DEPARTMENT OF THE AIR FORCE
AIR UNIVERSITY (AETC)

5 Mar 24

Dr. Scott Graham
AFIT/CZ
2950 Hobson Way
Wright-Patterson AFB OH 45433

Mr. Ethan Krimins
Quantum Research Sciences, LLC
130 North 3rd Street
Lafayette Indiana 47901

Dear Mr. Krimins,

I am pleased to submit this letter and accompanying proposal as the Air Force Institute of Technology's (AFIT's) commitment to partner with Quantum Research Sciences, LLC on the "Blue Optimization" project. Specifically, Laurence D. Merkle from AFIT's Department of Electrical and Computer Engineering (AFIT/ENG) will lead AFIT's portion of the project.

The attachments provide AFIT specific information for the submittal, including a statement of work, budget, and cost justification with an explanation of our incremental direct costs (IDCs). The total AFIT funding request is $20,000 for the one-year project. AFIT reserves the right to revise the budget allocations as required by the needs of the project, unless we receive directions indicating otherwise.

If you have any questions regarding the technical aspects of this proposal, please contact the faculty involved, Dr. Merkle, at (937) 656-5550, or via email at laurence.merkle.1@us.af.mil. Questions regarding administrative matters should be addressed with the Office of Research and Sponsored Programs at (937) 255-3633, or proposals@afit.edu. Thank you for your assistance.

Respectfully,

GRAHAM.SCOTT.R.1158436376 Digitally signed by GRAHAM.SCOTT.R.1158436376 Date: 2024.03.06 11:52:39 -05'00'

DR. SCOTT R. GRAHAM, PhD
Interim Dean for Research
Air Force Institute of Technology

Attachments: AFIT Proposal #2024-077_Merkle

Research Proposal #2024-077

Blue Optimization

Date:	03 Mar 2024
Desired Initial Funding Period:	1st QTR/FY25
Proposed Duration of Project:	3 Months
Technical Period of Performance:	01 Oct 2024 – 31 Dec 2024
Principal Investigator:	Dr. Laurence D. Merkle AFIT/ENG Air Force Institute of Technology 2950 Hobson Way Wright-Patterson AFB OH 45433 (937) 656-5550 laurence.merkle.1@us.af.mil
Submitted To:	Mr. Ethan Krimins Quantum Research Sciences, LLC 130 North 3rd Street Lafayette Indiana 47901 (513) 633-1604 ekrimins@quantumresearchsciences.com

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Executive Summary

The Air Force Institute of Technology (AFIT) proposes to support an Air Force Research Laboratory Phase I STTR project in collaboration with Quantum Research Sciences, LLC (QRS), Purdue University, and Atom Computing. The team will investigate the use of a 1000+ qubit neutral atom quantum computer to optimize resource use within the Advanced Battle Management System (ABMS) and Battle Management Command and Control (BCM2). This software will provide the Air Force with a dramatically faster and more accurate ability to manage, coordinate and schedule friendly force ("blue") assets. AFIT will reach out to one of more operational units to design, develop, and launch this technology.

AFIT/ENG's Maj Leleia Hsia will assist QRS, Purdue, and Atom Computing to elicit design requirements from the sponsor. Among other things, requirement elicitation will allow the selection and refinement of an appropriate mathematical model of the resource optimization problem, which Dr. Merkle will guide. It will also allow QRS, Purdue, and Atom Computing to design a software framework. Dr. Merkle and Maj Hsia will also perform an independent critical analysis thereof.

AFIT will provide QRS with a final report discussing all findings related to requirements elicitation, mathematical modeling, and AFIT's independent critical review of the proposed software framework. The projected period of performance is 1 Oct 24 – 31 Dec 24.

Requested Sponsor Funding by Fiscal Year: FY25: $20,000

TECHNICAL PROPOSAL

Statement of Work

The Air Force Institute of Technology (AFIT) proposes to support an Air Force Research Laboratory Phase I STTR project in collaboration with Quantum Research Sciences, LLC (QRS), Purdue University, and Atom Computing. The title of the STTR proposal is "Blue Optimization," in reference to the optimal use of "blue" assets that the final system will enable.

Current BMC2 tools exist that manage, coordinate and schedule friendly force ("blue") assets. However, they require hours to execute, and they perform only best-effort resource optimization. Time consuming manual plan modification is often required, especially when mission requirements change more quickly than the tools can be rerun. Apparently making an implicit reference to the famous quotation by hockey legend Wayne Gretsky, the situation is described as follows by Col Gillaspie, Combat Ops Division, 613 AOC:

> Today's technology inefficiently estimates where assets are needed and then updates infrequently. Dynamic optimization can much more effectively ensure assets are being allocated where the need *will* be.

Real-world combat environments demand a dynamic approach because of multiple changing requirements and temporal expansions/contractions; all while there is the potential for physical or economic fluctuation of resources. As put by Maj Paul Garcia, PACAF 613 AOC Chief of

Technology and Innovation, “F-22 operations shouldn't be constrained by spreadsheet scheduling.”

To address the mission critical need for more efficient and effective BMC2 optimization, the STTR team will investigate the use of Atom Computing’s 1000+ qubit neutral atom quantum computer to optimize resource use. Although not part of the Phase I proposal, the team’s vision is for the quantum computing system to eventually be integrated directly within the ABMS and BCM2.

During this Phase I effort, QRS, Purdue, and Atom Computing will lead the determination of system design requirements. (TASK 1) Maj Hsia will assist in these efforts by participating in team meetings with end users in the PACAF/613 AOC. The requirement solicitation process will begin with the following questions, as determined by QRS.

PACAF Operations and quantum application integration:

- What compatibility challenges might occur when integrating quantum algorithms into existing ABMS (legacy software, data formats, etc.)?
- Are there anticipated difficulties in ensuring seamless communication between classical ABMS systems and quantum components?

Classical/Quantum Connectivity:

- How will classical and quantum components exchange info in an integrated system, especially during real-time decision-making scenarios?
- How will the integrated system handle feedback loops between classical and quantum processes?

Cyber Security:

- How do we protect sensitive data during both processing and transmission within the ABMS and quantum cycle?
- How will the quantum algorithm align with existing AF security policies and encryption processes?

Simulation and Testing:

- What test environments or simulation tools can be used to evaluate the quantum software effectiveness?
- How will we simulate realistic scenarios to ensure the quantum tech robustness in operational PACAF conditions?

Benchmarking and Validation:

- Are there predefined datasets that can be used to validate results obtained from the quantum algorithm against classical optimization methods?
- How will the criteria for success be identified (performance metrics, thresholds, etc.) and what benchmarks will be used?

Scaling Quantum Computing Resources:

- What is the scaling plan for the quantum computing resources as the complexity of asset optimization problems increases?

AF Commercialization, non-Def commercialization & P2 traction:

- What AF, other DoD and Defense Corporations will benefit from this tech and how do we impress them?
- Are we listening to what 613 AOC & PACAF are telling us and delivering substantial value to 'Operationally Focused ABMS'?

Among other key decisions, the design requirements will enable the team to select and refine a mathematical model for the problem. (TASK 2) Dr. Laurence D. Merkle will assist in this effort, the result of which will be validated by the AOC. A likely starting point is the mixed integer model proposed by Rossillon [1] for intratheater operations in a JAOC. This model considers:

- the set of available aircraft over a set time horizon;
- the set of available tankers assigned to refueling those aircraft;
- the fuel consumption rates, fuel capacities, and airspeeds of the tankers and other aircraft;
- a list of candidate "missions" of any type, each
  - requiring a "package" of aircraft types to complete,
  - having a "value" reflecting their importance to campaign success,
  - having duration times, and
  - having time windows within which they can be completed; and
- anchor refueling area (meeting points).

Given the above information, the objective function to be maximized is the total value of missions completed while satisfying aircraft availability, travel time, time window, and fuel constraints. Rossilon also describes straightforward ways in which to extend the proposed model, for example to consider

- relative time window constraints among missions (i.e. missions that must be completed concurrently, or those that must be completed sequentially),
- similarly, combined values of sets of related missions (e.g. there is no value to any particular mission in the set, but there is value with completing all of them),
- the possible necessity of assigning specific aircraft (vs. aircraft types) to a mission,
- munition-level details such as location and overall availability.

However, for the sake of reducing computational complexity, Rossilon's model makes several simplifying assumptions, thus limiting the set of solutions it admits. The STTR team will specifically discuss these assumptions with the AOC and then extend Rossilon's model by relaxing any unacceptable assumptions.

One example of Rossilon's assumptions which likely has little impact is that on-air refueling takes place prior to mission completion, as opposed to following completion or both prior to and following completion. Other examples, though, are likely to have significant impact, especially for missions requiring large packages:

- aircraft must start from their home base prior to a mission and return to it afterwards (in particular, aircraft complete no more than one mission prior to returning home),

- all aircraft packages must meet in entirety at a single anchor point prior to a mission and return to it afterwards,
- tankers can only refuel aircraft at a single anchor point per flight,
- air refueling takes negligible time, and
- only a single tanker can refuel the aircraft for any given mission.

In addition to the mathematical model, the requirements elicitation will enable QRS, Purdue, and Atom Computing to design the software framework. (TASK 3) Dr. Merkle and Maj Hsia will provide an independent critical review of the framework.

As the team moves into the development phase, Dr. Merkle will also leverage his expertise in quantum algorithm design and optimization to ensure efficacious execution of the quantum algorithm. A high-level schedule for the Phase I effort is shown in Table 1. Additional detail is presented in

Table 2.

Table 1. Monthly Schedule for Proposed Phase I STTR Effort "Blue Optimization."

OBJECTIVES	WHAT WILL BE DONE	SUCCESS	Timing	R&D for Increasing Feasibility
PACAF Collaboration	Recurring weekly meetings	Customer Discovery	continuous	✓
PACAF & other AF Input	Research w/End Users, Customers and other stakeholders	Process Chart	Month 1	✓
Non-AF Input	Research w/End Users, Customers and other stakeholders	Process Chart	Month 1-2	✓
Quantum Tech Design	Finetune quantum algorithm and layout integration	Software Architecture	Month 2	✓
System Integration Design	Layout system integration (cloud, cyber, etc.)	System Architecture	Month 2-3	✓
P2 Program Plan	End User, Cust & Stakeholder engagement	P2 MOU	Month 3	

Table 2. Weekly Schedule for Proposed Phase I STTR Effort "Blue Optimization."

Tasks	Duration	Description	Perf.
Kickoff meeting	Days 0-5	Coordination schedules and identify users, customers, stakeholders & leaders	All
Engagement & research	Days 6-14	Start obtaining input from stakeholders (see questions)	QRS
ID current state & future state processes	Days 15-21	Build out ABMS process chart to work into software and system architectures	AFIT
High-level quantum framework design	Days 22-28	Begin draft architectures in collaboration with team	QRS
Commercialization pre-work	Days 29-35	ID ABMS, JADC2, etc. stakeholders, non-AF users and Corp ABMS teams	QRS
AFIT critical review of framework	Days 36-42	Independent review (inclusion of AF & DoD needs, capabilities, etc.)	AFIT
Preliminary report (**DELIVERABLE**)	Days 43-49	To incl: draft architectures, U/I plan, end user/customer input	QRS
Obtain support for P2	Days 50-56	PEO engagement, integration of tech, MOU	QRS
Map out quantum hardware connectivity	Days 57-63	Detailed process for using Atom's quantum computer	Atom
Simulation	Days 64-70	Detailed walk thru of future state, data/inputs, etc. and refine architecture	QRS
Ensure ABMS engagement	Days 71-78	Hard review that we are working towards is ABMS-feasible	QRS
Obtain MOU	Days 79-86	Obtain MOU's from DAF/Com'l End Users/Cust's	QRS
Final report (**DELIVERABLE**)	Days 87-90	To incl: process chart, software architecture, system architecture, P2 plans, …	QRS

Once available, this software will provide the Air Force with a dramatically faster and more accurate ability to manage, coordinate and schedule friendly force ("blue") assets.

Deliverables

After coordination with QRS, AFIT will deliver a final Phase I report to include all findings related to (TASK 1) requirements elicitation, (TASK 2) mathematical modeling, and (TASK 3) AFIT's independent critical review of the proposed software framework.

COST PROPOSAL

A top-level summary of the total proposed project support is shown below. A detailed budget breakout is provided on subsequent pages.

	FY24	FY25
Sponsor Funds Requested	**$0**	**$20,000**

Cost Justification

1. Salaries and Fringe Benefits

Research faculty members at AFIT need to secure external funding to cover their salary and fringe benefits. Dr. Merkle is requesting $13,970.00 to provide 3 weeks of dedicated support to this project in FY25. A 3% cost increase is assumed for FY25. Dr. Merkle will be participate in selection and refinement of the mathematical model as well as the independent critical review of the software framework.

Government employee civilian labor costs in support of the project include an estimated fringe benefit rate of 33.2%. This rate is consistent with established FY24 DoD civilian fringe benefit rates. The actual personnel costs, however, will be billed if this project is funded.

2. Contract Services

None

3. Equipment

None

4. Supplies

None

5. Travel

Maj Hsia will travel to PACAF 613 AOC for requirements elicitation.

6. Tuition

None

7. Incremental Direct Costs (IDCs)

AFIT does not charge indirect costs (F&A) but is permitted to recover incremental direct costs attributable to specific sponsored project types. The incremental cost recovery rate applied to a specific project depends on the nature of the research effort and is designed to provide a reasonable estimate of the applicable incremental direct costs. For the purposes of this Modeling/Computational proposal, the FY24 incremental rate is 10%. The actual IDC rate applied to the project will be the rate established for the government fiscal year in which the funding award is received, IAW the AFIT Business Plan for Sponsored Programs.

Cost Sharing

None

AFIT Post-Award Financial Information

AFIT accepts federal funding as 'Reimbursable Funding' using various mechanisms and processes or Direct Budget Authority (DBA). Please contact AFIT's Post-Award team at enbudget@AFIT.edu or call (937) 255-3633 to speak to an AFIT financial representative.

Direct Budget Authority Funding:
AFIT accepts DBA funding from Air Force Research Laboratories (AFRL) and Space Force Research Laboratories (SFRL) for Research, Development, Test and Evaluation (RDT&E) related efforts. Technical Directorate PMs provide Center analysts with a listing of proposal efforts (PI name and AFIT proposal number), sponsor line of accounting, and funding amount needed, then initiate DBA through the Automated Funds Management (AFM) system directly to AFIT/CZ for distribution. Templates and funding requests are processed by the AFRL/FZAS BA Request Workflow box (AFRL.BA.Requests@us.af.mil).

AFIT may also accept DBA funding from other federal agencies through the AFM funds distribution process. The BA Request process will vary by agency. Sponsors can contact AFIT's Post-Award team for more information.

Reimbursable Funding:
Unclassified support agreements for reimbursable orders must be administered using the computer-based government invoicing (G-Invoicing) system. If a support agreement is required, please contact enbudget@afit.edu to begin the process of generating the support agreement. Note: AFIT's staffing process can take several weeks to complete.

Reimbursable funding exchanged between the DoD and other federal agencies requires a two part Interagency Agreement (IAA) "support agreement" using G-Invoicing to generate FS Form 7600A as directed in DoDI 4000.19, "Support Agreements." The FS Form 7600A (first section) documents the General Terms and Conditions (GT&C) when requiring payment from one party to another prior to accepting reimbursable funding, unless the sponsoring organization has and can forward a valid waiver signed by an appropriate authority.

The second section of the IAA is a qualified funding document. Funding documents must indicate a specific Period of Performance (PoP) with start and end dates. These dates are required to accept funds and identify project execution milestones. AFIT uses the latest starting date and the earliest ending date from the funding document, potentially limiting the project execution cycle if the PoP is not included. An example of the desired specific PoP wording (taken from a FY23 Project Order) follows:

8. DESCRIPTION OF WORK TO BE PERFORMED AND OTHER INSTRUCTIONS *(If additional space is required, use Supplemental Data Section on reverse or attach additional sheets).*

The purpose of these funds is to support GL 2.0 activities via AFIT's Starlink/Starshield Research Task AFIT Proposal #2019-067.

Funding PoP: 15 September 2023 - 30 September 2024
Funds Expiration Date: 30 September 2024

Federal sponsors may forward funds via a DD Form 448 Military Interdepartmental Purchase Request (MIPR), Project Order (AF Form 185) or FS Form 7600B Order Requirements and Funding Information (Order) form. These funding documents must provide sufficient information to identify the work requested (i.e. AFIT Proposal Number and Faculty Member Name) and statutory authority (usually the Economy Act of 1932 for MIPRs, AF Form 185s default to 41 U.S.C. § 6307 and DoDI 7220.1), 7600B refers to the GT&C of the 7600A. MIPRs require a PoP and normally accepted as Category I Reimbursable. In certain instances a portion of funds provided by MIPR can be provided as a direct cite for the expressed purpose of putting those funds on another organization's R&D contract.

AIR FORCE INSTITUTE OF TECHNOLOGY

Funds Requested from Sponsoring Agency

				FY24	**FY25**	**Total**
1. Salaries and Fringe Benefits						
Title	Last Name	Weeks/Yr		**$0**	**$13,970**	**$13,970**
Dr.	Merkle	3			$13,970	**$13,970**
2. Contract Services (In-house)				**$0**	**$0**	**$0**
3. Equipment				**$0**	**$0**	**$0**
4. Supplies				**$0**	**$0**	**$0**
5. Travel						
Purpose/Destination		# days	# travelers	**$4,212**	**$0**	**$4,212**
				$4,212		**$4,212**
6. Tuition						
Student Name or # Students		#Qtrs		**$0**	**$0**	**$0**
7. Subtotals				**$4,212**	**$13,970**	**$18,182**
IDC Rate		10%		10%	10%	
Incremental Direct Costs				$421	$1,397	$1,818
Total Funding Request				**$4,633**	**$15,367**	**$20,000**

Updated: Oct 2023

Proposal Number: 2024-xxx

Works Cited

[1] K. J. Rossillon, "Optimized Air Asset Scheduling Within a Joint Aerospace Operations Center (JAOC)," MIT The, Cambridge, 2015.

[2] C. T. Allen, "Air Tasking Order Dissemination: Does it Get the Job Done?," 2002.

[3] K. Conner, P. Lambertson and M. Roberson, "Analyzing the Air Operations Center (AOC) Air Tasking Order (ATO) Process Using Theory of Constraints (TOC)," 2005.

[4] M. A. Mak, J. Jaynes, J. Karnis, L. A. Haydon and E. Kennedy, "Battle Management: DoD and Air Force Continue to Define Joint Command and Control Efforts," 2023.