Summing Up: Take-Away Messages and Answers to Panel Questions

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RHIC is in its prime: it is poised to address a host of compelling science questions that remain or have been raised by the important discoveries to date; the facility performance continues to improve dramatically; the user base remains energized and committed; the Nuclear Physics community's visions for the long-term future of QCD-related research are best realized using RHIC as a primary base.

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The Four Most Important Reasons for Continuing RHIC

1) RHIC has pioneered a vibrant new subfield – condensed QCD matter physics – and has led the rapid climb up a steep learning curve marked by continuing S&T breakthroughs. **If RHIC operations were terminated, the U.S. would unilaterally cede leadership in this high-impact field.**

2) Discoveries and techniques at RHIC have established deep intellectual connections to other physics forefronts. **These give RHIC broader scientific impact than other Nuclear Physics research avenues.**

3) Critical directions for future research in this subfield involve probing hot QCD matter from below to above the transition to Quark Gluon Plasma. **This transition appears to occur within the RHIC energy range, at energies not accessible at LHC. This is NOT energy frontier science!**

4) RHIC has nearly completed major performance upgrades that facilitate the next decade's science. It provides the most cost-effective base to realize the next QCD frontier with EIC. **Crisis management for the coming decade must preserve a viable path to a vibrant future in the next decade.**

Terminating RHIC ops. would lead with certainty to a devastating loss of U.S. scientific leadership, and in all likelihood simultaneously to a significant loss of funding for the U.S. NP program.

Delivery on Promises from Past Long Range Plans

RHIC goals from 1983, 1989, 1996, 2002 Long Range Plans: ***to create QCD matter at early universe energy densities, discover Quark-Gluon Plasma and study its properties***

- ***Done! It's not your father's QGP – strong coupling has raised many new questions, established compelling connections to other physics forefronts, and opened new discovery possibilities***

RHIC goals from 2007 Long Range Plan: ***broad quantitative study of fundamental properties of QGP, via significant advances in collider luminosity, detector performance and theoretical modeling***

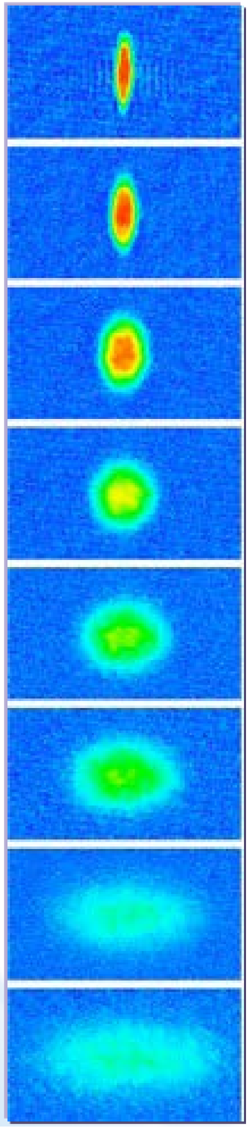
- ***Well along the path! Luminosity upgrade done faster & cheaper, detector upgrades on schedule, theory advances dramatic. We now have a clear set of improvements in modeling and a clear set of systematic flow measurements to quantify η/s and, quite likely, other QGP transport properties as well.***

- ***This is a young, vibrant subfield. We are still learning, with amazement, the sorts of questions we can hope to answer quantitatively – e.g., initial quantum fluctuations; QCD sphaleron impacts …***
- ***Field has also had deep intellectual impact on theoretical issues in QCD and other studies of strongly correlated many-body systems***
- ***This field requires colliders for facilities, and colliders are expensive to operate. Among colliders worldwide, RHIC operations are lean.***

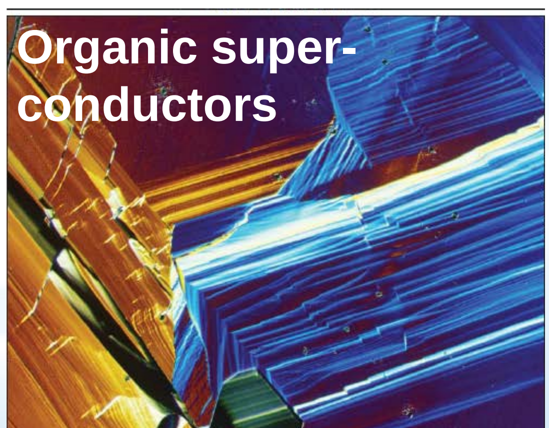
Unanticipated Intellectual Connections

RHIC results have established ties to other forefront science:

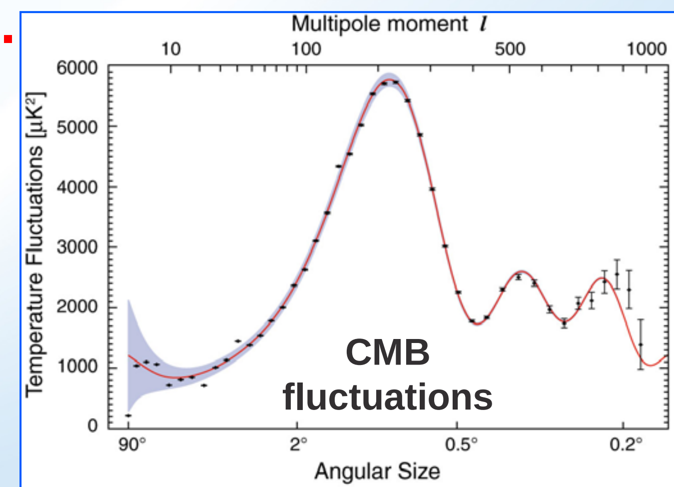
- String Theory studies of black hole behavior led to prediction of quantum lower bound on η/s
- Ultra-cold atomic gases, at temperatures 19 orders of magnitude below QGP, can also be "nearly perfect liquids"
- Similar liquid behavior seen and studied in a number of strongly correlated condensed matter systems
- Hints of symmetry-violating bubbles in QGP analogous to speculated cosmological origin of matter-antimatter imbalance in universe
- Power spectrum of flow analogous to power spectrum of cosmic microwave background, used to constrain baryon acoustic oscillations & dark energy, and to explore inflation-era quantum fluctuations.



Trapped ultra-cold atom clouds



Organic super-conductors



CMB fluctuations

Compelling Questions For the Next Decade…

Question	Facilities Needed to Answer	Comments	Related Table 1 Question #'s
1) How perfect is "near-perfect" liquid?	RHIC & LHC (& ⇒ BOTH REQ'D)	Flow power spectra, next 5 years	1 + 2
2) Nature of initial density fluctuations?	RHIC, LHC & EIC	Benefits from asymmetric ion collisions at RHIC	2 + 8
3) How does strong coupling emerge from asymptotic freedom?	RHIC & LHC	Following 5 years @ RHIC; jets need sPHENIX upgrade	2 + 4
4) Evidence for onset of deconfinement and/or critical point?	RHIC; follow-up @ FAIR, NICA	Phase 2 E scan in following 5 years, needs low-E electron cooling	3 + 7
5) Sequential melting of quarkonia?	RHIC & LHC	LHC mass resolution a plus; RHIC det. upgrades help; $\sqrt{s}$-dependence important	5
6) Are sphaleron hints in RHIC data real?	Mostly RHIC	Exploits U+U and $\mu_B \neq 0$ reach at RHIC	6
7) Saturated gluon densities?	RHIC, LHC & EIC	Want to see onset at RHIC; need EIC to quantify	8
8) Where is missing proton spin?	RHIC & EIC	EIC will have dramatic impact	9 + 10

Addressing these questions requires an ~10-year program of A+A (various ion species), p+p and p/d + A runs at various RHIC energies.

…and a Clear Plan for Addressing Them

Years	Beam Species and Energies	Science Goals	New Systems Commissioned
2013	• 500 GeV $\vec{p} + \vec{p}$ • 15 GeV Au+Au	• Sea antiquark and gluon polarization • QCD critical point search	• Electron lenses • upgraded pol'd source • STAR HFT
2014	• 200 GeV Au+Au and baseline data via 200 GeV p+p (needed for new det. subsystems)	• Heavy flavor flow, energy loss, thermalization, etc. • quarkonium studies	• 56 MHz SRF • full HFT • STAR Muon Telescope Detector • PHENIX Muon Piston Calorimeter Extension (MPC-EX)
2015-2017	• High stat. Au+Au at 200 and ~40 GeV • U+U/Cu+Au at 1-2 energies • 200 GeV p+A • 500 GeV $\vec{p} + \vec{p}$	• Extract $\eta/s(T_{min})$ + constrain initial quantum fluctuations • further heavy flavor studies • sphaleron tests @ $\mu_B \neq 0$ • gluon densities & saturation • finish p+p W prod'n	• Coherent Electron Cooling (CeC) test • Low-energy electron cooling • STAR inner TPC pad row upgrade
2018-2021	• 5-20 GeV Au+Au (E scan phase 2) • long 200 GeV + 1-2 lower $\sqrt{s}$ Au+Au w/ upgraded dets. • baseline data @ 200 GeV and lower $\sqrt{s}$ • 500 GeV $\vec{p} + \vec{p}$ • 200 GeV $\vec{p} + A$	• x10 sens. increase to QCD critical point and deconfinement onset • jet, di-jet, γ-jet quenching probes of E-loss mechanism • color screening for different $q\bar{q}$ states • transverse spin asyms. Drell-Yan & gluon saturation	• sPHENIX • forward physics upgrades

RHIC Operations Funding Recent History

	FY2007	FY2008	FY2009	FY2010	FY2011	FY2012	FY2013P
RHIC Ops. @year $M	135.5	137.0	149.8	158.7	159.4	157.6	156.6
# cryowks.	20	19	22	28	26	~23	~15
Comments	Budget arrived late, other-wise could have supporte d more weeks	Unexpec-ted Omnibus bill causes early run termina-tion	Budget could have suppor-ted 25 weeks, but long CR led to very late start	Robust run, should maintain carry-over for early start on Run 11 even with CR	Long run possible due to carryover from FY10 + salary freeze. Finished end of June 2011	Extended via Xmas $3M add + lower power costs w/ new NYPA contract. Will end June 27.	Mandated 2-year salary freeze ends.

1) *“RHIC Ops”= (collider + det.) [Ops. + R&D + CE] + AIP*
2) *Actual collider runs are funded from last 10-15% of the budget (next slide) ⇒ # weeks subject to year-to-year changes in conditions, costs*
3) *At present power rates (~$50/MW·h), incremental cost/week ≈ $470K*
4) *Flat-flat budgets ⇒ lose ~$5M/year to inflation ⇔ ~10 cryoweeks/year w/o mitigation. Beginning to run short of mitigation strategies – details below.*

Overview of FY2012 RHIC Operations Budget

Budget authorization:

Category	Funding Level ($M)	Comments
Accel. Ops.	117.1	
Accel. R&D	1.5	
Accel. CE	1.2	
AIP	2.3	
Exp’t Support Ops.	31.9 (mostly salaries)	7.3 to C-AD, 24.6 to Physics
Exp’t CE	3.6	
Total	**157.6**	

Expenses by category (does not include carry-over from FY11 or to FY13):

Category	C-AD $M	% C-AD Total	Physics $M	% Physics Total	RHIC $M	% RHIC Total
Salaries	48.9	54.1%	10.1	51.4%	59.0	**53.6%**
Salary O/H	21.1		4.4		25.5	
Base Power	3.0	6.1%			3.0	**5.0%**
Increm. Ops. Power	4.9				4.9	
M&S	13.4	14.2%	5.4	19.1%	23.8	**15.1%**
M&S O/H	5.0					
R&D	In M&S	2.7%	1.5	18.1%	8.6	**5.5%**
CE & AIP	3.5		3.6			
Space Charge	11.6	22.9%	3.2	11.3%	32.8	**20.8%**
Org. Burden	5.4					
Mat’l Handling	0.5					
ODC/Allocations	3.0					
User Support	0.6					
Other O/H	8.6					
Total	**129.4**	**100%**	**28.2**	**100%**	**157.6**	**100%**

Breakdown among categories very similar to all NP labs in 2006 Operational Efficiency Review, except RHIC power costs a bit below lab average of 6%.

Collider-Accelerator Staffing Level History

- *Current level = 353 FTE (+72 for in Physics for exp't ops.), ~same as FY2003, still below optimal levels suggested in 2002 (and repeated in 2006) NP Facility Operations Review*
- *Technical areas redistributed over the years to address needs, but no net growth to address new systems*
- *Lowest annual level for stable operations was ~340 FTE. DOE support for 320 FTE in FY2006 could not have supported a RHIC run without other funds.*
- *Minimal staffing levels determine the deepest multi-year cuts RHIC can survive.*

Answers to Panel Questions

(1) What *major* scientific accomplishments and discoveries have occurred in your research area or at your facility since the 2007 LRP was drafted?

- **QGP formation in RHIC collisions confirmed by more definitive n_q-scaling of hadron yields & flow, plus early temperature measurement**
- **Viscous 3+1-D event-by-event hydro + flow power spectrum measure-ments ⇒ clear path to quantify η/s vis-à-vis lower quantum bound**
- **LHC heavy ion results confirm basic RHIC findings**
- **Heavy quarks lose energy in QGP at ~ same rate as light quarks**
- **Anti-hypertriton and anti-helium4 produced at detectable levels @ RHIC**
- **Gluon and quark spins contribute comparably to overall proton spin**
- **Forward di-hadron suppression in d+Au consistent w/ CGC expectation**
- **Development of bunched-beam stochastic cooling leads to order of magnitude improvement in RHIC HI luminosities**

(2a) What compelling and unique science can be carried out at the facility (or in the program) in the next five years assuming support similar to FY13 that includes cost of living increases?

- **Outlined in earlier "compelling questions" and "timeline" tables**

(2b) What additional impact would flat-flat funding to FY18 have on (2a)?

- **It would be very difficult to maintain viable operations beyond ~FY2015 – see later answer re budget cuts. Would have to go to short (~15 week) runs every other year, making it impossible to serve both HI and spin user communities.**

Answers to Panel Questions

(3) What is the minimum level of support (beam hours, upgrades, etc.) needed to maintain a viable program?

- **Cannot run effectively at less than 15 cryoweeks/year. Even that level will occasionally require bridging runs across fiscal years.**
- **Completion of ongoing upgrades fuels program through ~2017. Science beyond that requires detector upgrades of scope ~$25M (could sacrifice one year of operations to help project funding).**

(4) What workforce is needed to maintain a viable program?

- **~1000 users to operate & maintain PHENIX & STAR and analyze data.**
- **Need at least 410 (direct-funded) FTE @ BNL for stable machine & detector operations.**

(5) What science would you expect to pursue at your facility (or in the program) in 2020 and beyond. What is needed to support this? What science would you expect to pursue without your facility?

- **By mid-2020's, turn focus to e+p, e+A @ eRHIC to probe & image gluon-dominated cold nuclear matter.**
- **Goal is Total Project Cost ~$600M for eRHIC ($500M for electron ERL & IR's, $100M for detector upgrades), with project start ~end of decade.**
- **Without RHIC operations, BNL NP research opportunities would include: storage ring proton EDM exp't @ BNL (uses AGS); LHC heavy-ion collisions; still aggressive accelerator R&D aimed at eRHIC.**

Answers to Panel Questions

(6) What is role of the science in your research area in the international context? If the US effort in this area were seriously curtailed, to what degree would efforts in other countries fill the gap? And, to what degree would US scientists be able to advance research in this area by working outside of the country?

- **Exploration of QGP could proceed only at LHC w/o RHIC – quantification of properties would suffer seriously & discovery potential lost**
- **Ability of LHC experiments to absorb more US scientists is limited**
- **FAIR could cover low-energy range in fixed-target mode after SIS300, but funding not yet available; NICA @ Dubna also potentially relevant, with uncertain timeline; both might fall below QCD critical point**
- **Bottom line: the science would be severely diminished w/o RHIC**

(7) How does the facility (or program) contribute to the educational mission of training the future workforce in nuclear physics and associated applied areas?

- **RHIC produces ~25 NP Ph.D.'s/year. Many stay in field, but many go into applied areas.**
- **Accelerator science produces ~1-2 additional Ph.D./year – expect to grow with additional support for SBU/BNL CASE program.**
- **In addition, many post-docs supported on RHIC-related grants.**
- **Also have extensive outreach programs to high school and undergrad students and teachers.**

Answers to Panel RHIC-Specific Questions

(1) What additional compelling science becomes available by major upgrades to the RHIC detectors and/or accelerator beyond those now underway?

- **Possibility to locate QCD critical point and/or onset of deconfinement**
- **Ability to measure parton energy loss parameters as fcn. of temperature to determine strength of effective coupling vs. scale**
- **Systematic measurements of quarkonium survival vs. $\sqrt{s}$ to constrain color screening length**
- **Forward Drell-Yan and p+A transverse spin asymmetries to constrain QCD origin of transverse spin effects and gluon saturation scale**

(2) What additional science can be carried out over the next ten years without major facility and detector upgrades?

- **Quantification of shear viscosity and other transport coeffs. of QGP**
- **Pursuit of discovery potential for nature of initial quantum fluctuations and possibility of QCD sphaleron effects**
- **Further constraints on low-x gluon densities in nuclei, and on gluon and sea quark contributions to proton spin**
- **Probing participation of heavy quarks in parton energy loss, flow and thermalization**
- **Further tests of chiral symmetry restoration via di-lepton spectra**
- **First tests of QCD theory predictions for relation of transverse spin asymmetries in e+p vs. p+p**

What Would be Lost if RHIC Were Terminated?

- Opportunity to map QGP properties vs. temp., explore QCD phase diagram, and discover the possible Critical Point.
- Unique polarized pp access to nucleon spin structure.
- U.S. leadership in a vibrant NP subfield it pioneered.
- A major fraction of the productivity for U.S. NP over the better part of a decade – is this survivable for the field?
- The unmatched track record of RIKEN-BNL Research Center in funding outstanding Fellows and placing them in high-profile tenured positions.
- The last operating U.S. collider, hence a critical attractor for talented accelerator scientists and cutting-edge R&D.
- Cost-realizable path to a future EIC, taking advantage of ~$2B replacement cost (avoiding ~$1B D&D cost) of RHIC complex.
- Home research base for >1000 domestic + foreign users.
- Unusually strong foreign (esp. RIKEN) investment in U.S. facility.
- ~750 (direct, including research + indirect) FTE's @ BNL.
- Associated efforts will suffer collateral, possibly fatal, damage:
  - Lattice QCD thermodynamics leadership
  - Strong medical radioisotope production program @ BNL
  - NASA Space Radiation studies @ BNL
  - Accelerator physics offshoots, esp. in hadron radiotherapy
- Probably a sizable chunk of DOE ONP funding will be siphoned off to other agencies or program offices.

Backup Slides

Recent and Ongoing Improvements to Cost-Effectiveness of RHIC Operations

I. Cost and Staffing Reductions

- Cut cryopower by ~half in FY04-08, reducing power usage by ~5 MW
- Renegotiated BNL power contract with NYPA $\Rightarrow$ rates ~\$60/MW·h over 5-10 year period
- Reduced Superconducting Magnet Division staff supported by RHIC ops: 18 $\rightarrow$ 9 over FY08-11
- Phasing out Tandem Van de Graaff support staff of 12 FTE during FY12-13
- Improved age distribution and neutralized inflation in cost per FTE during FY09-11
- FY06-07 Merger of RHIC and ATLAS Computing Facilities permits savings of ~6 FTE to RHIC operations budget, by exploiting synergies with HEP-funded efforts
- Have replaced electron cooling plan with stochastic cooling to achieve RHIC heavy-ion luminosity upgrade during FY08-12

Bottom line: above changes have led to >\$100M cumulative savings in the FY07-13 period

II. Performance Improvements FY08-14

- Increasing effective collision luminosity by order of magnitude via stochastic cooling upgrade and steady incremental enhancements to operational modes
- Increased ratio of sampled/delivered luminosity by factor ~1.5 for PHENIX detector and factor ~2.5 for STAR detector
- Steady and ongoing performance upgrades to the detectors are improving the quality and selectivity of the data acquired
- Adding improved reliability and ion species variability with new EBIS source
- Have extended RHIC energy range down to 7.7 GeV per nucleon pair for heavy ions, exposing interesting energy dependences in QGP signatures

III. Investments in the Future via RHIC Operations and ARRA Funds

- R&D on bunched-beam stochastic cooling, plus ARRA funding, allowed ~$80M savings in RHIC luminosity upgrade
- FY10-12 staffing "bump" alleviated single points of failure among aging support staff with unique knowledge and subsystem familiarity
- Have added sufficient FTE's (essentially replacing Tandem FTE's) to operate new accelerator subsystems (e.g., stochastic cooling, EBIS, electron lenses) efficiently
- AIPs on electron lenses (including ARRA funding) have potential to boost polarized proton collision luminosity by factor ~2
- Ongoing R&D on critical accelerator technologies address the boosts in state-of-the-art performance needed to design an Electron Ion Collider that can meet scientific demands: high beam power ERL; coherent electron cooling; high-current polarized electron source; eRHIC design

IV. Investments in the Future with BNL Funds

- ~$2M of royalty funds invested in development of superconducting RF capability
- >$5M of BNL funds invested in RHIC-ATLAS Computing Facility space expansion
- ~$7M of LDRD/Program Development funds over FY10-13 invested in eRHIC accelerator and detector R&D and science case development
- RSL-II project (~$35M) invested in Physics Dept. lab and research space renovations
- Part of ~$8M/year overhead investment in core Instrumentation Division staff ⇒ direct benefits to eRHIC polarized source development, RHIC detector ASIC development, …

V. Investments in RHIC's Future with Funds from Other Sources

- NASA invested ~$4M in new EBIS source for RHIC
- ONR has invested several $M in ERL development relevant to eRHIC