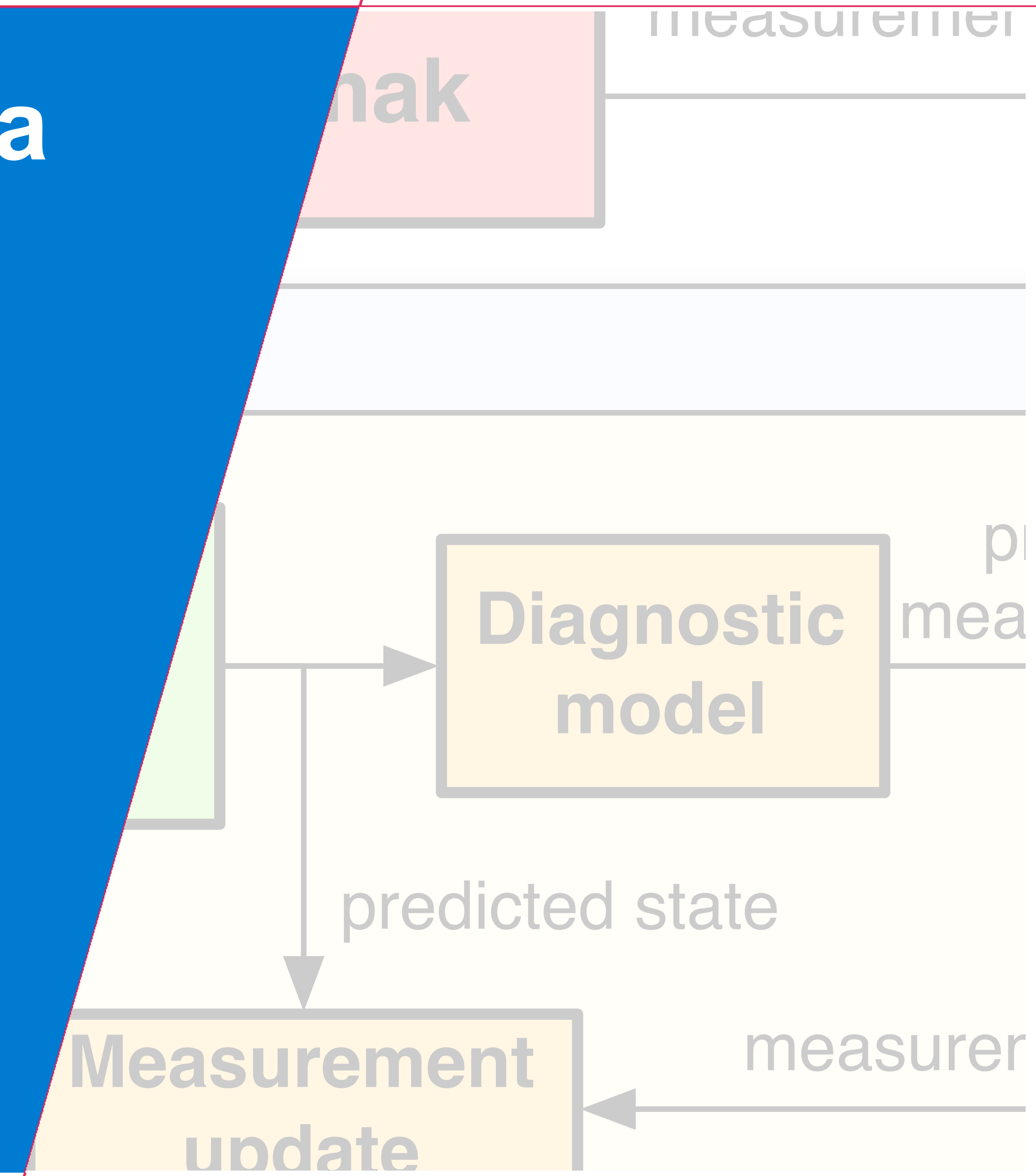
RAPTOR capabilities for plasma simulation and control in ITER



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CRPP

ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

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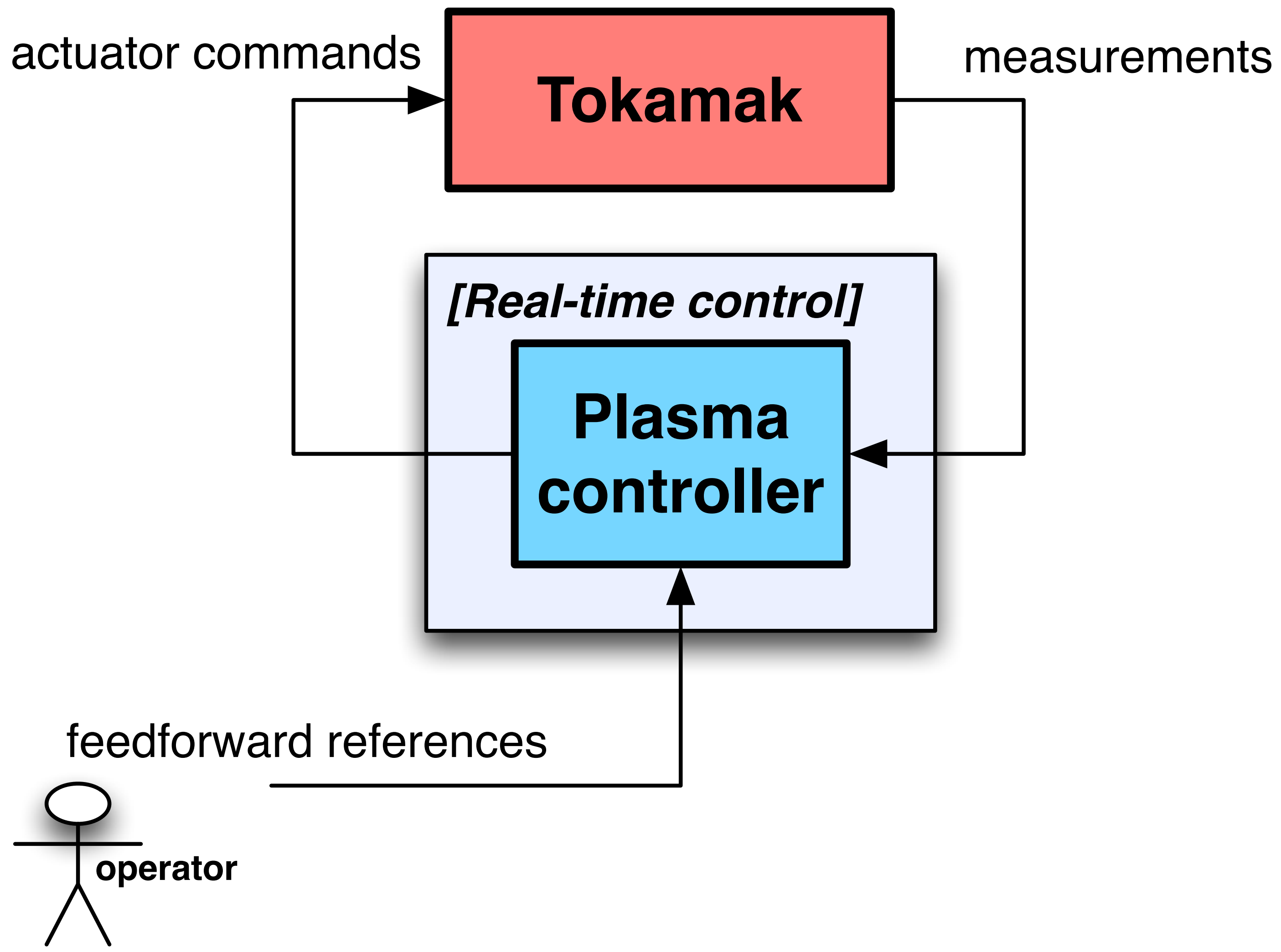
2nd ISM working Session 2013 CEA Cadarache, France

Where innovation starts

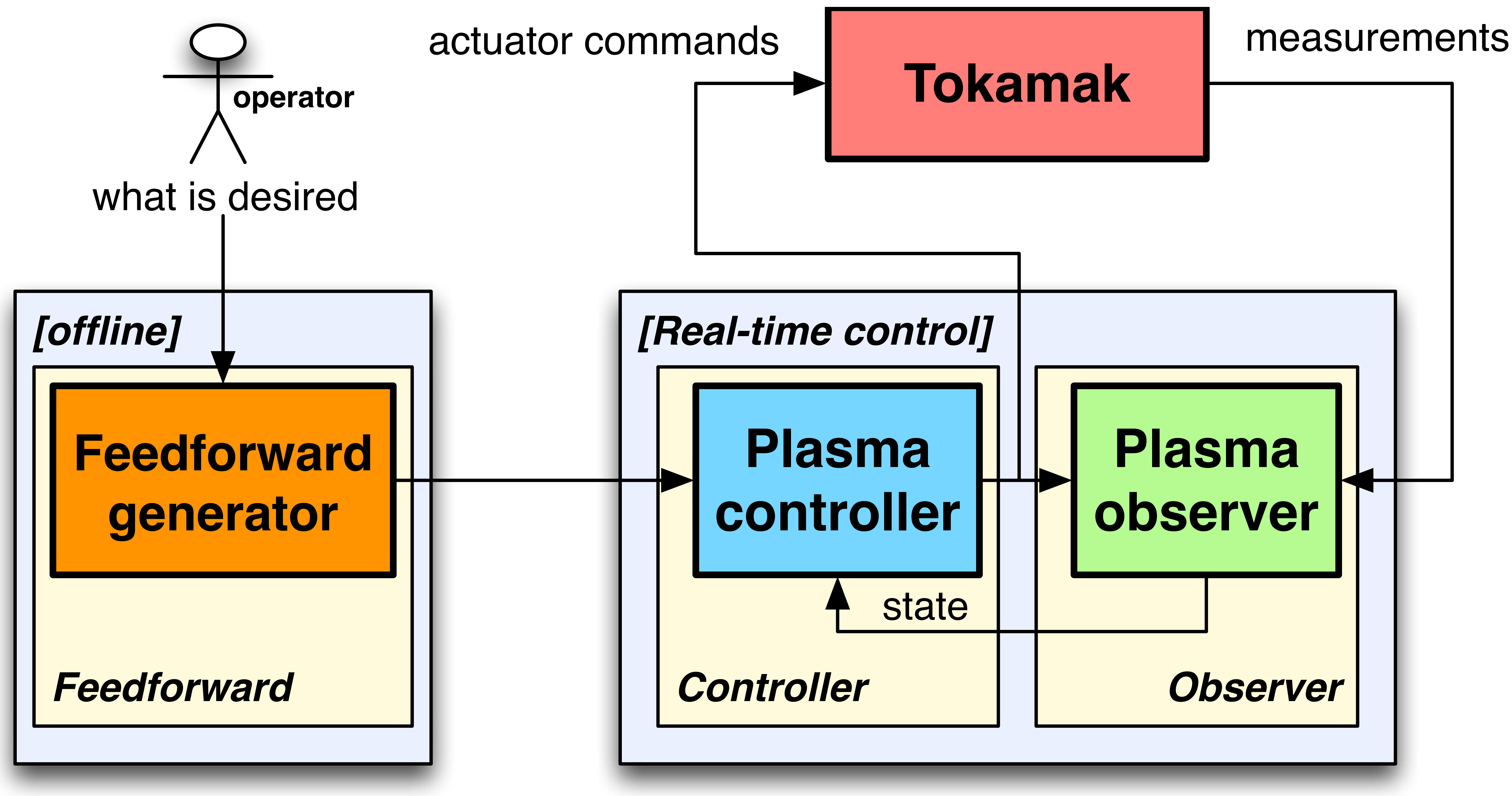
RAPTOR features and status

- RApid Plasma Transport Simulator
- 1D plasma profile evolution
  - Coupled evolution of poloidal flux and T_e
  - Fixed 2D MHD equilibrium
  - Includes key nonlinear physics of profile coupling
  - Simplified source models
  - Ad-hoc transport models, parameters can be automatically tuned to experiment or higher-fidelity simulations
- Control-oriented implementation, very fast and flexible
  - Few milliseconds per time step
  - Returns local linearization for feedback controller design
  - Robust numerics via fully implicit solver
  - Real-time capability demonstrated on TCV and AUG control systems
  - Already faster than real time for ITER. Full discharge simulation in few tens of seconds.

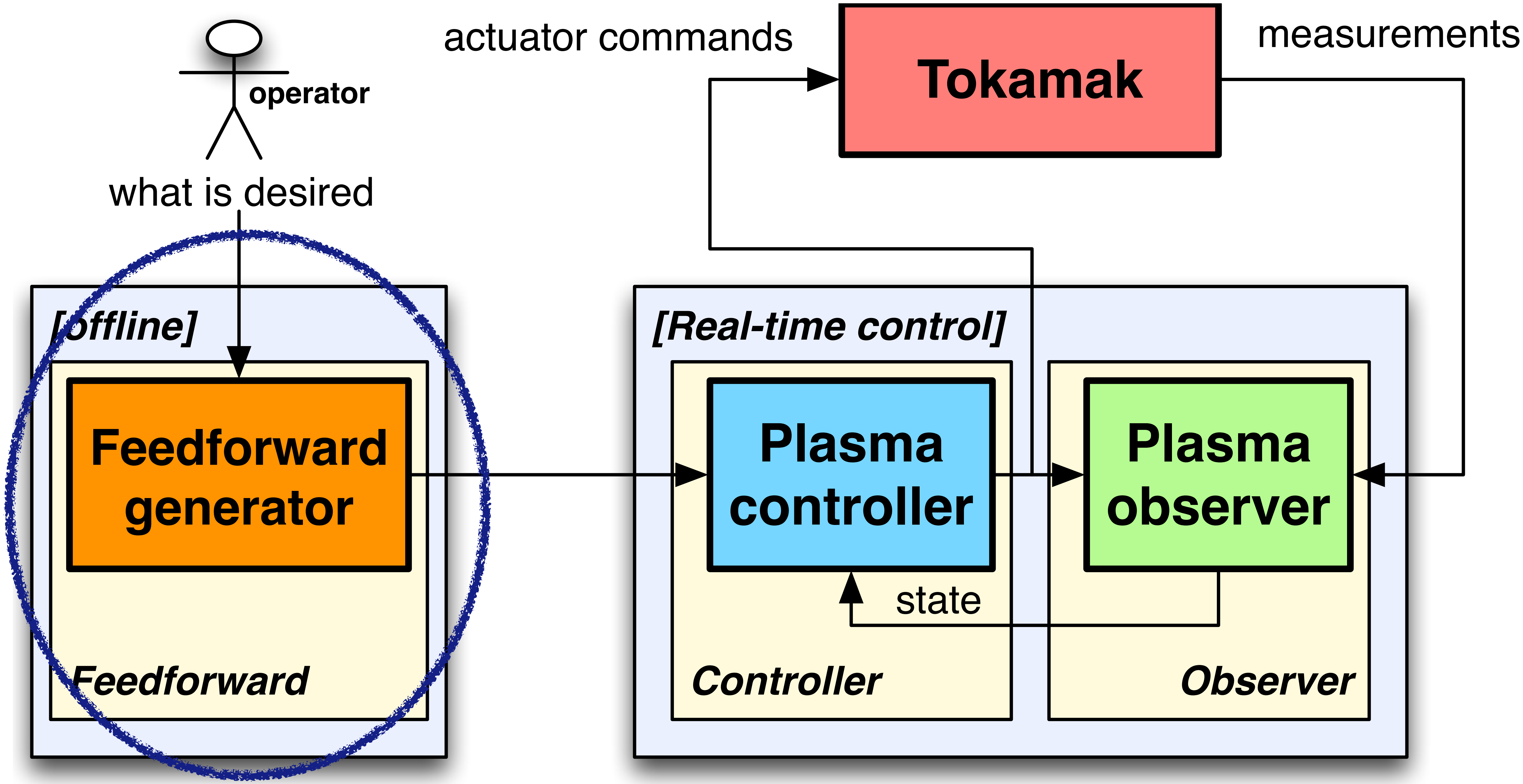
Most control loops as used in tokamaks today



Model-based control: components



Model-based control: components



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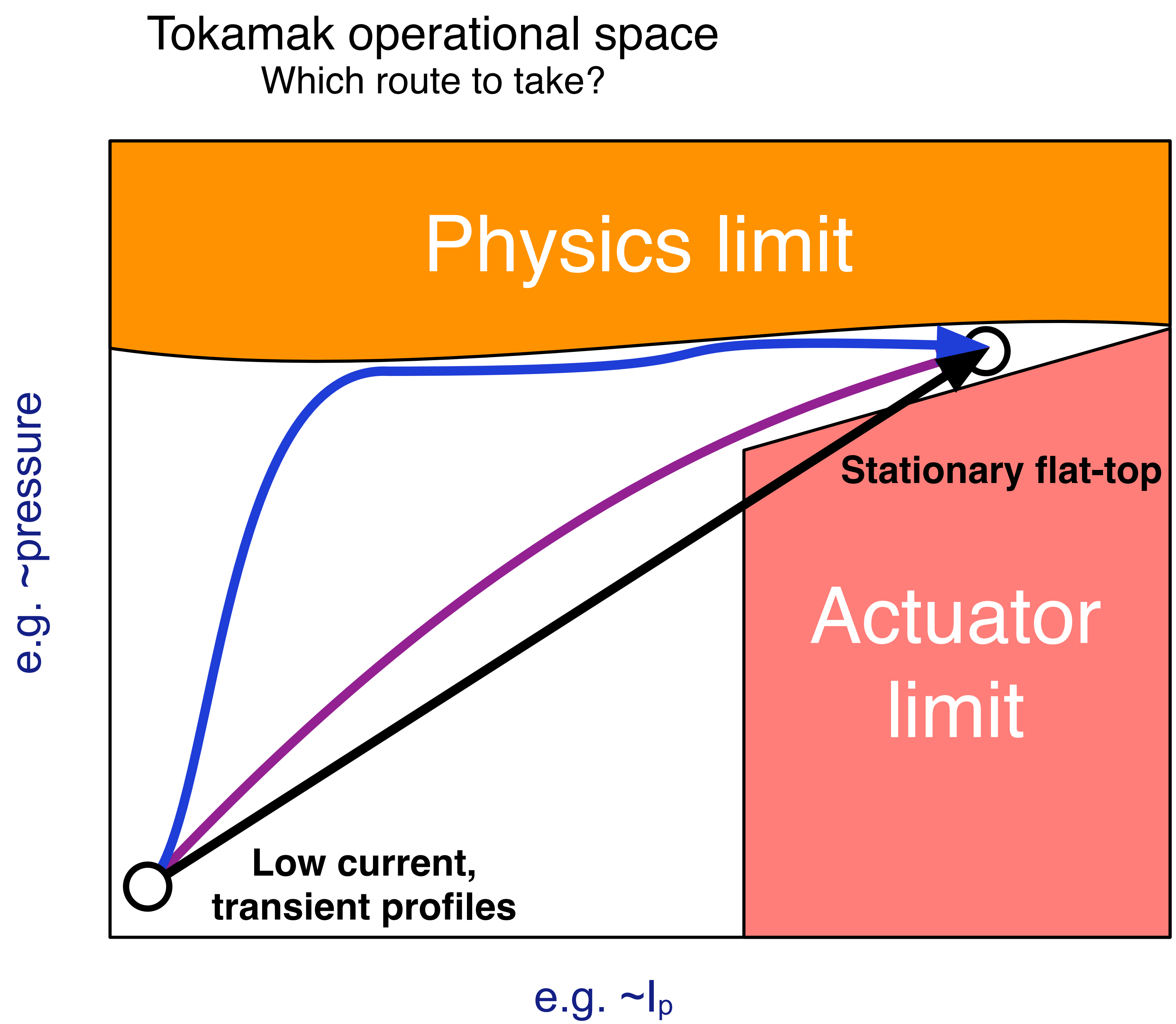
Model-based optimization of feedforward actuator trajectories



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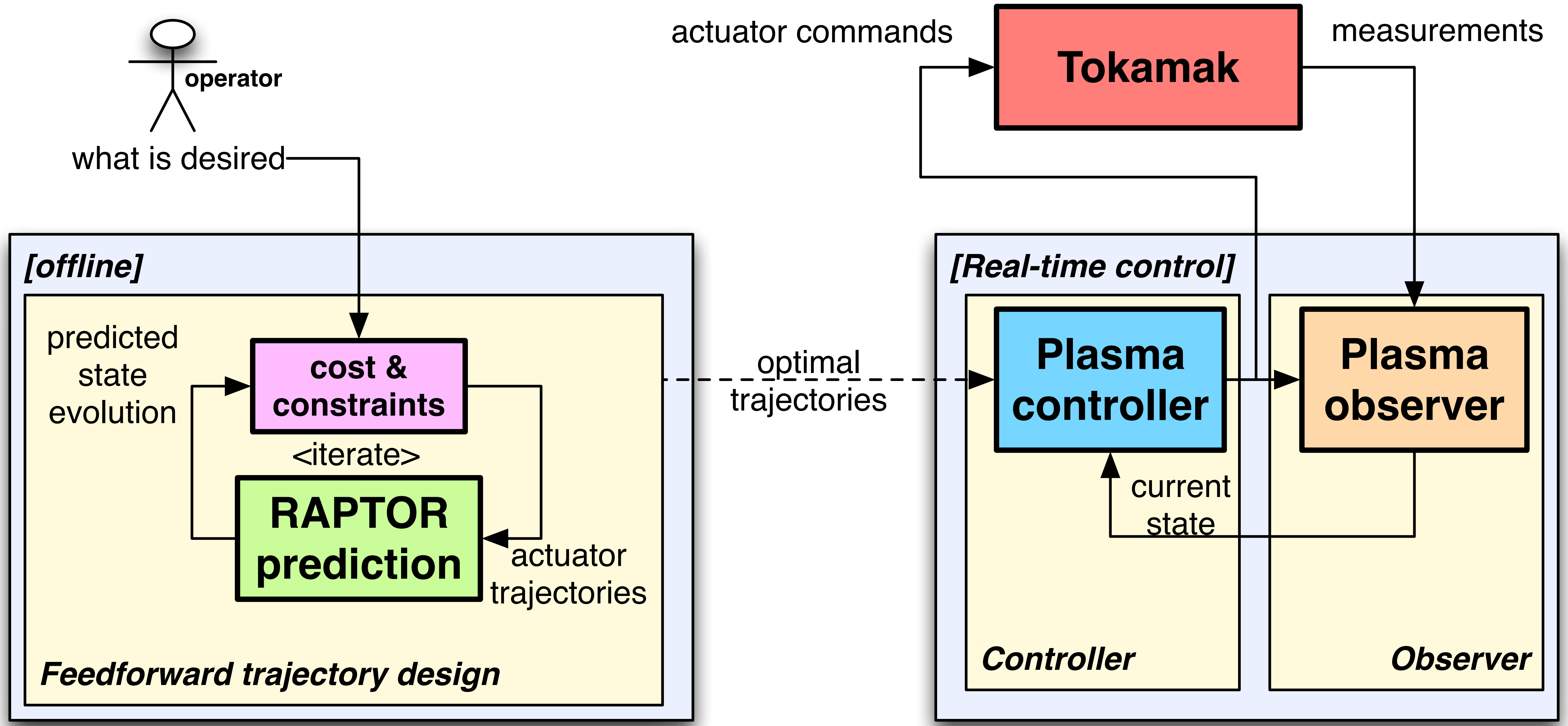
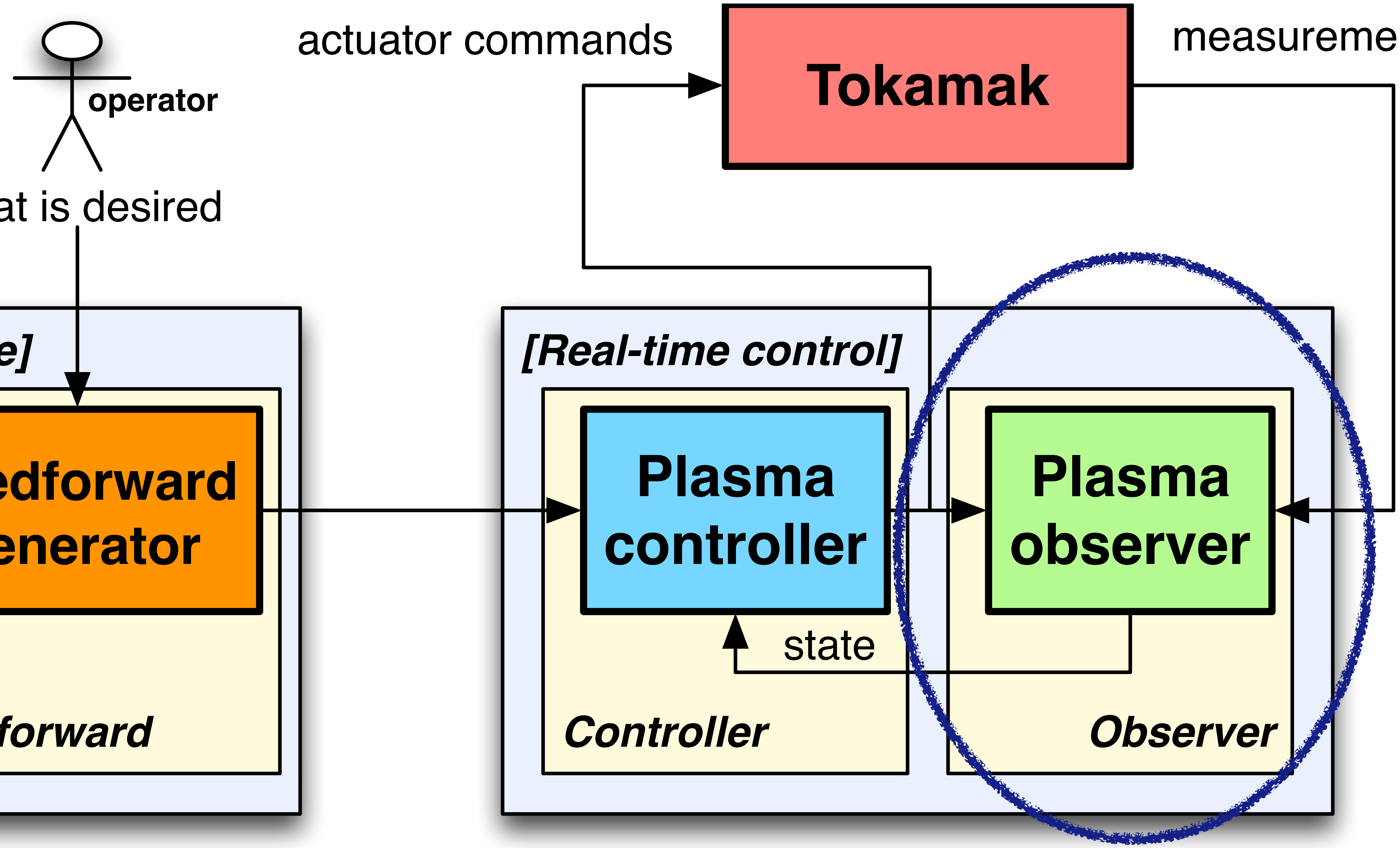
Feedforward trajectory design: iteratively solve optimal control problem





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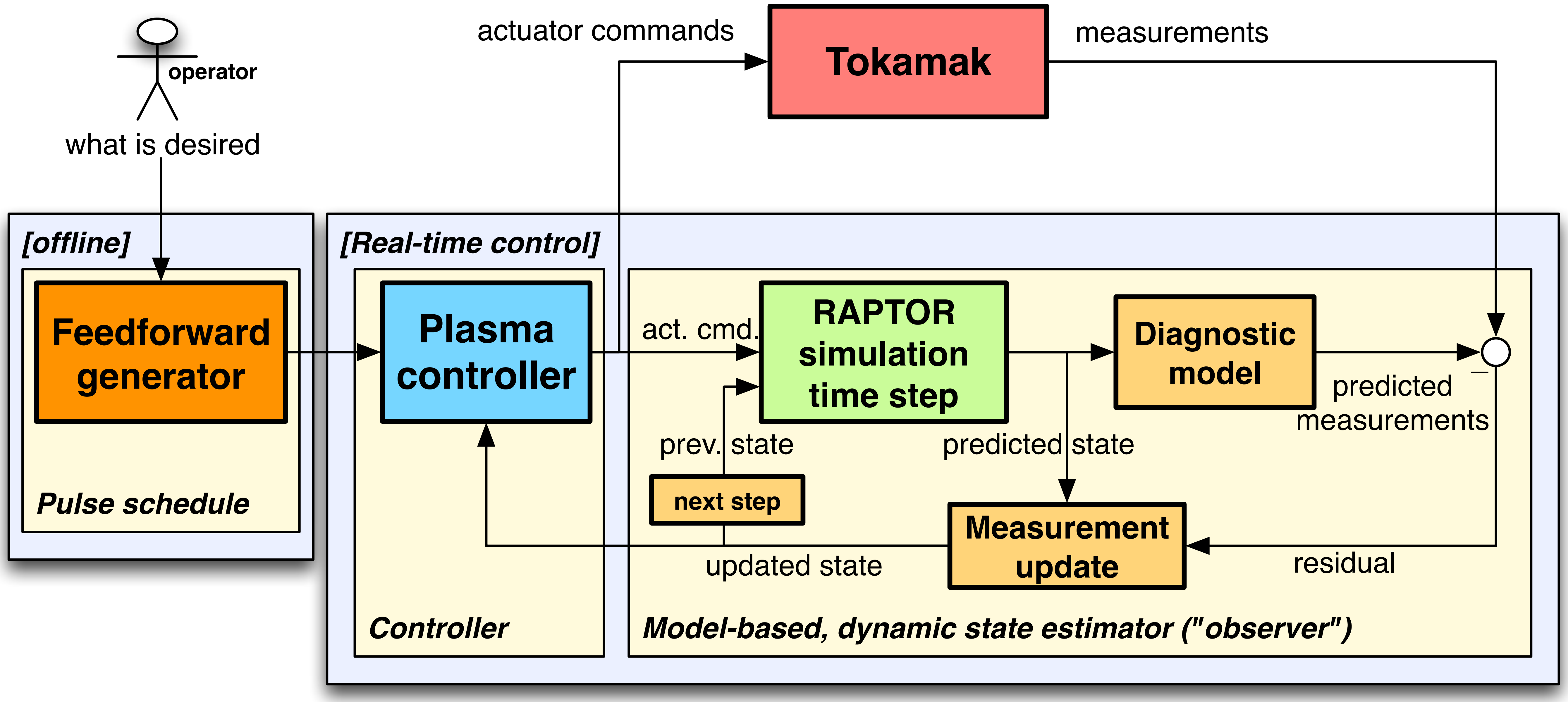
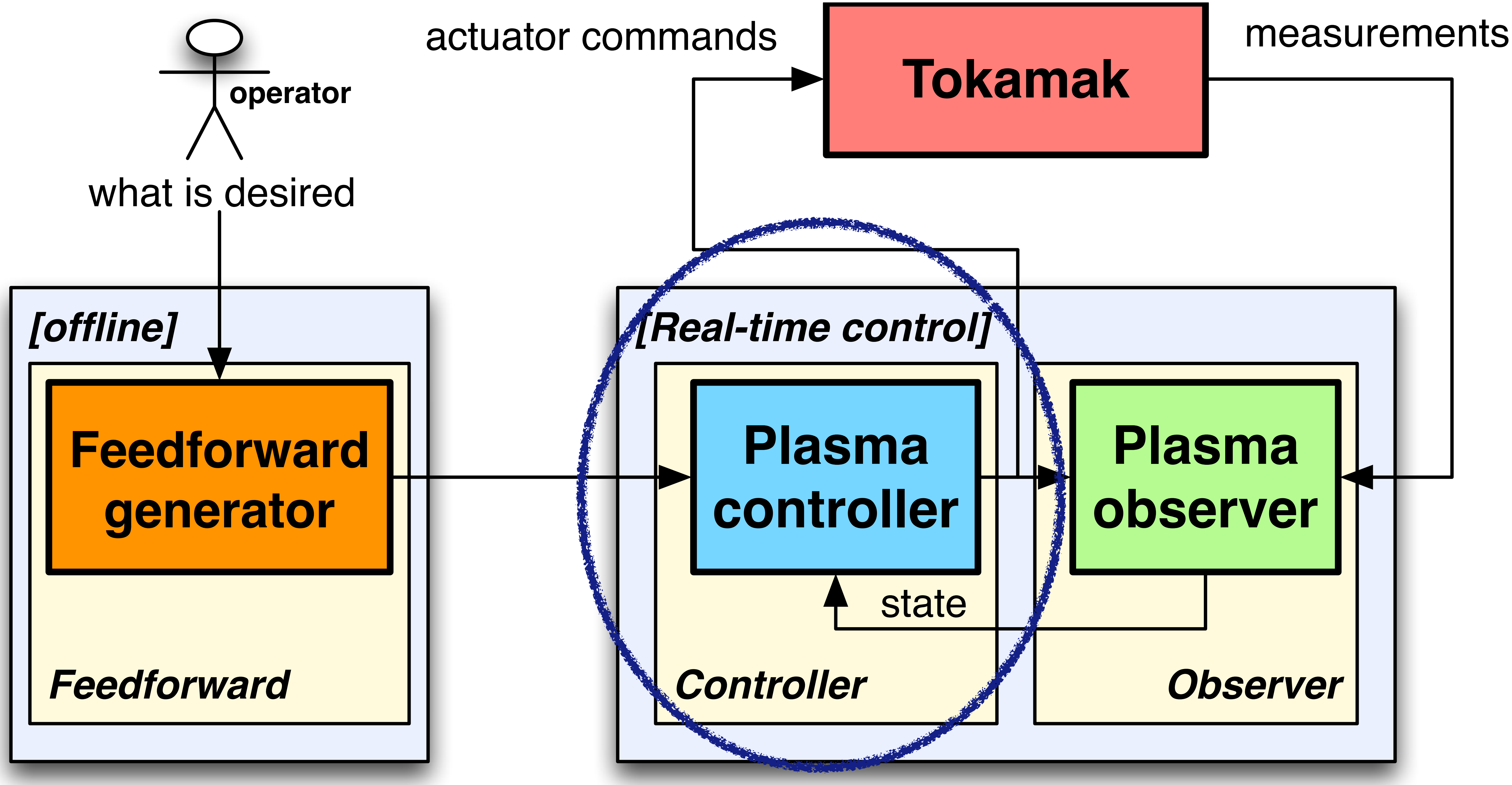
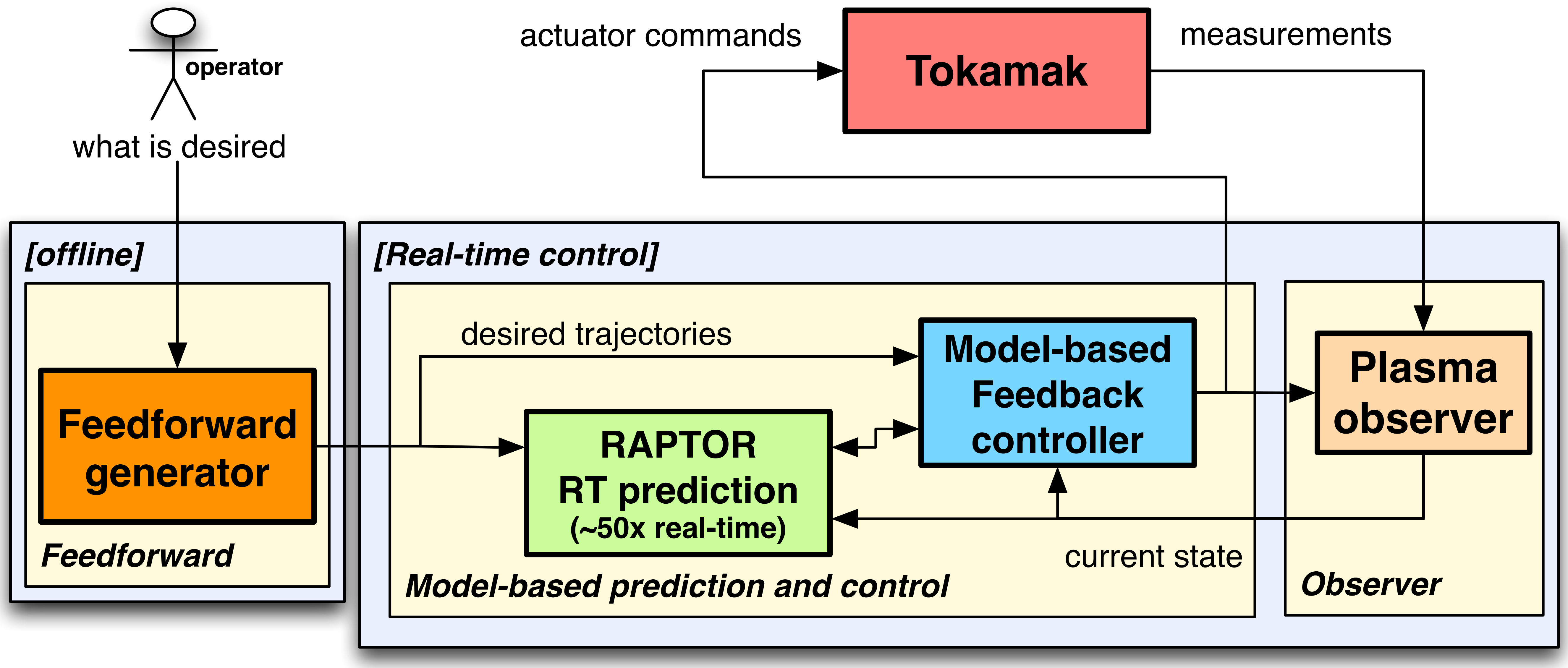
State observer: merging real-time diagnostics and real-time model prediction




actuator commands
Tokamak
measurements
operator
what is desired
[offline]
Feedforward generator
Feedforward
[Real-time control]
Plasma controller
Plasma observer
state
Controller
Observer

Faster-than-real-time prediction and model-based feedback control



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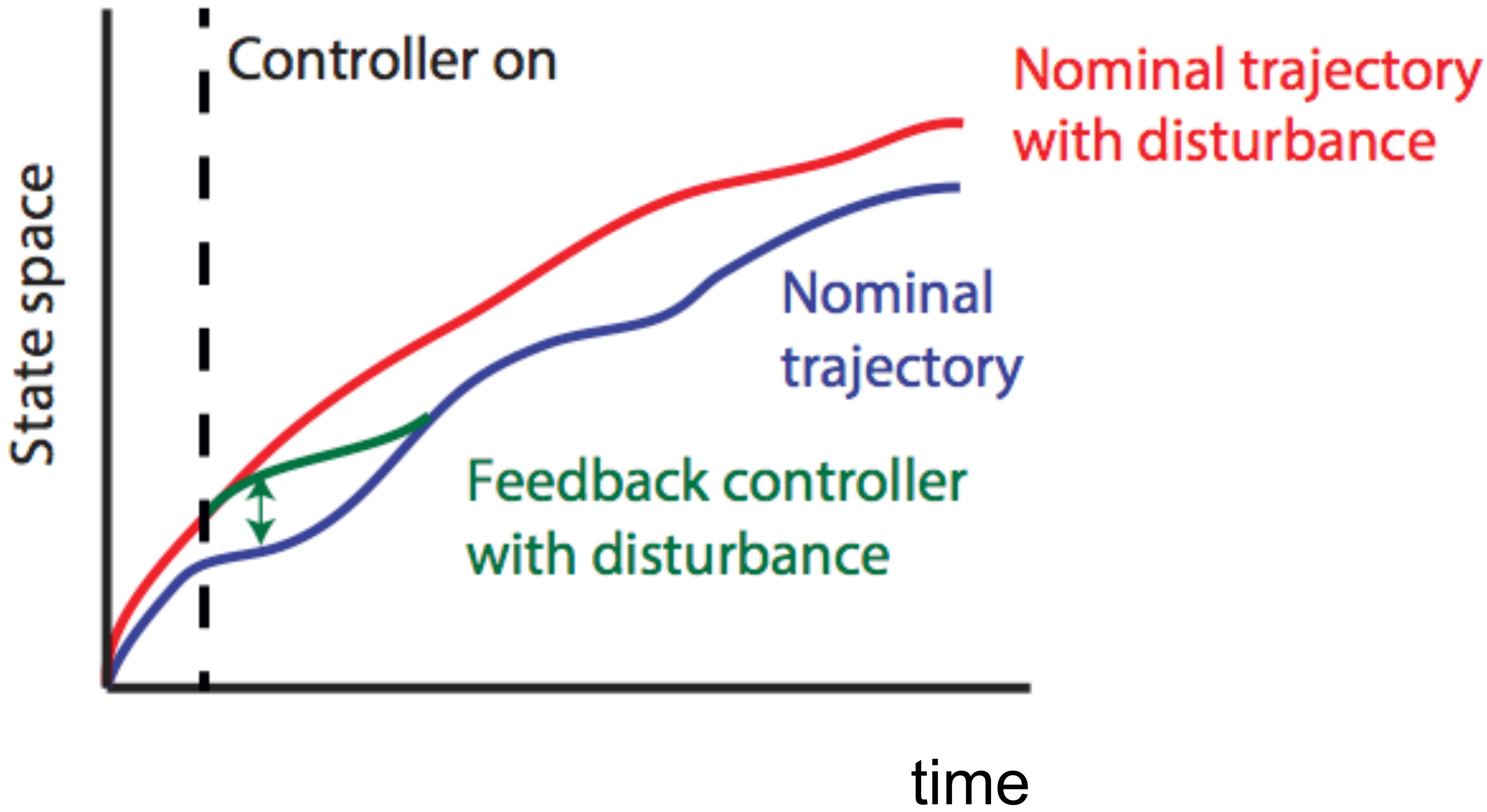
Feedback control around nominal trajectory, knowing expected variation of profile dynamics



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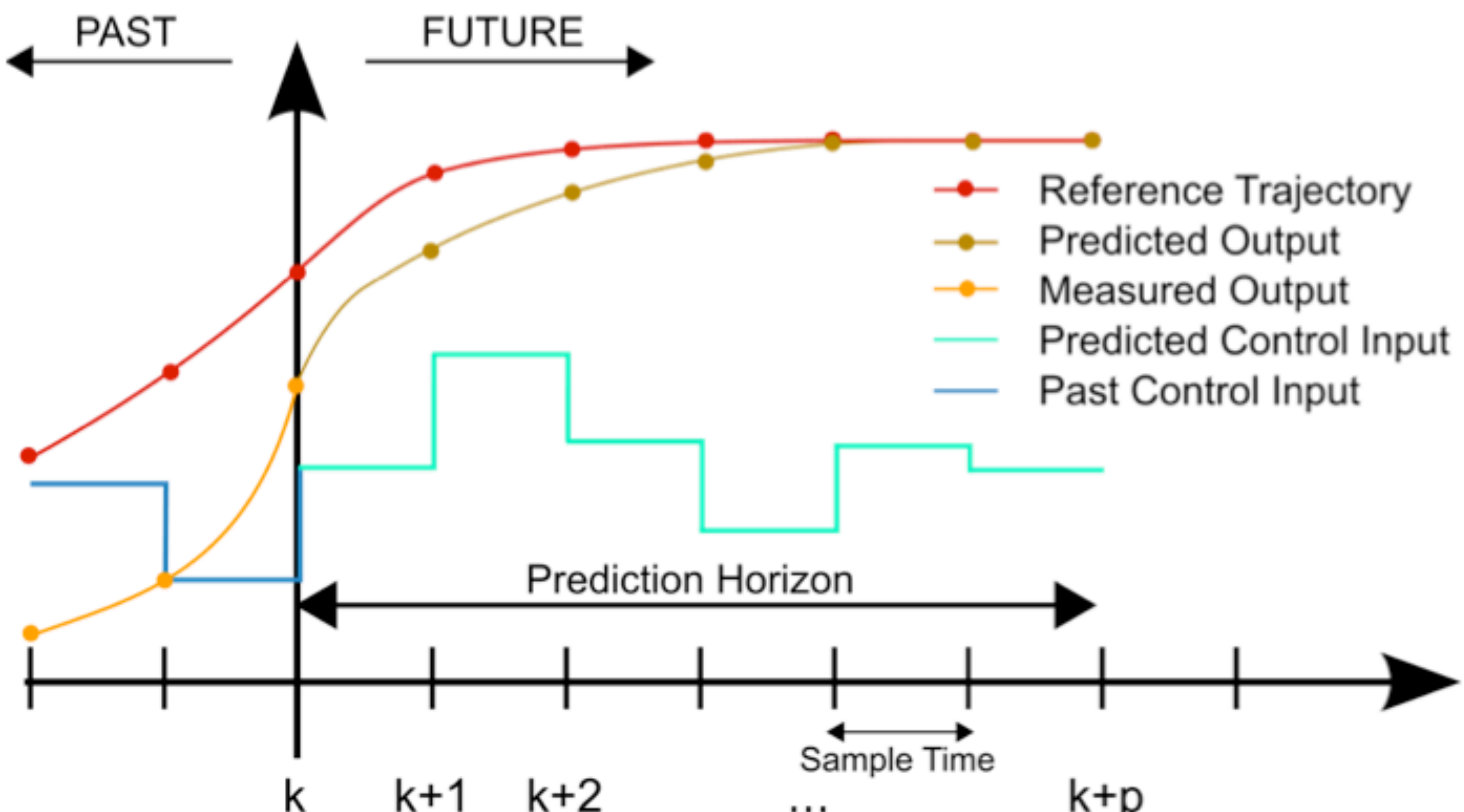
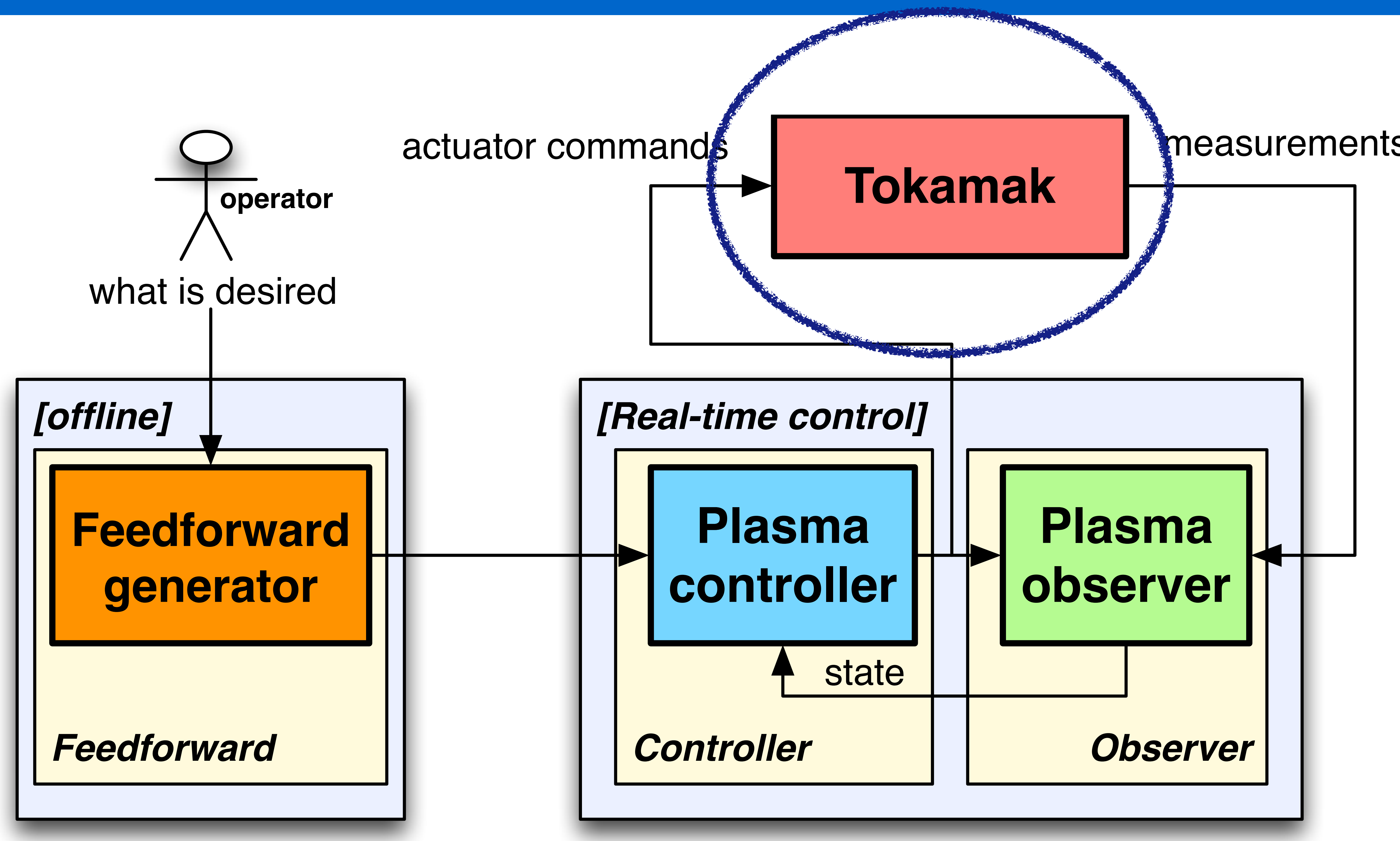
Model predictive control: determine optimal future actuator trajectory to go back to reference

- Naturally include (varying) constraints for state and actuator
- Early warning if constraints can not be met (disruption pred.)




operator
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Plasma controller
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Controller
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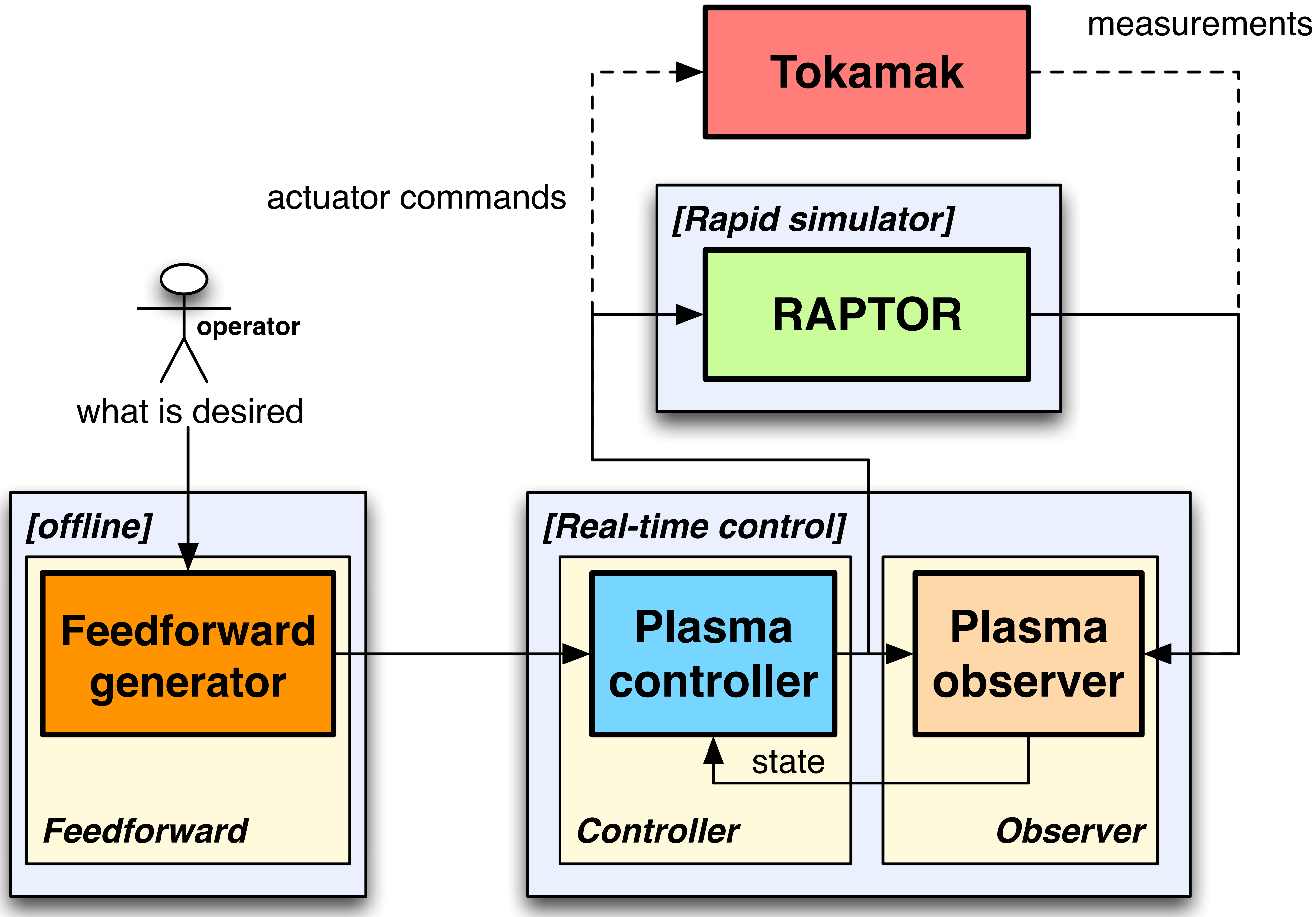
Rapid simulator for PCS and pulse schedule validation



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RAPTOR usage possibilities and present status

Use case	Status
Trajectory optimization	Simulations done for TCV and ITER Validation planned in existing tokamaks
Real-time observer	Pilot demonstration on TCV, t=1ms (flux only) Successfully installed in AUG DCS, t=3ms (flux+T_e)
Real-time prediction	Should achieve 5x RT on AUG DCS 100x RT for ITER time scales should be easy To be used for disruption prevention studies (ITPA-MHD)
Model-based control	Controller simulations for ITER underway Controller design for TCV or AUG planned
Controller testing and validation	Being used for TCV profile controllers design study (CRPP,CEA,Lehigh,TU/e) In use for ITER profile controller design at TU/e