Hands-on Basic Radio Astronomy with 4-m telescope

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On behalf of Radio Physics Laboratory

RADIO TELESCOPES OF WORLD

Parkes

Jodrell Bank

Green Bank

Ehffelsberg


http://www.vla.nrao.edu/

RAS -2013-Aug 19, 2013

Plan of talk

- Introduction
- 4-m Radio Telescope
- Coordinate Systems
- Timekeeping in Astronomy
- Coordinate conversion
- Resolution of a radio telescope
- Organisation of experiments

Feel free to ask questions

http://www.ncra.tifr.res.in/rpl/experiments/winter-school-experiments

Introduction

- Hands-on experiment with 4-m telescope using Sun as an astronomical source
- Understanding how a telescope is pointed and what is its resolution
- Process of a radio astronomy experiment
  - Planning and preparation of a radio astronomy experiment
  - Observations
  - Data selection and analysis
  - Interpretation
- Process similar to more complex experiments

4-m Radio Telescope

- Parabolic dish antenna located at RPL in NCRA East campus
- Diameter - 4 m
- Equipped with a single polarisation 21 cm horn feed at focus
- Can be pointed to any part of the sky by two rotation
  - Altitude
  - Azimuth
- Rotation on two axis by hand cranking
- Position read out by two absolute encoders on a PC

4-m Radio Telescope

4-m Radio telescope Receiver

- **Super-heterodyne Receiver**
- **Feed is backed up by a low-noise high gain amplifier (30K, 33dB)**
- **RF 1420 MHz**
- **Bandpass 4 MHz**
- **Triple conversion - 1 GHz, 70 MHz, basband**
- **Receiver parameters can be set up from a GUI on a PC**
- **Data is recorded and displayed on a PC**

4-m Radio Telescope – Receiver

Low Noise Amplifier

4-m Radio Telescope – Receiver

Receiver

4-m Radio Telescope – Receiver

- **Data Format**
- **Header followed by ASCII data**

```
/media/Transcend/lsun2012.42011-12-20 15 19 26 UTC.1
Tue Dec 20 20:50:22 2011          1
c 12 20 2011 15 19 26 0.200000 0 360 5 0
3.520499
3.522940
3.525382
3.525382
3.530264
3.535147
3.535147
3.537589
3.540030
3.542471
3.542471
3.544913
3.549796
3.552237
3.557120
3.559561
3.559561
3.559561
3.562003
3.562003
3.562003
3.564444
3.566885
3.566885
3.566885
3.569327
3.569327
3.566885
3.564444
3.566885
3.564444
3.566885
3.566885
3.566885
3.566885
3.566885
3.566885
3.566885
3.564444
3.562003
3.562003
3.562003
3.559561
3.559561
3.559561
3.557120
3.557120
3.554678
3.554678
3.552237
3.552237
3.554678
3.554678
3.557120
3.557120
3.557120
3.557120
3.559561
3.559561
3.562003
3.562003
3.562003
```

GMRT data format for comaparison

- **Pulsar data**
- **Header – stokes - freq channel – time order binary data**

```
psrdata.hdr        Mon Aug 19 11:13:17 2013        1
Data file                          : /psrdata/temp/temp130813/J2051-0827.56517.9336706286
2.fil
Header size (bytes)                : 352
Data size (bytes)                  : 4966045696
Data type                          : filterbank (topocentric)
Telescope                          : GMRT
Datataking Machine                 : ????
Frequency of channel 1 (MHz)       : 339.300748
Channel bandwidth      (MHz)       : -0.065104
Number of channels                 : 512
Number of beams                    : 1
Beam number                        : 1
Time stamp of first sample (MJD)   : 56517.933670628619
Gregorian date (YYYY/MM/DD)        : 2013/08/13
Sample time (us)                   : 61.44000
Number of samples                  : 4849654
Observation length (minutes)       : 5.0
Number of bits per sample          : 16
Number of IFs                      : 1
```

GMRT data format for comaparison

- **Interferometery data**
- **Header followed by random groups – time baseline – channel – correlation counts**

ltahdrtyp.dat Mon Aug 19 11:07:45 2013 1

VERSION: COR30x2 LTA1.10 DAS1.10 HST03
OBS_MODE: INDIAN_POLAR CORR_HOST: GSB BASELINES: 930 CHANNELS: 512

SCN	OBJECT	RA(MEAN)	DEC(MEAN)	DATE	IST	RF(MHz)	CW(kHz)	Nrecs
0	1822-096	18h23m13.67	-09d38'29.62"	17/Aug/2013	19:24:40	306.00	65.104	20
0	1822-096	18h23m13.67	-09d38'29.62"	17/Aug/2013	19:24:40	306.00	65.104	20
1	G025.0-6.2	18h59m59.75	-09d50'46.98"	17/Aug/2013	19:31:12	306.00	65.104	26
1	G025.0-6.2	18h59m59.75	-09d50'46.98"	17/Aug/2013	19:31:12	306.00	65.104	26
2	NV1936-002	19h37m35.56	-00d20'07.48"	17/Aug/2013	19:39:37	306.00	65.104	13
2	NV1936-002	19h37m35.56	-00d20'07.48"	17/Aug/2013	19:39:37	306.00	65.104	13
3	G027.0-6.2	19h03m35.24	-08d04'00.63"	17/Aug/2013	19:44:24	306.00	65.104	27
3	G027.0-6.2	19h03m35.24	-08d04'00.63"	17/Aug/2013	19:44:24	306.00	65.104	27
4	G029.0-6.2	19h07m10.46	-06d17'19.31"	17/Aug/2013	19:52:57	306.00	65.104	26
4	G029.0-6.2	19h07m10.46	-06d17'19.31"	17/Aug/2013	19:52:57	306.00	65.104	26
5	G031.0-6.2	19h10m45.83	-04d30'44.59"	17/Aug/2013	20:01:13	306.00	65.104	27
5	G031.0-6.2	19h10m45.83	-04d30'44.59"	17/Aug/2013	20:01:13	306.00	65.104	27
6	NV1936-002	19h37m35.56	-00d20'07.48"	17/Aug/2013	20:09:24	306.00	65.104	13
6	NV1936-002	19h37m35.56	-00d20'07.48"	17/Aug/2013	20:09:24	306.00	65.104	13
7	G033.0-6.2	19h14m21.76	-02d44'18.05"	17/Aug/2013	20:14:30	306.00	65.104	26
7	G033.0-6.2	19h14m21.76	-02d44'18.05"	17/Aug/2013	20:14:30	306.00	65.104	26
8	G035.0-6.2	19h17m58.64	-00d58'01.29"	17/Aug/2013	20:22:53	306.00	65.104	27
8	G035.0-6.2	19h17m58.64	-00d58'01.29"	17/Aug/2013	20:22:53	306.00	65.104	27
9	G037.0-6.2	19h21m36.91	+00d48'04.02"	17/Aug/2013	20:31:17	306.00	65.104	27
9	G037.0-6.2	19h21m36.91	+00d48'04.02"	17/Aug/2013	20:31:17	306.00	65.104	27
10	NV1936-002	19h37m35.56	-00d20'07.48"	17/Aug/2013	20:39:38	306.00	65.104	14
10	NV1936-002	19h37m35.56	-00d20'07.48"	17/Aug/2013	20:39:38	306.00	65.104	14
11	G039.0-6.2	19h25m16.96	+02d33'56.22"	17/Aug/2013	20:44:47	306.00	65.104	27
11	G039.0-6.2	19h25m16.96	+02d33'56.22"	17/Aug/2013	20:44:47	306.00	65.104	27
12	G041.0-6.2	19h28m59.21	+04d19'33.55"	17/Aug/2013	20:53:24	306.00	65.104	26
12	G041.0-6.2	19h28m59.21	+04d19'33.55"	17/Aug/2013	20:53:24	306.00	65.104	26
13	G043.0-6.2	19h32m44.11	+06d04'54.15"	17/Aug/2013	21:01:36	306.00	65.104	27
13	G043.0-6.2	19h32m44.11	+06d04'54.15"	17/Aug/2013	21:01:36	306.00	65.104	27
14	NV1936-002	19h37m35.56	-00d20'07.48"	17/Aug/2013	21:09:58	306.00	65.104	15
14	NV1936-002	19h37m35.56	-00d20'07.48"	17/Aug/2013	21:09:58	306.00	65.104	15
15	G045.0-6.2	19h36m32.07	+07d49'56.14"	17/Aug/2013	21:14:55	306.00	65.104	27
15	G045.0-6.2	19h36m32.07	+07d49'56.14"	17/Aug/2013	21:14:55	306.00	65.104	27
16	G024.0-6.8	19h00m23.14	-11d00'11.16"	17/Aug/2013	21:25:45	306.00	65.104	26
16	G024.0-6.8	19h00m23.14	-11d00'11.16"	17/Aug/2013	21:25:45	306.00	65.104	26
17	G026.0-6.8	19h03m58.13	-09d13'25.27"	17/Aug/2013	21:33:44	306.00	65.104	27
17	G026.0-6.8	19h03m58.13	-09d13'25.27"	17/Aug/2013	21:33:44	306.00	65.104	27
18	NV1936-002	19h37m35.56	-00d20'07.48"	17/Aug/2013	21:42:35	306.00	65.104	14
18	NV1936-002	19h37m35.56	-00d20'07.48"	17/Aug/2013	21:42:35	306.00	65.104	14
19	2047-026	20h47m52.86	-02d33'19.90"	17/Aug/2013	21:47:46	306.00	65.104	16

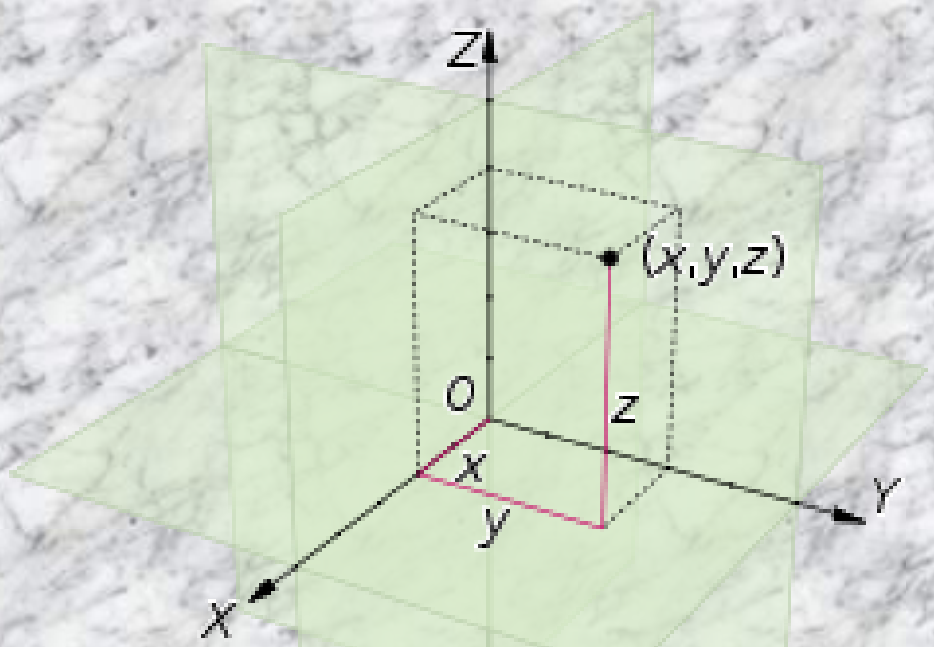
-2013-Aug 19, 2013

Understanding the instrument

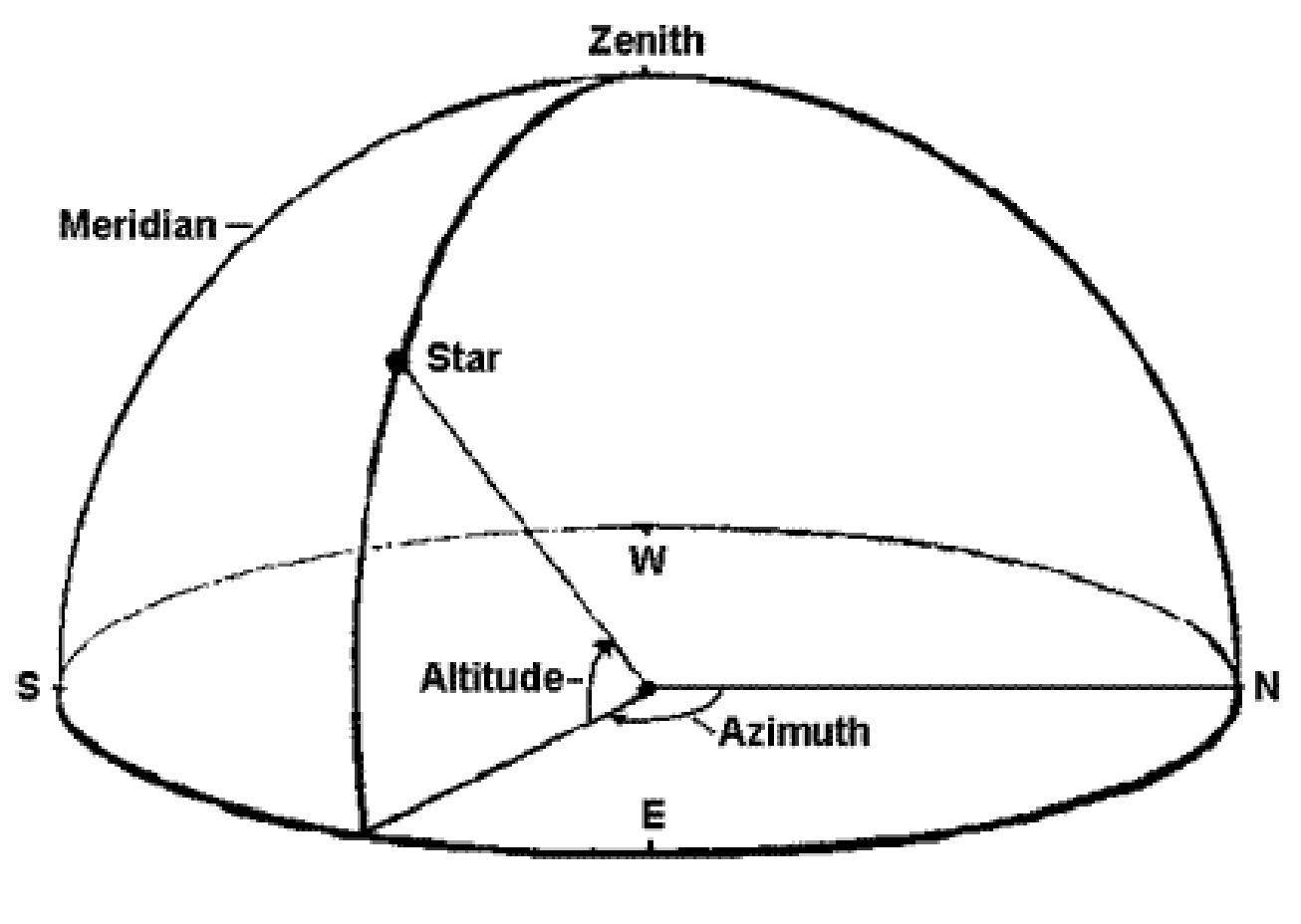
- Where is the radio telescope pointing ?
- What is its resolution ?
  - Directivity
- What is the background noise ?
- What is the minimum strength of detectable radio source ?
  - Collecting area
  - Efficiency
  - Tsys

Coordinate system basics

- **Locate an object in the sky**
- **Cartesian coordinate system**

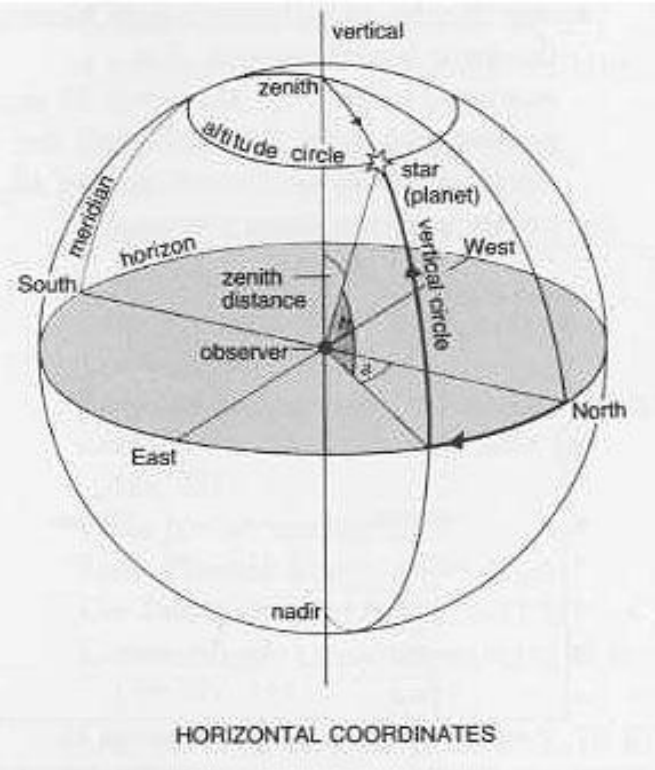


Coordinate systems



Horizon Coordinate system

- Locate an object at a locality
- Reference planes - horizon plane & meridional plane
- Zenith



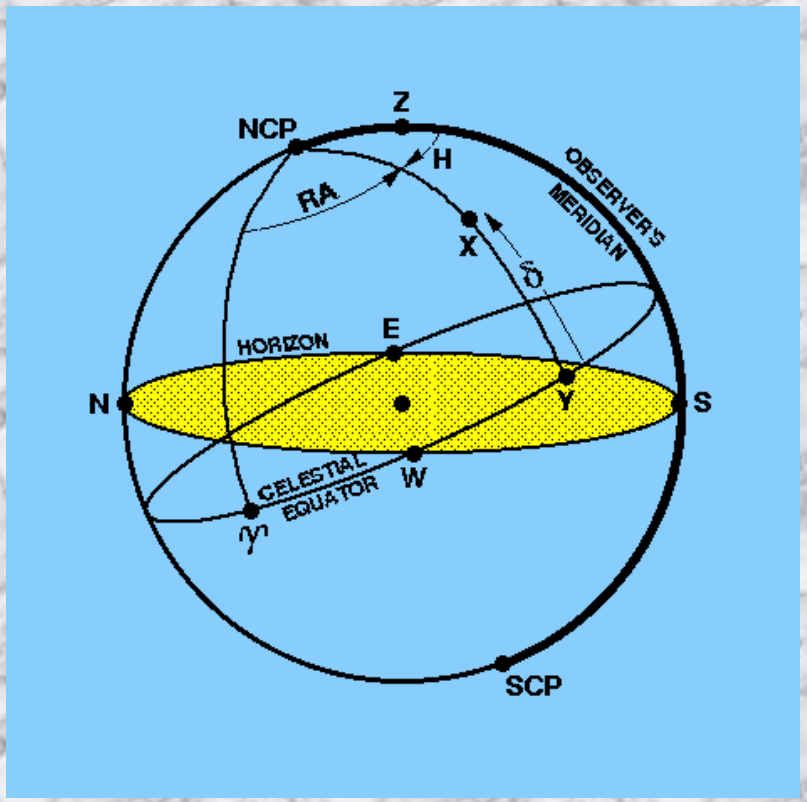
HORIZONTAL COORDINATES

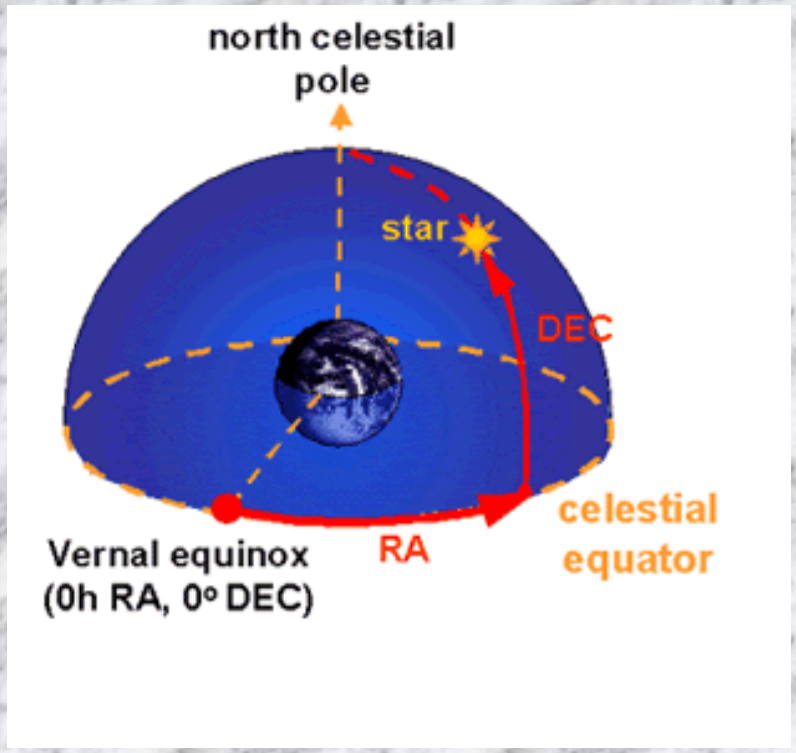
- Pros & cons

Equatorial Coordinate system

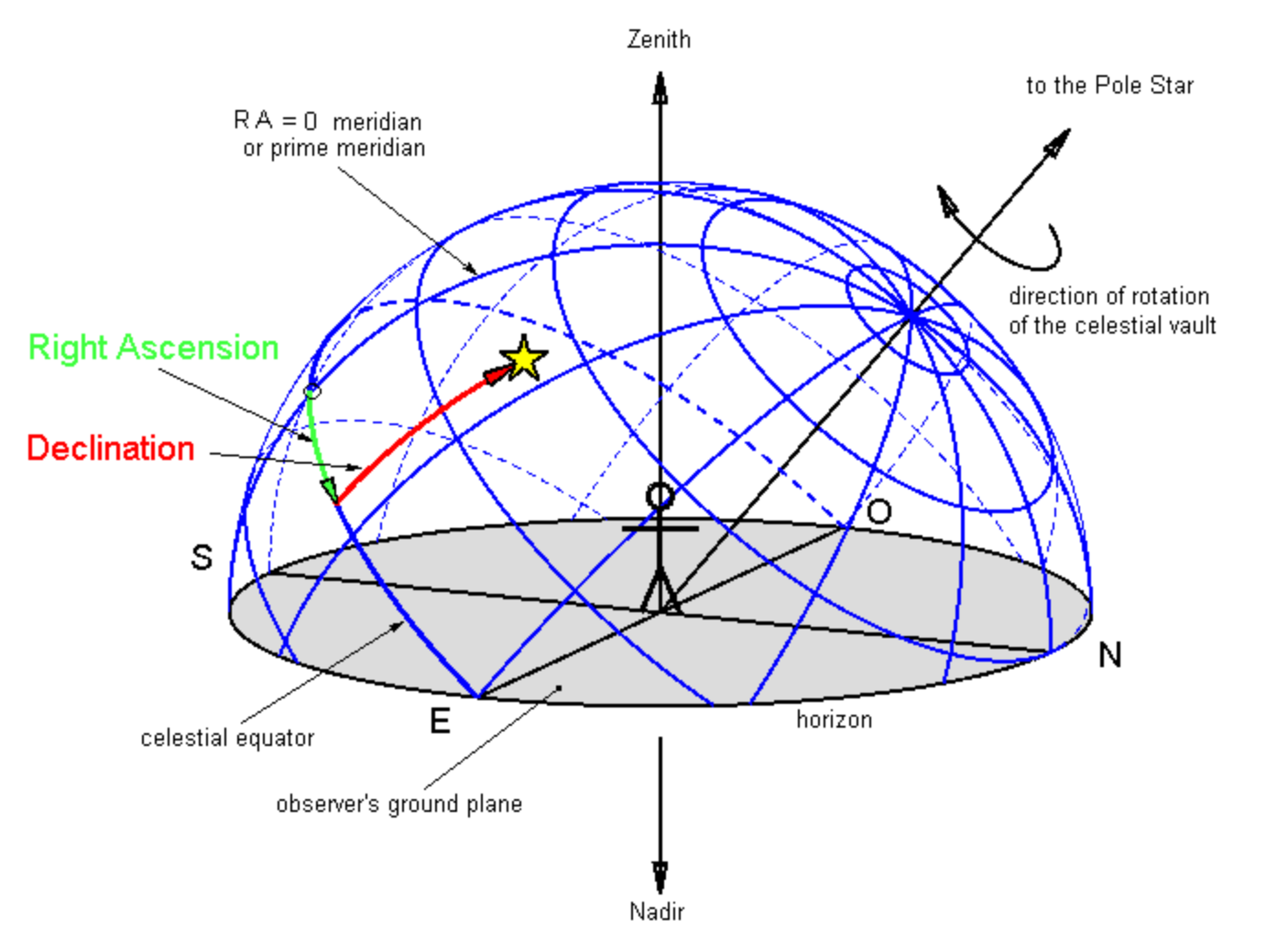
-**Locate an object in a place independent and time independent manner**

-**Reference planes – equatorial plane, plane of equinoxes**





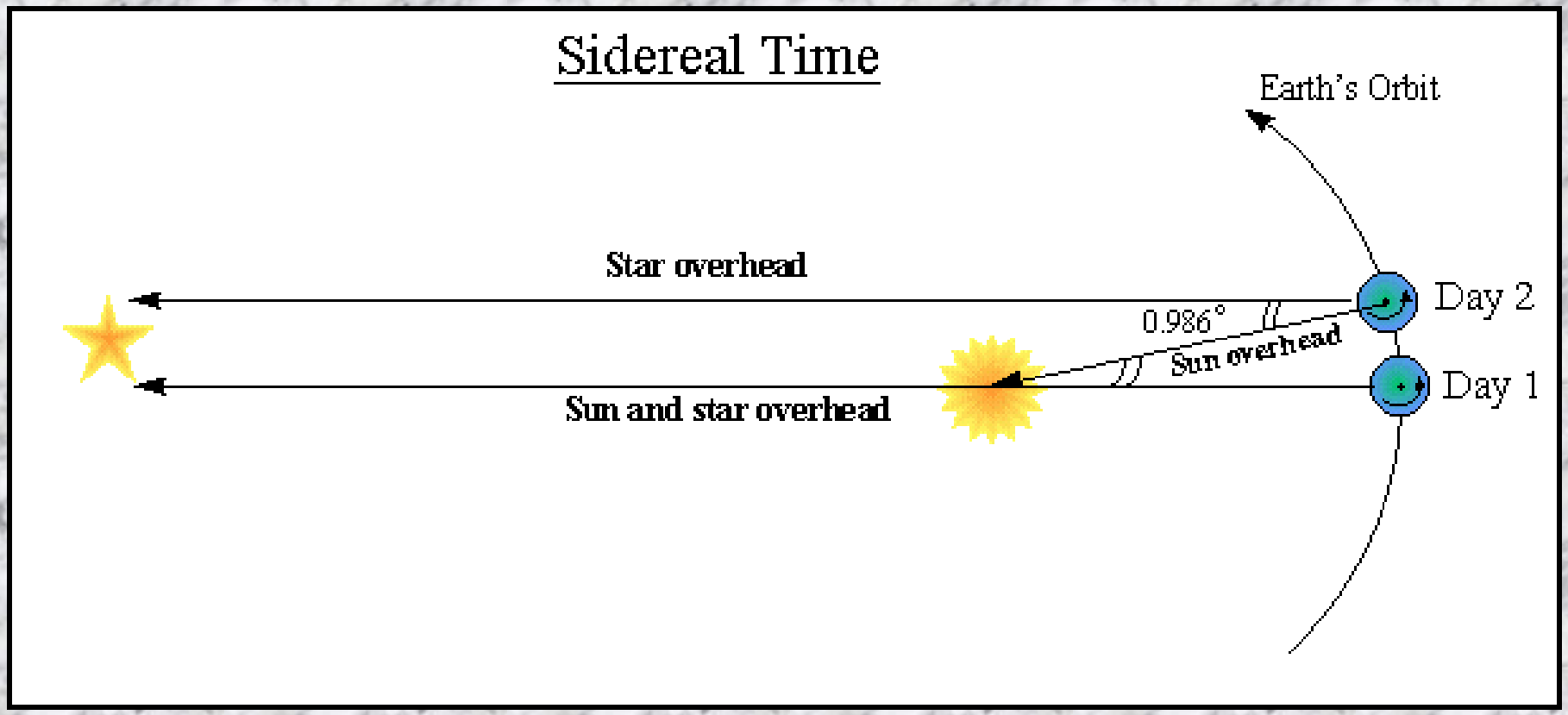
Coordinate systems



Astronomical Time

- Solar Time - noon to noon - related to earth rotation
- UT1 and TAI - rotation and atomic standards
- Sidereal Time - star to star
- 1 sidereal day < 1 solar day ~ 3 min 56 s
- GMST & LMST
- HA , GHA

Solar time and Sidereal time



Coordinate systems

Conversions between equatorial and horizon

Altitude

$$\sin(alt) = \sin(lat) * \sin(dec) + \cos(lat) * \cos(dec) * \cos(HA)$$

Azimuth

$$\cos(az) * \cos(alt) = \cos(lat) * \sin(dec) - \sin(lat) * \cos(dec) * \cos(HA)$$

$$\sin(az) * \cos(alt) = -\cos(dec) * \sin(HA)$$

Derivations using spherical trignometry - Smart

Other coordinate systems

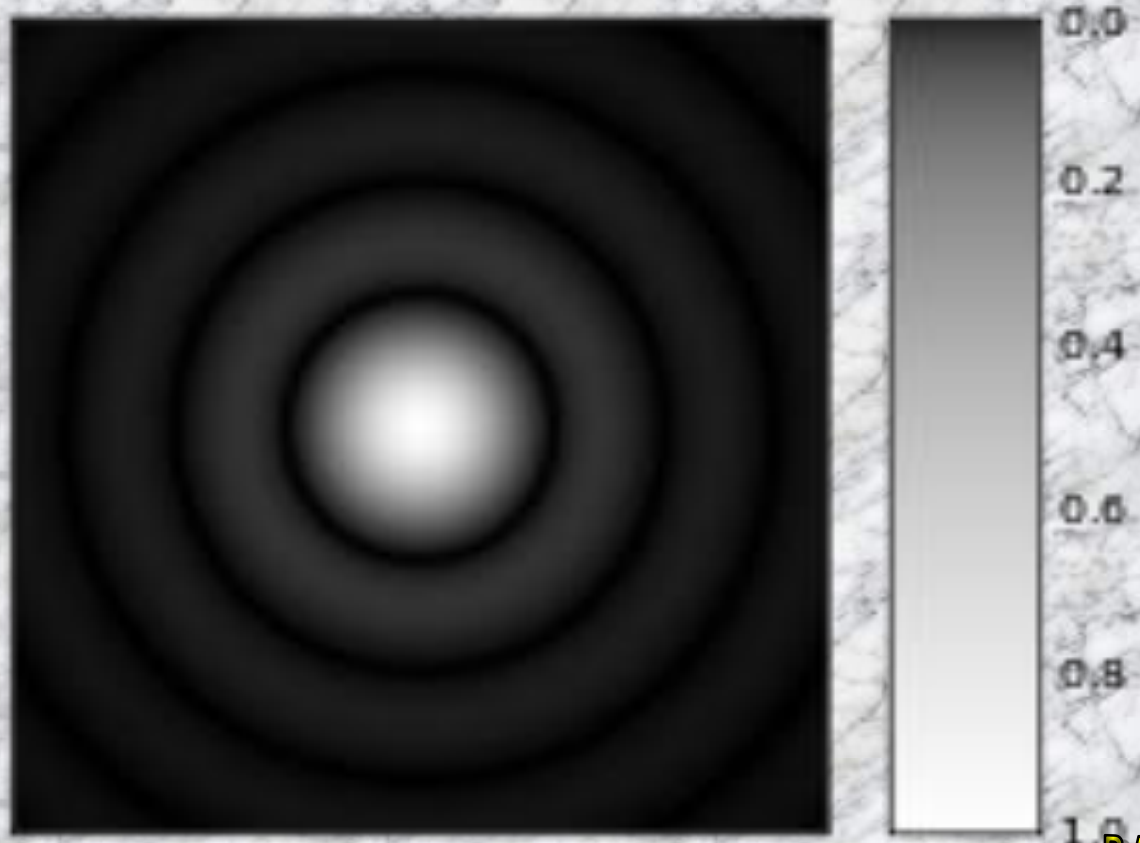
- **Galactic coordinate system**
  - **Reference planes**
    - **Galactic plane - Galactic latitude (b)**
    - **Plane with Galactic centre – Galactic longitude (l)**
  - **Useful for denoting coordinates of objects in the Milky Way – SNR, HII regions etc**
  - **Coordinate conversion**
- **Supergalatic coordinate system**

Alignment of coordinate systems

- **Alignment between telescope and astronomical coordinate systems - pointing offsets**
- **4-m - altitude azimuth mount - Horizon system**
- **Use an astronomical source with well known position - we use Sun**
- **Procedure given in**
- **http://www.ncra.tifr.res.in/rpl/experiments/winter-school-experiments**
- **Observe Sun's apparent position with the 4-m telescope**
- **Compare with Sun's expected position**
- **Nautical Almanac**
- **www.tecepe.com.br/scripts/AlmanacPagesISAPI.dll/**
-

Beam width

- A telescope represents an aperture
- Diffraction effects limit the resolution ~ λ/D
- Radio telescopes directivity – FWHM - beamwidth



Characterizing FWHM of 4-m

- **Experiment involves determination of beamwidth of 4-m telescope**
- **Sun is used as an astronomical point source (Why ?)**
- **A slew across sun should ideally give give a sin x/x beam**
- **For analysis, Gaussian approximation is used**

Tailpiece

- Coordinate systems, Time and resolution of telescope revisited
- RPL experiment – hands-on feel for these measurements
- Not covered - Tsys, A, Eff, Smin
- Detailed procedure on
- www.ncra.tifr.res.in/rpl/experiments/winter-school-experiments
-
- Batches
- Contact Jesu

Thank you

Extracting information

Assumptions for analysis

- Frequency of line is red or blue shifted by doppler effect due to relative velocity

- Multiple peaks are due to different clouds with different velocities

- Line profile is Gaussian

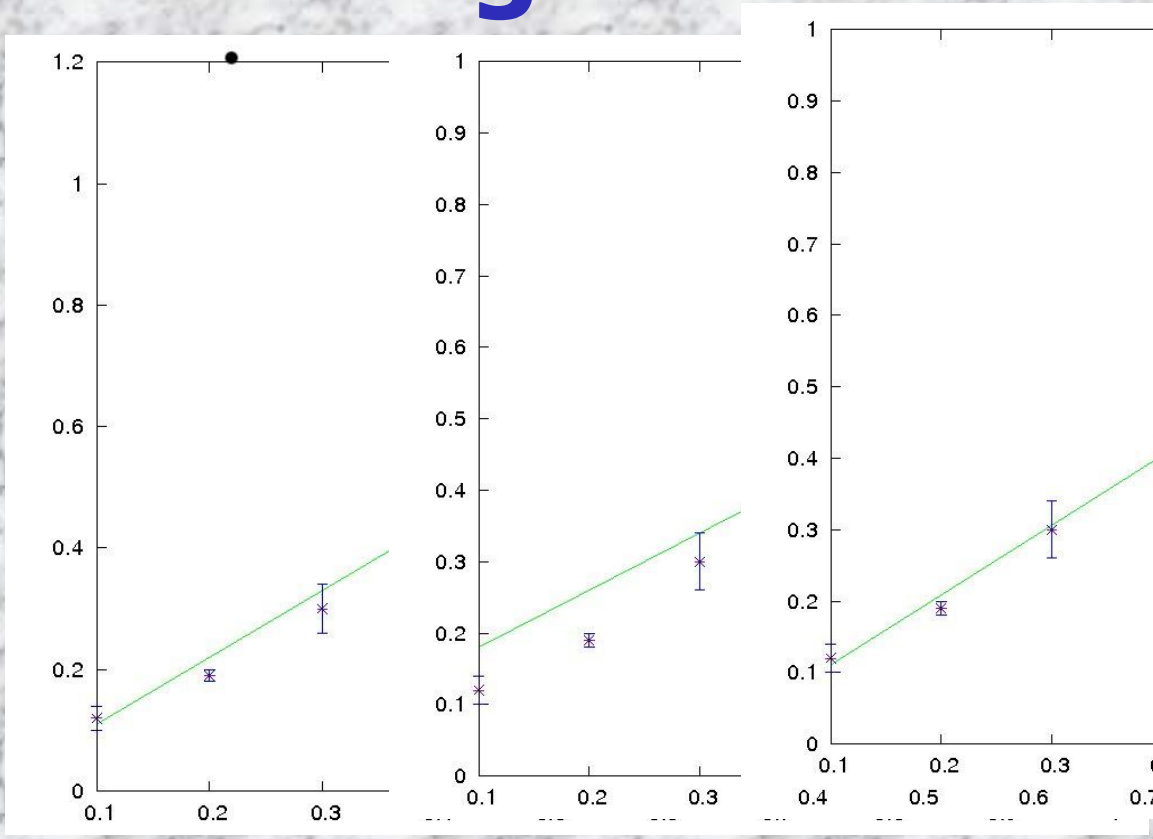
$$y(x) = A \exp(- ((x-B)/C)^2)$$

A = strength of line

C = width of line

B = position (frequency of the line)

Extracting information



Interpretation

- Look for trends
- difference in velocity ??

Observations of Galactic HI

4-m Radio Telescope – Receiver

Block Diagram