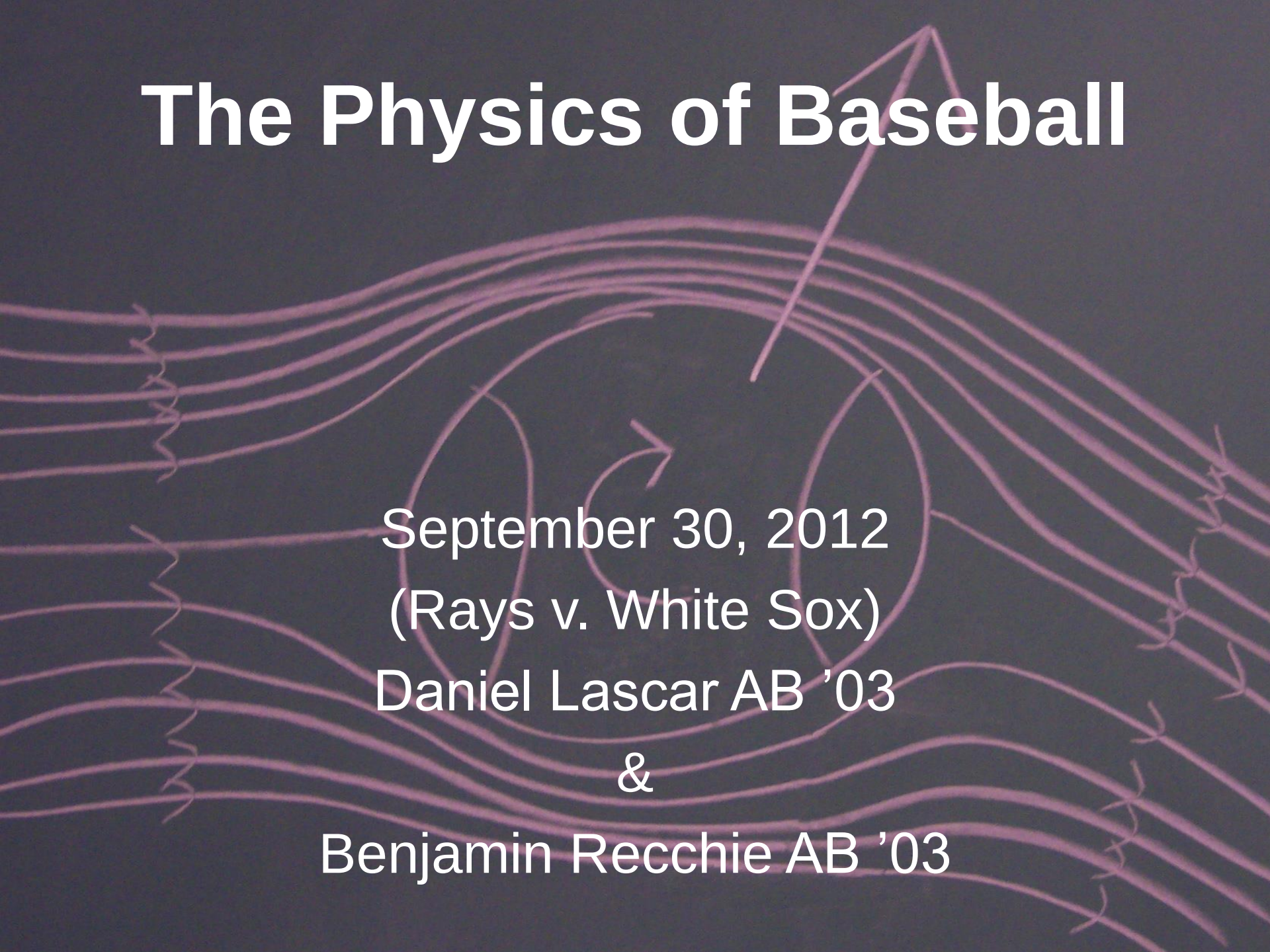
The Physics of Baseball



September 30, 2012

(Rays v. White Sox)

Daniel Lascar AB ’03

&

Benjamin Recchie AB ’03

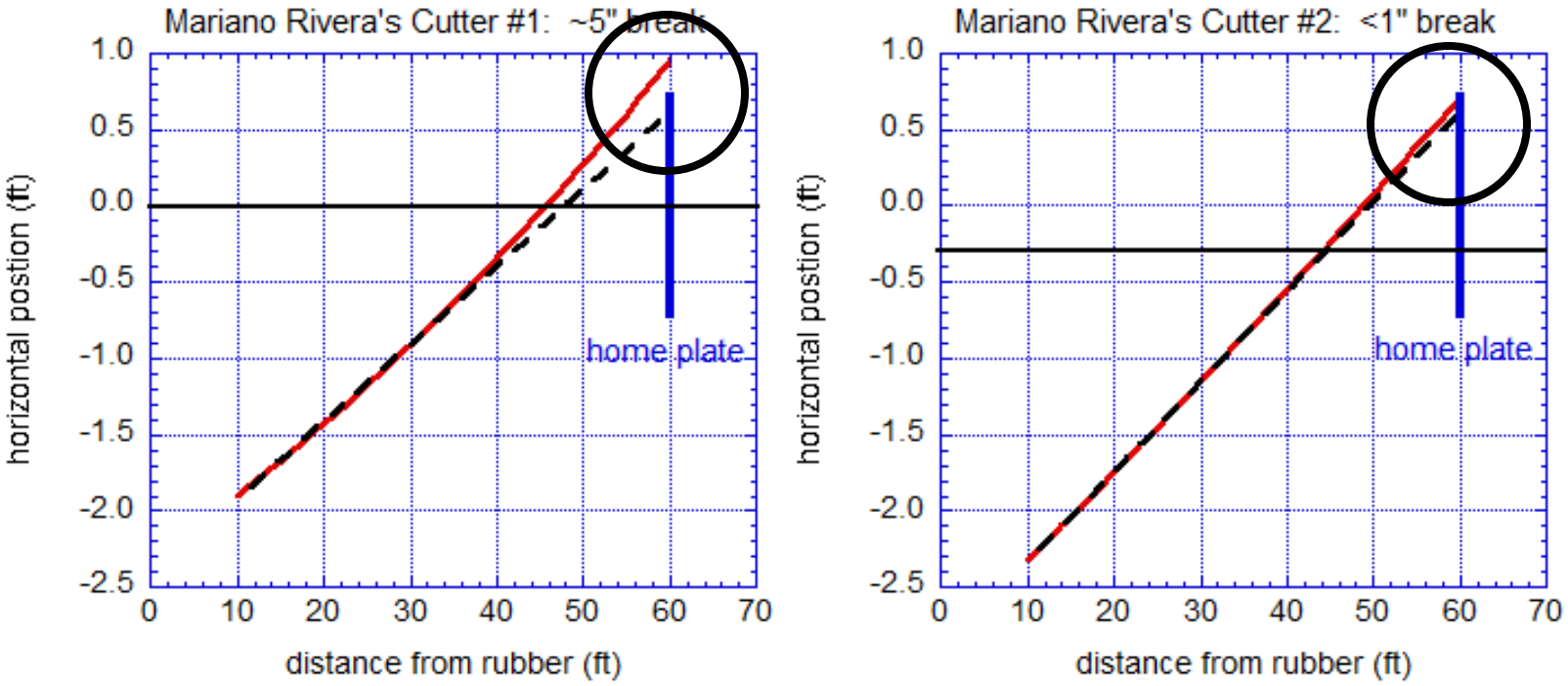
Talk Outline

- Pitching
  - Current Measuring Technology – PITCHf/x
  - Forces on the Ball
  - Different Pitches
- Batting
  - Coefficient of Restitution (COR)
  - Timing
  - Batting Kinematics

“Late Break”: Truth or Myth?

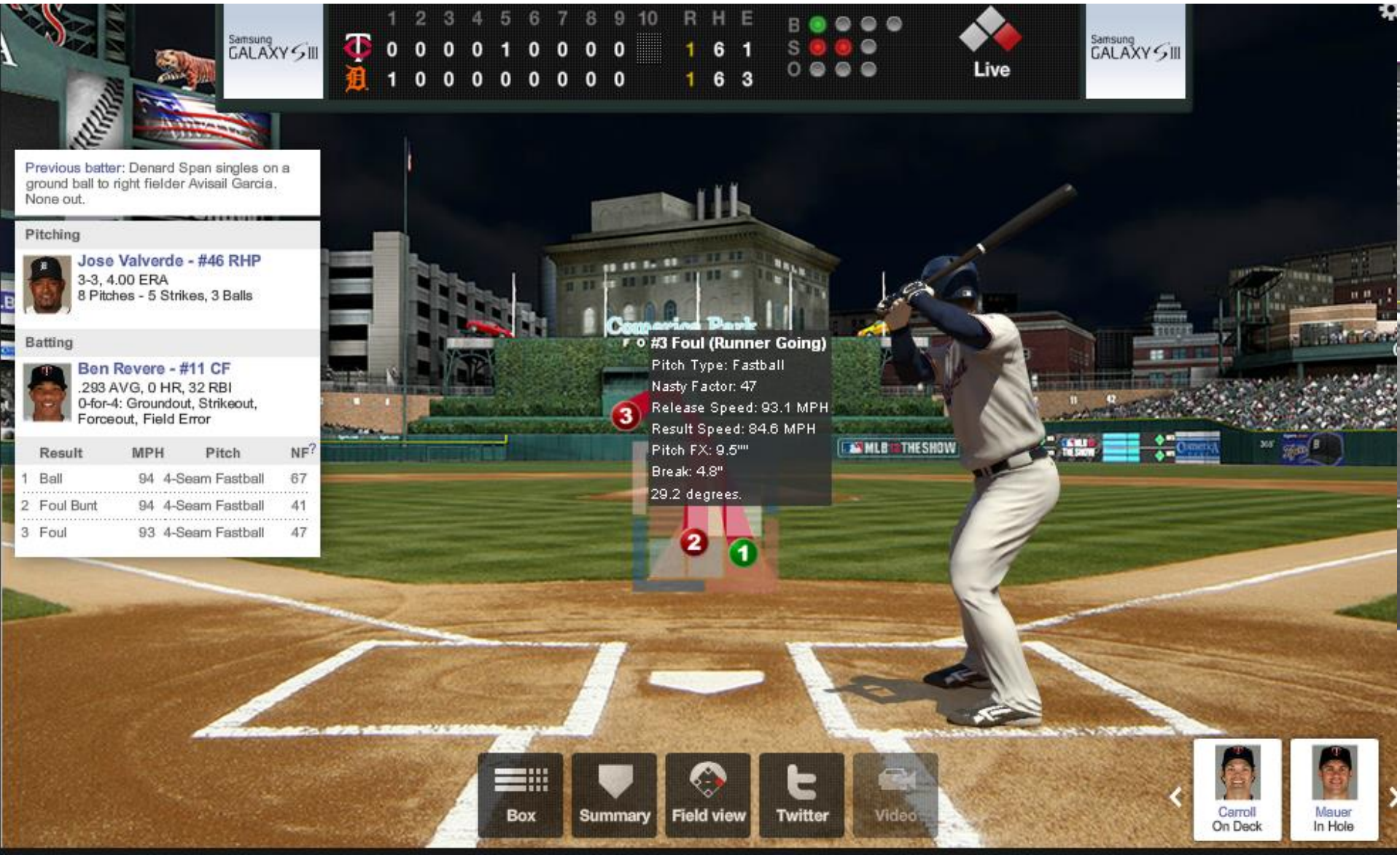
Mariano Rivera’s Cut Fastball

View from above:
actual trajectory --------
linear extrapolation - - - -



Courtesy of Alan Nathan

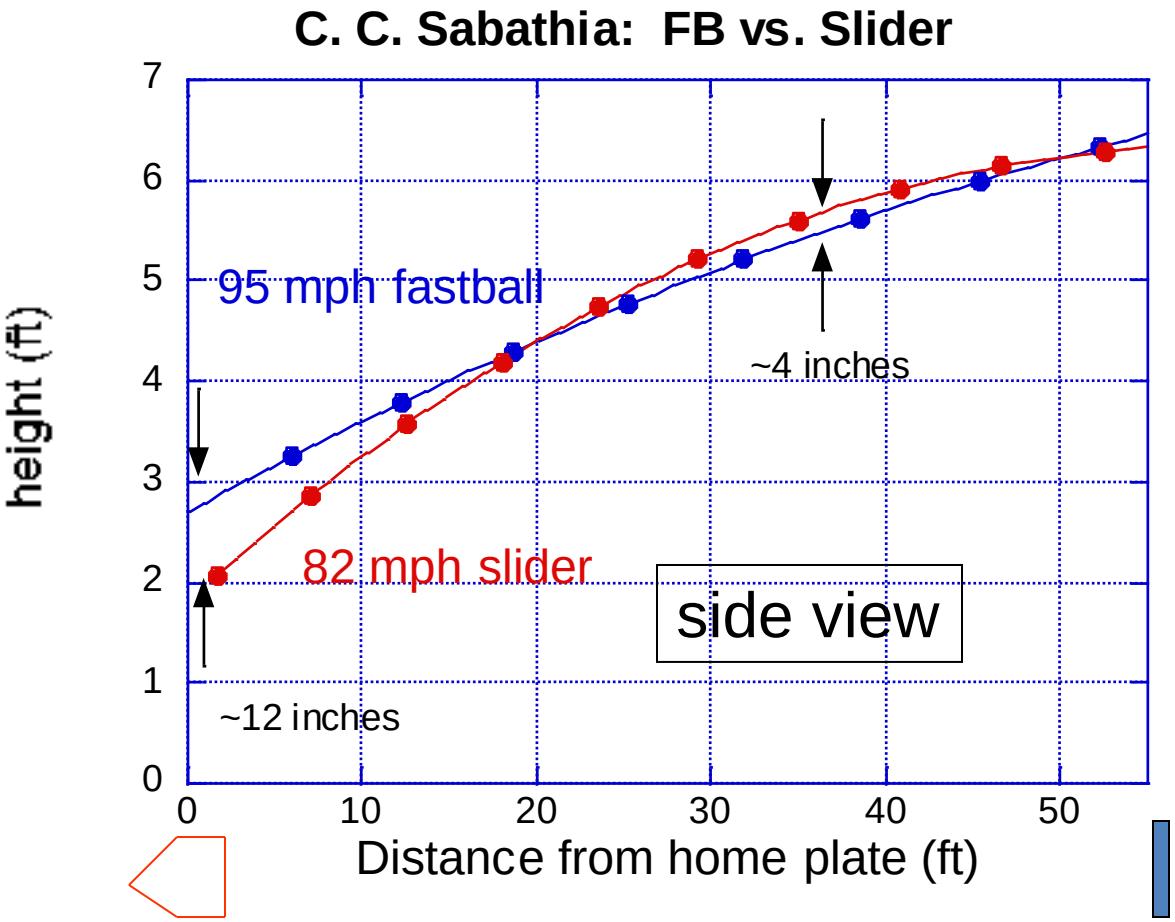
Today we can follow the ball better than a well-trained scout



What makes an effective slider

Josh Kalk, THT, 5/22/08

The Hardball Times



This slider is very effective since it looks like a fastball for over half the trajectory, then seems to drop at the last minute ("late break").

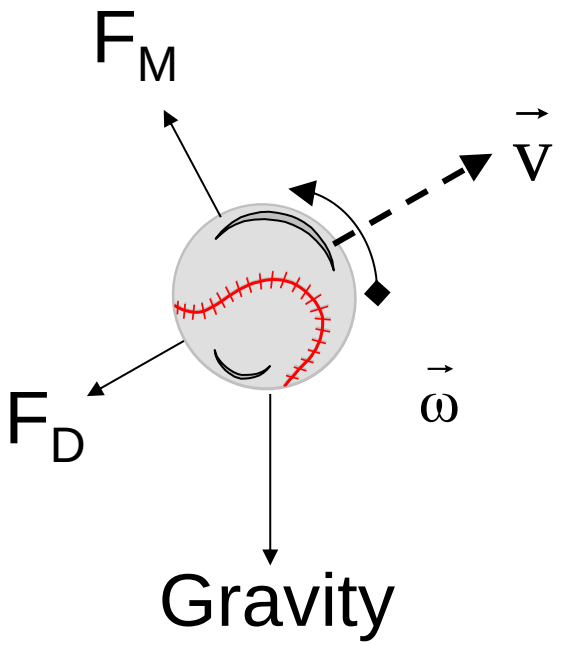
Forces on a Spinning Baseball in Flight

- **Drag slows ball down**

$$\vec{F}_D = -\frac{1}{2} C_D \rho A v^2 \hat{v}$$

- **Magnus + mg deflects ball from straight line**

$$\vec{F}_M = -\frac{1}{2} C_L \rho A v^2 (\hat{\omega} \times \hat{v})$$

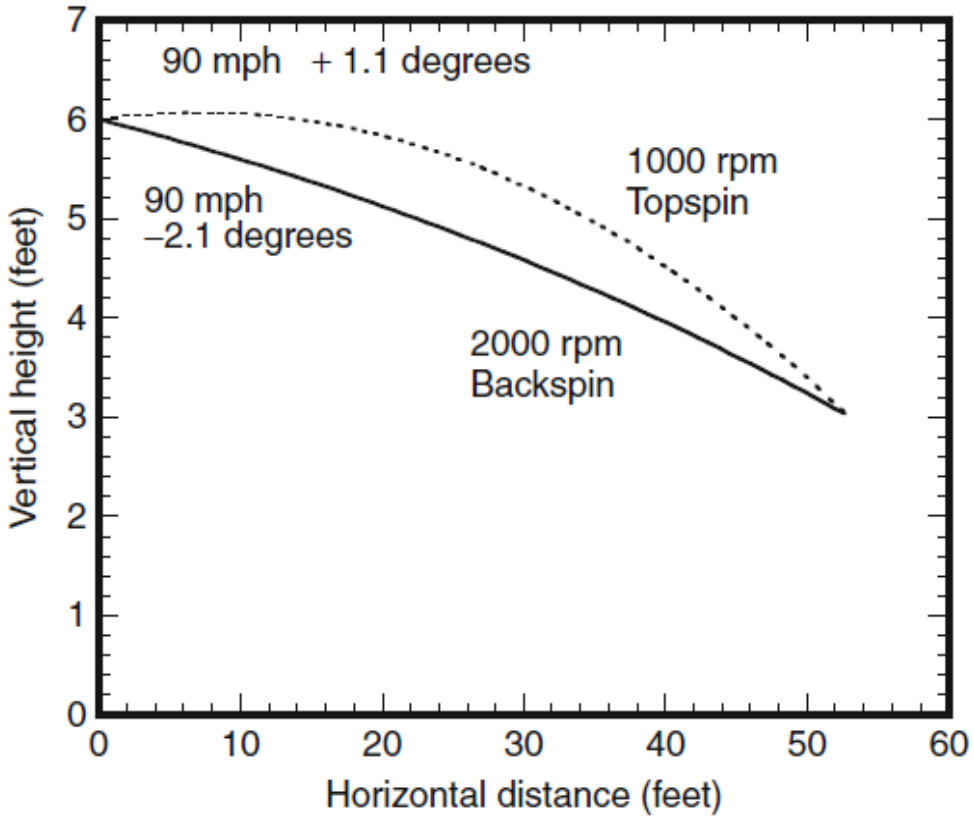


Courtesy of Alan Nathan

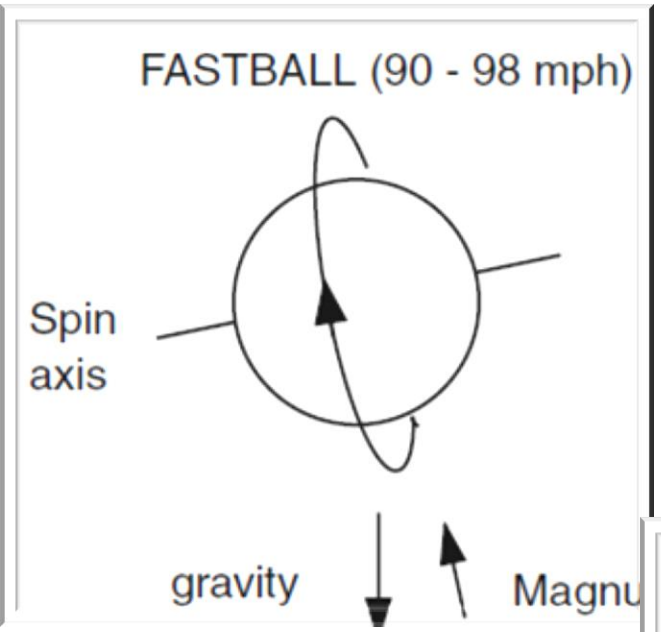
Magnus Force:

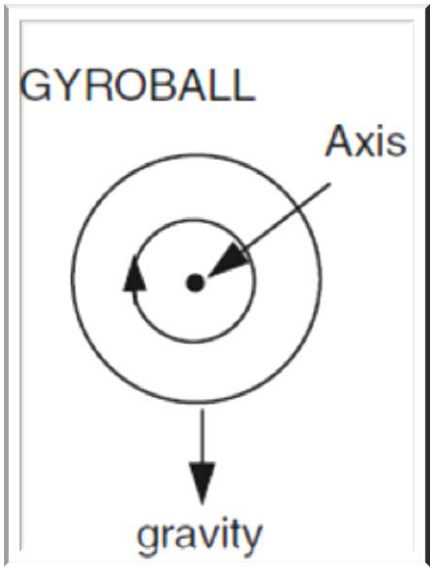
How A Pitch Breaks Across the Plate

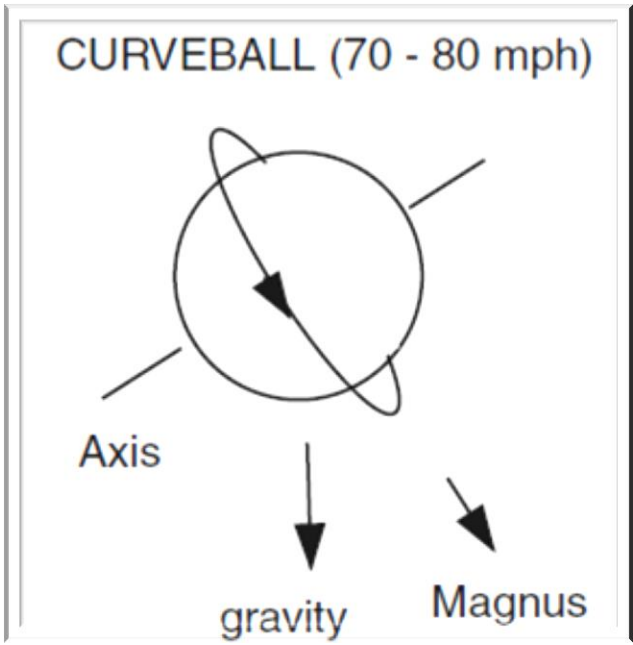
- Without the magnus force, all we have is gravity and drag.
- Stitches make it all possible.
  - Regions of turbulence exist at velocities where humans can throw.
- Rotational Speeds: 2 Pitches, Same Target, <u>Different Rotations</u>
  - Fastball
    - 90 mph & 2,000 rpm backspin
    - Thrown 2.1^{o} downward
  - Curveball
    - 90 mph & 1,000 rpm topspin
    - Thrown 1.1^{o} <u>upward</u>

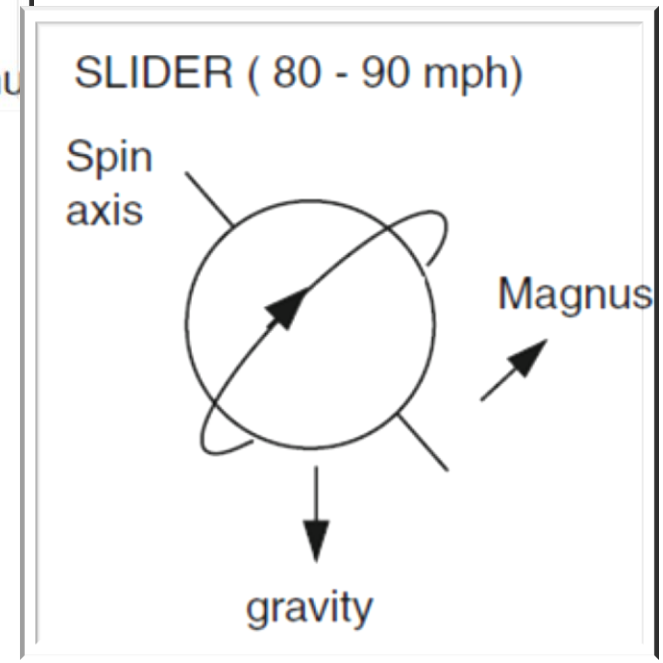


Types of Pitches

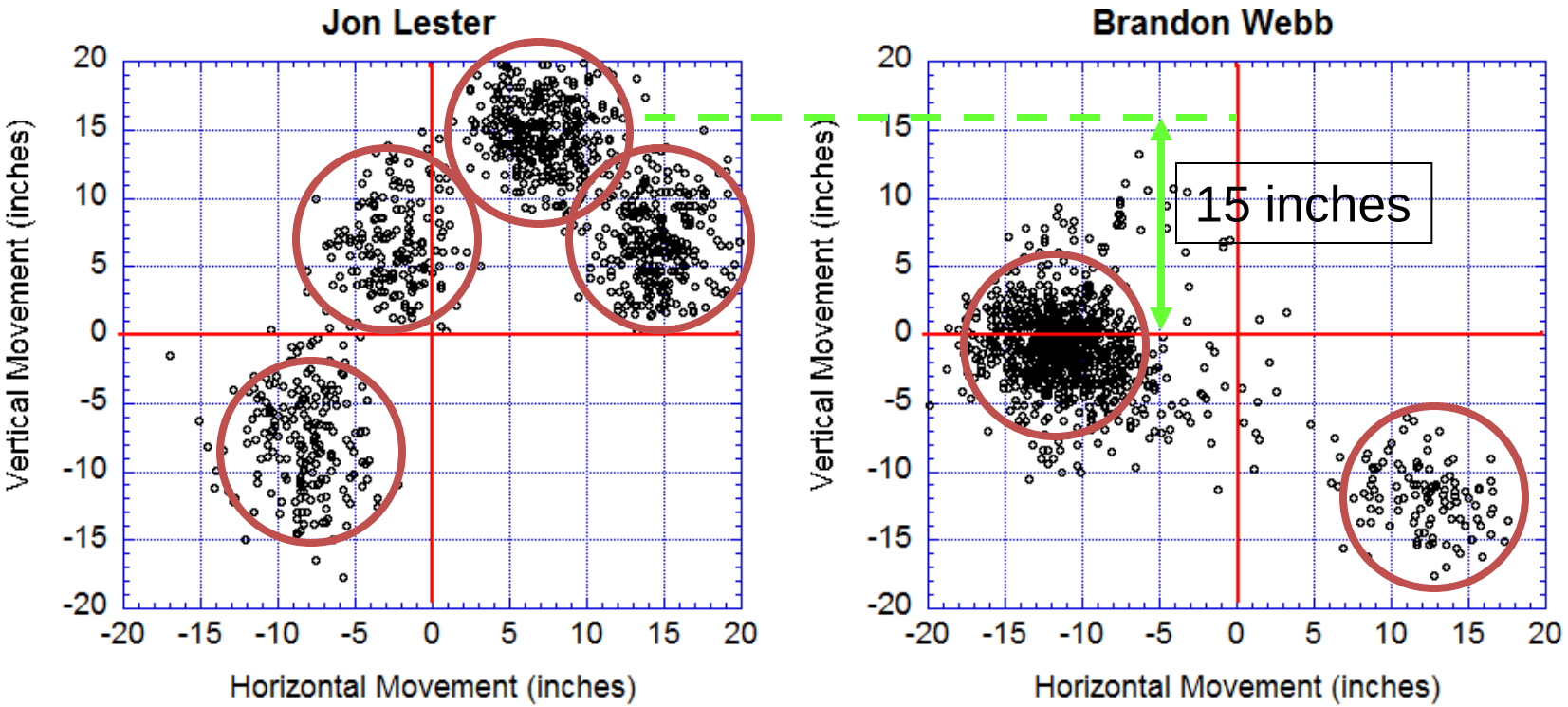








Jon Lester vs. Brandon Webb



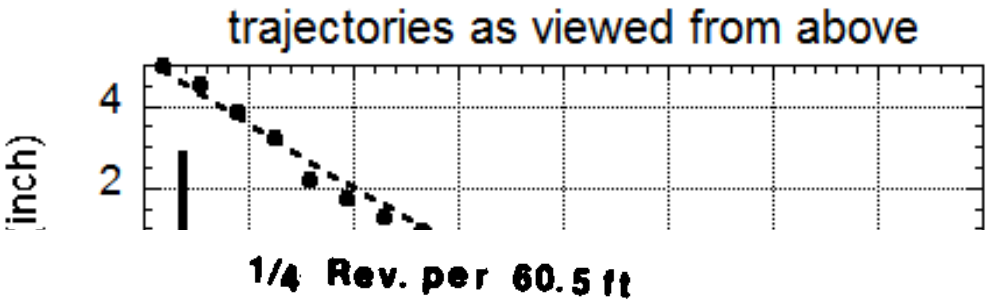
Brandon Webb is a
“sinkerball” pitcher:
Almost no rise on his fastball

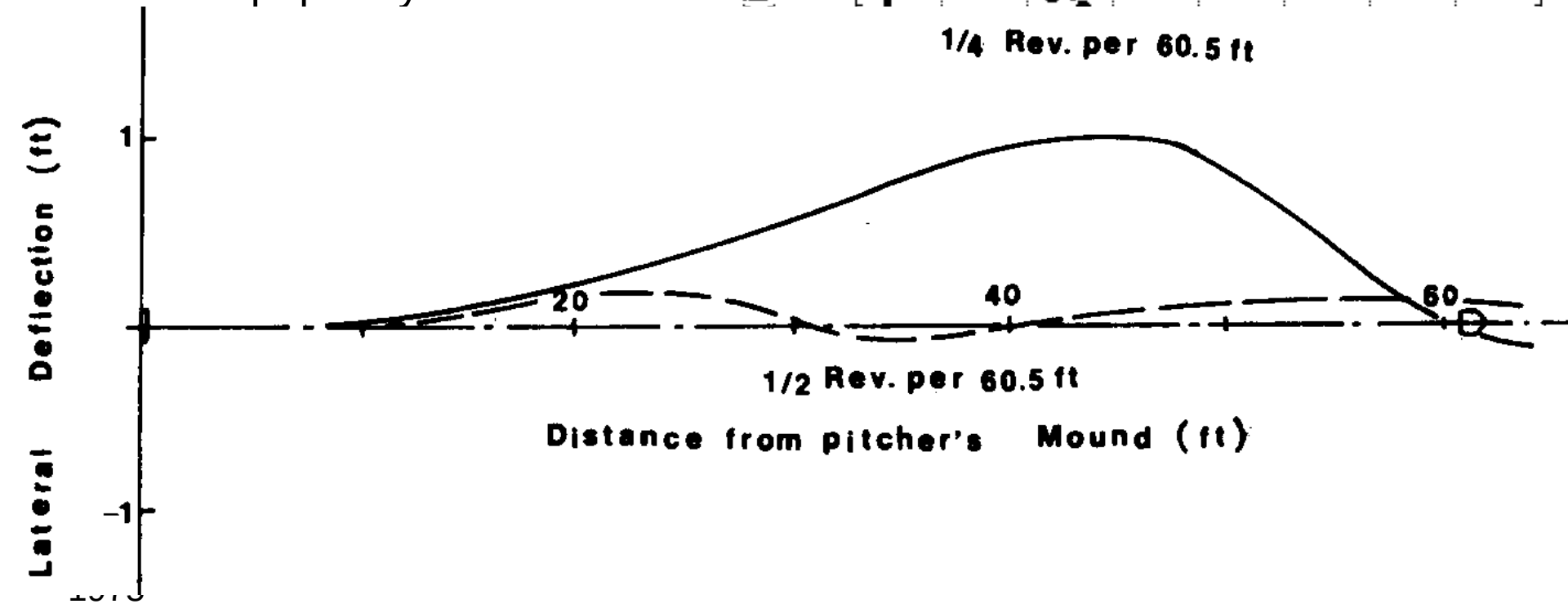
Courtesy: Alan Nathan

Knuckleball Research

- Myth or Fact: The knuckleball "jumps around" or zigzags.

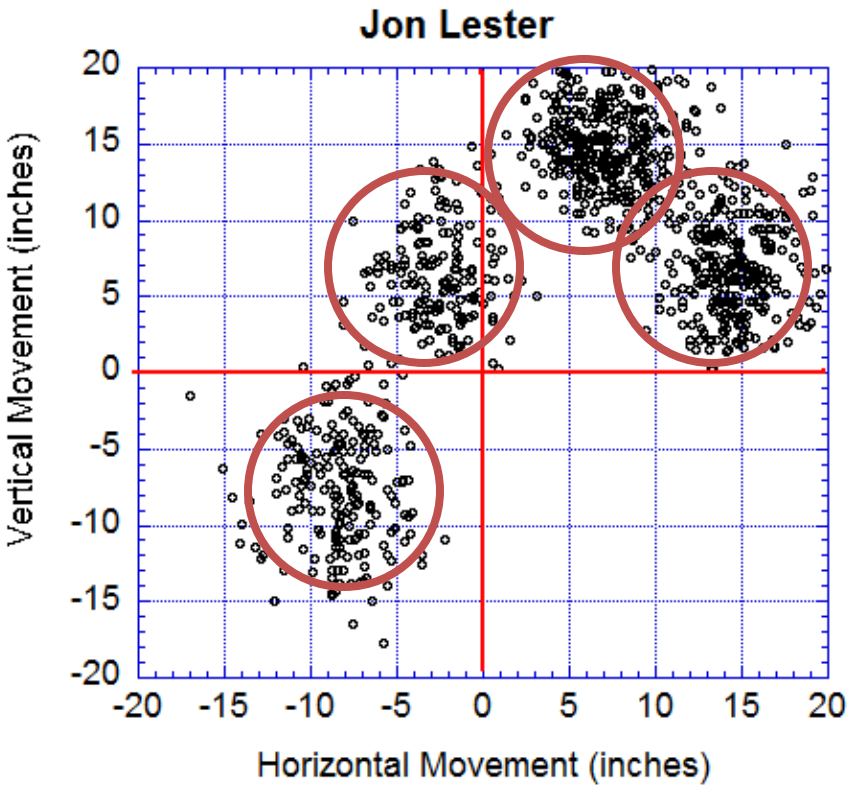
- Recent paper by Alan Nathan

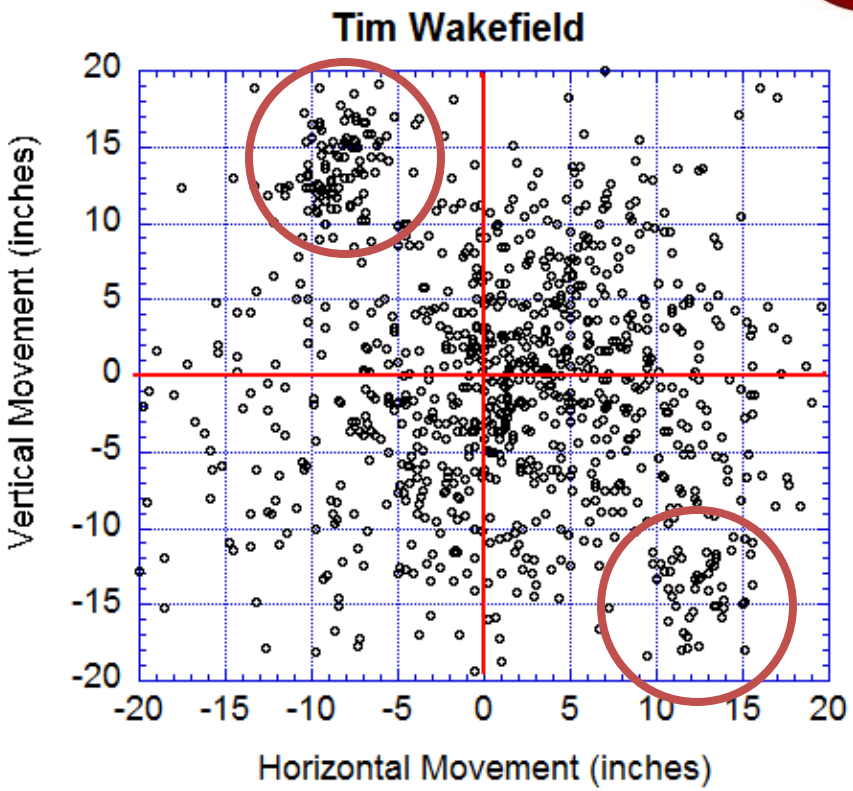




R. G. Watts, E Sawyer, *Am. J. Phys* **43** (11) 1975

The Knuckleball





Tim Wakefield is a knuckleball pitcher: Chaotic Movement

Courtesy: Alan Nathan

Where you hit a baseball depends on...

- Coefficient of restitution (COR) for bat/ball
- Angle of bat at impact
- Trajectory of ball at impact
- Kinetic energy of bat
- Kinetic energy of ball
- Timing
- Where on the bat ball hits
- Spin motion of the ball
- Humidity
- Temperature
- Wind

Coefficient of restitution

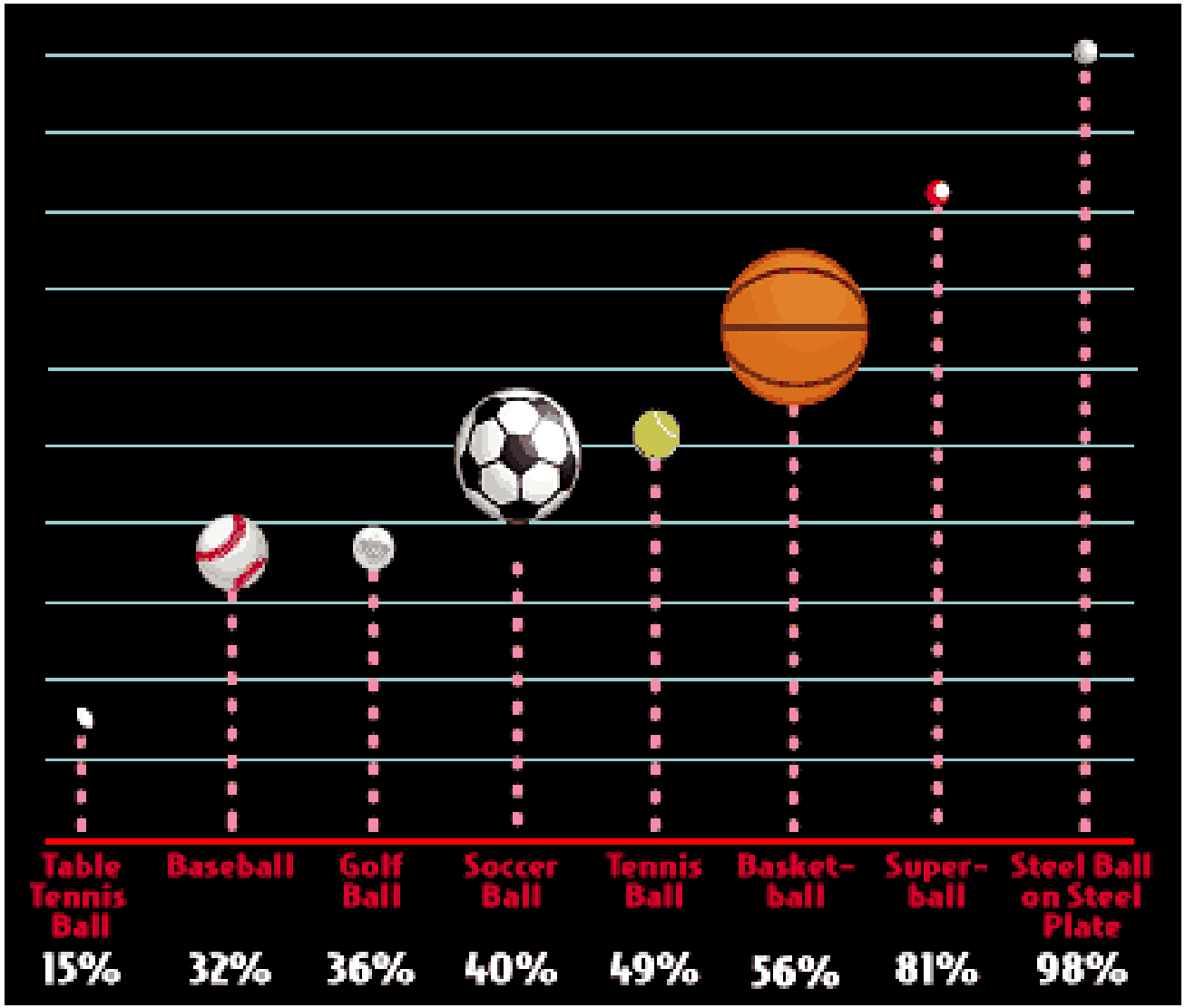
- **Defined as:**

$$e = \frac{v_{ball,after} - v_{bat,after}}{v_{bat,before} - v_{ball,before}}$$

- **MLB standard is *e*=0.55**
- **Varies with temperature; cold balls "dead," warm balls "live"**

http://memagazine.asme.org/Articles/2010/april/Our_Favorite_Pastime.cfm

Coefficient of restitution



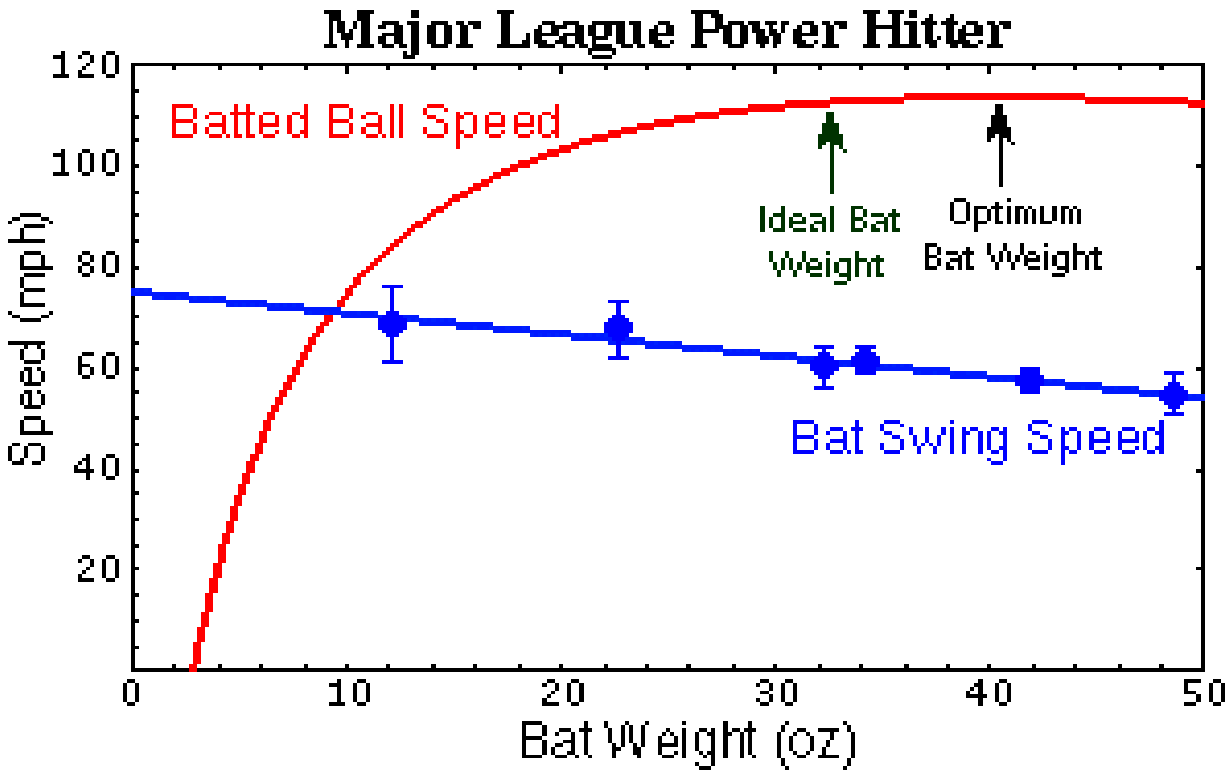
A few words about timing

- 0.000 s: ball released
- 0.100 s: batter's eye registers ball
- 0.175 s: batter's brain registers ball
- 0.175-0.200 s: batter decides to swing
- 0.200-0.225 s: batter decides which swing
- 0.215-0.240 s: batter moves body
- **0.240-0.400 s: batter swings**

Bat materials

Material	Density (g/cm^3)
Mahogany (Spanish)	0.85
Hickory	0.82
Ash	0.638
Maple (black)	0.620
Cork	0.24
Balsa	0.11
Aluminum	*2.70*

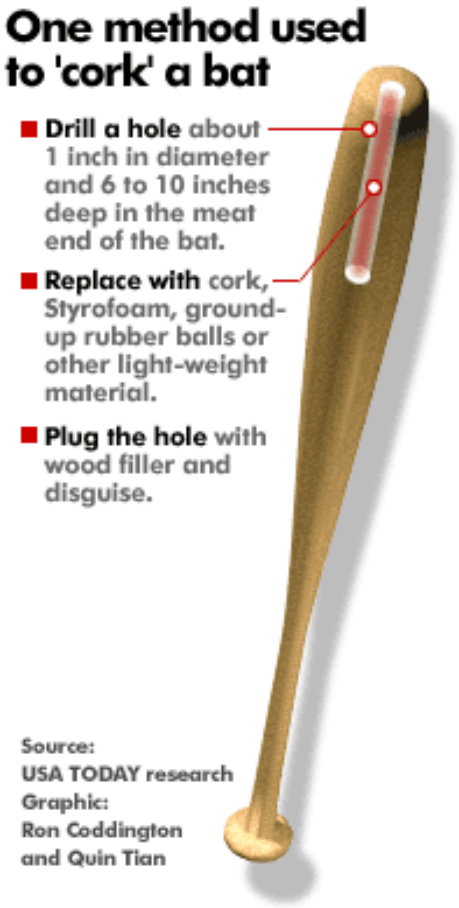
Heavy versus light



- Average bat weight in pro baseball is 32 oz, but “optimum” bat weight is 40.5 oz
- Your mileage may vary!

http://www.acs.psu.edu/drussell/bats/batw8.html

Corking

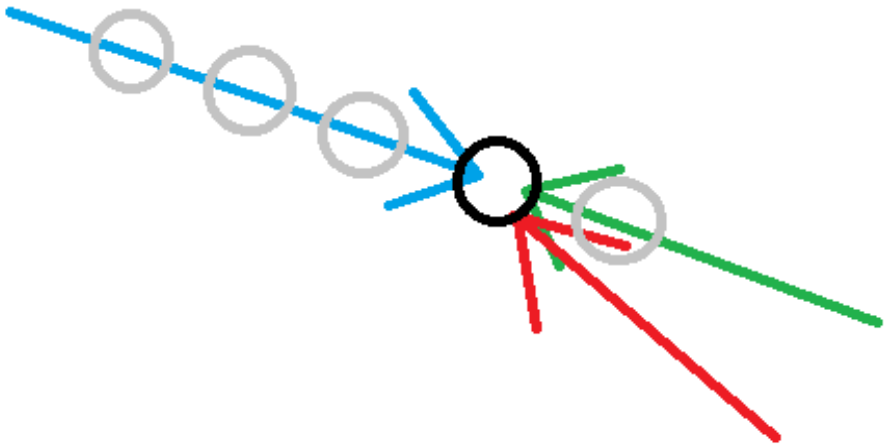


- Increases chances of hitting ball (maybe)
- Does not increase power
- Save your time and don't bother

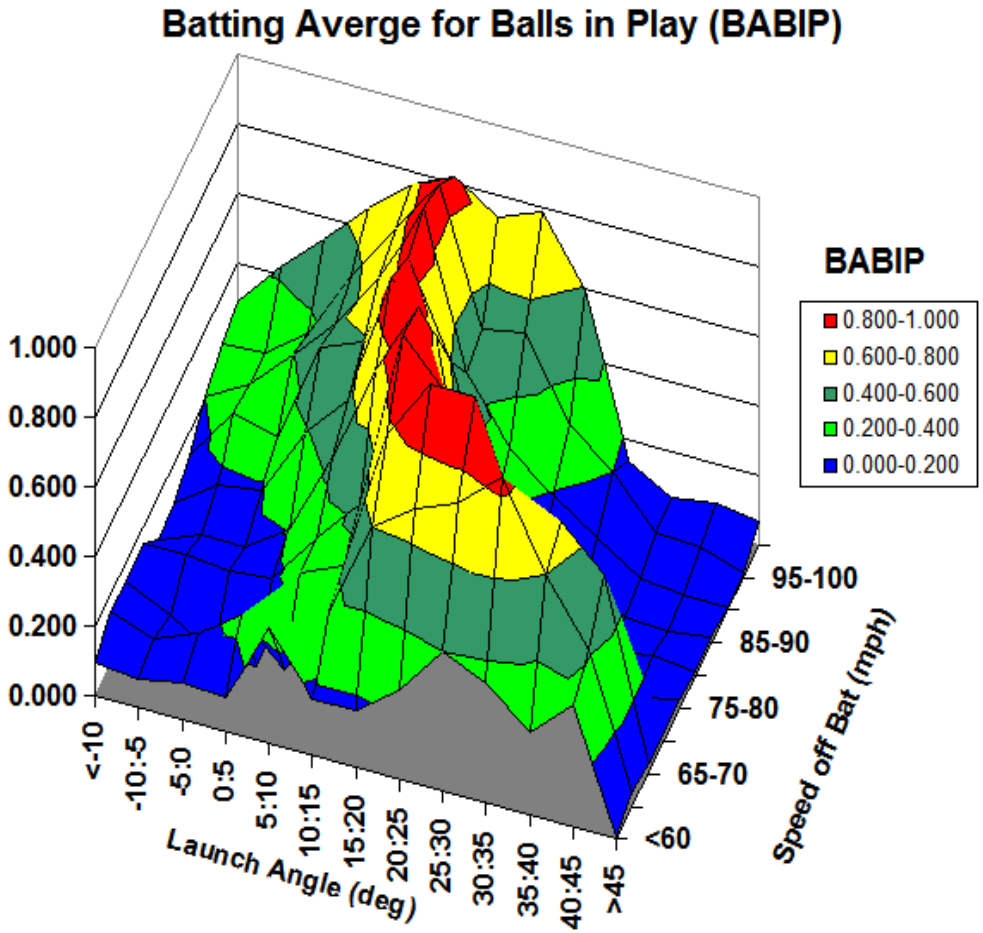
Optimum angles

- For average
  - "Level" swing (10 degrees up)
  - Maximizes chances of good contact

- For power
  - Uppercut swing (≤ 20 degrees)
  - Maximizes flight time, distance



Where a ball goes once put into play



http://webusers.npl.illinois.edu/~a-nathan/pob/ppt/APS-March10-v6.ppt

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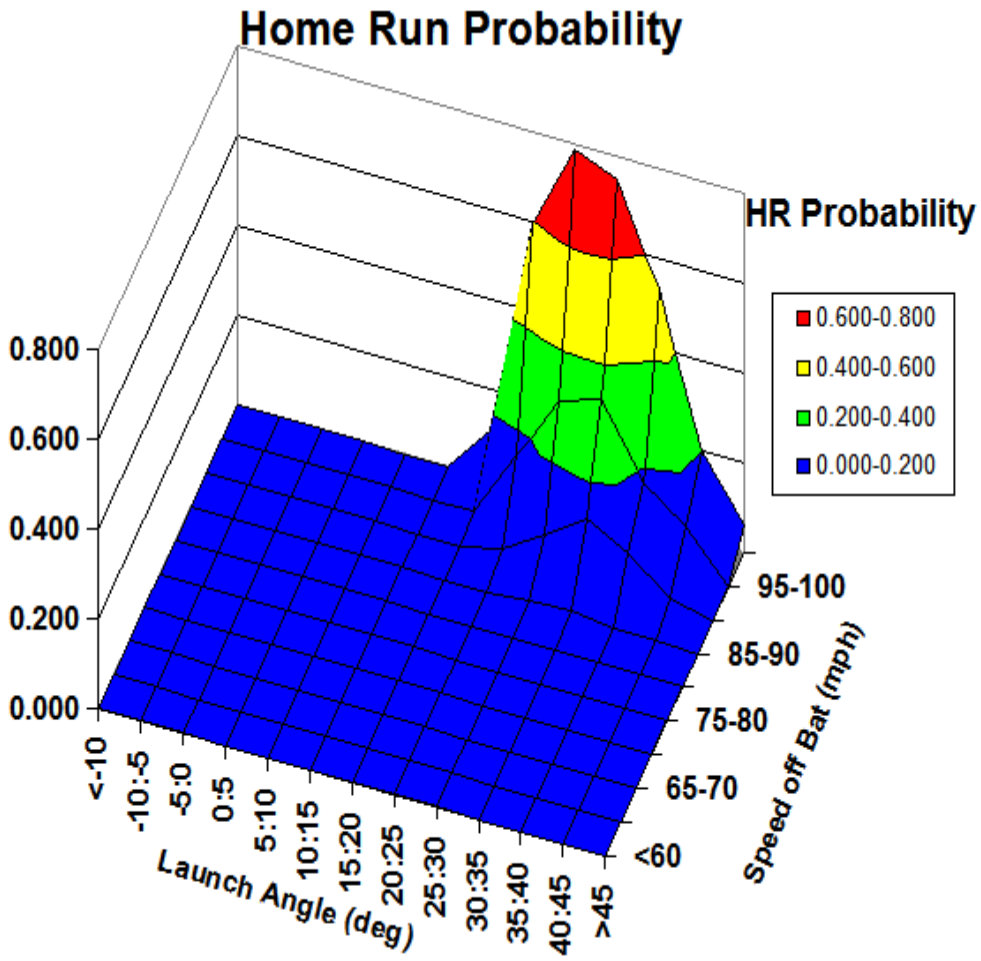

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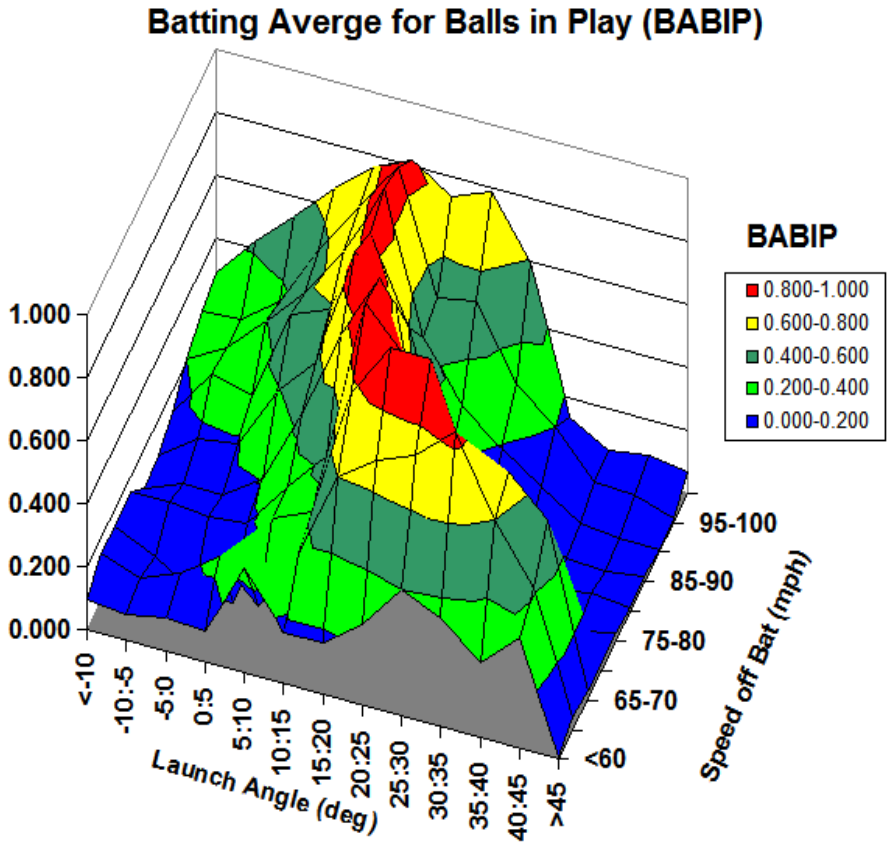

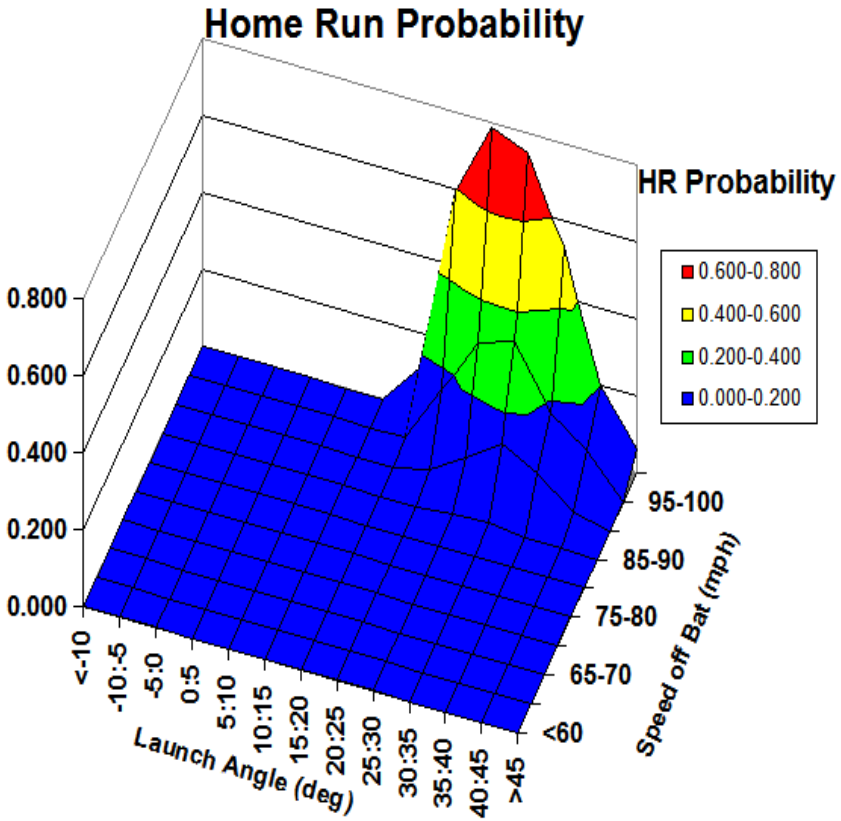

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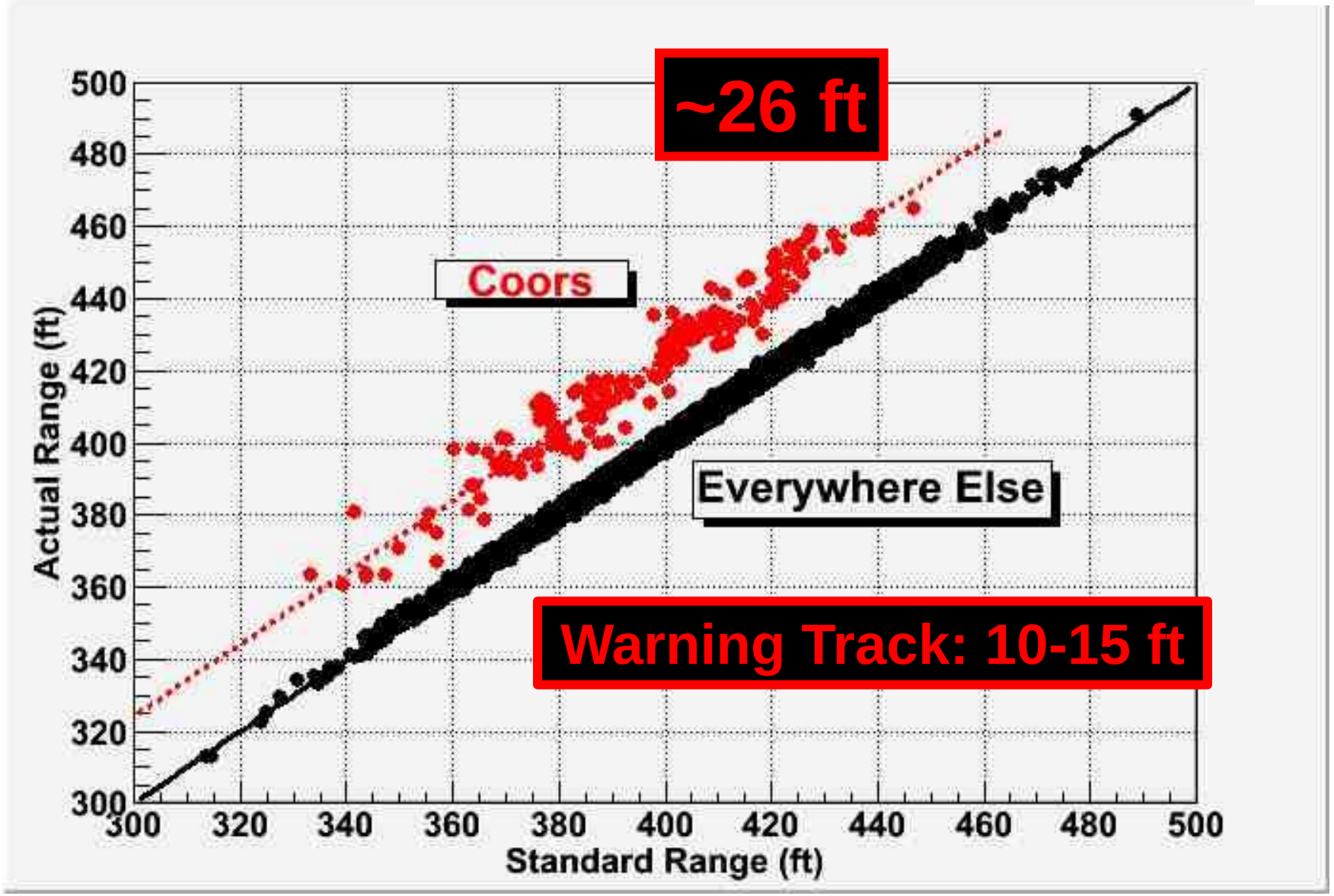
The Coors Effect



Home Runs and Humidors

- Coors Field in Denver:
  - Pre-humidor (1995-2001):
    - Rockies home: 3.20 HR/game away: 1.93 HR/game
  - Post-humidor (2002-2010):
    - Rockies home: 2.39 HR/game away: 1.86 HR/game

25% Reduction!

The Humidor

- Coors Field uses a humidor to prepare baseballs.
- Higher humidity:
  - Decreases the COR (less “bouncy”)
  - Makes the ball heavier (ball isn’t hit as hard)
  - Makes the ball larger (ball doesn’t fly as well)

Summary of Findings

with RH increased from 30% to 50%

- Weight increases by **1.6%**
- COR decreases by **3.7%**
- Diameter change negligible

For typical long fly ball (100 mph, 30 deg)

- Batted ball speed decreases by about 3 mph
- Fly ball distance decreases from 415 ft to 402 ft

Corked bats, juiced balls, and humidors: The physics of cheating in baseball

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A Bit More On The Knuckleball

- These are the RMS deviations of all the pitches in Mets-Marlins game on Aug. 29, 2011
  - Knuckleballs in red
  - All other in blue
- Using just the blue pitches, the precision of PITCHf/x = ± 0.3 in
  - Sportvision claims ± 0.5 in