The Formation of the First Star in the Universe

Abel, Bryan, Norman 2001

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PHY 689 Galaxy Formation

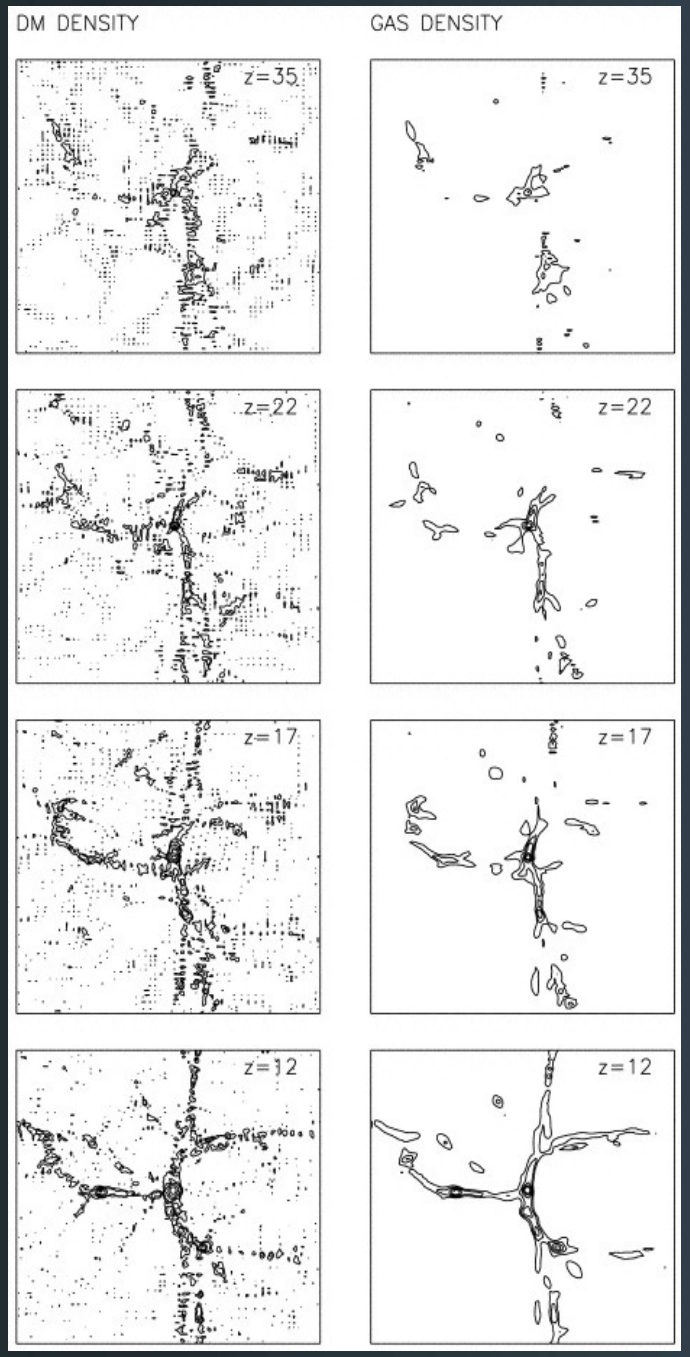
Initial Conditions

Simulating the birth of the very first star has straightforward requirements:

- **Basic Chemical and Radiative processes**
- **Negligible *B*-fields**
- **No other stars**
- **Given initial conditions**

Motivation

- **Metals in young universe** Heavy elements had to have been released and distributed in the IGM within first billion years
- **Supernova source** Only known producers of such metals; massive stars must have been amongst the earliest-formed objects



The Simulation

- Following from previous work,
- **Eulerian structured Adaptive Mesh Refinement**

- **Previous studies** traced the evolution of a molecular-cloud like structure

Fig 2., Abel, Anninos, Norman, & Zhang 1998

What determines the scale of collapse?

- **Critical mass for gravitational collapse:** Isothermal Bonner-Ebert mass $M_{BE}=1.18M_{\odot}(c_s^4/G^{3/2})P_{ext}^{-1/2}$

  $c_s^2=dP/d\rho = \gamma k_B T/\mu m_H$

- **Causes for fragmentation?**

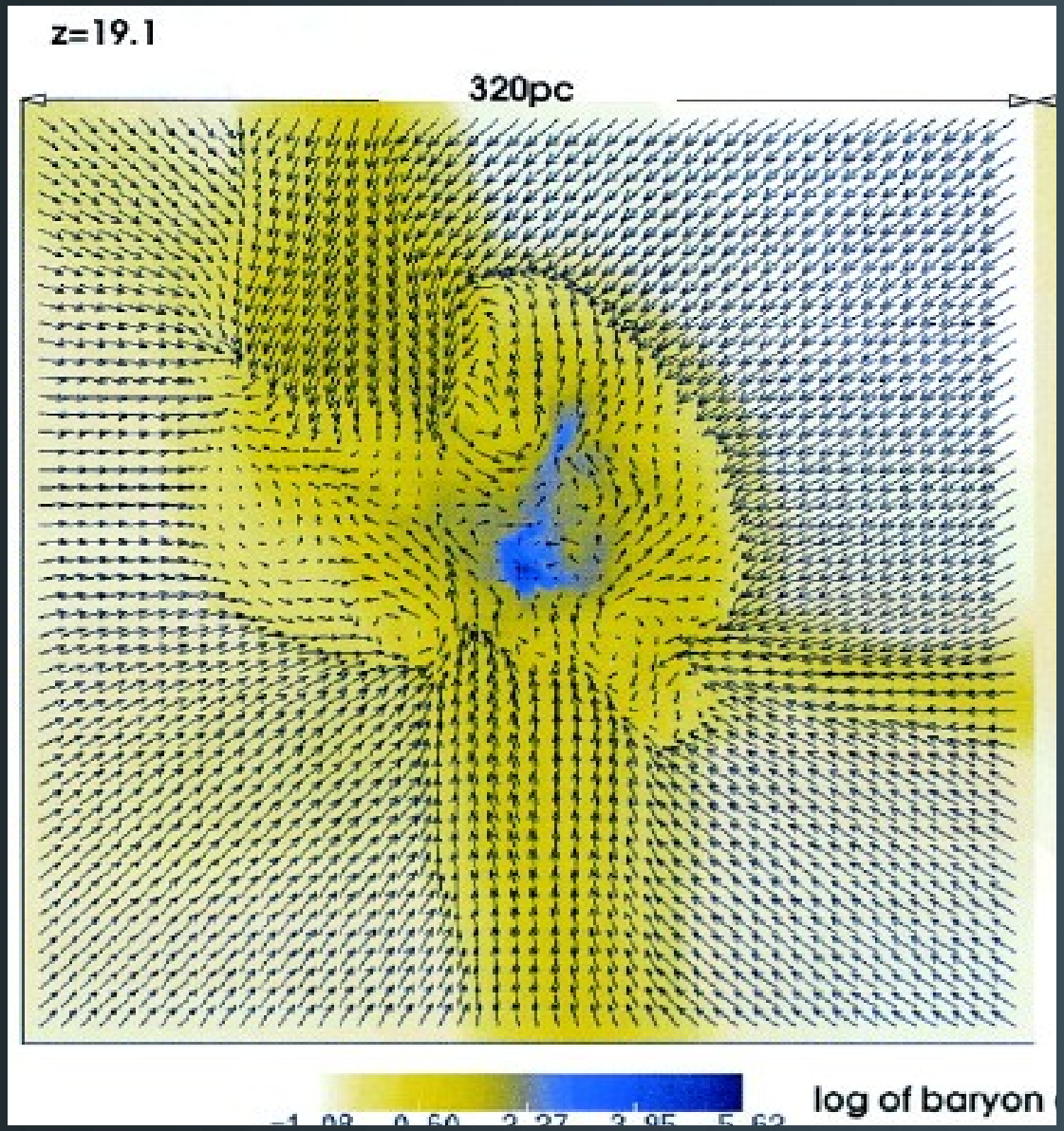
Study builds on previous results by modeling chemical processes that may affect the growth of high-mass stars in early universe

Mass Scales

Four Characteristic Mass Scales emerge

- $7 \times 10^5 M_\odot$ falls onto the pregalactic halo
- Temperature drops and molecular hydrogen fraction increases: temperature rises cooling becomes more efficient
- 100 solar mass core
- At center, 1 solar mass H_2 protostar

Accretion Snapshot



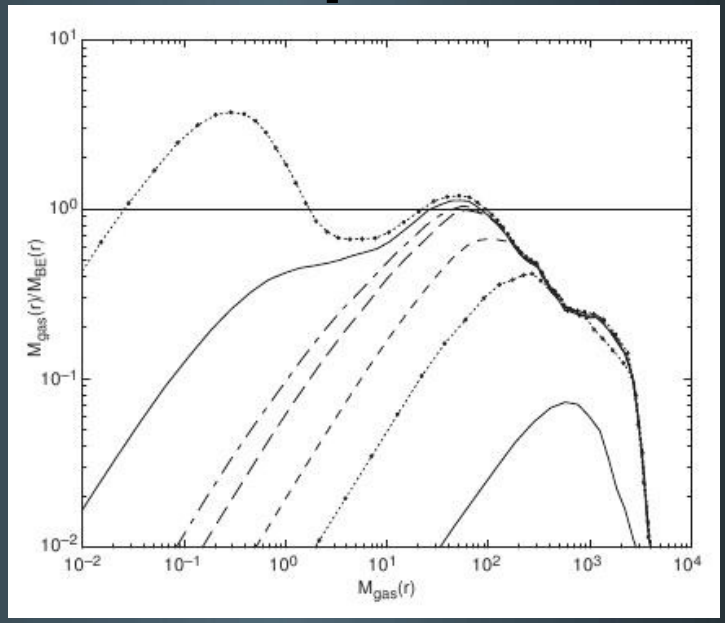


Fig 3.,
Abel, Bryan & Norman 2001

Fig 2.,
Abel, Bryan & Norman 2000

Simulation Overview

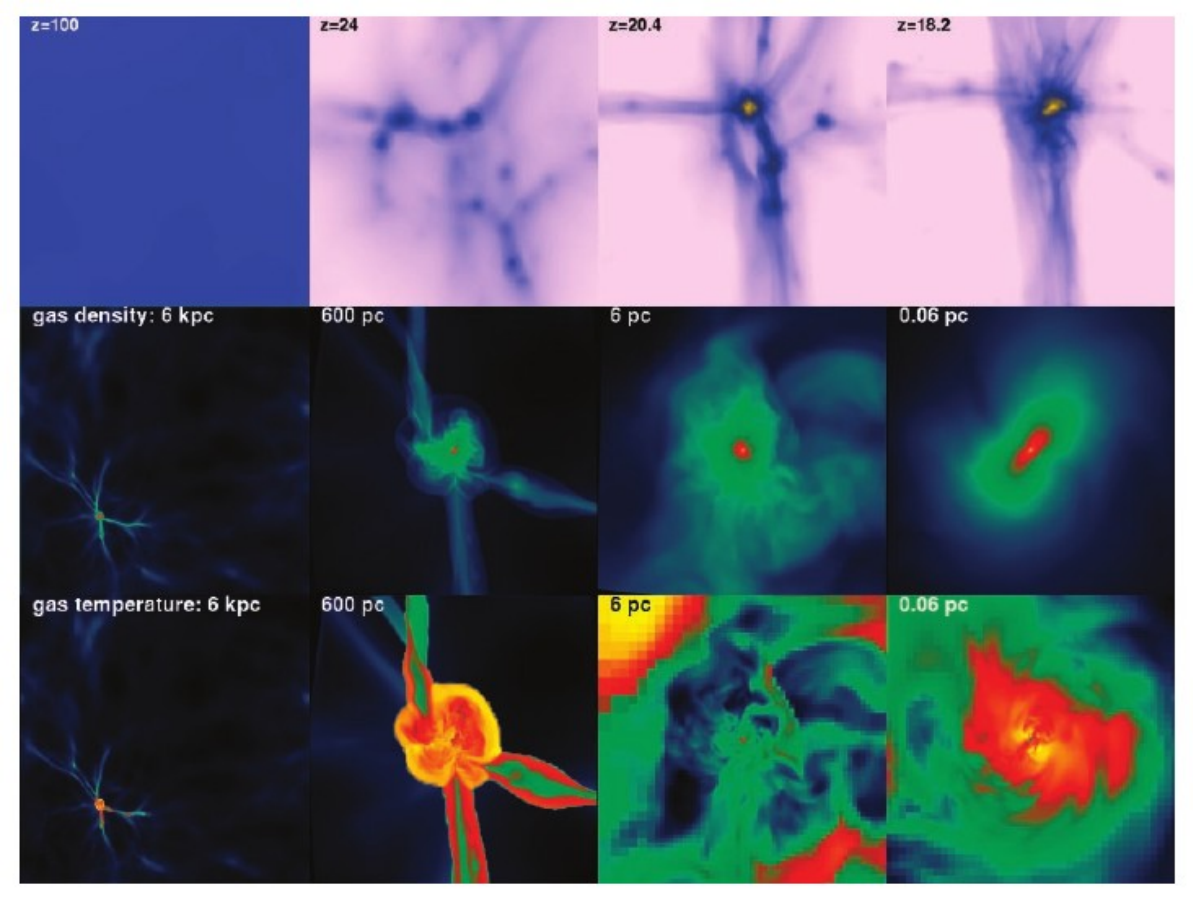


Fig 1., Abel, Bryan & Norman 2001

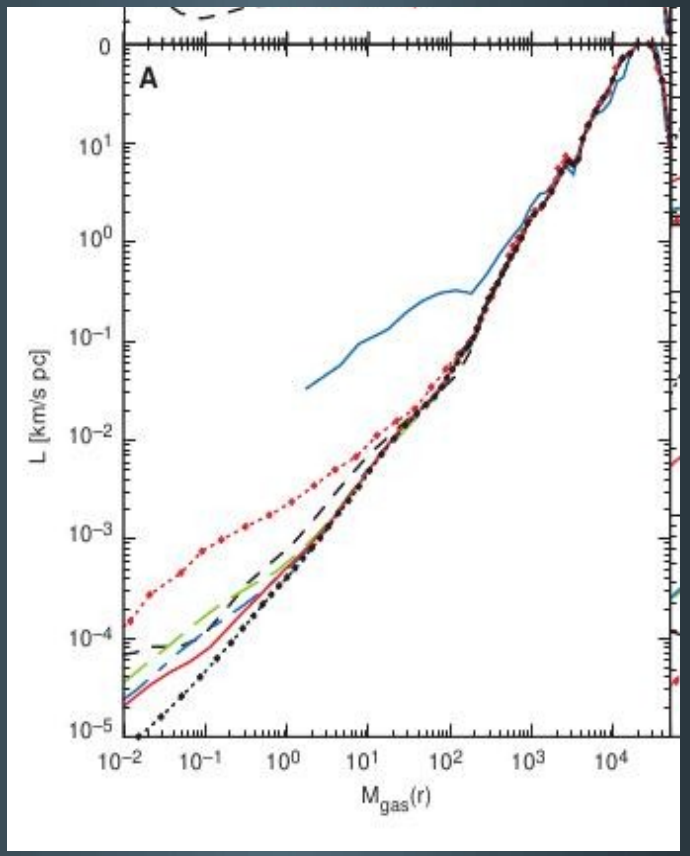
Chemo-Thermal Instability

The big question in undertaking this simulation was whether further cooling would cause fragmentation

- 3-body H interaction
  $H^- + H = H_2 + e^-$
- No correspondingly large density inhomogeneities are found and fragmentation does not occur

Angular Momentum

Rotational support does not halt collapse



- Protostellar gas starts out with little angular momentum to lose

- Angular momentum is transported outwards from the inner accreting

Magnetic Fields?

- Influence of magnetic fields at early times considered negligible
- Difference in physics of early fields may account for QCD phase transitions and Electro-weak contributions
- Ionized fraction of particles drops rapidly; would be sustained in present day by cosmic ray interaction

Results in brief

- This work extended previous studies by simulating molecular formation of H_2 via 3-body interaction
- Previously was uncertain whether this process would lead to fragmentation of the collapsing cloud
- Simulation runs out before final stellar mass is established, unknown how much more of the cloud will accrete
- Feedback from forming star may limit further accumulation

In Conclusion

- At most one massive metal-free star forms per pregalactic halo

- Possibility that all metal-free stars are massive and form in isolation; explains absence of purely metal-free low mass stars in Milky Way

- Consequences for galaxy formation: metals, entropy, ***B***-fields and possibly baryon power spectrum perturbation