SAGE Committee Meeting – December 19 & 20, 2008

Correlator Status and Growth of Capabilities

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Outline

- Overall schedule
- Prototype Correlator
- WIDAR-0 (10 antenna correlator)
- Beyond OSRO
- Full WIDAR capabilities

Overall schedule

- 24jun08-mar09: Prototype Correlator
  - Correlator hardware tests, leading to CDR
- Mar09-Q1 2010: WIDAR-0 (10 antennas)
  - Wideband (3-bit) sampler checkout
  - Systems integration, software development, & testing leading to Open Shared Risk Observing (OSRO) in "VLA-emulation" mode
- Q1 2010 & on
  - First priority: "VLA emulation" mode (two fully tunable subband pairs, all EVLA antennas)
  - Open Shared Risk Observations (OSRO)
  - Resident Shared Risk Observations (RSRO)
  - N.B. Current schedule has *all* WIDAR hardware at the VLA by Q1 2010

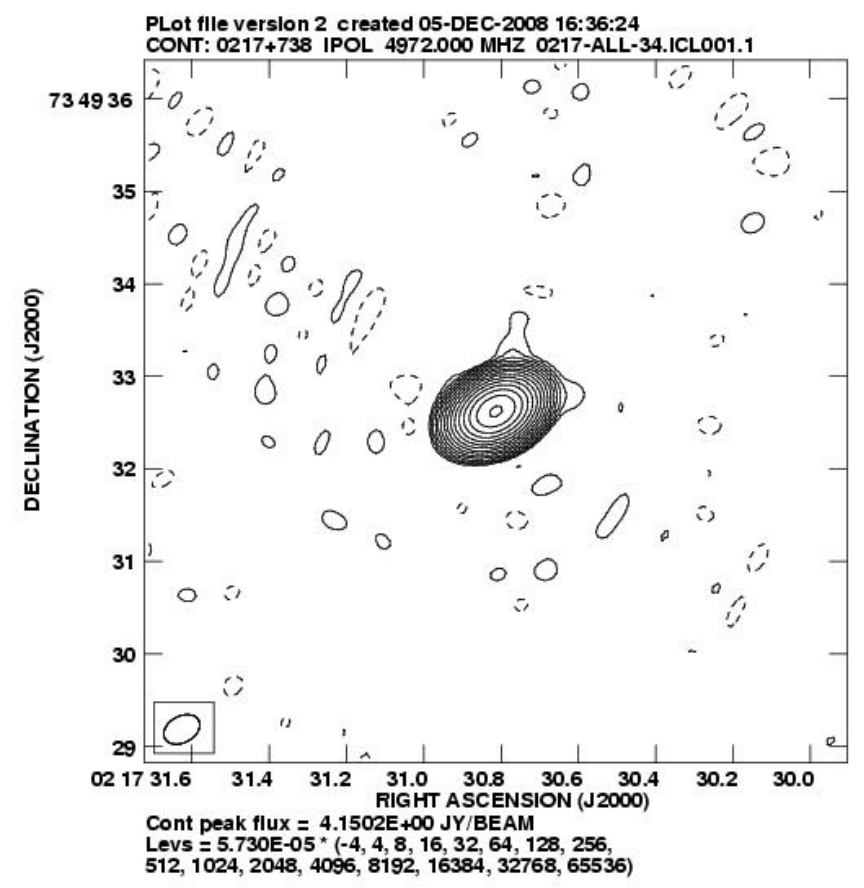
Prototype Correlator

24jun08-mar09

PTC Accomplishments

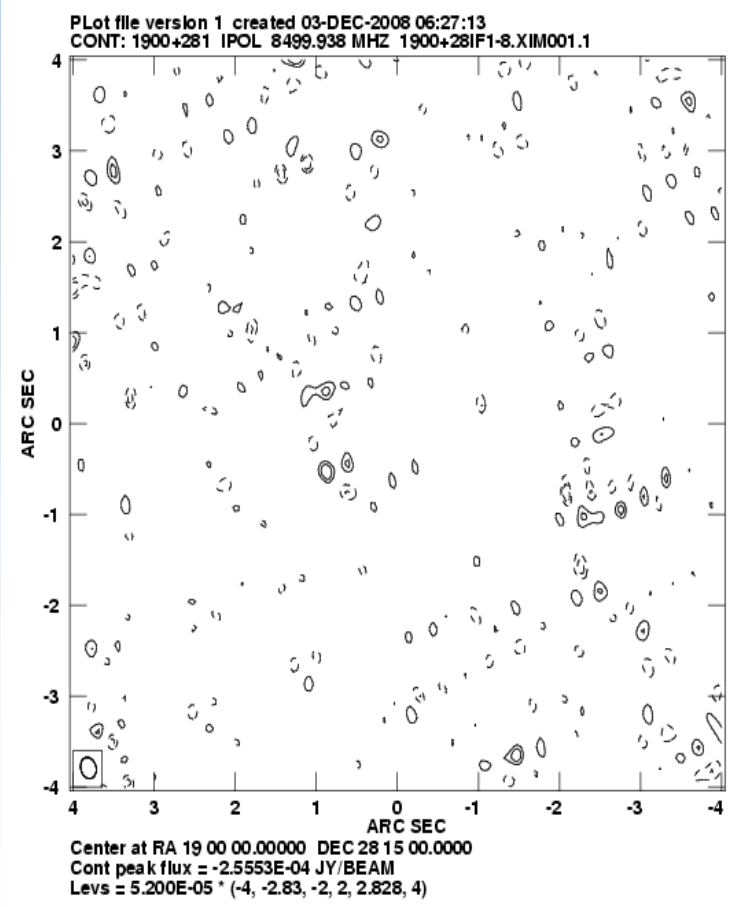
- Critical hardware tests
  - Dynamic fringes 1-45 GHz
  - Switching antennas, source, frequencies, bands
  - Closure phase and channel/time averaging
  - Deep integrations: high dynamic range (72,800:1), blank field
  - Deep spectral line integration (3C84 HI)
  - Getting data into CASA & AIPS

Image not limited by closure errors



- 0217+738
  - 4 Jy “dot”
  - 2hr10min on-source
- 4588-5612 MHz
- Self-cal’d image
- Peak:rms= 72,800:1

Deep image of a blank field



- J1900+2815
- 9012-7988 MHz
- 2.3 hours on-source
- Rms in 125 kHz: 2.84 mJy/beam
- Rms in 103 MHz (825 channels): 0.11 mJy/bm
- Rms in 825 MHz (825x8 channels): 0.052 mJy/bm

PTC on-going development

- Reliability and basic usability
- Software checkout
- Initial data for post-processing tests
  - RFI excision
  - MFS
  - Calibration transfer over wide bandwidths
- Demonstration observations
  - Narrow subbands
  - Maximum recirculation
  - Multiple lines at once
  - Deep integrations
  - Fast dumping

WIDAR-0

Mar09-Q1 2010

Correlator room: racks & wires

- Racks installed & fully cabled up

WIDAR-0 basics

- First part of final correlator
  - New correlator room, with final wiring
  - Production boards
  - 10 antennas
  - Full polarization
  - 256-640 MHz (2-5 x 128 MHz subbands)
  - 1 MHz resolution for wide bandwidth, dual pol’n mode

WIDAR-0 priorities

- Test wide-band (3-bit) samplers before production order
  - Mar-apr09
- Get ready for OSRO: “VLA-emulation” modes
  - 2x128 MHz independently tunable subband pairs (full pol’n capability)
  - See Claire’s talk for details
- **NOT** for science
- **NOT** open use

WIDAR-0: preparing for OSRO

- Correlator configuration
- Tsys application
- On-line flags
- CBE processing: time/frequency averaging
- Polarization

WIDAR-0: tests and demonstrations

- Support for post-processing improvements
  - Calibration techniques
  - Large data sets
  - RFI excision
  - MFS
- Demonstration observations
  - Absorption line survey
  - Rotation measure demonstration
  - 1-50 GHz spectral energy distribution
  - Deep continuum images
  - Interaction with OSRO?
  - SAGE recommendations useful here!

Open Shared Risk Observing

Q1 2010-2012?

see Claire's talk

Beyond OSRO

Q1 2010 and beyond

RSRO & commissioning

- Correlator hardware will be here in Q1 2010
- Use of full WIDAR will be limited by software
  - OPT (must be very flexible, but also easy to use)
  - Executor
  - Correlator Backend
  - Post-processing
- Adding bandwidth
  - 8-bit samplers allow 2 GHz/pol'n
  - 3-bit samplers allow 8 GHz/pol'n (20 antennas in Q1 2011; 27 in Q3 2011)
  - OPT (correlator setup) issues
  - Calibration & imaging issues

RSRO & commissioning

- Adding flexibility
  - Different bandwidths and number of channels per subband
  - Trading subbands for channels
  - Independently-tunable subbands
- Adding capabilities
  - Recirculation
  - 7-bit correlation
  - Faster dumps (down to 10 msec)
  - Subband stitching (and cross-subband averaging)

Not part of construction

- Phased array and VLBI
- “Radar mode”
- Pulsar binning and gating
- Burst dumps

Final WIDAR capabilities

Overall EVLA Performance Goals

Parameter	VLA	EVLA	Factor
Point Source Sensitivity (1-σ, 12 hr.)	10 μJy	1 μJy	10
Maximum BW in each polarization	0.1 GHz	8 GHz	**80**
# of frequency channels at max. BW	16	16,384	**1024**
Maximum number of freq. channels	512	4,194,304	**8192**
Coarsest frequency resolution	50 MHz	2 MHz	**25**
Finest frequency resolution	381 Hz	0.12 Hz	**3180**
# of independent sub-correlators	2	64	**32**
(Log) Frequency Coverage (1 – 50 GHz)	22%	100%	5

WIDAR's flexibility

- 64 independent full-pol'n correlators (subband pairs)
  - 128 MHz in each pol'n
  - 256 channels split among pol'n products
  - Trade bandwidth for channels (up to x16 recirculation: 4096 channels)
  - Bandwidths selectable in factors of 2, 128 MHz to 31.25 kHz
  - Can independently set each subband's:

    Tuning Bandwidth Nchan Requantization (4/7-bit)

    Phase/delay center Pulsar binning/gating Full-array phasing

    Windowing
  - Can split each independent correlator (subband pair) into two single-pol'n correlators for even more flexibility
- Correlators are linked
  - Can trade subbands for channels

WIDAR's flexibility

- Flexible time resolution
  - Dumps basically limited by output rate, down to few msec
  - Burst mode to 10s-100s of microsec
- Direct access to raw data stream (VLBI output, radar mode, etc.)
- As many completely independent subarrays as you want
- Autocorrelations
- Subband-based real-time RFI blanking

etc. etc. etc.

VLA correlator vs. WIDAR: one simple setup

Current VLA

Bandwidth MHz	Single Pol. Prod. No. Channels	Single Pol. Prod. Freq. Separ. kHz	Two Pol.Prod. No. Channels per pol	Two Pol.Prod. Freq. Separ. kHz	Four Pol.Prod. No. Channels per pol	Four Pol.Prod. Freq. Separ. kHz
100	16	6250	8	12500	2	50000
50	16	3125	8	6250	4	12500
25	32	781.25	16	1562.5	8	3125
12.5	64	195.313	32	390.625	16	781.25
6.25	128	48.828	64	97.656	32	195.313
3.125	256	12.207	128	24.414	64	48.828
1.5625	512	3.052	256	6.104	128	12.207
0.78125	512	1.526	256	3.052	128	6.104
0.19531	512	0.381	256	0.763	128	1.526

EVLA/WIDAR

Bandwidth MHz	Single Pol. Prod. No. Channels	Single Pol. Prod. Freq. Separ. kHz	Two Pol.Prod. No. Channels per pol	Two Pol.Prod. Freq. Separ. kHz	Four Pol.Prod. No. Channels per pol	Four Pol.Prod. Freq. Separ. kHz
8192	16,384	500	8,192	1000	4,096	2000
4096	16,384	250	8,192	500	4,096	1000
2048	32,768	62.5	16,384	31.25	8,192	250
1024	65,536	15.625	32,768	31.25	16,384	62.5
512	131,072	3.906	65,536	7.813	32,768	15.625
256	262,144	0.977	131,072	1.953	65,536	3.906
128	262,144	0.488	131,072	0.977	65,536	1.953
64	262,144	0.244	131,072	0.488	65,536	0.977
32	262,144	0.122	131,072	0.244	65,536	0.488
16	262,144	0.061	131,072	0.122	65,536	0.244
8	262,144	0.031	131,072	0.061	65,536	0.122
4	262,144	0.015	131,072	0.031	65,536	0.061
2	262,144	0.008	131,072	0.015	65,536	0.031
1	262,144	3.8 Hz	131,072	7.6 Hz	65,536	0.015
0.5	262,144	1.9 Hz	131,072	3.8 Hz	65,536	7.6 Hz
0.25	262,144	0.95 Hz	131,072	1.9 Hz	65,536	3.8 Hz
0.125	262,144	0.48 Hz	131,072	0.95 Hz	65,536	1.9 Hz
0.0625	262,144	0.24 Hz	131,072	0.48 Hz	65,536	0.95 Hz
0.03125	262,144	0.12 Hz	131,072	0.24 Hz	65,536	0.48 Hz

Wideband observations: full pol'n

Band (GHz)	BW (GHz)	Dnu (kHz)	Dv (km/sec)	Nch
1-2	1.024	31	6	131,076
2-4	2.048	125	12	65,536
4-8	4.096	500	25	32,768
8-12	4.096	500	16.5	32,768
12-18	6.144	2000/500	37/12	24,576
18-26.5	8.192	2000	27	16,384
26.5-40	8.192	2000	13	16,384
40-50	8.192	2000	6	16,384

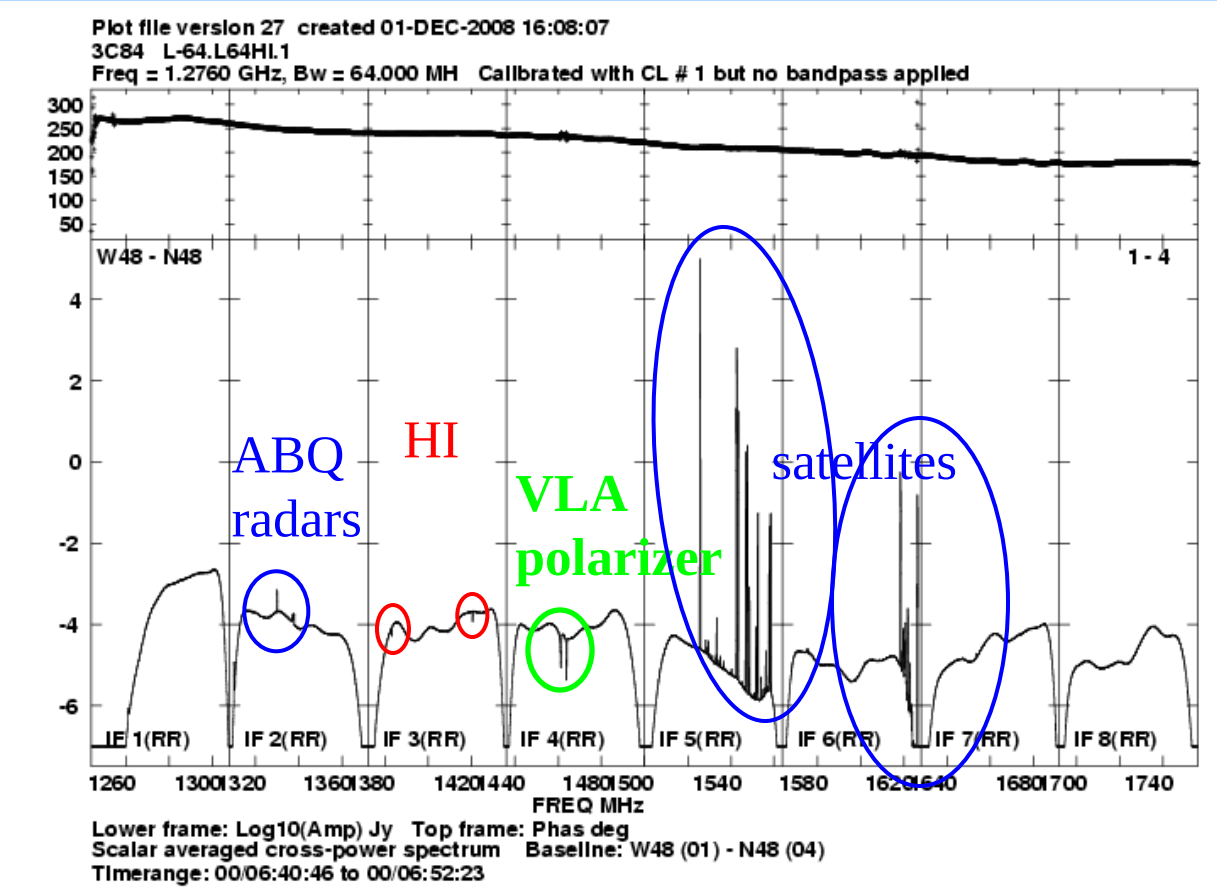
64 different lines: 1 km/s, full polarization

Band (GHz)	BW (MHz)	Nch	Dnu (kHz)	Dv (km/s)	Vel.Cov. (km/sec)	Total Nchan
1-2	4	2048	2.0	0.39	800	524,288
2-4	8	1024	7.8	0.78	320	262,144
4-8	8	1024	7.8	0.39	400	262,144
8-12	16	512	31	0.94	480	131,072
12-18	16	512	31	0.63	320	131,072
18-26.5	16	512	31	0.41	210	131,072
26.5-40	32	256	125	1.1	282	65,536
40-50	32	256	125	0.83	213	65,536

Backup slides

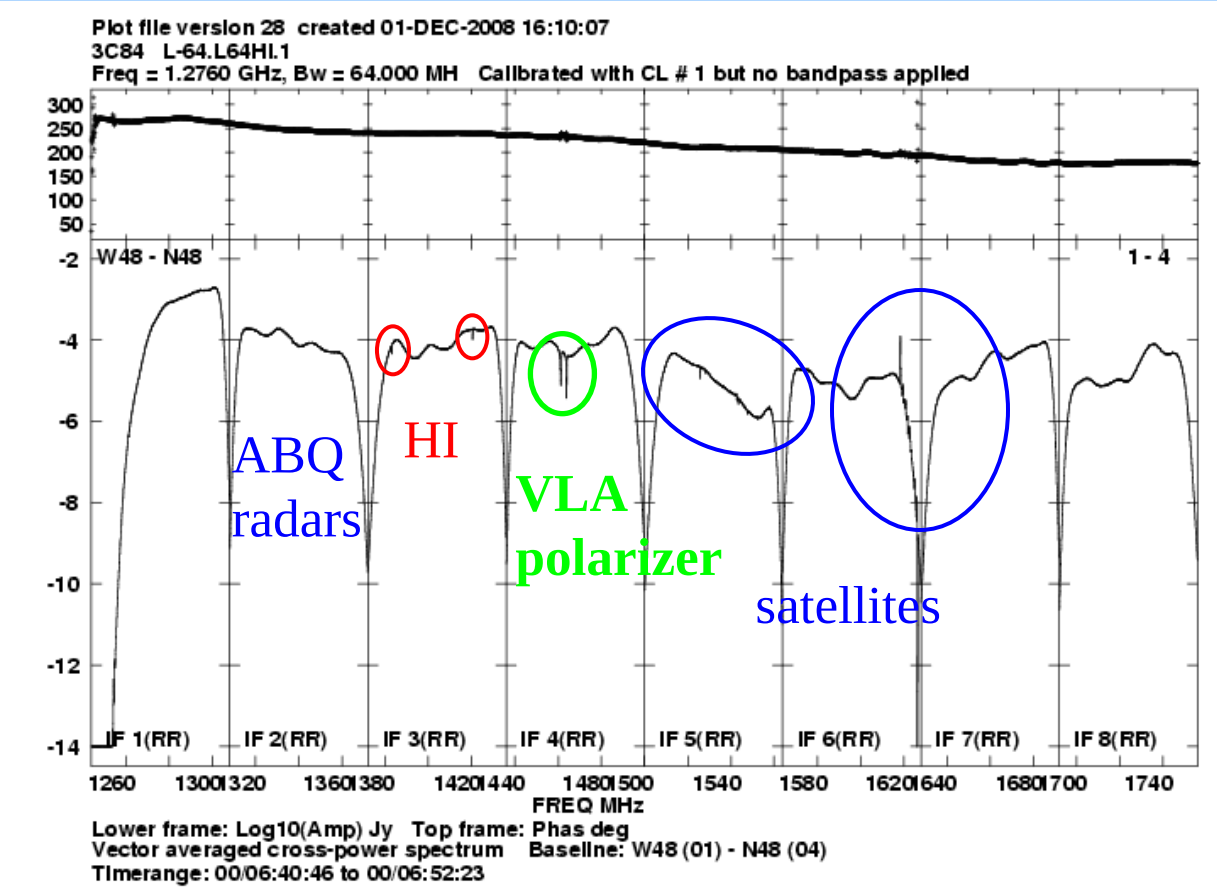
PTC results & WIDAR science example

Cross-correlation fringes



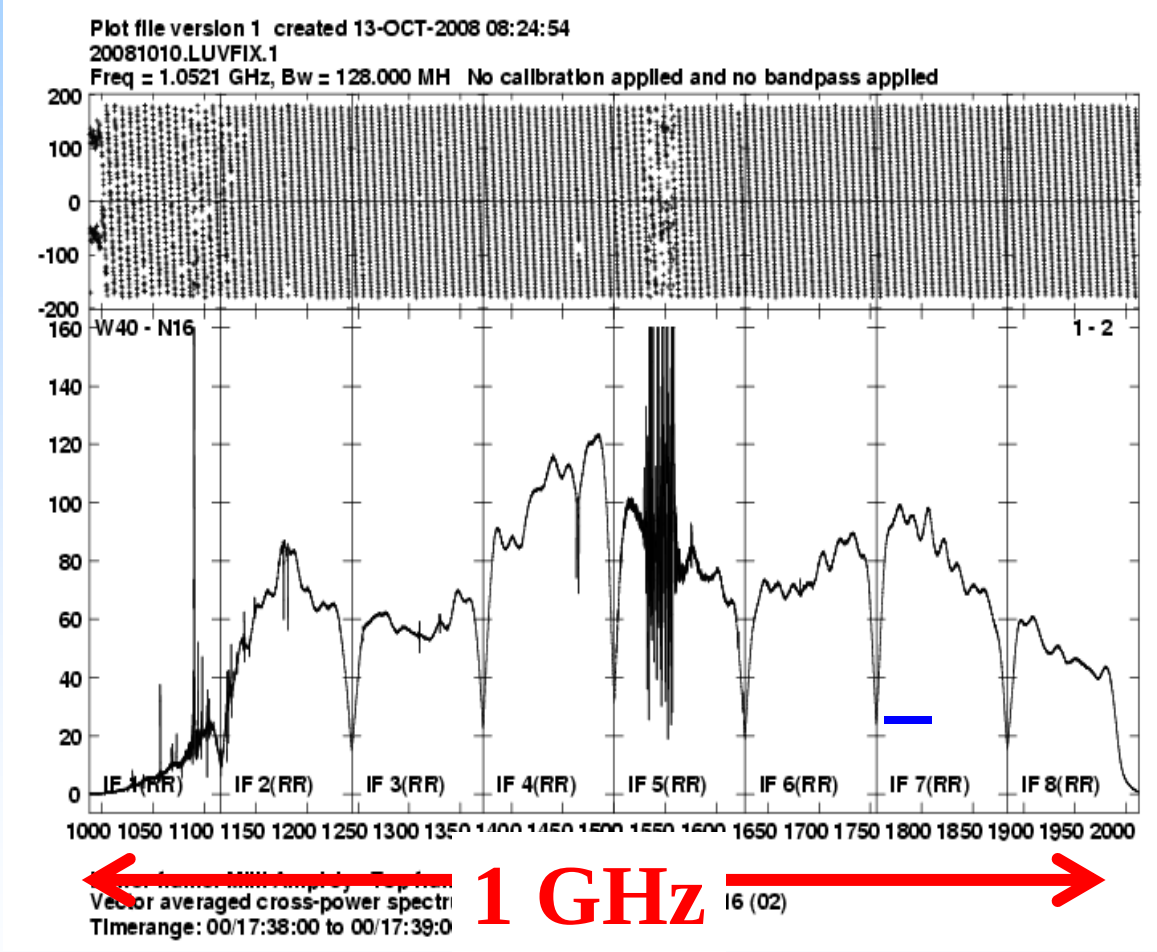
- 3C84
- 1244-1756 MHz
- 64 MHz/sb
- 1024 chan./sb
- Continuous phase
- Subband filter response

Cross-correlation fringes

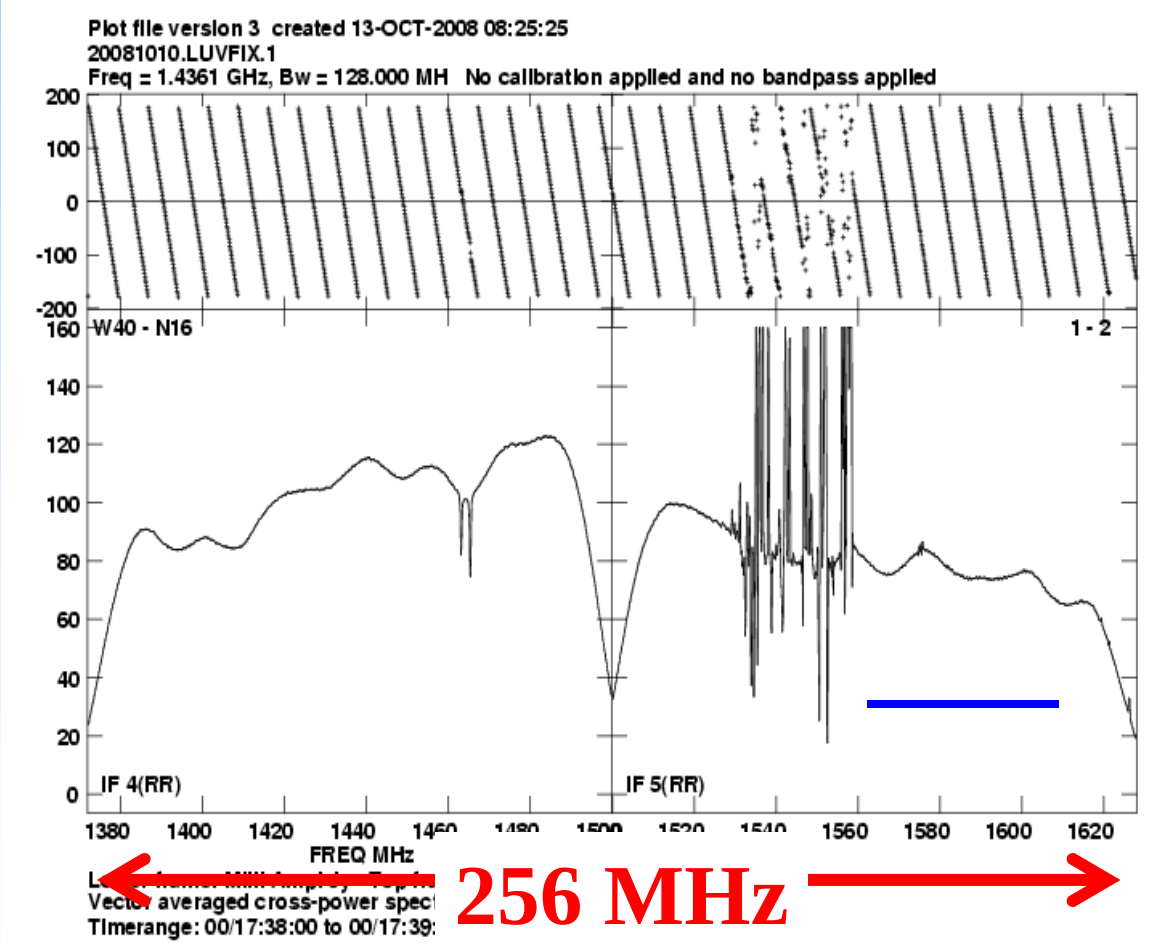


- 3C84
- 1244-1756 MHz
- 64 MHz/sb
- 1024 chan./sb
- Continuous phase
- Subband filter response

1-2 GHz: continuum + RFI

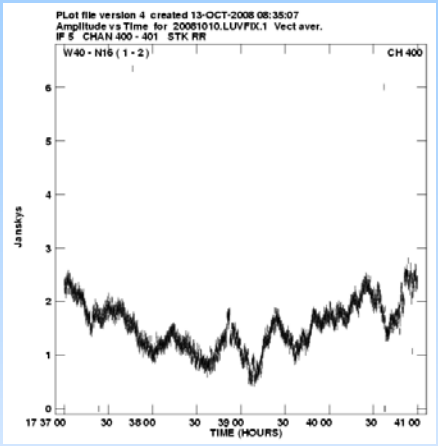


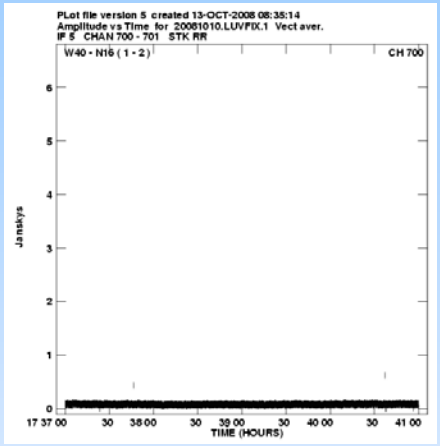
1372-1628 MHz: continuum + RFI



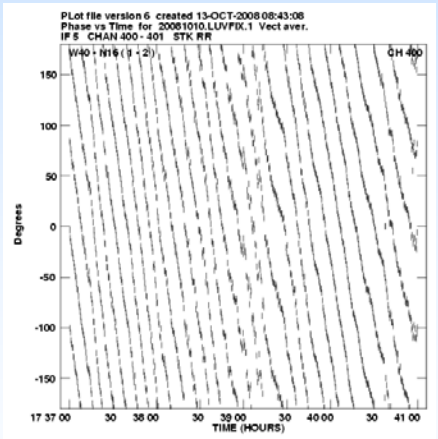
On/off RFI

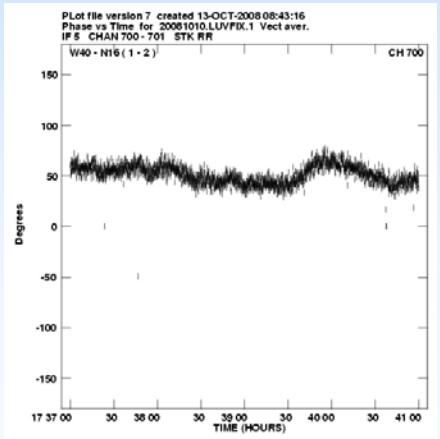
Amplitude





Phase





On RFI

Off RFI

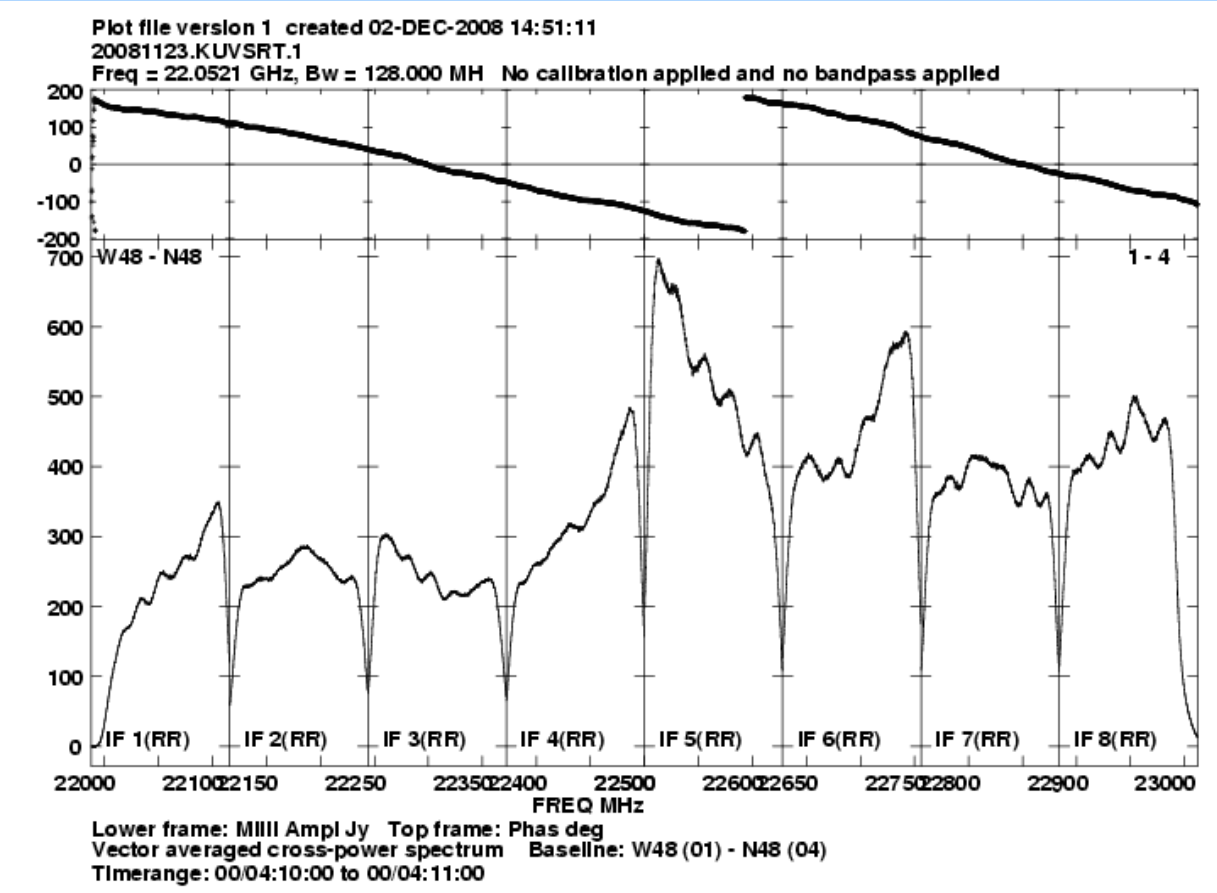
Looking at data: dynamic spectra

Amplitude

Phase

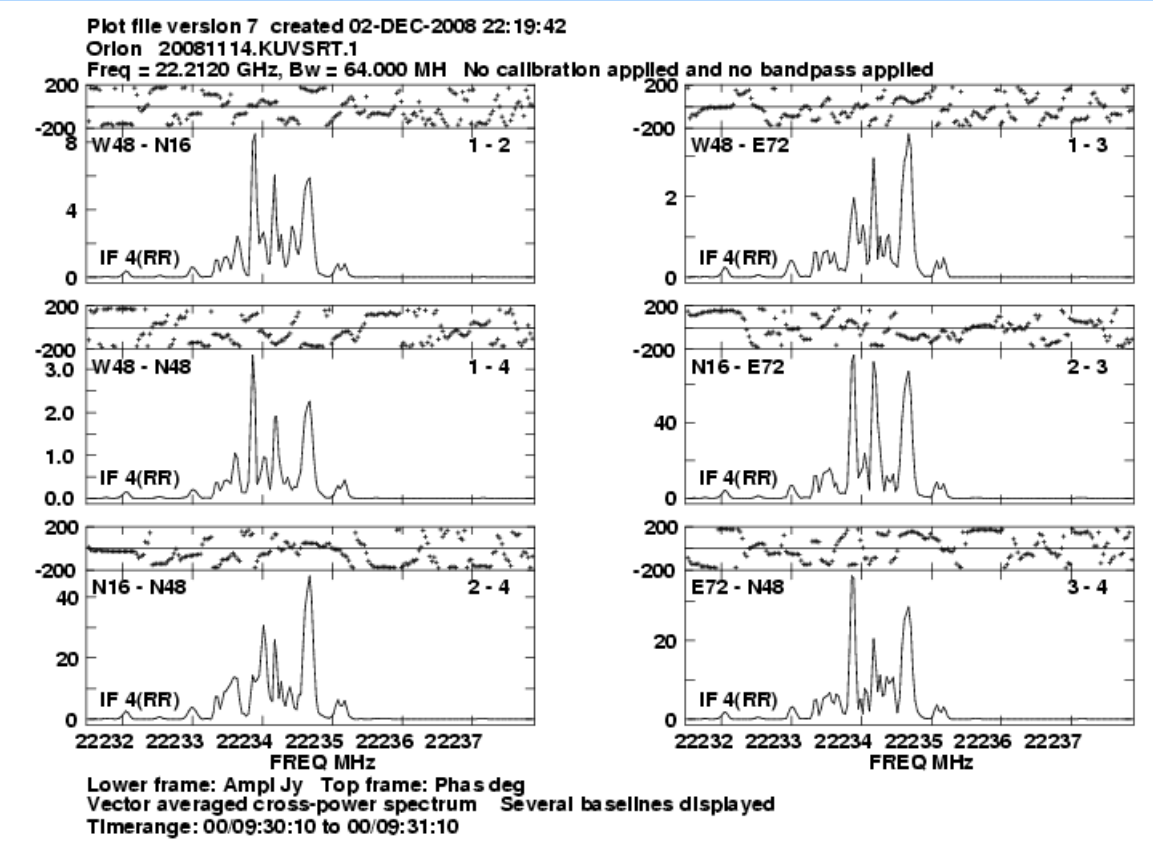
SPFLG: 1500-1628 MHz

22 GHz fringes



- 3C84
- 21988-23012 MHz
- 128 MHz/sb
- 1024 chan./sb

Orion water masers



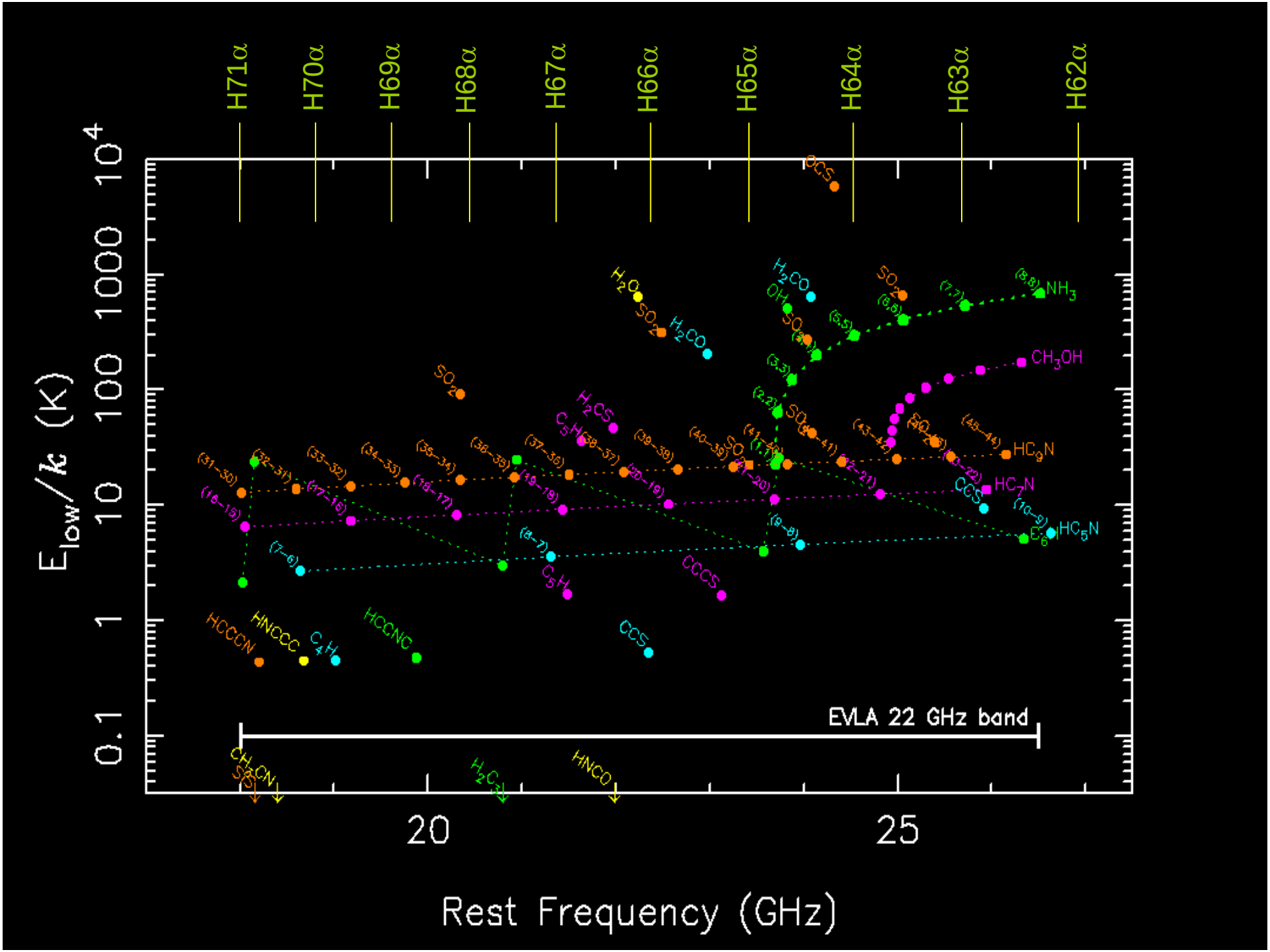
- 64 MHz, x2 recirc.
  - –31.25 kHz/channel

Massive star-forming region

- observe high-density tracers NH_3, all available transitions from (1,1) to (8,8), and CH_3OH
  - gives density and temperature structure of hot cores (very young, massive, protostars)
- observe shock tracers, interaction of protostars with surrounding cloud
  - transitions of SO_2, H_2O, OCS, H_2CS, H_2CO, OH
- observe radio recombination lines and continuum emission from a nearby HII region
- spectral resolution required for molecular lines: 0.2 km/s
- spectral resolution required for RRLs: 1 km/s
- need as much line-free continuum as possible for the free-free emission

Cold dark cloud

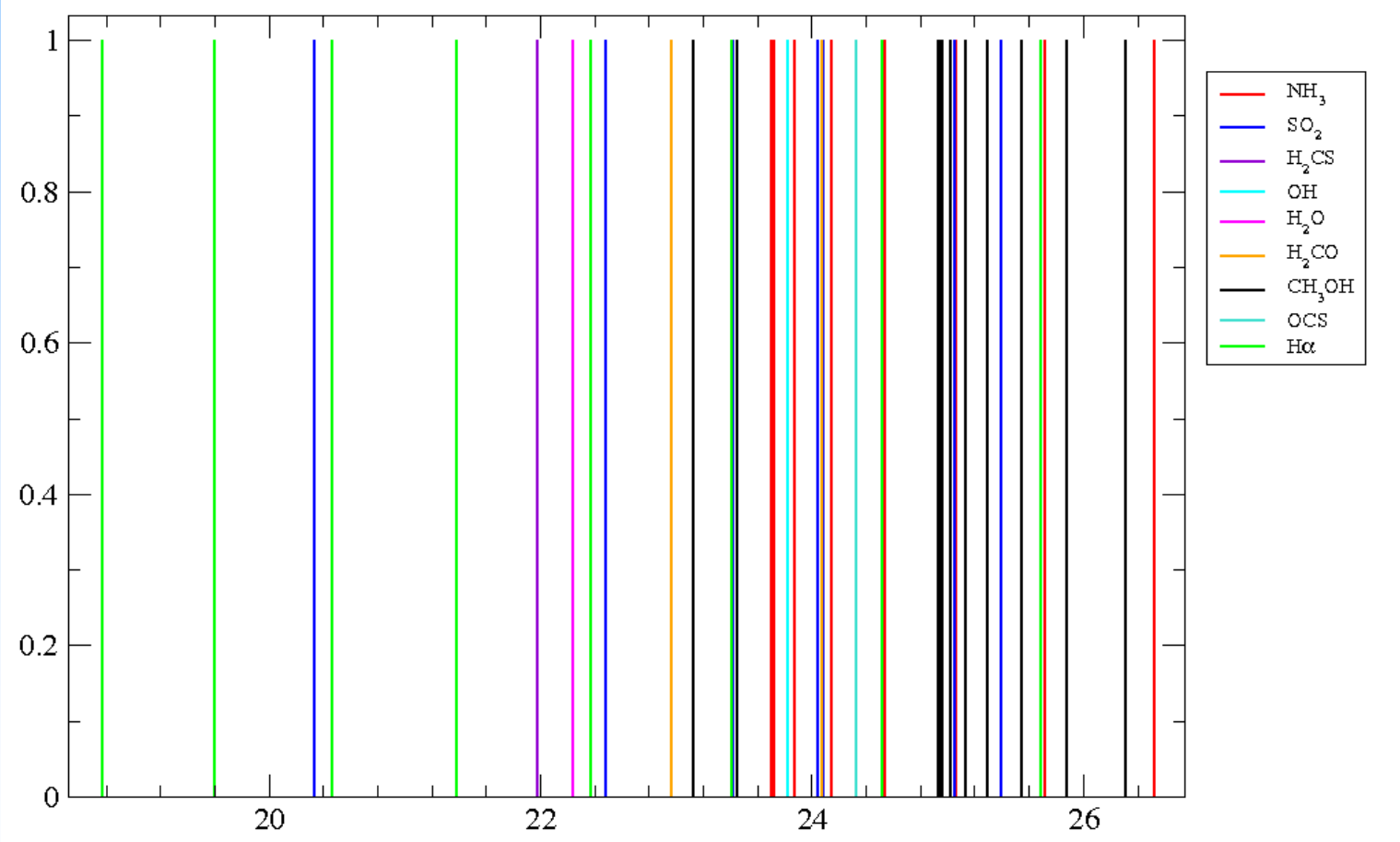
- observe low-energy, long carbon-chain molecules and high-density tracers in a dark cloud to study pre-biotic chemistry
  - NH_3, HNCO, C_4H, C_5H, C_6H, C_3N, CCS, CCCS, HCCCN, HCCNC, HNCCC, HC_5N, HC_7N, HC_9N, H_2C_3, CH_3CN, c-C_3H_2
- observe continuum to detect embedded protostars/disks/jets
- spectral resolution required for molecular lines: 0.01 km/s
- need as much line-free continuum as possible for the dust/ionized gas emission


H71α
H70α
H69α
H68α
H67α
H66α
H65α
H64α
H63α
H62α
E_{low}/k (K)
0.1
1
10
100
1000
10^4
EVLA 22 GHz band
20
25
Rest Frequency (GHz)
H_2O
SO_2
H_2CO
OCS
OH
NH_3
CH_3OH
H_2CS
C_3H
SO
HC_9N
CCS
HC_7N
HC_5N
C_5H
CCCS
HCCCN
HNCCC
C_4H
HCCNC
CH_3CN
SO
H_2C_3
HNCO

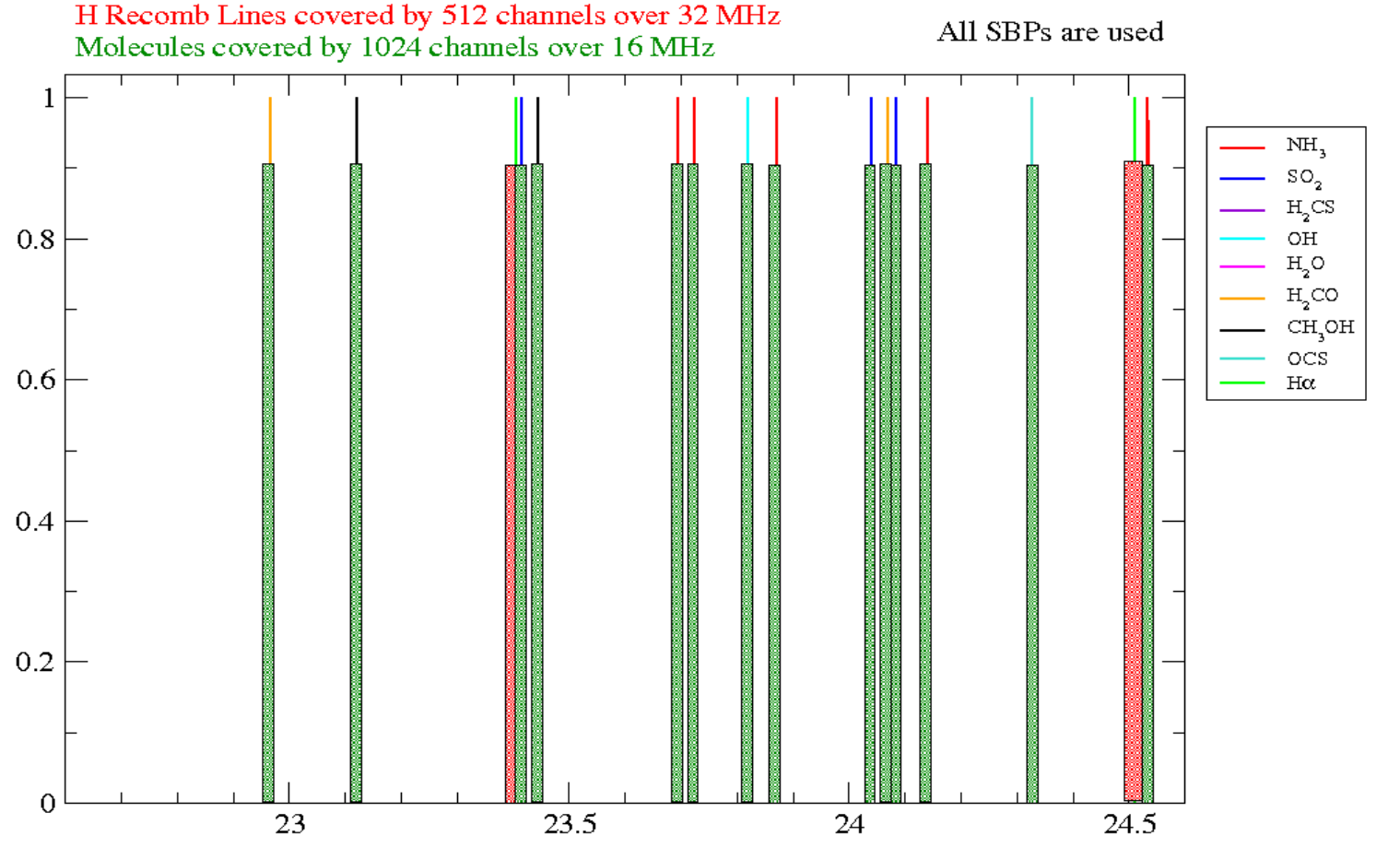
Massive SFR

- Tune the four frequency pairs to:
  1. 18.6 – 20.6 GHz 3RRL + 1 Mol (12 SBP free)
  2. 20.6 – 22.6 GHz 2 RRL + 3 Mol (11 SBP free)
  3. 22.6 – 24.6 GHz 2 RRL + 14 Mol (all SBP used)
  4. 24.6 – 26.6 GHz 1 RRL + 14 Mol. (one SBP free)
- Set the 32 SBPs covering the molecules to a BW = 16 MHz, providing 1024 channels in both RR and LL.
- Set the 8 SBPs covering the RRLs to BW = 32 MHz, providing 512 channels in both RR and LL.
- This leaves 24 SBPs to cover the continuum (at 128 MHz BW each), or for other transitions.

The entire spectrum



One 2 GHz chunk



Cold Dark Cloud

- In this experiment, there are a total of 51 transitions between 18 and 26 GHz
- Tunings:
  1. 18 – 20 GHz: 17 transitions (uses all 16 SBP)
  2. 20 – 22 GHz: 13 transitions (uses 12 SBP, leaving 4 free)
  3. 22 – 24 GHz 12 transitions (uses 12 SBP, leaving 4 free)
  4. 24 – 26 GHz 9 transitions (7 SBP free)

– The required resolution can be obtained with BW = 4 MHZ, providing 4096 channels in each of RR and LL.

– A total of 417792 channels are required for these lines.

– 15 SBPs remain for continuum observations.

Backup slides

WIDAR-0 spectral capabilities

Subband bandwidth[a] [MHz]	Single Pol. Prod. No. Channels per sb	Single Pol. Prod. Freq. Separ.	Two Pol. Prod. No. Channels per pol per sb	Two Pol. Prod. Freq. Separ.	Four Pol. Prod. No. Channels per pol per sb	Four Pol. Prod. Freq. Separ.
128 MHz 38,400 km/s	256 ...	500 kHz 150.0 km/s	128 ...	1000 kHz 300.0 km/s	64 ...	2000 kHz 600.0 km/s
64 MHz 19,200 km/s	512 ...	125 kHz 37.5 km/s	256 ...	250 kHz 75.0 km/s	128 ...	500 kHz 150.0 km/s
32 MHz 9,600 km/s	1024 ...	31.25 kHz 9.37 km/s	512 ...	62.5 kHz 18.75 km/s	256 ...	125 kHz 37.5 km/s
16 MHz 4,800 km/s	2048 ...	7.81 kHz 2.34 km/s	1024 ...	15.63 kHz 4.69 km/s	512 ...	31.25 kHz 9.37 km/s
8 MHz 2,400 km/s	4096 ...	1.95 kHz 0.59 km/s	2048 ...	3.91 kHz 1.17 km/s	1024 ...	7.81 kHz 2.34 km/s
4 MHz 1,200 km/s	4096 ...	0.98 kHz 0.29 km/s	2048 ...	1.95 kHz 0.59 km/s	1024 ...	3.91 kHz 1.17 km/s
2 MHz 600 km/s	4096 ...	0.49 kHz 0.15 km/s	2048 ...	0.98 kHz 0.29 km/s	1024 ...	1.95 kHz 0.59 km/s
1000 kHz 300 km/s	4096 ...	244 Hz 73 m/s	2048 ...	488 Hz 146 m/s	1024 ...	977 Hz 293 m/s
500 kHz 150 km/s	4096 ...	122 Hz 37 m/s	2048 ...	244 Hz 73 m/s	1024 ...	488 Hz 146 m/s
250 kHz 75 km/s	4096 ...	61 Hz 18 m/s	2048 ...	122 Hz 37 m/s	1024 ...	244 Hz 73 m/s
125 kHz 37.5 km/s	4096 ...	30 Hz 9.2 m/s	2048 ...	61 Hz 18 m/s	1024 ...	122 Hz 37 m/s
62.5 kHz 9.375 km/s	4096 ...	15 Hz 4.6 m/s	2048 ...	30 Hz 9.2 m/s	1024 ...	61 Hz 18 m/s
31.25 kHz 9.375 km/s	4096 ...	7.6 Hz 2.3 m/s	2048 ...	15 Hz 4.6 m/s	1024 ...	30 Hz 9.2 m/s

[a]Subband bandwidth in MHz and in km/s at 1 GHz.

[b]Spectral resolution (before any smoothing) in kHz and in km/s at 1 GHz.

Note. — This table gives the spectral resolution of the WIDAR-0 Correlator. This reflects the capabilities of one pair of Baseline Boards handling one subband pair. We expect to have between 2 and 5 Baseline Board pairs operational in WIDAR-0. Note that this table does *not* depend on the number of antennas or the baseband bandwidths (1 or 2 GHz). Each Baseline Board handles up to 32

WIDAR-0 spectral capabilities