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Room-Temperature Valley-Spin Photonic Devices Based on TMDC Metasurface Heterostructures: Enabling Nanophotonic Quantum Technologies for Space Applications

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Space-based quantum technologies — spanning satellite quantum key distribution (QKD), inter-satellite optical links, quantum sensing, and distributed network nodes — demand photonic hardware that operates without cryogenic cooling, external magnetic fields, or thermally sensitive components. Transition metal dichalcogenides (TMDCs), atomically thin 2D semiconductors, present a platform inherently compatible with these constraints. Large exciton binding energies (100–500 meV) sustain excitonic resonances at room temperature, while the intrinsic valley pseudospin enables direct spin-photon coupling via helicity-dependent optical selection rules at the K^+ and K^- valleys.

Pan et al. (Nature Communications, 2025) demonstrated room-temperature valley-selective emission in $MoSe_2$ monolayers on silicon chiral metasurfaces, achieving a record circular polarization degree of 0.5 at 294 K, independent of excitation polarization — overcoming the valley dephasing bottleneck at ambient conditions. Parallel work on strain-engineered WSe_2 has produced deterministic single-photon emitters with $g^2(0) < 0.03$ and 92% circular polarization, with ferromagnetic proximity coupling removing the need for external magnetic fields.

Together, these advances define a nanophotonic platform — planar, silicon-foundry-compatible, and thermally passive — well suited to space deployment. This presentation reviews the physics of room-temperature valleytronics in TMDCs, surveys the state of the art across key device metrics, and identifies remaining integration challenges — spectral inhomogeneity, radiation tolerance, photon extraction efficiency, and free-space coupling — in the context of space qualification and next-generation quantum space systems.

Biography:

Rohit K. Ramakrishnan is Co-Founder and CTO of QOSMIC, building optical and quantum communication infrastructure for space. He holds a PhD in quantum technologies and was a C.V. Raman Postdoctoral Fellow at the Indian Institute of Science. His research spans quantum communications, quantum AI, and optical satellite networks. He was part of quantum satellite research team at the NUS and the Australian Defence Force Academy. A keynote and invited speaker at major global conferences, he has contributed to The Quantum Internet: The Second Quantum Revolution (Cambridge University Press) and serves as a reviewer for Springer Nature and SPIE peer-reviewed journals.