# Photospheric counter Evershed flows in the penumbra of sunspots

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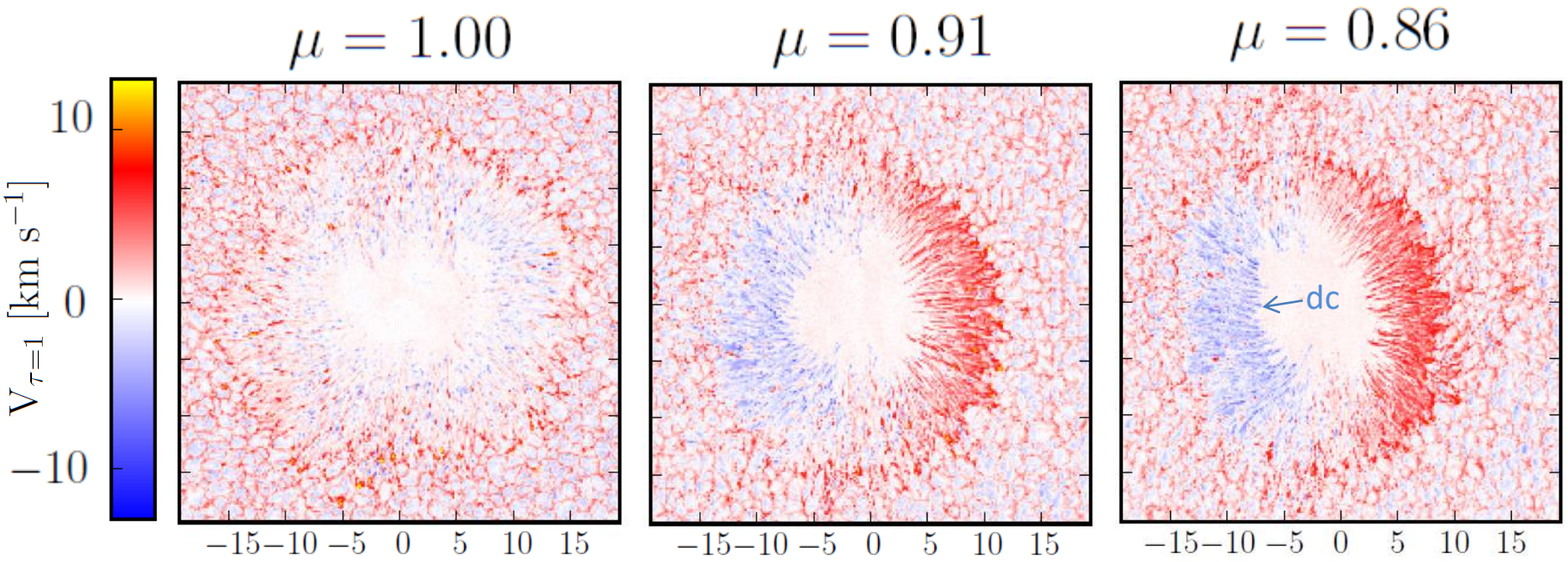
# The Evershed effect




AR10933, Hinode SOT/SP
SPINOR inversions by M. van Noort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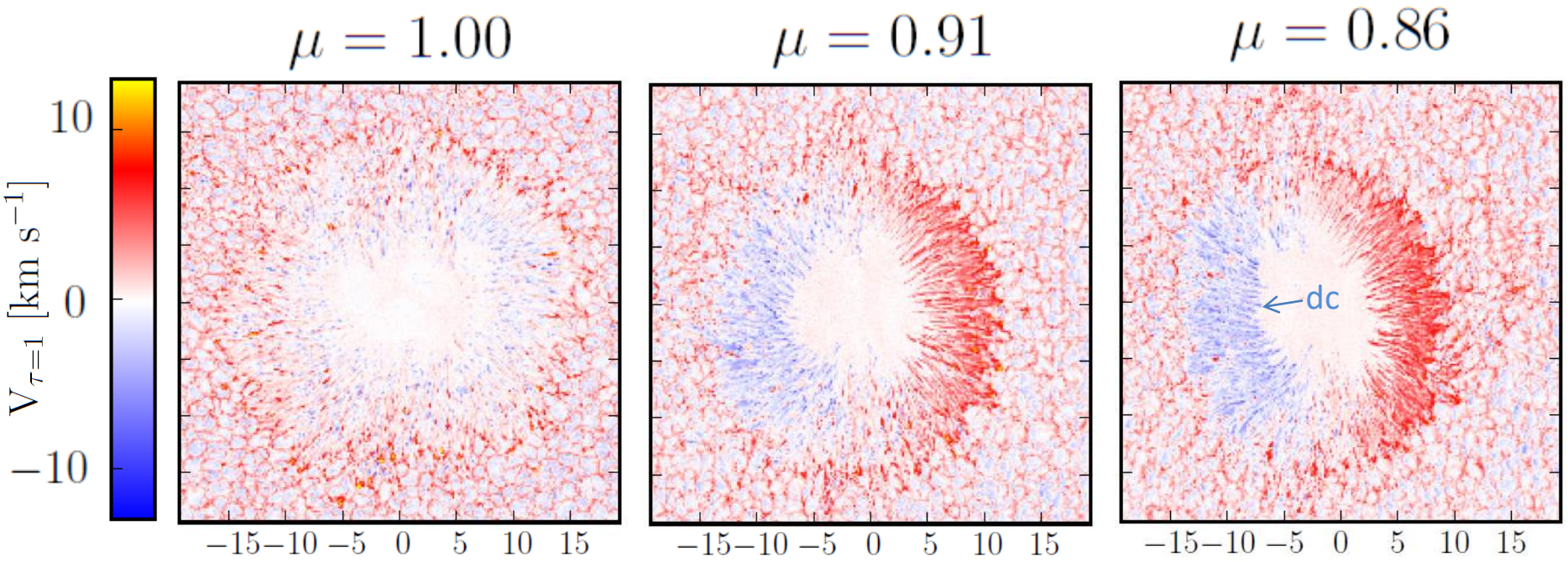
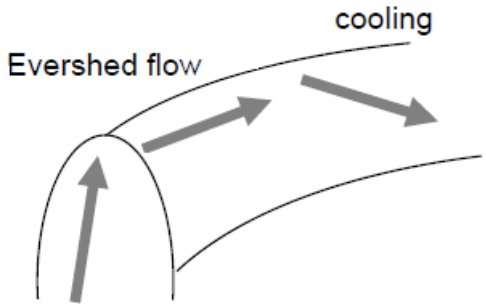
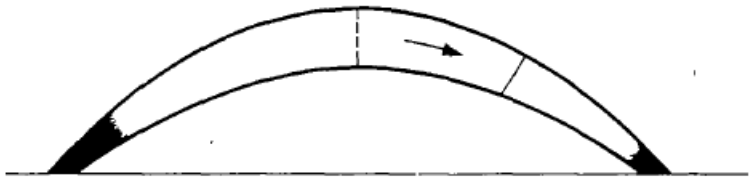
# The Evershed effect




(Ichimoto et al., 2007)



$Pg_1$ > $Pg_2$

(Meyer and Schmidt, 1968)



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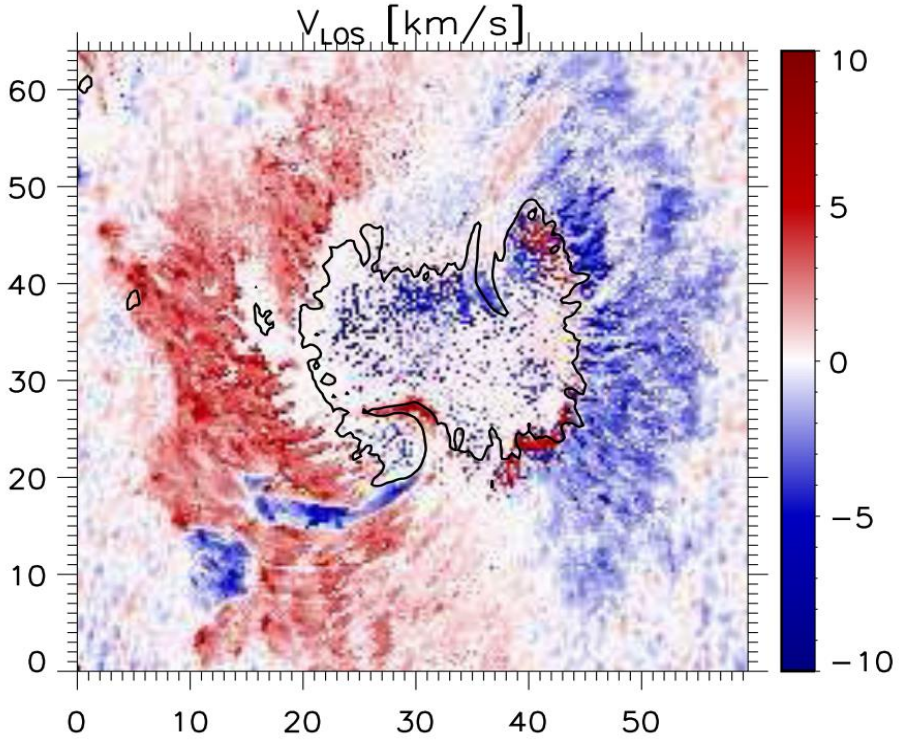
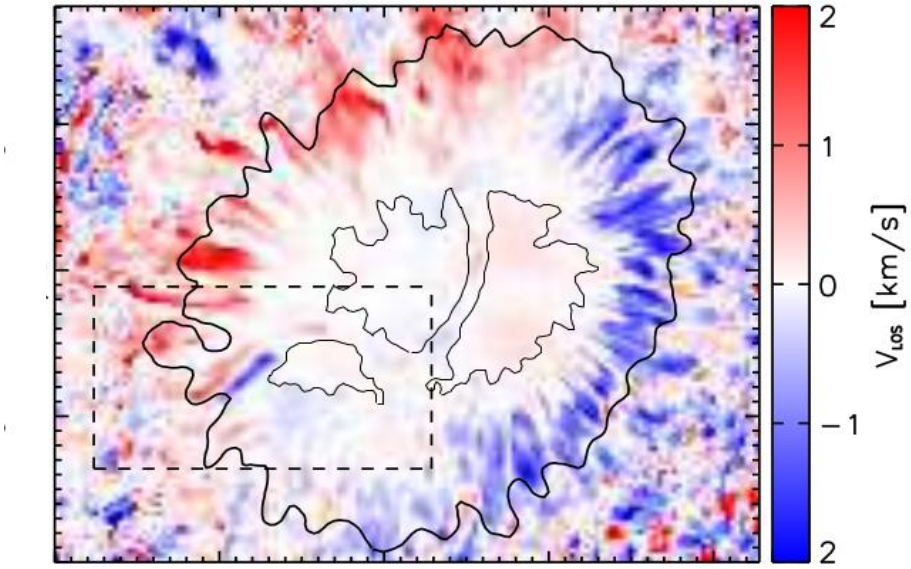
# Photospheric counter-Evershed flows (singular filaments)

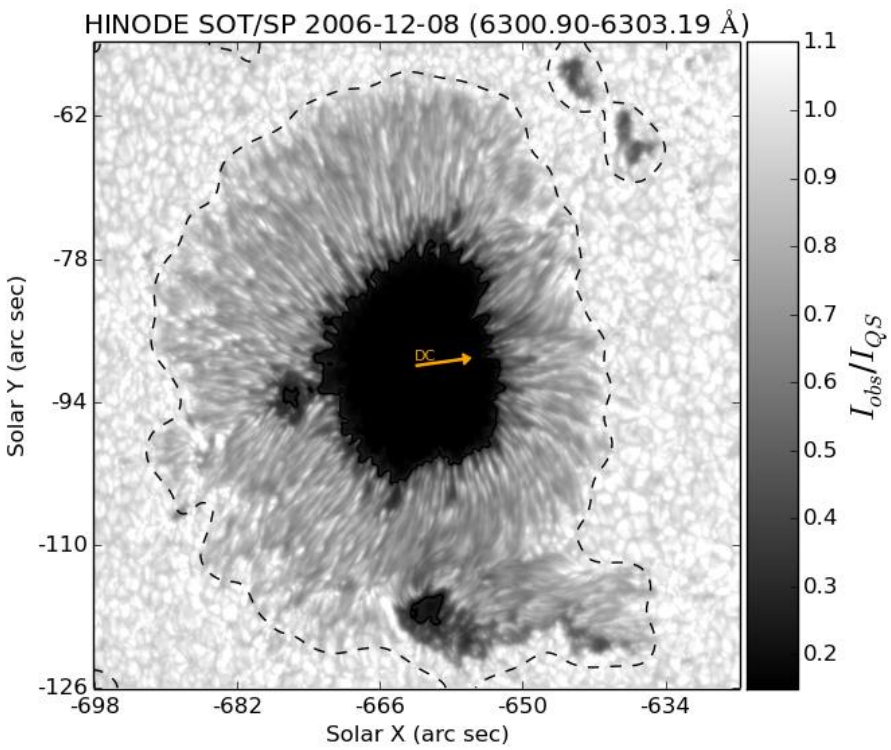



**NOAA AR 11302 Hinode/SP**
(Kleint and Sainz Dalda, 2013)



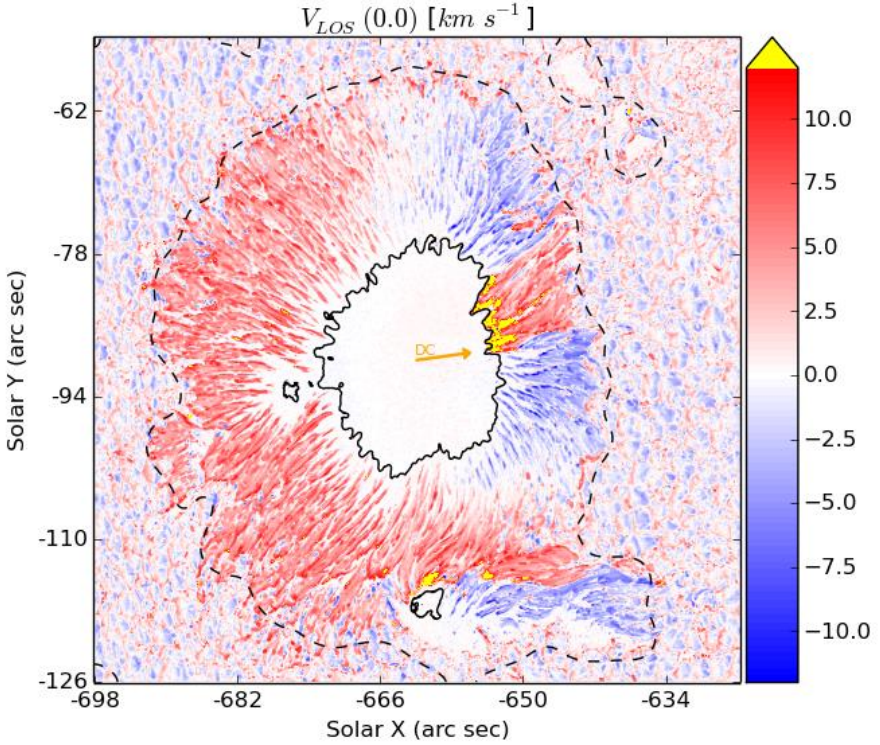

**NOAA AR 11271 Hinode/SP**
(Louis et al., 2014)

# Photospheric counter-Evershed flows (large penumbral region)




**NOAA AR 10930 Hinode/SP**

1 pixel=0.16''

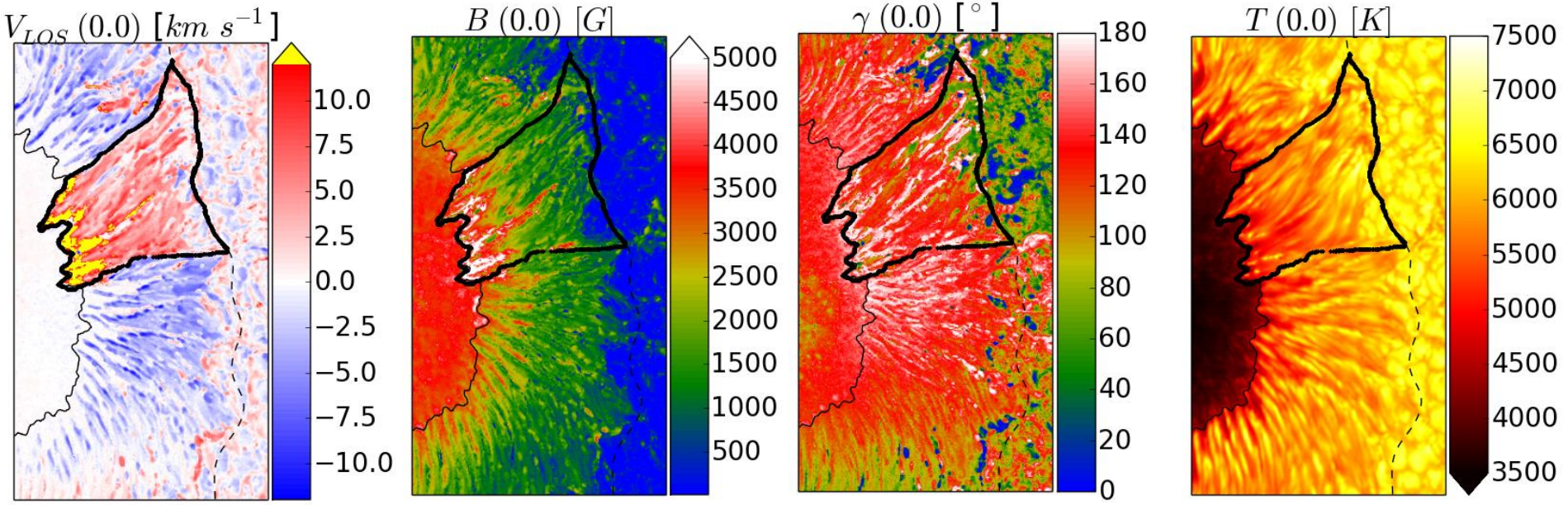



**SPINOR 2D inversions**

1 pixel=0.08 ''

heliocentric angle: $\theta \approx 47°$

# SPINOR 2D: log(τ)=-2.0, -0.8 and 0



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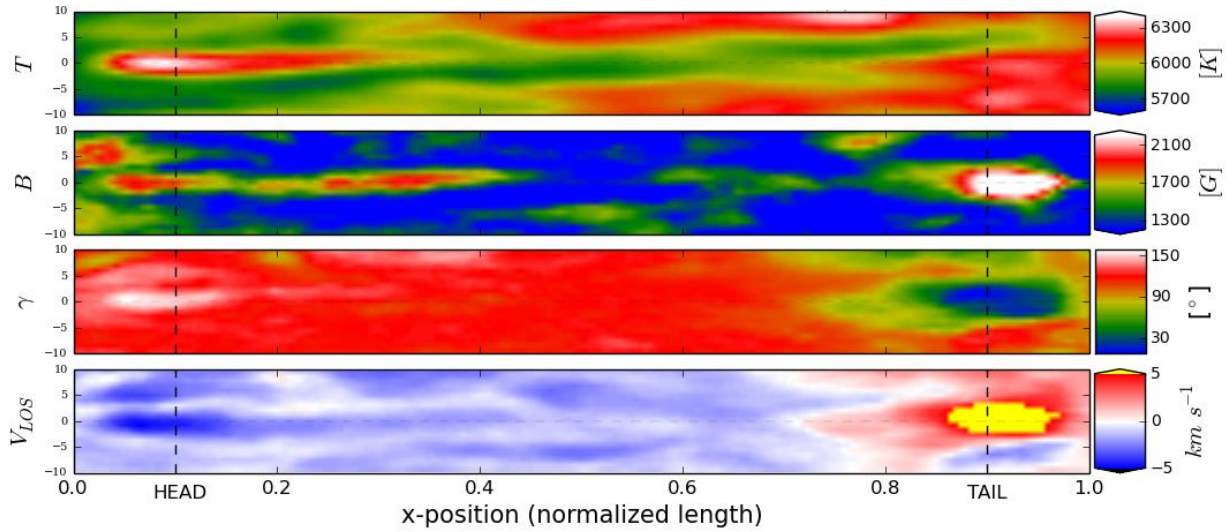
# Characteristic filaments

umbra

Quiet sun

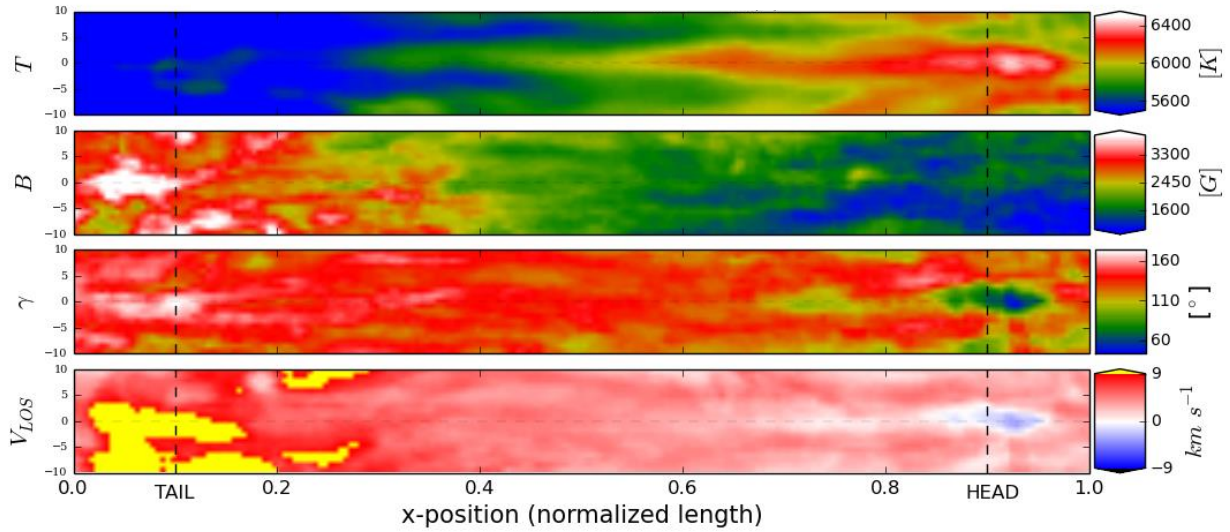
**Normal EF**




umbra

Quiet sun

**Counter EF**



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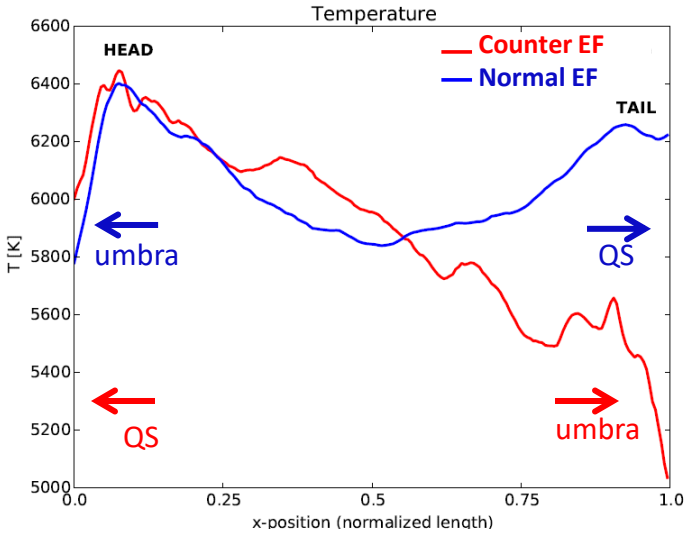
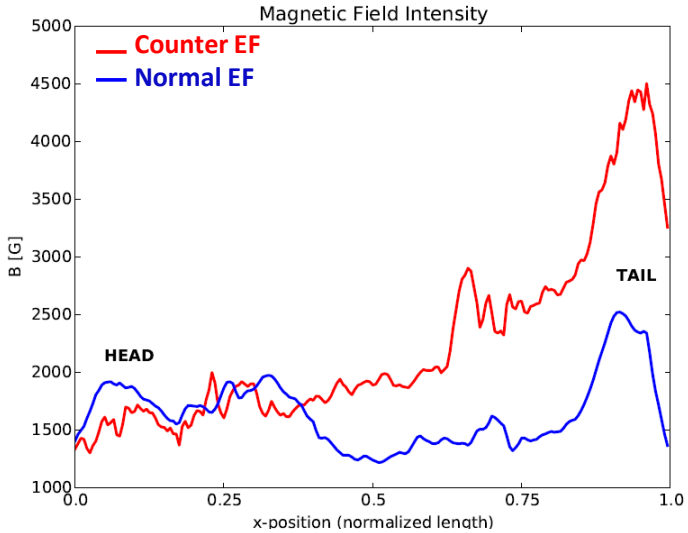
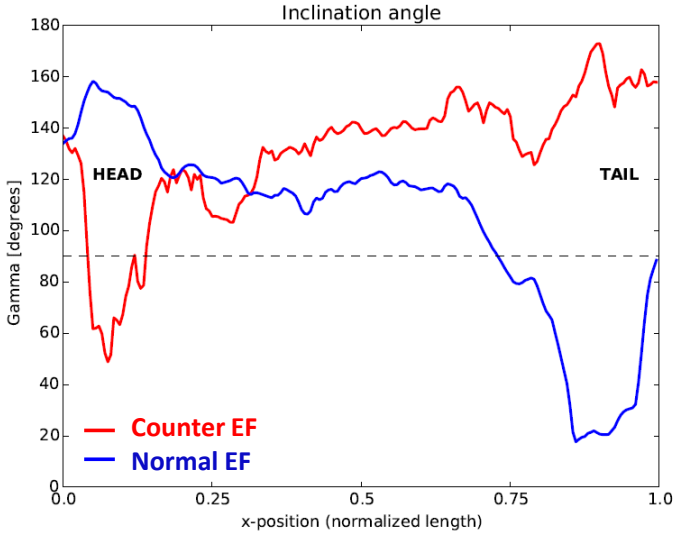
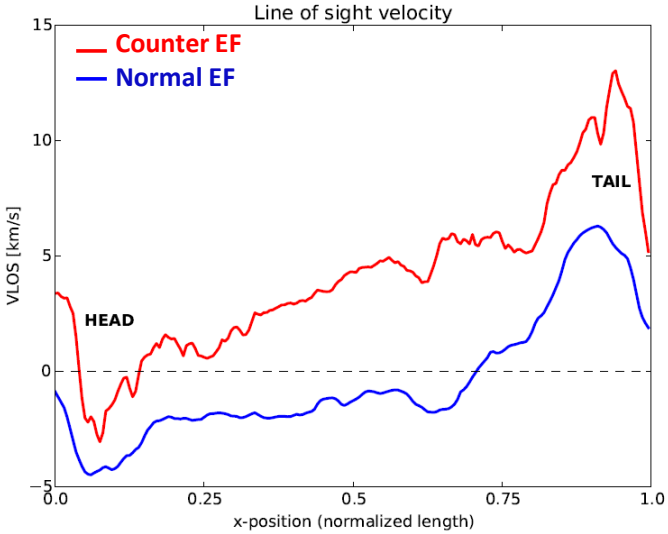
# Central axes of filaments



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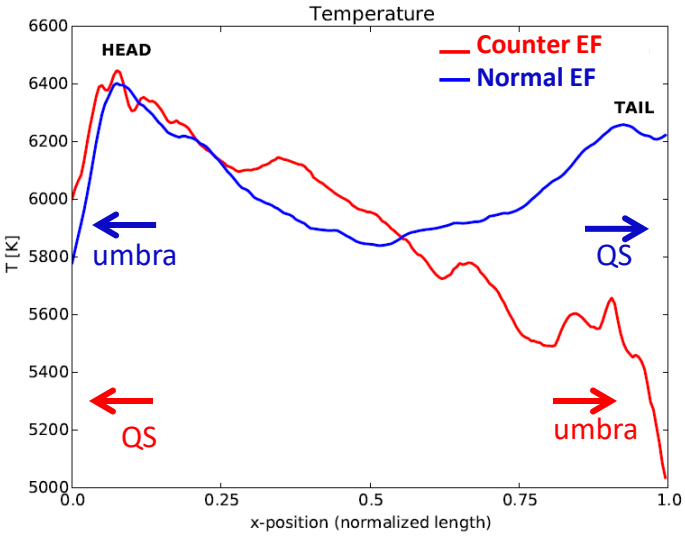
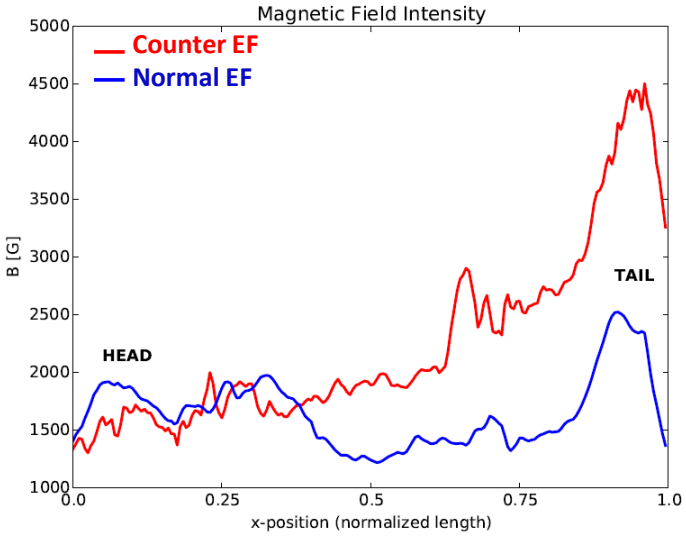
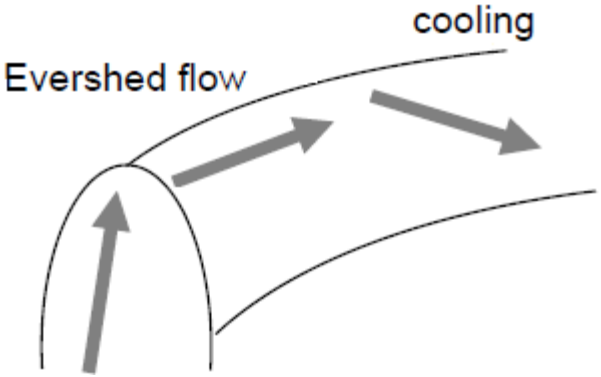
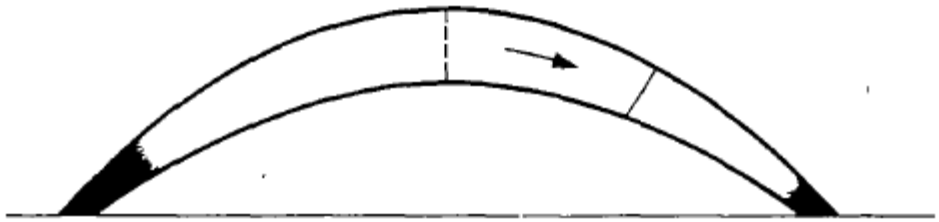
# Central axes of filaments



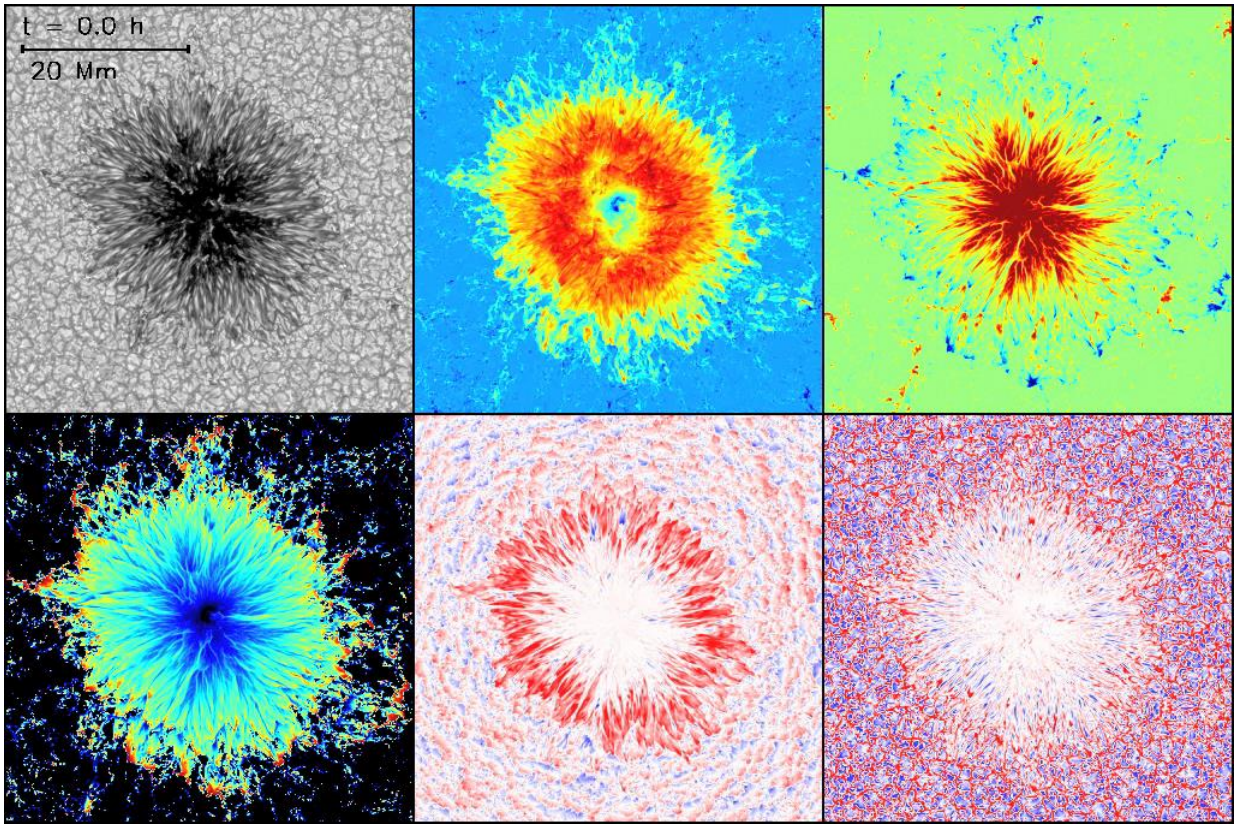

(Ichimoto et al., 2007)



$Pg_1$ > $Pg_2$

(Meyer and Schmidt, 1968)

# MURaM simulation: Formation of a penumbra




(Rempel 2015)



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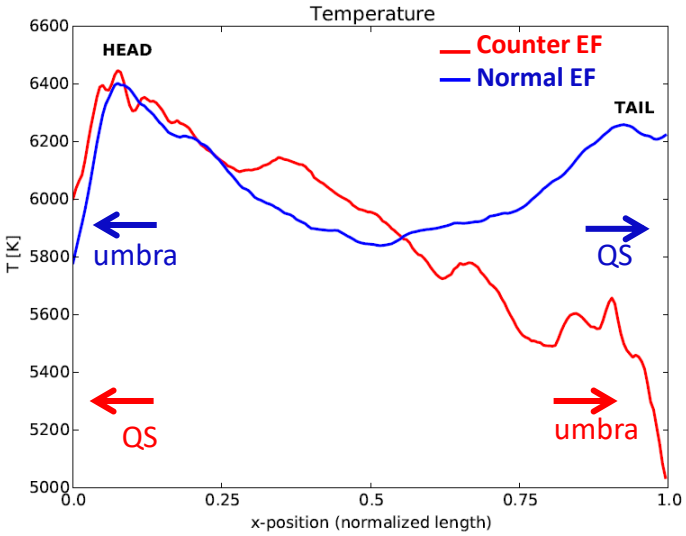
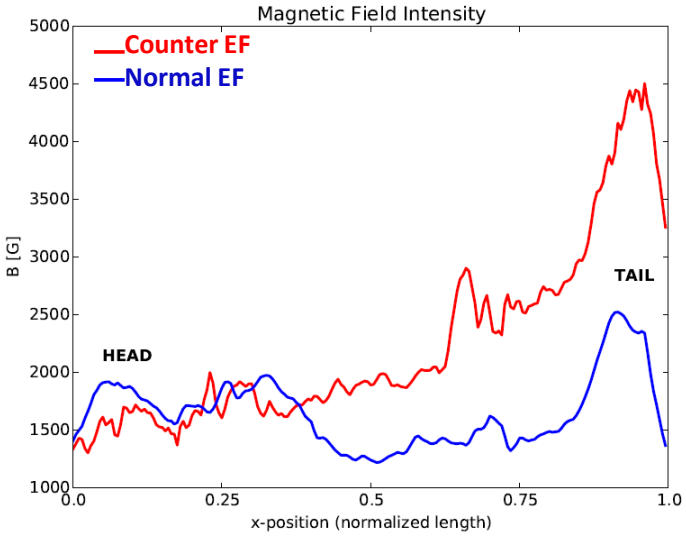
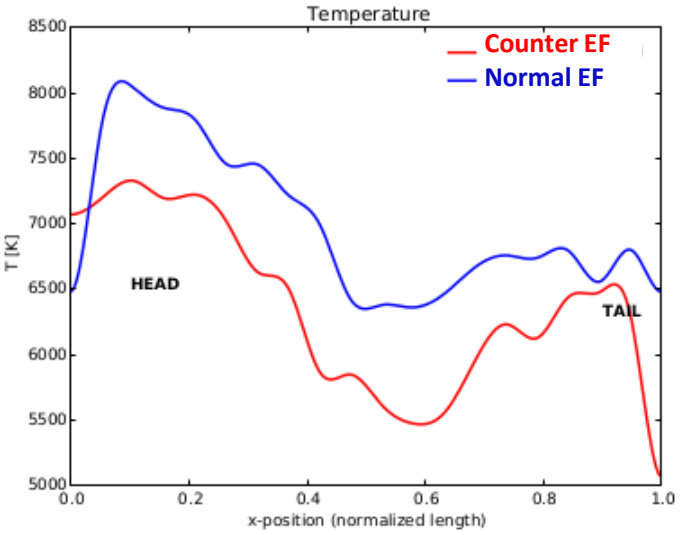
# Comparison: Observations vs simulations

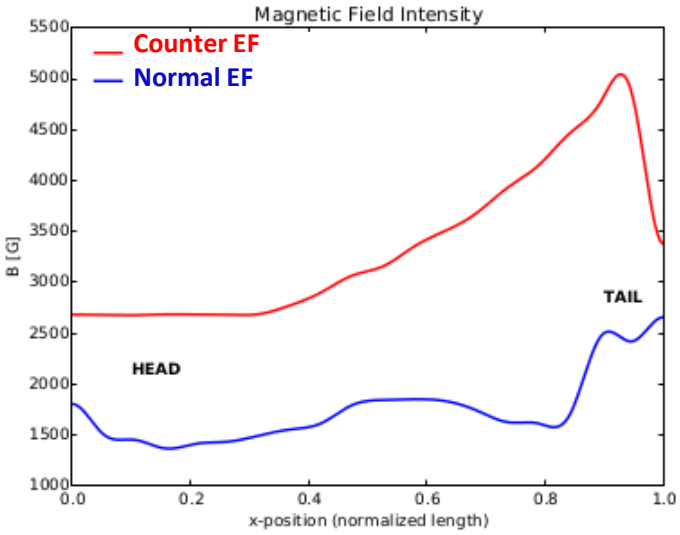
**Observations**
$\tau = 1$




**Simulations**
$\tau = 1$





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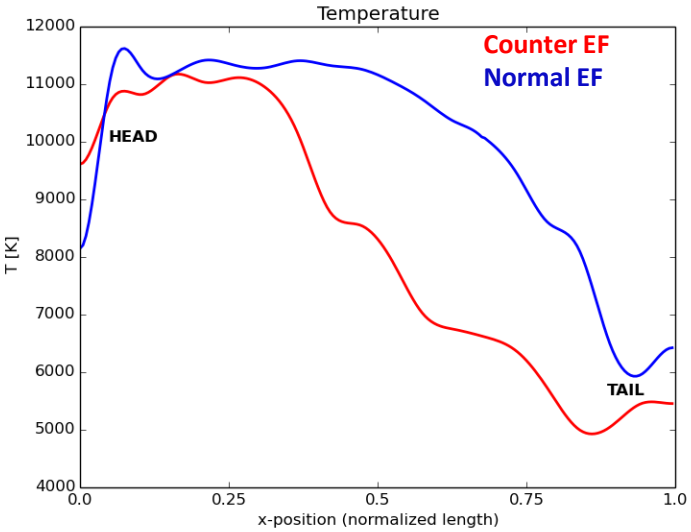
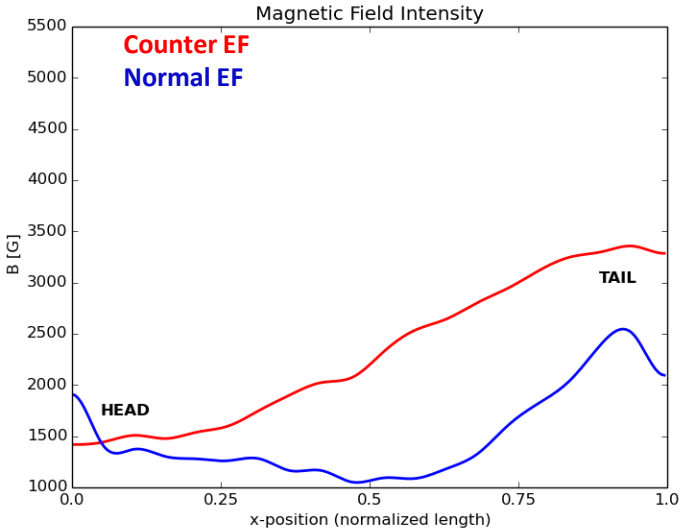
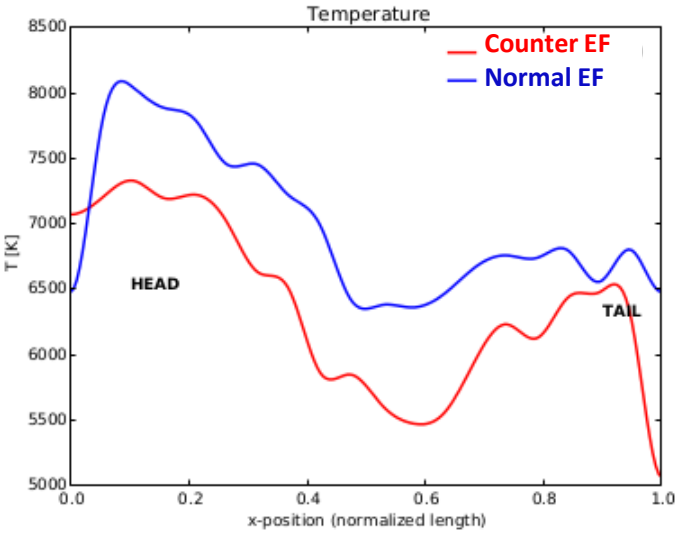
# Comparison: optical depth vs geometrical height

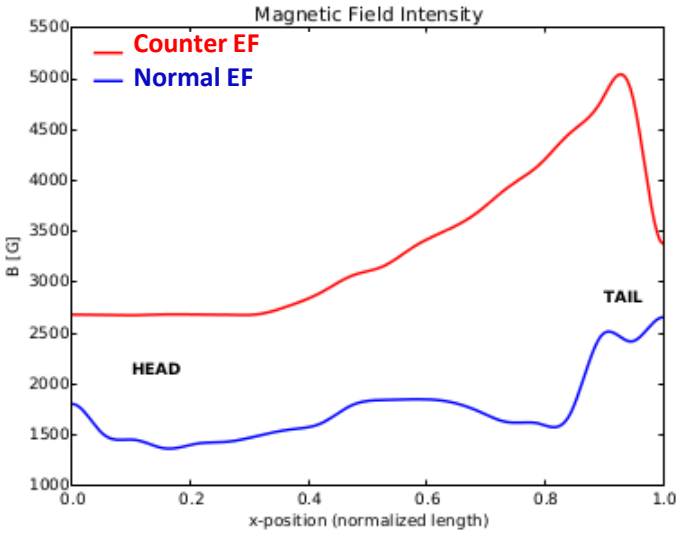
**Simulations**
$h = -226\ km$




**Simulations**
$\tau = 1$





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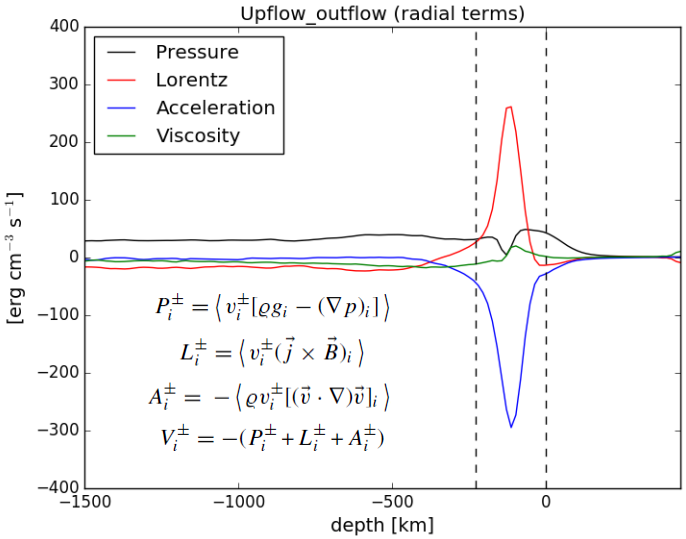
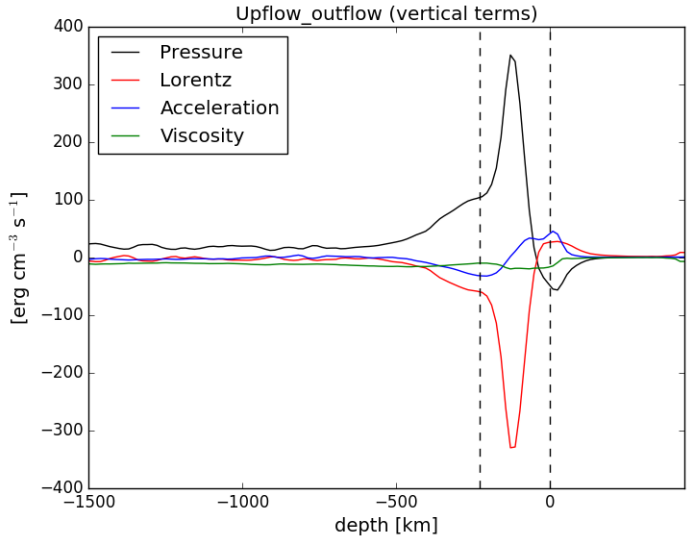
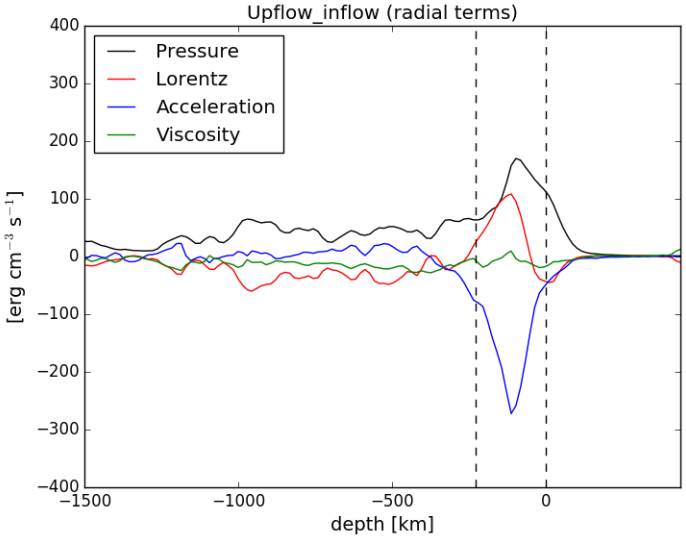
# Driving mechanisms: 10 h average

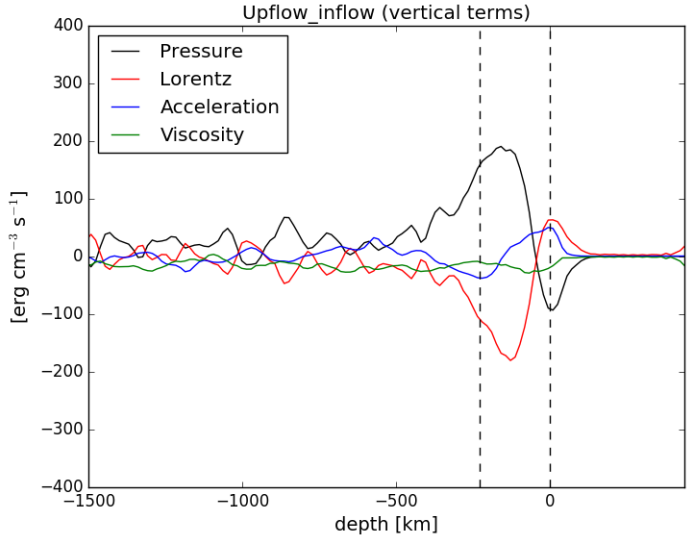
**Normal EF**




**Counter EF**



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# Summary and outlook

- Unusual observation of photospheric CEFs in a large penumbral region
  → Photospheric flows are confined in penumbral filaments
  → NEF and CEF show anti-correlated flow structures
  → Both, $\nabla T$ and $\nabla B$ are consistent with the flow direction in each case, NEF and CEF.

- MHD simulations reproduce CEFs
  → Qualitative similarities as in observations near $\tau = 1$ (but no compact footpoints)
  → NEF and CEF are driven in a thin boundary layer near $\tau = 1$
  → Driving mechanisms:
    - NEF: convection + magnetic deflection (quasi-stationary)
    - CEF: siphon flow + magnetic deflection (transient)

- Future work
  → To study the temporal evolution of CEFs: observations and simulations.