Tackling the real-time challenge in strongly correlated systems

Spectral properties from Euclidean path integrals

Welcome, we're happy to see you all - at last!

Timeline of this workshop:

- Continuation of a series of events: CERN workshop, Amherst workshop, ...

Previous "installments"

- https://indico.cern.ch/event/783115/
- https://www.physics.umass.edu/acfi/seminars-and-workshops/qcd-real-time-dynamics-and-inverse-problems

Due to Pandemic

- 1 year delay, thank you all for your continued interest and participation!
- Re-arranged program thanks to virtual format

Organisational

Indico:

- Remember to upload your talk at the indico:
- https://indico.ectstar.eu/event/101/

Zoom link and password:

- https://fbk-eu.zoom.us/j/81347304018 (Passcode: 003568)

Please fill out the privacy policy agreement:

- https://docs.google.com/forms/d/e/1FAIpQLSdM09wfDdAkql5Ct2Pu4qNedFNFo8YSG-AwOfFhaN1CiFNr9Q/viewform

Further info on where to watch the recordings to follow

Organisational

Timetable:

- Alternating morning and afternoon sessions

Emphasis on discussions:

- Informal sessions
- Guided sessions:
  - Broad picture (Max)
  - Methods (Alexander)

Thank you to our sponsors

Scope & Challenge

Foster exchange and collaboration between fields and topics

- From high-energy nuclear to condensed matter physics

Elucidate the range of phenomena for which real-time dynamics is relevant & challenging

- Hadronic resonances, transport and momentum in the QGP and electron conduction in complex functional materials

Explore new conceptual and technical advances to address the inherent inverse problem. Compare strengths and weaknesses of different methods with focus on systematic uncertainties.

Scientific Themes: bridging the gap

Numerical methods for inverse problems

Talks and interdisciplinary dialogue to address:

- Advances in extraction of spectral functions in nuclear and condensed matter physics.
- Advances in finite-volume spectral analysis of vacuum states in lattice QCD.
- Connecting spectral function reconstruction and specific finite volume approaches.
- The systematics and complementarities of methods for inverse problems.

Scientific Themes: novel techniques

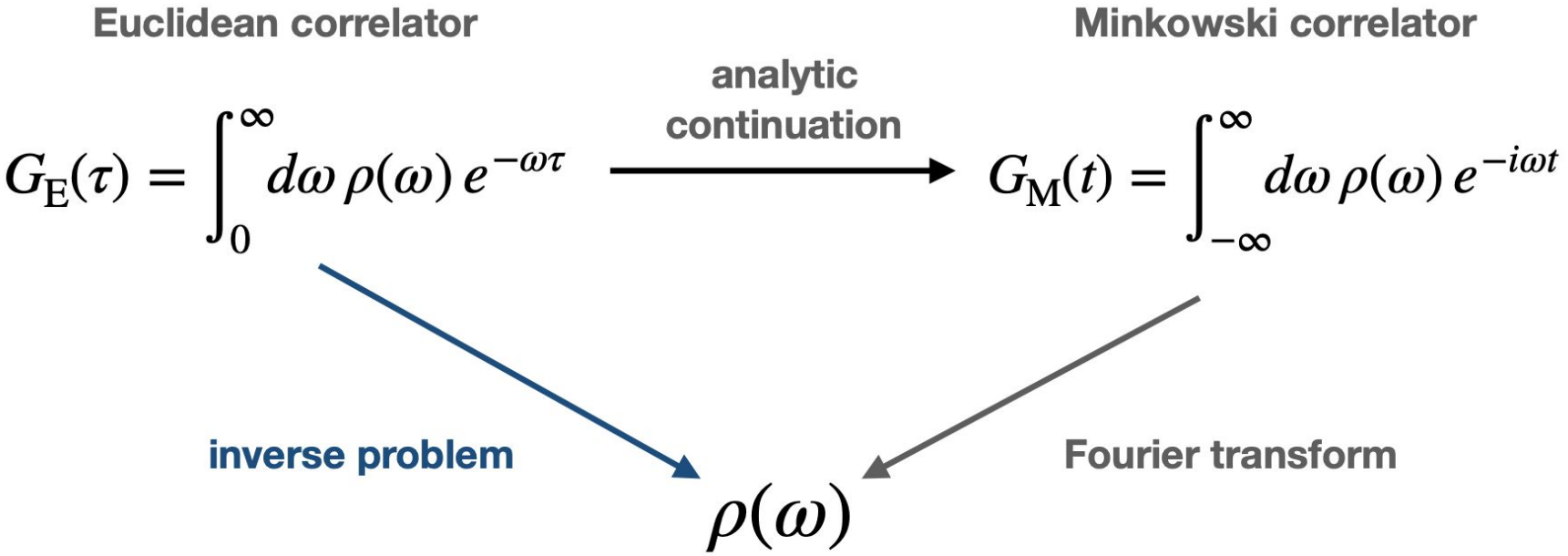
Improving access to real-time properties

High-precision simulation data opens new avenues towards spectral information but demands novel techniques for noise reduction (algorithmically or through physics input) while also providing fertile ground for machine learning techniques.

The workshop will examine:

- Machine/deep learning for spectral functions.
- Noise reduction for high-precision simulations.
- Noise distributions for improved access to spectral information.

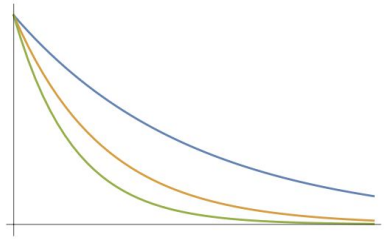
Setting the stage: inverse problems & analytic continuation

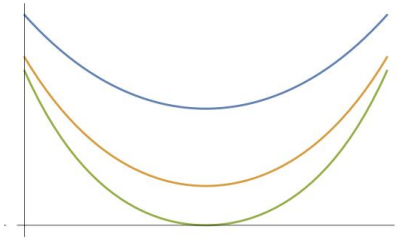


Setting the stage: information loss

The specific problem sets the kernel entering the inverse problem

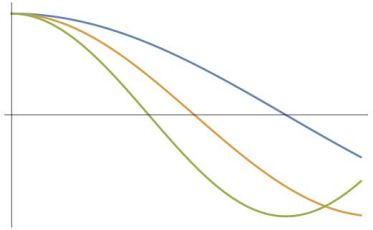
$$G_{\mathrm{E}}(\tau) = \int_0^\infty d\omega\, \rho(\omega)\, \kappa(\omega, \tau)$$





In this workshop we will often see kernels corresponding to:

- Zero-temperature quantities $\kappa(\omega, \tau) = e^{-\omega\tau}$
- Nonzero-temperature $\kappa(\omega, \tau) = \dfrac{\cosh(\omega(\beta/2-\tau))}{\sinh(\omega\beta/2)}$
- Parton distribution functions $\kappa(\nu, x) = \cos(\nu x)\,\Theta(1-x)$



A common challenge: exponential decay of Eigenvalues of the linear transformation

Solving the problem: setting expectations

Jacques Hadamard established three conditions for a well-posed problem

1. Existence of the solution
2. Uniqueness
3. Stability (solution's behavior changes continuously with the initial conditions)

The problems we consider fail in the sense of 2. and 3. and are thus ill-posed.
This is a problem due to discrete sampling and finite precision.

Solving the problem: community overview

An Open Question: a matter that is *not yet* decided or is *unable* to be decided

[Oxford English dictionaries]

Observation 1: common themes and questions have emerged in discussions at previous workshops - uncertainty quantification, robustness, global fits.

Observation 2: we are in data-rich environment (different to previous decades). This facilitates new techniques e.g. ML/NN, with the caveat that not all data are created equal.

Solving the problem: domain knowledge

Giving meaning to an ill-posed problem requires extra information

- On the level of input data: identify complementary observables to constrain target quantities
- On the level of methods: identify where prior information enters and how it can be adapted to specific physics problems

Observation 3: Some communities have made progress in the former category but no concerted efforts in the latter so far.

Solving the problem: gathering methods

A number of methods will be discussed at this workshop, including

- Frequentist (models and parameter minimisation techniques)
- Bayesian (MEM, BR and similar)
- Linear (Backus-Gilbert and HLT)
- Machine learning & neural networks (classical and quantum)

Each method has its own inherent and problem-dependent pros and cons

Observation 4: unlikely there is a *single* best solution. It is important to quantify the benefits of each method. It is not enough to simply observe results agree.

Solving the problem: improving & extending methods

Consider spectroscopy at zero temperature - a combination of new ideas has led to rapid progress.

Can ideas that have worked well in this regime be adapted for inverse problems? Some we will hear about:

- Finite volume as a tool
- The role and use of smearing
- GEVP with Backus-Gilbert and improving input data
- EFTs to simplify/clarify relevant physics

Challenges

- Can the relevant systematics in methods be articulated a priori?
- Is there a hierarchy of systematics ie some which dominate or are enhanced when fed through an inverse problem, others not?
- How to compare results from different methods in a meaningful way?
- Prospects and priorities for *FLAG* style averages?

We wish you a great and fruitful week!

- The miracle of virtuality.
  - 10 participant institutes in America,
  - 10 in Asia,
  - 14 in Europe.

Thank you for joining us from all around the world!