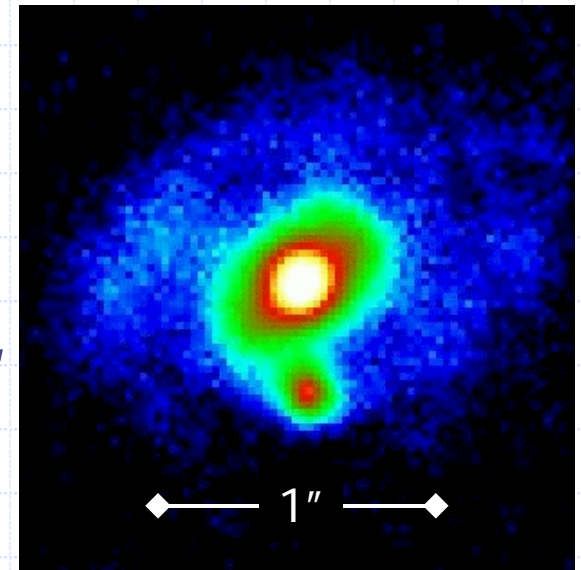


Galaxy Evolution at the Keck Diffraction Limit

James Larkin, Matthew Barczys, Charlie
Reyerson (UCLA)

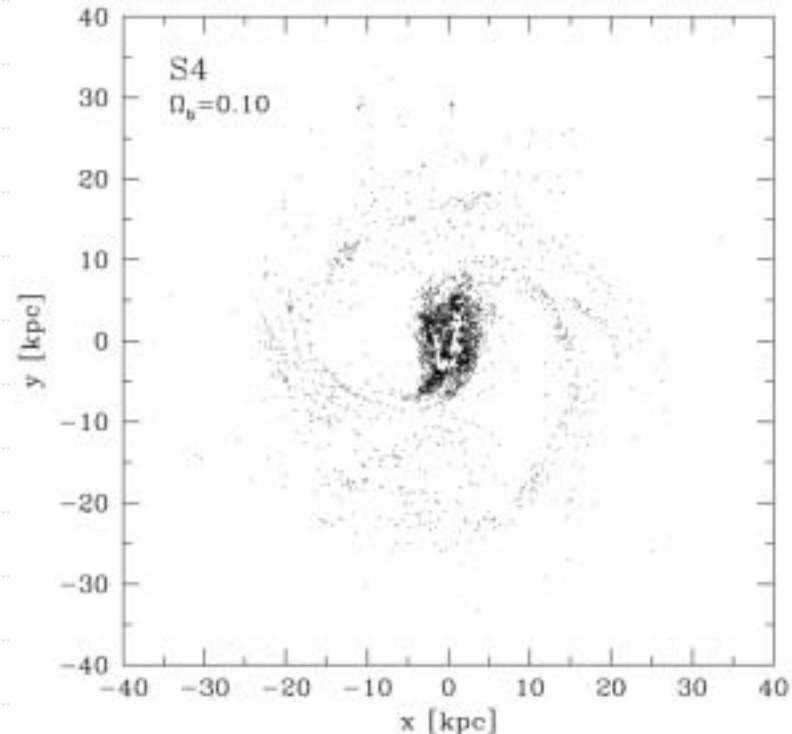
Keck AO: Peter Wizinowich, David Le Mignant,
Scott Acton

NIRC2: Keith Matthews (NIRC2 – PI),
Ian McLean (UCLA), Tom Soifer (Caltech),
Dave Thompson (Caltech), Eichii Egami
(Caltech)



Galaxy Formation Models

- ◆ Until very recently complex models have been miserable at producing reasonable galaxies and galaxy distributions
- ◆ New Models are doing much better by adding new physics or by varying cold dark matter.
 - Dark Energy – Cosmological Constant (Λ CDM)
 - Very Early Star formation to heat gas and prevent premature collapse
 - Self-interacting cold dark matter.
 - Warm dark matter (WDM)



WDM simulation (largest galaxy produced)
Sommer-Larsen & Dolgov, 2001

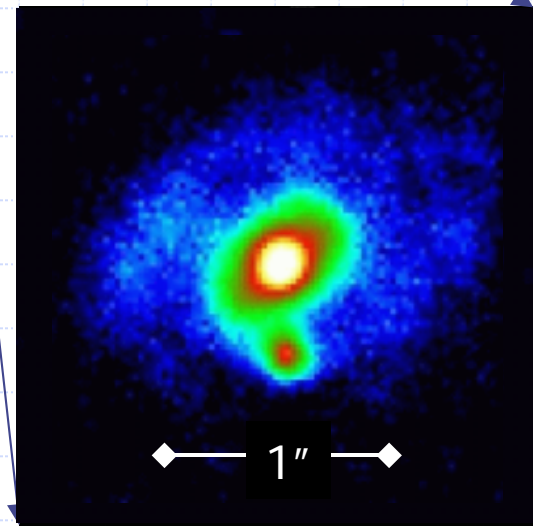
We can directly test these models by directly observing the evolution of disks, bulges, star formation rates, AGN, and mergers.

Galaxy Sizes



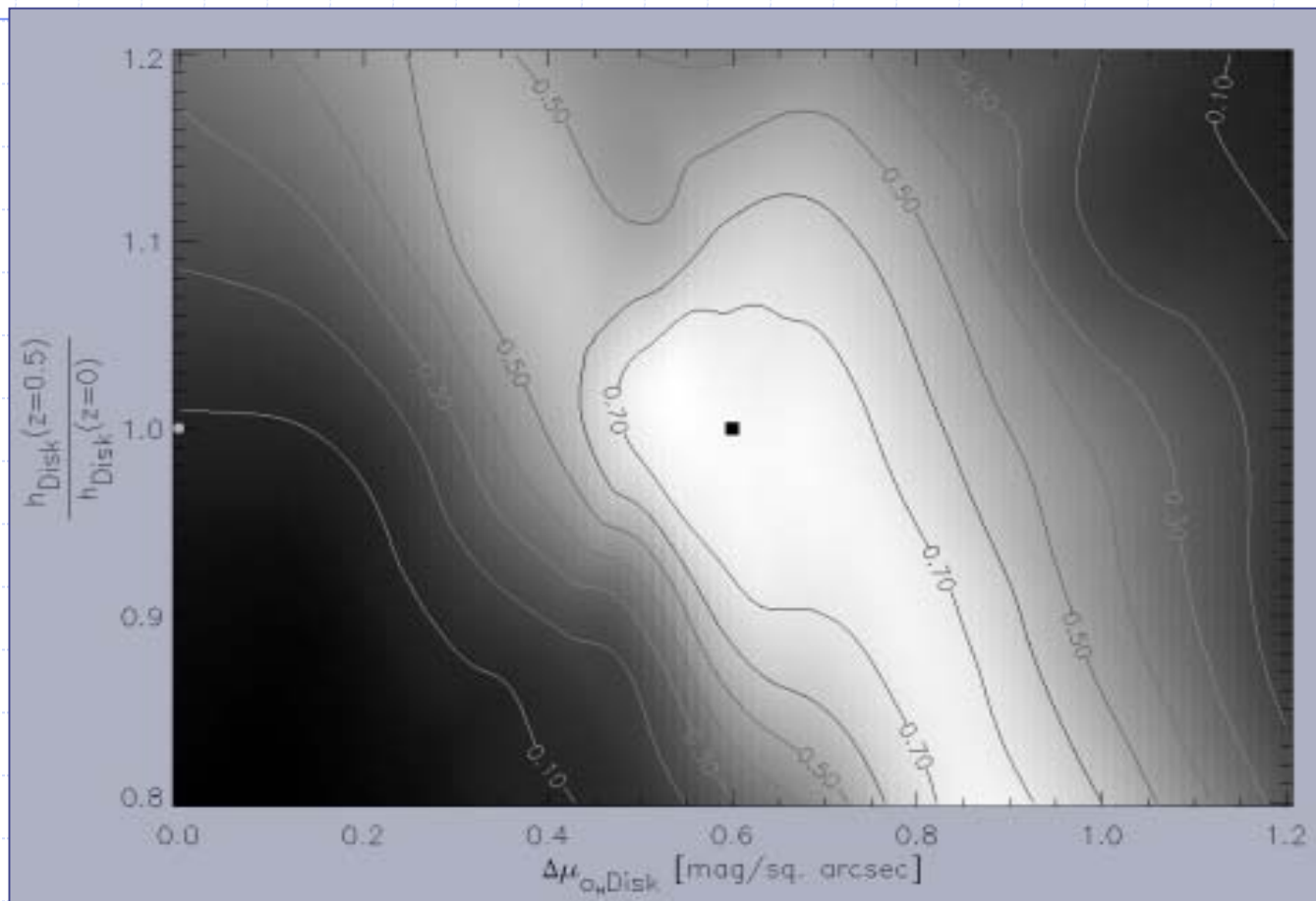
Large Nearby Galaxy
@55 million light years

@5000 million light years



Disk evolution since 5 Gyr Ago

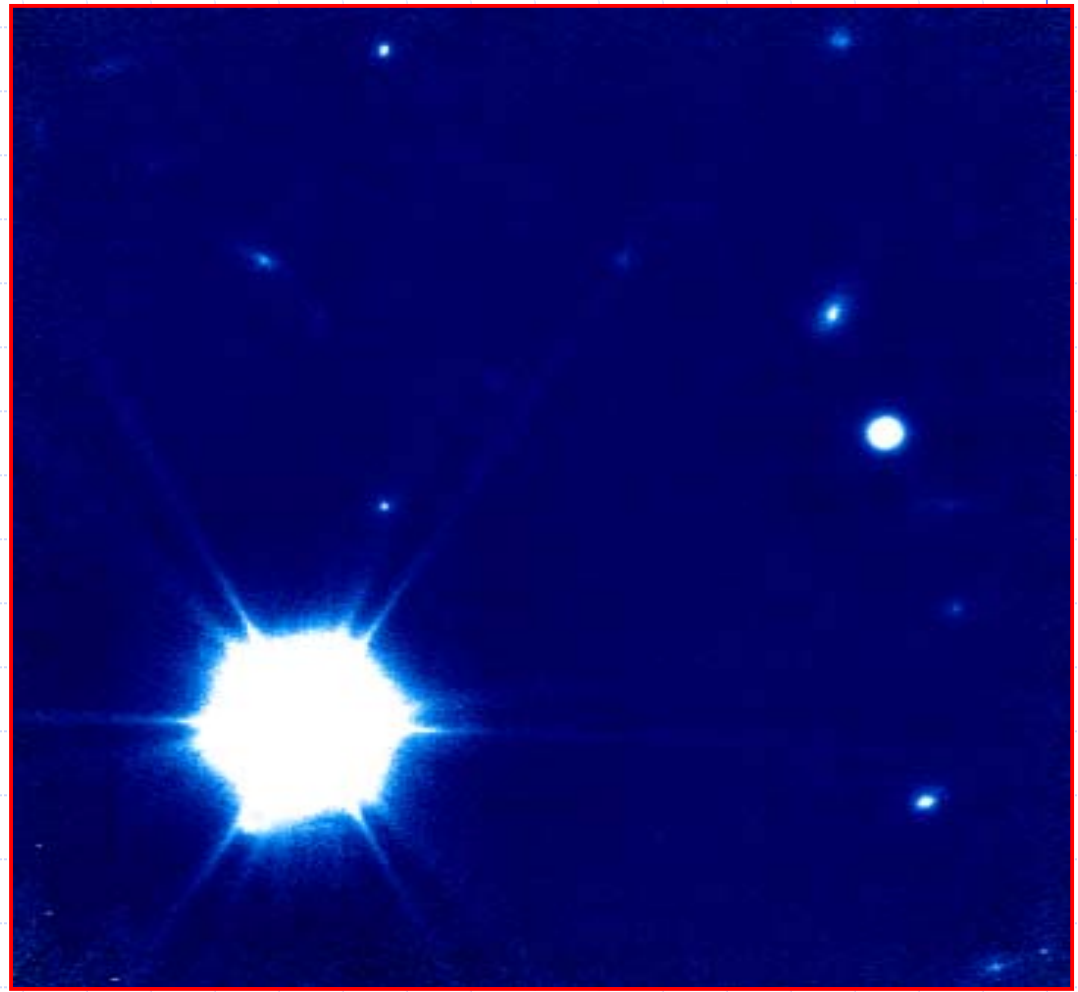
Tiffany Glassman's Thesis (Successfully defended Dec, 2002)



Disks of 10 Galaxies as a group were 70% brighter than similar galaxies today.

New NIRC2 Survey

- ◆ 17 Fields in H
(~8 square arcmin)
- ◆ Avg Exposure = 60 minutes
- ◆ >300 Galaxies
- ◆ Typical Strehl ratios @20" about 10%

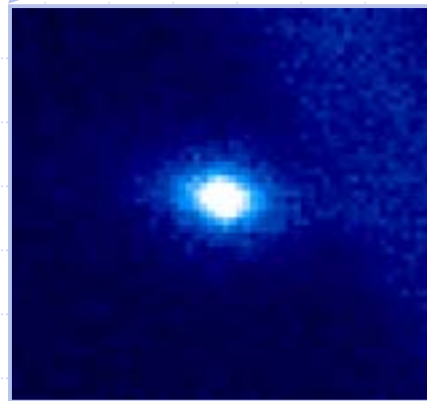
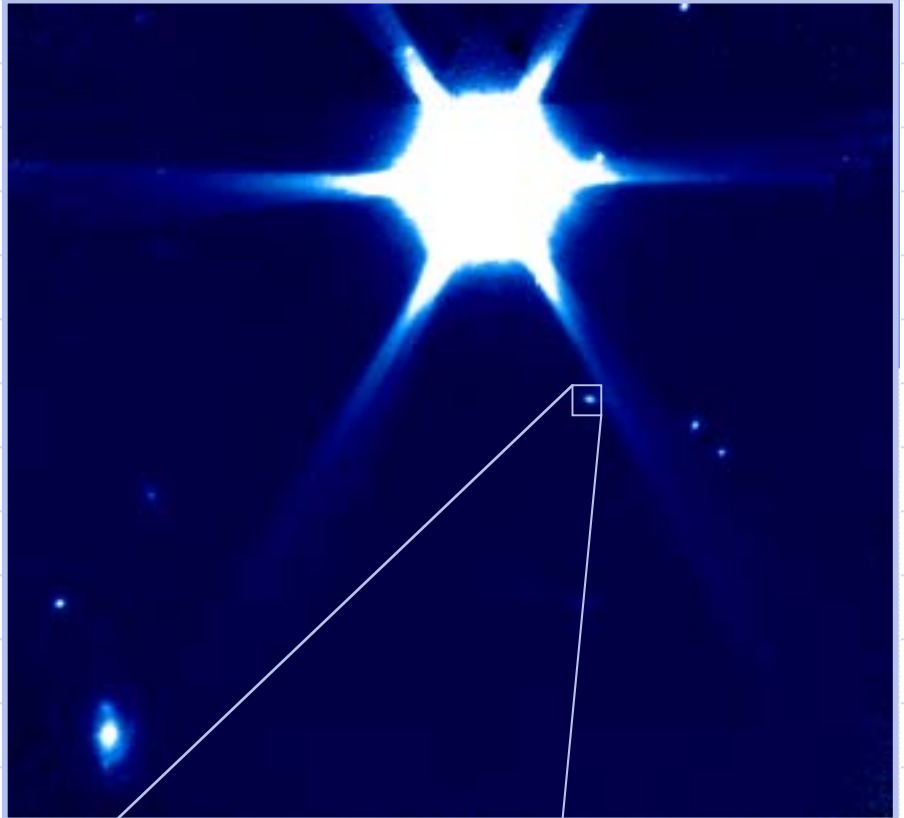


40"

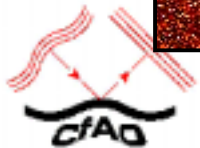
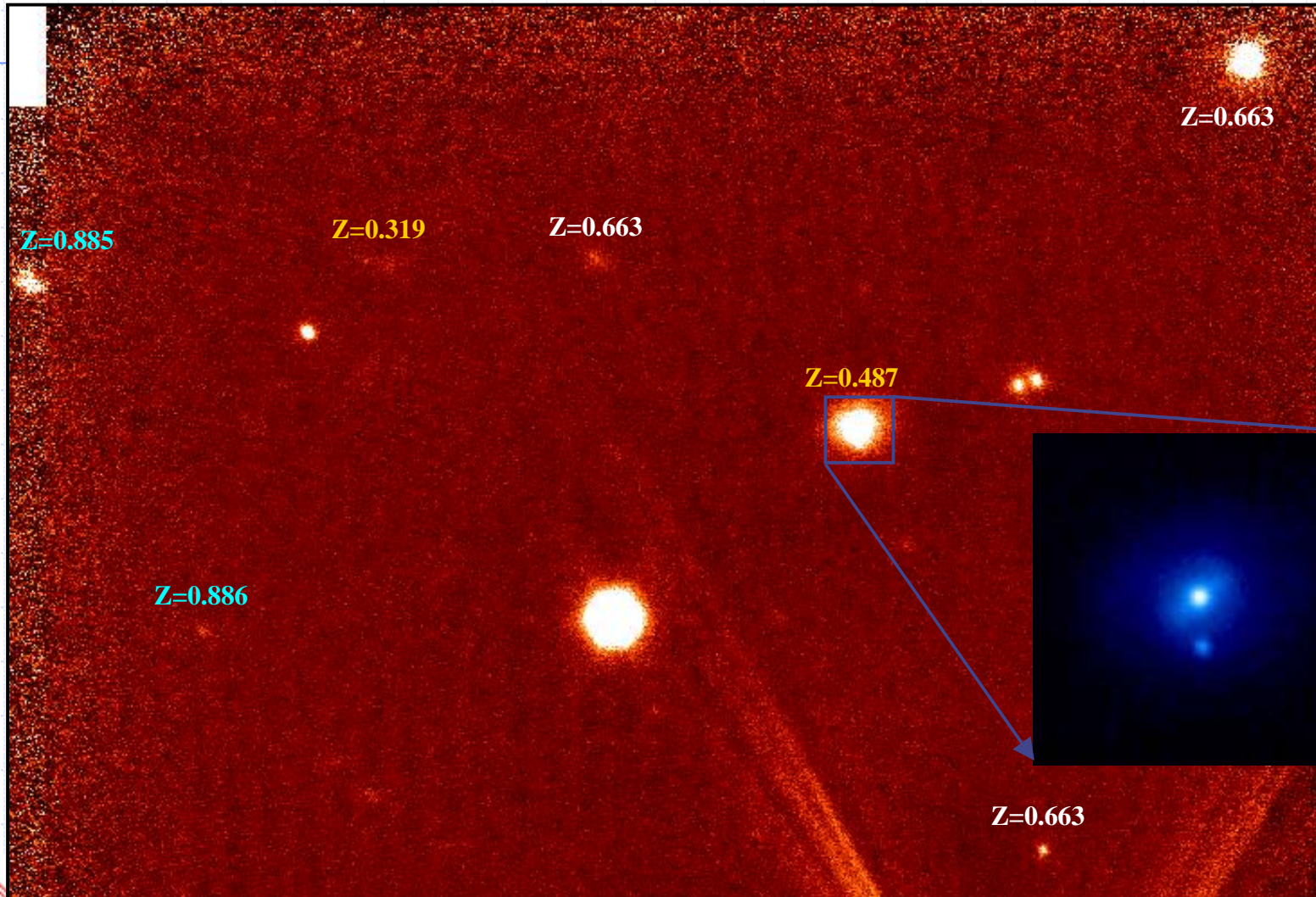


Depth

- ◆ Galaxies identified down to $H=23.5$ mag (in 1 field).
 - Average sensitivity $H \sim 22$ mag ($H(AB) \sim 23.5$).
 - Previous survey was only down to $H=18.5$ (25 times deeper).
- ◆ Very irregular sampling due to isoplanatic effects and bright diffraction spikes.
- ◆ Point source sensitivity (5σ) $\sim 25^{\text{th}}$ mag in hour.



New Redshifts (50 galaxies)



$$\bar{z}=0.36$$

H < 18 mag

◆ Each image = 4"

PPM 115192+21-31
H=16.5
z=0.18

PSF Star (15" Sep)

PPM 115610-29+11
H=17.0
z=0.413

PPM 115610-17+3
H=17.6

PPM 114182+6+27
H=17.7
z=0.487

PPM 115610+2-15
H=17.9
z=0.331

PPM 115610-16+15
H=17.8
z=?

PPM 115192-6-12
H=17.8

PPM 115610-13-6
H=17.7

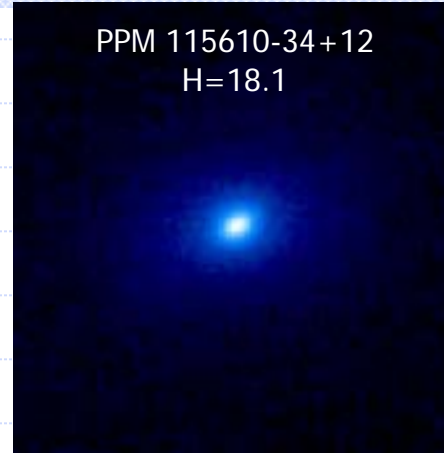
PPM 50296-7-24
H=17.6
z=0.366

$$\bar{z}=0.51$$

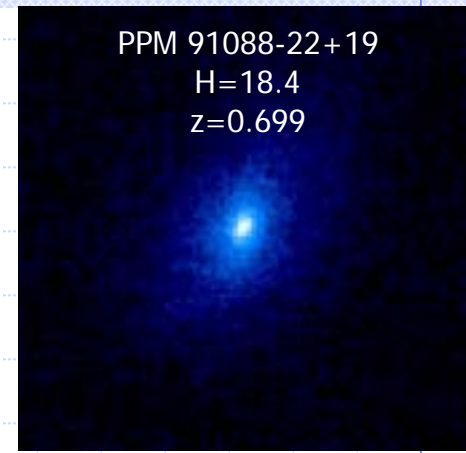
18 mag < H < 19 mag

◆ Each image = 4"

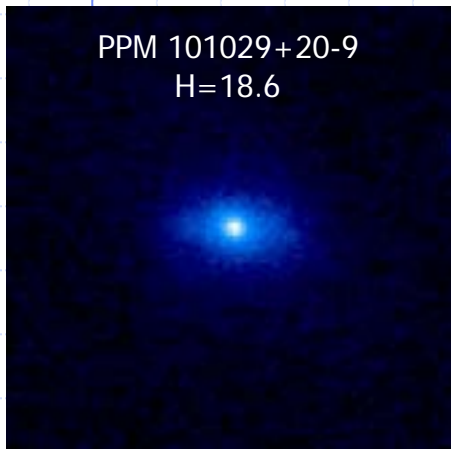
PPM 115610-34+12
H=18.1



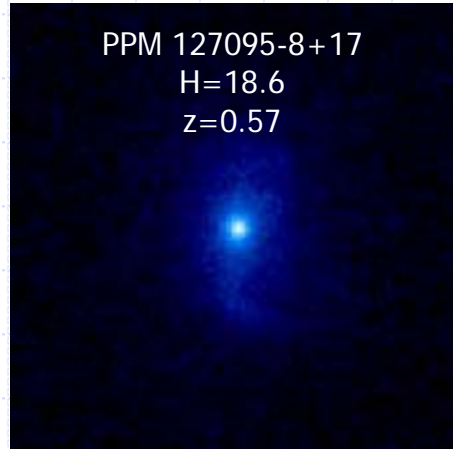
PPM 91088-22+19
H=18.4
z=0.699



PPM 101029+20-9
H=18.6



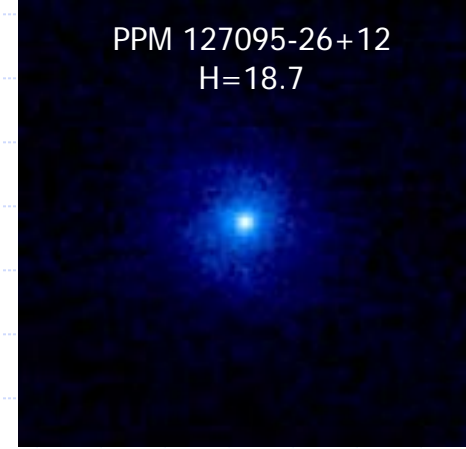
PPM 127095-8+17
H=18.6
z=0.57



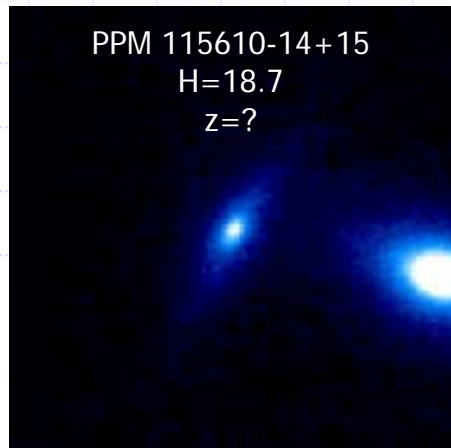
PPM 91088-26-4
H=18.7
z=0.472



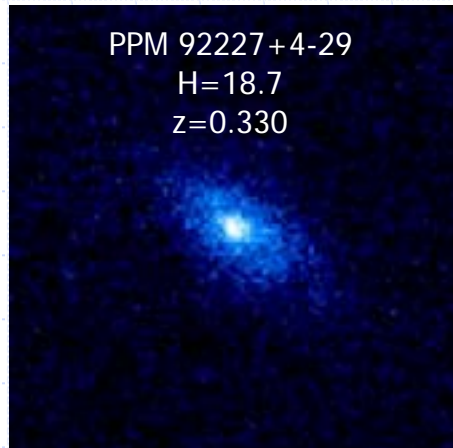
PPM 127095-26+12
H=18.7



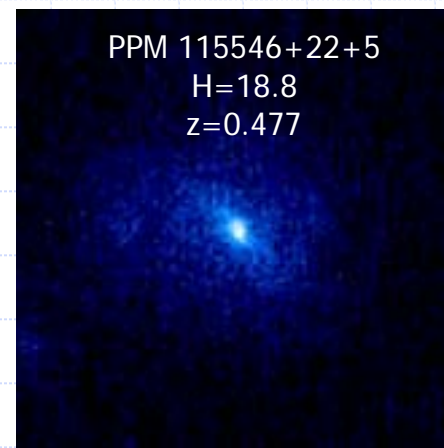
PPM 115610-14+15
H=18.7
z=?



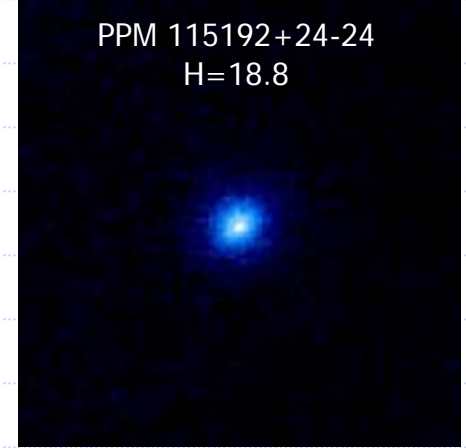
PPM 92227+4-29
H=18.7
z=0.330



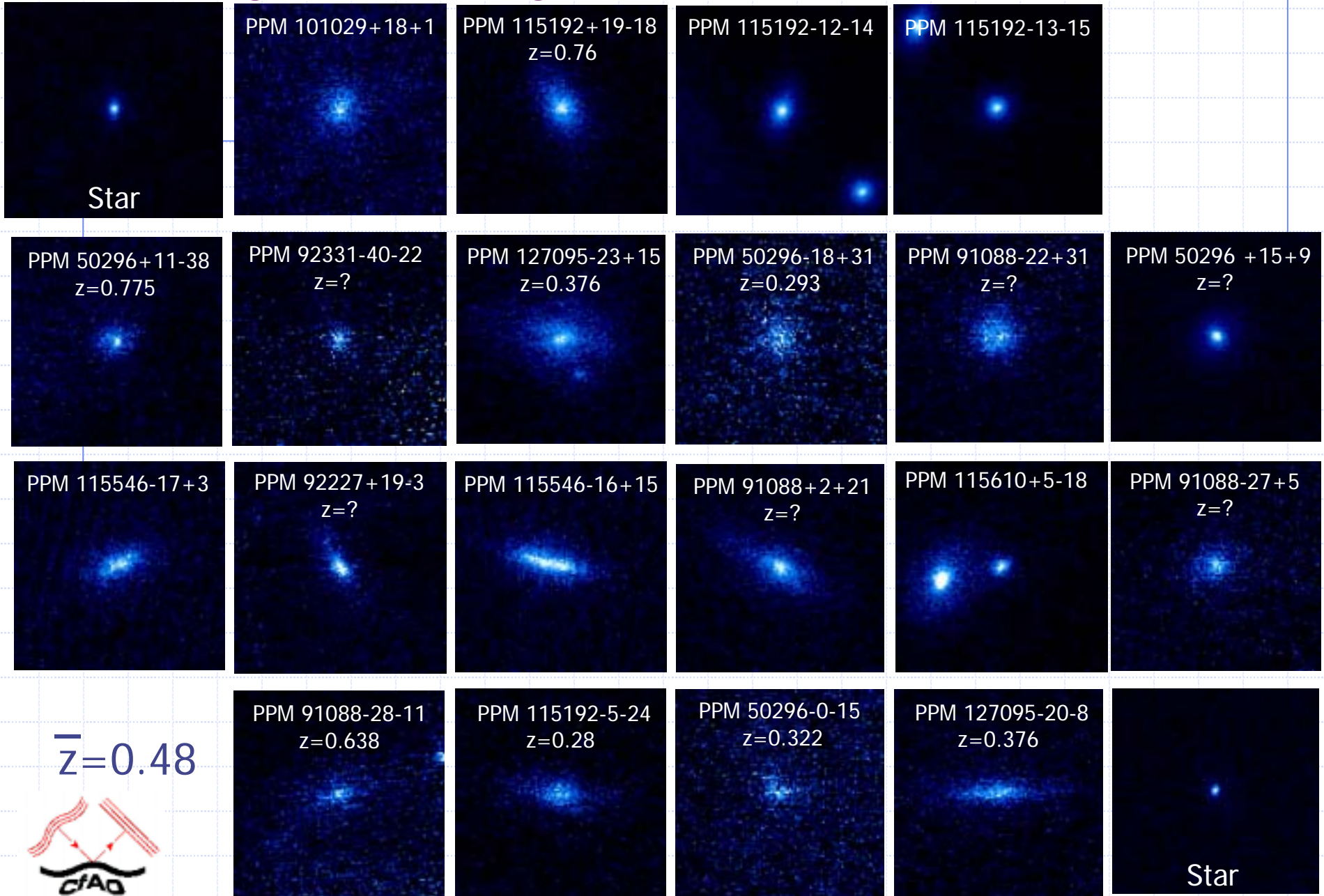
PPM 115546+22+5
H=18.8
z=0.477



PPM 115192+24-24
H=18.8



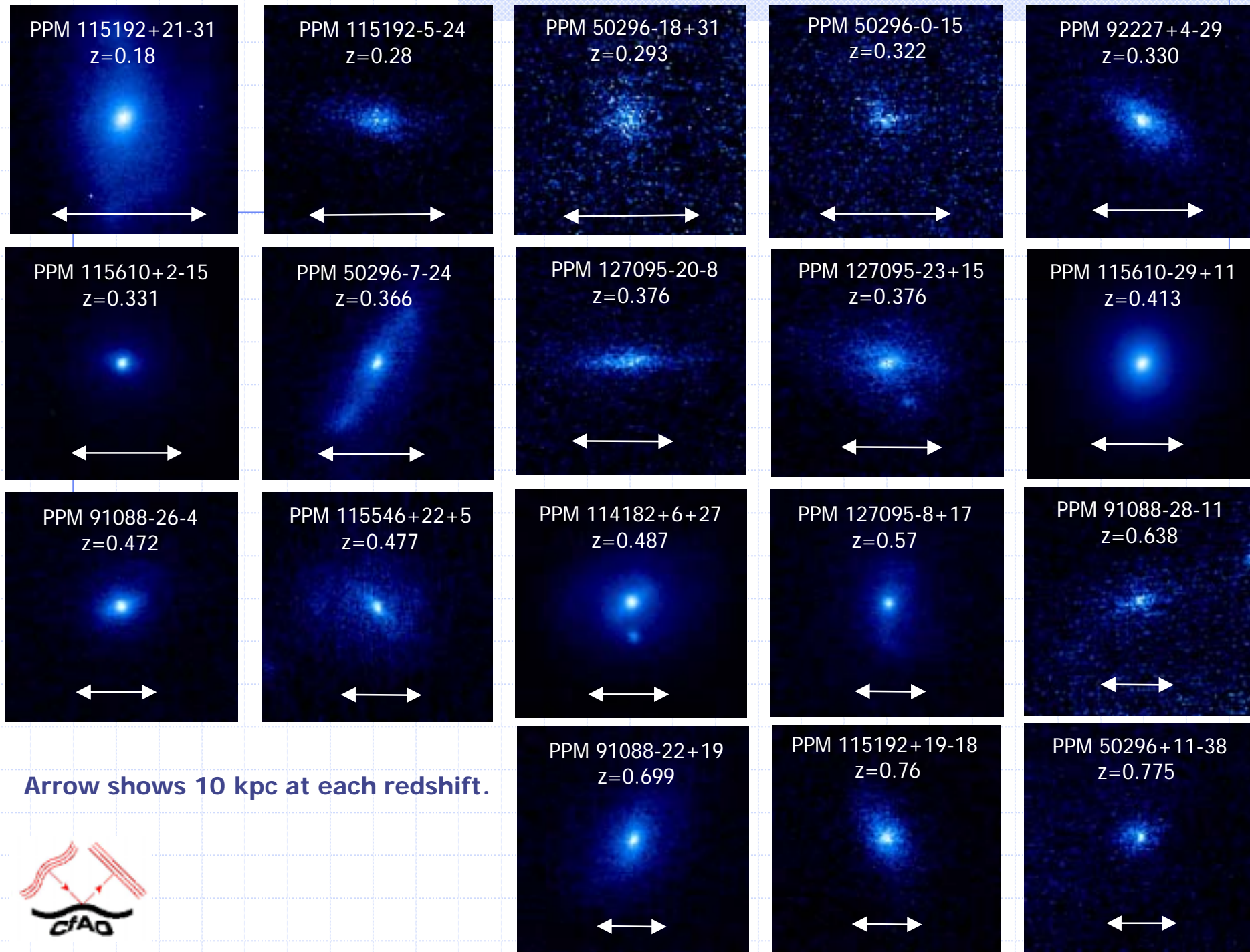
19 mag < H < 20 mag



Faint Fuzzies

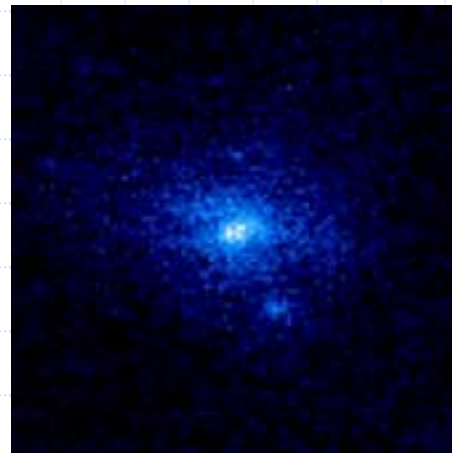
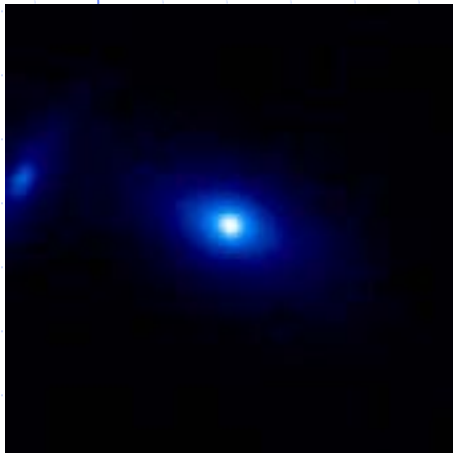
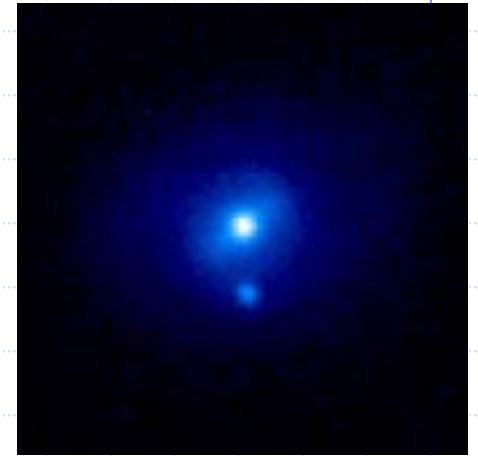
- ◆ Most objects fainter than $H=20$ don't show central core.





Close point sources

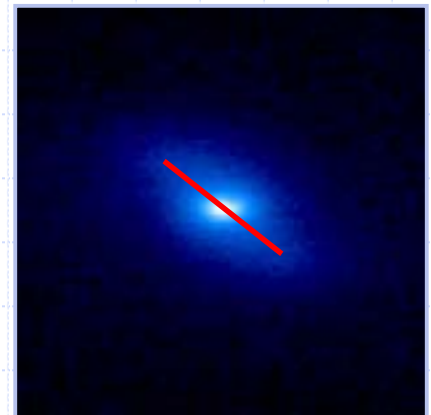
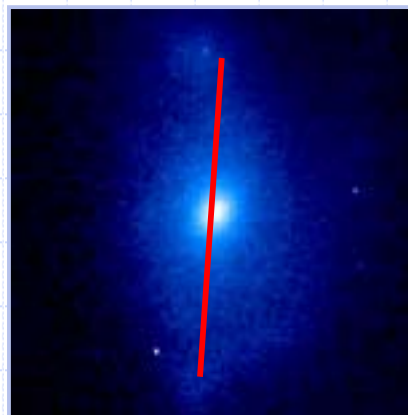
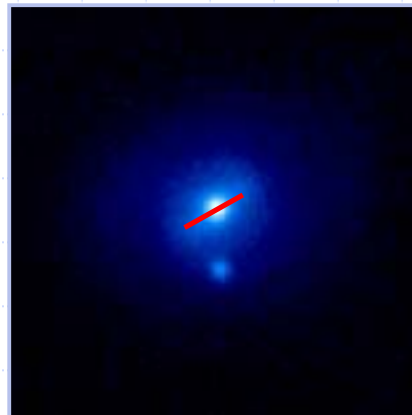
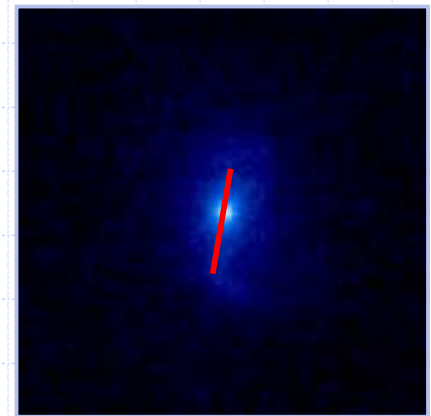
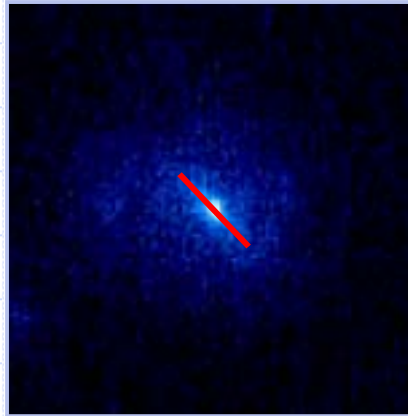
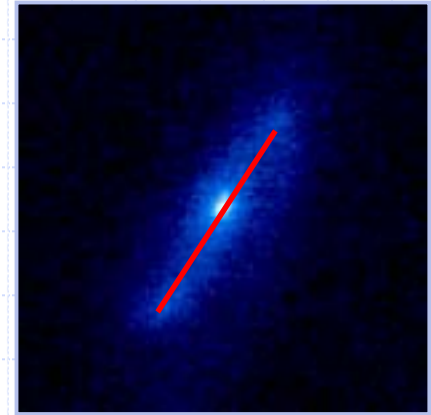
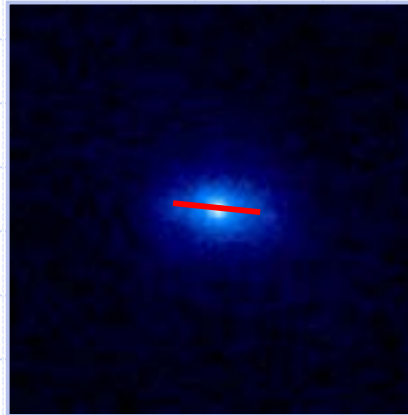
- ◆ 20% of the galaxies have very nearby companions ($<2''$)
- ◆ These will most likely merge together in the next Billion years.



Bars

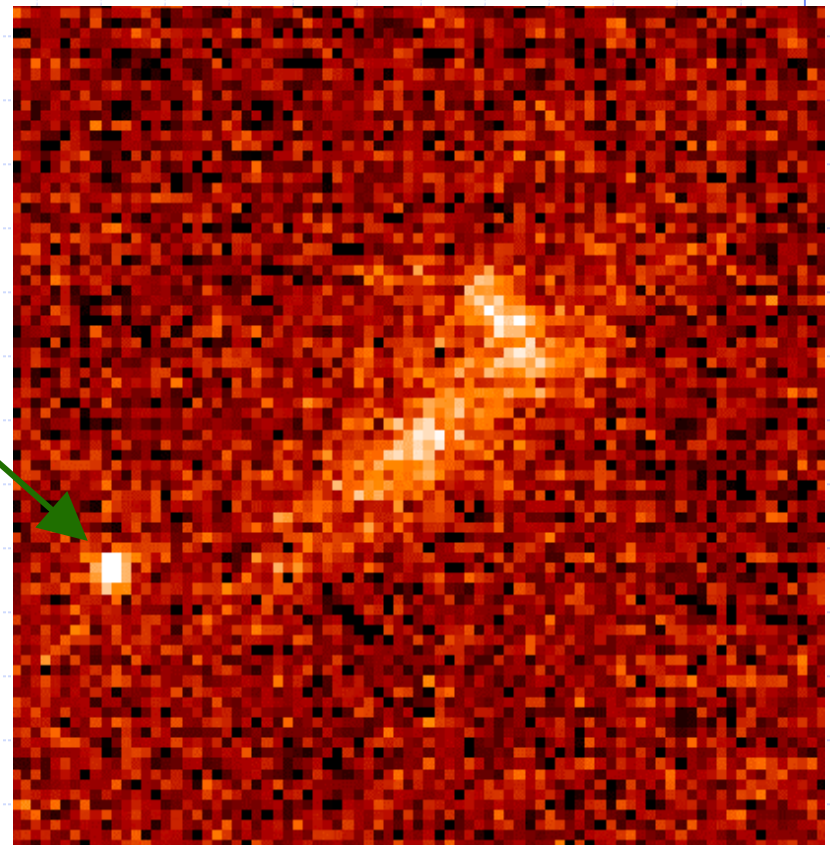
@1/2 disk age

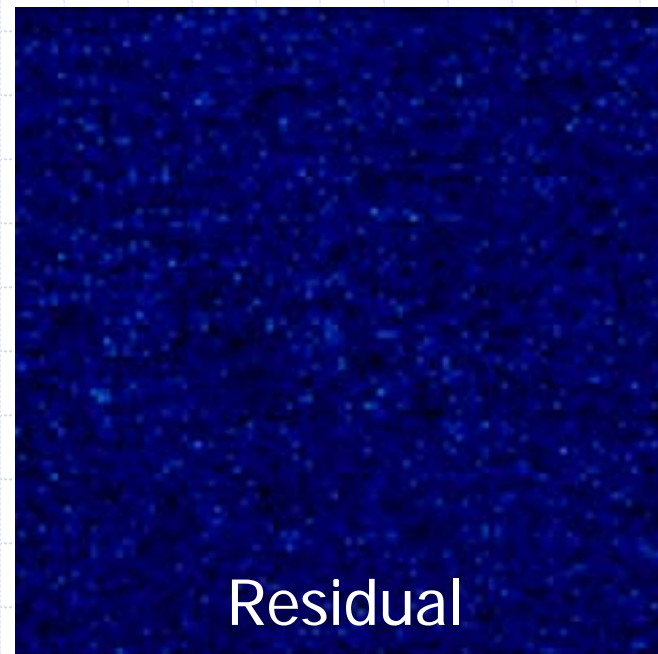
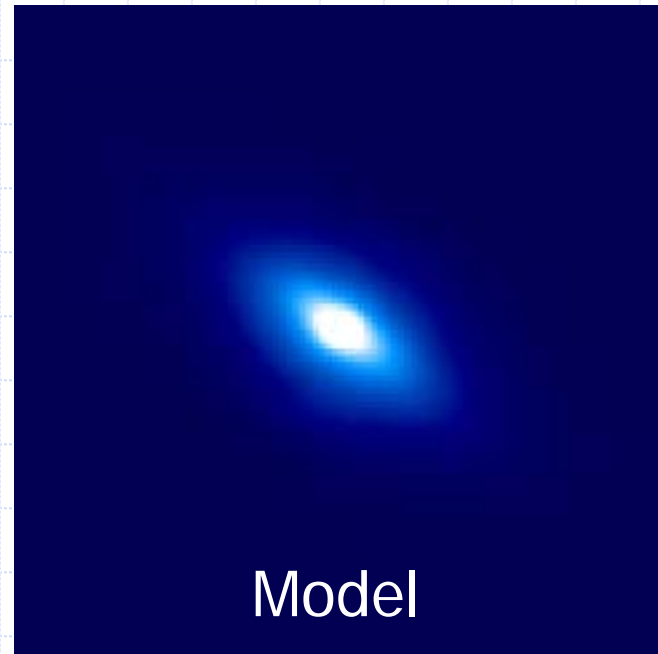
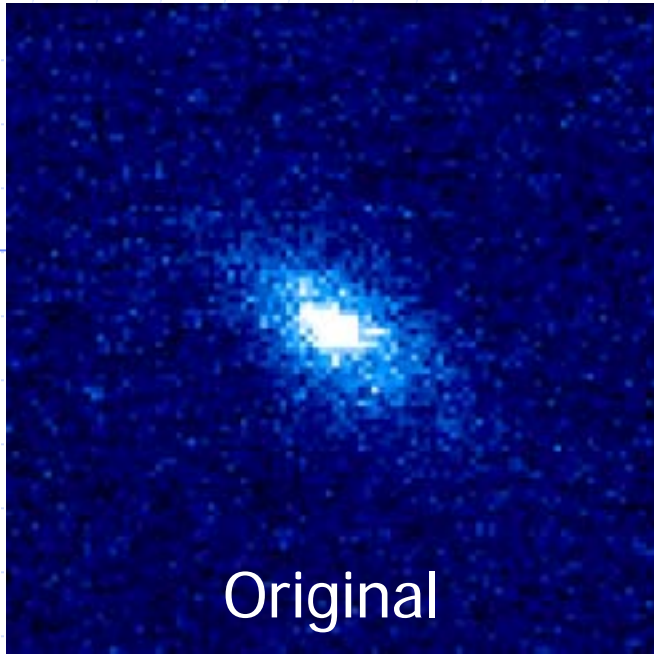
- ◆ 20% of galaxies have a stellar bar.
- ◆ 4% of galaxies in the HDF have bars at this epoch (Van den Bergh, 2002)

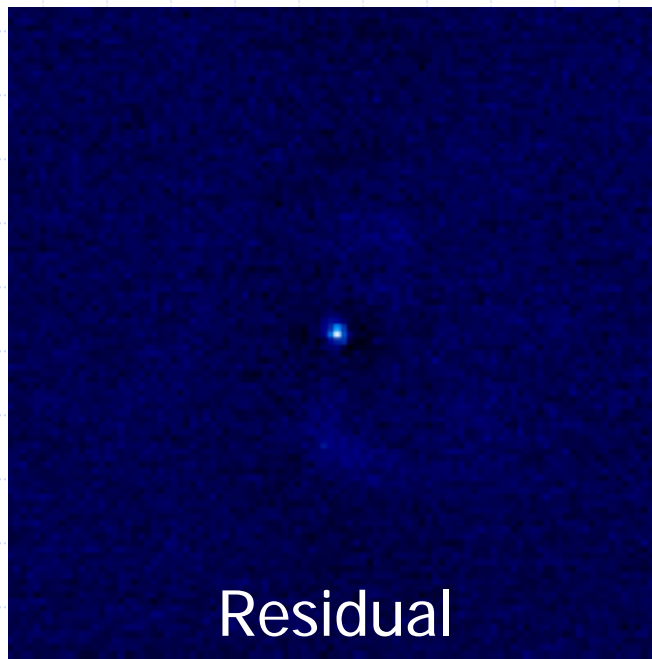
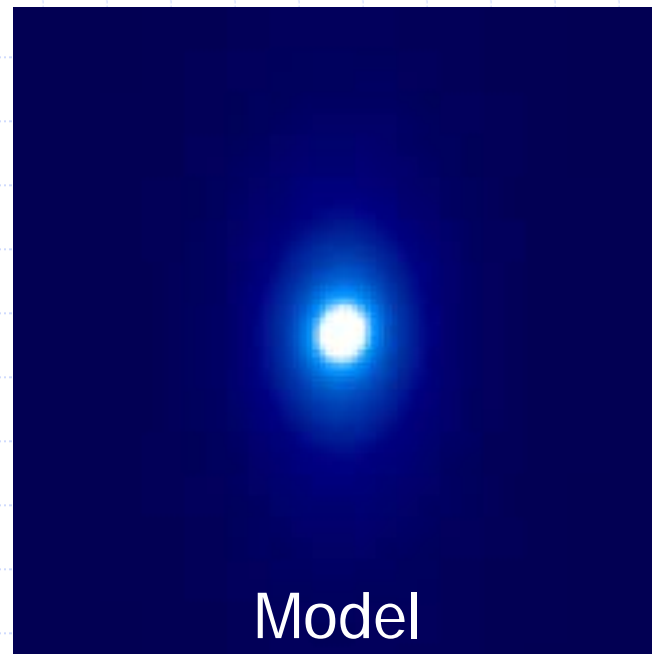
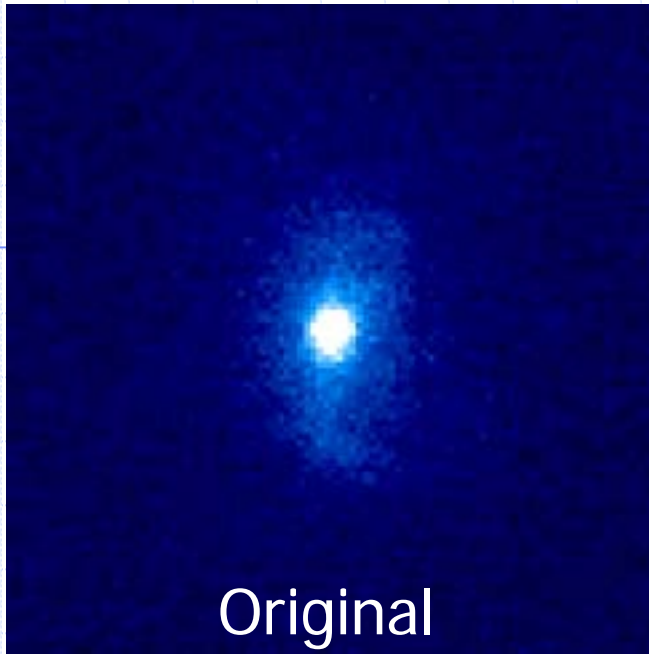


Interaction and SN?

- ◆ Interacting Galaxies
- ◆ Supernova?

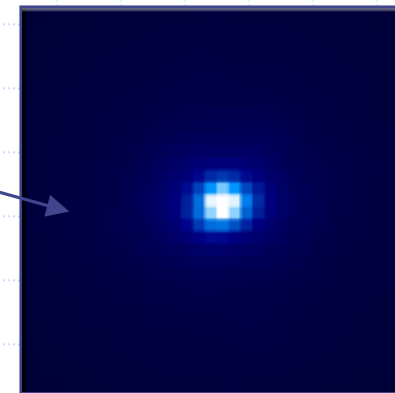
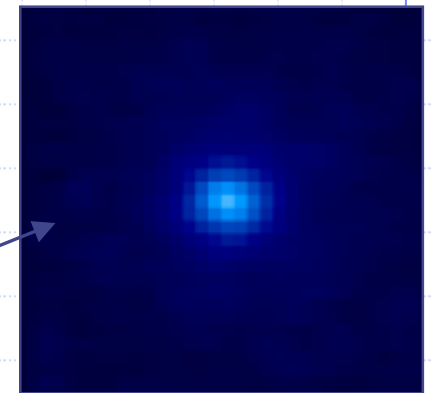
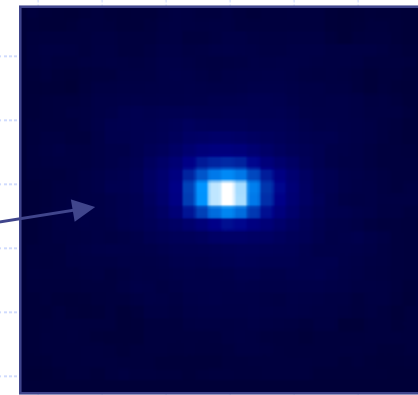
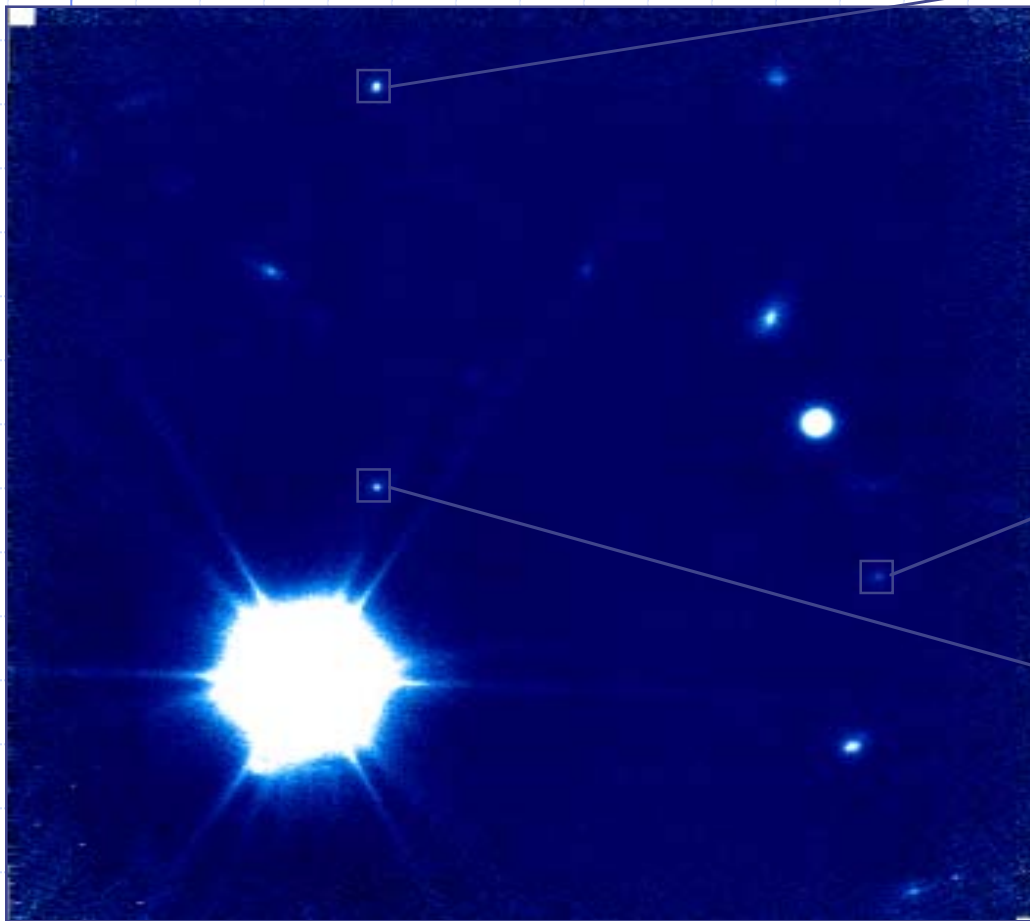






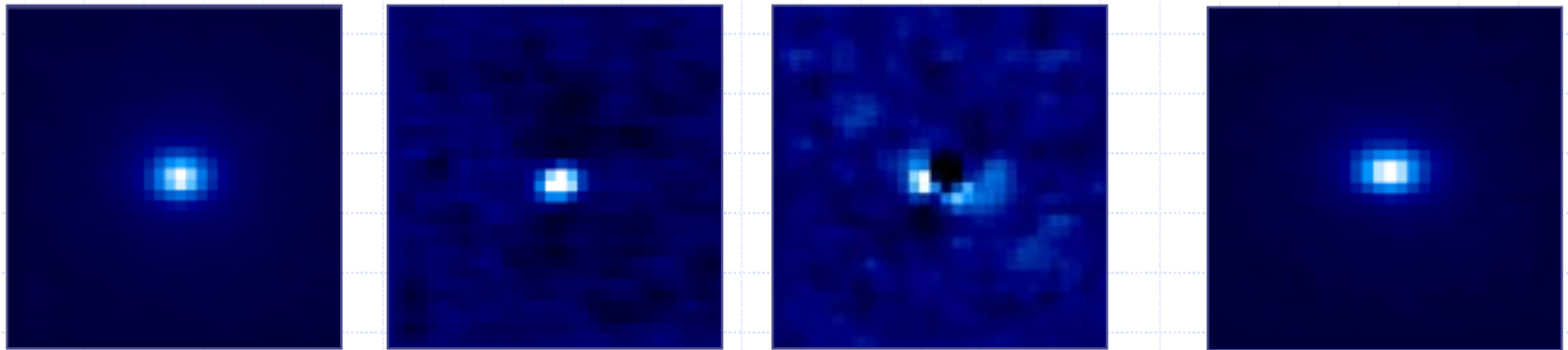
Eigenimage Decomposition

1. Extract and normalize



Eigenimage Decomposition

Rotate to common orientation and decompose.



$$0.9 * \text{Eigen}[0] + 0.15 * \text{Eigen}[1] - 0.05 * \text{Eigen}[2] = \text{PSF1}$$

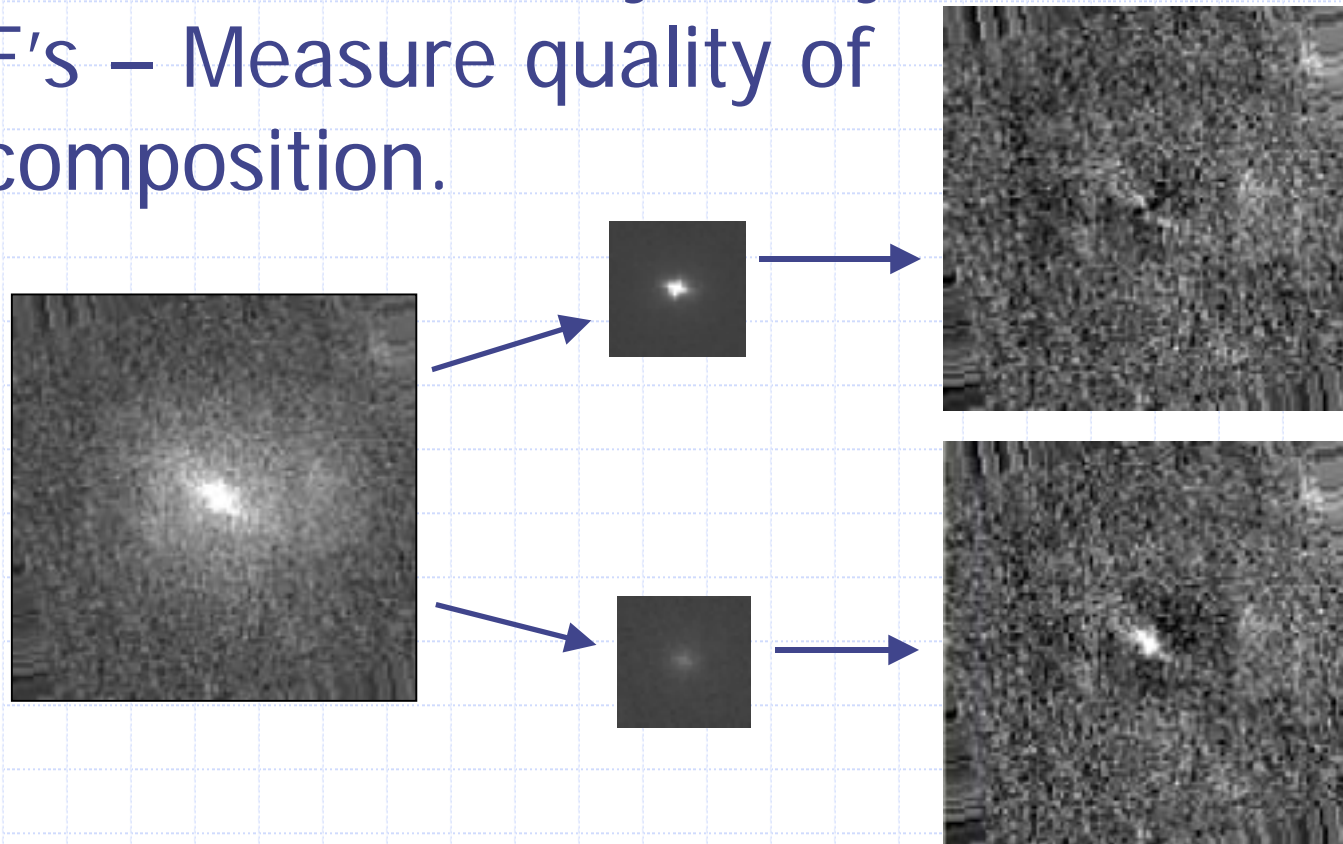
Determine coefficients for all PSF's in the field. Fit these coefficients as a function of guide star separation. For OSIRIS field, interpolate coefficients for its separation and produce broad band OSIRIS PSF.

Main complication has been optical aberration within science camera.
Does not follow same rotational symmetry.



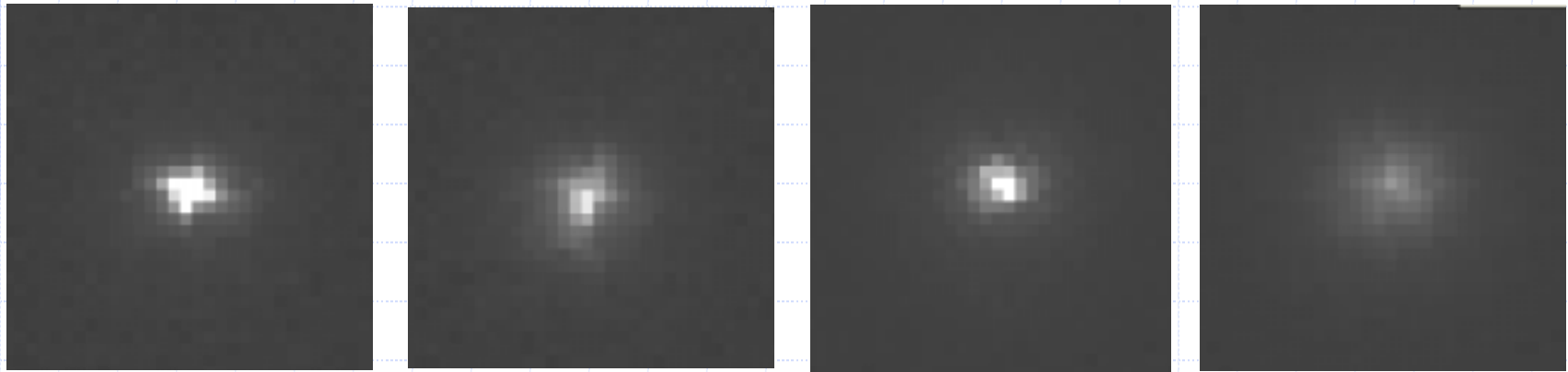
New Idea

- ◆ Use brute force – try many available PSF's – Measure quality of decomposition.



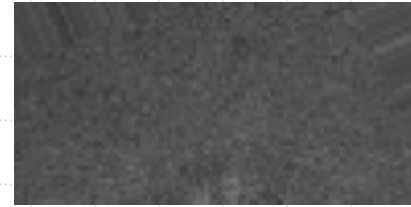
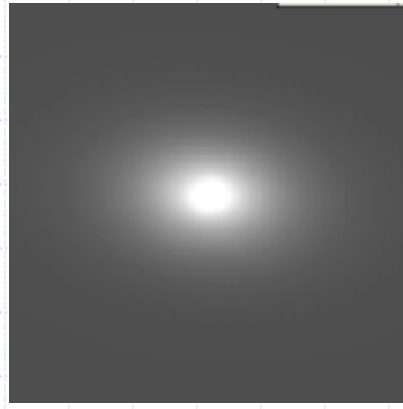
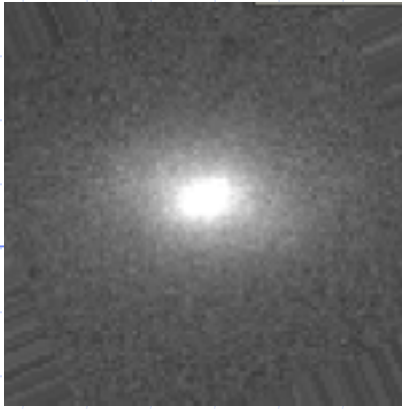
PSF's

- ◆ Produced 18 guide stars from 10 fields.
- ◆ Rotated all to one orientation compared to guidestar.



- ◆ Rotate galaxies to same orientation then fit.
- ◆ Model minimizes total chi-sq
- ◆ Best models selected for best core stdev.





Inclination	Disk Bright	Disk Size	Bulge Bright	Bulge Size	Error	Core error
53.5003	190.104	11.1314	389.644	0.682095	1.05669	2.21857
54.1585	194.444	10.8209	355.013	0.913645	1.05980	2.06700
55.1474	181.531	11.4735	386.982	0.919668	1.05163	2.03059
55.1719	194.374	10.6031	390.040	1.00626	1.03190	1.66940
52.4252	190.250	11.0529	408.227	0.668925	1.05066	2.13471
52.1665	193.573	10.9710	384.921	0.873845	1.03317	2.02399
54.6499	190.678	10.9095	392.093	1.01154	1.04773	1.93616
57.1725	211.569	10.0332	384.932	0.955084	1.09438	2.31938
56.0203	187.325	10.9798	396.092	0.967714	1.05370	2.13525
55.2594	208.981	10.3518	391.068	0.913072	1.05363	2.16584
53.4764	173.450	11.7516	369.644	1.38914	1.03887	1.73606
60.2977	213.078	9.69238	391.449	1.24506	1.07359	1.95251
54.3004	200.416	10.2924	390.672	1.06921	1.02322	1.75565
54.3028	162.906	11.9061	389.731	1.30411	1.03077	1.97852
61.5792	247.761	8.99976	368.589	1.25295	1.12167	2.14399
61.2849	210.188	9.89913	404.224	1.11851	1.05358	1.96837
55.6387	193.888	10.2703	401.185	1.37815	1.04137	1.83743
69.2949	188.926	9.35825	424.910	1.83028	1.11011	1.90303
57.5765	190.211	10.4551	395.290	1.33461	1.04909	1.78031
6.60308	10.2174	0.861170	20.1164	0.327416	0.0348284	0.0910909

