To the question about estimations of the effective heights, sizes and brightness temperatures of the solar cyclotron sources

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The modeling of microwave emission from spot associated cyclotron source was done to refine the method of estimations of effective brightness temperature, size and height above photosphere in treatment of RATAN-600 observations.

Model of sunspot

1. Emission mechanism. The thermal cyclotron emission at 1-4 harmonics in strong magnetic fields
2. Magnetic field. A dipole approximations of magnetic field was used with 2 parameters: a strength of magnetic field Hcentr (3000 G) at sunspot axis at photosphere level and the depth of the dipole below photosphere level (deep=1.5 and deep=2, this parameter changes the divergence of magnetic force lines and consequently source size).
3. A two-step transition region: the cold dense chromosphere (T=10 000 K) and the hot corona (2 mln K) and a barometric law for density distribution were used.

The of magnetic lines of force and gyroresonance levels for two magnetic dipole model (deep=1.5 and deep=2, Hcentr=3000 G) and for two wavelengths (2 cm and 4 cm) are presented. The gyroresonance levels are purple (s=1), red (s=2), green (s=3) and blue (s=4). The base of corona at 2000 km is shown by dashed magenta line.
The area of sunspot was calculated for x=[-2,2] and y=[-2,2] in ten thousands km.

Model of sunspot:

dipole magnetic approximation, H_{centr}=3000 G

Harmonic number:
s=4
s=3
s=2
s=1

Two step temperature model:

T=10 000 K - 2 mln K,

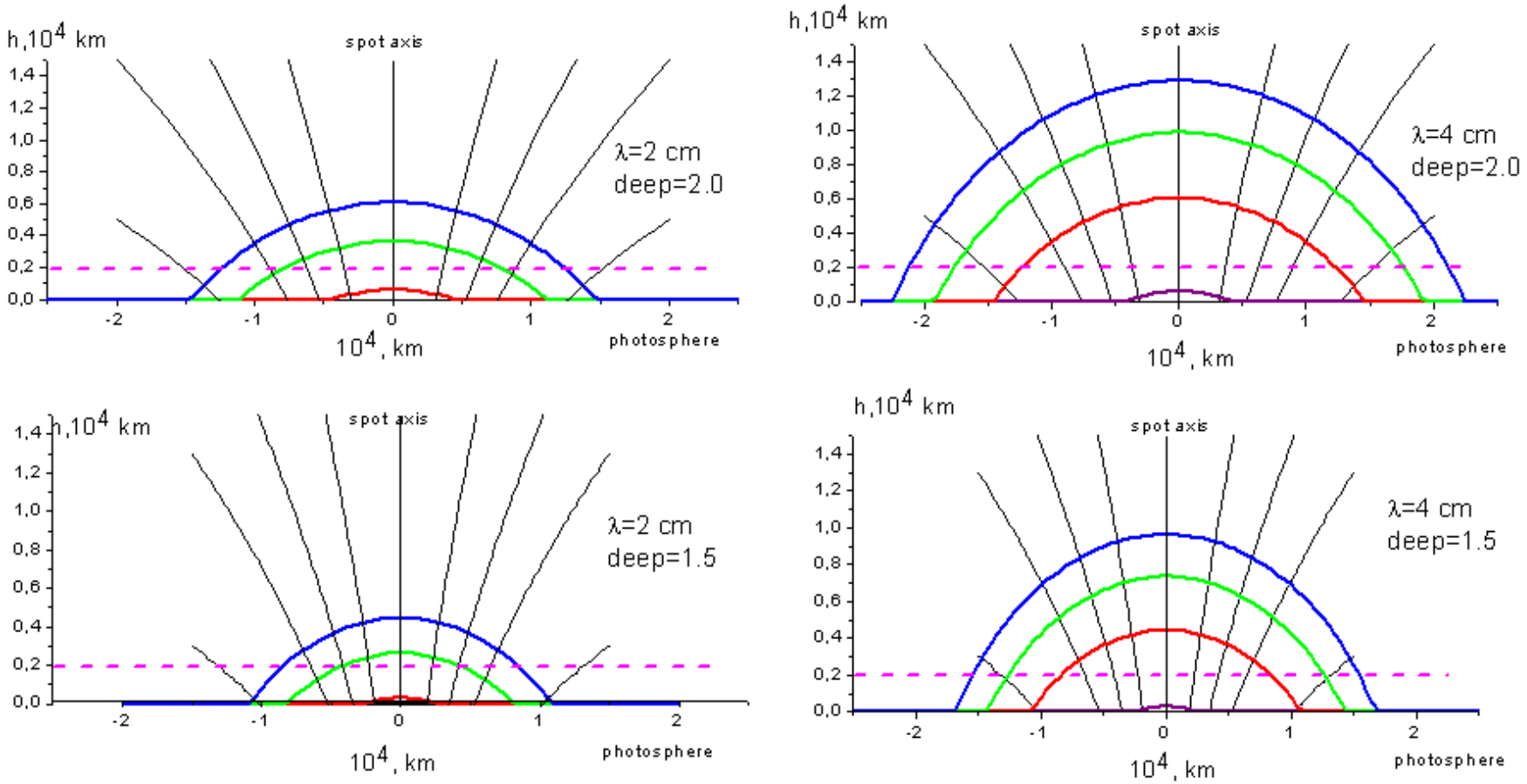
N= 1.5e16/T,

h_{model}=2000 km

Sunspot area:

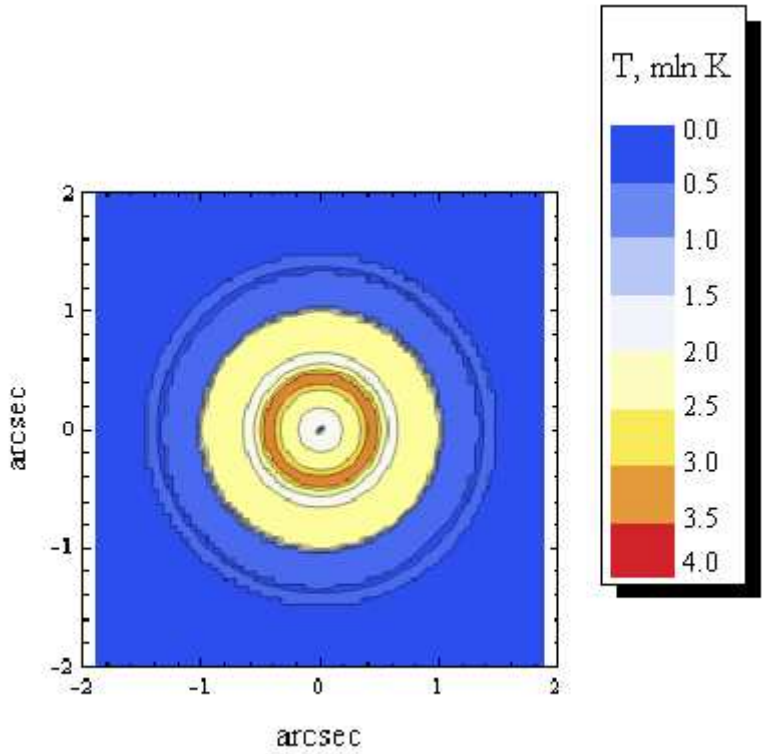
x=[-2,2] 10^4 km

y=[-2,2] 10^4 km

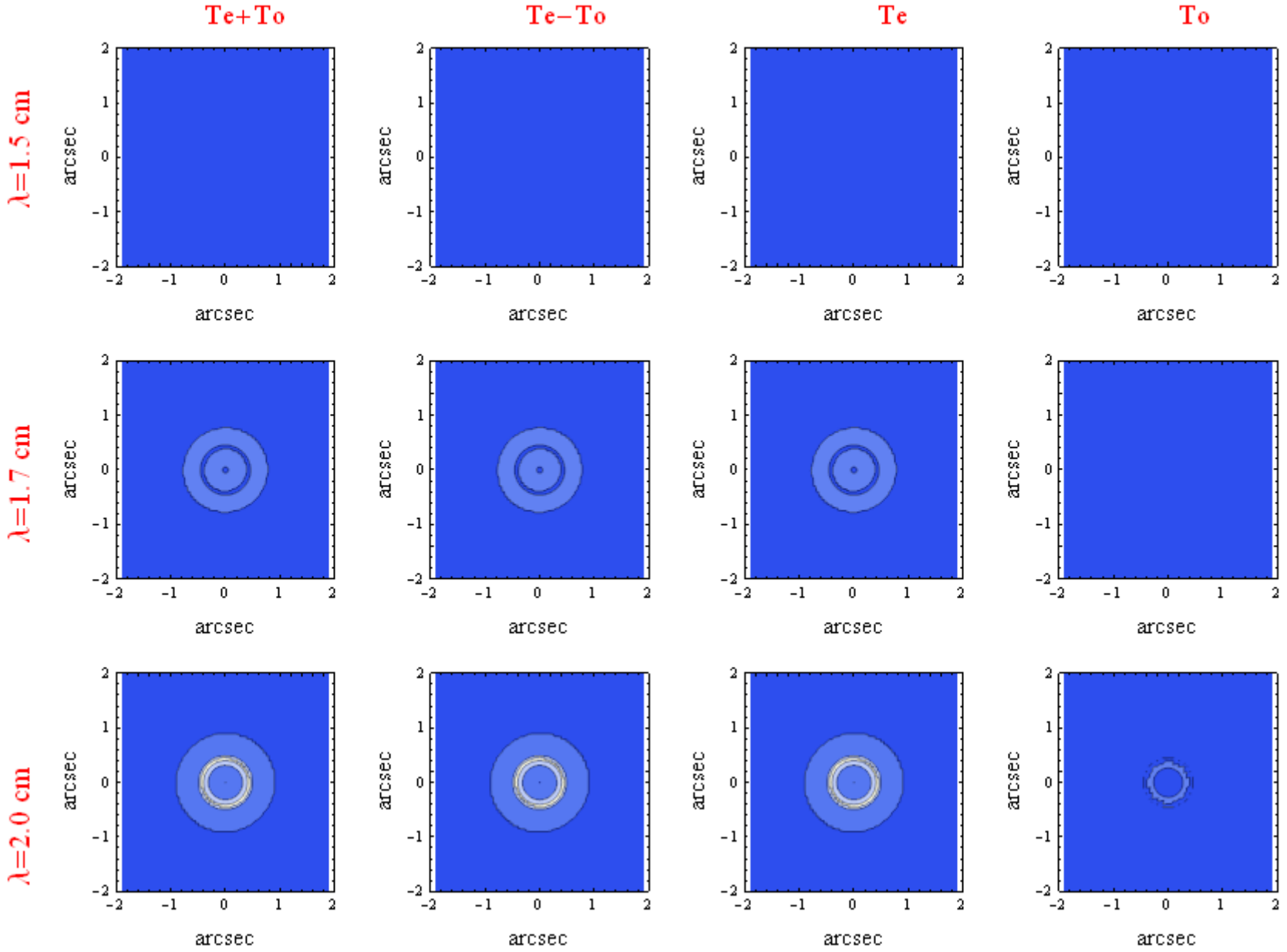


Zheleznyakov, V.V.: 1970, Radio Emission from the Sun and Planets, Pergamon Press, Oxford.

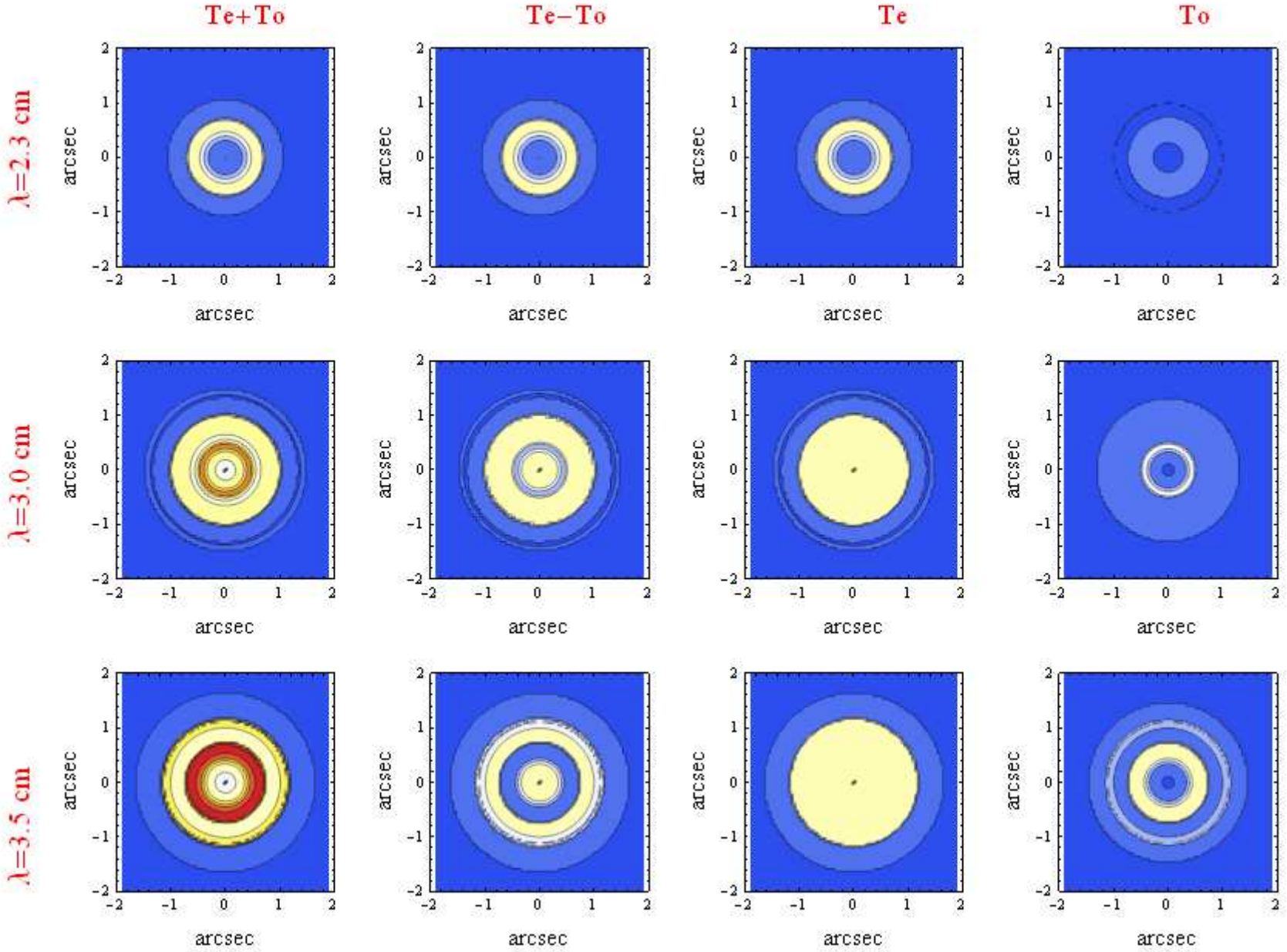
Zlotnik, E.Ya.: 1968, Astron. Zh. , 45, 310, 585.


T, mln K
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
arcsec
arcsec
2
1
0
-1
-2
-2
-1
0
1
2

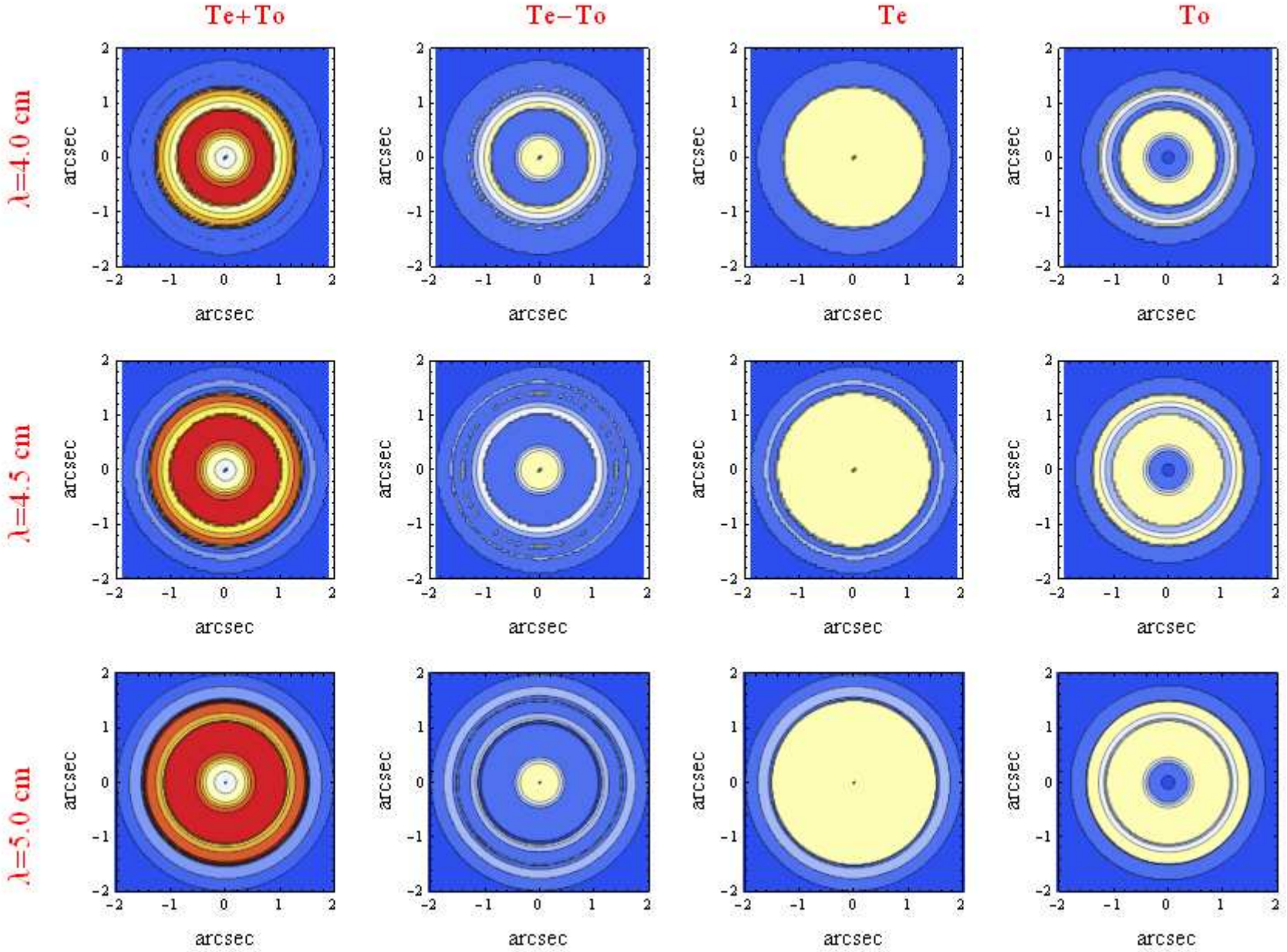
deep=1.5 H=3000 G Θ=90°

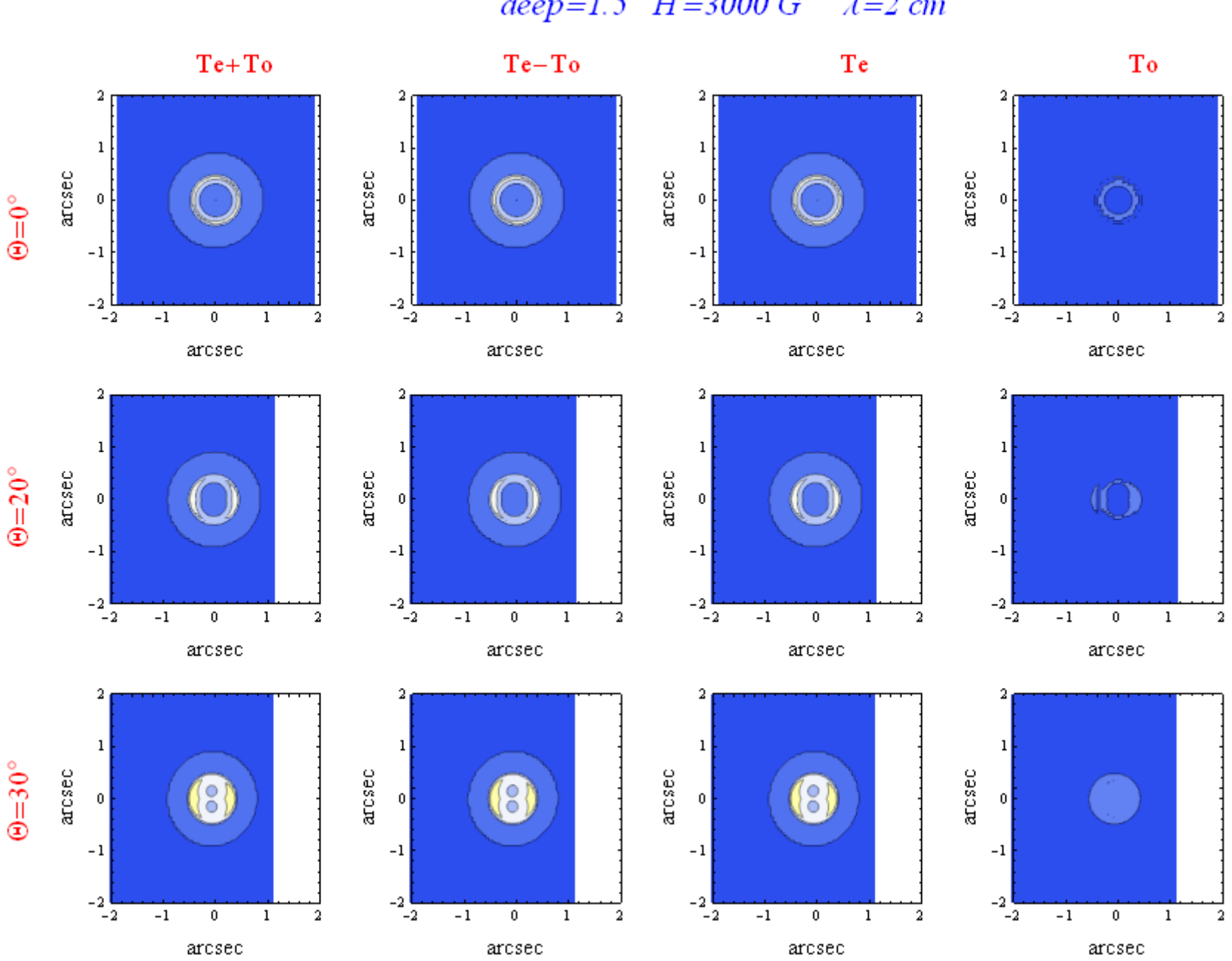


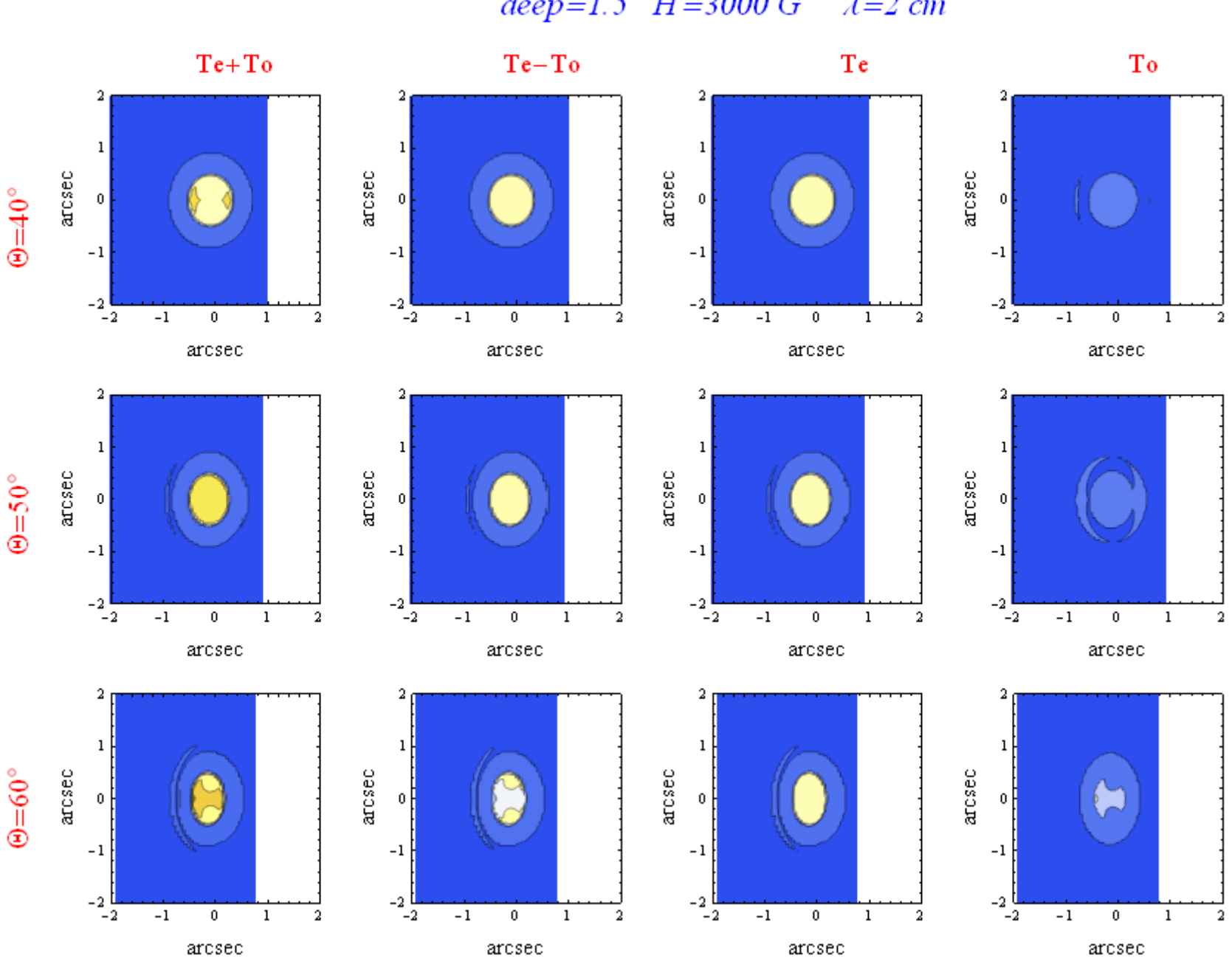
deep=1.5 H=3000 G Θ=90°

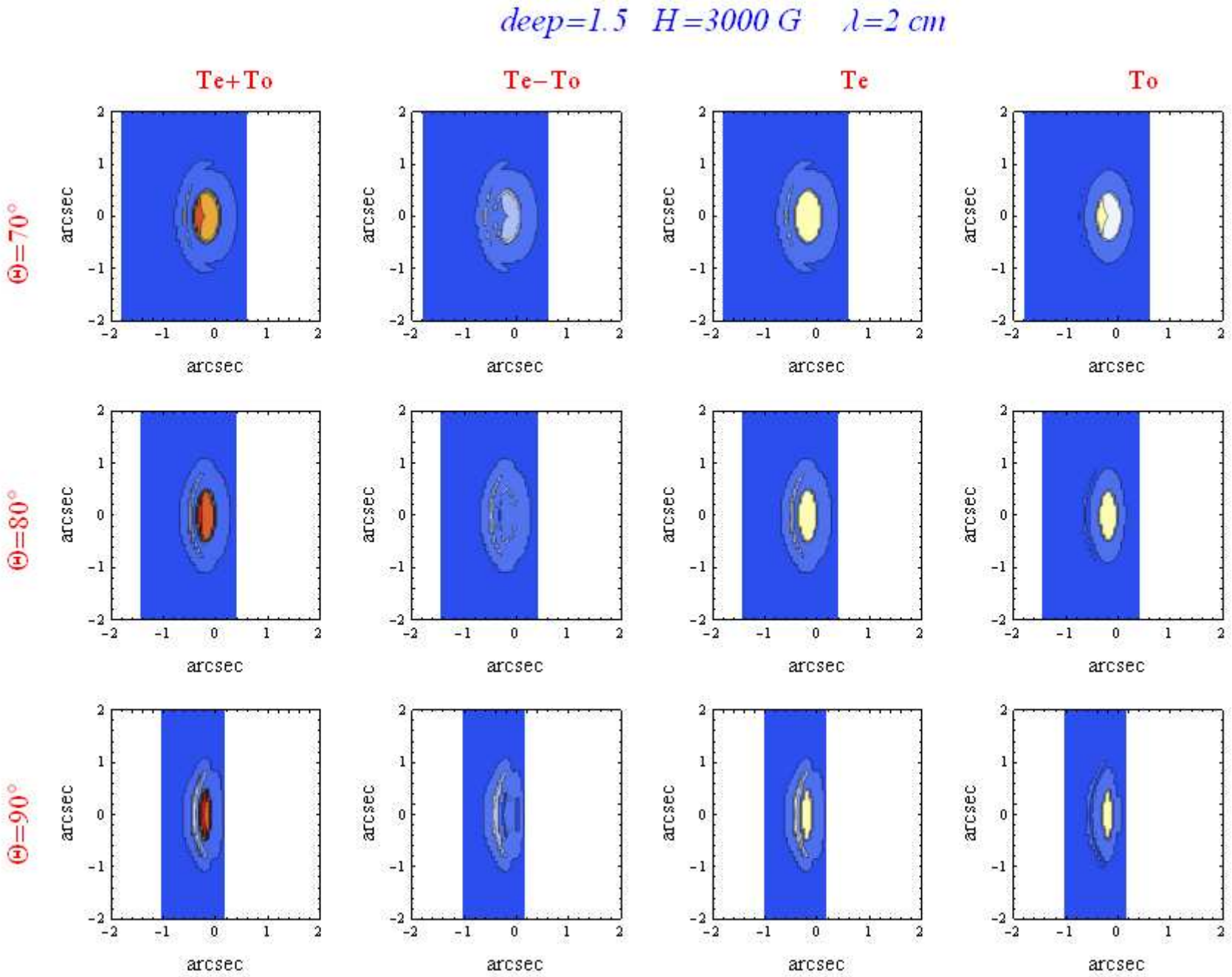


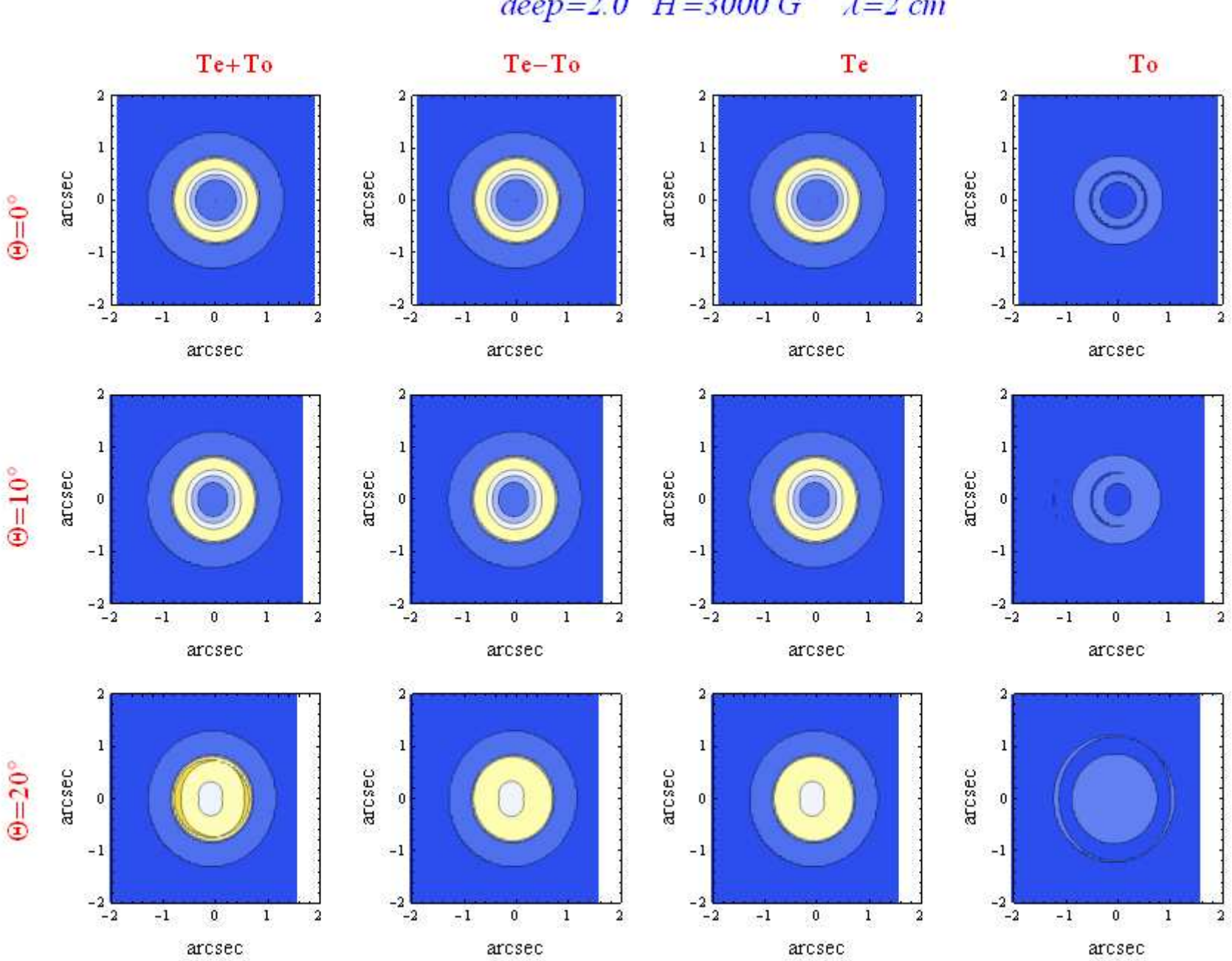
deep=1.5 H=3000 G Θ=90°

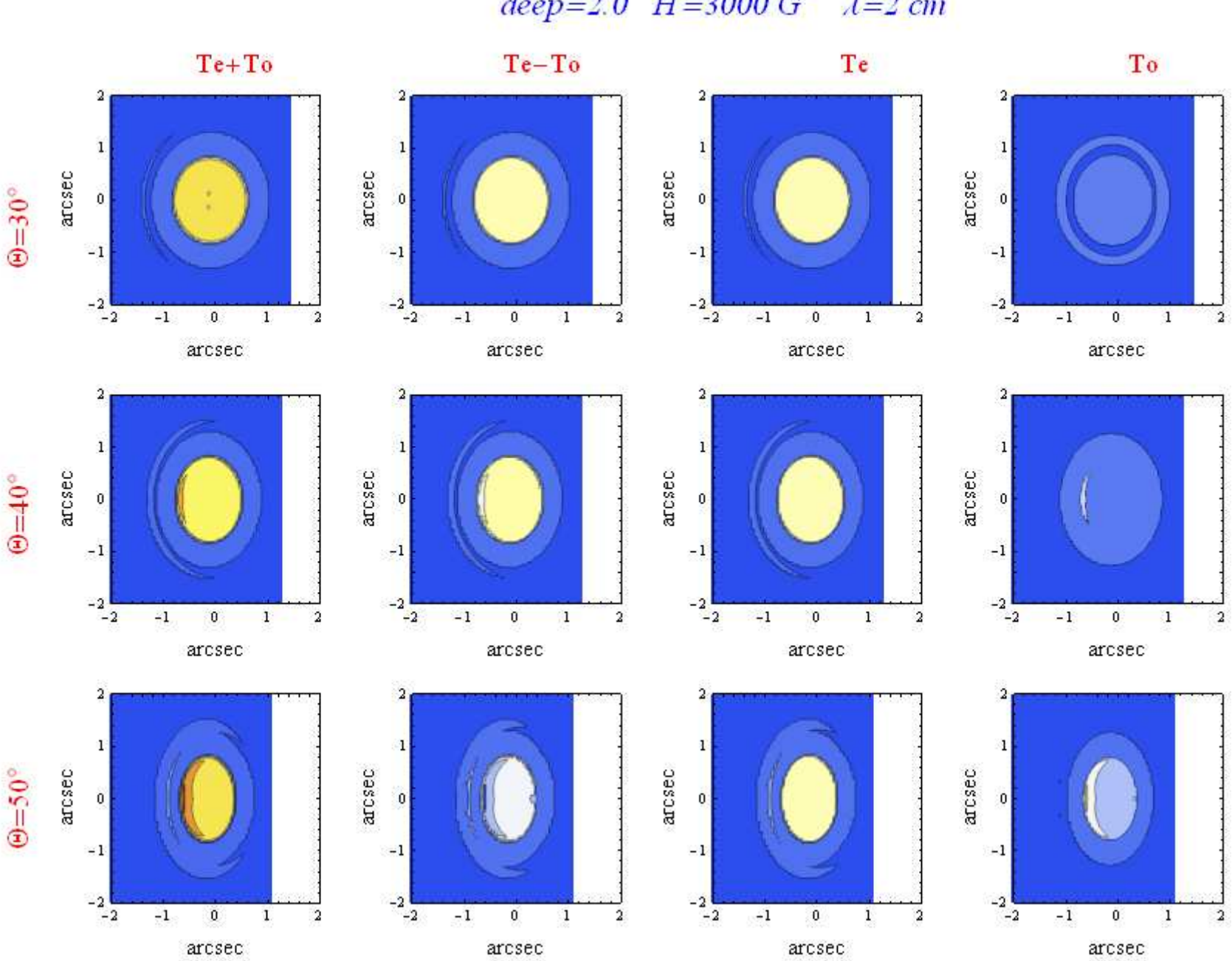


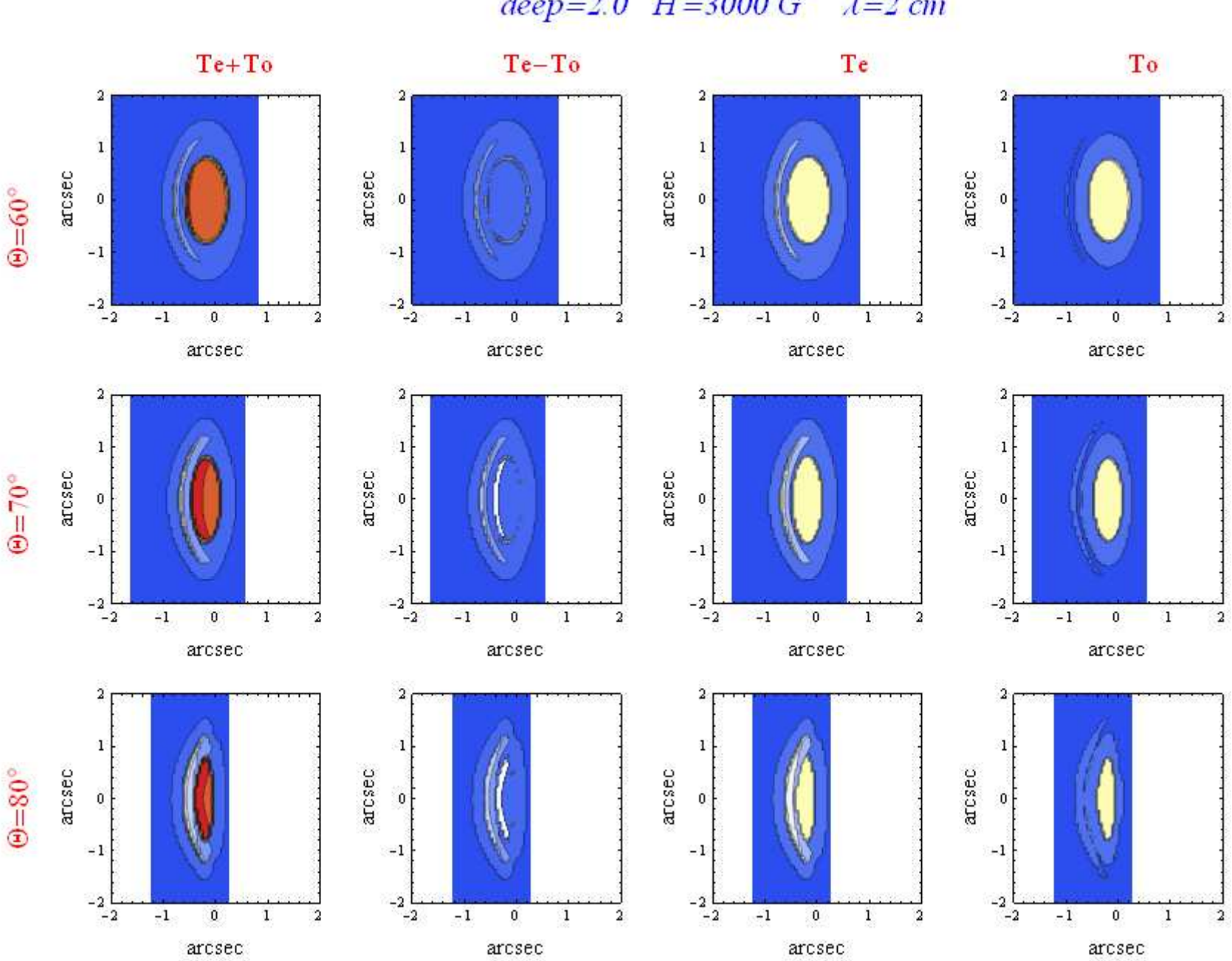

deep=1.5 H=3000 G λ=2 cm
Te+To
Te−To
Te
To
Θ=0°
Θ=20°
Θ=30°
arcsec
arcsec

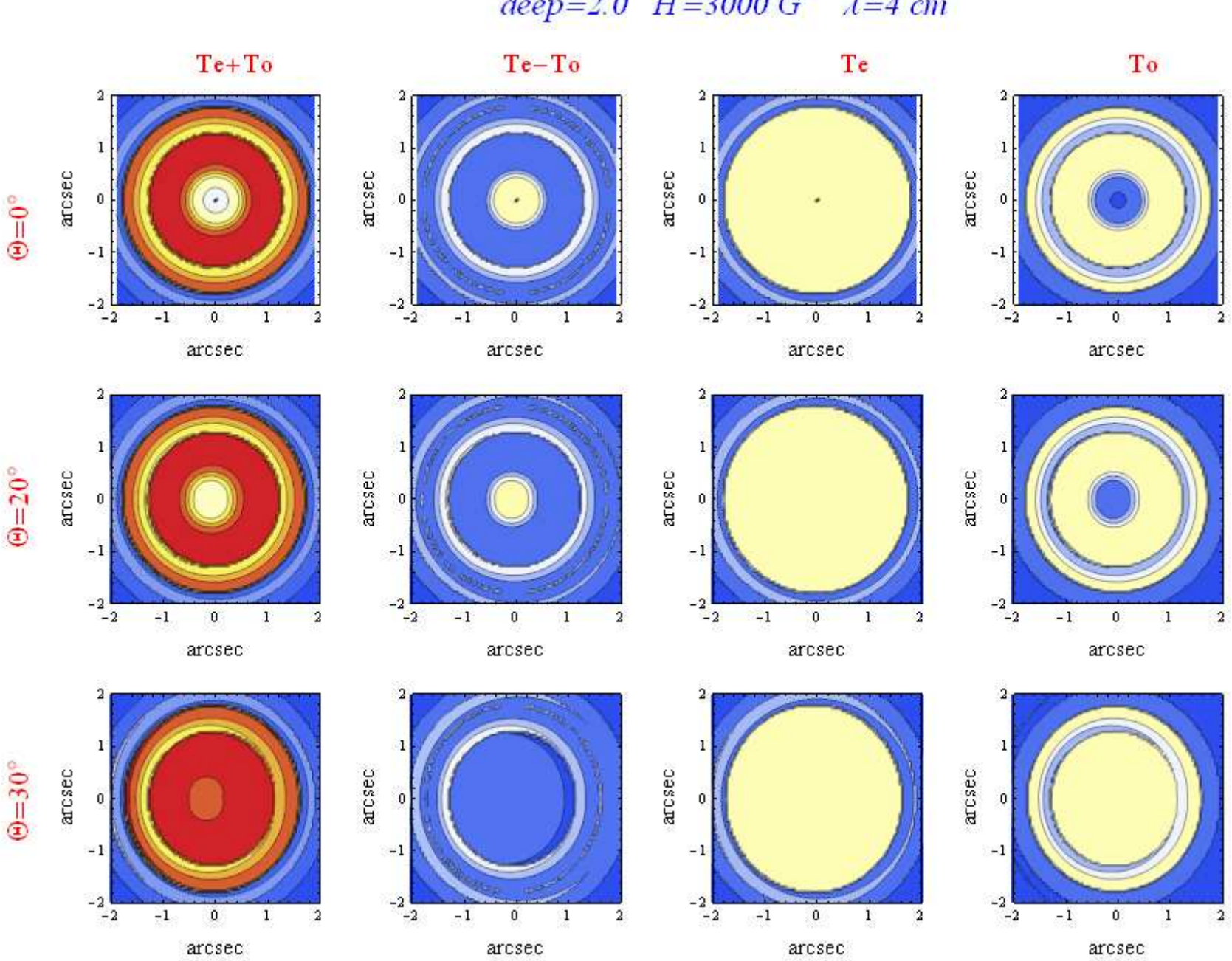

deep=1.5 H=3000 G λ=2 cm
Te+To
Te−To
Te
To
Θ=40°
Θ=50°
Θ=60°
arcsec

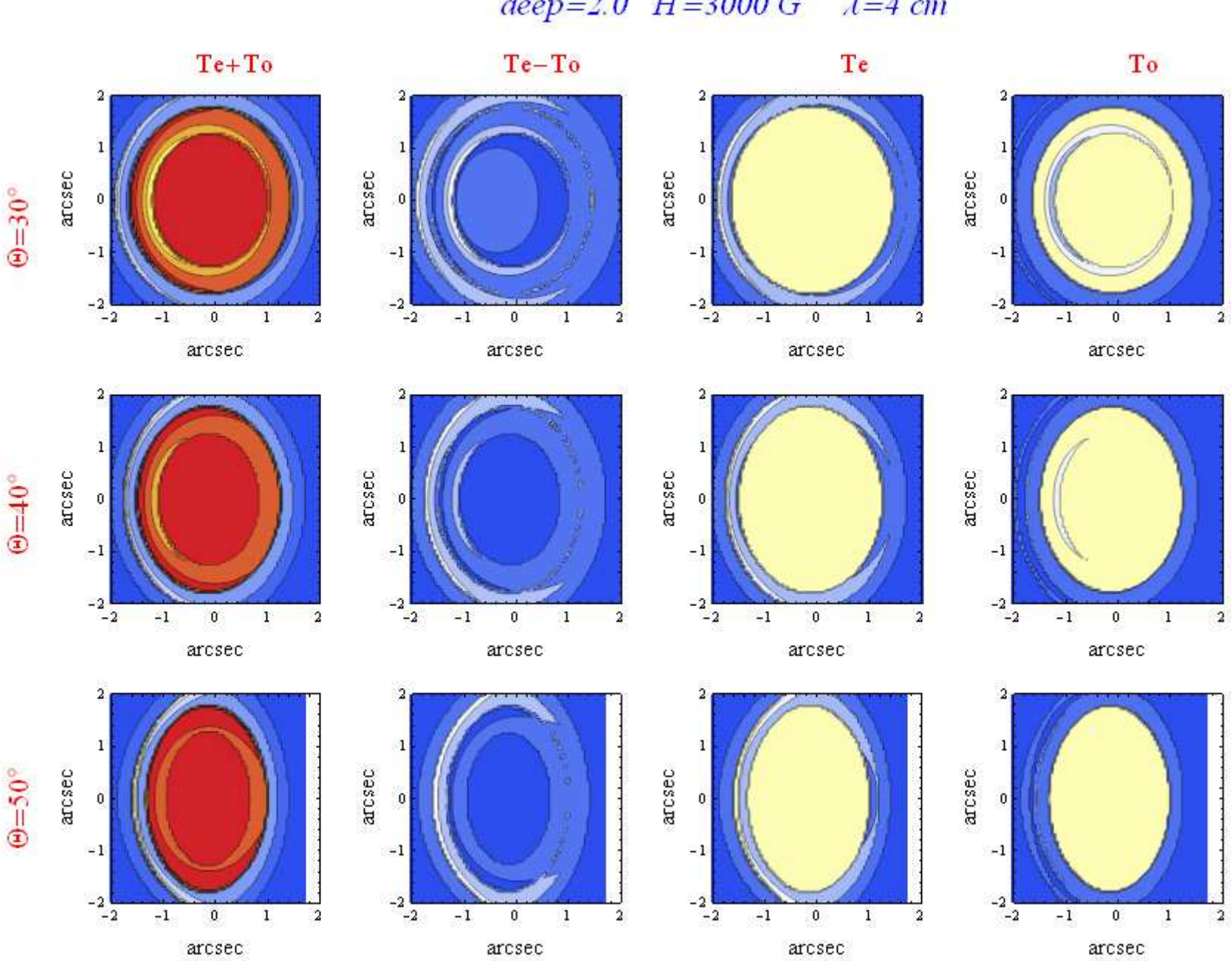

deep=1.5 H=3000 G λ=2 cm
Te+To
Te−To
Te
To
Θ=70°
Θ=80°
Θ=90°
arcsec

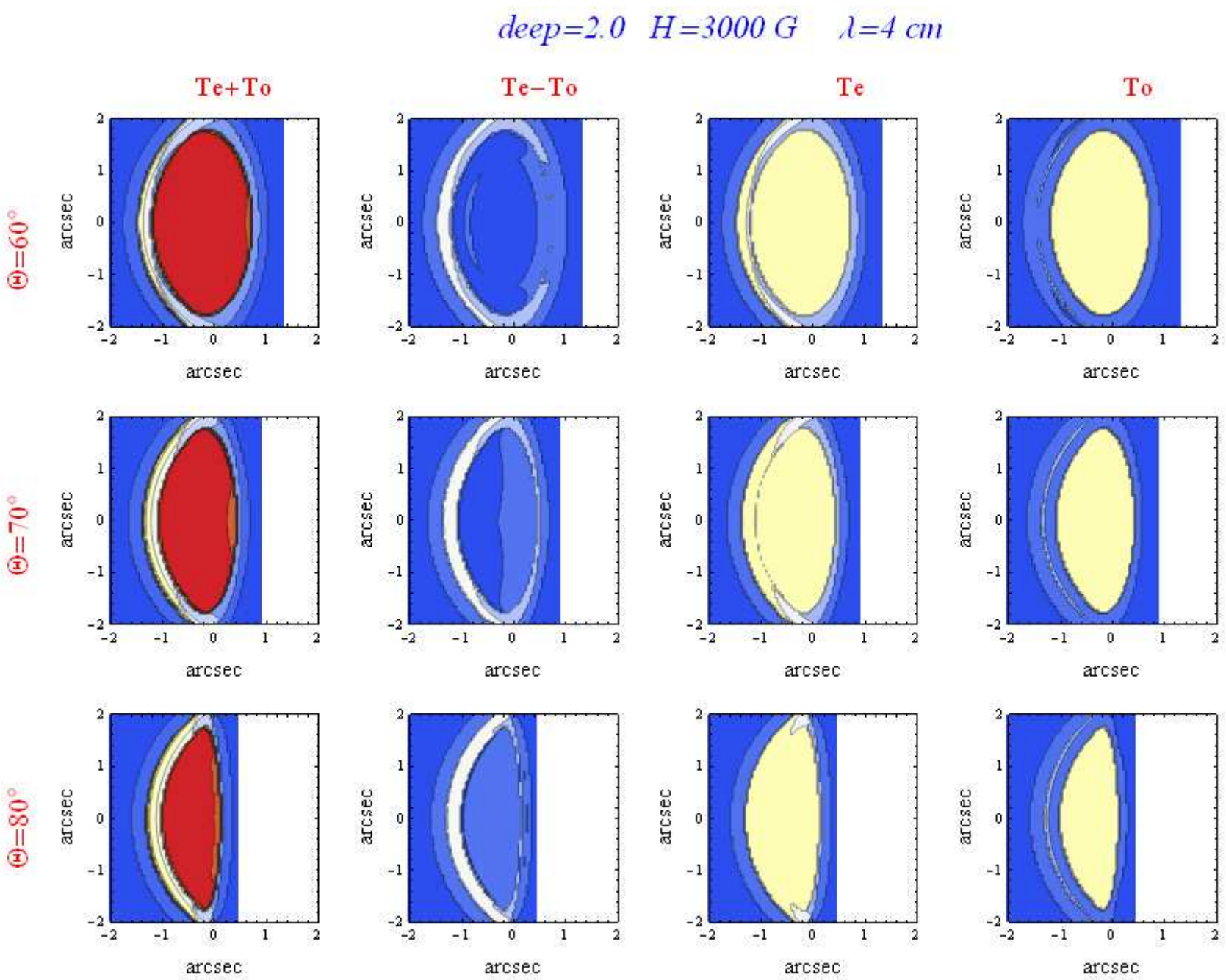

deep=2.0 H=3000 G λ=2 cm
Te+To
Te−To
Te
To
Θ=0°
Θ=10°
Θ=20°
arcsec
arcsec

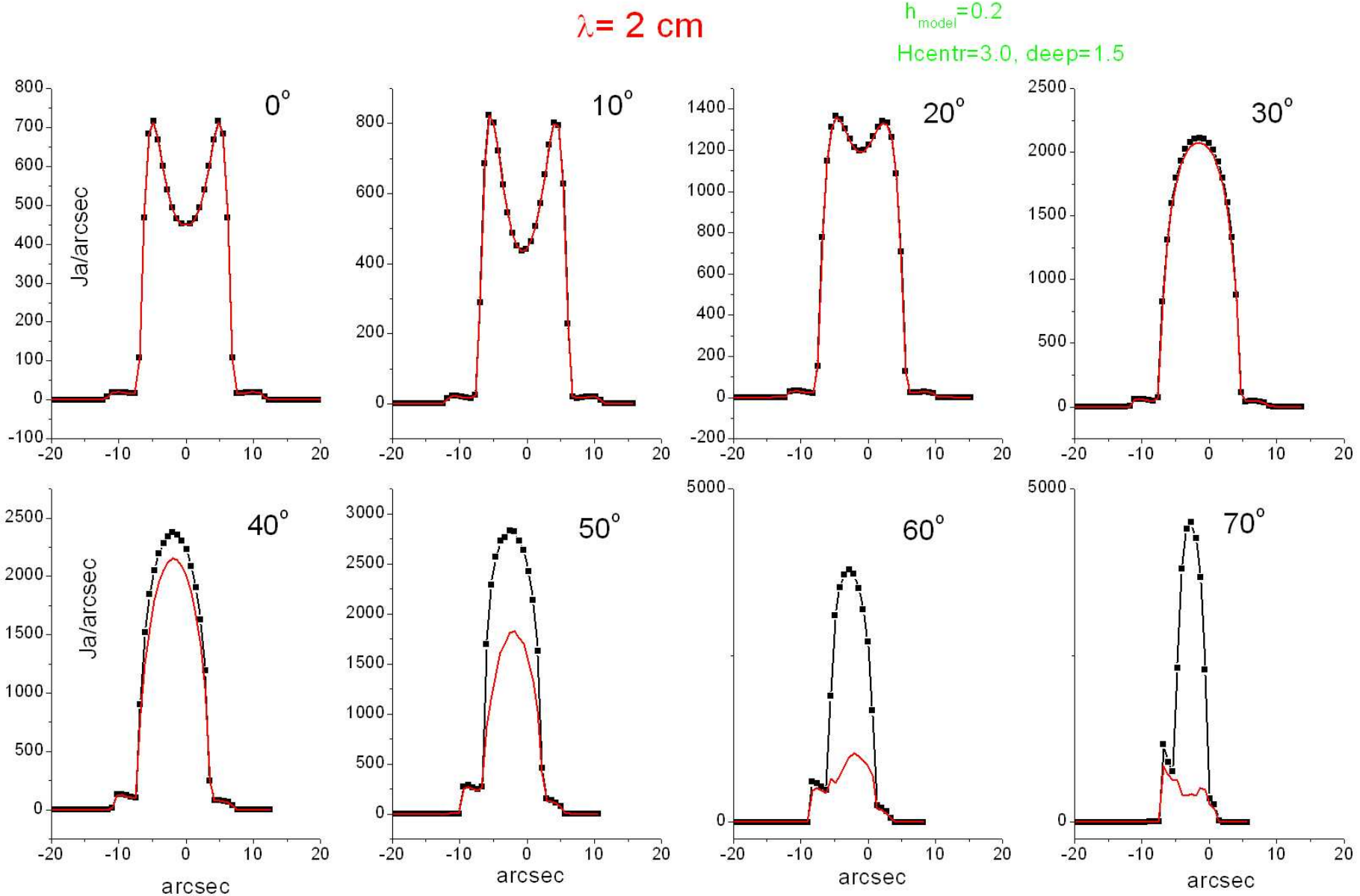

deep=2.0 H=3000 G λ=2 cm
Te+To
Te−To
Te
To
Θ=30°
Θ=40°
Θ=50°
arcsec
arcsec

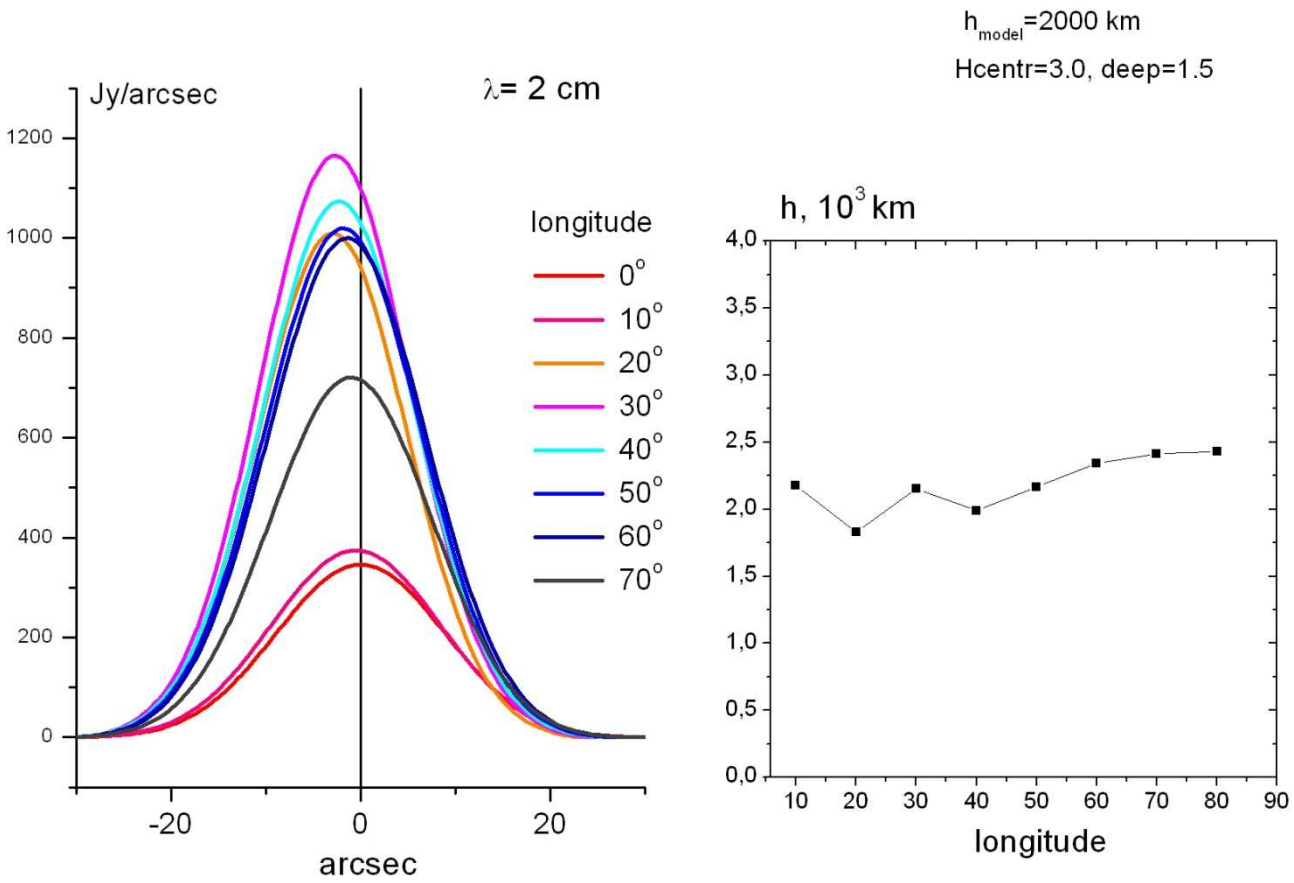

deep=2.0 H=3000 G λ=2 cm
Te+To
Te−To
Te
To
Θ=60°
Θ=70°
Θ=80°
arcsec
arcsec


deep=2.0 H=3000 G λ=4 cm
Te+To
Te−To
Te
To
Θ=0°
Θ=20°
Θ=30°
arcsec
arcsec


deep=2.0 H=3000 G λ=4 cm
Te+To
Te−To
Te
To
Θ=30°
Θ=40°
Θ=50°
arcsec
arcsec


deep=2.0 H=3000 G λ=4 cm
Te+To
Te−To
Te
To
Θ=60°
Θ=70°
Θ=80°
arcsec
arcsec


λ= 2 cm
h model=0.2
Hcentr=3.0, deep=1.5
0°
10°
20°
30°
40°
50°
60°
70°
Ja/arcsec
arcsec



To the left: the calculated distribution of intensity (color lines for different longitude) emission (convoluted with RATAN-600 beam) distributed along the spot associated source are presented for 2 cm and for magnetic dipole model with deep=1.5.

We can see that observed maximum of scans is displaced depending on longitude of sunspot.

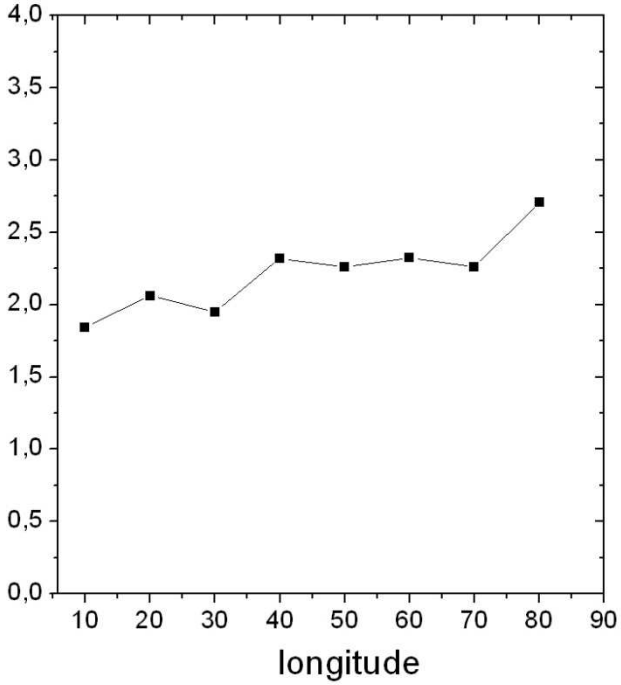
To the right: the estimates of the effective height of emission above photosphere level by measurements of emission centre of weight declination from source geometrical centre at approaching to the limb are presented.

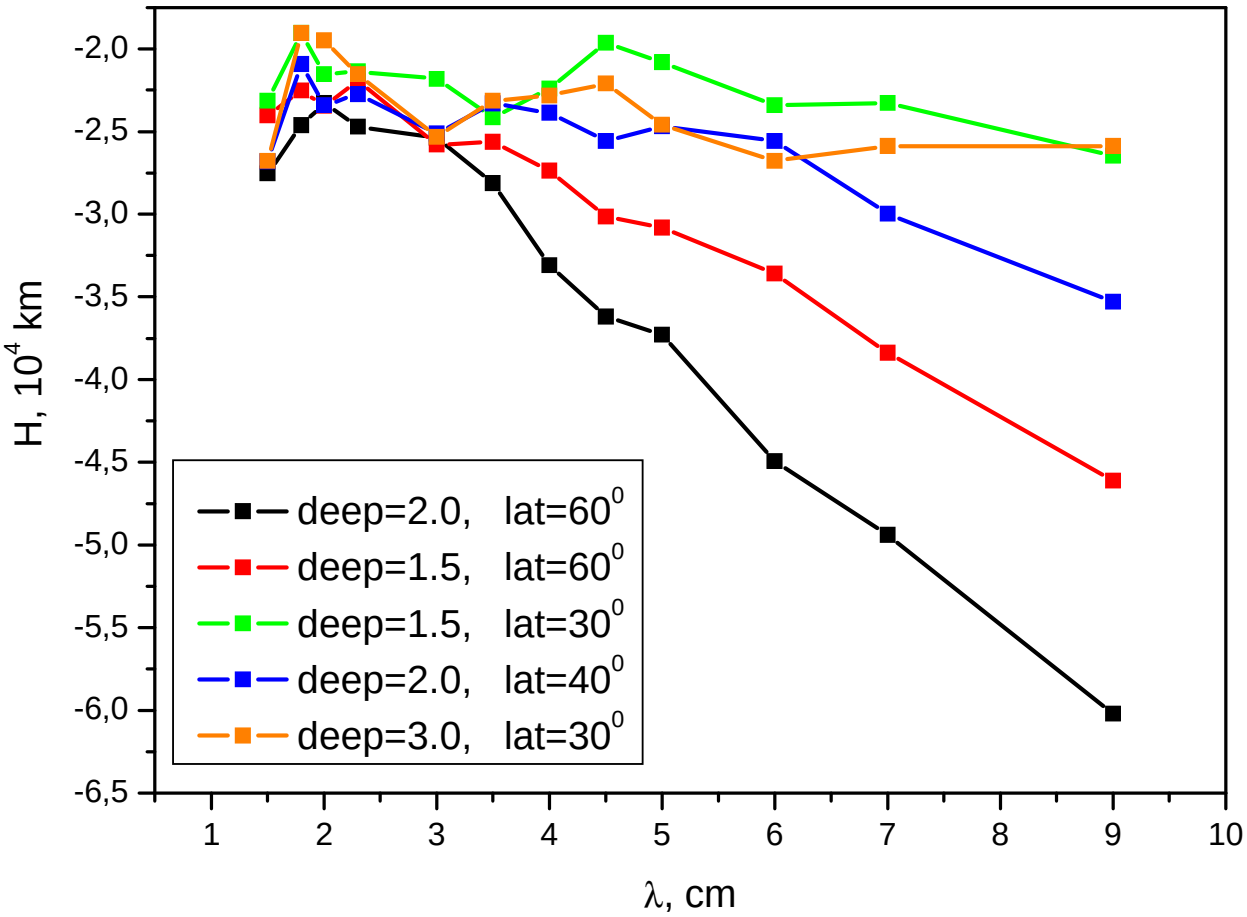
The more credible estimates in this one and in the following examples are for approximately 60 longitude, where the estimated height value better corresponds to the model one (h=2000 km).

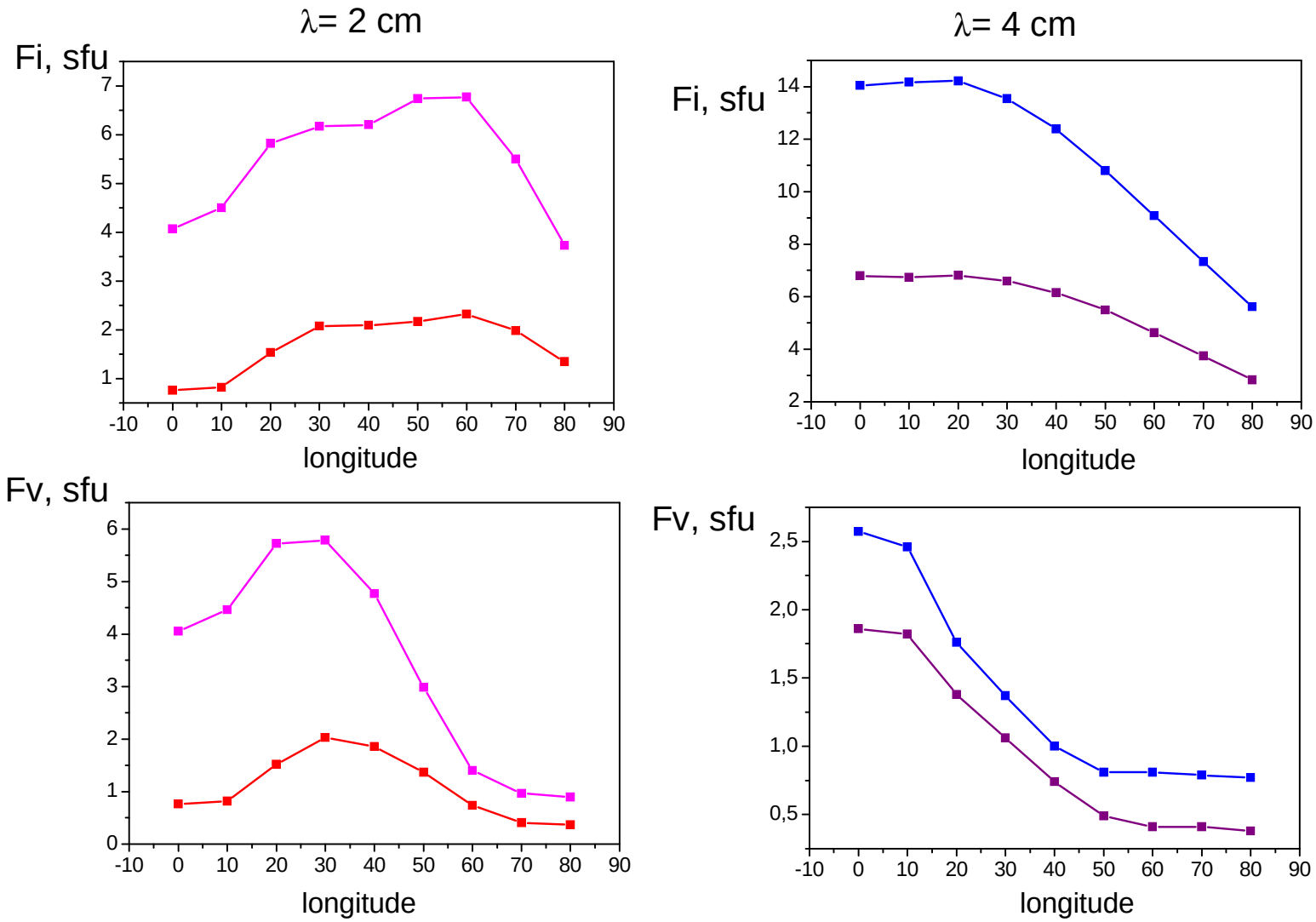
h_{model}=2000 km

Hcentr=3.0, deep=2.

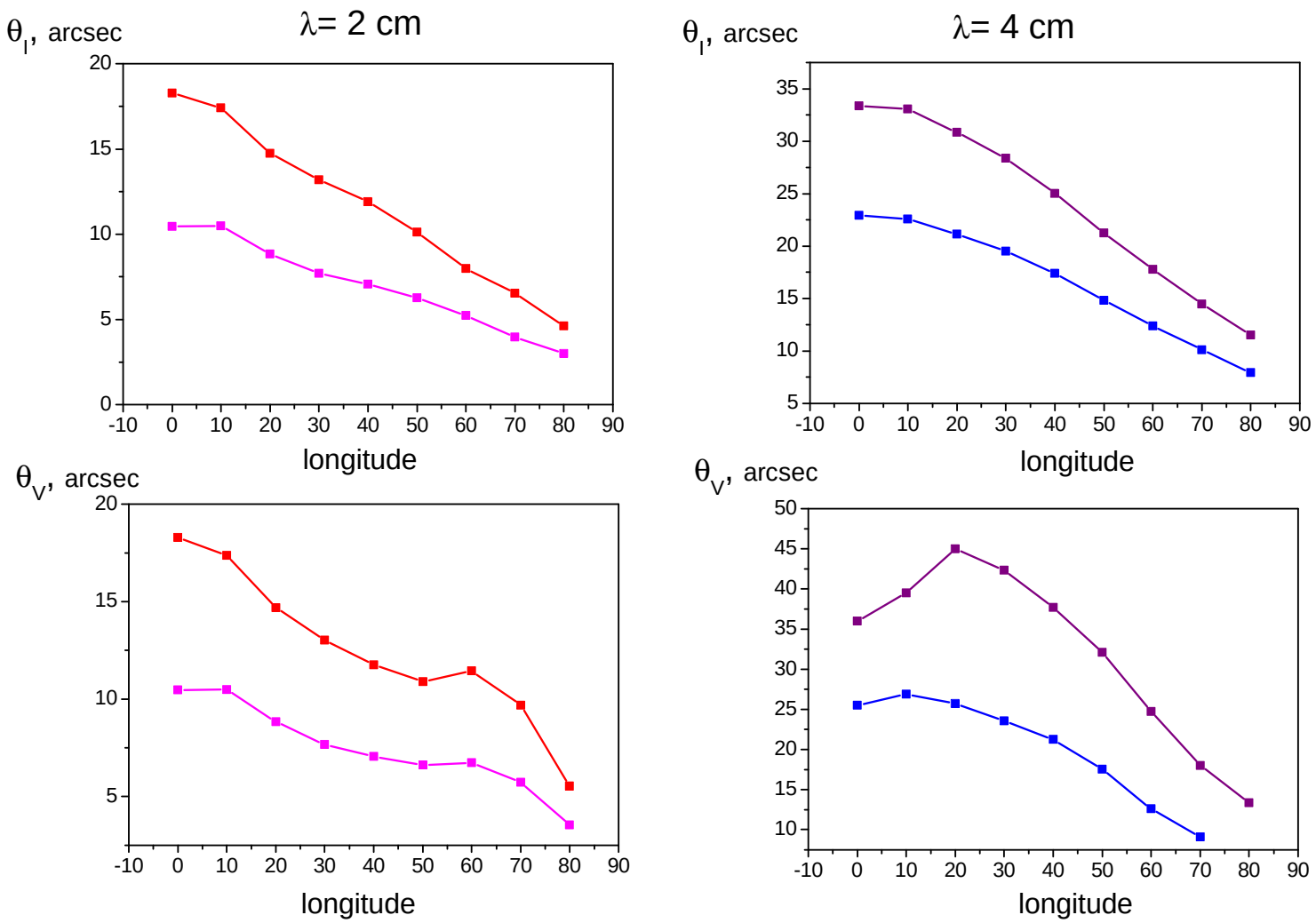
λ=2 cm




-2,0
-2,5
-3,0
-3,5
-4,0
-4,5
-5,0
-5,5
-6,0
-6,5
H, 10^4 km
1
2
3
4
5
6
7
8
9
10
λ, cm
deep=2.0, lat=60^0
deep=1.5, lat=60^0
deep=1.5, lat=30^0
deep=2.0, lat=40^0
deep=3.0, lat=30^0



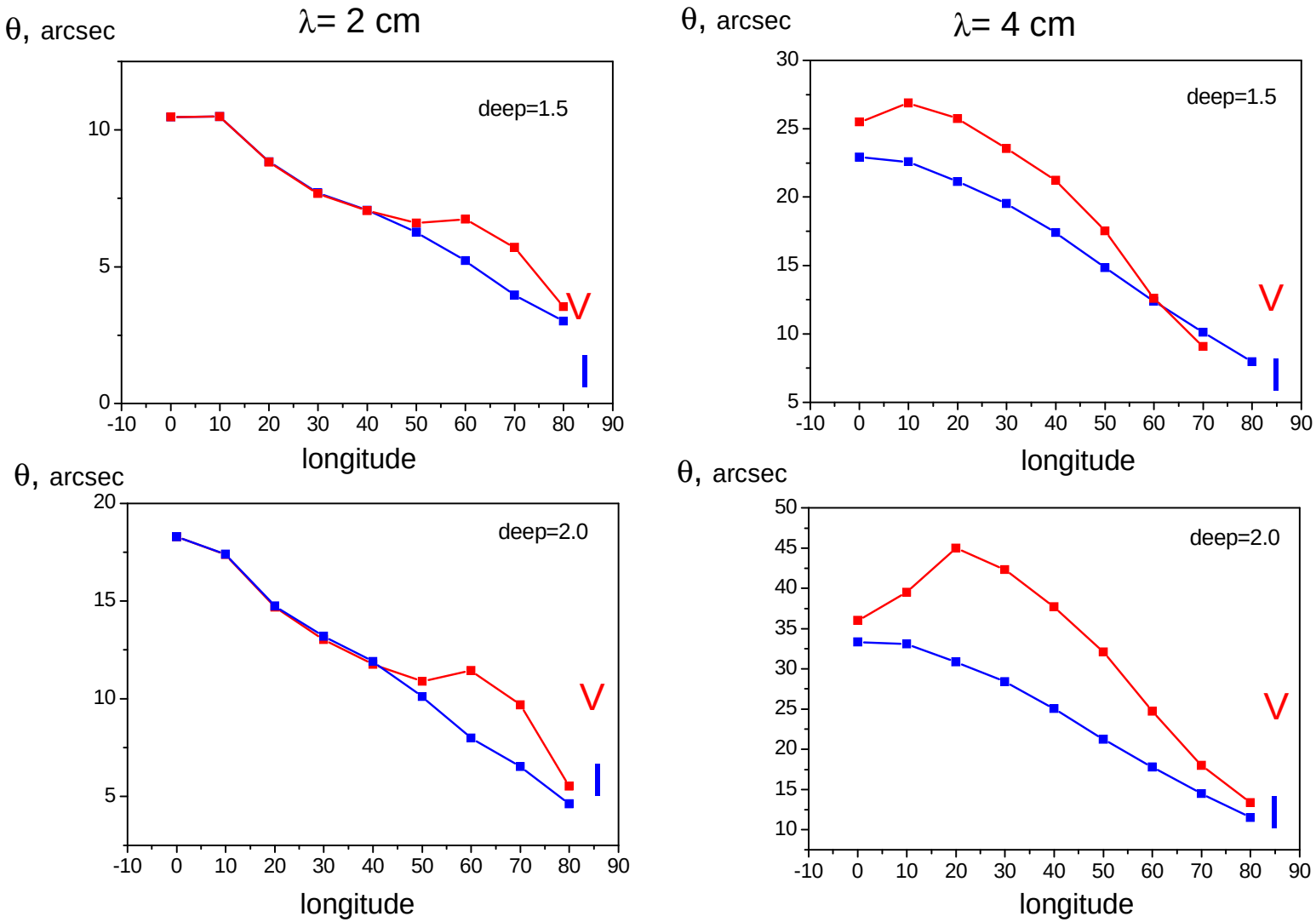
The calculated integral flux of intensity (top panel) and polarization (low panel) emission of sunspot at 2 and 4 cm at different longitudes, for two magnetic dipole models (deep=1.5 – low line at all graphs and deep=2 – top line at all graphs) .



The calculated sizes of source accordingly to gauss-analysis of RATAN-600 observation data treatment are presented for different longitudes.

The sizes of sources in intensity (top panel) and in polarization (low panel) emission at 2 cm and 4 cm, for two magnetic dipole models (deep=1.5 -low line at all graphs and deep=2 – top line at all graphs) .

The decreasing of effective sizes is seen while the source approaches to the limb.



The same as in previous figure , but at every graphs we now can see the comparison of source sizes in intensity and in polarization emission. Because of the projection effect the sizes of source observed in polarized emission (Stokes parameter V) exceed the sizes of the source in full intensity emission (Stokes parameter I) due to ring distribution of polarized emission.

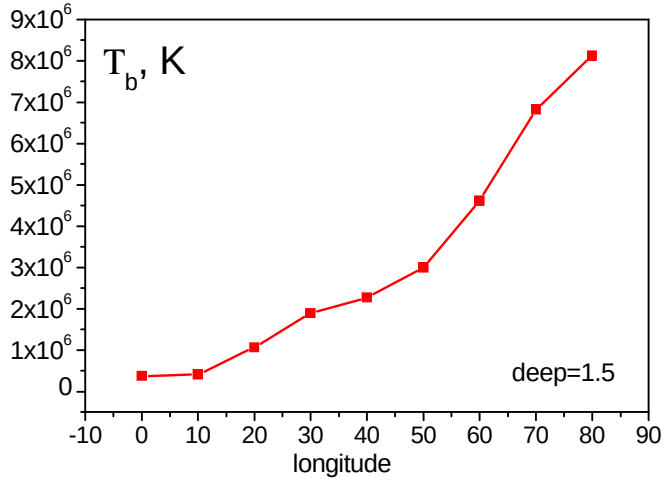
Two step chromosphere-corona model:

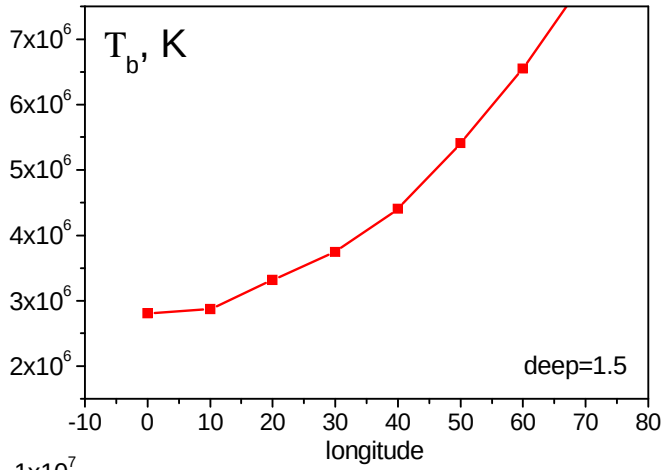
T=10 000 K - 2 mln K,

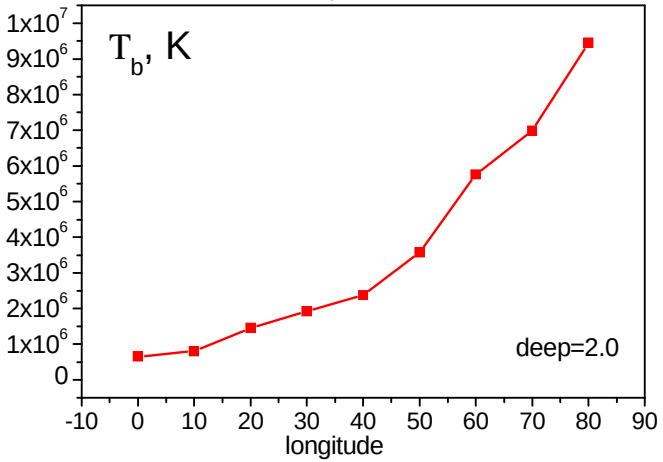
N= 1.5e16/T, h=2000 km

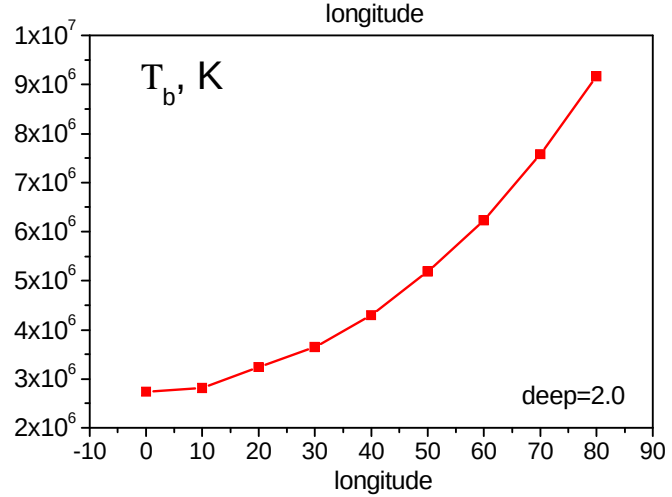
λ= 2 cm

λ= 4 cm



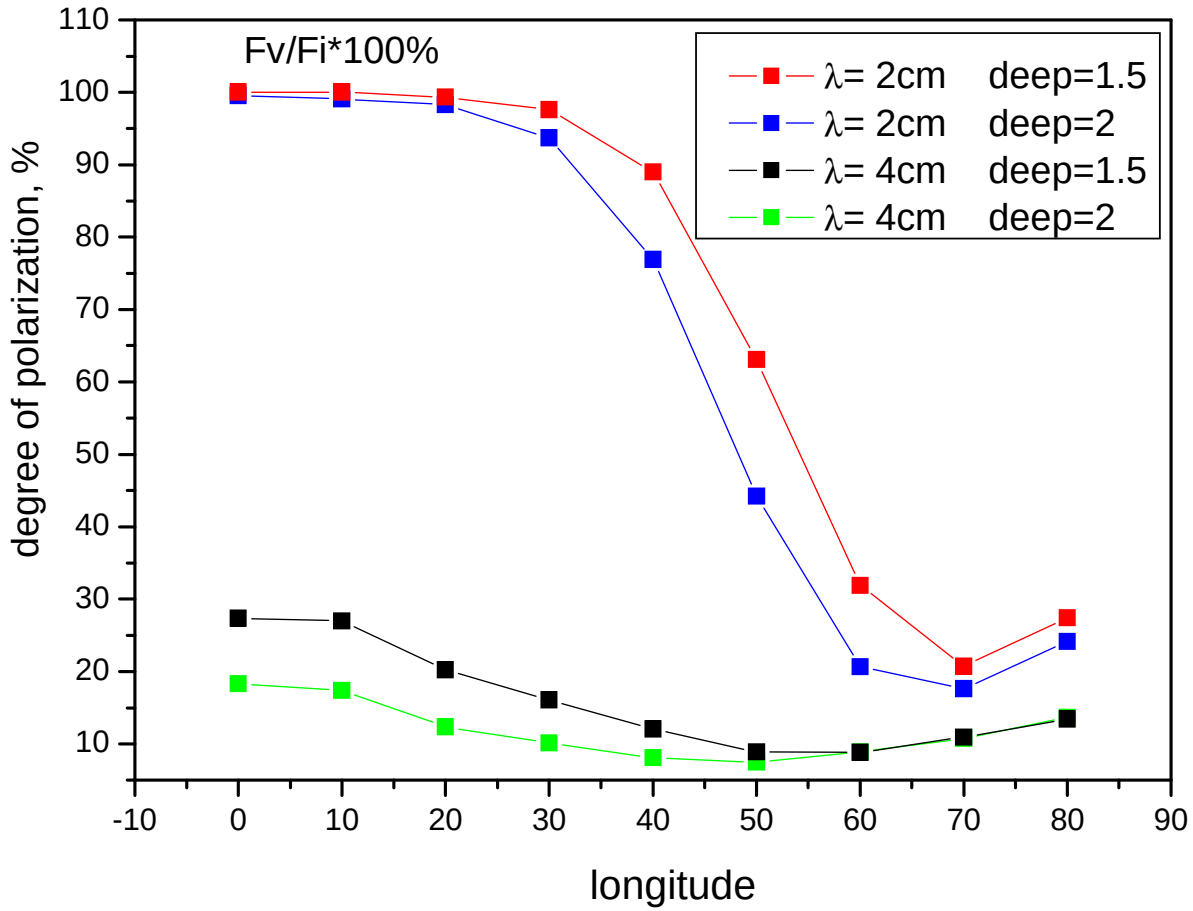






The calculated effective brightness temperatures at 2 and 4 cm at different longitudes, for two magnetic dipole models (deep=1.5 and deep=2.0). The calculated value at high longitudes are greatly exceed the modeled corona temperature value 2 mln K.

Due to the decreasing of effective sizes the following gauss-analysis would overestimate the values of brightness temperatures if necessary corrections were not done.


Fv/Fi*100%
λ= 2cm deep=1.5
λ= 2cm deep=2
λ= 4cm deep=1.5
λ= 4cm deep=2
degree of polarization, %
longitude
110
100
90
80
70
60
50
40
30
20
10
-10
0
10
20
30
40
50
60
70
80
90

Summary

- The modeling of microwave emission from spot associated cyclotron source was done to refine the method of estimations of effective brightness temperature, size and height above photosphere in treatment of RATAN-600 observations.
- While source approaches to the limb a decreasing of source visible size in E-W direction takes place due to projection effect, which causes a decreasing of its effective size in treatment of one-dimensional scan of RATAN-600.
- The following gauss-analysis would overestimate the values of brightness temperatures if necessary corrections were not done.
- The same projection effect leads to the fact, when the sizes of source observed in polarized emission (Stokes parameter V) exceed the sizes of the source in full intensity emission (Stokes parameter I) due to ring distribution of polarized emission.
- The method of estimates of the effective height of emission above photosphere level by measurements of emission centre of weight declination from source geometrical centre at approaching to the limb was modeled and presented. The more credible estimates are for approximately 60° longitude, where the estimated heigh t values better correspond to the model one.