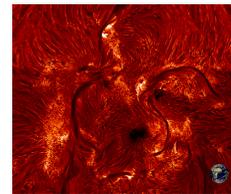


# THE SUN WITH ALMA

Rob Rutten

2017A&A...598A..89R

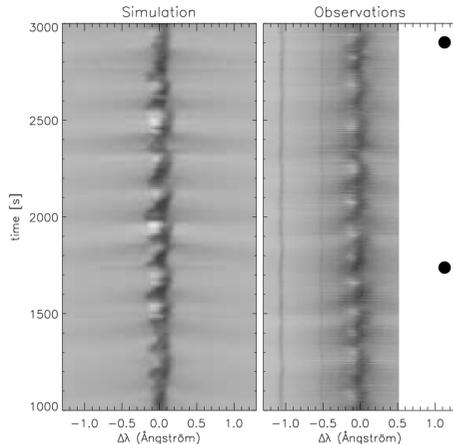
2016arXiv161105308R = IAUS 327 = tutorial



- *solar observing with ALMA*
  - technique: blocking filters  $\Rightarrow$  detector detuning (Pavel Yakoubov)
  - tests: 2014 and 2015 – [images public 2017](#)
  - Cycle 4, started December 2016 – [program list](#)
- *simulation predictions: low-chromosphere shocks and magnetism*
  - Wedemeyer et al. 2007A&A...471..977W: [CO5BOLD quiet-sun shocks](#)
  - Loukitcheva et al. 2015A&A...575A..15: [Bifrost quiet-sun plage](#)
  - Loukitcheva et al. 1702.06018v1: [Bifrost quiet-sun field measurement](#)
- *my predictions: high-chromosphere heating events and post-hot contrail canopies*
  - $H\alpha$  fibrils are opaque post-hot [contrails](#)
  - ALMA continua have yet larger post-hot extinction than  $H\alpha$
  - ALMA will show high-chromosphere canopies and hopefully the heating events

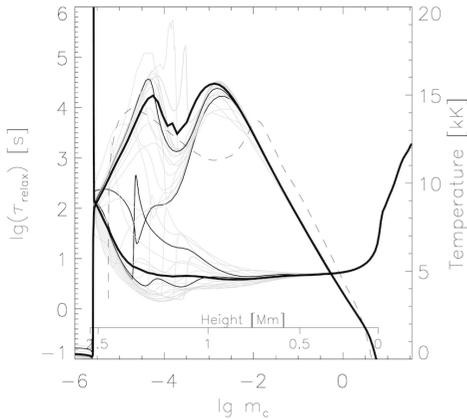
# INTERNETWORK $H_{2V}$ GRAINS = ACOUSTIC SHOCKS

- *Ca II  $K_{2V}$  grains (Rutten & Uitenbroek 1991SoPh..134...15R)*
  - extended and confused literature (600 references)
  - most likely non-magnetic phenomenon
  - most likely acoustic shocks
  - wave interference reminiscent of “clapotis”



- *observation (Lites, Rutten & Kalkofen 1993ApJ...414..345L)*
  - sawtooth line-center shift
  - triangular whiskers
  - $H_{2V}$  grains
- *simulation (Carlsson & Stein 1997ApJ...481..500C)*
  - 1D radiation hydrodynamics
  - subsurface piston derived from Fe I Doppler
  - emulation of observer’s diagnostics
- *analysis*
  - source function breakdown
  - dynamical chromosphere

## DETAILED BALANCING



*Hydrogen ionization/recombination relaxation timescale throughout the solar-like shocked RAdyn atmosphere. The timescale for settling to equilibrium at the local temperature is very long, 15–150 min, in the chromosphere but much shorter, only seconds, in shocks in which hydrogen partially ionizes.*

*Carlsson & Stein 2002ApJ...572..626C*

net radiative and collisional downward rates (Wien approximation)

$$n_u R_{ul} - n_l R_{lu} \approx \frac{4\pi}{h\nu_0} n_l^{\text{LTE}} b_u \sigma_{\nu_0}^l \left( B_{\nu_0} - \frac{b_l}{b_u} \bar{J}_{\nu_0} \right) \quad \text{zero for } S = \bar{J}, \text{ no heating/cooling}$$

$$n_u C_{ul} - n_l C_{lu} = n_l C_{lu} \left( \frac{b_u}{b_l} - 1 \right) = b_u n_l^{\text{LTE}} C_{lu} \left( 1 - \frac{b_l}{b_u} \right) \quad \text{zero for } b_u = b_l, \text{ LTE } S^l$$

dipole approximation for atom collisions with electrons (Van Regemorter 1962)

$$C_{ul} \approx 2.16 \left( \frac{E_{ul}}{kT} \right)^{-1.68} T^{-3/2} \frac{g_l}{g_u} N_e f$$

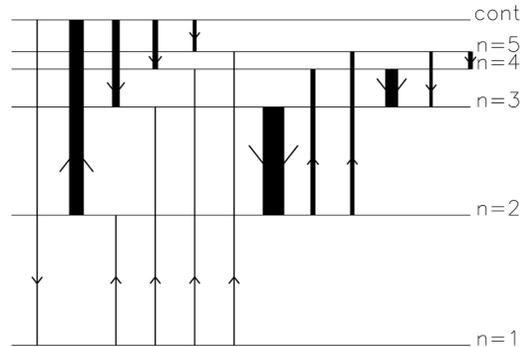
Einstein relation

$$C_{lu} = C_{ul} \frac{g_l}{g_u} e^{-E_{ul}/kT}$$

$C_{ul}$  is not very temperature sensitive (any collider will do);  $C_{lu}$  has Boltzmann sensitivity

# NON-EQUILIBRIUM HYDROGEN IONIZATION IN 1D SHOCKS

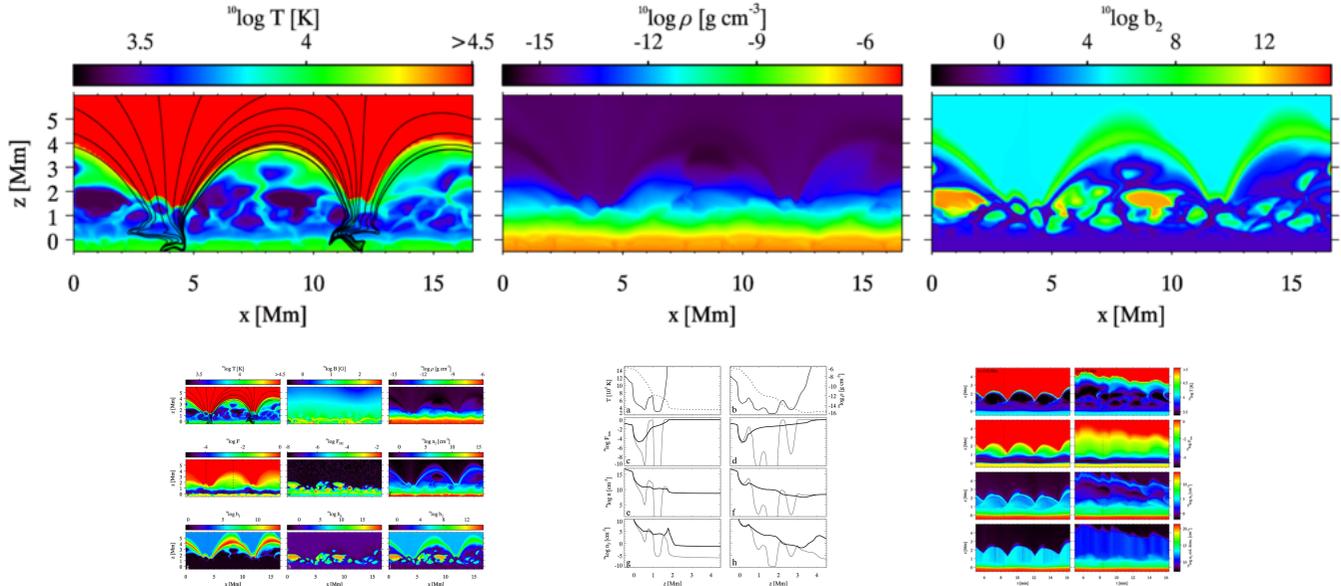
Carlsson & Stein 2002ApJ...572..626C



- RADYN code: 1D(t) hydrodynamics, time-dependent, NLTE radiation, simple PRD
- observed subphotosphere piston drives acoustic waves up that shock near  $h = 1000$  km
- $\text{Ly}\alpha$  scatters in radiative balance and controls  $n=2$ . Within shocks  $S \approx J$  saturates to  $B$  from radiation lock-in (increased  $\epsilon$  from partial hydrogen ionization) so that  $b_2 \approx 1$
- collisional  $\text{Ly}\alpha$  balancing has Boltzmann temperature sensitivity: fast (seconds) in hot gas, slow (minutes) in cool gas, resulting in retardation: post-shock cooling gas maintains the high  $n_2$  shock value at increasing  $b_2$  during minutes, up to huge overpopulation ( $b_2 \approx 10^{10}$ )
- ionization from  $n=2$  in the 3.4 eV alkali-like hydrogen top is an instantaneous statistical-equilibrium balance driven by Balmer continuum  $J \neq B$  and closed by cascade recombination, with  $b_{\text{cont}}/b_2 \approx 10^{-1}$  in hot and  $\approx 10^{+3}$  in cool gas, adding to the retarded  $b_2$
- between shocks hydrogen remains hugely overionized versus SE and LTE predictions

# NON-E HYDROGEN IONIZATION IN 2D MHD SHOCKS

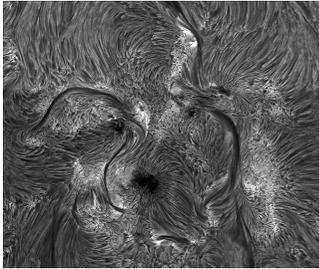
Leenaarts et al. 2007A&A...473..625L



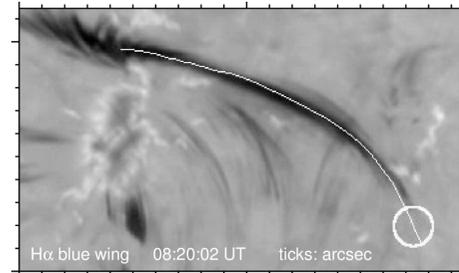
- in shocks  $\text{Ly}\alpha$  has  $S \approx B$  from high  $T$  (fast balancing) and  $N_e$  (10% H ionization)
- retarded collisional balancing in  $\text{Ly}\alpha$ :  $n_2$  hangs near high shock value  $n_2 \approx n_2^{\text{LTE}}$
- gigantic post-shock  $n=2$  overpopulations versus LTE (“S-B underestimates”)
- yet larger post-shock overionization from hydrogen-top Balmer balancing
- no Lyman RT: green arches artifacts, no lateral  $N_e$  boost from  $\text{Ly}\alpha$  scattering

# LONG H- $\alpha$ FIBRILS AS CONTRAILS AFTER HEATING EVENTS

Rutten 2017A&A...598A..89R



Rutten & Rouppe van der Voort 2017A&A...597A.138R



- *scenes*

- Ca II H: instantaneous, bright = hot, internetwork shocks, thin active-region fibrils
- H $\alpha$ : long memory in cooling gas, ubiquitous long fibrils = contrail tracks
- Ly $\alpha$ : dark = past, bright = instantaneous sampling of heating events

- *contrail example*

- propagating heating event extending in H $\alpha$  wing, He II 304, Fe IX 171
- three-four minutes later followed by dark H $\alpha$  core fibril
- retracting with increasing redshift

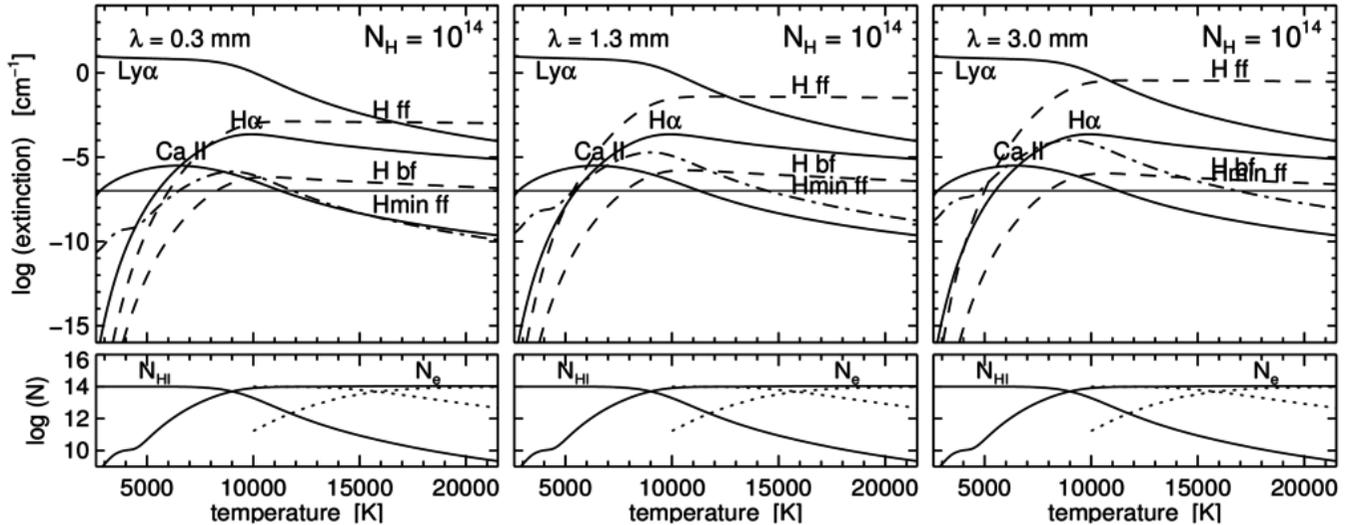
- *issues*

- are all long H $\alpha$  fibrils contrails?
- do they map magnetic field topography only at launch = H ionization?
- precursor nature? [Spicule-II-like](#)? Component reconnection? Alfvénic wave burst?

# SOLAR MM-WAVELENGTH EXTINCTION

Rutten 2017A&A...598A..89R

tutorial 2016arXiv161105308R



- ALMA: “linear thermometer” since H ff and Hmin ff have  $S = B$  (“source function LTE”) but where is  $\tau = 1$ ? (“extinction non-LTE”  $\Rightarrow$  “non-E extinction”)
- H $\alpha$  at high T: LTE or larger instantaneous extinction enforced by Ly $\alpha$
- H ff at high T: yet larger extinction  $\propto \lambda^2$
- cooling recombining contrail fibrils: large post-hot H $\alpha$  extinction, larger H I ff extinction
- prediction: fibril canopies more opaque than in H $\alpha$ , hiding shock regime underneath, dark from low actual temperature, less lateral contrast from lack of scattering and Dopplershifts
- ALMA = game changer: linear thermometer with extraordinary PSBE feature opacities

# PREDICTIONS FOR SOLAR ALMA

- *conclusion 2017A&A...598A..89R = prediction list*

1. ALMA sun mostly covered by long fibrils (unlike simulations sofar)
2. similar to  $H\alpha$ , good dark–dark correspondence, more opaque at longer ALMA wave-lengths, less lateral contrast (no Dopplershifts)
3. temperatures: above 10 000 K in heating events propagating outward from activity, around 7000 K in initial fibrils, cooling down to 5000 K or less in long contrail fibrils
4. heating events best detectable with large-array ALMA (@ temperatures)?
5. if so, darker aureoles vanishing above 15 000 K ( $Ly\alpha$  scattering)
6. small precursors produce 0.2–0.5 arcsec  $H\alpha$  and ALMA contrail widths ( $Ly\alpha$  scattering)
7. precursors better field mappers than subsequent contrail fibrils (@ check and employ)
8. internetwork shocks only in quietest areas, with 4000 K cooling clouds (@ how cool?)
9. no Ellerman bombs (hidden by fibrils)
10. flaring active-region fibrils poke through (@ reconnection temperature?)
11. off-limb spicules-II more opaque than in  $H\alpha$  and Ca II H (@ check and employ)
12. coronal rain much more opaque than in  $H\alpha$  (@ check and employ)

*“Hopefully these predictions will soon be verified with actual ALMA observations. I look forward to be proven right or wrong.”*

- *conclusion 2016arXiv161105308R*

- line(s):  $H\text{I}30-\alpha$  in Band 6? potentially PSBE-cleaned [wonderful Zeeman diagnostic!](#)

# SOLAR PRIORITY PROPOSALS IN CYCLE 4

<https://almascience.nao.ac.jp/observing/highest-priority-projects>

*total: 376 prioritized proposals out of 1600*

*solar: 4%*

*started: December 2016*

1. 2016.1.00030.S Shimizu et al.: Micro- and nano-flaring heating events
2. 2016.1.00050.S De Pontieu et al.: Chromospheric heating
3. 2016.1.00070.S Shimojo et al.: High-energy electrons
4. 2016.1.00156.S Okamoto et al.: Wave heating in prominences
5. 2016.1.00166.S Fleischman et al.: Chromosphere hermal structure
6. 2016.1.00182.S Bastian et al.: Spicules
7. 2016.1.00201.S Yokoyama et al.: Chromospheric jets
8. 2016.1.00202.S White et al.: Quiet-Sun chromosphere
9. 2016.1.00298.S Leenaarts et al.: Plage chromosphere
10. 2016.1.00423.S Wedemeyer et al.: Chromospheric heating
11. 2016.1.00572.S Bastian et al.: Quiet sun
12. 2016.1.00788.S Kobelski et al.: Microflares
13. 2016.1.01129.S Reardon et al.: Internetwork waves
14. 2016.1.01408.S Antolin et al.: Coronal rain
15. 2016.1.01532.S Chen et al.: Penumbral energy release events

# CLAPOTISPHERE

*Rutten 1995soho....1..151R "The internetwork chromosphere is inherently a clapotisphere"*

"The extensive literature on the Ca II  $K_{2V}$  grains and related cell-interior phenomena leads us to the conclusion that bright cell grains are of hydrodynamical origin, due to oscillations that are present all over the solar surface but which produce grains only at places and moments set by pattern interference between the velocity oscillations in the  $K_3$  layer and the evanescent wave trains of the  $p$ -mode oscillation deeper down. They remind us of what is called "clapotis" on sea charts for areas where wave interference produces waterspouts on the ocean (Dowd 1981)."

*Rutten & Uitenbroek 1991SoPh..134...15R*

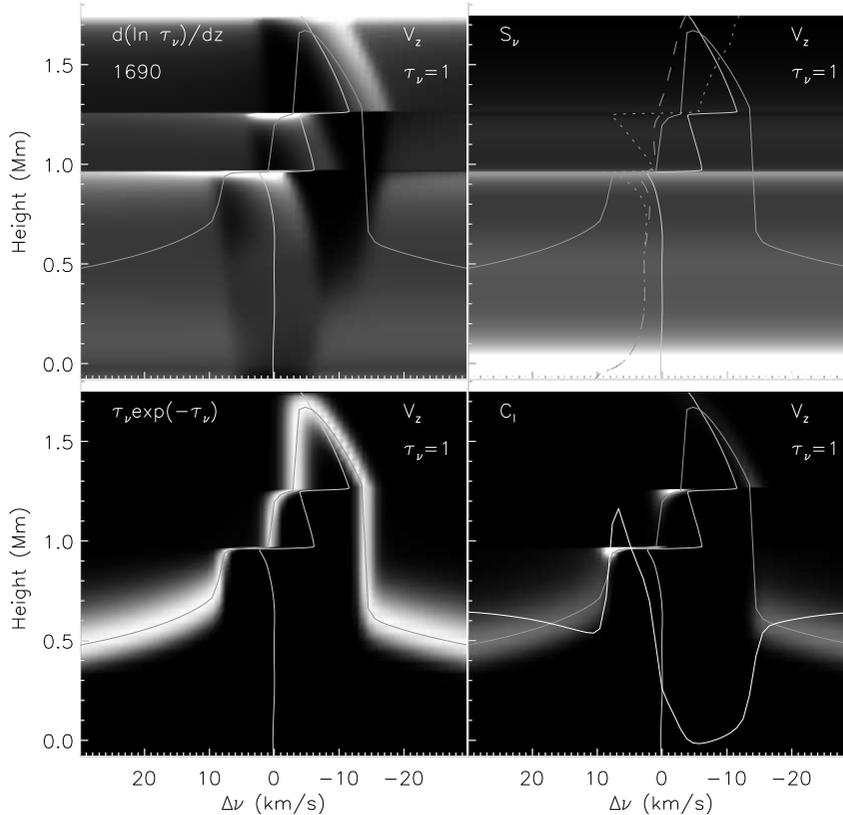
"When the crests of such waves coincide, their amplitudes combine, creating huge standing waves, much steeper than traveling waves. This phenomenon is called "clapotis". Off the northern tip of New Zealand, where major wave patterns collide in deep water, clapotis is regularly seen. The pinnacled waves formed here have so much vertical power that they can throw a laden kayak clear out of the water."

*Dowd 1981 (not on ADS)*

# SHOCK GRAIN DIAGNOSIS

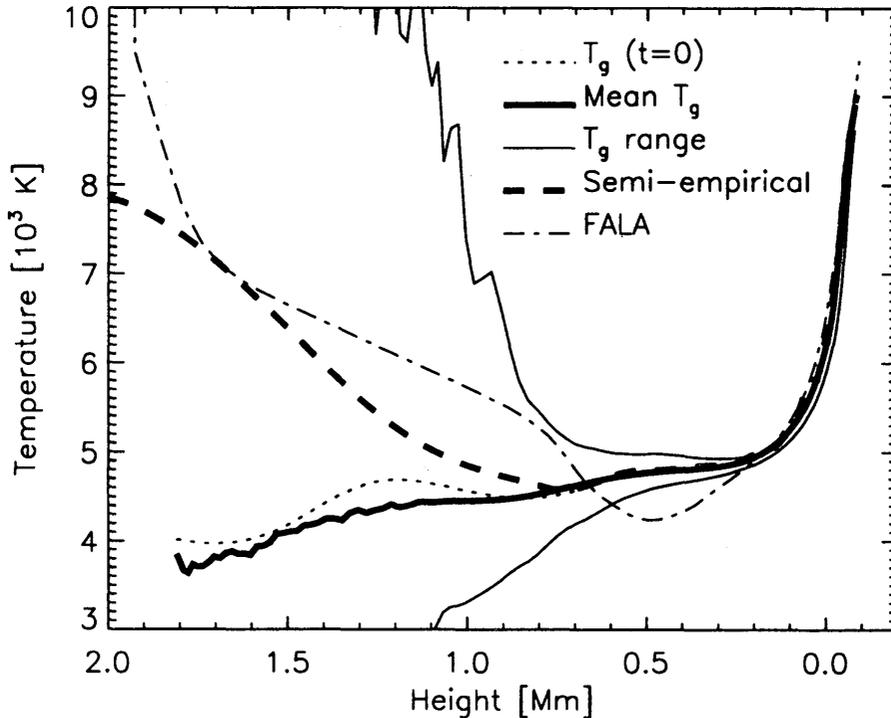
*Carlsson & Stein 1997ApJ...481..500C*

$$I_\nu(0) = \int_0^\infty S_\nu e^{-\tau_\nu} d\tau_\nu = \int_0^\infty S_\nu \tau_\nu e^{-\tau_\nu} \frac{d \ln \tau_\nu}{dz} dz$$



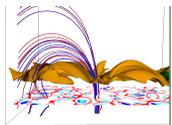
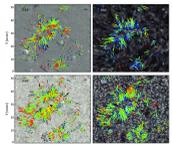
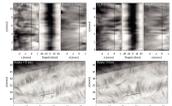
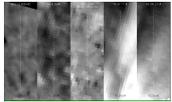
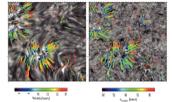
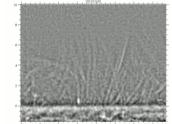
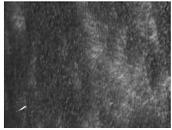
# SHOCK-RIDDEN COOL LOWER CHROMOSPHERE

*Carlsson & Stein 1995ApJ...440L..29C*



- mean  $T(h)$  (thick solid) remains close to RE starting model (dotted)
- bandwidth of  $T$  fluctuations (thin solid borders) very large above 1000 km
- a fit of the mean ultraviolet intensities needs a temperature rise (dashed)

# STRAWS / SPICULES-II / RBEs / RREs



- *observations*

- “straws”, DOT Ca II H  
*Rutten 2006ASPC..354..276R*
- “spicules-II”, Hinode Ca II H  
*De Pontieu et al. 2007Sci...318.1574D*
- “rapid blue excursions”, SST H $\alpha$   
*Roupe van der Voort et al. 2009ApJ...705..272R*
- “coronal heating events”, Hinode H $\alpha$  + SDO EUV  
*De Pontieu et al. 2011Sci...331...55D*
- “torsion-swaying jets”, SST H $\alpha$  + Ca II 8542 Å  
*De Pontieu et al. 2012ApJ...752L..12D*
- “rapid red excursions”, SST H $\alpha$   
*Sekse et al. 2013ApJ...769...44S*

- *simulation: Martínez-Sykora et al. 2011ApJ...736....9M*

- feature called a spicule-II but questionable
- no others in simulations so far
- driver unknown (Pereira et al. 2012ApJ...759...18P)

- *upshot: ubiquitous small magnetic heating events possibly important in*

- quiet-sun (also unipolar) coronal heating
- fast solar wind driving
- solar wind element segregation

# SOLAR RYDBERG LINES WITH ALMA?

Rutten 2016arXiv161003104J

- “*linear thermometer*”
  - $\text{H}^-$  free-free +  $\text{H I}$  free-free:  $S = B$
  - thick feature:  $T_b = T(\tau_\nu = 1)$
  - thin feature: cloud contribution  $\Delta T_b = \tau T$
- *solar Rydberg lines so far*
  - in  $\mu\text{m}$  range  $\text{Mg I}$  stronger than  $\text{H I}$
  - prediction  $\text{H I } \alpha$  lines  $n = 4 - 18$
  - $\text{H I } 19\alpha, 21\alpha$  observed at limb
- *H I Rydberg lines with ALMA?*
  - $\text{H I } 30\alpha$  in Band 6 (1.3 mm, 0.5 arcsec resolution)
  - cleanly present thanks to large post-hot non-E extinction?
  - on disk as  $T(\tau_\mu = 1)$  emission at steep  $T(\tau)$  gradient
  - at limb as  $\tau T$  extension
  - Zeeman in  $I$  and Stokes: [super-sensitive chromospheric magnetometer?](#)

### THE SUN WITH ALMA

2017A&A...586A...89R  
2016arXiv161003089v1 [AUAS 2017] : tutorial

Rob Rutten

- solar observing with ALMA
  - technique: blocking filters → detector detuning (Pavel Valukouv)
  - tests: 2014 and 2015 → images public 2017
  - Cycle 4, started December 16 → program list
- simulation predictions: low chromosphere shocks and magnetism
  - Wiedemeyer et al. 2007A&A...471...377W: COBOLD quiet sun shocks
  - Loukicheva et al. 2015A&A...578A...15L: SDO quiet sun shock
  - Loukicheva et al. 1702.5601v1: Broadest quiet-sun field measurement
- my predictions: high chromosphere heating events and post-hot coronal canopies
  - H<sub>α</sub> fibrils are coarser post-hot coronals
  - ALMA continua have yet larger post-hot extinction than H<sub>α</sub>
  - ALMA will show high chromosphere canopies and hopefully the heating events

1

### NON-EQUILIBRIUM HYDROGEN IONIZATION IN 1D SHOCKS

Carlsson & Stein 2002ApJ...572...620C

- RADYN code: 1D hydrodynamics, time-dependent, NLTE radiation, simple PRD
- observed subphotosphere piston shock velocities are of that shock near  $v = 1000$  km
- L<sub>yr</sub> scatters in radiative balance and controls  $\Rightarrow 2$ . Within shocks  $S \approx J$  saturates to  $I$  from radiation lock in (increased  $\rightarrow$  from partial hydrogen ionization) so that  $\eta_1 \approx 1$
- collisional  $\gamma$ -balancing has Boltzmann temperature sensitivity: fast (seconds) in hot gas, slow (minutes) in cool gas, resulting in retardation; post-shock cooling gas maintains the high  $\eta_1$  shock value as increasing  $\eta_1$  during minutes, up to huge overpopulation ( $\eta_1 \approx 10^{17}$ )
- ionization from  $\Rightarrow 2$  in the 0.4 of alkali like hydrogen top is an instantaneous statistical-equilibrium balance driven by Balmer continuum  $J$  and  $I$  and cooled by cascade recombinations with  $N_{e1} \approx 10^{17}$  m<sup>-3</sup> in hot and  $\approx 10^{11}$  m<sup>-3</sup> in cool gas, adding to the recombined  $N_e$
- between shocks hydrogen remains highly overionized versus SE and LTE predictions

4

### SOLAR MM-WAVELENGTH EXTINCTION

Rutten 2017A&A...586A...89R tutorial 2016arXiv161003089R

- ALMA: "linear thermometer" since H<sub>α</sub> lines fit  $\tau_{\text{H}\alpha} S = B$  ("source function LTE") but where  $\tau_{\text{H}\alpha} \approx 1 \rightarrow$  "non-E extinction")
- H<sub>α</sub> at high T<sub>l</sub> or LTE or larger instantaneous extinction over  $\tau_{\text{H}\alpha}$  (space)
- H<sub>α</sub> at high T<sub>l</sub> yet larger extinction  $\propto \tau_{\text{H}\alpha}^2$
- cooling/recombining central fibrils: large post-hot H<sub>α</sub> extinction, larger H<sub>α</sub> extinction, much deeper  $\Rightarrow$  more opaque than in H<sub>α</sub>, hiding shock regime underneath, dark from low actual temperature, less lateral contrast from lack of scattering and Doppler shifts
- ALMA:  $\gamma$ -game changer: linear thermometer with extraordinary PSBE wave optically

7

### CLAPOTISHERE

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"The extensive literature on the Ca II K<sub>1</sub> grains and related cell-interior phenomena leads us to the conclusion that bright cell grains are of hydrodynamical origin, due to oscillations that are present all over the solar surface but which produce grains only at places and moments set by pattern interference between the velocity oscillations in the K<sub>1</sub> layer and the expansion wave trains of the  $\gamma$ -mode oscillation deeper down. They remind us of what is called 'clapots' on sea charts for areas where wave interference produces retroscarpes on the ocean (Dowd 1981)."

Rutten & Ulmerbock 1995SoPh...134...15R

"When the crests of such waves coincide, their amplitudes combine, creating huge standing waves, much deeper than traveling waves. This phenomenon is called 'clapots'. Off the northern tip of New Zealand, where major wave patterns collide in deep water, clapots is regularly seen. The windrows and waves formed here have so much vertical power that they can throw a laden kayak clear out of the water."

Dowd 1981 (not on ADS)

10

### INTERNETWORK H<sub>α</sub> GRAINS → ACOUSTIC SHOCKS

- Ca II K<sub>1</sub> grains (Rutten & Ulmerbock 1995SoPh...134...15R)
  - extended and confused literature (900 references)
  - most likely non-radiogenic phenomenon
  - most likely acoustic shocks
  - wave interference reminiscent of "clapots"
- observation (Eiles, Rutten & Kalkofen 1993ApJ...414...345J)
  - sawtooth fine-center shift
  - triangular whitens
  - H<sub>α</sub> grains
- simulation (Carlsson & Stein 1997ApJ...481...500C)
  - 1D radiation hydrodynamics
  - subsurface piston derived from Fe I Doppler
  - emulation of observer's diagnostics
- analysis
  - source function breakdown
  - dynamical chromosphere

2

### NON-HYDROGEN IONIZATION IN 2D MHD SHOCKS

Leenarts et al. 2007A&A...473...625L

- in shocks L<sub>yr</sub> has  $S \approx J$  from high T<sub>l</sub> (last balancing) and  $N_e$  (100% H ionization)
- retarded collisional balancing in L<sub>yr</sub>:  $\eta_1$  hangs near high shock value  $\eta_1 \approx 10^{17}$
- gigantic post shock  $\Rightarrow 2$  overpopulations versus LTE ("S II underestimates")
- yet larger post-shock overpopulation from hydrogen ionization
- no Lyman RT; green arches artifacts, no lateral  $N_e$  boost from L<sub>yr</sub> scattering

5

### PREDICTIONS FOR SOLAR ALMA

2017A&A...586A...89R → prediction list

- ALMA sun mostly covered by low fibrils (unlike simulations solar)
- similar to H<sub>α</sub>, good dark-dark correspondence, more opaque at longer ALMA wavelengths, less lateral contrast (no Doppler shifts)
- temperatures above 10000 K in heating events propagating outward from activity, around 7000 K in initial fibrils, cooling down to 5000 K or less in low central fibrils
- heating events best detectable with large array ALMA (@ temperatures?)
- if  $\Rightarrow$  cooler structures vanishing above 15000 K (L<sub>yr</sub> scattering)
- small precursors produce 0.2-0.5 arcsec H<sub>α</sub> and ALMA central widths (L<sub>yr</sub> scattering)
- precursors better field mappers than subsequent central fibrils (@ check and employ)
- internetwork shocks only in quietest areas, with 4000 K cooling coils ( $\Rightarrow$  how cool?)
- no Clemens bombs (hidden by fibrils)
- flaring active-region fibrils poke through (@ reconnection temperature?)
- off-lob spicules II more opaque than in H<sub>α</sub> and Ca II H (@ check and employ)
- coronal rain much more opaque than in H<sub>α</sub> (@ check and employ)

"hopefully these predictions will soon be verified with actual ALMA observations. I look forward to be proven right or wrong"

conclusion 2016arXiv161003089R

- Ineq3: H130 → in Band 6? potentially PSBE cleaned wonderful Zeeman diagnostic

8

### SHOCK GRAIN DIAGNOSIS

Carlsson & Stein 1997ApJ...481...500C

$$I_{\lambda}(0) = \int_0^{\infty} S_{\lambda} e^{-\tau_{\lambda}} d\tau_{\lambda} = \int_0^{\infty} S_{\lambda} \tau_{\lambda} e^{-\tau_{\lambda}} \frac{d\tau_{\lambda}}{d\tau_{\lambda}} d\tau_{\lambda}$$

11

### DETAILED BALANCING

Hydrogen ionization/recombination relaxation timescale throughout the solar atmosphere

Carlsson & Stein 2002ApJ...572...620C

net radiative and collisional downward rates (Wien approximation)

$$n_e R_{\text{rad}} - n_e R_{\text{coll}} = \frac{d\eta_1}{dt} \approx \frac{d\eta_1}{d\tau} \left( \frac{d\tau}{dt} \right) \approx \frac{d\eta_1}{d\tau} \left( \frac{v_{\text{flow}}}{H} \right)$$

zero for  $S = J$ , no heating/cooling

$$n_e R_{\text{rad}} - n_e R_{\text{coll}} = n_e n_{e1} \left( \frac{d\eta_1}{d\tau} \right) \left( \frac{v_{\text{flow}}}{H} \right) \approx n_e n_{e1} \left( \frac{d\eta_1}{d\tau} \right) \left( \frac{v_{\text{flow}}}{H} \right)$$

zero for  $\eta_1 \approx \eta_1$ , LTE  $\tau$

dipole approximation for atom collisions with electrons (Van Regemorter 1962)

$$C_{12} \approx 2.16 \left( \frac{v_{\text{flow}}}{H} \right)^2 T^{-1/2} N_e f$$

Einstein relation

$$C_{12} = C_{12}^{\text{rad}} e^{-\tau_{12}} N_e f$$

$C_{12}$  is not very temperature sensitive (any cooler will do);  $C_{12}$  has Boltzmann sensitivity

3

### LONG H-alpha FIBRILS AS CONTRAILS AFTER HEATING EVENTS

Rutten 2017A&A...586A...89R Rutten & Roupe van der Voort 2017A&A...597A...183R

- scenes
  - Ca II H: instantaneous, bright = hot, internetwork shocks, thin active-region fibrils
  - H<sub>α</sub>: long memory in cooling gas, ubiquitous long fibrils = contrails
  - L<sub>yr</sub>: dark = past; bright = instantaneous scattering of heating events
- central escape
  - propagating heating event extending in H<sub>α</sub>, wing: He II 304, Fe II 171
  - three-four minutes later followed by dark H<sub>α</sub> core fibril
  - retracting with increasing redshift
- issue
  - are all long H<sub>α</sub> fibrils contrails?
  - do they map magnetic field topology only at launch = H ionization?
  - precursor nature? Spicule II-like? Component reconnection? Alfvénic wave burst?

6

### SOLAR PRIORITY PROPOSALS IN CYCLE 4

<https://almascience.nso.gov/observing/highest-priority-projects>

total: 376 prioritized proposals out of 1600 solar 4% started: December 2016

- 2016.1.00030 S Shimizu et al.: Micro- and nano-faring heating events
- 2016.1.00050 De Pontieu et al.: Chromospheric heating
- 2016.1.00070 Shoup et al.: High-energy electrons
- 2016.1.00156 Okamoto et al.: Wave heating in prominences
- 2016.1.00166 Flechtner et al.: Chromosphere neutral structure
- 2016.1.00182 Bastian et al.: Spicules
- 2016.1.00201 Yokoyama et al.: Chromospheric jets
- 2016.1.00202 White et al.: Quiet-Sun chromosphere
- 2016.1.00268 Leenarts et al.: Fringe chromospheres
- 2016.1.00423 Wiedemeyer et al.: Chromospheric heating
- 2016.1.00572 Bastian et al.: Quiet sun
- 2016.1.00788 Reardon et al.: Microflares
- 2016.1.01129 Kibicki et al.: Internetwork waves
- 2016.1.01408 Antolin et al.: Coronal rain
- 2016.1.01522 Chen et al.: Pneumatic energy release events

9

### SHOCK-HIDDEN COOL LOWER CHROMOSPHERE

Carlsson & Stein 1995ApJ...461...29C

- mean T<sub>th</sub> (thick solid) remains close to RE stranding model (dotted)
- bandwidth of T fluctuations (thin solid borders) very large above 1000 km
- all of the mean ultraviolet intensities needs a temperature rise (dashed)

12

13

STRAWS / SPICULES-II / RBES / RRES

- observations
  - "straws", DOT Ca II H  
Rutten 2016ApJ...824...270R
  - "spicules II", Hinode Ca II H  
De Pontieu et al. 2007So...318.1574D
  - "rapid blue excursions", SST H $\alpha$   
Roupev van der Voort et al. 2009ApJ...705.272R
  - "coronal heating events", Hinode H $\alpha$  + SDO EUV  
De Pontieu et al. 2011So...331...65D
  - "tension-swaying jets", SST H $\alpha$  + Ca II 8542 A  
De Pontieu et al. 2012ApJ...755L.12D
  - "rapid red excursions", SST H $\alpha$   
Sekse et al. 2013ApJ...769...44S
- simulation: Martinez-Sykora et al. 2011ApJ...736...5M
  - feature called a spicule II but questionable
  - no others in simulations so far
  - driver unknown (Pereira et al. 2012ApJ...759...18P)
- upshot: ubiquitous small magnetic heating events possibly important in
  - quiet sun (also unipolar) coronal heating
  - fast solar wind driving
  - solar wind element segregation

14

SOLAR RYDBERG LINES WITH ALMA?

Rutten 2016arXiv161003104J

- "linear thermometer"
  - H free-free + H I free-free:  $S = B$
  - thick feature:  $T_e = T(\tau_e = 1)$
  - thin feature: cloud contribution  $\Delta T_e = \tau T$
- solar Rydberg lines so far
  - 80  $\mu\text{m}$  range Mpl stronger than H I
  - prediction H I  $\nu$  lines  $\nu = 1 - 15$
  - H I  $1\nu_2$ ,  $2\nu_1$  observed at limb
- H I Rydberg lines with ALMA?
  - H I  $3\nu_1$  in Band 6 (1.3 mm, 0.5 arcsec resolution)
  - clearly present thanks to large post-hot non-E extinction?
  - on disk as  $T(\tau_e = 1)$  emission at steep  $T(\tau)$  gradient
  - at limb as  $\tau T$  extension
  - Zeeman in  $\tau$  and Stokes: super-sensitive chromospheric magnetometer?

15

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16.jpg

thumbs/thumb-\par .jpg