The GyroKineticDataBase (GKDB) project: a community tool for code benchmarks and building fast turbulent transport models

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EUROfusion Enabling Research support

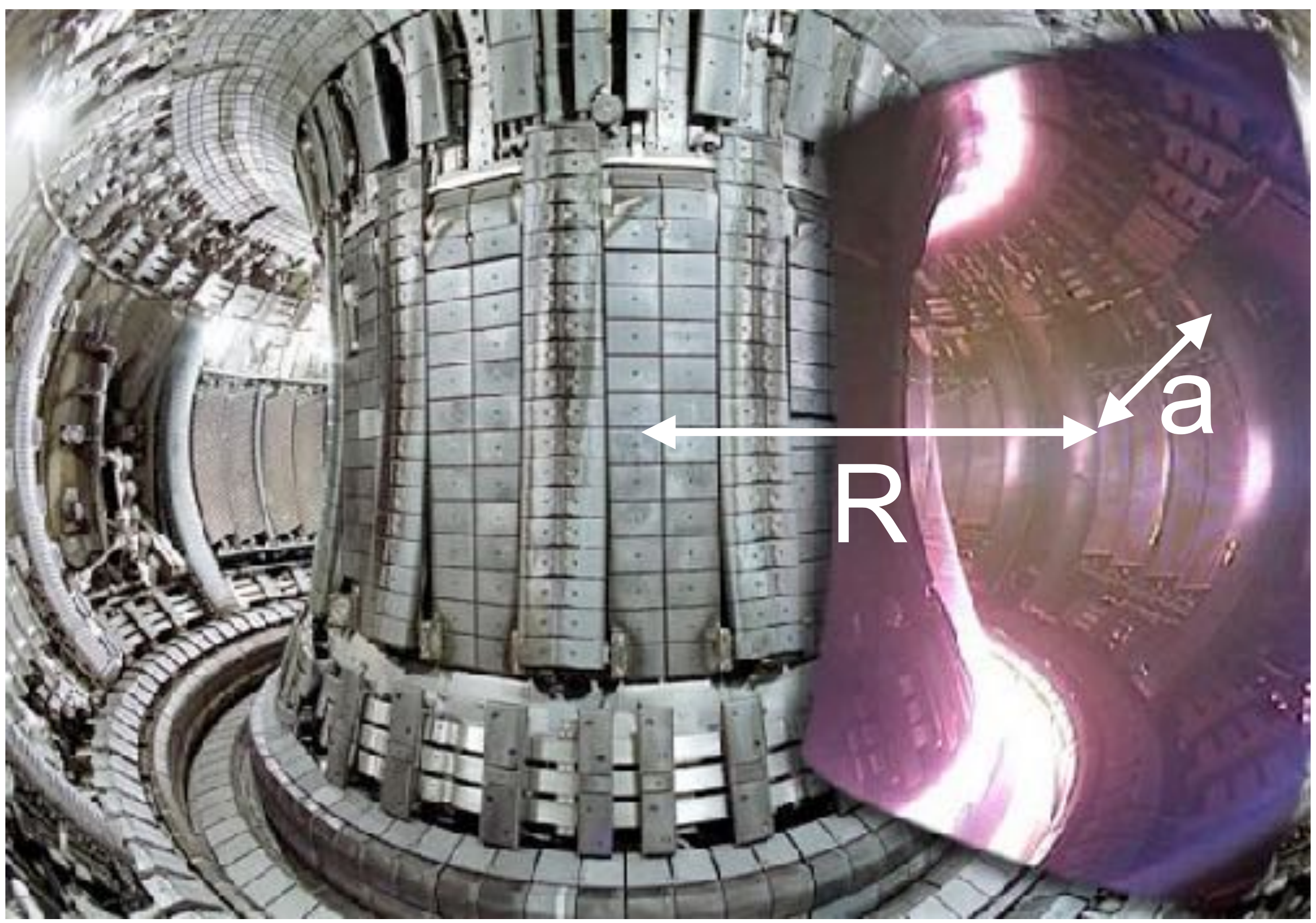
Context

Magnetic fusion research

Aim: energy production from fusion reactions (D+T→He+n) in magnetically confined plasmas with auxiliary heating

Difficulty: minimize transport and radiation losses

Tokamak: device with the best performance (so far)



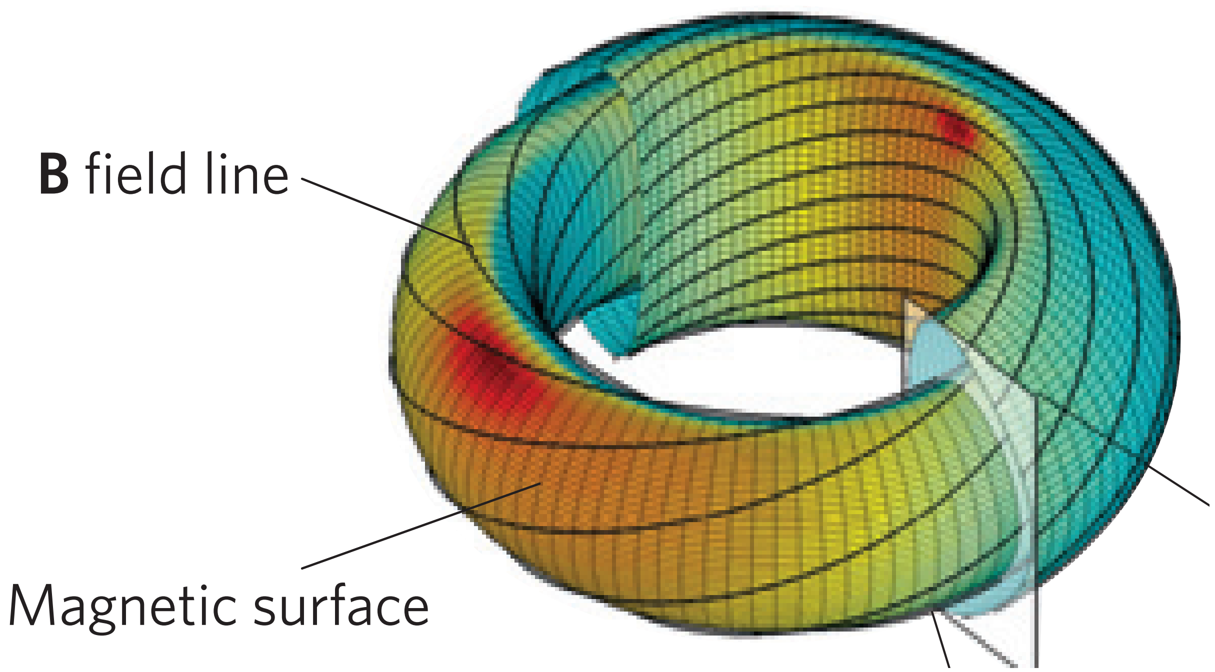
Joint European Torus (JET)

Tokamak

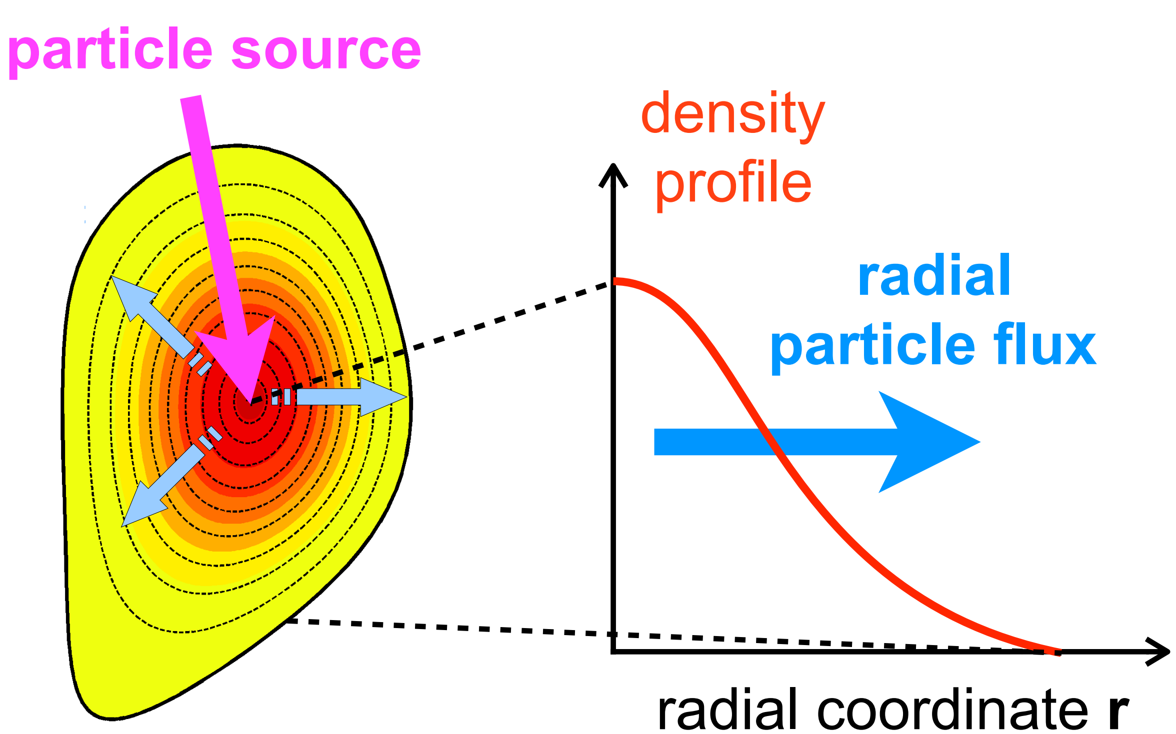
JET parameters

Torus	$R = 3\,\mathrm{m} \quad a = 1.25\,\mathrm{m}$
Magnetised	$B_T < 3.4\,\mathrm{T}$
	$I_p < 4\,\mathrm{MA}$
Injected power	$P_{\mathrm{inj}} < 38\,\mathrm{MW}$
Hot	$T = 1 - 20\,\mathrm{keV}$
Thin	$n = 1 - 10 \times 10^{19}\,\mathrm{m}^{-3}$

The issue of transport in tokamaks



- Nested magnetic flux surfaces
- Radial transport << parallel transport
- But radial transport is still finite...

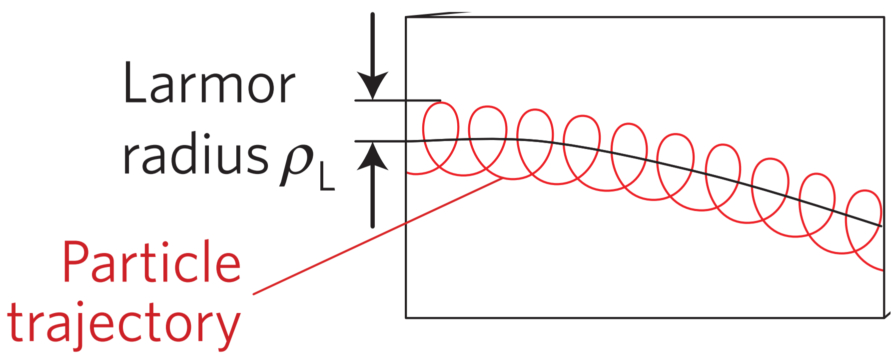


- Radial transport
  → link between sources and profiles
- Lower transport
  → better confinement
- What drives transport?
- How to predict and control transport?

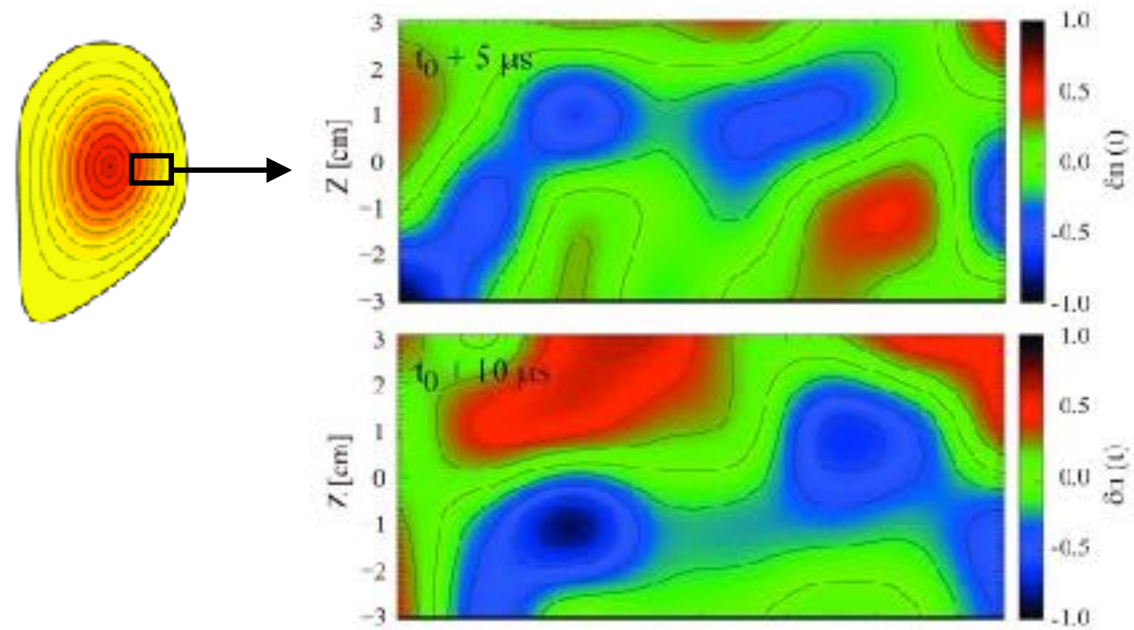
The gyrokinetic description of turbulent transport

- Kinetic description desirable (wave/particles interaction)
- 6D + fast and short scales → very costly!!
- Exploit scale separation between gyro-motion and plasma fluctuations

Gyro-motion



Density fluctuations



Larmor radius	Cyclotron frequency
$\rho_e = 0.02 - 0.1\,\mathrm{mm}$	$f_{c,e} = 10^9\ \mathrm{Hz}$
$\rho_i = 1 - 6\,\mathrm{mm}$	$f_{c,i} = 10^7\ \mathrm{Hz}$

$$L_\perp \sim 5 - 20\rho_i$$
$$f \sim 10^4 - 10^5\ \mathrm{Hz}$$

- **Drop the gyro-phase: 6D → 5D**
- **Gyrokinetic Vlasov-Maxwell system**

Model hierarchy

- Good but numerically too expensive, simplifying further:
  - Frozen magnetic equilibrium $\partial \mathbf{B}_0/\partial t = 0$ ~10^7-10^8 CPU hours
    Global full-f codes (e.g. GYSELA, GT5D, ORB5)
  - Frozen background (δf approximation) $\partial F_0/\partial t = 0$ with $F = F_0 + \delta f$
    Global delta-f codes (e.g. GYRO, GENE, GKW)
  - Local approximation $F_0(r) = F_0(r_0)$ and $\nabla F_0(r) = \nabla F_0(r_0)$
    Local delta-f codes (e.g. GYRO, GENE, GKW) ~10^4-10^5 CPU hours
  - Quasi-linear approximation
    Local delta-f linear codes ~10^2-10^3 CPU hours
    - Cross-phase assumed to be given by the linear response
    - Saturation amplitude is modelled
  - Quasi-linear + additional simplifications ~0.01 CPU hours
    Gyro-fluid (e.g. TGLF)
    Gyro-kinetic with fluid eigenfunctions (QuaLiKiz)

A gyrokinetic database, what for?

- Wishlist:
  - Store inputs/outputs of linear gyrokinetic runs
  - Possibility to store/access millions of entries (SQL requests)
  - Open access
- Purposes of the database (non exhaustive):
  - Repository for data presented in publications and conferences
  - References for benchmarks
  - Instantaneous linear stability calculations (from fits of the database content)
- Opens the route to ultrafast 1st principle QL transport models
  - Proof of principle demonstrated for a 5D database using neural network fits *[Citrin NF2015]*
  - Applications: real-time control, fast integrated modeling, uncertainty propagation, etc..

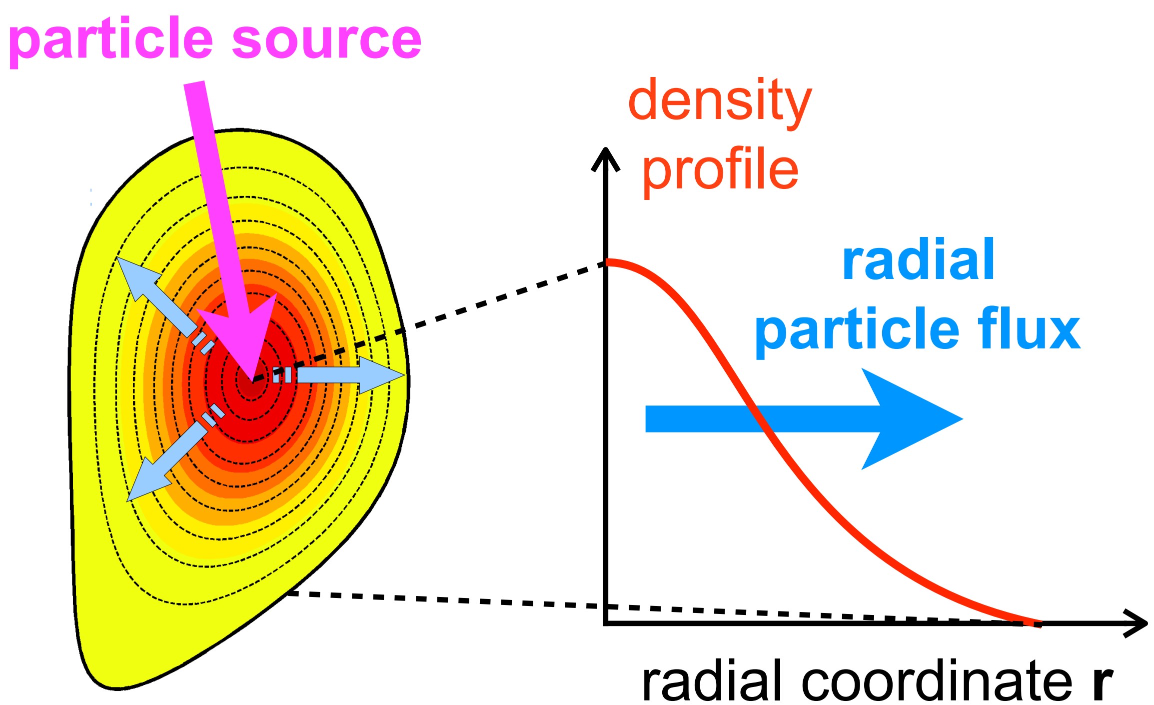
The GKDB project

- **Project** hosted on Gitlab: https://gitlab.com/gkdb/gkdb
  - Source for the SQL/Python interface
  - Routines (matlab, python,…) to convert data from various GK codes to the GKDB format (unified normalisations)
  - Documentation (wiki): GKDB format, coupling to GK codes, how to download/upload data, etc…

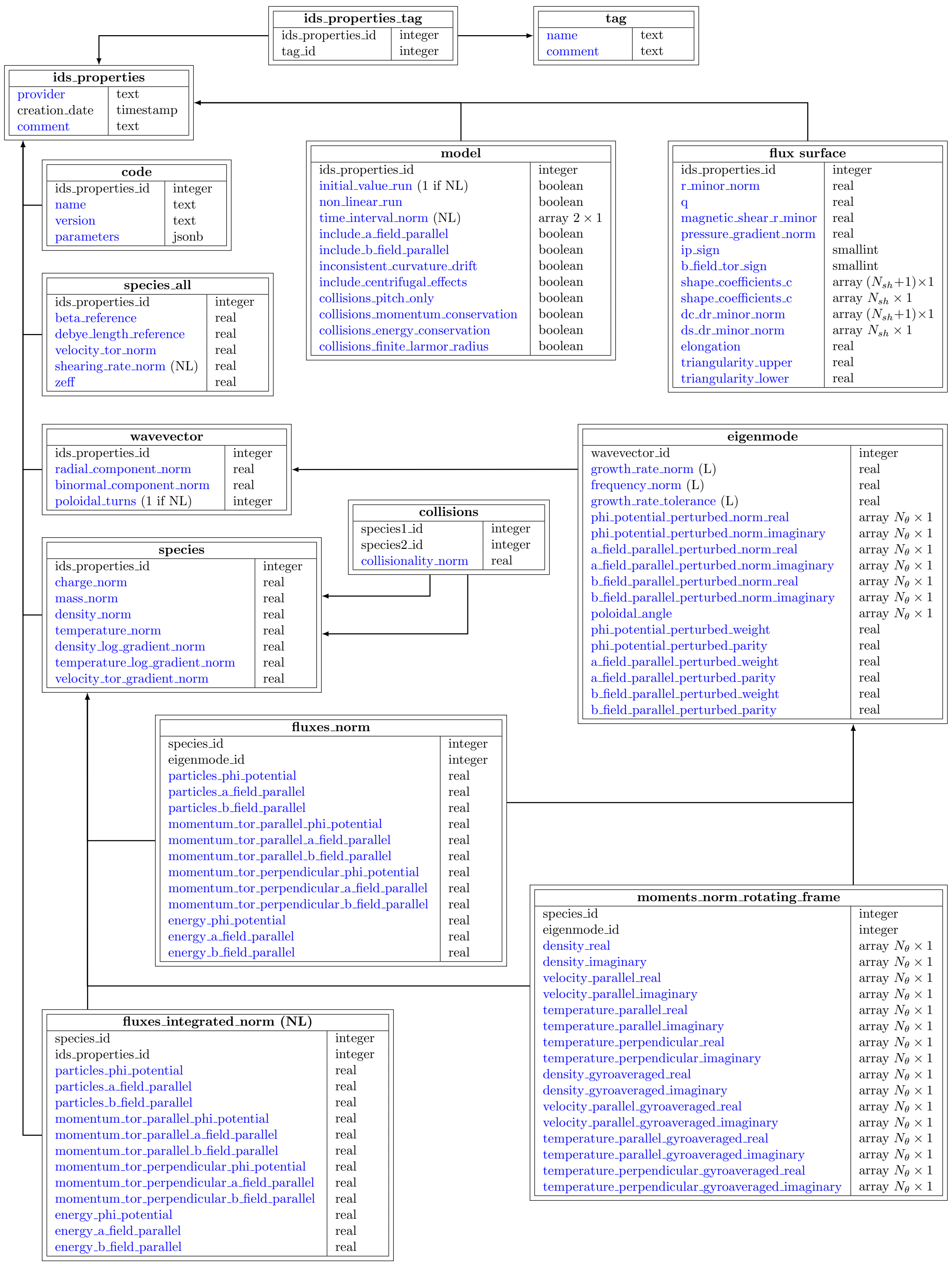
- **Database** on gkdb.org (hosted by DigitalOcean at the moment)
- User access managed by LDAP
  - Account created on request
  - Read access for everybody
  - Write access once validated reference cases are provided

Database content

- Flux-tube δf simulations (linear and non-linear runs)
  - Inputs
    - Mag. equilibrium
    - Species
    - Wavevectors
    - Model (collisions, EM effects,…)
  - Outputs
    - Eigenvalues
    - Eigenfunctions
    - Fluxes
  - Metadata
    - Code name and version
    - Code specific parameters
    - Date
    - Contributor
    - Comments

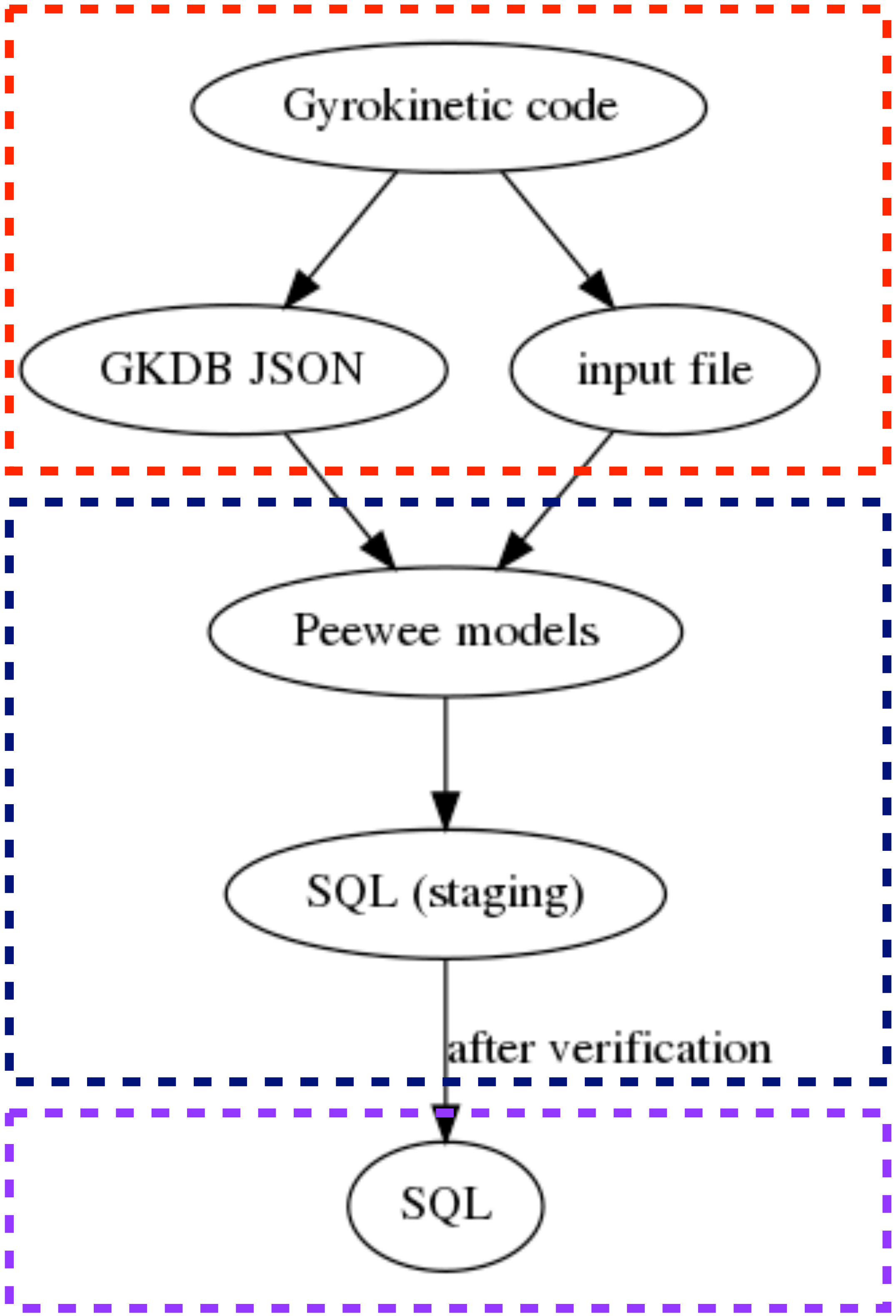


Database structure



- Relational database (SQL)
- Possibility to “tag” entries

Uploading entries to the database



- User to provide:
  - a JSON file with a GKDB entry
  - including code specific inputs (grids, dissipation, etc…)
- Python scripts:
  - Convert the JSON file to SQL
  - Compute derived quantities for queries
  - Check mandatory fields, ranges, dimensions (implemented)
  - Check entry sanity (numerical stability, quasineutrality...)
  - Database server

Querying the database

- GKDB web browser: http://database.gkdb.org
- Direct SQL queries can be performed from Python, Matlab and IDL
- Possible to run Python (and maybe Matlab/Octave) directly on the GKDB server: http://jupyter.gkdb.org
- Small subsets could also be exported via zipped JSON files

Present status and next steps

- Database online at gkdb.org,
- Project repository at https://gitlab.com/gkdb/gkdb
- Database format and conventions documented
- GKDB presently interfaced with gyrokinetic code GKW

- Near future actions:
  - Interface with gyrokinetic code GENE (in progress), and hopefully other codes
  - Use the reference cases to validate the interface with GKDB
  - Finalize Python scripts to check the entries integrity
  - Start populating the database and test the pipeline

Open issues

- **Licensing**
  - Open Database License from Open Data Commons?
- **Storage**
  - Where? Maintenance?
  - Not an issue at present, but needs to be anticipated
  - Database scale:
    - >10 millions of entries
    - 0.1 - 10 Mo per entry → database: ~10To
    - <100 users