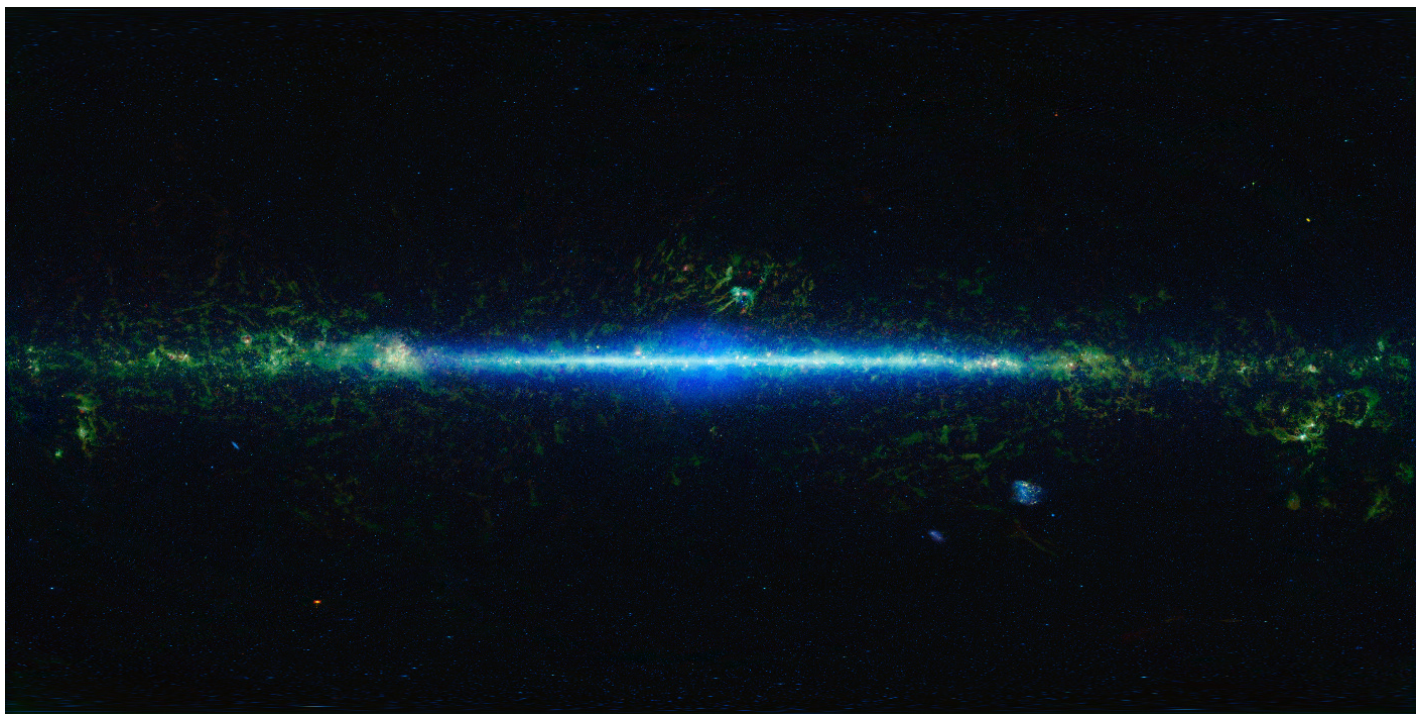
Testing AGN unification with WISE

Robert Nikutta (PUC)
Željko Ivezić, Nicholas Hunt-Walker (UW),
Maia Nenkova (Seneca College), Moshe Elitzur (UKY, UCB)

WISE at 5, Caltech, Pasadena, 11 February 2014



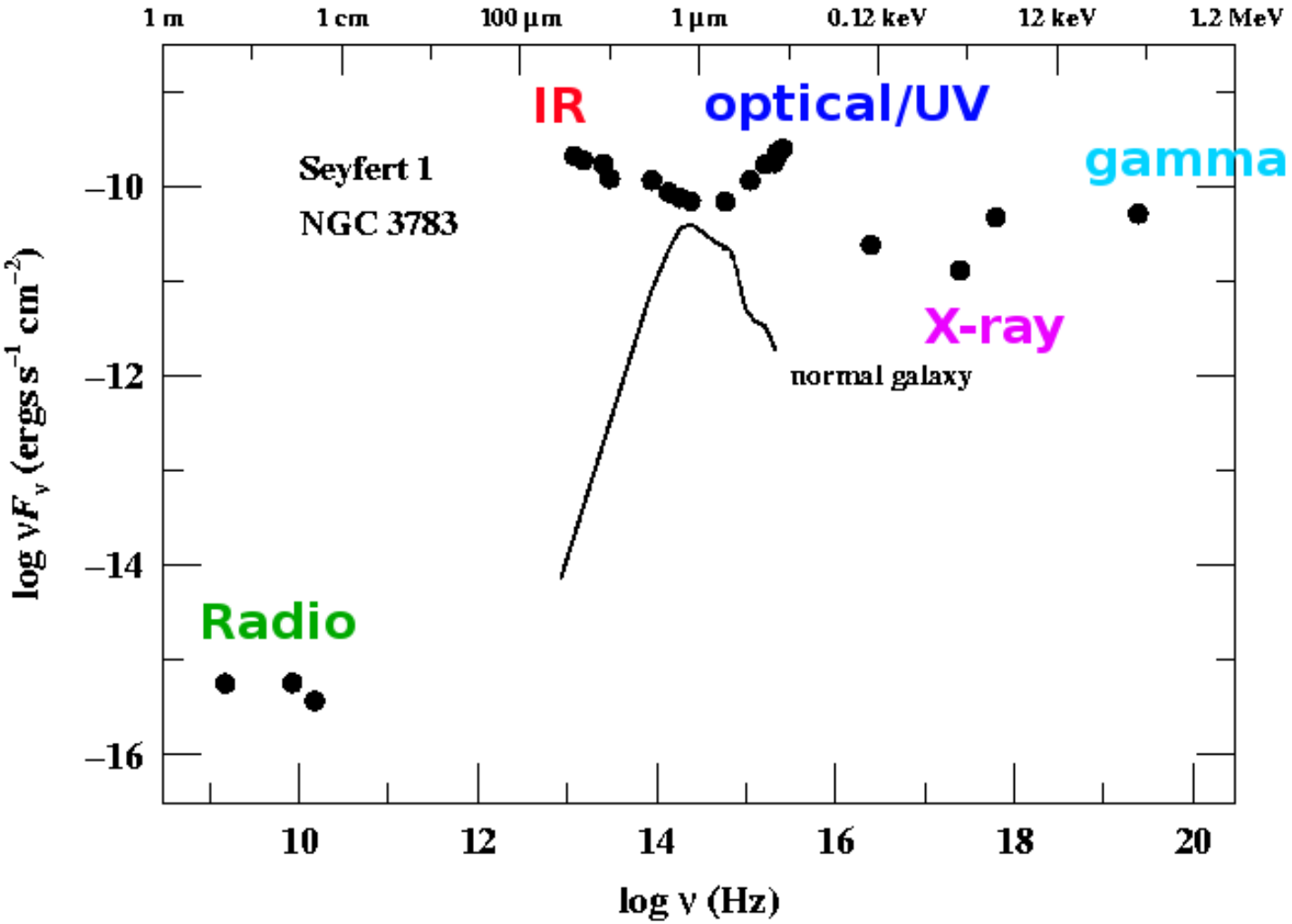
NASA/WISE/JPL press release March 14, 2012

AGN: point-like source of light at nucleus of host galaxy

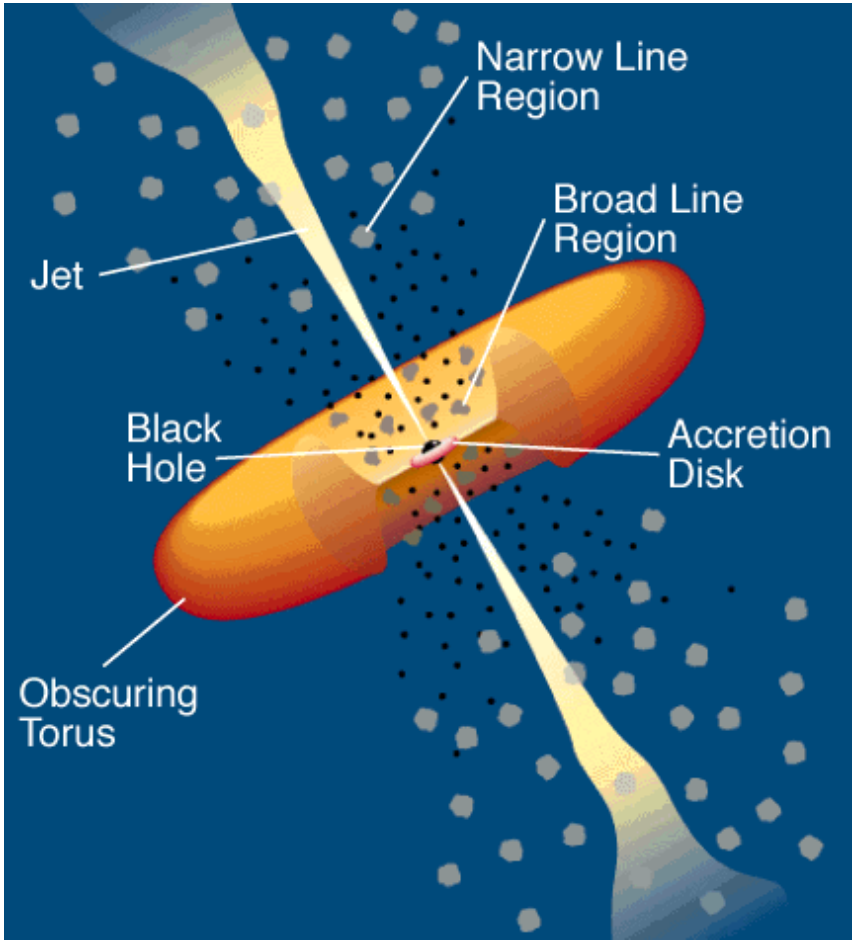
CenA optical (Rejkuba et al., ESO/VLT)

CenA IR (Keene, SSC/Caltech)

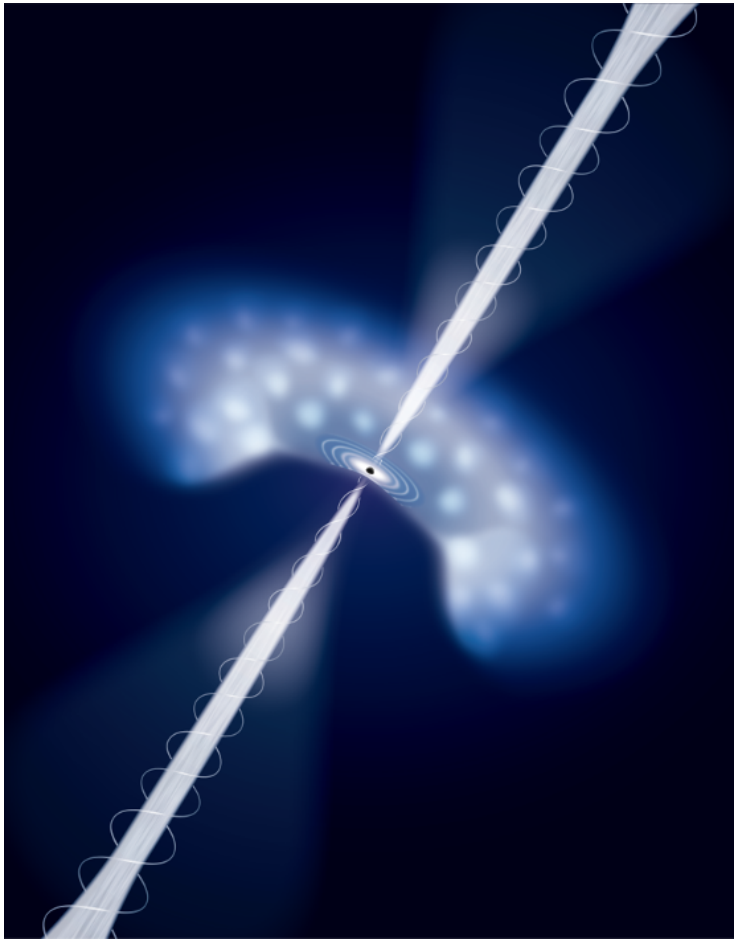
Active galaxy spectrum



Geometrically & optically thick toroidal structure



Antonucci 1993, Urry & Padovani 1995

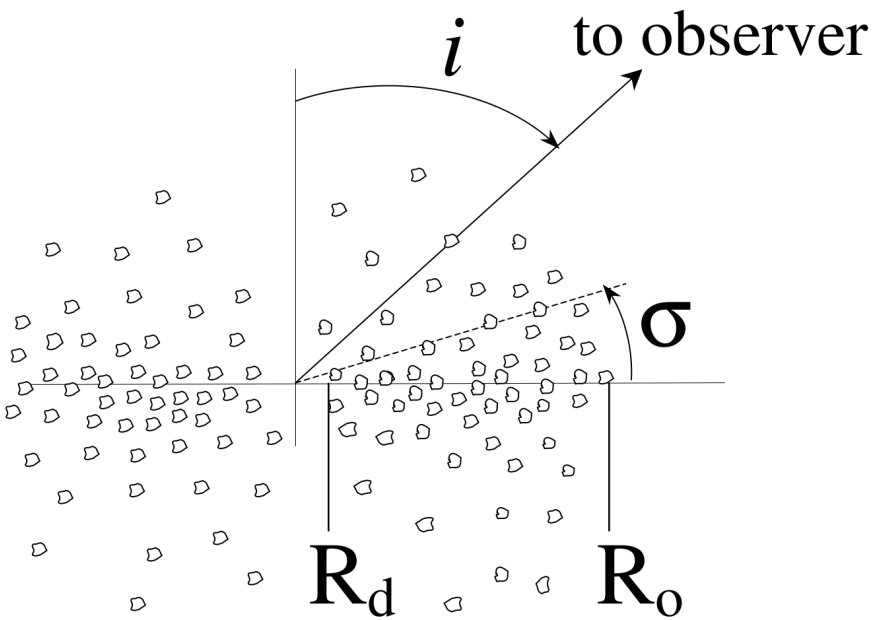


art credit: Annie Mejia / Caltech

Is axisymmetric torus the right geometry?

→ **Martin Elvis' poster #8 "Tilted/warped tori"**

CLUMPY torus model



Nenkova+2008b

single cloud optical depth
τ_v

clouds/ray in equatorial plane
N_0

angular torus width
σ

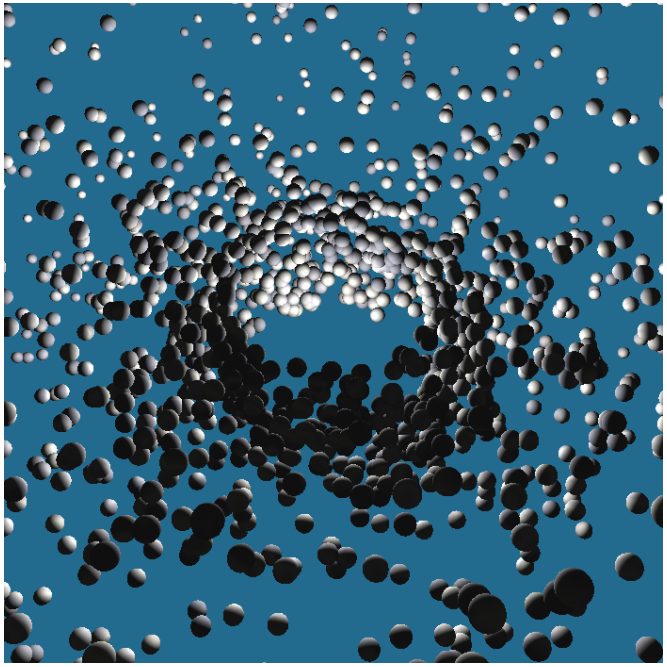
torus thickness
$Y = R_o/R_d$

radial cloud distribution
r^{-q}

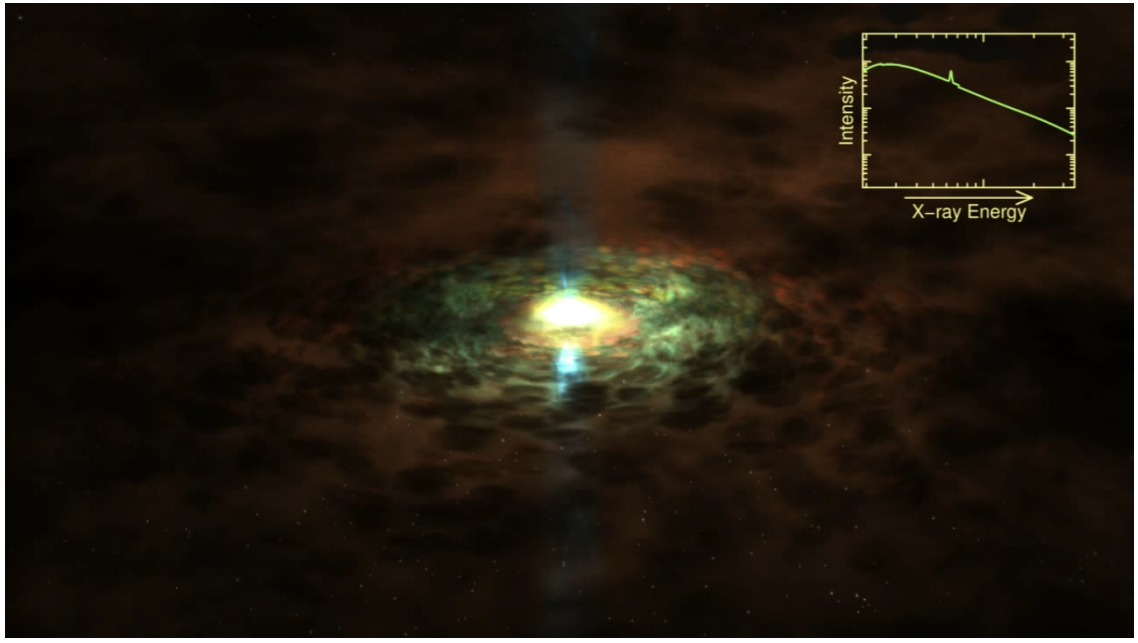
observer viewing angle
i

It looks like...

Toy model



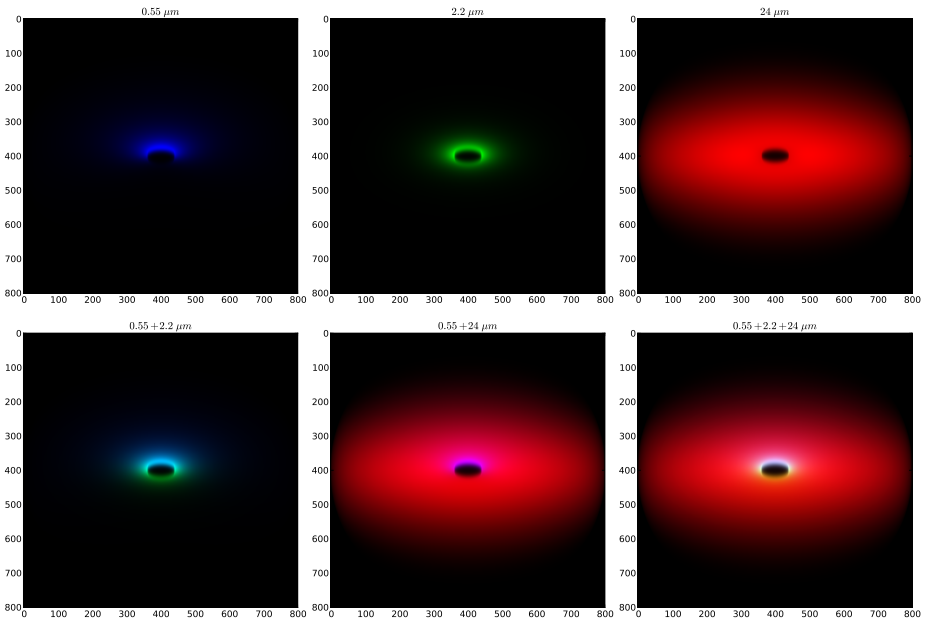
More realistic



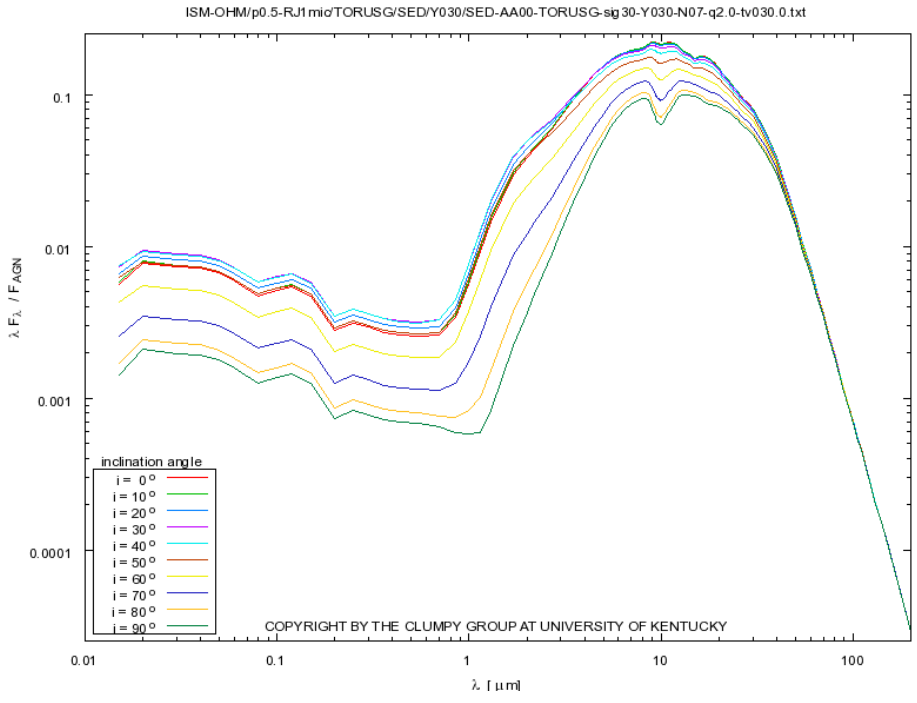
Astronomy picture of the day Feb 24, 2014
`http://apod.nasa.gov/apod/ap140224.html`
Markowitz, Krumpe, Nikutta, MNRAS 2014,
Video: Wolfgang Steffen (UNAM)

Emission maps look rather like this...

Brightness maps

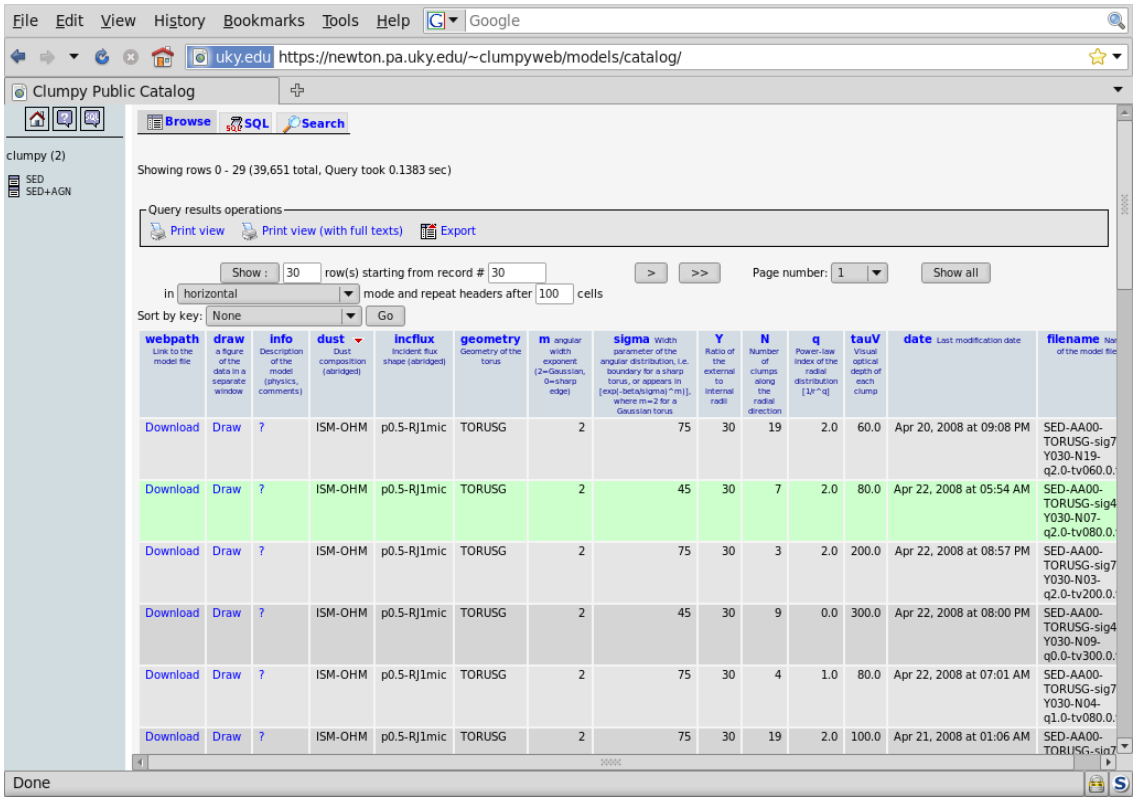


Spectral energy distributions (SED)



Public database of model SEDs

www.clumpy.org

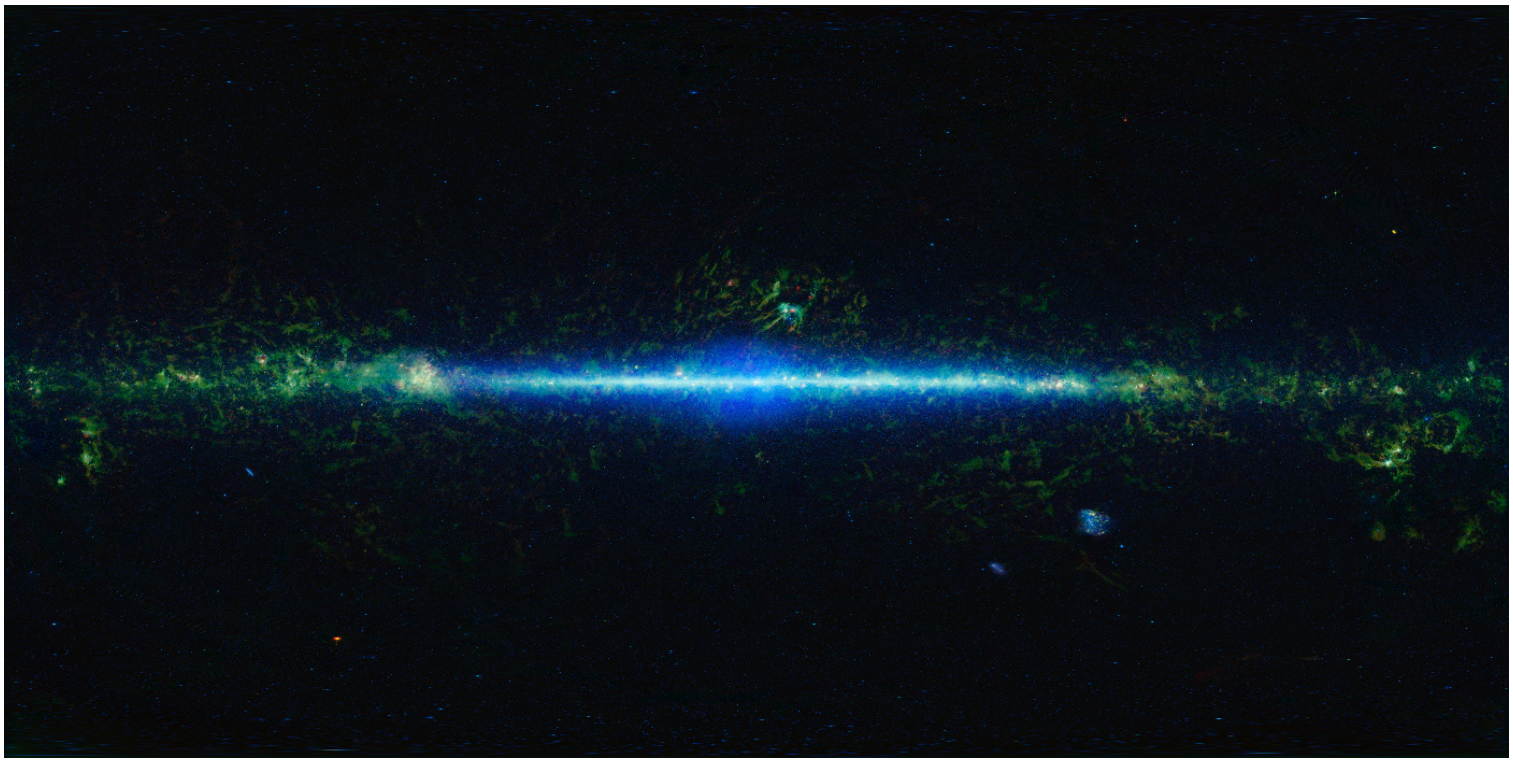


- Large parameter space covered
- $\sim$ 1.3 million models
- freely accessible
- can run own models

Until now: So many models, so little data...

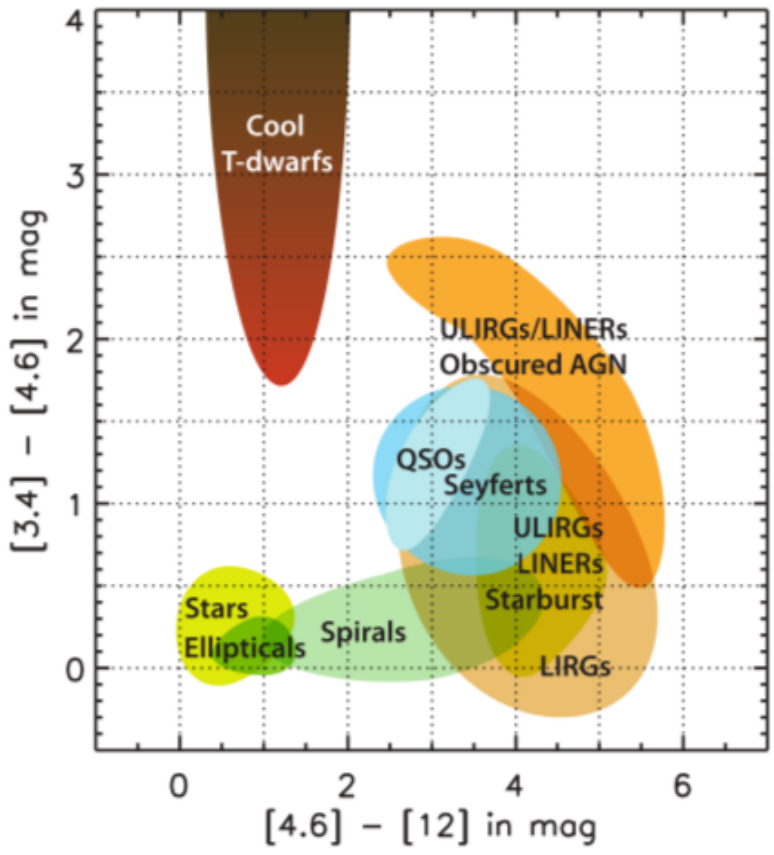
But now: observations (surveys) are finally catching up.

- SDSS: 10^5 QSOs
- LSST: 10^6 QSOs
- WISE: 10^5 QSOs in IR

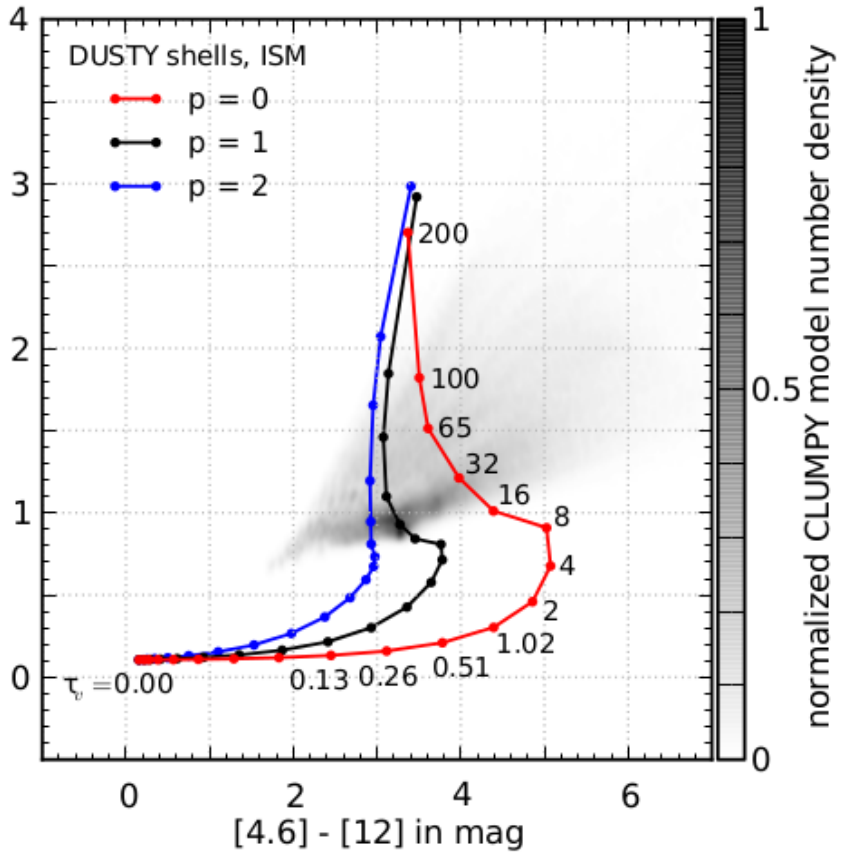


NASA/WISE/JPL press release March 14, 2012

Models vs. WISE colors



Wright+2010

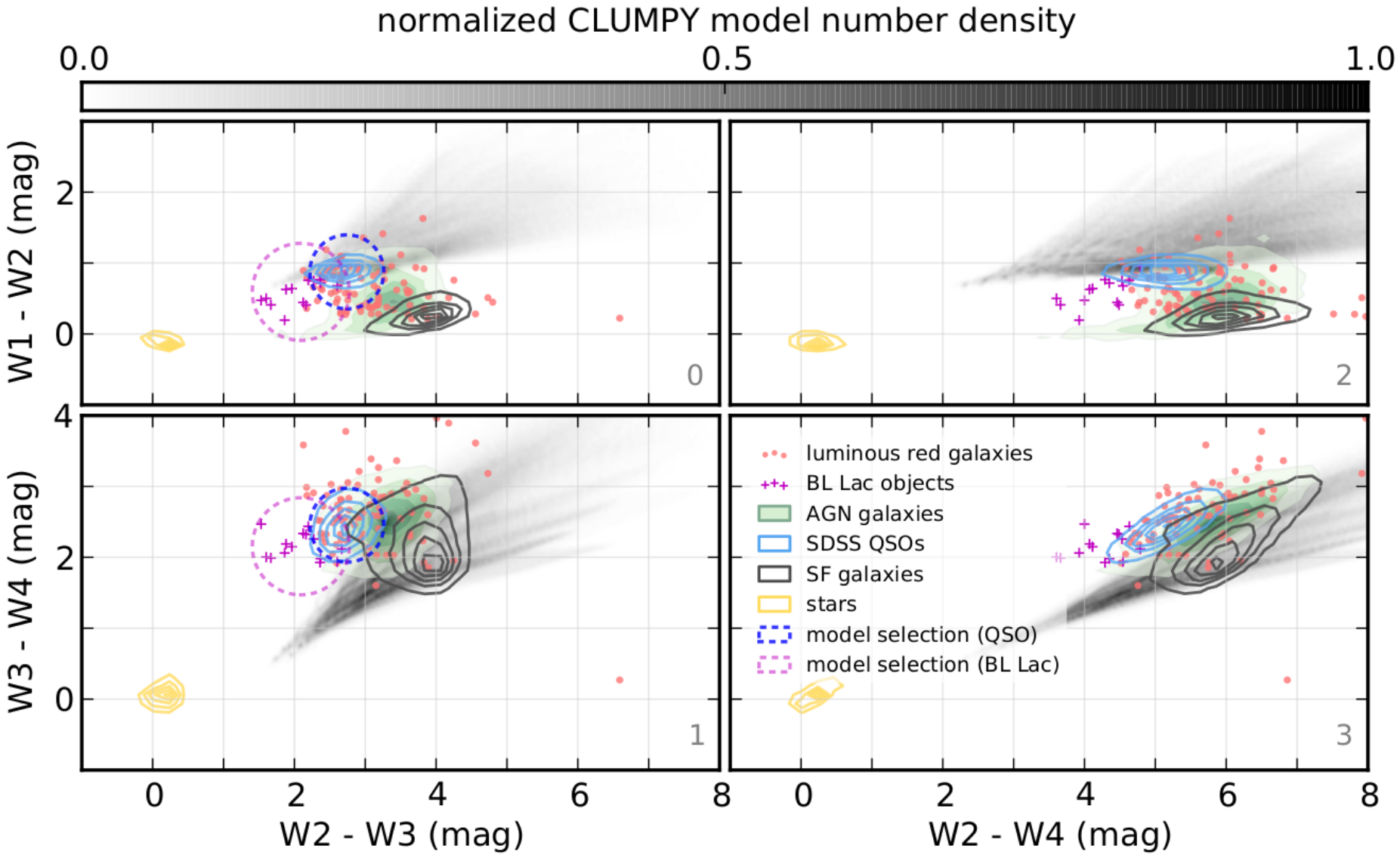


Nikutta+2014

For Galaxy and satellites, see Željko's talk, and Nikutta+2014 (MNRAS)

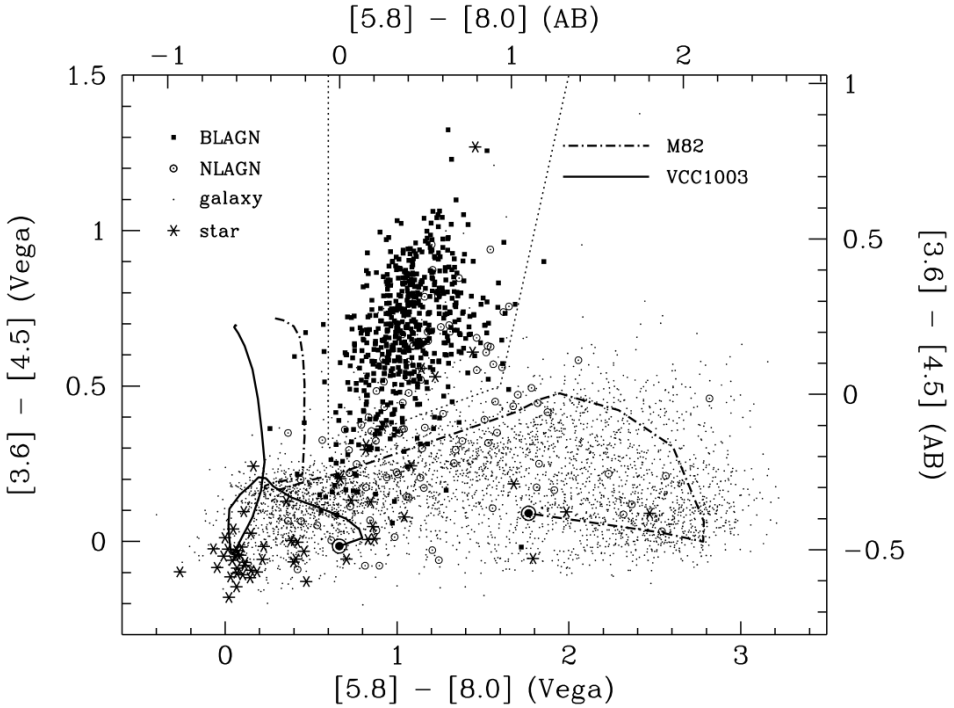
CLUMPY WISE colors match QSOs & Seyferts (Nikutta+, in prep.)

CLUMPY models vs. WISE colors

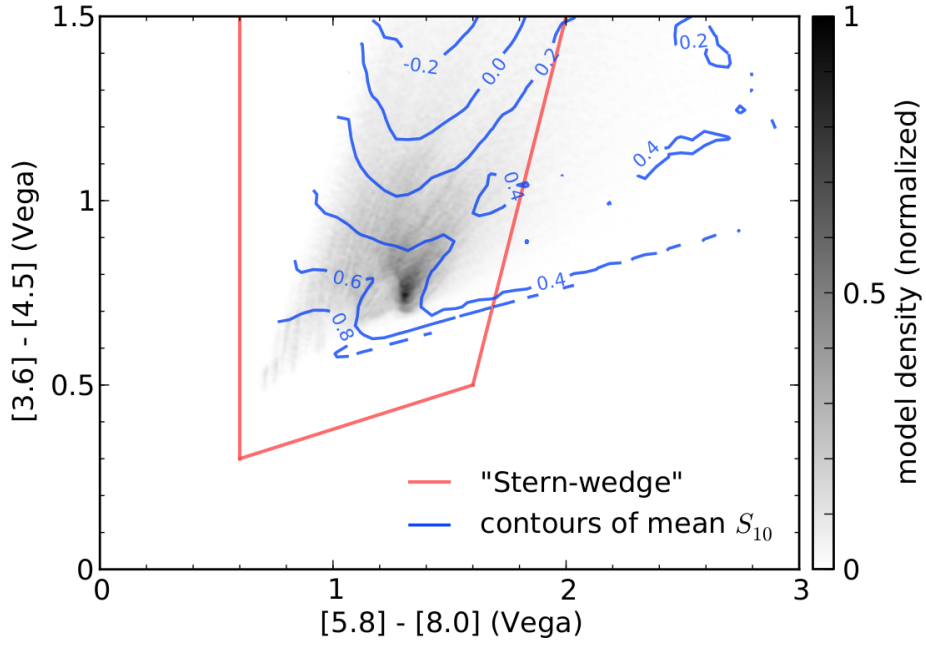


Nikutta+ (in prep.)

CLUMPY models vs. Spitzer/IRAC AGN colors



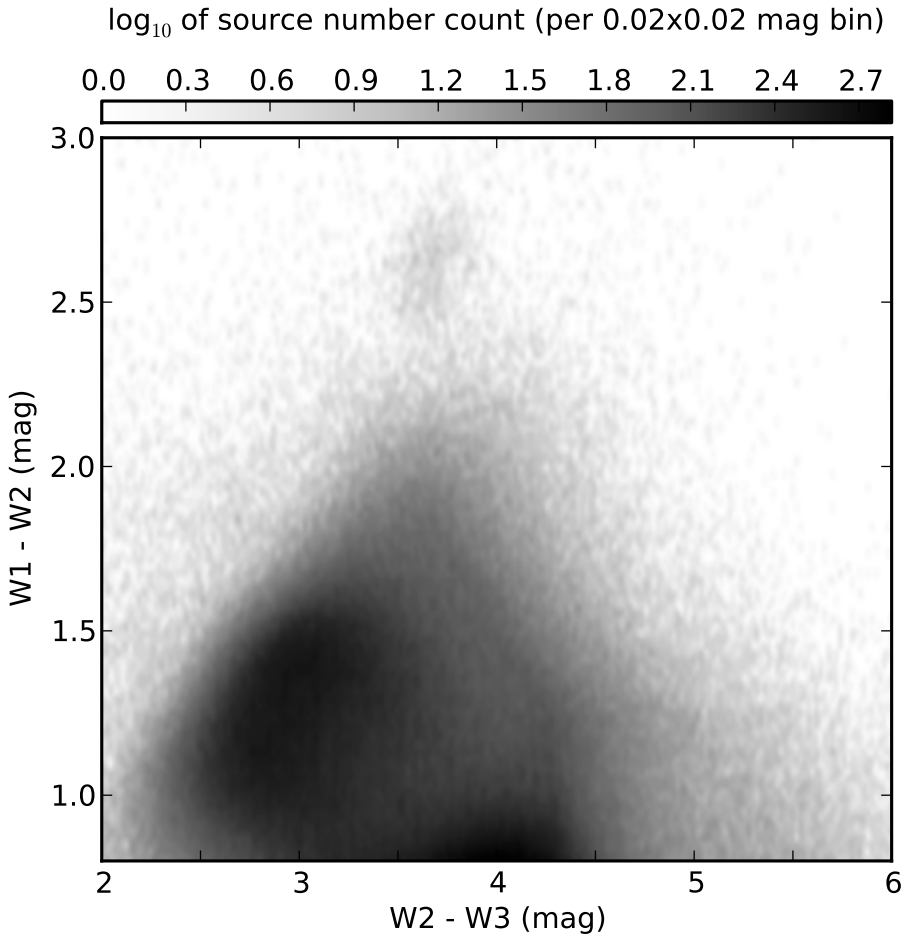
Stern et al. 2005



Nikutta 2012

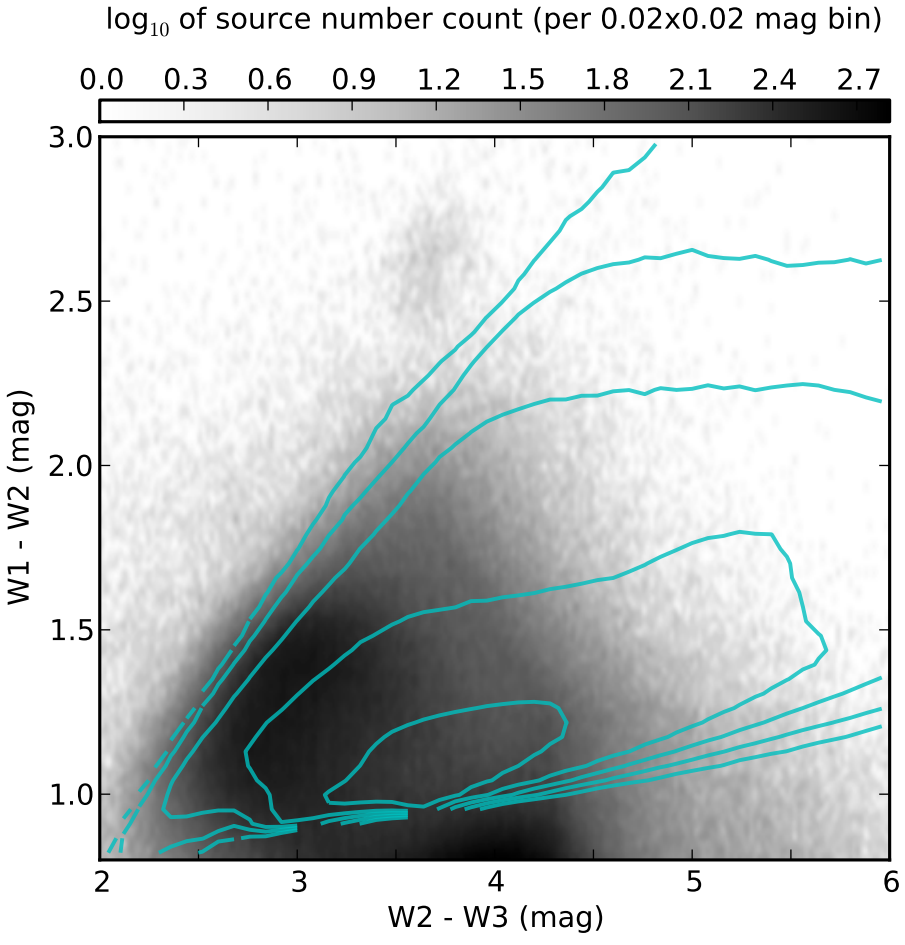
CLUMPY colors match "Stern et al. 2005 wedge" very well.

Testing unification - Distribution in WISE CC diagram



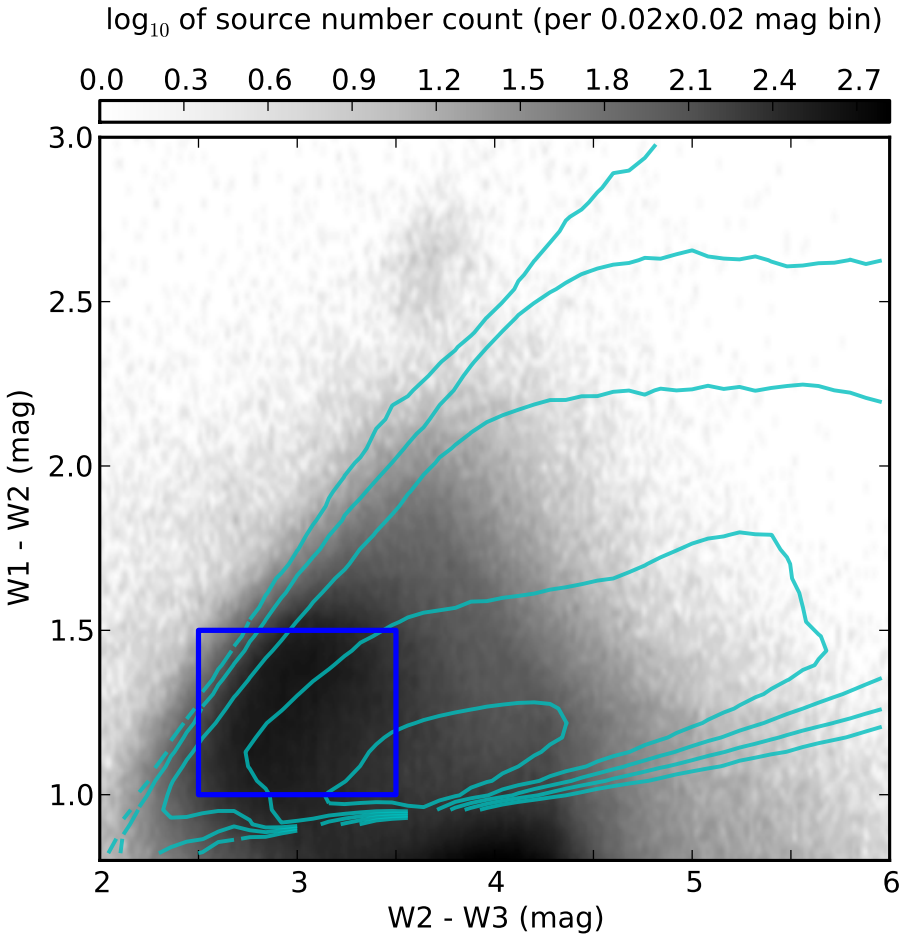
5-σ limits & saturation limit W1 & $|b| > 10$ &
Stern et al. 2012. AGN color cut

Testing unification - Model density



Density contours: CLUMPY models; make a bit more blue b/c they are missing the "K-bump" (e.g. Mor+2009) $\rightarrow$ **Marvin Rose's poster #29**

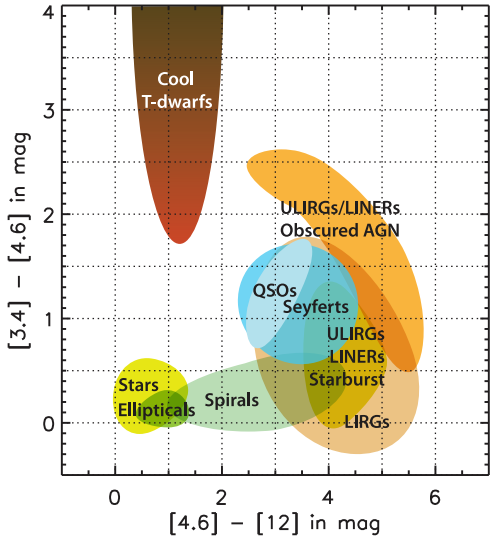
Testing unification - QSO locus



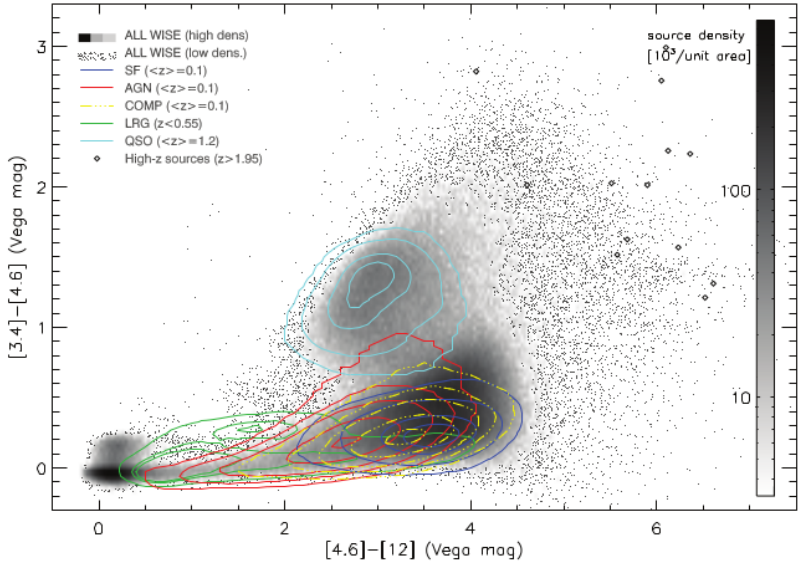
Blue box: approximate QSO locus

e.g. Wright+2010, Yan+2013

QSO/type-1 AGN locus



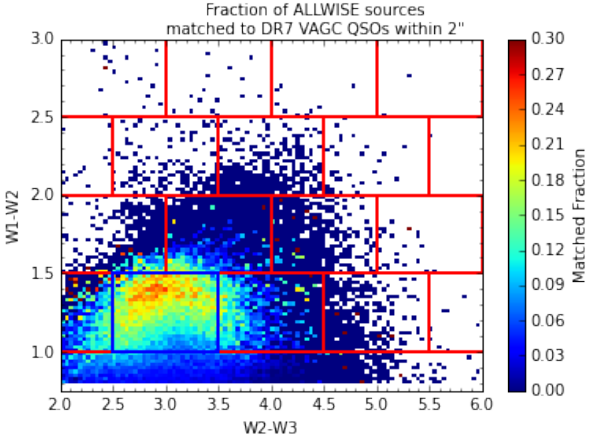
Wright+2010



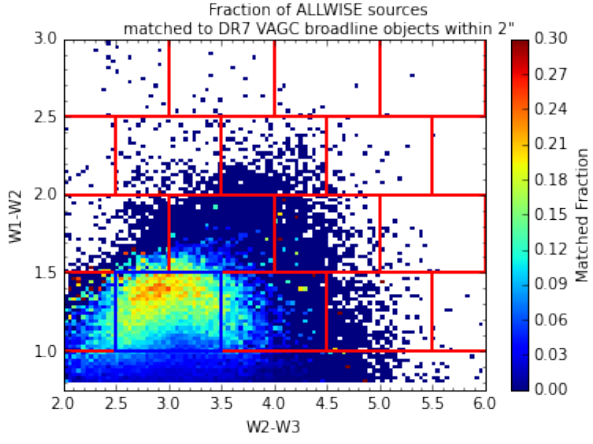
Yan+2013

Matching ALLWISE vs. SDSS DR7 VAGC subclass: (N. Hunt-Walker)

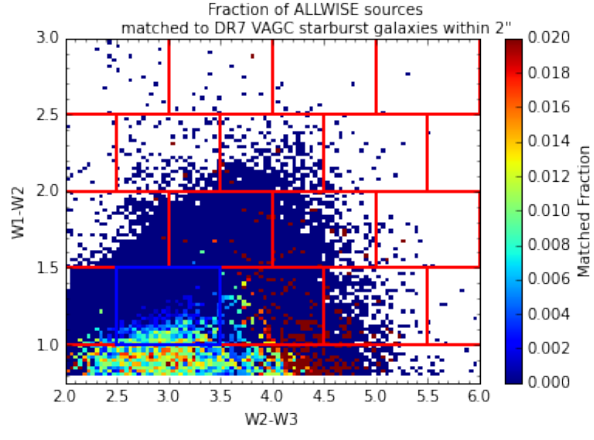
"QSO"



"broadline"



"SB broadline"

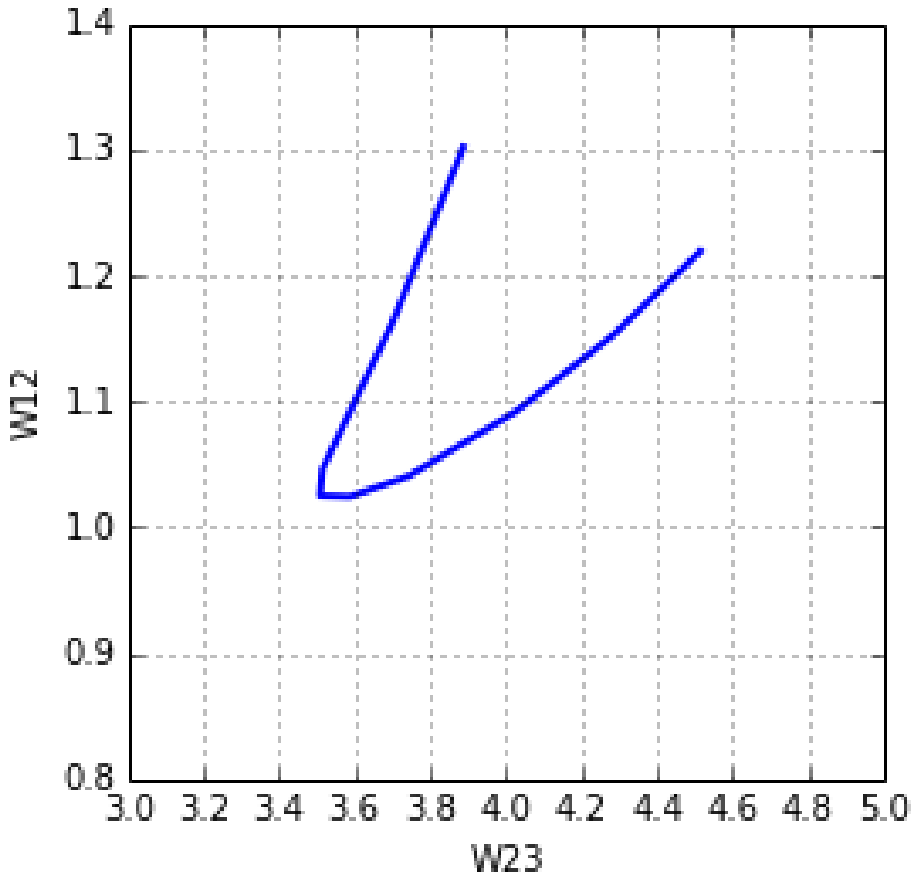


Where is the type-2 population, i.e. type-1 counterparts?

Inspired by Kevin Luhman's Next-Gen/Gen-X remark yesterday...

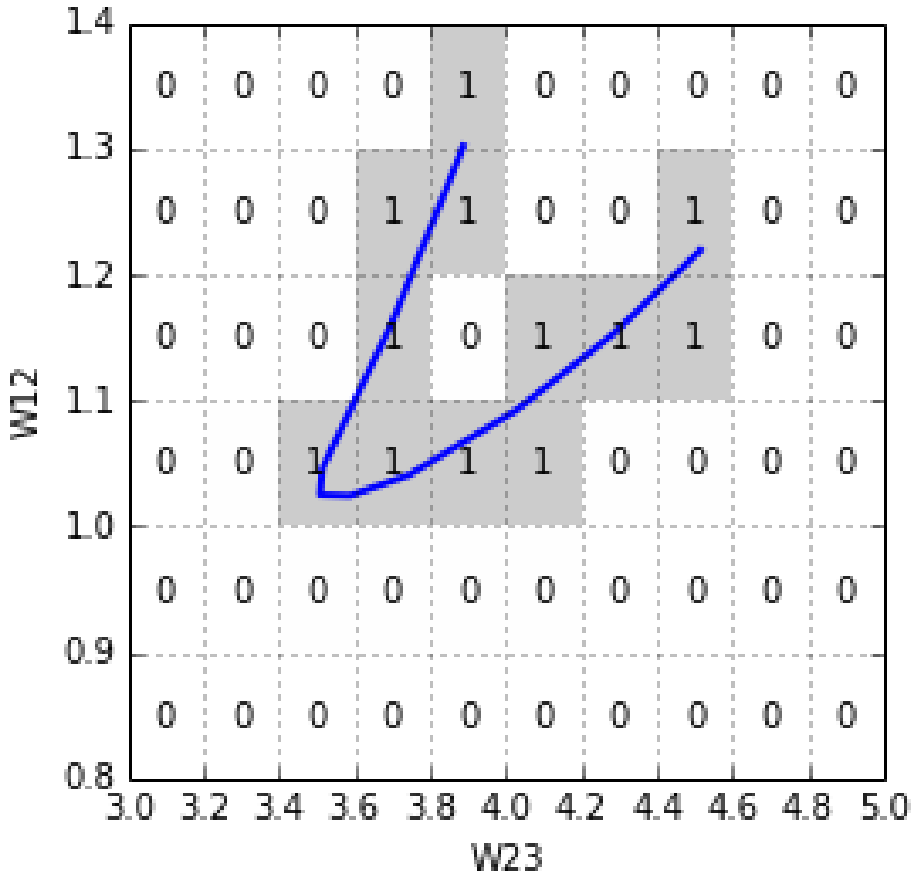
Shamelessly borrowed from: `http://robby-robert.deviantart.com/`

Reproduce the CC (CCM) distribution with linear combination of models



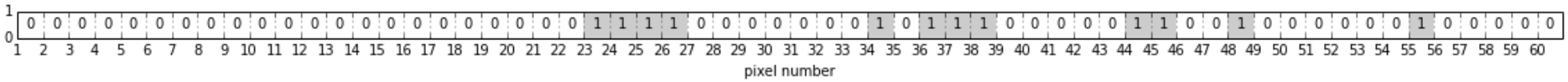
One model = one track; function of viewing cos(i)

Reproduce the CC (CCM) distribution with linear combination of models



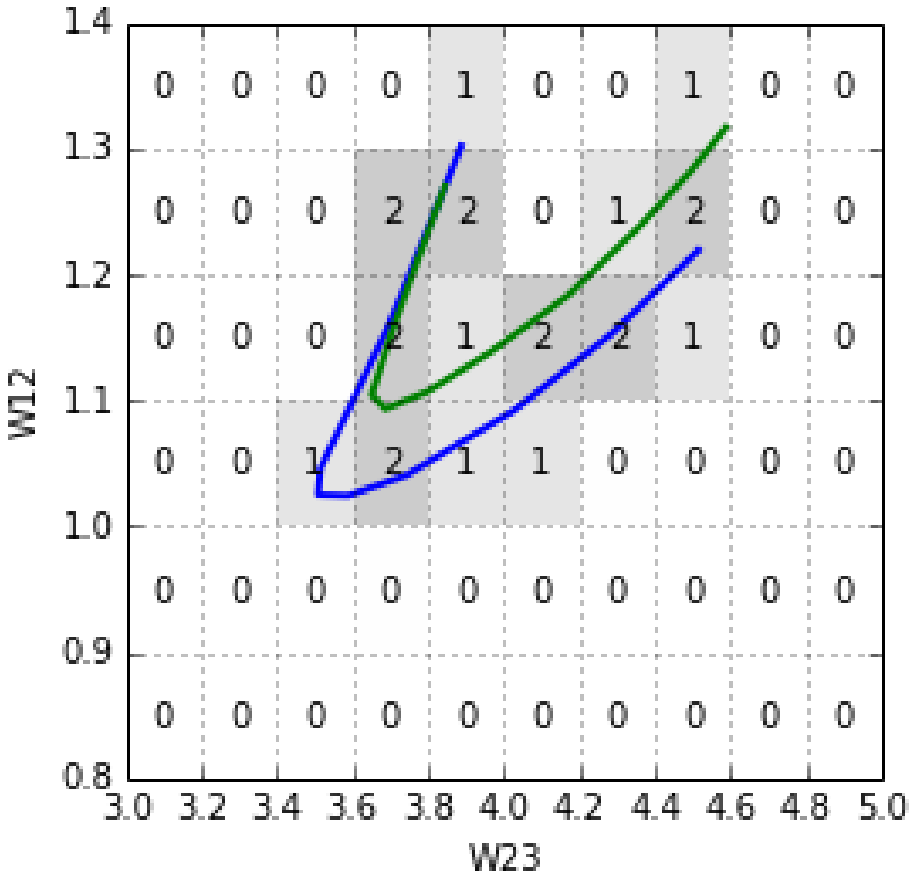
grid cells intersected by a track; model can only contribute here

Reproduce the CC (CCM) distribution with linear combination of models



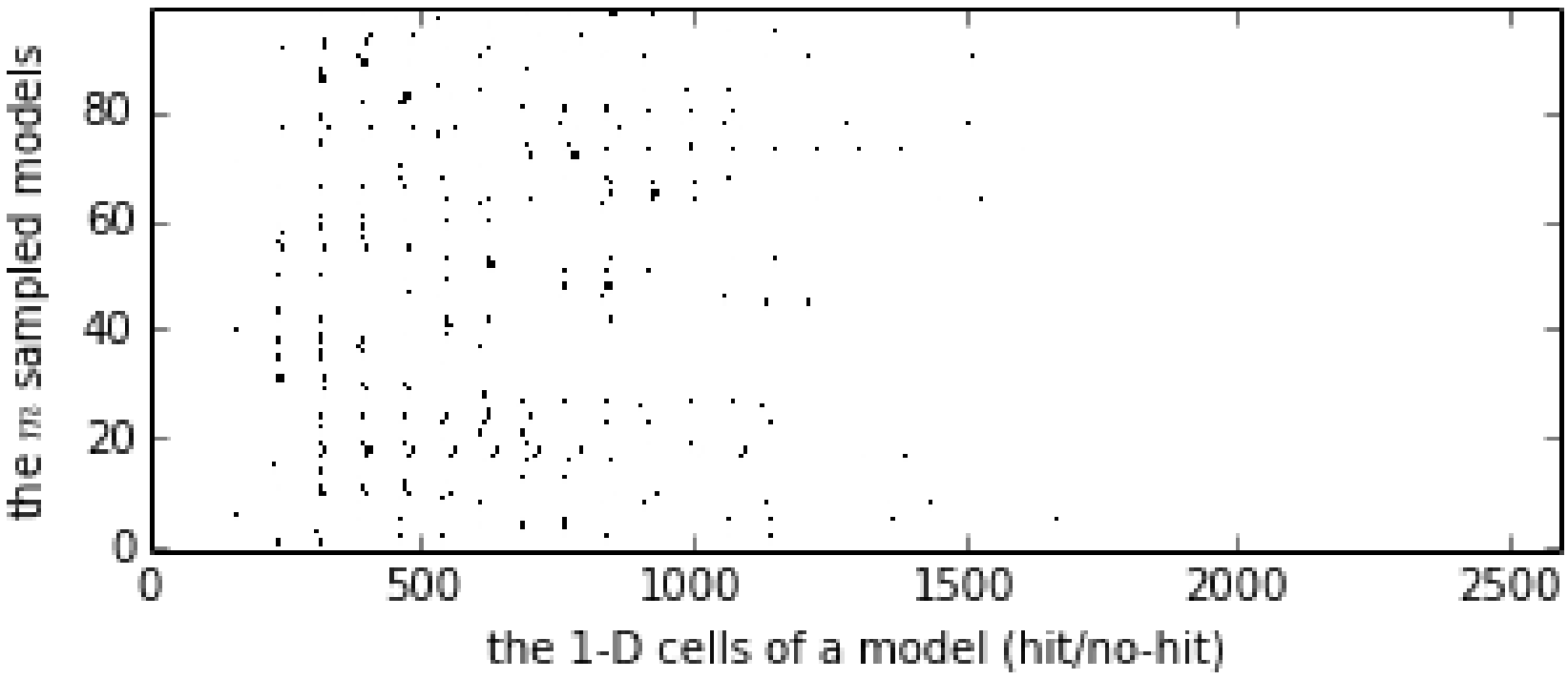
pixels independent $\longrightarrow$ flatten the array, 1-d problem

Reproduce the CC (CCM) distribution with linear combination of models



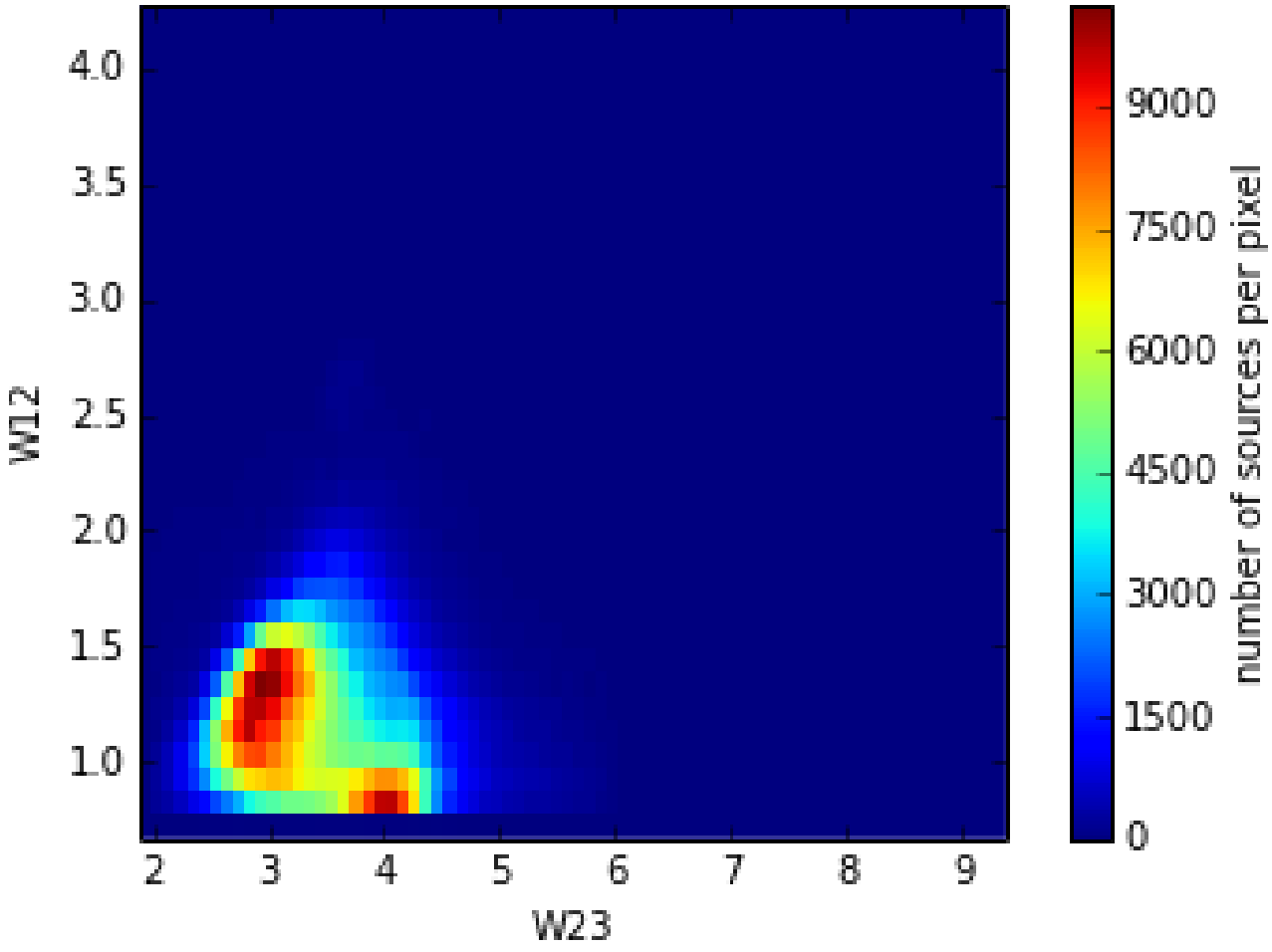
Multiple tracks can contribute to a cell

Reproduce the CC (CCM) distribution with linear combination of models



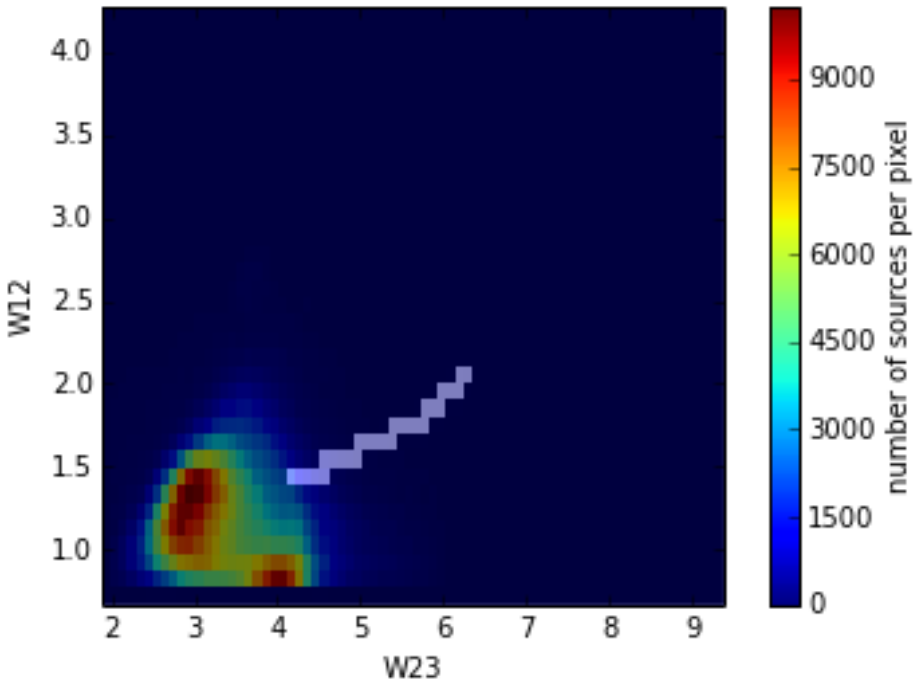
Array of 100 flattened track contributions (hit-or-miss matrix)

Reproduce the CC (CCM) distribution with linear combination of models

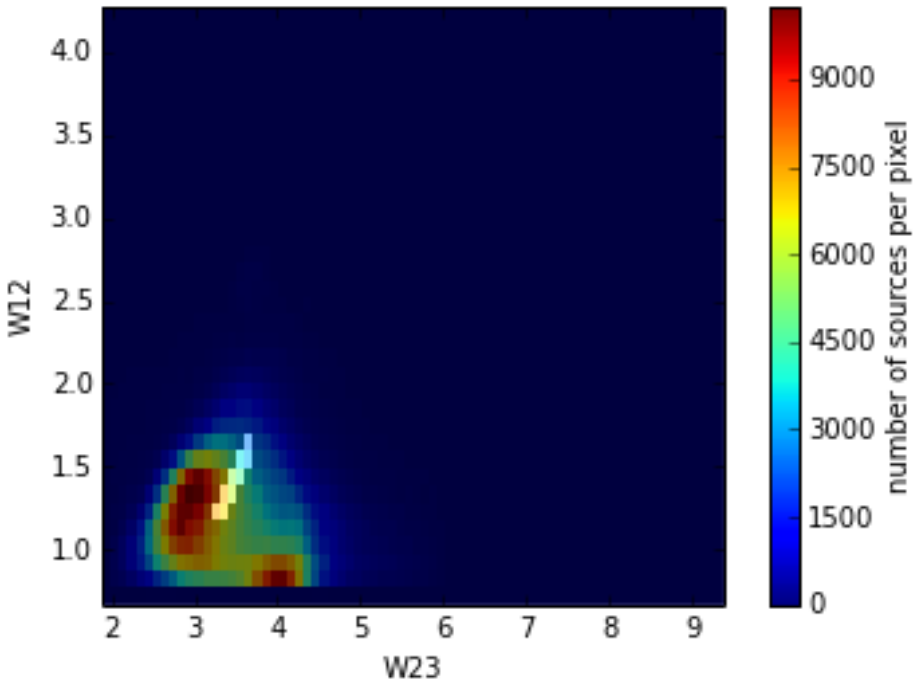


Data

Reproduce the CC (CCM) distribution with linear combination of models



Data + one track (i.e. one model)



Another track ("tracklet"?)

Solve linear regression function for the vector of weights θ

$$Y = M\theta$$

data vector

$$Y = \begin{bmatrix} y_1 \\ y_2 \\ \cdot \\ y_{Npix} \end{bmatrix}$$

model/design matrix

$$M = \begin{bmatrix} m_{1,1} & m_{1,2} & \cdot & m_{1,Npix} \\ m_{2,1} & m_{2,2} & \cdot & m_{2,Npix} \\ \cdot & \cdot & \cdot & \cdot \\ m_{Nmod,1} & m_{Nmod,2} & \cdot & m_{Nmod,Npix} \end{bmatrix}$$

vector of regression coefficients (not model parameters!)

$$\theta = \begin{bmatrix} \theta_1 \\ \cdot \\ \theta_{Nmod} \end{bmatrix}$$

Math and methods straight from...

Ivezić, Connolly, VanderPlas, Gray, "Statistics, Data Mining, and Machine Learning in Astronomy", Princeton Univ. Press 2013

A zoo of regression methods:
linear regression, polynomial, basis functions, ...

General MLE solution: $\theta = (M^T C^{-1} M)^{-1} (M^T C^{-1} Y)$

Can yield very large regression coefficients.

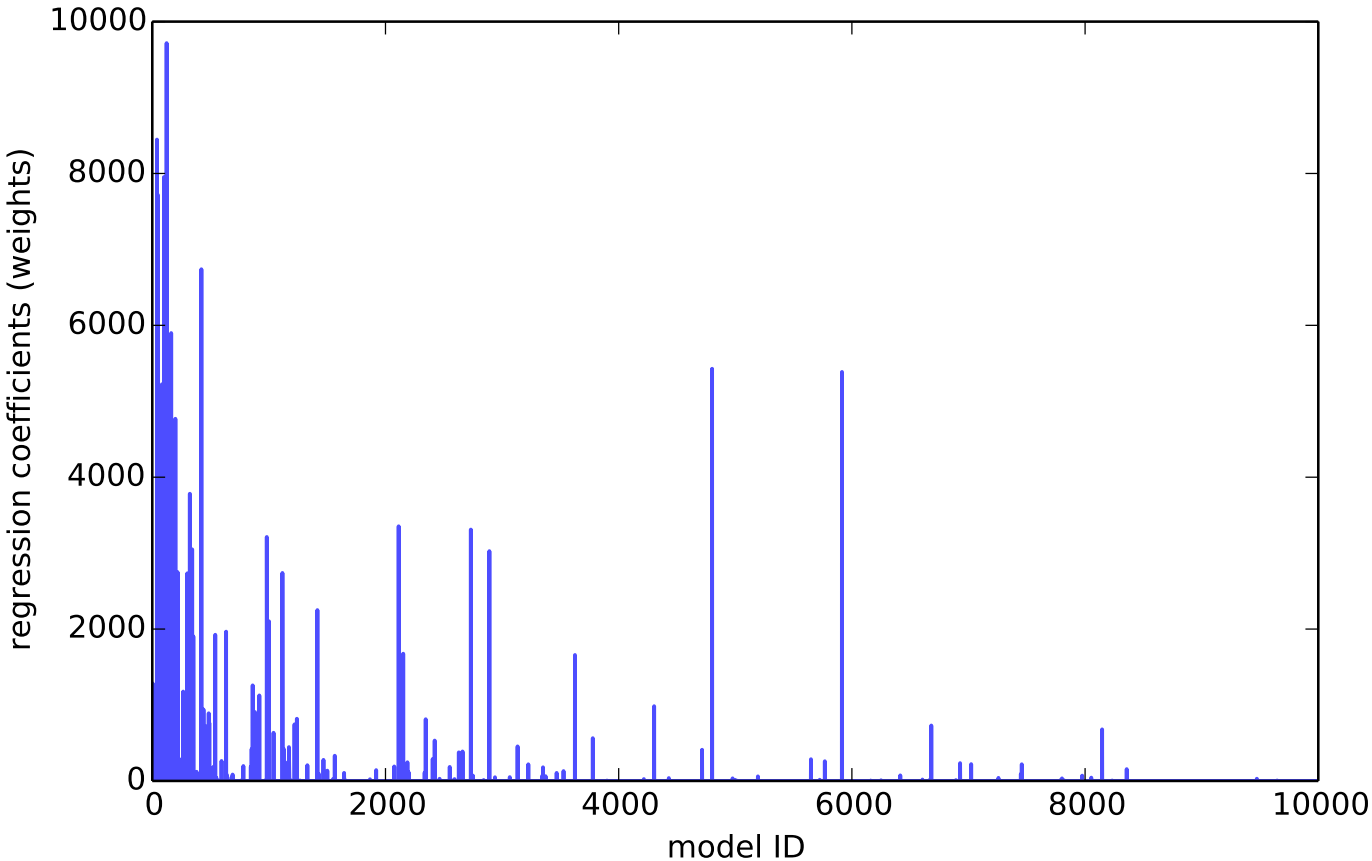
Introduce regularization (penalize large coefficients):
Ridge regression, **Lasso regression**, *Bayesian regression, elastic net, ...*

Use Python (to paraphrase Frank Masci: it's REALLY addictive!)

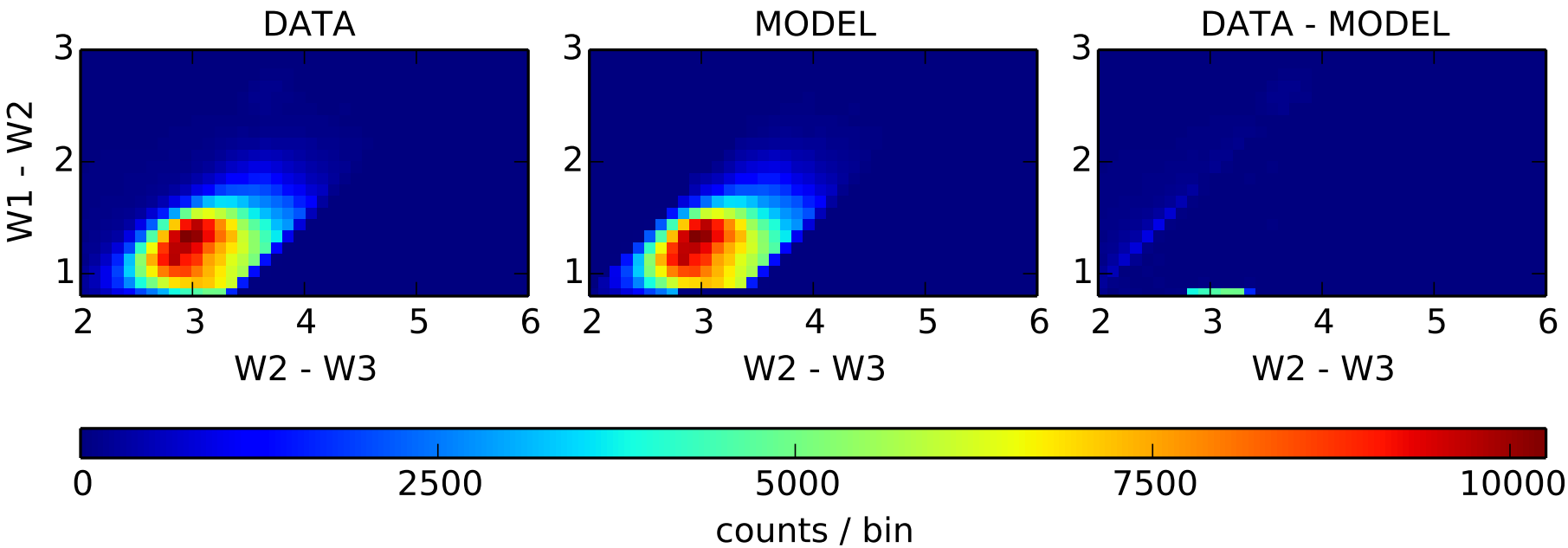
numpy, scipy, scikit-learn, astroML, pyfits, CASA (ALMA data red.), ...

```
from sklearn.linear_model import Lasso
# set up design matrix M and data vector Y...
model = Lasso()
model.fit(M,Y)
# regression coefficients are now ready in model.coef_
```

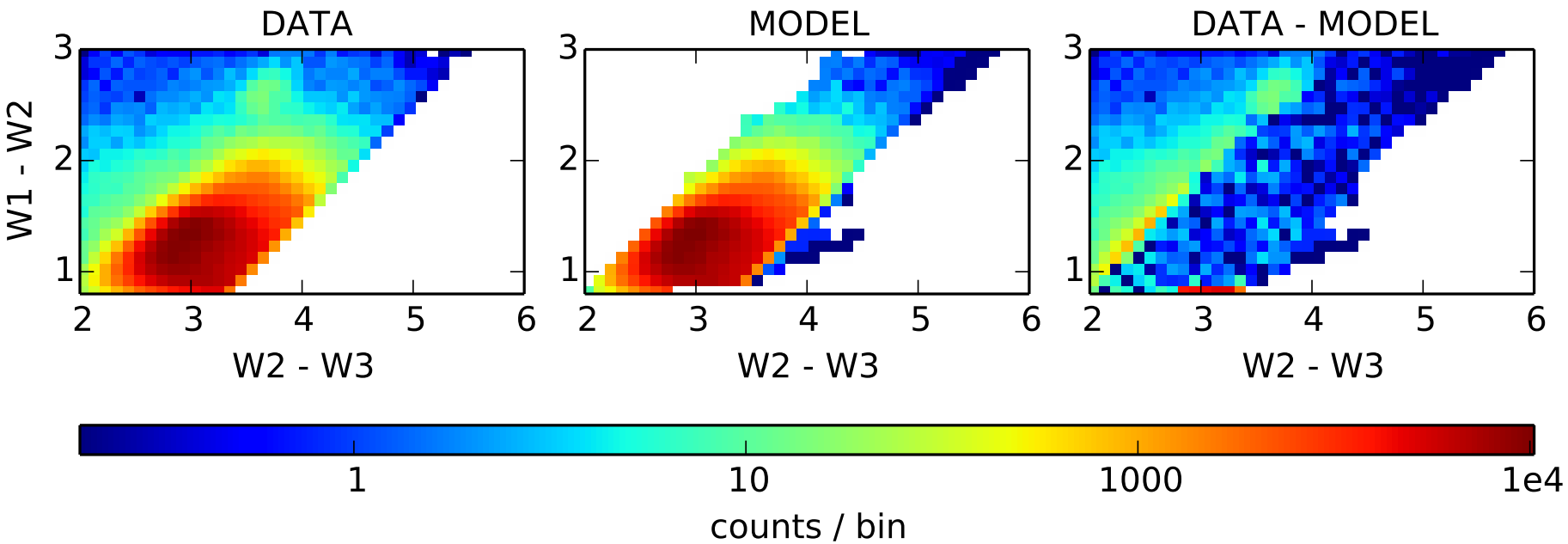
Regression weights



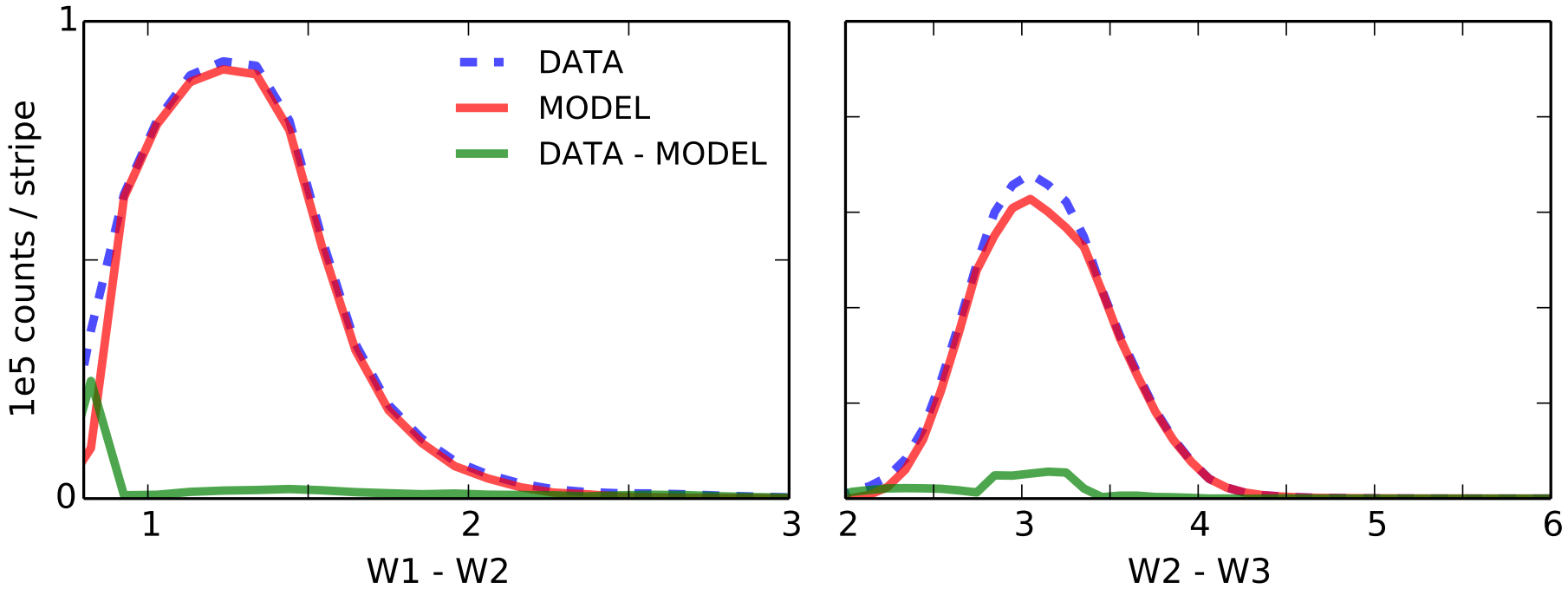
Lasso regression - Results



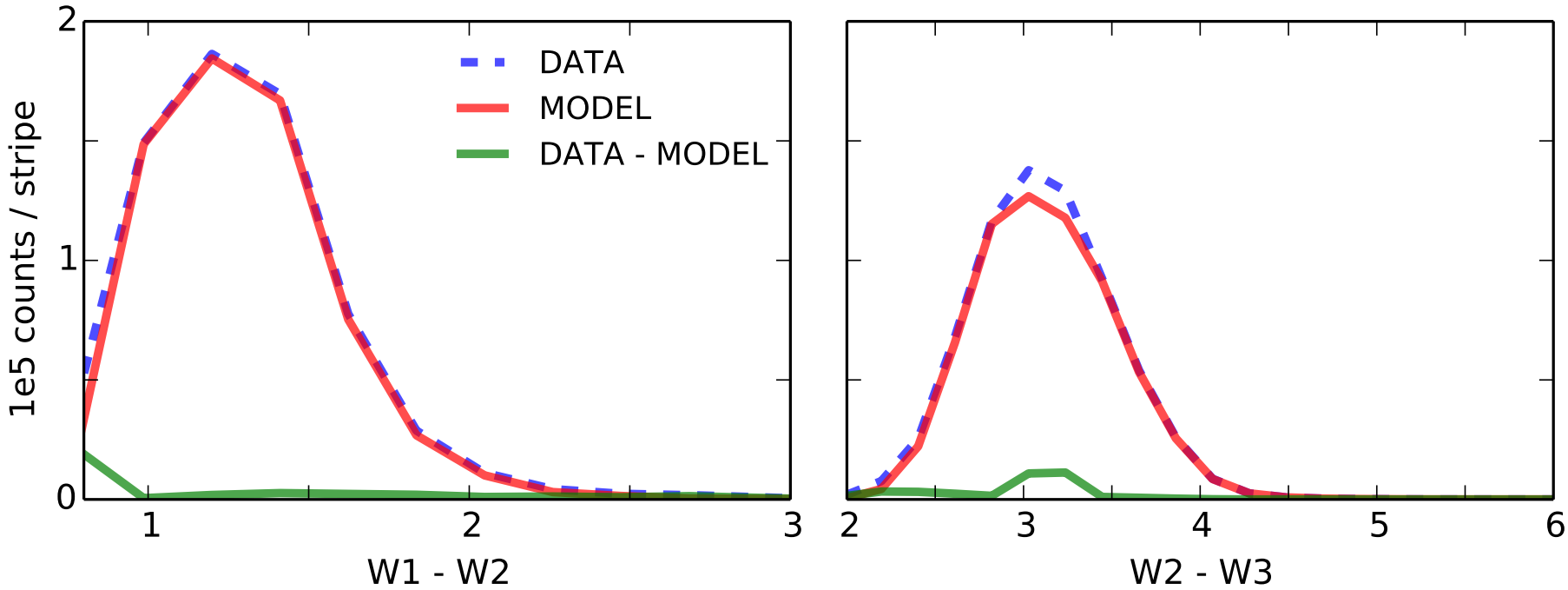
Lasso regression - Results



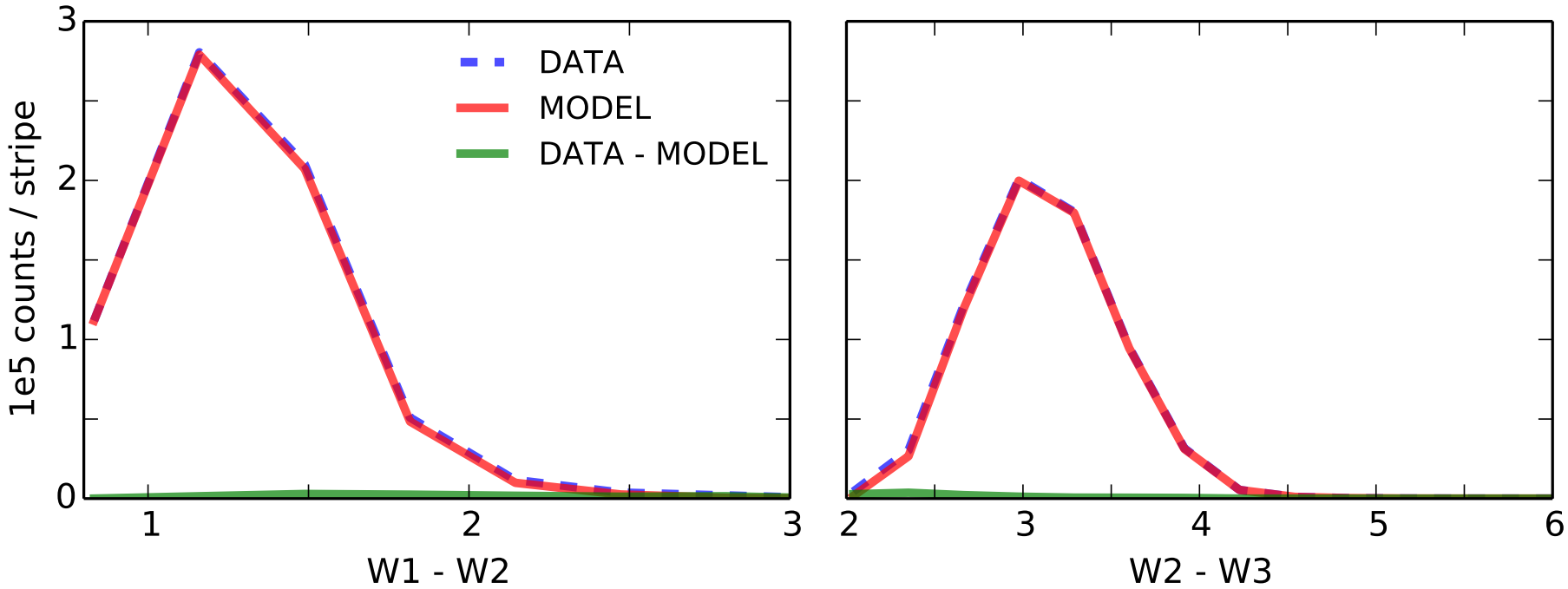
Collapsed histograms - binsize ∼0.1 mag



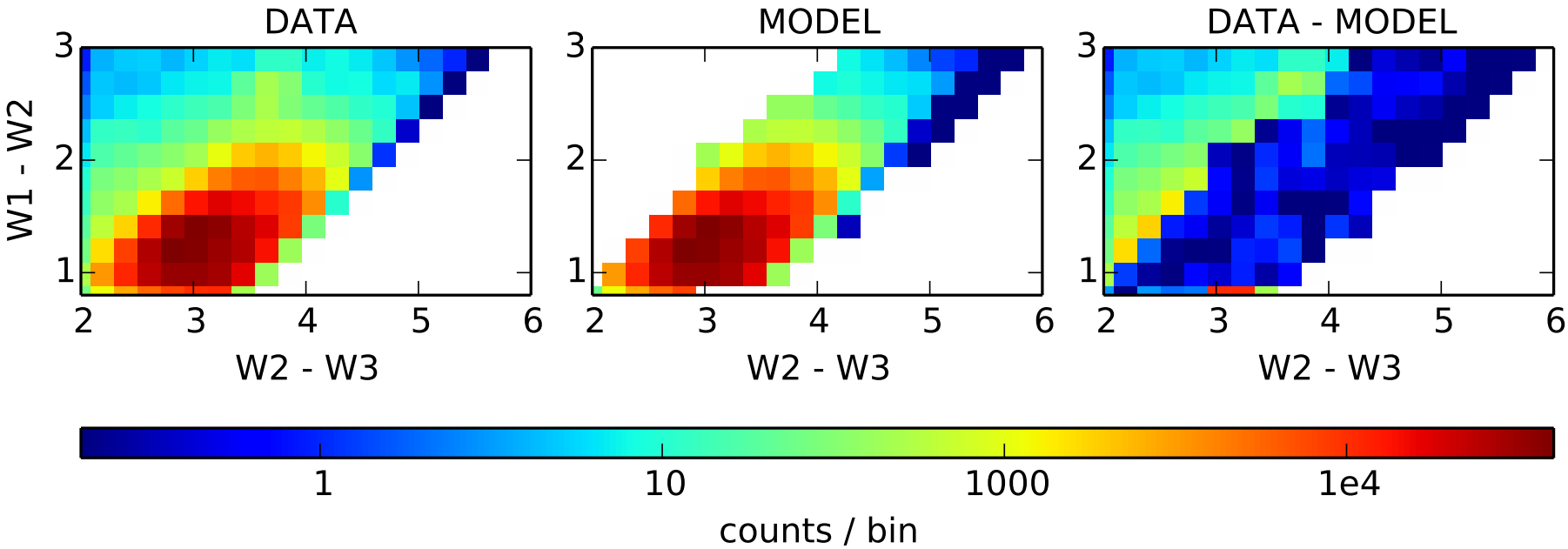
Collapsed histograms - binsize ∼0.2 mag



Collapsed histograms - binsize ∼0.3 mag

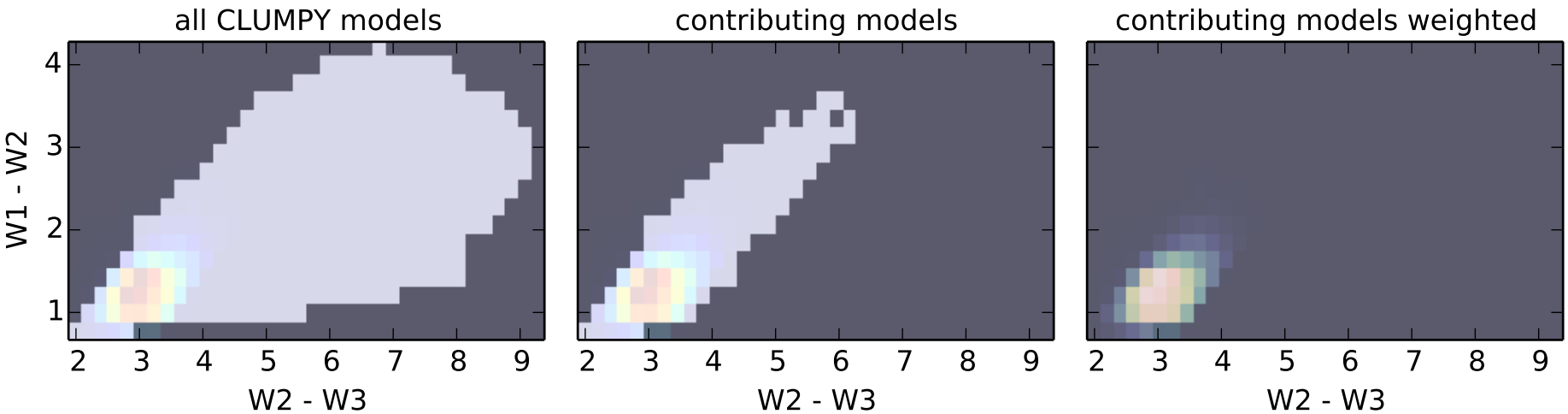


Lasso regression - binsize ∼0.2 mag

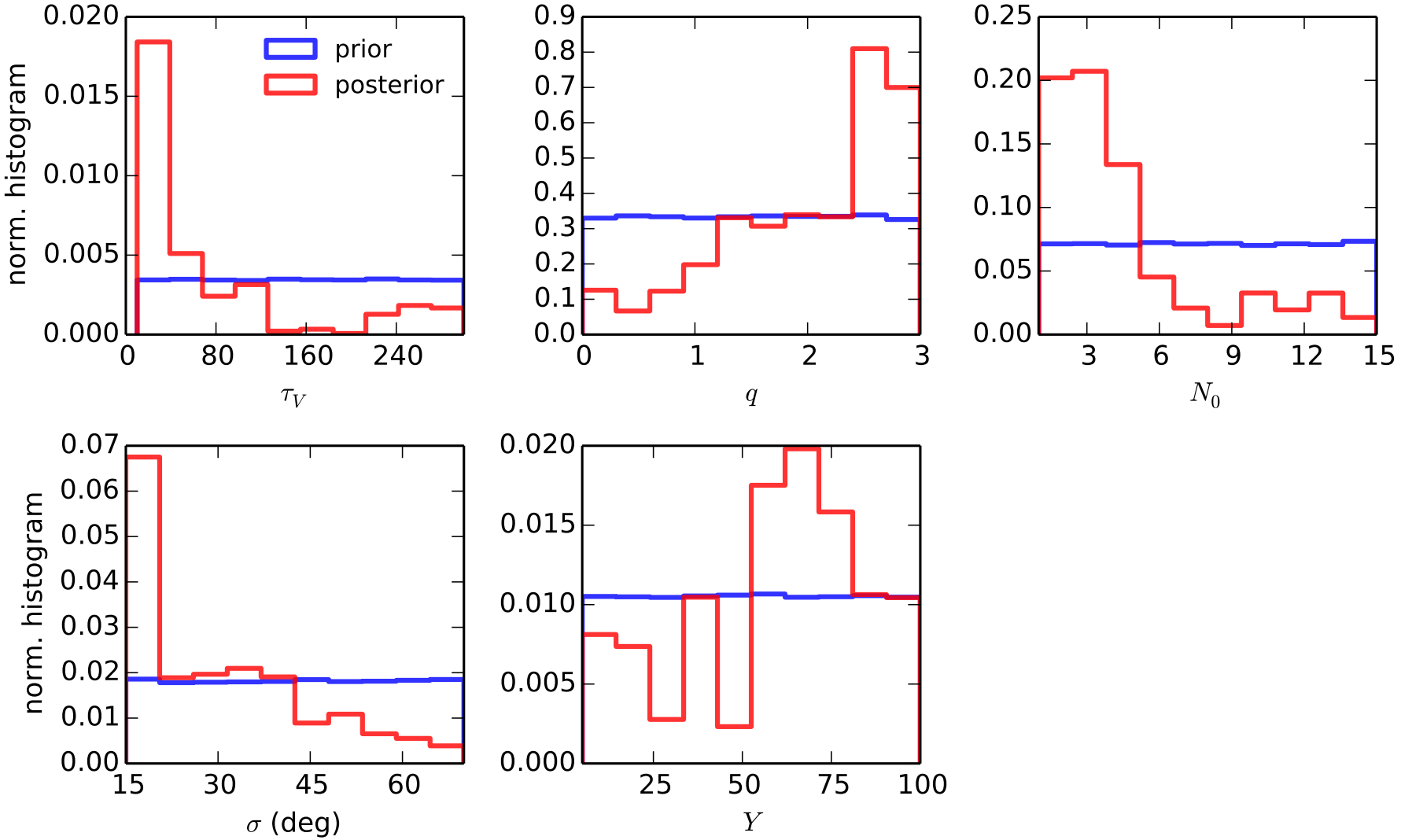


Recipes for matching infinitely thin spaghetti to distribution of mathematical points? (or better: to points with fuzzy locations?)

Coverage by models

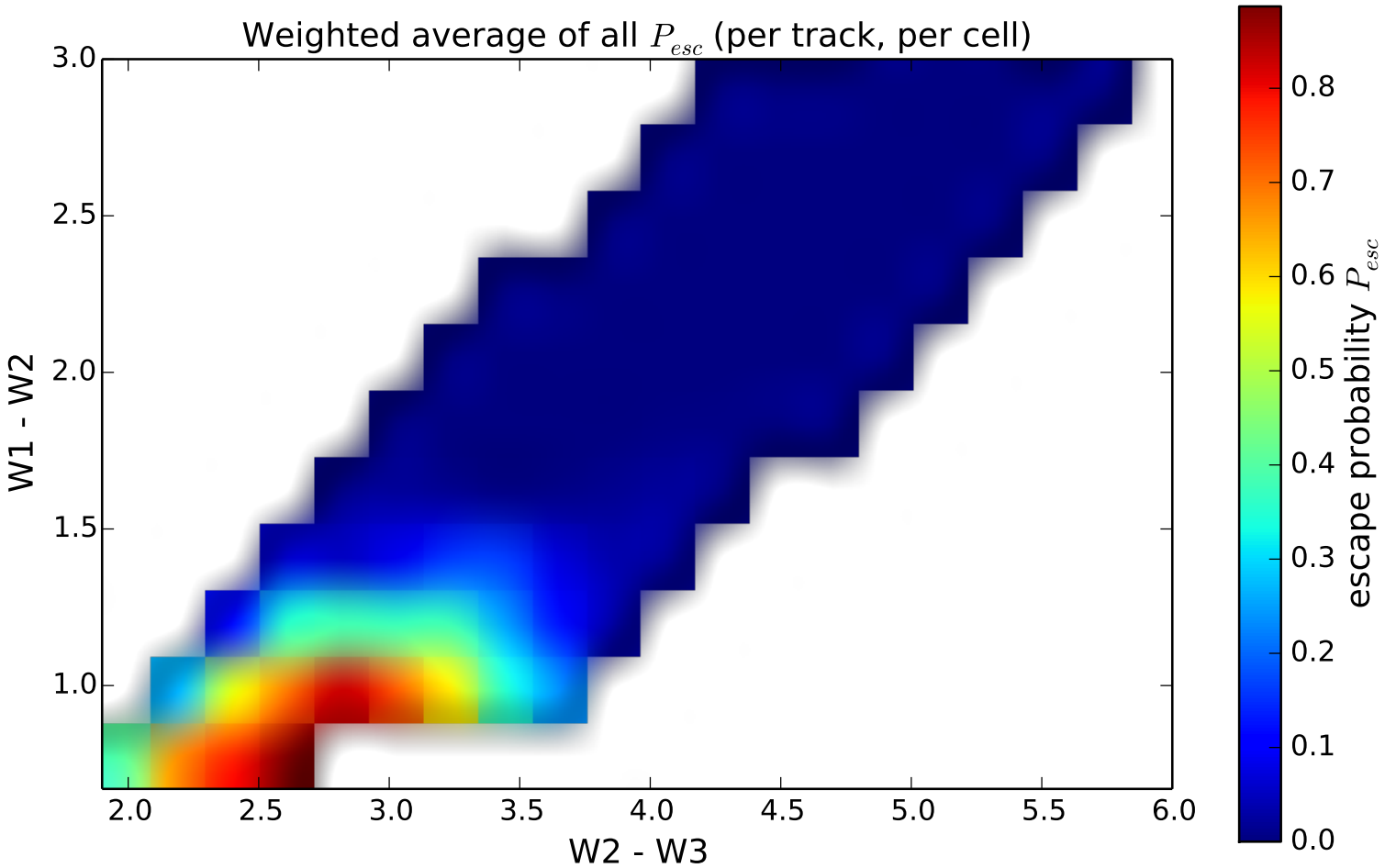


Parameter distributions - weighted histograms



Probably only the modelers like myself are interested in these...

Prediction of type-1 and type-2 locations in CC space



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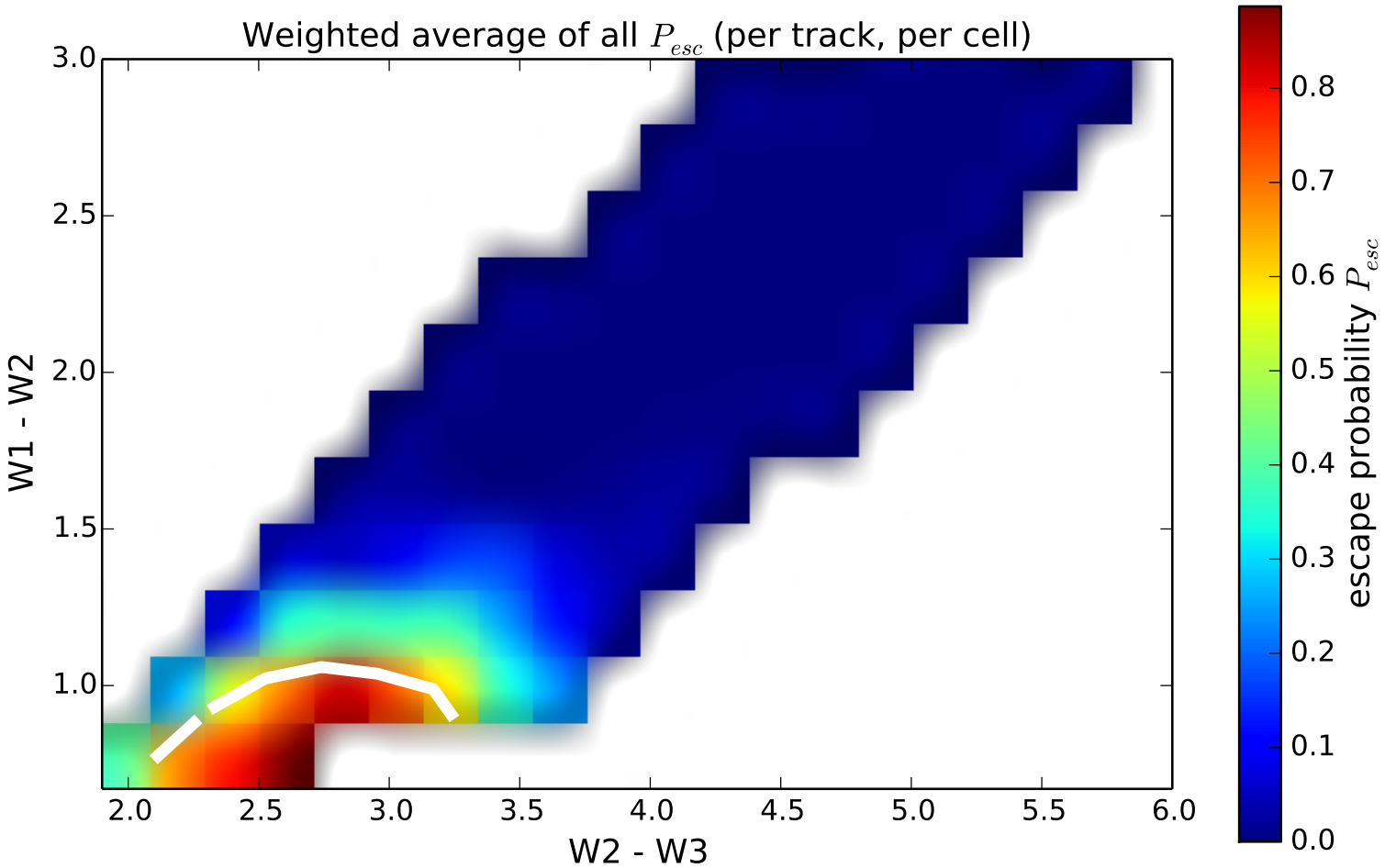
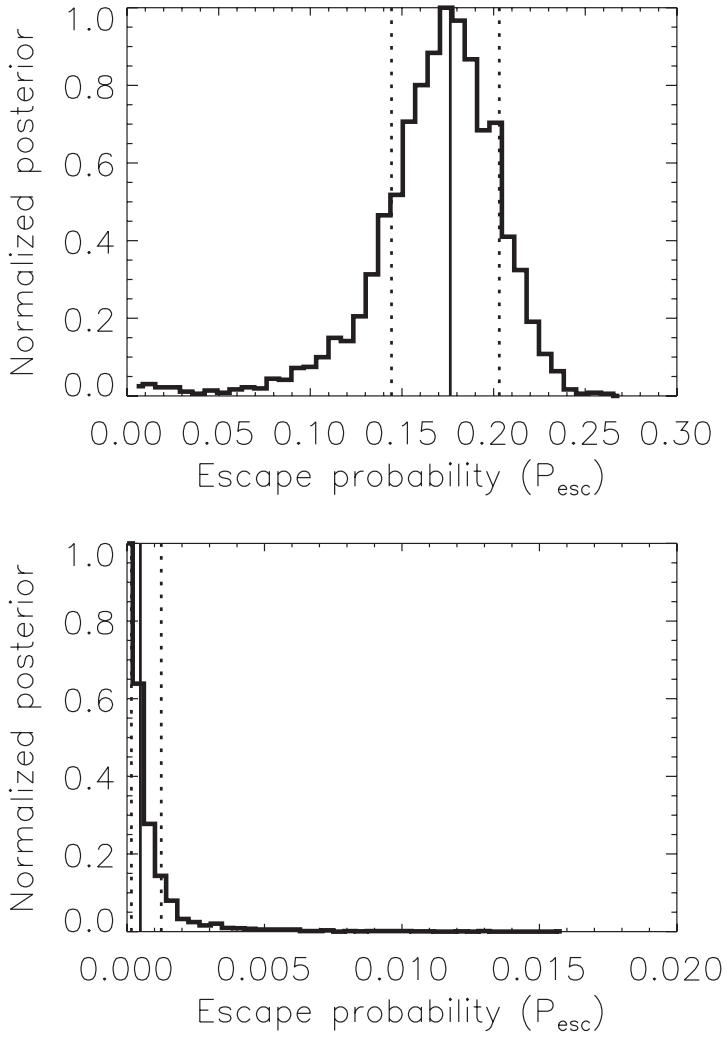
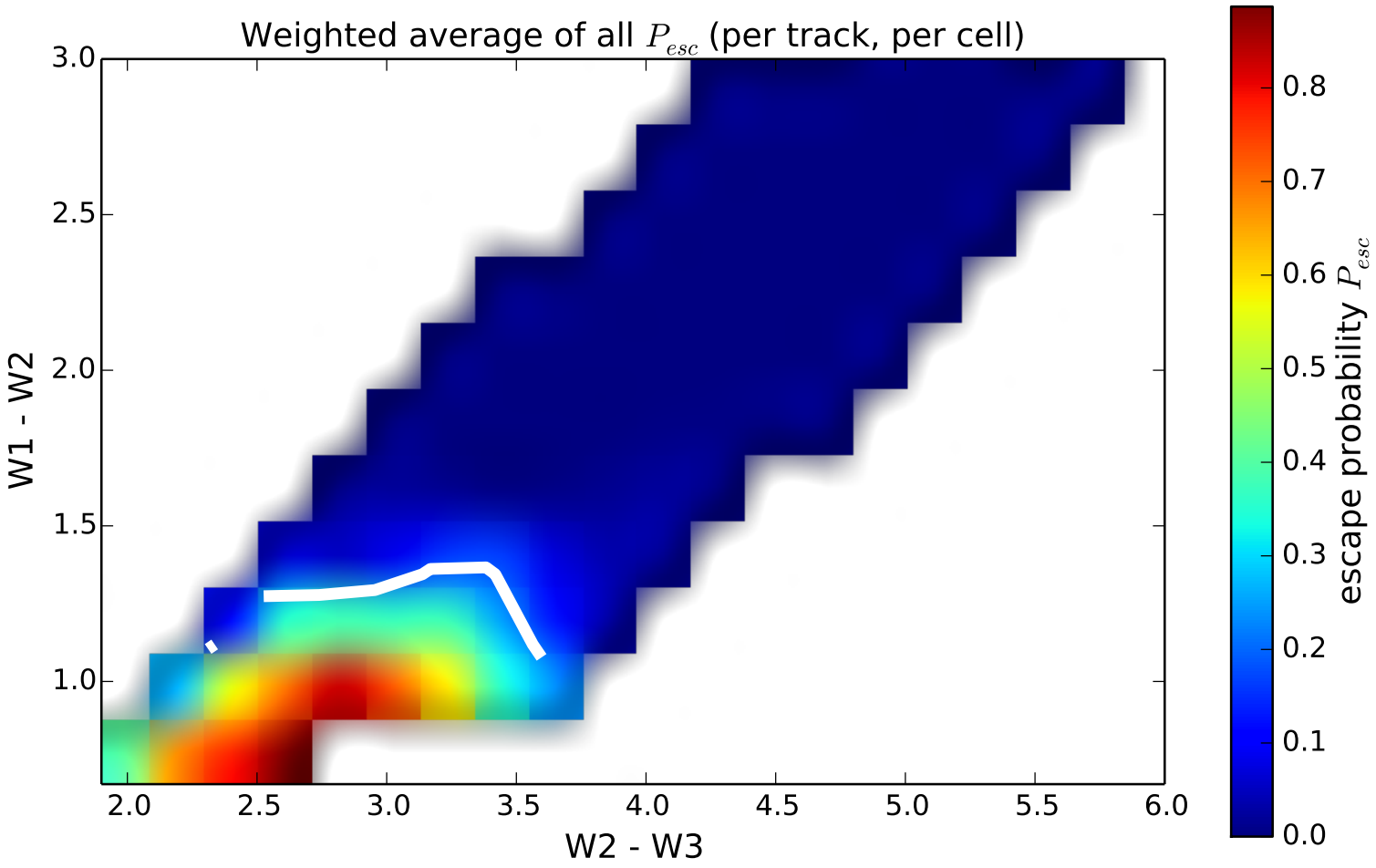


Prediction of type-1 and type-2 locations in CC space



Ramos Almeida et al. 2011

Prediction of type-1 and type-2 locations in CC space



Proof of concept works. What's missing?

- Add (at least) one more axis: W1
  some model viewings will drop out when changing orientation
- Regression will find appropriate CCM distribution of models
- Use e.g. results from clustering measurements to derive z-distribution
  See Lin Yan's talk yesterday, and Alex Mendez' poster 24
- Then we know everything, including luminosity distribution of QSOs, observable type-1/2 counts, their locations in CC spaces, ...

Thank you.

robert.nikutta@gmail.com

www.clumpy.org

Why do we probably need a clumpy torus?

- Dynamical requirements (how to sustain vertical height?)
- Both hot and cooler dust found co-existing close to AGN (VLTI)
- Anisotropic obscuration, more or less isotropic IR emission
- Apparent shifts of 10μm silicate emission peaks in type-1s
- Distribution of observed 10μm silicate feature strengths
  (No deep absorption, No strong emission)
- Discrete X-ray absorption events

K-corrected QSO colors