1. Angular momentum (j) distribution in a 20 $M_\odot$ star evolved from an initially rigidly rotating main sequence star with equatorial velocity 200 km s^{-1} by Heger, Langer, & Woosley (1998). The solid line gives j on the main sequence; the dotted line is at hydrogen depletion; the dashed line, at helium depletion; and the dash-dotted line is the presupernova star. A decrease of the total stellar mass by mass loss during hydrogen and helium burning is apparent. The distribution of j in the presupernova star shows sharp decreases at the outer edges of convective shells and the helium core mass is 8 $M_\odot$. The helium cores considered here are more massive, but may have a similar distribution of angular momentum. The numbers plotted here have been averaged over spherical shells and the actual equatorial angular momentum is about 50% higher.

2. Density, radial velocity, specific angular momentum, and enclosed mass in the equatorial plane of the two initial models used for this study. The solid line shows Model 14A derived from a 35 $M_\odot$ presupernova star (Woosley & Weaver, 1995). The dashed line shows Model 9A derived from a 25 $M_\odot$ presupernova model. The former is our standard case. The material with low j falls in very early and most of the calculation was for $j \approx$ constant $\approx 10^{17}$ cm^2 s^{-1}.

3. The velocity field in Model 14A at 0.751 s showing early disc formation as centrifugal force begin to halt accretion near the equator and a toroidal accretion shock forms at about 550 km. Meanwhile accretion along the polar axis proceeds relatively uninhibited. The largest infall velocities just outside the accretion shock in the equator are about 25,000 km s^{-1} and at the pole 55,000 km s^{-1}. Material impacting the disk at high latitude in channeled into the accretion column. Some circulation in the disk is apparent. Because velocity arrows in this and subsequent figures have their tails in the zone they represent, the spherical inner boundary at 50 km is obscured.

4. The velocity field at 0.751 s color coded by composition. The color shows the logarithm mean atomic weight of the nuclei in the accreting gas. Here that weight ranges from 1 (nucleons) to 24 (oxygen and silicon). The shock heats the infalling gas to temperatures above 10 billion degrees causing heavy nuclei to disintegrate. The dark blue inner torus is composed of free neutrons and protons.

5. The mass accretion rate as a function of radius within 45 degrees of the equator. Farther out, where most of the mass is, the rate is just given by the dynamical response of a star that has had its central pressure support removed. The accretion rate is about 0.14 $M_\odot$ s^{-1}, but roughly half as much is flowing outwards at polar angles between 15 and 40 degrees . Closer to the disk centrifugal forces, shocks, photodisintegration, and multidimensional flows come into play and the accretion rate

varies from about 0.06 $M_\odot$ s^{-1} (solid line; "low" state; t = 7.540 s) to 0.12 $M_\odot$ s^{-1} (dash-dot line; "high" state; t = 7.598 s).

6. The simulation (crosses; density, temperature, radial velocity, disk scale height, angular frequency, and angular momentum) at t = 7.39 s during a state of high mass accretion rate (0.12 solar masses per second) compared with the semianalytic solution of Popham, Woosley & Fryer (1998; solid lines). The equatorial values for the the 2D simulation are plotted here. Interior to a transition region between 200 km and an accretion shock at 250 km, the simulation matches the steady-state disc extremely well. The temperature, to which the neutrino emission is sensitive, is matched closely which gives us confidence in using the total neutrino emission calculated by Popham et. al. for their steady-state discs. The dashed line in the angular momentum plot is the Keplerian value required to support the disc entirely by centrifugal forces. The slight upturn at small radius is an effect of general relativity. The dashed line in the scale height plot is the line H = r. The decrease below this line is due to photodisintegration.

7. The ratio of centrifugal force to gravity in Model 14A at a time 7.39 s after core collapse. An accretion shock is located at about 200 km where a disk forms. Matter initially overshoots the radius for centrifugal support and the ratio exceeds unity. In the inner disk the ratio is about 0.85. The remaining 15% is supplied by pressure.

8. The density in the central regions of Model 14A 7.60 seconds after core collapse. A dense disk (red, 10^9 g cm^{-3}) of gas is accreting into the black hole. The centrifugally supported torus has a radius of 200 km. Still higher densities exist in the disk inside the inner boundary of our calculation (50 km). Gas is accreting much more readily along the polar axis due to the lack of centrifugal support and has left behind a channel with relatively low density (blue, 10^6 g cm^{-3}). Should energy be deposited near the black hole, this geometry will naturally focus jets along the rotational axis.

9. A larger view of the density structure in Model 14A at a later time (in a calculation where no jet was initiated), 15.63 s. The inner disk with its higher density is unresolved here. The density along the polar axis has declined to 10^4 g cm^{-3}, approximately the mean density of the star.

10. The radial Mach number, M_r, at 7.60 seconds in the standard run, Model 14A, This figure highlights regions of supersonic flow and the location of shocks, especially the one at the edge of the accretion disk at 350 km. The yellow arrows near the equator represent the gas which feeds the disc (the tan toiroidal region interior to 350 km). The red arrows indicate outflow due to centrifugal bounce and viscous heating.

11. Top panel: Mass accretion rate in Model 14A for the entire 20 seconds the model was calculated within 45 degrees of the equator. After an initial accretion transient during the first several seconds, the accretion below 45 degrees is mediated through the accretion disc. An average rate of .07 solar masses per second during the next twelve seconds is modulated by fluctuations of more than 30% on time scales between tens and hundreds of milliseconds. After 15 seconds the average accretion rate dips below .05 solar masses per second. Bottom panel: A mass accretion spike near 7.6 seconds representing a high state of about 0.1 solar masses per second. The black boxes indicate times when full model dumps were written for analysis of the flow variables. The time between 7.5 and 7.7 s is spanned by 17,500 model calculations.

12. Mass accretion rate as a function of angle during the episode highlighted in Fig. 11. The integrated accretion rate is given between the equator and 22.5 degrees (dashed line); 45 degrees (solid line); and 90 degrees (dash-dotted line). Most of the accretion is through the disk and not from the polar accretion column.

13. On a smaller scale the surface mass density (Σ, top panel) and radial velocity in the equatorial plane (lower panel) as a function of radius in the equatorial plane at two different times. The dash-dotted line is for 7.540 s, the solid line for 7.598 s. The dashed vertical line is where gas with $j_{16} = 10$ is supported by Keplerian rotation. The velocity in the inner disk stays roughly constant while the density during a high accretion episode increases due to the higher rate it is fed mass through the shock. Fig. 14 shows the mass flow patern at these two times.

14. The mass flux field, ρ times $\mathbf{v}$ at the same times as Fig. 13. The top panel is at 7.540 s; the lower at 7.598 s. The largest arrows are for $\rho\mathbf{v} \sim -8 \times 10^{17}$ g cm^{-2} s^{-1}. During a high accretion state the gate is open, the disk briefly collapses and matter flows in. During a low state the disk grows and flow stagnates as matter swirls at the outer boundary of the disk.

15. Fourier power spectrum of the accretion rate shown in Fig. 11. Significant power peaks are seen at time scales of 50 ms and 25 ms. The former is approximately the viscous time of the disk and also approximately the orbit time at the outer edge of the disk. The latter is its first overtone. The sampling of models every 100 timesteps has a characteristic time scale of $\sim$ 1 ms (the Courant condition in the innermost disk set the timestep at $\sim 10^{-5}$ s), so even time scales of 25 ms were well sampled in the calculation.

16. Flow patterns in Model 14A at 9.48 s on a larger scale (50000 km). This figure shows, for a calculation in which no neutrino energy deposition was included, powerful

outflows still developing with speeds exceeding 40,000 km s^{-1} and moving outwards at approximately 15 to 40 degrees off axis. As they approach the surface (not shown) the velocity increases and mildly relativistic mass ejection may occur. These outflows are absent in Model 14B with a low disk viscosity. The black regions are still accreting and continue to feed the accretion disk and black hole.

17. Origin of the viscosity driven "wind" shown in Fig. 16. Regions of high entropy (red; $S \approx 55$) are heated by viscous dissipation. Typical ratios of orbital velocity to radial velocity are about 10 in the high entropy region and the orbital speed is about 10^{10} cm s^{-1}. Density in the high entropy region is about 5×10^7 g cm^{-3} and the temperature, 1.5×10^{10} K. Viscous dissipation in releasing 5×10^{29} erg cm^{-3} s^{-1}. All the material shown in the figure, except that along the accretion column, is composed of nucleons. When these reassemble the composition will be mostly ^{56}Ni and helium.

18. Upper panel: The total outward directed kinetic energy in the "plumes" (Fig.16) grows with time. After 8 sec, material begins to leave the computational grid, but a total energy of 2 - 3 $\times 10^{51}$ erg is estimated to have been generated in 20 sec. Lower panel: Total energy dissipated in the disk exterior to 50 km integrated over time. A much larger amount of energy is dissipated interior to 50 km but is not included here. The energy in the plumes is about 2% of that dissipated in the disk on the grid carried.

19. The hole mass and normalized Kerr parameter grow rapidly in the first second as the dense stellar core collapses through the inner boundary at all polar angles. After the first solar mass is accreted (in approximately one second) centrifugal forces begin to halt the collapse along the equator and an accretion disk forms. The upper panel shows the increase in the Kerr parameter for various models for the disk interior to the inner boundary at 50 km. "Thin" (dash-dot), neutrino-dominated (thick solid) and advection dominated (short dash) models are shown for initial Kerr parameter $a_{\rm init} = .5$. The thin solid line shows the neutrino dominated case for $a_{\rm init} = 0$. The value of a at 20 s for the four lines given is .9849, .9752, .8591, and .9274. The lower panel shows the growth of the gravitational mass of the black hole. The short-dashed line shows the growth in baryonic mass of the black hole since for a pure advective model no energy escapes the inner disc.

20. Energy deposition rate due to neutrino annihilation in the polar regions for Model 14A assuming an initial Kerr parameter of 0.5 which increased with time as in Fig. 19. The rates were calculated by interpolating the models of PWF in mass accretion rate and Kerr parameter. A constant black hole mass of 3 $M_\odot$ was assumed in this interpolation. The top panel shows the time history of the energy deposition; the

middle panel, an expanded version of the energy deposition from an accretion spike (Fig. 11). The lower panel shows the total neutrino luminosity of the disc that gave the deposition in the top panel. After about 15 s, the energy deposition declines due to a decreasing mass accretion rate.

21. Time integrated neutrino annihilation energy. The top panel shows the running integral of the energy deposited for two choices of initial Kerr parameter($a_{\rm init} = 0$: dashed lines; $a_{\rm init} = 0.5$: solid lines) and for two assumptions regarding the efficiency of neutrino annihilation (see text). The higher lines for each case use the "optimistic" neutrino rates. The bottom panel gives the *total* neutrino energy radiated from the disk for the same assumptions.

22. Density structure at 7.52 s in the low viscosity run, Model 14B. Note the higher density contrast and more massive disk than in the calculation with high viscosity (Fig. 8). The opening angle of the accretion column is also larger and viscosity induced outflows are absent.

23. Despite its low viscosity, the accretion rate in Model 14B is about the same as in 14A (Fig. 11). Mass flow through the disk is in steady state with the rate at which it is being fed by stellar collapse. Unlike Fig. 15, a Fourier power spectrum of this rate shows no preferred frequencies. The narrow spikes are numerical noise.

24. Velocity vectors show the onset of a mild explosion produced by a combination of rotation and oxygen burning. The largest velocity vector shown in the outflow is 17,000 km s^{-1}.

25. Velocities in the equatorial plane for two runs that did (upper line) and did not (lower line) include energy generation from oxygen burning.

26. Density, temperature, internal energy per gram, and pressure along the polar axis (i.e., in the center of the jet) in Model 14A at a time of 8.43 s, 0.83 s after 5×10^{50} erg s^{-1} began to be deposited just above and below the hole (see text). All quantities are in cgs units. Pressure jumps about a factor of 100 in the jet. The shock is very strong. Entropy in the shocked region is $\sim 10^4$.

27. Energy density in the jet and surrounding area 0.824 s after its initiation. The jet has now moved 7,000 km. While its velocity cannot be accurately determined in the non-relativistic code used for this calculation, the energy density is typical of highly relativistic matter with Γ over 10. The jet remains highly focused with an opening angle (half width) of about 10 degrees. The red regions at polar angles of 35 degrees are the plumes formed earlier by dissipation in the disk (§4.1.5 and Fig. 16).