SEGMENTATION OF HYPER SPECTRAL CUBES VELOCITY MAPS FOR SPIRAL GALAXIES

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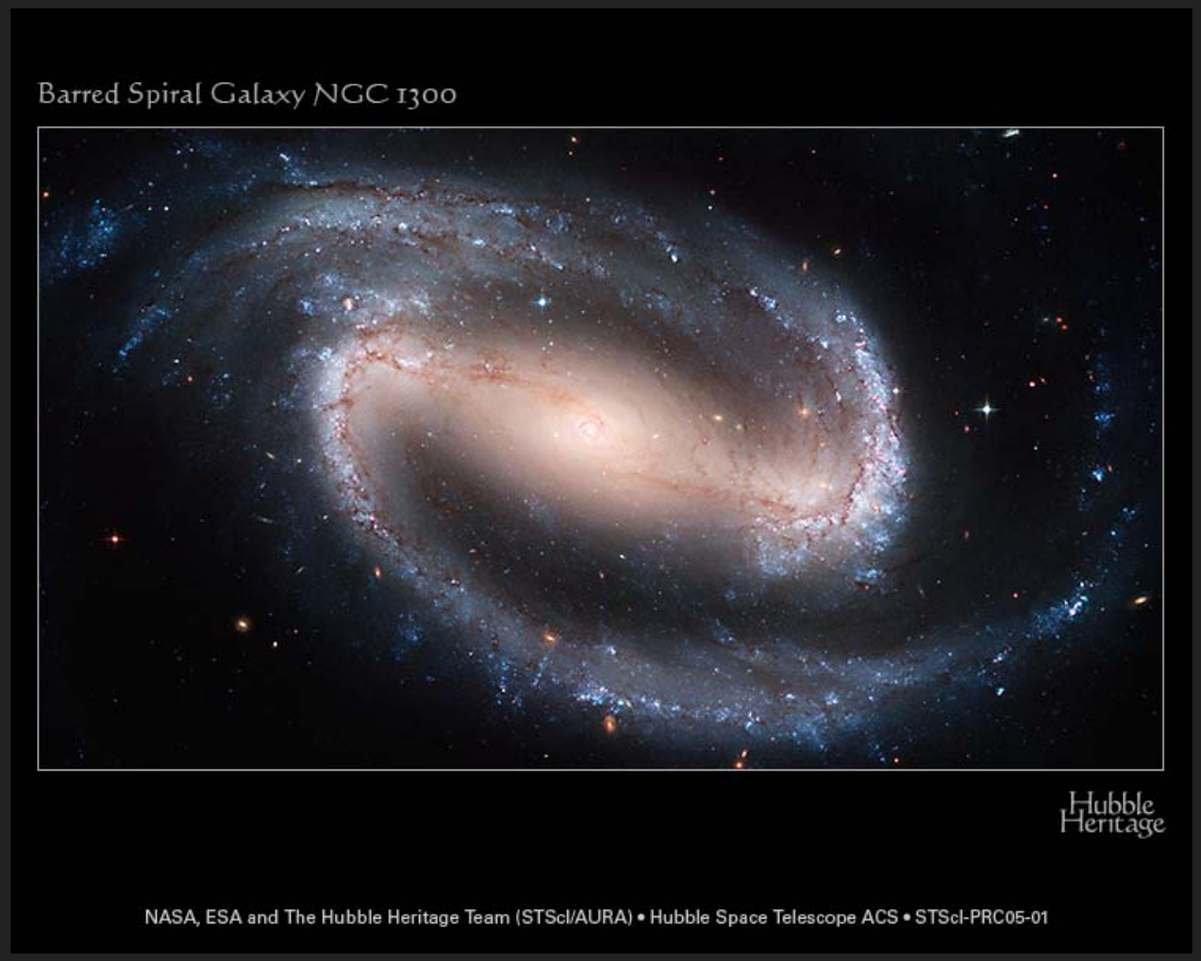
MIREILLE LOUYS, CHRISTIAN BOILY, T. BUCHERT, L. BIDEGAIN, J.-B. COURBOT & V. MAZET
OBSERVATOIRE ASTRONOMIQUE & IPSEO-IMAGES, ICUBE, STRASBOURG

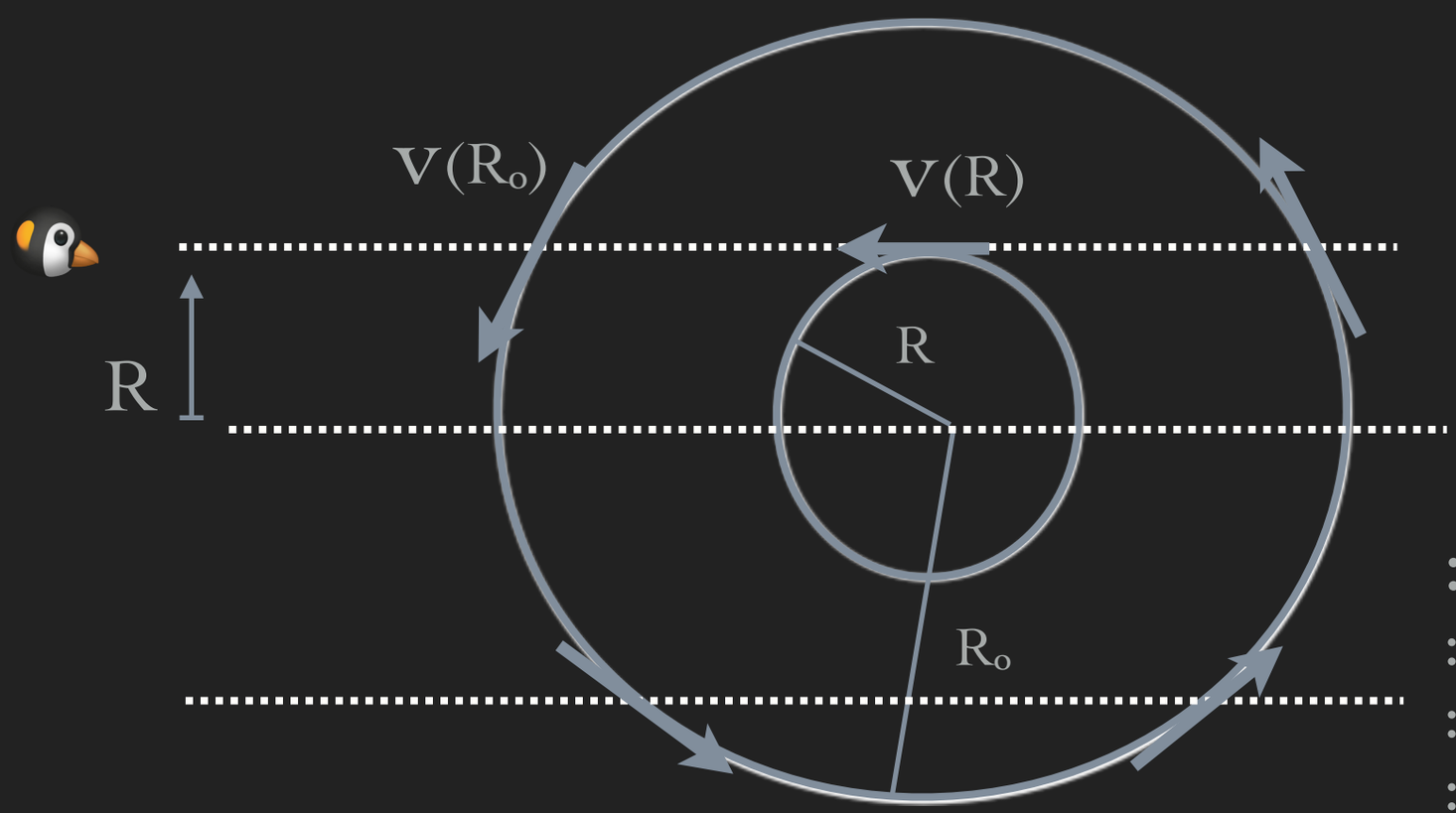
SPIRAL GALAXIES – CLASSIC EXAMPLES FROM HST IMAGES

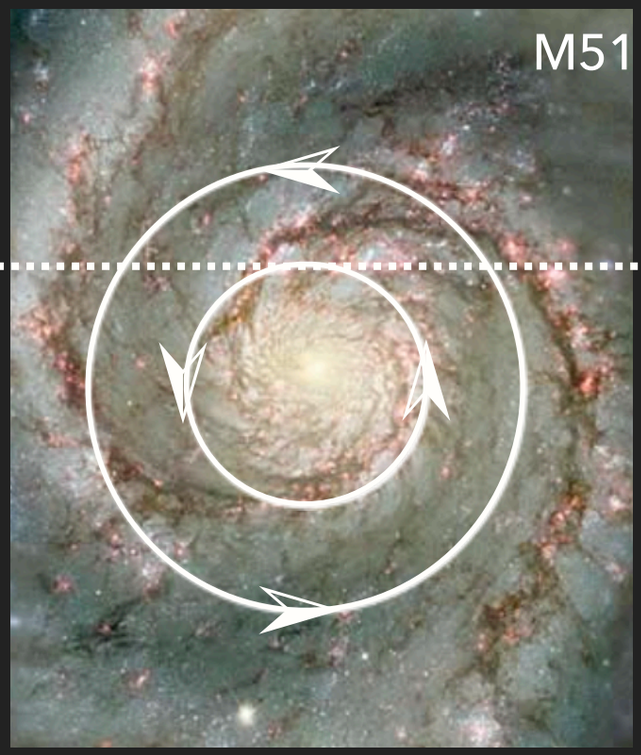
- Some ≈ 80% of galaxies are spirals / grand-design or barred



THE ROTATION CURVE: MEASUREMENT, LINE OF SIGHT VELOCITY

- Edge-on view : simplest configuration





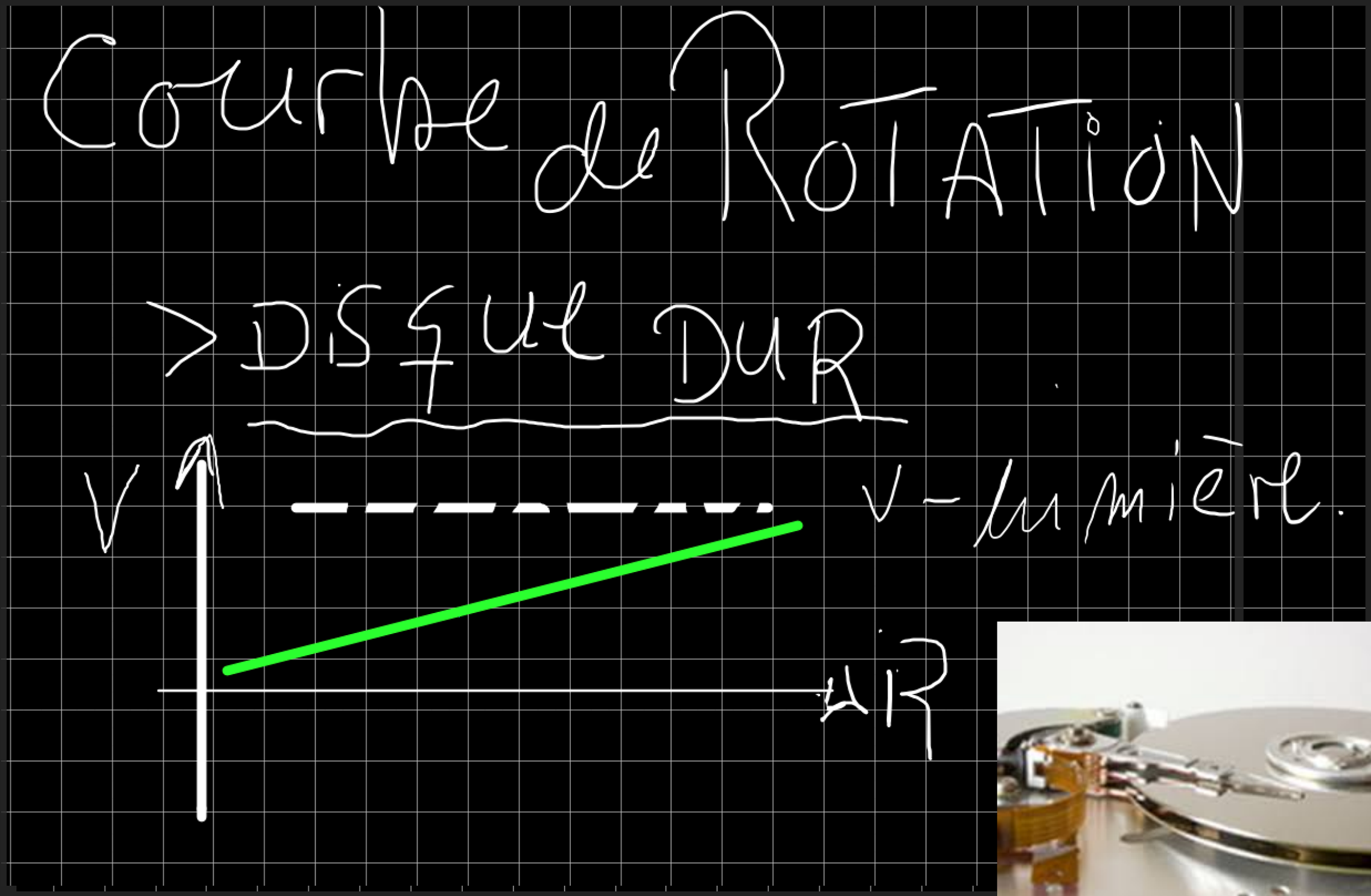
:: Projection effects
:: mean the los measurement
:: covers a range of values.
:: The peak value *possibly*
:: coincides with smallest
:: projected radius R on the los.

:: Important hypothesis:
matter on ≈ **circular** orbits

ROTATION CURVES OF SPIRALS: DÉJÀ VU .. THEORY

- basic assumption: velocity field is everywhere continuous
- Circular velocity v_c is a measure of enclosed mass
- Antonucci's rule: bump in light / morphology → bump in v_c
- Spiral arm, central bar, burst of star formation

ROTATION CURVES OF SPIRALS: DÉJÀ VU .. THEORY



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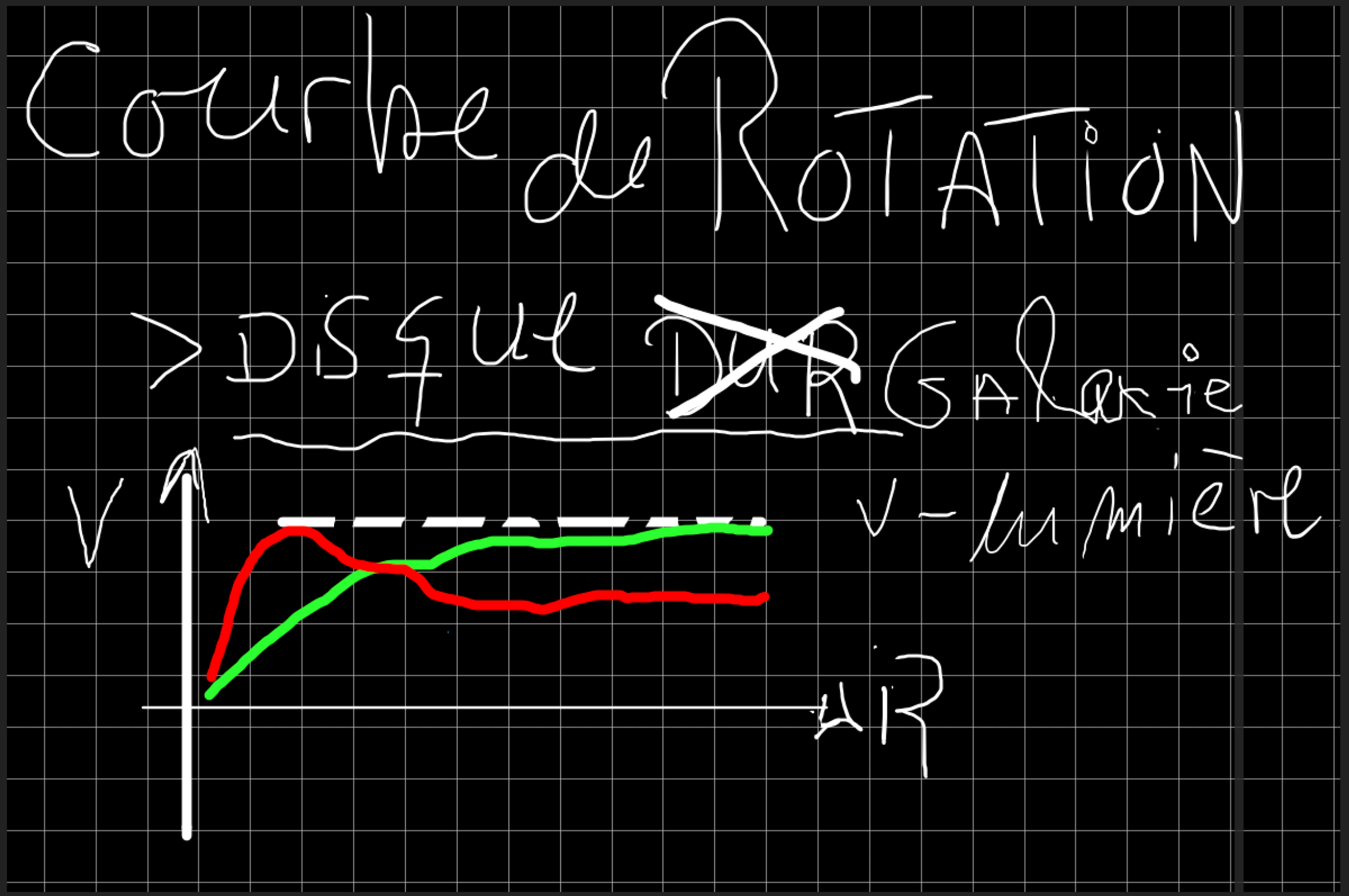

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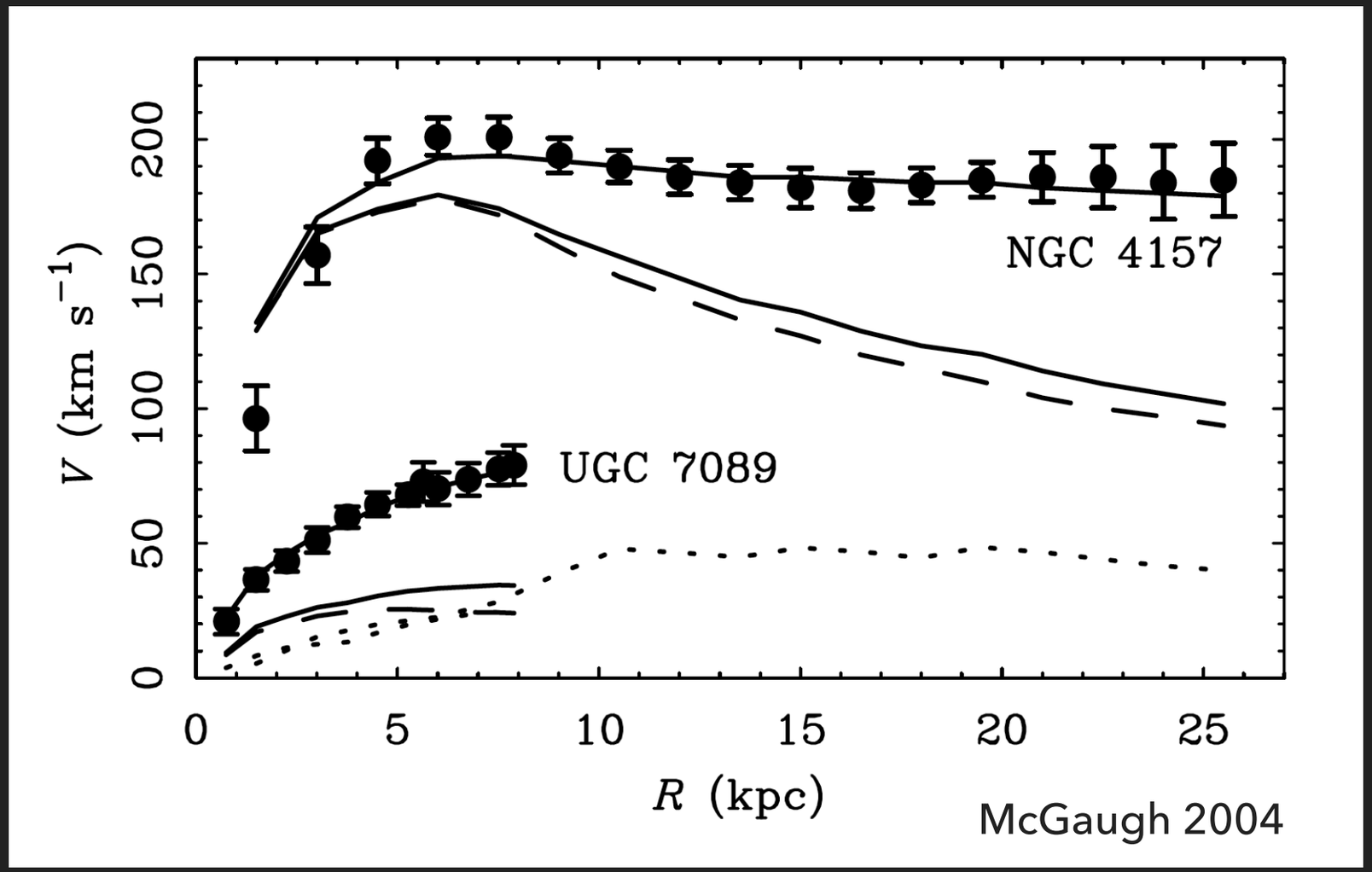
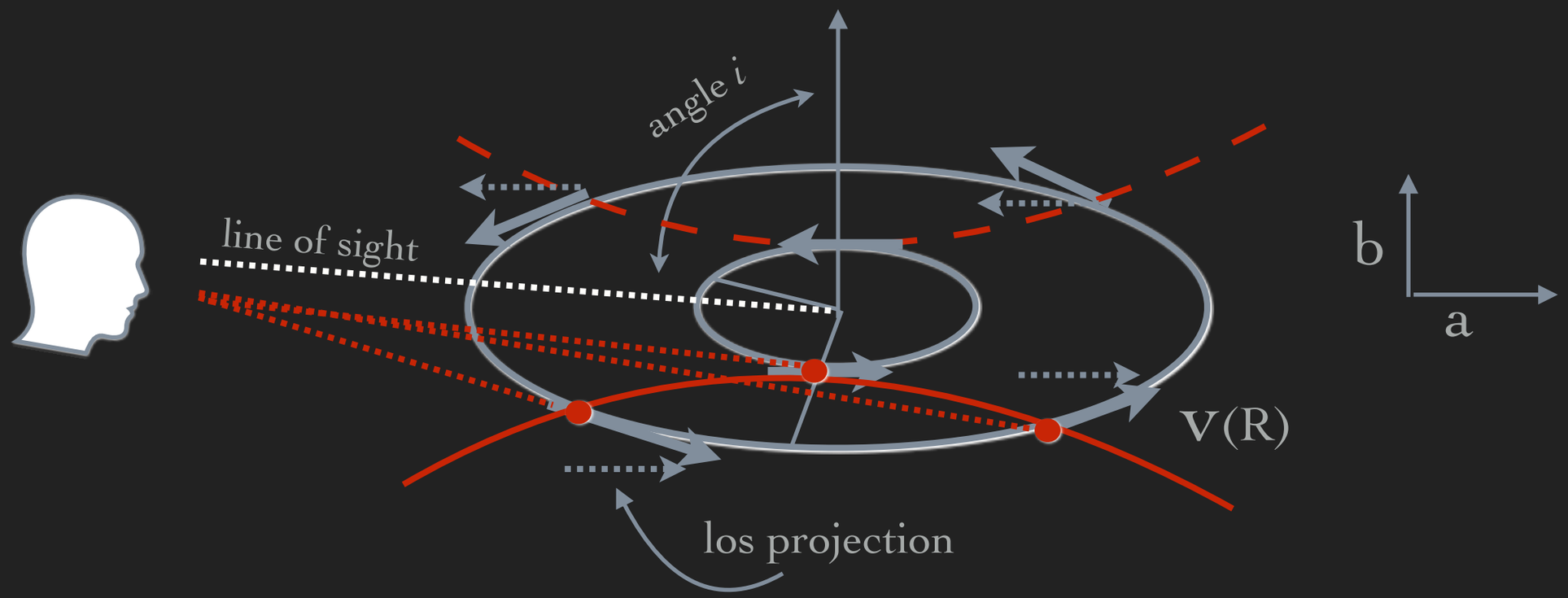


McGaugh 2004

THE ROTATION CURVE: SPIDER MAPS

- When viewed at a projection angle *i* the situation is completely different. The disc now appears ellipsoidal, of photometric (semi-) minor- and major axes b/a: b = a cos *i* . The los velocity has its norm modulated by sin *i* : v → v sin *i* at all cylindrical radii R. The edge-on view has i = 90˚. **Note: "line of sight" is "los" in short form.**



:: The plane of the disc is now resolved spatially, points with the same los velocity fall on e.g. the red curve (solid or dash).

:: The *shape* of the curve of iso-velocity clearly depends on the profile v[R].

THE ROTATION CURVE: SPIDER MAPS

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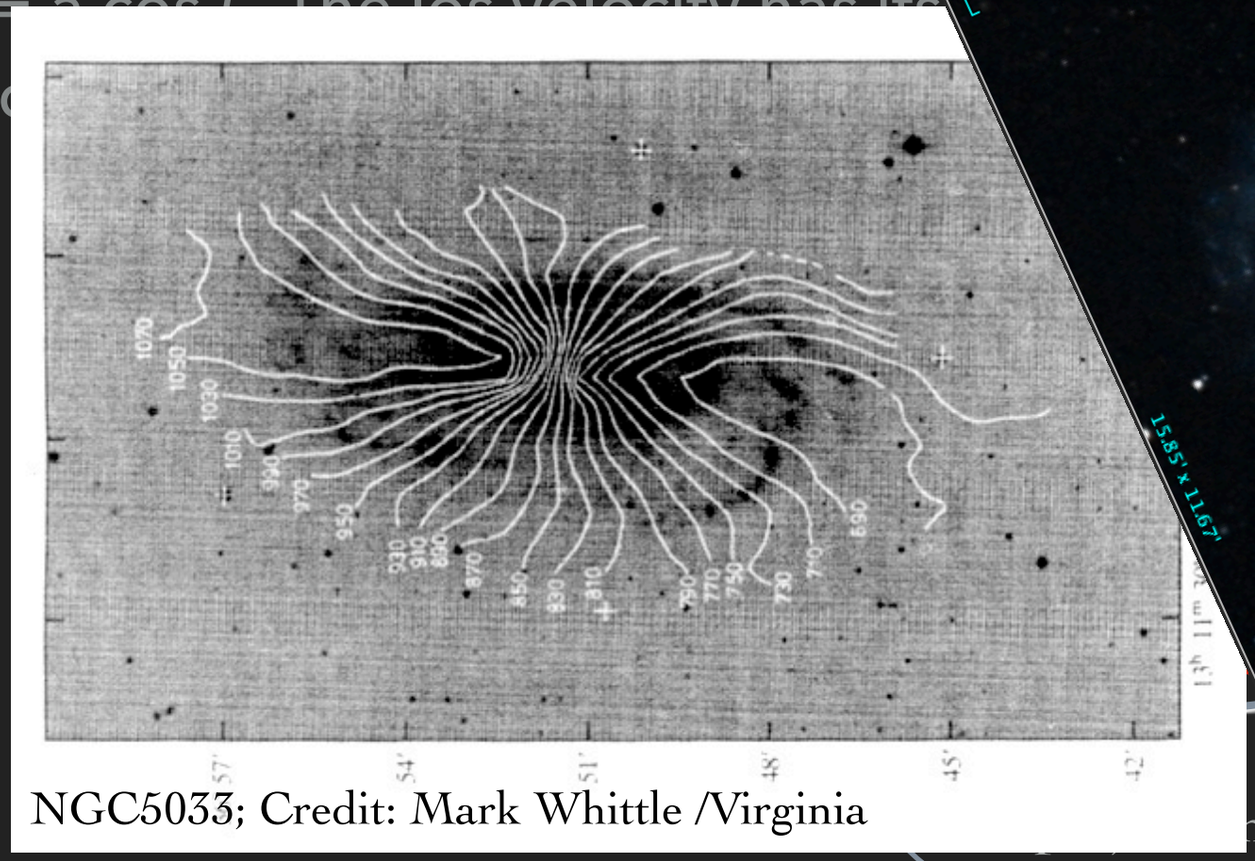
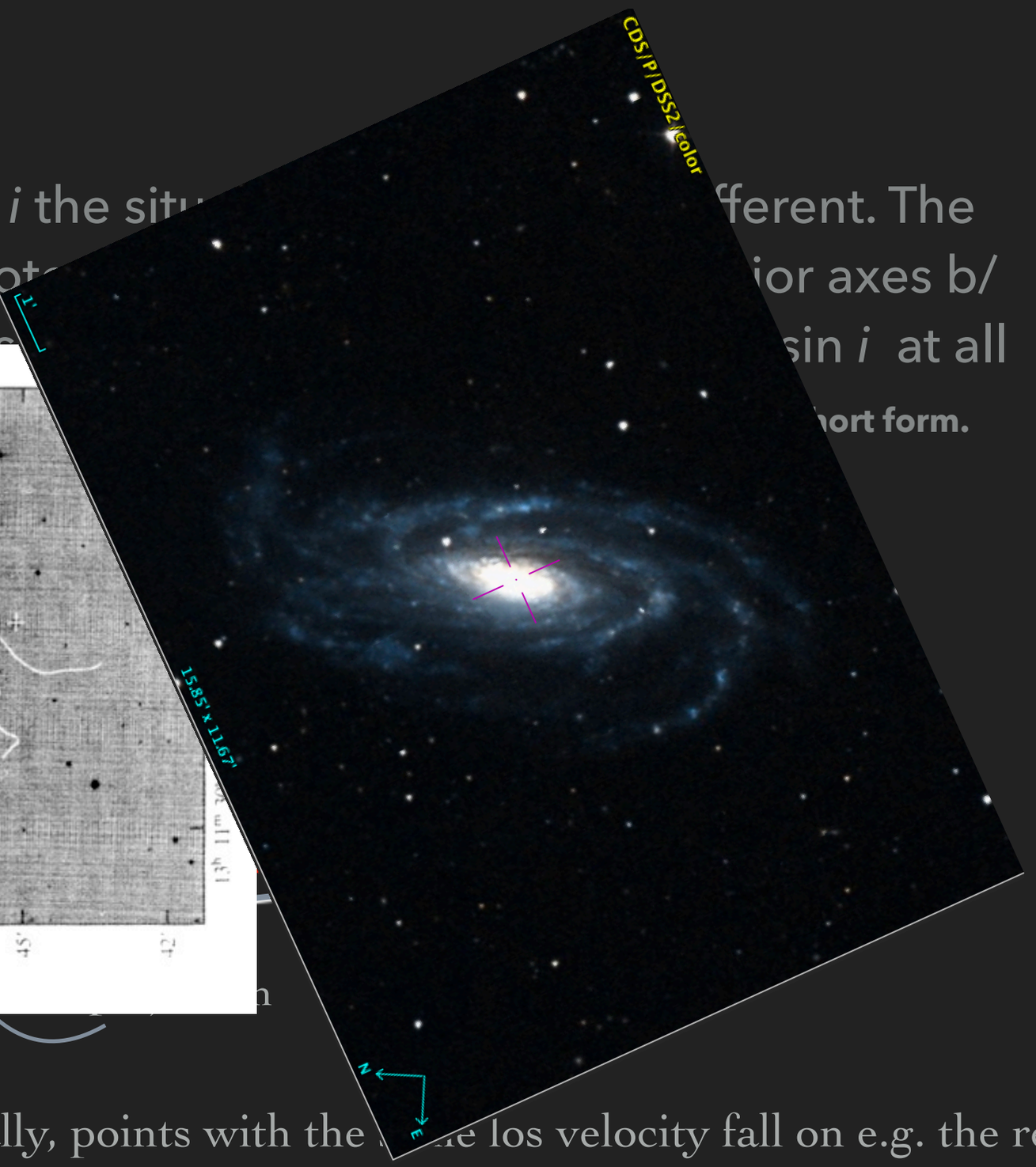


NGC5033; Credit: Mark Whittle /Virginia



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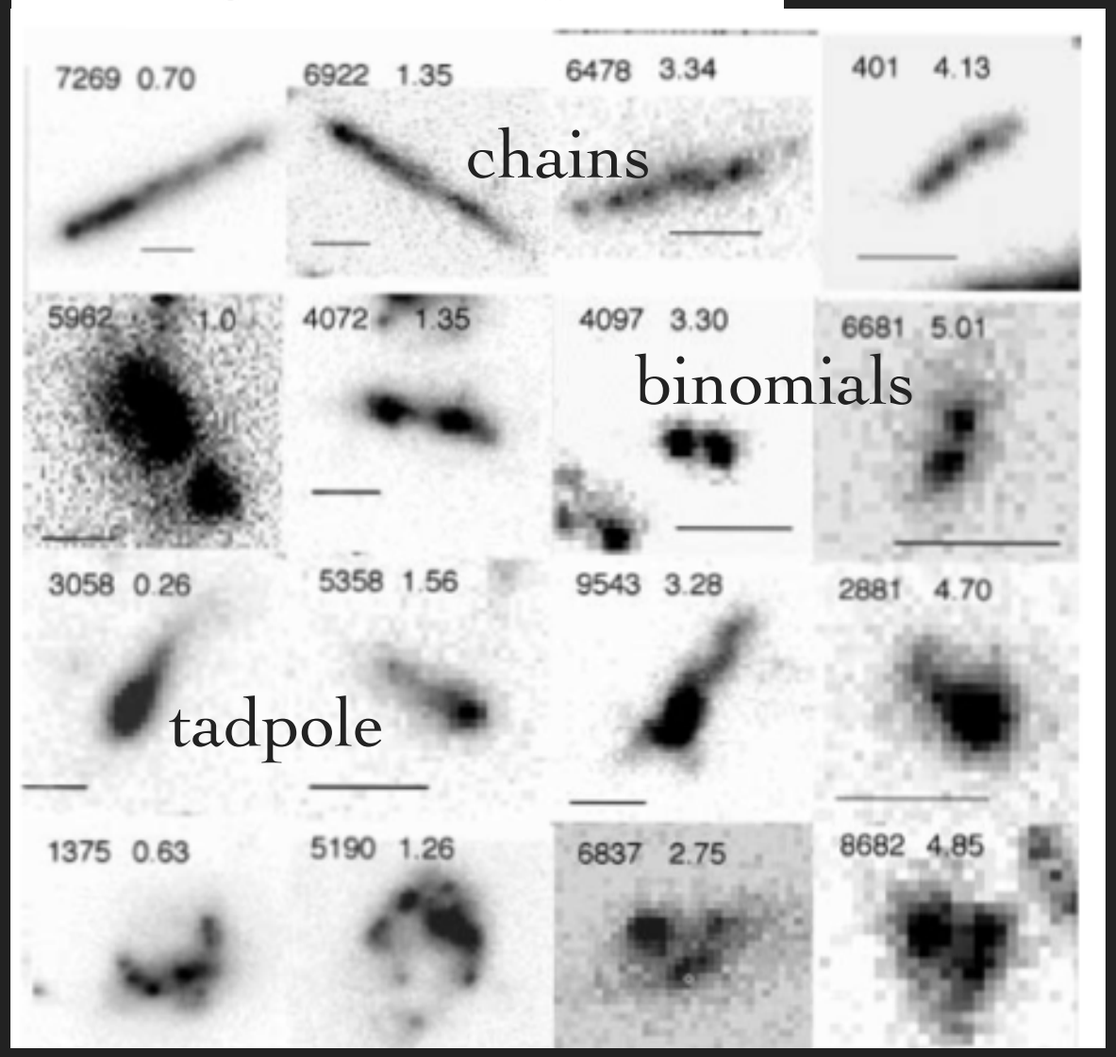
HIGH Z SURVEY : HUBBLE ULTRA DEEP FIELD (HUDF)

D. Elmegreen et al. (ApJ, 2007)



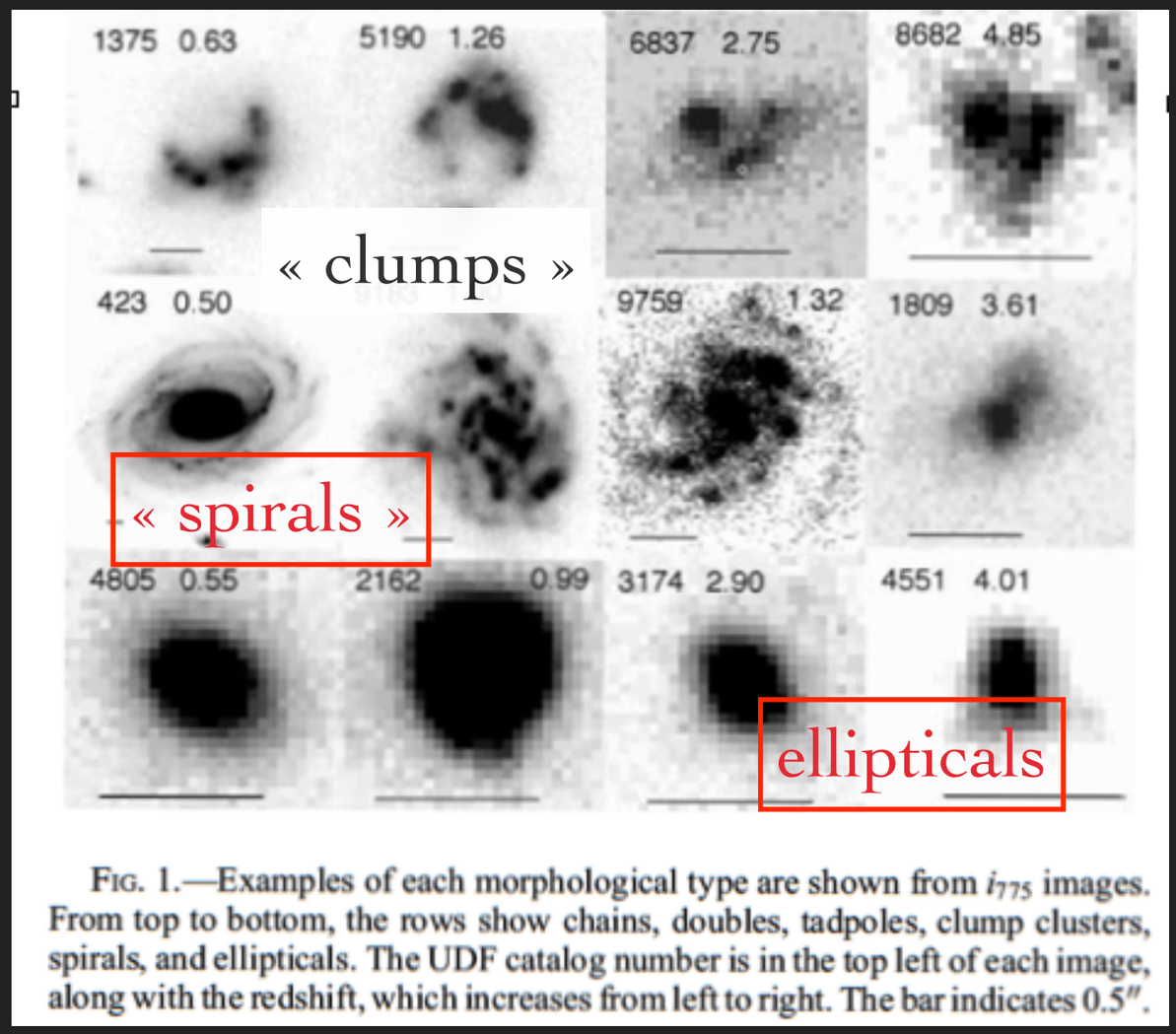


FIG. 1.—Examples of each morphological type are shown from i_{775} images. From top to bottom, the rows show chains, doubles, tadpoles, clump clusters, spirals, and ellipticals. The UDF catalog number is in the top left of each image, along with the redshift, which increases from left to right. The bar indicates 0.5″.

- Observations of galaxies out to z ~ 2 - 3
- Irregular morphology, colorful names ..
- Hubble types relatively rare, reference angular size = 0.5″

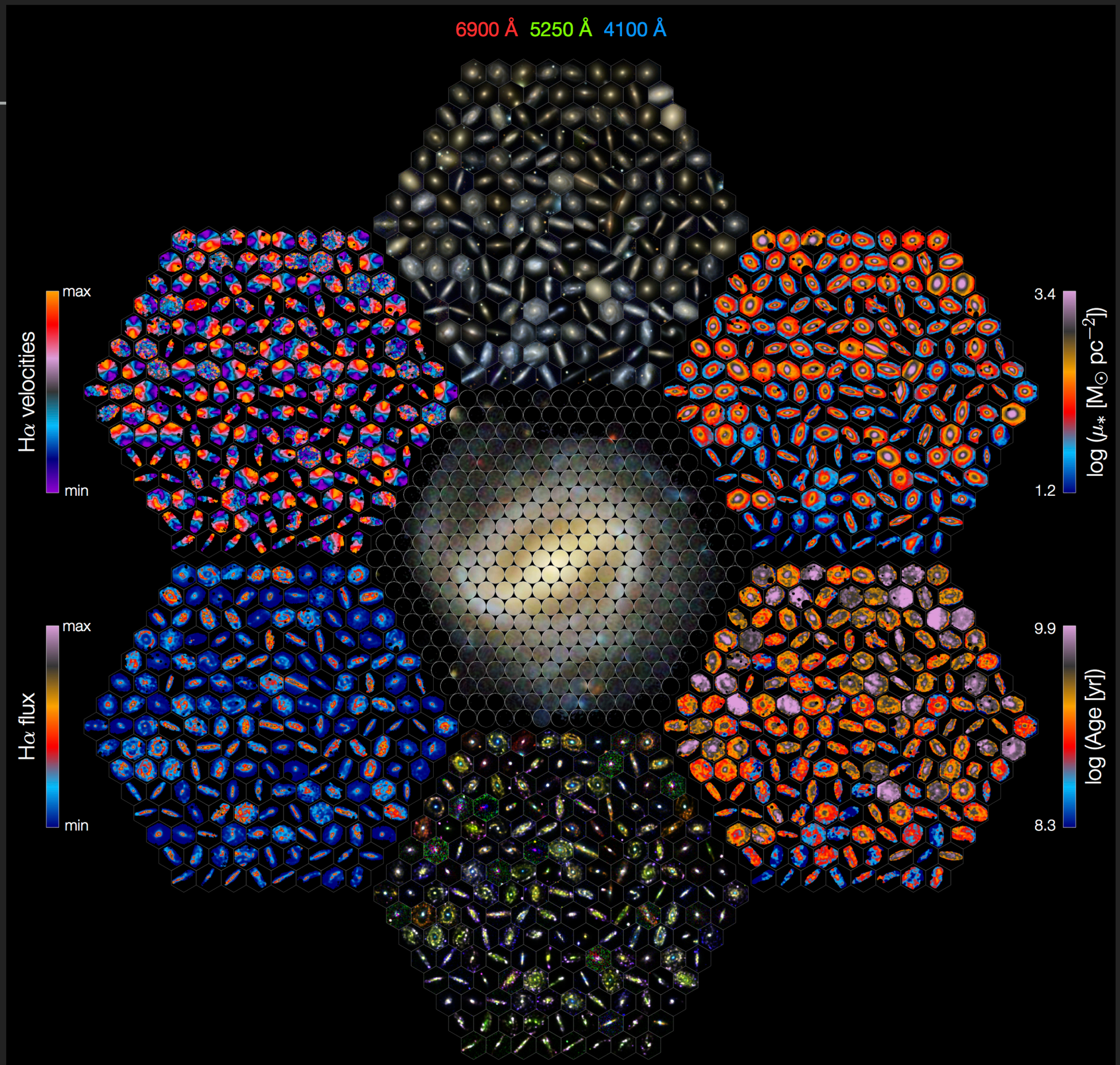
See Guérou et al. 2017 AA: The MUSE HUDF z ~ 0.2 - 0.8 resolved galaxies survey for an update

CALIFA SURVEY DR2 HYPER-SPECTRAL CUBES

- CALIFA SURVEY DR2 on-line archive
- A collection of around 600 galaxies in the Local Universe chosen from the Sloan Digital Sky Survey (SDSS) data collection with $0.005 < z < 0.03$
- Data taken at Calar Alto 3.5 telescope with PPAK integral field unit (IFU)
- Hexagonal field-of-view of ~1.3'radius, median spatial resolution 2.5 arctic
- V500 setup covering the nominal wavelength range 3745-7500 Å with a spectral resolution of 6.0 Å (FWHM, or 2 - 3 channels)
- Spectral calibration error in wavelength ~10 km/s → 20 km/s

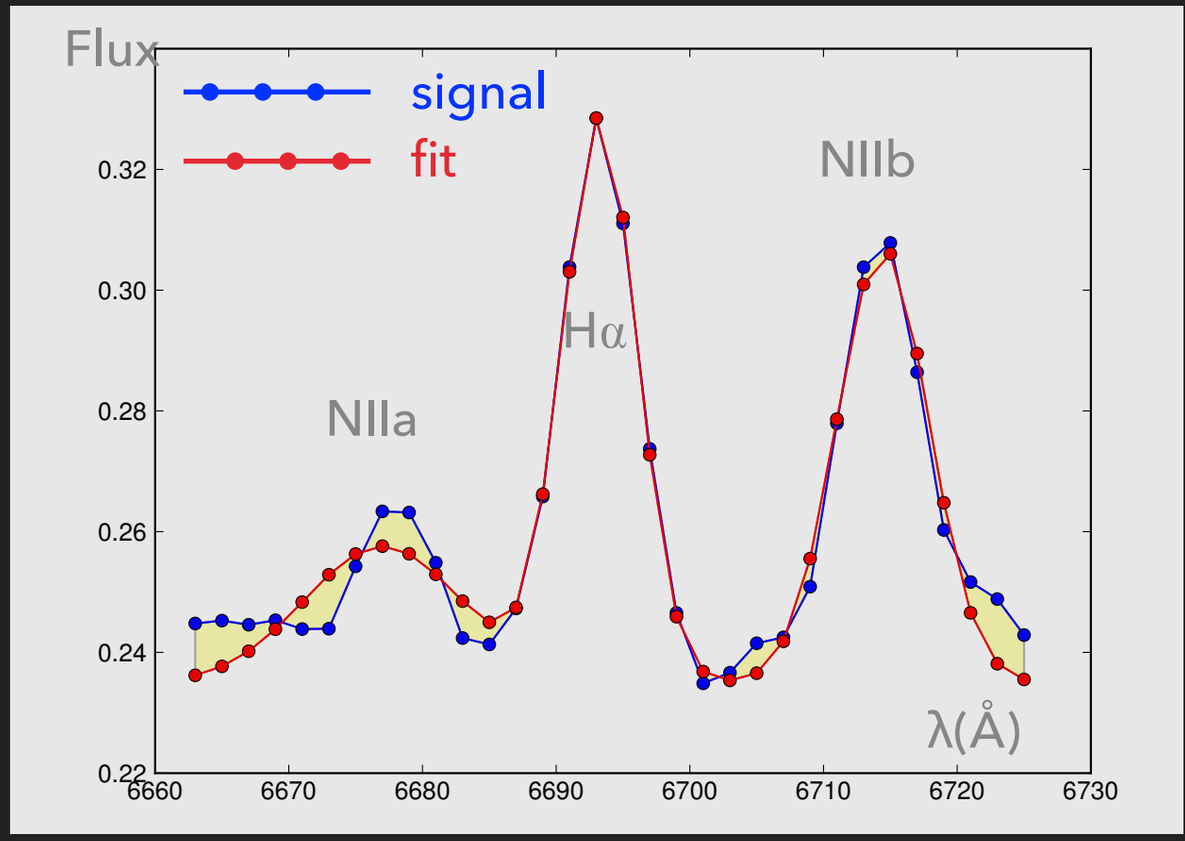
CALIFA DR2

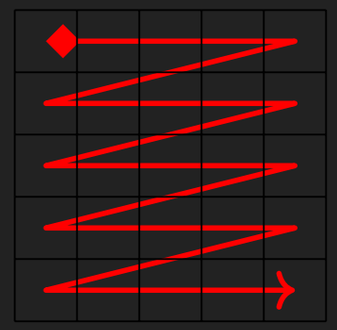
- Map emission- and absorption lines
- Derive velocity maps, gas and stellar content
- mass & age distributions



METHOD: EXTRACTION OF EMISSION LINES

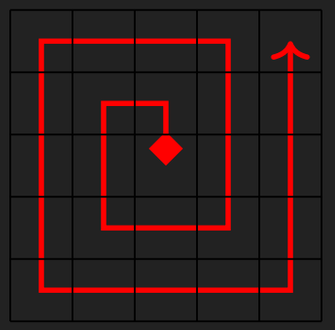
- Spectral Line Extraction and spectral shift estimation –> Radial Velocity
- Choice for a line pattern (NIIb, Halpha, NIIa)
- 3 Gaussian profiles to fit on expected lines in each *spaxel* –> 9 params :($\lambda H\alpha$, $\mu H\alpha$, $\sigma H\alpha$), and 2 triples for NIIa, NIIb .
- Fitting algo : gradient descent (Levenberg-Marquardt)
- Image path for fitting: Initialize position from neighbouring visited pixels : spatial redundancy assumption
- Python code for modularity





(a) Premier script

Row-wise scan



(b) Second script

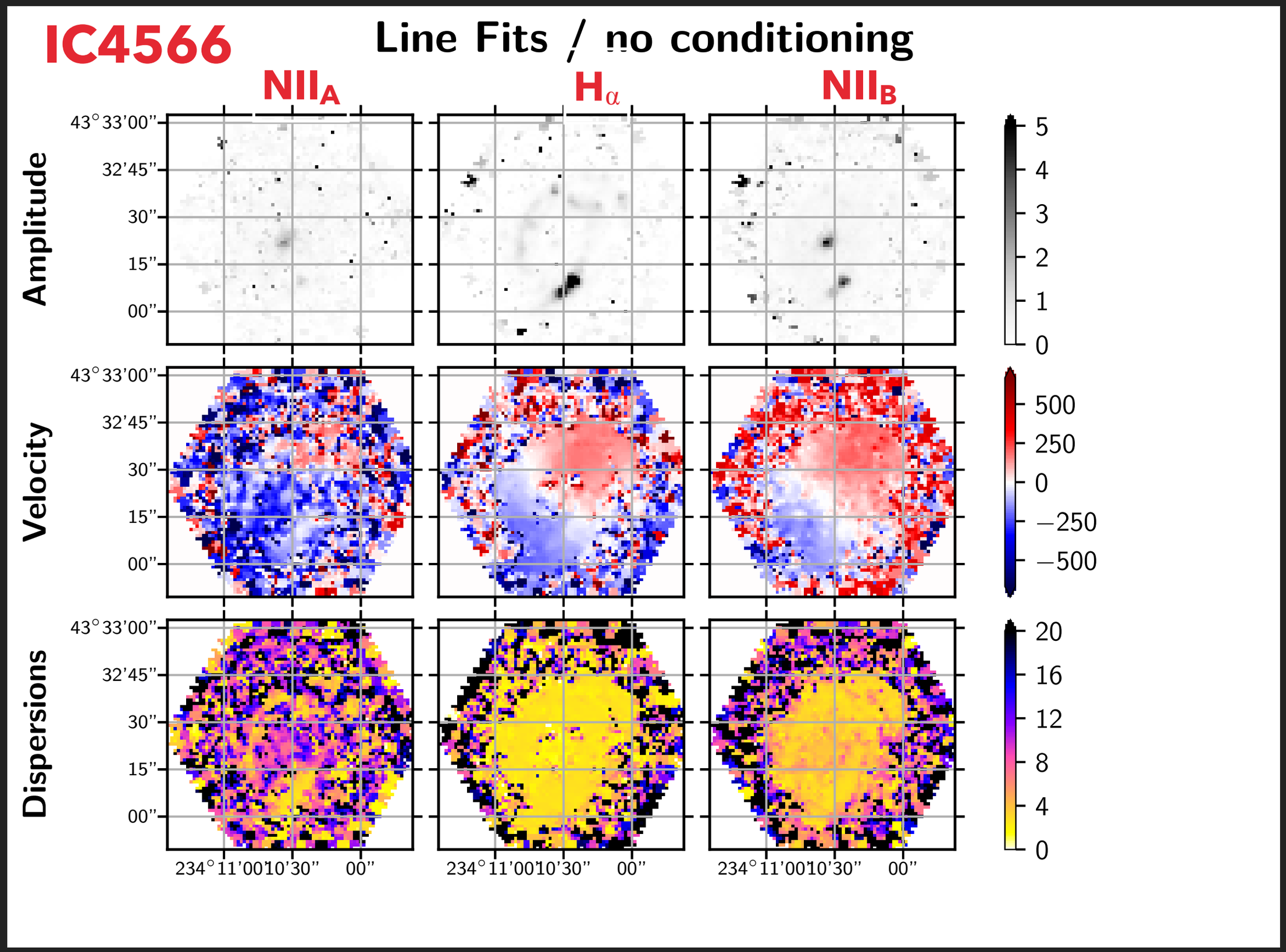
Spiral scan with seeded values

Note : 32 channels used out of ~ 1800

CODE PROPERTIES AND OPTIMIZATION STRATEGY

- ++ Python is modular
- ++ Graphics are easy to compute and check
- –- slow in processing : 1 cube > 10mn (600 s) 🕓
- Optimisation for computation
- Select non-linear fitting with constraints for the Gaussian fit in C
  - NLOPT for residual computation mainly
  - CBLAS for vector and matrix manipulation
  - 1cube –> 3 maps and residuals in 6s or less 🕓
- Can easily be extended to fit more lines (with priors)

RESULTS : DENSITY, VELOCITY AND DISPERSION MAPS



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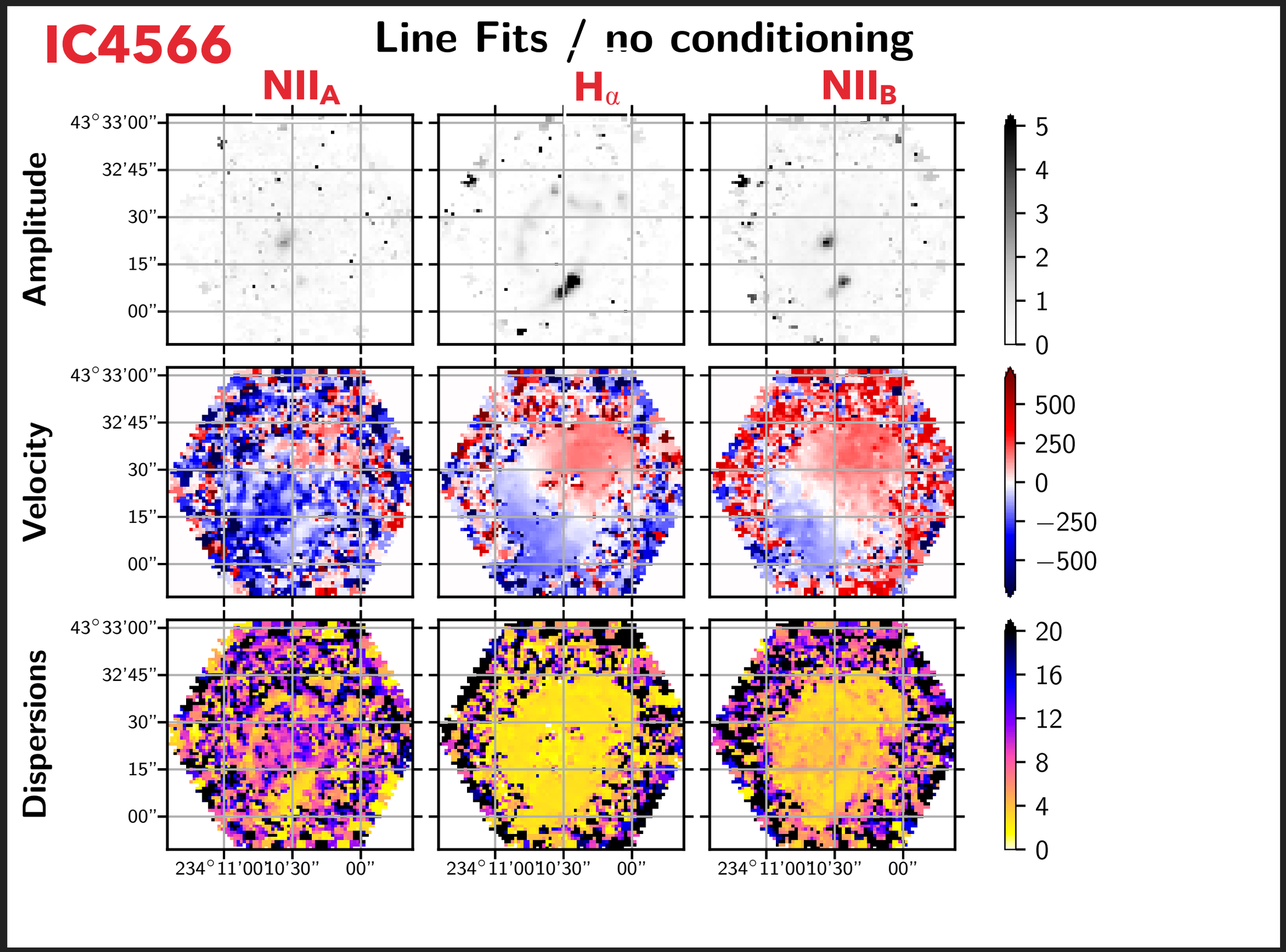

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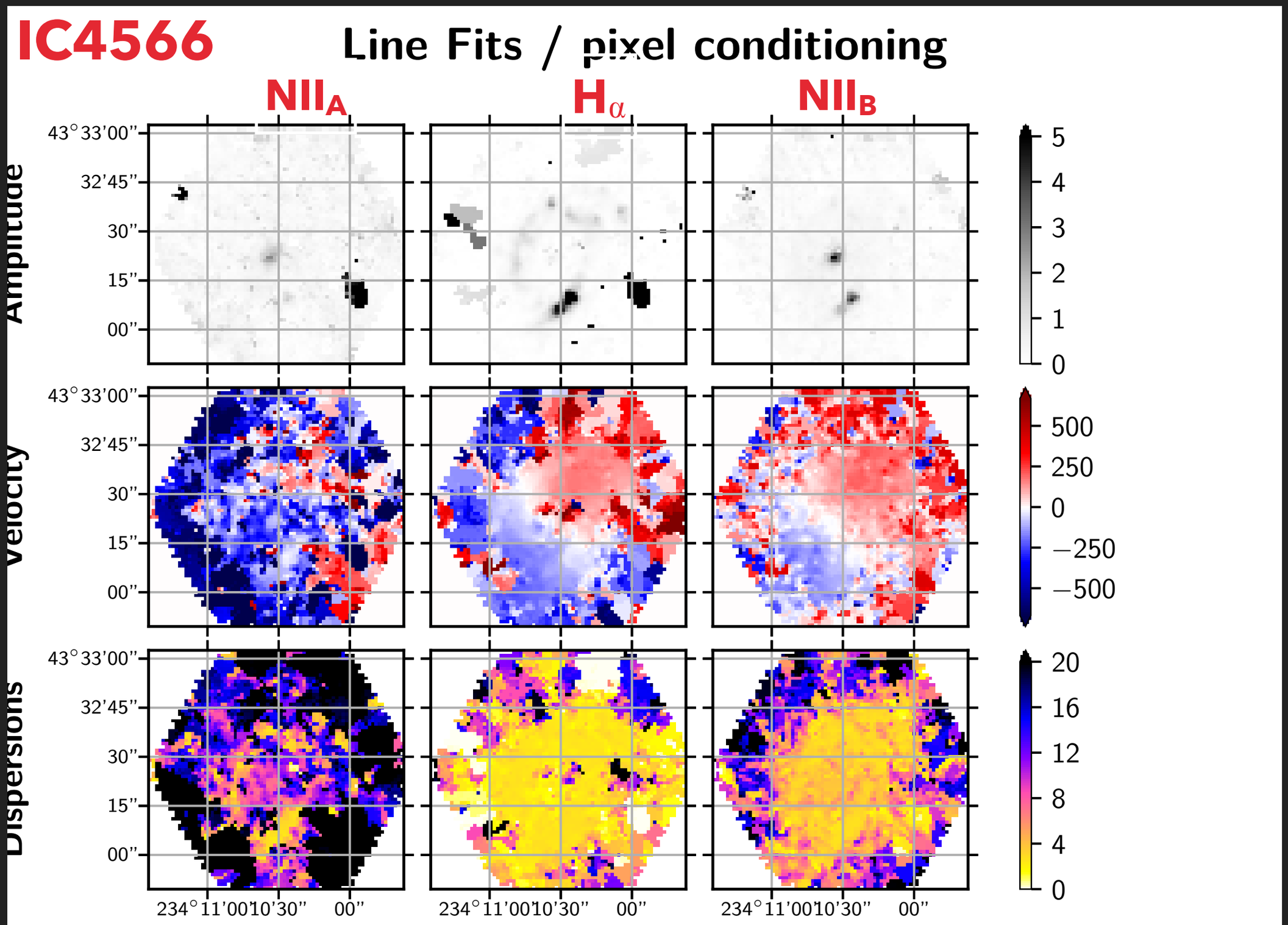

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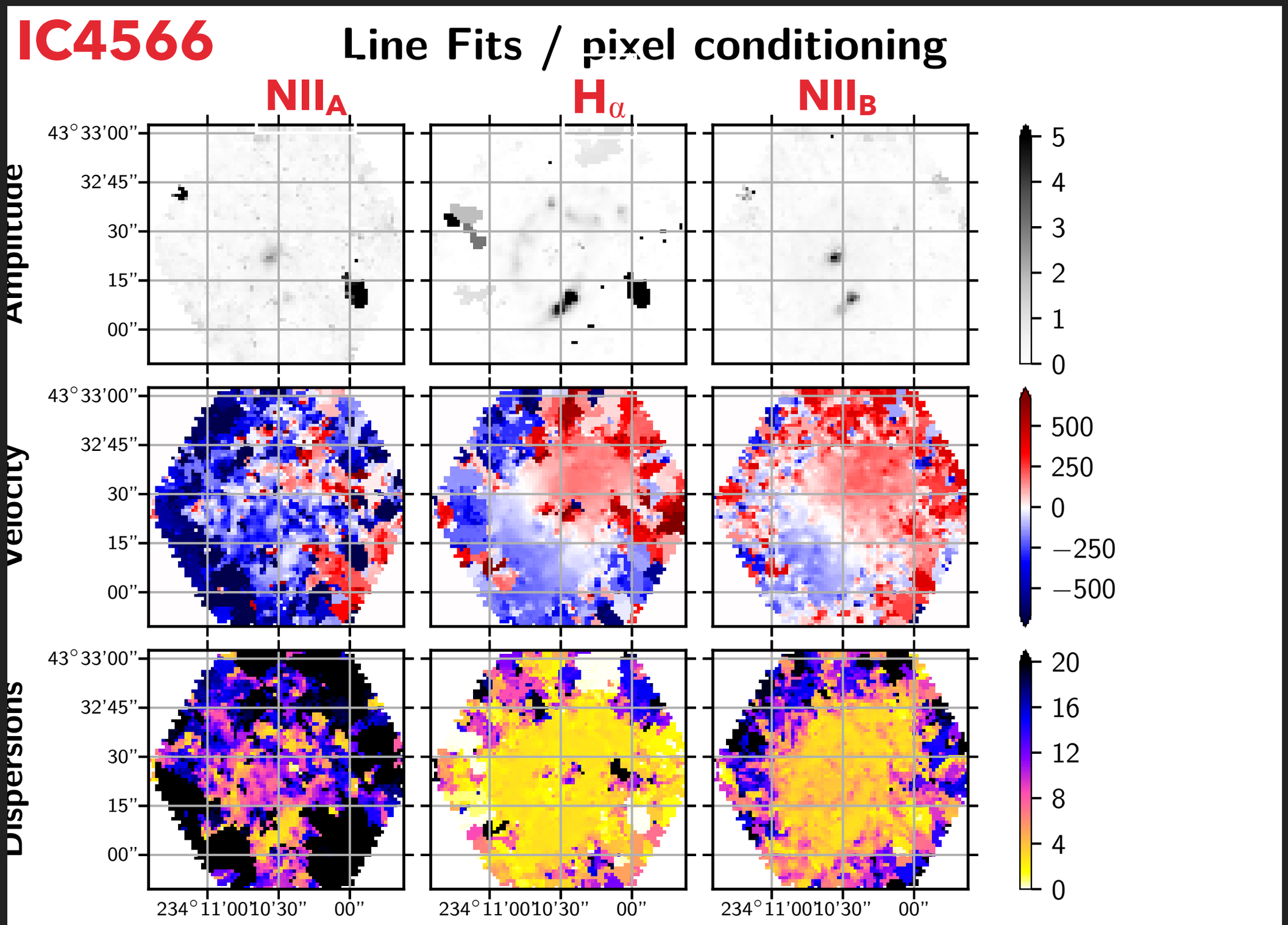

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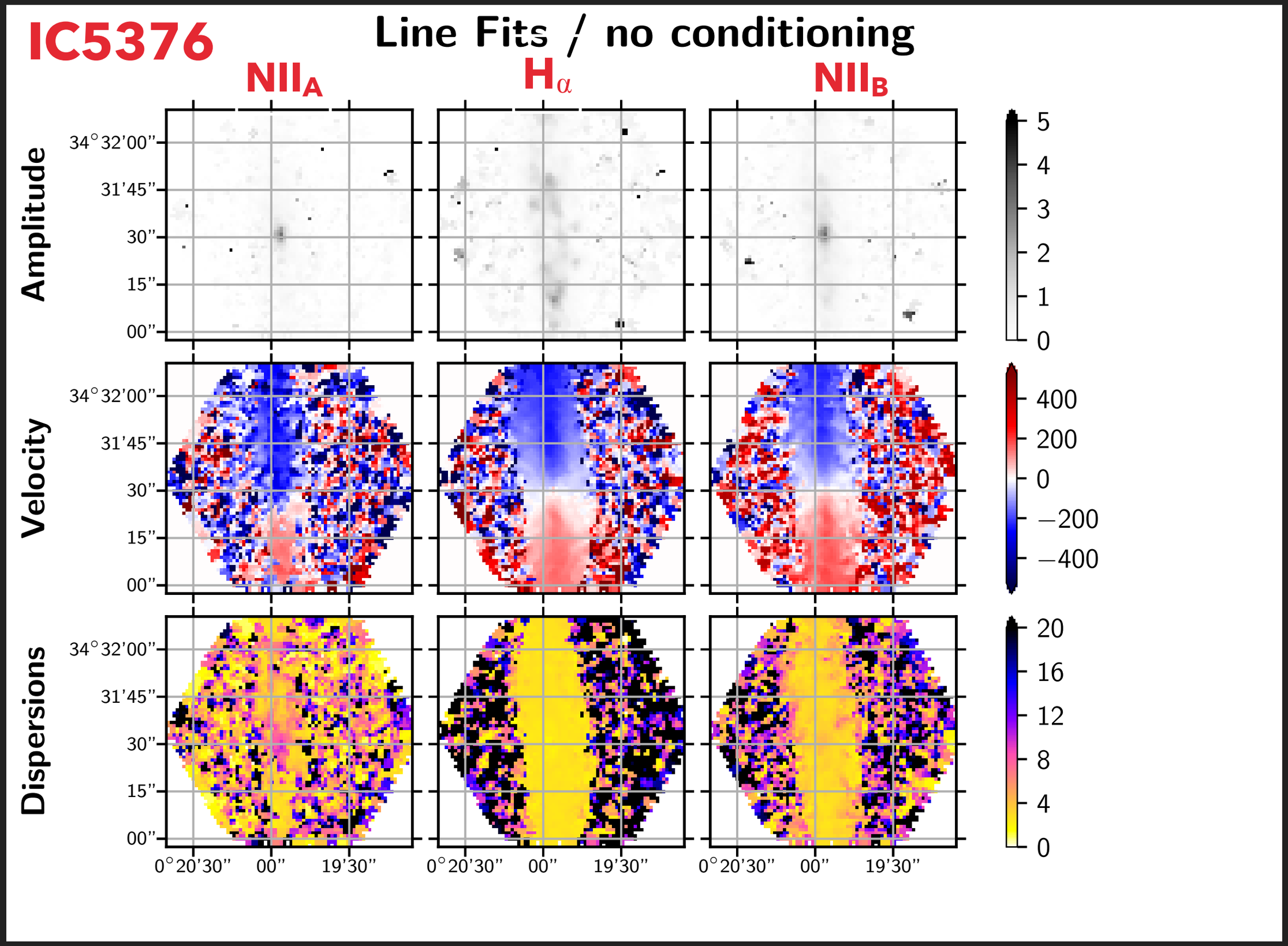

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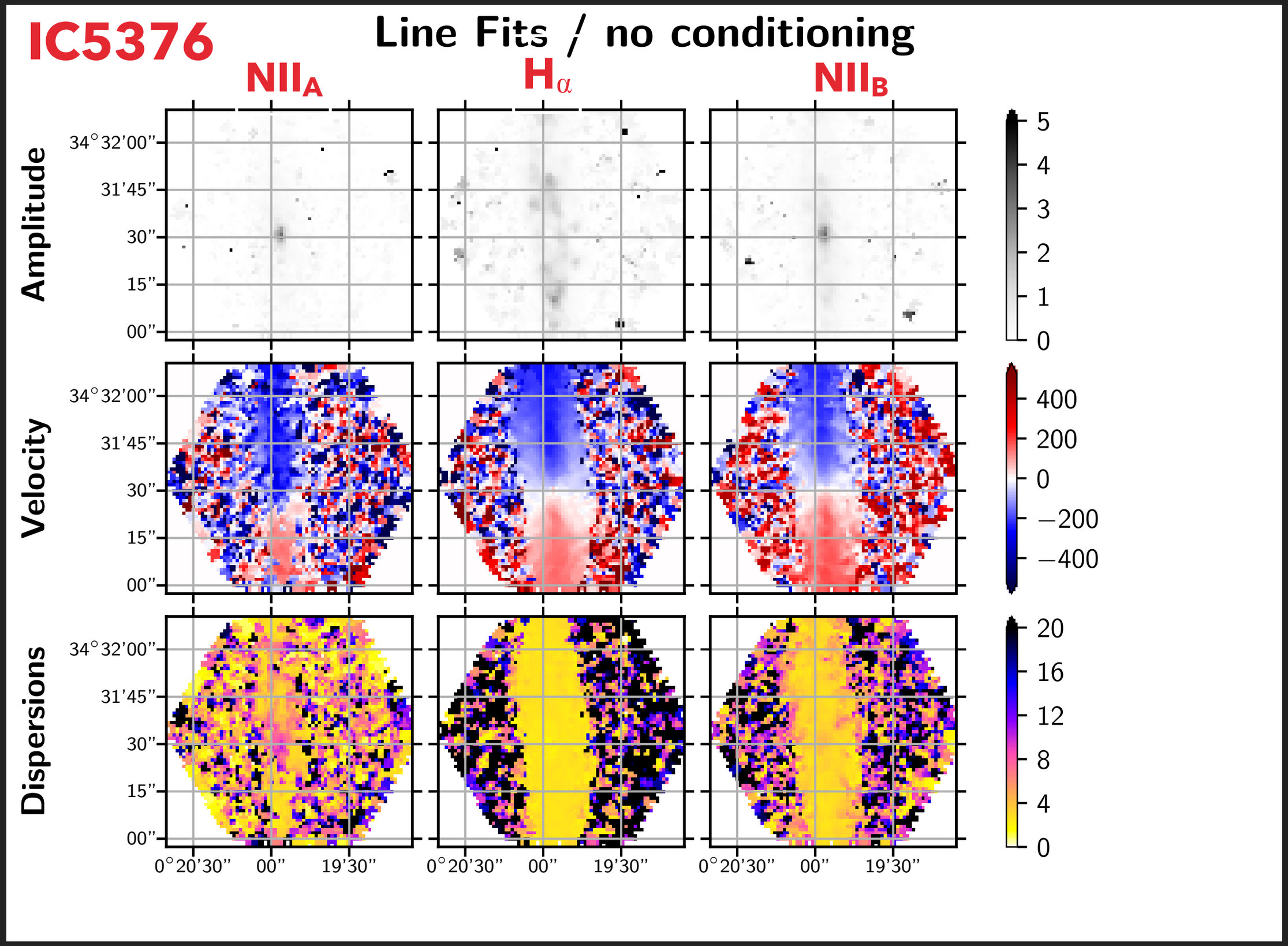

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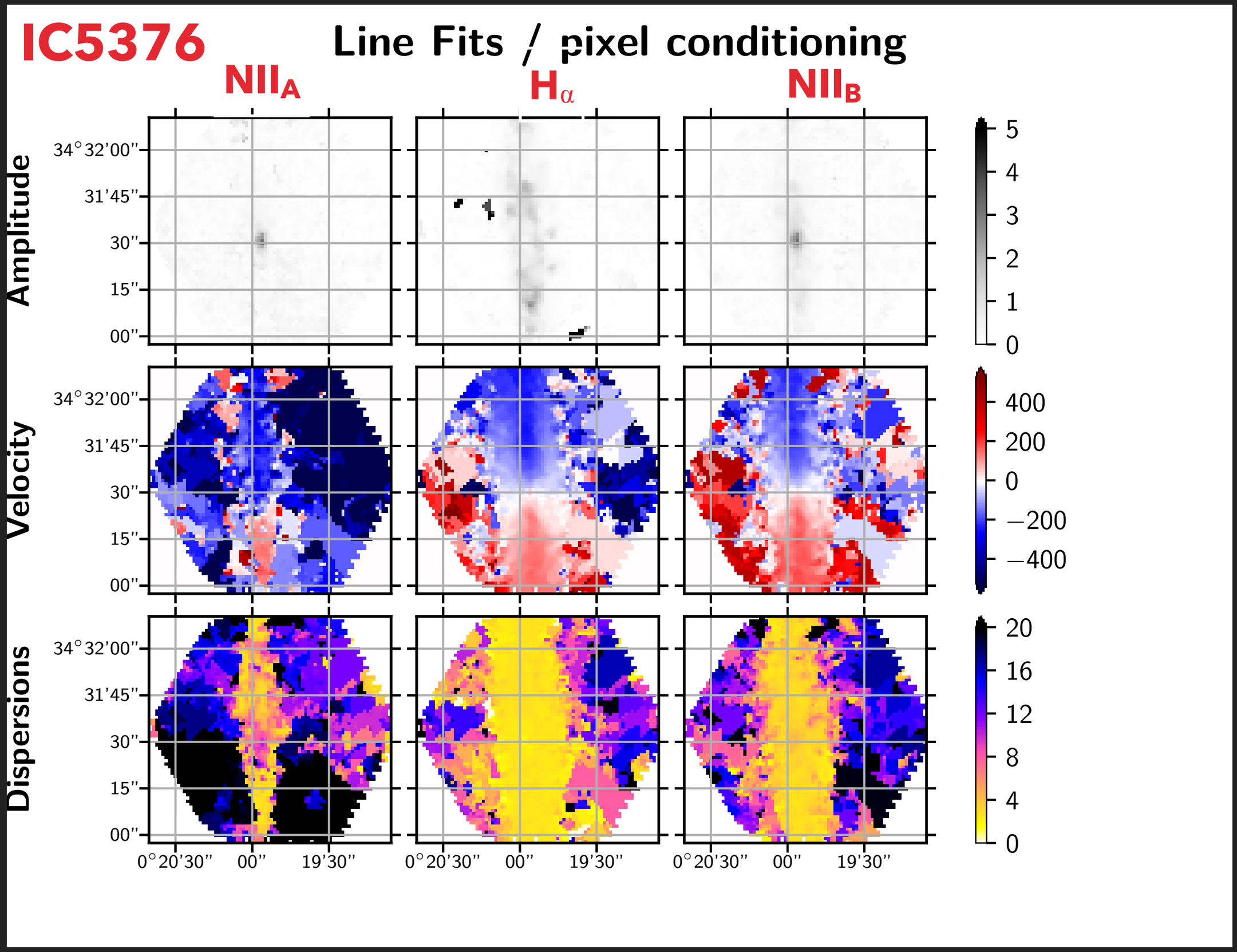

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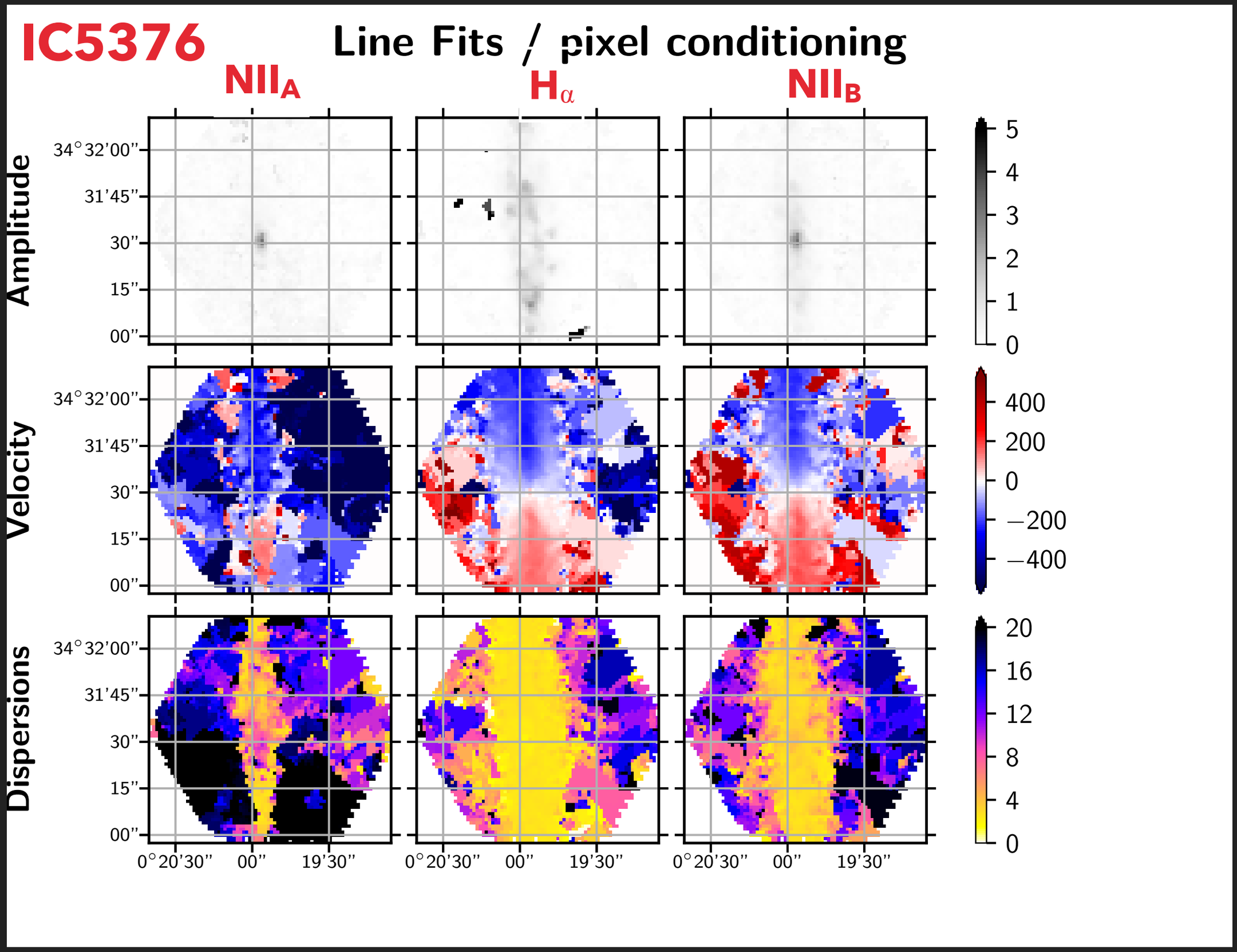
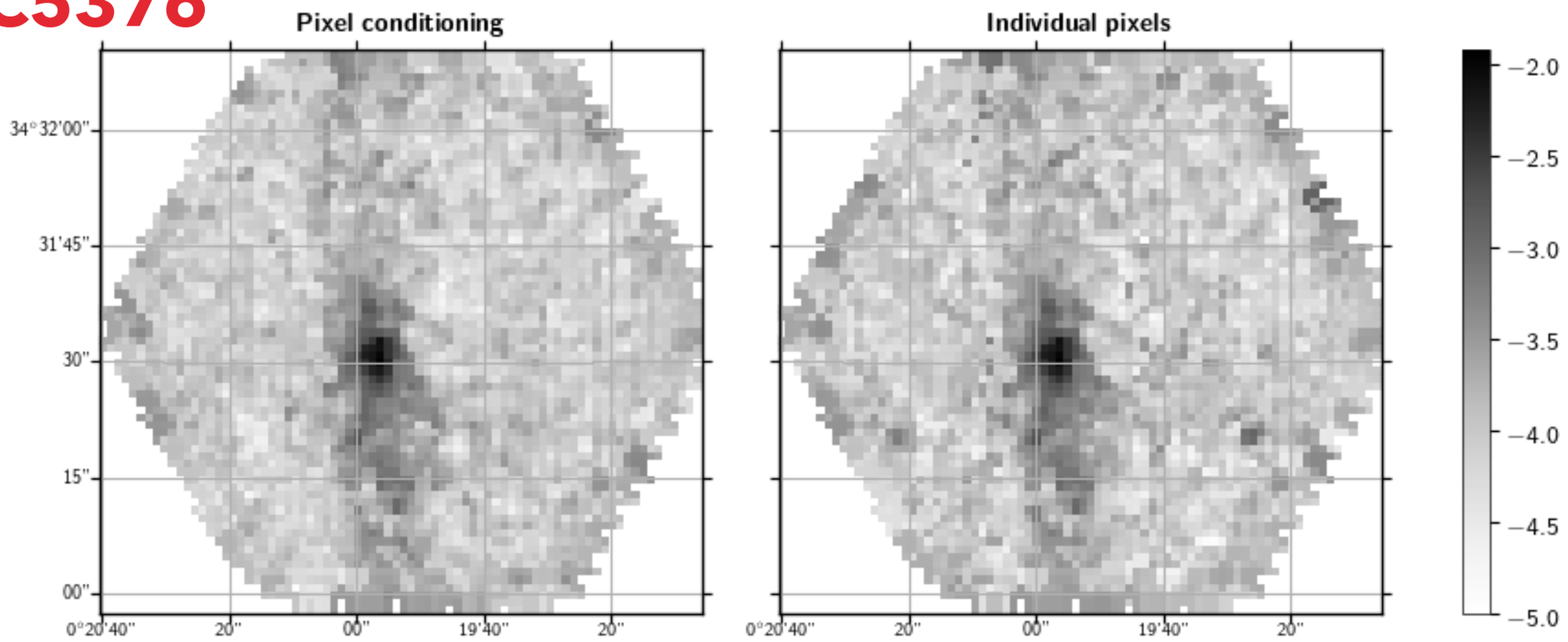


RESIDUALS

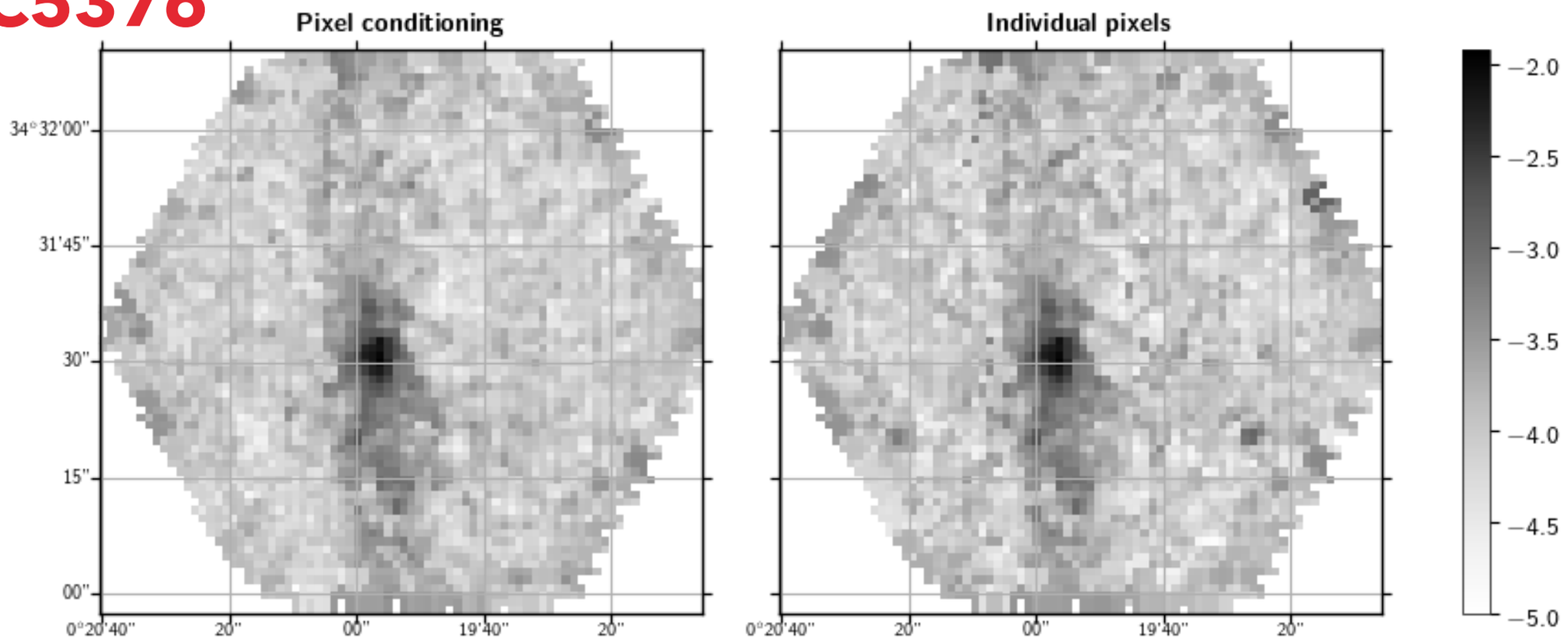
IC5376



- Amplitude of the residuals (log scale)
- Left panel: with pixel conditioning
- Right panel: no conditioning (independent pixels)

RESIDUALS

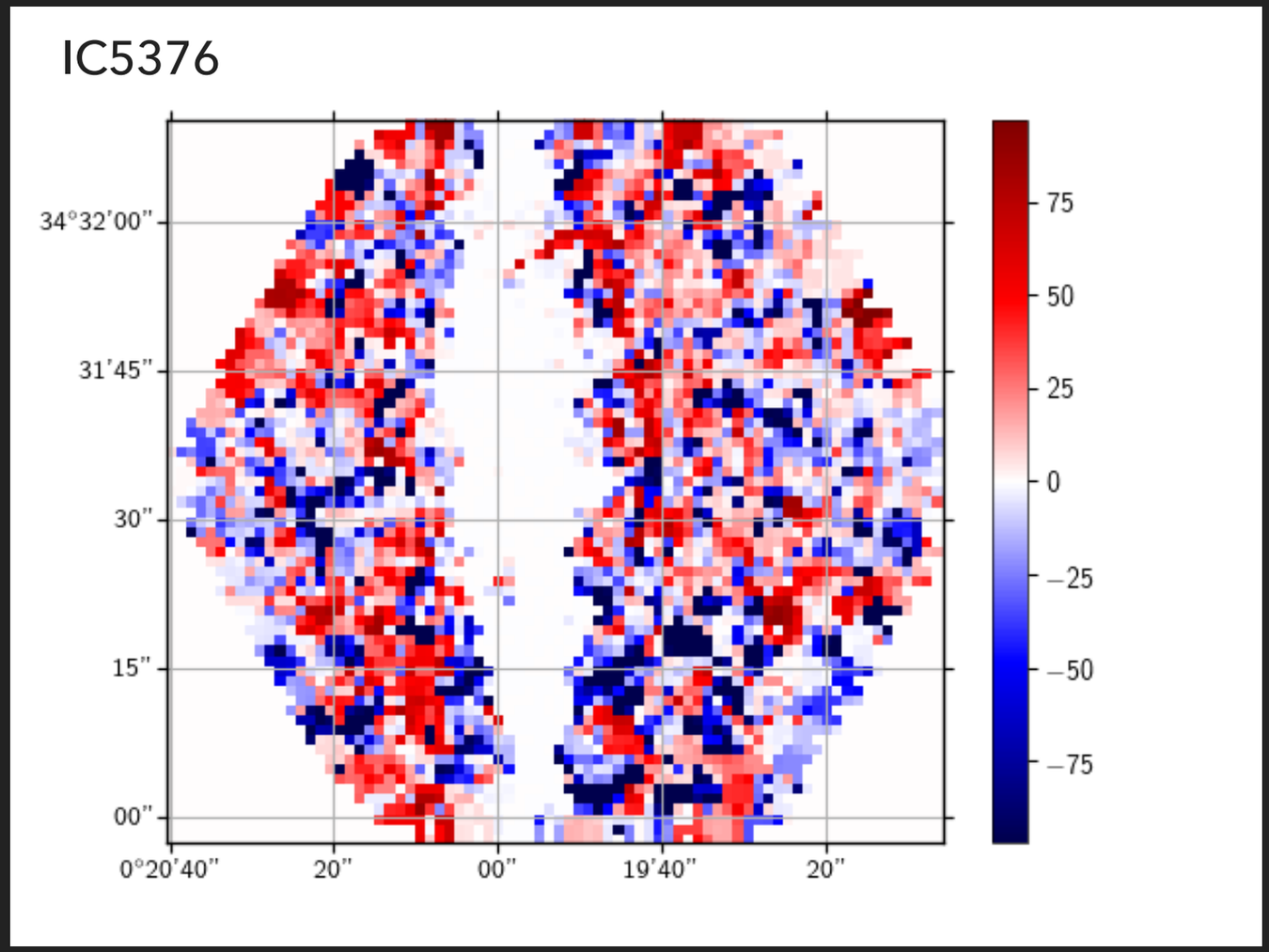
IC5376



- Amplitude of the residuals (log scale)
- Left panel: with pixel conditioning
- Right panel: no conditioning (independent pixels)

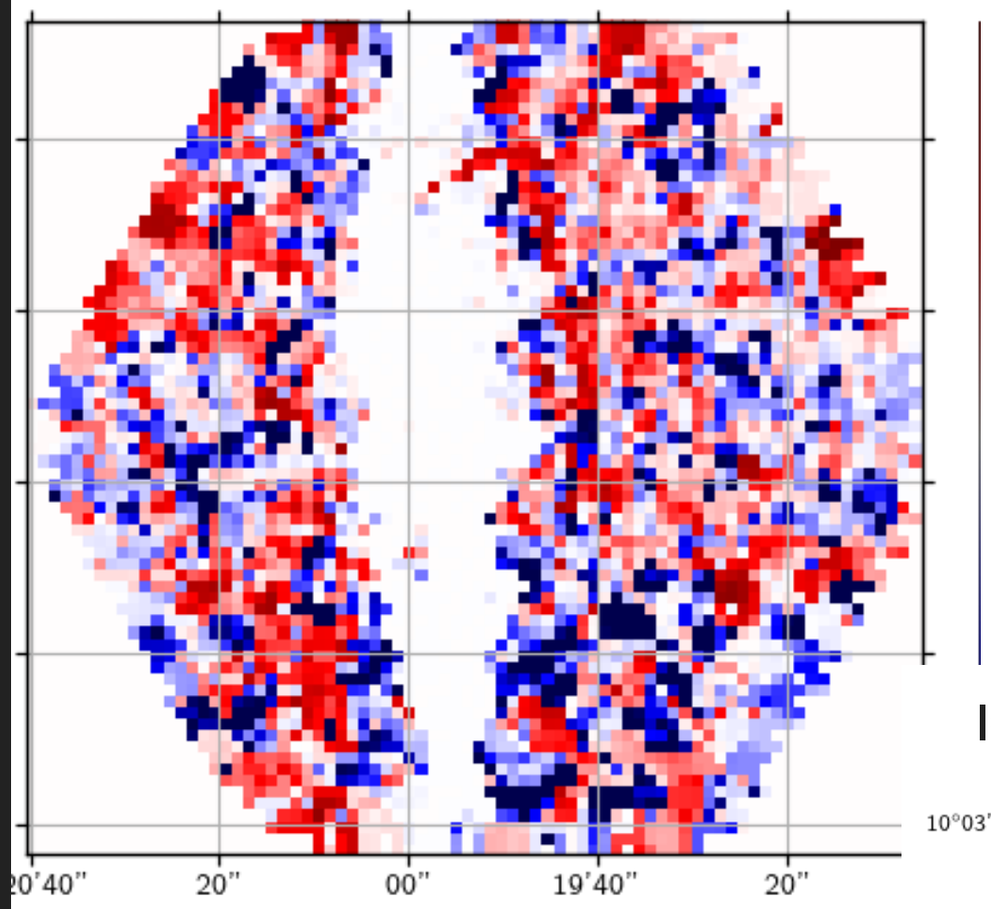
RESIDUALS IN Hα

- Residual map for Hα fits
- Linear scale in % of the amplitude w/r to individual pixels fits
- Red: smaller residuals
- Blue: worse off with pixel conditioning

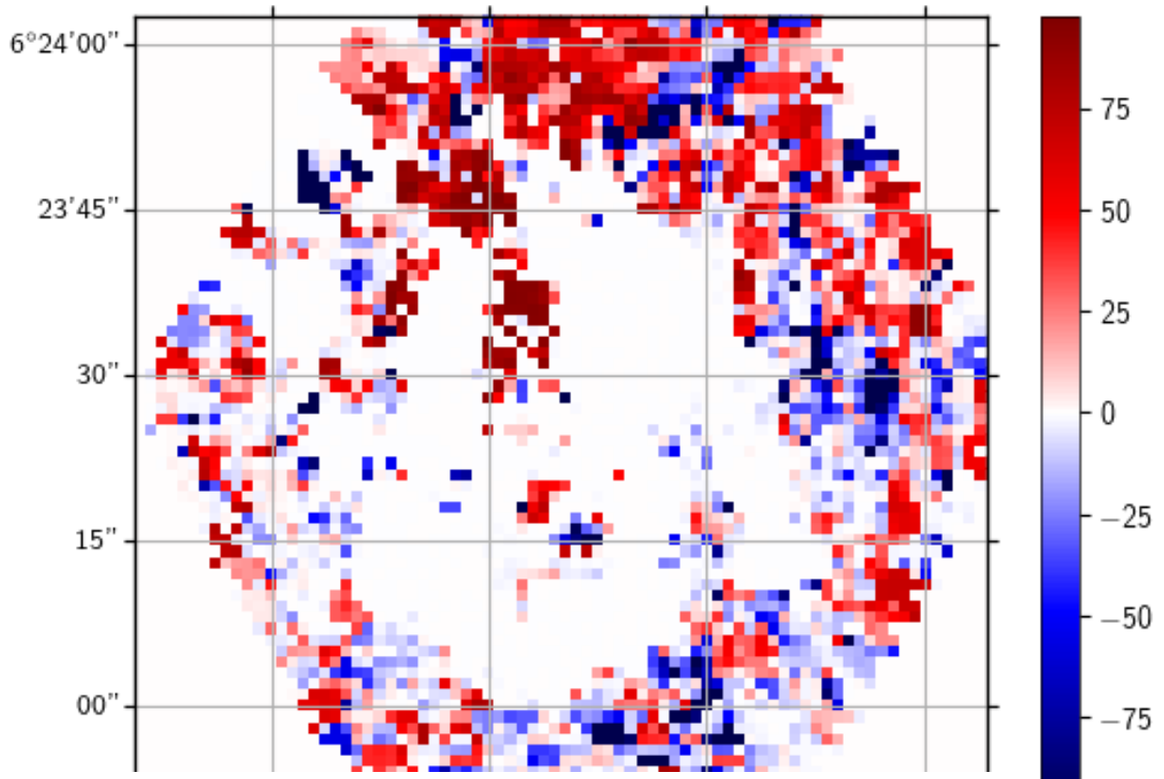


RESIDUALS IN Hα

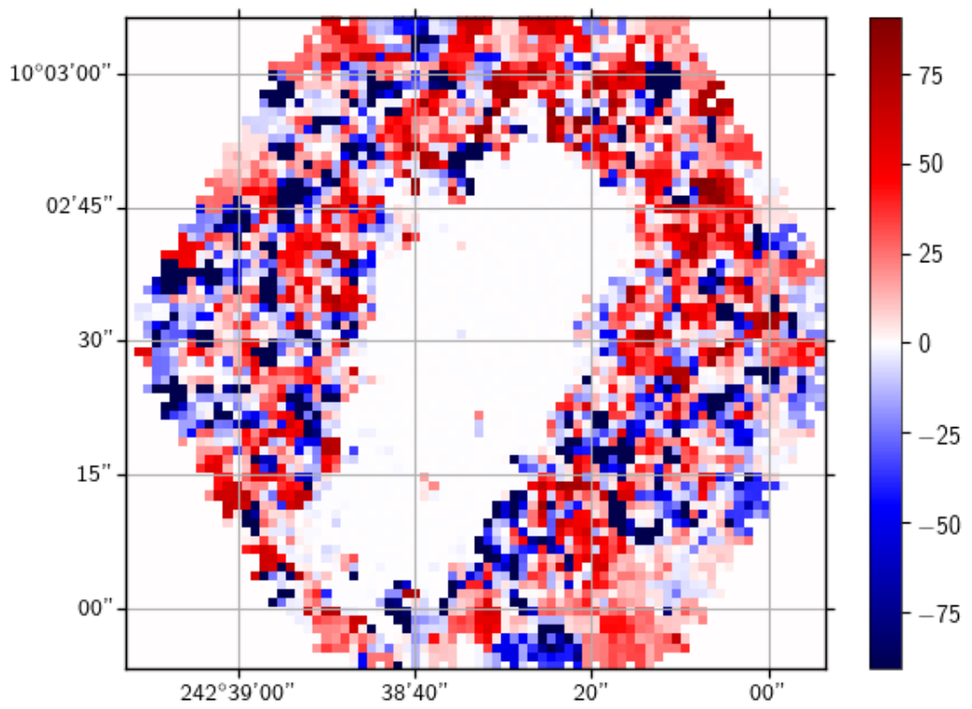
IC4566



NGC0036



IC1199



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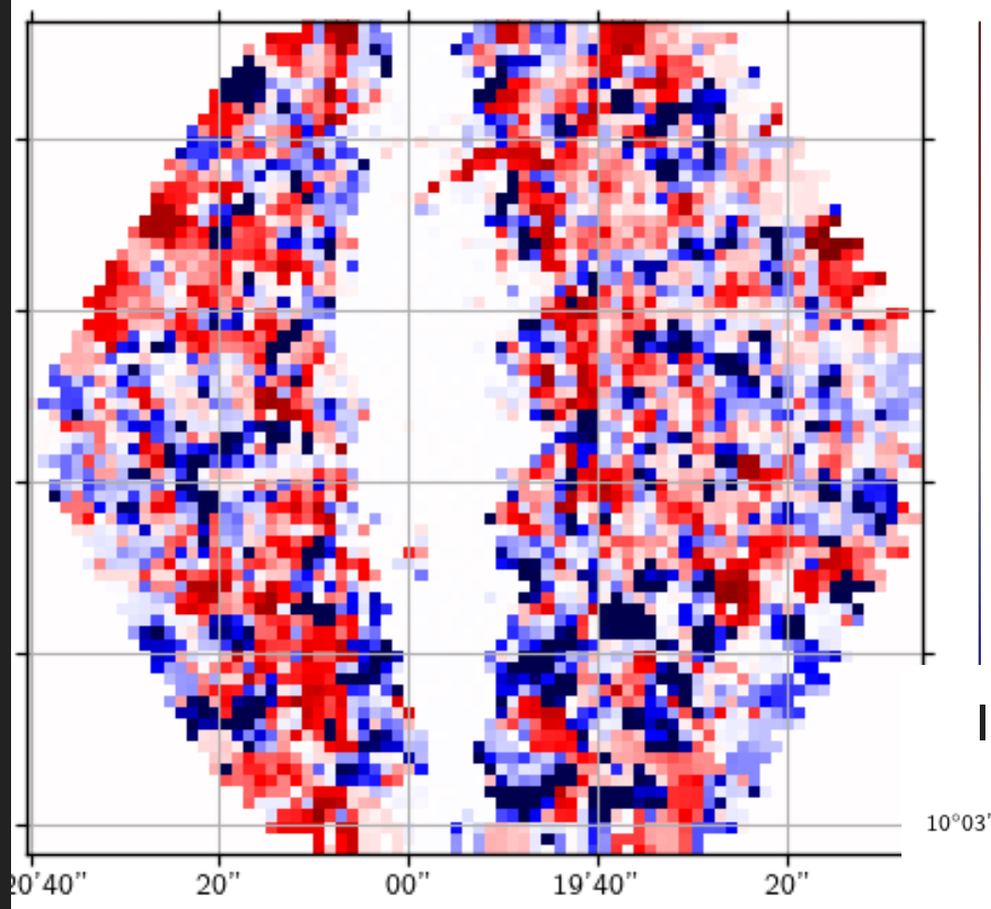

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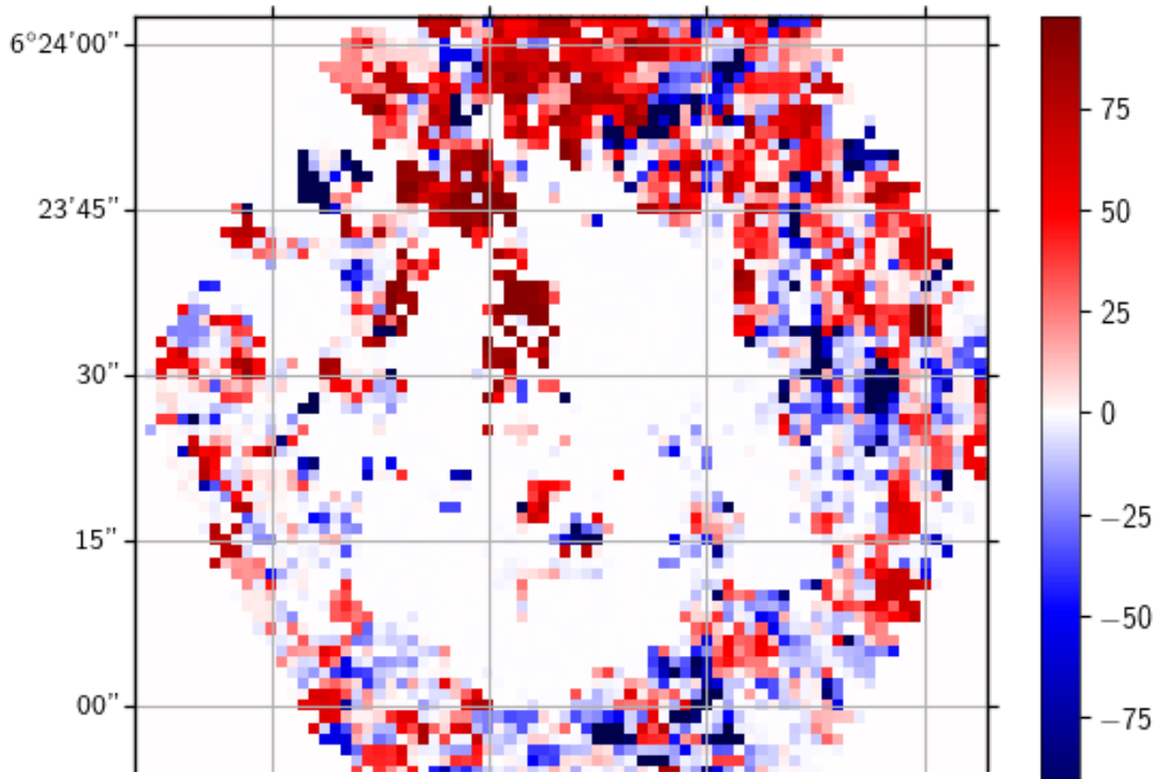

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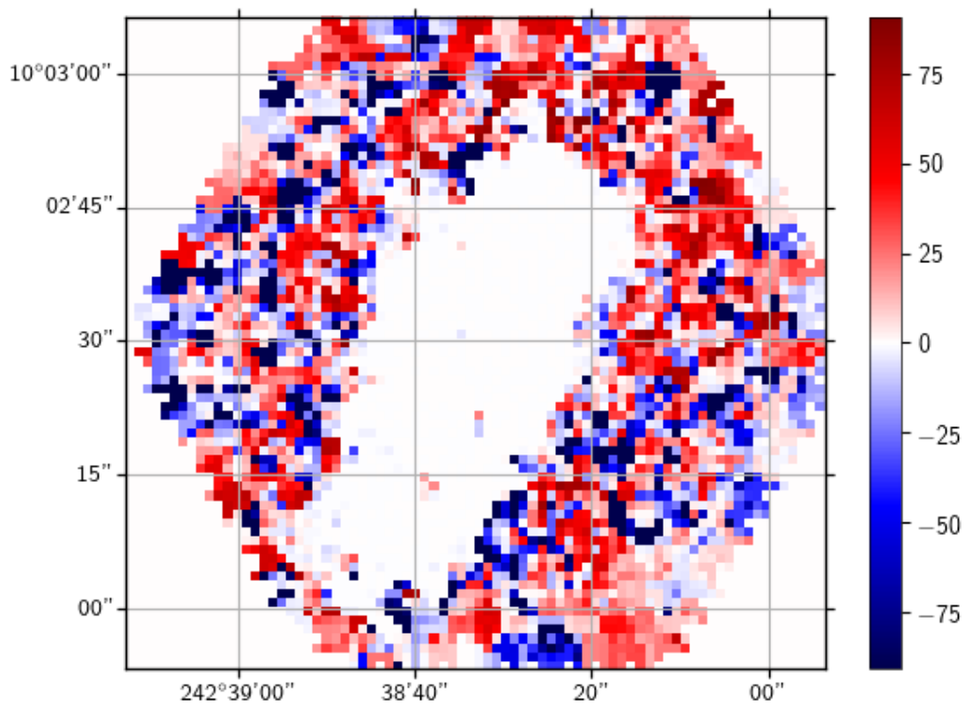
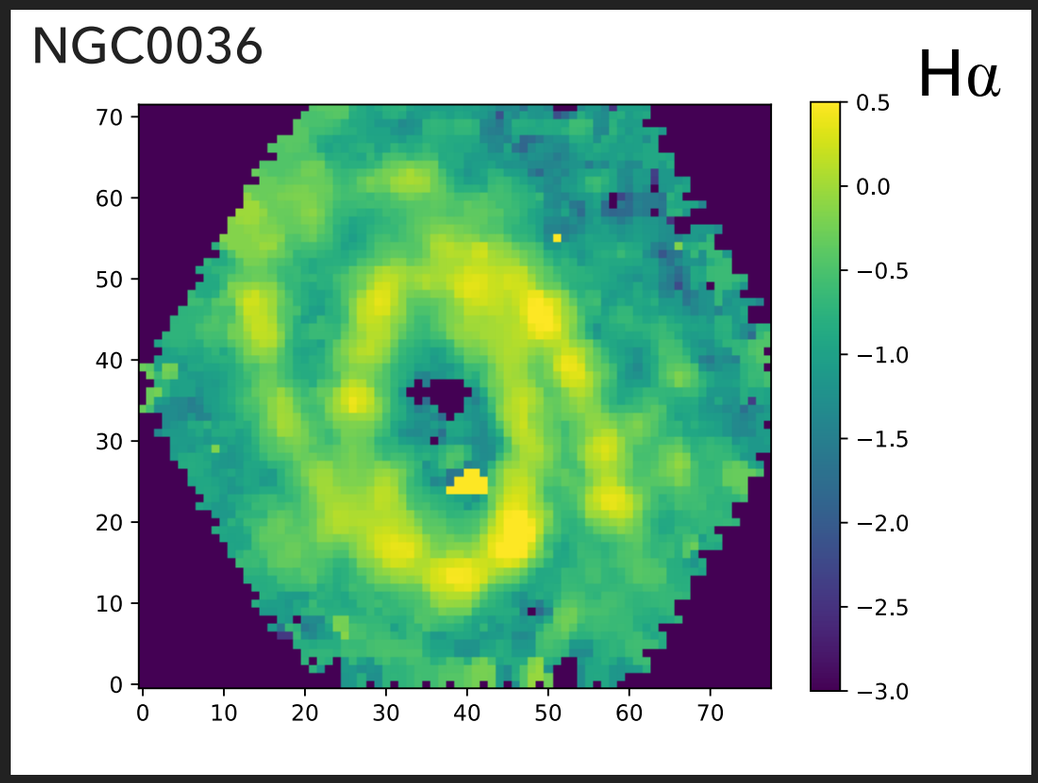
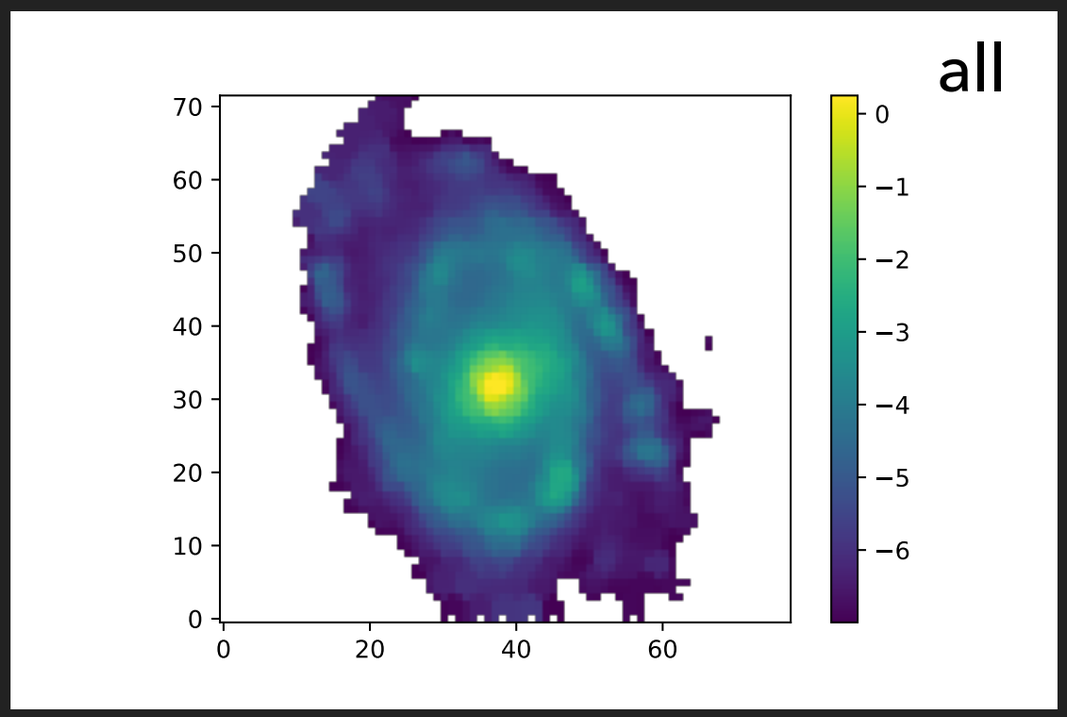


GONE WITH THE NOISE .. @ THE EDGE? WHERE?

- How to pick a “sensible” area to start with?
- Idea - look for intensity of specific line
- Intensity may be flat / in area where other lines are weak ..
- Better: use the full power spectrum, all lines + noise in (selected) channels

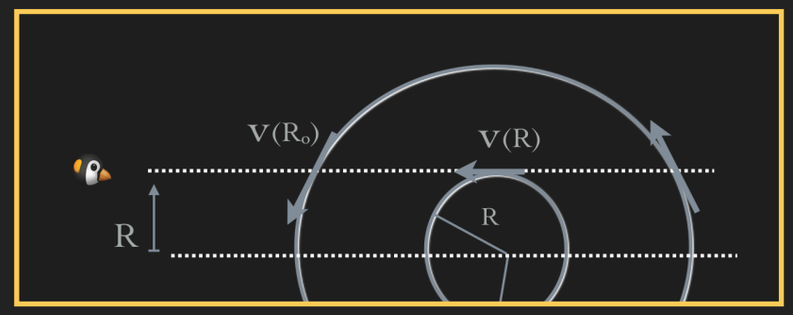




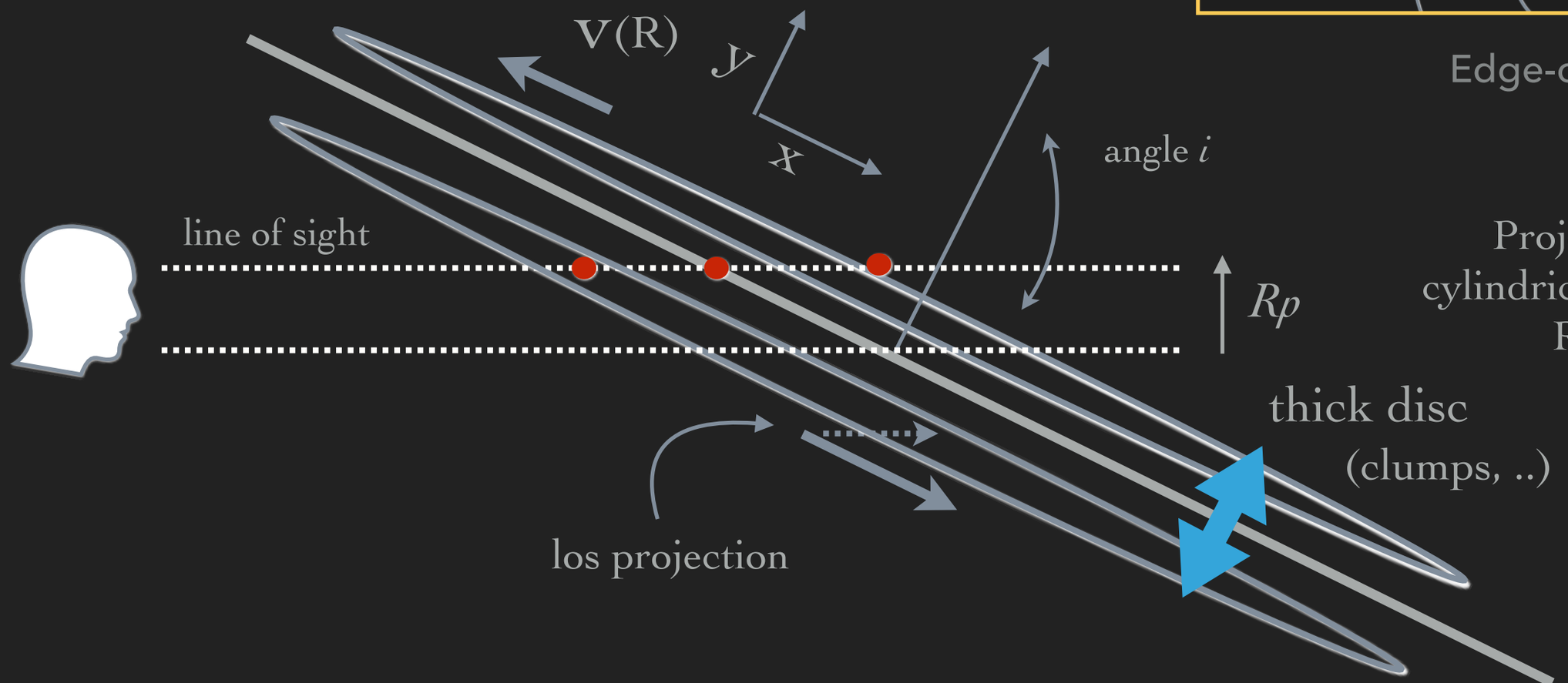
GOING FURTHER

- Training on a larger set of galaxies → 80 to 200
- Publish code and data: update the GitHub site ..
- Examine the effect of the disk thickness
- Need for parallelism ?
- Discrete fits ..

THE THICK DISC AND PROJECTION EFFECTS



Edge-on case



- Shape of the lines .. ? Asymmetric (not single Gaussian)
- Velocity at projected R_p is contribution from a range of {R} in the galaxy's frame of coordinates (x,y)
- Convoluted signal implies partial space correlation
- Similar situation: warps. Parametric fits for vertical disc structure are "no go" at z ~ 1 …

CONCLUSION / THANKS

- Assumption on continuous velocity field is valid for nearby galaxies
- Speeds up the computation , enhances the maps interpretation
- Dictionary of lines extendable at will
- Less sensitive to noise , especially on the NIIb line , whose detection is strongly noise-dependent

- ***Acknowledgement :***
- ***"This study uses data provided by the Calar Alto Legacy Integral Field Area (CALIFA) survey (http://califa.caha.es/) based on observations collected at the Centro Astronómico Hispano Alemán (CAHA) at Calar Alto, operated jointly by the Max-Planck-Institut fűr Astronomie and the Instituto de Astrofísica de Andalucía (CSIC)."***