Examination of the magnetic field and motion of an emerging active region (EAR)

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Buoyancy Theory

- (Parker 1955): Magnetic flux tubes are brought up to the solar surface by magnetic buoyancy force.
- (Schuessler 1979): Horizontal magnetic cylinder of radius a

$$F_B \approx \frac{B_0^2 \cdot a^2}{8\Lambda} \quad (\text{Thin tube } a/\Lambda \ll 1) \tag{1}$$

$$F_B \approx \frac{B_0^2}{4(2\pi)^{1/2}}(a \cdot \Lambda)^{1/2} \quad (\text{Thick tube } a/\Lambda \gg 1) \tag{2}$$

(Λ: pressure scale height)

- (Chou&Wang 1987): Buoyant velocity

$$V_r = V_A \left(\frac{\pi}{2C_d}\right)^{1/2} \left(\frac{a}{\Lambda}\right)^{1/2} \quad (\text{Thin tube } a/\Lambda \ll 1) \tag{3}$$

$$V_r = V_A \left(\frac{\pi}{2C_d^2}\right)^{1/4} \left(\frac{\Lambda}{a}\right)^{1/4} \quad (\text{Thick tube } a/\Lambda \gg 1) \tag{4}$$

Buoyancy Theory

Buoyant velocity

$$V_r = \left(\frac{1}{8C_d\Lambda\rho}\right)^{1/2} B\ a^{1/2} \quad (a/\Lambda \ll 1) \tag{5}$$

$$V_r = \left(\frac{\pi}{2C_d^2}\right)^{1/4} \frac{\Lambda^{1/4}}{\sqrt{4\pi\rho}} B\ a^{-1/4} \quad (a/\Lambda \gg 1) \tag{6}$$

$$\Rightarrow V_r \propto B\ a^{1/2} \quad (a/\Lambda \ll 1) \tag{7}$$

$$\Rightarrow V_r \propto B\ a^{-1/4} \quad (a/\Lambda \gg 1) \tag{8}$$

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Questions:

- Are the equations for the buoyant velocity still valid?
- How significant are the effects of other realistic effects?

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- **direct observables (from magnetogram):**
  - EAR size
  - apparent motion
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How do we compare V_r with these observables?

(Chou&Wang 1987)

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Current study (**2015**):

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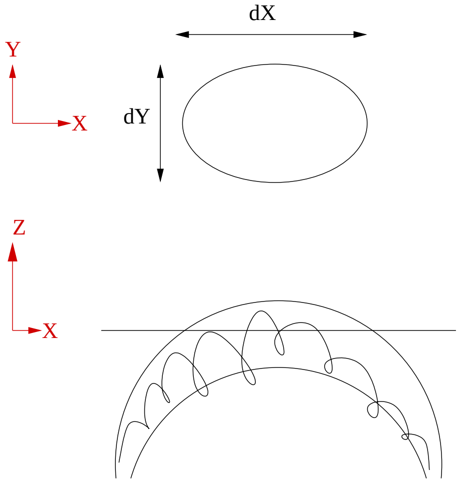
- Result ? Please wait for a few minutes.

How do we measure the observables?



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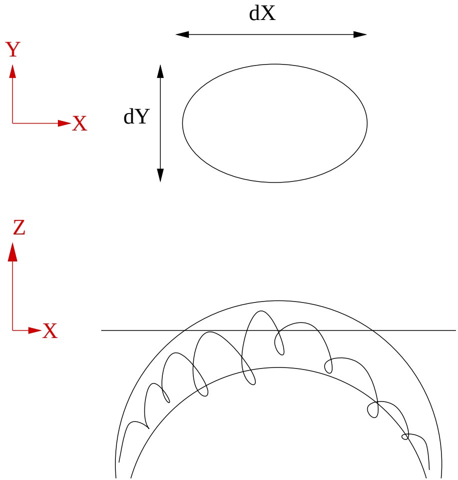

- Separation of the two legs:

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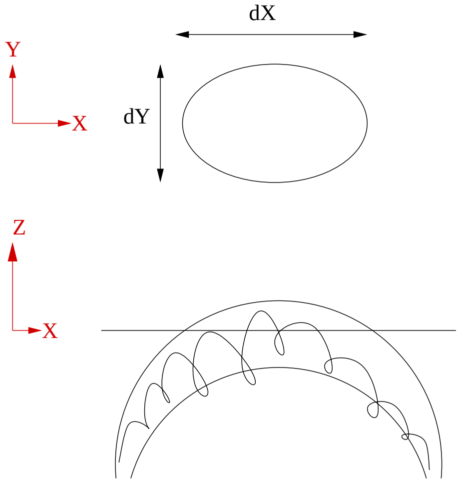

- Separation of the two legs: **dX**

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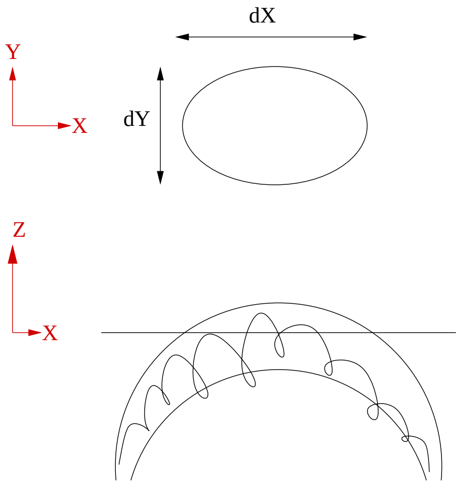
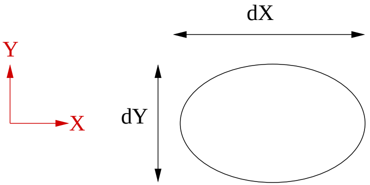
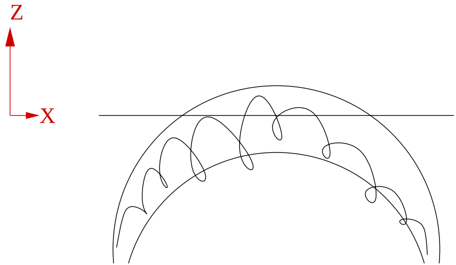


- Separation of the two legs: **dX**
- Radius:

How do we measure the observables?





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- Radius: **dY/2**

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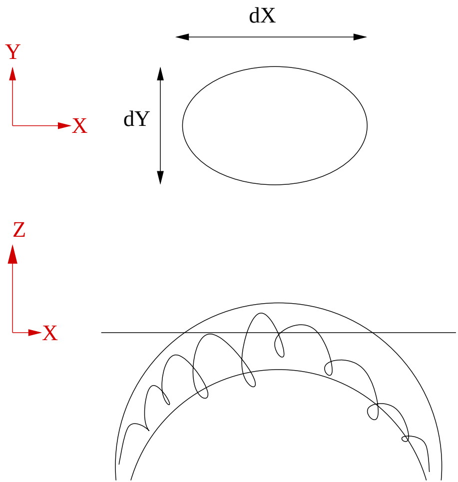

- Separation of the two legs: **dX**
- Radius: **dY/2**
- B:

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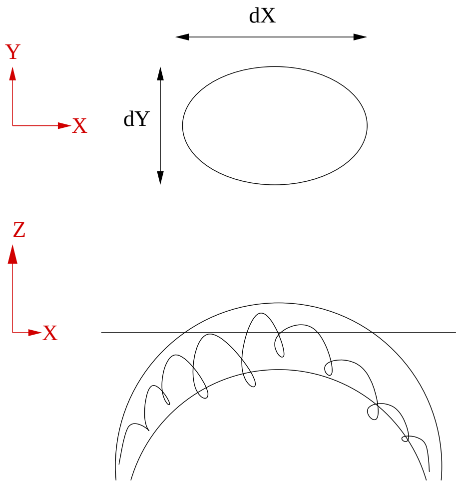

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- B: $B_{\rm ave}$ of dX$\times$dY

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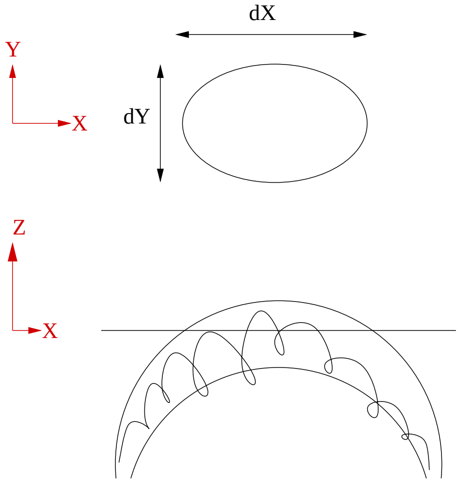
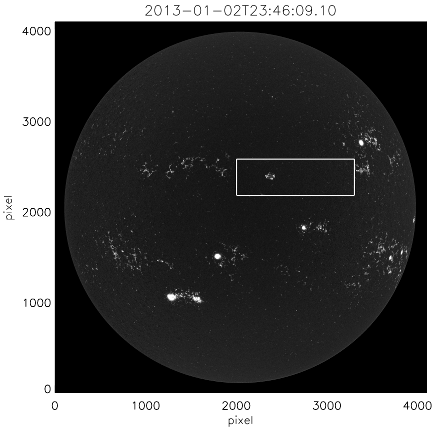


- Separation of the two legs: **dX**
- Radius: **dY/2**
- B: $B_{\rm ave}$ of dX×dY
- Define:
  - $V_{\rm bn} \equiv \frac{B\ dY^{1/2}}{\max(B\ dY^{1/2})}$
  - $V_{\rm bk} \equiv \frac{B\ dY^{-1/4}}{\max(B\ dY^{-1/4})}$

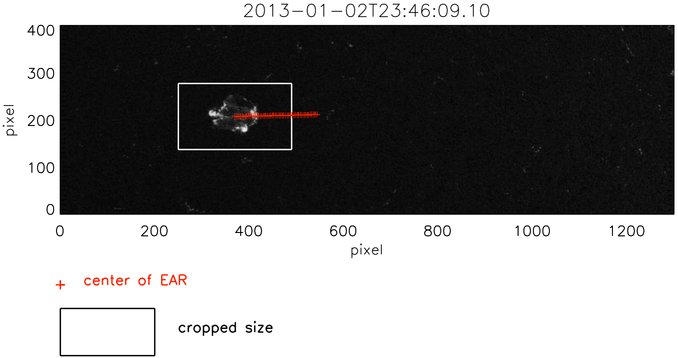
Observation

180° **rotated Sun**

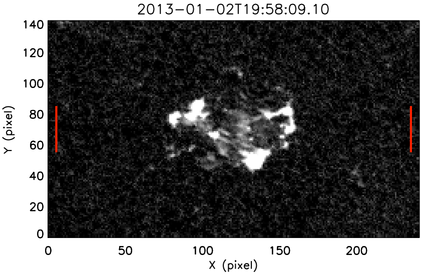


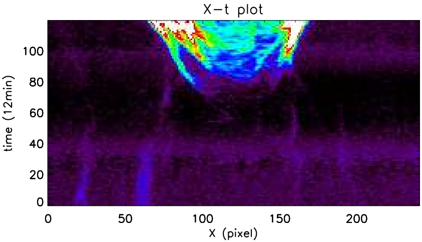
- Data: HMI vector magnetogram total field B
- AR number: 11645
- Location: $\sim$ S13E17 to S13E7
- Time:
  - earliest sign: $\sim$ 2013-01-02T10:30
  - clear structure: $\sim$ 2013-01-02T16:00

Observation



How to determine dX



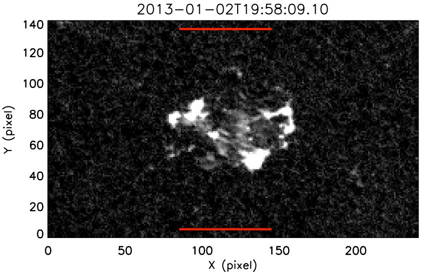


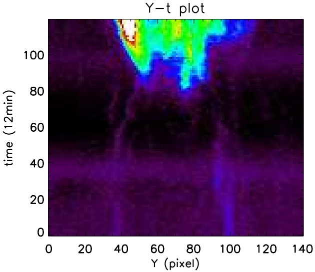
1. Make an X-t plot:

$$B(x, \bar{y}, t) = \frac{1}{N2-N1+1} \sum_{j=N1}^{N2} (B(x, y_j, t))$$

2. dX: distance between the two bright edges

How to determine dY



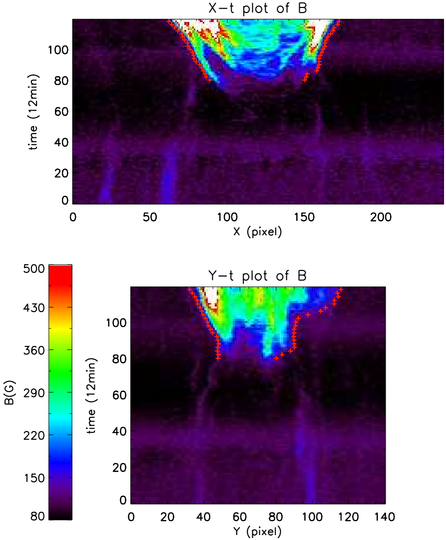


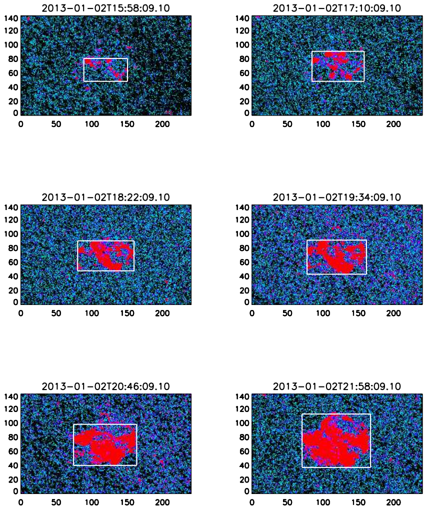
1. Make an Y-t plot:

   $$B(\bar{x}, y, t) = \frac{1}{N2-N1+1}\sum_{i=N1}^{N2}(B(x_i, y, t))$$

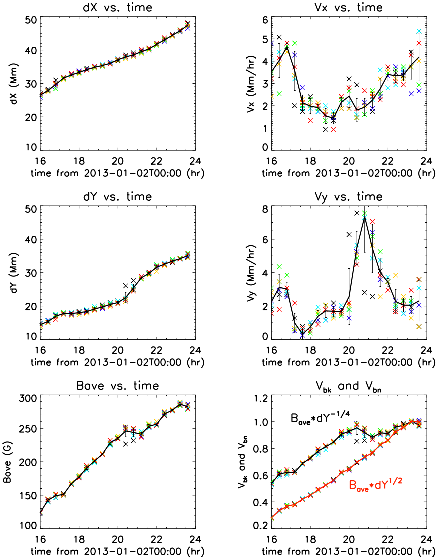
2. dY: distance between the two bright edges

Result 1/3


X−t plot of B
time (12min)
X (pixel)
B(G)
500
430
360
290
220
150
80
Y−t plot of B
time (12min)
Y (pixel)


2013−01−02T15:58:09.10
2013−01−02T17:10:09.10
2013−01−02T18:22:09.10
2013−01−02T19:34:09.10
2013−01−02T20:46:09.10
2013−01−02T21:58:09.10

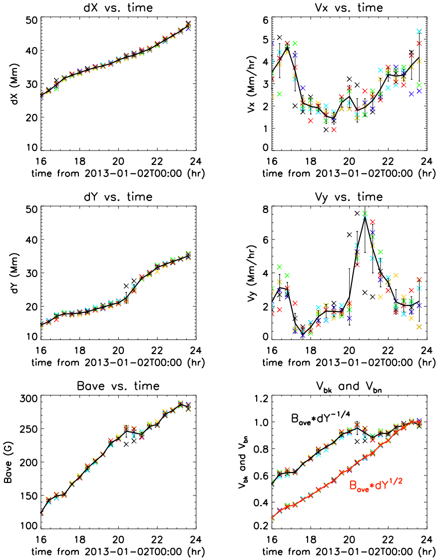
Result 2/3



- symbol: i^{th} point-and-click result (PAC_i)
- line: $\frac{1}{N}\sum_{i=1}^{N}\mathrm{PAC}_i$,

Why does Vx decrease before 19hr and increase afterward?

Result 2/3



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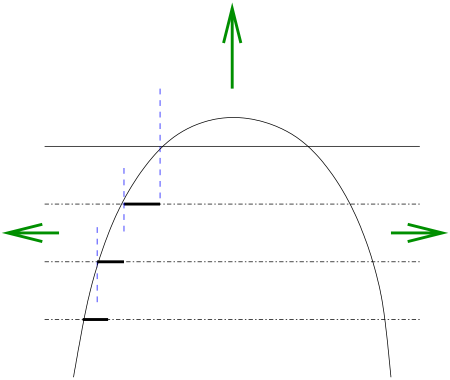
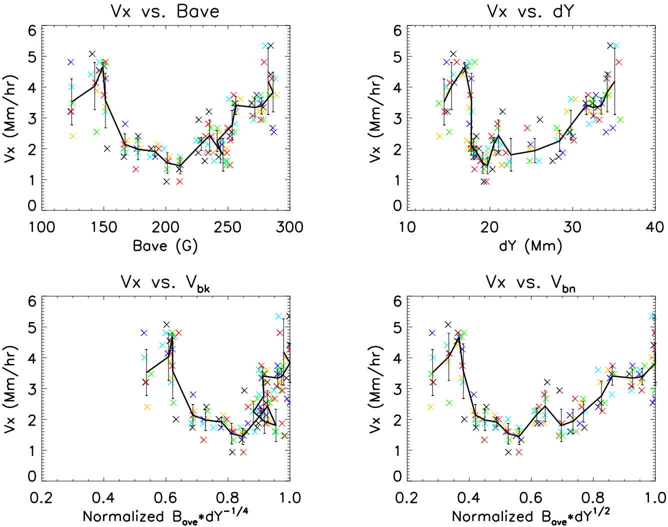
Why does Vx decrease before 19hr and increase afterward?

change of the emerging tube inclination angle?



Rising field lines become more vertical may result in reduced V_x

Result 3/3


Vx vs. Bave
Vx (Mm/hr)
Bave (G)
Vx vs. dY
dY (Mm)
Vx vs. V_{bk}
Normalized $B_{ave}*dY^{-1/4}$
Vx vs. V_{bn}
Normalized $B_{ave}*dY^{1/2}$

Past vs. Current

Chou&Wang 1987

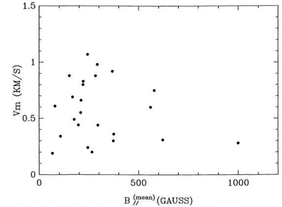


Fig. 5. Separation velocity of maxima, v_m, versus line-of-sight component of mean magnetic field, $B_\parallel^{(mean)}$. The statistical error in $B_\parallel^{(mean)}$ is about 15%.

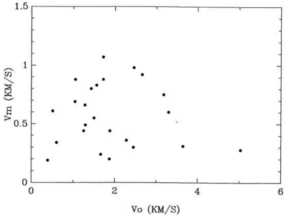
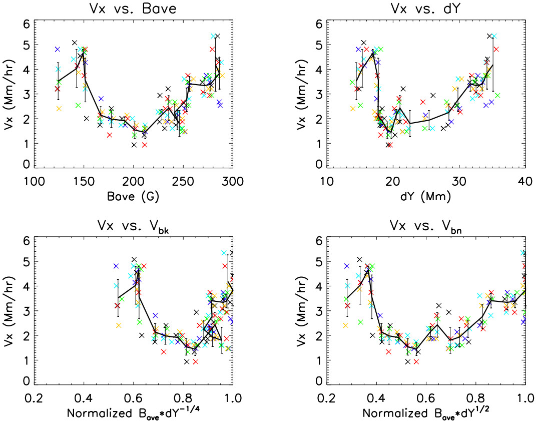


Fig. 7. Measured separation velocity, v_m, versus v_0, which is $B_\parallel^{(mean)} a^{-1/4}$.

2015



Conclusion

- Our qualitative comparsion showed correlations between the observed separation velocity and
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    - radius
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  of the emerging active region.

- A rigorous quantitative comparison is necessary to examine the consistency level between the observation and theory:
  - buoyancy theory
  - thin and thick tube approximations