# GALAXY SPIRAL ARMS, DISK DISTURBANCES AND STATISTICS

- Part I: NGC3081 to build background for NGC4622. Co-authors for Parts I and II:
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  - Support NASA STScI and NSF RUI

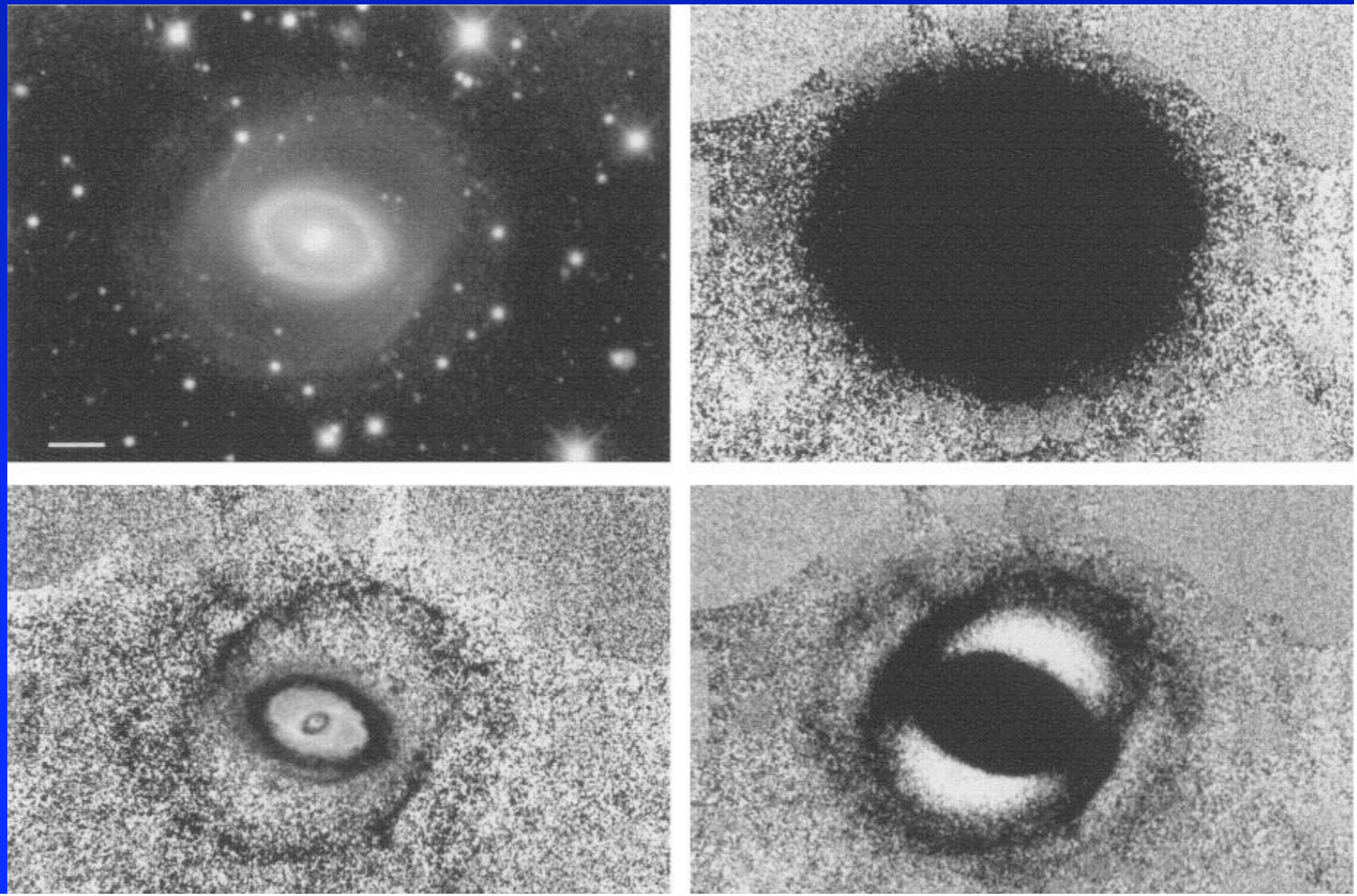
# NGC 3081

- Galaxy type (R1R2')SAB(r,nr)0/a according to Ron Buta
- quintessential resonance ring galaxy
- results of ground based and HST WFPC2 studies
- analysis of individual point sources in inner ring

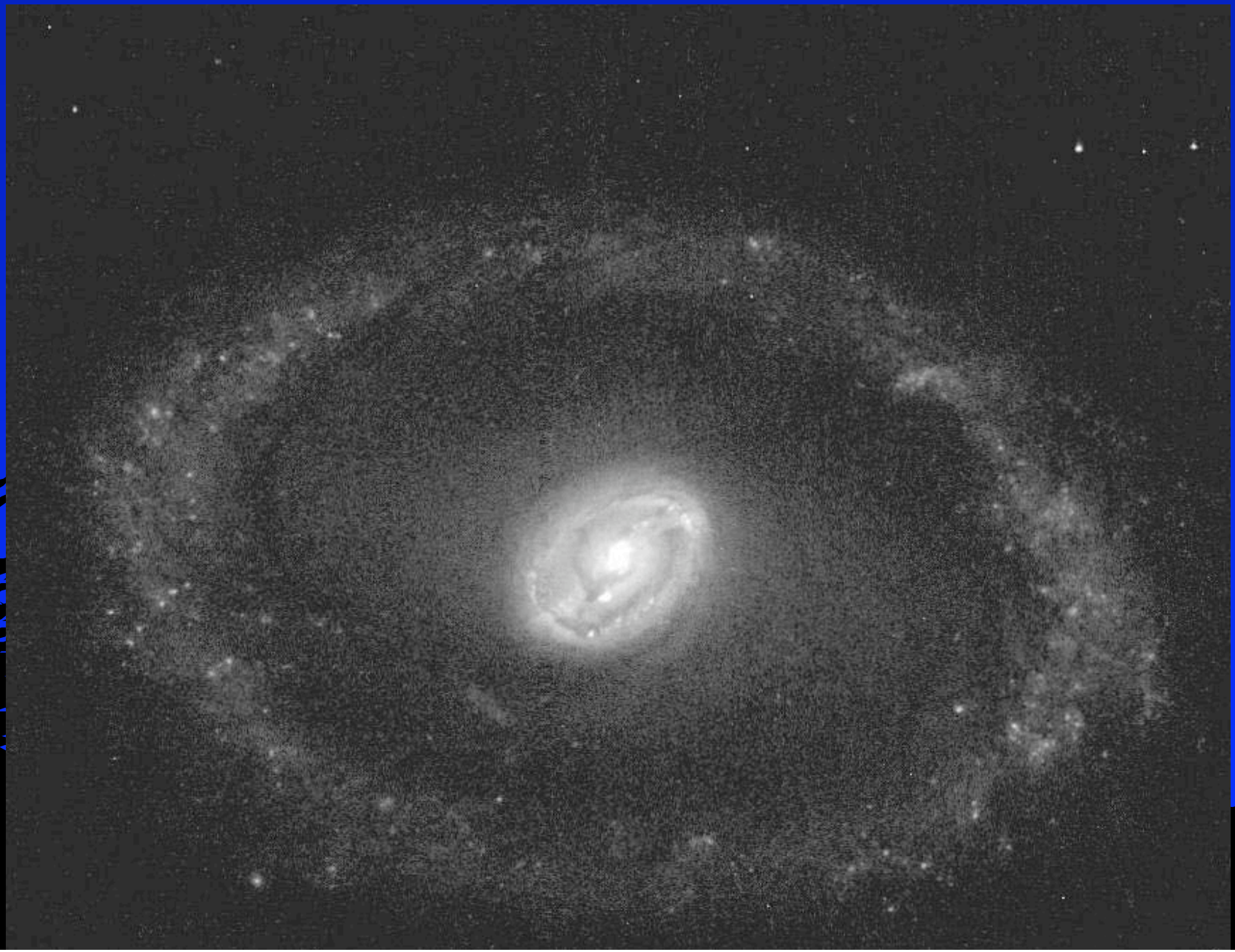
# NGC 3081 Observational Studies

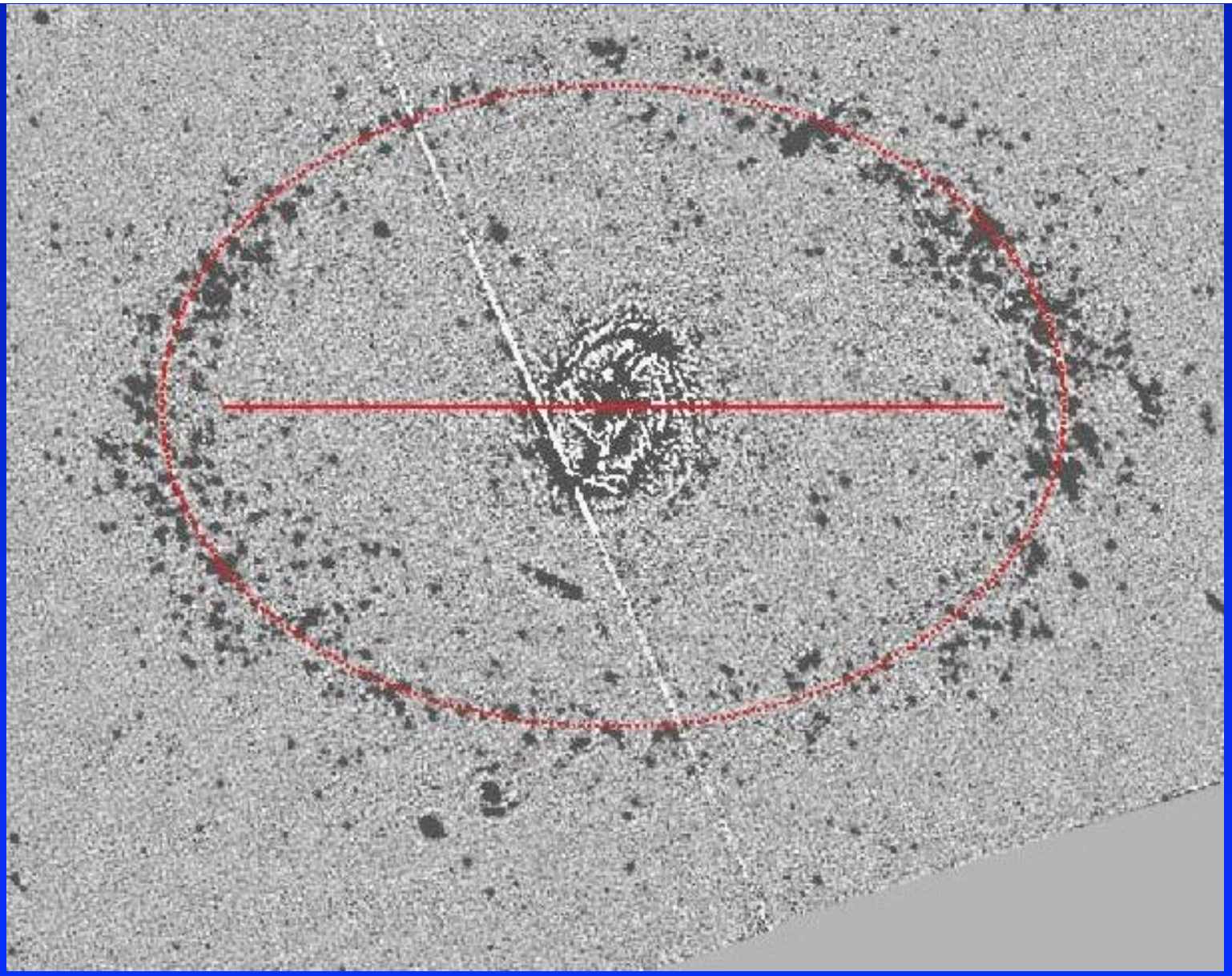
- HST study Buta, Byrd, & T. Freeman 2001
- Surface photometry & kinematics Buta & Purcell 1998
- Goals:
- Star Formation Dynamics
- Bar Strength
- Disk Surface Density

[1]. North is top. UL is B band. Bar=30”≈ 5.4 kpc. UR is a deep B. LL is B-I. LR is B with disk subtracted.

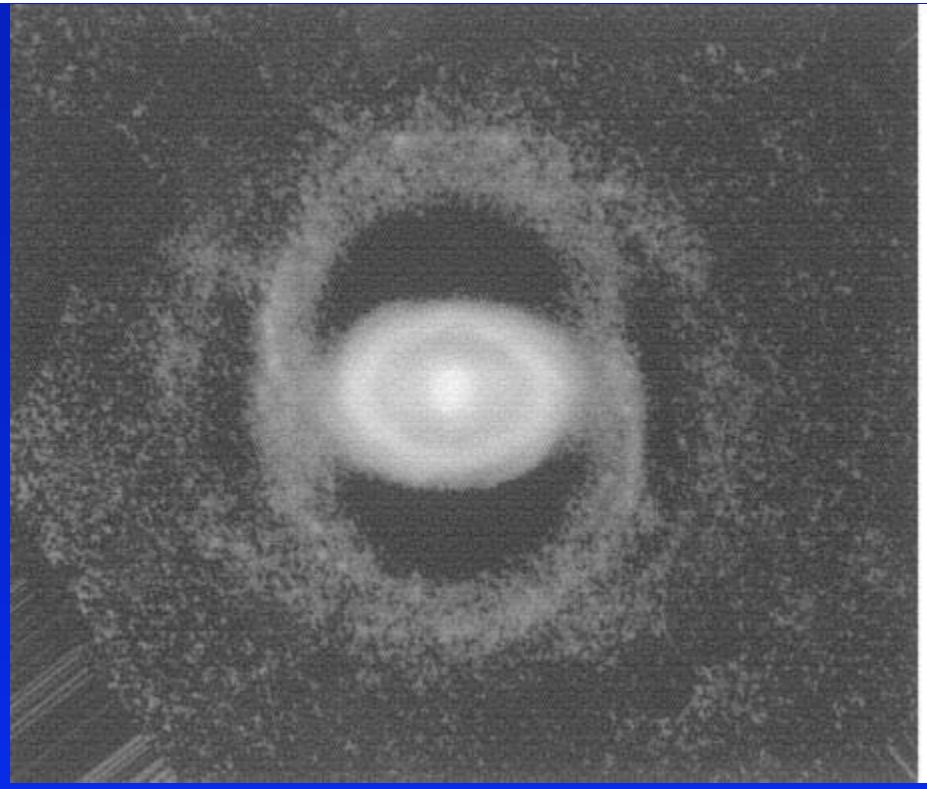


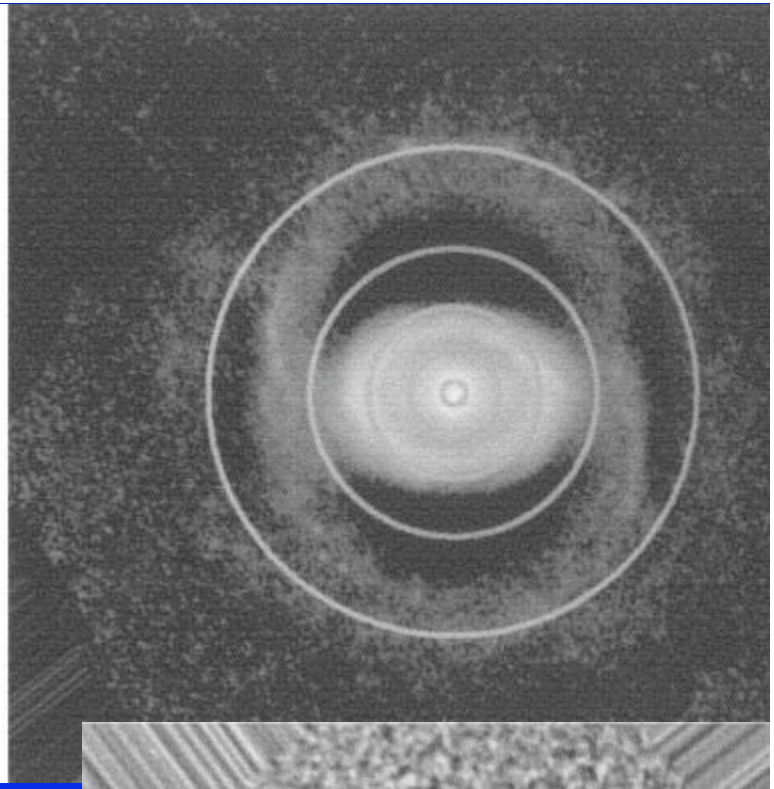
- HST blue image.

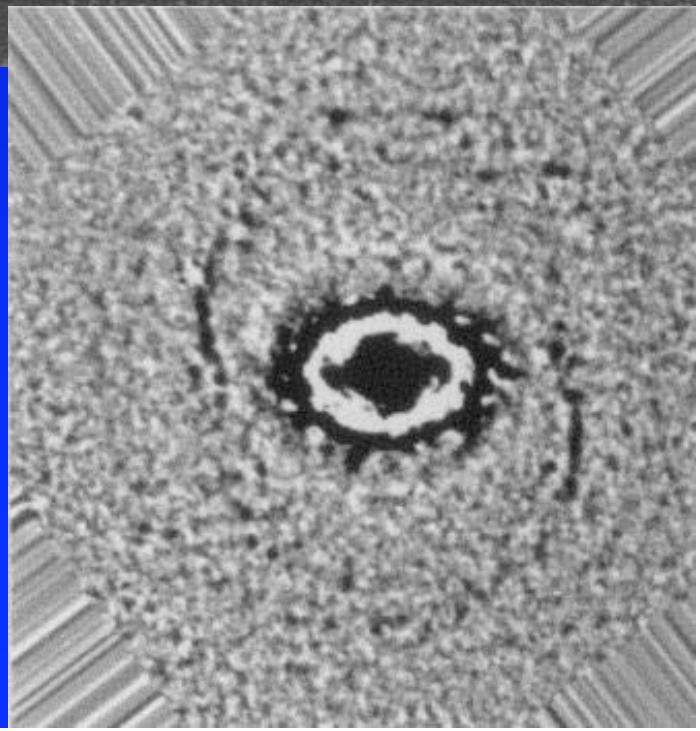




HST image processed to reveal individual associations.

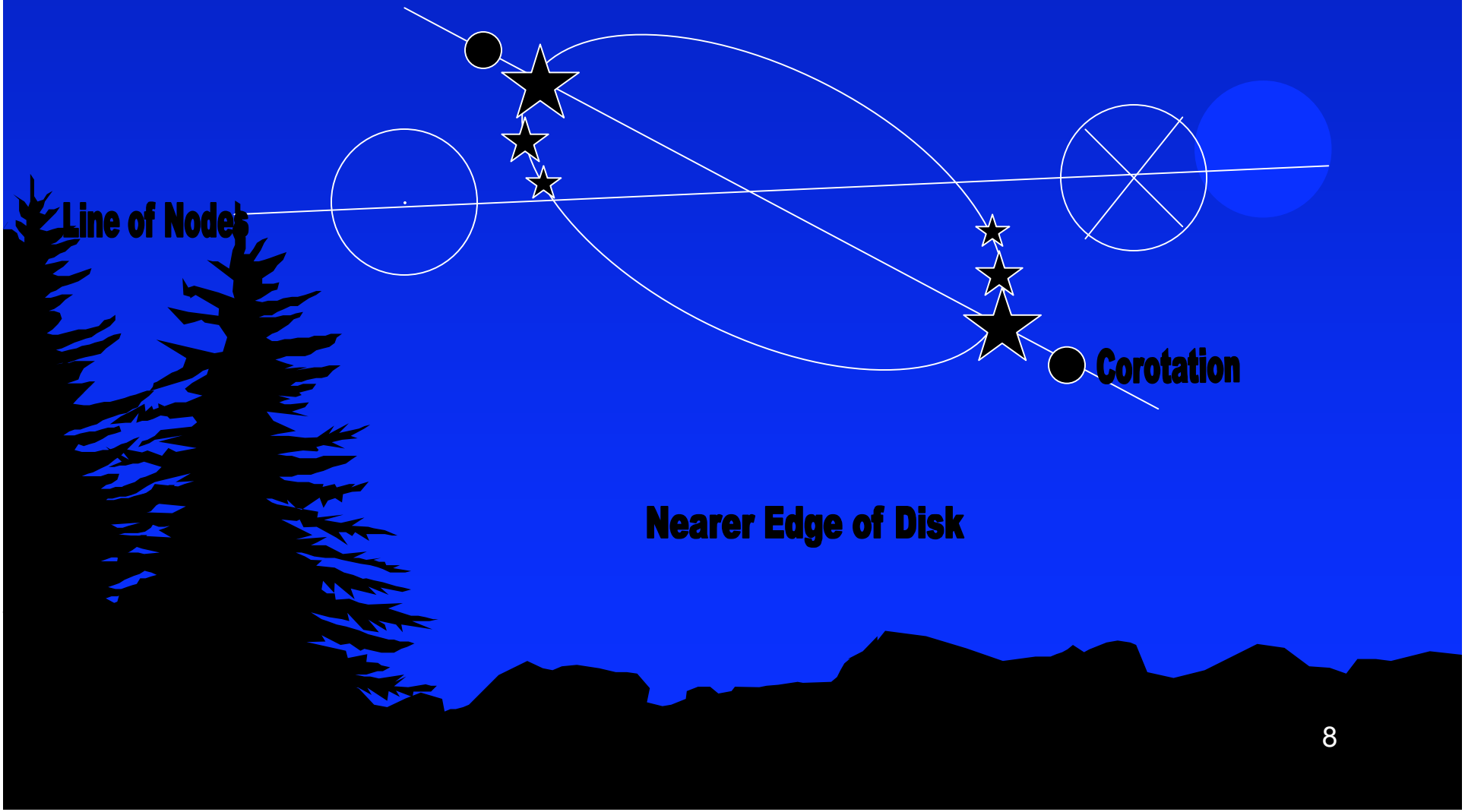


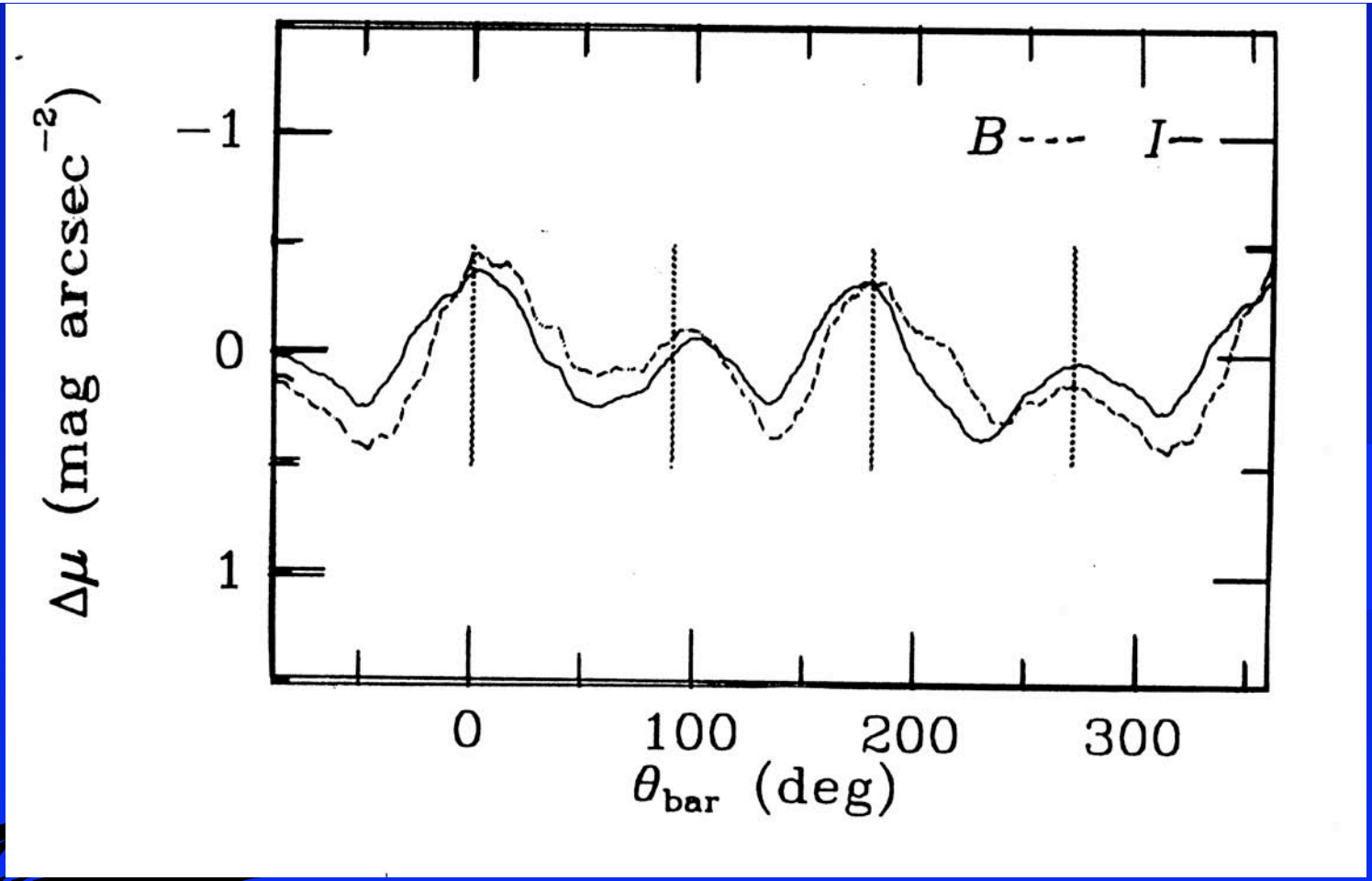




- Images with possilbe ILR, CR, and OLR marked.
- CR most important here.
- Note gap between ``r'' ring and R1 with CR in middle.

- Nodes, Doppler shifts, CR. Disk must turn CCW.
- Stars formed near CR age in CCW sense.



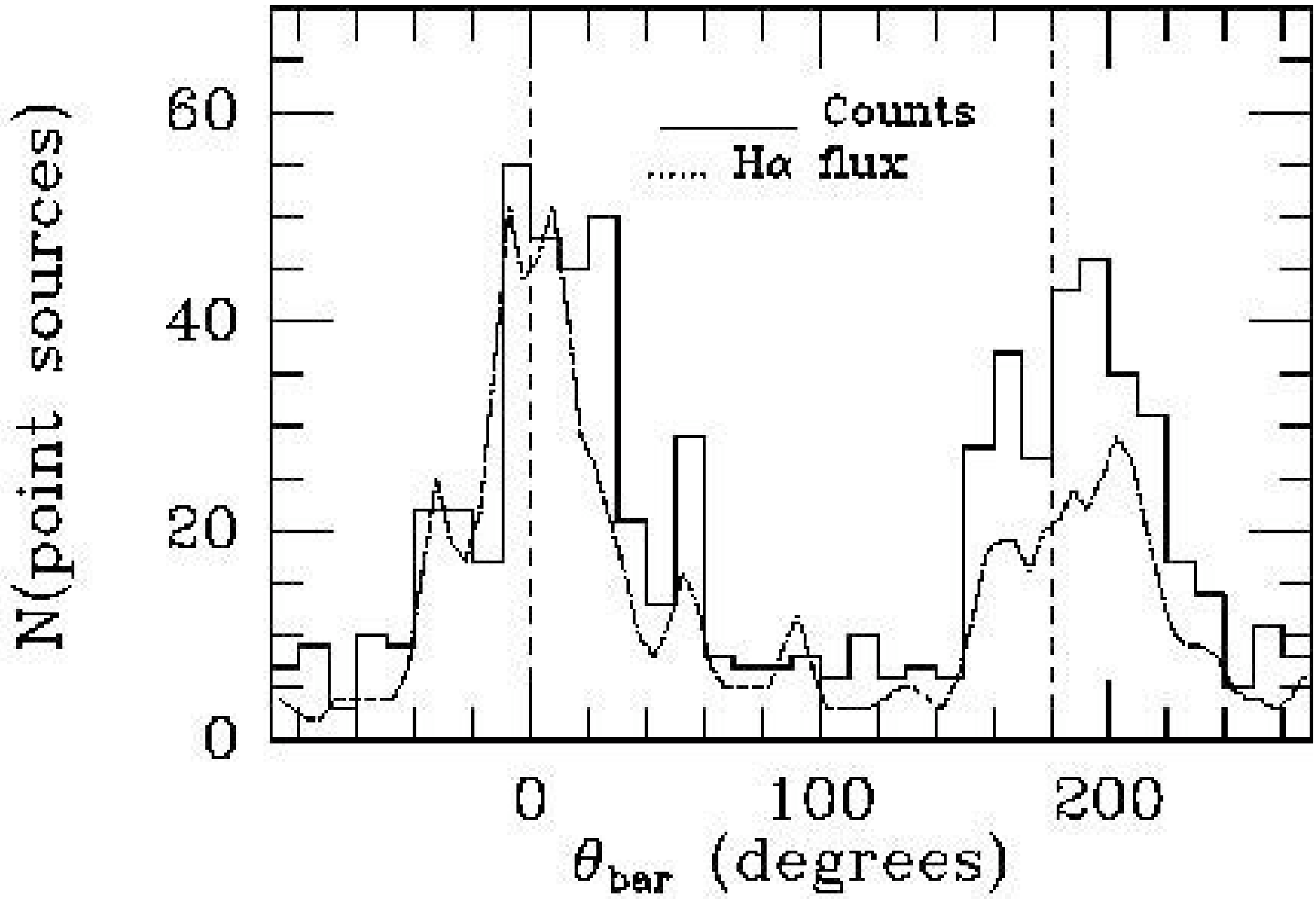


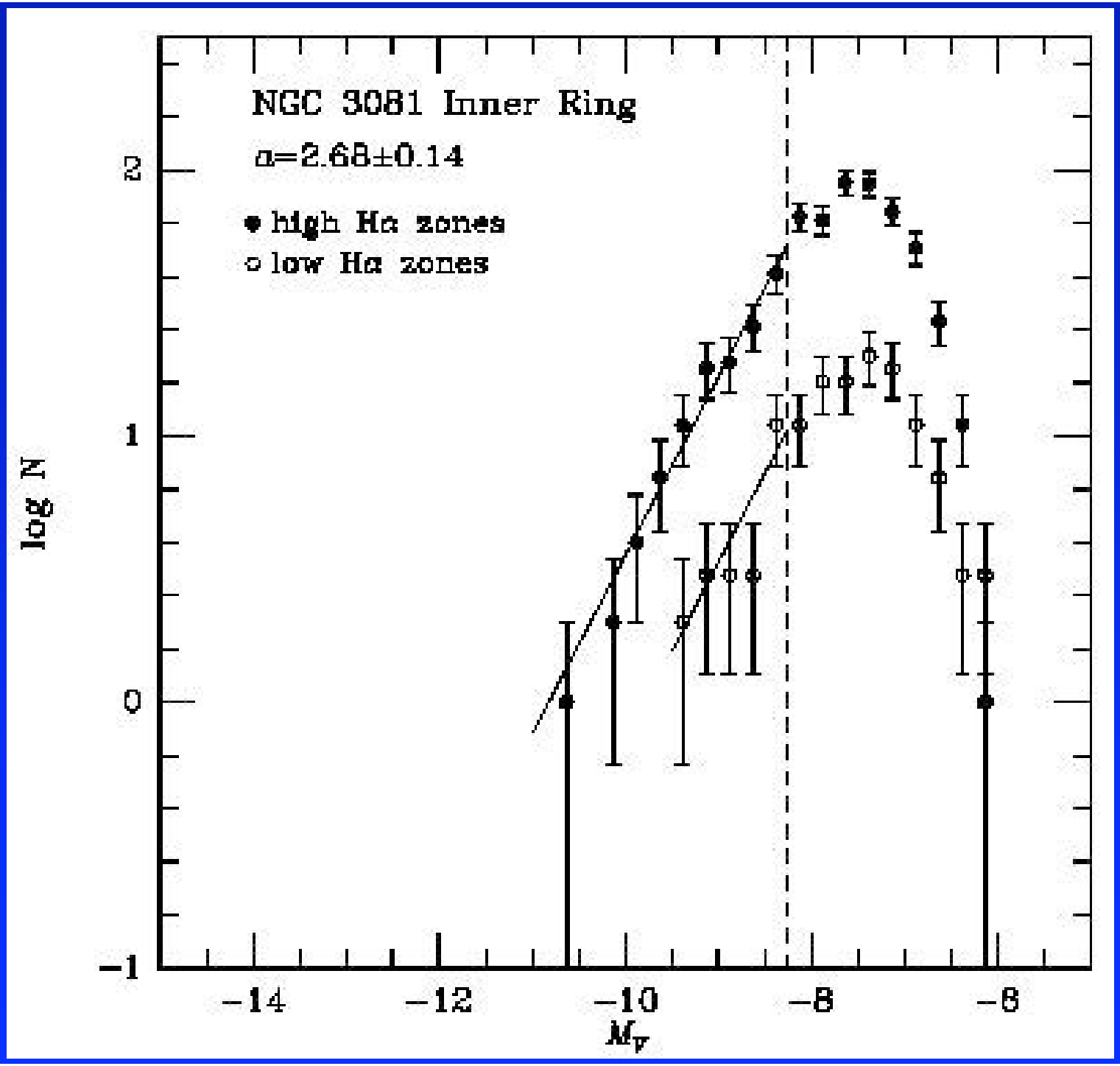

B and I band colors around ``r" ring.

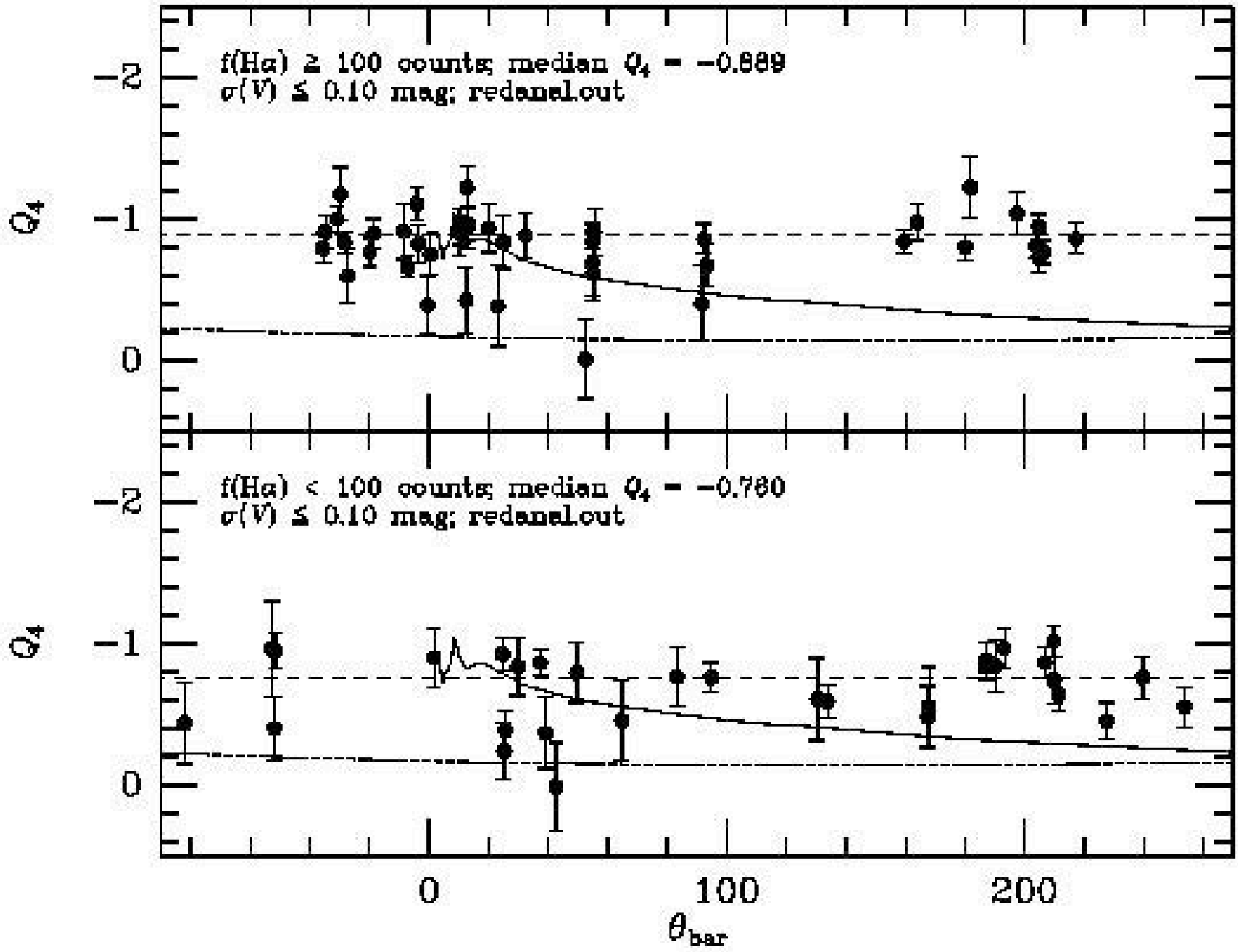
B higher than I implies blue, young stars have formed.

Blue stars 0 to 90° and 180 to 270°

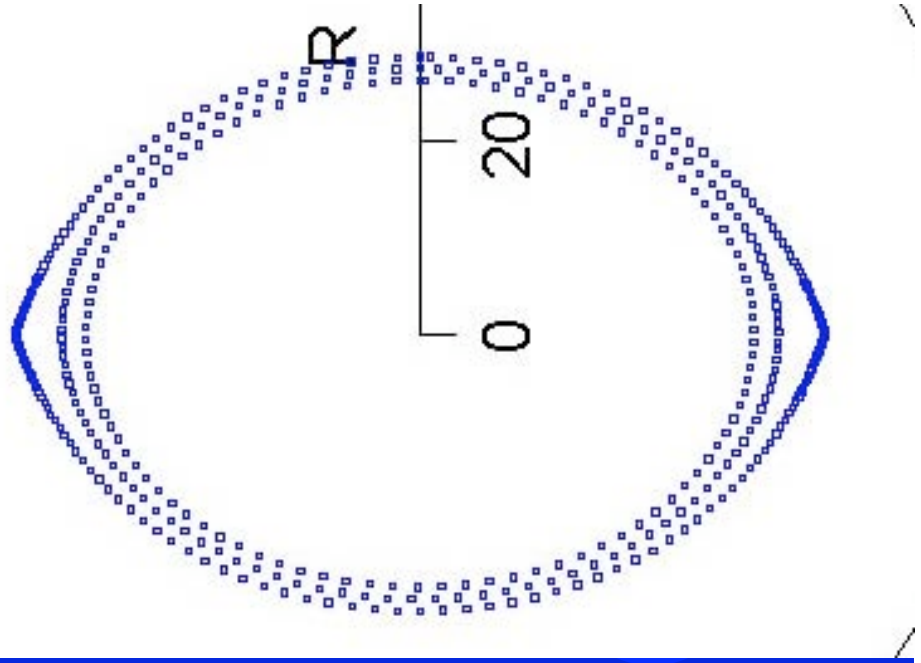
Like previous diagram => CCW orbit.


N(point sources)
60
40
20
0
Counts
Hα flux
0
100
200
θber (degrees)


NGC 3081 Inner Ring
α=2.68±0.14
high Hα zones
low Hα zones
log N
2
1
0
−1
−14
−12
−10
−8
−6
$M_V$


f(Hα) ≥ 100 counts; median $Q_4$ = −0.889
σ(V) ≤ 0.10 mag; redsnelout
f(Hα) < 100 counts; median $Q_4$ = −0.760
σ(V) ≤ 0.10 mag; redsnelout
$Q_4$
−2
−1
0
0
100
200
$\theta_{bar}$

# Analytic Solution for the Inner Ring. 37'' outer edge is well inside CR) at 52".

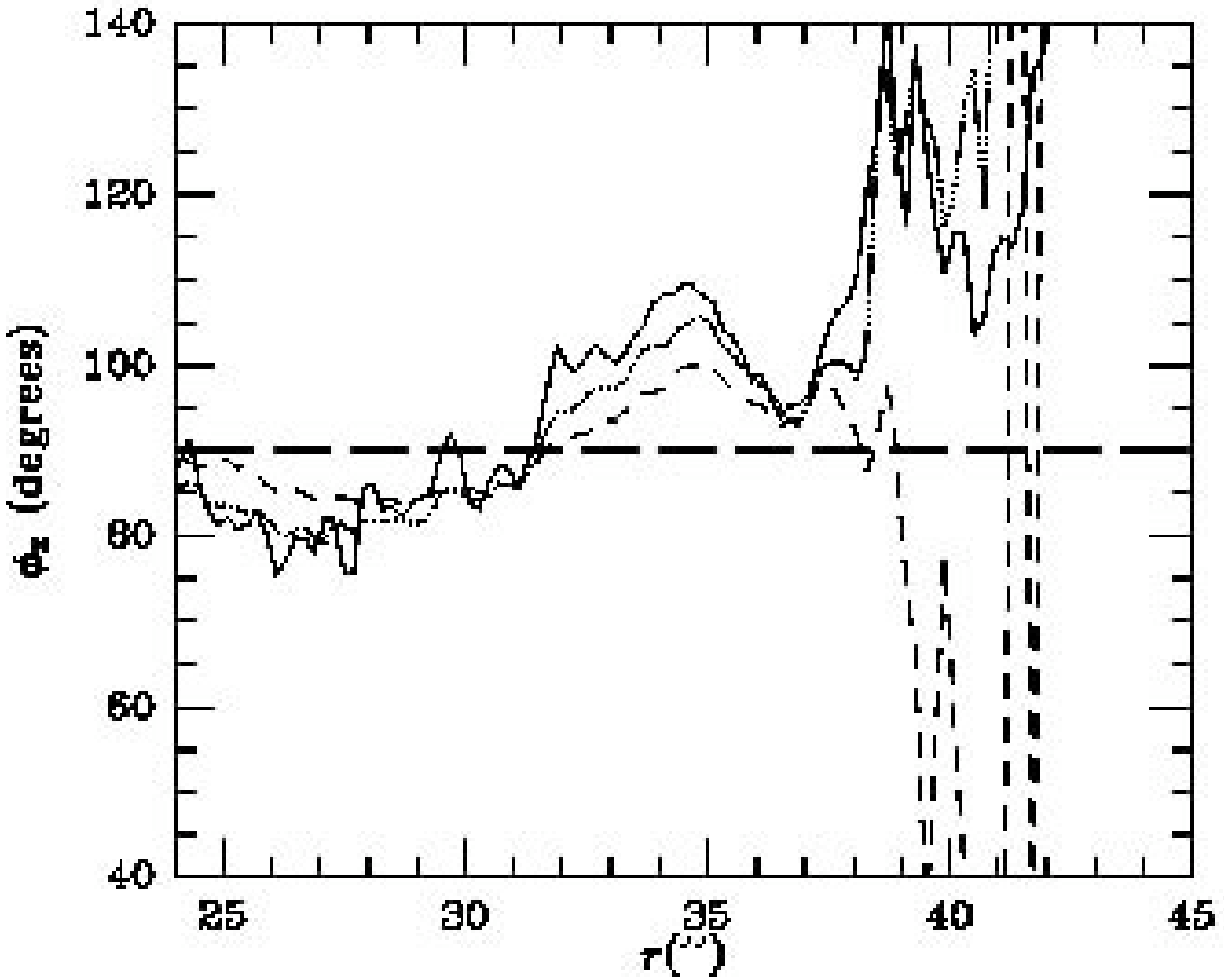



- $V_o$=221 km/s, 18 kpc equal to 100", and
- a perturbation pot amp. $-qV_o^2$ where q=0.025.
- Pointy ends match our images and our simulations. Inside of the ring is more circular as observed [1].
- Points are at equal intervals of t. At smaller radii, the angular displacement is larger as observed.

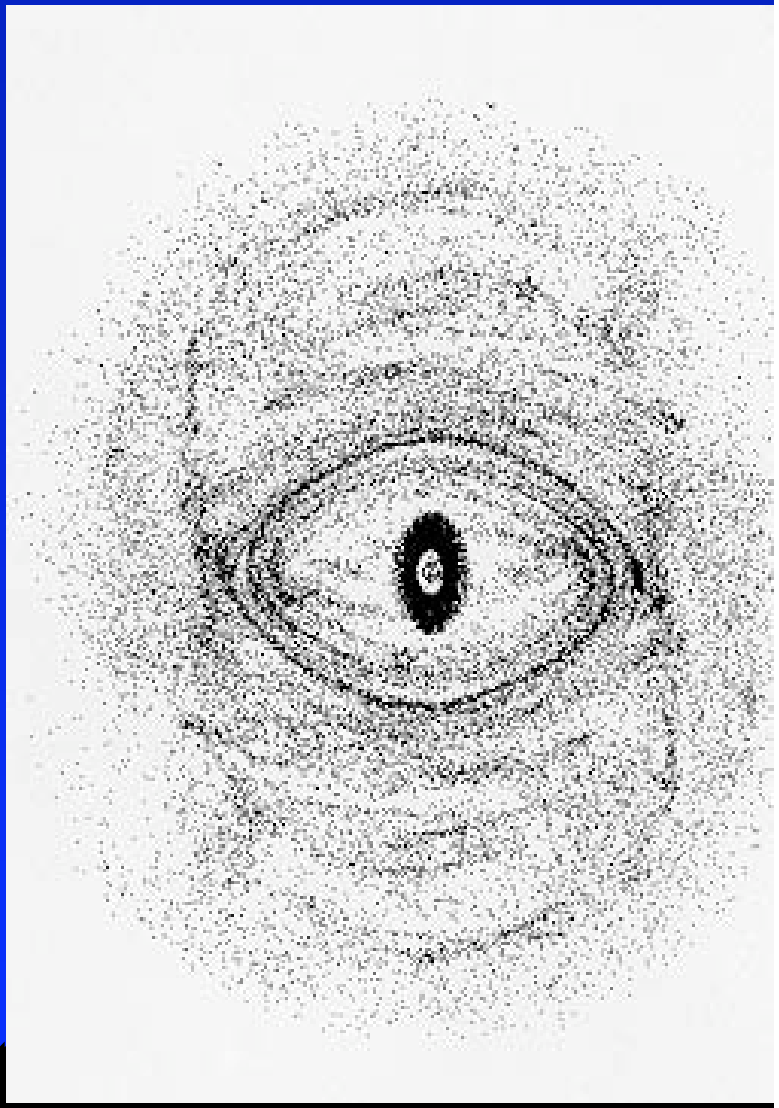
Fourier m=2 component position angles from major axes around ``r'' ring.

Note I, V, B going CCW from major axis

IVB is a CCW color-age sequence



- Simulation (and analytic) ring shape like our HST image.
- The gas cloud disk + inert high dispersion stellar disk and halo 221 km/s=$V_o$. Cloud disk surface mass density 1/15 to produce $V_o$.
- Clumps of gas clouds (``associations") form.
- Simulation ring life is several $10^9$ yrs < ~$400 \cdot 10^6$ yr.
- Too low a halo _ a chaotic non-ring disk;
- too high _ ring but no associations.



# Obtaining Disk Parameters

- For flat rotation curve.
- More general formulas are possible.

- Ratio a/b inner ring, r, = (1-sqrt(2q))/(1-2 sqrt(q))
- $F_{tan}/F_{rad} = 2q$
- Sur. Density = $(q/(I_2/I_0))x(V_o^2/(2\pi G r_o))$ = $(q/(I_2/I_0))x$(100% Mestel disk)
- Halo/Disk = 100% disk/ 3081 disk surface density = $f = (I_2/I_0)/q$

Radius“,kpc $I^2/I^O$ $M^{sun}/pc^2$Halo/disk40 or 7.20.6

Conclusions: ``r'' and ``R'' rings are star formation laboratories.

IVB color age sequence.

M/L disk is not constant with radius.

May actually rise.

# GALAXY SPIRAL ARMS, DISK DISTURBANCES AND STATISTICS:

- PART II: THE STRANGE CASE OF NGC4622, AN EXCEPTION TO THE RULE

# Do spiral arms lead or trail outward relative to orbital motion?

- Lindblad (1941) said they lead. The sketch shows thin arms & arrow for disk orbital motion.
- Hubble (1943) said they trailed. =>
- G. deVaucouleurs (1958) found all to trail in a small sample of highly inclined spirals.
- Trailing accepted as the rule today.

Byrd et al 1989 pointed out NGC4622's two-way arms.

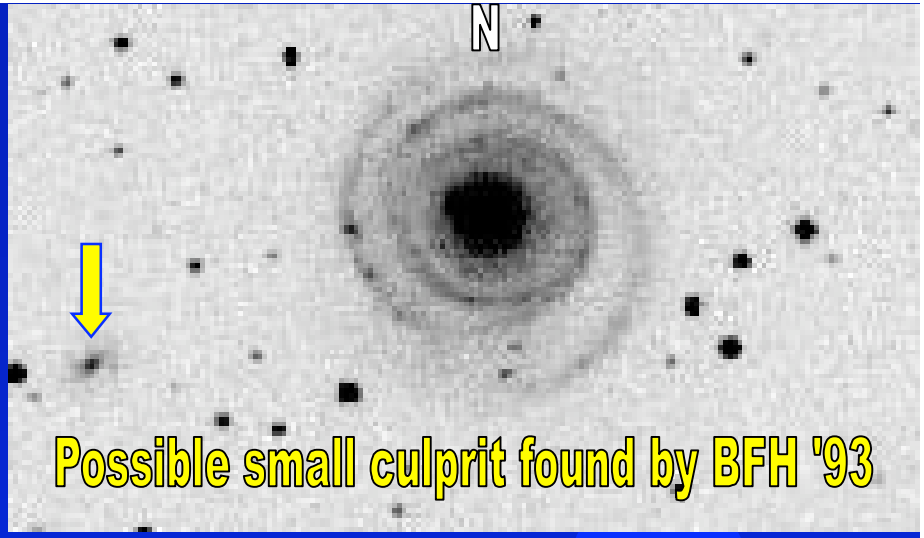
It must have leading arm(s)!

HST photo shows arms in disk & young blue associations

Outer pair winds out CW

Inner arm CCW

# Simulating NGC4622's Arms




- Byrd, Freeman, and Howard (BFH 1993) found a new, plunging, disk plane passage by a small perturber produced a two-way pattern.
- Assuming a flat rotation curve, two trailing outer arms and a single inner leading arm could be produced.
- Predicted that NGC4622's disk turns counter-clockwise (CCW on the sky). Wanted to check[2] this.

# Checking predicted disk rotation

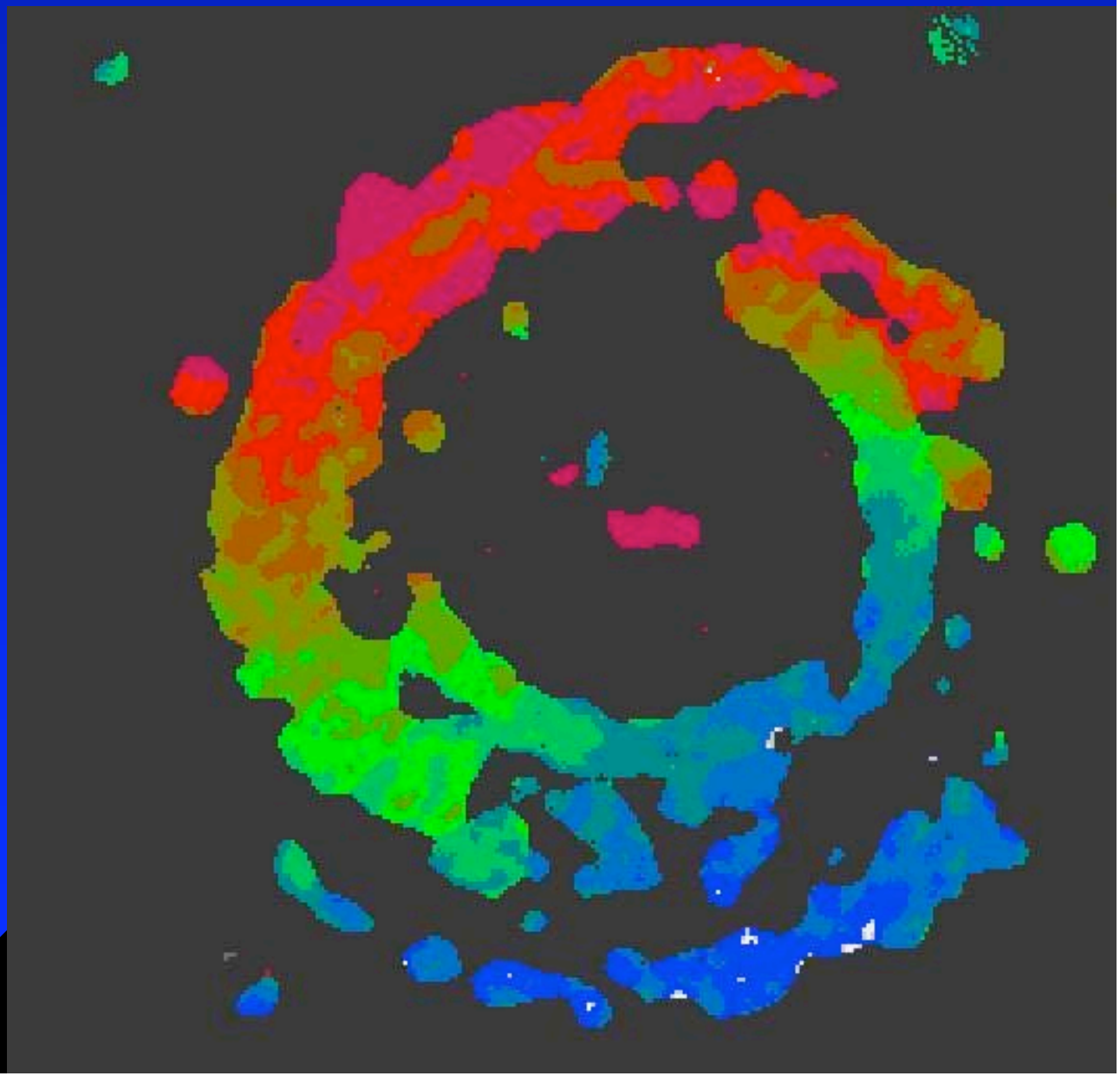
Need NGC4622's velocity field and disk orientation.

Ground-based H Alpha emission velocity field for NGC4622. =>

Red = away

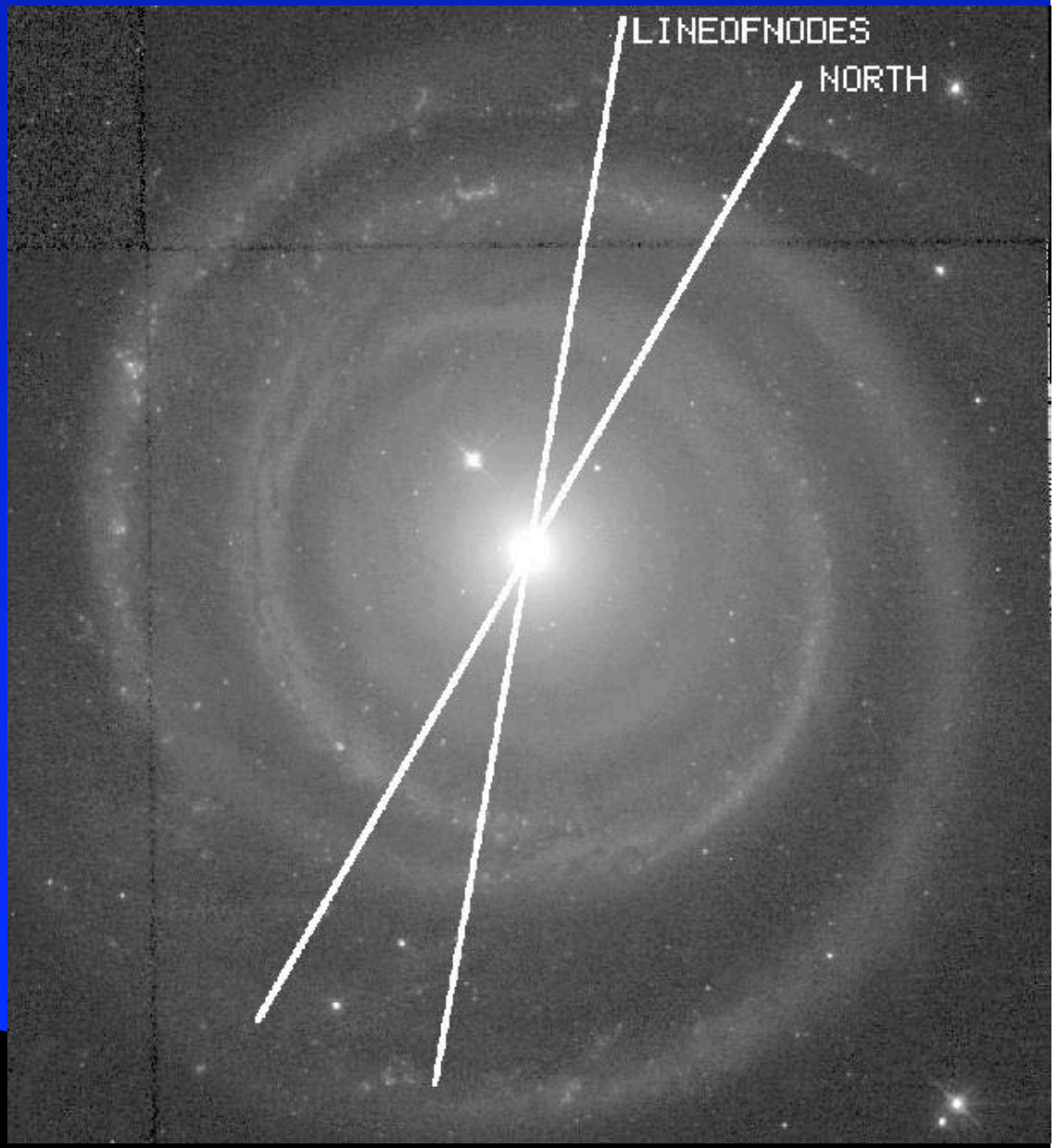
Blue = toward

Ref. Scott 1996 MS thesis



# NGC4622 Disk orientation

- The line of nodes is the intersection of the disk with the sky plane.
- The line is obtained from the elongation of NGC4622's outer isophotes ~NNE toward SSW.
- Need to know which edge of disk is near



# Obtaining Orientation: HST V-I image

Use GdV method.

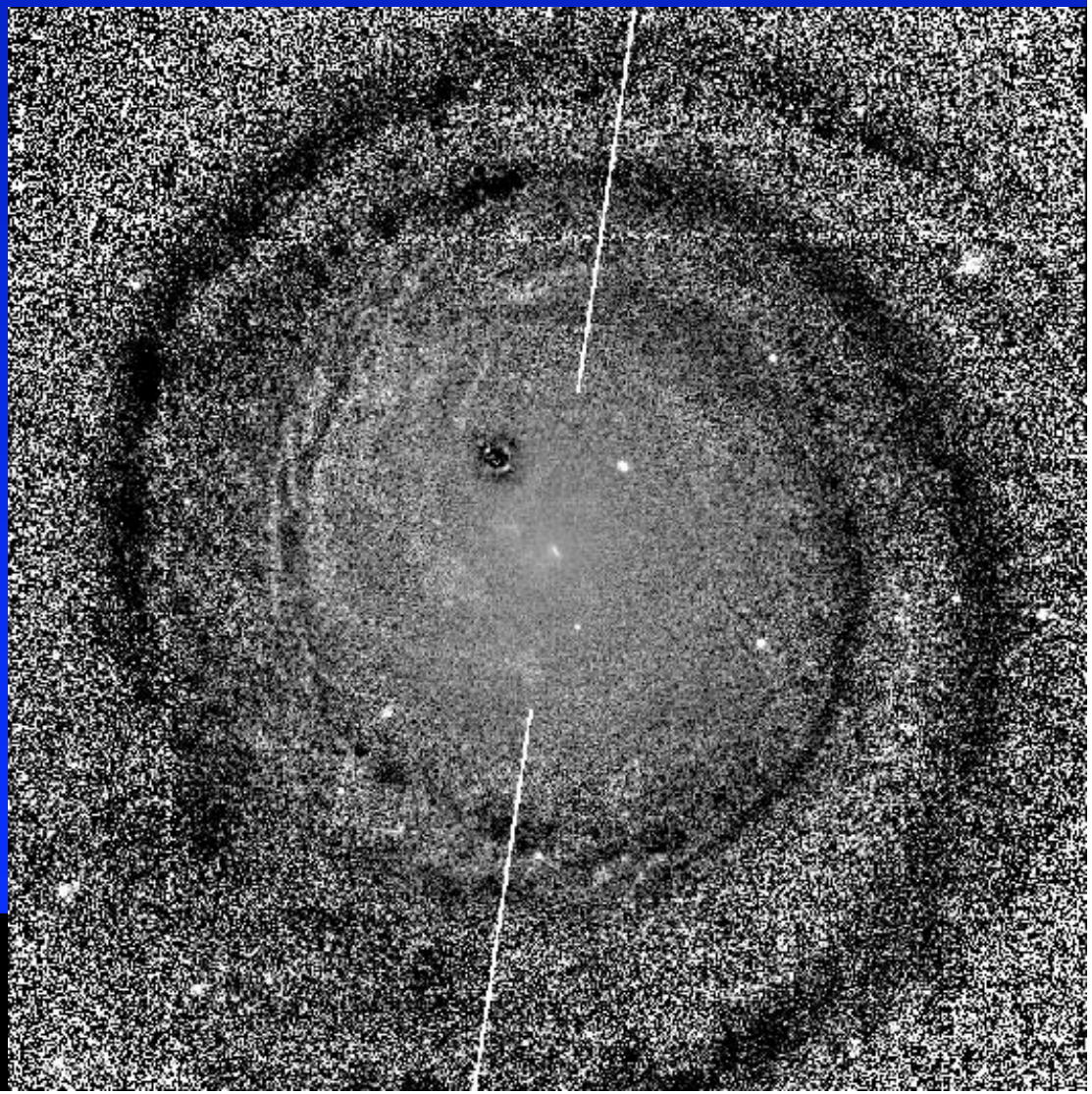
Darker bluer. Whiter redder.

Note blue spiral arm associations along outer arms.

Central regions, nuclear bulge.

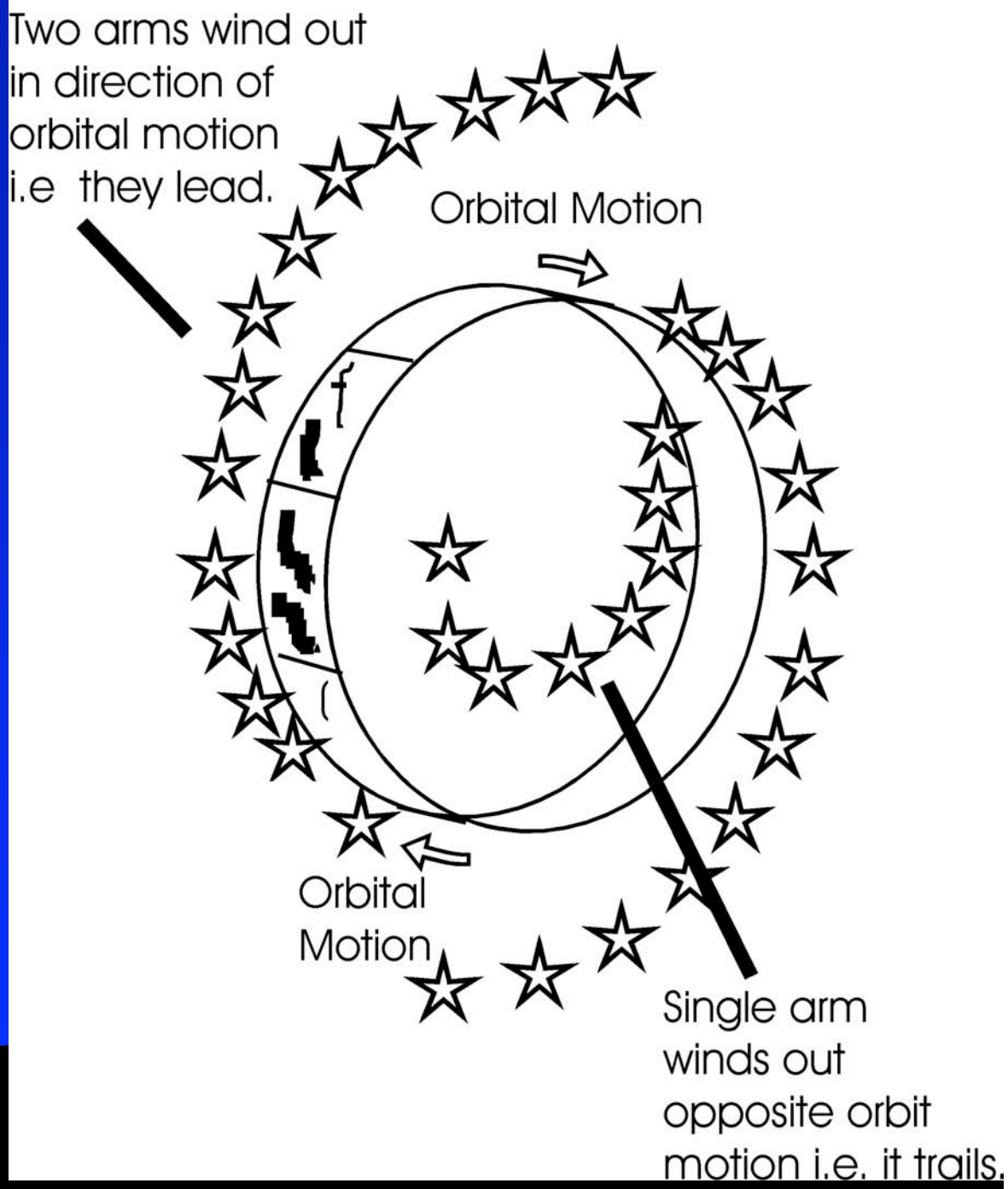
Near side of NGC4622 disk shows sharper dust silhouettes with redder color than far side.

East side is nearer.



# Boy, were we surprised!

- Why is the result so surprising?
- East edge is nearer. =>
- North line of nodes recedes.
- The disk thus orbits CW on the sky, opposite prediction.
- Inner single arm trails & the outer pair leads!



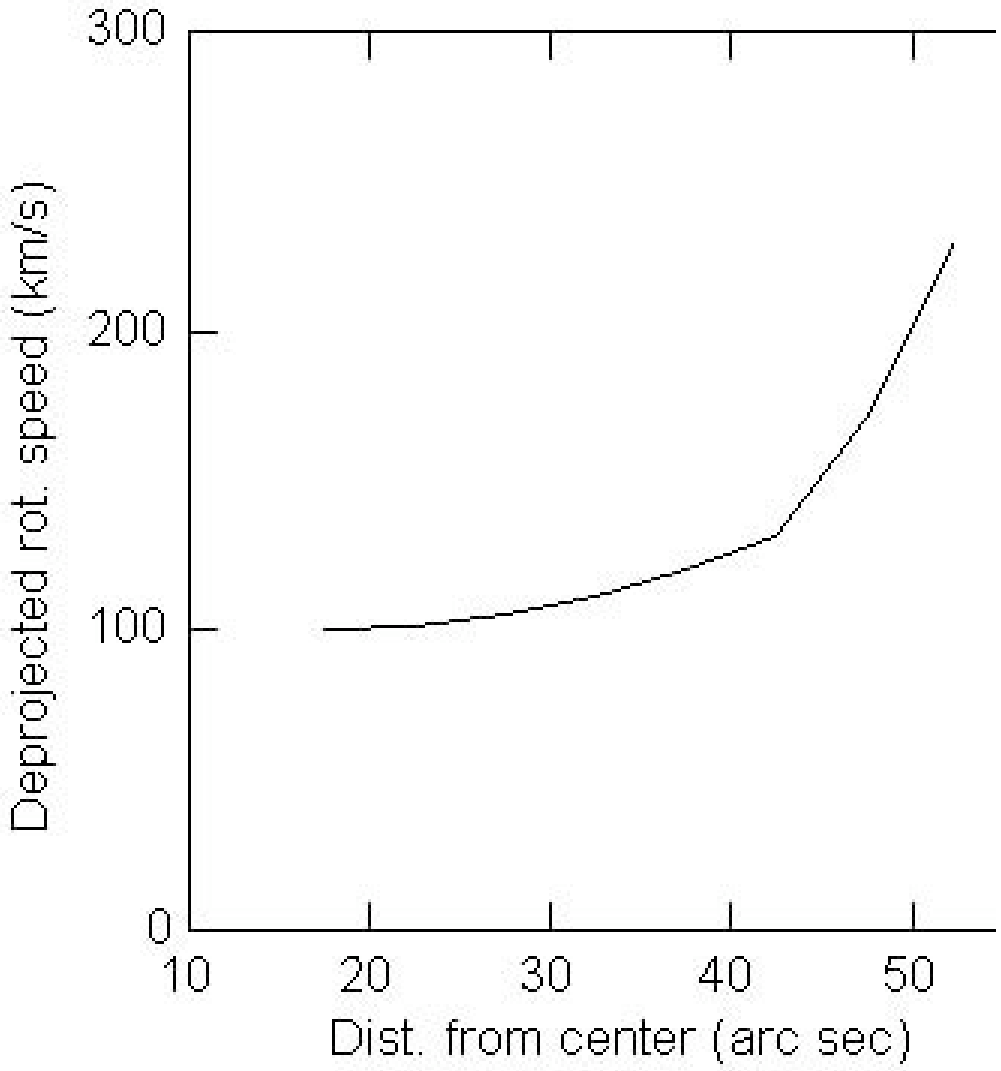
# How can the outer two leading arms and inner trailing arm be triggered?

As in BFH, we simulate a small, planar plunging perturber .

However , we must use a new unusual rising, steepening rotation curve from the observations.

We fit the observed curve v with a formula giving

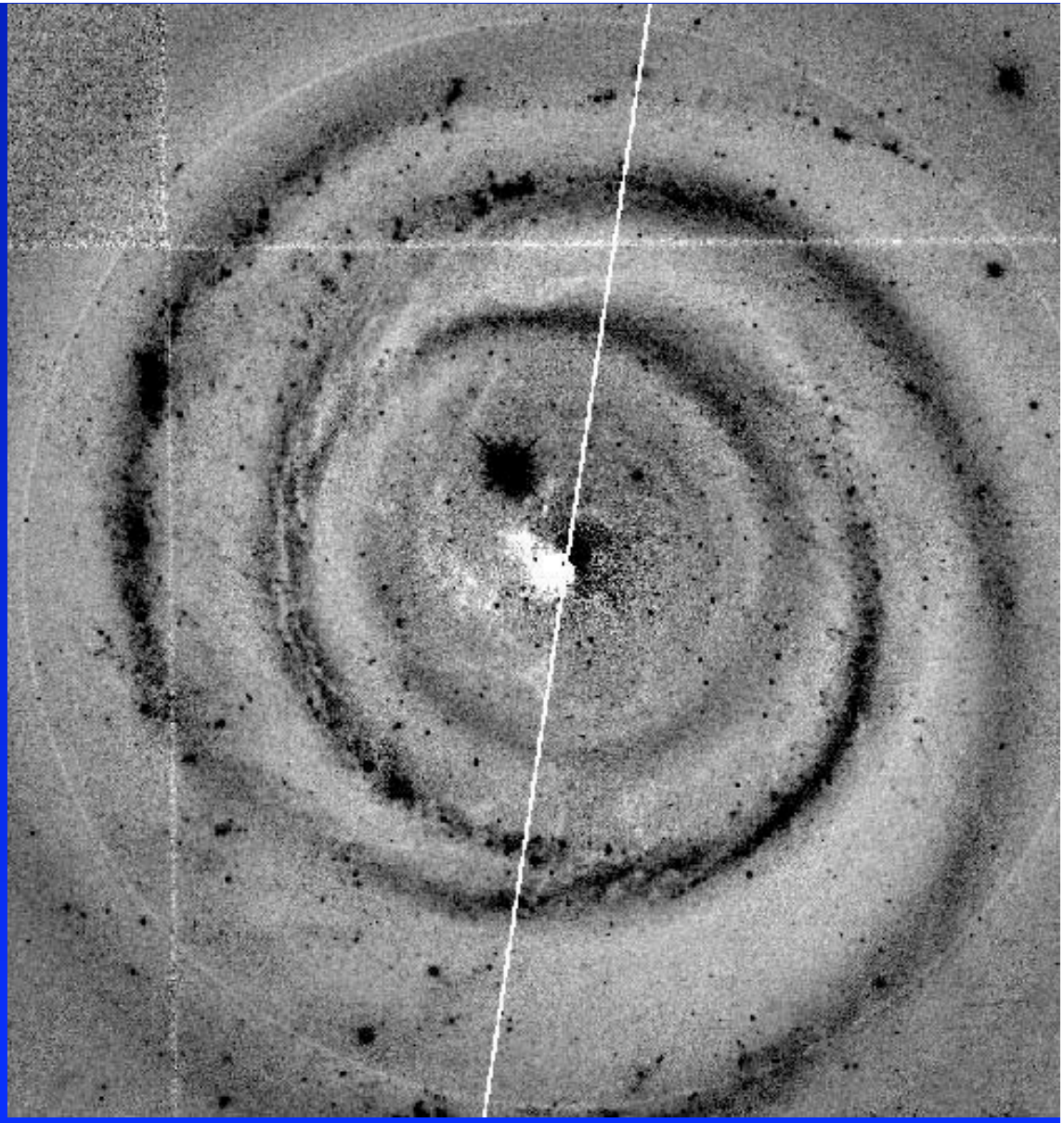
- v~ 100 km/s 16 to 30arcsec
- v~ 0.08r^2 km/s at 45 to 60 arcsec.

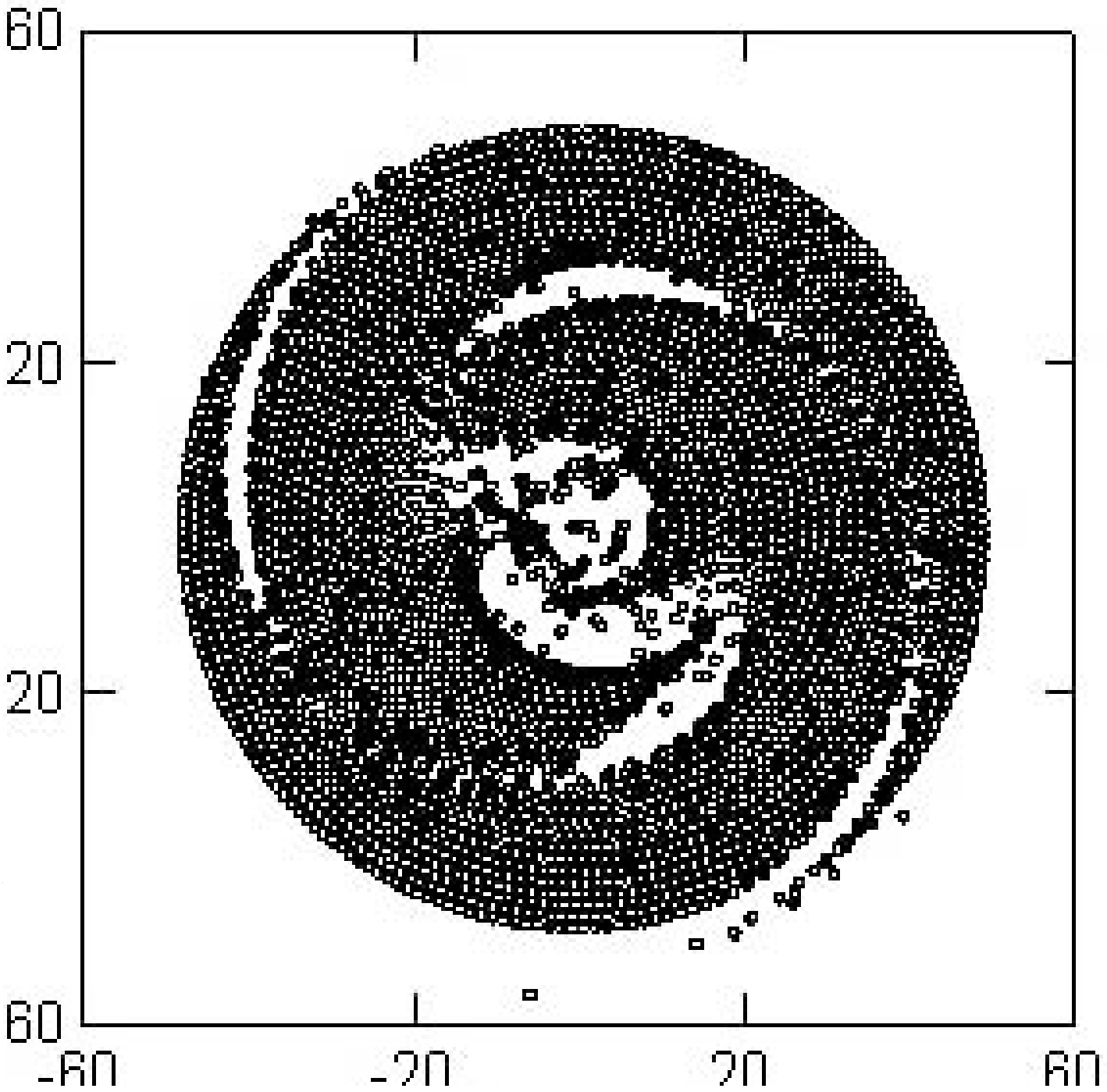


# Simulation vs HST image

High contrast image. m=0 disk subtracted =>

Simulation plot follows.



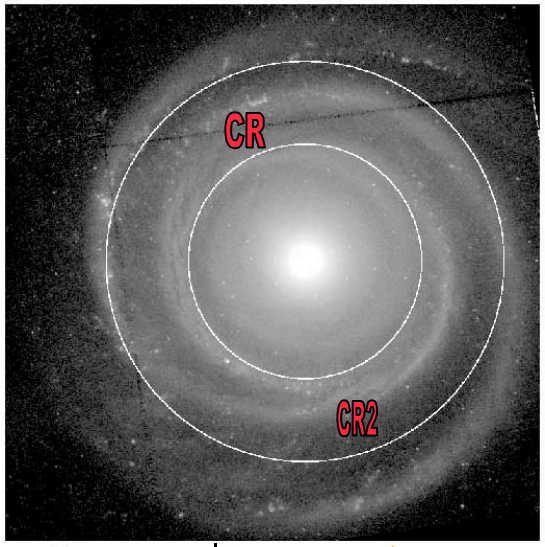


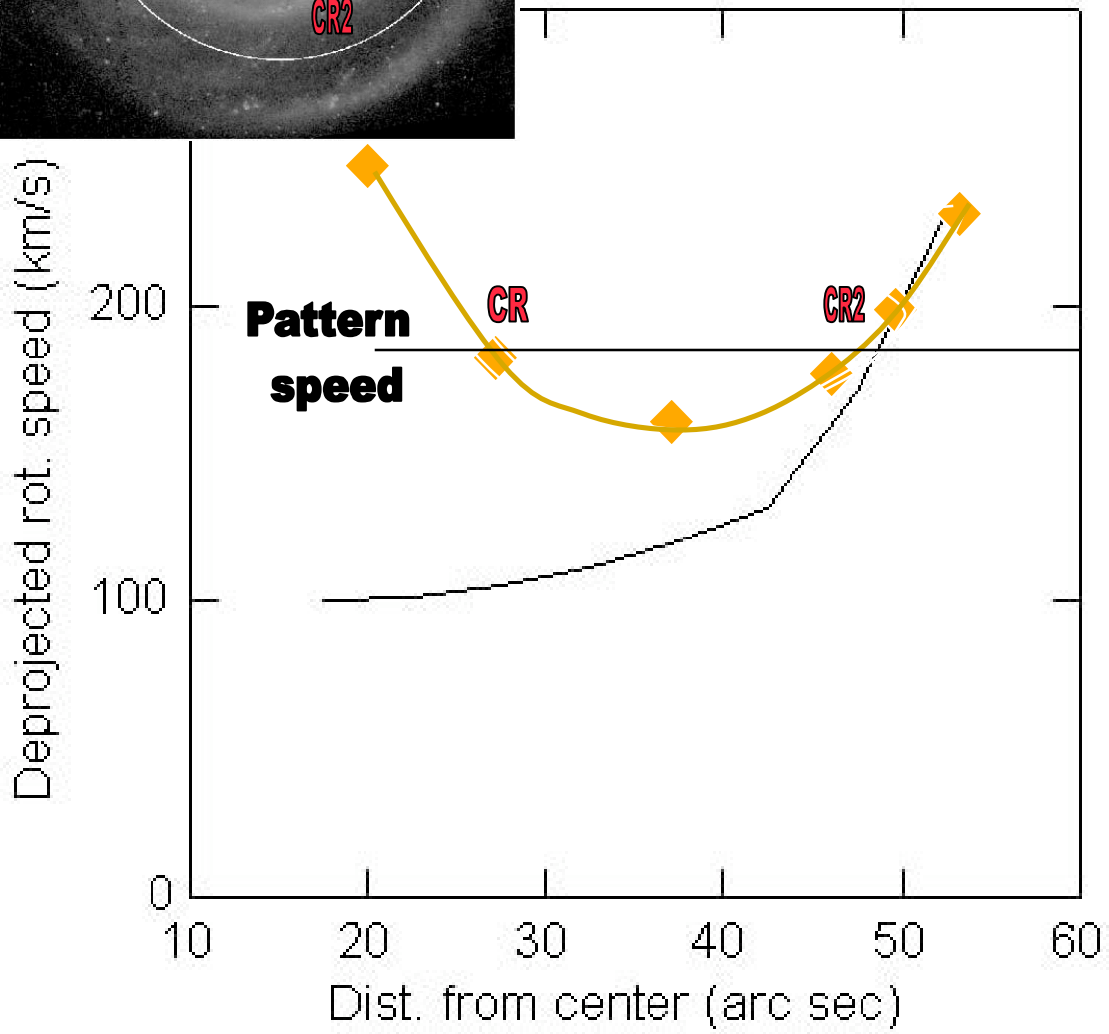

Simulation disk 390x10^6 yr after a low mass plunging perturber entered then left along disk plane.

Outer arms lead out CW like disk orbital motion.

Inner arm trails surrounded by oval.

# Two CR Disk Resonances

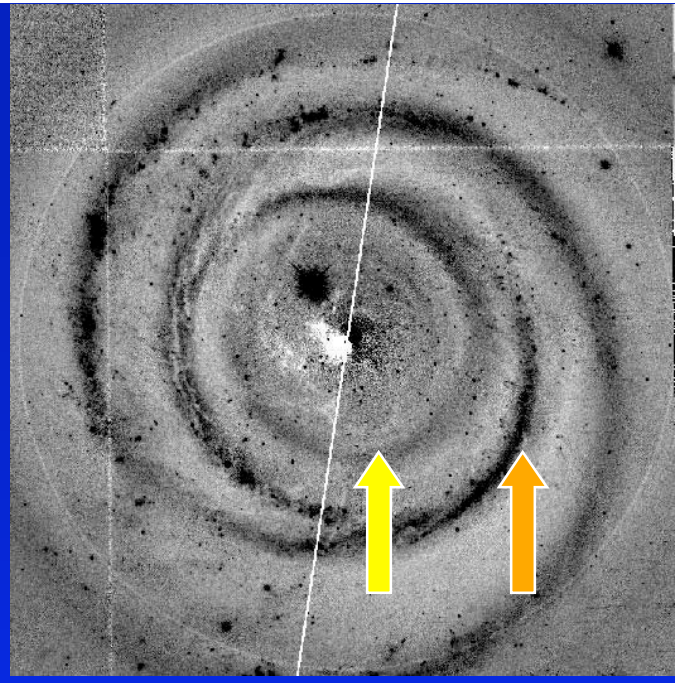


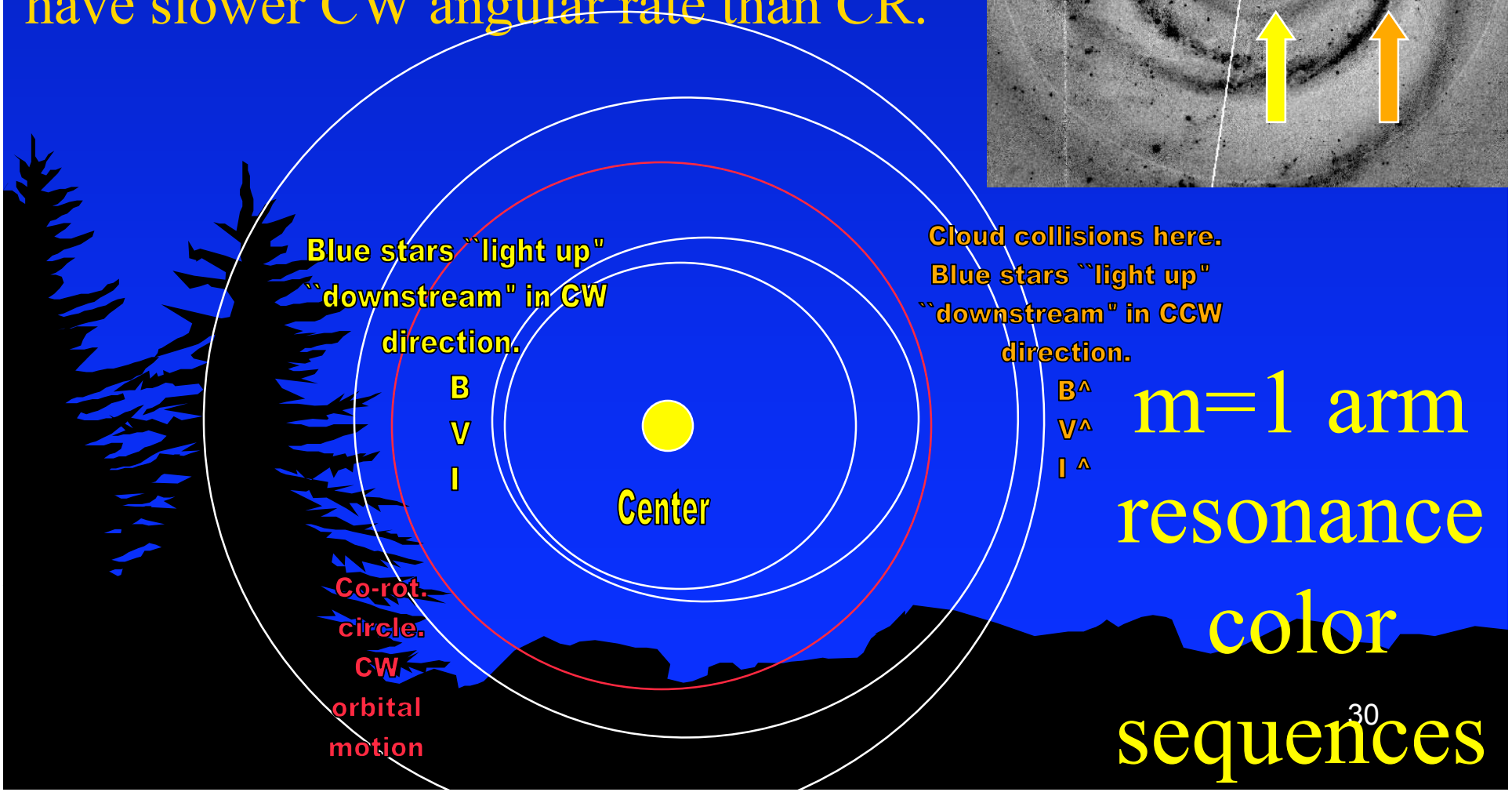




- A declining orbital angular rate through first CR.
- A rising orbital angular rate through second CR.

Inner set of perturbed orbits inside first CR of turning m=1 (one sided) disturbance. Orbits have faster CW angular rate than smaller CR.

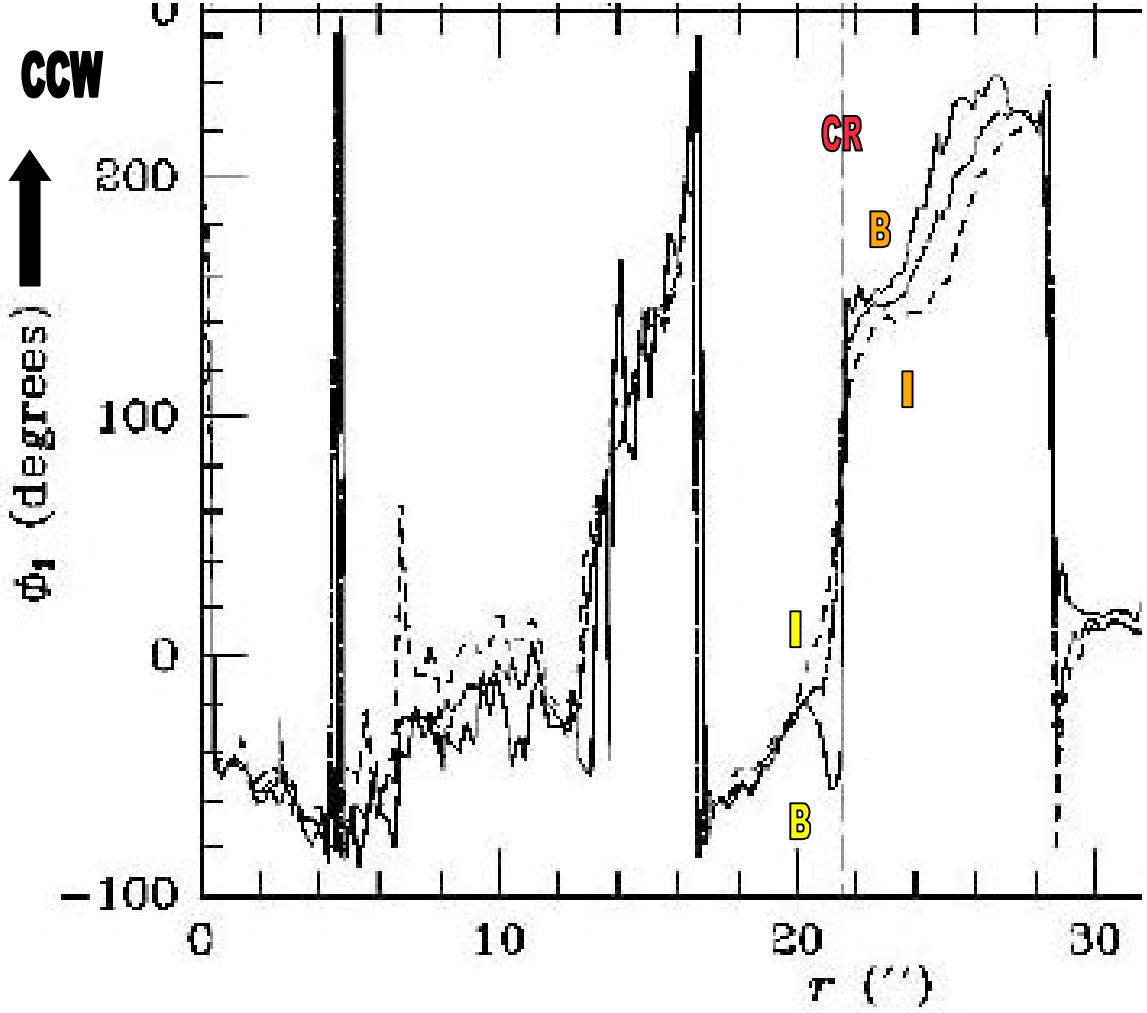
Another set outside first CR. Orbits have slower CW angular rate than CR.





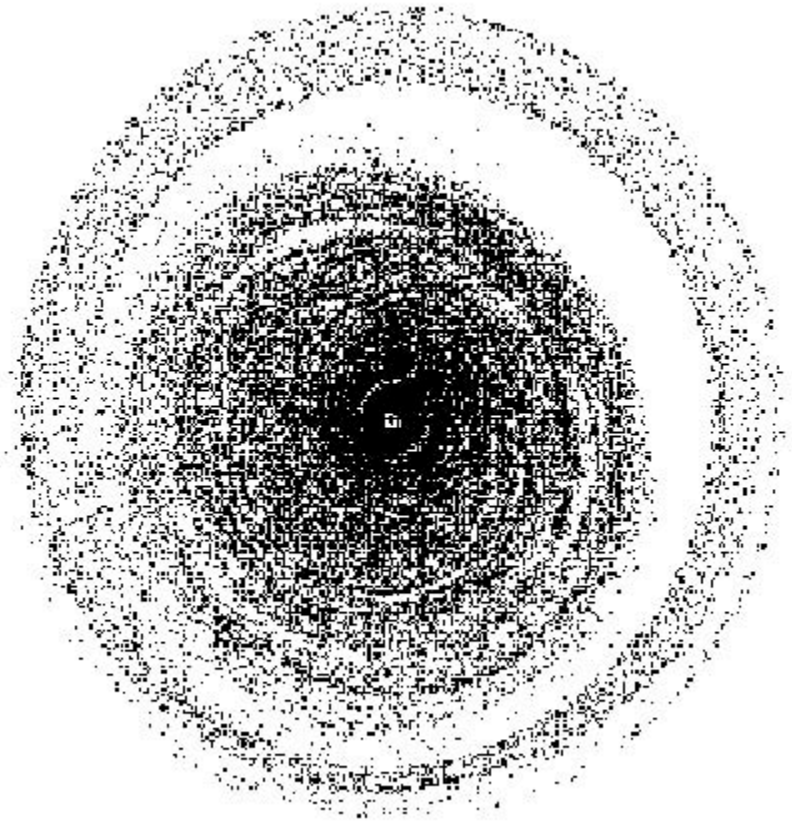

# m=1 arm resonance color sequences

- Position angle vs r of m=1 intensity peaks.
- I---, V…, & B solid
- 180$^{o}$ jump at ~21” ( first CR) as expected for one set of m=1 perturbed orbits inside CR & one outside.
- Expected reversal of I, V, B color peak sequence CW inside and CCW outside 21”.
- ==> CW orbital motion & trailing single inner arm.



# Simulation demonstrating m=1 CR resonance

- Flat rotation curve region.
- Rotating m=1 perturbation acts on disk of particles. Little self-gravity produces best match.
- Empty region is CR resonance radius.
- Trailing arm and ring inside and outside CR.

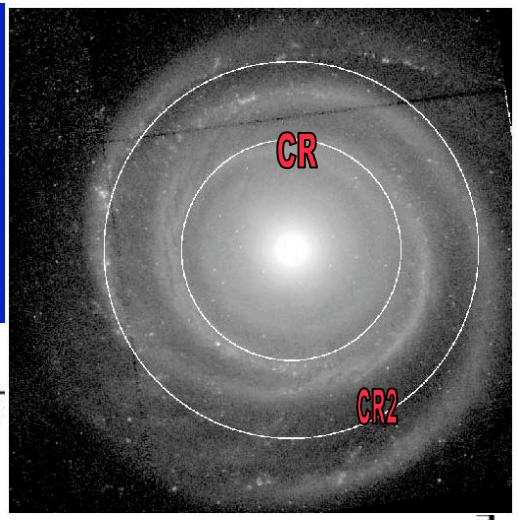


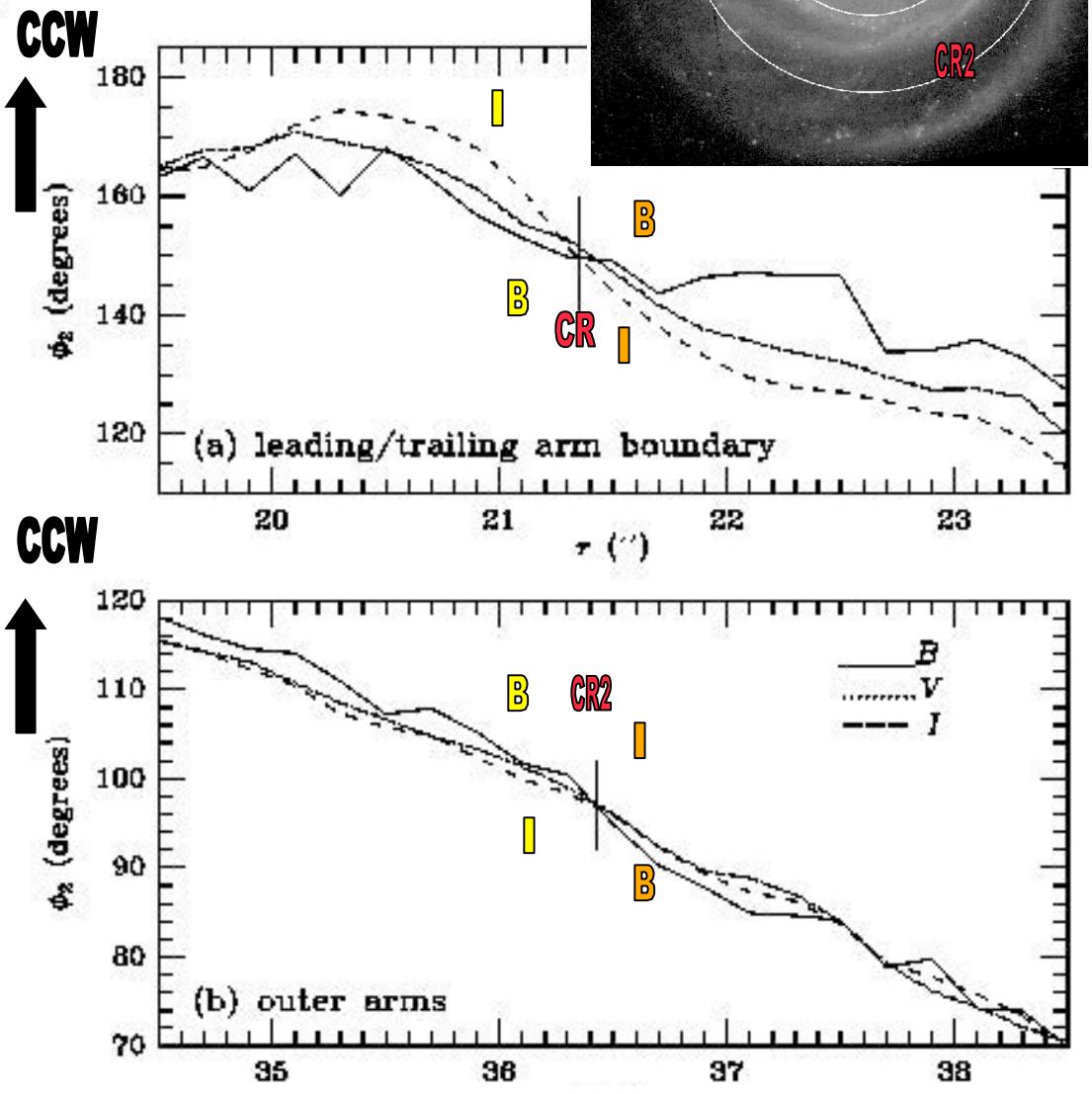
# Position angle vs r of m=2 IVB peaks

m=2 IVB order switches at CR= 21” & CR2= 36” where orbital angular rate equals pattern speed. Similar to m=1.

Confirms CW orbit & leading outer pair of arms!

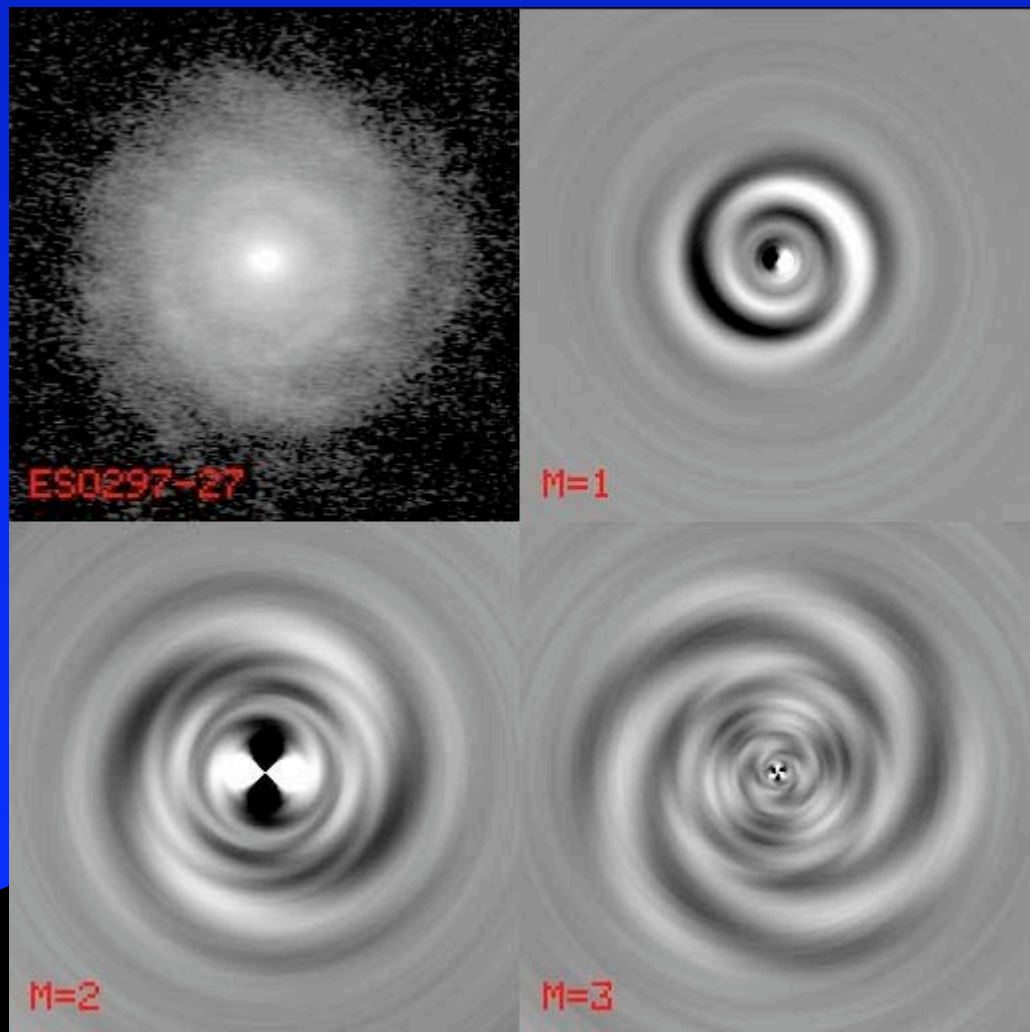
Will use CR,CR2 to revise rotation curve.



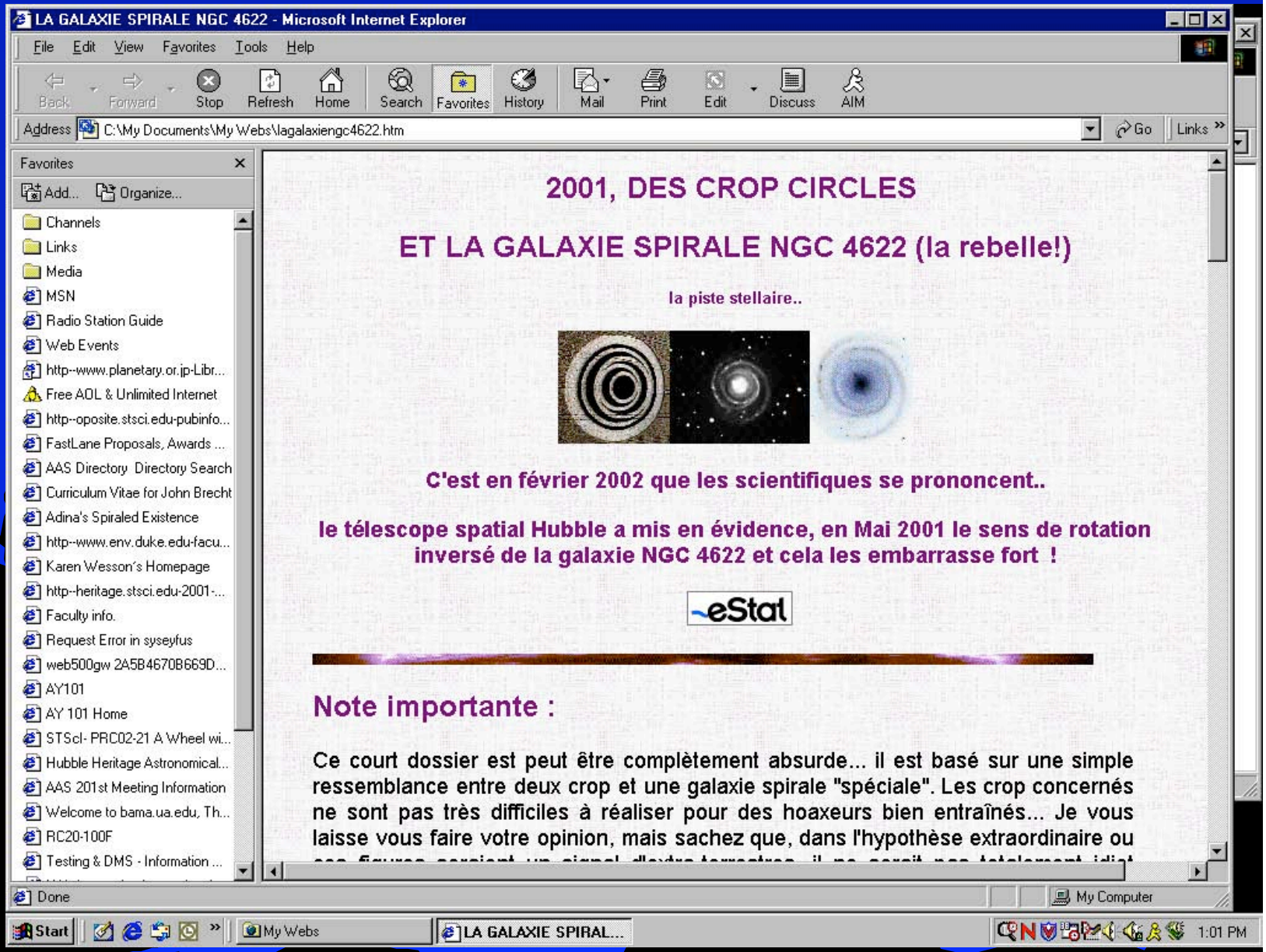
# Another 2 Way Galaxy Found

- R. Buta and graduate student R. Grouchy in recent observations have identified another two-way galaxy, ESO297-27
- It has a single inner arm and two and three fold oppositely winding outer arms.



# Summary

- Our conclusion from HST images that the two outer NGC4622 arms lead was simply not acceptable to some. One prominent astronomer stated, ``You're the backward astronomers who found a backward galaxy."
- Here we have substantiated our conclusion. With the observed flat then rising rotation curve
  - a plunging passage of a small galaxy could have triggered the inner trailing arm & outer leading pair.
  - NGC4622's disk orientation & m=1, 2 IVB sequences versus radius are consistent with an inner trailing + an outer leading pair of density waves.




- Now we know the origin of crop circle creators!