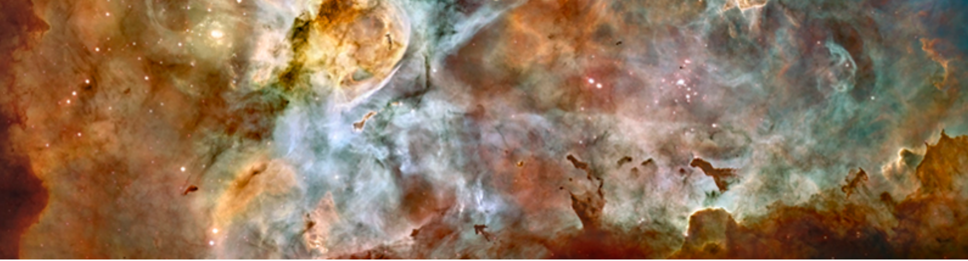


EVIDENCE FOR A DIRECT COLLAPSE BLACK HOLE IN THE LYMAN-ALPHA SOURCE CR7

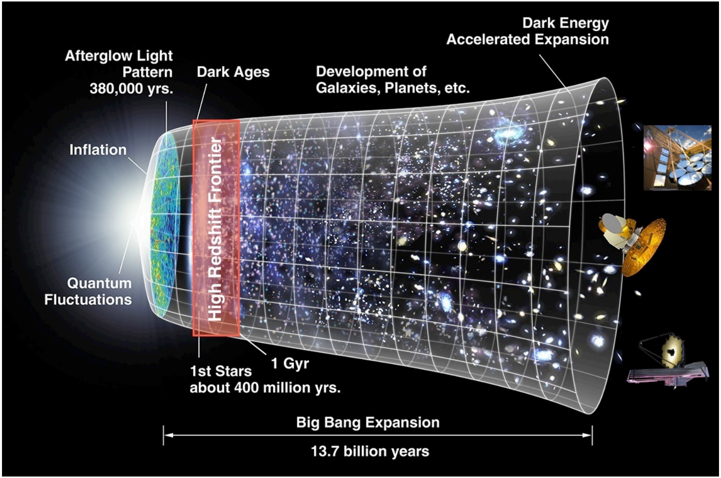
AARON SMITH

The Reionization Epoch: New Insights and Future Prospects

March 11, 2016

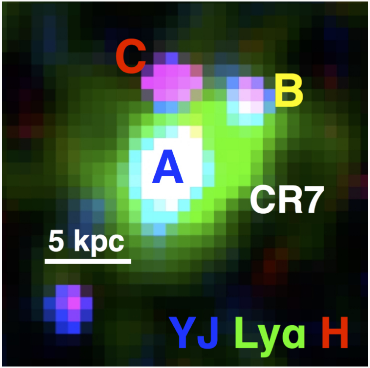
Volker Bromm & Avi Loeb

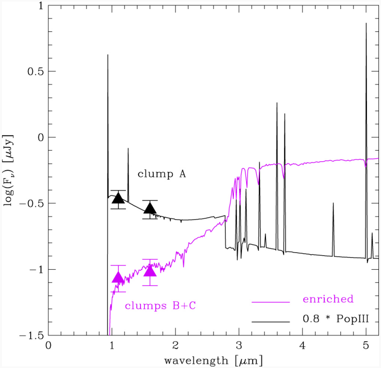
THE HIGH REDSHIFT FRONTIER



Lyα radiative transfer helps to connect simulations and observations. We focus on modeling the first galaxies.

Lyα emission from the CR7 source

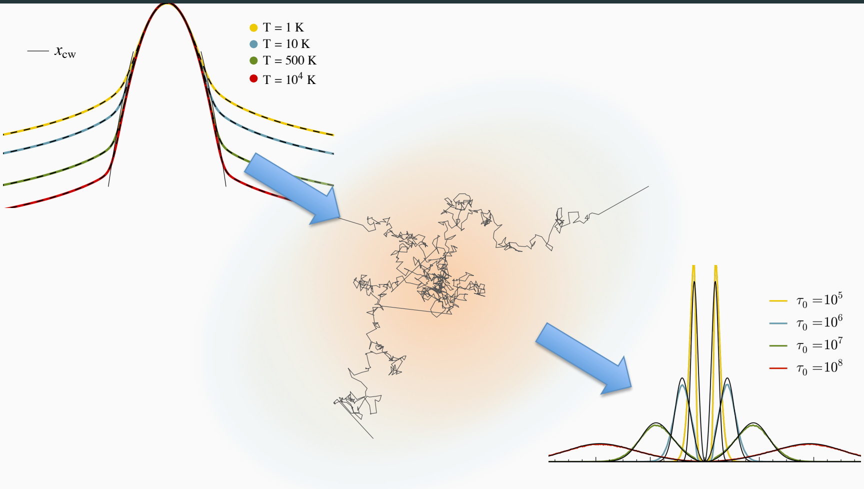




- Component A dominates the Lyα emission
- Nature of the source? Pop III or DCBH?
- Unlikely: AGN, Wolf-Rayet stars, SNe, Pop II stars (Lyα line not broad, no metal lines, hard spectrum)

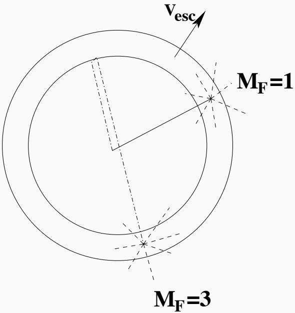
* Sobral et al. (2015) & Matthee et al. (2015)

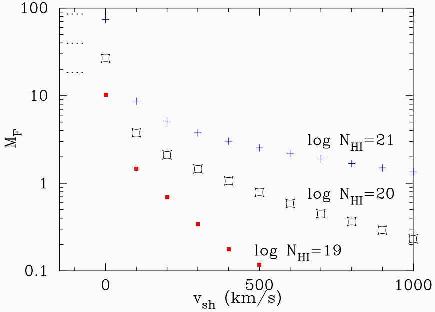
LYMAN-ALPHA RADIATIVE TRANSFER



- Resonant scattering $\Rightarrow$ diffusion in position and frequency!
- Rare excursions to the wing facilitate escape ($\tau \gtrsim 10^6$)

LYα TRAPPING IN THE EXPANDING SHELL MODEL

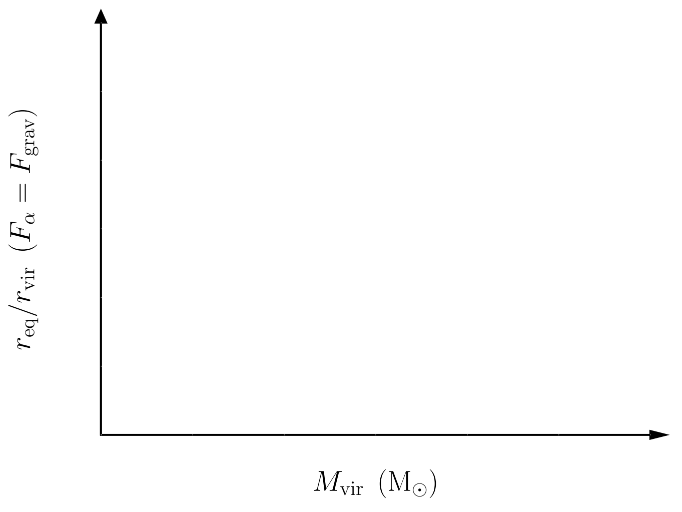




$$M_F \equiv \frac{\sum F_\alpha}{L_\alpha / c}$$

- Multiple scattering acts as a force multiplier   * Dijkstra & Loeb (2008)
- Order of magnitude estimates based on idealized Lyα RT:
  Cox (1985), Bithell (1990), Haehnelt (1995), Henney & Arthur (1998), Oh & Haiman (2002), McKee & Tan (2008), Milosavljević et al. (2009), Wise et al. (2012)

DYNAMIC IMPACT OF LYα RADIATION PRESSURE



- $r_{\mathrm{eq}} \equiv$ radius at which Lyα force exceeds gravity
- Post-processing hints warrant further study

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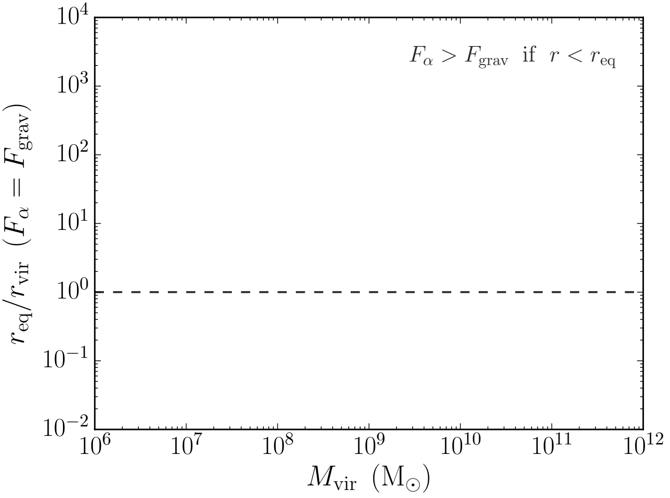

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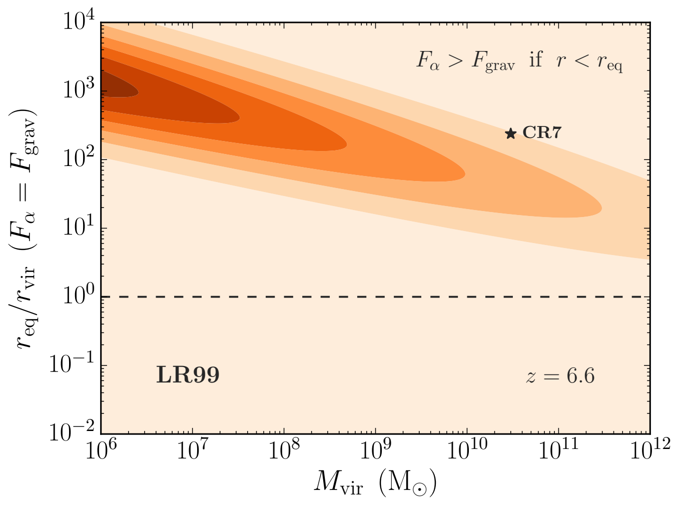


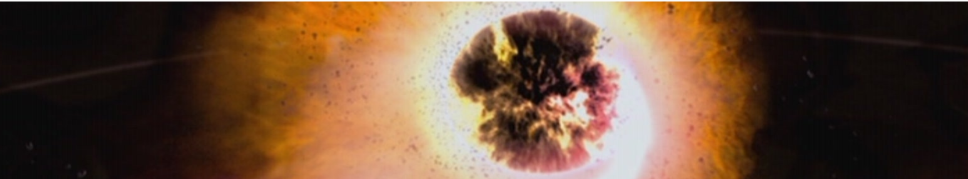
- $r_{\rm eq} \equiv$ radius at which Lyα force exceeds gravity
- Post-processing hints warrant further study

- Radiation-hydrodynamics simulations incorporating Lyα feedback have not been performed.

  Why? (sub-dominant or too expensive)

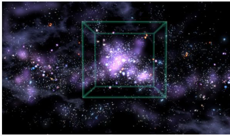
- However, assessing the impact of Lyα radiation pressure must include hydrodynamical coupling.

- Necessary physics and helpful simplifications:
  (i) Accurate Lyα radiative transfer (COLT)
  (ii) Self-consistent ionizing radiation
  (iii) Spherical symmetry – computationally feasible, simplifies algorithms and hydrodynamics

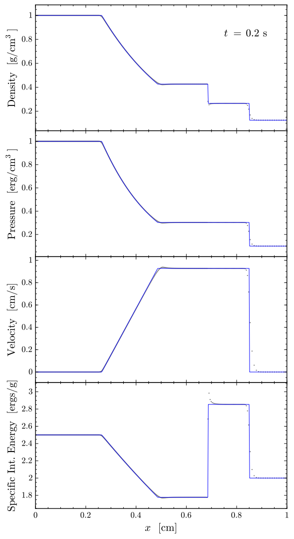


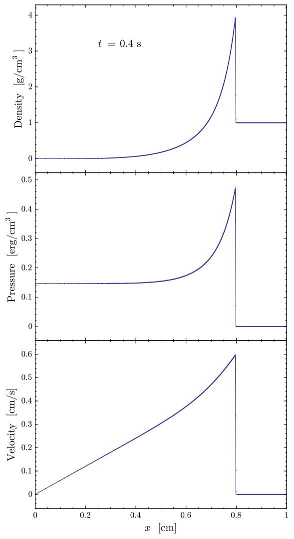
COSMIC LYα TRANSFER CODE (COLT)

- Monte-Carlo Radiative Transfer (MCRT)
- Massively parallel (MPI+OpenMP workflow)
- 3D ray tracing with mesh refinement (octrees)
- Additional optimizations:
  - Core-skipping $\rightarrow$ wing photons
  - Generating atomic velocities
  - Local approximation of the optical depth
- Calculates line-of-sight flux and surface brightness for (x, y, λ) output
- MC estimators for energy, force, and pressure



$$\left[\ \tau_\nu = \int n\sigma_\nu d\ell\ \right]$$





Shock Tube

and

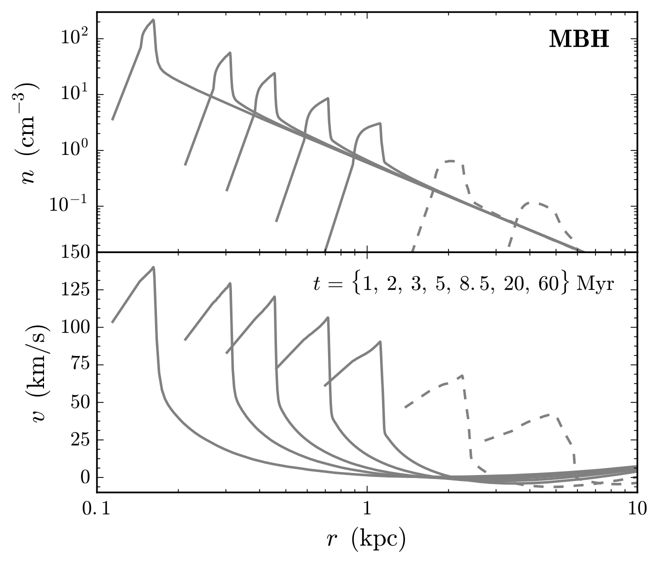
Blast Wave

Tests

pydro: 1D Lagrangian hydrodynamics solver (Lyα uses C++)

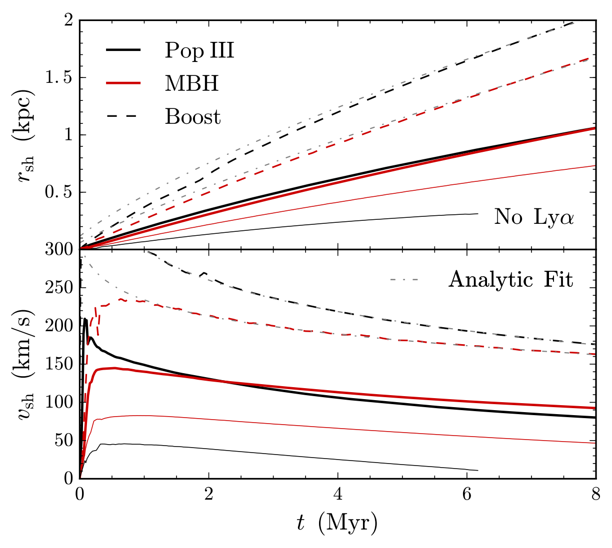
Ionizing radiation and Lyα radiation pressure

HYDRODYNAMICAL EVOLUTION OF CR7



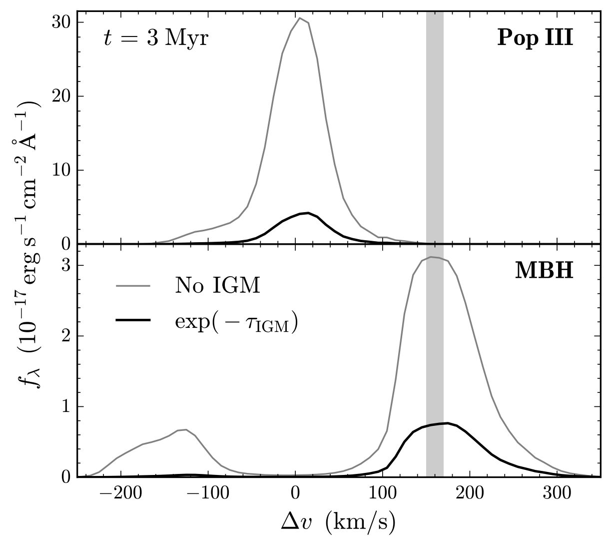
- Evolution of the gas number density and velocity.

PROPAGATION OF THE SHELL FRONT



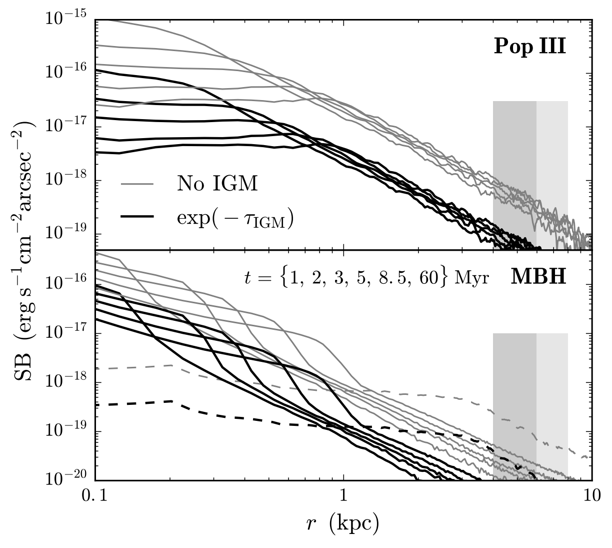
- Models: Pop III starburst (10^5 K blackbody) and massive black hole (MBH) Compton-thick spectrum from Pacucci et al. (2015)

Lyα LINE FLUX



- Residual neutral hydrogen significantly affects the emergent Lyα spectrum (160 km/s velocity offset).

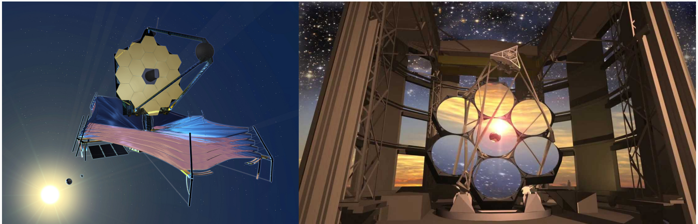
Lyα radial surface brightness



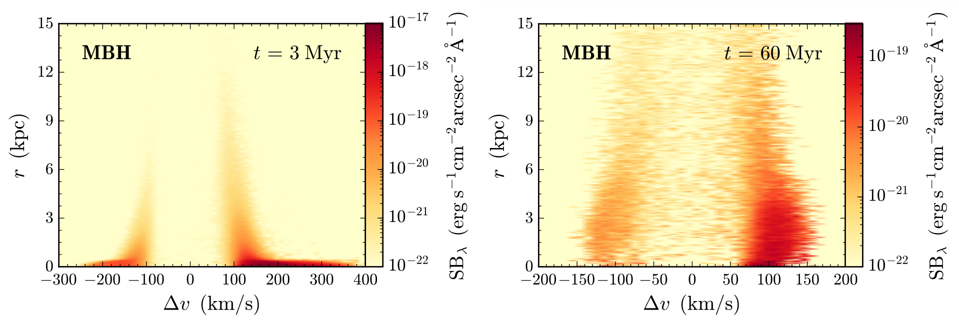
- The spatial extent of the Lyα emitting region corresponds to the shell size ($\sim$ 16 kpc diameter $\Rightarrow$ need more time).

SUMMARY AND OUTLOOK

- Lyα sources provide observational clues about the formation and evolution of the first galaxies ($\lesssim 1$ Gyr).
- Lyα radiation pressure turns out to be dynamically important.
- Our Lyα RHD simulations support the direct collapse black hole model of CR7. Pop III stars ionize too efficiently, $\Delta v \sim 0$.
- See also arguments related to DCBH formation (Pallottini et al. 2015, Agarwal et al. 2015), metal enrichment (Hartwig et al. 2015, Visbal et al. 2016), the Lyα signature (Dijkstra et al. 2016), and *ab initio* cosmological simulations (Smidt et al. 2016).

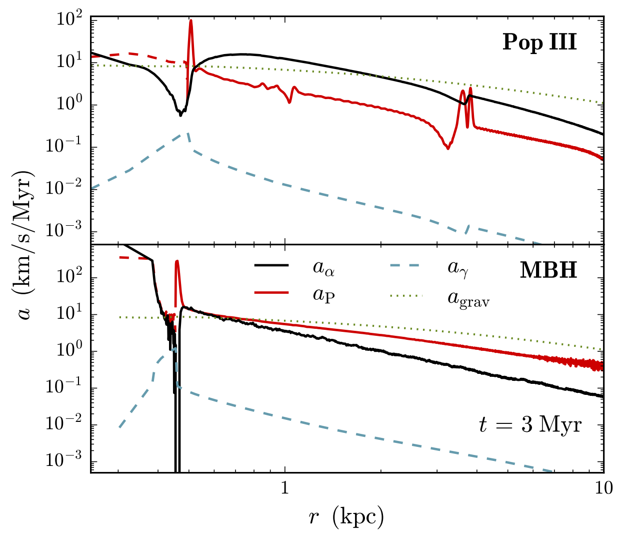


LYα RADIAL SURFACE BRIGHTNESS DENSITY



- The black hole model provides time for shell expansion.
- However, Δv decreases. Limitations of 1D calculations?
- Further caveats? Anisotropic escape, continuum leakage, self-shielding clumps, low column density holes?

RADIAL PROFILE OF ACCELERATION COMPONENTS



- Contributions from Lyα photons, gas pressure, ionizing momentum transfer, and gravity.