Atacama Large Millimeter Array

Science Requirements
and
Outline of Performances

Alain Baudry
TFB Card PDR Meeting
Bordeaux, October 18-20, 2004

Science Requirements (1)

- *Only Requirements with potential impact on the Tunable Filter Bank (TFB) and Correlator are to be considered*
    - All top level requirements are met by Correlator with TFB cards
        - » Will be confirmed during this meeting
    - TFB enhances ALMA capabilities

- *Frequency Requirements*
    - – It shall be possible to tune ALMA completely across the observable windows i.e. reach a spectral line transition at any arbitrary observable frequency. [SCI-90.00.00.00-00020-00]
    - – It shall be possible to configure the correlator to achieve sufficient resolution (0.01 km/s) at 100 GHz to resolve thermal line widths. [SCI-90.00.00.00-00030-00]
    - – It shall be possible to retune ALMA to a new frequency in a different band that is currently on standby (″warm″) in a time not greater than 1.5 seconds. [SCI-90.00.00.00-00050-00]

Science Requirements (2)

- *Sensitivity Requirements*
  - ALMA shall be comprised of 64 12-m antenna. [SCI-90.00.00.00-0100-00]
  - The full 8 GHz IF bandwidth per polarization per antenna must be processed by the entire signal chain, from the front end element (mixer) through to the correlator. [SCI-90.00.00.00-0180-00]
  - Correlator and electronic losses shall not exceed those expected for two bit correlation after a filter, or 13.3 %. [SCI-90.00.00.00-0190-00]
- *Imaging Requirements*
  - Both total power and interferometric data must be collected. All antennas must be capable of collecting total power data, and at least 4 antennas must be equipped with wobbling subreflectors in order to do atmospheric emission cancellation. [SCI-90.00.00.00-0230-00]
- *Polarization Requirement*
  - It shall be possible to measure all polarization cross-products simultaneously. [SCI-90.00.00.00-0310-00]
- *Sub-arraying Requirement*
  - It shall be possible to have at least four subarrays where the observing frequency and antenna control in each is completely independent of the others. [SCI-90.00.00.00-0390-00]

Science Performances (1)

- Driven by main properties of the Tunable Filter Bank (TFB) which permits the Lag Correlator to work as a digital hybrid correlator
  - *(i)* In frequency division mode => 32 sub-channels per 2 GHz Baseband
    - FXF correlator <=> number of sub-channels goes as number of antennas
  - *(ii)* Sub-channels are tunable over Baseband

- *(i)* & *(ii)* provide Enhanced Spectroscopic capability and Flexibility in line or line versus continuum studies
  - More channels in broad bandwidth modes
    - => impact on nearby or distant Extragalactic studies & on Galactic studies of objects with broad line emission processes
  - Grouping different sub-channels permits simultaneous observation of different lines with high spectral resolution and broad band continuum
    - => Flexible observation of complex multi-line sources (see example later)

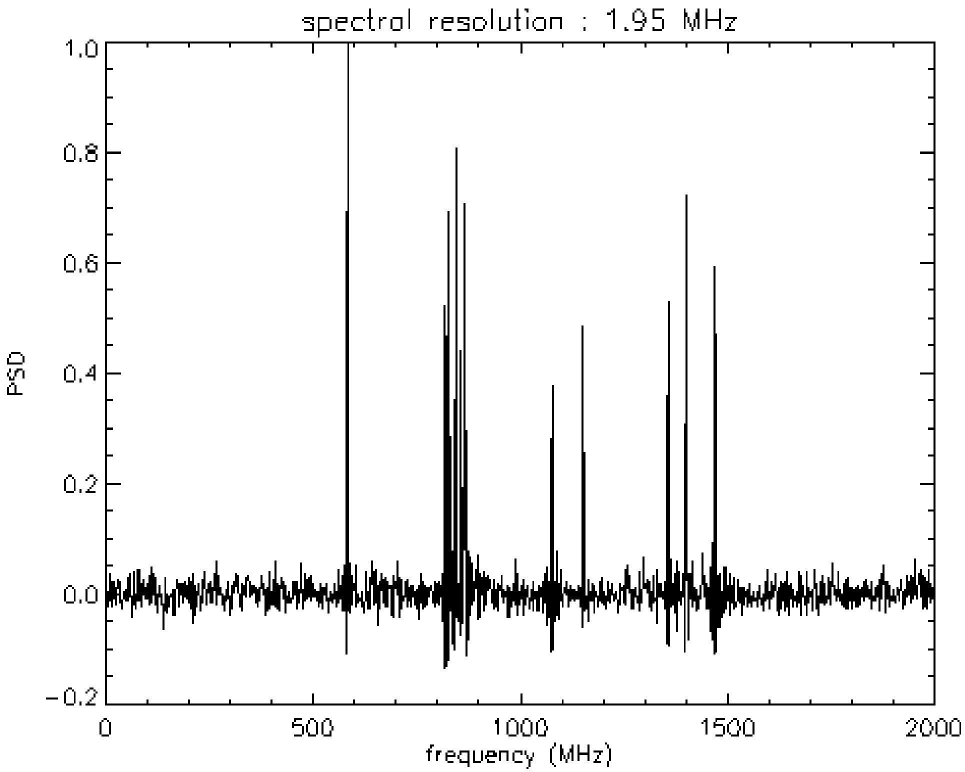
Science Performances (2)

- Tunability of sub-channels (digital LOs and mixers) is essential
  - For spectral flexibility
  - To eliminate sub-channel edge effects and provide seamless coverage

- Two kinds of sub-channel edge effects are eliminated when sub-channel are overlapped (critical because stop-band attenuation is not infinite)
  - Aliasing of spectral lines in sub-channel of interest
  - Avoid line intensity reduction or line profile distortion of lines or profiles falling on sub-channel edges

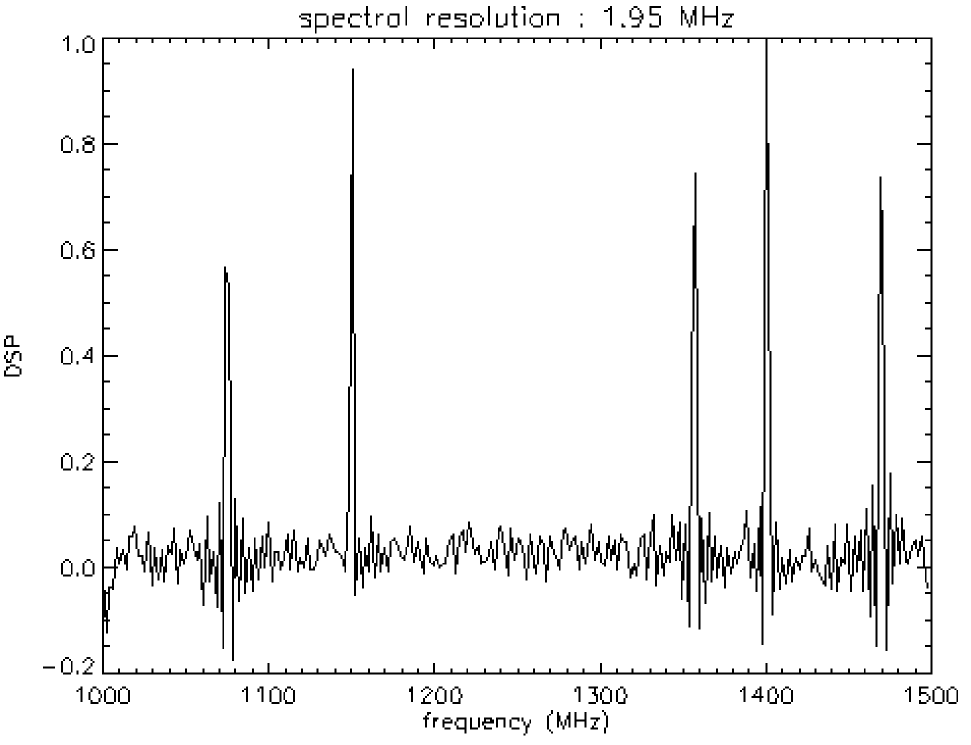
Spectral Flexibility (1)

- Example of 13 lines arbitrarily distributed in 2 GHz
  - Actual 'Line Forest' sources exhibit even more lines ~ 20 to 25 lines per GHz -eg Orion-
- With TFB cards these 13 lines can be analyzed simultaneously with different spectral resolutions



Spectral Flexibility (2)

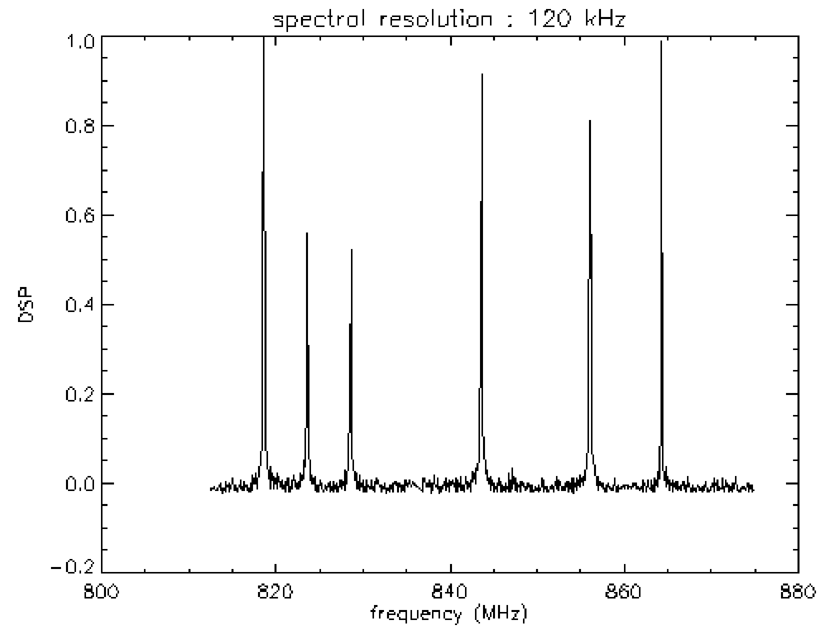
- With 8 sub-channel filters one can have (see Mode Tables)
  - Correlated BW = 500 MHz
  - Spectral resolution = 0.976 MHz with all 4 X-products and smooth result to get effective resolution of 1.95 MHz



Spectral Flexibility (3)

- Use just another sub-channel filter to obtain high frequency resolution at appropriate IF frequency around 840 MHz
  - Correlated BW = 62.5 MHz
  - Spectral resolution ~ 120 kHz with all 4 X-products

- One still has several filters and spectral channels available for other scientific purposes



Many Correlator Mode Options

- *Frequency division mode* (max of 8192 spectral points in 1 Baseband per Quadrant) or *Time division mode* (64 spectral points in 1 Baseband per Quadrant)
- *Several Modes*
  - Select Number of Sub-channels <=> Correlated Total Bandwdth
  - Select Efficiency
    - » Sample Factor: Nyquist or Twice Nyquist (with twice less spectral points)
    - » Improve further Efficiency: 4-bit x 4-bit Quantization (less spectral points)
  - Select Polarization <=> 1 Baseband or 2 Basebands without or with (full Stokes analysis) polarization cross-products
- *Resources are exchangeable* among
  - Basebands = 1 or 2 max per Correlator Quadrant
  - FIR filters = 32 max per Baseband
  - X-products 4 max

Example of Correlator Modes

(no polarization X-products)

Table 2 Mode chart with one baseband channel per quadrant being processed

Number of sub-channel filters	Total Bandwidth	Number of Spectral Points	Spectral Resolution	Velocity resolution at 230 GHz	Correlation	Sample Factor	Sensitivity*
32	2 GHz	8192	244 kHz	0.32 km/s	2-bit x 2-bit	Nyquist	0.88
32	2 GHz	4096	488 kHz	0.64 km/s	2-bit x 2-bit	Twice Nyquist	0.94
32	2 GHz	2048	976 kHz	1.28 km/s	4-bit x 4-bit	Nyquist	0.99
16	1 GHz	8192	122 kHz	0.16 km/s	2-bit x 2-bit	Nyquist	0.88
16	1 GHz	4096	244 kHz	0.32 km/s	2-bit x 2-bit	Twice Nyquist	0.94
16	1 GHz	2048	488 kHz	0.64 km/s	4-bit x 4-bit	Nyquist	0.99
16	1 GHz	1024	976 kHz	1.28 km/s	4-bit x 4-bit	Twice Nyquist	0.99
8	500 MHz	8192	61 kHz	0.08 km/s	2-bit x 2-bit	Nyquist	0.88
8	500 MHz	4096	122 kHz	0.16 km/s	2-bit x 2-bit	Twice Nyquist	0.94
8	500 MHz	2048	244 kHz	0.32 km/s	4-bit x 4-bit	Nyquist	0.99
8	500 MHz	1024	488 kHz	0.64 km/s	4-bit x 4-bit	Twice Nyquist	0.99
4	250 MHz	8192	30 kHz	0.04 km/s	2-bit x 2-bit	Nyquist	0.88
4	250 MHz	4096	61 kHz	0.08 km/s	2-bit x 2-bit	Twice Nyquist	0.94
4	250 MHz	2048	122 kHz	0.16 km/s	4-bit x 4-bit	Nyquist	0.99
4	250 MHz	1024	244 kHz	0.32 km/s	4-bit x 4-bit	Twice Nyquist	0.99
2	125 MHz	8192	15 kHz	0.02 km/s	2-bit x 2-bit	Nyquist	0.88
2	125 MHz	4096	30 kHz	0.04 km/s	2-bit x 2-bit	Twice Nyquist	0.94
2	125 MHz	2048	61 kHz	0.08 km/s	4-bit x 4-bit	Nyquist	0.99
2	125 MHz	1024	122 kHz	0.16 km/s	4-bit x 4-bit	Twice Nyquist	0.99
1	62.5 MHz	8192	7.6 kHz	0.01 km/s	2-bit x 2-bit	Nyquist	0.88
1	62.5 MHz	4096	15 kHz	0.02 km/s	2-bit x 2-bit	Twice Nyquist	0.94
1	62.5 MHz	2048	30 kHz	0.04 km/s	4-bit x 4-bit	Nyquist	0.99
1	62.5 MHz	1024	61 kHz	0.08 km/s	4-bit x 4-bit	Twice Nyquist	0.99
1	31.25 MHz	8192	3.8 kHz	0.005 km/s	2-bit x 2-bit	Twice Nyquist	0.94
1	31.25 MHz	2048	7.6 kHz	0.01 km/s	4-bit x 4-bit	Twice Nyquist	0.99
Time Division Mode	2 GHz	64	31.25 MHz	40.8 km/s	3-bit x 3-bit	Nyquist	1.00

*** Multiply numbers in this column by the 0.96 sensitivity imposed by the 3-bit input digitizer.**

Example of Correlator Modes

(full Stokes analysis)

Table 4 Mode chart with two baseband channels per quadrant processed with polarization cross products.

Number of sub-channel filters	Total Bandwidth	Number of Spectral Points	Spectral Resolution	Velocity resolution at 230 GHz	Correlation	Sample Factor	Sensitivity*
32	2 GHz	2048	976 kHz	1.28 km/s	2-bit x 2-bit	Nyquist	0.88
16	1 GHz	2048	488 kHz	0.64 km/s	2-bit x 2-bit	Nyquist	0.88
16	1 GHz	1024	976 kHz	1.28 km/s	2-bit x 2-bit	Twice Nyquist	0.94
8	500 MHz	2048	244 kHz	0.32 km/s	2-bit x 2-bit	Nyquist	0.88
8	500 MHz	1024	488 kHz	0.64 km/s	2-bit x 2-bit	Twice Nyquist	0.94
8	500 MHz	512	976 kHz	1.28 km/s	4-bit x 4-bit	Nyquist	0.99
4	250 MHz	2048	122 kHz	0.16 km/s	2-bit x 2-bit	Nyquist	0.88
4	250 MHz	1024	244 kHz	0.32 km/s	2-bit x 2-bit	Twice Nyquist	0.94
4	250 MHz	512	488 kHz	0.64 km/s	4-bit x 4-bit	Nyquist	0.99
4	250 MHz	256	976 kHz	1.28 km/s	4-bit x 4-bit	Twice Nyquist	0.99
2	125 MHz	2048	61 kHz	0.08 km/s	2-bit x 2-bit	Nyquist	0.88
2	125 MHz	1024	122 kHz	0.16 km/s	2-bit x 2-bit	Twice Nyquist	0.94
2	125 MHz	512	244 kHz	0.32 km/s	4-bit x 4-bit	Nyquist	0.99
2	125 MHz	256	488 kHz	0.64 km/s	4-bit x 4-bit	Twice Nyquist	0.99
1	62.5 MHz	2048	30 kHz	0.04 km/s	2-bit x 2-bit	Nyquist	0.88
1	62.5 MHz	1024	61 kHz	0.08 km/s	2-bit x 2-bit	Twice Nyquist	0.94
1	62.5 MHz	512	122 kHz	0.16 km/s	4-bit x 4-bit	Nyquist	0.99
1	62.5 MHz	256	244 kHz	0.32 km/s	4-bit x 4-bit	Twice Nyquist	0.99
1	31.25 MHz	2048	15 kHz	0.02 km/s	2-bit x 2-bit	Twice Nyquist	0.94
1	31.25 MHz	512	61 kHz	0.08 km/s	4-bit x 4-bit	Twice Nyquist	0.99
Time Division Mode	2 GHz	64	31.25 MHz	40.8 km/s	2-bit x 2-bit	Nyquist	0.88

*** Multiply numbers in this column by the 0.96 sensitivity imposed by the 3-bit input digitizer.**

Some Science Applications

- Example of Line and Dust Study in **Young Stellar Objects**
  - 1 sub-array of 16 antennas for CO line observation (230 GHz) in 62.5 MHz bandwidth (~ 80 km/s velocity coverage) with high spectral resolution (7.6 kHz or 0.01 km/s)
  - 2 other sub-arrays of 24 antennas each in 2 other frequencies to provide spectral imaging of other weaker lines in narrow total BW ((~ 80 km/s) and accurate spectral index measurement of dust in broad 'continuum' bandwidths

- Line Survey & Imaging in **Massive Star Forming Regions** (Orion-like sources)
  - Requires both broad & narrow BWs … now possible with many more channels

Some Science Applications

- High number of channels in broad BWs essential to search for **new molecular species** … glycine
- Broad BWs with several spectral channels and different receiver bands useful to measure **unknown *z* in distant CO galaxies**
- Large fraction of projects (~ 40%) in Design Reference Science Plan requires **resolution better than 1 km/s**
  - => TFB ideal and achieves better than 5 kHz max resolution as required
- Send 16 (or 8) antennas of ACA to one sub-array of Correlator with TFB capability to **improve imaging** of main array or perform FX (ACA) versus FXF **comparison** of high spectral resolution modes
  - => patch panel(s) permitting main array and ACA antennas exchange
  - Science/ calibration benefits … important during these 'rebaselining days'