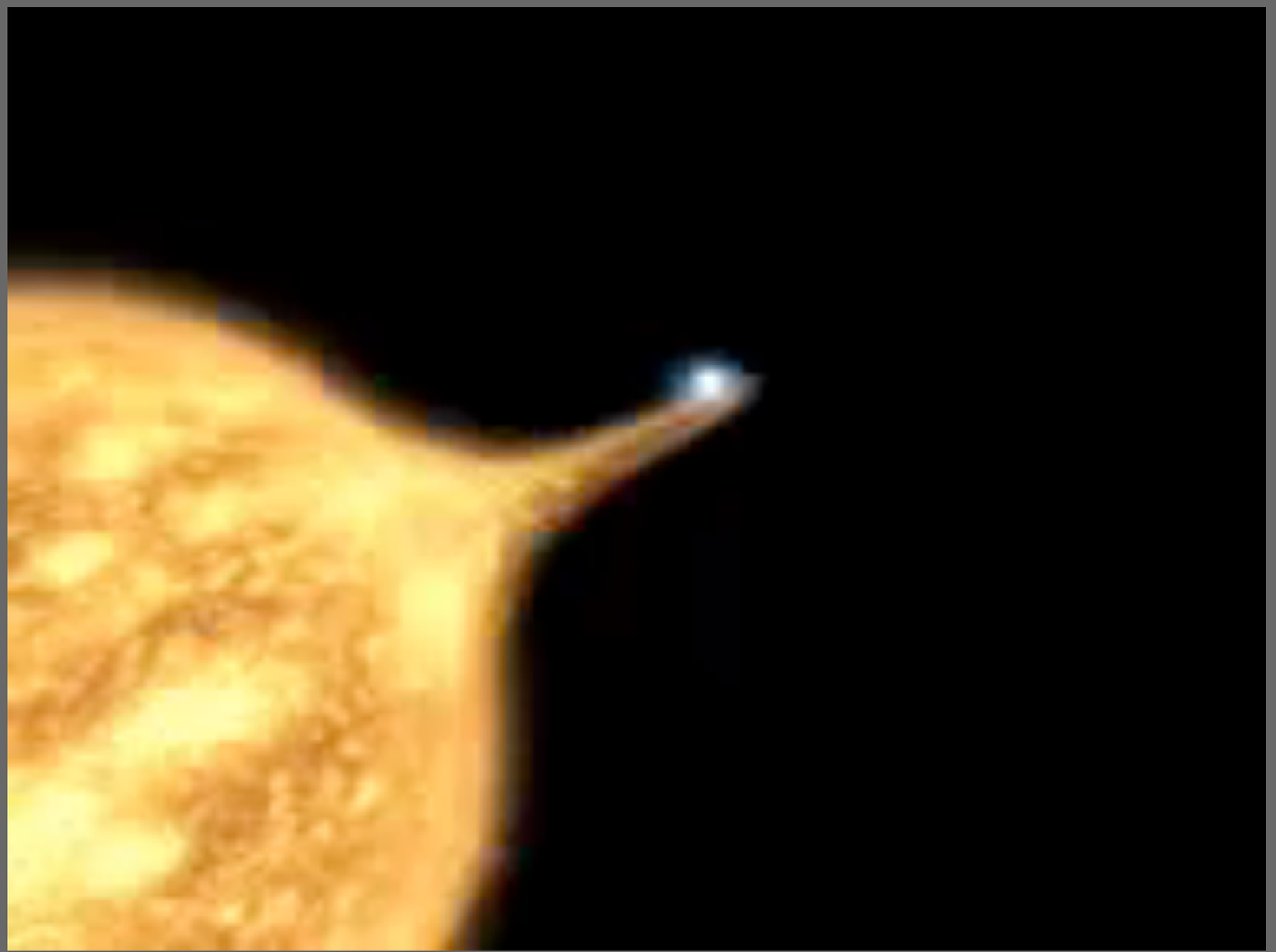
Type Ia Supernovae: Standardizable Candles and Crayons

Ryan Foley
Clay Fellow
Harvard-Smithsonian
Center for Astrophysics

Collaborators:
Stephane Blondin
Dan Kasen
Bob Kirshner
Kaisey Mandel &
Nathan Sanders

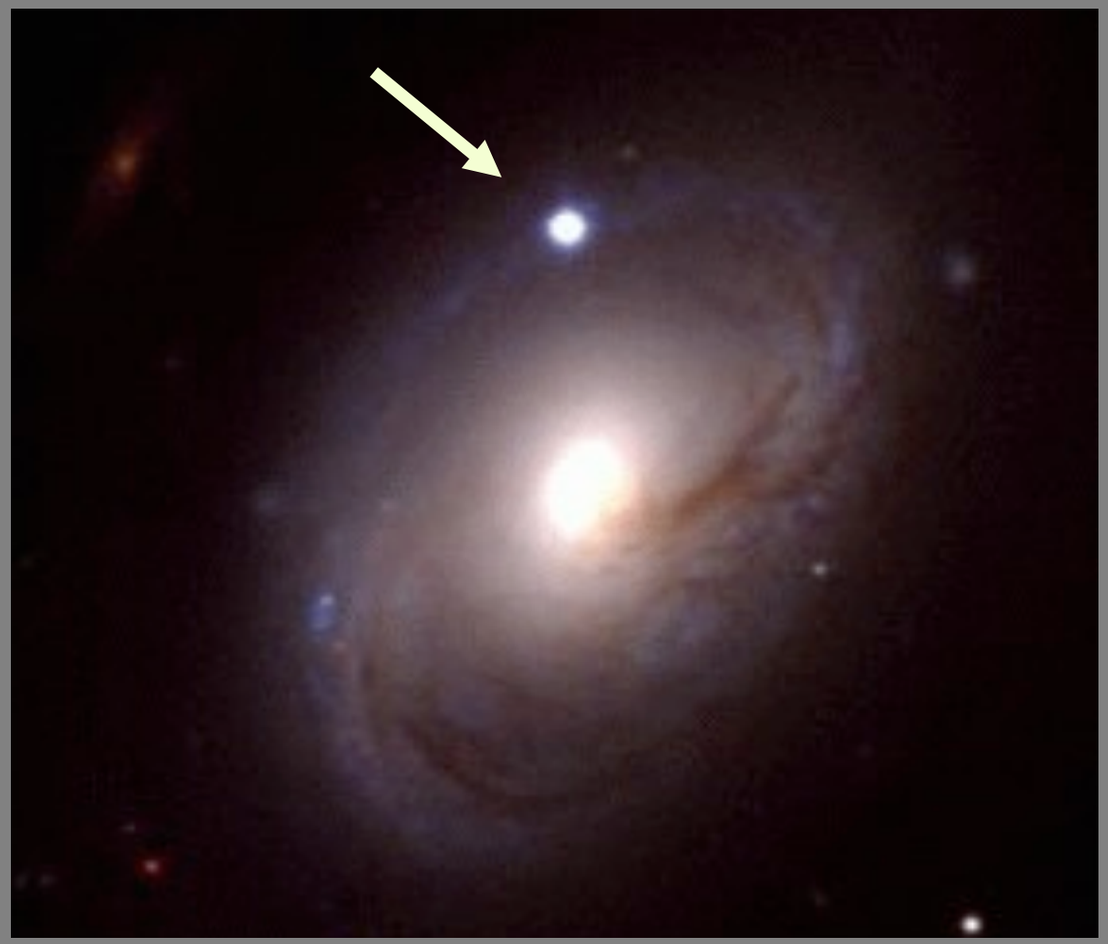
SNe Ia Are Exploding White Dwarfs

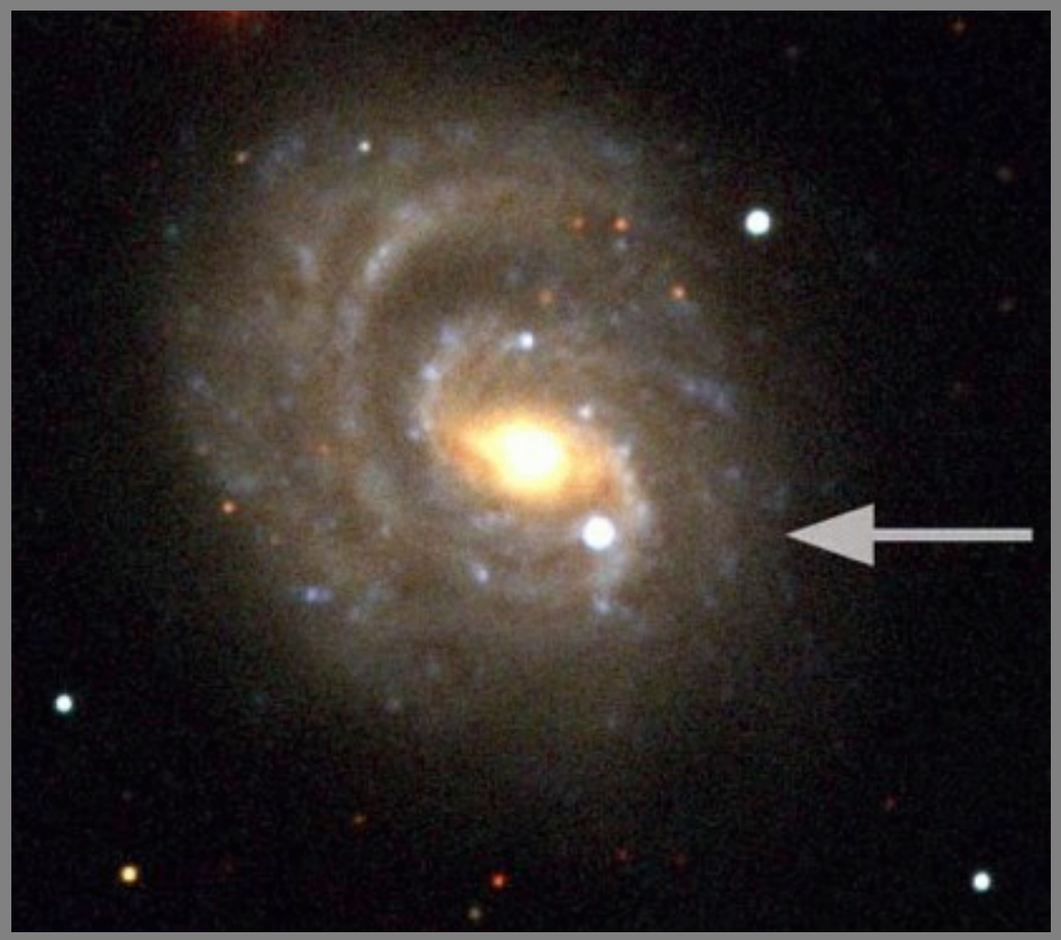


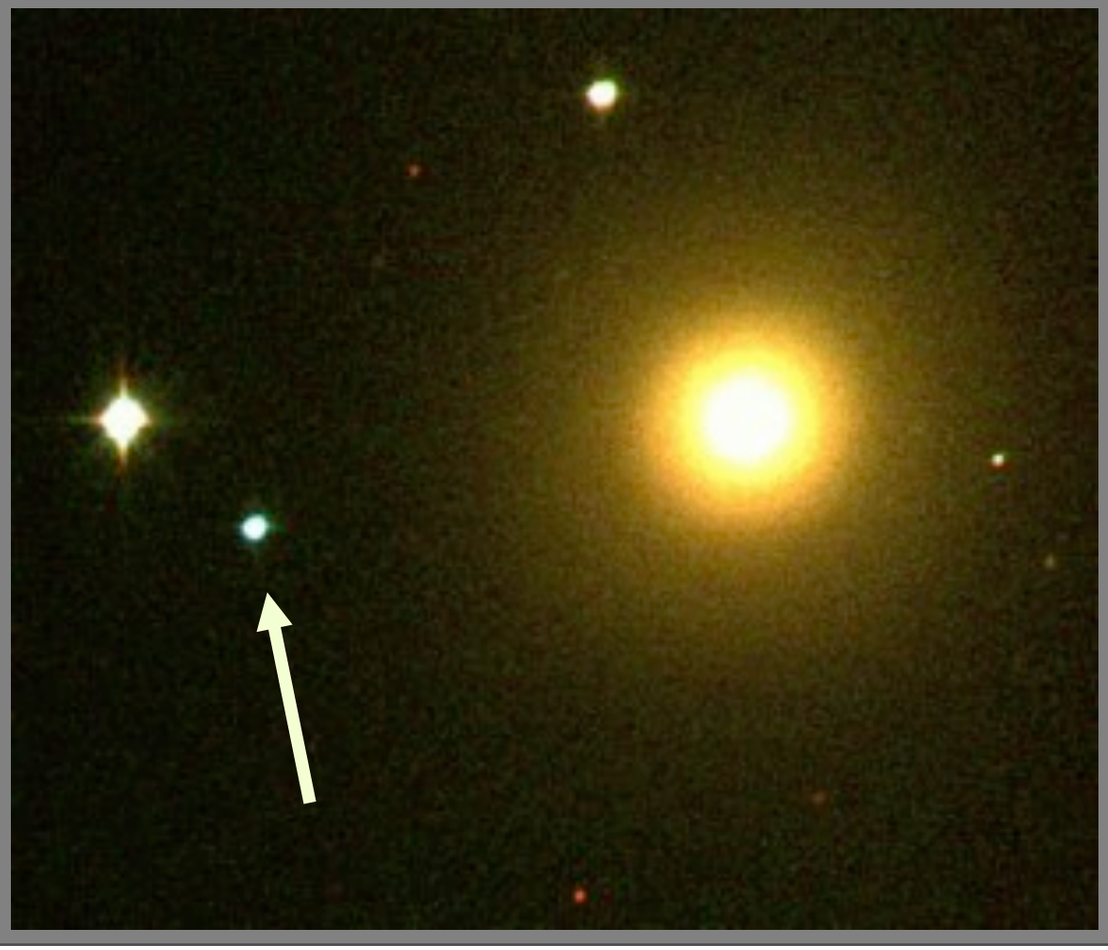
White Dwarf in Binary System

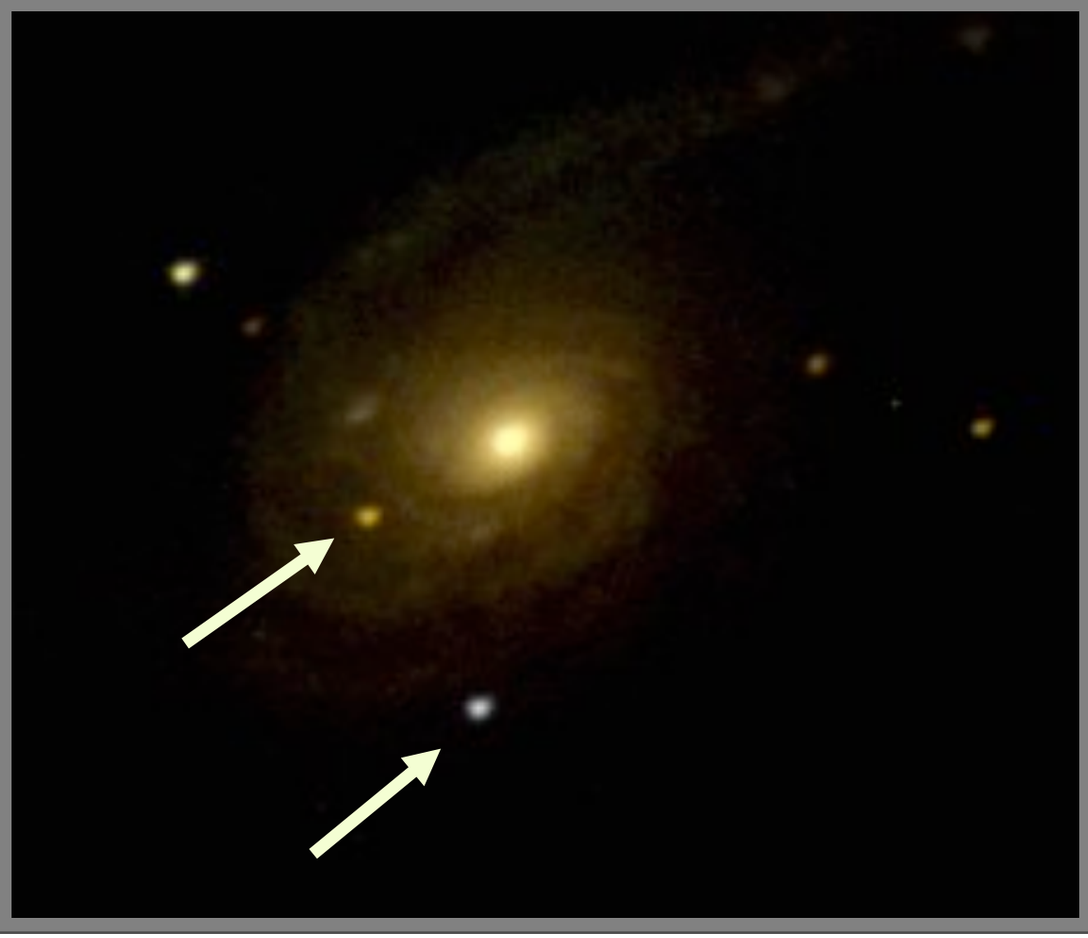
Accretes Matter Until ~1.4 times the Mass of the Sun

Explodes and is Very, Very Luminous









SNe Ia Are Standard Candles

Peak luminosity
σ = 0.6 mag

Peak absolute mag
V ≈ -19.5 mag!

Detectable at high redshifts

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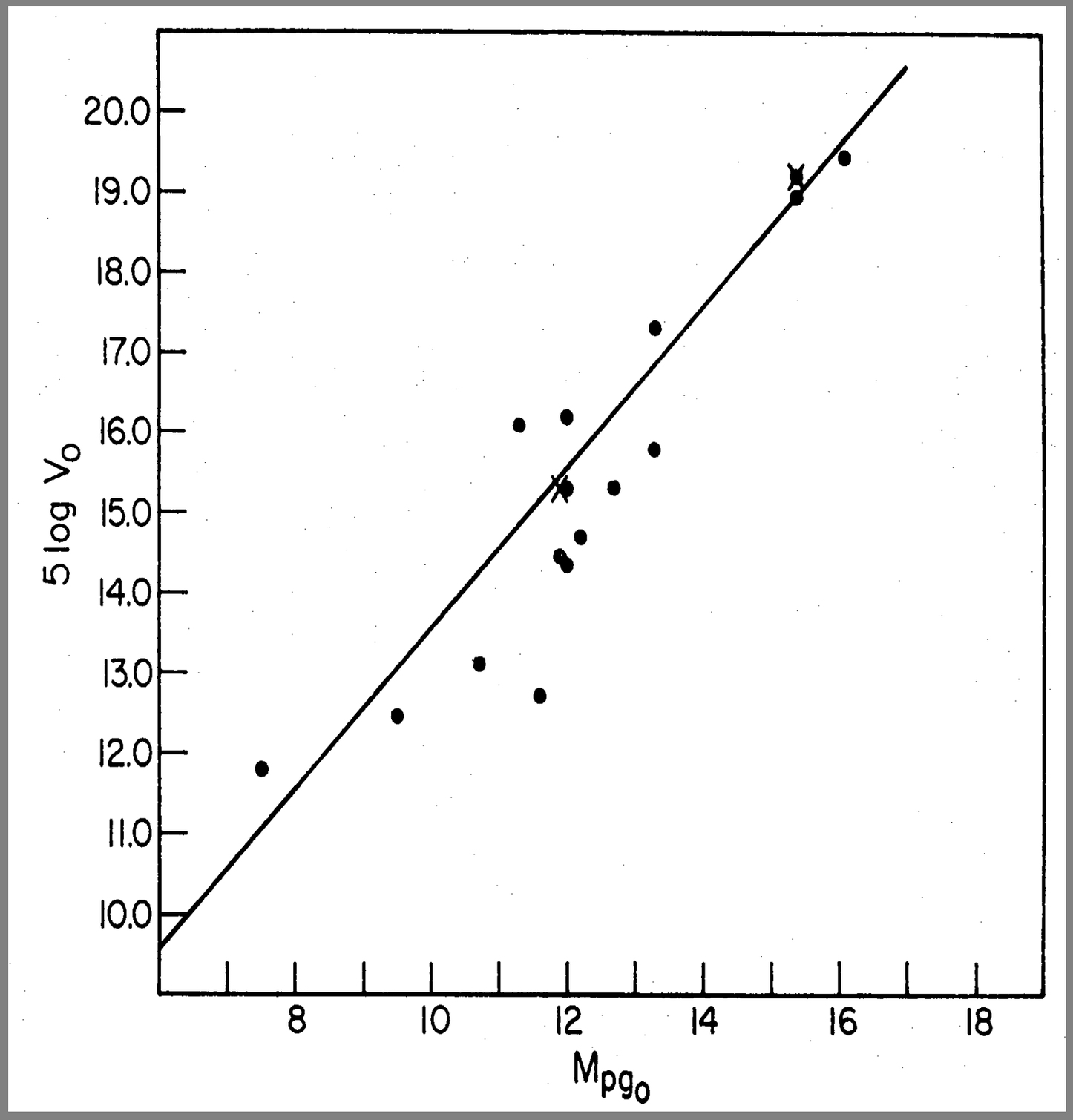
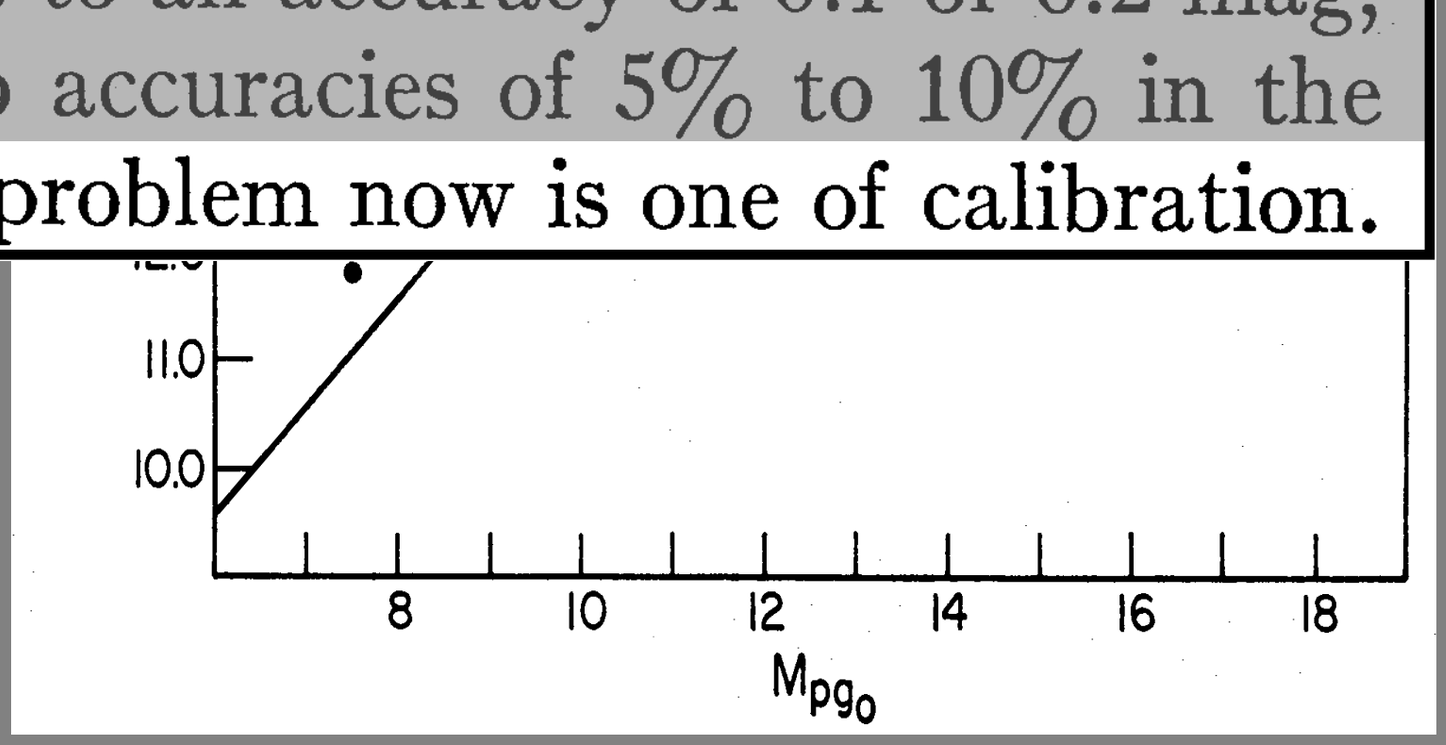


Kowal 1968

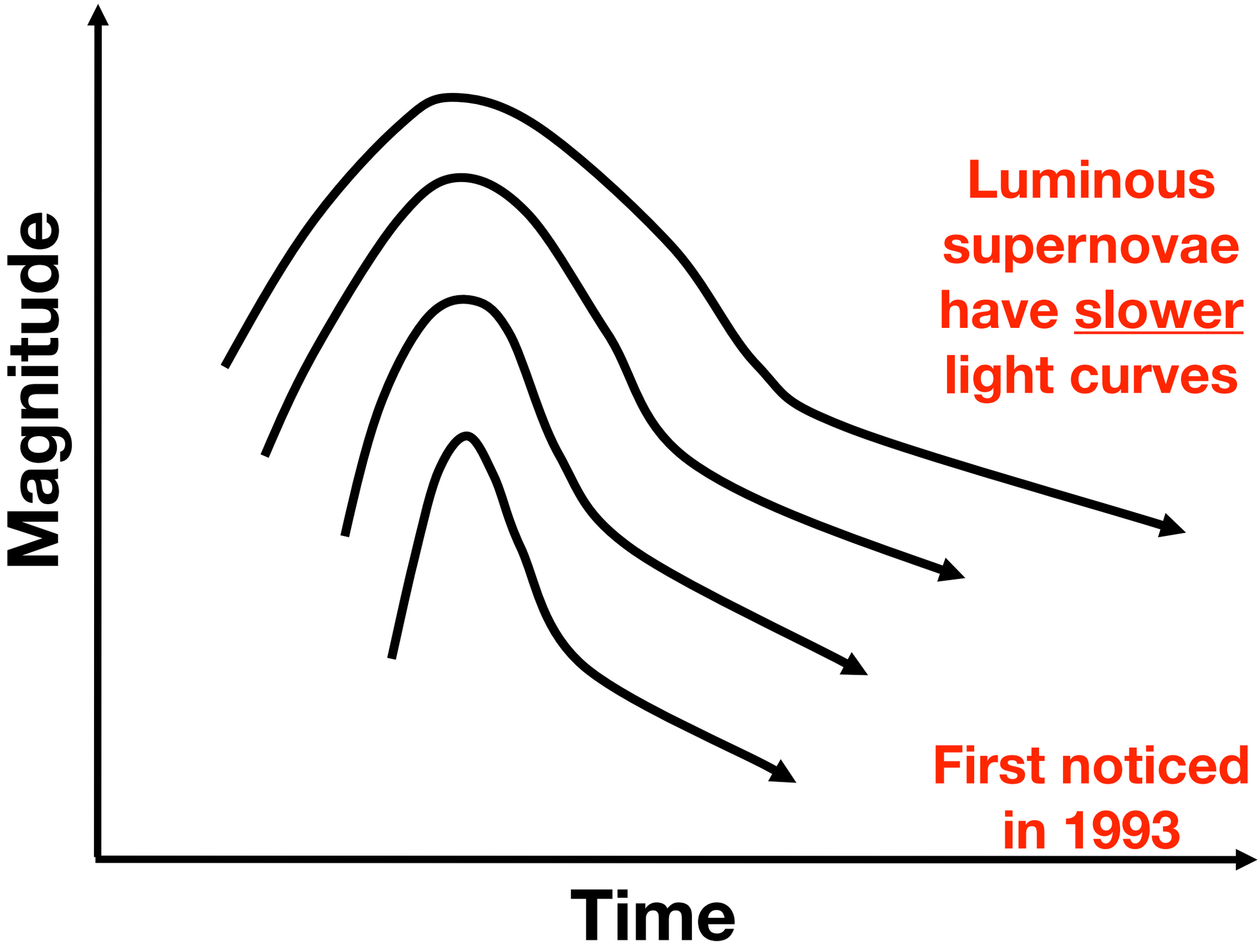
SNe Ia Are Standard Candles

As shown earlier, the observed dispersion in the maximum magnitudes of supernovae of type I is about $0^m.6$, and the intrinsic dispersion should be even smaller. It is obvious, therefore, that these supernovae could be exceedingly useful indicators of distance. It should be possible to obtain average supernova magnitudes in clusters of galaxies to an accuracy of 0.1 or 0.2 mag, which corresponds to accuracies of 5% to 10% in the distances. The main problem now is one of calibration.



Kowal 1968

Calibrating the Nearly Standard Candle



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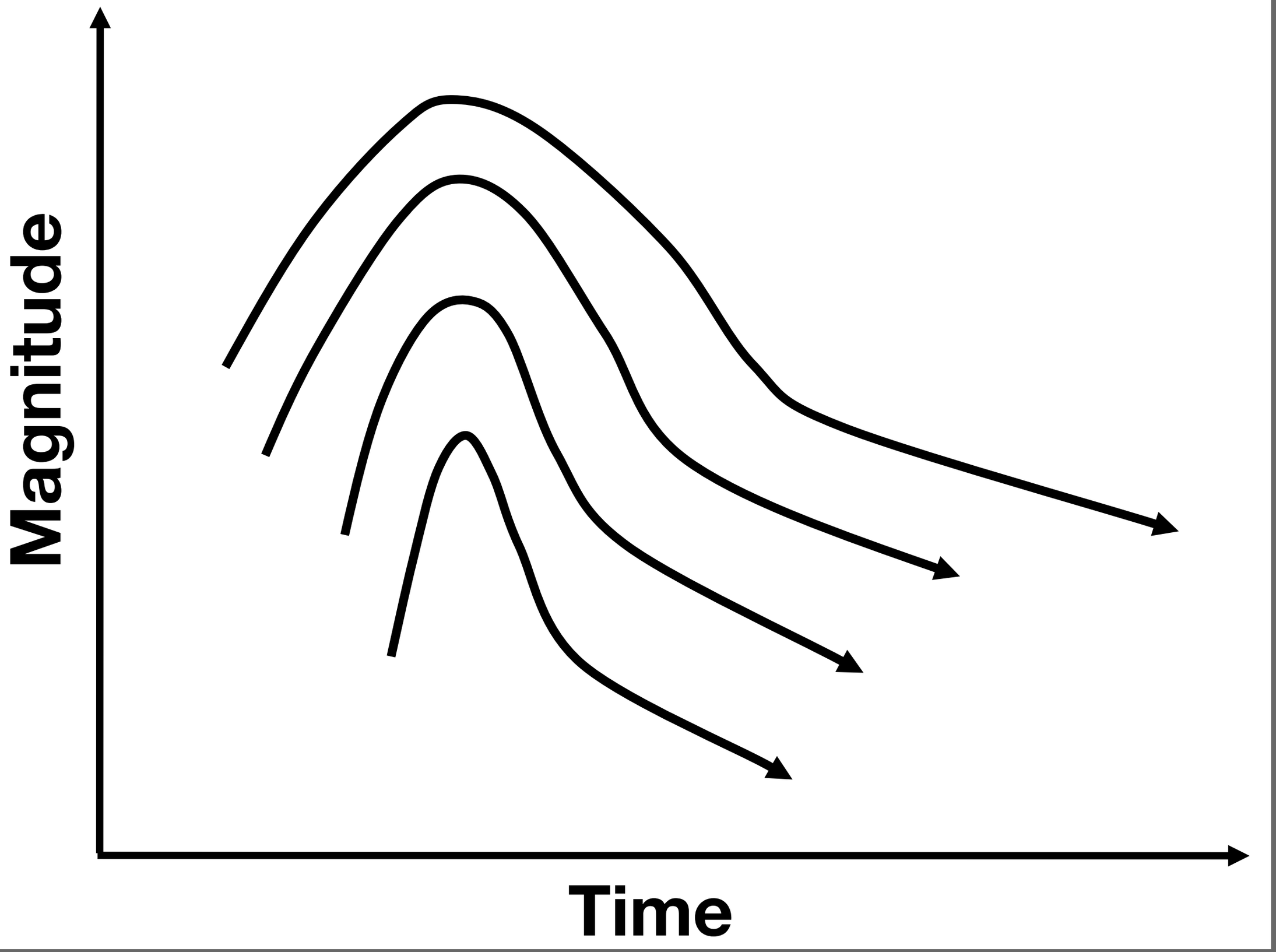

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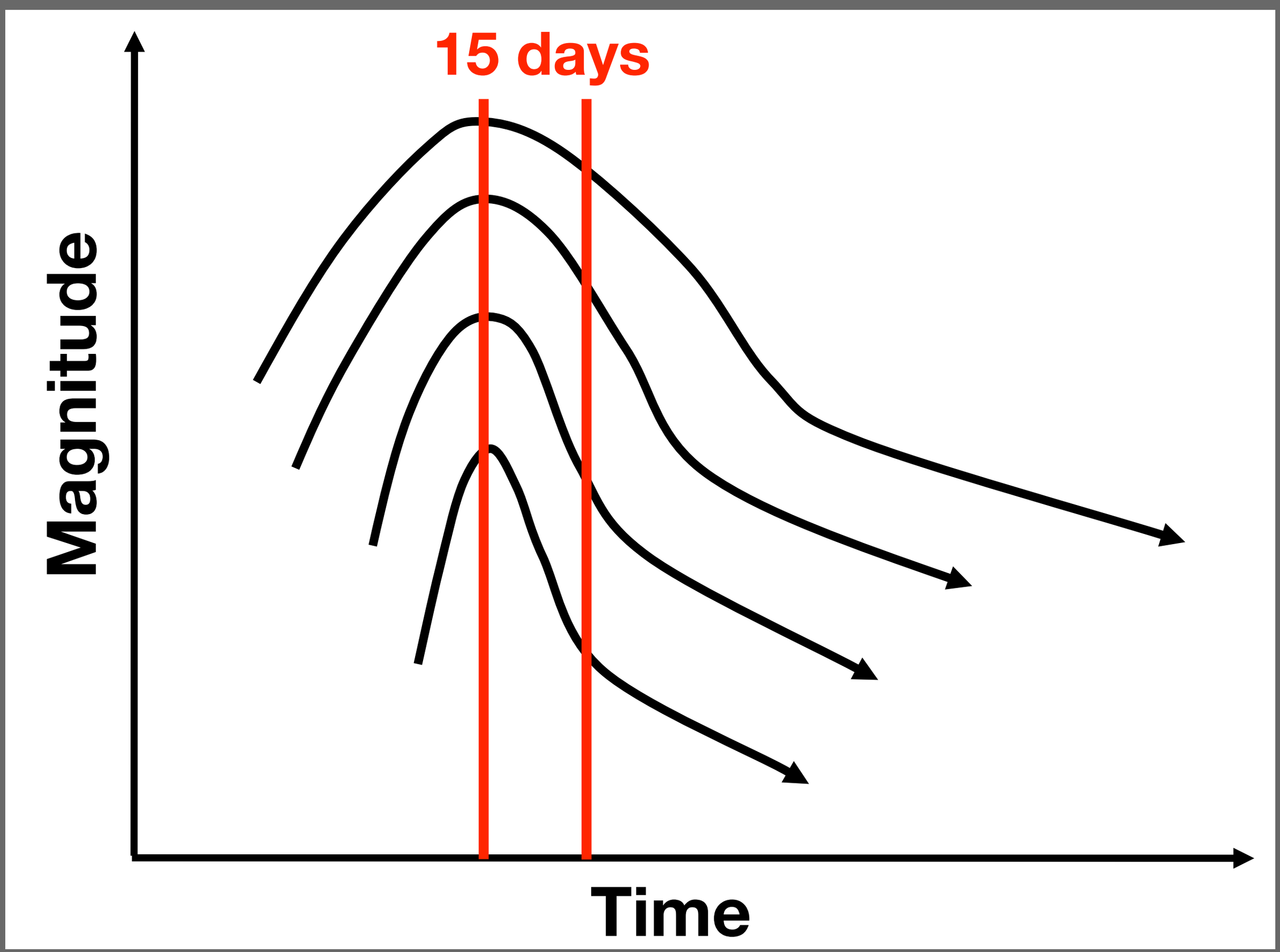

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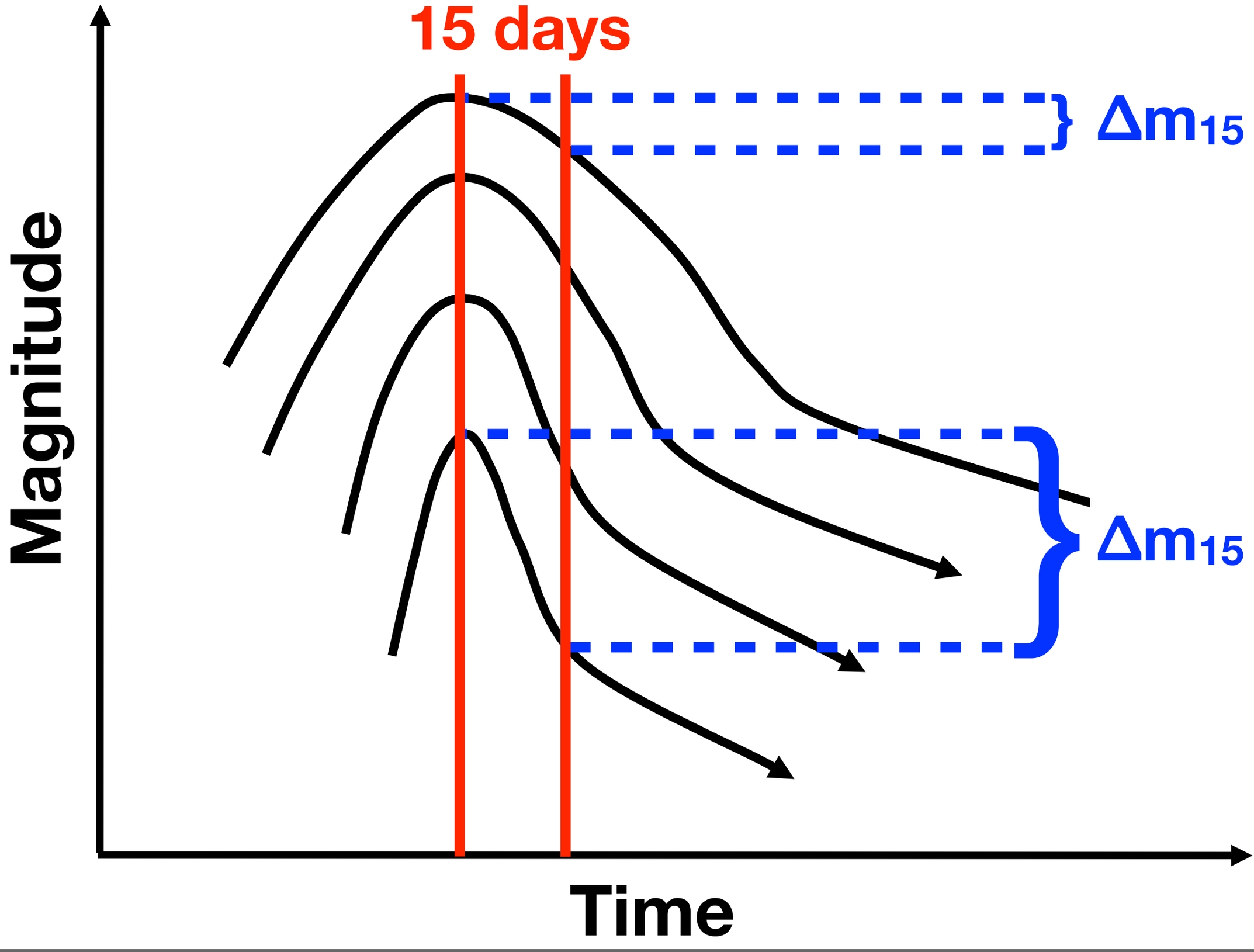
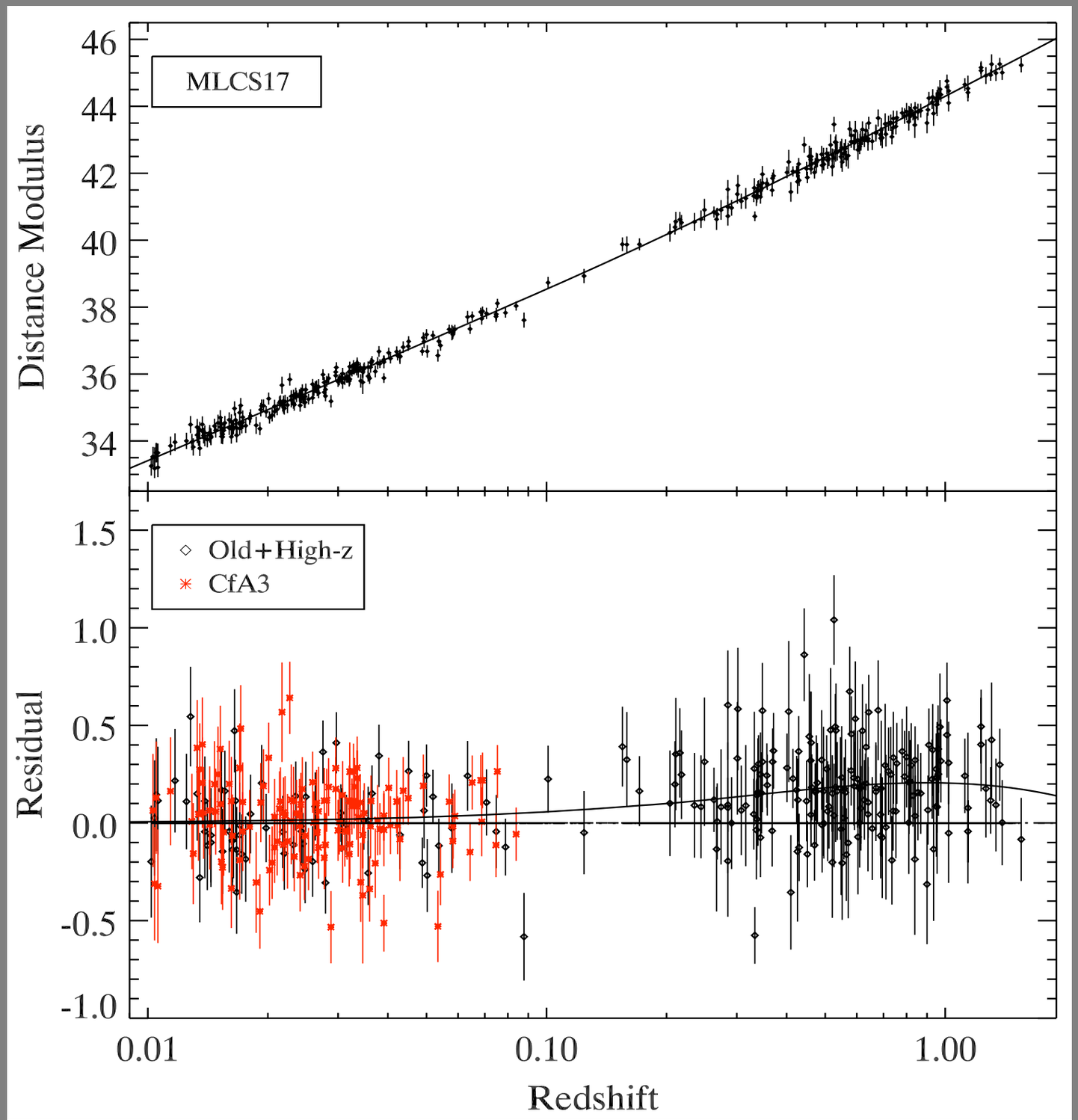


SNe Ia Are Standardizable Candles



Hicken et al. 2009

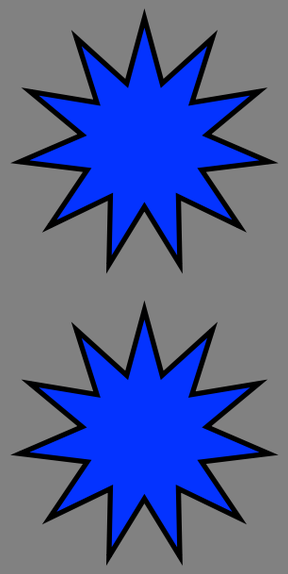
σ = 0.18 mag
(9% in distance)

Constraints on nature of dark energy:

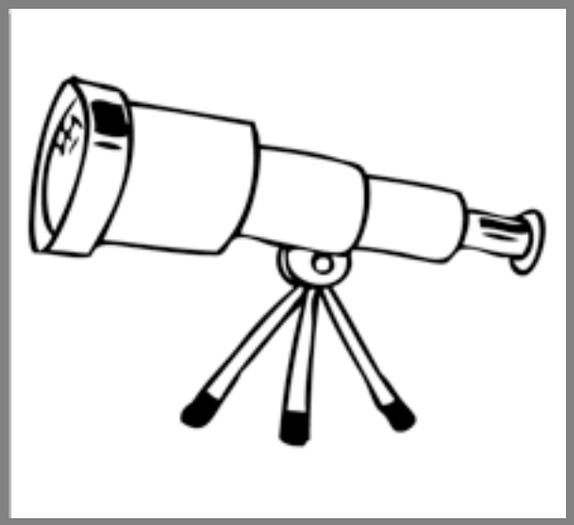
w = 1 ± 0.08
(stat + sys)

Equal stat and sys errors

Dust Makes Things Fainter/Redder



Dust



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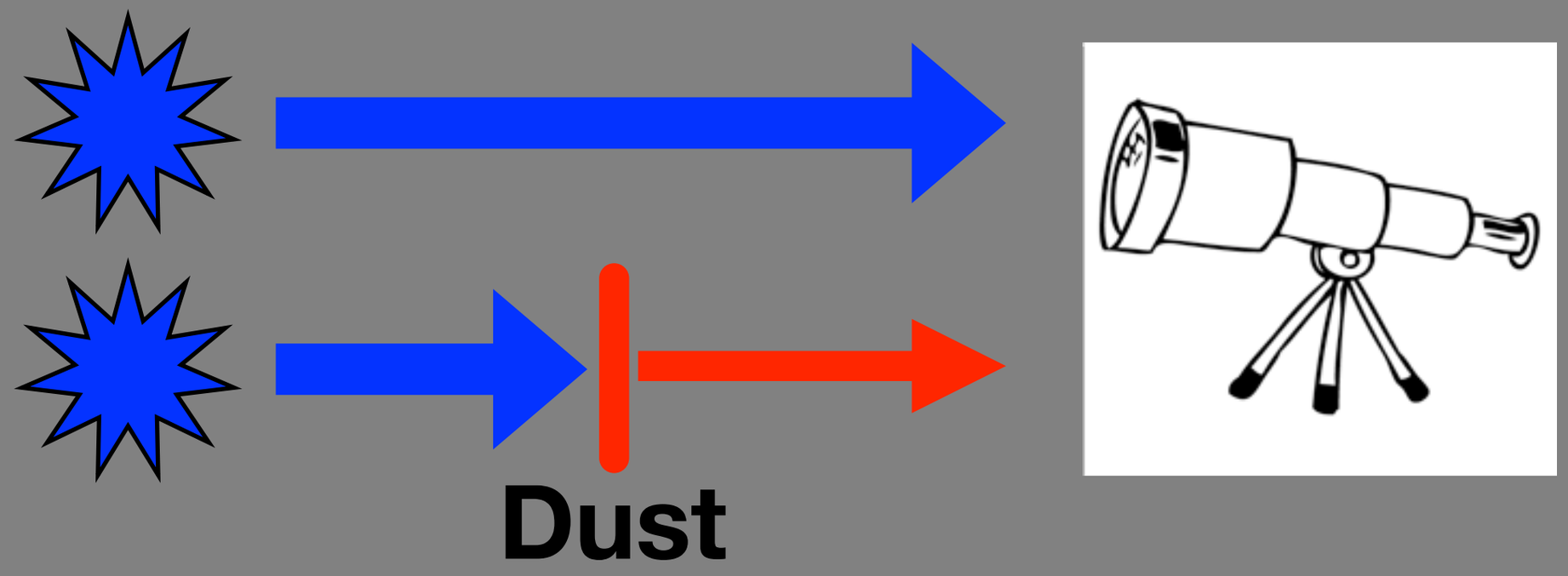

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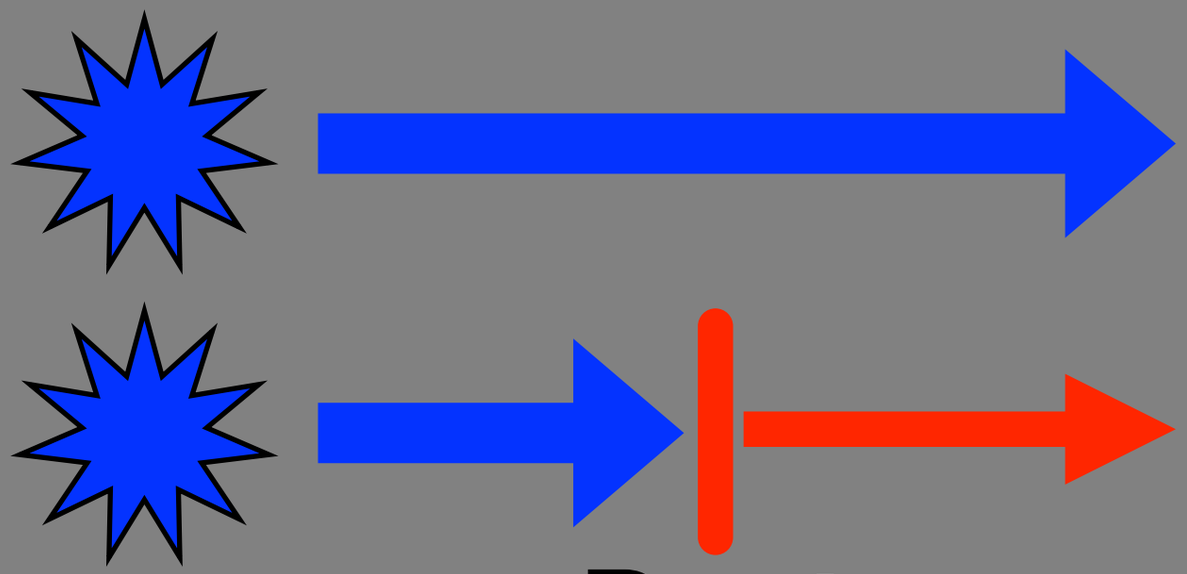
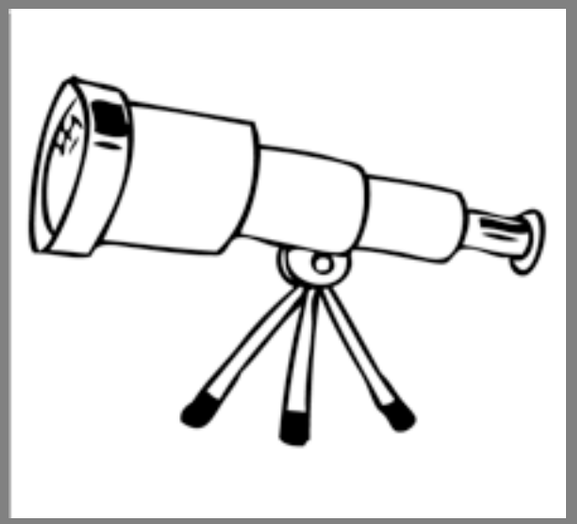
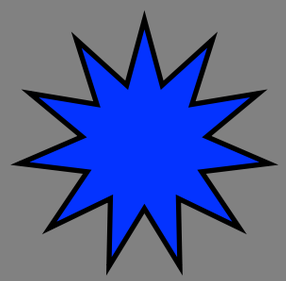
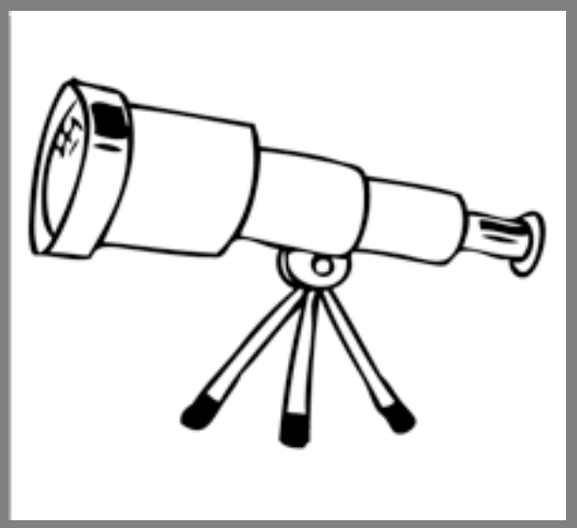




Different Intrinsic Colors





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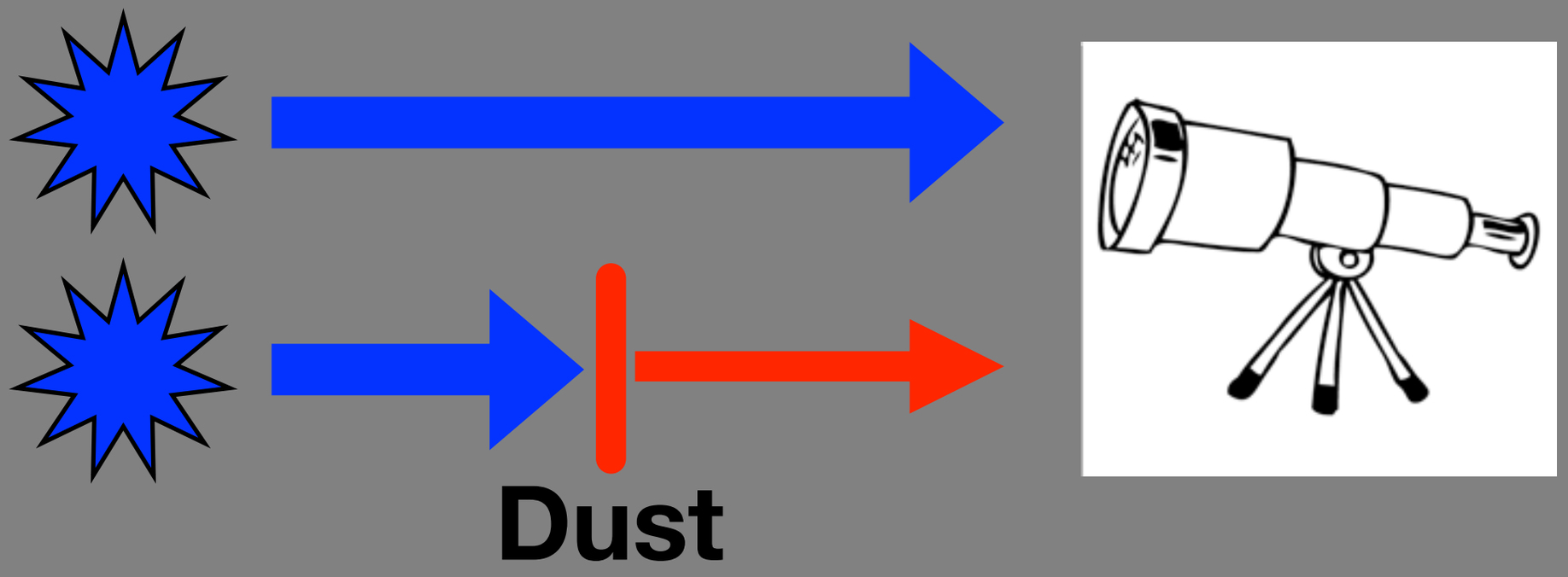

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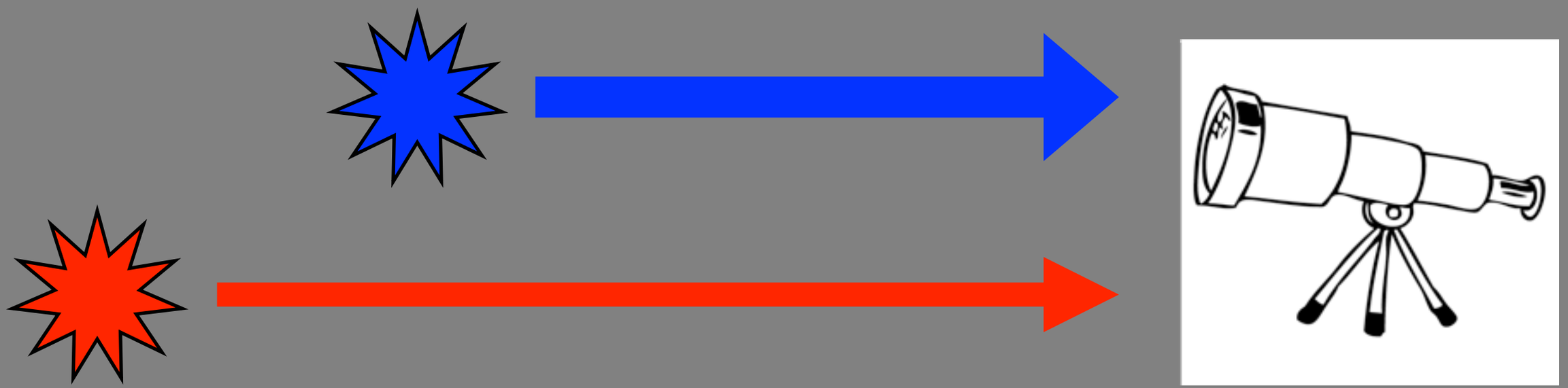
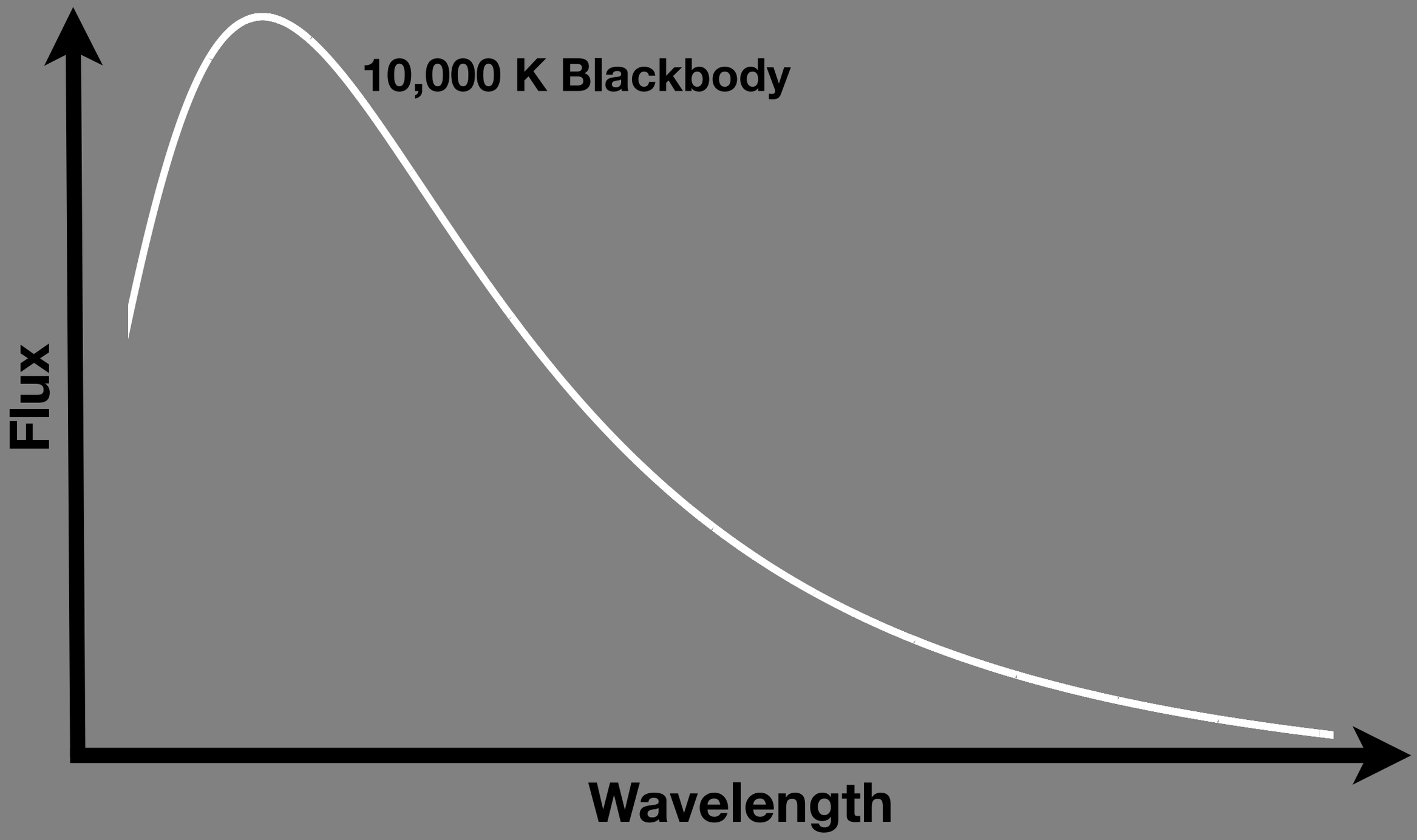


Supernova SED



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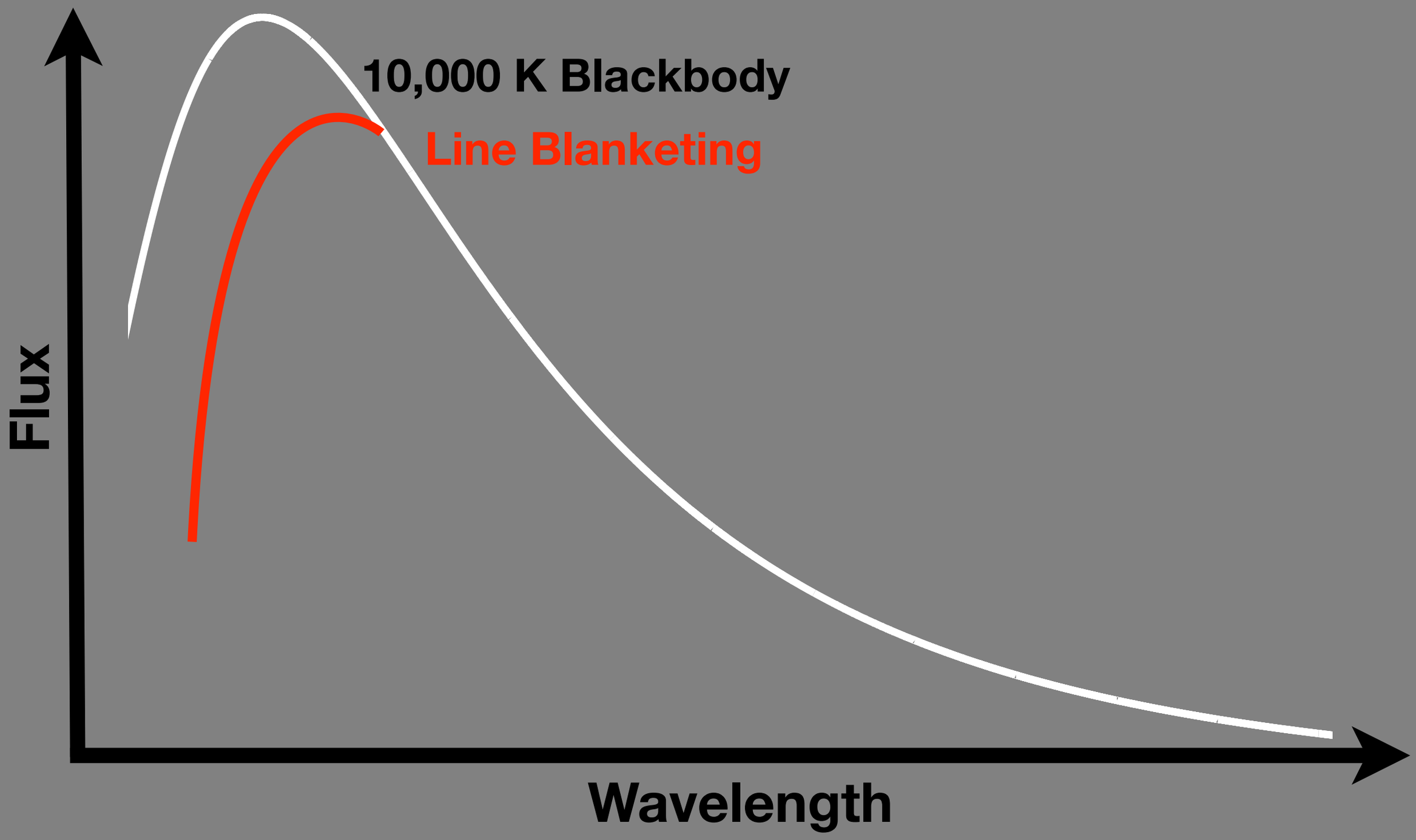

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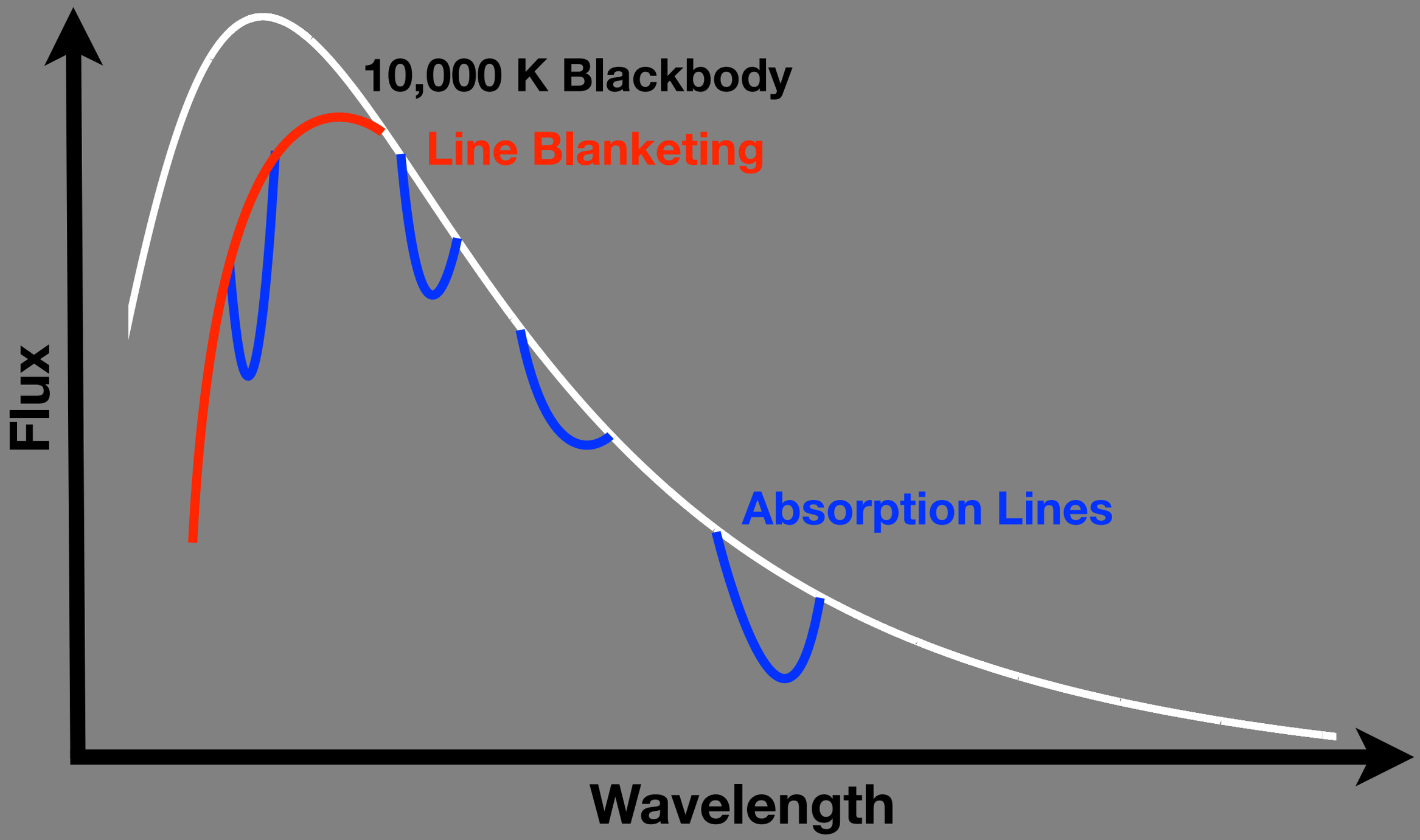
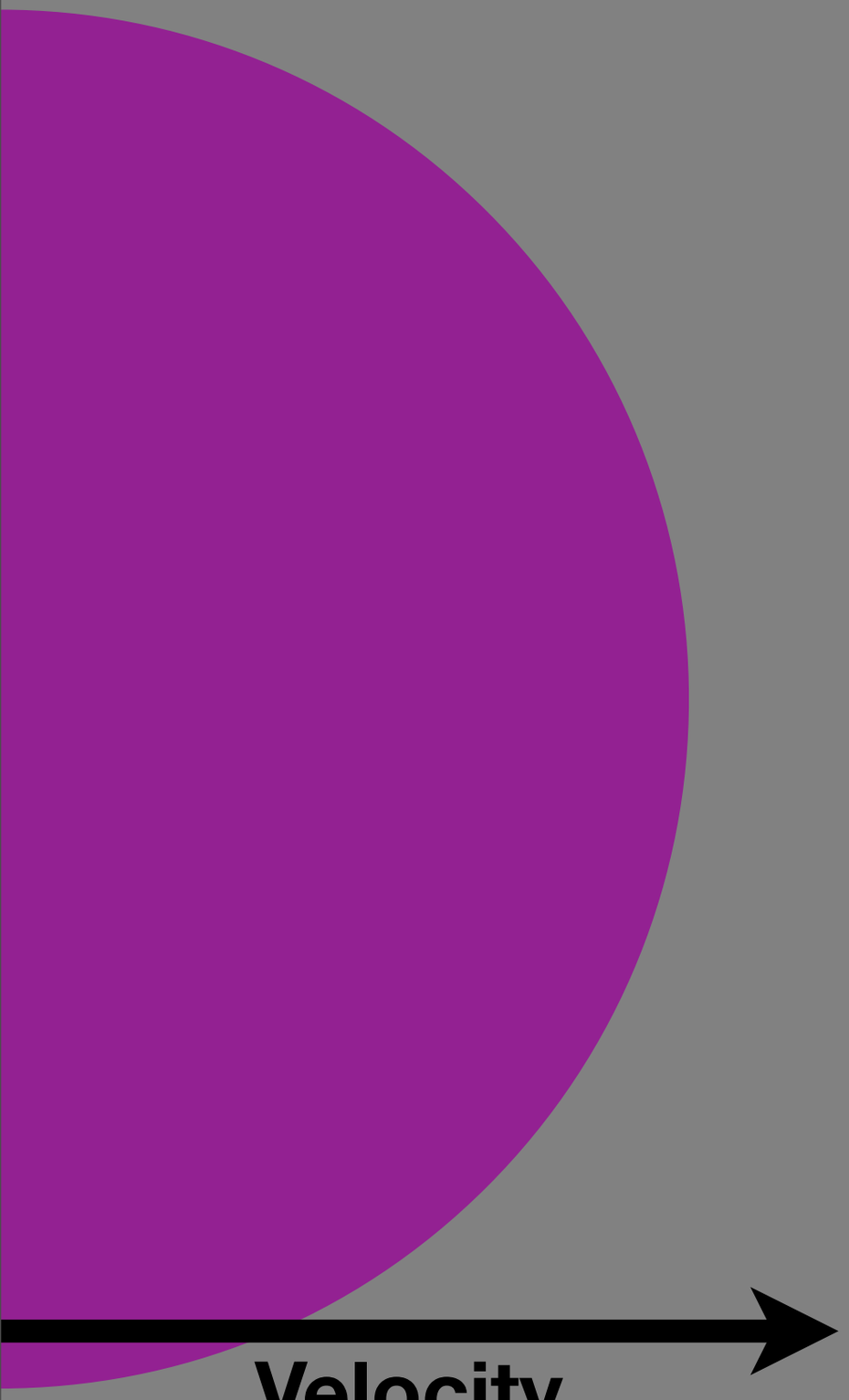
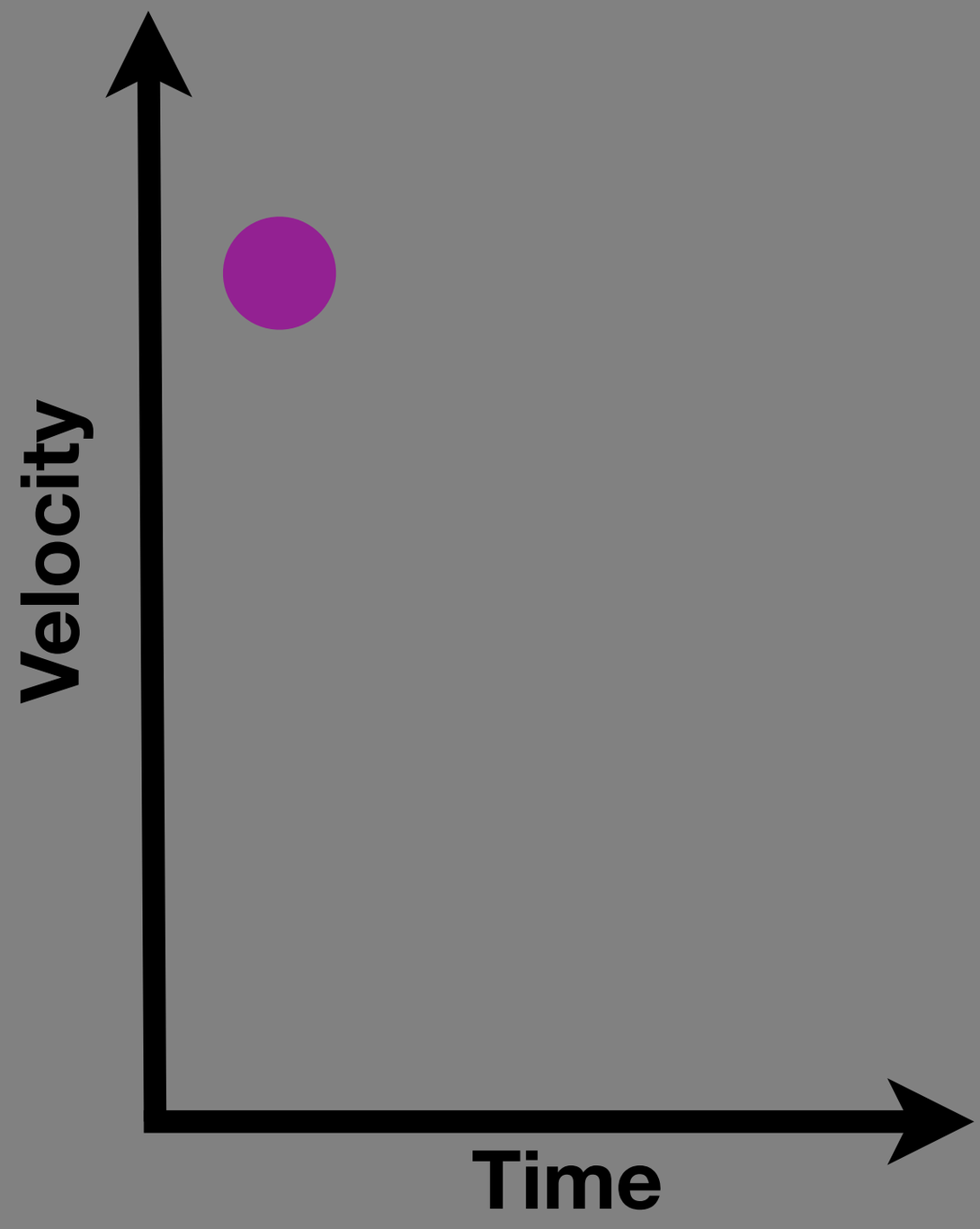


Supernova Explosions, an Analogy

Receding Photosphere



Velocity



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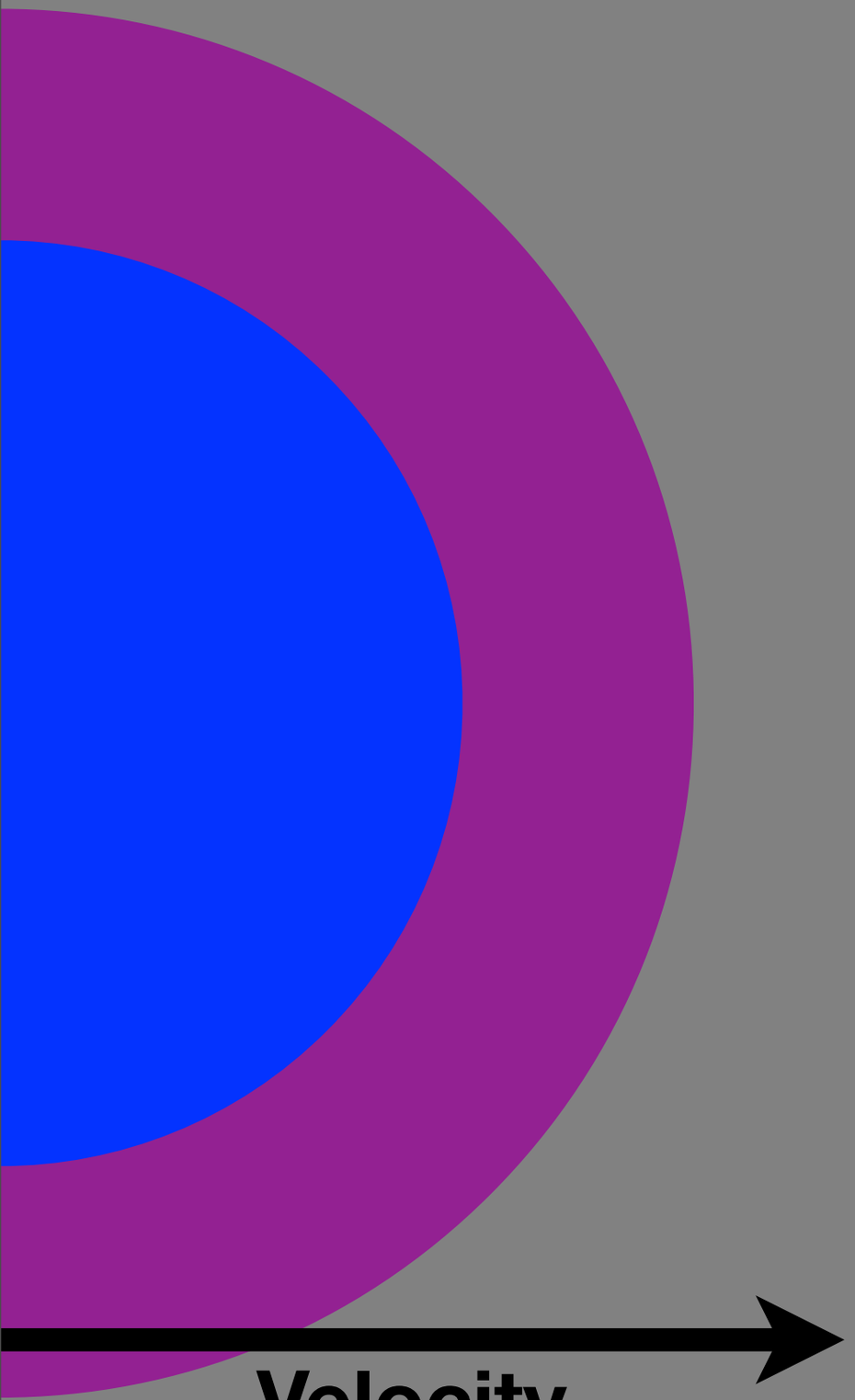

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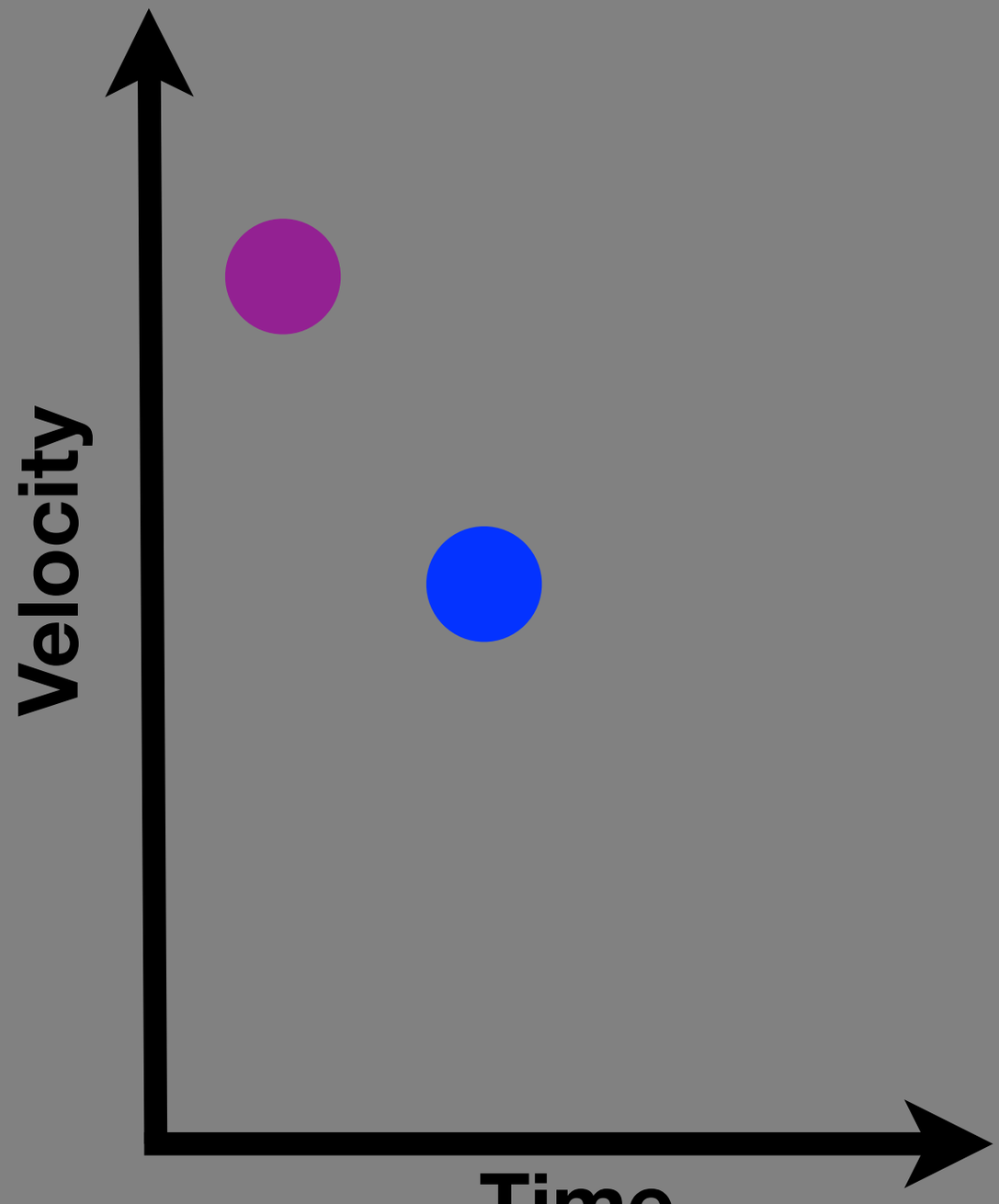

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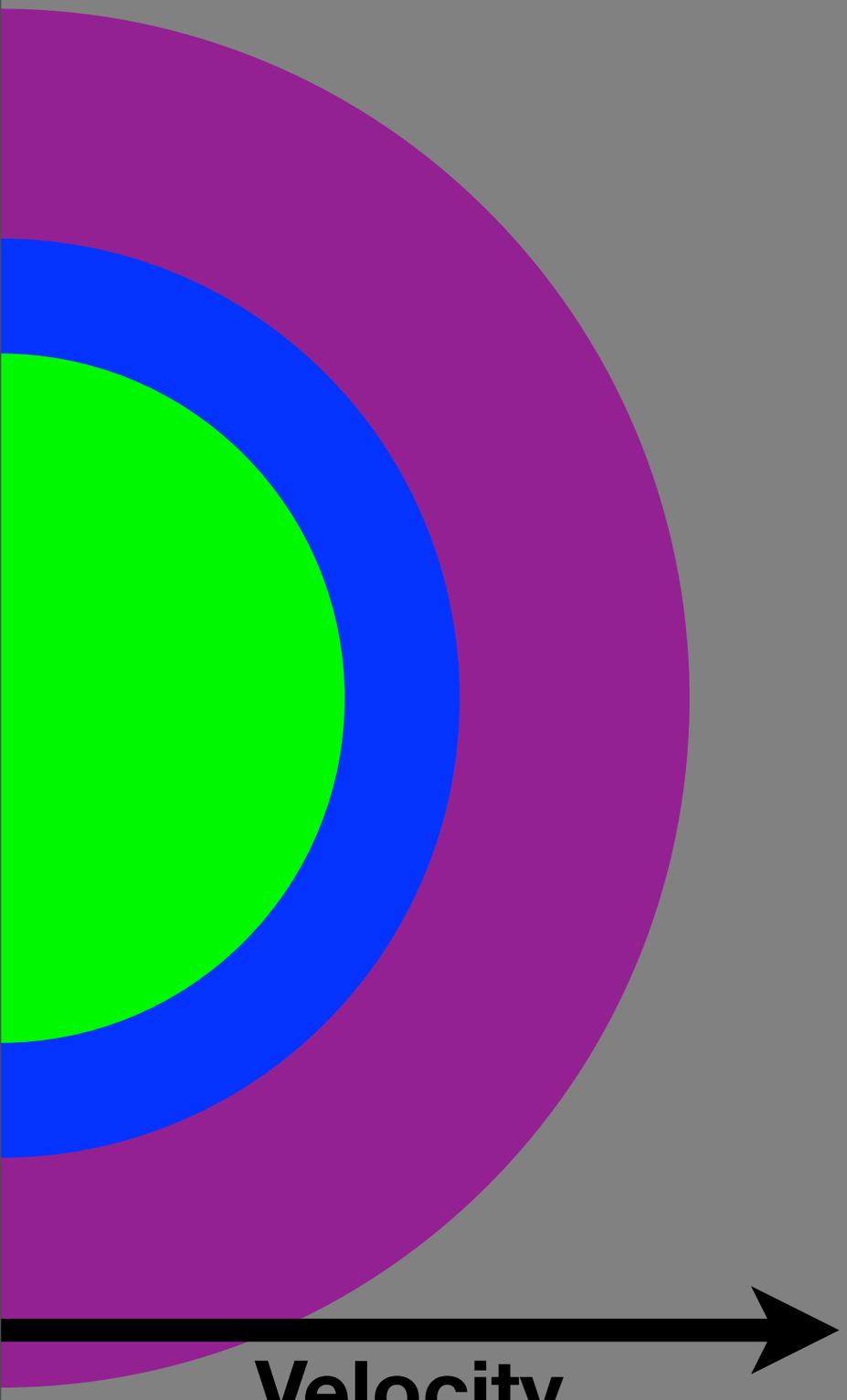

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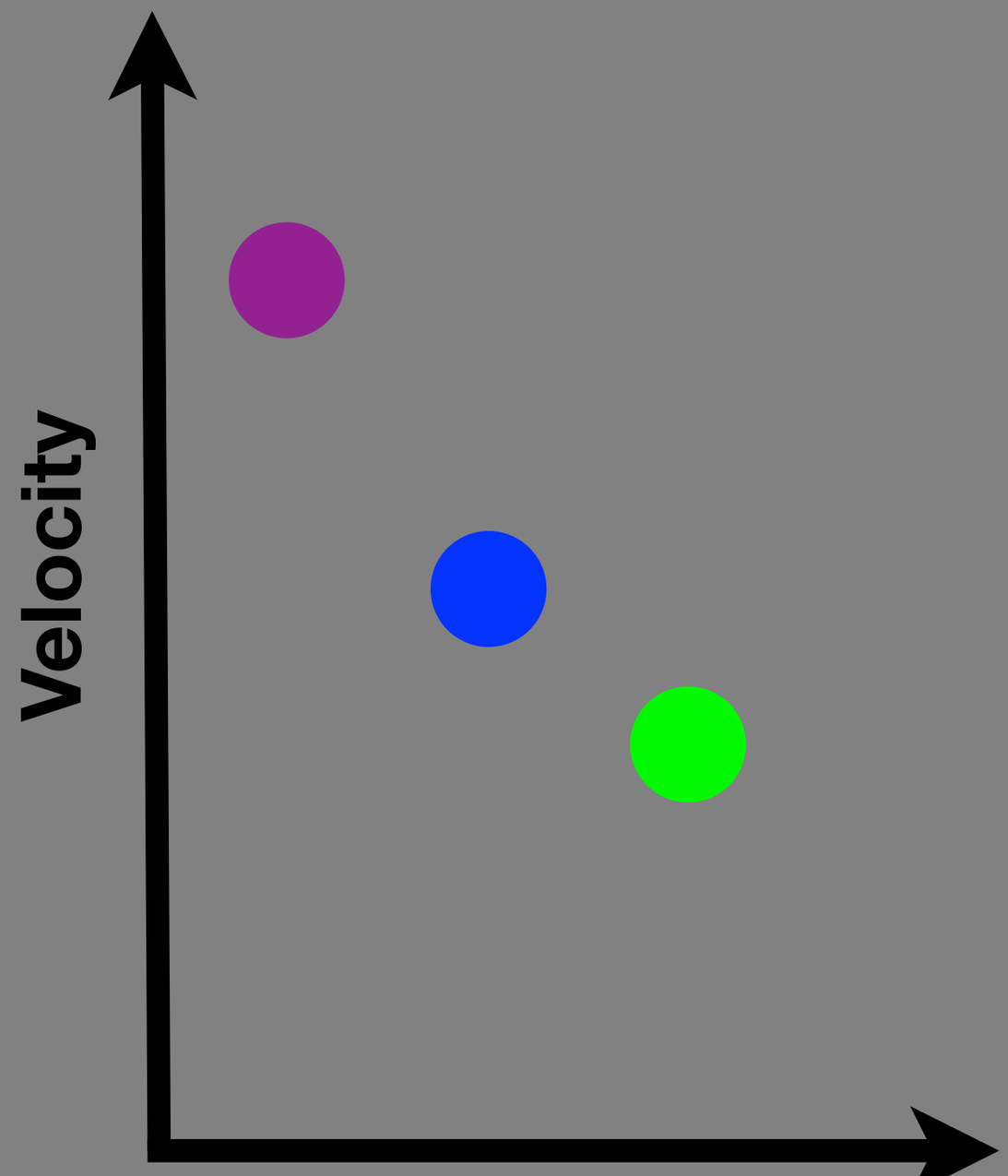

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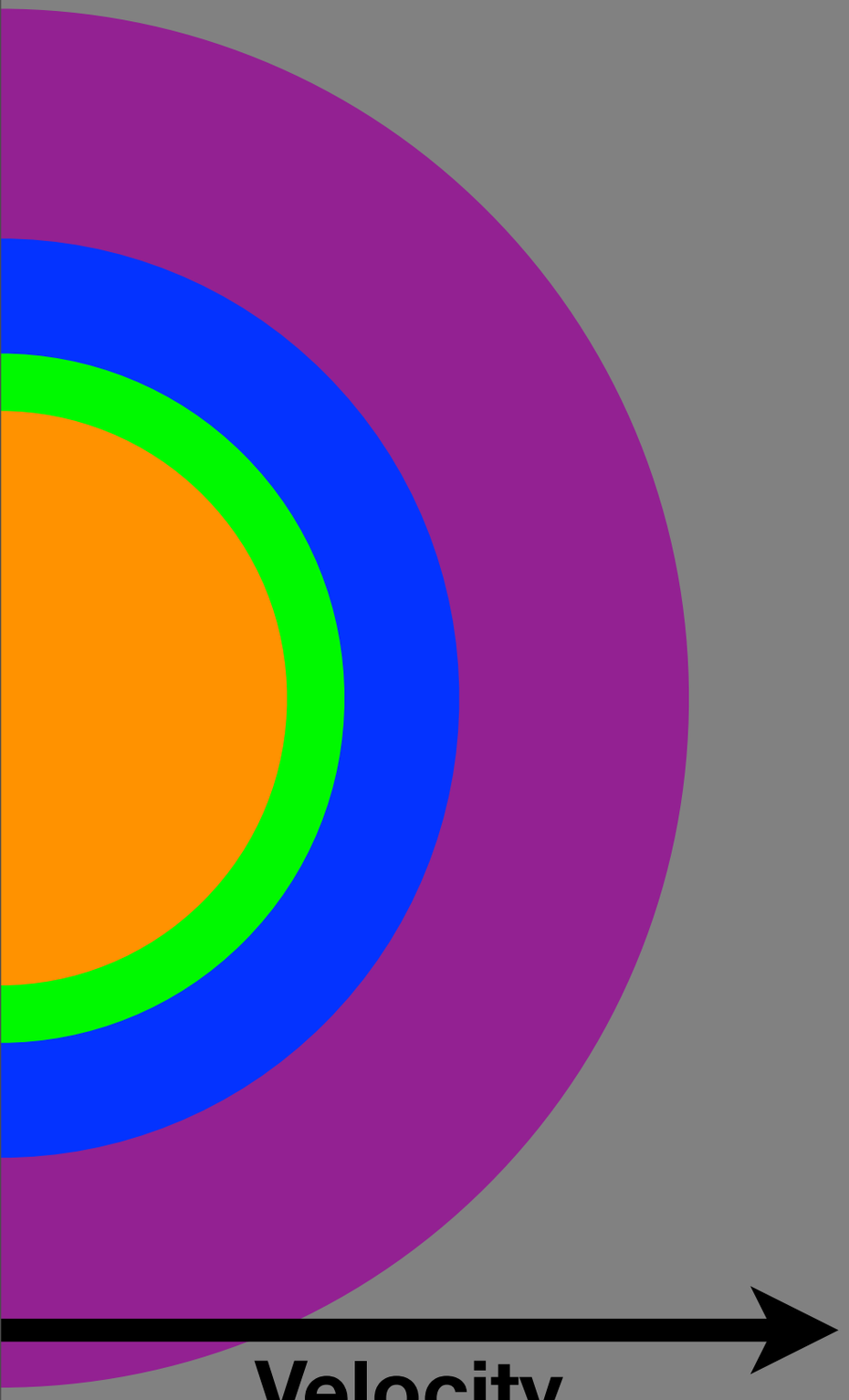

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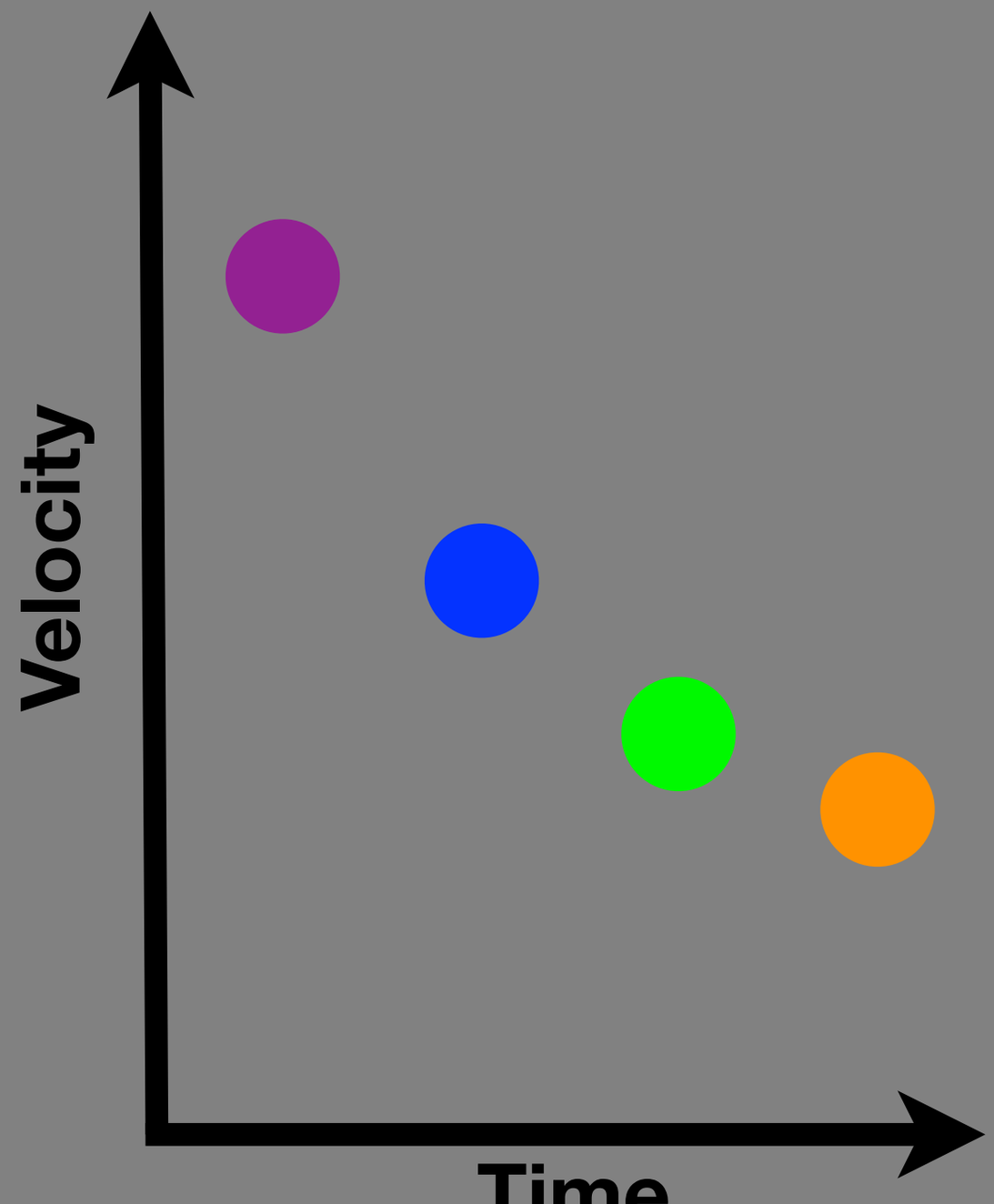
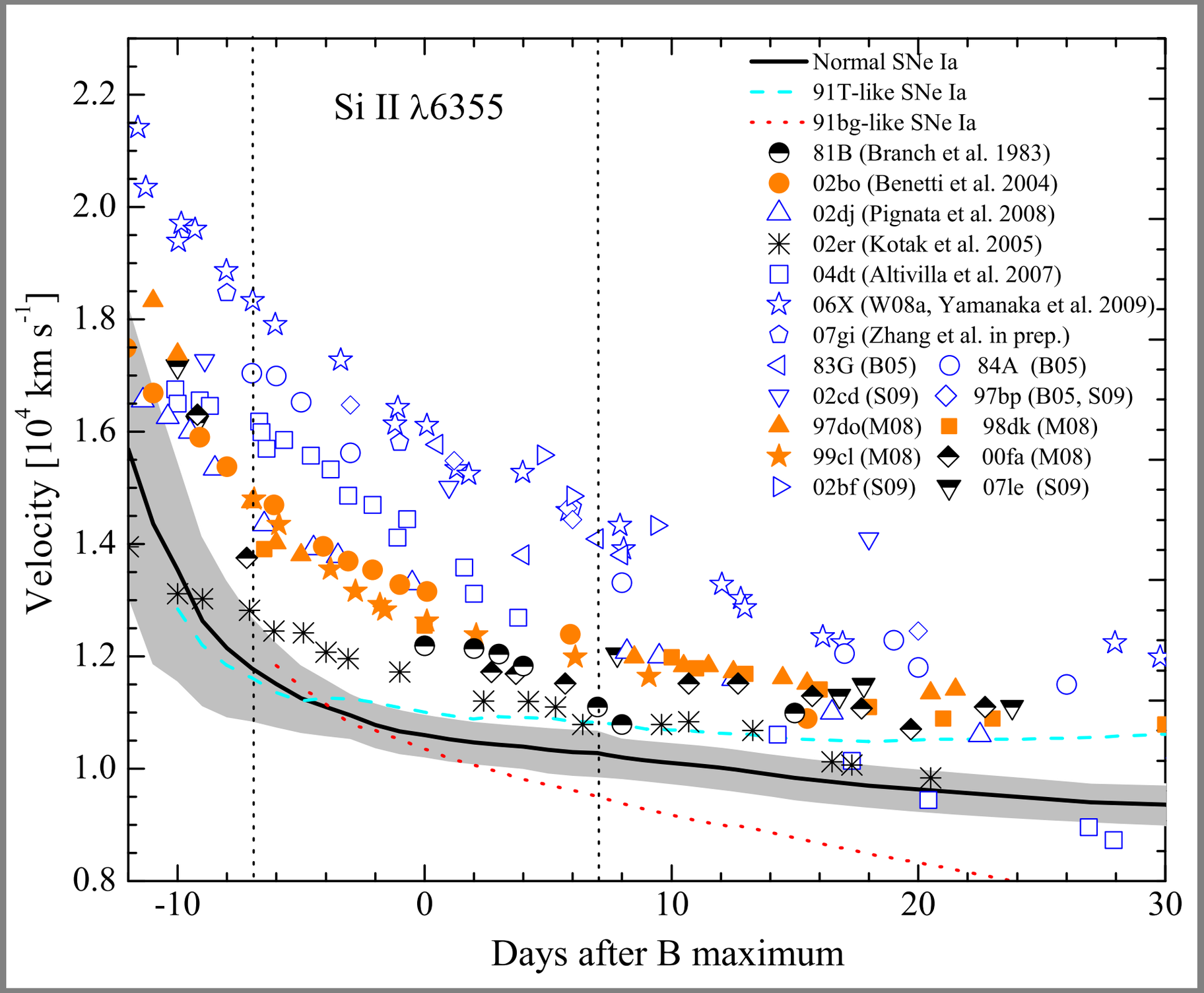
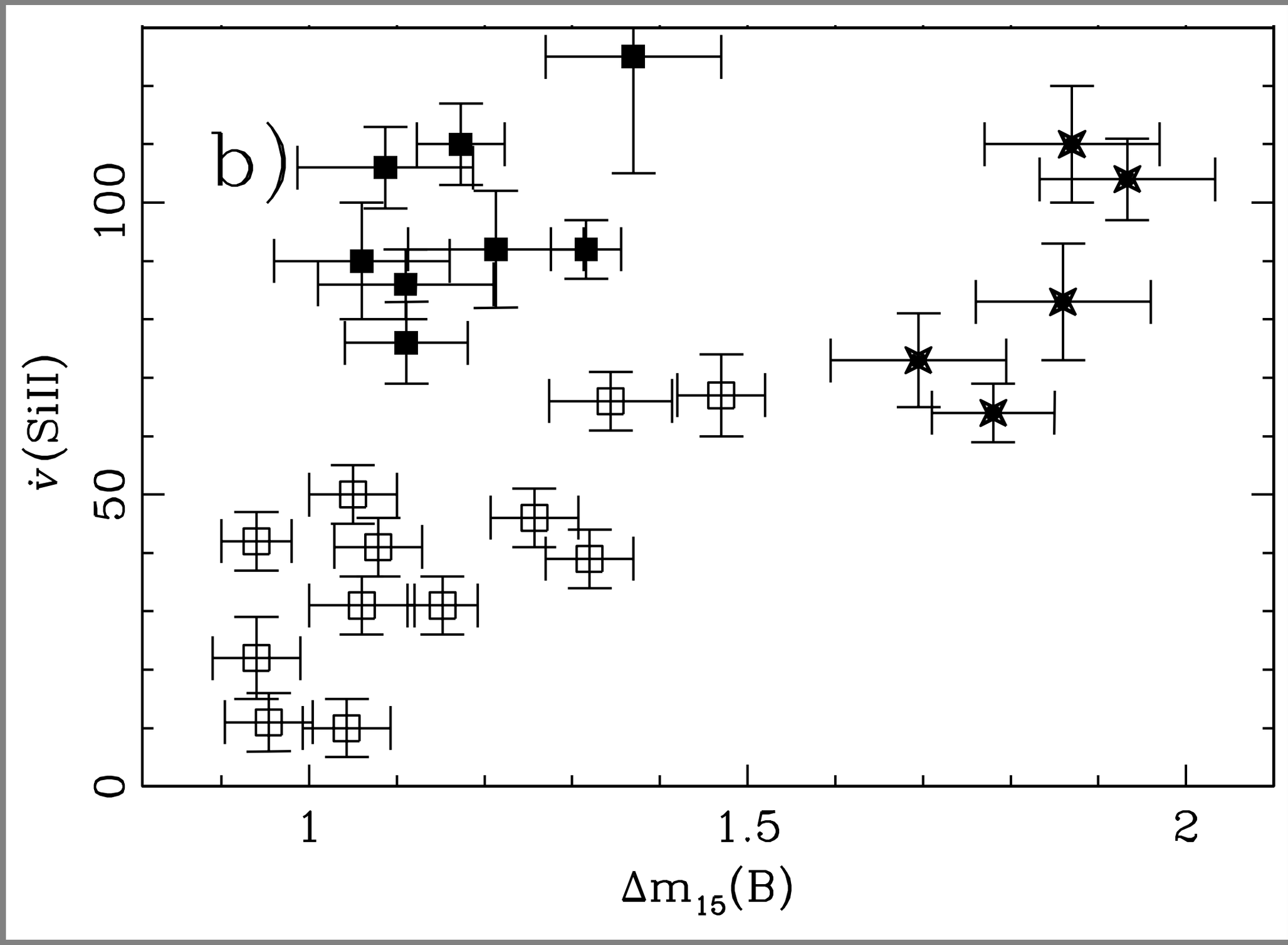


Velocity Gradient



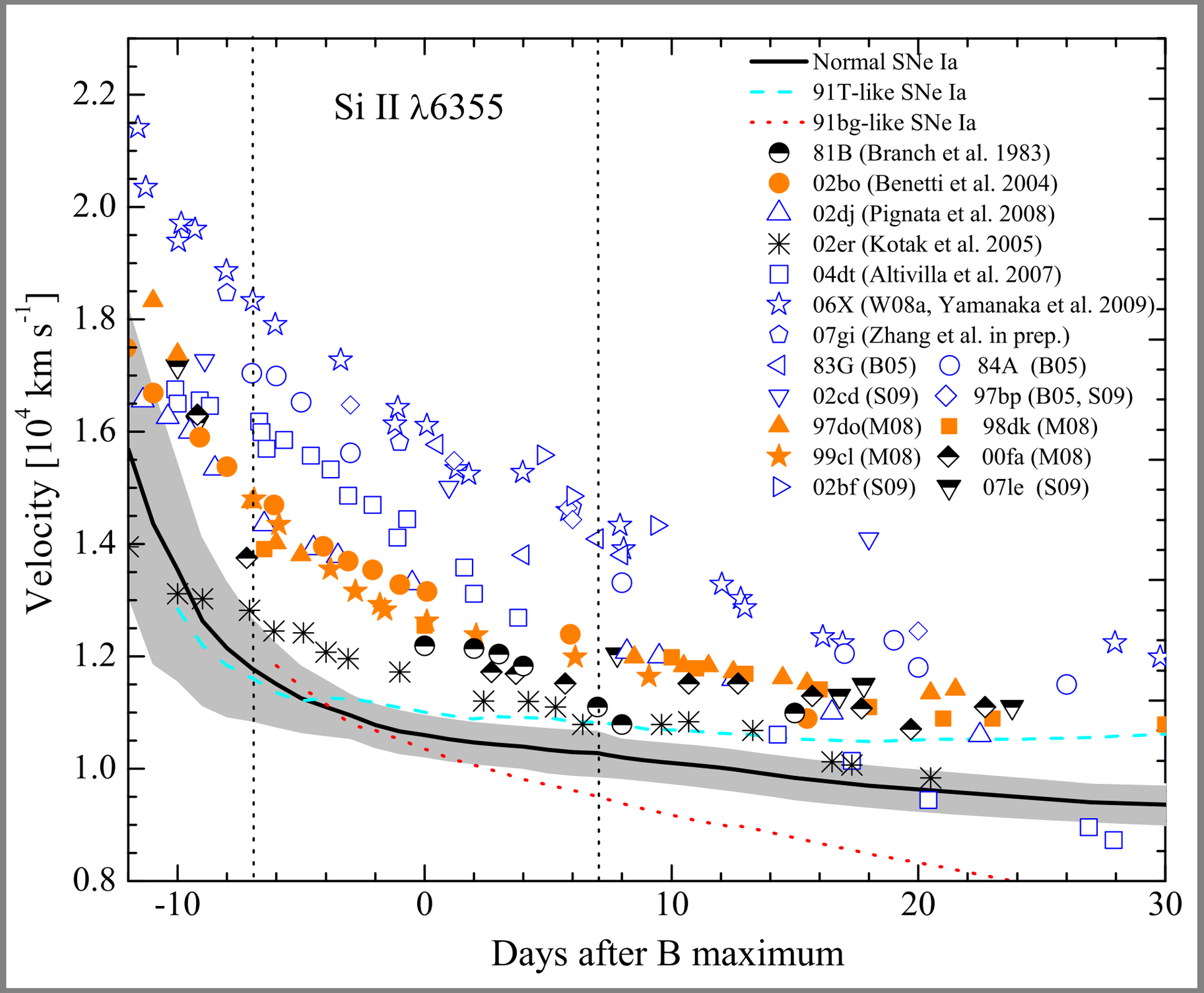
Wang et al. 2009

Velocity Gradient



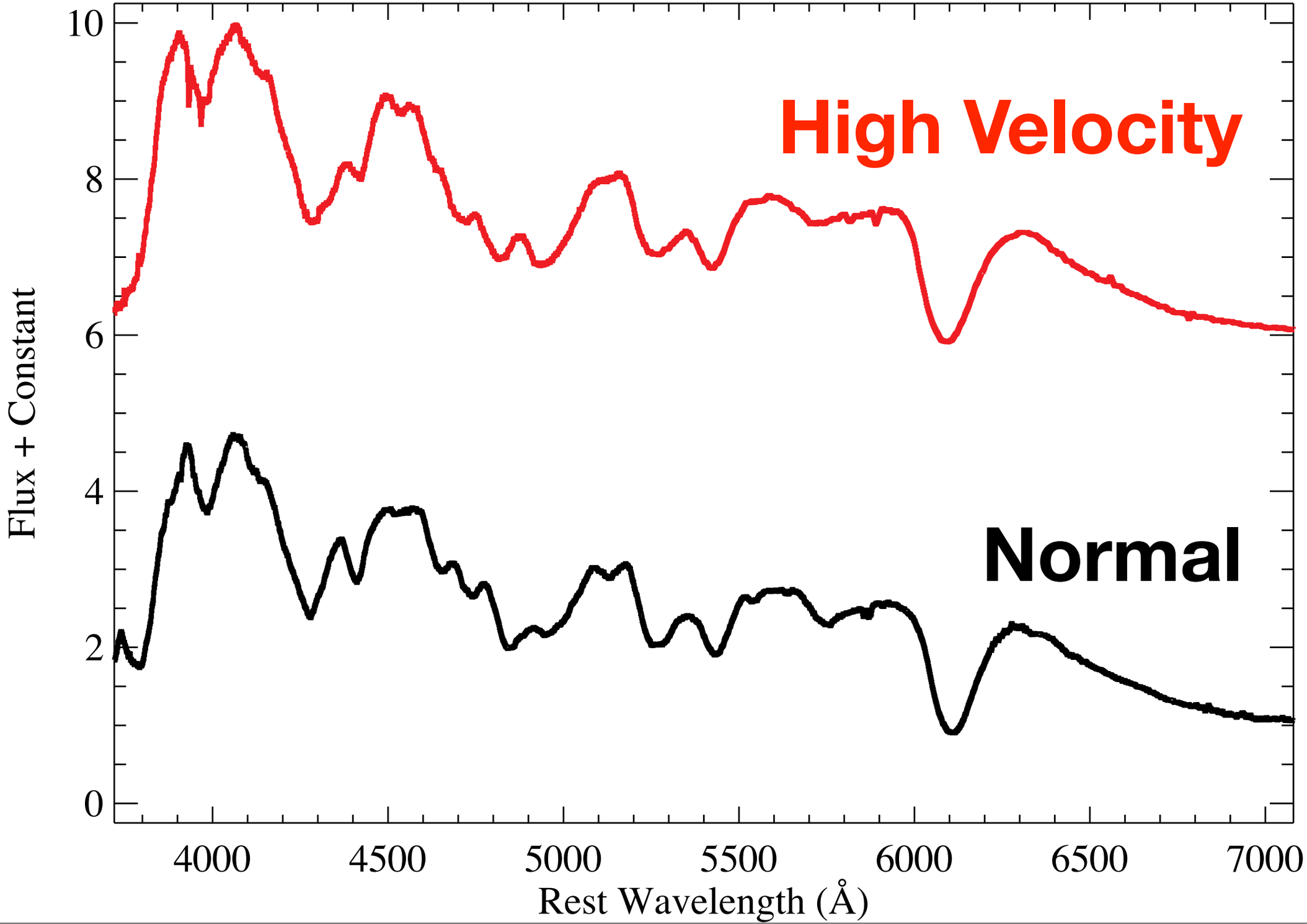
Benetti et al. 2005

Velocity



Wang et al. 2009

Optical Spectrum to Measure Velocity



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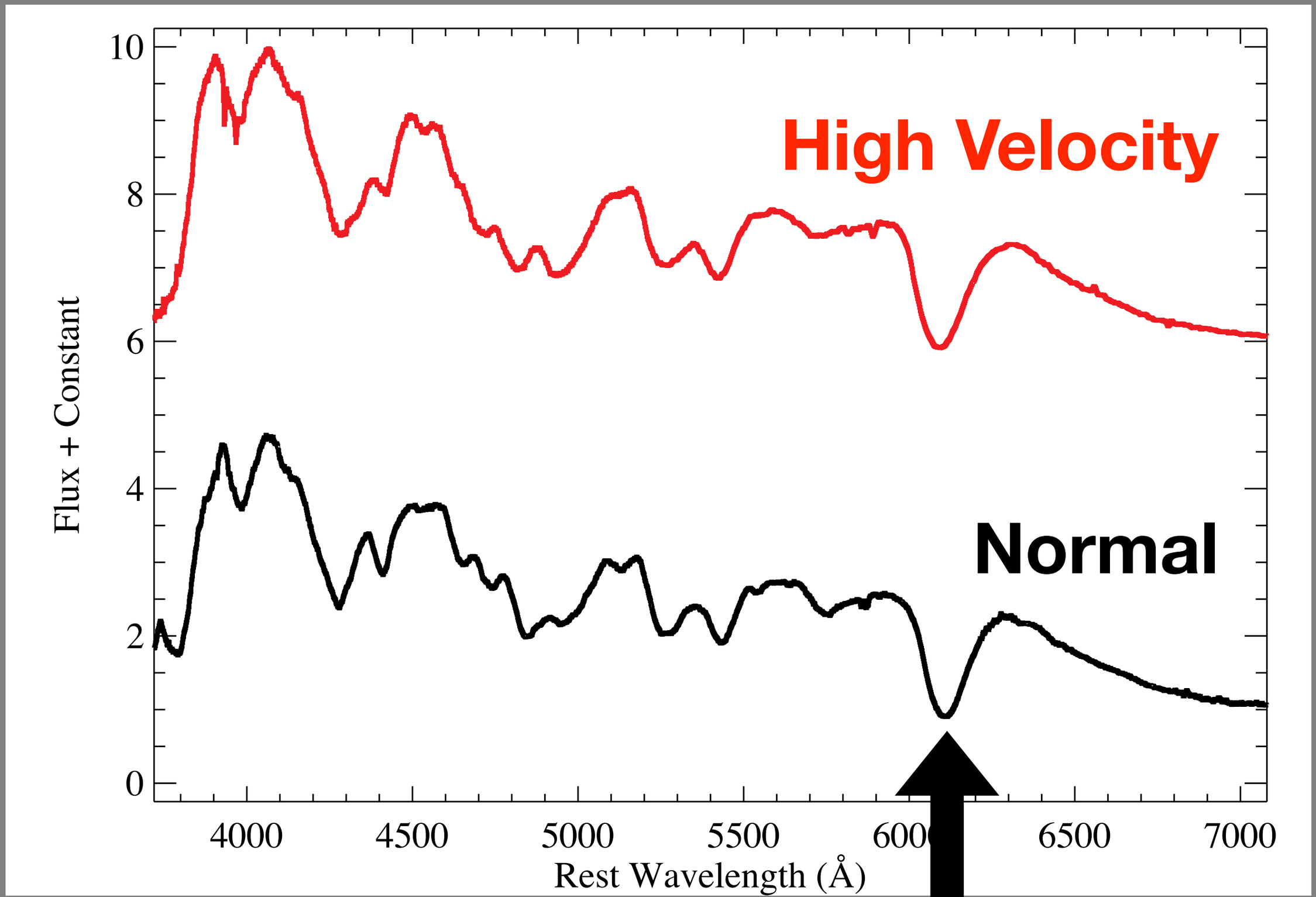
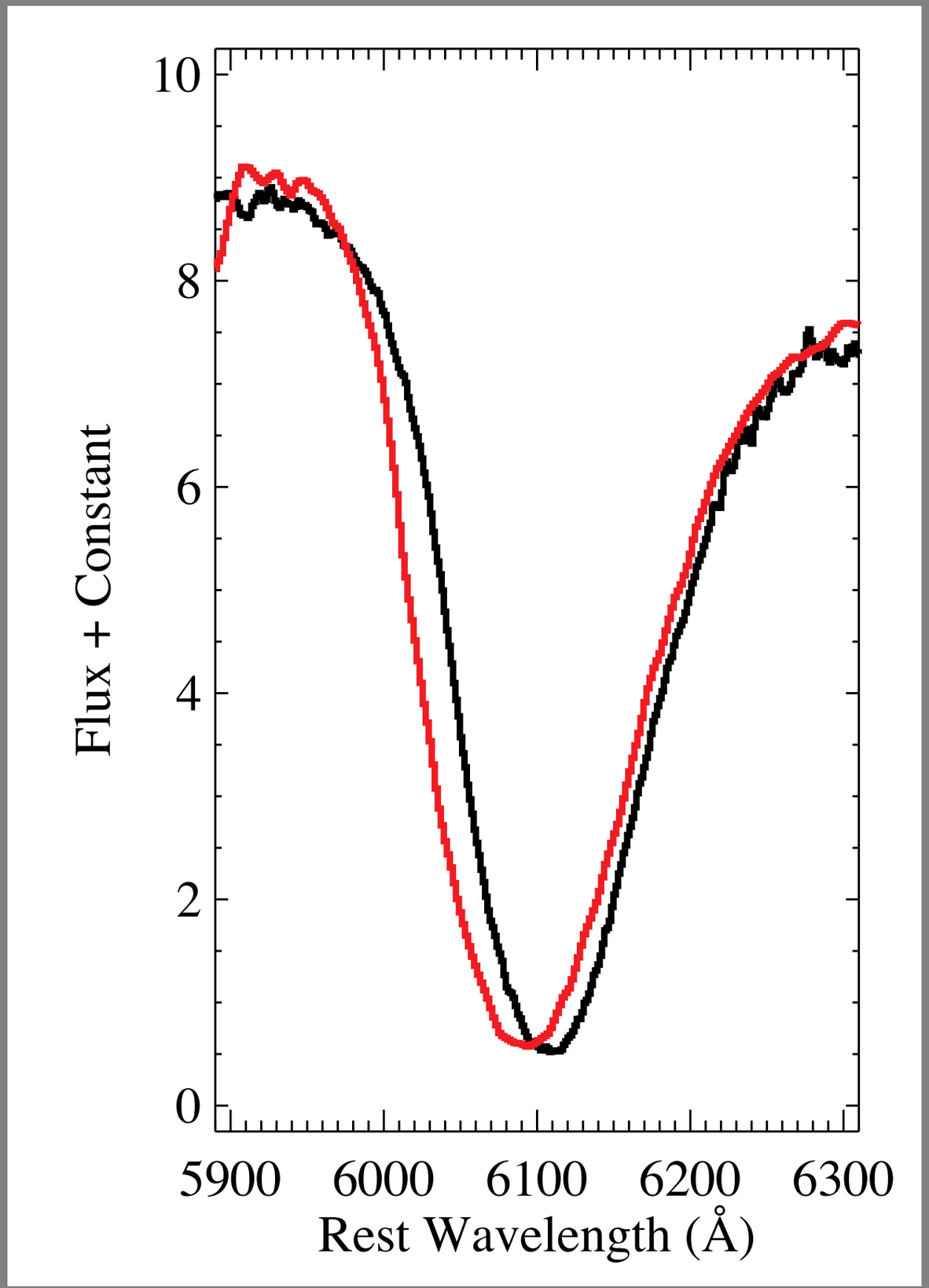


Measure Silicon Velocity



High-Velocity
~ -13,000 km s^{-1}

Normal:
~ -10,000 km s^{-1}

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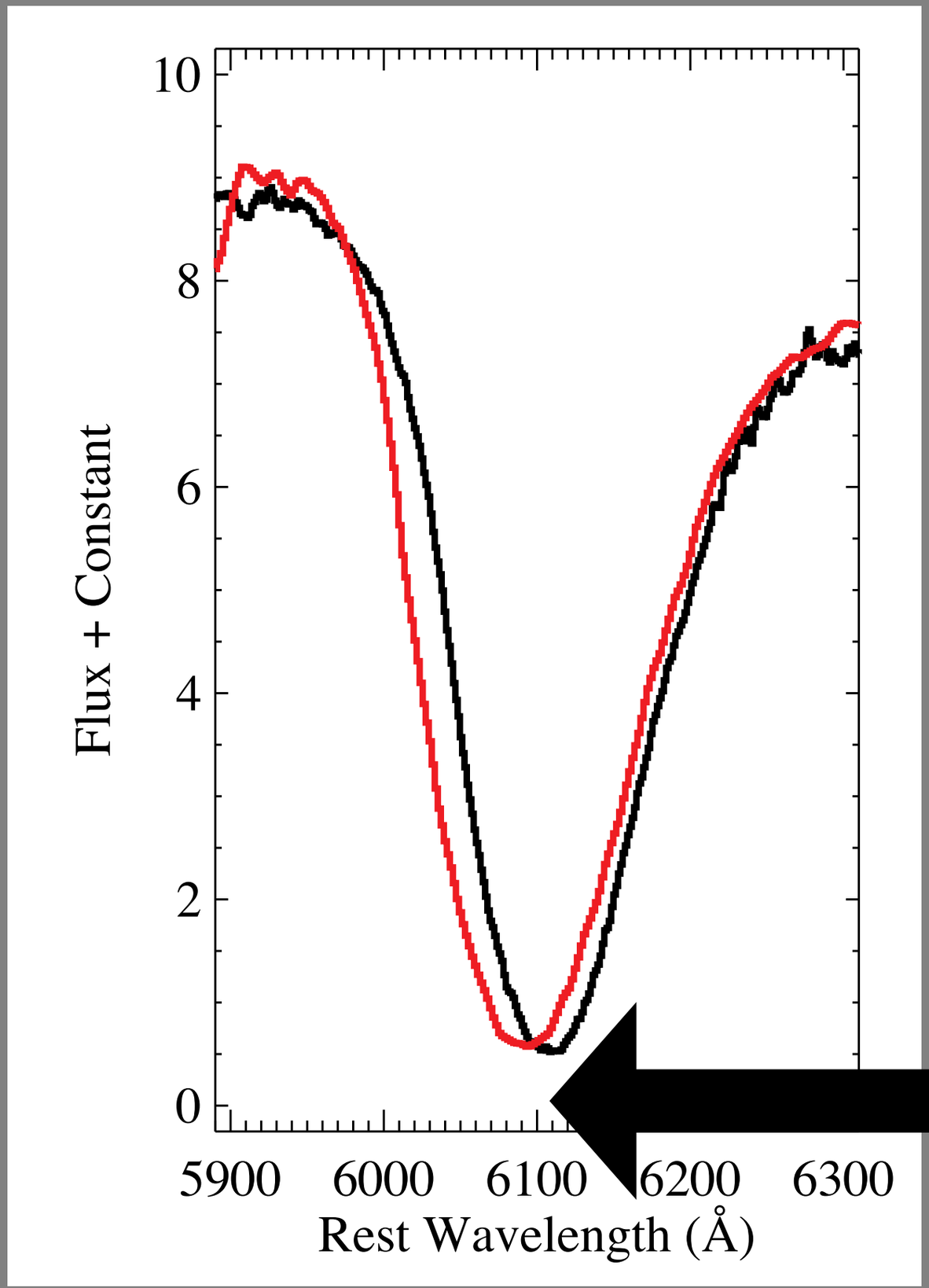

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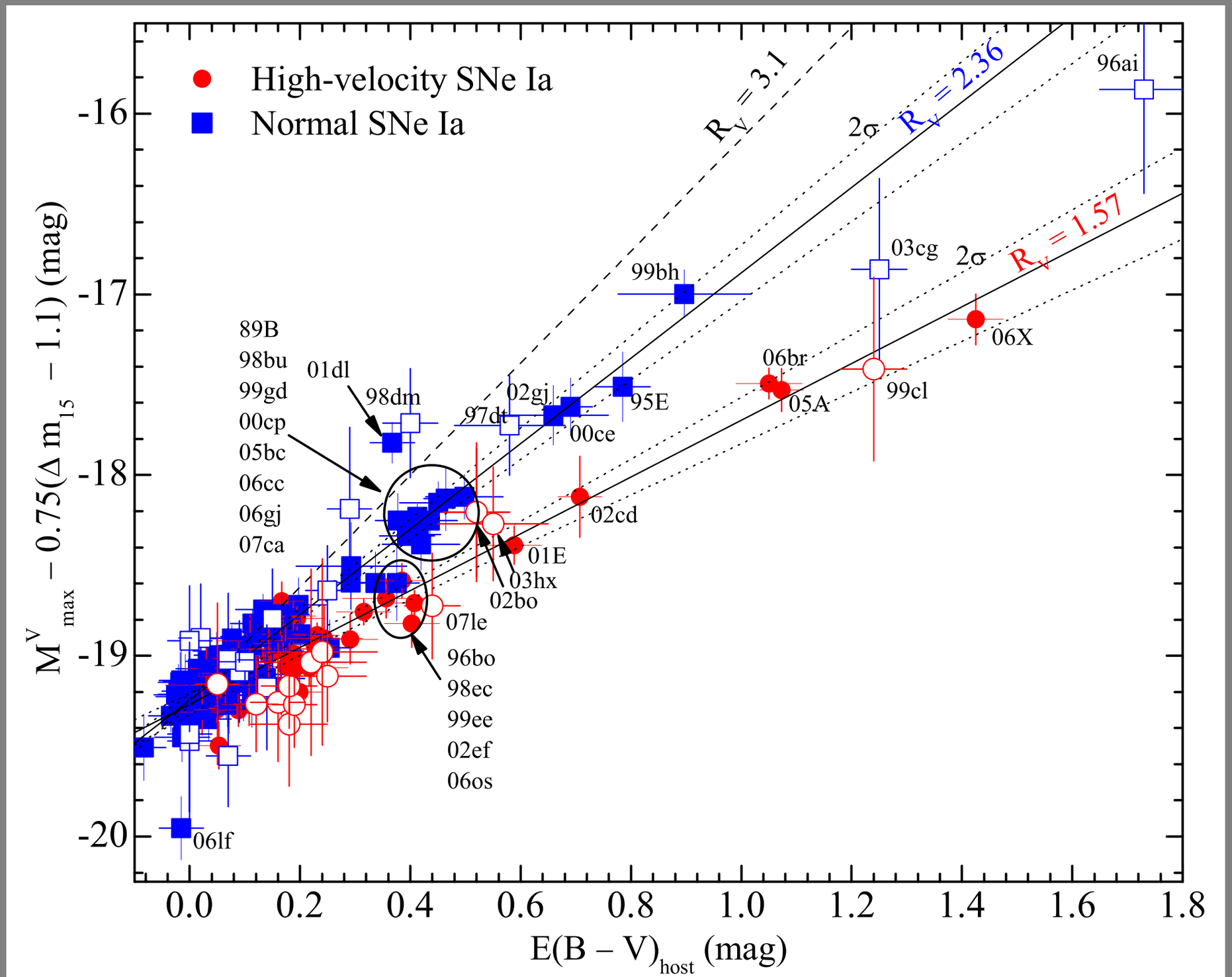
2 Values of Rv?



Wang et al. 2009

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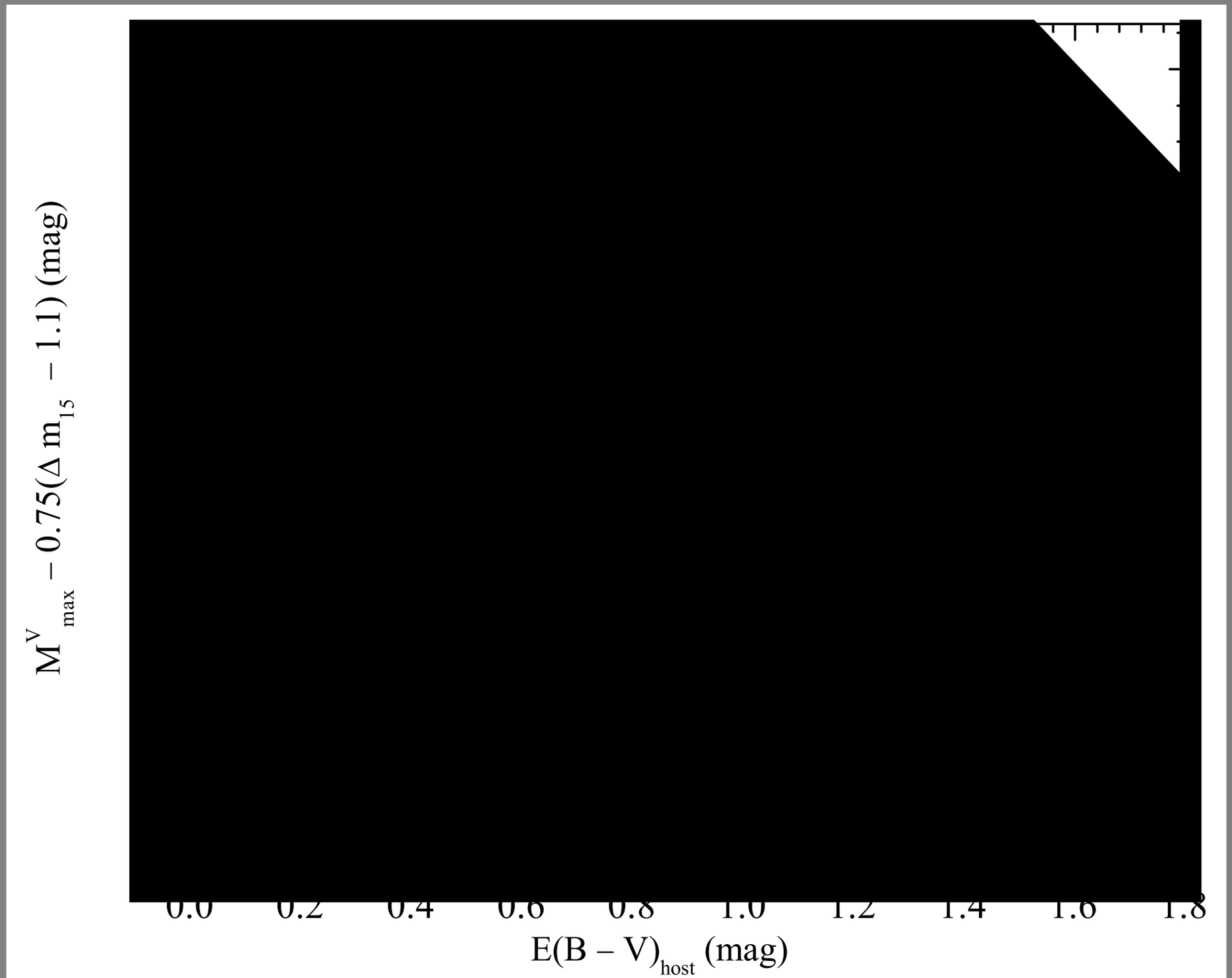

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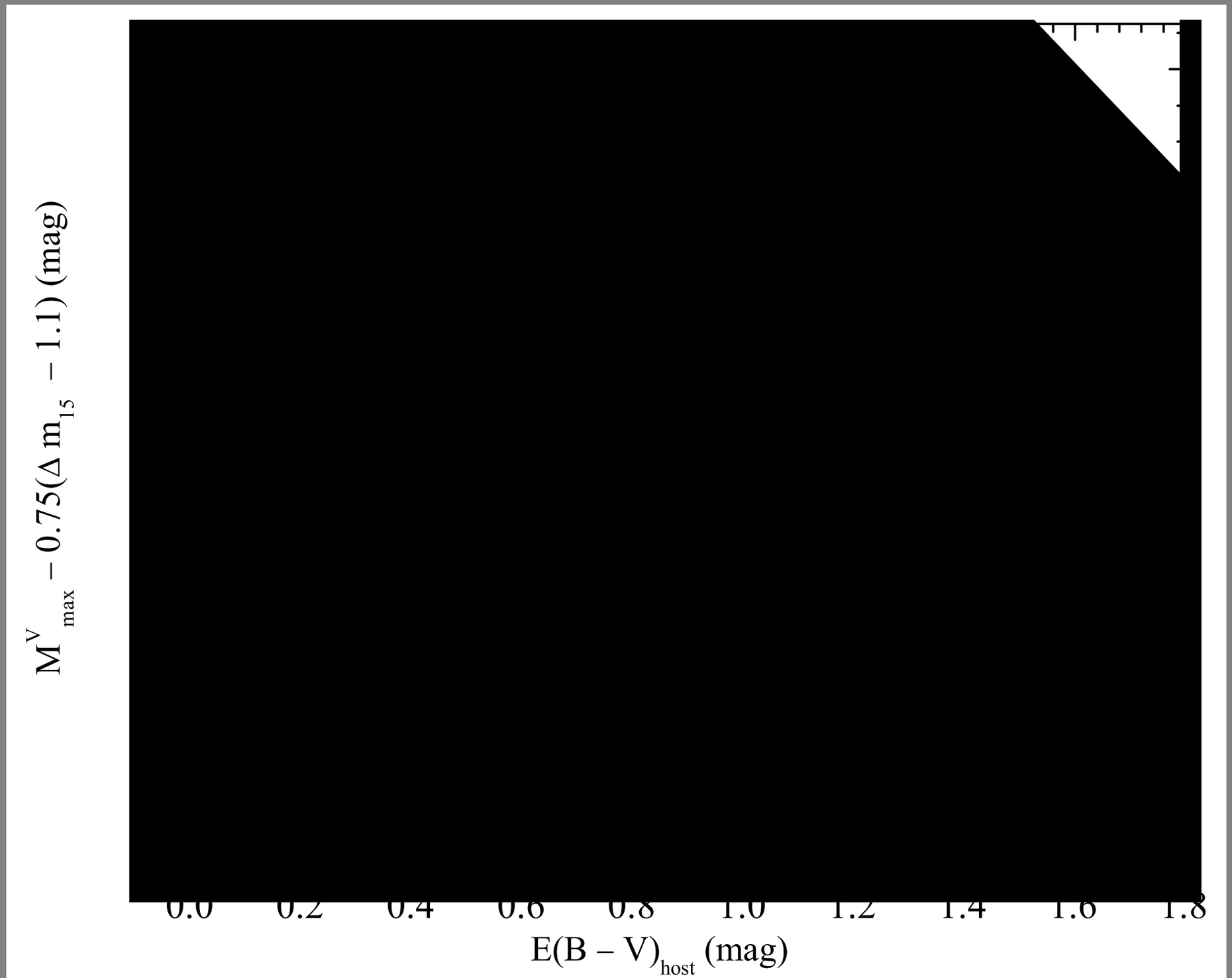

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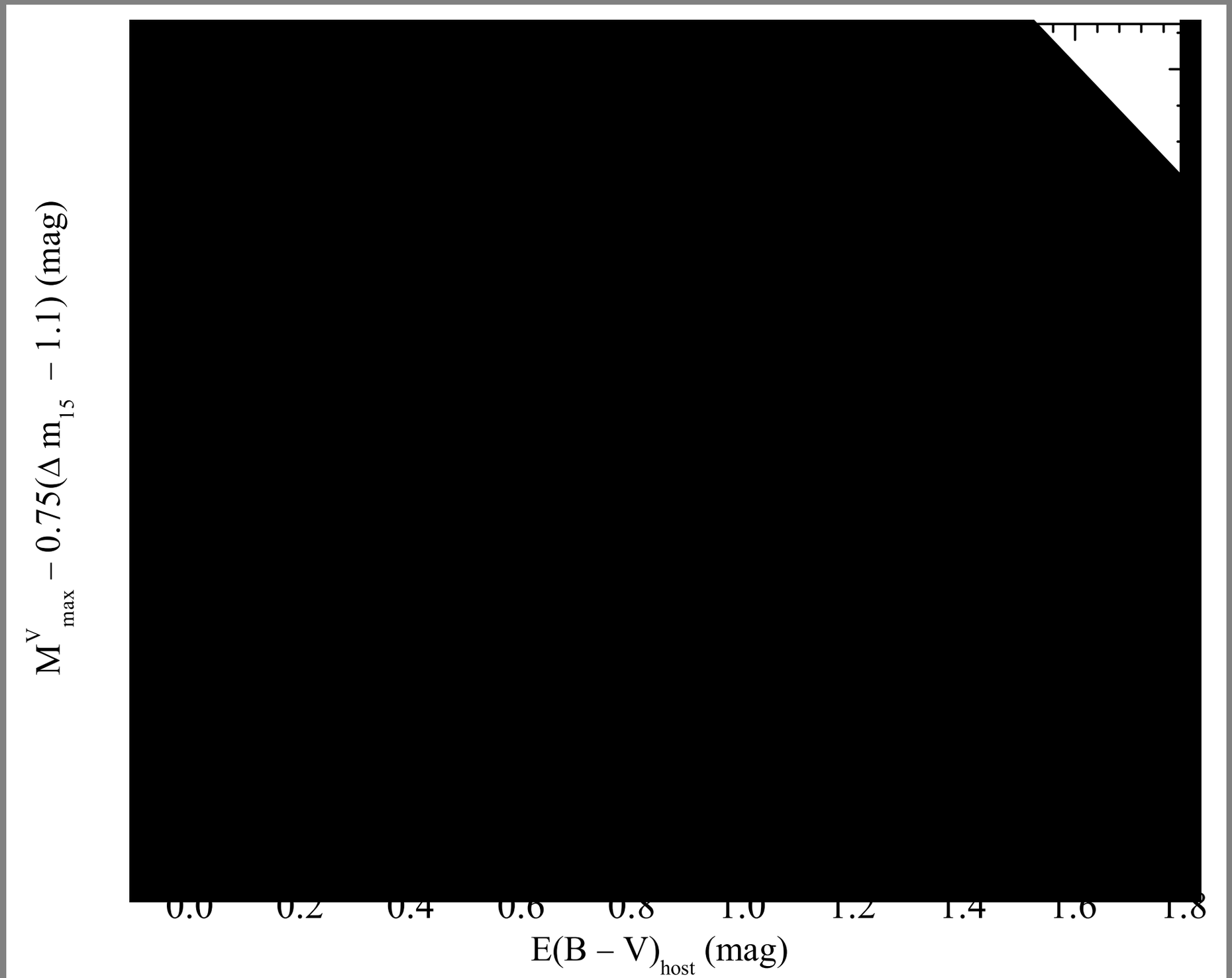

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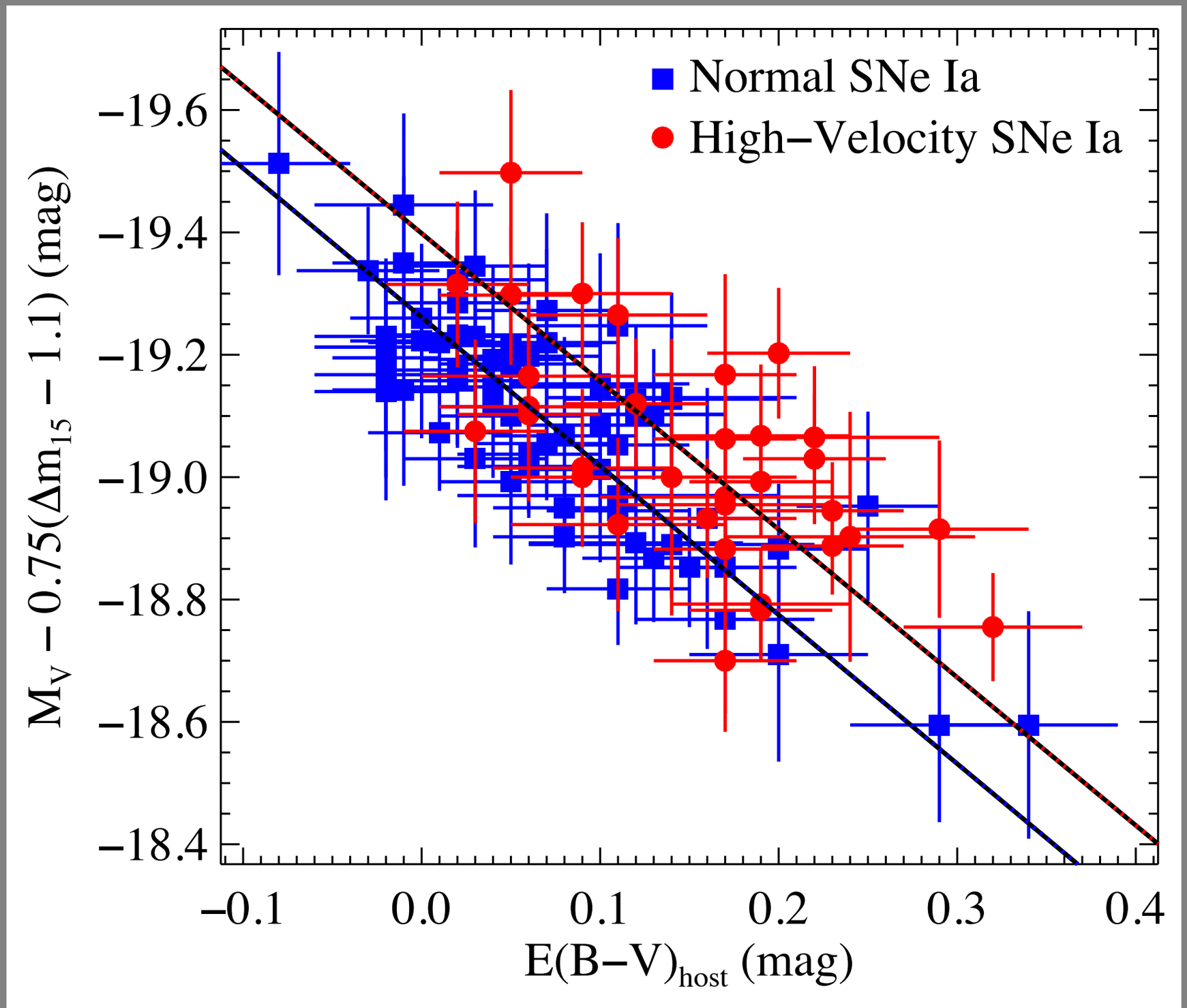
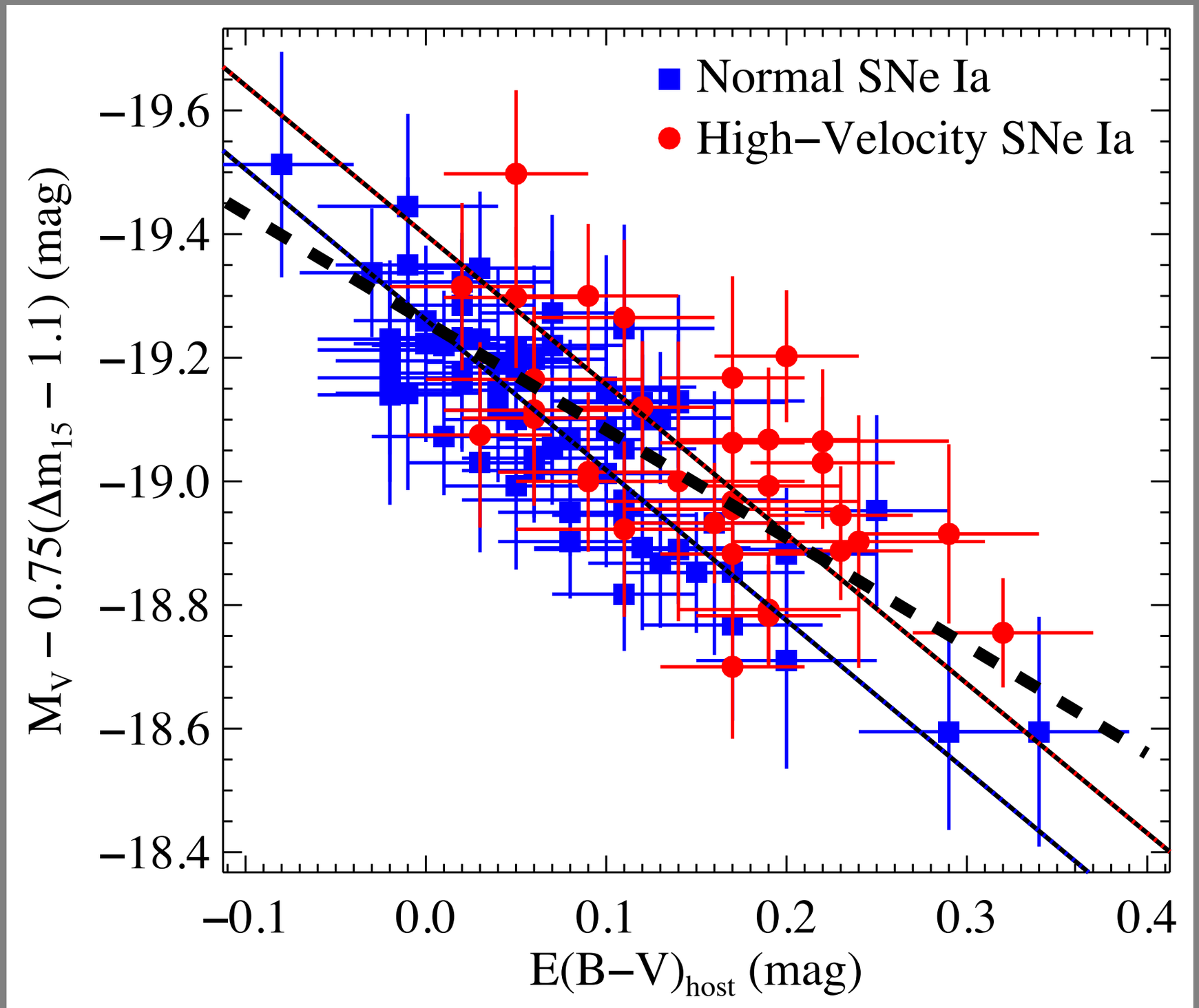


121 SNe

Foley & Kasen 2011

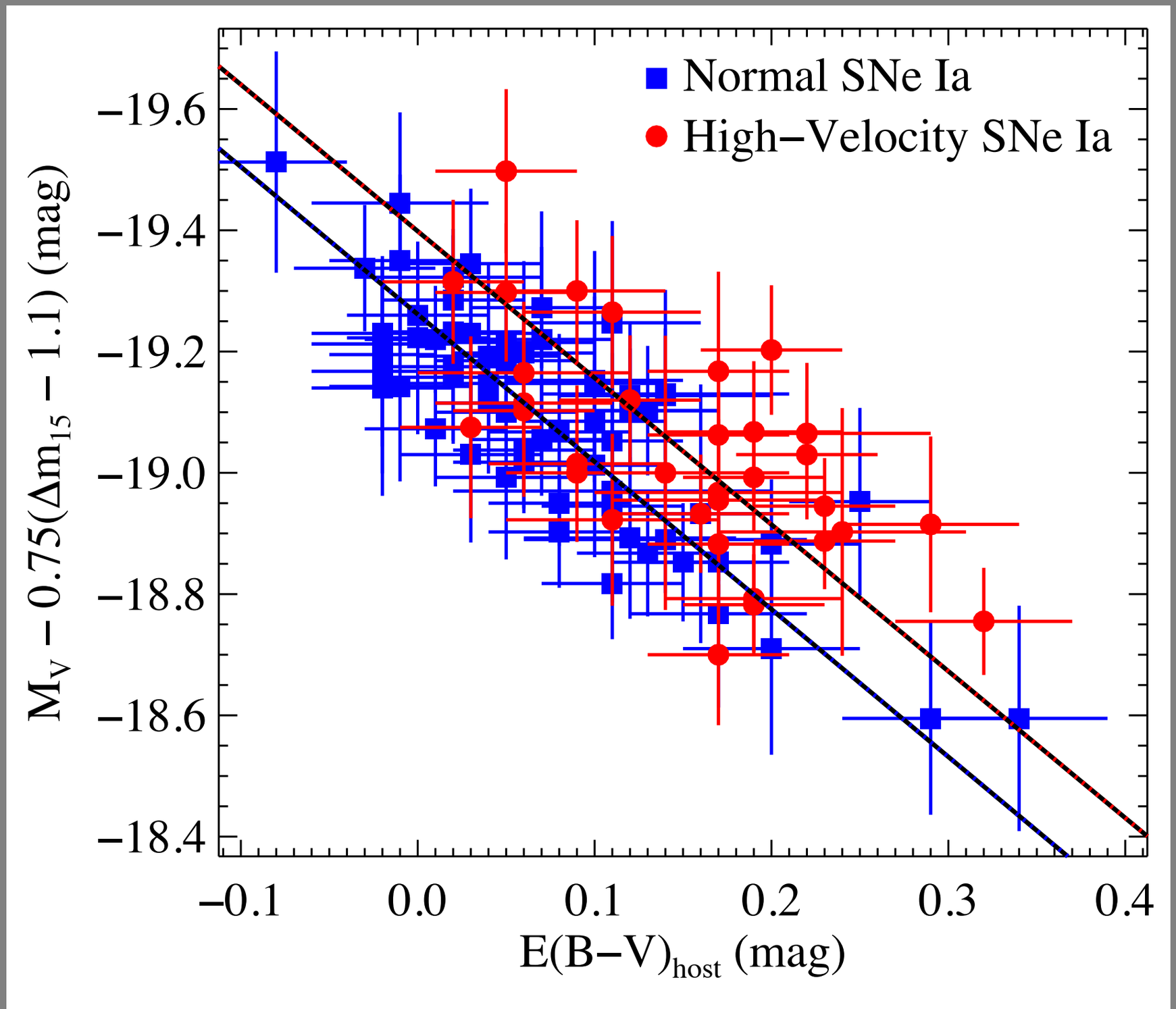
2 Values of Rv?



121 SNe

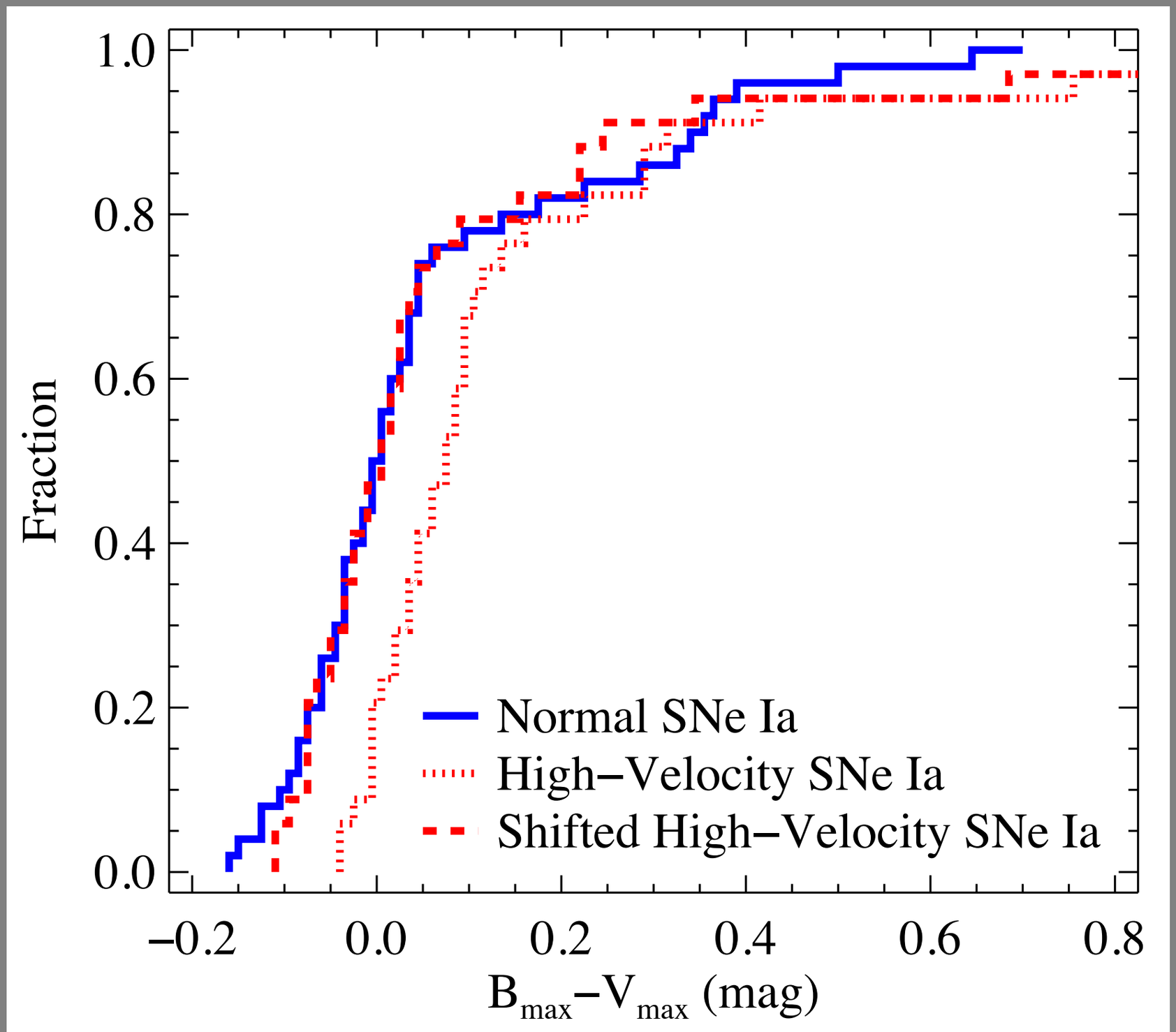
Foley & Kasen 2011

High-Velocity Supernovae Are Redder



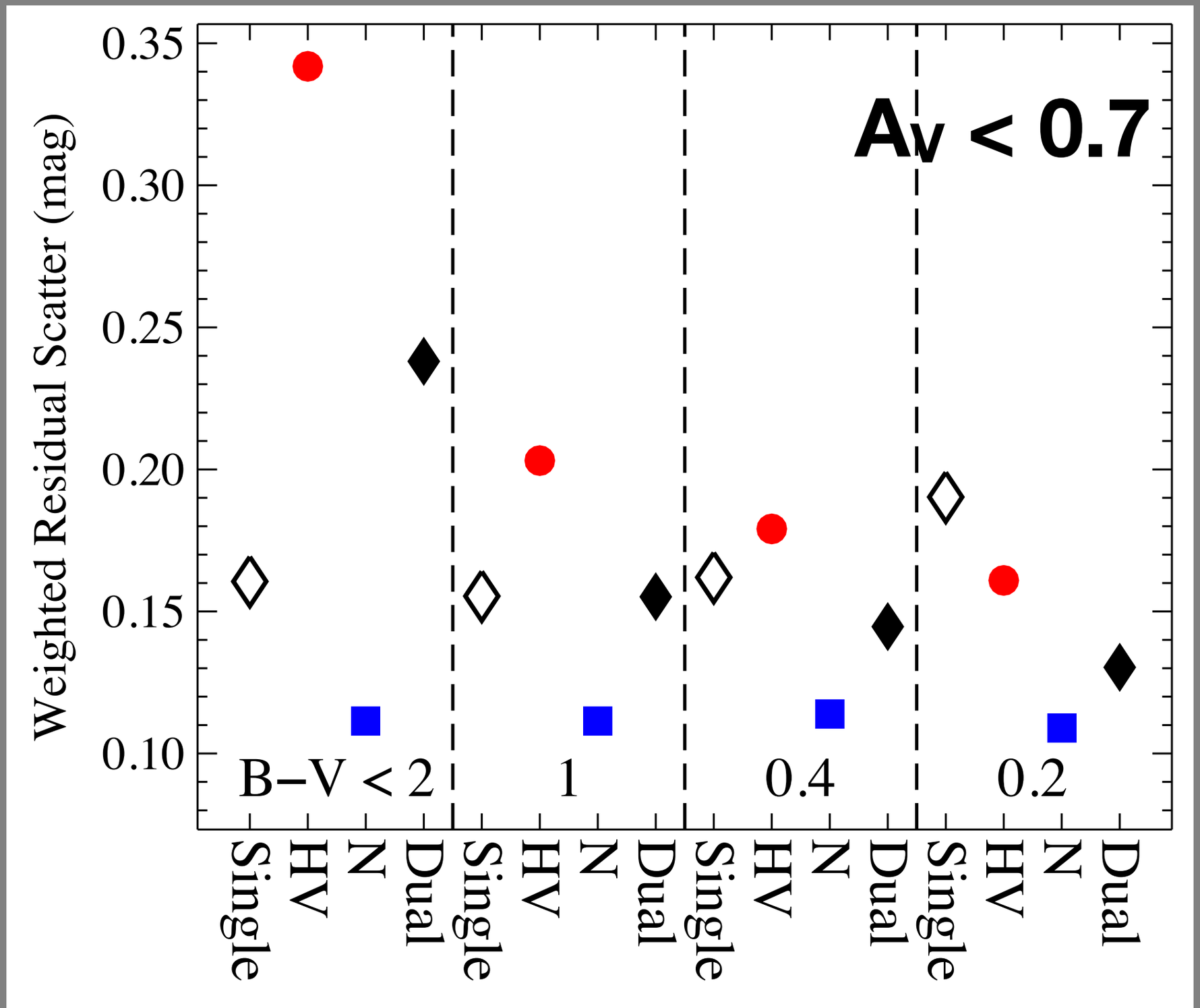
Foley & Kasen 2011

Shift in Color



Foley & Kasen 2011

Knowing Velocity Improves Distances



Foley & Kasen 2011

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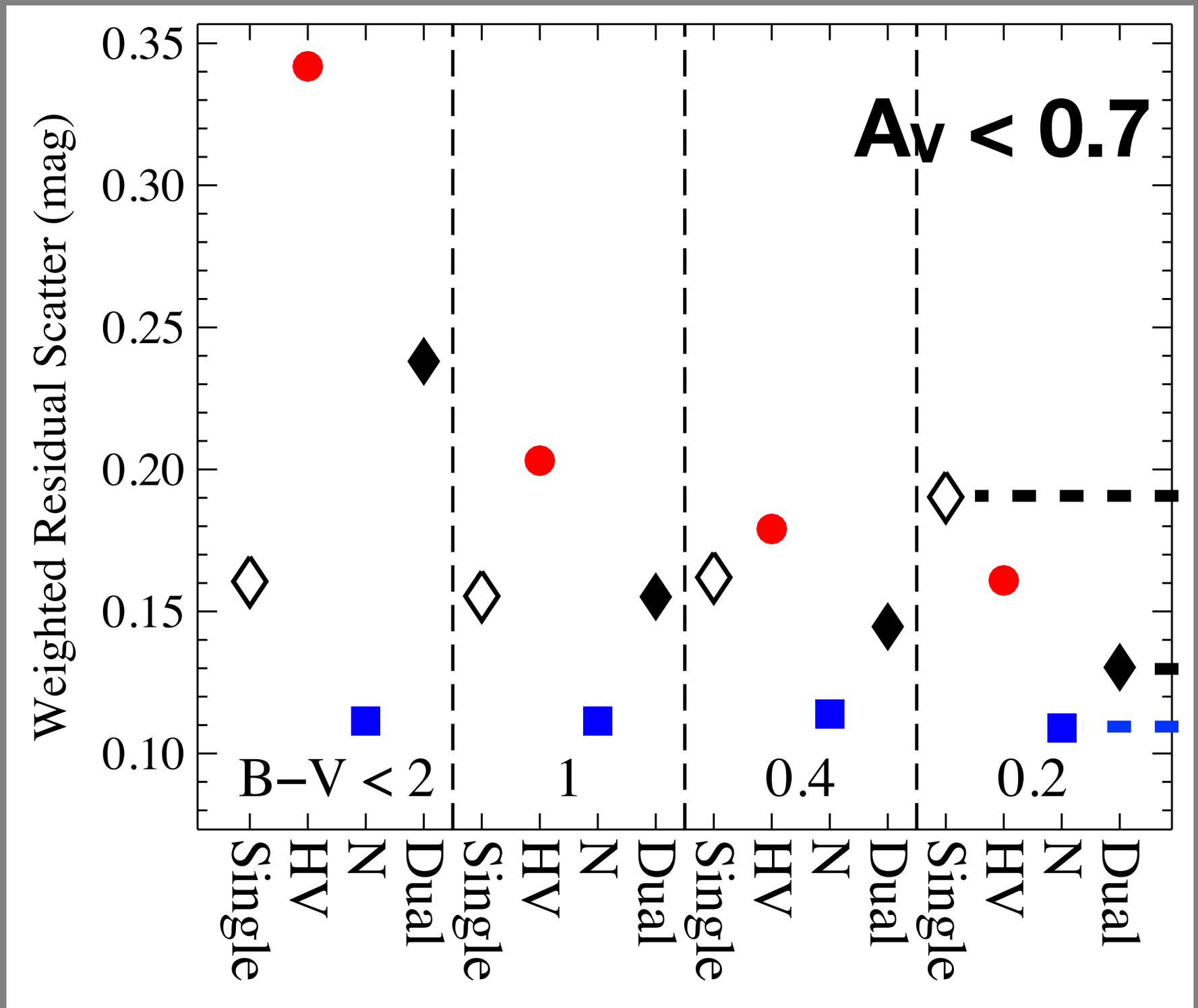
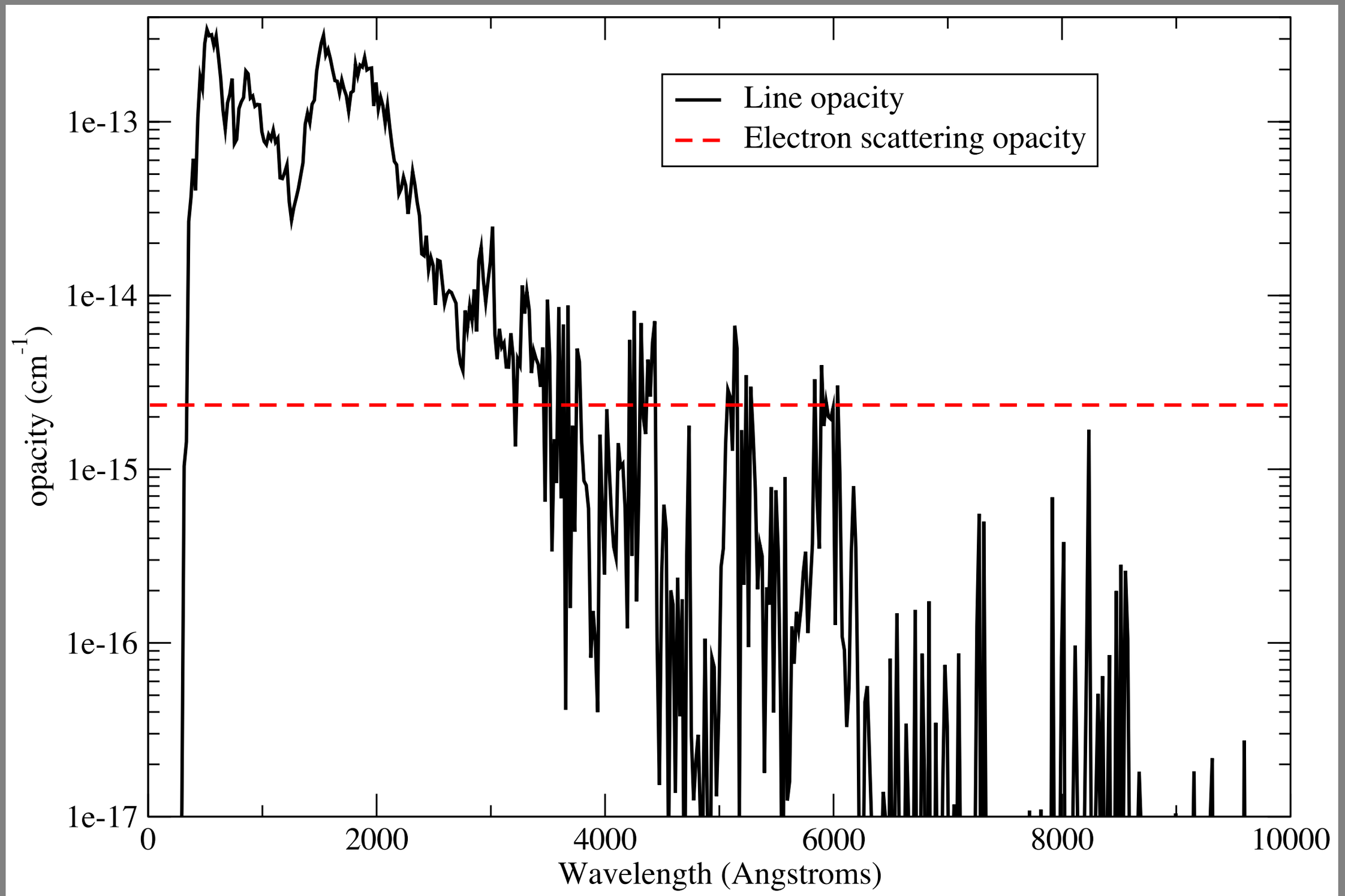


Distance Precision

- 9%
- 6%
- 5%

Foley & Kasen 2011

Opacity Depends on Velocity



Ellis et al. 2008

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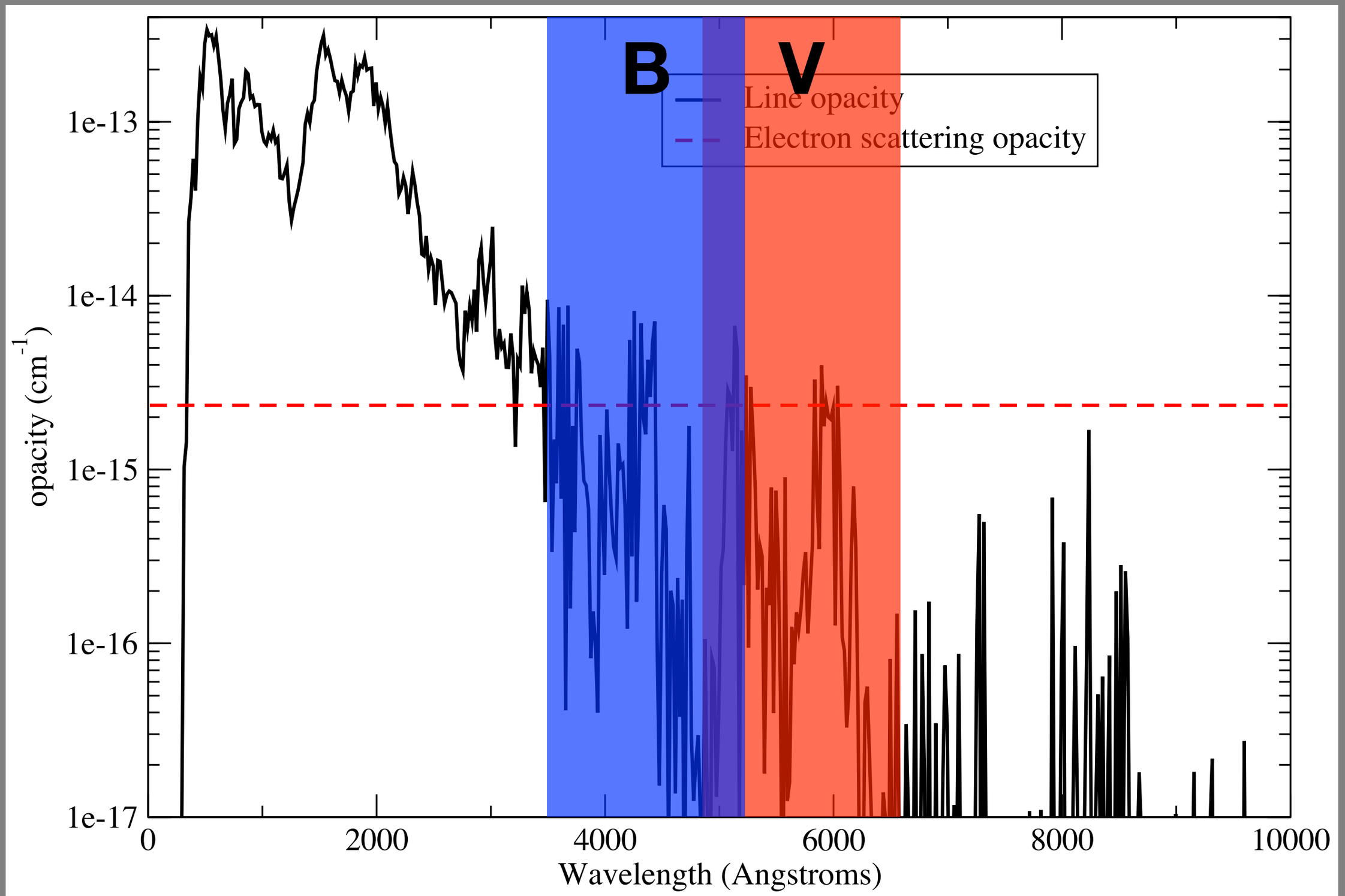
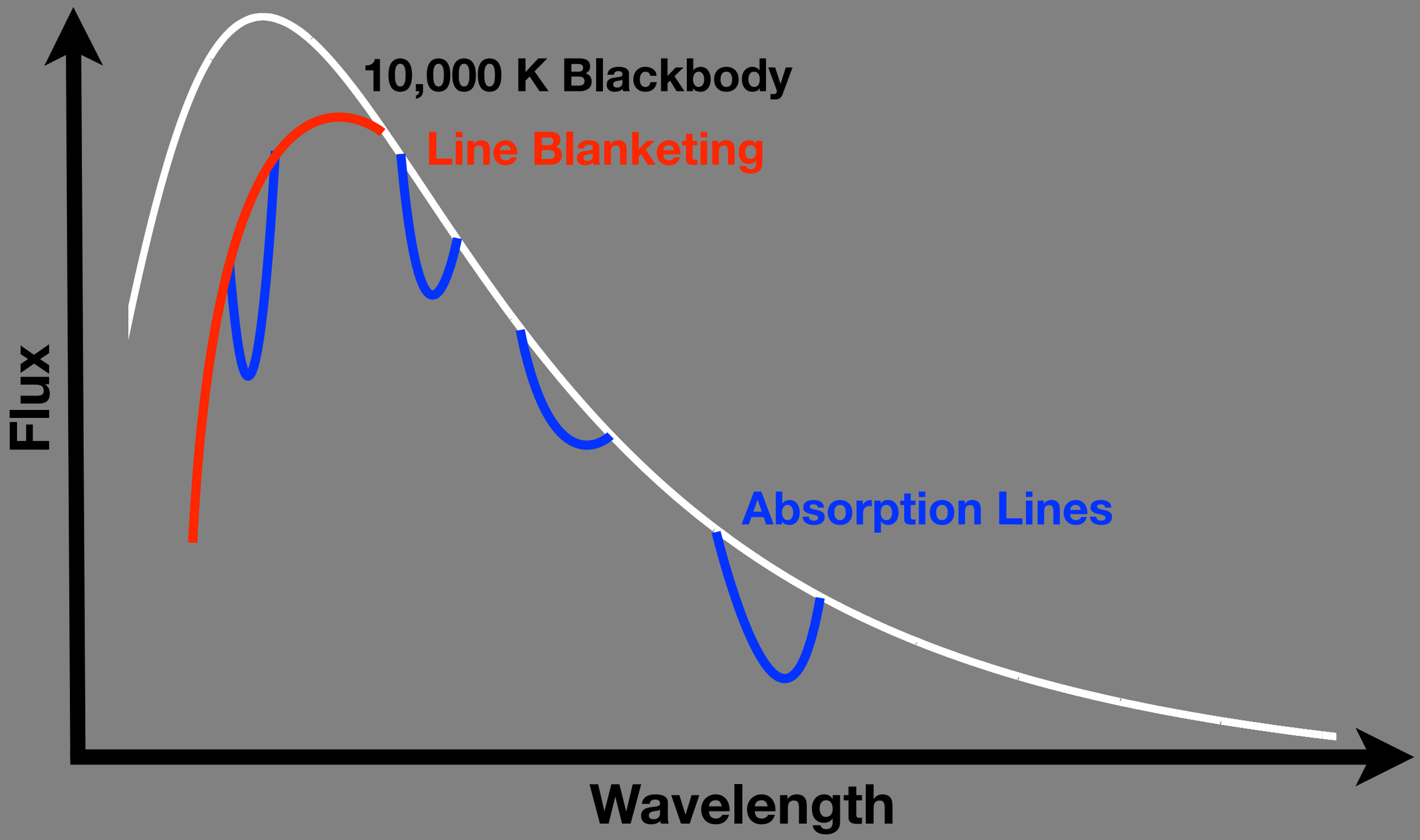


Ellis et al. 2008

Supernova SED



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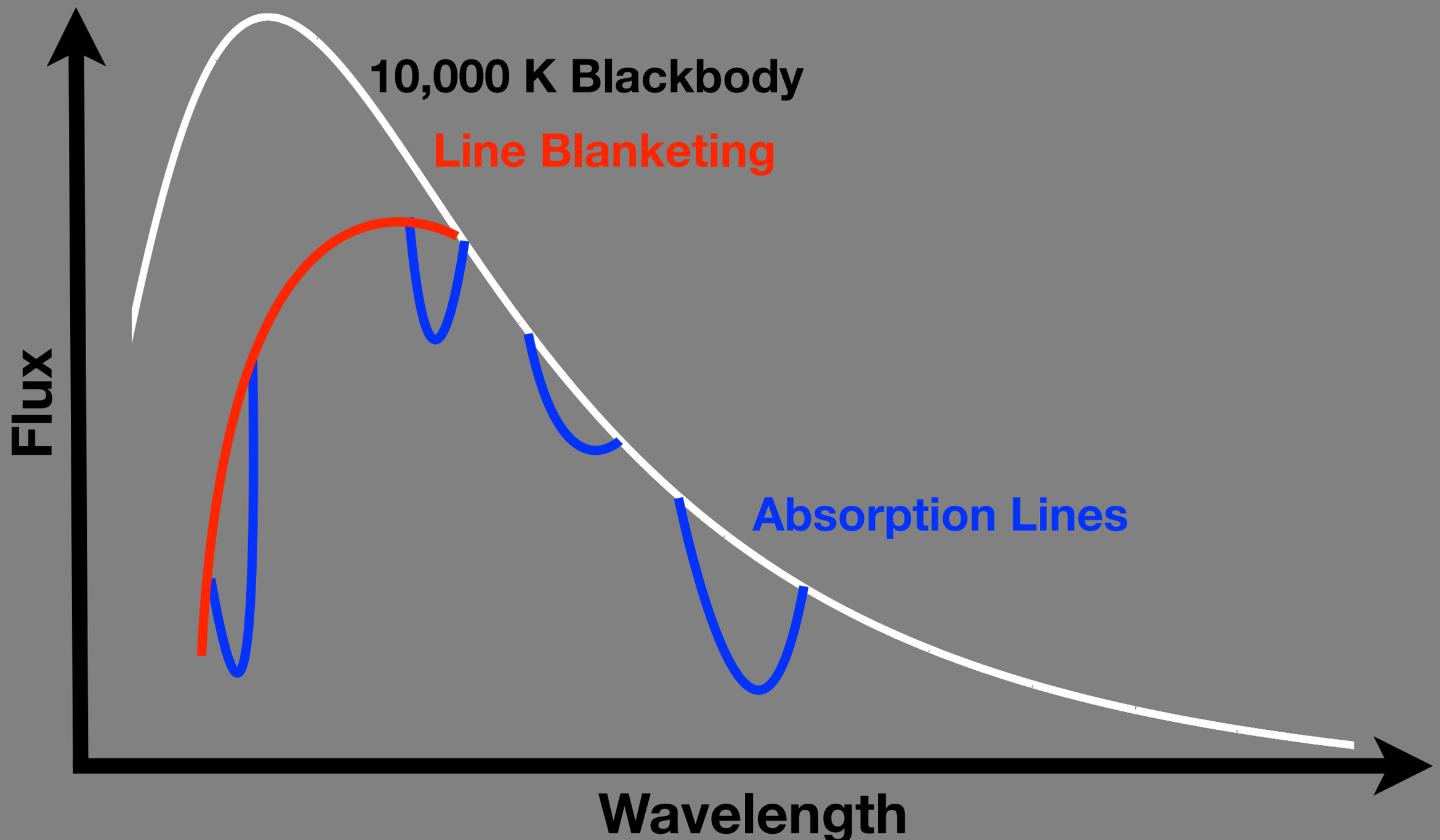
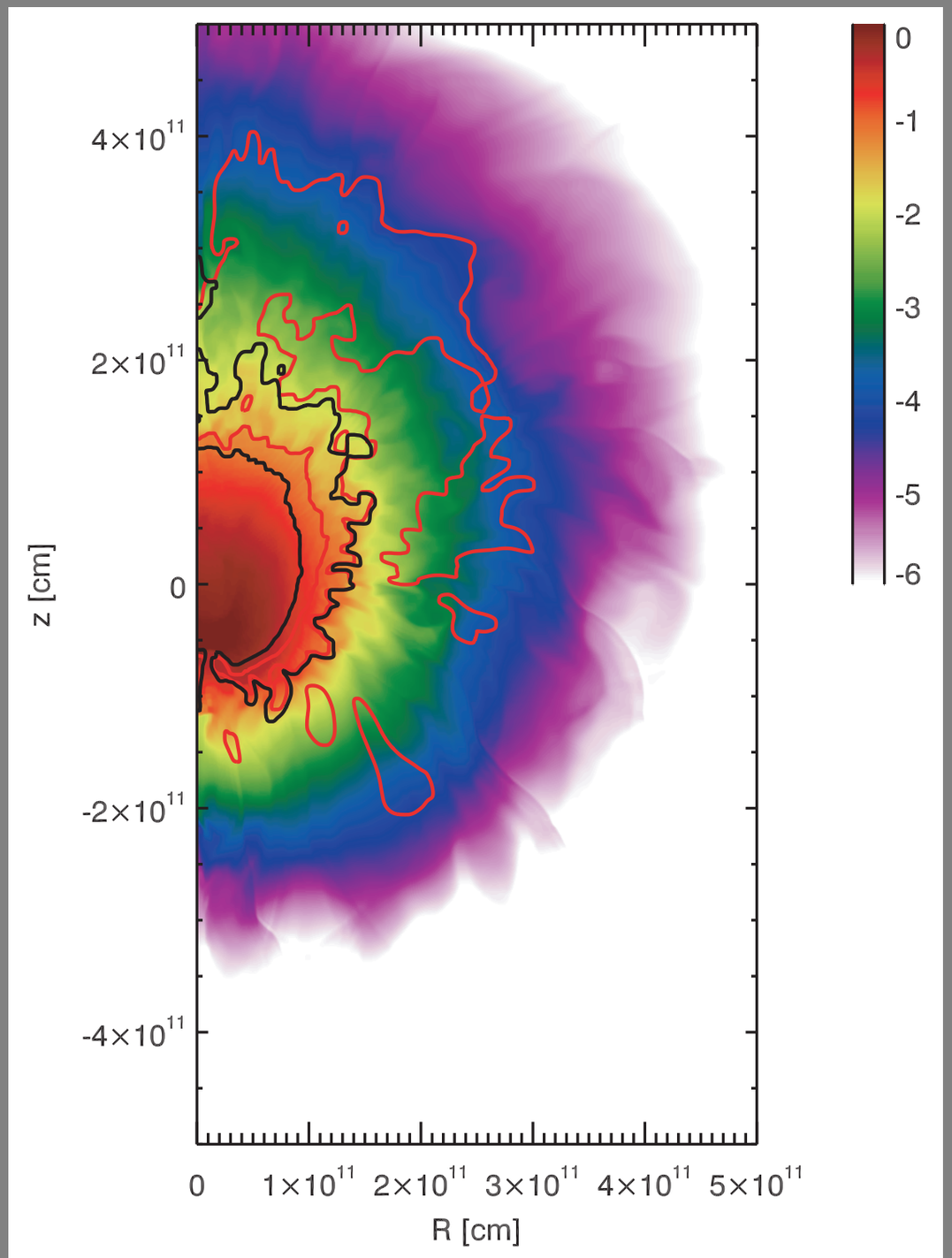
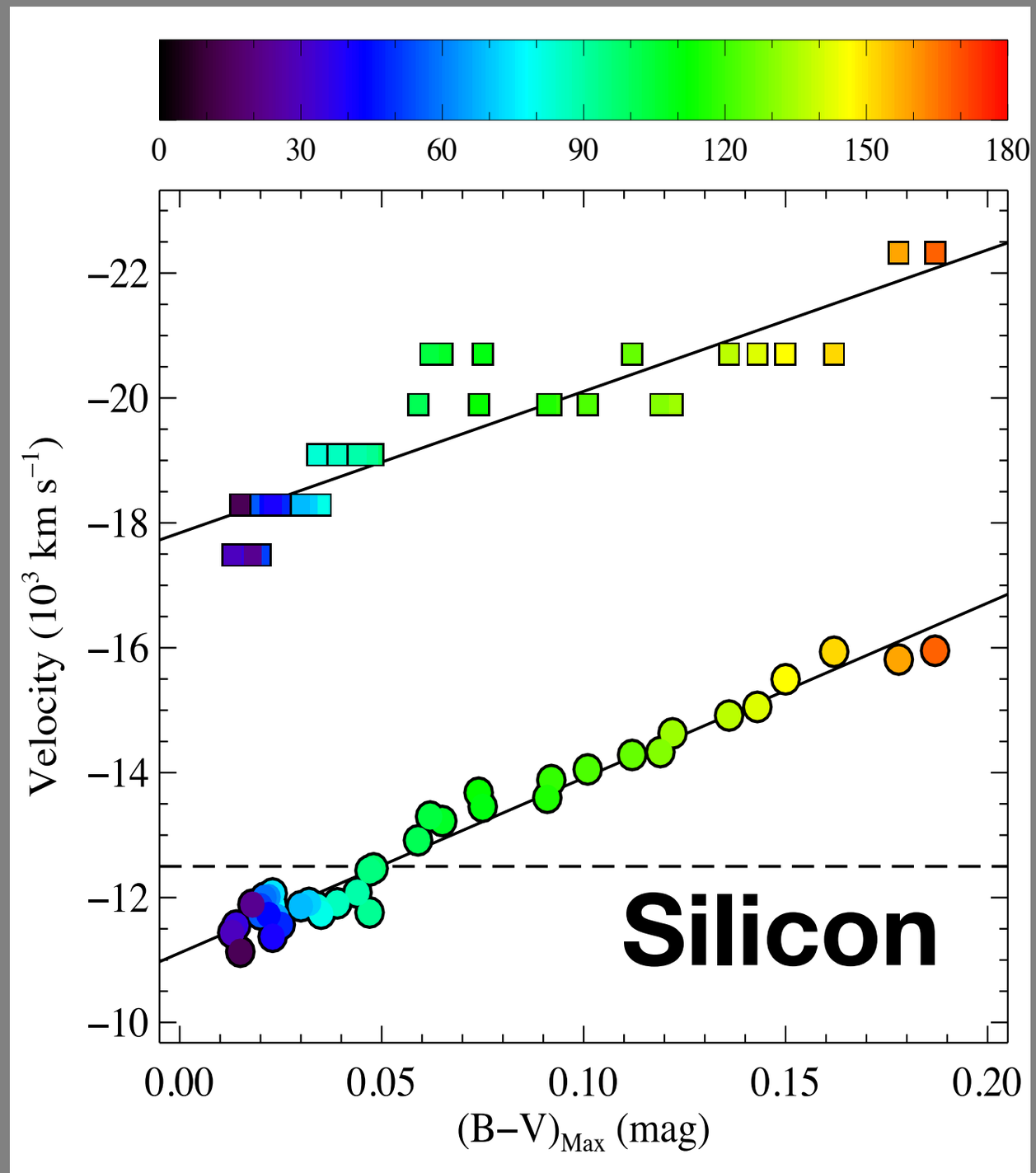


Asymmetric Explosion?

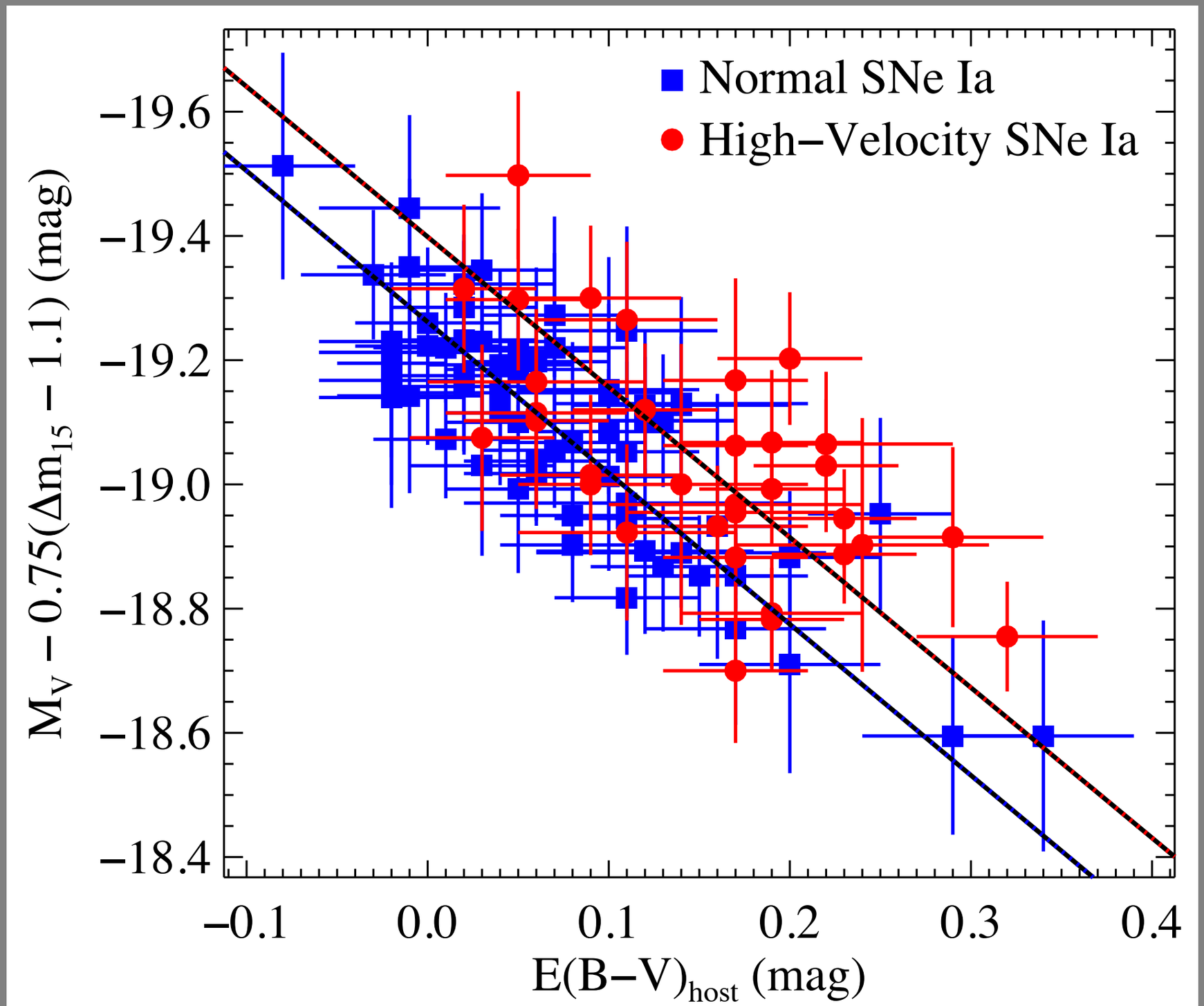


Kasen & Plewa 2007



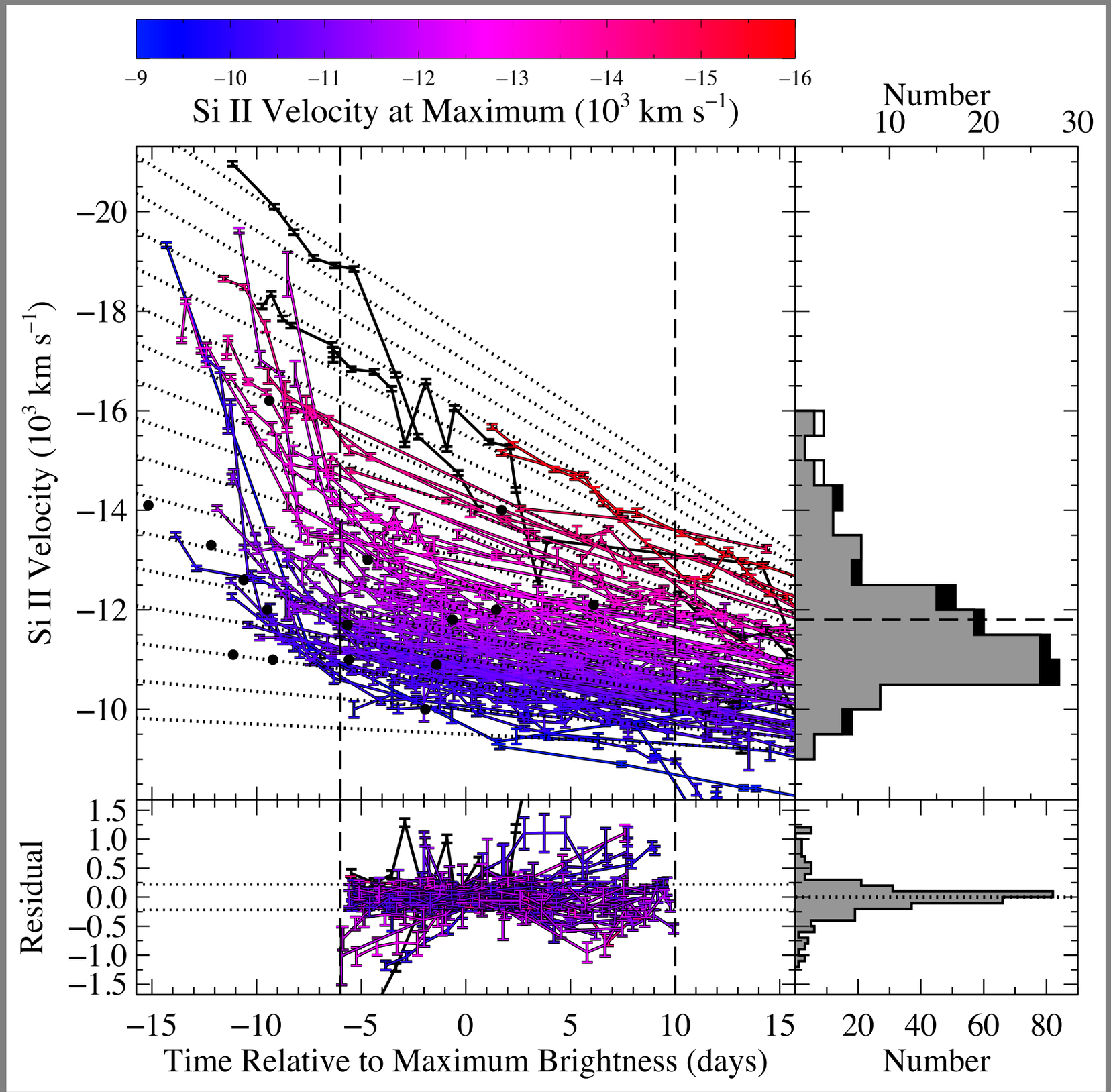
Foley & Kasen 2011

Two Distinct Groups?



Foley & Kasen 2011

Velocity / Velocity Gradient



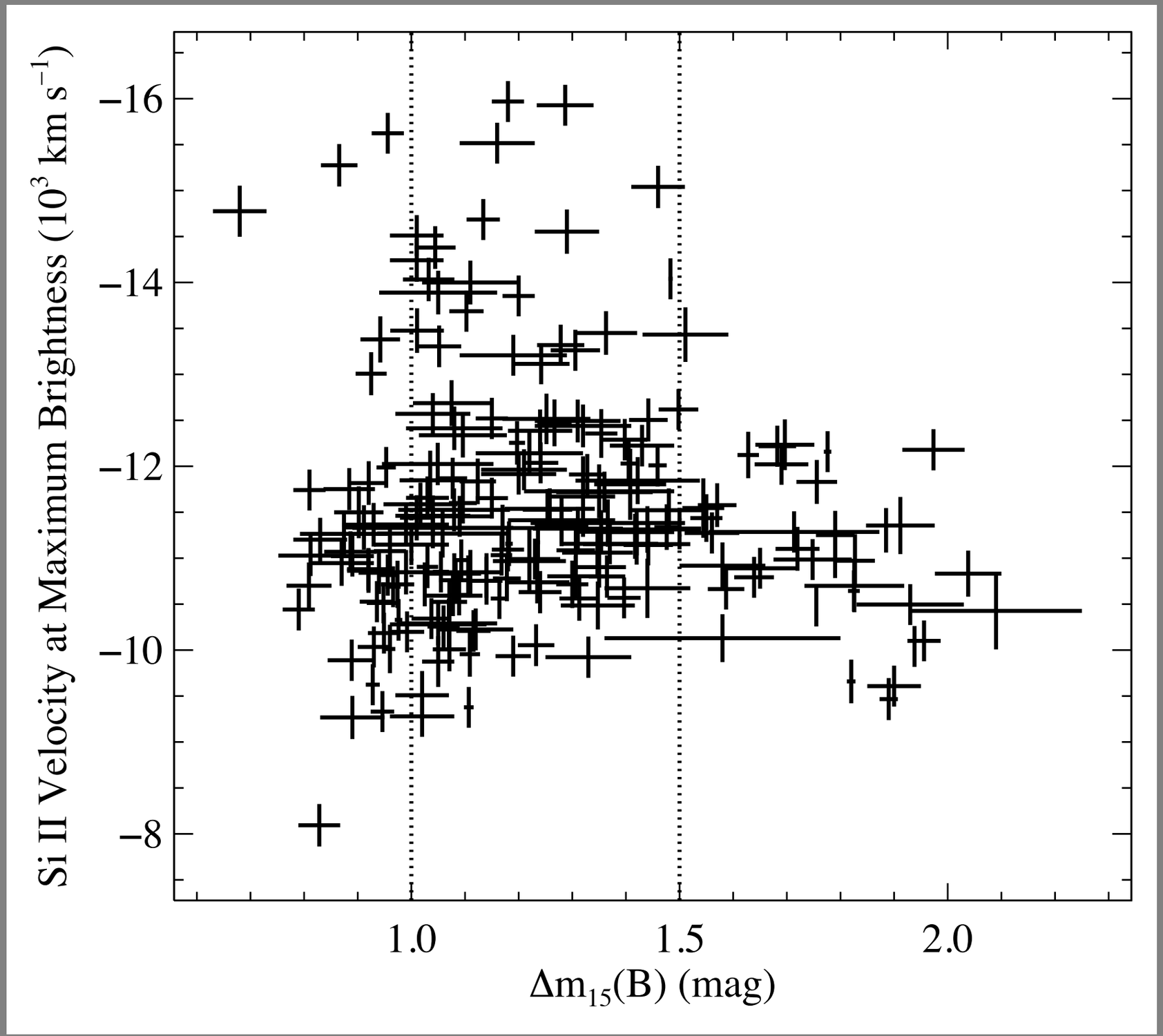
Total:
255 SNe
1630 Spectra

$1 < \Delta m_{15} < 1.5$:
141 SNe
939 Spectra

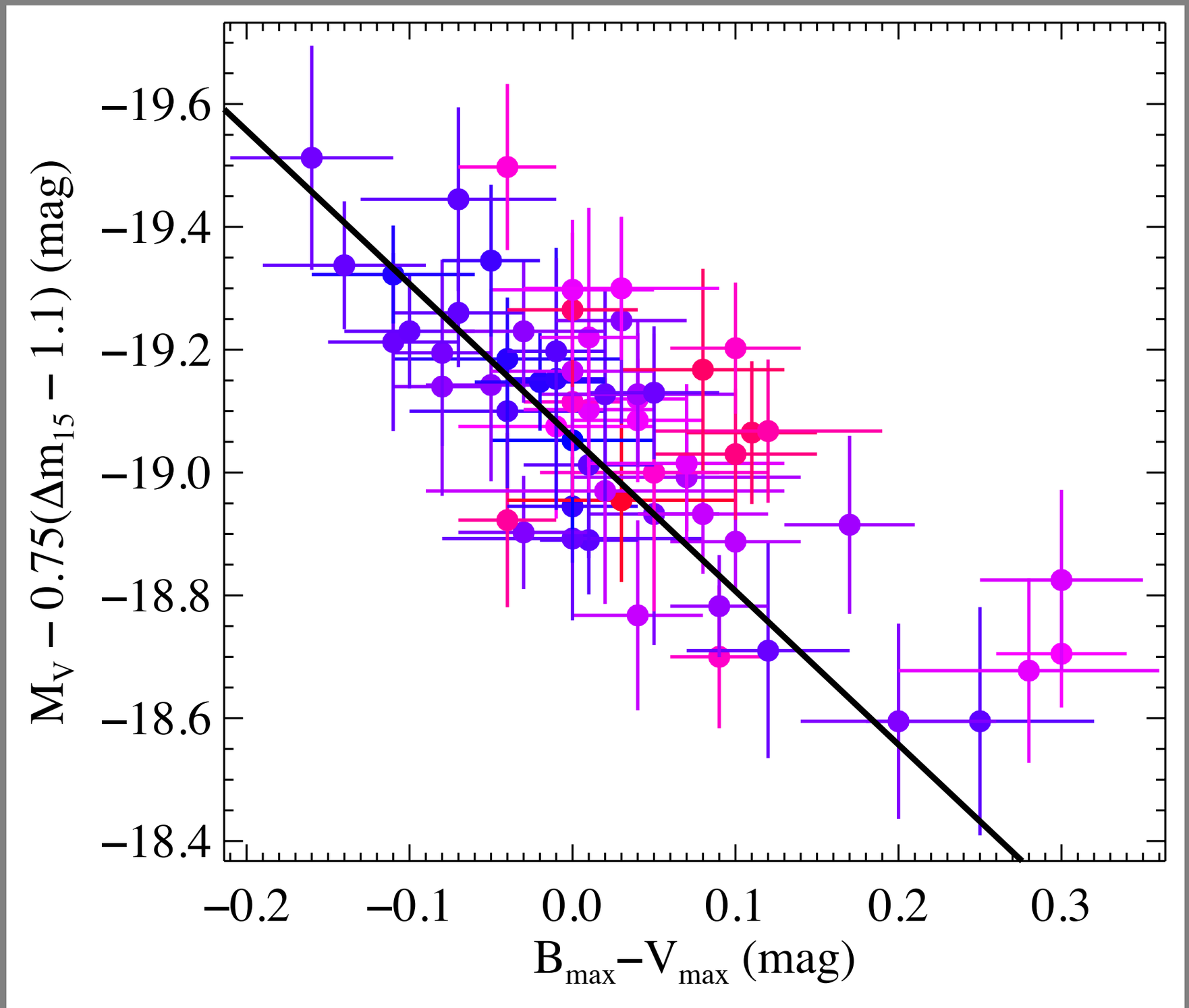
σ = 220 km/s

Foley, Sanders,
& Kirshner 2011

Velocity and Light-Curve Shape

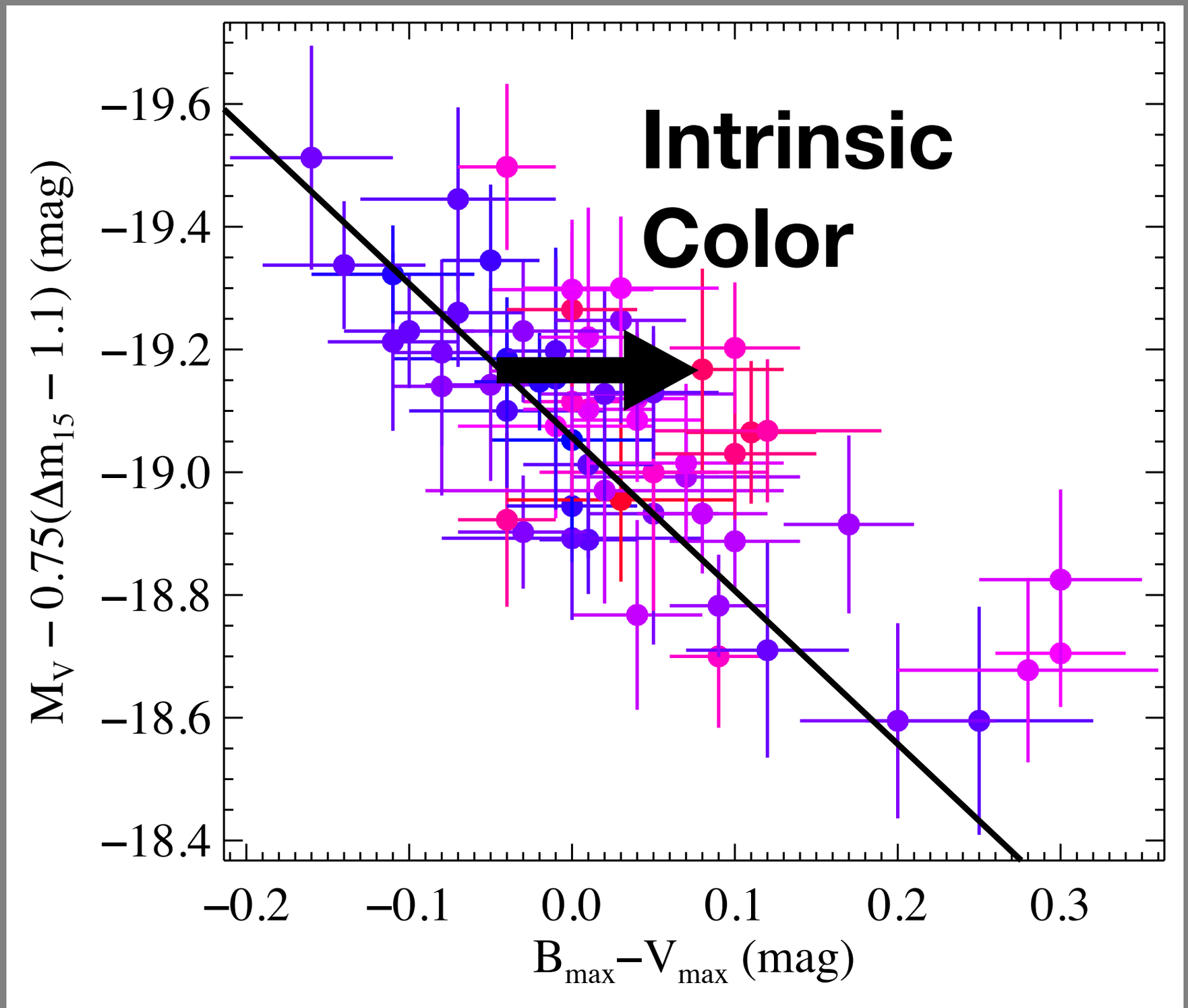


Finding Intrinsic Color



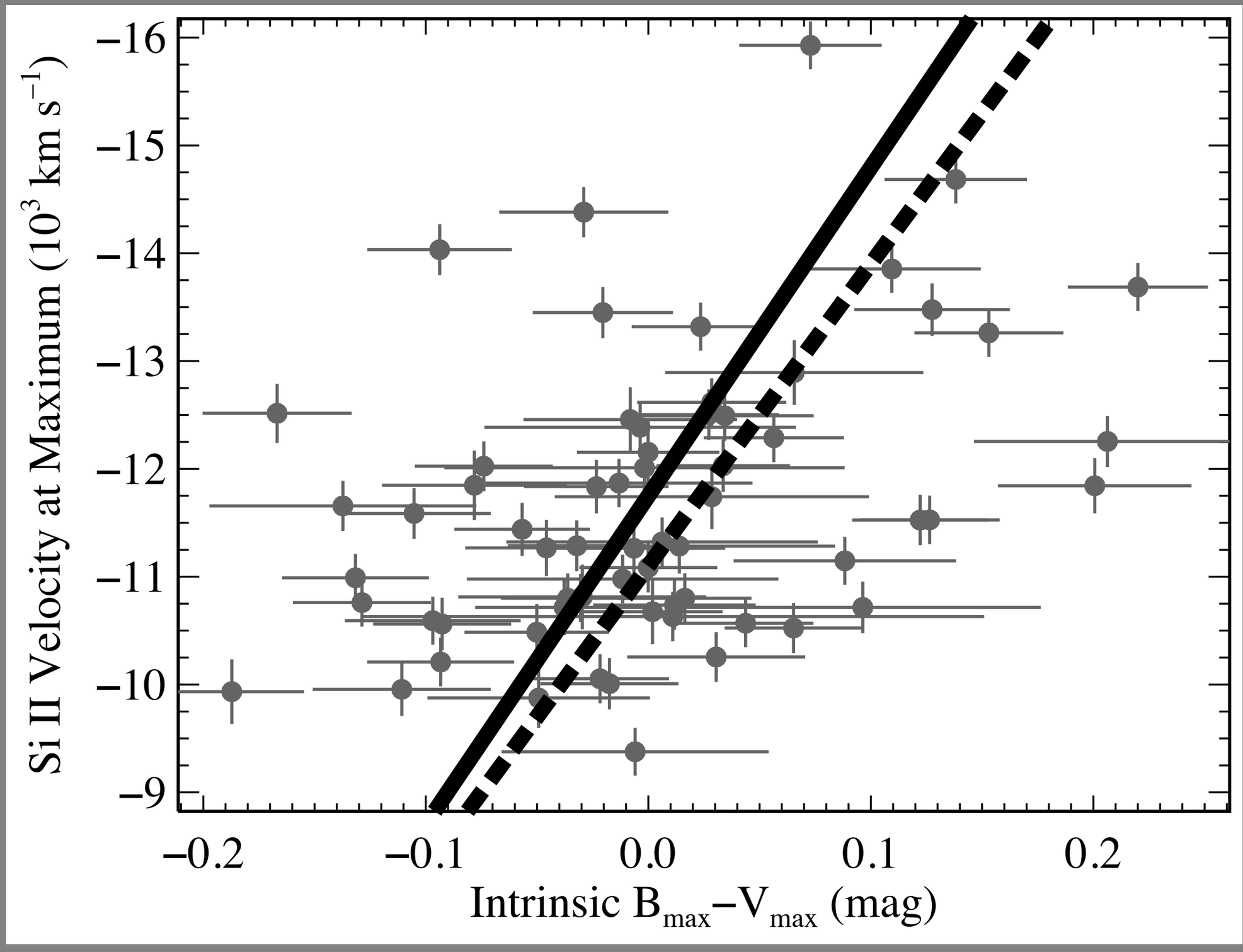
Foley, Sanders, & Kirshner 2011

Finding Intrinsic Color



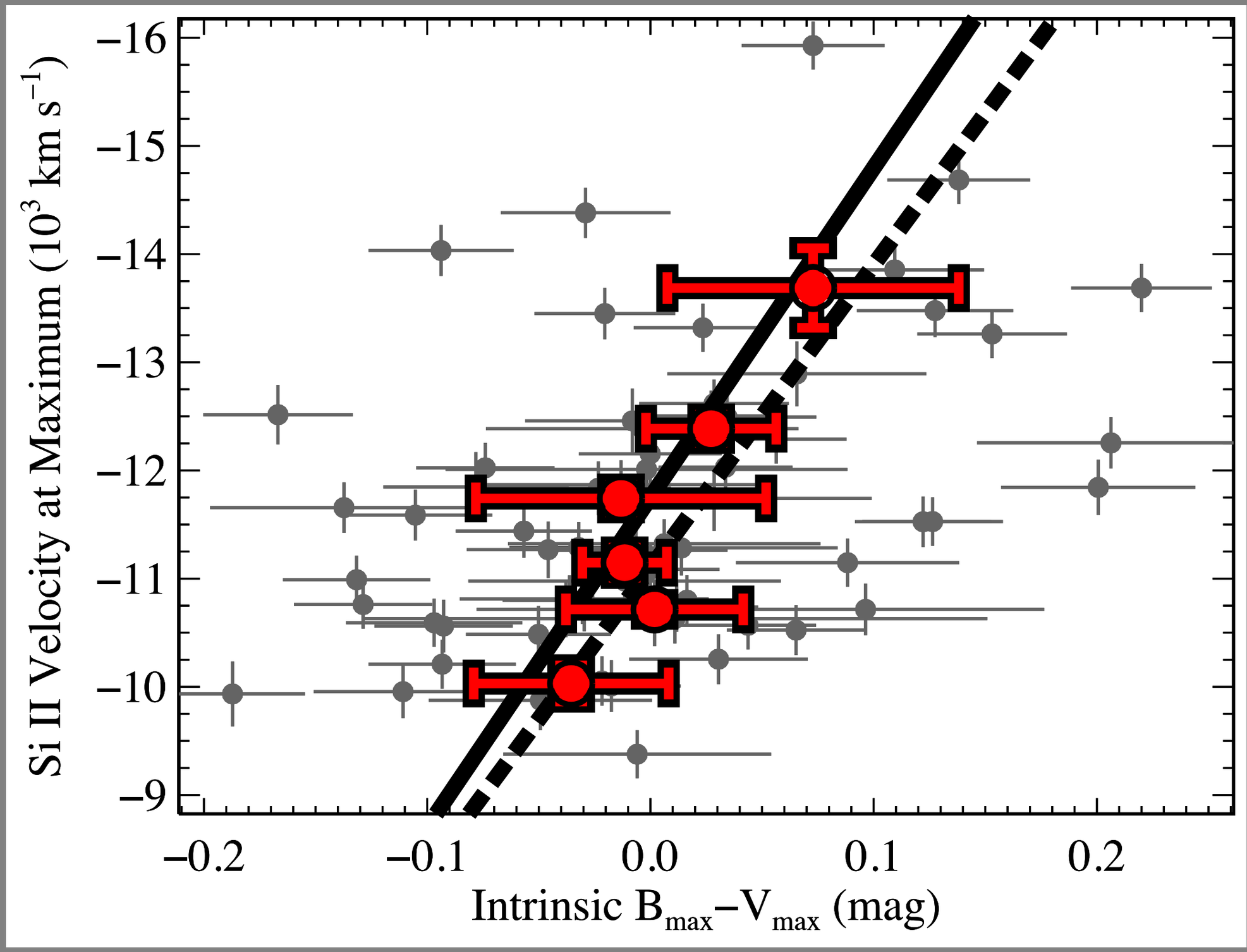
Foley, Sanders, & Kirshner 2011

Intrinsic Color Depends on Velocity



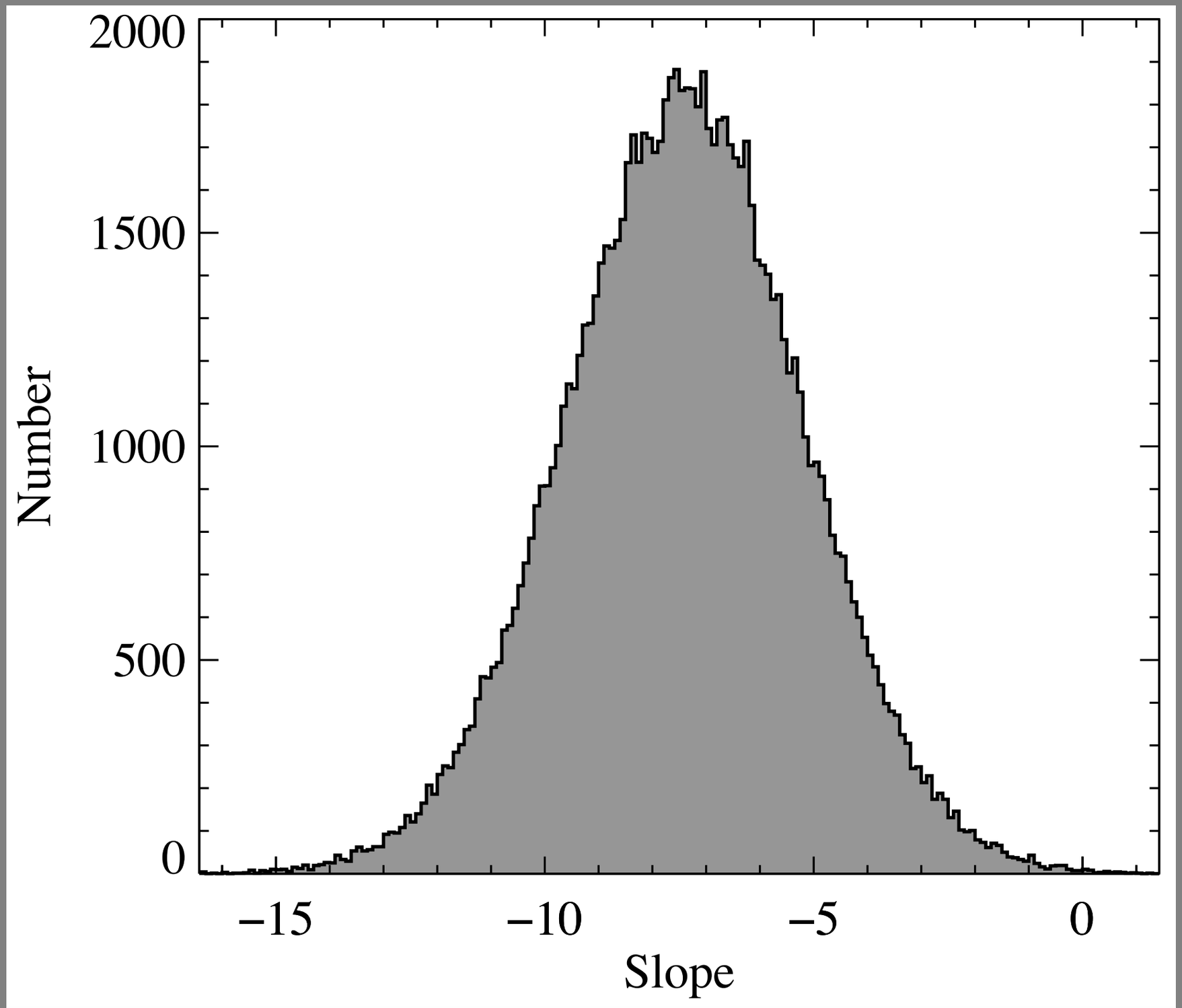
Foley et al., in prep.

Intrinsic Color Depends on Velocity



Foley et al., in prep.

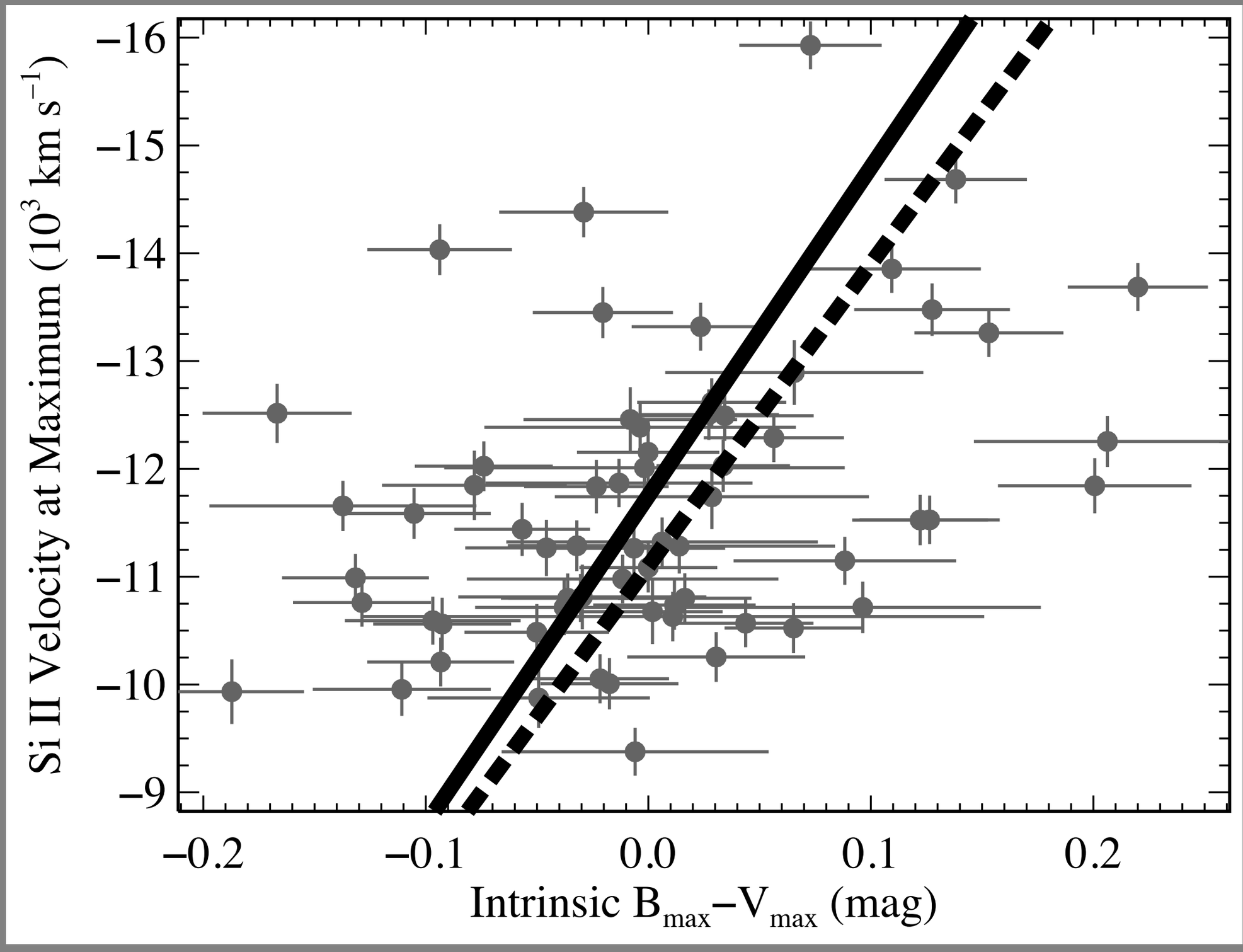
Intrinsic Color Depends on Velocity



Monte Carlo Simulation

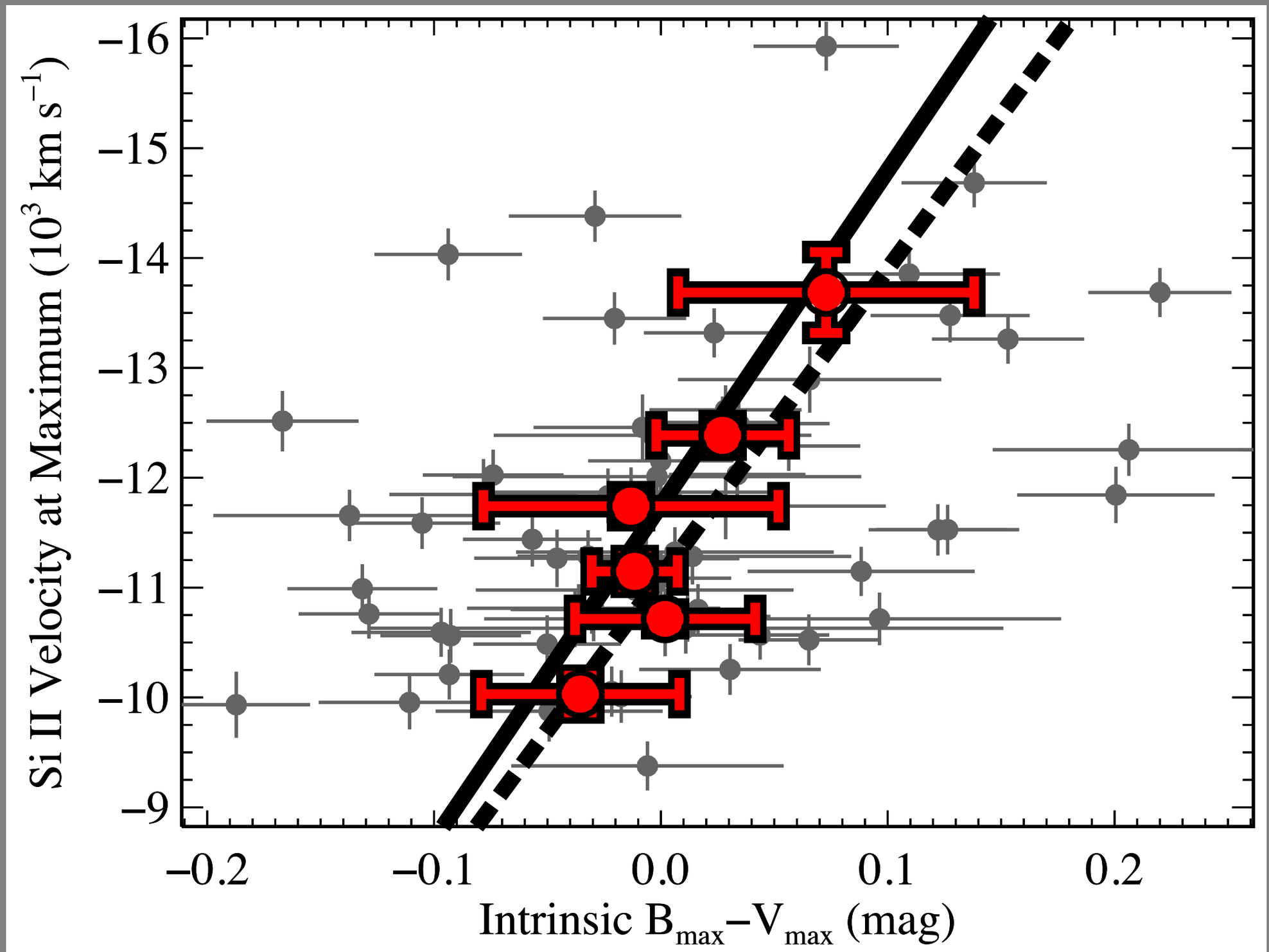
99.949% Negative Slope

Intrinsic Color Depends on Velocity



Foley, Sanders, & Kirshner 2011

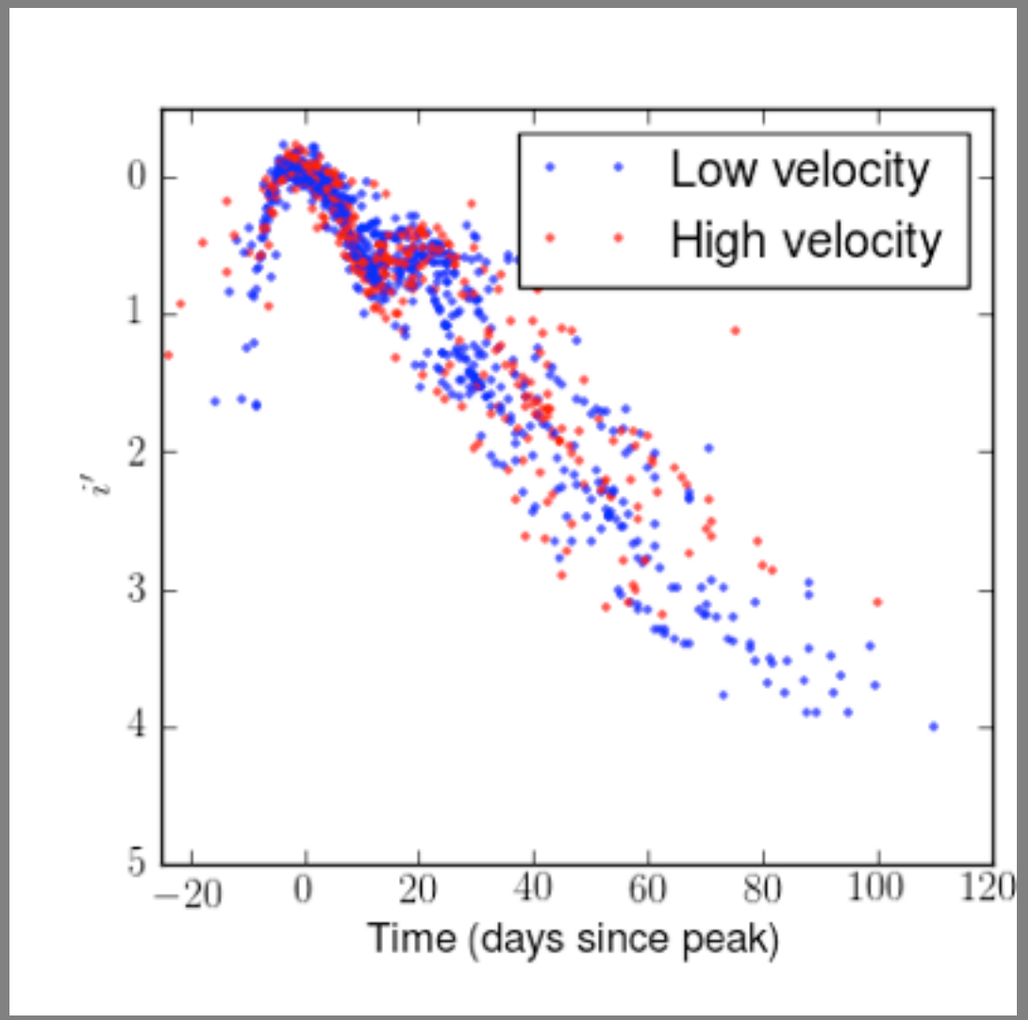
Intrinsic Color Depends on Velocity



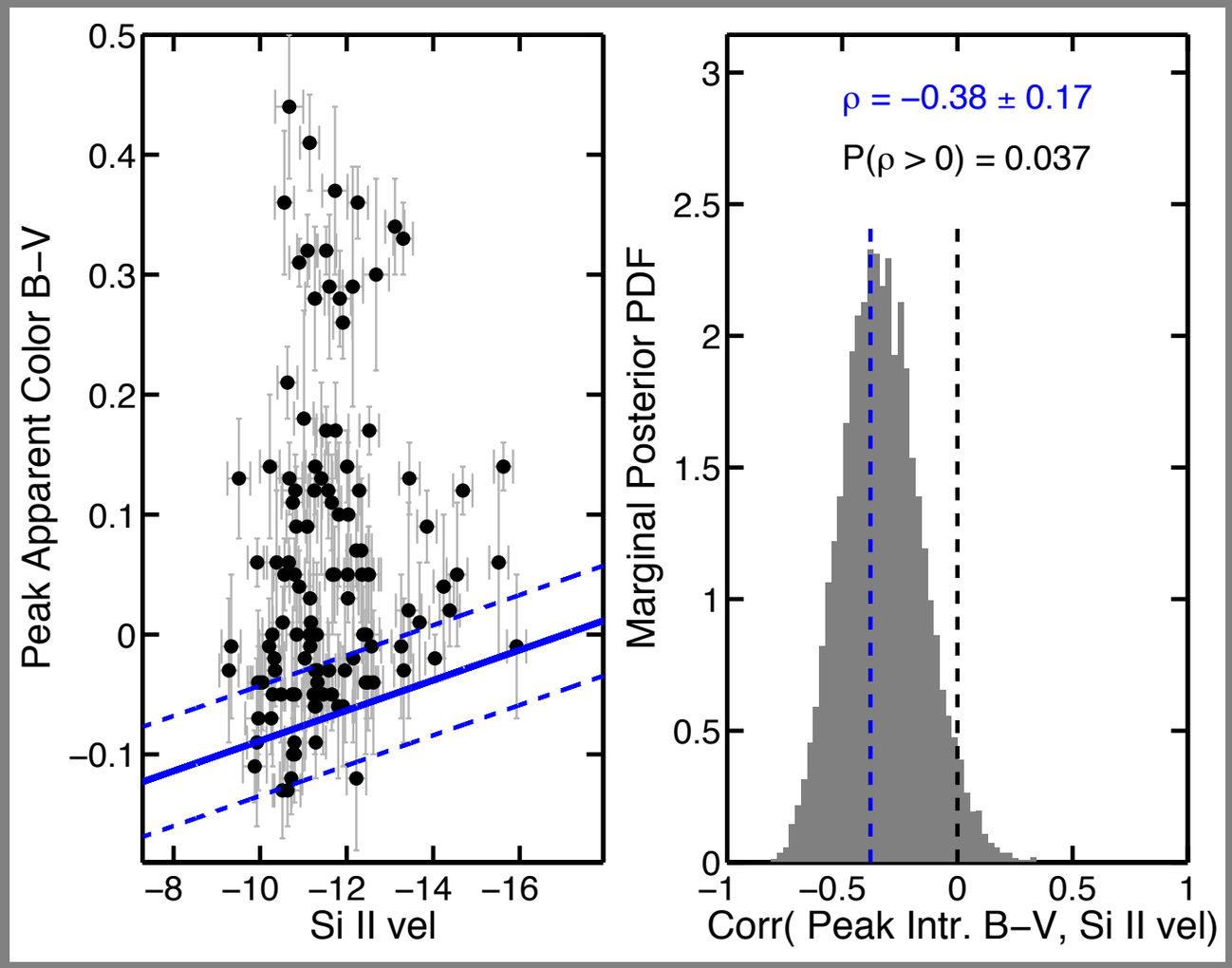
Foley, Sanders, & Kirshner 2011

Standardizable Crayons

Additional Projects



Sanders et al., in prep.



Mandel et al., in prep.

Implications

Previous SN Ia distances are biased

***If* average color/velocity shifts with redshift, cosmology measurements are biased**

Future SN cosmology surveys (DES, LSST, WFIRST) may need spectroscopy

Looking for a new improvement for two decades

Higher velocity supernovae are redder

Color used to determine amount of dust and distance

Measuring velocity (standardizing the crayon) reduces bias and scatter → more accurate and precise distances

Dark Energy measurements will improve