Some history: Millimetron (official RosKosmos name ”Spectrum-M”) has been started approx 20 years ago during the Soviet Union time. It is a part of ambitious program called Spectrum intended to cover the whole electromagnetic spectrum with world class facilities. Due to break up of Soviet Union and associated economical difficulties the project was effectively put on hold until a few years ago, when the improving financial situation in Russia allowed to continue. It is an approved mission included in Russian space program that has a status of law in Russia. As said, the head organization of Millimetron mission is Astro Space Center (ASC) of Lebedev Physical Institute of Russian Academy of Sciences (RAS). Russian side is responsible for launch, AIV, satellite platform, space earth VLBI segment and project coordination. The launch date is in 2017..2019 time frame.

The Millimetron satellite (see fig. 1) has a deployable 12 m diameter antenna with inner solid 4 m dish and a rim of petals. The mirror design is largely based on Radioastron mission concept that will be launched in 2009. If the antenna is passively cooled by radiation to open space, it would operate at approx. 50 K surface temperature, due to presence of a deployable three layer radiation screen. As a goal, there is a consideration of active cooling of antenna to 4 K, but this will depend on resources available to the project.

There are two options considered for Millimetron, Lagrangian libration point L2 and elongated elliptical orbit of 70000-300000 km. The final decision will depend upon the scientific priorities and possibility of telescope active cooling possibilities.

There are four groups of scientific instruments envisioned

**SVLBI instruments**  Space-Earth VLBI, will allow to achieve unprecedented spatial resolution. Millimetron mission will attempt to achieve a mm/submm wave SVLBI. For that purpose, a SVLBI instrument covering selected ALMA bands and a standard VLBI band is envisioned, accompanied by a mazer reference oscillator, a data digitizing and memory system, and a high speed
data transmission ling to ground. The ALMA bands can be extended to a water lines of detector technology allows. Type of detector – heterodyne.

Photometry/polarimetry  Recent progress in direct detector cameras with low spectral resolution, allows to propose a large format (5-10 kPixel) photometer camera on board of Millimetron mission. This camera can cover 0.1 - 2 THz region (with adequate amount of pixels per each subband).

Wide band moderate resolution imaging spectrometer  Wide band moderate $R = 1000$ imaging spectrometer type instrument similar to SPICA SAFARI in parameters is planned as well, taking advantage of large cooled dish. It will cover the adequate spectral range allowable by antenna and possibly will also fork below 1 THz, as no ground instrument can have a cold main dish.

High resolution spectrometer  For high resolution spectroscopy a heterodyne instrument is proposed, conceptually similar to HIFI on Herschel. This instrument will cover interesting frequency spots in 0.5..4 THz frequency range (using central part of antenna for higher frequency). It is sure that advances in LO and mixer technology will allow. For lower frequency part of the band small focal plane arrays could become an option.

It is recognized, the choice exact content of instrumentation will depend on many criteria: to name a few: scientific interest, mass/cooling power/cooling scheme of mission, funding/technology availability etc. An international discussion is planned on scientific and instrument content of the Millimetron mission to define its shape.

In order to aid the scientific discussion we present in this document a rough estimate of Millimetron mission sensitivities in different observing modes compared with major ground/space missions. The list is not exhaustive. If one fills that there is an error of estimate for other missions or data is missing that is important, please send e-mail (a.m.baryshev at sron.nl) containing frequency, sensitivity ASCII data for a missing mission and the graphs will be updated. Only having basic principles in mind, curves for Millimetron have a continuous frequency coverage. The most interesting wavelength regimes are the matter of discussion.

Below, we assume the following technical data for the antennae and instrumentation:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>specification</th>
<th>comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>operating temperature</td>
<td>50 K</td>
<td>active cooling 4 K as goal</td>
</tr>
<tr>
<td>mirror reflectivity</td>
<td>96 %</td>
<td></td>
</tr>
<tr>
<td>surface roughness</td>
<td>$5 \mu$m (central 4 m)</td>
<td>can be pushed to $1 \mu$m if good arguments</td>
</tr>
<tr>
<td></td>
<td>$10 \mu$m (12 m)</td>
<td></td>
</tr>
</tbody>
</table>

The model assumes that the background is composed of a 10 K “effective” background (the antenna sees mostly sky and only a small fraction of the background stems from the 50 K dish) and the CMB. It also assumes a direct leakage of 4 K background towards the detector array (not through spectrometer, or telescope optics).
Table 2: Millimetron instrument detector NEP

<table>
<thead>
<tr>
<th>Parameter</th>
<th>NEP</th>
<th>comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>sensitivity</td>
<td>$10^{-17} - 10^{-19}$ W$/\sqrt{\text{Hz}}$</td>
<td>$10^{-17}$ is currently available $10^{-18}$ can be achieved over the next few years $10^{-19}$ is the best ever measured in a lab</td>
</tr>
</tbody>
</table>

Figure 2: Predicted photometric performance of the 4 m Millimetron central dish compared to SPICA and other instruments (taken from Fig. 1 of Swinyard & Nakagawa 2008). The three red Millimetron curves are for an NEP of $10^{-17}$, $10^{-18}$ and $10^{-19}$ W$/\sqrt{\text{Hz}}$, respectively. The accuracy of the mirror is 5 µm (left) and 1 µm (right).

**Point source photometry and polarimetry**

For photometry, we assume a resolution of $R = 3$. Fig. 2 and 3 show how the Millimetron sensitivities compare to other space and ground based missions such as Herschel, JWST, SPICA and ALMA. Observations with the 12 m dish are probably also limited by pixel cross talk and the PSF at wavelength much shorter than 150 µm. This is not taken into account for modeling the sensitivities here. From Fig. 2, it is also clear that the central 4 m dish cannot compete with SPICA which will be actively cooled to $\sim 4$ K. However, the background temperature becomes less important at longer wavelength (a 50 K blackbody peaks at 60 µm). Hence, the 12 m dish reaches sensitivities comparable to SPICA, simply because of the larger collecting area. Assumed optics system efficiency is 0.5.

**FTS or grating spectroscopy**

For FTS or grating spectroscopy, we assume a resolution of $R = 1000$. This is comparable to the maximal resolution of PACS and SPIRE (Herschel). Fig. 4 and 5 show the Millimetron sensitivities compared to other missions such as Herschel, JWST and ALMA. For the central 4 m dish, the point source sensitivity longwards of 30 µm is limited by the background (temperature of the telescope and RMS of the dish) and no longer by the detector. At very long wavelength, the CMB takes over, leading to a decrease in sensitivity with increasing wavelength. Assumed optics system efficiency is 0.1. FTS spectrometer was taken as guideline.
Figure 3: Predicted photometric performance of the outer 12 m Millimetron antenna compared to SPICA and other instruments (taken from Fig. 1 of Swinyard & Nakagawa 2008). The three red Millimetron curves are for an NEP of $10^{-17}$, $10^{-18}$ and $10^{-19}$ W/$\sqrt{\text{Hz}}$, respectively. The accuracy of the mirror is 10 $\mu$m. Antenna temperature 50 K (to the left) and antenna temperature 4 K as a goal (to the right).

**Heterodyne spectroscopy**

Millimetron is the only next mission in firm plans that will use heterodyne technology for high resolution spectroscopy work. Heterodyne instruments can use whole 12 m dish for frequencies below 2..2.5 THz and central 4m mirror for frequencies below 4..5 THz. Theoretical performance of heterodyne instruments is limited by quantum noise as shown in figure 6 for 4 m and 12 m mirrors. State of art performance of heterodyne instruments is currently at the level of about five photons which is shown in the same figure 6. It is expected that instrument performance will be improved over coming few years if development in the area will be continued. The intermediate frequency bandwidth of heterodyne instruments for frequencies below 2 THz will be 8..12 GHz, and for frequencies above 2 THz will be limited to 6..8 GHz. Progress that was made past few years on digital back-end electronics allows to conclude that adequate back-end can be already made without degradation of system performance.

**Some thoughts on instruments**

There is some advantage of building a direct detection camera without spectral resolution (only filter wheels). It would have a much higher efficiency — and hence higher sensitivity — and also allow for more pixels (many thousand pixels even at long wavelength), thus higher spatial resolution. A camera with spectral capabilities and a very large number of pixels is not feasible at long wavelength (beyond $\sim 100 \mu$m).

Thoughts are to put a heterodyne instrument with some bands using the full 12 m antenna and some working with the solid 4 m dish (to be discussed).
Figure 4: Predicted spectroscopic performance of the 4 m Millimetron central dish compared to SPICA and other instruments (taken from Fig. 2 of Swinyard & Nakagawa 2008). The three red Millimetron curves are for an NEP of $10^{-17}$, $10^{-18}$ and $10^{-19}$ W/$\sqrt{\text{Hz}}$, respectively. The accuracy of the mirror is 5 $\mu$m (left) and 1 $\mu$m (right).

References

Swinyard, B., Nakagawa, T. and the SPICA Consortium 2008, “The space infrared telescope for cosmology and astrophysics: SPICA A joint mission between JAXA and ESA”, Experimental Astronomy, 7
Figure 5: Predicted spectroscopic performance of the outer 12 m Millimetron antenna compared to SPICA and other instruments (taken from Fig. 2 of Swinyard & Nakagawa 2008). The three red Millimetron curves are for an NEP of $10^{-17}$, $10^{-18}$ and $10^{-19}$ W/√Hz, respectively. The accuracy of the mirror is 10 µm. Antenna temperature 50 K (to the left) and antenna temperature 4 K as a goal (to the right).

Figure 6: Predicted high resolution $R = 1000$ spectroscopic sensitivities for Millimetron mission: quantum limit and state of art performance of 5 times quantum limit. Calculation is presented for different antenna diameter and dish accuracies.