IRAM 30-meter Telescope

Observing Capabilities and Organisation

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This document is updated twice a year to reflect the current capabilities of the 30-meter telescope at the time of the Call for Proposals publication. Non-trivial changes with respect to the previous version are marked in red. Note that this document contains active links marked with a different font for an easy access to documentation, e.g. `IRAM web pages`.

Contents

1 The Telescope

This section gives a brief description of the 30-meter telescope characteristics. A more detailed summary is available on the `IRAM web pages`.

1.1 Pointing and Focusing

The telescope absolute rms pointing accuracy is better than $3''$ [1]. Observers are recommended to check the telescope pointing every 1 to 2 hours, depending on frequency, and the focus values every 2 to 4 hours and at sunrise/sunset.

1.2 Wobbling Secondary

- The beam–throw is $\leq 240''$ depending on wobbling frequency. At 2 Hz, the maximum throw is $90''$
- Standard phase duration: 2 sec for spectral line observations, 0.26 sec for continuum observations.

Unnecessarily large wobbler throws should be avoided, since they introduce a loss of gain [2], particularly at the higher frequencies, and imply a loss of observing efficiency as the dead time increases.

1.3 Telescope beam widths and efficiencies

Updated tables of telescope efficiencies and error beam parameters between 80 and 350 GHz, as measured with the heterodyne receivers, are provided in [3]. These numbers are valid since September 2002, and they supersede the values compiled in [4] which

were measured before 1998. The history of telescope main beam and aperture efficiencies, as well as the half power beam widths, are also listed on the `30m homepage`. Note that the antenna point source sensitivity is a function of elevation and observing frequency [5, 6].
NIKA2 half power beam widths, beam efficiencies, antenna diagrams are described in [14].

2 Frontends

2.1 EMIR

Overview: The spectral line receiver EMIR (**E**ight **MI**xer **R**eceiver) operates in the 3, 2, 1.3 and 0.9 mm atmospheric windows (Fig. 1). These four bands are designated as E 090, E 150, E 230, and E 330 according to their approximate center frequencies in GHz. Each band provides two orthogonal linear polarization channels tuned to the same frequency as they share a single common local oscillator. The eight individual receivers of EMIR are very well aligned with offsets below 2″ between bands and below 1″ between polarizations of any one band. EMIR offers very competitive noise temperatures and wide bandwidths.
All EMIR bands are equipped with dual sideband (2SB) mixers that offer 8 GHz of instantaneous bandwidth per sideband and per polarization (Fig. 2).
Table 1 lists the main characteristics of the EMIR receiver. A thorough description of the EMIR receiver is available in Carter et al. [7], and its users guide is available at the EMIR web page at:

`http://www.iram.es/IRAMES/mainWiki/EmirforAstronomers.`

Since end of 2015, the 3 mm band of EMIR is equipped with NOEMA-type mixers and an orthomode transducer to split the two polarisations received via only one horn, leading to a perfect co-alignment of both polarisations. The new band mixer and optics extends the available frequency range down to 73 GHz (center of outer IF subband of 4 GHz width) without impinging on the upper frequency limit. Though the atmospheric transmission slowly degrades when going from 81 to 73 GHz due to an atmospheric oxygen line at 60 GHz, the atmospheric transmission hardly varies over this frequency range with respect to varying water vapour and is therefore robust against changing weather conditions. This frequency range can now be reached with excellent receiver temperatures and well determined image band rejections, allowing well calibrated observations of bright cooling lines of redshifted objects and allowing to access a number of important chemical tracers of local molecular clouds like the low lying rotational transitions of deuterated species, e.g. DCO^+, DCN, DC_3N, DNC, N_2D^+, CH_3OD, or of other heavy rotators.

Selection of EMIR bands: A set of warm switchable mirrors and dichroic elements are used for combining EMIR beams, or for directing the beams towards calibration loads.
In its simplest configuration, the warm optics unit selects a single EMIR band for observation. This mode avoids the use of slightly lossy dichroic elements and therefore offers the best receiver noise temperatures.
In its dual-beam configuration, the dichroic mirrors combine the beams of two receivers such that they look at the same position on the sky and have the same focus values within 0.3 mm. The following band combinations are possible: E 090 and E 150, E 090 and E 230, or E 150 and E 330 (see Tab. 1). The combination of bands is not polarization selective, i.e. the combined beams will stay dual polarization. The loss of these dichroic mirrors, which is small over most of the accessible frequency range, increases however the receiver temperatures by 10–15 K.
A new dichroic mirror was installed for dual-band operation of EMIR bands E090 and E230. The improved performance of the dichroic has led to much improved receiver noise temperatures above 240 GHz, now allowing e.g. for efficient, simultaneous observations of the 1-0 and 3-2 transitions of HCN, HNC, HCO^+.

Calibration Considerations: EMIR has its own calibration system. The external warm optics provides ambient temperature loads and mirrors reflecting the beams back onto the 15 K stage of the cryostat. This system is expected to be very reliable and constant over time. The absolute calibration accuracy is around 10% or better depending on the band considered.
All EMIR bands are equipped with tunerless sideband separation mixers, allowing simultaneous observations of both sidebands in separate IF bands. These mixers have been characterized in the laboratory for their image rejection and are expected to have the same performance on site (about −13 dB).
Filters have been installed in the Local Oscillator (LO) chains of the EMIR bands E 090 and E 150 which successfully suppress unwanted LO harmonics that had caused ghost lines. Few ghost lines have

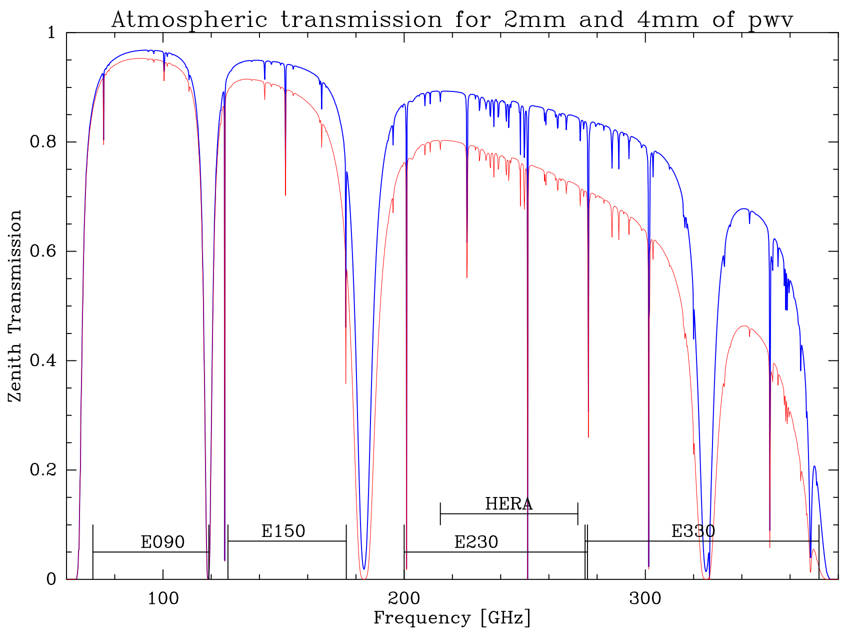

Figure 1: Atmospheric transmission at the 30m site between 60 and 400 GHz for 2 and 4 mm of precipitable water vapor, derived from the ATM model. The EMIR and HERA bands are indicated.

Table 1: EMIR Frontend characteristics foreseen for this semester. *The sky frequency range, F_{sky}, refers to the center of the outer IF sub-bands.* The lower (LSB) and upper (USB) sideband frequency range is also specified. 2SB stands for dual sideband mixers, and H/V for horizontal and vertical polarizations. T_{sb} and T_{db} are the SSB receiver temperatures in single– and dual–band observations, respectively, with T_{db} including a 15 K noise contribution from the dichroics. The standard frequency range of the E 330 band can be extended to 375 GHz with the YIG Local Oscillator, on a shared-risk basis. The nominal frequency range of E 150 can be extended to 184 GHz with good performances of receiver temperatures and sideband ratios but the calibration around the atmospheric water line at 183.31 GHz would require special care.

EMIR band	F_{sky} GHz	mixer type	polarization	bandwidth GHz	T_{sb} K	G_{im} dB	combinations E 0/2	E 1/3	E 0/1	T_{db} K
E 090	73 – 117	2SB	H/V	8	50	> 10	X		X	65
(LSB)	*73 – 97*									
(USB)	*89 – 117*									
E 150	125 – 184	2SB	H/V	8	50	> 10		X	X	65
(LSB)	*125 – 168*									
(USB)	*141 – 184*									
E 230	202 – 274	2SB	H/V	8	80	> 10	X			95
(LSB)	*202 – 268*									
(USB)	*217 – 274*									
E 330	277 – 350 (375)	2SB	H/V	8	80	> 10		X		95
(LSB)	*277 – 335*									
(USB)	*293 – 350 (375)*									

also been detected in the E 230 band and a filter is in preparation.

Doppler–tracking and velocity scale: It is common practice at radio observatories to correct the frequency of an observation for the strongly time

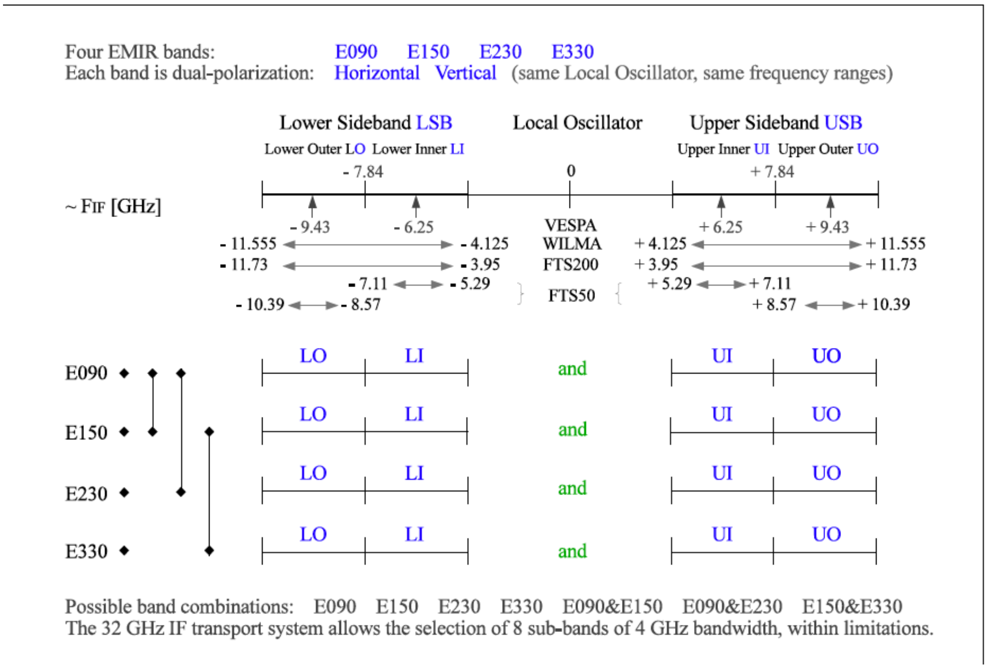

Figure 2: Visual overview of EMIR bands. Eight sub-bands can be transported to backends for a total of 32 GHz instantaneous bandwidth. Frequencies shown above the frequency scale indicate the central frequencies of the (sub-)bands. Frequencies at the sideband edges give the frequency coverage of the backends.

variable velocity of the Observatory with respect to the solar system barycenter. This guarantees that lines observed near the Doppler–tracked frequency, usually the band center, always have the correct barycentric velocity, independent of the time of observation. At the 30m, the local oscillator and its synthesizers are constantly adjusted during observations to track the changing Doppler factor for one spectral line with its rest frequency. This causes a slight shift of lines observed simultaneously at a different frequency. This shift is proportional to the frequency difference and the Doppler factor. CLASS corrects for this shift by adapting the spectral resolution [8].

Connection to backends: The IF transport system consists of eight IF cables, each with a 4 GHz bandwidth, thus providing a total bandwidth of 32 GHz. This bandwidth can be entirely covered by the FTS units, within limitations, at a spectral resolution of 200 kHz (see the backends section below for details).

An **IF switch box** in the receiver cabin is used to select 8 EMIR channels of 4 GHz bandwidth each. The design of the box allows the selection of all commonly used combinations of EMIR bands. A detailed description of the (im)possible sub-band combinations is available on the `EMIR homepage`.

EMIR frequency setups can be prepared using a set of commands in `ASTRO\PICO` (GILDAS versions of July 2016 or younger). These take into account the available frequency limits, band combinations, and spectrometers, and plot the covered frequency ranges together with known spectral lines, taking into account source velocities or redshifts. This functionality is still under development and is likely to be upgraded in the future. Examples are given here, but see also the online help.

2.2 HERA

The **HE**terodyne **R**eceiver **A**rray (HERA) consists of 9 dual–polarization pixels arranged in the form of a center–filled square separated by 24″. Each beam is split into two linear polarizations which couple to separate SIS mixers. The 18 mixers feed 18 independent IF chains. Each set of 9 mixers is pumped by a separate local oscillator system. The same positions can thus be observed simultaneously at any two frequencies inside the HERA tuning range:

HERA1: 210 - 276 GHz

HERA2: 210 - 242 GHz

Observations have shown that the noise temperature of the pixels of the HERA2 array may vary across the 1 GHz IF band. The highest noise occurs towards the band edges which are, unfortunately, picked up when HERA is connected with VESPA whose narrow observing band is located close to the lower edge of the 1 GHz band. Therefore, while not as important for wide band observations with centered IF band, the system noise in narrow mode is higher (factor $1.5 - 2$) as compared to the HERA1 array. We do not recommend to use HERA2 for frequencies > 241 GHz.
A derotator optical assembly can be set to keep the 9–pixel pattern stationary in the equatorial or horizontal coordinates.
HERA is operational in two basic spectroscopic observing modes: *(i)* raster maps in position, wobbler, or frequency switching modes, and *(ii)* on–the–fly maps of moderate size (typically $2' - 10'$) in position or frequency switching mode.
HERA can be connected to three sets of backends: the FTS, VESPA, and WILMA. When connected to HERA, these backends offer spectral resolutions ranging from 20 kHz to 2 MHz over bandwidths ranging from 40 MHz to the entire 1 GHz bandwidth of HERA. The backend section below provides a description of the available backend configurations.
For details about observing with HERA, consult the HERA manual [9], the HERA paper [10], or the following wiki page:

`http://www.iram.es/IRAMES/mainWiki/HeraforAstronomers`

2.3 NIKA2

NIKA2 is a dual-band camera working simultaneously at 1 and 2 mm wavelengths. It comprises three arrays of Kinetic Inductance Detectors, 2×1140 pixels at 1 mm and 616 pixels at 2 mm. NIKA2 images an instantaneous circular field-of- view of $6.5'$ in diameter. It exhibits half power beam widths (HPBW) angular resolutions of $\sim 11''$ and $17.5''$ at respectively 1 and 2 mm. Regarding sensitivities, the noise equivalent flux densities (NEFD) are 33 and 8 mJy$\sqrt{s}$ at 1 and at 2 mm, respectively. More information is given on the NIKA2 home page and in Adam et al. (2018, A&A, 609, 115). The NIKA2 home page also links to the observing time estimator.
NIKA2 1 mm polarimetry is currently being commissioned, and is not yet offered to the community for the upcoming semester.

3 Backends

The following three spectral line backends can be individually connected to any EMIR band or to HERA. Specific documentation on the backends available at the 30-meter telescope can be found on the wiki page at:

`http://www.iram.es/IRAMES/mainWiki/Backends`

3.1 FTS

The Fast Fourier Transform Spectrometers, FTS, can be connected to EMIR or HERA. It consists of a series of 24 FTS modules purchased from Radiometer Physics (Klein et al. [15, 16]). All FTS units work either at 200 kHz resolution or 50 kHz resolution. It is not possible to set them individually to different resolutions. At 200 kHz resolution, the 24 units provide 32 GHz of instantaneous bandwidth where each block of 3 FTS units covers a contiguous 4 GHz band of EMIR. At 50 kHz resolution, 3 FTS units cover the inner 1.8 GHz of the 4 GHz EMIR bands (see Fig. 2 for the exact frequency coverage). When connected to HERA, the FTS can cover each of the 18 pixels over a bandwidth of 1 GHz in the low spectral resolution mode, or over a reduced bandwidth of 625 MHz in the high spectral resolution mode.
Note that spectra may show platforming between the FTS units. For deep integrations on faint broad lines, we recommend to use WILMA in parallel.

3.2 VESPA

The Versatile Spectrometric and Polarimetric Array can be connected to HERA and EMIR. It is also used for polarimetry measurements (see Polarimetry section below). When connected to a set of 4 IF channels from EMIR, VESPA typically provides up to 12 000 spectral channels (up to 18 000 channels are possible in special configurations). Nominal spectral resolutions range from 3.3 kHz to 1.25 MHz. Nominal bandwidths are in the range 10 to 512 MHz. VESPA basebands can be offset from band center by up to ± 250 MHz. When VESPA is connected to HERA, up to 18 000 spectral channels can be used with the following combinations of nominal resolution (kHz) and maximum bandwidth (MHz): 20/40, 40/80, 80/160, 320/320, 1250/640. For each one of these configurations, the maximum bandwidth can actually be split into two individual bands for each of the 18 detectors at most resolutions. These individual bands can be shifted separately by up to ±250 MHz offsets from the sky frequency. The many VESPA configurations and user modes are summarized in the VESPA users guide [17].

3.3 WILMA

The wideband autocorrelator WILMA consists of 18 units. Each unit provides 512 spectral channels, spaced out by 2 MHz and thus covering a total bandwidth of 1 GHz. WILMA can be connected to the 18 detectors of HERA, thus covering the entire bandwidth of both polarizations. A subset of 16 units can also be connected to EMIR covering a bandwidth of 4×4 GHz at a 2 MHz resolution. A technical overview of the architecture of WILMA is available at the following URL:

`http://www.iram.fr/IRAMFR/TA/backend/veleta/wilma/index.htm`

3.4 Continuum backends

The broad band continuum backend `bbc` with 8 GHz width, fully exploiting the bandwidths of EMIR, is available since 2-Aug-2011. `bbc` cannot be connected to HERA.
A narrow band continuum backend `nbc` with 1GHz width is available for HERA and EMIR.
These continuum backends are mostly used for pointing and focus observations. They have been successfully used for flux monitoring observations of quasars (cf. e.g. [20]). `bbc` has been used for monitoring of pulsars (cf. e.g. [21]).

4 Special observing modes

4.1 Frequency switching

Frequency switching is available for both HERA polarizations as well as for EMIR. This observing mode is interesting for observations of narrow lines where flat baselines are not essential. Certain limitations exist with respect to maximum frequency throw ($\leq$ 45 km/s), backends, phase times etc.; for a detailed report see [11]. This report also explains how to identify *mesospheric lines* which may easily be confused in some cases with genuine astronomical lines from cold clouds.

4.2 XPOL

Polarimetric observations can be made using a dual–polarization band of EMIR connected to VESPA in a setup designated as XPOL [18]. XPOL generates simultaneous spectra of all 4 Stokes parameters. The following combinations of spectral resolution (kHz) and bandwidth (MHz) are available: 40/120, 80/240, and 320/480. More complex observing modes where VESPA is split into two bands are also possible (see the VESPA `user guide` [17]). A technical description of XPOL, along with sample observing scripts and beam maps, are available on a new webpage at:

`http://www.iram.es/IRAMES/mainWiki/PolarimetryforAstronomers`

XPOL profits from the improved performance of EMIR in several respects: smaller or negligible phase drifts, small and stable offsets between the two polarizations, and negligible decorrelation losses. The alignment between both polarisations of the 3 mm band E 090 is perfect after the installation of an ortho-mode transducer with a single horn in November/December 2015.
The presence of polarised sidelobes makes observations of extended sources complicated as those sidelobes rotate with elevation, possibly because of the off–axis installation of EMIR. *Proposals for observation of extended sources should demonstrate that their observations are feasible in the presence of the known sidelobes.*
The 3mm instrumental circular polarisation has increased after the installation of new receiver cabin optics in April 2015 and after the installation of NIKA2 in October 2015. This can be calibrated in continuum observations, but strongly hinders spectroscopic XPOL observations to measure the Zeeman effect. Details of the ongoing investigation are presented `here`.
Potential XPOL users are asked to contact Gabriel Paubert (paubert@iram.es).

4.3 VLBI

The 30-meter telescope is open for 3 mm and 1 mm VLBI proposals.

5 Data processing software

5.1 EMIR, HERA

`CLASS` and `GREG` are the two main `GILDAS` software packages[1] available for off-line data reduction of EMIR and HERA continuum and spectral-line data.

[1] http://www.iram.fr/IRAMFR/GILDAS

MRTCAL is a new GILDAS software package to calibrate EMIR and HERA data. Data processing at the telescope was switched from MIRA to MRTCAL in February 2017 for standard spectroscopic EMIR and HERA data. For the moment, polarimetry (XPOL) and continuum (pointing, focus, skydip) data will continue to be automatically calibrated with MIRA. As soon as possible, these will also be calibrated by MRTCAL.
As usual, only one version of the automatically calibrated CLASS files is delivered to the observer. The MRTCAL package has been distributed in the standard GILDAS distribution, since the jun16 version. The development team nevertheless requires to upgrade your GILDAS version to feb17 (or a more recent version), as bugs of MRTCAL were only fixed starting with this version. While still distributed for some time in the GILDAS distribution, the MIRA package will not be supported anymore for standard spectroscopic data.
MRTCAL was first devised to give a higher calibration accuracy. In particular, the calibration is now a function of the RF/IF frequency with a determination of the calibration parameters, e.g., $T_{\rm sys}$, typically every 20 MHz. This particularly improves the calibration in the vicinity of atmospheric absorption lines. MRTCAL was also revised to be efficient. It is fast, in preparation of the arrival of the next generation of multi-beams receiver at the 30-meter telescope. The current speed limits are the reading and writing of the data on disk. MRTCAL is able to calibrate data sets that do not fit in RAM memory.
MRTCAL documentation includes:

- A quickstart tutorial
- The user manual
- The developer manual
- An overview of the MRTCAL project

5.2 NIKA2

5.2.1 Online data reduction

A real-time monitor, the IDL pipeline[14], which has been developed by the NIKA2 consortium, is used to view pointing and focus results, and give a first view of the uncalibrated data in general.
The PIIC-monitor software for NIKA2, developed at IRAM, is used in-parallel with the aim of a first data assessment, and in particular to display pointing and focus results. PIIC uses the most recent 225 GHz atmospheric opacities measured by the taumeter to obtain a first, rough calibration to the Jy/beam scale.

5.2.2 Offline data reduction

The IDL data pipeline is being used for the offline data reduction and has been further enhanced in the past months.
In October this year, PIIC will be made available to the users for offline data reduction, together with a user guide.

6 Observing time estimates

6.1 EMIR, HERA

For EMIR and HERA, the concise on-line time estimator shall be used, which is available at the following URL:

http://www.iram-institute.org/EN/content-page-150-7-55-150-0-0.html

If very special heterodyne observing modes are proposed which are not covered by the Time Estimator, proposers must give sufficient technical details so that their time estimate can be *reproduced*. In particular, the proposal must give values for $T_{\rm sys}$, the spectral resolution, the expected antenna temperature of the signal, the signal/noise ratio that is aimed for, all overheads and dead times, and the resulting observing time.
For summer semesters, proposers should base their time request on normal Summer conditions, corresponding to 7 mm of precipitable water vapor (pwv). And for winter semesters, proposers should base their time request on normal winter conditions, corresponding to 4 mm of precipitable water vapor (pwv). All over the year, conditions during afternoons can be degraded due to anomalous refraction. The observing efficiency is then reduced and the flux/temperature calibration is more uncertain than the typical 10 percent.
Proposers requesting observations which need pwv values lower than 7 mm (for summer semesters) or 4 mm (for winter semesters) should enter the maximum acceptable pwv value on the PMS proposal page. Very demanding proposals, e.g. observations using E 330 above 300 GHz, or some very deep and/or high frequency continuum observations, may need pwv values $\leq$ 2mm. These observations will be scheduled in a pool.

6.2 NIKA2

The NIKA2 time estimator python script is available on the NIKA2 home page.

7 Organizational aspects

7.1 Pooled observing

The pooled observing mode offers a flexible way of scheduling weather demanding projects. Contrary to the traditional scheduling where a fixed time slot is reserved in advance for a given project, pooled projects are scheduled dynamically during pool sessions, typically one weeks long, to better exploit the best weather conditions at the Pico Veleta. For instance, accepted EMIR or HERA high frequency ($\lambda \leq 1.3$ mm) proposals may be pooled into the "1 mm weather" queue, in which case they would be observed when the atmospheric precipitable water vapor column (pwv) falls below 5 mm. Similarly, projects requesting less than 2 mm of pwv are usually pooled into the "best weather" queue. A correct specification of the pwv on the technical summary page is therefore very important. Heterodyne proposals which are particularly weather-tolerant are used as backup projects during pool sessions to fill in the gaps between periods of good weather conditions. Pooled observations are offered since 2002 at the 30-meter telescope, and they have proven to be a very efficient and successful mode of observations. *Participation in the pools may be requested explicitly by ticking the appropriate box on the proposal form.* The 30m scheduler may also select projects that would benefit most from the pool scheduling flexibility, or are otherwise well suited to be included in the pools. Pooled observations should be simple and straightforward to carry out, using only standard setups. For instance polarization measurements using XPOL are not appropriate for pool observing.
Proposals participating in the pools will be observed by the PIs and Co-Is of participating projects, and the IRAM staff. The organization of the observing pools is described in more details on the `IRAM 30-meter web site`. Questions concerning the pool organization can be directed to the scheduler (kramer@iram.es) or to the pool coordinators.

7.2 Service observing

To facilitate the execution of short (≤8 h) programs, we propose "service observing" for some easy to observe programs *with only one set of tunings*. Observations are made by the local staff using precisely laid–out instructions by the principal investigator. For this type of observation, we request an acknowledgement of the IRAM staff member's help in the forthcoming publication. If you are interested in this mode of observing, specify it as a "special requirement" in the proposal form. IRAM will then decide which proposals can actually be accepted for this mode.

7.3 Remote observing

`Remote observations` with the 30-meter telescope are now routinely possible. The telescope is controlled in real time via vnc–viewers. Remote observations are restricted to experienced 30m observers only.
Note that remote observations are best conducted from dedicated remote stations (Granada or Madrid), which offer large screens to accommodate the various displays necessary for the command interface and to monitor the observations. Other advantages are the readily available documentation and a phone, as well as local help that is usually available. As a safeguard, please email observing instructions and macros to the Astronomer of Duty (AoD) and/or operator. A detailed user guide for remote observing is available on request.

Reminders: For any questions regarding the telescope and the control programs, we recommend to consult the `summary of telescope parameters` and the `NCS web pages`. The applied calibration procedure for heterodyne observations is explained in in a dedicated report [19]. A new report describing calibration with `MRTCAL` is in preparation. More reports and publications related to the calibration are compiled here:

`http://www.iram.es/IRAMES/mainWiki/CalibrationPapers`

The astronomer on duty may be contacted for any special questions concerning the preparation of an observing run. The AoD schedule is available at

`http://www.iram.es/IRAMES/mainWiki/AstronomerOnDutySchedule`

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