Data Reduction and Analysis Techniques

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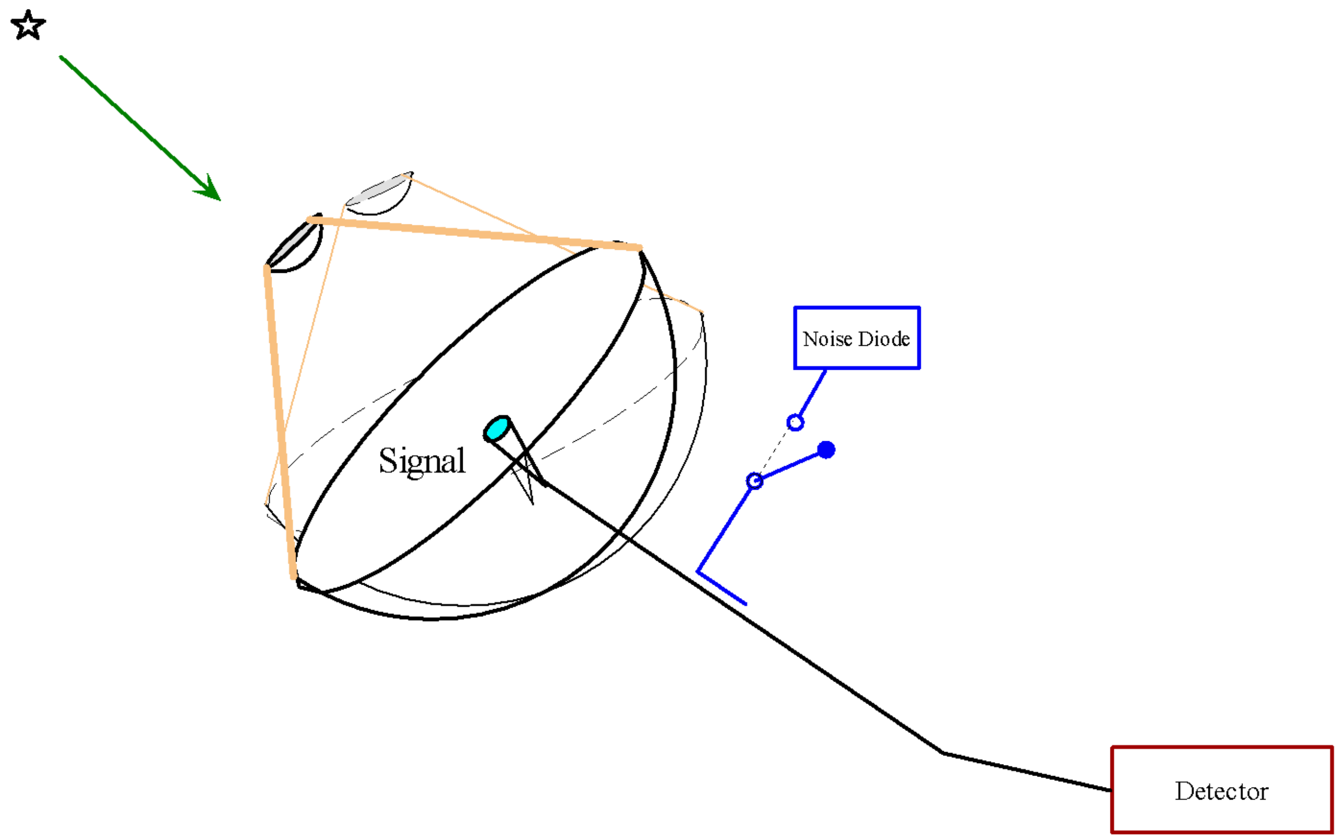
Existing Analysis Systems

Package	Telescopes	Web Address
Aips	NRAO 12m	www.cv.nrao.edu/aips
Aips++	NRAO 100m	www.aips2.nrao.edu/docs/aips++.html
Analyz	NAIC 305m	www.naic.edu/menuimag/astronomy.htm
CLASS	IRAM 30m and others	www.iram.fr/doc/class/class.html
IDL	NAIC 305m and others	www.idlastro.gsfc.nasa.gov/homepage.html
SPECX	JCMT	www.jach.hawaii.edu/JACpublic/JCMT/User_documentation/SPECX/part6/node2.html
UniPops	NRAO 43m and 12m	www.cv.nrao.edu/unipops

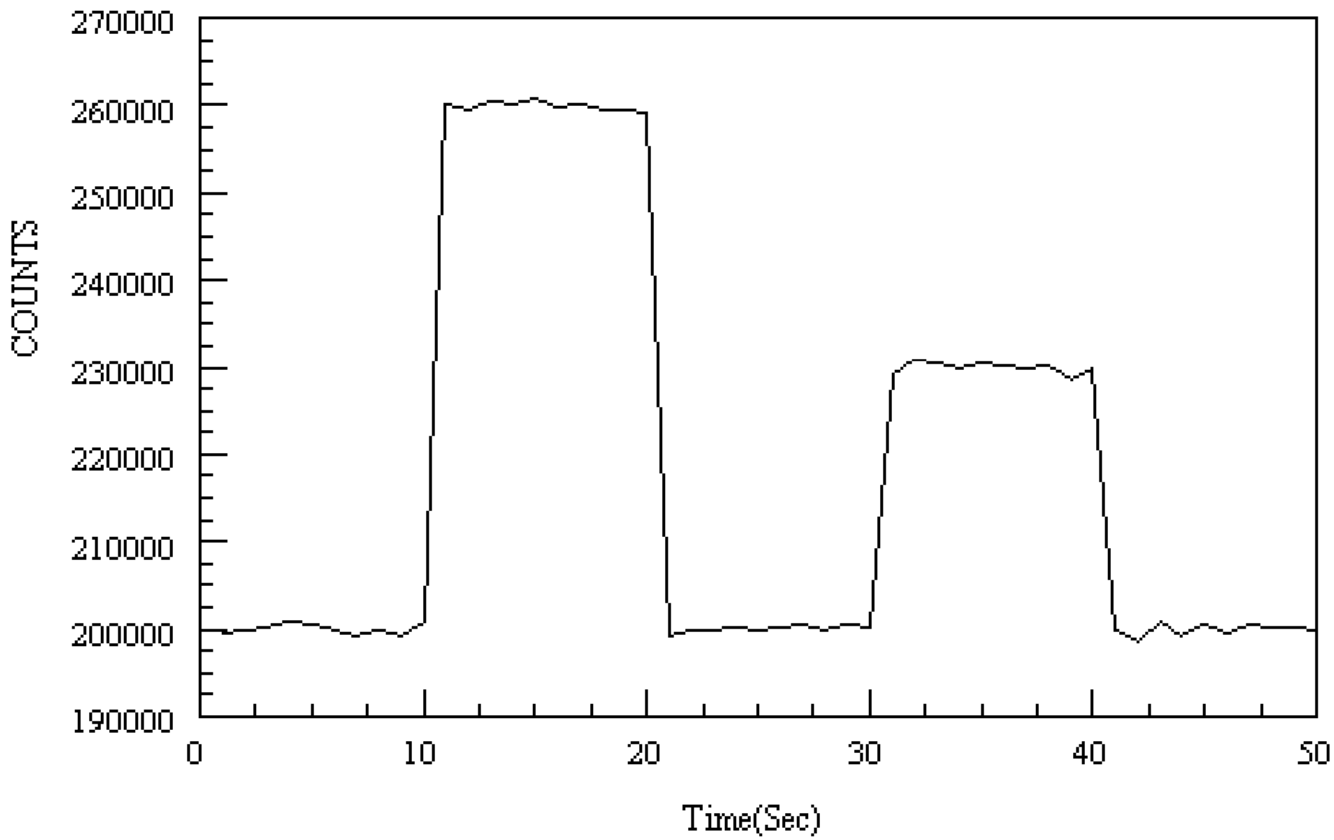
Continuum - Point Sources

On-Off Observing



Continuum - Point Sources

On-Off Observing



Continuum - Point Sources

On-Off Observing

- Known:
  - Equivalent temperature of noise diode or calibrator (T_{cal}) = 3 K
  - Bandwidth (BW) = 10 MHz
  - Gain = 2 K / Jy
- Desired:
  - Antenna temperature of the source (T_{src})
  - Flux density (S) of the source.
  - System Temperature(T_{sys})
  - Accuracy of antenna temperature (σ_{src})

Continuum - Point Sources

On-Off Observing

$$T_{src} = \frac{T_{cal}}{P_{cal\_on} - P_{cal\_off}} \cdot \left(P^{signal} - P^{reference}\right)$$

$$T_{sys} = \frac{T_{cal} P_{cal\_Off}}{\left(P_{cal\_on} - P_{cal\_off}\right)}$$

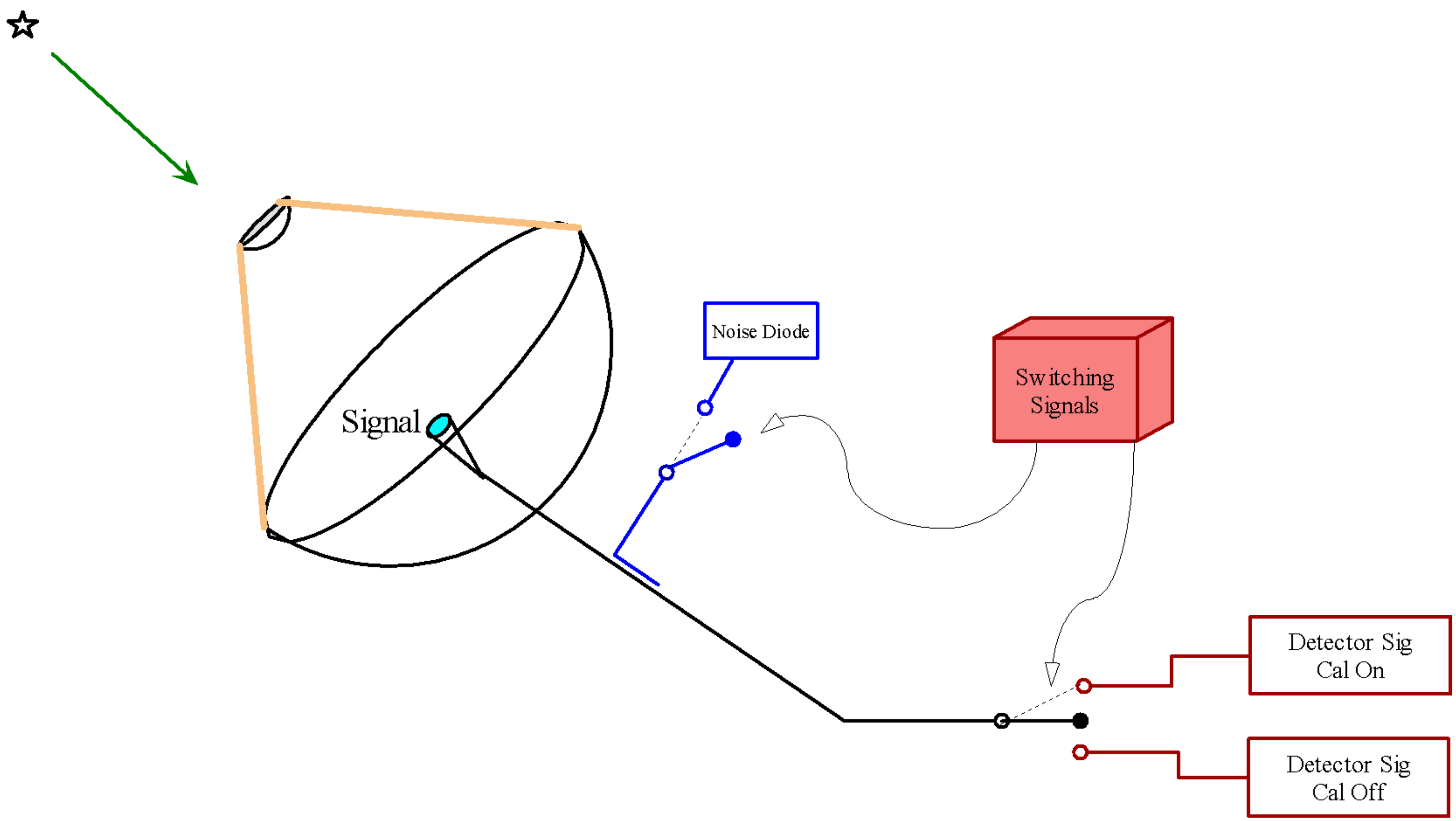
$$\sigma_{T_{src}} = \left(T_{sys} / \sqrt{BW}\right) \cdot \sqrt{\frac{1}{t^{reference}} + \frac{1}{t^{signal}}}$$

Continuum - Point Sources

Assumptions:

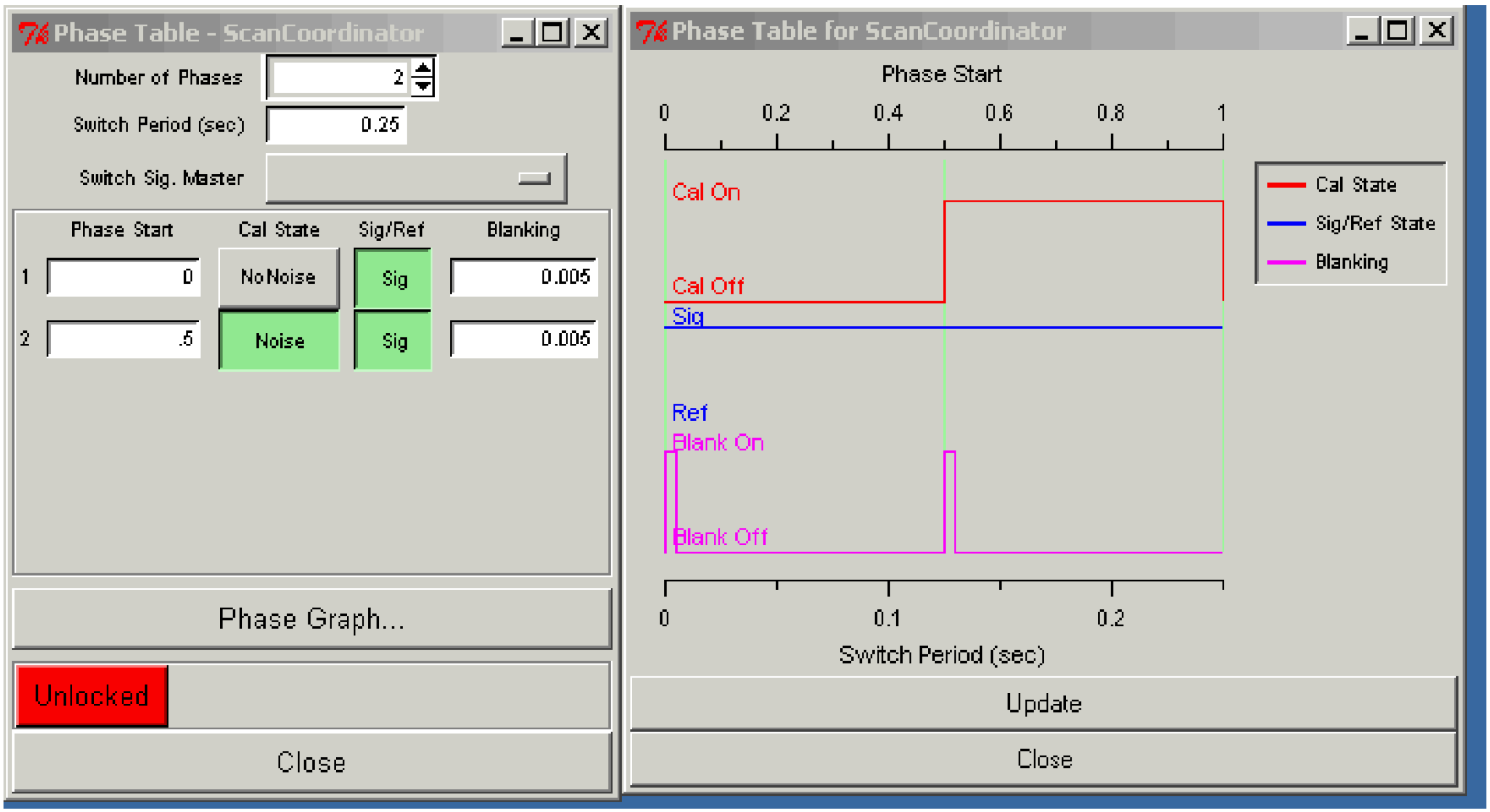
- Narrow bandwidths,
- Linear power detector,
- Source intensity << Tsys,
- Noise diode temperature << Tsys,
- $t^{reference} = t^{signal}$
- $t_{cal\_on} = t_{cal\_off}$
- Blanking time << t^{signal}

Phases of a Observation
Total Power



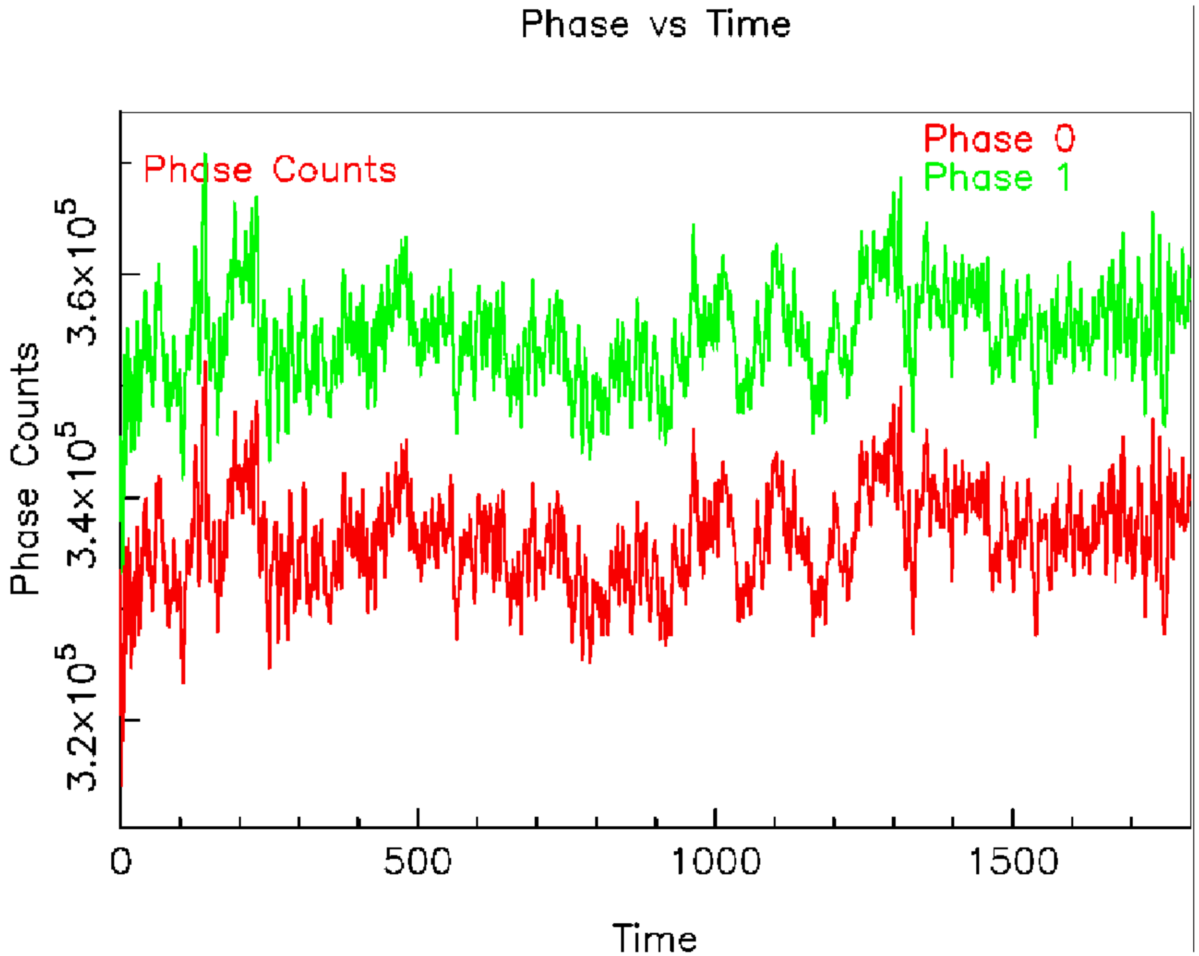
Phases of a Observation

Total Power



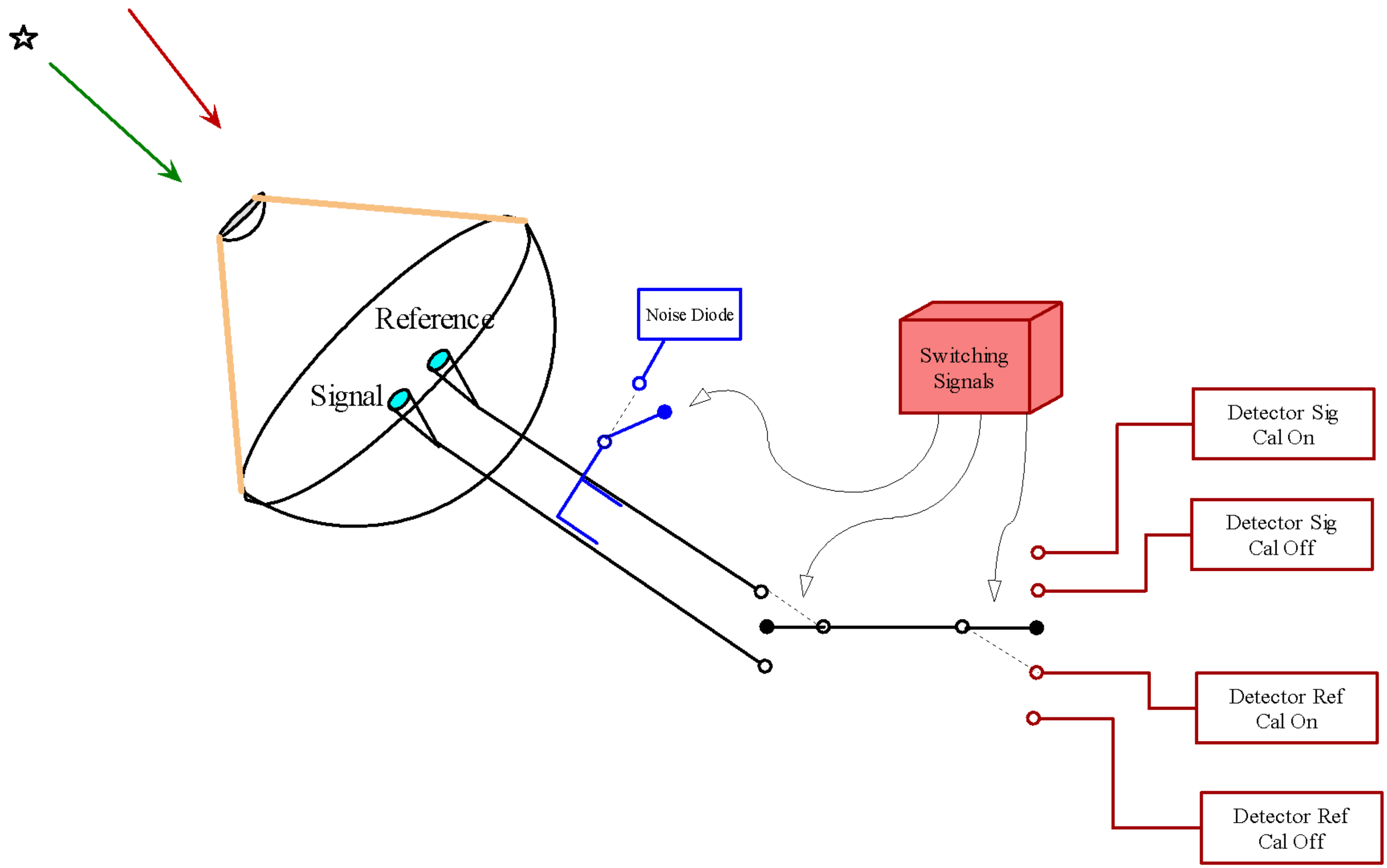
Continuum - Point Sources

Total Power



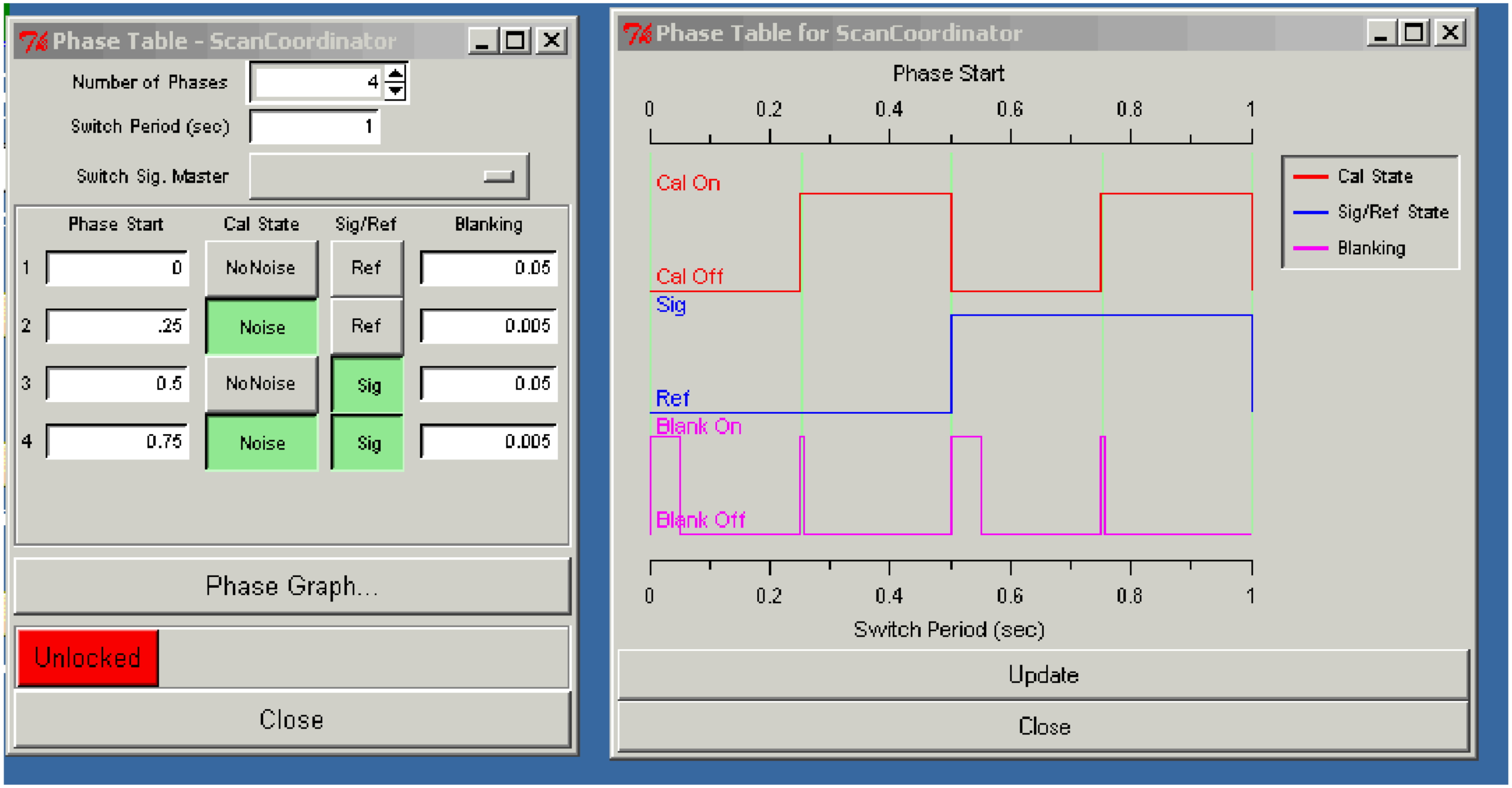
Phases of a Observation

Switched Power



Phases of a Observation

Switched Power



Continuum - Point Sources

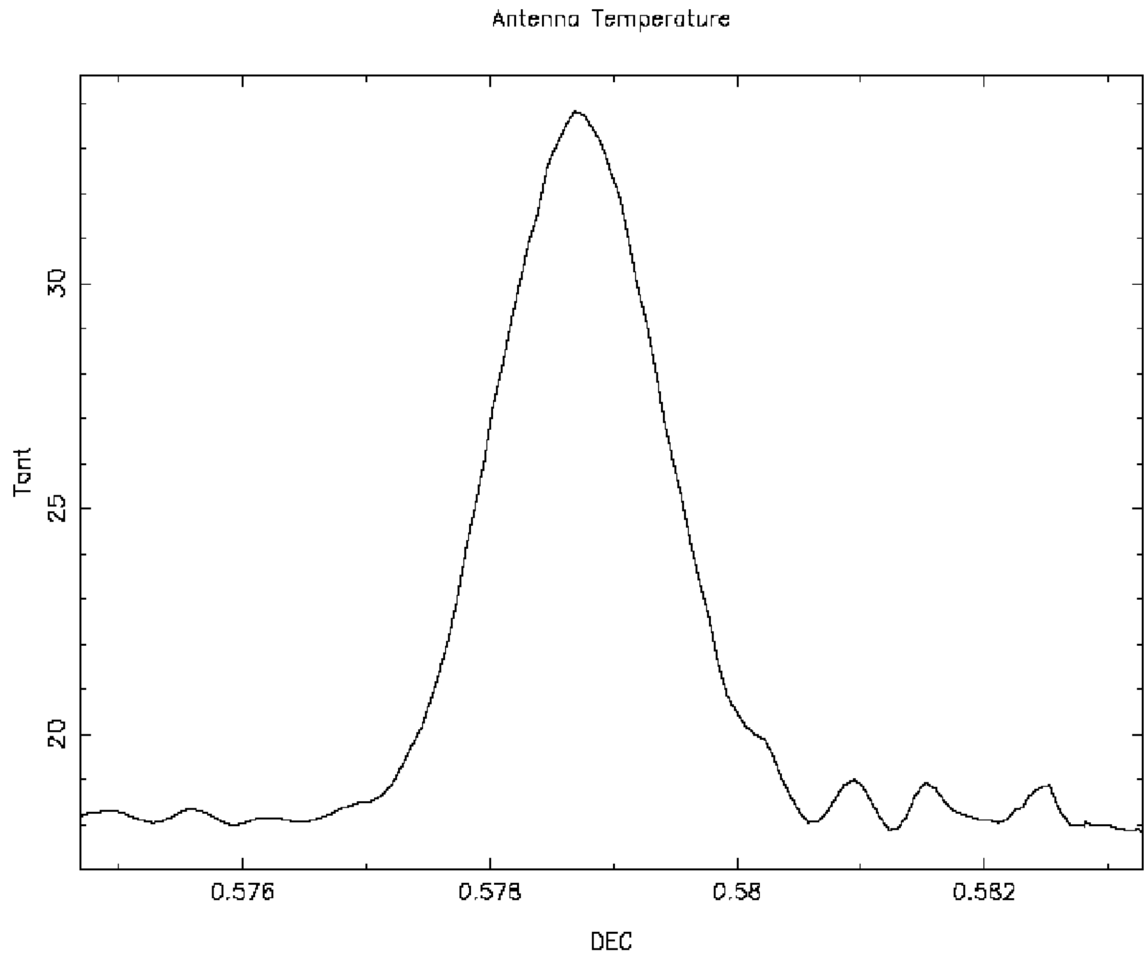
Beam-Switched Observation

$$T_{ant}^{reference}(i) = \left\langle \frac{T_{cal}}{P_{cal\_on}^{reference}(i) - P_{cal\_off}^{reference}(i)} \right\rangle \cdot \frac{\left(P_{cal\_on}^{reference}(i) + P_{cal\_off}^{reference}(i)\right)}{2}$$

$$T_{ant}^{signal}(i) = \left\langle \frac{T_{cal}}{P_{cal\_on}^{signal}(i) - P_{cal\_off}^{signal}(i)} \right\rangle \cdot \frac{\left(P_{cal\_on}^{signal}(i) + P_{cal\_off}^{signal}(i)\right)}{2}$$

$$T_{src} = \left\langle T_{ant}^{signal}(i) - T_{ant}^{reference}(i) \right\rangle$$

Continuum - Point Sources
On-The-Fly Observation



Continuum - Point Sources

On-The-Fly Observation

If total power:

$$T_{ant}(i) = \left\langle \frac{T_{cal}}{P_{cal\_on}(i) - P_{cal\_off}(i)} \right\rangle \cdot \frac{\left(P_{cal\_on}(i) + P_{cal\_off}(i)\right)}{2}$$

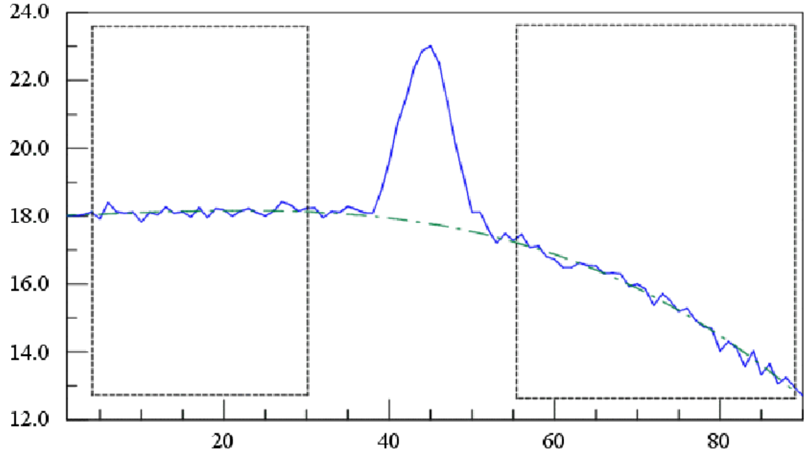
If beam-switching (switched power):

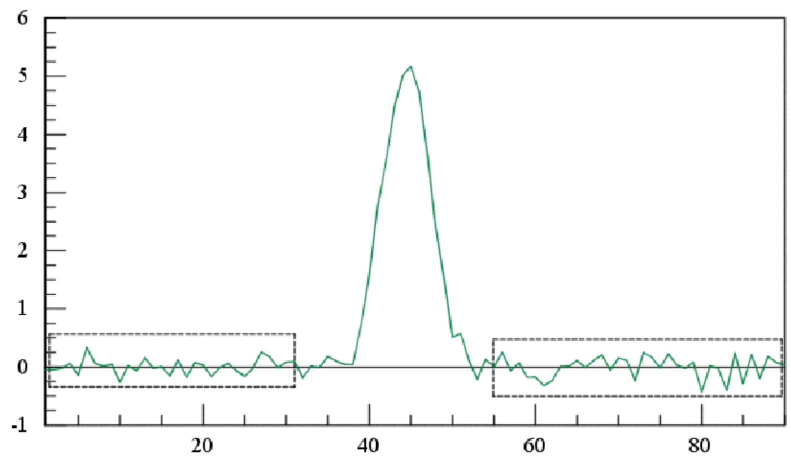
$$T_{ant}^{reference}(i) = \left\langle \frac{T_{cal}}{P_{cal\_on}^{reference}(i) - P_{cal\_off}^{reference}(i)} \right\rangle \cdot \frac{\left(P_{cal\_on}^{reference}(i) + P_{cal\_off}^{reference}(i)\right)}{2}$$

$$T_{ant}^{signal}(i) = \left\langle \frac{T_{cal}}{P_{cal\_on}^{signal}(i) - P_{cal\_off}^{signal}(i)} \right\rangle \cdot \frac{\left(P_{cal\_on}^{signal}(i) + P_{cal\_off}^{signal}(i)\right)}{2}$$

$$T_{ant}(i) = T_{ant}^{signal}(i) - T_{ant}^{reference}(i)$$

Baseline Fitting
Polynomials



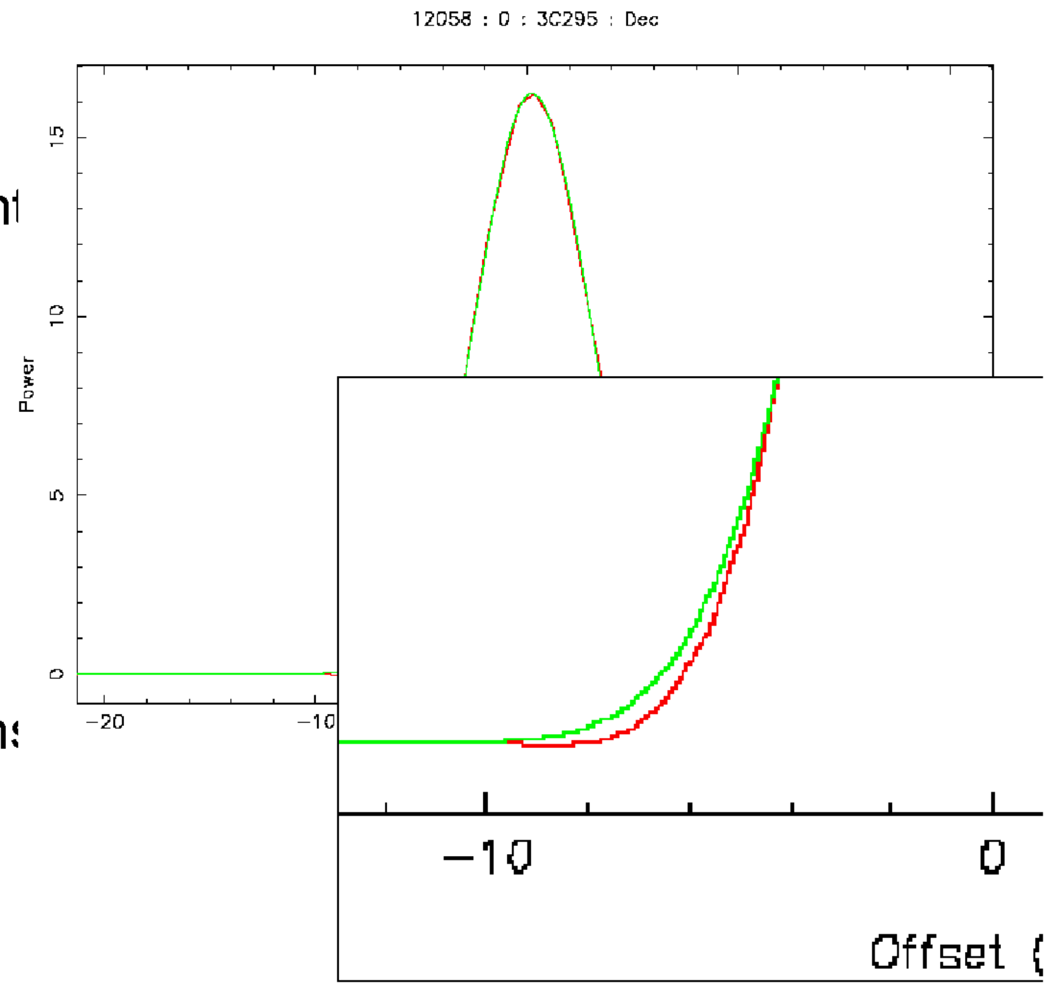


- Set order of polynomial
- Define areas devoid of emission.
- --------------------------
- Creates false features
- Introduces a random error to an observation,

Continuum - Point Sources

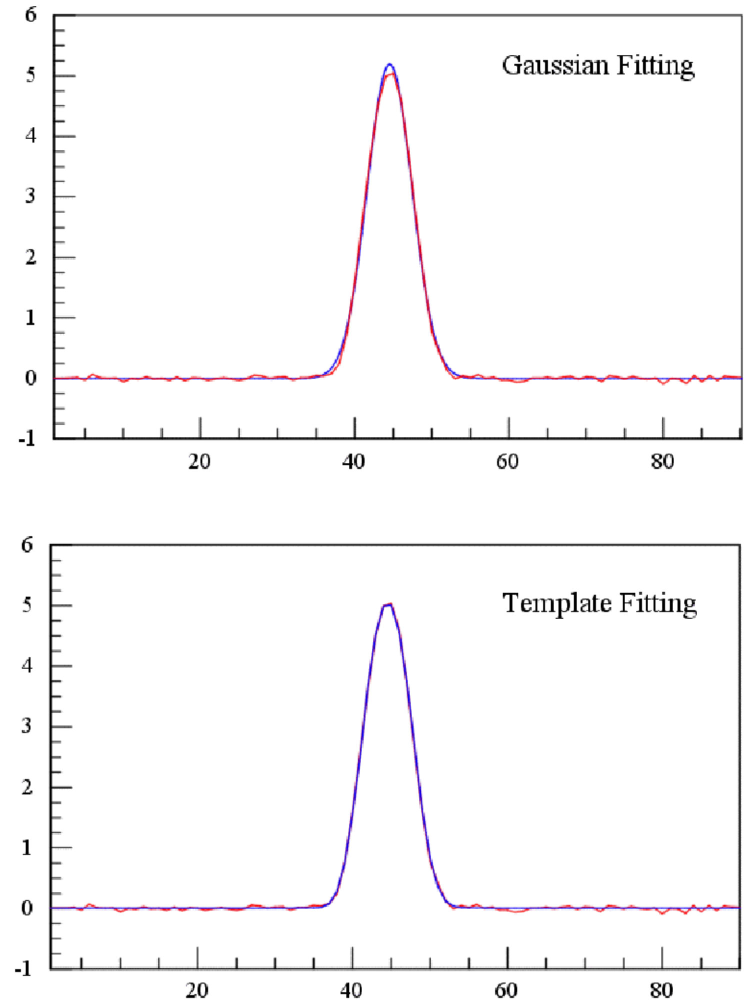
Gaussian Fitting

- Restrict data to between the half power points,
- Define initial guesses
- Set flags to fit or hold constant each parameter
- Set number of iterations
- Set convergence criteria
- ----------------------------
- Fitted parameters
- Chi-square of the fit
- Parameter standard deviations

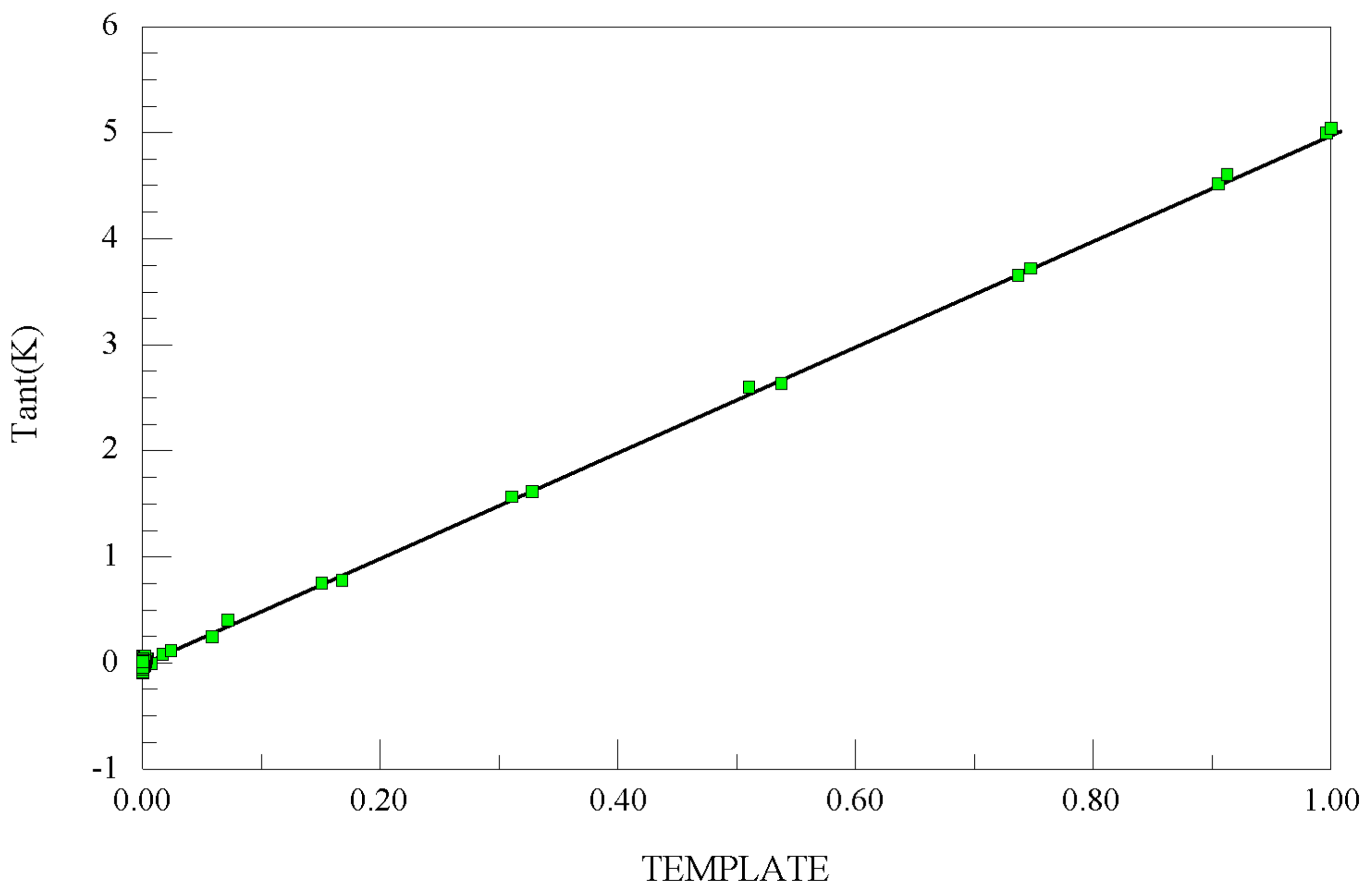


Template Fitting

- Create a template:
  - Sufficient knowledge of the telescope beam, or
  - Average of a large number of observations.
- ---------------
- Convolve the template with the data => x-offset.
- Shift by the x-offset.
- Perform a linear least-squares fit of the template to the data:



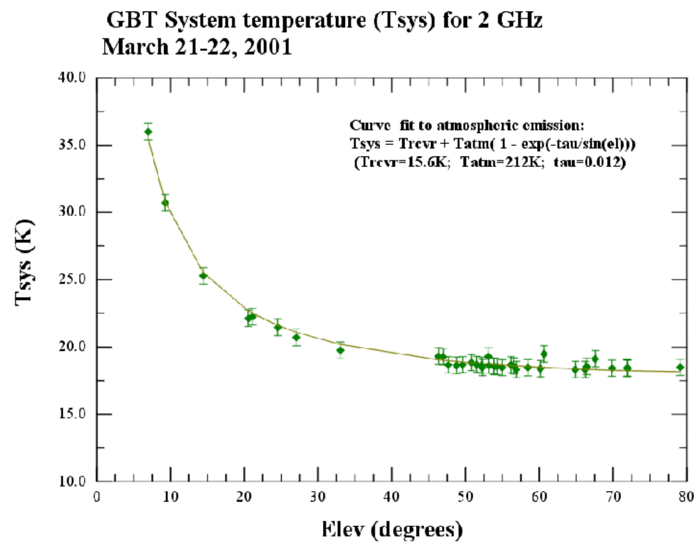
Template Fitting

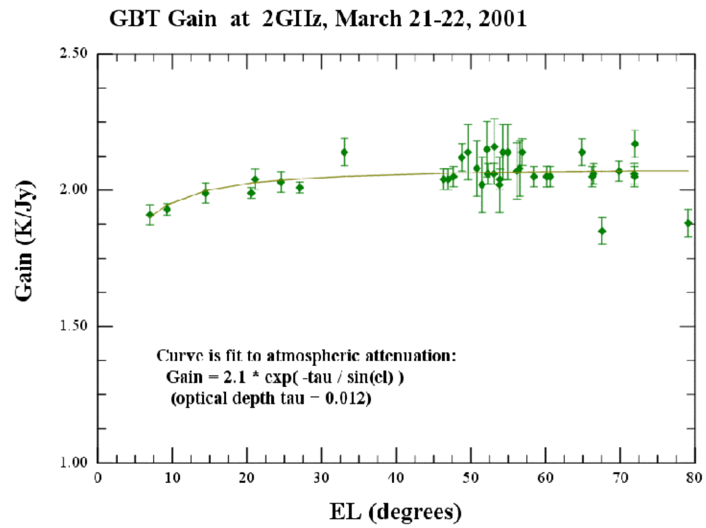


Averaging Data

- T_{sys} changes due to atmosphere emission.
- T_{ant} changes due to atmosphere opacity.
- --------------------
- Use weighted average
- Weights: $1/\sigma^2$.

$$\sigma_{avrg} = \frac{1}{\sqrt{\sum_j \frac{BW_j \cdot t_j}{Tsys_j^2}}} = \frac{1}{\sqrt{\sum_j \frac{1}{\sigma_j^2}}}$$

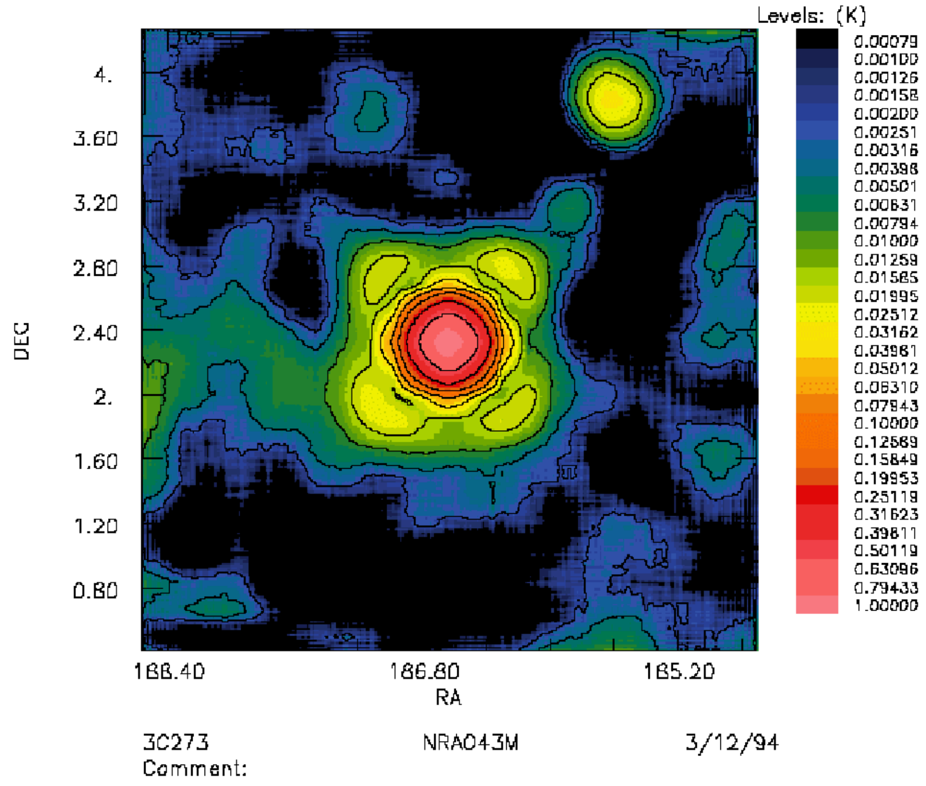




Continuum - Extended Sources

On-The-Fly Mapping

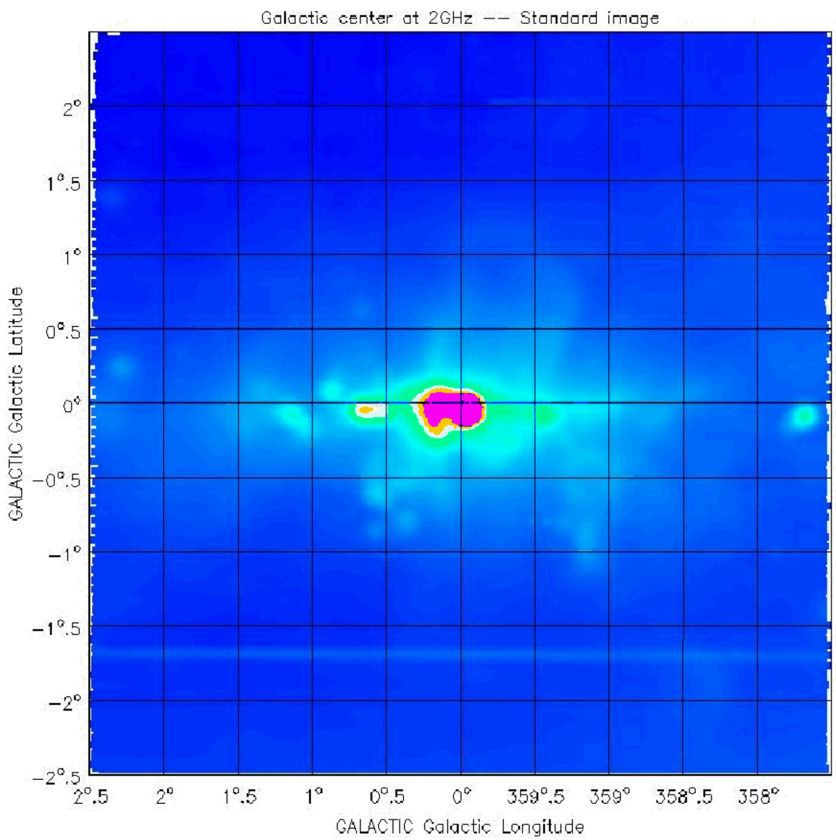
- Telescope slews
- A few samples /sec.
- Highly oversampled.
- Could be beam switching
- ----------------------
- Convert Power into T_{ant}.
- Fit baseline to each row?
- Grid into a matrix



Continuum - Extended Sources

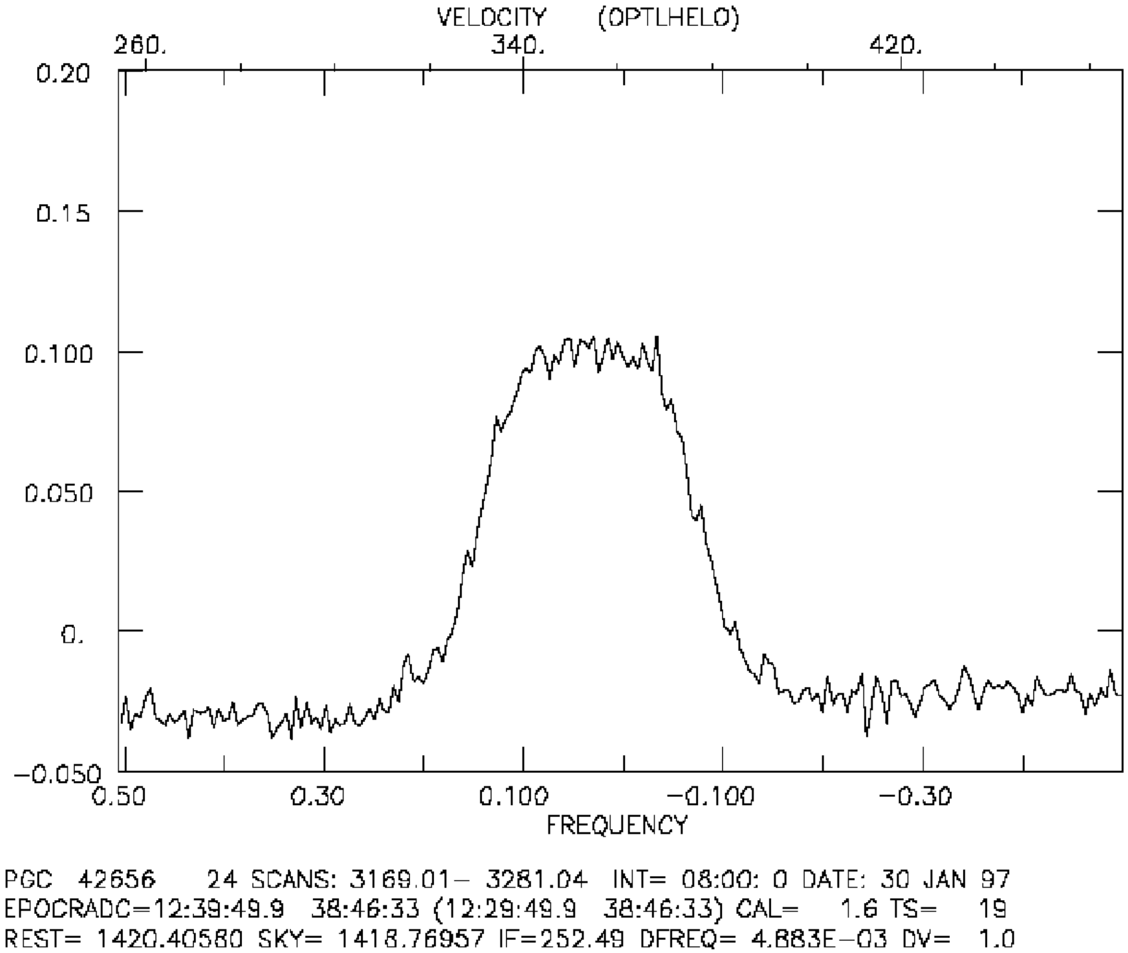
On-The-Fly Mapping - Common Problems

- Striping (Emerson 1995; Klein and Mack 1995).
- If beam-switched, Emerson, Klein, and Haslam (1979) to reconstruct the image.
- Make multiple maps with the slew in diferent direction.



Spectral-Line - Point Sources

Position-Switched Observing



Spectral-Line - Point Sources

Position-Switched Observing

$$T_{ant}(f) = \frac{T_{cal}(f)}{2} \cdot \left[\frac{\left(P_{cal\_on}^{signal}(f) + P_{cal\_off}^{signale}(f)\right) - \left(P_{cal\_on}^{reference}(f) + P_{cal\_off}^{reference}(f)\right)}{\left(P_{Cal\_On}^{reference}(f) - P_{Cal\_Off}^{reference}(f)\right)} \right]$$

$$= \left(T_{sys}(f) + \frac{T_{cal}(f)}{2} \right) \cdot \left[\frac{\left(P_{cal\_on}^{signal}(f) + P_{cal\_off}^{signale}(f)\right) - \left(P_{cal\_on}^{reference}(f) + P_{cal\_off}^{reference}(f)\right)}{\left(P_{cal\_on}^{reference}(f) + P_{cal\_off}^{reference}(f)\right)} \right]$$

Avrg Tsys

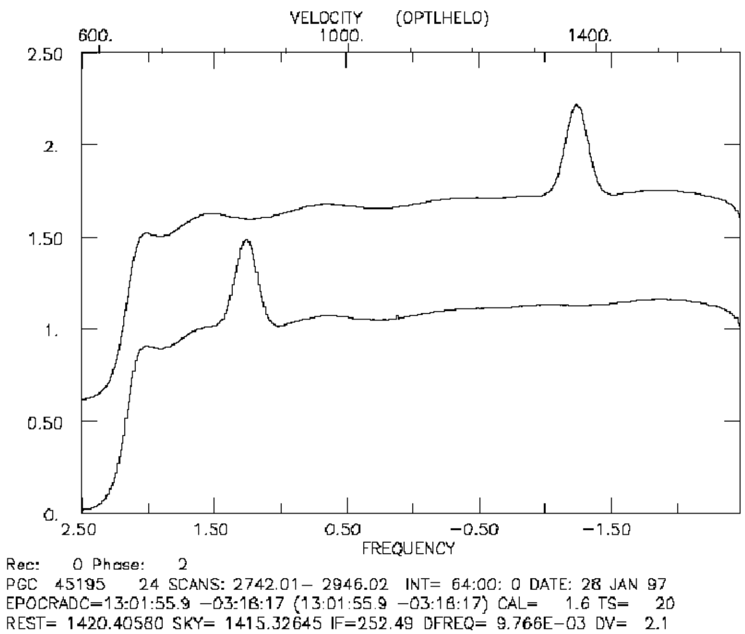
SIGNAL

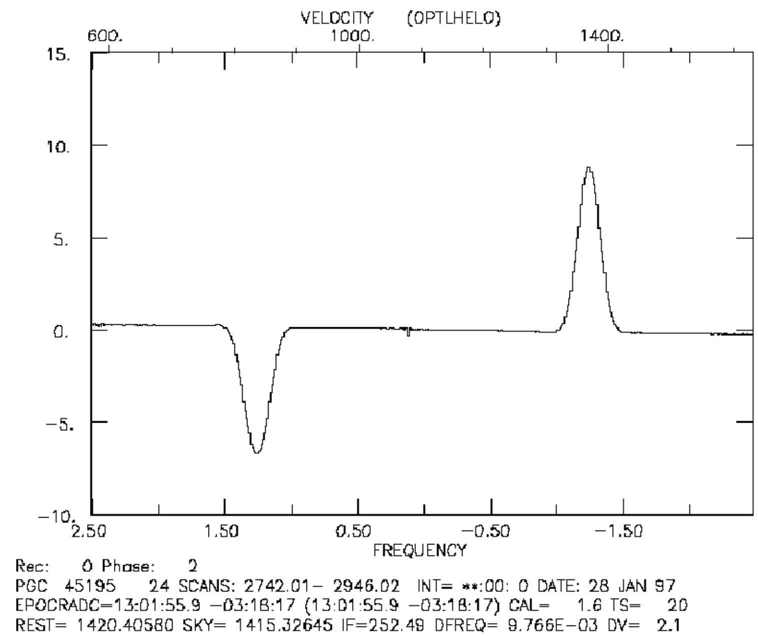
REFERENCE

$$\sigma_{T_{ant}} = \text{Constant} \cdot \left(T_{sys} / \sqrt{BW / N} \right) \cdot \sqrt{\frac{1}{t^{reference}} + \frac{1}{t^{signal}}}$$

Spectral-Line - Point Sources

Frequency-Switched Observing - In band





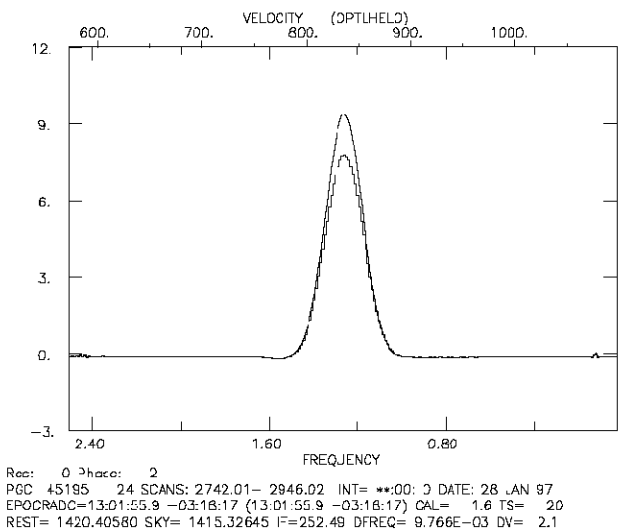
Tsys(REF)*[(SIG-REF)/REF -
(SIG'-REF')/REF'

Spectral-Line - Point Sources

Frequency-Switched Observing - In Band

$$T_{ant}(f) = \frac{T_{cal}(f)}{2} \cdot \left[\frac{\left(P_{cal\_on}^{signal}(f) + P_{cal\_off}^{signal}(f)\right) - \left(P_{cal\_on}^{reference}(f) + P_{cal\_off}^{reference}(f)\right)}{\left(P_{Cal\_On}^{reference}(f) - P_{Cal\_Off}^{reference}(f)\right)} \right] +$$

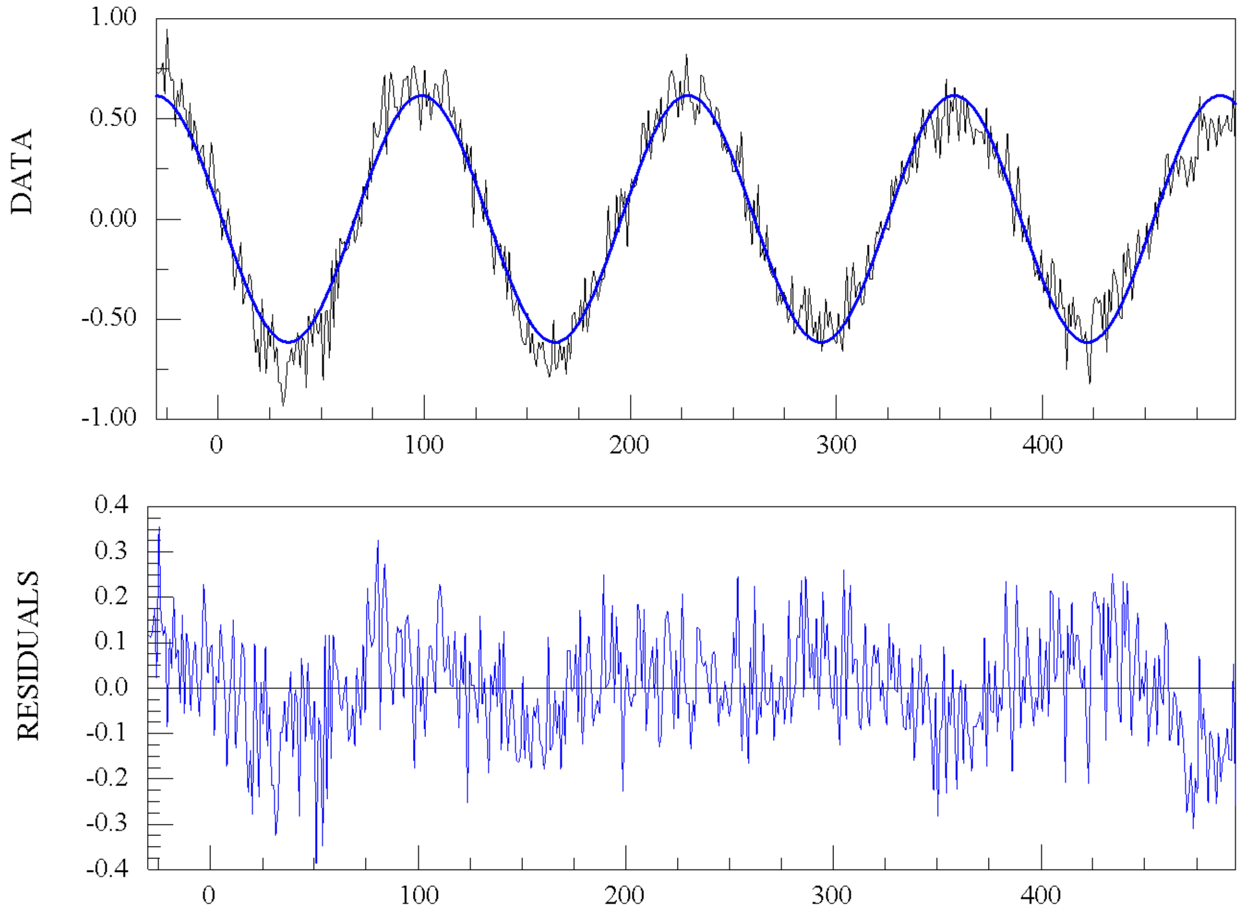
$$\frac{T_{cal}(f)}{2} \cdot \left[\frac{\left(P_{cal\_on}^{reference}(f+\Delta f) + P_{cal\_off}^{reference}(f+\Delta f)\right) - \left(P_{cal\_on}^{signal}(f+\Delta f) + P_{cal\_off}^{signal}(f+\Delta f)\right)}{\left(P_{Cal\_On}^{signal}(f+\Delta f) - P_{Cal\_Off}^{signal}(f+\Delta f)\right)} \right]$$



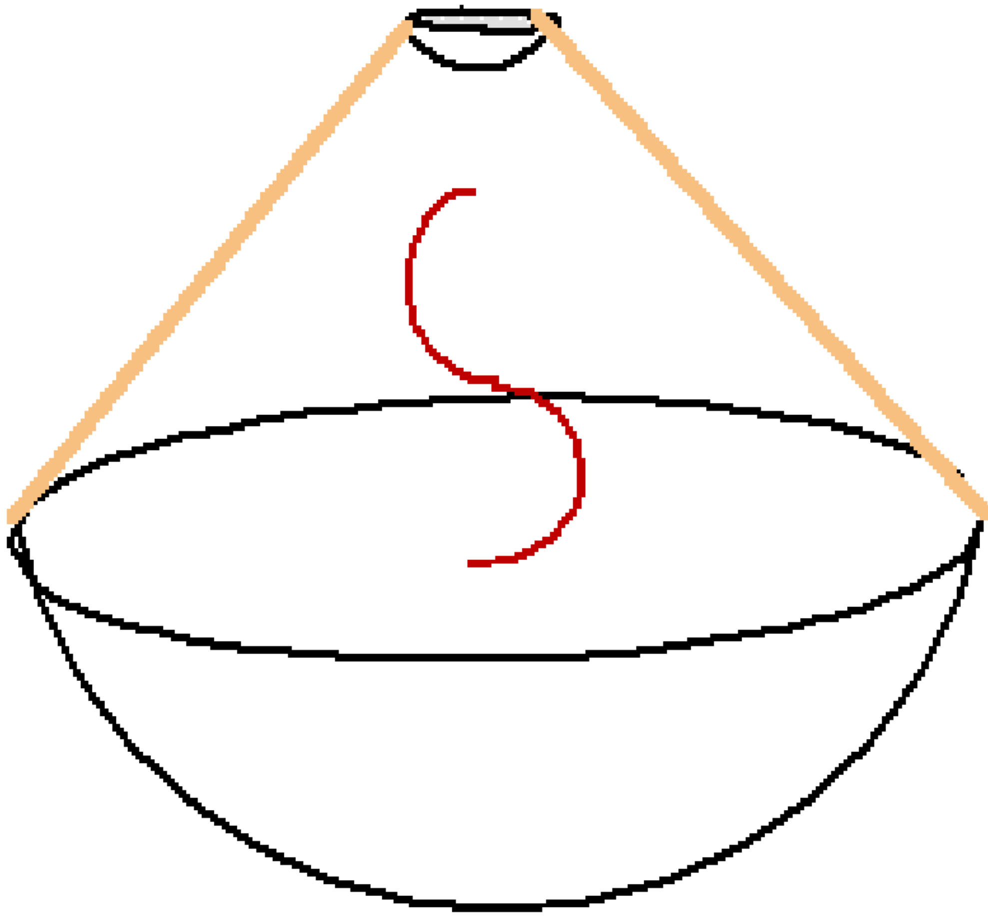
Tsys(REF)*(SIG-REF)/REF +
Tsys(SIG)*(REF'-SIG')/SIG'

Spectral-Line
Baseline Fitting

- Polynomial: same as before
- Sinusoid



Spectral-Line
Ripples



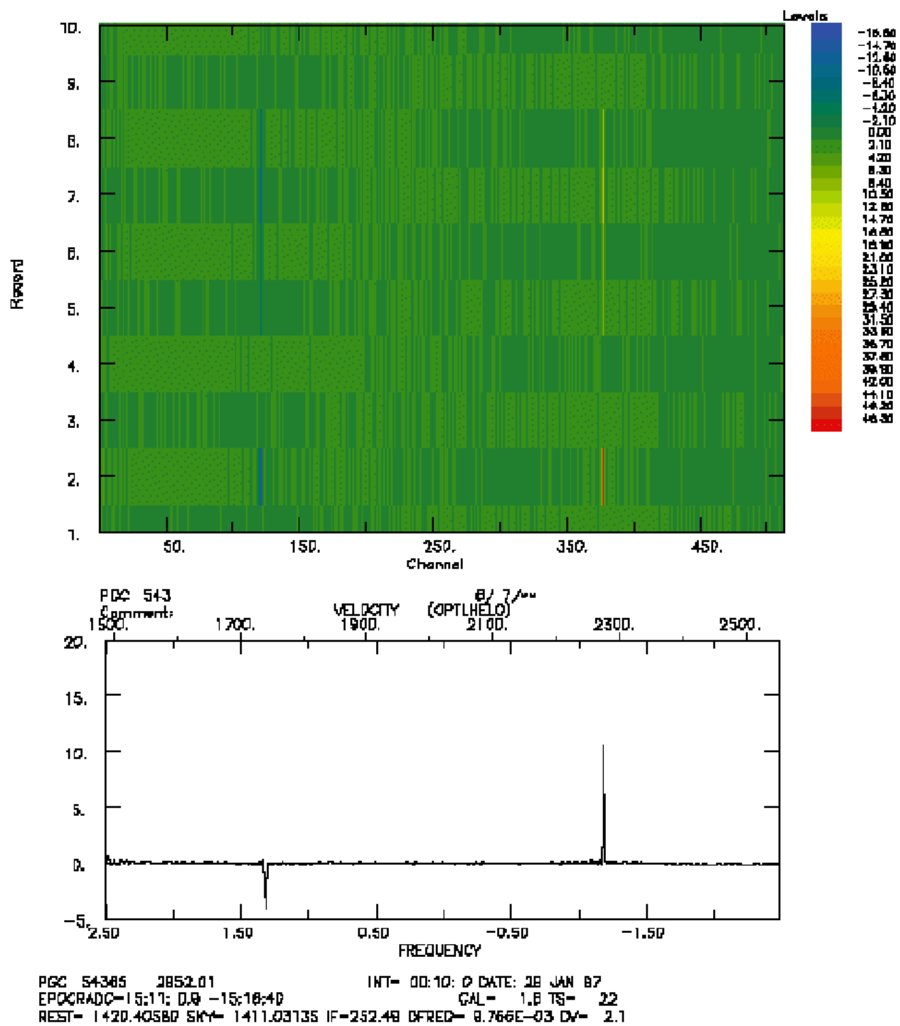
Spectral-Line

Other Algorithms

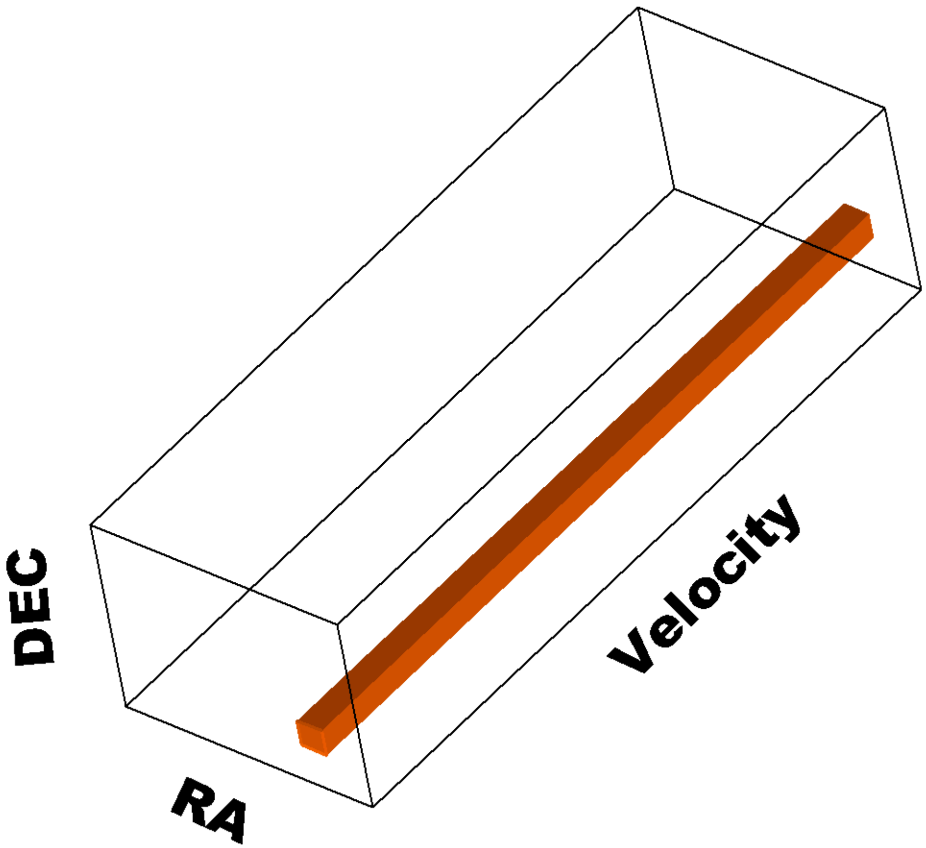
- Averaging: Weighted by $1/\sigma^2$
- Velocity Calibration
- Velocity/Frequency Shifting
  - Doppler tracking limitations
- Gaussian fitting
  - Multi-component fits should be done simultaneosuly
- Smoothing
  - Decimating vs. non-decimating routines
- Moments for Integrated Intensities; Velocity centroids, ….

Spectral-Line

RFI Excision

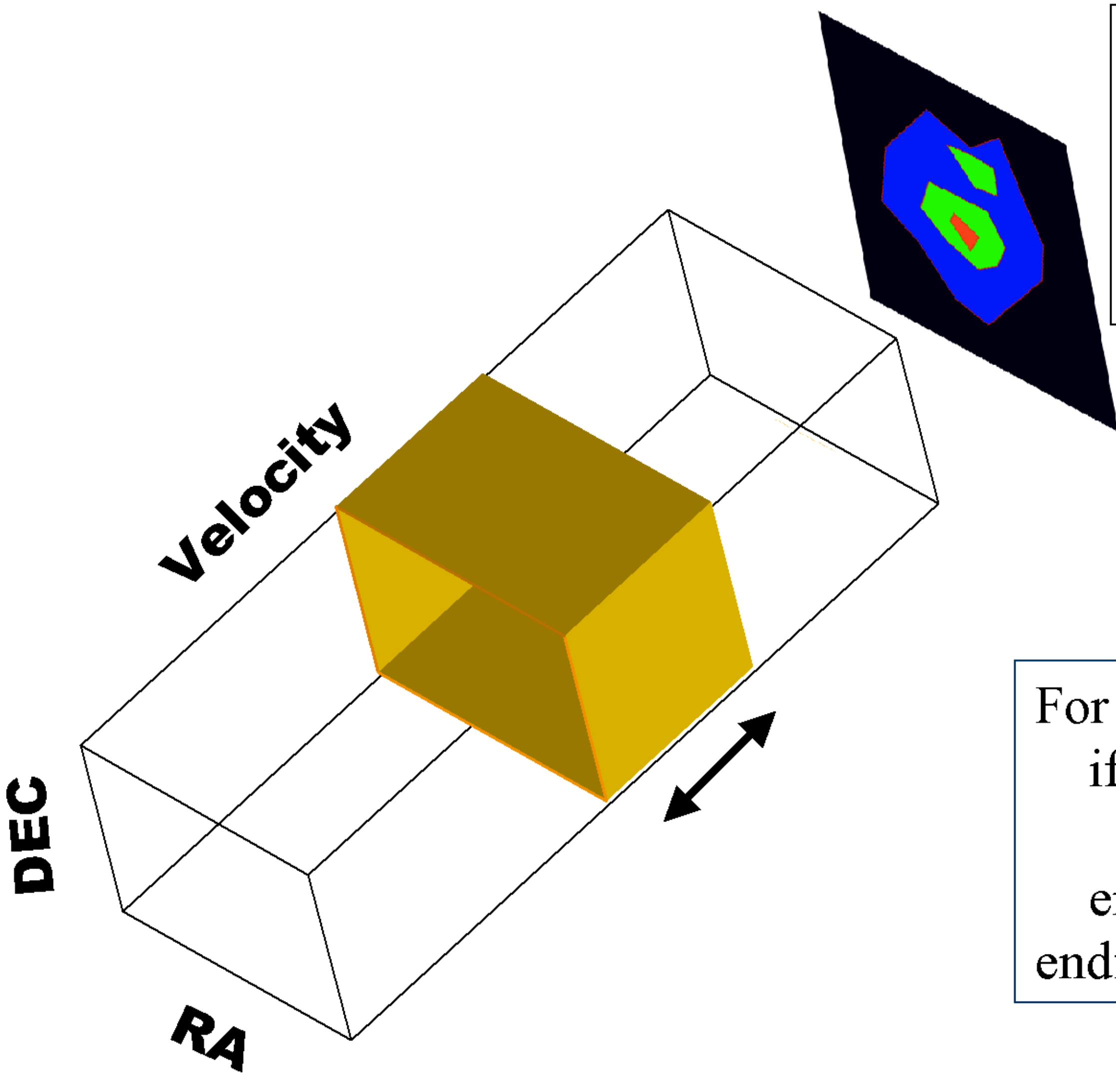


Spectral-Line Mapping
Grid and On-the-Fly



Spectral-Line Mapping

Grid and On-the-Fly



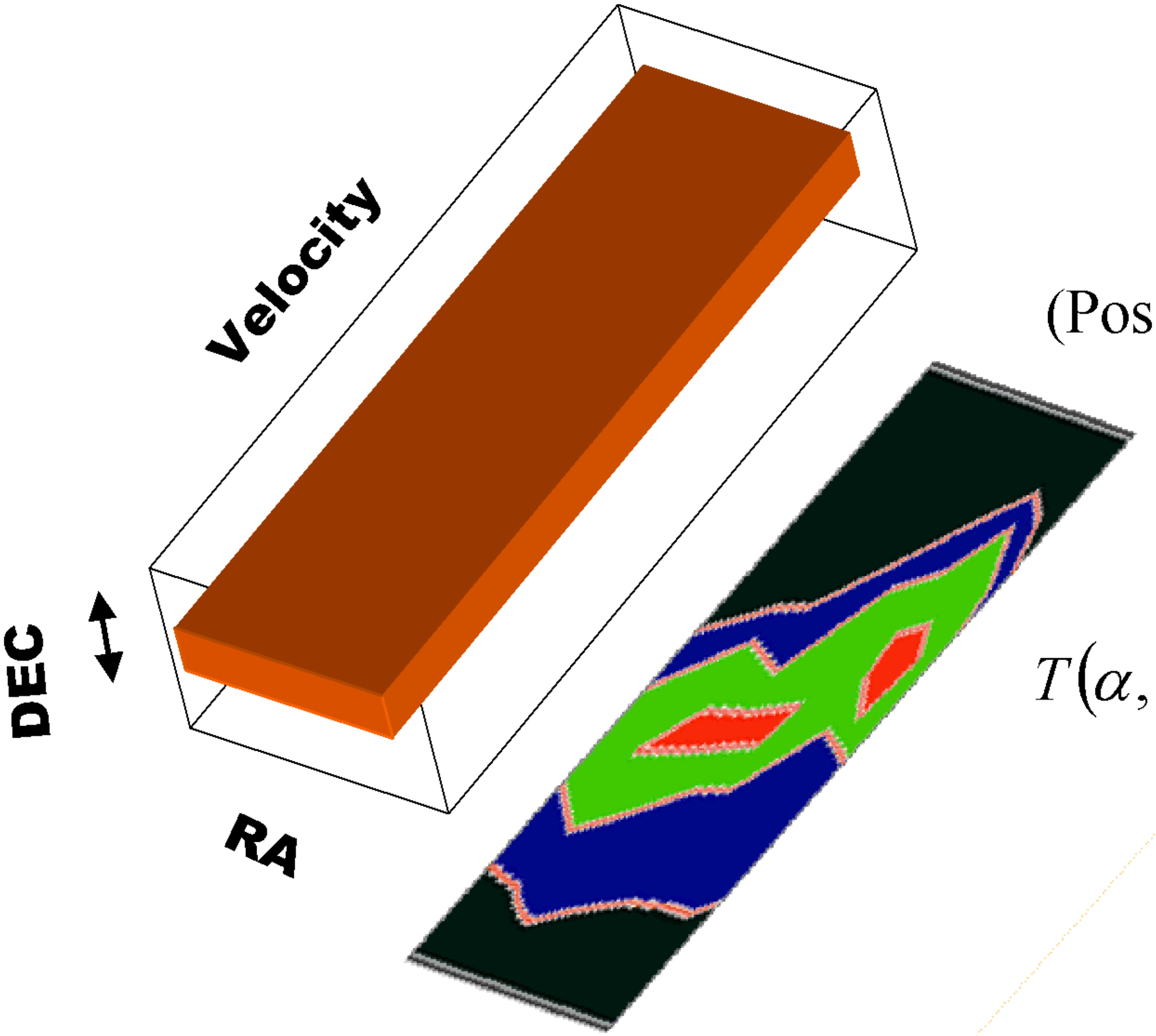
$$W(\alpha,\delta) = \sum_{V_i = V_{\min}}^{V_{\max}} T(\alpha,\delta,V_i) \cdot \Delta V_i$$

(If V1=V2 => Channel Map)

```
For {v=vmin} {v <=vmax} {v++} {
   if T(α,δ,v) > Tmin then
      W(α,δ)=W(α,δ)+ T(α,δ,v)
   endif
endfor
```

Spectral-Line Mapping

Grid and On-the-Fly

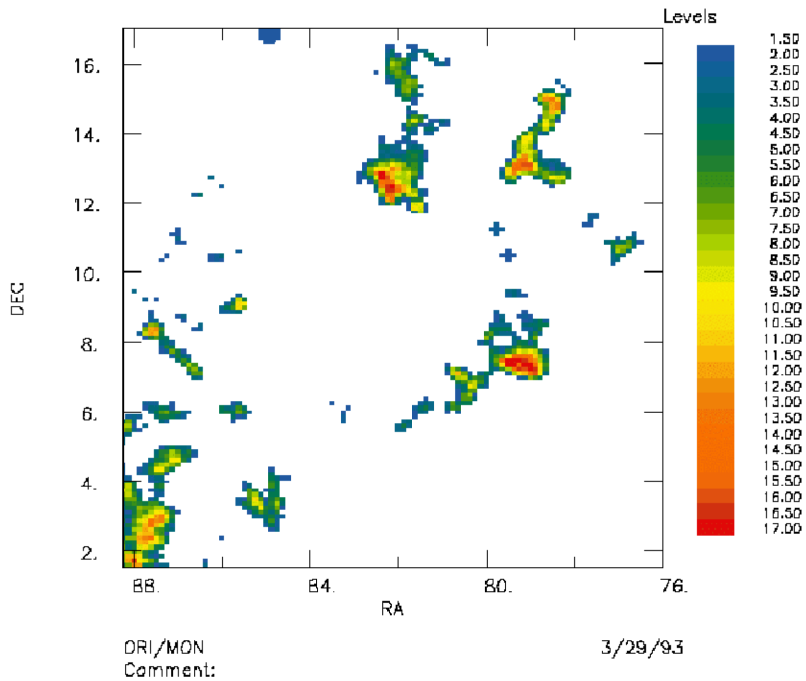


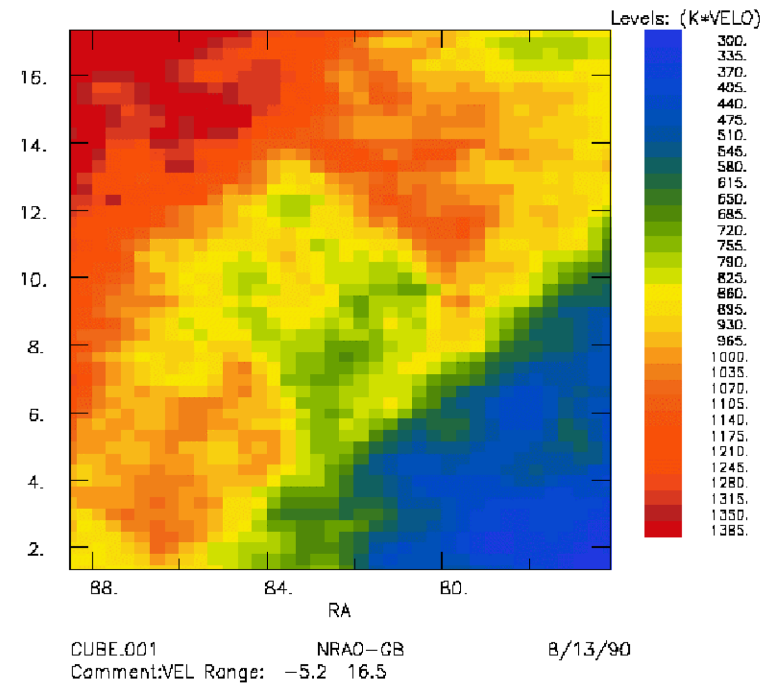
(Position-velocity map)

$$T(\alpha, V) = \sum_{\delta=\delta_{\min}}^{\delta_{\max}} T(\alpha, \delta, V)$$

Spectral-Line Mapping

Rudimentary Analysis





Conclusion
The Future of Single-Dish Data Analysis

- Increase in the use of RDBMS.
- Support the analysis of archived data.
- Sophisticated visualization tools.
- Sophisticated, robust algorithms (mapping).
- Data pipelining for the general user.
- Automatic data calibration using sophisticated models of the telescope.
- Algorithms that deal with data sets.
- Analysis systems supported by cross-observatory groups