Stellar Wind Simulations: The Bubble Nebula

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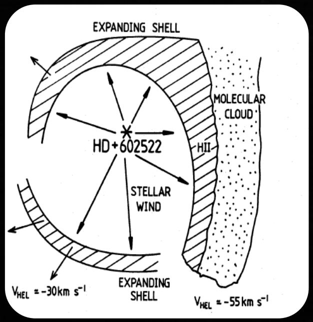
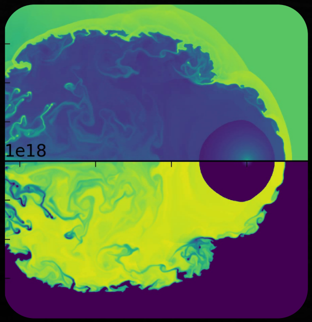
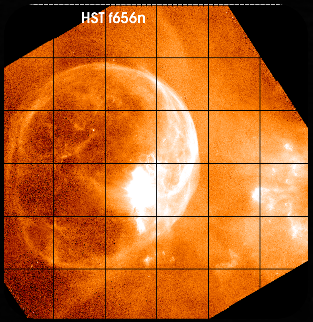
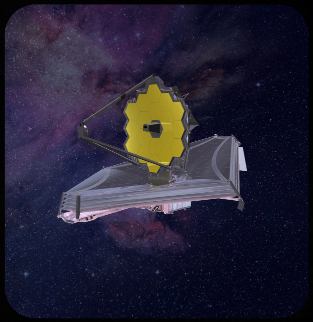
Content









Overview of NGC7635

Old Model

Proposed Model:

Simulations

Future Analysis

Satellite Predictions

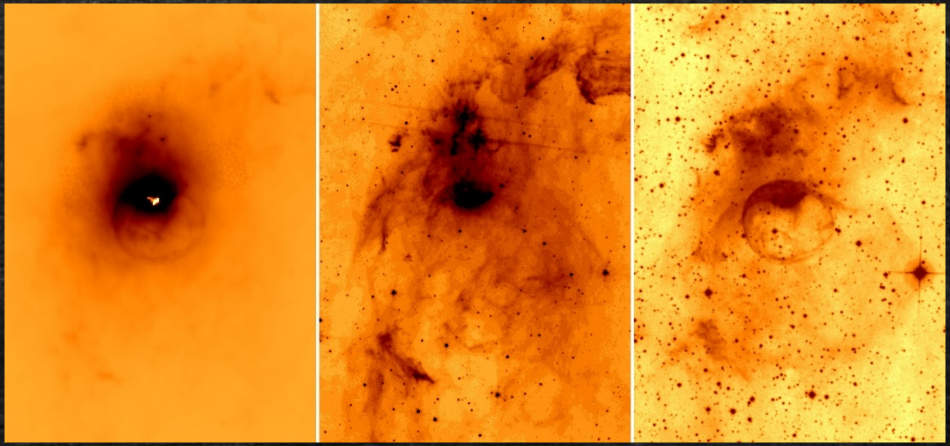
The Bubble Nebula

Hubble optical image of NGC 7635 (Bubble Nebula).
Credit: NASA / ESA / Hubble Heritage Team

- As stellar wind expands out from a star, its kinetic energy is converted to thermal energy as it interacts with gas from the Interstellar Medium (ISM).
- A low density bubble is created from this interaction, expanding with time.
- Detailed observations and modelling have been carried out by Christopoulou et al. (1995), and HST observations by Moore et al. (2002). Since then it hasn't attracted much interest.

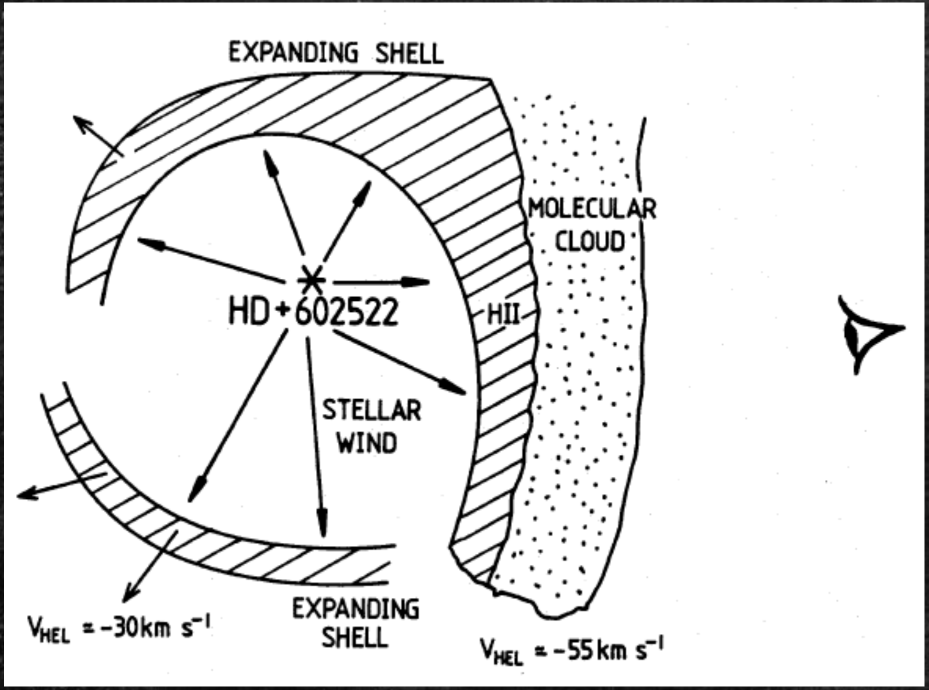
The Bubble Nebula

- These stellar wind bubbles are difficult to detect.
- Only our nearest star (the Sun) and stars with the strongest winds (Wolf-Rayet stars) have wind bubbles that have been directly detected through radiation emitted by the wind bubble.
- The Bubble Nebula is unique in that it is a clearly observed circular bubble around a main-sequence O star.



The Bubble Nebula observed with Spitzer at 24μm (left), 8μm (centre) and optical image from the DSS (right). These images show the IR arcs lining up with the optical arcs which could show the edge of a stellar wind bubble. Credit: Vasilii V. Gvaramadze.

Schematic Model



A sketch of the schematic model in which the stellar wind from BD+60°2522 creates NGC7635. Credit: Christopoulou et a. (1995)

- Christopoulou et al. (1995) present a model which shows that the bubble is expanding at ≈25km/s into a dense ISM.
- The ionizing star (O star named BD+60°2522) associated with the Bubble Nebula is in or near a molecular cloud.
- The expansion of the bubble has shocked the ISM at the bubble's edge. This means the shocked ISM is denser, and hence brighter, than the undisturbed ISM.

Problems with the Model

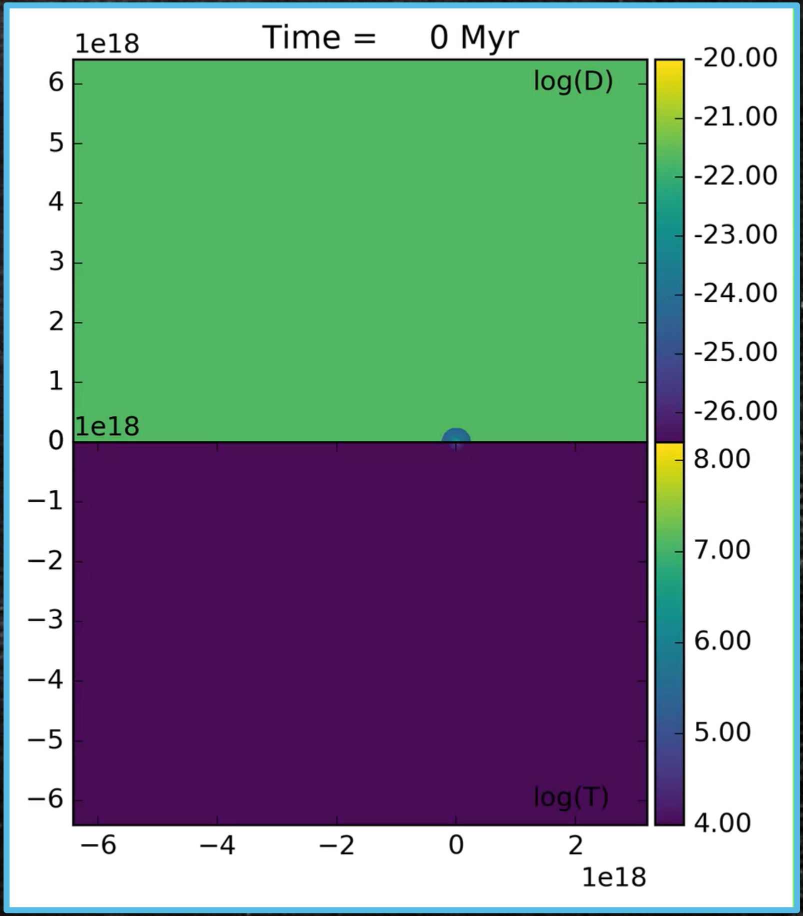
- The bright-rimmed clouds are illuminated from the front.
- The radial velocity of the star differs from that of the molecular cloud by ~25km/s, in the sense that the star is redshifted relative to the cloud.
- Christopoulou et al. (1995) find two velocity components in the bubble spectra. This has been interpreted as an expanding bubble.
- The expansion timescale ~ 50000 years but the Cas OB2 association contains evolved supergiants.

Project Hypothesis

- Our Hypothesis is that the Bubble Nebula is a bow shock created from the interaction between the star's stellar wind and the ISM the star is moving into.
- This bow shock is what then creates the "bubble" shape we see in the optical, x-ray, and radio images.
- The first aim is to either confirm or refute the existing model and, if necessary, to replace it with a better model.
- In the event the bubble is a bow shock we will quantitatively test the observed brightness of nebular emission lines [OIII] 5007Å, H-alpha 6563Å, [NII] 6584Å, the dust brightness and also the velocity of each component.
- Then we can make predictions for future observations (e.g. X-ray).

New Model: Hydrodynamic Simulations

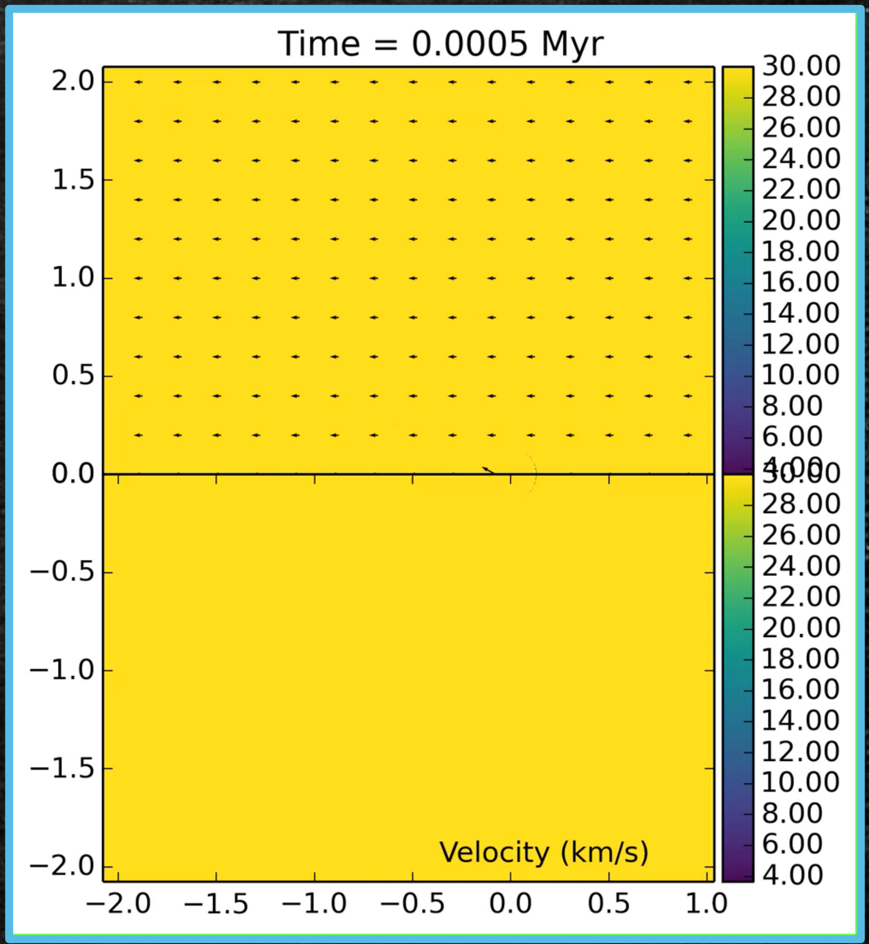
- 2D hydrodynamical simulations of the gas flow towards a star with a strong stellar wind have been performed to obtain a realistic picture of how wind bow shocks are produced by an O star.
- These simulations have been carried out with the PION (PhotoIonization Of Nebulae) hydrodynamical code, Mackey (2012).
- A range of ISM densities, n_H= 50, 100, and 200 cm^{-3}, with corresponding stellar velocities v_*= 20, 30, and 40km/s were modelled.



- All simulations were run using ICHEC's supercomputer, FIONN.

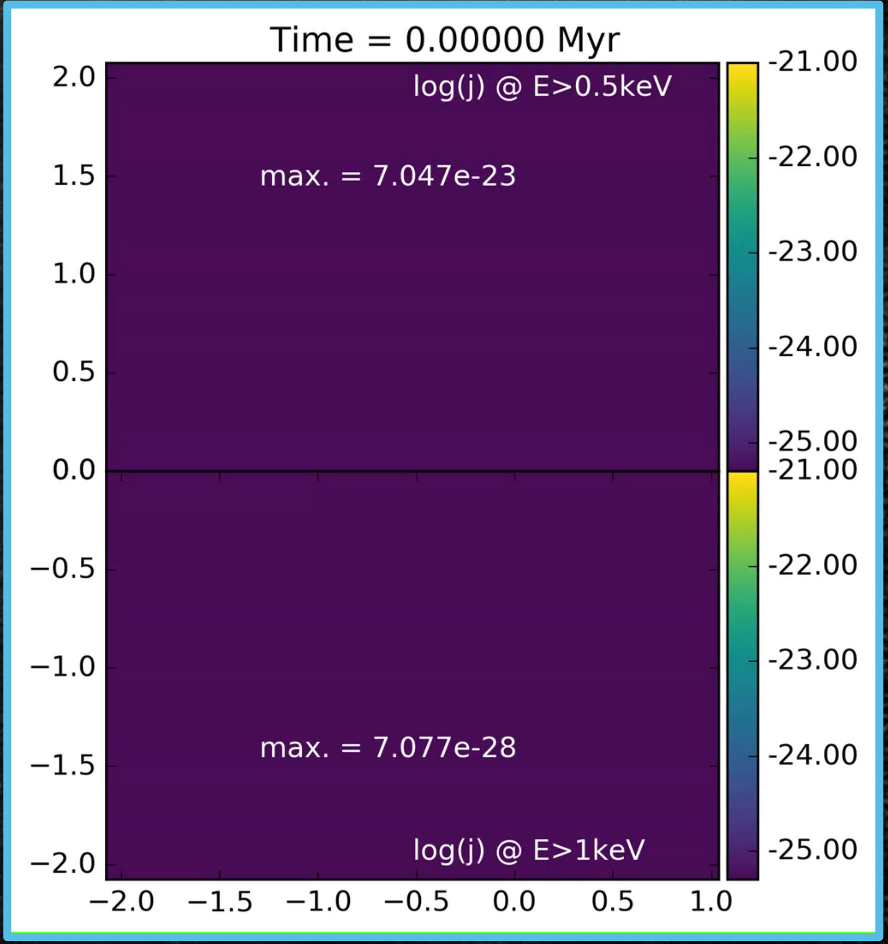
Velocity Profile

- $PION$ also solves for the gas velocity in the x- and y-direction.
- Vector arrows show the direction of each part of the bow-shock and bubble.
- These plots will be used to predict what the radial velocity of the ISM, star, and bow-shock would be.
- Anything more than 30km/s is plotted as yellow.

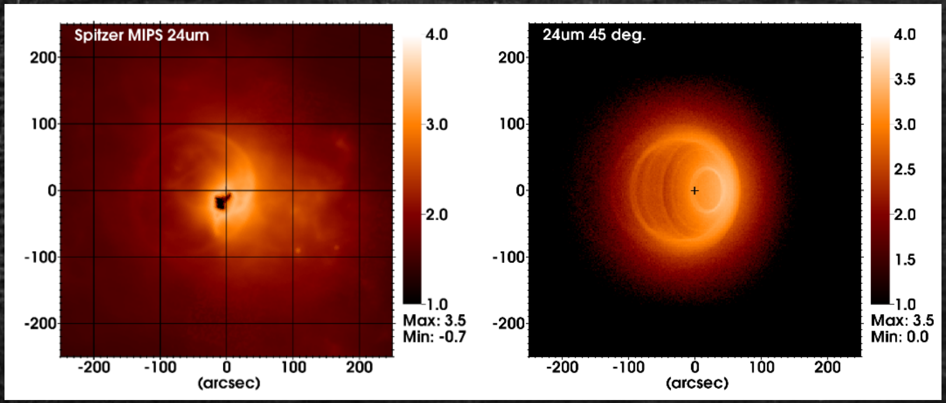


X-ray Emissivity Profile

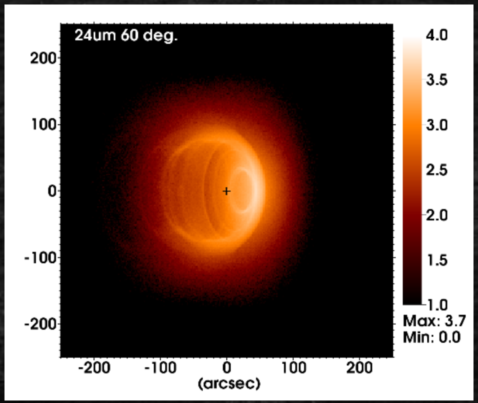
- From the density and temperature profiles produced by PION we can calculate the x-ray emissivity profile of the bow-shock and bubble.
- Most of the x-ray emission occurs inside the bubble region in a thin layer near the bubble boundary.
- From this we can predict what values new satellites can see observationally.
- X-ray luminosity graphs can also be created from this data.



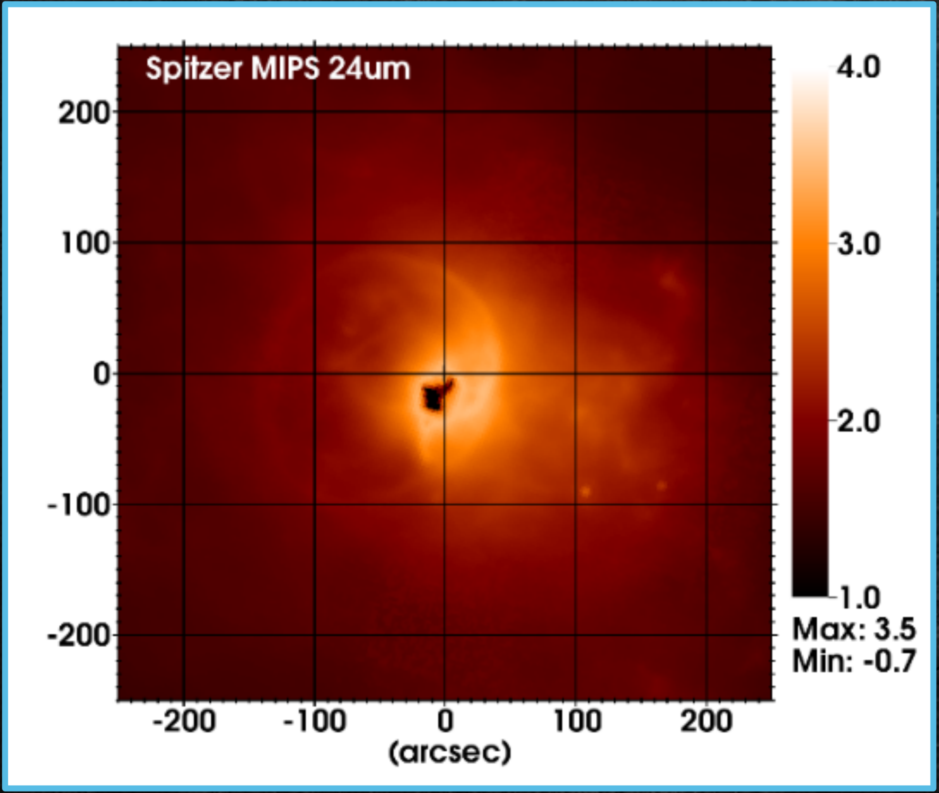
TORUS



Synthetic infrared emission maps of bow shock, coordinates in arcseconds, and scale in $log_{10}(MJy/ster)$.



- The dust emission is modelled using a Monte Carlo radiation transport and hydrodynamics code called TORUS.
- The code produces dust images (24μm) at angles ,to the symmetry axis, from 0^o - 90^o for each snapshot.
- The scale on the right of each plot shows the total brightness of the bow shock in the infrared, future work will compare these values quantitatively with observed data.


Spitzer MIPS 24um
200
100
0
-100
-200
-200
-100
0
100
200
(arcsec)
4.0
3.0
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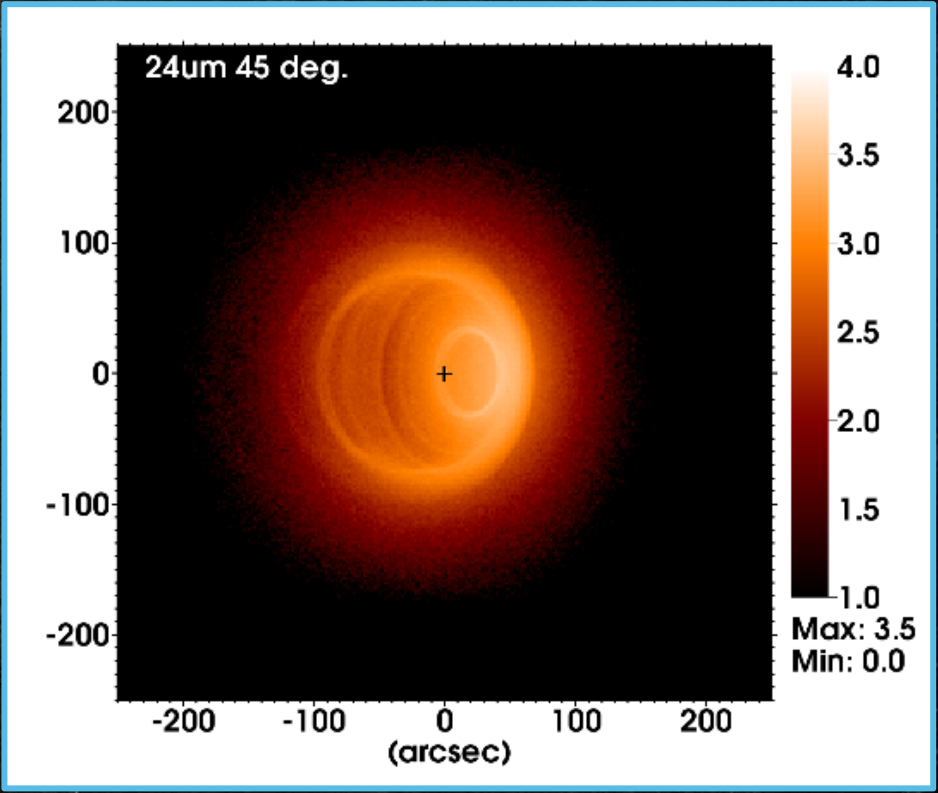
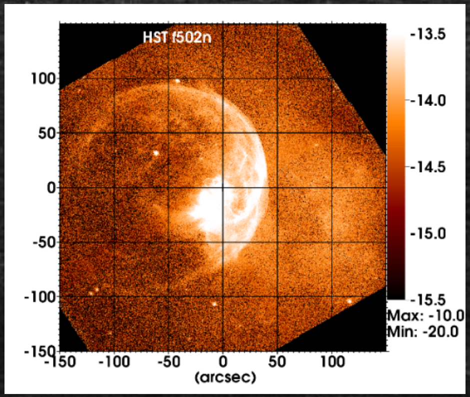
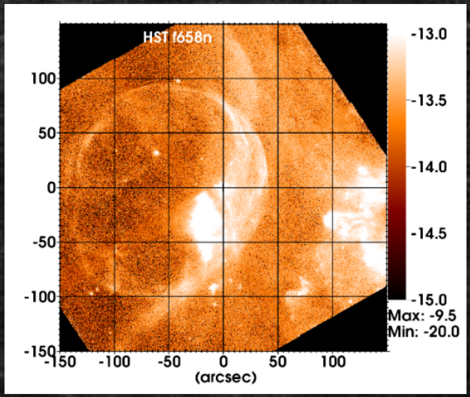
Max: 3.5
Min: -0.7

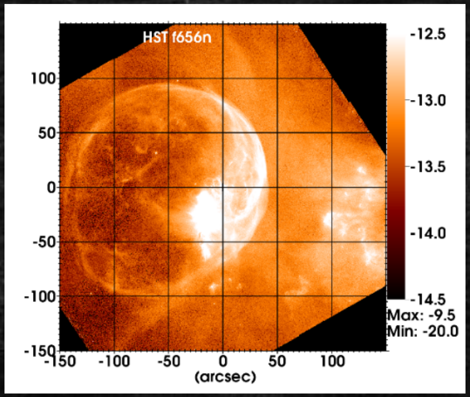

24um 45 deg.
200
100
0
-100
-200
-200
-100
0
100
200
(arcsec)
4.0
3.5
3.0
2.5
2.0
1.5
1.0
Max: 3.5
Min: 0.0

Future Work

- A projection code will be produced to observe the data in these wavelengths.
- This code will allow us to view the simulated bubble as if it was 3D.
- Once this is done we can quantitatively compare the brightness to the observed brightness.
- We plan to extend this work to 3D simulations.







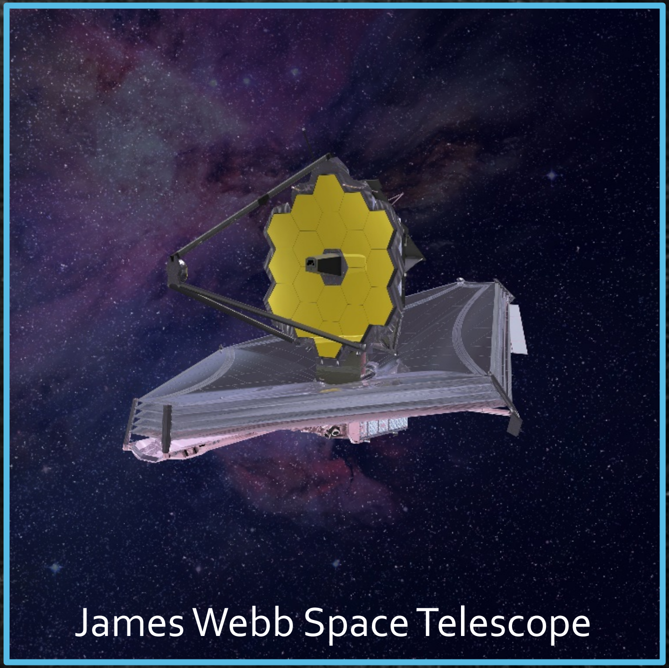
Emission maps of bow shock [OIII] 5007Å (top-left), H-alpha 6563Å (bottom-left), [NII] 6584Å (right) captured with the HST

What we can Learn

- Closest and brightest bubble.
- Good lab for studying stellar wind bubbles.
- Mixing between hot gas and ISM is poorly understood.
- Simulations with different physical assumptions, compared with observations, can help us understand these mixing processes.

Satellites

XMM-Newton



James Webb Space Telescope

Chandra

Conclusions

- Early results suggest that the Bubble Nebula is a bow shock caused by the interaction between the star's wind and the ISM wind. However more analysis is still needed to create a new model for the Bubble Nebula.

- We need to predict what the radial velocity of the ISM, star, and bow-shock material would be, and if the near-side and far-side of the bow shock would have significantly different radial velocities.

- We need to quantitatively compare all data and analysis to images of the Bubble Nebula to determine similarities/differences.

- We also need to test the observed brightness of nebular emission lines [OIII] 5007, Halpha 6563, [NII] 6584, the dust brightness, and the x-ray emissivity to compare with observational values.