GASNet-EX RMA Communication Performance on Recent Supercomputing Systems

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Parallel Applications Workshop, Alternatives to MPI+X
Held in conjunction with SC22:
The International Conference for High Performance Computing, Networking, Storage, and Analysis

Outline

- Background
  - **GASNet-EX**
  - Methodology and Systems
- Performance Results
- Closing

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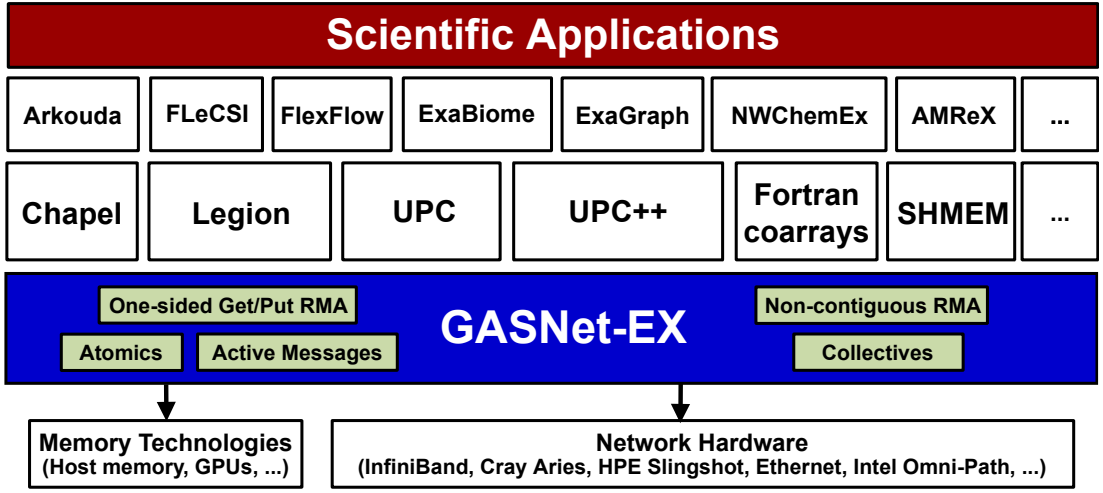
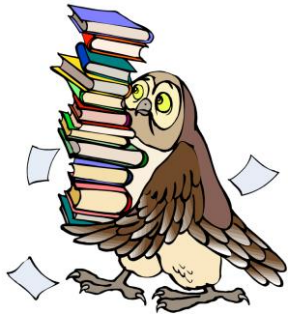
The Pagoda Project

https://go.lbl.gov/pagoda

Support for lightweight communication in exascale applications, frameworks and programming models:

- **GASNet-EX:** low-level communication layer that provides a network-independent interface suitable for Partitioned Global Address Space (PGAS) runtime developers
- **Berkeley UPC:** portable implementation of the UPC language over GASNet-EX
- **UPC++:** C++ PGAS library for application, framework and library developers, a productivity layer over GASNet-EX





GASNet-1: Overview

- Started in 2002 to provide a portable network communication runtime for three PGAS languages:
  - UPC, Fortran Coarrays and Titanium

- Primary features:
  - Non-blocking RMA (one-sided Put and Get)
  - Active Messages (a restricted form of RPC)
- Motivated by semantic issues in (then current) MPI RMA
  - Dan Bonachea, Jason Duell, "Problems with using MPI 1.1 and 2.0 as compilation targets for parallel language implementations", IJHPCN 2004. doi.org/10.25344/S4JP4B

GASNet-EX: Overview

- GASNet-EX is the next generation of GASNet
  - Provides Remote Memory Access (RMA) and Active Message (AM) interfaces for implementing Partitioned Global Address Space (PGAS) programming models
  - Updates GASNet-1 design to address the needs of newer programming models such as UPC++, Legion and Chapel
  - Incorporates 20 years of lessons-learned and focuses on the challenges of emerging exascale systems
  - Provides backward compatibility for GASNet-1 clients
- Motivating goals for GASNet-EX include:
  - Support more client asynchrony
  - Enable more client adaptation
  - Improve memory footprint
  - Improve threading support
  - Increase offload to network hardware
  - Support for device memory

GASNet: Adoption and Portability

Client runtimes

LBNL UPC++	Legion (Stanford/NVIDIA/…)	Caffeine
Berkeley UPC	Titanium	OpenSHMEM reference impl.
GCC/UPC	Rice Co-Array Fortran	Omni XcalableMP
Clang UPC	OpenUH Fortran coarrays	PARADISE++ Devastator
Chapel (Cray/HPE)	OpenCoarrays in GCC Fortran	At least 6 others known to us

Network conduits

OpenFabrics Verbs (**InfiniBand**)	IBM DCMF (BG/P)	Myricom GM (Myrinet)
Mellanox MXM and VAPI (InfiniBand)	IBM LAPI (Colony and Federation)	Dolphin SISCI
Cray uGNI (Gemini and **Aries**)	Cray Portals3 (Seastar)	Sandia Portals4
Intel PSM2 (Omni-Path)	SHMEM (Cray X1 and SGI Altix)	
IBM PAMI (BG/Q and others)	Quadric elan3/4 (QsNet I/II)	
UDP (any TCP/IP network)	**OFI/libfabric (Slingshot, Omni-Path)**	**Shared memory (no network)**
MPI 1.1 or newer	**UCX (multiple)**	

Supported platforms

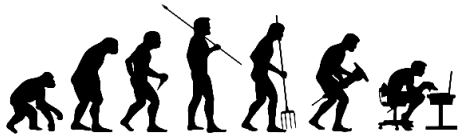
Over 10 compiler families, 15 operating systems and dozens of architectures

* These lists and counts include both current and past support

GASNet-EX: Some New Features

- Subset teams
- Local completion control
  - Explicit control over buffer lifetime to improve overlap
- Immediate-mode injection
  - Avoid stalls in low-resource conditions
- Negotiated-payload Active Messages
  - Construct messages in GASNet's buffers to avoid `memcpy()`
- Remote atomic operations
  - Utilize offload capabilities in modern network interfaces
- Device memory RMA (e.g. GPUs)
  - Offload data movement via PCI peer-to-peer transfer technologies

GASNet-EX: Status



- GASNet-EX is still evolving
  - New features on the previous slide are implemented
  - They bring benefits demonstrated in prior work
  - Additional capabilities to appear in the future
- Several programming models have adopted GASNet-EX
  - UPC++ and Berkeley UPC require GASNet-EX
  - Legion has a new backend to use EX-specific features
  - Chapel embeds GASNet-EX
  - Many others (see `gasnet.lbl.gov`)
- Delivers excellent performance on current systems

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Experimental Methodology

Two RMA performance metrics

- Flood bandwidth
- Latency

GASNet tests contained in the 2022.3.0 release

- **`testlarge`** for flood bandwidth
- **`testsmall`** for latency

MPI tests from the Intel MPI Benchmarks (IMB) v2021.3

- **`IMB-RMA`** subtests **`Unidir_put`** and **`Unidir_get`**
- **`IMB-MPI1`** subtests **`Uniband`** and **`PingPong`**
- Built with each system's default version of the vendor-provided MPI

See also the reproducibility appendix and

Bonachea D, Hargrove P. GASNet-EX: A High-Performance, Portable Communication Library for Exascale, Proceedings of Languages and Compilers for Parallel Computing (LCPC'18). Oct 2018. doi.org/10.25344/S4QP4W

Production HPC Systems Evaluated

OLCF Summit

- IBM Power 9 GPUs — IBM AC922 / Mellanox InfiniBand network
- IBM Spectrum MPI — GASNet-EX ibv-conduit

NERSC Cori Haswell

- Intel Haswell CPUs — Cray XC-40 / Aries network
- Cray MPI — GASNet-EX aries-conduit

NERSC Perlmutter SS-10

- AMD Milan CPUs — HPE Cray EX / Slingshot-10 (Mellanox ConnectX-5 NICs)
- HPE Cray MPI — GASNet-EX ofi-conduit over libfabric verbs provider

NERSC Perlmutter SS-11

- AMD Milan CPUs — HPE Cray EX / Slingshot-11 (HPE Cassini NICs)
- HPE Cray MPI — GASNet-EX ofi-conduit over libfabric cxi provider

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Bandwidth on OLCF Summit

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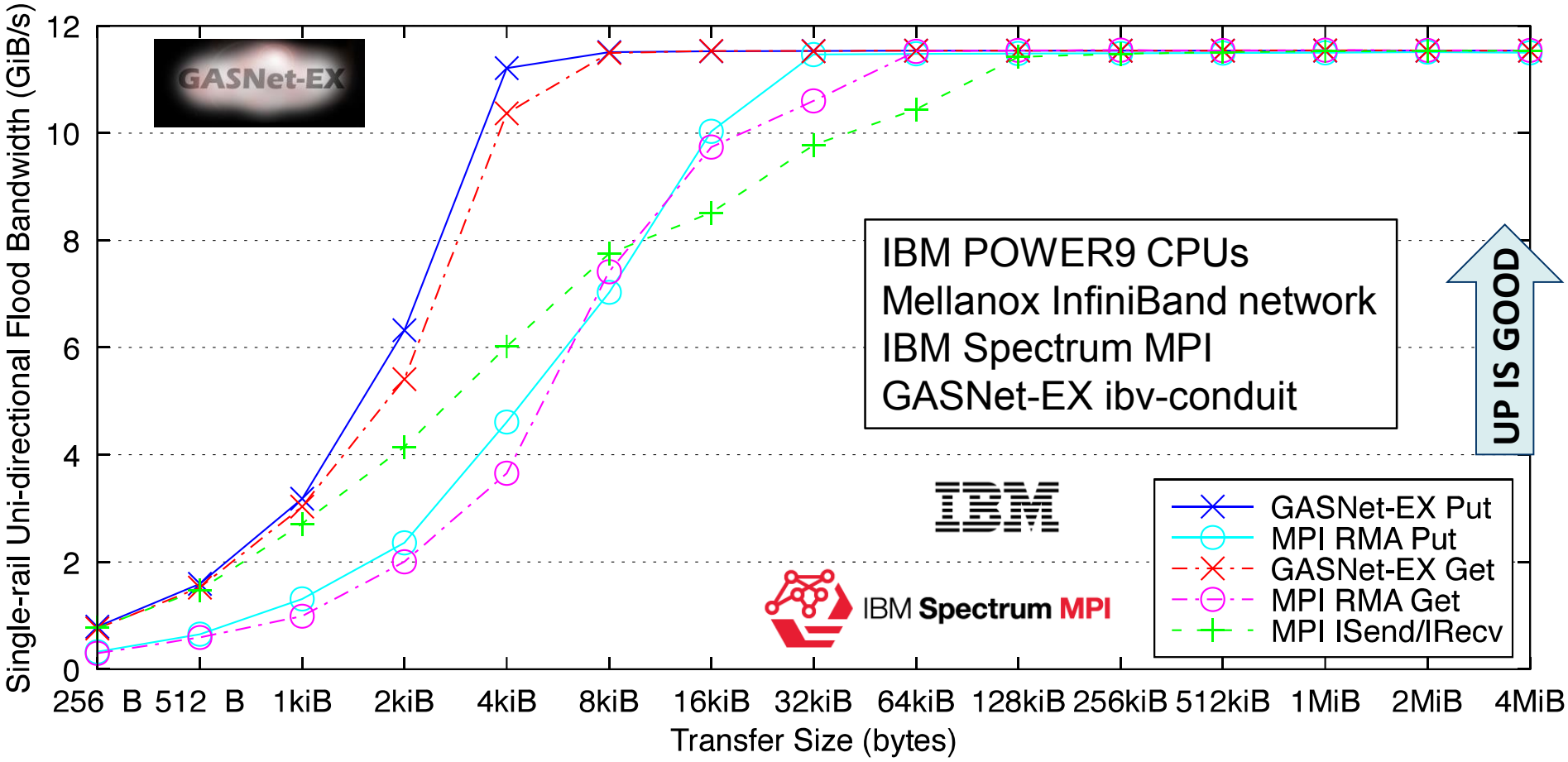
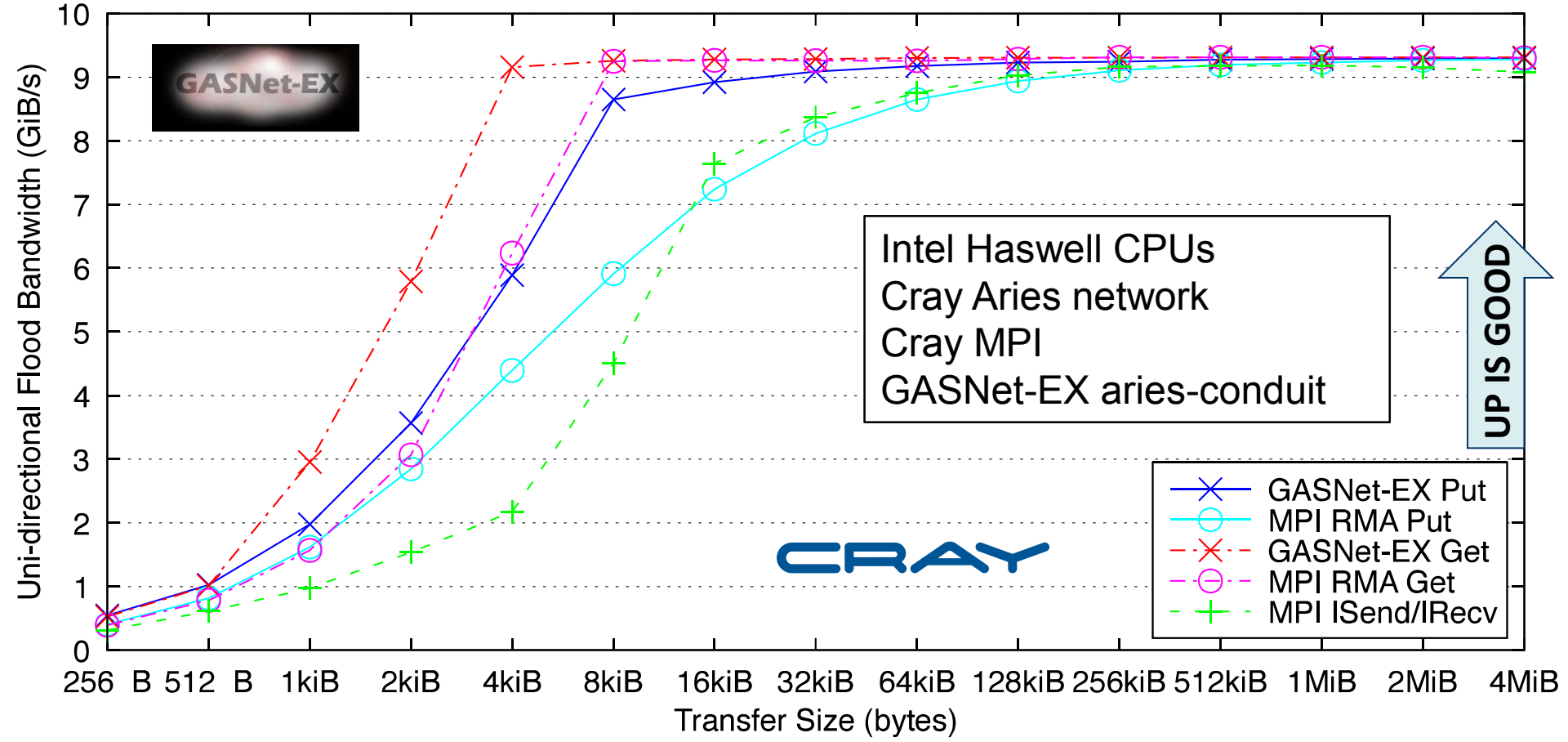
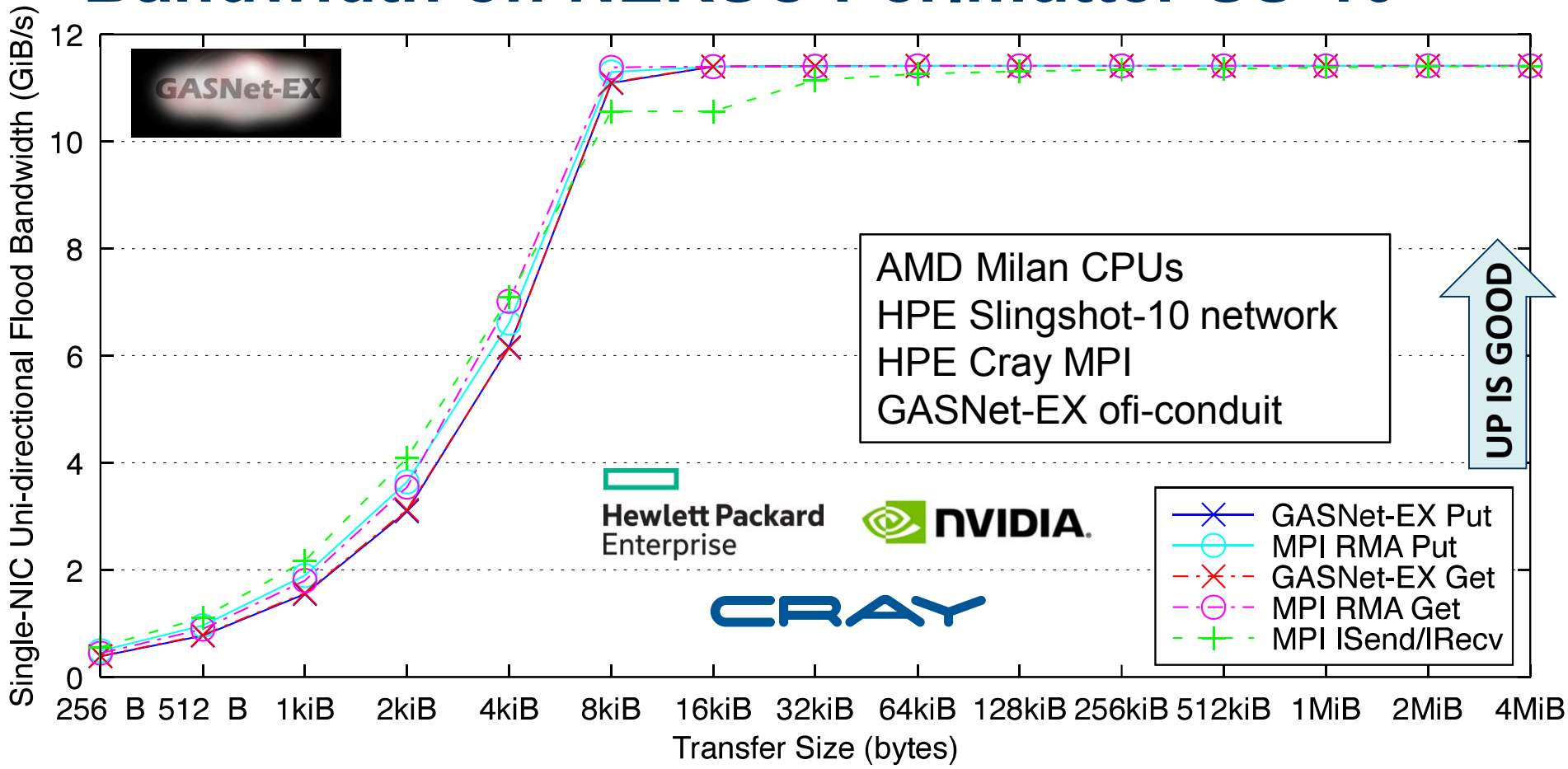


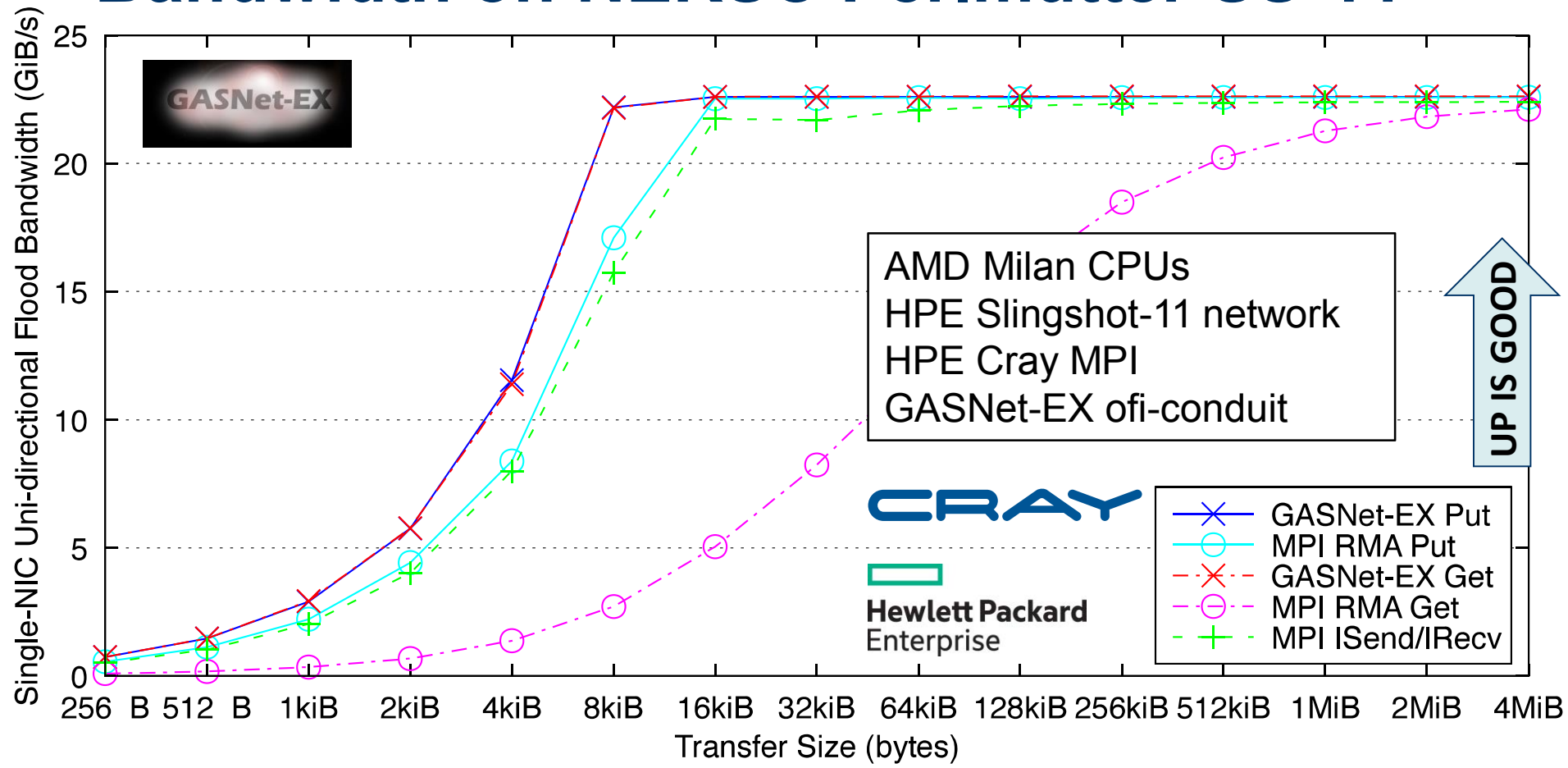
Bandwidth on NERSC Cori Haswell



Bandwidth on NERSC Perlmutter SS-10



Bandwidth on NERSC Perlmutter SS-11



Crusher: HPE Cray EX / Slingshot-11, HPE Cray MPI

A pre-production system precursor to OLCF's Frontier system

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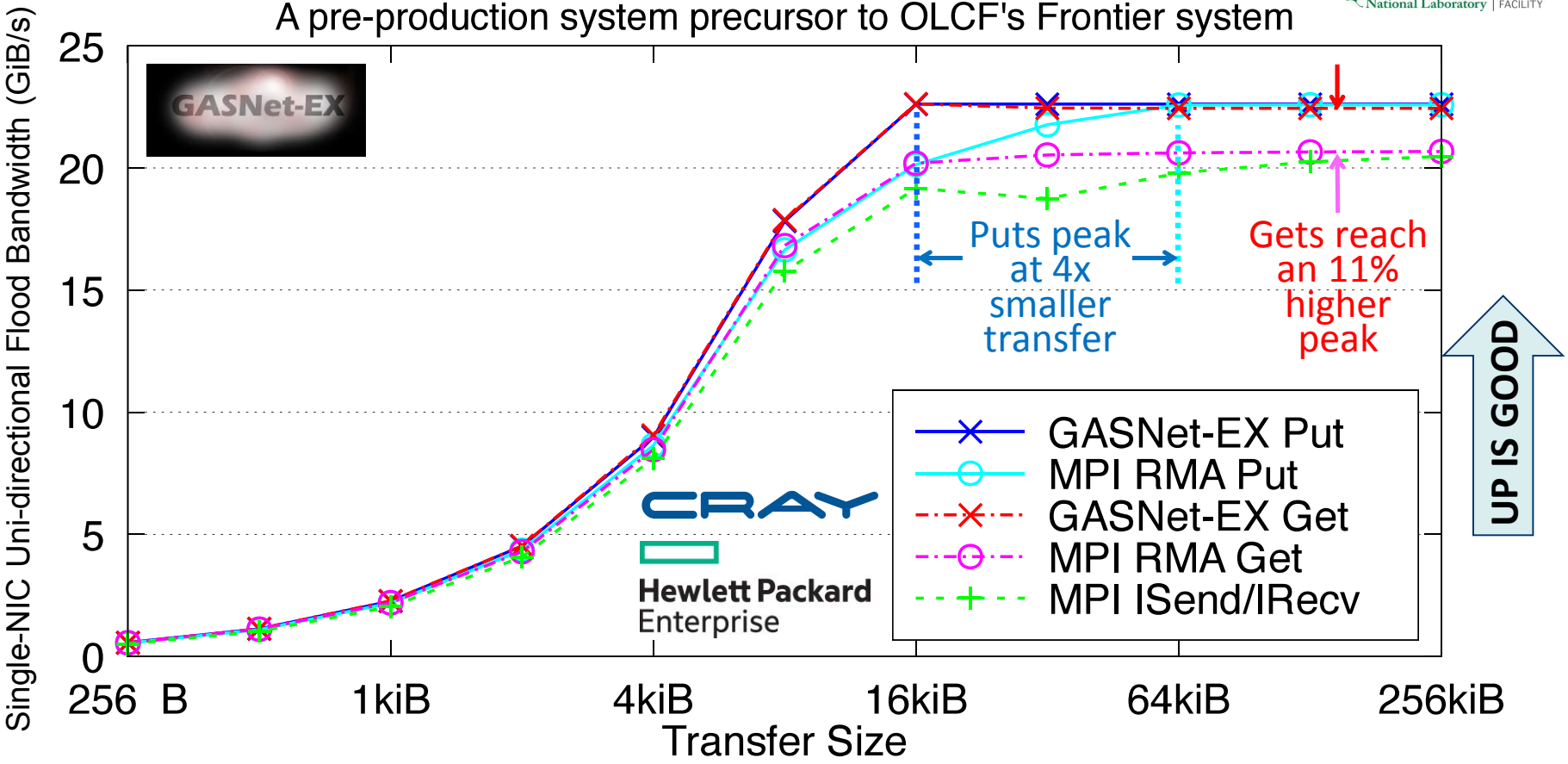
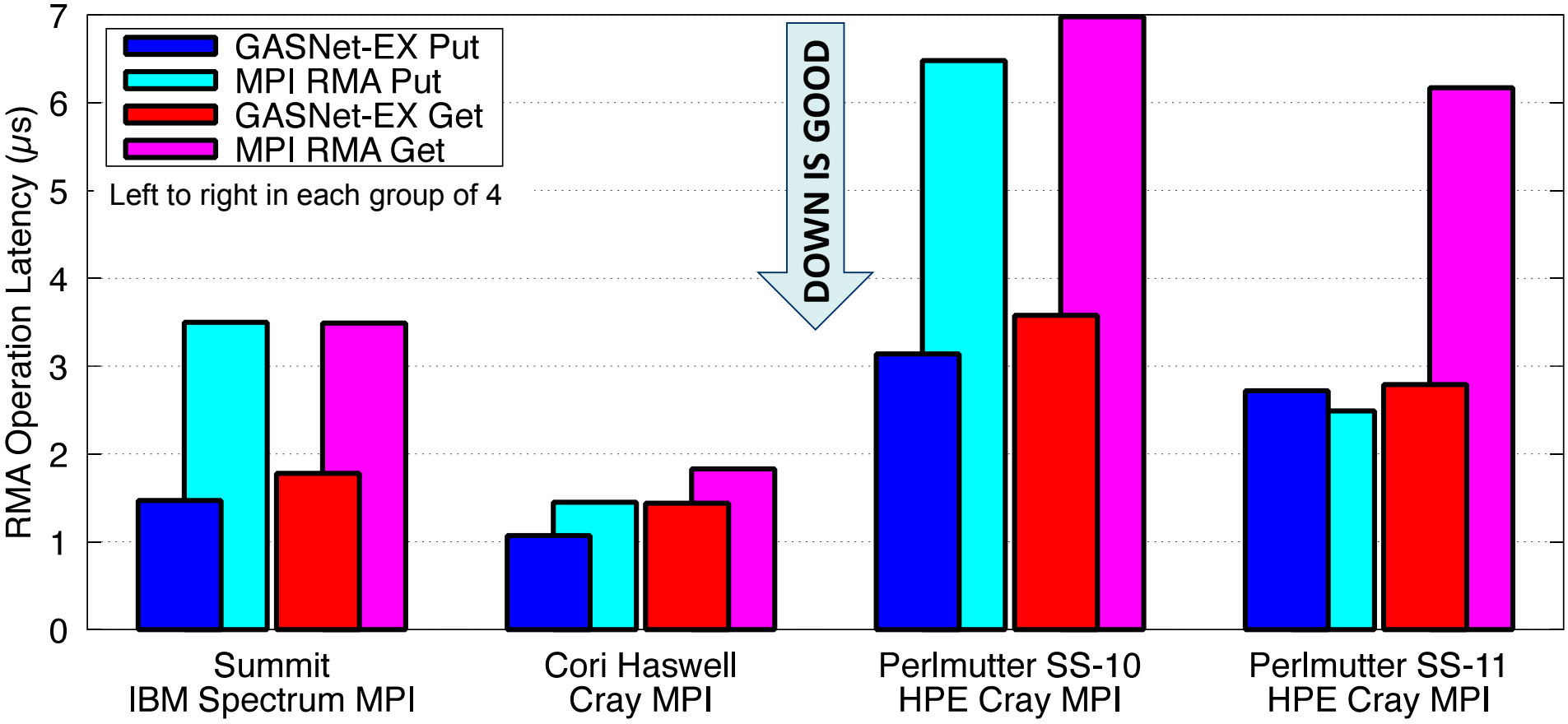


A comparison of uni-directional point-to-point host-memory flood bandwidth benchmarks, run March 2022 on OLCF's Crusher system.
Shows the performance of RMA (Put and Get) operations using GASNet-EX and both RMA and message-passing (Isend/Irecv) using HPE Cray MPI.
Results were obtained using then current GASNet tests and Intel MPI Benchmarks, respectively.

Eight-byte RMA Latency



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In Conclusion…

- GASNet-EX is a widely adopted communication library in PGAS programming model implementations
- RMA microbenchmarks comparing GASNet-EX to vendor's MPI on four representative systems show†
  - GASNet-EX bandwidth outperforms the equivalent MPI RMA operations
    - Up to 2.7x faster for Puts and up to 3.1x faster for Gets
    - GASNet-EX reaches peak bandwidth at up to 8x smaller transfer sizes
  - For small-transfer latency
    - GASNet-EX RMA outperforms MPI RMA by up to 2.38x

† The anomalously poor outlier behavior of MPI RMA Get on Perlmutter SS-11 has been excluded from this summary.

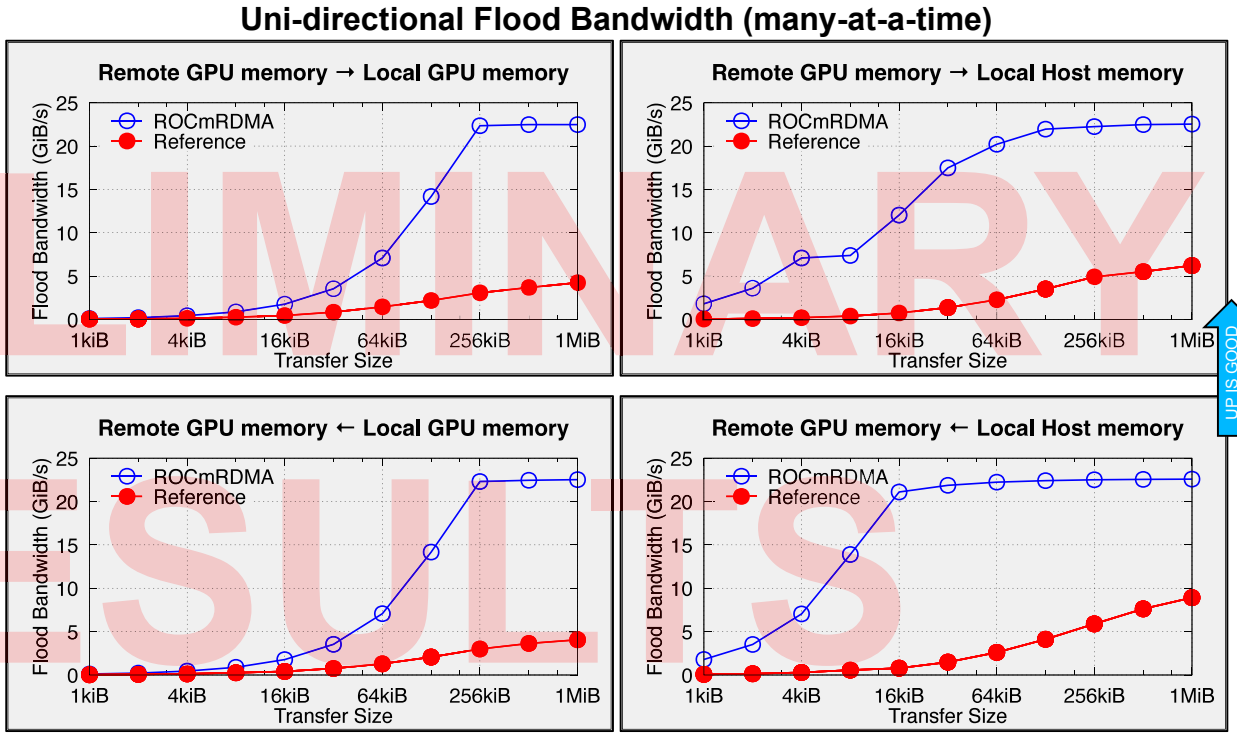
Future Work

- Continued development on the Slingshot-11 network
  - The least mature networking stack
  - Anomalous performance of MPI Get on Perlmutter SS-11
    - Similar on Crusher (though less severe)
  - MPI Puts slightly faster than GASNet-EX
    - Investigate this difference

- Benchmarking of device memory RMA
  - Preliminary results on Crusher on next slide

PREVIEW: GPU Memory RMA on OLCF Crusher†

- GASNet-EX 2022.9.0 added support for zero-copy communication involving GPU memory over HPE Slingshot networks
  - Direct data movement between the NIC+GPU (PCI peer-to-peer transfer)
  - Prior "reference" implementation staged transfers through host memory
- A UPC++-level benchmark shows the benefits of this optimization relative to staging through host memory:
  - Left-hand plots: bandwidth to/from local GPU memory 2.9x to 7.4x better
  - Right-hand plots: bandwidth to/from local host memory 2.4x to 34x better



Results were collected using the `gpu_microbenchmark` test from the 2022.9.0 release of UPC++, run between two nodes of OLCF Crusher, over its Slingshot-11 network using one process per node and one NIC per process.

† Crusher is a preproduction system precursor to OLCF's Frontier system.

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THANK YOU

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Upcoming roundtable discussion:
"Pagoda: UPC++ and GASNet-EX for Lightweight Communication and Global Address Space Support"
Tue Nov 15 2:00p CST in DOE Booth (#1600)