Interferometric Spectral Line Imaging

Martin Zwaan

(Chapters 11+12 of synthesis imaging book)

Topics

- Calibration
- Gibbs phenomenon
- Continuum subtraction
- Flagging
- First reduction steps

After imaging: Bärbel's talk

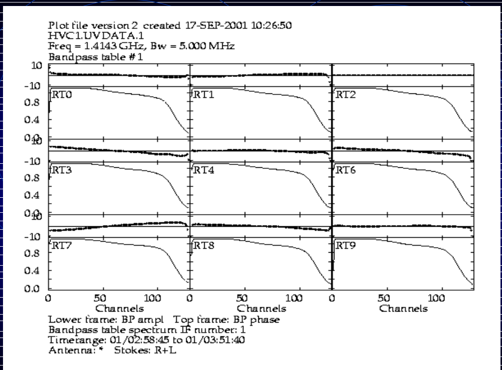
Why Spectral Line Interferometry?

- Spectroscopy
  - Important spectral lines
    - HI hyperfine line
    - Recombination lines
    - Molecules (CO, OH, H_2O, masers)
  - Calculate column densities (physical state of ISM) and line widths (rotation of galaxies)
- Continuum
  - Reduce bandwidth smearing
  - Isolate RFI

Calibration

- Continuum data: determine complex gain solutions as function of time
- Spectral line data: same, but also function of ν
- Bandpass: complex gain as function of frequency
- Factors that affect the bandpass:

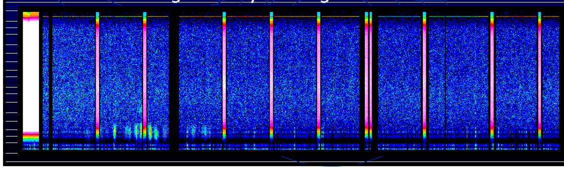
  Front-end system, IF transmission system (VLA 3 MHz ripple), back-end filters, Correlator, atmosphere, standing waves
- Different for all antennas
- Usually not time-dependent



Calibration

- Determine bandpass $B_{i,j}(\upsilon)$ o…
  Pcal-Scal-target-Sca…
- Pcal: strong (point) source with known …(υ), observe at same υ as target
- Observe Pcal more often for high spectral DR
- Observe long enough so that uncertainties in BP do not contribute significantly to image

Peak continuum/
rms noise image



Calibration procedure

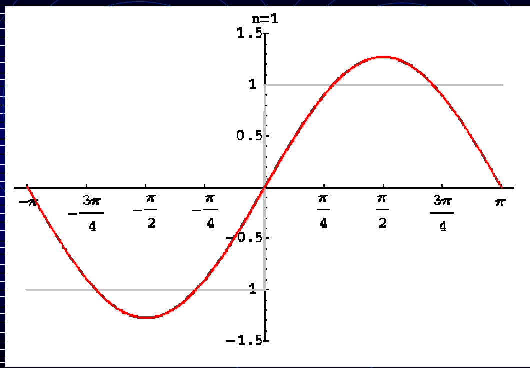
- Create pseudo-continuum (inner 75% of channels)
- Determine complex gains $G_{i,j}(t)$
- Determine $B_{i,j}(\upsilon)$
- Effects of atmosphere and source structure are removed by dividing by pseudo-continuum
- N unknowns, $N(N-1)/2$ measurables
- Compute separate solution for every observation of Pcal

Check bandpass calibration

- Smooth variation with frequency
- Apply BP solution to Scal: should be flat
- Compare BP solutions of different scans (for all antennas)

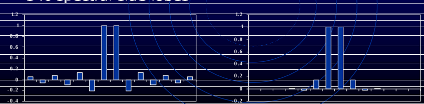
Gibbs Phenomenon

- Wiener-Khintchine theorem:
  Spectral content I(ν) of stationary signal is Fourier transform of the time cross-correlation function R(τ)
  - Need to measure R(τ) from -∞ to ∞!
  - In practice: only measure from -N/2B to N/2B
    → Multiply R(τ) with a window function (uniform taper)
  - In ν domain: I(ν) convoluted with sinc(x)
  - Nulls spaced by channel separation
  - Effective resolution: 1.2 times channel separation
  - -22% spectral side lobes



Solutions

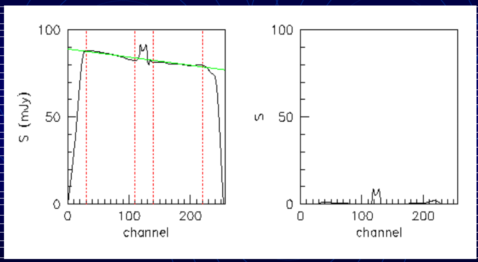
- Observe with more channels than necessary
- Remove first channels
- Tapering sharp end of lag spectrum R(τ)
  - Hanning smoothing: f(τ)=0.5+0.5 cos (πτ/T)
  - In frequency space: multiplying channels with 0.25, 0.5, 0.25
  - After Hanning smoothing:
  - Effective resolution: 2.0 times channel separation
  - -3% spectral side lobes



Continuum Subtraction

- Every field contains several continuum sources
- Separate line and continuum emission
- Two basic methods:
  Subtract continuum in map domain (IMLIN)
  Subtract continuum in UV domain (UVSUB, UVLIN)
- Know which channels are line free
- Use maximum number of line free channels
  Iterative process

Continuum Subtraction



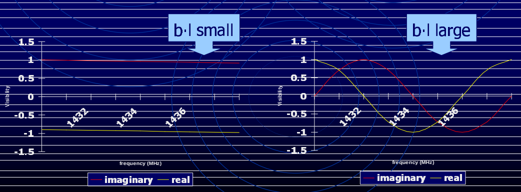
IMLIN

- Fit low-order polynomials to selected channels (free from line emission) at every pixel in image cube and subtract the appropriate values from all channels
- Don't have to go back to uv data
- Can't flag data
- Clean continuum in every channel
  - Time consuming
  - Non-linear: noisy data cube
  - Noisy continuum map

UVLIN

- Linear fits to real and imaginary components versus channel number for each visibility and subtracts the appropriate values from all channels
- Visibilities: (Baseline length; Distance from phase center)

  $V=\cos(2\pi\upsilon bl/c) + i\sin(2\pi\upsilon bl/c)$



UVLIN (cont'd)

- Allows to shift visibilities to move single strong source to image center → do fitting → shift back
- No need to deconvolve continuum sources in all channels (deconvolution is non-linear)
- Yields better continuum image
- Fast
- Allows flagging (remove baselines with high residuals)
- Corrects for spectral slope
- Only works for restricted field of view

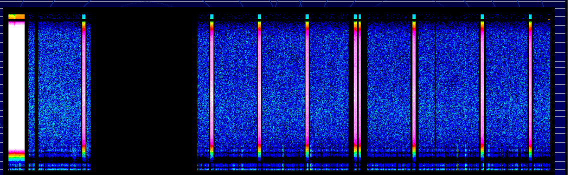
UVSUB

- Subtract Fourier transform of specified model from visibility data set. Input model may consist of the CLEAN components, input images, or specified model
- Works well for strong sources far away from phase center
- Non-linear: introduces errors in maps
- Slow!

A procedure for continuum subtraction

- Make large continuum map to find far field sources
- UVLIN on large number of channels
- Do Fourier transform and find line emission
- Look for artifacts from strong continuum sources
- Use UVLIN if one source dominates
- Use UVSUB if many sources dominate, then UVLIN
- Quality of continuum subtraction depends on quality of bandpass calibration

Flagging of Spectral Line Data



- Try UVLIN
- Try to maintain similar uv coverage in all channels

Basic Reduction Steps

- Read data
- Check quality and edit (flag)
- Make pseudo-continuum
- Determine gain solutions
- Determine bandpass
- Split off calibrated program source
- Subtract continuum
- Make image cube