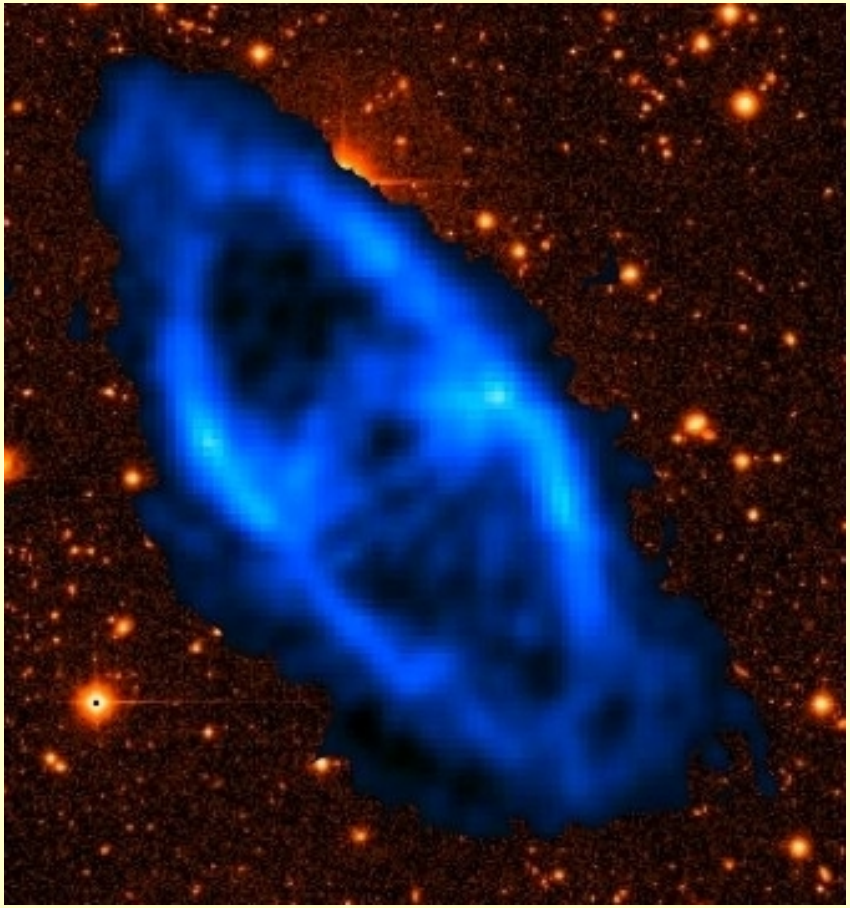
Netherlands Institute for Radio Astronomy

TiRiFiC



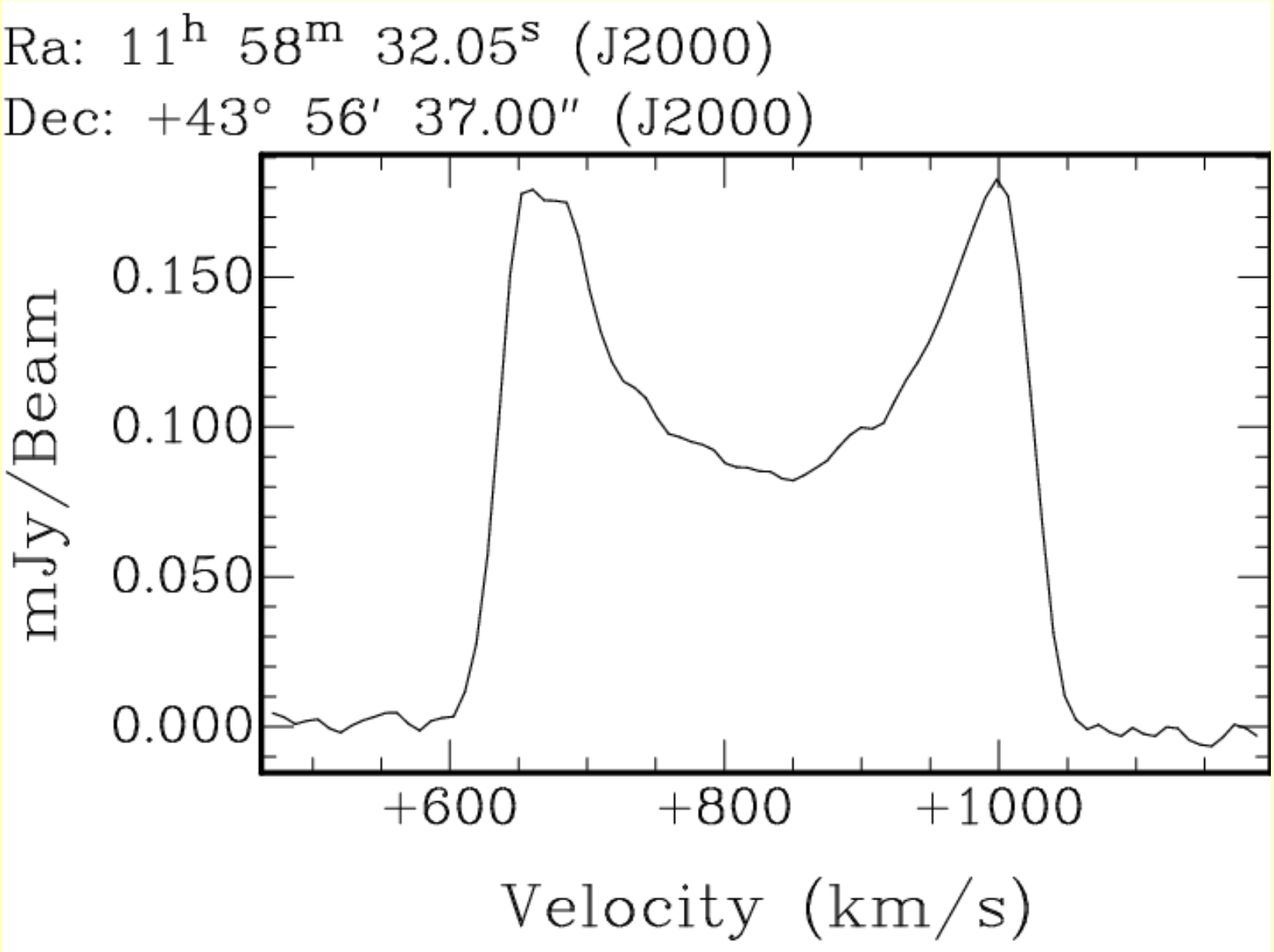
→

Gyula I. G. Józsa

ASTRON is part of the Netherlands Organisation for Scientific Research (NWO)

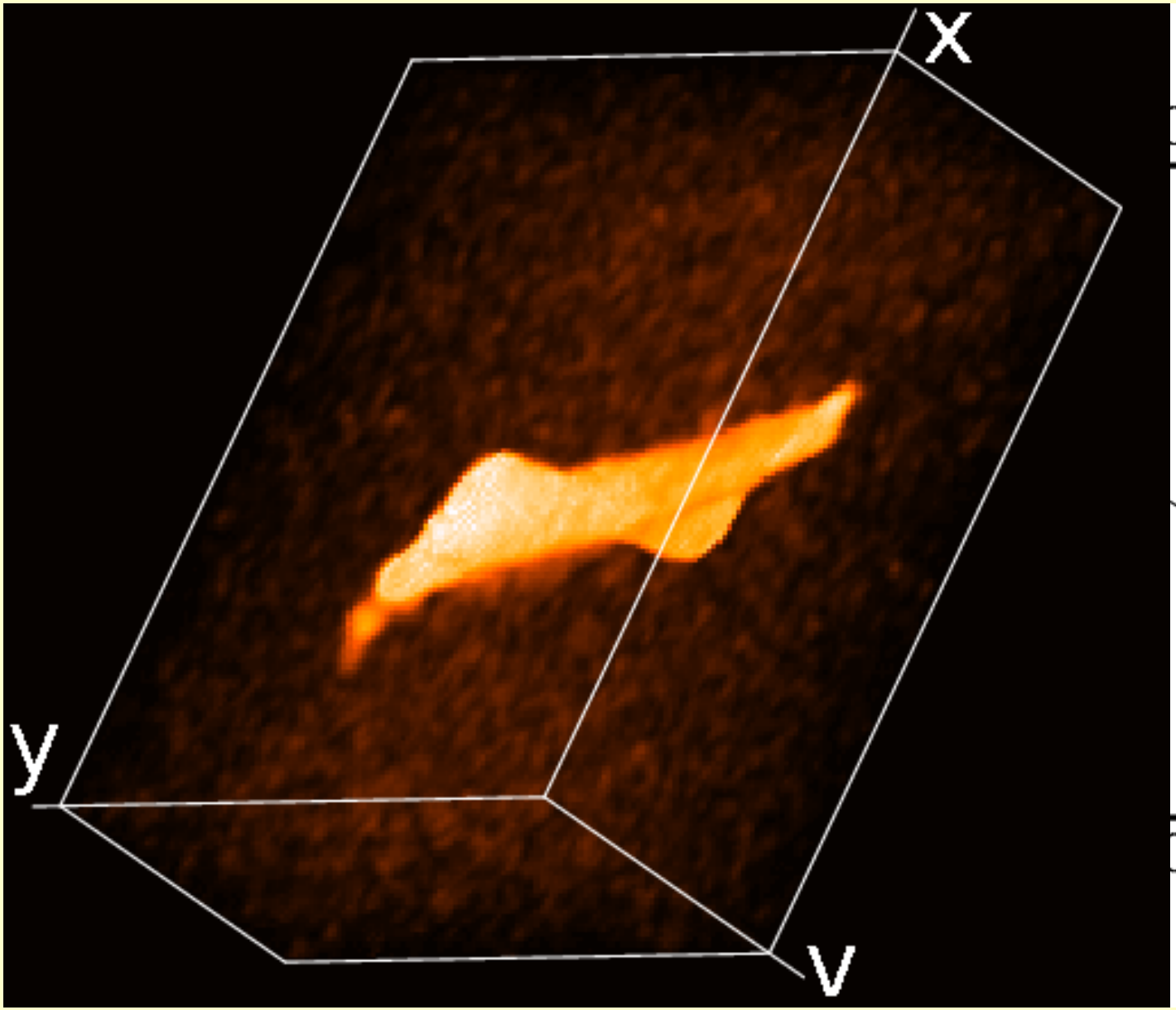
The task for HI WFSs

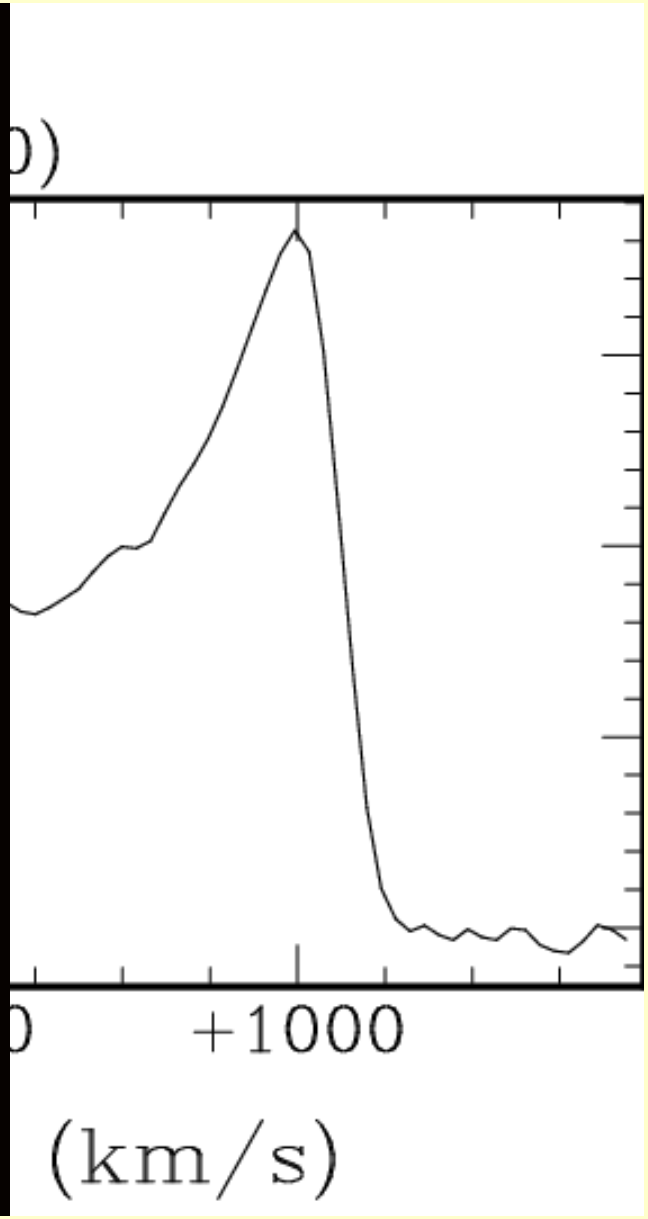
- HI in large galaxy surveys today -> interpret 1D spectra



The task for HI WFSs

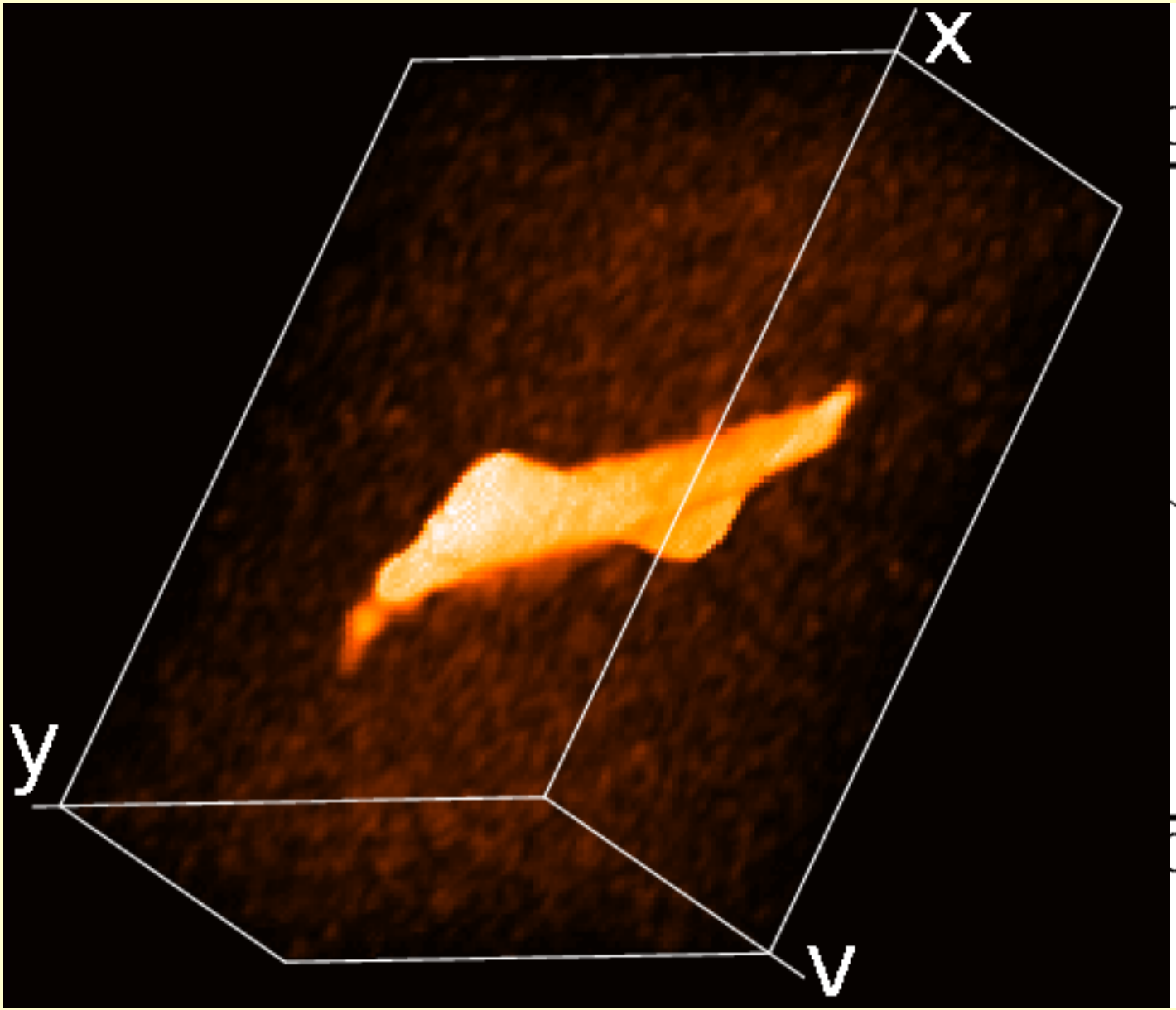
- HI in large galaxy surveys tomorrow -> interpret 3D data cubes

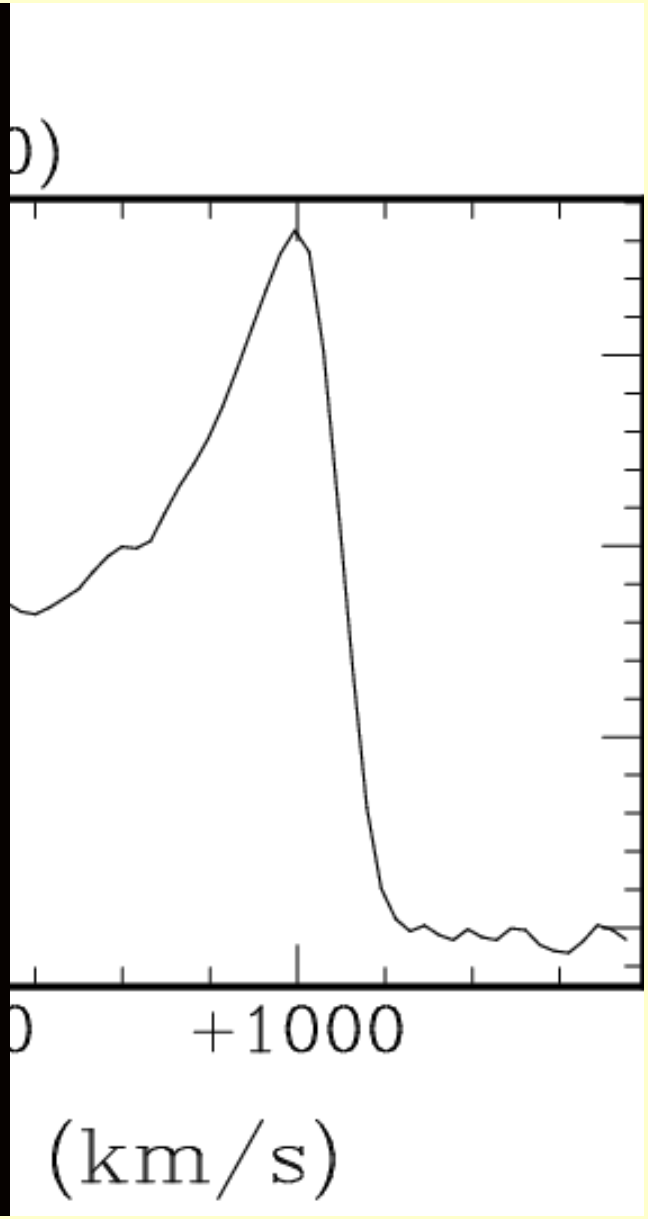




Exercising

- HI in galaxy surveys ~~tomorrow~~ **today** -> interpret 3D data cubes





Goals for parametrisation

Spatially not well/marginally resolved/shallow:
Current surveys: up to n·10^2 galaxies
(most recent: ATLAS^{3D} HI survey, Serra et al. 2011, arXiv 1111.4241)
WALLABY, WNSHS (n·10^4 galaxies)

- Automated parametrisation necessary
- Rotation curves, rotation amplitude
- HI surface density profiles, "aperture photometry"
- Orientation of (inner and outer) disks
- physical status (interacting?)
- morphology (symmetry, clumpiness)
- Environment ("aperture photometry")

Spatially well resolved (medium/deep):
Current surveys (e.g. **HALOGAS,** Heald et al. 2011)**:** n·10^{1-2} galaxies
WALLABY, WNSHS (n·10^3 galaxies)
...
MHONGOOSE (30 galaxies)

- (Semi-)automated fitting necessary
- Higher-order kinematics and morphology
- Anomalous components (tracing accretion)

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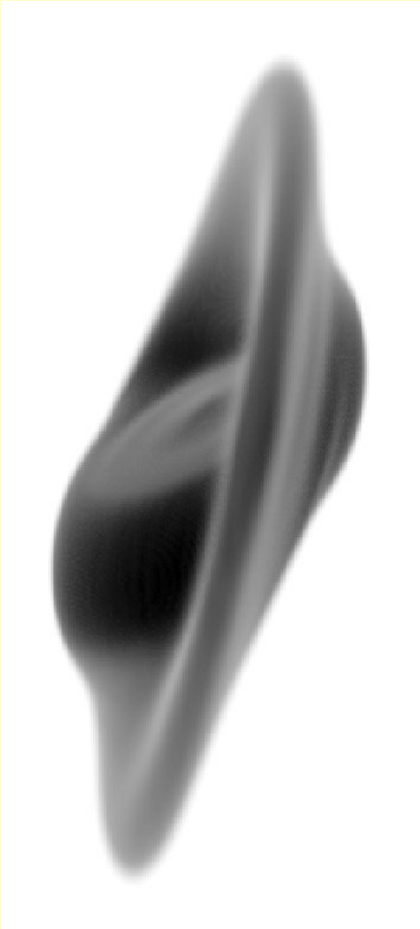
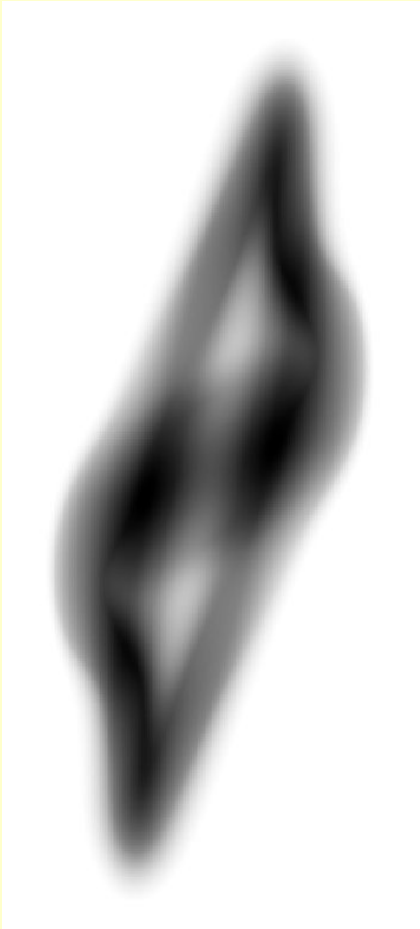
The tilted-ring model

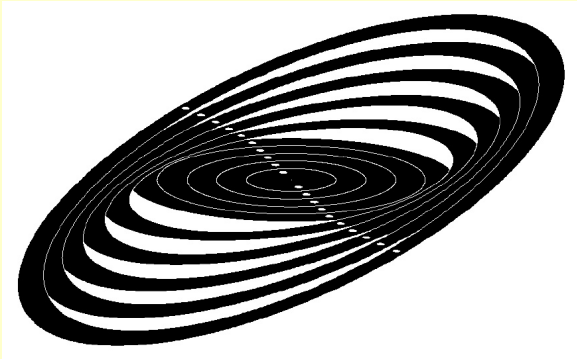




Tilted-Ring-Model
(Rogstad et al. 1974):

parametrise rings at different radii by

- two orientation parameters (inclination, position angle)
- central position
- surface brightness (thickness)
- rotation velocity



García-Ruiz 2001

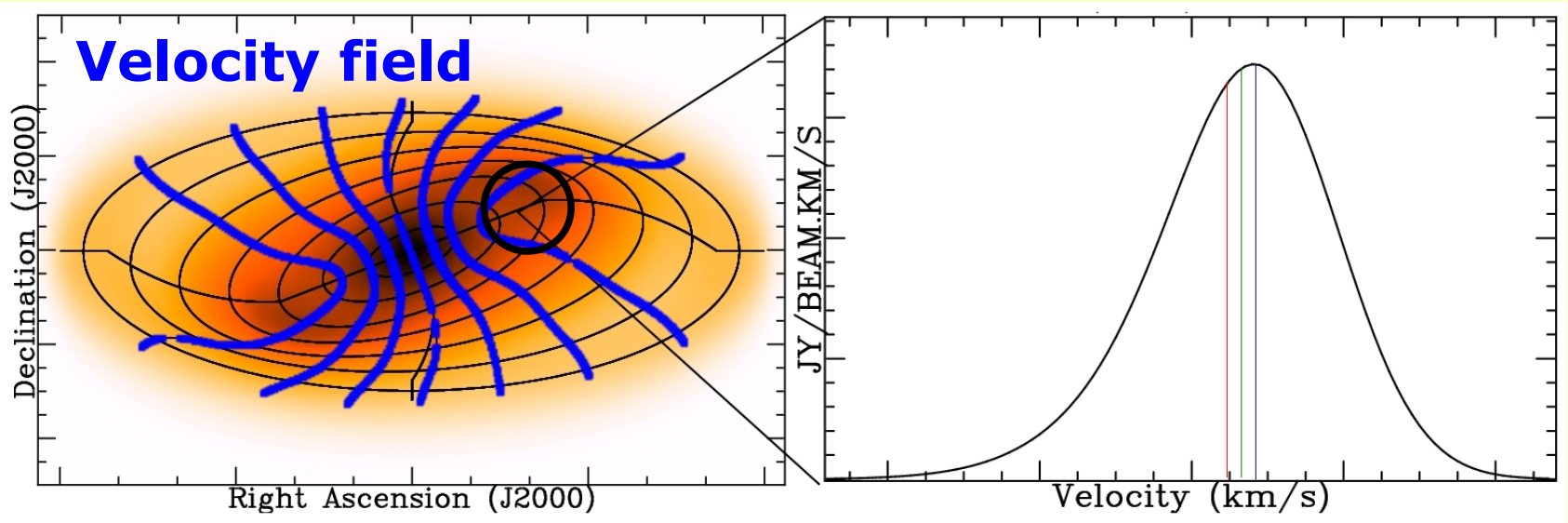
Tilted-ring modelling

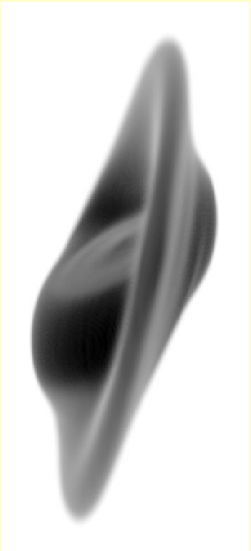
Method 1: Fit to a "velocity-field" (Begemann 1987, Schoenmakers 2001, ..., Spekkens 2007)

- Velocity field is impossible to be constructed if the line-of sight crosses the disk twice, does not reproduce any thickness

Method 2: direct fit to the data cube ("Galmod", (Corbelli & Schneider 1997, Józsa et al. 2007, Wiegert et al. 2006)

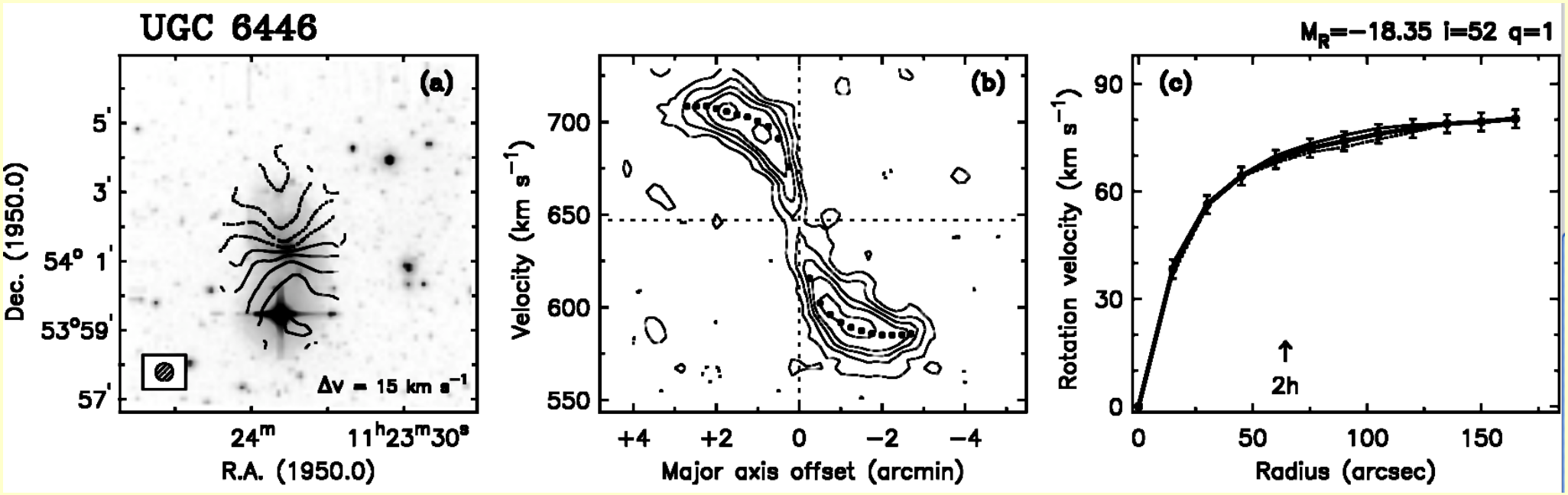
- Slow





Tilted-ring modelling: velocity field

- Works very well for data cubes with **high spatial resolution** (de Blok et al. 2008)
- Fast
- **Beam smearing** stabilises solutions at high resolution
- For lower resolution (compared to the extent of the disk) **beam smearing** becomes an issue.
- filtering of anomalous components



Swaters 1999

WALLABY/WNSHS

- WALLABY/WNSHS parametrisation group (**Spekkens**, Oh, Elson, de Blok, Westmeier, Józsa)
- Current focus: automated tilted-ring modelling
- Strategy:
  - Use velocity field method for moderately inclined and well resolved galaxies

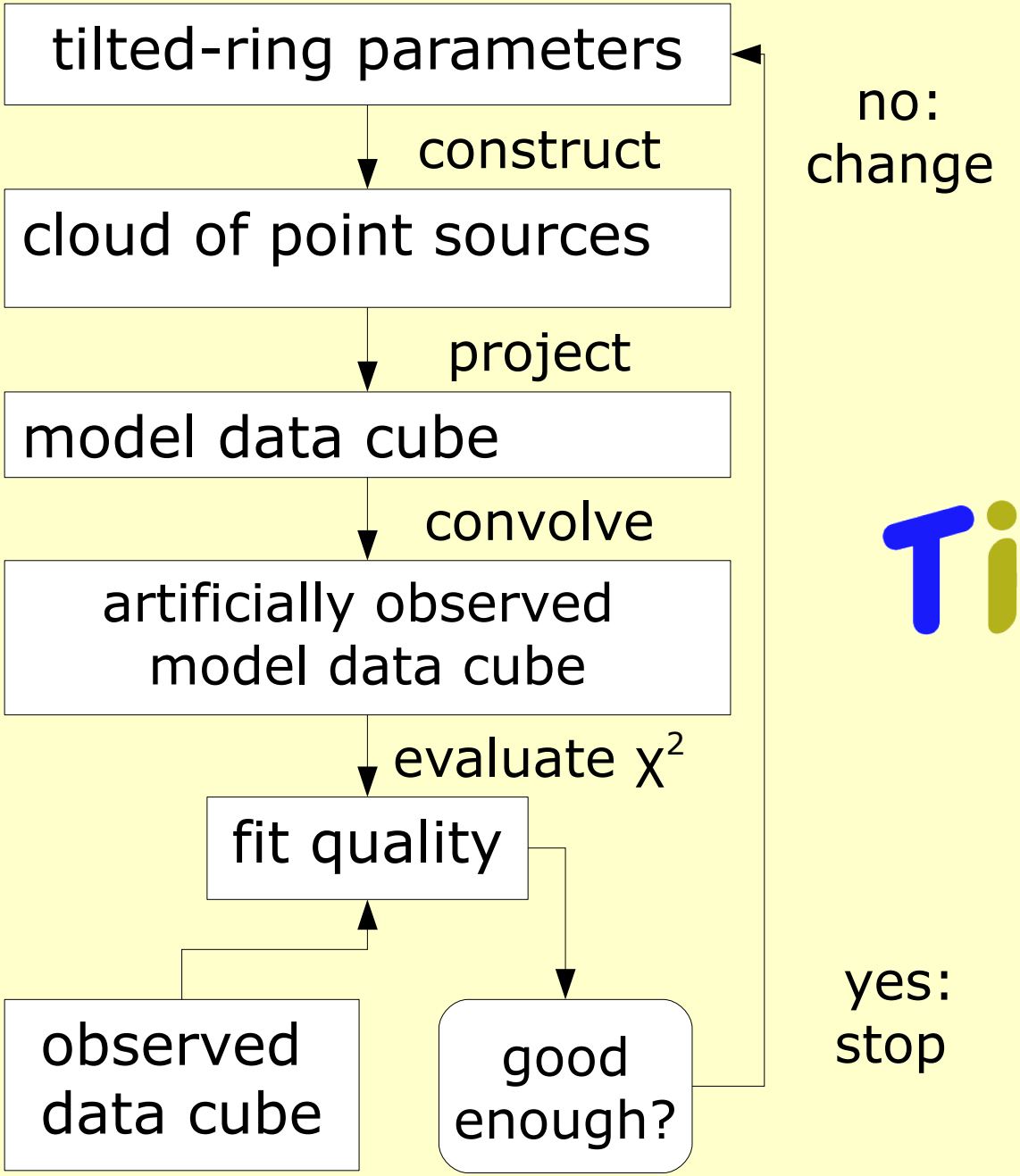
    ➔ **DiskFit/velfit** (Spekkens 2007, Spekkens et al.)

    http://www.physics.rutgers.edu/~spekkens/velfit/
  - Use direct fit method for highly inclined or poorly resolved galaxies

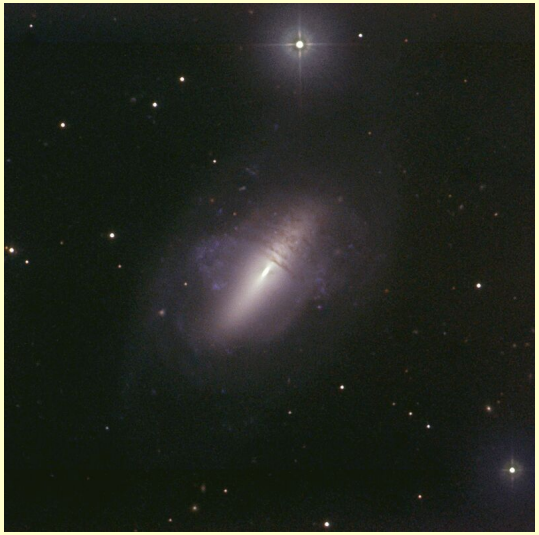
    ➔ **TiRiFiC** (Józsa et al. 2007)

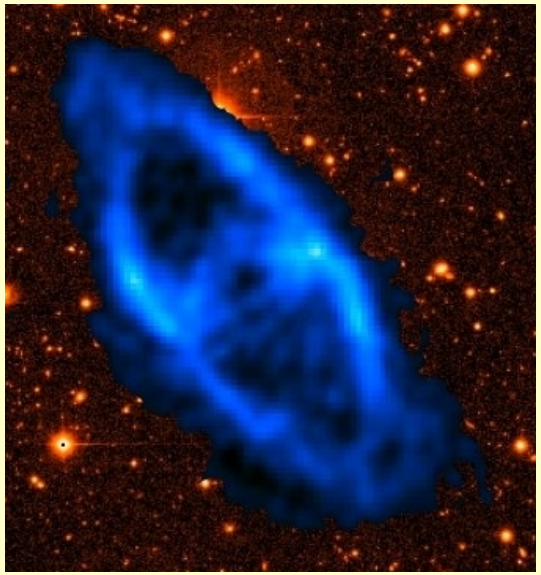
    http://www.astron.nl/~jozsa/tirific/ (v2 in progress)

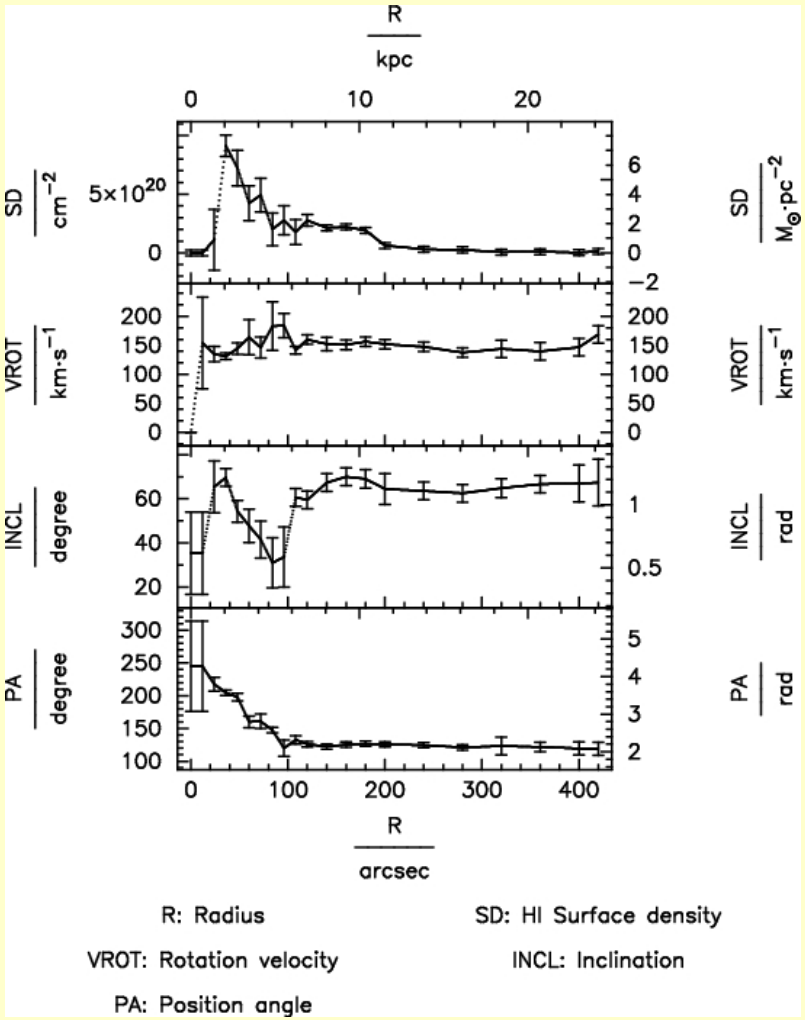
TiRiFiC basic functionality

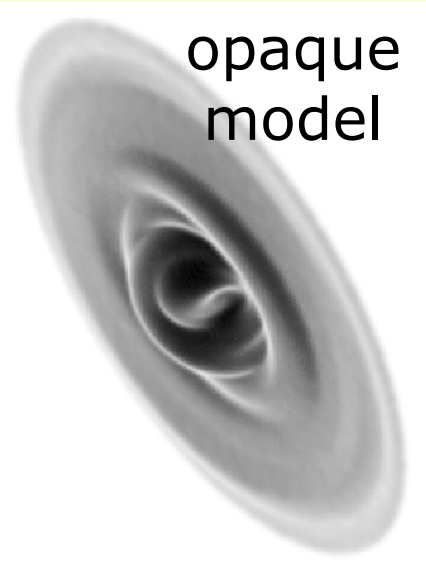


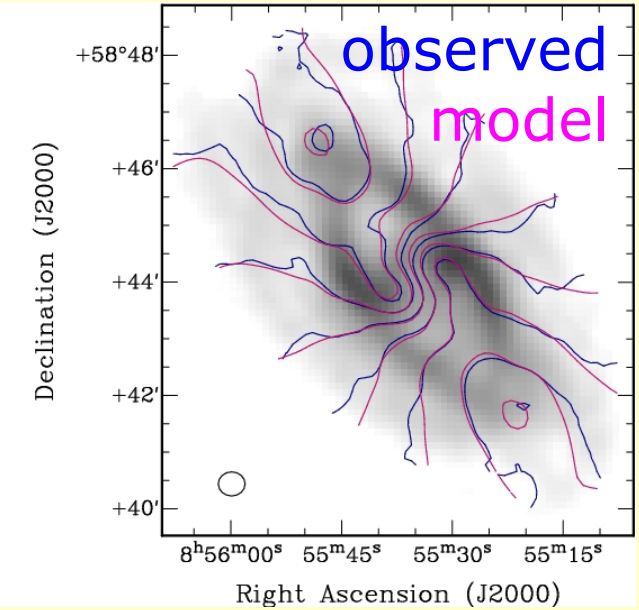
NGC 2685











- Modelling of some (even complicated) galaxies possible

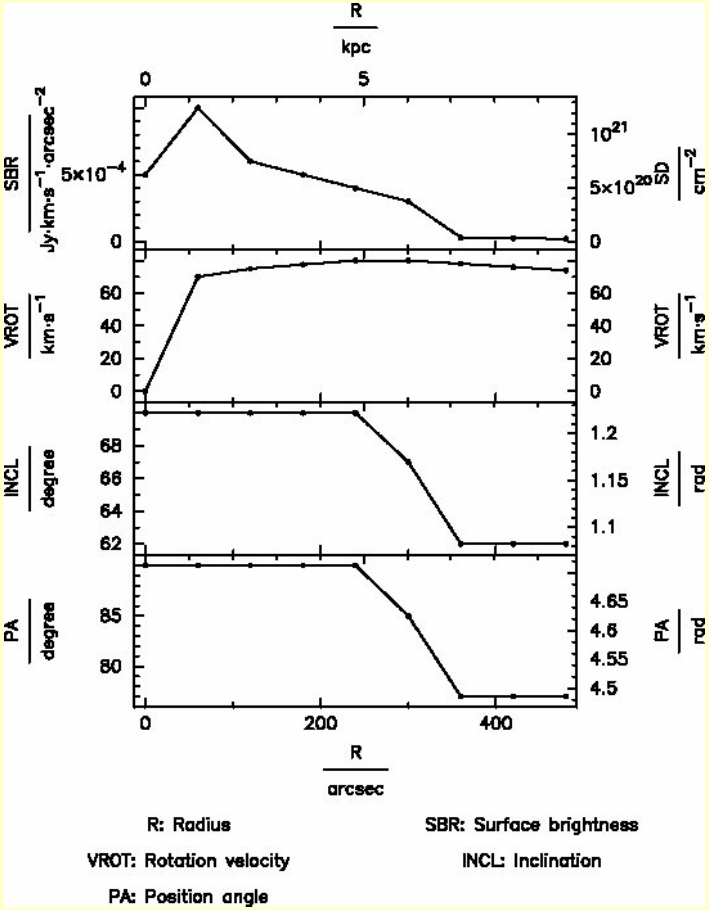
TiRiFiC milestones

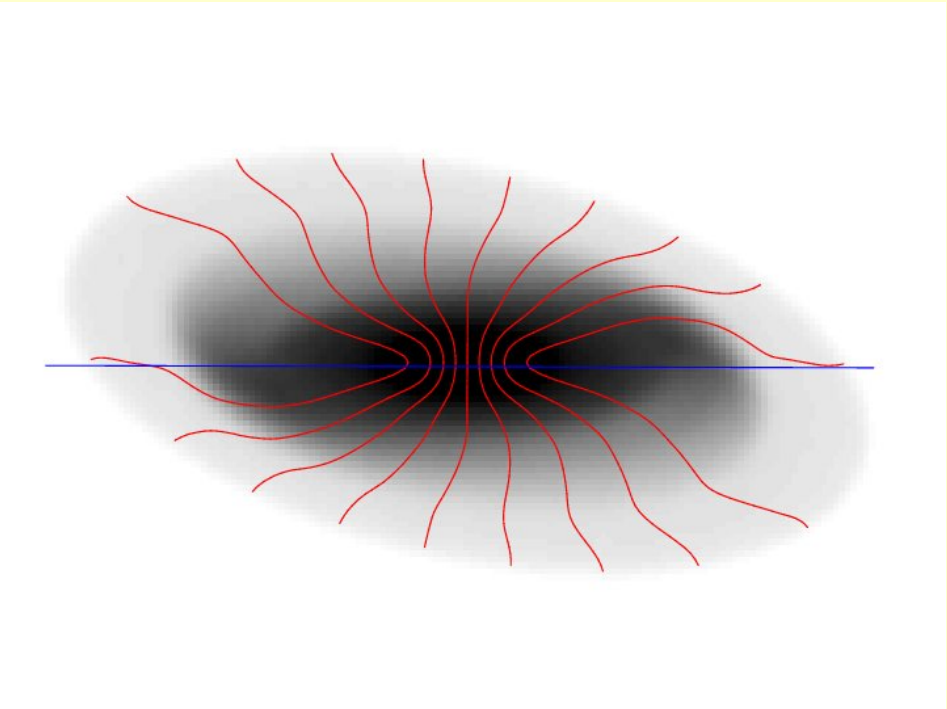
- Enable complex tilted-ring modelling for well-resolved galaxies
- Speed-up
- Publication (online description, download)
- User-interface
- Establish fitting pipeline for moderately and marginally resolved galaxies
  - Script TiRiFiC to enable automated quality control
  - Find optimal χ^2-minimisation scheme
  - Regularise parametrisation
  - Alternative parametrisation schemes to reduce number of parameters

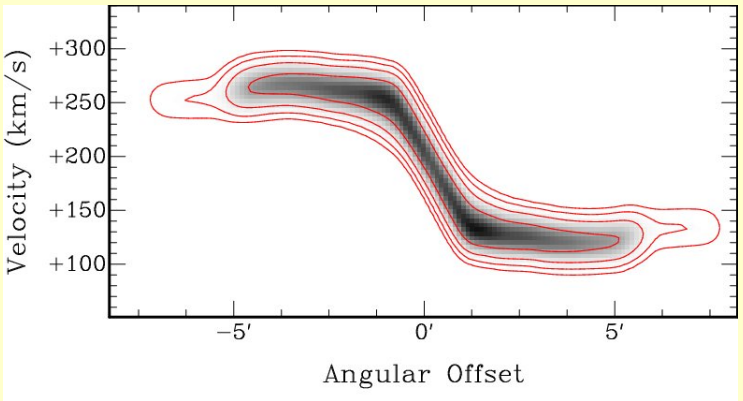
TiRiFiC parameters

Basic TRM (galmod)
for each radius

- Surface brightness SBR (Jy km s^{-1} arcsec^{-2})
- Rotation velocity VROT (km s^{-1})
- Position angle PA (°)
- Inclination INCL (°)
- Scale height Z0 (arcsec)
  LTYPE (Gaussian, sech^2, constant)
- Dispersion SDIS (km s^{-1})
- Ring centre RA XPOS (°)
- Ring centre Dec YPOS (°)
- Systemic velocity VSYS (km s^{-1})





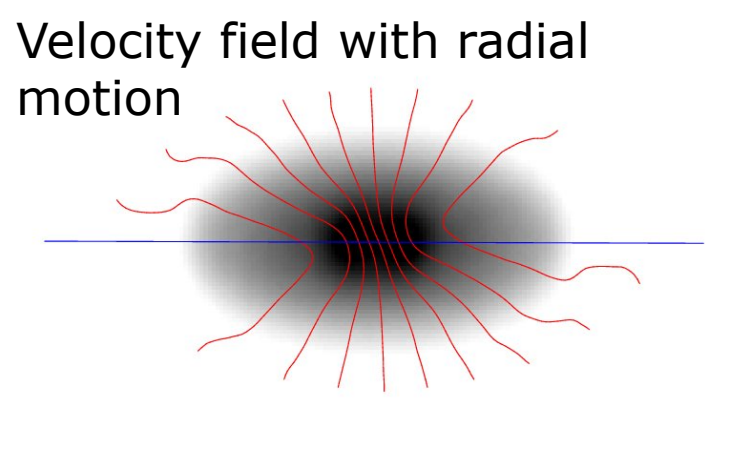


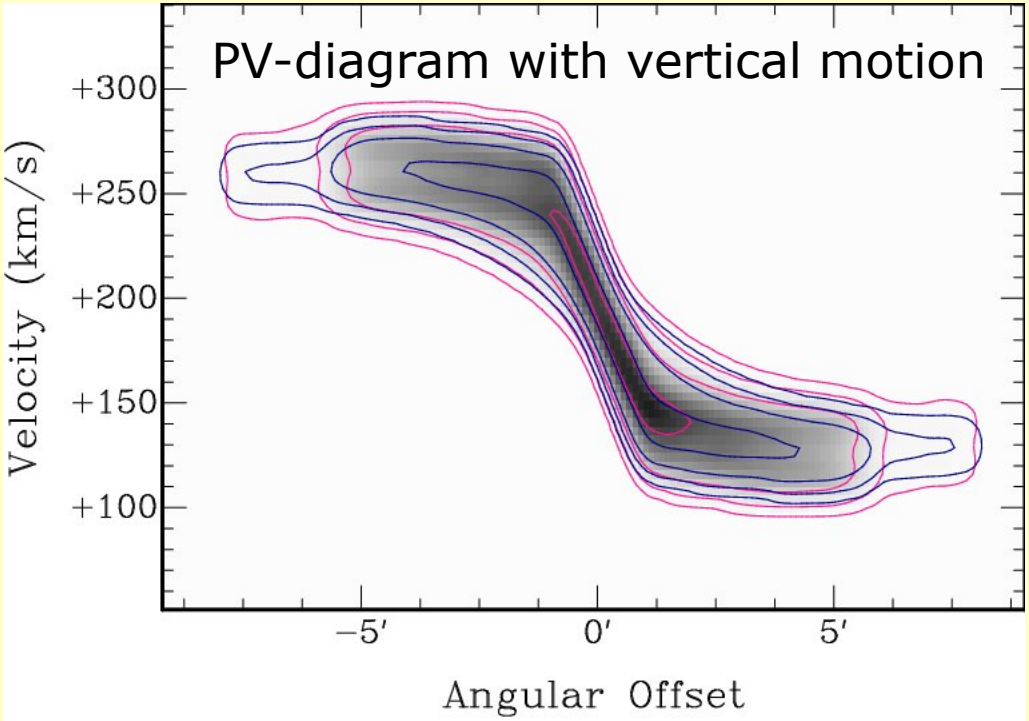
TiRiFiC parameters

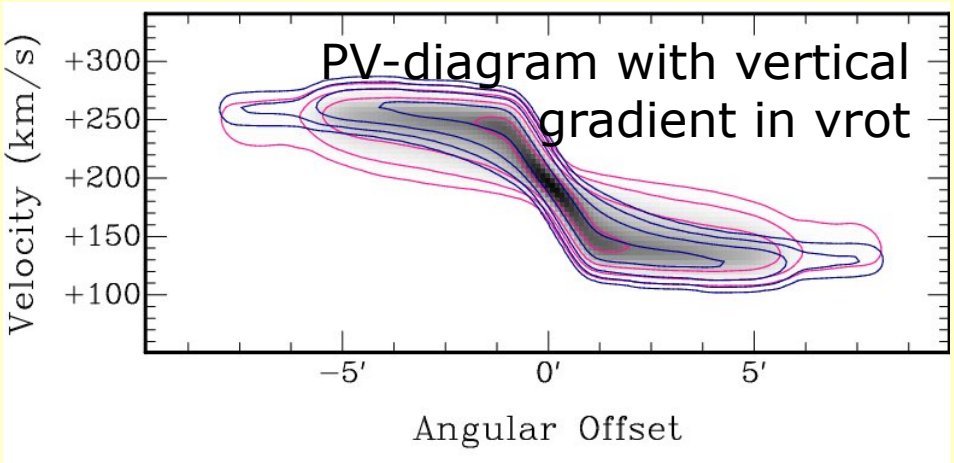
Global symmetric motion and gradients

- Radial motion VRAD (km s^{-1})
- Vertical motion VVER (km s^{-1})
- Vertical gradients DVRO (VROT, km s^{-1} arcsec^{-1})
  DVRA (VRAD, km s^{-1} arcsec^{-1})
  DVVE (VVER, km s^{-1} arcsec^{-1})

Example: flat disk, i = 60°, thick disk

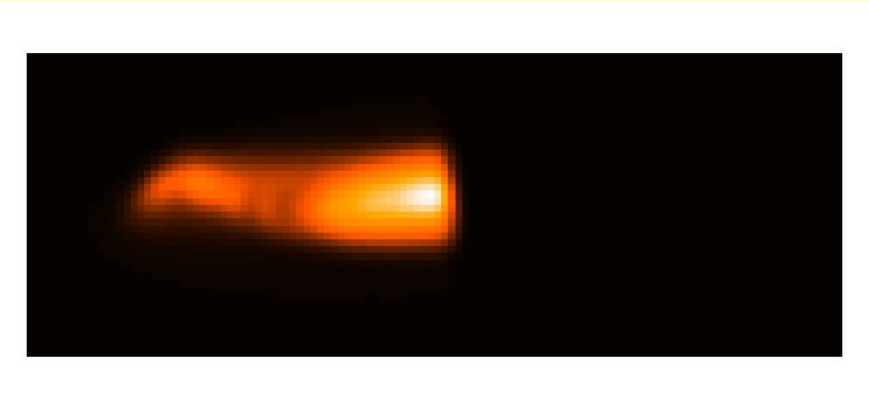






Asymmetric galaxies

- asymmetric disks, modelled as two half disks



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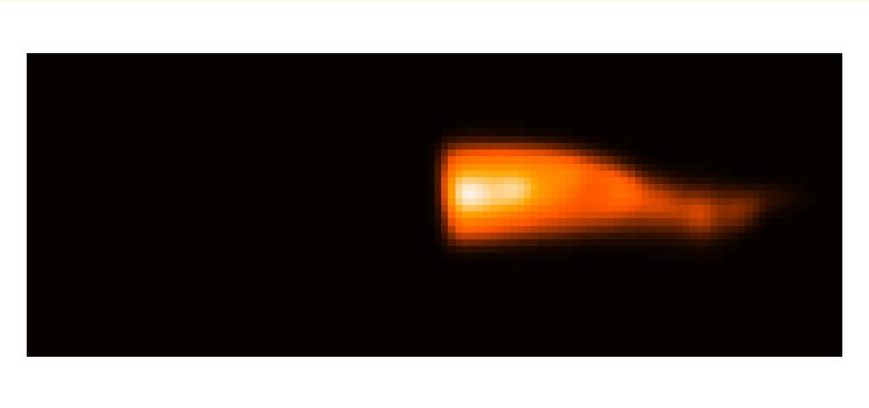

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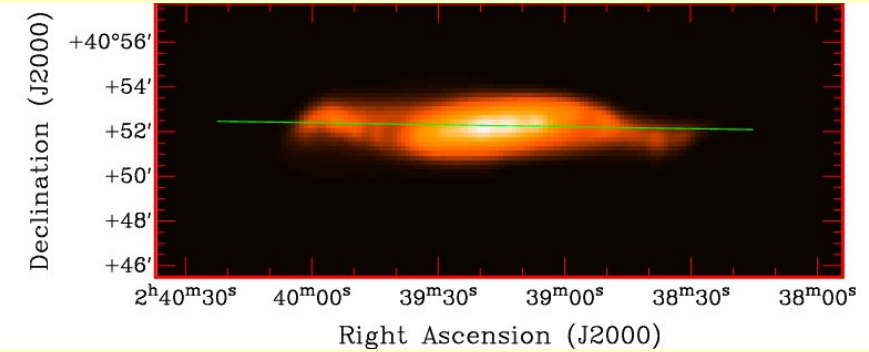
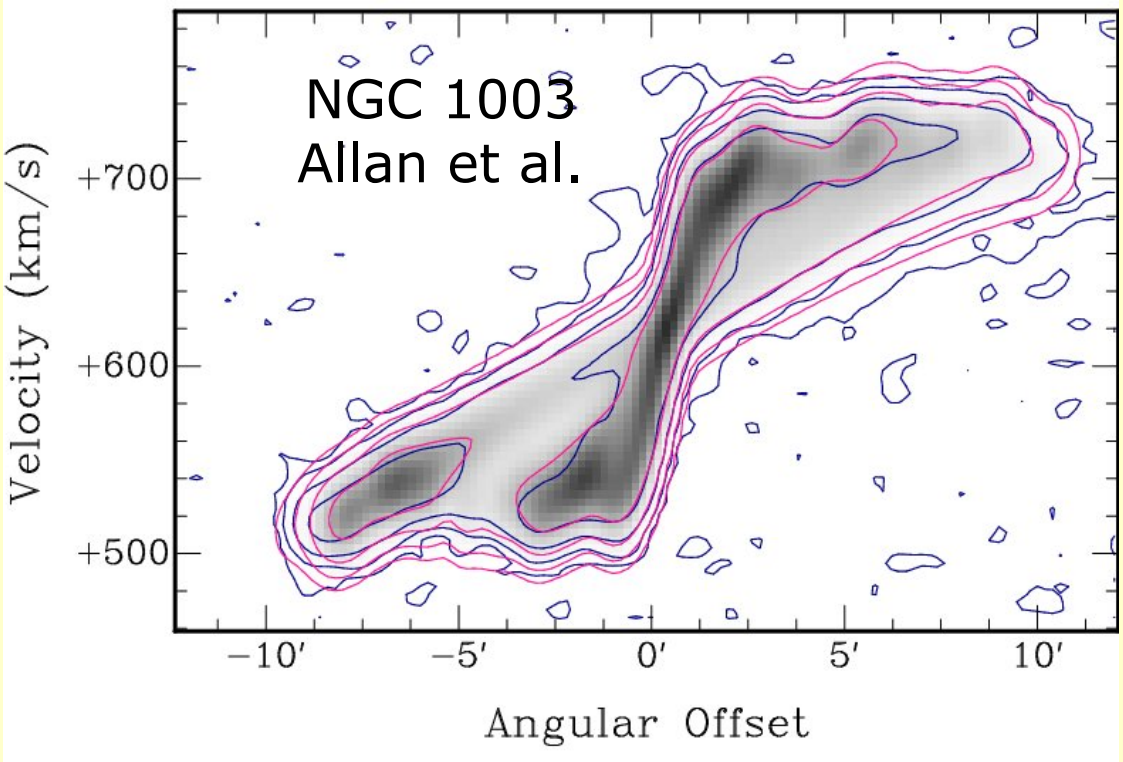


Heald et al. 2011



TiRiFiC parameters

- Enable complex tilted-ring modelling for well-resolved galaxies
  - Basic tilted-ring model (galmod)
  - Radial, vertical motion, vertical gradients in velocity
  - Higher-order warps
  - Global shifts along projected axes
  - Harmonics in surface brightness
  - Bar-like and spiral distortions in surface brightness
  - Harmonic terms in velocity
  - Multiple disks and partial disks

Use with great care!

Btw….

TiRiFiC can be used without automated fitting (faster than alternatives)

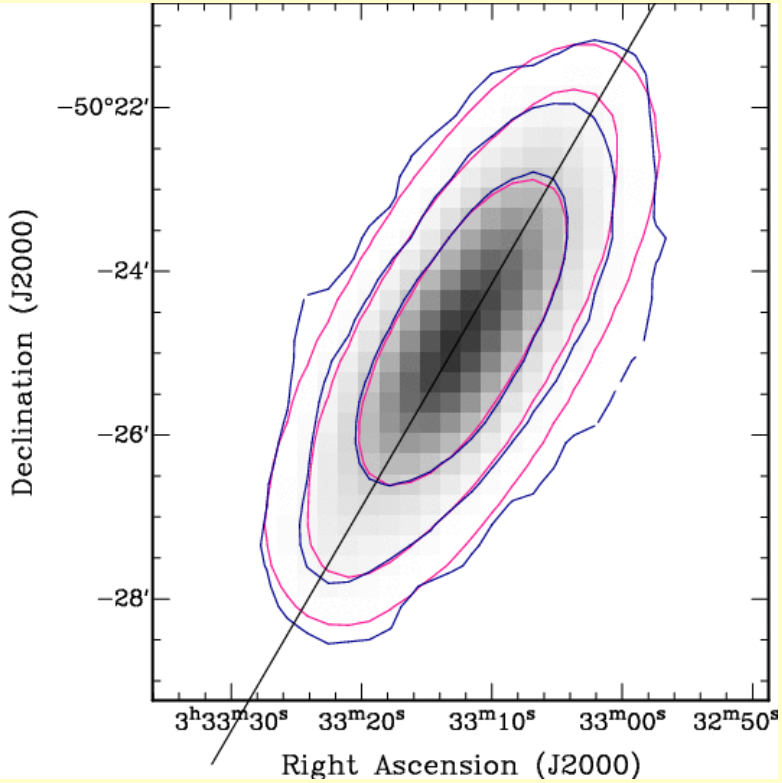
TiRiFiC speed

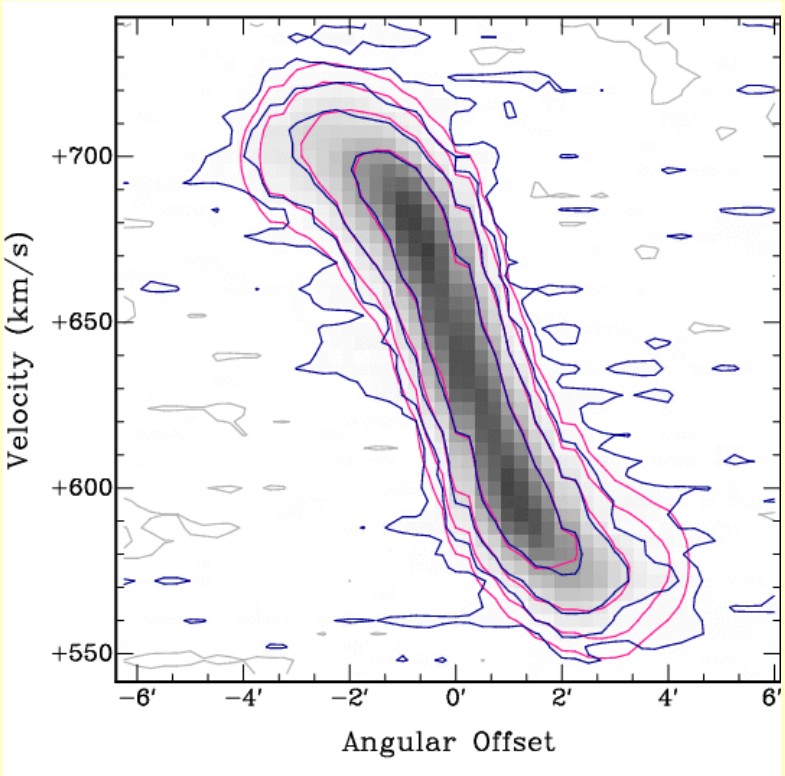
- Enable complex tilted-ring modelling for well-resolved galaxies ✓
- Speed-up:
  - Optimisation of I/O
  - Internally adjusting methods to demand
  - Partial model generation (re-calculate only what's needed)
  - Crude parallelisation (multi-threading with OMP, thanks to Hyun-Jin Bae, Yonsei Univ.)

TiRiFiC speed

IC 1959 (ATCA, LVHIS, Koribalski et al.), minimisation method 1

- 500 kB data cube
- corresponding to D_{HI} = 7.5 arcmin @ HPBW = 60 arcsec
- 34 parameters, simple TRM
- 8 Intel Xeon 2.4 GHz cores
- 1 fitting run (1000 models) 2 minutes (7 minutes 1 core)
- 5 re-iterations -> 10 minutes/galaxy (35 minutes 1 core)
- 2 8-core computers -> 250-300 galaxies/day (660 using 1 core per gal.)
- **BUT** no quality control, no errors

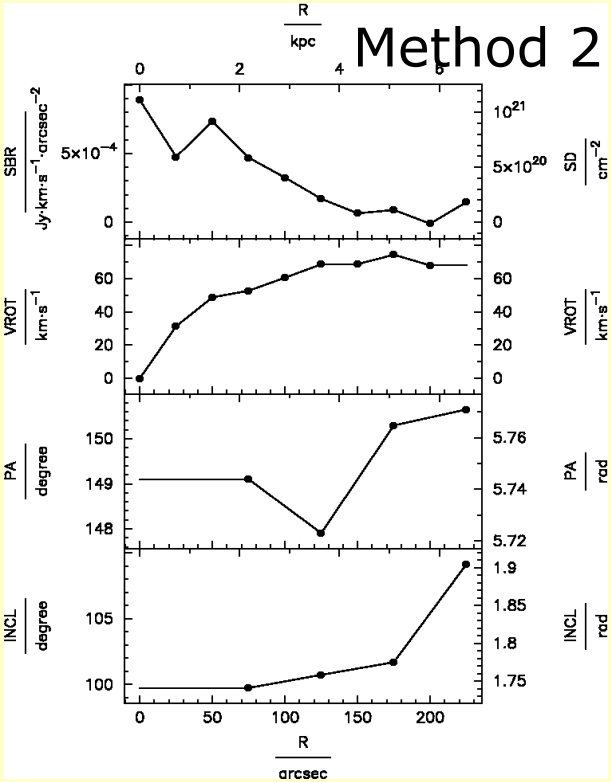


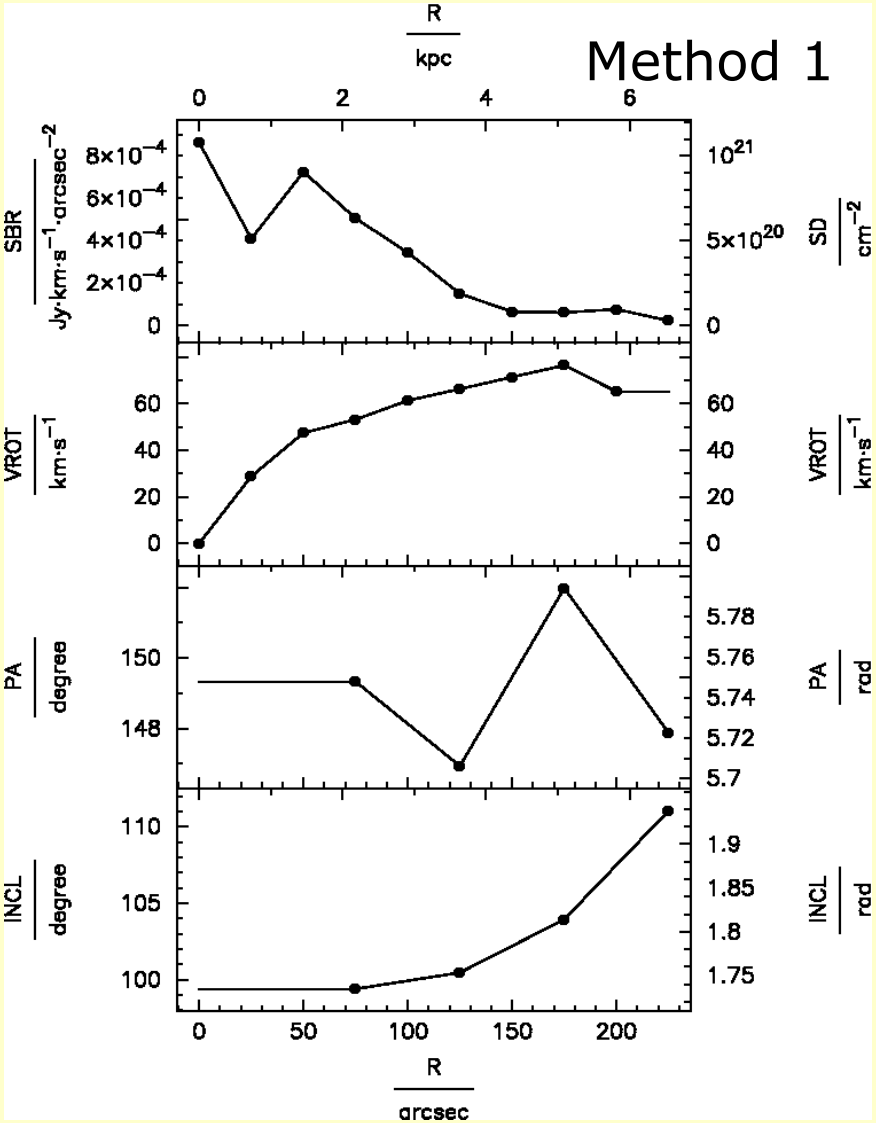


TiRiFiC speed

IC 1959 (ATCA, LVHIS, Koribalski et al.), minimisation method 2

- 500 kB data cube
- corresponding to D_{HI} = 7.5 arcmin @ HPBW = 60 arcsec
- 34 parameters, simple TRM
- 1 Intel Xeon 2.4 GHz core
- 2 fitting runs (2500 models) 50 minutes
- 2 8-core computers -> 450 galaxies/day
- **BUT** no quality control, no errors





TiRiFiC milestones

- Enable complex tilted-ring modelling for well-resolved galaxies ✓
- Speed-up ✓
- Publication (online description, download)
- User-interface
- Establish fitting pipeline for moderately and marginally resolved galaxies
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TiRiFiC publication

- Enable complex tilted-ring modelling for well-resolved galaxies ✓
- Speed-up ✓
- Publication (online description, download):
  - 90% finished

http://www.astron.nl/~jozsa/tirific

(currently: contact info)

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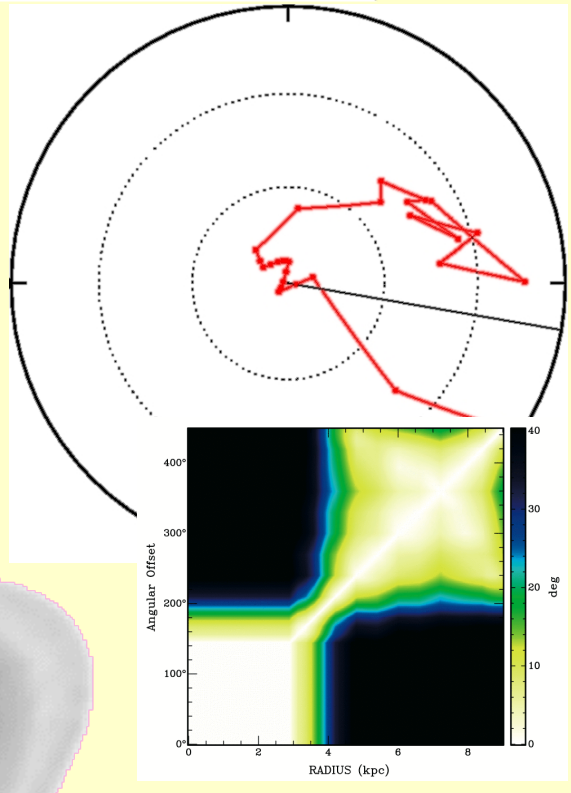
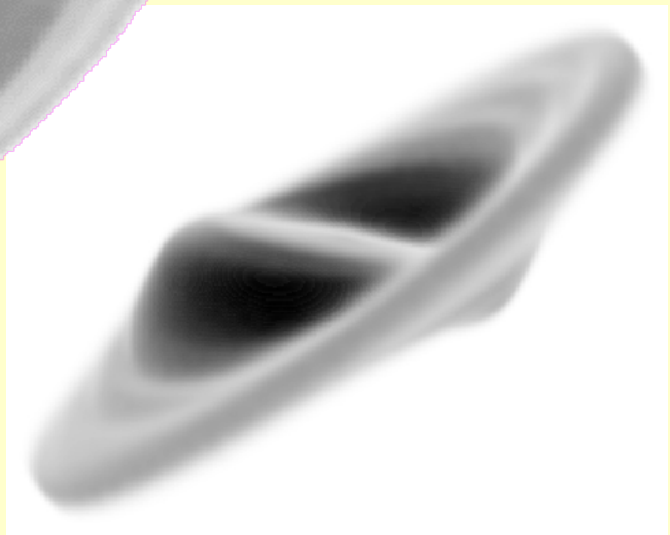
TiRiFiC user interface

- GIPSY (http://www.astro.rug.nl/~gipsy/)
  - Most complete package for HI analysis
  - Installation time consuming (esp. Mac)
  - Complex data structure
  - TiRiFiC standalone planned, but low priority
- Several output possibilities (tables, plots, data sets, verification in progress)
- GUI possible, Python prototype, but low priority





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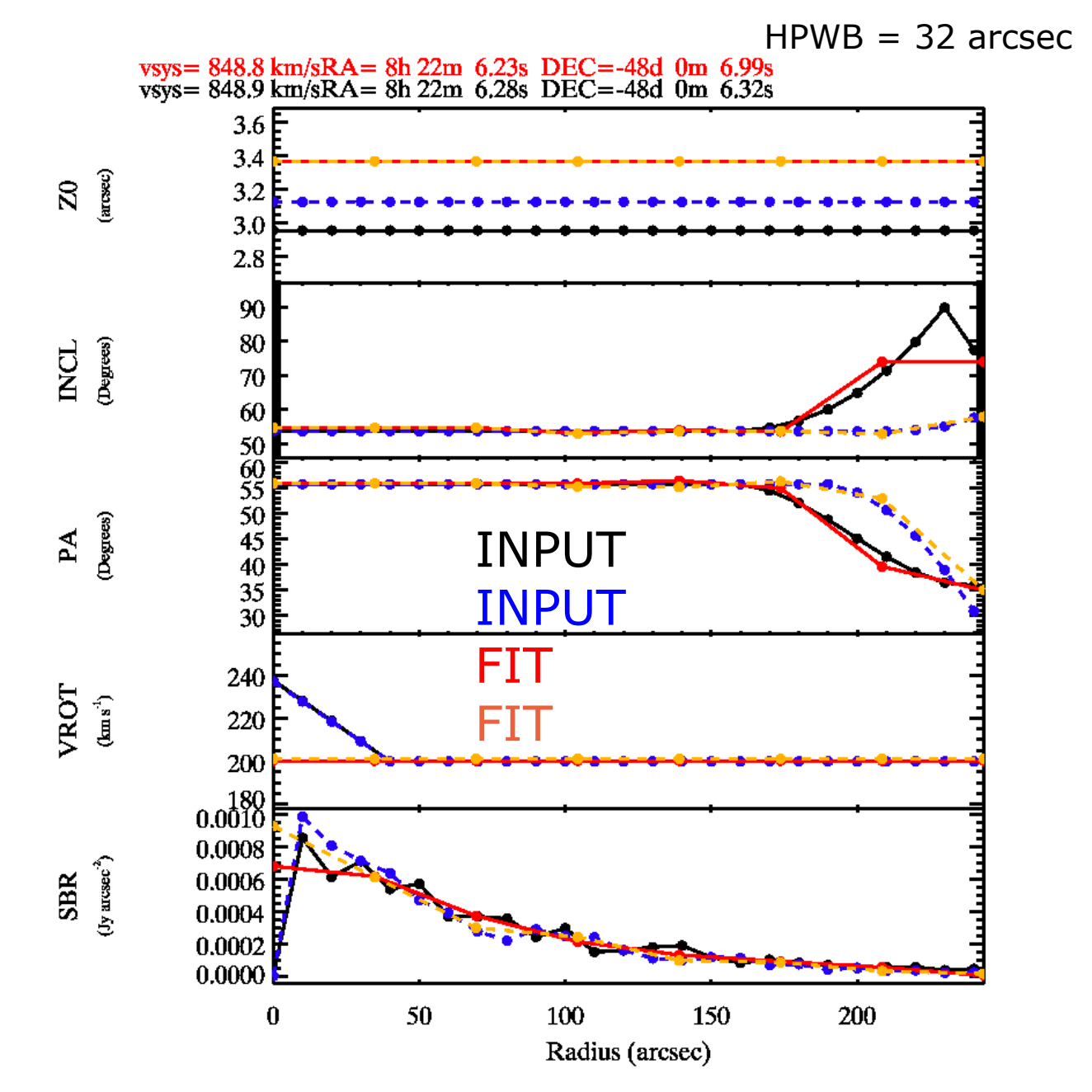
Scripting TiRiFiC

- Currently, TiRiFiC requires human control
- Implementation of automated wrapper in progress (by Peter Kamphuis, nearly ATNF)
- Combination of TiRiFiC with several GIPSY routines
- Final fit always with TiRiFiC
- No error-bars yet
- On average 5 runs

➔ 1h/galaxy (again)



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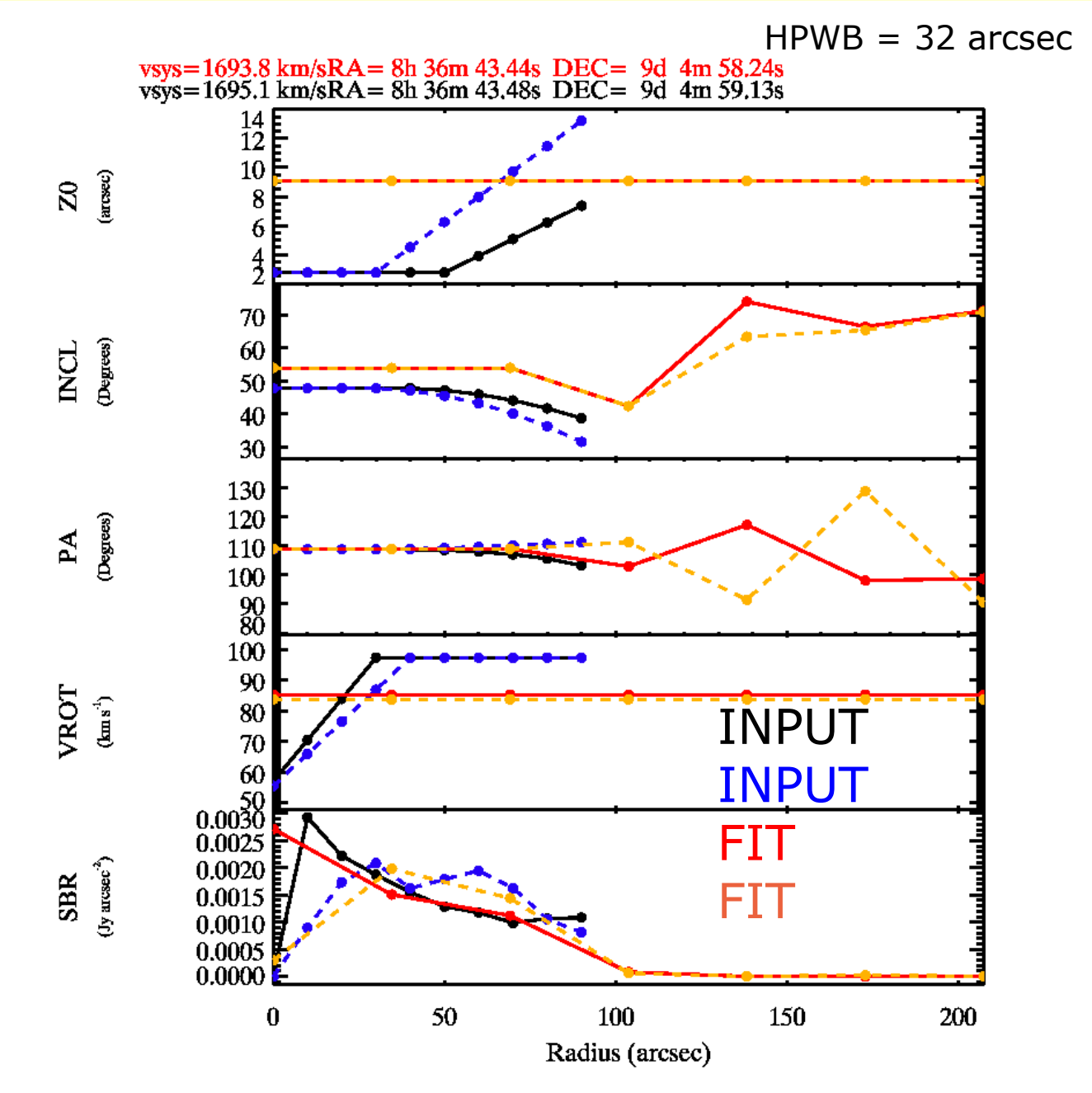
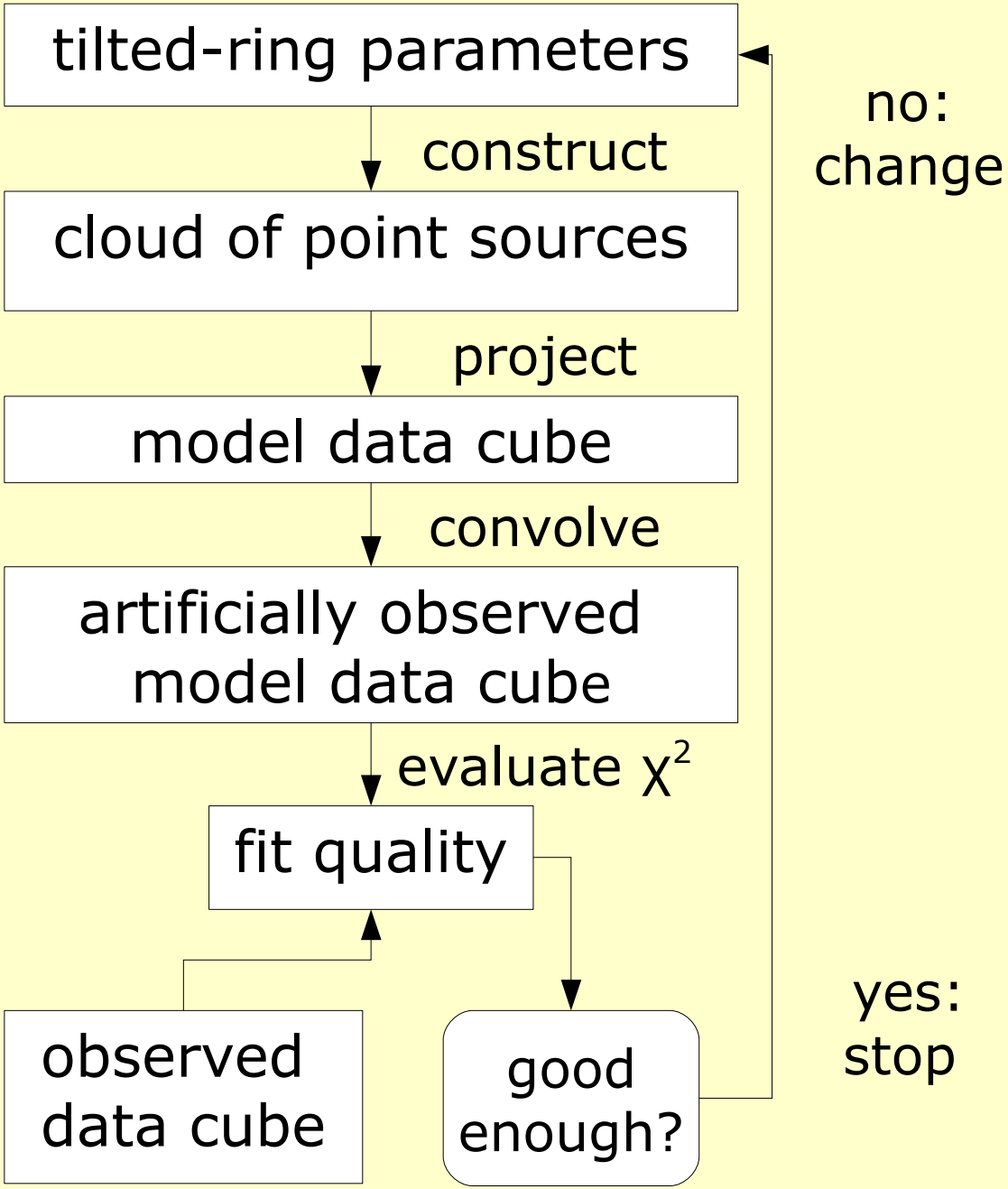


TiRiFiC minimisation schemes



- χ^2-minimisation methods:

  - **Metropolis** (not successful)

  - **Downhill simplex** (not very successful, only for small number of parameters)

  - Simple one-by-one **golden-section** nesting:

    i) Optimise the first parameter of the first ring

    ii) Optimise the same parameter of the next ring

    n) Optimise the last parameter of the last ring

    n+1) return to start

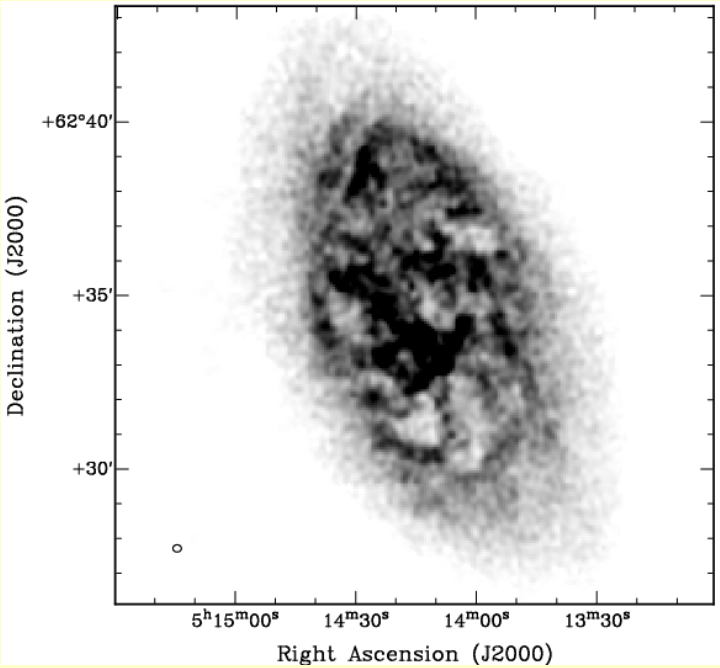
Minimisation schemes

- Establish fitting pipeline for moderately and marginally resolved galaxies
  - Script TiRiFiC to enable automated quality control
  - ➔ Starting, promising, but highly depending on
  - Finding the optimal χ^2-minimisation scheme
    - HUGE room for improvement (**Suggestions welcome!**):
      - Minimiser (MCMC? Genetic?)
      - Errors

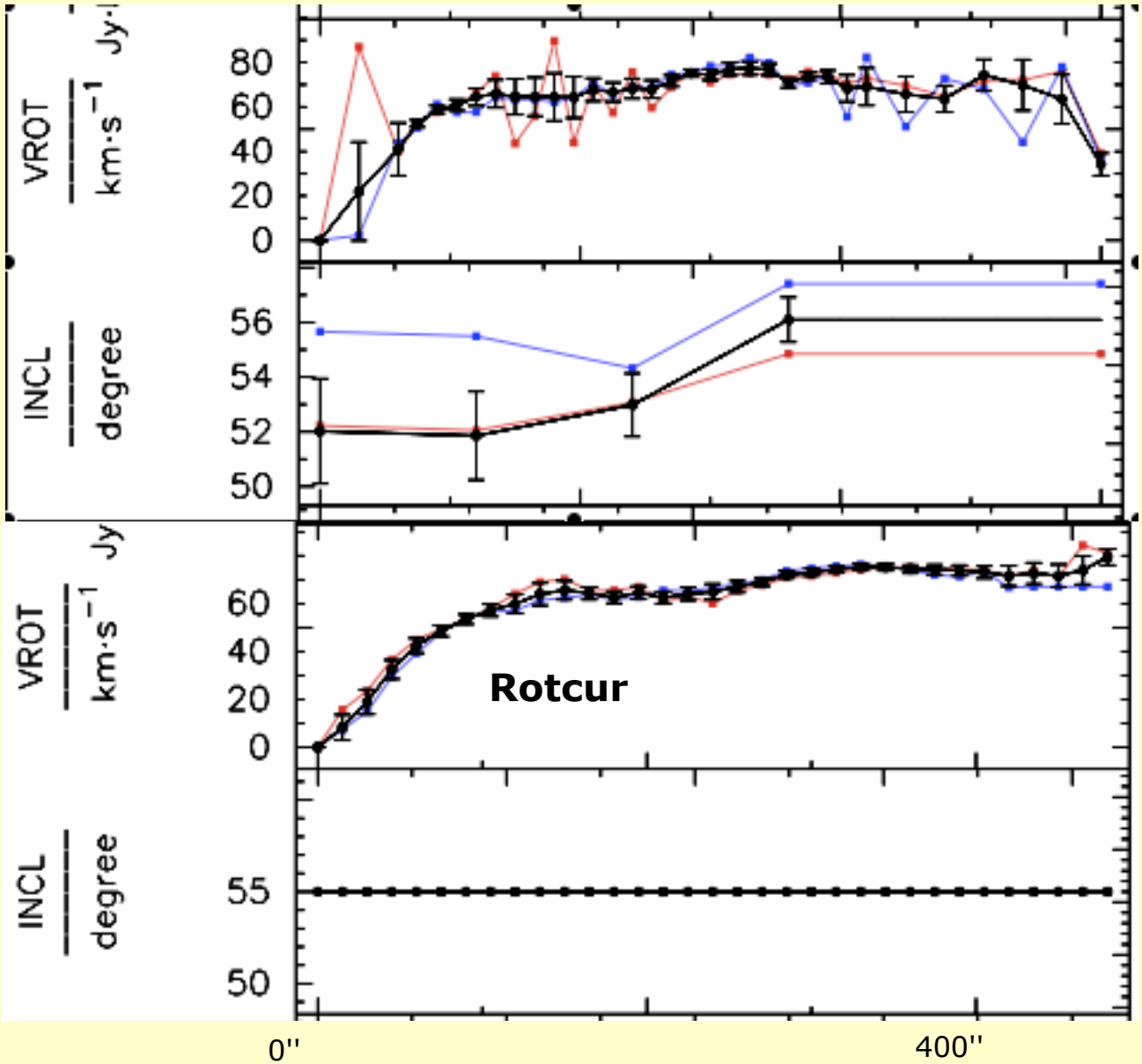
TiRiFiC milestones

- Enable complex tilted-ring modelling for well-resolved galaxies ✓
- Speed-up ✓
- Publication (online description, download): not quite, but soon ✓
- User-interface ✓
- Establish fitting pipeline for moderately and marginally resolved galaxies
  - Script TiRiFiC to enable automated quality control ✓
  - Find optimal χ^2-minimisation scheme ✗✗✗
  - Regularise parametrisation
  - Alternative parametrisation schemes to reduce number of parameters

TiRiFiC parameters



WSRT HI UGCA 105 (Schmidt et al.)



- Unreliable fit results for irregular disks (not at low resolution)
- Regularisation
- So far not successful

TiRiFiC milestones

- Enable complex tilted-ring modelling for well-resolved galaxies ✓
- Speed-up ✓
- Publication (online description, download): not quite, but soon ✓
- User-interface ✓
- Establish fitting pipeline for moderately and marginally resolved galaxies
  - Script TiRiFiC to enable automated quality control ✓
  - Find optimal χ^2-minimisation scheme ✗✗✗
  - Regularise parametrisation ✗✗✗
  - If failing -> alternative parametrisation schemes to reduce number of parameters

Summary

- TiRiFiC is a tool to fit an extended tilted-ring model to data cubes
- Ready as a semi-automated application
- Possible part of WALLABY & WNSHS parametrisation pipeline
- First pipeline implementation promising
- Better minimisation scheme needed (**suggestions?**)
- Regularisation and alternative parametrisation to be implemented