Baseline Correlator Upgrade Study

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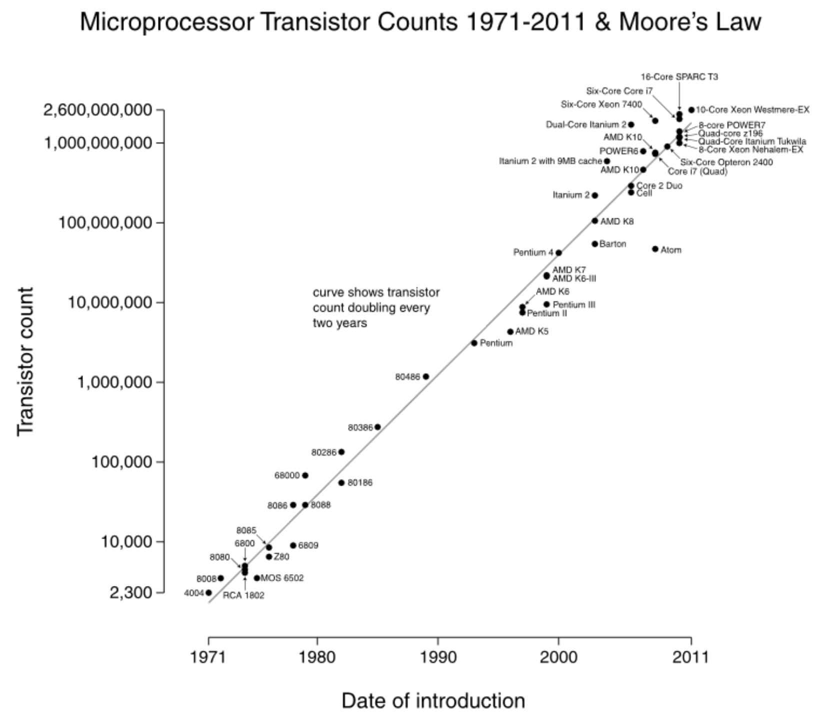
Motivation

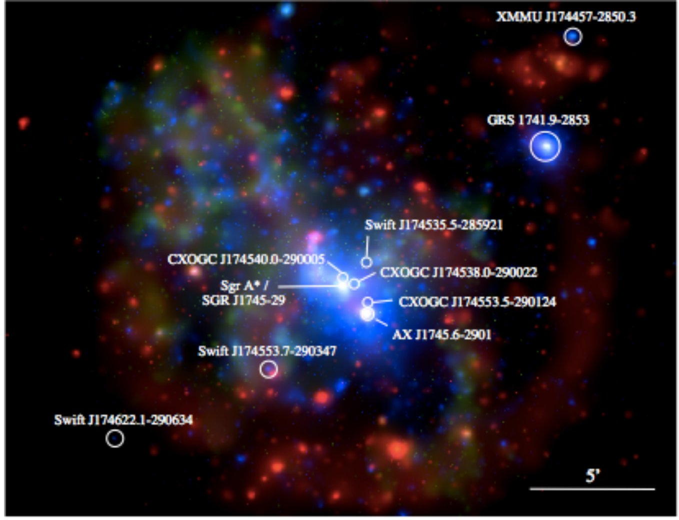
- Technology has evolved
  - Over a decade since hardware was designed
  - Order of magnitude improvement possible without major disruption??
  - Moore's Law



Baseline Correlator Upgrade Study

- See NAASC Memos 114, 115
- Current Cycle 3 NA Study, R. Lacasse, PI, with Escoffier, Greenberg, Saez, Treacy, Webber, Baudry, Amestica, Stan
- Target study completion 2017

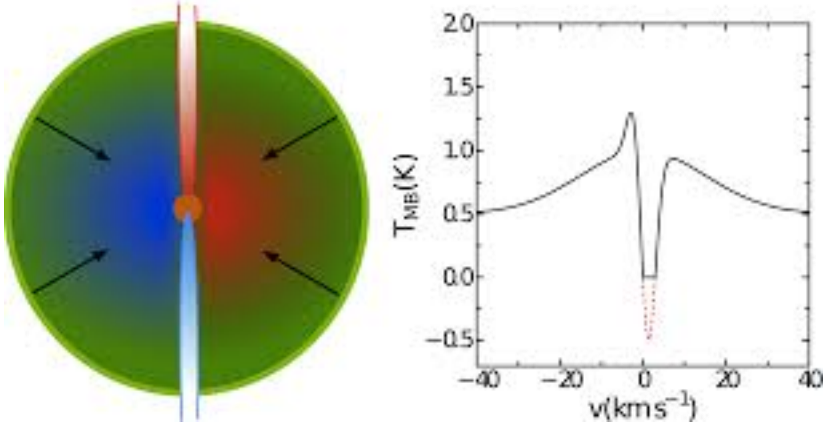
New science



- Temporal resolution is useful for observations of quickly evolving events
  - Solar observations
  - Pulsars—Sgr A* magnetar pulses seen to 1mm*
- One could trade temporal resolution for spectral resolution, increasing the number of spectral points per baseband.
- ***Wider bandwidths observed at higher resolution, a current constraint***
- Long term: Band 6, 9 and 10 currently can present more bandwidth to the correlator than it can process, also true of the prototype B2 cartridge being tested at CDL.
- Ultimate goal: increase bandwidth processed by correlator by ~2x to 16 GHz x 2 polzns. Study would design new chips with this ultimate goal in mind.
- With additional sensitivity and subarrays for instance a survey might be undertaken faster--relatively less overhead due to calibrations.

* Cordes study under way on pulsar observations with phased ALMA

Correlator Upgrade



Infall Cartoon—for First Hydrostatic Core candidates envelope Δv~

- Study under way by Escoffier, Lacasse, Webber, Greenberg, Saez (with Baudry)
- Science advantages:
  - ALMA does not currently meet its specification for resolving thermal line widths in cold contracting cores at its lower implemented frequencies though it does at B6 using uncommissioned 'twice Nyquist' correlator modes.
  - In the upgraded correlator proposed here, where the highest spectral resolution is not needed, 4-bit X 4-bit and double Nyquist modes could be used in a higher percentage of observations.
  - Sensitivity increase by using more sensitive modes made more accessible with the upgrade cuts integration times 12 % (for full array, equivalent of 8 antennas).

Infall Asymmetry

- Need ~4 resolution elements = 1 sigma for a line with a dip or a red shoulder.
- Consider e.g. an HC_3N line at 100 GHz, in a cold, slowly contracting starless core with a central temperature of 8 K.
  - The thermal velocity dispersion would be 0.036 km/s
  - The spectral resolution should be about 0.018 km/s to resolve a gaussian line or 0.01 km/s to resolve a self-absorbed gaussian line [SCI-90.00.00.00-00030-00].
  - The baseline correlator could provide a resolution of 0.011 km/s, meeting this need.
  - But the best resolution now available is 0.092 at 100 GHz using 58.6 MHz bandwidth, with a Hanning smoothed resolution of 30.5 kHz
    - Phase 2 smoothing choices available include Uniform: 1.2xchannel width (this is what SMA uses, but narrow features will ring)
    - Welch: 1.59xchannel width (provides 19dB of ringing suppression)
    - Cosine: 1.64xchannel wdith (provides 20dB " ")
  - With these choices one could obtain 0.021 km/s resolution for instance in the middle of B7.

Resolving narrow lines (cont)

- Could use (uncommissioned) Correlator mode 31:
  - Twice Nyquist mode, yet to be commissioned
  - Bandwidth 31.25 MHz, ΔV=0.046 km/s at 100GHz
  - Or hope that the infall layer is dense enough to excite population at 1.3mm, where ΔV=0.023 km/s or better at higher frequencies
- Band 1 and Band 2 prototype receivers, for which detection of infall absorption is a science driver, are coming on line and will be challenged to resolve narrow lines in the infall envelope.

Broadest Bandwidth

- Currently, broadest bandwidth is 2 GHz per baseband, 2x2 mode
  - In 4x4 mode, broadest bandwidth is 1 GHz
  - *Polarization:* The widest bandwidth currently available for 4x4 with cross-pol products is 125 MHz.
- Upgraded bandwidth would double in 2x2 mode
  - In 4x4 mode, broadest bandwidth would be 2 GHz
  - *Polarization:* 4x4 with cross-pol products would increase to 250 MHz with the upgrade.
  - *Polarization:* One can get 1 GHz, full polarization, with 2XNyquist which is only a little less sensitive that 4X

Performance Enhancements

- frequency and time resolution, and sensitivity

- X8 enhancement in **frequency resolution**.
  - Spectral resolution for every mode increases by a factor of **eight** for integration times of 128 msec and greater. For example, from Table 2 of the correlator specification (next slide) (http://edm.alma.cl/forums/alma/dispatch.cgi/documents/docProfile/100591)
- Time resolution enhancement for auto and cross products
- And if you don't need either improved frequency or time resolution, there is still something in it for you: **higher sensitivity** or **shorter observing times** can be obtained using 4-bit x 4-bit modes and/or double Nyquist mode (95% efficiency versus 85% including the effect of the 3-bit sampler). This is equivalent to adding about 8 antennas to the array or cutting integration times down by 12%! ***True only for BW < 2 GHz.*** See comparison of modes 2 and 53 on the next slide…

Mode Table Changes

N.B. Mode 38 is single polzn! Max 4x4 BW is 1 GHz without upgrade.

Mode #	Number of sub-channel filters	Total Bandwidth	Number of Spectral Points		Spectral Resolution (KHz)		Correlation	Sampling	Sensitivity (x 0.96)
			Current	Proposed	Current	Proposed			
1	32	2 GHz	8192	65536	244	30.5	2-bit x 2-bit	Nyquist	0.88
19	32	2 GHz	4096	32768	488	61	2-bit x 2-bit	Twice Nyquist	0.94
38	32	2 GHz	2048	16384	976	122	4-bit x 4-bit	Nyquist	0.99
2	16	1 GHz	8192	65536	122	15.25	2-bit x 2-bit	Nyquist	0.88
20	16	1 GHz	4096	32768	244	30.5	2-bit x 2-bit	Twice Nyquist	0.94
39	16	1 GHz	2048	16384	488	61	4-bit x 4-bit	Nyquist	0.99
53	16	1 GHz	1024	8192	976	122	4-bit x 4-bit	Twice Nyquist	0.99
3	8	500 MHz	8192	65536	61	7.625	2-bit x 2-bit	Nyquist	0.88
21	8	500 MHz	4096	32768	122	15.25	2-bit x 2-bit	Twice Nyquist	0.94
40	8	500 MHz	2048	16384	244	30.5	4-bit x 4-bit	Nyquist	0.99
54	8	500 MHz	1024	8192	488	61	4-bit x 4-bit	Twice Nyquist	0.99
4	4	250 MHz	8192	65536	30	3.75	2-bit x 2-bit	Nyquist	0.88
22	4	250 MHz	4096	32768	61	7.625	2-bit x 2-bit	Twice Nyquist	0.94
41	4	250 MHz	2048	16384	122	15.25	4-bit x 4-bit	Nyquist	0.99
55	4	250 MHz	1024	8192	244	30.5	4-bit x 4-bit	Twice Nyquist	0.99
5	2	125 MHz	8192	65536	15	1.875	2-bit x 2-bit	Nyquist	0.88
23	2	125 MHz	4096	32768	30	3.75	2-bit x 2-bit	Twice Nyquist	0.94
42	2	125 MHz	2048	16384	61	7.625	4-bit x 4-bit	Nyquist	0.99
56	2	125 MHz	1024	8192	122	15.25	4-bit x 4-bit	Twice Nyquist	0.99
6	1	62.5 MHz	8192	65536	7.6	0.95	2-bit x 2-bit	Nyquist	0.88
24	1	62.5 MHz	4096	32768	15	1.875	2-bit x 2-bit	Twice Nyquist	0.94
43	1	62.5 MHz	2048	16384	30	3.75	4-bit x 4-bit	Nyquist	0.99
57	1	62.5 MHz	1024	8192	61	7.625	4-bit x 4-bit	Twice Nyquist	0.99
25	1	31.25 MHz	8192	65536	3.8	0.475	2-bit x 2-bit	Twice Nyquist	0.94
58	1	31.25 MHz	2048	16384	15	1.875	4-bit x 4-bit	Twice Nyquist	0.99

Impact on ALMA Operations

- Resolution enhancement is not a major perturbation to ALMA operations…
  - There are significant challenges in chip, firmware, and software design and test, but these can mostly be done off-line.
  - No racks to rip out
  - No change in power and clock distribution
  - No change in cooling requirements
  - From the hardware point of view, it's mostly a matter of swapping cards and adding some cables.
- Bandwidth doubling has significant impact
  - Major portion of Back End electronics needs replacement—size and complexity can be reduced
  - See Quertier presentation

Summary

- We are reasonably certain that an upgrade of the ALMA correlator is possible.
- The upgrade would provide a factor of eight improvement in spectral resolution as well as improvements in time resolution. Improved spectral resolution could be traded for improved sensitivity.
- An increase in processed bandwidth could be achieved; further system work would be needed.
- An ALMA study proposal is under way.
- We would be interested in some feedback from the scientific community.

- Further reading:
  - Enhancing the Performance of the 64-antenna ALMA Correlator (Escoffier, Lacasse, Saez, John Webber, Rodrigo Amestica, Alain Baudry) http://library.nrao.edu/public/memos/naasc/NAASC_114.pdf

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