Supernova Morphology & H_0

with Intensity Interferometry

I-Kai Chen 11/01/2024

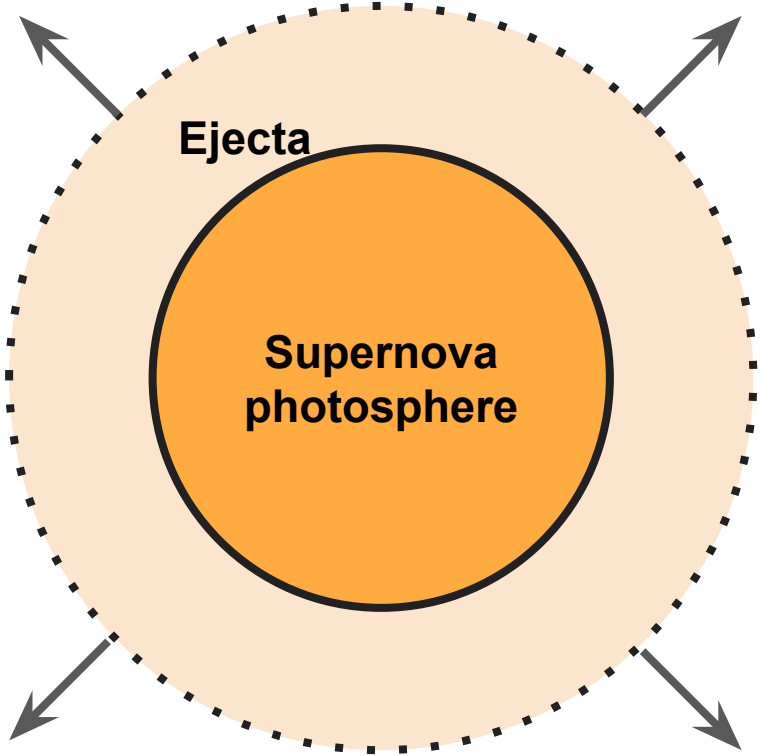
w/ David Dunsky, Junwu Huang, Ken Van Tilburg, Bob Wagoner

NYU

Overview

- Learn about ejecta, photosphere shape and property of spectrum
- Bright supernova distance to calibrate “standard candles”
- Distance ladder free hubble measurement

Supernova Expansion - P Cygni Line



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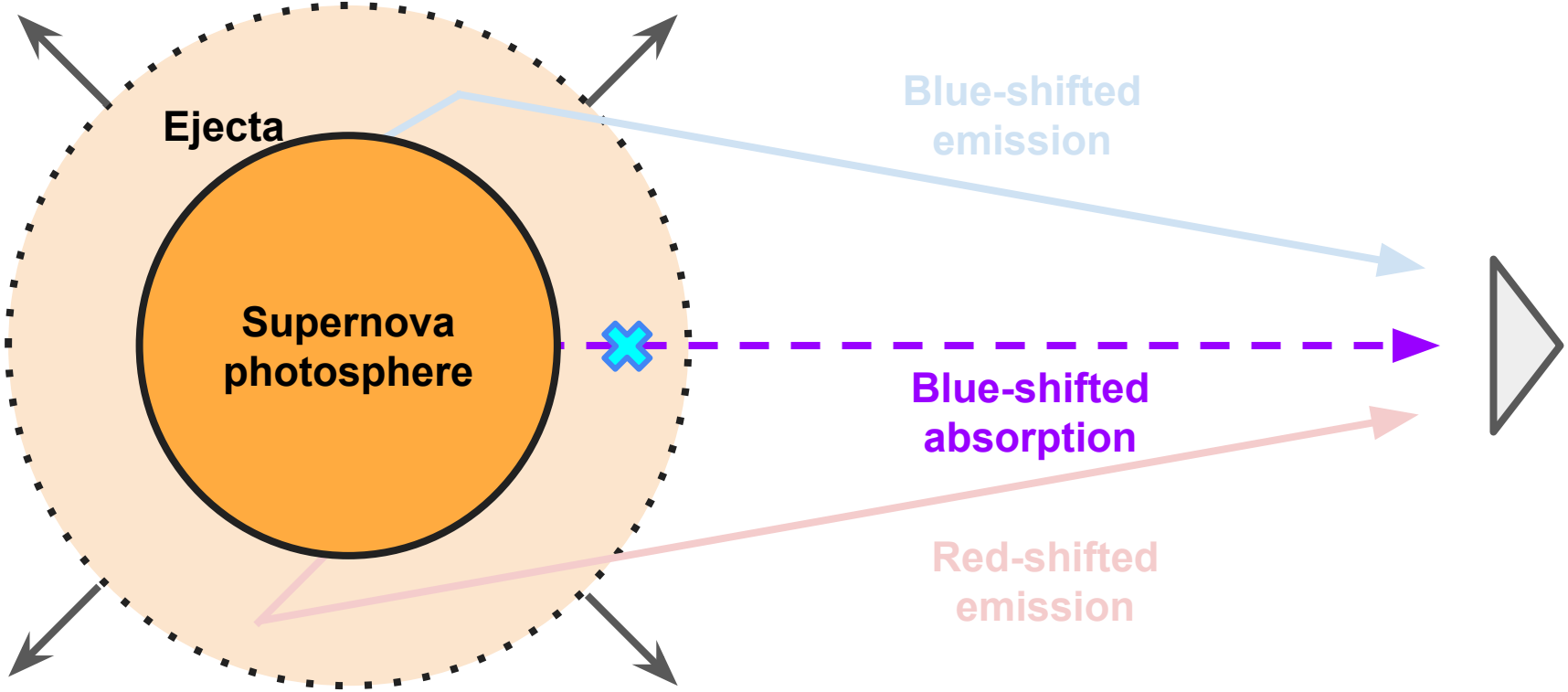

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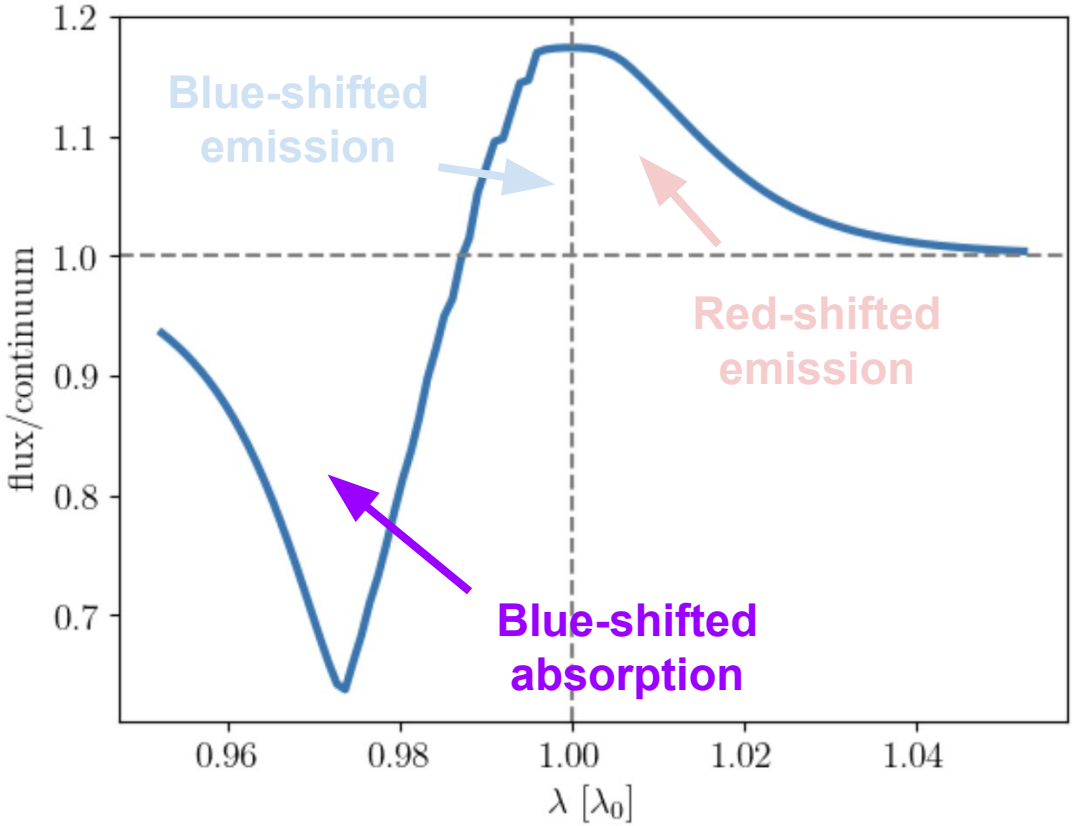

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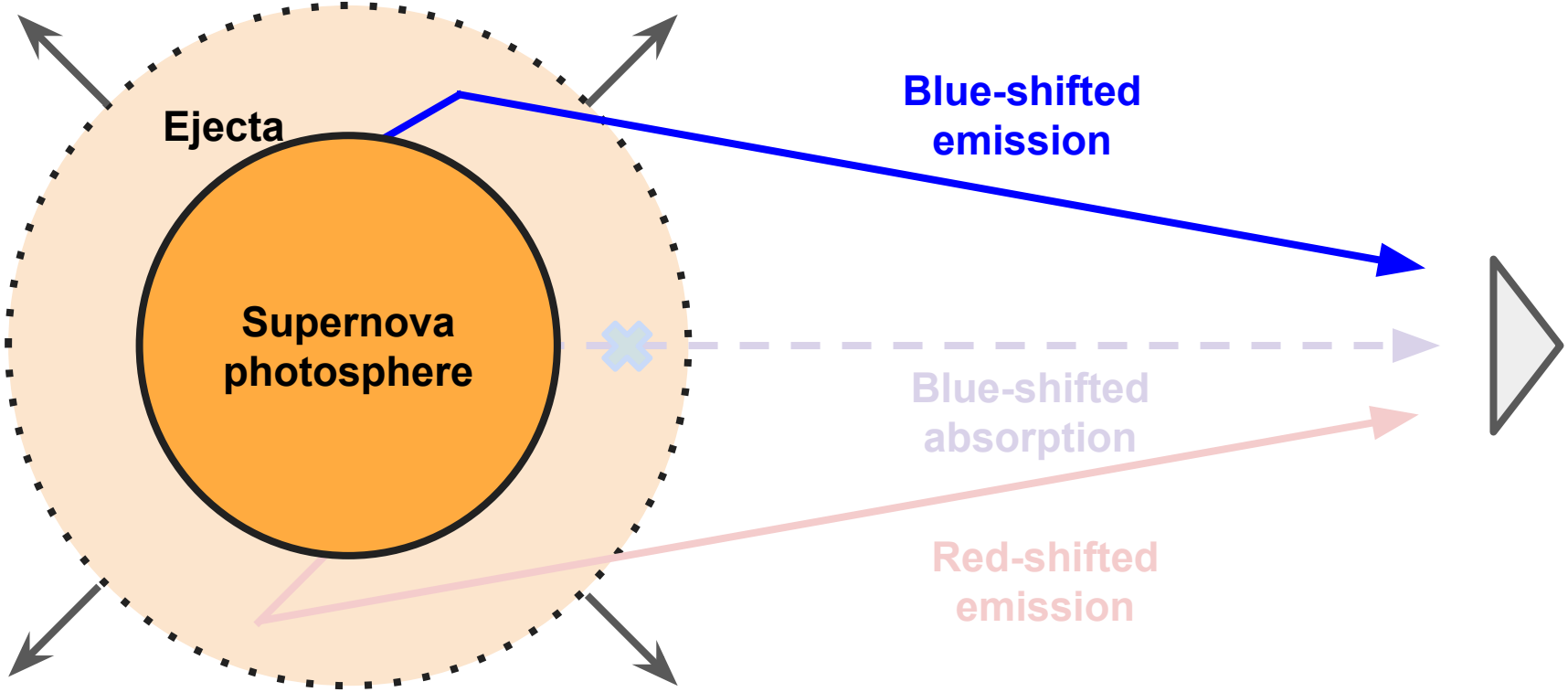

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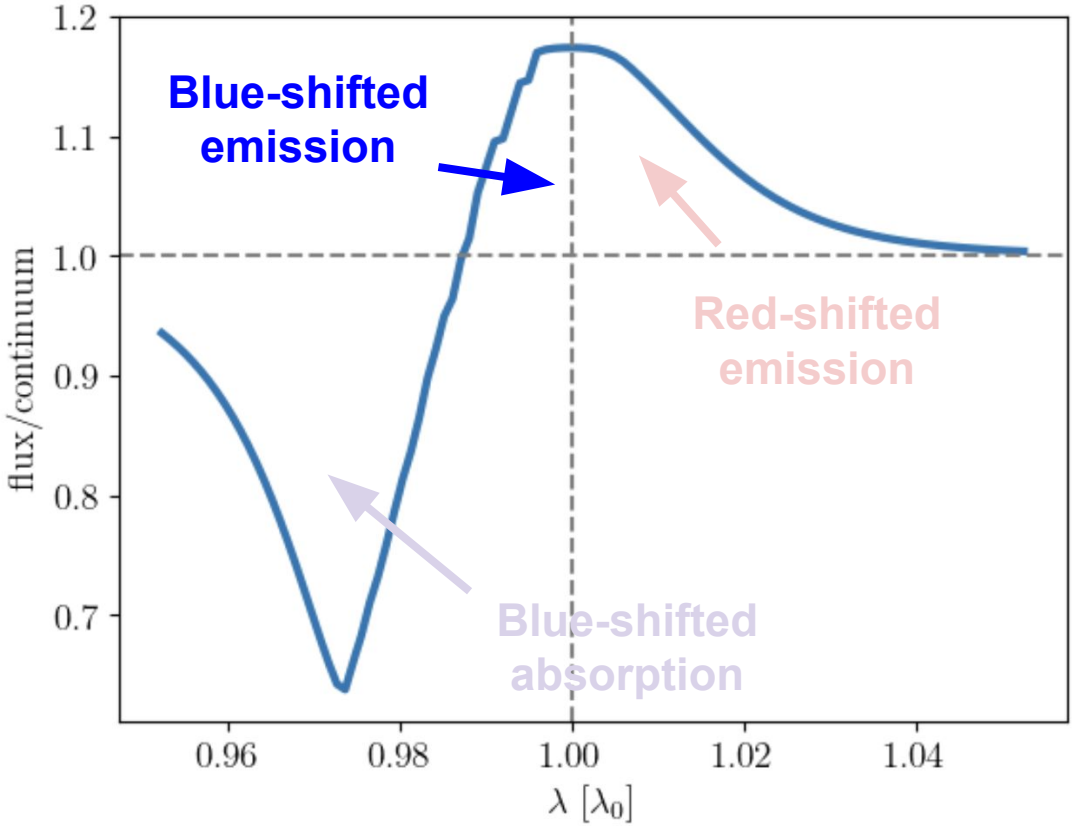

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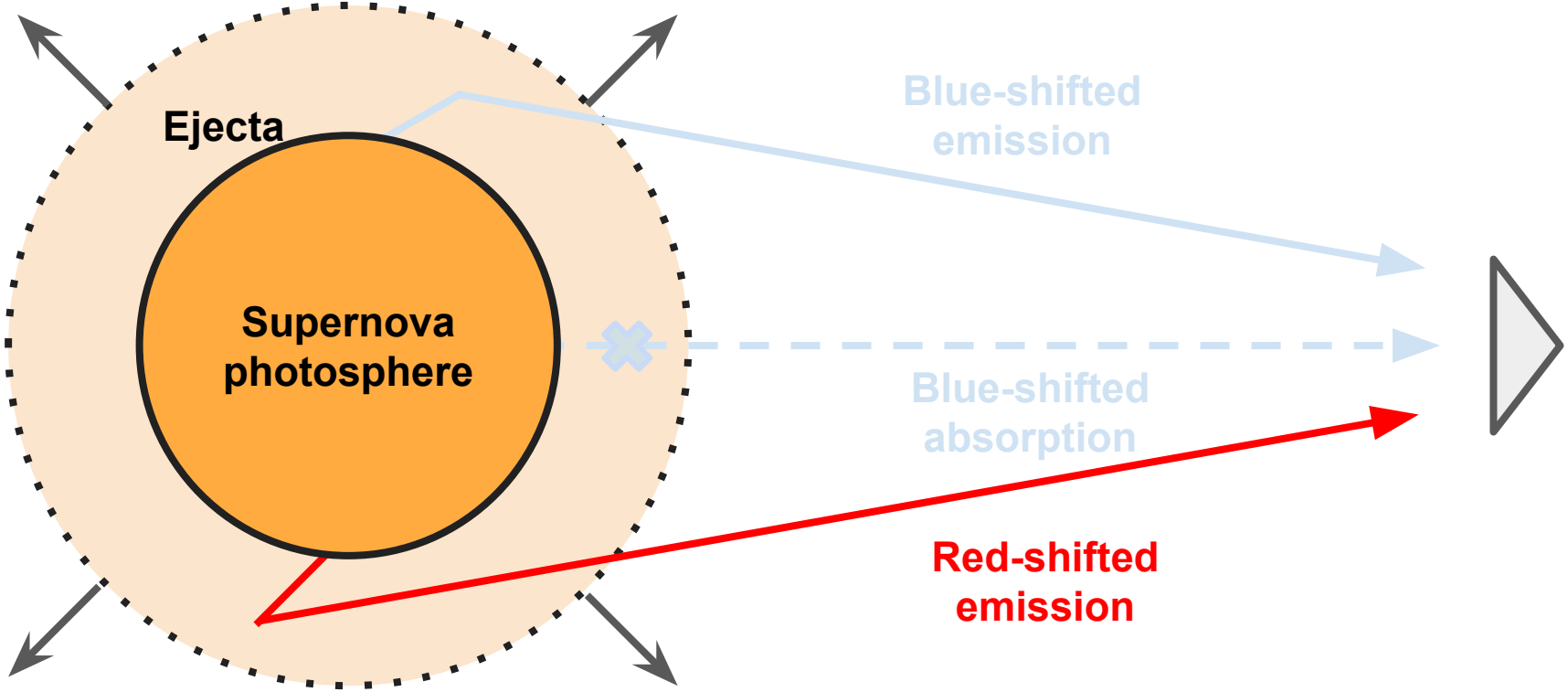

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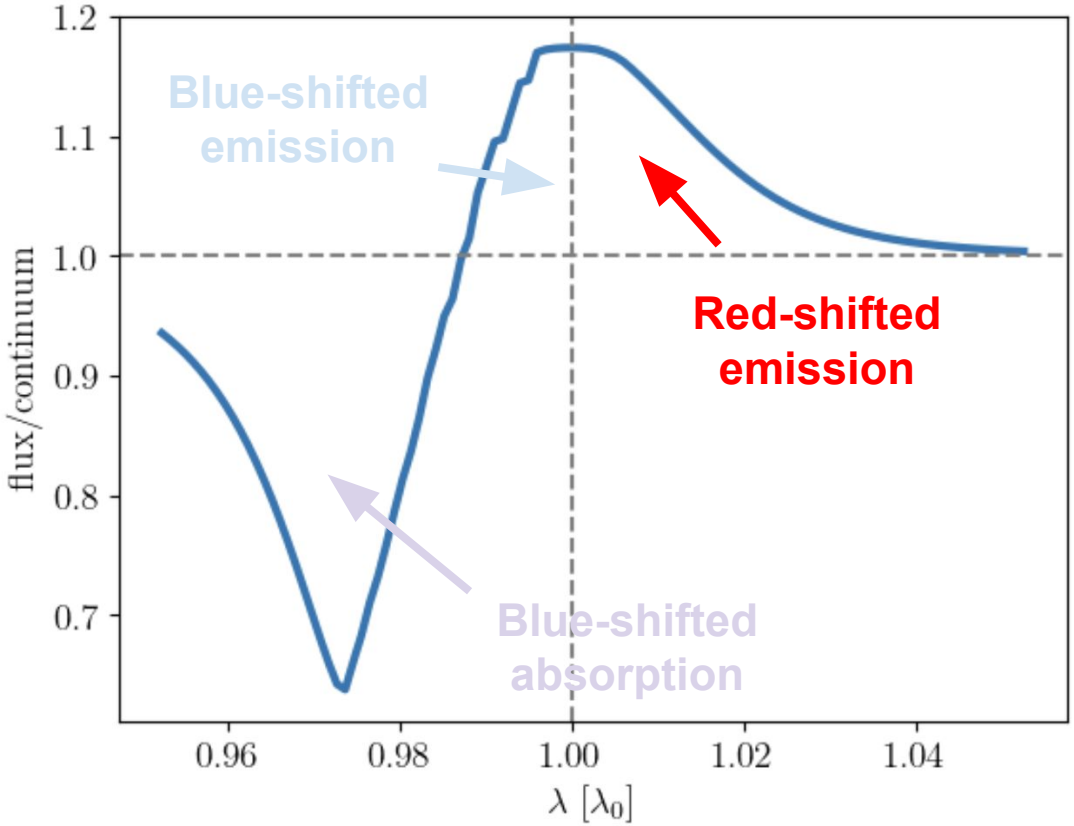

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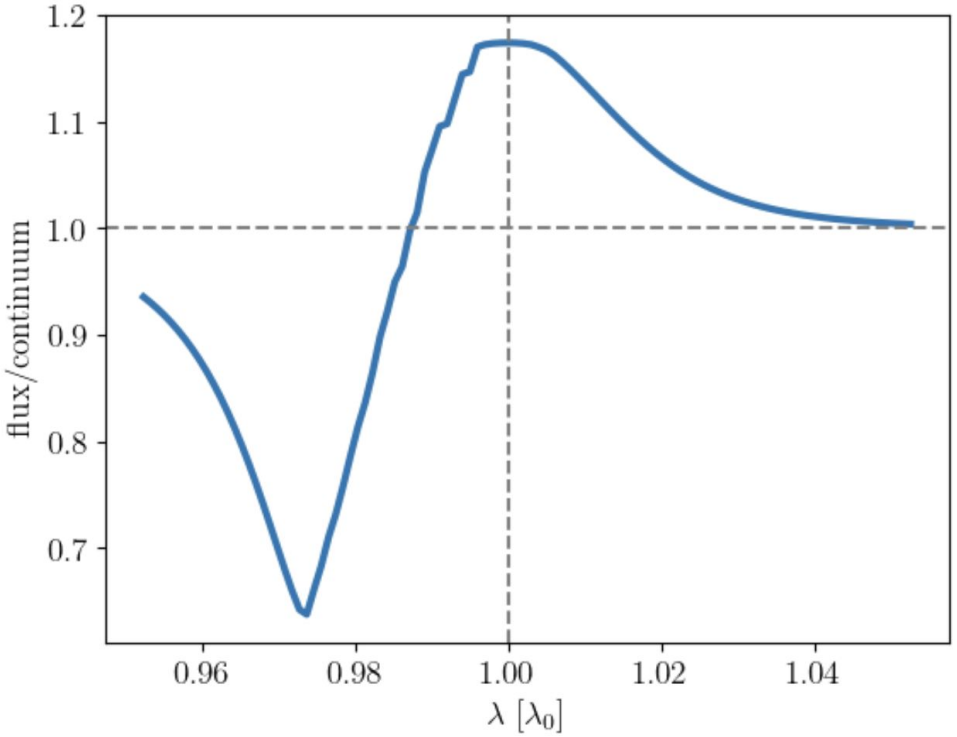


Gutiérrez et al. [10.3847/1538-4357/aa8f52](https://doi.org/10.3847/1538-4357/aa8f52)

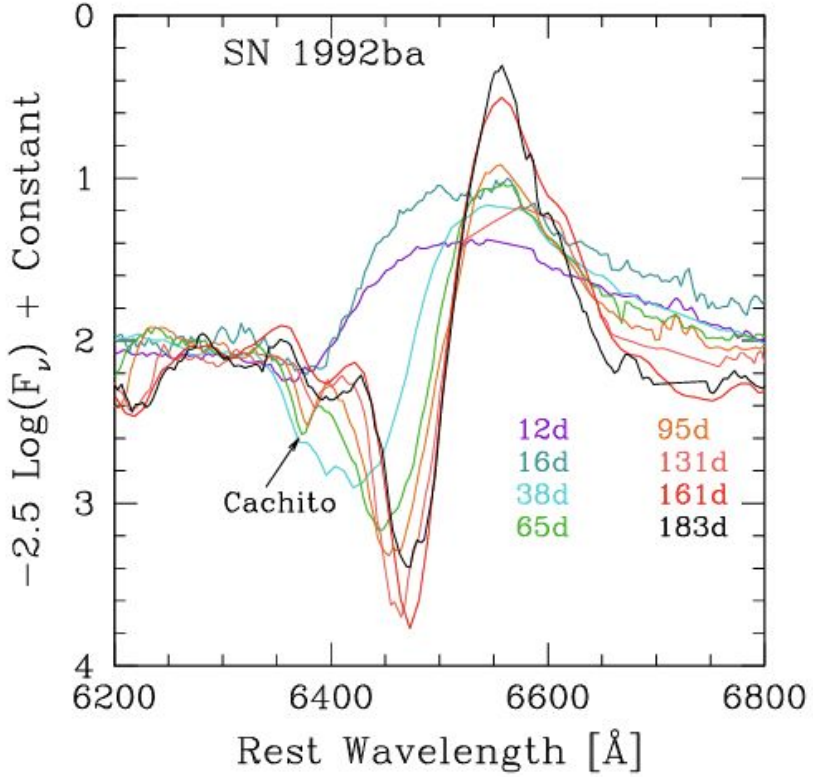
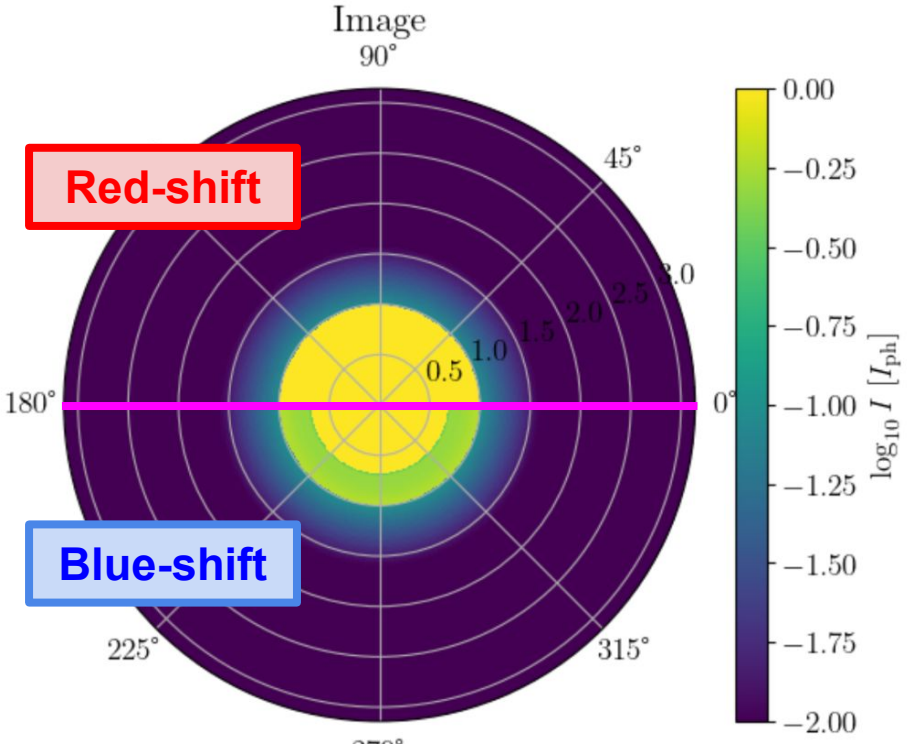
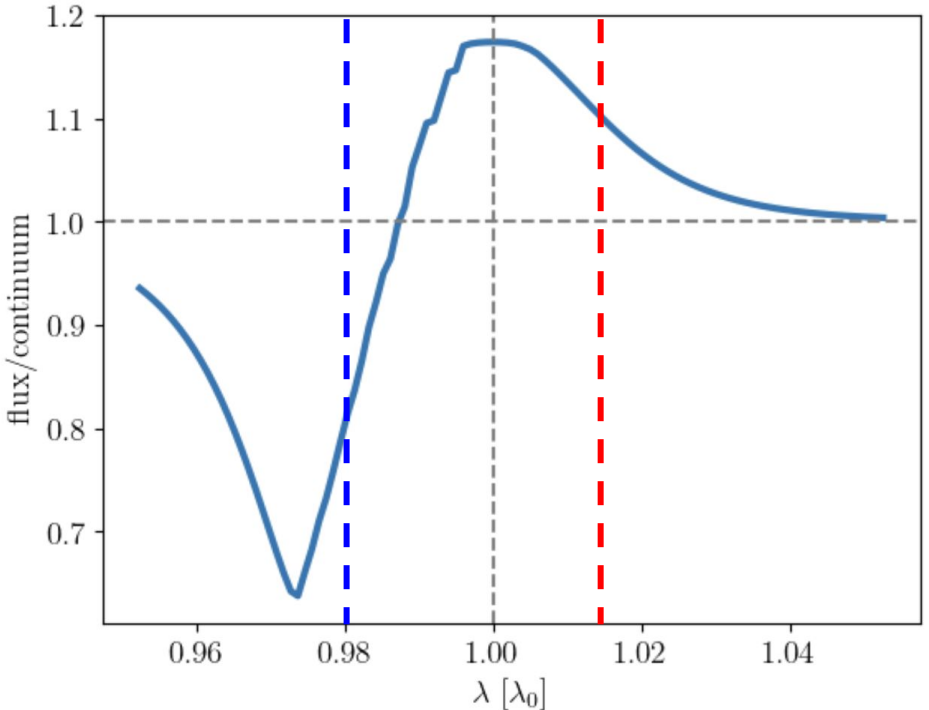


Figure 12. H_α P-Cygni profile evolution in SN 1992ba. The epochs are labeled on the right.

P Cygni Profile with Spatial Resolution

3D spatial distribution of ejecta: x, y (image plane), & λ (line-of-sight)





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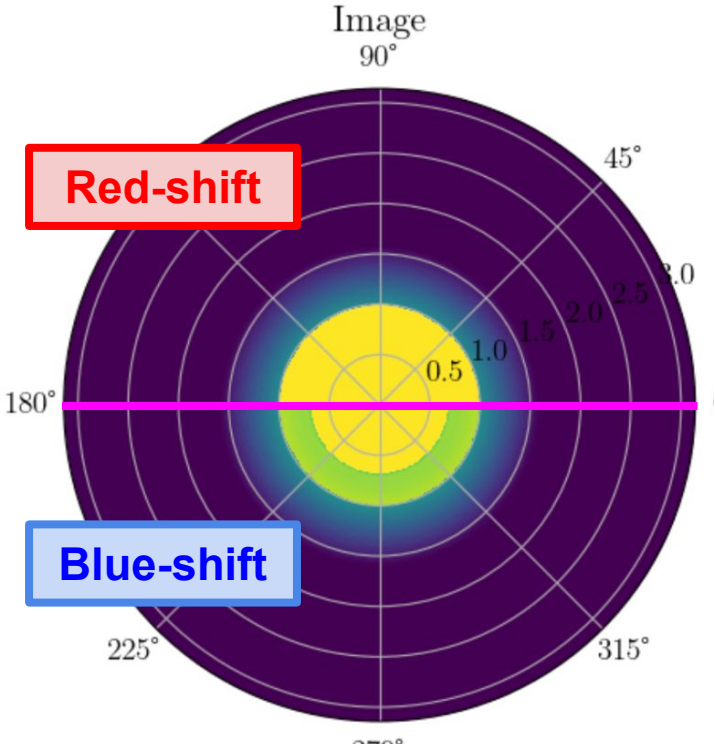

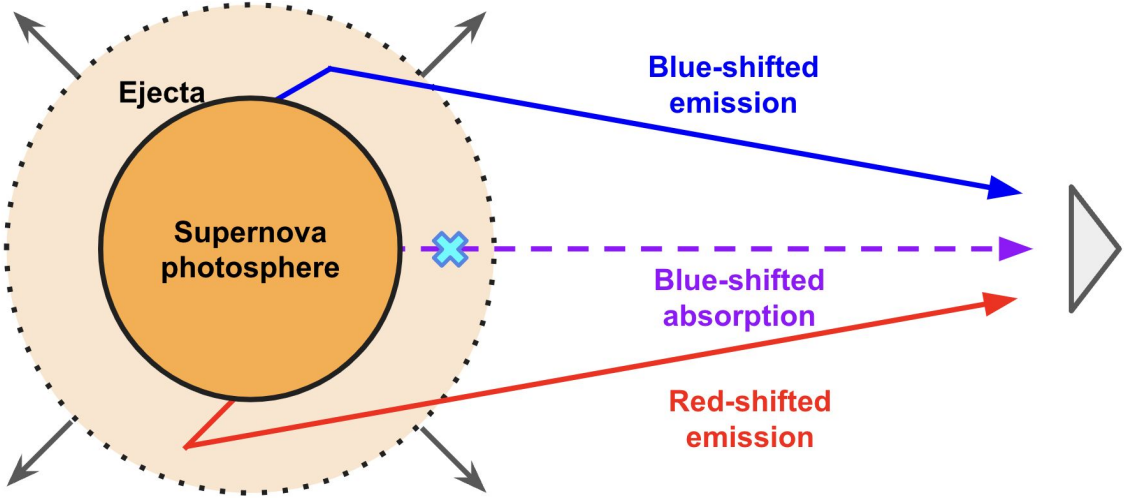

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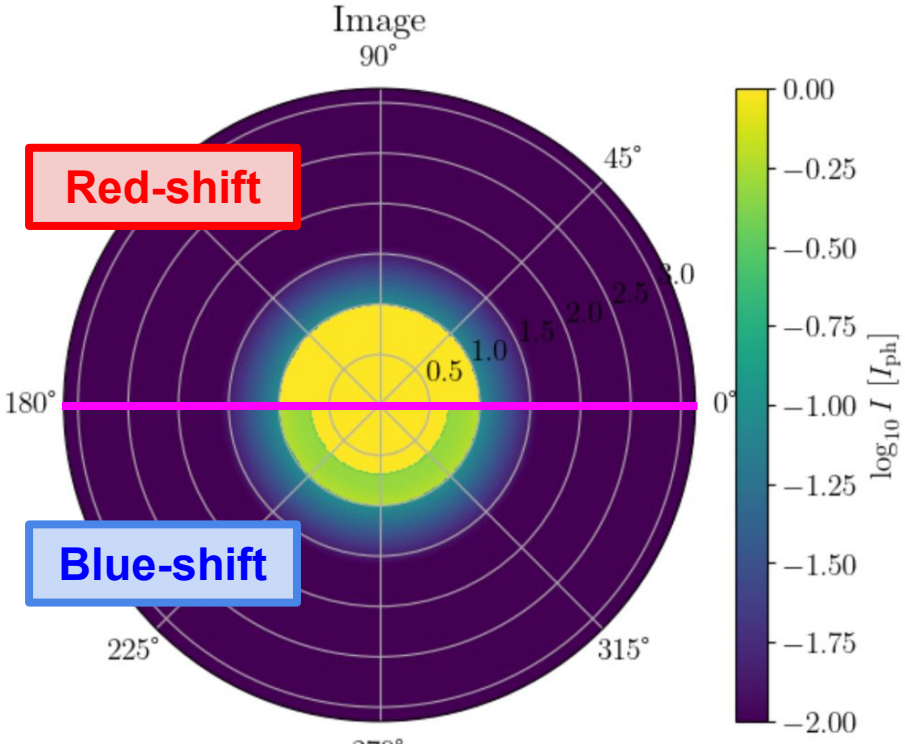
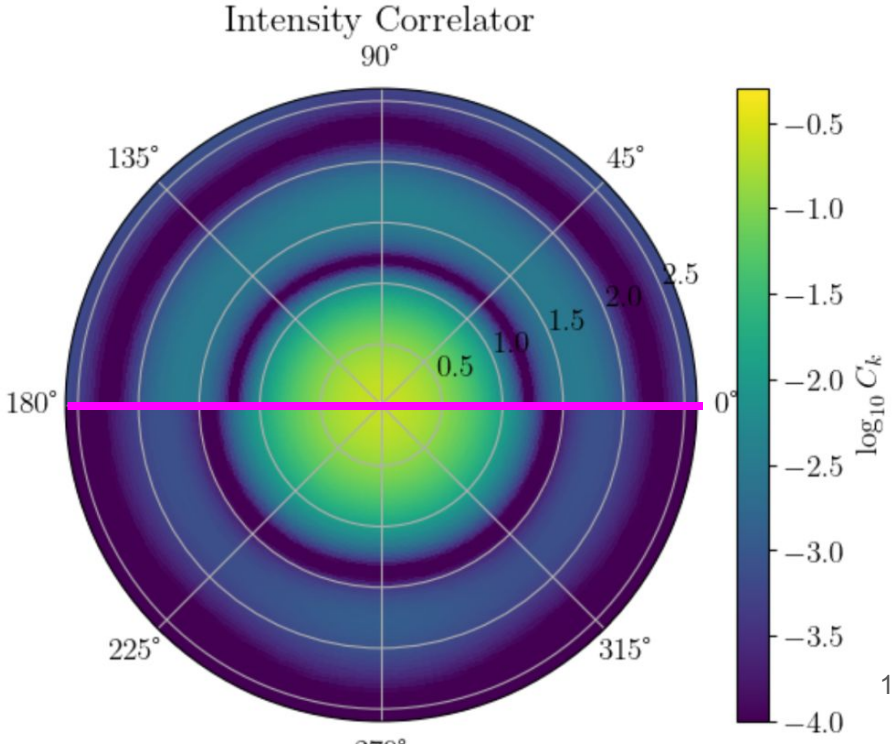
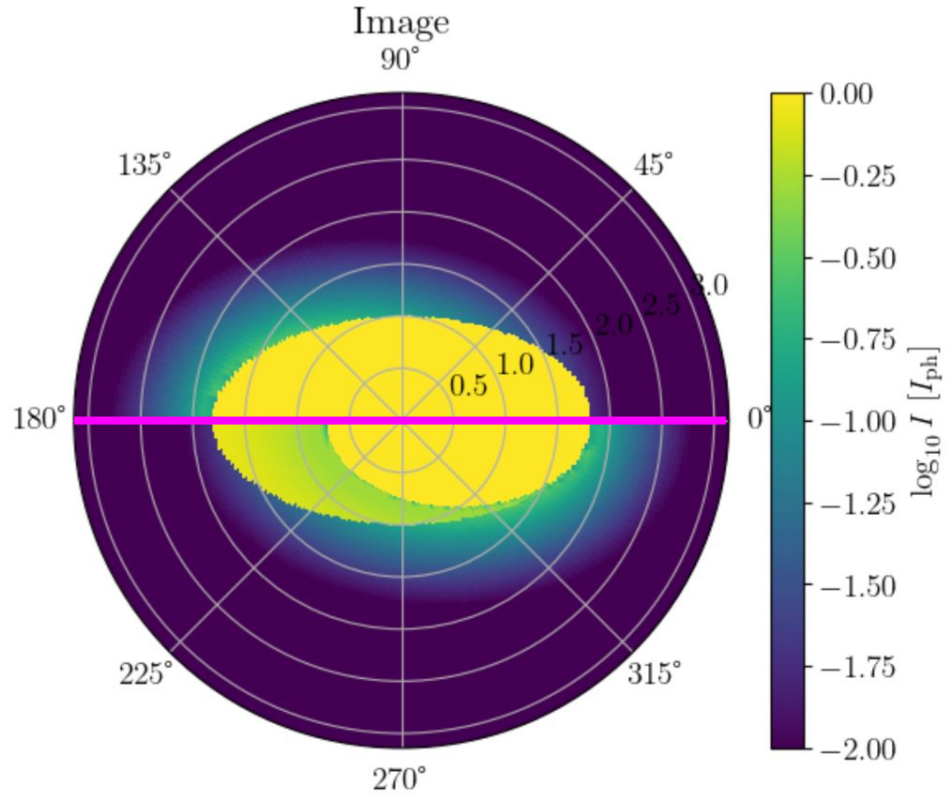
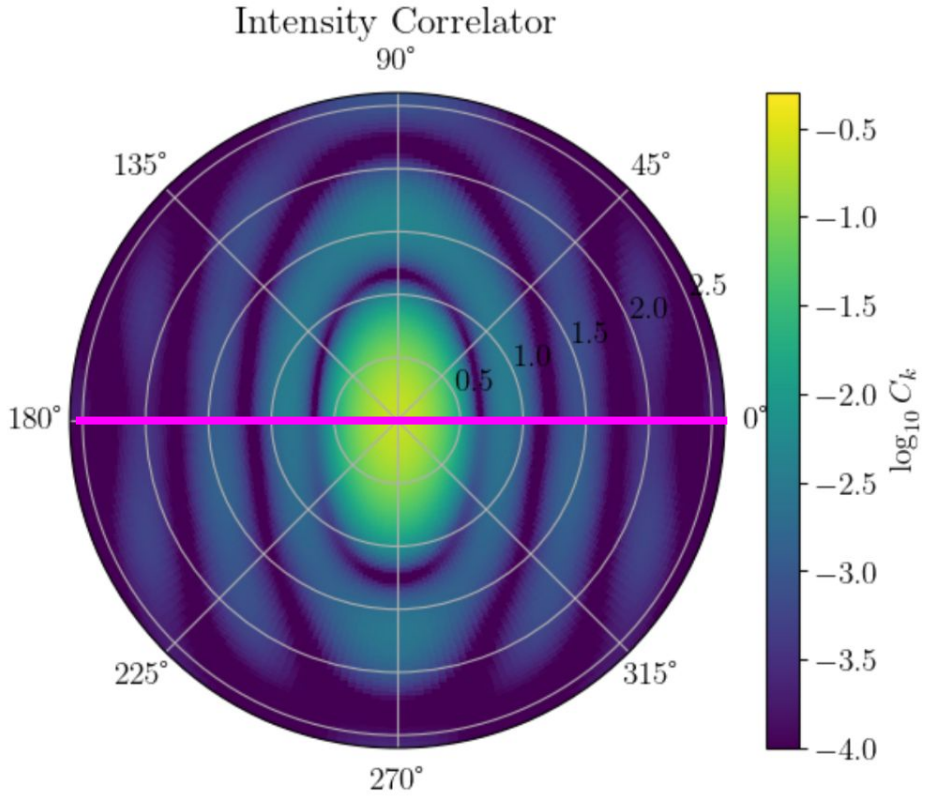




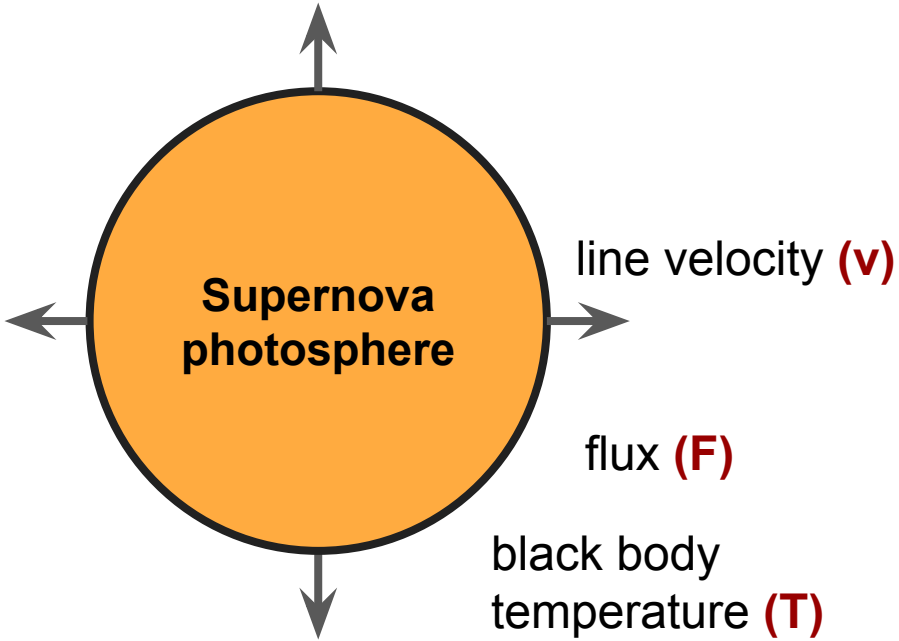
Supernova Morphology - Asymmetry





Measure Supernova Distances

History: Expanding Photosphere method (Baade 1926, Krishner & Kwan 1974)



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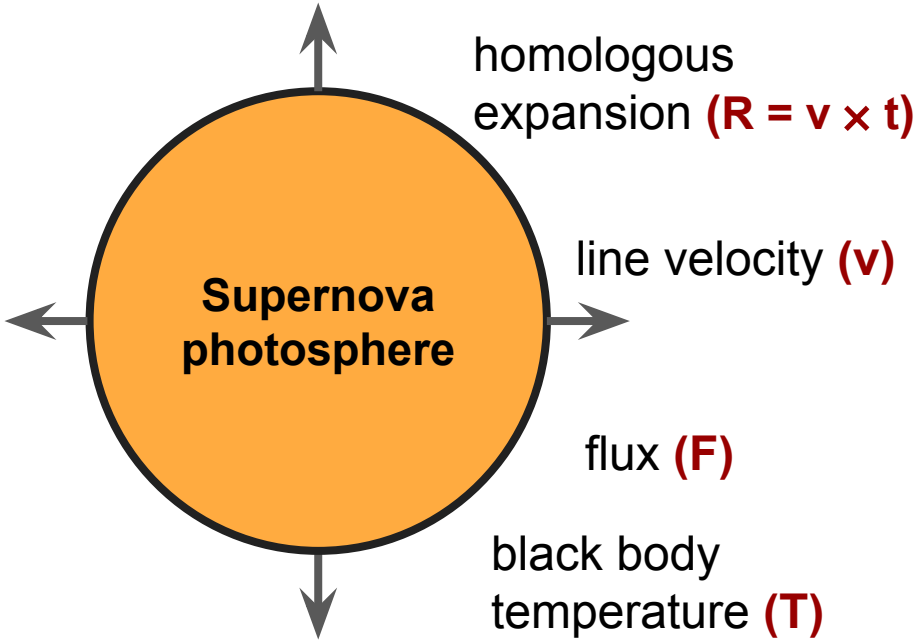

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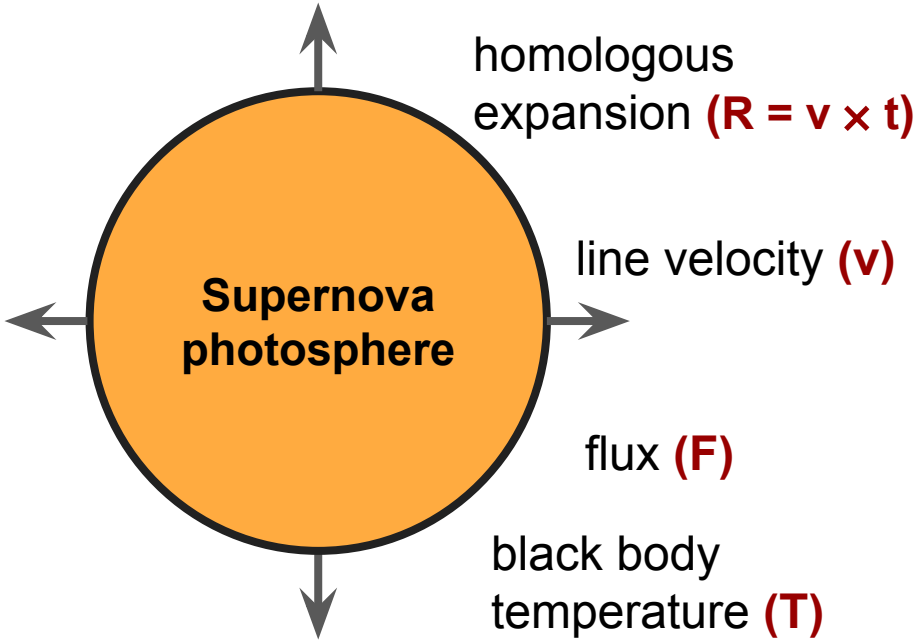


Derive:

- Luminosity Distance **(D_L)**
  $L = 4\pi R^2 \sigma T^4$
  $D_L^2 \sim L/F$

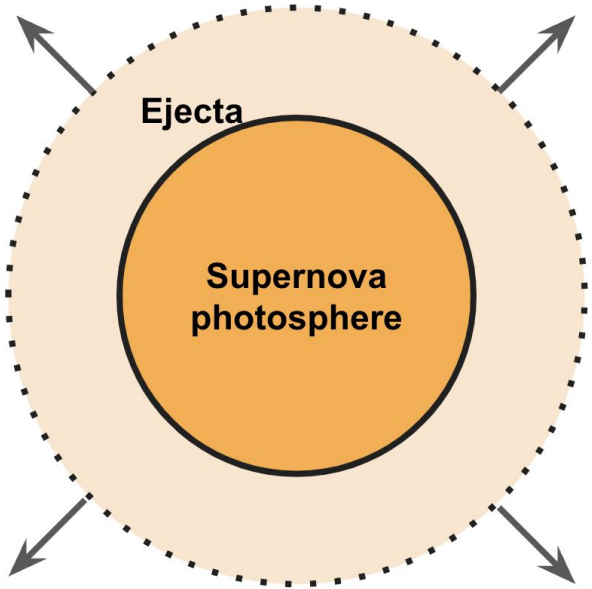
Systematic Uncertainties:

- Black body?
- Attenuation?
- Line emitting region = photosphere?

Intensity Interferometry: Expanding Ejecta Method

homologous
expansion **(R = v × t)**

line velocity **(v)**

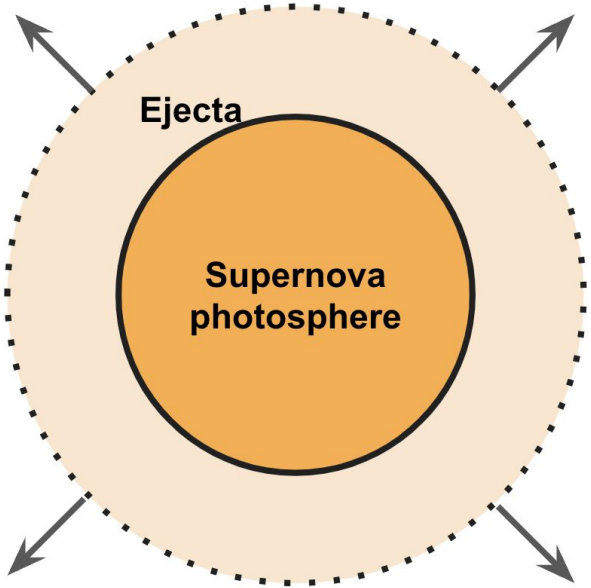


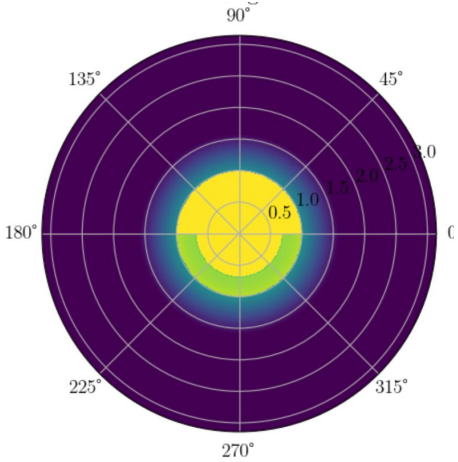
Intensity Interferometry: Expanding Ejecta Method

homologous expansion **(R = v × t)**

line velocity **(v)**

Angular size of the **line** producing region **(θ)**





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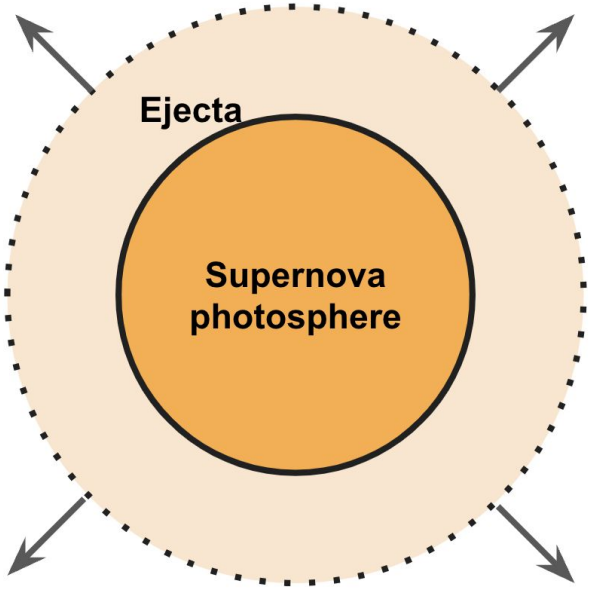

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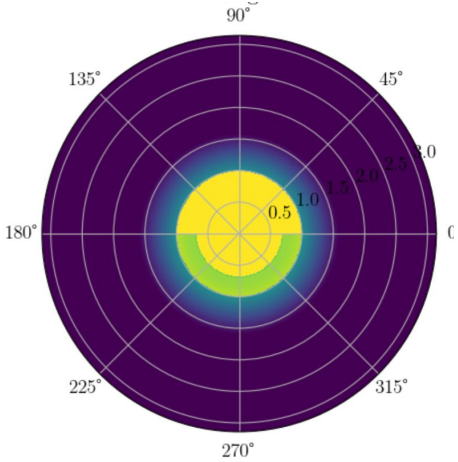
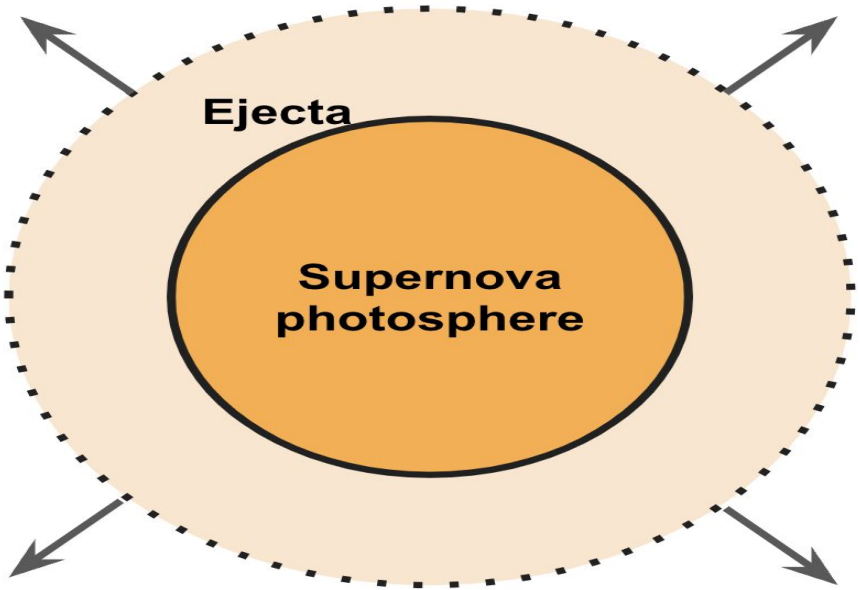


Derive:

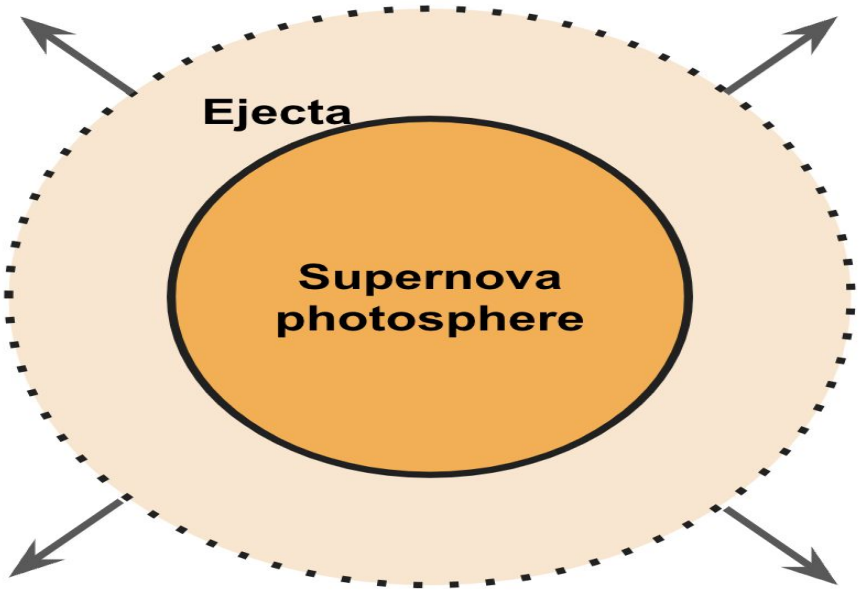
- Angular diameter distance **(D_A)**
  $D_A = v/\theta'$

Example: A Simple Ellipsoidal Supernova Model



Example: A Simple Ellipsoidal Supernova Model

v_0: velocity of ejecta @ photosphere



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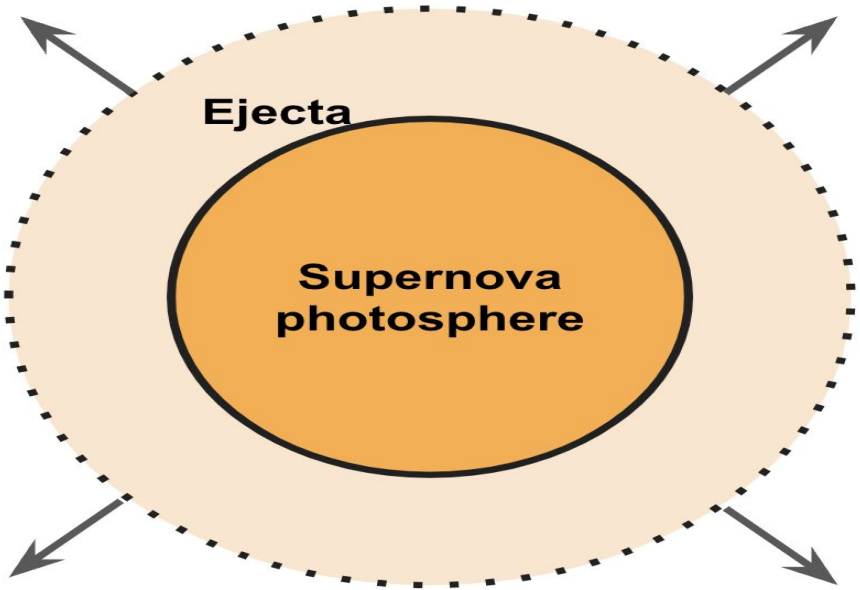

Line parameters

- τ_0: line optical depth @ photosphere
- **n**: spectral index of optical depth

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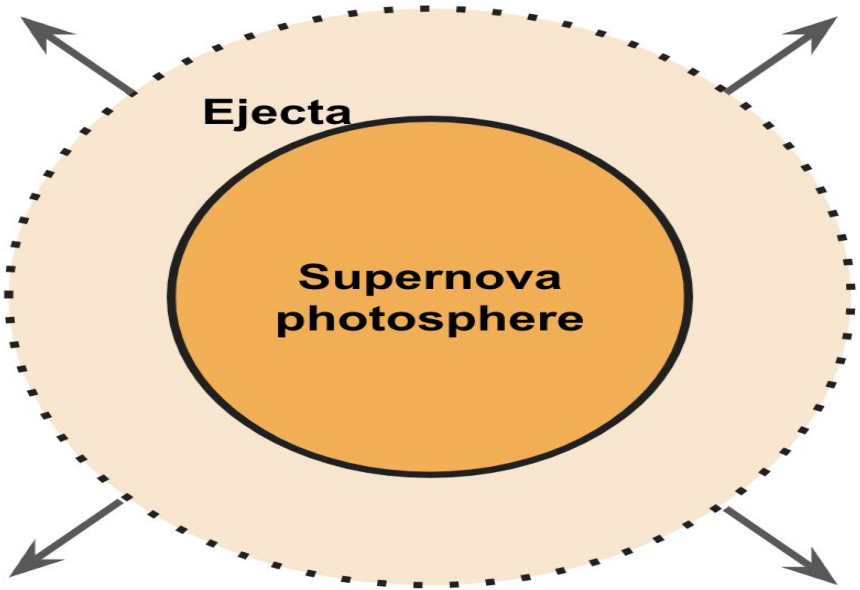


Line parameters

- τ_0: line optical depth @ photosphere
- n: spectral index of optical depth

Geometric parameters

- η: long-to-short axis ratio
- θ, φ: two Euler angles

Example: A Simple Ellipsoidal Supernova Model

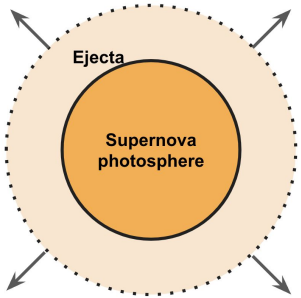
Parameters:

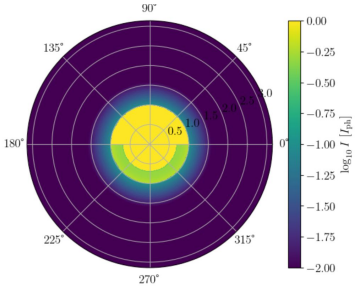
- $\mathbf{v_0}$: velocity of ejecta @ photosphere
- $\boldsymbol{\tau_0}$: line optical depth @ photosphere
- **n**: spectral index of optical depth as a function of distance to photosphere
- **D**: distance
- η: long-to-short axis ratio
- $\boldsymbol{\theta}$, $\boldsymbol{\varphi}$: two Euler angles

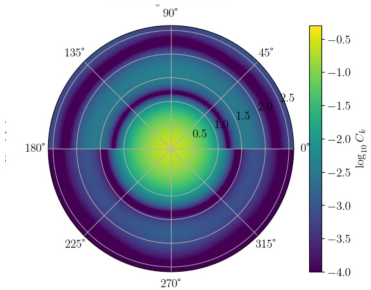
Two other spectral parameters:

- **T**: black body temperature
- **norm**: scaling of spectrum accounting for attenuation

Analysis Pipeline







Supernova Parameters

Simple Model

Image

Fourier Transform

Intensity Correlator

MCMC

Parameter Inference

Fisher Information

Uncertainty Estimates

Scenario: A Type II-P Supernova @ Plateau Phase

- **Parameter evolution:**
  - Photosphere location: constant
  - Homologous expansion: $v_0 \sim t^{-1}$
  - $\tau_0 \sim t^{n-2}$
- **Measured @ 3 different time point**

n = 4	30 days	45 days	60 days
v_0	6,000 km/s	4,000 km/s	3,000 km/s
τ_0	2.0	4.5	8.0

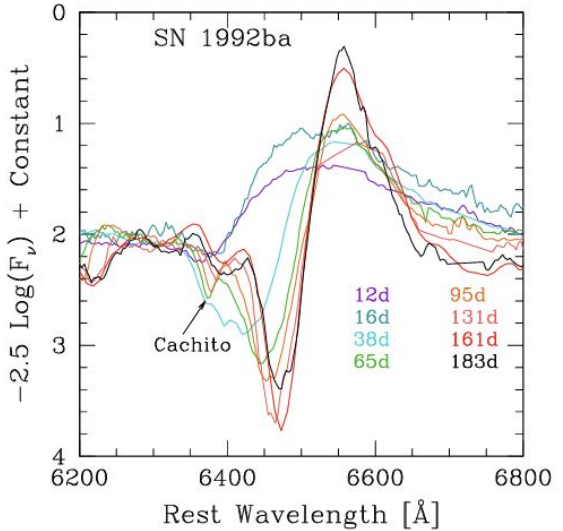


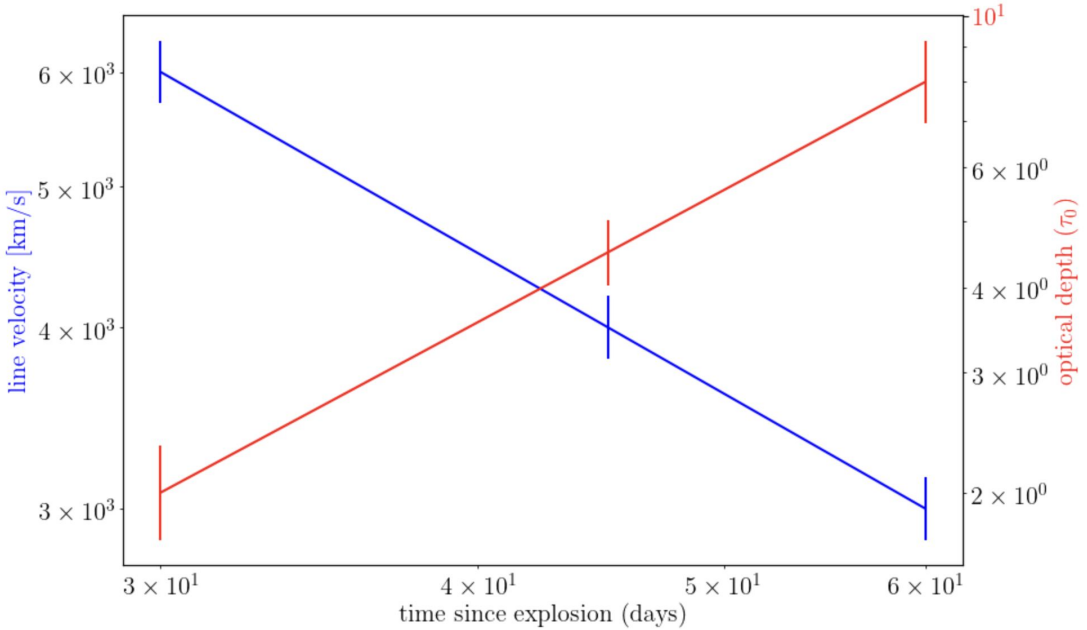
Figure 12. H_α P-Cygni profile evolution in SN 1992ba. The epochs are labeled on the right.

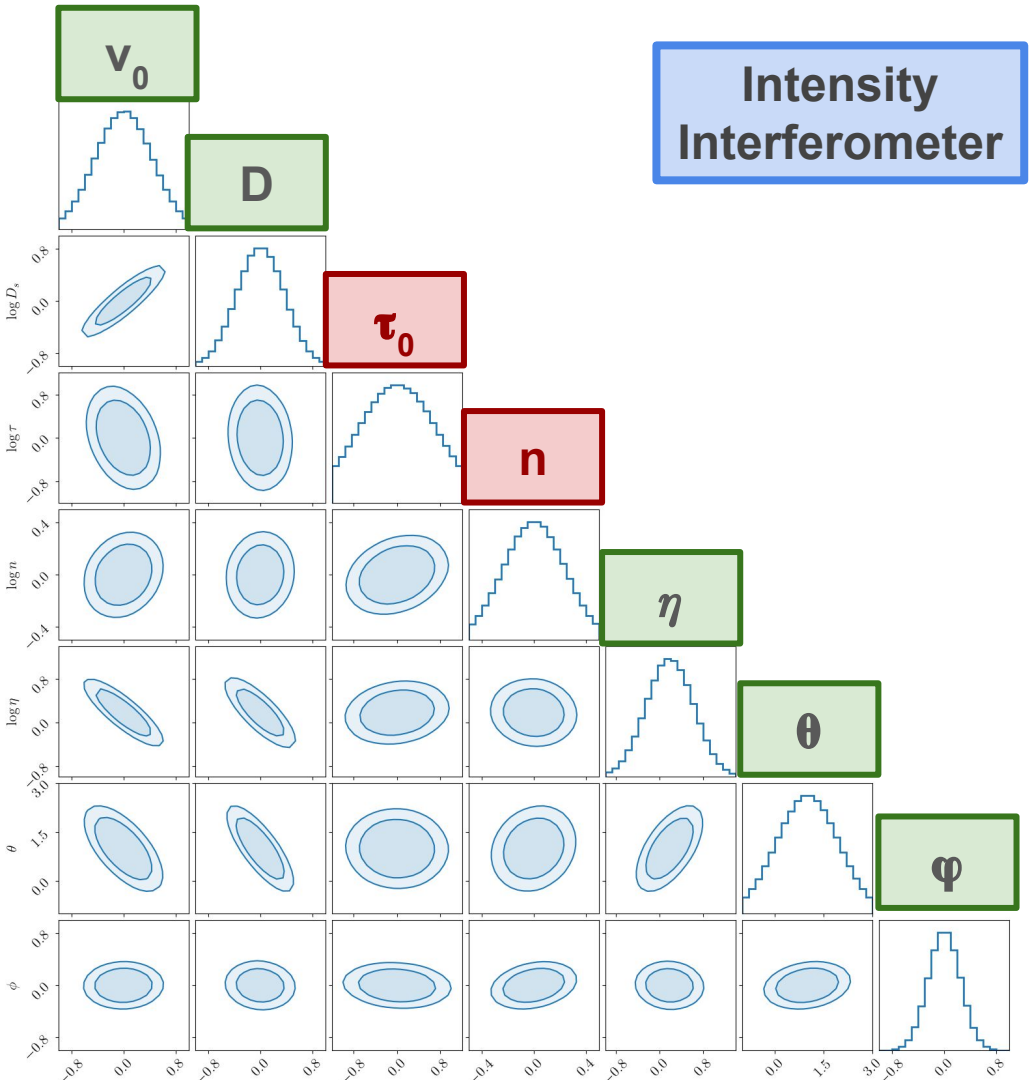
Gutiérrez et al.
10.3847/1538-4357/aa8f52

Scenario: A Type II-P Supernova @ Plateau Phase

Fisher information with intensity interferometer + spectrum:

- Supernova:
  - M = -16.0
  - D = 1 Mpc, m = 9.5
- Interferometer parameters:
  - σ_t = 10 ps
  - R_{spec} = 10^4
  - 1000 channels
  - Diameter = 10 m
  - SNR ~ 5 per channel
  - T_{obs} = 6 hrs





Intensity Interferometer

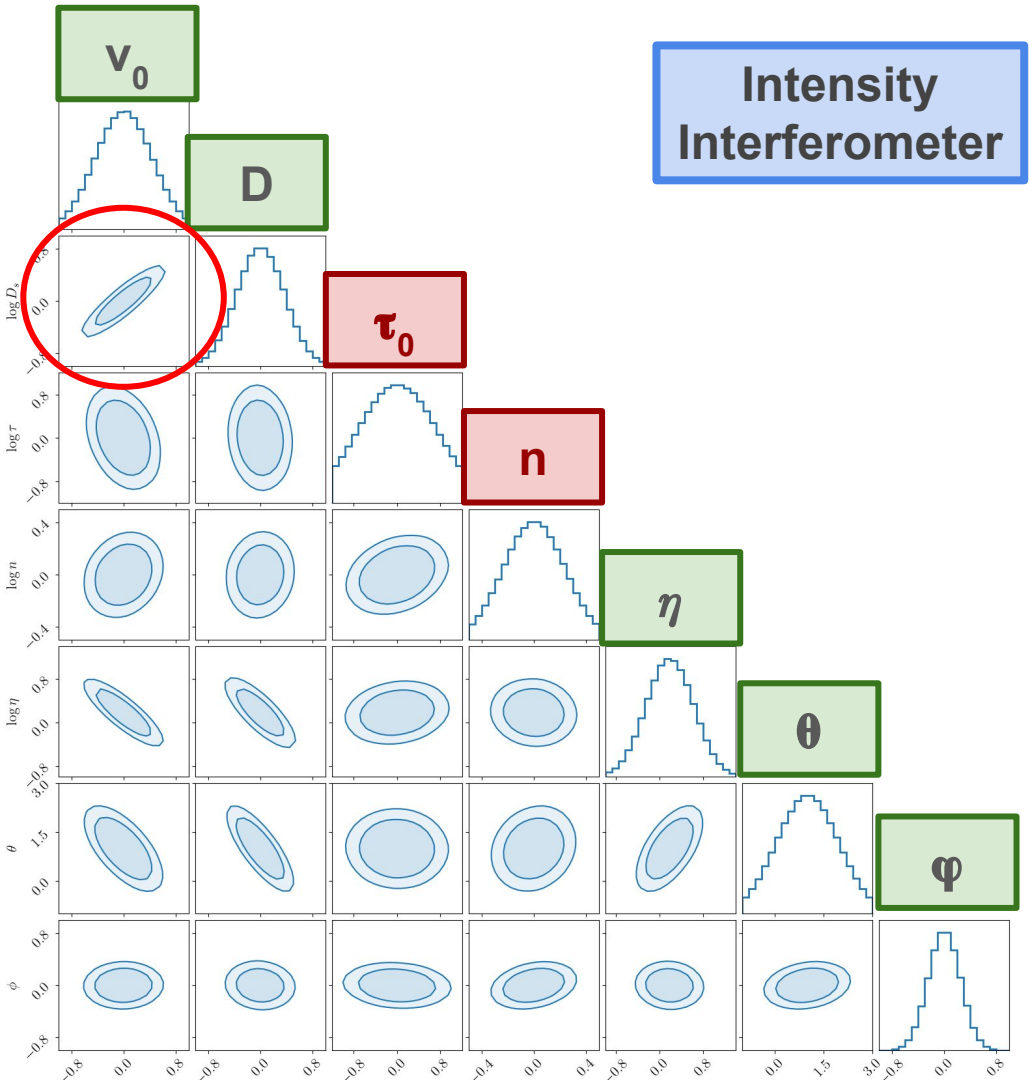
Scenario

Fisher information with intensity interferometer

- Intensity interferometer measures angular size well **(v_0/D)**

Geometric parameters

Line profile parameters



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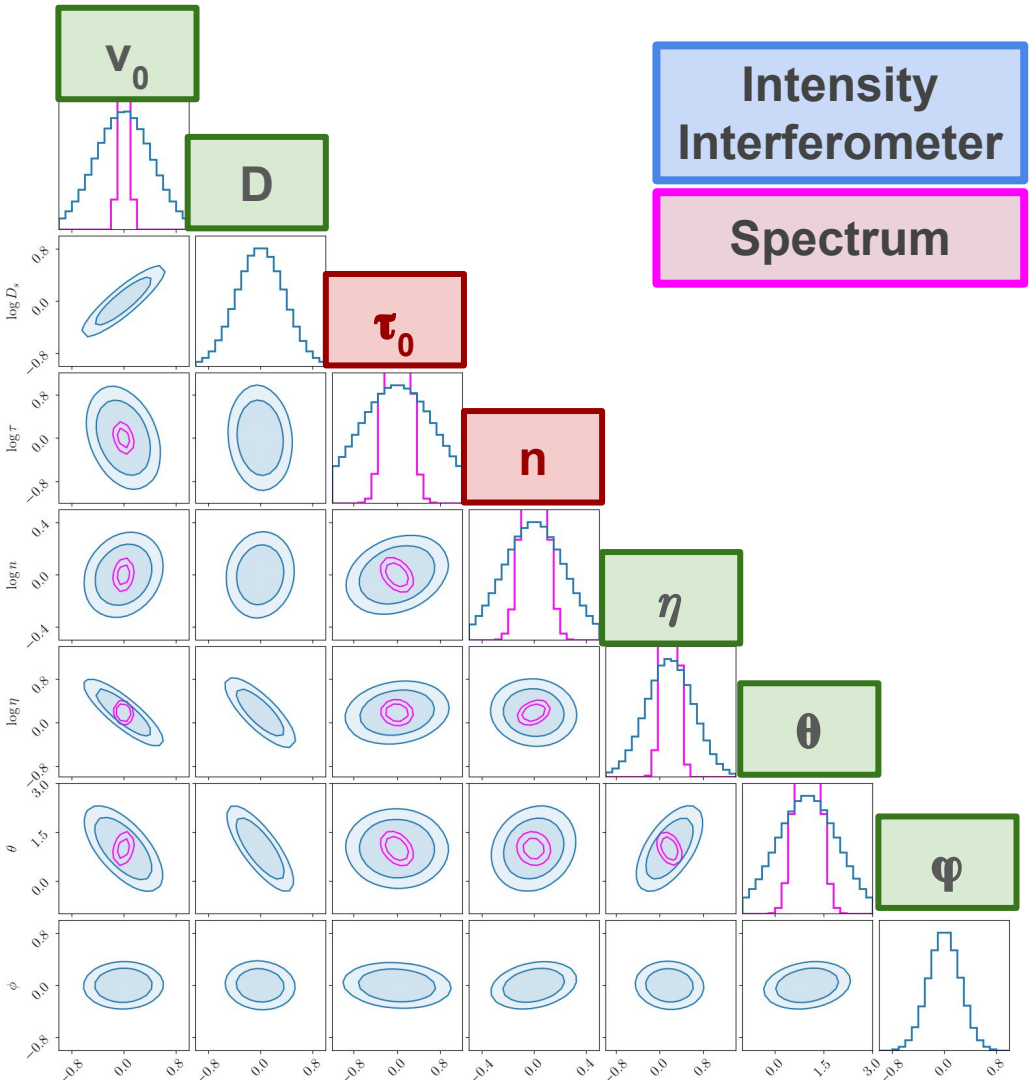
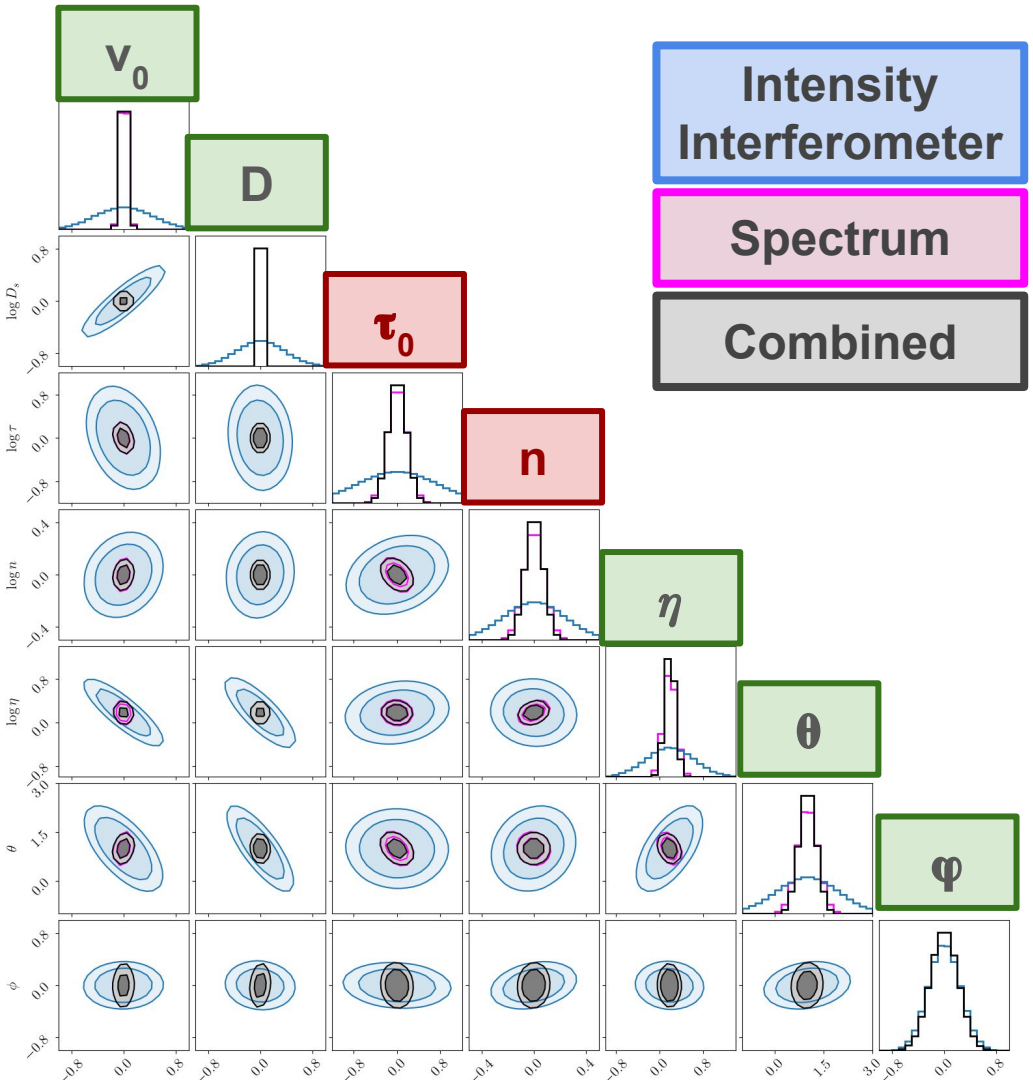


Scenario

Fisher information with intensity interferometer & spectrum:

- Spectrum gives better measurement on some parameters **(v0, τ0, n, η, θ)**
- Spectrum give no information about **distance** and **φ**

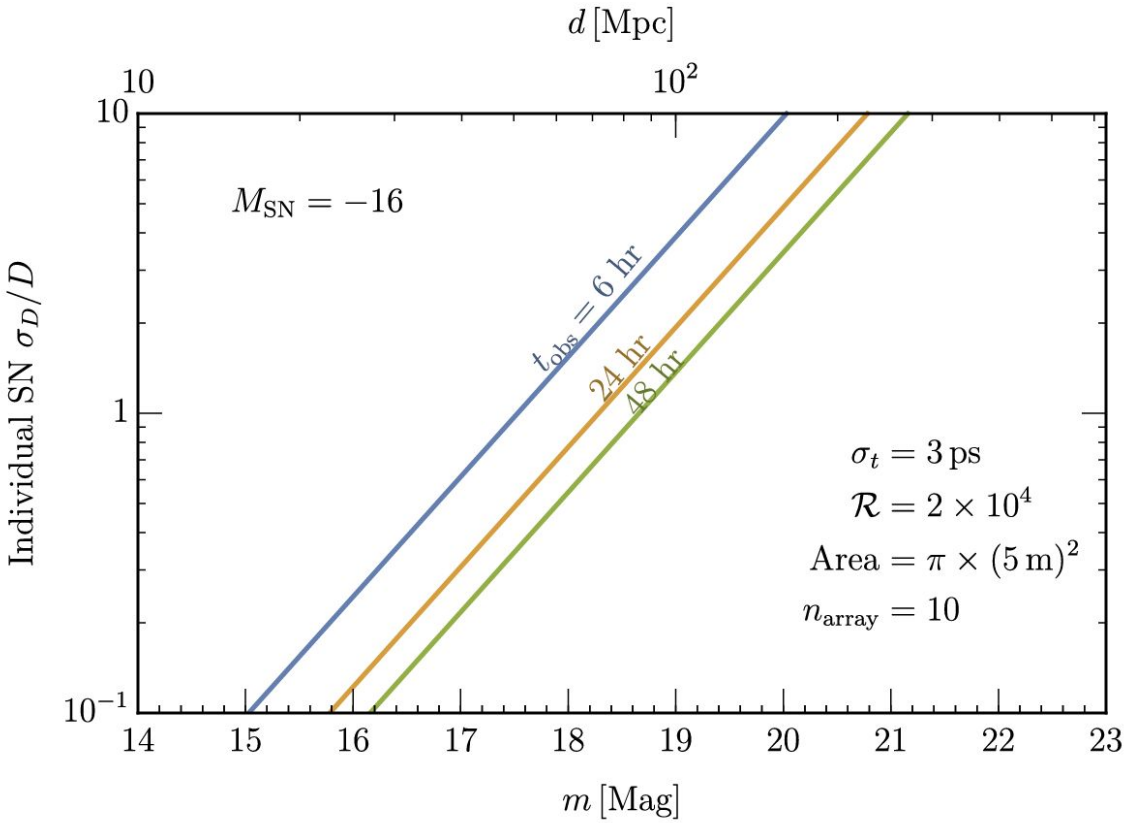


Scenario

Fisher information with intensity interferometer & spectrum:

- Combine intensity interferometry & spectrum give better distance measurement on fainter supernovae

Results: Hubble Measurement (bright SN)

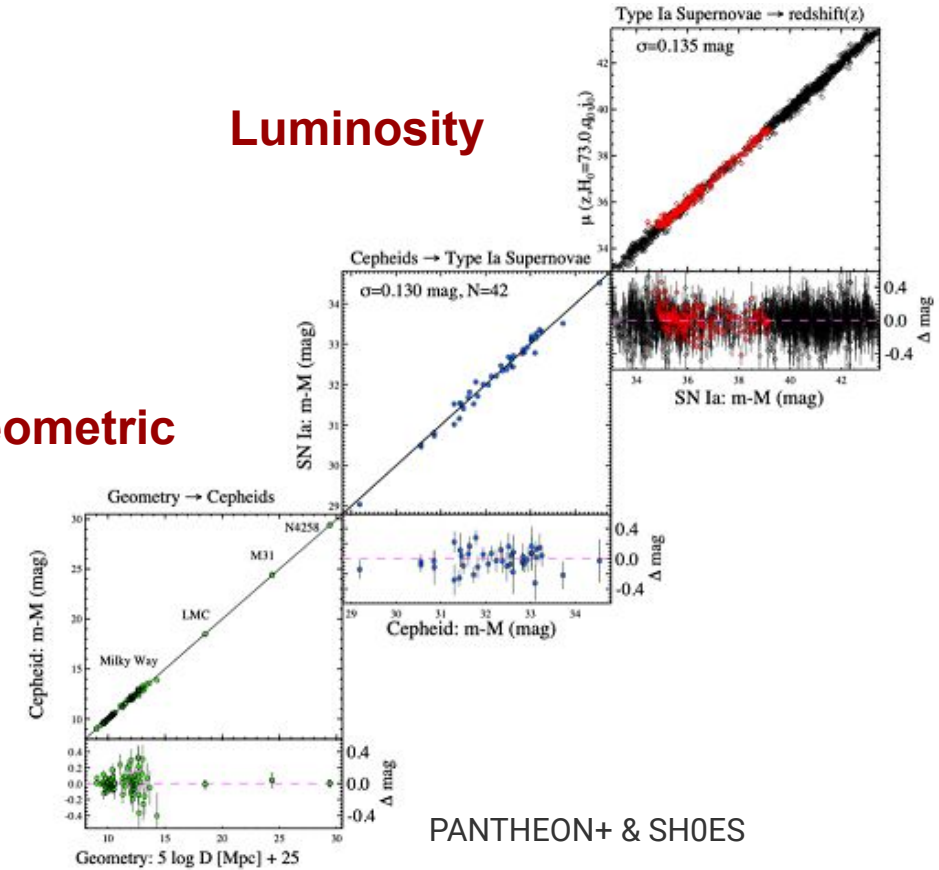


- Measure distance of the brightest SN to ~1% with a few night of exposure
- Calibrate the distance ladder with bright SN

Results: Hubble Measurement (bright SN)

Luminosity

Geometric



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PANTHEON+ & SH0ES

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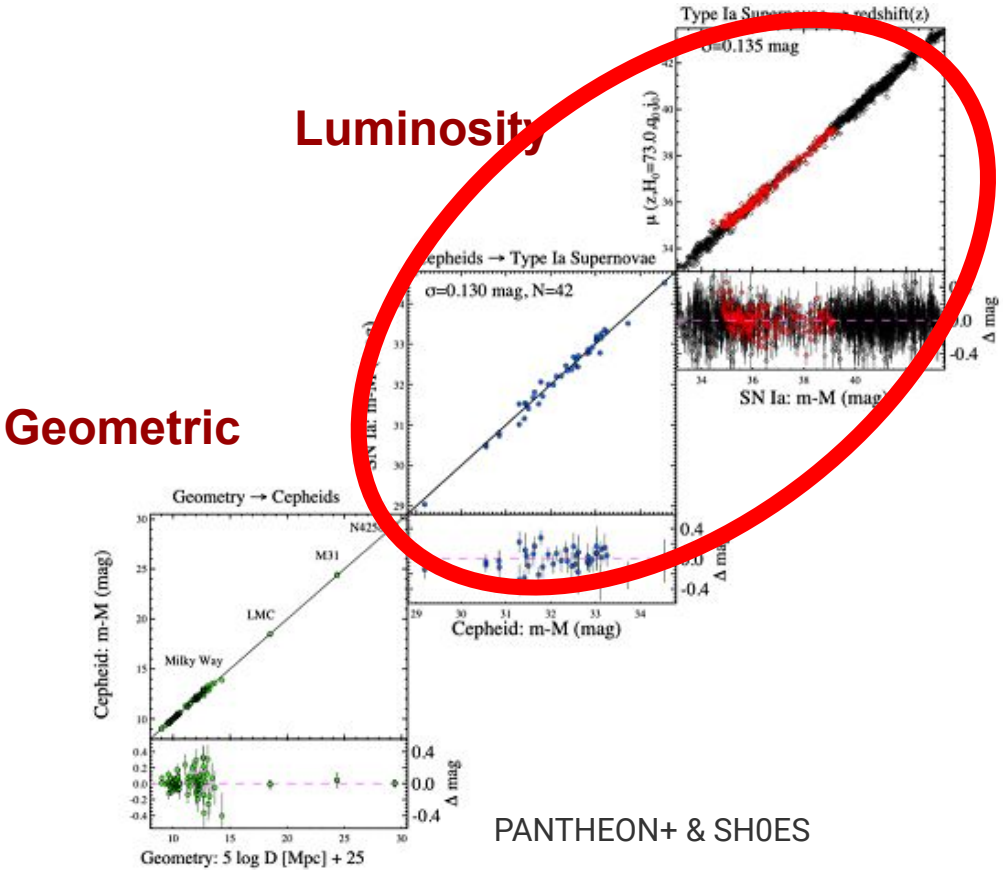

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PANTHEON+ & SH0ES

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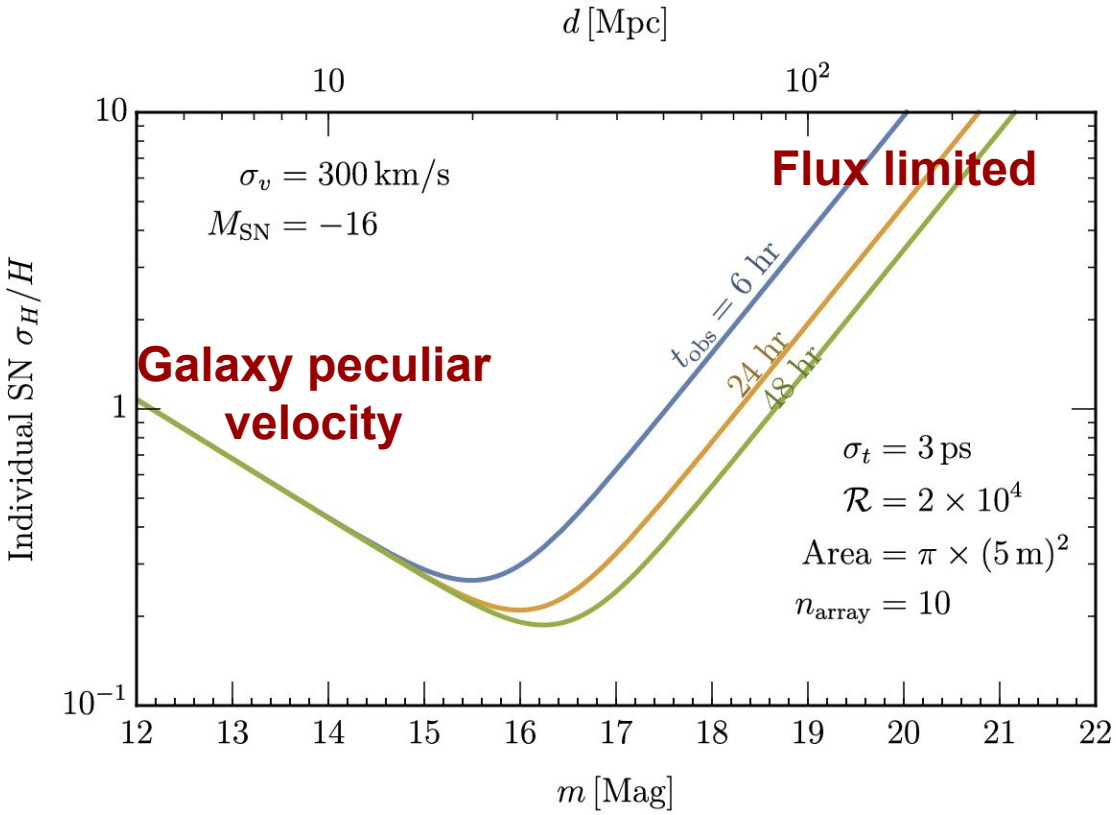
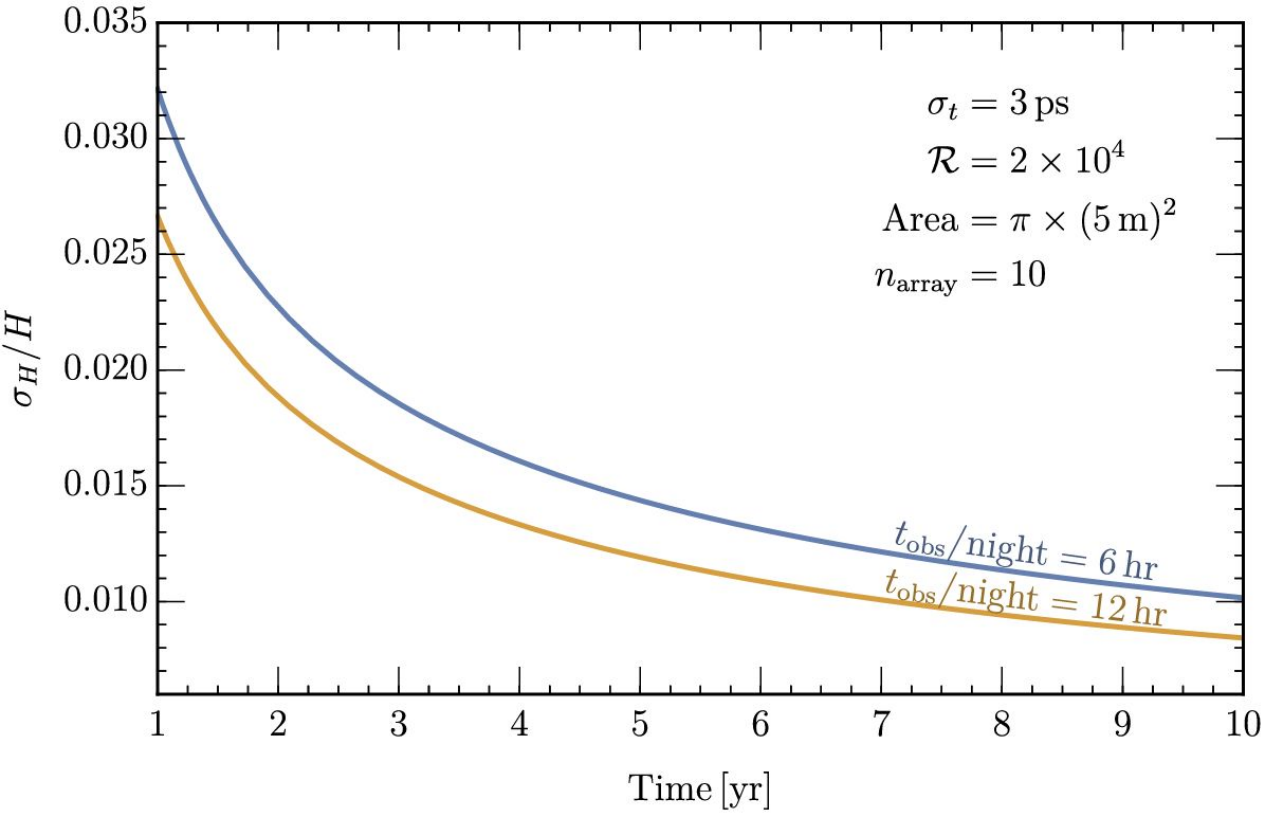


Optimal observation strategy based on SN occurance

Results: Hubble Measurement (standard candle free)



Measure Hubble to ~1% with a decade of operation (independent of distance ladder)

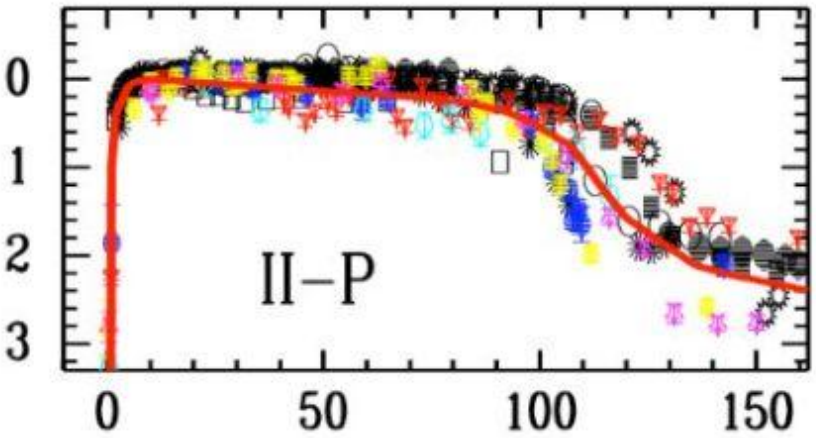
Summary

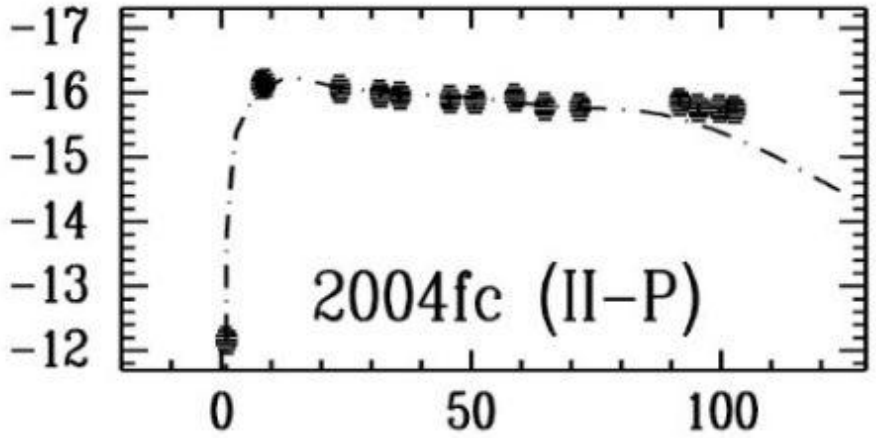
- Learn about ejecta, photosphere shape and property of spectrum
- Bright supernova distance to calibrate “standard candles”
- Distance ladder free hubble measurement

Summary

- **Intensity Interferometry measures the spatial distribution of supernova ejecta**
  - Supernova shape
  - Angular diameter distance
- **We built a analysis pipeline to demonstrate the measurement**
  - ~1% distance measurement to bright supernova
  - ~1% Hubble measurement with a few years of operation

Light curve of II-P





Optimal observation strategy of SN for Hubble