Tools for cosmology: the CLASS and Monte Python codes

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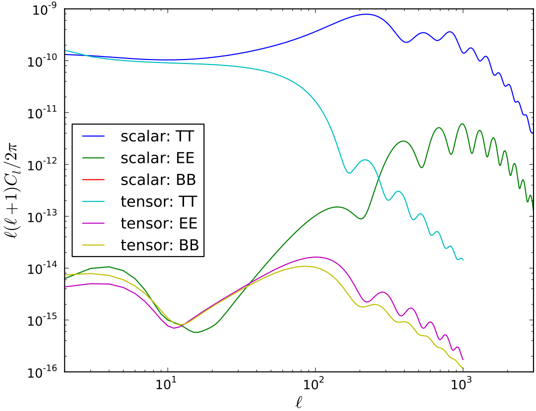
Kavli IPMU, Tokyo, 27-31.10.2014

Almost any type of research activity in cosmology will use a Boltzmann code at some point

Computing CMB anisotropy spectra:



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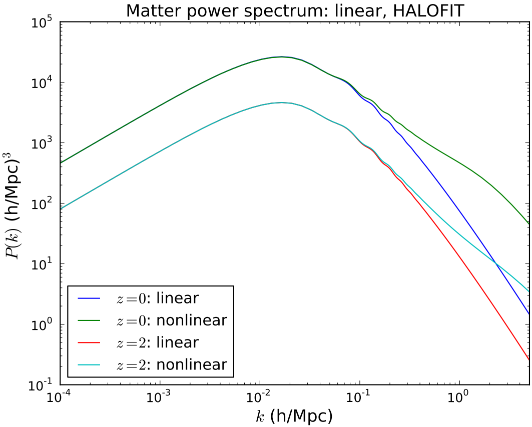
Computing matter power spectrum:



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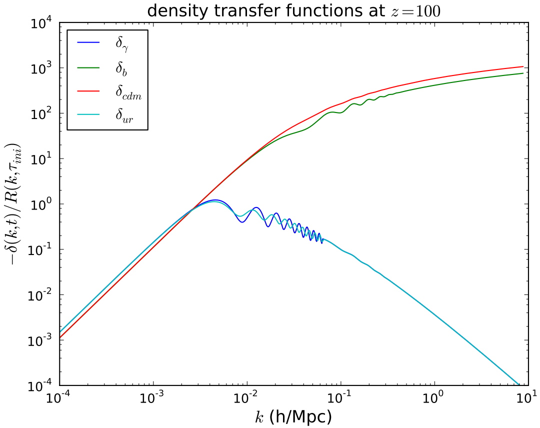
Computing transfer functions (e.g. initial conditions for N-body):



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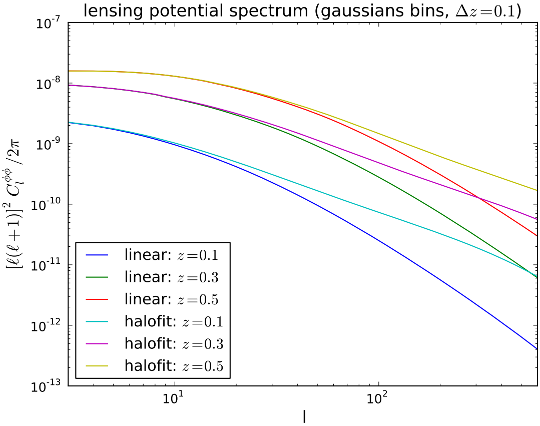
Computing matter density (number count) spectra, or lensing angular spectra:



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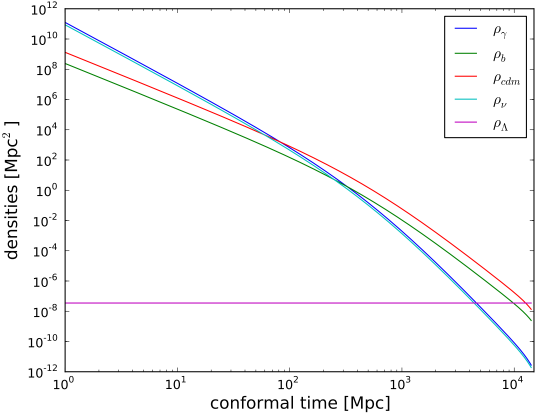
Computing background evolution in a given cosmological model:



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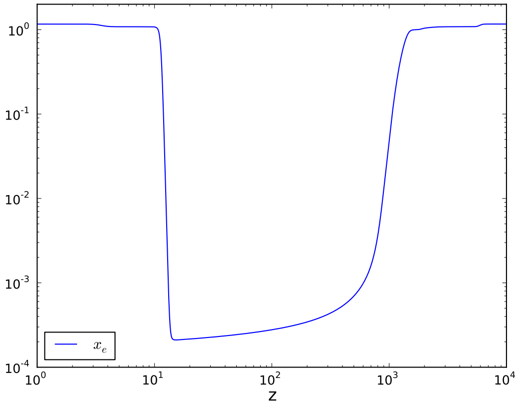
Computing thermal history in a given cosmological model:



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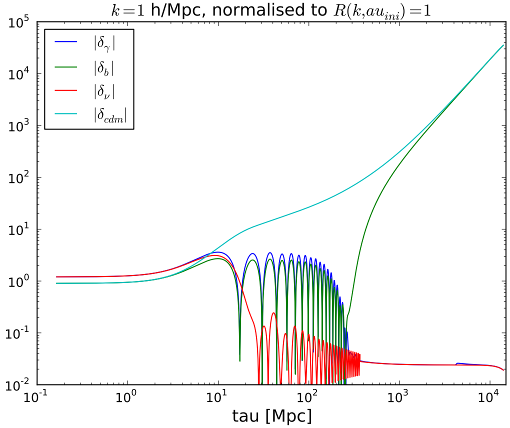
Computing evolution of perturbations for individual Fourier modes:



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As both...

... you want to infer constraints on cosmological parameters from a new dataset
... you want to test your own favorite model, given existing data
... you want to predict the sensitivity of a future experiment to a given parameter

Program: Day 1

DAY I : Monday 27th October

09:30-10:15	CLASS	History, goals & philosophy.	JL
10:15-11:00	General	Bayesian parameter extraction.	BA
		Coffee	
11:30-12:15	CLASS	Overall style and structure.	JL
		Lunch	
13:30-14:15	CLASS	Input and output files. Basic running.	JL
14:15-15:00	CLASS	How to visualise the output.	TT
		Tea	
15:45-16:30	Optional	Lecturers will answer questions and provide help on exercises	

Brief history of Boltzmann codes

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- later: CAMB maintained and improved over the years; others not.

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2. Accurate: need more and more precision. Analysing Planck and WMAP data required very different accuracy settings. Before, CAMB precision could only be calibrated w.r.t itself. CLASS played important role in pushing precision to Planck level. Similar efforts in the future (LSS, next CMB satellite, 21cm, etc.)

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3. Fast: for parameter extraction (Metropolis-Hastings, Multinest, Cosmo Hammer, grid-base methods). Typical project: 10'000 to 1'000'000 executions

The philosophy of `class`

Our efforts for ensuring flexibility and friendliness in CLASS, summarised in 14 key points

Friendliness and flexibility in 14 points

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Examples:
- expects only one out of $\{H_0, h, 100 \times \theta_s\}$, otherwise complains;
- missing ones inferred from given one
- same with $\{T_{\rm cmb}, \Omega_\gamma, \omega_\gamma\}$, $\{\Omega_{\rm ncdm}, \omega_{\rm ncdm}, m_\nu\}$, $\{\Omega_{\rm ur}, \omega_{\rm ur}, N_{\rm ur}\}$,...

Look at beginning of explanatory.ini!!!

```
class$ more explanatory.ini
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3. Perturbation equations and notations taken literally from well-known Ma & Bertschinger (`astro-ph/9506072`) paper ...

... rather than specific notations of one given group, or mixed notations from various origins.

For non-flat universes we found and published the simplest possible generalisation of Ma & Bertschinger notations, (`arXiv:1305.3261`).

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7. No global variables

All variables passed as arguments of functions. Important for readability and parallelisation.

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8. Clear modular structure

Dinstinct modules with separate physical tasks. No duplicate equations.

```
 1. input.c
 2. background.c
 3. thermodynamics.c
 4. perturbations.c
 5. primordial.c
 6. nonlinear.c
 7. transfer.c
 8. spectra.c
 9. lensing.c
10. output.c
```

E.g.: Friedmann equation appears in one single place. Same for linearised Einstein equations. Ideal for implementing modified gravity theories.

Search `Friedmann` in source/background.c

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- adding new physics does not slow down the code or compromise its readability.
- incentive to add lots of new things even if rarely used, with no drawback.
- with a search, one can localise all the parts of the code related to a given ingredient.

Examples:

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if (has_fld == TRUE) {...}
if (has_cmb_lensing == TRUE) {...}
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11. Adding new ingredient...

... can be done by searching for occurrence of another similar ingredient, copy/pasting, and adapting the new lines.

Example: if you want to add a new Dark Energy component, you may search for '_fld', duplicate all corresponding lines, change '_fld' into e.g. '_myde', and adapt the physical equations.

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12. Error management

In principle, public CLASS should never crash. In case of problem, it returns an error message, with a well-documented error (line, function, what caused the crash, how to avoid it). Most of this message is generated automatically by the code.

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Old versions can always be downloaded. In most cases, new versions feature new ingredients and avoid (whenever possible) to modify or erase the old ones. Try to develop in such way that modifications to an old version can still be pasted in a new version (as much as possible).

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14. Git repository and GitHub website.

The code can be downloaded as a `.tar.gz`, or as a git repository. Then, user can develop his own modification with the advantage of git (branching, memory of changes...); or merge his changes with a newer version almost automatically; or submit his modifications to the CLASS team in view of an easy merging with the public version.