

# **Hypervelocity Stars** and **Massive Black Holes**

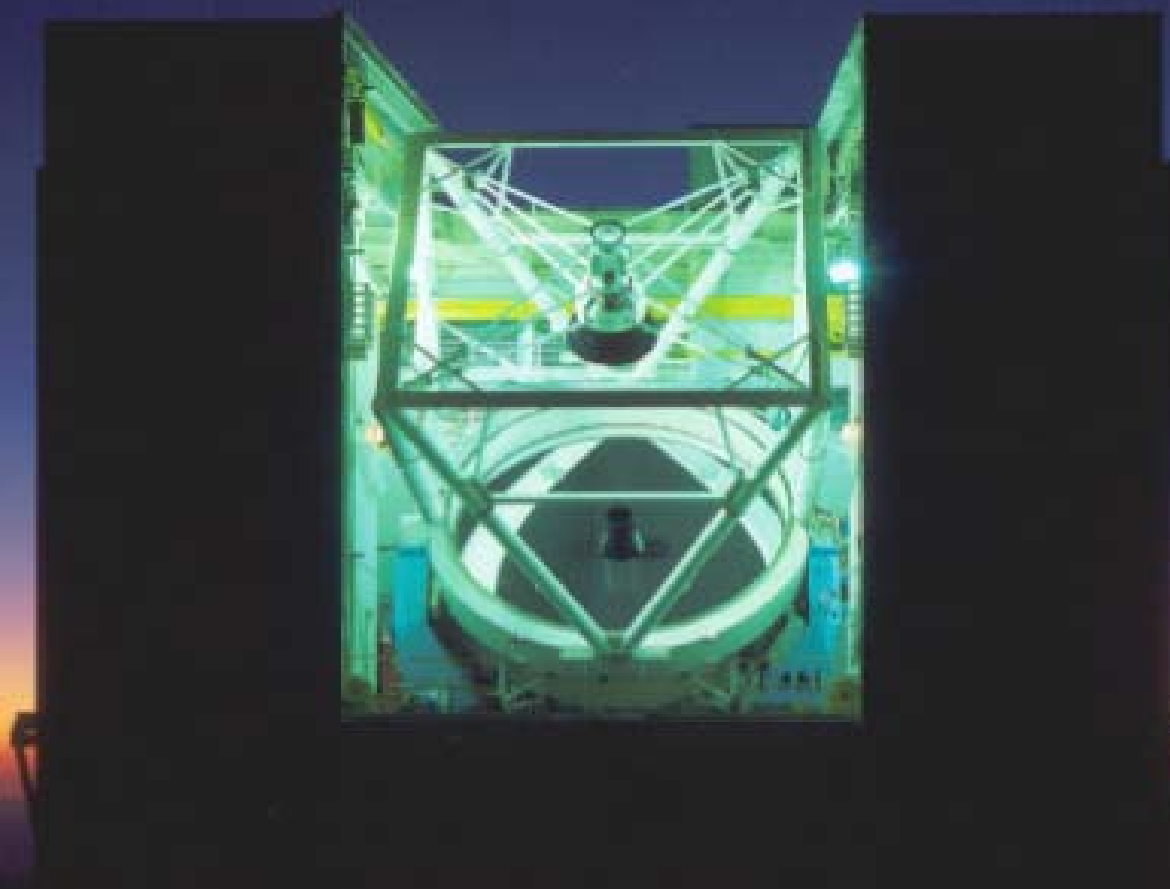


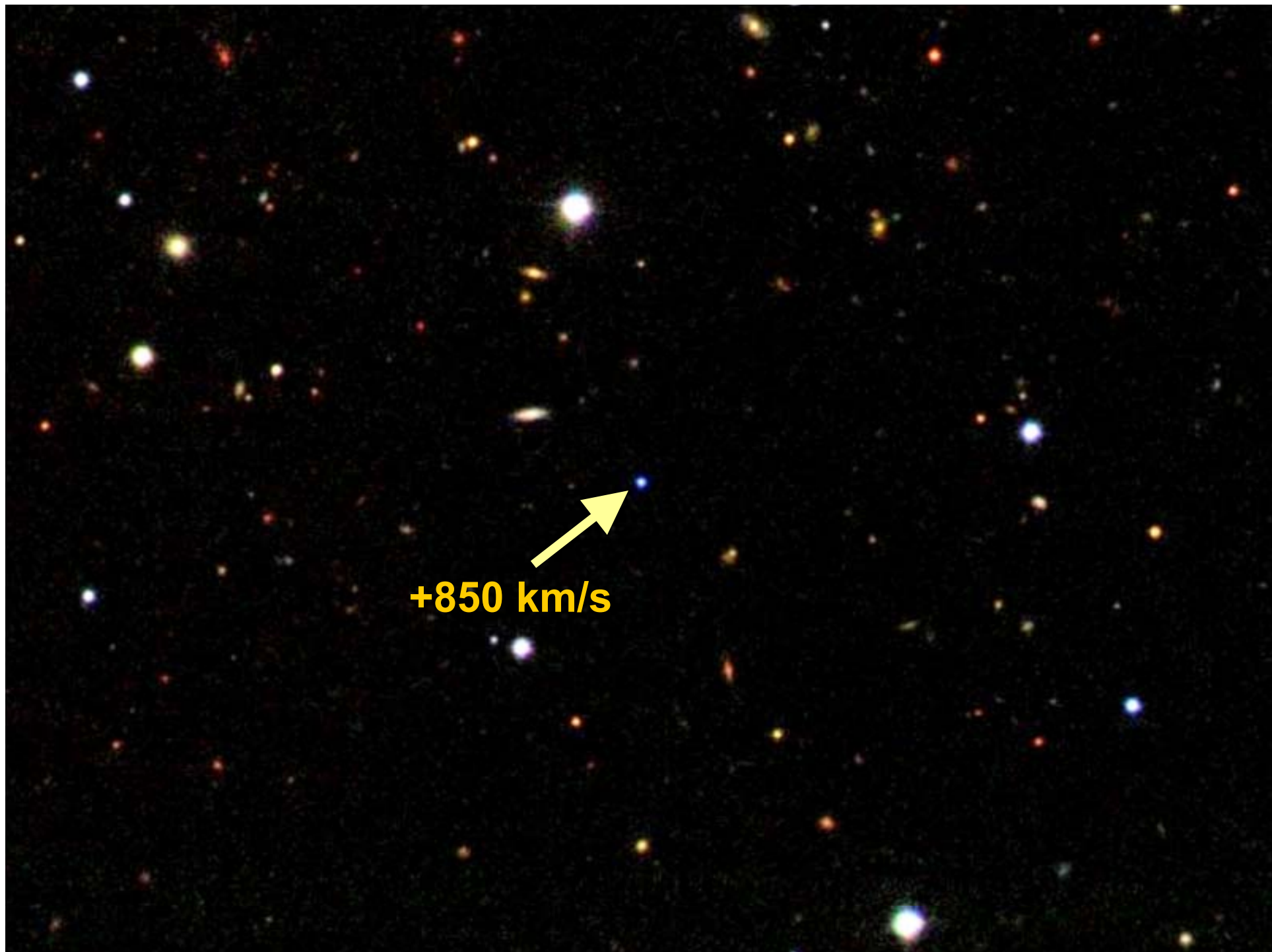
**Back to the Galaxy II**  
**KITP Conference**  
Oct 3, 2008

**Warren R. Brown**  
**SAO / CfA**

**Collaborators:**  
Margaret Geller, Scott Kenyon

# Radial Velocities from the MMT





**+850 km/s**

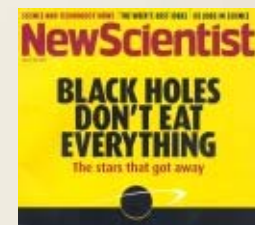
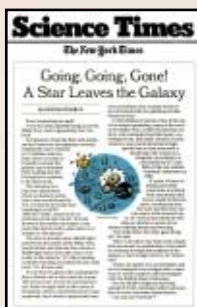
# Predictions

**Hills, 1988, Nature: prediction**

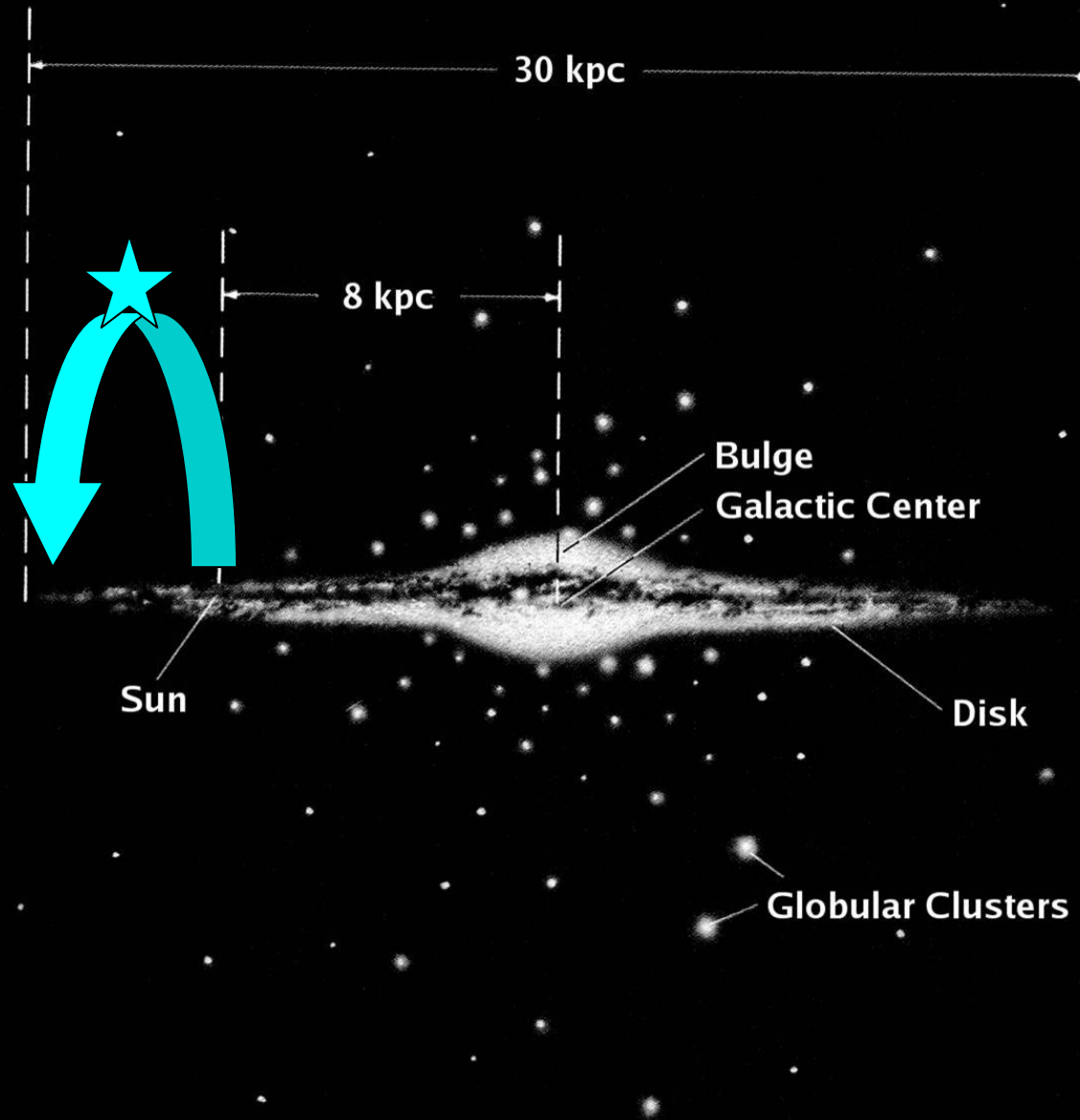
**Hills, 1991, AJ: orbits**

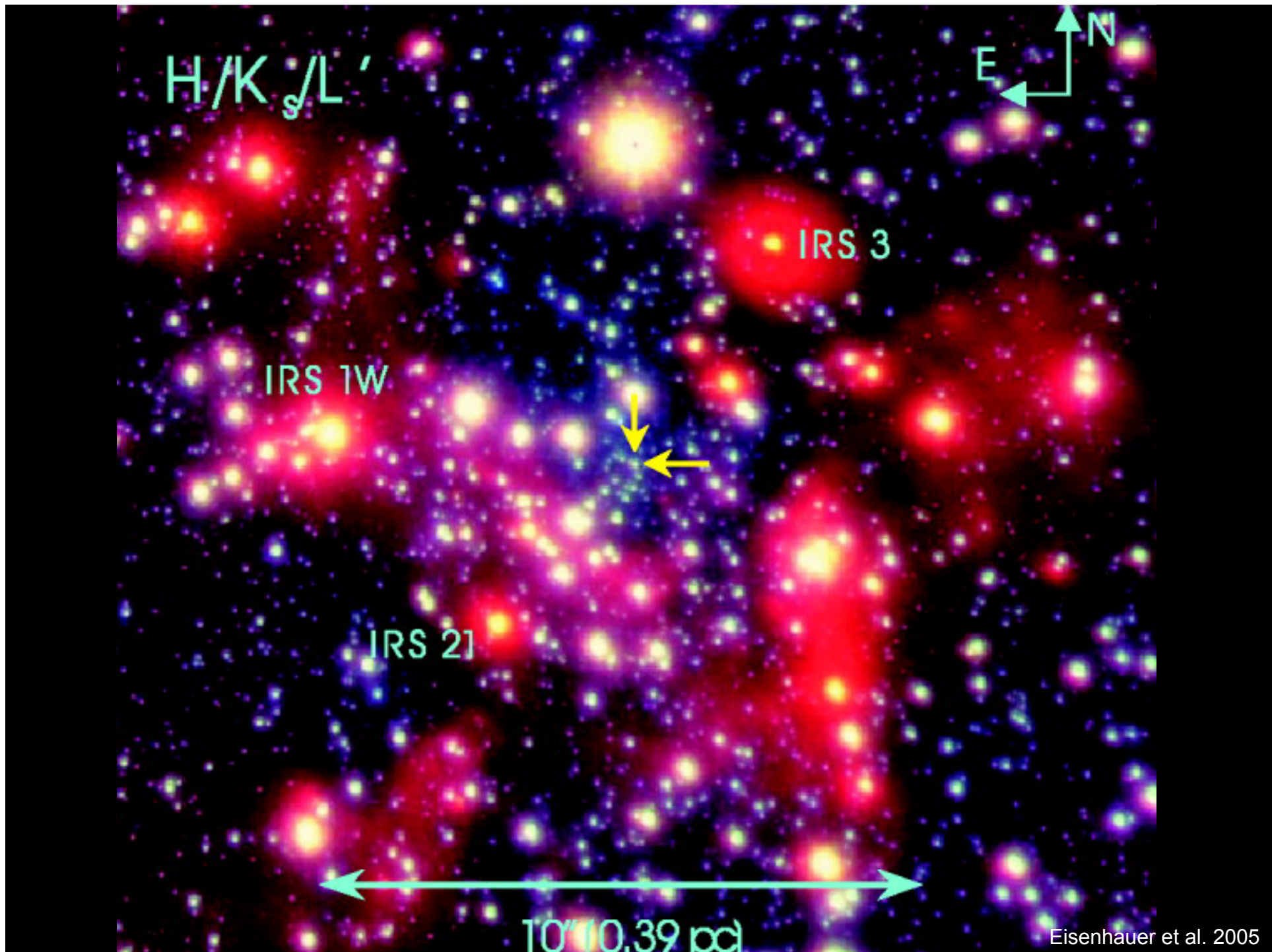
**Yu & Tremaine, 2003, ApJ: rates**

**“It’s high time someone found it.” - Jack Hills**  
SF Chronicle, 2/11/2005

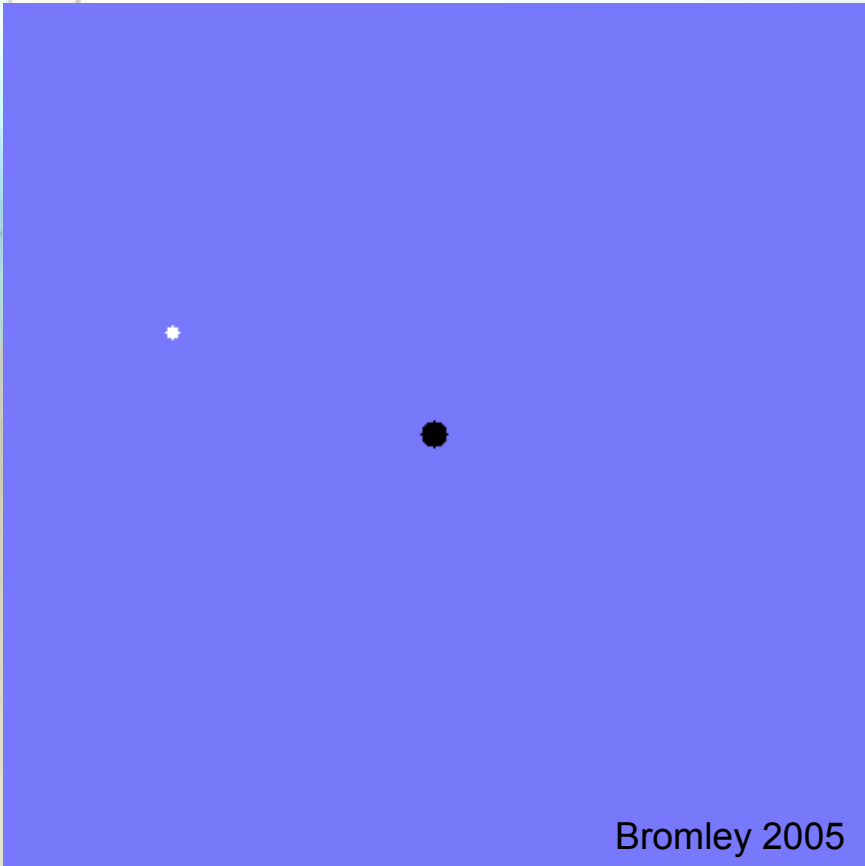


# The Milky Way





# Three-body exchange



Near the MBH:

$$|E| \approx GM/r; \quad \mathbf{v} = (GM/r)^{1/2} \approx \mathbf{10^4} \text{ km/s}$$

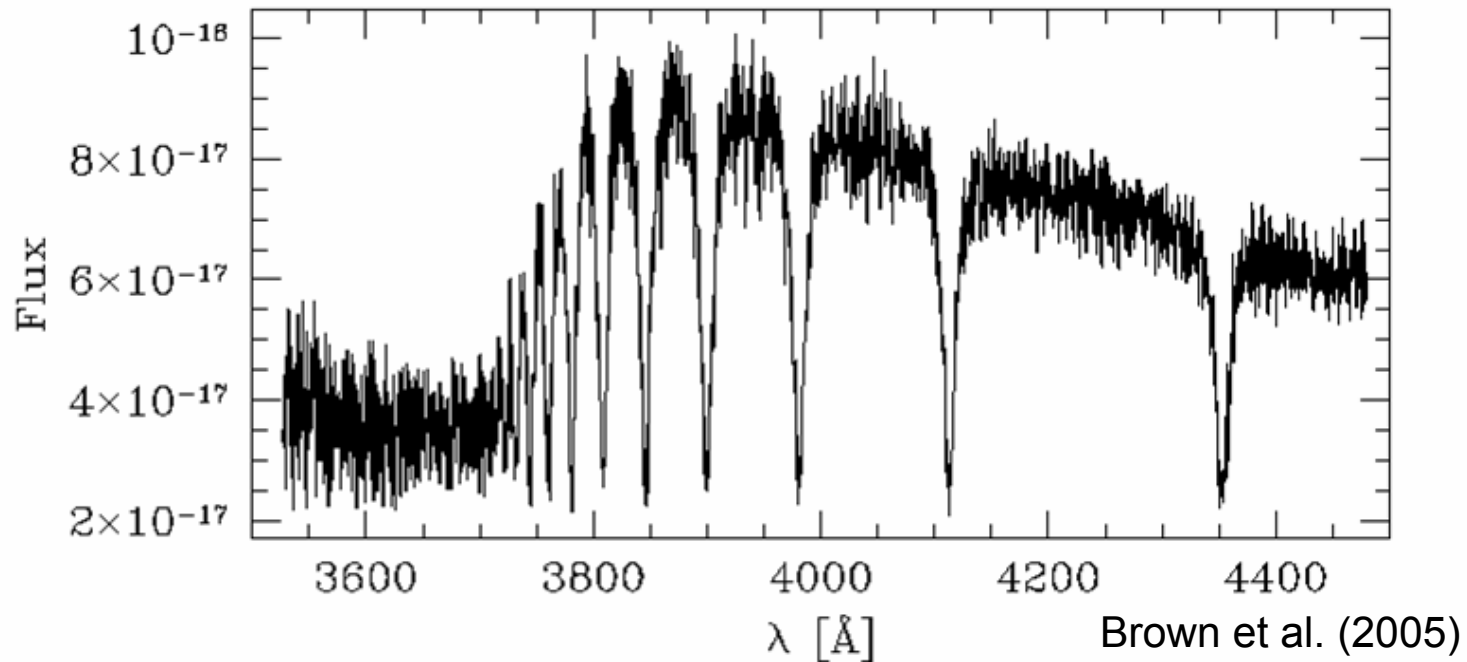
If perturbed by  $\delta\mathbf{v} \approx \mathbf{10^2} \text{ km/s} \ll \mathbf{v}$ ,

$$\delta E = \frac{1}{2} (v+\delta v)^2 - \frac{1}{2} v^2 \approx v \delta v.$$

Thus the velocity at infinity is:

$$v_\infty = (2 v \delta v)^{1/2} \approx \mathbf{10^3} \text{ km/s}$$

# The First Hypervelocity Star

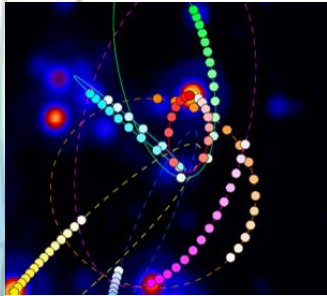


- **B9 main sequence star, thus  $d \approx 110$  kpc.**
- **Solar metallicity.**
- **Travel time  $\sim 160$  Myr.**

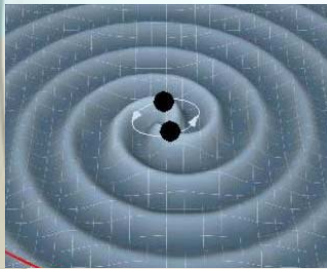


# Hypervelocity Stars link to Black Hole

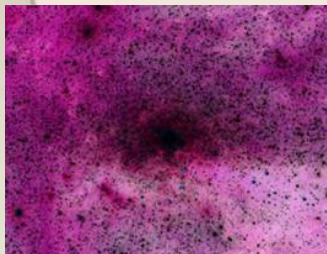
## Ejection Mechanism ↔ Observed Properties



Single MBH + binary star  
(Hills 1988)

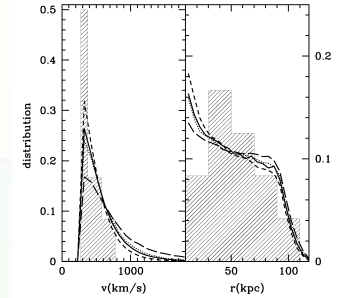


Binary MBH + single star  
(Yu & Tremaine 2003)



Stellar BH + MBH + star  
(O'Leary & Loeb 2008)

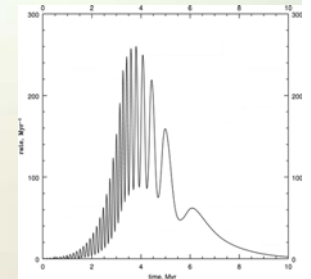
▪ Velocity distribution



▪ Spatial distribution

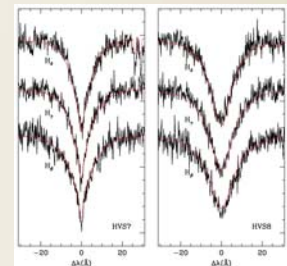
(Sesana et al 2007)

▪ Temporal distribution



(Levin 2006)

▪ Stellar Rotation distribution

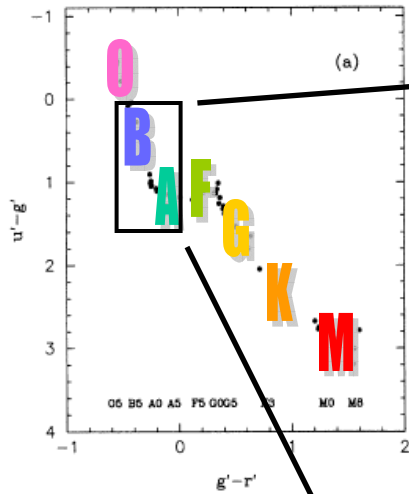


Hansen (2007)

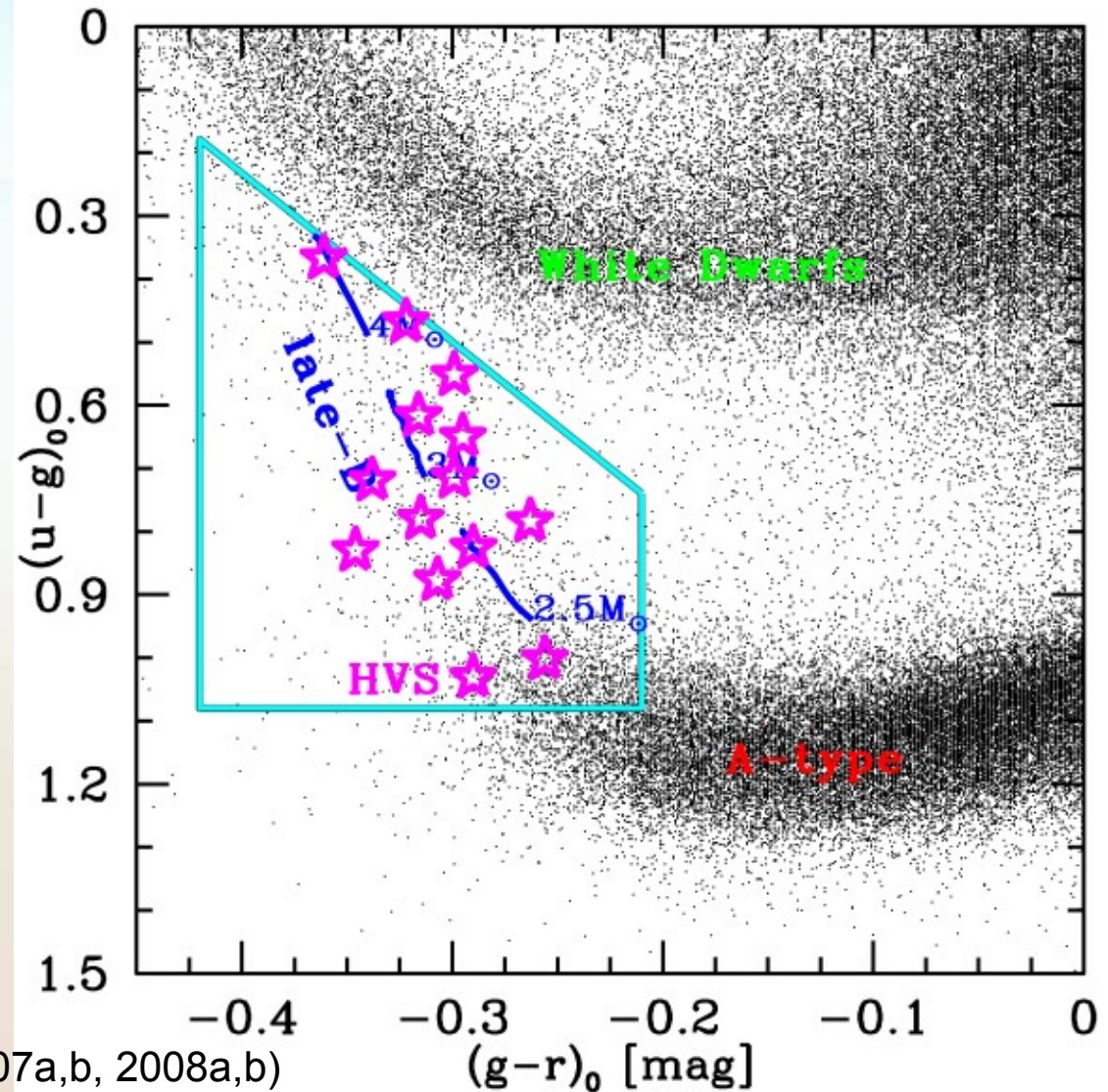
Lockmann & Baumgardt (2008)

Lopez-Morales & Bonanos (2008)

# Our Search for more Hypervelocity Stars

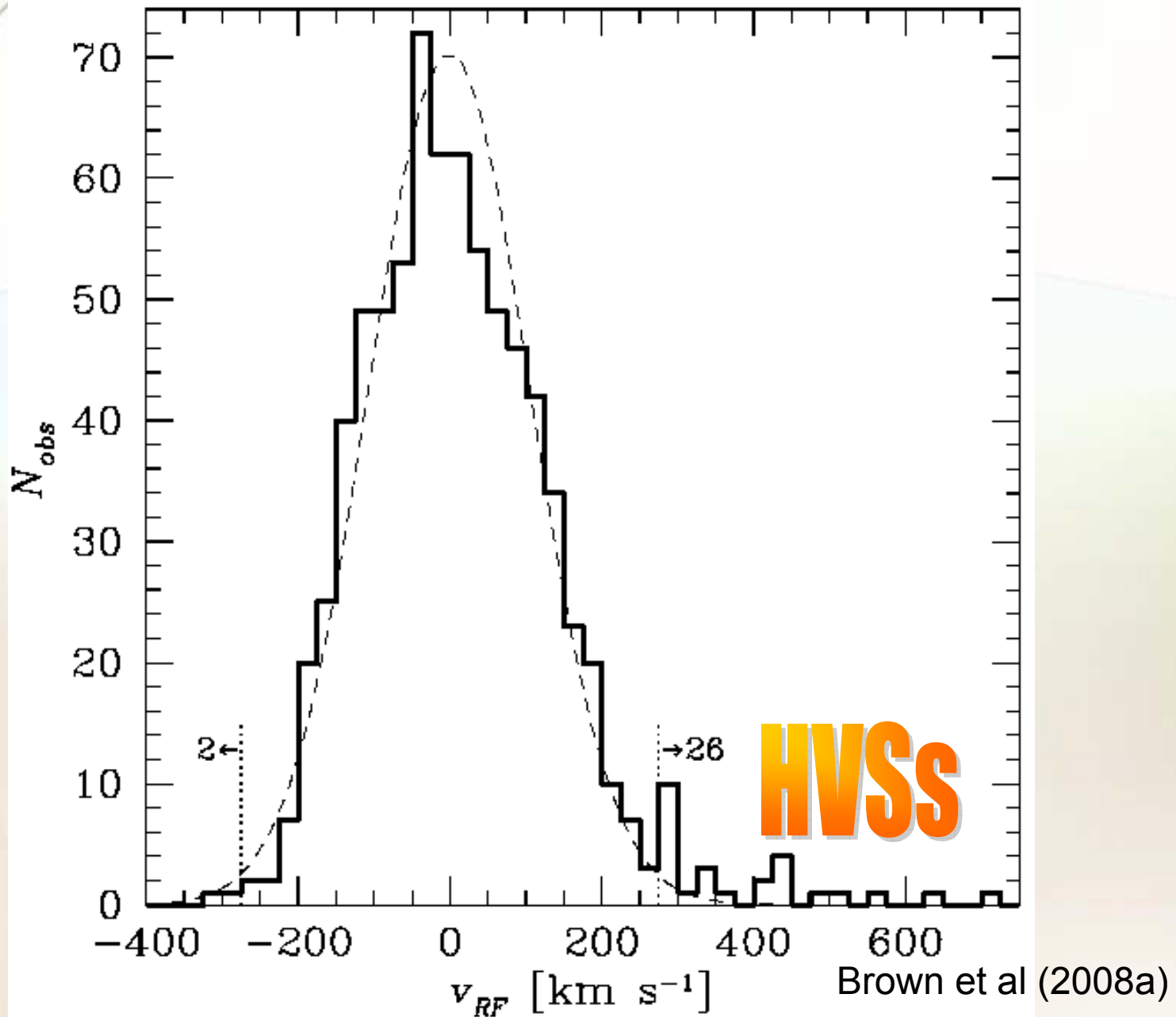


Fukugita et al (1996)

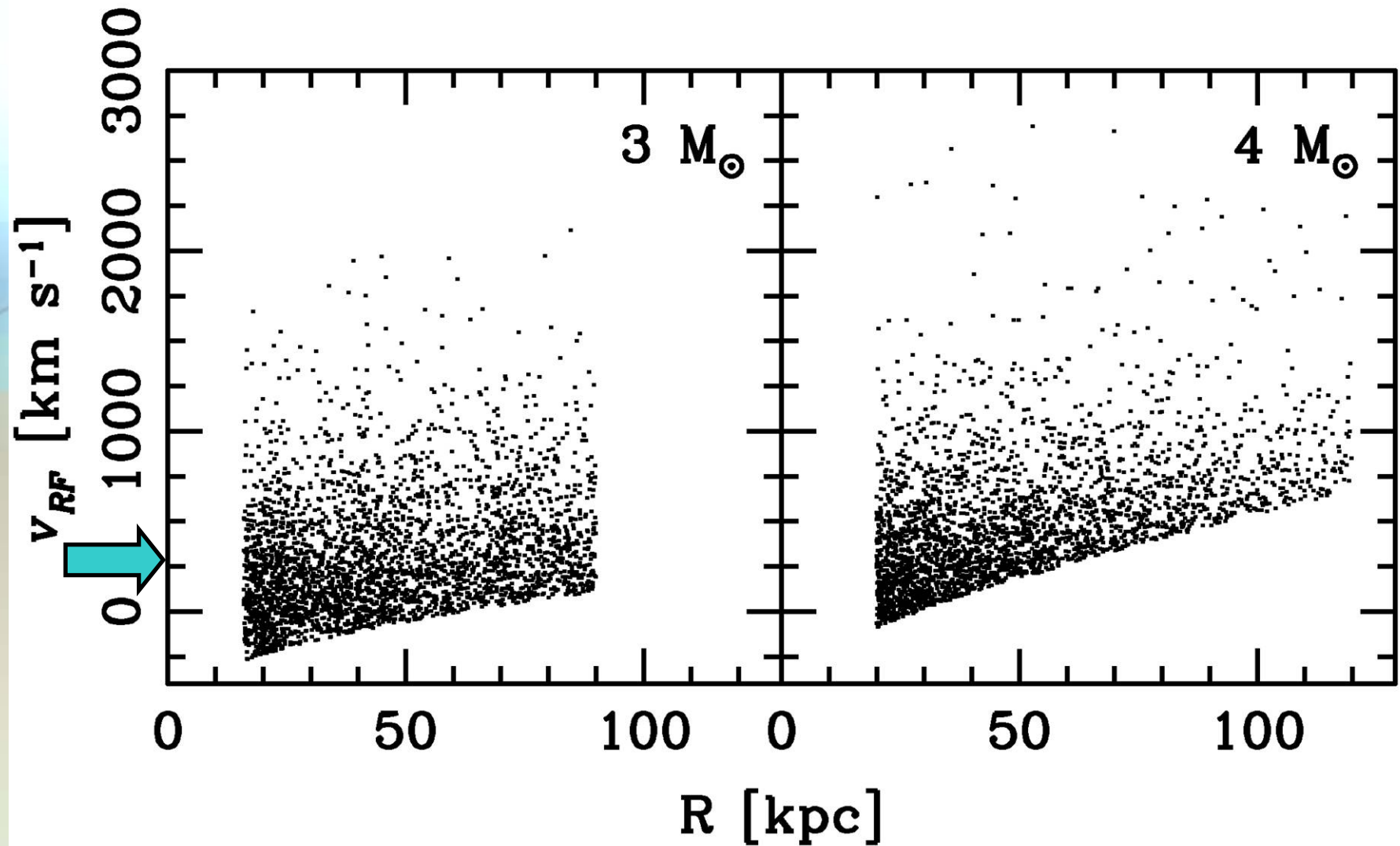


Brown et al. (2006a,b, 2007a,b, 2008a,b)

# Velocity Distribution

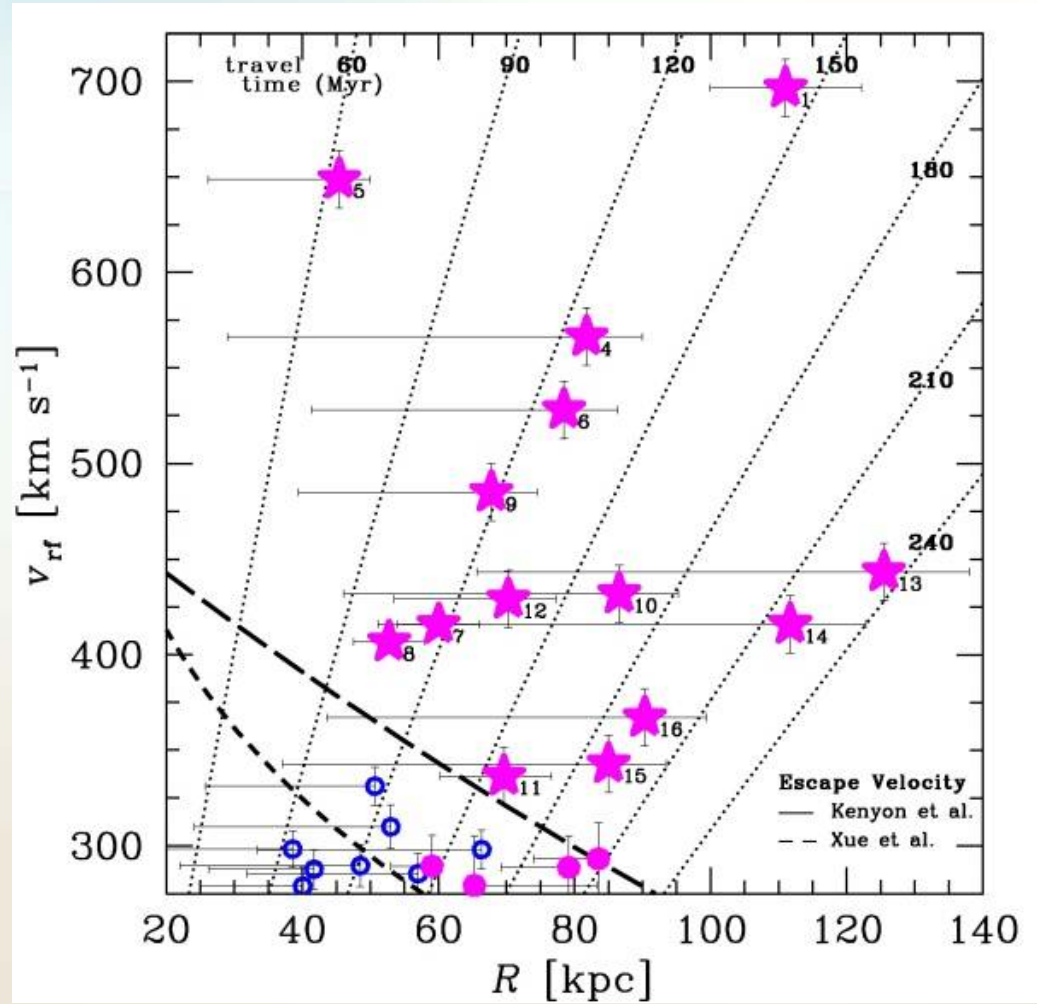
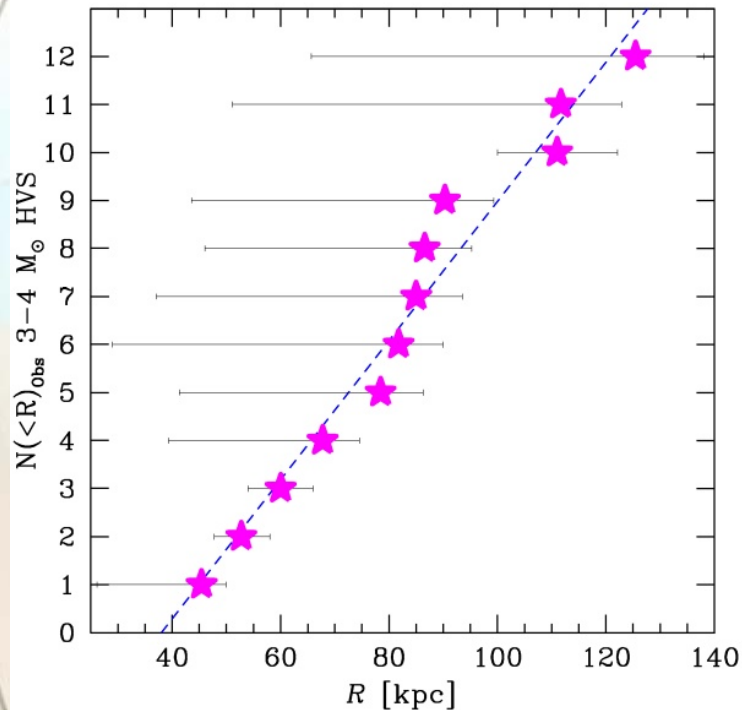


# HVS Model Predictions



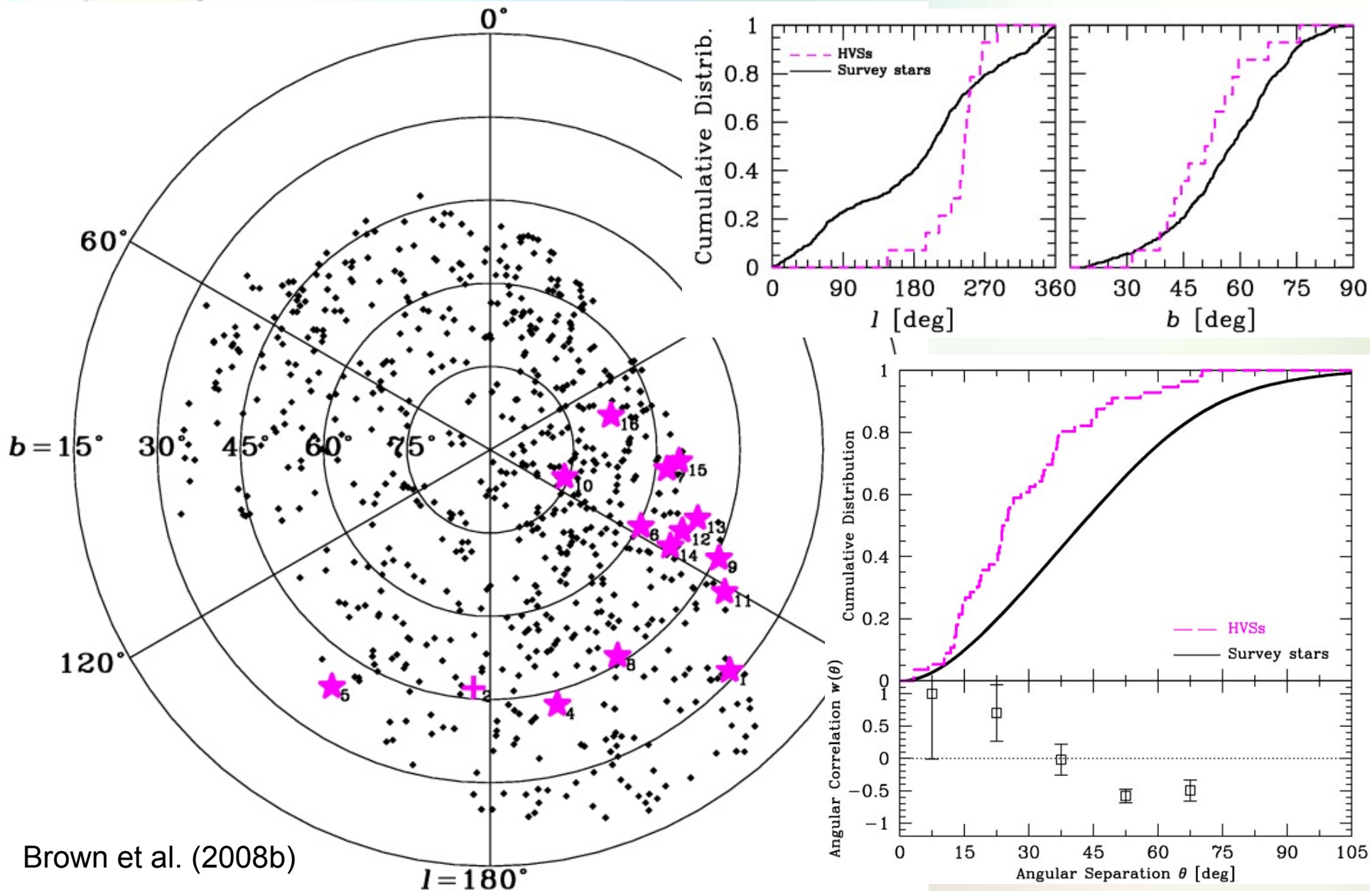
Bromley et al (2006); Brown et al. (2007a); Kenyon et al (2008)

# HVS Ejection History



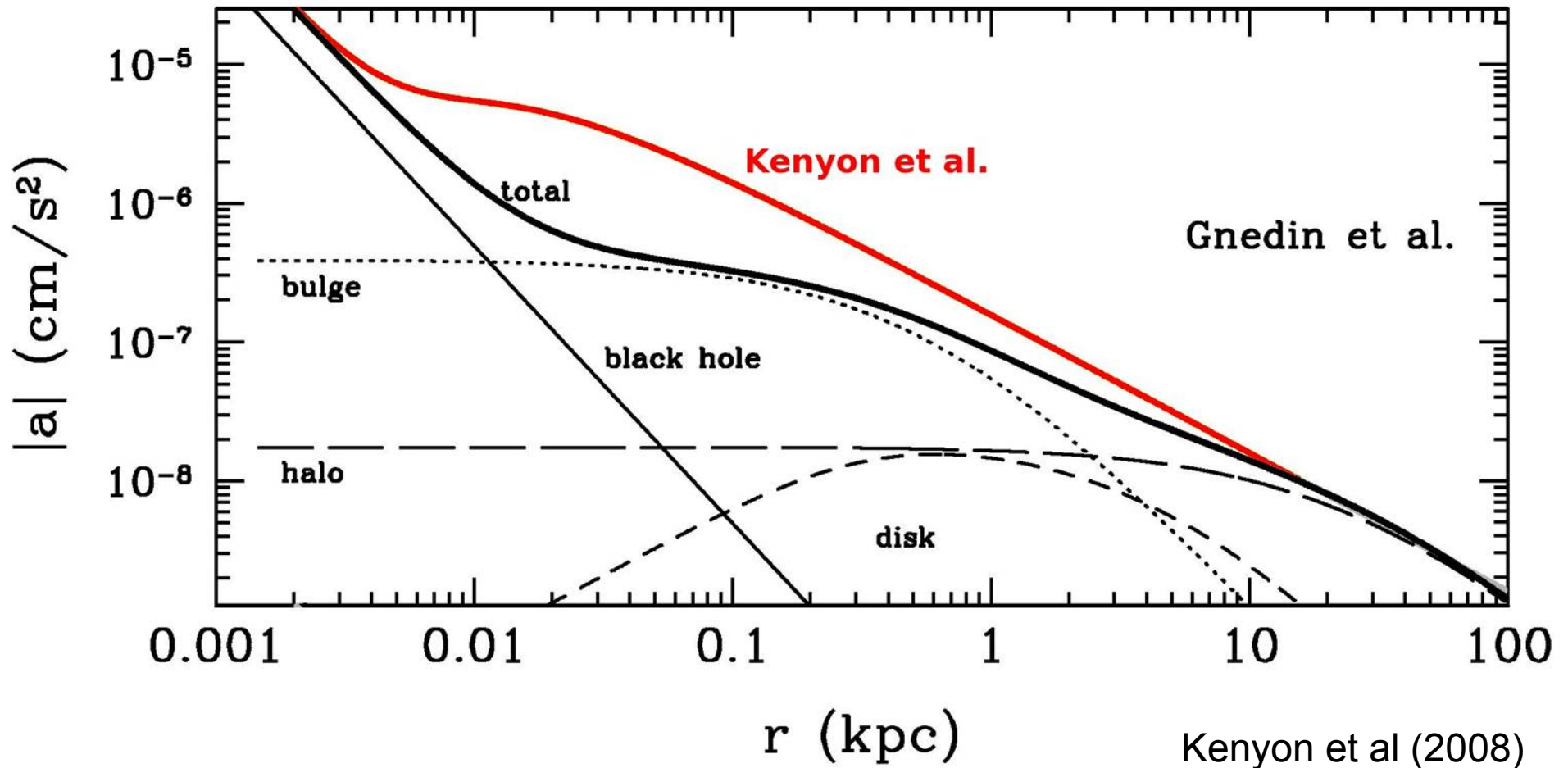
Brown et al. (2008a)

# HVS Anisotropic Sky Distribution



Brown et al. (2008b)

# Galactic (Dark Matter) Potential



# Future Work



- **Discovery survey: MMT, Magellan.**
- **Spectroscopic identifications: VLT (Heber), WHT (Keenan).**
- **Space velocities: HST (Gnedin).**
- **Variability: MDM (Stanek).**
- **Numerical simulations: (Bromley).**
- **Other unusual objects: low mass white dwarfs, extremely metal poor galaxies.**



# Conclusions

- **MBH = hypervelocity stars.**
- **We've found 14-18 HVSs.**
- **Distribution of HVSs linked to:**
  - **In-fall history**
  - **Mass function of stars**
  - **Black hole (binary?) ejection**
  - **Dark matter potential**



NY Times