# Oval Orbiting Stellar Winds


## Andrew Elliott & Francis P. Wilkin

### Union College Physics Department



## Abstract

Stars typically eject a continuous supersonic flow of gas known as a stellar wind. Most stars are in multiple systems with two or more members, and their orbital motions affect the wind morphology. The Wilkin and Hausner (2017) orbiting wind model made the assumption that the wind was initially isotropic at launch. Here, we generalize this wind to a non-isotropic launch that is concentrated to the poles or equator of the star. This paper presents a self-consistent solution to this problem for the wind velocity and density structure.


## Introduction

- In a binary or multiple star system, the orbital motion affects the overall flow of the winds.
  - As the stars follow their orbits, their motion continuously changes the launch locations as the position and velocity of the star varies.
- The flow stellar winds in space exhibit similar features to the fluid flow of liquids and especially gases, which is why they can be expressed using fluid dynamics.
  - Fluid dynamics describe the motion of gases and liquids as functions of space and time. In particular the relationship between the density, pressure and velocity are all functions of position and time.

## Background and Formulation

- In previous work, Wilkin & Hausner (2017), considered the effects of a circular stellar orbit on an initially isotropic wind (see Fig.1). Here, I will generalize the wind to be dependent on latitude at launch. This initially oval wind will be distorted by the orbital motion as studied here.
- I assume:
  - Pressure-less (cold) fluid flow
  - No net force on fluid particles after launch
  - Steady-state solution in the corotating frame
  - Initial wind symmetry axis normal to orbital plane
  - Circular stellar orbit
  - No interaction between the two stellar winds

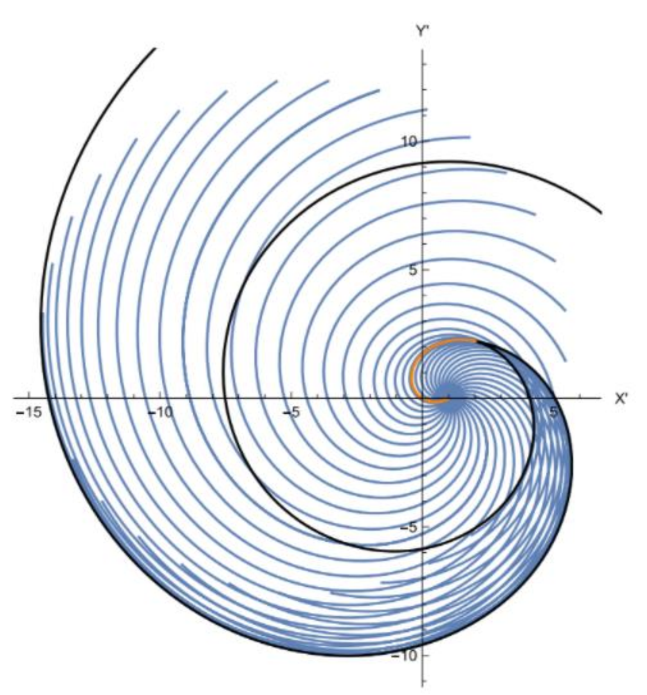


Figure 1. Wind Streamlines(in blue) from the WH17 Solution in the orbital plane. The wind is launched from position (1,0,0) in units of the orbital radius. The thick black curves indicate locations where the streamlines cross and a shockwave exists.

## Flow Kinematics

- In an inertial frame, a fluid element travels in a straight line at constant speed. This behavior is expressed in Equation 1, where the first term on the right hand side is the launch location (the stellar location, treated as a point). The second term describes how the fluid travels a distance from the launch point proportional to the elapsed time (t - τ). $V_*(\tau)$ is the star's velocity in the inertial frame at the time of launch and $V'_w(\alpha,\delta,\tau)$ is the launch velocity in the moving frame.

$$\mathbf{R}(t) = \mathbf{R}_*(\tau) + (t-\tau)[\mathbf{V}_*(\tau) + \mathbf{V}'_w(\alpha,\delta,\tau)], \quad (1)$$

- The functions of $V'_w(\alpha,\delta,\tau)$ are dominated by the δ term due to the fact that $V'_w(\alpha,\delta,\tau)$ is equal to $V_w$avg * h(δ) * $\dot{V}'_o$ . This makes $V'_w(\alpha,\delta,\tau)$ dependent on the latitude δ only, which is reasonable for most stars.
  - $\dot{V}'_o$ is a unit vector that points away from the star radially (see Fig .2).

$$\hat{\mathbf{v}}'_o = \hat{\mathbf{x}}'(\tau)\cos\delta\cos\alpha + \hat{\mathbf{y}}'(\tau)\cos\delta\sin\alpha + \hat{\mathbf{z}}(\tau)\sin\delta. \quad (2)$$

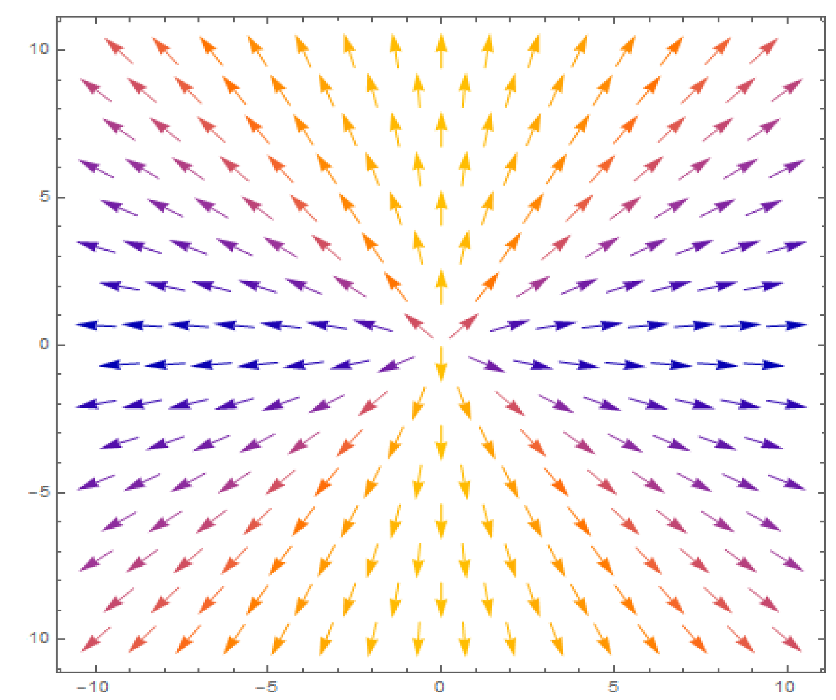


Figure 2. Velocity vector plot

## Fluid Density

- Fluid dynamics are based on the conservation laws of mass, linear momentum and energy. These dynamics follow the continuum assumption. This allows for the assumption that fluids are continuous and not discrete.
- The characteristics of the density can be expressed as a function by solving a mass conservation equation (Eq. 3) with a density unit. $\rho_o$ is the density unit and $M_w$ is the mass-loss rate of the wind (Eq .4).

$$\nabla \cdot (\varrho \mathbf{v}') = 0. \quad (3)$$

$$\rho_o = \frac{\dot{M}_w}{4\pi R_o^2 V_w} \quad (4)$$

- Figure 3 and Figure 4 show the isomomentum and isomass plots of the wind's density
  - These were solved for the flow of the velocity field using assumed functions. They have streamlines similar to the WH17 (Fig .1) model but have different density behavior
  - On both plots there are two points where all the lines intersect at y=1
  - The pivot angle is at Cos(μ) = 1/√3, where δ is equal to 54.7º degrees. This is the temperate latitude and values above this describe polar dominated winds, whereas values below it are dominated by equatorial winds.

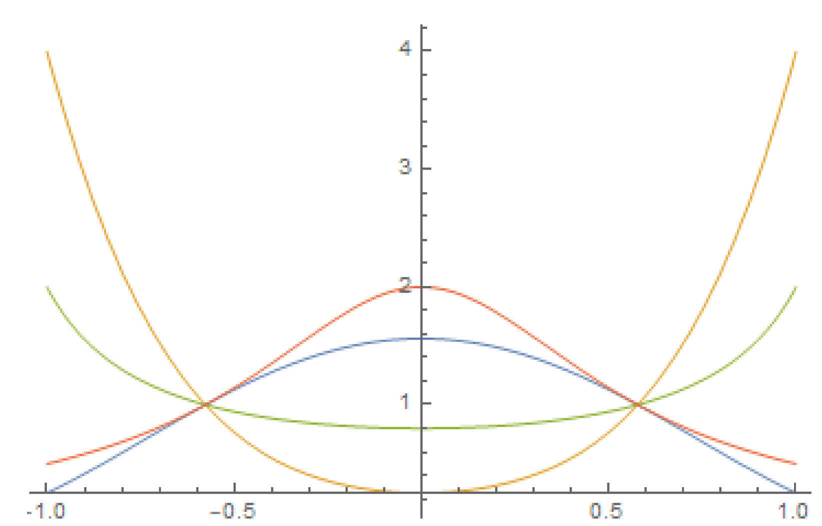


Figure 3.

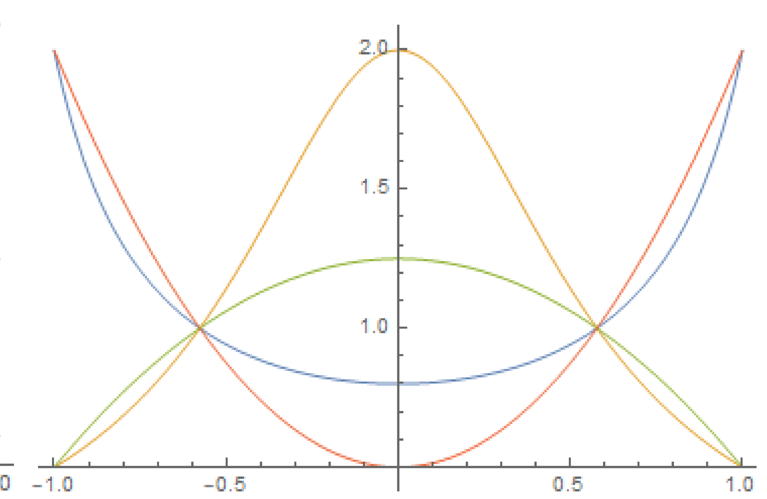


Figure 4.

## Summary and Conclusion

- I have analytically solved for the stellar wind's flow structure with an initially latitude-dependent stratification. This is solved specifically in the context of a binary star system that has circular orbits.
- The general flow of these winds consist of spiral streamlines and density that decreases with distance from the origin. However, streamlines converge in certain locations resulting in a shock-wave structure whose properties will be determined in future word.
  - We also anticipate creating tilted-axis models that relax the perpendicularity assumptions made here.

## References


- Wilkin, F.P. and Hausner, H 2017 Astrophysical Journal 844, 29



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