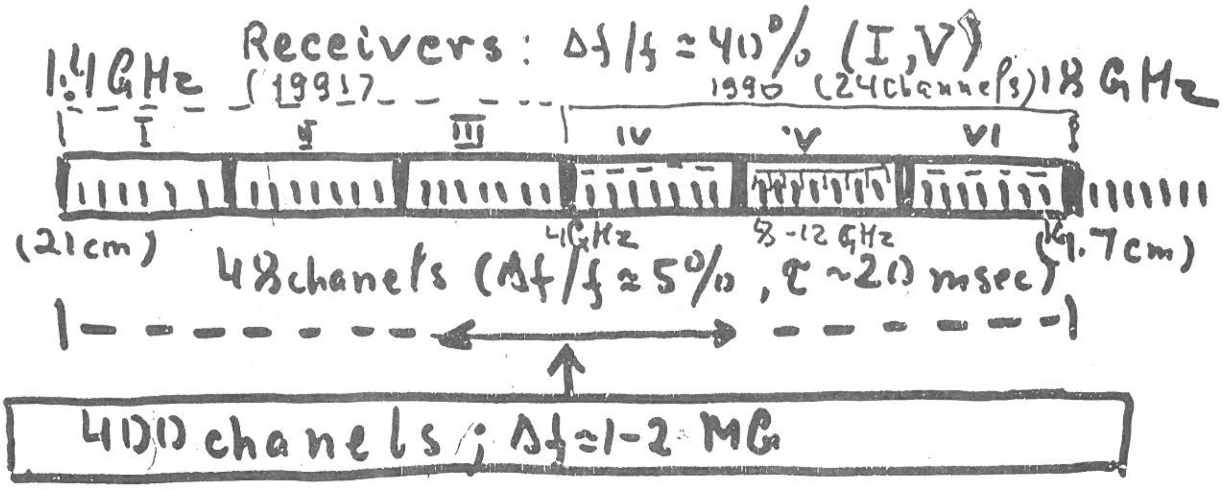
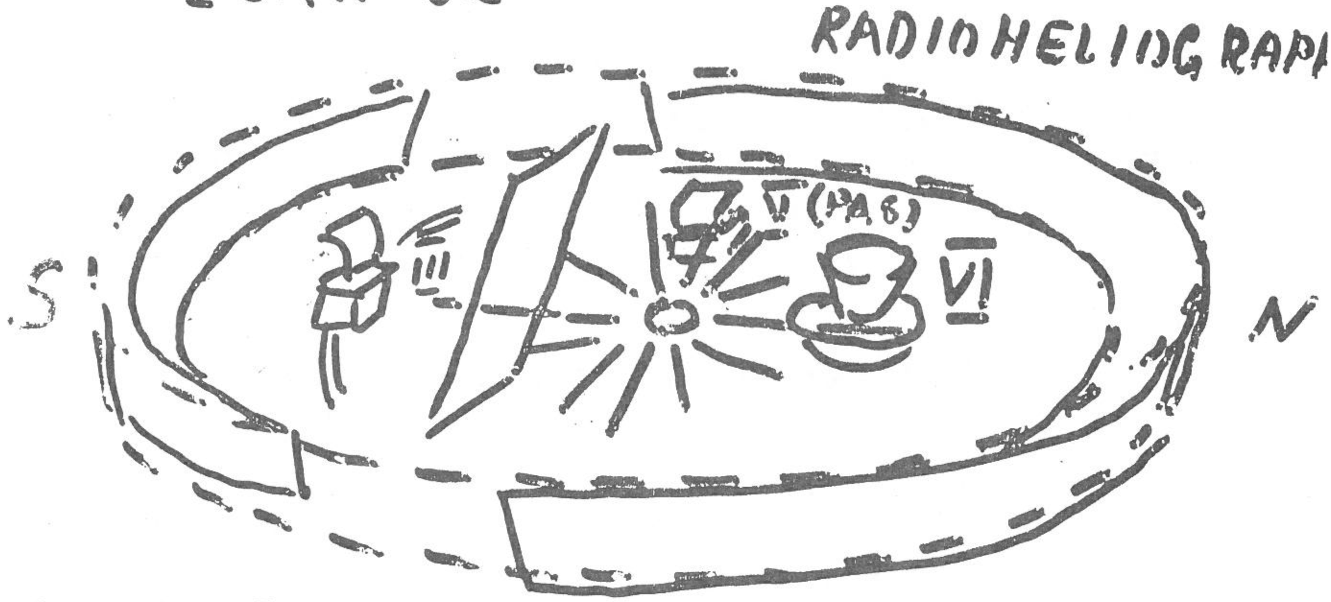
Modernization of the RATAN 600 for Solar Observations and the Results of Solar Investigations Made with the RATAN-600

G. B. Gelfreich

PAS (PANORAMIC ANALISER of SPECTRUM



ICAR-32



λ 0.8-75 cm (15 λ_i) I,V

$\Delta t \approx$ 5-10 min

(0.8; [1.3]; [1.7]; 2.0; 2.3; 2.7; 3.2; 4.0; 6; 8; 11.7; 21; 32; [45]; [75] cm)

$\lambda \sim 4$ cm $\theta \approx 10'' \times 15''$

"A" $\to \Delta t \approx 1^h$

"B" $\to \Delta t \approx 10$ msec.

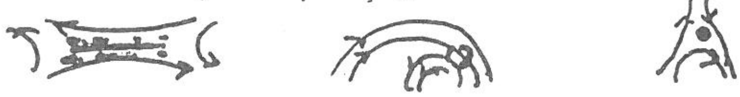
Current problems of Solar Physics

ENERGY
- source
- transfer
- accumulation
- release
- transformation

- Motions (MHD) of plasma
- MHD-waves/oscillation
- Electromagnetic waves
- Thermal motions
- Accelerated particles
- Plasma turbulence
- Magnetic energy.

Non-trivial but observed effect: structuring solar atmosphere
(loops, granules, streamers, sunspots, ...e.t.c.)

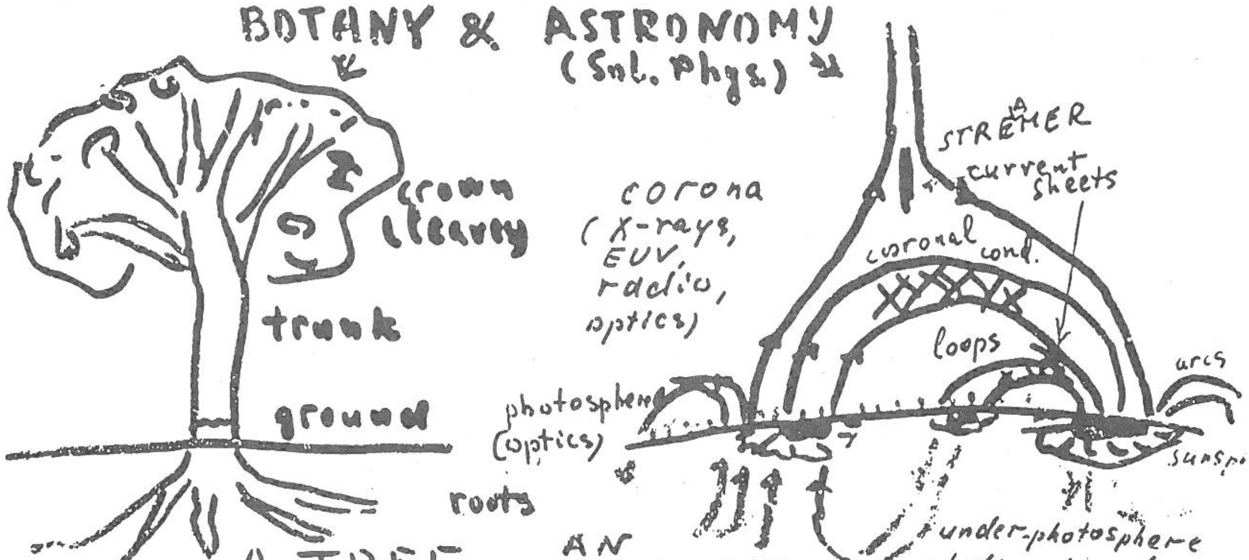
Our recent experience:
Theory connects (t), (a), (r), (tr) with certain structure



Note:
- All structures are essentialy 3D-units
- All structures are due to non-linear effects. and generally result from developing nonstability
- Structuring the plasma is a universal process but.. The Sun presents a unique opportunity to study The process[es] in more details than any other astrophys

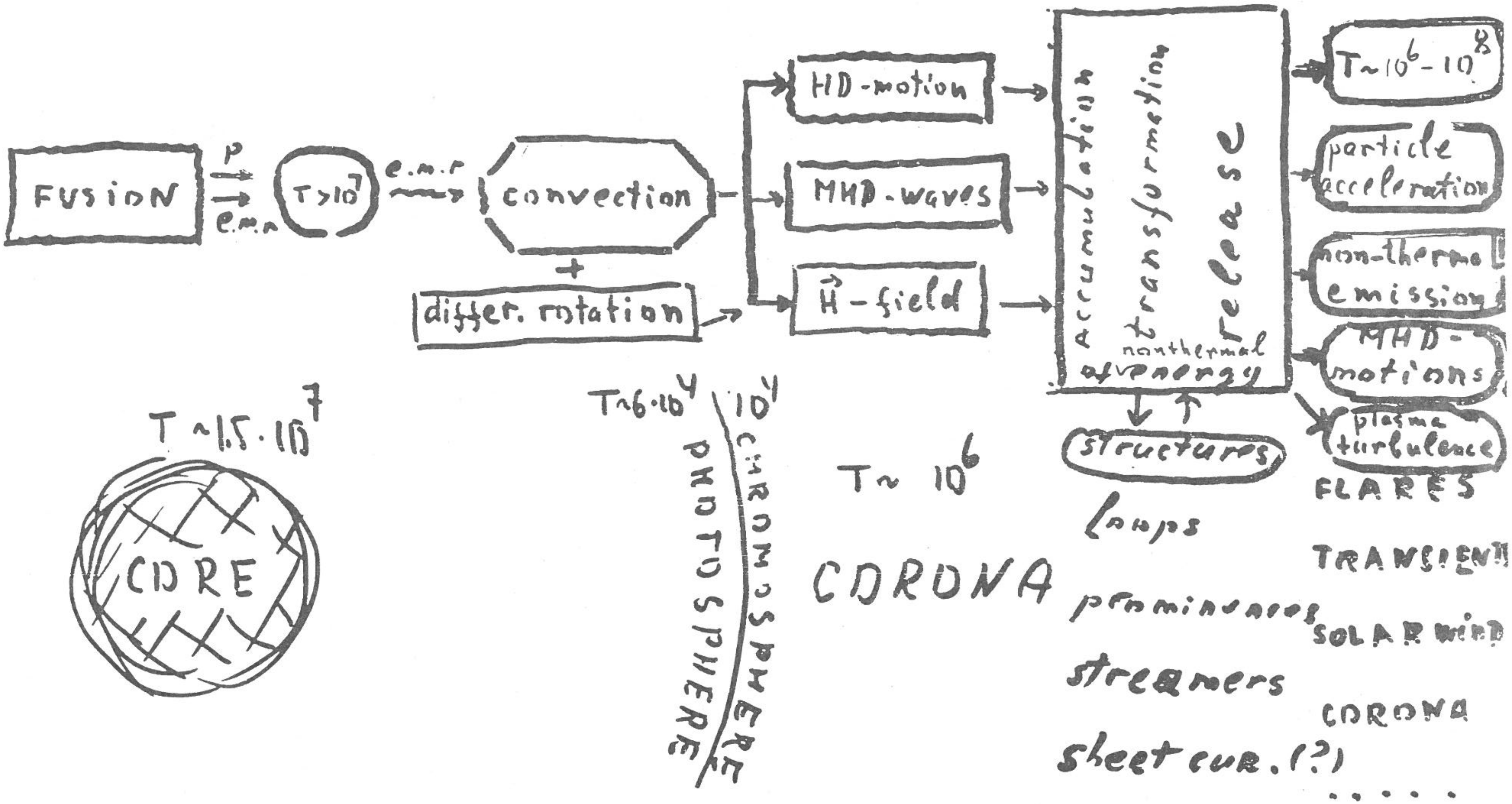
The problems: Why? What for? ...structures exist
How? structures develop
3-Dimensional study of structures

BOTANY & ASTRONOMY
(Sol. Phys.)



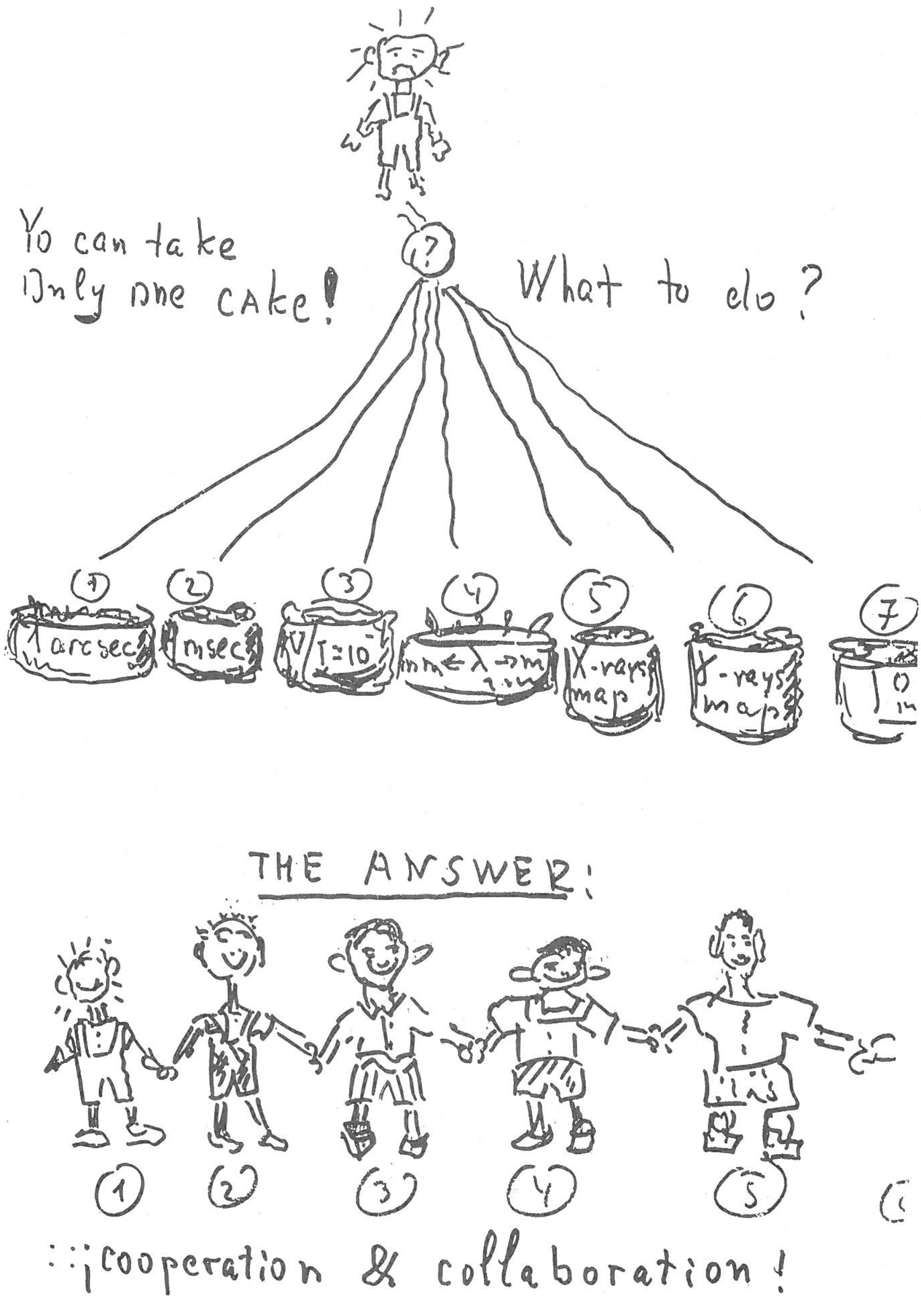
A TREE AN ACTIVE REGION

THE SUN



RADIO : H, acceleratzn., T_e, N_e, plasma turbulence

NEEDS : high spatial resol. ; spectrum . polarizat.


Yo can take
Only one cake!
What to do?
1 arcsec
msec
V I=10
mm ← λ → m
X-rays map
γ-rays map
THE ANSWER:
1
2
3
4
5
¡¡cooperation & collaboration!

RATAN-600 → Nauk
(RAdio Telescope of Acad. Sci. 600 m)

Limitations

* 1-D scans (mainly)
* Poor time resolution
* At dm poor spatial resolution

(Modernization of the RATAN is aimed to overcome some of these)

Advantages

* Good wavelength coverage
* High polarization sensitivity
* good at cm
* practically full disk
* Regular solar observ.
* Accurate position measurements

#

One can't understand the FLARE without understanding 3-D structure of the ACTIVE REGION
(At least such a programs seems unreasonable)

<u>Why?</u>

1. AR is the plasma-magnetic structure where a flare occurs
i.e. takes or transfers the energy)
2. There are slow nonthermal events in an AR which are in principle of the same physical nature as the flares are
(Shouldn't we understand them first?)

Main Results gained with the RATAN-600 (1975-1989)

Field	Object	Results	Problems
Quiet Sun	Limb Brigtness distr.	Flat distr, stable	Nature of r.e. $h \approx 7\text{-}30 \cdot 10^3$ km; Common Model.
	Radio granulation	Size, Distr., Ident, H	
	Prominences	T, grad T	Mod.
Dark features	Coronal holes	ΔT_B, Spectr.	Models; Geophys. effects (Forcast.)
	Filaments	Identif. size	
	Cavities	Ident., size	
Local Sources	CORES /sunspots/	Size, height, H	Inhomogen. models. Dynamics
	Faculae	H, grad T, T	Comprehensive model
	Loops/coron. cond.	EM, T, H	Loop / Diffuse cond.
	Peculiar sources	New typ sources	Mechanism; Nature of energy release
	Decimetr. halo	Spectr., struct.,	Mechanism; ? Plasma turb. / acceler. part. / H; (F10.7 ?)
Outer corona	Quasar's scintill.	Sol wind orig.	S.W. origin
	Faraday rot. - Crab A	H with cycle	I.p. H stuct. & dyn.
Magnetic fields	Thermal cyclotron	H, grad H, $H_{rad} \leftrightarrow H_{opt}$	$H_{rad} \leftrightarrow H_{opt}$ EU; Emergence
	Thermal bremstr.	facul., loops, prom	Adequate model.
	Inversion of polar.	AR at $h \sim 10^5$ km	3D - struct of H (potential?)
Flares	gradual r.f.	size, spectra	Models
	Impulsive /compl.	many comp. str.	Release of energy

MEASUREMENTS OF PARAMETERS OF SOLAR PLASMA AS BASED ON SPECTRAL POLARIZATION RADIO OBSERVATIONS OF LS

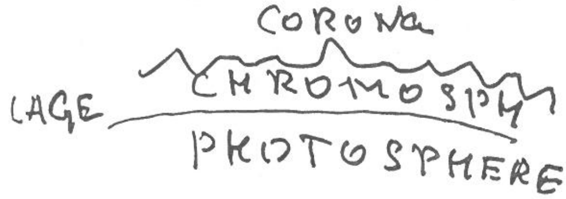
1. MAGNETIC FIELDS

A. THERMAL BREMSTRAHLUNG

$$\varkappa_{e,o} = \frac{5N^2}{T^{3/2}(f \mp f_H \cos\alpha)^2}$$

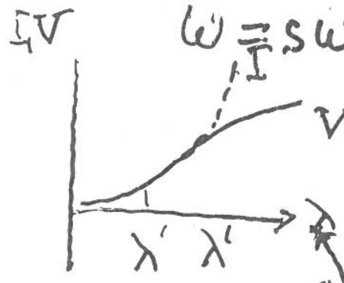
$$P = n\frac{f_H}{f}\cos\alpha \rightarrow \boxed{B_l(G) = \frac{107}{\lambda \cdot n}\cdot p\%}, \quad n = -\partial \ln T / \partial \ln f$$

for $\tau \ll 1$ $\quad B_l = \frac{54}{\lambda}\, p\%$ (Bogod, Gelfreikh Sol. Phys 1980, 67, 29)

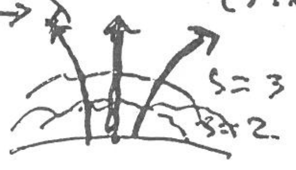


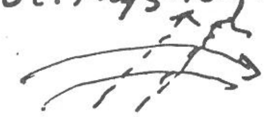
B. Cyclotron thermal emission

$$\omega = s\omega_H \; (s = 2, 3) \rightarrow \boxed{\underset{s=2}{B} = \frac{5400}{\lambda', cm}} \quad \boxed{\underset{s=3}{B} = \frac{3600}{\lambda'', cm}}$$



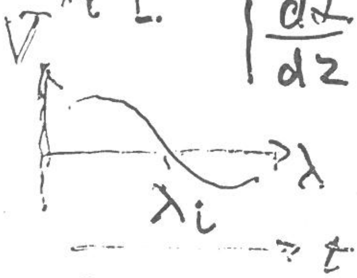
(Akhmedov, Gelfreikh et al. Sol. Phys 1982, 79, 42)

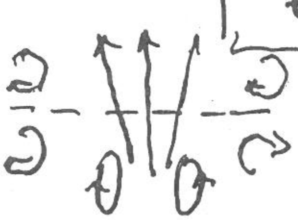




C. Inversion of polarization

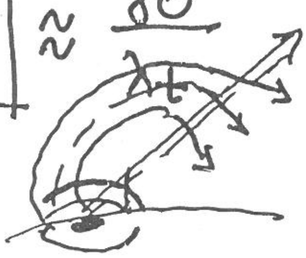
$$f_t = \left[\frac{2\cdot 10^{17} B^3 N}{\left|\frac{d\alpha}{dz}\right|}\right]^{1/4} \rightarrow \boxed{B_t = \frac{157}{\lambda_i \sqrt[3]{NL\lambda_t}}} \approx \frac{80}{\lambda_t}$$





$\lambda \ll \lambda_i$

$\lambda \gg \lambda_i$



2. TEMPERATURA $T_B \geq T$

3. EMISSION MEASURE $EM = K \cdot F\sqrt{T}$ $(\tau \ll 1)$

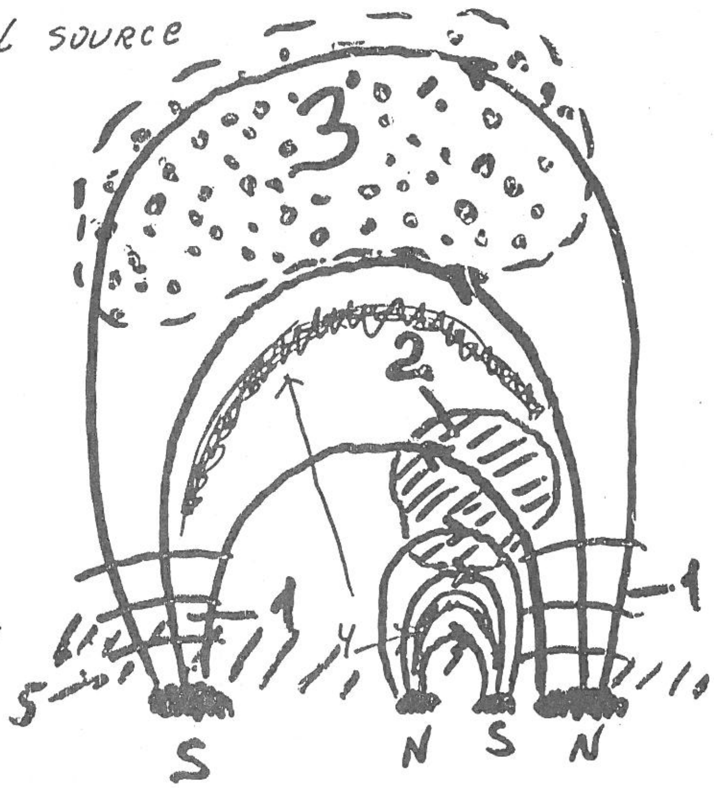
4. NON-THERMAL PARTICLES AND TURBULENCI

STRUCTURE of the LS

СТРУКТУРА ЛОКАЛЬНОГО ИСТОЧНИ

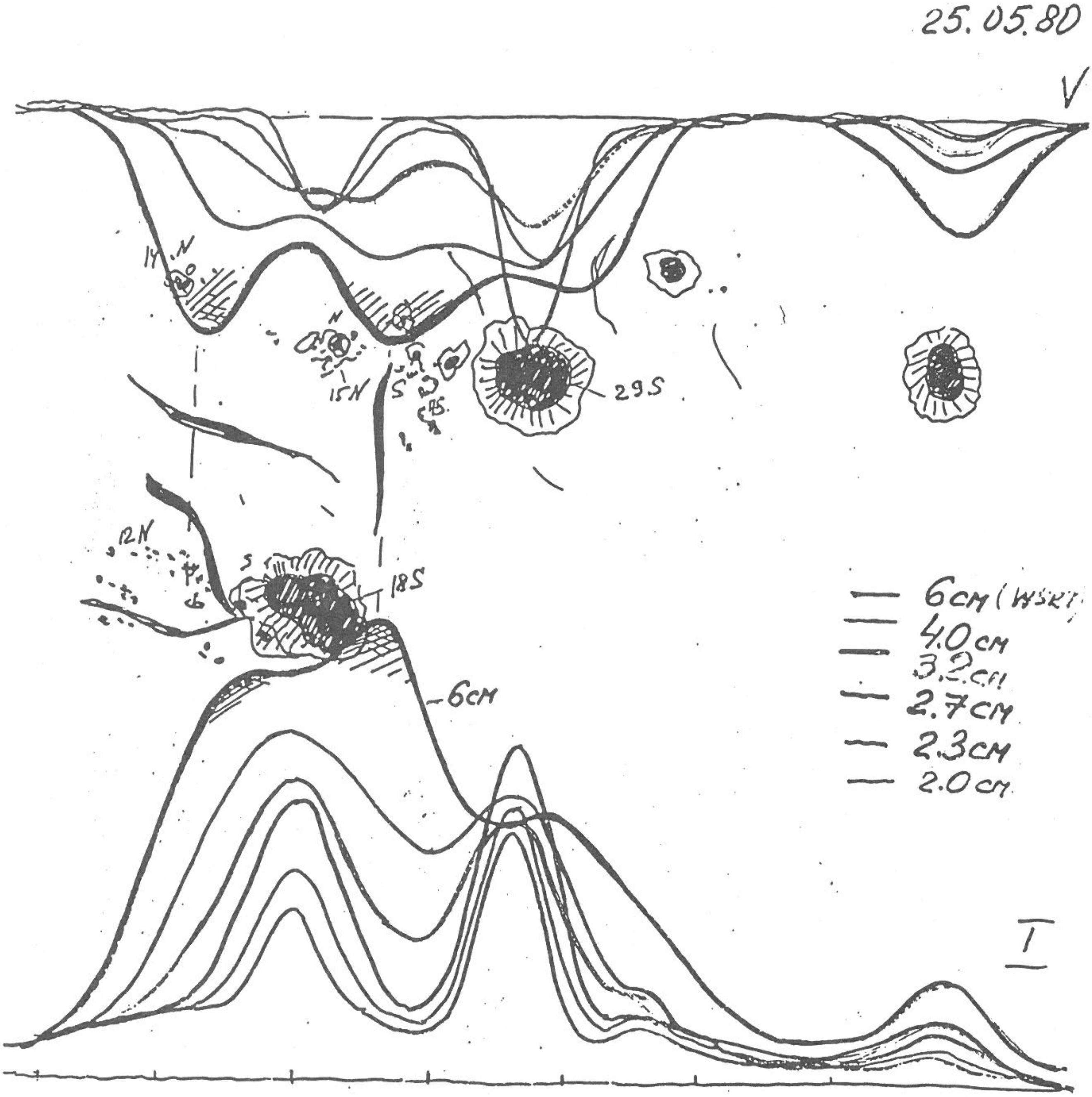
LS = local source

24 July 1987

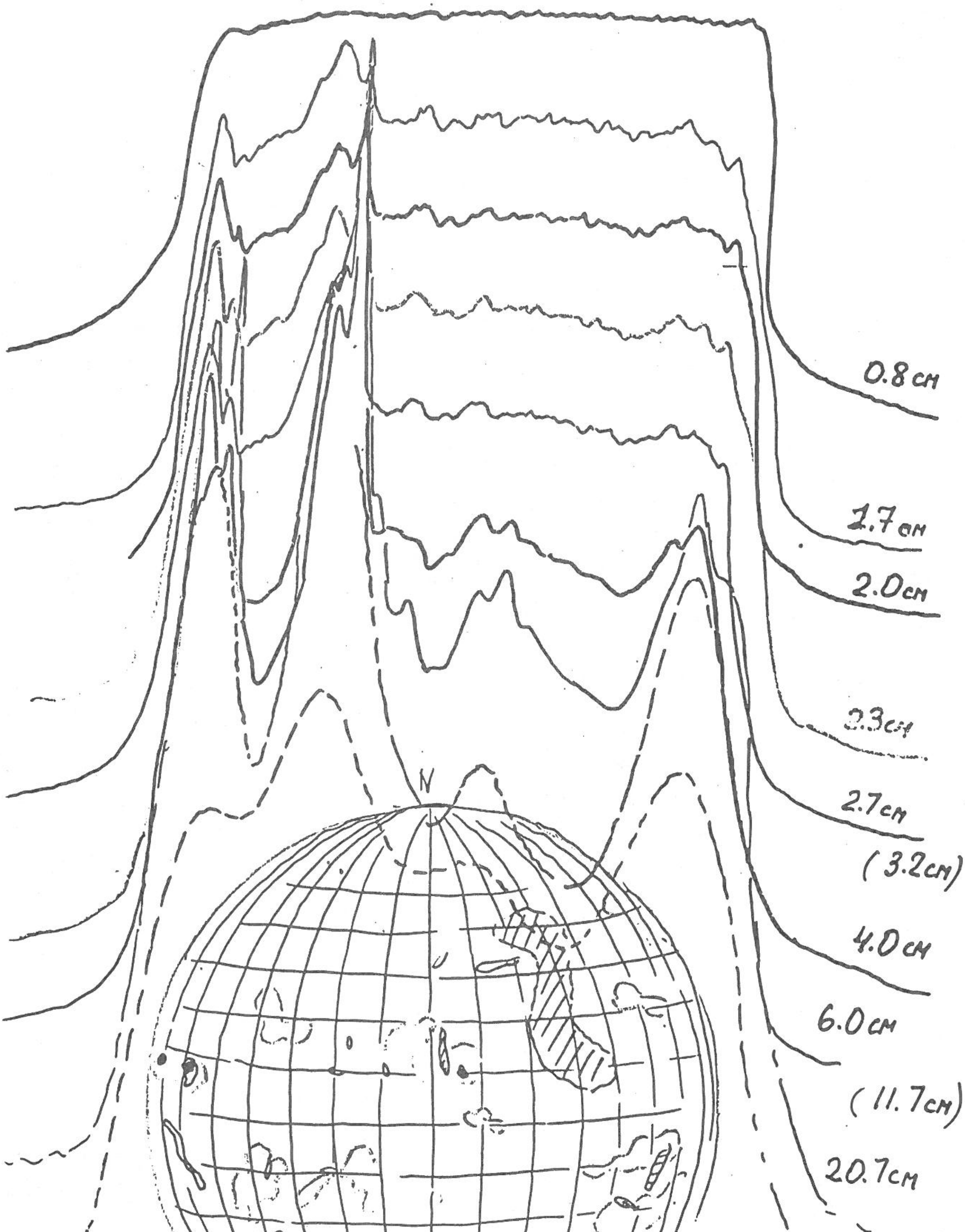


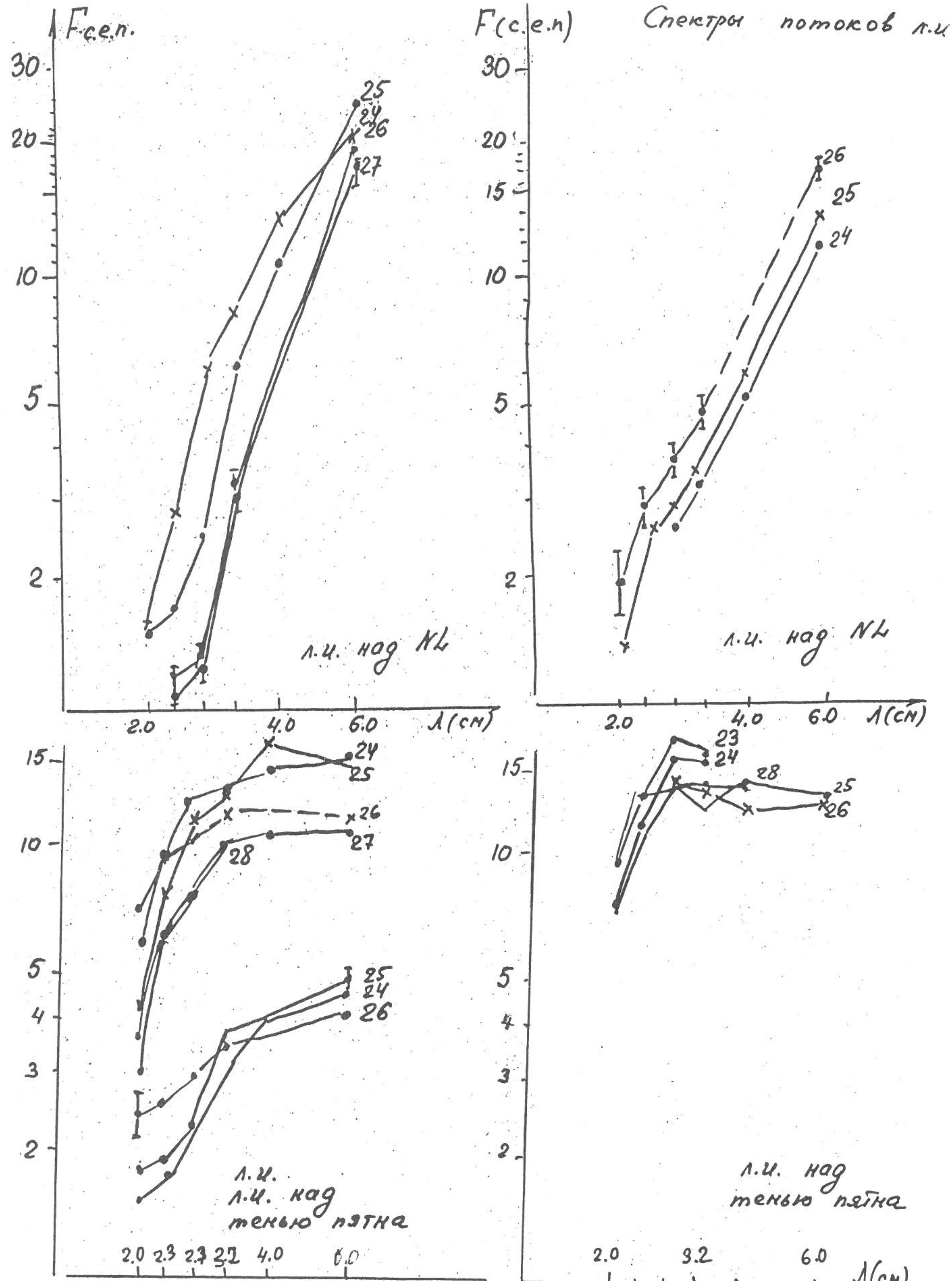
1. Пятенная компонента (циклотронное излучение электронов короны в поле пятна)
sunspot-associated
2. Пекулярные источник (токовый слой?)
peculiar source
3. Дециметровое ГАЛО (корональная конденсация с возбужденной плазменной турбулентностью <?>)
decemetric halo
4. Корональные петли (= конденсации) (тормозное излучение)
coronal loops
5 facula component (chromospheric level)

RATAN 2.0 2.3 2.7 3.2 4.0 cm
WSRT 6 cm



PAIAH-600 20.01.90





F с.е.п.
F(с.е.п)
Спектры потоков л.и
л.и. над NL
л.и. над NL
л.и.
л.и. над
тенью пятна
л.и. над
тенью пятна
λ(см)
λ(см)
λ(см)

Mechcnism:

a) thermal gyroresonance emission at 2-4-th gyro-harm
(strong magnetic field $H > 1500$ Gs in corona)

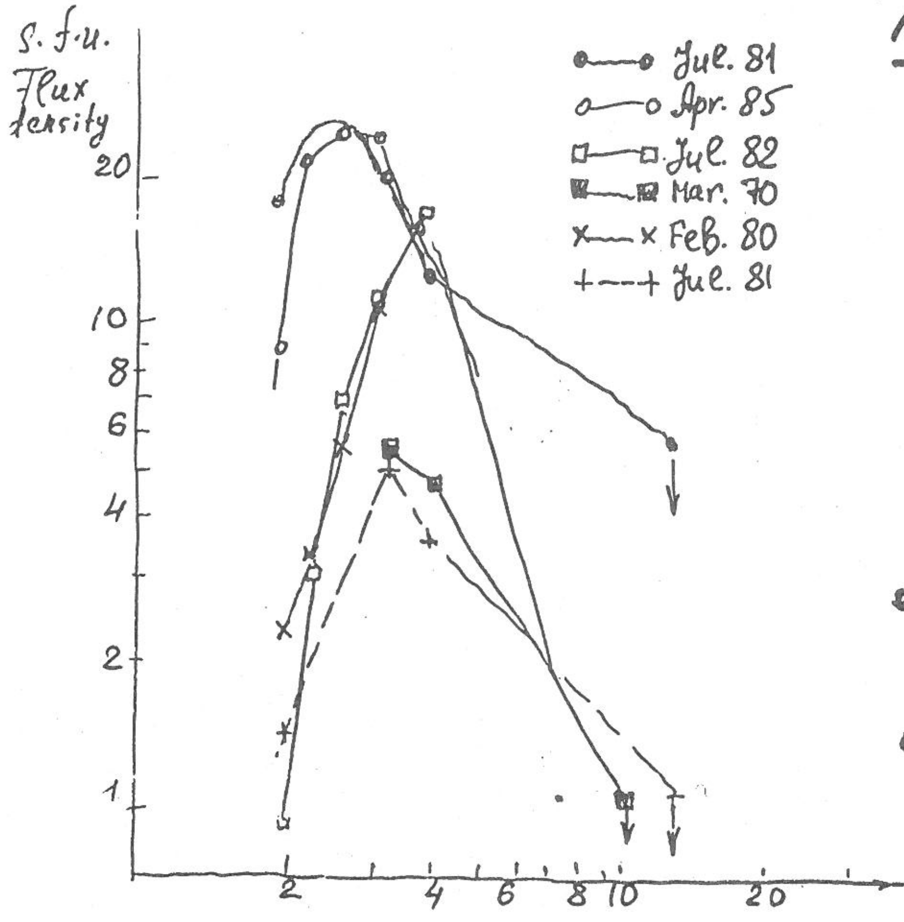
б) thermal cyclotron emission of higher harmonics
($\sim 10^8 T$ and $N_e \sim 10^{10}$ cm^{-3}) $H \sim 100 \div 300$ Gs

May be expected in high temperature current sheets.
Stability?

в) Thermal bremstrahlüng $T \approx 10^7 \div 10^8 K$ $N = 10^{12} \div 10^{13}$ cm^{-3}
Abnormal high density in hot corona.

г) Nonthermal mechanism of radio emission

Local and long-lasting release of nonthermal energy in active (flaring) region
Strong currents (current sheets?)



λ(cm)

"PECULIAR" SOURCES

- $\lambda \sim 2 \div 4$ cm
- $n \sim 10$
- $T_B \sim 10^7 K$
- $T \sim 3^d - 5^d$
- $h \approx D \simeq 10^4$ km
- at neutral magn. lines
- appears simultan. with new magnetic flux* photosph. *currents

КОММЕНТАРИИ К РИСУНКАМ.

Условные обозначения :

- h – высота источника;
- t – часовой угол;
- F – расстояние от центра круга до фокуса;
- Af – азимут фокуса;
- N – число щитов в установке;
- df – смещение по частоте от основной частоты;
- dx – интервал между отсчетами по оси A(азимутов);
- dy – интервал между отсчетами по оси H(высот).

На всех рисунках, приведенных ниже, диаграммы направленности расчитаны на поле 32*32 точки, с интервалом между отсчетами dx=dy=10". Основная длина волны λ=8 см. Параметры Af и F одинаковы для всех установок и равны: Af=180°, F=130 м.

Рис.1-2. Диаграмма направленности радиогелиографа в режиме A.
Параметры источника: h=61°10′
t= 0°
Параметры установки: N=645

Рис.3-5. Изменение диаграммы направленности режима A с изменением часового угла источника:
рис.3 – h=61°5′ ; t= 2°.5 ; N=587
рис.4 – h=60°51′ ; t= 5°.0 ; N=522
рис.5 – h=60°28′ ; t= 7°.5 ; N=447

Рис.6-7. Диаграмма направленности радиогелиографа в режиме Б.
Параметры источника: h=61°10′
t= 0°
Параметры установки: N=645

Рис.8-10. Изменение диаграммы направленности в режиме Б с изменением частоты:
рис.8 – df= 2 Мгц
рис.9 – df= 6 Мгц
рис.10 – df=10 Мгц

Рис.11-13. Изменение диаграммы направленности в режиме A с изменением частоты (режим AБ):
рис.11 – df= 4 Мгц
рис.12 – df=10 Мгц
рис.13 – df=40 Мгц

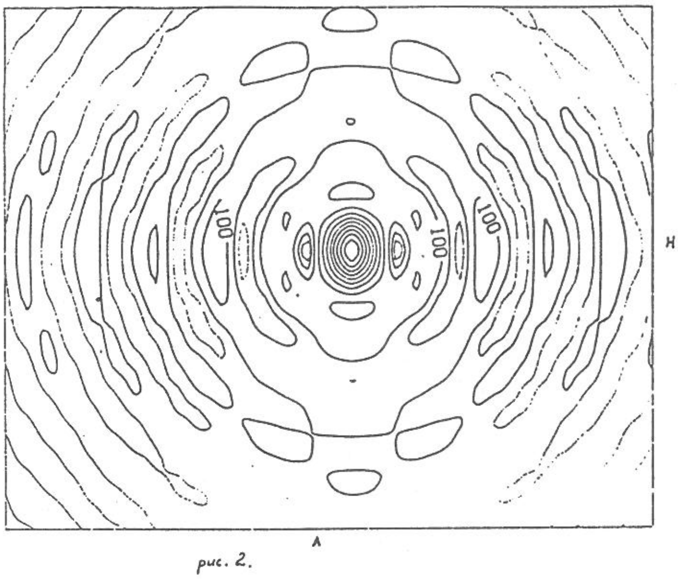


рис. 2.

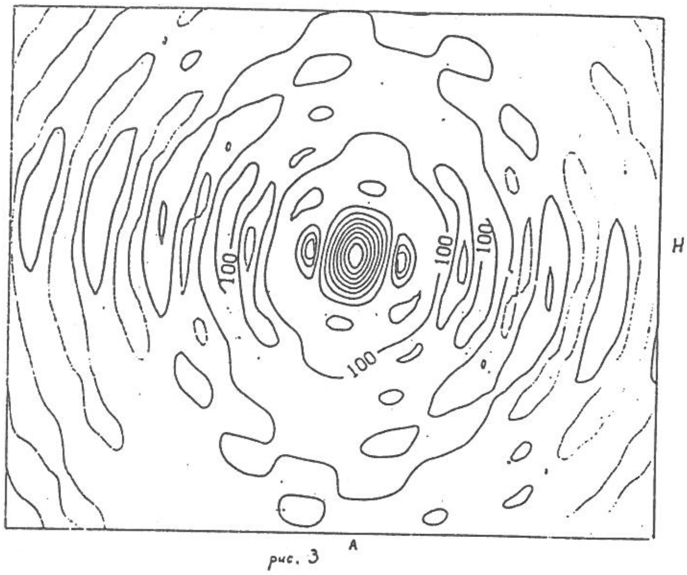


рис. 3

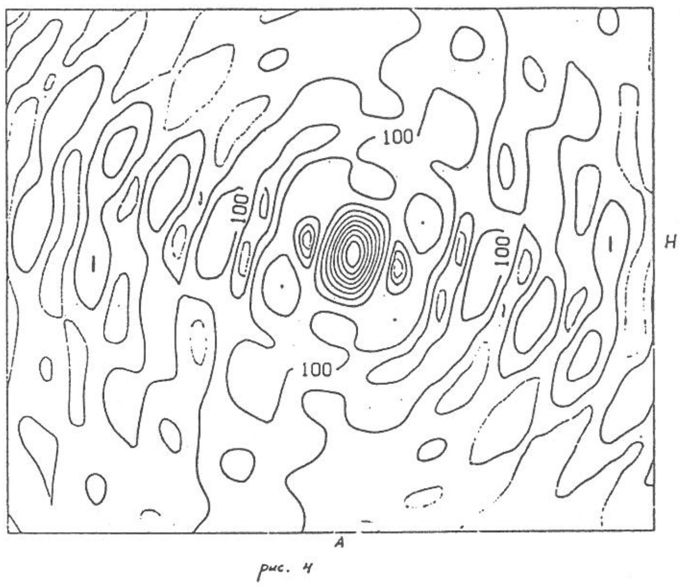


рис. 4

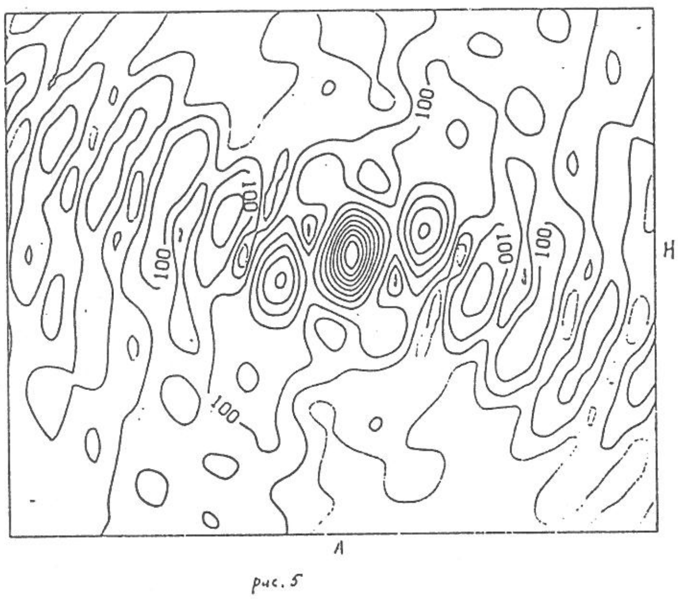


рис. 5

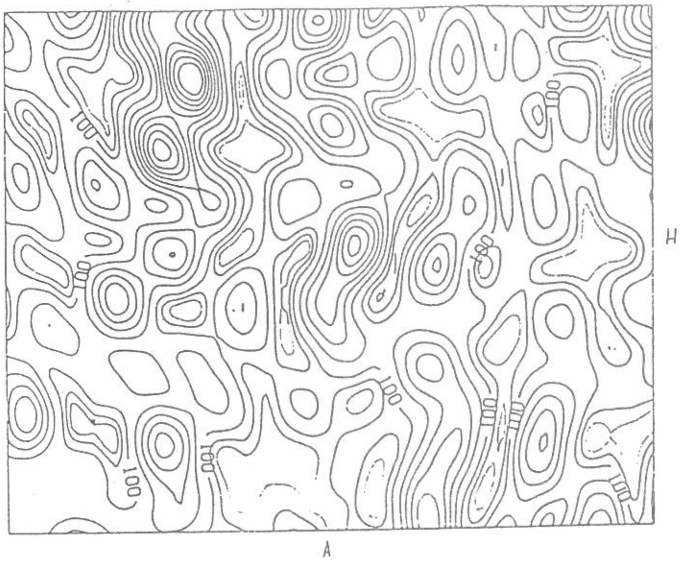


рис. 7

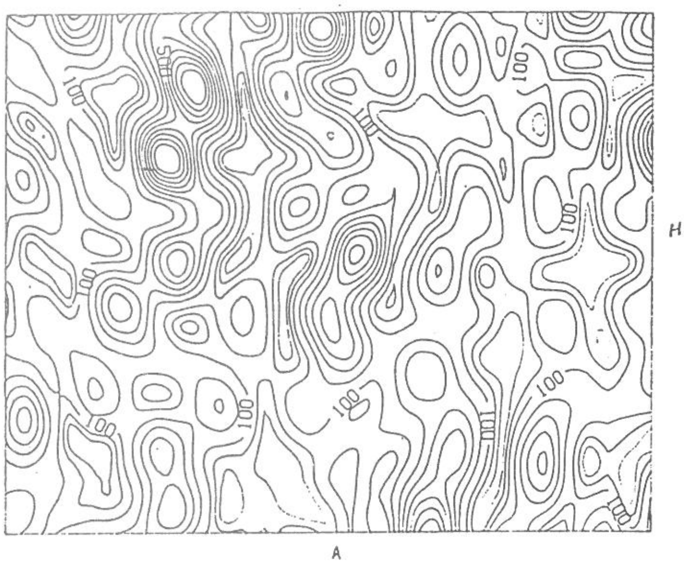


рис. 8

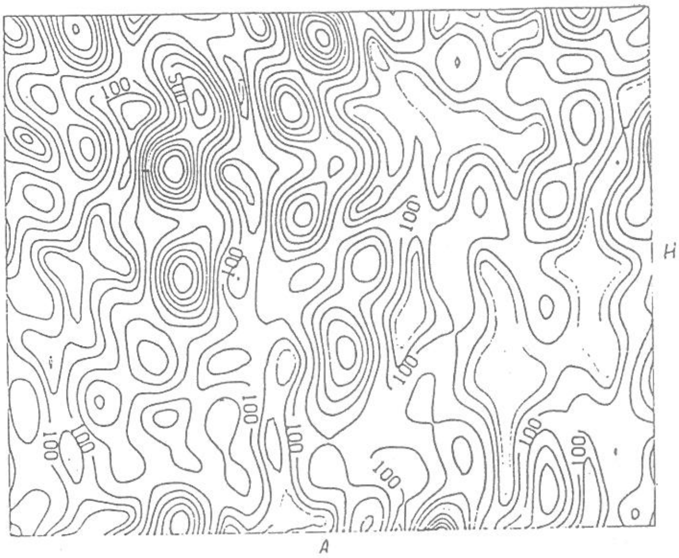


рис. 9

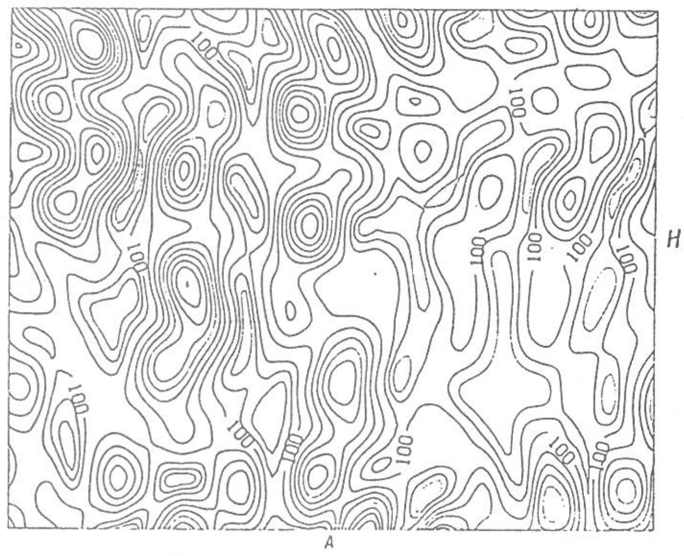


рис. 10

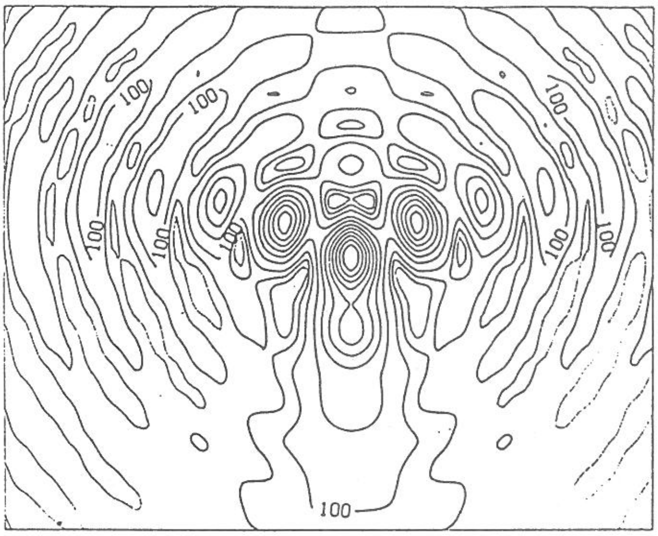


рис. 11

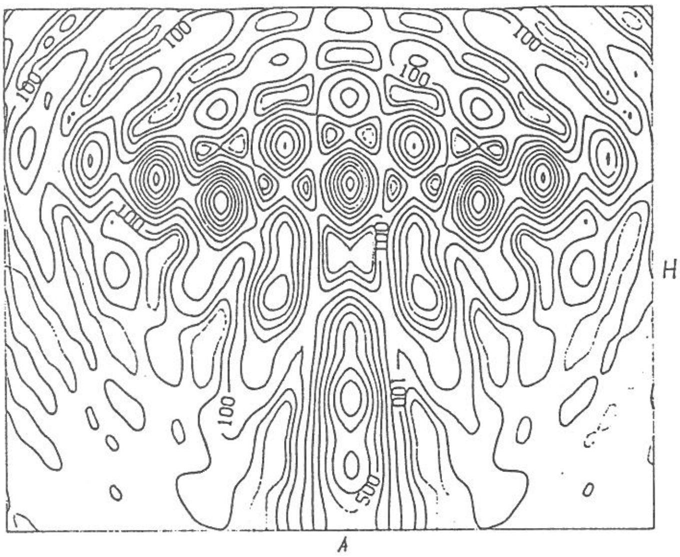


рис. 12

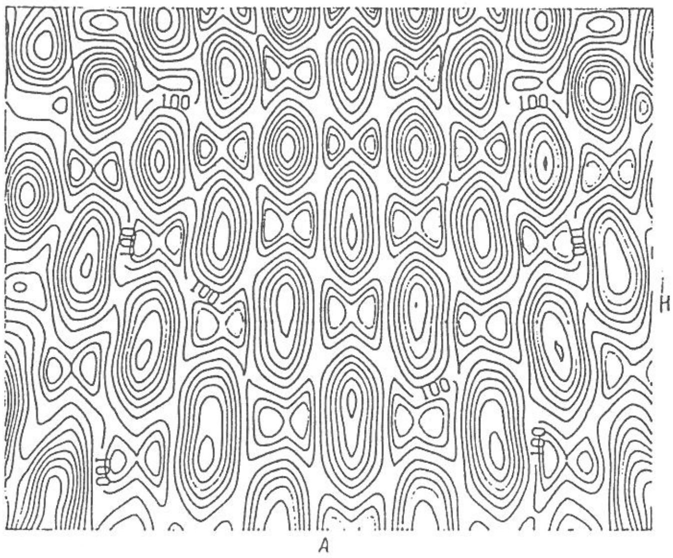


рис. 13

THE 22nd CYCLE PROGRAM OF MODERNIZATION OF THE RATAN-600 FOR SOLAR OBSERVATIONS

G.B. Gelfreikh

Central (Pulkovo) astronomical observatory
of the Academy of Science of the USSR

The program intends to improve significantly all the parameters of the radio telescope RATAN-600 to gain better spectral, temporal and spatial resolution of the instrument. The program includes 3 main project: ICAR-32, PAS and Radioheliograph.

ICAR-32. A new system of registration (Intellectual Complex of Automatic Registration, 32 channels) is used in the mode "South sector + periscope" of the antenna. It is installed on the feed system # 3 which is moved along the arc railway track and allows about 4 hours of observations per day (+ 2 hours around local meridian i.e. ~9 hour UT). One dimensional scans of the Sun can be made at least each 10 minutes on up to 16 frequencies in the wavelength range from 8 mm to 75 cm with registration both intensity and circular polarization (I and V Stokes parameters). At present we have 12 frequencies at disposal (l 0.8, 2.0, 2.3, 2.7, 3.2, 4.0, 6, 8, 11.7, 21, 32 cm) and one observation per day at the meridian. The reconstruction of the arc railway track and south sector of the main reflector are under way.

The example of the records of the whole Sun and an active region are shown on Fig. 1 - 3. Optimum amplification for each of 32 channels is controlled every 0.1 sec.

PAS. Panoramic Analyser of the Spectrum (PAS) is intended to gain full continuous coverage of the main part of the wavelength band of the RATAN-600 (2 - 20 cm). It is supposed to be mounted on the feed system # 6 which is capable for usage both with radial and arc railway tracks of the telescope. The PAS consists of 6 wide-band receivers which cover wavelength range from 1.7 cm to 21 cm (see Fig. 4). Each of the receivers has 8 channels with relative wavebands about df/f = 5%. So the full number of channels used in parallel is 6X8X2=96 including registration both left and right-handed circular polarization (I and V Stokes parameters). A more detailed spectral analyser with the resolution up to 1 - 2 MHz may be used with one of the receivers above. At the present stage of construction one receiver with 8 bands, covering 8 - 12 GHz has been completed. The receivers for 4 -8 GHz and 12 - 16 GHz are expected to be at work at the end of this year. The system PAS is supposed to be applicable also for study milisecond processes on the Sun. An example of using PAS for Solar eclipse observation is given in Fig. 5.

Radioheliograph. The radioheliograph of the RATAN-600 is to use feed system # 6 which is normally works with the full ring of the main mirror while the beam is directed to near the zenith. For solar work, however, only about 2/3 of the main reflector is attainable. To this end the feed system # 6 is placed about 130 m to the North of the antenna center. The size of the aperture is about 600 m X 400 m (corresponding resolution 10 X 15 arcsec at l = 4 cm). Three modes of observations have been proposed for radioheliograph.

Mode A. Synphase aperture and one-main-beam diagram is used. To attain synphase aperture the separate reflecting elements (full number in this mode is about 600) are shifted on the (digital X wavelength). The observation on a set of discrete frequencies can be used such as e.g. 12, 6, 4, 3 and 2 cm. To obtain a two-dimensional map of an active region one needs to make a dozen or more scans with intervals say about 6 minutes at different declinations. Owing to strong side-lobes (see Fig. 5) a cleaning procedure to improve a map is desirable.

Mode B. Asynphase aperture diagram-pattern consisting of large number of comparable in intensity lobes is used (see Fig. 6). This diagram pattern is strongly frequency-dependent. Using a spectrometer with large number of channels we can get enough information to restore the radio map of the whole solar disk providing the source has not a very complecated spectrum. This mode can be applicable even for mapping some bursts of solar radio emission.

Mode AB. This mode is a combination of the two previous ones. For a single frequency we use a single beam synphase diagram and on other frequencies of a spectrograph we register the Sun with multi-beam diagram pattern (see Fig. 7).

At present all three modes of the radioheliograph of the RATAN-600 are being modelled with the computators. The necessary parameters of the receiver system has been found.