

# SOLAR ERUPTIONS and SHOCK WAVES

## (Observable Predictions from Theory)

Bojan Vršnak, Tomislav Žic

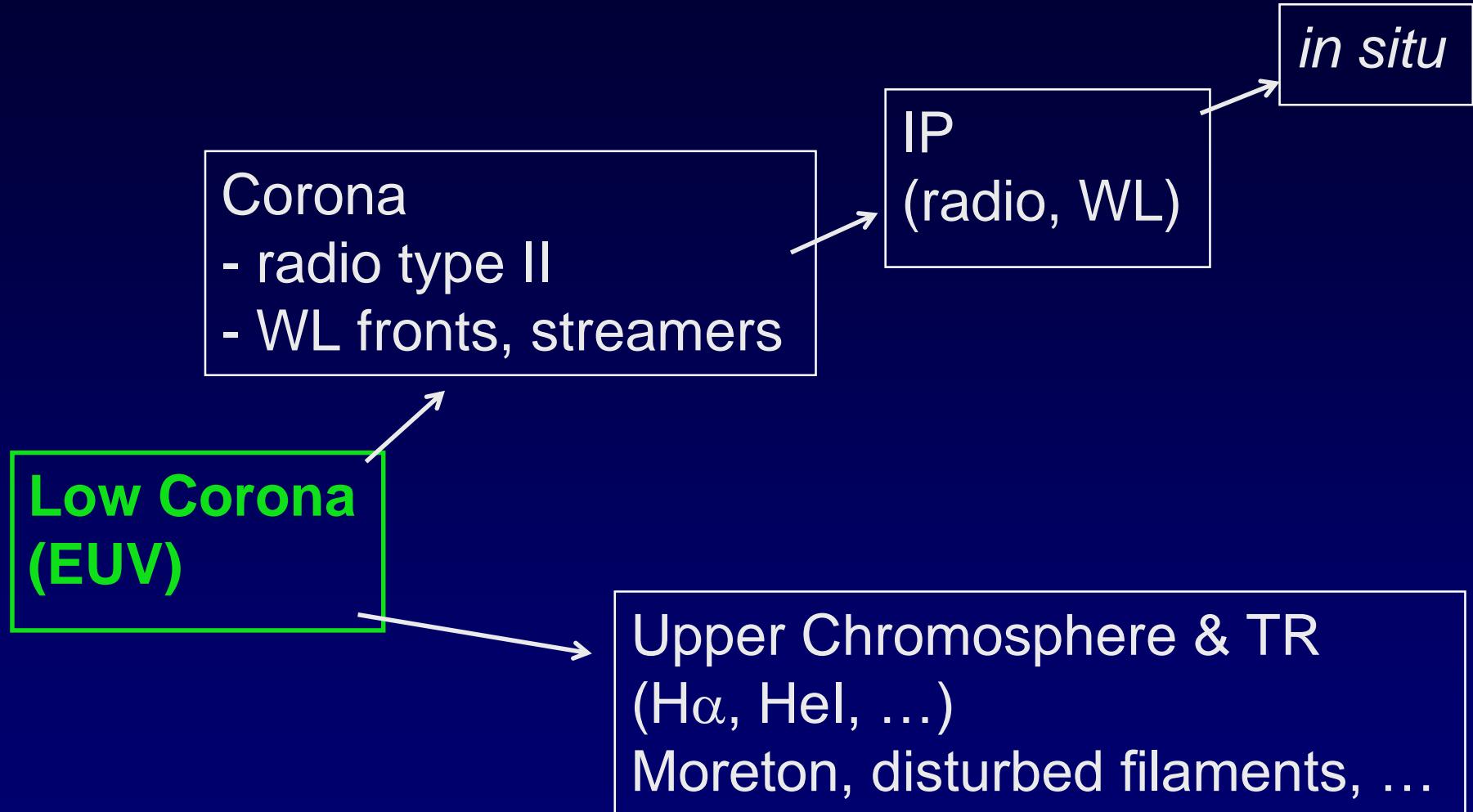
*Hvar Observatory, Faculty of Geodesy Croatia*



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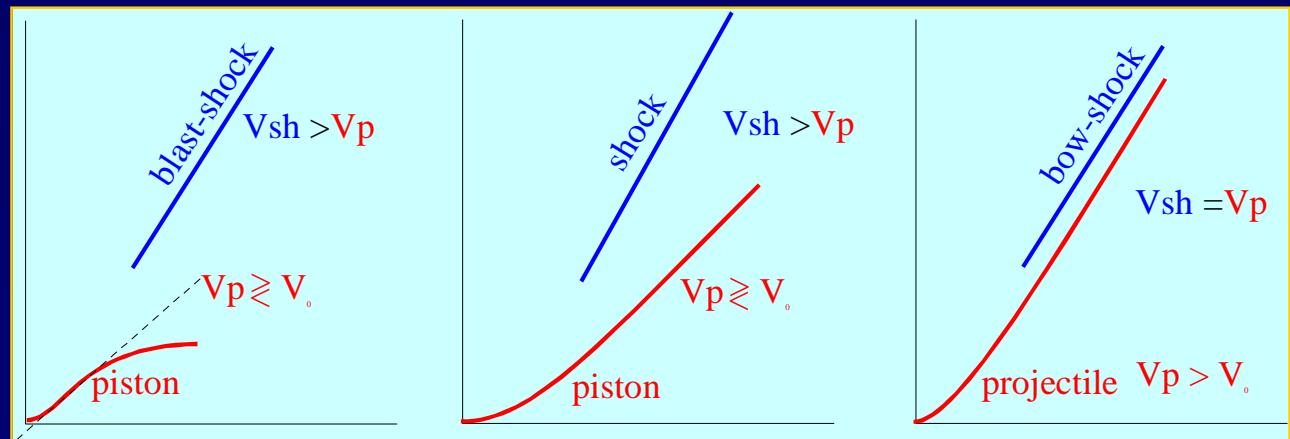
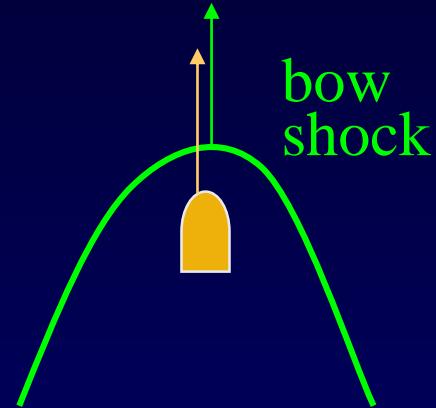
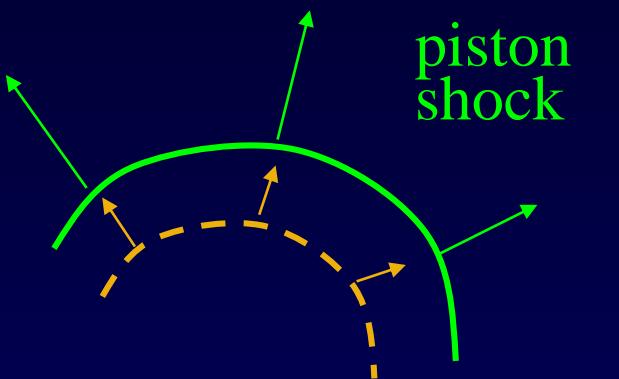


# Domain / Signature

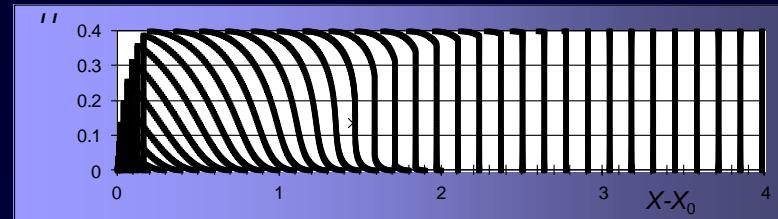


timing, kinematics, intensity, spectral, morphology, ...

# Terminology

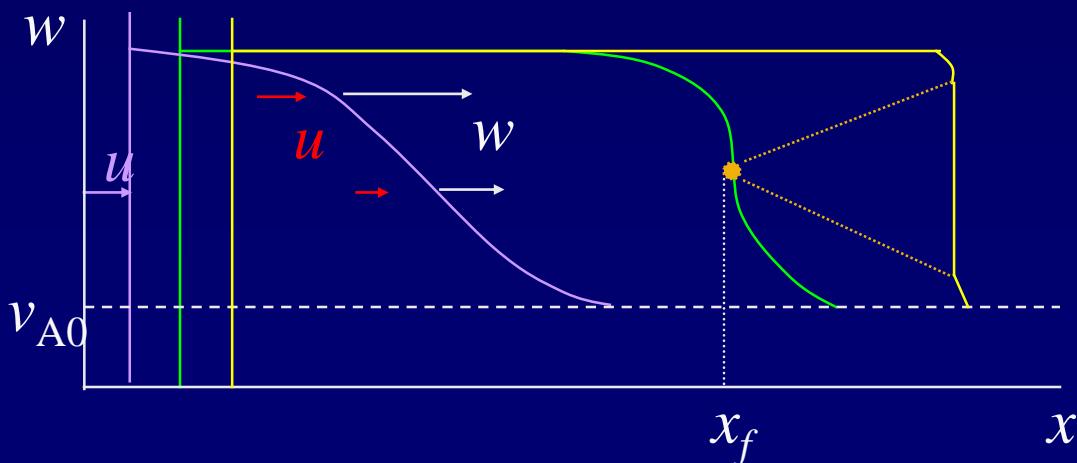


# Large-amplitude wave (shock)



- impulsive plasma motion perpendicular to the magnetic field ("strong" acceleration)
- large amplitude wavefront is created
- shock forms after certain time/distance due to the nonlinear evolution of the perturbation (**signal velocity depends on the amplitude!**)

$$\frac{\partial u}{\partial t} + (v_0 + \frac{3}{2}u) \frac{\partial u}{\partial x} = 0$$

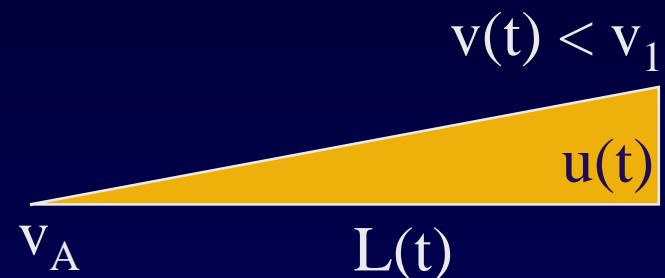
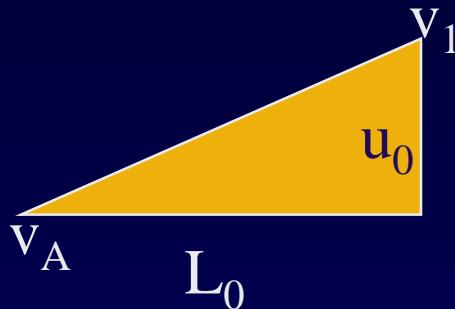
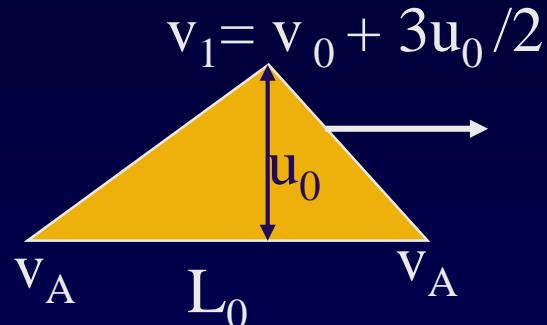


$$w(t) = w_0 + k u(t)$$

$$k=4/3, w_0=c_{s0} \text{ at } \beta \gg 1$$

$$k=3/2, w_0=v_{A0} \text{ at } \beta \ll 1$$

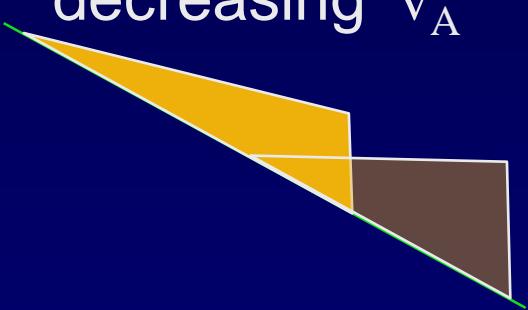
# Simple Wave (temporary piston)



decreasing  $v_A$

increasing  $v_A$

3-D



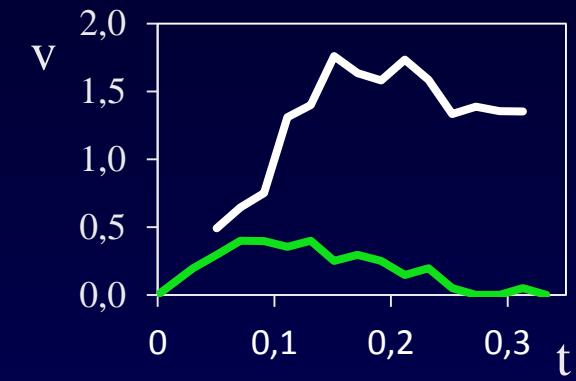
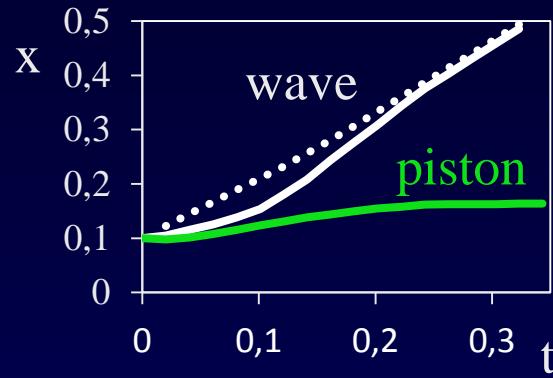
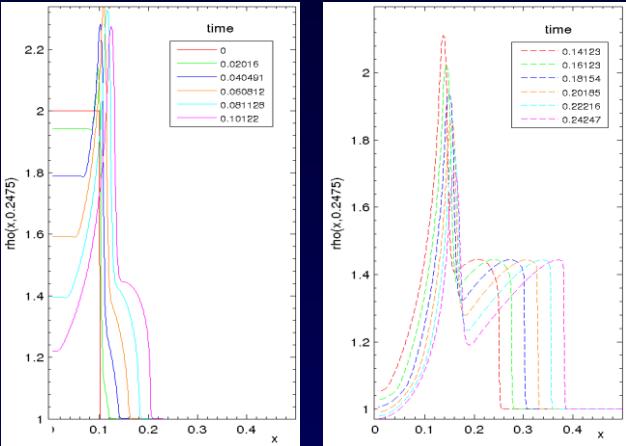
$v_A(R)$   
quiet corona

$v_A(R)$   
AR corona

$v_A(d)$   
AR corona

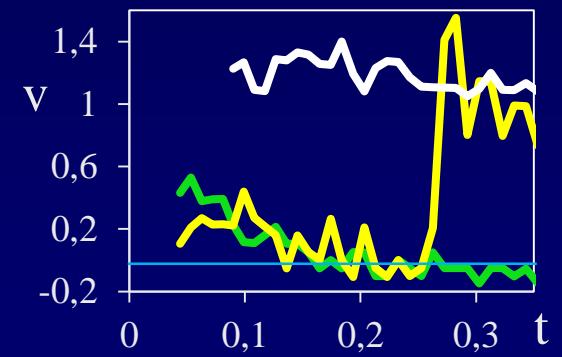
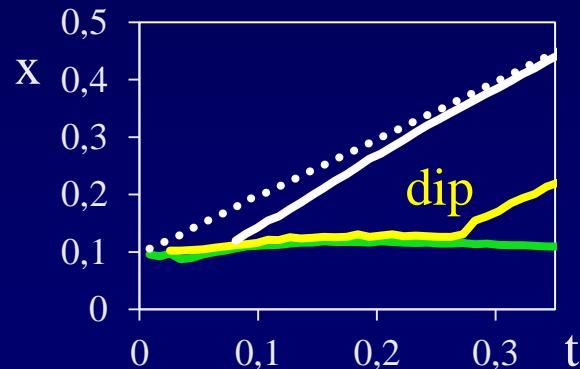
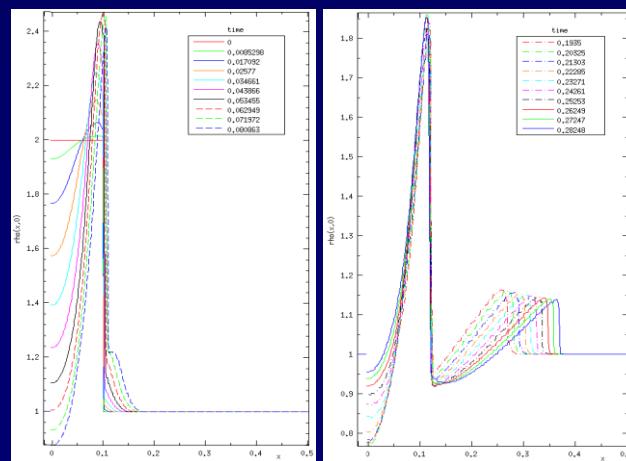
# Piston Mechanism (simulations)

1D - planar



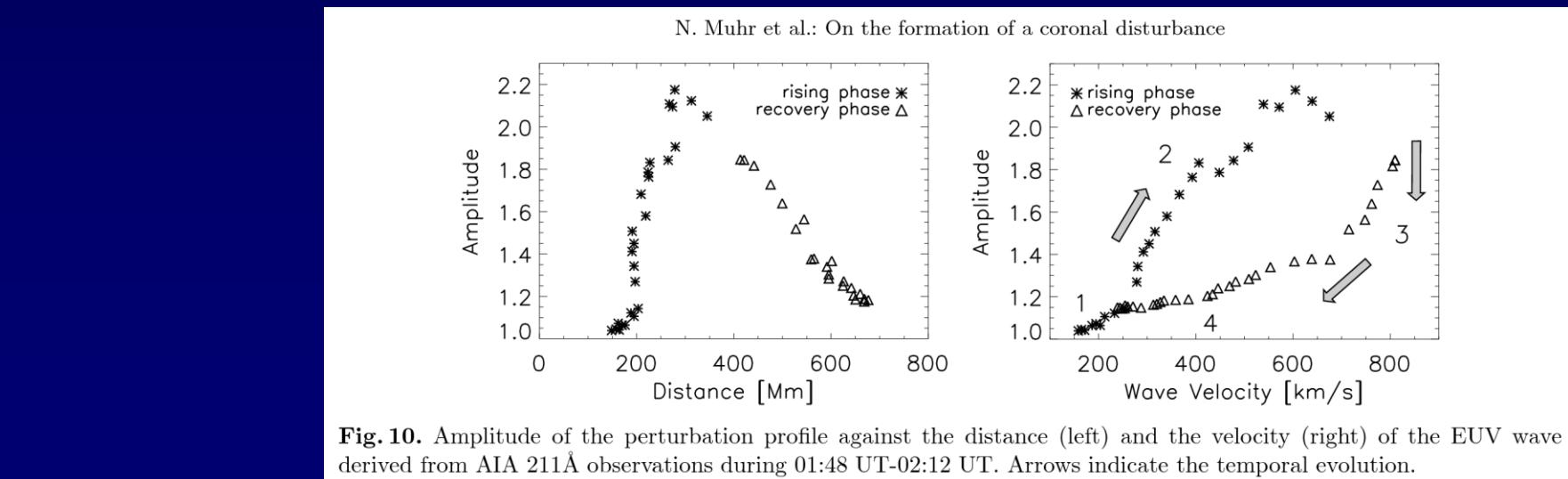
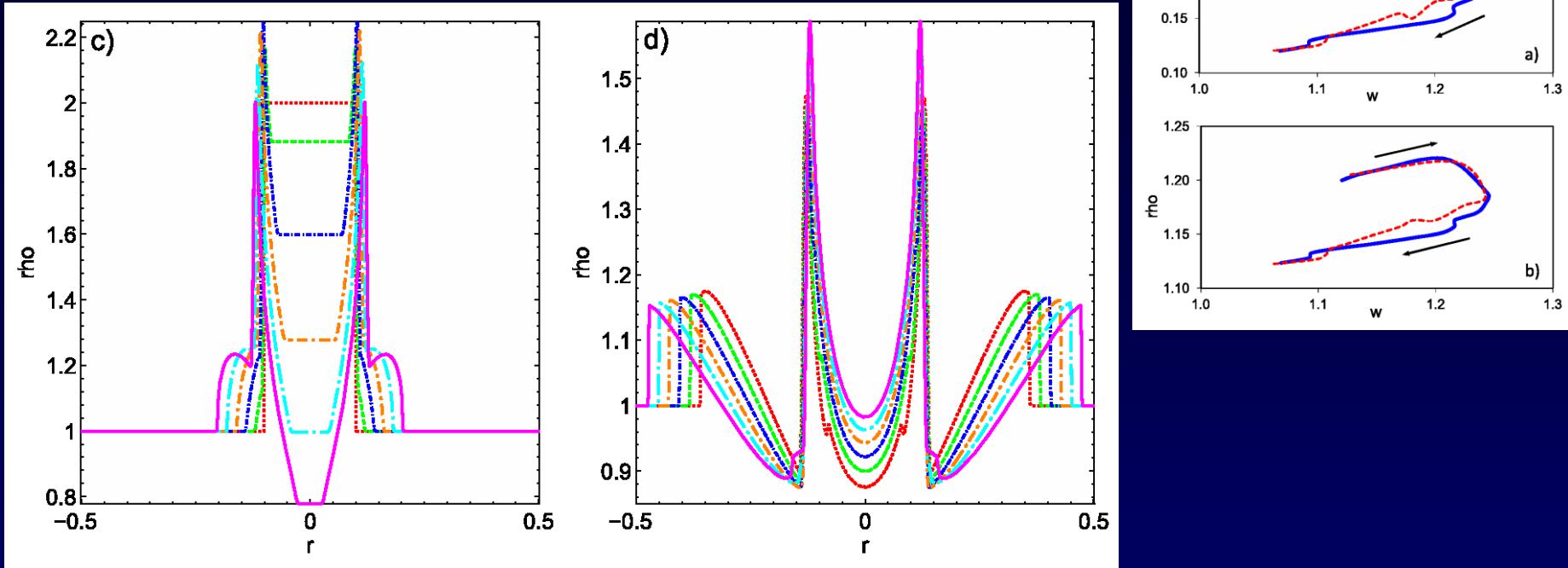
- amplitude growth + steepening  $\rightarrow$  shock formation
- after  $t \sim 0.15$   $\sim$ const. amplitude/velocity phase

1.5D - cylindrical



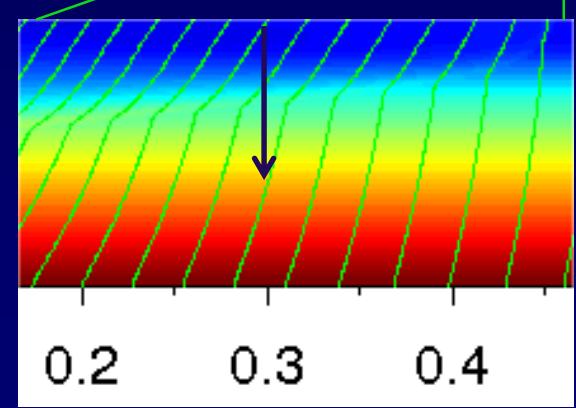
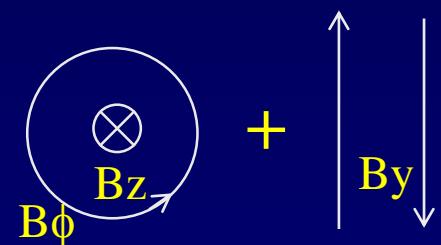
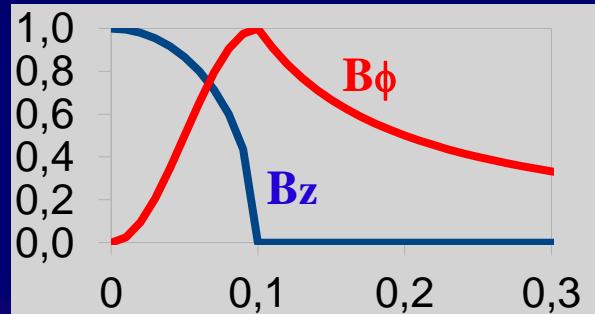
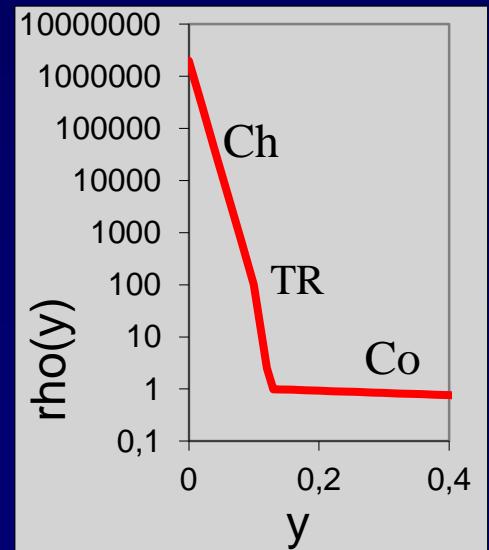
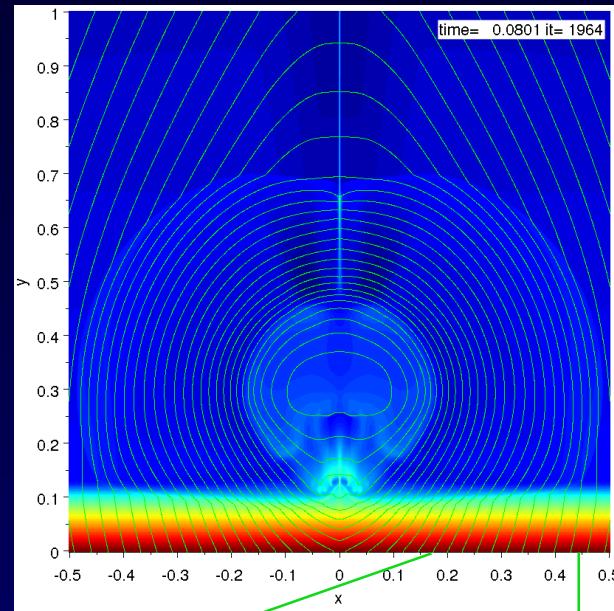
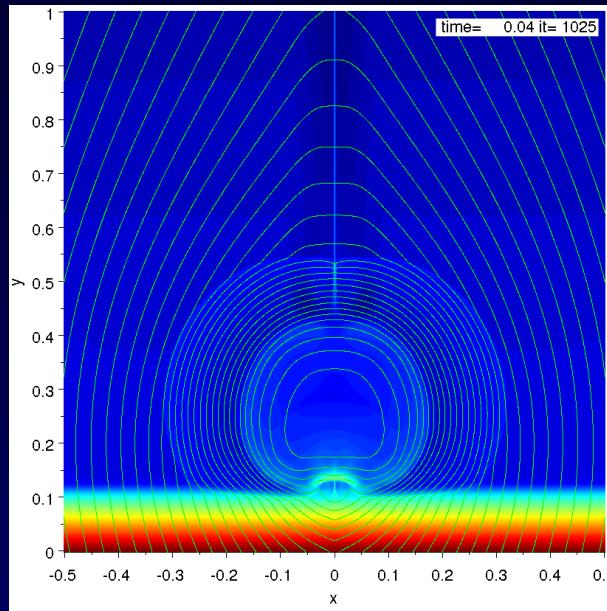
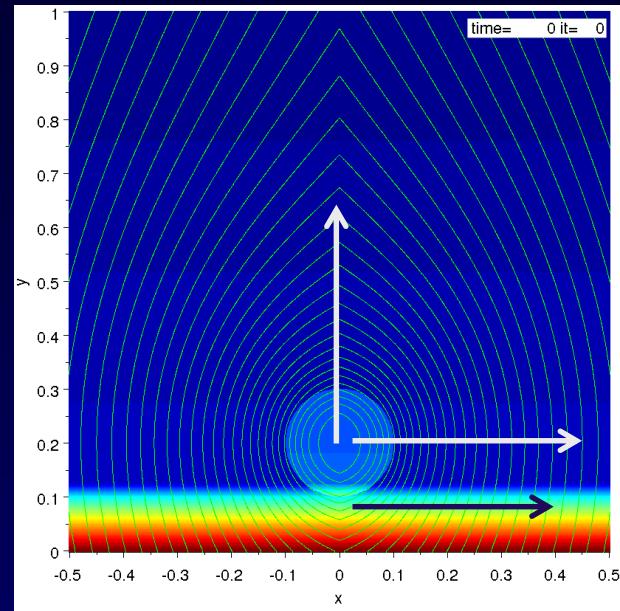
- amplitude growth + steepening  $\rightarrow$  shock formation
- lower amplitude, formation of rarefaction region
- after  $t \sim 0.08$  decreasing amplitude/velocity

# Wave evolution



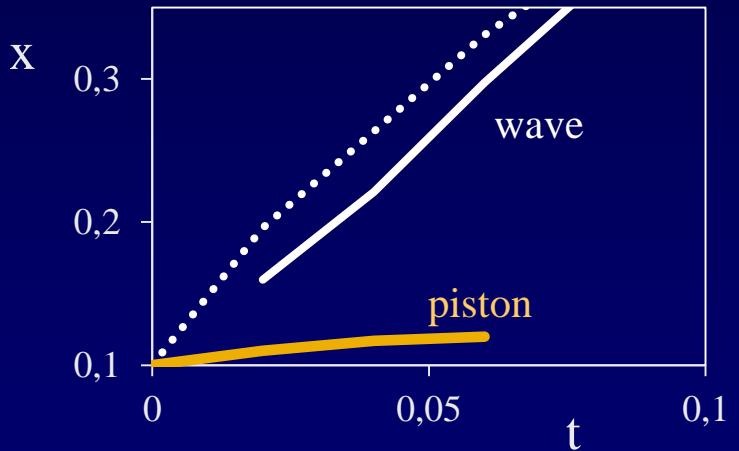
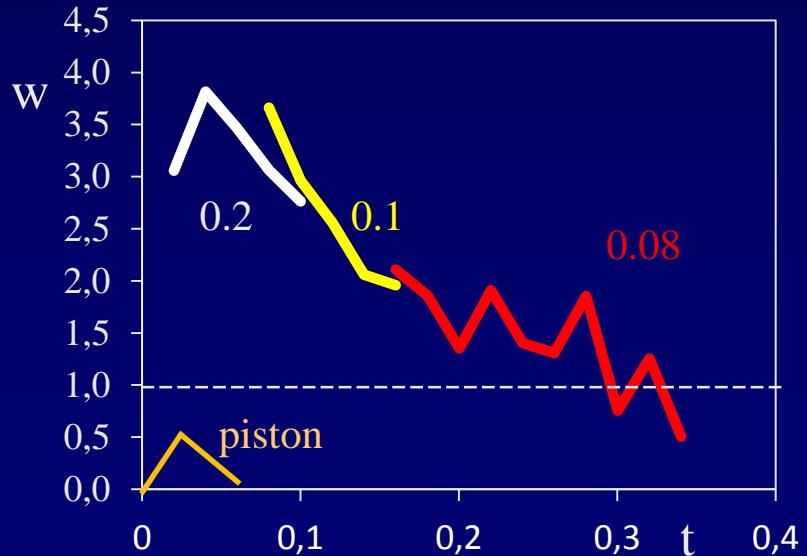
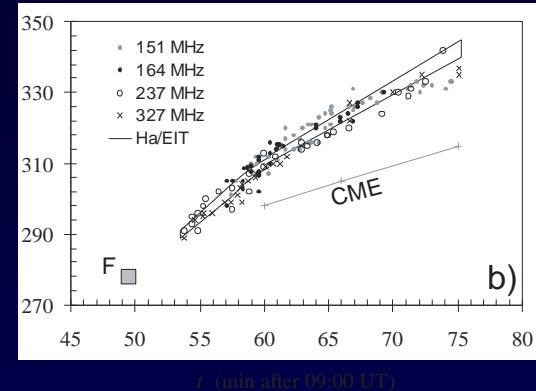
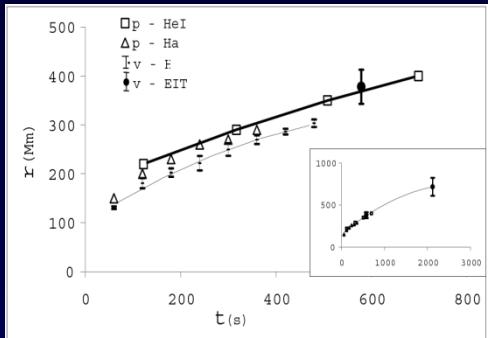
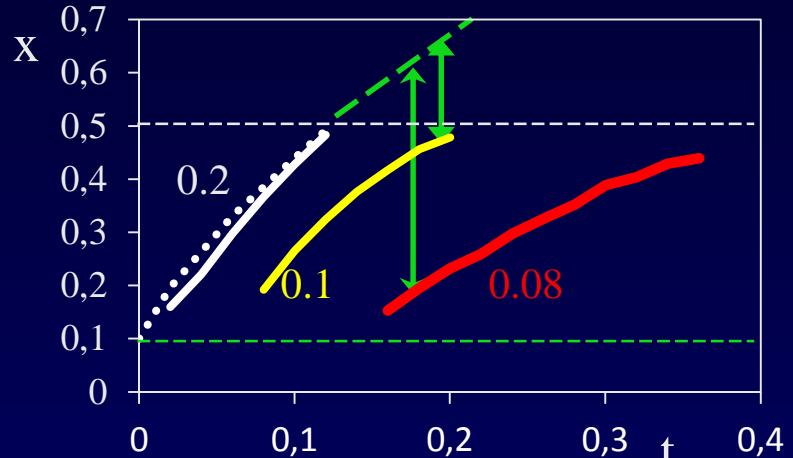
**Fig. 10.** Amplitude of the perturbation profile against the distance (left) and the velocity (right) of the EUV wave derived from AIA 211Å observations during 01:48 UT-02:12 UT. Arrows indicate the temporal evolution.

# 2.5-D MHD simulation



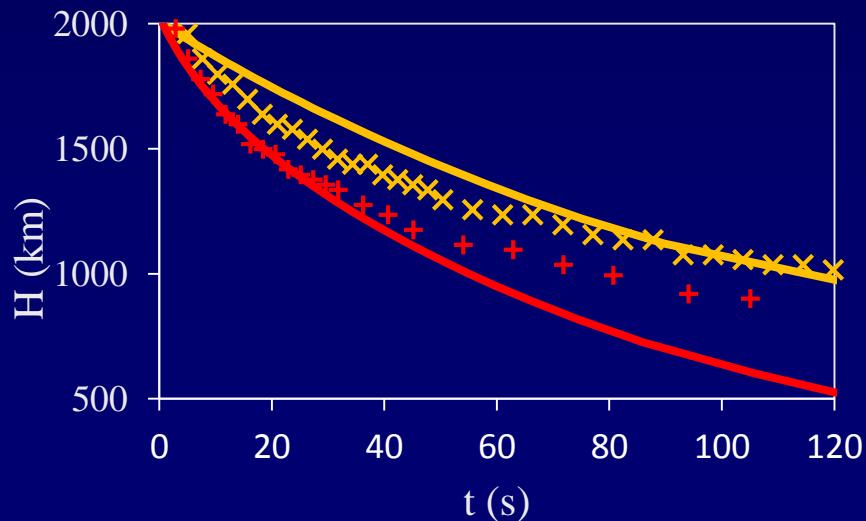
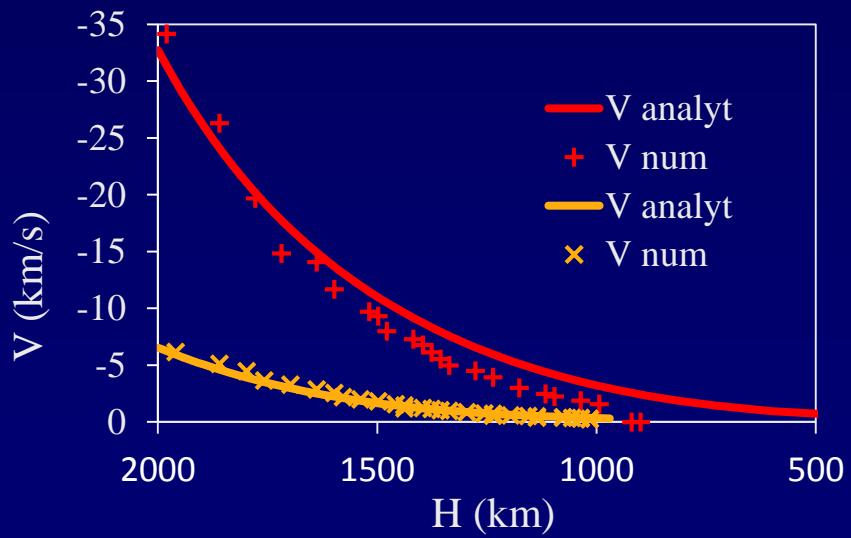
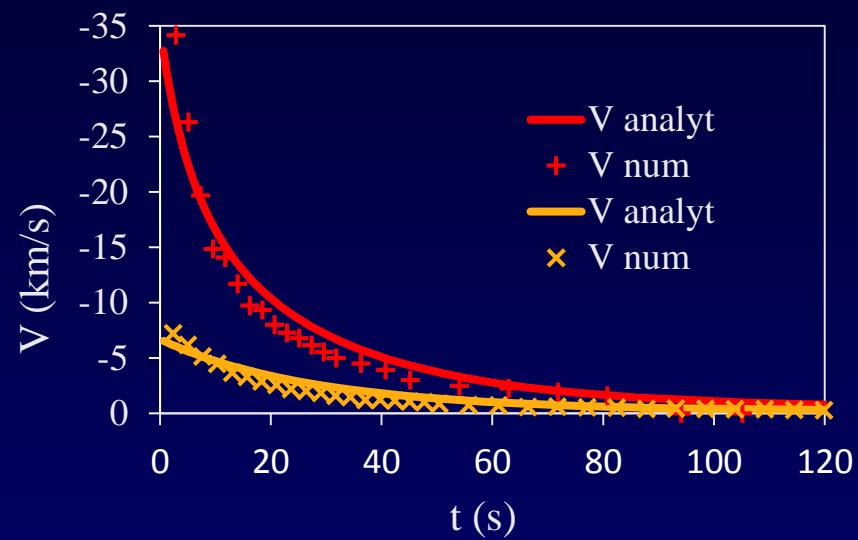
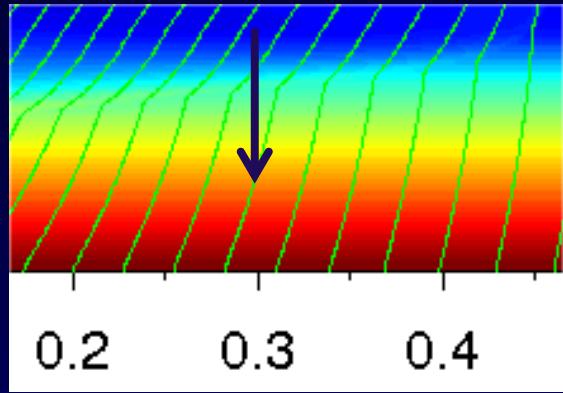
$$\beta = 0$$

# MHD simulation: Corona



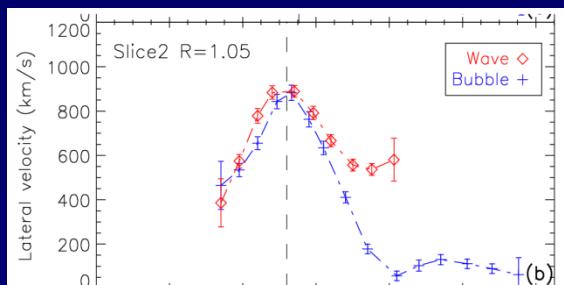
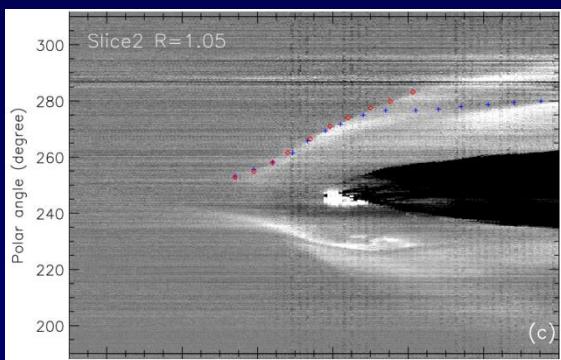
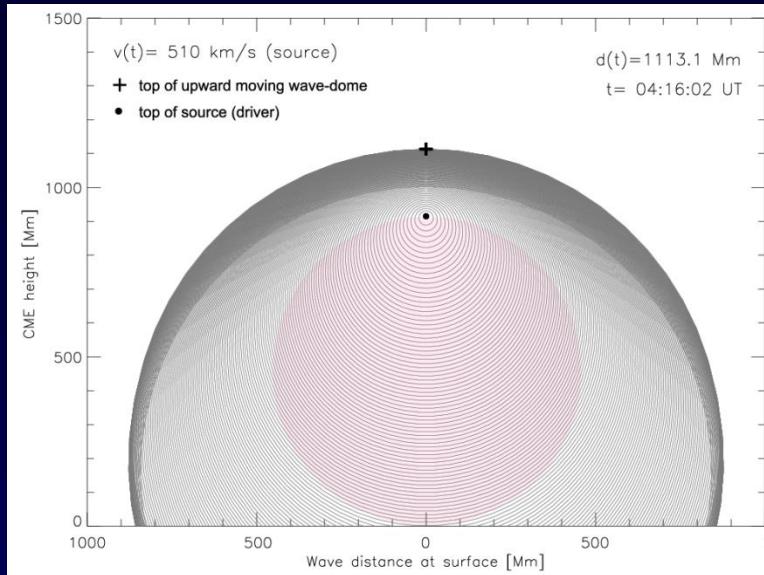
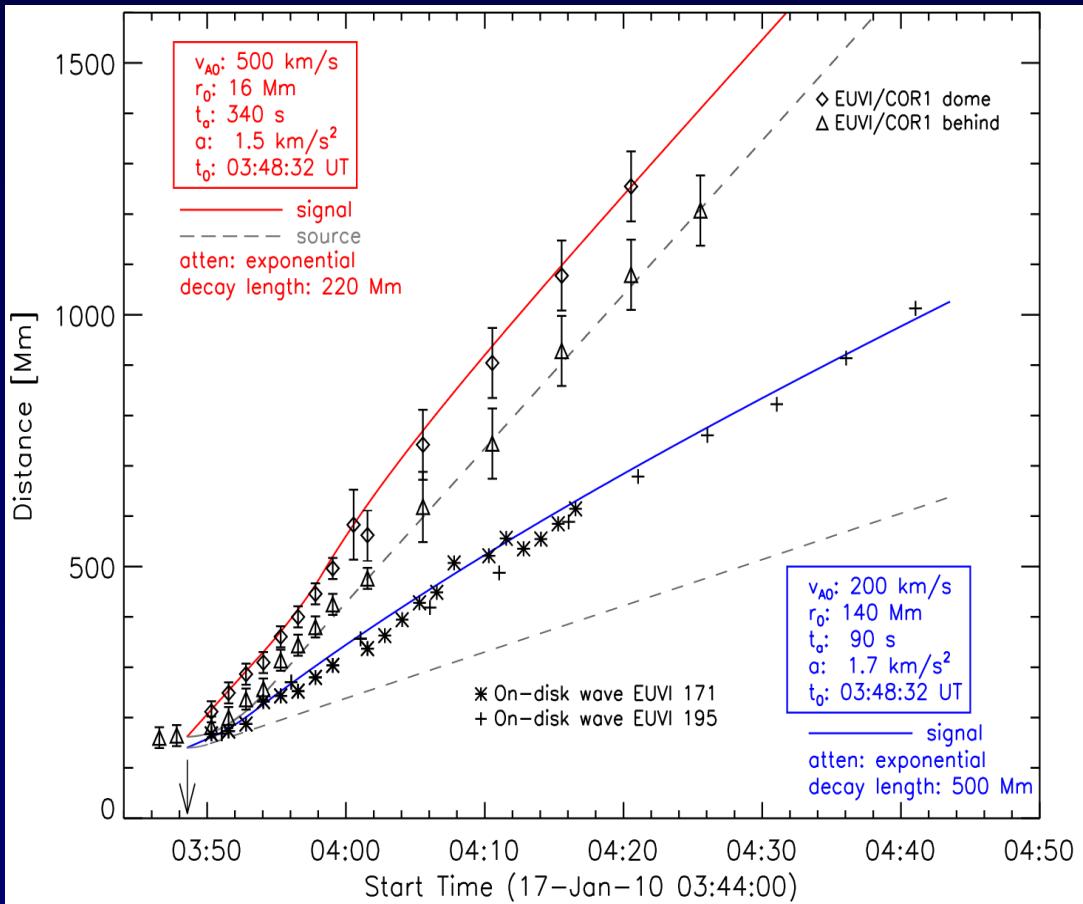
- steepening + ampl. increase  $\rightarrow$  shock
- deceleration; ampl. decrease
- corona/Moreton offset
- corona/Moreton delay

# MHD simulation: Moreton wave

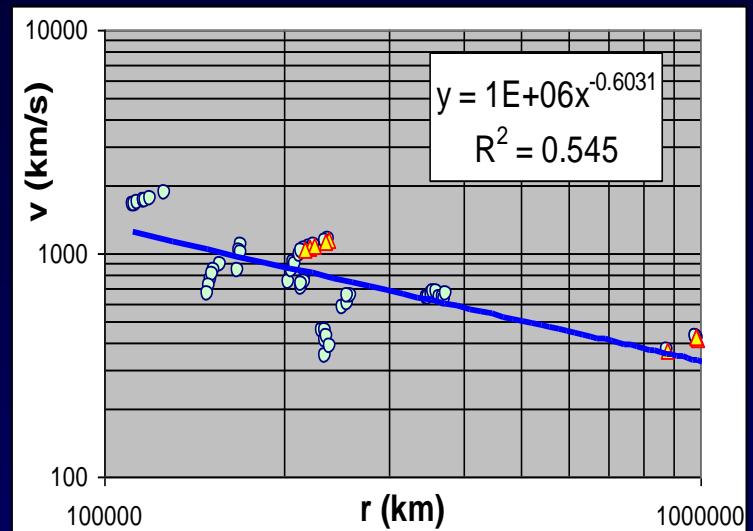
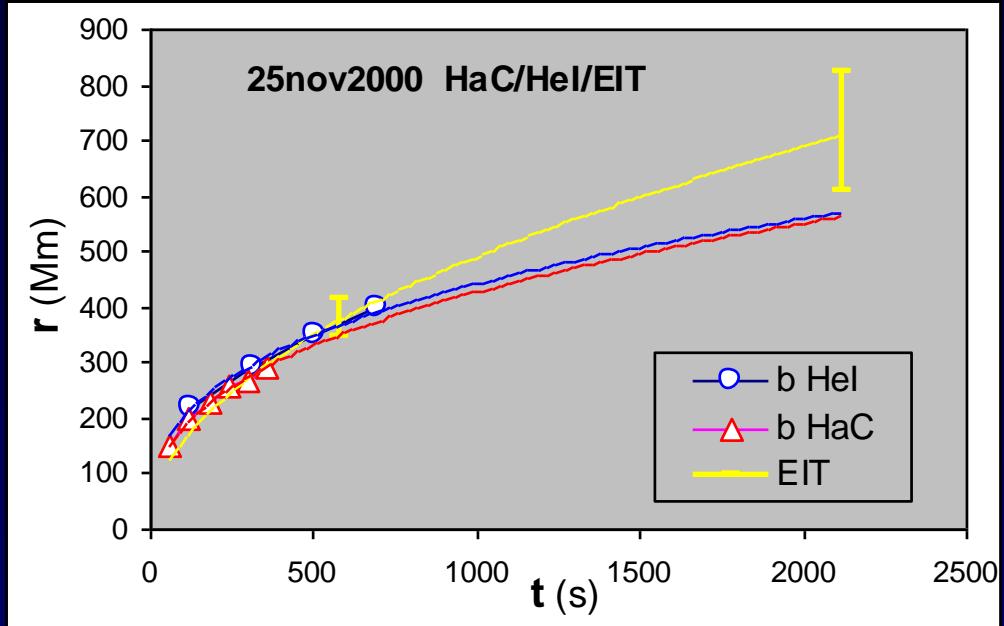


# Bow/piston combination

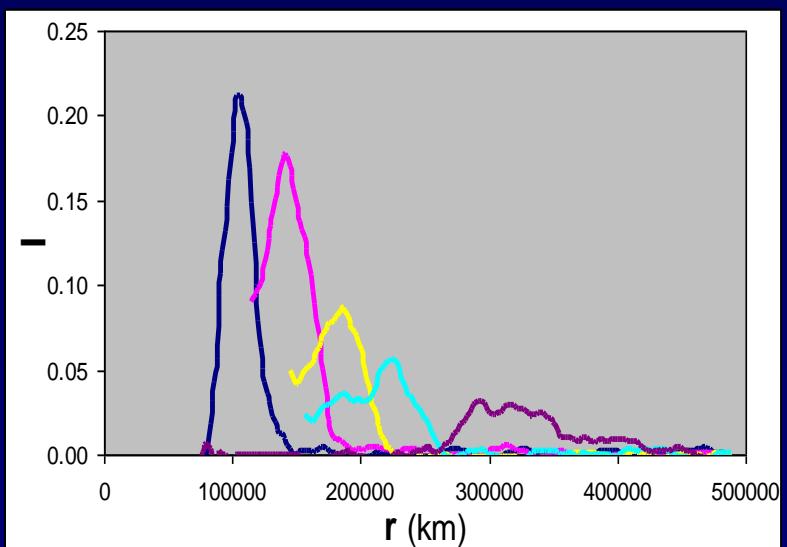
Temmer et al. 2012  
(submitted)



# H $\alpha$ -He-EUV kinematics & evolution of perturbation



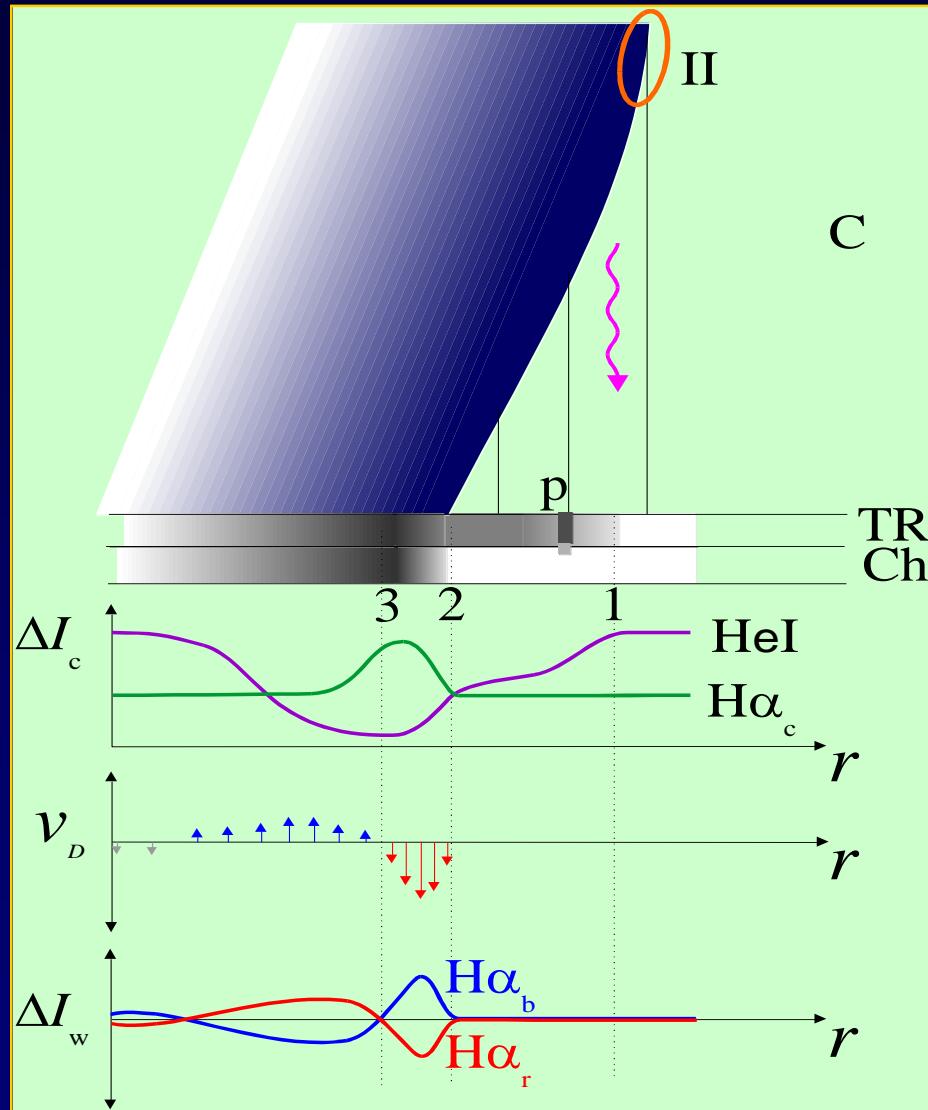
- ◆ Deceleration  
( $v \approx 1000$  km/s  $\rightarrow v \approx 200$ -400 km/s)  
( $v \propto r^{-1/2}$ )
- ◆ Decreasing amplitude
- ◆ Broadening



# Additional support for the fast-mode interpretation:

- Limb morphology/evolution
- Directivity = refraction into low-Alfven velocity
- Winking filaments
- Interaction with coronal holes (reflection)
- "Oscillatory relaxation" of the chromosphere
- Homologous events
- ....

# Moreton-type II: the fast-mode interpretation (after Uchida: Sol. Phys. 1968, 4, 30 → 1974, 39, 431)



**Moreton** = initial, large amplitude phase

$(M_{ms} \approx 2-5)$

**HeI** = “missing link”

**EIT** = distant, low amplitude phase

$(M_{ms} \rightarrow 1)$

**Type II burst** = coronal signature

$(M_{ms} \approx 1.1-2)$

# Conclusion

- upward (type II) = driven bow/piston shock
- lateral (EUV, He, H $\alpha$ ) = temporary piston (“CME overexpansion”)
- the time/distance of the shock formation depends strongly on the spatial behavior of Alfvén speed
- to form a high-frequency type II burst and a Moreton wave ( $d_0 \sim 100$  Mm;  $t_0 \sim 1$  min), the source-region has to be compact, the expansion has to be very impulsive, and the Alfvén speed has to decrease with distance
- Moreton wave appears only if shock is sufficiently strong (fast); only upper Ch is affected

Thank you  
for  
your attention

X

■ XXX