Local helioseismic investigation of emerging active regions

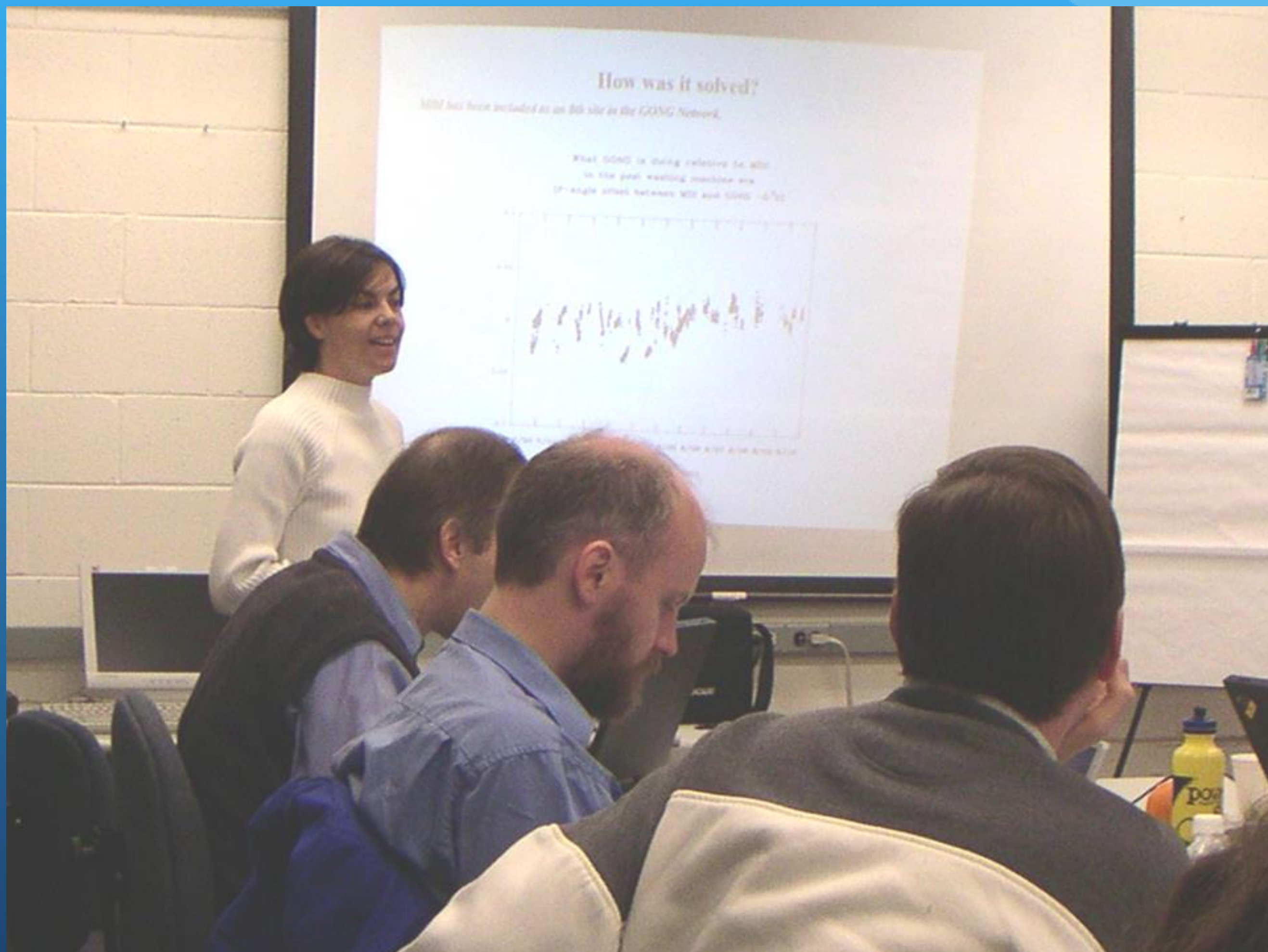
NWRA
Since 1984

D Braun (NWRA), H Schunker, A. Birch (MPS)

& using MHD simulations from

M Rempel (NCAR/HAO) & R Stein (MSU)

Irene González Hernández



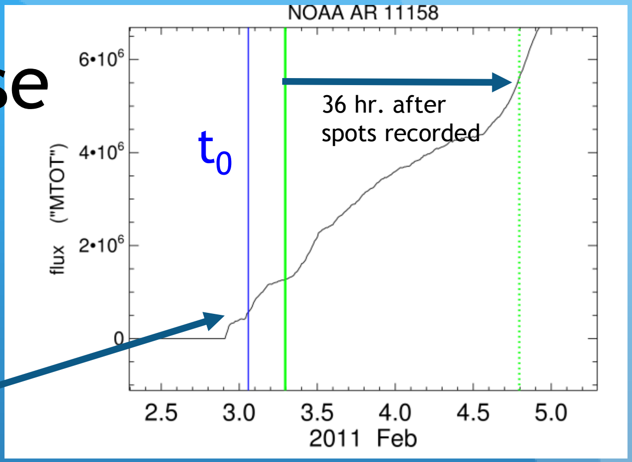
helioseismic surveys of emerging ARs (EARs)

- advantage of consistent analysis applied to many regions:
  - statistical (e.g. compare populations of emerging vs non-emerging regions)
  - enhance signal-to-noise (e.g. ensemble averaging)
- prior ring-diagram surveys (Komm, Howe & Hill 2009; 2011)
  - larger, broader survey than this one (flows & active region *evolution*)
- prior NWRA survey (GONG; Leka et al. 2013; Birch et al. 2013; Barnes et al. 2014)
  - goal: detect subsurface "precursors" of emerging flux
  - holography of ~100 ARs and 100 quiet regions
  - 0-20 Mm below photosphere & up to 28 hr. prior to emergence
- ongoing NWRA/MPS Survey (HMI-SDO data)
  - goal: explore physics of emergence & extend prior survey in time and depth
  - holography analysis & ensemble averages of ~100 EARs (2010 – 2012)

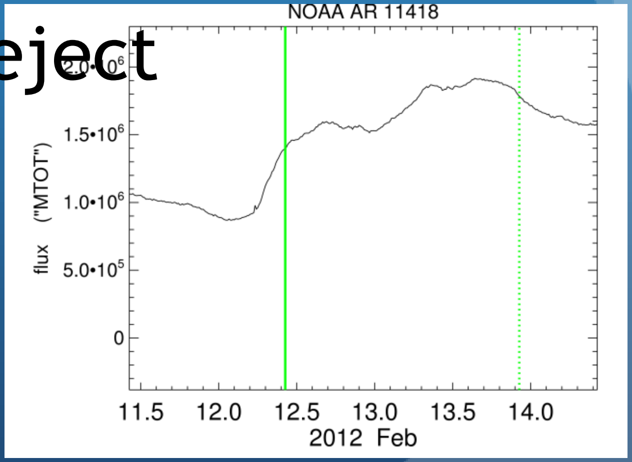
EAR selection

- discussed earlier by Hannah…
- “clean” emergence for simplicity in interpretation
  - use HARP information + visual inspection of magnetograms
- definition of emergence time, time intervals, identical to prior GONG survey
- results here use 80 cleanest EARs

use

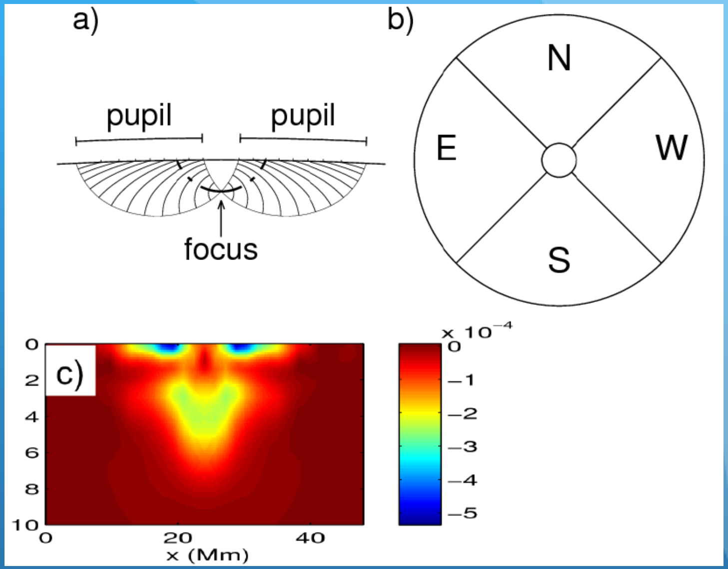


reject

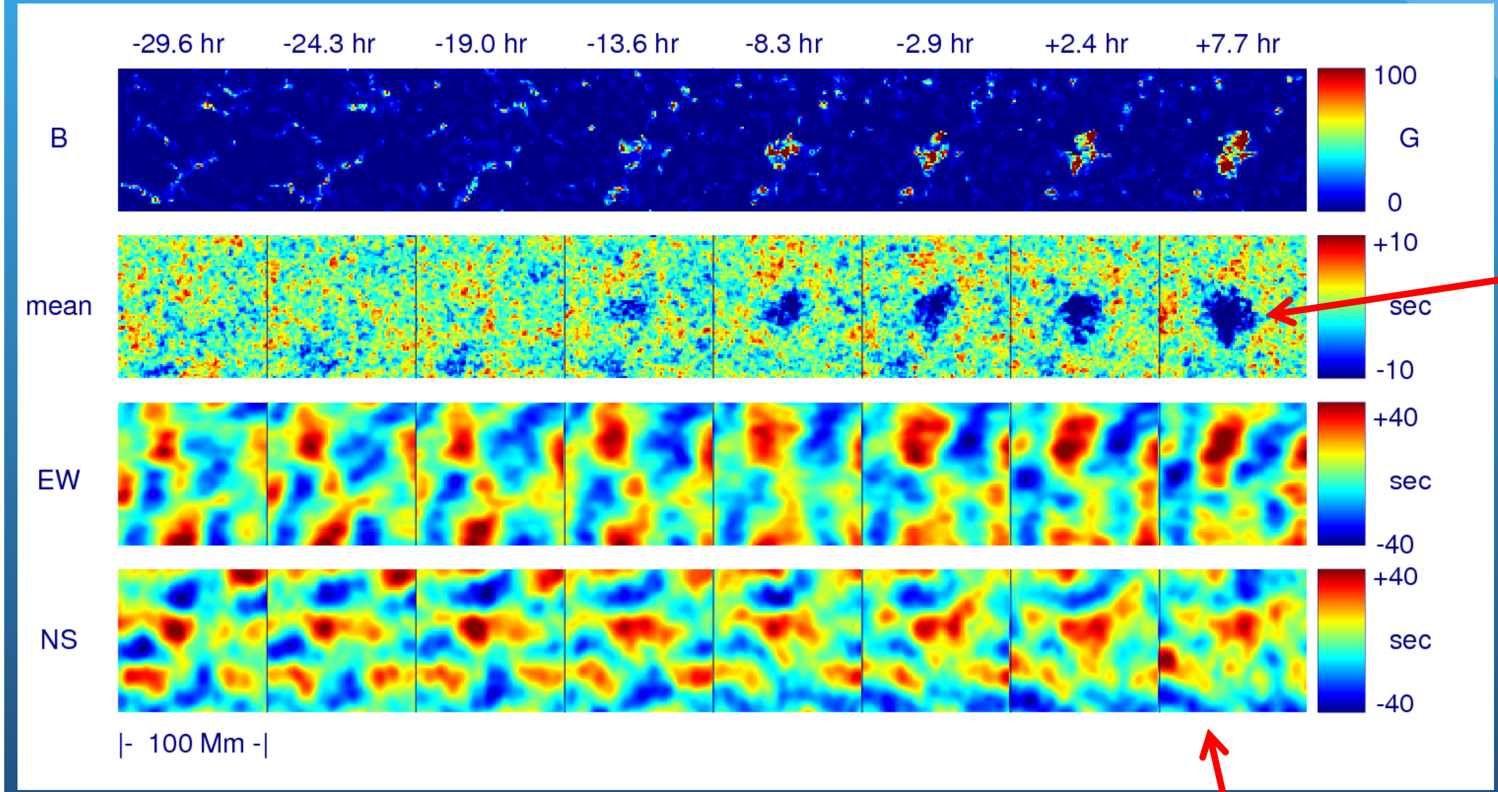


holography

- deep-focus geometry results
  - 3 Mm focus depth shown
- travel-time shifts
  - EW, NS differences (flows)
  - mean shifts (EW & NS; wave-speed perturbations)
- EW, NS shifts as proxies for flows
  - avoids inversions (for now)
  - take simple operations (e.g. horizontal divergence component) on vector travel-time shifts



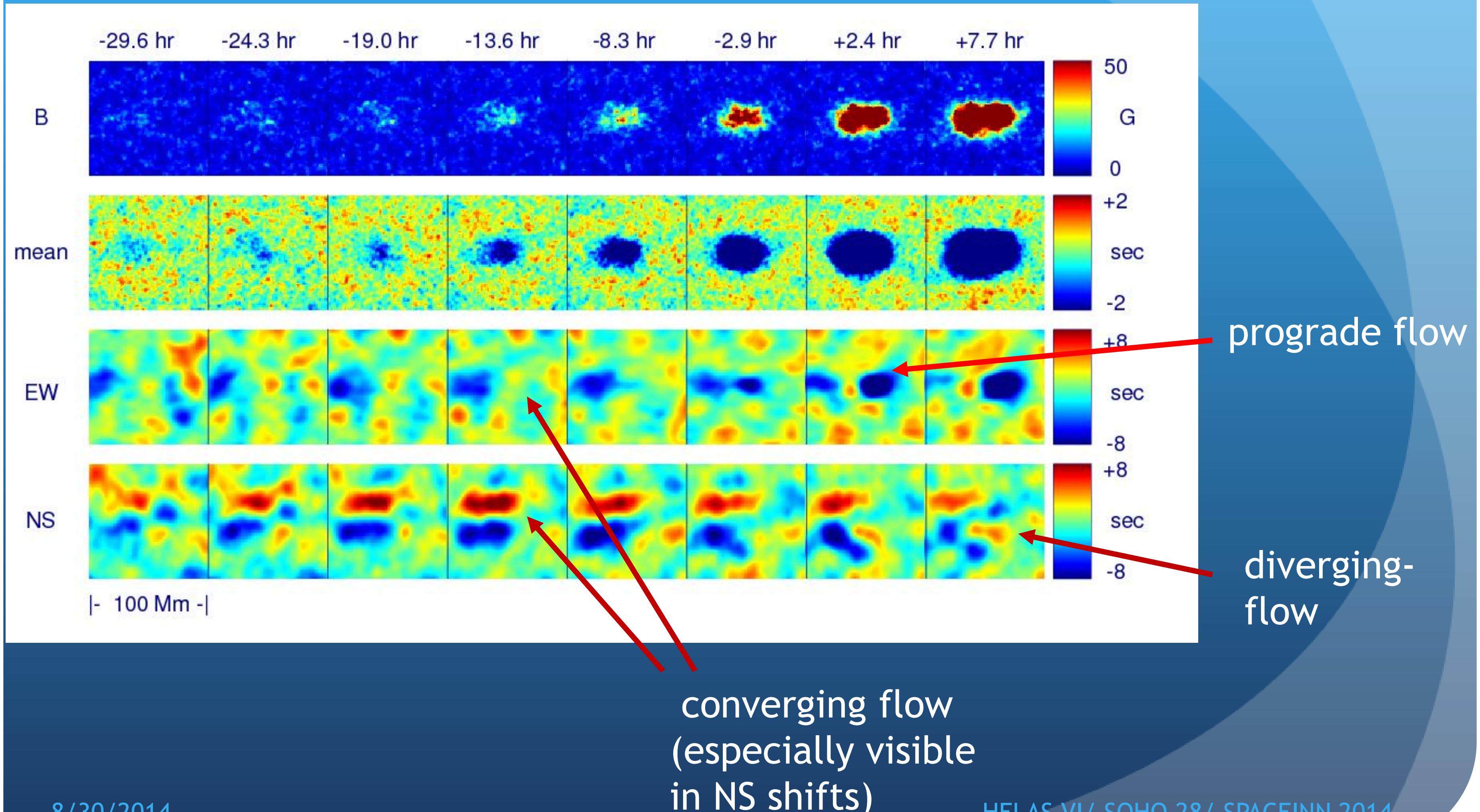
single AR (NOAA 11136)



mean travel-time reduction

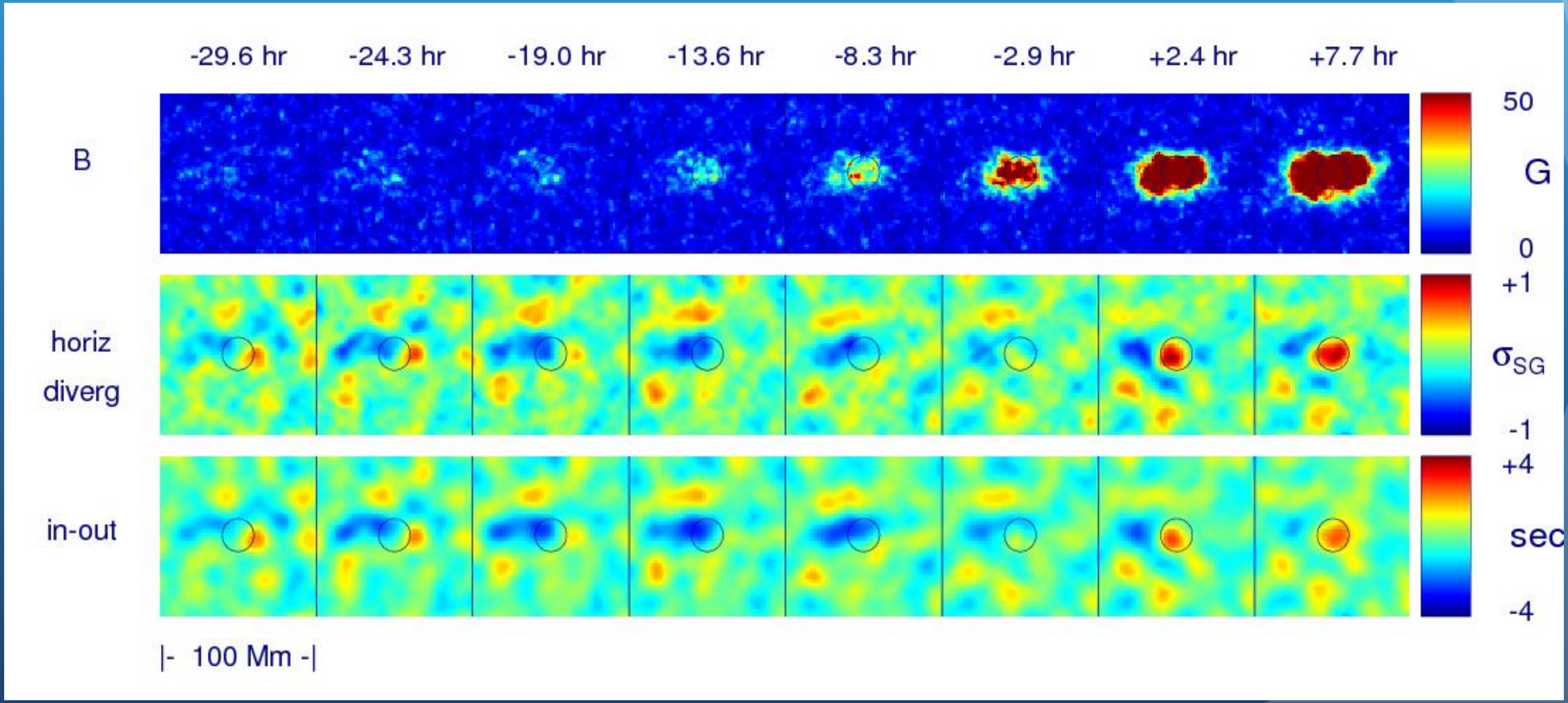
EW, NS diffs dominated by supergranulation

ensemble average (~80 EARs)

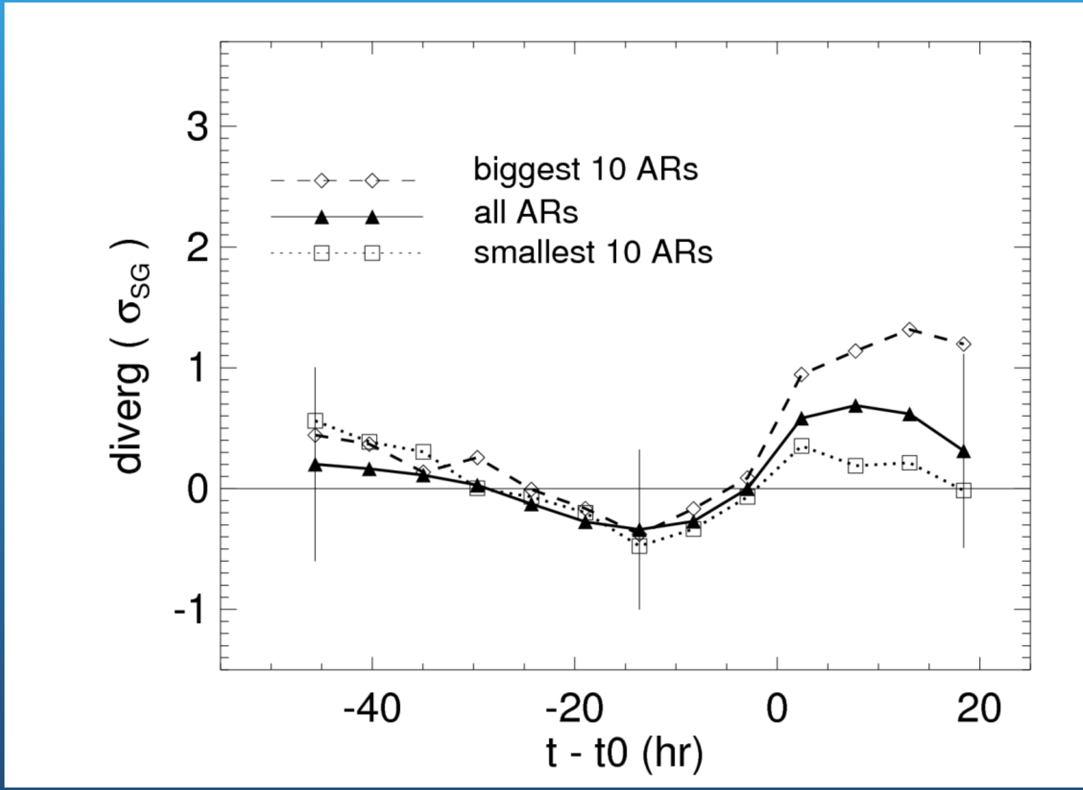


horizontal component of divergence

- converging flows from -30hr ; changes to outflows t > t_0
- amplitude ~σ_{SG} (RMS in quiet-Sun supergranulation)
- also observed "in-out" travel-time differences



time evolution of in-flows -> out-flows

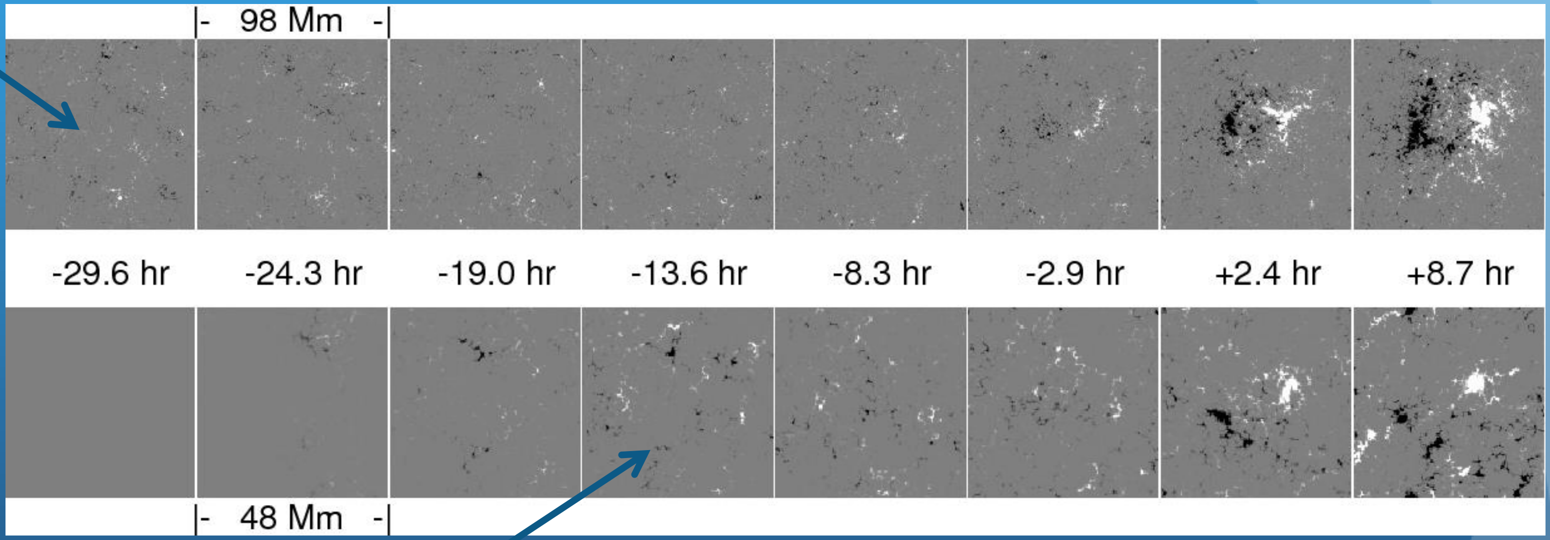


amplitude of pre-emergence converging flows not strongly dependent on resulting AR size.

post-emergence outflows increase with AR size

magnetoconvective simulations of emerging flux

M Rempel (custom runs provided; as per Rempel & Cheung 2014 ApJ)



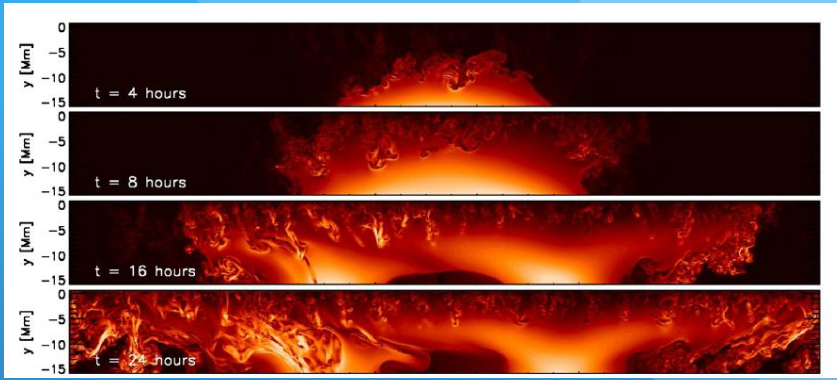
R Stein ("mhd48-1" see Stein & Nordlund 2012 ApJL)

Note: Stein's simulation emerges a pore (not sunspot!) through convection of horizontal field at the bottom – included for context only!

MURaM simulations (Rempel & Cheung 2014)

upward advected semi-torus:
torus radius=16Mm

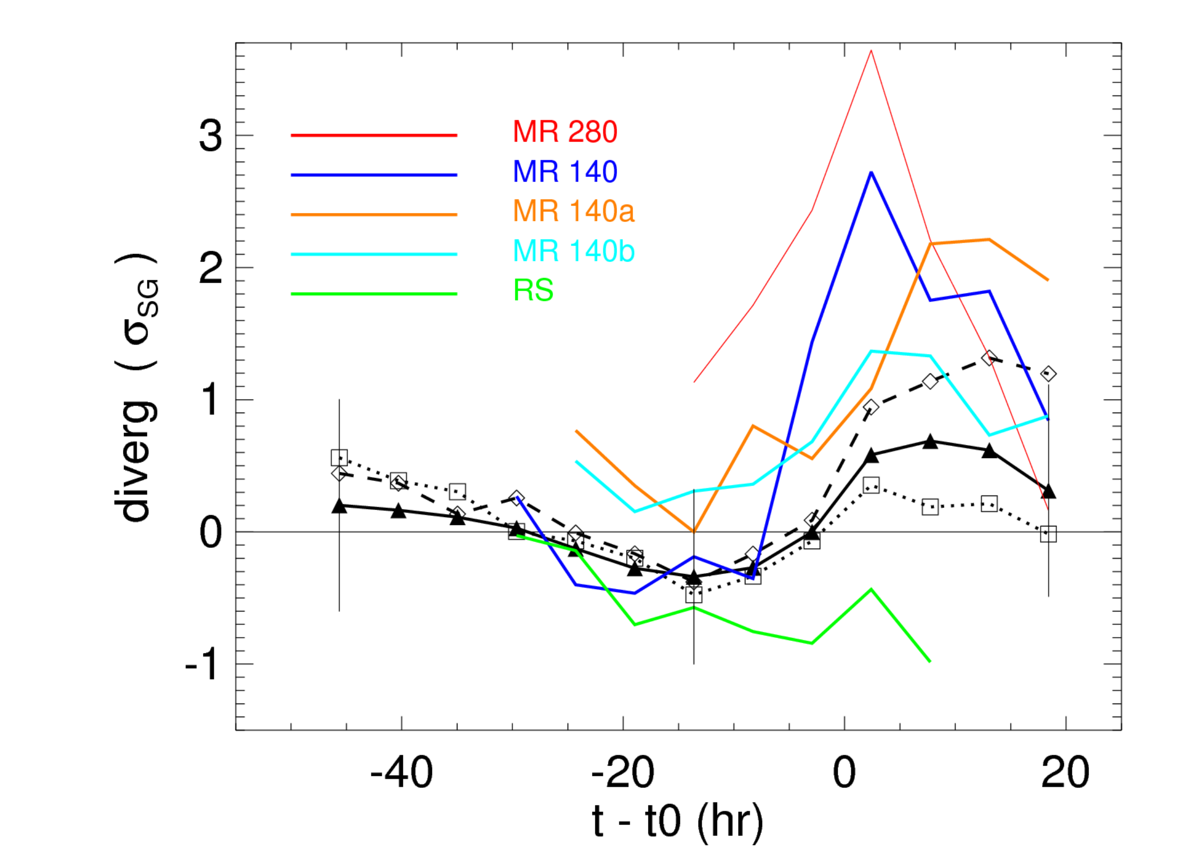
$$B = B_o\, e^{-r^2/r_o^2} \quad \frac{r}{r_o} \leq \sqrt{2}$$



identifier	Upward flow	total flux	tube radius r_o	field strength B_o
"MR 280"	280 m/s	10^{22} Mx	4.3 Mm	20 kG
"MR 140"	140	10^{22}	4.3	20
"MR 140a"	140	5×10^{21}	4.3	10
"MR 140b"	140	5×10^{21}	3	20

140m/s = average convective upflow at bottom (18Mm)

divergence comparisons: averaged EARs & simulations



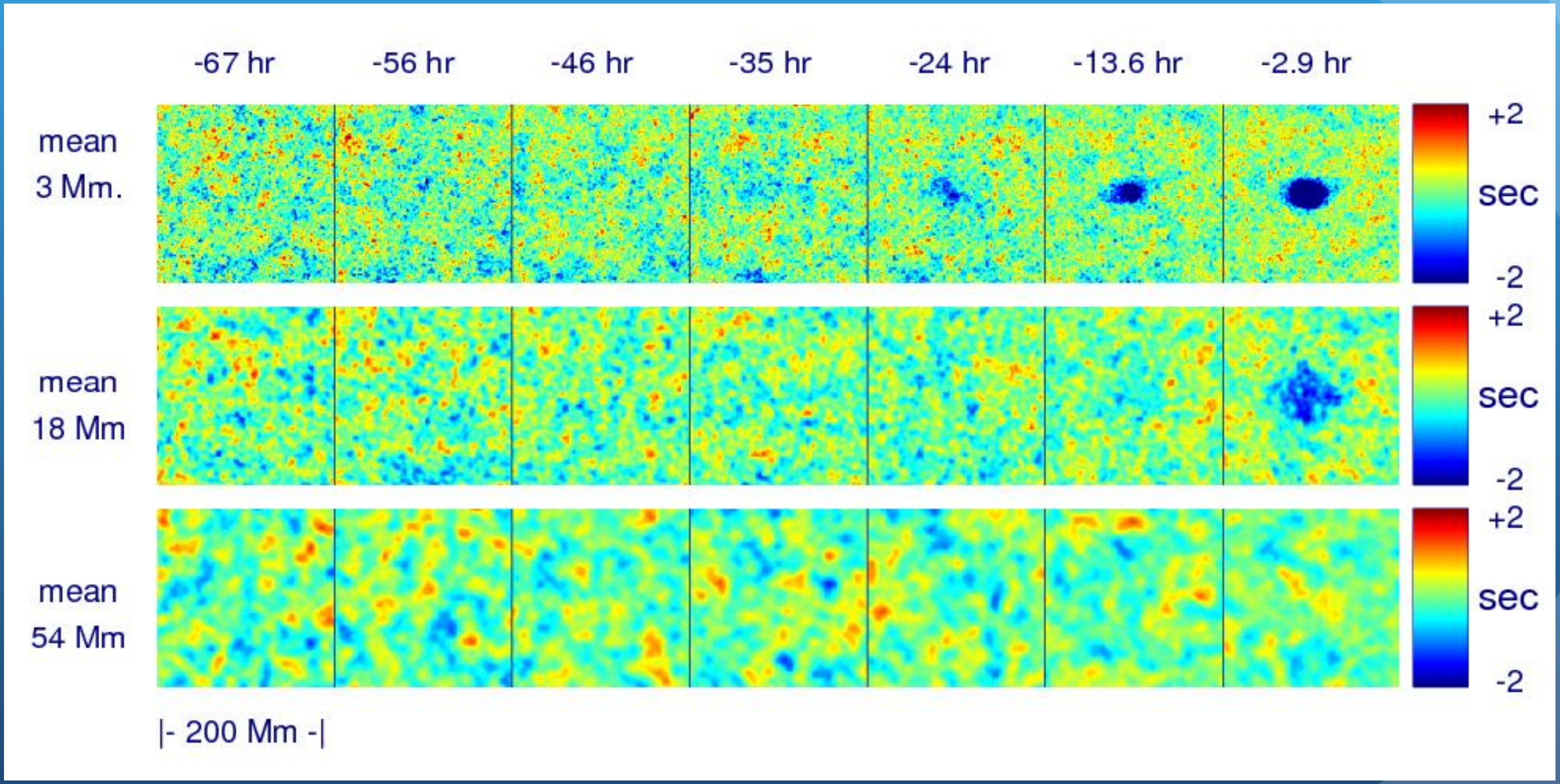
observations more consistent with gentler emergence

caveats:

10^{22} Mx flux in Rempel simulation larger than typical EAR in sample

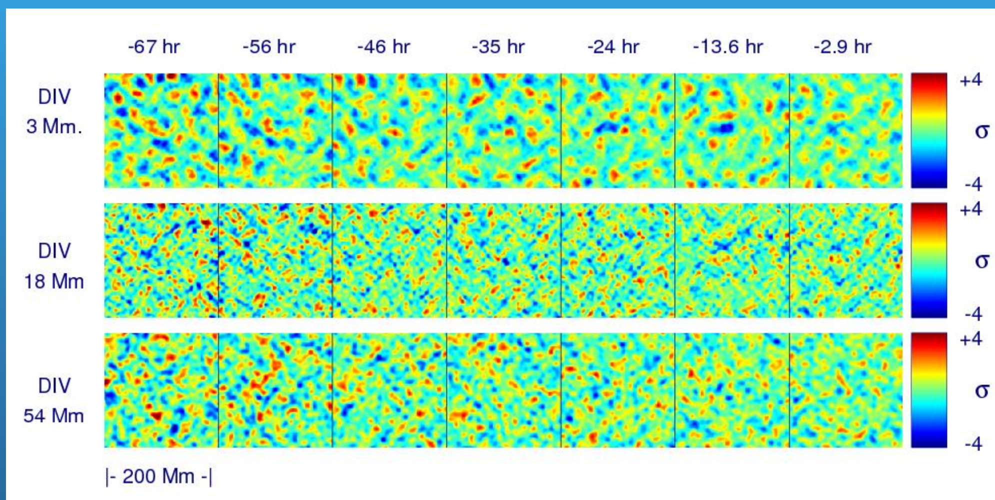
deeper, further (back) in time?

- nothing obvious in mean shifts below ~few Mm (σ ~ 0.4 sec)

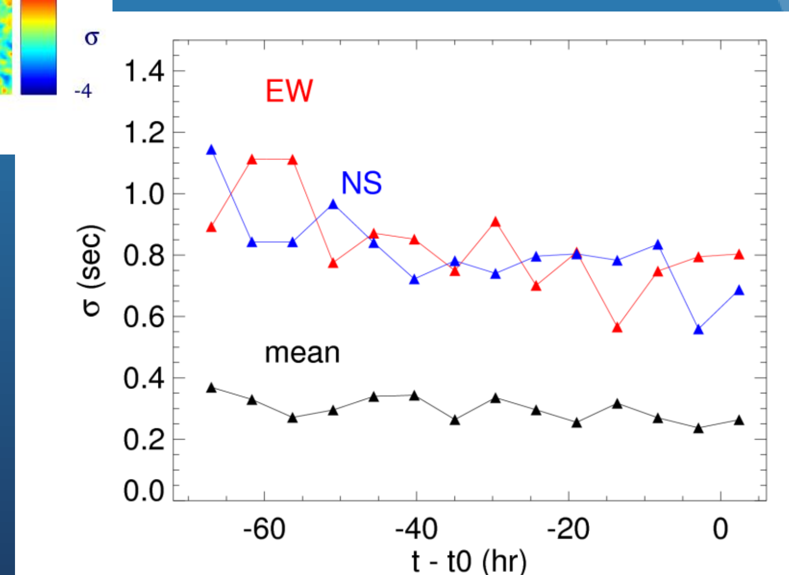


deeper, further continued…

- nothing obvious in flows; divergence signatures either...



- noise at 54 Mm ≤ 1 sec (EW, NS)
  0.4 sec (mean)



conclusions

- near-surface magnetic and mean travel-time shifts present in ensemble-averaged maps ~30 hr prior to "emergence time"
- pre-emergence converging flows, followed by outflows and prograde flows
- plausible sources are supergranulation boundaries
- comparisons with MHD simulations suggest emergence is "gentle" with upflows not much greater than convective flows
- lots more to do…

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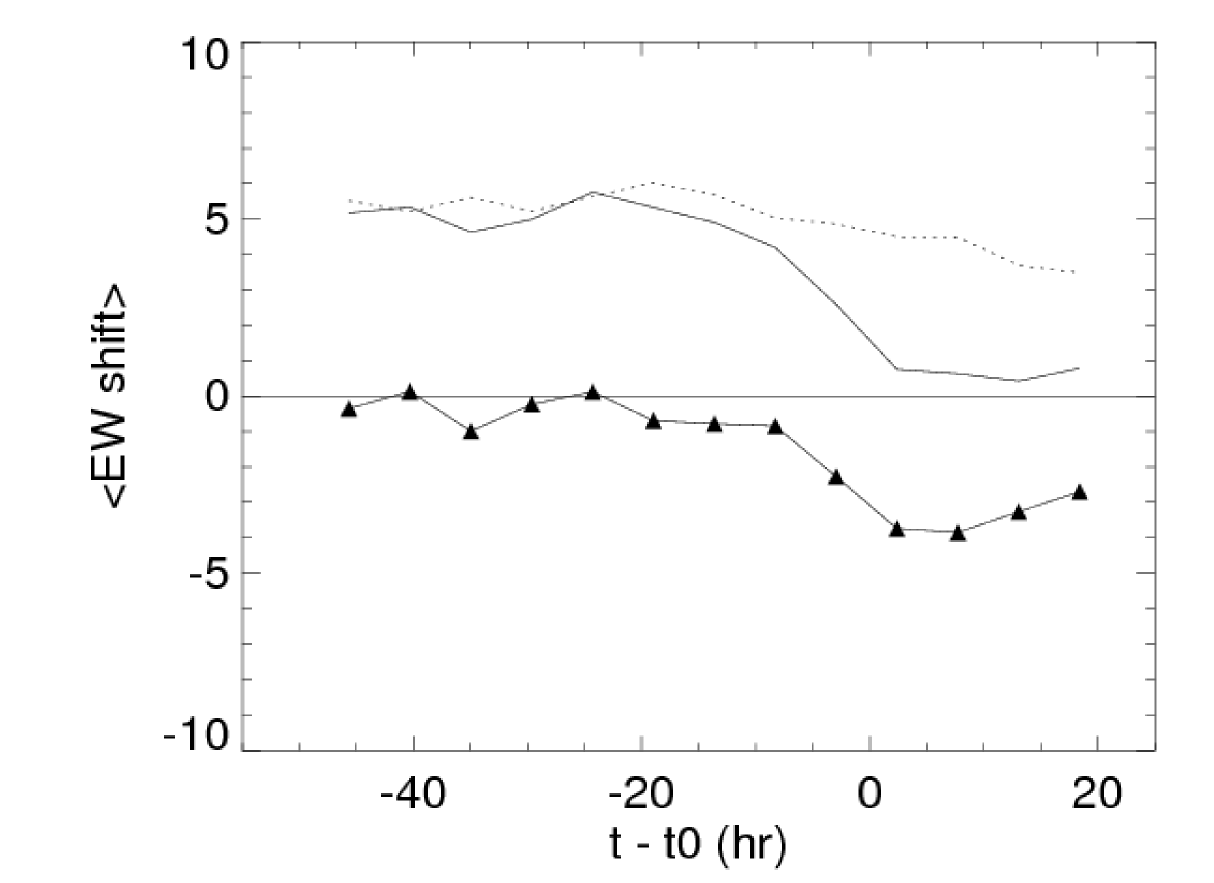
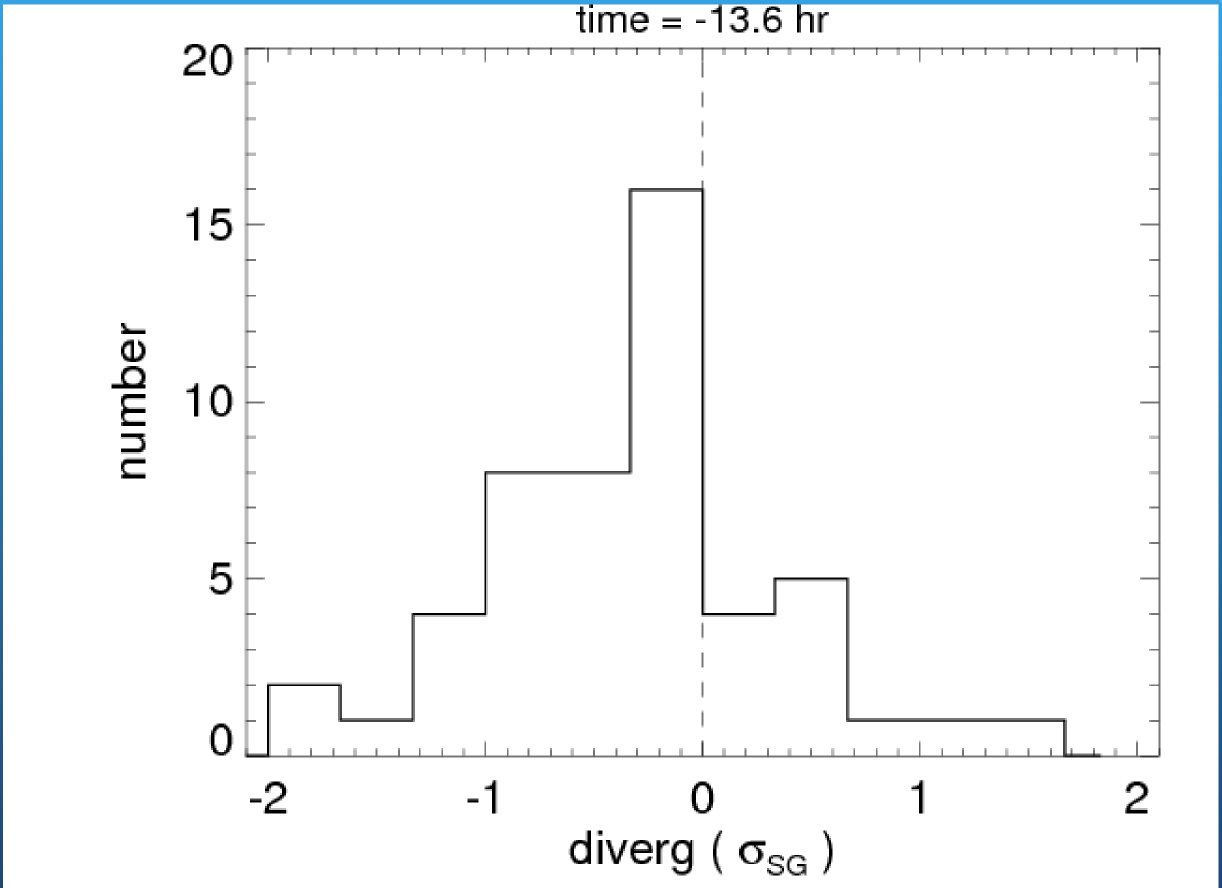
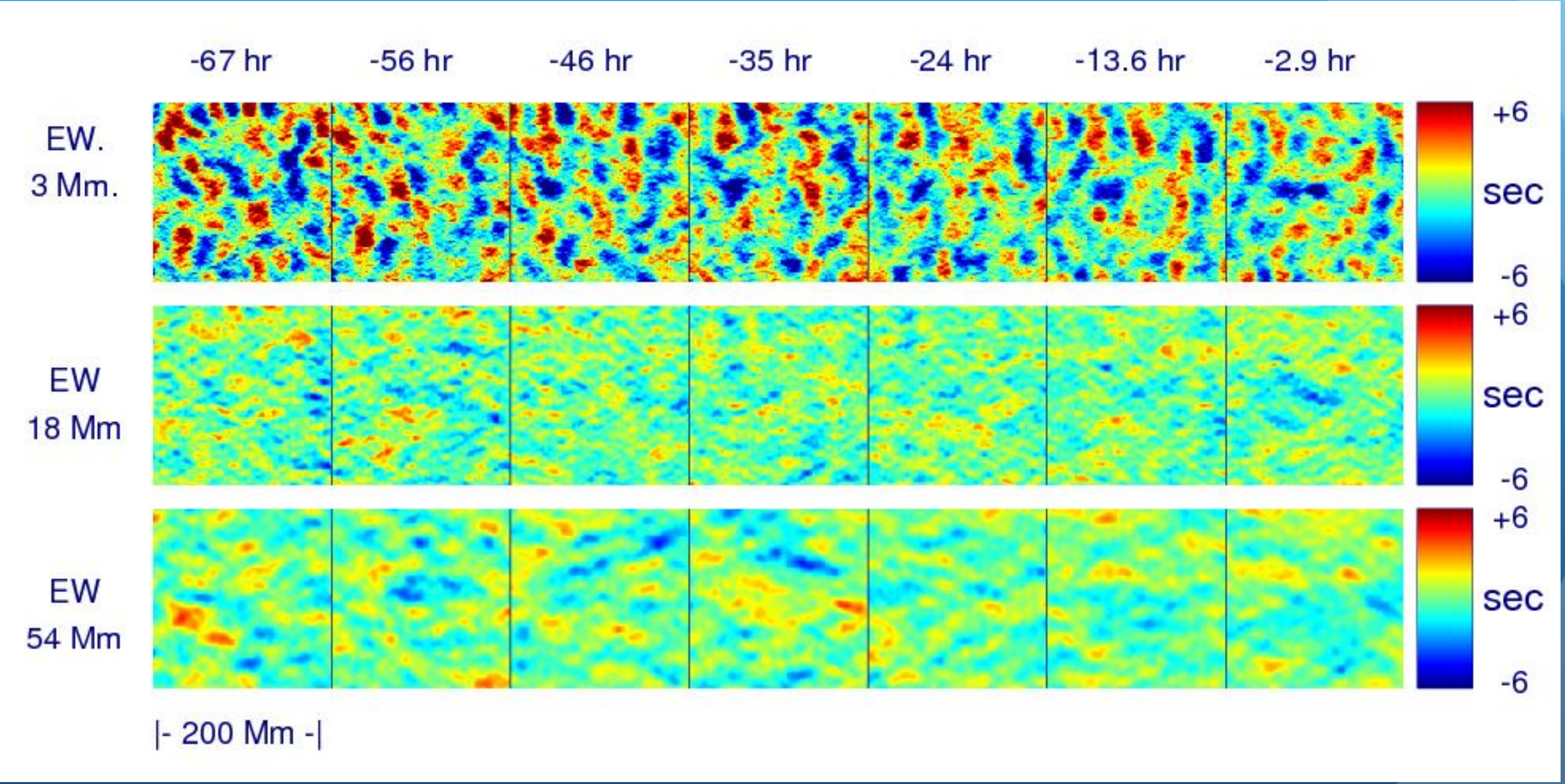
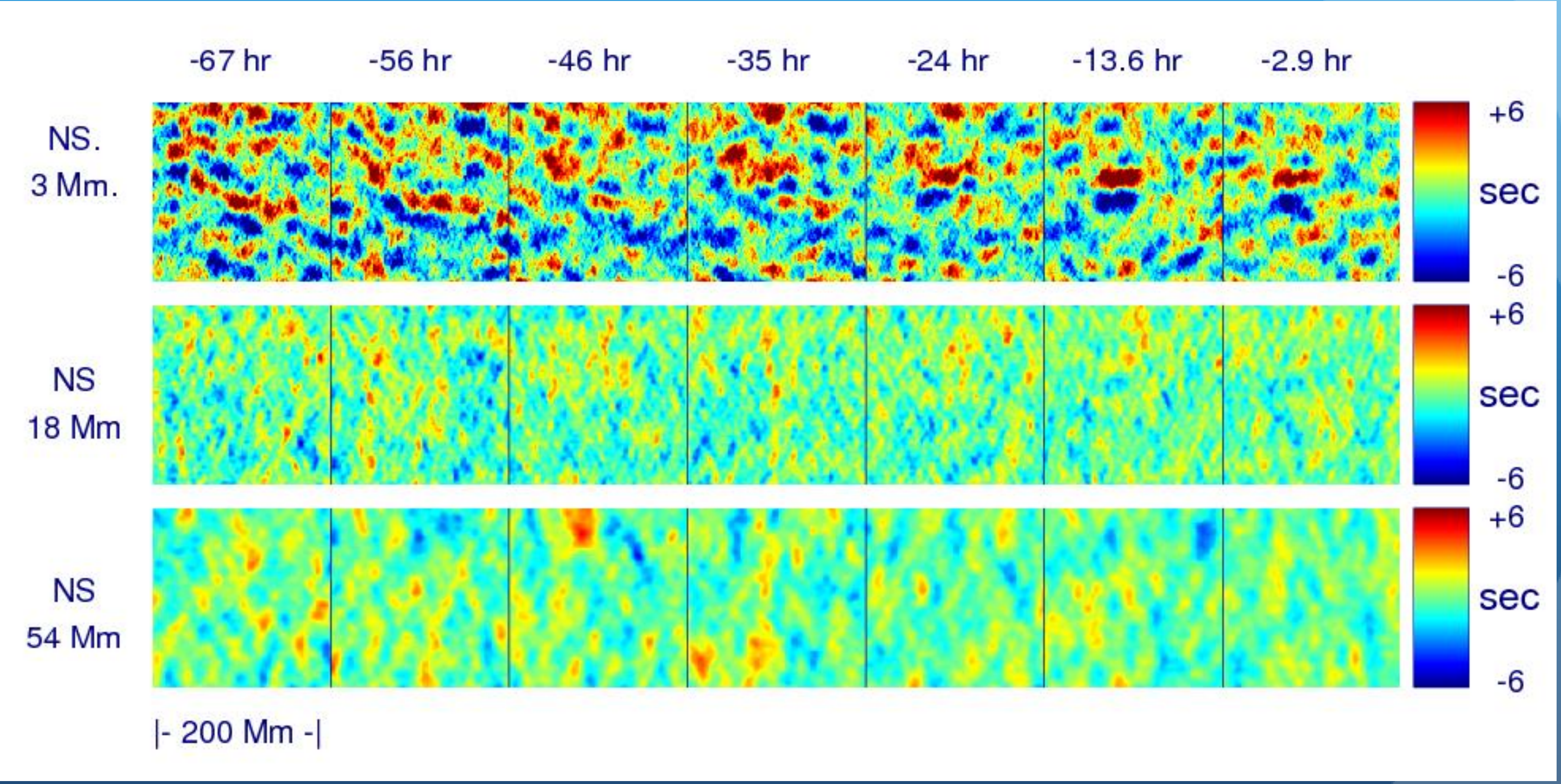
Data courtesy NASA/SDO and the AIA, EVE, and HMI science teams

evolution of prograde feature




time = -13.6 hr
number
diverg (σ_{SG})
20
15
10
5
0
-2
-1
0
1
2


-67 hr
-56 hr
-46 hr
-35 hr
-24 hr
-13.6 hr
-2.9 hr
EW.
3 Mm.
EW
18 Mm
EW
54 Mm
+6
sec
-6
+6
sec
-6
+6
sec
-6
|- 200 Mm -|


-67 hr
-56 hr
-46 hr
-35 hr
-24 hr
-13.6 hr
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NS.
3 Mm.
NS
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+6
sec
-6
+6
sec
-6
+6
sec
-6
|- 200 Mm -|