מכון ויצמן למדע
WEIZMANN INSTITUTE OF SCIENCE

Balmer-dominated shocks in Tycho's SNR: Omnipresence of CRs

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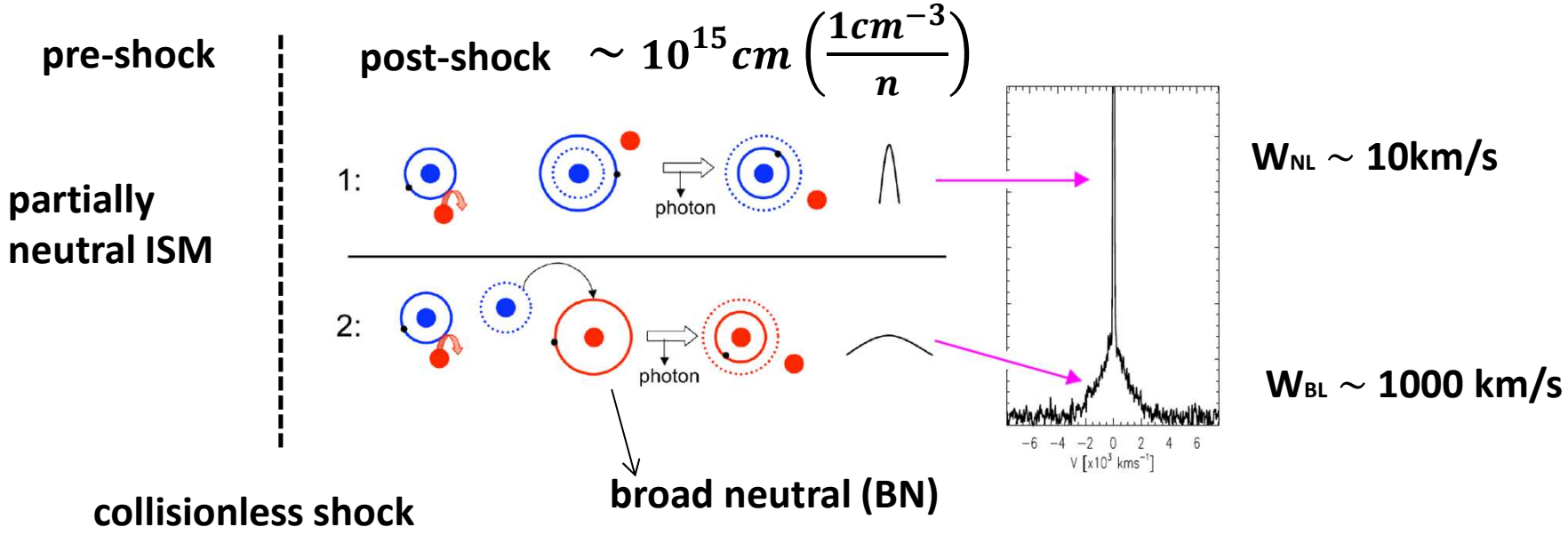
Balmer-dominated shocks (standard picture)

- Spectral characteristic: two-component Hα line (Chevalier & Raymond, 1978, ApJ,225)



- Each line represented by a Gaussian

- Estimates: T_{pre}, T_{pos}, V_s, D, $\beta = T_e/T_p$

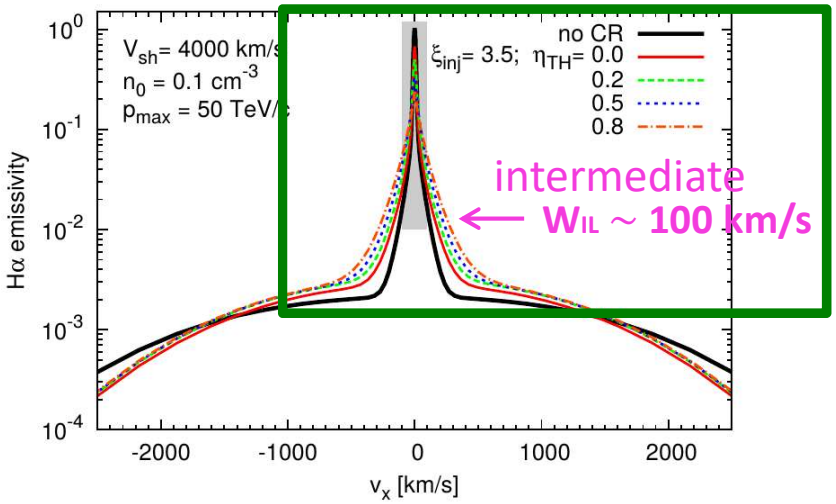
Balmer-dominated shocks with precursors

➢ Various SNRs show Hα-line W_{NL} >> 20 km/s → Tpre >> 20 000 K → no neutral H on this temperature → no Hα emission…but we still see it!

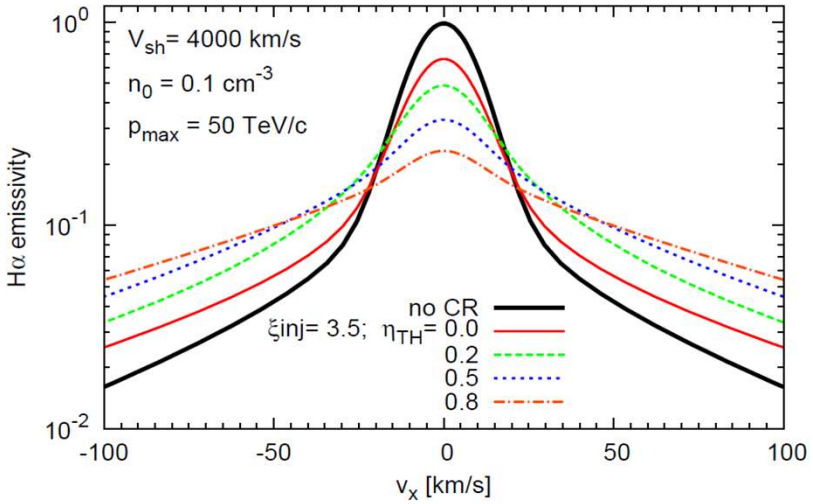
➢ <u>Precursors:</u>

CR precursor: **W_{NL} >> 20 km/s** + **$\Delta\mu_{NL}$** (inclined shock)
BN precursor: **W_{IL}~ 100 km/s**, W_{NL} = const

$W_{IL}=W_{IL}(f_n, V_s, \varepsilon, \eta_{th}, \beta_{down}, \beta_{up})$

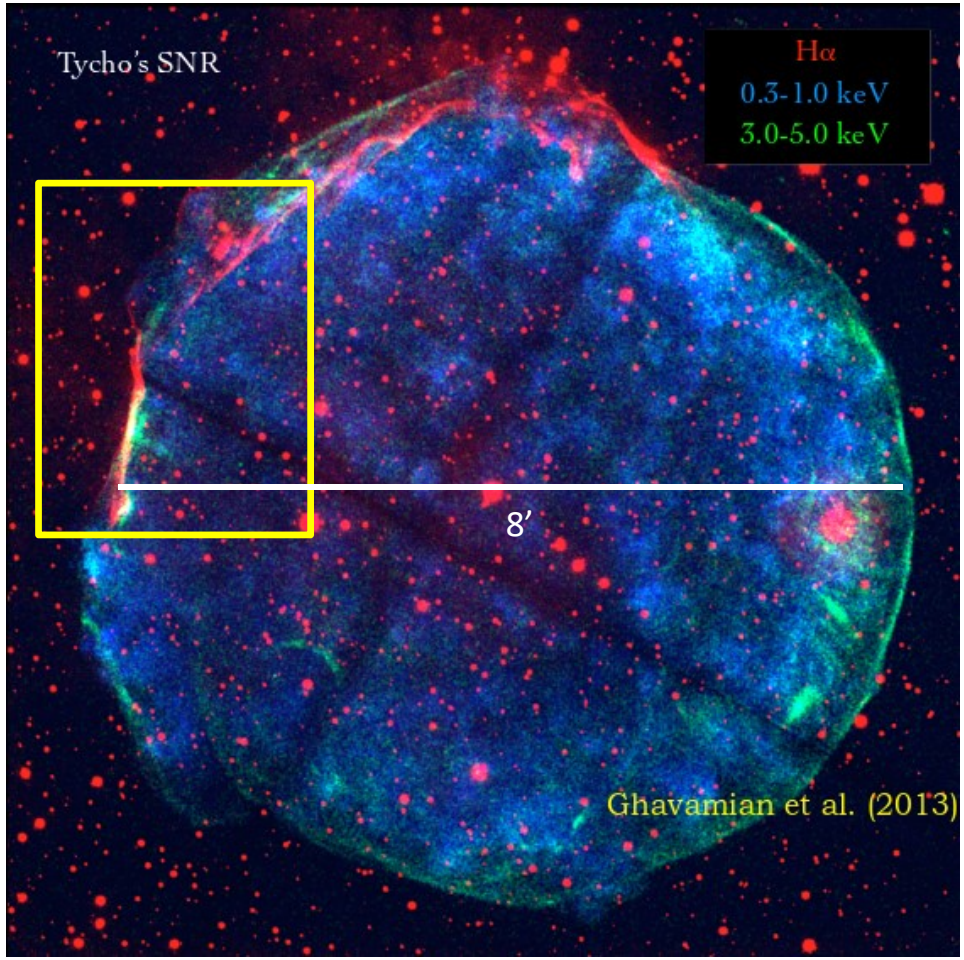


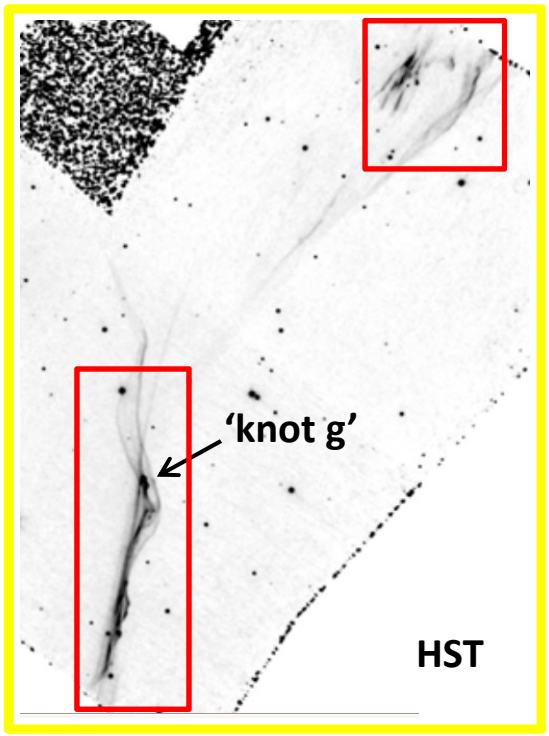
$W_{NL}=W_{NL}(p_{max}, V_s, \varepsilon, \eta_{th}, \beta_{down}, \beta_{up})$



Morlino, G., et al., 2012, ApJ, 760, 137
Morlino, G., et al., 2013, ApJ, 768, 148

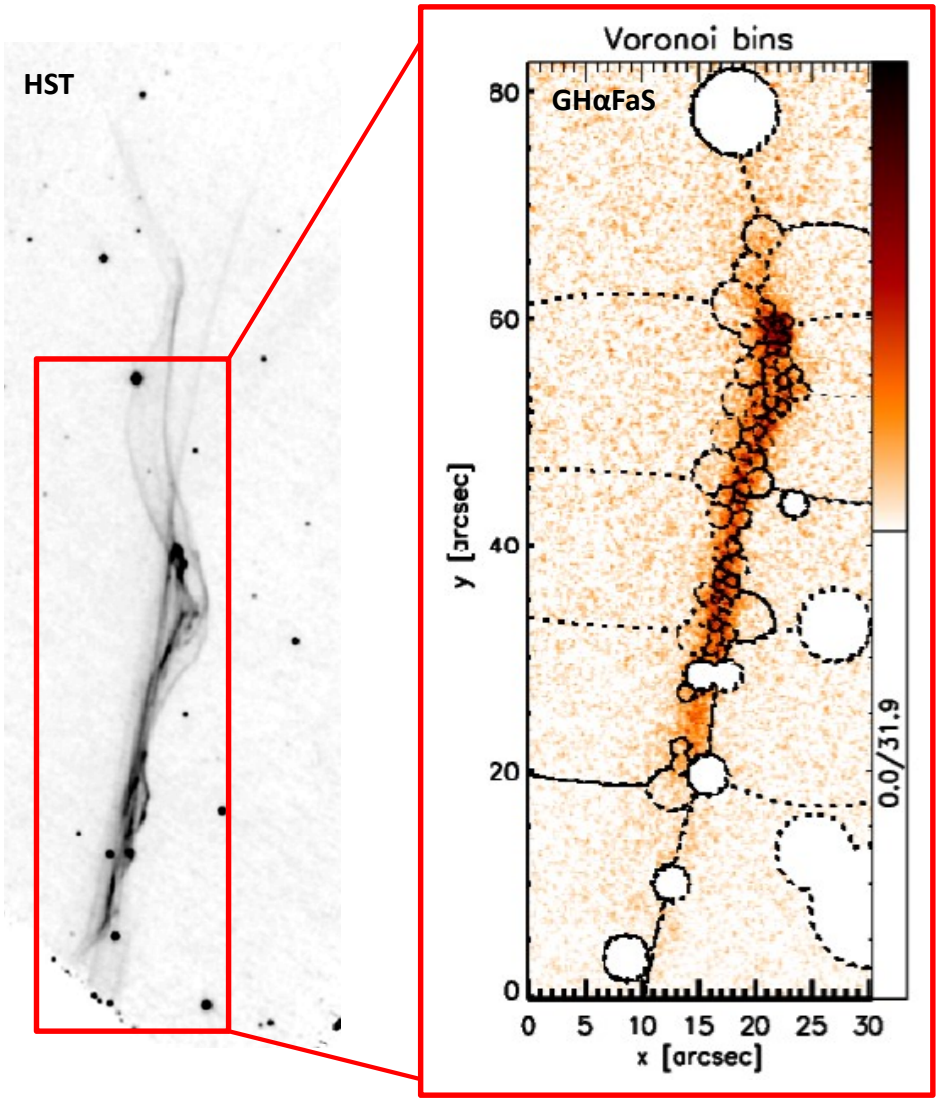
Tycho: Minimizing contribution of projection effects and correction for spatial variation





D ~ 2.5 kpc
fn ≈ 0.9

Tycho: 82 spatial-spectral bins



GHαFaS on the WHT
(Fabry-Perot interferometer)
FoV: 3.4'x3.4'
Angular resolution: 1''
Spectral resolution: 8 km/s
Spectral coverage: 400 km/s

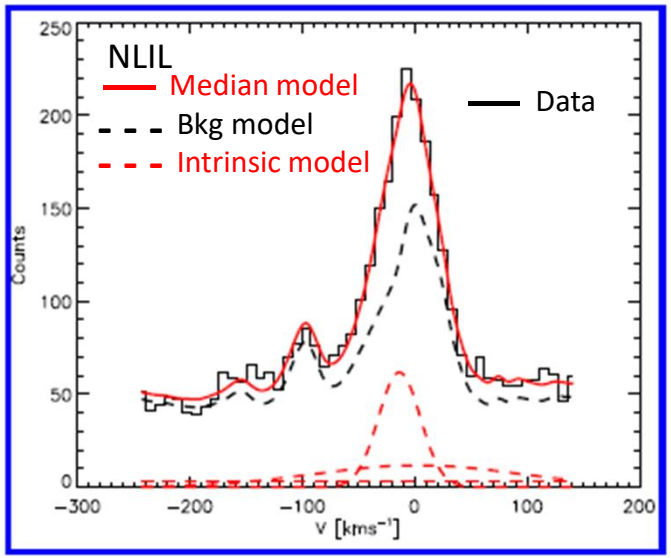
Voronoi binning by Capellari
& Copin (2003) for S/N≈10: 82 bins

Bayesian analysis: parameter estimation
& model comparison

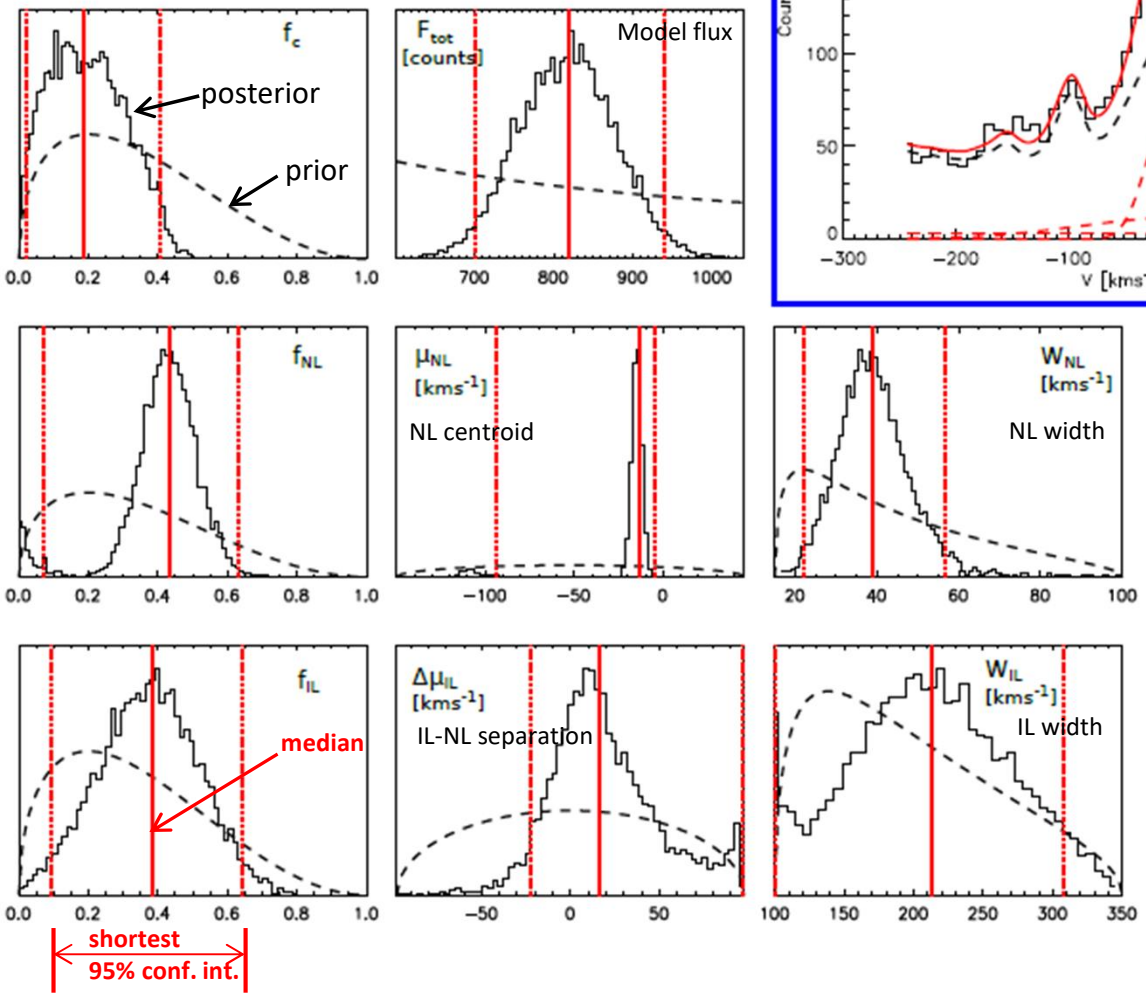
Models: NL, NLIL, NLNL, NLNLIL

NLIL model: 1D-marginalized posteriors

We use MCMC to calculate posterior from data and prior.



Flux fractions in the continuum + lines



$\mathrm{Log}(E_{NLIL}/E_{NL}) \geq 1$ dex

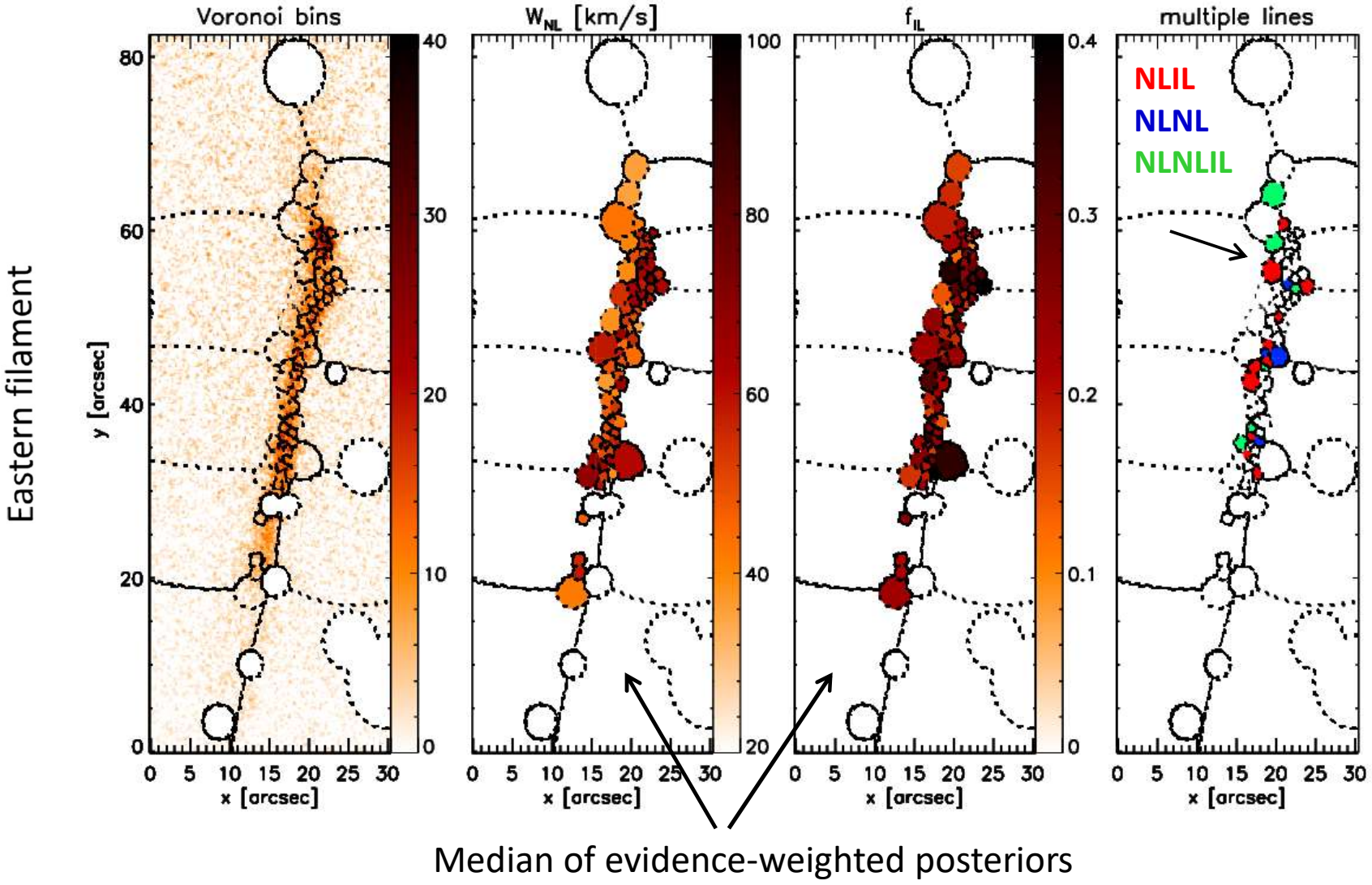
$\mathrm{Log}(E_{NLIL}/E_{NLNL}) \geq 1$ dex

W_{NL}=[15, 100] km/s

W_{IL}=[100, 350] km/s

median parameters:
$W_{NL} \approx$ 40 km/s
$f_{IL} \approx$ 40%, $W_{IL} \approx$ 210 km/s

Spatial variation of W_{NL} and f_{IL}; evidence for multiple-line models



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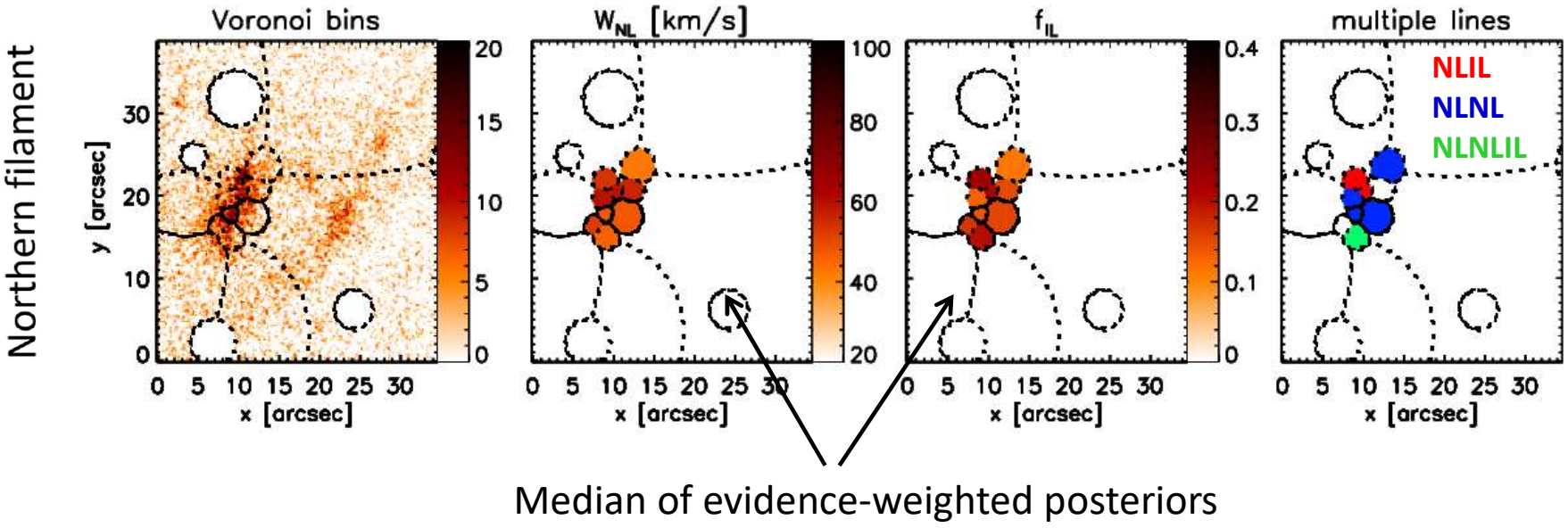
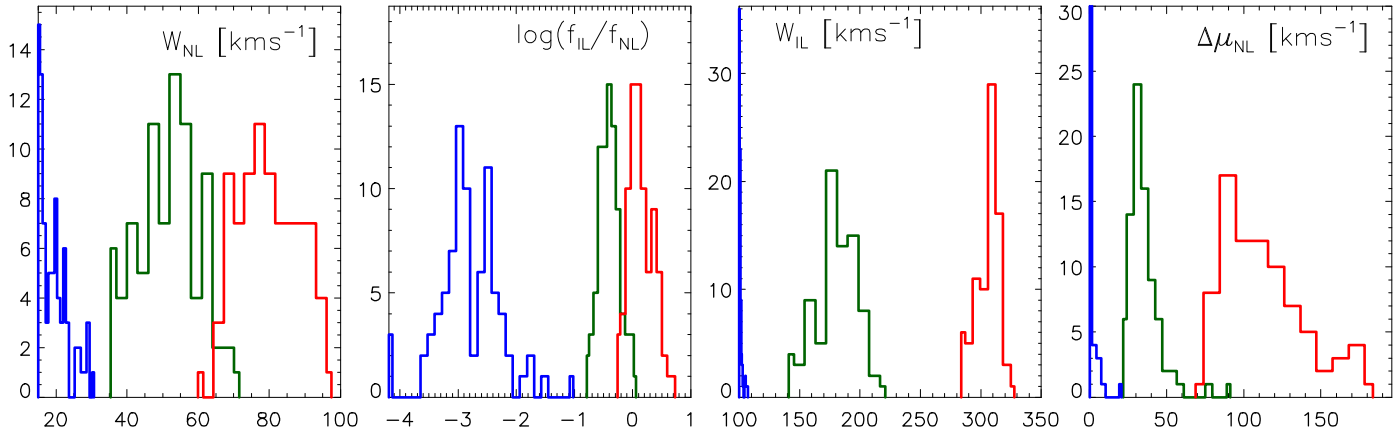


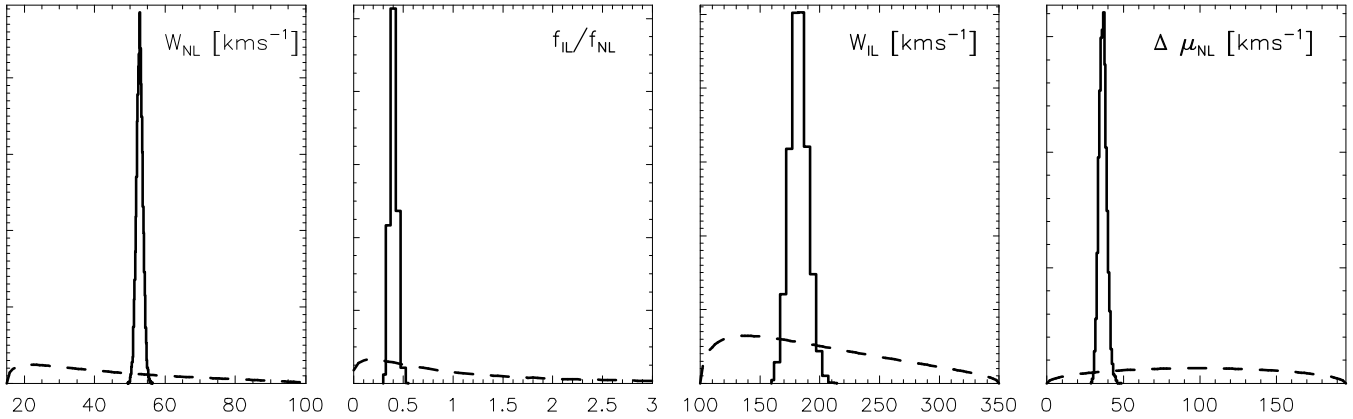
Combined results of all 82 bins in the Tycho's NE rim

Distributions of median parameters and their shortest 95% conf. int.



Median
2.5% quantile
97.5% quantile

Posteriors for the median parameters



$W_{NL} \approx 53$ km/s

IL: 24% of Nbins
$W_{IL} \approx 185$ km/s
$f_{IL}/f_{NL} \approx 0.5$

NLNL: 18% of Nbins
$W_{NL} \approx 47$ km/s
$\Delta\mu_{NL} \approx 35$ km/s

Summary

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

b) Our analysis is based on **Bayesian inference** that enables a quantitative, probabilistic and well-defined model comparison, and a comprehensive, complete characterization of the parameter probabilities.

c) Suprathermal NL widths (W_{NL} >> 20 km/s) + NLNL in 18% of the bins (also with W_{NL} >> 20 km/s) → **clear confirmation of CR precursor**

d) Need for additional (intermediate) component (Bayes factor):
24% of the bins with $W_{IL} \approx 185$ km/s and $f_{IL}/f_{NL} \approx 0.5$ on average
→ **presence of broad-neutral precursor**

THANK YOU FOR YOUR ATTENTION!