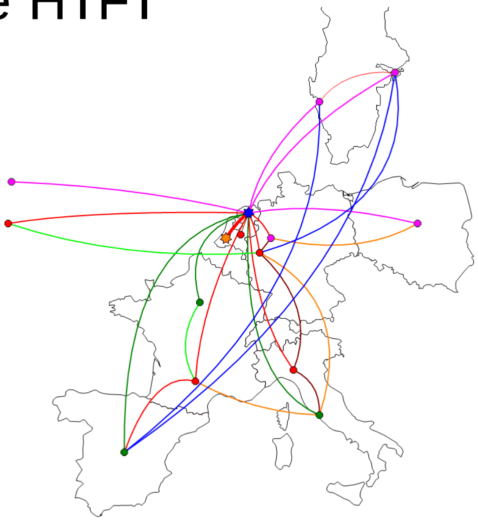
HIFI – Instrument and Calibration

Frank Helmich (SRON) on behalf of the HIFI Calibration Group



Overview

- What is HIFI
- How to observe with HIFI?
- Calibration: Baseline, goals and requirements
- The importance of Celestial Sources

What is HIFI?

- HIFI is just an ordinary heterodyne spectrometer with 6 frequency bands over 7 channels!
- But, HIFI is complex and very sensitive!!
- Some facts and figures:
  - HIFI is on-axis in Herschel
  - HIFI has a cold focal plane (15K) in which the mixers themselves are cooled to about 4 K
  - The sky and LO-signals are combined through beam-splitters and diplexers (Martin-Puplett interferometers)
  - The LO signal is generated in the service module and send through waveguides to the focal plane
  - The sky signal goes from primary to the (stiff) subreflector, and via M3 the 7 (14) sky beams enter HIFI
  - HIFI has two loads in its Calibration Source Assembly (100 and 15K)
  - Chopper chooses between loads, sky-on and sky-chop

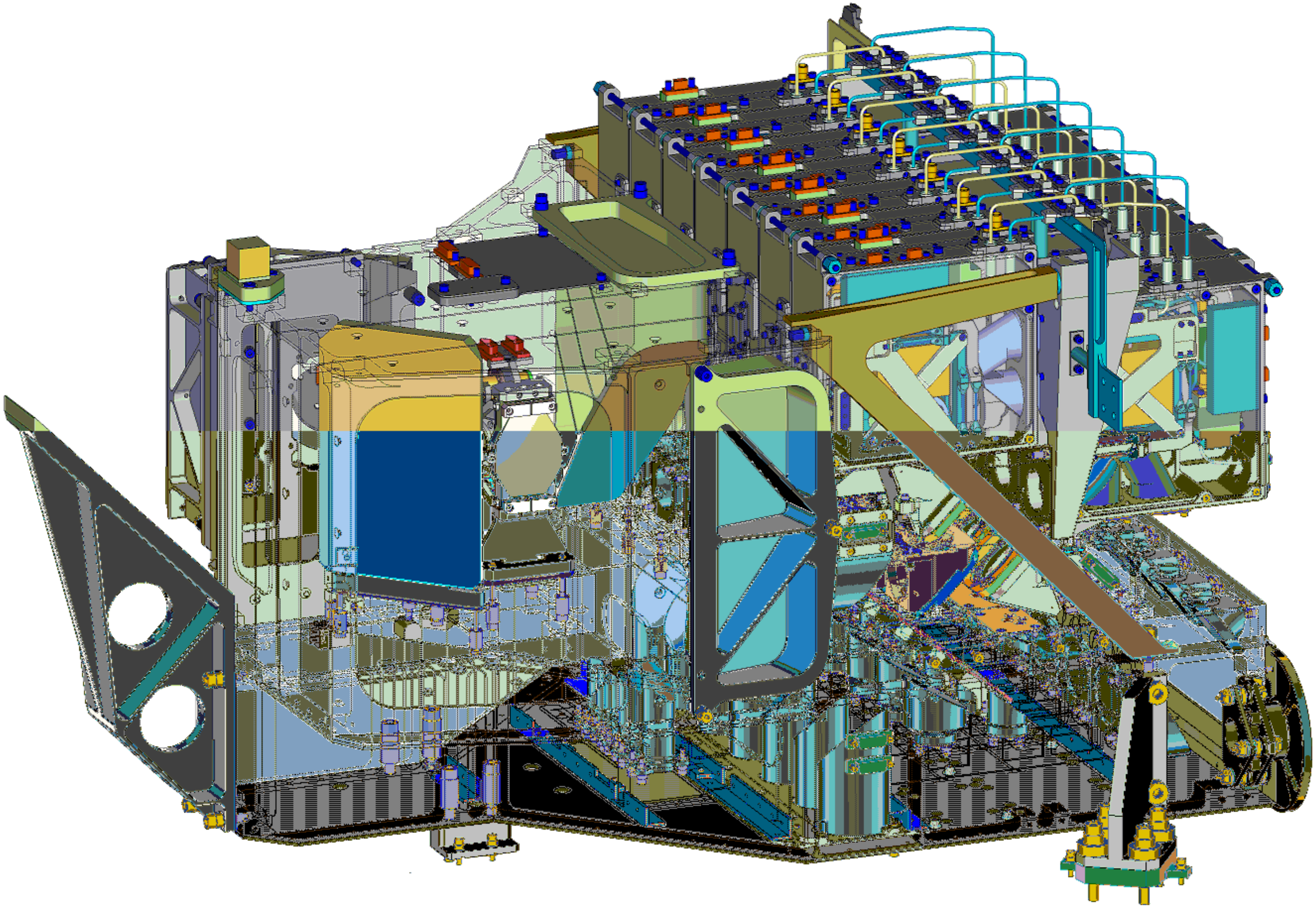
What is HIFI?

- Complexity:
  - So, HIFI has different optical paths for different chopper positions (hot load, cold load, sky-on, sky-off)
  - HIFI has 14 different LO chains and 14 mixers
  - HIFI has 2 spectrometers (1 AOS array spectrometer, one auto-correlator spectrometer)
  - HIFI has many different observing modes to be combined in three AOTs – only few can be exercised in ILT
- Sensitivity: State-of-the-art mixers!
- HIFI is thus a sensitive, versatile instrument ideally suited for measurements of high spectral resolution
  - Very deep for a single frequency
  - Relatively shallow over a large (even complete) wavelength range
  - Essentially a single-pixel instrument (map by moving the telescope)

HIFI Facts and Figures

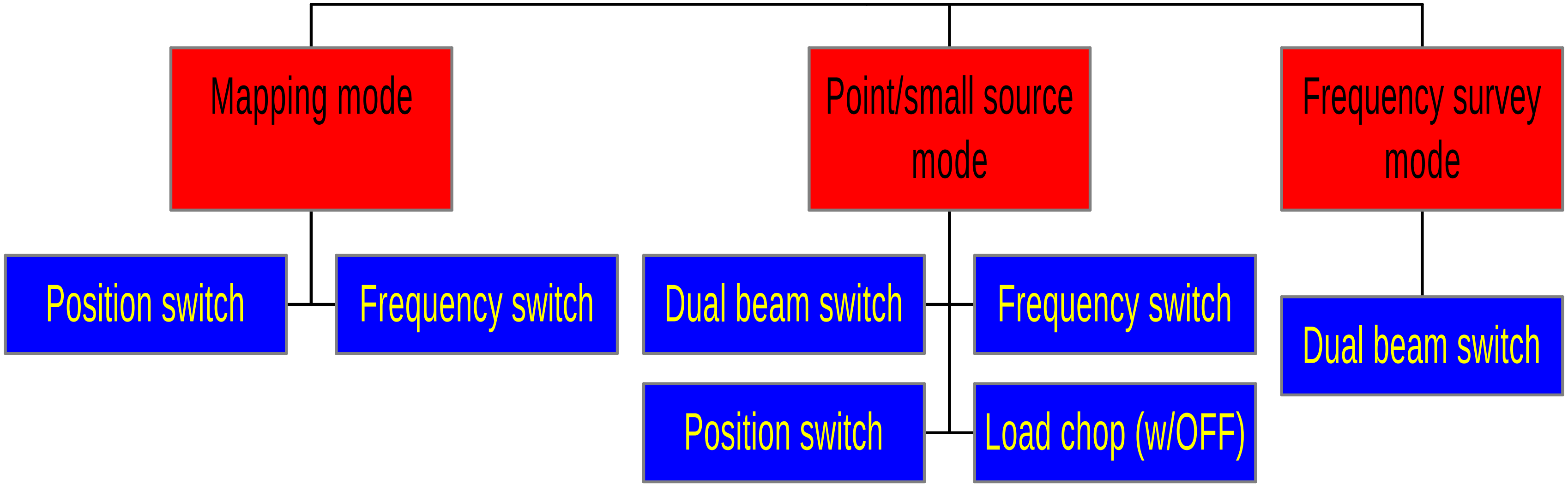
- Band 1: 480-640 GHz;
- Band 2: 640-800 GHz;
- Band 3 800-960 GHz;
- Band 4 960-1120 GHz;
- Band 5: 1120-1250 GHz;
- Band 6: 1410-1910 GHz
- 480 GHz is 625 micrometer; 1910 is 158 micrometer
- At 480 GHz the beam is 42"; at 1910 GHz 13"
- T_{sys}(SSB) = 200-500K (480-1250 GHz);
- T_{sys}(SSB) = 1600K in Band 6
- Bandwidth is up to 4 GHz;
- Resolution of 135-270-539-1100 kHz

HIFI Focal Plane Unit



Observing Modes

HIFI Observing Modes



Science

- HIFI is very well suited for **any** measurement requiring very high spectral resolution in the Far-IR/submm region

- Special emphasis on:
  - The water Universe – water in all kinds of astrophysical environments
  - Spectral surveys – unbiased frequency sweeps

Calibration Goals: accuracy

- Science User Requirements Document specifies the intensity calibration to be accurate within 10%
- There are more parameters:
  - Frequency
  - Position
  - Temporal
  - Polarization

- Goal for the intensity calibration is 3%
- Based on experience with ground-based telescopes the baseline should easily be reached in space

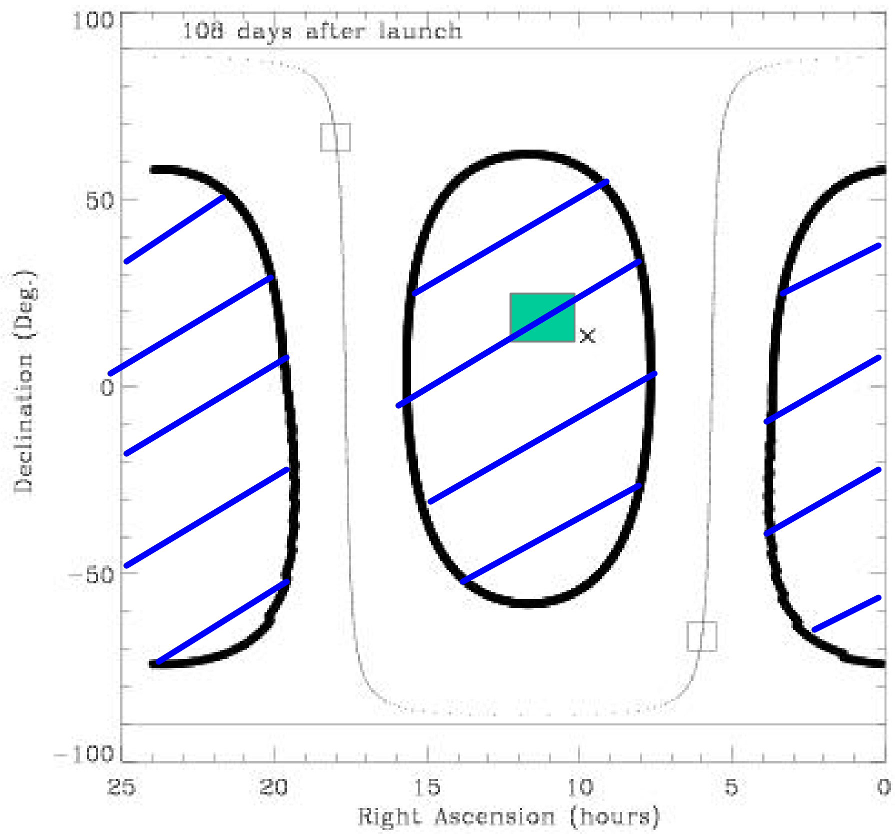
The HIFI Calibration Framework

- The "old" chopper wheel calibration method seemed not directly applicable because of high sensitivity and wide bandwidth
- The calibration framework describes in detail the
  - Frequency calibration
  - Spatial reponse calibration
  - Bandpass calibration
  - The temporal aspect is treated in the Use Cases
- We should be able to reach the goal at some frequencies
- Note that ALMA has done very similar studies (memo series)

General Scheme

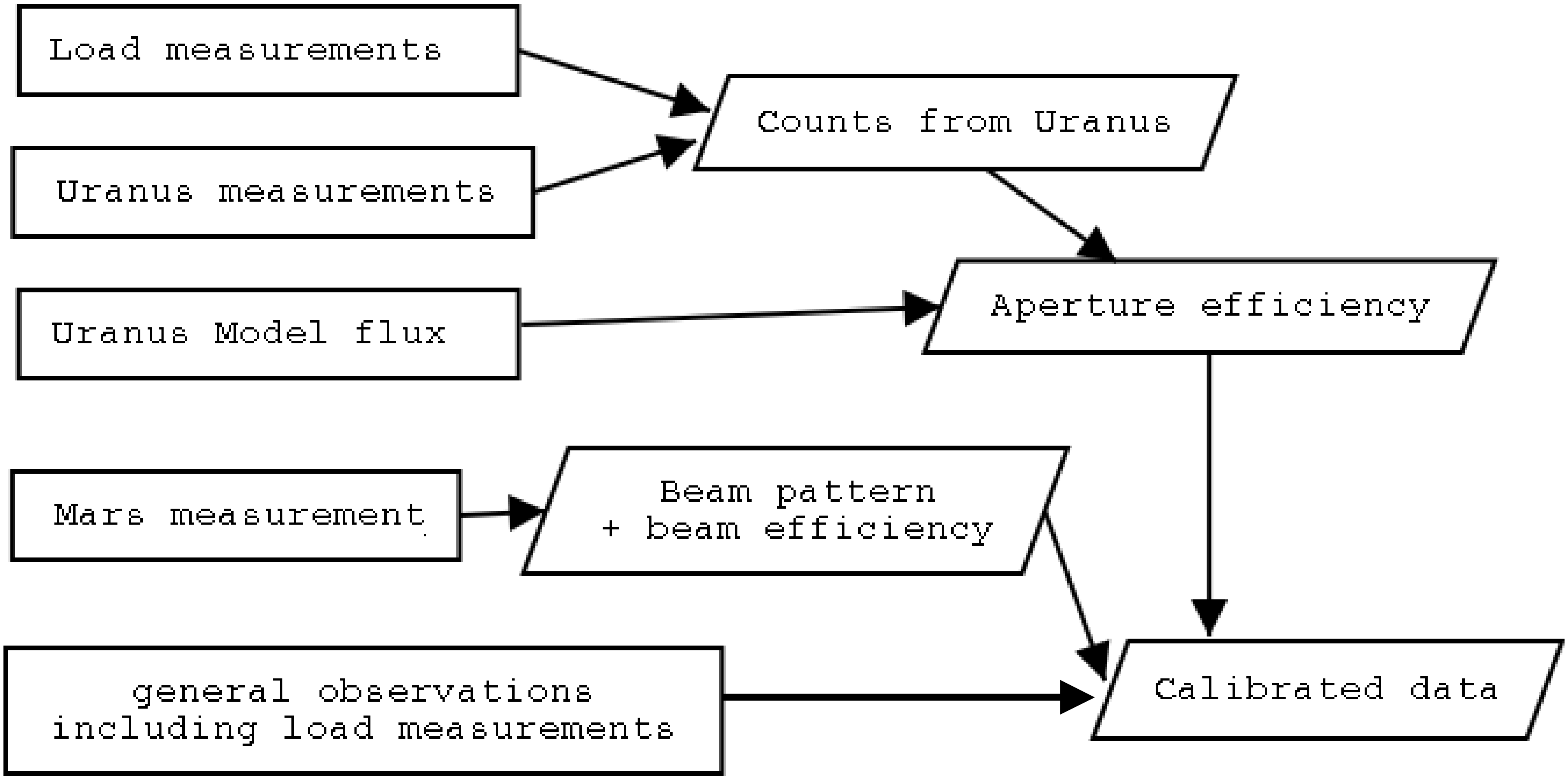
- Measure Mars for beam pattern and beam efficiency Measure Uranus or asteroids for aperture efficiency (models of Uranus and asteroids necessary) [Primary calibrators]
- Loads provide the internal scale (bandpass calibration)

- The above can be applied to all other observations (observing modes calibration)
- Observing few sources very often will provide long term instrumental effect knowledge (AGB stars and planets)



Visibility: more than one source needed

General Scheme

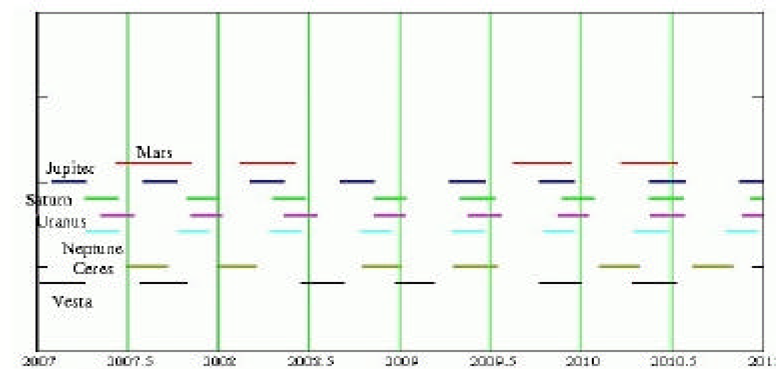


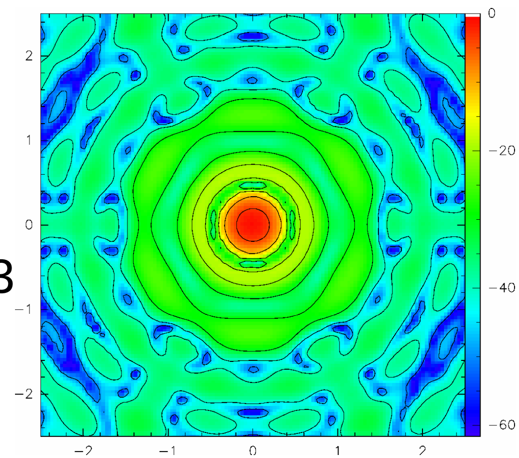
Calibration of frequency

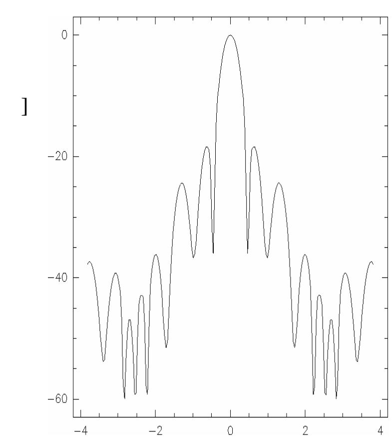
- For a heterodyne instrument like HIFI, frequency calibration should not be difficult – WBS comb & HRS locked to Master Oscillator
- Instrument spectral response must be measured by S/S & in ILT
- Special attention must be given on ground-characterization of
  - Spurious signals/responses
  - DRO up-converter (Band 6)
  - Side-band ratios

Calibration of the beam

- Measuring the beam in-orbit will preferably be done on Mars. If Mars is unavailable we will rely on other planets for a characterization of the beam
- Some coupling factors may be derived from the weaker planets and asteroids (aperture efficiency)
- We will have a full quasi-optical description of the 3 ports: LO, sky and loads to the mixers







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Bandpass calibration – general

- Together with the beam knowledge the bandpass calibration provides the *total* intensity calibration

- Bandpass includes the IF ripple, the backend profiles and the standing wave contribution
- Main conclusion is that we are sensitive to many effects, but that observing smart, with good choice of reference and/or OFF, many effects will cancel

Bandpass calibration – scale

- Intensity scale comes from measurements of the hot and cold load. These loads have different optical paths from the sky-mixer path
- The combined intensity scale with beam and load couplings are checked on the flux of Uranus (derived from models) and maybe asteroids
- The loads are thus giving the relative intensity scale compared with Uranus, they provide the stable transfer function and may (especially at higher frequencies) serve as absolute calibrators. Celestial calibrators will become dominant if the loads are unstable!
- Ground measurements are mandatory when using the loads as absolute calibrators

Pointing Calibration

- APE (Absolute Pointing Error) pointing requirement is 3.7 arcsec with a goal of 1.5 arcsec (both 68% of the time)
- The beam of HIFI at 1.6-1.9 THz is about 13 arcsec: Pointing is an issue!
- Same holds for scanning APE
- The AME (Attitude measurement error = A posteriori knowledge) is about 2.8 arcsec (vs 3.1 required) and its goal is 2 arcsec actual (vs 1.2 required)
- Note that most goals will never be met in normal observations with HIFI

- We need pointing calibration in Band 6, star tracker calibration through PACS and peaking up

The importance of celestial sources

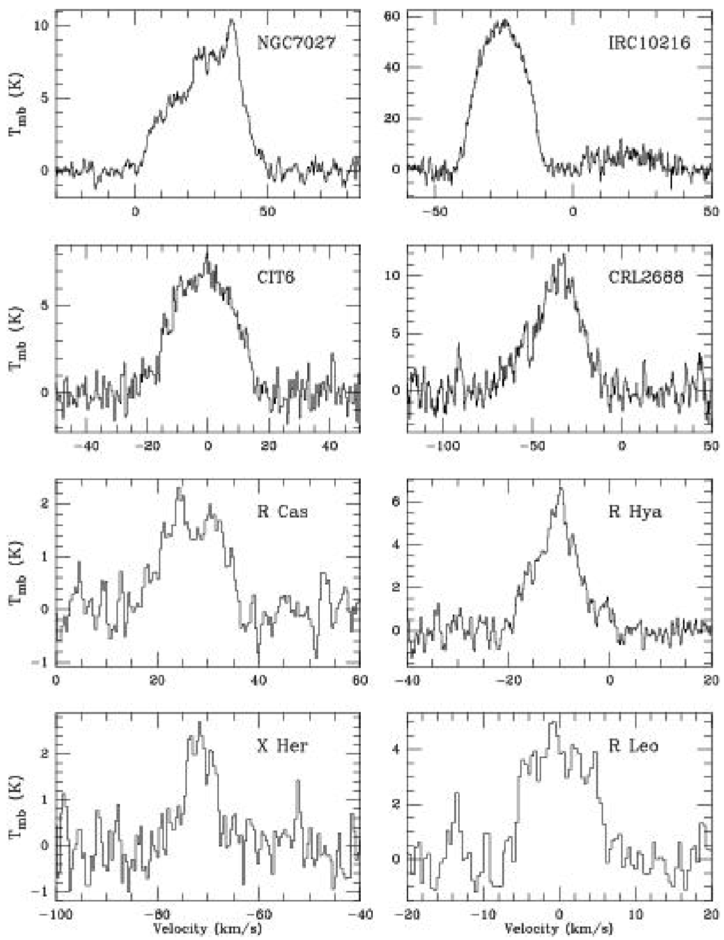
- AGB stars are strong, point-like, line-sources:
  - Monitoring,
  - Spectral calibration
- Asteroids are point-like continuum sources:
  - Aperture efficiency
- Planets and their atmospheres:
  - Aperture efficiency
  - Beam characterization
  - Monitoring
  - Spectral Calibration

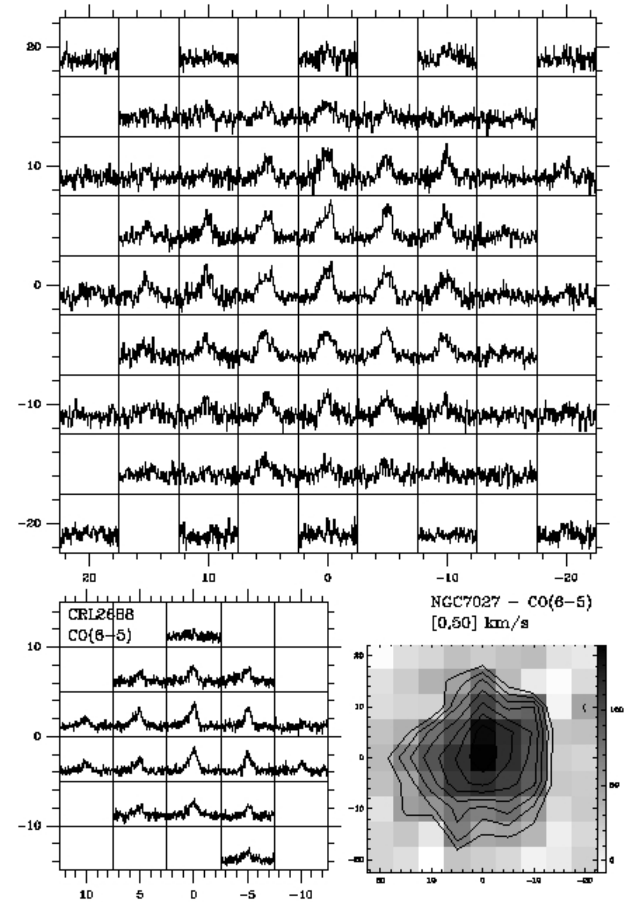
- We need models better than 5%!

Ground-based preparation

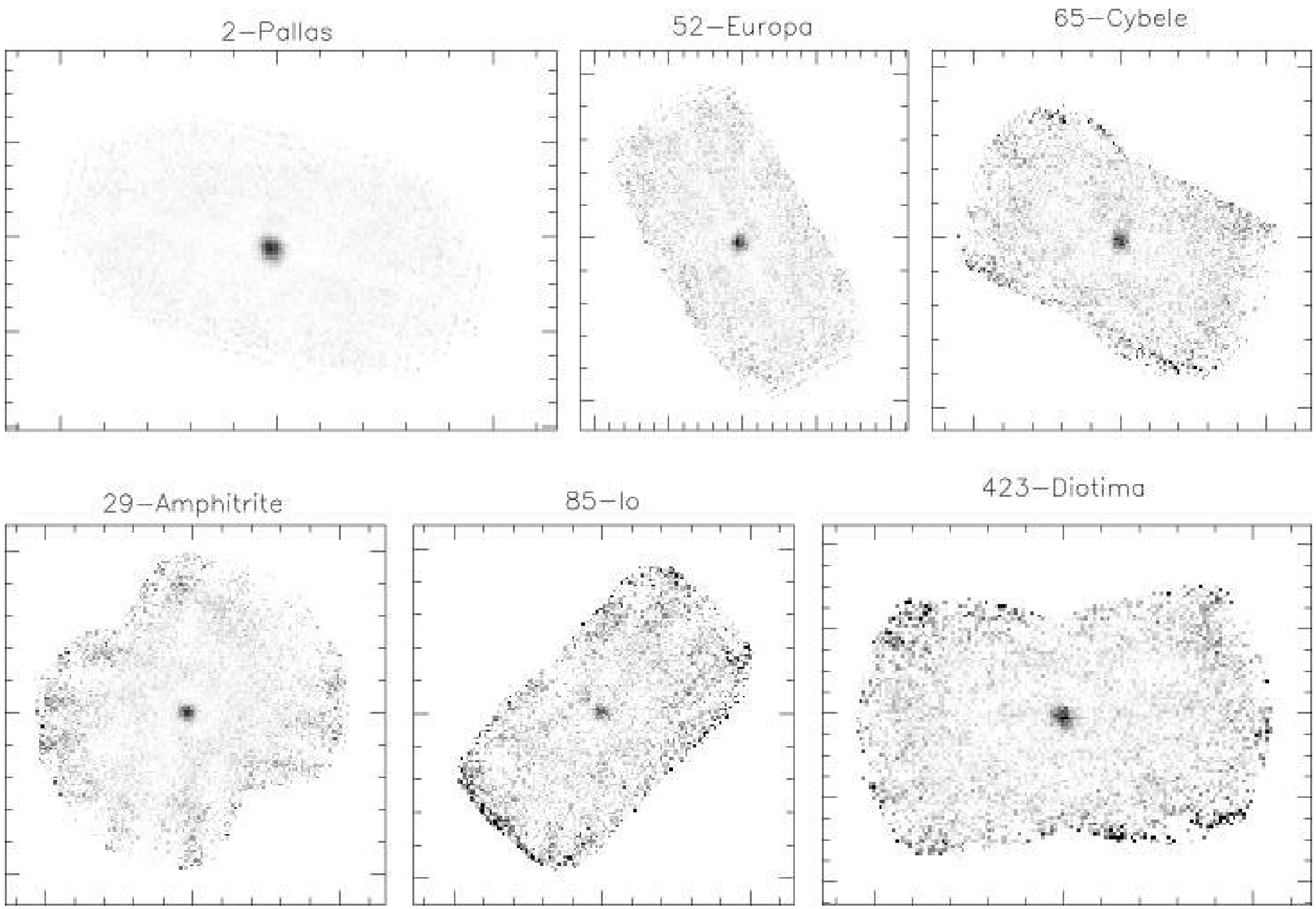
- Ground-based preparation is difficult for a 3.5 m dish operating at frequencies (almost) unaccesible from the ground
- We opted for two targets
  - Asteroids
  - CO in AGB stars
- The asteroids will be used for telescope properties and likely for flux calibration. Models of light curves can be tested on the ground
- CO lines in AGB stars provide pointing calibration, standard spectra and sizes of emitting regions (input for modelling/predicting the higher lines)

CO 6-5 in AGB stars (Teyssier/Bujarrabal)

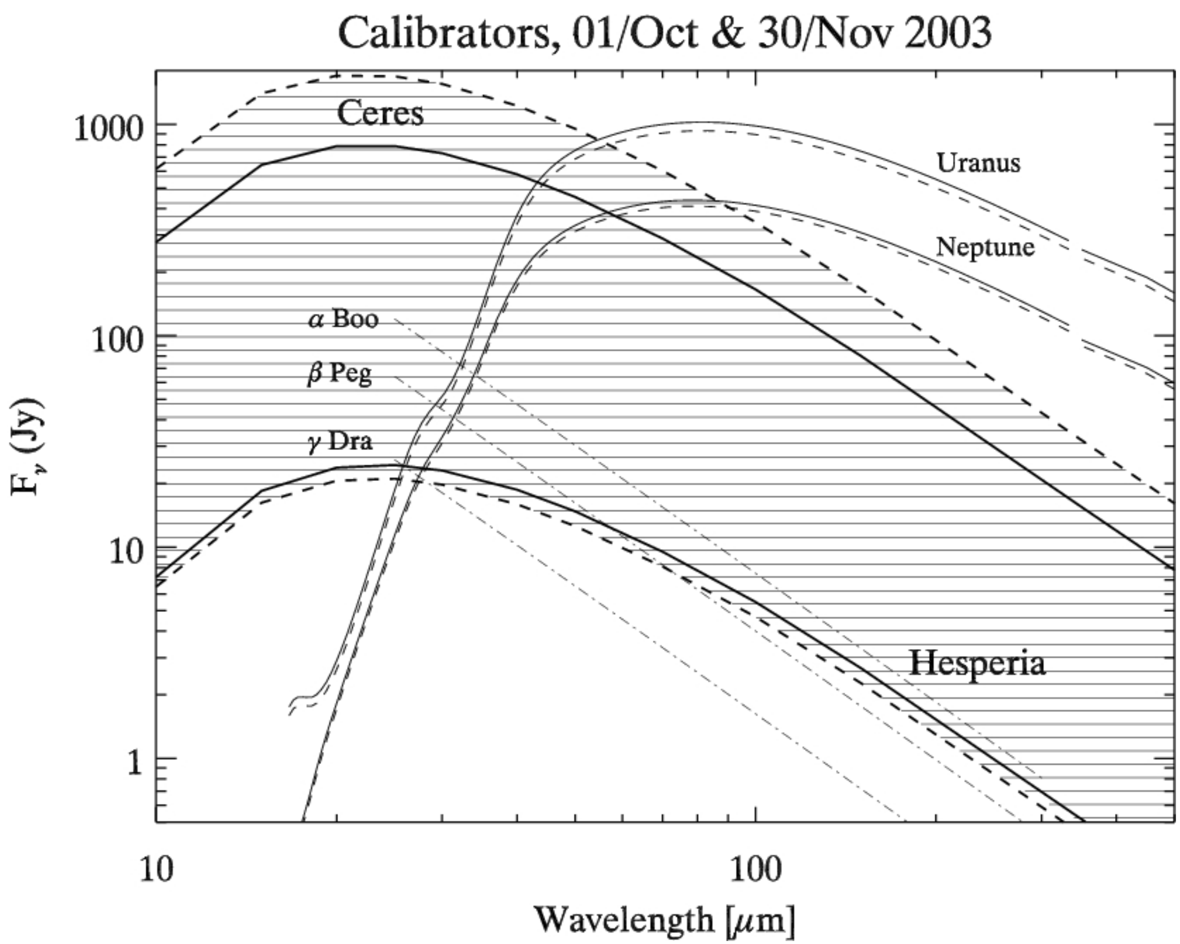




Asteroids (Teyssier / Mueller)



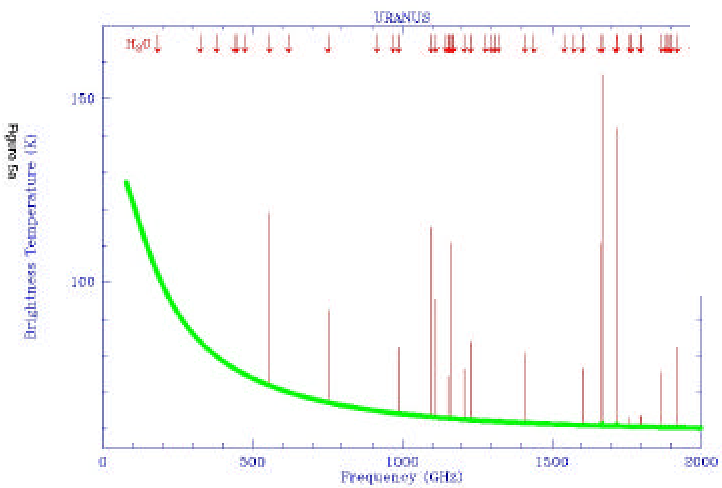
Asteroids



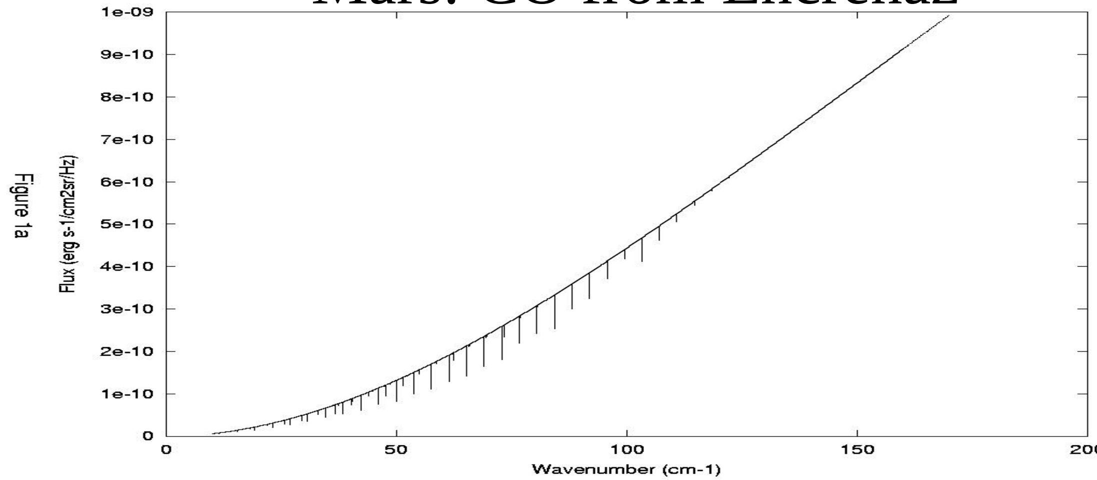
From Mueller

Uranus & Mars

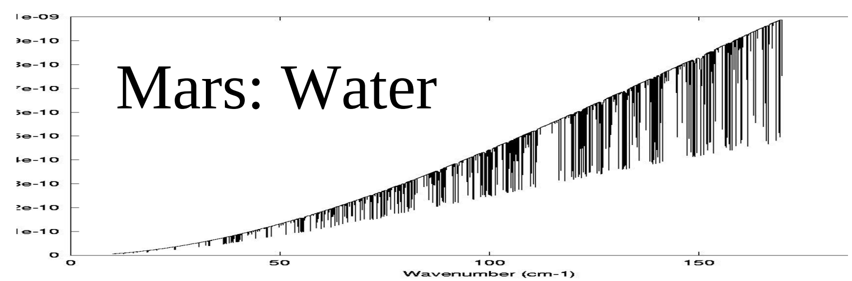
From Moreno



Mars: CO from Encrenaz



Mars: Water



Flexibility: What if..?

- We established the general scheme but:
  - In case Mars is unavailable, we will use other planets (Jupiter, Saturn)
  - In case Uranus is unavailable we use the asteroids
  - In case the internal loads are very reliable & stable they may be promoted as calibrators
  - In case the asteroid model/observations turn out to be very reliable they may replace Uranus
  - In case of chopper failure or failure of loads the celestial sources become much more important

- ALL of the above imply preparation! Especially to reach the goal of 3%. Together we may succeed.