Sky Mapping:
Continuum and polarization
surveys with single-dish
 telescopes

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What is a ‘Survey’?

A **Survey** is an *unbiased* observation at a certain frequency of a specific area with uniform sensitivity and angular resolution to provide the distribution of sources and/or diffuse emission in that field.
Examples of All-Sky Surveys

EGRET
> 100 MeV

ROSAT
0.1-2.4 KeV

COMPTEL
1.809 MeV
\(^{26}\)AL

Effelsberg
408 MHz
Types of Sky Surveys

- **Source surveys**
  - remove all extended emission from the data
  - deep source surveys

- **All-Sky surveys**
  - include extended emission and sources
  - time consuming observations
  - moderate angular resolution

- **Galactic plane surveys**
  - need higher angular resolution to resolve sources/objects from diffuse emission
Why are Surveys needed?

- **Source surveys**
  - Source evolution
  - Confusion term

- **All-Sky surveys**
  - Thermal - non-thermal emission, spectral index distribution, Galactic 3D model, CMB foreground

- **Galactic plane surveys**
  - Resolve sources and diffuse emission, identify SNRs and HII-regions
Source survey made with the former 300-ft Green Bank transit dish

Field size $8.3^\circ \times 8.3^\circ$, $\lambda = 6$ cm, 7-beam RX, HPBW $\sim 3.7'$

Condon et al., 1989, AJ, 97, 1064

$\Rightarrow$ NVSS 1.4 GHz (much better)
Source counts from surveys

NVSS = Northern VLA Sky Survey
HPBW $\sim 40''$

Effelsberg 1.4 GHz survey
HPBW = 9.3'
Uyaniker et al., 1999, AAS, 138, 31

Fig. 1. Source counts from an area in the Galactic anticentre as described in Sect. 3
Total Intensity All-Sky Surveys

408 MHz
Haslam et al., 1982,
AAS, 47, 1
Jodrell Bank 76m,
Effelsberg 100m,
Parkes 64m
HPBW=51’, 2K (3σ)

1420 MHz
Reich et al. 1982, 1986,
2001, AA
Stockert 25m,
Villa Elisa 30m
HPBW=36’, 50 mK (3σ)
Total Intensity All-Sky Surveys

Groundbased all-sky surveys up to 1.4 GHz
HPBW = 36' (or less)

All-sky surveys from satellites: WMAP at 22.8 GHz or higher
HPBW 51' or higher
Groundbased all-sky survey at 1.4 GHz
Wolleben et al. 2006, AA, 448, 441
Testori et al. 2008, AA, 484, 733
HPBW = 36’

WMAP at 22.8 GHz and higher
HPBW 51’ or higher
Total intensity versus polarization

PI at 1.4 GHz (26m DRAO+30m Villa Elisa)
Galactic Plane Surveys
Effelsberg 2.7 GHz Galactic Plane Survey

Reich et al. 1990, AAS, 85, 633
HPBW 4.3'
Sino - German (Urumqi)  
4.8 GHz Galactic Plane Survey

Gao et al. 2010, AA, 515, A64
HPBW 9.5'}

Galactic Latitude

Galactic Longitude
DRAO 26m + Effelsberg 100m + CGPS
Polarization Survey

Landecker et al. 2010
‘Standard Mapping’ versus ‘Surveys’

Singe-dish surveys require *non-standard* observing, data reduction and calibration techniques to preserve large scale emission with highest possible accuracy.

**Standard mapping - local zero-level**

**All-Sky Survey - absolute zero-level**
Observed components

Centimetre wavelengths:

- Signal of interest
- Galactic emission
- CMB 2.7K + unresolved EG sources \( f(\text{beam}) \)
- Atmospheric noise/Ground radiation \( f(\text{AZ, EL, t}) \)
- System noise \( f(t) \)

System gain \( f(t) \)
Are you big enough for the telescope?
What is observed?

- **Sky emission:**
  - Galactic diffuse emission + discrete sources
  - resolved and unresolved extragalactic sources
  - CMB (almost) isotropic background 2.71 K

- **Antenna pattern dependent components:**
  - atmospheric emission $f(\text{EL, t})$
  - ground radiation $f(\text{AZ, EL, sidelobes})$

- **Receiver dependent components:**
  - receiver noise level stability $f(t)$
  - gain stability $f(t)$
Survey strategies

All-sky surveys:
- long scans – fixed AZ, or EL
- fast scanning
- baseline adjustment (e.g. ‘Nodding Scans’)

Galactic plane surveys:
- long latitude scans (inner Galactic plane)
- latitude + longitude scans elsewhere
- survey area split into many sections (no strong source complexes at map boundaries)
What is observed?

- The observed temperature $T_{\text{obs}}$ at a certain frequency consists of:

$$T_{\text{obs}} = T_{\text{gal}} + T_{\text{cmb}} + T_{\text{ex}} + T_{\text{off}}$$

with:

- $T_{\text{gal}}$ = Galactic brightness temperature
- $T_{\text{cmb}}$ = 2.71 K Cosmic Microwave Background
- $T_{\text{ex}}$ = unresolved extragalactic sources

$$\approx 15 \text{ mK} \left(\frac{\nu}{1.4 \text{ GHz}}\right)^{-2.9} \text{ (\textit{confusion})}$$

- $T_{\text{off}}$ = deviation from true zero-level $f(AZ, El, t)$

Survey strategy important
Survey reduction

In general:
  editing of each scan for RFI and other distortions
  - as for standard mapping

All-sky surveys:
  • iterative baseline adjustment in case of ‘Nodding Scan’ observations
  • ‘groundradiation profile’ subtraction

Galactic plane surveys:
  • many sections, processing similar to standard mapping
    + edge adjustments of adjacent maps
Survey reduction

Theoretical and observed antenna temperature as a function of elevation. A: theoretical atmospheric contribution as described in Sect. 3. B: "mean" scan as the average of all observed scans. C,D: examples of original scans (Their positions are indicated in Fig. 3). Scans B,C and D are shown with a positive offset of 1 K, 2 K and 3 K respectively. The difference scans D-B and C-B are shown below. The temperature scale is relative.

Stockert 25m telescope at 1420 MHz
Reich & Steffen 1981, AA, 93, 27
Survey Observing Method

- Example of the *nodding scan* technique:
  - The telescope is moved along the local meridian, ‘Up’ and ‘Down’
  - Sky rotation provides RA coverage
  - High antenna velocity $>10^\circ$/min
  - Full sampling
  - Ground radiation $= f(\text{dec}, t)$

408 MHz all-sky survey
Haslam et al. 1982
Survey reduction

Figure 2:
Frequency distribution of temperature differences at intersections of up and down scans. The shifting of the maxima and the decreasing standard deviation with iteration number shows the convergence of the procedure applied.

Reich & Steffen 1981, AA, 93, 27
Survey reduction

Survey of Loop IV at 1420 MHz

Reich & Steffen 1981, AA, 93, 27
**Absolute zero-level adjustment (total intensity)**

**All-sky surveys:**
- additional low resolution sky horn data needed
- convolution of all-sky survey to sky horn beam
- check temperature differences and correct all-sky survey

**Galactic plane surveys:**
- use all-sky surveys to find absolute zero-level
- e.g. Effelsberg 100-m 1.4/2.7 GHz surveys were calibrated with Stockert 25-m surveys
Sky horns to measure $T_{\text{sky}}$

$$T_{\text{obs}} = T_{\text{gal}} + T_{\text{cmb}} + T_{\text{ex}} + T_{\text{off}} = T_{\text{sky}} + T_{\text{off}}$$

Convolve a survey to the low resolution of a sky horn and find $T_{\text{off}}$
Bell Lab satellite antenna

Detection of 3K CMB radiation in 1963
Nobel Prize 1978 - Penzias & Wilson
Antenna pattern

- **HPBW** = \( k \frac{\lambda}{D} \)
  \( \lambda \) = wavelength, \( D \) = diameter of antenna
  \( k \) = illumination dependent (Effelsberg: 58 to 70)

- **Near sidelobes** (level is illumination dependent)
  diffraction: dish ➔ rings
  subreflector support legs ➔ radial response

- **Far sidelobes**:
  very low levels, but integration over a large area
Antenna diagram

Effelsberg 100-m four subreflector support legs

Fig. 1. Antenna pattern of the 100 m telescope at $\lambda = 21$ cm. The field size is $2^\circ \times 2^\circ$, north is at the top, west at the left. The $-3 \, \text{dB}$ level for the main beam is indicated by a circle. The levels from $-12.5 \, \text{dB}$ to $-40 \, \text{dB}$ are shown by isophotes separated by 2.5 dB. Sidelobe levels between $-25 \, \text{dB}$ and $-47 \, \text{dB}$ are indicated by the gray scale.
Brightness temperature

- **Antenna solid angle**: \( \Omega_0 = \int_{4\pi} P(\Phi,\Psi) \, d\Omega \)
  with \( \Omega_0 = \frac{\lambda^2}{A_{\text{eff}}} \)

- **Main beam**: \( \Omega_{\text{MB}} = \int_{\text{MB}} P(\Phi,\Psi) \, d\Omega \)
  \( T_{\text{MB}} = T_A \frac{\Omega_0}{\Omega_{\text{MB}}} \)
  main beam averaged sky temperature

- **Full beam**: \( \Omega_{\text{FB}} = \int_{\text{FB}} P(\Phi,\Psi) \, d\Omega \)
  \( T_{\text{FB}} = T_A \frac{\Omega_0}{\Omega_{\text{FB}}} \)
  Full beam includes sidelobes up to a certain distance (not well defined)

Main (Full) beam efficiency \( \sim 70\% \) (90\%) (typical values)

\( \Rightarrow \) all-sky surveys often have lower efficiencies!
Antenna diagram

ITALSAT at 11.7 GHz
Reich & Fürst, 2000

HPBW ~ 67"
sensitivity ~ -63 dB
contours at -3, -10, -20, -30, -40 dB of peak

Field size 81’ x 81’
Antenna diagram – far sidelobes

Fig. 3 Model for the far sidelobes of the 100 m telescope. Indicated are 4 stray cones centered in N, E, S, and W direction 33° from the main beam, 4 triangular shaped sidelobe regions caused by the roof of the apex cabin and a spill over ring for 90° ≤ R ≤ 100°. The shaded area indicates the section of the stray cone which is plotted in Fig. 4.

Fig. 4. Sidelobes which were found in the shaded area in Fig. 3. The solid line is the corresponding section of the stray cone circle. The isophotes are at the −56 dB, −59 dB, and −62 dB levels.

Kalberla, Mebold & Reich, 1980, AA, 82, 275
Absolute zero-level adjustment for polarized intensities

Problems:
• no sky horn data available, but ‘special’ experiments
• missing large scale polarization adds as a vector!
  (total intensity as a scalar)

All-sky polarization surveys:
• 1.4 GHz all-sky polarization survey – complex procedure
• WMAP surveys are on an absolute zero-level

Galactic plane surveys:
• 1.4 GHz plane survey calibrated by all-sky survey
• 5 GHz plane survey calibrated by WMAP 22.8 GHz survey
**Absolute** zero-level adjustment for polarized intensities

Stokes U/Q are measured “relative” as Stokes I

All-Sky PI maps require an “**absolute**” temperature level

most PI results from Faraday rotation
Absolute zero-level adjustment for polarized intensities

Large scale emission subtracted (relative measurement):

Percentage Polarization may exceed 100% !!

Vector addition !!

$$P_{\text{abs}}^2 = (U + U_{\text{off}})^2 + (Q + Q_{\text{off}})^2 \Rightarrow P_{\text{abs}} \neq P + P_{\text{off}}$$

$$\phi_{\text{abs}} = 0.5 \atan \left( \frac{U + U_{\text{off}}}{Q + Q_{\text{off}}} \right) \Rightarrow \phi_{\text{abs}} \neq \phi + \phi_{\text{off}}$$
Absolute zero-level adjustment for polarized intensities
DRAO 26m NCP Calibration

UQ-Diagram
NCP

M. Wolleben (PhD 2005)

blue: night-time
yellow: sun-rise
red: daytime
1.4 GHz Dwingeloo polarization survey

Brouw & Spoelstra, 1976, AAS, 26, 129

*absolute zero-level – rotating dipoles in focus*
Calibration steps of the 1.4 GHz polarization all-sky survey

Northern Sky

- Dwingeloo 25m: absolute zero undersampled incomplete coverage
- DRAO 26m: Scans in RA, 36'
- EMLS 100m: +/-20°, 9.4'
- DRAO CGPS: +5°/-4°, 1'

Southern Sky

- Parkes 64m: 14.5’ Extended sources
- Villa Elisa 30m: Fully sampled, 36’ SCP?
- ATCA Plane Survey: 1’

To convert: $T_b(MB) \times 0.94$
Why are Surveys needed?

- **All-Sky surveys**
  - Thermal - non-thermal emission, spectral index distribution, Galactic 3D model, CMB foreground

- **Galactic plane surveys**
  - Resolve sources and diffuse emission, finding SNRs and HII-regions

**Survey access sites:**
- http://www.mpifr-bonn.mpg.de/survey.html
- (http://cdsweb.u-strafbg.fr)
Using sky surveys for your purpose

a) Download data from MPIfR survey sampler:
   - Specify your field: sampling and coordinate system
   - Select the survey or several surveys (READ the documentation)
   - Coordinate transformations are provided (also for polarization)
   - Maps are provided in Fits format (also GIF, NOD2)

b) More processing needed?
   - Smoothing, high-/low-pass filter, relative zero-level, etc.

c) Analyse the maps or overlay with your data
Thermal/non-thermal separation using several surveys

Based on Effelsberg 1.4 GHz, 2.7 GHz and Urumqi 4.8 GHz Galactic plane surveys (Sun et al., 2010, AA submitted)
Zero-spacings from single-dish surveys

Interferometer observation of SNR HB21 (1')

Single-dish survey (9.4')

Combined 1.4 GHz image of HB21
Thank you!