OSKAR Sky Model

Version history:

Revision	Date	Modification
1	2012-04-20	Creation
2	2012-11-02	Fixed the order of table columns for reference frequency and spectral index (the examples were correct, though).
3	2013-11-14	Updated for rotation measure capability.

1 Introduction

This document describes the sky model file format used by OSKAR 2.x.

OSKAR sky model files contain a simple catalogue to describe the source properties for a set of point sources or Gaussian sources.

For each source in the model it is possible to specify:

- A position in equatorial coordinates (Right Ascension and Declination).
- Flux densities for all four Stokes parameters (I, Q, U, V), at a reference frequency.
- Reference frequency, spectral index and rotation measure.
- Gaussian source width parameters (FWHM and position angle).

2 Sky Model File

The sky model file holds a table of ASCII text, where each row corresponds to one source, and columns describe the source parameters. Most parameters are optional, and will be set to a default value if not specified.

In order, the parameter columns are:

Column	Parameter	Unit	Comment
1	Right Ascension	deg	Required. This is currently interpreted as the apparent rather than mean (J2000) Right Ascension.
2	Declination	deg	Required. This is currently interpreted as the apparent rather than mean (J2000) Declination.
3	Stokes I flux density	Jy	Required.
4	Stokes Q flux density	Jy	Optional (default 0.0)
5	Stokes U flux density	Jy	Optional (default 0.0)
6	Stokes V flux density	Jy	Optional (default 0.0)
7	Reference frequency for flux density values	Hz	Optional (default 0.0)
8	Spectral index	N/A	Optional (default 0.0)
9	Rotation measure	rad m^{-2}	Optional (default 0.0)
10	Major axis FWHM †	arcsec	Optional (default 0.0) †
11	Minor axis FWHM †	arcsec	Optional (default 0.0) †
12	Position angle East of North †	deg	Optional (default 0.0) †

Notes:

1. *When the file is read, parameters are assigned according to their column position. In order to specify an optional parameter, all columns up to the designated column must be specified.*

† In order for a source to be recognised as a Gaussian, all three of the major axis FWHM, minor axis FWHM and position angle parameters must be specified.

2. *The rotation measure column was added for OSKAR 2.3.0. To provide backwards compatibility with older sky model files containing extended sources, a check is made on the number of columns on each line, and source data is loaded according to the following rules:*
    a. *Lines containing between 3 and 9 columns will set all parameters up to and including the rotation measure. Any missing parameters will be set to defaults.*
    b. *Lines containing 11 columns set the first 8 parameters and the Gaussian source data (this is the old file format). The rotation measure will be set to zero.*
    c. *Lines containing 12 columns set all parameters.*
    d. *Lines containing 10, 13, or more columns will raise an error.*

The fields can be space-separated and/or comma-separated. Characters appearing after a hash ('#') symbol are treated as comments and will be ignored. Empty lines are also ignored.

2.1 Example

The following is an example sky file describing three sources, making use of a number of comment lines.

```
#
# Required columns:
# =================
# RA(deg), Dec(deg), I(Jy)
#
# Optional columns:
# =================
# Q(Jy), U(Jy), V(Jy), freq0(Hz), spectral index, rotation measure,
#                FWHM major (arcsec), FWHM minor (arcsec), position angle (deg)
#
#

# Two fully-specified sources
0.0 70.0 1.1 0.0 0.0 0.0 100e6 -0.7 0.0 200.0 150.0  23.0
0.0 71.2 2.3 1.0 0.0 0.0 100e6 -0.7 0.0  90.0  40.0 -10.0


# A source where only Stokes I is defined (other columns take default values)
0.1 69.8 1.0
```

2.2 Spectral Index

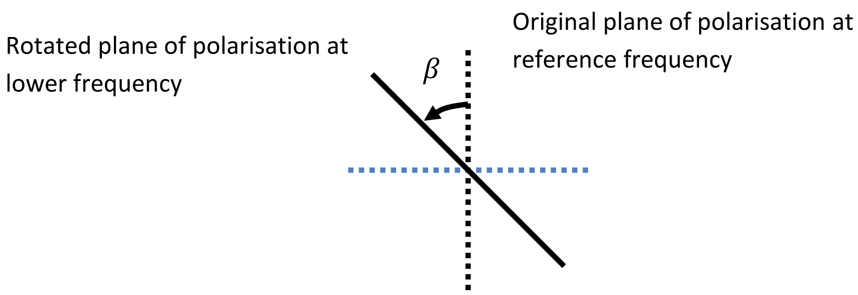
The spectral index α is defined according to the following equation:

$$\mathbf{F} = \mathbf{F_0} \left(\frac{\nu}{\nu_0} \right)^{\alpha}$$

where $\mathbf{F}$ is a 4-vector containing the Stokes (I, Q, U, V) fluxes of the source at the current observing frequency ν, and $\mathbf{F_0}$ is a 4-vector containing the fluxes at the reference frequency ν_0. Negative values for α will cause the flux at frequencies higher than the reference frequency to be reduced relative to the reference flux.

2.3 Rotation Measure

Faraday rotation will cause the plane of polarisation of radiation from a source to be rotated, relative to a reference frequency, by an additional angle β. This angle is defined in the normal right-handed sense for radiation towards the observer (β is positive as sketched below).



The rotation angle is given by the expression $\beta = \mathrm{RM}\,(\lambda^2 - \lambda_0^2)$, where λ_0 is the wavelength at the reference frequency, λ is the wavelength at the observing frequency, and RM is the rotation measure. The angle β is positive when RM is positive and the new wavelength is greater than the reference wavelength.

The source Stokes parameters are modified for the observing frequency using a normal 2D rotation matrix, and its transpose:

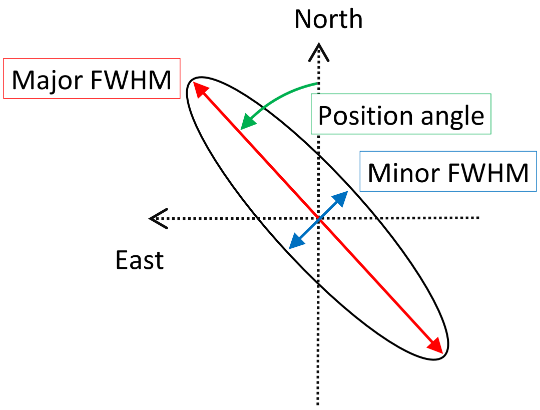
$$\begin{bmatrix} \cos(\beta) & -\sin(\beta) \\ \sin(\beta) & \cos(\beta) \end{bmatrix} \begin{bmatrix} I_0 + Q_0 & U_0 + iV_0 \\ U_0 - iV_0 & I_0 - Q_0 \end{bmatrix} \begin{bmatrix} \cos(\beta) & \sin(\beta) \\ -\sin(\beta) & \cos(\beta) \end{bmatrix}$$

Multiplying this out implies that

- Q_0 transforms to $Q = Q_0 \cos(2\beta) - U_0 \sin(2\beta)$,
- U_0 transforms to $U = Q_0 \sin(2\beta) + U_0 \cos(2\beta)$,
- I and V remain unchanged, as expected.

2.4 Gaussian Sources

Two-dimensional elliptical Gaussian sources are specified by the length of their major and minor axes on the sky in terms of their full width at half maximum (FWHM) and the position angle of the major axis (θ), defined as the angle East of North.



These three parameters define an elliptical Gaussian $f(x, y)$, given by the equation

$$f(x, y) = e^{-(ax^2+2bxy+cy^2)}$$

where

$$a = \frac{\cos^2\theta}{2\sigma_x^2} + \frac{\sin^2\theta}{2\sigma_y^2}$$

$$b = -\frac{\sin 2\theta}{4\sigma_x^2} + \frac{\cos 2\theta}{4\sigma_y^2}$$

$$c = \frac{\sin^2\theta}{2\sigma_x^2} + \frac{\cos^2\theta}{2\sigma_y^2},$$

and σ_x and σ_y are related to the minor and major FWHM respectively, according to

$$\sigma = \frac{\mathrm{FWHM}}{2\sqrt{2\ln(2)}}.$$

OSKAR simulates Gaussian sources by multiplying the amplitude response of the source on each baseline by the Gaussian response of the source in the u,v plane. This is possible in the limit where a Gaussian source differs from a point source in its Fourier (u,v) plane response only, and assumes that any variation of Jones matrices across the extent of the source can be ignored (e.g. a small taper due to the station beam changing across the source).

The Fourier response of an elliptical Gaussian source is another elliptical Gaussian whose width is defined with respect to the width in the sky as

$$\sigma_{uv} = \frac{1}{2\pi\sigma_{\mathrm{sky}}}.$$

The required modification of the *uv* plane amplitude response of each point source therefore takes the simple analytical form:

$$V_{\mathrm{extended}} = f(u, v)\, V_{\mathrm{point}} ,$$

where $f(u, v)$ is the equation for an elliptical Gaussian (defined above as $f(x, y)$) evaluated in the u,v plane according to the FWHM and position angle of the source.