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Receivers for ALMA: Preliminary Design Concepts

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ABSTRACT

The Atacama Large Millimeter Array (ALMA), a joint project between Europe and the U.S. and at present in its design and development phase, is a major new ground based telescope facility for millimeter and submillimeter astronomy. Its huge collecting area (7000 m^2), sensitive receivers and location at one of the driest sites on Earth will make it a unique instrument. We present preliminary design concepts for the overall receiver configuration. Optics and cryostat design concepts from OSO, OVRO, RAL, IRAM, NRAO and SRON and their main features are described.

Keywords: Interferometer, receivers, SIS receivers

THE ATACAMA LARGE MILLIMETER ARRAY (ALMA)

The Atacama Large Millimeter Array (ALMA) is a giant millimeter- and submillimeter wavelength telescope project. As presently envisaged, ALMA will be comprised of up to 64 12-meter diameter antennas distributed over an area 10 km across. The large number of antennas gives a total collecting area of over 7000 square meters. ALMA will cover all the atmospheric windows from 30 GHz to 950 GHz. ALMA emerged as a joint project from the U.S. MMA project (Millimeter Array) and the European LSA (Large Southern Array). The design and development phase of the project is now underway as a collaboration between Europe and the U.S., and Japan may also join in this effort. Assuming the construction phase begins about two years from now, limited operations of the array may begin in 2005 and the full array may become operational by 2009.

The chosen location for ALMA is Llano de Chajnantor in the Atacama desert, at 5000 meters altitude and 60 kilometers east of the village of San Pedro de Atacama, Chile. The Chilean government has set aside a large part of the Zona de Chajnantor as a scientific preserve under the stewardship of CONICYT, the Chilean agency for science and technology. ALMA will be the highest continuously operated observatory in the world.

The scientific case for this revolutionary telescope is overwhelming. ALMA will make it possible to witness the formation of the earliest and most distant galaxies. It will also look deep into the dust-obscured regions where stars are born, to examine the details of star and planet formation. But ALMA will go far beyond these main science drivers, and will have a major impact on virtually all areas of astronomy. It will be a millimeter-wave counterpart to the most powerful optical/infrared telescopes such as ESO's Very Large Telescope (VLT) and the Hubble Space Telescope, with the additional advantage of being unhindered by cosmic dust opacity.

The latest information on ALMA can be found at the ALMA web sites which are updates regularly: http://www.eso.org/projects/alma and http://www.alma.nrao.edu .

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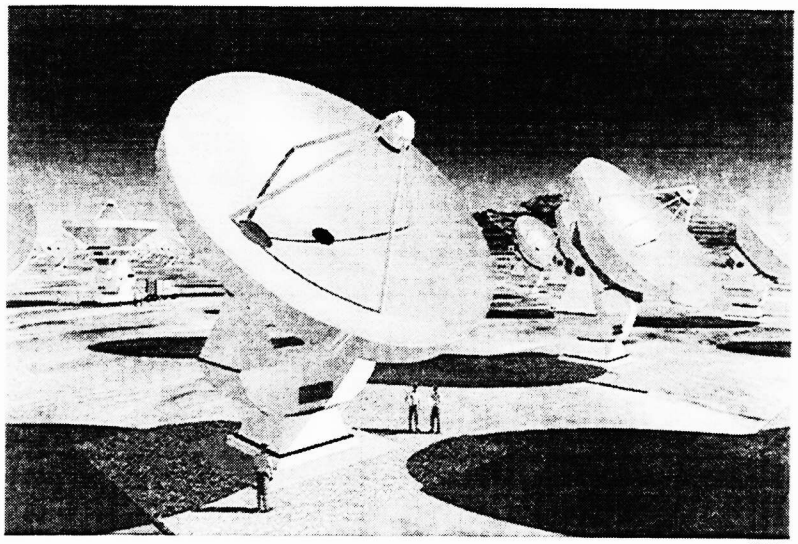

ESO PR Photo 2a/99 (5 June 1999) Artist's Impression of ALMA (Atacama Large Millimetre Array) © European Southern Observatory

Fig. 1: Artist's conception of ALMA

RECEIVER REQUIREMENTS

An important key element of ALMA are the receivers. In order to achieve maximum sensitivity, high bandwidth and lowest possible noise are required. In addition, high reliability and suitability for mass production are necessary. Each antenna will be equipped with receivers covering the atmospheric windows in 10 bands, each band in dual linear polarization. In total, ALMA requires 1280 receiving channels. For a preliminary design concept study, the main requirements for the ALMA receivers were:

1. **Optics:** The telescope will provide a f/8 beam. Locating receiver windows at an offset from the optical axis is possible within limits, and has been shown to lead to negligible efficiency loss (see ALMA memo series). The optics design needs to allow the add-on of band 1 (e.g. via a pick-off mirror), simultaneous 183 GHz water vapor monitoring (for the correction of phase fluctuations caused by water vapor in the atmosphere), and fast phase switching.

2. **Frequency bands:** 10 bands from 30 to 950 GHz (see Table 1), covering the atmospheric windows (Fig. 2). All bands dual linear polarization. There will be at least 9 frequency bands in the main dewar. Band no. 1 (30 – 40 GHz) can be outside of the main dewar. For the lowest frequency bands, HFET amplifiers will be used, and for the other frequencies SIS mixers. Although theoretically, single sideband receivers provide higher sensitivity than double sideband receivers (due to the suppression of atmospheric noise in the unwanted sideband), in practice, the gain achieved with a single sideband system may not justify the added complexity for the higher frequency channels. This issue is under discussion at present.

3. **Observing modes:** The following observing modes will to be supported:

   Single frequency, dual linear polarization. No simultaneous dual (or multiple) frequency observing is foreseen.

   In parallel and during all observations: a 183 GHz cooled Schottky water vapor monitor, wvm, (single or dual polarization, depending on the required sensitivity), as well coaligned as possible with the beam at the observing frequency. At present, a maximum of 3 arcmin between the observing beam and the Schottky beam seems acceptable.

   Fast phase switching: the receiver has to allow fast switching (settling time less than 1.5 sec) between the observing frequency, and a (fixed, predetermined) frequency in the 3 mm band. The switching has to preserve the phase. The ALMA antennas will be capable of changing the source position by 1.5 degrees within 1.5 seconds, and this has to be matched by the receivers.

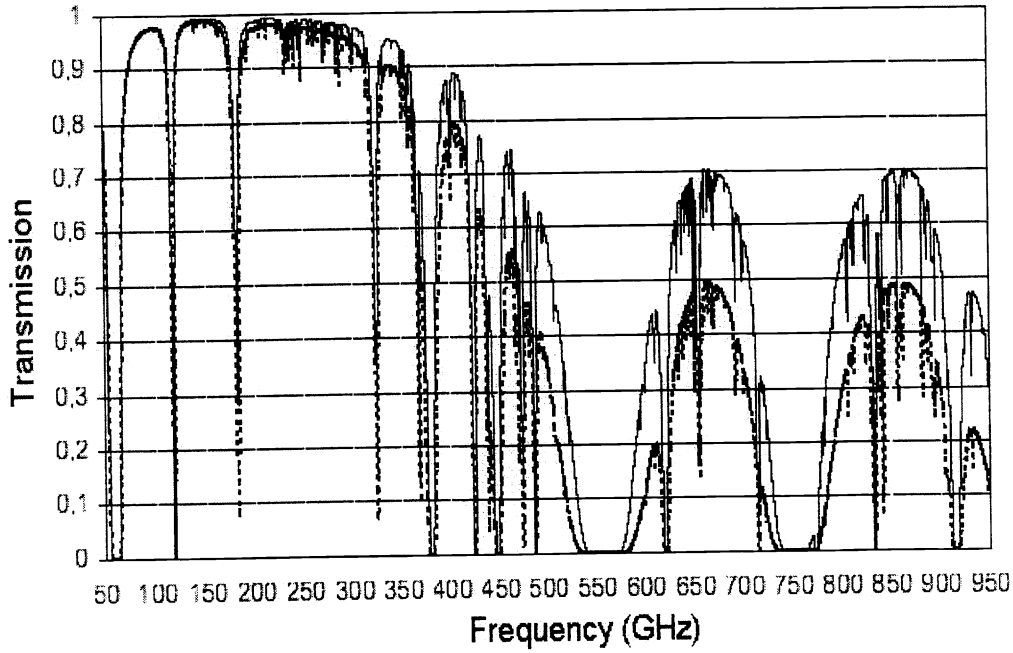

Fig. 2: Calculated atmospheric transmission for 0.5 mm (solid line) and 1 0 mm (dashed line) pwv at Chajnantor.

Frequency switching in single dish mode: frequency throw of 0.03 % of the observing frequency, switching time max. 10 msec.

4 **Cryogenics:** Cooling the mixers (and junctions) to 4 K is considered to be sufficient. Consequently, a 4 K system was considered in the conceptual design. Two more temperature stages, presumably around 15 K and 70 K, will be required.

5. **Modular design:** Given the large number of frequency channels and groups to provide them during the construction phase of ALMA, a modular approach seems inevitable. One option is to provide one module per frequency band. Sufficient space needs to be reserved in the dewar for the frequency modules. The exchange of whole modules and components should be as easy as possible.

Table 1: Frequency bands for ALMA

Band	low freq (GHz)	center freq (GHz)	high freq (GHz)	rel. bandwidth (high-low)/ctr	high/low
1	30	35	40	0,286	1,333
2	67	79	90	0,291	1,343
3	89	103	116	0,262	1,303
4	125	144	163	0,264	1,304
5	163	187	211	0,257	1,294
6	211	243	275	0,263	1,303
7	275	323	370	0,294	1,345
8	385	442	500	0,260	1,299
9	602	660	720	0,179	1,196
10	787	869	950	0,188	1,207

OVERALL DESIGN CONCEPTS

Receiver design concepts have been proposed by OSO, OVRO, RAL/ATC, IRAM, NRAO, and SRON. These concepts should be regarded as a first attempt to explore the design options. The optimum receiver configuration is under discussion at this point, and not all specs have been finalized. In the following we will briefly describe the main features of the different concepts.

ONSALA SPACE OBSERVATORY

Fig. 3 shows a design proposed by V. Belitsky (OSO) and S. Torchinsky (University of Calgary). Its main features include:

- Each frequency band has its own dewar window, located in a circle around the center of the dewar. Distribution of the central beam is achieved via a central flat mirror M1 mounted on a rotating plate. Flipping M1 allows a receiver to look into a central cold load for calibration. The design could be made more compact by replacing the flat mirror M1 with a refocusing mirror.

- The 183 GHz water vapor monitor (wvm) is located off-axis within 3 arcmin and also mounted on the rotating plate. This way the wvm is always placed away from the beam path , it does not interfere with the receiver beam and still stays close to the center.

- All mixers are placed around the center of the dewar which simplifies the 4 K cooling with a minimum length of a cold strap. This also allows a clean mechanical interface to the cryocooler.

- All frequency bands have a unified layout, thus simplifying the mechanical design and mass fabrication. Electrical connections are made through the top or bottom plates. The LO is coupled in from below.

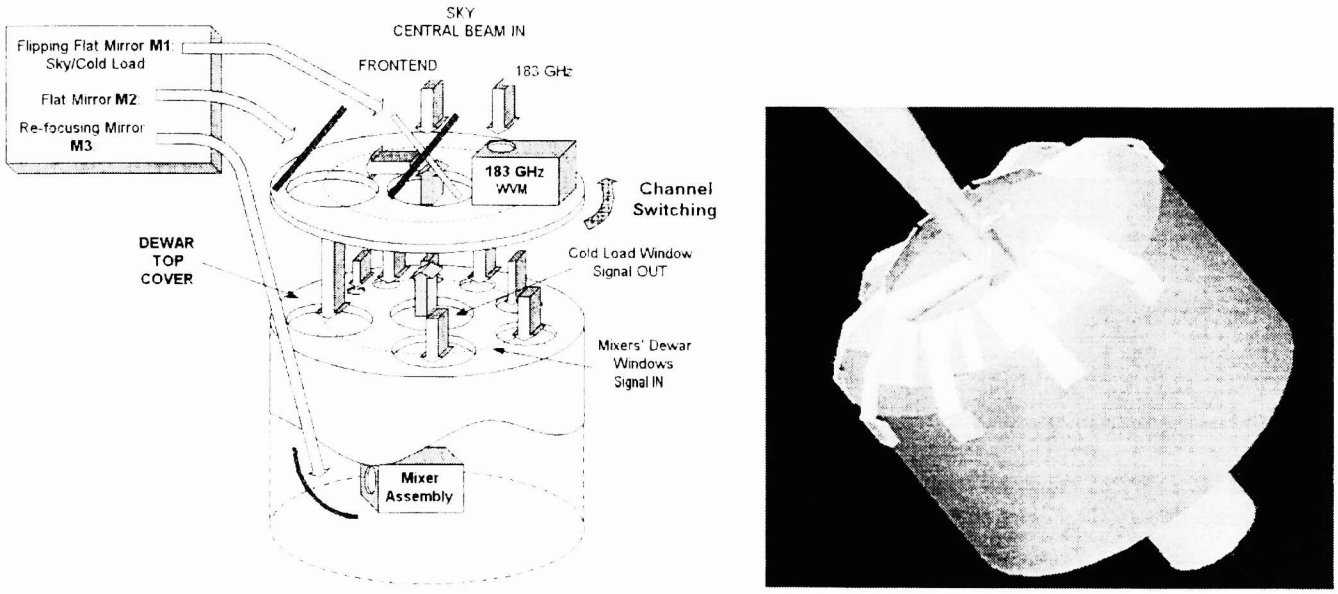

Fig. 3: Design proposed by the Onsala Space Observatory. Left: Optical configuration. Right: View of the dewar and external optics.

OWENS VALLEY RADIO OBSERVATORY

Fig. 4 shows a design proposed by J. Lamb from OVRO. Its main features include:

- As in the previous concept each frequency band has its own dewar window, located in a circle around the center of the dewar. Selection of the band is achieved via a rotating flat mirror placed off-axis and a band specific off-axis elliptical mirror.
- The 183 GHz water vapor monitor is placed at the center of the dewar and includes a rotating wedged plate to scan the beam in a circle on the sky. This allows to measure the tilt of the wavefront due to water vapor ("anomalous refraction").
- Corrugated feedhorns for the lower frequency bands (up to 370 GHz) are placed close to the dewar window. The higher frequency bands may have re-imaging optics, LO injection etc. inside the dewar.
- The optics design is optimized for each frequency band and provides high efficiency. The dewar is compact, has a small window area and is mechanically strong (non-flat top).

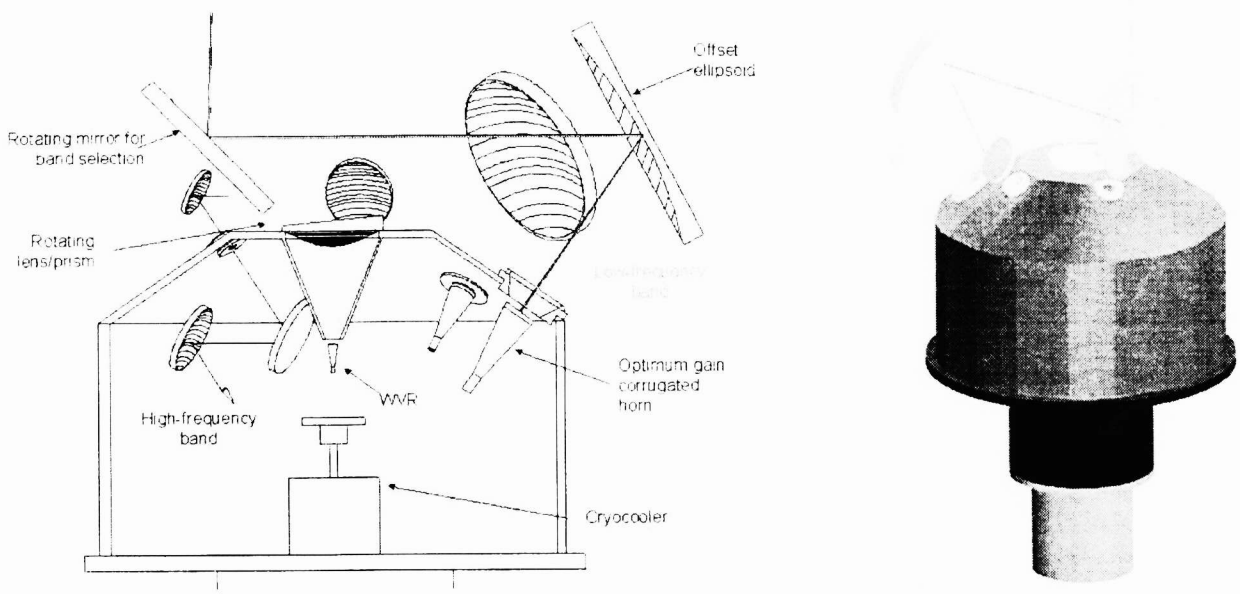

Fig. 4: Design proposed by OVRO. Left: Optical configuration. Right: View of the dewar and external optics.

RUTHERFORD APPLETON LABORATORY

Fig. 5 shows a design proposed by B. Ellison, M. Harman, T. Bradshaw, A. Orlowska and R. Wade from RAL. Its main features include:

- 10 windows (one for each frequency band, shown here with equal size for simplicity) are located on a ring on the top of the cryostat vacuum vessel. Selection of the band can be done by external mirrors, either fixed for each band, or a movable selection mirror. Inside the cryostat there are band dedicated cold re-imaging optics directing the beams onto tube shaped sub-assemblies called cartridges.
- There are 10 cartridges, seven of diameter 170 mm and three of diameter 100 mm. All band dedicated receiver components (such as mixers, amplifiers etc.) are mounted into the cartridges which are assembled from the base of the

cryostat utilizing a "plug in, pull out" design approach. This gives significant operating advantages (easy change of cartridges, standard size of cartridges, possibility of upgrades etc.)

- The cryocooler is a 2 stage pulse tube refrigerator (achieving 70 K and 15 K) and a JT system (achieving 3.8 K). Thermal connection is provided through flexible thermal links on three plates for the three temperatures.

- A cartridge consists of a flange on the base (providing the vacuum seal and electrical feed throughs), a tube shaped support structure, and cold plates for 4 K, 15 K and 70 K. During cooldown the flexible thermal links actively clamp the cold plates on the cartridges.

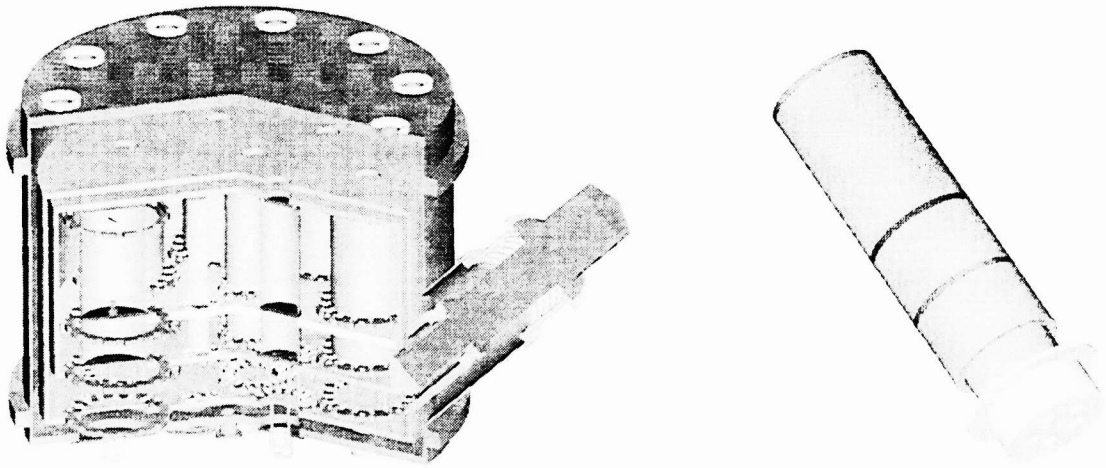

Fig 5: Cryostat design proposed by RAL. Left: Cryostat design. Right: Insertable cartridge.

INSTITUT DE RADIO ASTRONOMIE MILLIMETRIQUE

Fig. 6 shows an optics design proposed by M. Carter and B. Lazareff from IRAM. Its main features include:

- A central rotating flat off-axis mirror selects the observing band. By rotating 180 degrees, the observing band looks into a cold calibration load located at the center of the dewar.

- A small flat mirror directs the central beam to the 183 GHz water vapor radiometer (not located in the main dewar).

- Each frequency band has its own refocusing optics with an external mirror located on a ring and directing the beam at an angle into the dewar.

- Inside the dewar, dedicated optics focus the beam into corrugated feed horns or (in the case of the higher frequency bands) into Martin-Puplett diplexers for sideband separation.

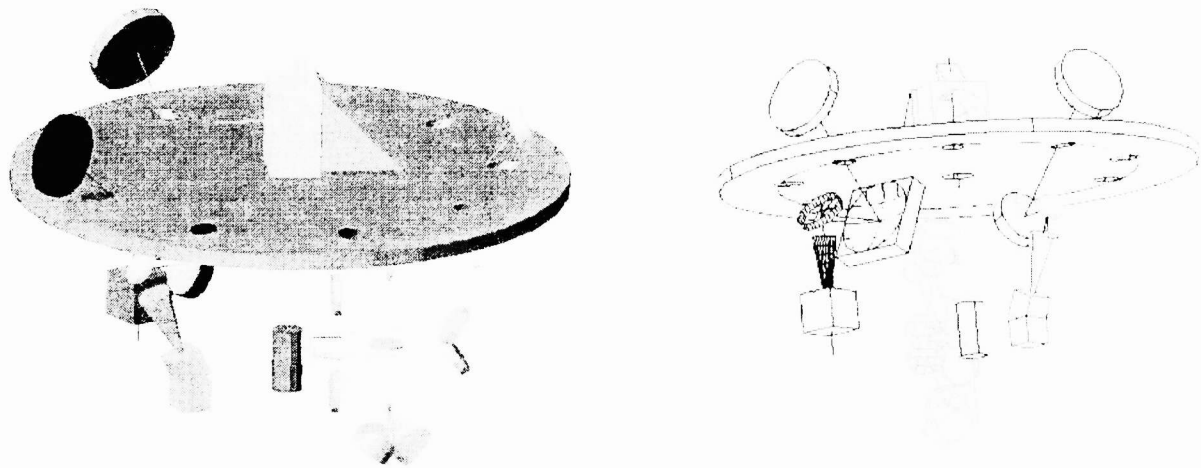

Fig 6: Optics design proposed by IRAM.

NATIONAL RADIO ASTRONOMY OBSERVATORY

Fig. 7 shows a design proposed by J. Payne from NRAO. Its main features include:

- Each frequency band has a cryostat window located on a ring around the dewar center. Band selection is via offset pointing of the antenna. Different optical schemes (e.g. a rotating selection mirror, fixed band specific mirrors) are possible.
- The mixer assemblies are mounted in rocket type support structures which are inserted from the bottom of the cryostat. They are connected to a 4 K plate with a cold strap.
- The cryocooler is located at the center of the dewar.
- The overall design aims for simplicity and compactness.

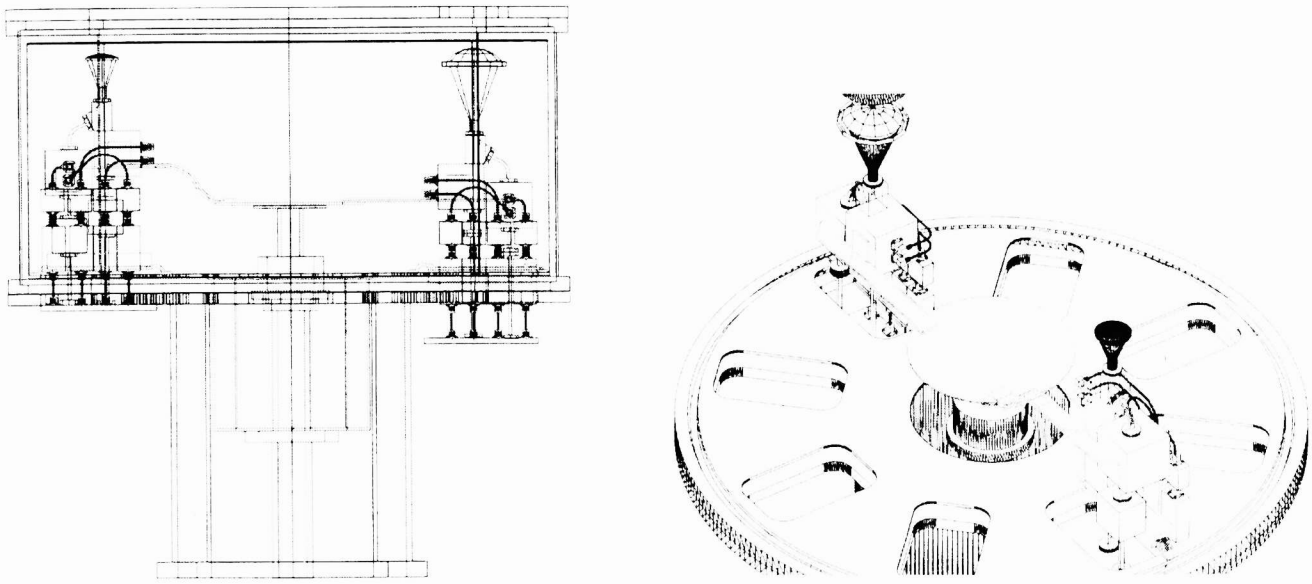

Fig. 7: Receiver configuration proposed by NRAO.

SPACE RESEARCH ORGANIZATION NETHERLANDS

Fig. 7 shows an optics design proposal by A. Baryshev and W. Wild from SRON. Its main features include:

- Fixed mirrors close to the dewar center distribute the beams to band specific mirrors (not shown) located further from the axis. The 183 GHz water vapor monitor is fed with the central beam, either directly in the dewar or via a pick-off mirror. All bands a re within 3 arcmin of the central beam.
- Each frequency band occupies a sector in the dewar. The sector for band 2 is larger to avoid shading of other beams by the band 2 fixed mirror. The radial location of the dewar entrance window can be chosen and can be different for each band. The optics can be optimized for each frequency band.
- The fixed mirror can be re-arranged such that the high frequency channel beams are closer to the center and the water vapor monitor (Fig. X right).
- The dewar diameter is 760 mm, the height is a free parameter within the receiver cabin limits.

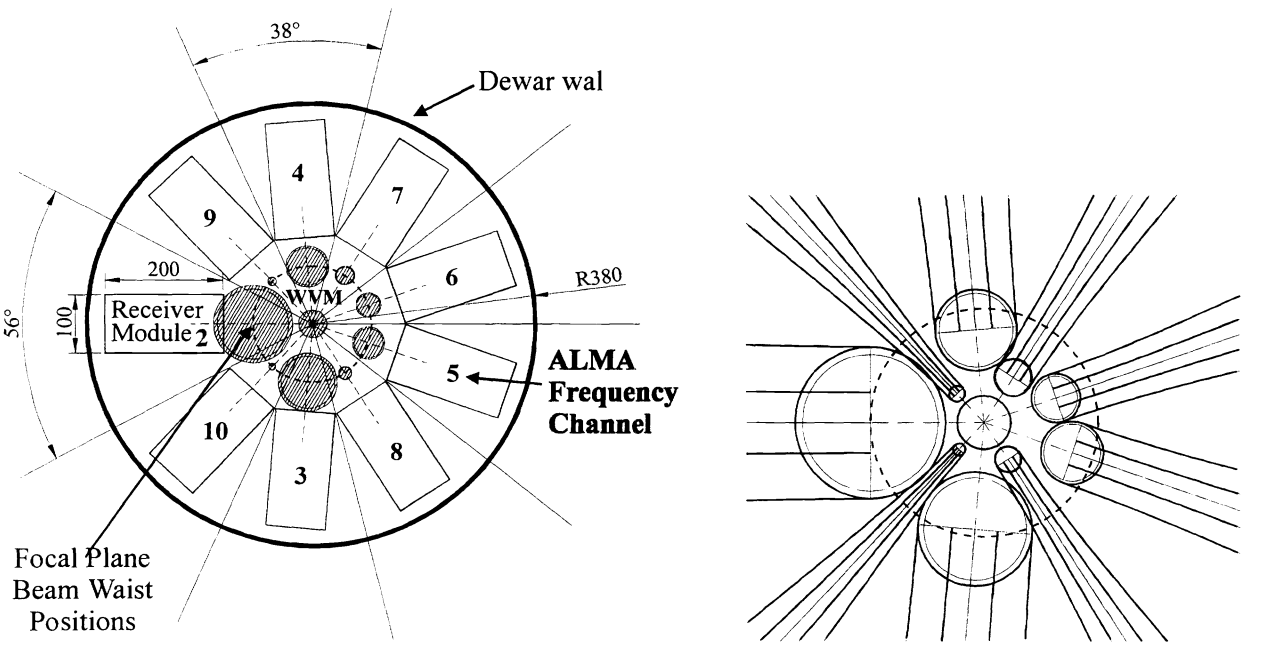

Fig. 7: Optics layout proposed by SRON. Left: Top view of the cryostat. Right: Distribution of fixed mirrors and beams.

CONCLUSION

We have presented various conceptual receiver designs for ALMA. Each of these design concepts emphasizes different aspects of the overall receiver configuration. One of the near term tasks will be to try to incorporate the best features of each design into a baseline concept which satisfies the specifications for ALMA receivers.