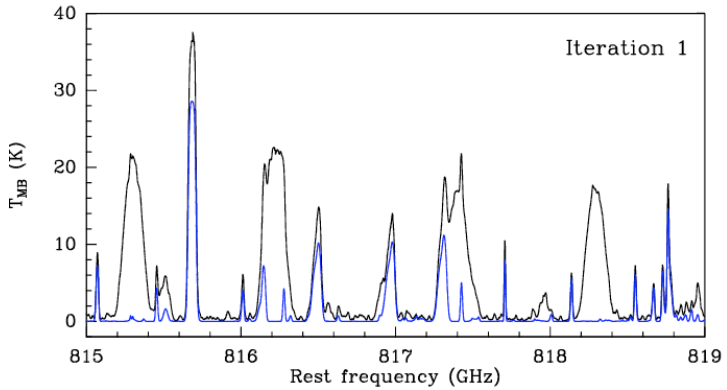
IPAC's Spectral Deconvolution Tool - Steve Lord

Unfolding Spectra for Herschel/ HIFI, CSO, ALMA, SOFIA, ...

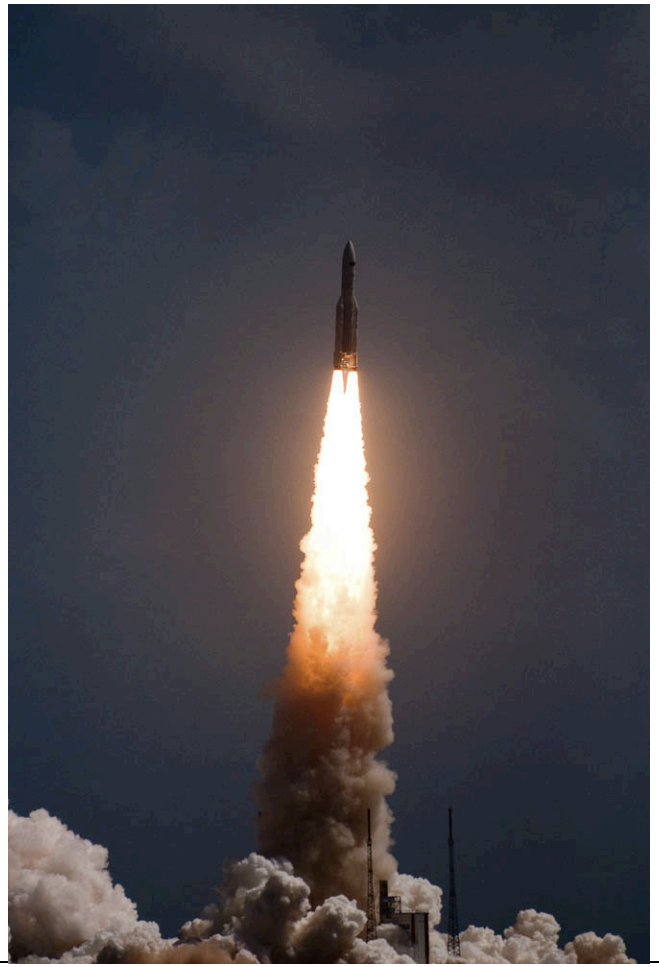


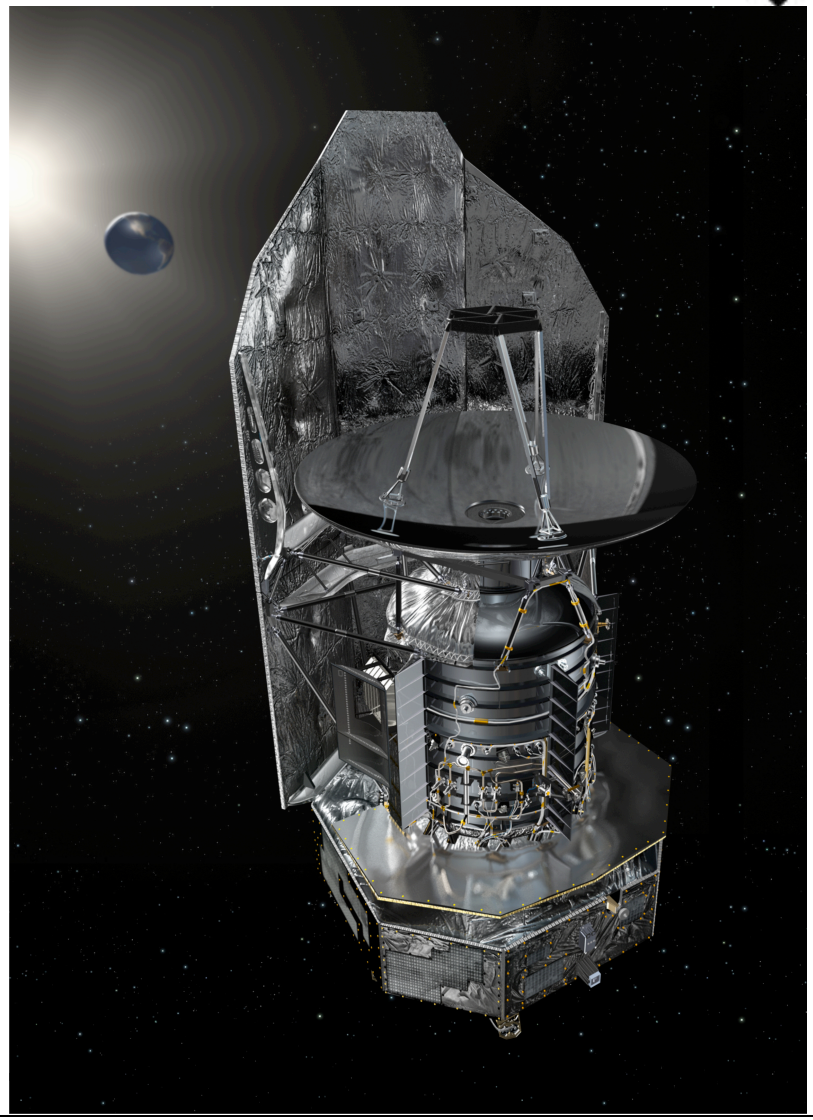
Why a Deconvolution Tool?

The whole story:

- Herschel has super high resolution spectrometer on board called “HIFI”.
- HIFI’s data suffer from an instrument artifact: all spectra are folded onto themselves.
- We have developed a numerical method and an accompanying User Tool that unscrambles the data, by deconvolving the data sets)
- This tool may be useful elsewhere

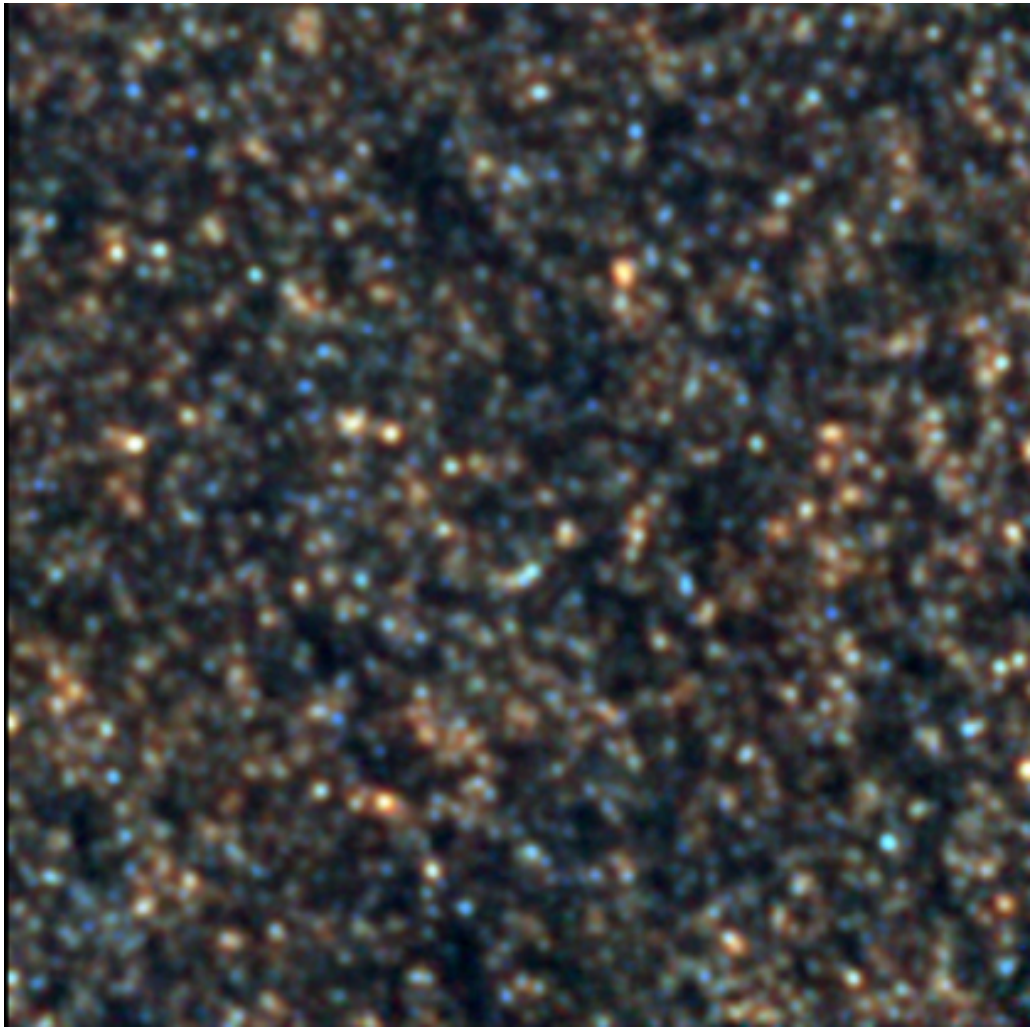
Herschel – The Largest Telescope in Space





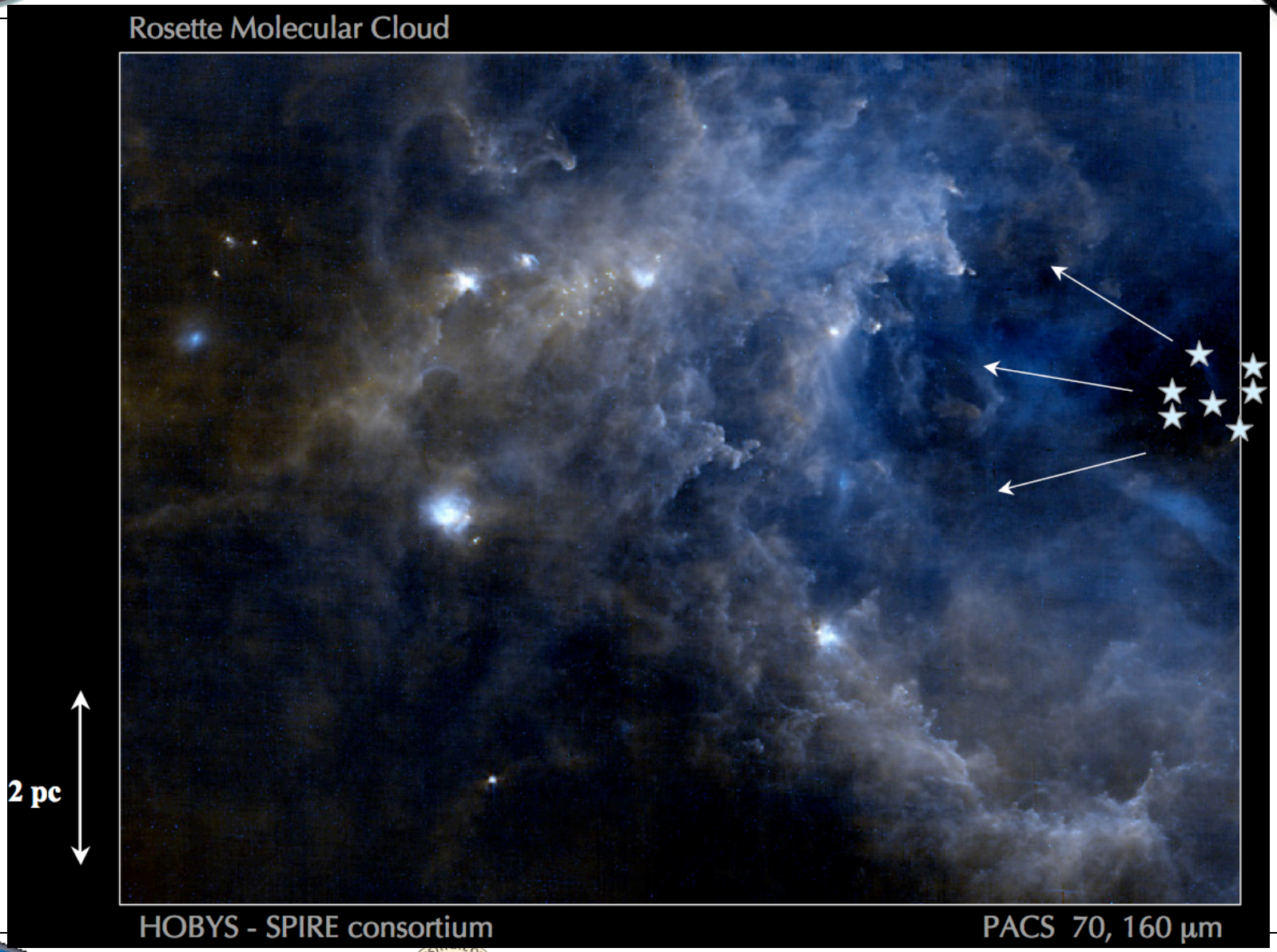
PACS and SPIRE Photometers

Imaging to 3"



Extragalactic
Background
Resolved

PACS and SPIRE Photometers



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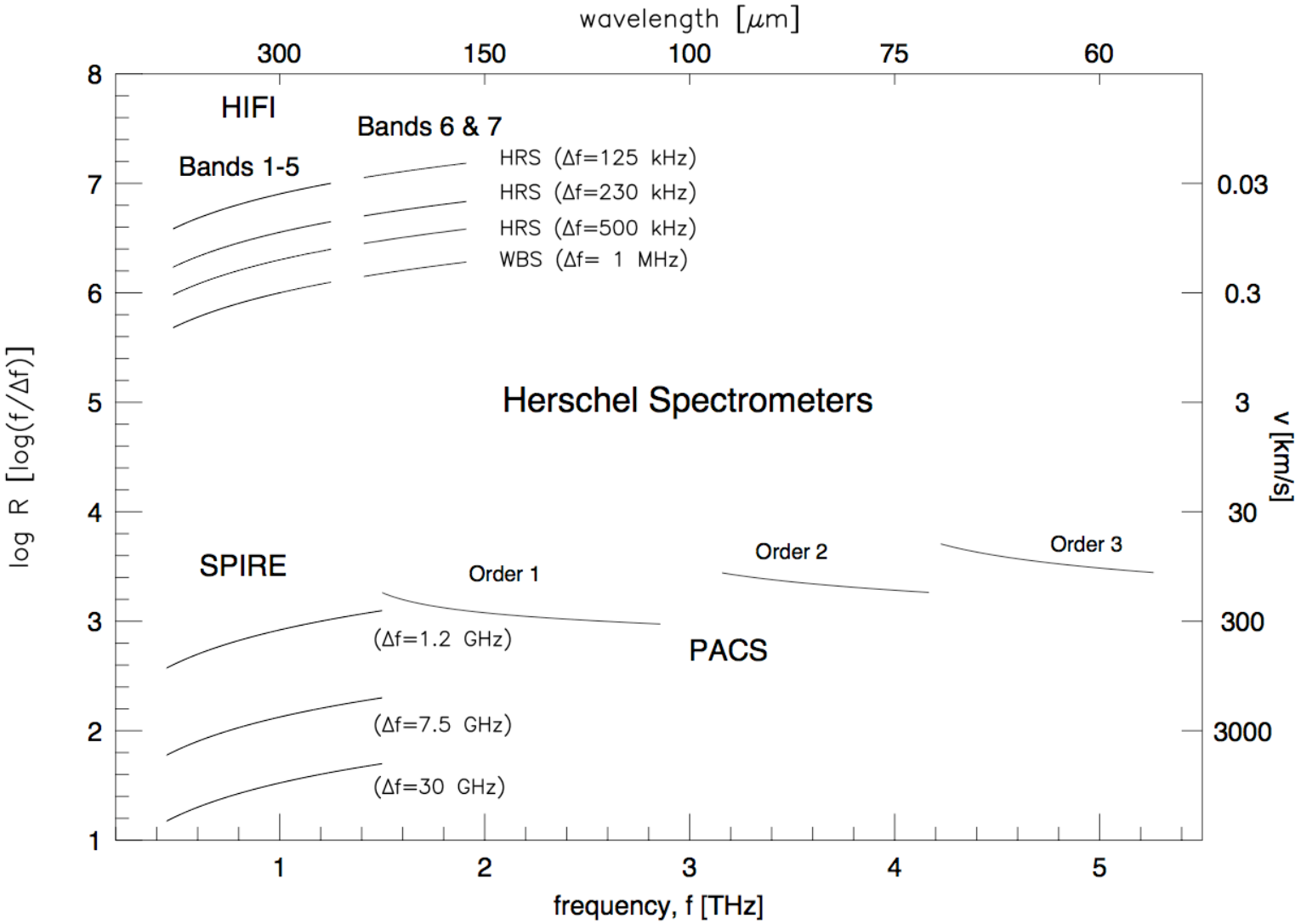
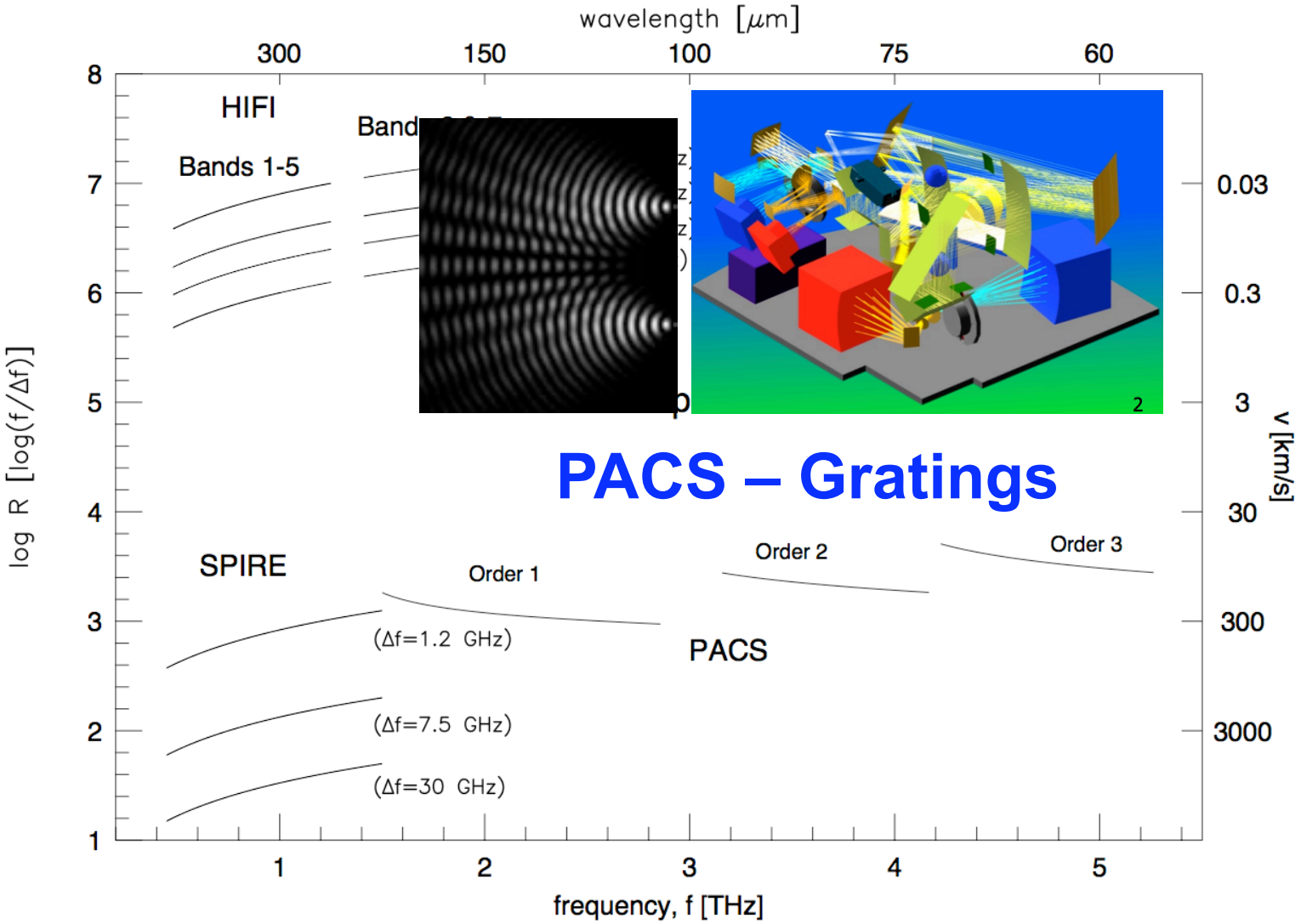
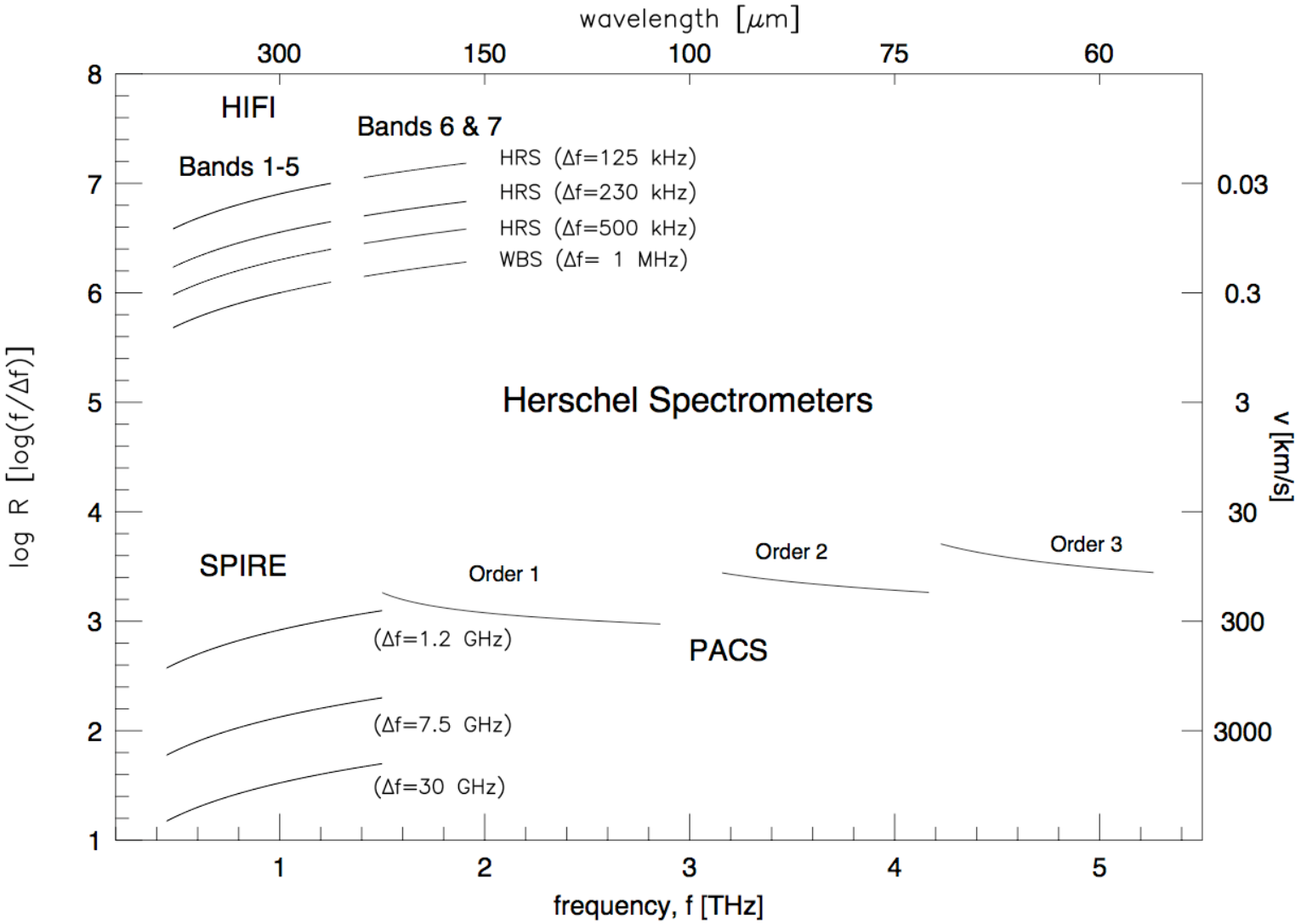
Herschel Spectrometers



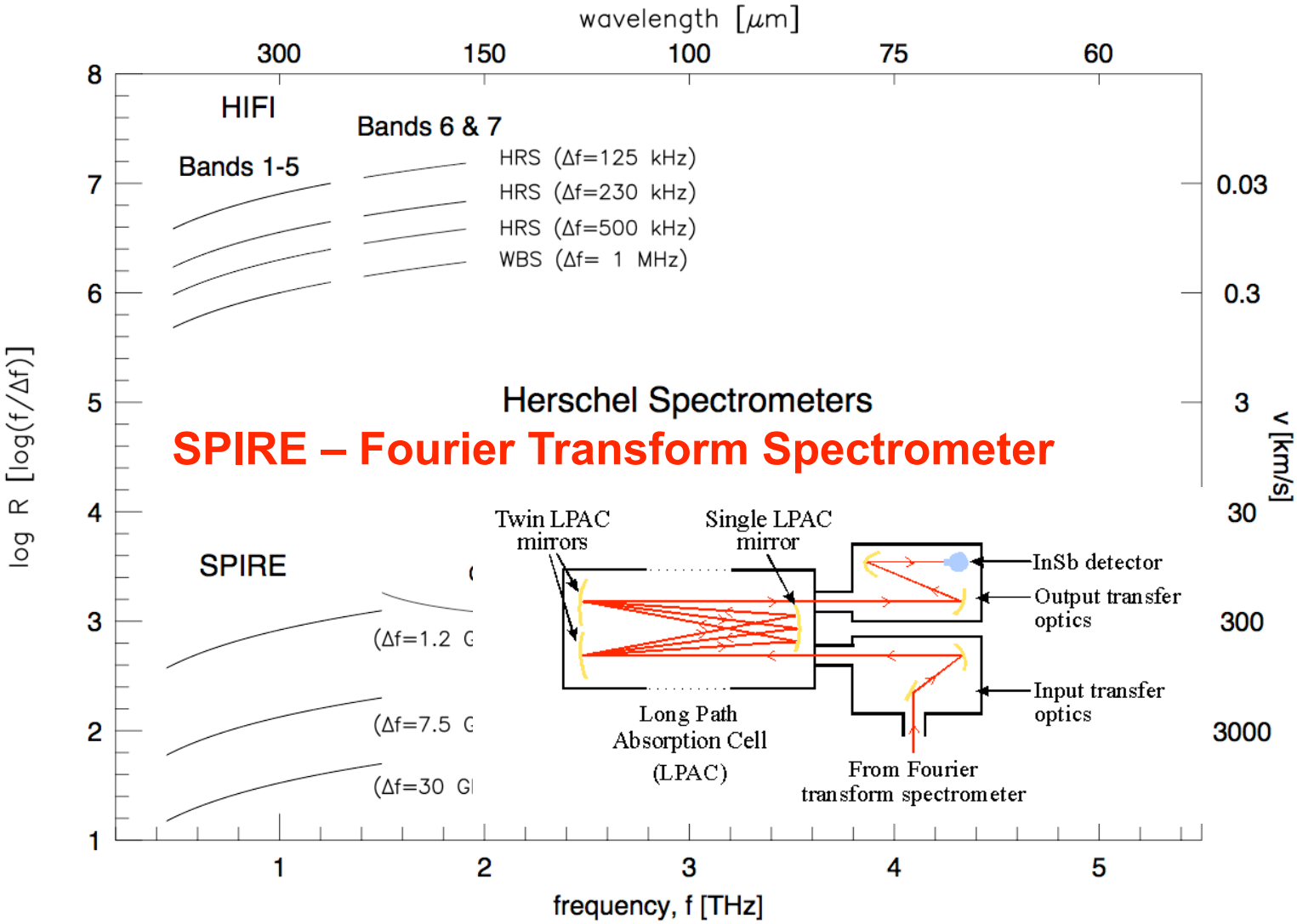
Herschel Spectrometers



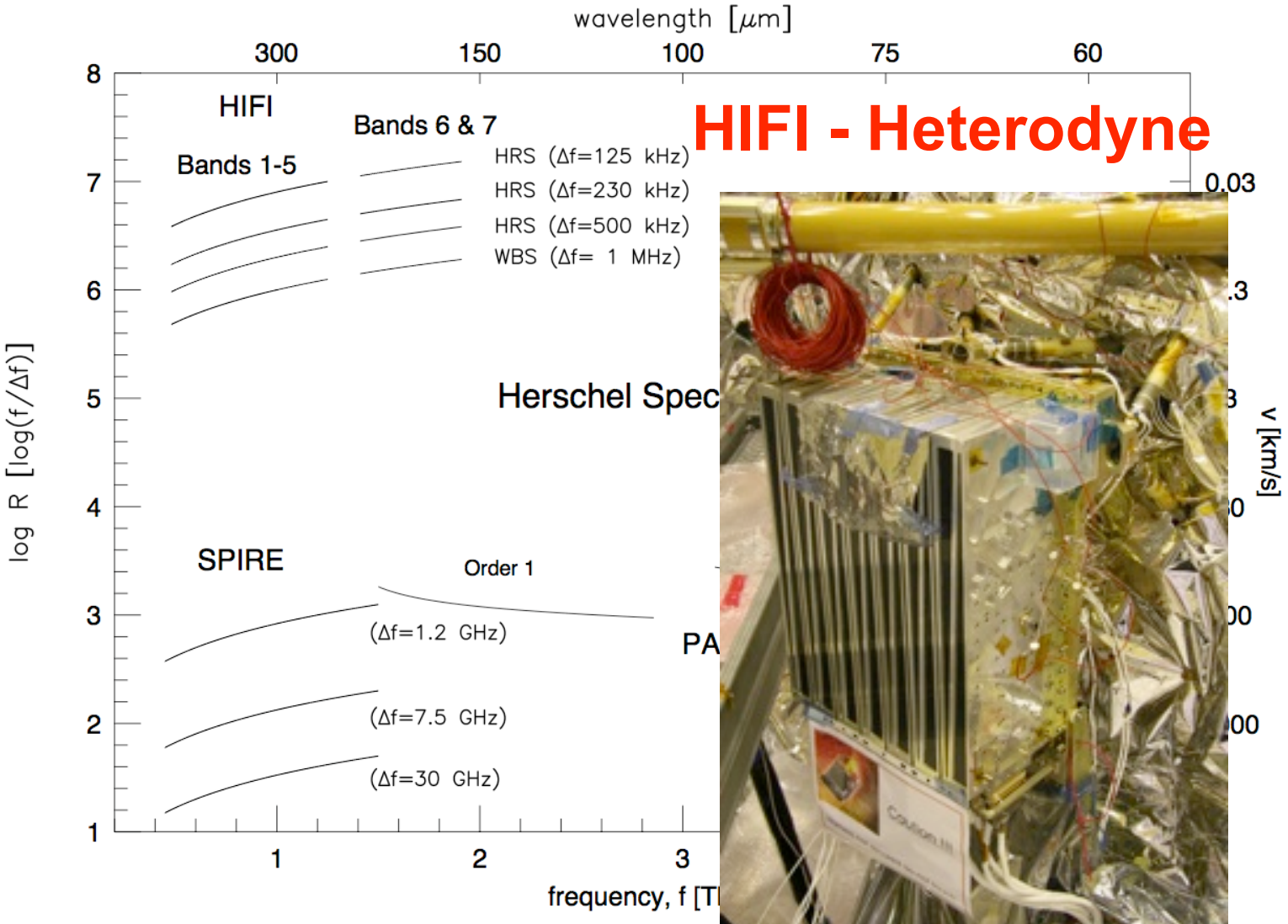
Herschel Spectrometers



Herschel Spectrometers

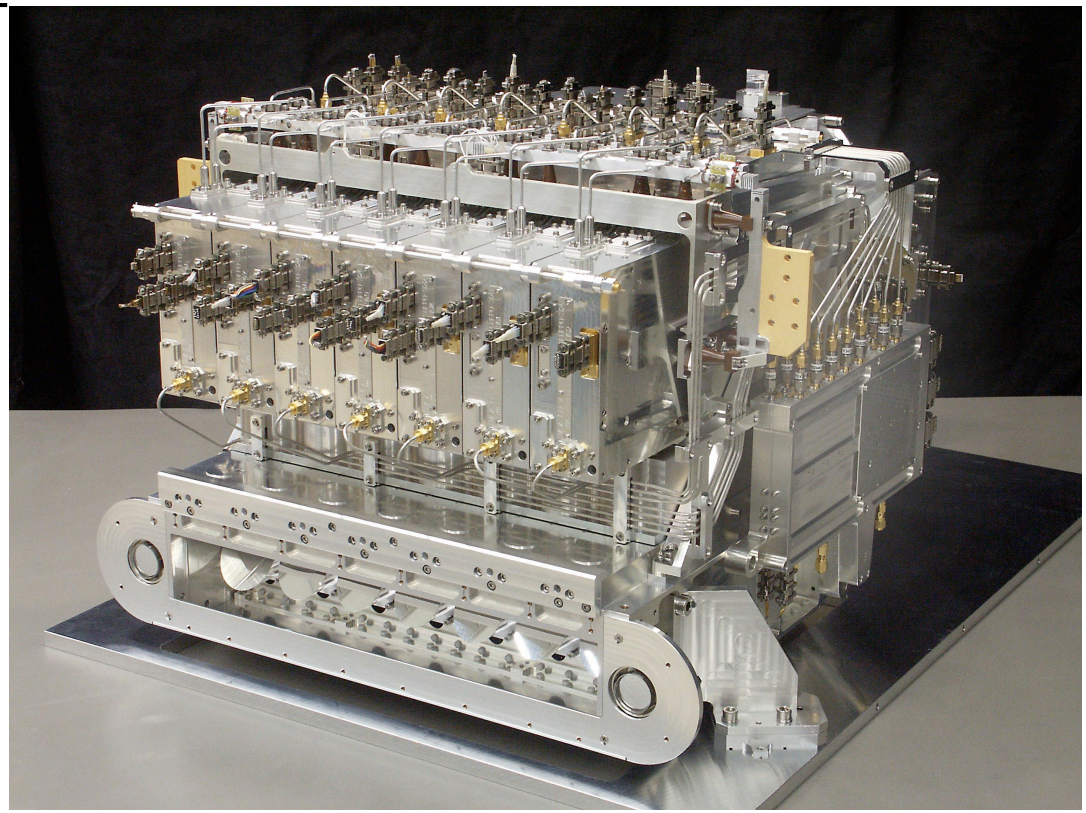


Herschel Spectrometers



Herschel/HIFI

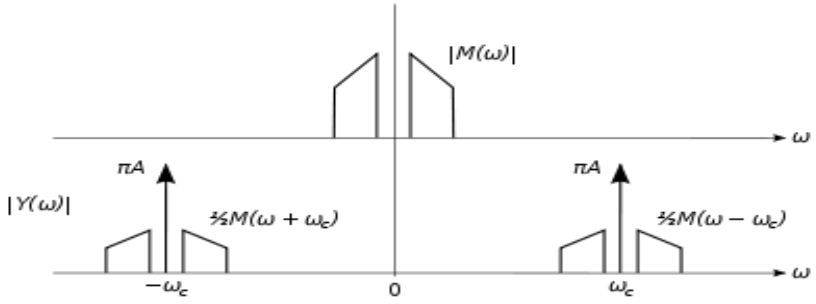
- 7 Submillimeter & Far Infrared Mixers Units
- 0.5 – 1.9 THz
- 150-600 um
- AOS backend
- A/C Backend
- R~10^7

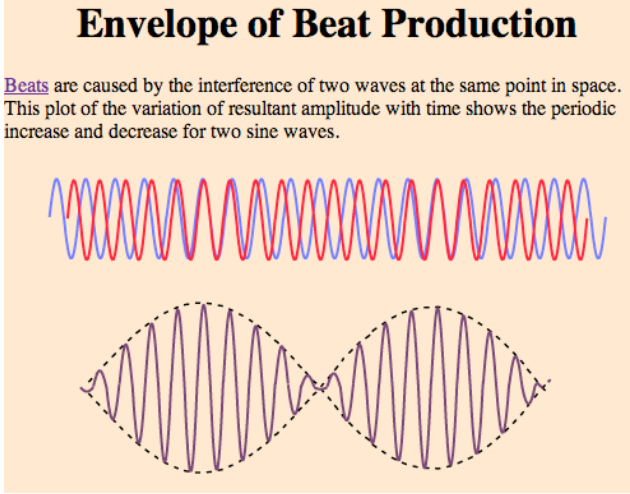


AM Radio – Your local Heterodyne Example

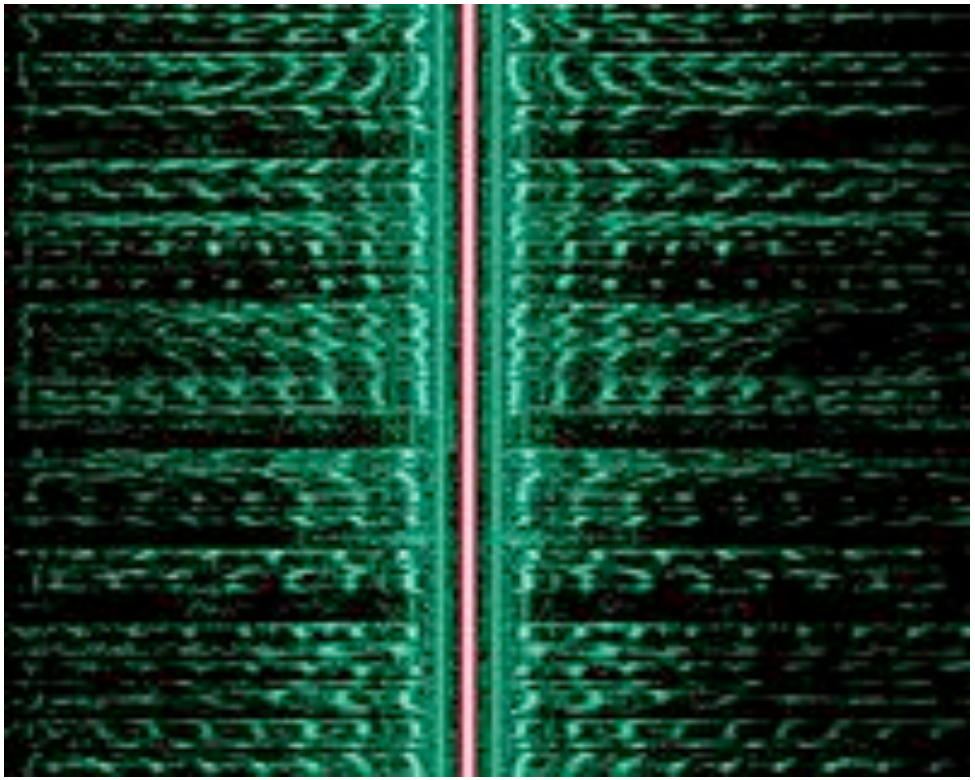
Amplitude modulation is created by forming the product: (same principle as piano tuning!)

$$\cos X \cos Y = (1/2) [\cos (X - Y) + \cos (X + Y)]$$



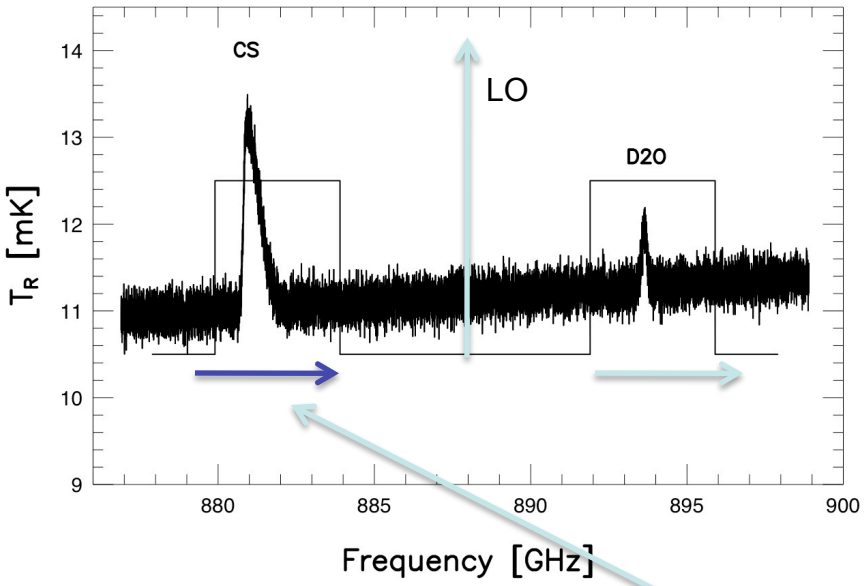


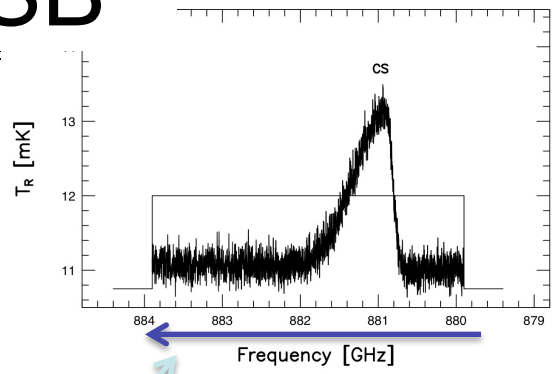
AM Frequency – Time Plot

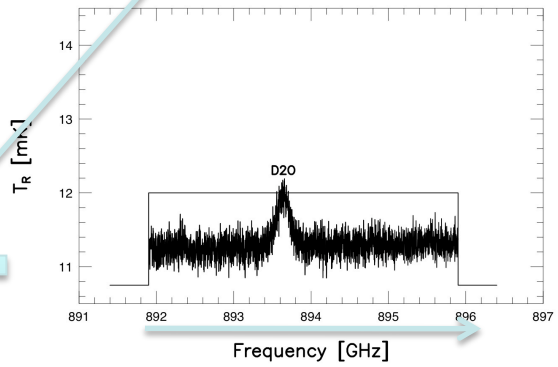


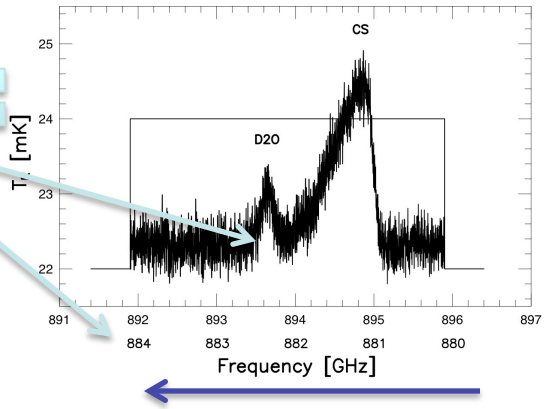
Center, colored red, is the carrier wave at 558 kHz; the two mirrored audio spectra (green) are the lower and upper sideband.

LSB + USB = DSB



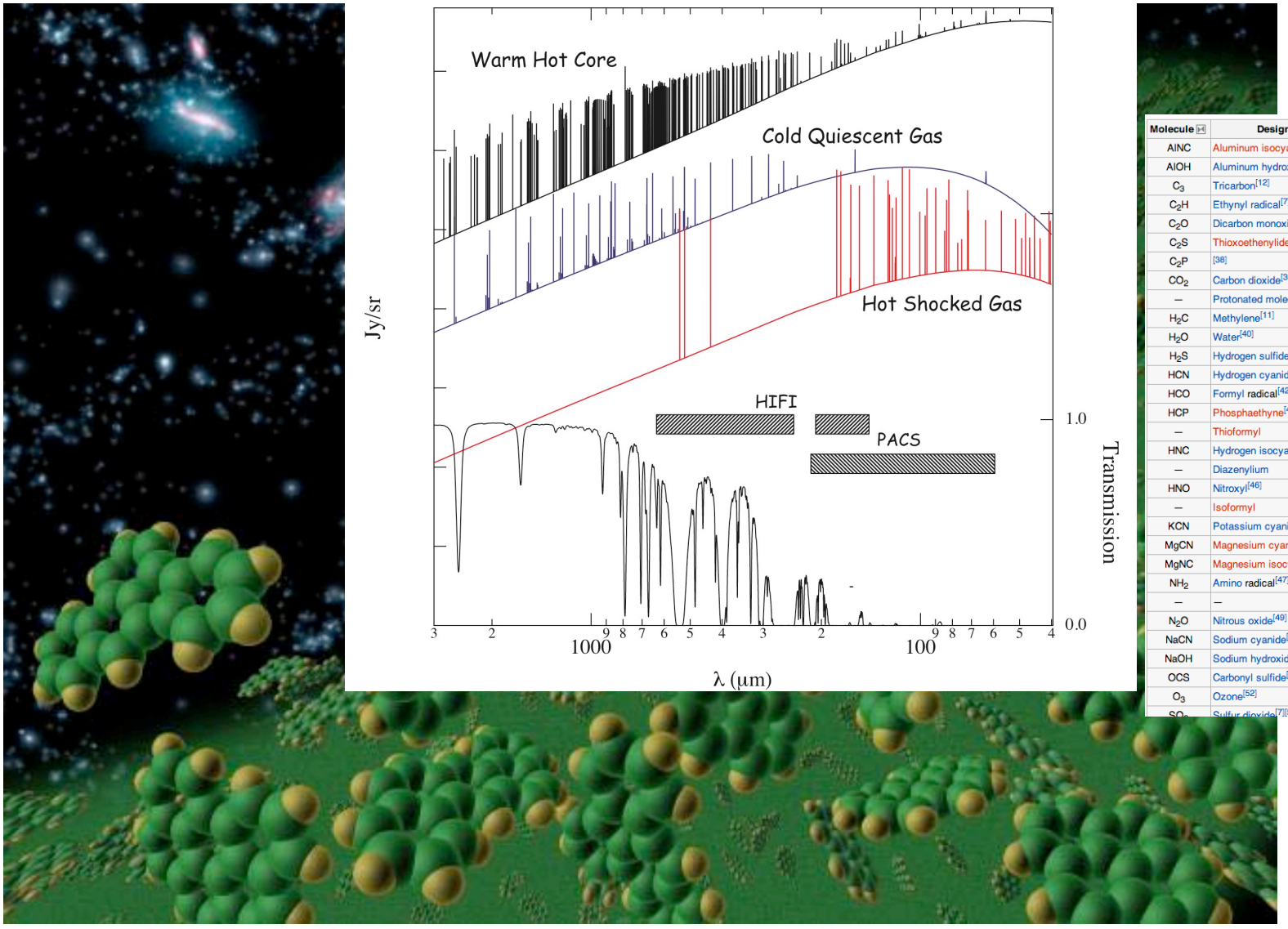






- Lower sideband spectrum is reversed and added
- Two frequency scales result in the DSB result
- The lines may blend but they can be recovered (deconvolved)
- The continuum levels add (double) in the DSB
- The continuum slope is flattened but may be recovered (deconvolved)
- The noise adds in quadrature , increasing as sqrt(2)

Astrochemistry



Molecule	Designation	Mass	Ions
AlNC	Aluminum isocyanide[7]	53	–
AlOH	Aluminum hydroxide[35]	44	–
C_3	Tricarbon[12]	36	–
C_2H	Ethynyl radical[7][16]	25	–
C_2O	Dicarbon monoxide[36]	40	–
C_2S	Thioxoethenylidene[37]	56	–
C_2P	[38]	55	–
CO_2	Carbon dioxide[39]	42	–
–	Protonated molecular hydrogen	3	H_3^+[3][34]
H_2C	Methylene[11]	14	–
H_2O	Water[40]	18	–
H_2S	Hydrogen sulfide[7]	34	–
HCN	Hydrogen cyanide[7][16][41]	27	–
HCO	Formyl radical[42]	29	HCO^+[15][43][42]
HCP	Phosphaethyne[44]	44	–
–	Thioformyl	45	HCS^+[15][43]
HNC	Hydrogen isocyanide[45]	27	–
–	Diazenylium	29	HN_2^+[43]
HNO	Nitroxyl[46]	31	–
–	Isoformyl	29	HOC^+[16]
KCN	Potassium cyanide[7]	65	–
MgCN	Magnesium cyanide[7]	50	–
MgNC	Magnesium isocyanide[7]	50	–
NH_2	Amino radical[47]	16	–
–	–	29	N_2H^+[15][48]
N_2O	Nitrous oxide[49]	44	–
NaCN	Sodium cyanide[7]	49	–
NaOH	Sodium hydroxide[50]	40	–
OCS	Carbonyl sulfide[51]	60	–
O_3	Ozone[52]	48	–
SO_2	Sulfur dioxide[7][53]	64	–

Formulation of the Problem

- Start with a guess of the answer – a model with no assumptions for the SSB spectrum – flat
- "Observe it" – using knowledge of the instrument
- compare the observations of the model with the real observations
- compute a chi square and a delta (differential) chisquare
- each model "spectral channel" was in part ressponsible for some of the chi square change
- follow the slope of the chi square downward
- always move at right angles – thus Conjugate Gradient Method
- Stop when asymptote is reached

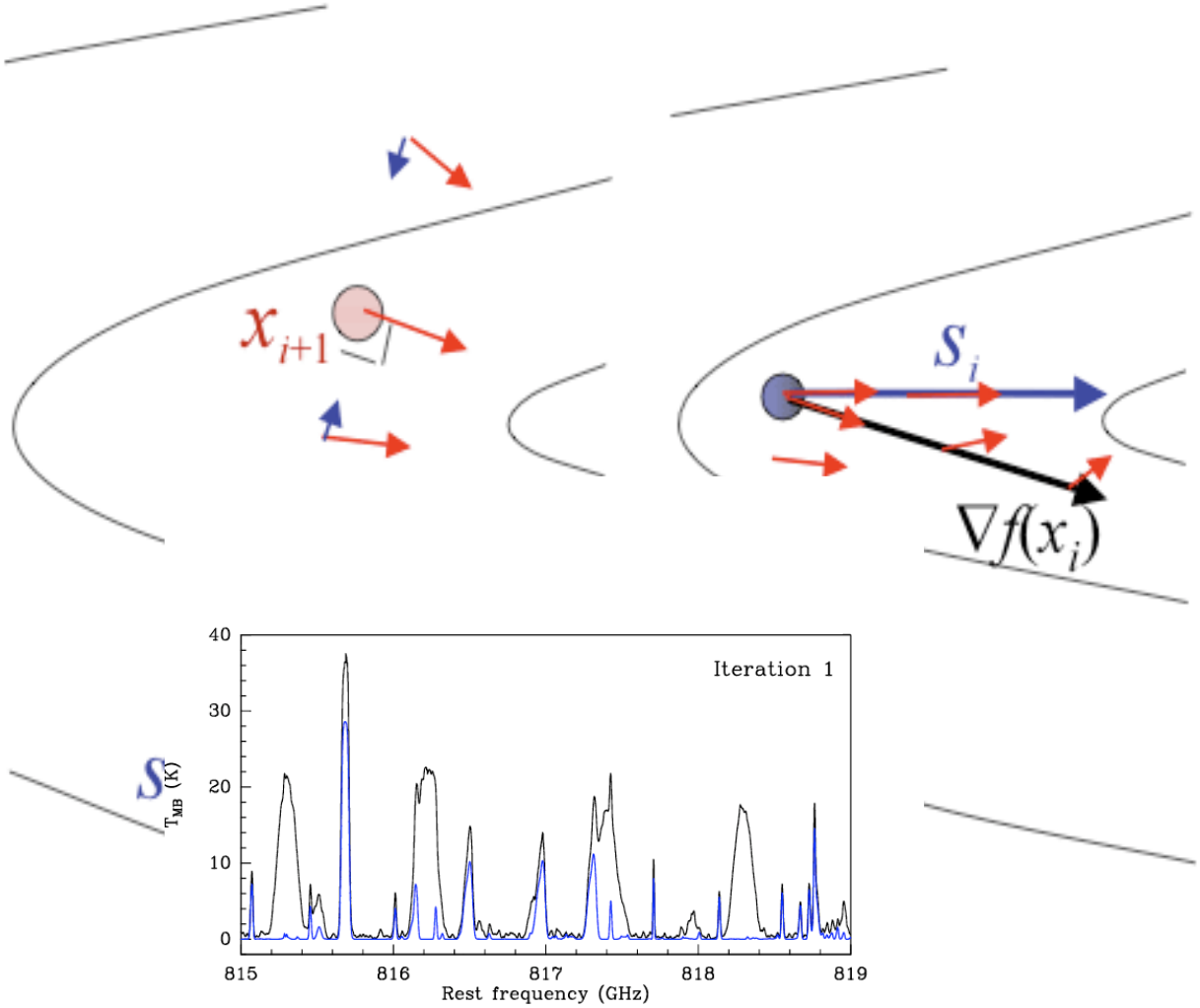


Figure 2. Left: Steepest gradient technique. Right: Conjugate gradient technique.

Other problems

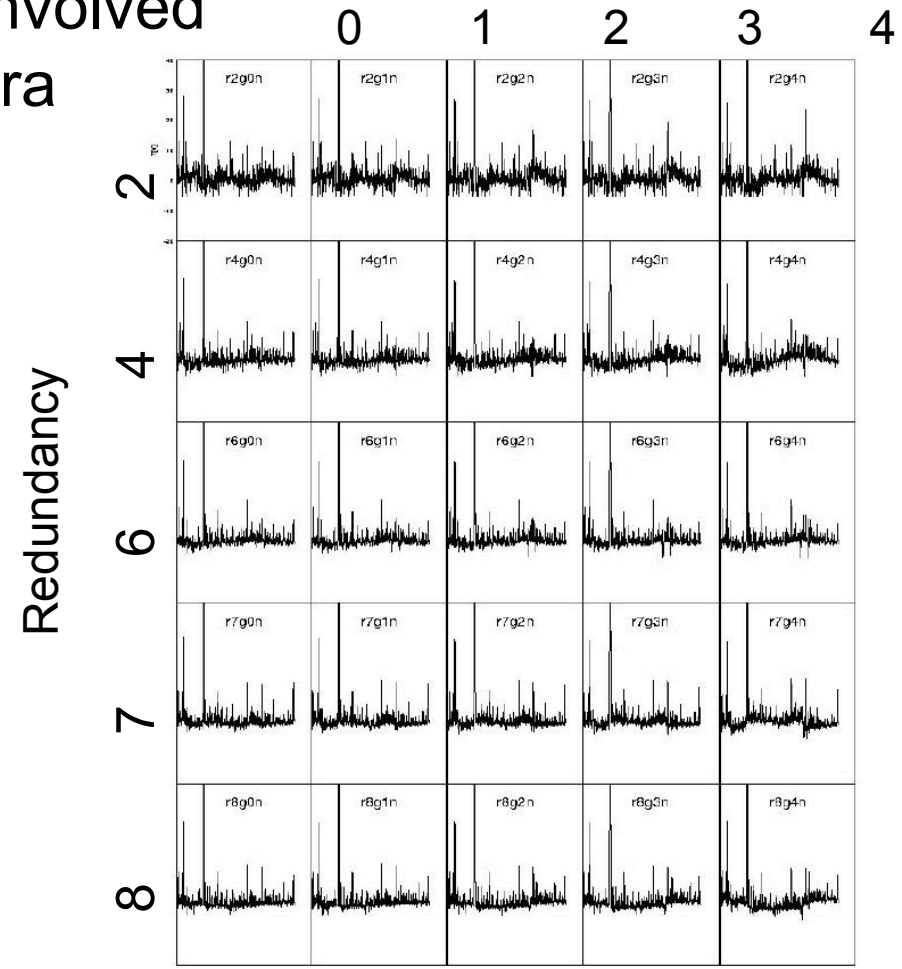
- Bad Standing Waves
- Bad Baselines
- "Spurs"

- Some mitigation possible
  - Data cleanup
  - Maximum Entropy added in....

Grain Drift Experiment for Line Rich Source

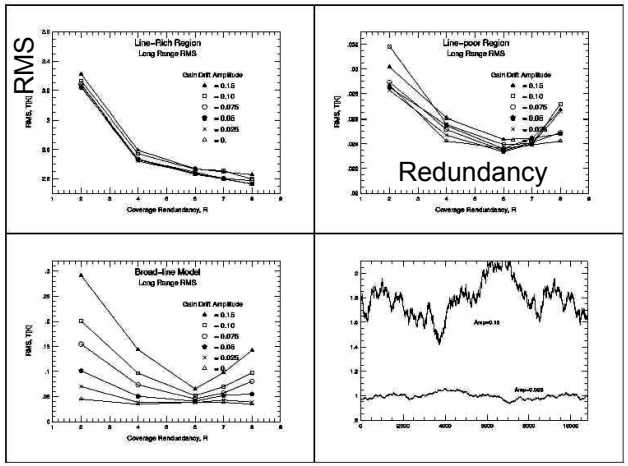
Gain Drift Amplitude (normalized)

Deconvolved Spectra



Conclusion:

Higher Redundancy offsets Gain Drift – to a point



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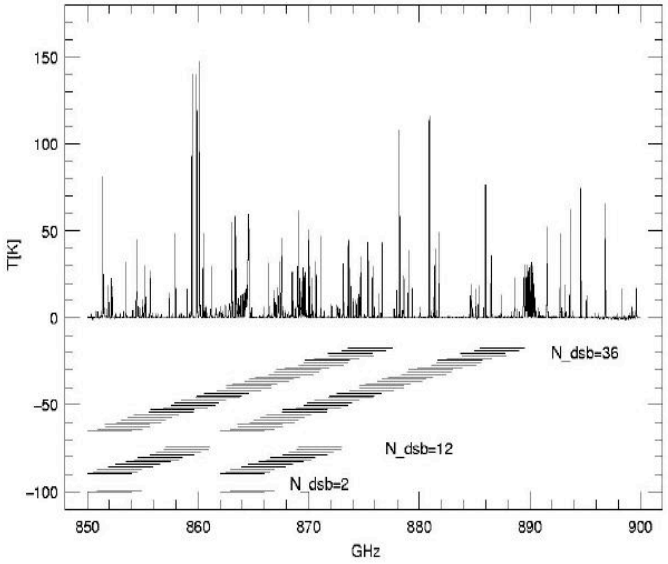
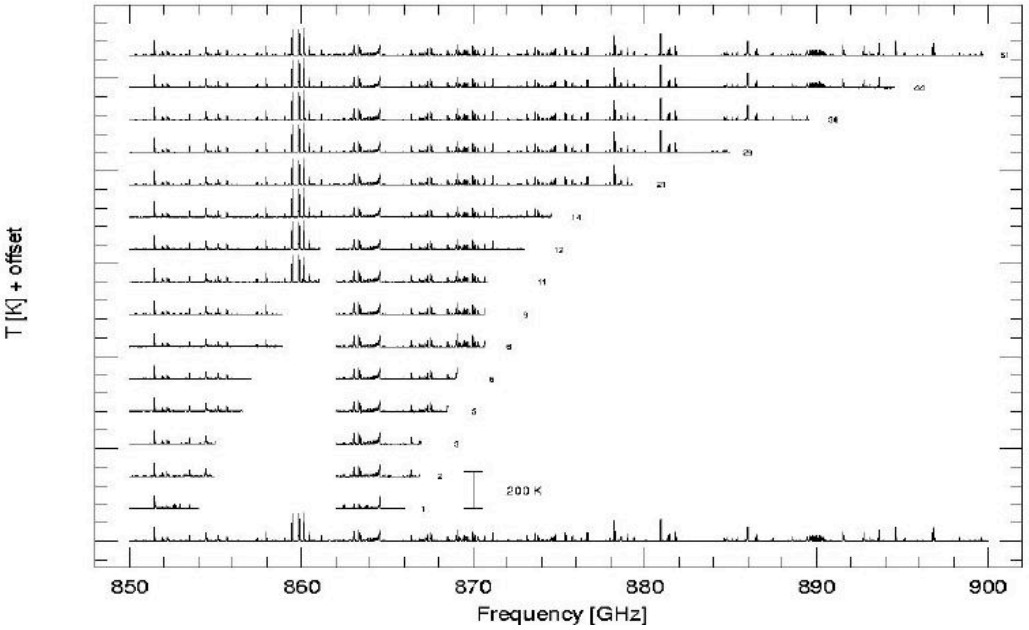
The Smallest Spectral Scan

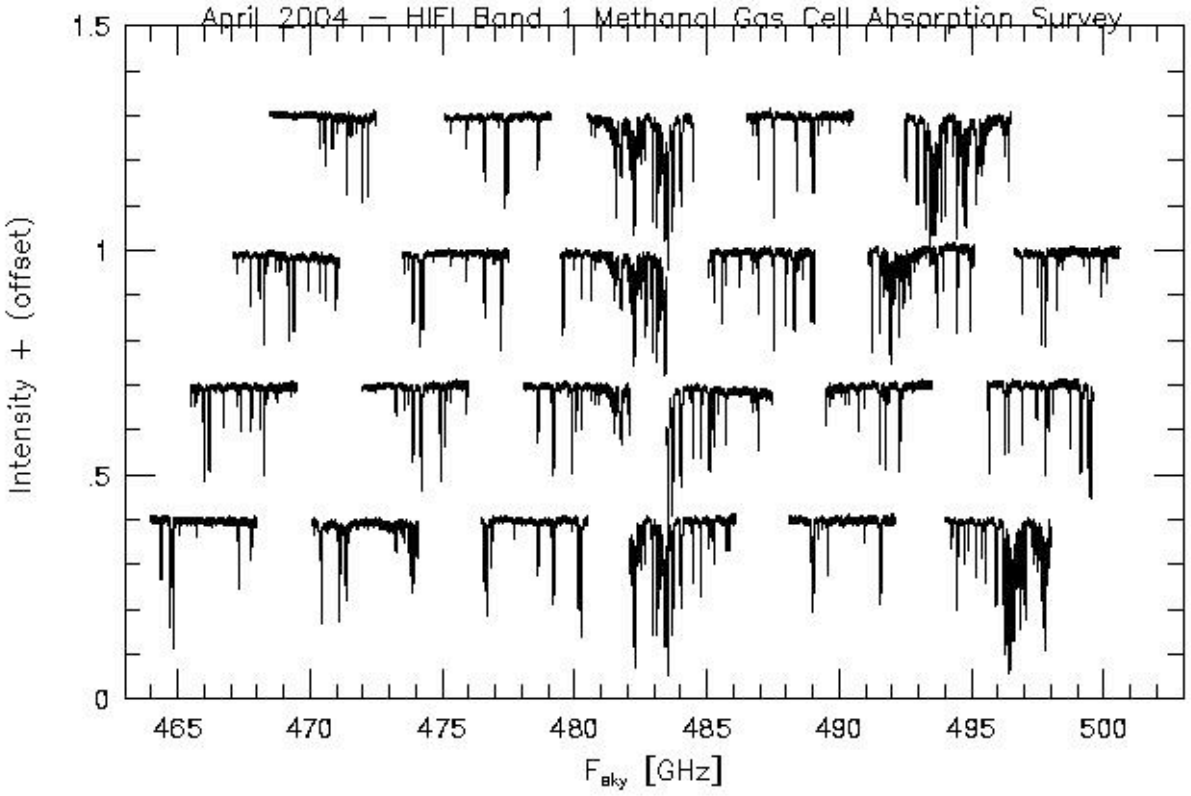
- Completed Deconvolution Study of minimum width survey

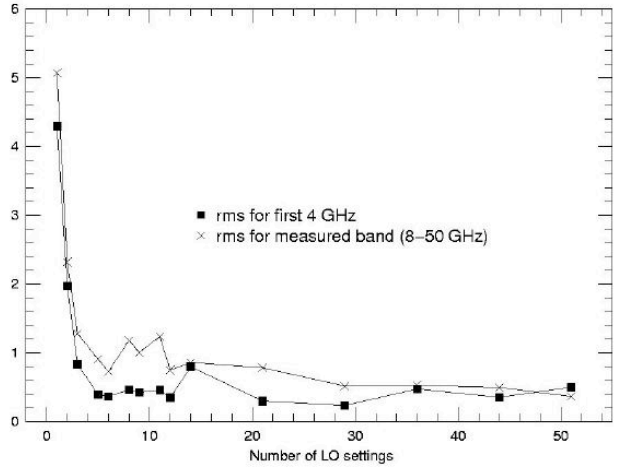




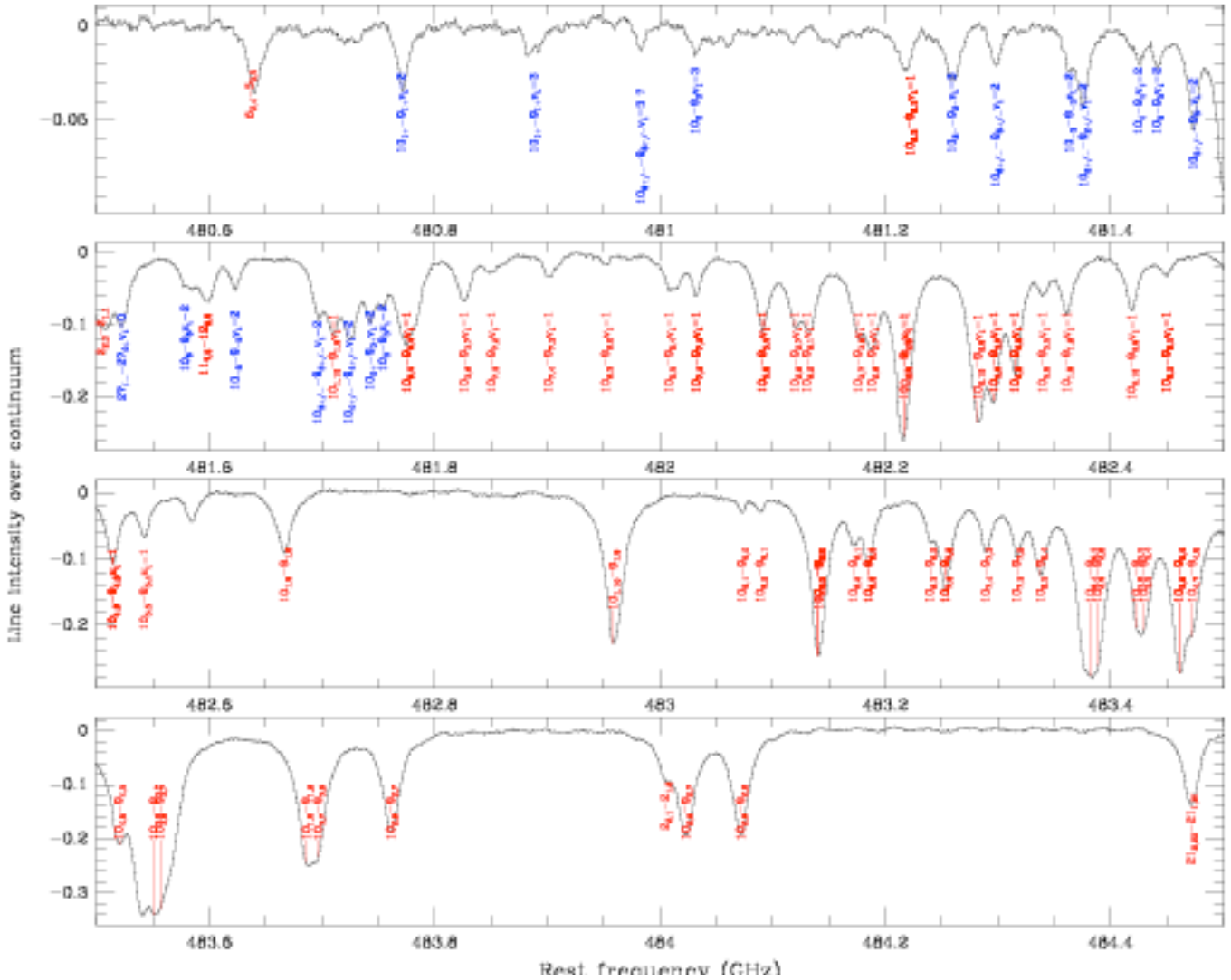
The Smallest Spectral Scan

- Completed Deconvolution Study of minimum width survey (con't)





Deconvolved Methanol Survey



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Tool Requirements Outlined

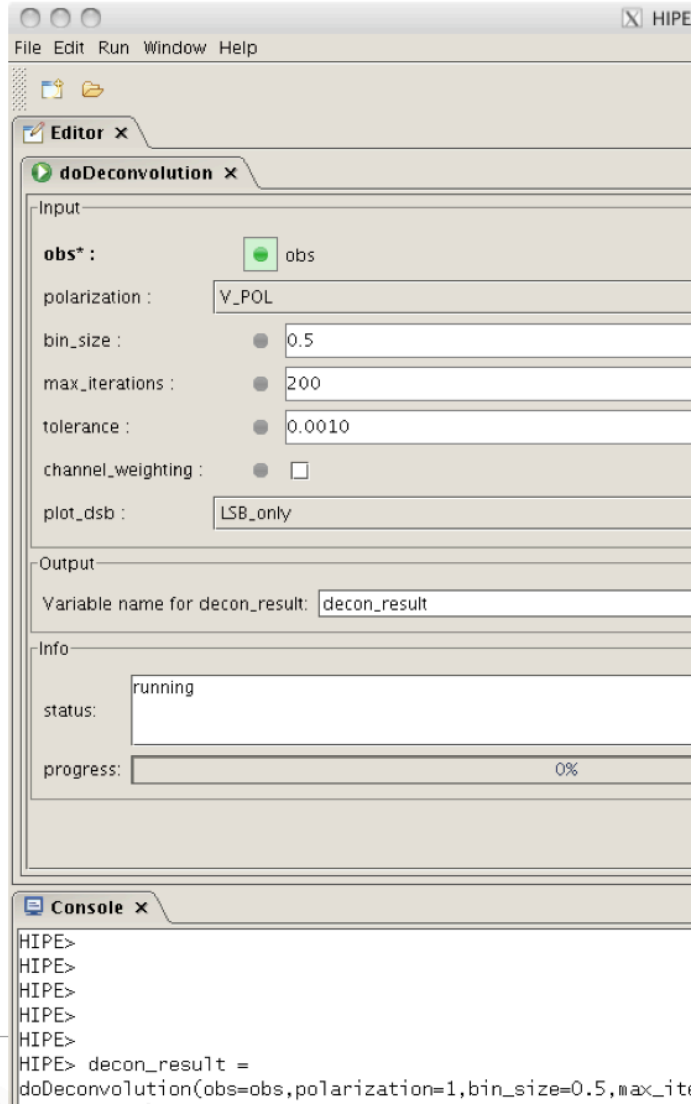
Requirements for JAVA Sideband Separation Tool

- Runs via a JAVA Widget or Jython Command Line Script
- Can save and reload intermediate steps
- Can output intermediate and final steps in various formats
- Runs as part of the Data Processing HCSS environment
- Allows (as a best effort) automatic processing
- Allows User control and intervention (with graphic output of steps)
  - User can change sequence of what is fit at each iteration (e.g., bias, fringes)
  - User can blank-out strong known lines for reinsertion later.
- Allows Ghost Identification Facilities - i.e. multiple DBS coverages showing where line must appear if it is indeed real
- Allows Ghostbusting Capabilities - i.e., shows location where ghost primaries, secondarys, etc. show up on the SSB spectrum
- Has labeled and easy to understand multi-colored displays and H/C
- Gives product quality information - “goodness of fit” results based on DSB residual and system noise.

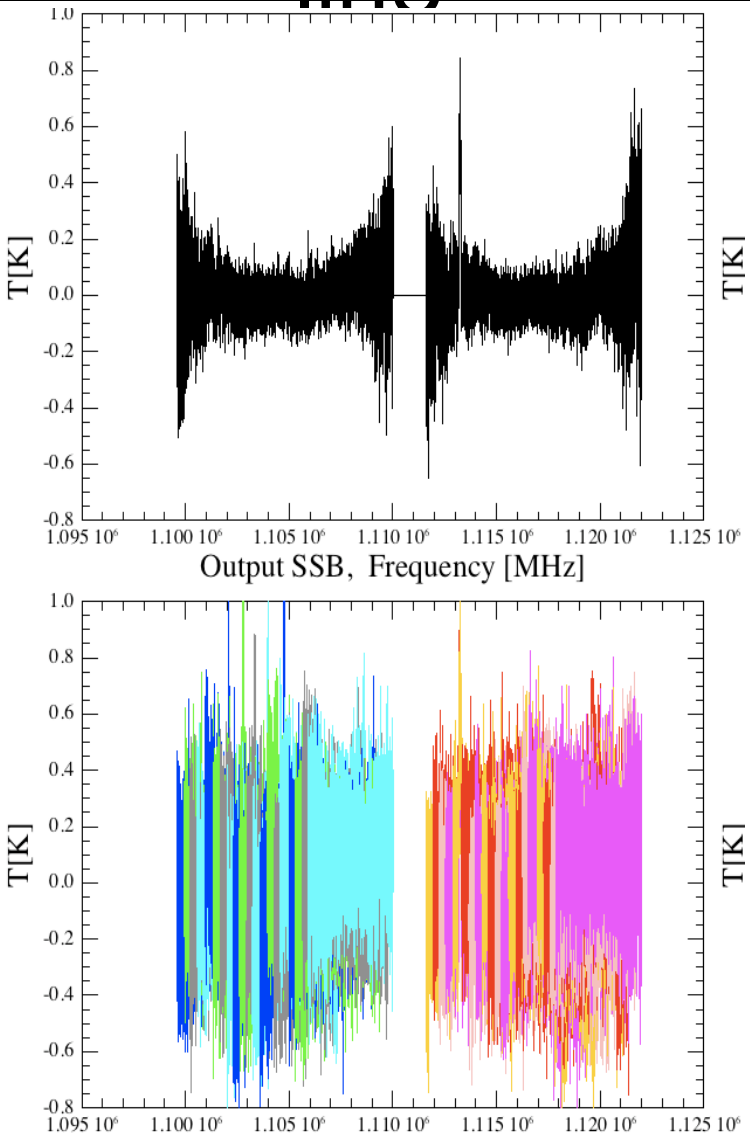
JAVA Tool

- IPAC Group (, S. Lord, J. Xie, C Borys) Produced The JAVA Tool for IA
  - Have Conjugate Gradient method running in JAVA
  - Have done speed test (JAVA vs. FORTRAN) of multidimensional deconvolution – and the speeds are comparable.

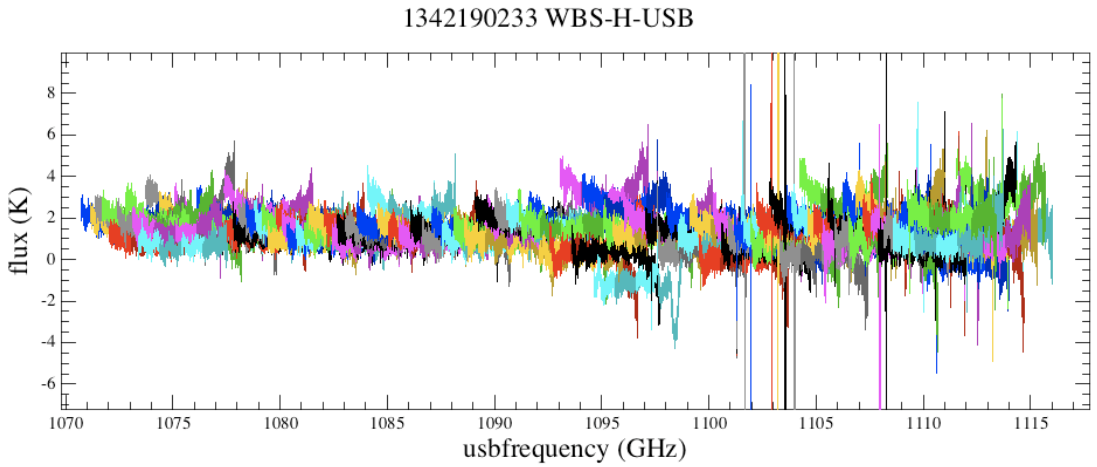
A Piece of the User's GUI



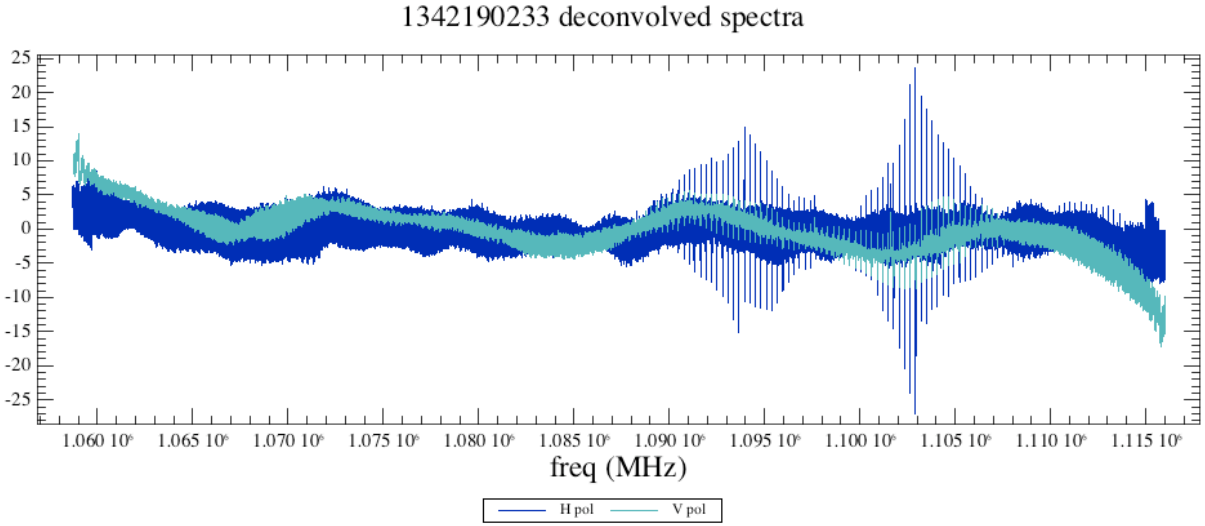
Successful processing – one line



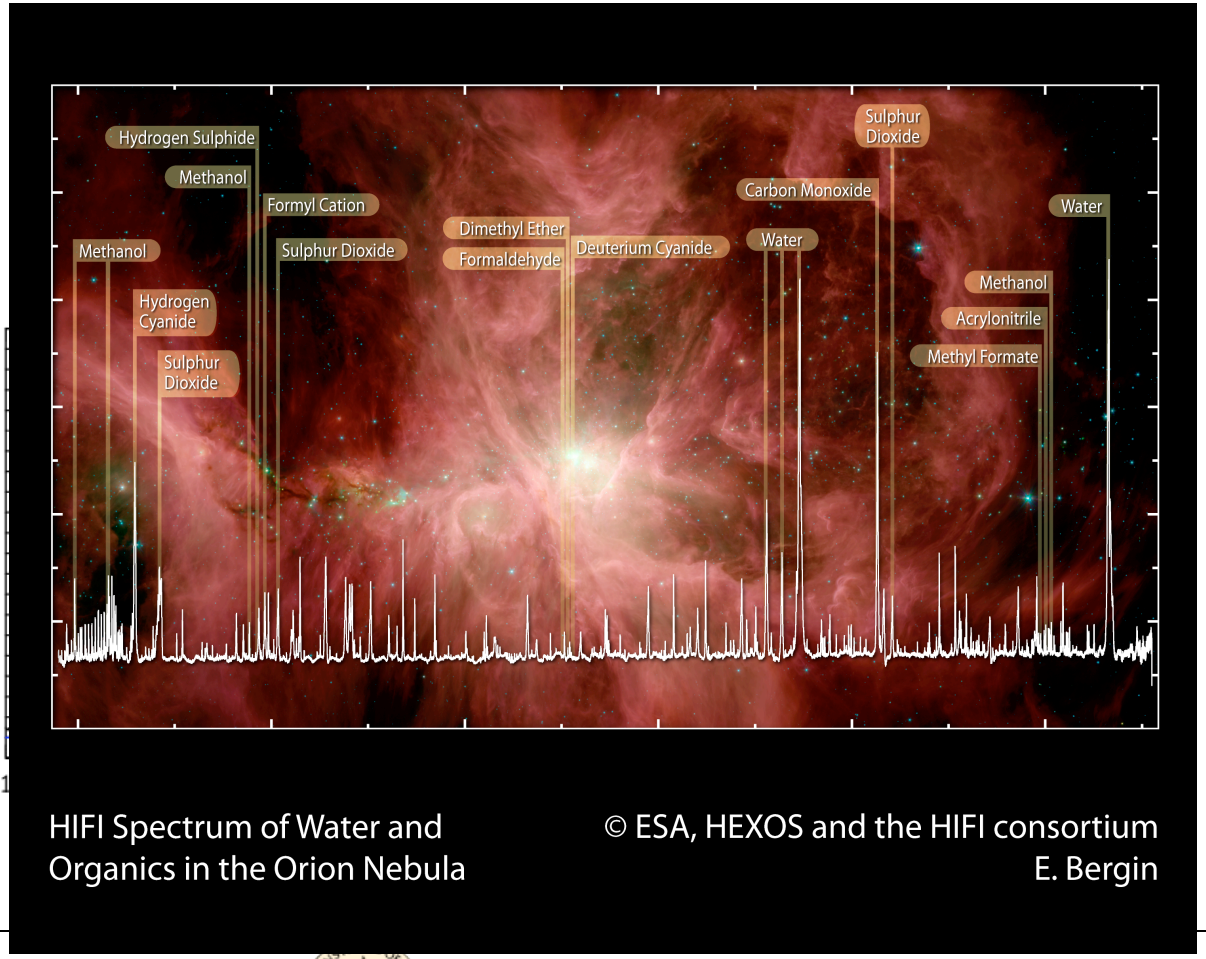
Real Data ...



3 scans:



Success – First Light - Orion Astrochemestry!



HIFI Spectrum of Water and Organics in the Orion Nebula

E. Bergin

Future Applications – SOFIA? ALMA?