Detecting Galactic Winds Using Broad Emission Lines

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Messier 82

Credit: NASA, ESA and the Hubble Heritage Team (STScI/AURA). Acknowledgment: J. Gallagher (University of Wisconsin), M. Mountain (STScI) and P. Puxley (NSF).

Starburst Galaxies

Starburst Galaxy: a galaxy undergoing a very high star formation rate

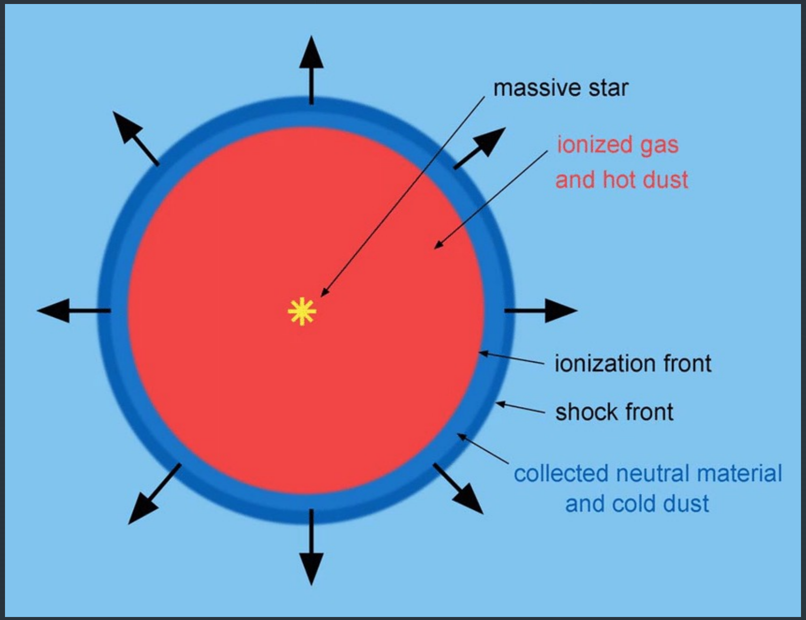
Messier 82 vs Milky Way

- The Milky Way is almost 3 times greater than M82
- In M82, stars are forming 10 times faster than in the Milky Way

→ M82 has a higher concentration of massive stars!

Massive Stars' Feedback

HII regions



Deharveng, L., et al. "A Gallery of Bubbles." *Astronomy & Astrophysics*, vol. 523, 2010

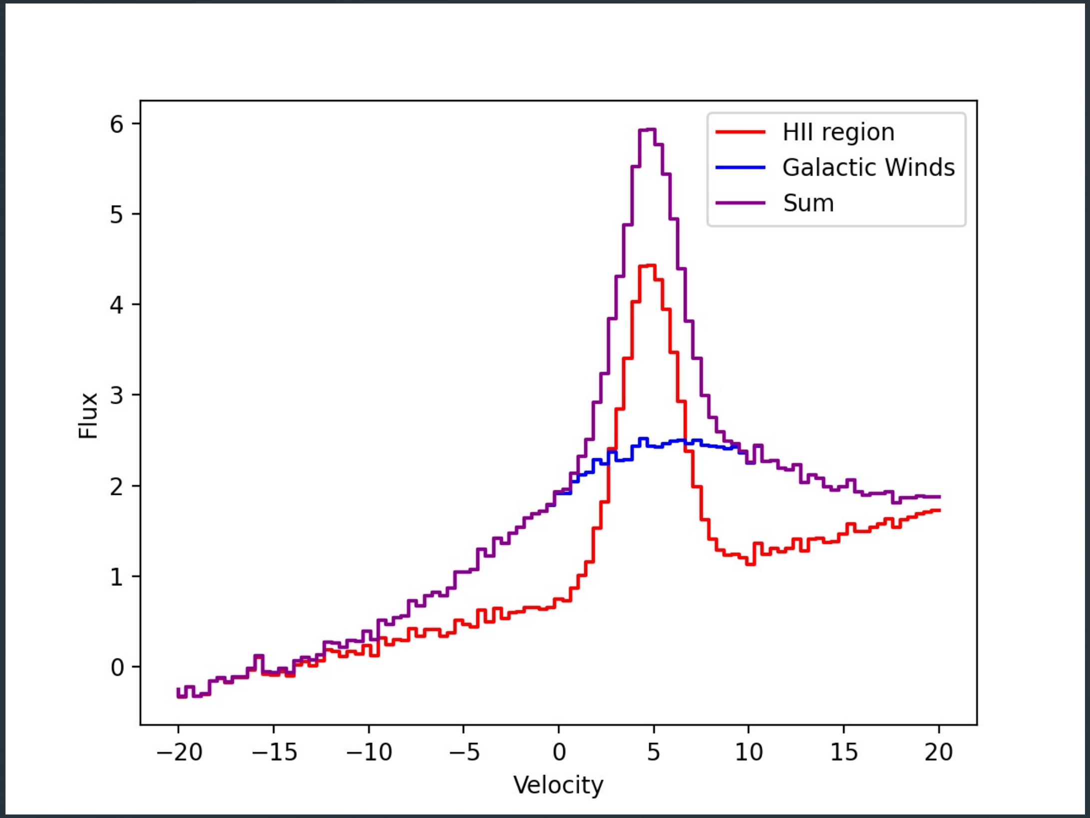
Supernovae

Credit: ESA/Hubble (L. Calçada)

Supernovae drive galactic winds!

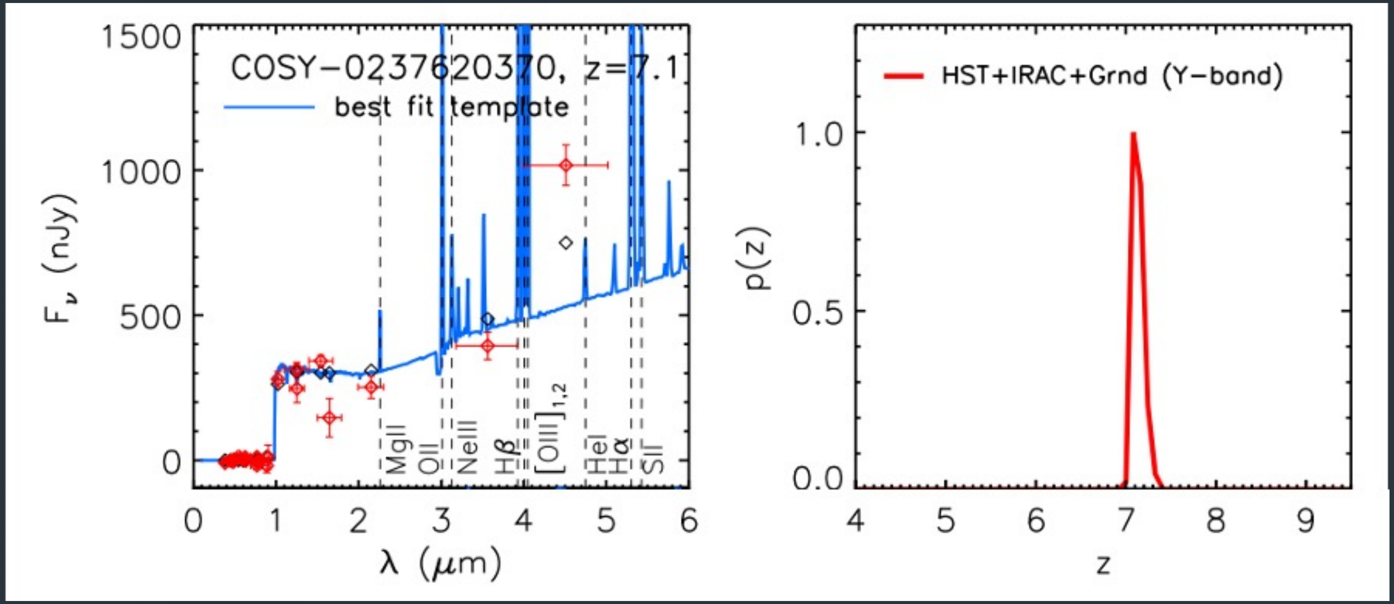
Emission Lines

Credit: X-ray: NASA/CXC/JHU/D.Strickland; Optical: NASA/ESA/STScI/AURA/The Hubble Heritage Team; IR: NASA/JPL-Caltech/Univ. of AZ/C. Engelbracht



Cosmological Redshift

Cosmological Redshift: An increase in the wavelength of an object's radiation due to the expansion of space itself



Roberts-Borsani, G. W., et al. "z≳ 7 Galaxies with Red *Spitzer*/Irac [3.6]–[4.5] Colors in the Full Candels Data Set: The Brightest-Known Galaxies at z~ 7–9 and a Probable Spectroscopic Confirmation at z= 7.48." *The Astrophysical Journal*, vol. 823, no. 2, 2016, p. 143., https://doi.org/10.3847/0004-637x/823/2/143.

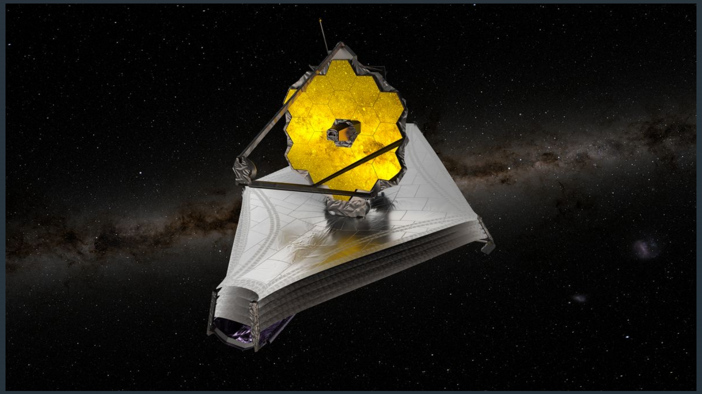
Strong emission lines at high redshifts → The optical spectrum needs to be observed in the infrared!

Summer Goal

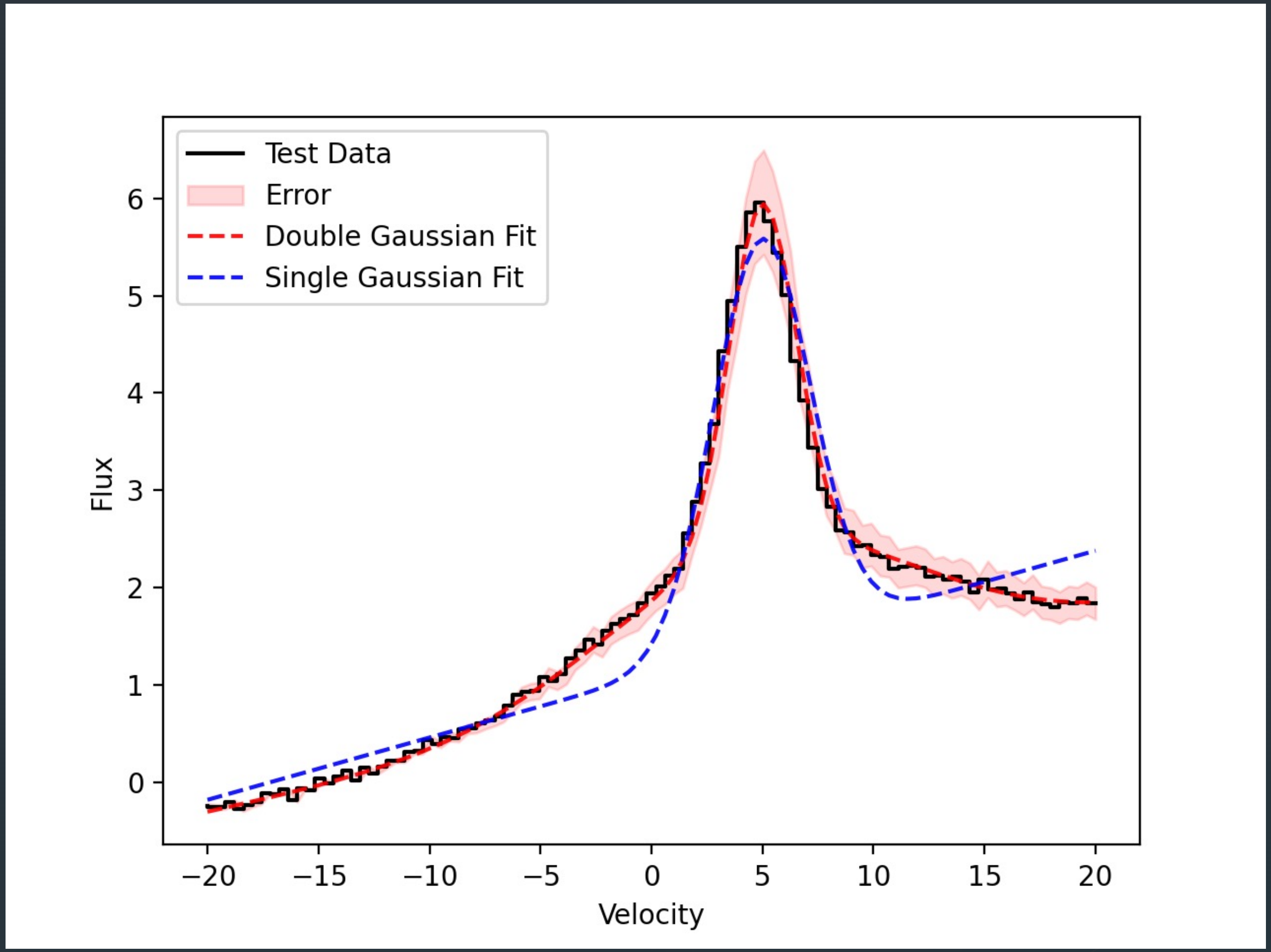
What kind of galactic outflows can be detected in the James Webb Space Telescope spectra?

1. Develop a statistical evaluation that yields the detection probability of the wind emission in an observed spectrum

2. Check whether out theoretical wind model can reproduce the broad component in the real JWST spectra



Gaussian fitting as a way to distinguish the outflow components



Statistical Evaluation: F-test

Statistical test that chooses best model by comparing the χ^2 values of the different models:

1)

$$F_0 = \frac{\chi_1^2 - \chi_2^2}{\Delta\nu} \bigg/ \frac{\chi_2^2}{\nu_2}$$

↓ Probability Density Function

Monte Carlo simulation

2)

Analytical F-distribution

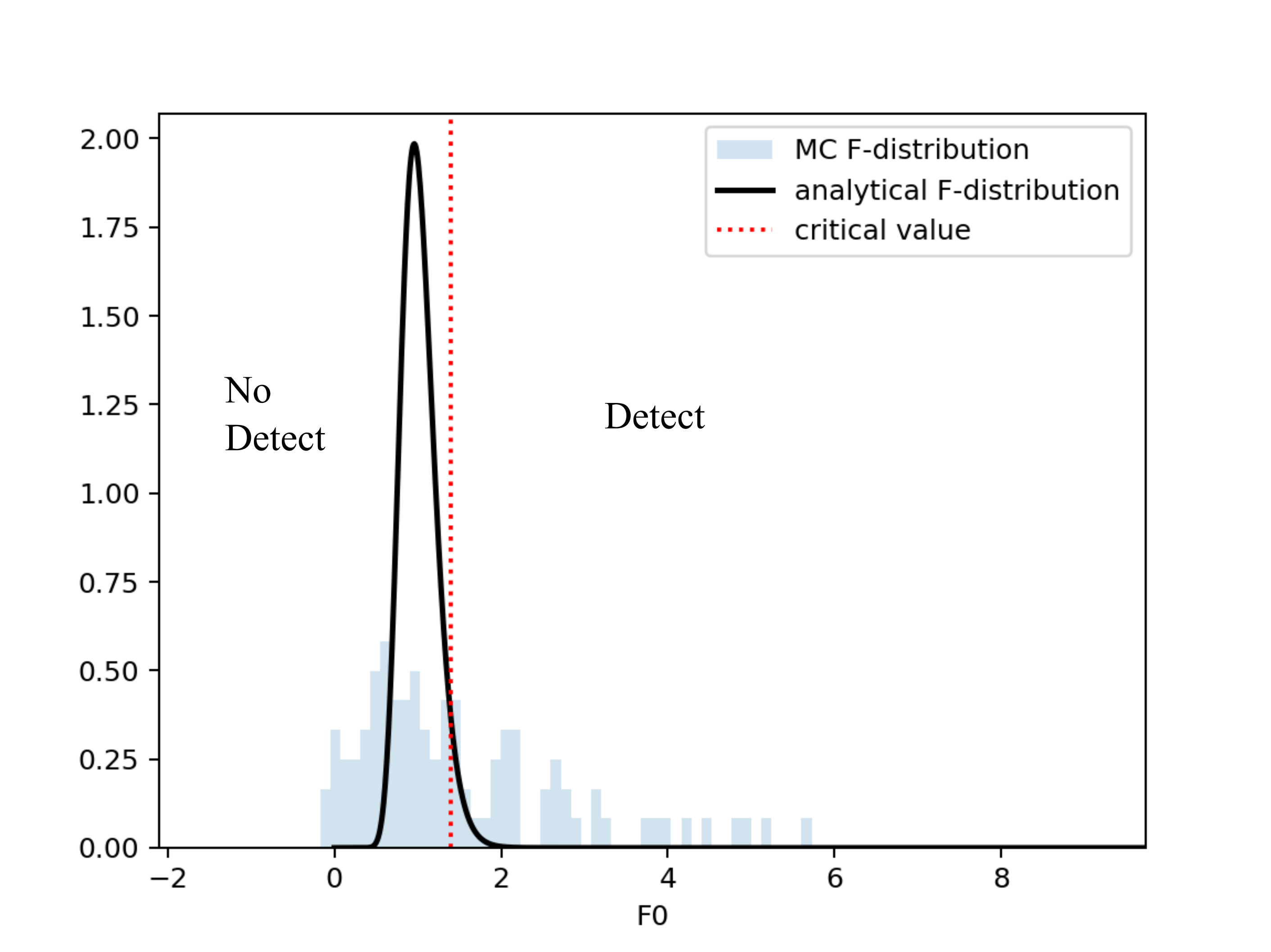
$$f(x; d_1, d_2) = \frac{\sqrt{\frac{(d_1 x)^{d_1} d_2^{d_2}}{(d_1 x + d_2)^{d_1+d_2}}}}{x\,\mathrm{B}\left(\frac{d_1}{2}, \frac{d_2}{2}\right)}$$

↓

Critical value when:

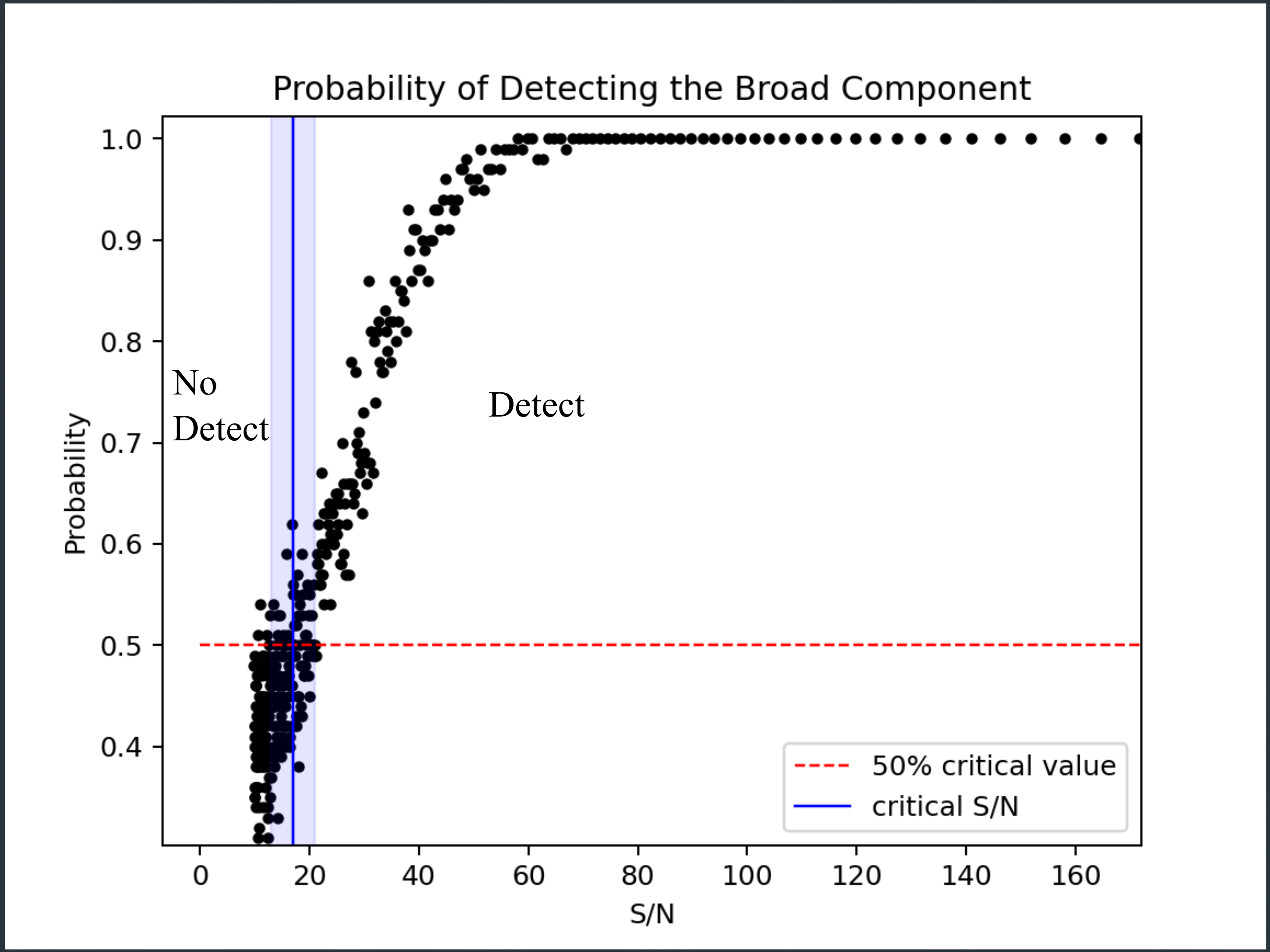
$$P(F > F_0) = 0.05$$

F-test plot



MC F-distribution
analytical F-distribution
critical value
No
Detect
Detect
2.00
1.75
1.50
1.25
1.00
0.75
0.50
0.25
0.00
−2
0
2
4
6
8
F0

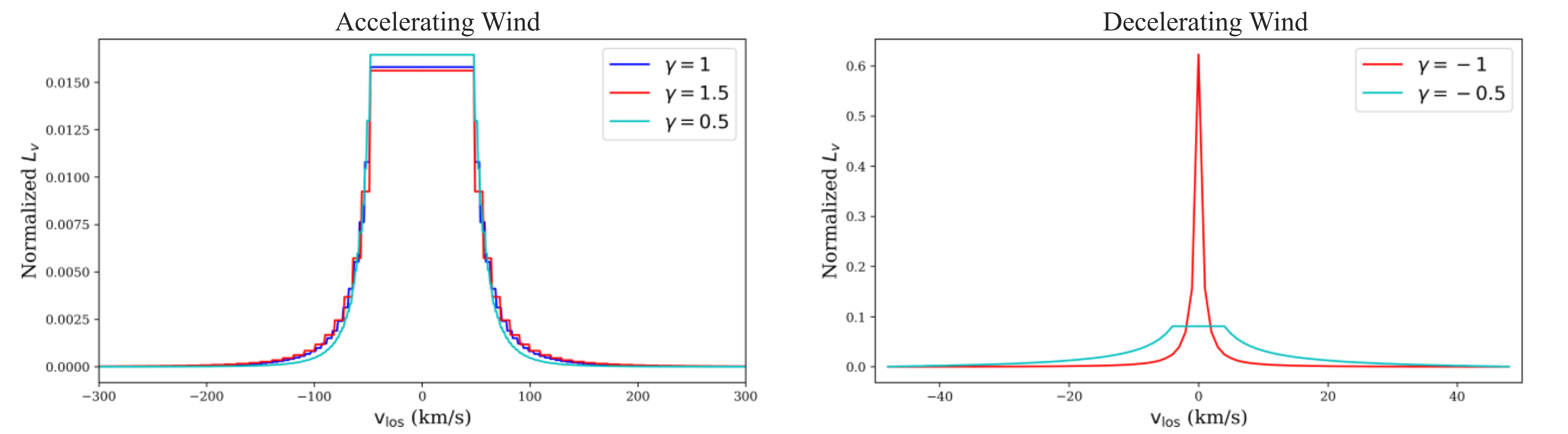
At what S/N ratio do we have at least 50% probability of detecting the wind emission?



Application to Real Spectra

$$\mathrm{EM}\,(\gamma, v_0, r_0)$$

- Convert galaxy spectra to physical units



- Apply methodology to JWST spectra

→ Which wind models have a detectable broad component?

Cosmic Evolution Early Release Science Survey
CEERS

In Summary…

1) What signal-to-noise ratio confirms the detection of the wind emission?

2) Which galactic wind model best reproduces the wind emission that will be seen in the JWST spectra?

Acknowledgements

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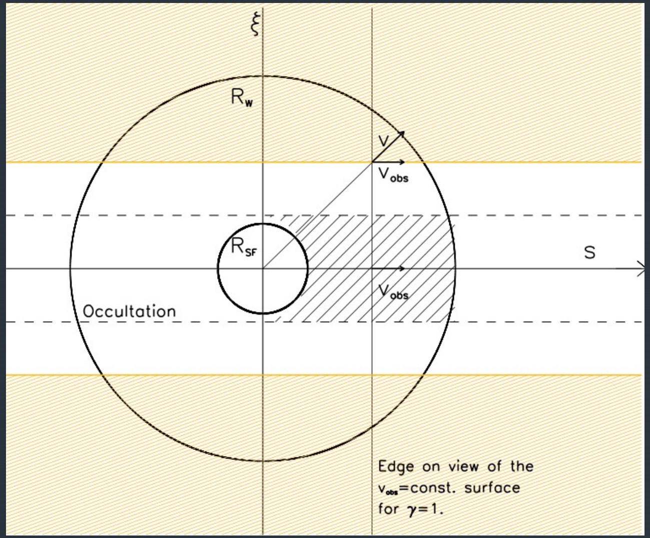
Additional Slides

Theoretical Wind Model:

$$L \propto 2\pi \frac{v_{\text{los}1} - v_{\text{los}2}}{3\gamma + 1} \left(r_1^{-3\gamma-1} - r_2^{-3\gamma-1} \right)$$



Scarlata, C., and N. Panagia. "A Semi-Analytical Line Transfer Model to Interpret the Spectra of Galaxy Outflows." *The Astrophysical Journal*, vol. 801, no. 1, 2015, p. 43., https://doi.org/10.1088/0004-637x/801/1/43.

HII Region Model:

$$L(H\alpha) = 1.27 \times 10^{41}\ SFR\ (M_\odot\ yr^{-1})\ (ergs\ s^{-1})$$

$$\lambda_{obs} = \lambda_{em}\ (1 + z)$$