

# **Colorful Investigations of WFIRST**

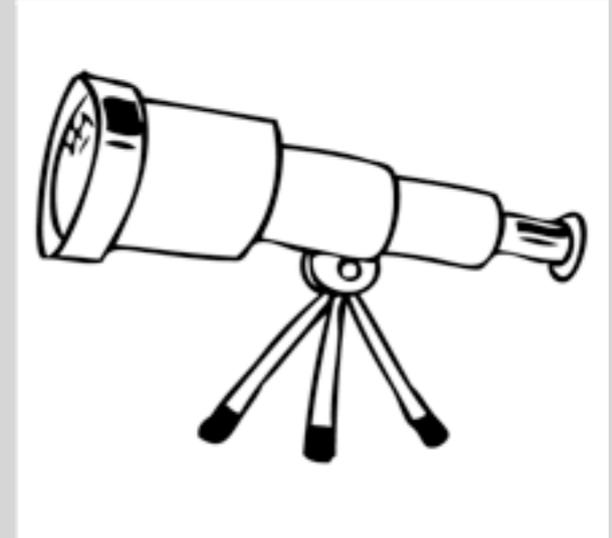
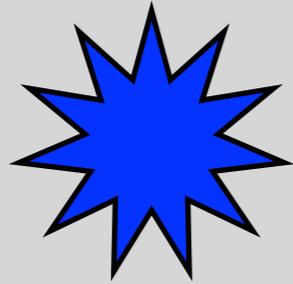
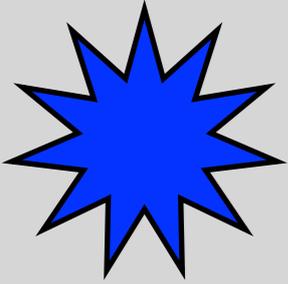
**Ryan Foley  
University of Illinois**

# **Colorful Investigations of WFIRST**

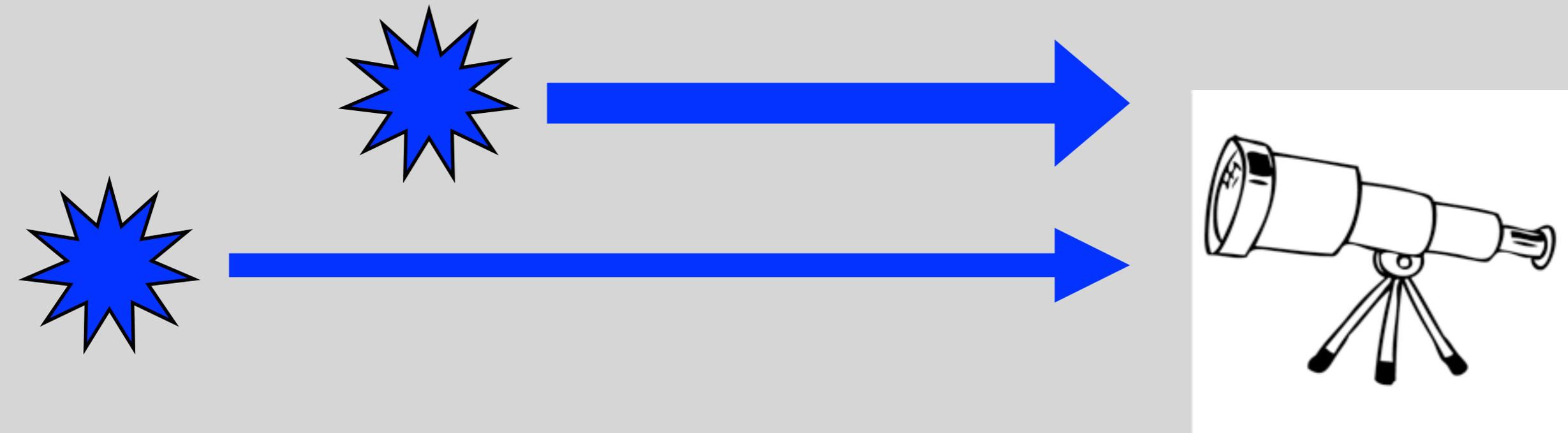
**Ryan Foley**  
**University of Illinois**

**Scolnic, Hounsell, Kessler**

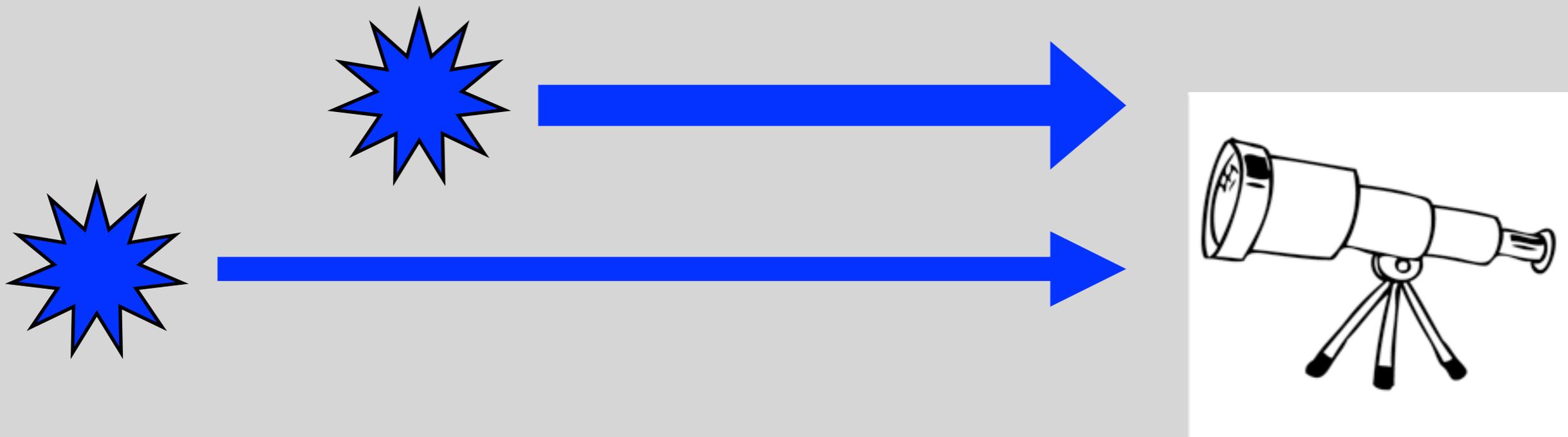
# Standard Candles And Distances



# Standard Candles And Distances

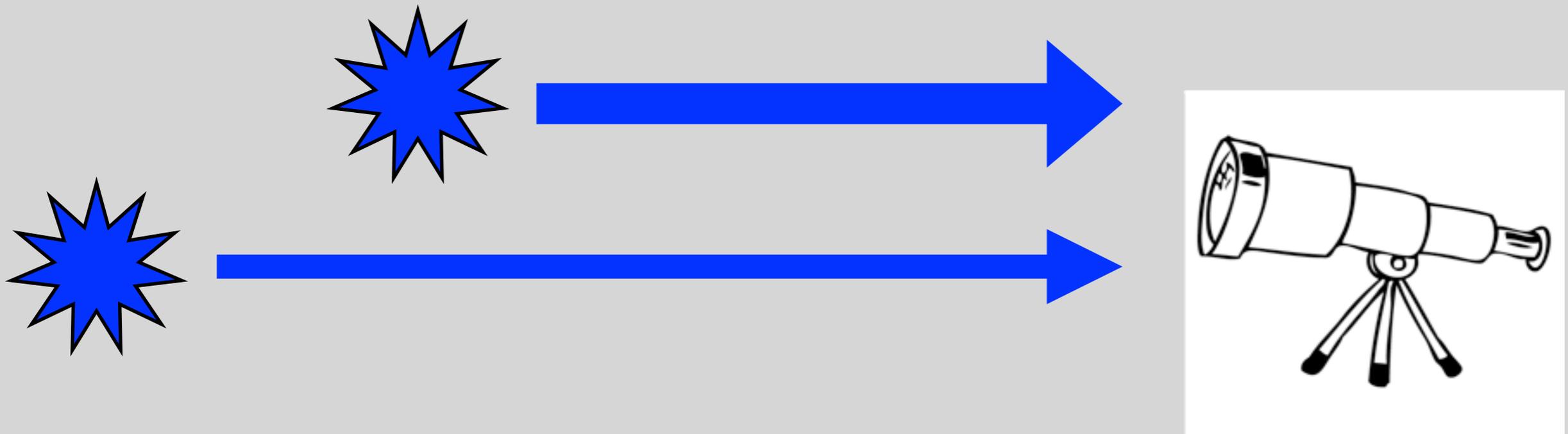


# Standard Candles And Distances



Obs:  $D = (L/4\pi F)^{1/2}$

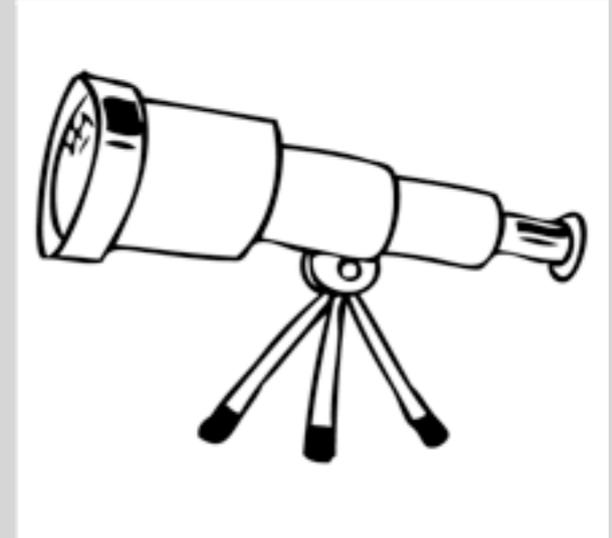
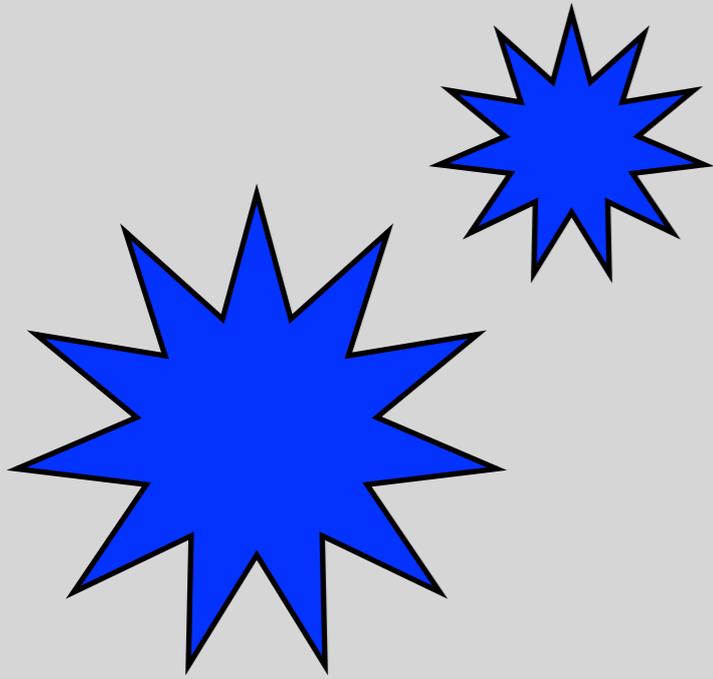
# Standard Candles And Distances



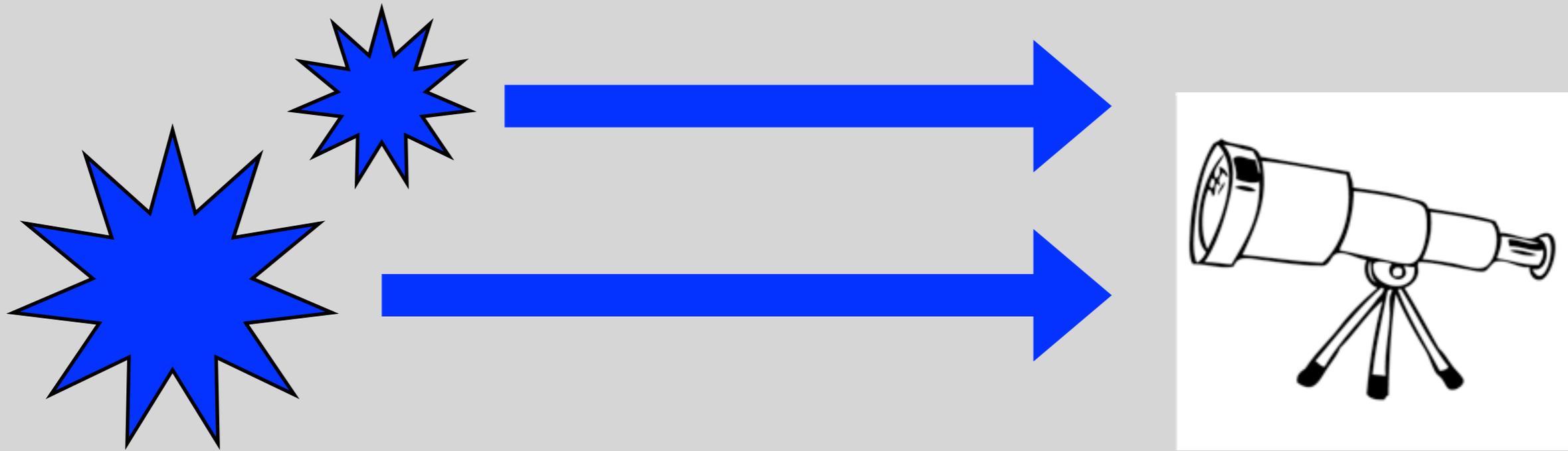
**Obs:**  $D = (L/4\pi F)^{1/2}$

**Theory:**  $D = f(z, \Omega, w(z), \text{etc})$

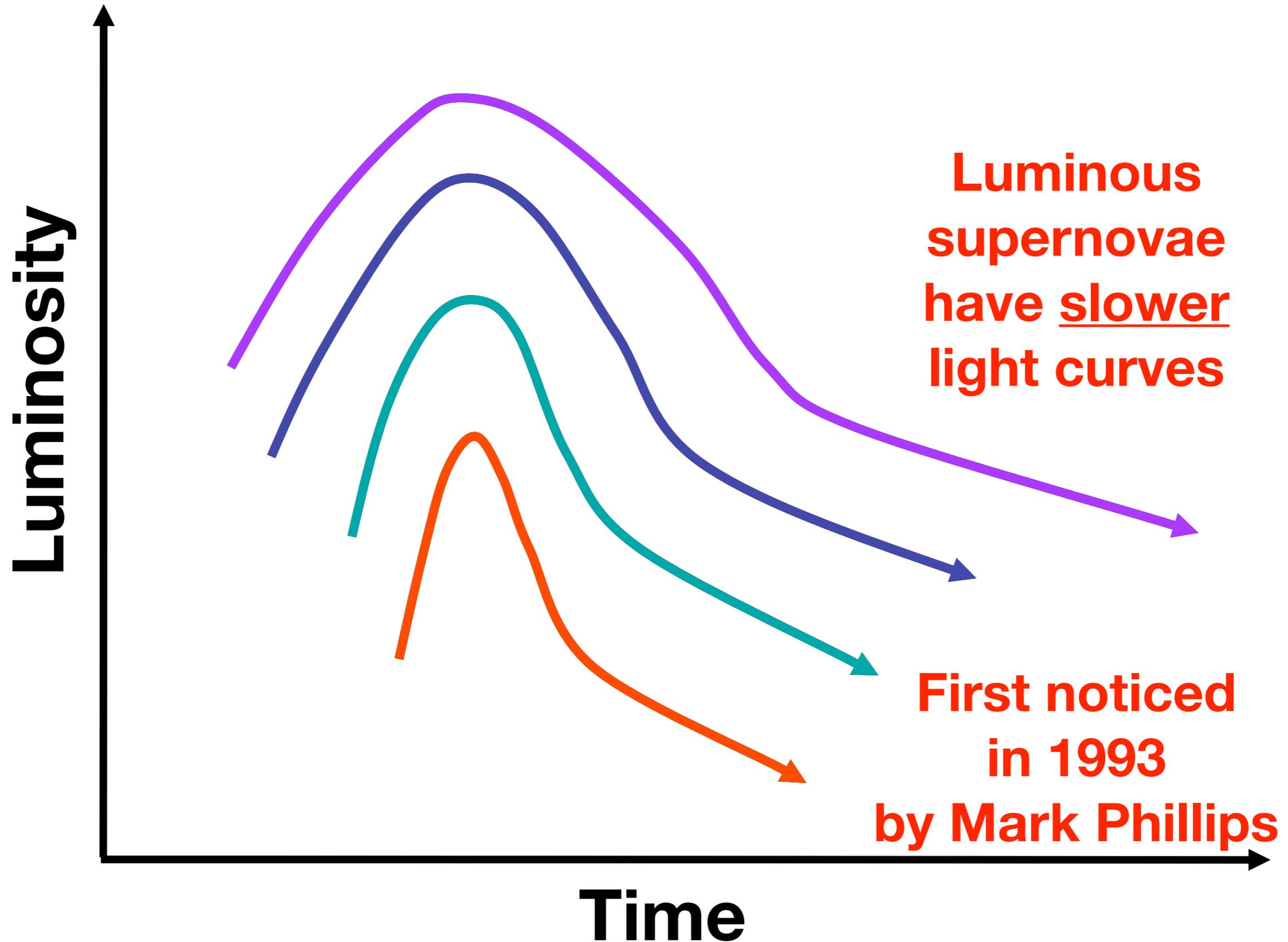
# SNe Ia are NOT Standard Candles!



# SNe Ia are NOT Standard Candles!



# Calibrating the Nearly Standard Candle



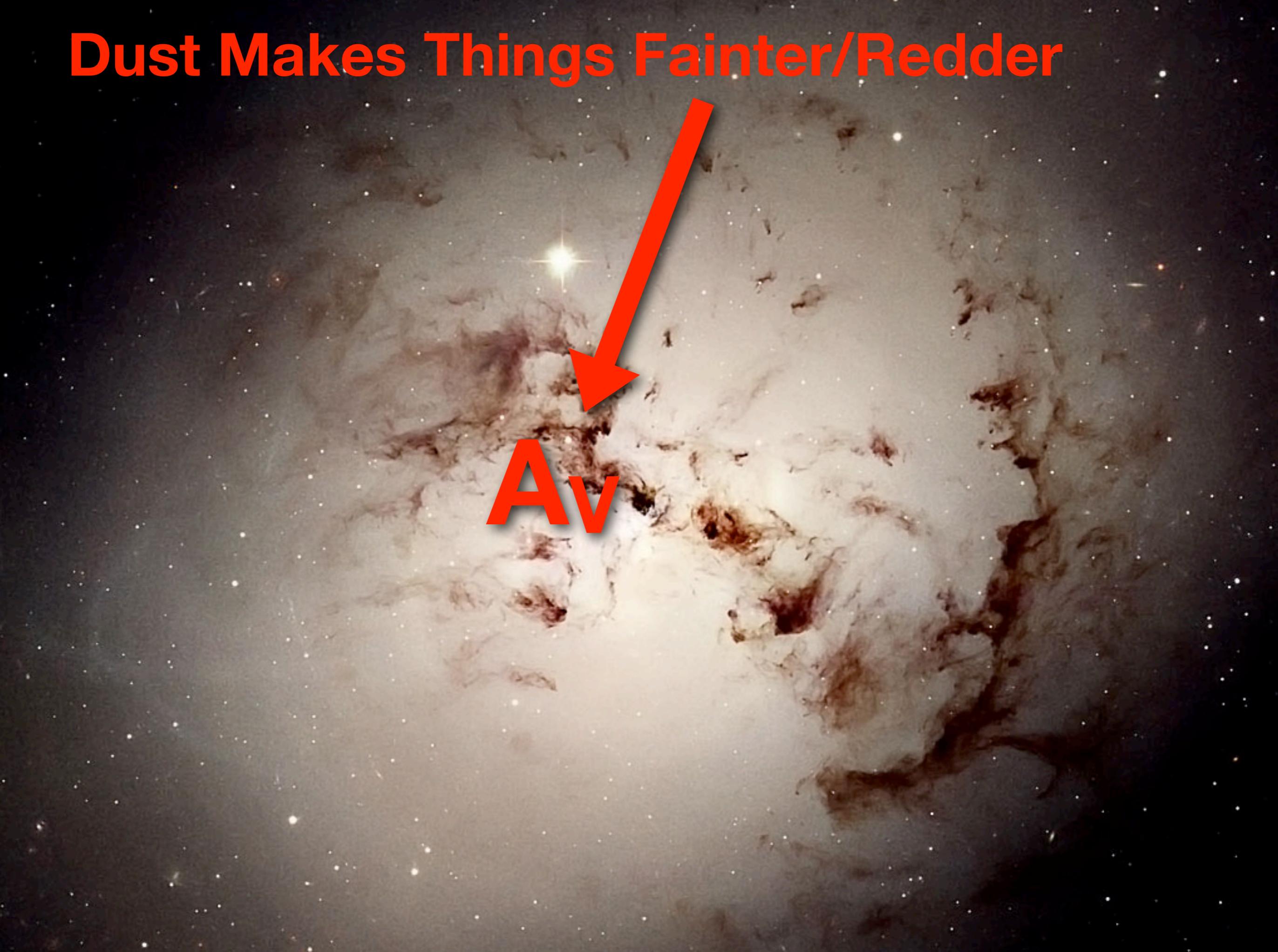
# Systematics Dominate SN Cosmology

Source	$dw$
<b>Total Uncertainty</b>	<b>0.072</b>
Statistical Uncertainty	0.050
<b>Systematic Uncertainty</b>	<b>0.052</b>
<b>Photometric calibration</b>	<b>0.045</b>
SN color model	0.023
Host galaxy dependence	0.015
MW extinction	0.013
Selection Bias	0.012
Coherent Flows	0.007

# Dust Makes Things Fainter/Redder

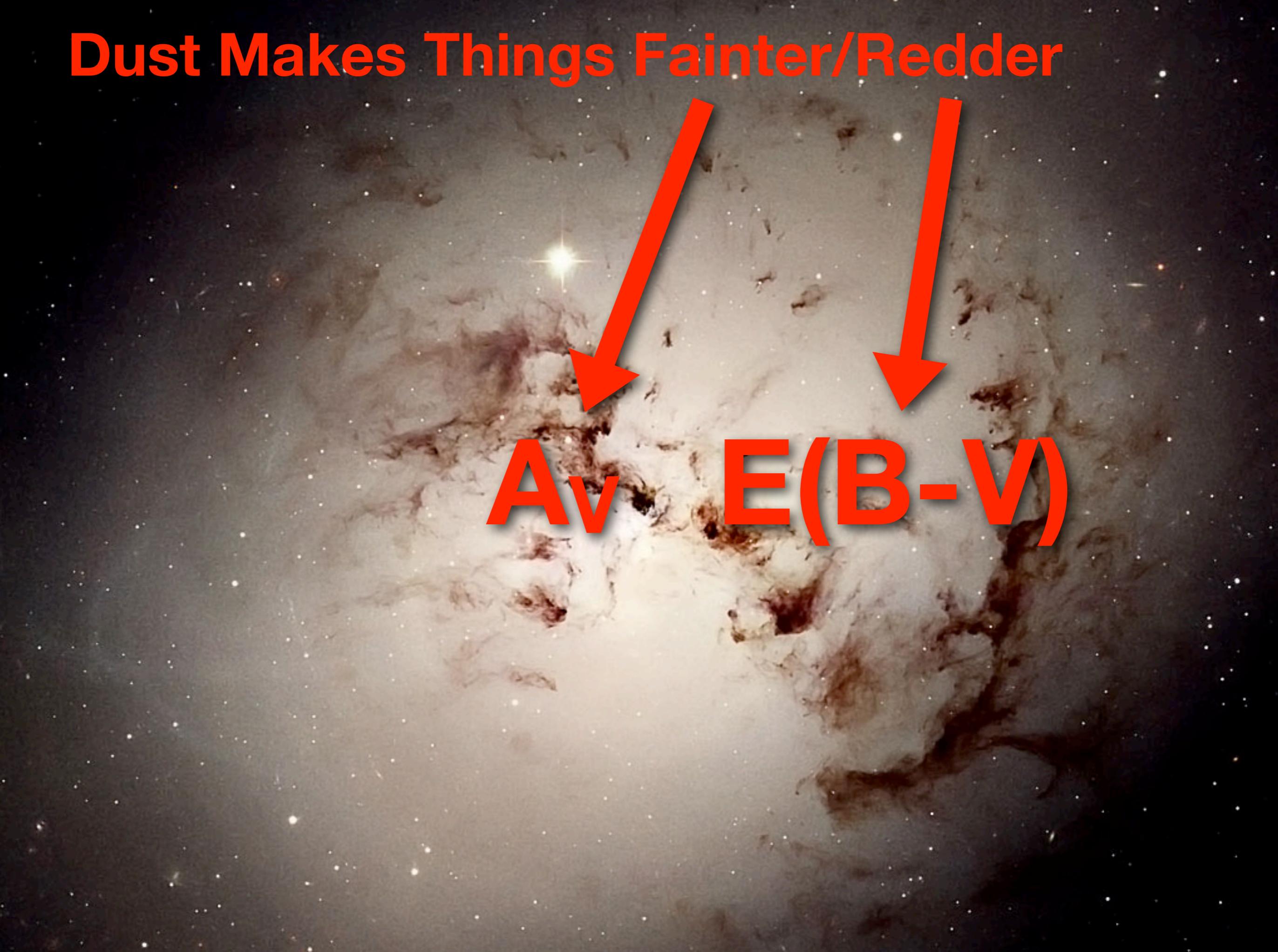


**Dust Makes Things Fainter/Redder**



**Av**

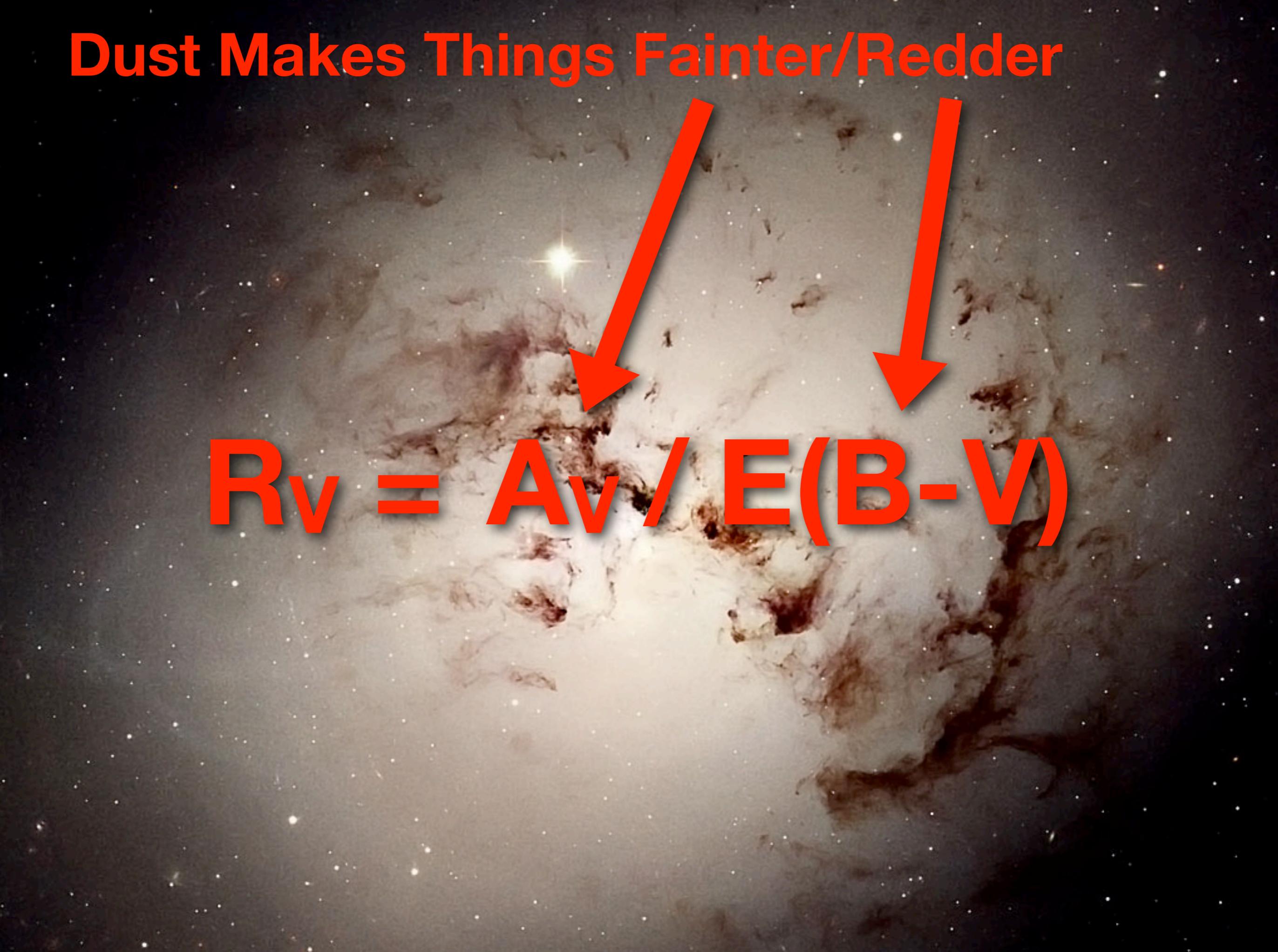
# Dust Makes Things Fainter/Redder



The image shows a star field with a prominent dust lane. A bright star is visible in the upper left. Two red arrows point from the title to the dust lane. The text  $A_v$  and  $E(B-V)$  are overlaid on the dust lane.

$A_v$   $E(B-V)$

**Dust Makes Things Fainter/Redder**

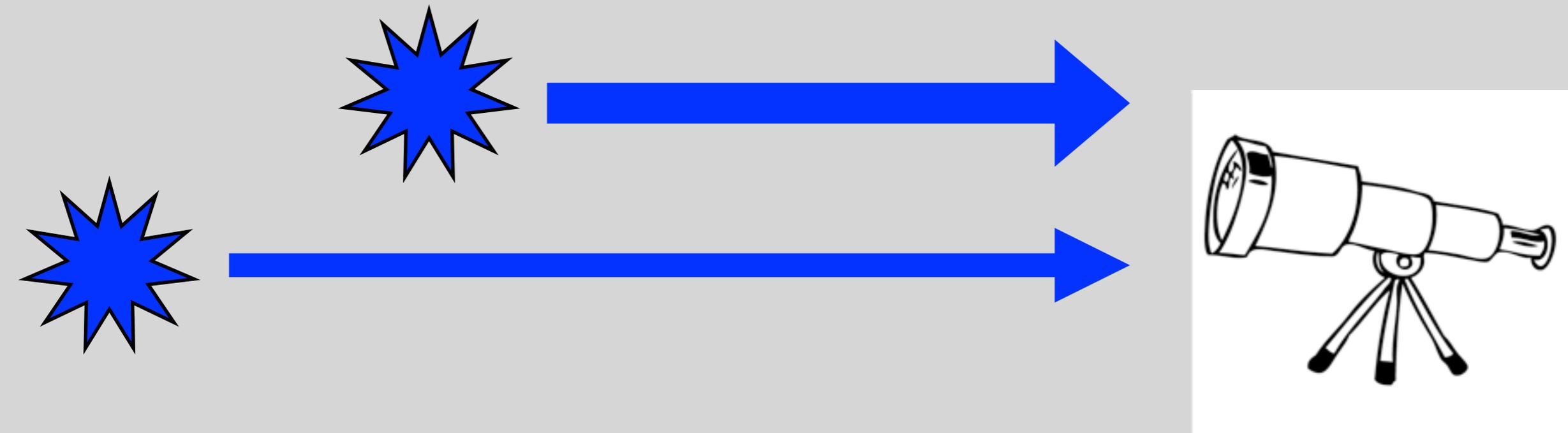
A photograph of a star-forming region, likely the Orion Nebula, showing a bright star with a four-pointed diffraction pattern. Two red arrows point from the top text towards dark, reddish-brown dust clouds. The background is a dark field of stars.
$$R_v = A_v / E(B-V)$$

# Dust Makes Things Fainter/Redder

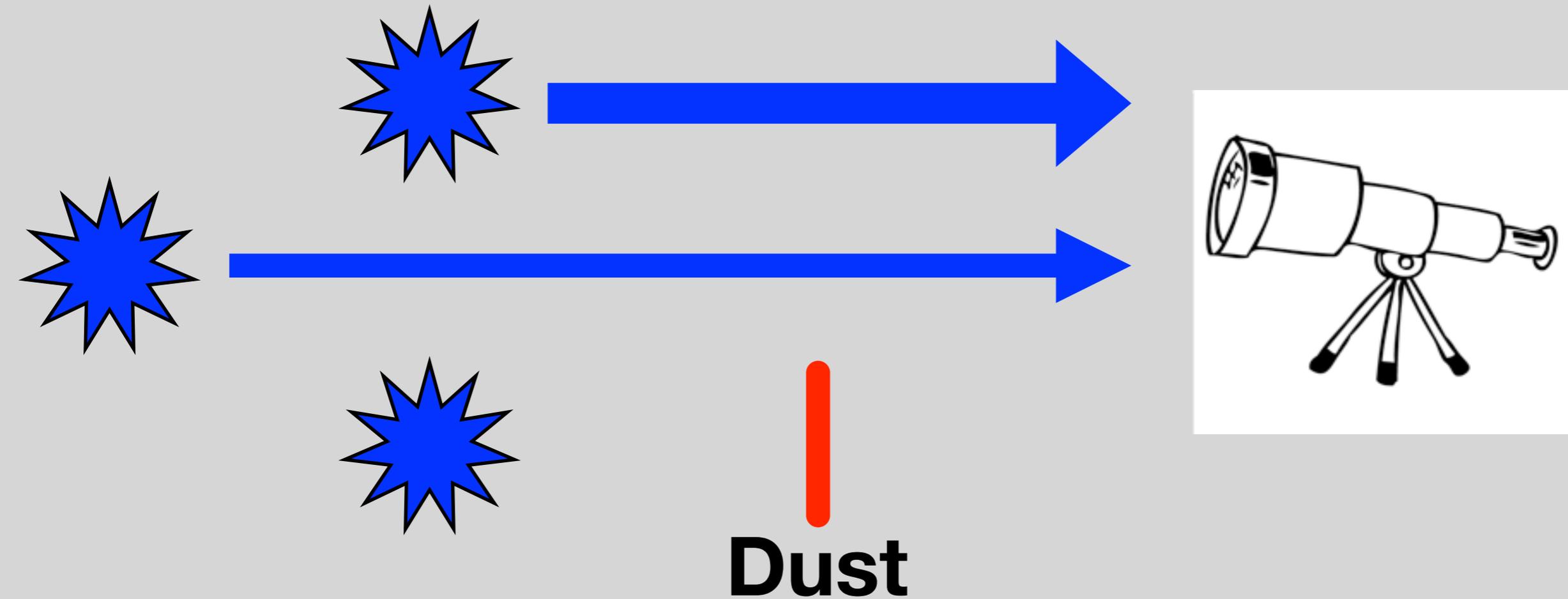

$$R_v = A_v / E(B-V)$$

$$\mu = m - M - A_v$$

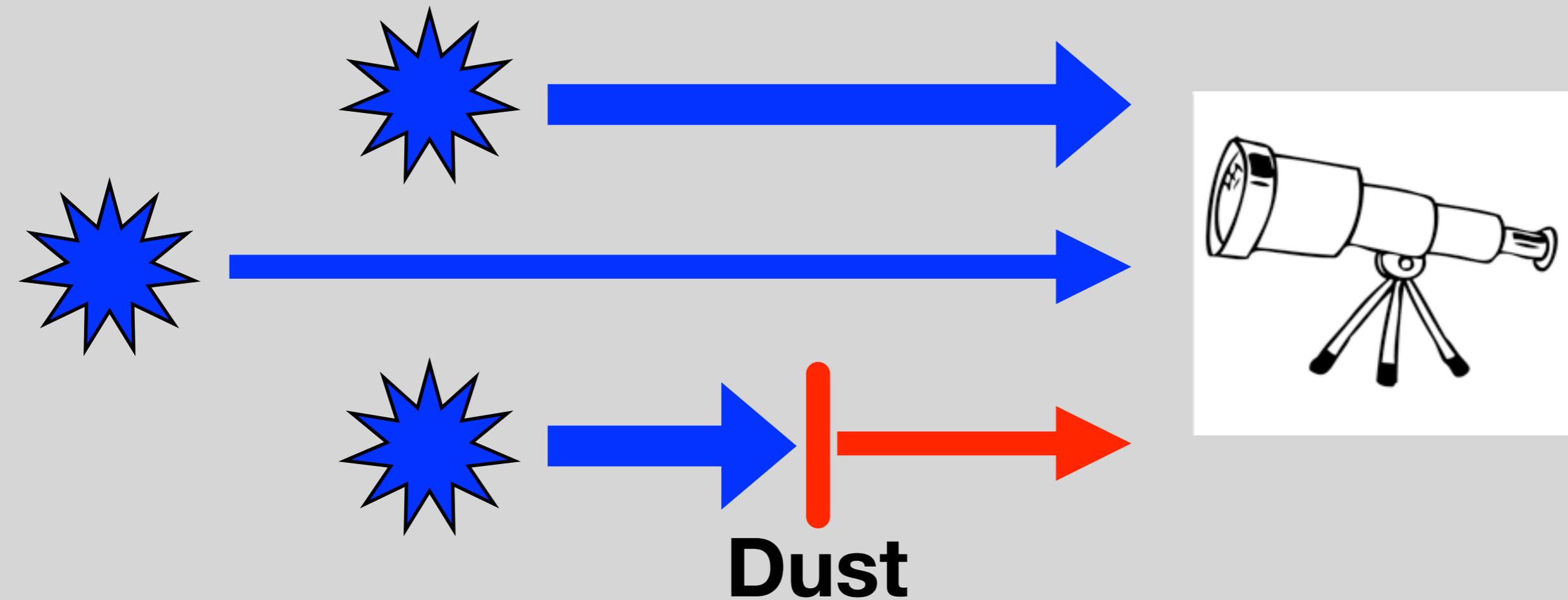
# Dust Makes Things Fainter/Redder



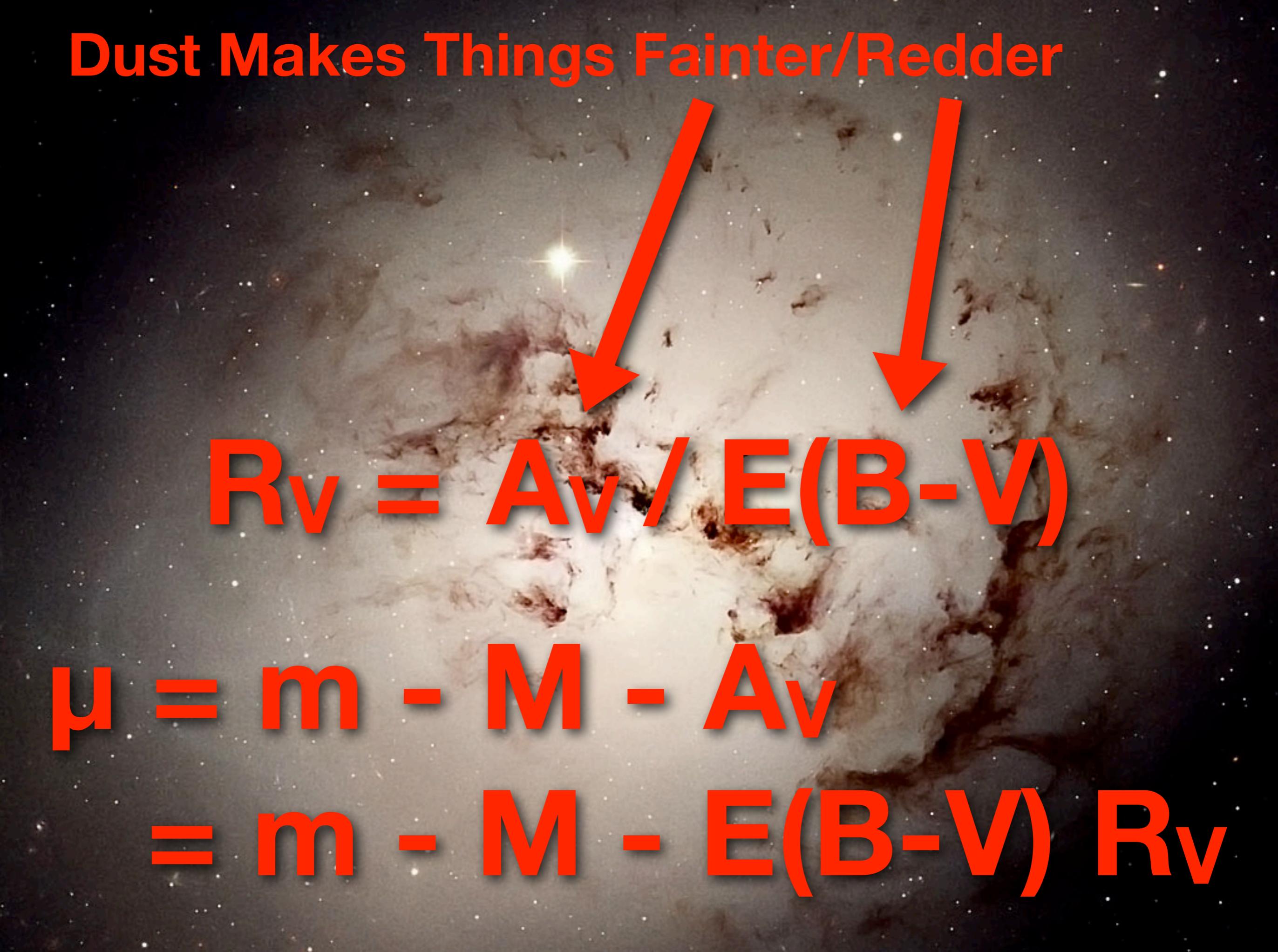
# Dust Makes Things Fainter/Redder



# Dust Makes Things Fainter/Redder



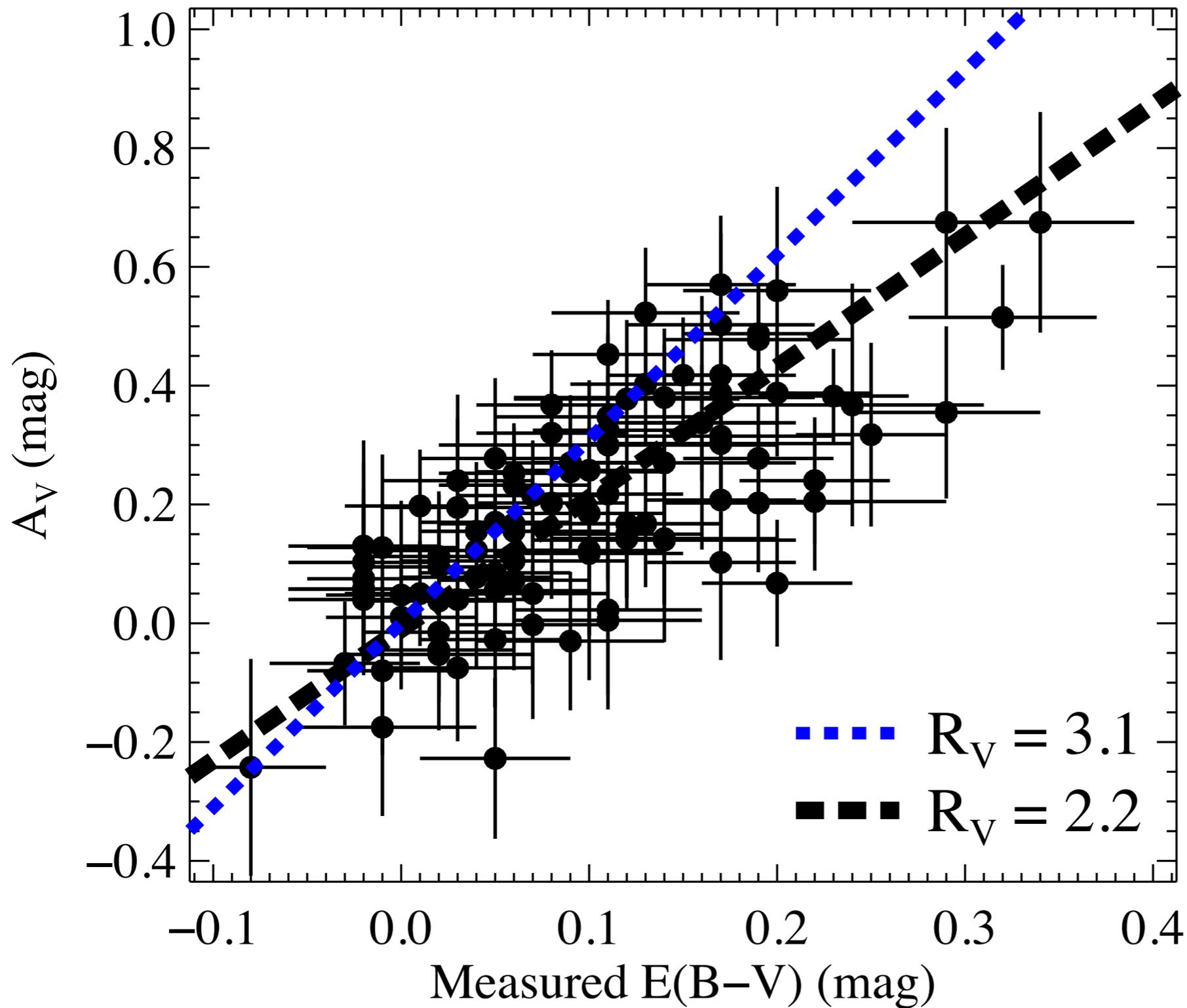
# Dust Makes Things Fainter/Redder

A photograph of a star-forming region, likely the Orion Nebula, showing a bright star and surrounding dust lanes. Two red arrows point from the title to the dust lanes, illustrating the concept of dust extinction.
$$R_v = A_v / E(B-V)$$

$$\mu = m - M - A_v$$

$$= m - M - E(B-V) R_v$$

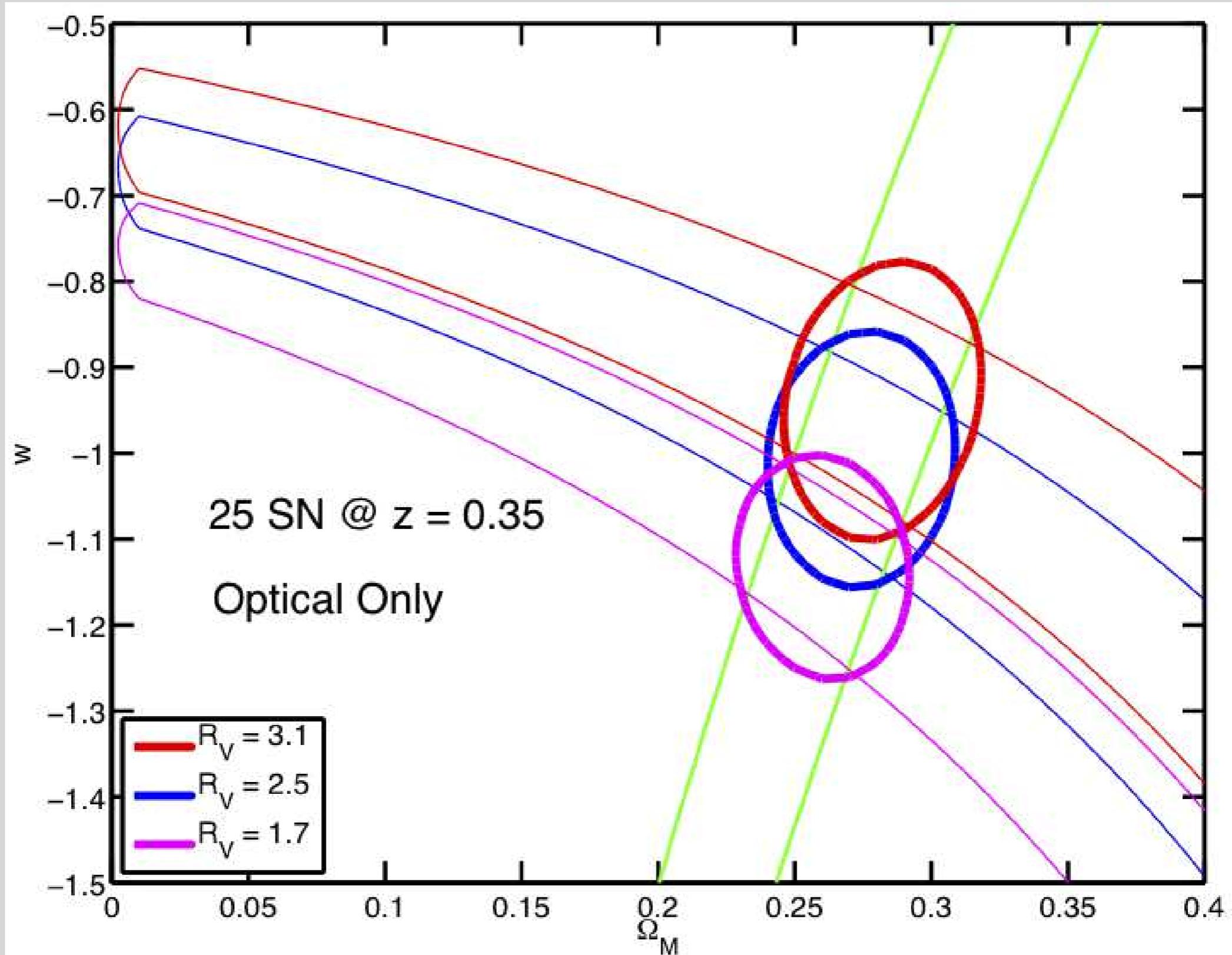
# Samples of SNe Ia have Low $R_V$



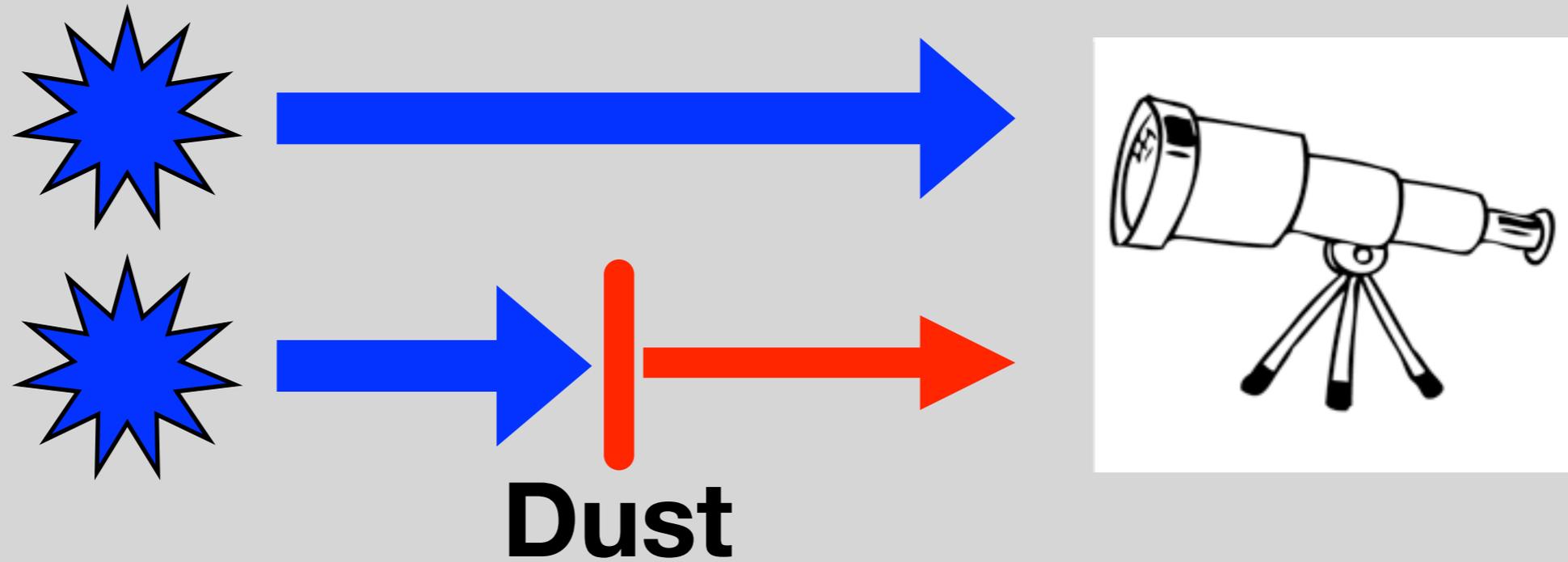
$$R_V = \frac{A_V}{E(B-V)}$$

Foley & Kasen 2011

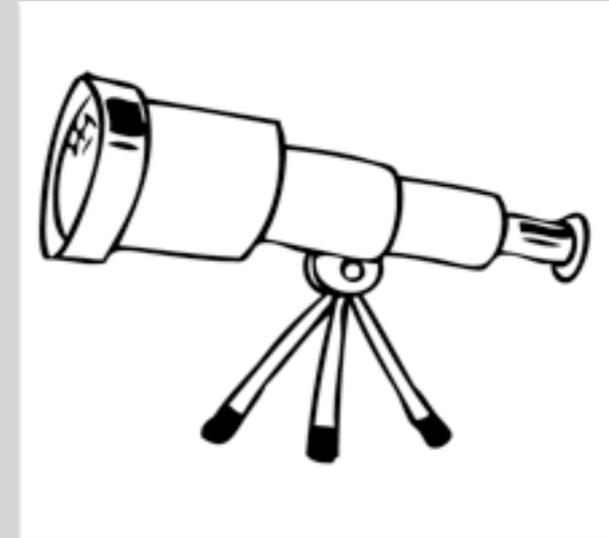
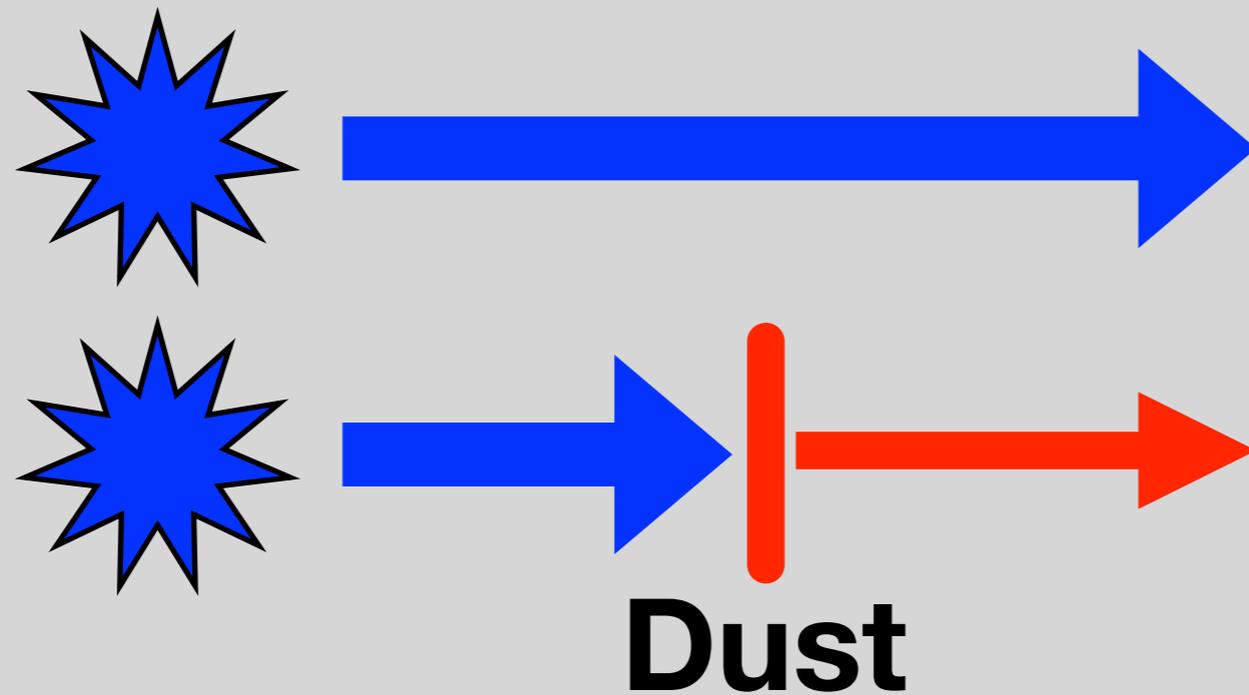
# $R_V$ Is A Significant Systematic



# Dust Makes Things Fainter/Redder

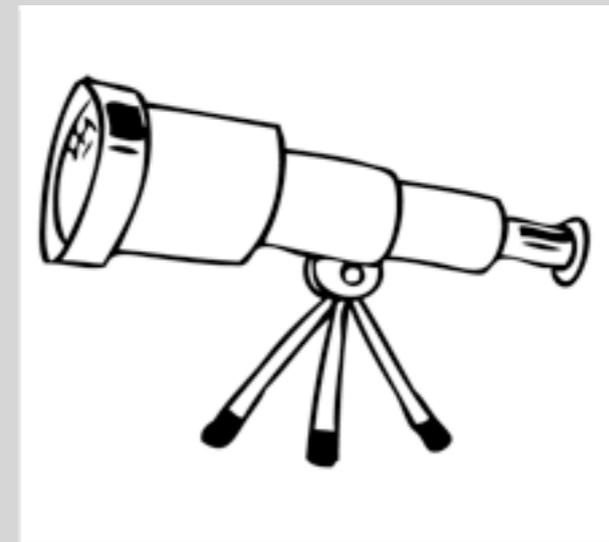
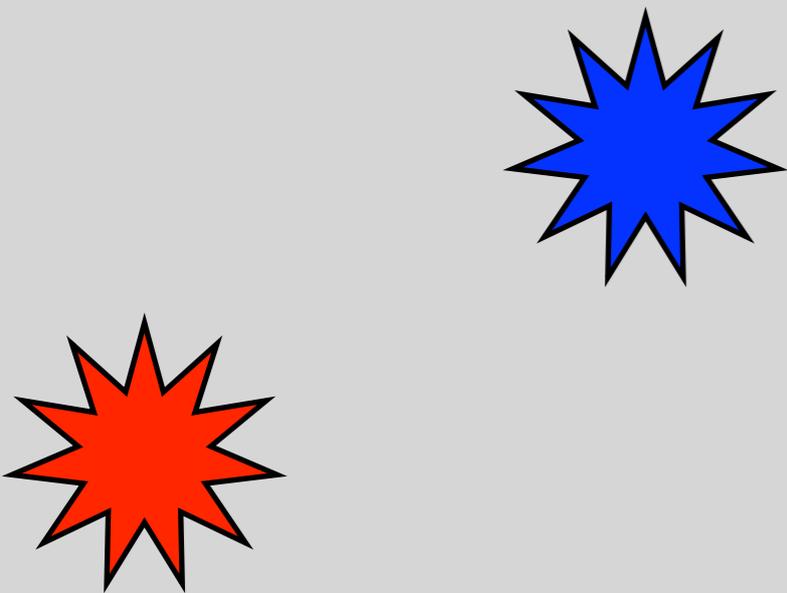


# Dust Makes Things Fainter/Redder

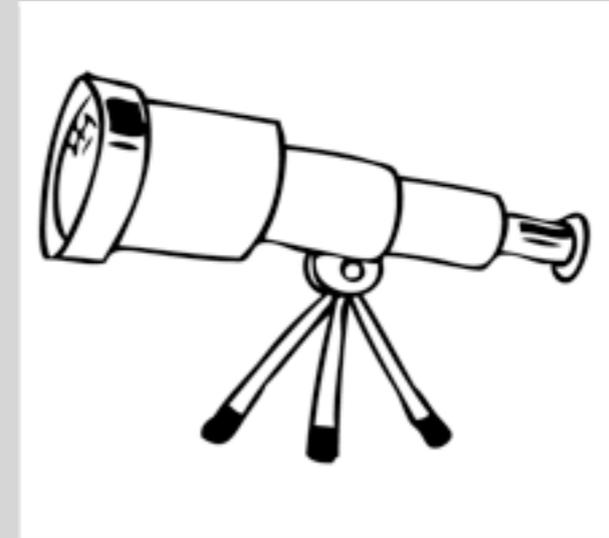
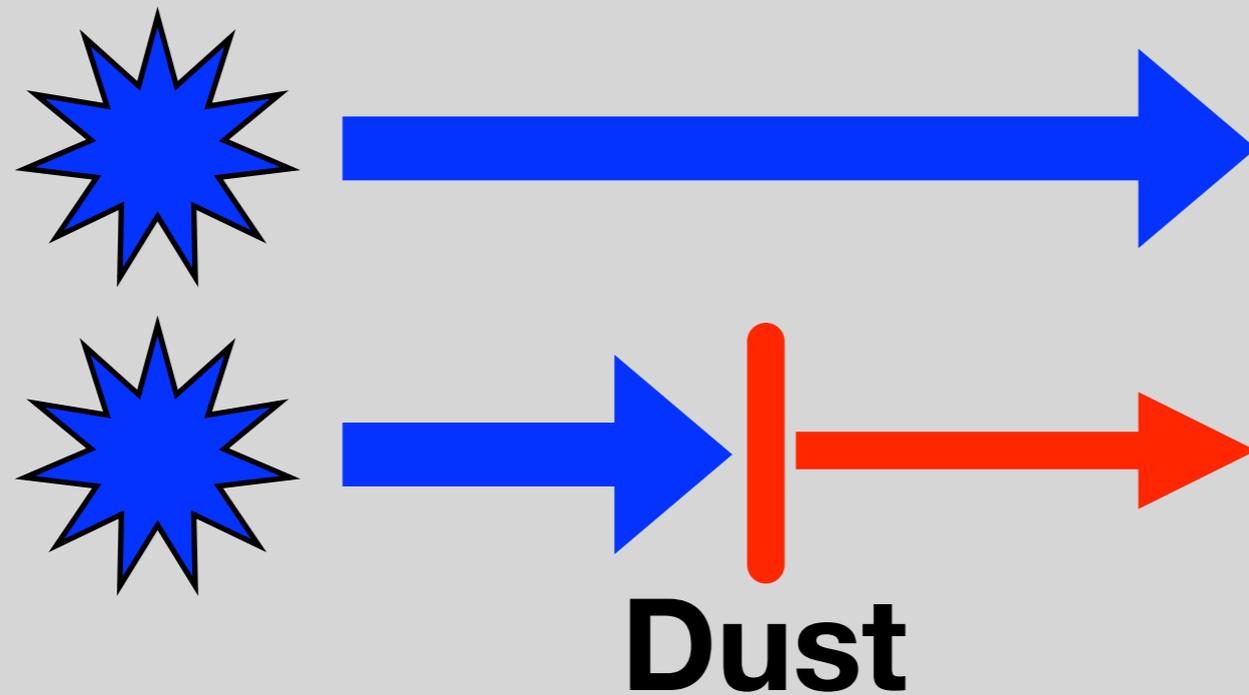


---

# Different Intrinsic Colors

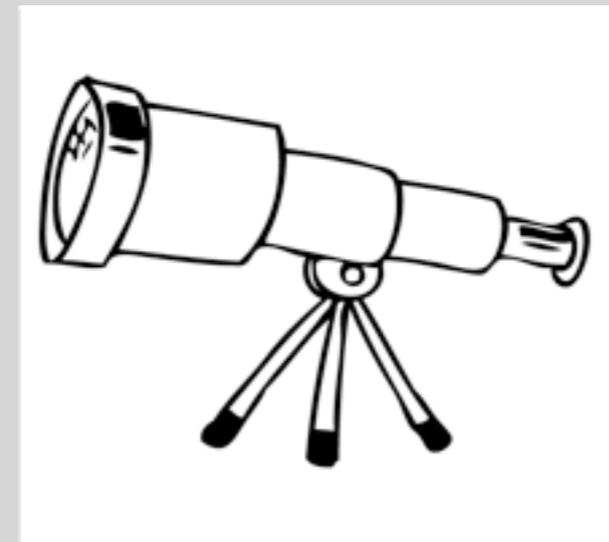
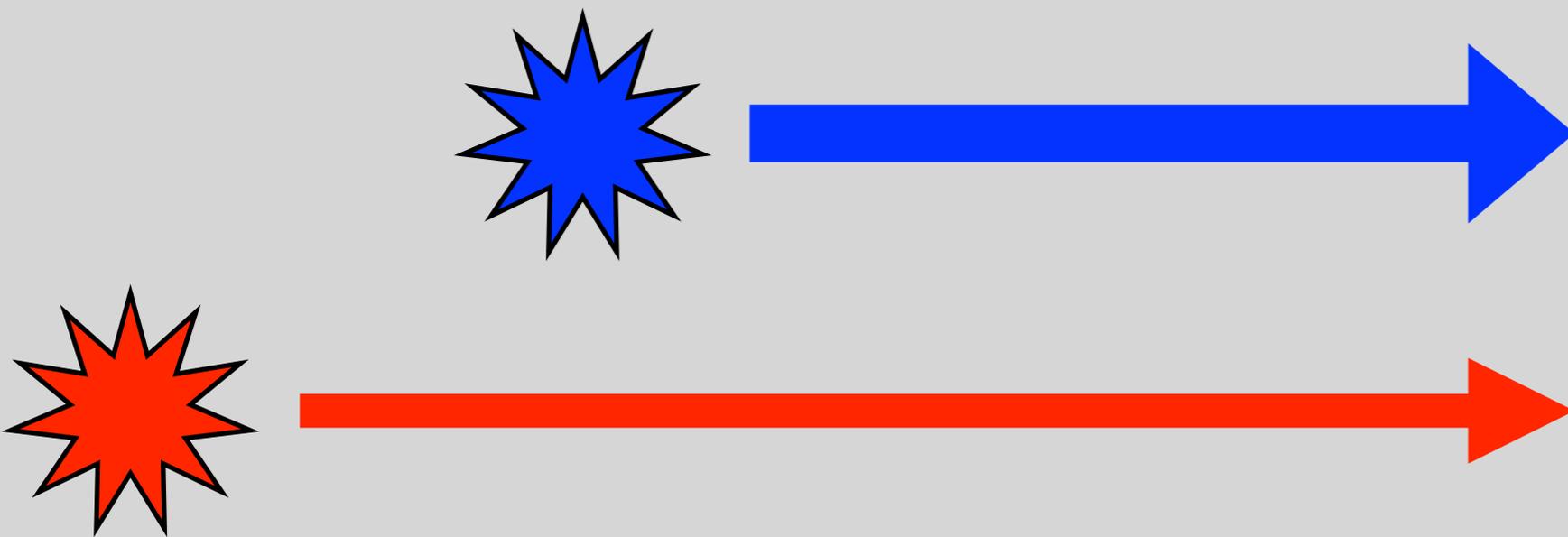


# Dust Makes Things Fainter/Redder

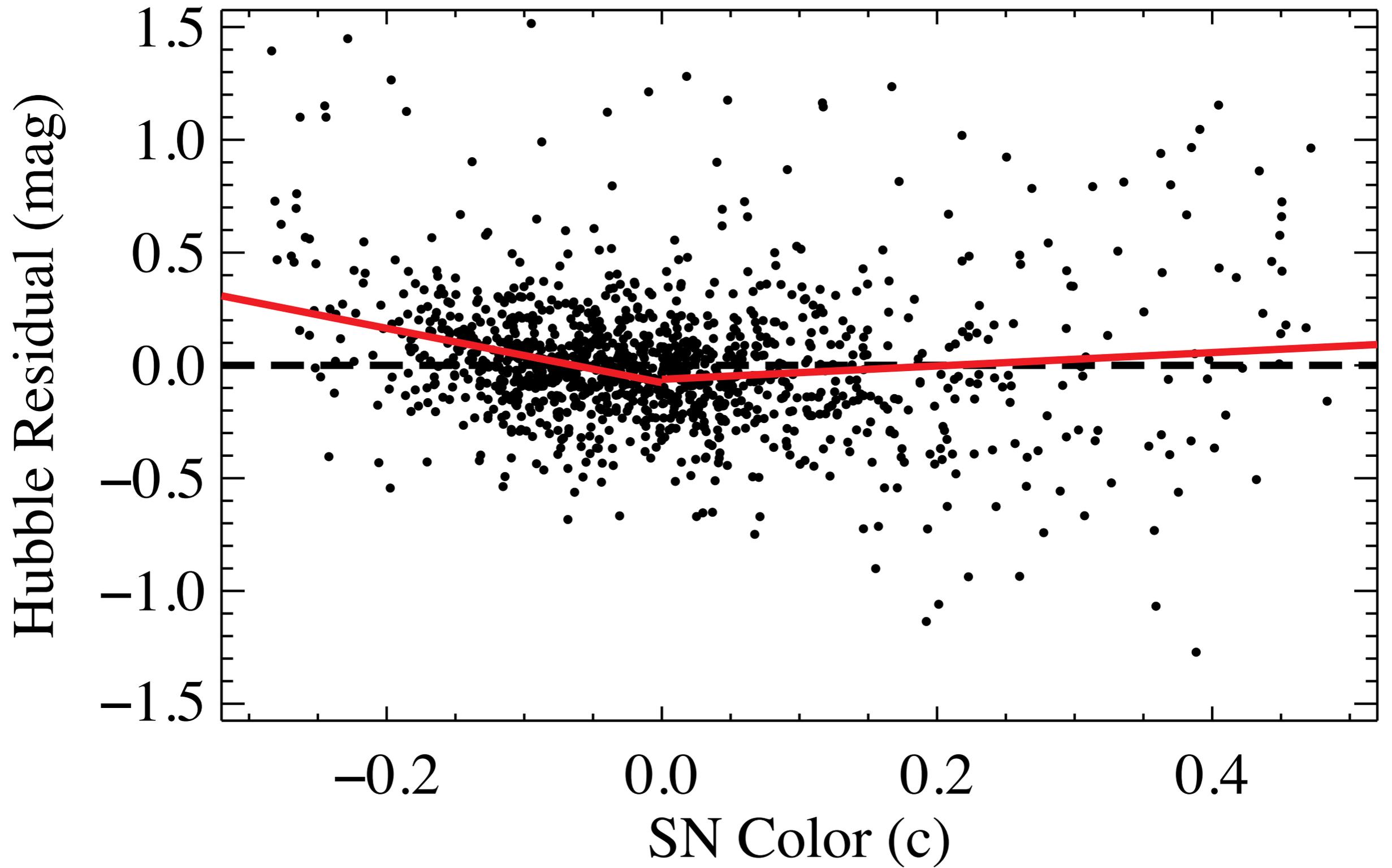


---

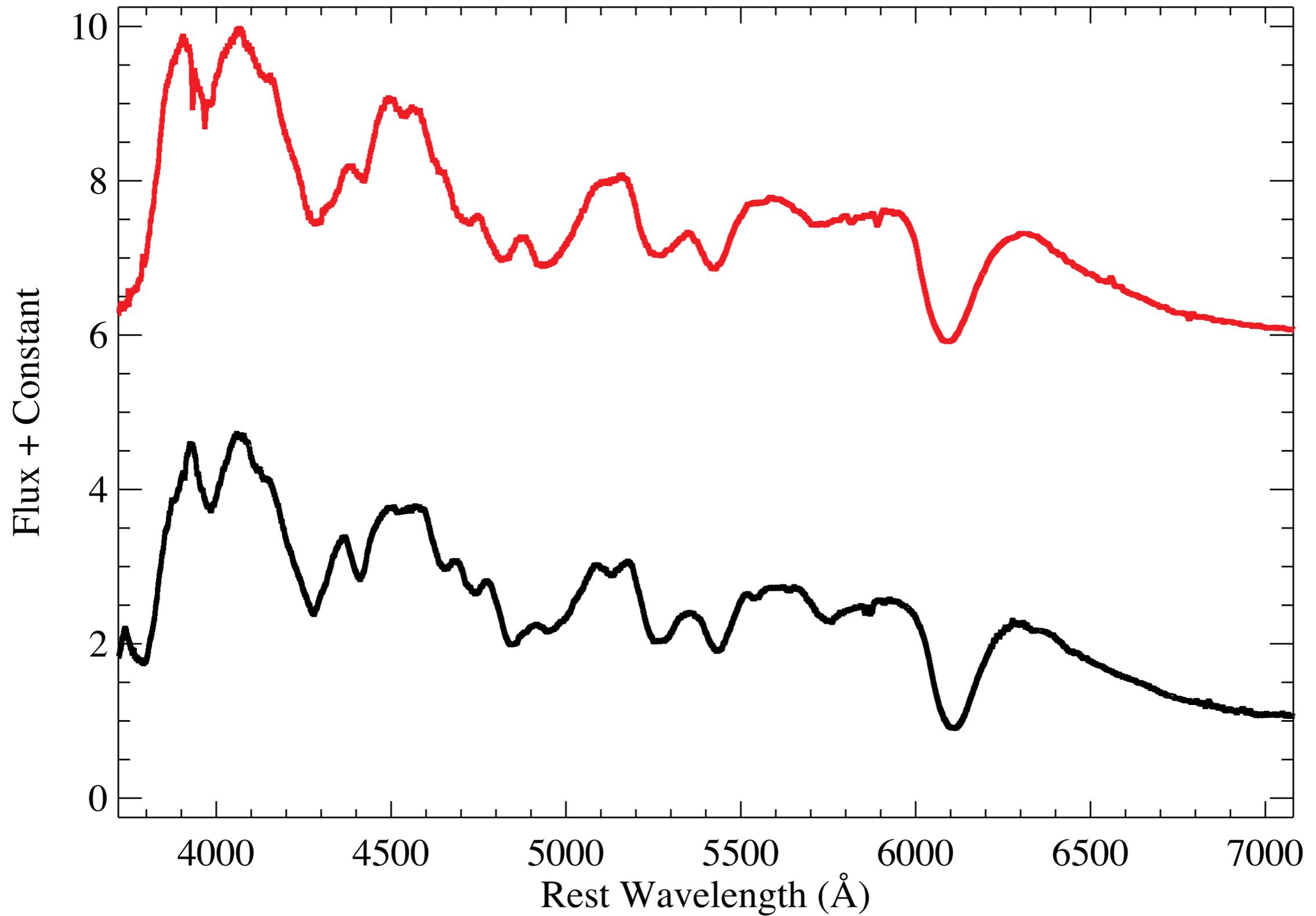
# Different Intrinsic Colors



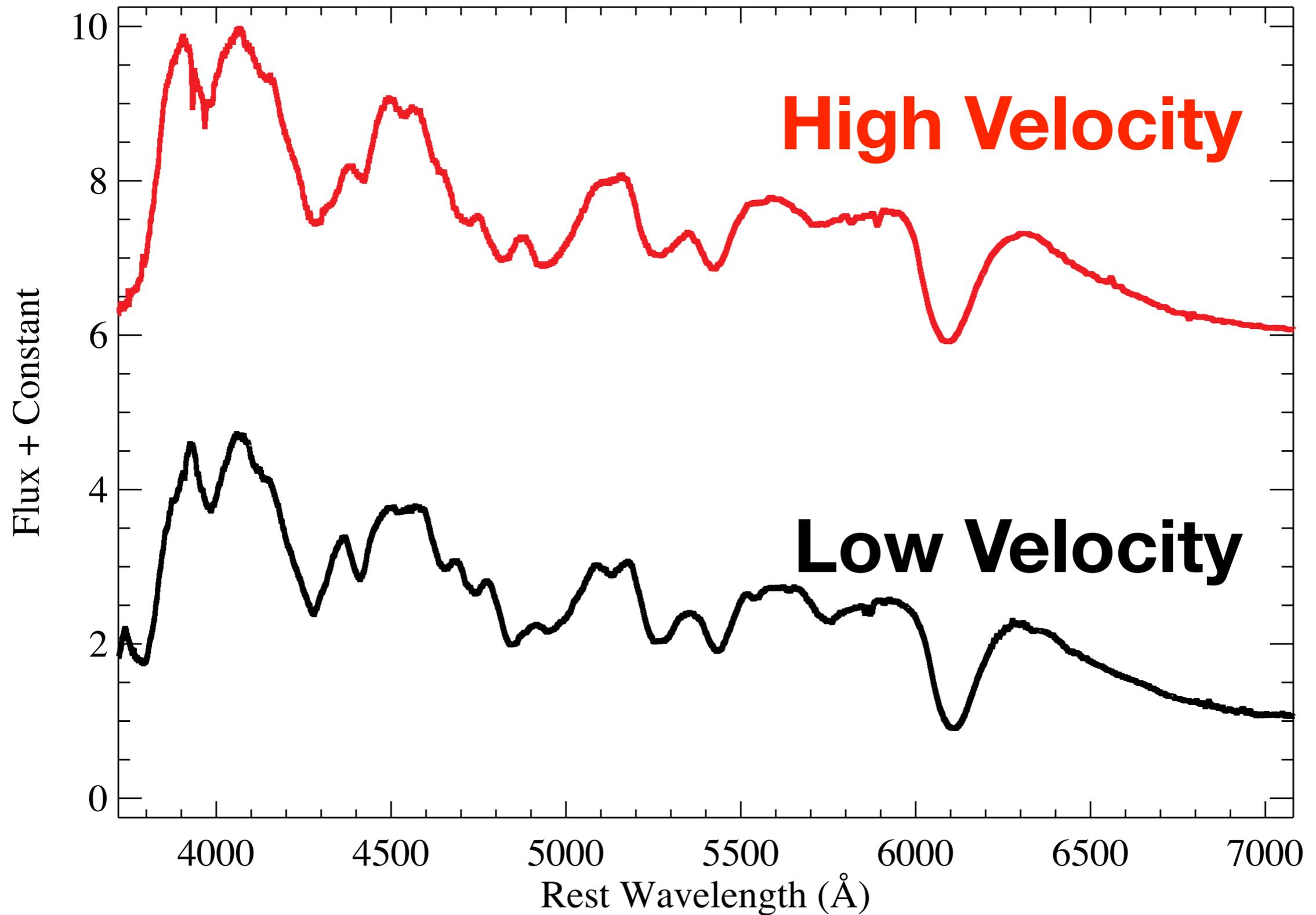
# Evidence for Two Color Components



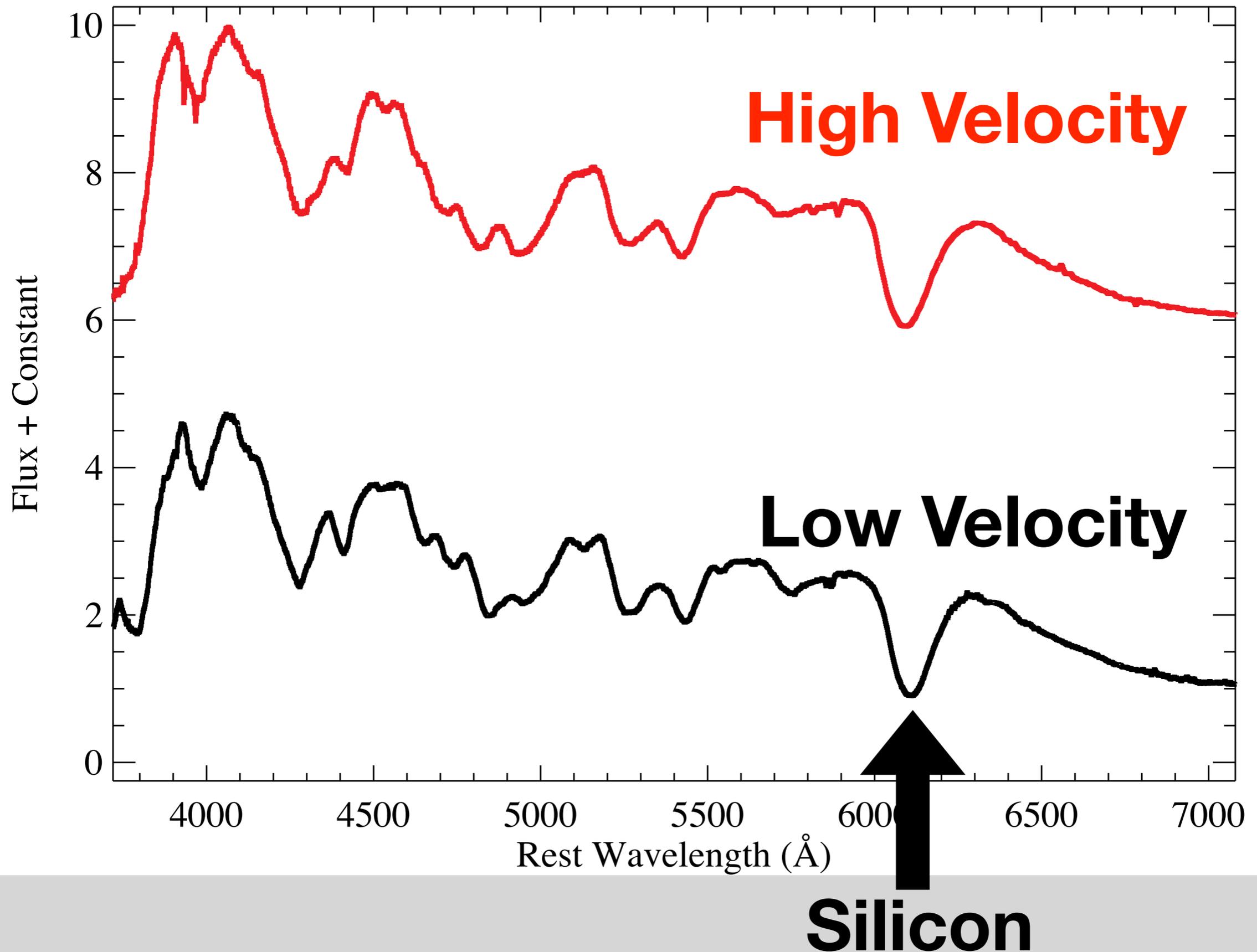
# Optical Spectrum to Measure Velocity



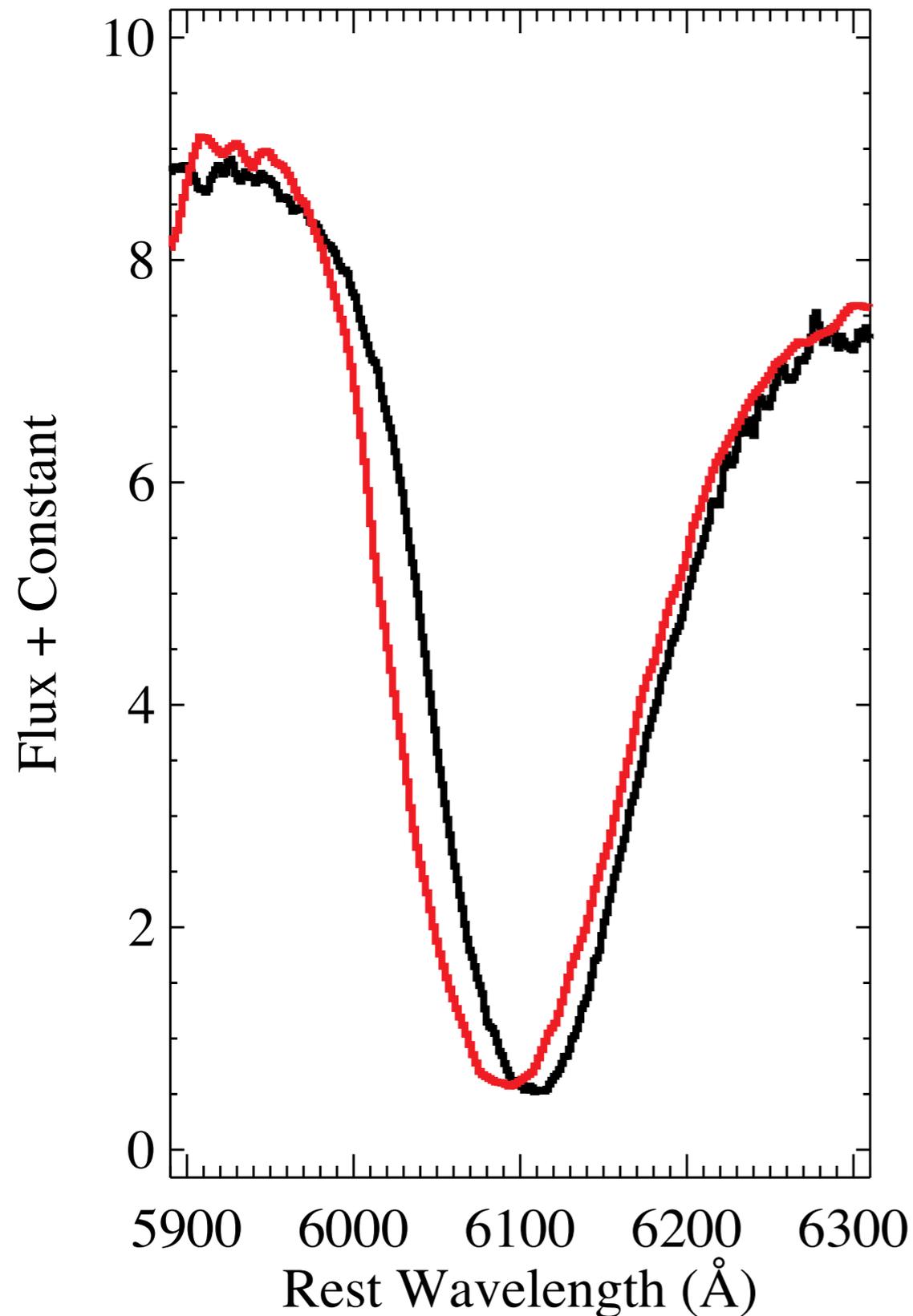
# Optical Spectrum to Measure Velocity



# Optical Spectrum to Measure Velocity



# Measure Silicon Velocity

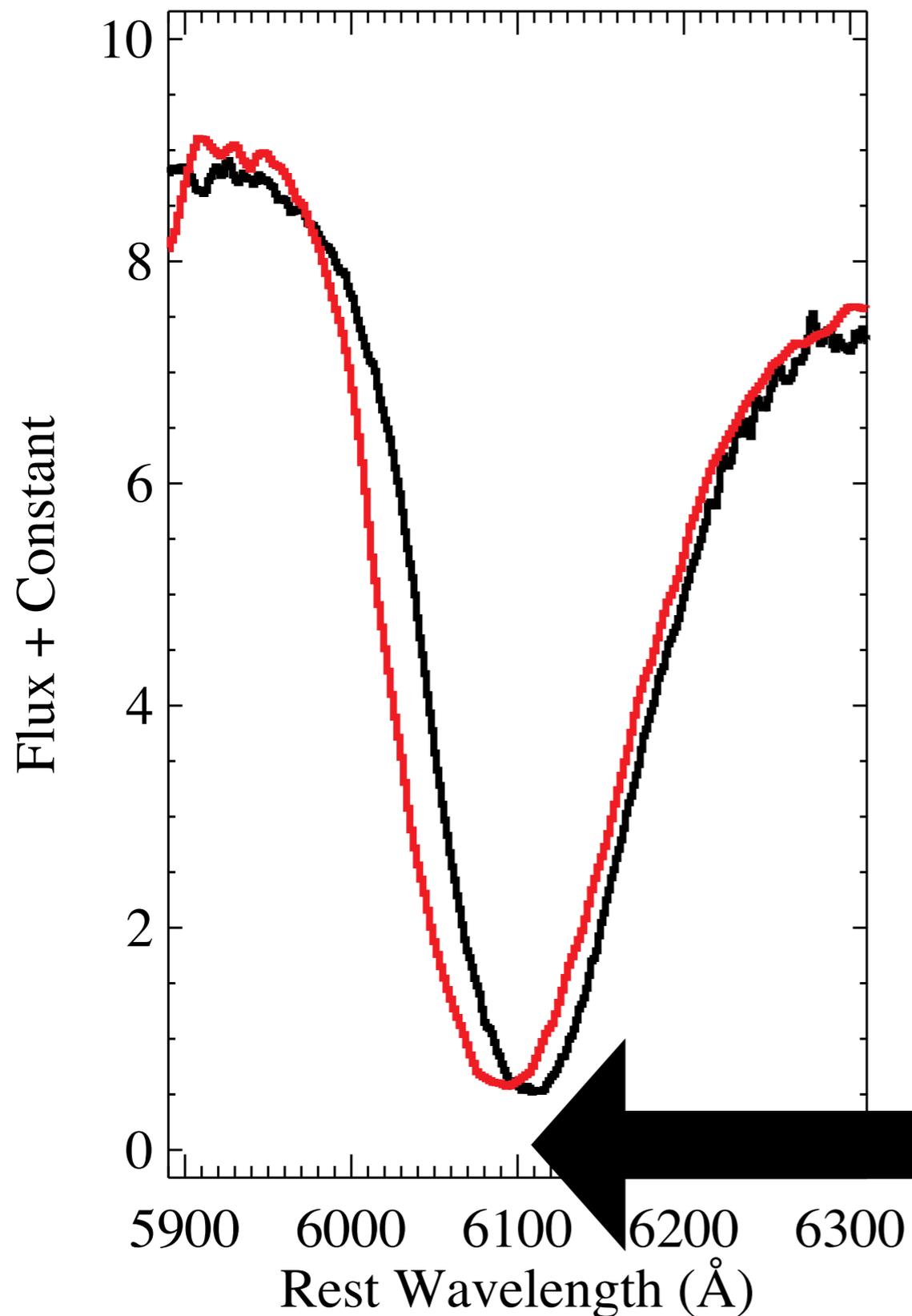


**High Velocity:**  
**~ -13,000 km s<sup>-1</sup>**

**Low Velocity:**  
**~ -10,000 km s<sup>-1</sup>**

**Wider Lines With  
Higher Velocity**

# Measure Silicon Velocity

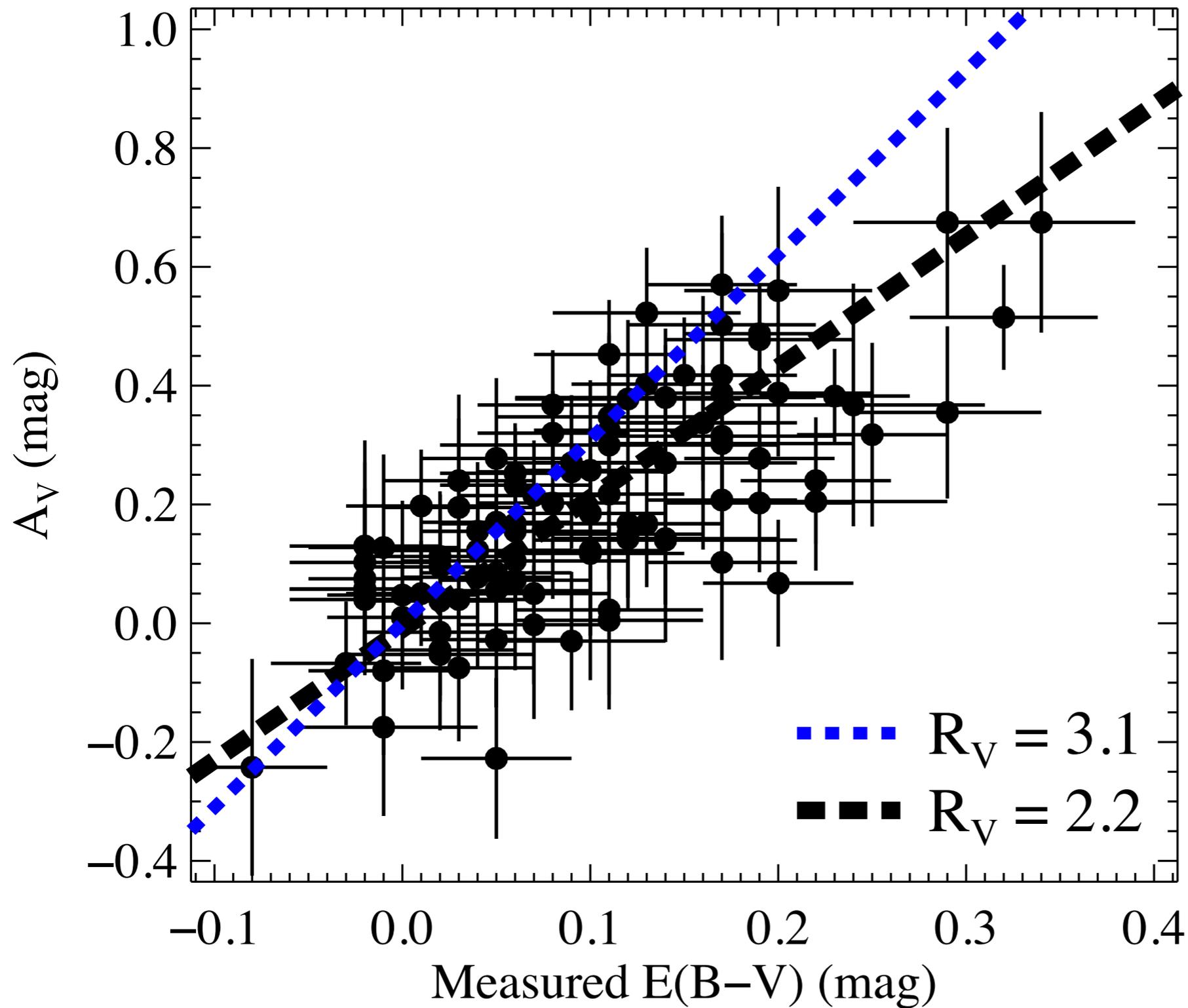


**High Velocity:**  
**~ -13,000 km s<sup>-1</sup>**

**Low Velocity:**  
**~ -10,000 km s<sup>-1</sup>**

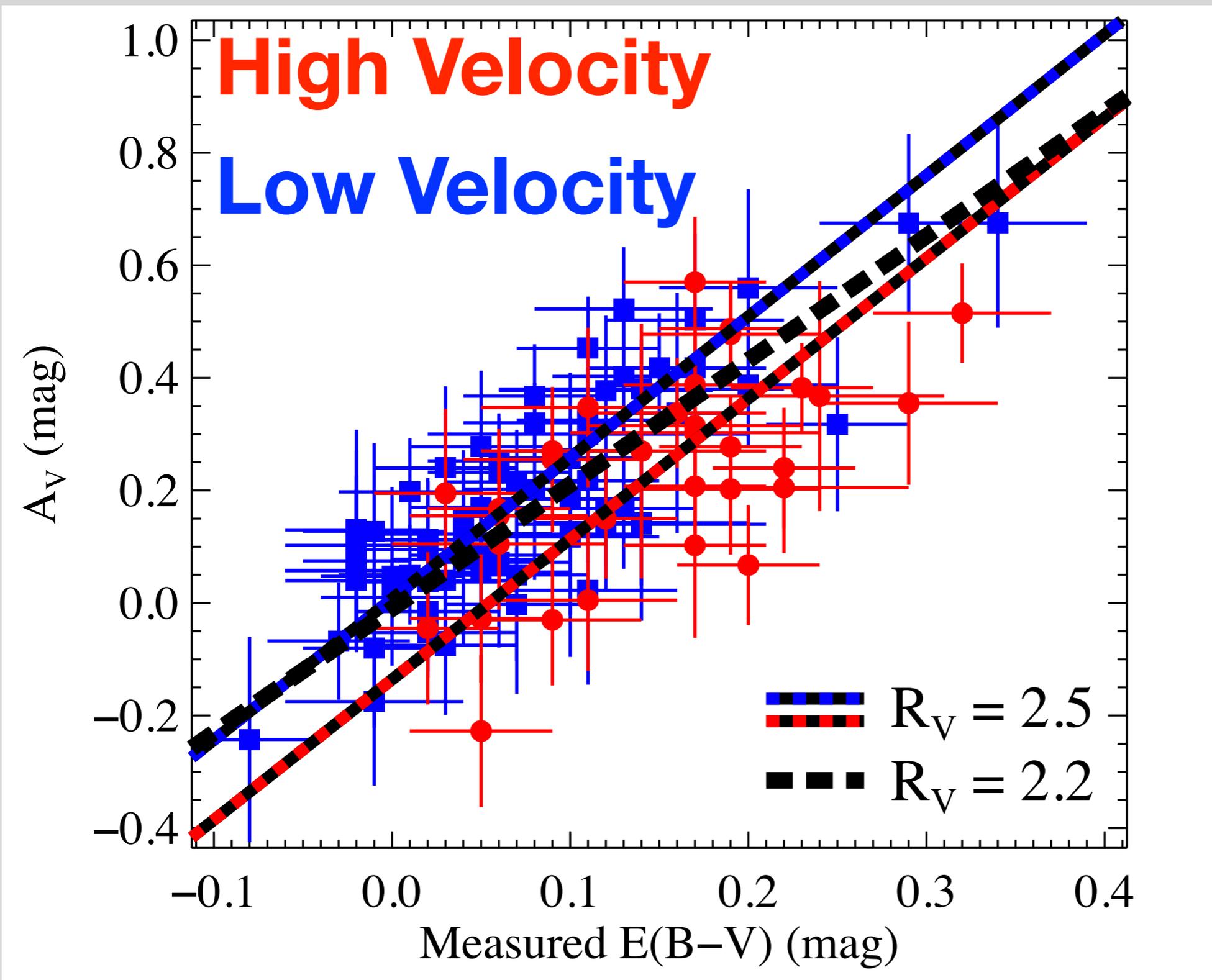
**Wider Lines With  
Higher Velocity**

# Samples of SNe Ia have Low $R_V$



$$R_V = \frac{A_V}{E(B-V)}$$

# Intrinsic Color Depends on SN Velocity



$$R_V = \frac{A_V}{E(B-V)}$$

Foley & Kasen 2011

also Foley 2012; Foley, Sanders, & Kirshner 2011; Mandel, Foley, & Kirshner 2014



# Ejecta Velocity is the “Next Parameter”



**Low Velocity**

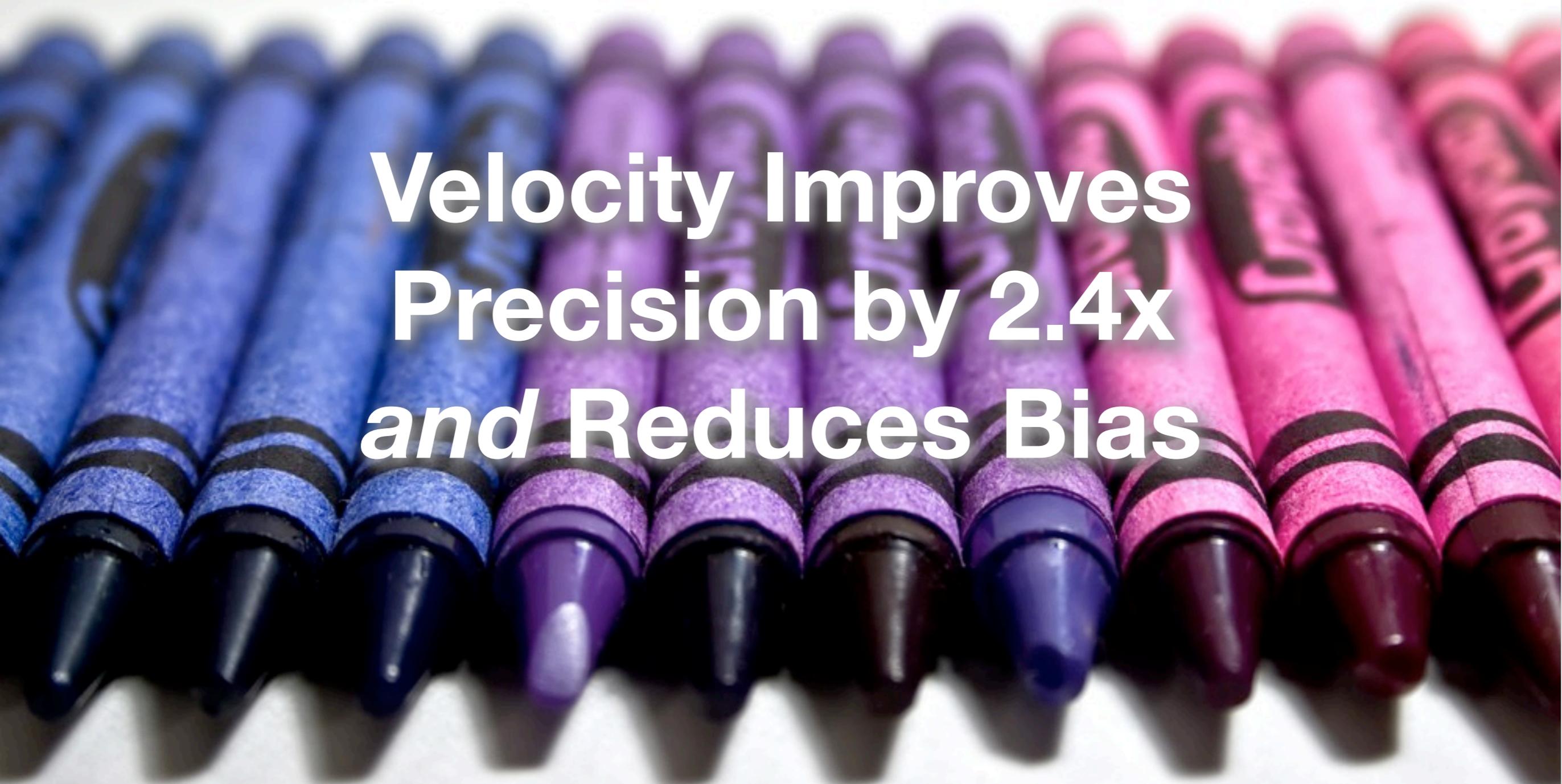
**High Velocity**

# Ejecta Velocity is the “Next Parameter”

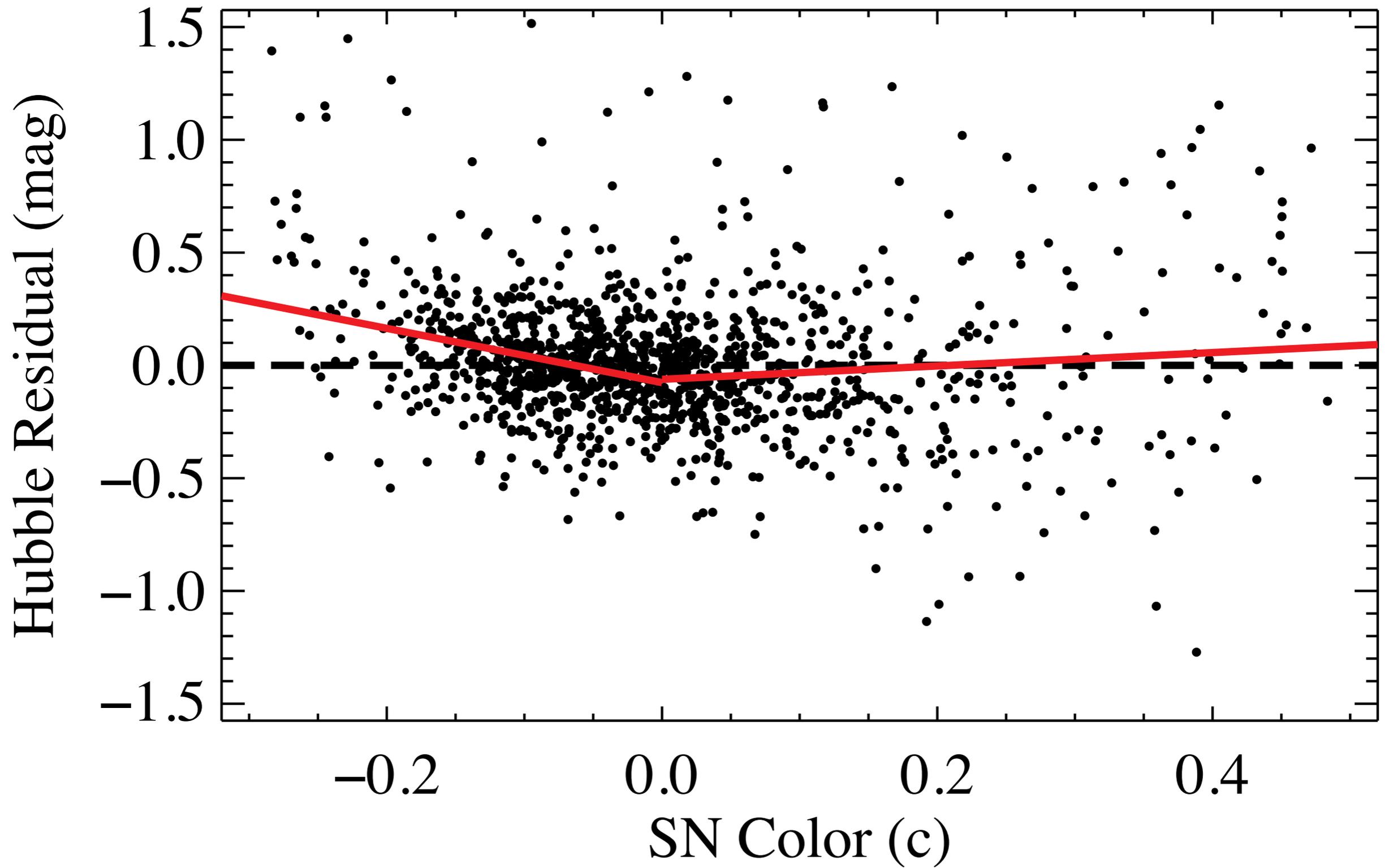
Velocity Improves  
Precision by 2.4x  
*and Reduces Bias*

**Low Velocity**

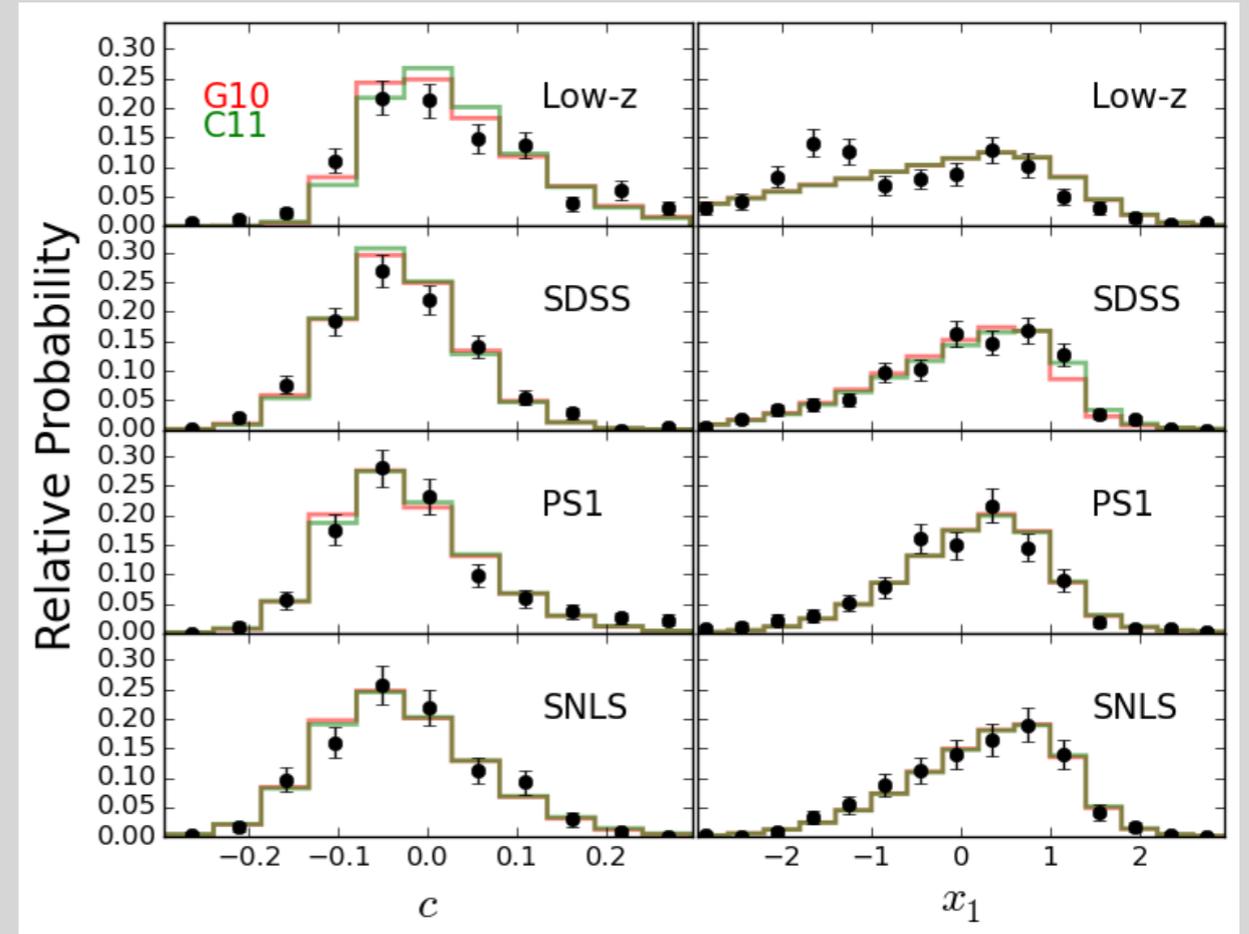
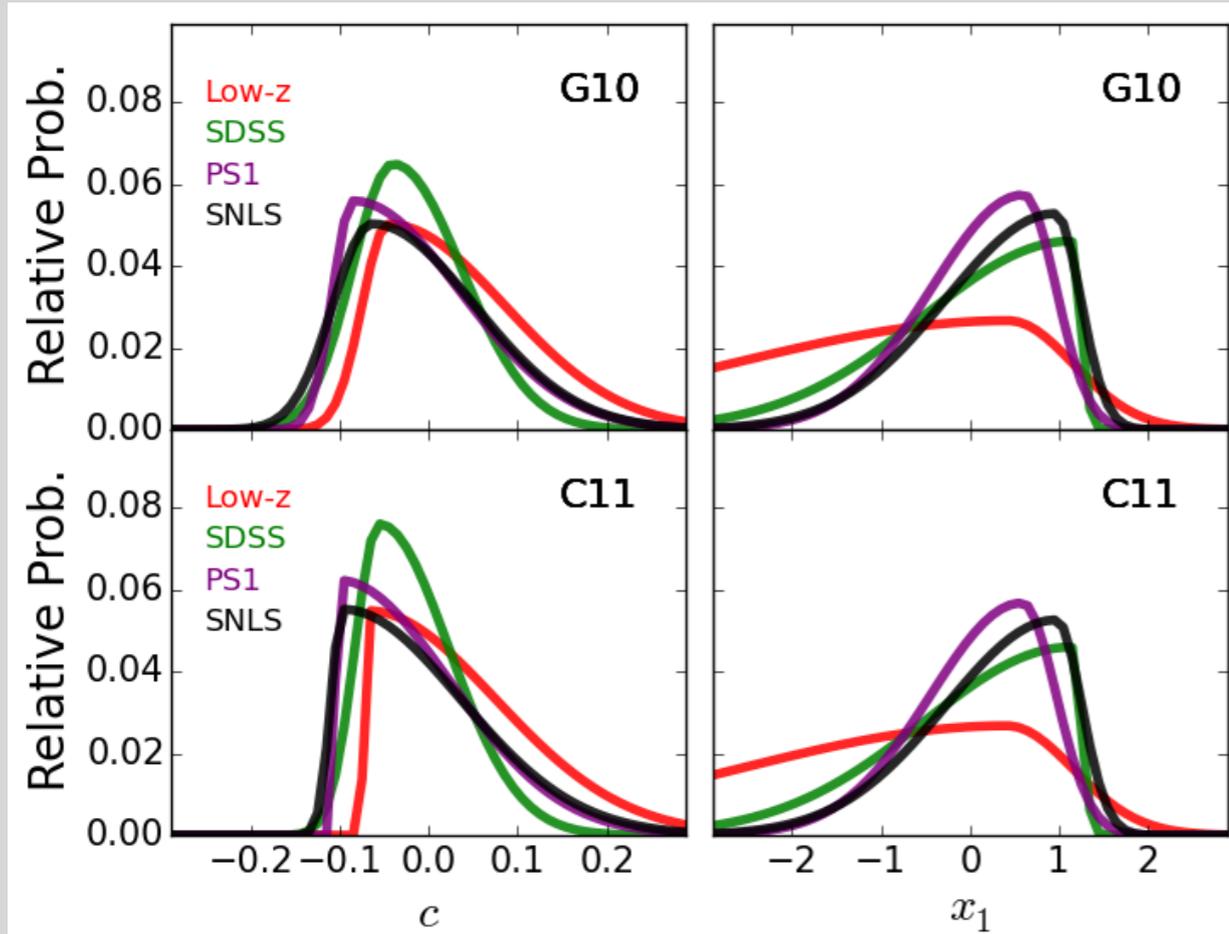
**High Velocity**



# Evidence for Two Color Components



# Populations from Simulations



Scolnic & Kessler 2016

# Simulations Predict (Remove) Biases

