FIRST STEPS IN
SHORT mm AND sub mm ASTRONOMY

Memories of a beautiful era

by V. Soglasnov

Submillimeters are not my area, but I had the opportunity to observe how, through the efforts of a small group of my colleagues, a new area of observational astronomy was created practically from scratch, real astronomical observations were carried out for the first time in the millimeter and submillimeter ranges. Two areas of their activity should be specially noted: these are observations at a high-mountain site in the Eastern Pamir (4350 m asl) at four windows of transparency (0.81, 0.58, 0,44 and 0.33 mm), and the development of a unique technology for calculating and manufacturing mesh filters for millimeter and submillimeter wavelengths. These results are a priority.

FIRST STEPS IN
SHORT mm AND sub mm ASTRONOMY

PREHISTORY

1953: Shklovsky creates the department of radio astronomy at the Sternberg Astronomical Institute (SAI)

From the very beginning, research was not limited only to the radio range, in fact it was the department of all-wave astronomy - far UV and X-ray, optics, except for the submillimeter range. At that time, there were not enough sensitive receivers for this wavelength range, but the main obstacle is the strong absorption in the earth's atmosphere of waves of short millimeters and submillimeters by molecules of oxygen and water (see slide 8), observations are possible only in separate windows of transparency, therefore good filters are needed to block radiation outside these windows. In the sixties (of the last century), the development of semiconductor technology led to the appearance of bolometric-type millimeter-wave detectors, suitable for astronomical observations. The first trial observations at a wavelength of 1mm were carried out by Low at the 5-m telescope of the Mount Palomar Observatory, 3 planets were observed, Venus, Mars and Jupiter.

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PREHISTORY

May 15, 1965: on the initiative of the President of the USSR Academy of Sciences M. V. Keldysh, by Decree No. 392-147 of the USSR Council of Ministers the Space Research Institute (IKI) of the USSR Academy of Sciences was founded.

1967: Shklovsky became the head of the astrophysics department at IKI, keeping the position at SAI.

IK&ISAI alliance: more money, more manpower, and the main hope: to go beyond the atmosphere! (unfortunately, it never came true)

FIRST STEPS IN
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Now HISTORY

1968: IKI&SAI Alliance: creation of a submillimeter group (later added by ASC). The very next year began the first astronomical observations at short millimeter wavelengths of planets, galactic and extragalactic sources, as well as SMB.

At various times, the group included:

Maslov, I. A.; Soglasnova, V. A.; Sholomitskii, G. B.; Gromov, V.D.; Nikolskii, Y. V.; Maslennikov, K. L; Khokhlov, M. Z. ; Artamonov, V. V. ; Zabolotnyi, V. F. ; Rizov, E. F. ; Iudin, B. F. ; Kostenko, V. I. ; Slysh, V. I. ; Pavlov, A. V. ; Shcherbina-Samoilova, M. B.

SUB– mm GROUP ACTIVITY

Observations:

1969–1973: RT22, Simeiz

1981–1987: 6 m telescope

1986–1990: Pamir

Instrumentation:

1969–2002: Radiometers

1969–2002: Band Pass Filters

International collaboration:

Germany, Italy, France

FIRST OBSERVATIONS

RT22, Simeiz, 1969–1973

First Astronomical Observations at short mm

Planets

Galactic&extragalactic sources

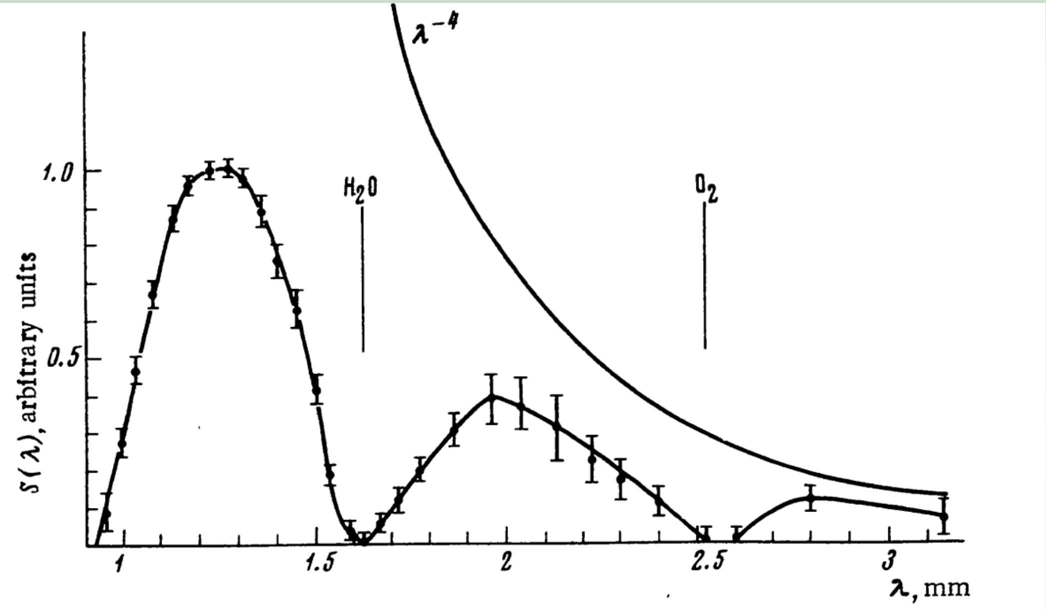


Fig. 8. Spectral distribution of radiation of the sun when its elevation was 64° and the humidity was 11 g/m^3, taken at sea level.

RT22, Simeiz, 1969–1973

First Astronomical Observations at short mm

Planets

Galactic&extragalactic sources

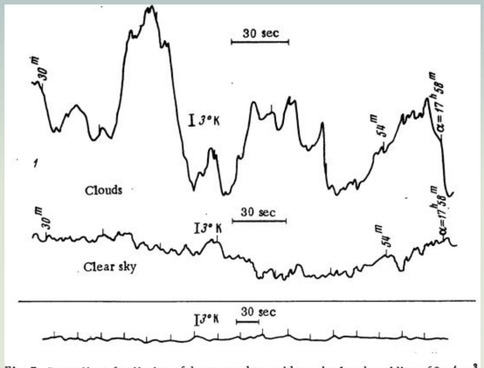


Fig. 7. Recording of radiation of the atmosphere with an absolute humidity of 8 g/cm^3 and a time constant of 1 sec; 1) with amplitude modulation; 2) with diagram modulation.

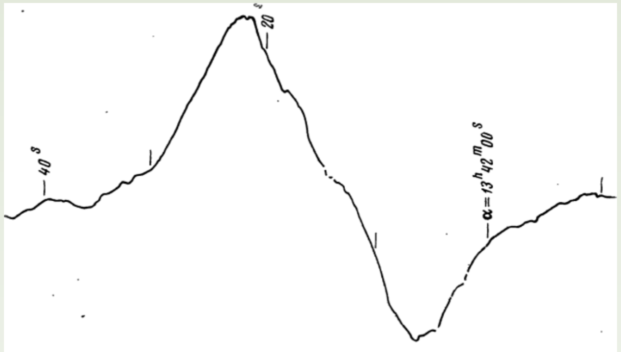


Fig. 9. Recording of the passage of Jupiter with beam-switching when its elevation was 35°, the absolute humidity of the air was 11 g/m^3, and with a time constant of 10 sec.

Planets

Brightness temperatures of the planets at λ1.4 mm

Planet	Brightness temperature (K)	Date of measurement	Phase angle (deg)
Mercury	$480+80$	25 July 1969	121
	162 ± 30	25–31 May 1970	129
	240 ± 30	7–8 June 1970	93
Venus	270 ± 30	18–25 July 1969	
	258 ± 42	May–June 1970	
Mars	180 ± 50	May–June 1970	
Jupiter*	145		
Saturn	120 ± 30	July 1969, June 1970	
Uranus	95 ± 28	31 May, 9–10 June 1970	
Neptune	160 ± 110	10 June 1970	

* Reference source

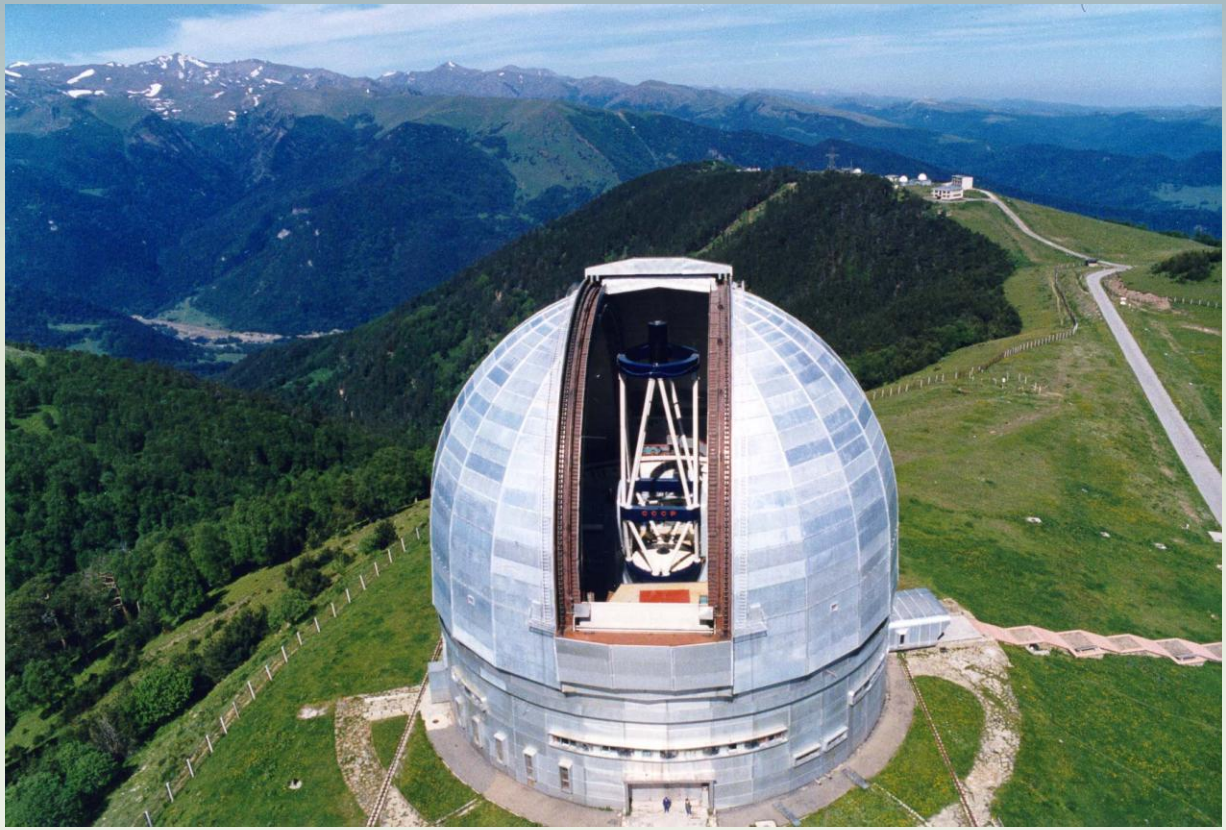
Sources

TABLE 1

Source	Coordinates $\alpha_{1950.0}$	Coordinates $\delta_{1950.0}$	Adopted angular size	Date of observation	Method of observation	Effective wavelength, mm	Flux density, 10^{-26} W $\cdot$ m^{-2} $\cdot$ Hz^{-1}	Error of measurement, 10^{-26} W $\cdot$ cm^{-2} $\cdot$ Hz^{-1}
DR 21	$20^h37^m14^s.2$	42°09′06″ [9]	0′.3×0′.3 [10]	1970 Jun	60 min, cum.	2.0	14	12
NGC 1275	03 16 30	41 20 [11]	0′.6×0′.45 [11]	Jun 11	90 min, cum.	1.8	67	10
NGC 4151	12 08 02	39 40 48 [11]	0′.7×0′.7 [11]	May 31	17 scans	1.8	<55	—
NGC 1976	05 32 46.8	−5 24 15 [12]	3′.4×2′.6 [12]	Jun 7	4 scans	2.0	580	100
NGC 3034	09 51 54	69 56 06 [11]	25″×6″ [13]	May 25	50 min, cum.	1.8	<50	—
NGC 7027	21 05 09.4	42 02 03 [14]	10″×10″ [14]	Jun 8-11	Cumulative	2.0	14	8
3C 273	12 26 33.0	02 19 38	<1″	May 25	40 min, cum.	1.8	101	29
—	—	—	—	Jun 4	80 min, cum.	1.8	80	23
—	—	—	—	Jun 7	100 min, cum.	1.8	82	15
—	—	—	—	Jun 10	70 min, cum.	1.8	47	13
W49 A1	19 07 48	09 00 12 [15]	3′.1×3′.1 [15]	May 31	70 min, cum.	2.0	165	43
W51 A1	19 21 25	14 23 42 [10]	1′.7×1′.4 [10]	Jun 7	90 min, cum.	2.0	200	29
IRC + 10216	09 45 14.8	13 30 40 [16]	2″×4″ [17]	May 23	80 min, cum.	1.4	15	16
3C 144	05 31 30	21 58 24	2′.4×4′.0 [18]	1969 Jul 21, 22, 25	Scanning	2.5	600	150
—	—	—	—	1970 May 23, 31	—	—	—	—
Sgr A	17 42 30	−28 59 12	2°×0°.5 [19]	May 25, 26, 29	Scanning	1.8	$<2\cdot10^6$	—

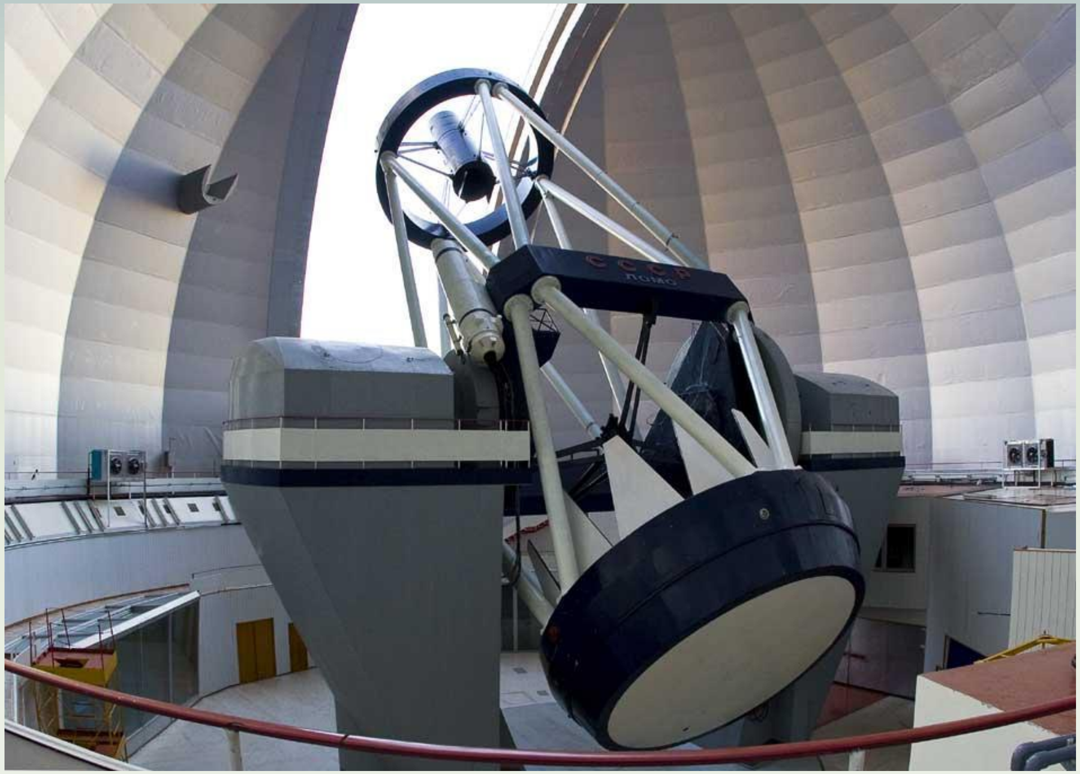
Note: cum. = cumulative observation.

1981–1987: 1.1 mm observations of galaxies with the 6 m telescope, joint work with MPIfR



1981–1987: 1.1 mm observations of galaxies with the 6 m telescope, joint work with MPIfR

1.1 mm observations with the SAO 6 m telescope in 1981 indicate the larger flux density of the parent galaxy of Cyg A as compared to that measured at 1.3 mm in 1987. The 1.1 mm flux density of the Vir A radiogalaxy is consistent with its steep power spectrum. Upper limits for the galaxies AKN 253 and MK 50 are also given.



EASTERN PAMIR

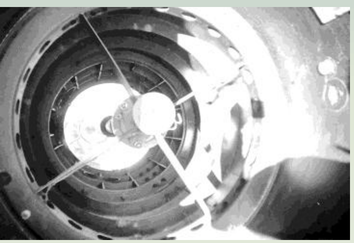
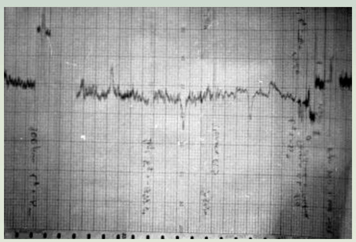
h=4350 m above sea level, 70-cm telescope

1986–1990: Pamir
h=4350 m above sea level, 70-cm telescope

1986–1990: Pamir, work and relax.
h=4350 m above sea level, 70-cm telescope

1986–1990: Pamir, work and relax.

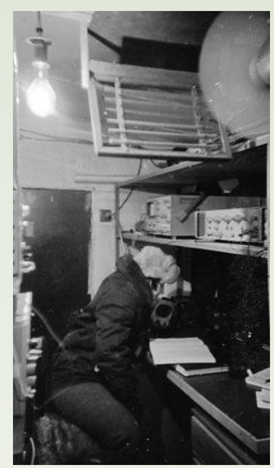
h=4350 m above sea level. At this altitude, it takes at least a week to acclimatize perfectly. In contrast of Tibet site they had no oxygen station.










1986–1990: Pamir

h=4350 m above sea level, submm transparency

TABLE I. Amount of Precipitable Water* and Clear Time at Shorbulak for 15 Months of 1976-1977

No.	Month	Number of probe launches	Average monthly precipitable water, mm	Root-mean-square scatter, mm	Fraction of time with an amount of precipitable water no more than, mm				Fraction of time with cloudiness not exceeding 0 and 3 points	
					0.5	1	2	3	0	3
1	January 1976	123	1.51	0.43	0.00	0.04	0.86	1.00	0.50	0.60
2	February	70	1.59	0.45	0.00	0.14	0.74	1.00	0.33	0.43
3	March	58	1.48	0.52	0.00	0.22	0.72	1.00	0.24	0.34
4	April	57	2.68	0.88	0.00	0.00	0.32	0.50	0.11	0.37
5	May	66	3.42	0.93	0.00	0.00	0.06	0.20	0.23	0.32
6	June	65	4.37	1.63	0.00	0.00	0.06	0.28	0.28	0.42
7	July	69	5.13	1.58	0.00	0.00	0.04	0.08	0.41	0.49
8	August	62	4.31	1.17	0.00	0.00	0.00	0.08	0.40	0.63
9	September	78	2.64	1.03	0.00	0.00	0.22	0.74	0.53	0.83
10	October	115	2.38	0.7	0.00	0.02	0.30	0.76	0.34	0.57
11	November	111	1.63	0.58	0.00	0.18	0.76	0.96	0.26	0.36
12	December	104	1.31	0.29	0.00	0.18	1.00	1.00	0.34	0.53
13	January 1977	122	0.85	0.45	0.22	0.72	1.00	1.00	0.18	0.26
14	February	111	0.93	0.34	0.06	0.64	1.00	1.00	0.43	0.50
15	March	70	1.24	0.64	0.18	0.43	0.78	1.00	0.40	0.50
	Average		2.36	0.70	0.03	0.17	0.52	0.71	0.33	0.48

* The amount of precipitable water was determined by integration for heights of more than 4350 m (the altitude of the telescope at Shorbulak) only for launches at a cloudless time.

1986–1990: Pamir
h=4350 m above sea level, submm transparency

TABLE II. Comparison of Amount of Precipitable Water at Three Sites above 4000 m*

Site	Altitude	Time	Average value, mm		Minimum value **
			Winter	Summer	
Mauna Kea, Hawaiian Islands, USA	4200	1971–1972	1.3	2.3	0.4
White Mountain, California, USA	4340		0.7? ***	3.0	0.3
Shorbulak, Eastern Pamirs, Tadzhik SSR	4350	1976–1977	1.39 1.01	3.75	0.31

* And below 5000 m (Mt. Chacaltaya not included).
** Determined from the five minimum readings.
*** The question mark is from Ref. 8.

1986–1990: Pamir
h=4350 m above sea level, 70-cm telescope

TABLE I. Calibration Data

Wavelength mm	Transmissivity of telescope optics	Diffractive transmittance for point source	Brightness temperature of sun, K	Brightness temperature measured for planets, K	
				Mars	Jupiter
0.34	0.42	0.60	4400	193 ± 30	155 ± 23
0.44	0.38	0.47	4500		157 ± 24
0.58	0.37	0.36	4680		154 ± 20
0.81	0.34	0.33	4990		167 ± 15

TABLE II. Program of Observations

Submillimeter source	α_0 1950.0	δ_0 1950.0	Wavelength mm	Survey region $\Delta\alpha$ 1'	Survey region $\Delta\delta$ 1'	N	Z
W3	$02^h21^m51^s$	$+61°52'20''$	0.34	0..+15	−15..0	8	0.0
Maffei-2	02 38 10	+59 23 32	0.34	−15..+15	−5..+10	26	+0.1
B5	03 44 29	+32 44 30	0.34	−10.. +5	−5..+ 5	14	+1.6
M42	05 32 47	−5 24 28	0.34	−20.. +5	−10..+20	22	+4.9
HFE11	09 55 07	+71 24 00	0.34	−20.. +5	−5..+15	27	+0.3
M51	13 27 47	+47 27 16	0.34	+10..+25	−15..+15	21	+1.6
FIRSSE-286	14 36 35	+44 46 30	0.34	−5.. +5	−5..+10	9	+0.2
W51	19 21 22	+14 25 10	0.34	0	0	1	+4.8
Serpens	18 27 25	+01 12 40	0.58	−5..+25	−25..+15	62	+4.0

1986–1990: Pamir
h=4350 m above sea level, 70-cm telescope

TABLE III. Measured Parameters

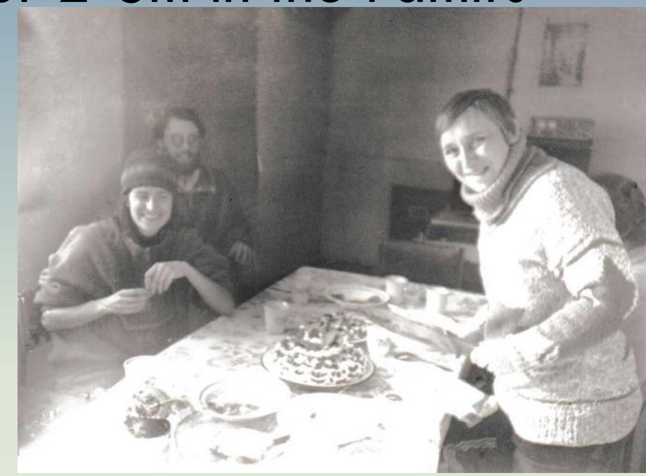
Source	Displacement of center		Size and position angle			T_0, K	Integrated flux density, Jy
	Δα	Δδ	*a*	*b*	*P*, °		
	1'		1'				
(0.34 mm)* M42	+2±2	+3±2	6±2	18±6	−37±9	0.19±0.03	29 000
HFE11	−9±1	+10±2	<3	9±4	28±8	0.14±0.04	3 800
Maffei-2	+12±1	−3±2	<3	5±2	−29±17	0.10±0.05	1 400
M51	+10±2	+1±1	7±3	<3	−16±10	0.09±0.03	2 000
FIRSSE-286	−3±1	+3±2	<3	>9	18±7	0.08±0.04	4 300?
B5	0±1	<−3	<3	>7	13±7	0.06±0.03	3 200?
W3	3±2	<−13	12±5	>15	−29±22	0.11±0.09	36 000?
W51	0	0				0.14±0.05	1 200
(0.58)* Ser	<−2	−9±3	>34	21±2	−26±7	0.42±0.11	230 000
Double-source approximation							
Ser−1	<−2	−11±1	>40	14±1	−22±2	0.37±0.05	140 000
Ser−2	9±2	>12	20±4	9±2	−10±6	0.23±0.05	22 000

*Wavelength of observation parenthesized.

1990: Italians in the Pamirs, the first after Marco Polo:

Paolo de Bernardis, Silvia Masi and Maurizio Perciballi

Purpose: to install a telescope with a mirror 2-3m in the Pamirs



The greatest progress of the submillimeter group has been achieved in the creation of bandpass filters for the millimeter and submillimeter ranges: theory and calculation of metal mesh filters, manufacturing technology (photolithography), measurement of characteristics. Numerous sets of filters of various types for different astronomical applications have been manufactured, in particular, for studying the Syunyaev-Zel'dovich effect.

RESONANT MESHES AS BANDPASS FILTER

Examples of various mesh structures of inductive and capacitive types

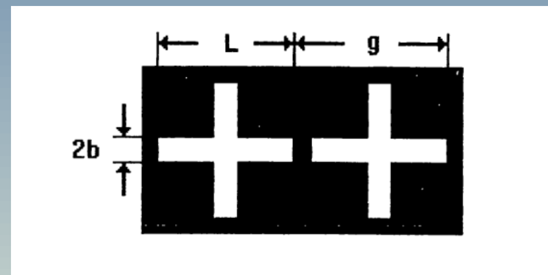
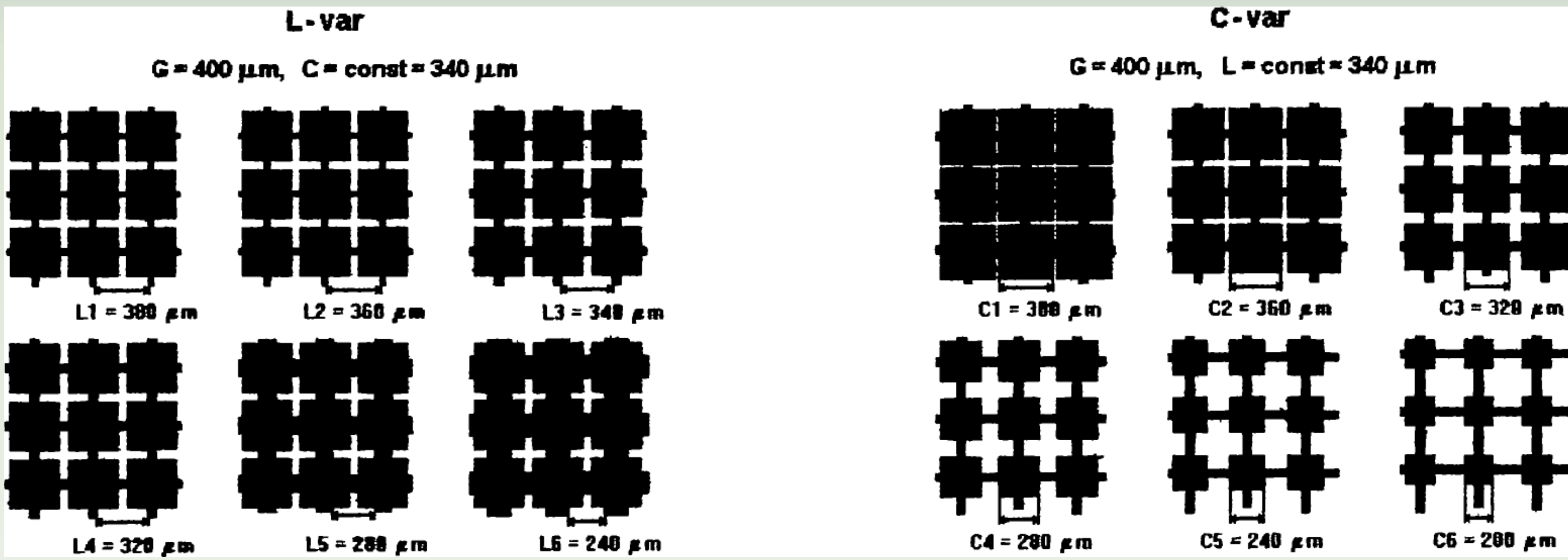


Fig. 1. The geometrical parameters of the resonant mesh consisting of an array of cross-shaped apertures.



RESONANT MESHES AS BANDPASS FILTER

Only three bandpass filter manufacturers over the whole world :

IKI submm group (Vera Soglasnova, Igor Maslov)

USA,Berkely University, bolo group (Paul Richards)

GB, Cardiff University (Peter Ade)

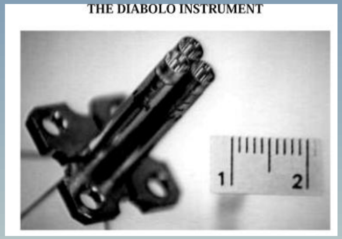
The last work:
Filters 1.2 and 2.1 mm for DIABOLO photometer, installed on 2.6m telescope TestaGrigia obsrvatory at Alps and 30m IRAM telescope

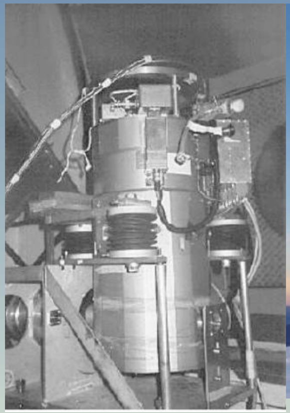
(Soglasnova, V. & Maslov, I.)

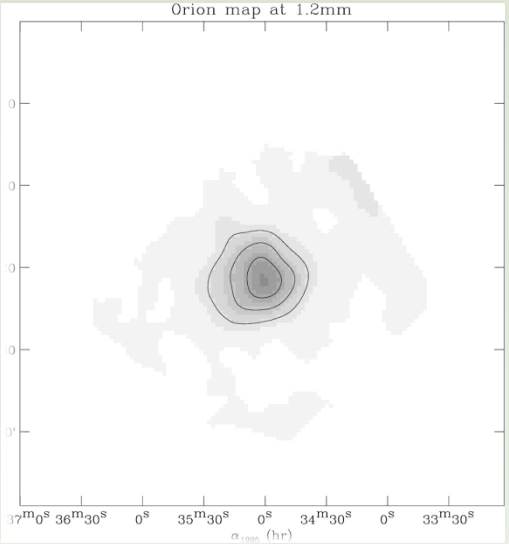
THE DIABOLO INSTRUMENT

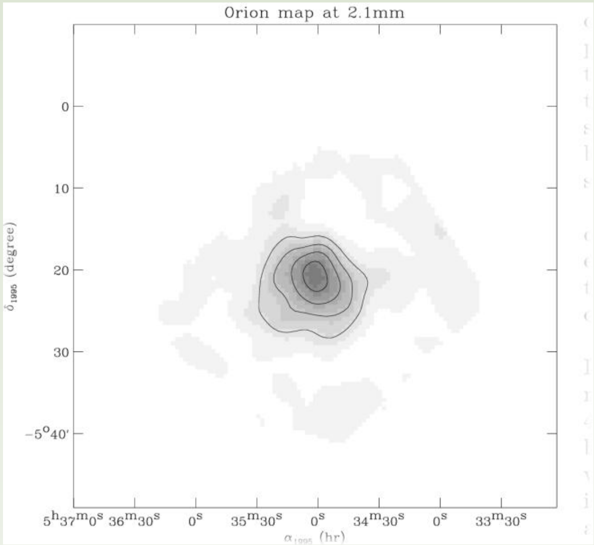
TestaGrigia

IRAM 30m









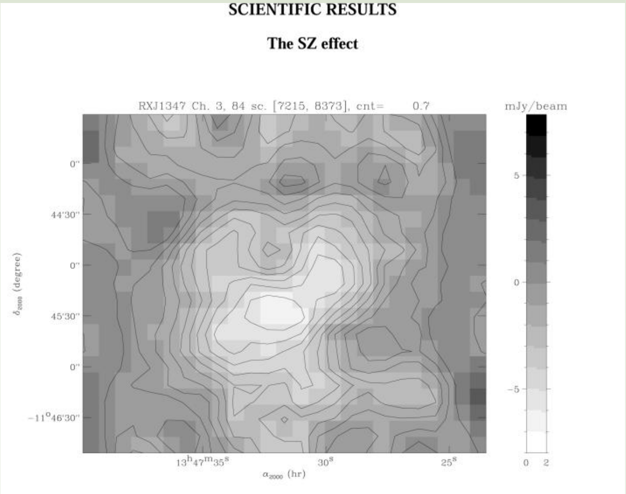


FIGURE 3. 2.1 mm map obtained with the Diabolo instrument in 1999 of the cluster of galaxies RXJ1347-1145. It corresponds to the coaddition of 84 independant rasters. The grey scale is from white (negative brightness) to black (positive brightness). Contours are in units of 0.7 mJy per beam (1σ level) from -9 to 0. Pixel size is 10 arcseconds. A smoothing by 3 pixels was applied.

Other Projects

unfortunately, not implemented for various reasons, mainly bureaucratic

Cooled onboard submillimeter telescope

БСТ2 (Sub_mm observation from the board of the Space Station Salyut),

AELITA

AIRPLANE FIR OBSERVATORY

… and others

Submillimeter Spaceboard Cooled Telescope

(35 years later: compare with Italian telescope at Tibet, presentation by Maria Salatino)

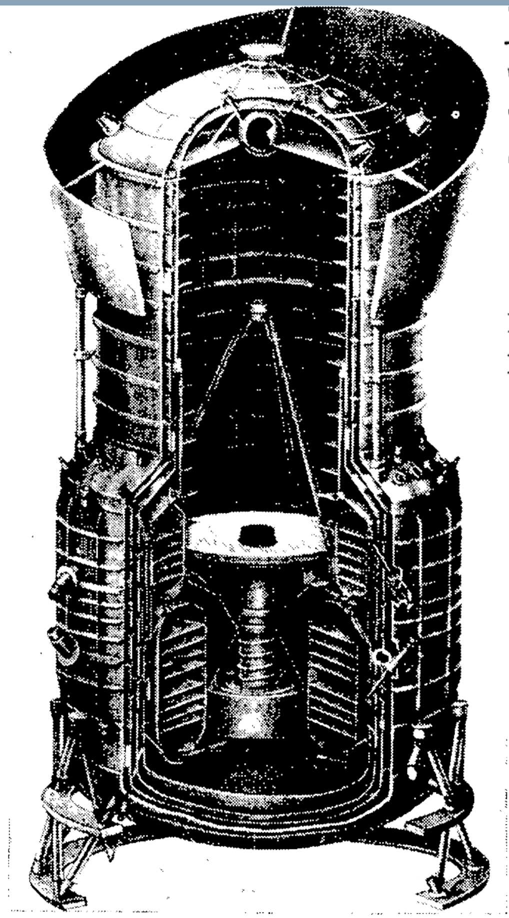


FIG. 4. A general view of the cooled telescope (not showing the conical aperture shield).

TABLE I. Basic Specifications of Cooled Telescope with Submillimeter Photometer

Wavelength range, mm	2-0.15	Sensitivity threshold, Jy	
Telescope diameter, mm	1000	at λ = 1 mm	0.1
Cooling temperature, °K:		at λ = 0.3 mm	0.03
for telescope	27	Brightness-temperature	
for photometer	1.8	sensitivity, °K	$1\cdot10^{-4}$
for bolometers	0.3	Pointing accuracy, arc sec	10
Beamwidth, arc min	15-3	Weight of cryoagents, kg	400
Number of channels:		Functional life, yr	1-1.5
operating concurrently	4		
maximum	9		

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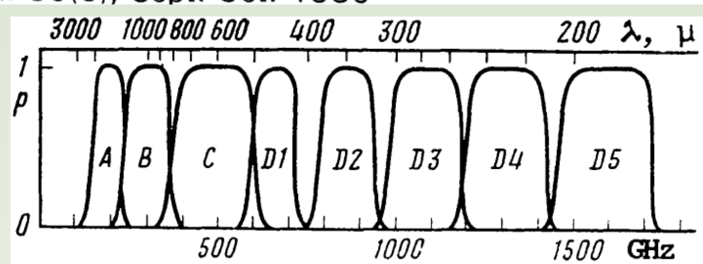

FIG. 6. Spectral profiles of the fixed (A, B, C) and interchangeable (D1–D5) interference filters in the submillimeter photometer (p represents the normalized transmittance).

Thanks for attention