Introduction to Radioastronomy:

Data Reduction and Analysis (II)

Observatoire astronomique
de Strasbourg

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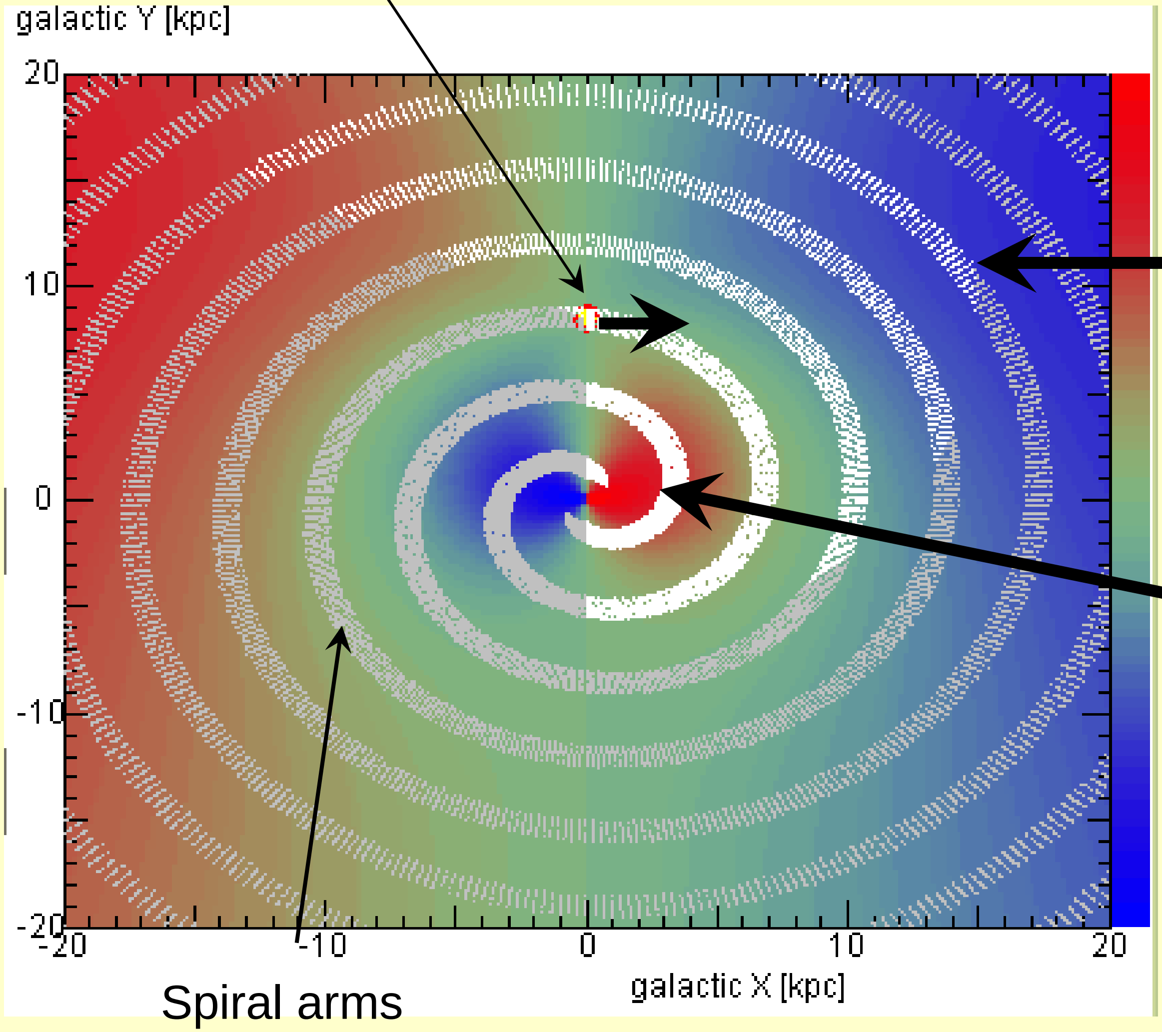
http://astro.u-strasbg.fr/~koppen/JKHome.html

The ESA-Haystack Telescope

- Frequency 1420 MHz (Wavelength 21 cm)
- Spectroscopy
- Radiometer (flux calibrator = Library wall)
- 2.3 m diameter parabolic reflector

- Rotation curve of the Milky Way
- (Solar temperature)

We live here in the Milky Way which rotates about its centre

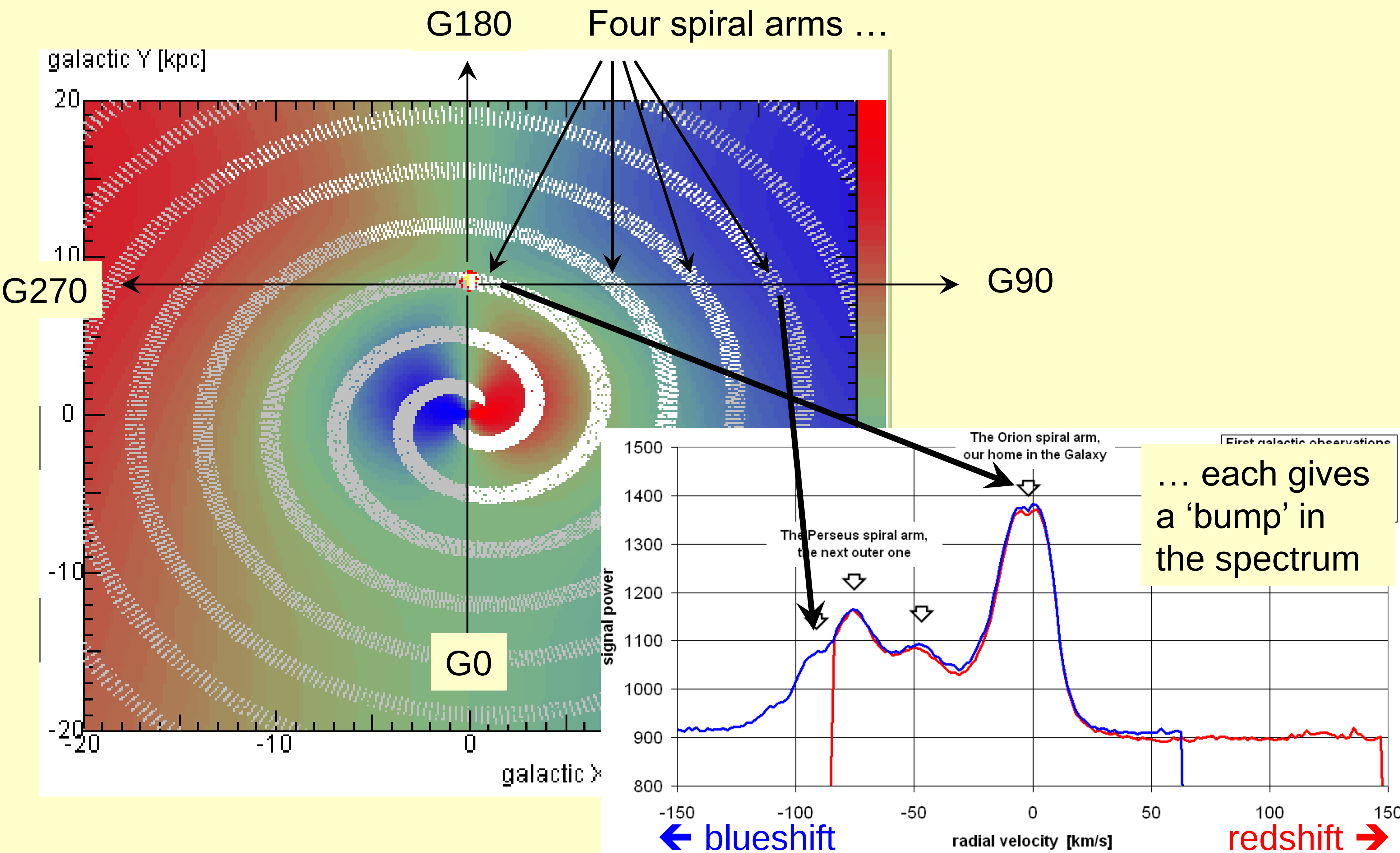


The emission from an object here will be seen by us 'blue-shifted', i.e. coming towards us.

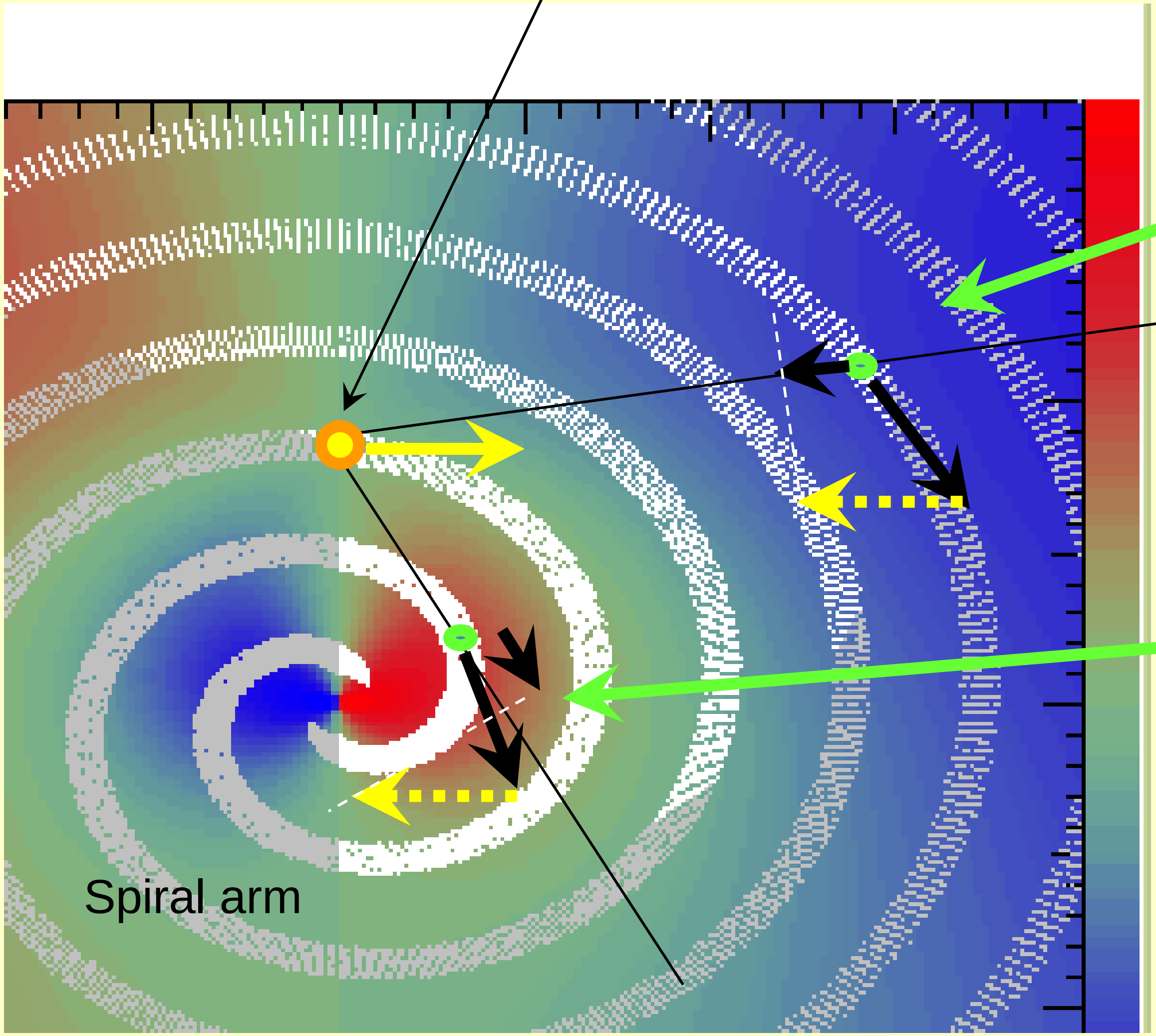
This object will be seen by us 'red-shifted', i.e. moving away from us.

http://astro/u-strasbg.fr/~koppen/Haystack/applets/rotation/

What we observe at G90



We live here in the Milky Way which rotates about its centre

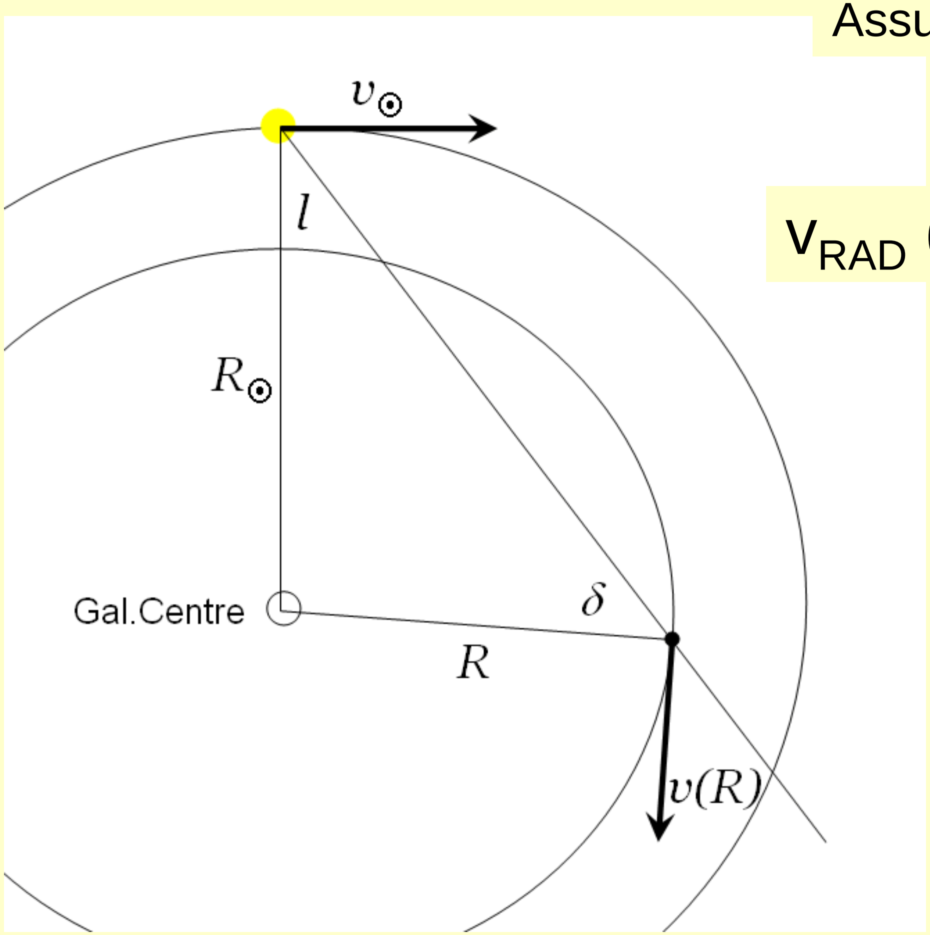


The emission from an object here will be seen by us 'blue-shifted', i.e. coming towards us.

This object will be seen by us 'red-shifted', i.e. moving away from us.

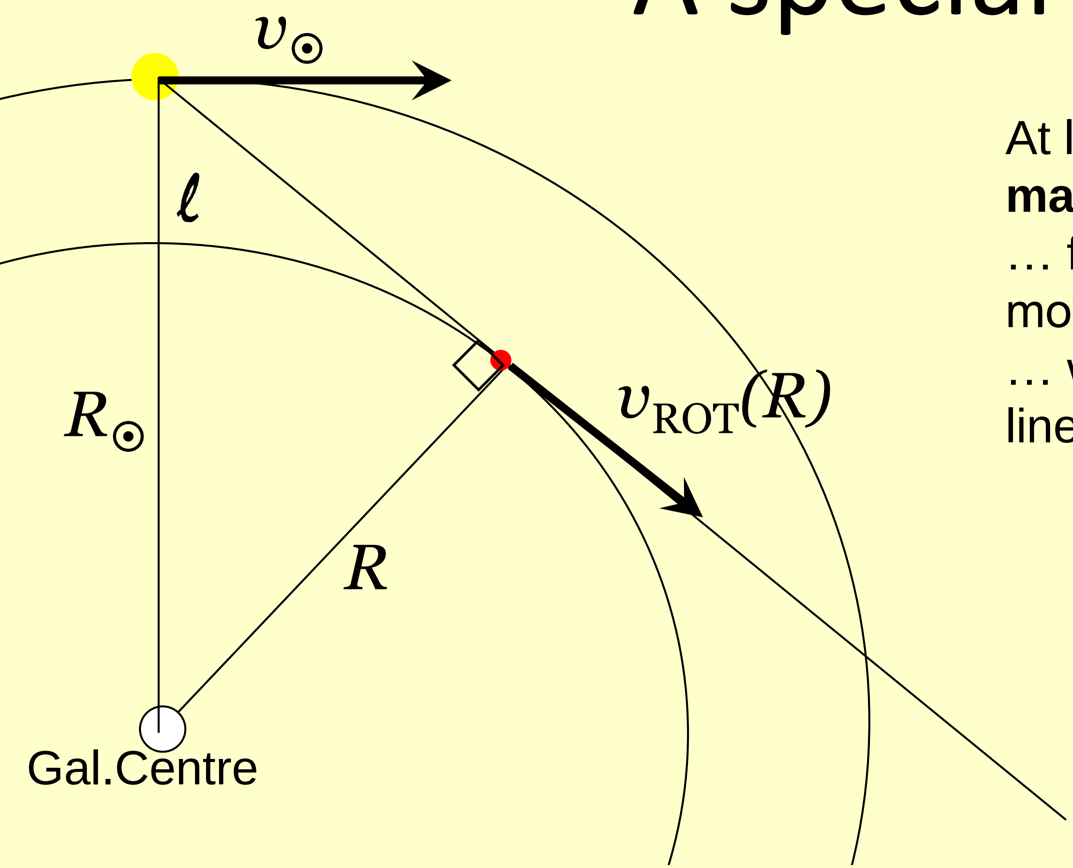
Oort's formula

Assume: all stars move on circular orbits

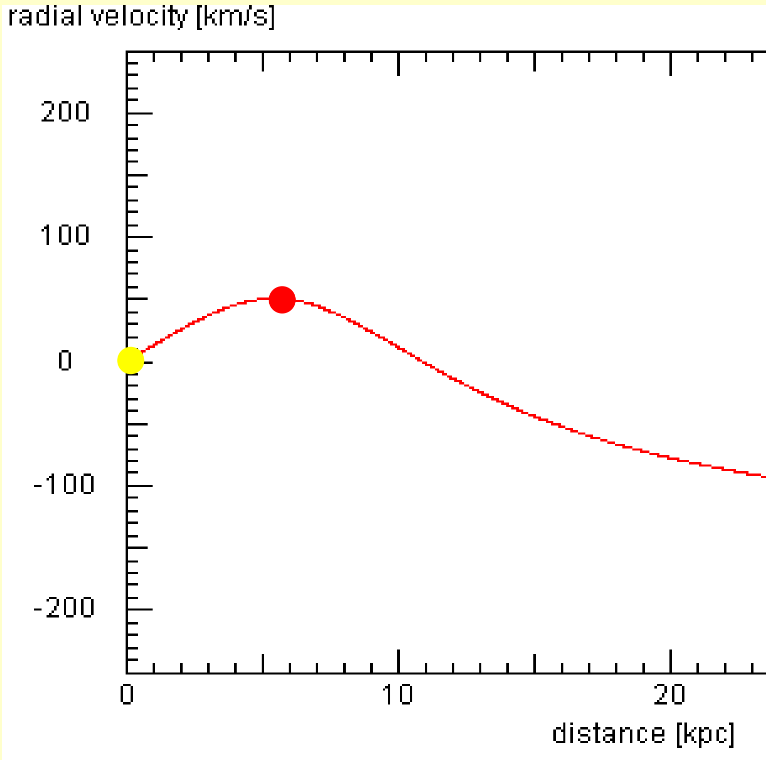


$$v_{RAD}(\ell) = (v_{ROT}(R) * R_\odot/R - v_\odot) \sin \ell$$

A special case



At longitudes l < 90° we observe a **maximum radial velocity** …
… from the matter that we see moving radially away from us …
… which is the radius to which our line-of-sight is a tangent!



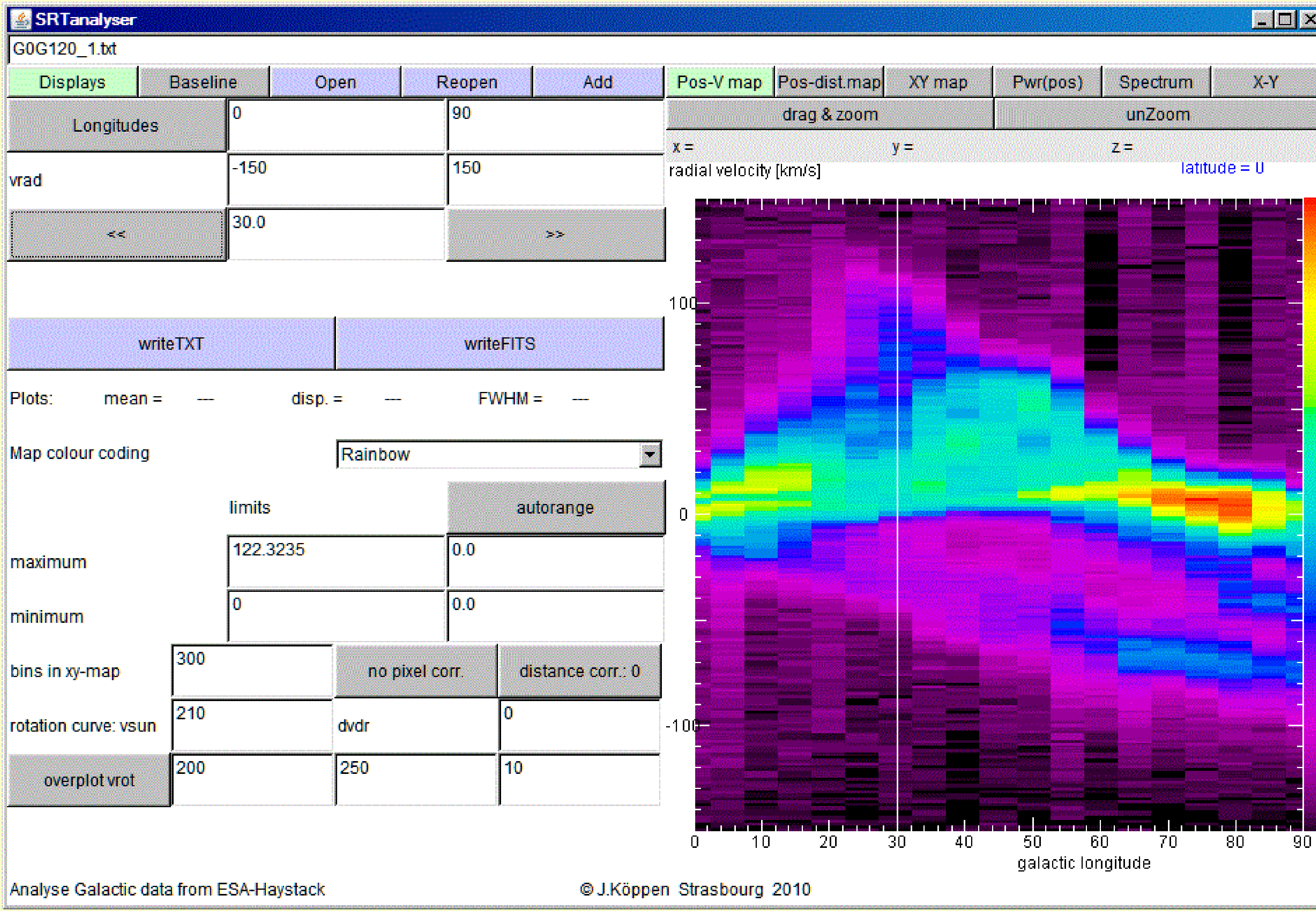
$v_{RAD,max}(\ell) = (v_{ROT}(R)\, R_\odot/R - v_\odot)\sin \ell$
with $R = R_\odot \sin l$

➔ $v_{ROT}(R_\odot \sin \ell) = v_{RAD,max}(\ell) + v_\odot \sin \ell$

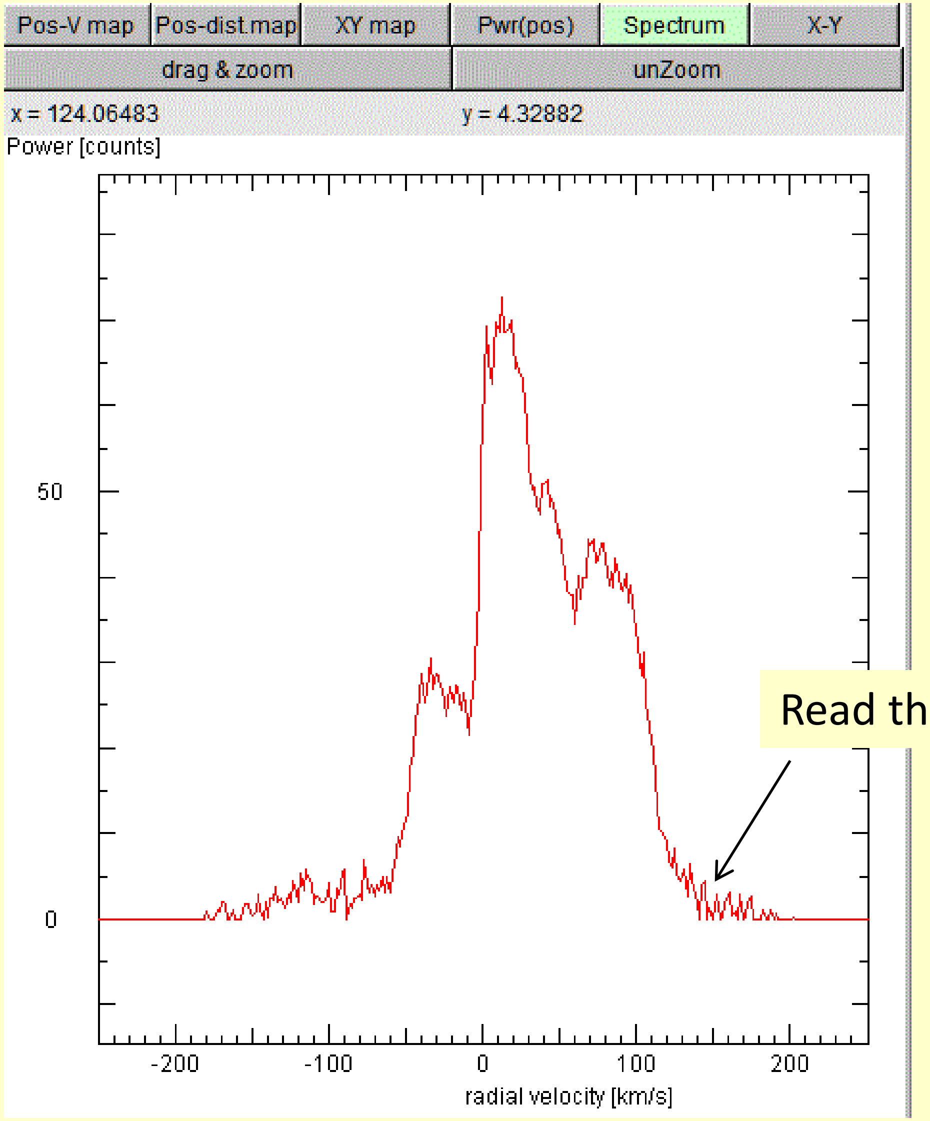
What we had done

- Spectra at various positions in the inner Galactic Plane (G0 = SgrA … G90)
  - Frequency centre and span chosen to cover the entire feature
  - Observed until the (red) averaged spectrum looked smooth and pretty noise-free
- Now we have all spectra in one data file …

… and we use SRTanalyser.java



… display the spectrum for G30



Read the maximum velocity

The data reduction

- How this is done?
- Let us look at it step-by-step
- You can write your own program in Basic, C, FORTRAN, Java, Python, …

Some generalities

- For galactic studies we won't do any flux calibrations
- We observe spectra = the powers at a range of frequencies (i.e. radial velocities)
- We take a number of spectra at each position ➔ we'll use the average spectrum
- My slang: 'spectrum' = all the 202.. points of data … i.e. do everything for <u>all</u> those points

Structure of the data file

(1) When we move to another position, this is recorded as a comment
* cmdfil: line 198 : galactic 65 0
(other comments are marked with an asterisk …)

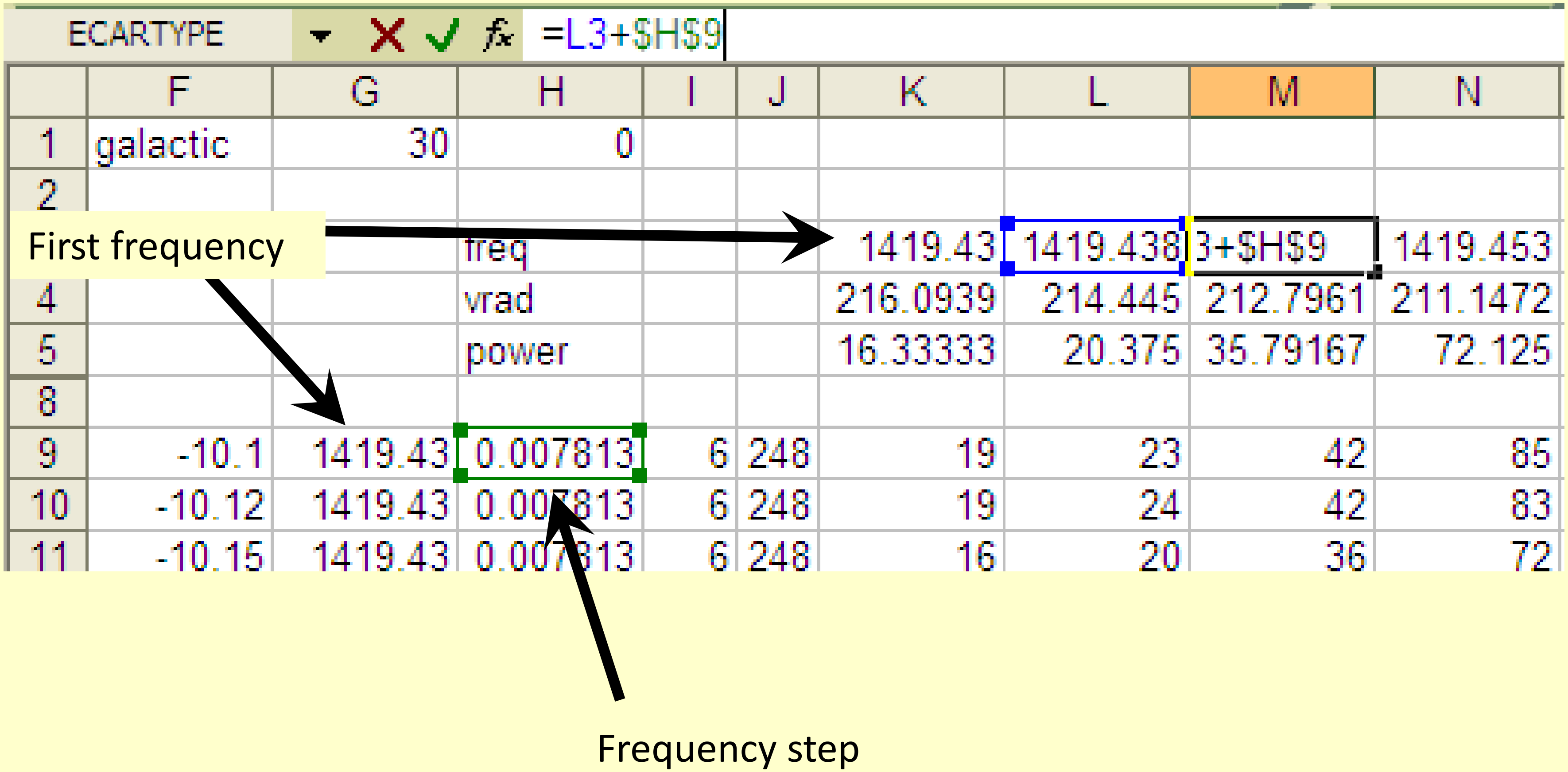
(2) Measurements are a number of data lines:
At each moment of time, the entire spectrum is recorded as

02:15:10	157.5 65.1 0 0	-35.78	1419.61 0.00781250 5 202	20.0 25.0 44.0 ….
Time [UT]	position	VLSR	← frequency grid info →	← spectrum ….
	AZ EL	[km/s]	freq1 fstep .. nf	p1 p2 p3 …
			[MHz] Number of frequencies	powers are given for all frequencies, starting with the first one (freq1) and with the step fstep:

(3) For each position, we average for each frequency the powers from this position, to get the average spectrum.

$$f(k) = freq1 + k*fstep$$

Step1: make the frequency grid



	F	G	H	I	J	K	L	M	N
1	galactic	30	0						
2									
			freq			1419.43	1419.438	3+H9	1419.453
4			vrad			216.0939	214.445	212.7961	211.1472
5			power			16.33333	20.375	35.79167	72.125
8									
9	-10.1	1419.43	0.007813	6	248	19	23	42	85
10	-10.12	1419.43	0.007813	6	248	19	24	42	83
11	-10.15	1419.43	0.007813	6	248	16	20	36	72

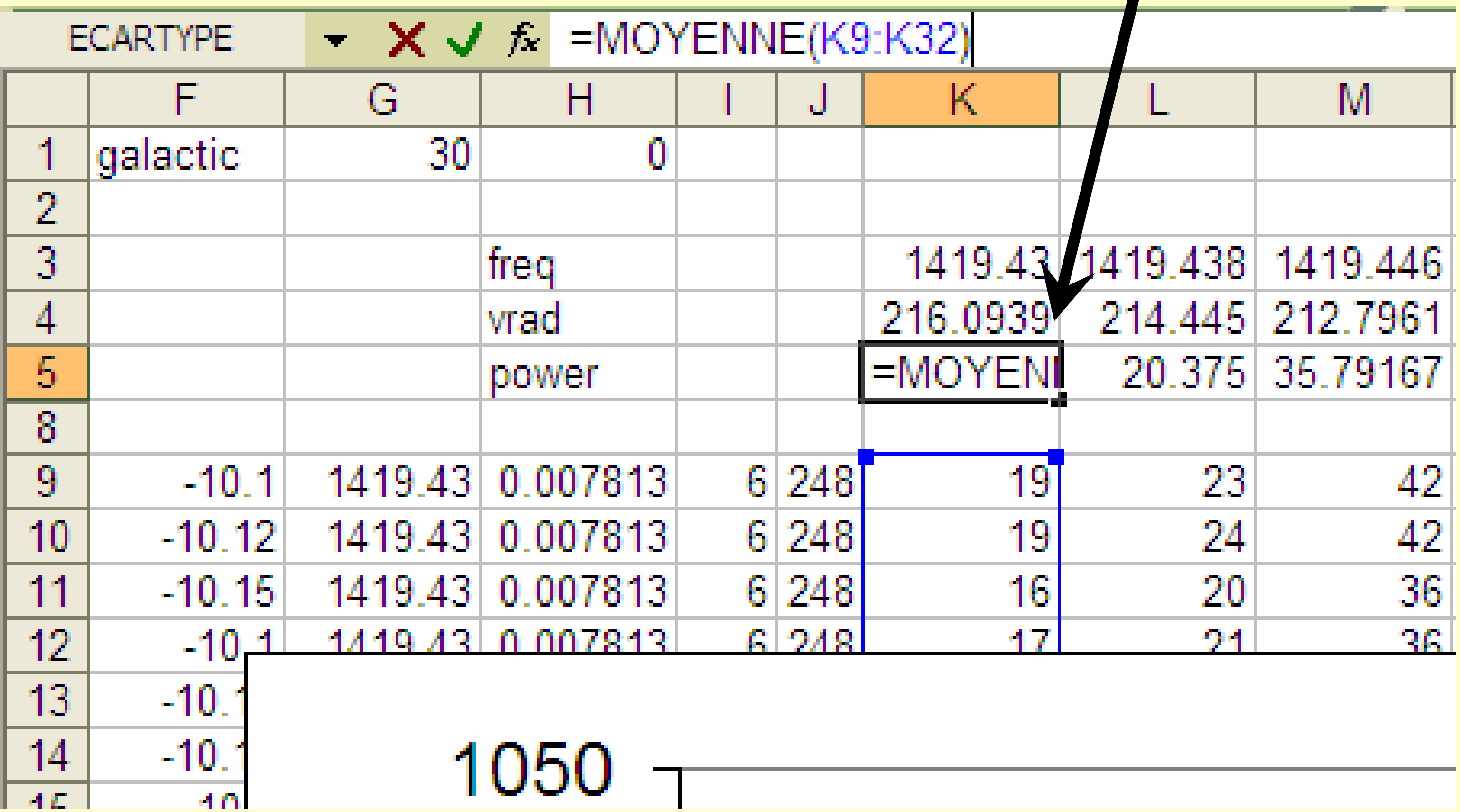
Step2: make the velocity grid

ECARTYPE | f_x | =-(K3/1420.406-1)*299790-F9

	F	G	H	I	J	K	L	M
1	galactic	30	0					
2								
3			freq			1419.43	1419.438	1419.446
4			vrad			=-(K3/142	214.445	212.7961
5			power			16.33333	20.375	35.79167
8								
9	-10.1	1419.43	0.007813	6	248	19	23	42
10	-10.12	1419.43	0.007813	6	248	19	24	42
11	-10.15	1419.43	0.007813	6	248	16	20	36
12	-10.1	1419.43	0.007813	6	248	17	21	36

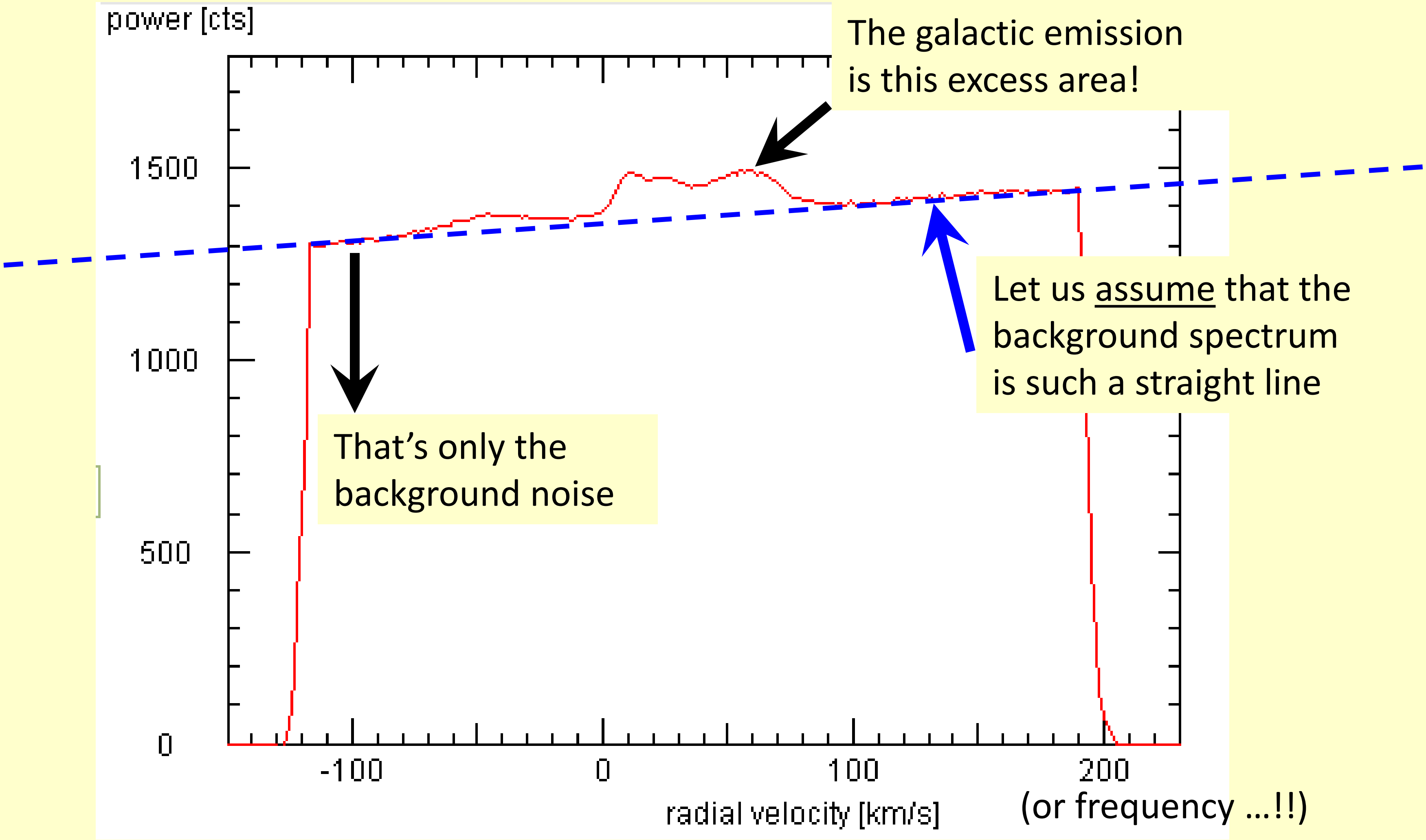
VLSR correction

Step3: get average powers

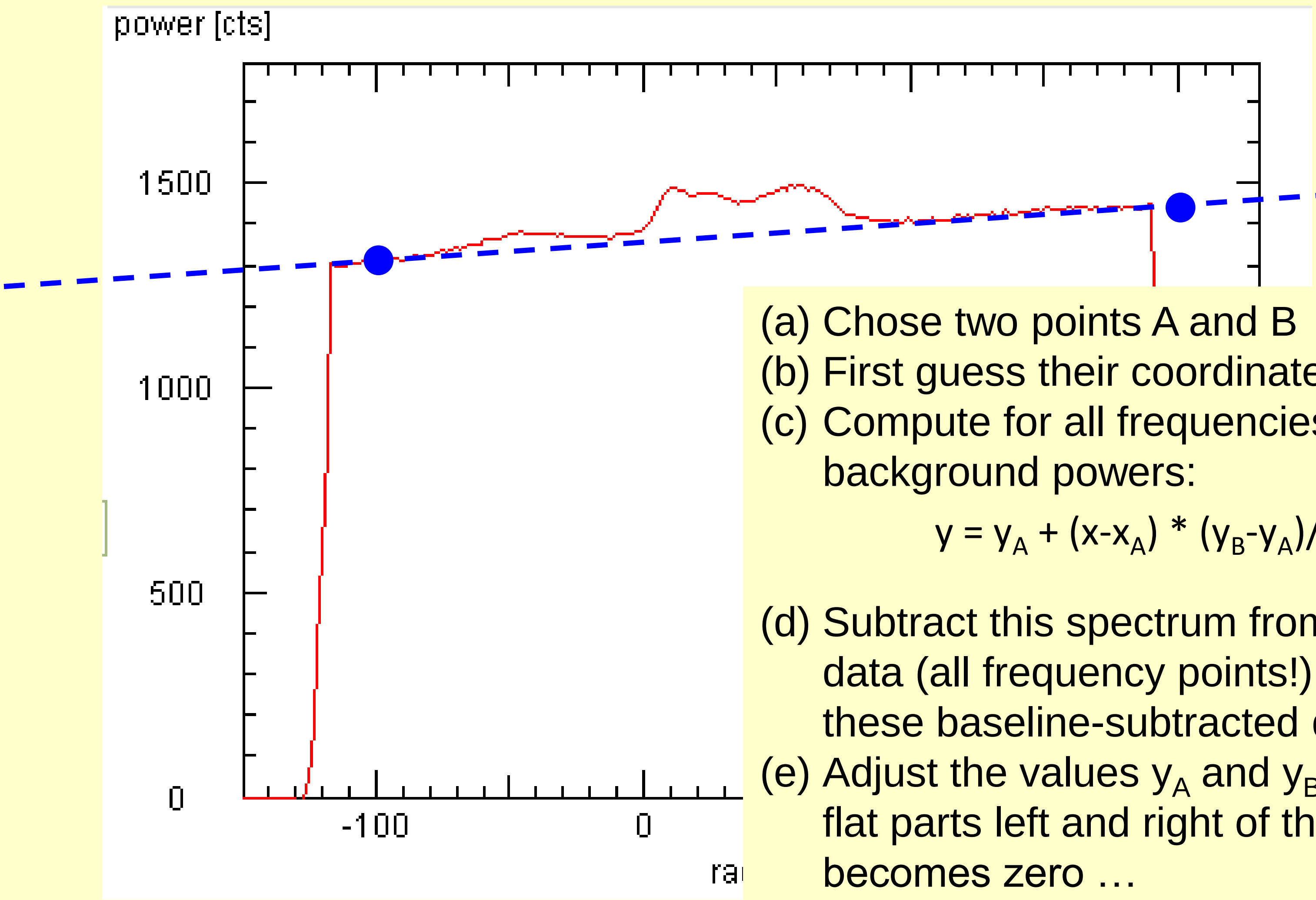


MOYENNE = AVERAGE

Step 4: Plot the average spectrum



Step 5: Subtract background (‘**baseline**’)



(a) Chose two points A and B

(b) First guess their coordinates

(c) Compute for all frequencies the background powers:

$$y = y_A + (x-x_A) * (y_B-y_A)/(x_B-x_A)$$

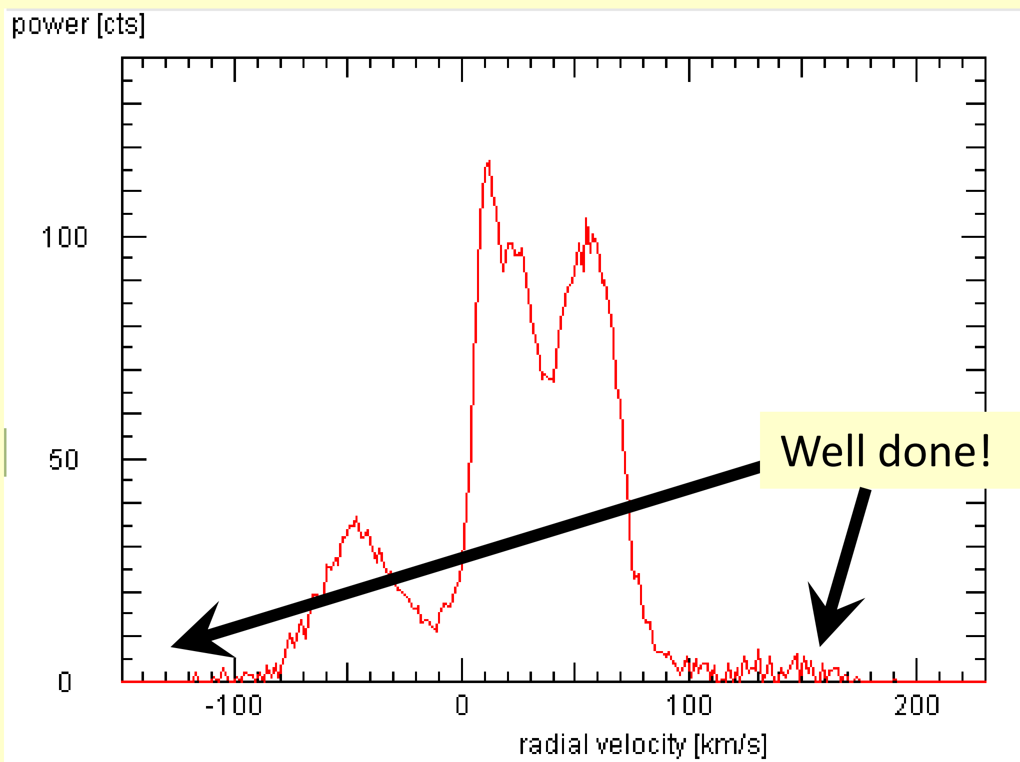
(d) Subtract this spectrum from the data (all frequency points!), and plot these baseline-subtracted data

(e) Adjust the values y_A and y_B until the flat parts left and right of the feature becomes zero …

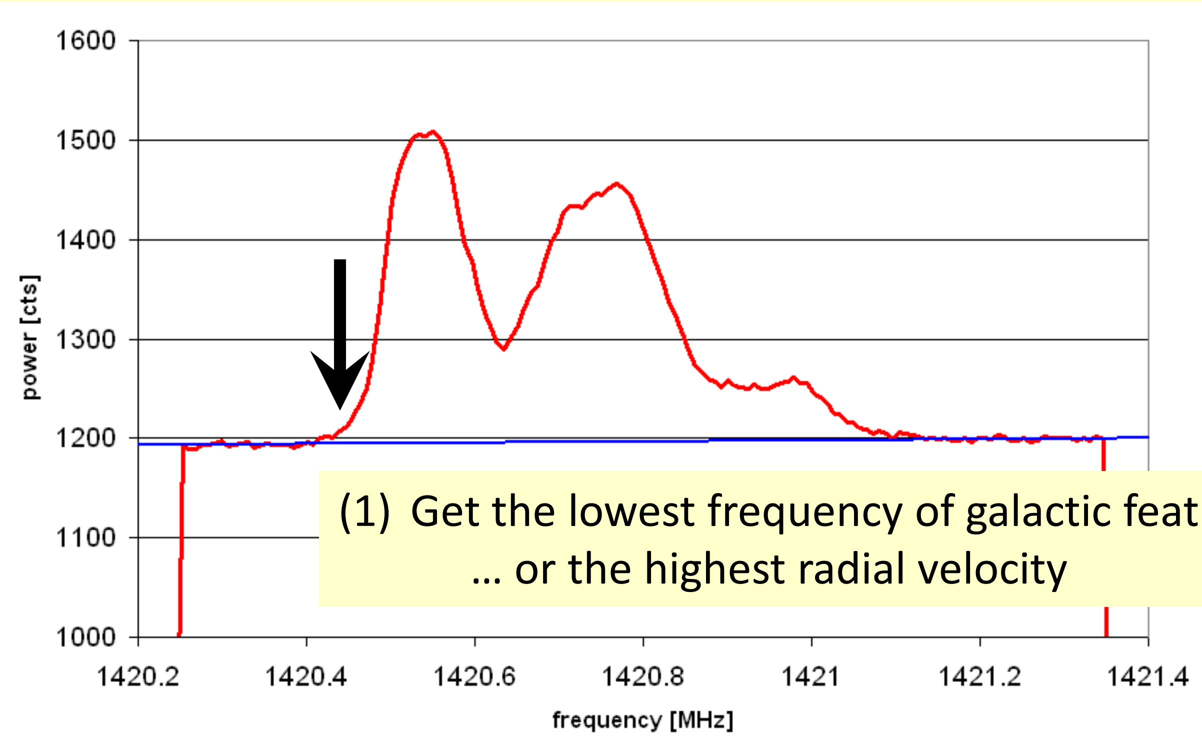
In Excel it looks like this

`NCE` `=K4-($G6+(K2-$K2)/($BV2-$K2)*($H6-$G6))`

C	D	E	F	G	H	I	J	K	L	M	N	O
							freq	1420.01	1420.02	1420.03	1420.03	1420.04
							vrad	58.25	56.60	54.95	53.30	51.65
							flux	12.20	15.21	26.34	52.79	101.78
			const.	baseline	560		f-base	-547.80	-544.79	-533.66	-507.21	-458.22
			basel:	552	565		f-base	=K4-($G6+(K	-537.000675	-526.072273	-499.824721	-451.045255
EL	Ao	Eo	VLSR	fstart	fstep	mf	nf					



Analysis



(1) Get the lowest frequency of galactic features
… or the highest radial velocity

(2) apply Oort's formula

at $R = R_{\odot} \sin \ell$ we have rotation speed

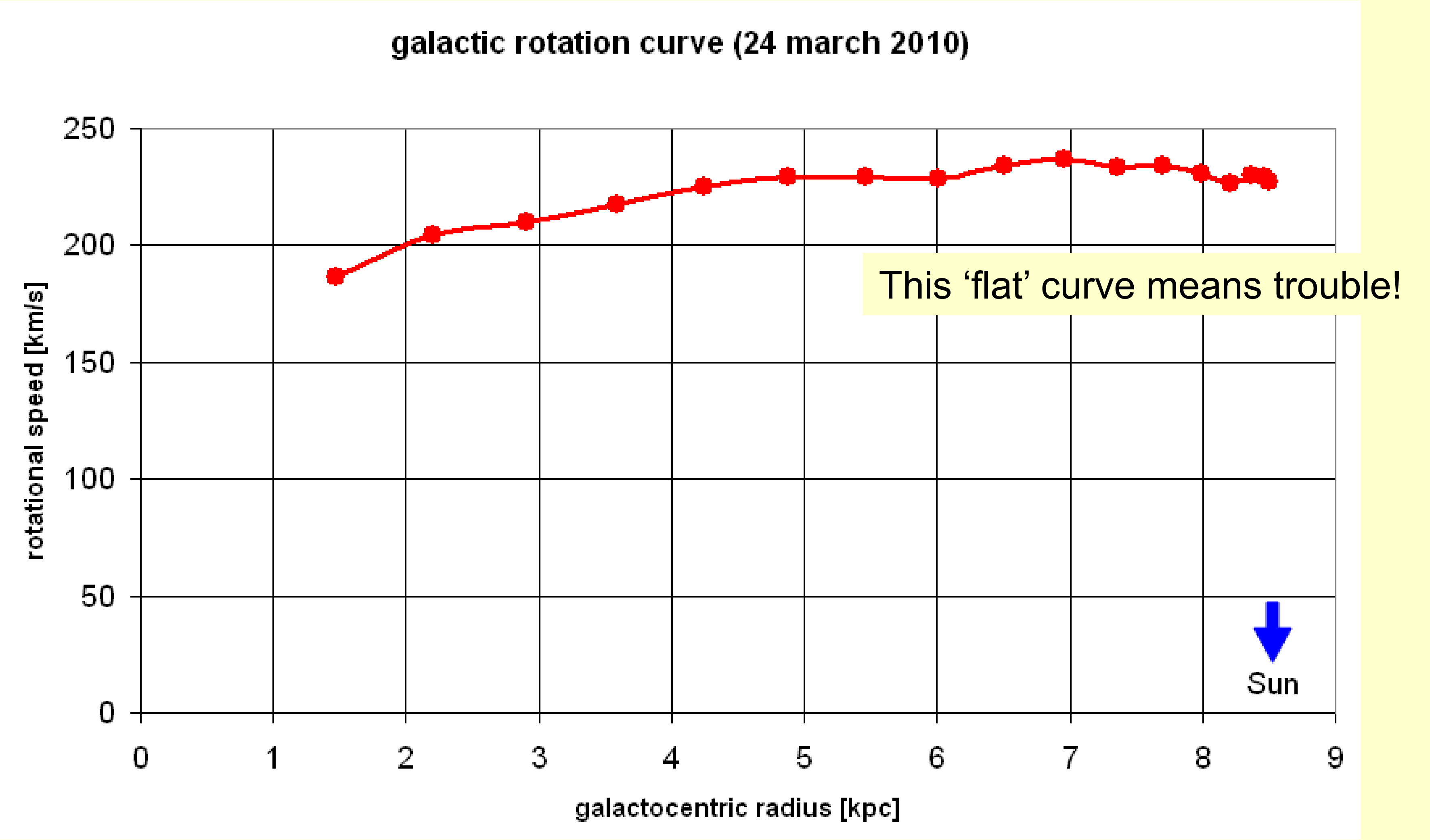
$$v_{ROT}(R) = v_{RAD,max}(\ell) + v_{\odot} \sin \ell$$

Collect the data from longitudes

ECARTYPE =B$24*SIN(RADIANS(A6))

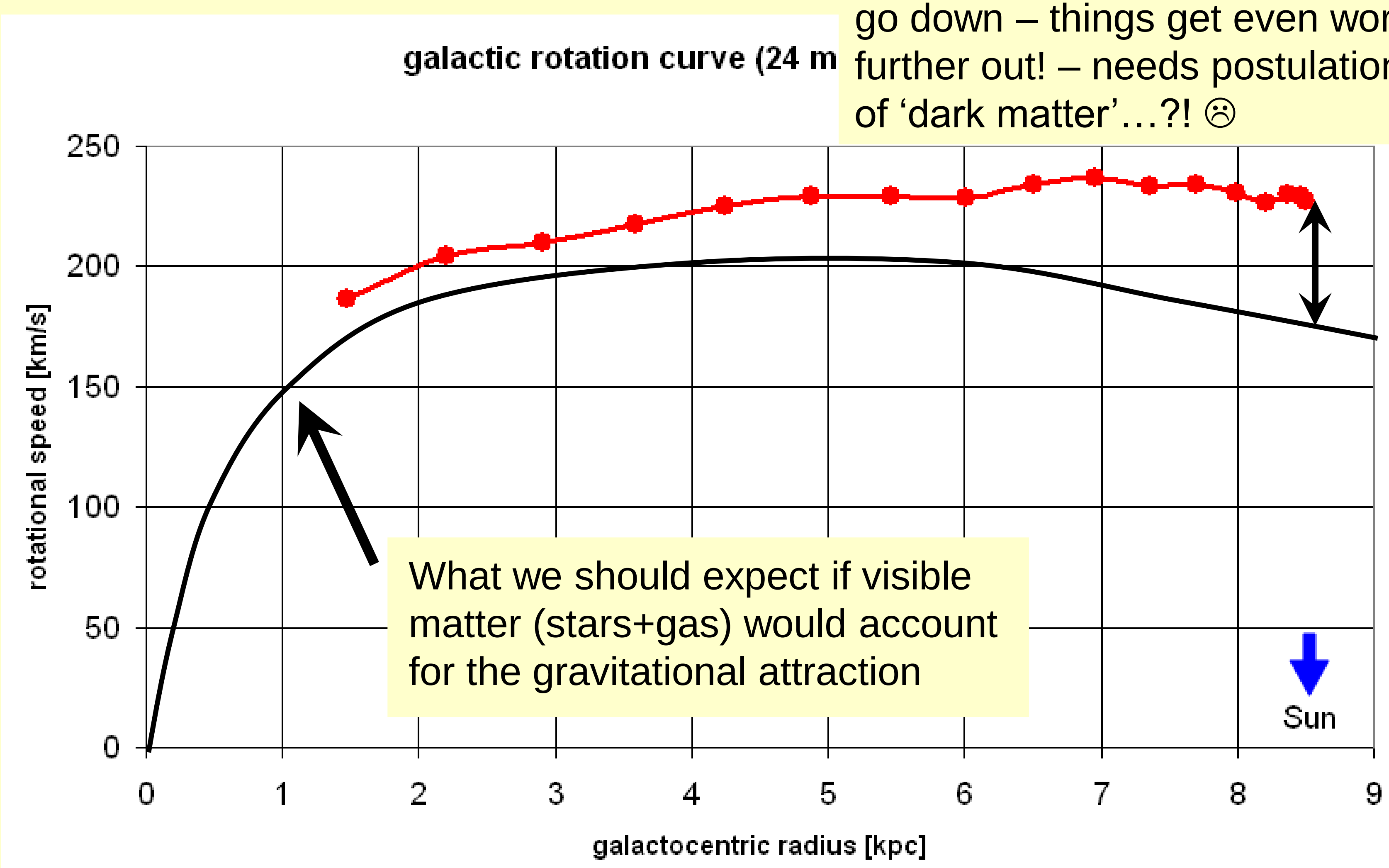
	A	B	C	D	E
1					
2					
3	gal.long	vrad_max	Rmax	v0 * sinl	vrot
4	10	48.5	1.47600951	38.2025991	86.7025991
5	15	70	2.19996188	56.9401899	126.94019
6	20	100	=B$24*SIN(R	75.2444315	175.244432
7	25	122	3.59225522	92.9760176	214.976018
8	30	118	4.25	110	228
9	35	109	4.87539971	126.186816	235.186816
10	40	94	5.46369468	141.413274	235.413274
11	45	80	6.01040764	155.563492	235.563492
12	50	73	6.51137777	168.529777	241.529777
13	55	65	6.96279238	180.21345	245.21345
14	60	51.7	7.36121593	190.525589	242.225589
15	65	44	7.70361619	199.387713	243.387713
16	70	33	7.98738728	206.732377	239.732377
17	75	24	8.21036952	212.503682	236.503682
18	80	23	8.3708659	216.657706	239.657706
19	85	20	8.46765493	219.162834	239.162834
20	90	17	8.5	220	237
21					
22					
23					
24	R0	8.5	kpc		
25	vsun	220	km/s		
26					
27					

What you might get …

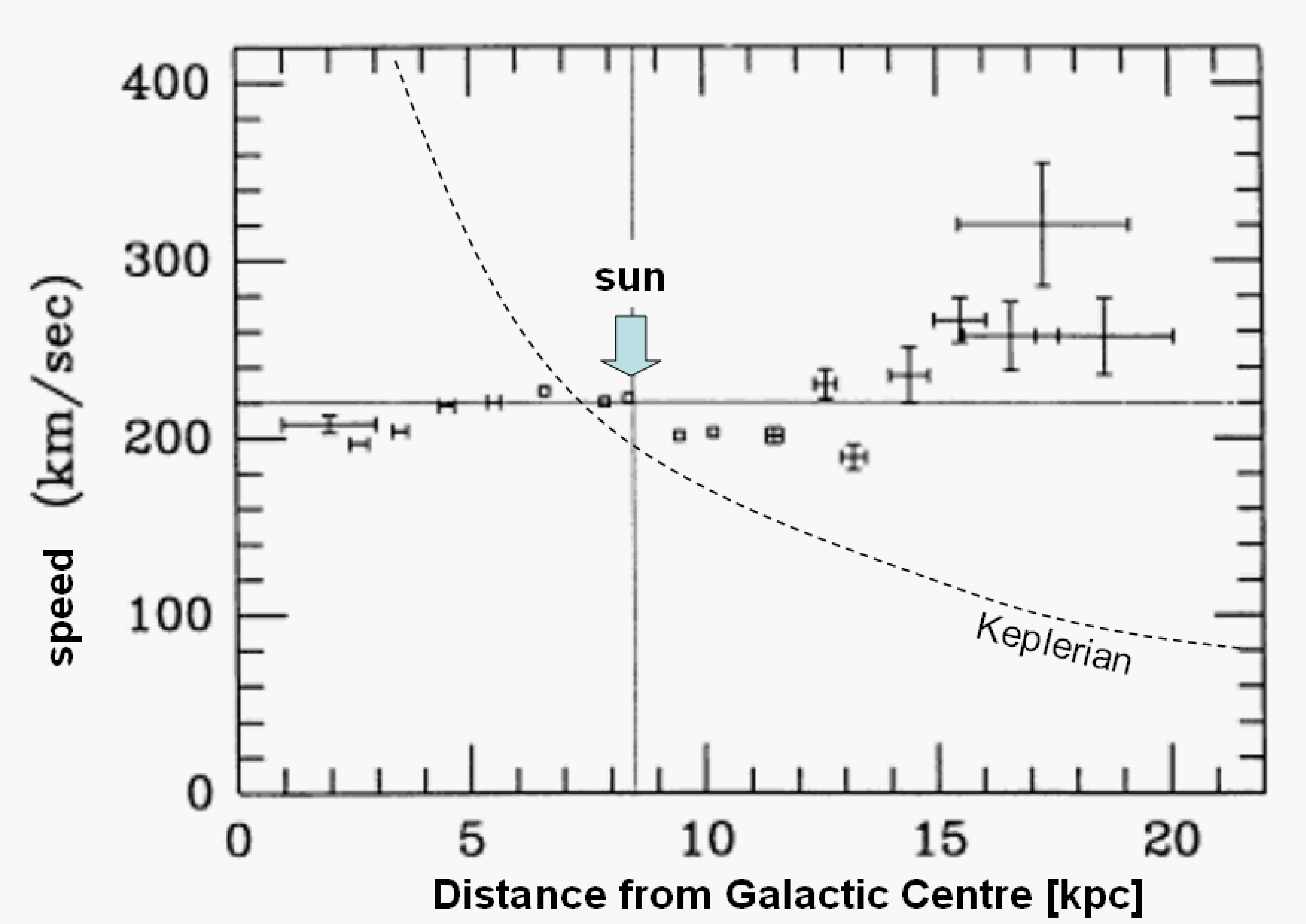


…flies in the face of physics

The observed curve does not go down – things get even worse further out! – needs postulation of ‘dark matter’…?! ☹



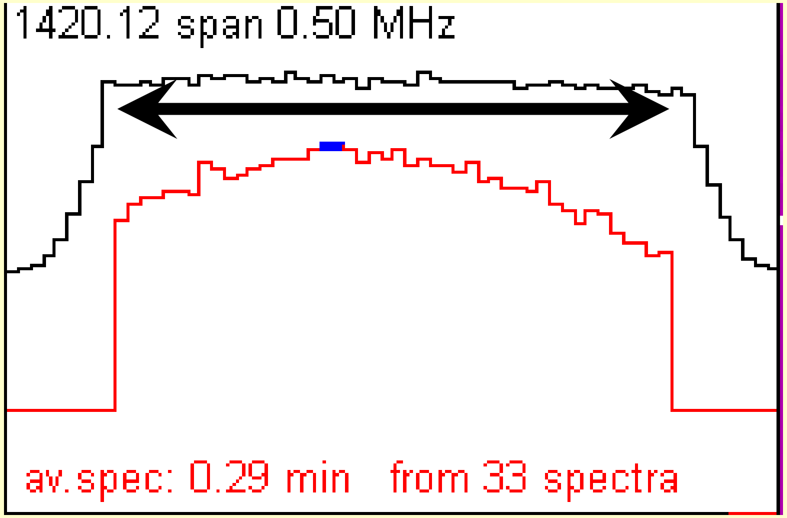
What we should expect if visible matter (stars+gas) would account for the gravitational attraction



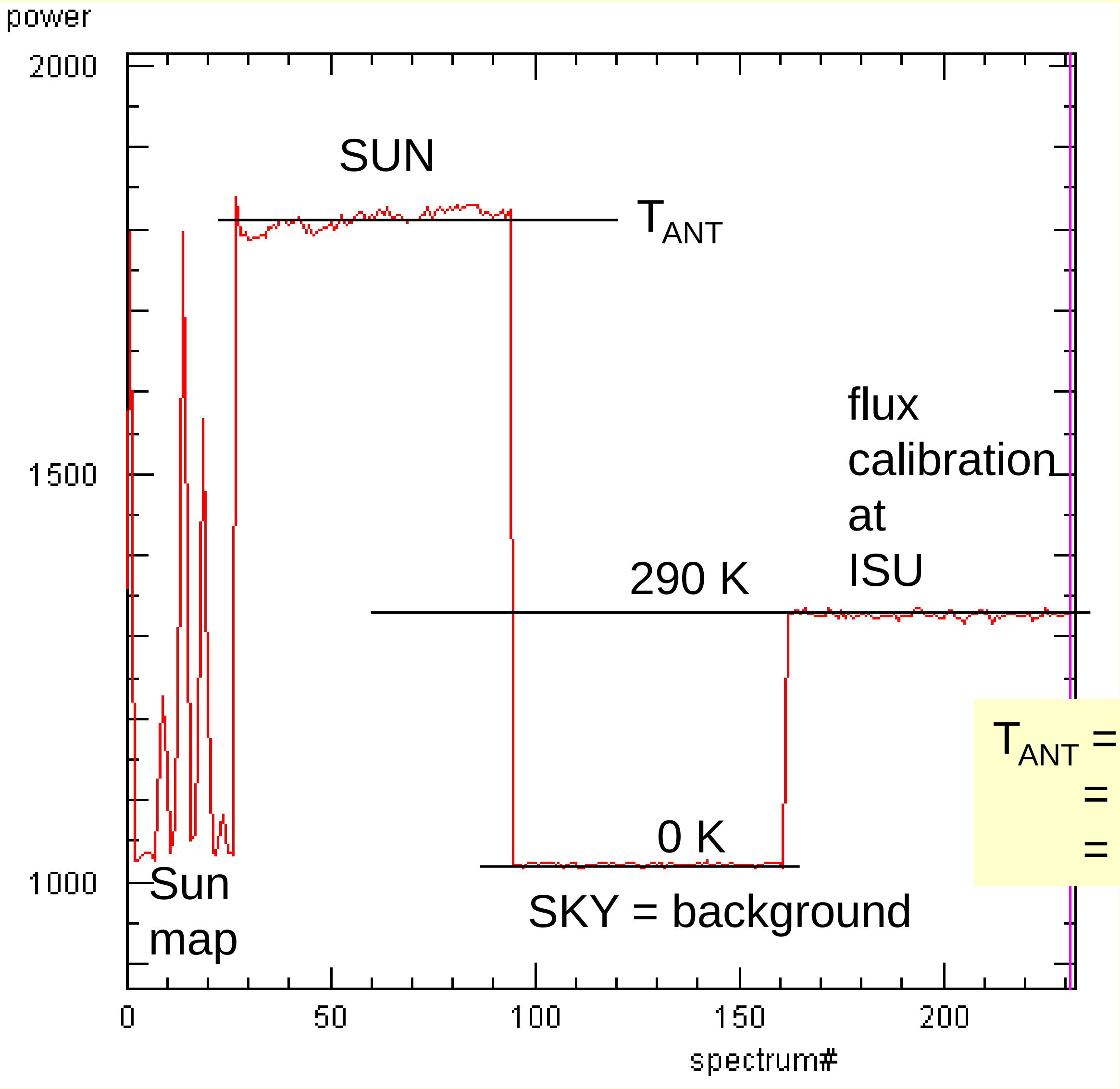
400
300
200
100
0
speed (km/sec)
sun
Keplerian
0
5
10
15
20
Distance from Galactic Centre [kpc]

Solar temperature I

- We do not need the spectral details
- Just add (SUM or AVERAGE) the fluxes of all frequencies in a spectrum …
- … but do NOT use the first 9 and the last 9 frequencies: the border regions!



Solar temperature II



Psun = 1800

Psky = 1000

Pcal = 1330

gives antenna temperature

T_{ANT} = 290K * (Psun-Psky)/(Pcal-Psky)
= 290K * 2.4
= 700 K

Solar temperature III

- The sun has a diameter of 0.5°, thus much smaller than the antenna beam (6°)
- Solar radiation fills the antenna beam with only a fraction of $(0.5°/6°)^2 = 1/144$
- The calibrator of T=290 K fills the entire beam, so if one wants to get a solar signal of 2.4 times the calibrator, the solar surface temperature must be 144 times higher than the antenna temperature:

The temperature of the solar surface is:

290 K * 2.4 * 144 = 100000 K

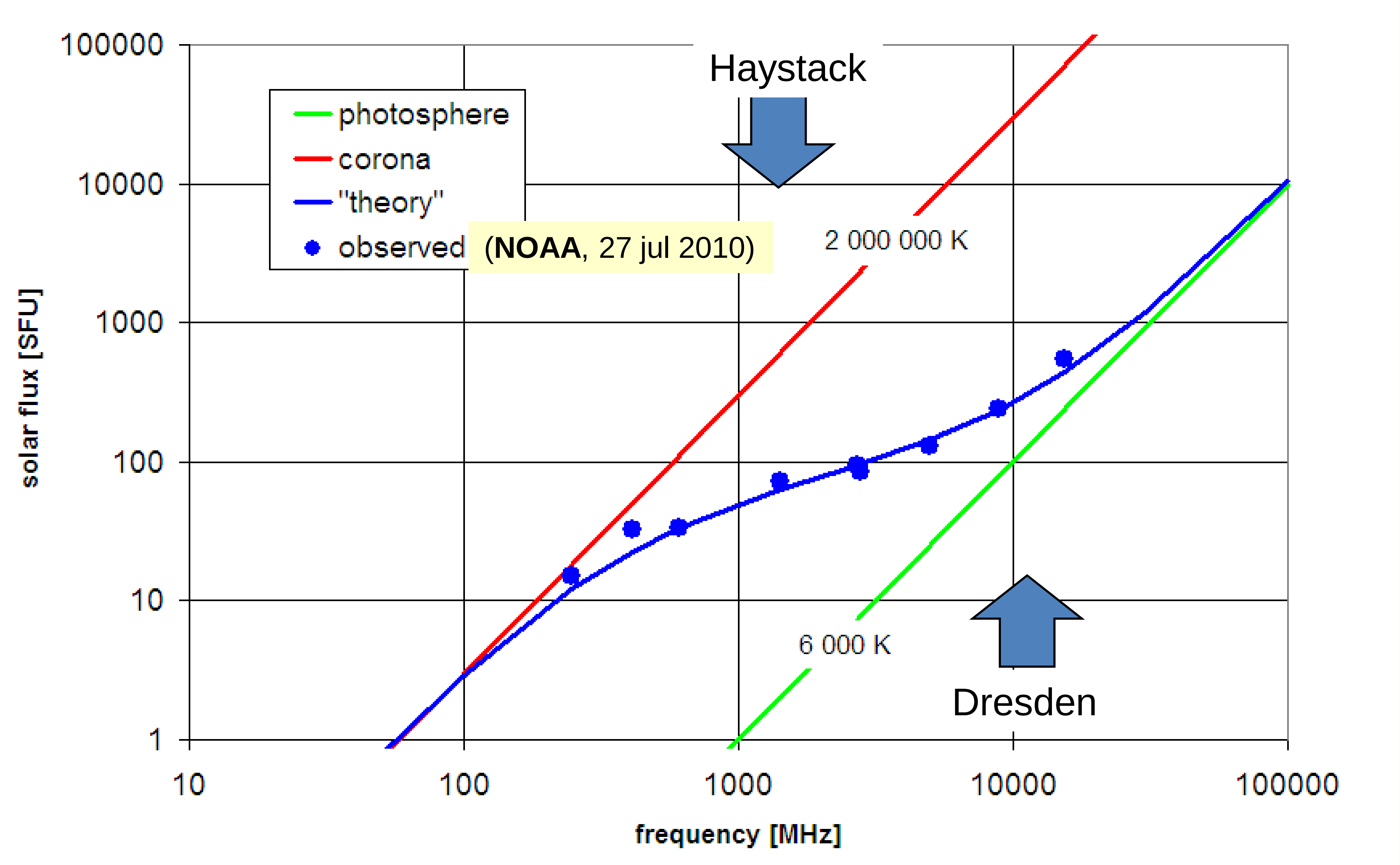
Ground calibration

Measured sun

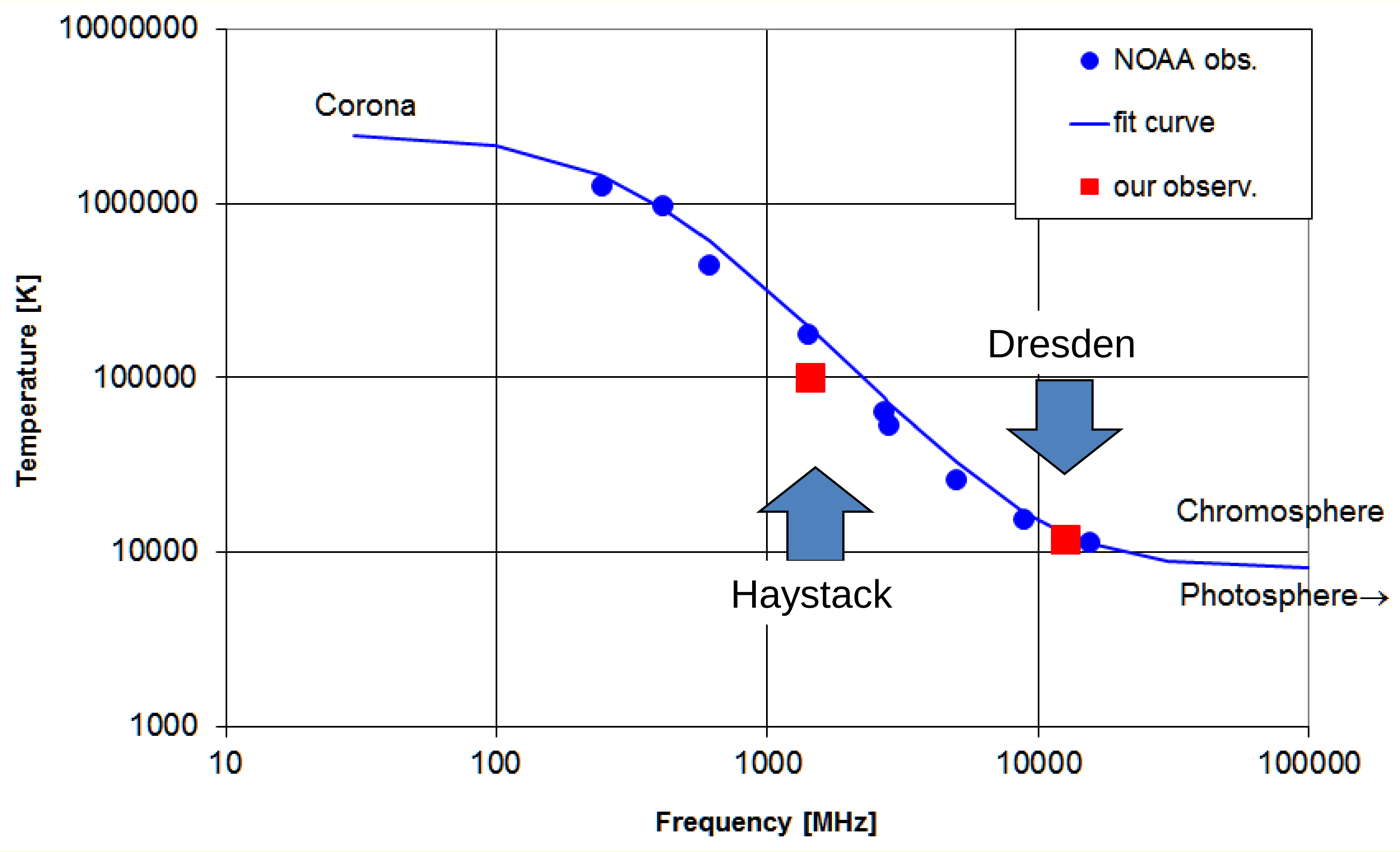
T_{ANT} = 700 K

Measured: Antenna beam width

Solar temperature IV



Solar temperature V



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