Some Illustrative Use Cases

Rick Perley

Science Use Cases

- We have begun careful consideration of science use cases, primarily to:
  - identify the primary correlator modes needed for early science, and
  - identify the modes which will cover all the anticipated science applications.

- I give a few examples to justify our belief that a very few correlator setups will cover an enormous range of early science.

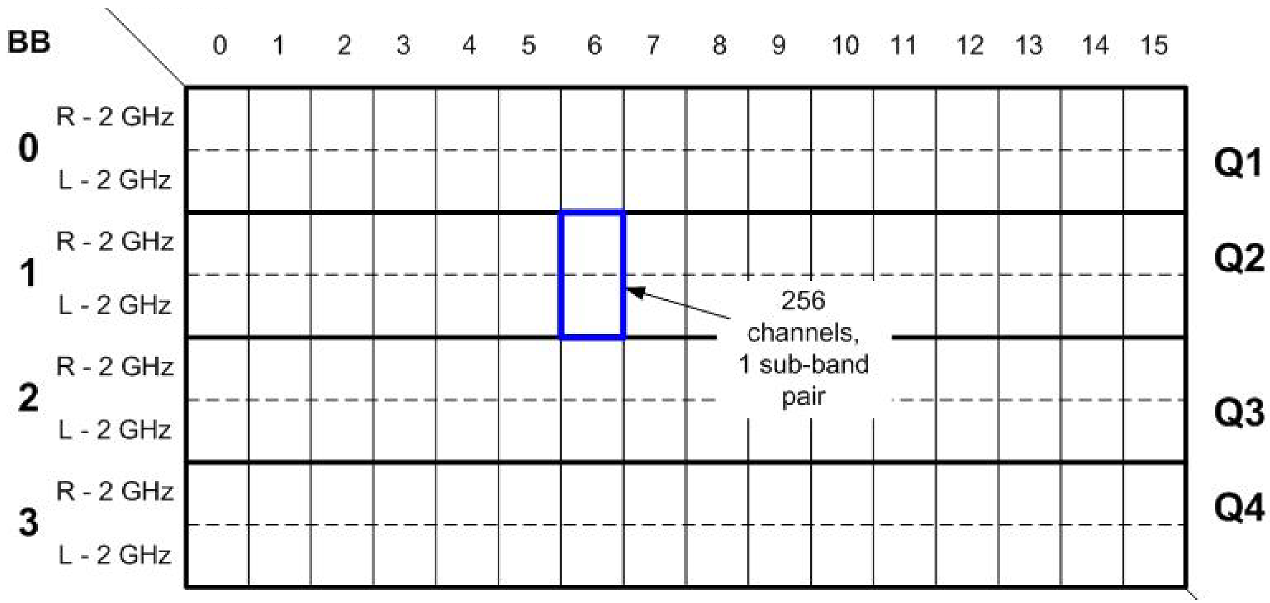
Correlator Basics
(3-bit Initial Quantization, 4-bit Re-Quantization)

- The correlator comprises four quadrants. Each processes all baselines, for all antennas, for one input baseband pair (BBP).
- Each BBP is subdivided into 16 sub-band pairs (SBP), with BW equal to any of 128, 64, 32, …, .03125 MHz.
- All 16 * 4 = 64 SBPs can be tuned independently to (almost) any frequency and BW.
- Each of the 64 SBPs provides 256 spectral channels, which can be divided amongst 1, 2, or 4 polarization products.
- The resources available to any SBP can be given to any other SBP to increase spectral resolution.
- Recirculation is available for any, and all, SBPs, to provide extra, higher spectral resolution.

Correlator Resource Allocation Matrix

- Each SBP (blue rectangle) provides 256 channels for one, two, or four polarizations (for IQ = 3, RQ = 4)
- Each of the 64 SBPs has a separate, independent frequency and bandwidth.

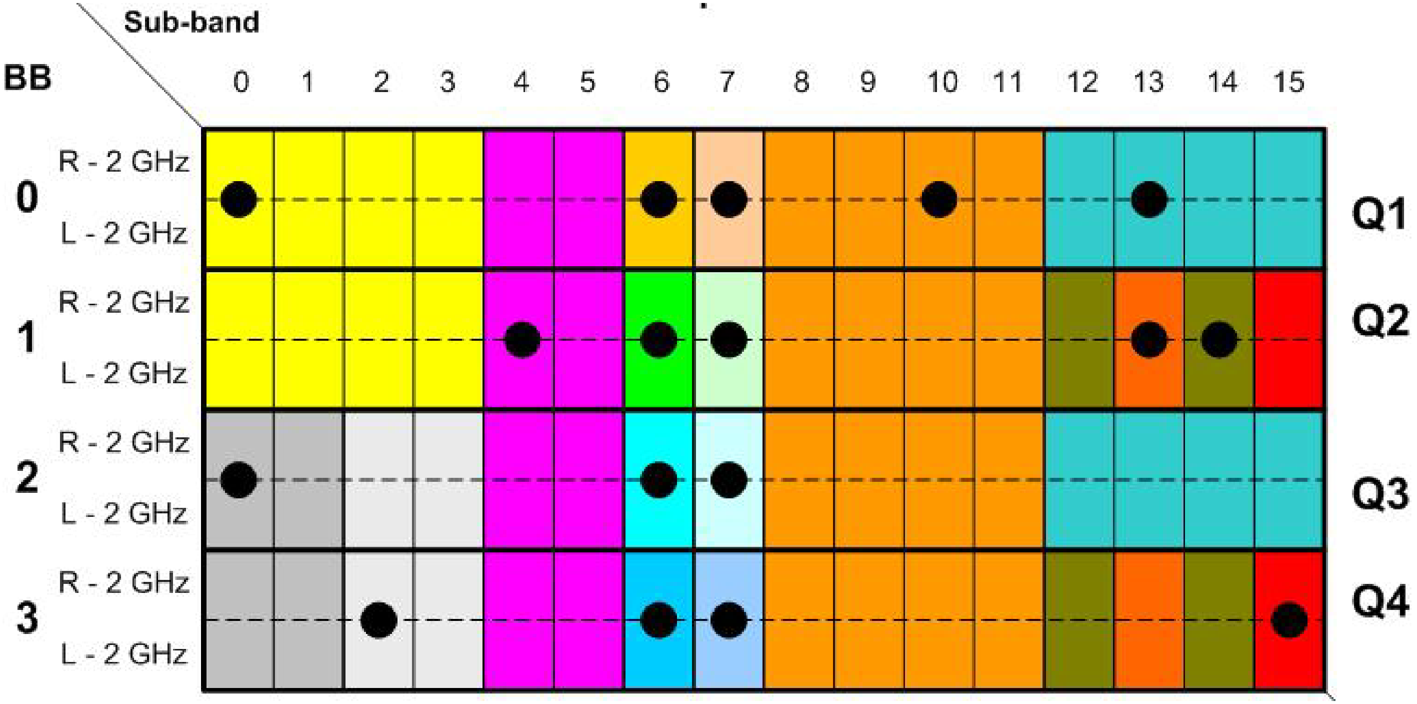
Four digital input data pairs, each at 4.096 GSam/sec.



16 independent digital sub-bands

CRAM example: Resource Concatenation

- Concatenation has been implemented to provide more resources to the 17 individual SBP tunings (black dots).
- In addition, recirculation is available for all SBPs.



Example 1: Full Band Coverage

- This means covering the maximum bandwidth, for each band, with all Stokes combinations, with uniform frequency resolution.
- This setup would be used for
  - ‘continuum’ (maximum sensitivity) observations, where very high spectral resolution is not needed.
  - spectral line surveys, for cases where the basic correlator channelization is sufficient to detect spectral transitions.

Summary of Coverage (with 4-bit RQ)

The output consists of 64 full-polarization data streams.

	BW	Δν	Δv	Nch
	GHz	kHz	km/sec	
L	1.024	31	6	131076
S	2.048	125	12	65536
C	4.096	500	25	32768
X	4.096	500	16.5	32768
U	6.144	2000/500	37/12	24576
K	8.192	2000	27	16384
A	8.192	2000	13	16384
Q	8.192	2000	6	16384

Data Rate Comment

- The correlator has the capability of producing a large volume of data in short time. ☺
- Roughly, the data rate is given by:

$$D \sim 5 N_{chan} N_{ant} (N_{ant} + 1) / t_{\sec} \qquad \text{Byte/sec}$$

- With 1 second averaging, 16384 channels will produce data at a rate of 62 MByte/sec.
- For A-configuration, an averaging time of 2.5 seconds is adequate for full-beam imaging => 25 MB/sec.
- (Previous example provides sufficient spectral resolution for full-beam, full-band imaging for all frequencies and configs.

High RFI Situations

- For L and S bands, we expect high RFI in some SBP.
- For this case, there is a 7-bit RQ mode, which can be turned on for individual SBPs.
- The extra bit depth comes at a cost in spectral resolution:
  - S-Band: Resolution of 500 kHz (50 km/sec) over full BW with (RR, LL) only, OR with full polarization over 1 GHz total bandwidth.
  - L-Band: Resolution of 500 kHz (100 km/sec) over full BW with all polarizations, OR, 125 kHz (25 km/sec) with (RR,LL) only.
- Most likely, we will be able to use 4-bit RQ in most sub-bands.

Example 2:
Multiple spectral lines.

- How many spectral lines can be simultaneously observed, with ~1km/sec. velocity resolution, and with full polarization?

64 Different Lines, with Full Polarization!

	BW	Nch	Δν	Δv	Vel.Cov.	Total
	MHz		kHz	km/s	km/sec.	Nchan
Q	32	256	125	.83	213	65536
A	32	256	125	1.1	282	65536
K	16	512	31	.41	210	131072
U	16	512	31	.63	320	131072
X	16	512	31	.94	480	131072
C	8	1024	7.8	.39	400	262144
S	8	1024	7.8	.78	320	262144
L	4	2048	2.0	.39	800	524288

Variable Resolution for Each Transition

- It is important to note that *each* of the 64 spectral lines can be observed with a different spectral resolution.
- With full polarization, the available resolutions will be: 125, 31, 7.8, 2.0, … kHz.
- With fewer transitions covered, or (RR,LL) only, other resolutions can be obtained.

High RFI environment at L-band.

- At L-band, many SBPs may be in high RFI environments.
- As a worst case, suppose ALL sub-bands need 7-bit RQ. Then:
  - 16 lines can be tuned with full polarization with 0.4 km/sec resolution, OR
  - 32 lines can be tuned with (RR,LL) polarization, and the same resolution.

Example 3: Continuum plus Targeted Spectral Lines

- Suppose an observer wants both the full continuum , and to be able to ‘target’ specific lines with ~1 km/sec spectral resolution.
- What are the possibilities?

For K, A, Q Bands

- In these bands, some continuum BW must be given up to obtain high-resolution spectral transitions. Some possibilities are:
  1. 6 GHz of continuum, and 16 spectral lines, or
  2. 4 GHz of continuum, and 32 spectral lines, or
  3. 2 GHz of continuum, and 48 spectral lines.
- – All of these with full polarization, and independently adjustable frequency and resolution for each line.
- – The continuum is resolved at 2 MHz/channel, the lines at any of 500, 125, 31.2, 7.8, … kHz.
- – This is not a practical example -- no zoom on the spectral lines within the reserved continuum bands.

C and X Bands

- In the 4-8, and 8-12 GHz bands, one would get:
  - Full 4 GHz BW continuum observed with 2 MHz channel resolution in all four polarization products, giving a total of 8192 channels.

    PLUS

  - 32 individual lines (of arbitrary frequency) observed with 512 channels/spectrum, full polarization, and frequency resolution of 31.2 kHz (1.56 km/sec at 6GHz)
- Total number of channels out = 67584.
- With a 1-second integration time, the output data rate is about 256 MB/sec.

Example Four: Claire's Challenge!

Claire has proposed two K-band experiments:

1. Studies of a Massive Star-Forming Region
   - 32 molecular transitions, to be observed at 0.2 km/sec, and
   - 8 RRLs, to be observed with 1 km/sec.
   - Some reasonable amount of continuum.
2. Studies of a Cold Dark Cloud.
   - 54 molecular transitions (mostly heavy molecules) requiring 0.01 km/sec resolution.
   - Some reasonable amount of continuum

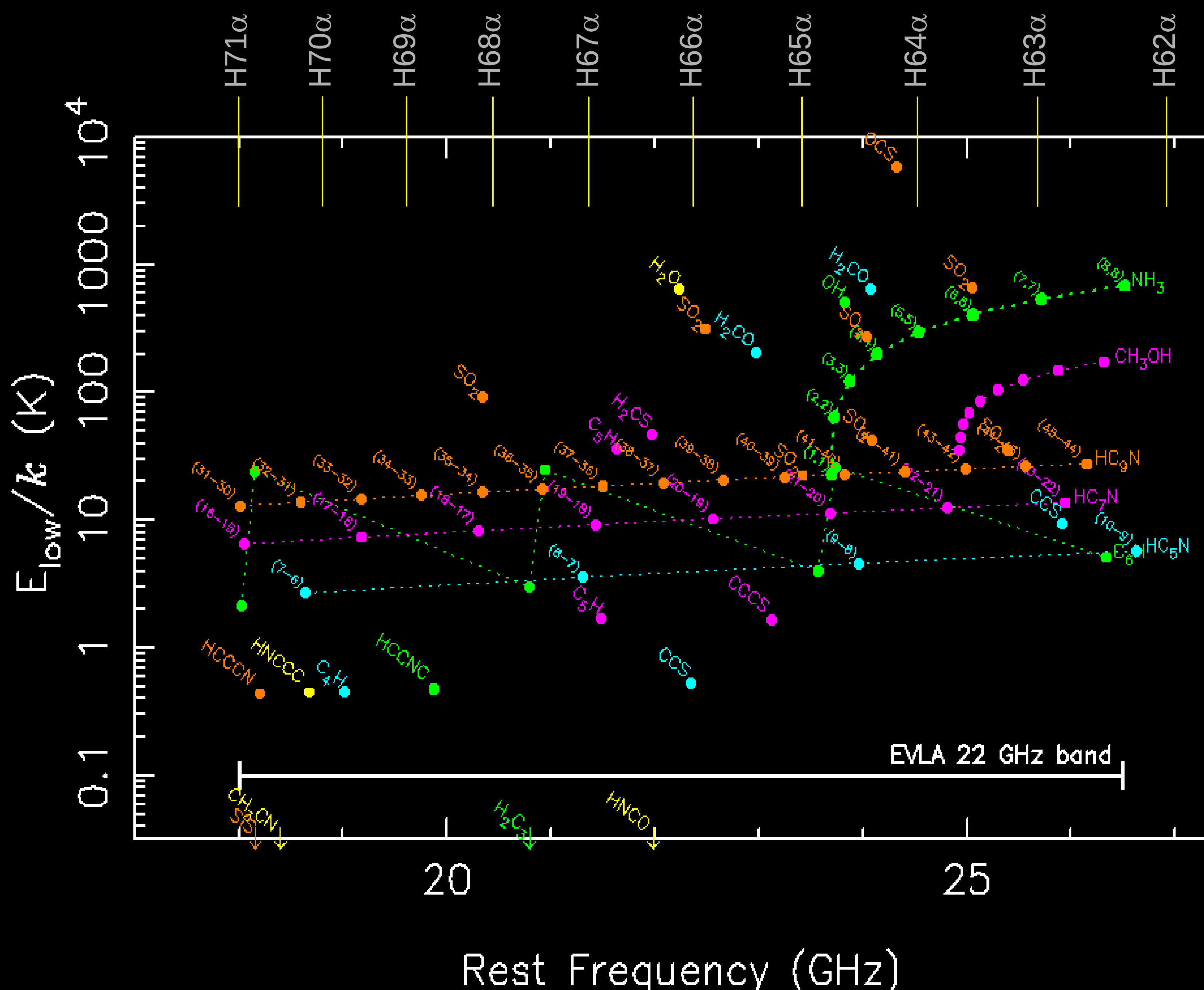
Can the EVLA do all this?

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

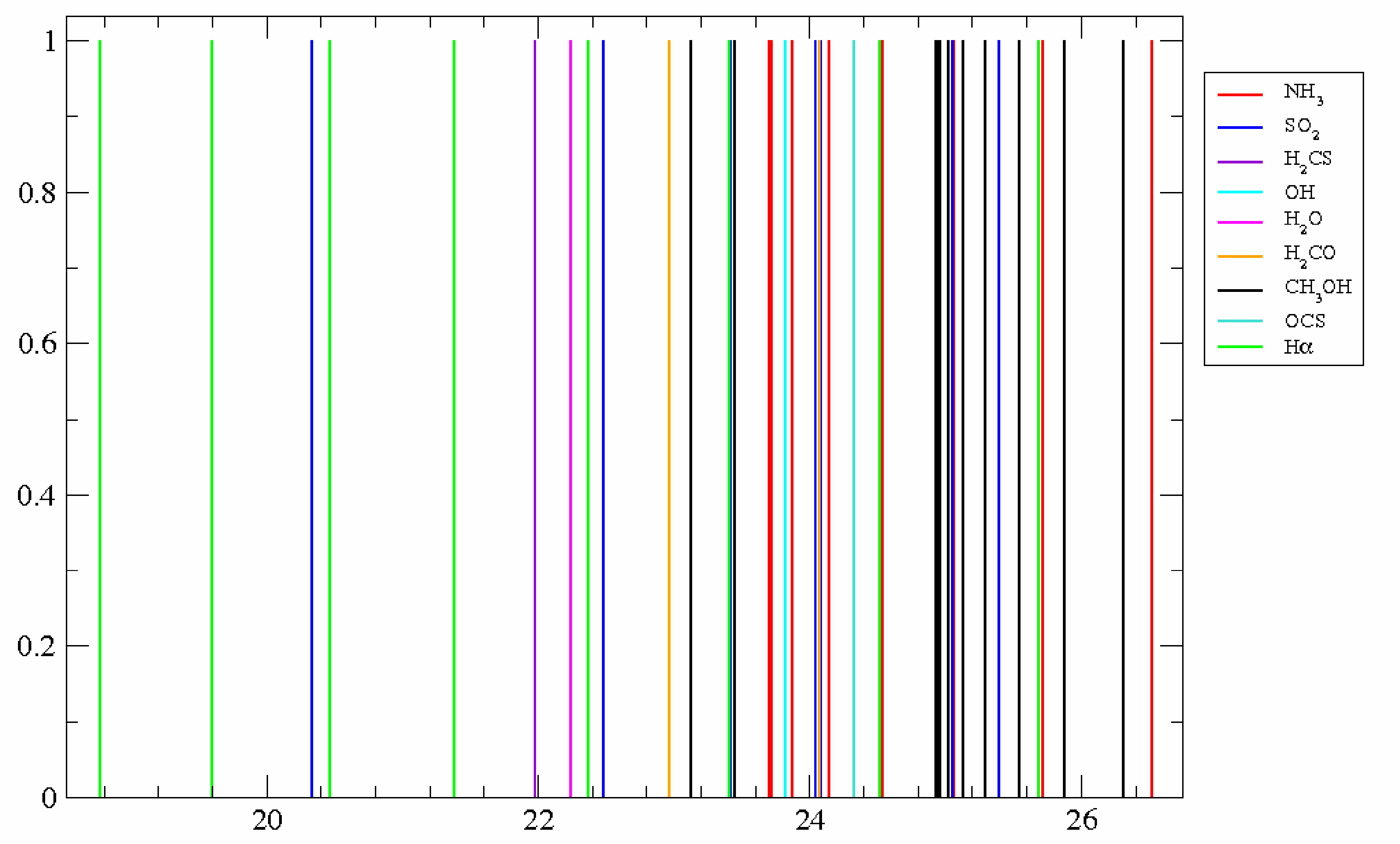


H71α
H70α
H69α
H68α
H67α
H66α
H65α
H64α
H63α
H62α
10^4
1000
100
10
1
0.1
E_{low}/k (K)
Rest Frequency (GHz)
20
25
EVLA 22 GHz band
OCS
H_2O
SO_2
H_2CO
OH
NH_3
CH_3OH
HC_9N
HC_7N
HC_5N
H_2CS
C_5H
CCS
CCCS
C_6H
HCCCN
HNCCC
C_4H
HCCNC
CH_3CN
SiS
H_2C_3
HNCO

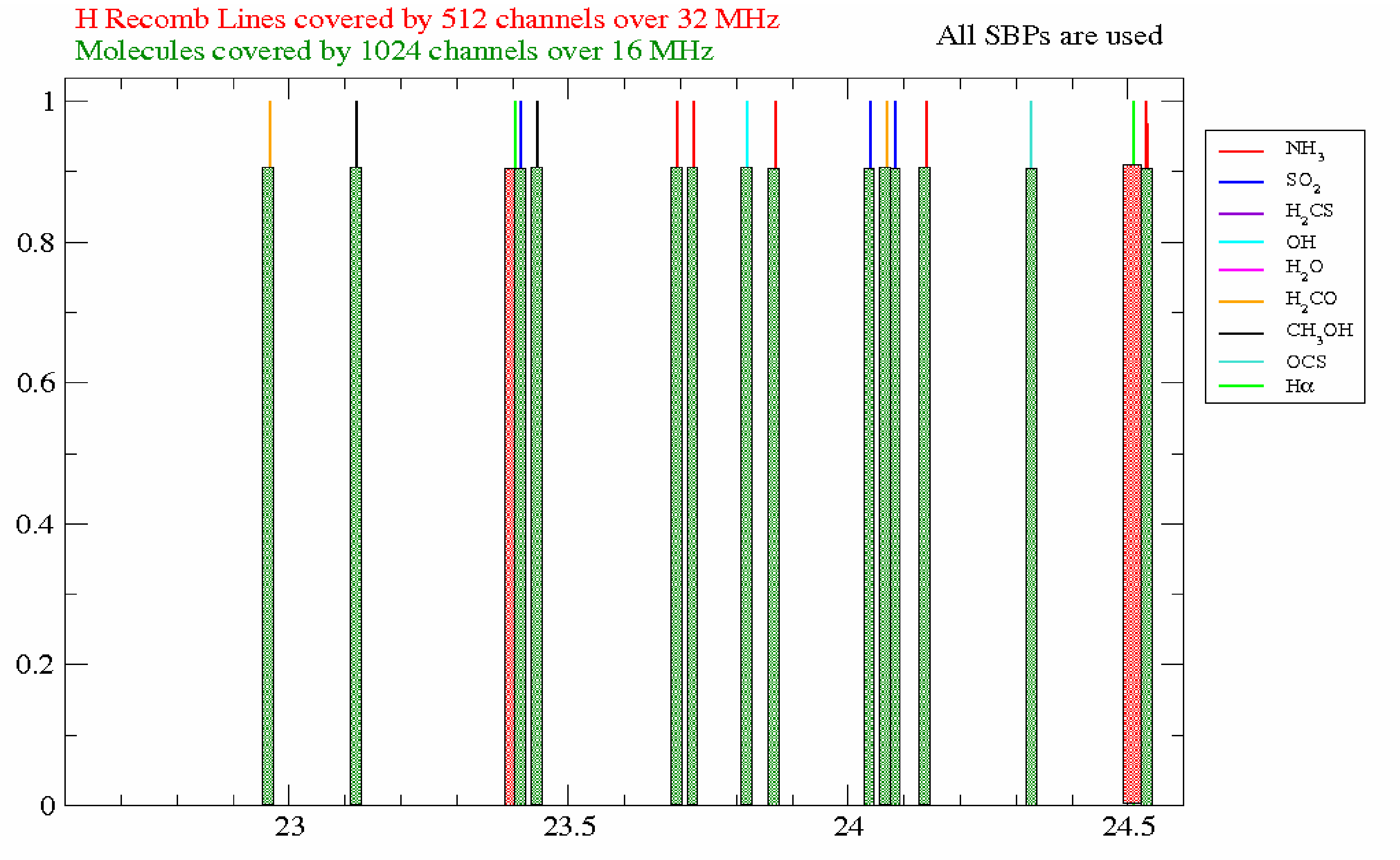
Massive SFR

- 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



Within One of the BBPs



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.

Tentative Conclusions

- The WIDAR correlator offers tremendous resources for science.
- Simple rules govern the allocation of resources.
- All challenging science cases have (so far) been easily accommodated.
- More tough experiments are eagerly sought!