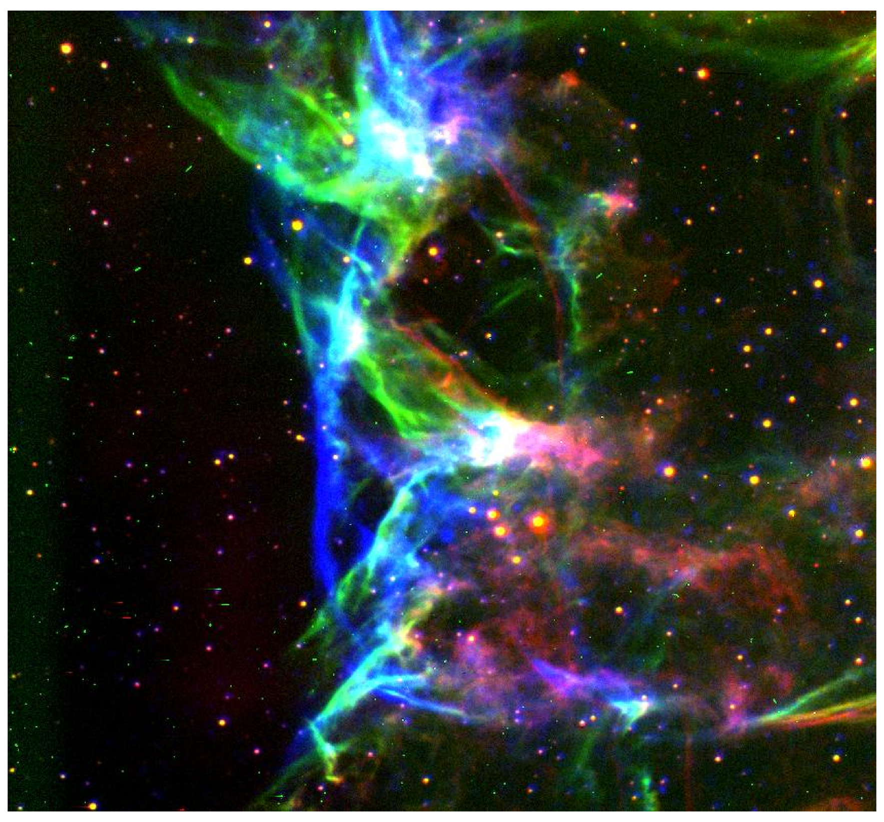
Simulating Shock Triggered Star Formation with AstroBEAR2.0

Shule Li†, Adam Frank and Eric Blackman. Department of Physics and Astronomy, University of Rochester, Rochester NY. †shuleli@pas.rochester.edu

Introduction

Star formation can be triggered by the compression from shocks running over stable clouds. Triggered star formation is a favored explanation for the traces of SLRI's in our solar system. We use the parallel AMR code AstroBEAR2.0[6] to study the shock-induced triggering of a stable Bonnor-Ebert cloud following, for the first time, the long-term evolution of the flow after a star has formed.

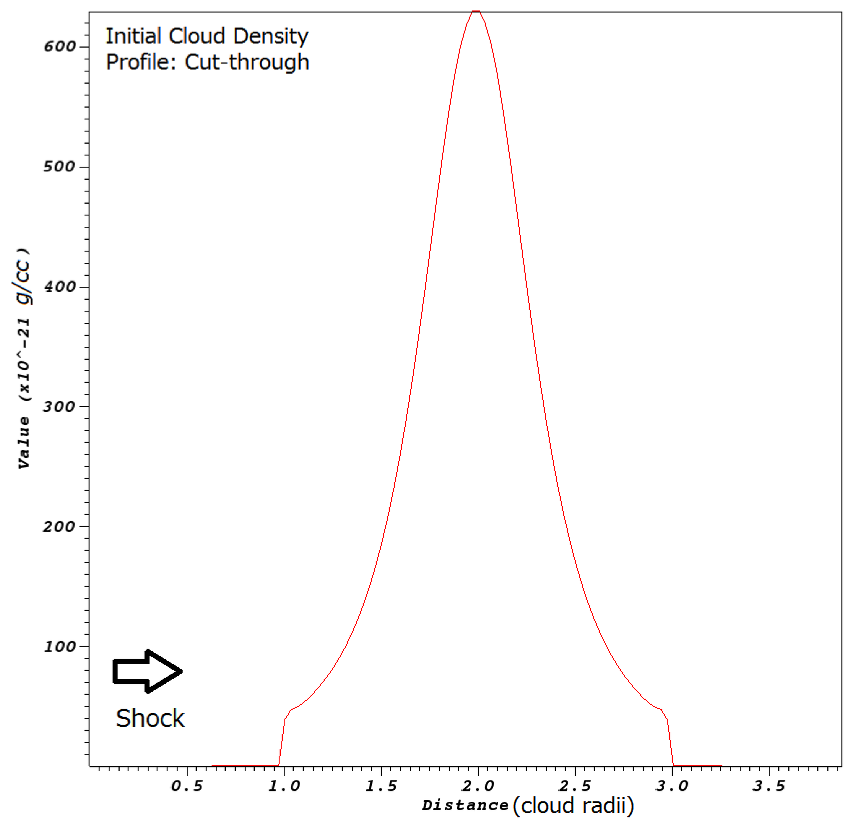


We explore:

- Non-rotating clouds, and the disruption of the protostellar envelope is by the post-shock flow terminating significant mass accretion.
- Rotating clouds, the formation of accretion disks and subsequent strong interaction of the disk and the post-shock flow.
- The evolution, in all cases, of important metrics for the evolution such as the stellar mass, accretion rate, mixing .

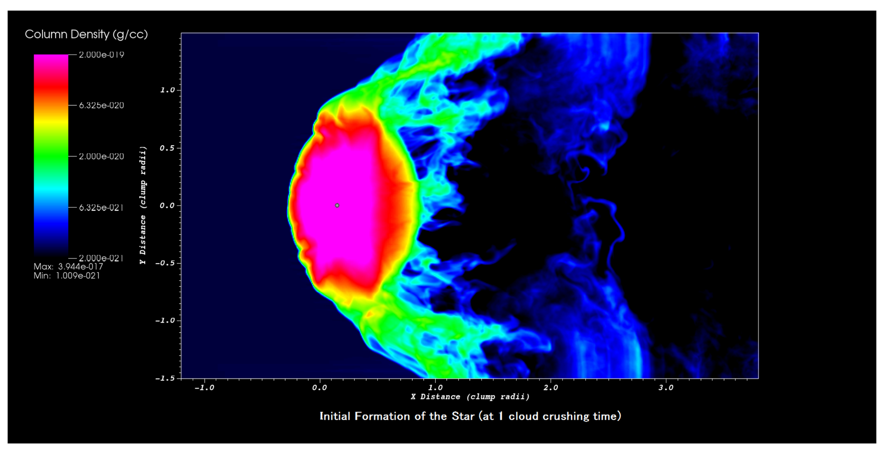
Initial Setup

We assume isothermal $\gamma = 1.0$, and an initial marginally stable Bonnor-Ebert sphere (tested to be stable within several sound crossing time) . The cloud (about 1 $M_{\odot}$) has a radius of $0.058pc$, central density $6.3 \times 10^{-19} g/cc$ and edge density of $3.6 \times 10^{-20} g/cc$, with temperature $10K$ inside. The ambient medium satisfies pressure balancing at the cloud edge, with density $3.6 \times 10^{-22} g/cc$ and temperature of $1000K$. The incoming shock has a Mach number of either 1.5 or 3.16. The cloud crushing time by the shock is $t_{cc} \approx 276kyrs$. The free-fall time of the cloud is $t_{ff} \approx 84kyrs$. We simulate the shock-cloud interaction through $4t_{cc}$ time. Krumholz accretion[4] is chosen as our sink particle accretion algorithm. With initial rotation added to the cloud, we identify $K = \Omega \times t_{ff}$ as a parameter characterizing the importance of the rotational energy: $K = 0.1$ for the rotational cases presented here.

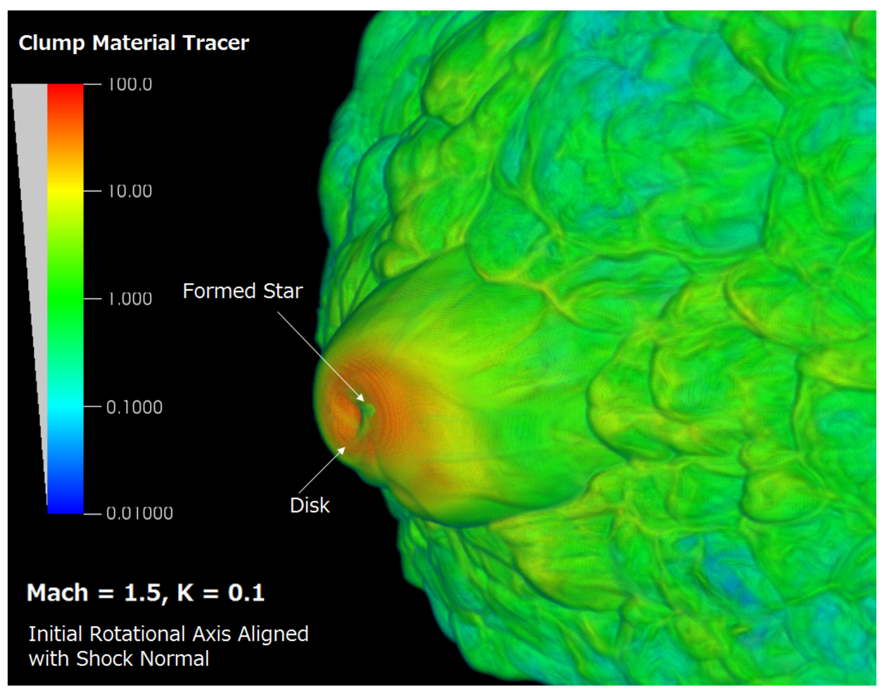


Initial Formation of the Star

For $t \leq t_{cc}$, the transmitted shock traverses and compresses the cloud. With self-gravity, the compressed cloud becomes Jean's unstable. As material continuously falls onto the compressed core, a star will eventually form accreting material from the "envelope" until this reservoir of material is swept away by the post-shock flow. For all cases presented, a star forms at cloud center at around t_{cc}. Based on the rotational property of the initial cloud, the post-star-forming evolution can be drastically different.

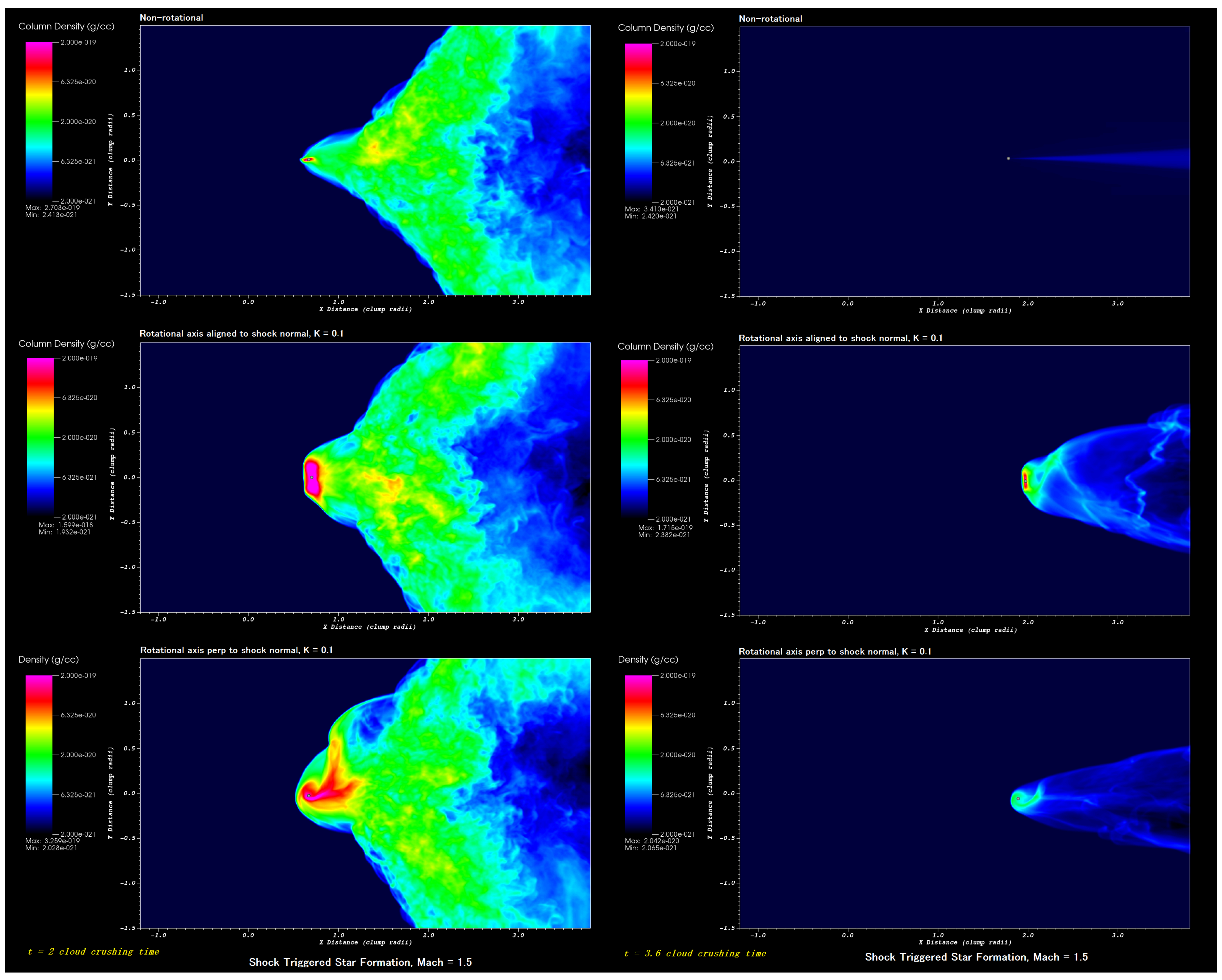


A Closer Look at Disk Formation



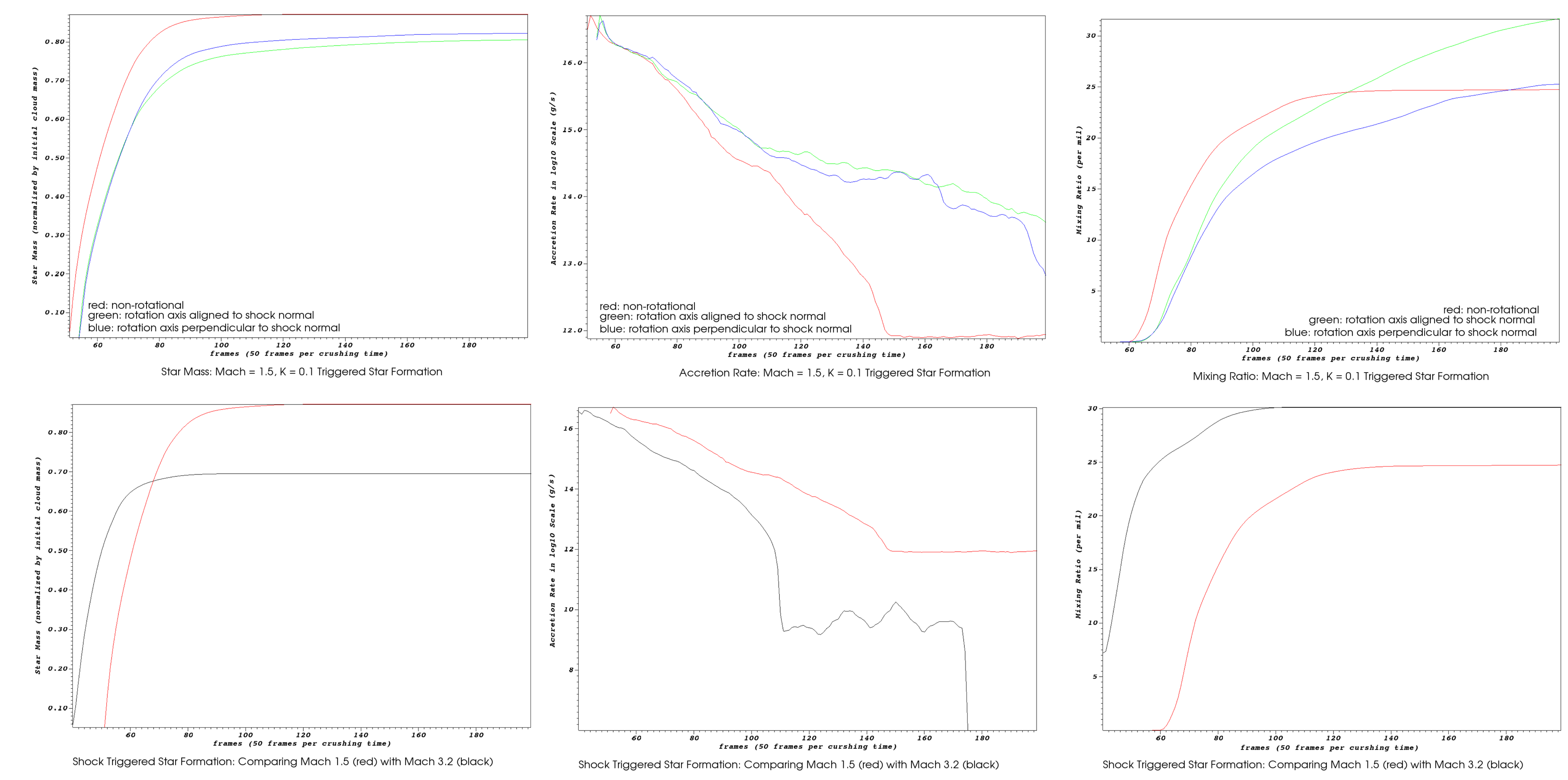
The 3D rendering of the case where the rotational axis is aligned with the shock normal, with $Mach = 1.5$ and $K = 0.1$ at $2t_{cc}$. The disk is the pancake shaped structure surrounding the star (marked in the image). As the evolution progresses disk material is ablated by the post-shock flow (see "Subsequent Star Evolution" section).

Subsequent Star Evolution



Star evolution and disk formation for the post-shock star for different rotational cases under $M = 1.5$, $K = 0.1$. Disk is formed only when there is an initial rotation. Note envelope disruption, disk formation and disk-post-shock flow interaction.

Star Mass, Accretion Rate, Mixing Ratio



Conclusions

- The lower the shock speed, the later the formation and the greater the mass of the star that forms. With $M = 1.5$, 90% of the initial cloud mass ends up in the formed star.
- Initial cloud rotation results in the formation of disk surrounding the formed star which is subsequently "harassed" by the post-shock flow.
- The accretion rate drops as the post-shock flow disrupts the envelope.
- The mixing ratio of wind material onto the star is about $20 \sim 30$ per mil in our simulations. This is enhanced with an initial rotation.

References

[1] A.P. Boss, 2010, ApJ, 708, 1268 **[2]** A.P. Boss, S.A. Keiser, 2010, ApJ, 717, 1 **[3]** A.P. Boss, S.A. Keiser, 2012, ApJ, 756, 9 **[4]** M.R. Krumholz, C.F.Mckee, 2006, ApJ, 638, 369 **[5]** C. Federrath, R. Banerjee, P.C. Clark, R.S. Klessen, 2010, ApJ, 713, 269 **[6]** Cunningham A. J. et al., 2009, ApJS, 182, 519

Acknowledgements

Financial support for this project was provided by the Space Telescope Science Institute grants HST-AR-11251.01-A and HST-AR-12128.01-A; by the National Science Foundation under award AST-0807363; by the Department of Energy under award DE-SC0001063; and by Cornell University grant 41843-7012.