On the Class II Methanol Maser Periodic Variability due to the Rotating Spiral Shocks in the Gaps of Disks Around Young Binary Stars

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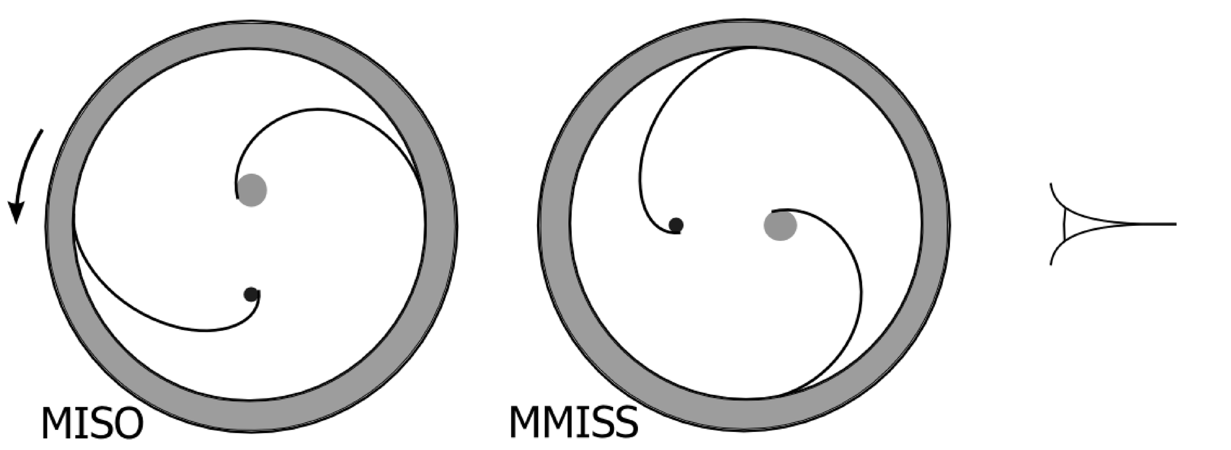
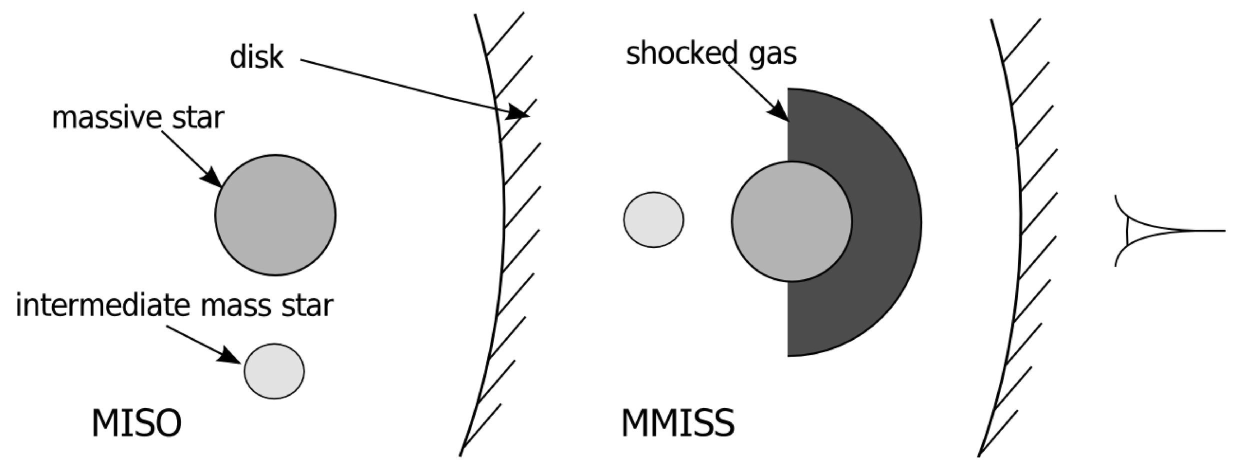
Class II methanol masers are widespread in the regions of star formation (Caswell 2013). Some of Class II methanol maser sources associated with massive star formation regions show periodic variability. We argue that the periodic variability of Class II methanol masers can be explained by variations of the dust temperature in the accretion disk around protobinary star with at least one massive component. The dust temperature variations are caused by rotation of hot and dense material of the spiral shock wave in the disk central gap.

The aim of this work is to show how different can be the Class II methanol maser brightness in the disk during the ***M***oment of ***M***aximum ***I***llumination by the ***S***piral ***S***hock material (MMISS) and the ***M***oment when the disk is ***I***lluminated by the ***S***tars ***O***nly (MISO).



The schematic view of protobinary and spiral shocks configurations in the disk inner gap for two time moments which differ by the half of the binary orbital period. Filled circles show positions of protobinary components, arcs correspond to the bow shocks and the ring corresponds to the inner boundary of circumbinary disk. The arrow indicates the direction of binary, disk and bow shocks rotation.

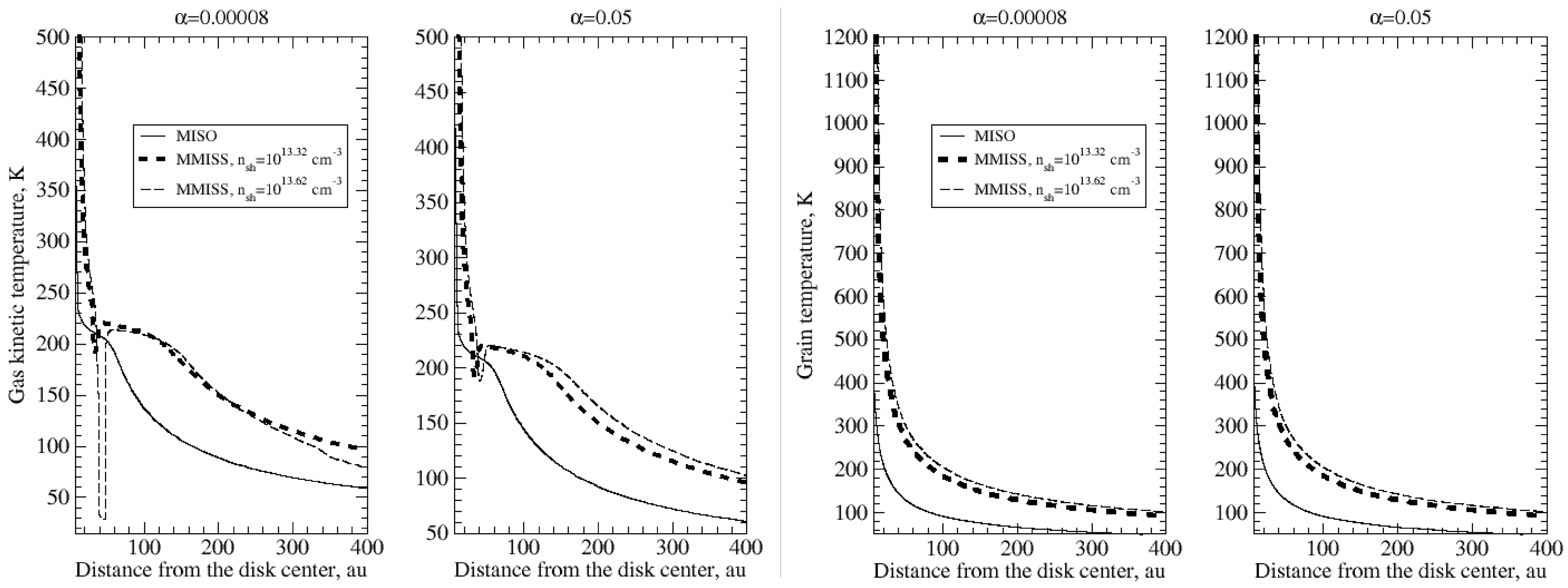


The schematic view of two models: in the MISO and in the MMISS. The difference of protobinary components positions relatively to the disk inner boundary is only for clarity and was not accounted for in the calculations. In the MISO the disk illuminated only by stars with mass M = 13 $M_\odot$ and M = 7 $M_\odot$. In the MMISS the disk is illuminated by the star with M = 13 $M_\odot$ and shocked gas layer with temperature 30222 K. We considered densities of the shocked gas layer n_{sh} of $10^{13.32}$ and $10^{13.62}$ cm^{-3}.

Disk model:

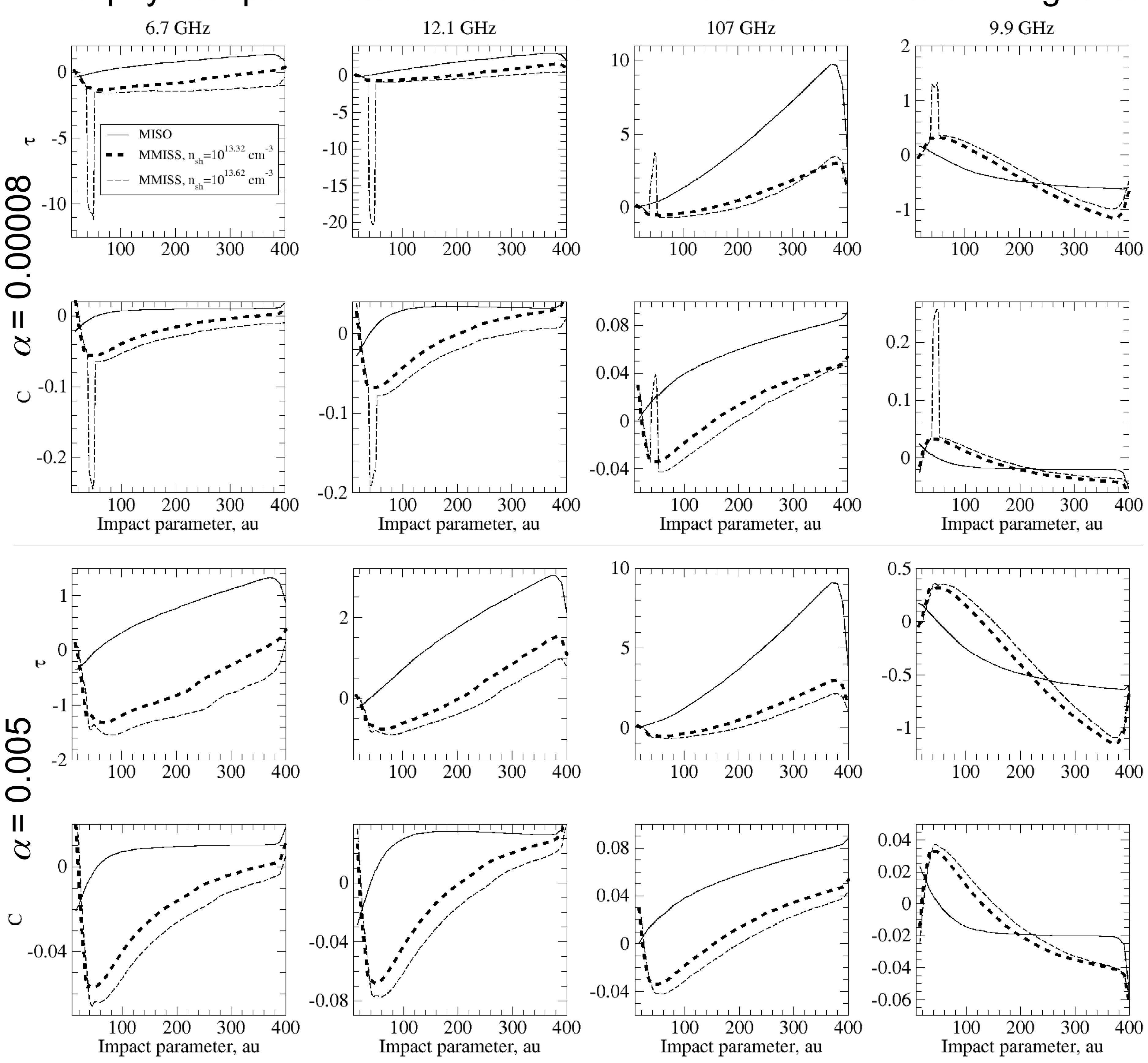
- flat disk with inner radius of 1.9 and outer radius of 1000 au; the disk height is 0.76 au
- hydrogen number density n_H ~ 1/r and ranges from $10^{9.8}$ to $10^{7.1}$ cm^{-3}
- additional heating due to the viscous dissipation is treated in the framework of α-disk model (Shakura & Sunyaev 1973); the disk models were computed with α = 0.00008 and α = 0.05
- the dust parameters are the same as in Baldwin et al. (1991); the grain physics described by Baldwin et al. (1991) and van Hoof et al. (2004).

Physical conditions in the disk in the MISO and MMISS were computed with photoionization code CLOUDY C13.02 (Ferland et al. 2013). Basic physical parameters included gas kinetic temperature, dust temperature and radiation intensity. In the MMISS and when α = 0.00008, n_{sh} = $10^{13.62}$ cm^{-3} in the disk center there is the thin disc region with relatively low gas kinetic temperature. It is caused by the thermal front where the gas changes its ionization state and transits to a different branch of the cooling curve. The greater the difference between the gas and dust temperatures, the higher the brightness of 6.7 GHz maser (Cragg et al. 2005).



The gas kinetic temperature and the temperature of small (grain radius of 0.03 μm) silicate grains in the disk region with potential for maser formation in the MISO (solid line) and in the MMISS. The disk region with potential for maser formation is a disk region with n_H < 10^9 cm^{-3} and dust temperature > 100 K (a limit for methanol thermal desorption).

Model physical parameters of the disc were used to estimate the brightness of 6.7, 9.9, 12.1 and 107 GHz masers at different impact parameters *p* using large velocity gradient approximation.



We used the approach from Sobolev & Deguchi (1994) to compute maser optical depths τ and excitation temperatures T_{ex}. To characterize T_{ex} we used the quantity $C = 1 - \exp(h\nu / kT_{ex})$, where ν – frequency of a maser transition, *h* and *k* are Planck and Boltzman constants, respectively. Negative values of τ and *C* mean that there is a maser amplification in a given transition, while the positive values mean that there is an absorption in this transition.

Three disc regions could be distinguished depending on the maser brightness behavior under the MISO and MMISS conditions:

- $p \in [12,50]$ au – the maser brightness in the MMISS depends on the disk viscosity; the brightness of 6.7 and 12.1 GHz in the MMISS increases with respect to MISO conditions; the brightness of 9.9 GHz in the MMISS decreases; the brightness of 107 GHz maser can increase or decrease depending on n_{sh} and α
- $p \in [12,200]$ au – absorption in 6.7, 107 and 12.1 GHz transitions under the MISO conditions changes to maser amplification under the MMISS conditions; absorption in 9.9 GHz transition increases in the MMISS
- $p \in [200,400]$ au – differs from two inner regions by behavior of the maser brightness of 9.9 GHz transition; the brightness of 9.9 GHz maser increases in the MMISS with respect to MISO.

Conclusions: the strong masers at 6.7 and 12.1 GHz experience considerable brightness increase during the MMISS with respect to MISO. There can happen both flares and dips of the 107 GHz maser brightness under the MMISS conditions, depending on the properties of the system. The brightest 9.9 GHz masers in the MMISS are situated at the greater *p* than the strong 6.7, 12.1 and 107 GHz masers that are situated at *p* < 200 au. The brightness of 9.9 GHz maser in the MMISS suppressed at *p* < 200 au and increase at *p* > 200 au. The occurrence of suppressed 9 GHz brightness considerably depends on parameters of the spiral shock in the disk center, which can be subject to time variability.