PPPL scope of work for GPI-related MAST-U collaboration

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DRAFT 7/25/17

1) **GPI gas nozzle**: design and build a collimated GPI gas nozzle which can be mounted on the outer wall of MAST-U, which is capable of producing a gas cloud of FWHM of length ≤ 15 cm along B at the outer midplane separatrix at a distance of ~ 50 cm from the nozzle tip (i.e. ~16º FWHM). This relatively small cloud length is needed in order to obtain good 2-D spatial resolution of the turbulence, based on a MAST-U viewing sightline ~50 cm along B (similar to the NSTX GPI system). This gas puffer must be capable of a gas flux of ~ 5 Torr-liters of D_2 or He within 0.1 sec, with a rise time of ~10 msec and a backing pressure of ~1 atmosphere. The piezoelectric valve, triggering system, and ex-vessel gas system will not be within the scope of the PPPL work. The poloidal extent of the gas cloud will be matched to the poloidal viewing range of the GPI optical system (see below).

This scope will be achieved using one or more of the following approaches:

a) design a nozzle based on existing and previously tested collimated gas nozzles (e.g. I. Shesterikov et al, RSI 84, 053501 (2013), V. Soukhanovskii et al, RSI 75, 4320 (2004), C.Y. Chen et al, Rev. Sci. Instr. 87, 093503 (2016), D. Liu et al, RSI 87, 123504 (2016), etc). None of these previous systems is optimized for the MAST-U GPI geometry, so some critical analysis and extrapolation will be needed.

b) test one or more of these nozzle designs in a vacuum chamber at PPPL, and characterize the gas flow pattern and rate vs. backing pressure, gas type, and chamber pressure. If possible, measure the level of gas pressure fluctuations in each case. Most of this work would be done by a technician at PPPL, who would build the nozzles and test them using existing equipment as much as possible.

c) model one or more of these nozzle designs using computational fluid dynamics (CFD) codes available at PPPL. This work would most likely be done by a PPPL engineer familiar with these codes. The results will be compared to the chamber measurements in (b), and to some extent the code may be used to design improved nozzles.

d) assess the possible use of an existing MAST-U gas nozzle for the GPI application, such as previously used for the HELIOS system [A.R. Field et al;. RSI 70, 355 (1999), Meyer et al, PPCF 46, 981 (2004)]. This part of the scope would be done in close collaboration with the MAST-U diagnostic team.

e) based on the results of (a)-(d), build at PPPL an optimized GPI gas nozzle for MAST-U GPI and deliver this in time for installation by MAST-U technicians in Sept. 2018. The gas connection between this nozzle and the existing MAST-U gas system will be made using SWAGELOK or similar vacuum-compatible fittings.

2) **GPI optical design**: help design and/or build the optical viewing system for the outer midplane GPI system in MAST-U. An optimized optical system is needed to obtain good GPI turbulence images using a minimum level of GPI gas puffing. The optics design will be based on existing designs from GPI on NSTX, Alcator C-Mod, EAST, etc [see S.J Zweben et al, RSI 88, 041101 (2017)], but adapted for the MAST-U environment. This scope will not include the GPI camera, optical interference filter(s), camera lenses, or camera control system.

This scope will be achieved using one or more of the following approaches:

a) assess the existing optical periscope designs used at MAST-U for their applicability to GPI, based on the experiences at NSTX and Alcator C-Mod. The presumption is presently that this periscope would be put into a re-entrant port with a mirror and lens mounted at the end to view the GPI puff. If this design is suitable for GPI, or could be made suitable with minor modifications, PPPL could help by designing and/or building such a periscope for MAST-U, if one is not already available at Culham.

b) assess alternative optical designs based on fiberoptic coupling such as previously used in NSTX and Alcator C-Mod. Possible fiberoptic designs will be compared with the periscope design with respect to optical throughput, ruggedness, and ease of installation. Two fiberoptic options are Schott IG-154 (800x1000 glass fibers, 5 meter length), as used at NSTX, and Fiberoptic Systems (custom 57x57 quartz fibers, 5 meters length), which as used at C-Mod.

c) assess the use of an in-vessel telescope for use with GPI on MAST-U, in case the re-entrant port option is not available, or for use with a 2^{nd} view of the GPI gas puff. This telescope would be designed similarly to the C-Mod GPI systems, with help from an optical engineer at PPPL. The coupling to the camera would be done using an existing Fiberoptic Systems bundle, previously used at C-Mod.

3) **Evaluation of initial GPI data:** PPPL will help evaluate the initial data from the GPI system at MAST-U and determine if the data is of usable quality for turbulence analysis. This will include evaluation of the spatial resolution of the system, the effect of the GPI gas puff on the plasma, the relative value of D_2 and He GPI puffing, possible effects of neutral particle shadowing on the turbulence structure, comparison with other edge turbulence measurements, etc.

4) **Extension of GPI harware for MAST-U**: PPPL will evaluate and propose extensions to the basic GPI system for the outer midplane as described above. These may include:

a) a 2^{nd} fast camera system to view the GPI cloud from the side, to determine the length of the GPI cloud along B, and possibly to measure the radial profile of the local B field line angle within the cloud, using a combination of both views, assuming the turbulence filaments lie along a B field line.

b) a high resolution GPI system, to spatially resolve turbulence structures on the scale of ~ 1 mm, compared to the expected spatial resolution of ~1 cm for the baseline system. These small-scale structures may be relevant to possible ETG and MTM modes. Such as high-resolution GPI system with zoom lenses was installed on NSTX-U for the 2016 run, but was not used before the termination of NSTX-U operations in 2016.

c) a multi-line HeI GPI system capable of measuring the n_e and/or T_e fluctuations using the line-ratio technique. Helium line ratio diagnostics were previously implemented on MAST with the HELIOS system (A.R. Field et al;. RSI 70, 355 (1999), Meyer et al, PPCF 46, 981 (2004), on RFX-mod (M. Agostini et al, RSI 81, 10D715 (2010)) and on TJ-II (E. de la Cal, Nucl. Fusion 56, 106031 (2016)), and analyzed theoretically (J.M. Burgos et al, Phys. Plasmas 23, 153302 (2016)). However, none of these systems has yet been able to resolve the 2-D structure of the edge or SOL n_e and or T_e fluctuations.

5) **analyzsis of divertor effects on GPI in NSTX:** There is a large database of GPI data from the NSTX run of 2010 which has not yet been systematically analyzed for the possible effects of the divertor conditions on the edge turbulence [S.J. Zweben et al, Nucl. Fusion 55, 093035 (2015), S.J. Zweben et al, Plasma Phys. Control. Fusion 58, 044007 (2016)]. The results of this analysis would be directly relevant to future experiments on the interaction between advanced divertors and edge turbulence in MAST-U. Some of the analysis questions which could be addressed within this proposal during FY18 based on existing NSTX data are:

a) does divertor detachment affect the outer midplane edge turbulence as seen by GPI ?

b) does the location of the divertor strike points affect the edge turbulence seen in GPI ?

c) does the extent edge/divertor impurity radiation affect edge turbulence seen in GPI ?

d) does the divertor plate heat flux width depend on the edge turbulence seen in GPI ?

This scope of work is directly related to the ongoing study of divertor leg/SOL filaments being done by F. Scotti of LLNL on NSTX and NSTX-U data, so would best be done in collaboration with him.

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