

QMC Workshop 2021

5 October – 23 November 2021

Week 1 Kickoff: Paul Kent, kentpr@ornl.gov

https://github.com/QMCPACK/qmc_workshop_2021

Funding: U.S. Department of Energy, Office of Science, Basic Energy Sciences, Materials Sciences and Engineering Division, as part of the Computational Materials Sciences Program and Center for Predictive Simulation of Functional Materials.

Welcome

We have >200 registrants for this workshop from across US, Europe, Asia

We will try to upload recordings of these presentations weekly



2019 QMCPACK Users Workshop

Goals for Today

Motivation: Why quantum Monte Carlo?

Logistics for the workshop

Using the workshop VirtualBox image

Covering any questions

Next week: Theory of real space Quantum Monte Carlo

Zoom Practicalities

We are recording these presentations for upload to YouTube

Questions and interaction improves the talks! Use the chat feature or Slack for questions. Indicate if you wish to ask the question “live”.

Slack will remain accessible after each presentation while the chat will not.

Thanks to Anouar Benali @ Argonne who is watching Slack & the chat today.

Acknowledgements

Thanks to the presenters:

Chandler Bennett, Jaron Krogel @ Oak Ridge National Lab, Anouar Benali @ Argonne National Lab, Cody Melton, Joshua Townsend @ Sandia National Labs, Gani Annaberdiyev, Lubos Mitas @ North Carolina State University

Website & administrative help @ ORNL: Laura Becker, Makysha Mitchell

Current QMCPACK developers and users

Registration Survey Results

Most common requests on the registration survey:

1. Cover the fundamentals of quantum Monte Carlo
2. Interested in learning capabilities QMC, given some familiarity with DFT, Quantum Chemistry, &/or Monte Carlo

Goals for Workshop

1. Cover the fundamentals of Quantum Monte Carlo
2. Provide foundation for practical molecular & solid-state calculations using QMCPACK in combination PySCF, Quantum ESPRESSO
3. Cover some new developments & recent research
4. Provide routes for follow-on support after the workshop

More advanced topics can be covered in our next workshop – put what you would like to see in the survey

Schedule Notes

Tuesdays 11am Eastern Time for up to 2 hours, covering presentations and worked examples. Work through these and make your own experiments during each week.

“Out of hours” support via Slack.

In case of “bad network weather” we will reschedule later the same week based on speaker availability to stay on our overall schedule.

Caution! Daylight savings ends on 7 November in USA (-1hr). Check with e.g. timeanddate.com for correct start time.

Schedule

Week 1 / 5 October	Workshop Introduction and Kickoff (Paul Kent)
Week 2 / 12 October	Fundamentals of Quantum Monte Carlo (Paul Kent)
Week 3 / 19 October	Computational workflows with NEXUS. Statistical Analysis (Jaron Krogel)
Week 4 / 26 October	Molecular Calculations (Anouar Benali)
Week 5 / 2 November	Solid-State Calculations (Joshua Townsend)
Week 6 / 9 November	Pseudopotentials in QMC. Observables (Lubos Mitas, Gani Annaberdiyev, Chandler Bennett)
Week 7 / 16 November	Guest lecture and Research Presentations (Claudia Filippi and others)
Week 8 / 23 November	Spin-orbit Calculations. Workshop wrap-up and next steps (Cody Melton and Paul Kent)

QMC Workshop Slack

Short link to register: <https://bitly.com/qmcworkshopsslack>

Pick appropriate channels:

#general

#installing

#nexus

#molecules

#solid-state

We encourage an interactive workshop

Mute or leave enabled Slack notifications as you prefer

Support after the Workshop

Slack channel will remain open

Use the QMCPACK Google Group

Open an issue on QMCPACK GitHub for more technical issues

Contact us directly

This is a screenshot of the QMCPACK Google Group interface. At the top, there's a header with 'Groups' and a search bar. Below that, a list of messages is shown. A specific message from Paul R. C. Kent about the QMCPACK Workshop is highlighted with a green border. The message content includes a link to the workshop registration page.

This is a screenshot of the QMCPACK GitHub Issues page. It shows a list of pinned issues at the top, including 'Welcome' and 'Tests wanted / List of untested functionality'. Below this, there's a search bar and a list of open issues. One issue titled 'Convert4qmcp crashes while processing PySCF h5' is highlighted with a red border. The GitHub interface includes standard navigation bars like 'Issues', 'Pull requests', and 'Discussions'.

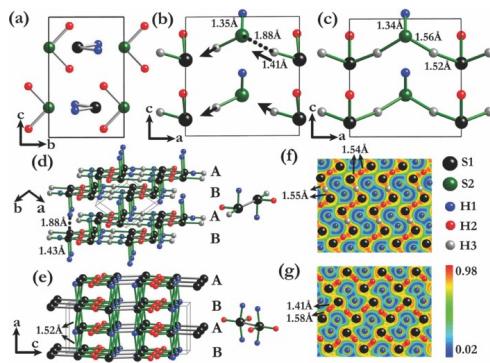
Why Quantum Monte Carlo?

Successes of Electronic Structure Methods & Quantum Chemistry

Aiding discovery of high-temperature superconductors

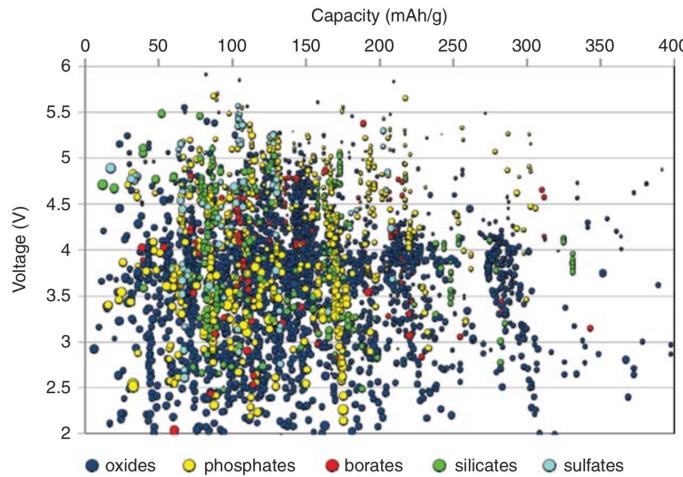


Snider et al. Nature
586 373 (2020)
A “carbonaceous sulfur hydride”



Li et al. JCP **140** 174712 (2014)
“unravels a superconducting potential of metallic H₂S”

High throughput screening of battery materials. Cheap & reliable enough to guide synthesis, and elucidate trends



Ceder MRS Bulletin (2010)

Modern research uses a range of methods each with their own strengths and weaknesses: tight binding, GW, DMFT, CI, CASSCF, CCSD(T), DFT, QMC

Key Features of Quantum Monte Carlo

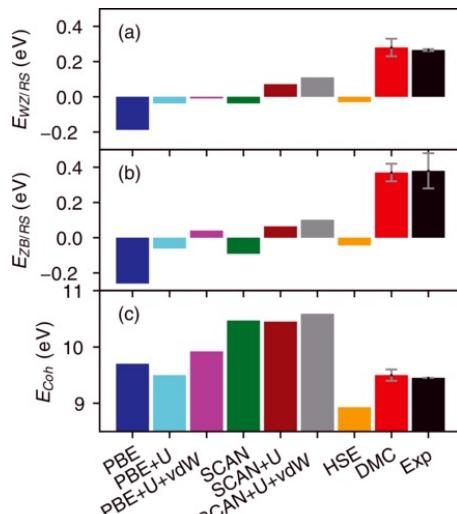
1. The methods are very accurate even in their simplest forms.
2. The few approximations made are known, testable and increasingly able to be converged.
3. The methods provide access to the full many-body wavefunction and many-body physics.
4. The methods are increasingly affordable and usable for timely science problems.

...

Accuracy in standard forms

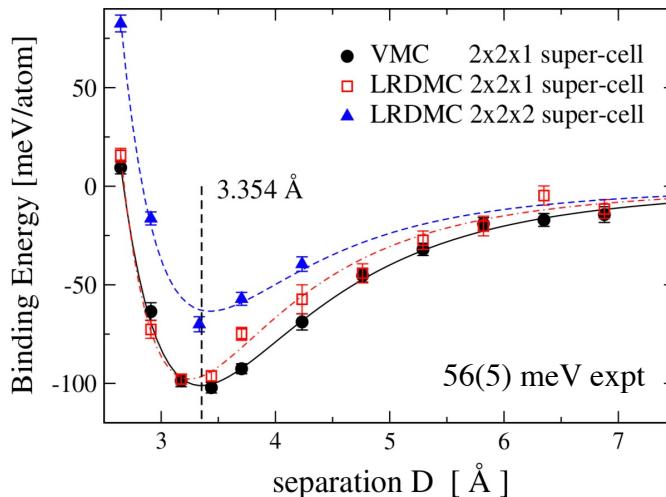
QMC methods naturally avoid double counting & self interaction errors, and accurately account for the van der Waals interaction. This avoids key problems with most density functional theory approximations.

Scandium oxide polymorphs



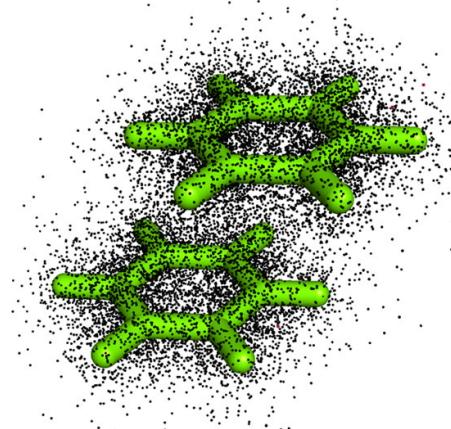
K. Saritas et al.
PRB **98** 155130 (2018)

Graphite



L. Spanu et al.
PRL **103** 196401 (2009)

Molecular Systems



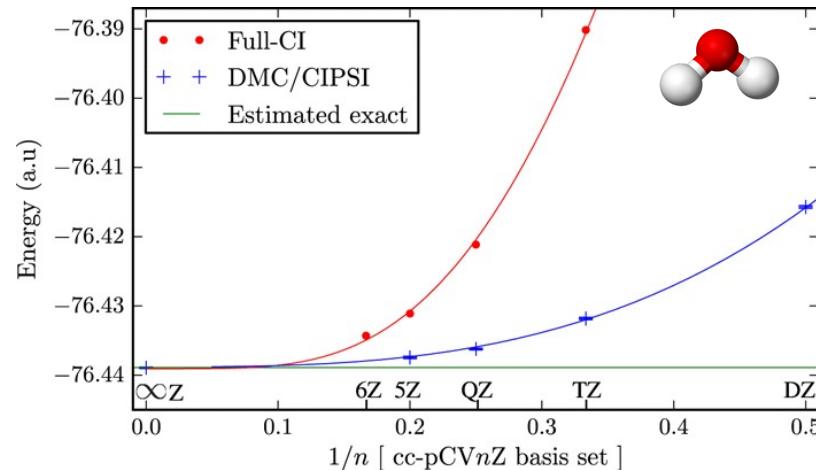
M. Dubecky et al.
Chem Rev. **116** 5188 (2016)

Improvability (rare/unique capability)

QMC methods are not “magically” accurate, and as typically applied, make a few approximations in solving the Schrodinger equation.

The approximations can increasingly be tested and converged. E.g. Using large multideterminant expansions to refine and converge the nodal error due to the Fermion sign problem.

For periodic systems, larger supercells can be used in estimating finite size effects.



H₂O molecule
-76.438 94(12) a.u. CIPSI-DMC
vs -76.438 9 a.u. Experiment

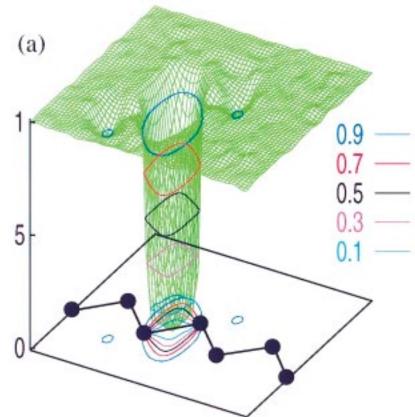
Most accurate theory calculation to-date

Caffarel et al. JCP **144** 151103 (2016)

Many-body wavefunctions

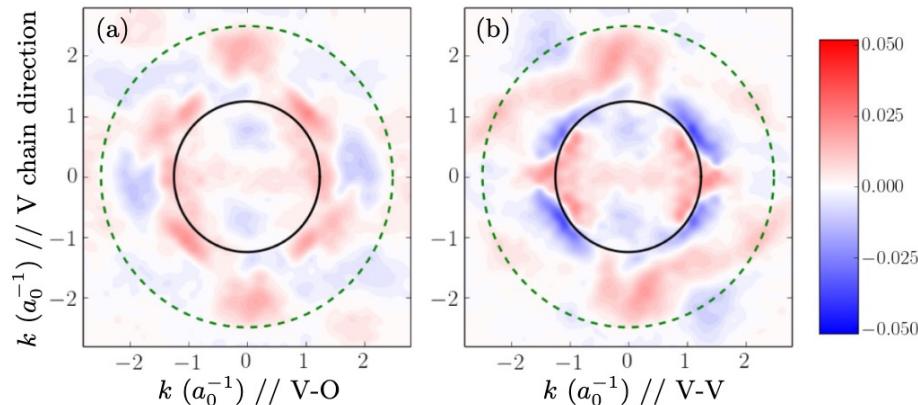
QMC methods give access to the full many-body quantum mechanical wavefunction. Consequently, density matrices, pair-correlation functions, momentum distributions and ‘beyond single particle physics’ can be studied in general.

Under exploited in my opinion!



$g(\mathbf{r}, \mathbf{r}')$ spin parallel, one electron on bond center, Si (110) plane

R. Q. Hood et al. PRL **78** 3350 (1997)



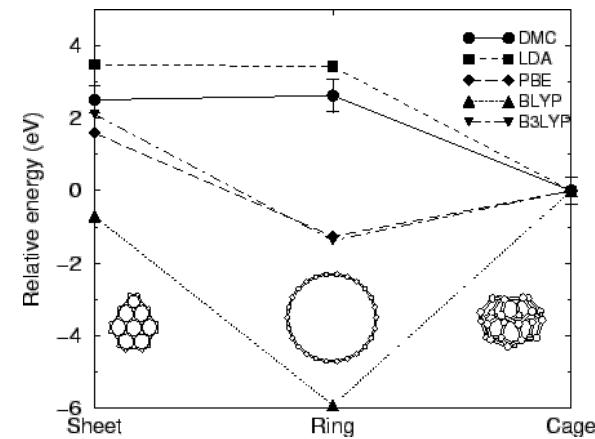
Difference in momentum distribution $n(\mathbf{k})$ in VO_2 through R-M1 phase transition

I. Kylanpaa et al. PRB **99** 075154 (2019)

Computational Cost

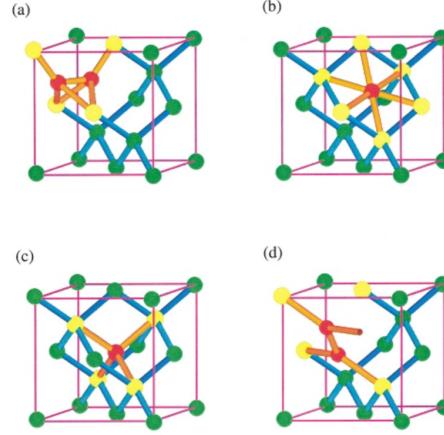
Many of the earliest-but-still-accurate nanostructure and solid-state defect calculations can now be run on workstations! Light element systems are in scope with departmental level resources. Heavier element systems & delicate properties still need HPC and careful planning.

Smallest stable fullerene



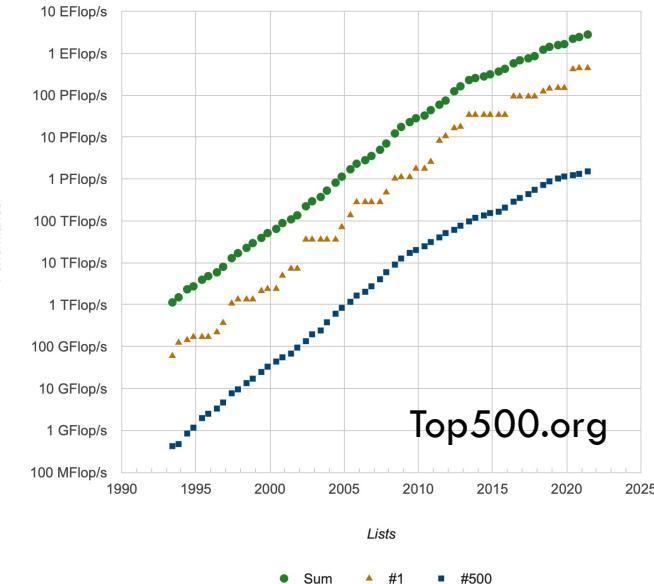
P. R. C. Kent et al.
PRB **62** 15394 (2000)

Si self-interstitial defects



W. K. Leung et al.
PRL **83** 2351 (1999)

Performance Development



Top500.org

● Sum ▲ #1 ■ #500

Workshop Virtual Machine

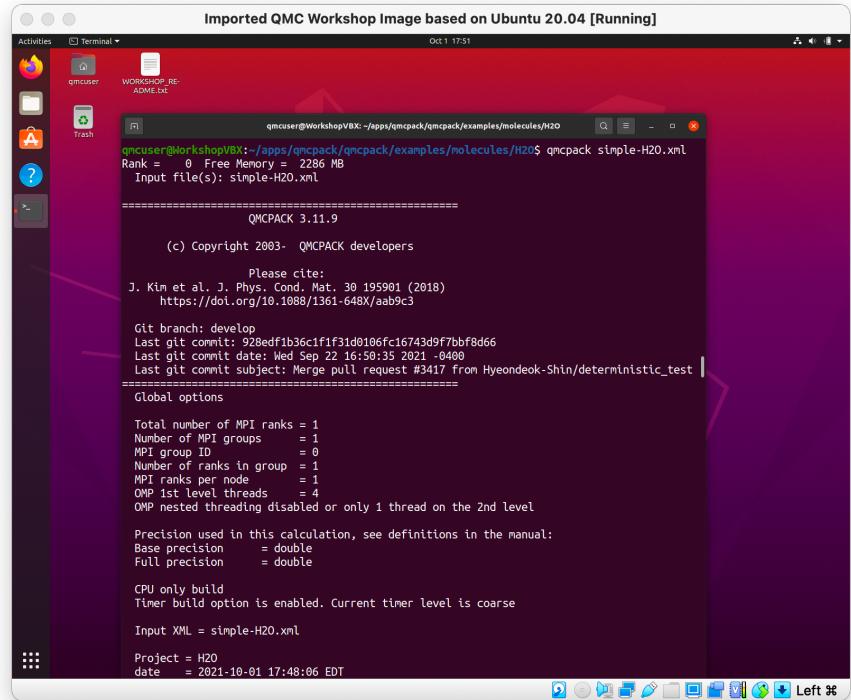
The VirtualBox Virtual Machine image is a complete desktop for running QMC, DFT and quantum chemical calculations.

The VM is a Ubuntu 20.04 desktop with QMCPACK, NEXUS, Quantum ESPRESSO (QE), PySCF, DIRAC, VESTA, and xcrysden installed, as well as the workshop files.

We support running the provided VirtualBox image on x86 architectures. Problems are sized to be runnable on a recent/strong laptop.

Workarounds & alternatives will be covered after these setup instructions.

While the Virtual Machine is only really needed by week 3, please try earlier so that any problems can be debugged. Feedback welcomed: we hope to make a live QMCPACK image going forward.

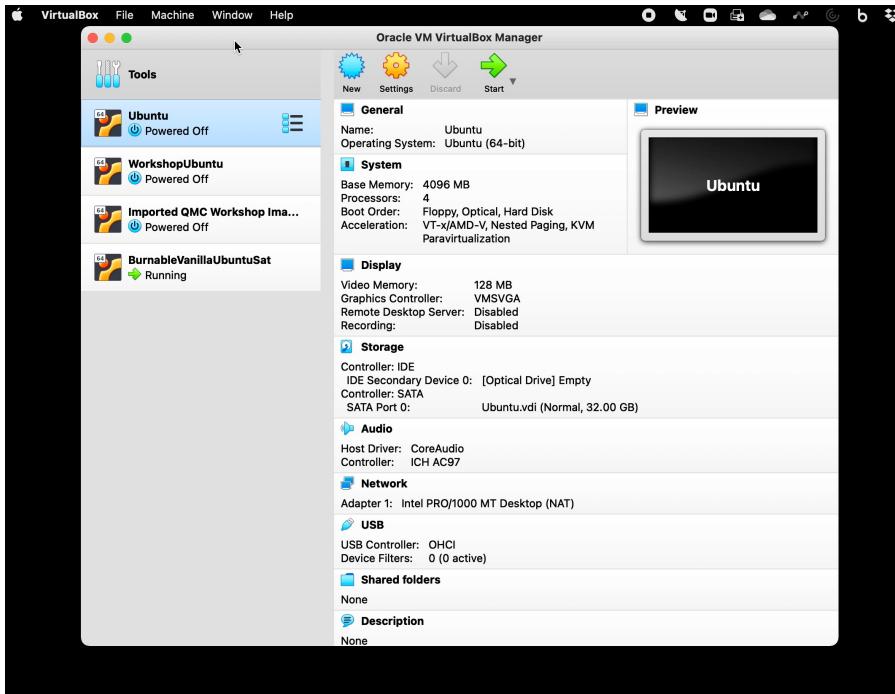


Using the Workshop VM

- Install the latest version of VirtualBox (free), currently v6.1.26. <https://www.virtualbox.org/> or package manager.
- Download the workshop image file <https://bit.ly/qmcworkshopimage>
- The file is 5GB in size, so will take several minutes to download even on the fastest networks, and potentially several hours. Be patient and try again at a different time or using a different network if initially unsuccessful.
- Run VirtualBox and import the image to setup the workshop virtual machine:
- In VirtualBox, select the menu File->Import Appliance. Import the QMCWorkshopImage.ova.
- **Customize the "Appliance" Settings during Import to suit your computer.** e.g. Increase the CPU count to match the machine you are running on (maybe 4 for laptop, 16-128 for a workstation), Increase the memory (4GB should be OK on laptops). Not setting the core count and memory sufficiently large will result in poor performance. Consider renaming the machine.

Using the Workshop VM

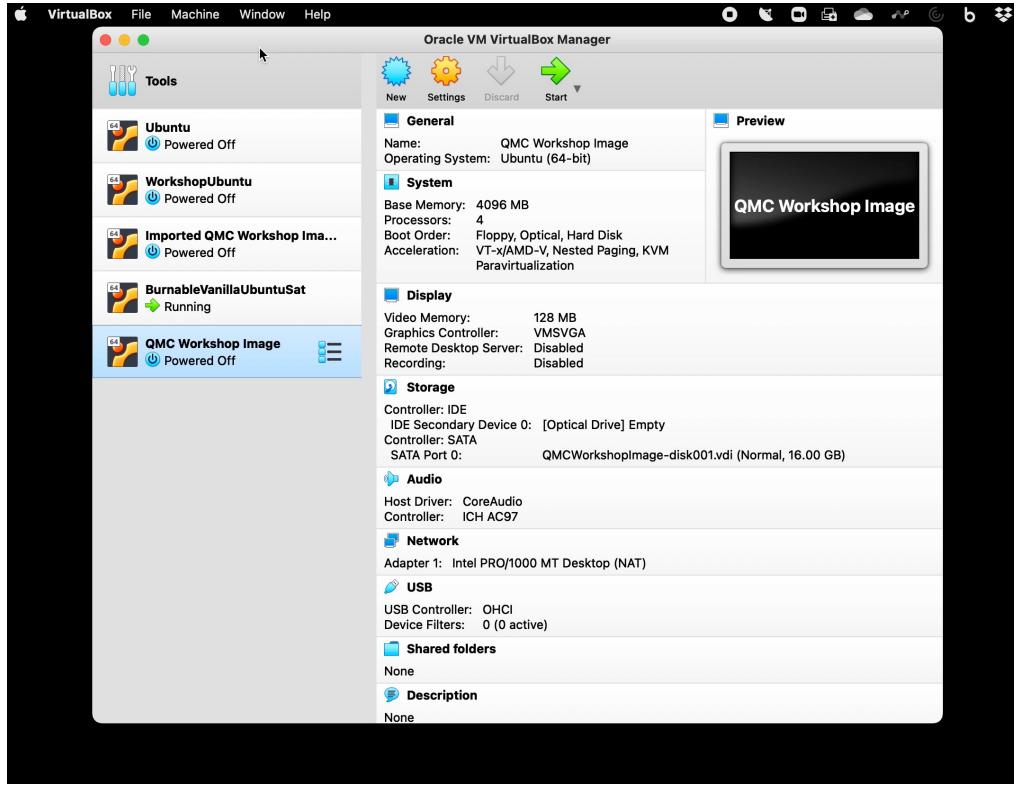
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Using the Workshop VM

- Select the new machine, then "Start". You should see Ubuntu boot and a standard desktop appear.
- The virtual machine is setup to automatically log in as user "qmcuser". Should you need to authenticate the word you need is "workshop21" (no quotes).
- You can get a Terminal (or other application) by clicking the square of dots icon at the bottom left and either typing or selecting the application you want.
- "qmcpack", "qmcpack_complex", "pw.x", "pam-dirac", and "VESTA" are on the path. NEXUS and PySCF are available through python. These are installed in \$HOME/apps
- "sudo apt-get install your_favorite_editor" to install software
- Convenience tip: Right click on the Terminal icon & make a favorite to keep in the task bar.

Using the Workshop VM



Alternatives

1. Install VirtualBox on a remote workstation and access over X11. You will need root to install. Better than using a weaker laptop, highly advantageous if a powerful workstation.
2. Install the software directly: Adopt the setup script for other UNIXes by changing the package manager. Besides the simulation software, only standard Ubuntu packages are used.

Workshop image setup script and instructions are in
https://github.com/QMCPACK/qmc_workshop_2021

Updating Files

Workshop example files and slides (expect weekly updates):

```
cd $HOME/qmc_workshop_2021
```

```
git pull
```

QMCPACK & NEXUS python updates:

```
cd $HOME/apps/qmcpack/qmcpack
```

```
git pull
```

We try to minimize full rebuilds or redownloads!

Things to do

1. Register on Slack: <https://bit.ly/qmcworkshopslack>
2. Install VirtualBox via <https://virtualbox.org> or package manager
3. Setup the workshop image <https://bit.ly/qmcworkshopimage> (5GB)

Questions?

Next week: Theory of real space Quantum Monte Carlo