Mid-infrared interferometry of AGN cores

Leonard Burtscher

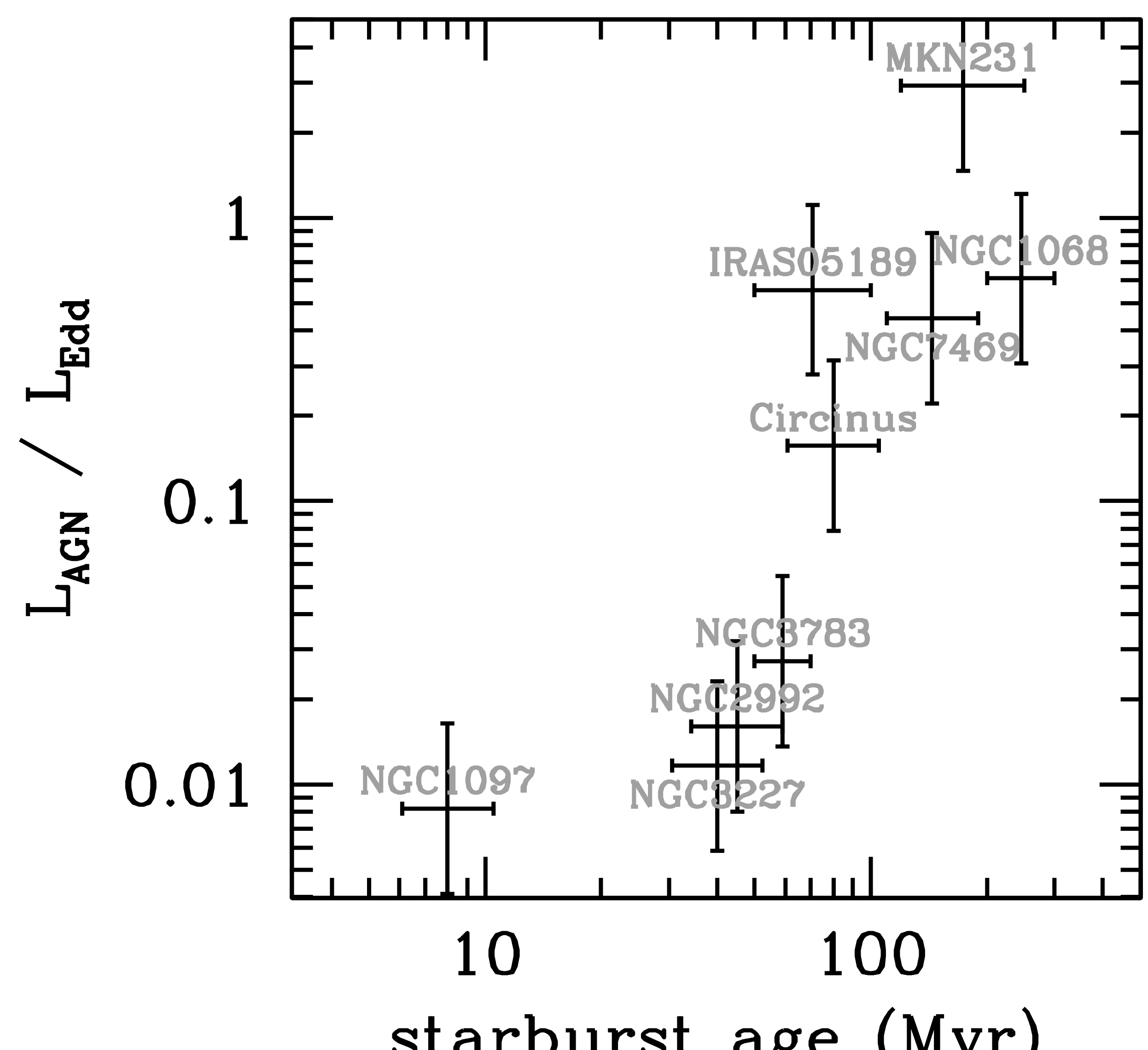
MPIA – Heidelberg

with Klaus Meisenheimer (MPIA), Konrad Tristram (Bonn), Walter Jaffe (Leiden) and the Large Programme team: Sebastian Hönig, Makoto Kishimoto, Jörg-Uwe Pott, Huub Rottgering, Marc Schartmann, Gerd Weigelt, Sebastian Wolf

Max-Planck-Institut für Astronomie Heidelberg
Max Planck Institute for Astronomy Heidelberg

26 Oct 11
Ten Years VLTI conference, ESO, Garching

Why study Active Galactic Nuclei (AGNs)?



Davies+ 2007, Friedrich+ 2010

Credit: ESO/WFI (Optical); MPIfR/ESO/APEX/A.Weiss et al. (Submillimetre); NASA/CXC/CfA/R.Kraft et al. (X-ray)

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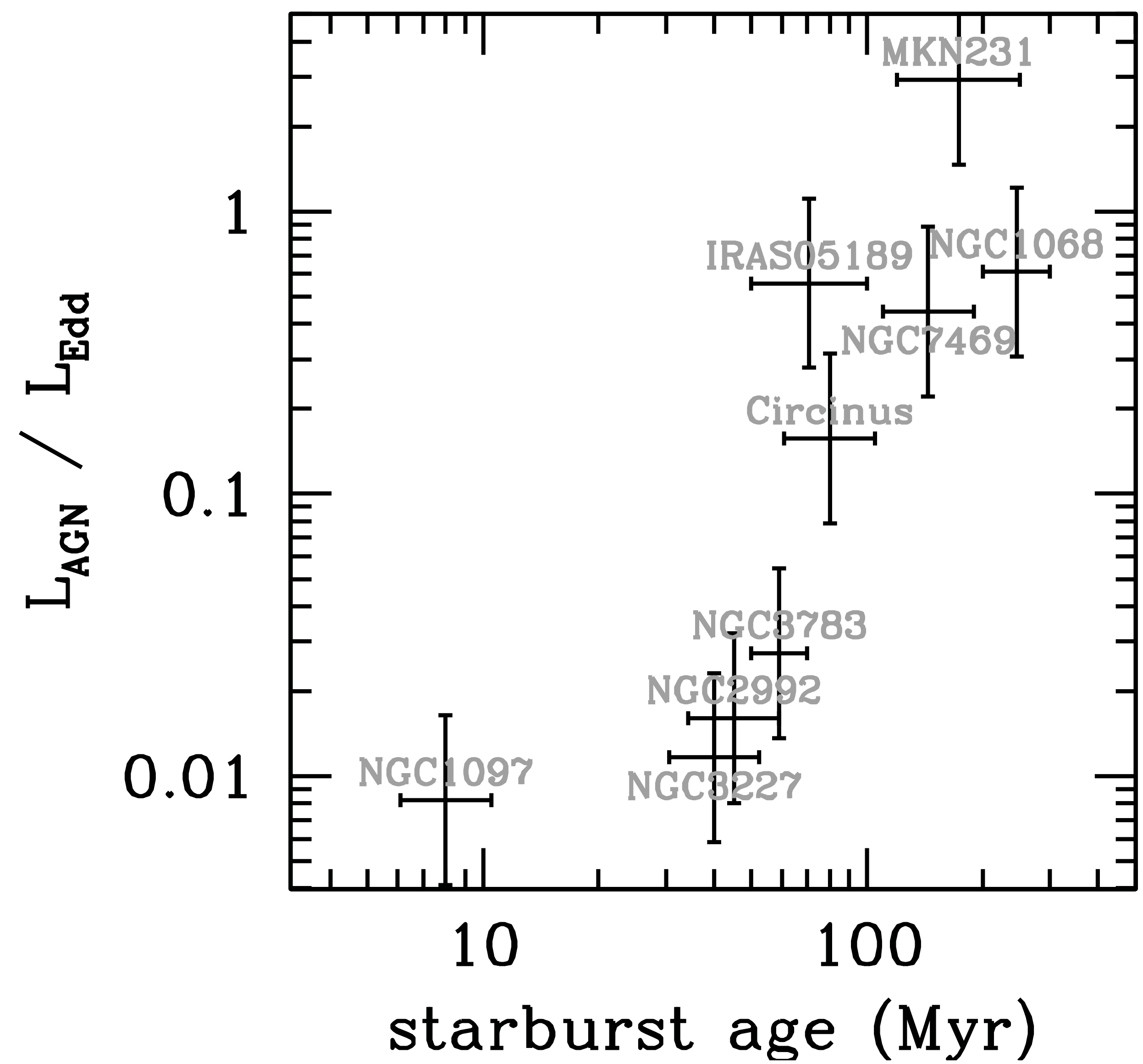

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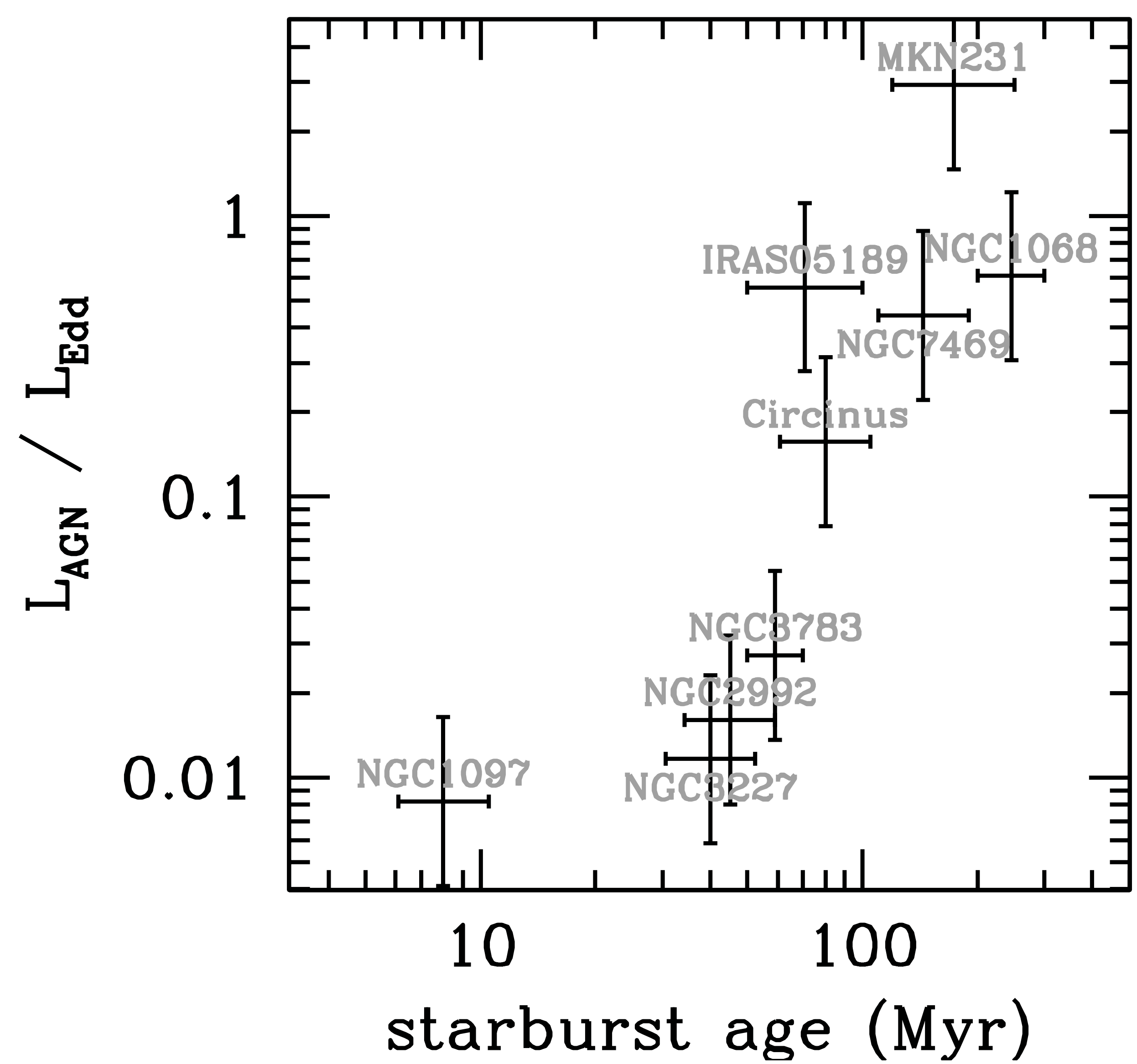

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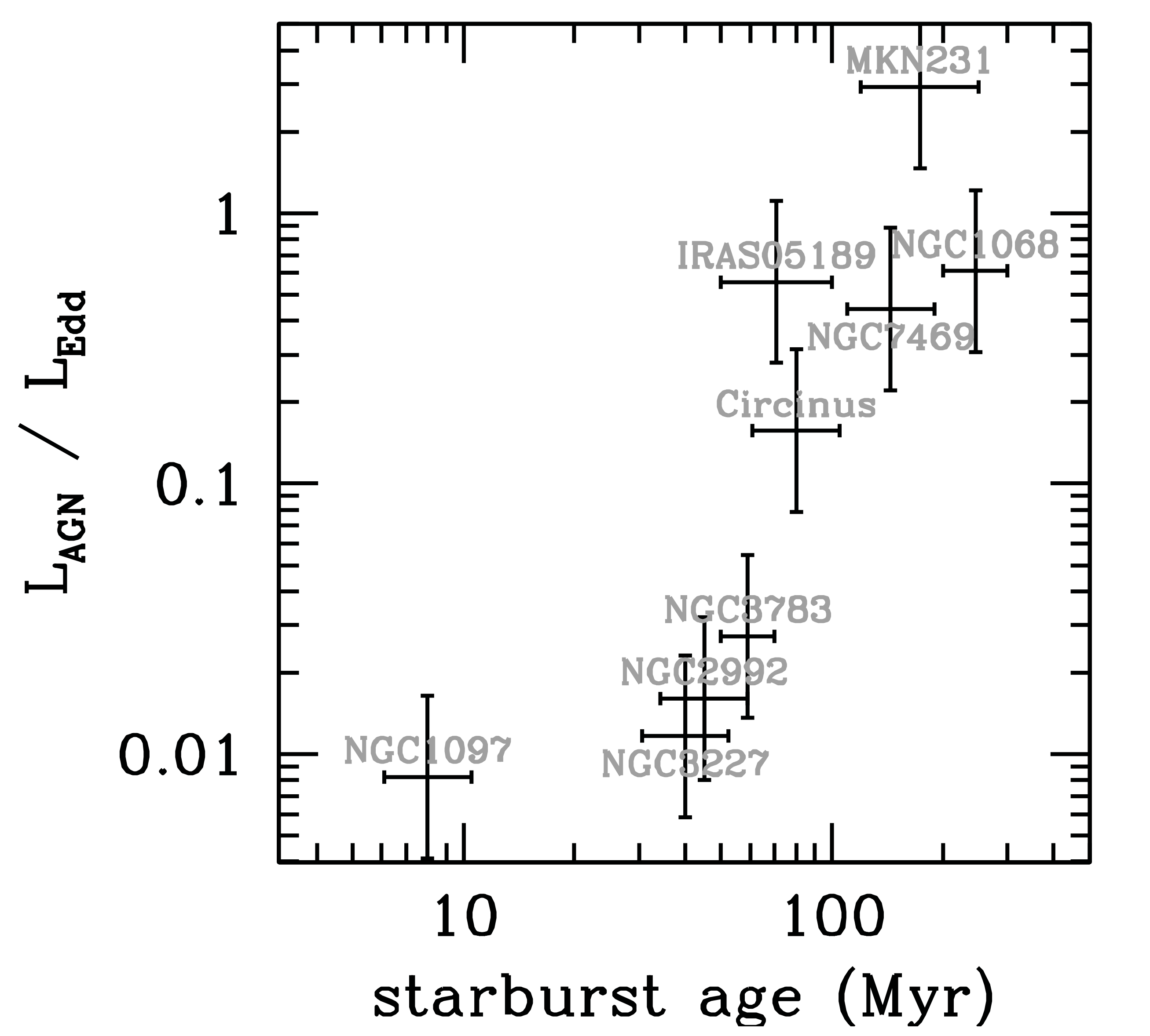

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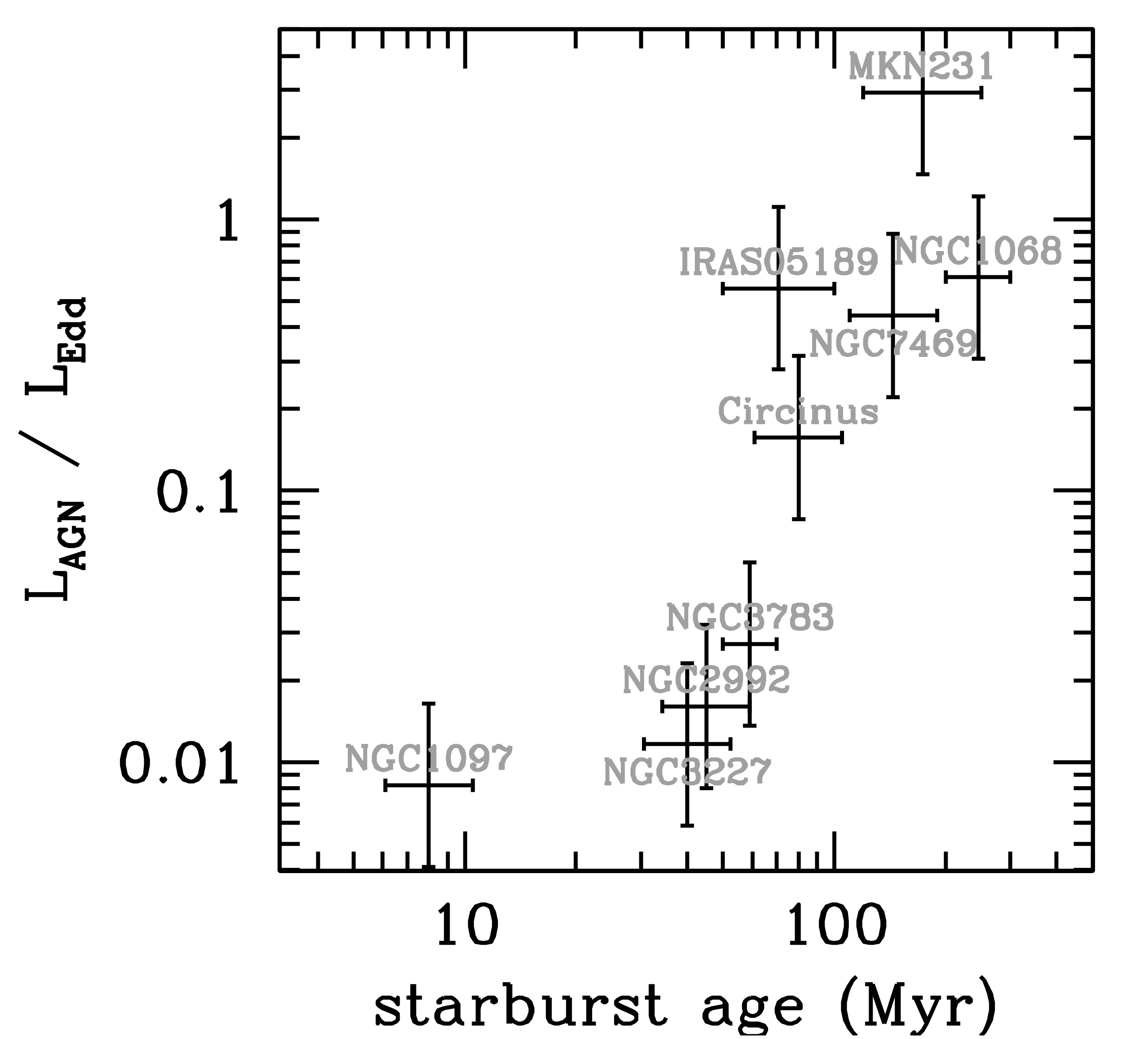
- most powerful non-transient phenomenon in the universe
- role in galaxy evolution?
- probes of the early universe
- ubiquitous (depending on definition)



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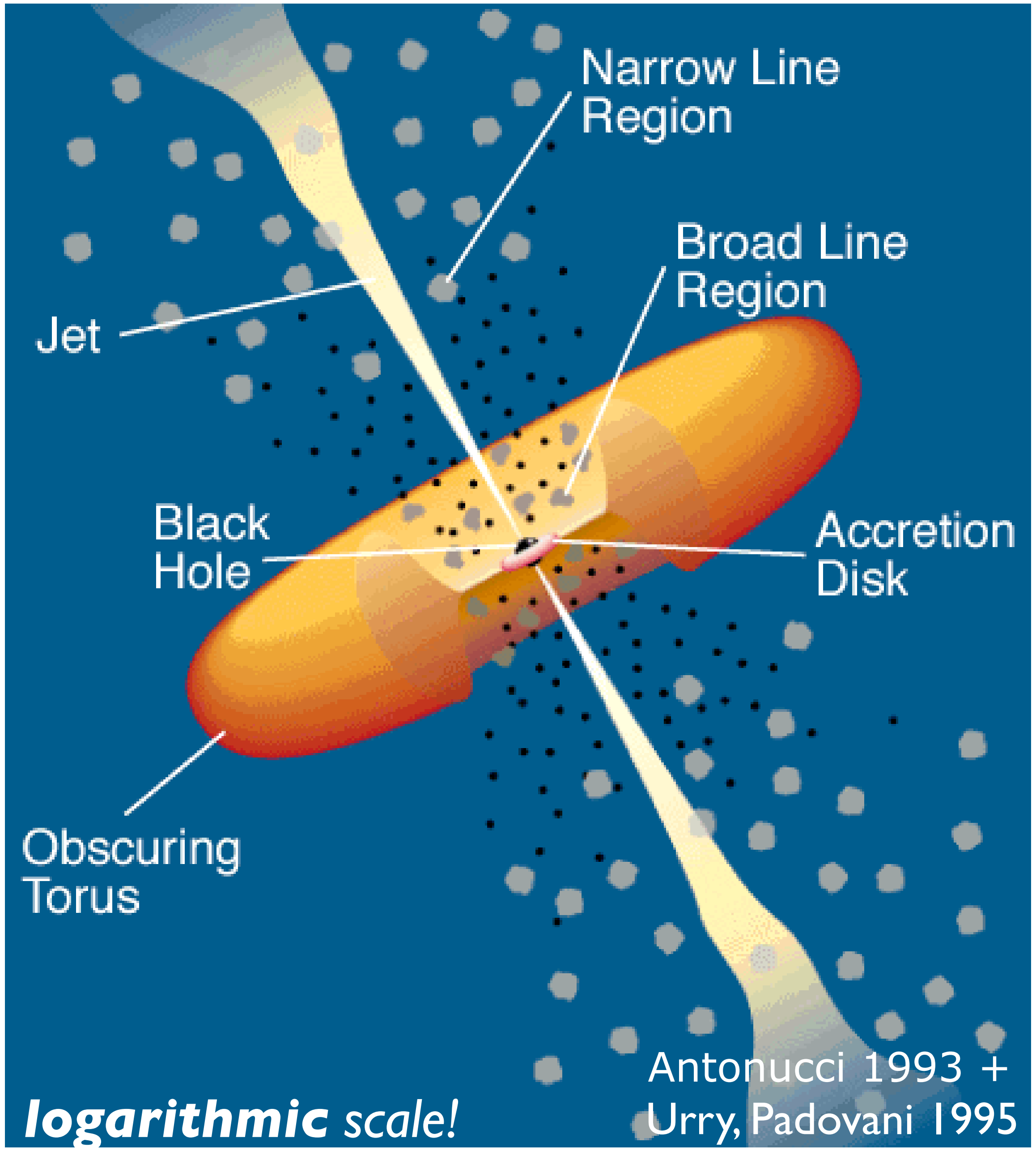

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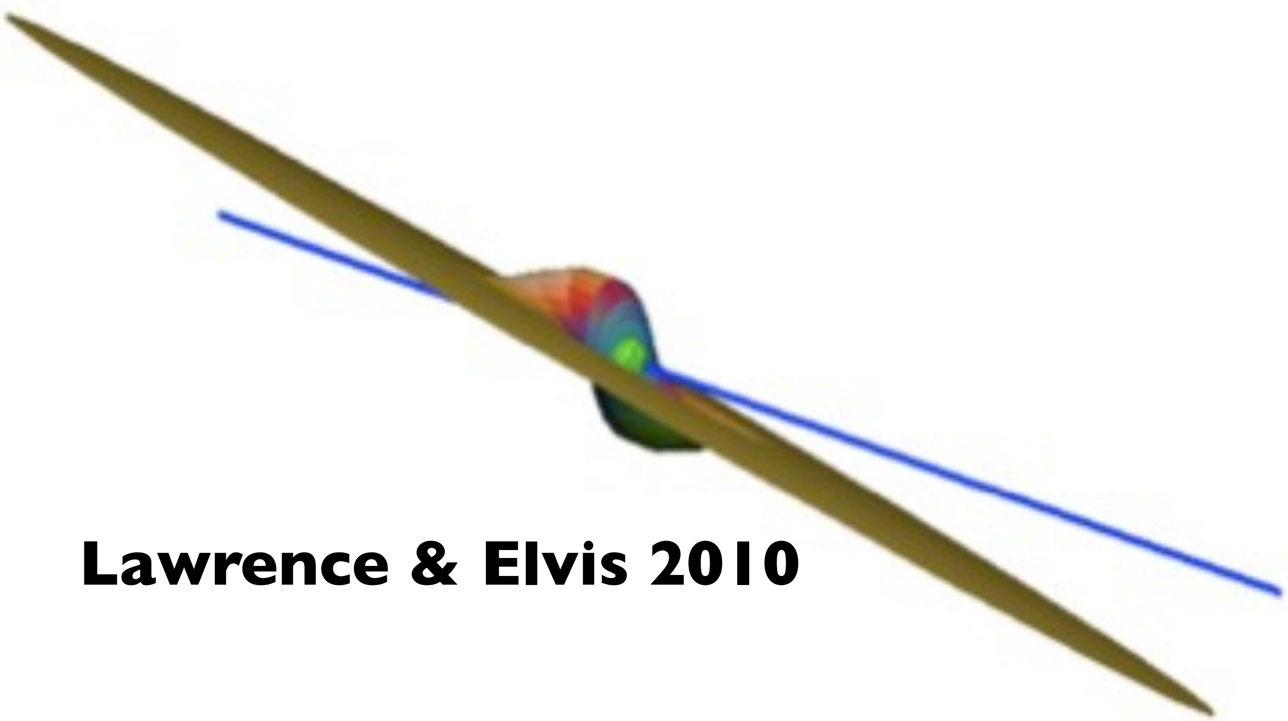

Lawrence & Elvis 2010

Is the „torus“...

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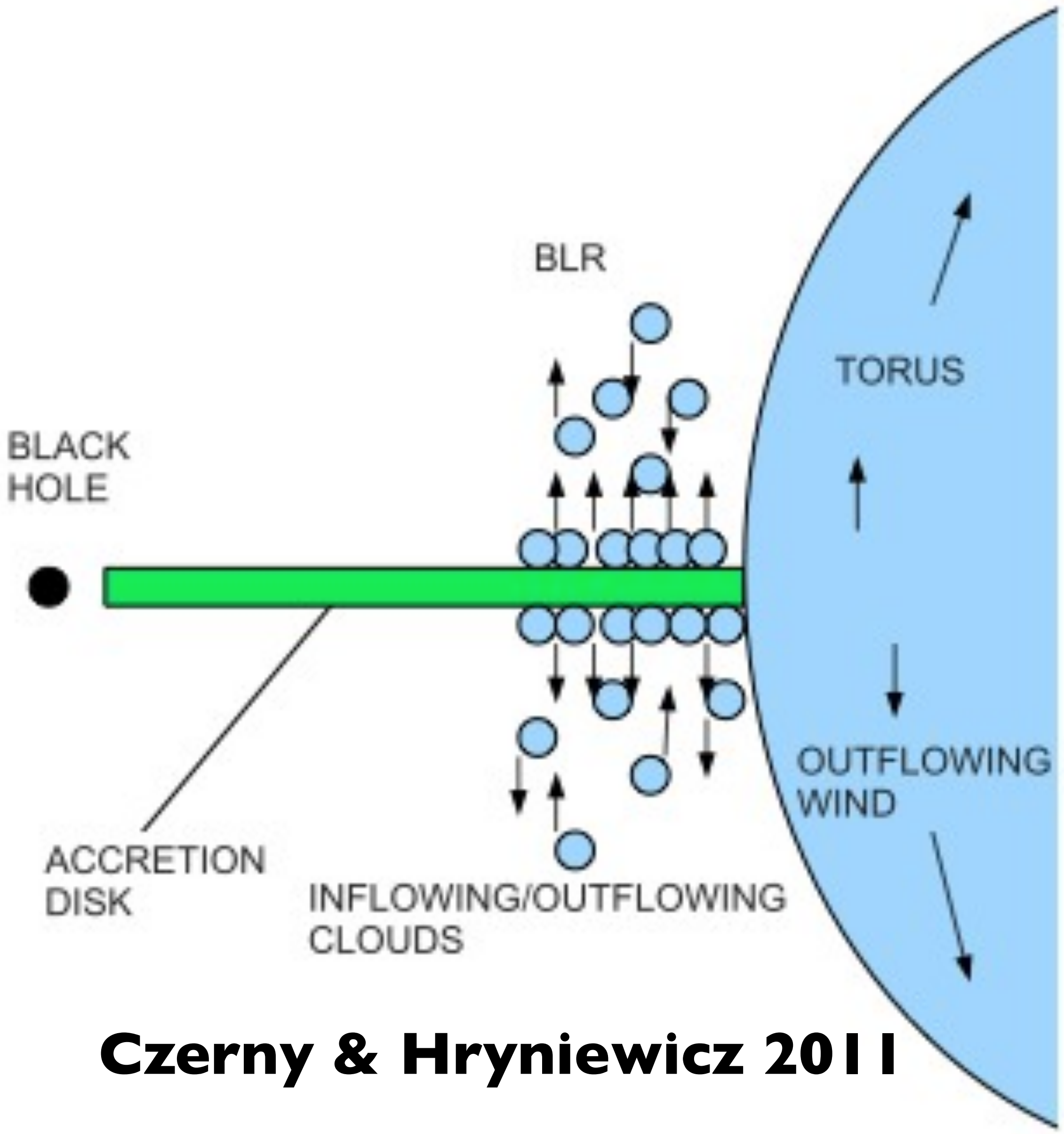
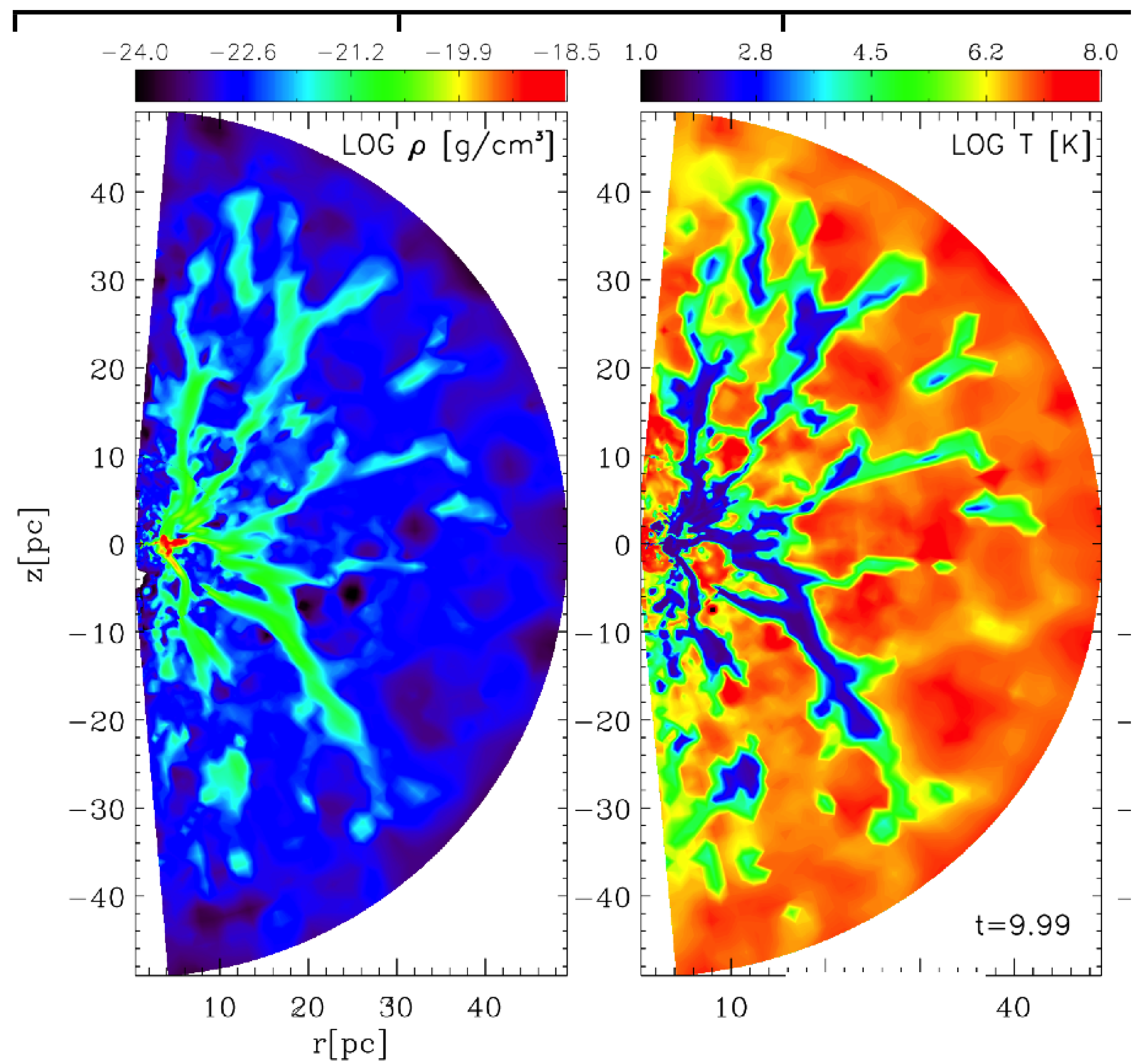
- a (geometrically thick) outflow, starting from a disk in the center?



Czerny & Hryniewicz 2011

Is the „torus“...

- ~~a homogeneous, thick structure~~ (scale height problem)
- a warped disk causing obscuration?
- a (geometrically thick) outflow, starting from a disk in the center?
- a (geometrically thick) supernova-driven inflow, leading to a disk in the center?



Schartmann+ 2009

MIDI + AGNs

Reference	main finding	source

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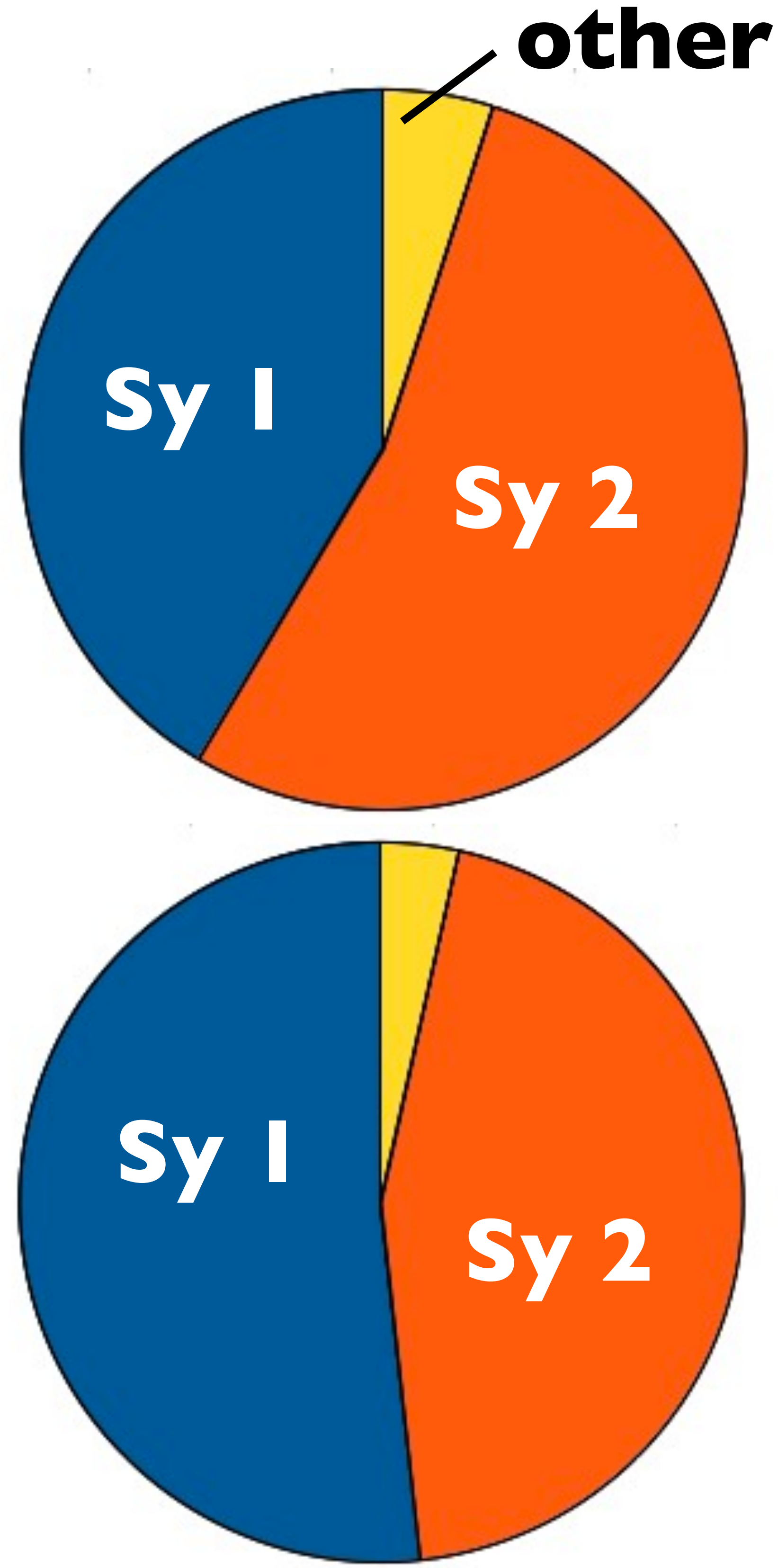
Kishimoto+ 2011	Revised size–luminosity relation, s constant with L at 13 μm!	6 sources

MIDI Large Programme + Archive

- Have a **statistically useful** sample of resolved AGN tori to compare with various other AGN properties

all AGNs
(41 targets)

successful observations
(29 targets)



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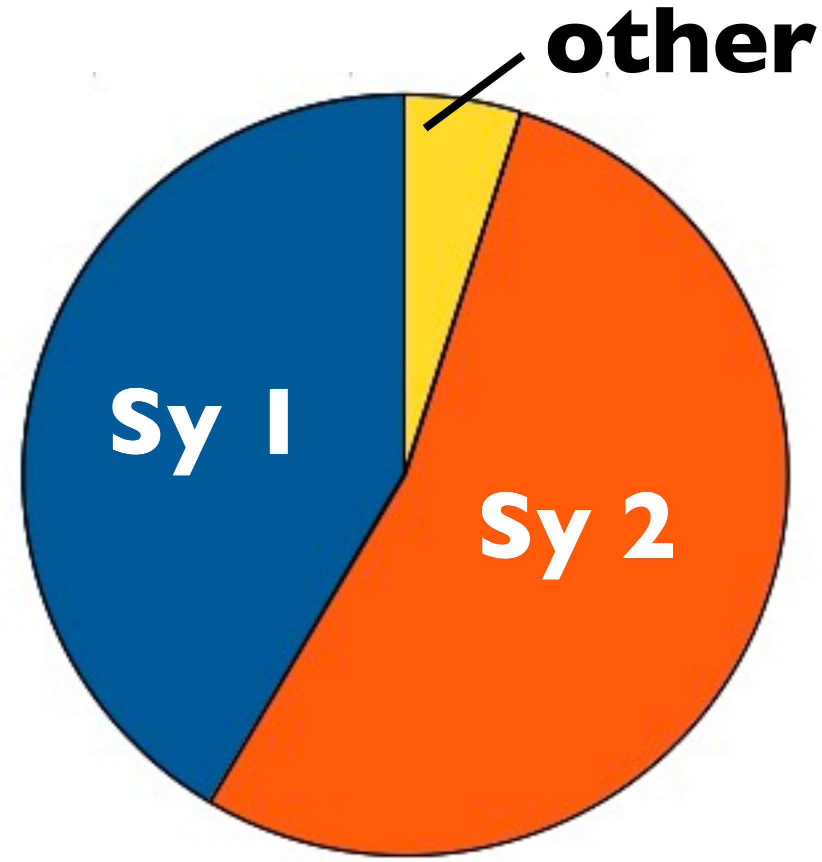

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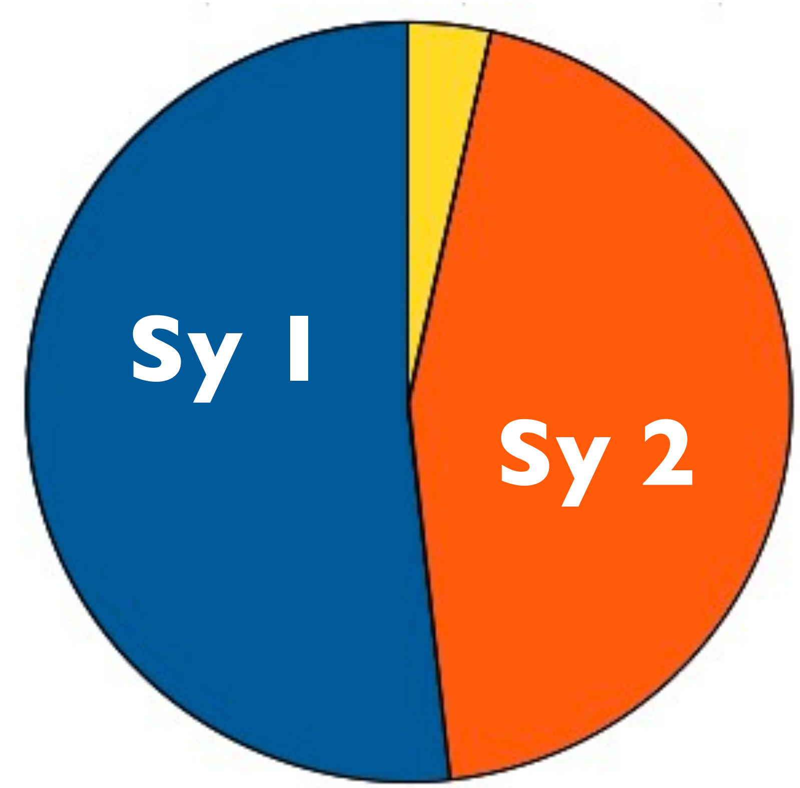

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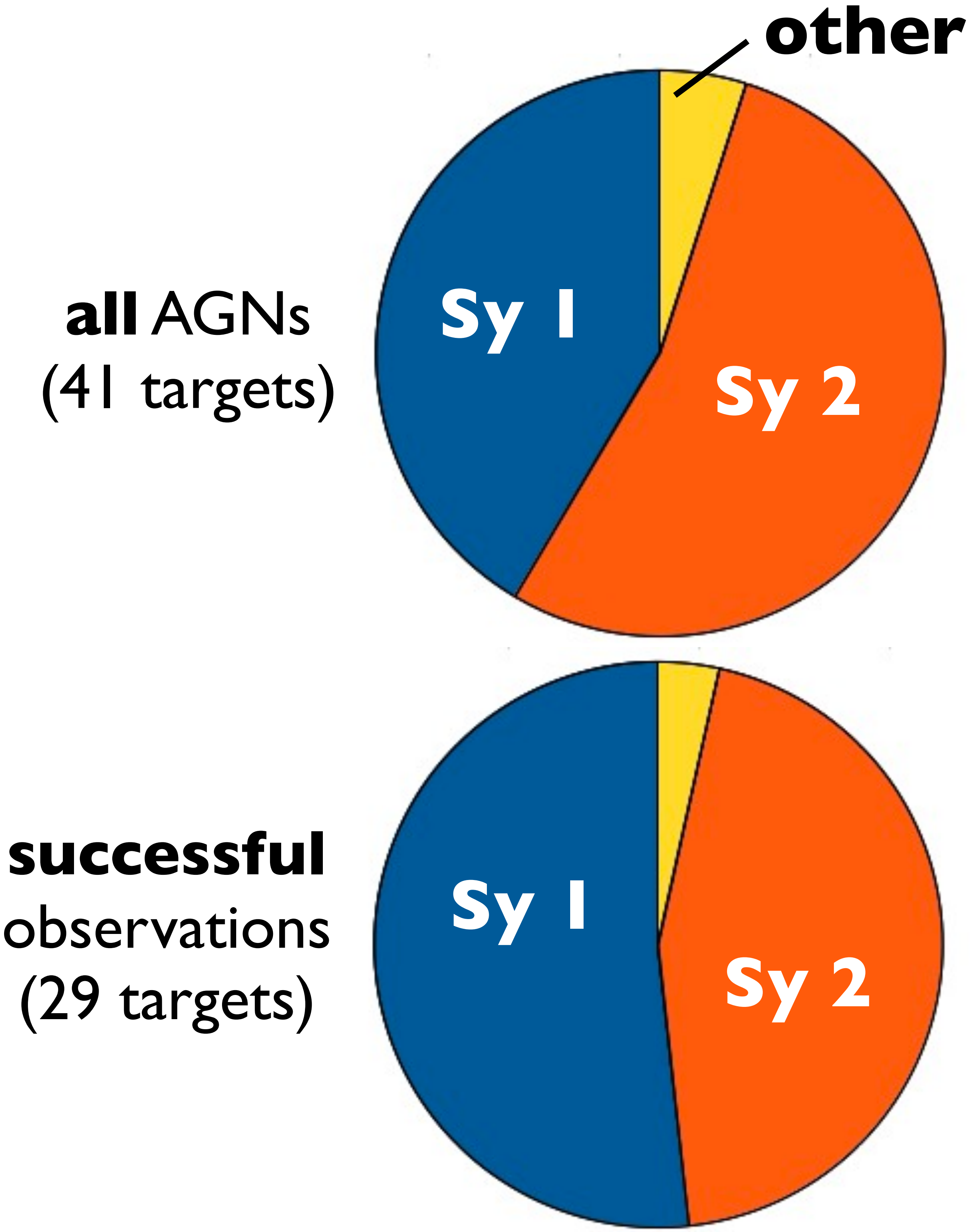
- LP+: 15.6 UT nights observed, ca. 10 million frames



MIDI Large Programme + Archive

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But: to increase the sample, one needs to observe sub-Jy targets!

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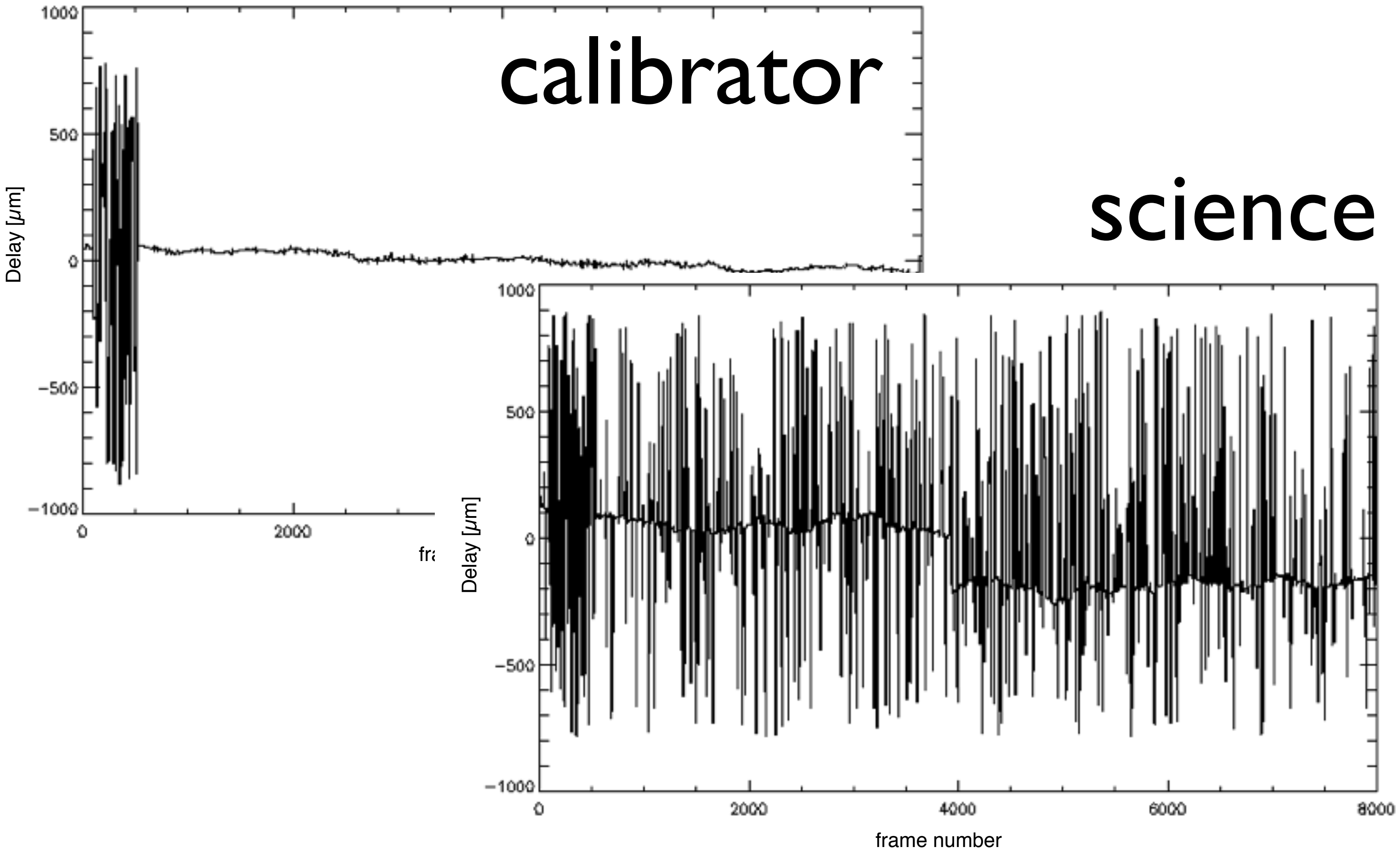
successful observations (29 targets)

Observing faint targets

- Different observing mode: cal track – sci track – cal track – ...; now also offered by ESO in SM: „correlated flux mode“
- New data reduction (EWS 2.0 – soon to be released, see http://www.strw.leidenuniv.nl/~jaffe/ews/)



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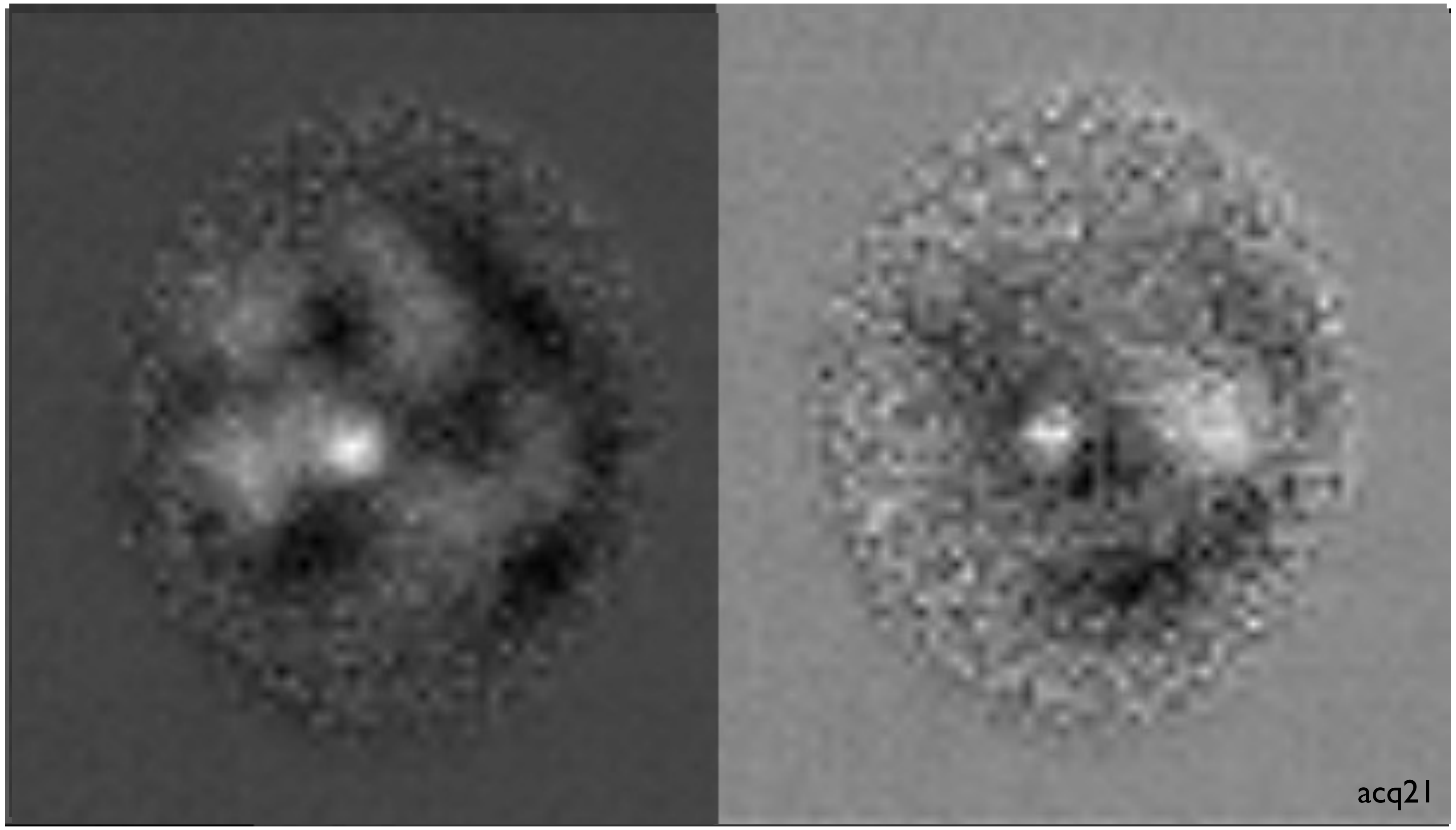

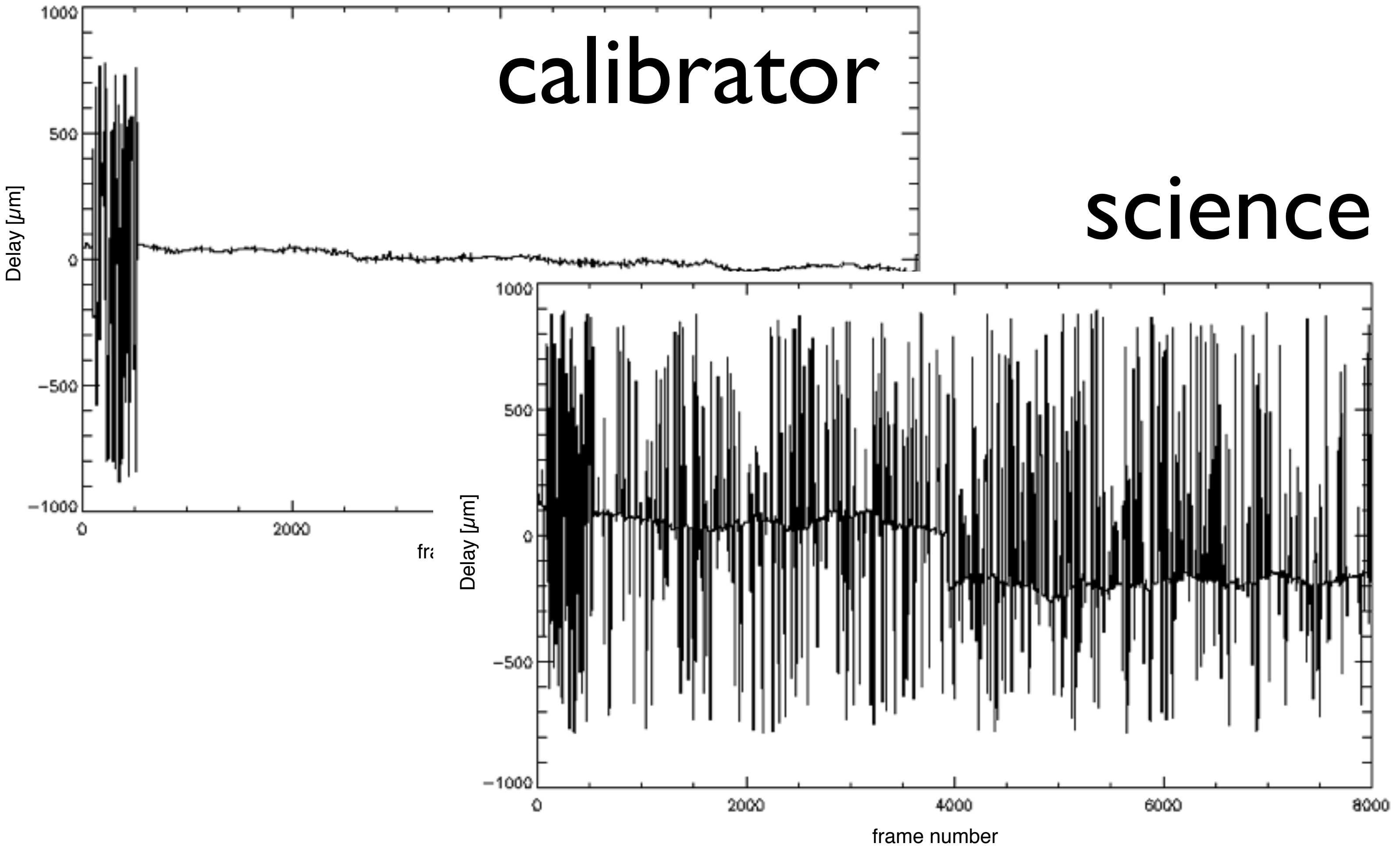

Observing faint targets

- Direct calibration of correlated fluxes, no visibilities + revised error bars

does not depend on atmospheric transmission (so much)

$$V = \frac{V_{\mathrm{ins,target}}}{V_{\mathrm{ins,cal}}} \cdot V_{\mathrm{cal}},$$

$$V_{\mathrm{ins,target}} = \frac{F_\nu}{F_{\mathrm{total}}}$$

sensitive to atmospheric variations, but less noisy

$$F_\nu = \frac{I_{\mathrm{corr}}}{I_{\mathrm{corr,cal}}} \cdot F_{\nu,\mathrm{cal}}$$

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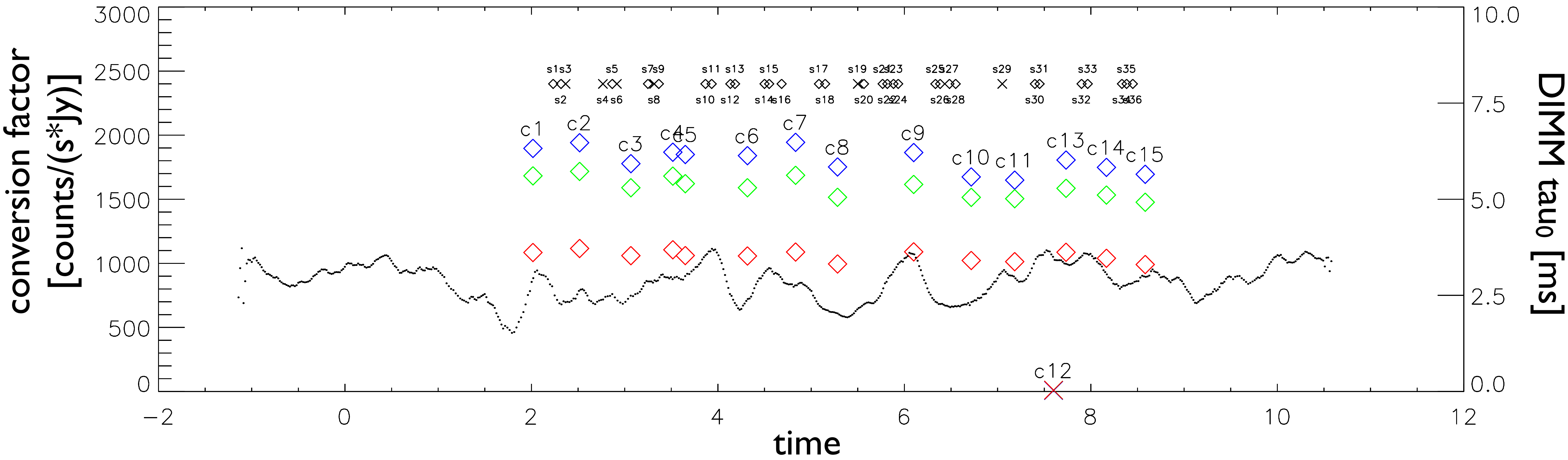

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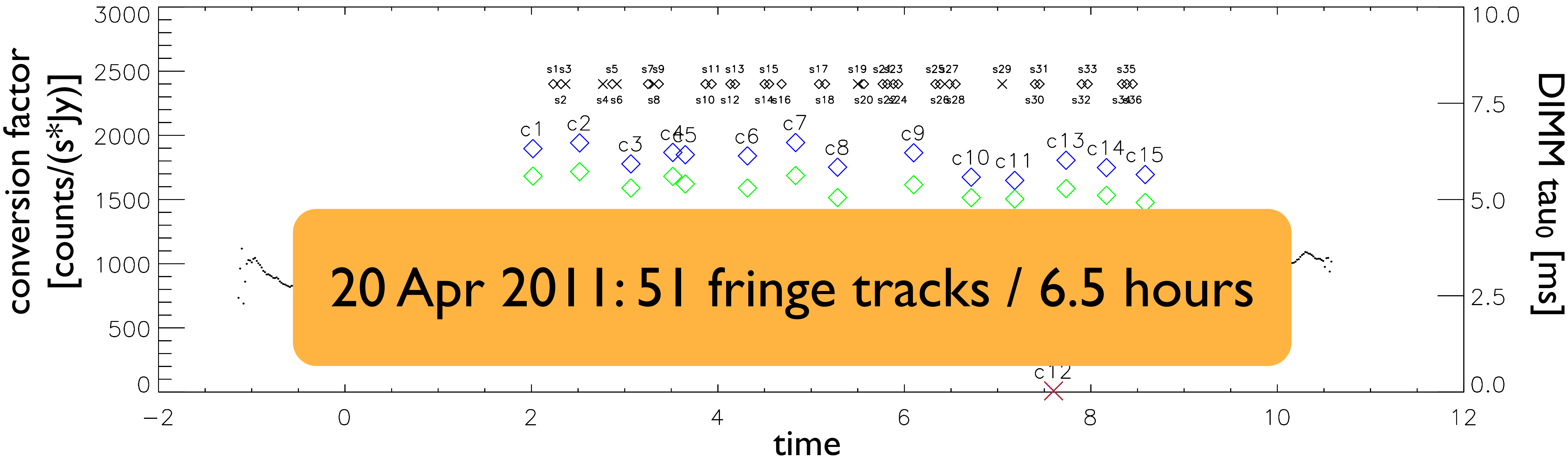

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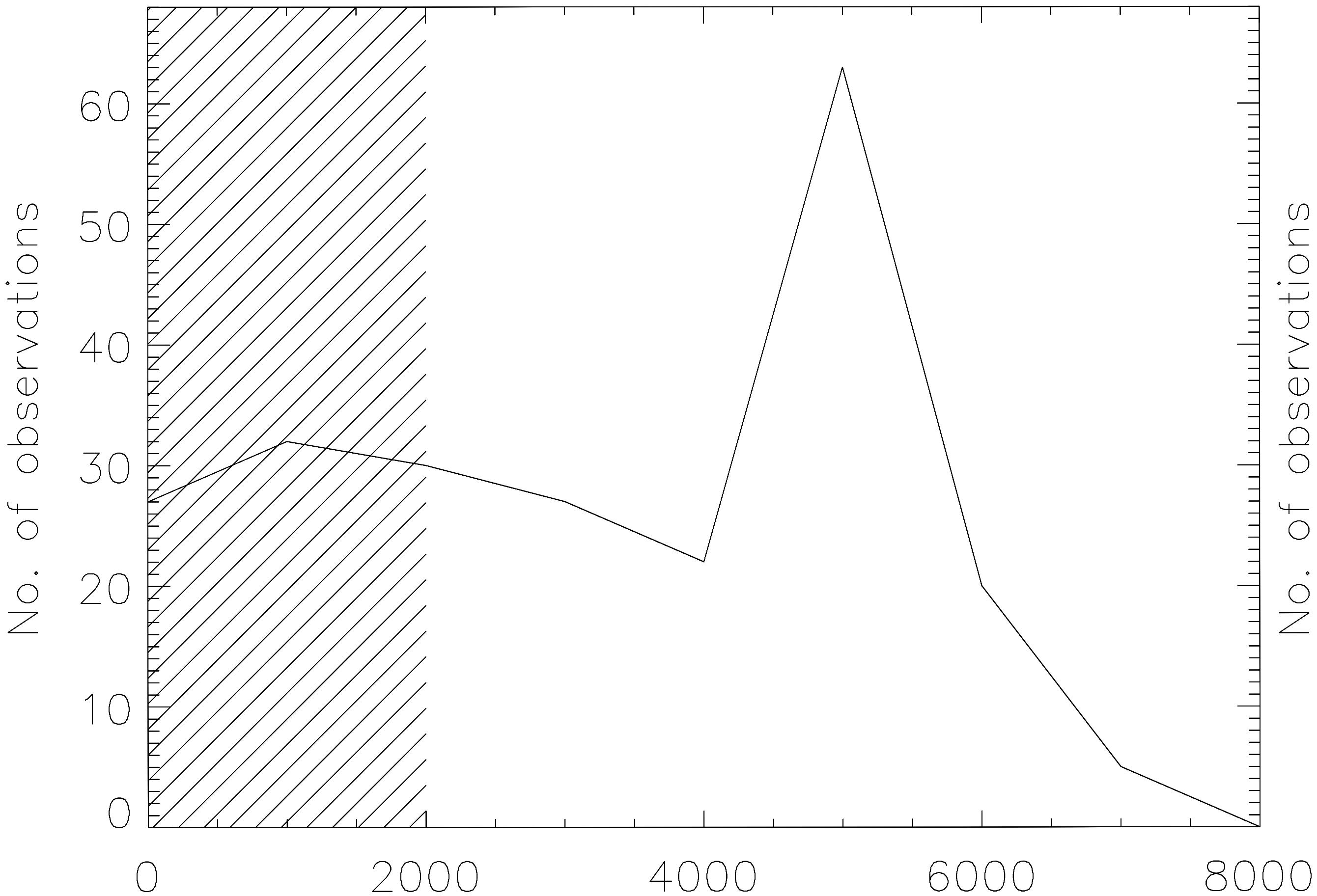
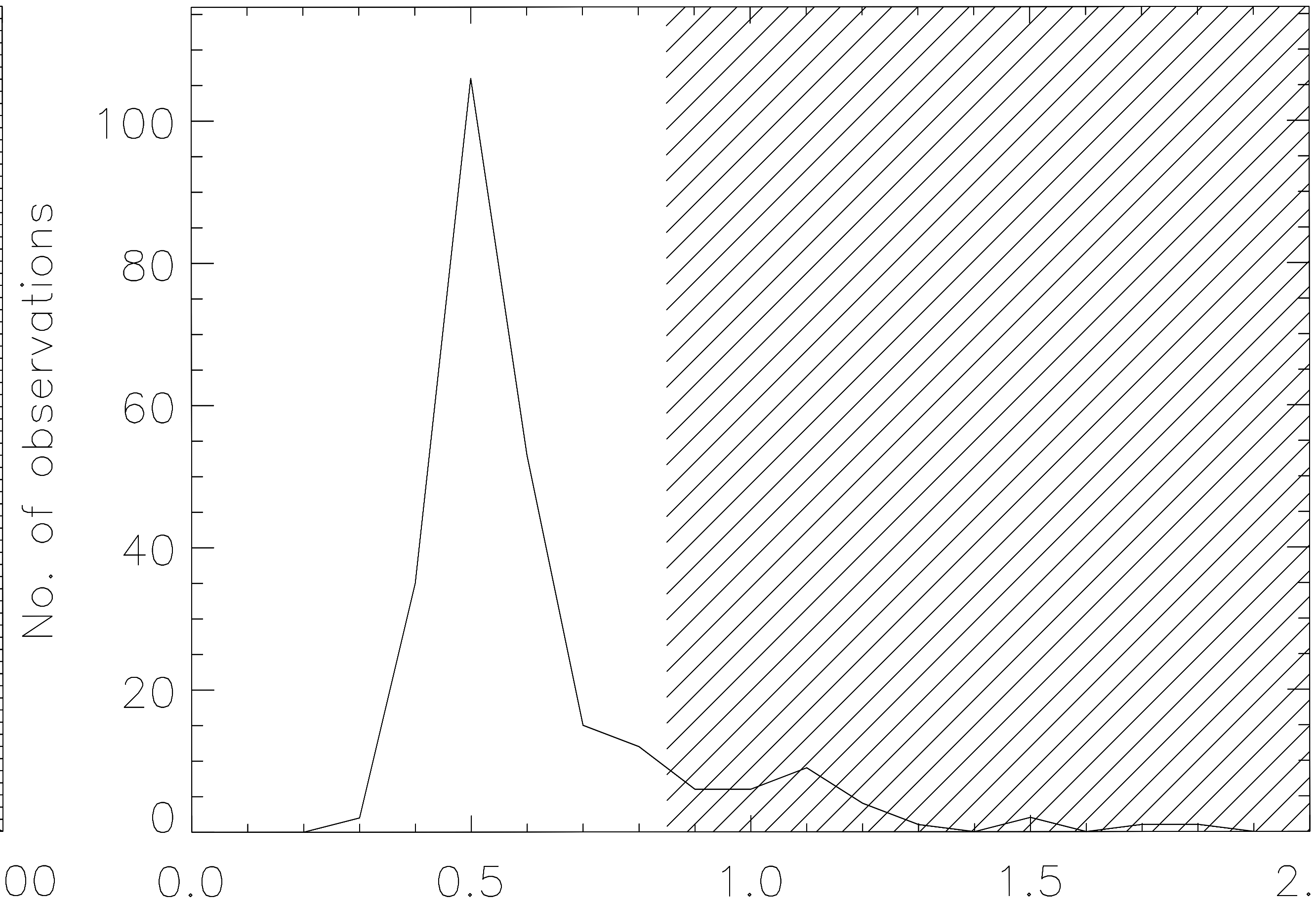
Observing faint targets

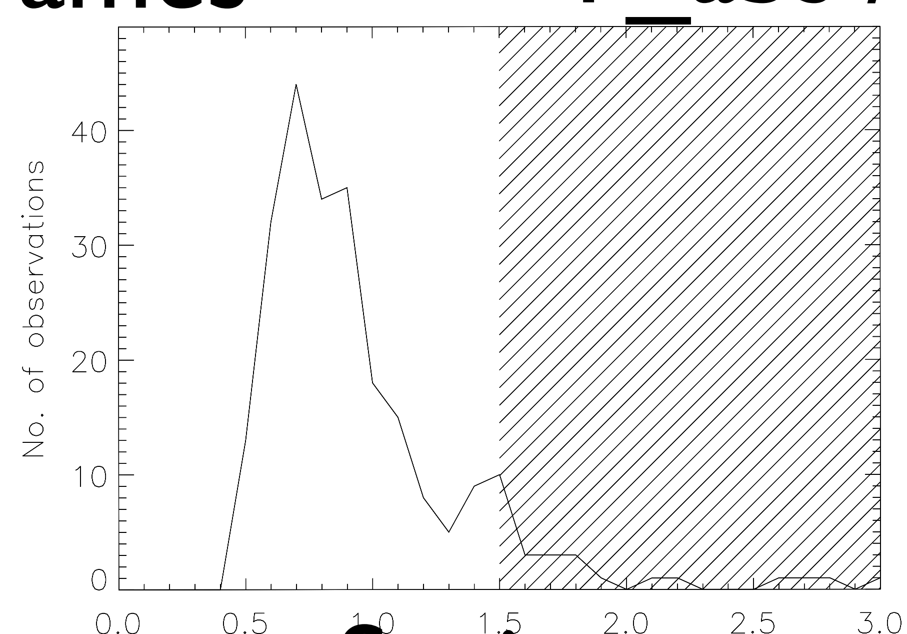
- Automatic (and objective?) flagging of observations



Number of good frames

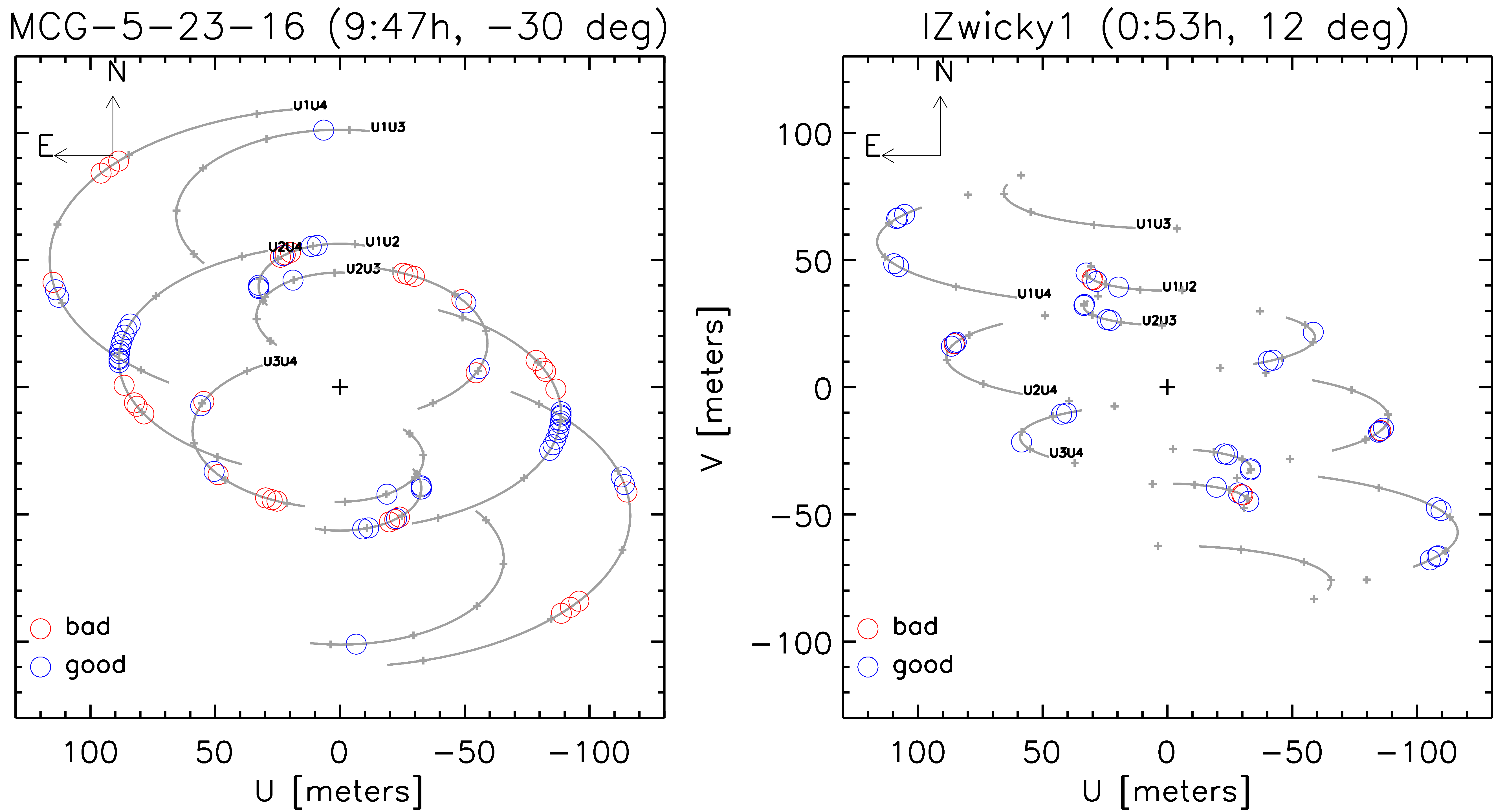


F_abs / F_deabs (Ozone)

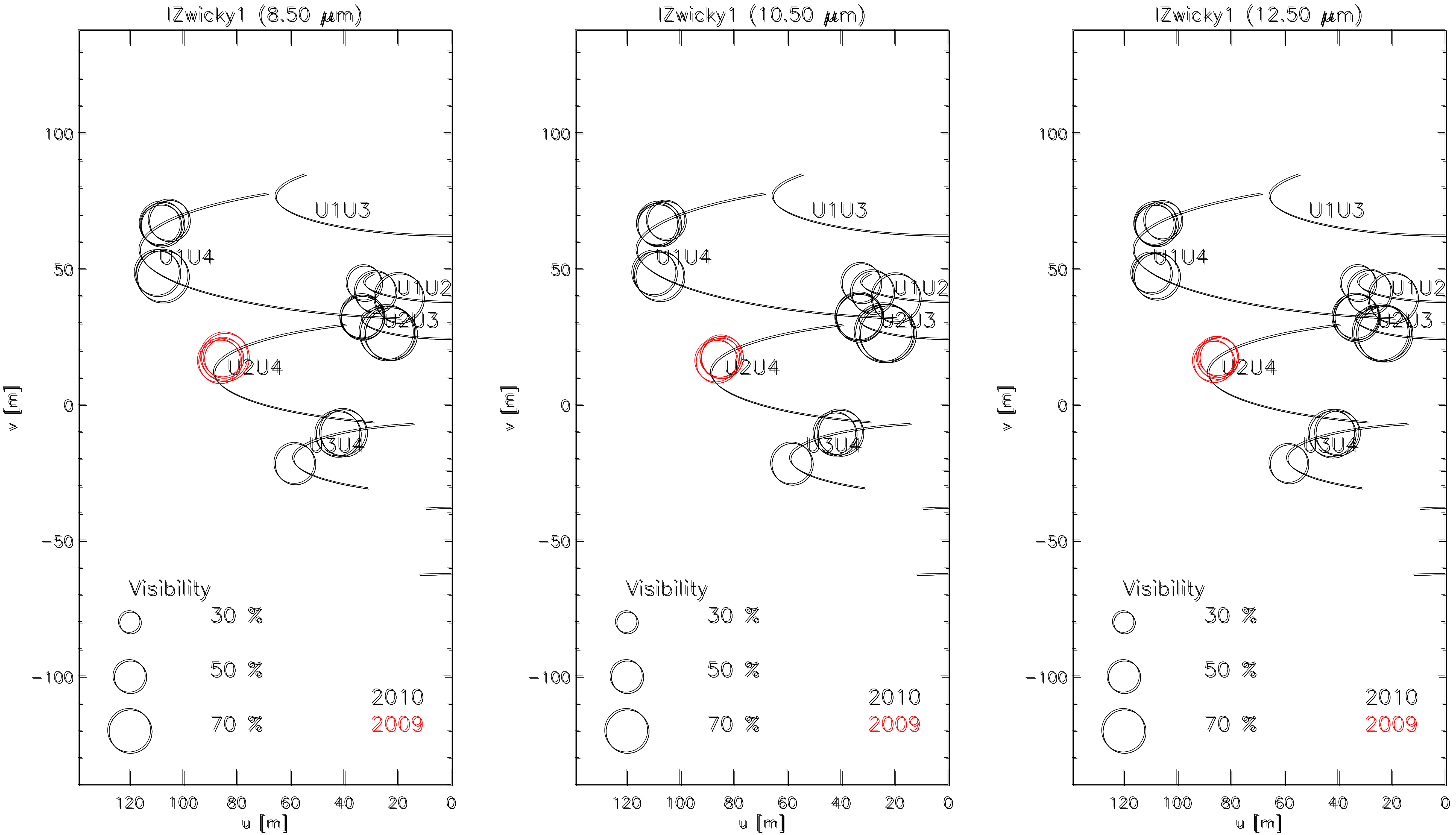


Seeing

(u,v) coverages



Asymmetries?



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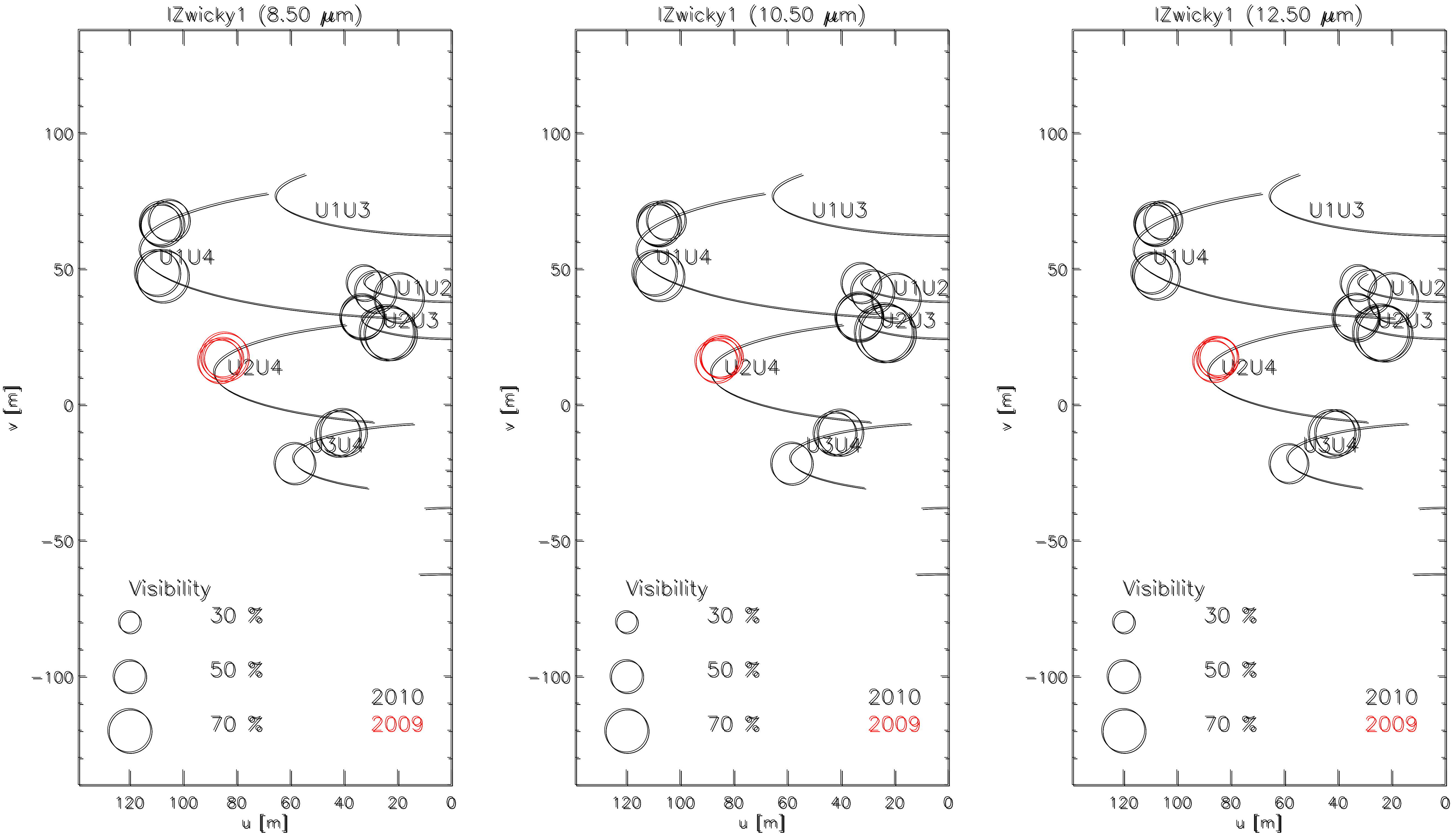
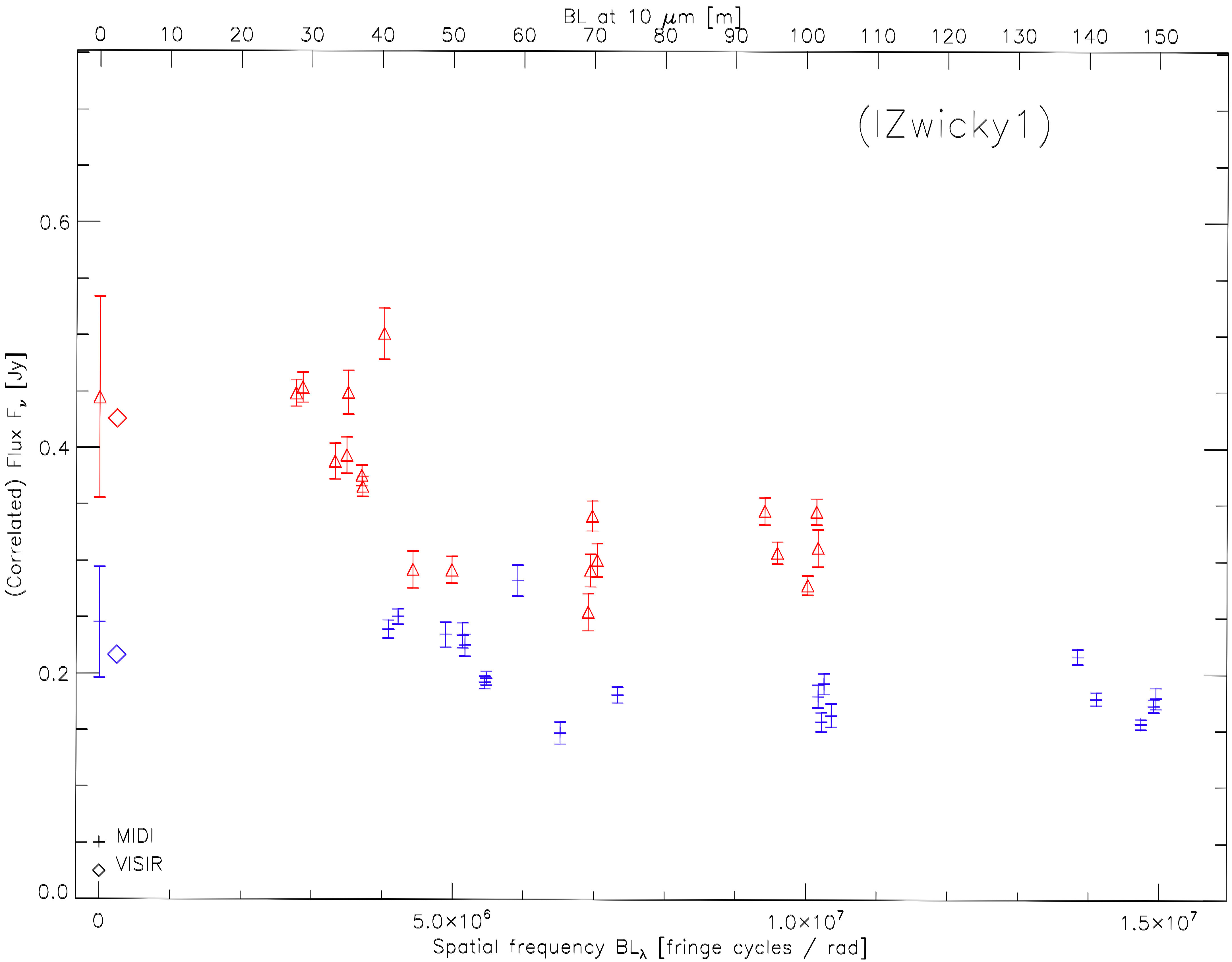
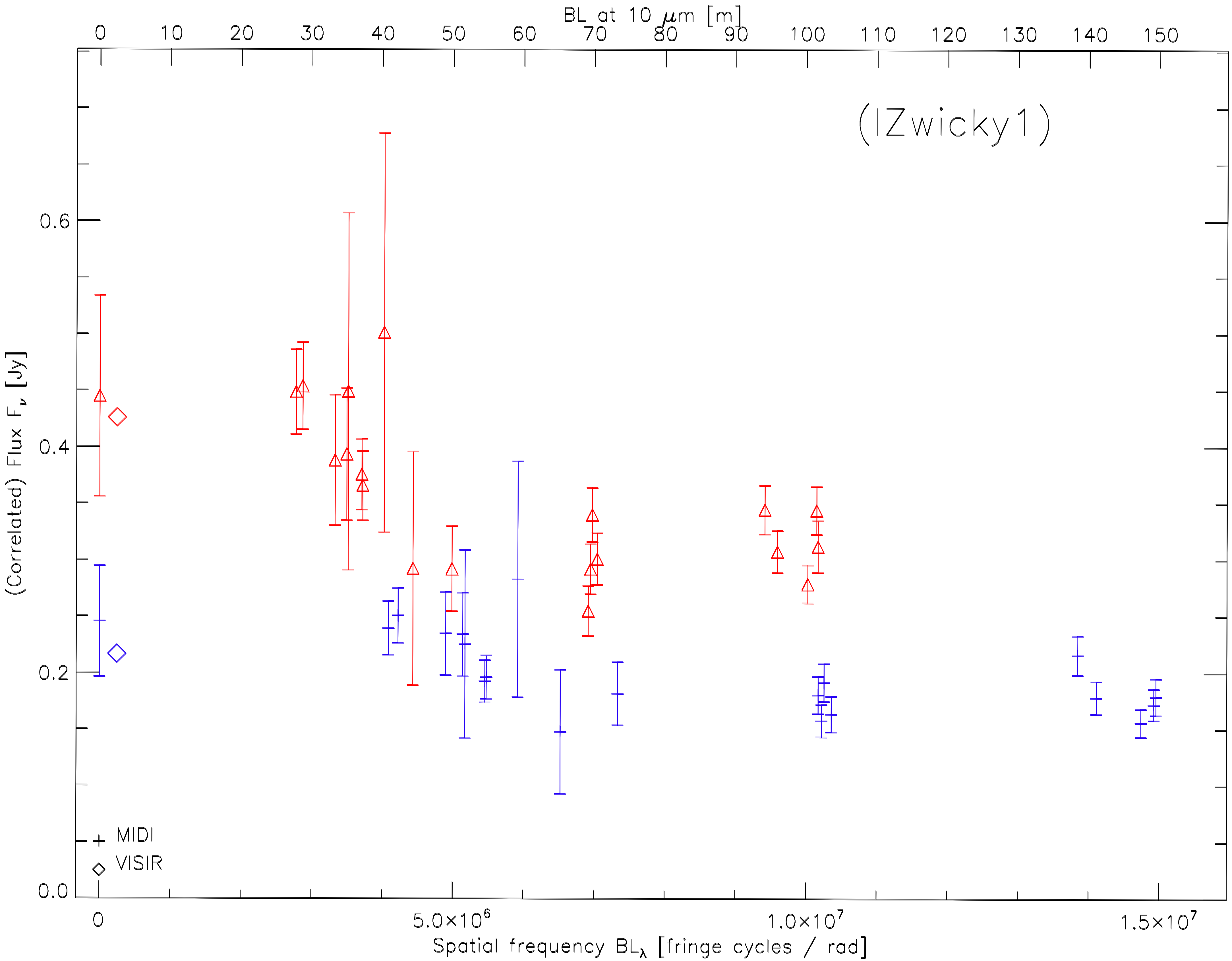


...at least no obvious ones.

I Zwicky 1


BL at 10 μm [m]
0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150
(IZwicky1)
(Correlated) Flux F_ν [Jy]
0.0 0.2 0.4 0.6
+ MIDI
◇ VISIR
0 5.0×10^6 1.0×10^7 1.5×10^7
Spatial frequency BL_λ [fringe cycles / rad]

I Zwicky 1


BL at 10 μm [m]
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
(IZwicky1)
(Correlated) Flux F_ν [Jy]
0.0
0.2
0.4
0.6
MIDI
VISIR
0
5.0×10^6
1.0×10^7
1.5×10^7
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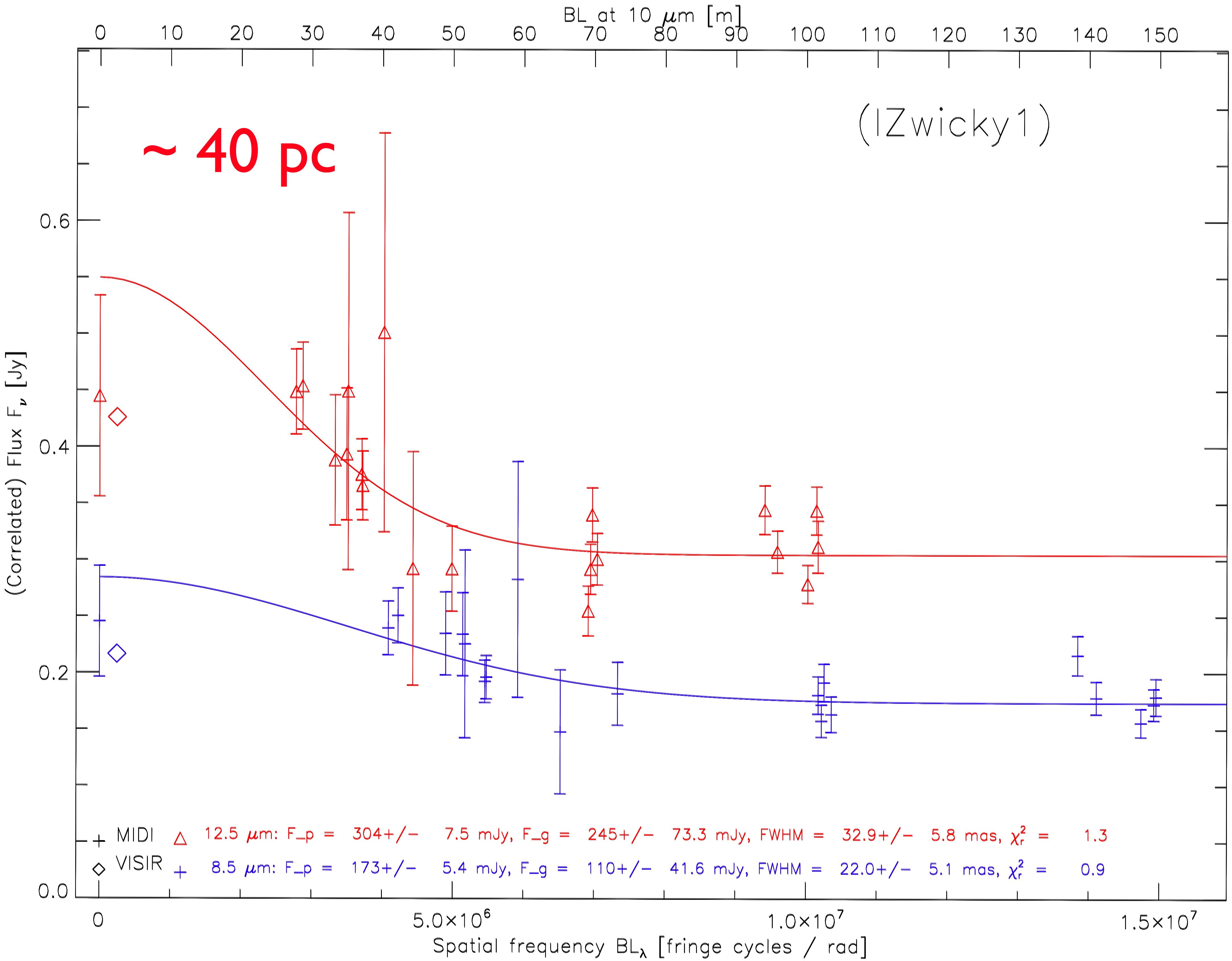
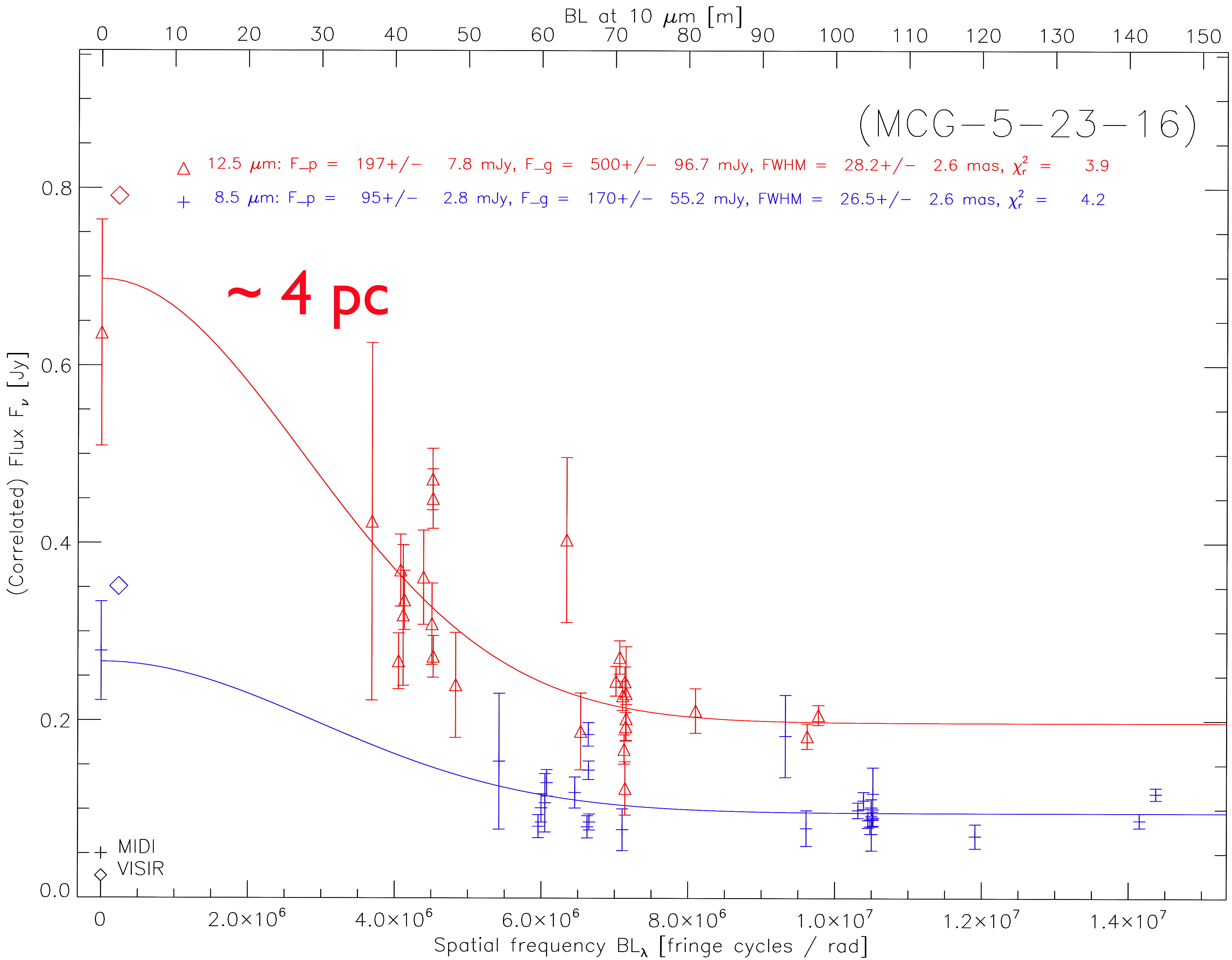
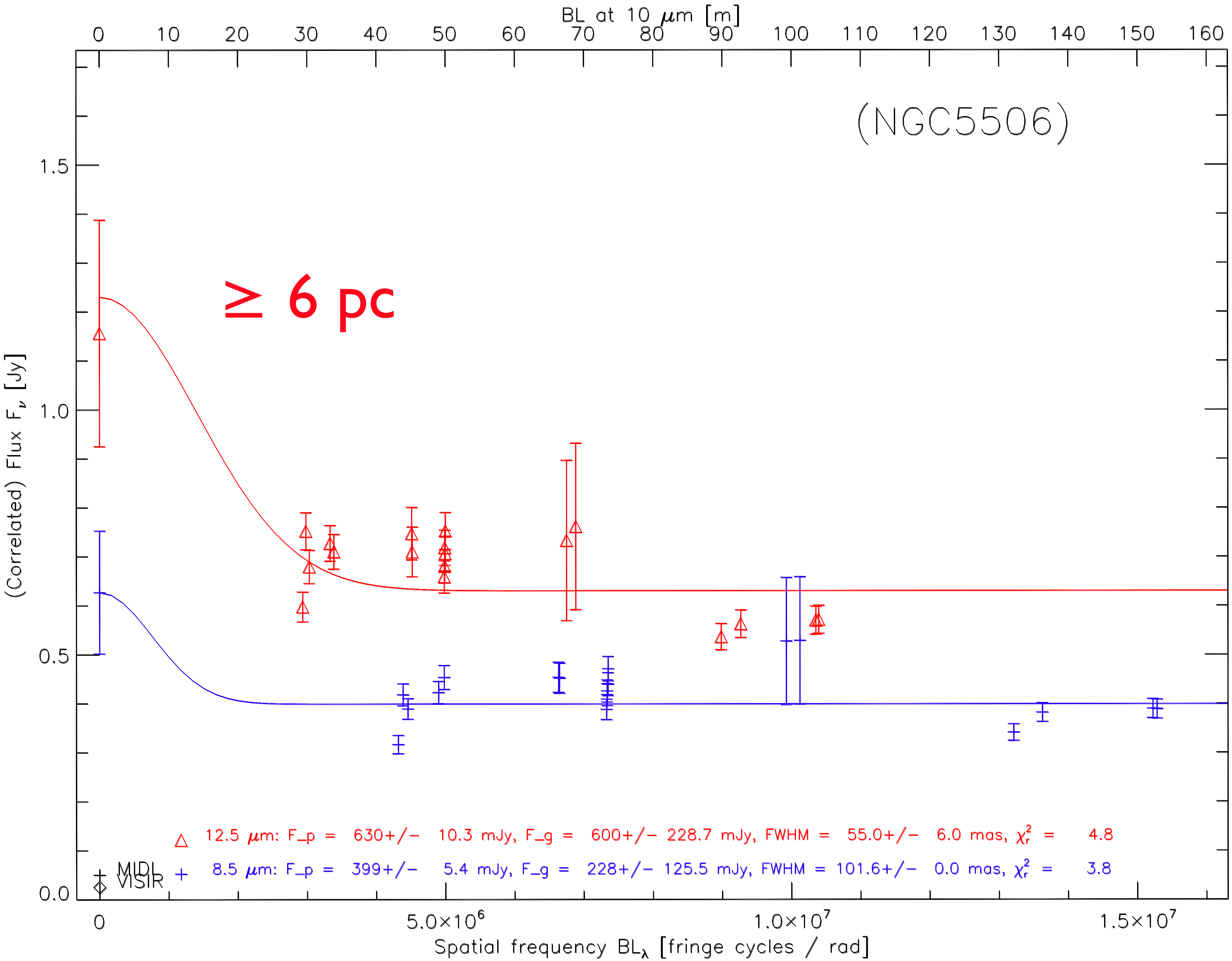


BL at 10 μm [m]
0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150
(IZwicky1)
~ 40 pc
(Correlated) Flux F_ν [Jy]
0.0 0.2 0.4 0.6
MIDI
VISIR
12.5 μm: F_p = 304+/− 7.5 mJy, F_g = 245+/− 73.3 mJy, FWHM = 32.9+/− 5.8 mas, χ²_r = 1.3
8.5 μm: F_p = 173+/− 5.4 mJy, F_g = 110+/− 41.6 mJy, FWHM = 22.0+/− 5.1 mas, χ²_r = 0.9
0 5.0×10⁶ 1.0×10⁷ 1.5×10⁷
Spatial frequency BL_λ [fringe cycles / rad]

MCG-5-23-16


BL at 10 μm [m]
(MCG−5−23−16)
12.5 μm: F_p = 197+/− 7.8 mJy, F_g = 500+/− 96.7 mJy, FWHM = 28.2+/− 2.6 mas, χ²r = 3.9
8.5 μm: F_p = 95+/− 2.8 mJy, F_g = 170+/− 55.2 mJy, FWHM = 26.5+/− 2.6 mas, χ²r = 4.2
~ 4 pc
(Correlated) Flux Fν [Jy]
MIDI
VISIR
Spatial frequency BLλ [fringe cycles / rad]

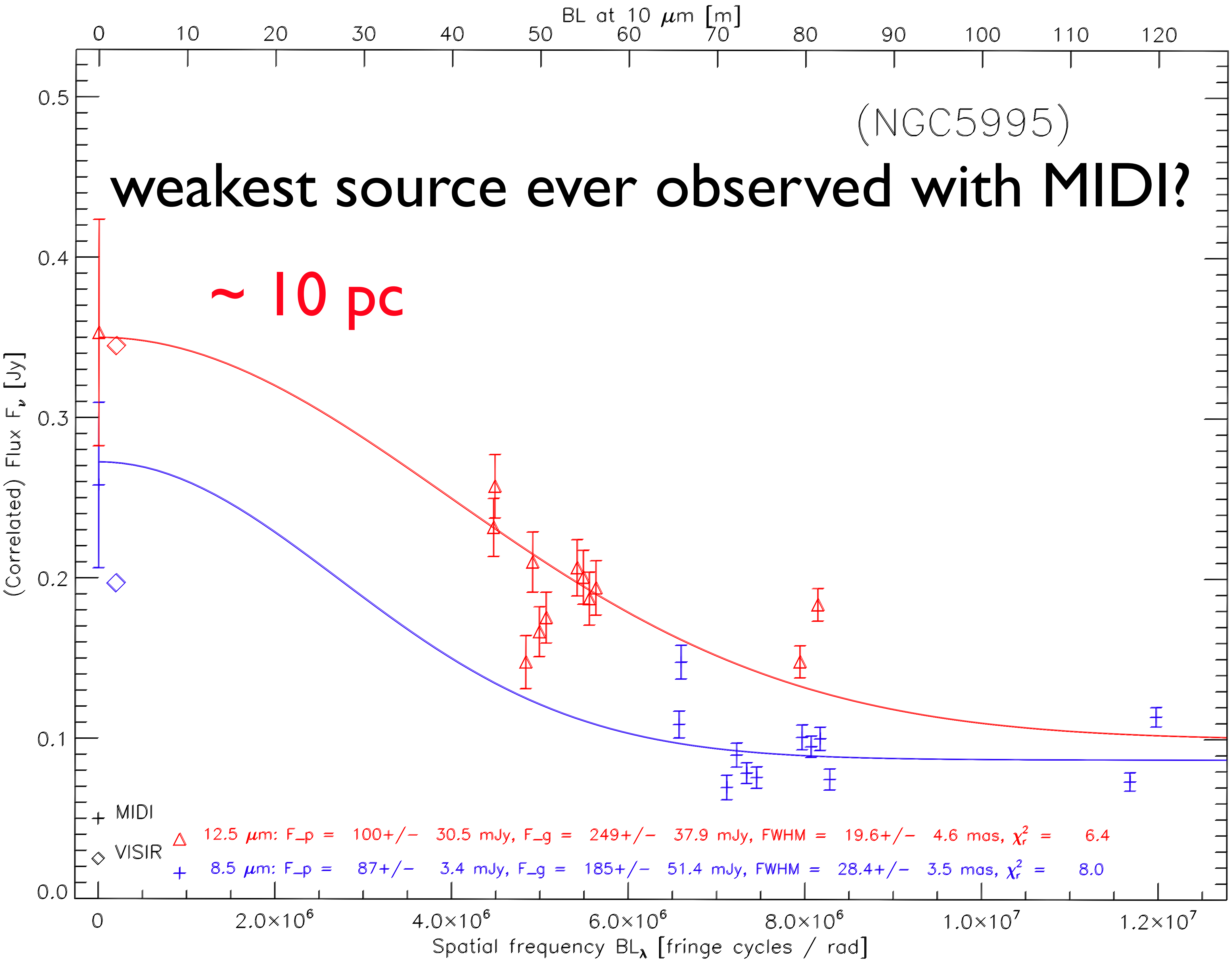
NGC 5506


BL at 10 μm [m]
0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160
(NGC5506)
≥ 6 pc
(Correlated) Flux F_ν [Jy]
1.5
1.0
0.5
0.0
12.5 μm: F_p = 630+/- 10.3 mJy, F_g = 600+/- 228.7 mJy, FWHM = 55.0+/- 6.0 mas, χ²_r = 4.8
8.5 μm: F_p = 399+/- 5.4 mJy, F_g = 228+/- 125.5 mJy, FWHM = 101.6+/- 0.0 mas, χ²_r = 3.8
MIDI
VISIR
0 5.0×10⁶ 1.0×10⁷ 1.5×10⁷
Spatial frequency BL_λ [fringe cycles / rad]

NGC 5995

weakest source ever observed with MIDI?

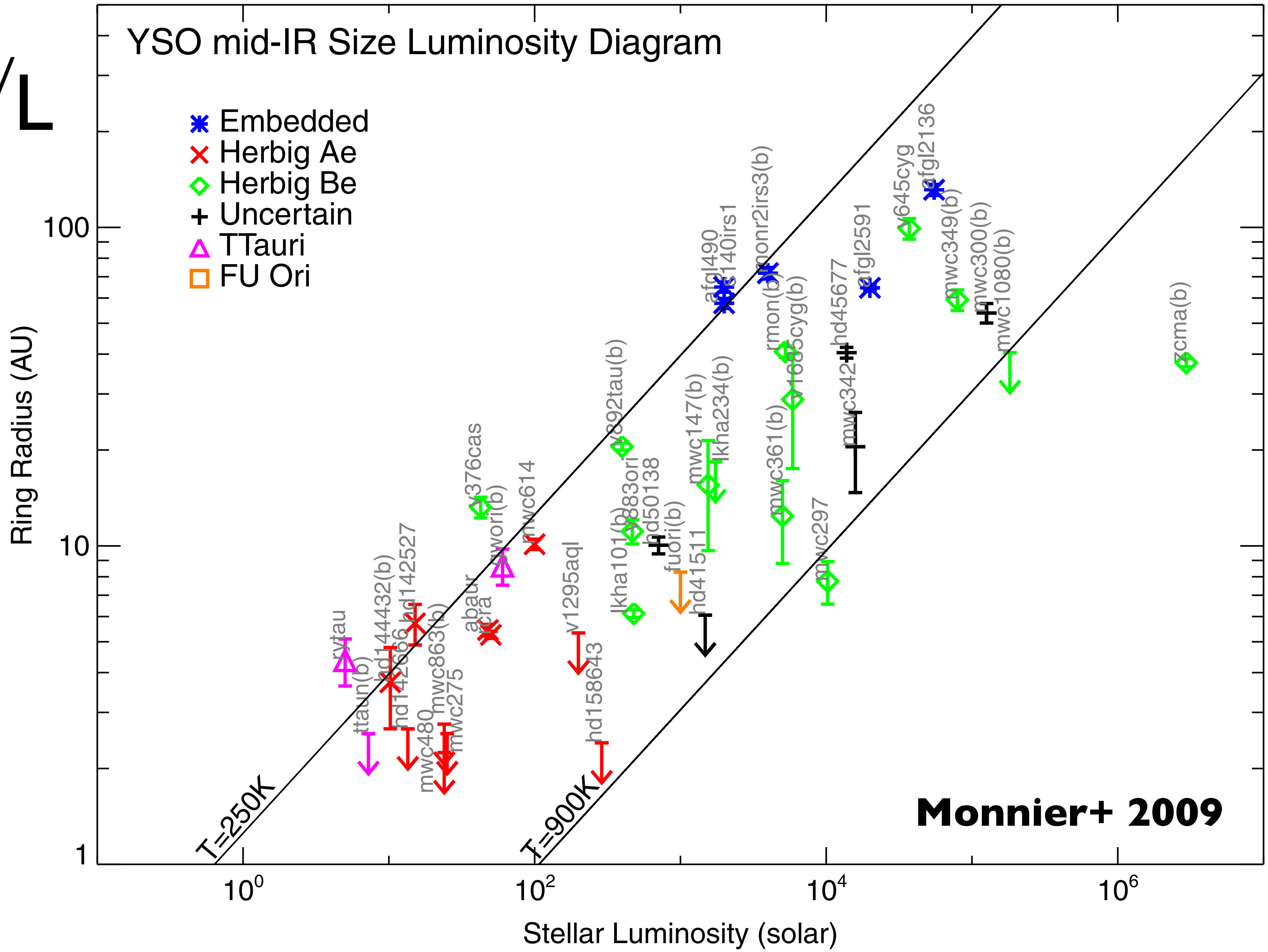
~ 10 pc



Size–luminosity relation

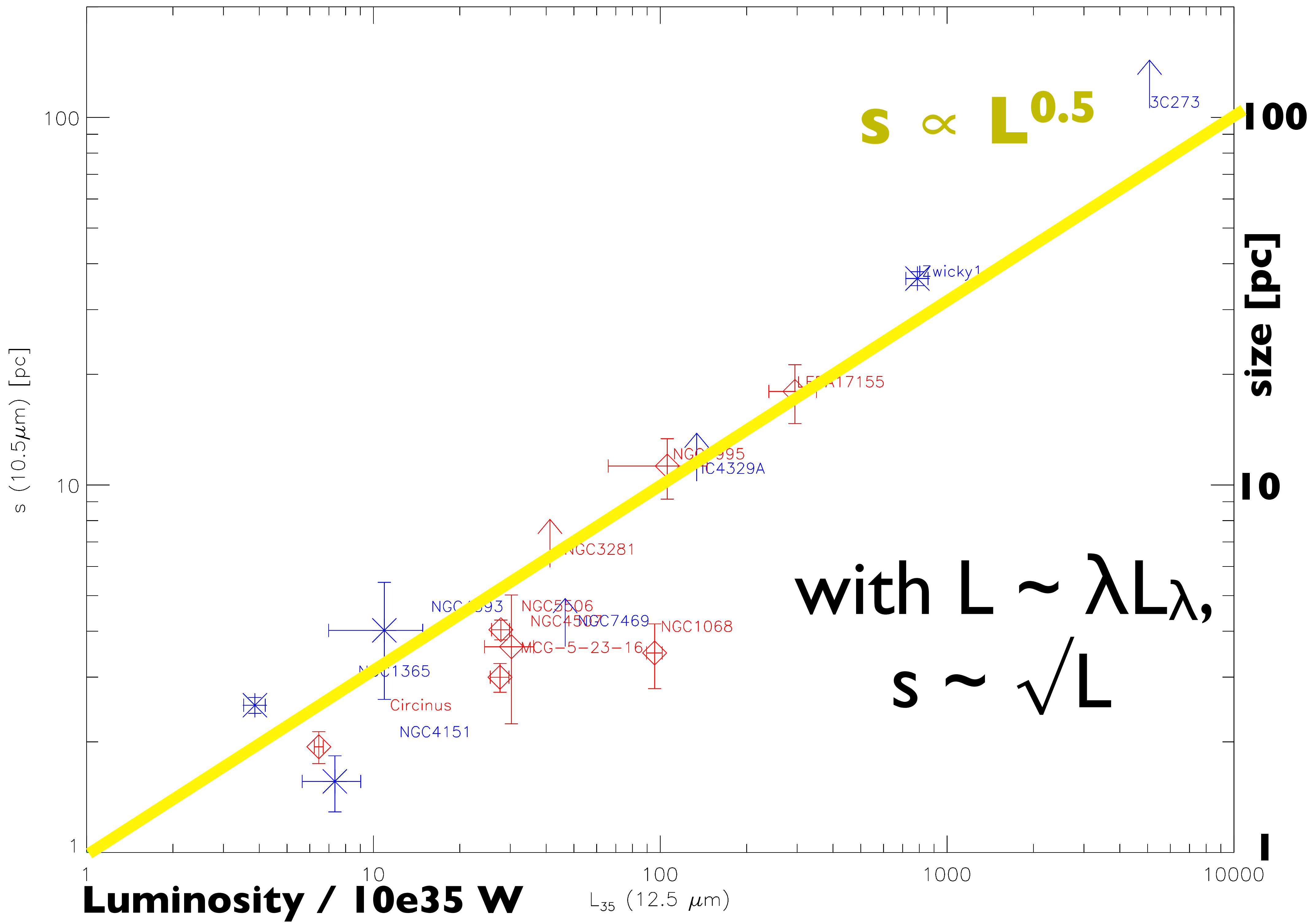
Young Stellar Objects

$s \sim \sqrt{L}$



Size–luminosity relation

Active Galactic Nuclei



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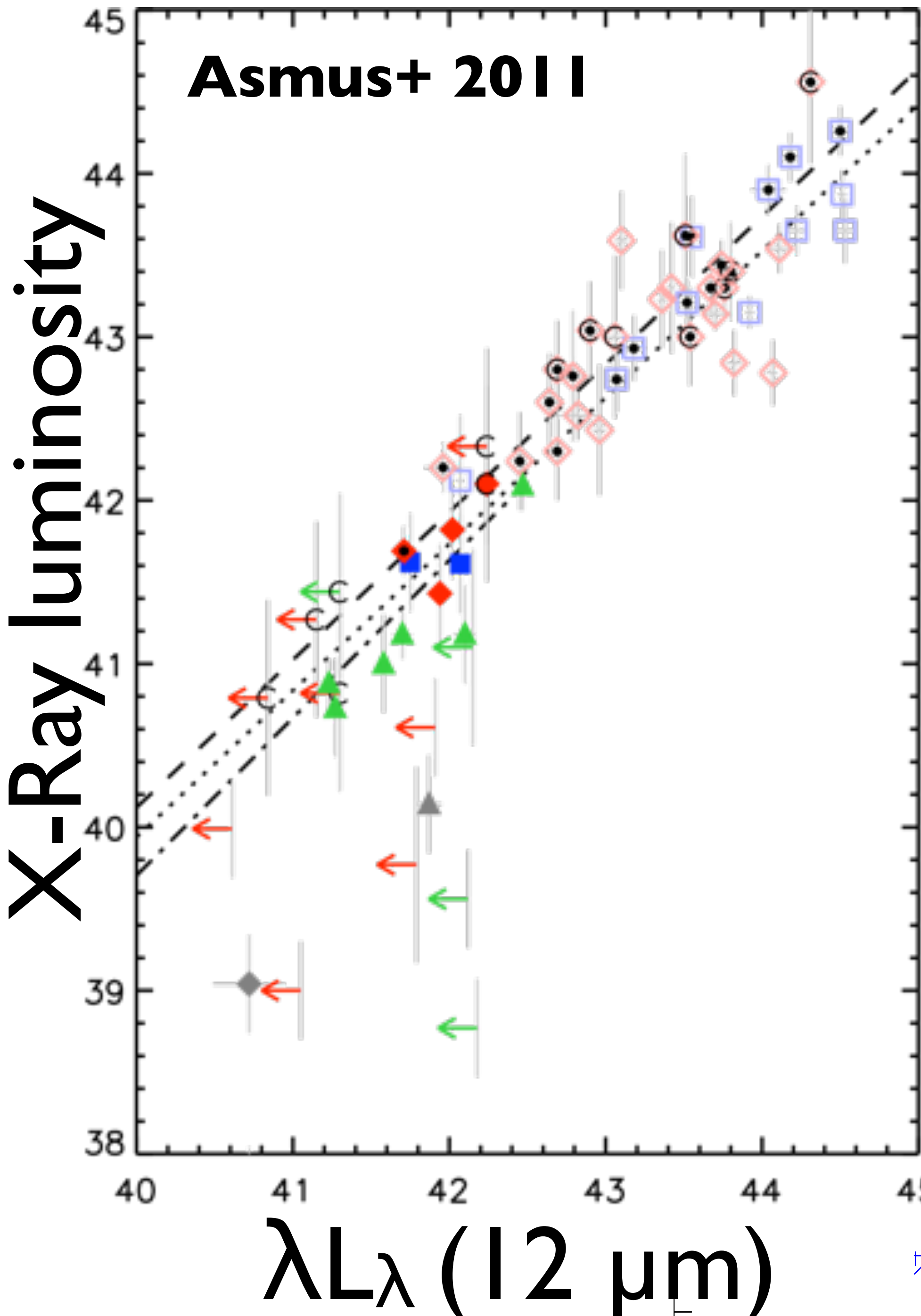
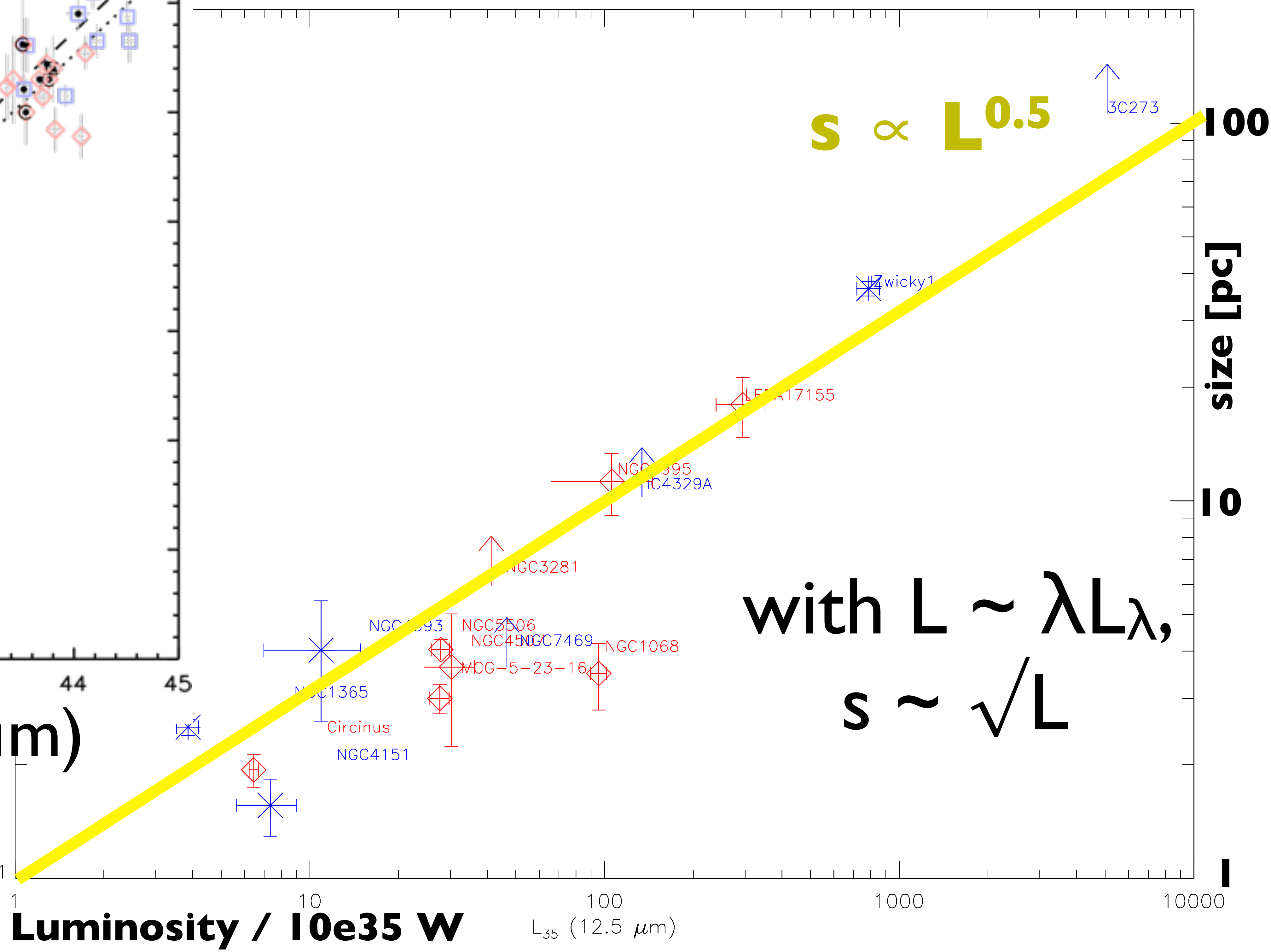


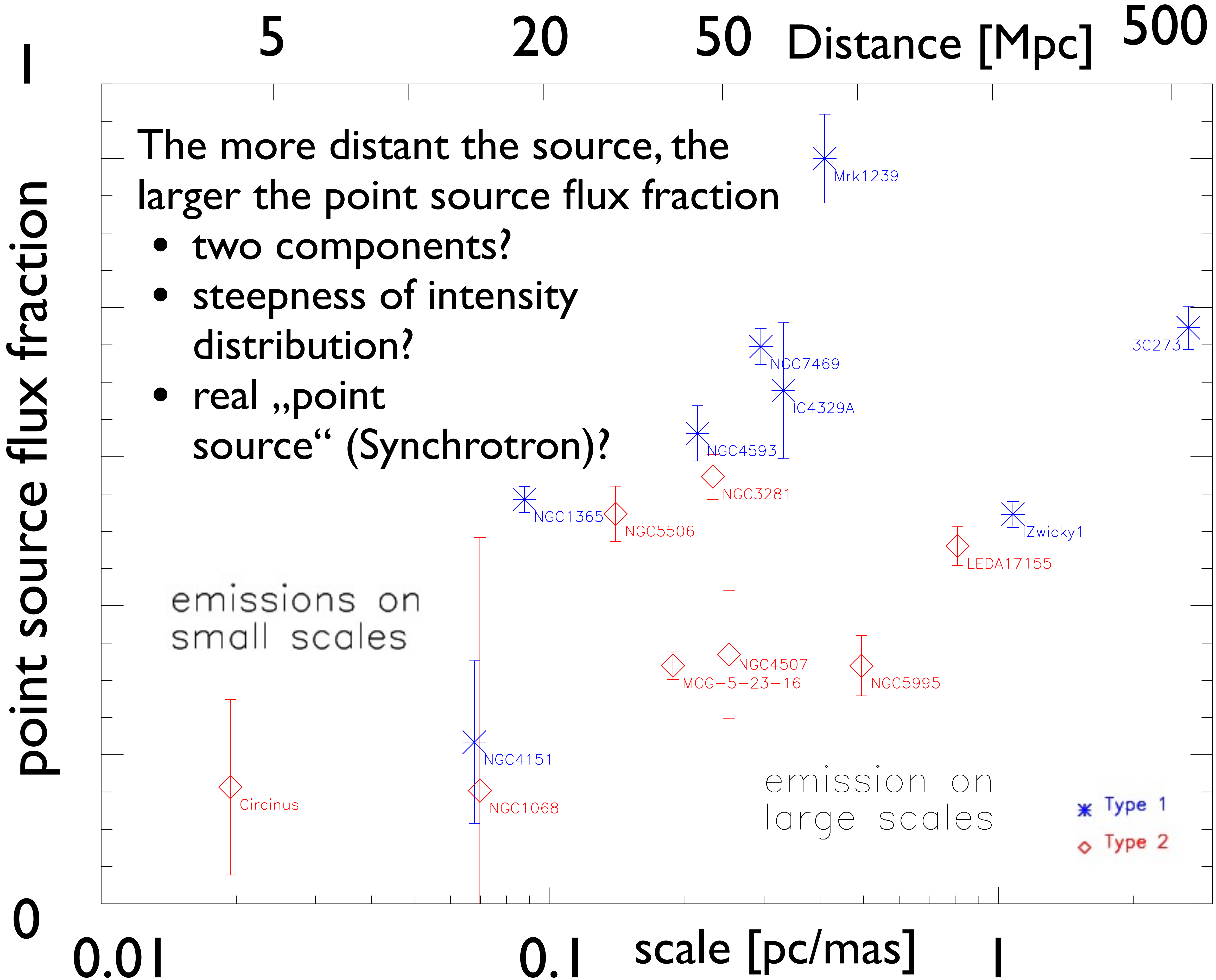
Active Galactic Nuclei



with L ~ λLλ,
s ~ √L

The more distant the source, the larger the point source flux fraction

- two components?
- steepness of intensity distribution?
- real „point source“ (Synchrotron)?



Wishlist

for interferometry at the VLTI

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Image: G. Hüdepohl / ESO

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Image: G. Hüdepohl / ESO

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- More **reliability** of the results through better controlled observing techniques: IRIS images, reliable MACAO Strehls
- Hybrid AT-UT combinations will allow ~4x more sensitivity + new unique baselines: **constrain extended emission**
- Most-efficient fringe trackers to **increase integration time**

Image: G. Hüdepohl / ESO

Conclusions

- Mid-IR interferometry enables the observation of high surface-brightness compact objects and paves the way for the 2nd generation instruments. We can now observe fringes with MIDI that are ~ 10x fainter than originally expected – thanks to continous (software) developments both on Paranal and offline.
- Only with interferometry can AGN „tori“ be resolved. Their sizes are ~ 10-100 mas (~ 1-10 parsecs); their structure is probably complex.
- The VLTI/MIDI Large Programme increased the sample of resolved tori by 13; resolved dust on the parsec scale has been found in (almost) all mid-IR bright AGNs, both type 1 and type 2
- The torus size s scales with luminosity L as $s \sim L^{0.5}$
- The nature of the ‚point source‘ is not yet clear