Cosmological Radiative Transfer Code Comparison Project IV
Austin, Dec. 2012

TRAPHIC
TRAnsport of PHotons In Cones

Current TRAPHIC team:

Andreas Pawlik (MPA)
Joop Schaye (Leiden)
Ali Rahmati (Leiden)
Milan Raicevic (Leiden)
Myoungwon Jeon (Austin)

Collaborators:

Volker Bromm (Austin)
Milos Milosavljevic (Austin)
Claudio Dalla Vecchia (MPE)

Outline

- Cosmological Radiative Transfer
- TRAPHIC
- Tests
- Applications
- Summary

Cosmological Ionizing RT

- Large dynamic range
  - Resolve dwarf galaxies with size ~1 kpc in volumes of size ~100 comoving Mpc
- Many ionizing sources
  - tens of thousands to millions
- Accurate knowledge of gas distribution (clumping factor)
  - hydrodynamical simulations including feedback

Andreas Pawlik
(MPA)

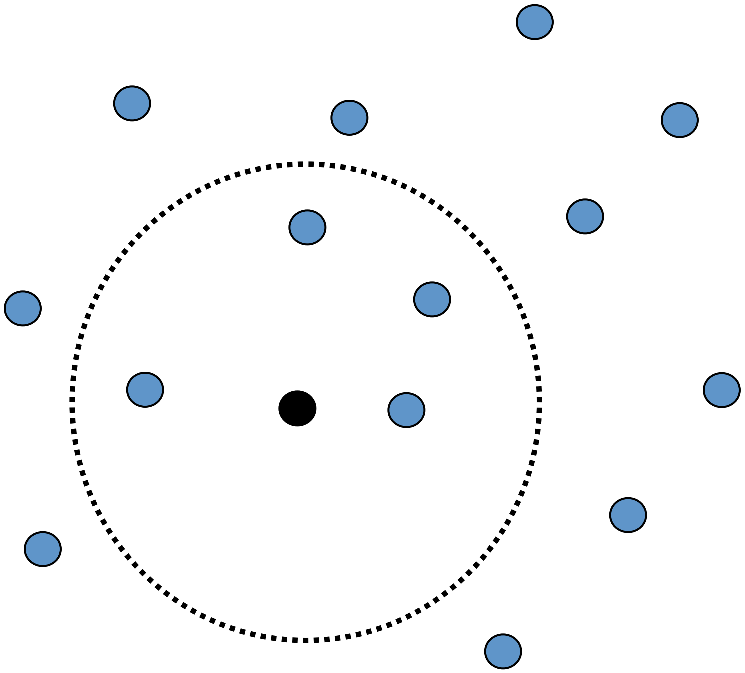
TRAPHIC –
TRAnsport of PHotons In Cones

(AP & J. Schaye 2008, 2010)

- Spatially adaptive transport in SPH
- Computation time independent of the number of ionizing sources
- Hydrodynamically coupled to Gadget

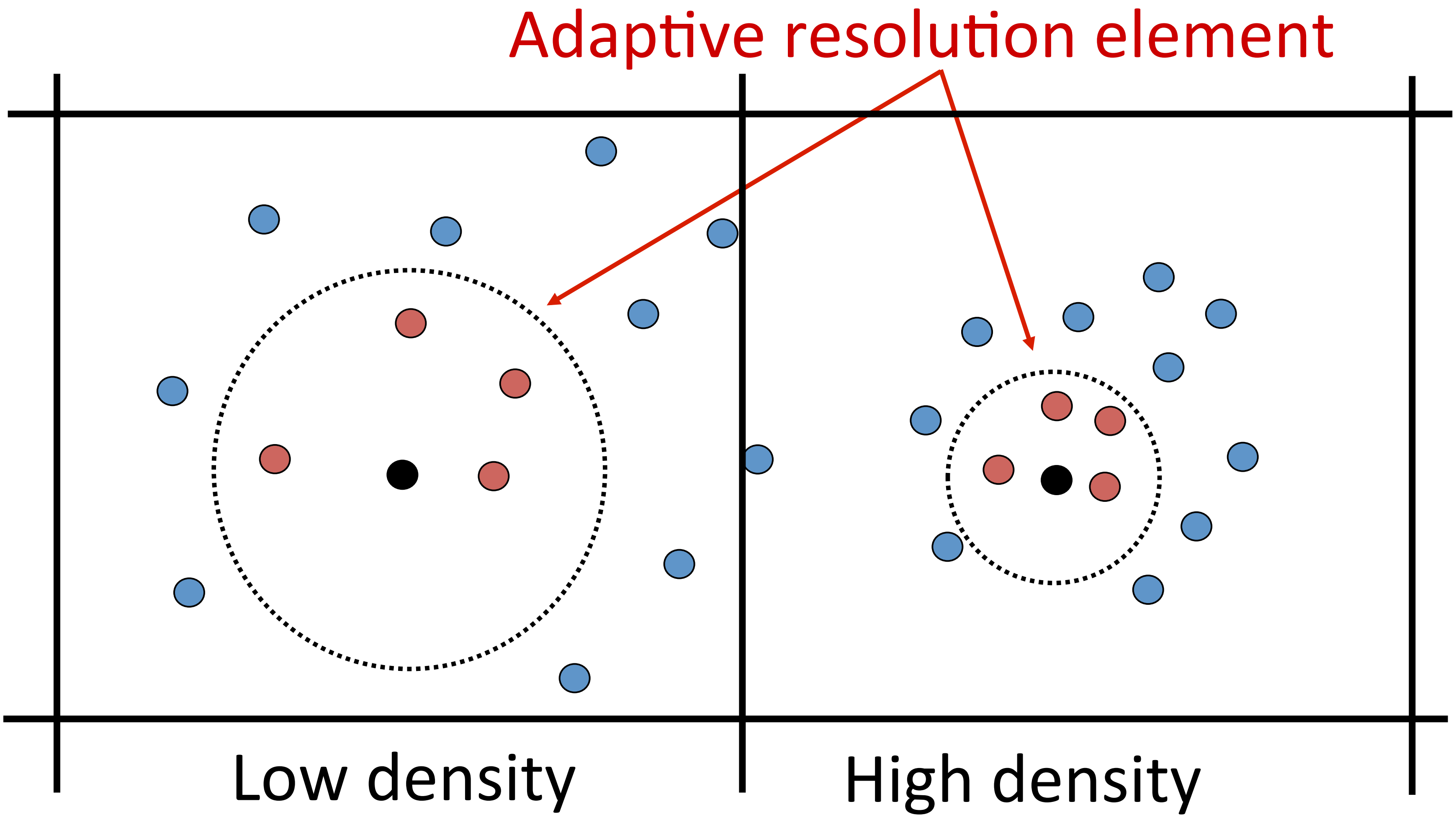
Andreas Pawlik
(MPA)

SPH



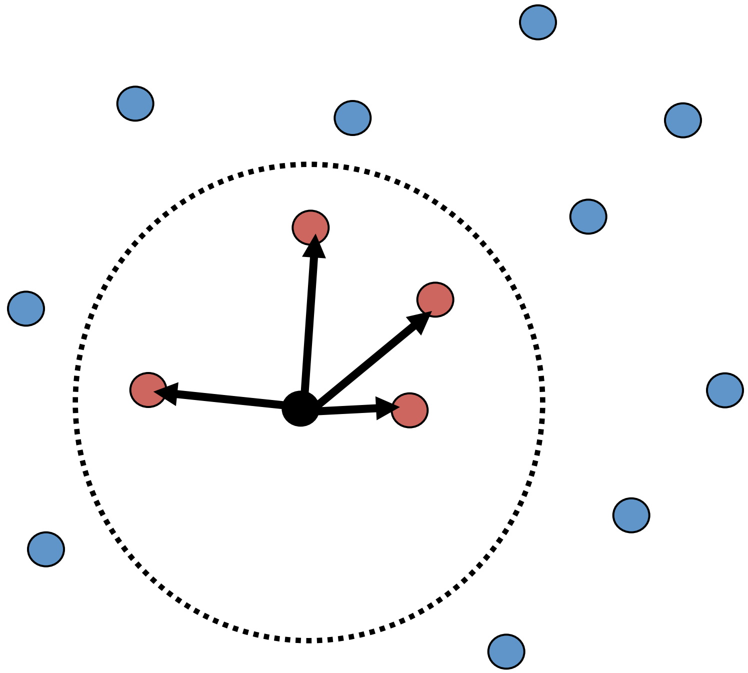
Andreas Pawlik
(MPA)

SPH - Adaptivity



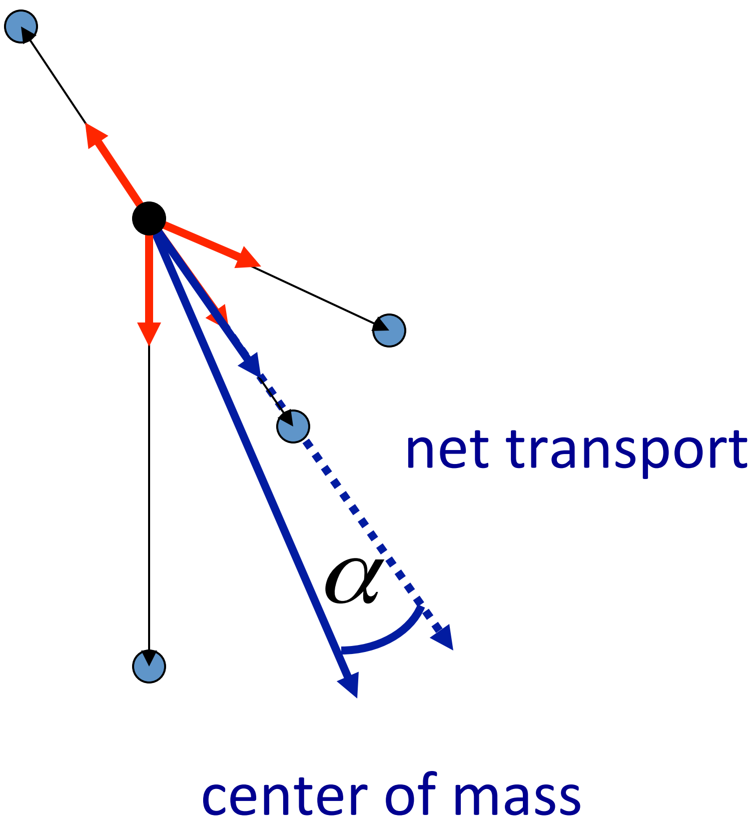
Andreas Pawlik
(MPA)

TRAPHIC in SPH - Adaptivity



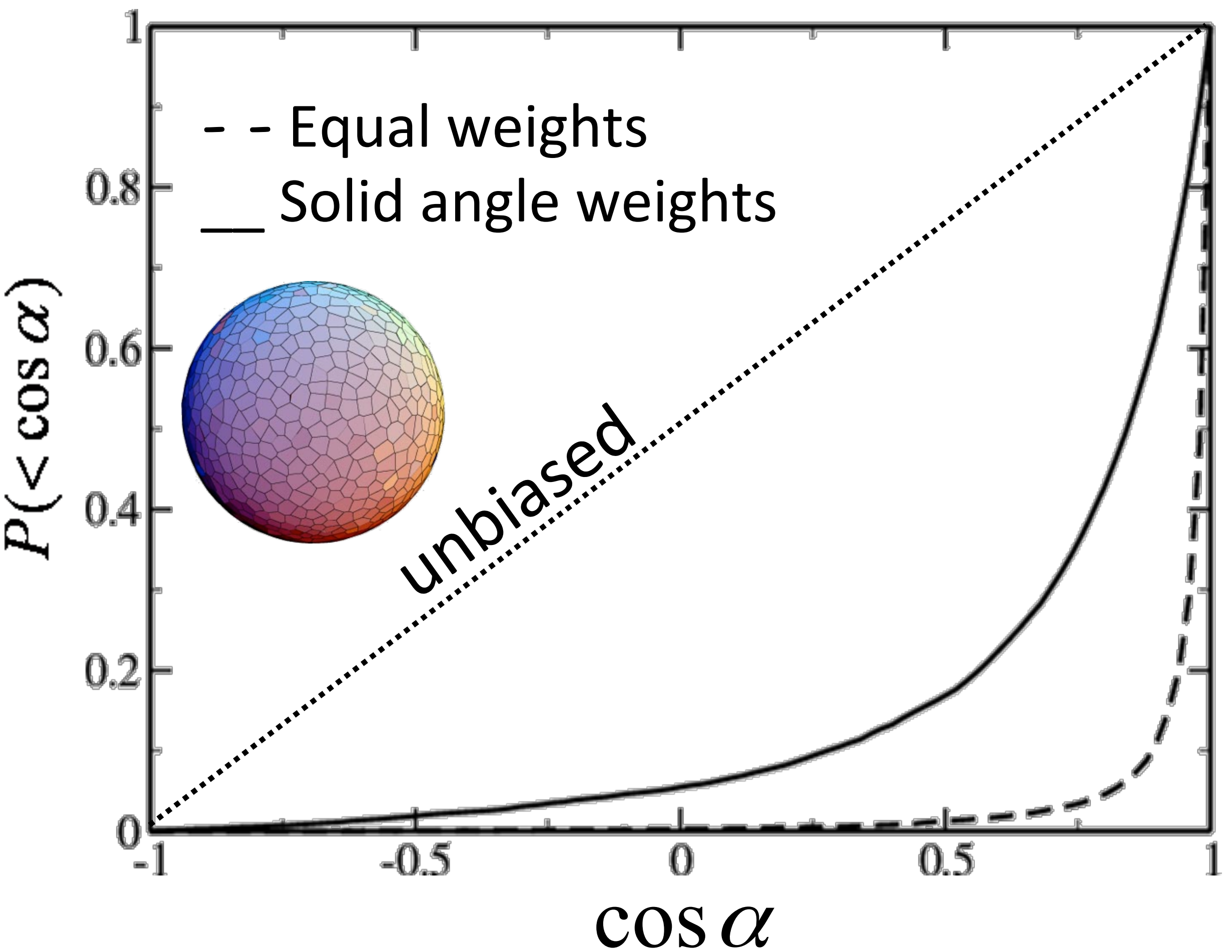
Andreas Pawlik
(MPA)

Particle-to-neighbor transport is biased towards center of mass

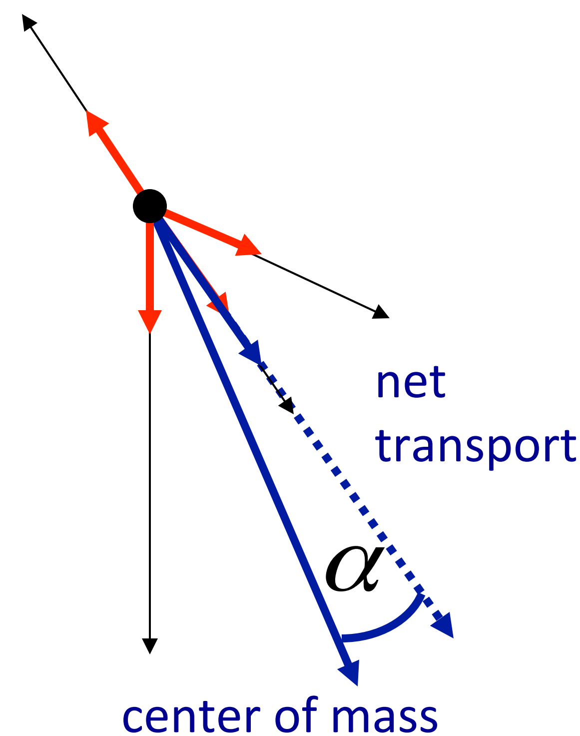


Andreas Pawlik
(MPA)

A weighted transport does not remove the intrinsic bias (AP & J. Schaye 2008)



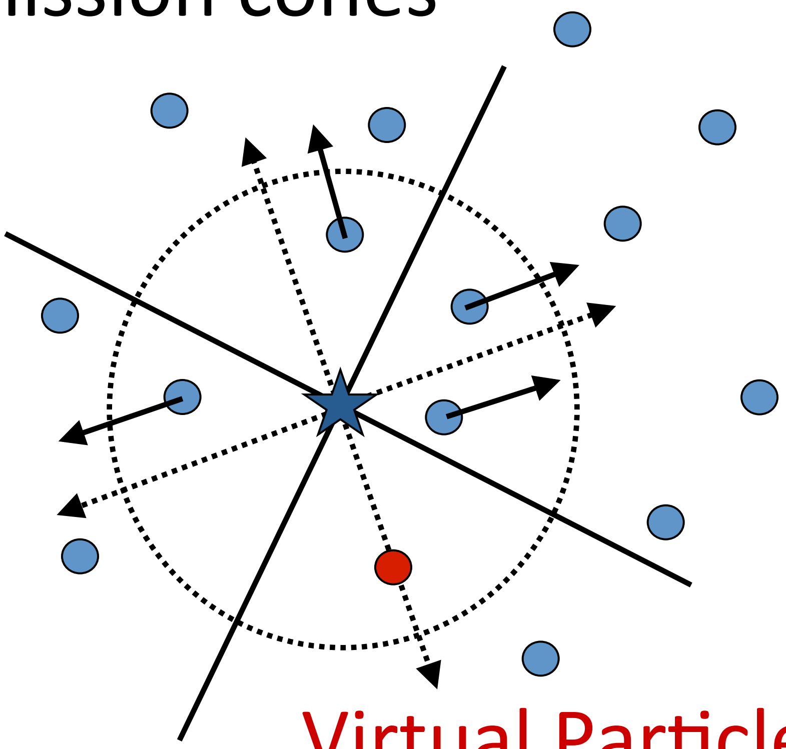
Random distribution of 64 neighbours



Andreas Pawlik (MPA)

TRAPHIC – Emission

Randomly oriented emission cones



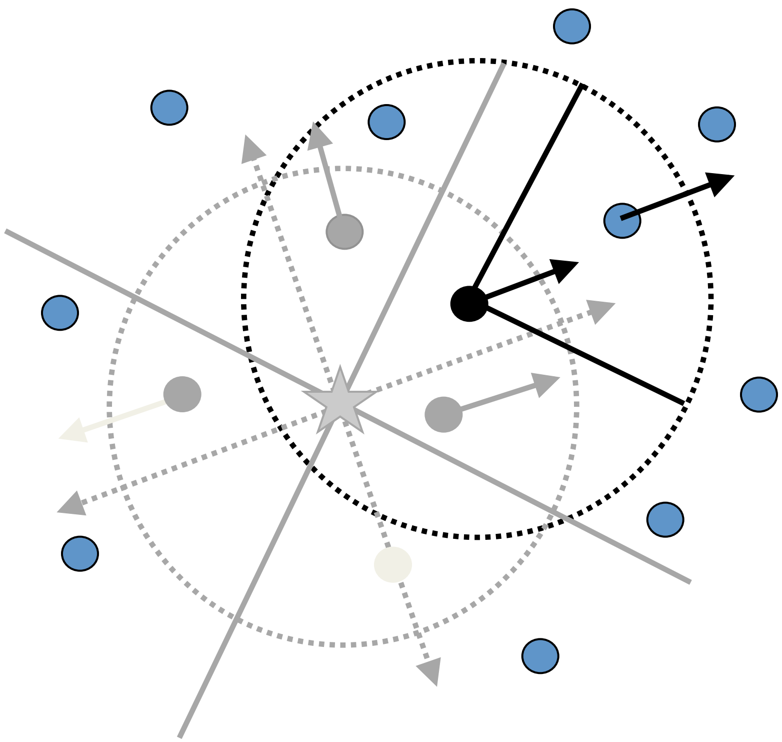
here: $N_{ngb} = 4$

here: $N_{EC} = 4$

Virtual Particle: create new directions as needed

Andreas Pawlik (MPA)

TRAPHIC – Transmission

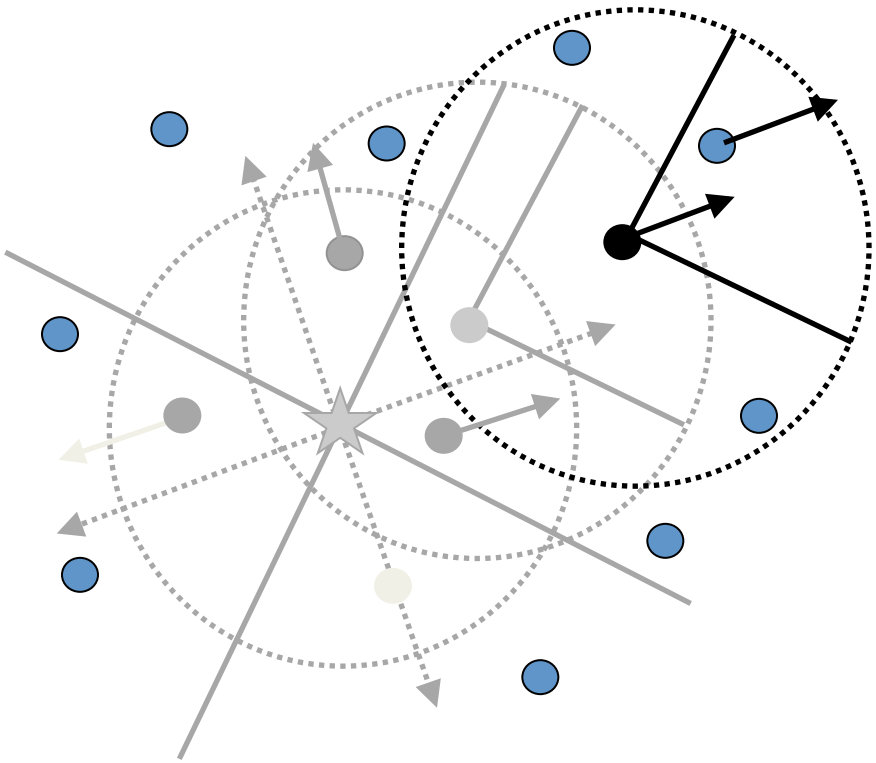


here: $N_{ngb} = 4$

here: $N_{EC} = 4$

Andreas Pawlik
(MPA)

TRAPHIC – Transmission

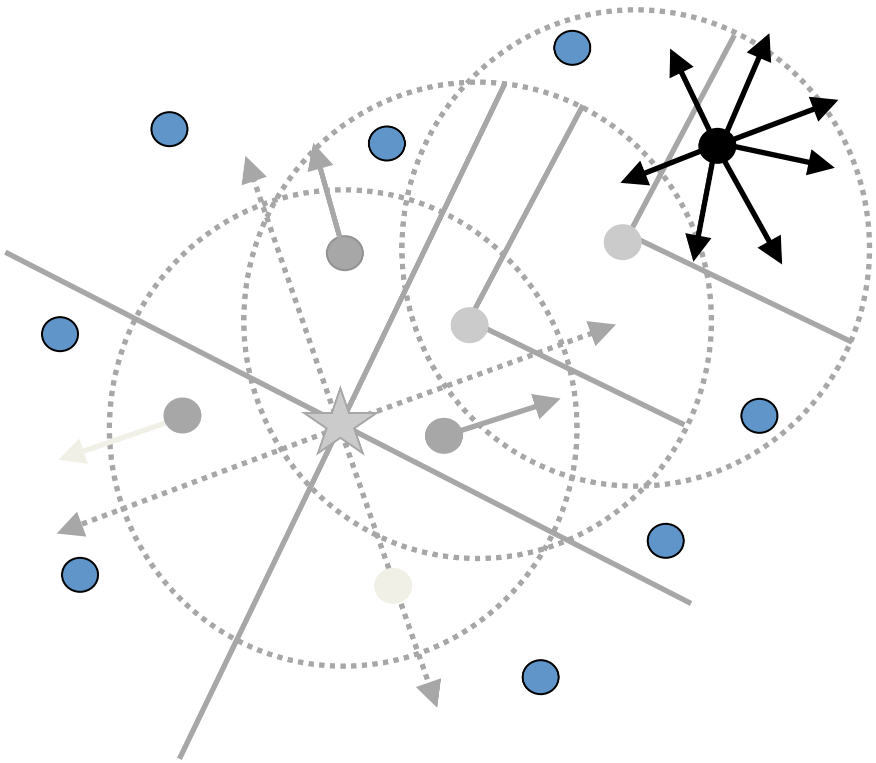


here: $N_{ngb} = 4$

here: $N_{EC} = 4$

Andreas Pawlik
(MPA)

TRAPHIC – Transmission

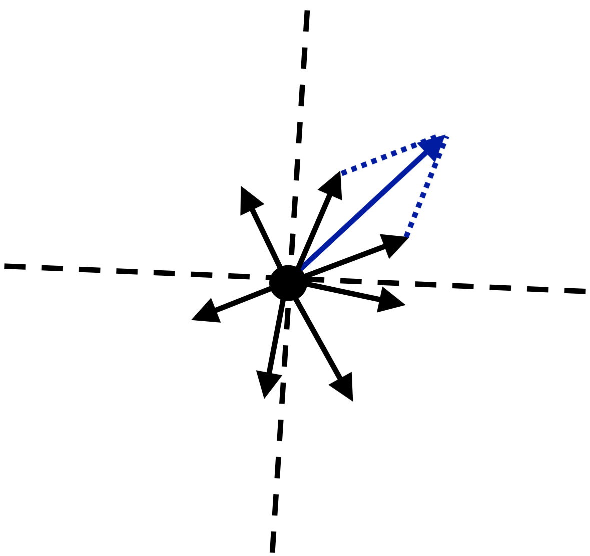


here: $N_{ngb} = 4$

here: $N_{EC} = 4$

Andreas Pawlik
(MPA)

TRAPHIC – Merging

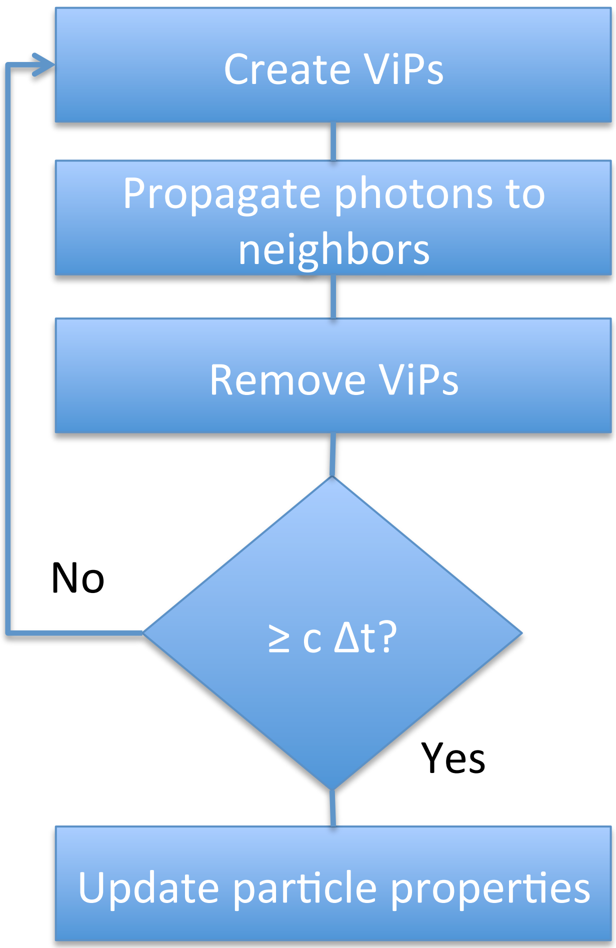


Randomly oriented reception cones (here: $N_{RC} = 4$)

-> Computation time scaling:
independent of # sources

Andreas Pawlik
(MPA)

Flow chart - single RT time step



<u>Full control of:</u>

- Directional sampling
- Angular resolution of the transport
- Angular resolution of the merging
- Speed of light

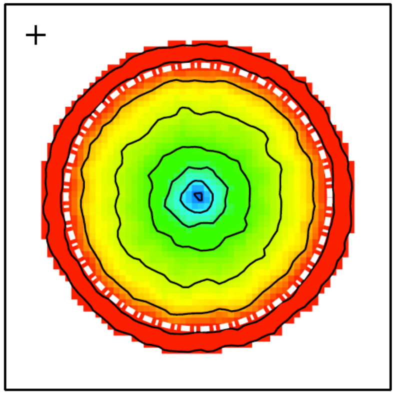
Validation by convergence: in the limit of high angular resolution, TRAPHIC becomes equivalent to a classical Monte Carlo code

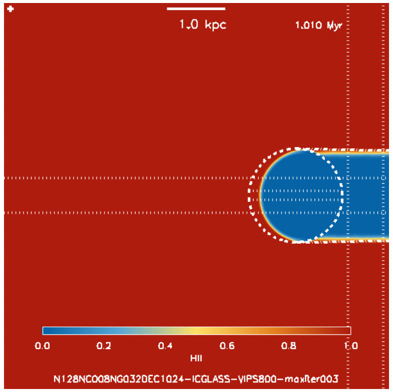
TRAPHIC in GADGET 2008/2012

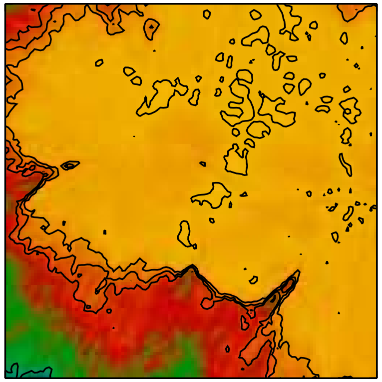
- SPH - no additional grid (regular/unstructured)
- Photon packet merging – computational cost independent of number of sources
- MPI parallel/Gadget2
- Multifrequency transport
- Helium
- Photoheating/cooling (including H_2/HD)
- RHD/Gadget3 (+ new dynamical time stepping, Durier & Dalla Vecchia 2011)
- X-ray secondary ionization (Jeon et al.)
- Recombination radiation (Raicevic et al.)
- UV background (Rahmati et al. 2012)

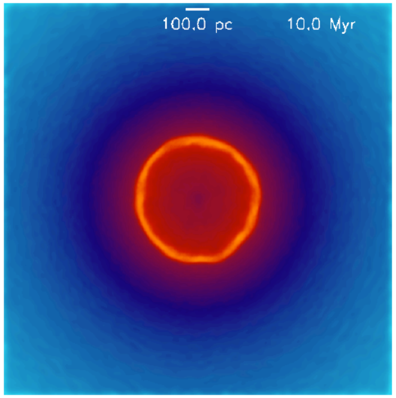
} new

Andreas Pawlik
(MPA)







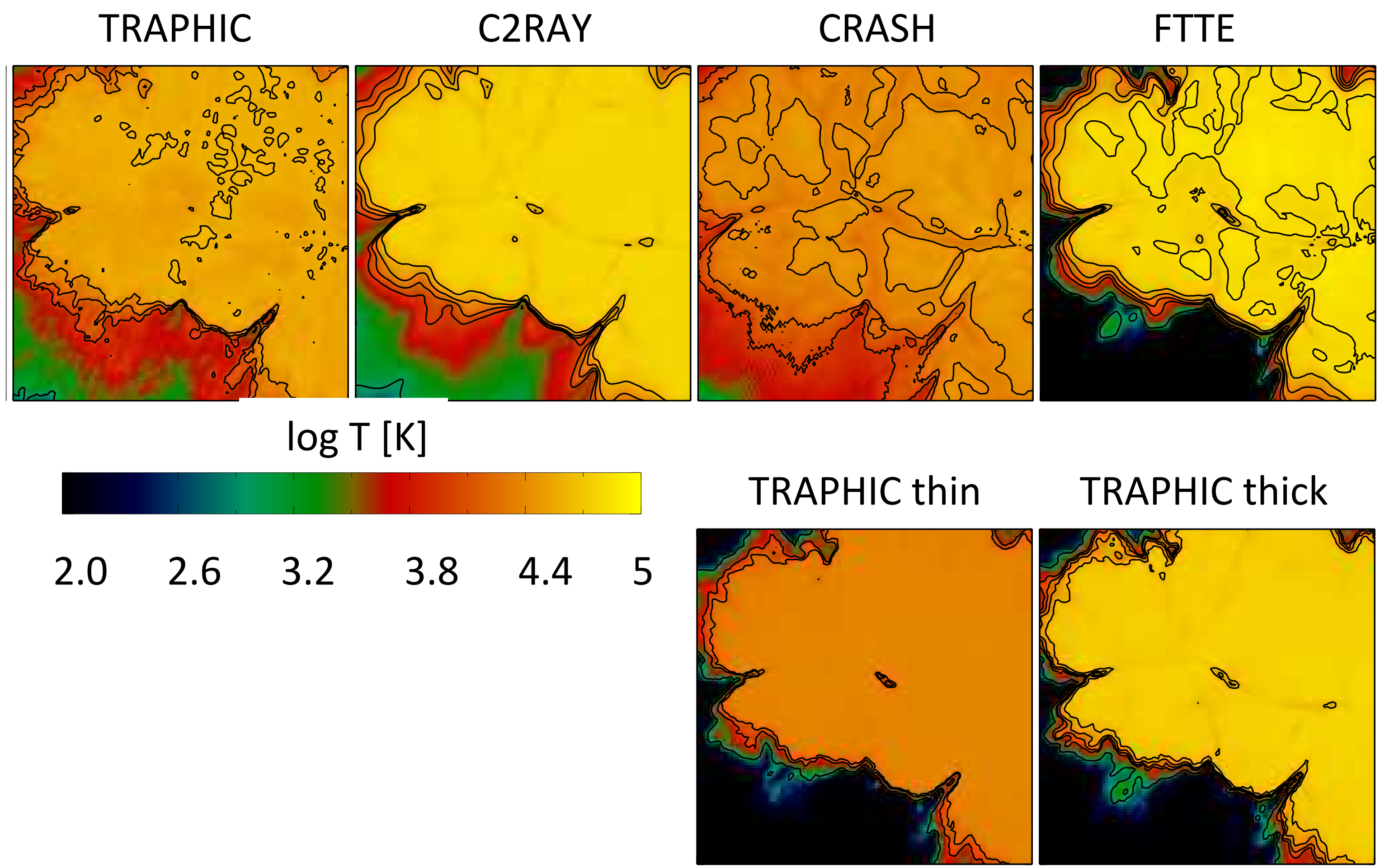


Tests

- RT code comparison tests (Iliev et al.)
- Comparison with 1d code (“testtraphic1d”)
- Convergence tests

Andreas Pawlik
(MPA)

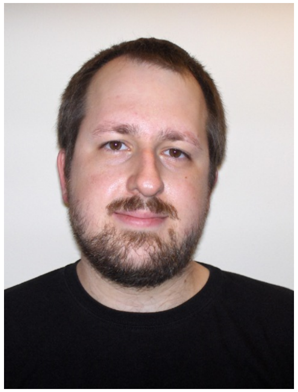
Test 4 – optically thin vs. optically thick heating rates (AP & Schaye 2010)

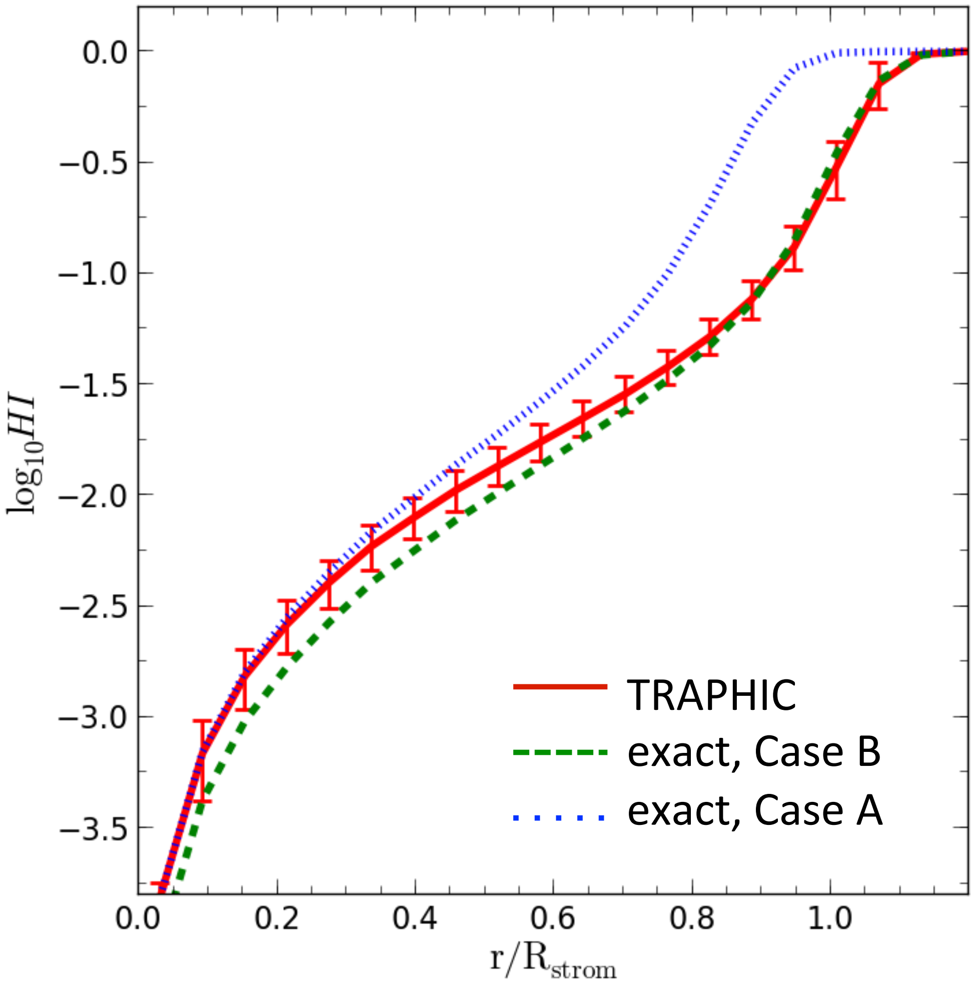


Andreas Pawlik
(MPA)

Recombination radiation

Milan Raicevic

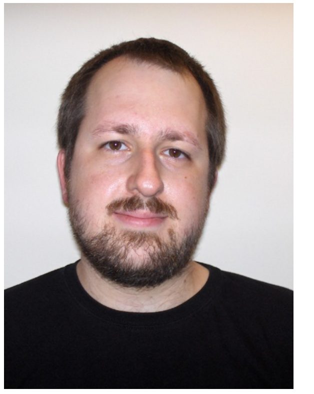


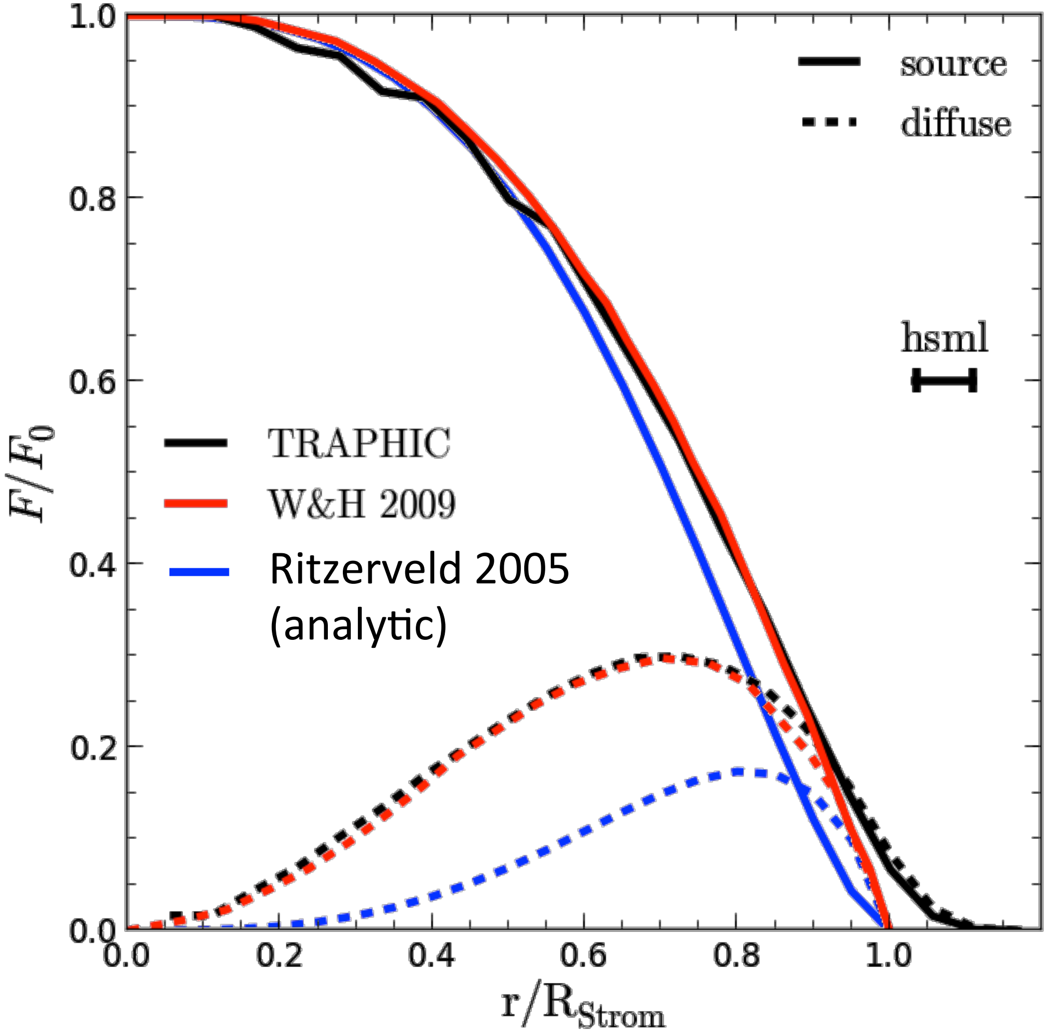


Andreas Pawlik
(MPA)

Recombination radiation

Milan Raicevic





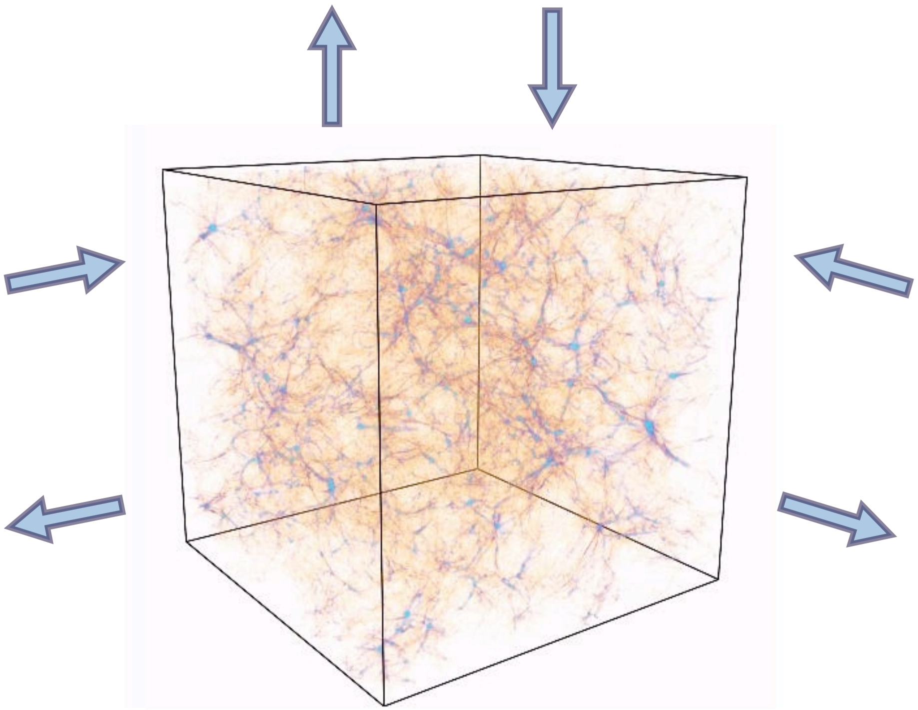
Andreas Pawlik (MPA)

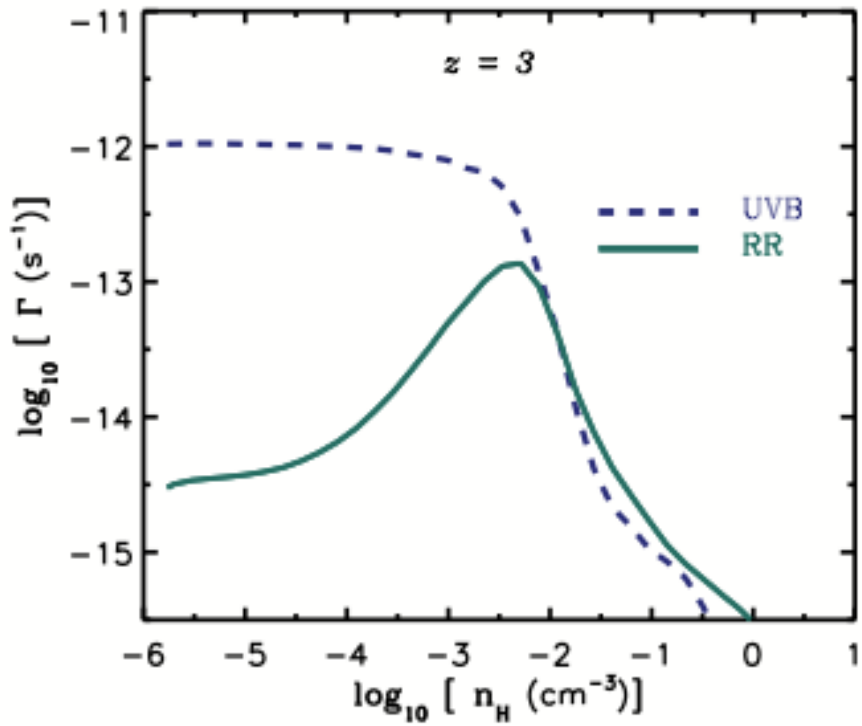
Applications

- The first stars
  (Jeon et al., in prep)
- The first galaxies
  (AP, Milosavljevic, Bromm 2012, arxiv:1208.3698)
- Reionization
  (AP, Schaye, et al., LOFAR, in the future)
- HI absorption systems after reionization
  (Rahmati et al. 2012, arxiv:1210.7808+)

HI absorption systems in the UV background at z = 0-5

Ali Rahmati





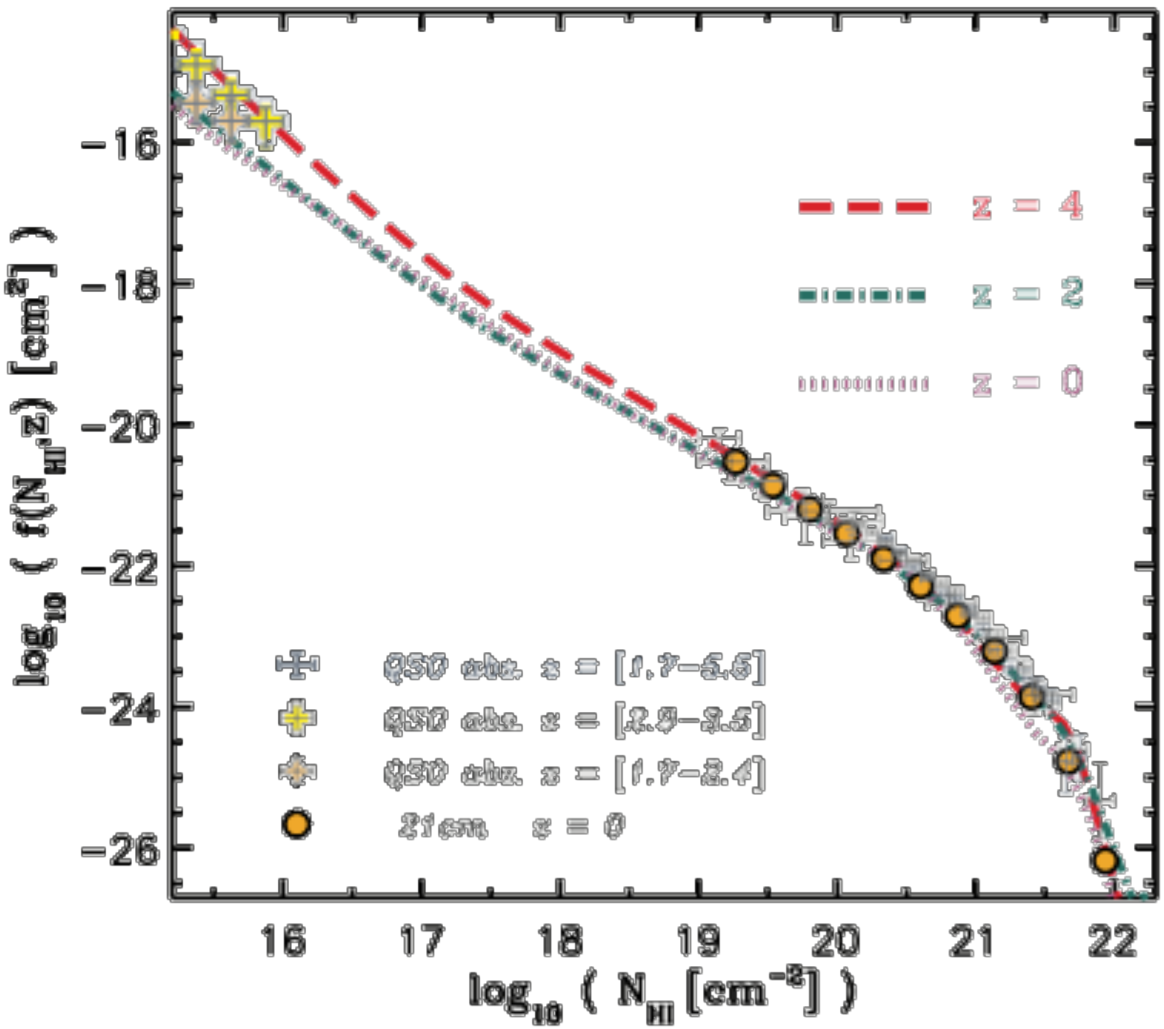
L ~ 6-100 Mpc/h

m_{gas} ~ 10^5 – 10^8 solar (128^3-512^3)

See also talks by Ken Nagamine, Gabriel Altay, Matt McQuinn

(non-) Evolution of the HI column density distribution

Ali Rahmati, AP, Raicevic, & Schaye 2012a

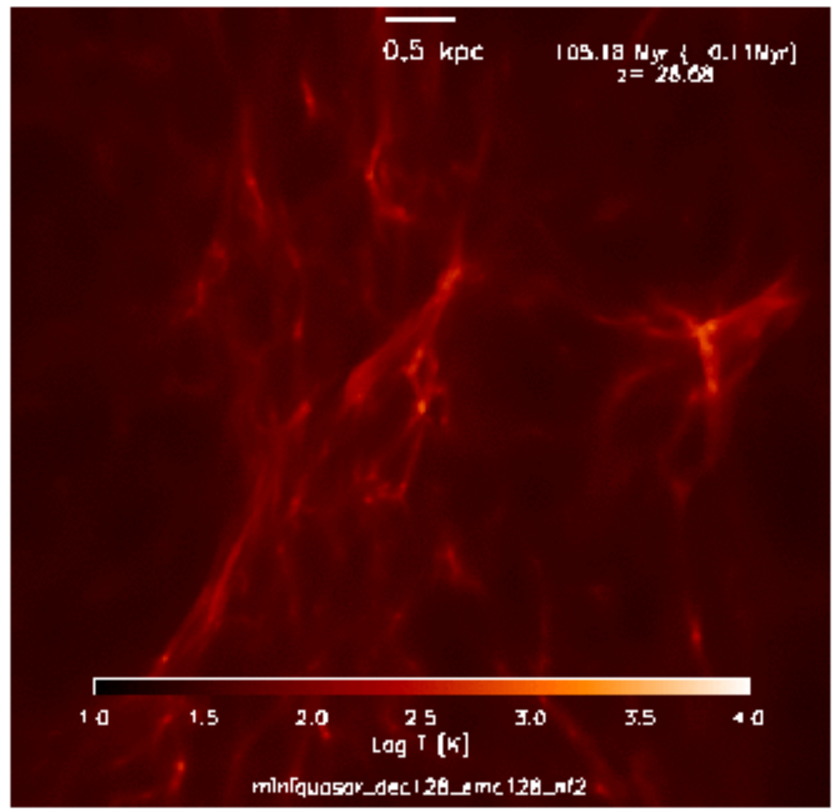


Andreas Pawlik (MPA)

The first miniquasars

Myoungwon Jeon

- The first stars form in minihalos with masses 10^{5-6} at z ~ 30
- Miniquasars; binaries evolve into HMXBs
- Strong emitters of X-rays
- Preheating of the IGM



Andreas Pawlik (MPA)

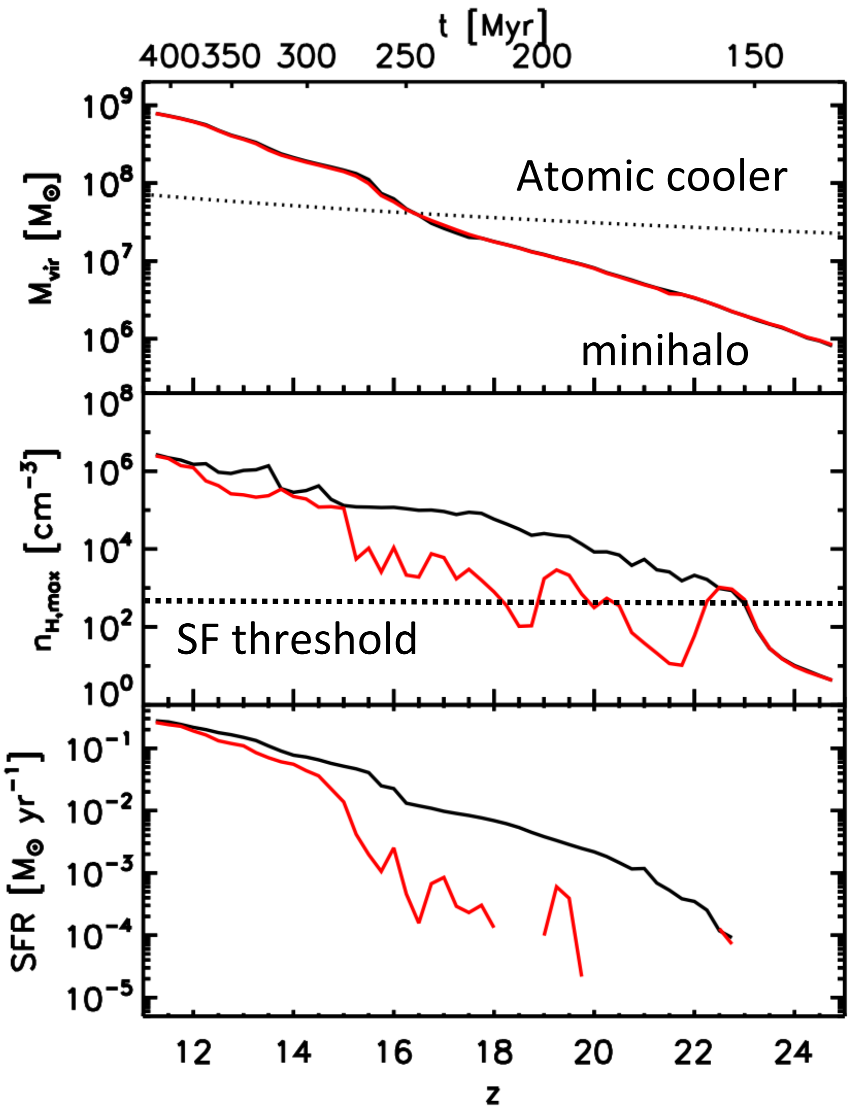
Radiative feedback in the first galaxies

AP, Milosavljevic, & Bromm 2012

Virial mass

Maximum density

SFR



Dwarf galaxy reaching a halo mass of 10^9 solar at z = 10

Radiative feedback

No feedback

Andreas Pawlik (MPA)

Summary

- TRAPHIC – spatially adaptive transfer at the speed of light and at a computational cost independent of the number of sources
- Many new features since first publication, including RHD, recombination radiation, etc.
- We apply TRAPHIC: feedback in the first galaxies, HI absorption systems, reionization