APEX: Five Years of Operations

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ABSTRACT

APEX, the Atacama Pathfinder EXperiment, is being operated successfully, now for five years, on Llano de Chajnantor at 5107 m altitude in the Chilean High Andes. This location is considered one of the worlds outstanding sites for submillimeter astronomy, which the results described in this contribution are underlining. The primary reflector with 12 m diameter is cautiously being maintained at about 15 μm by means of holography. This allows to access all atmospheric submillimeter windows accessible from the ground, up to 200 μm. Telescope and instrument performance, operational experiences and a selection of scientific results are given in this publication.

Keywords: telescope, submillimeter

1. INTRODUCTION

APEX, the Atacama Pathfinder EXperiment,[1] is a single dish telescope for millimeter and submillimeter astronomy, and operates since its inauguration in September 2005. As its name suggests, the project is set to pioneer scientific exploration of the millimeter and submillimeter wavelength range, which will be followed up by other projects currently in planning or construction at the same site, especially by the Atacama Large Millimeter Array (ALMA).[2] The full description of the telescope is given in the SPIE paper by Güsten et al. (2006).[3] This follow-up paper will summarize the basic information of the project, and present changes and results from the first five years of the operations. This paper is structured as follows: Section 2 describes the telescope and its performance. The experimental character of the project is on purpose, facilitating a versatile instrumentation strategy, which is outlined in section 3. Operations involve new approaches to staff management and safety measures, as discussed in section 4. We give a summary of the statistics in section 5 and list selected science results in section 6. Finally we give an outlook in section 7 on what the future has for us.

APEX is a collaboration between the Max-Planck-Institut für Radioastronomie (MPIfR), the Onsala Space Observatory (OSO) and the European Southern Observatory (ESO). The observing time (45% MPIfR, 24% ESO, 21% OSO) is shared along the Partners investments, with 10% allocated to the host nation. The operation of the observatory has been entrusted to ESO (Chile).

The team comprises 19 staff members (astronomers, telescope and instrument operators, electronics/mechnical engineers, and technicians), contracted through ESO, and support visitors from the partner institutes. A group of ten contractors is in charge of the facility maintenance and canteen operations.

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1.1 Facilities

The facilities of APEX comprise two locations: the antenna site on Llano de Chajnantor, at 5107 m a.s.l., and the base camp in Séquitor, an Ayllu* of San Pedro de Atacama. The Chajnantor site offers an oxygen-enhanced control room, a server room, laboratory space, storage for spare parts and other maintenance related devices, a kitchen and sanitary compartment, as well as a power generation house, containing three redundant Diesel generators of 250 kVA each†. In Séquitor, there are dormitories for staff and visitors, a control room for remote operations, a server room for data mirroring and offline data reduction, electronics and mechanical workshops for smaller repairs, developments and fleet maintenance, storage spaces, a canteen, and rooms for meetings and entertainment. A 36 Mbit/s microwave link connects high site and base camp for remote operation and data relay.

A fleet of five double–traction vehicles allows commuting between base camp and high site, and a mini van facilitates commuting to the Calama airport for staff exchange.

1.2 Observatory Site

The APEX site, located at an elevation of 5107 m in the main cordillera of the Andes, is accessed through the service road that the ALMA project has constructed. It passes through the ALMA basecamp, about 30 km distant from San Pedro de Atacama, and continues another 35 km to the Chajnantor site. There, both air pressure and humidity are unique: At a pressure of about 555 hPa and frequent relative humidities of below 15%, the atmospheric opacity permits to access the millimeter and submillimeter windows up to $200\,\mu m$ (1.5 THz).

2. TELESCOPE

The APEX telescope was designed and constructed by VERTEX Antennentechnik GmbH, Germany, and is a modified copy of a prototype for the ALMA project. It accommodates two additional Nasmyth cabins to host a larger number of instruments, a container for supplementary equipment and a compressor compartment for the closed–cycle cryocoolers.

The 12 m diameter main dish consists of 264 aluminium panels in 8 rings fixed on a carbon fiber reinforced plastic (CFRP) backup structure of 24 sandwich backup structure (bus) segments. Each panel is supported by five vertical (four corners and center) and three lateral adjustment elements. The panels, which have been chemically etched to scatter visible and IR radiation and thus allow daytime observations, have been manufactured to an average surface accuracy of $8\,\mu$m rms. The bus is supported by an INVAR cone, which is attached to the top of the Cassegrain cabin. The total mass of the modified antenna is ≈125 tons.

2.1 Surface quality

The surface accuracy is routinely measured using near-field holography, which is described in Güsten et al. (2006).[3] If it is found that the surface accuracy has degraded to more than $15\,\mu$m rms during the altiplanic summer season, the surface is adjusted and the result is verified in the beginning if the altiplanic winter season. A typical surface error pattern of the APEX main reflector after a holography run is presented in Figure 1.

2.2 Pointing

Since early 2010, we are using an extended pointing model, which consists of 28 pointing parameters. Most parameters do not change with time, and are therefore kept fixed. Some parameters show long term variations (∼month), and are recalculated each pointing run. A few parameters vary on time scales <24h, and are updated regularly using pointing checks or other sources of information. All pointing modelling is done in TPOINT.[4]

A **master** pointing model is created using the optical telescope. Each instrument is associated with a **delta** pointing model that accounts for the difference with respect to the master model.

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[*] A former settlement for Atacamenian family clans, nowadays forming a sub–village in the outskirts of the San Pedro de Atacama village

[†] At an altitude of 5107 m, this power is de–rated. At sea level, the generators can produce 400 kVA each

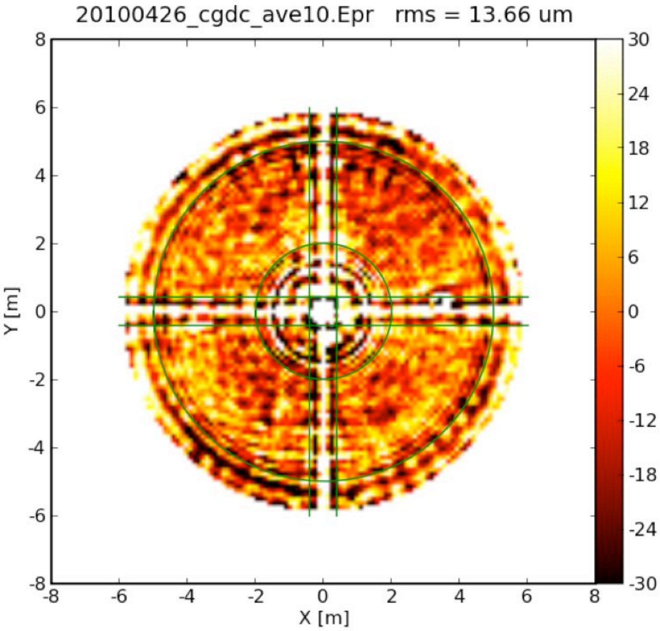

Figure 1. A surface error pattern of the APEX main reflector after the April 2010 holography run. The map is an average of 10 individual maps and the dish is optimized for observations at 50 degrees elevation (i.e. pre-loading has been applied to the surface). Masking the inner 1 m and the projected area of the quadripod legs, but without radial tapering, the surface accuracy is calculated to 13.7 μm rms (including pre-loading).

Each master model pointing run consists of 100-150 stars, which takes 1 hour to observe. All pointing runs are added to a data base and to fit the pointing model, we use pointing results from about 20 pointing runs. The strategy that is followed for a master model calculation is:

- 18 parameters do not show variations with time (HASA, HASA2, HACA2, HACA3, HESE, HECE2, HECE6, HESA2, HECA2, HESA3, HECA3, HESA4, HESA5, HSCA, HSCA2, HSSA3, HSCA5, and NPAE) and are therefore fitted overall in TPOINT. The typical error in determining the value is $0.05''$ (1σ), but it can for certain parameters be higher (e.g. NPAE $0.3''$, HESE $0.6''$).
- 6 parameters (IA, IE, HECE, CA, AN, AW) are fitted per pointing run. Typical errors are $0.6''$ for IA, IE, HECE, CA and $0.2''$ for AN and AW.

The typical pointing rms for a master model run (2000-3000 stars) is $1.5''$ (dR, 1σ), see Fig. 2 for an example of the residuals. The best sky rms one could obtain using the old model was $1.9''$,[3] but in most cases the sky rms was $2.0 - 2.2''$.

For the delta model, we freeze the parameters that were fitted overall in the master model calculation, fit some of the other parameters overall, and let a few parameters vary from run to run. In order to keep the free parameters to a minimum, the antenna tilt parameters (AN and AW) are treated separately; They are derived using a method we call ”tiltmeter run”, where the yoke tiltmeters are read while the antenna is rotated ∼400° in azimuth. Each pointing run is kept to be less than 2 hours, and we usually get about 15-20 pointing measurements in that time. After a new tiltmeter run, the pointing measurements can continue if neccessary. The data set are coadded to the data base of previous pointing runs for the same instrument.

A typical delta model is calculated following the strategy:

- IA, HECE, HSCA are fitted overall.

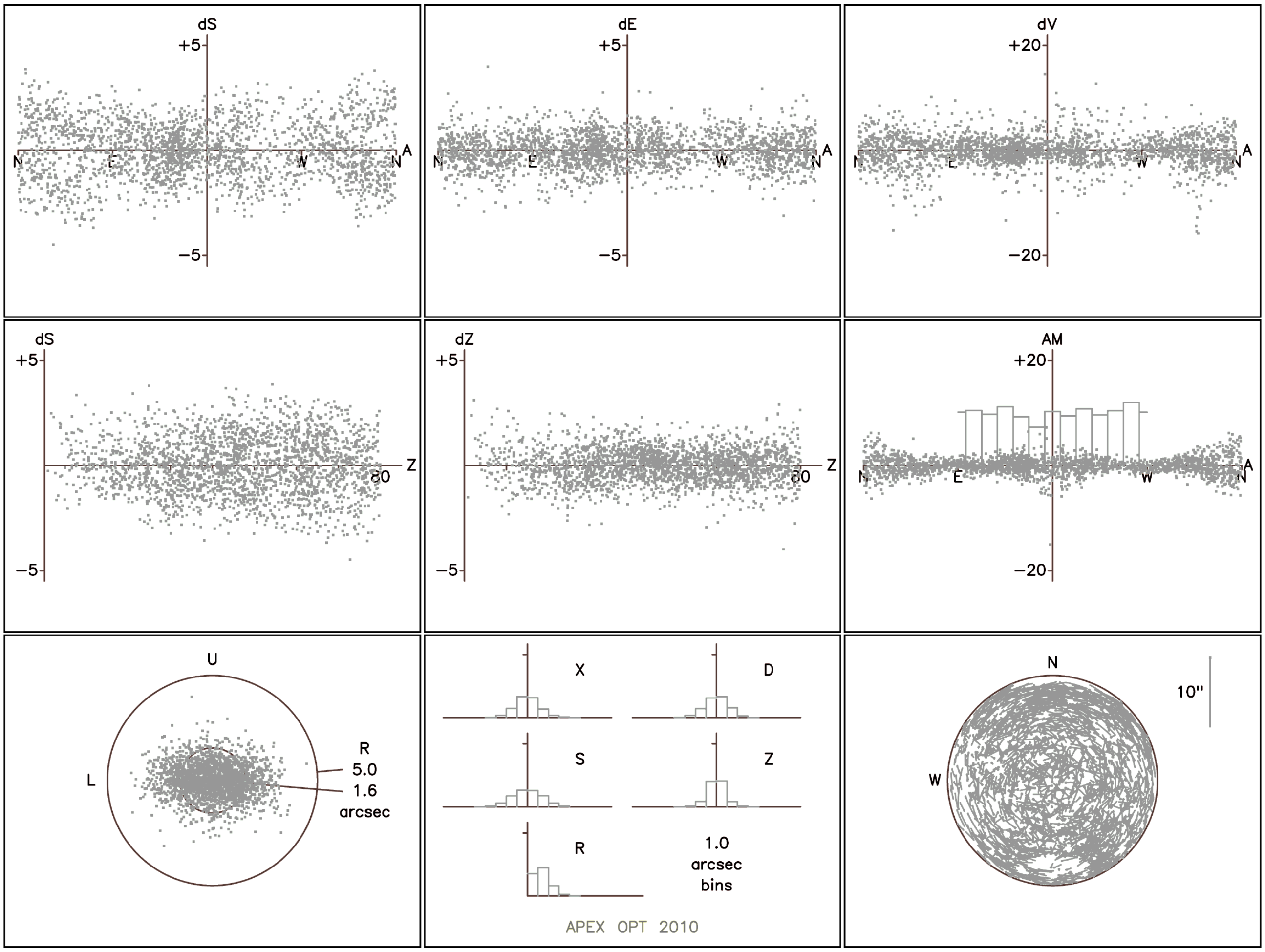

Figure 2. The output of the command .a9 in TPOINT. The upper three panels show the optical pointing residuals (in arcsec) in azimuth (dS), elevation (dE), and Az/El nonperpendicularity (dV) as a function of the azimuth. In the middle row, the two left panels show the residuals (in arcsec) in azimuth (dS) and zenith distance (dZ) as a function of the zenith distance, and the right panel shows the axis misalignment (AM). The lower row shows from left to right: pointing residuals as a scatter diagram, distributions of the pointing residuals, and finally a map of the pointing residuals as error projected on sky. In total this image consists of 2371 pointing measurements, and the sky rms is 1.55″.

- For the instruments in the Nasmyth cabins, NRX and NRY are determined overall, and then kept fixed. These parameters are closely coupled to other parameters, mainly IA and HECE, and in addition NRY is coupled to CA.
- AN and AW are fixed to the result from the tiltmeter run carried out most closely in time.
- Only two parameters, CA and IE are free to vary from run to run.

The typical rms for a delta model run is about $2''$ (1σ). A normal pointing data set consists of 100-200 pointing measurements in 5-10 pointing runs obtained during typically a few months time. The value is slightly higher for the lower frequency receiver (APEX-1) and lower for the higher frequency receivers (like APEX-3).

Both the master model and the delta model rms have been verified on sky.

2.3 Chopping Secondary

The chopping secondary was installed in late 2007. The practical frequency range for observations is 0.5-1.5 Hz, and the chopping amplitude can be up to 150", which means that the OFF-beam can be placed up to 300" away from the ON-beam.

The secondary, lightweight mirror is made out of carbon fiber with an aluminum coating. It was observed that the corrosive environment, most probably caused by the abandoned Purico sulfur mine upstream of the prevailing wind direction, deteriorates the metallization significantly. Therefore, the aluminum layer of the spare subreflector was coated with silicon monoxide as passivation layer. So far no degradation was observed.

2.4 Observing and Control Software

The APEX telescope is controlled by the APEX Control System (APECS).[5] APECS is based on the ALMA Common Software (ACS)[6] and the (ALMA) Test Interferometer Control Software (TICS).[7] ACS provides the CORBA-based[8] middleware communication layer to interface the hardware components to the control system. TICS provides the basic CORBA objects for antenna control in horizontal and equatorial coordinates. In addition to that, there are utilities to record several kinds of time stamped monitor points into a database (IBM DB2) and to perform optical pointing runs.

The ACS and TICS packages fulfill the requirements of common network communication, automatic monitoring, real-time tracking and remote observing. The overarching software to use all hardware devices in a coordinated way necessary for astronomical observations was developed by the APEX software development group.[5] This included defining the instrument and device interfaces[9–11] and the raw data format interface MBFITS.[12]

After its initial deployment in 2003, APECS has been continuously developed and improved. In 2005 the system was fully usable for standard observing modes. From 2006 on more complex modes such as drift scans, spiral and Lissajous patterns have been added. APECS now supports array receivers including active field derotation. Complex IF processing setups and sideband separating receivers can be handled automatically.

Until the end of the year 2008 APECS was based on a very early version of ACS and TICS which had been used to test and characterize the ALMA prototype antennas at the VLA site in New Mexico, USA. This ACS version exhibited problems in some of the basic interprocess communication schemes which led to slowing down or crashing APECS. It also required using an old version of the Linux operating system (RedHat 7.2). The latter prevented us from upgrading the server hardware which was beginning to age and which was not able to handle the higher data rates of current and future instruments.

It thus became increasingly urgent to upgrade to a more recent version of ACS which had been much improved within the ALMA project. During 2007 and 2008 TICS and APECS were ported to the latest ACS. Technical problems in the deployment of the CORBA libraries on the VxWorks real-time computer delayed the upgrade. In early 2009 the new software was deployed at APEX in Chile. Parallel to the software upgrade the network infrastructure was changed from 100 Mbps to gigabit speeds and physical network separation for the control and data acquisition parts of APECS.

The new APECS version 2.0 was based on Scientific Linux 5.2, VxWorks 6.6 and ACS 8.0. It was able to handle higher data rates than the old setup and it was much more stable. After this rather larger upgrade we now try to keep APECS aligned with new ACS versions. In early 2010 version 2.2 of APECS under Scientific Linux 5.3 and ACS 8.1 was installed in Chile. This year we plan to move to ACS 9.0 and VxWorks 6.8. The upgrades are always performed during the shutdown and maintenance times in the Chilean summer time.

Keeping ACS current will allow to continuously upgrade hard- and software and to benefit from software improvements. In addition to these upgrades we also keep adding new features to APECS for new observing modes and instruments.

3. FACILITY INSTRUMENTATION

The instrumentation that is available to the communities of the APEX partners and Chile are described in the following. For their performances, individual calibration strategies we refer to M. Dumke et al. in this issue.[13]

3.1 Swedish Heterodyne Facility Instrument (SHeFI)

The facility receivers which are open to the public for spectral line observations are the ones available in the Swedish Heterodyne Facility Instrument (SHeFI). This instrument was built by the GARD group at the Chalmers University, Sweden with the Onsala Space Observatory. The SHeFI consists of four wideband heterodyne receiver channels for 230 GHz (APEX–1), 345 GHz (APEX–2), 460 GHz (APEX–3) and 1300 GHz (APEX–T2). All the bands are located inside a single closed-cycle cryostat which cools the coldest part at a temperature close to 4 K. The first three bands for 230, 345 and 460 GHz employ superconductor-insulator-superconductor (SIS) mixers. APEX–1 and –2 behave as single sideband receivers (SSB) and APEX–3 as double sideband receiver (DSB). The 1.3 THz band is built using hot electron bolometer (HEB) mixer technology and is a DSB receiver. For a complete description, please refer to Vassilev et al. (2008)[14] and Lapkin et al. (2008).[15]

SHeFI is located in the Nasmyth-A cabin of the telescope. The optical path is fairly complex and includes not less than 11 mirrors with the main dish and the subreflector. The SHeFI receiver support structure is firmly attached to the Nasmyth elevation tube flange and therefore temperature deformations of the A cabin have little to no effect on the receiver alignment.

The cryostat was built at the Chalmers University and uses a closed-cycled Sumitomo cooling machine providing temperatures at the coldest stage below 4 K, which is needed for the best operations of the superconducting mixers.

One receiver band is in operation at a time. A rotating mirror selects the desired band and the receiver output is routed to the backends (spectrometers and total power). These heterodyne instruments all use direct multiplication chains for the local oscillator (LO) injection. The reference signal comes from a signal generator providing a strong clean signal from 10 to 20 GHz.

In detail, the available bands are:

- APEX–1: 210–280 GHz, with an average noise temperature of $T_{\rm rec} = 140\,{\rm K}$ (SSB).
- APEX–2: 285-380 GHz, with an average noise temperature of $T_{\rm rec} = 160\,{\rm K}$ (SSB).
- APEX–3: 385-500 GHz, with an average noise temperature of $T_{\rm rec} = 100\,{\rm K}$ (DSB).
- APEX–T2: 1220-1385 GHz, with an average noise temperature of $T_{\rm rec} = 1250\,{\rm K}$ (DSB).

The output of these receivers is spectrally resolved in a pair of Fast Fourier Transform Spectrometers[16] (FFTS), performing an optimized FFT on the data in a 1 GHz bandwidth.

3.2 LABOCA

The Large APEX BOlometer CAmera (LABOCA) is a 295-pixel, 345 GHz (870 μm) bolometer array. The field of view (FoV) is 11x11 arcmin^2. It was successfully commissioned in May 2007. It was built by the bolometer development group of the MPIfR. A complete description is given in Siringo et al. (2009).[17]

The instrument was first installed at APEX in September 2006. It was then continuously improved until the commissioning and science verification in May/June 2007. Since then, it is available for regular observations. The sensitivity of LABOCA is 60 mJy s$^{1/2}$. The LABOCA observations is usually organized in dedicated time-blocks because the operation depends on the availability of liquid helium on site. These time-blocks will usually be announced in the corresponding calls for proposals.

The software system offers various observing modes for LABOCA: **Spiral mode.** In this mode the telescope moves - relative to the tracking position - from a start radius to an end radius along a spiral pattern. This allows to obtain a fully sampled map of the total FoV of LABOCA. The spiralling is done with a constant angular speed. This mode can be combined with a raster mode that allows for larger map sizes than the instrument's FoV. **On-the-fly mode.** This is a mode used for mapping sources larger than $30'$. The telescope scans along map rows or columns in either horizontal or equatorial coordinates with a continuos speed. **Photometry, or On-Off mode.** During source tracking, a combination of nodding and chopping allows to obtain highly accurate photometry measurements of compact sources (i.e. smaller than a pixel's beam).

3.3 SABOCA

The Submillimetre APEX BOlometer CAmera (SABOCA) is a bolometric continuum receiver operating at 810 GHz (in the 350 μm atmospheric window). The FoV is 1.5x1.5 arcmin^2 and its detector array consists of 39 superconducting transition edge sensor (TES) bolometers with SQUID (Superconducting Quantum Interference Device) amplification and time-domain multiplexing. The receiver has been designed and integrated by the bolometer group at the MPIfR in collaboration with the Institute of Photonic Technology (IPHT, Jena, Germany). The MPIfR group has a long track record in the development of bolometers and bolometric cameras for astronomical applications. IPHT is known for building state-of-the-art superconducting devices for over 15 years. The collaboration to build SABOCA merges the technology expertise provided by the two groups.

The active development process took several years as it involved a large number of theoretical studies, cycles of manufacture and tests in the laboratory. A prototype system was successfully tested on APEX during May 2008. Some technical problems were identified and fixed. Thus, commissioning began in September with an improved version of the receiver. The final version of SABOCA was installed in 2009 and commissioning was completed in 2010, see Siringo et al. (2010)[18] for details. The observing modes available for LABOCA can also be used by SABOCA.

3.4 Principal Investigator instrumentation

A number of PI instruments are or have been installed at the different instrument slots. **CONDOR**: a 1.5 THz heterodyne receiver from the University of Köln;[19] **PI1100**: a 1.1THz single pixel heterodyne SIS receiver (4 GHz IF bandwidth) from MPIfR; **CHAMP$^+$**: a dual-color 2×7 element heterodyne array from MPIfR for operation in the 810 GHz and 690 GHz atmospheric windows;[20, 21] **FLASH**: a dual-color (initially 810/460, now 460/345 GHz) single pixel heterodyne receiver from MPIfR;[22] **p-ArTeMiS**: a prototype bolometer (450 μm) from CEA Saclay;[23, 24] **APEX-SZ**: a 150 GHz bolometer designed from University of California at Berkeley for studying the Sunyaev-Zel'Dovich Effect;[25] **PolKa**: A polarization add-on for LABOCA from MPIfR , see Siringo et al. (2010),[26] this SPIE. Detailed descriptions of these instruments are beyond the scope of this paper.

4. OPERATIONS

The APEX science operations are carried out by the *science operations group* and can be considered either *facility* observations or *principal investigator* (PI) observations.

The idea during *facility* observations is to work through a queue of observing projects that have been approved by *time allocation committees* (TAC) of the partner's communities. There we operate in service mode, observing the projects that are scheduled around the constraints of instrument requirements, instrument availability, and weather conditions (mostly determined by the content of precipitable water vapor along the line-of-sight).

PI observations usually include more staff of the investigator group, operating instrumentation which requires staff presence at the antenna, and their observing projects are as well approved and granted by a TAC.

During daytime the antenna and the instruments are operated from the Chajnantor control room by a team of at least two persons, of which at least one is an APEX staff member and site certified (i.e. trained to handle the antenna, knowledgeable to take safety measures). They also, shared with members of the engineering branch, take care of instrument maintenance (e.g. refilling cryogenics, recycling of instrument fridges etc.). During night time, the antenna and instruments are normally operated from the Sequitor control room.

4.1 16 h to 24 h – operations experiences

Since the inauguration in 2005, the baseline facility observations were carried out in a 16 h observation mode, covering the night shift from sunset to sunrise and a morning shift until local noon. The afternoon times were reserved for engineering access.

In June 2009, the APEX team adopted *24 h Operations Plan* for its implementation on tentative basis. The reason for this decision was to optimize the efficiency of the observatory by switching from 16 h operations per day to 24 h, which resembles an increase of 50% with respect to the conventional shift system. This plan foresees to invite at least three external support visitors (SV) sent by the partners that complement operations teams in order to cover three daily shifts. Finally, there are always two persons in either a night shift, morning shift or afternoon shift. Since the day shifts are to be executed at the Chajnantor site for antenna safety reasons, one of the SVs per team requires to be site certified. The 24 h Operations plan was formally accepted by the APEX board in February 2010.

4.2 Efficiency improvement

The efficiency measurement requires some detailed explanations: At APEX, we currently have two facility instruments that require a manual refilling with cryogenic refrigerants (liquid helium and nitrogen) and recycling of the focal plane fridge to reach mK temperatures. For LABOCA, this takes 2.3 hours (once or twice per day, depending on demand), and for SABOCA about one hour every 48 h. These recyclings cannot be done in parallel due to geometric constraints in the telescope. These can sum up to 4.5 h of "dead time" daily, if both instruments are requested, but the loss is mitigated due to the fact that observations with another instrument may continued in a limited elevation range while recycling LABOCA.

In the 16 h operations scheme, 2.5 hours of these recycling times can be scheduled to one of the day shifts (typically in the afternoon shift with least favorable weather conditions), so that they were not counted as hours lost to science operations.

In the 24 h operations scheme, these 4.5 hours on average, must be deducted from the total time available, so that, on average, 19.5 hours are available for observations per day. This renders an effective efficiency increase of 22% (effectively 3.5 hours per day), when shifting from the 16 h operations to the 24 h operations scheme.

In the summer months, the total time available is even further reduced due to the "sun avoidance" time in which the telescope shall not be operated due to the angular proximity of the sun to the zenith position (sun avoidance time). Of course, instrument recycling is usually scheduled during sun avoidance time, hence these dead times are used for instrument maintenances.

5. STATISTICS

5.1 Observing statistics

As the problems got fewer and operations got more streamlined, the on-sky integration time has increased at APEX. The total on-sky time rose steadily from 2291 h in 2007 via 3093 h in 2008 to 3443 h in 2009. With on-sky time we mean the accumulated times of each scan time, where each scan time is counted from the timestamp the scan was submitted to the observing engine to the timestamp where it was successfully finished.

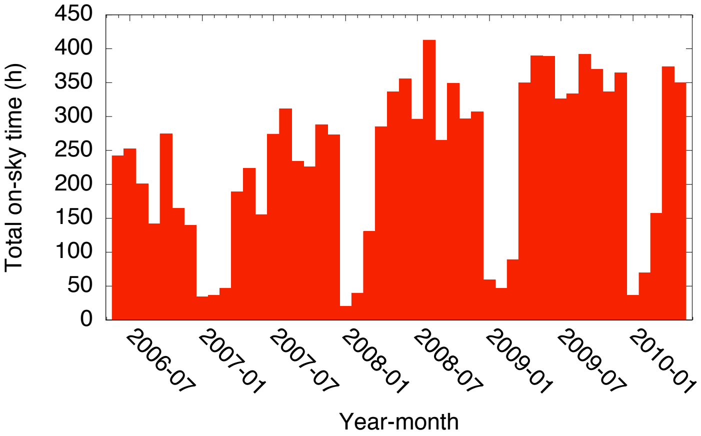

Figure 3. The on-sky time as function of year (and month) between June 2006 end of May 2010. The on-sky time is defined as the time between an observing command has been sent until the scan has finished. No science observations are scheduled during the summer months (Jan-Mar). During these months, and when the weather and staffing situation allows, the antenna is used for technical observations, such as pointing, calibration, technical verification, etc.

Figure 3 shows the on-sky time as function of month and year since mid-2006, and it seems as if we have reached a plateau of ~350 h on-sky time per month. As from June 2009 we are most of the time in 24 h operations mode (see Sect.4.1), and this has a discernable, positive effect on the usage of the antenna.

5.1.1 Statistics per instrument

Taking 2009 as an example, and summing the on-sky time per instrument, see Table 1, we see that the facility receivers APEX-1, APEX-2 and LABOCA account for about 2/3 of the total on-sky time. SABOCA and the THz instruments (APEX T2 and PI1100) were still under commissioning and received relatively little on-sky time. The PI instruments APEX-SZ, p-ArTeMiS, FLASH, and CHAMP+ were only operated during limited time periods.

The total time on sky is 3136h, which amounts to about 348 h per month (calculated over 9 months), or about 12 h per day. The remaining time is on average spent as 5 h on non-science operational time (tuning, refilling and recycling, optical pointing, holography, etc.), and 7 h downtime (mostly weather, hardware and software problems).

Table 1. The number of hours spent on-sky per instrument during 2009. Instruments in roman font are facility instruments, and instruments in italic font are PI instruments. The instruments are ordered in frequency and divided in heterodyne and bolometer. Non-scientific frontends, like the holography receiver, are not listed here. See section 3 for description of the instruments.

Heterodyne		**Bolometer**	
APEX T2	3	SABOCA	79
PI1100	11	*p-ArTeMiS*	116
CHAMP+	287	LABOCA	811
FLASH	102	*APEX-SZ*	402
APEX-2	685		
APEX-1	640		
Total	1728		1408

5.2 Weather statistics

Apart from science data, APEX has also been collecting climatological data for the past 5 years. A key parameter for submillimeter astronomy observations is of course the precipitable water vapor (PWV). Figure 4 shows the

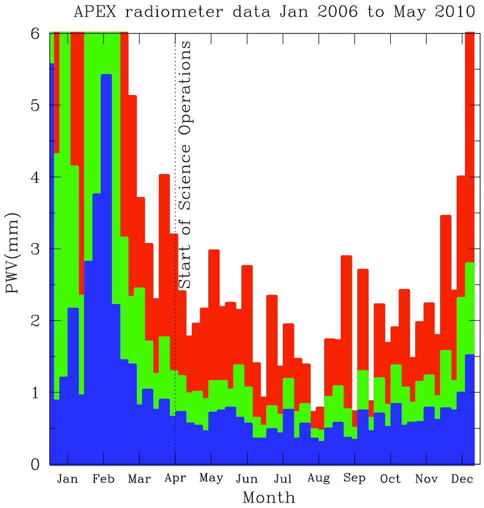

Figure 4. The precipitable water vapor measured by the APEX radiometer as function of the time of the year. Data have been collected over the years 2006-2010. The blue, green, and red bars show the 1st, 2nd, and 3rd quartile of the data.

PWV measured by the APEX radiometer as function of the time of the year. This image shows that during more that 50% of the time during the period when we are conducting science operations (April 1st to January 1st), the PWV is below 1mm (green quartile), and during the 5 best months (May-September), the PWV is below 0.5 for more than 25% of the time (blue quartile). We have seen PWV<0.5mm during all weeks of the year, and PWVs as low as 0.07mm (confirmed by heterodyne calibration observations) has been seen a few times, or zenith opacity $\tau < 0.1$ at $870\,\mu$m (LABOCA).

Furthermore, Figure 5 shows temperature, humidity, windspeed, and barometric pressure as function of time of the year. The southern winter (June-August) is characterized by low temperatures, low humidity, higher wind speeds, and slightly lower pressure. The figures is based on median values per hour, which tends to smooth the appearance, and sorted per week. The reason for taking the median value and not the average value is that the median value is not affected by non-representative data (e.g. wind gusts or the occasional bad data). The smoothing of the data affects in particular the plot of the wind; There are in the raw data base measurements of wind gusts up to 46 m/s, and sustained wind for more than one hour up to 32 m/s.

The diurnal variation of temperature and wind in winter (June) and summer (December) is shown in Figure 6. Typical night-time temperatures are -6 to -10 °C during winter and 0 to -4 °C during summer, and the temperatures rising slowly after sunrise, reaching normally around -4 °C and 4 °C in winter and summer, respectively. Extreme night and day temperatures are -20 °C and 12 °C, respectively.

The wind pattern is during winter characterized by steady wind 5-7 m/s during night time, increasing steadily after sunrise, reaching 6-11 m/s at 12-14 (CLT), and then starting to drop. The wind pattern during summer look slightly different, with a minimum at 22-02 (CLT) and 2-4 m/s, gradually increasing up to 19 (CLT) and 8-10 m/s, after which the wind speed drops relatively abrupt. This winter pattern normally starts in October and continues until March.

6. SELECTED SCIENCE RESULTS

Over its first five years of operations, APEX has significantly contributed to a wide variety of science areas. A total of 26 articles appeared in a special (August 2006) issue of Astronomy and Astrophysics with the telescope receiving title page prominence. Since then, about 50 further refereed papers have appeared in journals (out of which 29 during 2009) and many more are in the process of being published. To name but a few highlights:

- Red-shifted 0.89 absorption of the ground-state lines of ortho-water and -ammonia has been detected toward a gravitational lens[27]

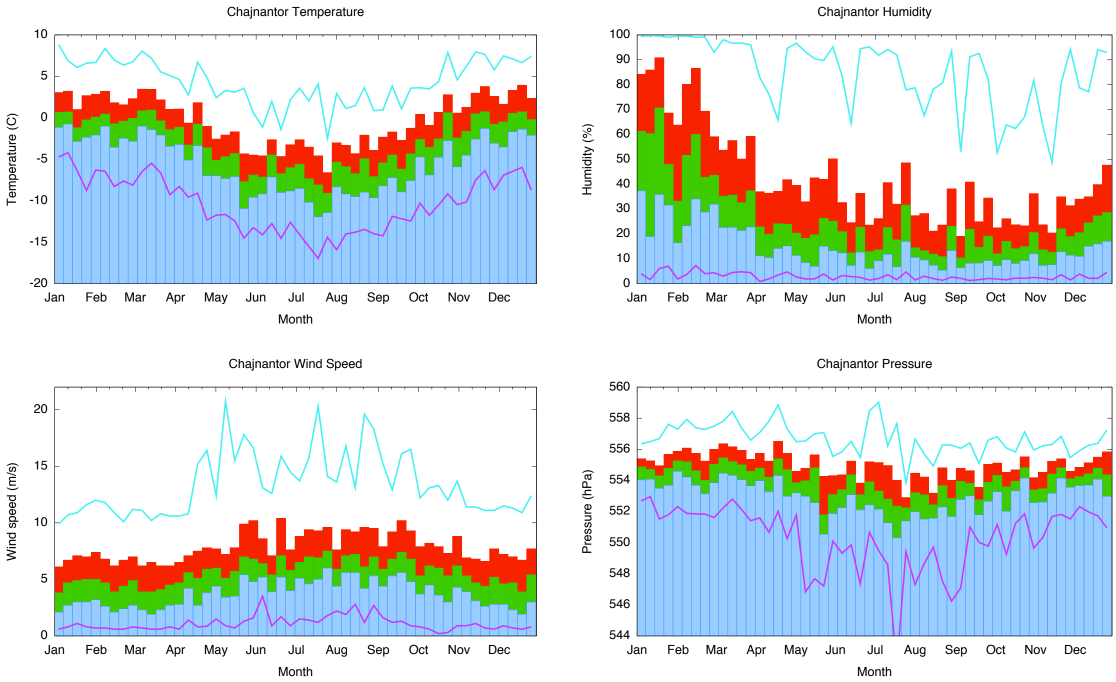

Figure 5. Weather statistics (temperature, humidity, wind speed, and pressure) measured at the APEX weather station. Data have been collected over the years 2006-2010. The blue, green, and red bars show the 1st, 2nd, and 3rd quartile of the data. The raw data have a dump rate of 1 minute. From the raw data, the median value per hour was calculated and these median values were sorted per weeks. The thin cyan line shows the tenth largest value in the data base, and the thin purple line shows the tenth lowest value among the median values, per week.

- The first imaging results with the 14 element CHAMP$^+$ heterodyne array have published[28–30]
- as have the first articles reporting results from the APEX Sunyaev Zeldovich survey project[25, 31]
- LABOCA mapping of nearby active galaxies, including the detection of, both, dust emission from the plane of the Sombrero galaxy[32] and synchrotron emission from the jets and lobes of the archetypical radio galaxy Centaurus A[33]
- Galactic and extragalactic molecular line studies in the 650 and 350 μm windows, very few of which were made in the past, e.g. the 1mm line survey in the Orion bar[34]
- The first detection of several molecular ions, including CF+, which is a ubiquitous component of the interstellar medium,[35] and the first interstellar detection of OH+[36]
- ATLASGAL, a submillimeter dust continuum survey of the inner Galactic plane with LABOCA has been completed, and first results have been published[37]
- The first LABOCA 870 μm cosmological deep field imaging of a Ly α proto-cluster at z = 2.38[38]
- Discovery of strong [CII] emission in a lensed galaxy at high redshift (z=4.43)[39]
- The first results from the LABOCA survey of the Extended Chandra Deep Field South (ECDFS)[40–42]
- The finding of a sub-millimetre galaxy at redshift z=2.3259, which has been gravitationally magnified by a factor of 32 by a massive foreground galaxy cluster lens[43]

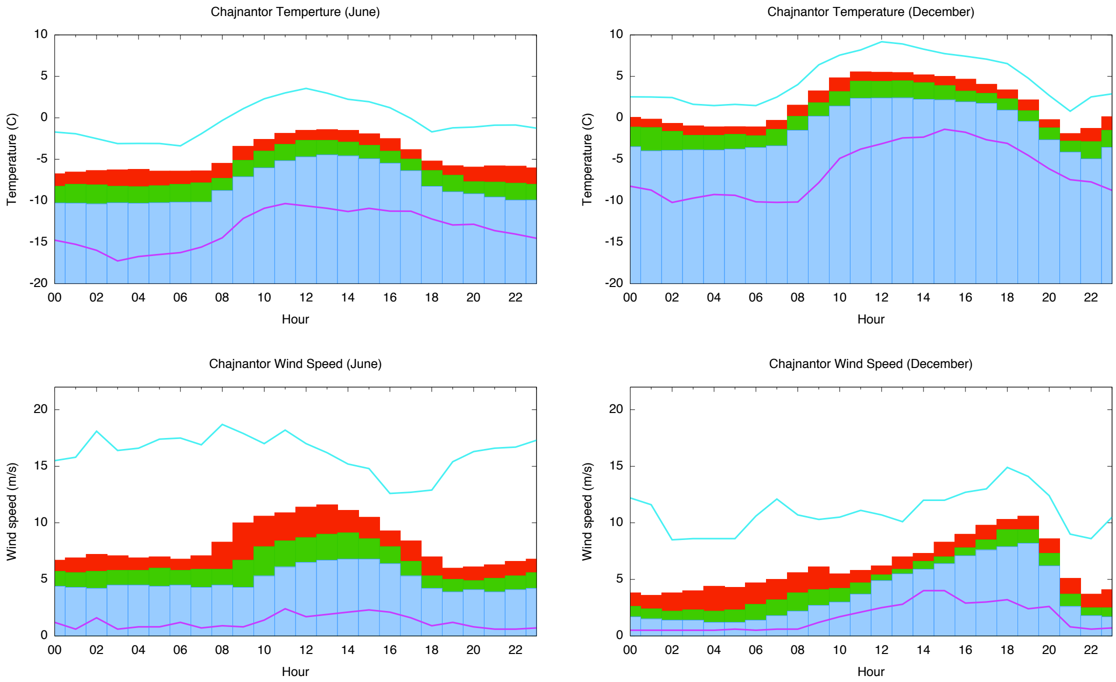

Figure 6. Diurnal variation of temperature (upper row) and wind speed (lower row) in June (left column) and December (right column) as function of time (CLT). Data have been collected over the years 2006-2010. The blue, green, and red bars show the 1st, 2nd, and 3rd quartile of the data. The raw data have a dump rate of 1 minute. From the raw data, the median value per hour was calculated and these median values were sorted per weeks. The thin cyan line shows the tenth largest value in the data base, and the thin purple line shows the tenth lowest value among the median values, per week.

7. OUTLOOK

7.1 Project lifetime

The future is bright for APEX. The excellence of the site calls for more observations, both focussed as well as surveys, and the oversubscription rate in the various partner's time slots underlines this. Also, the experimental character of APEX makes it suitable as a platform for testing new and/or different detection technologies. Therefore, an extension of the lifetime of APEX beyond 2012 is under discussion among the project partners.

7.2 Future instrumentation

A second generation instrumentation suite is already being contemplated. State–of–the–art technologies for both heterodyne and bolometer instruments are available, and it is a matter of funding and extension of the project's lifetime to get them to APEX.

On the spectroscopy side, heterodyne receiver arrays with ever wider bandwidth will allow to investigate much more in–depth extragalactic features with more scrutiny.

The rather large optical field of view of the telescope calls for larger format bolometer cameras. Currently, transition edge sensors (TES) or kinetic inductance detectors (KID) are under evaluation for larger formats. The outcome of first tests as visiting instruments at APEX will allow to set course for developing more mature incarnations of these technologies.

Also, a large dual-color heterodyne array is under development at MPIfR: 19 (7) pixels in the 460 (345) GHz window respectively. Installation planned during 2011.

See Siringo et al. (2010),[44] this SPIE conference, for more details about future receivers for APEX.

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