Constraints on Cosmic Ray Acceleration Efficiency in Balmer Shocks of the Two Young Type Ia Supernova Remnants in the Large Magellanic Cloud

The 33rd Annual New Mexico Symposium

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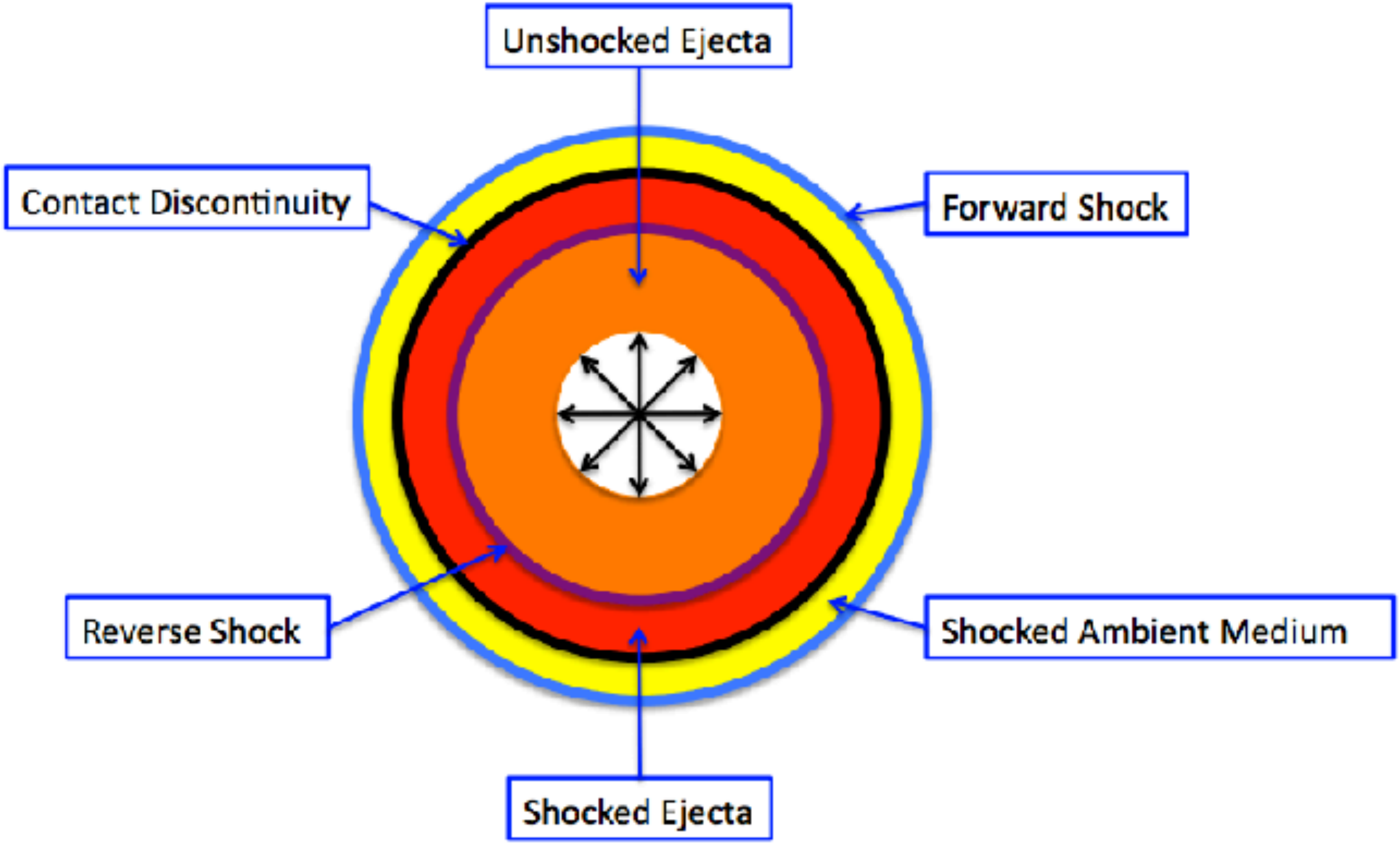
Curtis McCully - Las Cumbres Observatory Global Telescope
University of California, Santa Barbara
Viraj Pandya – UCO/Lick Observatory
University of California, Santa Cruz

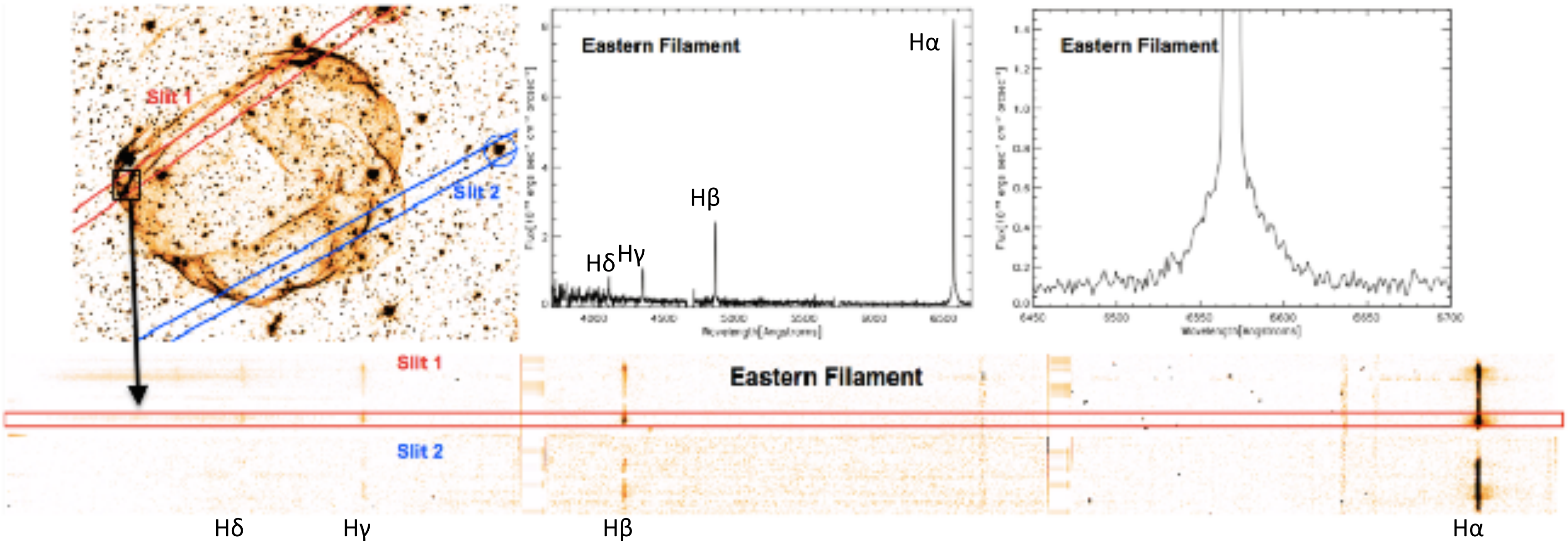
Image Credit-Hubble Heritage

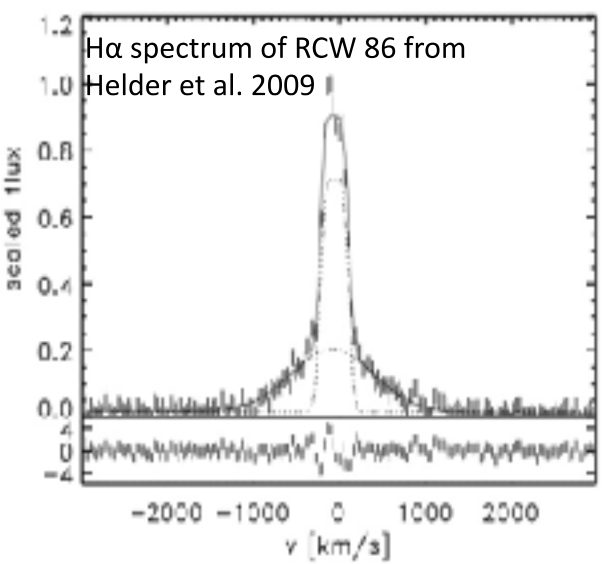
Two Shock Structure



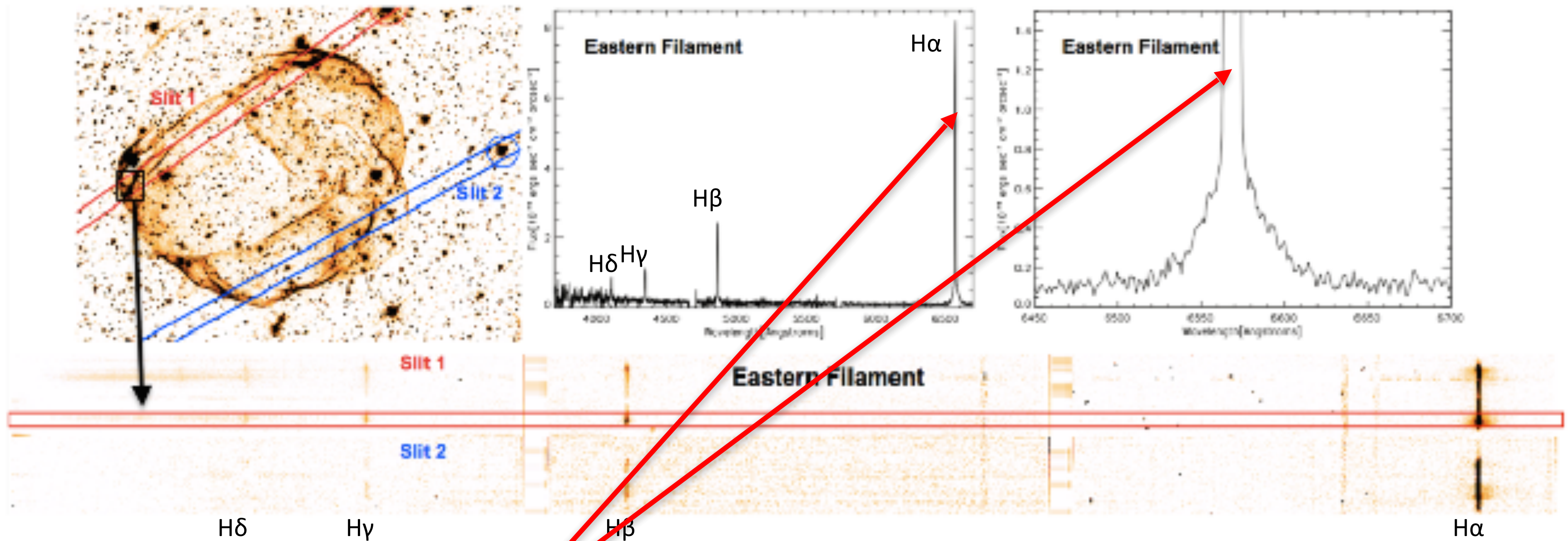
https://youtu.be/jA0v1Mh_Oq8

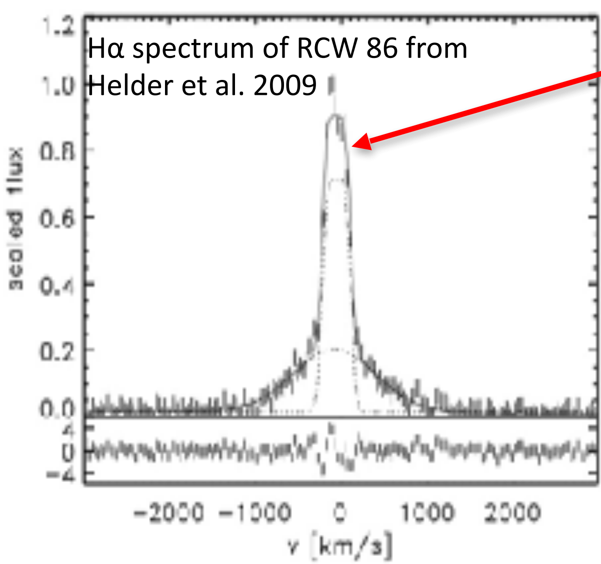
Balmer-dominated Shocks





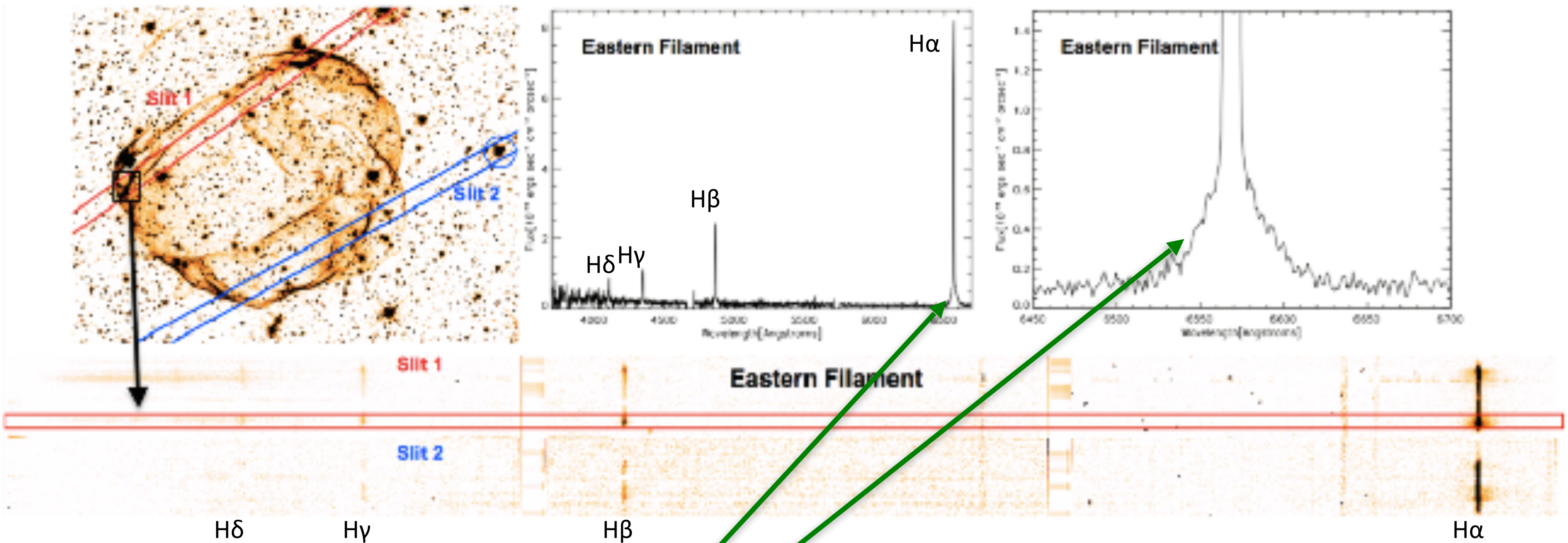
Balmer-dominated Shocks

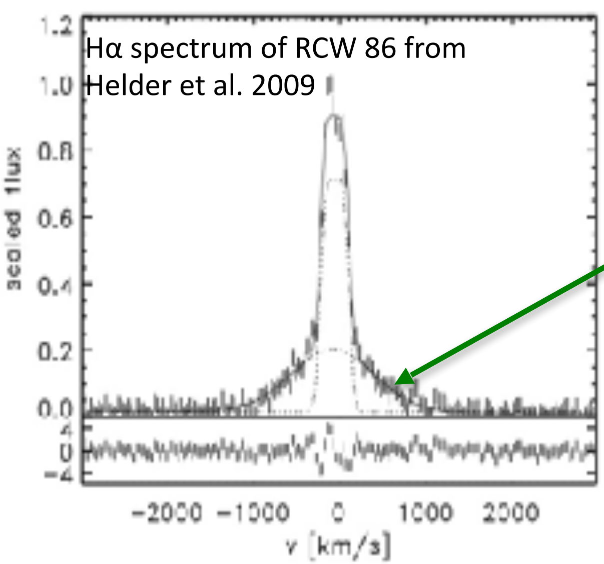




Narrow Hα – collisional excitations of hydrogen entering the forward shock

Balmer-dominated Shocks

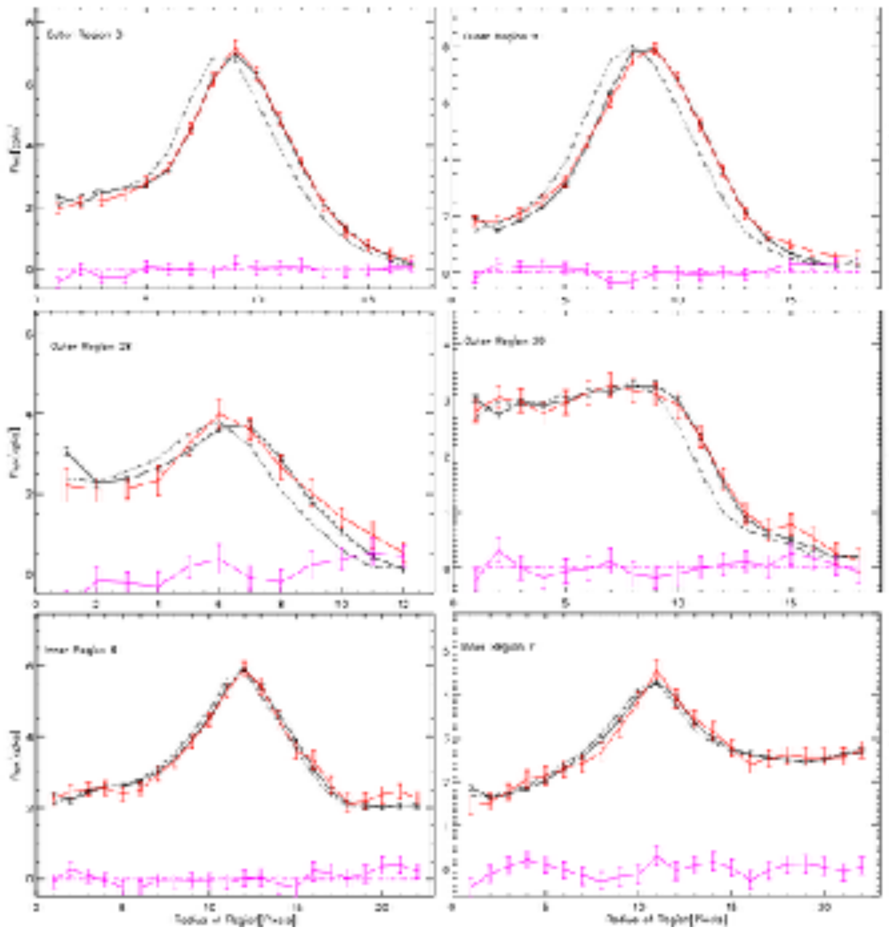


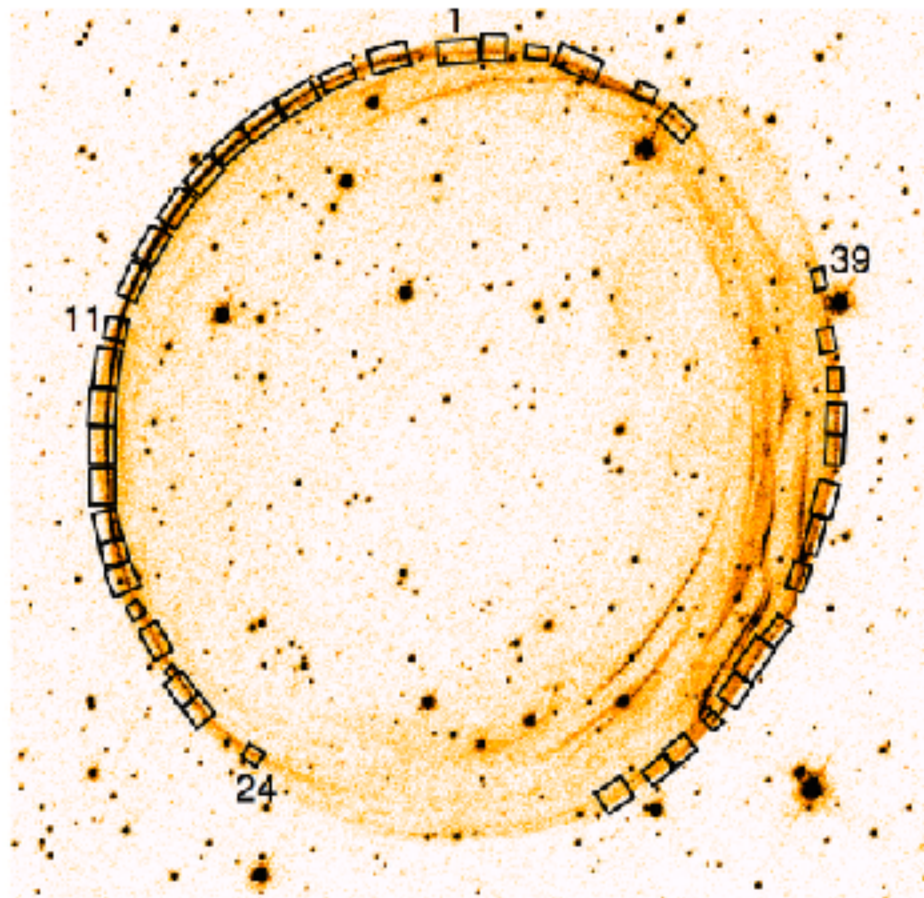


- Narrow Hα – collisional excitations of hydrogen entering the forward shock
- Broad Hα – Charge transfer from neutral hydrogen entering the forward shock that exchange their electron with a post-shock proton

Measuring Global Shock Speed

Results from Hovey, Hughes, and Eriksen 2015





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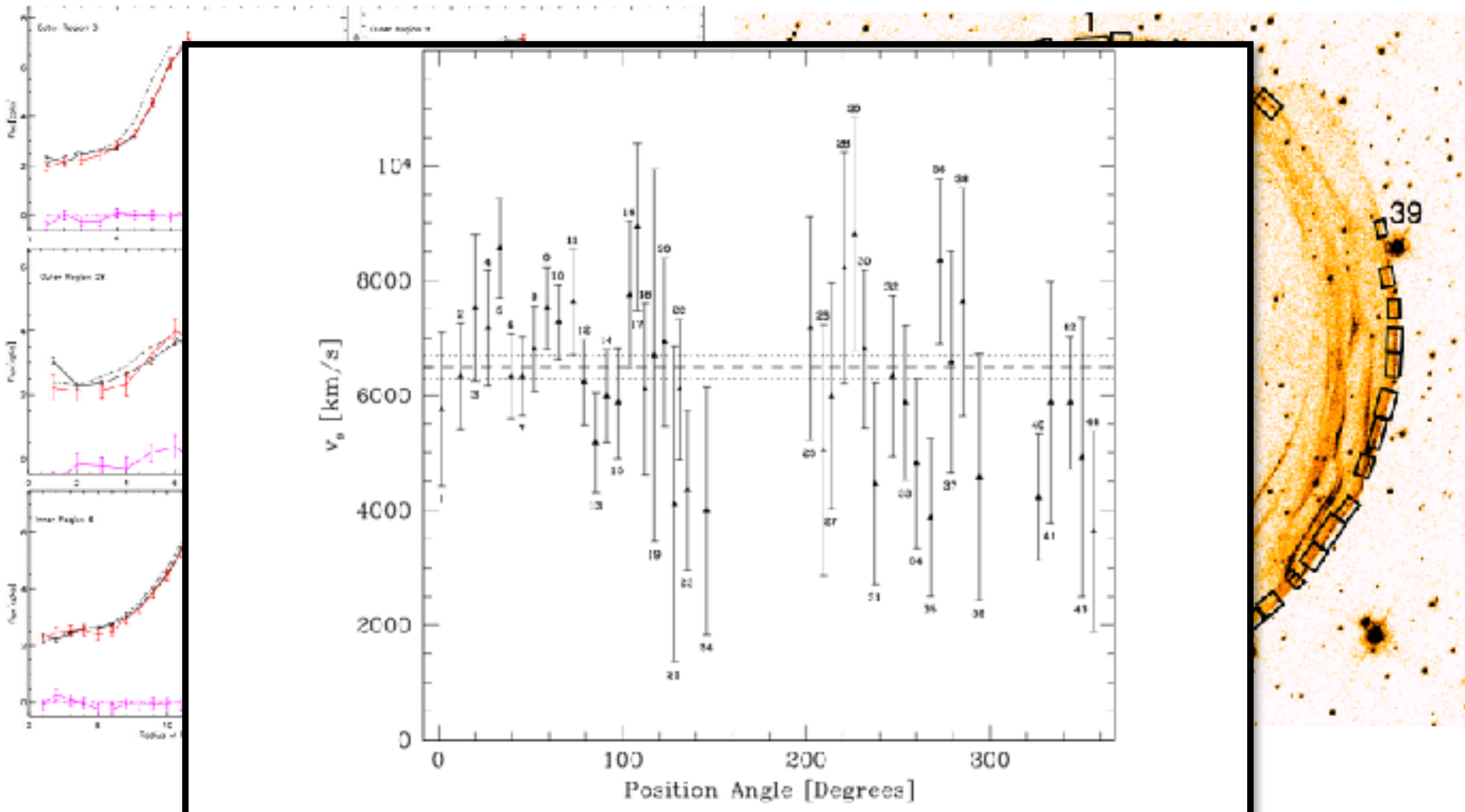
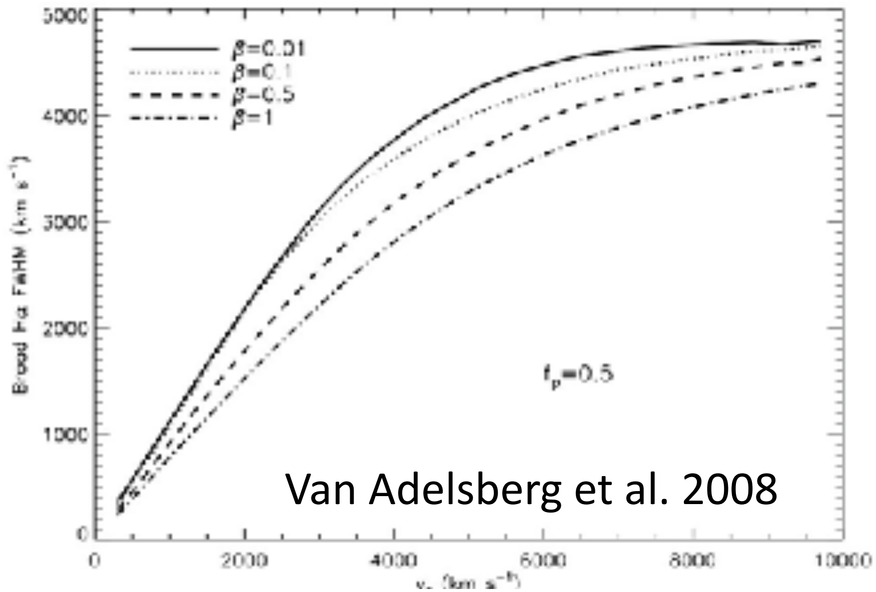


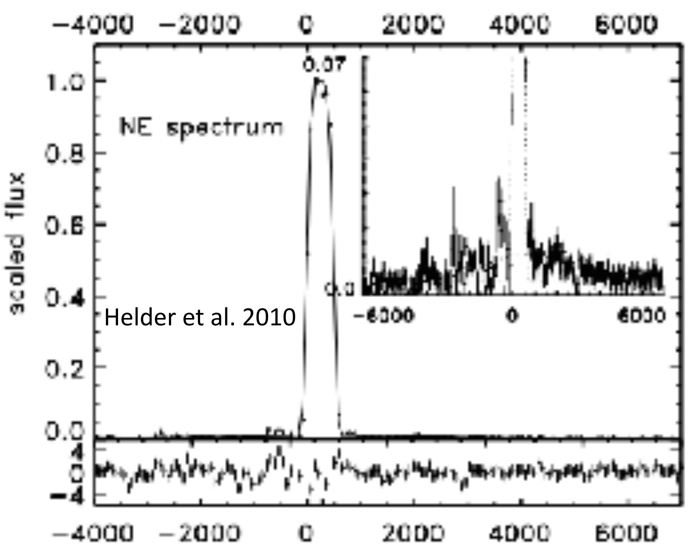
Signatures of Efficient CR Acceleration



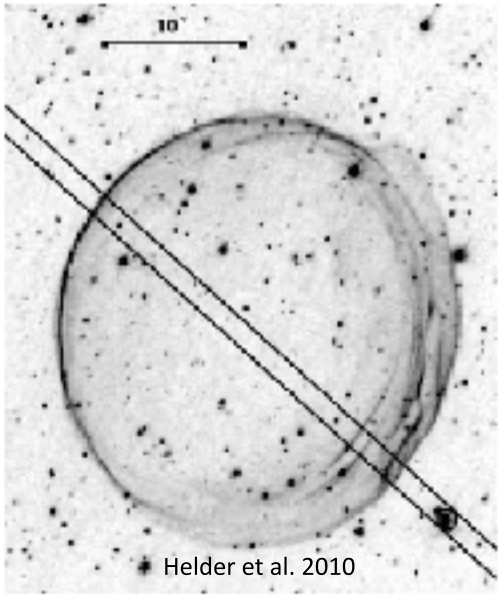
Van Adelsberg et al. 2008

$$k_B T_{e,p} = \frac{3}{16} m_{e,p} V_{FS}^2$$

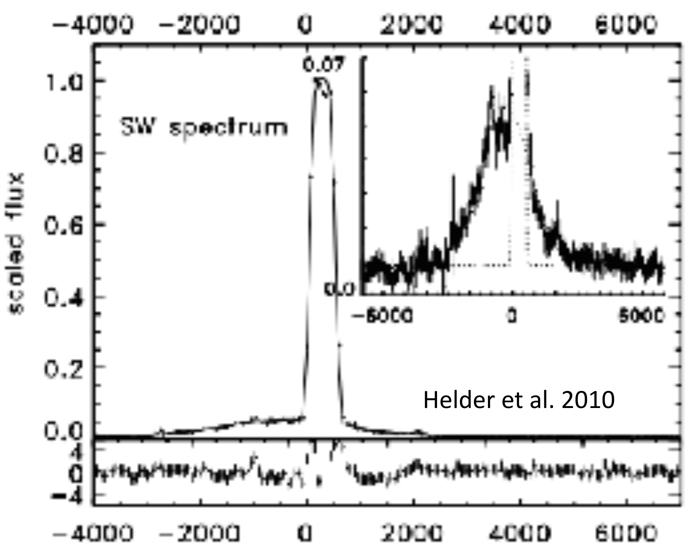
$$\beta = \frac{T_e}{T_p} = \frac{m_e}{m_p}$$



Helder et al. 2010



Helder et al. 2010



Helder et al. 2010

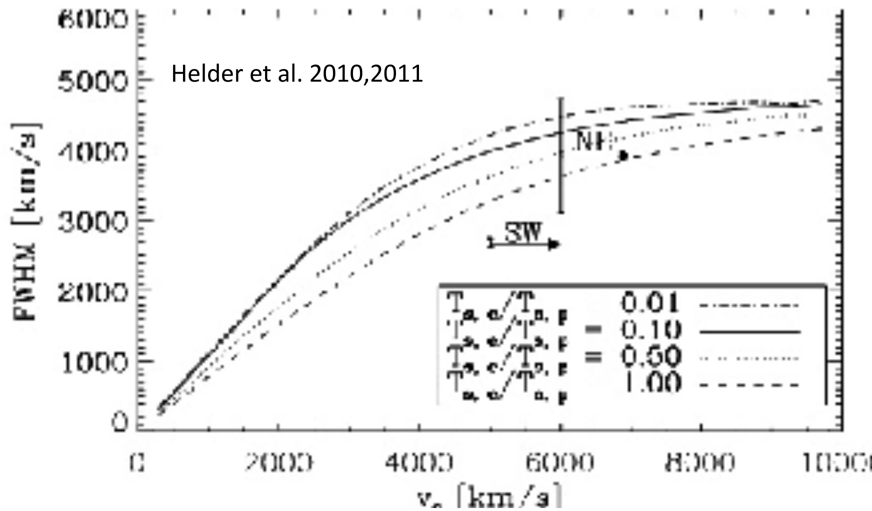
Previous Claims of Temperature Equilibration in SNR 0509-67.5

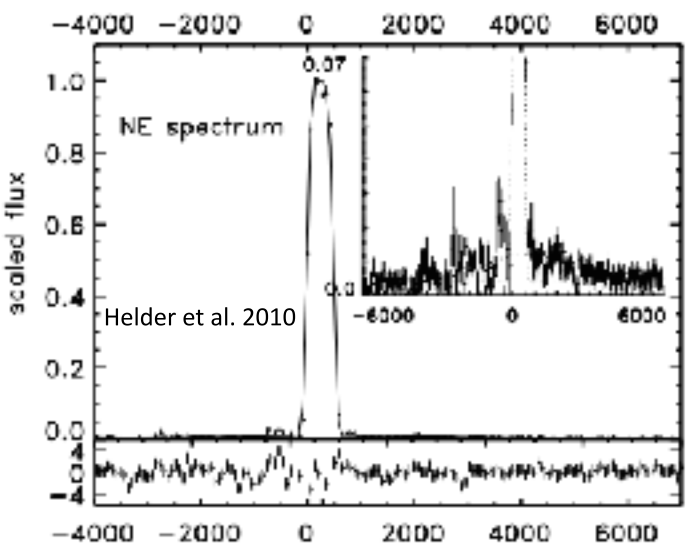
Table 1
Best-fit Parameters for the Hα Lines of both the NE and SW Spectra

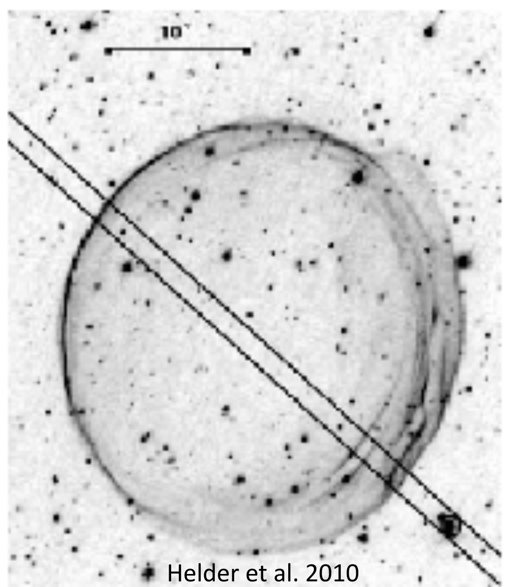
Parameter	SW	NE
Center narrow (km s^{-1})	287.0 ± 1.4	286.0 ± 1.5
Center broad (km s^{-1})	-342 ± 28	459 ± 220
FWHM broad (km s^{-1})	2680 ± 70	3900 ± 800
Total flux[a] (10^{-16} erg s^{-1} cm^{-2} $arcsec^{-2}$)	8.6	5.3
I_b/I_n	0.29 ± 0.01	0.08 ± 0.02

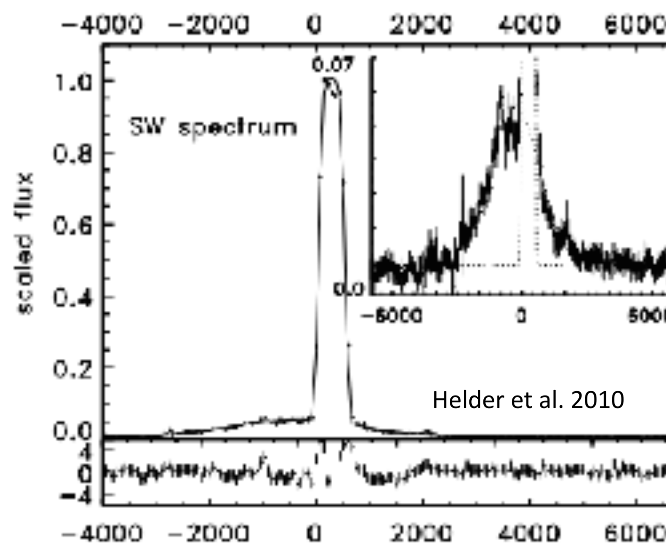
Helder et al. 2010

Notes. [a] Approximate flux calibration based on an observation of a photometric standard star (LTT 2415; Hamuy et al. 1994) taken on 2010 November 11.

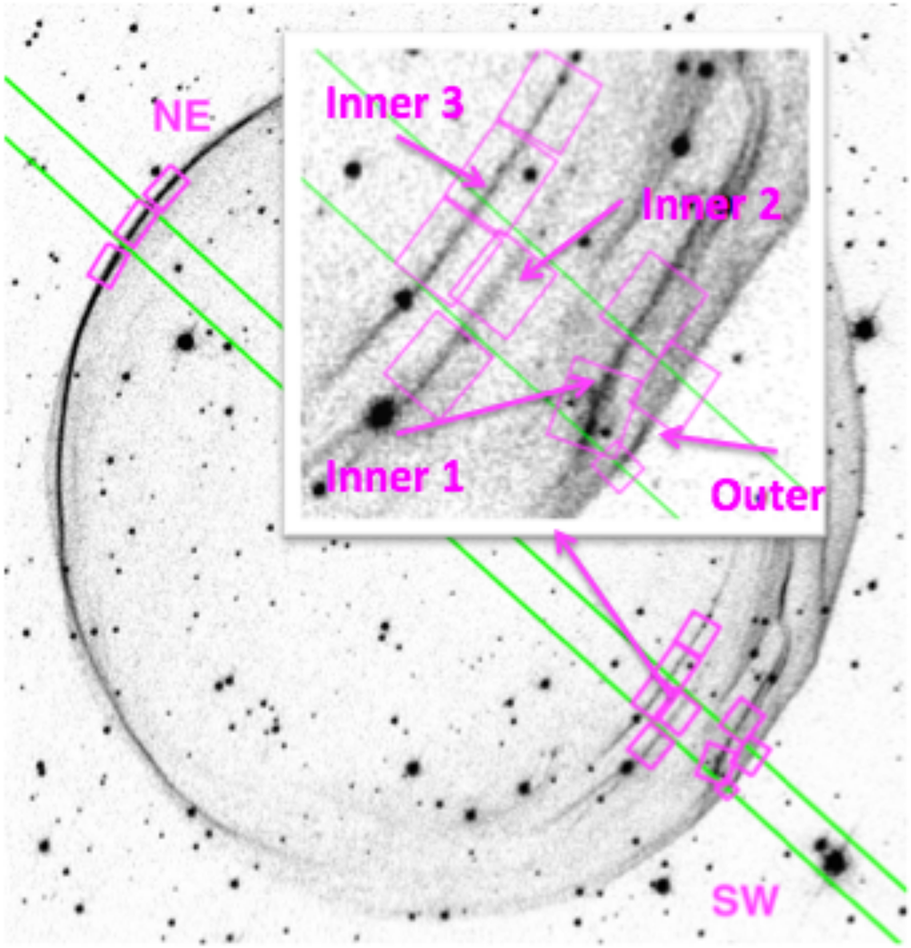


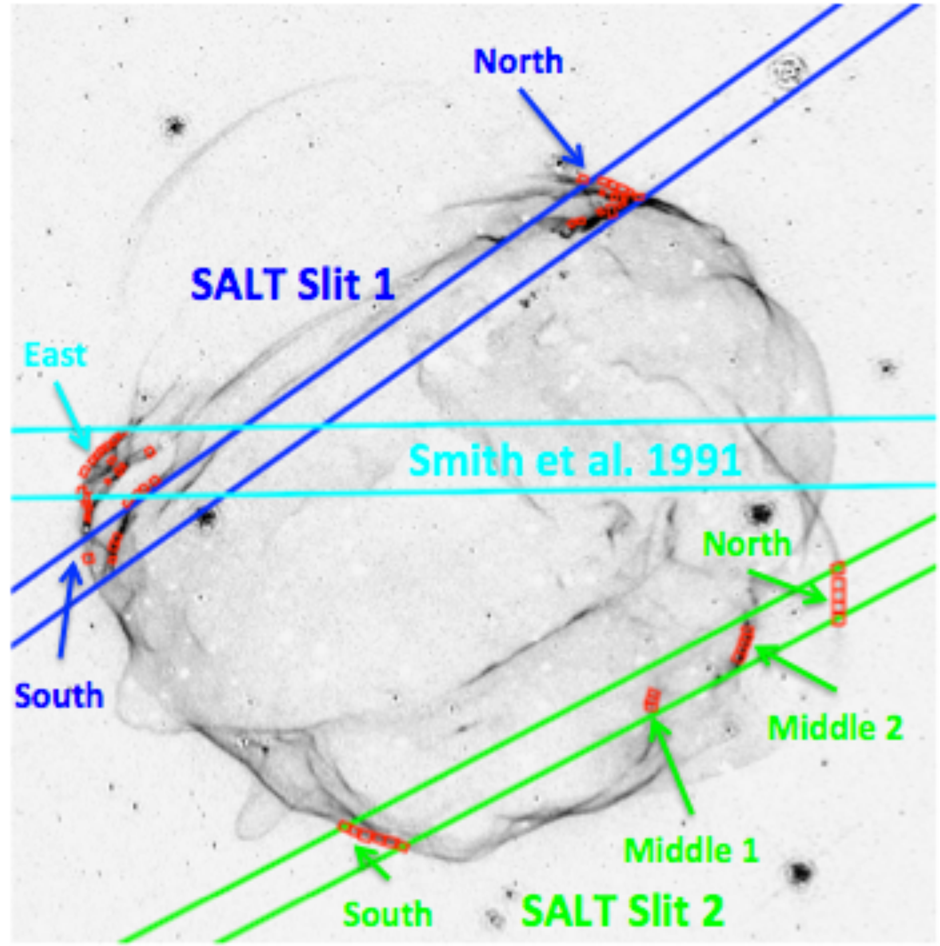




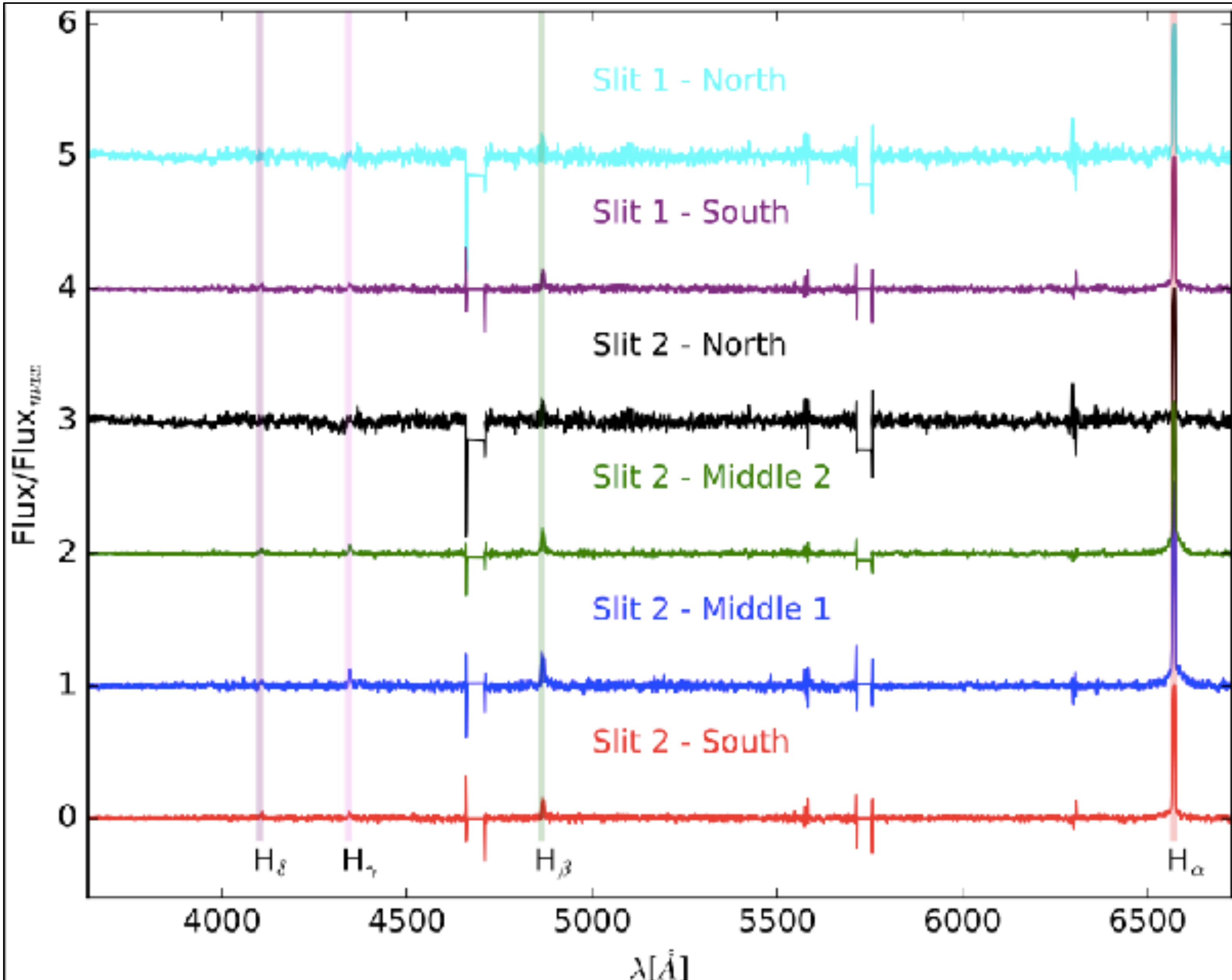


SNR 0509-67.5 and 0519-69.0 Longslit Locations

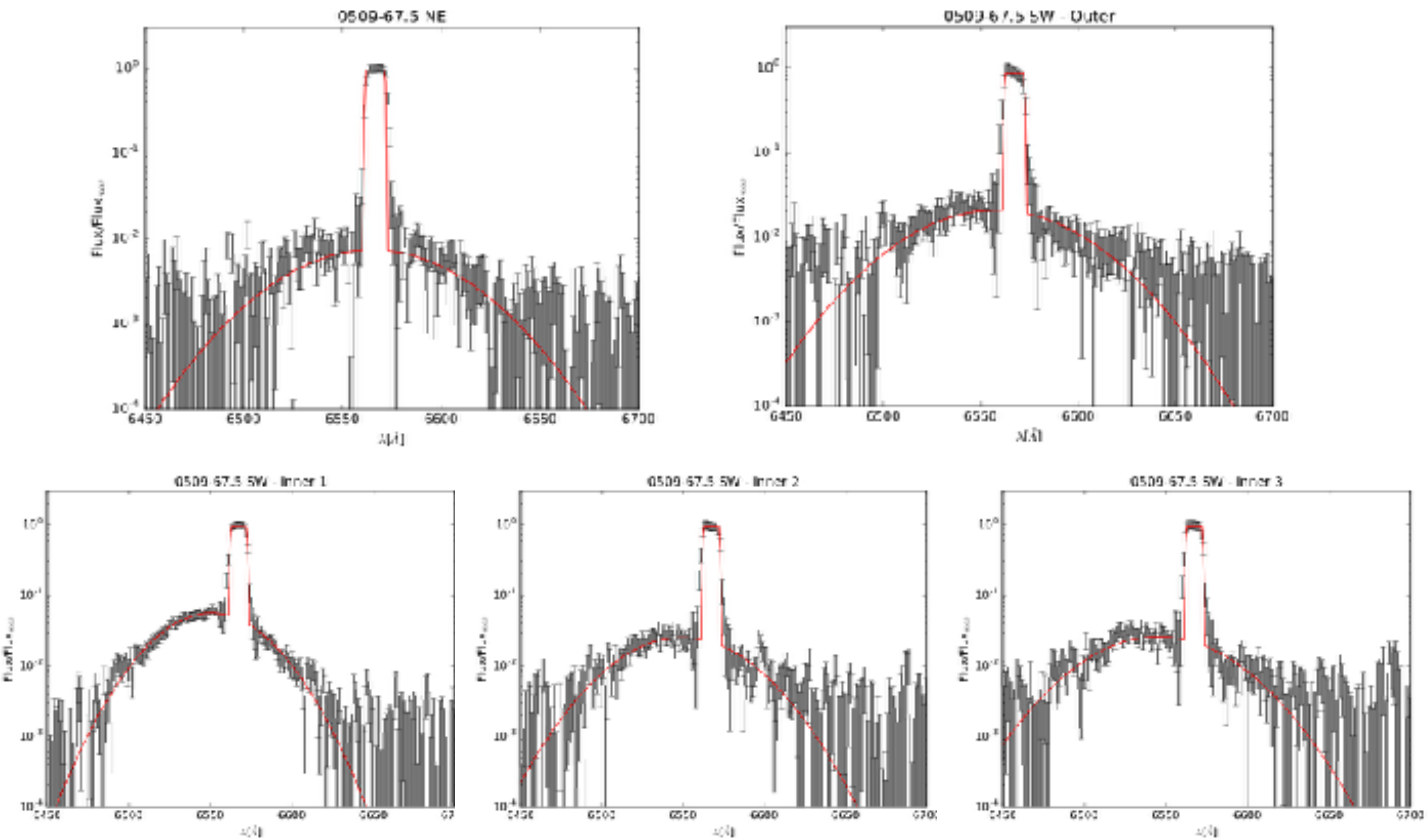




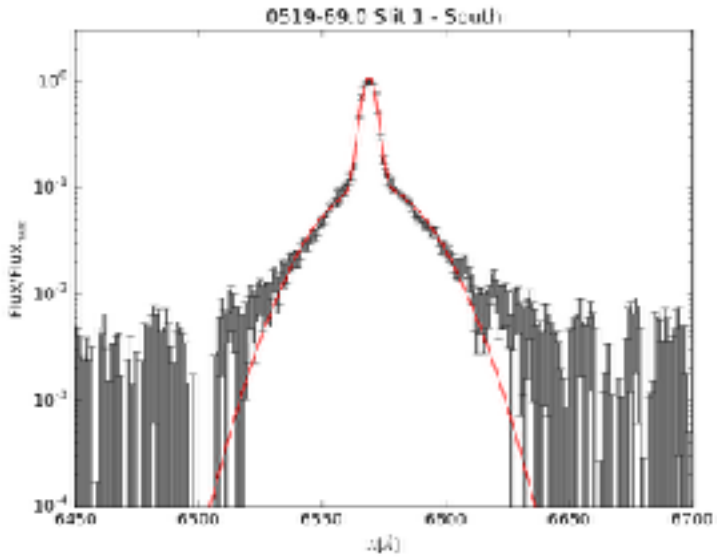
SNR 0519-69.0 Spectra

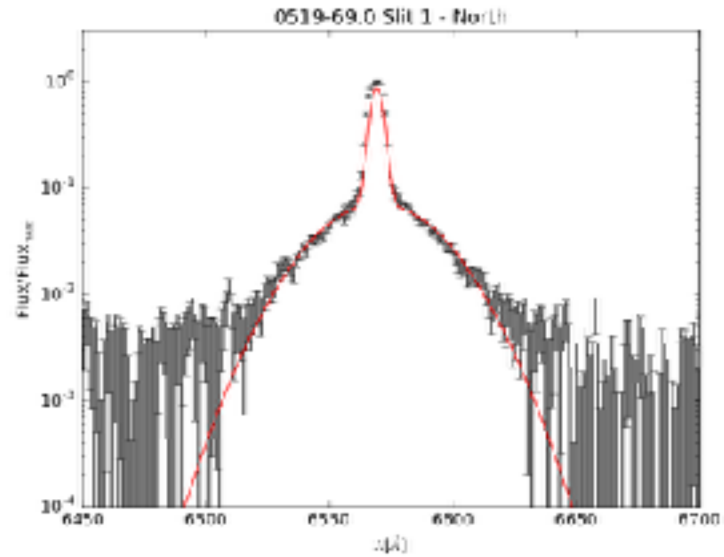


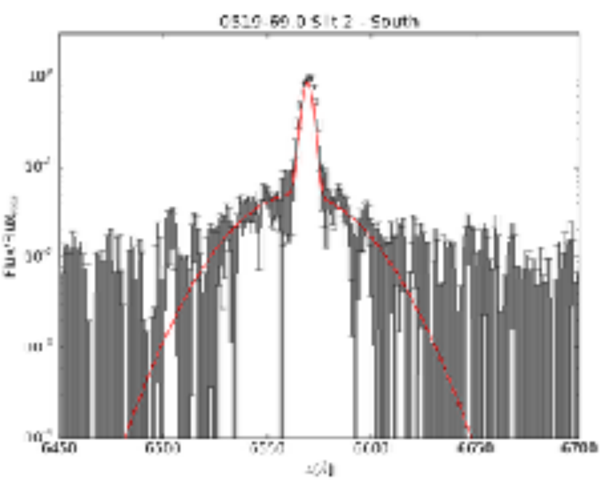
SNR 0509-67.5 FORS2 Spectrum

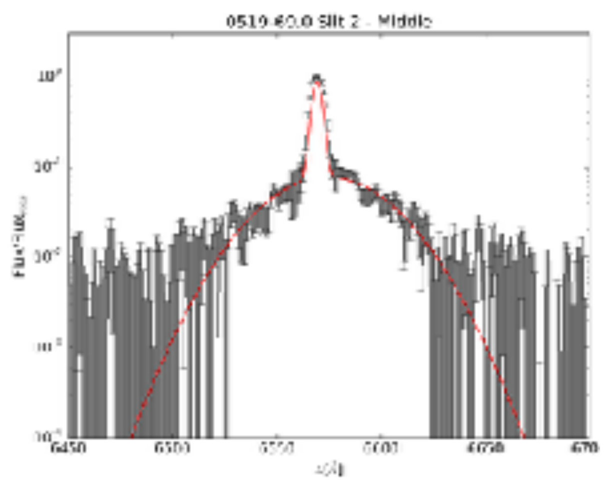


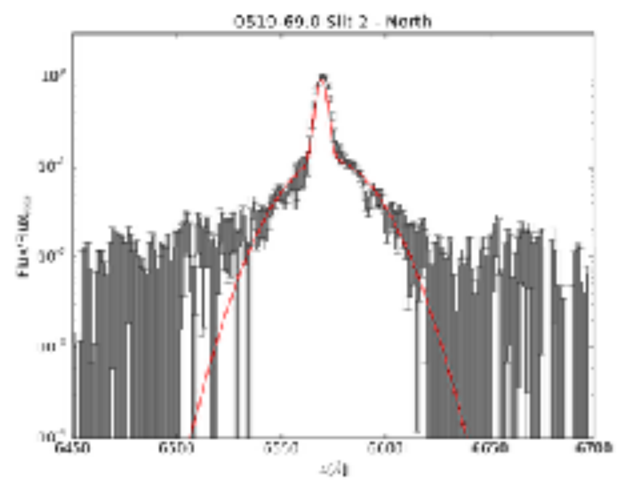
SNR 0519-69.0 SALT Spectra



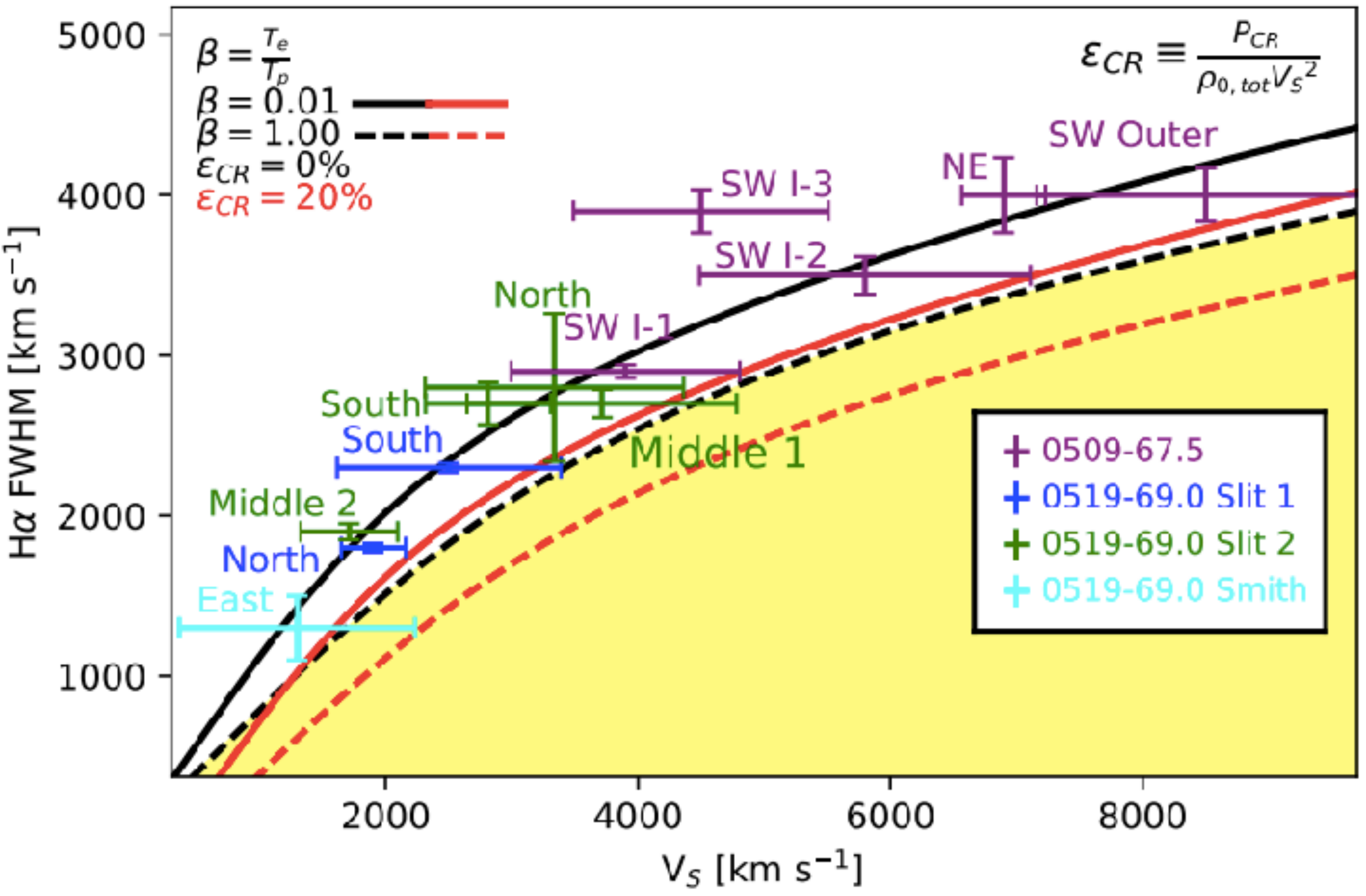








Comparing Shock Speeds to Broad Hα Widths



Constraining CR Acceleration Efficiencies

CR Acceleration Efficiency Limits and Temperature Equilibration Ratios for 0509−67.5 and 0519−69.0

Extraction Region	$\epsilon_{\mathrm{CR;upper}}$ (1)	β_{upper} (2)
0509−67.5 NE	0.13	0.42
0509−67.5 SW Outer	0.29	...
0509−67.5 SW Inner 1	0.28	...
0509−67.5 SW Inner 2	0.33	...
0509−67.5 SW Inner 3	0.00	...
0519−69.0 Slit 1 North	0.21	0.84
0519−69.0 Slit 1 South	0.35	...
0519−69.0 Slit 2 North	0.46	...
0519−69.0 Slit 2 Middle 2	0.19	0.56
0519−69.0 Slit 2 Middle 1	0.41	...
0519−69.0 Slit 2 South	0.13	0.38
0519−69.0 Smith '91 East	0.66	...
0509 − 67.5	0.06	0.47
0519 − 69.0	0.11	0.55
All Points	0.07	0.25

Note. — (1) - Upper limits at 95% confidence for CR acceleration efficiency assuming no equilibration between electron and ion temperatures ($\beta = 0.01$).
(2) - Upper-limit values at 95% confidence for β, unless it cannot be unconstrained between the limits of $0.01 \leq \beta \leq 1$.

$$\epsilon_{CR} = \frac{P_{CR}}{\rho_{0,tot} {V_{SH}}^2}$$

$$\epsilon^* = \frac{P_{CR}}{\rho_{0,ion} {V_{SH}}^2} \equiv \frac{\epsilon}{\chi}$$

SNR 0509-67.5

$\epsilon^* < 12\%$

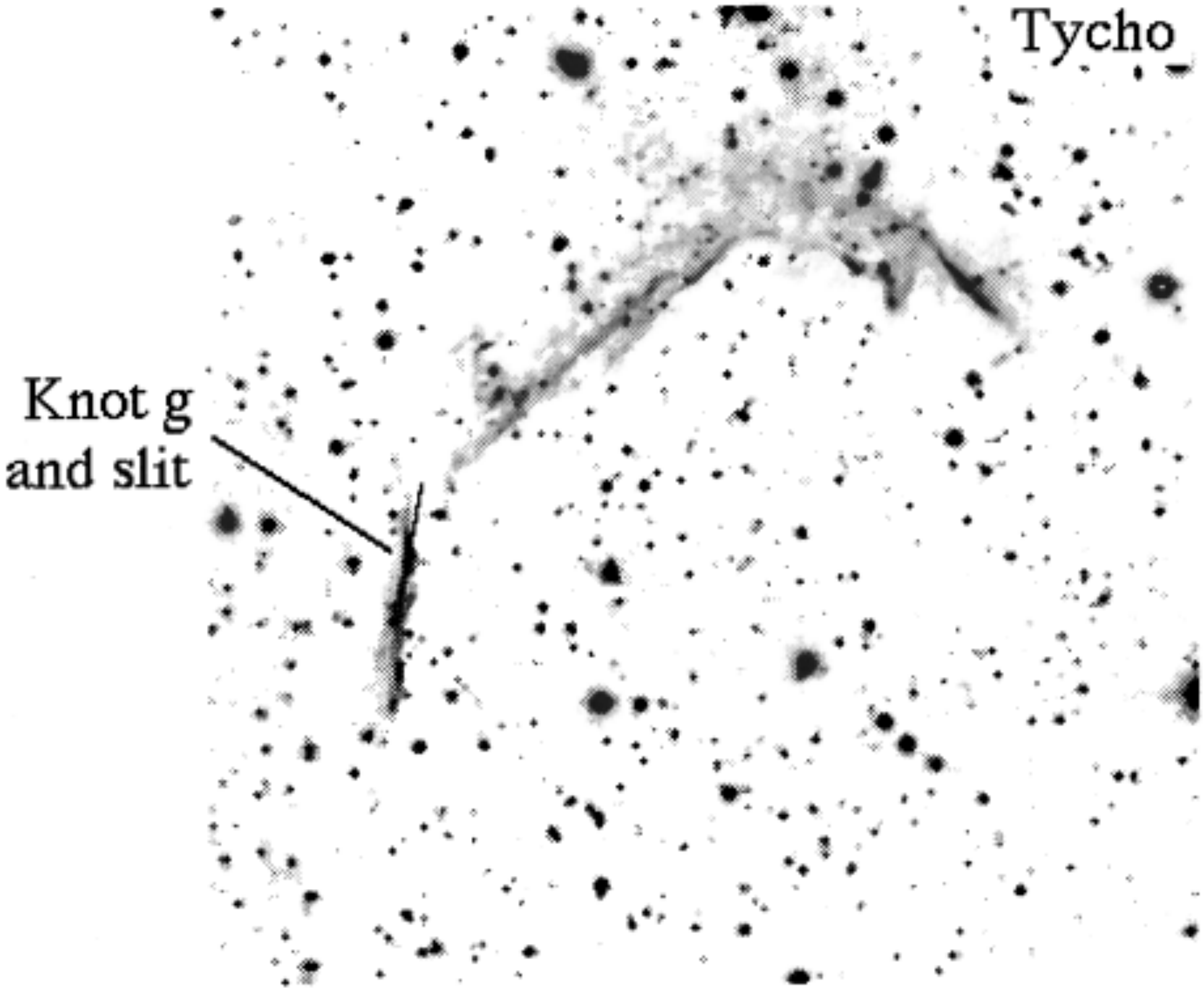
SNR 0519-69.0

$\epsilon^* < 22\%$

Full Ensemble

$\epsilon^* < 14\%$

Comparison to Tycho's SNR



Smith et al. 1991

Comparison to Tycho's SNR

- Using hydrodynamic modeling, Slane et al. (2014) concluded that:
  - ≈16% of KE has been converted into relativistic particles
  - ≈11% of these particles have escaped as CRs
  - Diffuse shock acceleration efficiency of 26%

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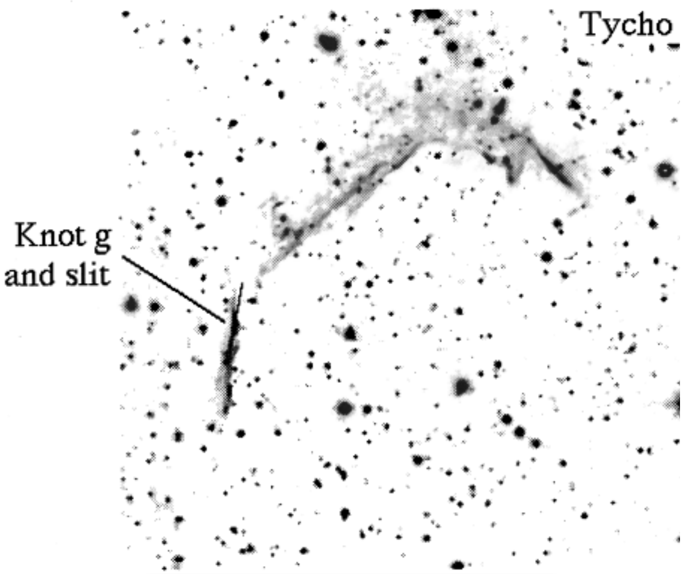
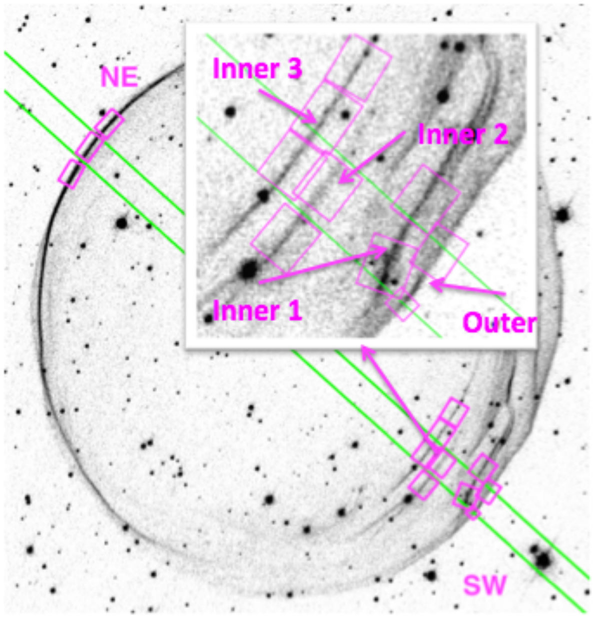
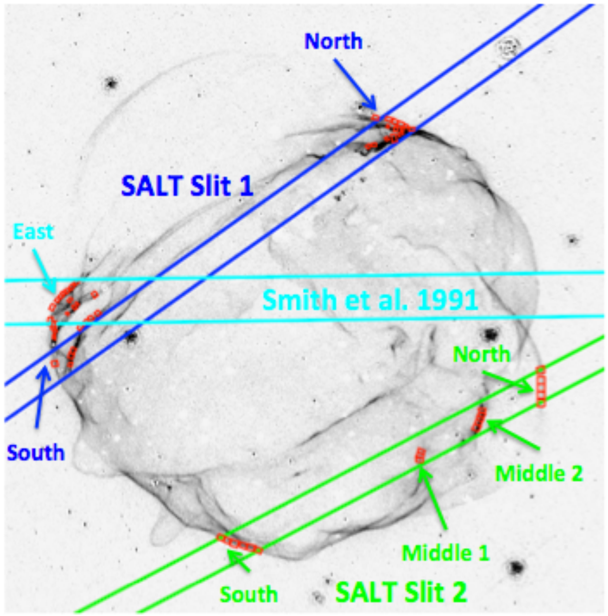


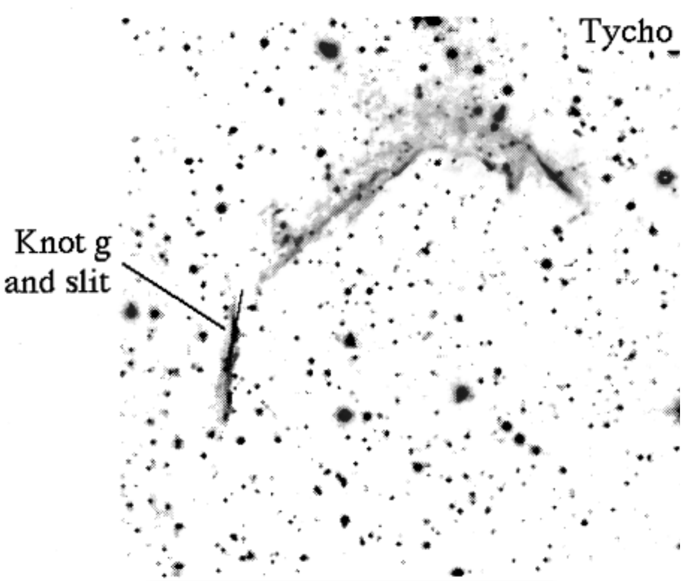
Smith et al. 1991





Conclusions

- Bright BD shocks are regions of minimal CR acceleration efficiencies
- SNRs 0509-67.5 and 0519-69.0 accelerate CRs with significantly lower efficiency than Tycho's Remnant
- Further work needed to break degeneracy between post-shock temperature ratios and CR acceleration efficiencies



Smith et al. 1991