Introduction to Radioastronomy:

The ESA-Haystack telescope

Observatoire astronomique
de Strasbourg

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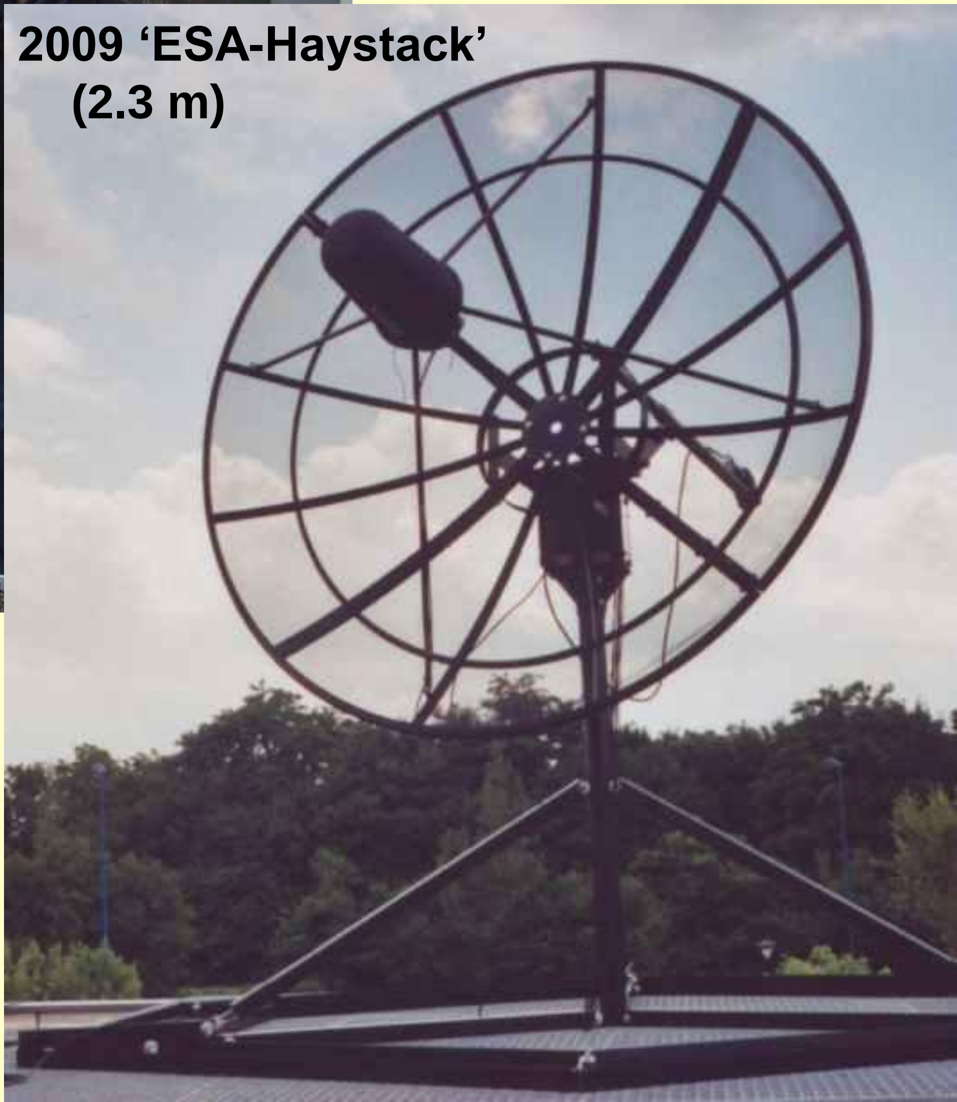
http://astro.u-strasbg.fr/~koppen/JKHome.html

2007 ‘ESA-Dresden’
(1.2 m)

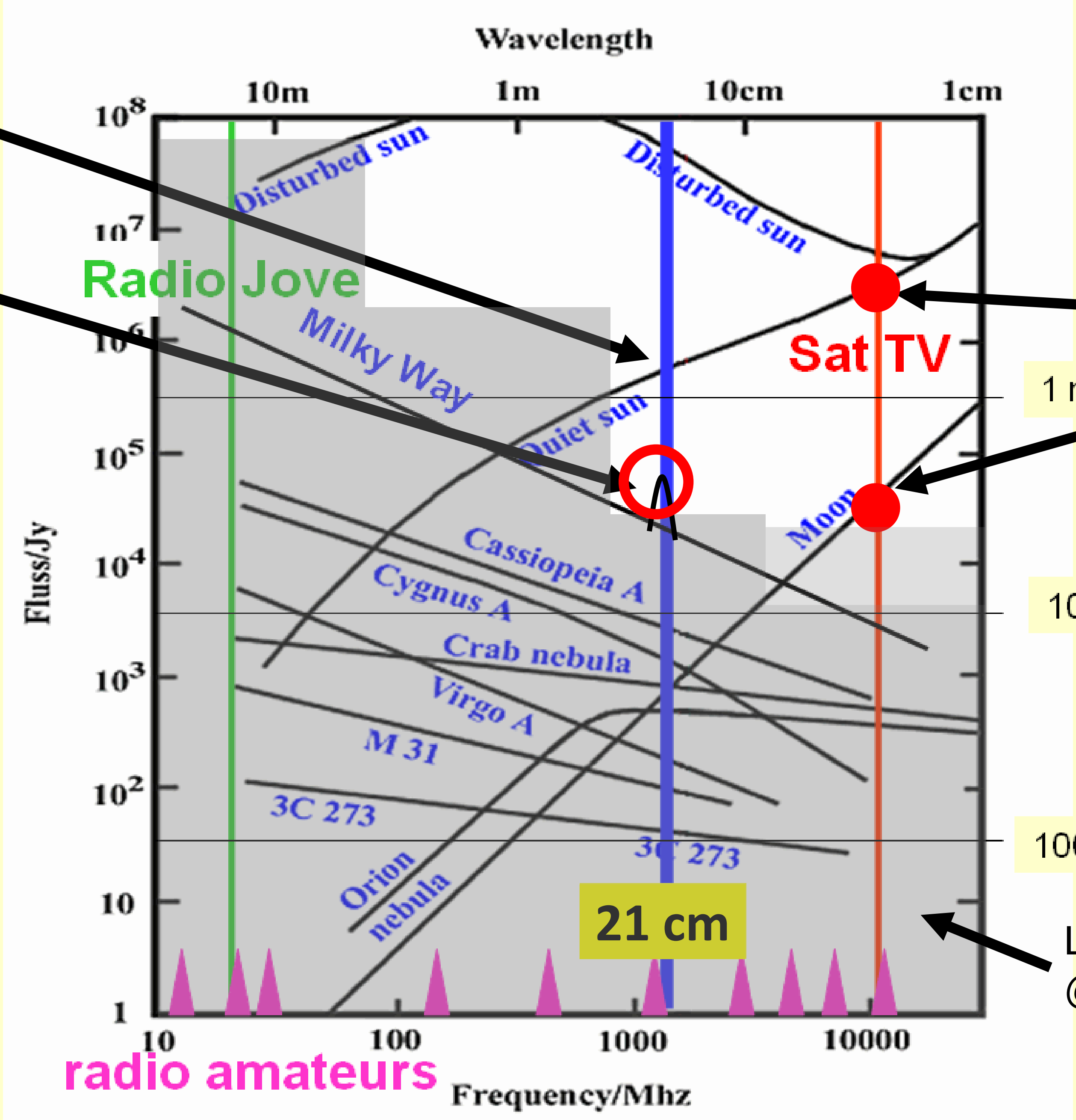


2009 ‘ESA-Haystack’
(2.3 m)

1956 Jodrell Bank 75m

What we can observe

Haystack



Dresden

Local noise @ ISU

GENSO

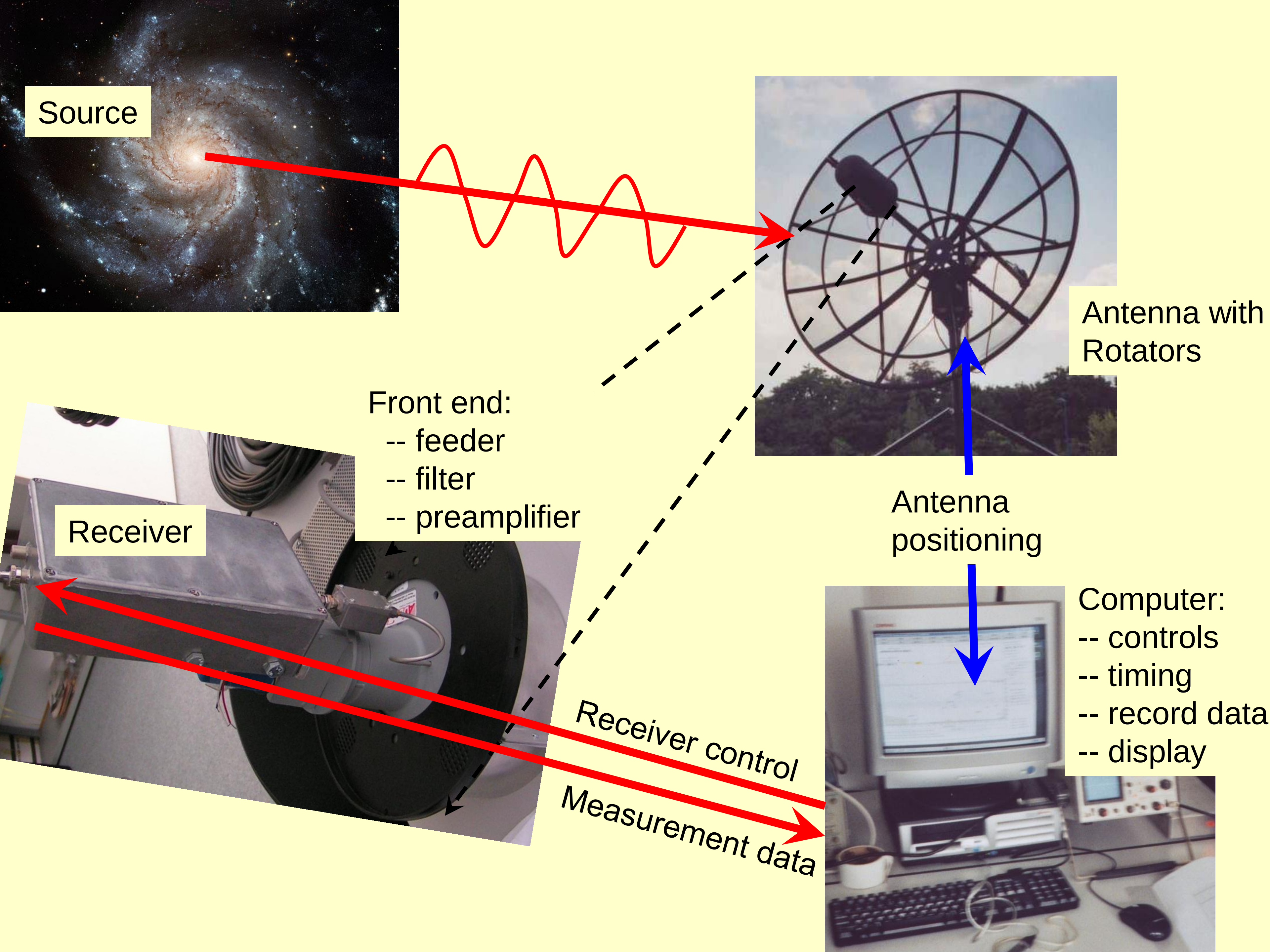
ISU’s two Radiotelescopes

	ESA-Dresden	**ESA-Haystack**
Frequency	**10 ... 12 GHz (continuum)**	**1.420 GHz (HI line)**
Wavelength	**3 cm**	**21 cm**
Dish diameter	**1.2 m**	**2.3 m**
HPBW (ang.resolution)	**1.5°**	**6°**
Time for full solar scan	**30 min**	2 hrs (!)
Suitable objects	**Sun, Moon**, (TV satellites)	Sun, **Milky Way**
We measure	**absolute fluxes (give temperatures, Radiometer)**	**spectra, radial velocities of H gas clouds (Spectrometer)**
Positional accuracy and stability	**±1° (at best!)**	**±0.5°**
operation	**manual**	Manual & **Batch**

The ESA-Haystack Telescope

- Frequency 1420 MHz (Wavelength 21 cm)
- Spectroscopy
- Radiometer
- 2.3 m diameter parabolic reflector

- HI gas in the Milky Way
- Sun



Source

Antenna with Rotators

Front end:
- feeder
- filter
- preamplifier

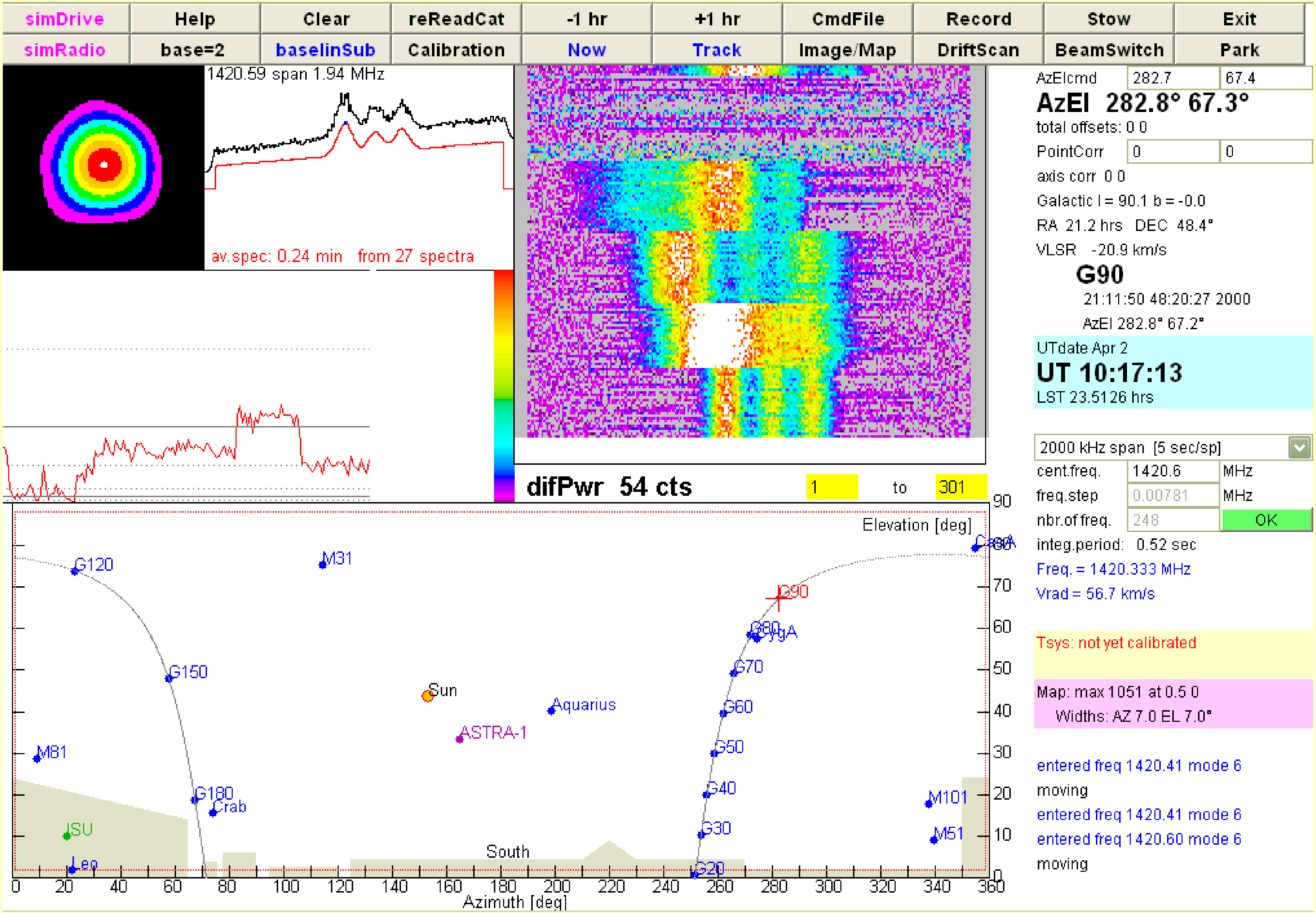
Antenna positioning

Receiver

Computer:
- controls
- timing
- record data
- display

Receiver control

Measurement data



1420.59 span 1.94 MHz

av.spec: 0.24 min from 27 spectra

difPwr 54 cts 1 to 301

AzElcmd 282.7 67.4

AzEl 282.8° 67.3°

total offsets: 0 0

PointCorr 0 0

axis corr 0 0

Galactic l = 90.1 b = -0.0

RA 21.2 hrs DEC 48.4°

VLSR -20.9 km/s

G90

21:11:50 48:20:27 2000

AzEl 282.8° 67.2°

UTdate Apr 2

UT 10:17:13

LST 23.5126 hrs

2000 kHz span [5 sec/sp]

cent.freq. 1420.6 MHz

freq.step 0.00781 MHz

nbr.of freq. 248 OK

integ.period: 0.52 sec

Freq. = 1420.333 MHz

Vrad = 56.7 km/s

Tsys: not yet calibrated

Map: max 1051 at 0.5 0

Widths: AZ 7.0 EL 7.0°

entered freq 1420.41 mode 6

moving

entered freq 1420.41 mode 6

entered freq 1420.60 mode 6

moving

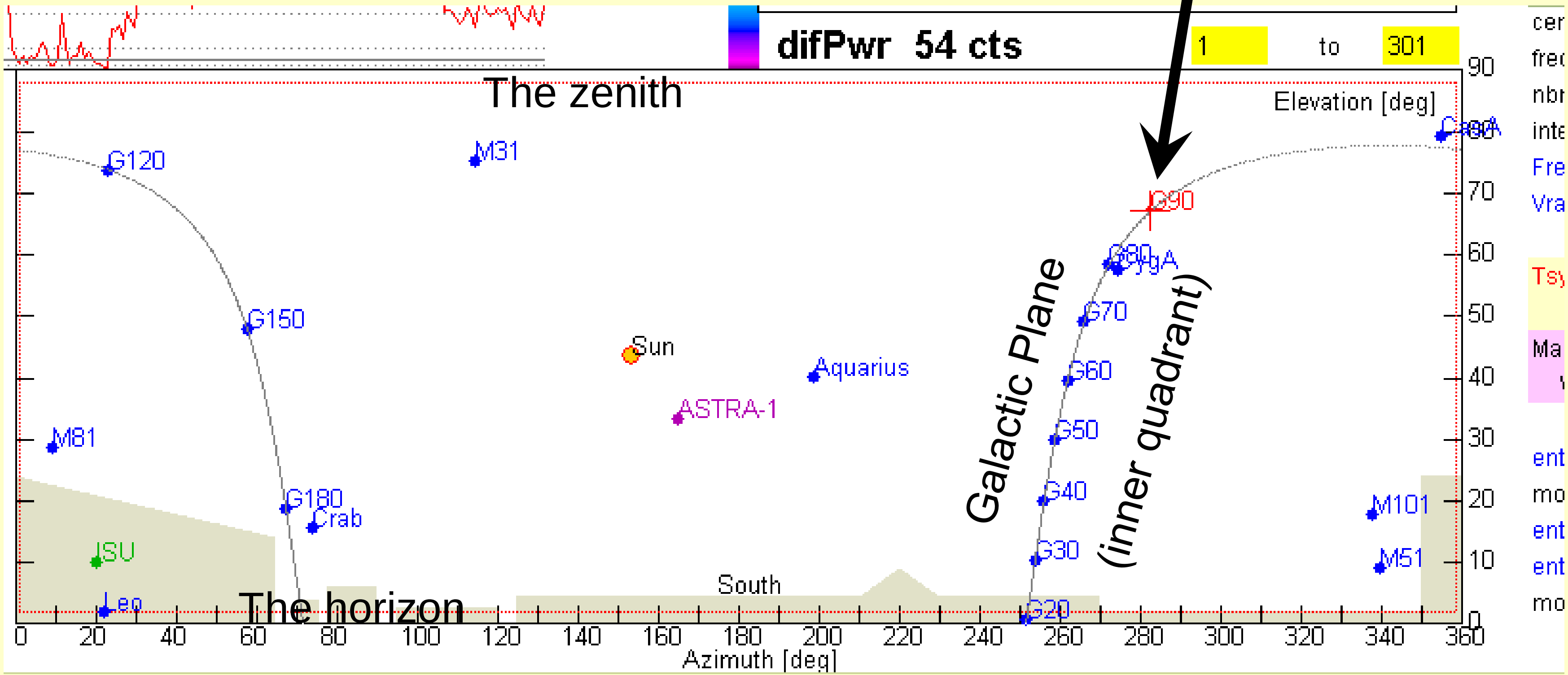
The real GUI

is identical to the
Trainer applet at

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

The visible Sky

We’re observing this source



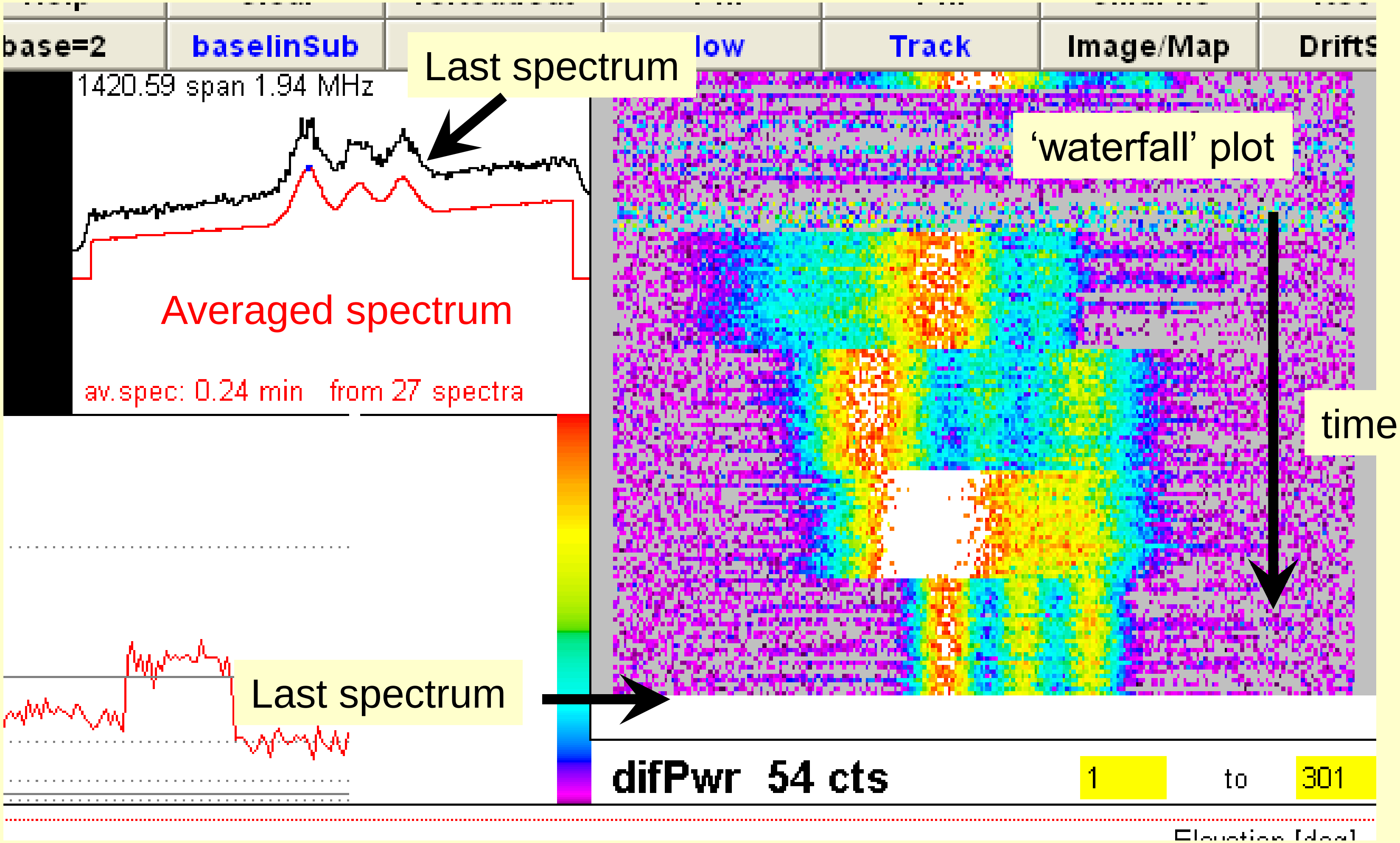
The zenith

The horizon

Galactic Plane (inner quadrant)

Click on a source ➔ we’ll move there …

Current results



Last spectrum

Averaged spectrum

'waterfall' plot

time

Last spectrum

spectrum-integrated power

Numerical Information

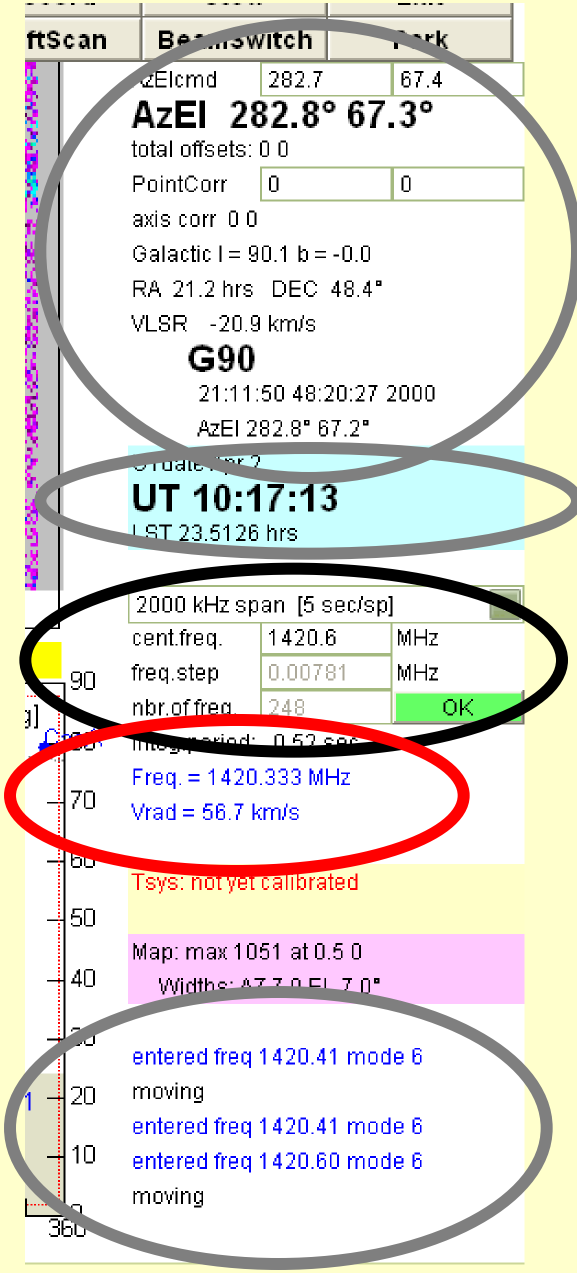
Current position

Current time

Set centre frequency and span of spectrum

A click on the spectrum or waterfall displays frequency and radial velocity

Messages: actions, errors



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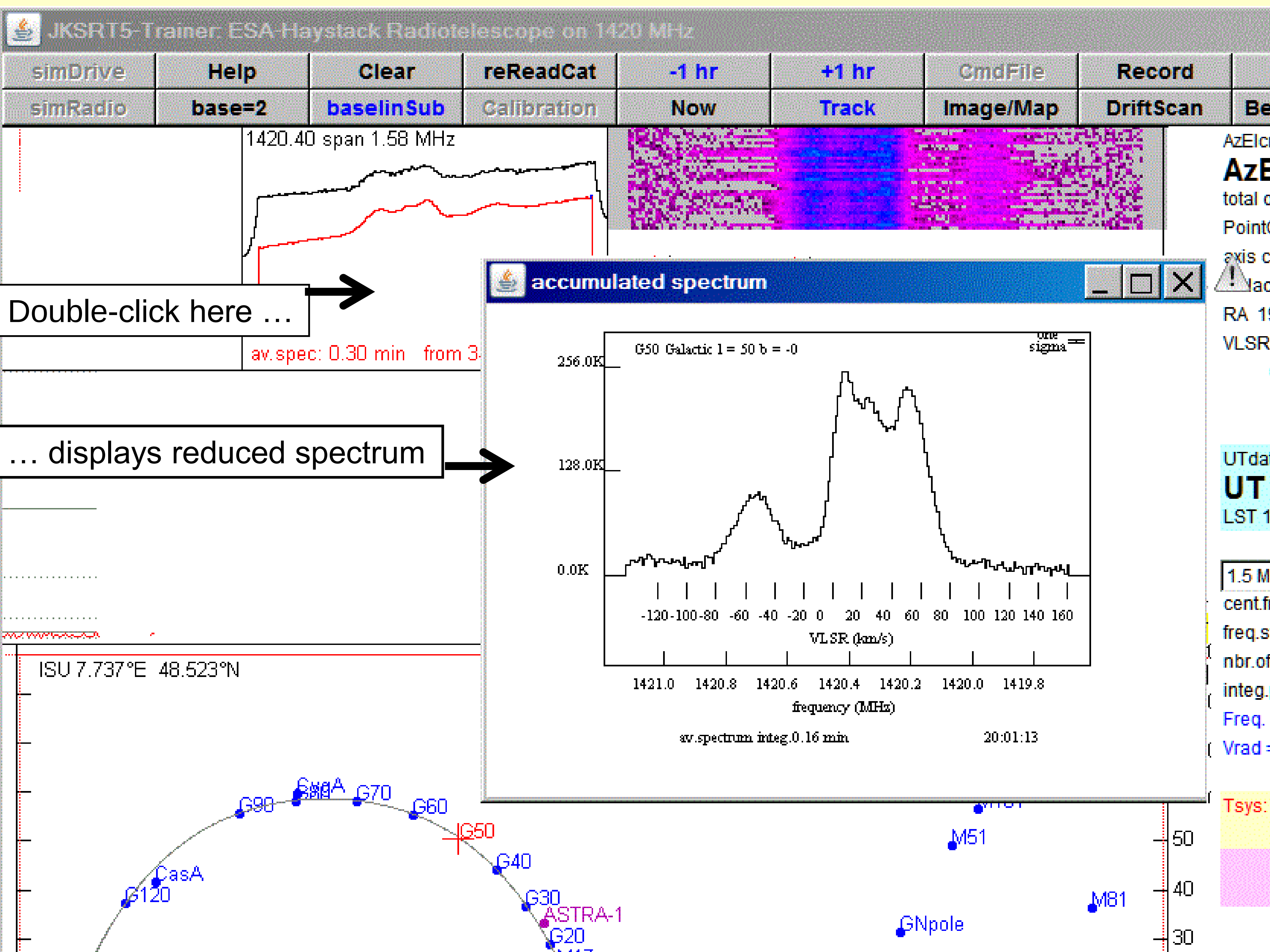
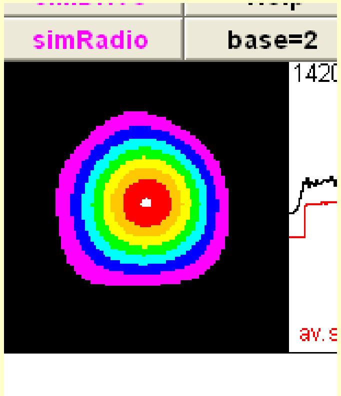


Double-click here …

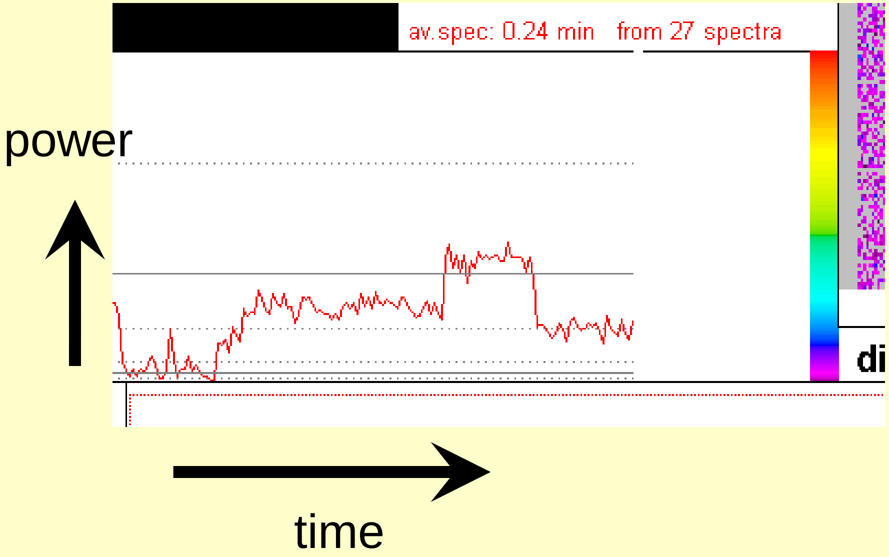
… displays reduced spectrum

Some more …



results of making
an Image/Map
of the Sun

A plot of the history of the signal power



power

time

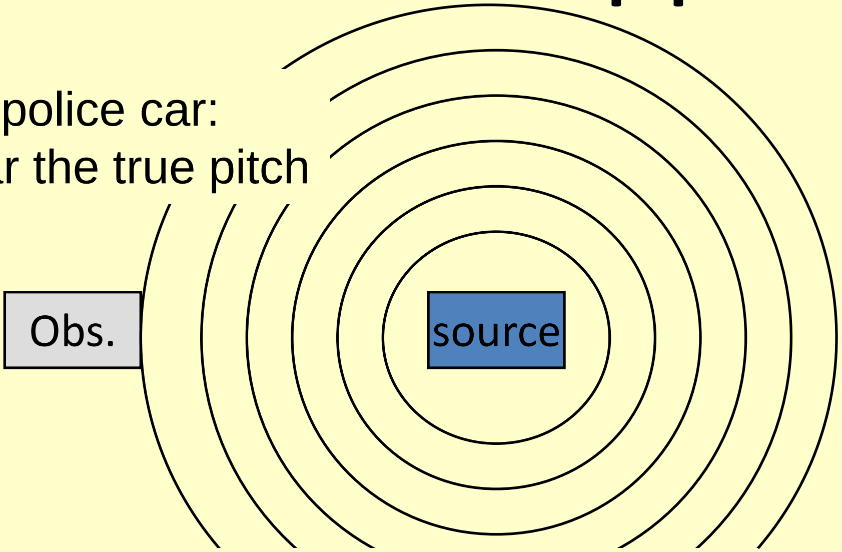
What we shall do …

- Galactic Rotation Curve

- Thickness of the Galactic Disk
- The Milky Way’s spiral arms
- Temperature of the Sun

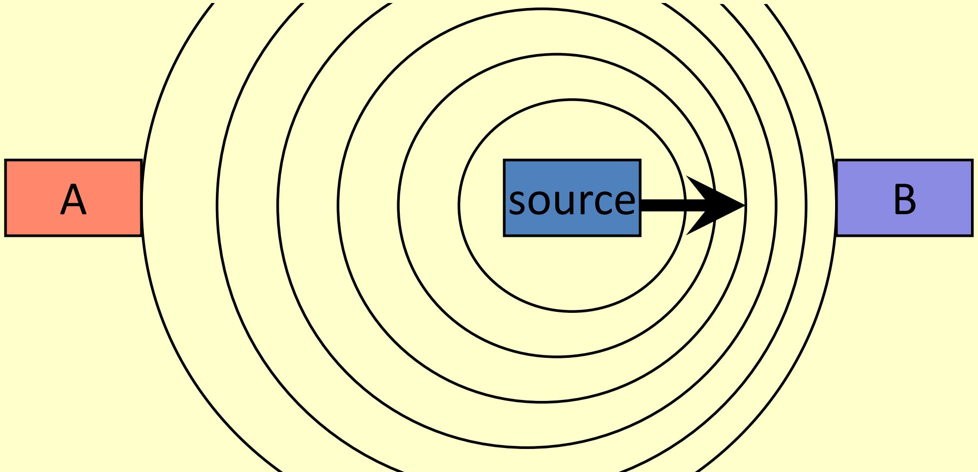
Reminder: Doppler effect

Listening to a police car:
at rest we hear the true pitch

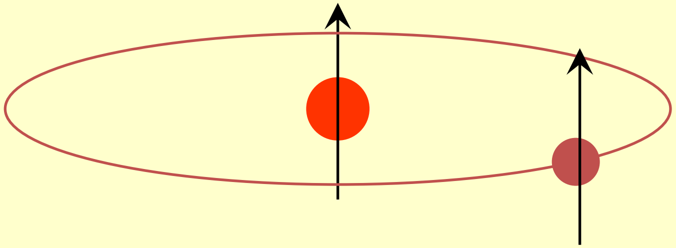


… but when it moves **away** from us at A,
we hear a **lower** frequency tone
(= longer wavelength)

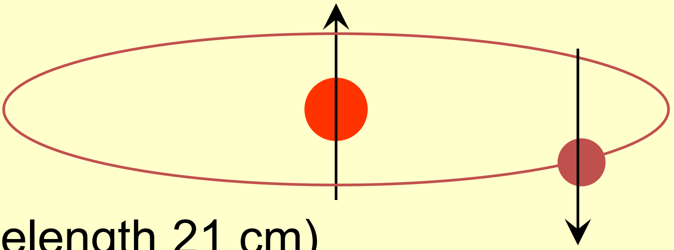
When it comes **towards** us at B,
we hear a **higher** frequency tone
(= smaller wavelength)



Hydrogen: both proton and electron have a ‘spin’



Spins parallel = higher energy
= less tightly bound

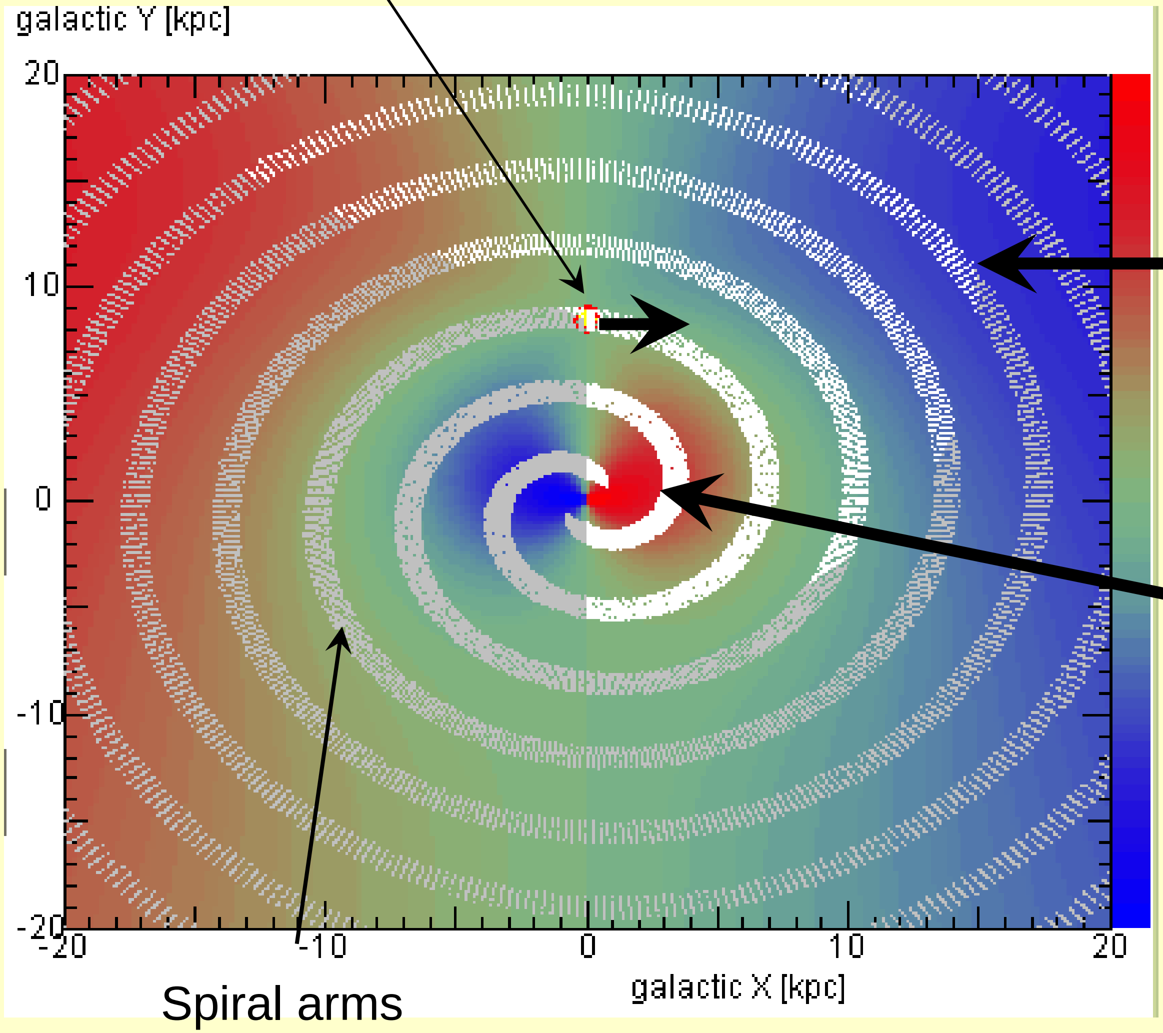


Energy difference corresponds
to a spectral line at f_0 = 1420.406… MHz (wavelength 21 cm)
-- H.C.van de Hulst 1944

➔ observe clouds of hydrogen gas in the Galaxy and elsewhere
➔ measured frequency difference gives radial velocity

$$v_{RAD} = - 300000 \text{ km/s} *(f-f_0)/f_0$$

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



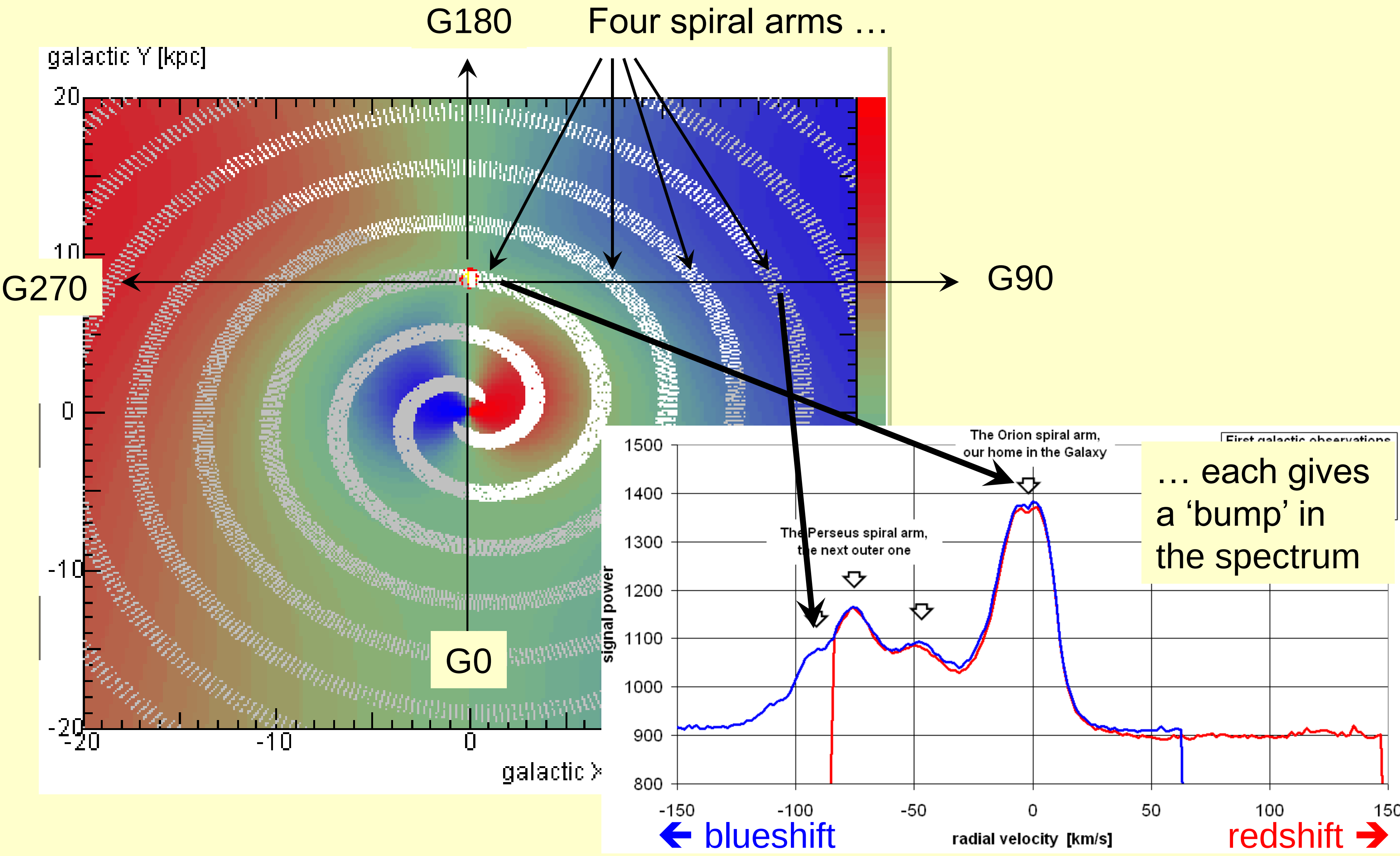
The emission from an object here will be seen by us ‘blue-shifted’, i.e. coming towards us.

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

Spiral arms

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

What we observe at G90



G180

Four spiral arms …

G270

G90

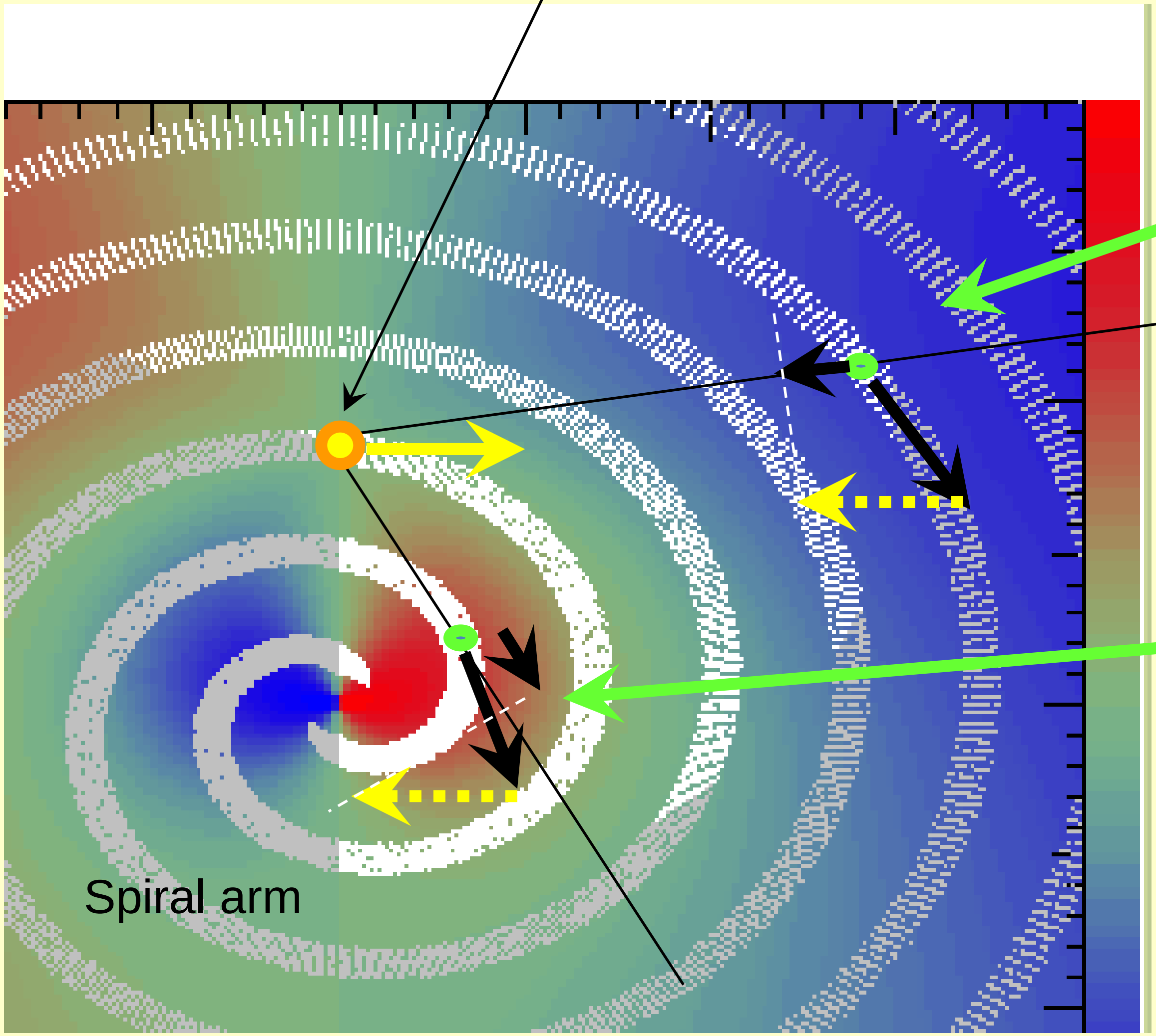
G0

… each gives a ‘bump’ in the spectrum

← blueshift

redshift →

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.

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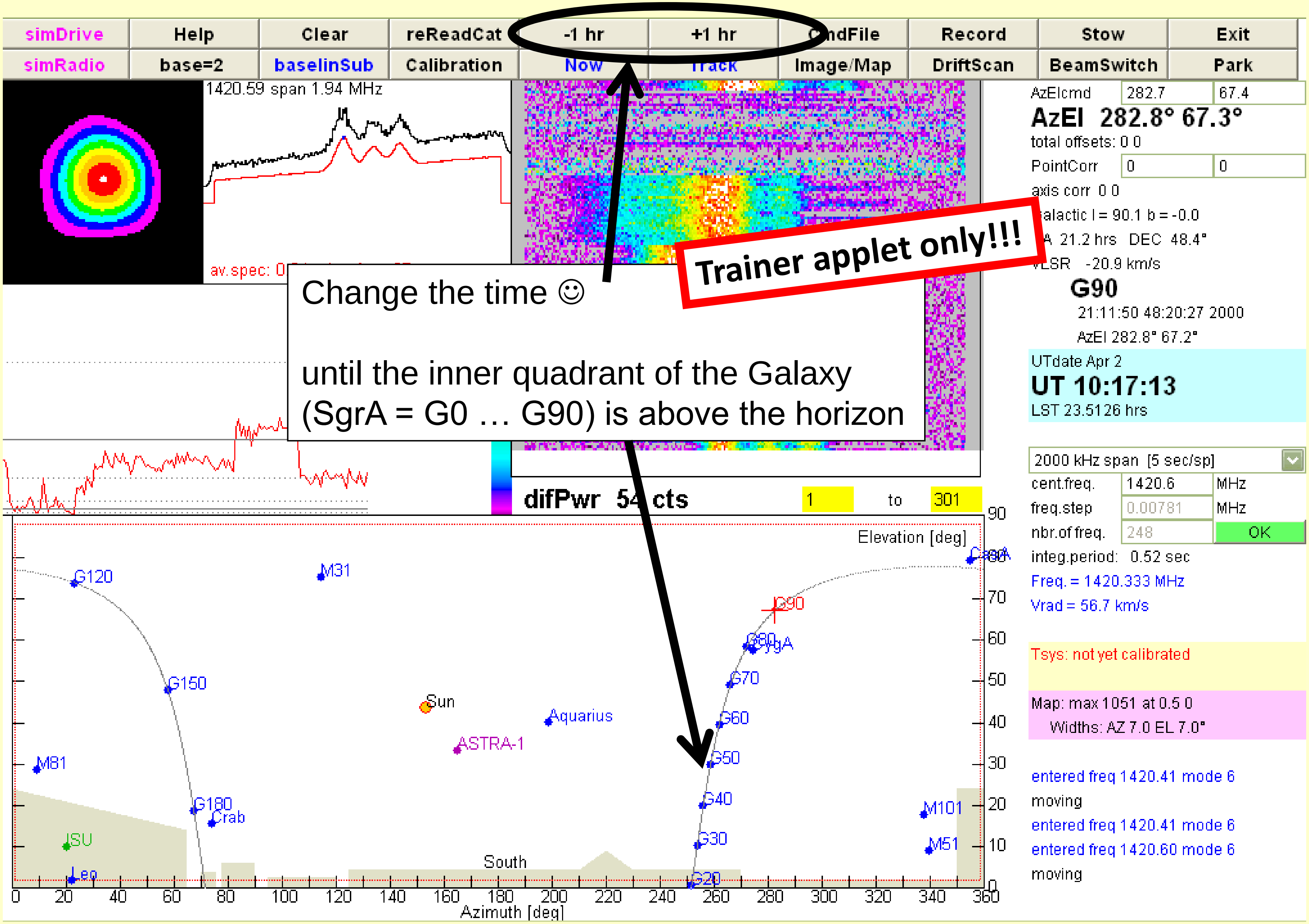
How to do it

- Observe spectra at various positions in the inner Galactic Plane (G0 = SgrA … G90)
  - Set frequency centre and span to cover the entire feature
  - Observe until the (red) averaged spectrum looks smooth and pretty noise-free
- The maximum radial velocity observed towards a position allows to determine the rotational speed at a certain distance from the Galactic Centre
- more at http://astro.u-strasbg.fr/~koppen/Haystack/rotation.html



Change the time ☺

until the inner quadrant of the Galaxy (SgrA = G0 … G90) is above the horizon

Trainer applet only!!!

1420.59 span 1.94 MHz

av.spec: 0

difPwr 54 cts

1 to 301

AzElcmd 282.7 67.4

AzEl 282.8° 67.3°

total offsets: 0 0

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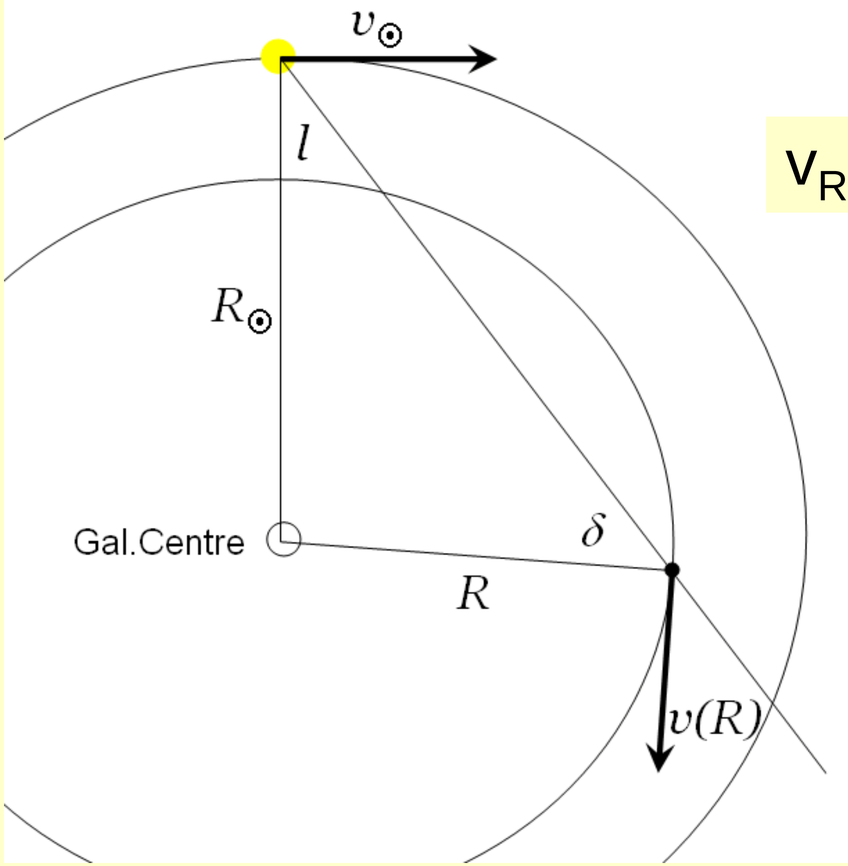
moving

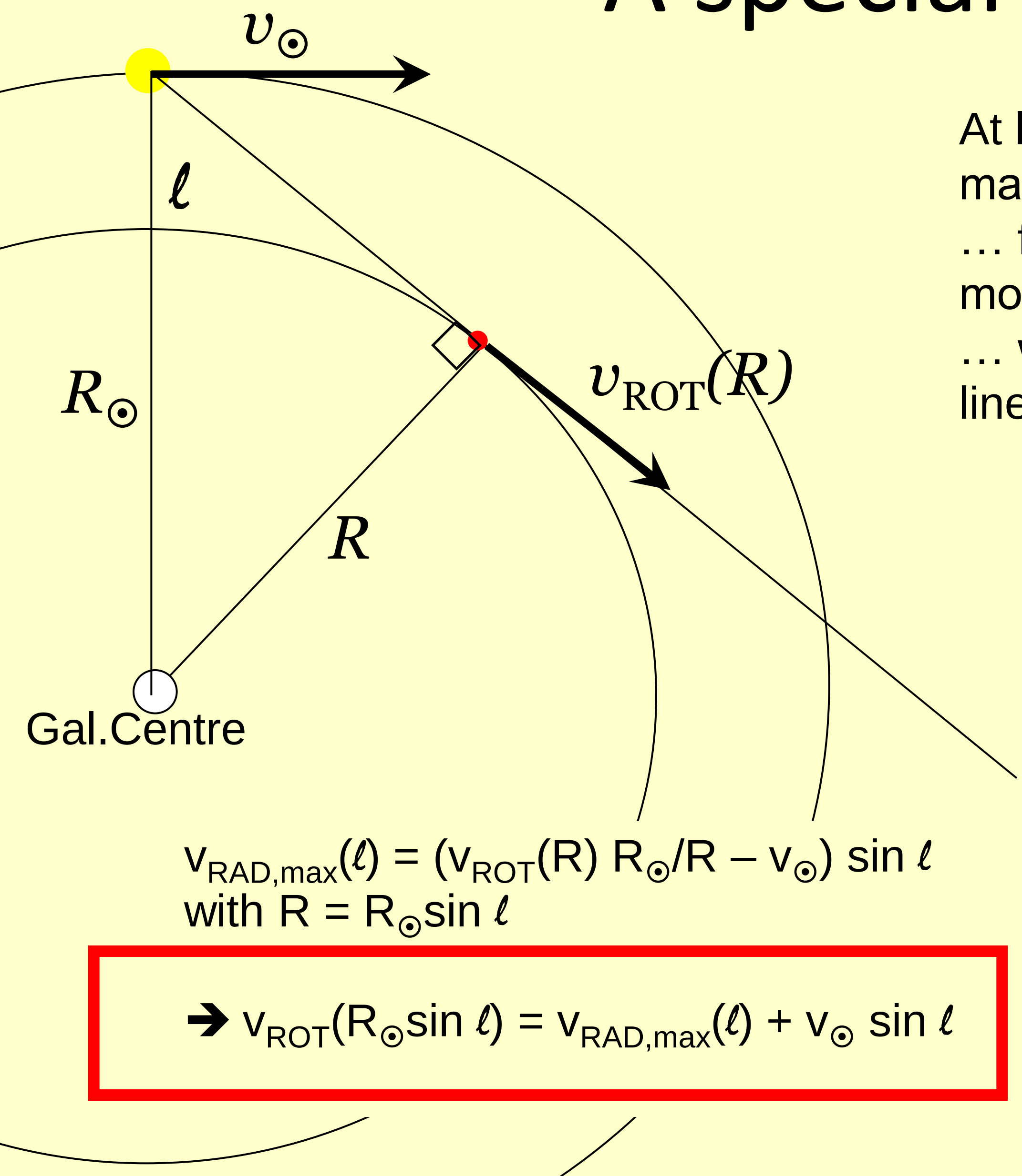
Oort’s formula

Assume: all stars move on circular orbits

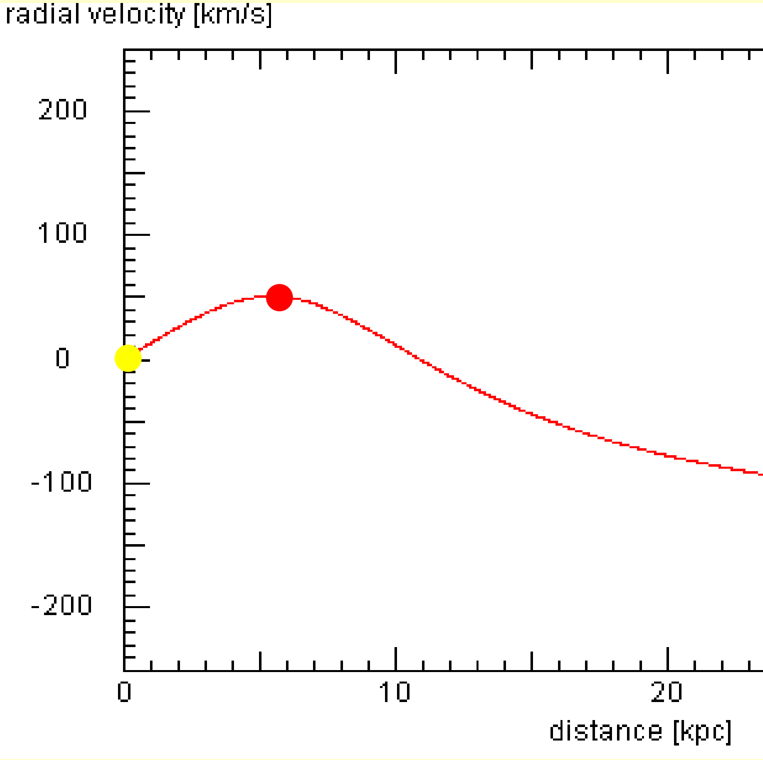


$$v_{RAD}\,(\ell) = (v_{ROT}(R) * R_\odot/R - v_\odot)\,\sin \ell$$

A special case



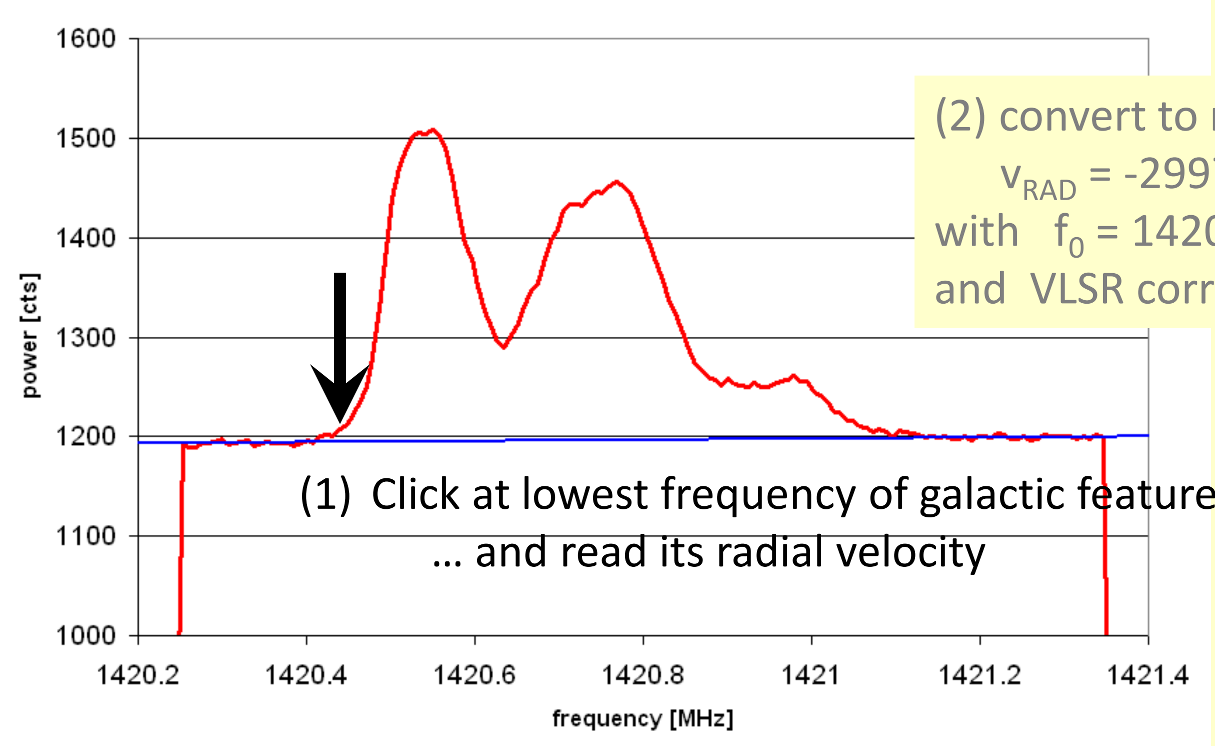
At longitudes l < 90° we observe a maximum radial velocity …
… from the matter that we see moving radially away from us …
… which is the radius to which our line-of-sight is a tangent!



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

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

Analysis



(1) Click at lowest frequency of galactic features
… and read its radial velocity

(2) convert to radial speed

$$v_{RAD} = -299790 * (f-f_0)/f_0 - VLSR \quad [km/s]$$

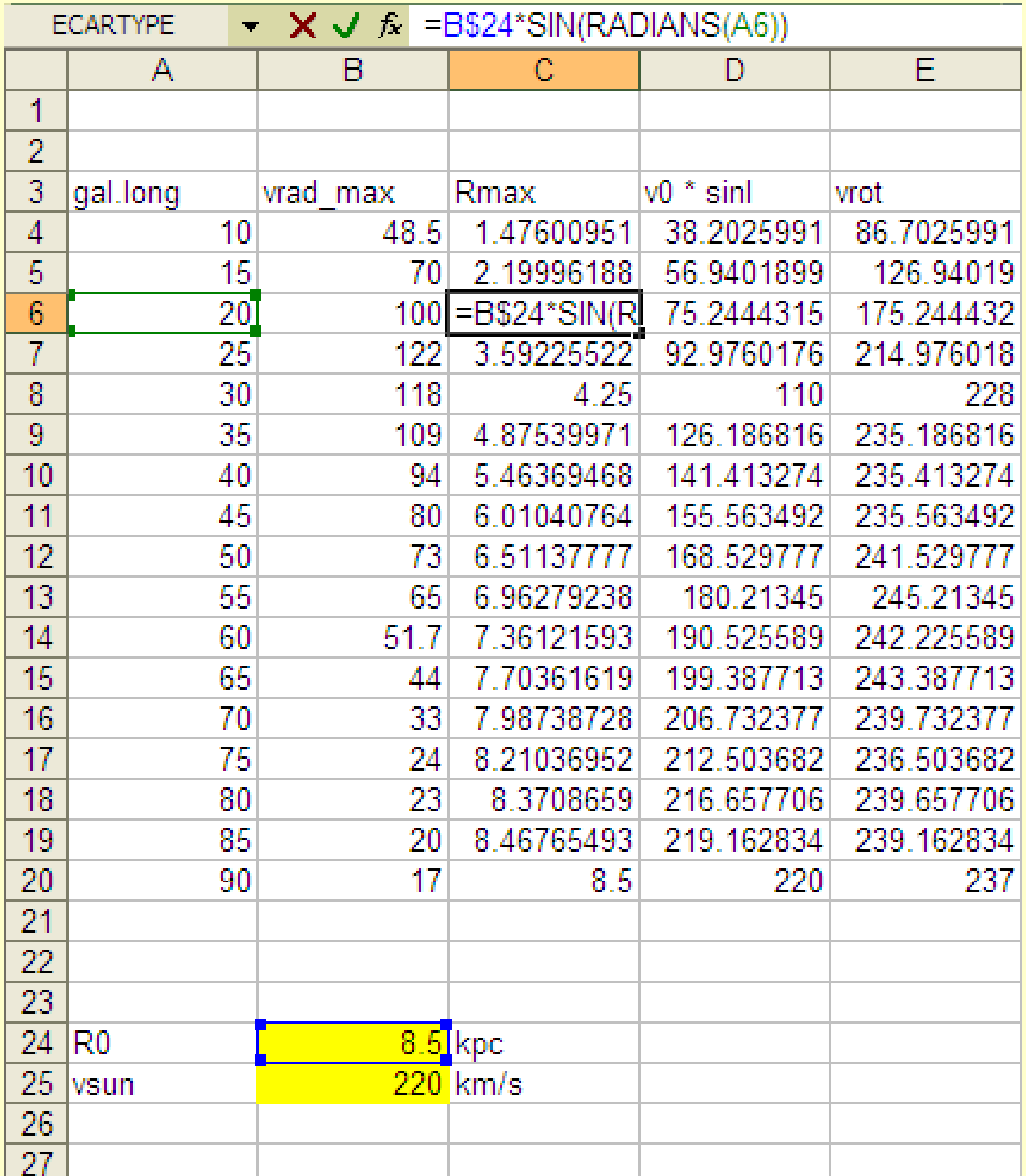
with f_0 = 1420.406 MHz
and VLSR correction (from 6th column)

(3) apply Oort's formula

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

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

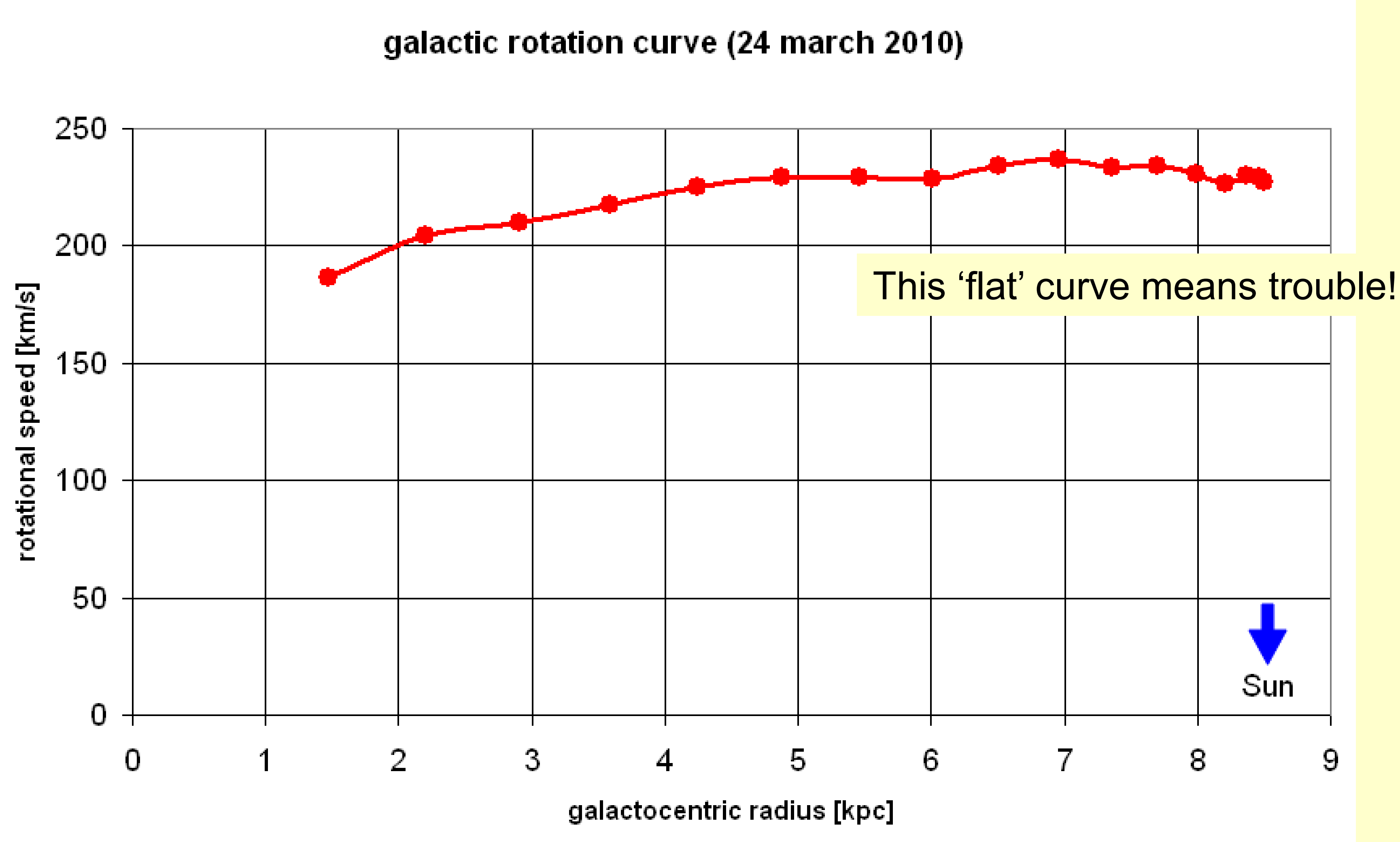
Collect the data from longitudes



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

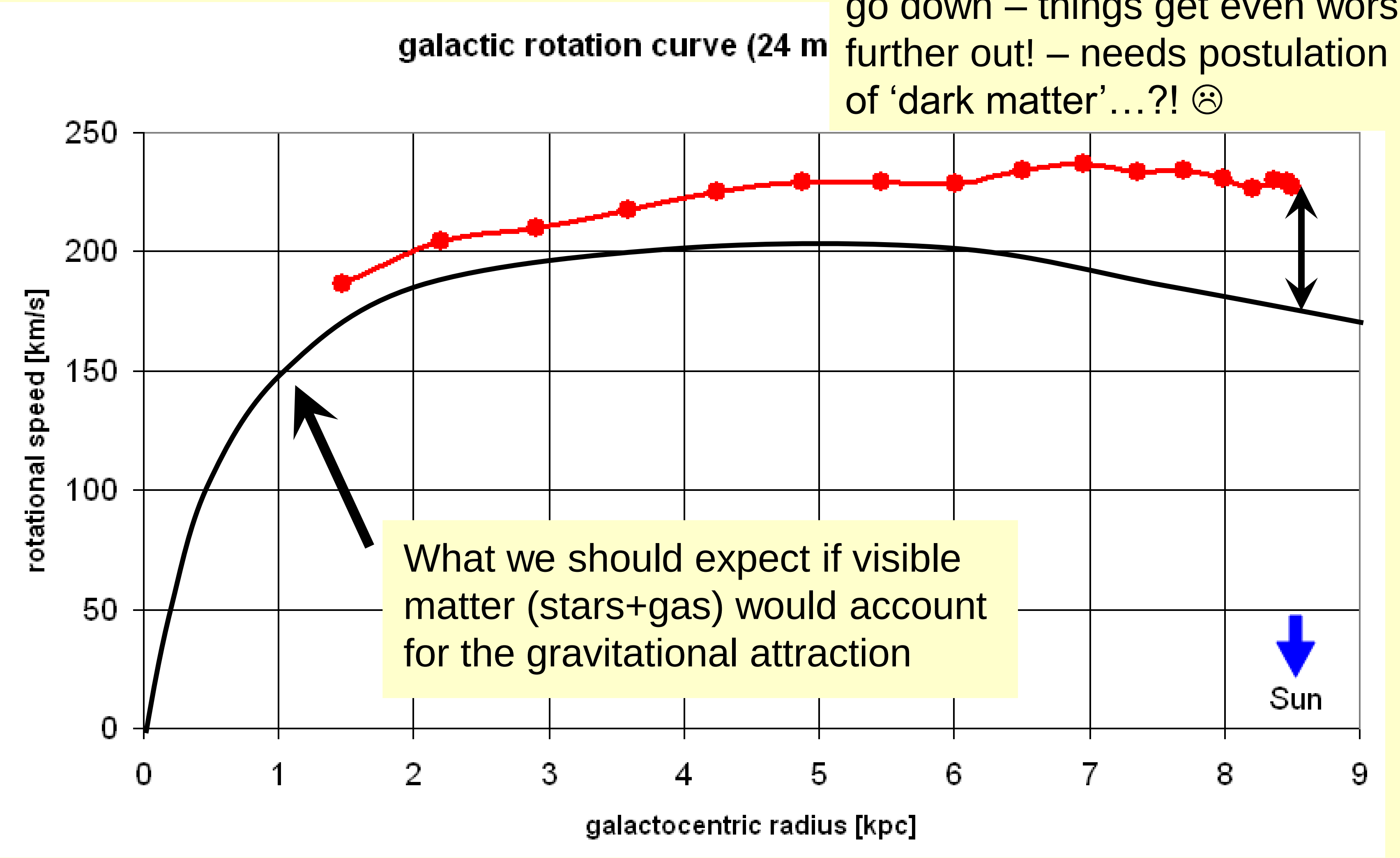
	A	B	C	D	E
1					
2					
3	gal.long	vrad_max	Rmax	v0 * sinl	vrot
4	10	48.5	1.47600951	38.2025991	86.7025991
5	15	70	2.19996188	56.9401899	126.94019
6	20	100	=B$24*SIN(R	75.2444315	175.244432
7	25	122	3.59225522	92.9760176	214.976018
8	30	118	4.25	110	228
9	35	109	4.87539971	126.186816	235.186816
10	40	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 …



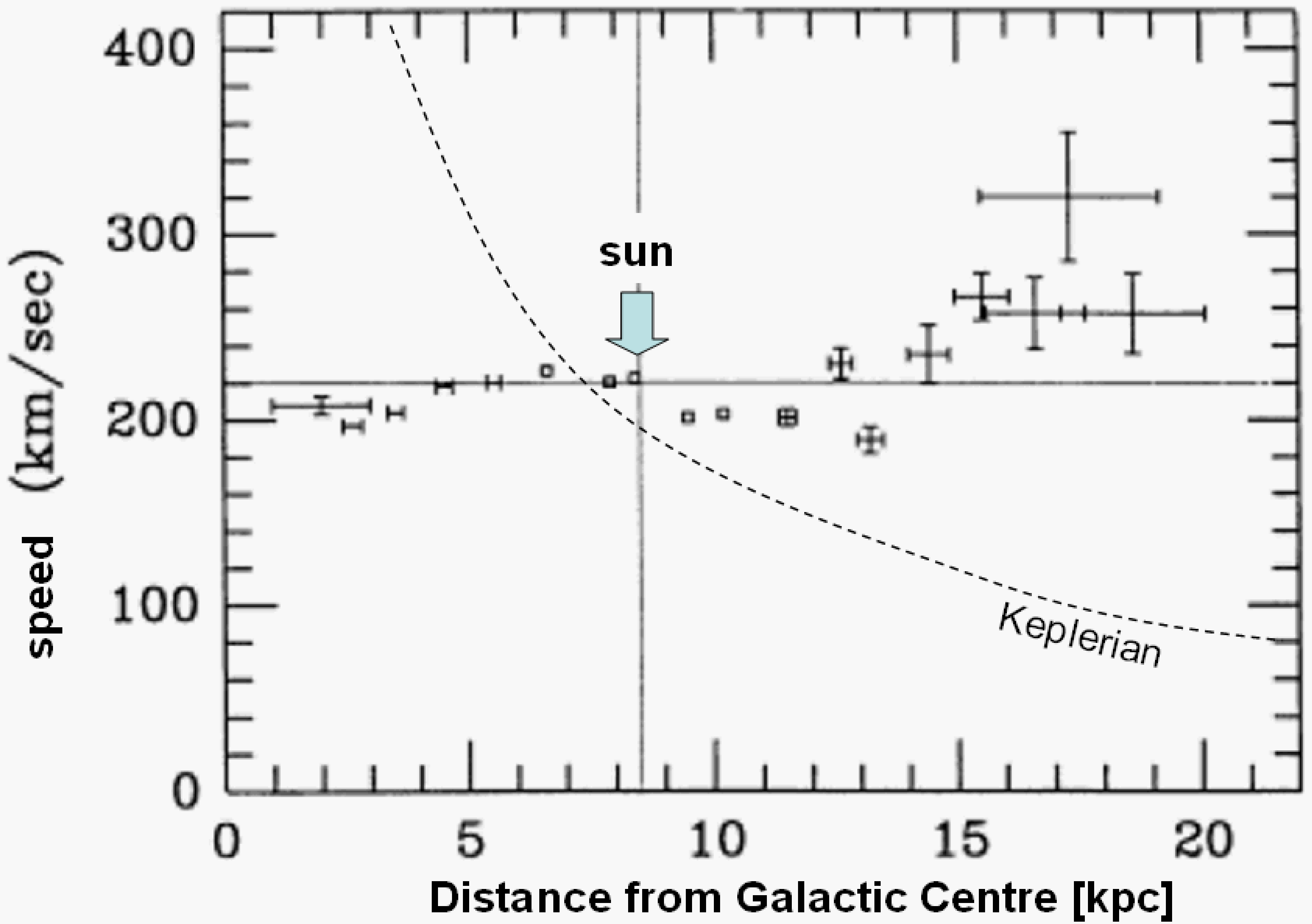
This ‘flat’ curve means trouble!

…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

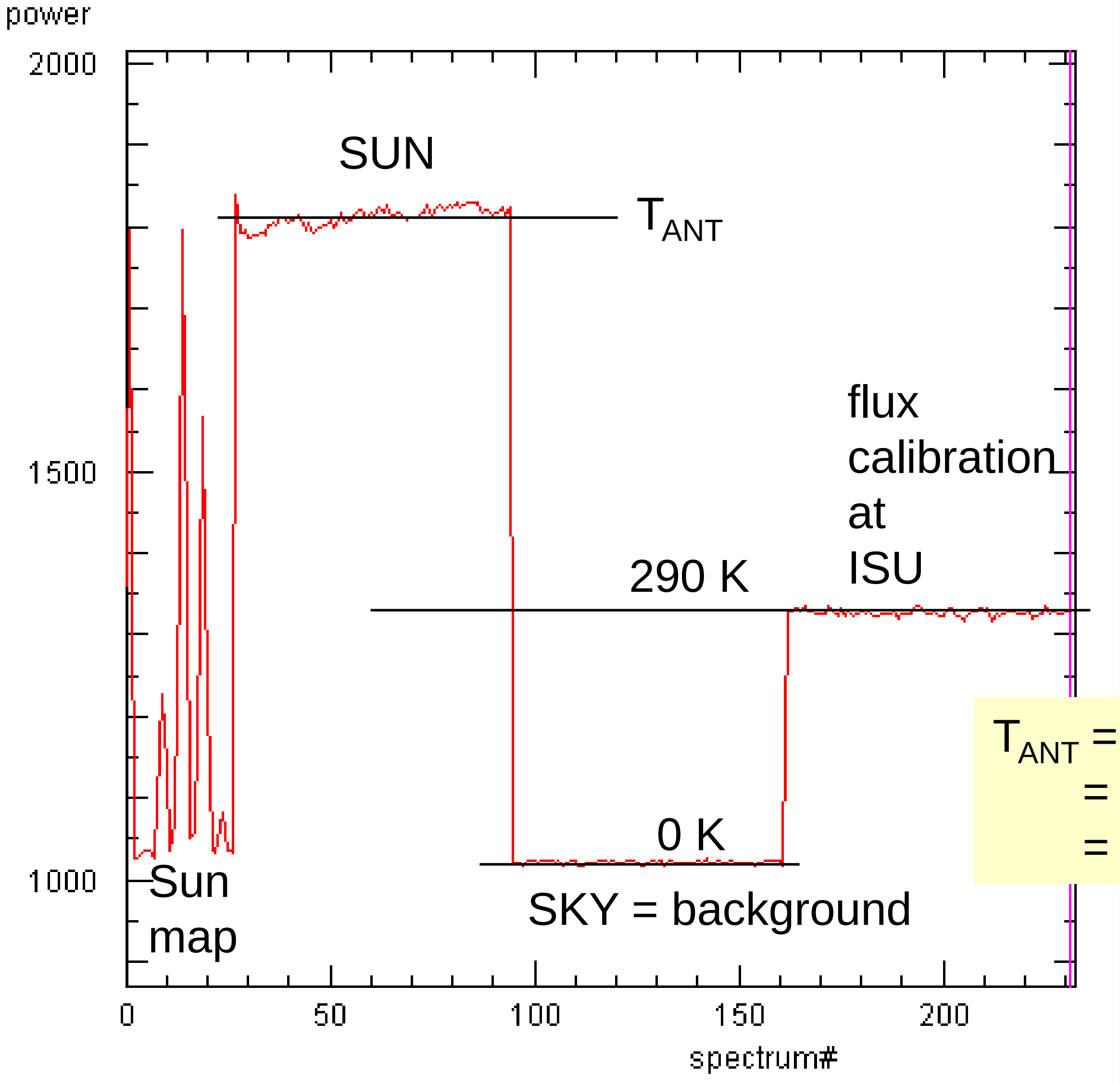
- We do not need the spectral details
- Just take the total **Pwr** …

- Go to the Sun, stay there for some time, read the displayed signal power: ➔ Psun

- Offset the telescope in Azimuth by -40° (i.e. go to the left or East): enter -40 and 0 in the **PointCorr** fields and hit 'Enter' key, ➔ Psky

- Go to ISU (the wall of our library) ➔ Pcal

Solar temperature II



Psun = 1800

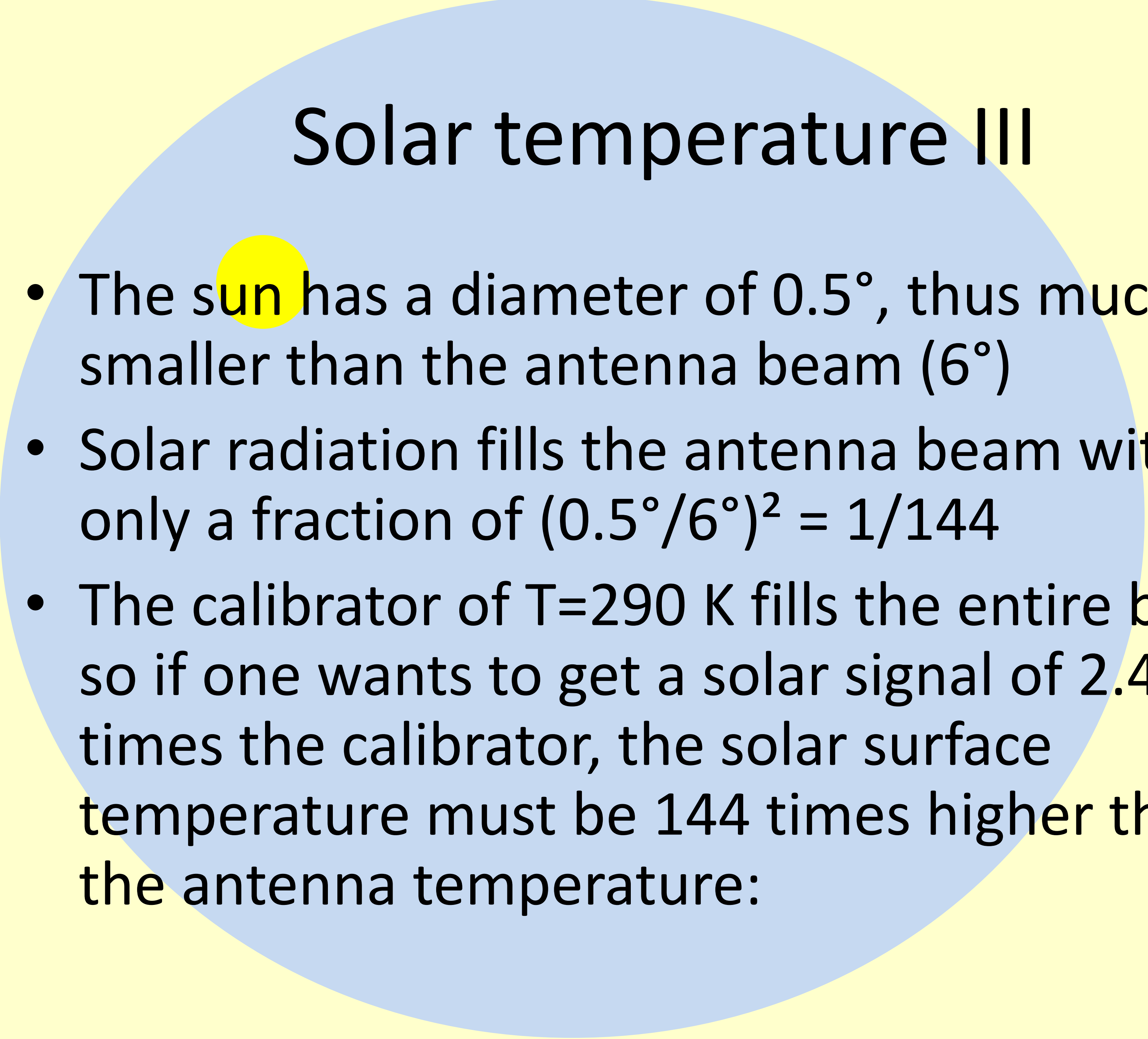
Psky = 1000

Pcal = 1330

gives antenna temperature

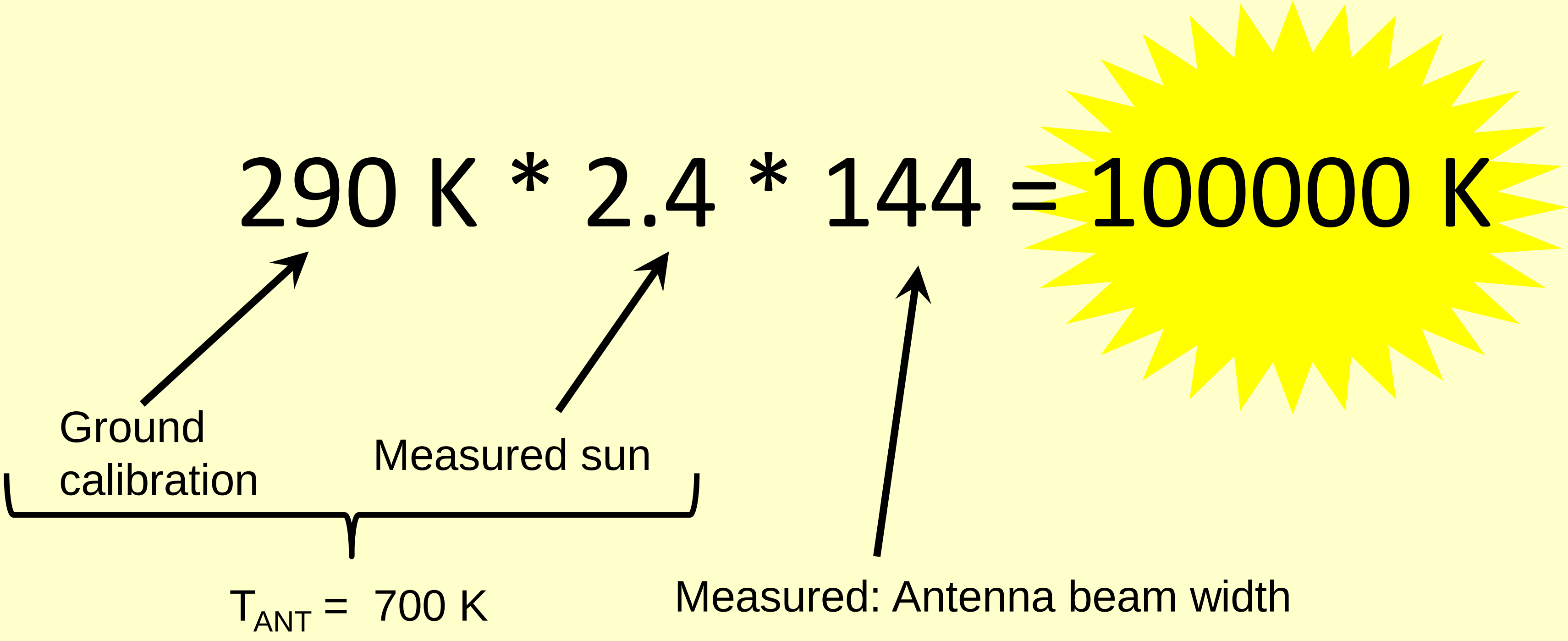
T_{ANT} = 290K * (Psun-Psky)/(Pcal-Psky)
= 290K * 2.4
= 700 K

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