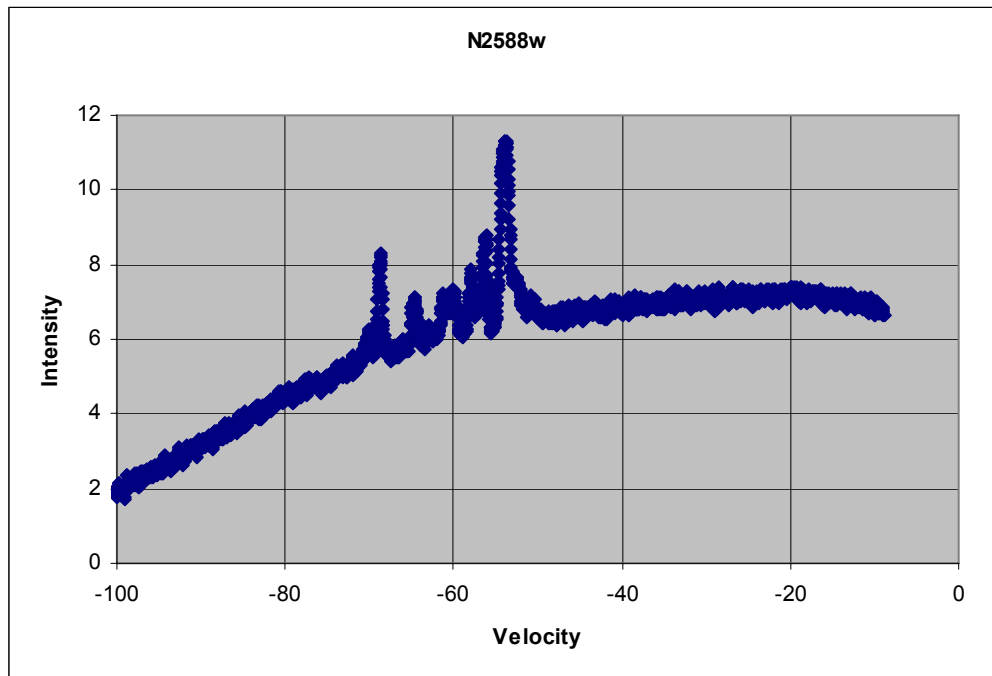
Removing the Baseline

Notice that the graphs you made are slanted. This phenomenon is due a systematic error in the instrumentation. You need to remove it! Also notice that there are several peaks. In order to remove the baseline, we will have to temporarily remove these peaks from the data.

1. Go to any graph and place the pointer right where the first peak starts. If you wait a few second, a box will show up. At the bottom you should see two numbers in parenthesis, which corresponds to the X Y coordinates for that data point. Record the Y coordinate for this data point.

    - **Y coordinate at beginning of first peak _____**

2. Repeat the same process to get the y coordinate for the end of the last peak. Record this value.

    - **Y coordinate at end of the last peak _____**

3. Highlight the Intensity column and go to the top menu.
    - Click on "Edit"
    - "Find…" and enter the Y coordinate for the beginning of the first peak. Record the row; you will need it in order to temporarily delete some data.

    - Row number for first peak _____

    Repeat to locate the end of the last peak. Record the row number.

    - Row number for last peak _____

4. Delete all the intensities between these two rows. Take a look at the graph and verify that all the peaks have been removed. **Don't save the data, as you will need it later on!!!**
    - Move the pointer to any value within the graph.
    - Right click "Add Trendline…"
    - Click on the "Type" tab, choose "Polynomial."
    - Try out 2nd and 3rd order and select the best one
    - Click on the "Options" tab, and check display equation on chart
    - Click "Ok".

5. Record the equation on your spreadsheet. Your graph should look like the one below:
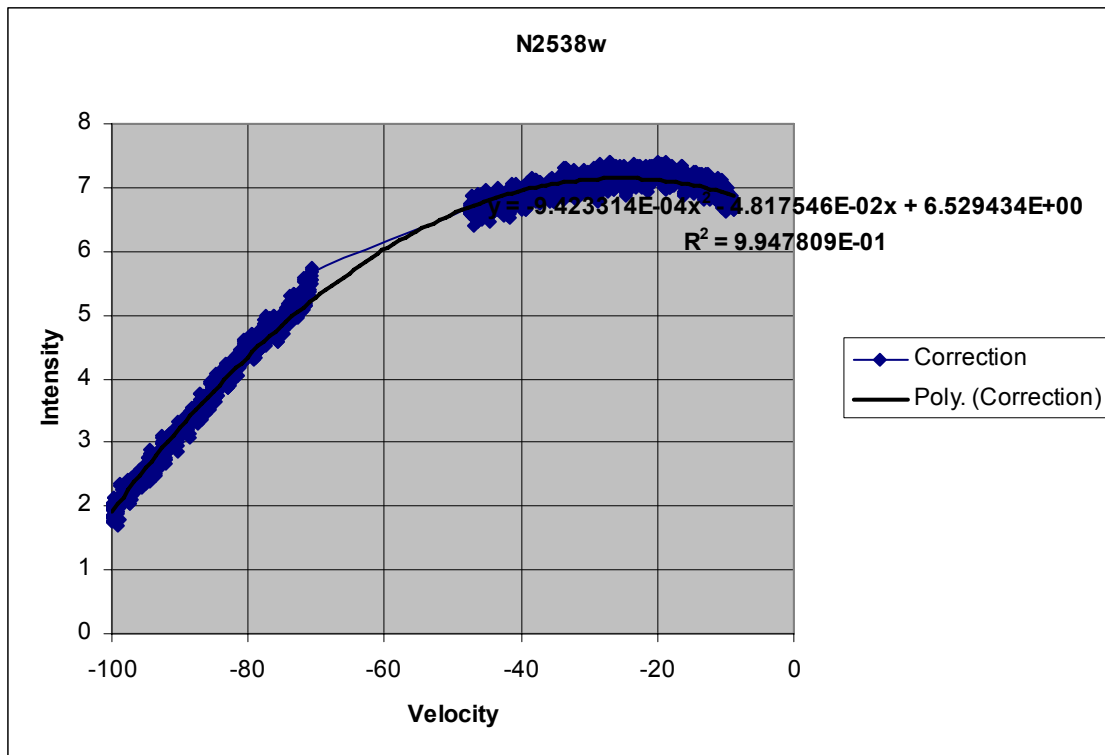
6. Before you do anything else, click the undo button until you have recovered **ALL** the deleted data that belongs to the peaks of the graph. **You will need in order to continue!**

7. The second order polynomial equation for the example graph is:

$y = 9.423 \times 10^{-4}\, x^2 - 4.8175 \times 10^{-2}\, x + 6.5294.$
Yours might be slightly different.

8. You will now need to subtract this equation from the each intensity value. This is how to do it using the example graph provided. (Remember that your equation is different that the one used for this example, so you will have to modify these values according to the polynomial equation obtained from _your_ graph. To make it easier for you, the numbers that you have to modify are highlighted in **blue**).

- Go to column D. In cell D2 type in "Baseline"
- Go **to** cell D3 and type:

"=(($9.423*10^{-4}$*(B3^2))+($-4.8175*10-2$*(B3))+6.5294)".   Remember that the values in **blue** correspond to the polynomial equation for the example graph. They will be different in your case, so make sure you change them.

- Highlight this cell and drag all the way down through empty cells in the column to complete the calculation.
- Press the "Ctrl-D" (fill down).
- Go to column E. In cell E2 type in "Baseline Removal"
- Go to cell E3 and type: "C3-D4" to subtract the baseline.
- **Highlight** this cell and drag all the way down through empty cells in the column to complete the correction.
- **Repeat** step 7 for the other two graphs.

9. Repeat step 5 to graph the Intensity vs. Velocity.
    - Graph column B on x-axis and column E on the y-axis.

10. Repeat the steps for the other two data sets.

Your graph(s) should look similar to the one below.
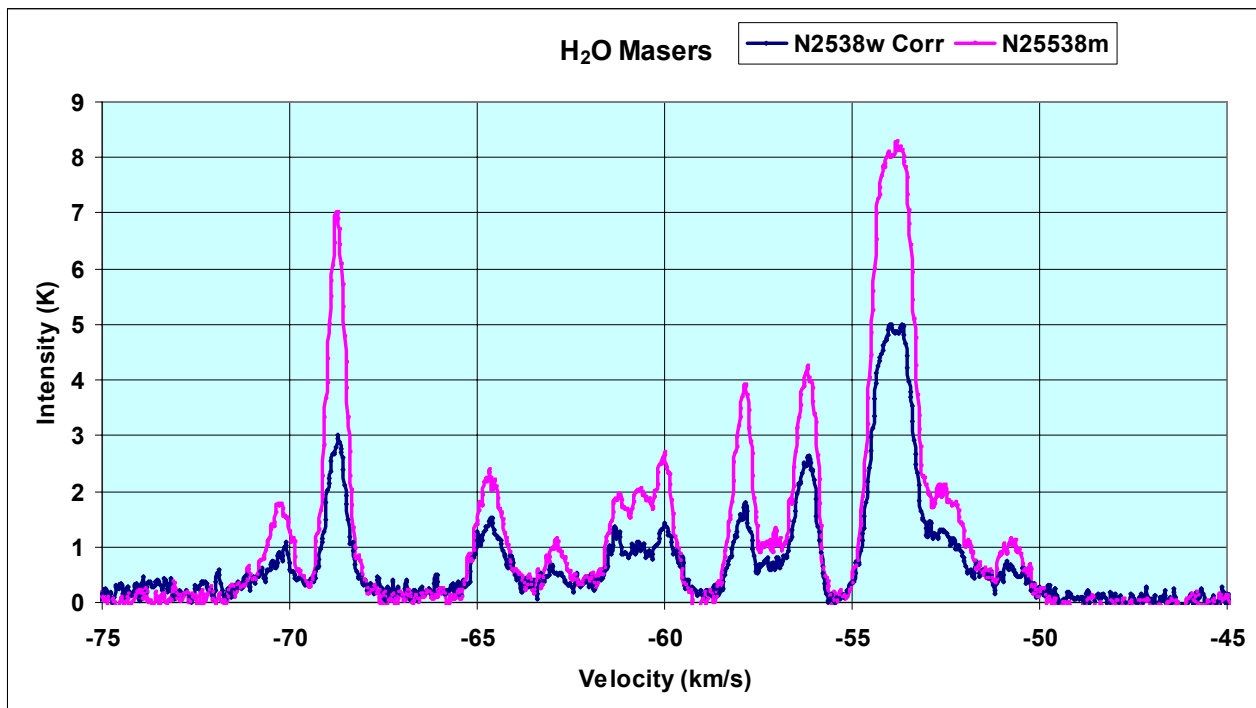
Name_____   Period _____   Date_____

MASER Activity 2: What You See…

Hand in your graphs and answer the following questions:

1. Do the spectra as they first came off the telescope look like the ones you first saw in the literature? Explain.

2. How are the spectra the same?

3. How are the spectra the different?

Now examine the three spectra you graphed.

4. What about the number of peaks for each line? Are they regular and predictable?

5. Suggest a method to remove the large and uneven background signal.

6. Notice that the peaks are not at the same location (velocity) for all the graphs. Explain why.

7. Examining the N2538 spectra, are the peaks the same as the others?

8. Examining the N2538 spectra, why are they different in intensity?

9. Compare the Dr21n with the N2538 spectra. Explain the difference.

N2528m Corr
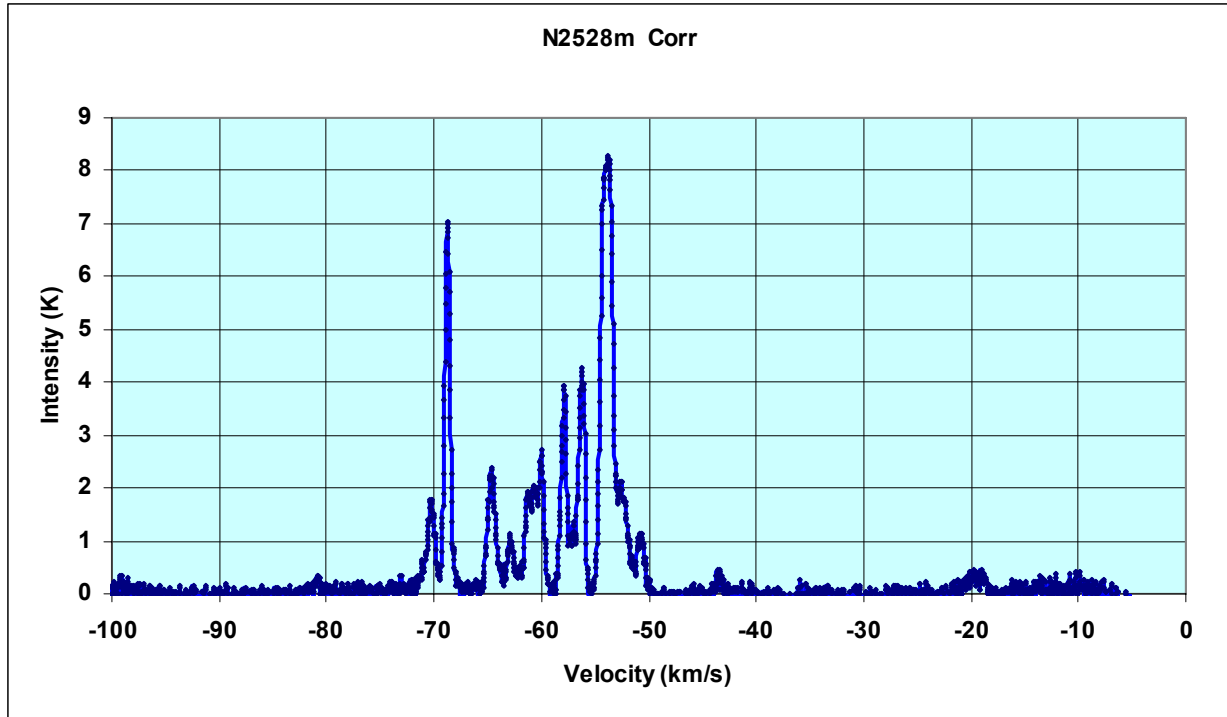
10. Your final spectrum should look like the one above which looks like the spectra in the examples you first looked at in the literature and **NOT** like the ones obtained from the radio telescope. Explain why this is so.

11. The title of this activity is "What you see…" Do you think it is valid for a scientist to "doctor" the data so that it looks pretty for other scientists? Everybody seems to do it, but is it right?