# Cosmic Reionization On Computers

# Nick Gnedin

**Fermilab**

THE UNIVERSITY OF **CHICAGO**

# Advantage of Going Numerical

- Can't run your dream simulation? Relax!

**2000-2010**

|  | Small box | Large box |
|---|---|---|
| physics | full | incomplete |
| spatial resolution | high | low |
| mass resolution | high | high |
| dynamic range | low | high |
| volume | small | large |

# Advantage of Going Numerical

- With peta-scale computing power we can run large-box simulations with full physics.

| | 2000-2010 | | 2015 |
|---|---|---|---|
| | Small box | Large box | |
| physics | full | incomplete | full |
| spatial resolution | high | low | high |
| mass resolution | high | high | high |
| dynamic range | low | high | high |
| volume | small | large | large |

# The CROC Project: Simulations
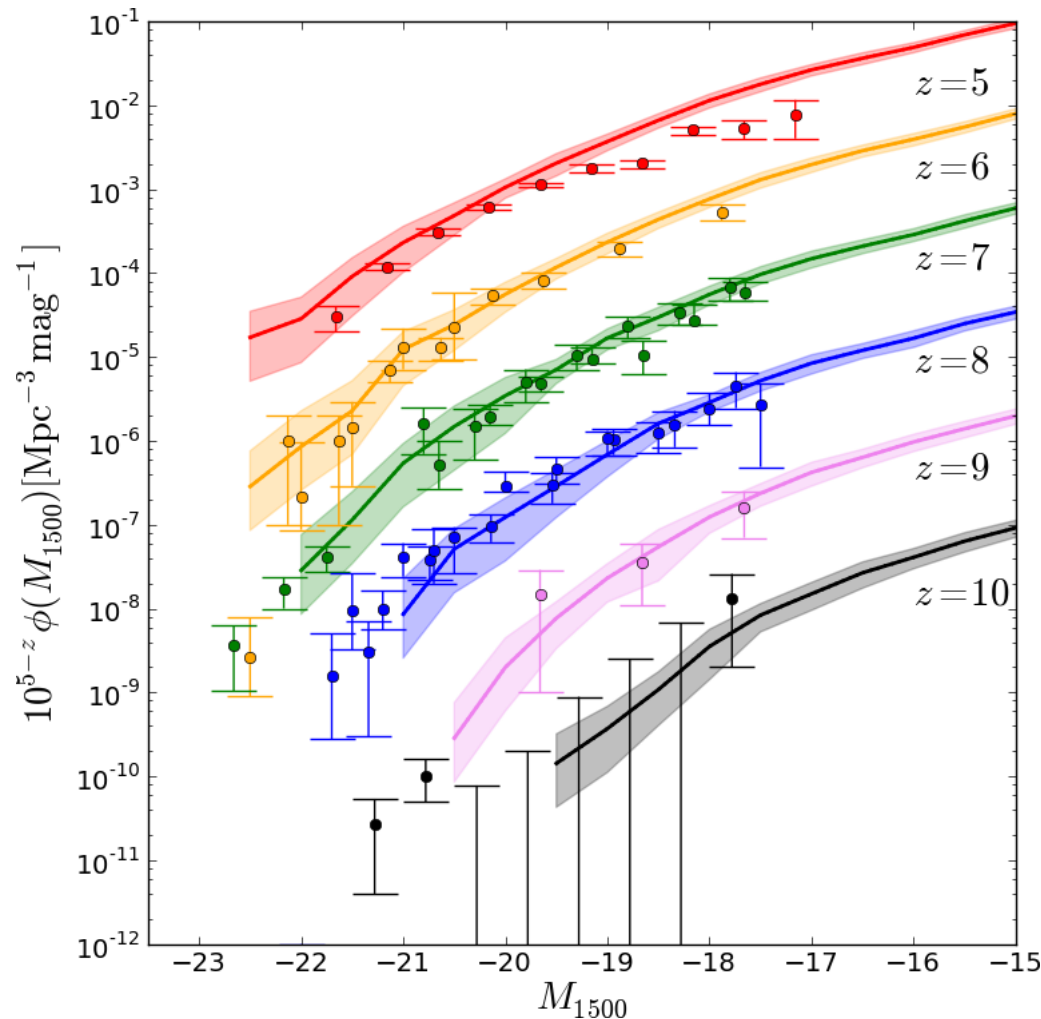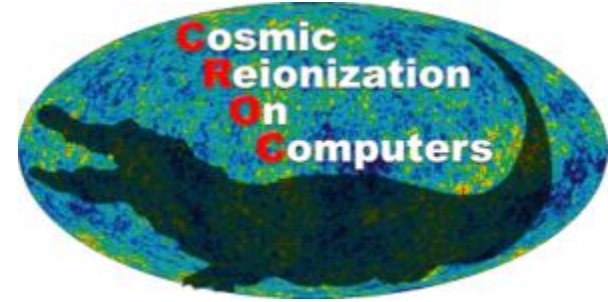
- $\Delta x$ = 100/200 pc with AMR (Deep/Shallow)
- $M_1 < 10^6\ M_\odot$
- Sets of boxes:                    Low/ Med/High
    - Small        20 CHIMP,   $256^3$/ $512^3$/$1024^3$
    - Medium     40 CHIMP,            $1024^3$/**2048³**
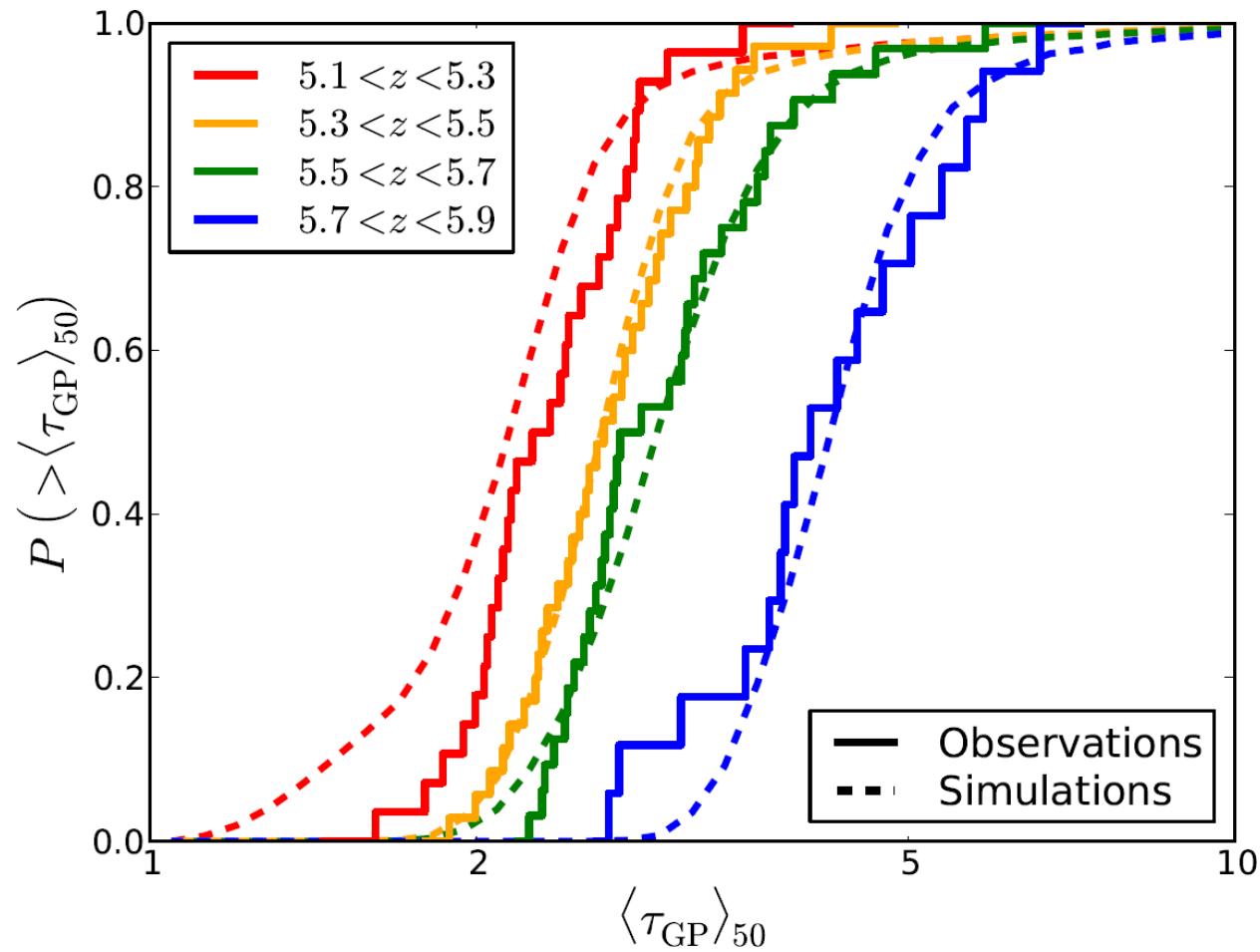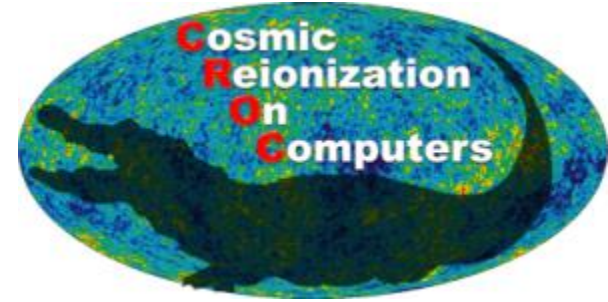    - Large        80 CHIMP,            **2048³**/4096³

"Ultimate" simulation

# The CROC Project: Survival Test #1



- Galaxy UV luminosity functions:

- **Sources** are modeled correctly (at least at z>5).
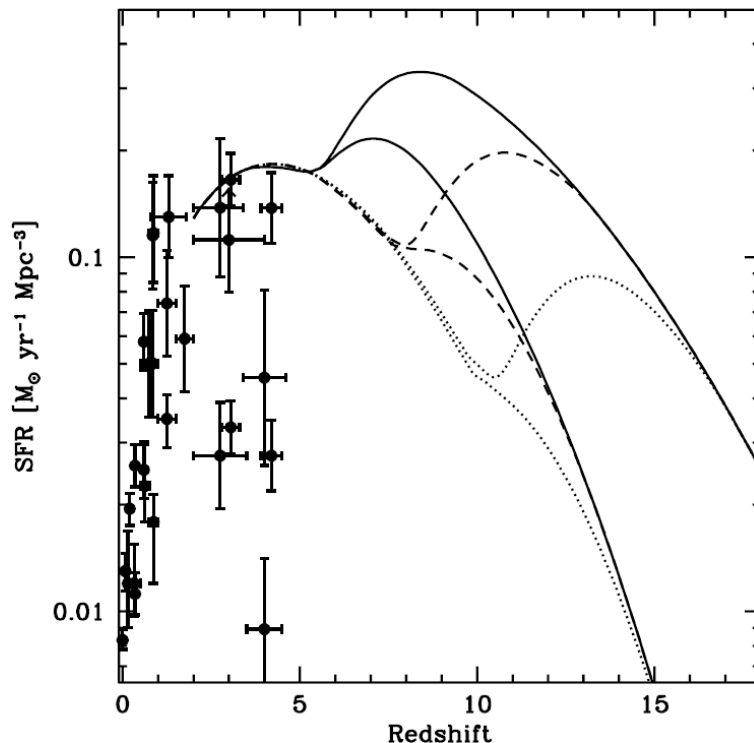
# The CROC Project: Survival Test #2



- Gunn-Peterson optical depth:
- **Sinks** are modeled correctly.

(Becker at al 2014)
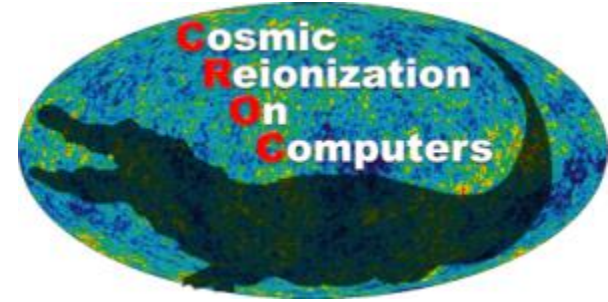
# Backreaction of Reionization on Galaxies

- Reionization suppresses gas accretion on low mass halos ("photoevaporation").

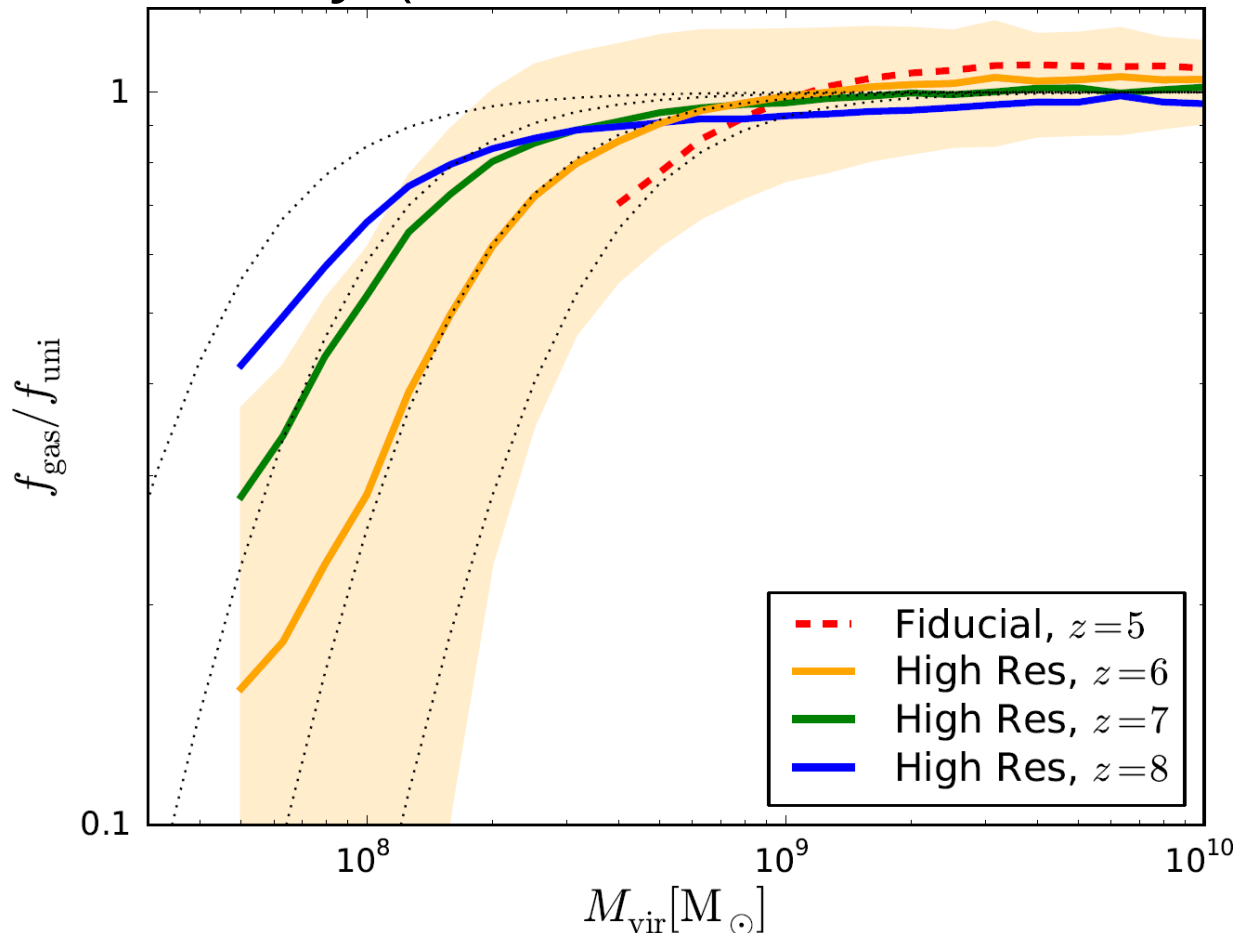- Reionization may affect global star formation rate ("Barkana & Loeb effect").

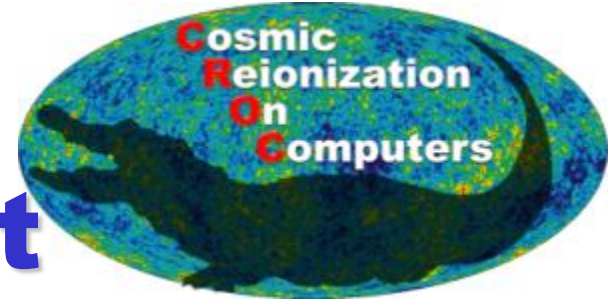- One of JWST science goals.

(Barkana & Loeb 2000)
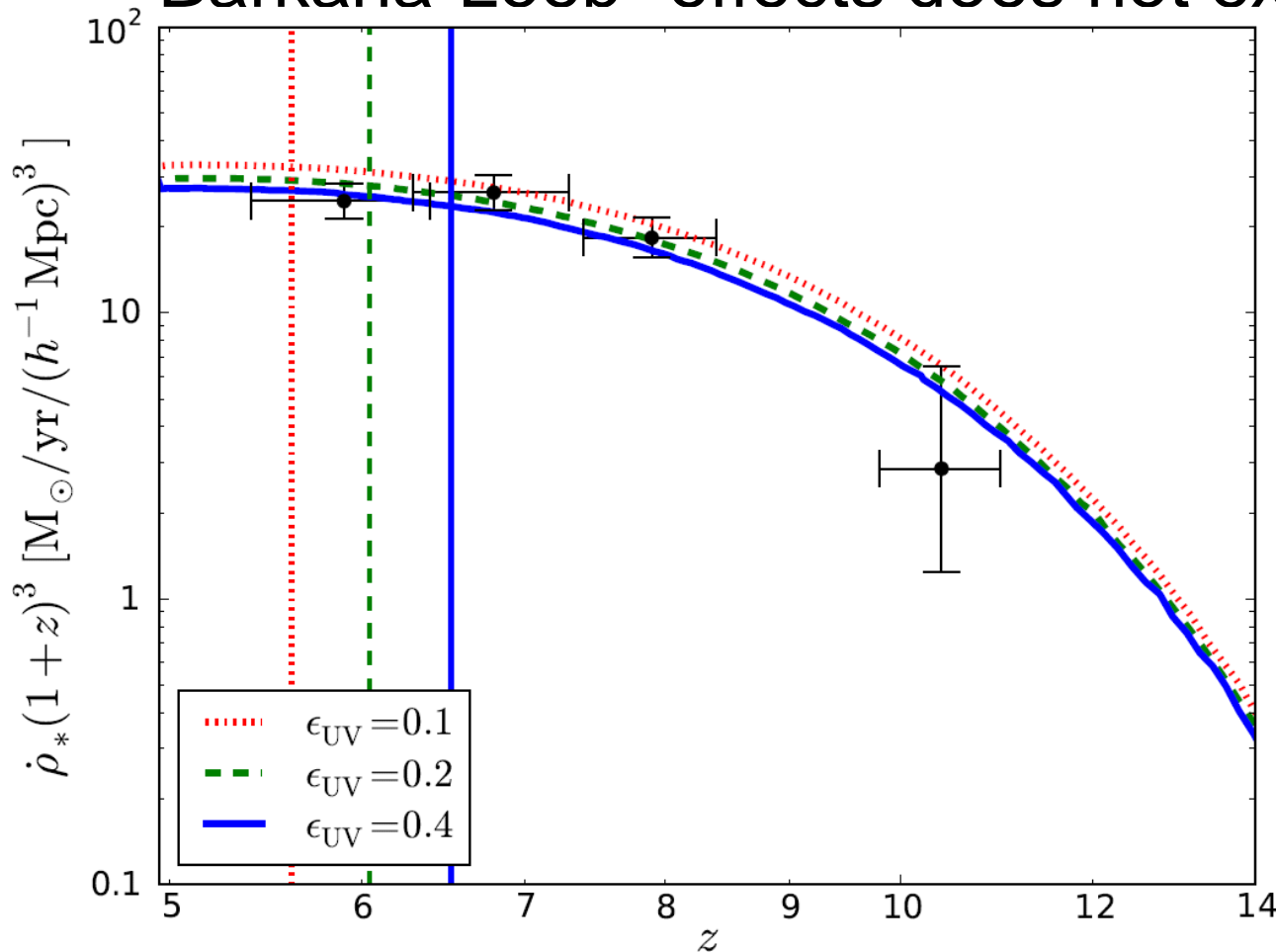
# Backreaction: Gas Fractions

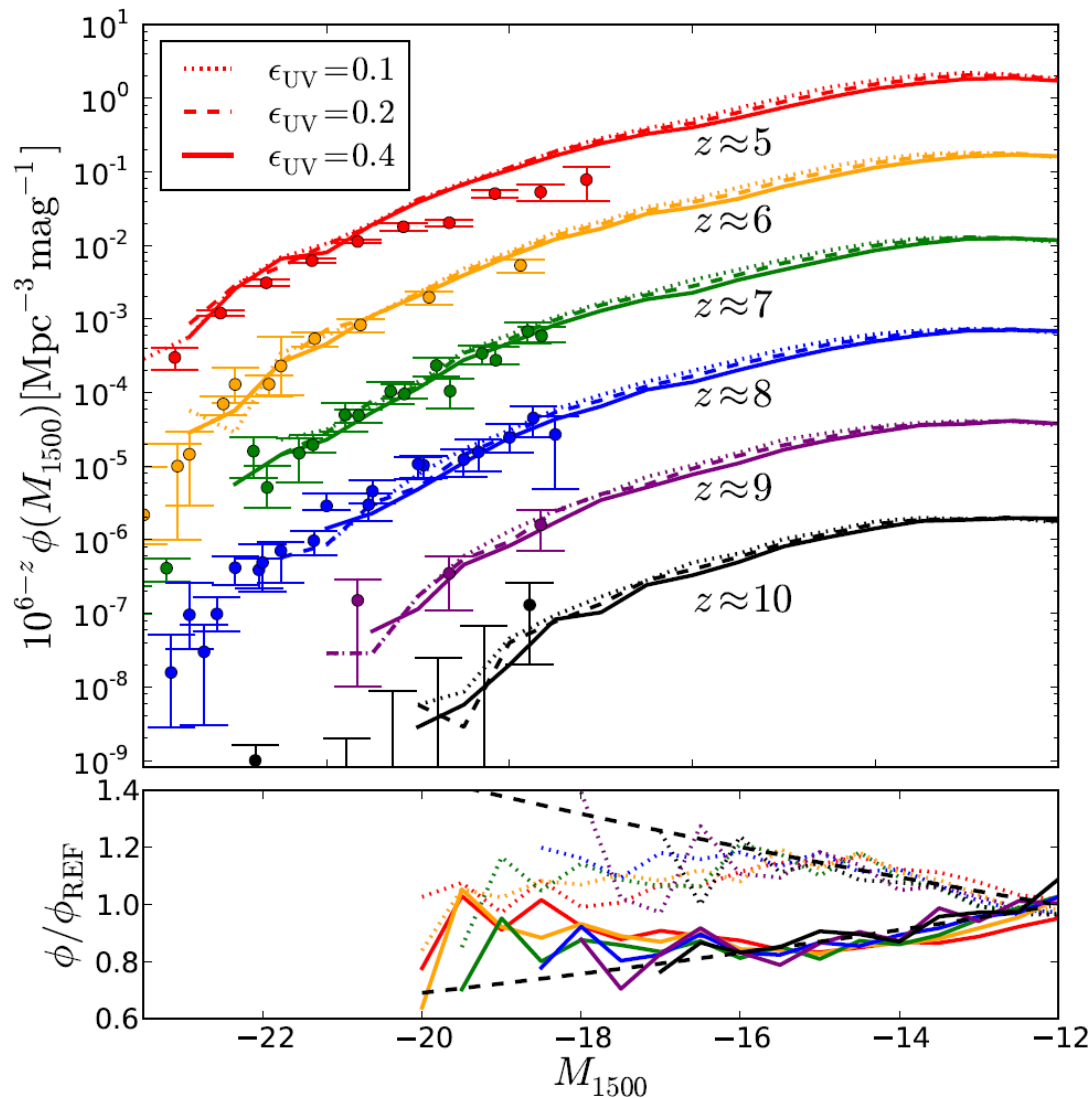- Match Okamoto et al (2008) results *exactly* (after reionization, of course).



Legend:
- Fiducial, $z=5$ (red dashed)
- High Res, $z=6$ (orange)
- High Res, $z=7$ (green)
- High Res, $z=8$ (blue)

Axes: $f_{\mathrm{gas}}/f_{\mathrm{uni}}$ versus $M_{\mathrm{vir}}[\mathrm{M}_\odot]$
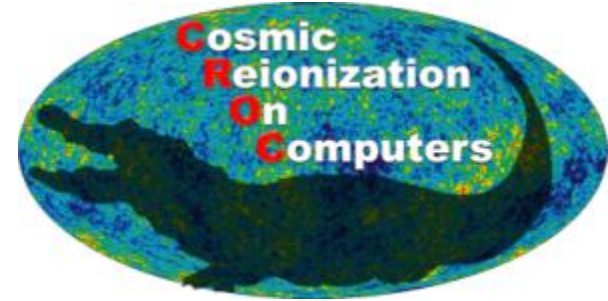
# Backreaction: Barkana-Loeb Effect

- There is no feature at reionization: "Barkana-Loeb" effects does not exist.
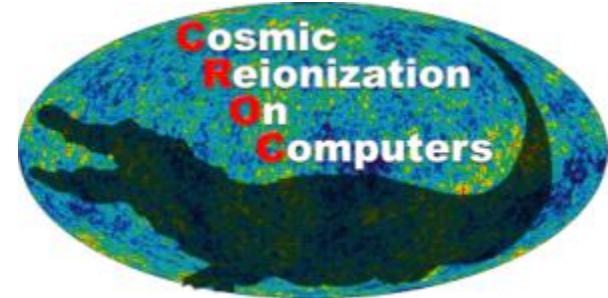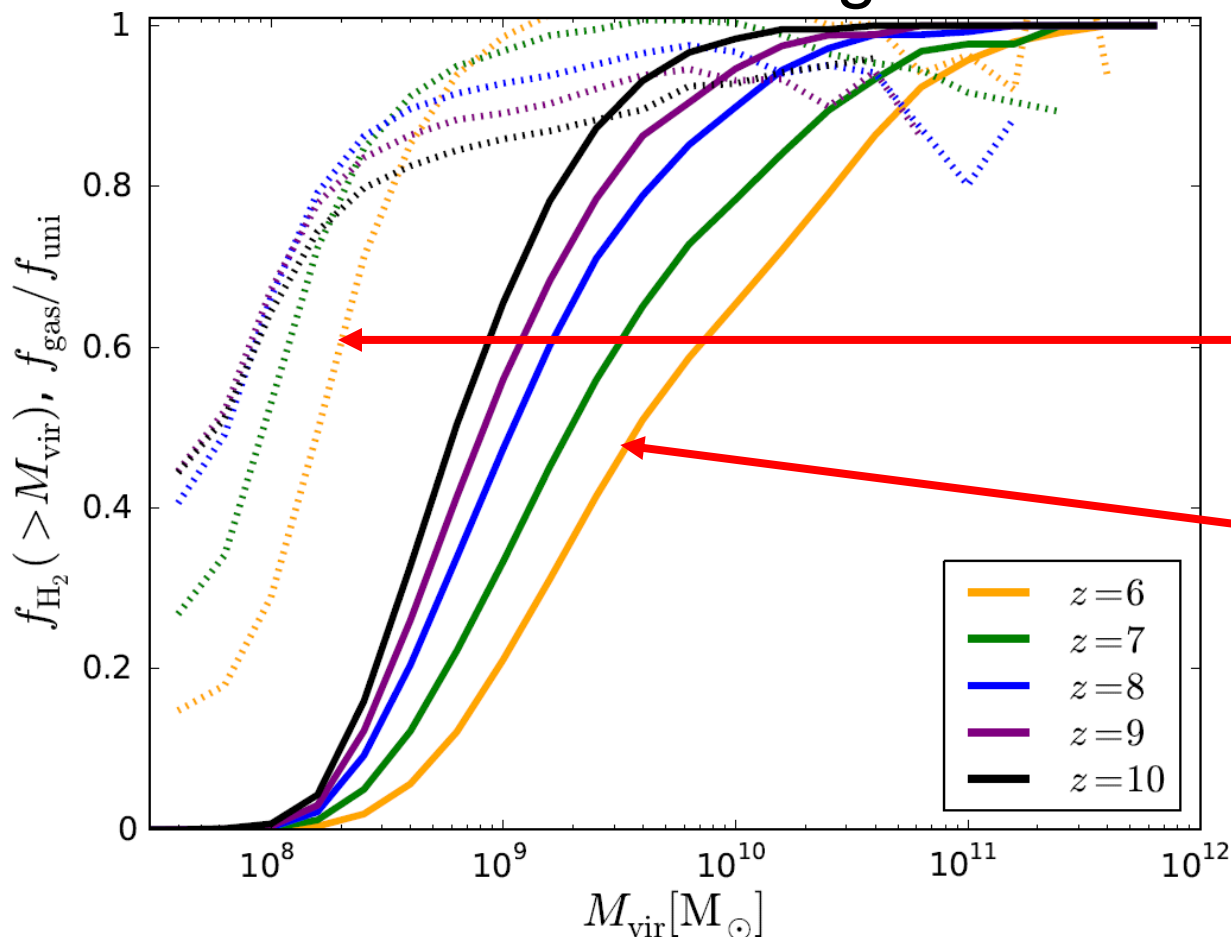
# Backreaction: Faint-End Slope



- Faint-end slope of UV luminosity function varies by $\sim 0.1$ for $\Delta z = 1$.

# Backreaction: Why?

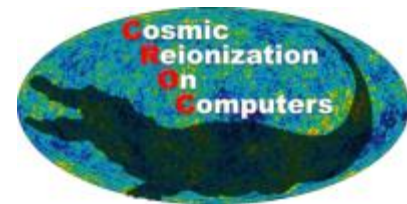- Galaxies affected by photoionization contain no molecular gas.



Gas fractions

Molecular gas

# Conclusions

- Supercomputing power has passed the "sustained peta-scale" mark.

- That power is just right for modeling cosmic reionization numerically.

- The first *realistic* (i.e. modeling both sources and sinks correctly) simulations of reionization are currently being worked on by several groups (CROC including).

- These simulations help us learn about the diverse range of physical phenomena: from cosmic dust to dark matter.

# Answers to Quintessential Questions:

- Does reionization proceed inside-out or outside-in? **Both (first inside-out, later outside-in)**.

- How does reionization affect global star formation rate? **It doesn't (galaxies that are affected by reionization have no molecular gas and, hence, form no stars)**.

- Can we use Lyman-alpha emitters to constrain reionization? **May be (but it is much harder than you think)**.

- Does dark matter annihilation contribute to reionization? **Not really.**