The Reverse Shock of SNR 1987A

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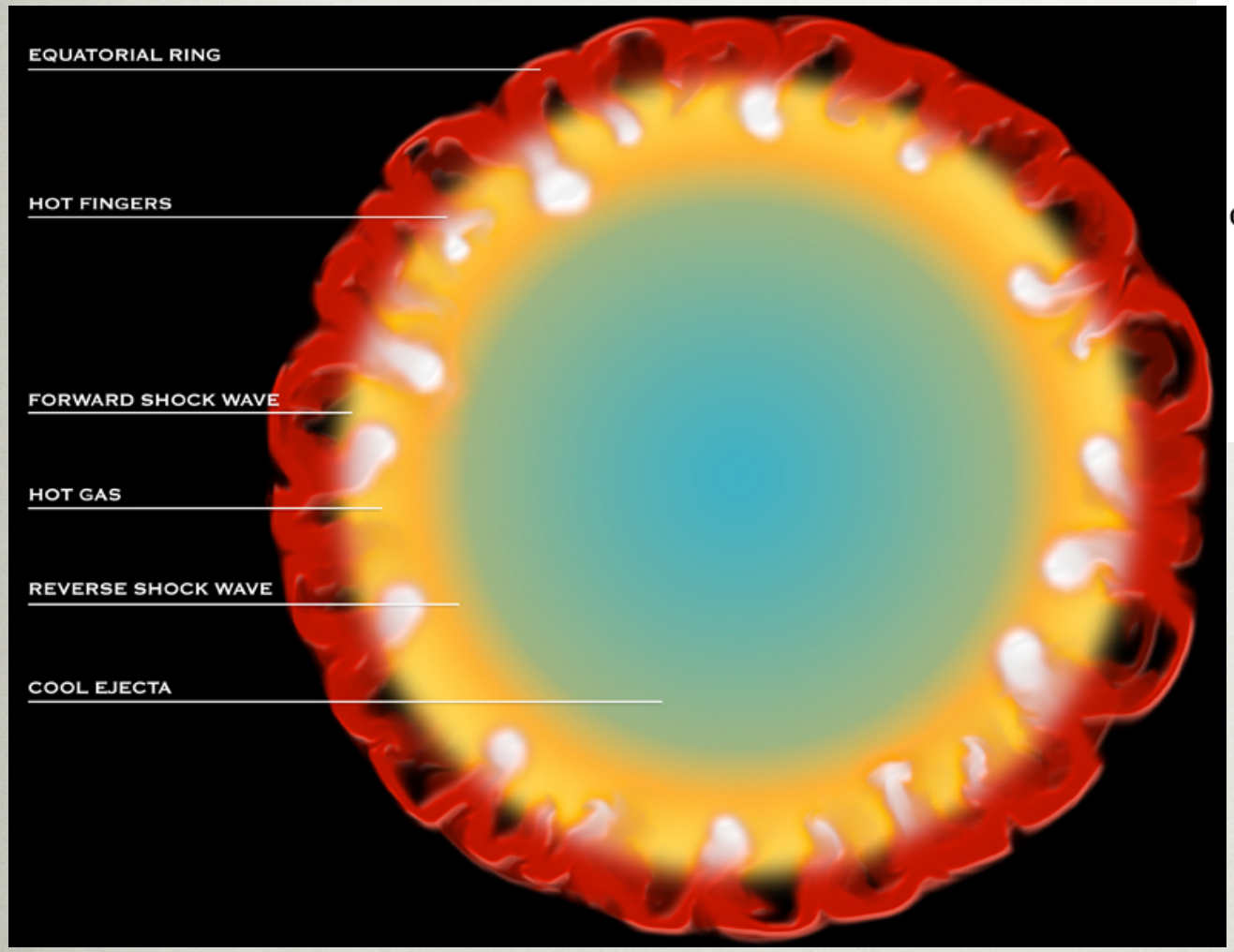
JILA
NIST CU

Overview

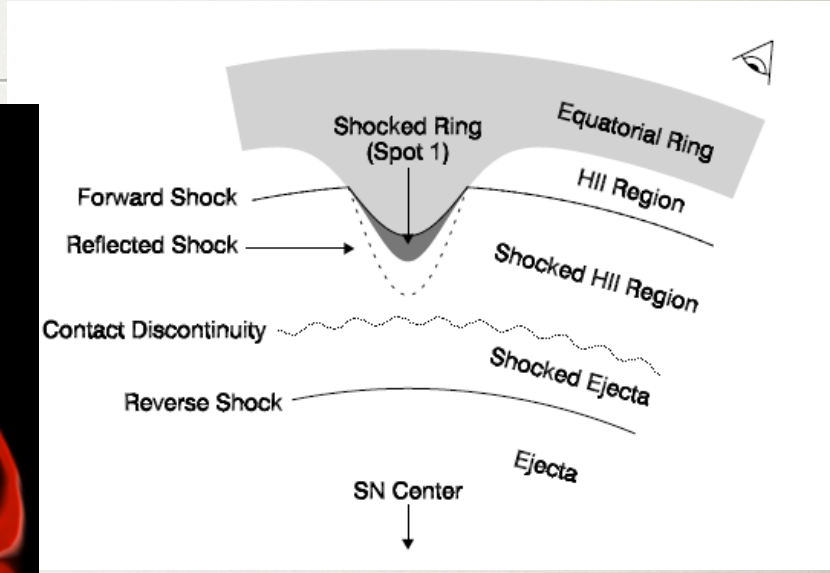
- SNR 1987A
- Balmer-Dominated Supernova Remnants
- Summary

SNR 1987A

The Double Shock Structure



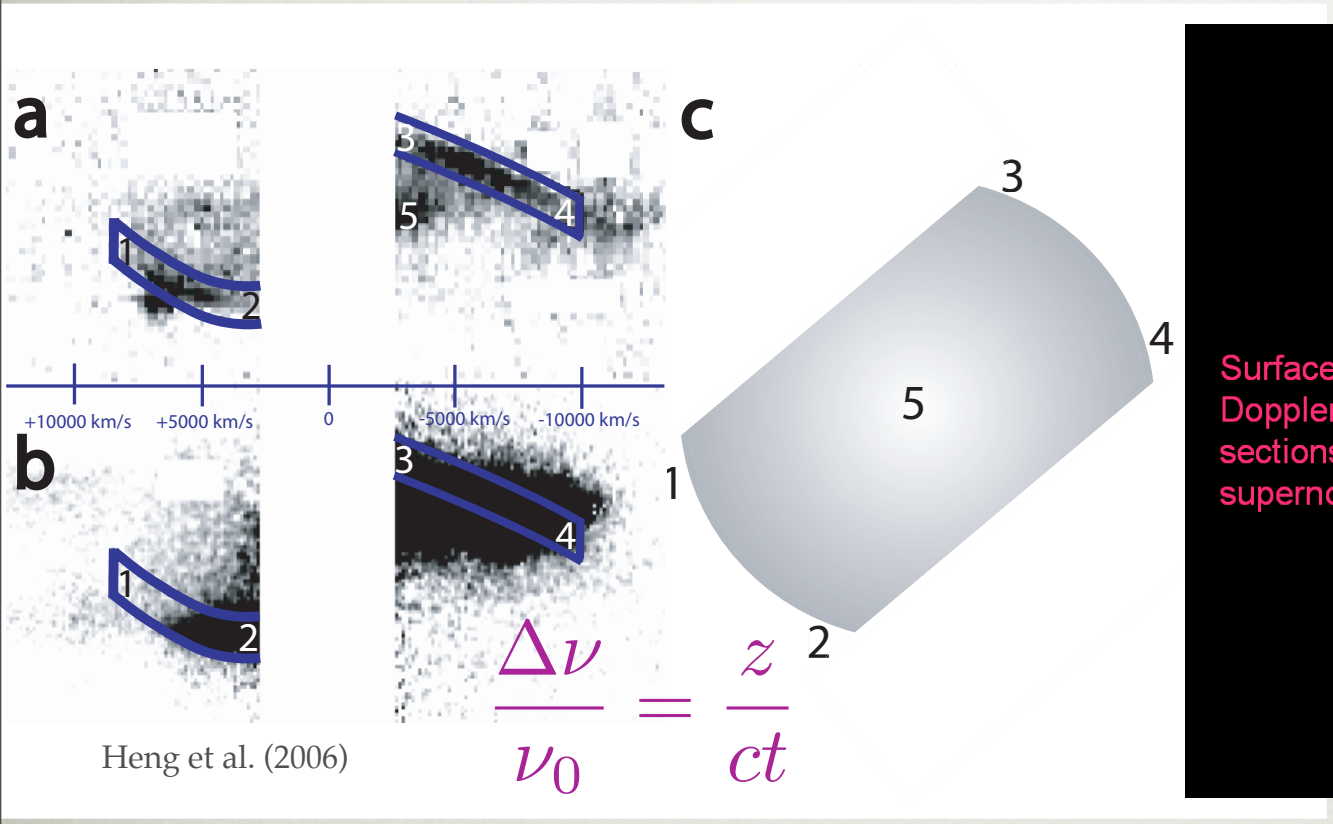
Courtesy of Dick McCray and Chandra Press Release Team



Pun et al. (2002)

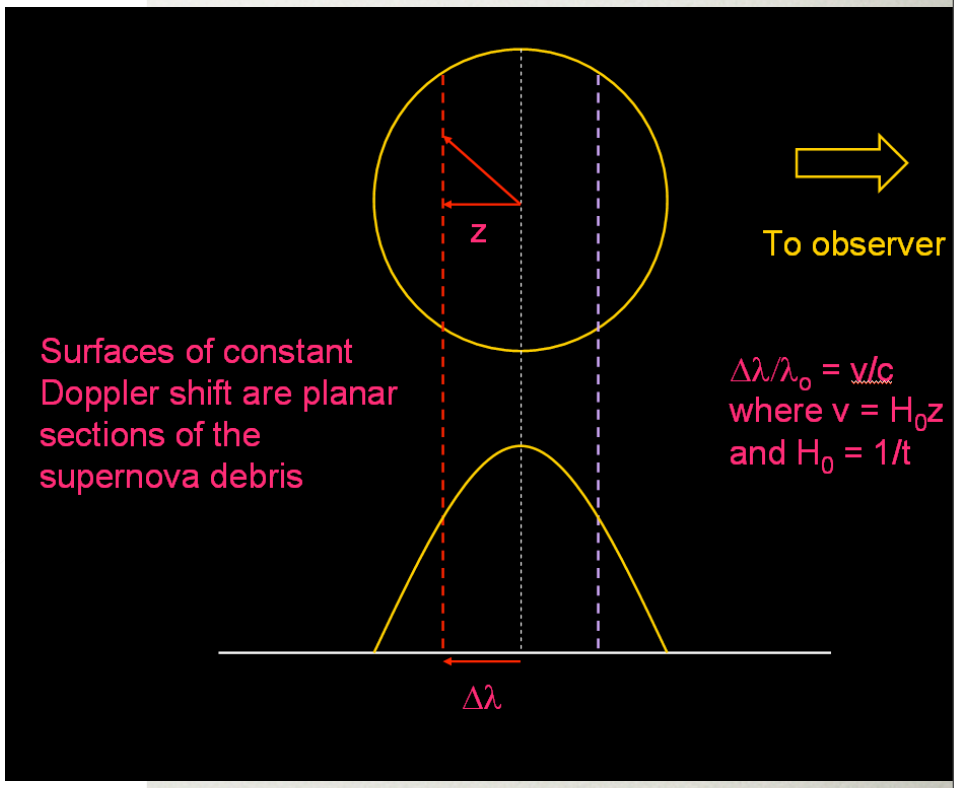
- High velocity debris crosses the reverse shock at ~ 12,000 km s^{-1}.
- "Shock velocity": freely-streaming hydrogen atoms in the rest frame of the reverse shock (~ 8000 km s^{-1}).
- Post-shock ions: ~ 2000 km s^{-1}.
- Key point: fast atoms, slow ions.

Surface vs. "Interior" Emission



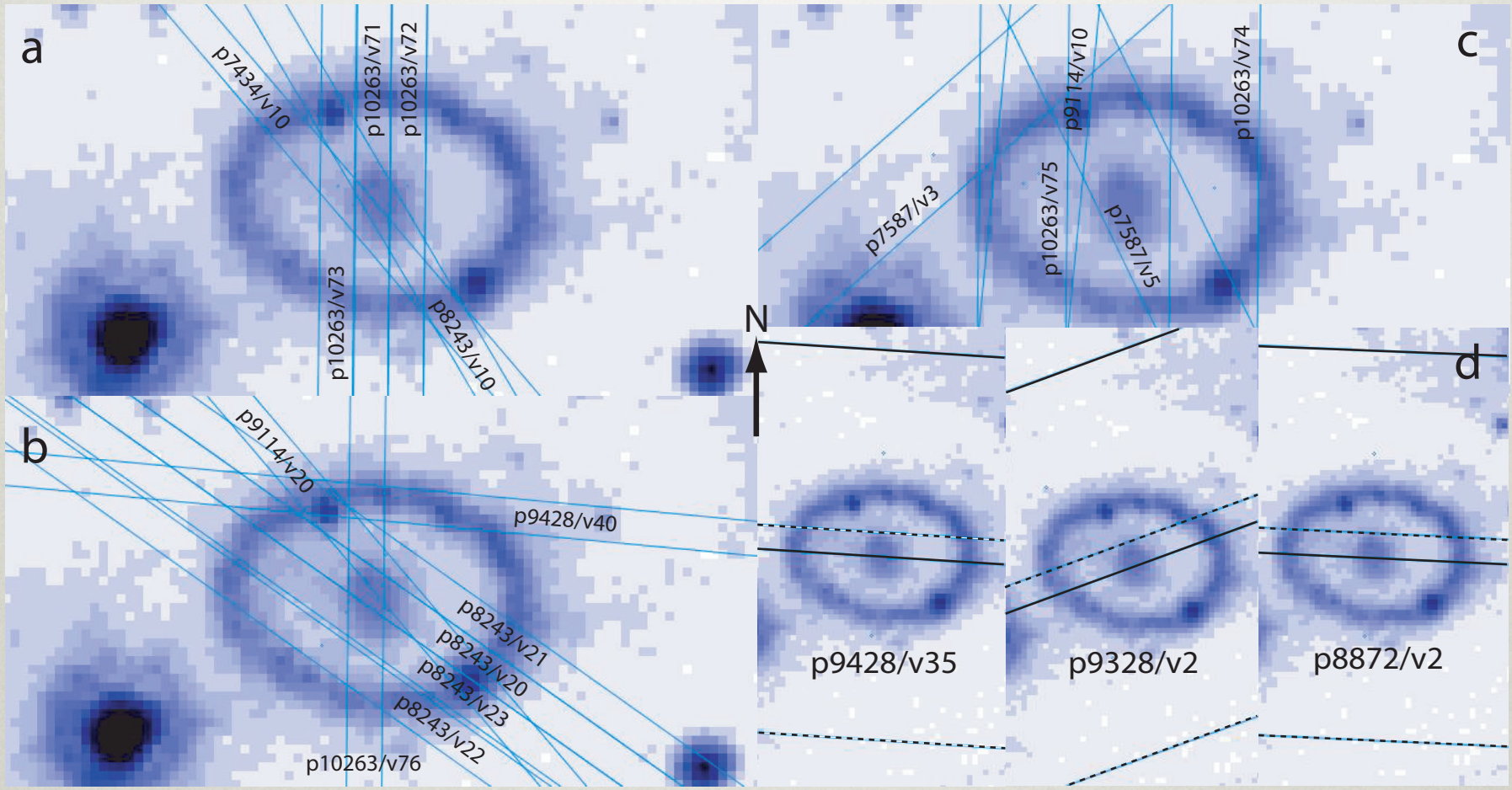
$$\frac{\Delta\nu}{\nu_0} = \frac{z}{ct}$$

Heng et al. (2006)



- Freely streaming assumption for debris means there is a unique mapping of redshift to depth.
- Surface emission: occurs at reverse shock surface.
- Interior emission: appears to originate from beneath reverse shock surface.
- "Interior" emission actually comes from charge transfers with the slower protons in the hot plasma beyond the reverse shock.

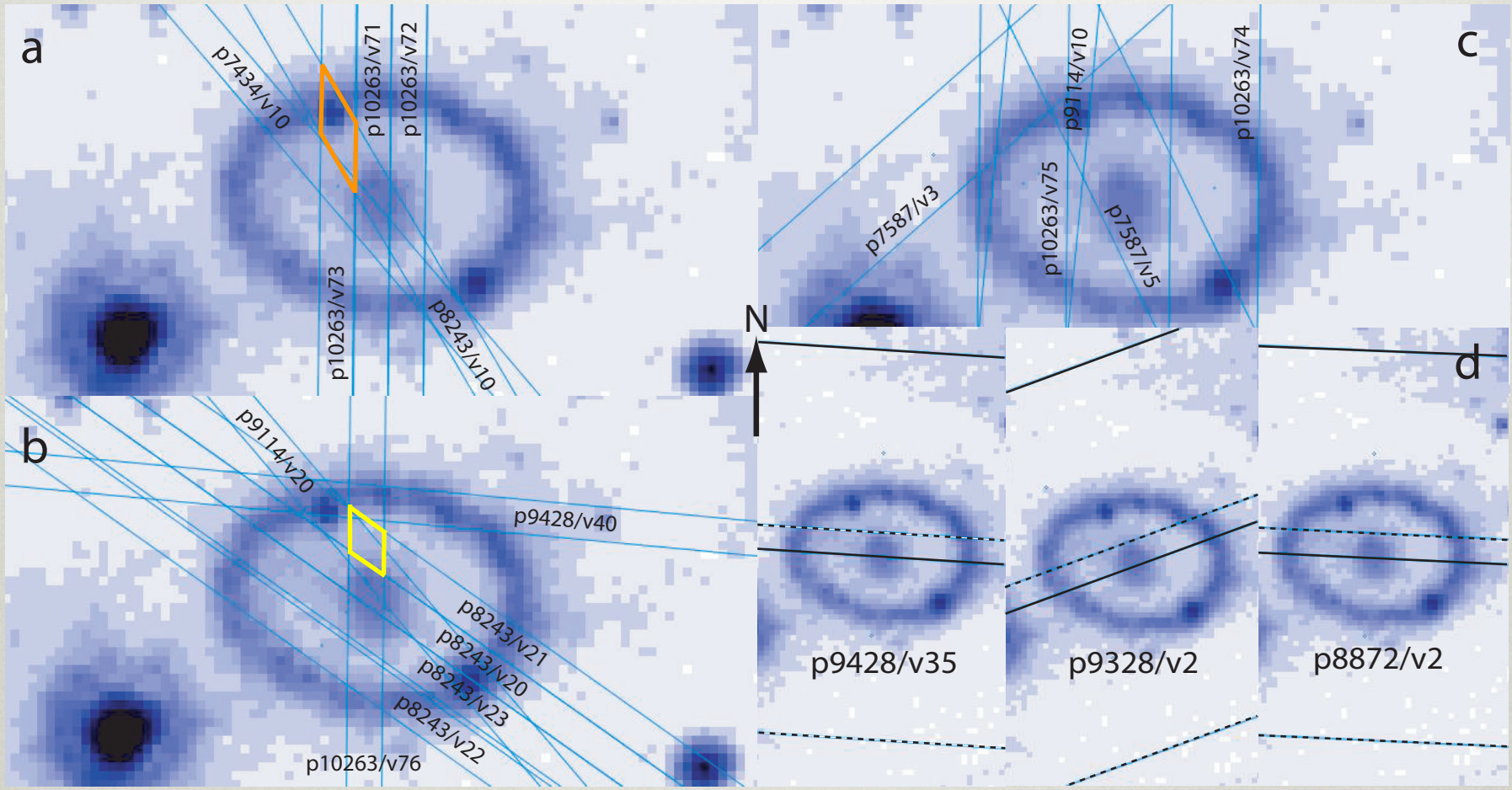
Low-Resolution Hubble/ STIS Spectroscopy



SAINTS Hubble Data

Heng et al. (2006)

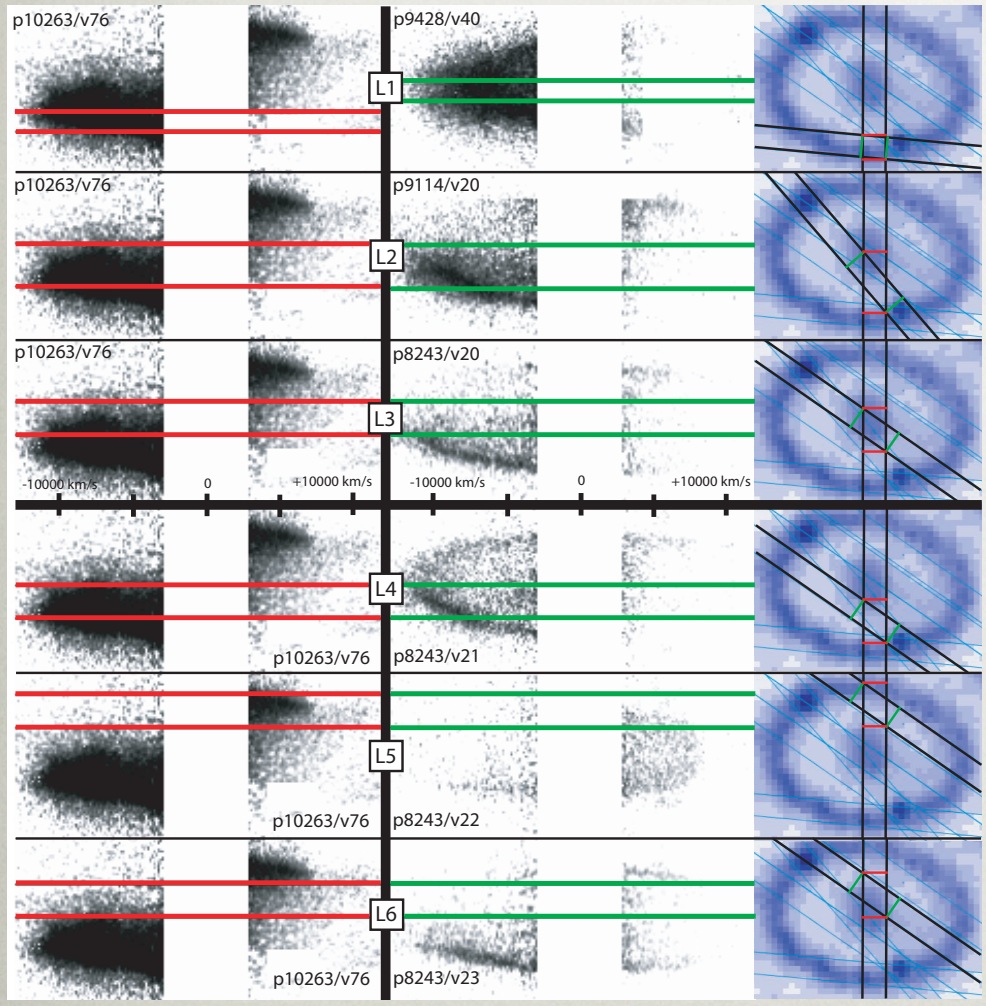
Low-Resolution Hubble/ STIS Spectroscopy

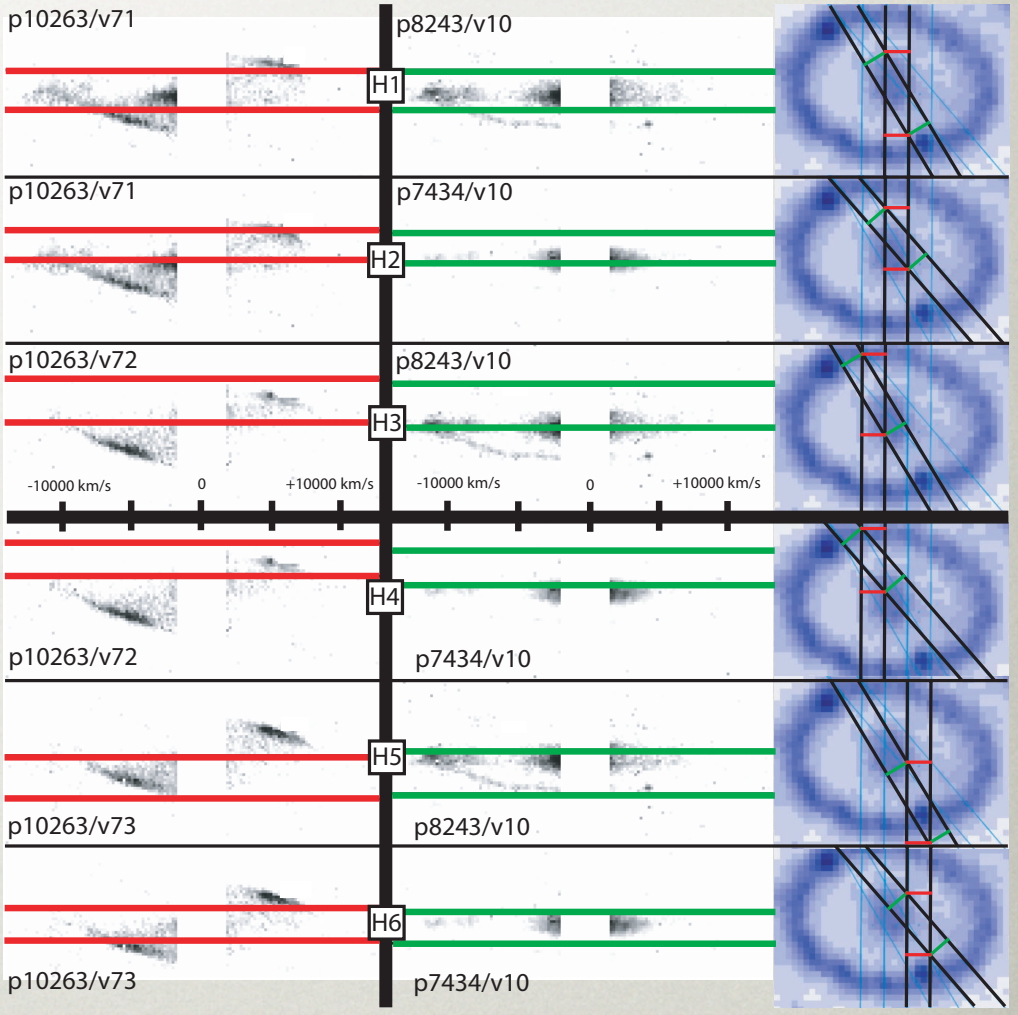


SAINTS Hubble Data

Heng et al. (2006)

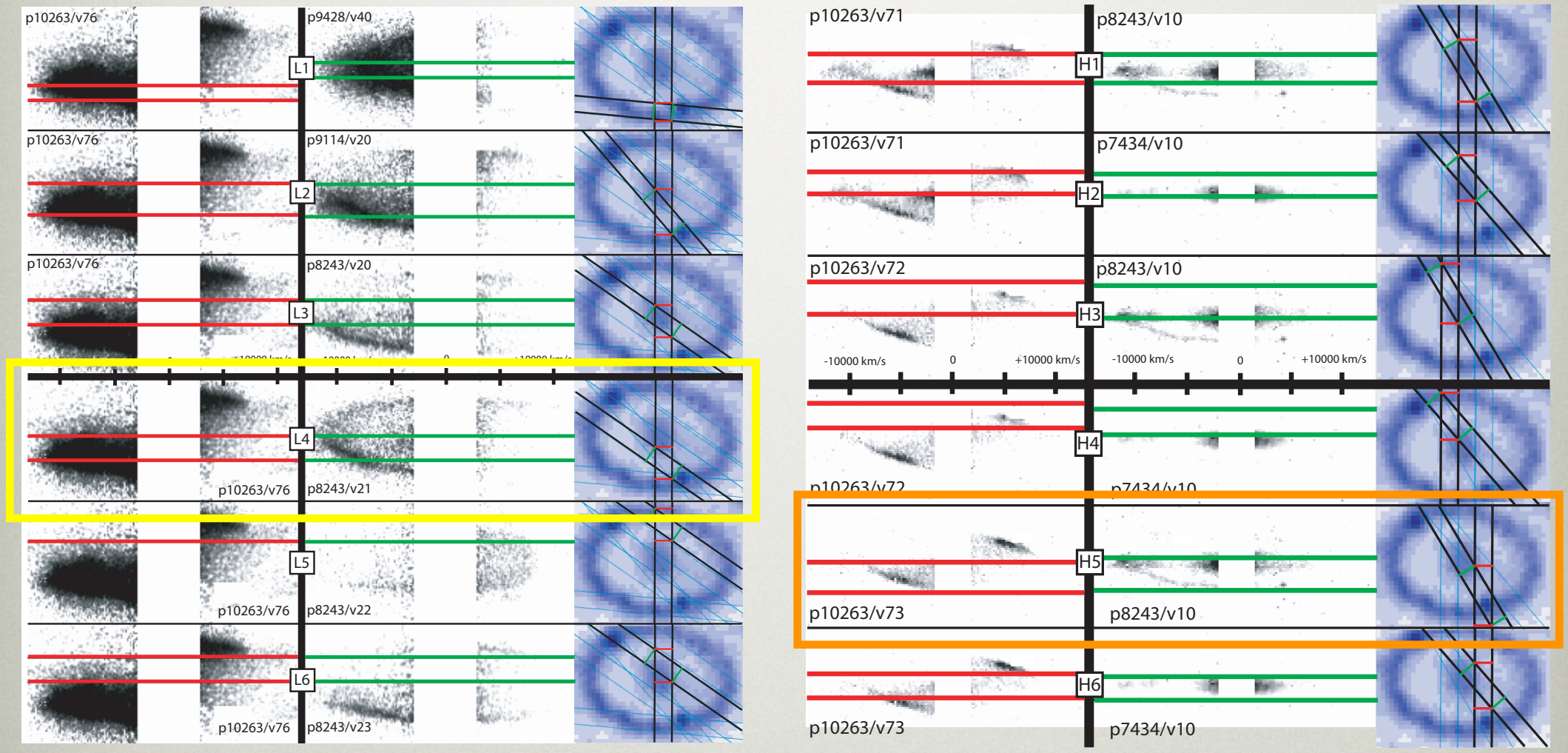
Evolution of the Hα & Lyα Reverse Shock Emission





Heng et al. (2006)

Evolution of the Hα & Lyα Reverse Shock Emission

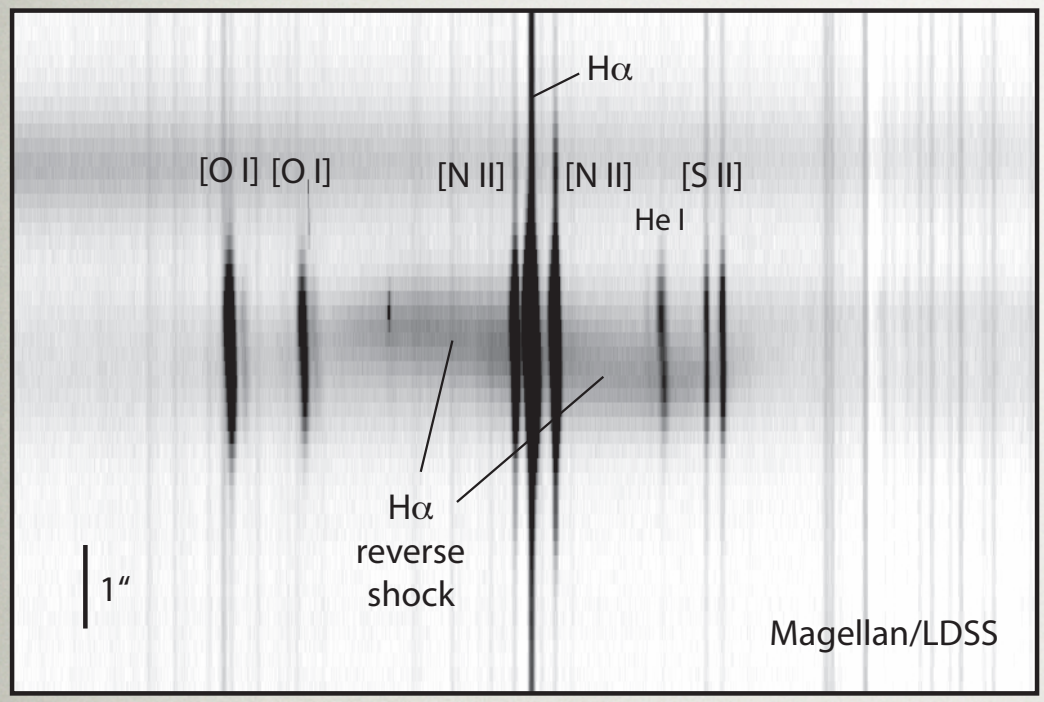


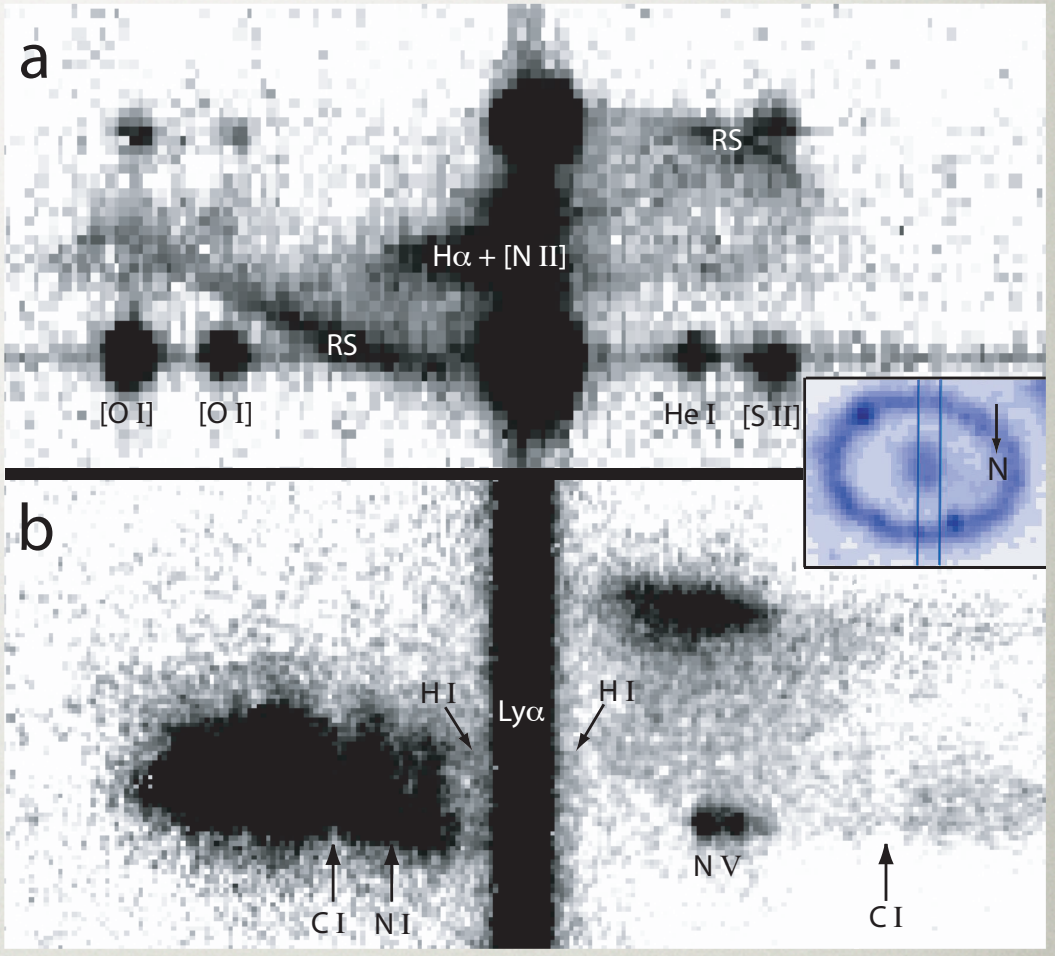
Hα: ~3 over 5 years.

Lyα: ~9 over 5 years.

Heng et al. (2006)

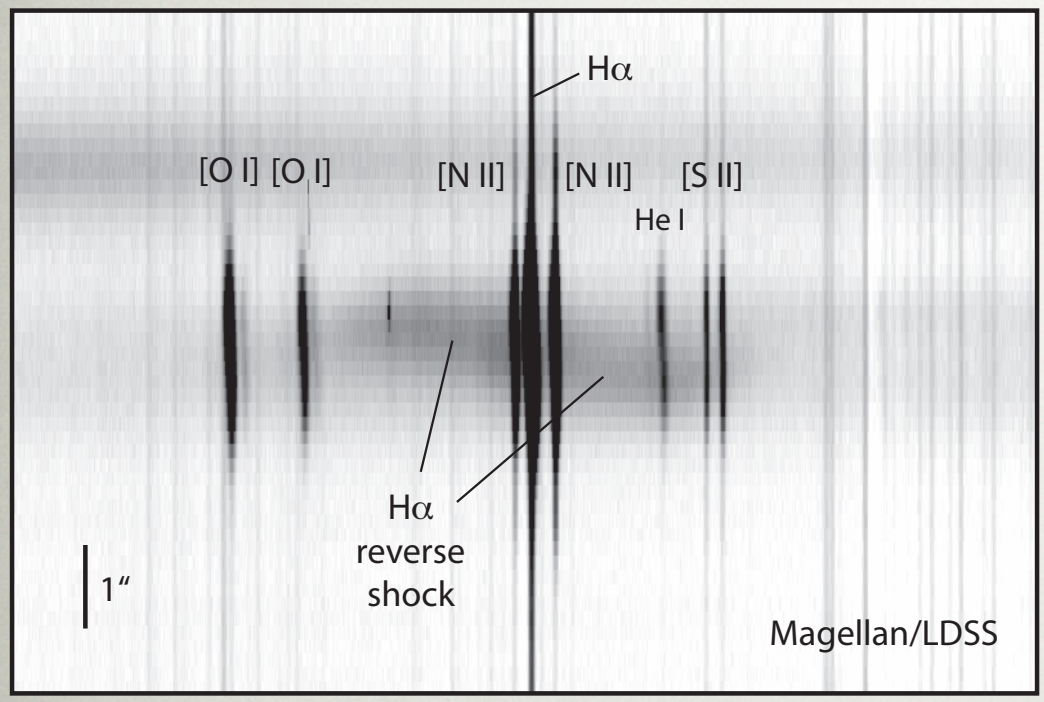
Bleaching Out of the Reverse Shock Emission?



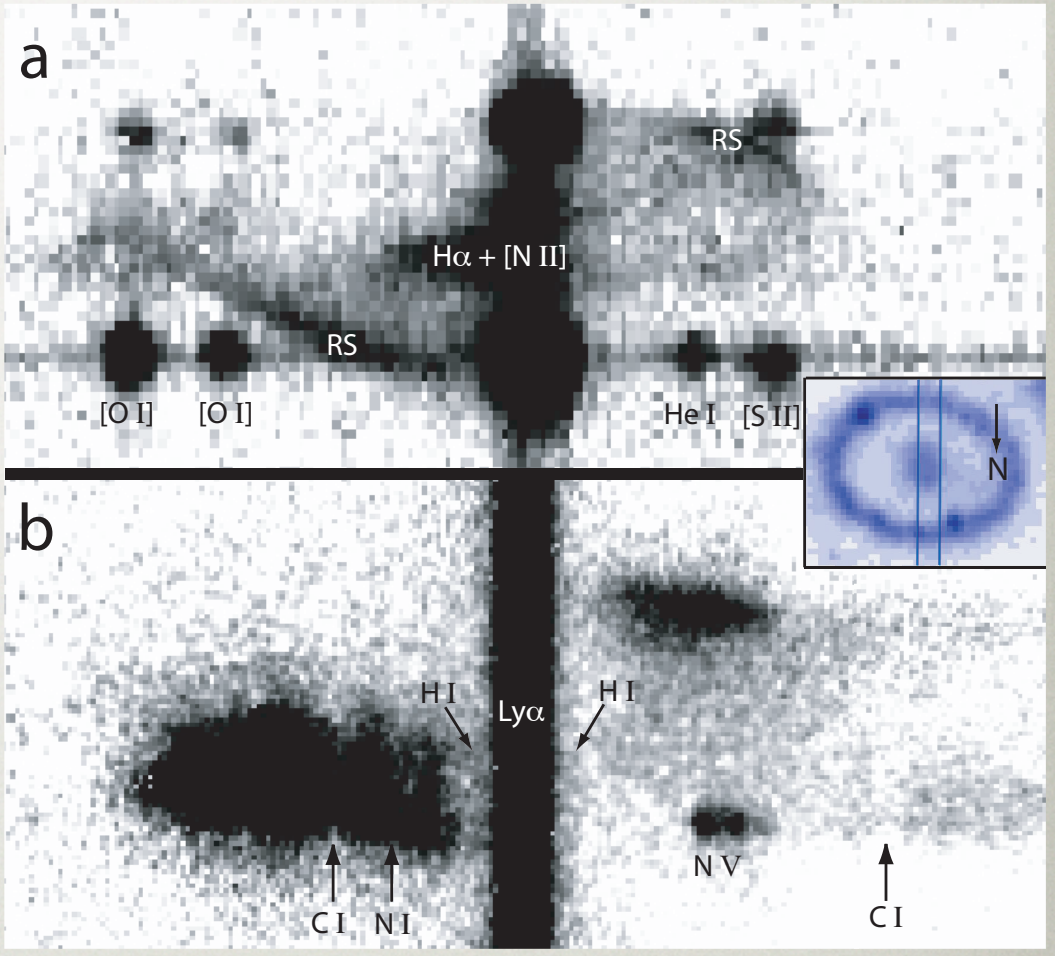


- Ground-based observations are optimal for tracking the global evolution of the reverse shock.
- Magellan: high spectral, low spatial resolution, higher S/N.

Bleaching Out of the Reverse Shock Emission?



Smith et al. (2005)



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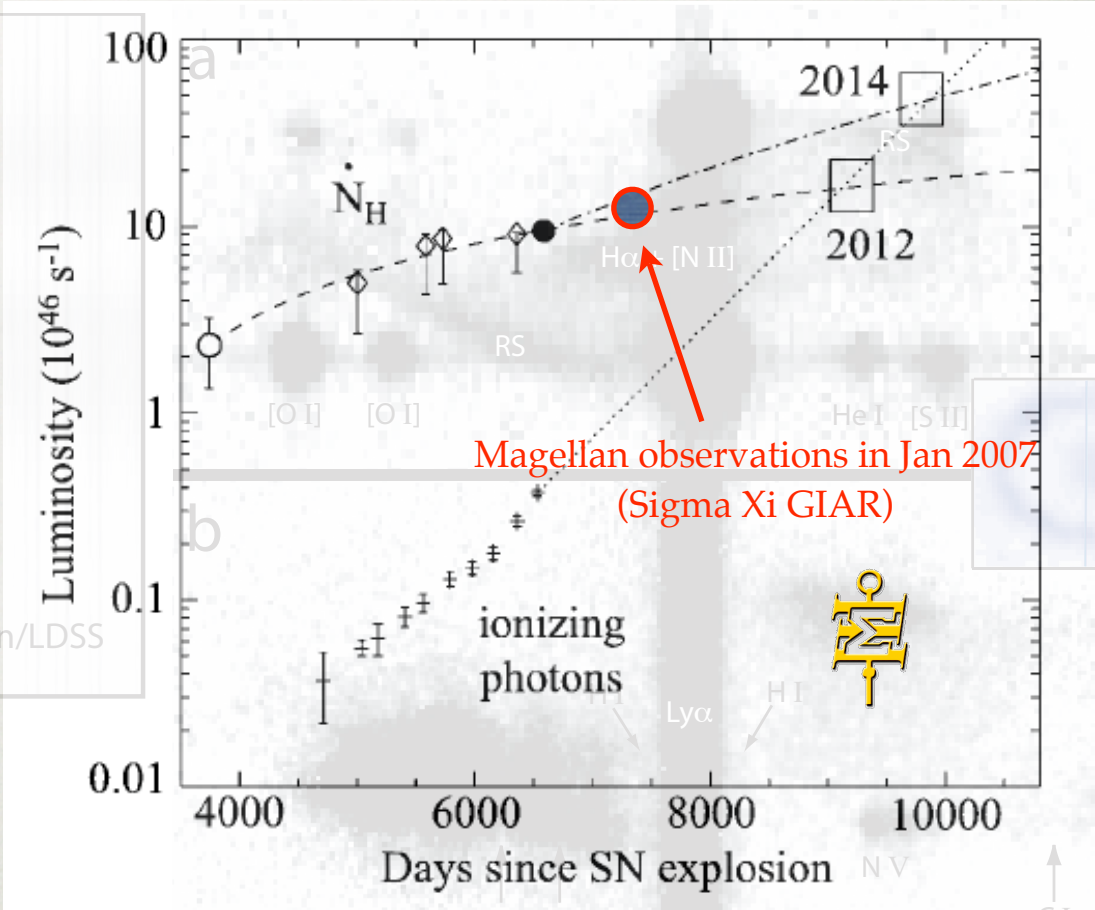
- COS:
  1. He II (1640 Å)
  2. N V (1239 & 1243 Å)



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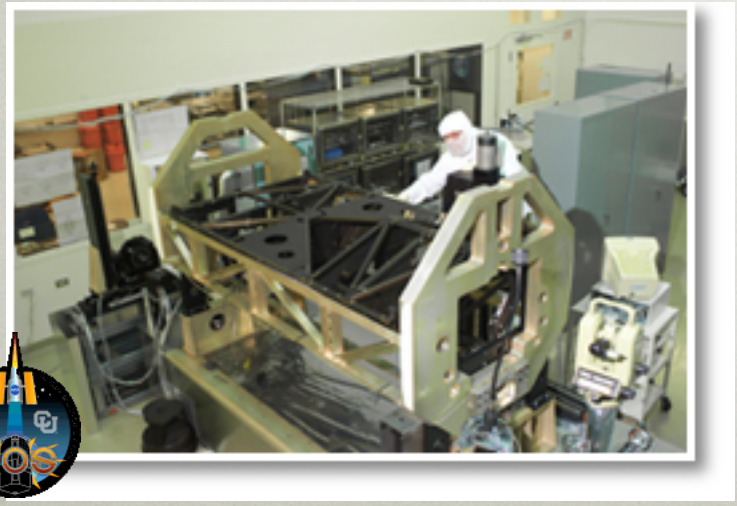
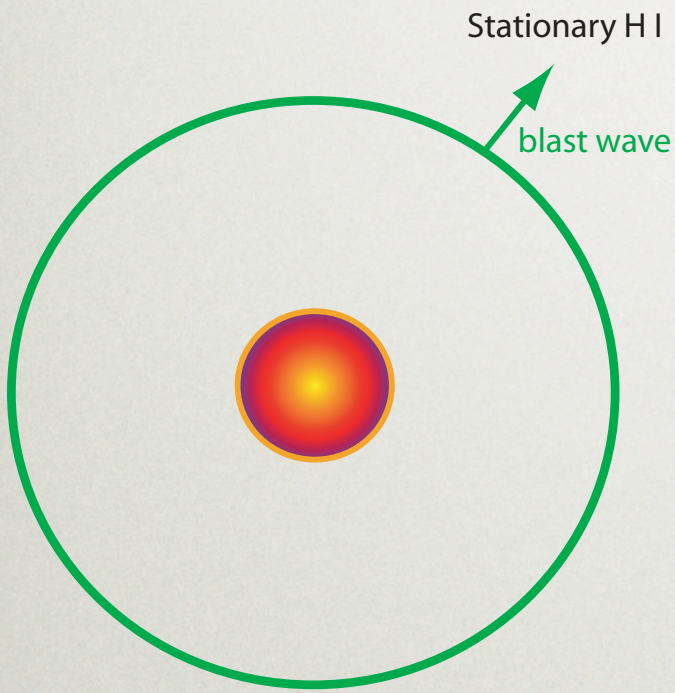


Balmer-Dominated SNRs vs. SNR 1987A



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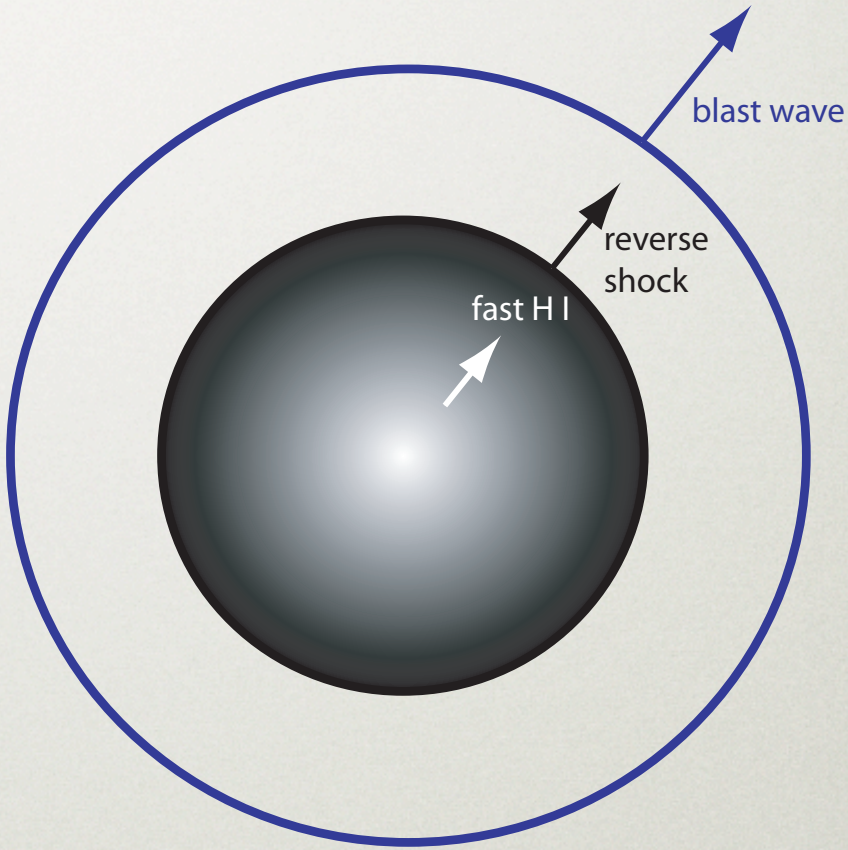
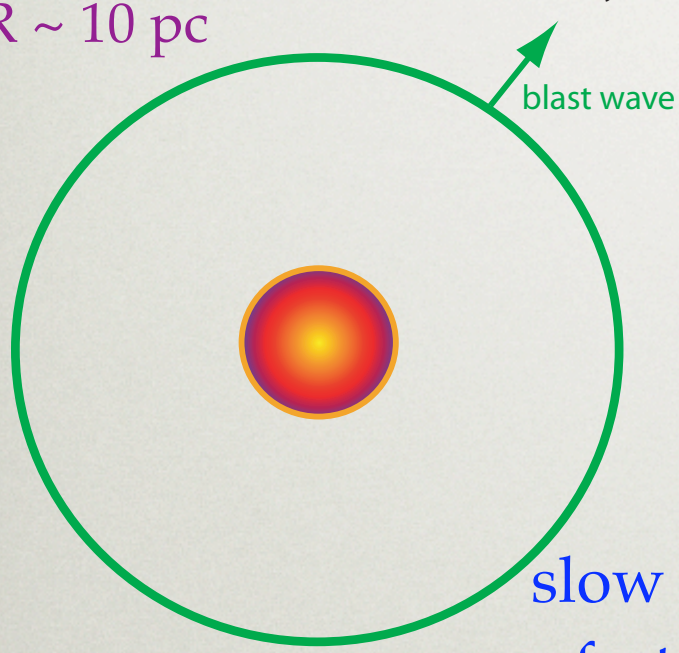


SNR 1987A

Balmer-Dominated SNRs vs. SNR 1987A

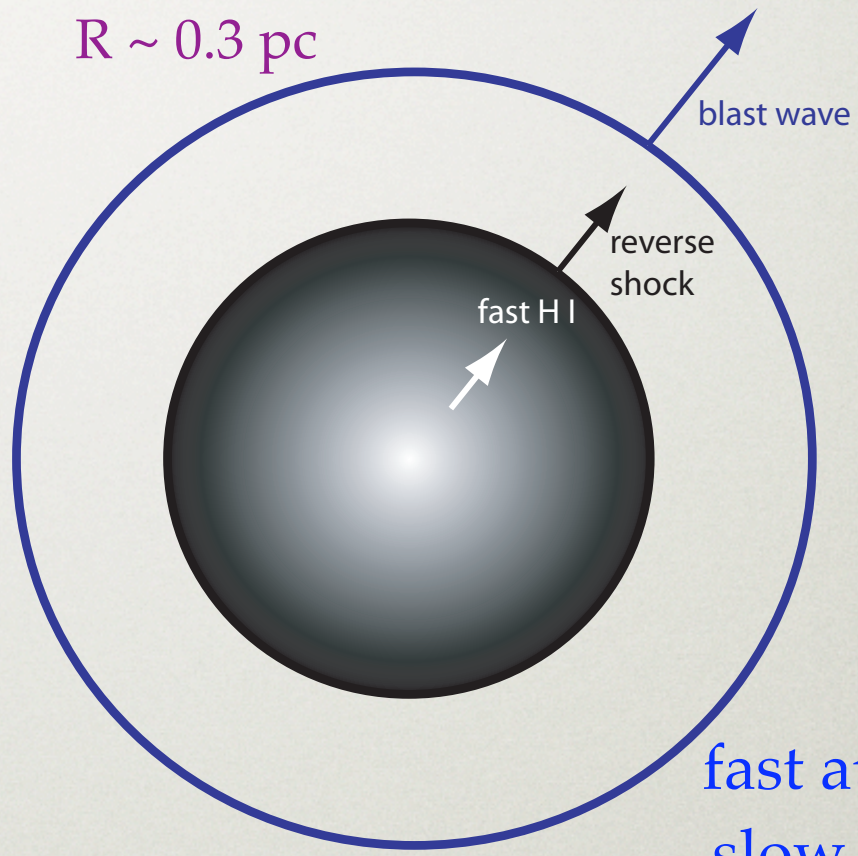
$v_s \sim 500$ km/s
$R \sim 10$ pc



slow atoms,
fast ions!

Balmer-Dominated SNRs

$v_s \sim 10{,}000$ km/s
$R \sim 0.3$ pc



fast atoms,
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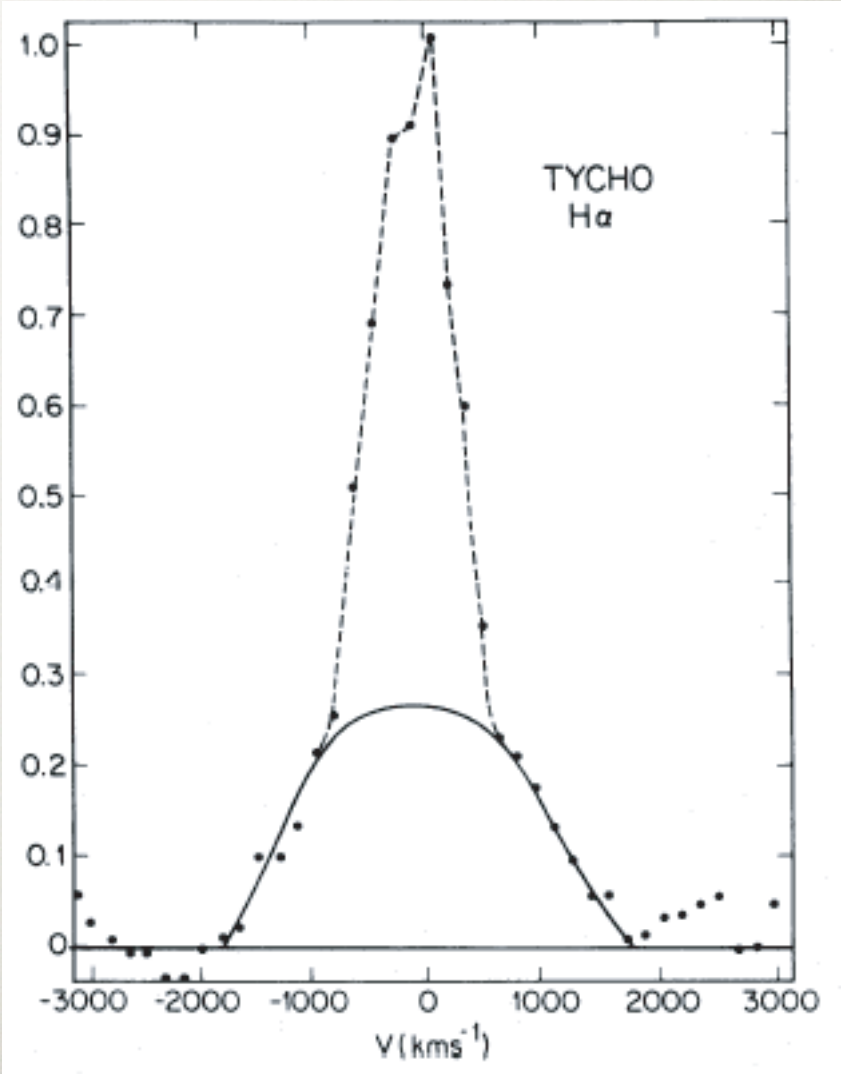
SNR 1987A

Balmer-Dominated SNRs

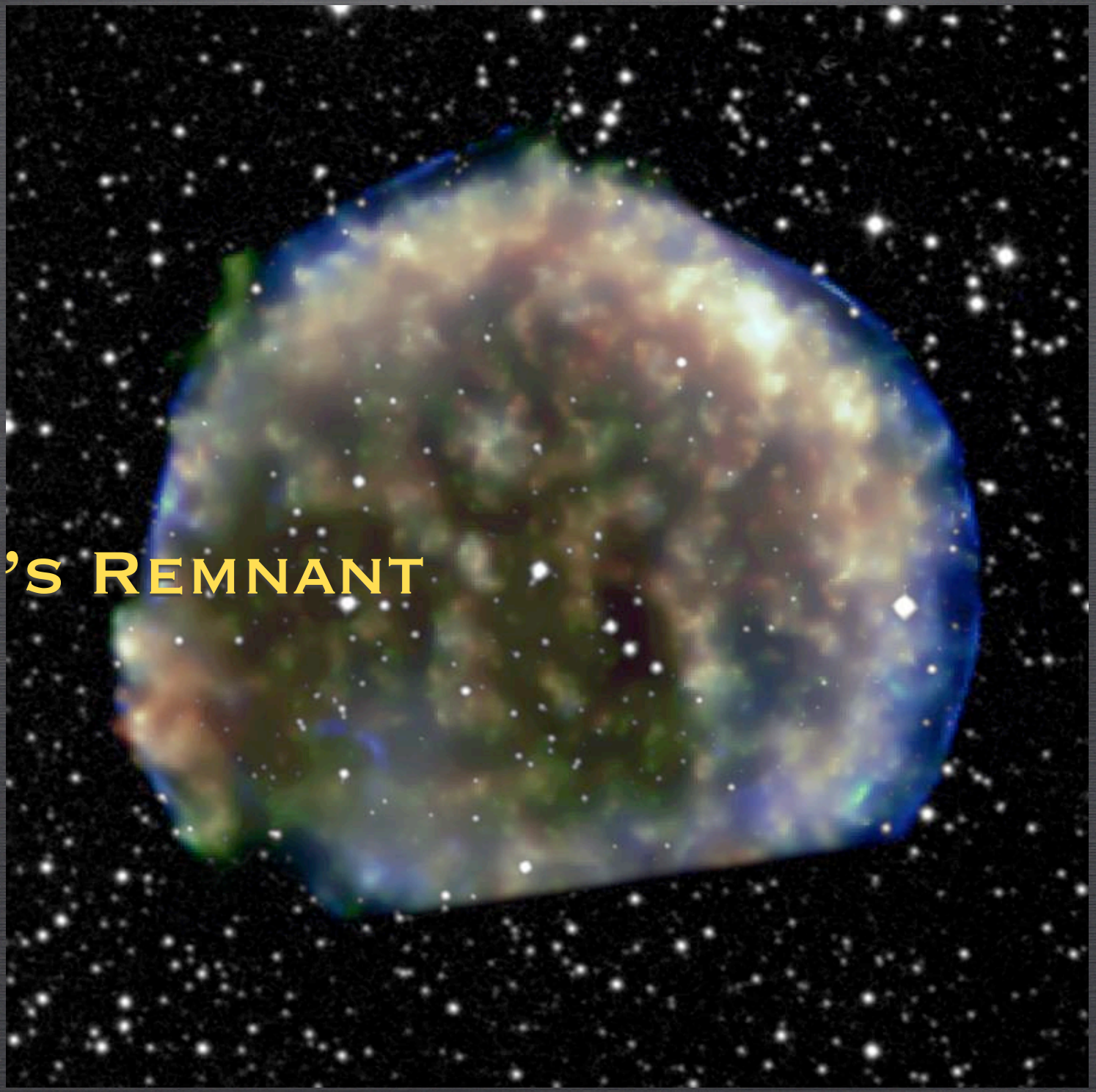
What are Balmer-Dominated Remnants?

- Supernova remnants whose spectra are dominated by Hα and other Balmer lines.
- Forbidden lines such as [S II] and [N II] are either absent or unusually weak.
- Chevalier & Raymond (1978) first predicted the two-component line profiles seen in such remnants.
- Two years later, Chevalier, Kirshner & Raymond (1980) observed the first example in Tycho's remnant.



Chevalier, Kirshner & Raymond (1980)

Tycho's Remnant



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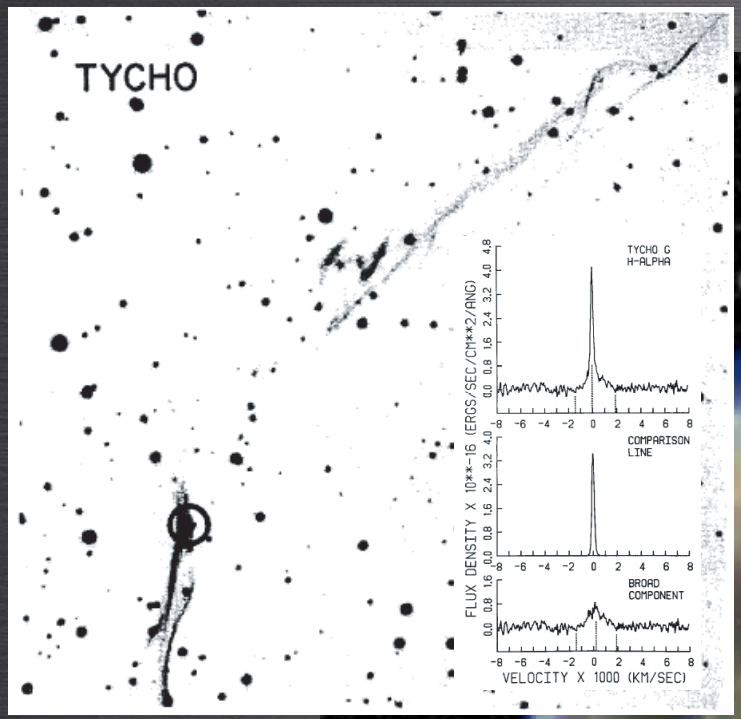
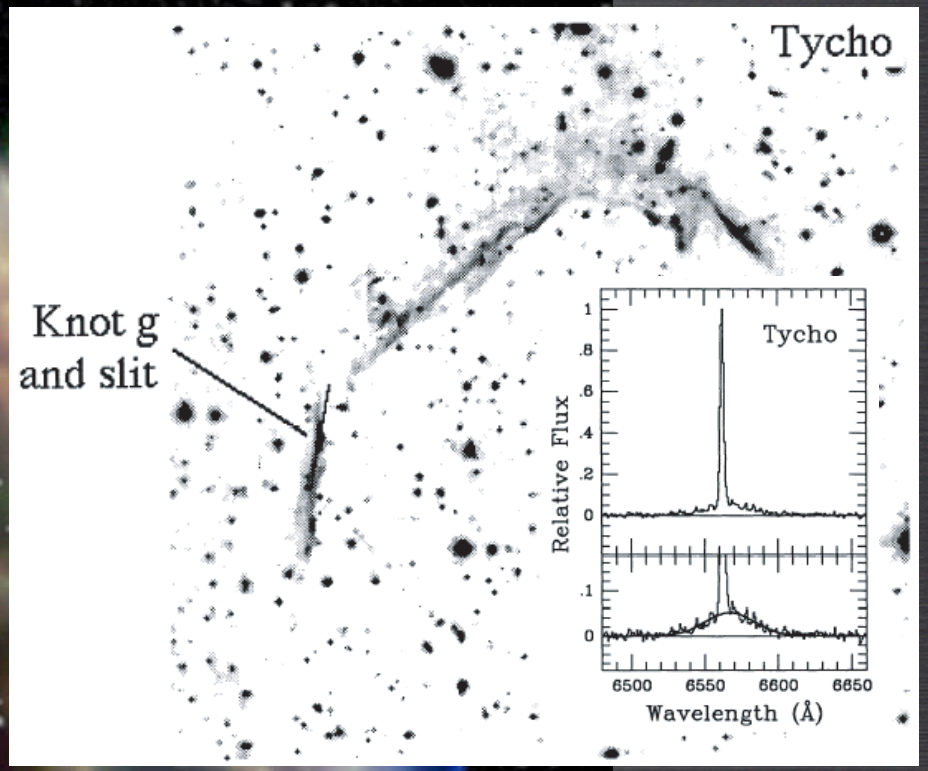
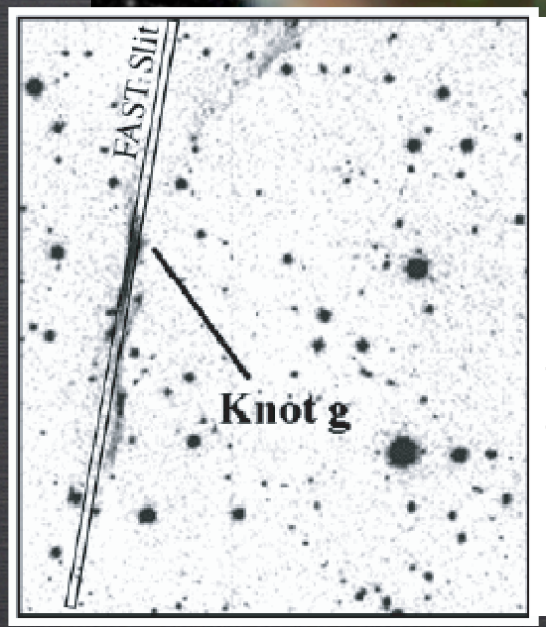
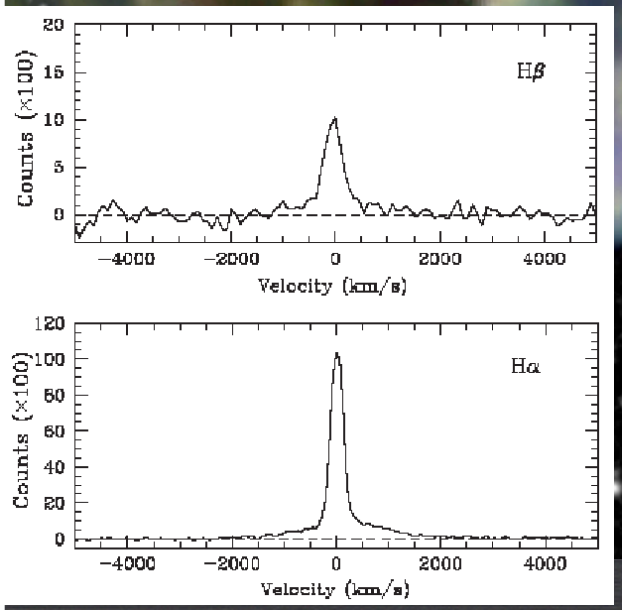


Kirshner, Winkler & Chevalier (1987)



Smith et al. (1991)





Ghavamian et al. (2001)

Line Emission Physics

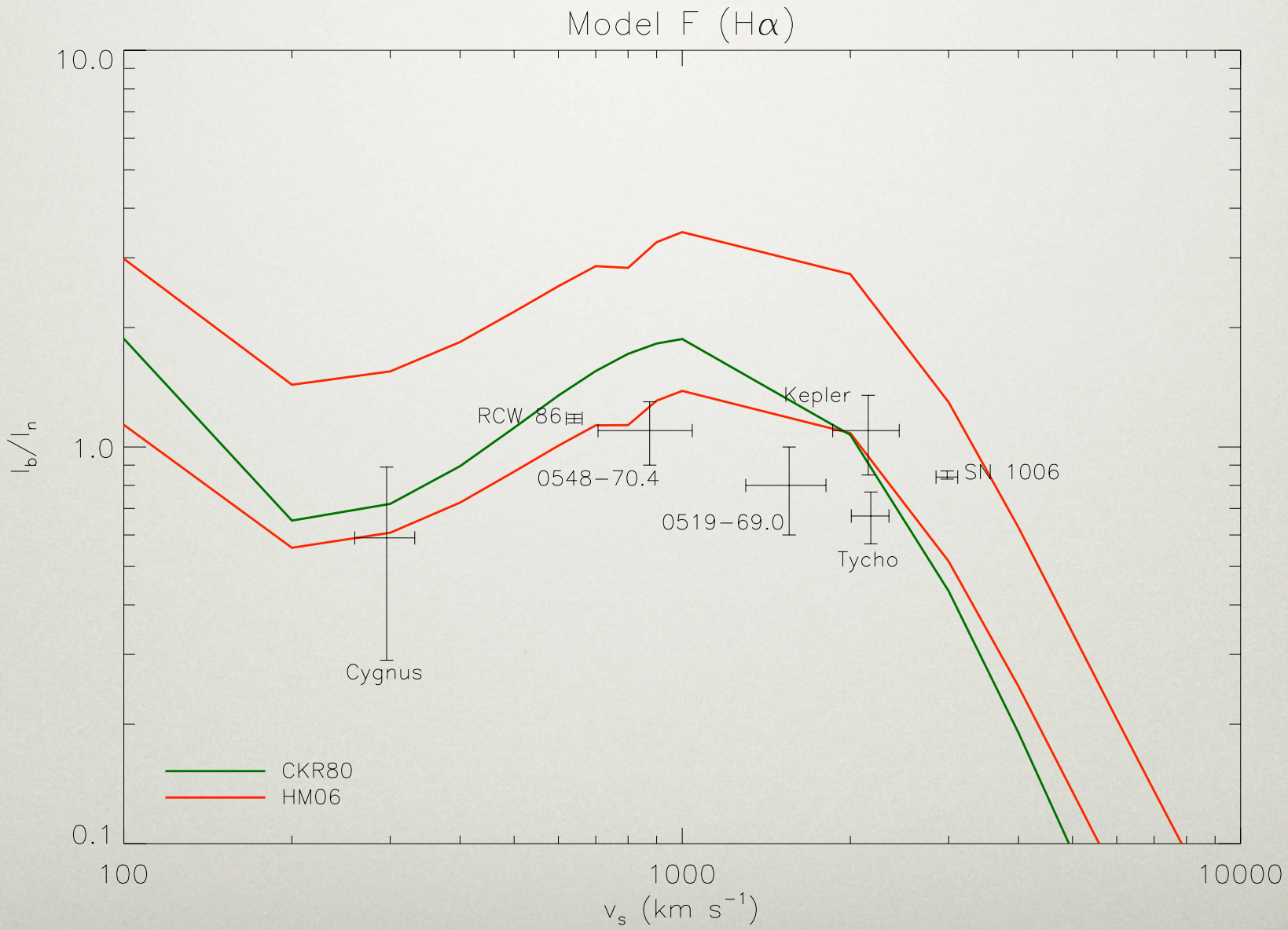
Narrow: H + p ---> H* + p

Broad: H + p ---> p + H ---> H*

Broad: H + p ---> p + H*

- Chevalier & Raymond (1978): collisionless shock running into a partially neutral medium.
- Line widths are characteristic of the temperatures of the media.
- Direct collisional excitation produces narrow line emission.
- Charge transfer reactions yield hydrogen atoms in broad distributions.
- Broad line emission comes from both excitation and charge transfer to excited states.

Broad-to-Narrow Ratio



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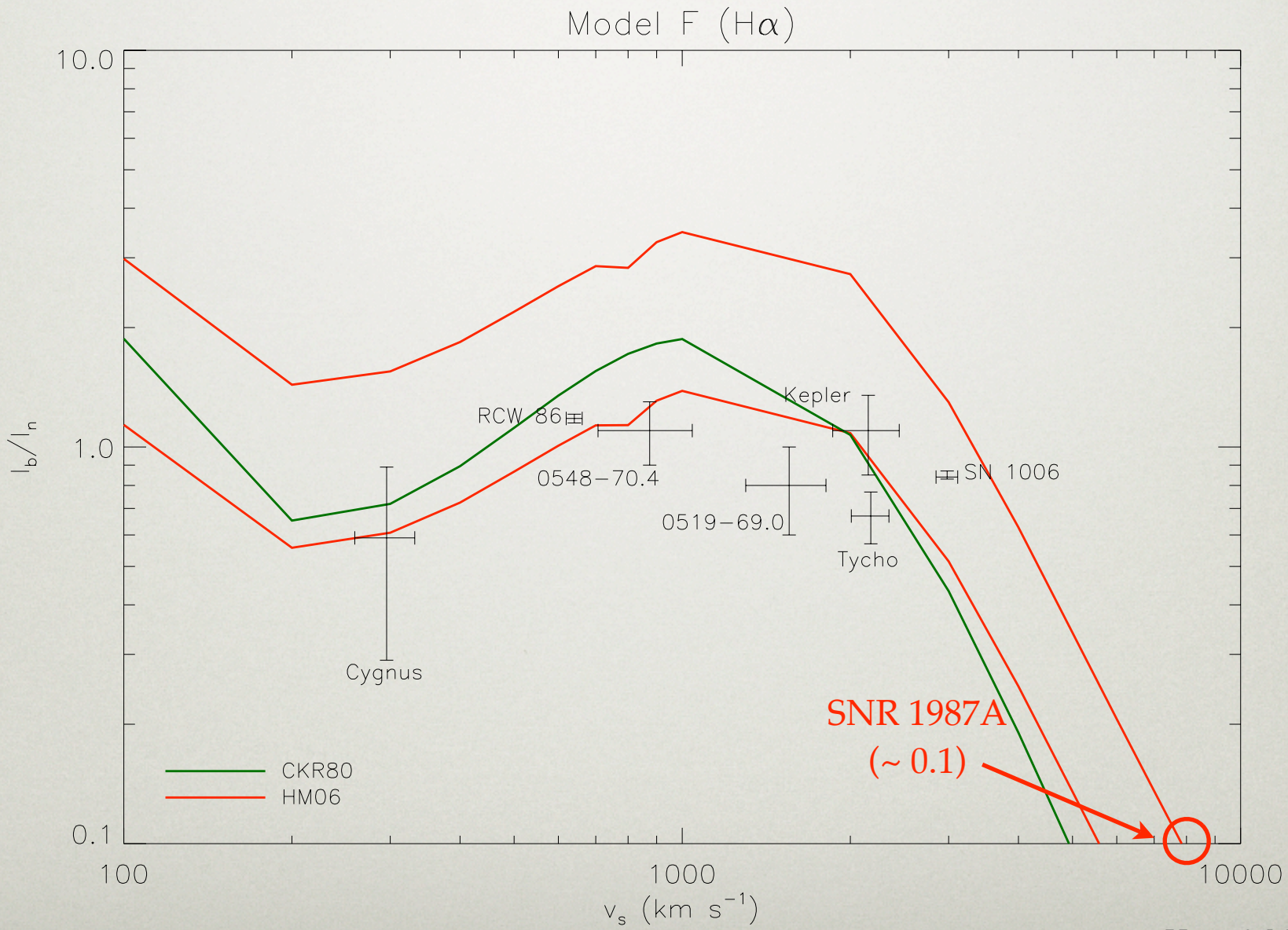

Heng & McCray (2007)

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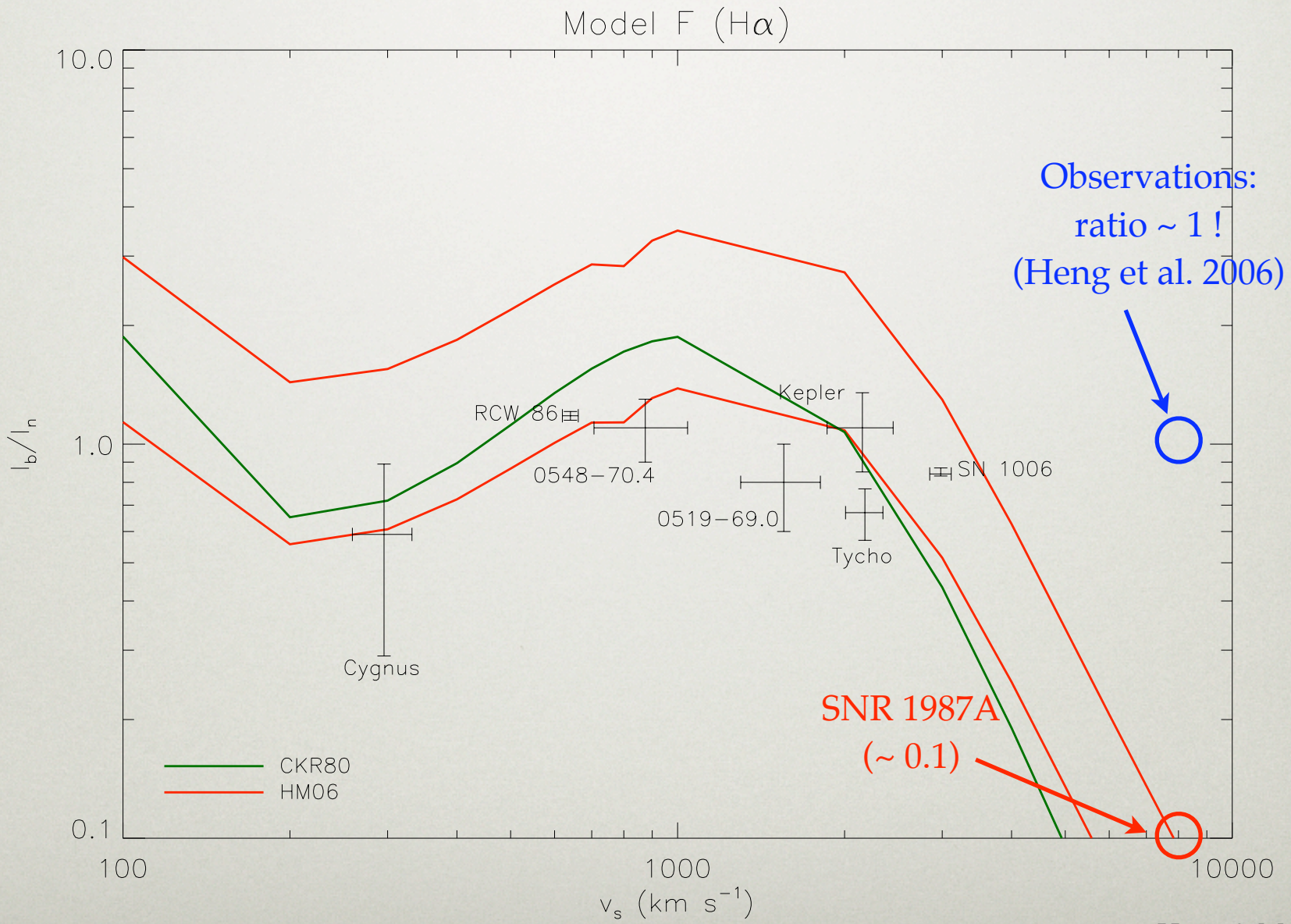
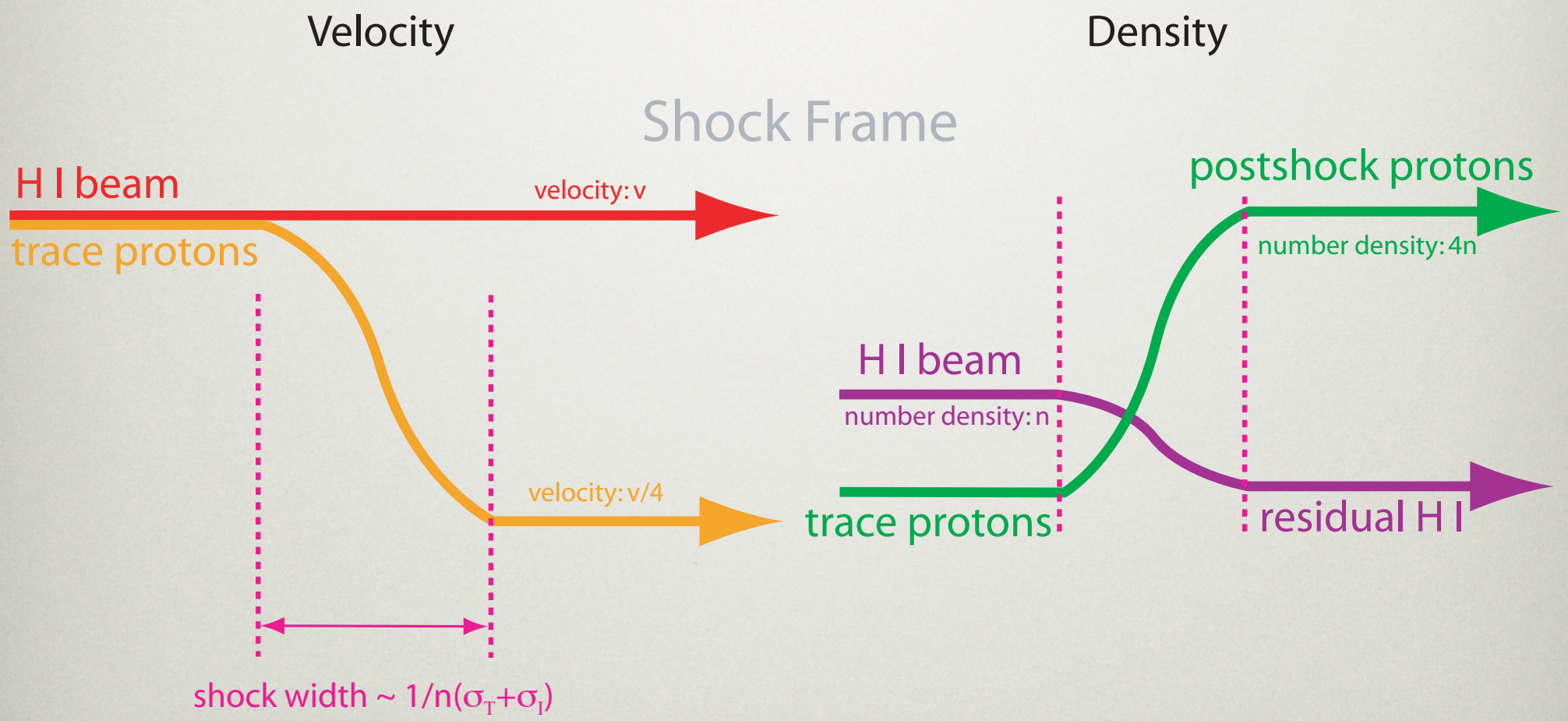


Heng & McCray (2007)

The Shock Transition Zone



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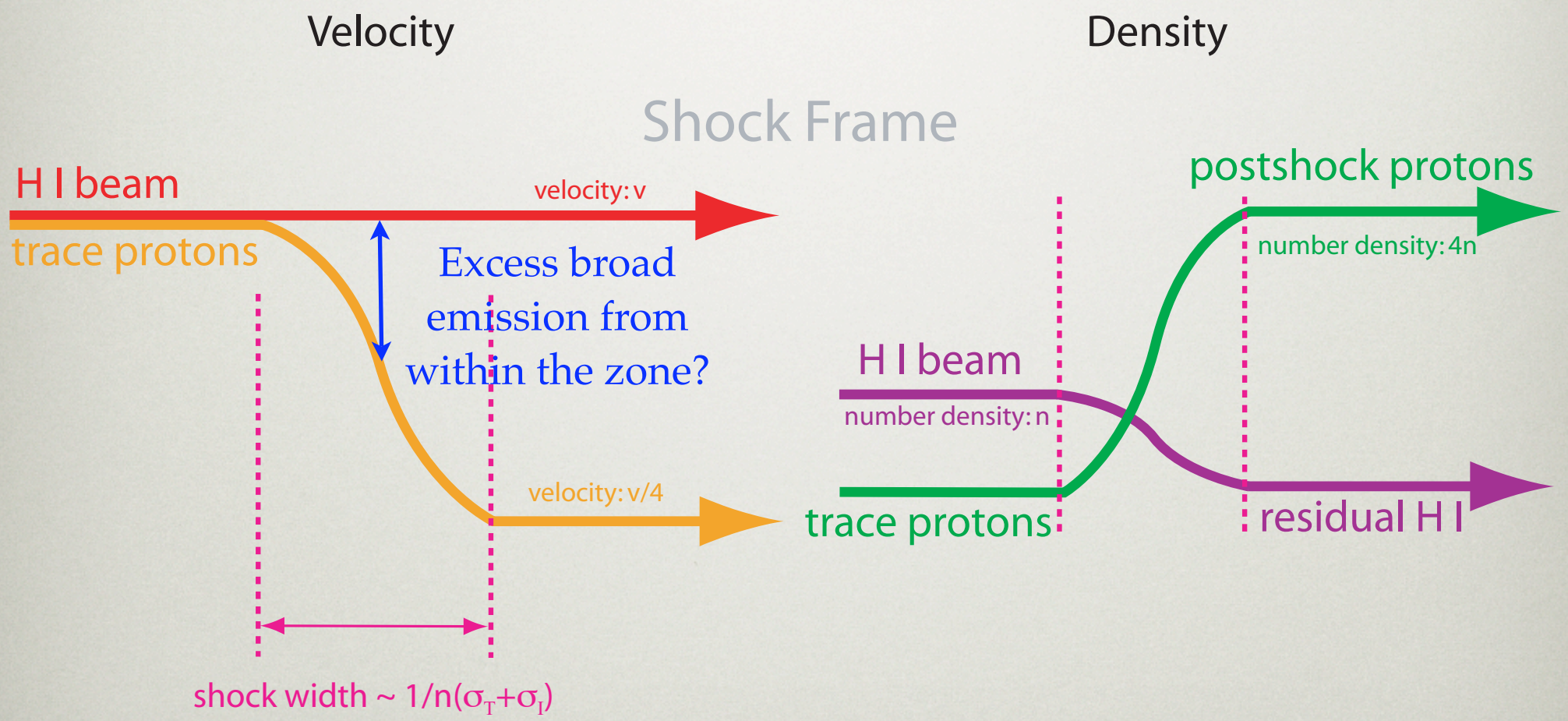

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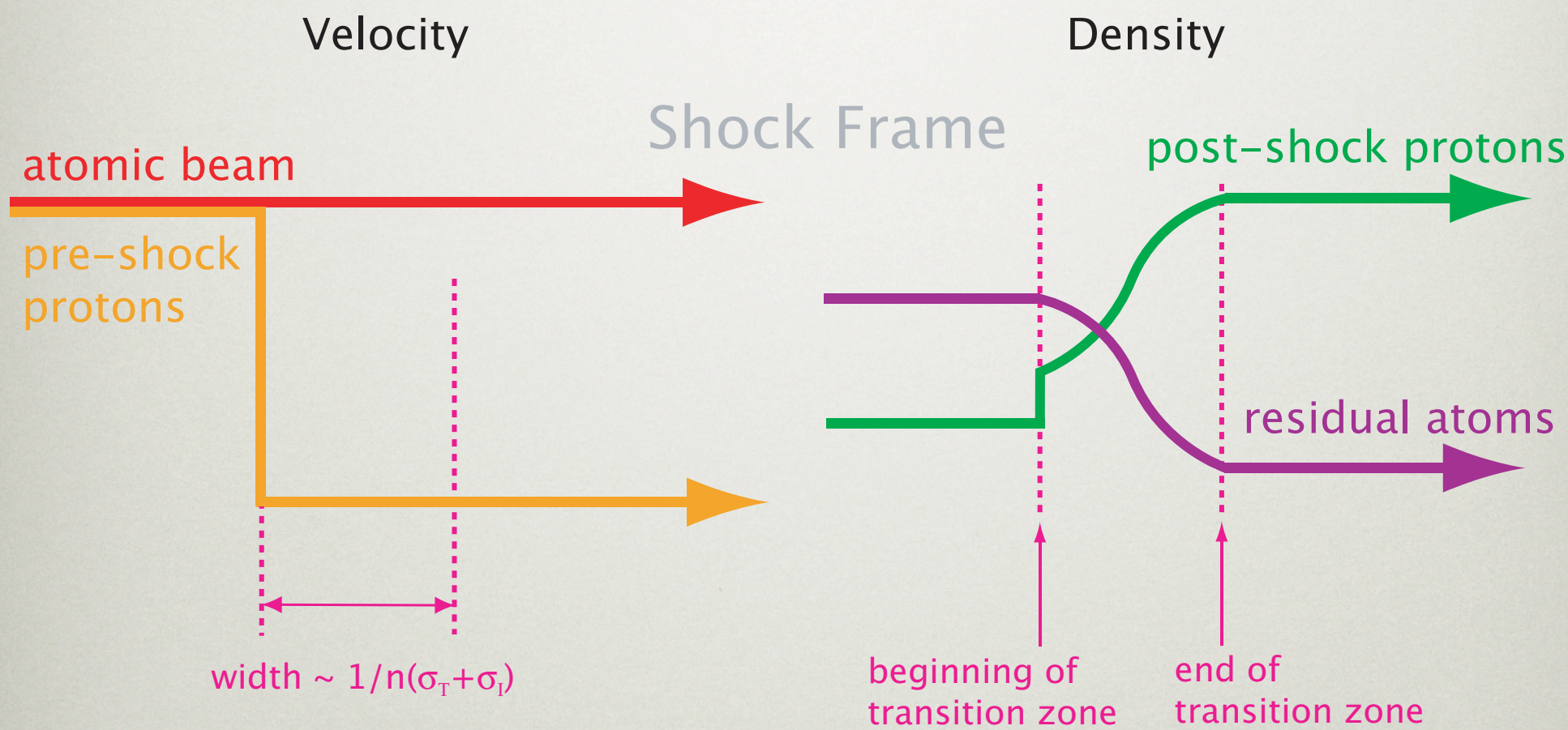

Heng, van Adelsberg, McCray & Raymond (2007, in prep)

Summary

Summary

- SNR 1987A is a dramatic example of a Balmer-dominated supernova remnant. Its surface and interior emission components are the "usual" narrow and broad lines.
- Open questions:
  1. How does one explain the excess interior (broad) emission in SNR 1987A?
  2. When will the "bleach-out" of the reverse shock occur?

Acknowledgments: SAINTS team