Las Vegas Athena++ Developers Meeting

Adaptive Ray Tracing

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Mar 18, 2019

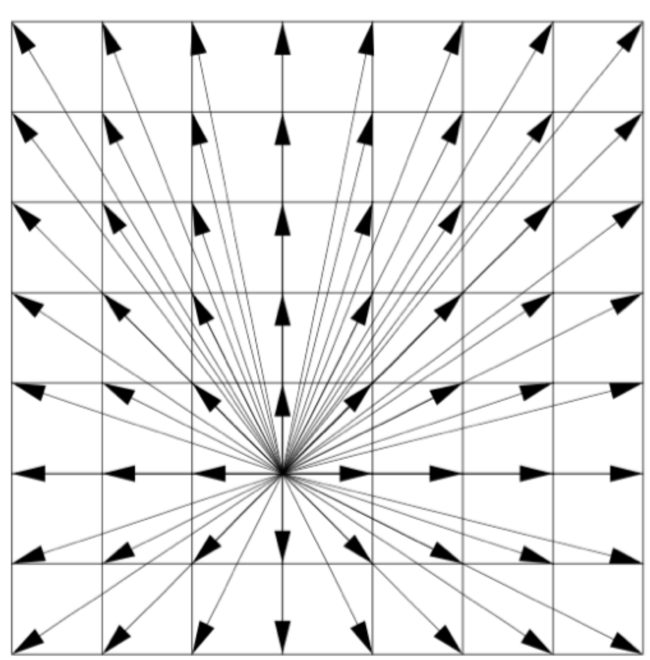
Characteristics Method for Point Source Radiative Transfer

- Solves RT equation along selected rays and computes radiation 4-force vector directly

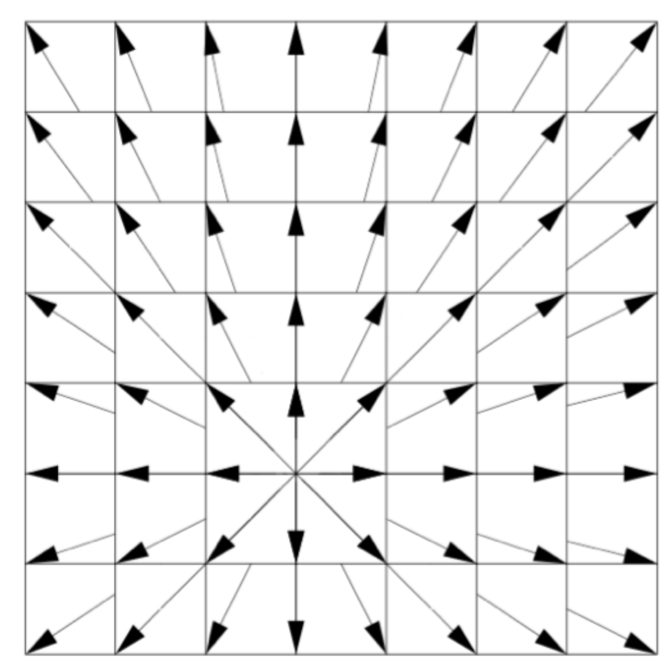
$$\frac{1}{c}\frac{\partial}{\partial t}I_\nu + \mathbf{n}\cdot\nabla I_\nu = \eta_\nu(\mathbf{n}) - \kappa_\nu(\mathbf{n})I_\nu$$

$$c\begin{pmatrix} G^0 \\ \mathbf{G} \end{pmatrix} = \int d\nu \int d\Omega\, [\kappa_\nu(\mathbf{n})I_\nu - \eta_\nu(\mathbf{n})]\begin{pmatrix} 1 \\ \mathbf{n} \end{pmatrix}$$

Long characteristics



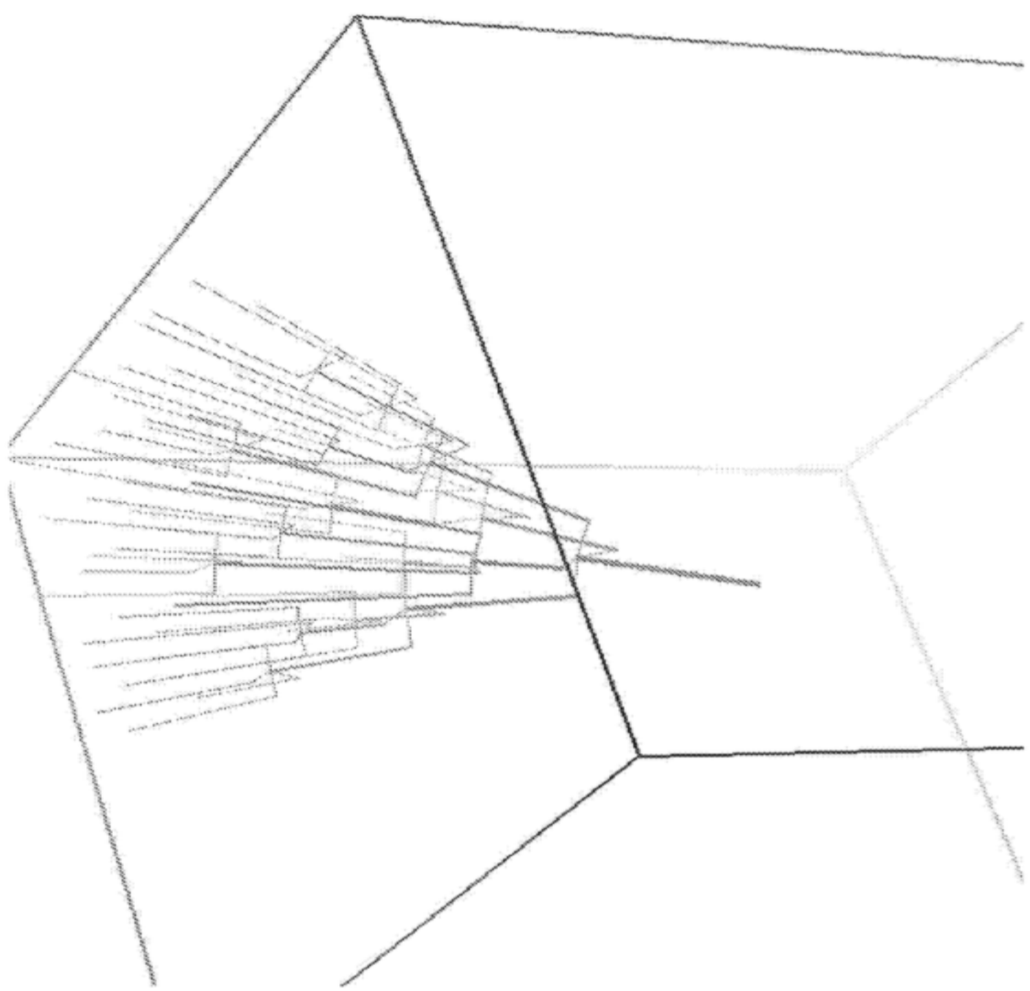
Short characteristics



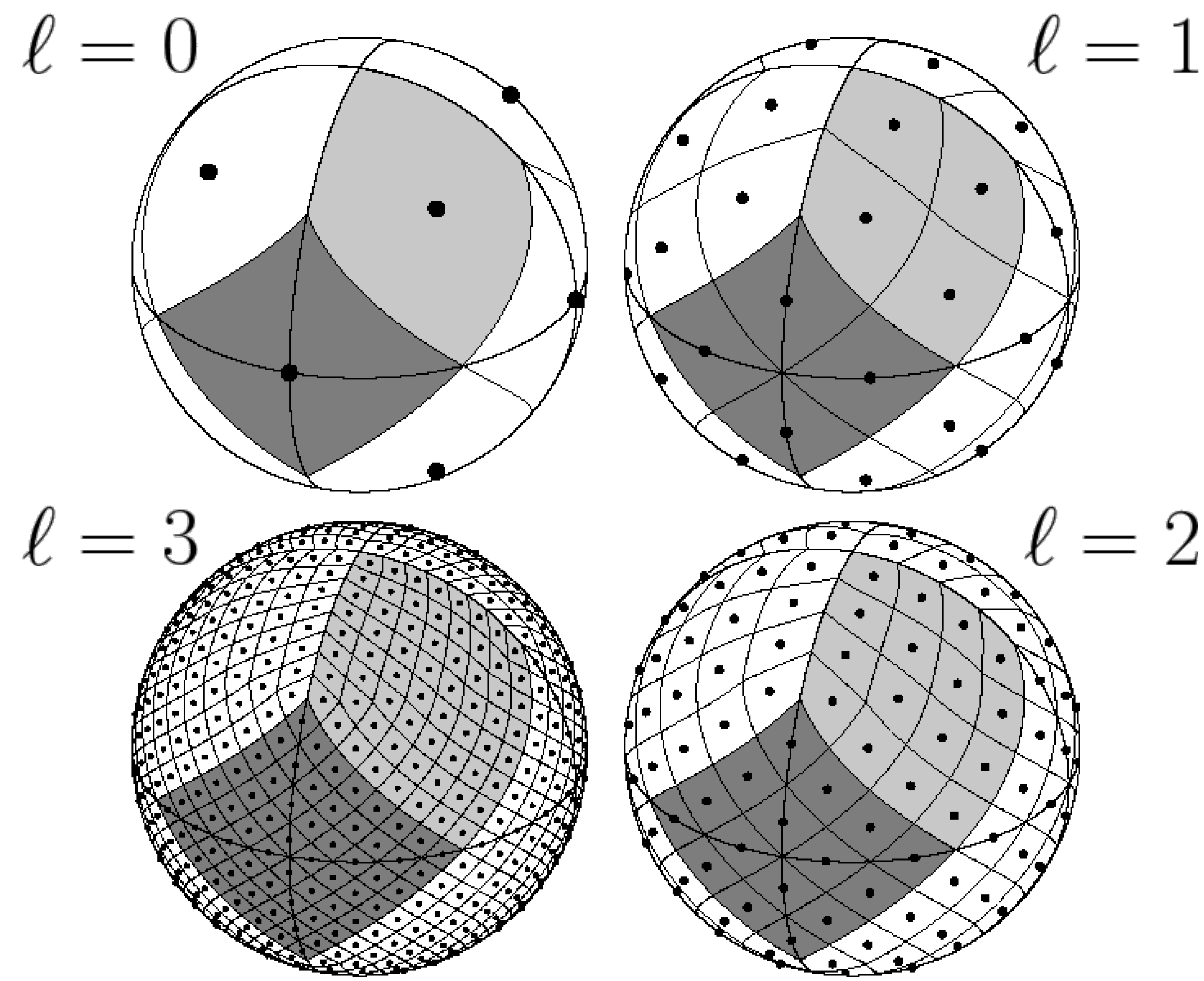
Rijkhorst+06

Adaptive Ray Tracing

- Spatially adaptive long characteristics
  - Split rays to match the angular resolution to that of grid cell
  - Angular discretization using HEALPix



Abel+02



Gorski 05

Pros and Cons

- Conservative of photon energy and momentum
- Retains full information about the directionality of radiation flux
- Best suited for UV radiation from a small number of massive stars
    - Photoionization/direct radiation pressure, coupling with chemistry

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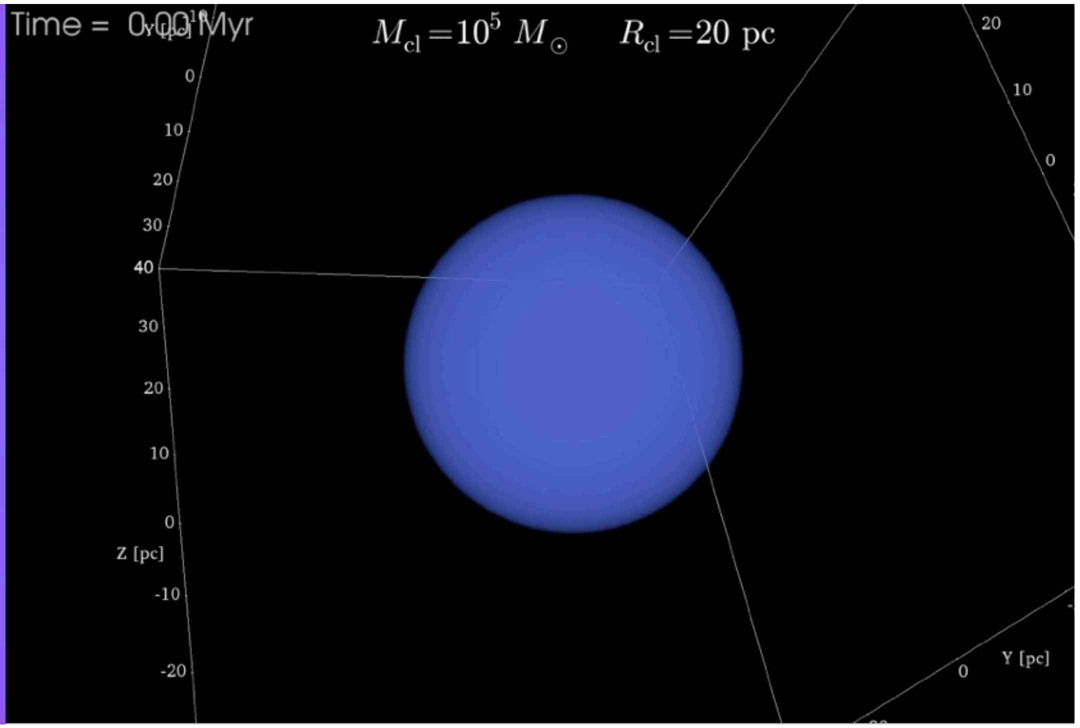
- Ill-suited to handling diffuse sources/scattering
- Computational cost scales as $N_{src} \times N_{cell} \times N_{freq} \times m_{ray}$.
    - In practice, cost depends on problem geometry, domain decomposition, and parallel algorithm
- Difficult to parallelize

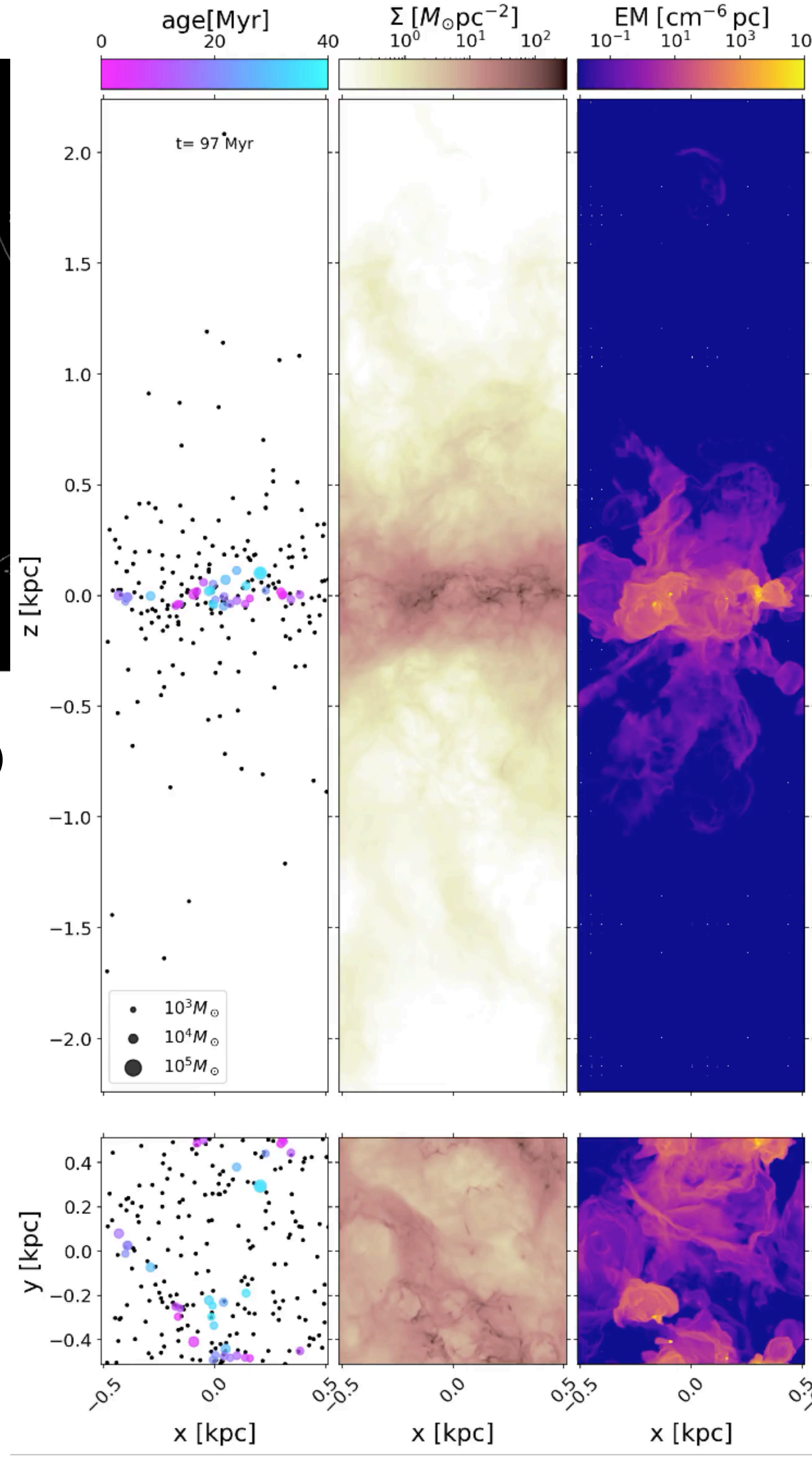
Science Applications

Rosen+16

Kim, J.-G.+18



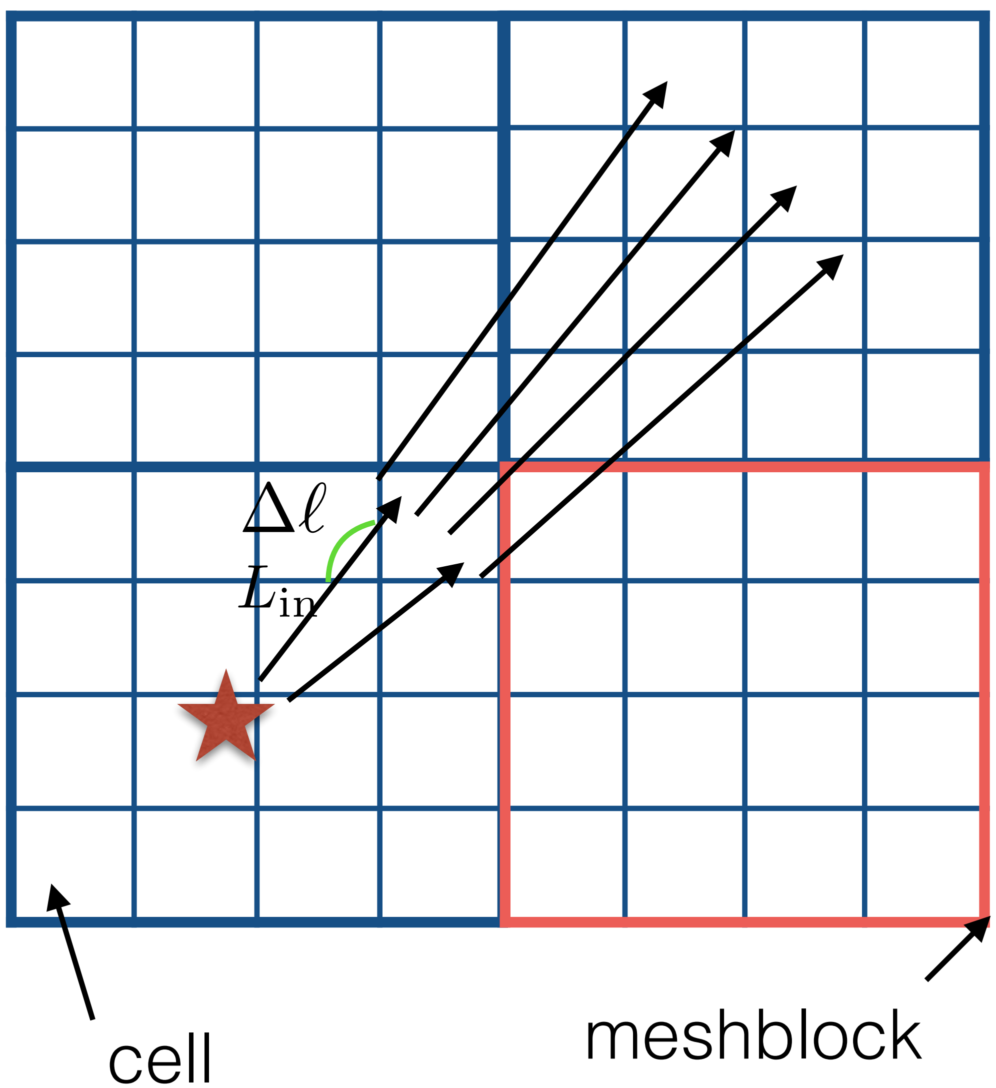
Kado Fong+19



- Massive star formation with radiation feedback (Rosen+16, 19)
- Destruction of molecular clouds (Kim, J-.G.+17, 18, 19)
- Post-processing kpc-scale galactic disk simulations TIGRESS (Kim, C-.G.+17,18)
    - Diffuse ionized gas (Kado Fong+19, in prep)
    - H_2 and X_{CO} (Gong+19, in prep)
- TIGRESS with ART (see also Peters+17)
- Escape of radiation (e.g., Wise+09, Kim, J-.h.+13)

Ray-cell Interaction

- Photon Packets (**PPs**) are transported radially outward from the source and attenuated by gas and dust.



$$\mathbf{n}\cdot\nabla I = -\chi I$$

$$\mathcal{E} = \frac{1}{c}\int I d\Omega = |\mathbf{F}|/c$$

$$\mathbf{F} = \int I\hat{\mathbf{n}}\, d\Omega = \hat{\mathbf{r}} L e^{-\tau(r,\hat{\mathbf{n}})}/(4\pi r^2)$$

$$\frac{\partial L_{\rm ray}}{\partial r} = -\chi L_{\rm ray}$$

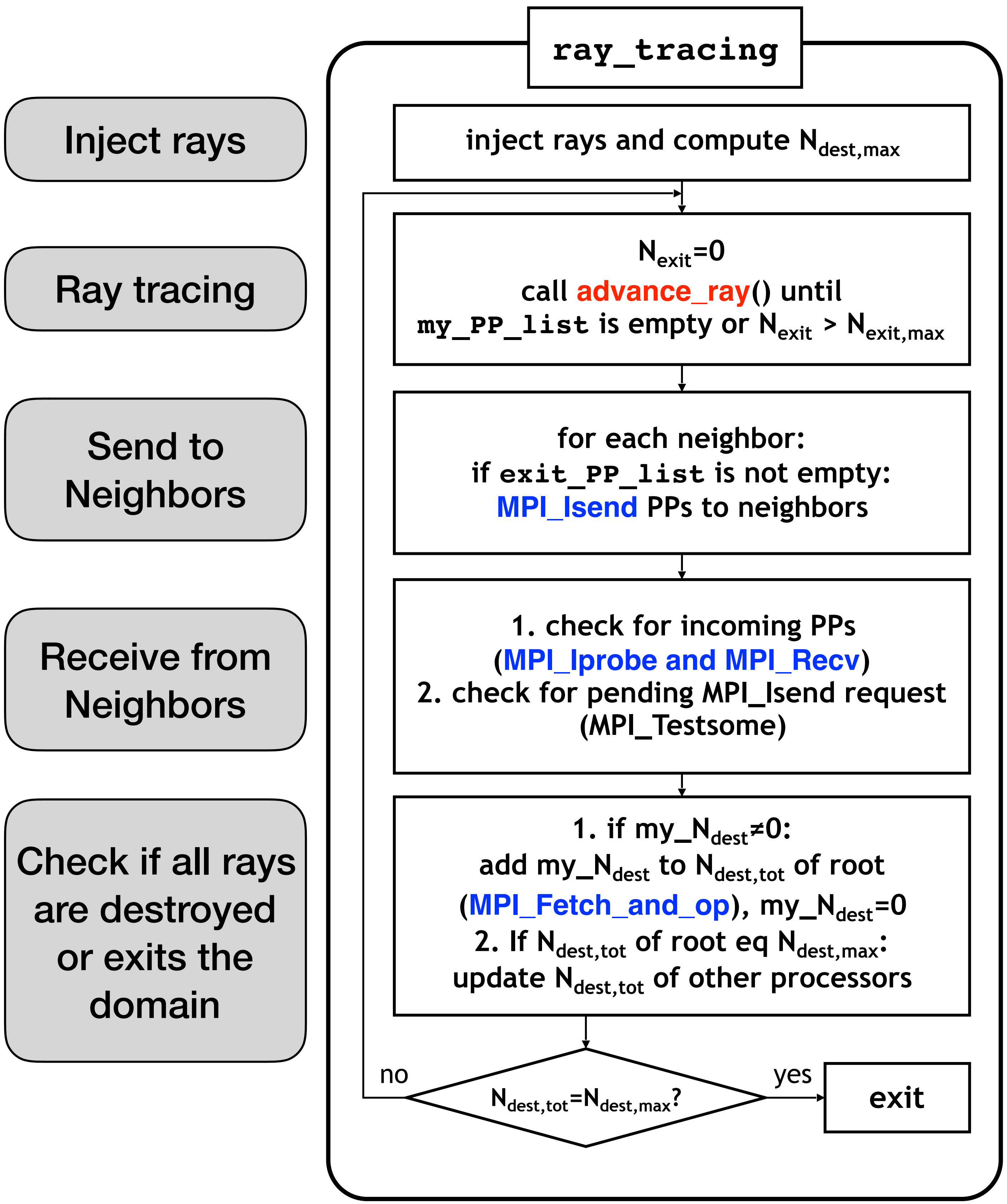
opacity per length

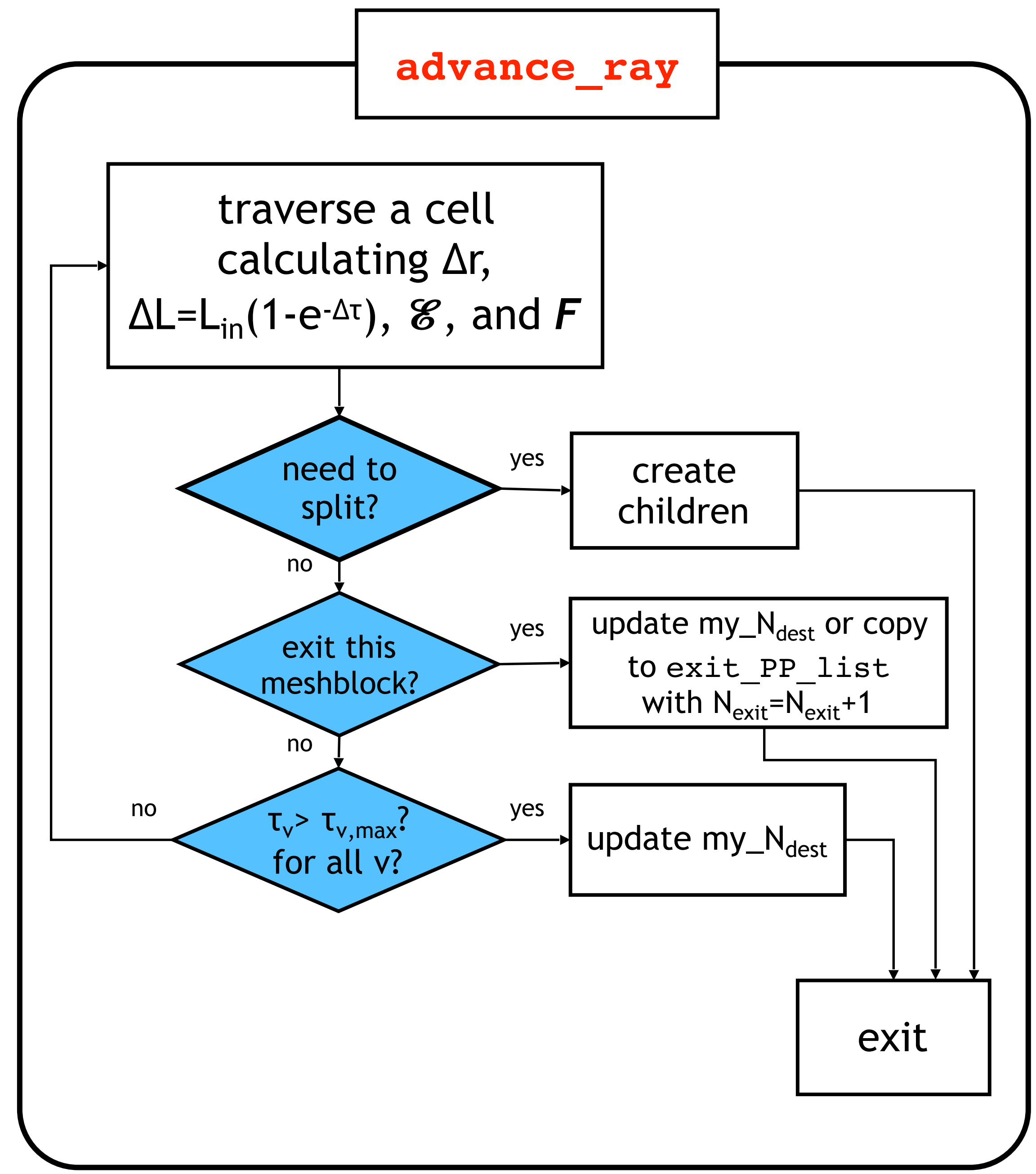
$$\Delta L = L_{\rm in}(1 - e^{-\Delta\tau})$$

$$\Delta\tau = \chi\Delta\ell$$

$$\mathcal{E} = \frac{1}{\chi\Delta V}\sum_{\rm rays}\frac{\Delta L_{\rm ray}}{c}, \qquad \boldsymbol{F} = \frac{1}{\chi\Delta V}\sum_{\rm rays}\Delta L_{\rm ray}\boldsymbol{n}_{\rm ray},$$

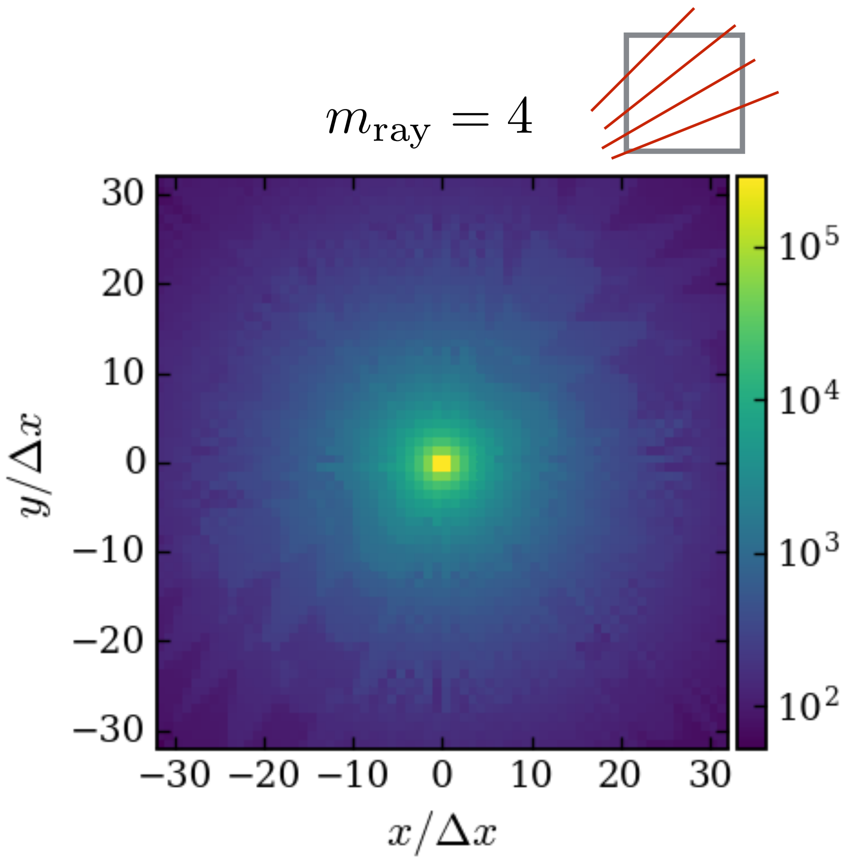
Flow Chart

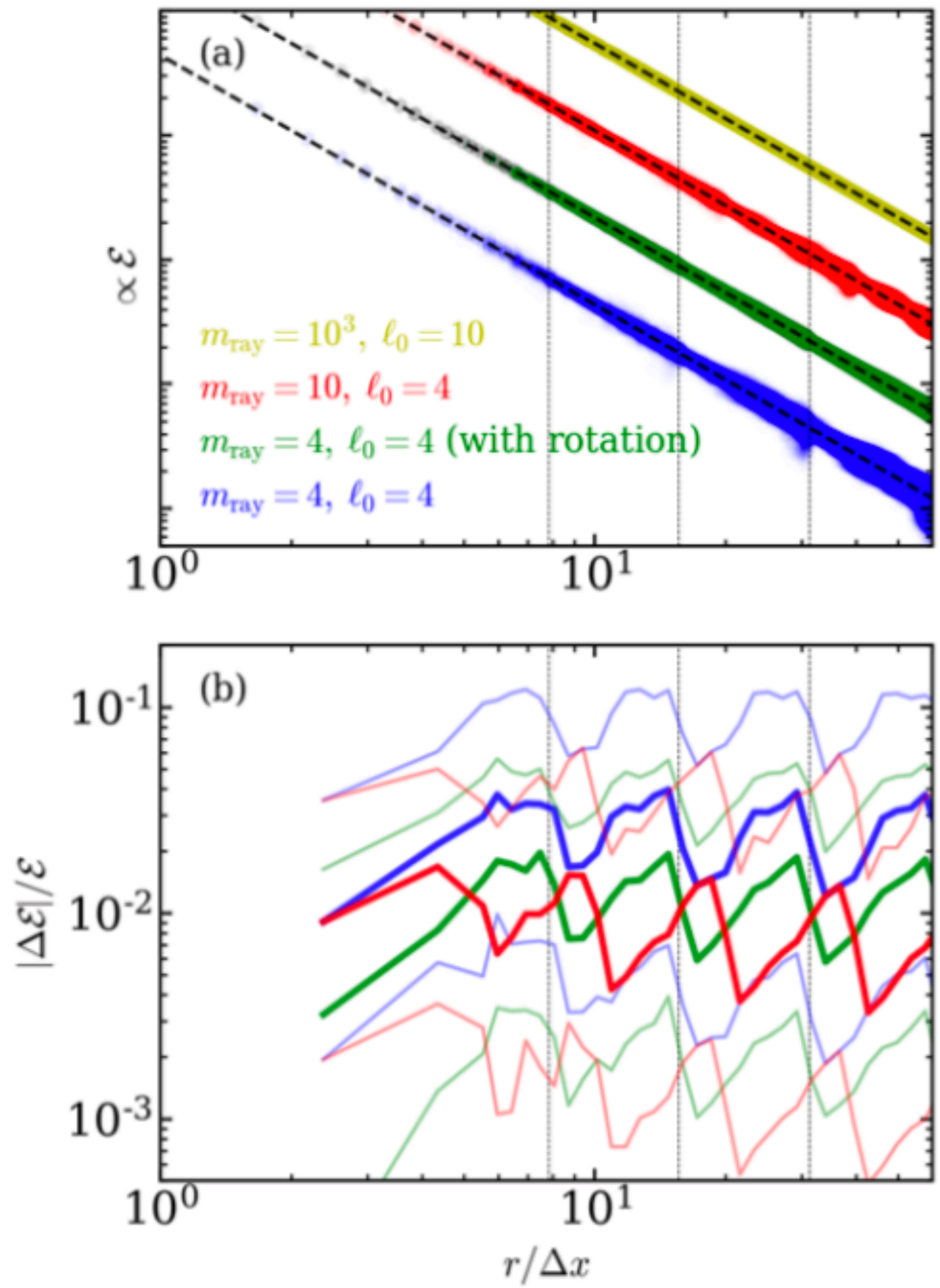


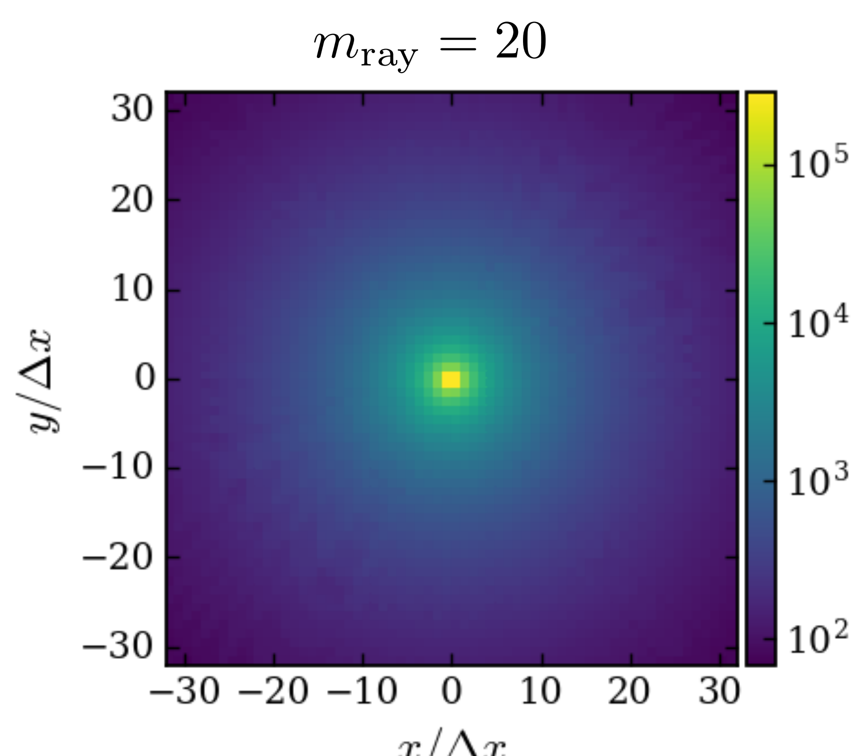


Kim, J-.G.+17, Rosen+17

Radiation in Vacuum

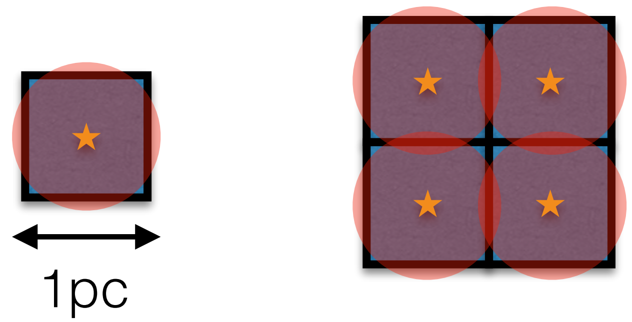






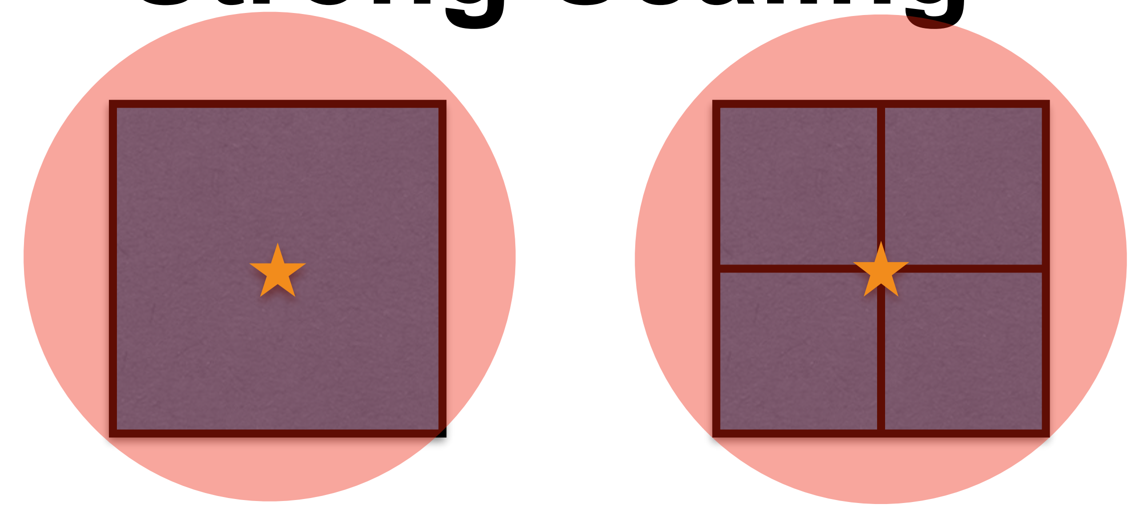
Kim, J-.G.+17

Weak Scaling

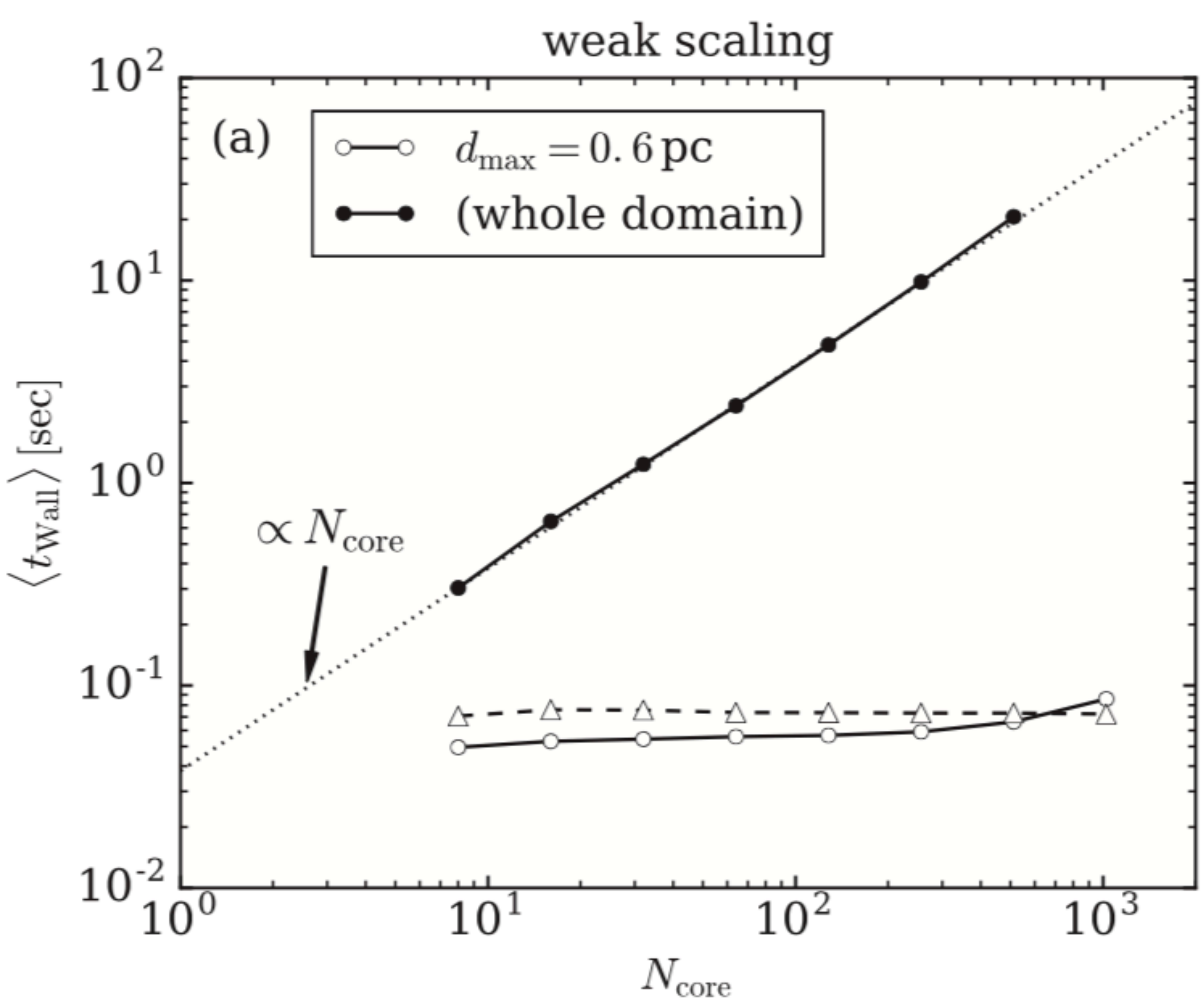


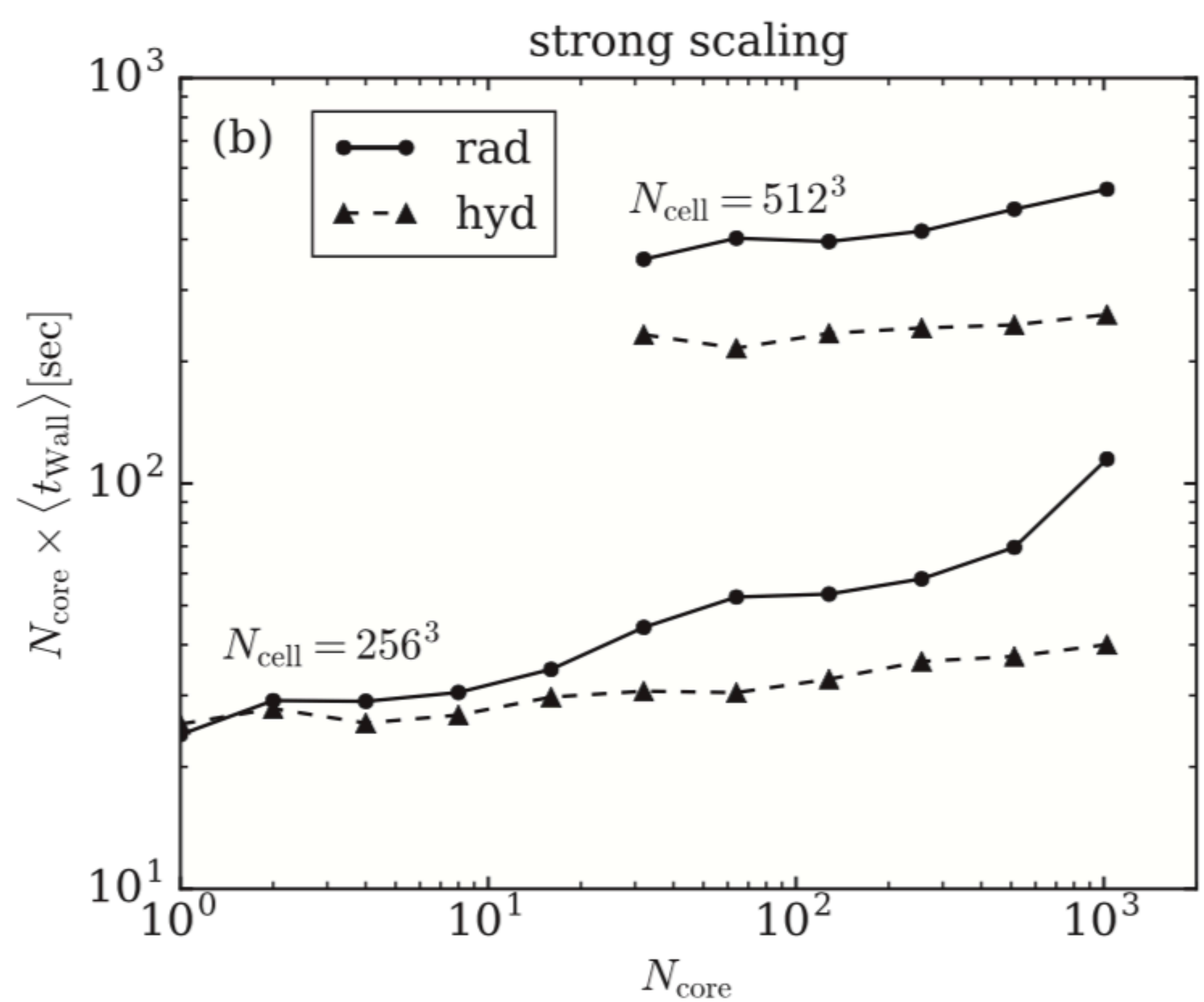
- Constant amount of work per process (32^3 cells/proc)

Strong Scaling



- Fixed problem size (256^3, 512^3 cells)





Kim, J.-G.+17

Thoughts

- Need to minimize the overhead associated with finding neighboring meshblocks when multiple meshblocks are assigned to a single processor
- Control flow with chemistry module
    - Update species abundances based on radiation field
    - Is operator split method with substepping best approach?
- Hybrid RT
    - Aborption of UV radiation calculated by ART
    - Moment method to follow diffuse IR emission from dust
- ART as an on-the-fly integration tool?
    - Synthetic observation, column density maps, etc.