2.9 Science IPT

During July-September, Science IPT activity concentrated on ALMA calibration, configuration, imaging and operations considerations. A complete revision of the ALMA Scientific Requirements, previously available as Chapter II of the Project Book, was submitted. A calibration plan for ALMA was also submitted. The ICD for the design of the long baseline pads in the configuration was submitted at the close of the previous quarter; the plan for moving among the innermost arrays was submitted in September. Investigation of system amplitude stability quantified the effects of different levels of electronic stability, sky stability and thermal noise on imaging performance. To aid in development of scientific aspects of ALMA Operations, the Science IPT undertook development of the ALMA "Design Reference Science Plan" (DSRP) which has as its goal to translate the ALMA science case into a more detailed plan of 3 years of observing with the full ALMA array. The DRSP will serve as a quantitative reference for developing the science operations plan, for performing imaging simulations, for software design, and for other applications within the ALMA project.

The Science IPT arranged the agenda, minutes and telecon for the monthly ASAC telecons and facilitated the ASAC face-to-face meeting in Hamilton, Ontario Sept 5-6 to develop its report to the ALMA Board addressing the charges it received. In Europe and North America, the related ESAC and ANASAC groups also hold telecons facilitated by the Science IPT. The Science IPT participated in miniALMA Week, the ANASAC and ESAC face-to-face. Joint NA/EU Science IPT staff and Calibration Group telecons were held monthly, and the weekly NA Science IPT telecons were continued.

ASAC

Figure 1 The ASAC on the sunny campus of McMaster University, Hamilton, Ontario

The Science IPT facilitated the ASAC Telecons held on 2 July, 6 August and 24 September. It supported the ASAC in the ASAC responses to the Charges posed to it by the ALMA Board, including discussions at the face-to-face meeting 5-6 September in Hamilton, and in preparing the written response to be presented to the Board at its 2

November 2003 meeting in Santiago. Studies supporting the ASAC investigations are covered below.

Science Requirements

Butler drafted and circulated a new version of the ALMA Scientific Requirements into which Wootten incorporated comments from van Dishoeck and others; it was finished and submitted as ALMA-90.00.00.00-002-A. This document is meant to describe and specify the scientific requirements for ALMA. It draws from a long list of historical documents describing the desired scientific emphasis of ALMA (and the MMA and LSA), but most directly from the Project Plan v1.0 and the Project Book Chapter II. It is the defining document for the high level science requirements for ALMA. The implications of these requirements on the instrumental hardware, software, and operations (including calibration) plan are to be laid out in separate documents. The Science Requirements document covers key science experiments to be performed with ALMA, including precision imaging of normal galaxies at high redshift, the gas kinematics in protostars and protoplanetary disks around young Sun-like stars. It then shows how accomplishing these key science elements results in requirements on various parts of the complex ALMA design.

Design Reference Science Plan

The Design Reference Science Plan attracted over 113 proposals from 75 scientists. The results were collected into web-accessible format, and also placed into a worksheet format for easy statistical study. Pseudo-proposals were collected for 4 themes and 21 sub-themes from the ESO proposal and from topics addressed at the 1999 ALMA Conference in Washington. The Plan can be used to:

- allow cross-checking of the ALMA specifications against "real" experiments
- allow a first look at the time distribution for
    - configurations
    - frequencies
    - experimental difficulty (fraction of projects that are pushing ALMA specs)
- start developing observing strategies
- derive "use-cases" for the Computing IPT

In addition, the pseudo-proposal process, which used a JAVA-based exposure time calculator at ESO, provided a learning experience for the community on how to use ALMA and what it can and cannot do in practice. Some new projects were submitted, which help to update and amplify the ALMA science case. Additionally, by reminding them of why ALMA is being built, it provided some fun for Science IPT members.

At present, the proposals are undergoing review by ASAC members. The DRSP is due for release to the project for a 15 October Milestone.

Some conclusions may already be drawn from the tabulation to date:

- Overall distribution over receiver bands reasonably consistent with weather statistics

- Fraction of continuum-only programs varies per receiver band and theme: Band 6 pre-dominantly line; Band 7 and 9 large fraction continuum
- Fraction of proposals which require total power continuum >10%
- Fraction of proposals which require baselines of at least 1 km: 50-60% (with peak around 0.1-0.2”)

Configuration

The main activity in this quarter was in making a final design for the reconfiguration logic for those configurations using the inner 172 pads. This reconfiguration logic defines how antennas are moved between pads; or alternatively how the pads are occupied in any given configuration.

Two reconfiguration sequences have been produced; one to be used when the array starts in its most compact array and is expanding outward, the other when the array is being reconfigured inward. The former reconfiguration sequence is optimized for observations of sources which have high elevation (i.e. for declination -55 to +15). In contrast for the inward reconfiguration sequence the pad occupation scheme of the smaller sized arrays is optimized to reduce the impact of shadowing for observations of far North or South sources. In these modified configurations the occupation pattern of pads is stretched North-South to both reduce shadowing and give a closer to circular beam for observations of sources at these high and low declinations. For the larger sized arrays, where shadowing is not a problem, simulations have shown that re-weighting the data can give close to a circular beam for losses of order only 10% in sensitivity - hence for these larger arrays the inward occupation scheme is chosen to be similar to the outward scheme. The reconfiguration schemes also make provision for the cases of a variable number of antennas (between 60 and 64) in the array. An example set of moves is shown in Figure 2.

A detailed description of the design philosophy adopted and the reconfiguration schemes themselves is given in submitted document ALMA-90.02.00.00-003-A-SPE.

Holdaway finished Specifications and Requirements for the Long Baseline (Y+) Array Configuration; see ALMA-90.02.00.00-002-A- SPE Version A. Holdaway also prepared a document which shows the Fourier plane coverage and beam properties for the entire set of Y+ array configurations.

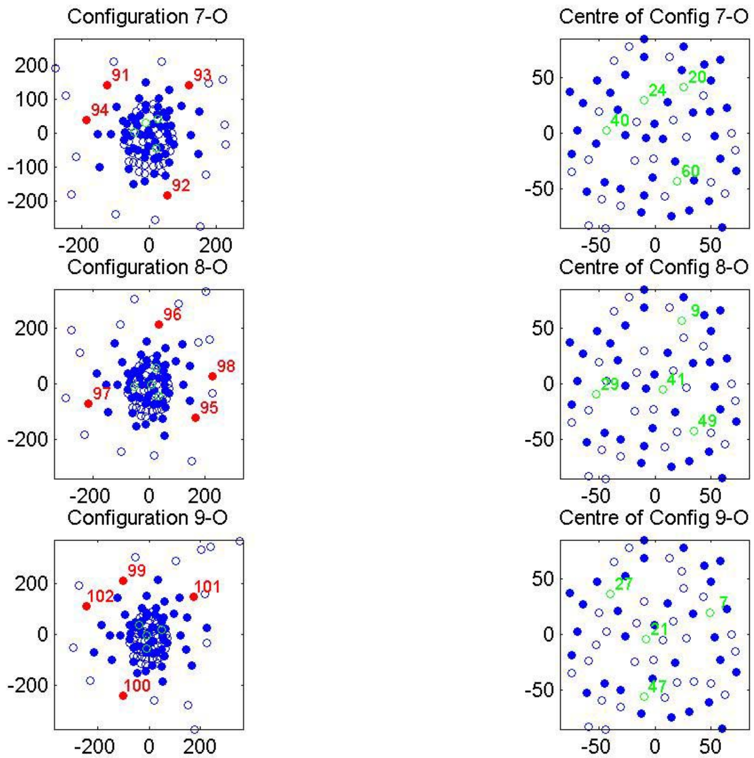

Figure 2 A portion of the outward reconfiguration sequence, showing newly deposited antennas (red) and recently vacated antenna pads (green).

Calibration

The Calibration of ALMA document by Butler, Guilloteau, Holdaway, Wootten and others, outlines the various quantities that will need to be measured or taken into account in order to collect and calibrate ALMA data. The document was submitted to the Project. It is an update of Chapter 3 of the old Project Book, and supersedes it. Traditionally, "calibration" has often been thought of as strictly a post-processing exercise in radio interferometry, essentially only involving things done to data after it has been collected. In this document we take a broader view, and include all things that must be measured *before* correlation of the antenna signals as well. These are still formally "calibrations", since they are measurements of instrumental parameters – they are generally just measured less frequently. They are, however, no less important than the post-processing calibrations. In addition, we address some topics that are not even direct measurements, but are rather things that affect the measurement of our desired quantities. An example is the relativistic deflection of radio waves in the gravitational potential of the sun, which is not really a directly measured or calibrated quantity (except indirectly), but does certainly affect our ability to properly calculate delay, which in turn affects our ability to calibrate, for example, antenna station locations.

Accounting for all of these types of calibrations, measurements and effects is critical for ALMA to achieve its full potential. We must understand what effects must be accounted for, and how we will measure and/or correct for them during the data collection and post-processing. Never before has a radio astronomical instrument been built with such a detailed understanding of the site and its impact on the telescope. With this knowledge in hand, we can optimize the full measurement and calibration strategy to produce the maximum scientific output for ALMA.

In addition to simply describing the different types of calibrations, measurements and effects anticipated for ALMA, we also provide some specifications on the accuracy to which the measured quantities must be determined or effects must be accounted for.

During the next month, the ALMA Calibration Plan, a more complete treatment which will include description of the techniques, with references if available how often the calibration observation(s) need(s) to be performed; and whether this is a function of frequency; how long it takes to do the calibration observation(s) and whether this is a function of frequency; what quantities need to be archived (and at what rate), and what further tests and/or studies are needed.

As contribution to the discussions on the Science Requirements and System Design documents, Hills made estimates of the sensitivity to path length fluctuations that can be expected from the water vapor radiometers. Also in MRAO Cambridge, recruitment of a new Science IPT member to work principally on issues relating to phase calibration with Richer and Hills, has been successfully completed. Alison Stirling will start work in early October. Work between the MRAO group and the Spanish group on ATM software related to 183 GHz water vapor monitors will begin in November.

Mangum worked at the ALMA test facility much of the month characterizing the pointing of the VertexRSI prototype antenna. With Mangum and Butler, Wootten supplied details of weather monitoring equipment to be installed on production antennas to be included in the Request for Proposals for those antennas.

Site Characterization

The Site Characterization group kept the flow of data from the site coming through the austral winter. A solar power system problem was identified and corrected on the ESO instrumentation, and a problem wind direction sensors was repaired with new sensors and a data logger. The main analytical work has been focused on the determination of the wind power spectrum, on which a memo is presently being produced. Most of the 183 GHz radiometer data has been reanalyzed with an improved algorithm. The control software for the two 183 GHz radiometers has been modified in order to allow them to point in different directions. This will allow us to determine the critical height of the turbulent layer without having to depend on wind speed data..

ALMA Memo No. 470 was published, reporting a radio frequency interference survey covering 10 MHz – 18 GHz which was conducted at Chajnantor, Chile on 2002 December 6 – 9. The survey provides a “snapshot” view of existing RF activity in the area. The detected signals fell into these categories: noise from nearby electronic equipment, broadcast TV and FM radio, and terrestrial and satellite radio services.

ALMA Memo No 471 was also published. The memo, "Site Properties and Stringency" contains the ASAC working group's response to a charge from the ACC to 'evaluate all available site (225 GHz opacity, 12 GHz phase stability, 350 micron and >1 THz) data for Chajnantor, and to discuss any significant trends and issues which may impact the scientific mission, design or mission emphasis of the baseline instrument.'

Imaging

A telecon on the subject of gain stability was held in July with members of the Science and Front End IPTs in attendance. At this telecon, results on measurements with pre-prototype ALMA receivers were exchanged with the Science IPT for use in simulations.

Hills circulated a note on the issue of total power stability, making a number of suggestions about scanning strategies and possible courses of action in the event that the proposed requirement of 1 part in 10^4 in one second cannot be met.

Mark Holdaway performed detailed numerical simulations of ALMA total power continuum observations. These simulations dealt with a range of On-The-Fly (OTF) and Beam Switching (BS) observing strategies with realistic antenna and subreflector motion, and included issues such as the range of observing frequencies (bands 1-10), a realistic distribution of variable atmospheric emission which is based on the site testing data, and 1/f-type gain errors. For the first time, our simulations sought to choose observing conditions using the joint probability distribution of opacity and stability. Using this, we matched the conditions to the observing frequencies, and found that the atmospheric stability accommodates the full complement of observing bands -- in other words, the atmosphere above Chajnantor will usually not add appreciable noise beyond the thermal noise. OTF is the favored method, being superior to BS in all but the most compact sources. 1/f noise at the level of 1×10^{-4} in 1 second will result in noise comparable to the thermal noise, thereby increasing the noise level by as much as 50%. However, if the proposed 1/f noise spec of 1.5×10^{-3} in 1 second is used, this increases the noise level by a factor of about 15. While this noise will average down like sqrt(N), such a large noise increase will clearly be detrimental to ALMA's ability to make conintuum observations of sources larger than the primary beam. This study was forwarded to the ASAC to aid in their consideration of a charge from the board on ALMA's amplitude stability.

Pety continued to help our Japanese colleagues in using the IRAM interferometric simulator with the goal to precise the design of ACA.

Organization, interaction with other IPTs

A monthly telecon continues for the whole Science IPT, and there is a weekly telecon of the NA Science Team. Topics under intense discussion continue to center on the calibration plan, discussed in several telecons of the Calibration Group. In addition, several discussions on Operations and on imaging, particularly with respect to amplitude stability, were held.

During August, the Science IPT supported the LO Group in further tests of the prototype ALMA 'conventional LO' in Green Bank, West Virginia. The Green Bank Telescope

Spectrometer provided the back end and was found to dominate amplitude stability in the system.

Meetings, Outreach and Public Education

Anne Dutrey presented a talk "Science with ALMA" at the "long baseline interferometry in mid-IR" workshop held in Ringberg Castle on September 5. Wootten made ALMA presentations at the University of Texas at Austin, and to the ANASAC and ASAC face-to-face meetings. van Dishoeck addressed a meeting of chemists in Dijon. Hills presented a talk on ALMA at the workshop on "Far-infrared astronomy from space" in Madrid in September 2003.

Concerns

During this period the Science IPT lost some of its most productive members. Stephane Guilloteau left the project at the beginning of July, though he continues occasional participation in email discussions. Aurore Bacmann and Bryan Butler left at the end of the period. Bacmann will continue to contribute to the Science IPT at a reduced level from her new position in Bordeaux. A search has begun for a successor to Butler.

Acronym Definitions

ABM	ALMA Bus Master
ACA	Atacama Compact Array
ACE	Alcatel/Costamasnaga/EIE
ACS	ALMA Common Software
ACU	Antenna Control Unit
AEG	Antenna Evaluation Group
AEWG	Antenna Evaluation Working Group
AIPS++	Astronomical Information Processing System
ALMAEDM	ALMA Electronic Document Manager
AOS	Array Operations Site
ASAC	ALMA Science Advisory Committee
ATF	Antenna Test Facility
BIMA	Berkeley Illinois Maryland Association
BUS	Back Up Structure
CDR	Critical Design Review
CFRP	Carbon Fiber Reinforced Plastic
CSIC	Consejo Superior de Investigacion Cientificas
CVS	Concurrent Version System
DC	Direct Current
DSB	Double Side Band
DTS	Data Transmission System
EAB	European ALMA Board
ESAC	European Scientific Advisory Committee
ESO	European Southern Observatory
FE	Front End
FEIC	Front End Integration Center
FIR	Finite Impulse Response
FPGA	Field Programmable Gate Array
FO	Fiber Optics
FTE	Full Time Equivalent
FTS	Fourier Transform Spectrometer
HIA	Herzberg Insititute of Astrophysics
ICD	Interface Control Document
IF	Intermediate Frequency
IPT	Integrated Product Team
IRAM	Institut Radio Astronomie Millimetrique
JAO	Joint ALMA Office
JBO	Jodrell Bank Observatory
LO	Local Oscillator
LORR	Local Oscillator Reference Receiver
LTA	Long Term Accumulator
LVDS	Low Voltage Digital Signal
MMIC	Millimeter Integrated Circuit
MRAO	Mullard Radio Astronomy Observatory
NAOJ	National Astronomical Observatory of Japan

NOVA	Netherlands Research School for Astronomy
NRAO	National Radio Astronomy Observatory
OAN	Observatorio Astronomico Nacional
OSF	Operations Support Facility
OVRO	Owens Valley Radio Observatory
PCB	Printed Circuit Board
PDR	Preliminary Design Review
PTC	PoinTing Computer
RAL	Rutherford Appleton Laboratory
RF	Radio Frequency
SE&I	System Engineering and Integration
SIS	Superconducting Insulator Superconducting
SRON	Space Research Organization Netherlands
SSR	Scientific Software Requirements
XML	Extended Markup Language
YO	Yebes Observatory
2GC	2nd Generation Correlator