The HIFI Instrument, It's Observing Modes and AOTs

Herschel Observation Planning Workshop

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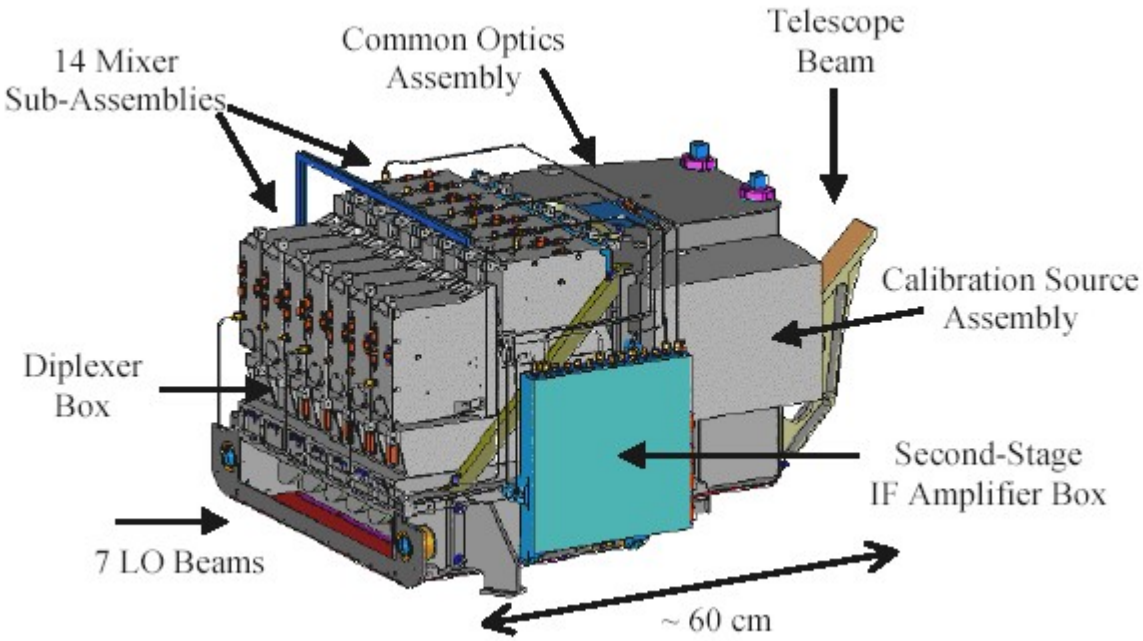
Introduction:

1. What is HIFI?
2. Dual Sideband Data
3. Need for HIFI Observing Modes
4. HIFI Reference Schemes
5. Observation Timing
6. HIFI Pointing Modes
7. The HIFI AOTs – combining reference schemes and pointing modes.
8. Point Source Observations with HIFI
9. Frequency Surveys with HIFI (point source)
10. Mapping with HIFI

1. What is HIFI?

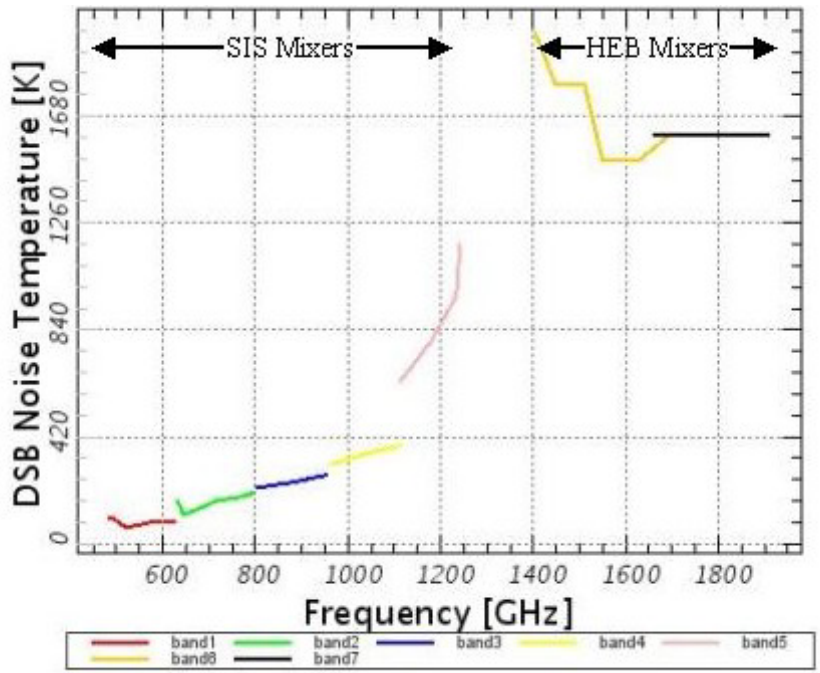


- Single pixel, **heterodyne** instrument with two polarizations.
- Frequency range **480 – 1250 and 1400-1916 GHz**.
- 2x7 heterodyne mixer bands, mix sky signal and local oscillator (LO) signals → **dual sideband** result.

- **Very high spectral resolution (up to 10^7).**
- **Beam size 44" (@480GHz) to 11" (@1916GHz)**
- **Instantaneous bandwidth of 4GHz (only 2.4GHz in 1400-1916GHz range).**
- **4 spectrometers (2xWBS and 2xHRS) that can be used simultaneously**

Sensitivities

- Given as single polarization, single sideband values in HSpot.
- Noise levels are for best placement within the visible 2.4 or 4GHz bandwidth of the IF band.



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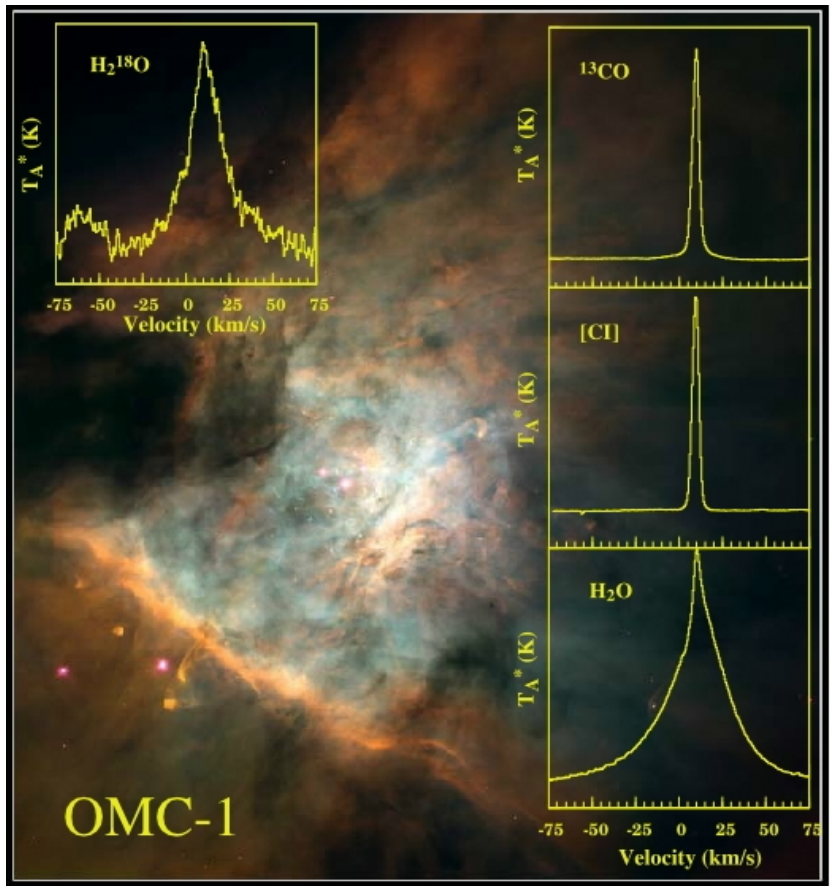
HIFI Spectrometers

- *WBS spectrometer* –
  - covers 4GHz range with 4 linear CCDs
  - only part used (2.4GHz) with bands 6 and 7 data).
  - single resolution of 1.1MHz (no user choice).

- *HRS spectrometer* –
  - up to 4 subbands available to user per polarization.
  - several selectable resolutions for the subbands (0.125, 0.25, 0.5 and 1.0MHz)
  - subbands can be placed anywhere in the 4GHz range.

Main Scientific Objectives

- Probe the physics, kinematics, and energetics of star forming (incl. H_2O)
- Molecular inventory of the wide variety of regions
- H_2O in planets and comets.
- Measure the mass-loss history of stars
- Measure C and N isotopic abundances



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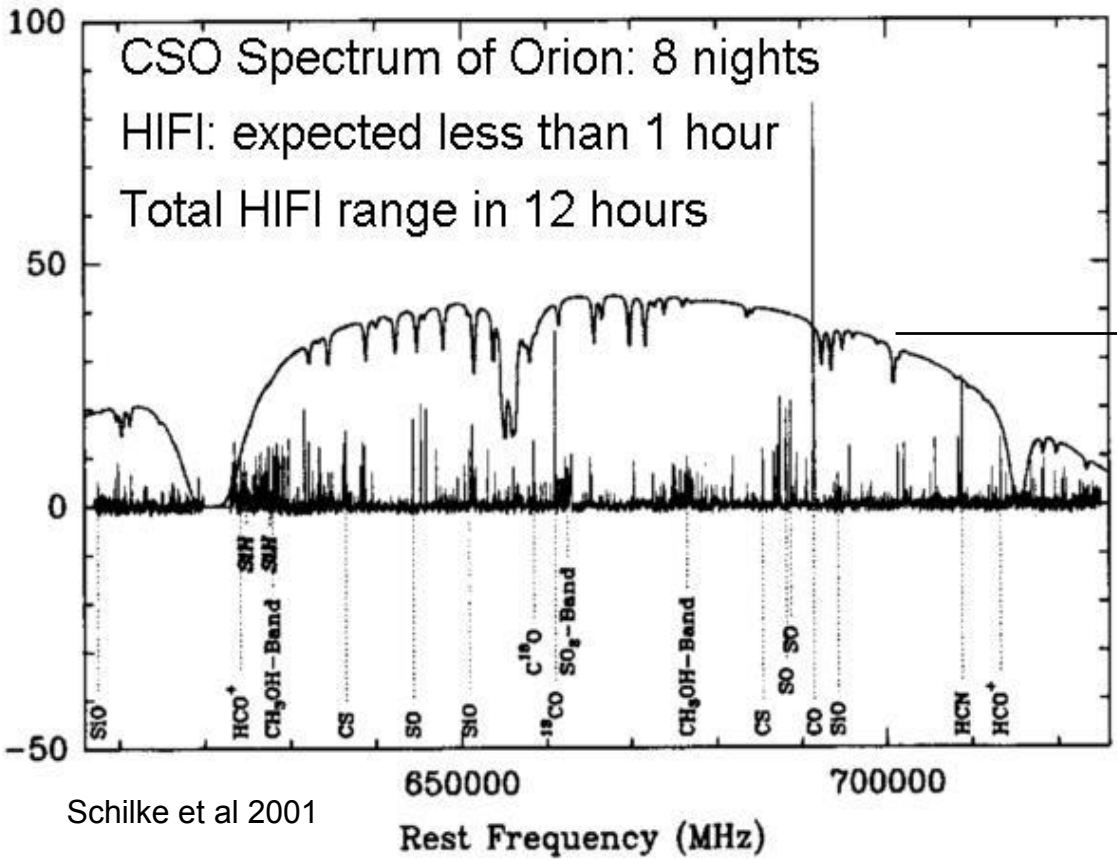
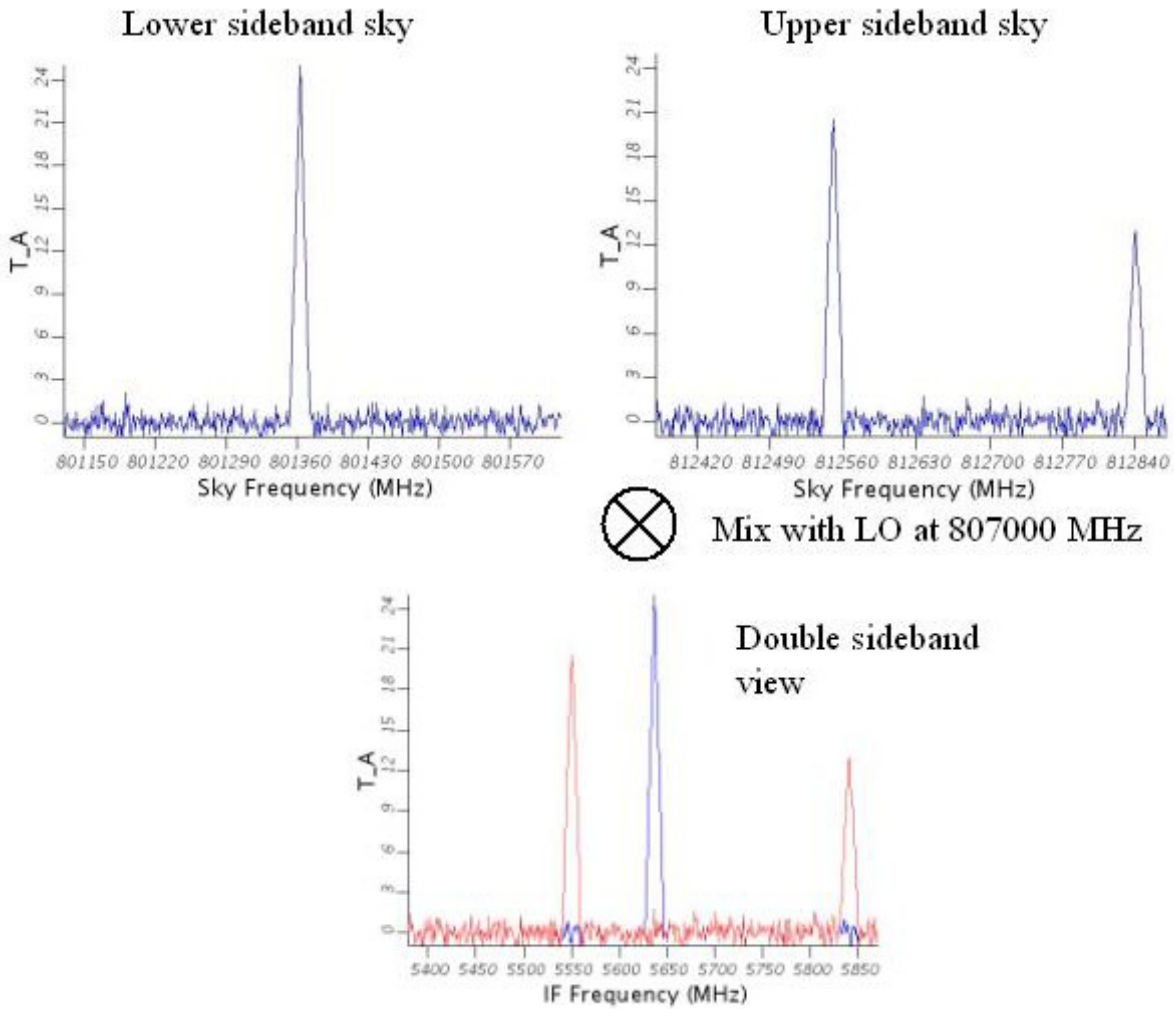
A Spectral Survey Machine



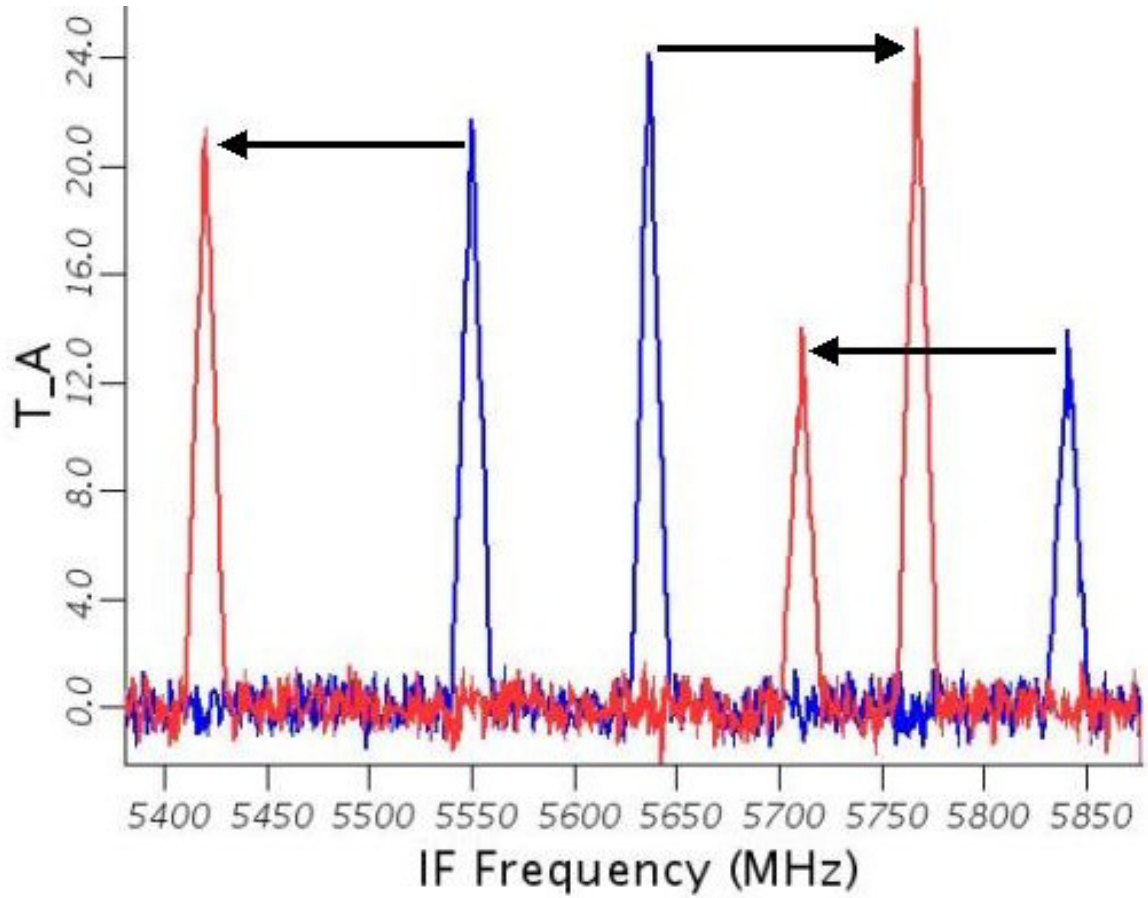
Atmospheric transmission

Schilke et al 2001

2. Dual Sideband Data



2. (cont) Small LO changes



3. Need for HIFI Observing Modes

- The HIFI detectors are affected by drifts, e.g. in detector gains, that need to be monitored and cancelled out on various timescales

→ Observing modes consist of sequences of single (*total power*) observations towards various line-of-sights

  - Observations *ON-source* and *OFF-source*
    - Cancel out sky background
    - Cancel out instrumental noise
  - Observations of *internal calibrators* (photometric references)
    - Calibrate instrument response function (*bandpass*)
    - Scale data into physical units (e.g. brightness temperature)

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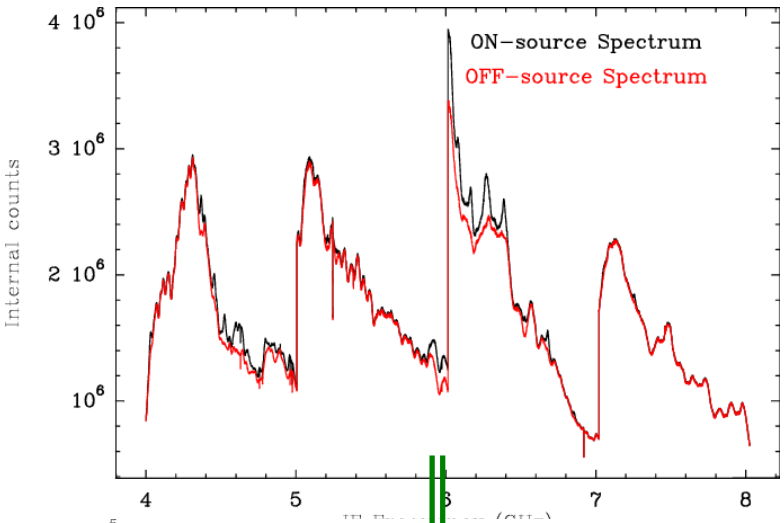
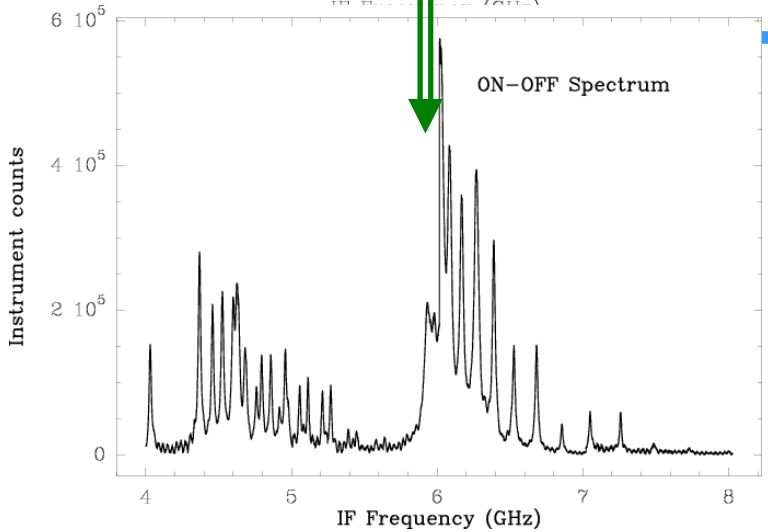
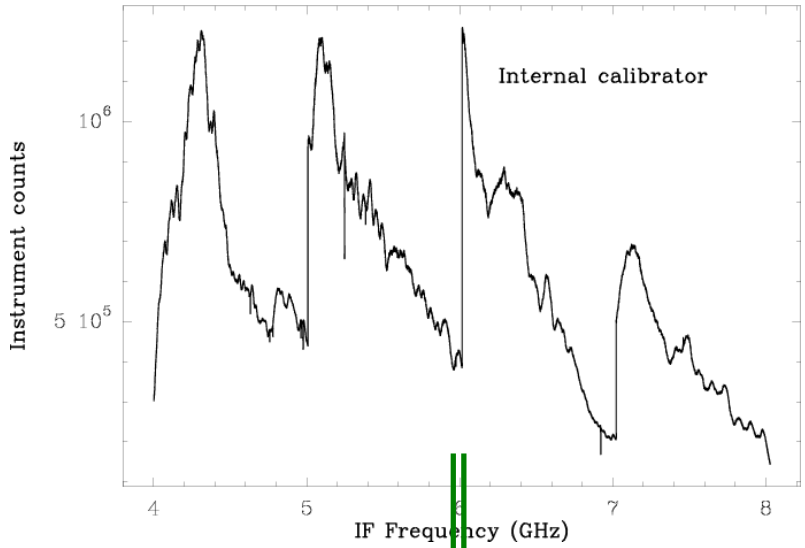
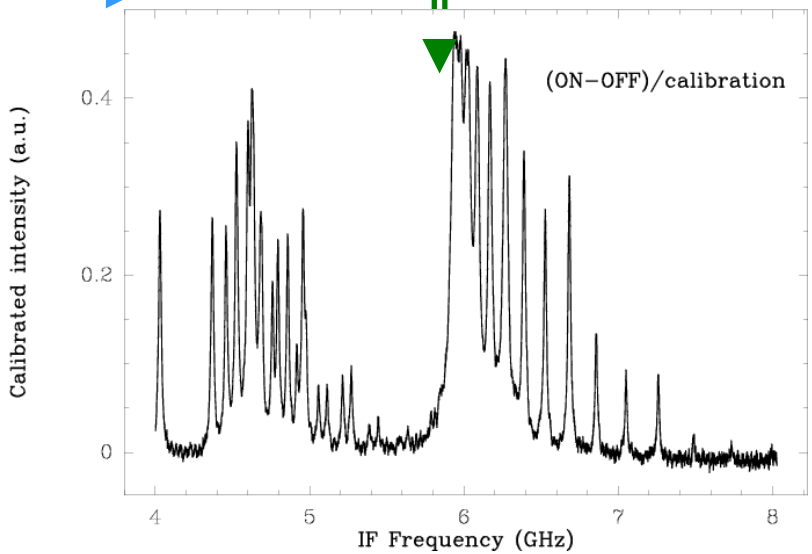

ON−source Spectrum
OFF−source Spectrum
Internal counts
4 10^6
3 10^6
2 10^6
10^6
4
5
7
8

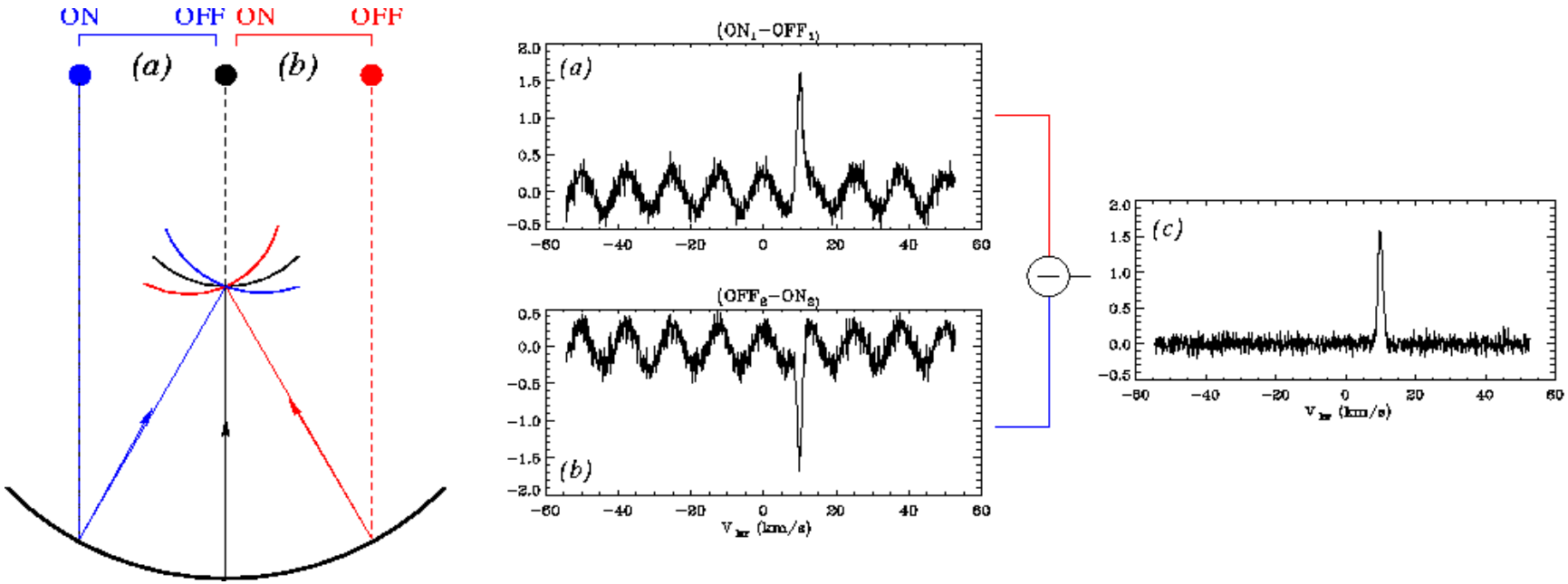

ON−OFF Spectrum
Instrument counts
6 10^5
4 10^5
2 10^5
0
4
5
6
7
8
IF Frequency (GHz)


Internal calibrator
Instrument counts
10^6
5 10^5
4
5
7
8
IF Frequency (GHz)


(ON−OFF)/calibration
Calibrated intensity (a.u.)
0.4
0.2
0
4
5
6
7
8
IF Frequency (GHz)

4. HIFI Reference Schemes

- *Position Switching*: the whole telescope is moved between two lines-of-sight on the sky
- *Dual Beam Switching*: the internal chopper mirror is switched to a nearby position (3 arcmin away)

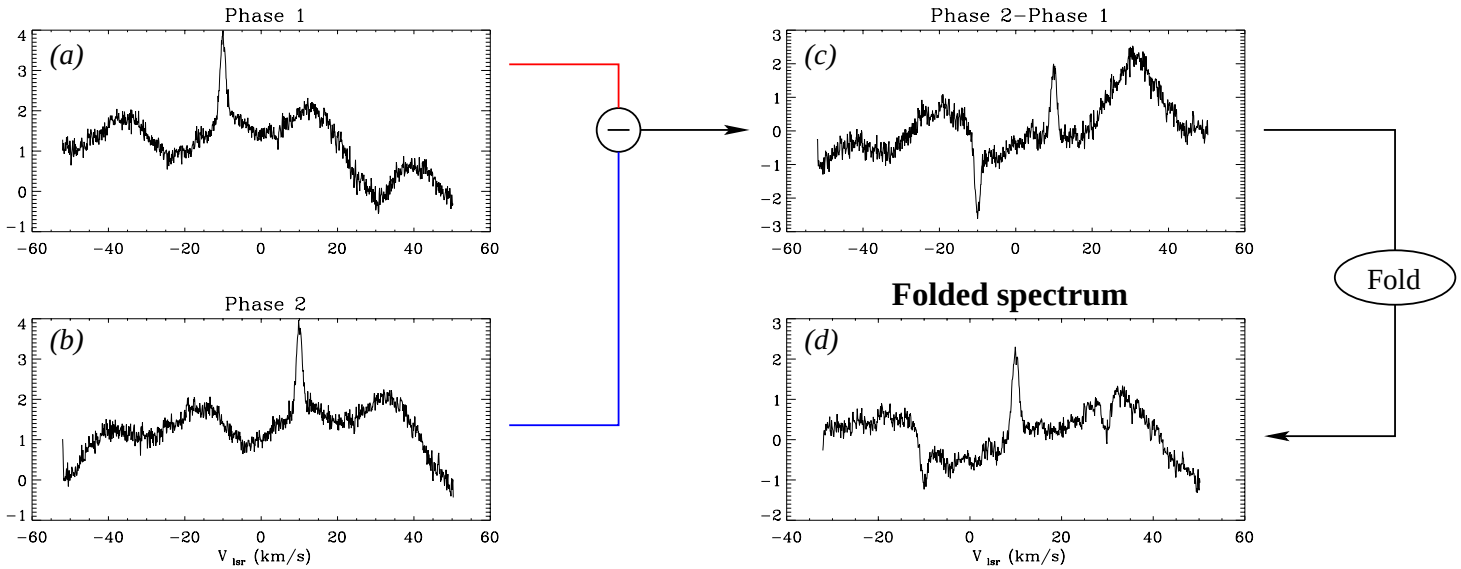


HIFI Reference Schemes, cont.

- *Dual Beam Switching*: continued
  - *Slow-chop* option: when not interested in accurate measurement of the continuum
  - *Fast-chop* option: for a more accurate measurement of the continuum (e.g. absorption line measurements), or *very* broad lines
  - Note that chopper direction on the sky moves with the date of observation.

HIFI Reference Schemes, cont.

- *Frequency Switching*: change the tuned frequency to shift the observed line to another part of the IF spectrum

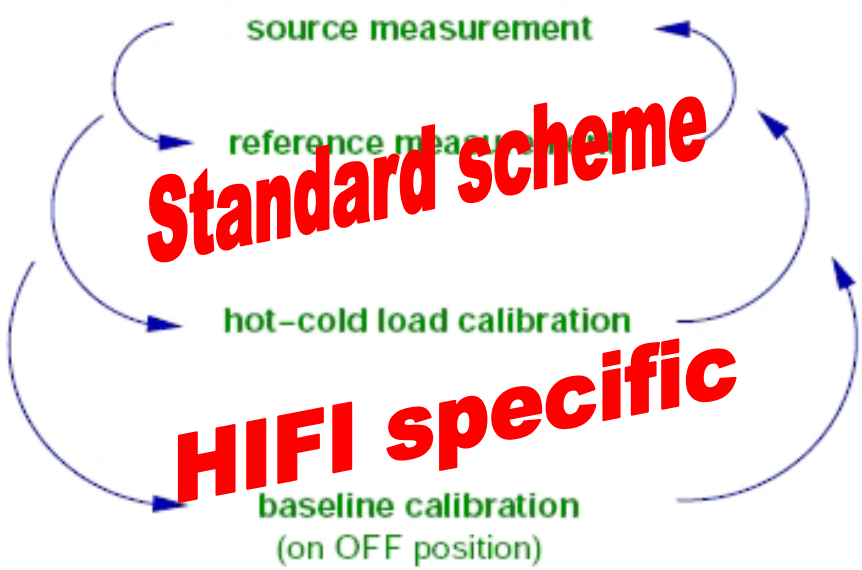


5. The Timing of Observations

Reference loop
length determined by system Allan time t_A

Bandpass calibration loop
length determined by band-pass stability time $t_{A,load}$

Baseline calibration loop
length determined by standing wave Allan time $t_{A,sw-diff}$



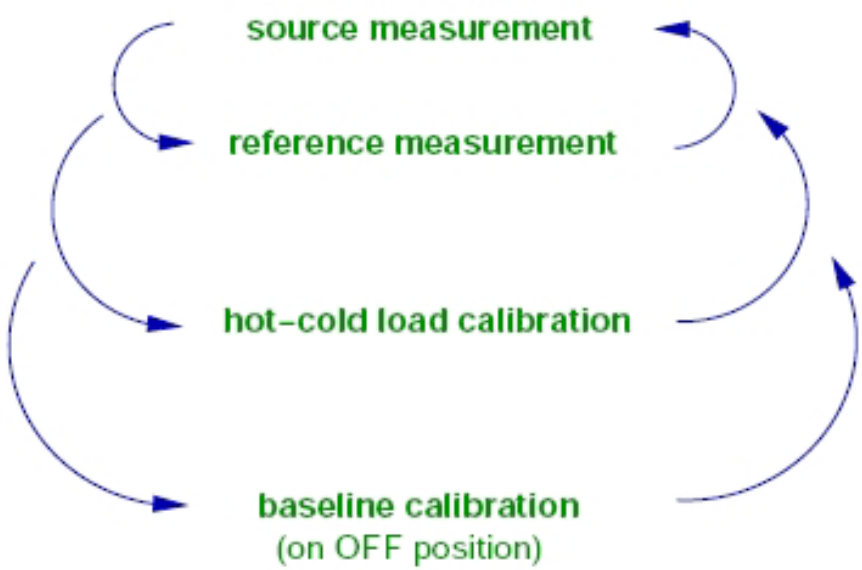
Observations are organised according to a hierarchical structure of loops reflecting the various timescales of the instrument stability (measured in terms of *Allan times)*

The Timing of Observations

Reference loop
length determined by system Allan time t_A

Bandpass calibration loop
length determined by band-pass stability time $t_{A,load}$

Baseline calibration loop
length determined by standing wave Allan time $t_{A,sw-diff}$



- Allan times vary with the instrument spectral resolution

→ the loop periods will depend on the spectral resolution

- *Continuum* Allan times ~4 times < *spectroscopic* Allan times

→ timing differ for observations aiming at the continuum

6. The HIFI pointing modes

- *Single point* observations
- *Mapping* observations (*raster*-like, or *On-the-fly*)

Observations are allowed for only 1 tuned frequency (*LO* frequency)

Combination of observations at several frequencies need clustering (*concatenation*)

- *Frequency surveys*

Observations offer several frequencies but are allowed for only 1 line-of-sight

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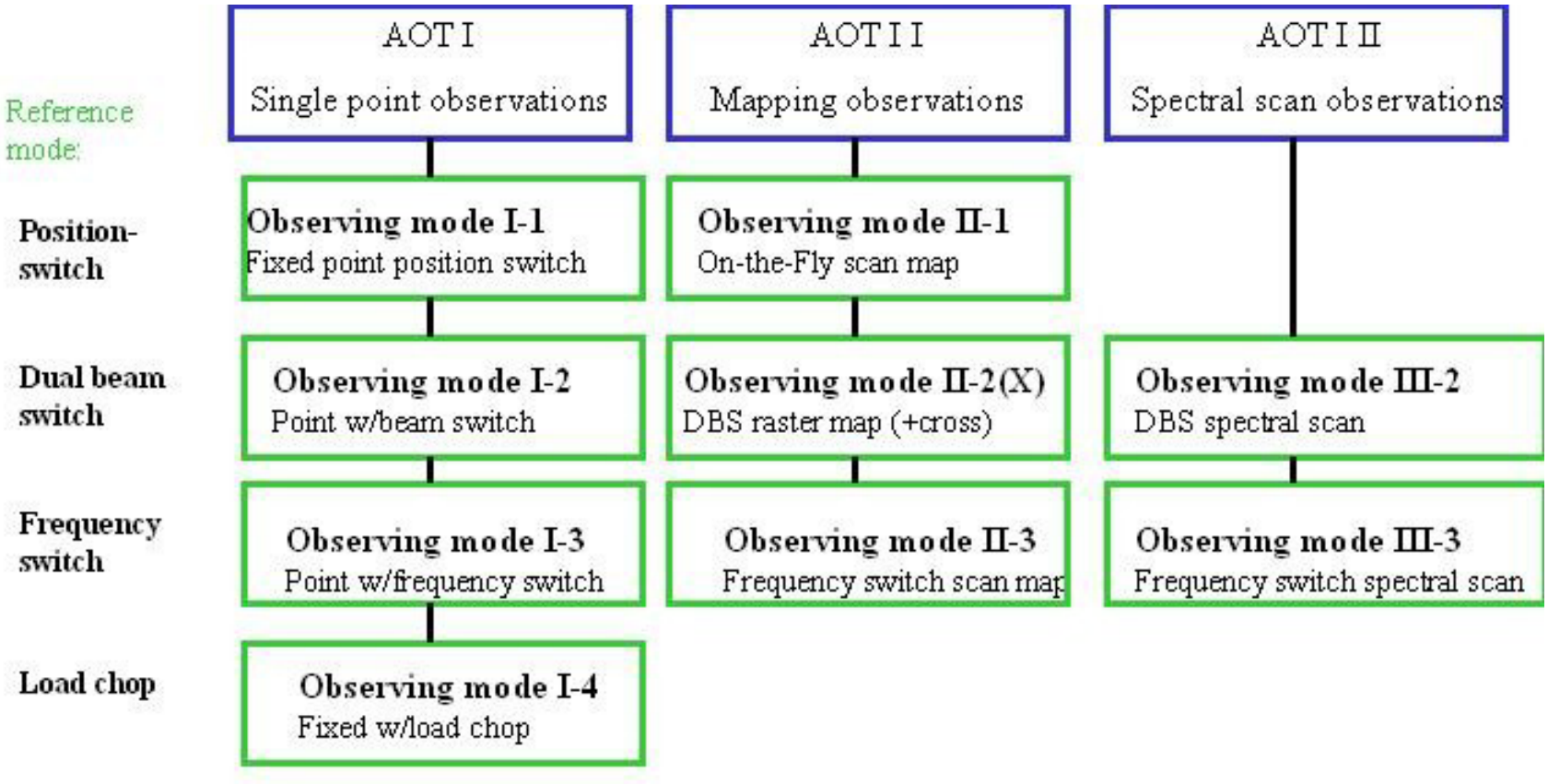
7. The HIFI AOTs

The resulting AOTs offer an as complete and versatile as possible combination of pointing and reference modes

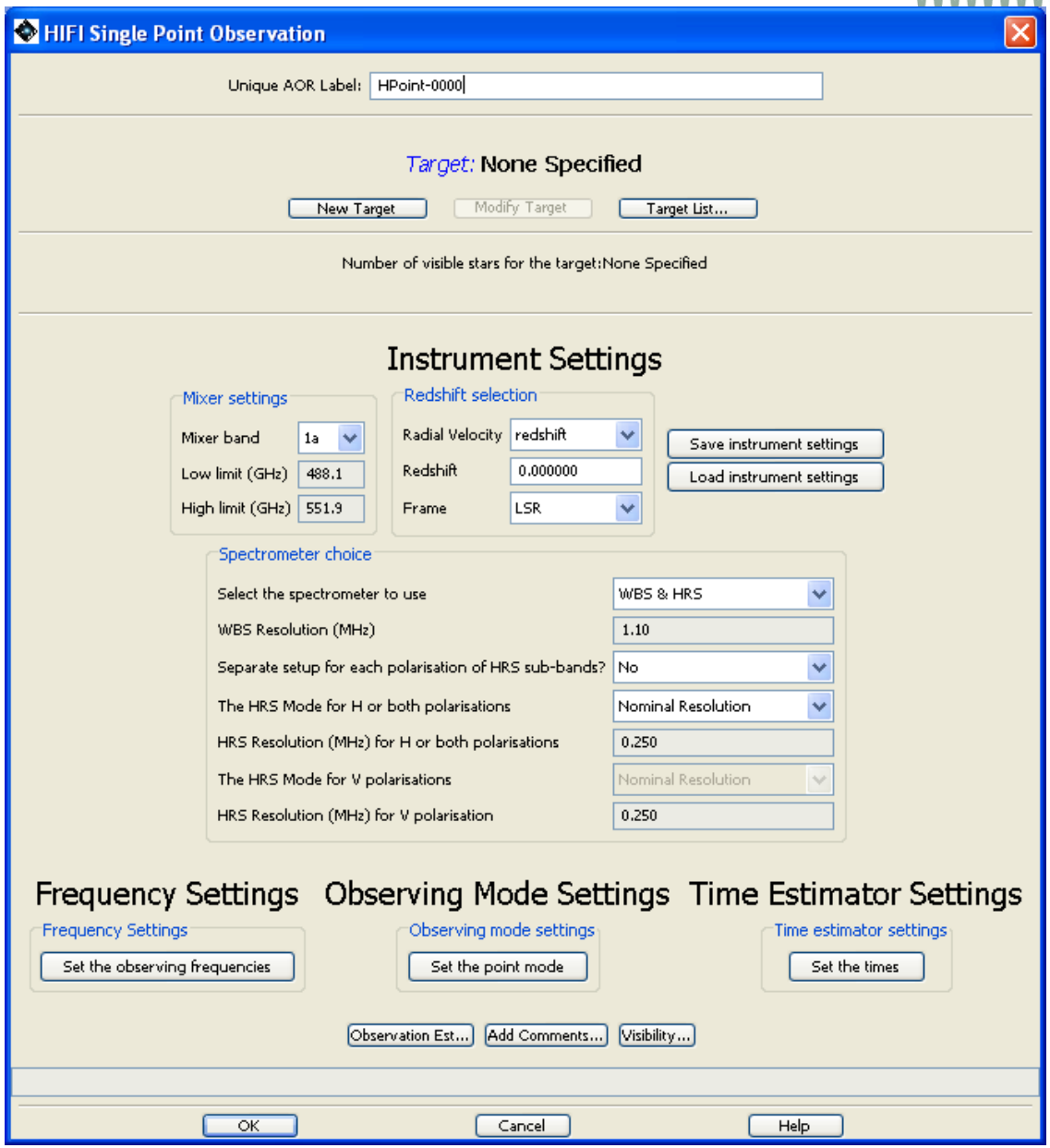


7. Point Source Observations with HIFI

Point Source Science

Scientific potential of point source observations with HIFI

- **Observe spectral lines unavailable from the ground, notably water lines (e.g., water in comets).**
- **High-resolution providing profile/velocity information – e.g. outflows in SF areas.**
- **Multiple lines provide physical conditions of stellar ejecta/ISM (AGBs, proto-planetary nebulae).**
- **Multiple lines available in single observations.**

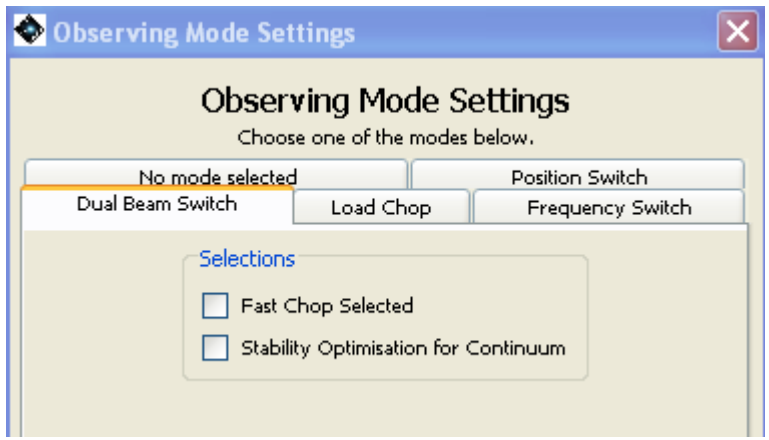

HIFI Single Point Observation
Unique AOR Label: HPoint-0000
Target: None Specified
New Target
Modify Target
Target List...
Number of visible stars for the target:None Specified
Instrument Settings
Mixer settings
Mixer band 1a
Low limit (GHz) 488.1
High limit (GHz) 551.9
Redshift selection
Radial Velocity redshift
Redshift 0.000000
Frame LSR
Save instrument settings
Load instrument settings
Spectrometer choice
Select the spectrometer to use WBS & HRS
WBS Resolution (MHz) 1.10
Separate setup for each polarisation of HRS sub-bands? No
The HRS Mode for H or both polarisations Nominal Resolution
HRS Resolution (MHz) for H or both polarisations 0.250
The HRS Mode for V polarisations Nominal Resolution
HRS Resolution (MHz) for V polarisation 0.250
Frequency Settings
Observing Mode Settings
Time Estimator Settings
Frequency Settings
Set the observing frequencies
Observing mode settings
Set the point mode
Time estimator settings
Set the times
Observation Est...
Add Comments...
Visibility...
OK
Cancel
Help

DBS Observations

- **Purpose:**

  Used for spectral line or continuum measurements of isolated point sources.

- **Mode User Options:**
  - **Continuum measurements** (telescope slews more frequently – better standing wave removal).
  - **Faster chopper switch** (necessary for cases where stability– Allan – times are < 1 second, e.g. low spectral resolutions).



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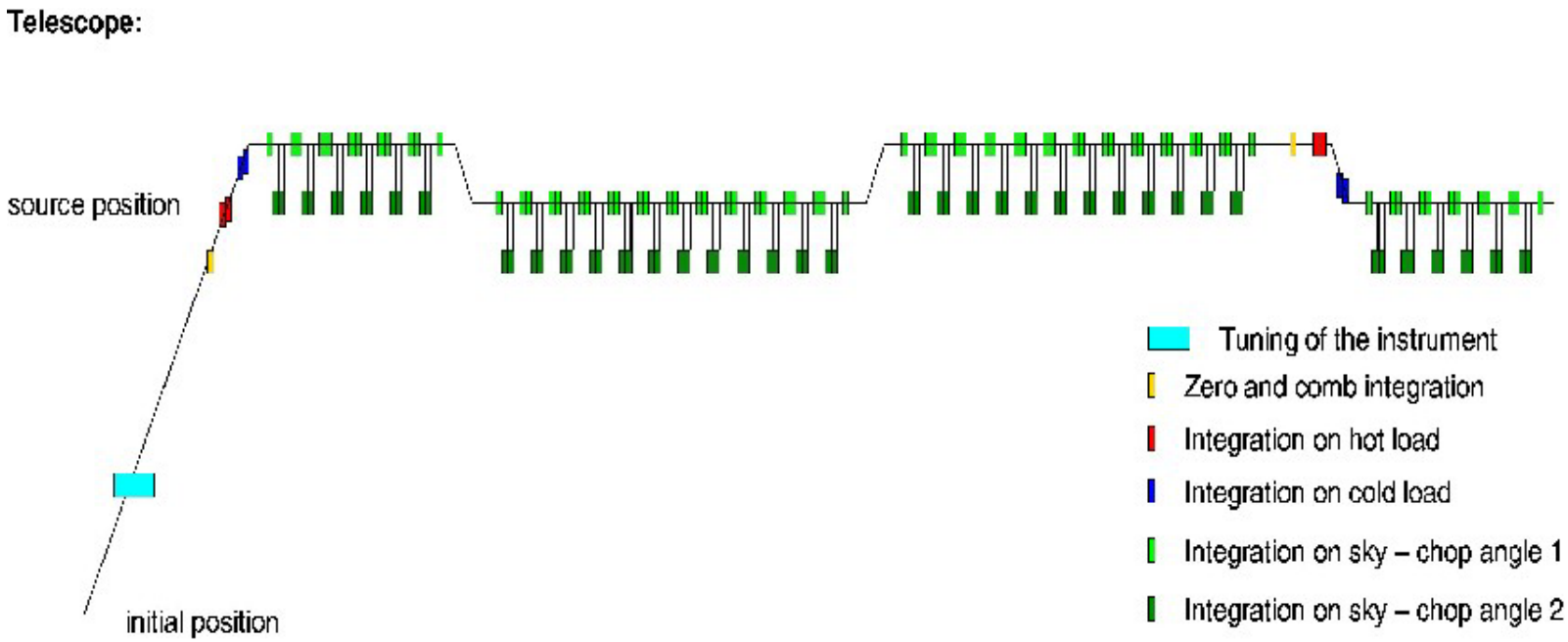
DBS Timeline



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Position Switch Observations

- **Purpose:**
- **For spectral line or continuum measurements for objects that are in regions of extended emission (> 3' across).**

- **Description:**
- Instrument integrated on the target with continuous data dumps to the satellite.
- After a period of time, based on the instrument stability, an OFF reference is made at a second telescope position.
- [Calibration is done against internal hot/cold load measurements – taken during slews.]

- **Mode User Options:**
- User MUST choose a reference OFF position – either by RA/Dec offset or RA/Dec (2000) position.

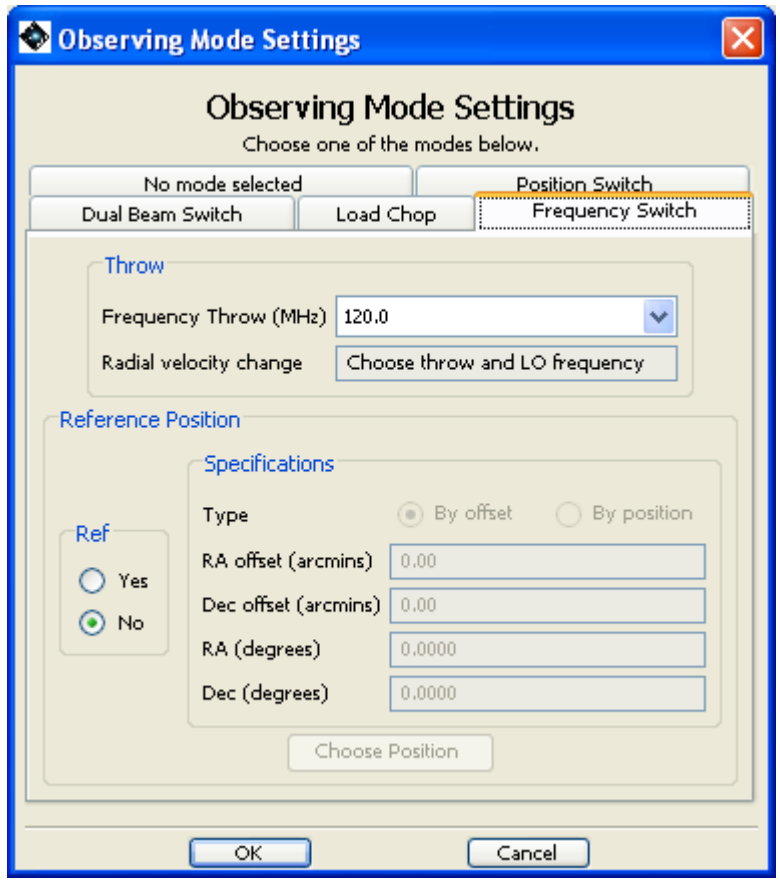
Frequency Switch (w/OFF)

Purpose:

Efficient mode for emission-line source measurements. No continuum information.

- **Description:**
- Reference is made between two observations at slightly different LO frequency settings.
- Accurate baseline measurements need the use of an OFF reference position. Viewed at both LO frequencies.
- Double differencing gives most accurate baselines but at a cost in terms of noise/time.

- **Mode User Inputs:**
  - Frequency throw (120, 240MHz)
  - OFF position, if needed.

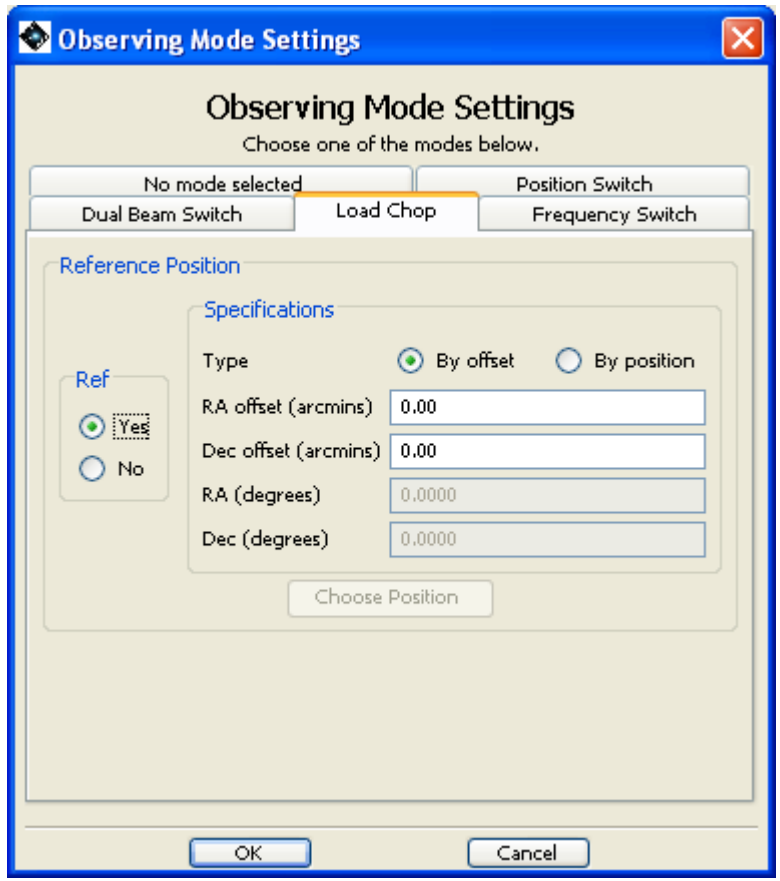


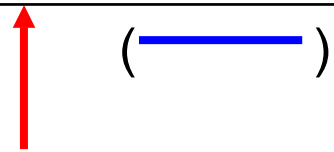
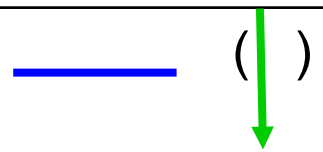
Load Chop (w/OFF)

Purpose:

Spectra of single sources, particularly where no nearby reference OFF position is readily available (and short stability times).

- ## Description:
- Cold internal calibration source is alternately viewed with source.
- Double differencing (by use of an OFF position) allows for accurate baseline determination.
- If spectral line resolution << resolution for standing waves then the OFF position may be omitted.
- **Mode User Inputs:**
  - Only an OFF position (if needed)



Mode	Best Used For….	Notes	Efficiency
DBS (+ fast chop)	For point sources, small extension	Fast chop for short stability times	
DBS (cont. timing)	Improved continuum accuracy.		
Frequency Switch (w/OFF)	For sources with low (narrow) line density + no near reference	No continuum measures	
Position switch	Basic mode – no clear nearby reference source		
Load Chop (w/OFF)	For sources with high line density or broad lines + no near reference	Fall-back wrt position switch	

8. Frequency surveys with HIFI

HIFI Spectral Survey: Specifications

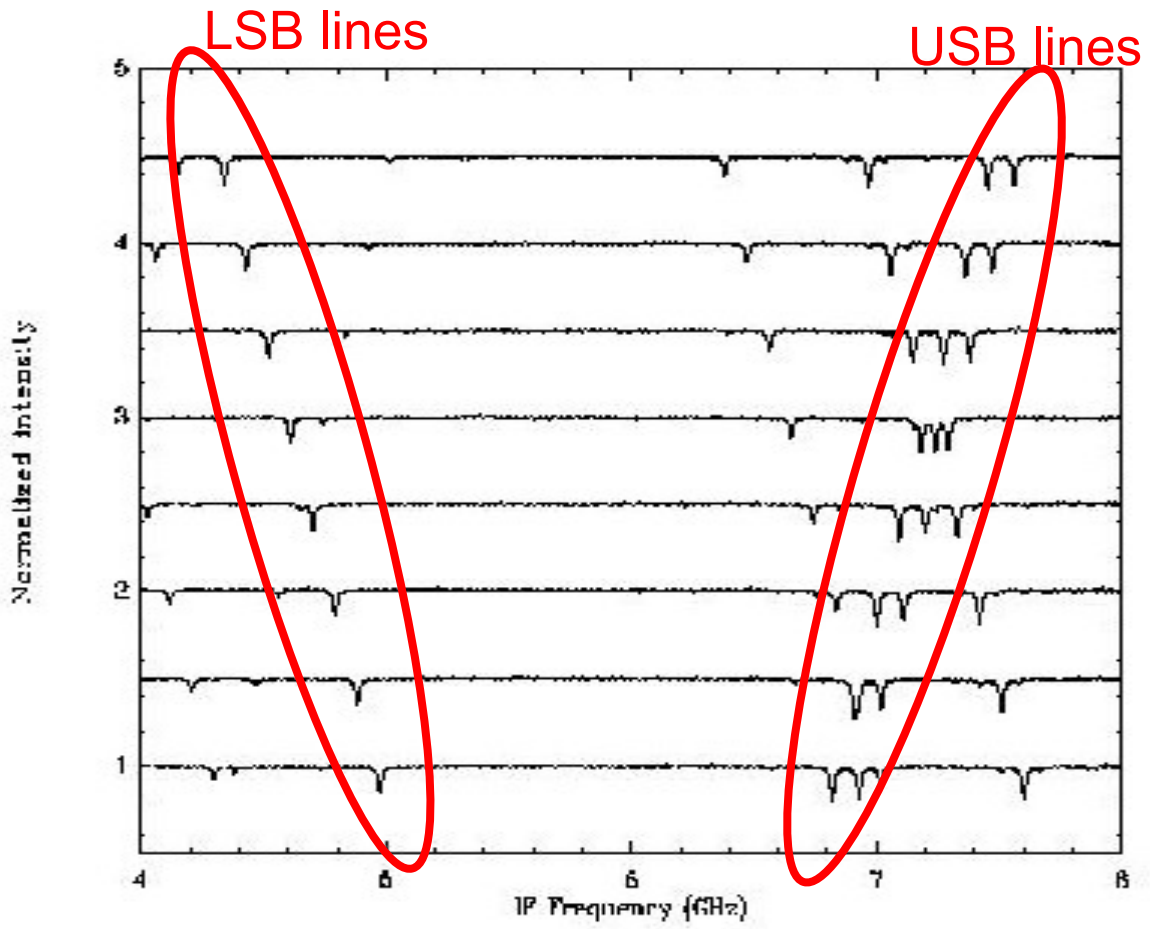
- *Single source* observations
- *Multiple frequency* settings extended over frequency coverages larger than the IF bandwidth
- Largest frequency coverage per AOR is presently limited to that of a complete LO subband.
- Use of the *WBS* spectrometer only (instantaneous coverages of 4 GHz @ 1.1 MHz resolution)
- Offered with 2 reference schemes
  - *Dual-beam-switching* (in *slow*-chop or *fast*-chop). Relatively inefficient mode (< 10%, frequent re-tuning and telescope motion)
  - *Frequency-switching (efficiency slightly improved).* Possible use of an additional *OFF-position* to cancel out standing waves

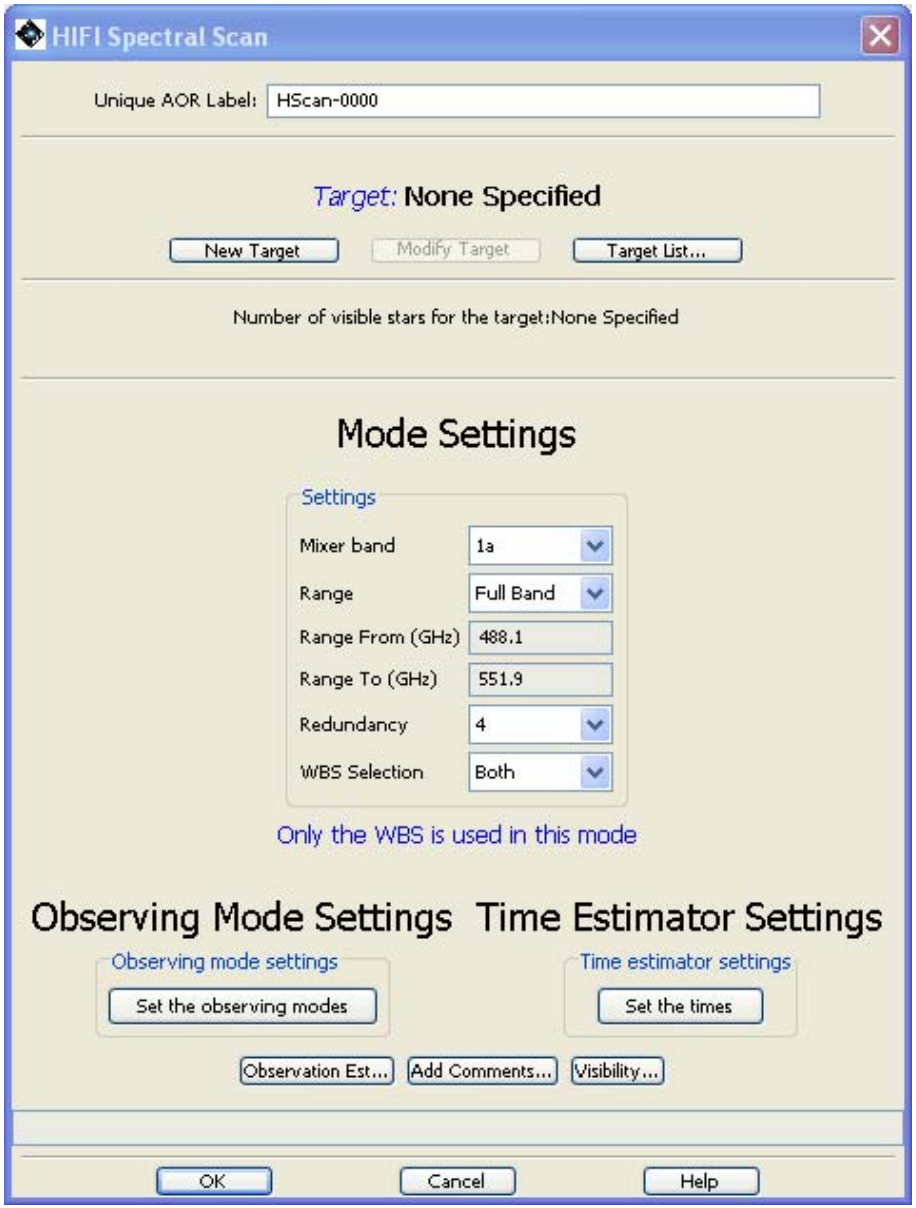
HIFI Spectral Survey: Redundancy

- Because HIFI is a *double-side-band (DSB)* instrument, observations need to be *deconvolved* in order to assign sky frequencies to spectral lines. Use multiple LO tunings.
- The number of independent LO tunings per IF bandwidth we refer to as the *redundancy*. High redundancy values are needed for crowded spectra.

HIFI Spectral Survey: Redundancy - II

Example of methanol survey with HIFI-QM: high redundancy




HIFI Spectral Scan
Unique AOR Label: HScan-0000
Target: None Specified
New Target
Modify Target
Target List...
Number of visible stars for the target:None Specified
Mode Settings
Settings
Mixer band 1a
Range Full Band
Range From (GHz) 488.1
Range To (GHz) 551.9
Redundancy 4
WBS Selection Both
Only the WBS is used in this mode
Observing Mode Settings
Time Estimator Settings
Observing mode settings
Set the observing modes
Time estimator settings
Set the times
Observation Est...
Add Comments...
Visibility...
OK
Cancel
Help

9. Mapping with HIFI

Mapping with HIFI

Scientific potential of mapping with HIFI

Reveals the spatial distribution of different kinematics components

- Evolved stars (AGBs, protoplanetary nebulae..)
- Star formation (outflows, ..)
- Interaction of stars with the ISM (PDRs, XDRs, Shocks..)
- Heating of the ISM in the center of galaxies

Multiline studies (H_2O, CI, ..) to derive the physical properties

- Combine lines measured with different beams

  The beam for band 1 is 4 times larger than for band 6

↓

Need to synthesized the larger beam by mapping

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Mapping Modes

HIFI provides the following mapping AOTs in HSPOT

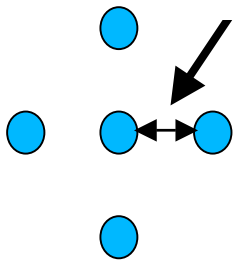
- Cross Map with Dual Beam Switch
- Raster Maps with Dual Beam Switch (3 arc min chop)
- On-the-fly (OTF) Maps:
  - Position-Switch Reference
  - Frequency Switch Reference

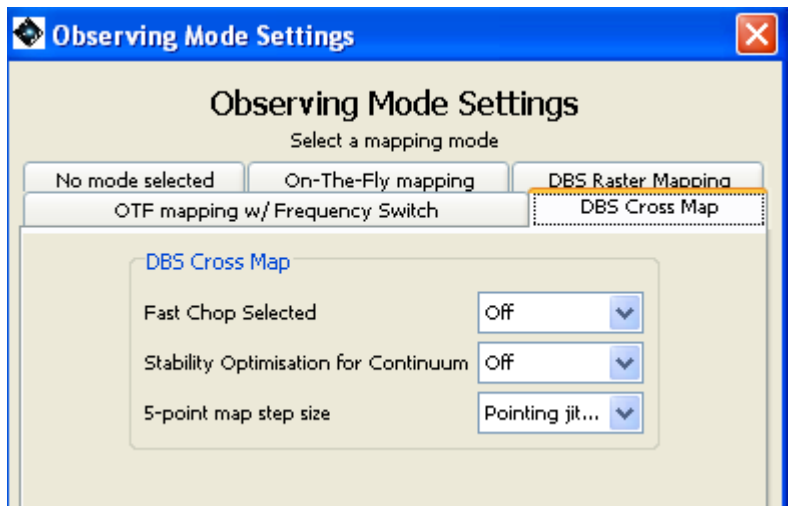
Cross Map DBS

Purpose:

Used for high accuracy flux measurement of lines or continuum in a point source correcting for pointing or position inaccuracies

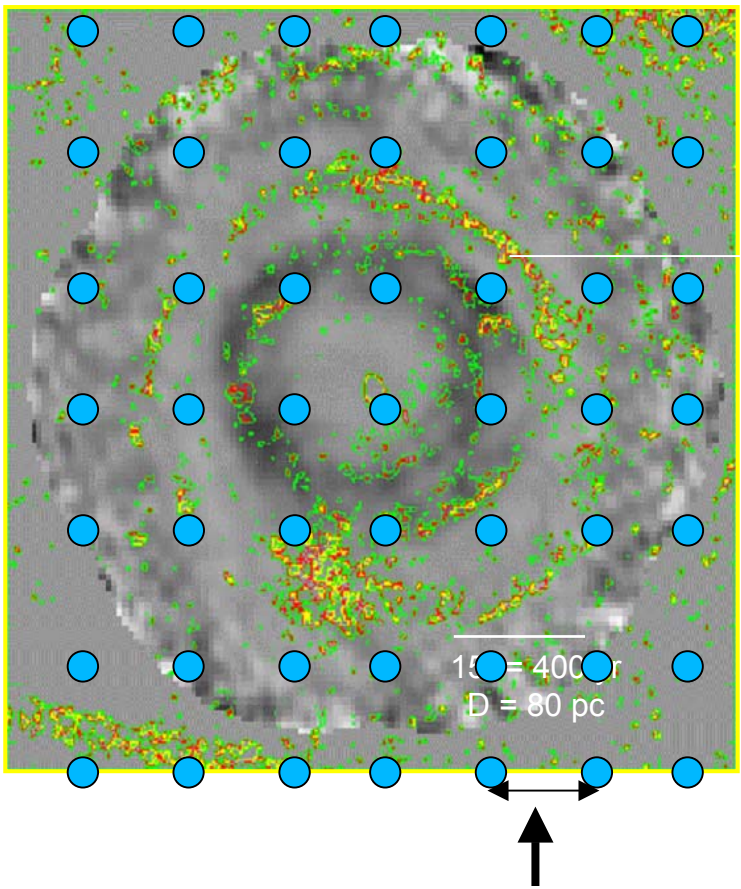
User selectable





Raster Maps DBS

IRC+10216 PDBI CN(2-1)

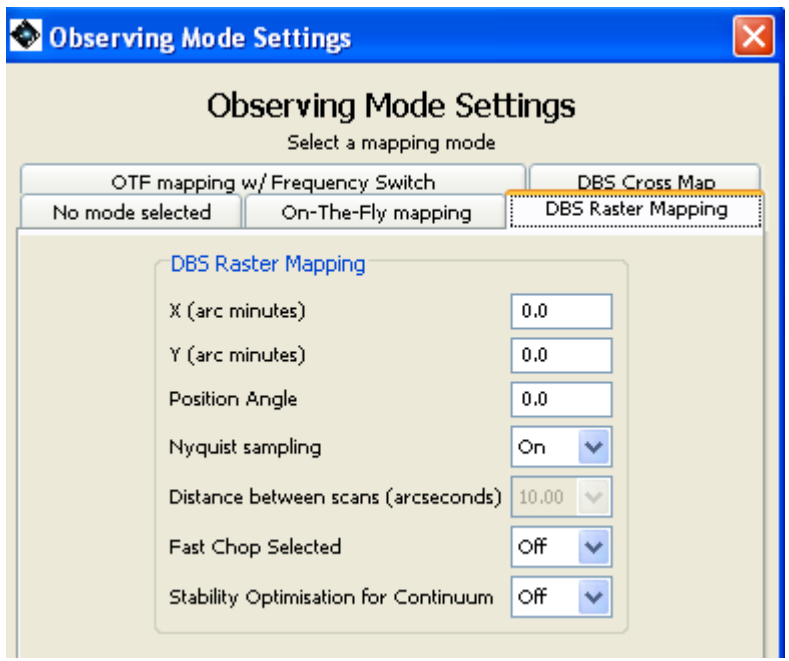


Nyquist, 10”, 20”, 40”

Purpose:

Used for mapping small extended sources in spectral lines and continuum

- No extended emission >3’
- Limited to 32x32
- Good baselines and continuum



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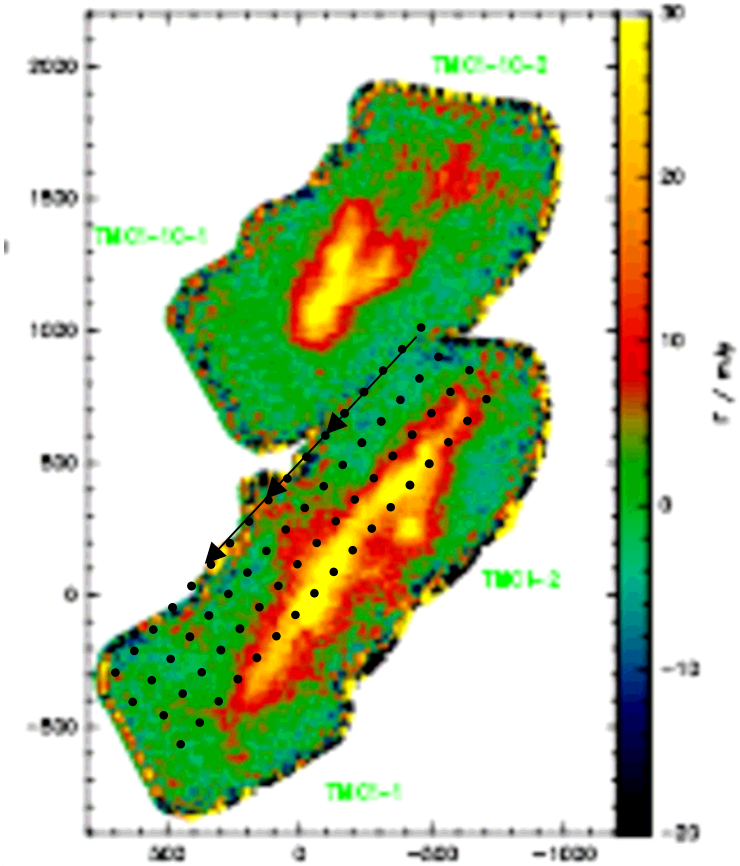
OTF Maps - FS

Purpose:

Used to create large-scale maps within very extended emission and narrow lines

MAMBO 30-m



- Mapping water, CI, CII, ..
- molecular clouds
- outflows with moderate velocities
- PDRs, and low velocity shocks

- Any sampling (Nyquist)
- Frequency throw: 120, 240 MHz
- Linewidths: <5 km/s (ripples)
- No continuum emission

Measuring a reference position

Baselines (ripple suppression)

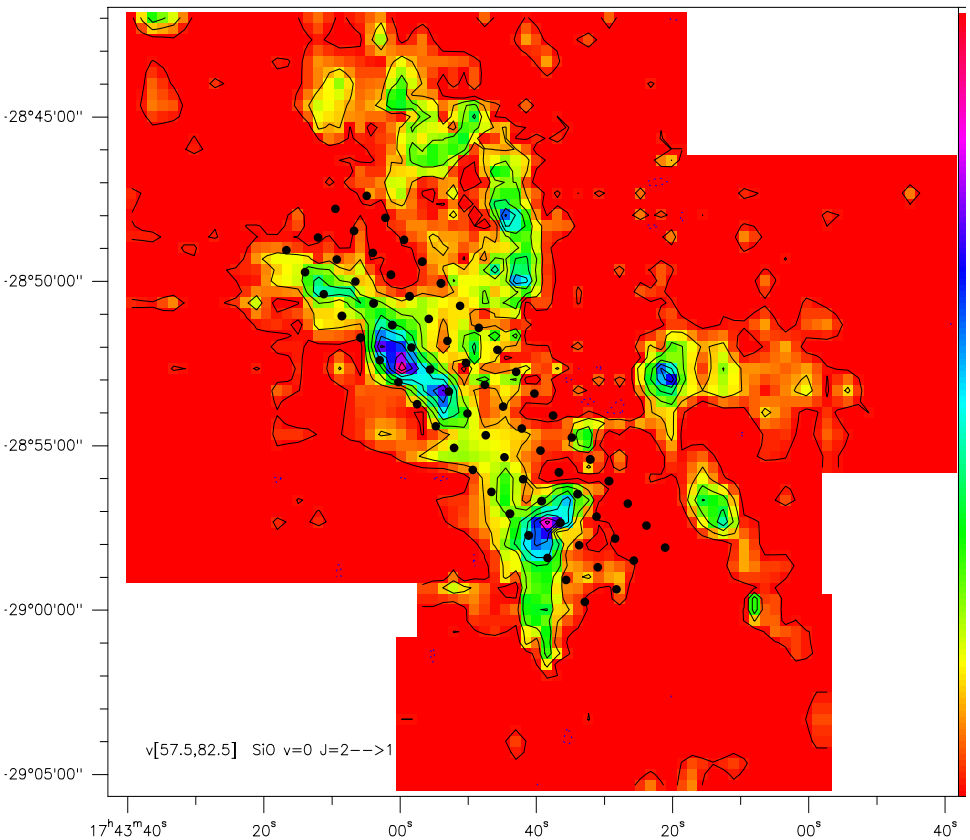
Linewidths: < 15 km/s

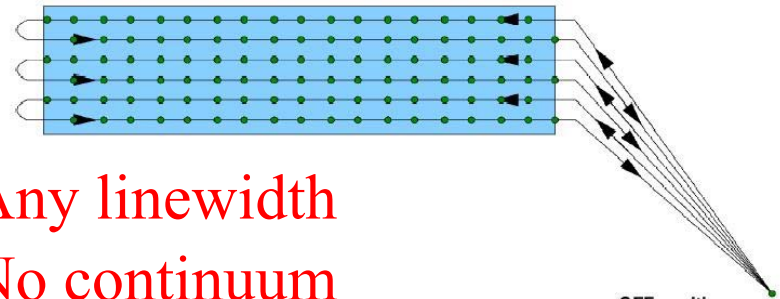
OTF Maps - PR

Purpose:

Create large scale-maps using a nearby reference position free from emission

Galactic Center SiO 2-1 30-m



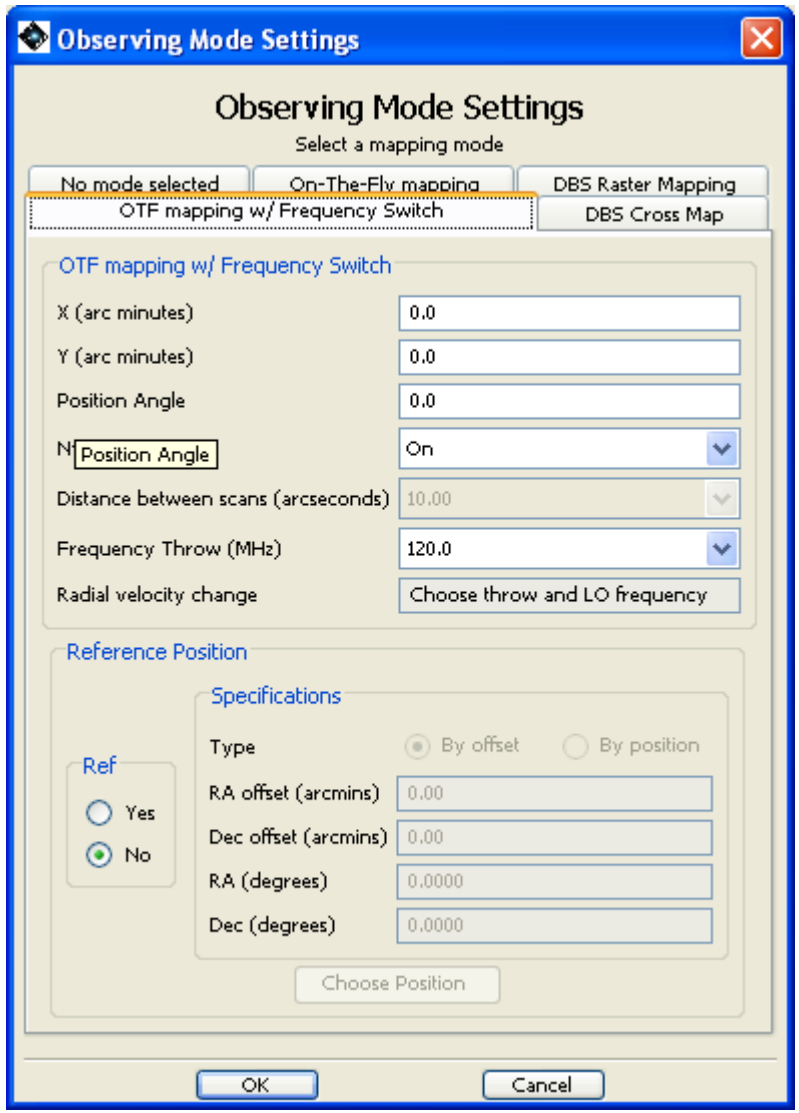


- Any linewidth
- No continuum
- Any sampling (Nyquist)

Fixed reference with emission

Measure in PS with clean ref.

Add to the map


Observing Mode Settings
Observing Mode Settings
Select a mapping mode
No mode selected
On-The-Fly mapping
DBS Raster Mapping
OTF mapping w/ Frequency Switch
DBS Cross Map
OTF mapping w/ Frequency Switch
X (arc minutes)
0.0
Y (arc minutes)
0.0
Position Angle
0.0
Position Angle
On
Distance between scans (arcseconds)
10.00
Frequency Throw (MHz)
120.0
Radial velocity change
Choose throw and LO frequency
Reference Position
Specifications
Ref
Yes
No
Type
By offset
By position
RA offset (arcmins)
0.00
Dec offset (arcmins)
0.00
RA (degrees)
0.0000
Dec (degrees)
0.0000
Choose Position
OK
Cancel

Summary of Mapping Modes

	Source size	Linewidths	Baselines Continuum	Efficiency
Raster DBS	Compact <3’	Any	Very good YES	↓
OTF FS	Any	<5 km/s	Ripples NO	↑
OTF FS +Reference	Any	<20 km/s	Good NO	—
OTF PR Clean Ref	Any	Any	OK NO	↑
OTF PR Add Ref.	Any	Any	OK NO	↑