# Catastrophic Cooling in Coronal Loops: Thermal Instability as a Road to Complex Evolution

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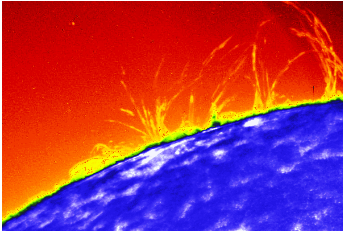


KIS

Turbulence in space plasmas
theory, observation and simulation

# Observations of dynamic loops

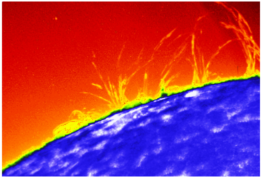
- Skylab observations: “dramatic evacuation” of loops

  (Levine & Withbroe 1977)

- SOHO/CDS: significant changes of loop systems within $\approx 1\,$hour, in particular seen in transition region lines

  (Kjeldseth-Moe & Brekke 1998)

- TRACE & SOHO: “Catastrophic cooling” and high-speed downflows (Schrijver 2001, De Groof et al. 2004)



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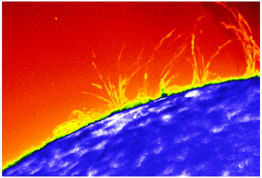
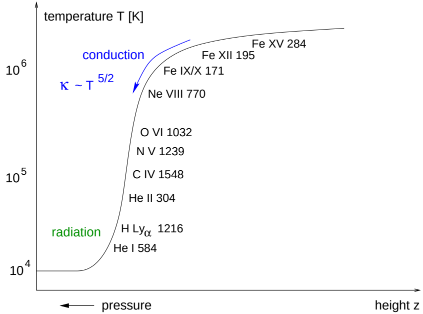


How much ’dynamics’ do we have to prescribe in a model?

# Energy balance in the transition region



conductive flux:

$$F_c = -\kappa_0 T^{5/2} \mathrm{d}T/\mathrm{d}z$$

radiative losses:

$$L_r = n_e n_H \Phi(T)$$

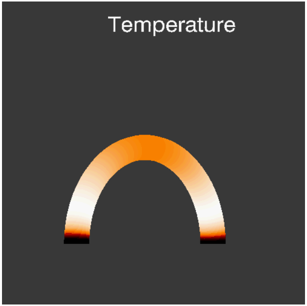
mech. energy flux (prescribed):

$$F_m = F_{m0} \cdot e^{-(z-z_0)/H_m}$$

- TTRANZ code (Hansteen 1993):
  1-D radiative HD code with adaptive grid,
  non-equilibrium rate equations / self-consistent radiative losses

The full story

# Loss of thermal equilibrium : The condensation cycle



Parker (ApJ 1953), Field (ApJ 1965)
Antiochos & Klimchuk (ApJ 1991)
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Müller, Hansteen & Peter (A&A 2003, 2004)

DO LOOP

- energy budget in the upper part of the loop becomes negative

→ temperature drops
→ pressure drops as well
→ mass flow towards pressure minimum
→ $\rho$ increases → higher radiative losses ($L_r \propto n_e^2$)

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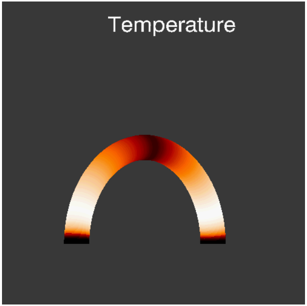

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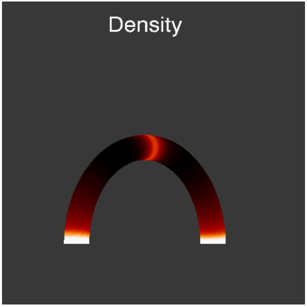

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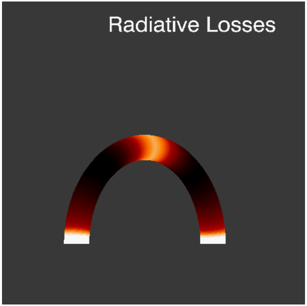

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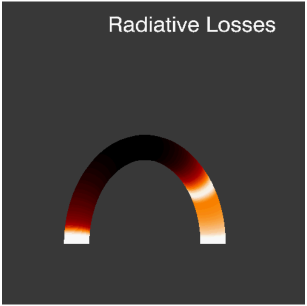

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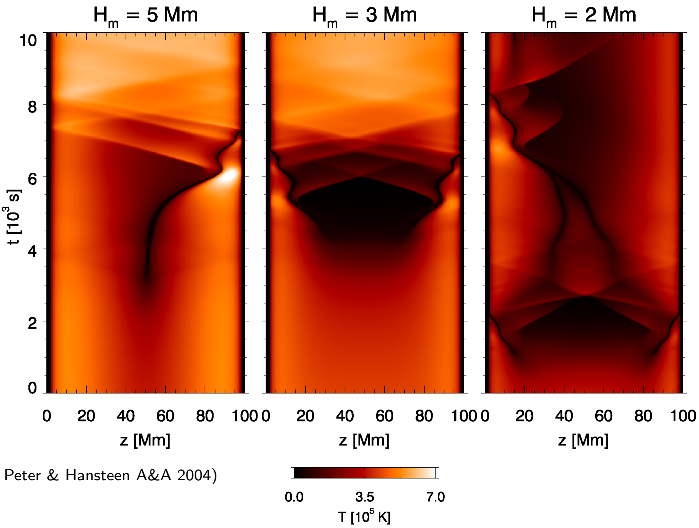
→ runaway cooling process leads to plasma condensation and the formation of a "micro-prominence" → condensation region is gravitationally unstable
→ depleted loop reheats

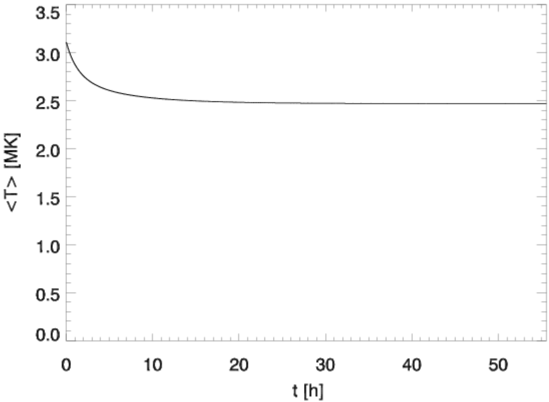
END DO

# Temperature evolution for different damping lengths



(Müller, Peter & Hansteen A&A 2004)

# Recurrent condensations in long loops (L = 300 Mm)



Damping length: $H_m = 12\,\mathrm{Mm}$ → stable

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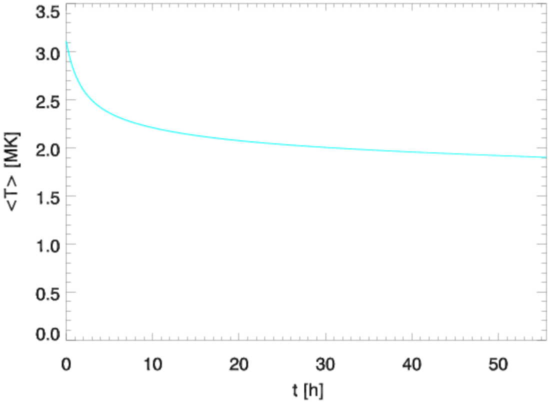

Damping length: $H_m = 8\,\mathrm{Mm}$ Period: P = 4.2 days

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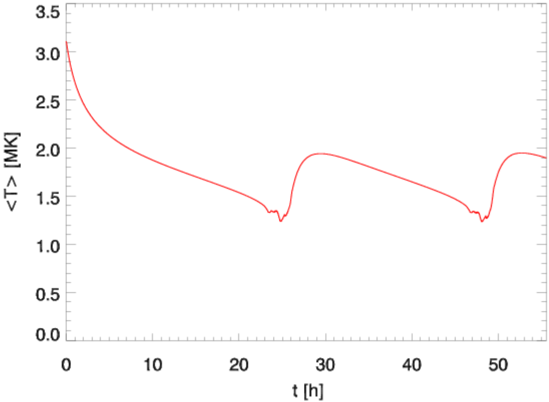
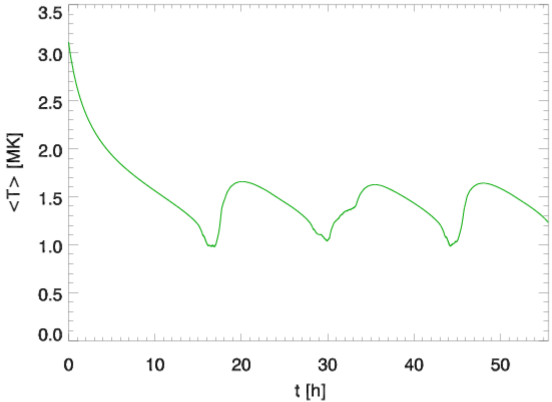


Damping length: $H_m = 5\,\text{Mm}$ Period: P = 1.0 days

# Recurrent condensations in long loops (L = 300 Mm)



Damping length: $H_m = 3\,\mathrm{Mm}$ Period: P = 0.6 days

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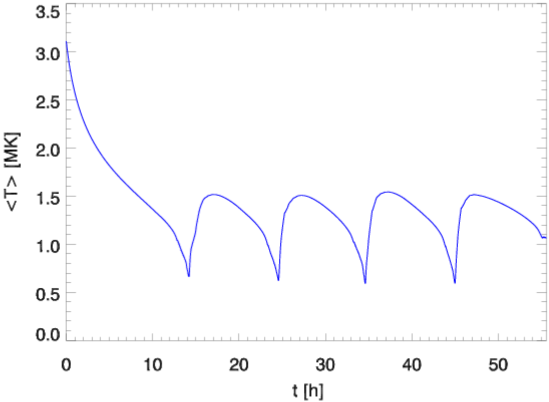
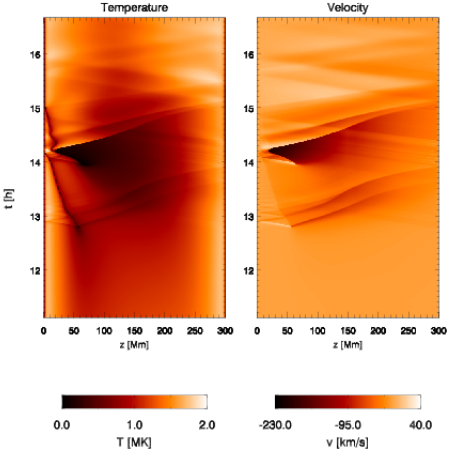


Damping length: $H_m = 2\,\mathrm{Mm}$ Period: P = 0.4 days

# *Slow* and *fast* blobs

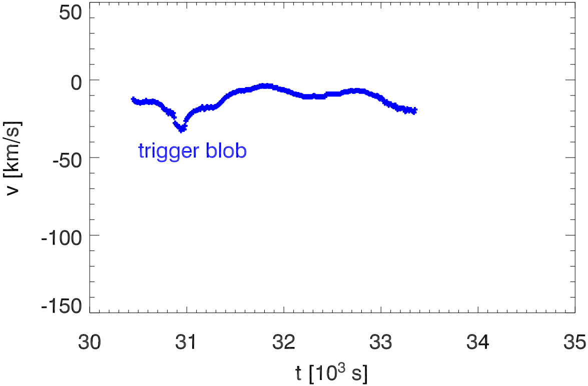


- a condensation region forms and drains, decelerated by the underlying plasma
- the rapid cooling leads to shocks which compresses the surrounding plasma

⇒ this can trigger a $2^{\text{nd}}$ condensation which reaches much higher velocities

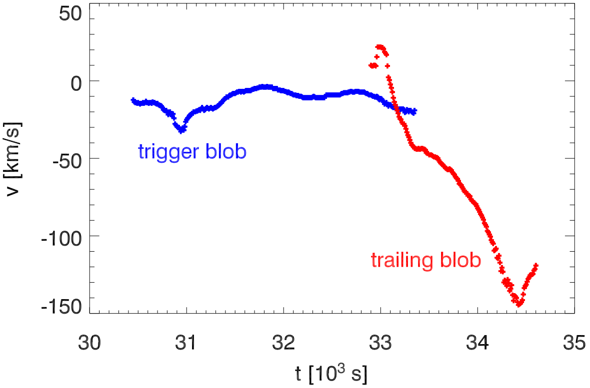
# The blob trigger I

## blob velocity



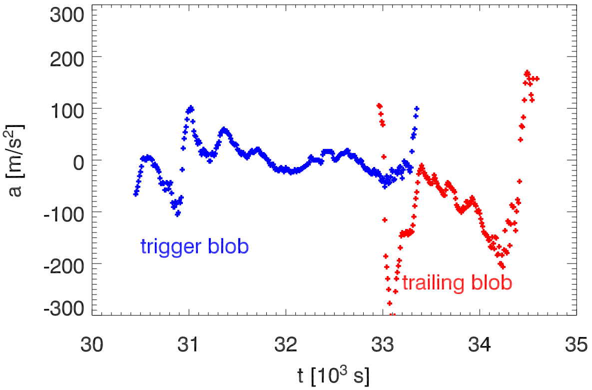
# The blob trigger I

## blob velocity

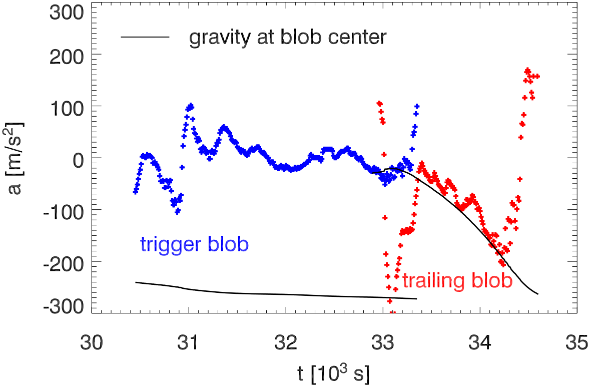


## The blob trigger II

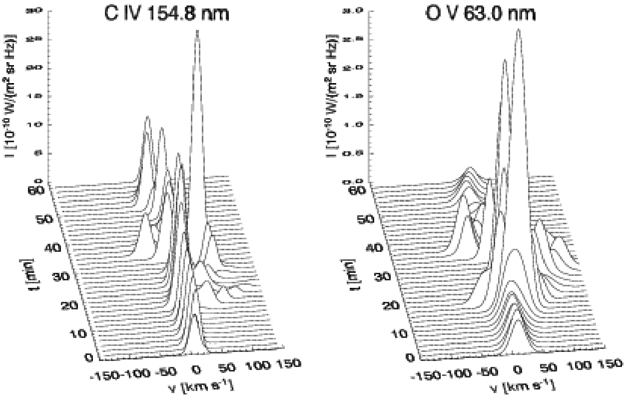
### blob acceleration



# The blob trigger II blob acceleration

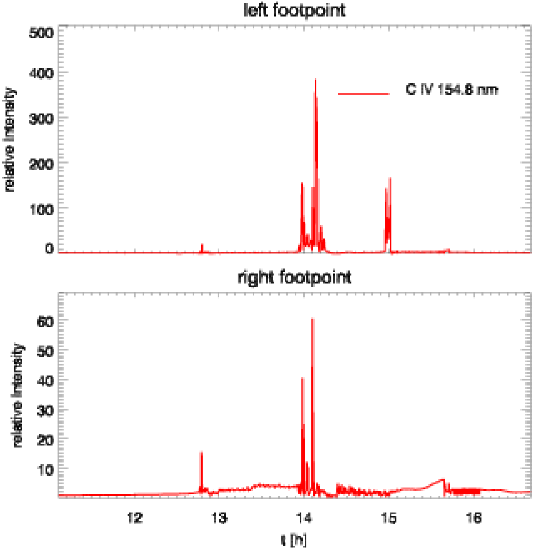


# Line profiles for C IV (154.8 nm) and O V (63.0 nm)



- strong brightenings when blob encounters the TR
- Doppler shifts of $\langle v_D \rangle = \mathcal{O}(100 \mathrm{km/s})$

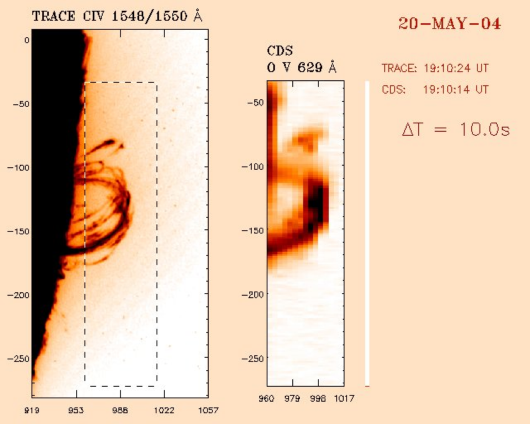
# Relative Intensity at the footpoints



When the falling blob hits the TR

- intensity increases by $\mathcal{O}(10^2)$!
- remarkable: also in other footpoints by $\mathcal{O}(10)$
  $\Rightarrow$ rarefaction wave pulls plasma upwards to higher temperatures

# JOP174: Condensation and temporal variation in AR loops



JOP 174 data (May 2004):

- high-resolution images from TRACE
- high-cadence rasters from CDS
- high-resolution spectra from SUMER

courtesy: T. Fredvik, ITA Oslo

# Outlook

Results:

A multitude of dynamical phenomena can result from thermal instability in coronal loops, even with **constant** heating

- Strong intensity variations in TR lines
- Transonic downflows with significant deceleration in the lower parts of the loop
- Different classes of solutions (static/periodic/irregular) are related to different energy dissipation scale lengths

Challenges:

- Detailed comparison with observations

# Basic Equations

- mass conservation

$$\frac{\partial \rho}{\partial t} + \frac{\partial}{\partial z}(\rho u) = 0$$

- momentum equation

$$\rho \frac{\partial u}{\partial t} + \rho u \frac{\partial u}{\partial z} = \frac{\partial}{\partial z}(p + \Lambda) - \rho g_{\|}$$

- energy equation

$$\frac{\partial}{\partial t}(\rho e) + \frac{\partial}{\partial z}(\rho u e) + (p + \Lambda)\frac{\partial u}{\partial z} = -\frac{\partial F_c}{\partial z} + Q - L_r$$

- ionization rate equations

$$\frac{\partial n_{ij}}{\partial t} + \frac{\partial}{\partial z}(n_{ij} u) = n_e \left[ n_{ij-1} C_{ij-1} - n_{ij}(C_{ij} + \alpha_{ij}) + n_{ij+1} \alpha_{ij+1} \right]$$

Go back