Sensitivity evaluation of submillimeter interferometer Earth - space telescope Submillimetron

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Abstract: For a progress in angular resolution of astronomical observations a submillimeter-wave space-ground interferometer is proposed. Realization of such interferometer is possible with use of space telescope for the International Space Station (project Submillimetron). An interferometer with this small telescope and ground-based radiotelescopes would have an angular resolution about 6 microarcsec and a sensitivity about 70 mJy for wavelength 0.35 mm. An improvement in sensitivity is possible with enlargement of mirror in second phase of Submillimetron and more in project Millimetron proposed for submicroarcsecond interferometry.

1 Introduction

An angular resolution achievable with interferometric techniques is superior to the angular resolution of other astronomical methods. The resolution 50 μarcsecond was achieved by global VLBI observation in short millimeter-wave region (Rantakyrö et al. 1998, and other publications). The angular resolution θ of a VLBI observation can be approximated by $\theta = \lambda/D$, where λ is the observing wavelength and D is the longest projected baseline used in observations. In ground-based experiments, D is limited by Earth dimensions. Larger D is possible with Earth-space interferometry, which was already initiated in cm-wave region (Hirabayashi et al. 1998). Radical improvement in angular resolution is possible by using submillimeter-wave interferometry in combination with Earth-space baselines.

Realization of such interferometer is possible in the frame of the space experiment Submillimetron (Gromov et al. 2001 a, b). It is an international project of the telescope for spectral region 0.3-1.5 mm using facilities of the Russian segment of the International Space Station (ISS). A free flying module for the project is under development in Korolev corporation Energia. Periodic dockings of the module to the ISS gives possibility to combine low cost with reliability, refilling, repairment and maintenance. The current concept of the telescope with 0.6 m mirror combines a direct detector instrument (microbolometers arrays) and a heterodyne one (receiver with liquid helium cooled mixers). Technologies of space submillimeter receivers comparable in sensitivity with ground-based ones was demonstrated in projects Hershel (Pilbratt 2001) and Planck (Tauber 2000). Hershel telescope has mirror diameter 3.5 m. In Millimetron project a space telescope with 12 m deployable mirror for interferometry on wavelengths 0.3-20 mm was proposed (Kardashev et al. 2001).

2 Sensitivity evaluations

Evaluations of sensitivity of a submillimeter-wave space-ground interferometer was made for space telescopes of the projects Submillimetron (1-st phase of deployment) and Millimetron. Results are shown in table 1.

Sensitivity σ was calculated on usual formula $\sigma = 2k\sqrt{T_1 T_2}\ /\sqrt{A_1 A_2 B \Delta t}$, where indexes 1 and 2 corresponds to radiotelescopes of the interferometer, k is Boltzmann constant, B - bandwidth, integration time $\Delta t = 100$ s. Similar to Weatherall (1999) system noise temperatures T was taken as:
$T = 333$ K at $\lambda = 0.35$ mm ($T = 8h\nu/k + 4$ K),
$T = 76$ K at $\lambda = 1.2$ mm ($T = 6h\nu/k + 4$ K),
$T = 50$ K at $\lambda = 3$ mm, where λ is wavelength.
Effective area A for Submillimetron telescope $A = 0.2$ m^2 corresponds to diameter $d = 0.6$ m (Gromov et al. 2001a,b). For large mirrors efficiency $\epsilon < 1$ was taken into account. It depends on λ and inaccuracy δ of the reflecting surface as $\epsilon = 0.8 \cdot exp(-(4\pi\delta/\lambda^2))$. For Millimetron (Kardashev et al. 2001) $A = \epsilon \cdot 113$ m^2, $d = 12$ m, $\delta = 25$ μm.

The Atacama Large Millimeter Array (ALMA) will have a largest collecting area available in nearest future for ground-based submillimeter observation (Kurz and Shaver 1999). It was taken for evaluations as on-ground partner of the interferometer. Taking into account atmospheric absorption with optical depth τ the efficiency $\epsilon_g = \epsilon \cdot exp(-\tau)$,. For ALMA $A = \epsilon_g \cdot 7238$ m^2 corresponds to 64 mirrors with $d = 12$ m, $\delta = 25$ μm, (Weatherall 1999, Butler et al. 1999). Typical values of atmospheric optical depth (Thompson and Kerr 1997, Guilloteau 1997) $\tau = 0.53$ at $\lambda = 0.35$ mm, $\tau \leq 0.03$ at $\lambda = 3$ mm and 1.2 mm.

Wavelength, λ, mm		0.35		1.2		3	
Angular resolution, μarcsec (low Earth orbit)		5.6		19		48	
Bandwith, B, GHz		8	1	8	1	8	1
Sensitivity, mJy (Point source, continuum, 1σ)	Submillimetron ALMA	67	190	7	21	13	5
	Millimetron ALMA	5	13	0.4	1	0.6	0.2

Table 1: Sensitivity and resolution of space-ground interferometers Submillimetron-ALMA, Millimetron-ALMA

3 Conclusions

Interferometer with Submillimetron space telescope and ALMA array as on-ground partner would have an angular resolution about 6 microarcsec and a sensitivity about 70 mJy for wavelength 0.35 mm. There is a number of unresolved objects with flux sufficiently greater of this threshold. Therefore first interferometric observations are possible with already functioning

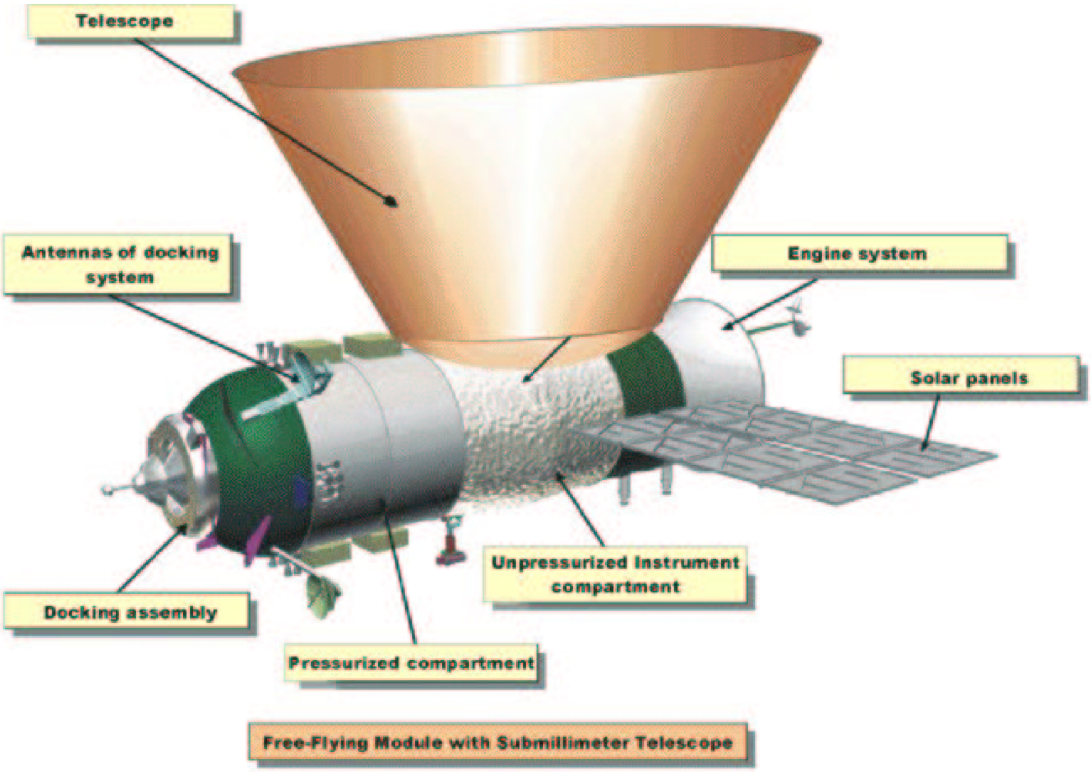

Figure 1: Free flying spacecraft with the Submillimetron telescope adapted for docking to ISS

single-dish ground-based telescopes. Sensitivity improvement is possible with enlargement of mirror up to 3.5 m in second phase of Submillimetron project. Figure 1 shows Submillimetron spacecraft after upgrade. A better sensitivity about 5 mJy is possible with realization of the Millimetron project. This interferometer with deployable 12 m mirror (Fig. 2) needs sufficient progress in space technology unlike Submillimetron, which based entirely on existing technologies and therefore is ready for realization. The Millimetron is designed for orbit distant from Earth. It promises sufficient progress in angular resolution to submicroarcsecond level.

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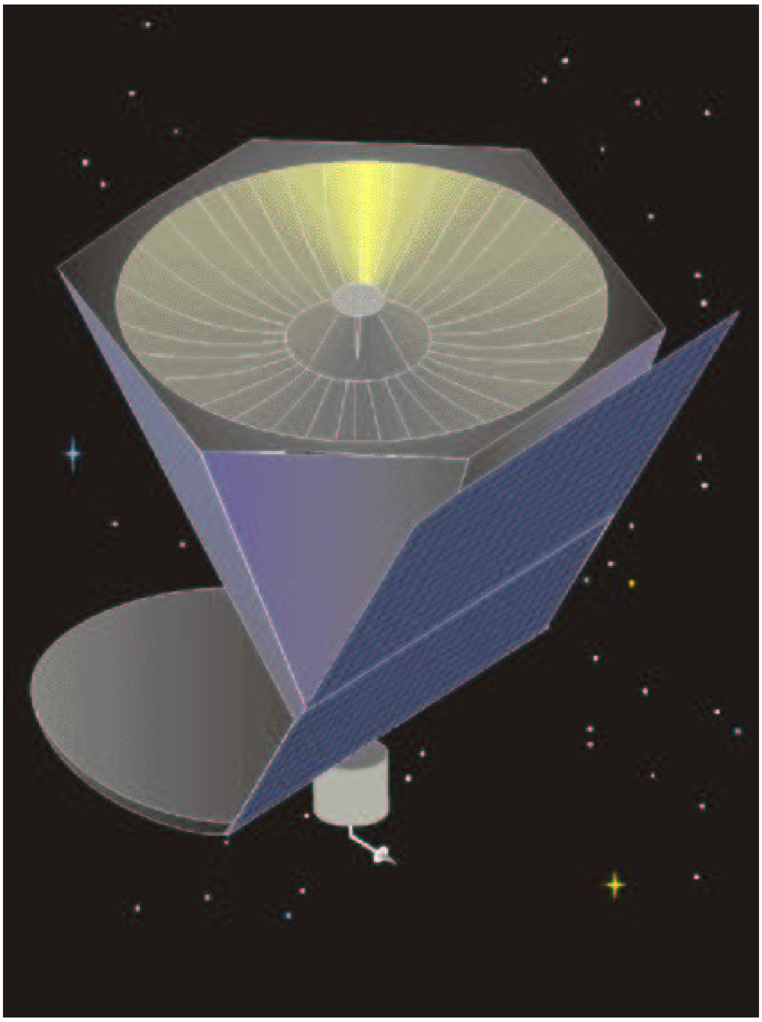

Figure 2: Millimetron spacecraft (artist view)

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