Hα imaging spectroscopy of Balmer- dominated shocks in Tycho's SNR

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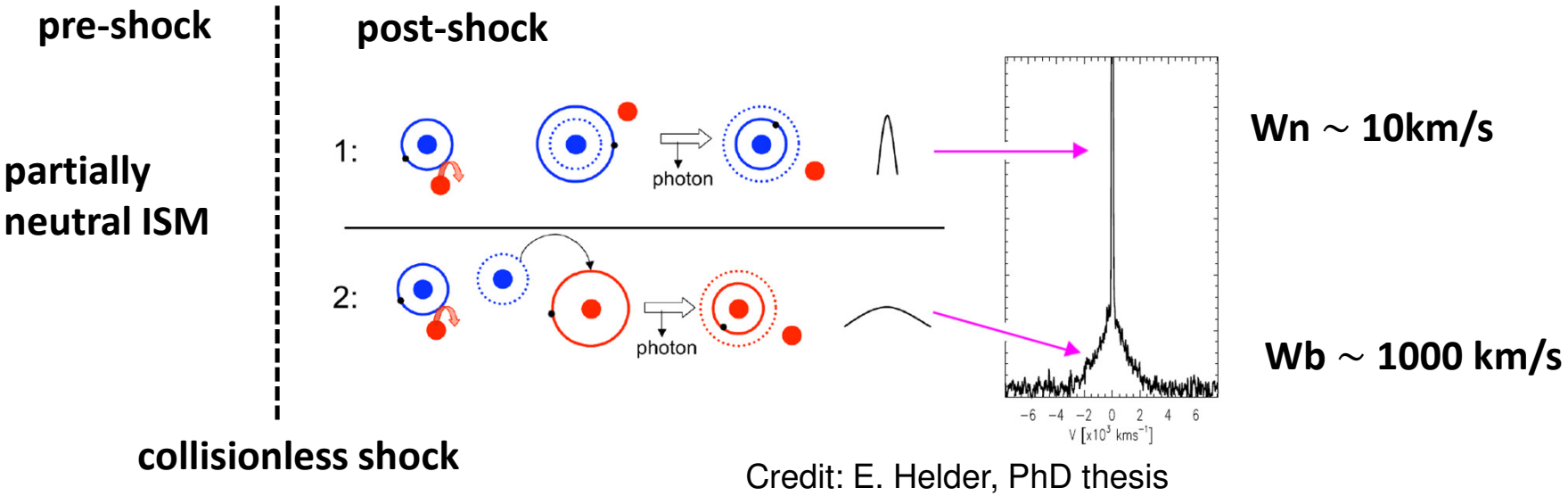
Balmer-dominated shocks

- Colllisionless, non-radiative shocks with strong two-component hydrogen lines.



Credit: E. Helder, PhD thesis

- Studying physical conditions in the shock: shock velocity and electron-to-proton equilibration ratio.

Precursors

➢ **Wn = 30–50 km/s** → pre-shock temperatures **20 000-60 000 K** → no neutral H at this temperature → no Hα emission…but we still see it!

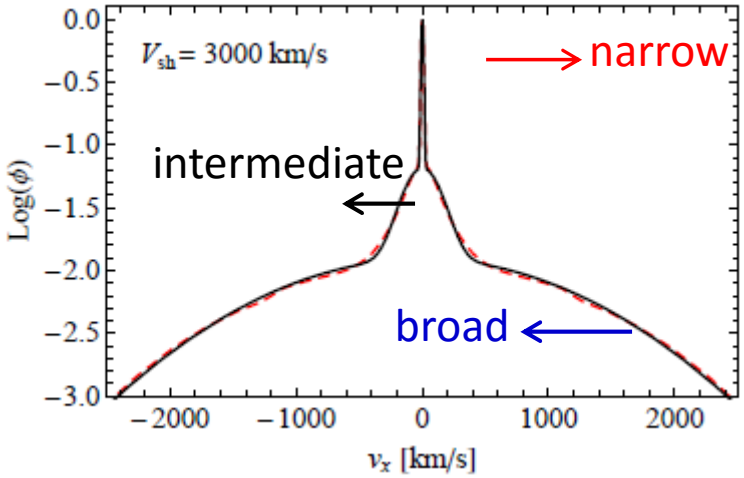
➢ A narrow line broadened beyond 20 km/s gives direct evidence of the non-thermal particle presence in the shock precursor (Morlino et al. 2013).

CR precursor:

Wn=Wn(p_{max},η_{th},Vs, ε, β_{down}, β_{up})

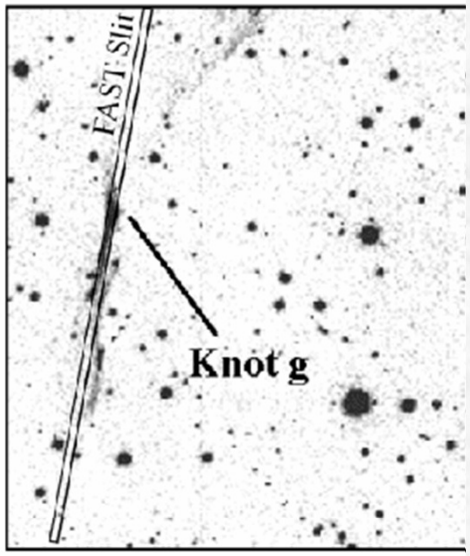
Broad-neutral precursor:

Wi=Wi(Vs,f_n,ε,η_{th},β_{down},β_{up})



Previous narrow Hα observations in NE Tycho

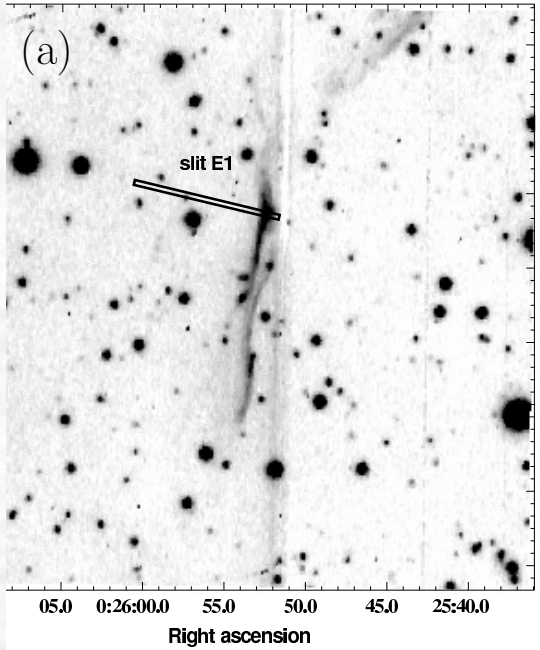
KPNO



Ghavamian et al. (2000)

Wn = 44±4 km/s
Wi≈ 150 km/s

HST

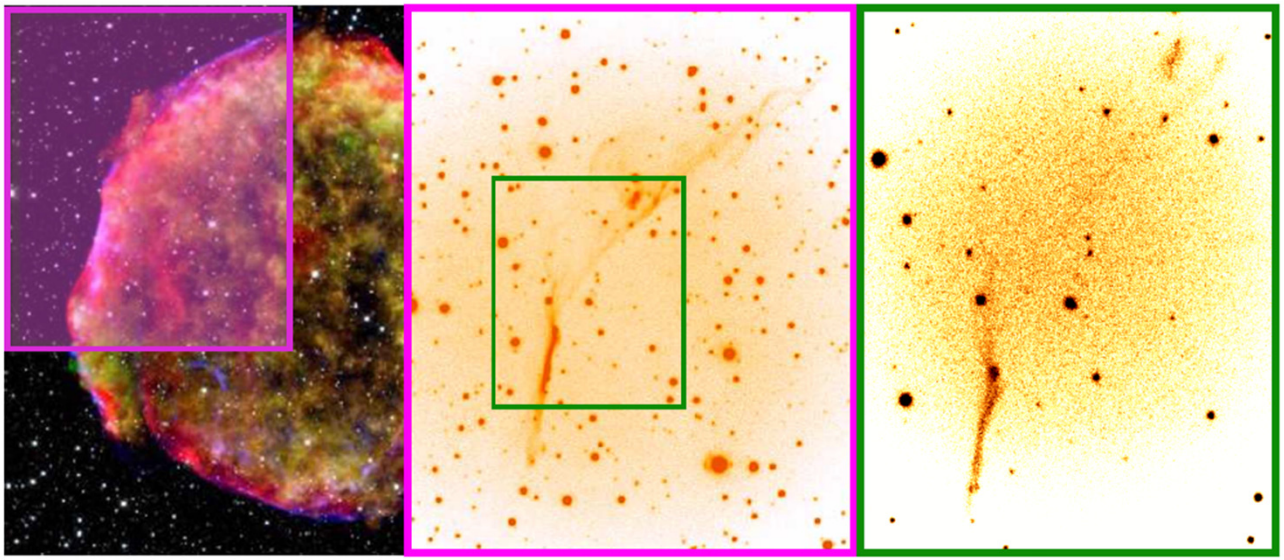


HDS Subaru

Lee et al. (2007)

Wn= 45.3±9.0 km/s
Wi= 108±4 km/s

Optical shocks in the NE rim of Tycho: Narrow Hα line component



GHαFaS on the WHT

d ~ 2.3 kpc

D ~ 8'

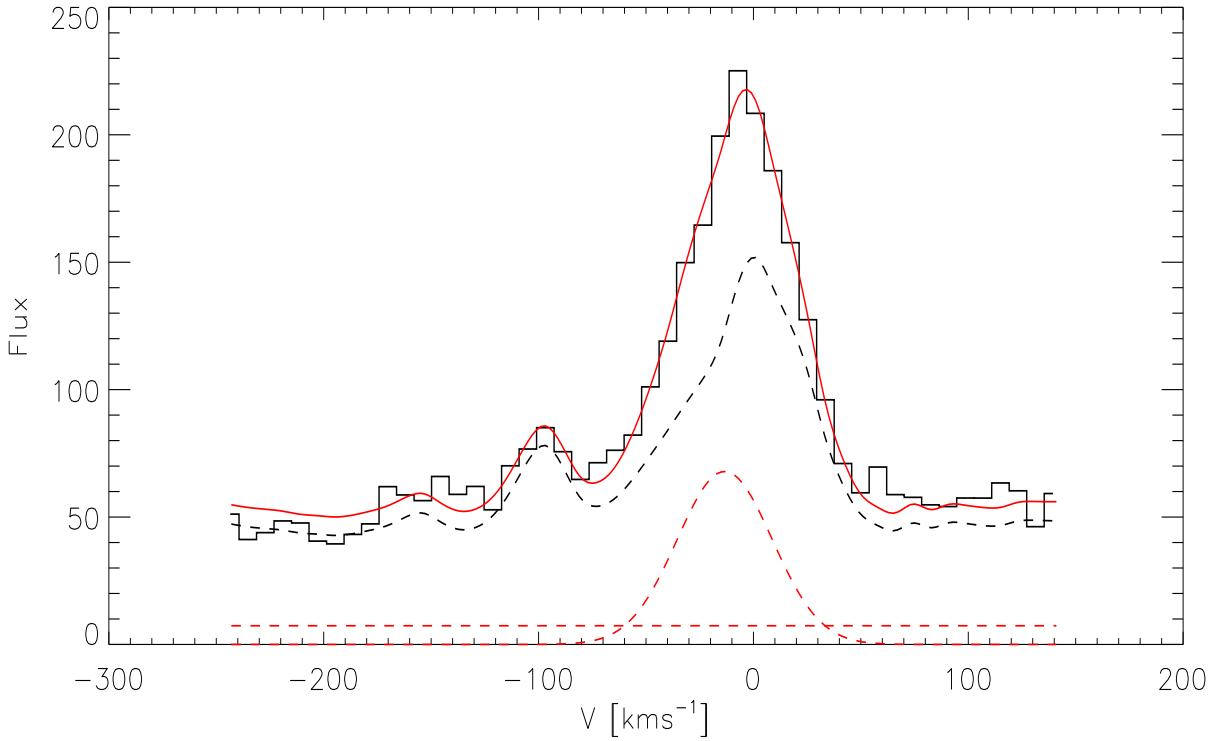
3.5 hours on-source

Mid-panel: ACAM camera on WHT; Hα narrow band imaging; FOV 4'x4', pixsize 0.125''.

Right-panel: GHαFaS Fabry-Pérot interferometer; FOV 3.4'x3.4', pixsize 0.2'', spectral coverage 400 km/s, spectral resolution 8 km/s.

Resolving the narrow Hα component only

One spatial bin out of 73



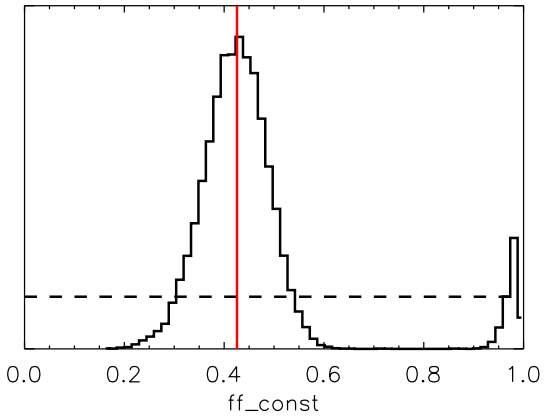
Bkg model (dashed black) + Intrinsic model (dashed red)

We use MCMC to calculate posterior from data and prior.

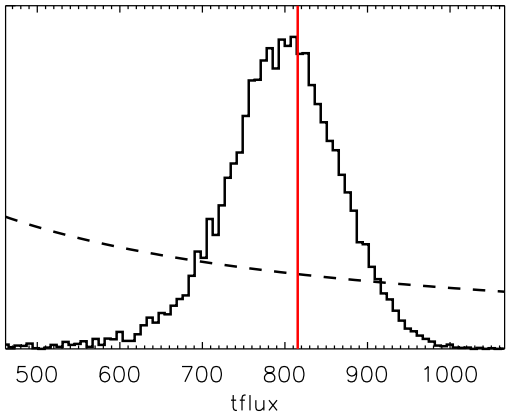
Deviations from NL model – Bayes factor.

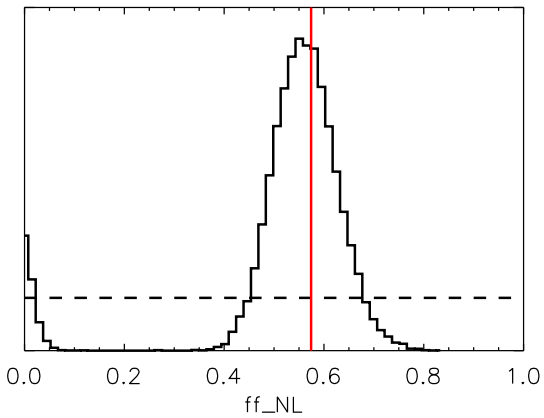
NL model posterior

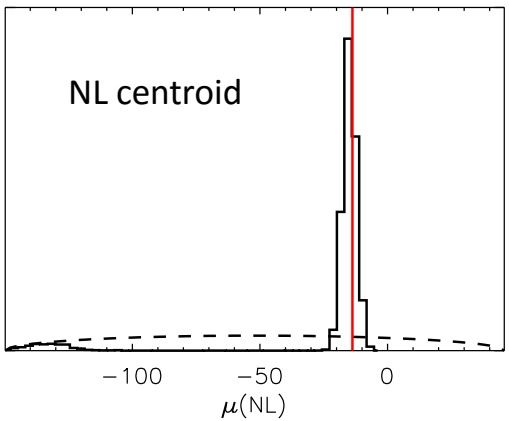
Flux fractions in the continuum + line

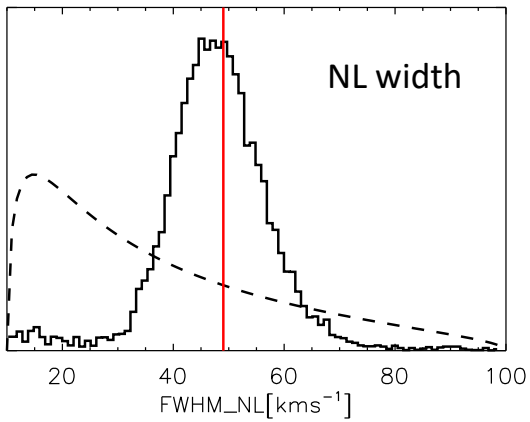


Model flux

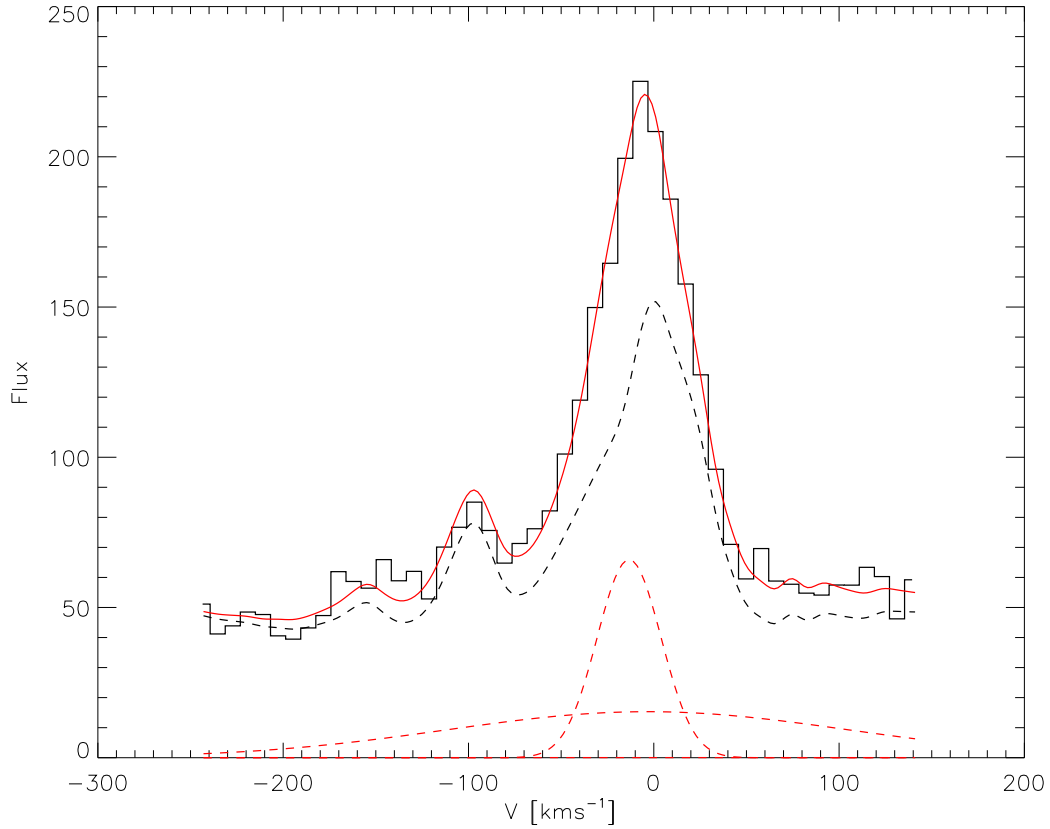




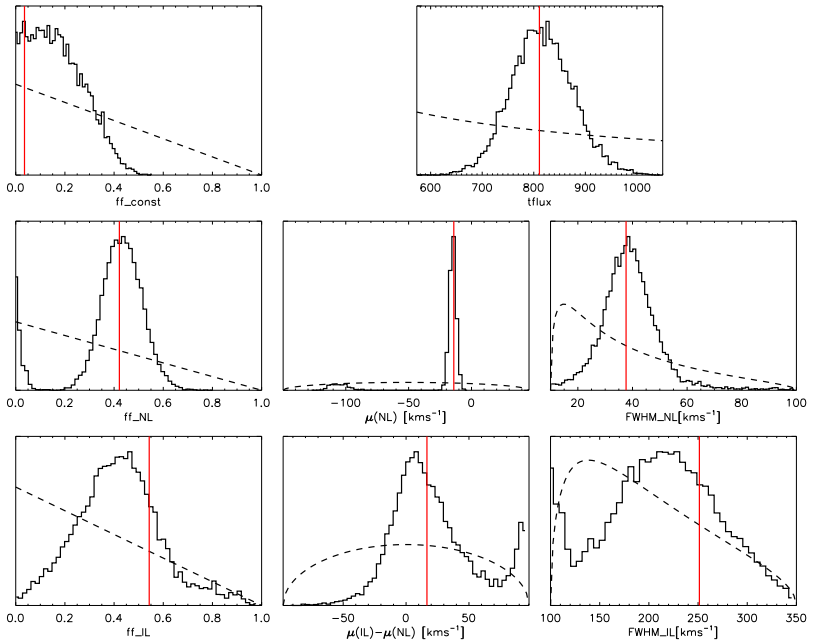




NLIL model



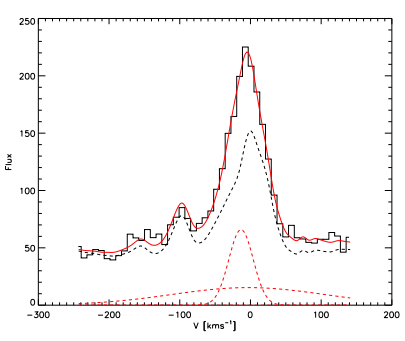
7 models:
0L, NL, 2NL, NLNL, NLIL, 2NLIL, NLNLIL

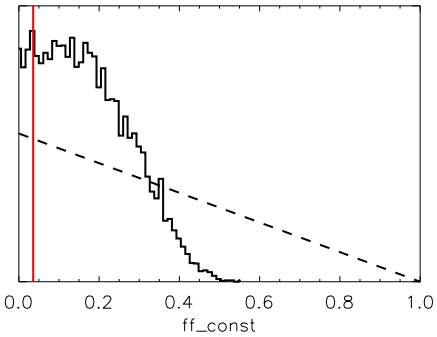


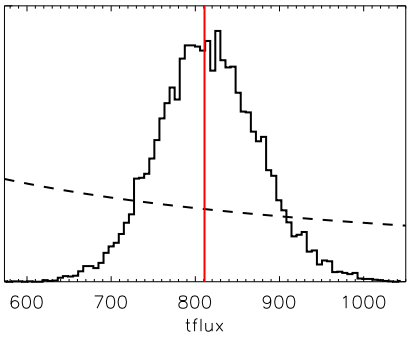
NLIL model posterior

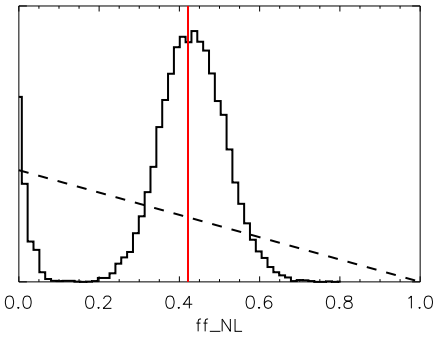
Flux fractions in the continuum + lines

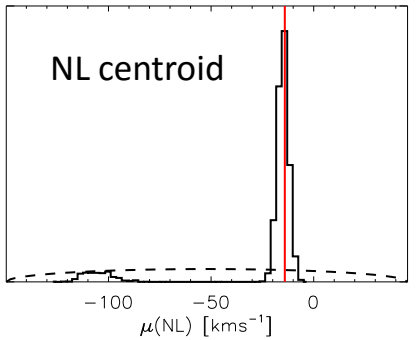
Model flux

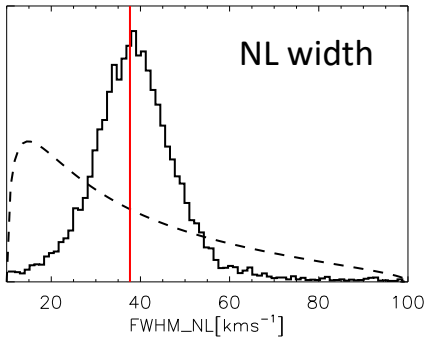




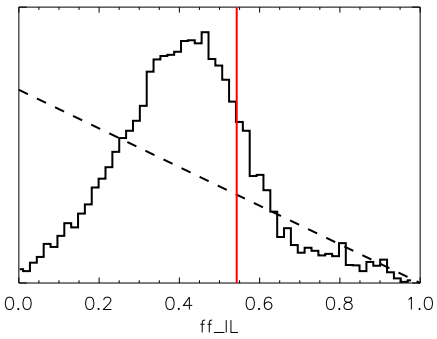


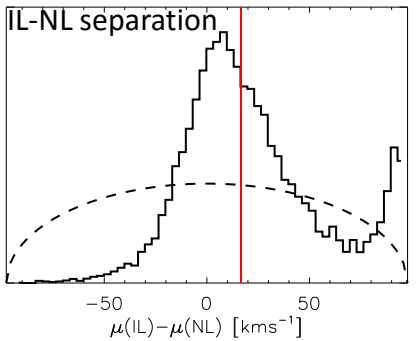


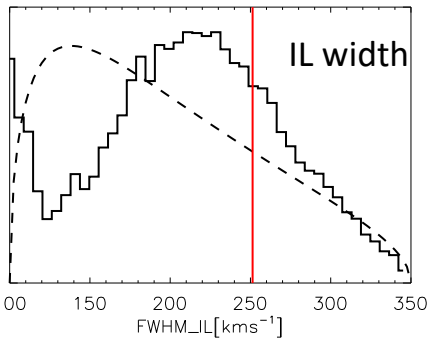




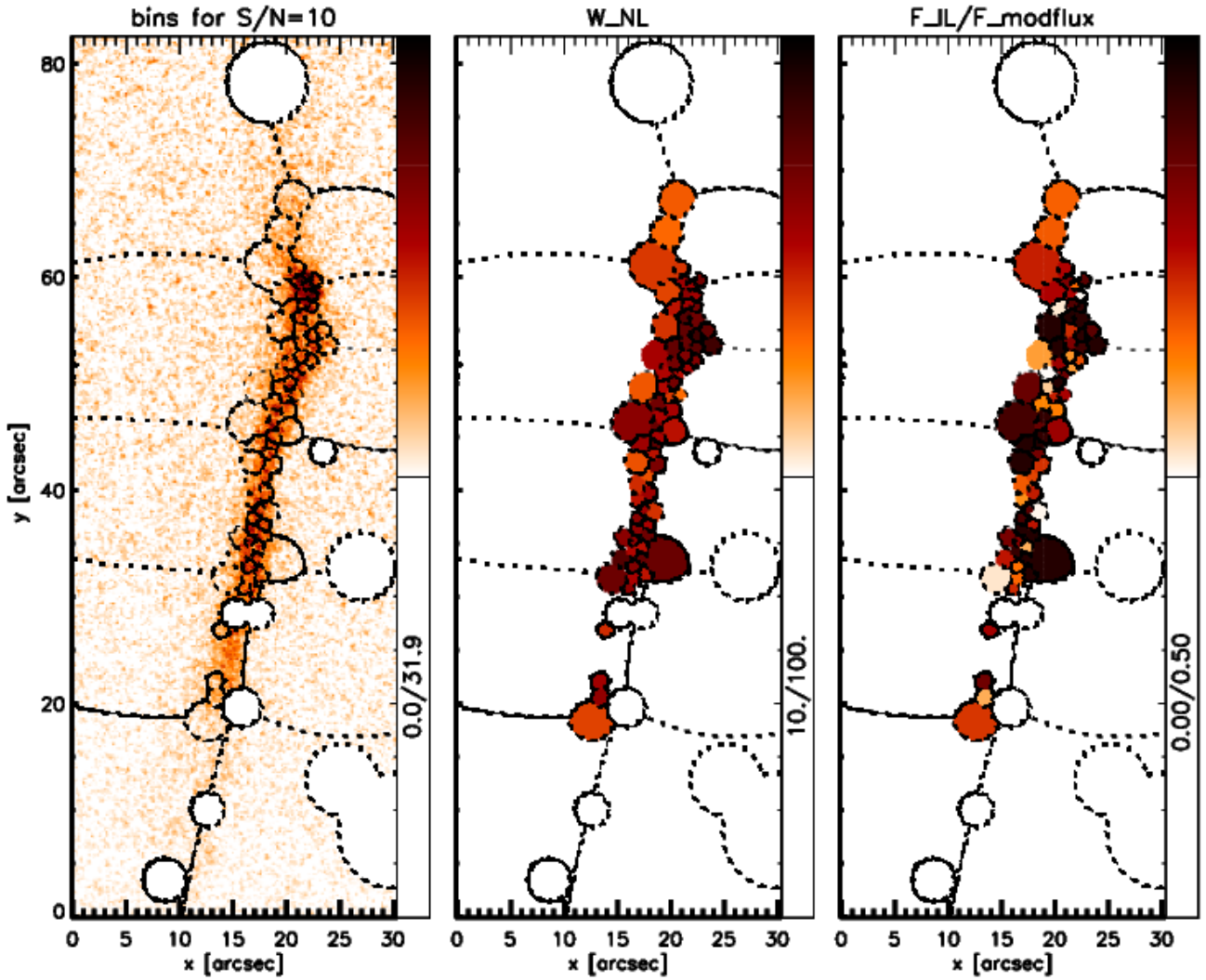
Log(E_{il}/E_{nl}) = 1 dex



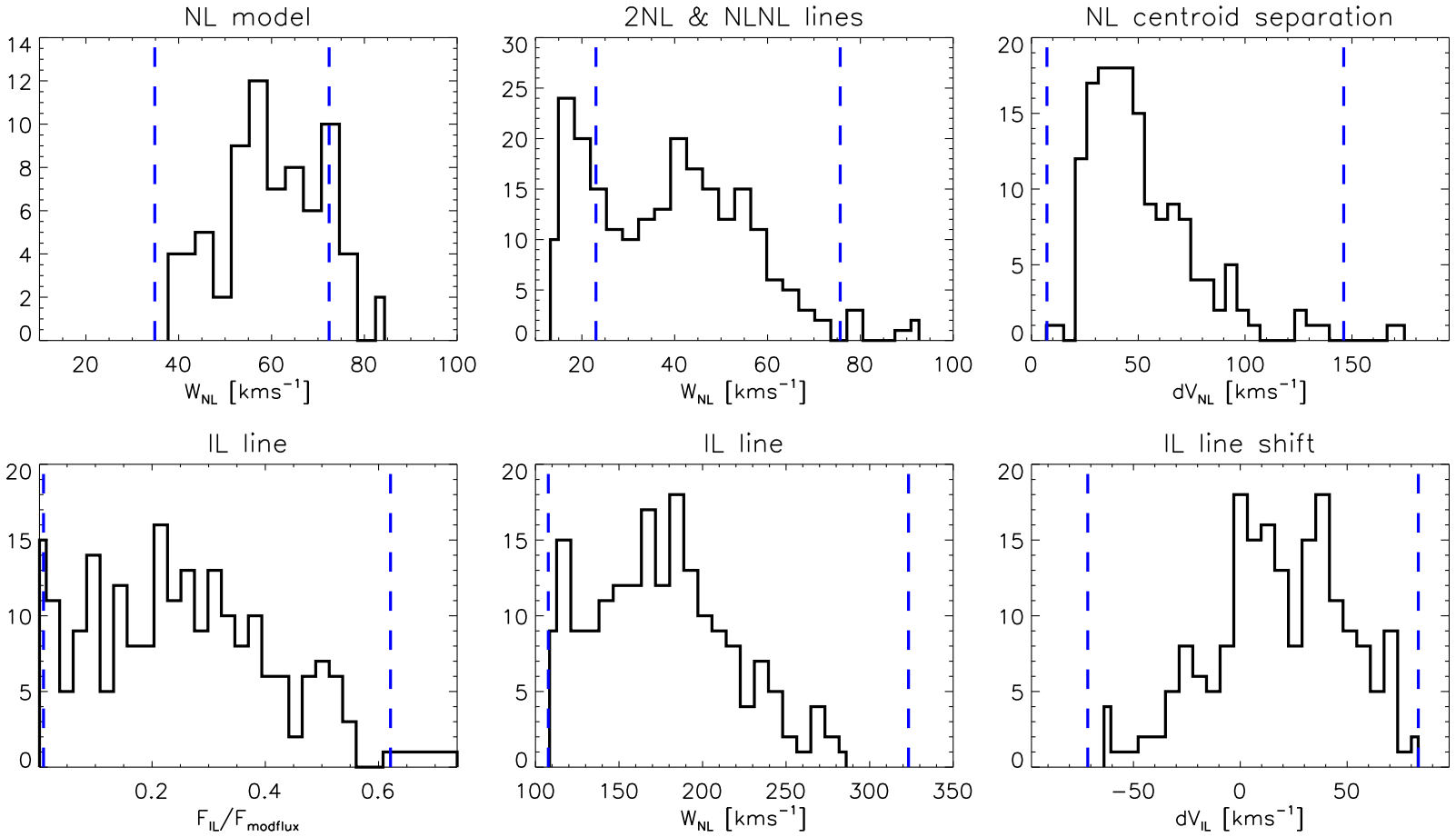




Spatial maps: S/N, narrow line width, and flux of intermediate line



73 spatial bins results



Results Summary

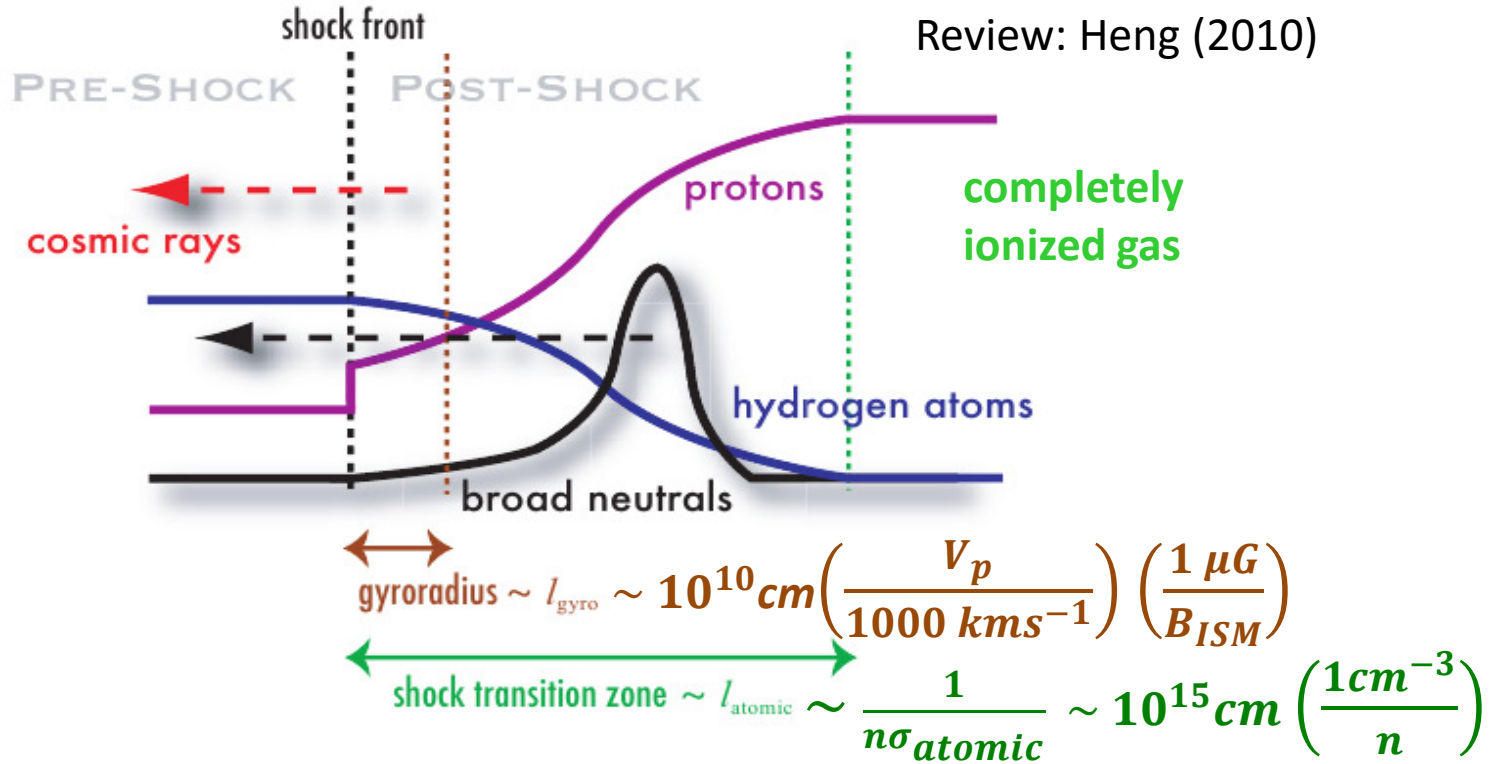
a) Spatially resolved the entire projected NE filament for the first time while also spectrally resolving NL

b) Single-line fit: width >> 20 km/s (~ 60km/s on average)
→ **clear confirmation of CR precursor**

c) Need for additional (intermediate) component
Wi≈100-300 km/s + fn ≈ 0.9 in NE rim Tycho
→ **broad-neutral precursor**

THANK YOU FOR YOUR ATTENTION!

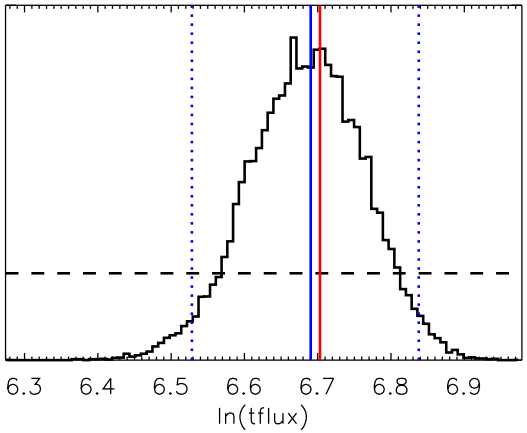
Balmer-dominated shocks

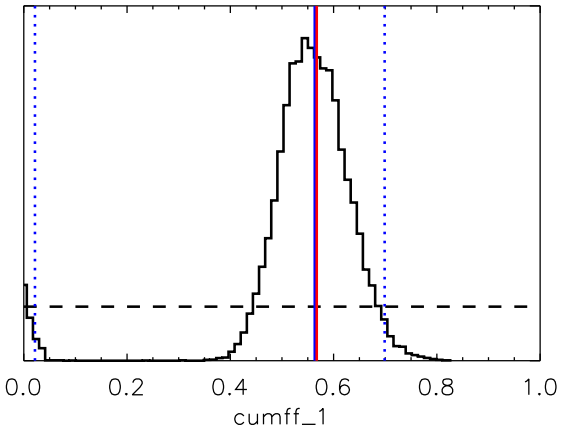


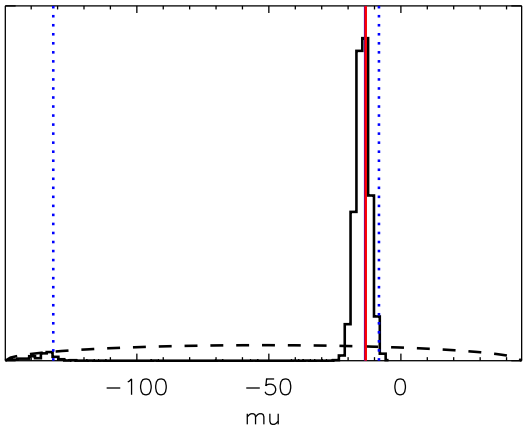
Review: Heng (2010)

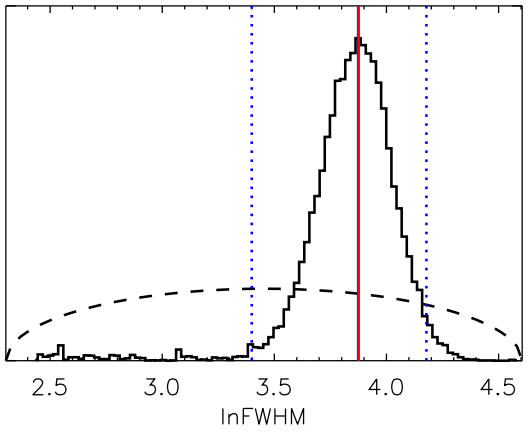
At shock velocities ~1000 km/s, three atomic reaction are comparably likely:
1) excitation
2) ionization
3) **charge exchange/transfer:** creates a secondary population of hydrogen atoms (**broad neutrals**) which encode information about the post-shock gas.

Additional figures: NL model posterior









Additional figures: NLIL model posterior