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ASAC Report to the ALMA Board

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General considerations

Prof. Giles Novak and Dr. Stephen White have joined ASAC, while Prof. Alberto Bolatto and Prof. Nagayoshi Ohashi left ASAC. We would like to thank both for their many contributions to the ASAC.

The ASAC Face-to-Face meeting was held at the Joint ALMA Observatory headquarters, Santiago, Chile, on March 16th and 17th, 2017, with nine ASAC members present, two joining remotely (Dr. R. Osten, Prof. H.J. van Langevelde) and one excused (Prof. Giles Novak). In addition, the JAO Director and Observatory Scientist were present, as well as the three regional Project Scientists (Leonardo Testi and Al Wootten in person, Daisuke Iono remotely). The JAO Deputy Director joined for part of the meeting.

ASAC briefly discussed its organization and finds the current frequency of telecons of about one every 1.5 months sufficient. Having the standard set of plots presented at each telecon is very useful and ASAC would like to add the following plot on completion to this set of plots:

- completed OUS/projects, current completion rate and predicted completion rate at end of Cycle

The availability of all documentation well ahead of the meeting helps tremendously in the preparation for the face-to-face meeting. ASAC would like to stress that availability of documents ahead of the regional SAC face-to-face meetings (ANASAC, EASAC, ESAC) is seen as extremely helpful for gathering the most effective regional input, and should be continued to the extent that it is possible. Access to all presentations a few days before the face-to-face meeting would further help ASAC members in the preparation for the face-to-face meeting. ASAC would like to thank the Observatory Scientist and all others involved for their efforts in providing the necessary information for its face-to-face meeting.

ASAC continues to be impressed by the high quality of scientific results from ALMA and would like to mention the following science highlights demonstrating ALMA's strengths and recent improvements:

- impressive science verification data on solar hotspot
- first direct evidence for fragmentation of protostellar disk via mapping
- extremely rich spectral scan of the hot core IRAS 16293-2422
- tentative [OIII] 88 micron detection in a z=8.35 galaxy

Significant progress has been made in several areas. In particular, ASAC notes the significant reduction in the backlog of data to be delivered, although there is a concern that this may be mostly because of the lack of new data in January and February. ASAC was also pleased to hear about the good progress already made on the Cycle 4 Large Program on the Hubble Ultra Deep Field. ASAC is in particular concerned about the following two items and would like to draw ALMA board's attention to them:

- The backlog in data delivery and the current lack of a sustainable long-term solution
- The fastly approaching decision point between Band 2+ and Band 2+3 apparently without a defined process toward final decision

We now go through each of the charges in turn, starting with recommendations for each, with the most important recommendations near the top of each list. Further completeness the reports on the prioritization of the receiver bands for wide-band up-grade (related to ad-hoc charge #4), collection of potential high impact science cases for a baseline extension and background information on the numbers for the new primary, high level science cases (both related to ad-hoc charge #5) are given as Appendix A, B and C, respectively.

Permanent Charge #1. **Assessment of the performance of ALMA scientific capabilities: The ASAC shall indicate what information is required from the Joint ALMA Observatory (JAO) to perform this assessment.**

Recommendations/Issues:

- ASAC recommends that all rank B and C projects of Cycle 3 that have not yet undergone the quality assurance checks are made accessible to principal investigators without further delay (evoking the "stale data" policy).
- ASAC remains concerned about the data delivery backlog and the long-term sustainability of the current data delivery processing model. ASAC would like to receive the report of the Tiger Team's recommendations and hear about the implementation steps at its May teleconference.
- ASAC recommends providing users with instructions on selecting the most appropriate observing options for projects requiring spectral scans in Cycle 5.
- ASAC is concerned about the lower than expected completion rates of rank A Cycle 3 projects and the difficulties to complete some Cycle 4 projects. The committee requests to receive regular updates (during its telecons and face-to-face meetings) on project completion rates from JAO to assess the magnitude of the problem.
- ASAC suggests that JAO provides an update to the users regarding the data delivery backlog (as a follow-up to the letter sent to the users in Fall 2017).
- ASAC is worried that the planned development and implementation of new ALMA capabilities seem very ambitious and might deflect the focus from meeting the Observatory's goals on observing efficiency and project completion rate during Cycle 5.
- ASAC would like to receive an update on progress in solving the astigmatism problem of the Vertex antennas and to hear about the impact of the surface adjustments on the antenna efficiency at high frequencies at its next face-to-face meeting.

Data backlog. ASAC was provided with a detailed update on the data delivery rate issue. The committee was concerned that the huge delays in the delivery of calibrated data have generated widespread dissatisfaction among Cycle 3 and Cycle 4 users and that these might have impacted scientific productivity. The committee was pleased to hear that the backlog has been significantly reduced, although it is hard to tell how much of this was due to the poor weather and shut-down in the first 2 months of 2017. ASAC considers it important for users to be informed about the current status of progress on achieving the 4-week goal for data delivery. ASAC reiterates that delivery of raw data should be assessed as a viable option for projects whose data have significantly passed the time goal for data delivery.

ASAC was reassured to see that regions and JAO have joined in a concerted effort to give highest priority to resolving the backlog problem. While the committee understands that work organization and priorities are still in the process of being adjusted to speed up data delivery in the short term, it nevertheless remains concerned that, despite the recent recruitments of additional data analysts, the root causes of the backlog might not have been fixed, that the current data processing rate of 80 MOUS/week would be at the average level for Cycle 5, and that the current processing model might not be sustainable in the long term. Along this line of reasoning, the committee recommends that JAO and the ARCs continue jointly to assess work organization and make projections for future ALMA cycles. The committee looks forward to seeing a strategic long-term plan to settle the issue, receiving a report of the Tiger Team, and hearing about the implementation steps at its May telecon.

ASAC was particularly concerned about the huge delays in the data deliveries of rank B and C projects from Cycle 3. The committee strongly recommends that these projects receive "stale-data" status and that the principal investigators of these projects be informed about the possibility of getting access to their uncalibrated data without further delay. The committee views it as important that access to uncalibrated data is granted soon so that principal investigators have a meaningful opportunity to submit follow-up science proposals by the Cycle 5 proposal deadline.

Completion rates. ASAC is concerned over the lower than expected completion rates of Cycle 3 projects (55.4% for grade A and DDT) and over the relatively low likelihood of completing them in Cycle 4. The committee is also concerned to hear that a number of rank A projects from Cycle 4 might never be completed. The committee notes that the transfer of rank A projects from Cycle 4 to Cycle 5 is potentially subject to project scheduling difficulties and that this might also become a problem for rank A projects in future cycles. ASAC seeks to better understand if the carry forward of rank A projects from cycle to cycle is likely to become a matter of increasing concern, and requests the observatory to provide regularly updated information on the project completion rates. If this is a long-time concern, then users should be given information in order to manage their expectations about completeness.

Implementation of new capabilities and observing efficiency. ASAC endorses the development and implementation of new ALMA capabilities designed to meet a level of operational performance as expected for steady-state operations of ALMA. The committee understands that a number of new capabilities are already in the process of being implemented, but given the lower than expected observing efficiency of the observatory (minimum of 85% expected in Cycle 5 for steady state operations of ALMA) and the risk of overloading it with technical downtime, the committee recommends that the implementation of new capabilities be carefully balanced against resource constraints and observing efficiency.

ASAC was also pleased to hear that work is in progress to implement the long-awaited fast spectral scan mode for Cycle 6. The available options in Cycle 5 to optimize the observing efficiency for short, medium and long integration times could be confusing to users. The committee notes that different options are described in the current ALMA Cycle 5 Proposer's Guide and recommends providing more detailed instructions to help ALMA users evaluate and select the most appropriate option for best performance and usage of the spectral scan mode.

The committee reiterates that allowing high frequency observations for ACA in stand-alone mode would likely help to increase the pressure on ACA and its scientific productivity

Antenna efficiencies. ASAC was informed about progress being made on resolving the astigmatism problem of the DV antennas. The committee remains concerned about the pace at which the work progresses and would like to receive an update at its next meeting. Further, ASAC would like to be kept informed about the surface adjustments of the next antennas and about the improvements on the antenna efficiency at high frequencies.

Permanent Charge #2. Assessment of the technical aspects of the ALMA system performance: The ASAC shall indicate what information is required from the JAO to perform this assessment.

Recommendations/Issues:

- ASAC recommends that observatory-wide policies (or guidelines) are established to ensure the same treatment of Large Programs across all Executives. It reiterates that PI access to uncalibrated/raw data can be vital for project success and should therefore be seriously considered as a possibility to request for Large Programs.
- ASAC recommends that JAO conducts a "lessons learned" at the end of each Large Program in Cycle 4 involving the PIs in this process. ASAC is looking forward to hearing about this exercise at its next face-to-face meeting.
- ASAC recommends that defining and standardizing archival data products is given a high priority as soon as the data backlog problem is solved.
- ASAC reiterates the need to solve the issue of dependence on CASA version for obtaining calibrated *uv* data and recommends storing these data (or at least calibration tables) in the archive until this issue is solved.
- ASAC remains concerned about the completion fraction of rank A and B projects in Cycle 4 and would like to receive (at the May telecon) an assessment of predicted completion fractions for these projects including remediation ideas if low completion fractions seem possible at that time.
- ASAC would like to hear about lessons learned from the ephemeris problems encountered during the December 2016 Solar observation campaign and to learn whether procedural changes to mitigate similar issues with new observations capabilities/modes have been implemented.
- ASAC encourages JAO to work on capabilities to enable a fringe test before mm-VLBI science observations start to ensure successful campaigns before large amounts of telescope time are used.

- ASAC encourages JAO to continue to explore ways to ensure allocating sufficient observing projects for the ACA 7-m array and total power antennas in the upcoming Cycle 5.
- ASAC would like to receive an update on the underlying cause(s) of the large scatter in the on-source efficiency to further assess the potential issue of over-calibration at its next face-to-face meeting.
- ASAC reiterates its recommendation to fully integrate duplication checks into the archive by the time of the Cycle 6 Call for Proposals.

Archive. ASAC understands that defining and standardizing the archive data products has been given a lower priority than improving the backlog, but nevertheless this is an important issue that should be addressed soon. We were told that discussion has been going on in the Archive Working Group, and ASAC wonders if there should be more visibility of that group to ASAC, so that we can understand what solutions are being proposed. We look forward to hear an update at the next F2F meeting. Further ASAC reiterates the need to solve the issue of the dependence on CASA version for obtaining calibrated data and prefers that the calibration tables should be stored until this issue is solved.

Large Programs. ASAC is pleased to see that the first Large Programs (LPs) are underway and that the systems in place seem to be coping well. It is also good to see ASAC's recommendation being adopted of the Observatory working closely with the proposal team in order to check the quality of the data as they come in. However, ASAC feels that this interaction has not been close enough, and that the Observatory should do everything it can to ensure the success of the Large Programs. Sharing some early uncalibrated data with the proposal team seems like the obvious solution, and if that currently violates an ALMA-wide policy, then this should be discussed as a possible exception.

Additionally ASAC feels that it is crucial that the way that LPs are treated should be the same across all Executives, and so observatory-wide guidelines should be established here. ASAC learned about the process adopted for the deep-field LP and the process planned for the disk LP. The committee believes that it is important that lessons are learned from the handling of the Cycle 4 LPs and that PIs get involved in the process. ASAC also recommends having this process at the end of each LP and is looking forward to receiving feedback.

ACA 7m supplementary call. A supplementary call for additional low frequency (Band 3, 6 and 7) projects is clearly the correct way to deal with the problem of not having enough ACA proposals in the queue for Cycle 4. However, ASAC feels that this issue could have been discussed earlier and input from ASAC could have been solicited (rather than the solution being presented at the face-to-face meeting). Additionally, it would be good to hear about the longer-term solution to avoid having ACA sitting idle in future cycles. We further encourage JAO to think about ways to ensure that a similar situation does not occur for the upcoming Cycle 5.

Solar observing campaign. The problem discovered with the ephemeris in the December 2016 Solar observing campaign (rendering most of the data of reduced scientific value) is clearly something that ALMA should learn from, in order to improve lines of communication so that such issues do not arise in future. ASAC wonders whether there will be a "lessons-learned" document coming out of this situation, and whether the JAO already has made some procedural changes to mitigate future issues.

On-source efficiency and over-calibration issue. ASAC is pleased to see that the observatory is in the process of addressing the data over-calibration problem. ASAC appreciated seeing a plot of the percentage of time spent on-source relative to the time spent on calibration (i.e. on-source efficiency) in different execution blocks. This issue should be studied further, however, to try to understand where improvements can be made to the overheads and to understand the significant scatter for a given execution block length at a given band. We look forward to receive an up-date at the next F2F meeting.

Project completion fraction. The goal of 90% completion (of rank A+B projects) for Cycle 4 is a laudable one. However, this issue of completion efficiency remains important, and needs careful attention. Therefore ASAC would like to see (by the next telecon) an assessment of predictions for the fraction of rank A and B projects that will be completed in Cycle 4. If there is an issue at that point with the possibility of a low completion fraction, then ASAC would like to hear about remediation ideas.

Preparation for mm-VLBI campaign. ASAC is very happy to note that the observatory is ready for the important first mm-VLBI science observations in April 2017, with a successful fringe test in January 2017 already, and relevant experts lined up to assist. However, ASAC encourages further technical work concentrating on capabilities to perform a fringe test among sub-millimeter stations shortly before the science run to ensure that technical anomalies can be addressed in time.

Cycle 5 readiness. ASAC acknowledges the current implementation for checking duplications in Cycle 5, however, it reiterates that a full integration of duplication checks in the archive should be available by Cycle 6.

ASAC is glad to see that there has been progress in solving the cryogenics problem that has threatened to reduce the number of antennas available for science, and slowed the installation of the Band 5 receivers. We hope that the solutions identified and presented to us continue to result in improved antenna performance and the timely completion of the Band 5 installation in Cycle 5.

Permanent Charge #3. Assessment of the science outcomes from ALMA: Statistics on publications, citations, press releases, web sites, etc. collected by the Executives shall be collated by the JAO, and analyzed by the ASAC.

Recommendations/Issues:

- ASAC recommends that JAO improves the way demographic data of ALMA users is collected.
- ASAC recommends that JAO looks into establishing metrics for tracking the impact of press releases.

- ASAC suggests an examination for common properties of projects where data has been delivered a while (e.g. more than 24 months ago) but no papers have been published.

Publication statistics show a promising trend, with a year-to-year increase of more than 100 papers published in 2016 compared to the number in 2015; these are good signs that ALMA users are producing publishable results. The trend toward increasing the number of citations for ALMA papers is expected, and good to see. Only about one quarter of the total publications are based on archival data, although this number may be expected to be low in the early years of an observatory, and as data accumulate in the archive the fraction of publications making use of archival data should increase. The relatively short publication time (compared with other major observatories) is noted by ASAC, but this may be biased by Cycle 1 projects, or the type of proposals accepted in early ALMA cycles (of the discovery type rather than in-depth analyses), and ASAC would not be overly concerned should the time to publication increase slightly.

While ASAC was heartened to see the overall impressive publication statistics of those programs for which published papers exist, it would also be useful to track the number of programs for which no publications have resulted yet, and understand if there is a systematic reason why those programs have not been able to produce publishable papers (i.e., do they belong to a certain category, e.g., band or observing mode).

The permanent charge includes an assessment of press releases, but no information on these was given. Being able to measure the number of press releases, their distribution among science categories, and the reach or number of impressions of each press release would be useful to be able to make more definitive statements about how impactful they are (particularly compared with other observatories).

The demographic information provided was very interesting, although the ASAC notes that it is based on only about 500 out of more than 7300 registered users in the ALMA Portal. The success rate of first time PIs, at 20%, is low, and appears to be declining from previous cycles. The lower success rate for first time PIs is worrying, although the roughly equal spread of success across areas of expertise (not just radio and sub-mm/mm but also optical and X-ray) perhaps suggests that ALMA proposers are coming from a wide swath of the astronomy community. ASAC notes that it is very cumbersome to provide or update this information in the portal, and making it easier for the community to give this information would vastly increase the robustness of the statistics generated using demographic information. Availability of demographic information is essential when studying potential biases (e.g. gender or seniority related) in the proposal review or other processes.

ASAC appreciates the results of the Cycle 4 ALMA user satisfaction survey, which contains very comprehensive statistics on various stages from proposal preparation to data delivery and their reduction. The small difference between novice and expert users could indicate that ALMA is achieving its mission goal of attracting a wide community. For deriving a firm conclusion related to the demography, however, the number of valid users' profiles is inadequate. There is significant room for improving the design of the web pages for the demographic survey in the science portal. ASAC encourages the observatory to restructure the relevant web pages and to ask all users to update their profiles regularly.

Permanent Charge #4. Recommendations of ways to maximize ALMA's scientific impact: This includes review of the scientific effectiveness of the Proposal Review Process after each Proposal cycle.

Recommendations/Issues:

- ASAC recommends that the Observatory investigate ways to provide direct access to calibrated Measurement Set data in the archive and to implement tools for data mining.
- ASAC recommends to review all steps in the ALMA proposal review process to find ways to ease the workload of panel members during the APR process.
- ASAC recommends that the demographic survey is continued and improved with emphasis on investigating the use of ALMA by non-experts, and studying gender balance, as well as the effects of seniority and the benefits of being a previously successful PI.

ASAC recognizes that there have been important improvements in the implementation of the ALMA archive system during the last cycles. However, there is still concern about the current implementation of the archive tools and the data products delivered through it. These are not set up for long term sustainability. There is particular consensus that the archive should provide direct access to calibrated Measurement Set (MS) products. This would speed up significantly the first inspection of data and analysis, which may translate into a faster publication turnaround. As ALMA enters full operations and the size of the data archives grows, it is critical to have easy ways to access archival data products for mining. It would thus be ideal to implement tools to ease this process (e.g., add archive log files, calibration scripts, etc. as separate downloadables).

ASAC also recognizes the improvements made in the APR process for Cycle 5. In particular the adjustments made to ensure a better review process of Large Programs is seen as a positive measure. Similarly, the addition of two assessors with background in solar science will enable a more detailed review of this type of proposal. The permanent presence of panel chairs during the writing of "consensus reports" will hopefully result in better and more detailed feedback given to the proposers. ASAC is still concerned about the overall workload of the review process, and hopes that new measures will improve this in future cycles. Also, we would like to see how these measures are reflected in an improvement in the relatively poor ranking shown by the "review process" in the user satisfaction survey of 2016.

ASAC believes that performing a demographics survey among its users is an important. It would be interesting to see the time evolution of these survey results, and thus it should be continued into the future with the aim to: investigate ways to increase the use of ALMA by non-experts; measure if there are advantages of being a previous successful PI of ALMA programs; and determine trends in gender balance and seniority among proposers. ASAC also recommends revising the current survey interface, as well as to look for unbiased ways to assess the different expertise of the survey participants.

Permanent Charge #5. Reporting on operational or scientific issues raised by the wider community as communicated by the three regional Science Advisory Committees (ANASAC, ESAC and EASAC).

Recommendations/Issues:

- ASAC would like to continue to receive statistics on the Helpdesk, including the topics of long-term open tickets.
- ASAC notes issues for projects that require several observations with a fixed temporal spacing and welcomes JAO's efforts to improve the success of such projects via the implementation of new modes of communication between PIs and Astronomers-on-Duty (AoDs). ASAC would like to learn about the effectiveness of this measure after it has been in use for a few months.
- ASAC welcomes the implementation by ALMA of changes for Cycle 5 to improve ALMA's ability to carry out observations of transients and other time-critical events.

The ASAC thanks the Integrated Science Operations Team (iSOpT) for providing the requested documentation clarifying the roles of contact scientists and the Helpdesk, and the details of the Helpdesk ticket workflow. However, there is anecdotal evidence in the community that some tickets receive replies later and are left open much longer than this document suggests, and therefore the ASAC would like to continue to receive statistics on processing of Helpdesk tickets.

The final paragraph of this document is relevant to an operational issue that has raised comment. Some observers have reported difficulty in obtaining complete observations that require fixed timing between successive SBs. An example is observations of rotating solar system bodies, where complete coverage of the body's surface requires multiple tracks with a spacing in time matched to the rotation period of the body. When this is of order a week or more, the institutional memory of the need for the next SB after a fixed time interval can be lost due to rotation of AoDs and inattention by contact scientists. The ASAC hopes that the new modes of communication between PIs and AoDs planned for Cycle 5 will allow PIs to be more proactive and help to remediate such problems, leading to a better success rate for projects of this nature.

The ASAC also welcomes the implementation by ALMA of changes for Cycle 5 that will improve ALMA's ability to carry out other types of time-critical observations, such as of transient sources. Specifically, removing the size limit on the time-constraint window, improving the ToO prioritization, and facilitating communication between PIs and AoDs should improve ALMA's ability to contribute to this scientific domain. ASAC notes that these changes proactively address concerns raised by the ALMA Time-domain Special Interest Group regarding ALMA's ability to carry out highly important science that requires time-coordinated and/or rapid-response observations. We recognize the limits imposed by the weather, the maintenance schedule and other unforeseen issues, and agree that it may not be possible to promise the same rate of completion as for non-time-constrained observations.

Permanent Charge #6. Assessment of the scientific impacts of the ALMA Development Program, and particularly of new projects that are proposed.

Recommendations:

- ASAC urges the Board to organize the process (with a definite schedule) to fairly compare the two on-going development project for Band 2+ and study for Band 2+3. In particular, ASAC recommends setting a definite date in the near future for a strategic decision on full-production (of receivers covering Band 2) to be made, in order to avoid unnecessary potential duplication of activities.
- The ASAC expects that the committee will be involved to some extent in the evaluation of the scientific merits for the Band 2+/2+3 receivers.

ASAC received the presentations by regional scientists summarizing the on-going efforts on development studies in each executive. The committee is pleased to see that a number of studies have been proposed and conducted. These include the call for community studies in NA based on the ALMA 2030 vision, release of Band 5 SV data sets led by EU (which already attracted community interest in the use of Band 5 in the coming cycles, as evidenced by the number of downloads), and progress of Band 1 production by EA. The proposed next generation OT and data viewer are expected to improve the science productivity of ALMA. The artificial calibration source, which provides a polarization standard, will be beneficial for the improvement of ALMA polarization capabilities. Development studies of SIS junctions and related key components for implementing wider bandwidth, such as "Band 2+", "Band 2+3", and "Band 7+8", are also acknowledged by the committee as activities in accord with the ALMA 2030 vision.

Among these activities, the committee is particularly concerned about reaching a decision between Band 2+ and Band 2+3 for a full development project soon. Given the progress of the Band2+ prototype project and the Band 2+3 study, ASAC urges the Board to organize the process (with a definite schedule) to fairly compare the two on-going development activities. We recommend setting a date in the near future for a strategic decision for full-production to be made, in order to avoid unnecessary potential duplication of activities. The timeline of the process and decision should also be clarified as soon as possible. ASAC expects that the committee will be involved to some extent in the evaluation of the scientific merits of the options.

Ad-hoc Charge #1. Assessment of the scientific and technical justification for the proposed Total Power spectrometer. The project team will provide the information needed to make this assessment to the ASAC.

Recommendations/Issues:

- ASAC continues to strongly endorse the Total Power Spectrometer project

ASAC finds that there are compelling scientific and operational justifications for the construction and implementation of the proposed Total Power Spectrometer and was very pleased to hear that it recently passed preliminary design review. The improved linearity compared to ACA should enable much more precise calibration, which is important for e.g. Solar spectral-line single-dish science. The improved time resolution compared to ACA is an advantage both from a scientific and operational point of view. A separate TP spectrometer should also improve the robustness of operations by relieving ACA of TP responsibilities and hence potentially removing a non-trivial fraction of ALMA downtime. ASAC had some questions about the preliminary specifications presented, especially with regard to the estimated calibration accuracy, and what time resolution can actually be achieved in practice. Both of these clearly require some further study. Nevertheless, from everything that ASAC heard, this seems like a very straightforward and cost-effective way of improving ALMA's capabilities.

Ad-hoc Charge #2. Comment on possible Joint Observing Proposals for ALMA, based on recommendations and information provided by the JAO.

Recommendations/Issues:

- ASAC agrees that implementation of a Joint Observing Proposal program is not appropriate for Cycle 6.
- ASAC encourages JAO to continue studies to explore the possibility of implementing Joint Observing Proposals with JWST in ALMA cycles no later than Cycle 8, with a possible trial run in Cycle 7.
- The committee also suggests that ALMA tries to gauge the interest and need within the community for joint observing proposals with JWST or other facilities.

ASAC acknowledges the report summarized by Observatory Scientist on the issues of joint observing proposals for ALMA. The report gives an analysis of various aspects of the joint proposals concept, summarizing the pros and cons concisely, along with the lessons from joint proposals among existing telescopes. The committee finds that there are likely to be strong scientific demands for such Joint proposals, specifically with JWST, whose emphasis on infrared observations dovetails with many of the prime science areas of ALMA. However, ASAC agrees that the highest priority for available resources should be given to stabilization of ALMA operations in order to achieve the proposed Cycle 5 goals, which include some challenging items such as a high completion rate of proposals. The ASAC therefore agrees with the IST recommendation that implementation of Joint Proposals is not appropriate for Cycle 6. Such joint proposals with JWST could be started in late 2019, when the JWST Cycle 2 call will be issued (JWST does not envisage any joint proposal operations in earlier cycles), and given that time scale, the ASAC encourages JAO to continue to explore the possibility of implementing joint proposals with JWST no later than ALMA Cycle 8, with a possible trial run in Cycle 7. Implementing joint proposals with HST or other facilities could also be considered as another possibility, and would be a good preparation for JWST joint proposals. In addition the committee suggests that ALMA try to gauge the level of interest in the community for joint proposals.

Ad-hoc Charge #3. Recommend the frequency and scope of future international scientific conferences organized and hosted by ALMA. ALMA will provide the ASAC with the survey results from the ALMA Palm Springs meeting.

Recommendations/Issues:

- The frequency of the ALMA Science Conference can be reduced to an interval of around 3 years.
- ASAC recommends to have the next Science Conference in the second half of 2019.
- The interval after 2019 will depend on community demand for networking.

The main scope of the ALMA Science Conference is to share epoch-making results with the wider community. While this aim will certainly remain important, ASAC agrees with the IST note that the frequency can be reduced to an interval of more than every 2 years, since ALMA science is now featuring widely in many topical meetings and workshops. On the other hand, the attendee feedback survey at the last ALMA Science Conference clearly shows that the conference provides the participants with a chance of forming networks with colleagues and collaborators, and to that extent was very worthwhile. To maximize this aspect, an interval of about 3 years seems most appropriate.

Based on the above considerations, ASAC recommends to have the next Science Conference in the second half of 2019. The interval after 2019 should be judged according to the demand of the community for networking and other considerations that are appropriate at that time.

Ad-hoc Charge #4. Provide recommendations for the scientific priorities in upgrading the receiver bands. The Development Working Group will provide technical information, but the ASAC should base their priorities on scientific grounds, understanding that other factors, such as technical readiness, will play a role in the final prioritization in the roadmap.

Recommendations/Issues:

- ASAC recommends that the following bands be prioritized: Band 7/6, Band 3 and Band 9. The bands are listed in order of scientific priority, with the exception of Band 6 and Band 7, which were deemed to have equal priority.

When prioritizing the receiver bands, we assumed a Band 2+ band (rather than Bands2+3), and that the upgrade will be to 8-GHz receivers. Below we justify our prioritization of the top four bands, comment on the advantages of further bandwidth increases and also comment on some of the bands that did not make it into the top four.

Band 6 and 7: Band 6 and 7 received joint highest priority. First, with an 8-GHz receiver all CO, ^{13}CO, and $C^{18}O$ lines could be covered in a single setting in either band, which is key to constrain gas masses in everything from protoplanetary disks to galaxies. With the current receiver, all isotopologues can only be covered for narrow lines in Band 6 and never in Band 7. Second, these are the bands of choice for most astrochemical studies because dense gas tracers and lines from complex organic molecules typically are brightest in these bands, considering both intrinsic line strengths and excitation conditions. A doubling of bandwidth together with an increase in spectral pixels would dramatically increase the efficiency of spectral surveys toward star forming regions and protoplanetary disks, reducing the required observing time by a factor of 8-16, assuming 0.25-0.5 km/s resolution can be achieved across the entire bandwidth. Third, these bands are the bands of choice for most local Universe continuum studies, because of a combination of good phase stability (giving access to long baselines), high intrinsic surface brightness and high spatial resolution compared to lower frequency bands. A doubling of bandwidth would increase the observing efficiency, enable constraints on the slope of the mm SED with a single observation (which is not only an efficiency gain, but also removes uncertainties from absolute calibrations), and expand the sample of sources that can be self-calibrated and therefore observed with long baselines. These are the bands currently in highest demand by the ALMA community, and projecting a similar demand into the future, upgrading Band 6 and Band 7 would result in the highest efficiency gain of all the bands.

Justification for a 16-GHz receiver: With a 16-GHz receiver for Band 7 the CO 3-2 isotopologues and dense gas tracers HCN and HCO+ 4-3 could be covered in a single setting.

Band 3: Band 3 received very high priority because of its importance for studies of high-z galaxies, as well as local Universe large and small-scale structures, both in lines and continuum. First, an 8-GHz receiver would enable simultaneous observations of the CO, ^{13}CO, and C^{18}O 1-0 lines, which is often required to characterize gas in local Galactic and extragalactic environments. Second, with an 8-GHz receiver the entire Band 3 can be covered in two settings, which would more than double the efficiency of spectral surveys of high-z galaxies (which are currently very inefficient because of overheads) used to obtain a spectroscopic redshift and characterize the gas. If the receiver upgrade is paired with a suitable correlator upgrade, the spectral survey observing efficiency of cold Galactic sources of astrobiology interests, e.g. pre-stellar cores, would increase with more than an order of magnitude. Band 3 also enables unique continuum science for both non-thermal and thermal emission, since the ratio of $(\boldsymbol{\nu}_{max}-\boldsymbol{\nu}_{min})/\boldsymbol{\nu}_{centre}$ over the central frequency is large with the proposed 8-GHz receiver, which is optimal to constrain the SED slope. Finally, ASAC notes, that Band 3 is also one of the more popular bands among proposers and the one that is the easiest to schedule of the currently operative ALMA bands because of the excellent atmospheric transmission.

Justification for a 16-GHz receiver: With a 16-GHz receiver, it would be possible to simultaneously trace all CO 1-0 isotopologues, HCN, HCO+, H^{13}CN, H^{13}CO+ and H^{2}CO lines, i.e. lines from all the most common molecular probes.

Band 9: The case for upgrading Band 9 to larger bandwidth is mainly to enable self-calibration for fainter sources on longer baselines. Of the bands in regular use, Band 9 gives access to the smallest spatial scales and an upgrade could thus enable new science, e.g. to find very small scale features in protoplanetary disks (1 AU in the nearest star-forming regions), including perhaps accreting protoplanets. Band 9 would also benefit tremendously from being switched to SSB operation, if this can be done without paying a huge penalty in system performance.

Lower priority bands: Of the remaining bands, ASAC advises that the Bands 1, 2, 5 and 11 need to be made available to the community and fully tested before they are considered for an upgrade. Bands 4, 8 and 10 received intermediate priority. Of these Band 4 was ranked highest for receiver upgrade because of the possibility to observe multiple CO lines in this band at redshift 1-4.5 (obtaining non-degenerate spectroscopic redshifts), and because it may turn out to be the optimal band to study optically thin dust in protoplanetary disks. However, compared to Band 3, Band 4 is currently used substantially less and it is therefore unclear how much would be gained from a receiver upgrade. While ASAC did not rank Band 8 highly in terms of an increase in bandwidth, we did note that this is perhaps the band that would most benefit from an upgrade in terms of lowered receiver noise. Such an improvement may facilitate new science, since this band gives access to unique CI and CO transitions. Band 10 does provide access to the highest spatial resolution and an increased bandwidth would enable longer baseline observations, since it makes self-calibration easier. This would potentially open up new science. However Band 10 can only be used during a very small fraction of time and it was therefore down-ranked by ASAC.

Ad-hoc Charge #5. Provide input on the primary, high level science goals for the major development paths identified in the ALMA2030 report; i.e., enhanced throughput, longer baselines, and focal plane arrays. The ASAC may also recommend additional studies that should be carried out to examine the technical requirements needed to refine the science goals.

Recommendations:

- ASAC suggests new primary, high level science goals for the major upgrade paths pertaining to a variety of science areas.
- ASAC recommends more detailed simulations to assess the robustness of the time estimate to obtain a confusion limited mm to sub-mm molecular inventory of a solar type protostar.
- ASAC recommends studies to refine the technical requirements for a high science return from a potential baseline extension. It further notes that the ALMA Workshop on Long Baselines is an excellent opportunity to better define possible studies required.
- ASAC recommends an in-depth investigation of science cases for focal plane arrays that also evaluates the optimal band(s) for such an up-grade.

ASAC discussed potential new primary, high level science goals. While it felt that certain areas were easier to capture than others, it views the following the most compelling ones for the three science areas. A more comprehensive document is provided in addition to the ASAC report.

Enhanced throughput

- Determine the redshift of a typical massive star forming galaxy at z~1-3 in 2 hrs
- Obtain a confusion limited mm-sub-mm (Band 3 to Band 10) molecular inventory of a solar type protostar in 10 hr

Longer baselines

- Map an Earth-like orbit in a low mass star at the distance of Taurus
- High-quality images of the radio photospheres of evolved stars like IRC+10216 up to distances of a few hundred parsecs and to track the dynamical evolution of their photospheres in time.

Focal plane arrays

- High fidelity mapping of the 3D gas structure at 50pc resolution in a typical star forming galaxy disk at 10 Mpc in 1 hr

Enhanced throughput and focal plane arrays

- Detect 50 high redshift Milky Way analogs in 10 hr

Enhanced throughput and longer baselines (potentially also more antennas)

- Study the GMC-scale properties (i.e., a few 10s of pc or less) of cold ISM in gravitationally lensed star-forming galaxies at z~3

Short justifications for time estimates listed in the primary science goals are presented in Appendix C.

Science cases for longer baselines:
ASAC finds significant scientific gain from 2-3 times longer baselines for a broad range of fields. One of the most promising science fields are spatially resolved proto-planetary disks, by allowing us to study Earth-like orbits of disks at a distance of up to ~150 pc (i.e., 3 times more distant than TW-Hya). The higher angular resolution from such baseline extension will significantly increase the number of potential targets (>100), with a sufficiently good surface brightness sensitivity for dust continuum emission in the inner portion of the disk. Regarding the sensitivity, even with the current bandwidth, 5 sigma surface brightness sensitivity for Band 6 continuum is 2.3 K (for a factor of 2 longer baselines, i.e., 12 mas beam) and 5.2 K (for a factor of 3 longer baselines, i.e., 8 mas beam), respectively, after 6 hours on-source integration (http://www.iram.fr/~neri/alma-x2-x3-v2.xlsx). These surface brightness sensitivities are already sufficient to image the thermal emission at least at the innermost (ergo hotter) regions of the protoplanetary disks.

Other potentially high impact research topics are spatially resolved observations of the radio photosphere of evolved stars like IRC+10216 up to distances of a few 100 pc, and gravitationally lensed high-z dusty galaxies like SDP.81. Further promising candidates for longer baselines, include nearby AGNs, young/massive stars, the gas and dust clumps in the Galactic center, and will require more detailed investigations in the upcoming ALMA long baseline science workshop, which will be held in Kyoto in October 2017, along with the study of possible ways to improve the image fidelity and sensitivity.

Appendix A: ASAC Input on Receiver Prioritization

Summary of Prioritization

ASAC recommends that the following bands be prioritized: **Bands 7, 6, 3 and 9**. The bands are listed in order of scientific priority, with the exception of Band 6 and Band 7, which were deemed to have equal priority. When prioritizing the receiver bands, we assumed a Band 2+ band (rather than Band 2+3), and that the upgrade will be to 8-GHz receivers, though we also comment on the utility of additional bandwidth upgrades below. In addition it is clearly desirable to switch to SSB for Band 9.

Scientific Justifications for High-Priority Bands

Band 6 and 7

Band 6 and 7 received joint highest priority. First with a 8 GHz receiver all CO, 13CO, and C18O lines could be covered in a single setting in either band, which is key to constrain gas masses in everything from protoplanetary disks to galaxies. With the current receiver, all isotopologues can only be covered for narrow lines in band 6 and never in band 7. Second these are the bands of choice for most astrochemical studies because dense gas tracers and lines from complex organic molecules typically are the brightest when considering both intrinsic line strengths and excitation conditions. A doubling of bandwidth together with an increase in spectral pixels would dramatically increase the efficiency of spectral surveys toward star forming regions and protoplanetary disks, reducing the required observing time by a factor of 8-16, assuming 0.25-0.5 km/s resolution can be achieved across the entire bandwidth. Third, these bands are the bands of choice for most local Universe continuum studies, because of a combination of good phase stability (giving access to long baselines), high intrinsic surface brightness and high spatial resolution compared to lower frequency bands. A doubling of bandwidth would increase the observing efficiency, enable constraints on the slope of the mm SED with a single observation, which is not only an efficiency gain, but also removes uncertainties from absolute calibrations, and expand the sample of sources that can be self-calibrated and therefore observed with long baselines. The bands are currently in highest demand by the ALMA community, and projecting a similar demand into the future, upgrading Band 6 and Band 7 would result in the highest efficiency gain of all the bands.

Justification for a 16-GHz receiver: With a 16-GHz receiver for Band 7 the CO 3-2 isotopologues and dense gas tracers HCN and HCO+ 4-3 could be covered in a single setting.

Band 3

Band 3 received very high priority because of its importance for studies of high-z galaxies, as well as local Universe large and small scale structures, both in lines and continuum. First an 8-GHz receiver would enable simultaneous observations of the CO, 13CO, and C18O 1-0 lines, which is often required to characterize gas in local Galactic and extragalactic environments. Second, with an 8-GHz receiver the entire band 3 can be covered in two settings, which would more than double the efficiency of spectral surveys of high-z galaxies (which are currently very inefficient because of overheads), to obtain a spectroscopic redshift and characterize the gas. If the receiver upgrade is paired with a suitable correlator upgrade, the spectral survey observing efficiency of cold galactic sources of astrobiology interests, e.g. pre-stellar cores, would increase with more than an order of magnitude. Band 3 also enables unique continuum science for both non-thermal and thermal emission, since the ratio of (max freq. - min freq.) over the central frequency is large with the proposed 8-GHz receiver, which is optimal to constrain the SED slope. Finally ASAC notes, that Band 3 is also one of the more popular bands among proposers and the one that is the easiest to schedule of the currently operative ALMA bands because of the excellent atmospheric transmission.

Justification for a 16-GHz receiver: With a 16-GHz receiver it would be possible to simultaneously trace all CO 1-0 isotopologues, HCN, HCO+, H13CN, H13CO+ and H2CO lines, i.e. lines from all the most common molecular probes.

Band 9

The case for upgrading Band 9 is mainly to enable self calibration for fainter sources at longer baselines. Of the bands in regular use, Band 9 gives access to the smallest spatial scales and an upgrade could thus enable new science, e.g. to find very small scale features in protoplanetary disks (1 AU in the nearest star forming regions), including perhaps accreting protoplanets. Band 9 would also benefit tremendously from being upgraded in terms of switching to SSB, if this can be done without paying a huge penalty in bandwidth.

Comments on Lower Priority Bands

Of the remaining bands, ASAC advises that the Bands 1, 2, 5 and 11 need to be made available to the community and fully tested before they are considered for an upgrade. Bands 4, 8 and 10 received intermediate priority. Of these Band 4 was ranked highest for receiver upgrade because of the possibility to observe multiple CO lines in this band at redshift 1-4.5 (obtaining non-degenerate spectroscopic redshifts), and because it may turn out to be the optimal band to study optically thin dust in protoplanetary disks. However, compared to Band 3, band 4 is currently used substantially less and it is therefore unclear how much would be gained from a receiver upgrade. While ASAC did not rank Band 8 high in terms of an increase in bandwidth, we did note that this is perhaps the band that would most benefit from an upgrade in terms of lowered receiver noise. Such an improvement may facilitate new science, since this band gives access to unique CI and CO transitions. Band 10 does provide access to the highest spatial resolution and an increased bandwidth would enable longer baseline observations, since it makes self-calibration easier. This would potentially open up new science. However Band 10 can only be used during a very small fraction of time and it was therefore down-ranked by ASAC.

Band 4

A receiver bandwidth upgrade for Band 4 offers the possibility to observe multiple CO lines in this band at redshift 1-4.5 (obtaining non-degenerate spectroscopic redshifts). Band 4 may turn out to be the optimal band to study optically thin dust in protoplanetary disks. Dust continuum emission from a young protoplanetary disk tends to be opaque at higher frequencies. Compared to Band 3, Band 4 is more sensitive to the surface density by a factor of ~9 (assuming $F_\nu \propto \nu^3$) at the same integration time and resolution. Finally Band 4 line observations have astrochemical applications, especially if Band 4 and Band 5 can be observed simultaneously

Band 8

There are several science cases that would strongly benefit from a Band 8 upgrade in terms of receiver sensitivity. A more sensitive Band 8 would give access to young galaxies via the ionized oxygen, [OIII] 88 um line, at a redshift of ~7.7-7.1, i.e., the epoch of the reionization (EoR). Other atmospheric windows available in Band 8 (i.e., ~428-438 GHz, 455-470 GHz, 475-485 GHz, and 490-500 GHz) could be used to trace galaxies at z = 6.9-5.8 (covering the end of EoR) via [OIII] 88 um. The Band 8 CI line has also not been fully utilized, e.g. to constrain the total extent and mass of clouds, including the CO-dark portions, due to the relatively high receiver noise. A wider bandwidth would also improve the line detection capability for galaxies with relatively large redshift uncertainty (note that 8-GHz bandwidth corresponds to delta_z ~ 0.13).

Band 10

Band 10 was not viewed as very urgent to upgrade in terms of bandwidth, since it is rarely used (because it is so weather limited), and when used, it is not generally for extragalactic or astrochemistry studies, where an increased bandwidth provides the greatest gain in observing efficiency. An upgrade should be considered on longer terms, since an increased bandwidth would enable long-baseline observations for fainter sources that cannot currently be self-calibrated. Additionally Band 10 would benefit tremendously from being upgraded in terms of switching to SSB, if this can be done without paying a large penalty.

Appendix B: ASAC input on science cases for longer baselines

Summary

ASAC finds significant scientific gain from 2 - 3 times longer baselines for a broad range of fields . One of the most promising science fields is spatially resolved proto-planetary disks, by allowing us to study Earth-like orbits of disks at a distance of up to ~150 pc (i.e., 3 times more distant than TW-Hya). The higher angular resolution from such a baseline extension will significantly increase the number of potential targets (>100), with sufficiently good surface brightness sensitivity for dust continuum emission in the inner portion of the disk. Other potentially high impact research topics are spatially resolved observations of the radio photosphere of evolved stars like IRC+10216 up to distances of a few 100 pc, and gravitationally lensed high-z dusty galaxies like SDP.81. Further promising candidates of science cases for longer baselines, include nearby AGNs, young/massive stars, the gas and dust clumps in Galactic centers, and will require more detailed investigations in the upcoming ALMA long baseline science workshop, which will be held in Kyoto in October 2017, along with the study of possible ways to improve the image fidelity and sensitivity.

Galactic cases

Proto-planetary disks

1. ALMA is already providing transformational views of protoplanetary disks in local star-forming regions. Spatially resolved images of TW Hydrae (one of the closest objects at a distance of ~50 pc) have suggested that a planet with an Earth-like orbit is forming there. Therefore the scientific attractiveness of longer baselines by a factor of 3 is rather obvious here; this would enable the use of ALMA to study Earth-like orbits in other low-mass star-forming regions, including Taurus (at a distance of ~150 pc), which results in a significant increase in the targets (> 100). Another importance of the longer baselines is the ability to obtain disk images at longer wavelengths (i.e., at 3 mm or longer when Band 1/2 becomes available) with a similar resolution to current Band 6/7 observations. This is important as more optically thin emission is expected at wavebands longer than ~3 mm (especially for ~7 mm or Band 1), and also the formation of "pebbles" can be investigated at these lower frequency bands.

Regarding the sensitivity, even with the current bandwidth, 5 sigma surface brightness sensitivity for Band 6 continuum is 2.3 K (for a factor of 2 longer baselines, i.e., 12 mas beam) and 5.2 K (for a factor of 3 longer baselines, i.e., 8 mas beam), respectively, after 6 hours on-source integration[*]. These surface brightness sensitivities are already sufficient to image the thermal emission at least at the inner most (ergo hotter) regions of the protoplanetary disks.

Protoplanetary disks can be one of the most demanding science targets for complete uv-coverage, given the fact that they have complicated structures, and quantitative comparison of different frequency bands is essential to derive β indices in the gaps of the disks. Combining observations from multiple configurations is a possible solution. More extensive studies will be required to verify the feasibility from the viewpoint of image fidelity (and sensitivity) of protoplanetary disks with the longer baselines proposed.

Evolved stars

1. With a resolution better than 10 mas, ALMA will resolve the surfaces of evolved stars, including their shapes, the structure of convective cells, and brightness variations. Continuum maps of stellar surfaces are particularly interesting in the case of interacting binaries, as they are expected to show significant deformations and rotation, and whose orbits around their common center of mass will provide accurate mass measurements. Given ALMA's excellent continuum sensitivity it will be possible to produce high-quality time-lapse images of hundreds of evolved stars, among which OH/IR, Mira variables, semi-regular and irregular variables, O-rich, C-rich and S-type, symbiotic and supergiant stars (see also ALMA Memo 475). A spatial resolution of 10 mas is comparable to what is achievable nowadays with NIR interferometers like the VLTI and LBTI, and has the potential of developing a widespread interest for ALMA in the optical stellar community.

2. ALMA should also be able to map in molecular line emission and with a resolution better than 10 mas the shocks driving the shaping of planetary nebulae. This extremely energetic phenomenon takes place within typically less than 20 mas of the central star, and involves impressive accelerations and changes of the physical conditions. By extending the baselines by a factor of 3, ALMA will unlock the means to observe several transitions of the same molecule with a resolution comparable to what will be possible in Band 10 in the 16-km baseline configuration. With expected brightness temperatures of up to 5,000 K, ALMA should have the ability to observe the acceleration of bright molecules like CO, SiO and HCO^+, and the propagation of shock-induced chemical reactions with a resolution of a few 10^{13} cm, in at least five protoplanetary nebulae.

3. By observing lines in absorption against the stellar photosphere, with resolutions better than 10 mas at several frequencies, ALMA should enable the study of the structure and dynamics of the pulsating molecular atmosphere of evolved stars, whose typical size is 10–20 mas at distances of a few hundred pc, and the study of the mass loss process, including the nucleation and growth of cosmic dust. ALMA should be able to observe the absorption features and the dynamical and physical evolution of

molecules like CO, SiO (O-rich) and HCN (C-rich) in the innermost regions of the expanding envelopes of a few tens of stars.

4. ALMA maps of the SiO, HCN, H_2O maser emission regions would help to study the structure, dynamics, temperature and density profiles of the inner circumstellar layers at scales of a fraction of one AU. With SiO and HCN masers stretching over regions much larger than the stellar photosphere, ALMA has the potential to observe a very large number of objects and to complement VLBI observations known to be less sensitive to extended and dim maser emission. Vibrationally excited H_2O maser lines are less well studied but surveys suggests these masers are ubiquitous and can be extremely bright. Ballpark estimates suggests that SiO masers could be mapped in hundreds of AGB stars, and HCN and H_2O masers in at least a dozen of stars.

Protostars

1. ALMA with a spatial resolution of 6 mas at 230 GHz will provide the means to address the key questions of when and how dust coagulation and assembly are achieved in protostars and protoplanetary disks, and thereby, the question of how the transition from sub-micron grains to rocky planets is starting and why. Only observations of the dust continuum SED of protostars and protoplanetary disks in the mm-range and at scales better than 1 AU will provide the means to address this issue.

2. ALMA should be able to observe the accretion shocks around the centrifugal barrier, namely the matter as it streams through the barrier into the inner circumstellar disk. Observing the dynamics at 1AU scale would further allow us to actually see whether a molecular outflow is launched from the inner disk or not. The 230–86 GHz band is particularly suitable, as in this wavelength range the dust is likely optically thin. Thermal emission from abundant species should be detectable at the location of the shocks, where temperatures exceed 300 K.

3. By achieving a 0.3 mas (at xx mm) or smaller beam, ALMA reveals disk formation around high-mass protostellar sources at a distance of 3 kpc. Recent ALMA observations show possible disk formation with a size scale of 100 AU even in high-mass star forming regions. Observing the molecular lines and dust at a 100 AU scale will allow for the study of their structure and kinematics. In addition to maser emission (e.g., H_2O), thermal emission of various species could be used. The accretion shocks around the centrifugal barrier may be studied, if they exist.

4. The launching mechanism of an ionized jet very close to young stars is not well understood. This is an example of an accretion disk/jet system and an ubiquitous phenomenon in astrophysics. One of the potential breakthroughs would be to reveal the configuration or a launching point of an jet/star/disk system at high angular resolution of < 0".01 at Band 1 where the dust emission contribution can be ignored. Since such a high resolution continuum image can define the jet axis precisely so that recombination line data obtained simultaneously can reveal a rotating motion across the ionized jet. In other words, angular momentum removal processes in the jet/accretion disk can be investigated to

separate different mechanisms proposed by theoretical studies. In addition, such an observation will be able to reveal embedded close binary systems at the earliest phase that cannot be identified in other methods.

The Galactic Center

1. Longer baselines will provide the ability to measure proper motions of compact HII clumps orbiting around the Galactic nucleus, Sgr A*. A 50 km/s transverse velocity corresponds to a proper motion of 1.3 mas/yr at the distance of 8.3 kpc, which is detectable with bands 6/7 observations (beamsize~20 mas) spanning a couple of years. Combining proper motion and radial motion, which is measurable from recombination line spectra, we can determine the 3-dimensional velocity distribution in the central minispiral. A similar study has already been done using the VLA data (beamsize >100 mas) spanning over 12 years (Zhao et al. 2009, ApJ, 699, 186). Proper motion studies of dust clumps will be also feasible. Knowledge of the 3-dimensional velocity distribution in the CMZ is essential to determine their configuration with respect to the nucleus and its importance for fueling the central supermassive black hole.

Extragalactic cases

Supermassive black holes and AGNs

1. Water vapor masers in the $6_{1,6}$–$5_{2,3}$ transition, at a rest frequency of 22.235 GHz, are known to provide evidence for emission from edge-on rotating disks on sub-parsec scales, as demonstrated in NGC 4258. On the other hand, H_2O masers in submm bands, such as the $10_{2,9}$–$9_{3,6}$ transition at 321 GHz, require much more extreme excitation conditions (Eu/k = 1,862 K for the 321 GHz H_2O maser line), implying that submm H_2O masers will potentially allow us to probe the innermost regions of the hot molecular (accretion) disks traced by water vapor emission. A bright H_2O submm maser at 321 GHz has been detected using ALMA towards the nucleus of the Circinus galaxy (at a distance of 4.2 Mpc). The emission is unresolved at 0.6” resolution, however VLBI measurements suggest that the 22 GHz water vapor maser line is resolved at 1 pc (or 60 mas) scale. Thus ALMA should be capable of resolving the 321 GHz H_2O maser structure with a factor 3 longer baselines (10 mas correspond to 0.2 pc at the distance of Circinus). The number of AGN with submm maser detections may be quite limited, however, this could potentially be very attractive as it gives a very precise SMBH mass. Note that this may also attract the VLBI maser science community. Here individual maser spots will remain unresolved, although the spatial distribution of these maser spots may be resolved across a rotating disk, as in the case of the maser disk in NGC 4258. In this case, sensitivity will not be a very critical issue. Nevertheless, the number of observable galaxies with such maser emission will be rather limited (i.e., a few 10s, not >100).

2. ALMA is expected to resolve the structure of the putative obscuring material ("torus" or "clumpy torus") in dust continuum and molecular emission. State-of-the-art near/mid-infrared interferometers like VLTI determine the size and structure of the hottest dust of an obscuring torus, whereas ALMA will reveal the much colder (i.e., more extended) part of the torus. Presumably, probing the outer part of the torus will be a key to understanding the mass transfer processes from a large-scale disk (>a few 10 pc) to the accretion-disk-scale structures (< pc), and variation of angular momentum as a function of the radii must be investigated. Recent ALMA Band 9 observations of NGC 1068, one of the nearest type-2 AGN-hosting galaxies, have successfully measured the size of a submm (430μm) counterpart of the putative obscuring torus in NGC 1068, with a spatial resolution of 60 mas or 4 pc. The derived torus radius is 3.5 +/- 0.5 pc, i.e., almost comparable to the spatial resolution. Given the fact that the ~15 km baseline observations at band 9/10 are not fully implemented yet, we need to wait for higher resolution band 9/10 observations of such tori before fully assessing the scientific values and their feasibilities with the proposed 2 – 3 times longer baselines. Although the number of observable AGN may be rather limited in the local Universe, such baseline extensions will be useful to increase the number of torus size measurements in the submm band.

3. Absorption line imaging using ALMA with an improved angular resolution of up to 10 mas or less will become a powerful tool to reveal the molecular structures and their physical/chemical conditions at ~pc scale in local AGN, which are almost inaccessible in emission. Much smaller beam dilution (than current ALMA beams) allows us to make more sensitive absorption measurements of molecules behind very compact continuum sources like the nuclei and jets. A kind of "absorption line forest" has been reported in the radio-loud AGN NGC 1052, and molecular absorption has been detected even at the VLBI scale, demonstrating that the absorption line studies at a 10 mas scale resolution are feasible and indeed productive. Again, the number of targets may be limited, because of the necessity of bright continuum sources.

4. Measuring the surface brightness of the infrared luminosity can give an indication of its heating source, particularly when it exceeds the theoretically expected threshold (i.e., the Eddington limit for dust against the radiation pressure from massive stars). This provides a unique diagnostic for heavily obscured nuclei, i.e., Compton-thick environment. An example of such measurements has been reported in one of the closest ULIRGs, namely Arp 220, at a distance of 77 Mpc. ALMA, with baselines extended by a factor of 3, will allow us to increase the number of observable ULIRGs significantly, given the rareness of such ultra-bright, extremely dusty objects in the local Universe. However, the current estimate for observable galaxies is on the order of a few 10s, and not more than hundred..

Galaxies in the early Universe

5. The combination of ALMA and "nature's telescopes", i.e., gravitational lenses, provides a powerful way to study the GMC-scale structure and physical properties of the ISM at a cosmological distance, as demonstrated by the ALMA observations of SDP81 at z = 3.1. It is intriguing to test if the GMC

scaling relations known from local galaxies are applicable to high-z star-forming galaxies, in order to understand star-formation laws that govern star formation in galaxies for various scales and environments. Currently, SDP81 observations allow us to study the properties of molecular clouds on the ~100 pc scale. For more direct comparison of cloud properties in high-z galaxies with those in local galaxies (i.e., typically with sizes of a few 10s of pc), ALMA baseline extensions by a factor of 2–3 will be necessary. Such higher resolution gas and dust images will also give opportunities to search for sub-halos, which are expected to be present in the current galaxy formation models, based on standard ΛCDM. For these observations it will be necessary to significantly improve the sensitivity; the dust continuum will still be bright enough for ~10 mas resolution in some cases, but CO lines become quite faint at this resolution, given the fact that the currently observed CO lines in the SDP81 SV data have at most a S/N~10 in the channel maps. Adding larger diameter dishes as longer baseline elements could be a possible solution. Brighter lines than CO, such as [CII], might be another promising route for such extended baselines. The number of lensed dusty sources is rapidly increasing from follow-up of Herschel, Planck, SPT, ACT, and other mm/submm deep surveys, ensuring that we should have >100 sources eventually.

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[*] See http://www.iram.fr/~neri/alma-x2-x3-v2.xlsx for sensitivity estimation.

Appendix C: Background for time estimates in new primary, high level science goals

Enhanced throughput

- Determine the redshift of a typical massive star forming galaxy at z~1-3 in 2 hrs
- Obtain a confusion limited mm-sub-mm (Band 3 to Band 10) molecular inventory of a solar type protostar in 10 hr

Longer baselines

- Map an Earth-like orbit in a low mass star at the distance of Taurus
- High-quality images of the radio photospheres of evolved stars like IRC+10216 up to distances of a few hundred parsecs and to track the dynamical evolution of their photospheres in time.

Focal plane arrays

- High fidelity mapping of the 3D gas structure at 50pc resolution in a typical star forming galaxy disk at 10 Mpc in 1 hr

Enhanced throughput and focal plane arrays

- Detect 50 high redshift Milky Way analogs in 10 hr

Enhanced throughput and longer baselines (potentially also more antennas)

- Study the GMC-scale properties (i.e., a few 10s of pc or less) of cold ISM in gravitationally lensed star-forming galaxies at z~3

Short justifications for time estimates listed in the primary science goals.

Redshift of high-z galaxy in 2 hours

Following the ASAC recommendations for ad-hoc charge #4, having 8-GHz bandwidth in Band 3 would imply that the full band can be covered by two tunings. The typical line strength of CO(3-2) from massive star forming galaxies at z=1-2 (Daddi et al. 2010, Tacconi et al. 2013) is 1-2 mJy for the peak intensity with a line FWHM of 300-400 km/s. The current 12-m array can detect a 1-mJy strong line at 4σ over 100 km/s wide channels at 90 GHz in about 1 hr (of total observing time). If we cover the full band in two tunings, this implies that detecting such a line would take 2×1hr = 2hr. The confirmation of the redshift would come from either detecting a second line in the same spectrum (very likely at higher significance) or through combination with photometric redshifts.

Confusion limited molecular inventory of a solar type protostar

The time estimates are based on ALMA Cycle 2 and 3 observations towards IRAS 16293, which yielded confusion-limited spectra in Bands 7 and 6, respectively. Assuming a factor 2 increase in sensitivity (compared to Cycle 2, arising from having better receiver sensitivity and more antennas) compared to Cycle 2, Band 7 can be covered with six settings (assuming an 8+8-GHz bandwidth) in 40min with integration times of 7min per frequency setting. Using the same number for Band 8 to Band 10 gives integrations times of 50min (Band 8 and 9) and 45min (Band 10). Similar considerations for the Cycle 2 Band 6 and 3 observations with a factor 2 improvement in sensitivity and an 8+8-GHz bandwidth gives 40min for Band 6 and via extrapolation 45min for Band 5, 80min for Band 3 and 120min for Band 4. This a total on-source time of 8 hours, allowing for uncertainties in the estimates this number is set to 10 hrs. Dedicated detailed simulations are required to obtain more accurate time estimates.

High fidelity mapping of 3D gas structure of an external galaxy disk

The Cycle 3 observations of the 10Mpc distant nearby spiral galaxy NGC3627 are taken as a reference point: An equivalent of 35s (Cycle 5) on-source integration per pointing is required to map the star forming disk in its $^{12}CO(2\text{-}1)$ transition down to a GMC mass of ~$10^5 M_{sun}$ at 50pc resolution. Covering 246 pointings with the 12m array required 2hrs. Assuming wide-band receivers with 8 GHz bandwidth will allow to simultaneously target the (2-1) transitions of ^{12}CO, ^{13}CO and $C^{18}O$. Considering a focal plane array in Band 6 with 4x4 receivers will reduce the number of pointings down to 15. Taking a typical line flux ratio of $^{12}CO/C^{18}O$ of ~66 translates into an on-source integration time of about 300s per pointing. Scaling from the Cycle 3 observations results in roughly 1.2 hr. Taking into account potential further improvements in observing strategy, the requirement is set to 1hr to map the (2-1) transitions in ^{12}CO, ^{13}CO and $C^{18}O$ at 50pc resolution across the star forming disk of a massive star forming galaxy at 10Mpc distance.

Detection of many high redshift Milky Way analogs

Assuming a single 16 GHz bandwidth tuning centered at 265 GHz (i.e. the upper end of Band 6) that can target CO(3-2),(4-3),(5-4) and CO(6-5) simultaneously. For a Milky Way analog with a stellar mass of $5\text{x}10^6$ M_{sun} lying on the main sequence of star forming galaxies and following roughly the Kennicutt-Schmidt relation between star formation rate and gas mass, one gets a number density of about 1.5objects per sq.arcmin for sources at z~1.6 with a CO(6-5) line flux of 0.3 Jy km/s or higher. A 5sigma dectection requires 13min on-source integration time per pointing, a 4x4 focal plane array covers instantaneously 2 sq.arcmin, thus we should detect about 3 sources with a single footprint of the focal plane array. Thus for a total on-source integration time of 5hr, a total of 3 times 23 separate focal plane array could be observed leading to a total of about 70 detection of Milky Way analogs. Assuming an overhead of ~100%, a total of 10hr is required. Note that more accurate estimates will require more detailed simulations. Similarly, utilizing the enhanced continuum sensitivity will likely lead to a higher source density across a wider redshift range, again this will require more dedicated effort.

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