M31 and M33 observations @ 21cm

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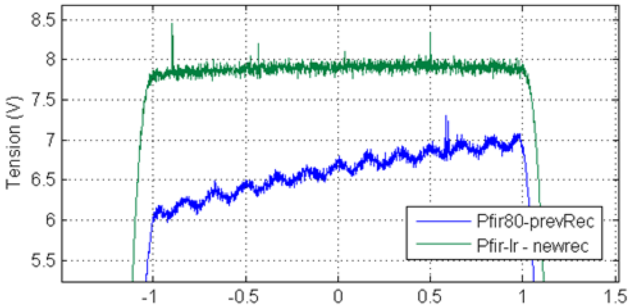
21cm radio telescope

This video [3] shows the main characteristics of the 21cm RT.

The analog receiver was modified by using larger IF filters to obtain a flat 5 MHz bandwidth. The SDR SW was upgraded to work with a DDC (Digital Down Converter) output sample frequency of 5MHz (2.5 MHz in 2013) and dedicated digital filters to improve the bandwidth smoothness (ripple and slope).



M31 – Andromeda Galaxy @ 21cm (NGC 224)

Wanted signals and detection criteria

Regarding [1], the figure below shows the H1 integrated profile of the M31 galaxy radio flux @ 21cm.

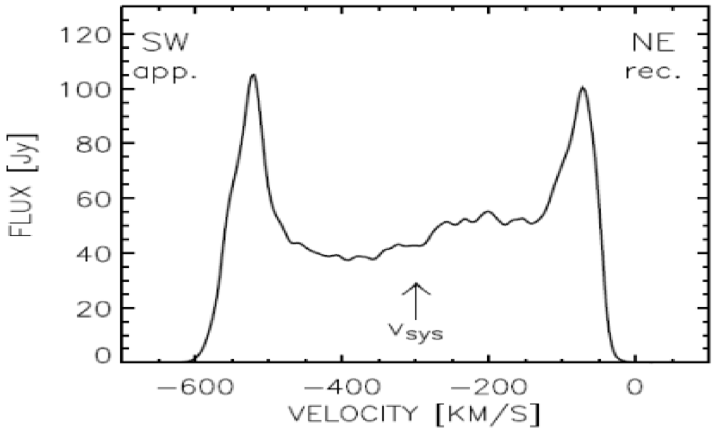


FIG. 3.— HI integrated profile of Messier 31. v_{sys} refers here to as the integrated weighted mean systemic velocity derived from the profile.

Regarding this curve, the flux F should be between 50 to 100 Jy (1Jy = 10^{-22} W/m²/Hz).
The effective area of the antenna Aeff is :

Antenna : D=3.3m, Gain=31dBi => G=1260,
Effective area : Aeff= G*λ²/4pi => 4.46m²

These values allow to calculate :

- The signal power spectral density received at the antenna feed :
  F * Aeff = 223 à 446 10E-26 W/Hz
- Corresponding at an antenna temperature Tant :
  Tant = F*Aeff / k = 0.16 to 0.32 K avec k = Bolzman cste

The antenna aperture is 4.4°. This aperture is over the M31 galaxy extension so a dilution factor could appear in measurement.

About velocity, we have to consider a max velocity Vmax = 600 km/s. So, the maximal Doppler shift will be aroud Vmax/λ that to say 600 / 0.211 in KHz => ab. 3000 KHz (including Doppler shift coming from our own movement). So we will use a bandwidth of 4 MHz (centered at 2 MHz). The sample frequency Fs will be 5MHz at the output, the digital filters allowing a bandwidth of 80% of Fs.

The main difficult is the very low level of signal. The system temperature Tsys is around 60K. To reveal signal of 0.2K, the detection sensitivity Sd must be better than 0.005 K that to say 10 000 times lower than Tsys !

Referring to the classic formulae : $Sd = \frac{Tsys}{\sqrt{Bw*T}}$

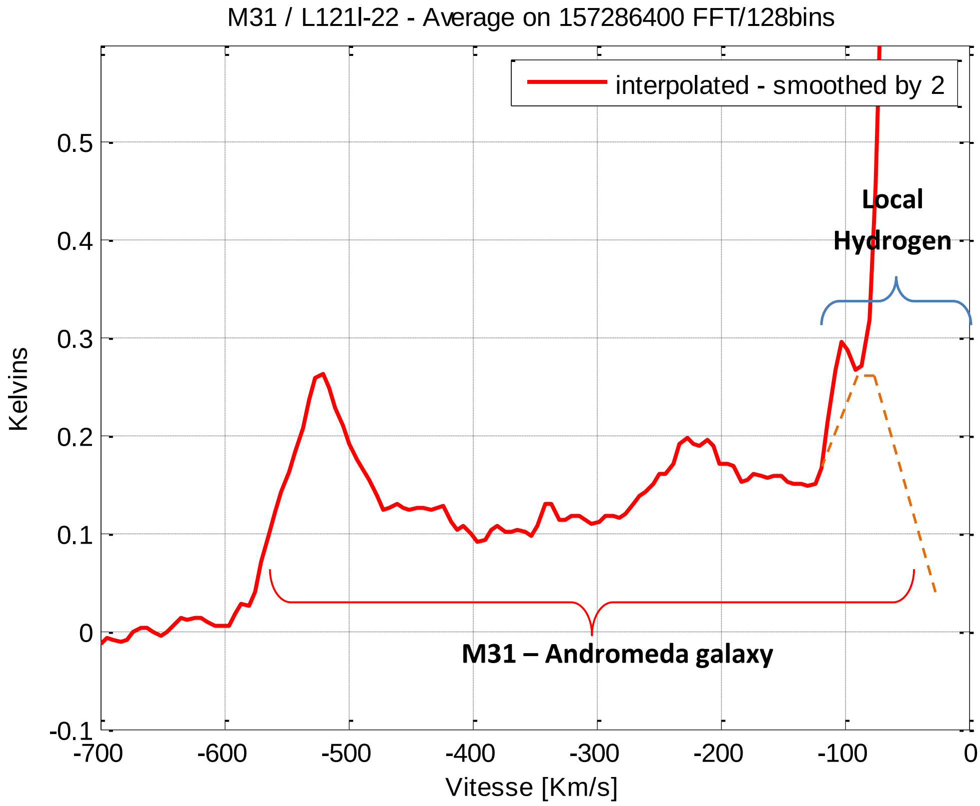
Tsys fixed by the equipment, we only can adjust Bw and T to obtain the sensitivity Sd.
The M31 spectrum is large and we don't need a velocity resolution better than 10km/sec. So an FFT processing of 128 bins gives a velocity resolution of 8 km/sec (Fs*λ/binFFT) and a bandwidth Bw of 39 KHz per FFT channel (for a sample frequency Fs of 5 MHz).

Now, we can calculate the integration time T : $T = \frac{Tsys^2}{Sd^2*Bw}$ soit T = 3600 s

We must multiply this time by 2 to include SDR init time for each data block recording, data arrangement and recording time to have the true time of measurement.
The high declination of M31 (41°) allows to find easily a 2h slot with high elevation (largely over the ground to limit the ground temperature effect).

M31 detection result:

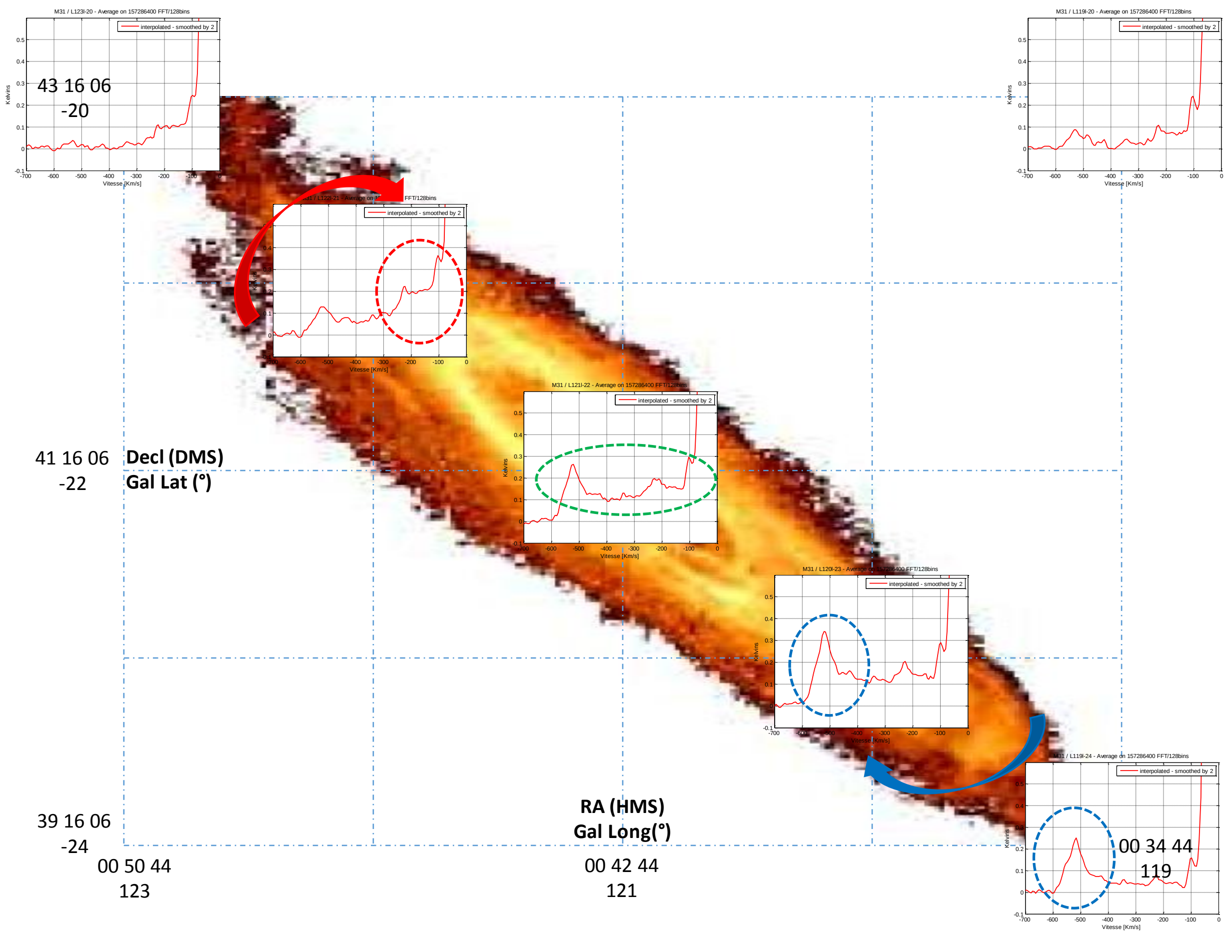
The signal level is a little bit smaller than expected probably coming from the dilution factor and the measurement accuracy.
The spectrum over -100 km/sec is perturbed/masked by the local hydrogen of our Galaxy. Next time, I have to try to remove manually the local hydrogen to reveal the complete spectrum.
From this measurement, we can see the major part of the profile of M31 up to -560 km/s (at 50% level).
This spectrum spreading reveals the M31 Galaxy rotation. M31 is approaching to us with an average velocity of about -300 km/s.



You will find image or more information about the Andromeda Galaxy M31 here :
https://en.wikipedia.org/wiki/Andromeda_Galaxy M31 detection result:

M31 rotating pattern :

I would add to this note the comparison of 21 cm measurements to the optical observations of M31 (see reference [1]). For this, a set of measurements was carried out around the M31 area. The data reduction and processing are still under work but the first spectra reveal the rotating pattern of M31 as shown with the figure below (to be continued with all spectra).

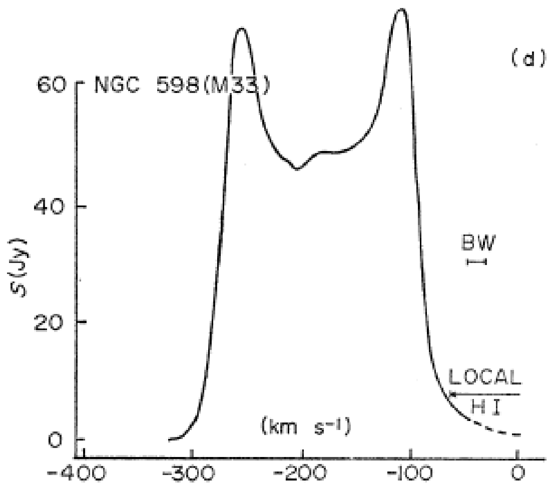


Velocity field along the major axis of M31. Spectra reveal the rotating pattern.

M33 – Triangulum Galaxy @ 21cm (NGC 598)

Wanted signals and detection criteria

Regarding [6], the figure below shows the profile of the M33 galaxy radio flux @ 21cm

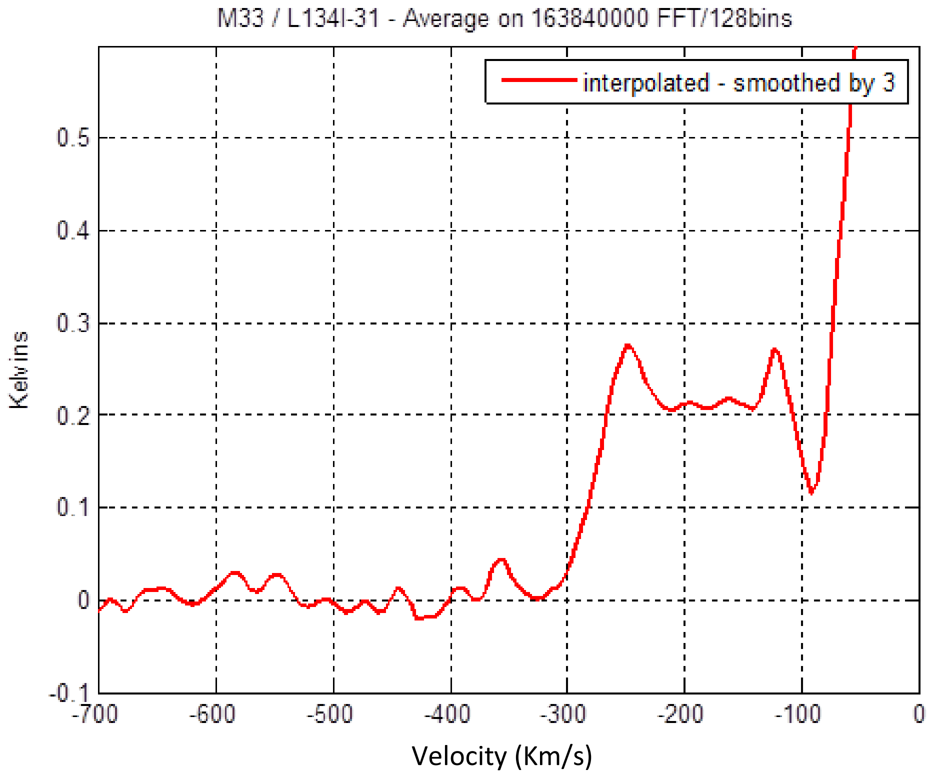


We can note the flux level of M33 is similar to the M31 one.

So, we can use the same radio telescope setup (report to the previous chapter) to make the measurement of the Triangulum galaxy (M33). The M33 area is smaller than the M31 one and it seems it is possible to reveal this galaxy in 1 pass with the "large" aperture of my antenna (4.4°).

M33 detection result:

The figure below shows the spectrum obtained after 1 hour data recording (2 hours of tracking beamed to M33).



The strong signal over -80 km/sec comes from our local hydrogen (Milky Way H1).

The main information included to this spectrum are :
- ✓ The spectrum spreading between – 80 and – 300 km/sec reveals the M33 Galaxy rotation.
- ✓ Both peaks at -246 and –122 km/s give the predominant approaching and receding velocity of M33 hydrogen clouds.
- ✓ The average velocity of both peaks is the approaching speed to the earth of M33 measured @ -184 km/s (including VLSR correction).

You will find image or more information about the Triangulum Galaxy M33 here :
http://en.wikipedia.org/wiki/Triangulum_Galaxy

Conclusions – Next measurement

The results of M31 and M33 observations @ 21cm (H1) are very close to that expected following a series of improvements to the station to get this detection. This shows that with precautions, the formula of detection sensitivity is still applicable even if signals are 10 000 times lower than the temperature system (Tsys).
This measurement was only possible by using a stable and perfect reference. This was a huge improvement.

The future developments of the radio telescope will focus on the reduction of Tsys passing by developments on the illumination of the reflector (lower side lobes) and a better low noise preamplifier.

With a complete mapping of M31, a datacube will be generated and should allow to edit a detailed map of M31. It will be also possible (I hope) to remove the local H1 of our Galaxy. At this time, 16 points on the area of M31 was observed.

The mapping of M33 is also planned to reveal its rotating pattern.

To be continue…

Références :

[1] *H1 KINEMATICS AND DYNAMICS OF MESSIER 31 - Laurent Chemin, Claude Carignan and Tyler Foster*

[2] *Joachim Köppen - http://www.astrophysik.uni- kiel.de/~koeppen/Haystack/index.html*

[3] *http://www.youtube.com/watch?v=HGwkZY4E64k*

[4] *http://www.astroccd.eu/index.html*

[5] http://f1ehn.pagesperso-orange.fr/pages_radioastro/Images_Docs/M31_mesures_ETE2013.pdf

[6] *THE INTEGRATED NEUTRAL HYDROGEN PROPERTY OF NEARBY GALAXIES – J.F. Dean and R.D. Davies*