Cosmic Anisotropies from Quasars

Vincent Pelgrims

–

Seminar

@

Observatoire de la Côte d'Azur

–

Nice, September 12, 2017

Past and Current Works

Strong gravitational lensing
Master thesis – Liege University, Belgium

- Asymptotic solutions for the case of nearly symmetric gravitational lens system
  [O. Wertz, V.P., J. Surdej 2012, MNRAS, 424 1543]

Large-scale alignments of quasar polarization vectors
Doctoral thesis – Liege University, Belgium

- A new analysis of quasar polarization alignments
  [V.P., J.R. Cudell 2014, MNRAS, 442 1239] ; [V.P., Proc. 2014 IAUS, S306 276]
- Polarization alignments of quasars from JVAS/CLASS 8.4-GHz surveys
  [V.P., D. Hutsemékers 2015, MNRAS, 450 4161]
- Alignment of quasar polarizations with large-scale structures
  [D. Hutsemékers, L. Braibant, V.P., D. Sluse 2014, A&A, 472 A18]
- Evidence for the alignment of quasar radio polarizations with large quasar group axes
  [V.P., D. Hutsemékers 2016, A&A, 590 A53]
- Cosmological-scale coherent orientations of quasar optical polarization vectors in the Planck era – Surviving to Galactic dust contamination scenario
  [V.P. 2017, A&A submitted]

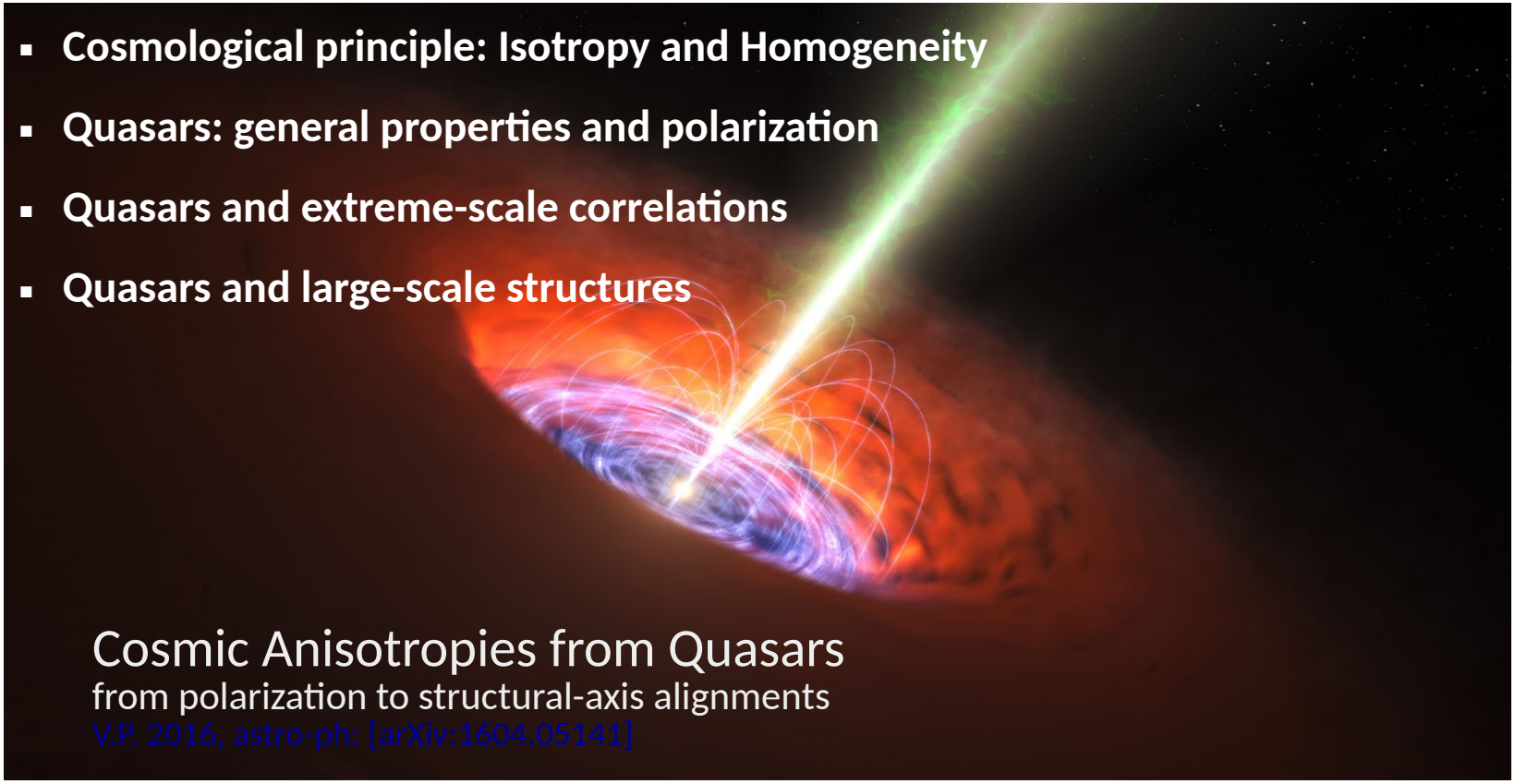
Radio Foregrounds and Galactic Magnetic Field
Postdoc – LPSC, Grenoble, France

- Constraints on regular Galactic magnetic field models from 353-GHz polarized sky
  [V.P., J.F. Macías-Pérez et al. 2017, in preparation]

RADIO FOREGROUNDS

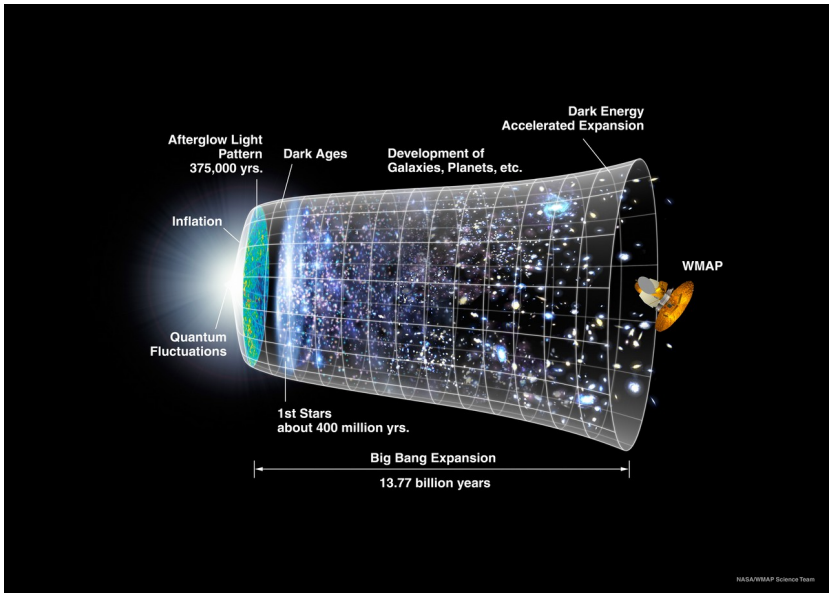
Quasars and Cosmology

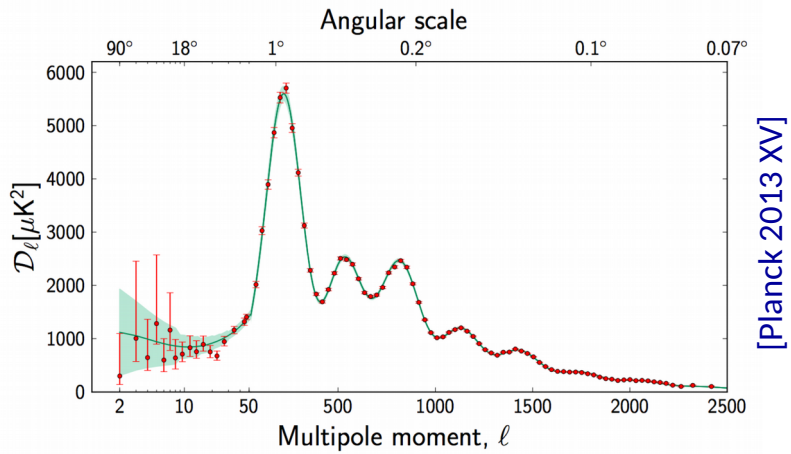
Large-scale alignments of quasar polarization vectors



Cosmological Principle

The ΛCDM: successful concordance model of cosmology





[Planck 2013 XV]

Cosmological principle + General Relativity → FLRW Universes [e.g Trodden & Carroll 2004]

Copernicus' generalized principle: no privileged observer in the Universe

The Universe has to be **homogeneous** and **isotropic** when it is viewed at *sufficiently* large scale.

It requires/implies that the part of the Universe that we observe and study is a statistically representative sample of its entirety.

- Homogeneity = same observation can be made from wherever
- Isotropy = same observation can be made by looking in whatever direction

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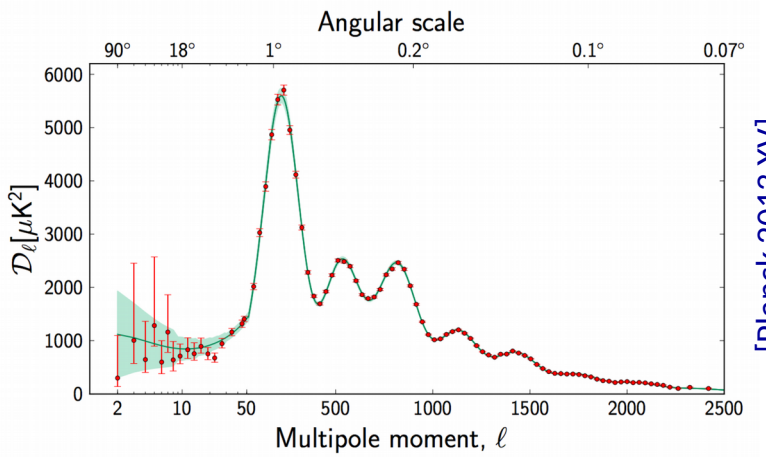
- Isotropy for all observers implies homogeneity
- Homogeneity for all does not imply isotropy

e.g. Bianchi cosmological models that are homogeneous and anisotropic

Resurgent interests to explain some anomalies such as:

- Low-*l* deficit in the TT angular power spectrum
- Small temperature variance
- Dipole and quadrupole alignment of moments
- …
- Departure from isotropic H_0 from SNIa
- Extreme-scale alignments of quasar (optical) polarization vectors
- …

Isotropy appears to be questionable …



[Planck 2013 XV]

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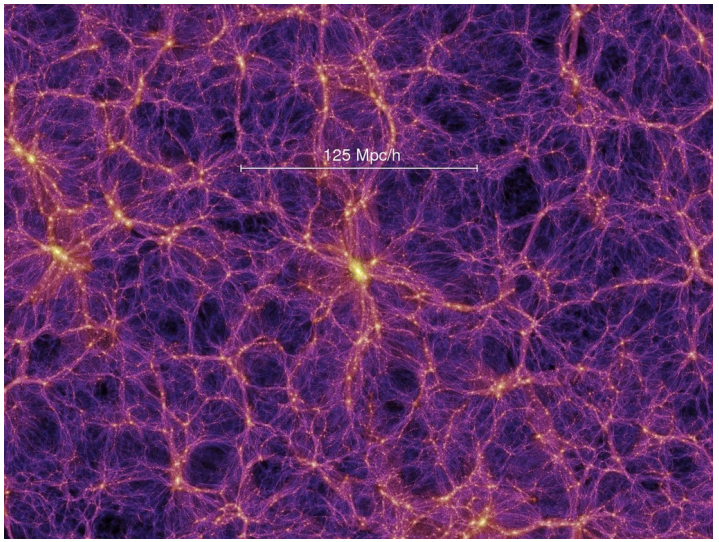
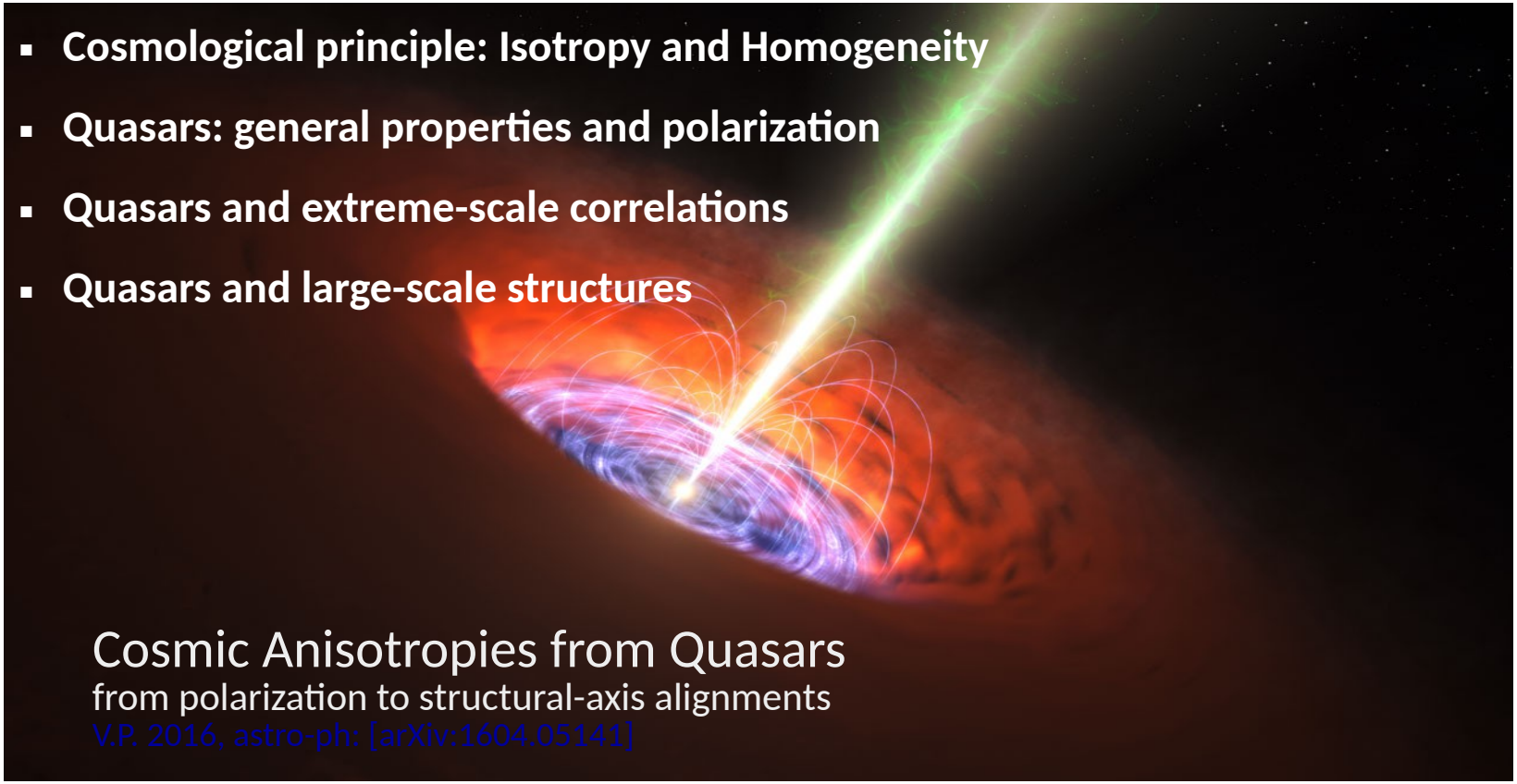
Isotropy appears to be questionable ...
Homogeneity as well, at least the value of the *homogeneity scale* has long been debated and most recently with quasars.



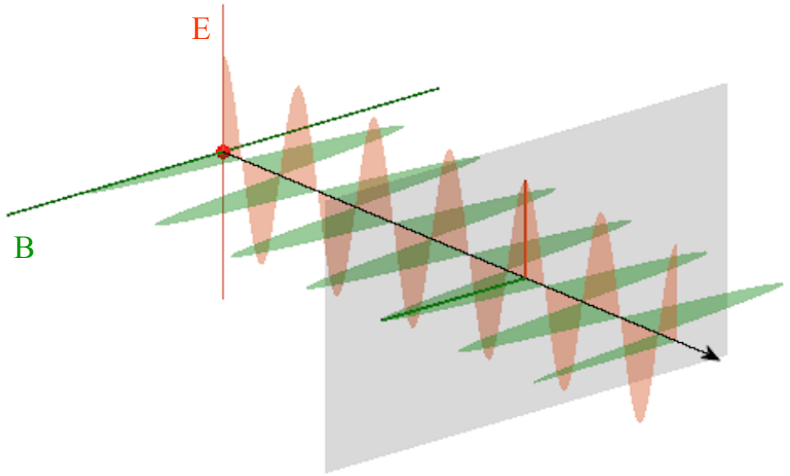
[Springel et al. 2005]

Quasars and Cosmology

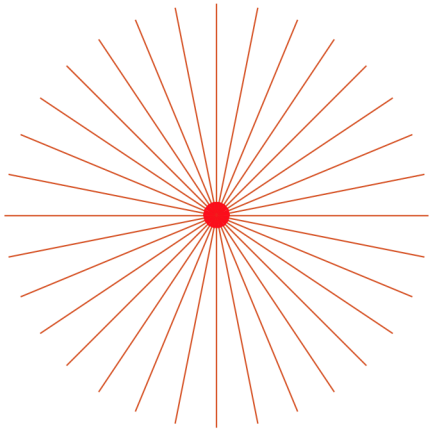
Large-scale alignments of quasar polarization vectors



Polarization of light



Un-polarized



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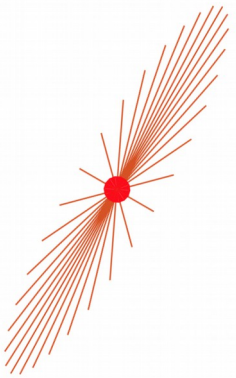

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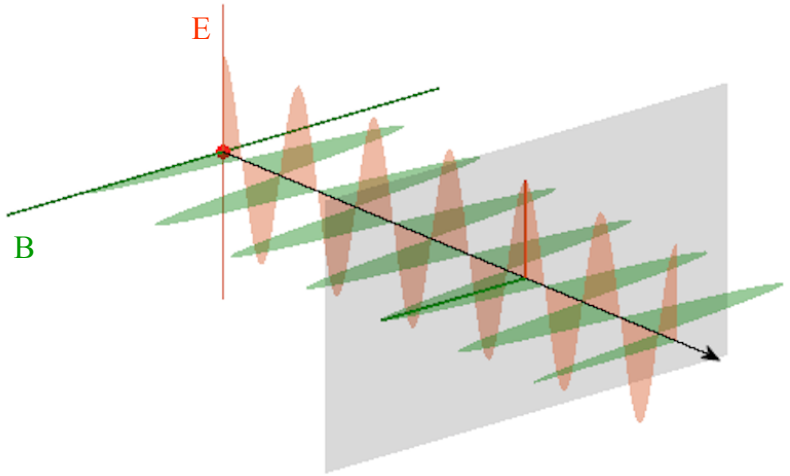

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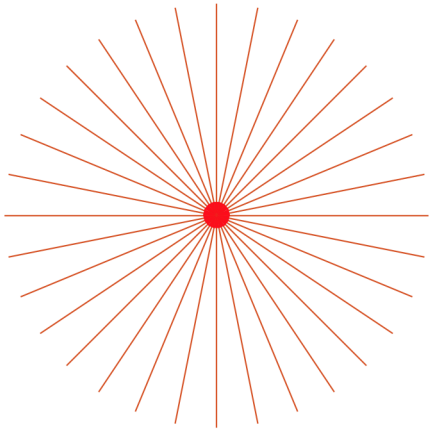
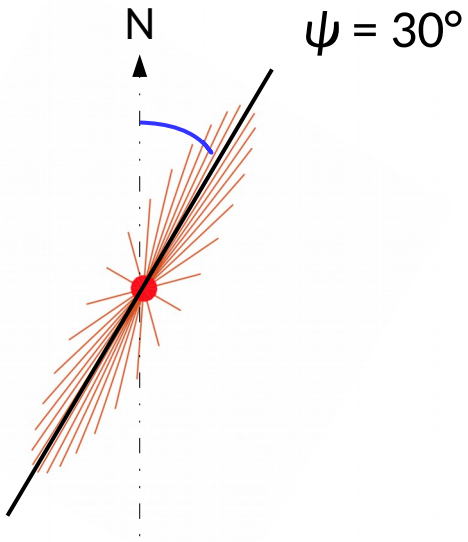


p_{lin} = 0 %

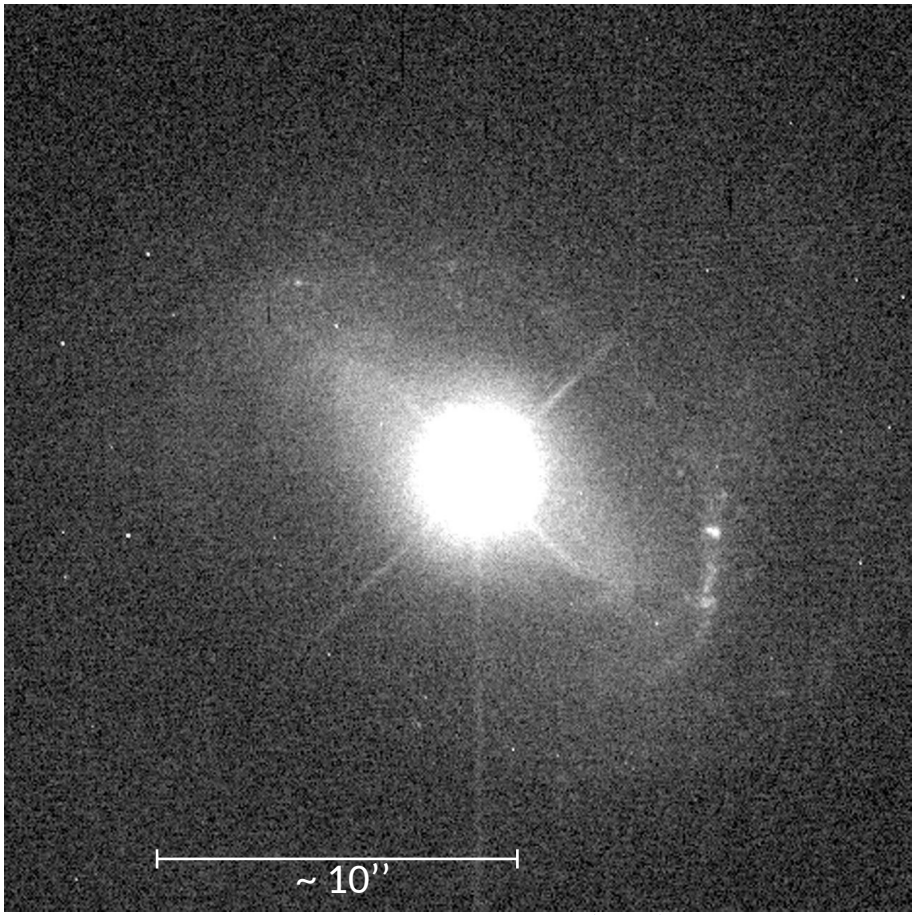
Polarized



p_{lin} >> 0 %

Quasars: some properties

- Most luminous Active Galactic Nuclei
- Ultra-bright point-like sources
- Emit light in the whole spectrum
- Observable at the far reaches of the Universe
- Tiny region at the center of a Galaxy (~ 10^{-3} – 10^{-4} pc)
  → matter accretion onto a Super Massive Black Hole (>10^8 $M_\odot$)
- Light is polarized at various wavelengths
  → no spherical symmetry
- Very-high resolution observations of a few showed the polarization orientation related to structural axis of the source (blue/UV continuum or radio jet) [Borguet et al. 2005]



[QSO 1229+204; Hutchings et al. 1994 (HST)]

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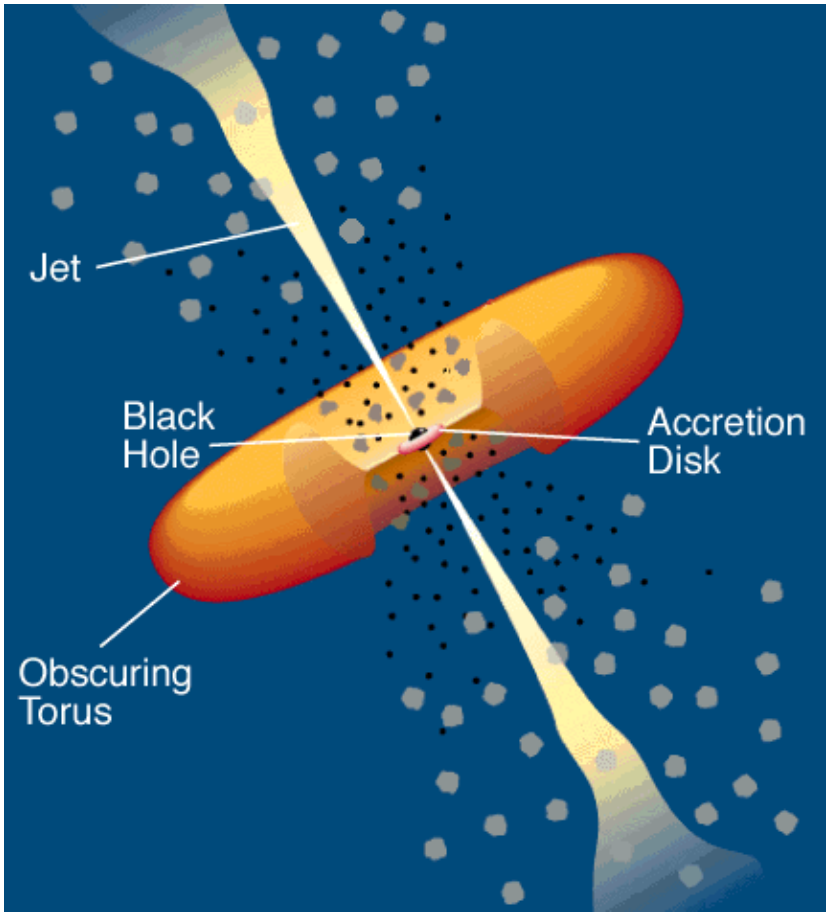


[Urry & Padovani; unified model]

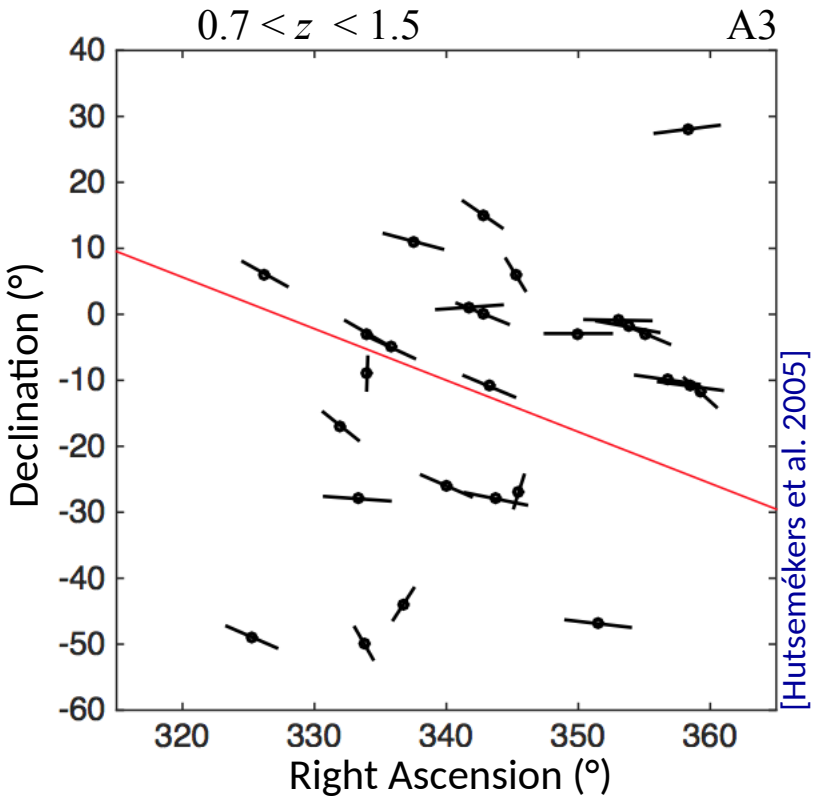
Quasars and extreme-scale correlations

Extreme-scale alignments of quasar optical polarization vectors

Originally discovered: [Hutsemékers 1998]

Confirmed with:

- new observations
  [Hutsemékers & Lamy 2001 ;
  Sluse et al. 2005]
- independent analyses
  [Hutsemékers & Lamy 2001 ;
  Jain et al. 2004 ;
  Cabanac et al. 2005 ;
  Hutsemékers et al. 2005 ;
  Pelgrims & Cudell 2012 ;
  Pelgrims 2017]



Probability of uniformity ~ $6\ 10^{-5}$

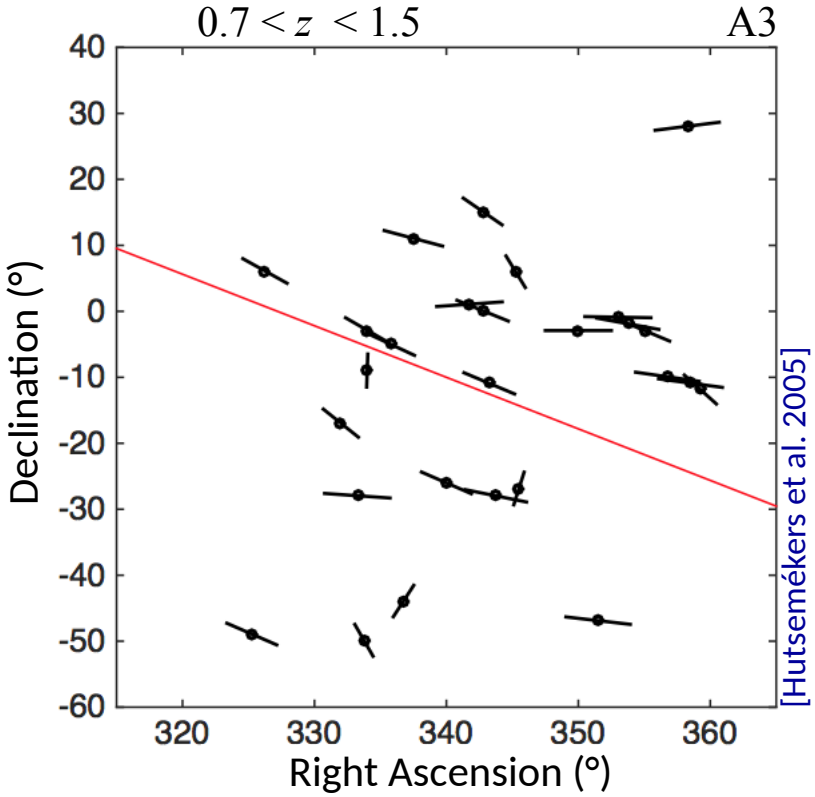
Quasars and extreme-scale correlations

Extreme-scale alignments of quasar optical polarization vectors

[Hutsemékers et al. 2005]

- Current sample:
  355 quasars with *reliable* opt. pol.

- Significant orientation correlations within few Gpc scale regions



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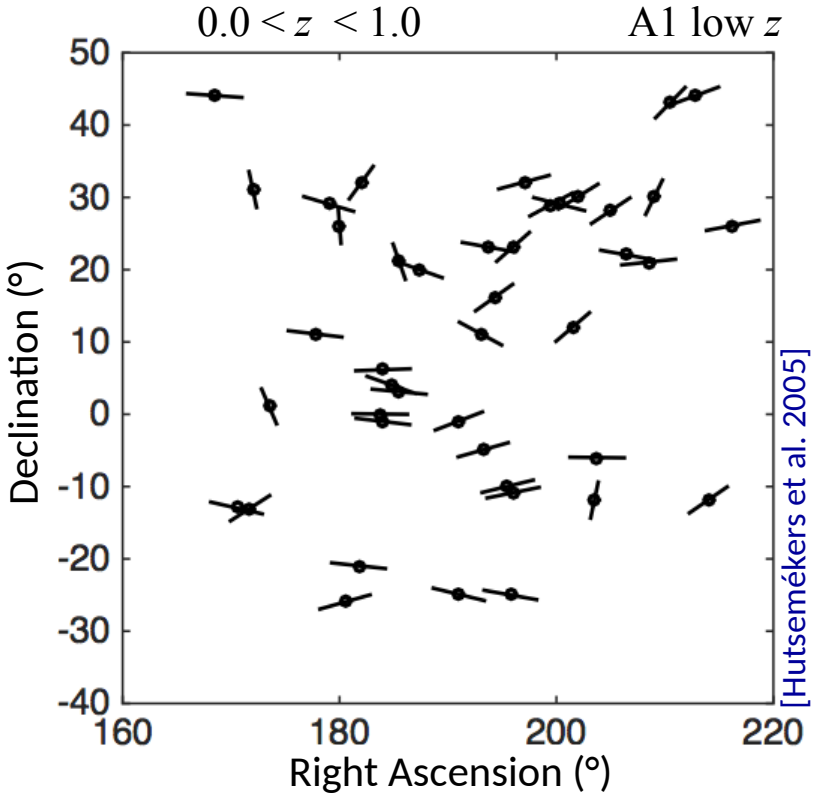

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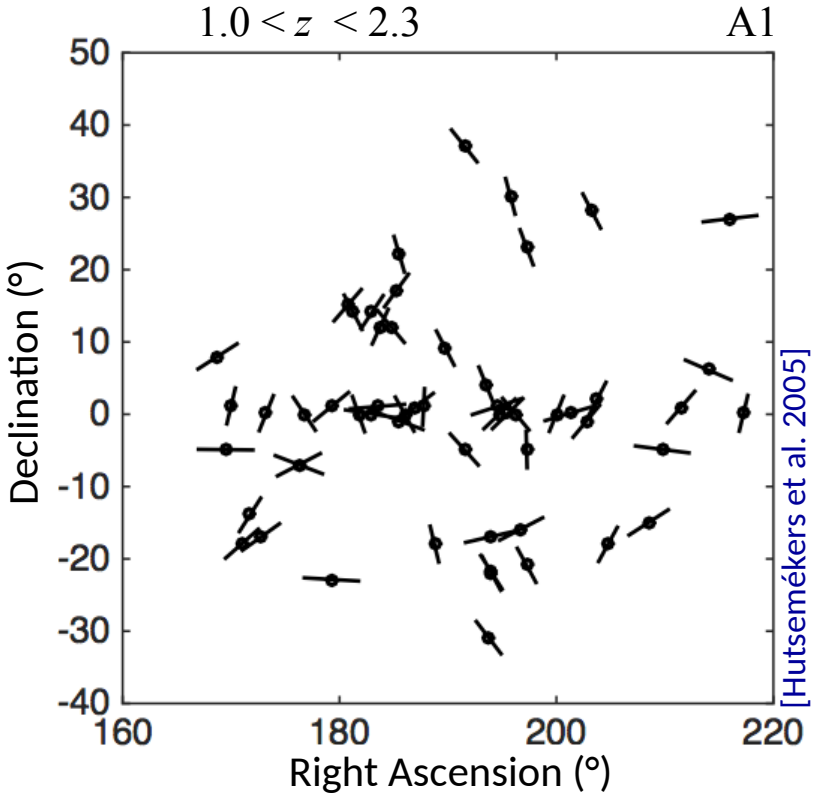

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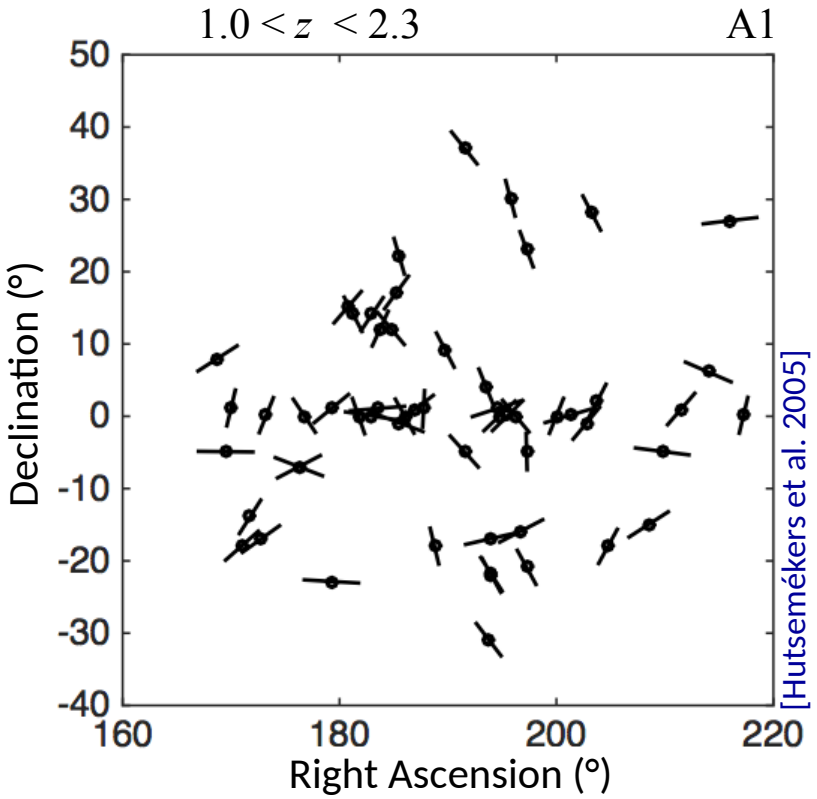

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Still *not* understood today !

No satisfactory explanation despite the various investigated scenarios

- Cosmic strings/loops
- Cosmological-scale magnetic field
- Axion-like Dark Matter particle
- Birefringence of the Universe
- **Anisotropic cosmological expansion**
- …

[V.P. & Cudell 2014 ; V.P. 2014]

- ✔ Confirmation of alignments with new and statistically independent methods
- ✔ Confirmation of redshift dependence but with no smooth and continuous rotation as suggested before

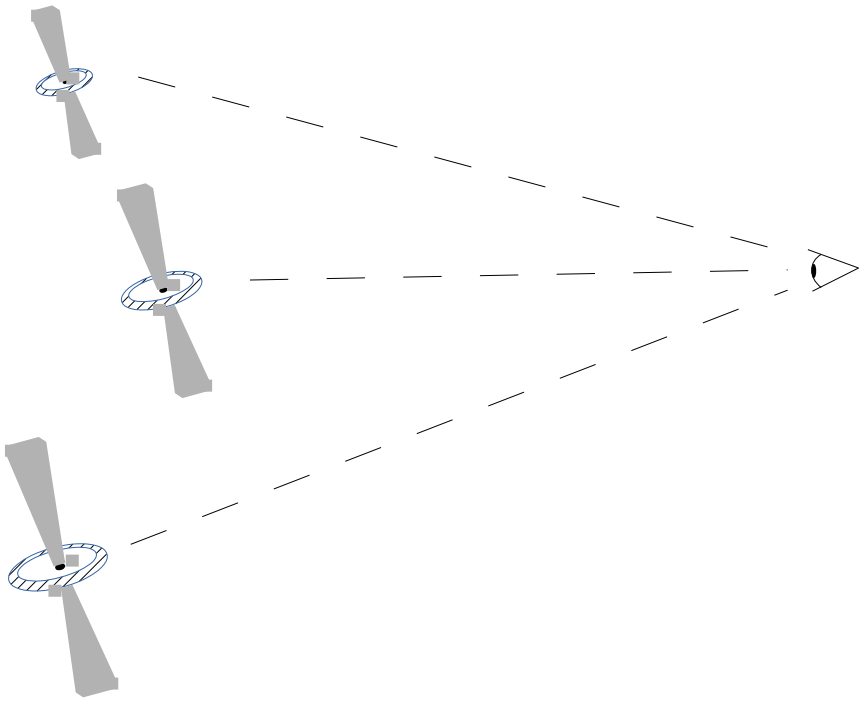
[V.P. 2017]

- ✔ Robustness of alignments regarding interstellar polarization contamination evaluated from *Planck* map

Quasars and extreme-scale correlations

Extreme-scale alignments of quasar optical polarization vectors

What can cause the polarization alignments ?



- Photon path effects
  - Modulation of the polarization state
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Quasars and extreme-scale correlations

Extreme-scale alignments of quasar optical polarization vectors

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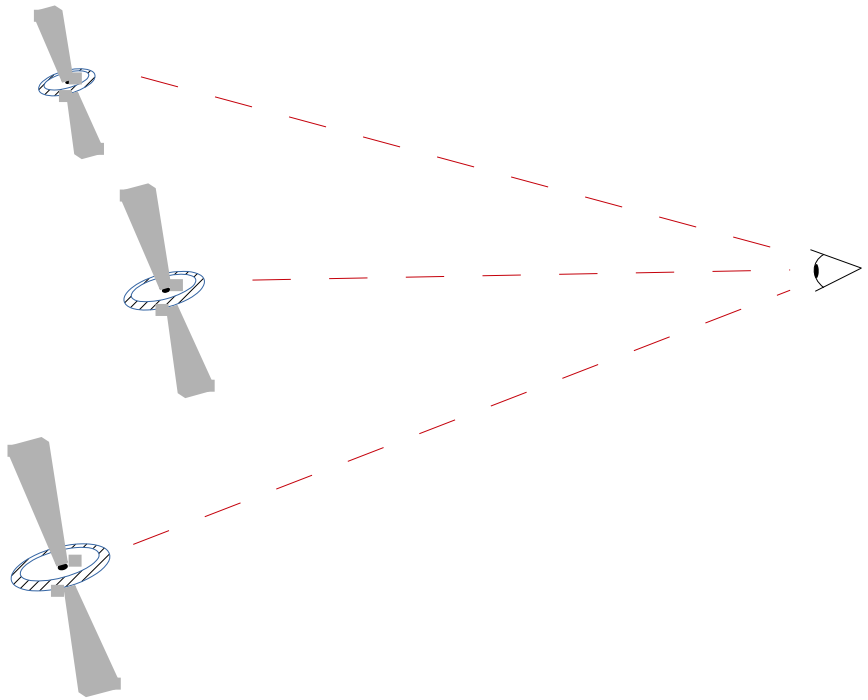

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Random — — — —?— — — —► Aligned

Quasars and extreme-scale correlations

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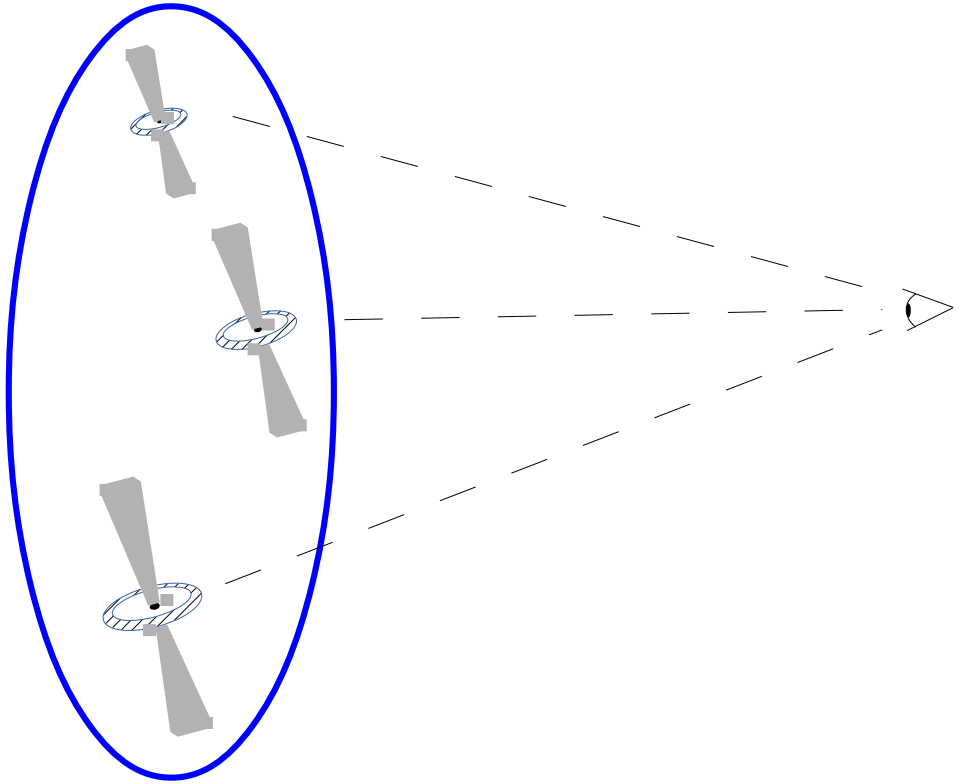

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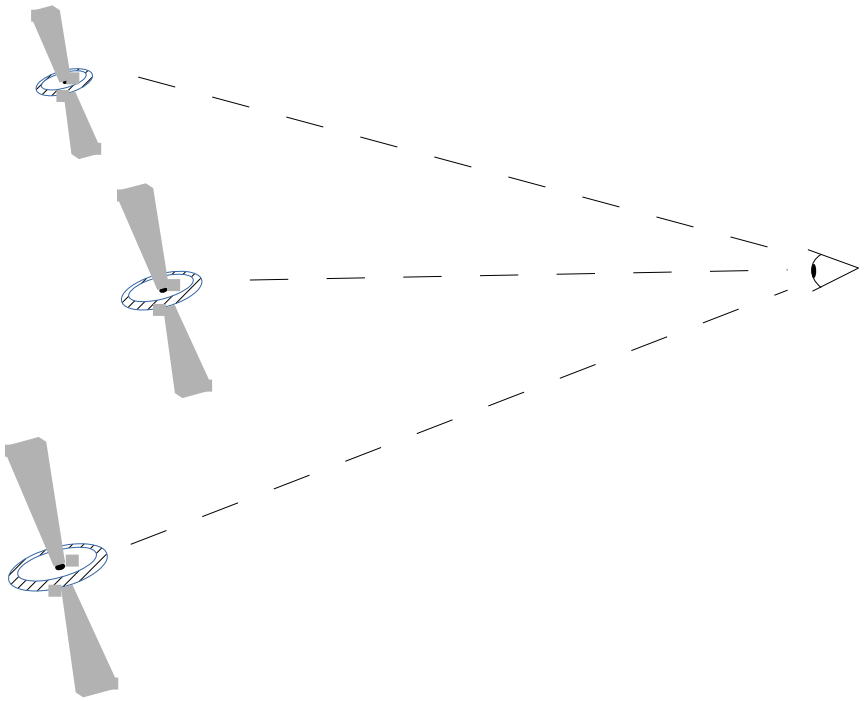

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These scenario have different observational signatures

Wavelength dependence of the alignments ?

Quasars and extreme-scale correlations

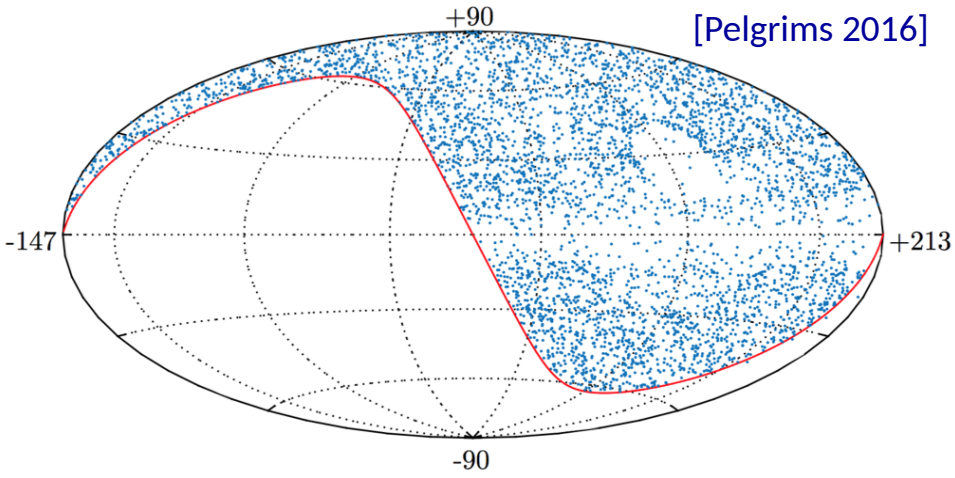
Quasar polarization alignments in JVAS/CLASS 8.4 GHz surveys

Based on JVAS/CLASS 8.4-GHz surveys
[Jackson et al. 2007]

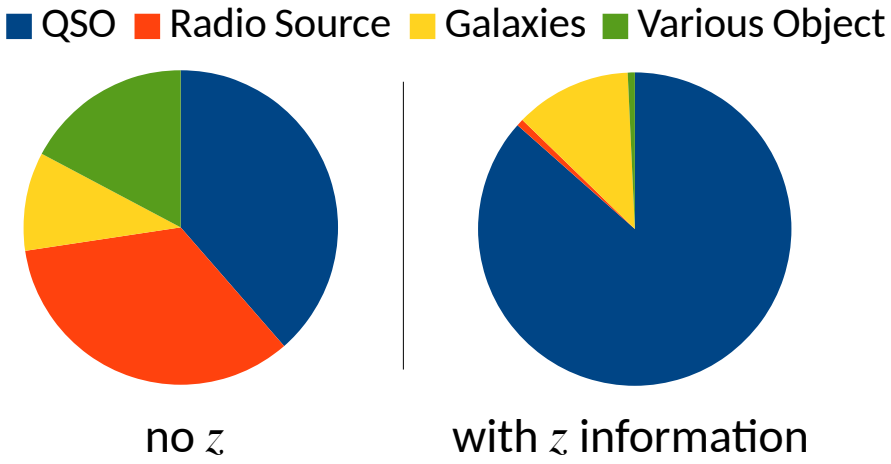
- Situation unclear from previous studies
  [Joshi et al. 2007 ; Tiwari & Jain 2013 ; Shurtleff 2014]
- Lack of consideration of the intrinsic properties of the sources (redshift, type, ...)

[V.P. & Hutsemékers 2015]

- Clear identification of 4155 Flat Spectrum Radio Sources with reliable polarization measurements
  (f_{pol} > 1 mJy ; $\sigma_\psi \leq 14°$)
- Nasa Extragalactic Database
  → redshift for 1531 sources
  → Classification in Object Types



[Pelgrims 2016]



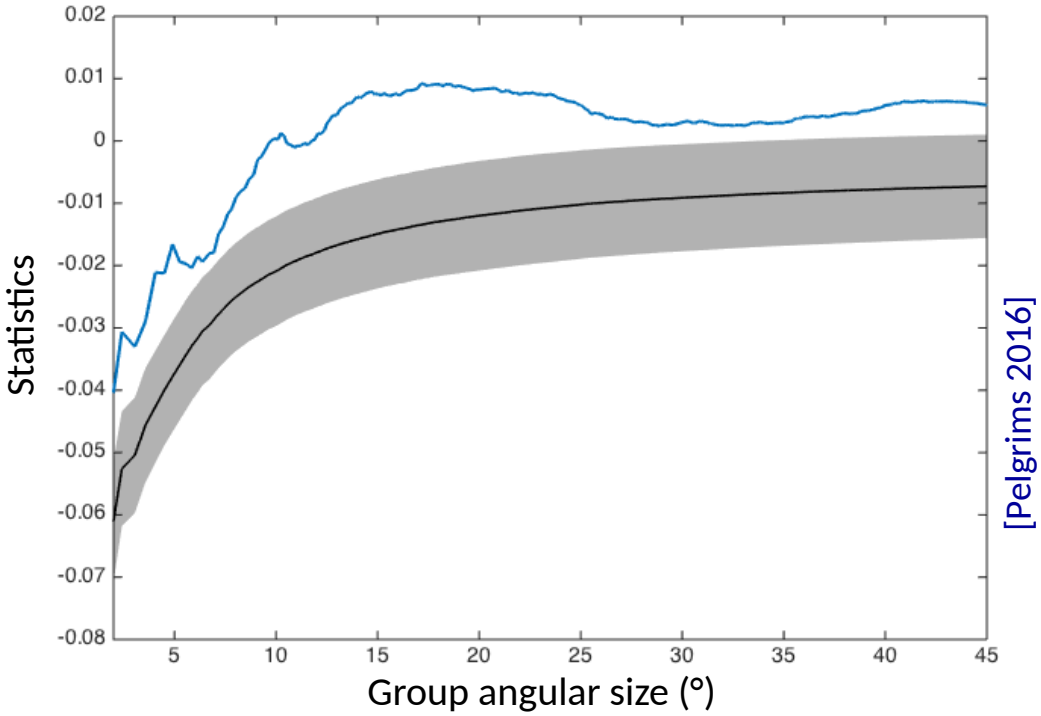
Quasars and extreme-scale correlations

Quasar polarization alignments in JVAS/CLASS 8.4 GHz surveys

[V.P. & Hutsemékers 2015]

- Evidence for alignment in one of the region of optical pol. alignment (~3σ)
- Stat. significant alignment features within the whole sample

  Dedicated global statistical tests:
  - comparison of polarizations in groups of nearest neighbors and averaged with the whole sample
  - 10^4 Monte Carlo simulations for random distribution
  - For any given size of groups of neighboring sources



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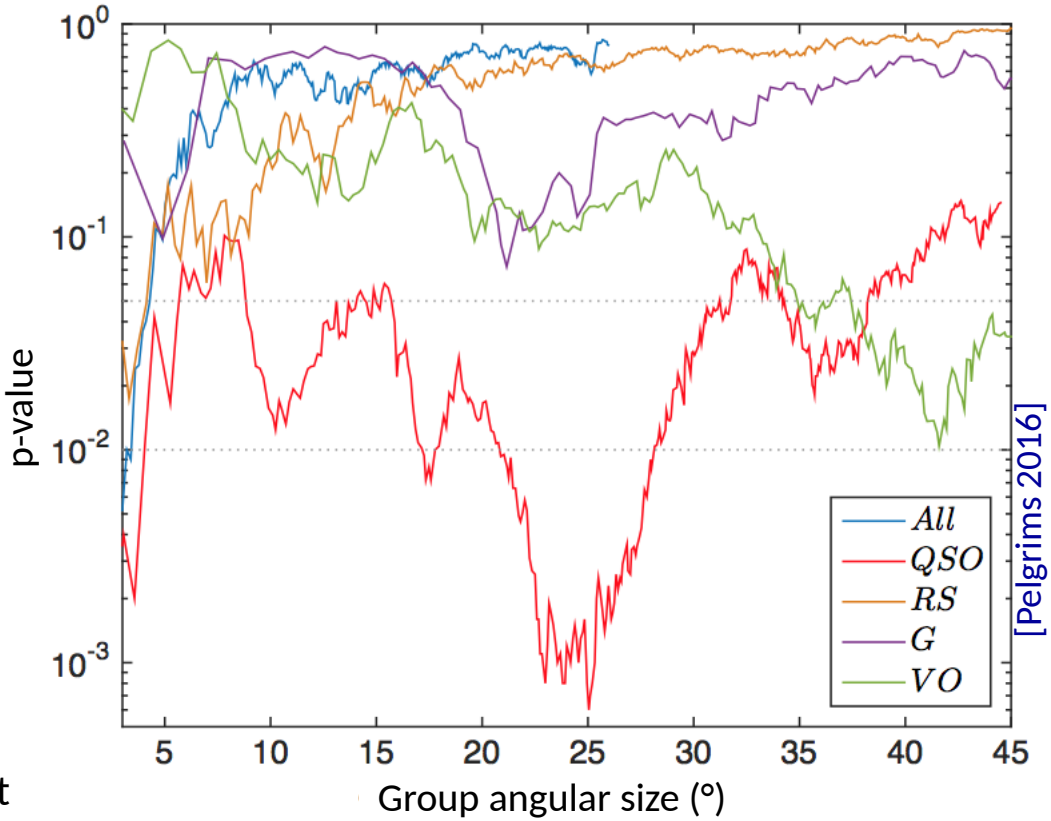

→ 2D analysis with no restriction on the redshift

→ For a wide range of size of groups of neighboring sources

→ For all subsamples at hand

Quasars and extreme-scale correlations

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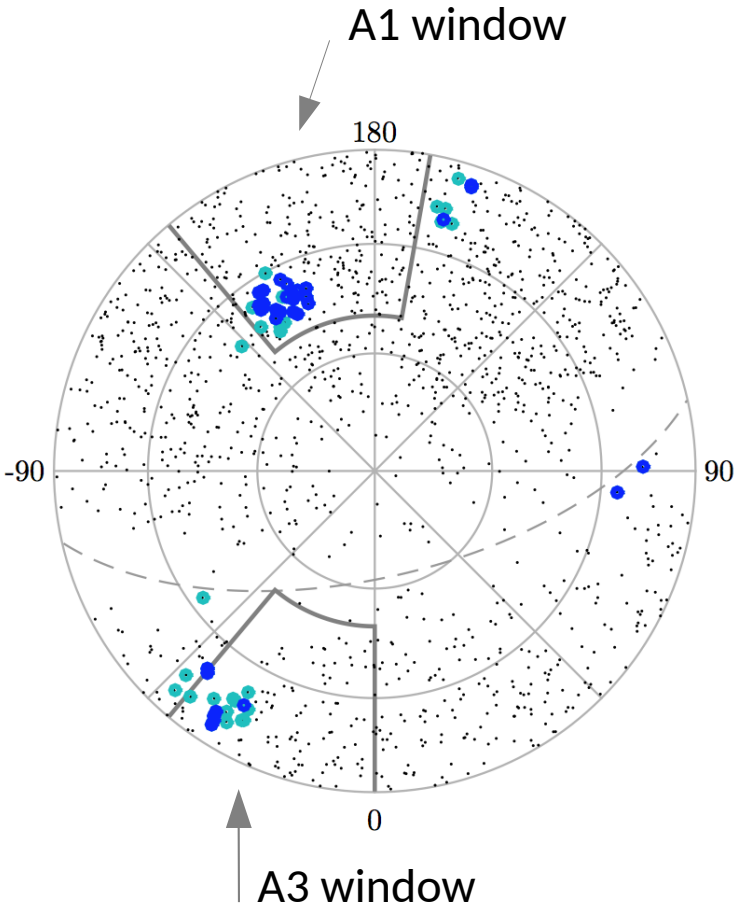
  Only for quasars!
- Identification of aligned groups

  clustered towards regions where quasar polarization vectors are aligned at optical wavelengths!



[Pelgrims & Hutsemékers 2015]

Quasars and extreme-scale correlations

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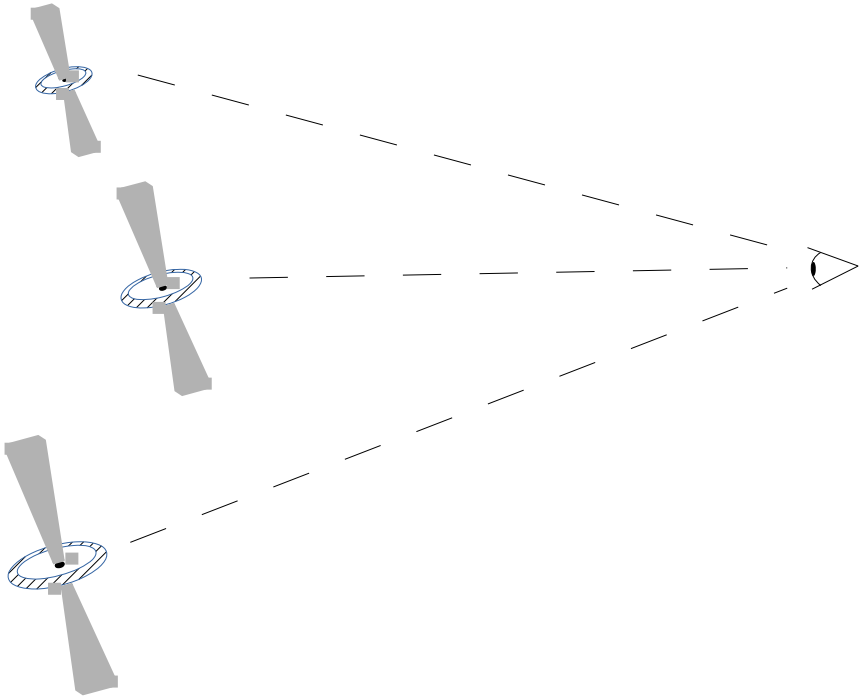

Radio wavelengths

- Photon path effects
  - Modulation of the polarization state
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- Structural axis alignment

Quasars and extreme-scale correlations

Quasar polarization alignments in JVAS/CLASS 8.4 GHz surveys

Radio wavelengths

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Optical wavelengths

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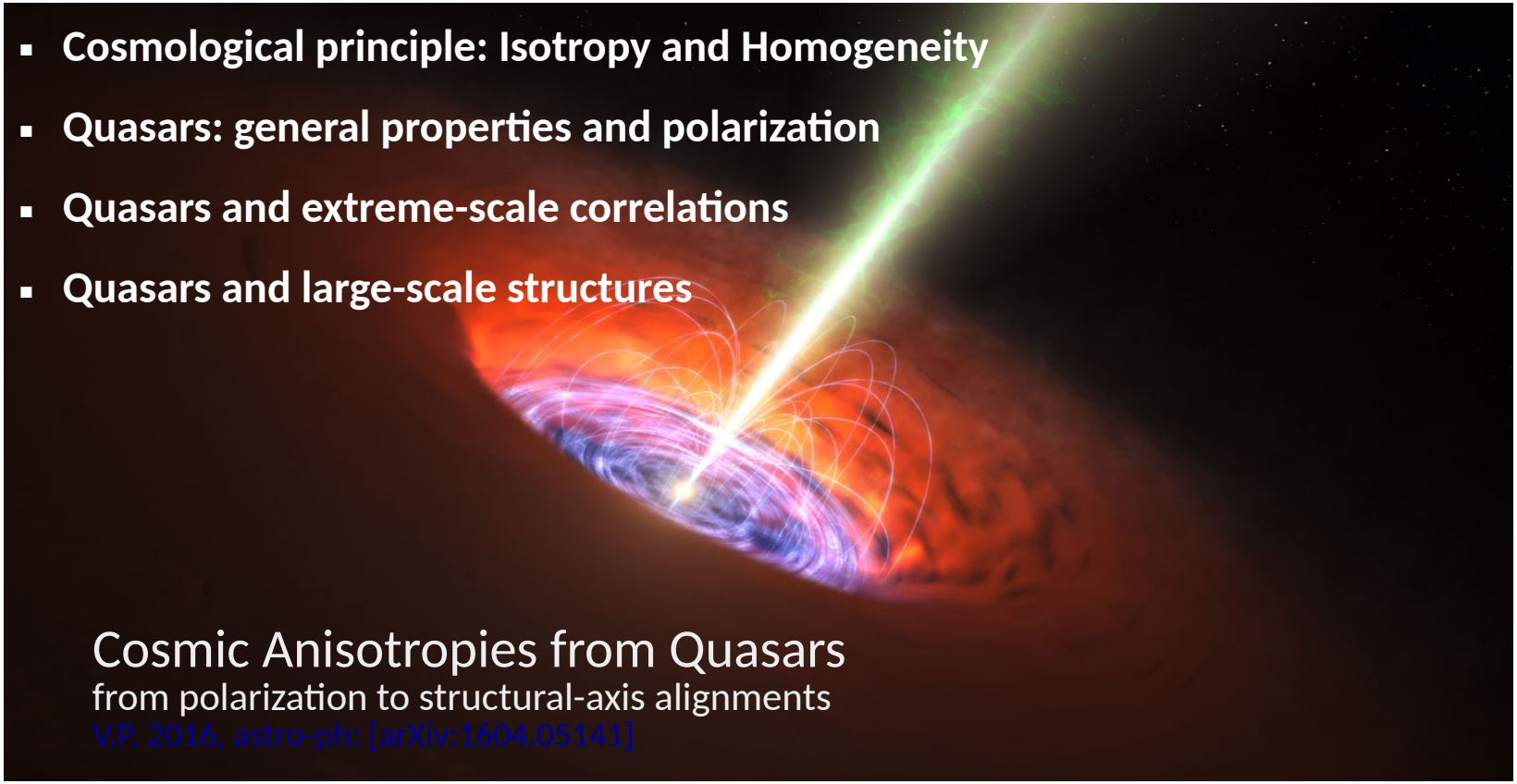
- Structural axis alignment

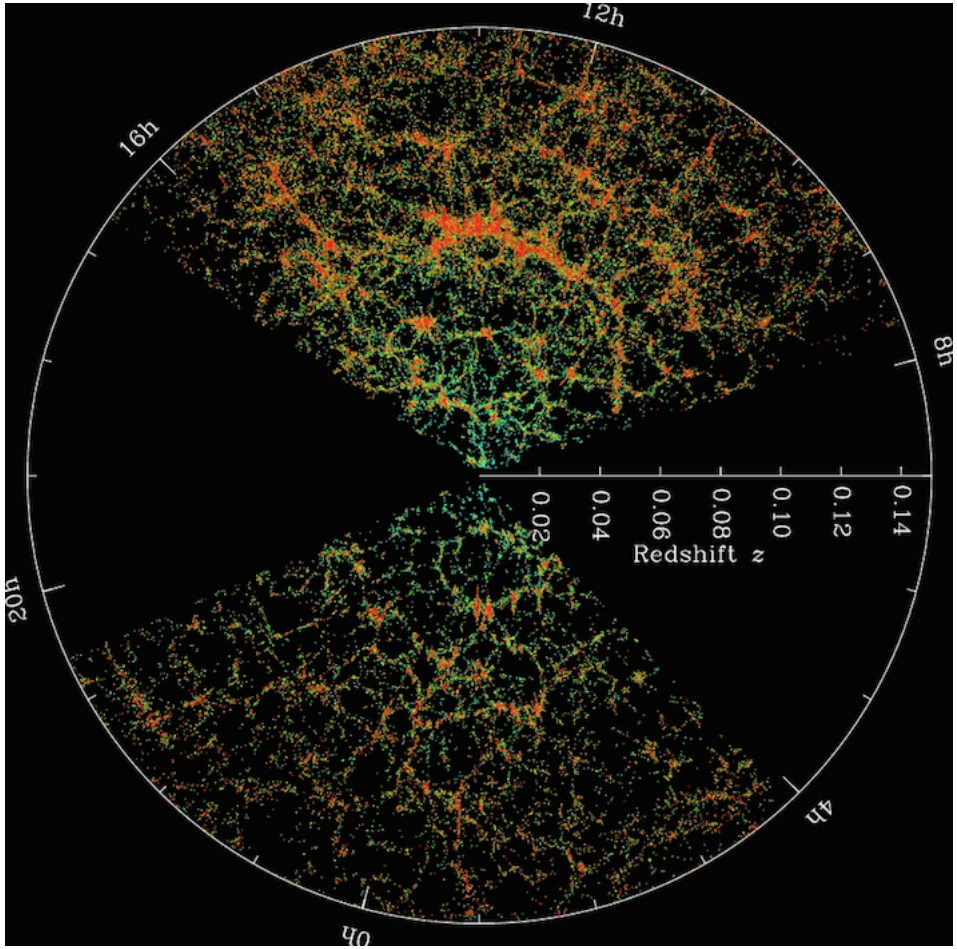
?!?

Quasars and Cosmology

Large-scale alignments of quasar polarization vectors



Quasars and large-scale structures

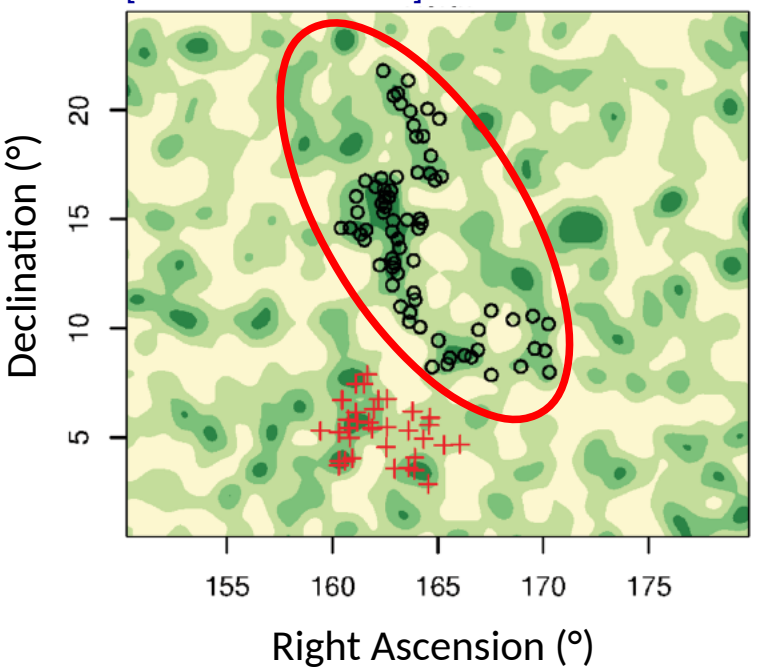


[SDSS Galaxies] a slice of our neighborhood

Quasars and large-scale structures

[Clowes et al. 2013] → discovery of a big inhomogeneity in the quasar distribution
the Huge-LQG, next to the CCLQG

[Clowes et al. 2013]



Huge-LQG

- z ~ 1.3
- 73 quasars
- elongation ~ 1 Gpc !

much bigger than the homogeneity scale of the Universe …
A problem that has finally been solved:
[see: Nadathur 2013 ; Einasto et al. 2014 ; Parkes et al. 2015 and finally [Marinello et al. 2016]

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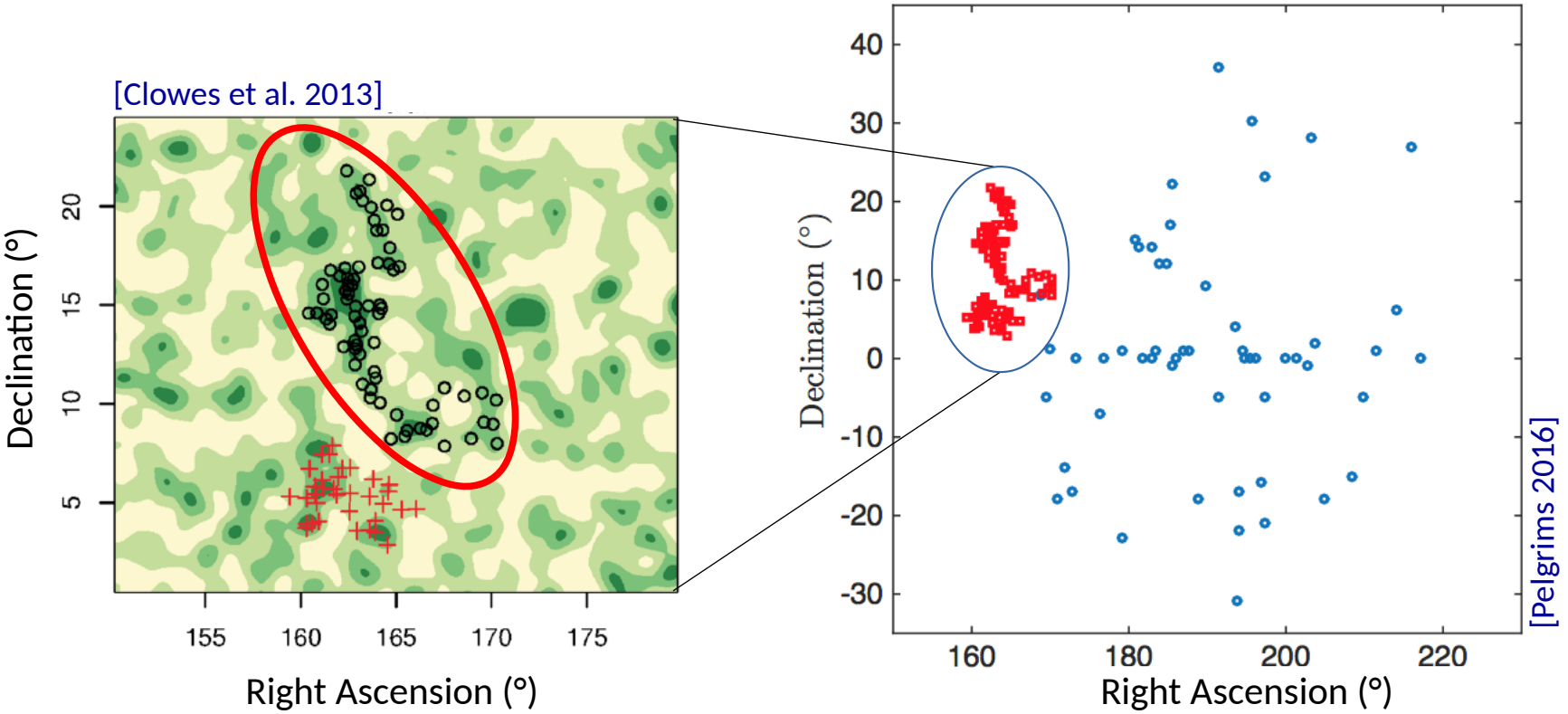


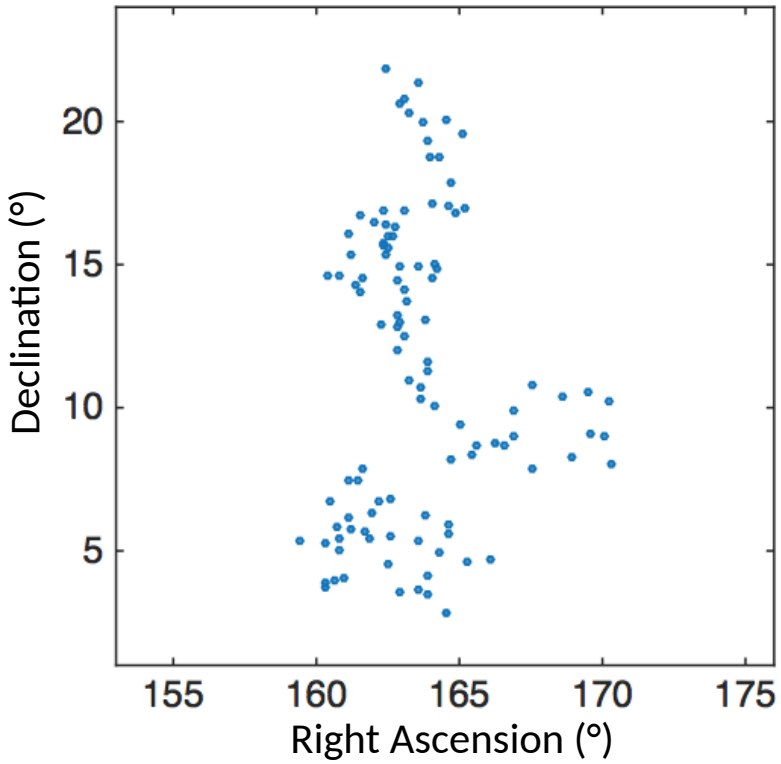
The Huge-LQG (and the CCLQG) is at the outskirt (3D) of one of
the regions of optical polarization alignments of quasars

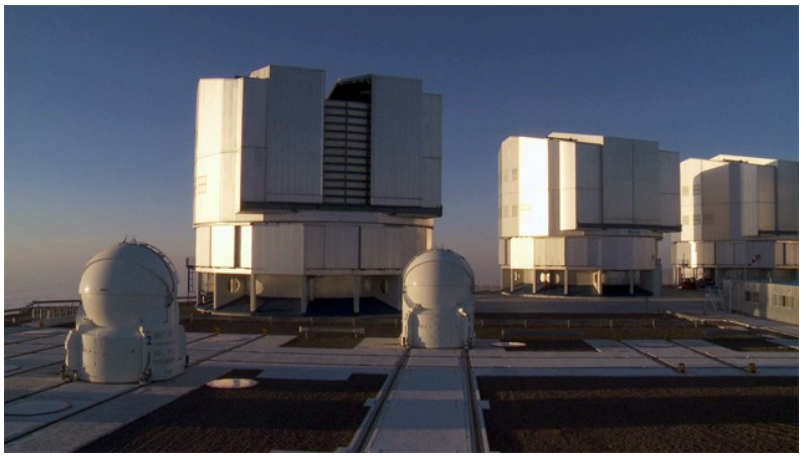
Quasars and large-scale structures

[Hutsemékers, Braibant, V.P., Sluse 2014]

- Polarization in the Huge-LQG and CCLQG

[Hutsemékers et al. 2014]



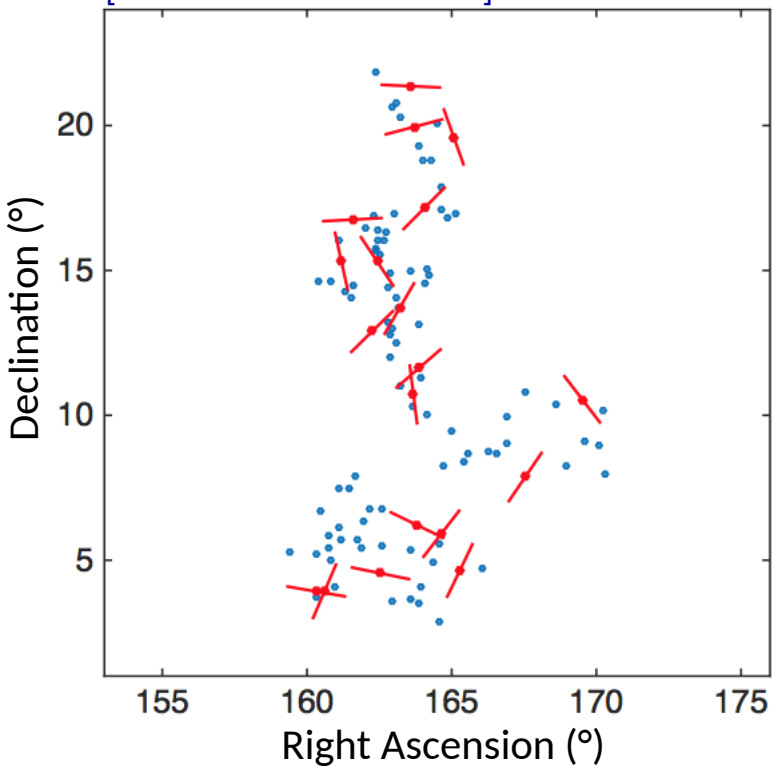


Quasars and large-scale structures

[Hutsemékers, Braibant, V.P., Sluse 2014]

- Polarization in the Huge-LQG and CCLQG

[Hutsemékers et al. 2014]



- z ~ 1.3
- 73 + 20 observed quasars
- 19 with $p_{lin} \geq 0.6\%$

Quasars and large-scale structures

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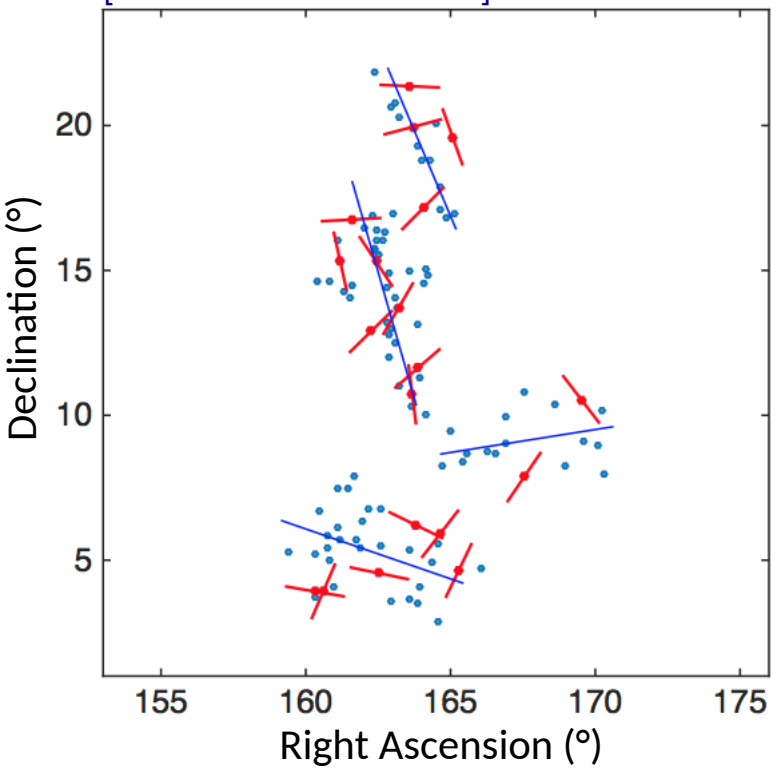
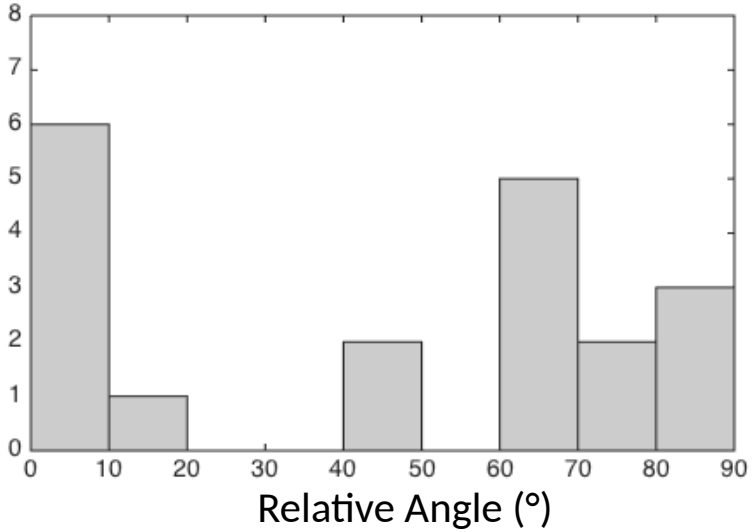




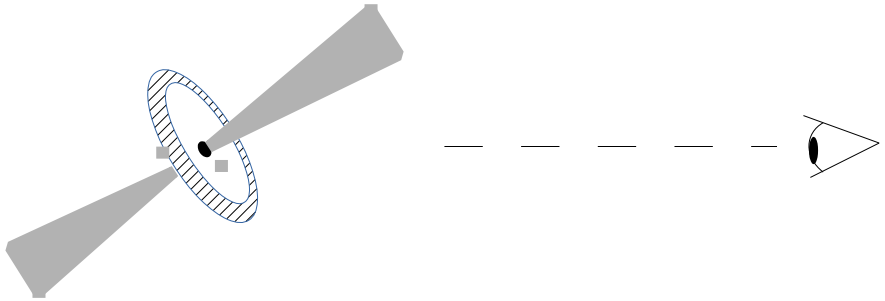
Quasar polarization vectors are either parallel or perpendicular to the large-scale structure

(probability of uniformity < 1%)

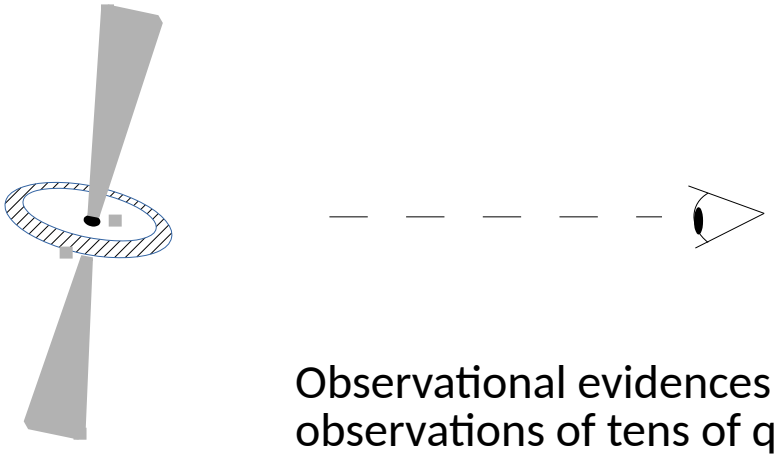
Quasars and optical polarization

Within Quasar Unification Scheme [e.g. Antonucci 1993 ; Urry & Padovani 1995]
observables depend on the inclination of the system w.r.t. the line of sight

- Optical polarization result from two competing components
  → either parallel or perpendicular to quasar morphological axis
  [e.g. Smith et al. 2004 ; Borget et al. 2008]
- Width low-ionization emission lines depends on inclination
  [e.g. Wills & Brown 1986 ; Brotherton 1996 ; Jarvis & McLure 2006]



- Polarization ∥ spin axis
- Small emission line width of MgII



- Polarization ⊥ spin axis
- Large emission line width of MgII

Observational evidences come from high resolution
observations of tens of quasars

Quasars and large-scale structures

[Hutsemékers, Braibant, V.P., Sluse 2014]

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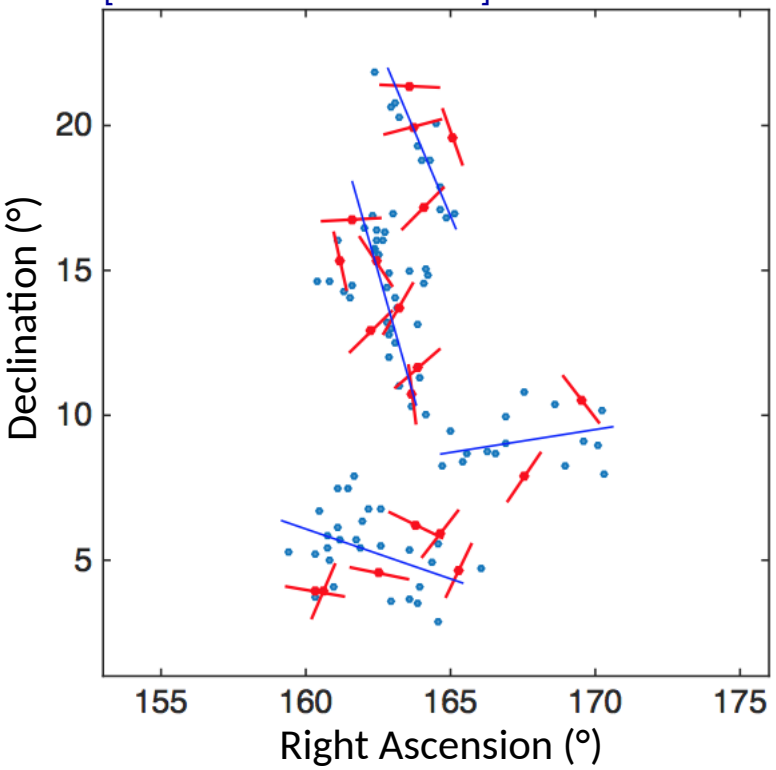

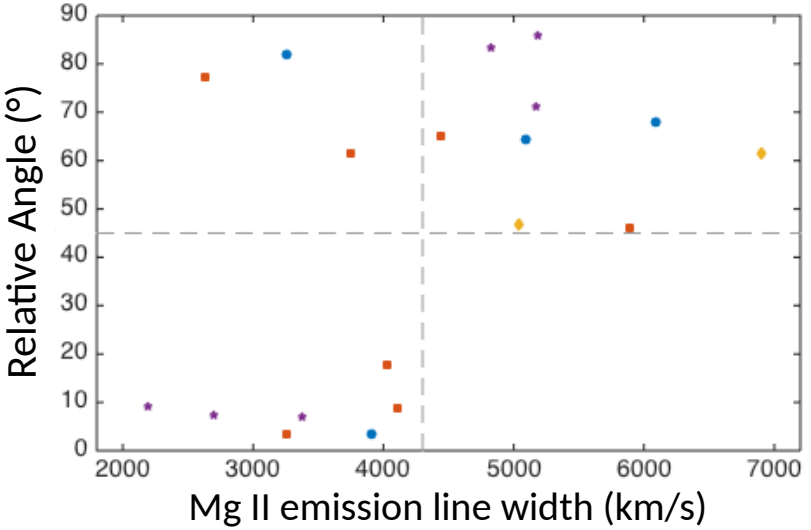

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Quasars and large-scale structures

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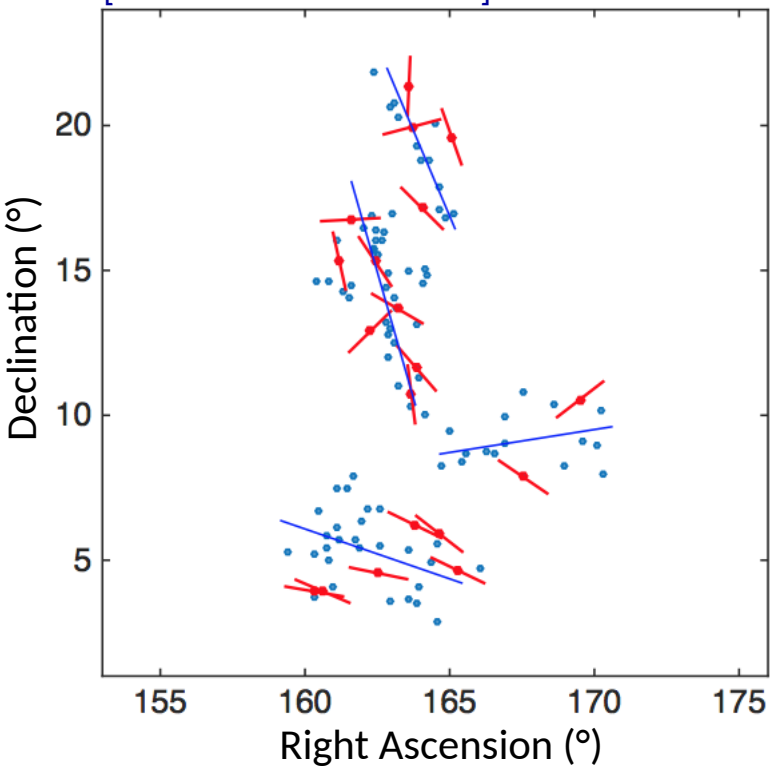

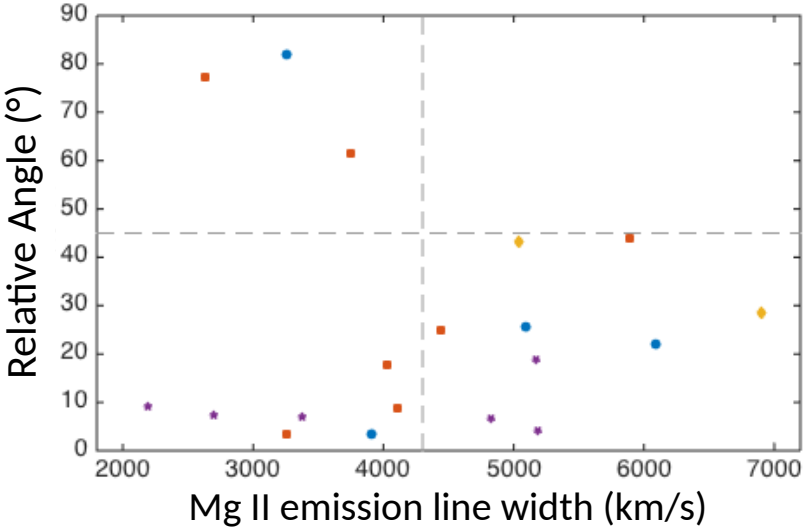

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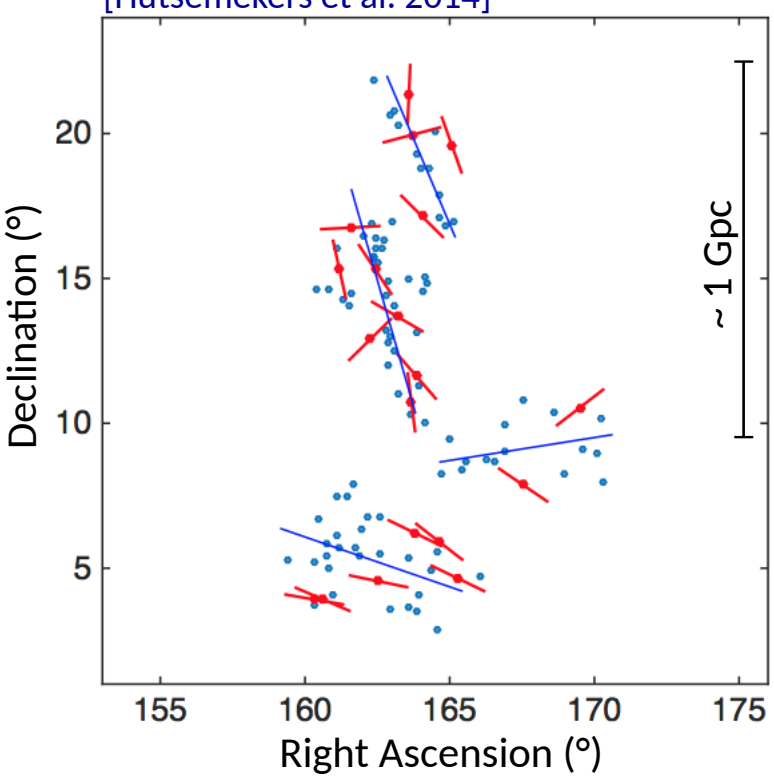
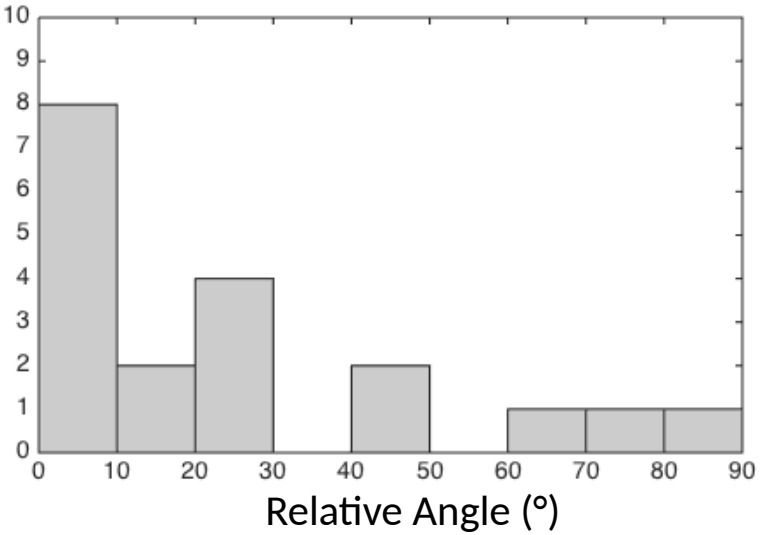


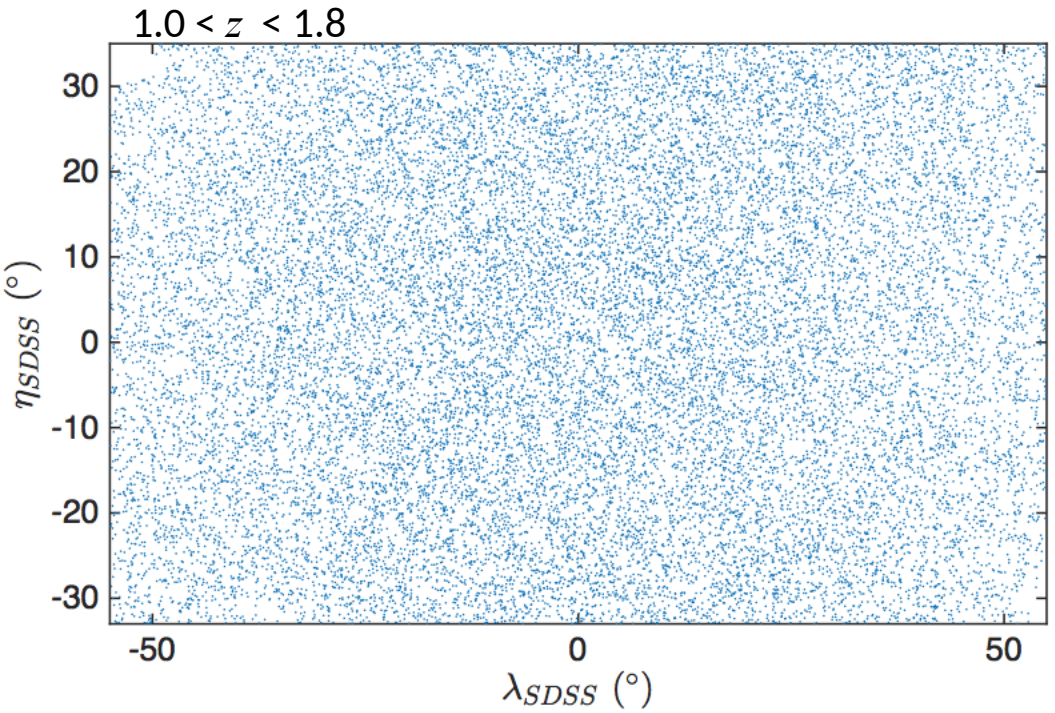


Quasar spin-axes align with
the large-scale structures at
z ~ 1.3 and over cosmological scales !

Quasars and large-scale structures

[V.P. & Hutsemékers 2016]

- Radio polarization in a large LQG sample



- SDSS DR7 : 22.381 quasars with 1.0 < z < 1.8 ; i_{mag}< 19.1
- Large sample of large quasar groups by [Einasto et al. 2014]

Quasars and large-scale structures

[V.P. & Hutsemékers 2016]

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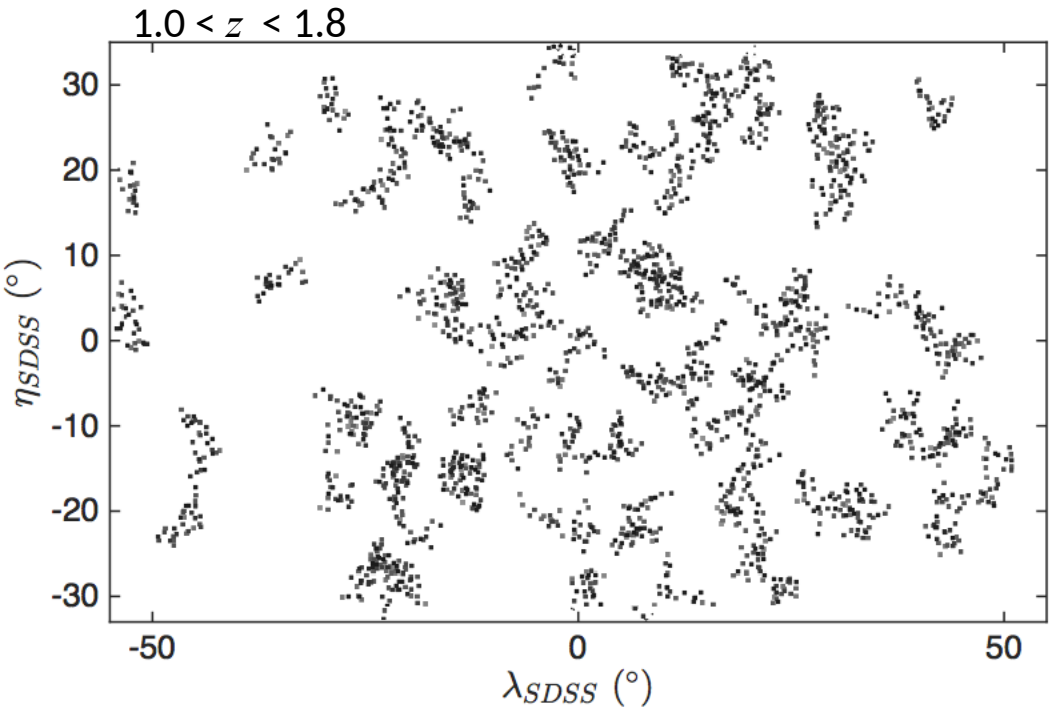

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Quasars and large-scale structures

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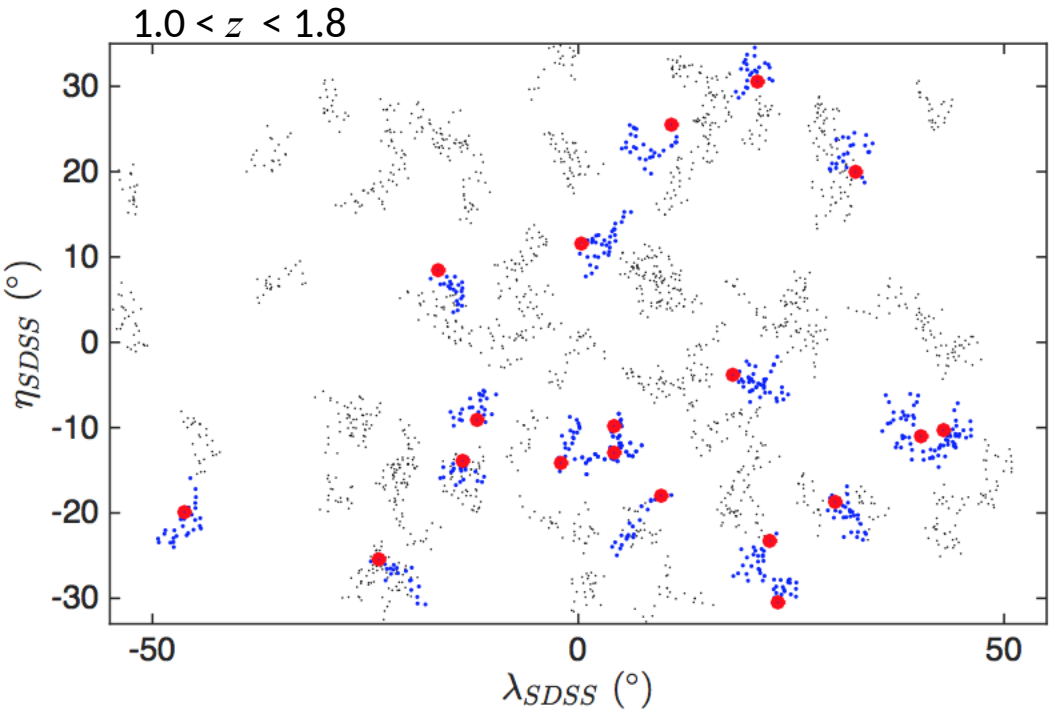

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- 19 quasars with pol. in LQG having > 20 members

Quasars and large-scale structures

[V.P. & Hutsemékers 2016]

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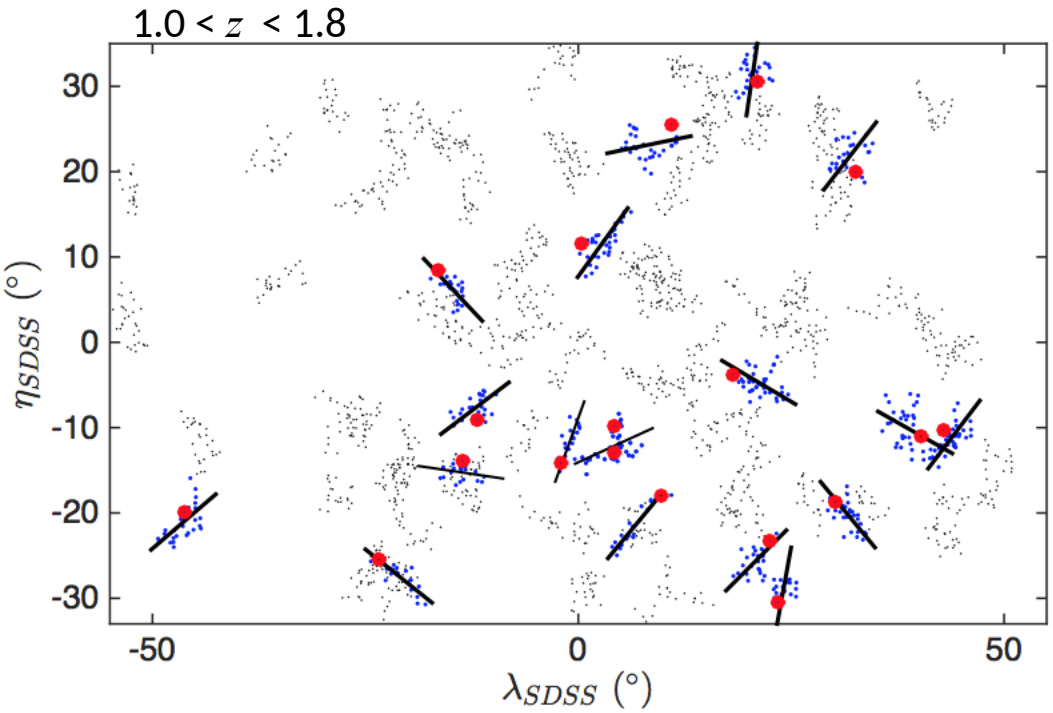

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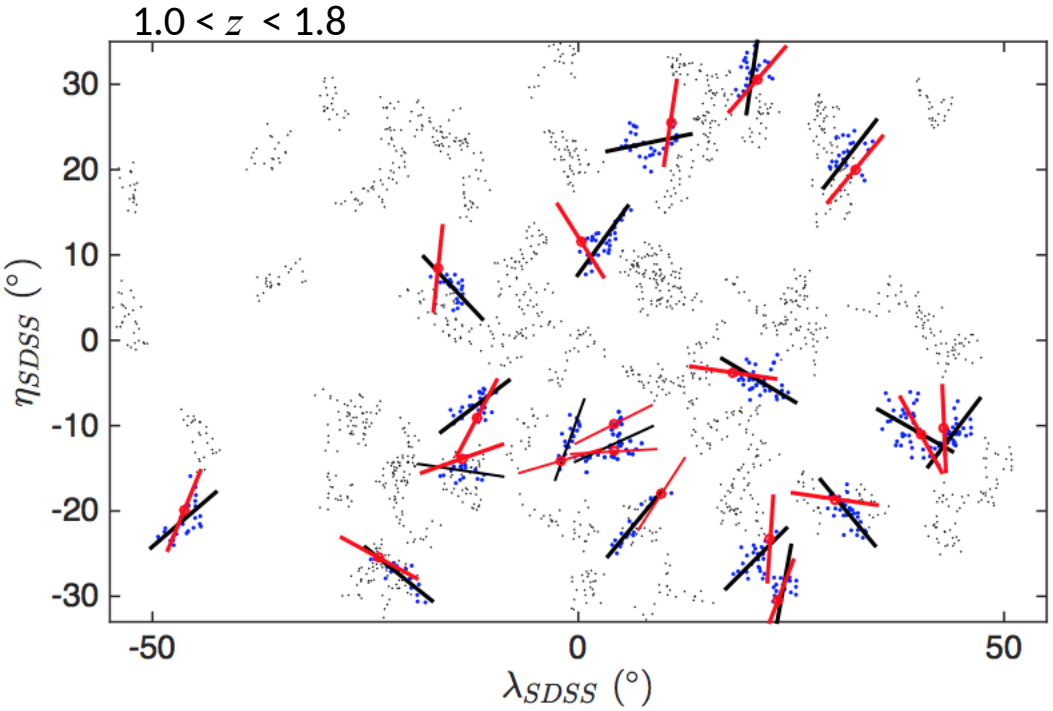
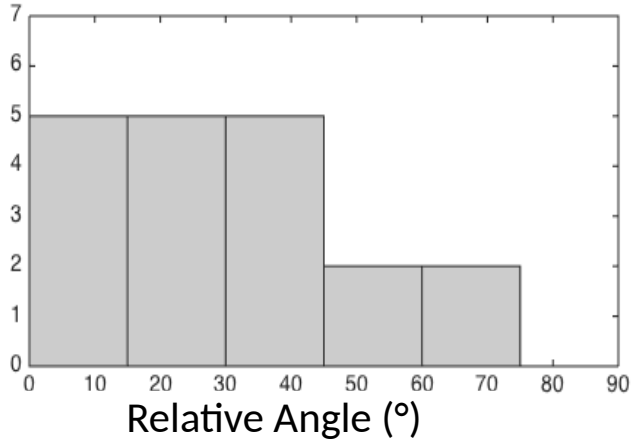
- 19 quasars with pol. in LQG having > 20 members
- LQG orientations from inertia tensors

Quasars and large-scale structures

[V.P. & Hutsemékers 2016]

- Radio polarization in a large LQG sample
- Polarization (synchrotron) is preferentially $\perp$ to quasar spin axis [Joshi et al. 2007]





Quasar spin-axes preferentially parallel to the major axes of rich large quasar groups at *high redshifts* and *over large scales* !

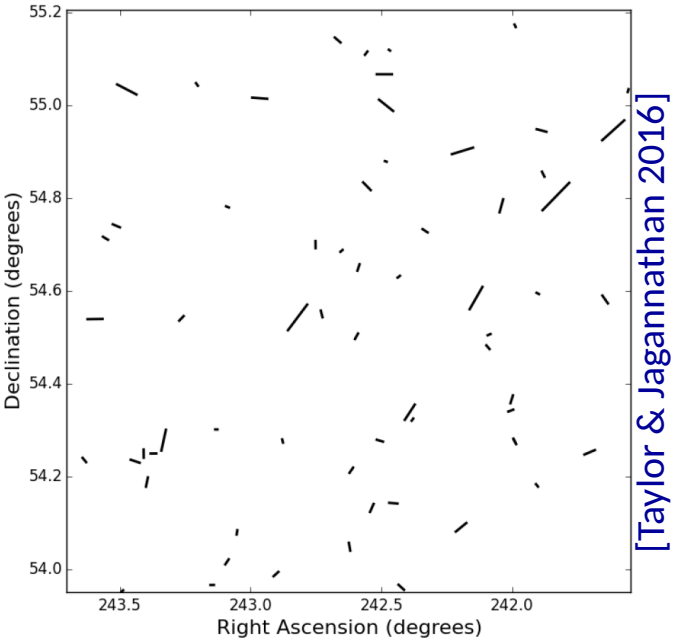
Quasars and large-scale structures

[Hutsemékers, Braibant, V.P., Sluse 2014 ; V.P. & Hutsemékers 2016]

- Made use of optical and radio polarization of quasars to infer their spin axes at *high redshift*
- Show quasar spin-axes correlate to the major axes of their host LQG

Corroborated by

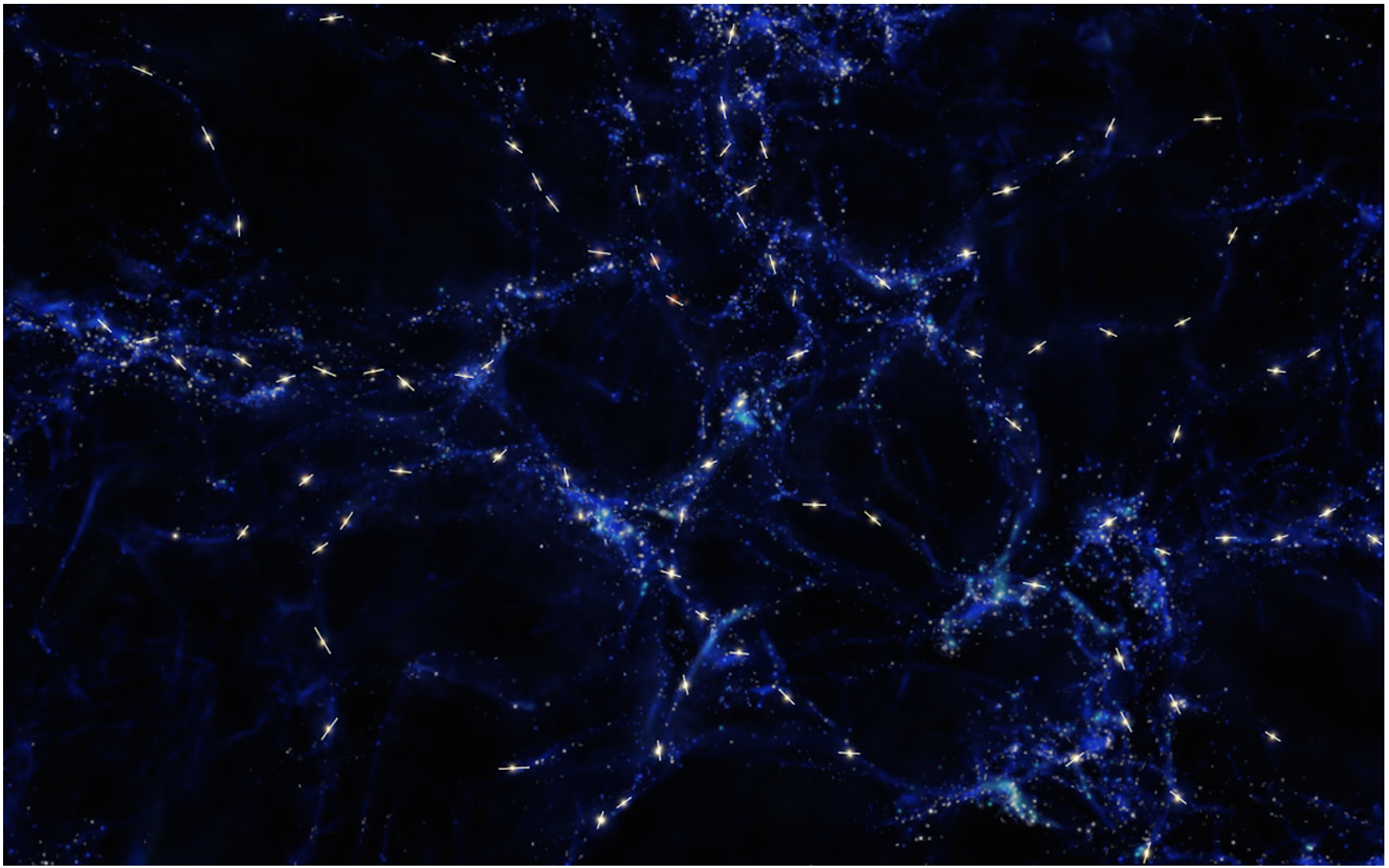
- degree scale radio-jet axis correlations
  - [Taylor & Jagannathan 2016]
    → alignments in 1.4 deg^2 ELAIS N1 field
  - [Contigiani et al. 2017]
    → alignments at scale 1.5–2.5 deg in 7000 deg^2 FIRST+RadioGalaxyZoo sample (30 059 sources)
- degree scale radio-polarization correlations
  - [V.P. & Hutsemékers 2015]
    → alignments < 5 deg found in JVAS/CLASS 8.4GHz



[Taylor & Jagannathan 2016]

Explained through coevolution of galaxy spin axes within the cosmic web ?

Involved scale seem too large …



[Artist view of the “spooky” alignment Credit: ESO/M. Kornmesser]

Take away

Quasar polarization alignments

There are evidences for extreme-scale alignments of the polarization of quasars when measured at optical and at radio wavelengths

- Origin is still to be found
- Could indicate departure from isotropy of the Universe given the characteristic size of the correlation
- Difference between optical and radio signatures needs to be clarified

The large-scale correlation of quasar spin axes with and within large quasar groups

- Could be due to coevolution of black hole spins in LSS
- Typical size involved are way larger than expected

If true…

the two types of alignments could find the same origin assuming extreme anisotropies in matter distribution

Thank you

BACKUP