Atacama
Large
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Array

Proposed Science Verification Targets for the Long Baseline Campaign – Additional Information

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MEMORANDUM

To: ALMA Science Advisory Committee

From: EOC Management; ALMA Deputy Director

Date: 11/16/2014

Subject: Proposed Science Verification Targets for the Long Baseline Campaign: Additional Information

The characterization and commissioning of baselines longer than 5 km with ALMA (hereafter, the "Long Baseline Campaign") is scheduled to take place starting in 2014 September and continue through the end of November. In addition to testing the integration of the various procedures necessary to calibrate and image sources (e.g. online/offline WVR corrections, band-to-band phase transfer, bandwidth transfer, baseline determination, fast switching etc.) a dedicated Science Verification (SV) effort is essential to the success of the overall Long Baseline Campaign in demonstrating these capabilities to the wider astronomical community.

In conjunction with members of the JAO, nine proposed SV targets have been selected, of which we intend to select five SV targets for our final list. These targets span the five ALMA Science Categories and have been checked for conflicts against existing accepted Cycle2 proposals. The final list will be announced in a news item on the Science Portal well in advance of the start of the Long Baseline Campaign. After the campaign, the successfully demonstrated SV data products (raw and calibrated data), scripts, and/or CASA guide will be made publicly available to the community.

The proposed SV targets are listed in the table below.

Suitability of the targets for SV and demonstration of the long baseline capability.
The specific requirements for selection of suitable targets were as follows:

- Possible bands are 3, 4 and 6 (higher frequencies will be done on test targets not SV since the outcome of higher frequency work at long baselines is too unknown prior to the campaign and is too weather dependent).
- There should be comparison data in the literature (i.e. imaging with other interferometers).
- Targets should be suitable for imaging on 5-10 km baselines. Only the 12-m array will be used (no ACA).
- At least one of the targets (out of the 5 selected) should be suitable for combining 10-km baselines at Band 3 and 5-km baselines at Band 6.
- Targets suitable for observation in both spectral line and continuum are ideal.

- Largest angular scales should be no larger than 2" in Band 3 and 1" in Band 6 (however the source extent (for the given spectral line) can be larger, up to ~20-30'" at Band 3 or 15" in Band 6).
- Targets should be observable during night time in October. An LST of 0-4h is ideal (but a suitable LST range could be 21h - 8h).
- As recommended by the ASAC, targets cover a range of the science categories.

The individual targets chosen were considered suitable for SV as follows:

- **MG0414+0534** is a well-studied gravitationally lensed radio-loud quasar at z~2.6. There is suitable comparison data in the literature from PdBI, VLA, MERLIN, VLBI and HST, in particular CO J=3-2 PdBI imaging with 2"x0.9" resolution, 22.5 GHz VLA imaging at 0.08" resolution, and VLBI 8.4 GHz imaging at 2.55x1.13 mas resolution (e.g. *Barvainis et al, 1998, ApJ, 492, 13; Katz et al. 1997, ApJ, 475, 512; Ros et al. 2000, A&A, 362, 845*). It is a good target for demonstrating similar-resolution (~0.06") imaging at two frequencies (Bands 3 and 6) and would be observed in a mixed mode spectral setup demonstrating both spectral line (CO J=3-2) and continuum long baseline capabilities.

- **SDP.81** is a high-z (z~3), lensed, ultra-luminous starburst galaxy first detected in the Herschel-ATLAS Survey. It has been detected in CO J=5-4 and H2O emission lines with the PdBI by *Omont et al. 2013, A&A, 551, 115*, at ~2.8"x1.8" angular resolution. It is a good target for demonstrating similar-resolution (~0.06") imaging at two frequencies (Bands 3 and 6) and would be observed in a mixed mode spectral setup demonstrating both spectral line (CO J=5-4 and H2O) and continuum. Together with MG0414+0534 above, these are the most suitable high-z targets within the LST range required for observation during the campaign.

- **3C 138** is a strongly polarized (12%) quasar with an extent of ~1", making it ideal for the demonstration of the polarization capability. It is also a good target for demonstrating similar-resolution (~0.06") imaging at two frequencies (Bands 3 and 6). In addition it could be used to test self-calibration of relatively weak and extended sources. There is suitable comparison data in the literature including e.g. MERLIN, VLA and VLBI observations from *Akujor et al, 1993, A&A, 274, 752*, with angular resolution of e.g ~ 0.06" at 22.5 GHz.

- **NGC 1068** is a well-known nearby Seyfert 2 galaxy whose central regions, containing a circumnuclear molecular disk, starburst ring or spiral, stellar bar and radio jet, have been well studied with other interferometers such as the SMA, PdBI and OVRO. Suitable comparison data in the literature includes *Krips et al. 2011, ApJ, 736, 37; Tsai et al. 2012, ApJ, 746, 129; Schinnerer et al., 2000, ApJ, 533, 850*, with angular resolutions ranging from 0.5" to 1". It is a good target for demonstrating similar-resolution (~0.06") imaging at two frequencies (Bands 3 and 6). It would be observed in a mixed mode spectral setup demonstrating both spectral line and continuum, and could also be used as a test of the polarization capability.

- **Orion KL**, source I, is a massive young star with associated very strong compact SiO maser emission. The extent of the emission is ~0.15" and so will be resolved with 10km baselines at Band 3. Suitable comparison data in the literature, from the VLA, VLBA, VLBI, Hat Creek millimeter array and ALMA, includes e.g. *Plambeck et al. 1990, ApJ, 348,*

L65; Greenhill et al. 1998, Nature, 396, 650; Kim et al. 2008, PASJ, 60, 991; Greenhill et al. 2004, IAUS, 221, 155; Niederhofer et al. 2012, A&A, 548, A69; Zapata et al. 2012, ApJ, 754, L17, with angular resolutions ranging from 0.2 mas to 2.6"x1.5" (~1.8"x1.2" for the published ALMA data).

- **HL Tau**, a young star with a circumstellar disk, has suitable comparison data from the VLA (0.08" angular resolution at 1.3cm), eMerlin and CARMA (0.13" angular resolution at 1.3mm) (e.g. *Greaves et al. 2008, MNRAS, 391, 74; Kwon et al. 2011, ApJ, 741, 3*). It is a suitable continuum-only target for Band 3 and 10km baselines. Potentially, ^{13}CO could be added as a gas tracer that does not force the window too high in band 3 to suffer from the O_2 line.
- **Juno**, an asteroid often used as an ALMA calibrator, is the most suitable ephemeris target that is within the LST range required for observation during the campaign. It would be observed with a TDM spectral setup in Band 6.
- **Mira** is a well-studied AGB star and is a prototypical Mira variable. With a proper motion of 240 mas/yr it would provide a possible astrometric test. It is also a good target for demonstrating similar-resolution (~0.06") imaging at two frequencies (Bands 3 and 6). It would be observed in a mixed mode spectral setup demonstrating both spectral line (SiO) and continuum long baseline capabilities.

Potential sources of conflict with Cycle 2 programs. The table also lists of Cycle 2 Science Goals on, or including (in the field), these targets. A full set of information on the Cycle 2 projects can be found in an accompanying spreadsheet. Note that this includes *any* Science Goal on these targets. Those which may potentially constitute a conflict are highlighted, where a potential conflict is defined as being a factor of two or less difference in angular resolution irrespective of band or spectral setup.

We note that the matched resolution for 10km baselines in Band 3 and 5km baselines in Band 6, for Briggs 0.5 weighting, is ~0.06".

Four out of the nine proposed SV targets have at least one A/B-ranked Cycle2 Science Goal that has an angular resolution within a factor of two of the aim for the long baseline campaign, though in no case are these the same band, target line, or spectral setup.

SV Long Baseline Target Parameters						Cycle 2 Science Goals on or including this target				
Target Name	Coord. (J2000)	Band & Res. (")		Line / Continuum	Sci. Cat.	Project Code	Band	Line	Res. (")	A/B/C Rank
MG0414+0534	04h	3&6	0.06	spectral line (CO(3-2)) & continuum; mixed mode	1	2013.1.01110.S	7	continuum	0.22	B
SDP.81	09h	6	0.03 - 0.06	spectral line (CO J=5-4, H2O) & continuum; mixed mode	1	2013.1.01005.S	7	spectral line ([NII]) only	0.3	C
						2013.1.01005.S	8	spectral line ([CII]) only	0.2	C
3C 138	05h	3&6	0.06	continuum; polarization; TDM, full pol	2	None	...	...	...	...
NGC1068	02h	3&6	0.06	spectral line (CO J=1-0, CO J=2-1, HCN&HCO+) & continuum; polarization; mixed mode	2	2013.1.00055.S	9	spectral line (CO(6-5), HCN, HCO+, SiO)	0.1	C
						2013.1.00055.S	3	spectral line (HCN, HCO+, CS, SiO)	0.5	C
						2013.1.00490.S	7	continuum; polarization	0.35	C
						2013.1.00014.S	9	continuum & spectral line (CO(6-5))	0.1	B
						2013.1.00014.S	7	continuum & spectral line (HCN)	0.15	B
						2013.1.00129.S	6	spectral line (HCO+(3-2))	0.5	C
						2013.1.00129.S	7	spectral line (N2H+(3-2))	0.5	C
						2013.1.00111.S	6	spectral line (H and He recombination lines) & continuum	0.2	B
						2013.1.00221.S	3	spectral line (SiO, CH3OH,	0.5	B

								CS) & continuum		
						2013.1.00221.S	4	spectral line (SiO) & continuum	0.5	B
						2013.1.00221.S	6	spectral line (SiO, 13CO, C18O) & continuum	0.5	B
						2013.1.00221.S	6	spectral line (SiO, CS) & continuum	0.5	B
						2013.1.00368.S	8	spectral line ([CI])	0.3	B
						2013.1.01151.S	3	spectral line (13CN, CN, CH3OH, CS)	3.4	B
						2013.1.01151.S	3	spectral line (CN, C17O, HC3N, H2CO)	3.4	B
						2013.1.00060.S	3	spectral line (CN, HC3N, CS, CH3OH)	1.1	B
						2013.1.00279.S	3	spectral line (C3H2, H13CN, C2H, HCN, CS, SO, HC3N)	1.0	B
						2013.1.00279.S	3	spectral line (HCO+, HNC, HC3N, H3CN, CH3CCH, H2CS)	1.0	B
						2013.1.00279.S	3	spectral line (N2H+, C34S, HNCS, SO2)	1.0	B
						2013.1.00188.S	7	spectral line (HCN, HCO+)	0.6	B
						2013.1.00188.S	7	spectral line (HNC) &	0.6	B

								continuum		
						2013.1.00188.S	6	spectral line (HCN, HCO+)	0.6	B
						2013.1.00188.S	6	spectral line (HNC) & continuum	0.6	B
						2013.1.00727.S	8	spectral line ([CI])	0.5	B
Orion KL	05h	3	0.06	spectral line (SiO); mixed mode	3	2013.1.00504.S	9	spectral line (H2O)	0.17	C
						2013.1.00451.S	9	spectral line (H2S)	0.9	B
						2013.1.01034.S	4	spectral line (CH3CN)	0.3	B
						2013.1.01034.S	4	spectral line (CH2DCN)	0.3	B
						2013.1.00367.S	9	spectral line (13CO, SiO, CH3OH) & continuum	0.18	B
						2013.1.00048.S	7	spectral line (o-H2O)	0.13	A
						2013.1.00048.S	8	spectral line (p-H2O)	0.13	A
						2013.1.00048.S	8	spectral line (p-H2O, SiO)	0.13	A
						2013.1.00048.S	8	spectral line (p-H2O)	0.12	A
						2013.1.00553.S	6	spectral line (O18O)	3.0	B
						2013.1.00553.S	6	spectral line (O18O)	3.0	B
						2013.1.00553.S	6	spectral line (O18O)	3.0	B
						2013.1.00553.S	6	spectral line (O18O)	3.0	B
						2013.1.00553.S	6	spectral line (O18O)	3.0	B
HL Tau	04h	3	0.06	continuum; TDM, dual pol or mixed mode with ^{13}CO	3	2013.1.00355.S	7	continuum only; polarization	0.122	B

Juno	08h	6	0.03 - 0.06	continuum; ephemeris; TDM	4	None	...	...	...	...
Mira	02h	3&6	0.06	spectral line (SiO) & continuum; mixed mode	5	2013.1.00156.S	7	spectral line (HNC, TiO, AlO, CO, HCN)	0.12	B
						2013.1.00323.S	7	spectral line (CO(3-2)) & continuum	0.2	C
						2013.1.00047.S	7	spectral line (CO(3-2)) & continuum	0.32	B
						2013.1.00047.S	9	continuum only	0.17	B
Betelgeuse	06h	3&6	0.06	spectral line & continuum; mixed mode	5	None	...	...	...	...

The Science Categories are: 1. Cosmology and the high redshift universe, 2. Galaxies and galactic nuclei, 3. ISM, star formation and astrochemistry, 4. Circumstellar disks, exoplanets and the solar system, 5. Stellar evolution and the Sun).

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