INAF ISTITUTO NAZIONALE DI ASTROFISICA
NATIONAL INSTITUTE FOR ASTROPHYSICS

Interplay between Physics and Geometry in Balmer filaments

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+

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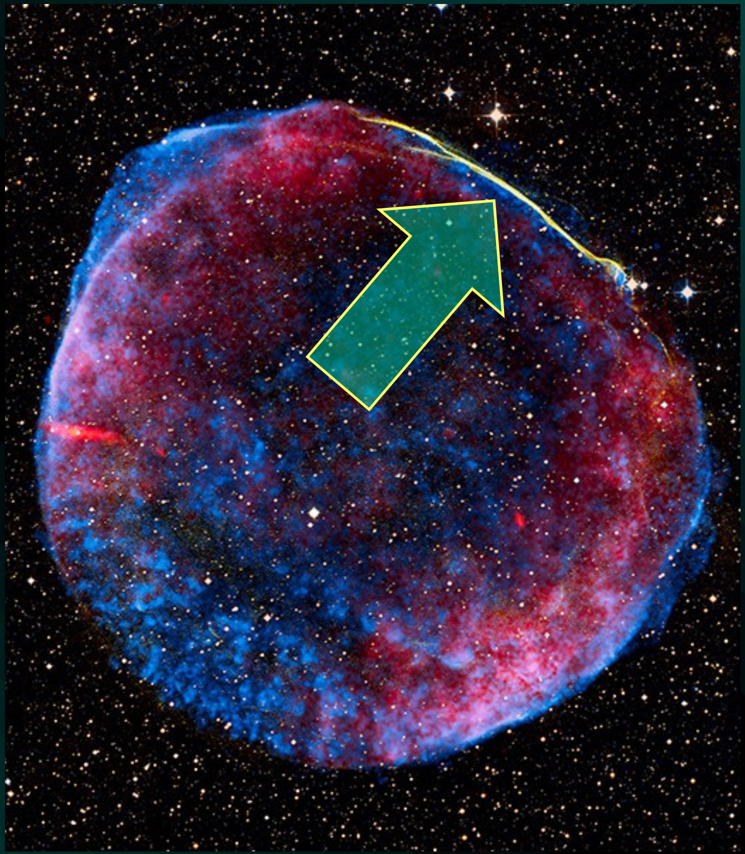
SUPERNOVA REMNANTS II
AN ODYSSEY IN SPACE AFTER STELLAR DEATH
3-8 June 2019, Chania, Crete, Greece



The background

Optical spectra dominated by Balmer lines.
⇒ collisionless shock moving in a partially neutral medium (Chevalier & Raymond 1978)

Peculiar Ha line profile: broad+narrow component ⇒ Kinetically hot neutrals as an effect of charge - exchange processes.

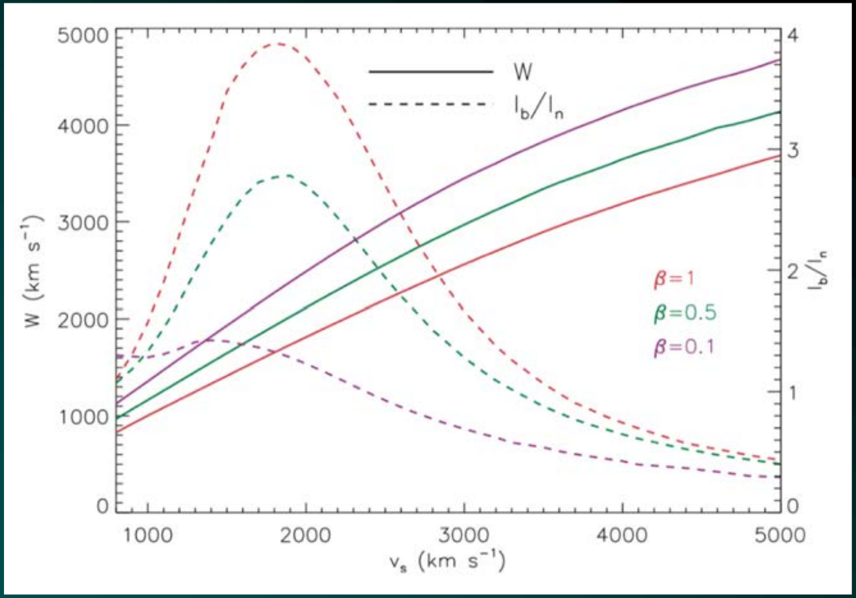
Transition region, until complete ionization

A powerful diagnostic tool

Need for more detailed modelizations

(e.g. Smith et al. 1991, Ghavamian et al. 2001, Heng & McCray 2007, van Adelsberg et al. 2008, Blasi et al. 2012, etc.)

Main observables: I_b/I_n, W



Diagnostics on:

V_{sh}, $\beta = T_e/T_i$ etc.

(Heng 2010)

Structure of transition region

Further information could be acquired (ultimately, on the CR efficiency)

BUT

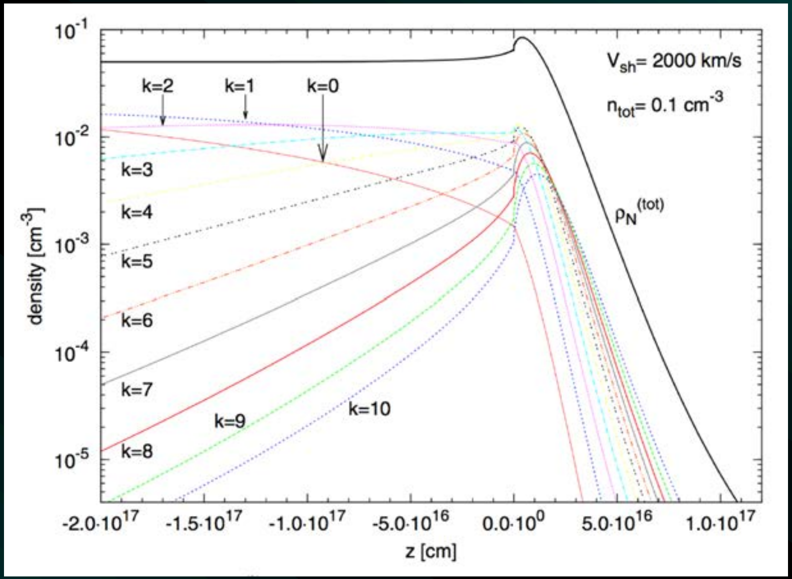
- Need for observations with high-spatial resolution $L_{ref} \sim$ 5-10 10^{15} cm $(n_0/0.1\ \mathrm{cm}^{-3})^{-1}$ $\sim$ 0.17″-0.33″ $(D/2\ \mathrm{kpc})^{-1}$ $(n_0/0.1\ \mathrm{cm}^{-3})^{-1}$
- Need for more detailed models of this transition region

(e.g. van Adelsberg et al. 2008, Blasi et al. 2012)

A kinetic treatment

(Blasi, Morlino & the team in Arcetri)

- Neutrals do not behave like a gas $\Rightarrow$ Vlasov eqs, deviations from Maxwellian
- Charge-exchange process (for H) $\Rightarrow$ more generations (k) of neutrals



- For k=1 or higher, they can cross the shock back ('neutral return flux')

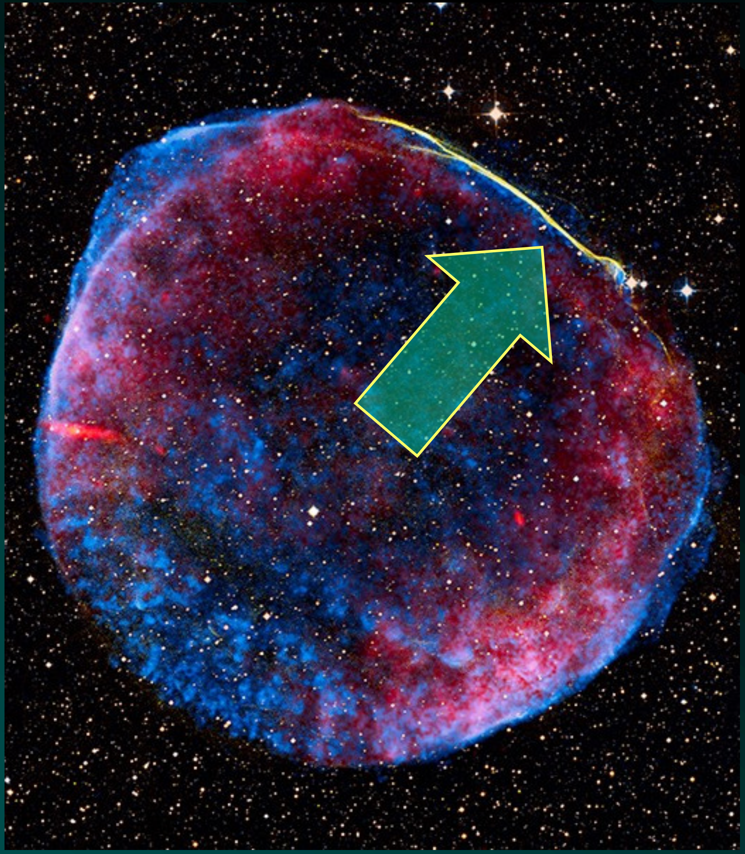
“Geometrical” effects

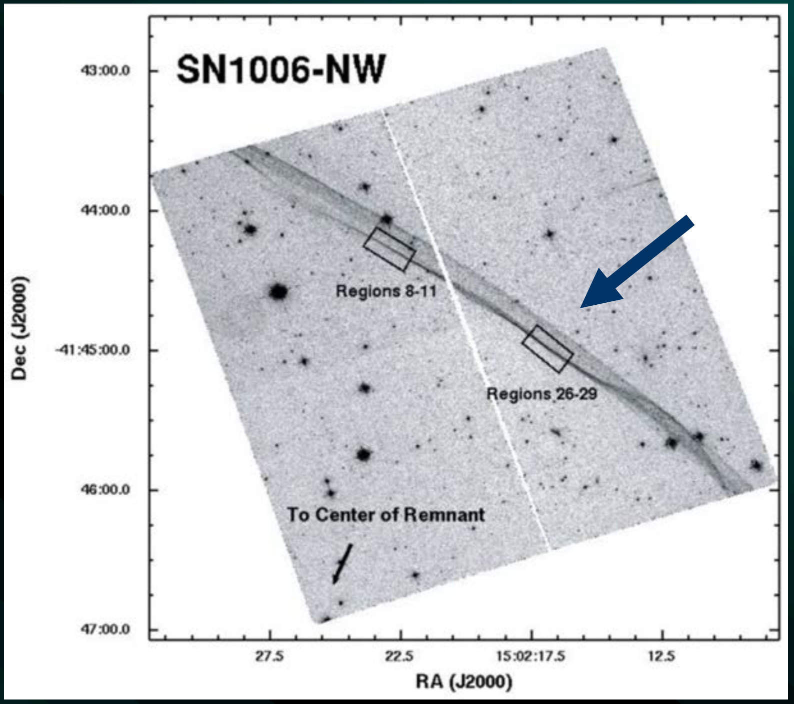
(Bandiera, Morlino, Knezˇevic´ & Raymond 2019, MN 483, 1537)

We are not observing, perfectly edge-on, a perfectly plane-parallel shock transition.

Effects of curvature / multiple emitting layers:
i. on the surface brightness profile
ii. on the profile of I_b/I_n
iii. on the width of the broad comp.
iv. on its spectral offset

The N-W edge of sn 1006





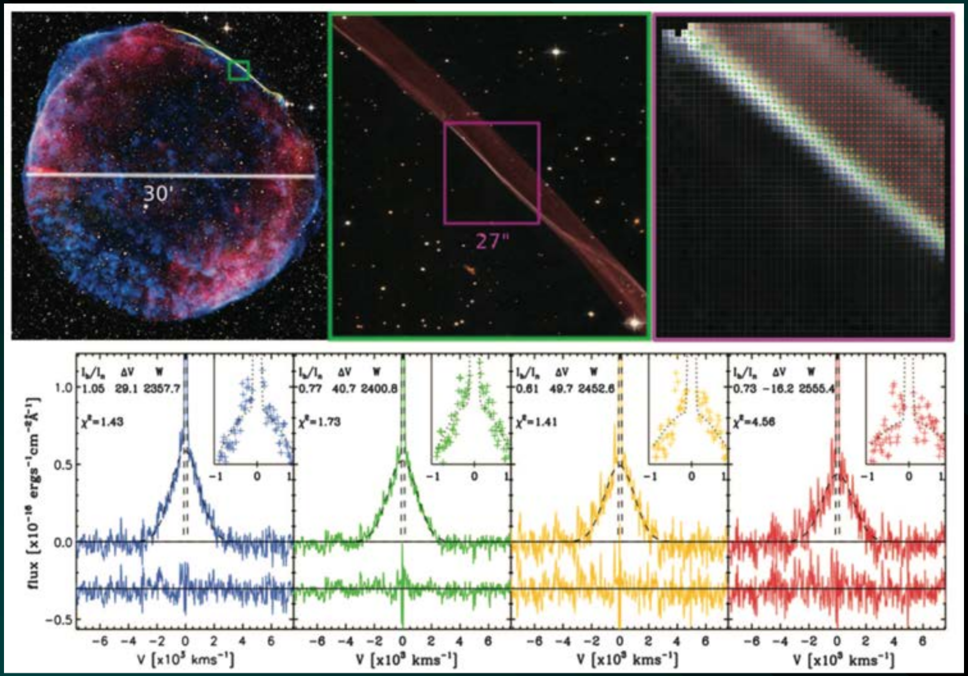
HST observation

(Raymond et al. 2007)

Observation with VIMOS-IFU @ VLT

(Nikolic' et al. 2013)

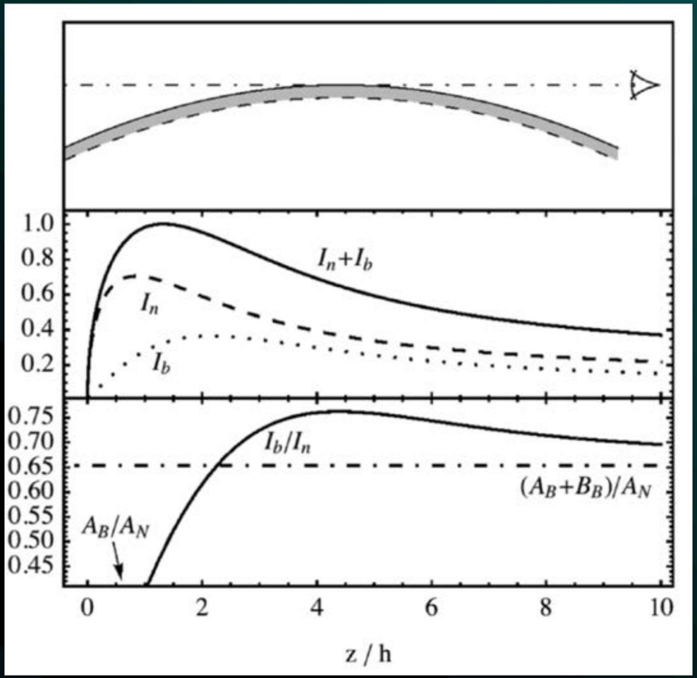
Lower spatial resolution but spectral info



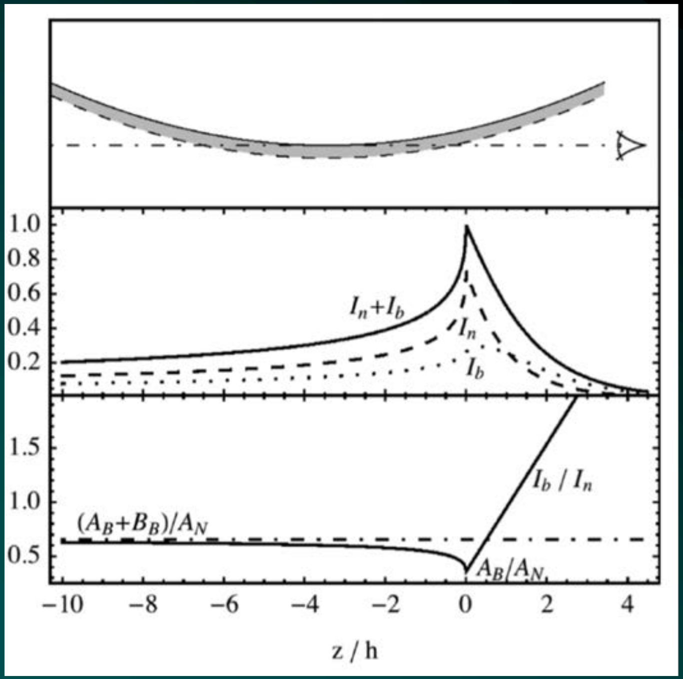
Combined analysis of HST & VLT data

Constant curvature geometries

Convex case

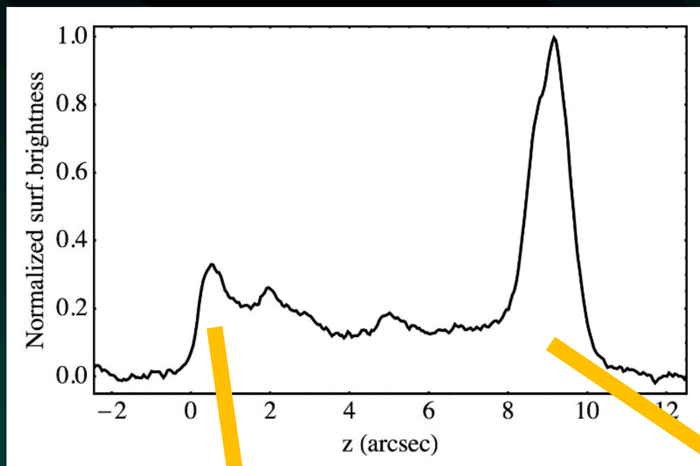


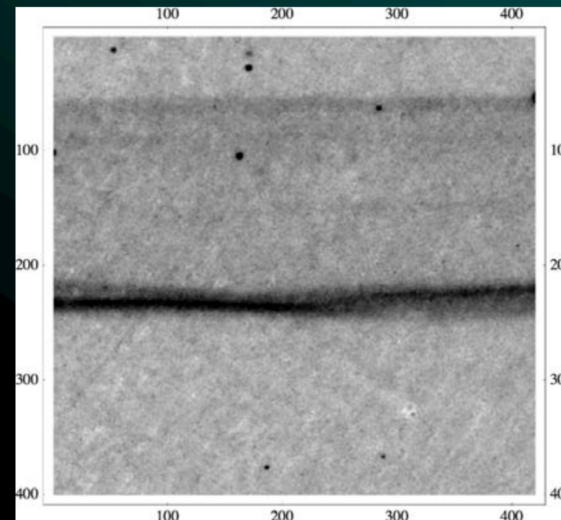
Concave case



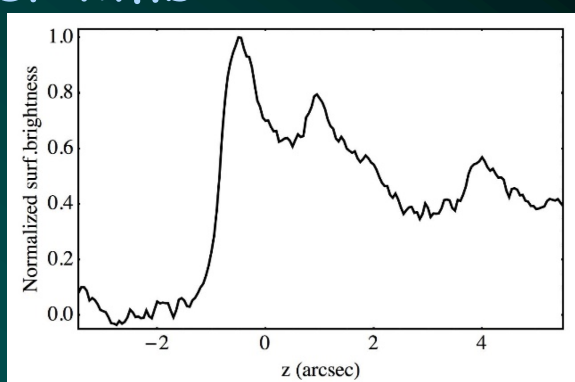
Distinctive profiles both for I_n+I_b and I_b/I_n

Filament structure: a closer view

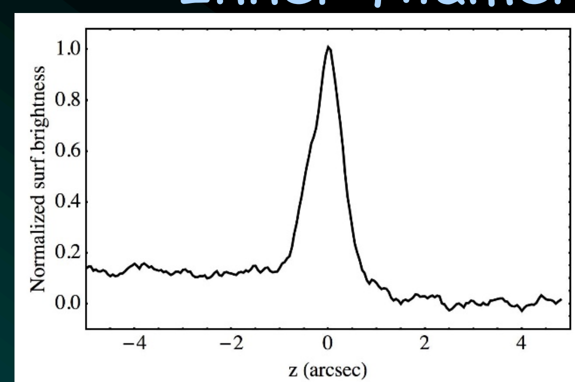




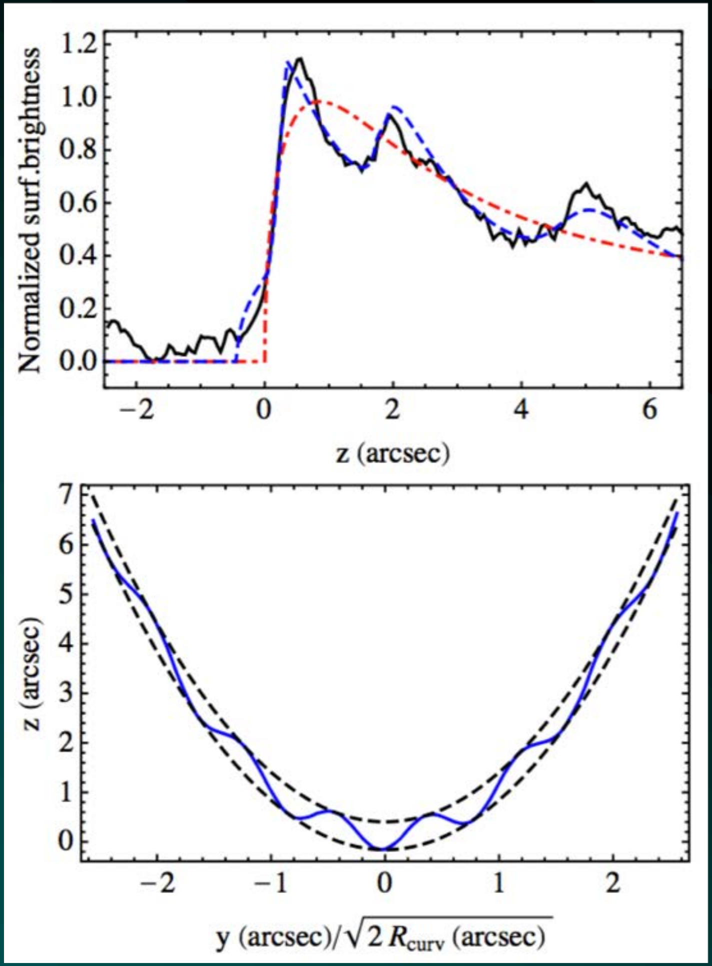
Outer limb



Inner filament



Fit to the outer limb



Convex constant curvat.

$h_{ref} \cong 0.69''$ $n_0 \cong 0.033$ cm^{-3}

(< previously published)

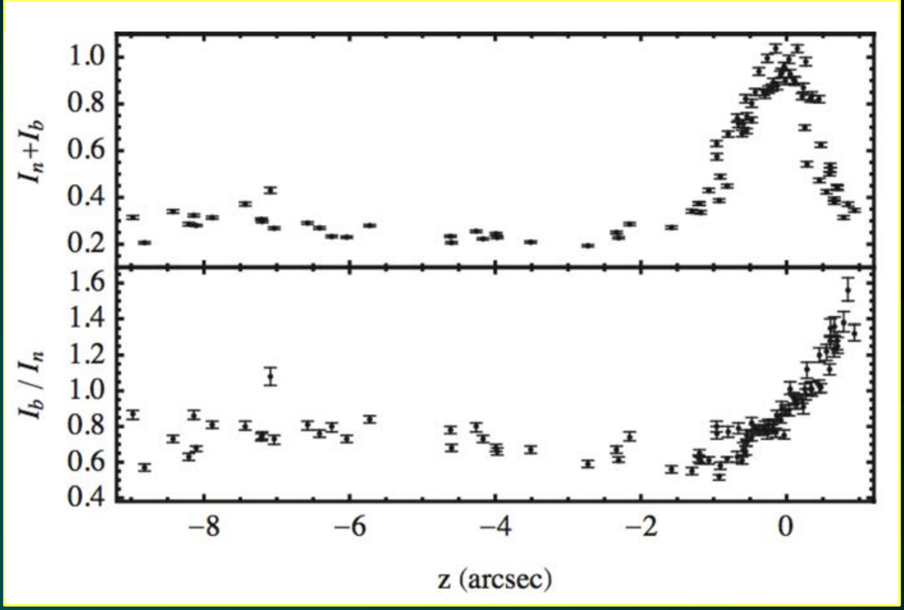
Intensity ripples, shorter length scales.

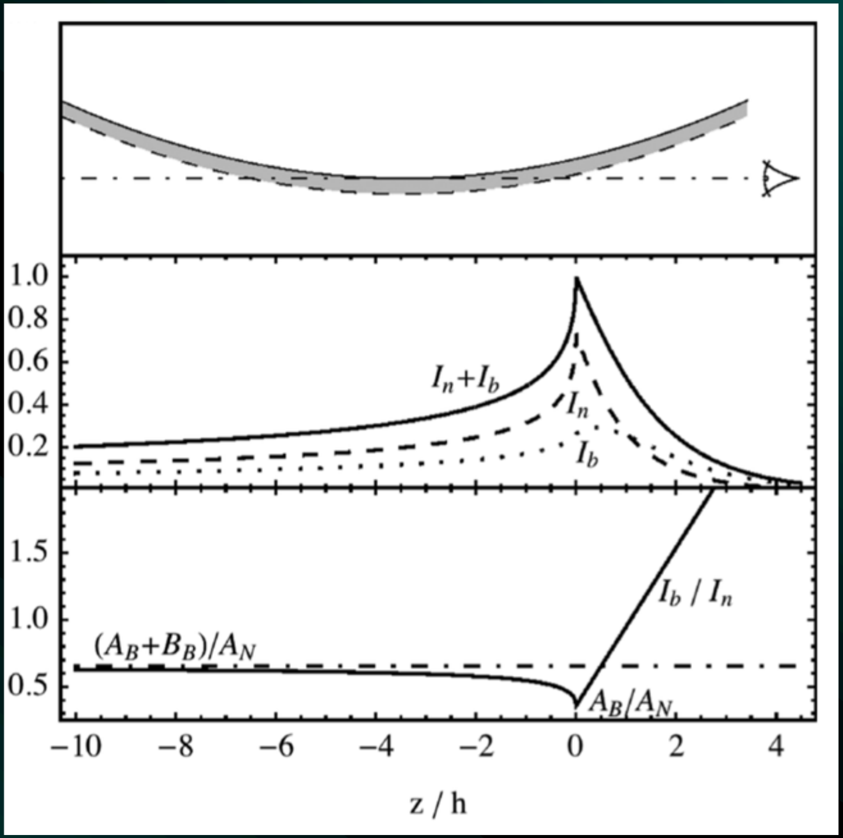
Convex curvat. + ripples

(very tiny ones)

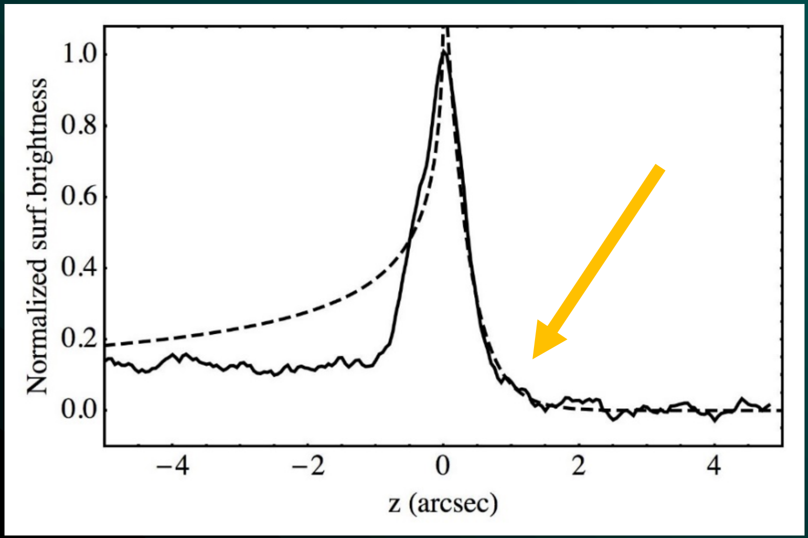
Geometry of the inner filament

Concave curvature ?





But concave - constant curvature $\Rightarrow$ excess in projected upstream.



1. Very small curvature radius OR
2. Multiple tangency points, along the LOS

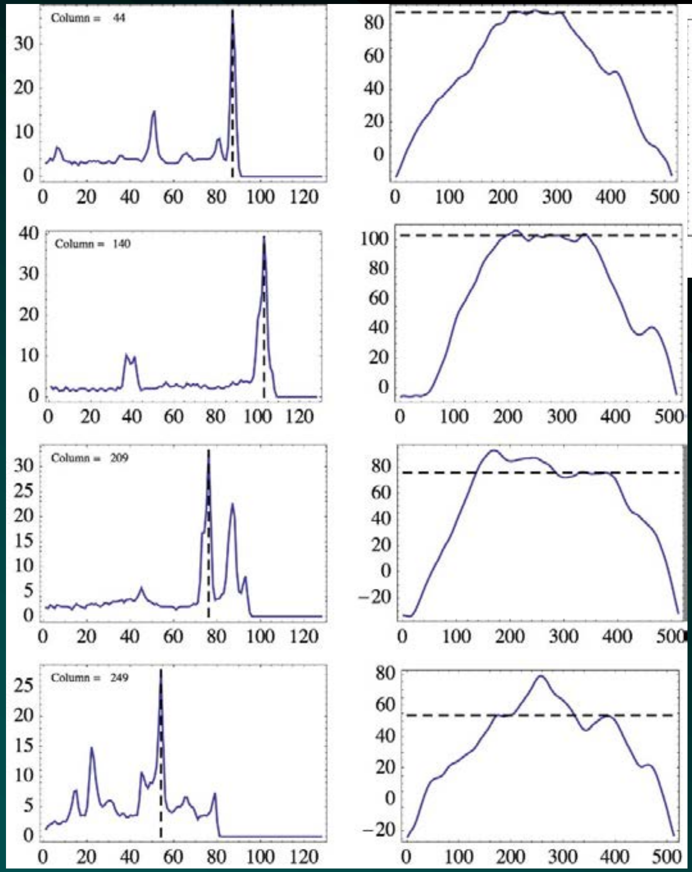
(Raymond et al. 2007)

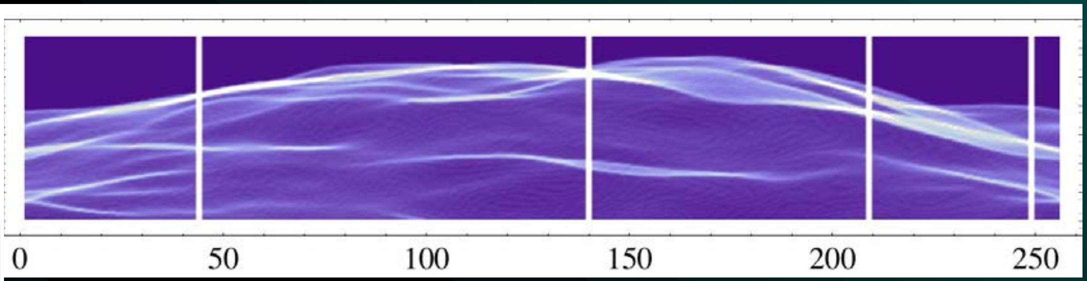
h_{ref} can be estimated from intensity drop on inner side: $h_{ref} \cong 0.24''$ $n_0 \cong 0.095$ cm^{-3}

Multiple tangency points

How likely are they?

Simulated maps:

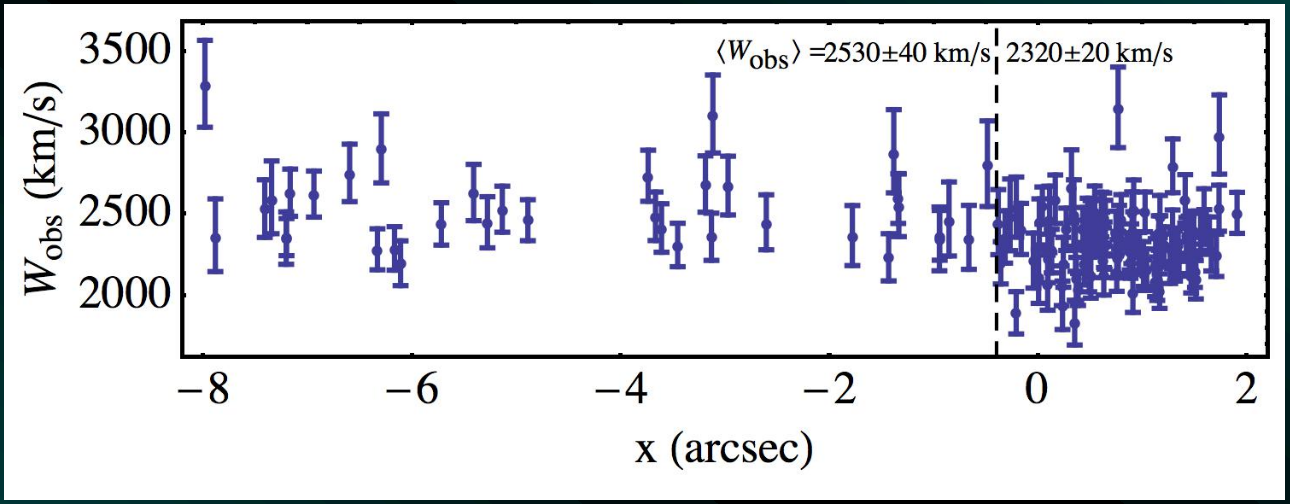




Select bright filaments

Selection effect favours multiple tangency points !

Measured broad-line width



Slightly larger in the projected upstream. Likely effect of combination of thermal spread and bulk motions (at least 2 layers).

Velocity shift of broad component

(Nikolic' et al. 2013)

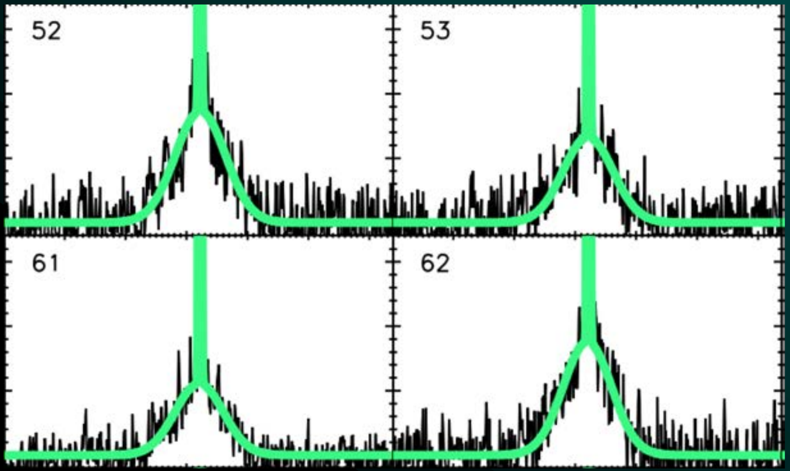
Fits to the line shapes

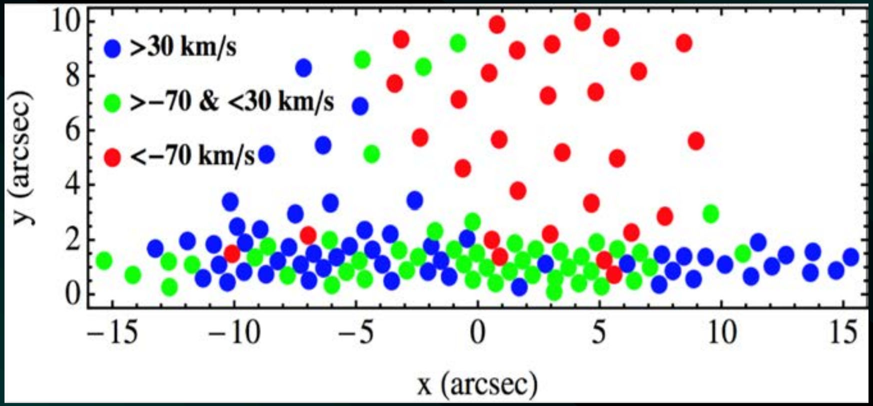
V offsets: $\sigma \approx$ 100 km/s

Even number of tangency points.

Face-on surf.brightness must be inhomogenous.

Fluctuations of at least ≈ 50 % over large (≈ 10") scales.





Analysis of the structure of the transition region, but only when spatially resolved.

Only nearby SNRs in a low density medium.

But no such limitation for:
- Observed widths of the broad component
- Velocity offsets of the broad component

An almost perfect test case $\Rightarrow$

SNR 0509 - 67.5 (in the LMC)

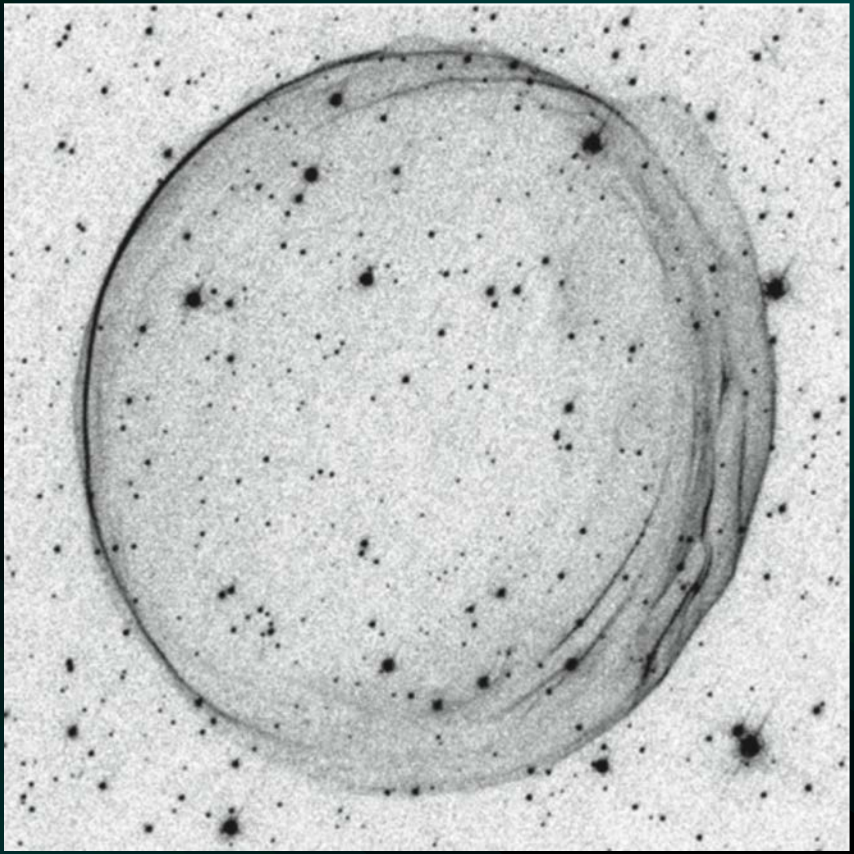
Radius ≈ 14.8 "
≈ 3.6 pc
Age: 400 ± 120 yr

(Rest et al. 2005)

Pure Balmer emiss.

HST image ⇒

(from Hovey et al. 2015)



Adding spectral information

MUSE : Integral field spectrograph @ ESO - VLT

Wide-field mode

Spatial sampling: 0.2 arcsec

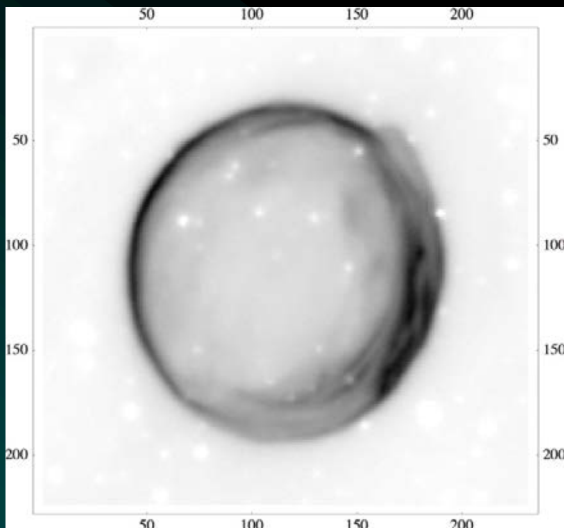
Spectral resol.≈ 100 km s^{-1} @ H_α

Field of view: 1 x 1 $arcmin^2$

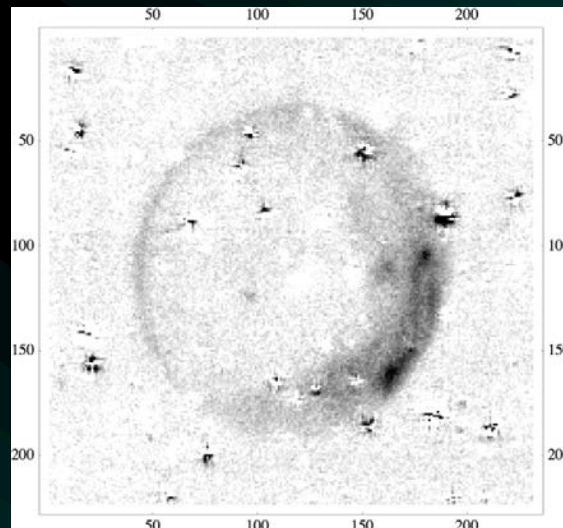
(Obs. P.I. Morlino)

PRELIMINARY RESULTS

Stellar subtraction

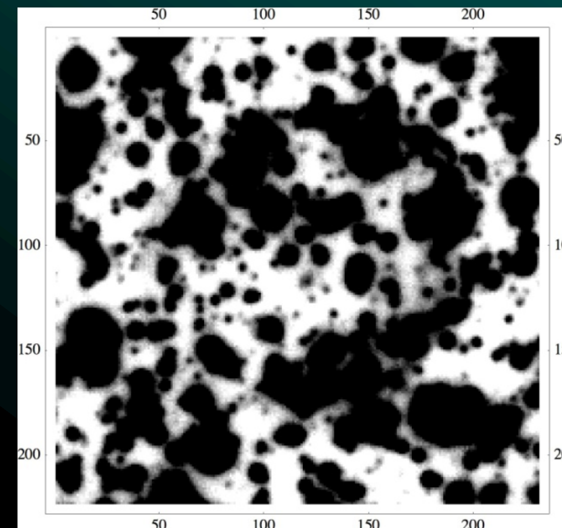


Narrow-line map



Broad-line map

(4 times deeper cuts)

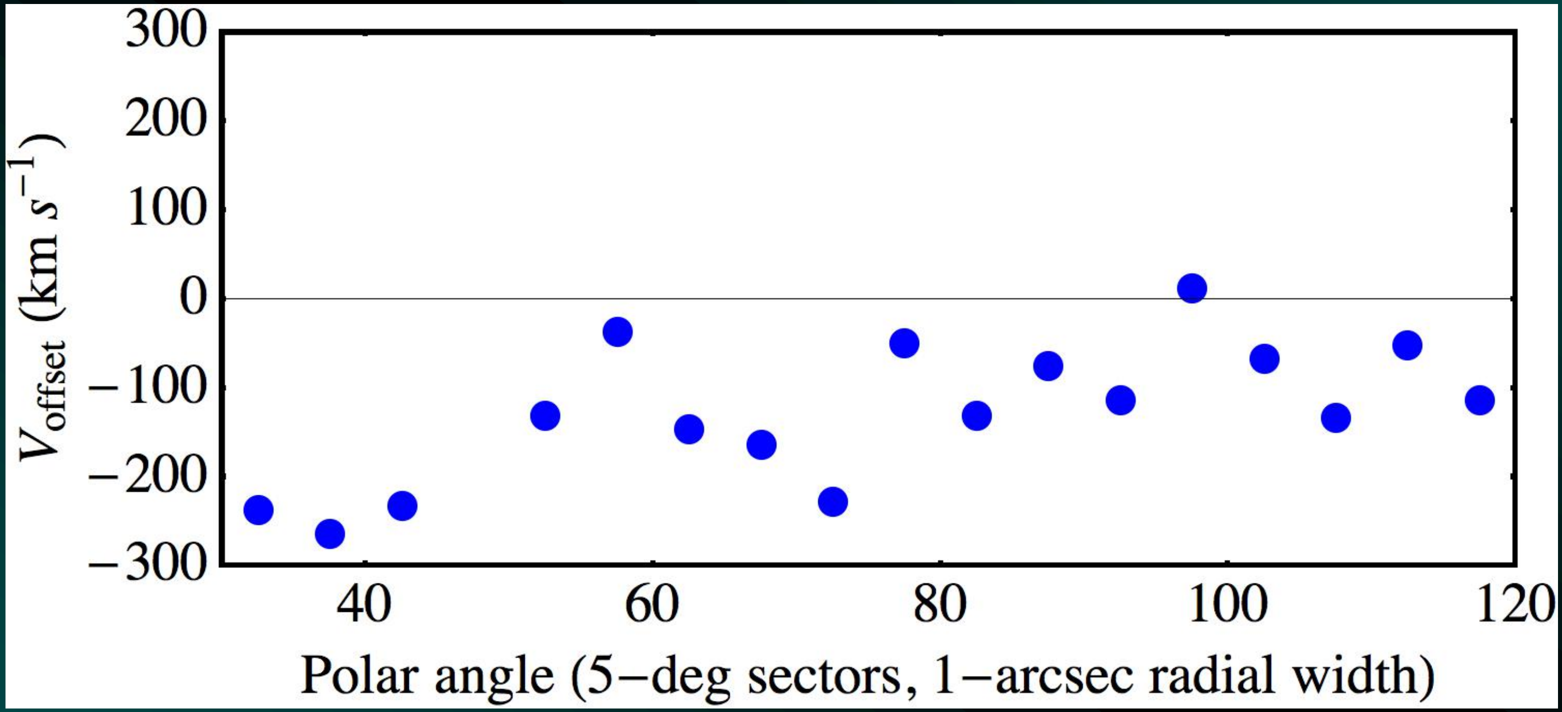


Broad-line map

before stellar subtraction

Even further, locations of brightest stars have masked out before proceeding with spectral analysis

Always negative velocity offset along the North-East edge



(SNR center derived from N-E edge)

Why, for an apparently highly spherical edge?

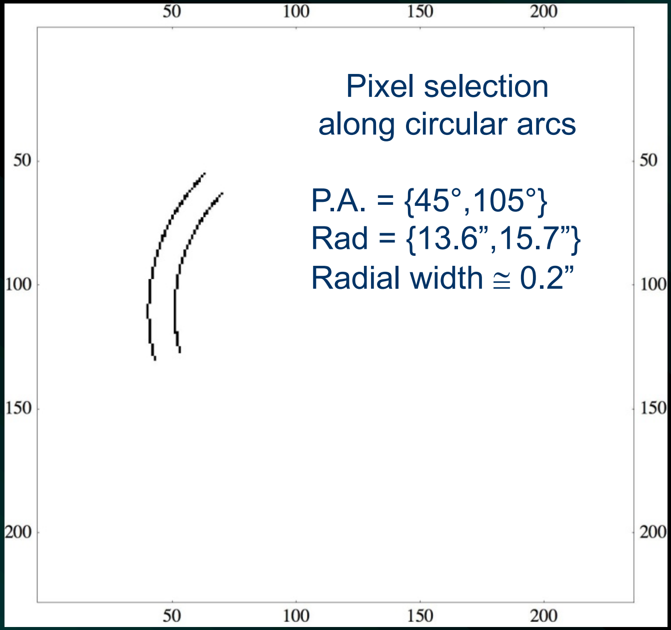
Just a geometrical effect ?

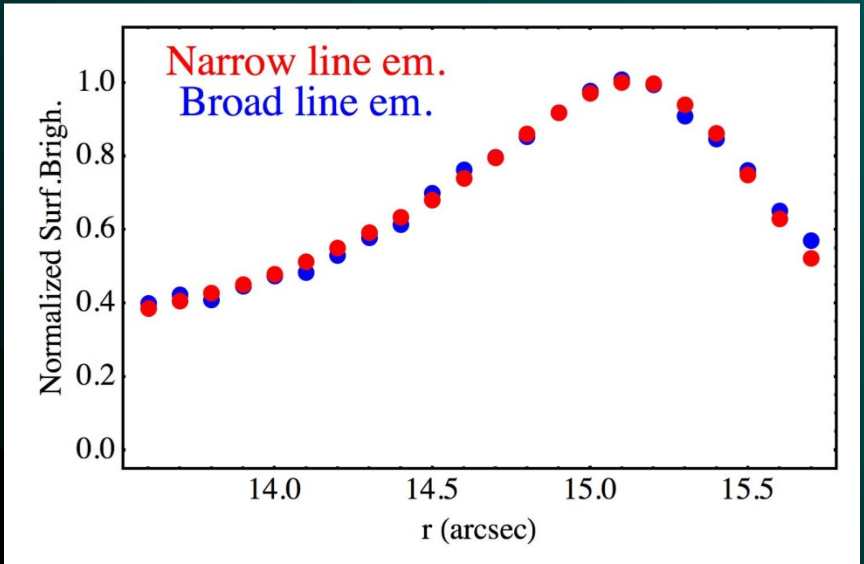
Neutral density gradient along LOS
+ limited spatial resolution.

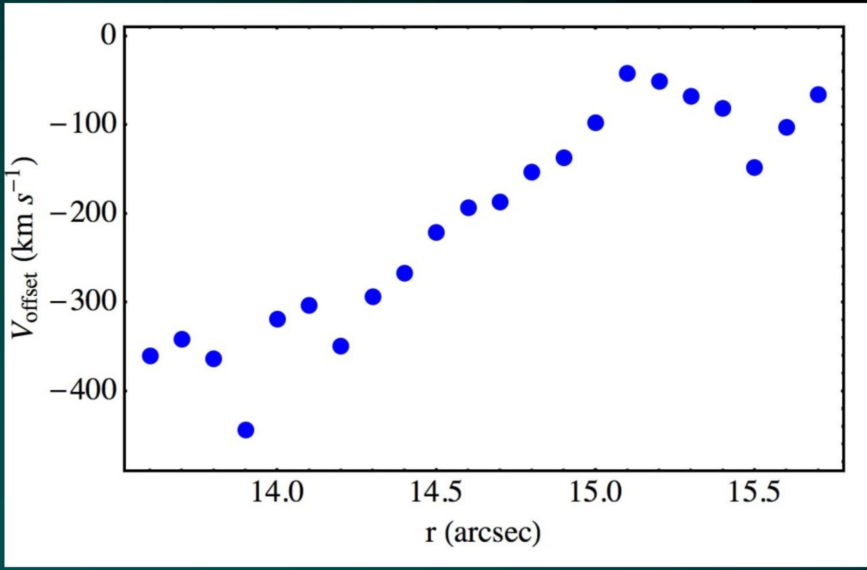
Predictions:

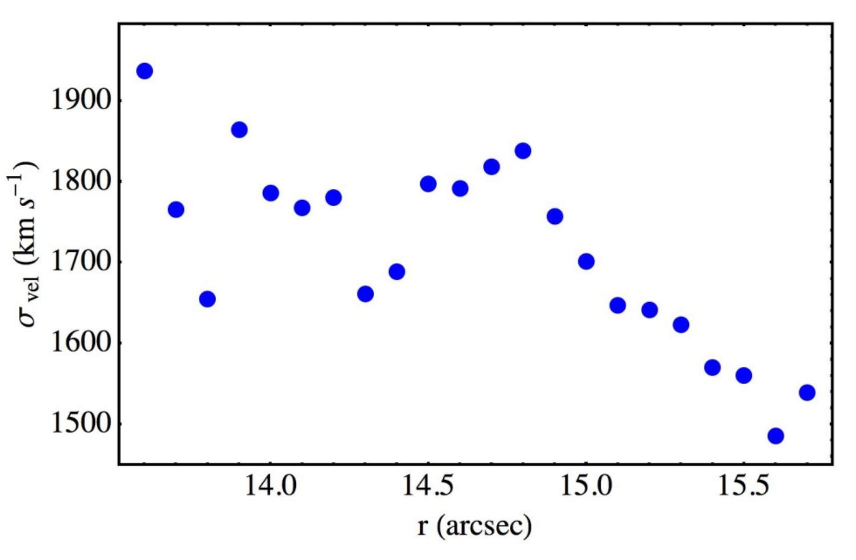
1. Velocity offset must increase towards the center.
2. Measured velocity width must increase towards the center.

Are they measurable?


Pixel selection
along circular arcs
P.A. = {45°,105°}
Rad = {13.6”,15.7”}
Radial width ≅ 0.2”
50
100
150
200


Narrow line em.
Broad line em.
Normalized Surf.Brigh.
r (arcsec)
1.0
0.8
0.6
0.4
0.2
0.0
14.0
14.5
15.0
15.5


V_{offset} (km s^{-1})
r (arcsec)
0
−100
−200
−300
−400
14.0
14.5
15.0
15.5


σ_{vel} (km s^{-1})
r (arcsec)
1900
1800
1700
1600
1500
14.0
14.5
15.0
15.5

A simple geometrical model

Spherical, thin-layer model (r_{sh})

- Thermal velocity dispersion (σ_{vel})
- Radial bulk velocity (V_{bulk})
- Neutral density gradients (logarithmic)
  on the sky plane ($grad_x$)
  along the LOS ($grad_z$)

Fitting the profiles

"Preliminary" best fit:

(models convoluted with PSF)

$r_{sh} \cong 15.4$ arcsec

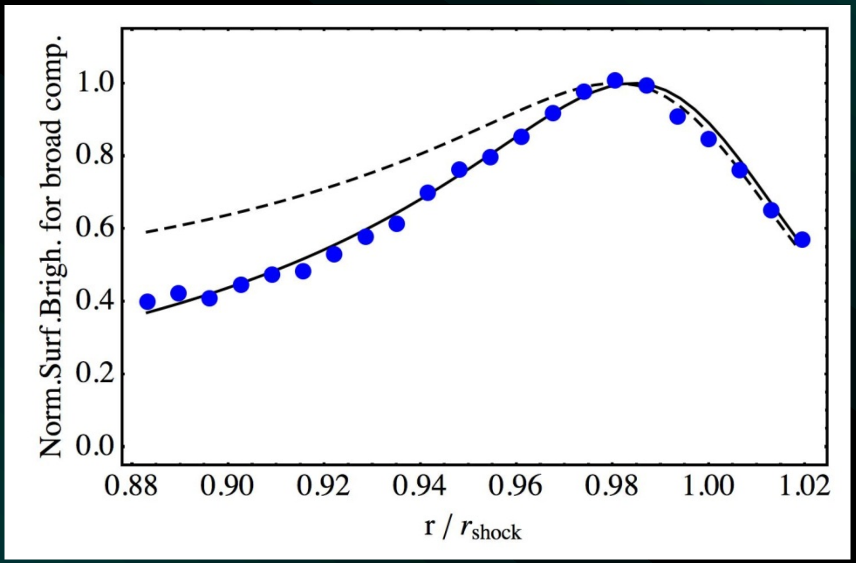
$\sigma_{vel} \cong 1500$ km s^{-1}

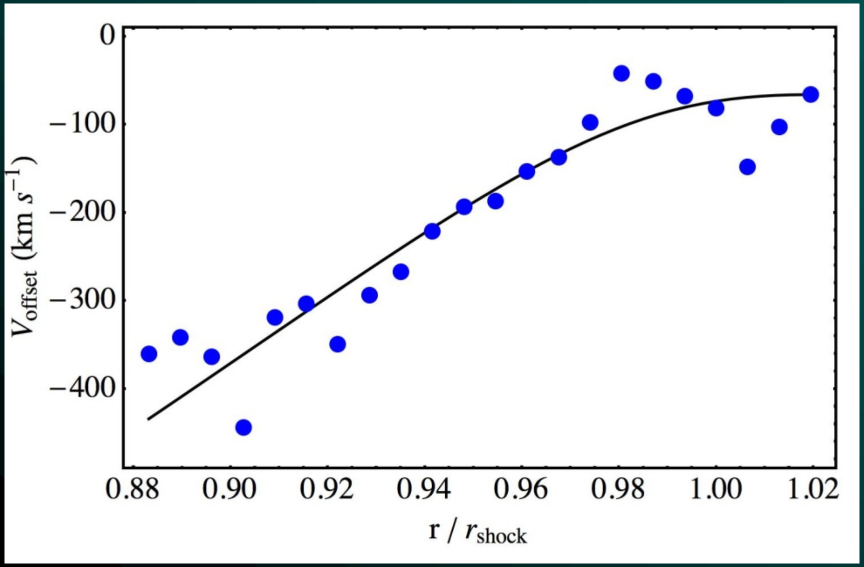
(i.e. $W \cong 3500$ km s^{-1})

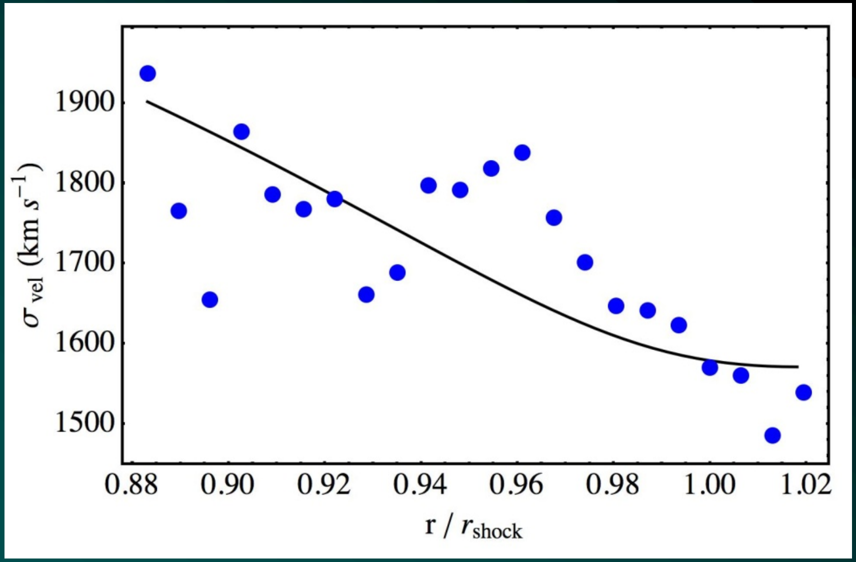
$V_{bulk} \cong 3000$ km s^{-1} (~ half of V_{sh})

$grad_x \cong +6.5\ r_{sh}^{-1}$ (i.e. outwards)

$grad_z \cong -0.85\ r_{sh}^{-1}$ (i.e. towards us)







Preliminary results:
- -Strong local gradient
- -Low thermal width
- -Low bulk velocity

(effect of $\sigma_{ch\text{-}ex}$?)

Summary

Analysis of the structure of transition zone.
Geometry may affect the observed:

- I_b+I_n profile
- I_b/I_n profile
- W of the broad-line component
- V offset of this component

The last 2 quantities can be effectively used also when the shock transition is not resolved.