FROM MICROSTRUCTURE TO MACROSCALE: NEUROIMAGING AND CONNECTOMICS IN HEALTHY AND DISEASED BRAINS

BORIS BERNHARDT, PHD

MCCONNELL BRAIN IMAGING CENTER

MONTREAL NEUROLOGICAL INSTITUTE

NEUROIMAGING AS A TRANSFORMATIVE TOOL

WIDELY AVAILABLE

NON-INVASIVE

QUANTITATIVE

WHOLE BRAIN

VERSATILE

VERSATILITY AND MULTI-SCALE

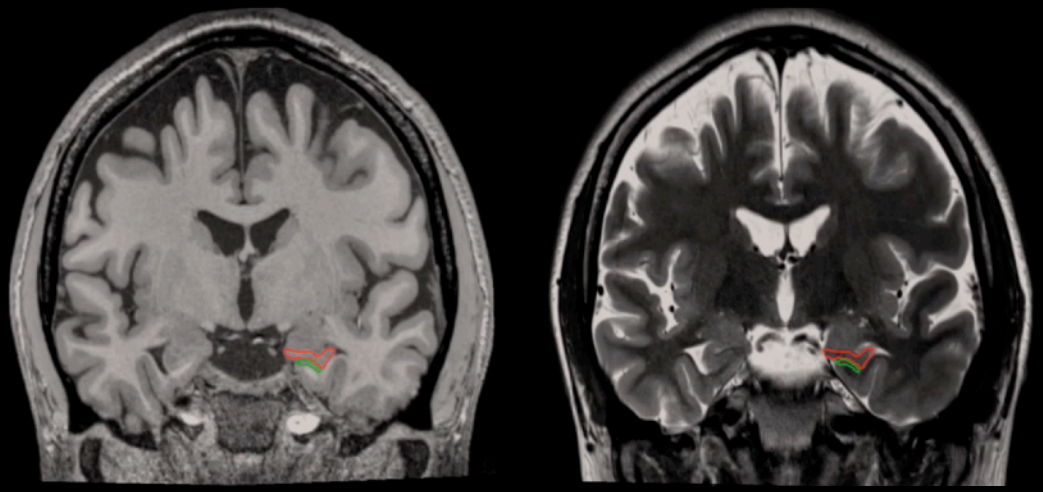
MULTIPLE TISSUE PROPERTIES

ROI AND WHOLE BRAIN ANALYSIS

STRUCTURAL AND FUNCTIONAL CONNECTIVITY

MACROSCALE NETWORK MODELS

Courtesy of Alfred Anwander



Courtesy of Jessie Kulaga-Yoskovitz

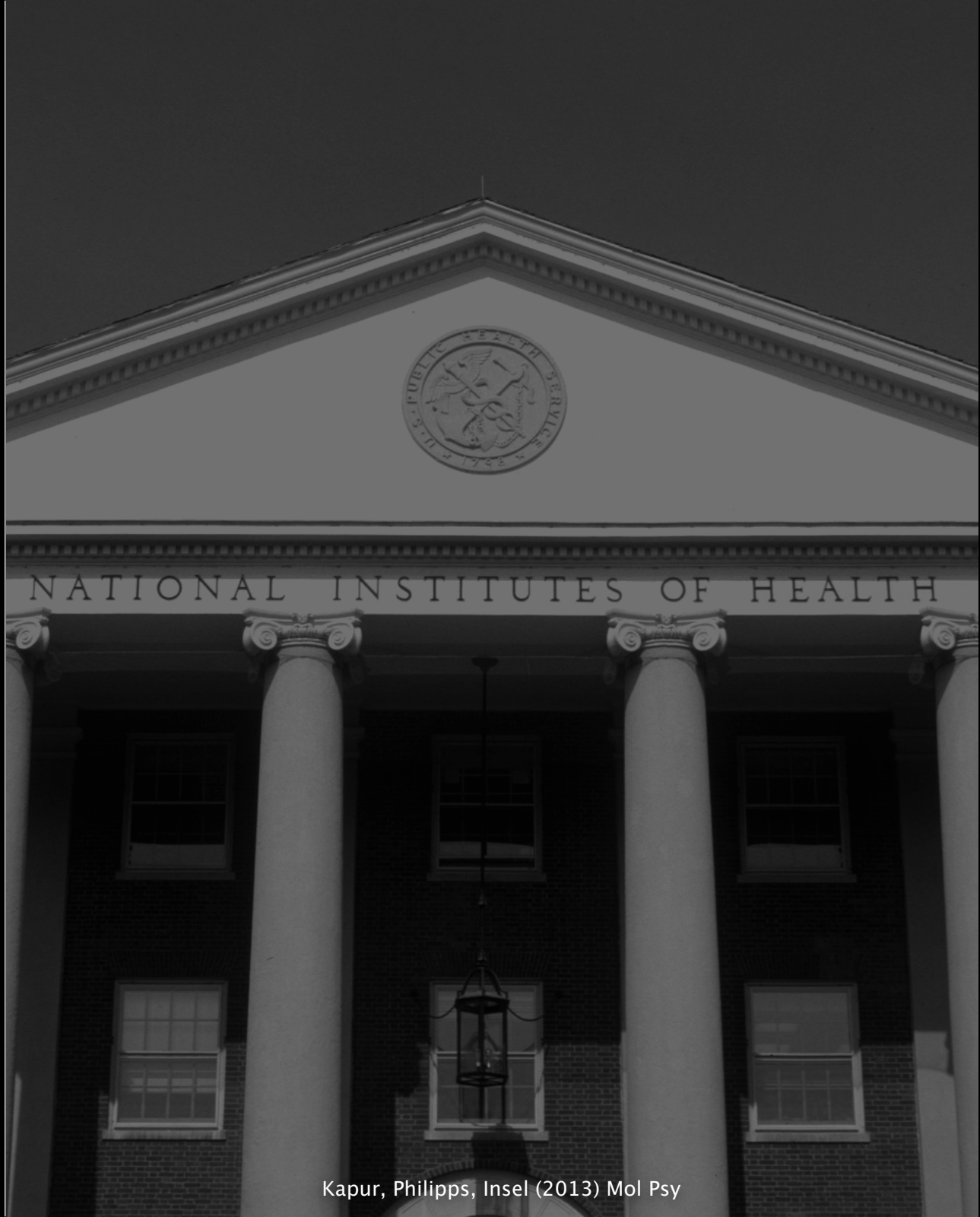
BETTER CHARACTERIZATION OF HEALTH AND DISEASE

STRUCTURE FUNCTION LINKS

MULIT-SCALE BRAIN ORGANIZATION

MULTIPLE DISEASE DIMENSIONS

CHALLENGE ESTABLISHED CATEGORIES



Kapur, Philipps, Insel (2013) Mol Psy

OUTLINE

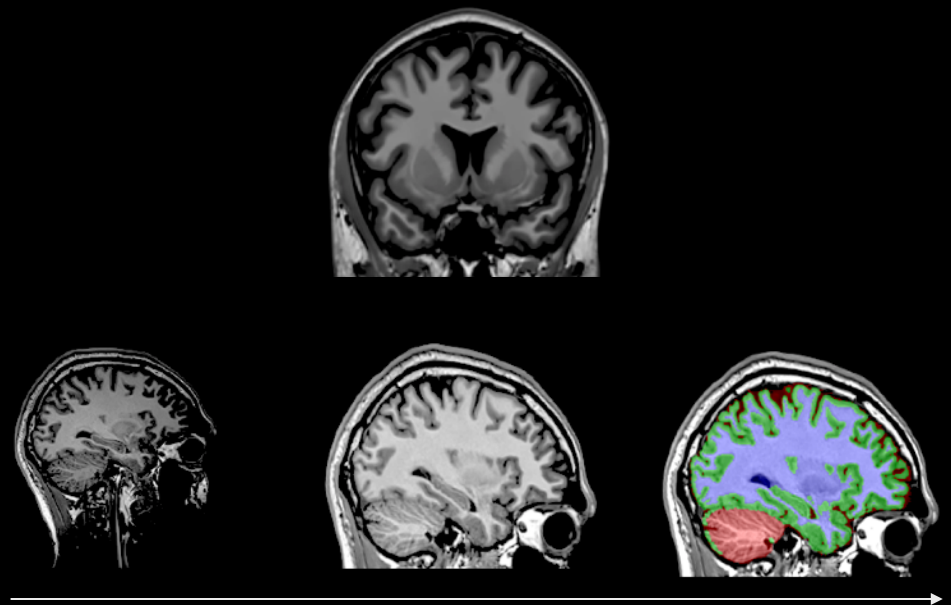
MULTIMODAL AND MULTISCALE MRI:
FROM CORTICAL MICROSTRUCTURE TO LARGE-SCALE NETWORKS

THE INTERPLAY BETWEEN HIPPOCAMPAL
ANATOMY, MICROSTRUCTURE, AND CONNECTOMICS
IN HEALTHY BRAIN

INTEGRATING HIGH-DEF MRI WITH LARGE-SCALE NETWORK
MODELS IN TEMPORAL LOBE EPILEPSY

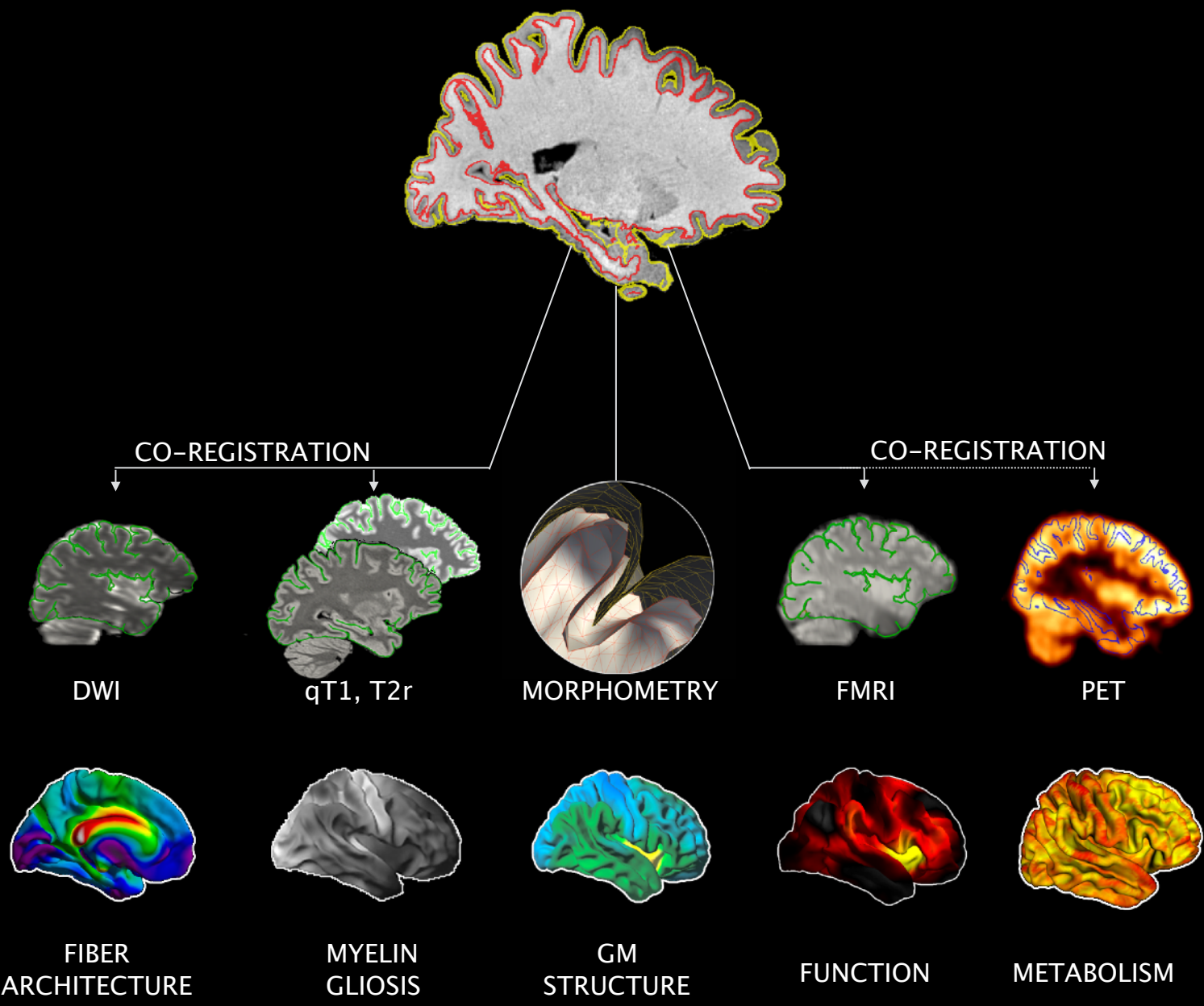
STUDY OF NEURODEVELOPMENT AND
DEVELOPMENTAL DISORDERS

MODELLING LOCAL STRUCTURE



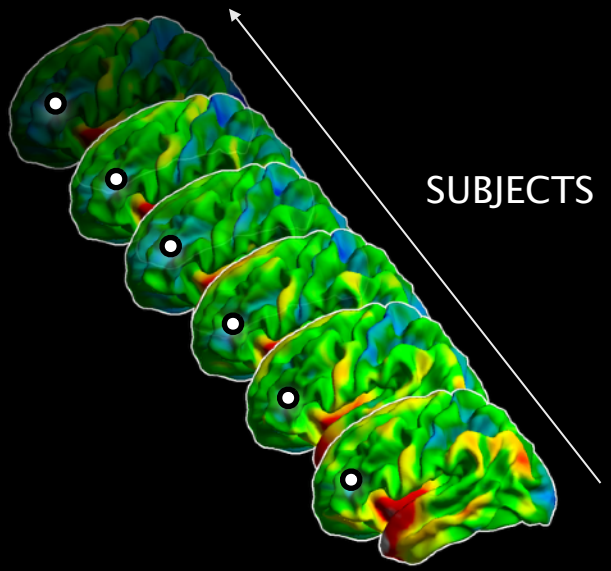
MacDonald et al. (1999) NIMG, Fischl and Dale (2000) Hum Brain Mapp, Kim et al. (2005) NIMG

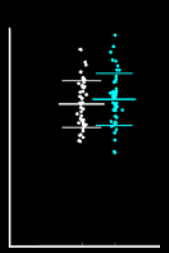
INTEGRATION OF MULTIPLE LOCAL MARKERS



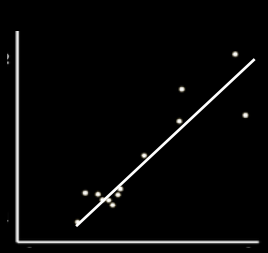
LOCO-REGIONAL STATISTICS

CROSS-SECTIONAL ANALYSES

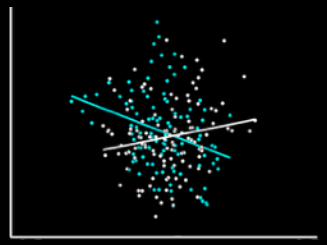




Y=1+G

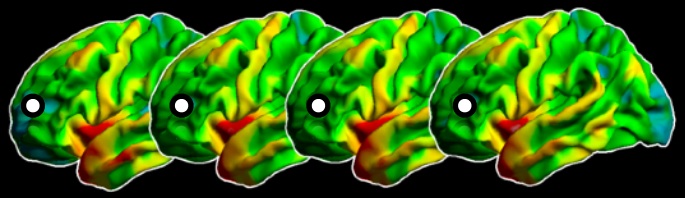


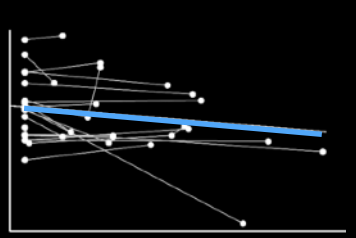
Y=1+A



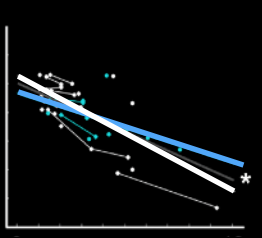
Y=1+G+A+G×A

LONGITUDINAL ASSESSMENTS





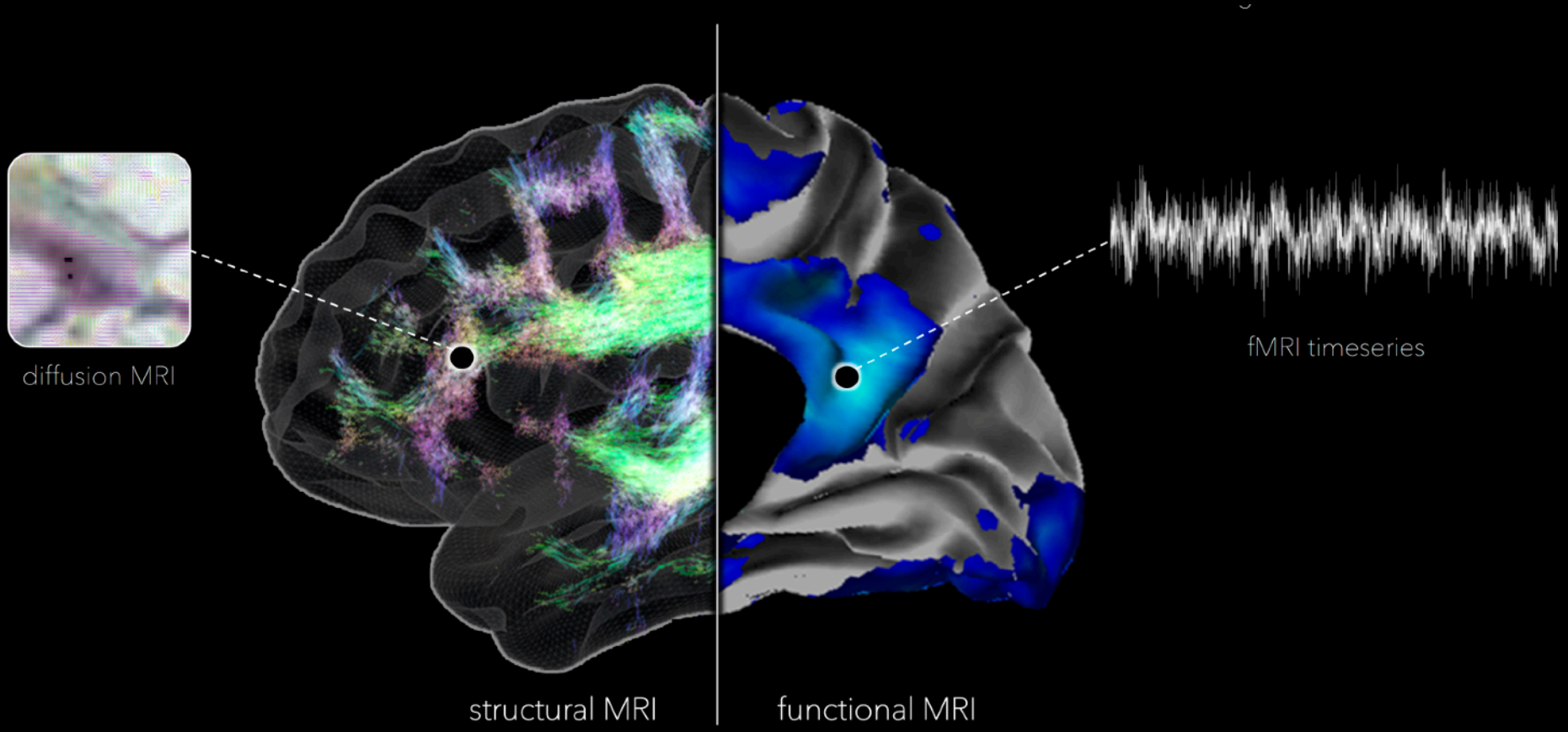
Y=1+r(S)+ISI



Y=1+r(S)+ISI+G+ISI×G

Y is univariate or multivariate data

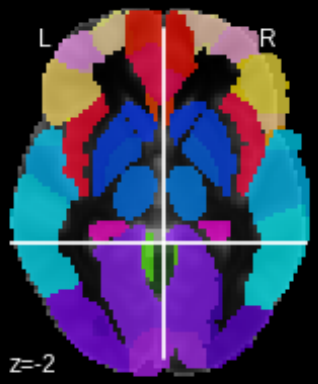
INTER-REGIONAL CONNECTIVITY



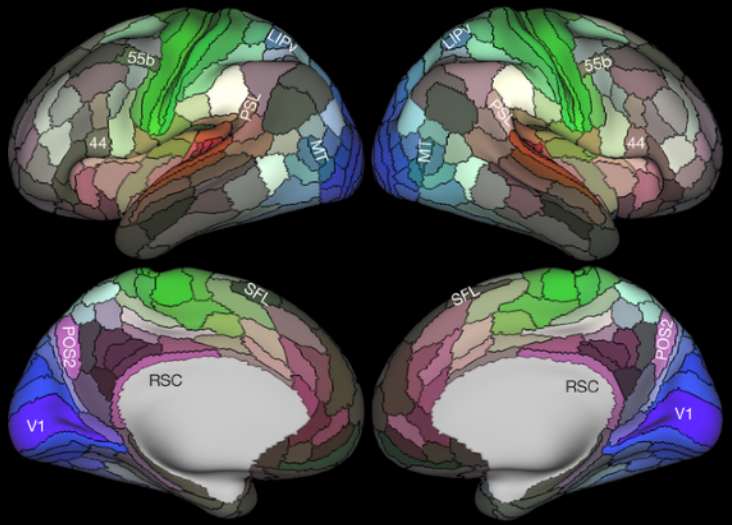
Mori et al. (1999) Ann Neu
Behrens et al. (2007) NIMG

Biswal (1995) MRM
Friston (1994) HBM
Smith (2012) NIMG

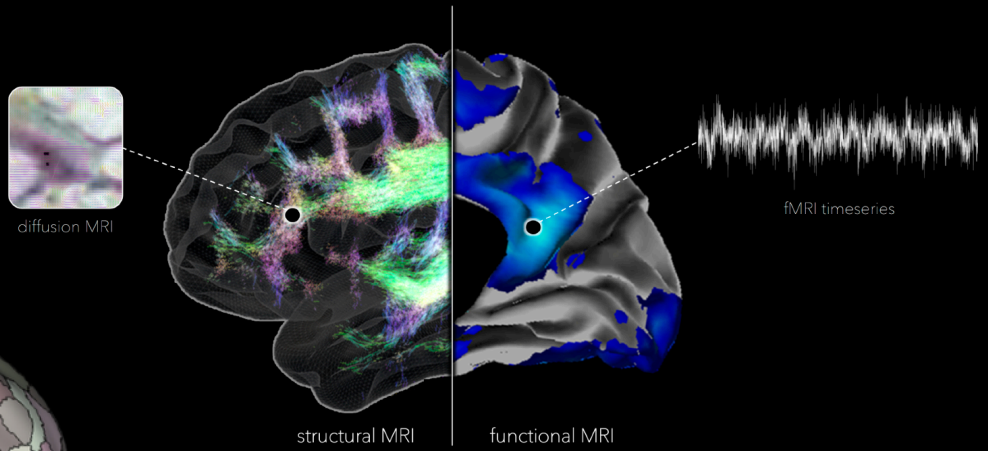
CONNECTOME ANALYSIS

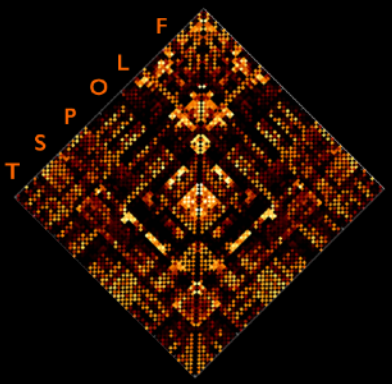


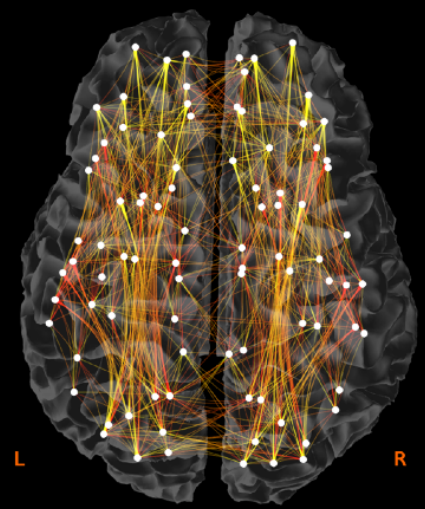
Tzuorio-Mazoyer (2002)
Neuroimage



Glasser (2016) Nature

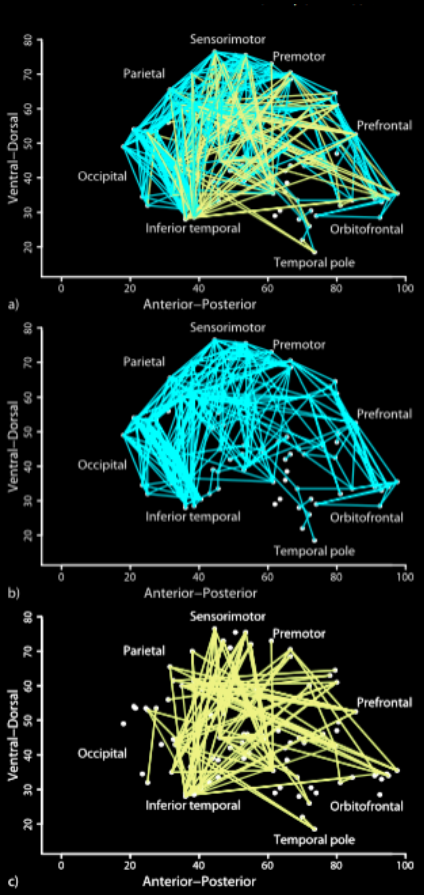






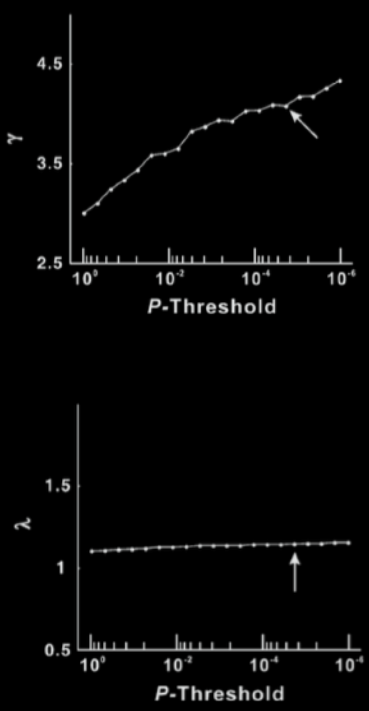
Bullmore and Sporns (2009) NRN

MACROSCALE: SMALL WORLD TOPOLOGY



$\theta = \gamma/\lambda > 1$

Archard et al (2006) JNeurosci



$\theta = \gamma/\lambda > 1$

Gong et al (2008) JNeurosci

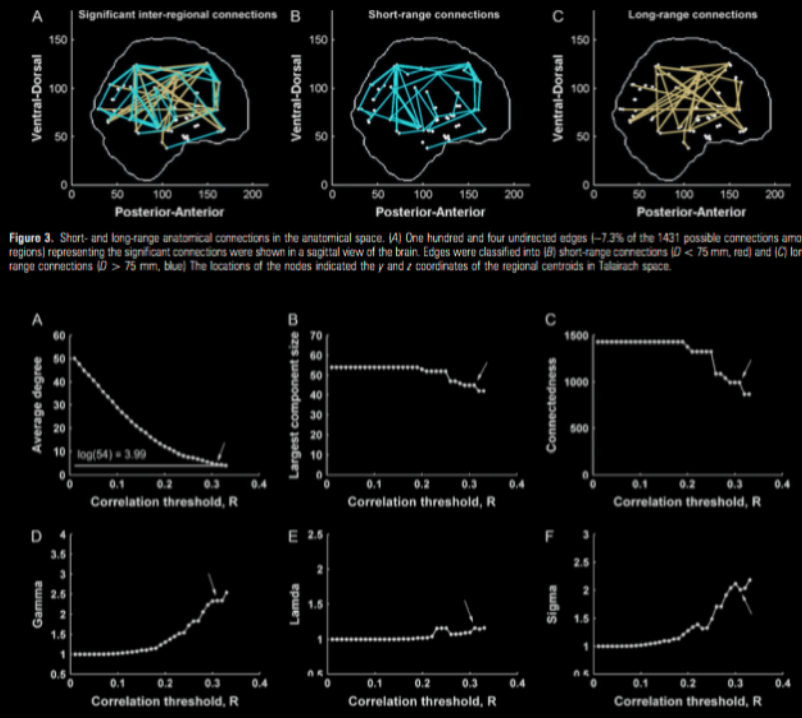
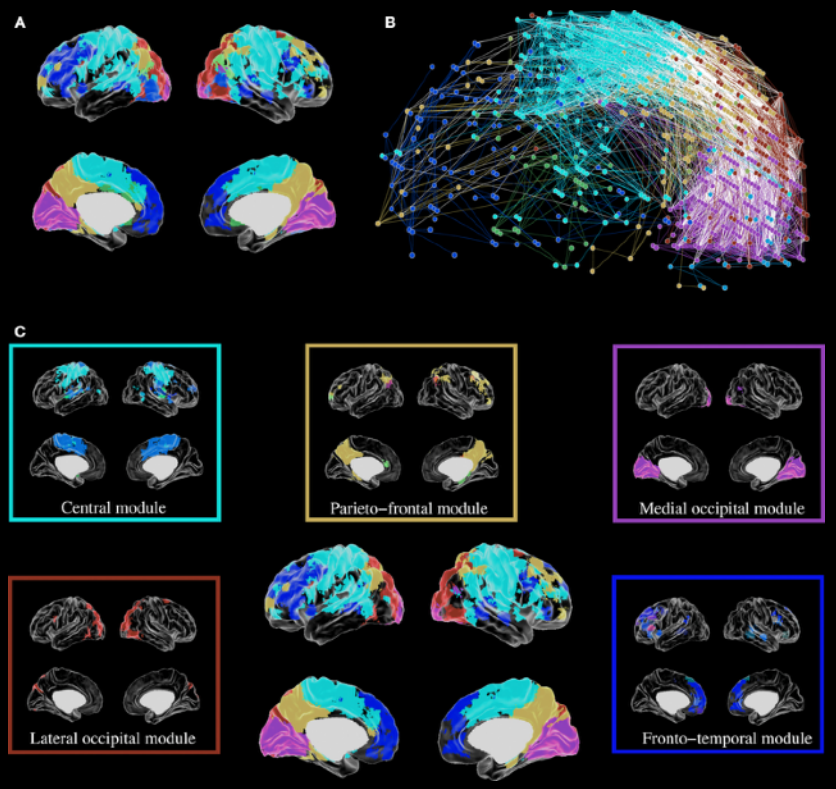


Figure 3. Short- and long-range anatomical connections in the anatomical space. (*A*) One hundred and four undirected edges (~7.3% of the 1431 possible connections among regions) representing the significant connections were shown in a sagittal view of the brain. Edges were classified into (*B*) short-range connections ($D < 75$ mm, red) and (*C*) long-range connections ($D > 75$ mm, blue) The locations of the nodes indicated the *y* and *z* coordinates of the regional centroids in Talairach space.

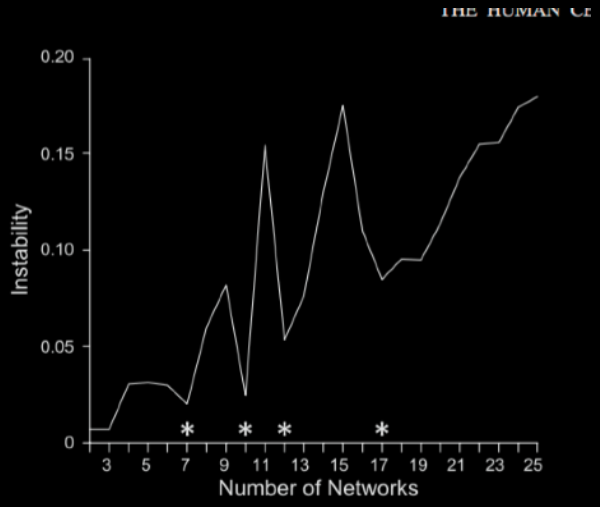
$\theta = \gamma/\lambda > 1$

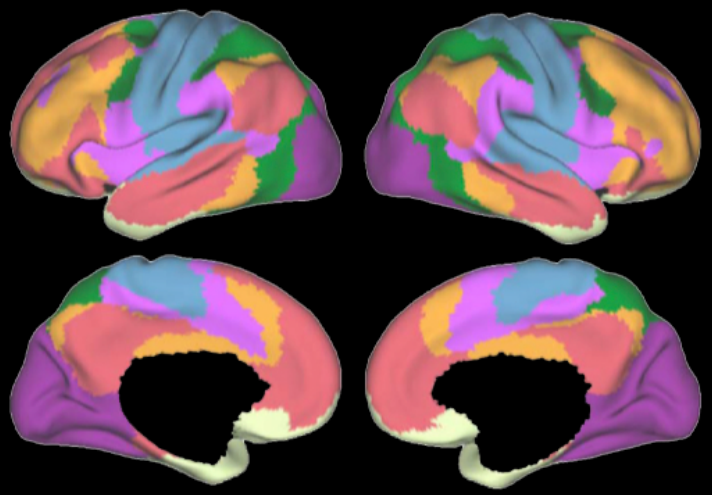
He et al (2008) Cerebral Cortex

MACROSCALE: MODULARITY



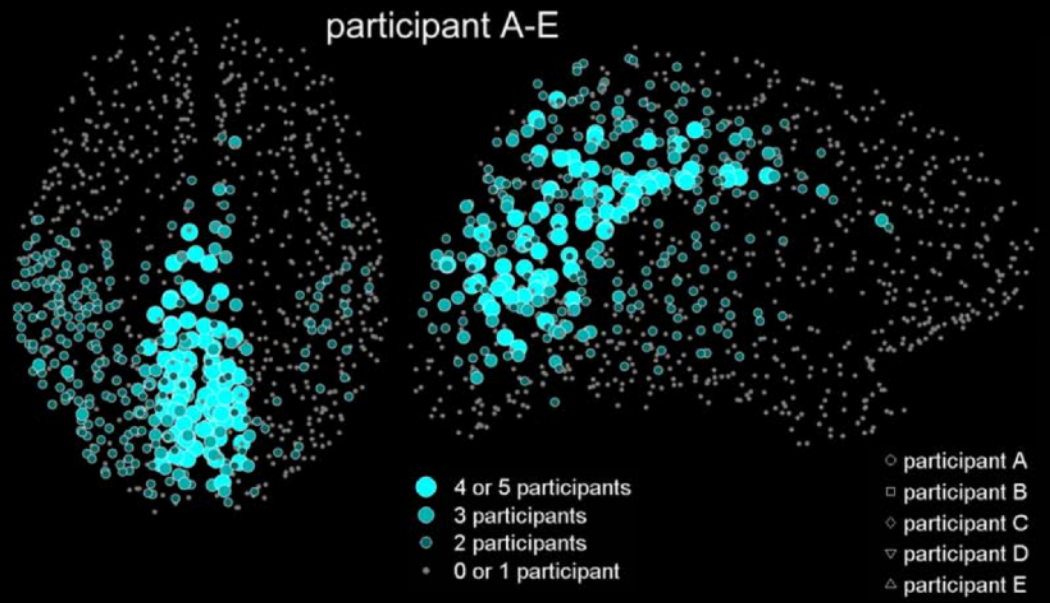
Meunier et al (2009) Front Neuroinf



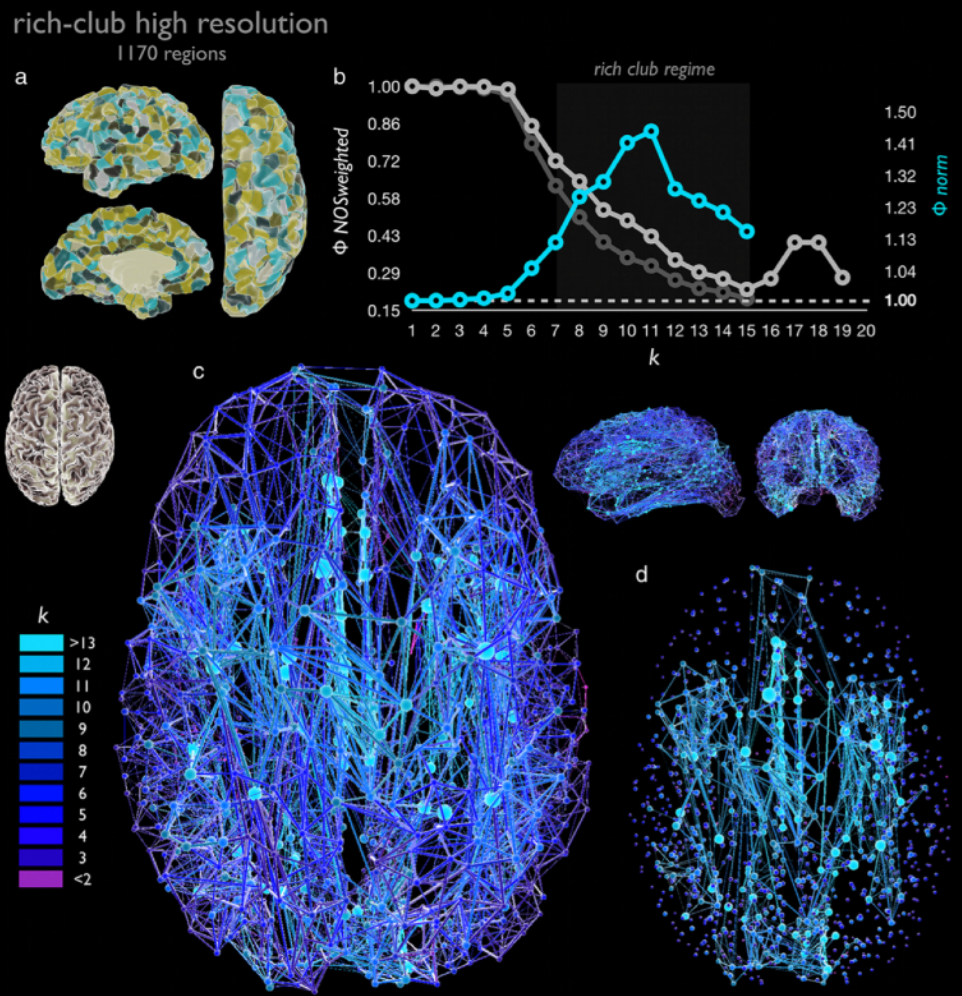


Yeo et al (2011) JNeurophysiol

MACROSCALE: CORE-PERIPHERY

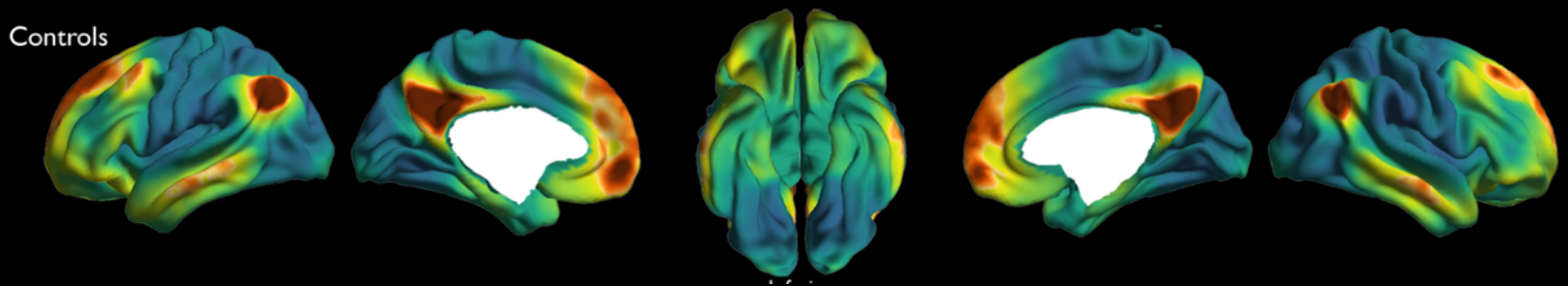


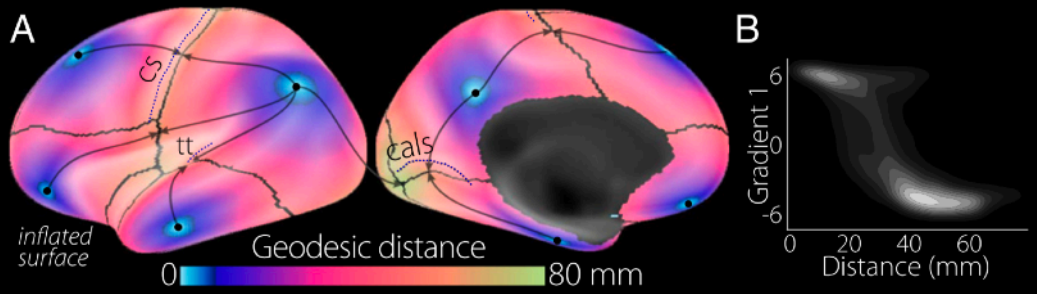
Hagman et al (2008) PloS Biol

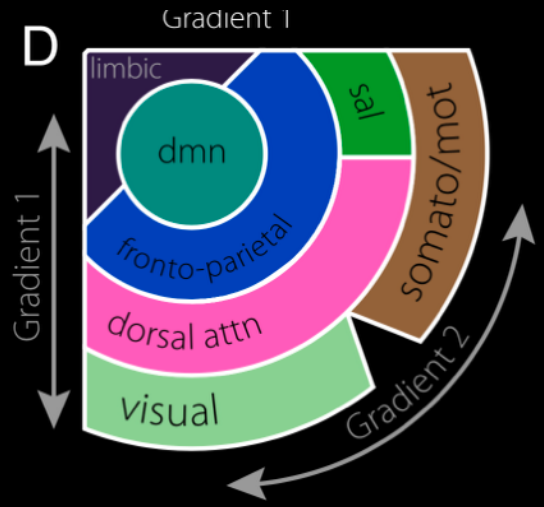


Van den Heuvel and Sporns (2011) JN

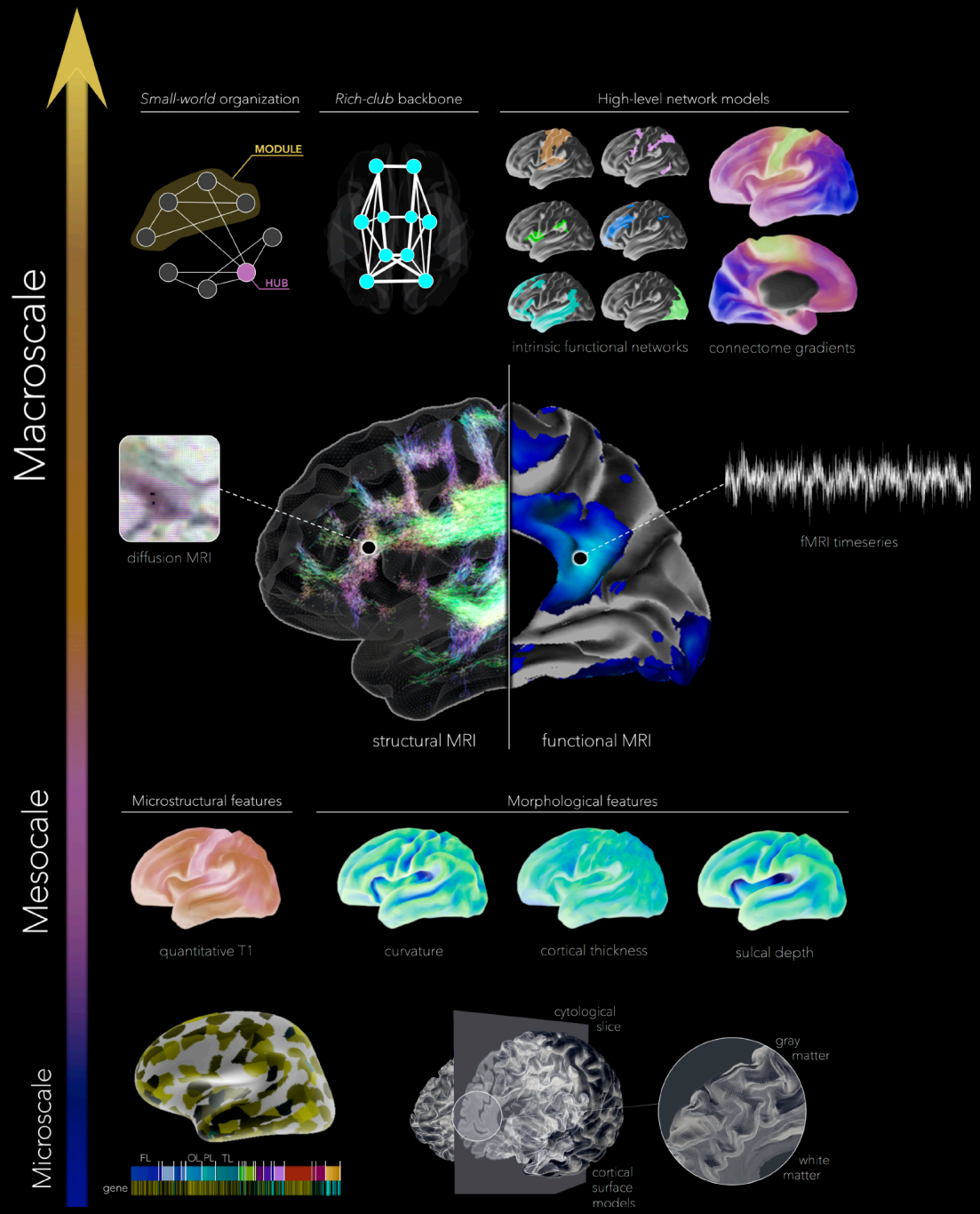
MACROSCALE: CONNECTOME GRADIENTS







Margulies 2016 PNAS



Lariviere et al (submitted), Betzel & Basset (2017) NIMG, Van den Heuvel & Yeo (2015) Neuron

MULTI-SCALE STUDIES OF THE
MESIOTEMPROAL LOBE
AND TEMPORAL LOBE EPILEPSY

METHODOLOGY
&
ANALYTICS

STRUCTURE-FUNCTION
ANALYSIS OF TYPICAL AND ATYPICAL
BRAIN DEVELOPMENT

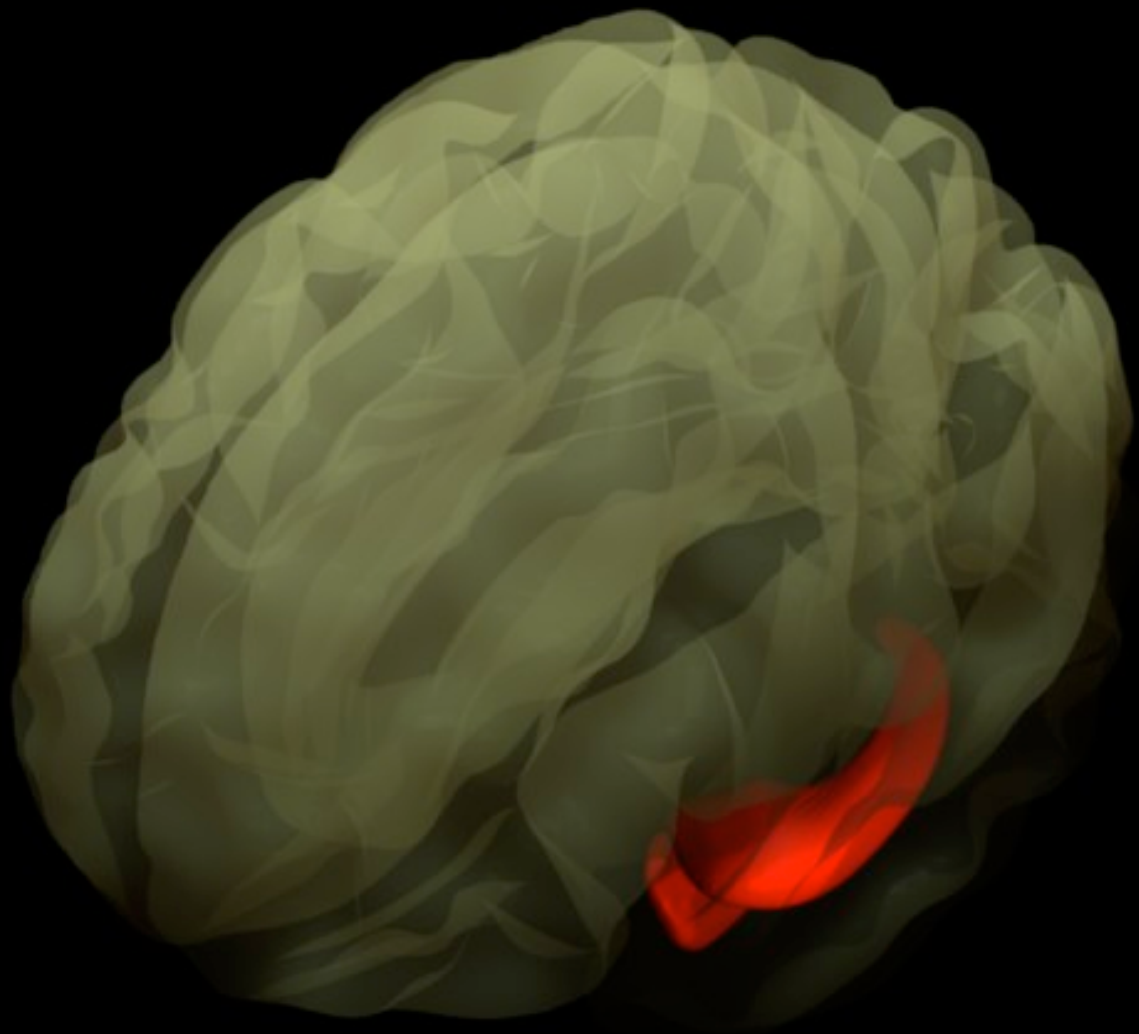
http://mica-mni.github.io

THE HIPPOCAMPUS

KEY ROLE IN NUMEROUS
COGNITIVE PROCESSES

ASSOCIATED TO SEVERAL
IMPORTANT BRAIN NETWORKS

AFFECTED ACROSS
MULTIPLE BRAIN DISORDERS



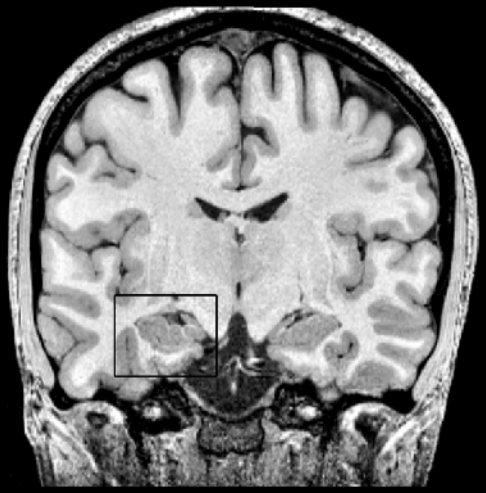
THE HIPPOCAMPUS

OFTEN TREATED AS
SINGLE STRUCTURE

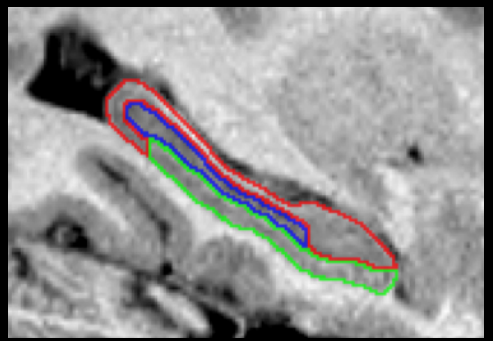
HOWEVER:
COMPLEX STRUCTURE

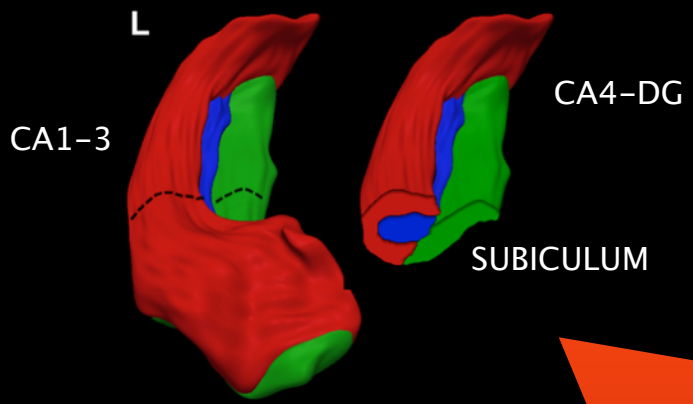
COMPOSED OF SEVERAL SUBFIELDS

LONG–AXIS SPECIALIZATION



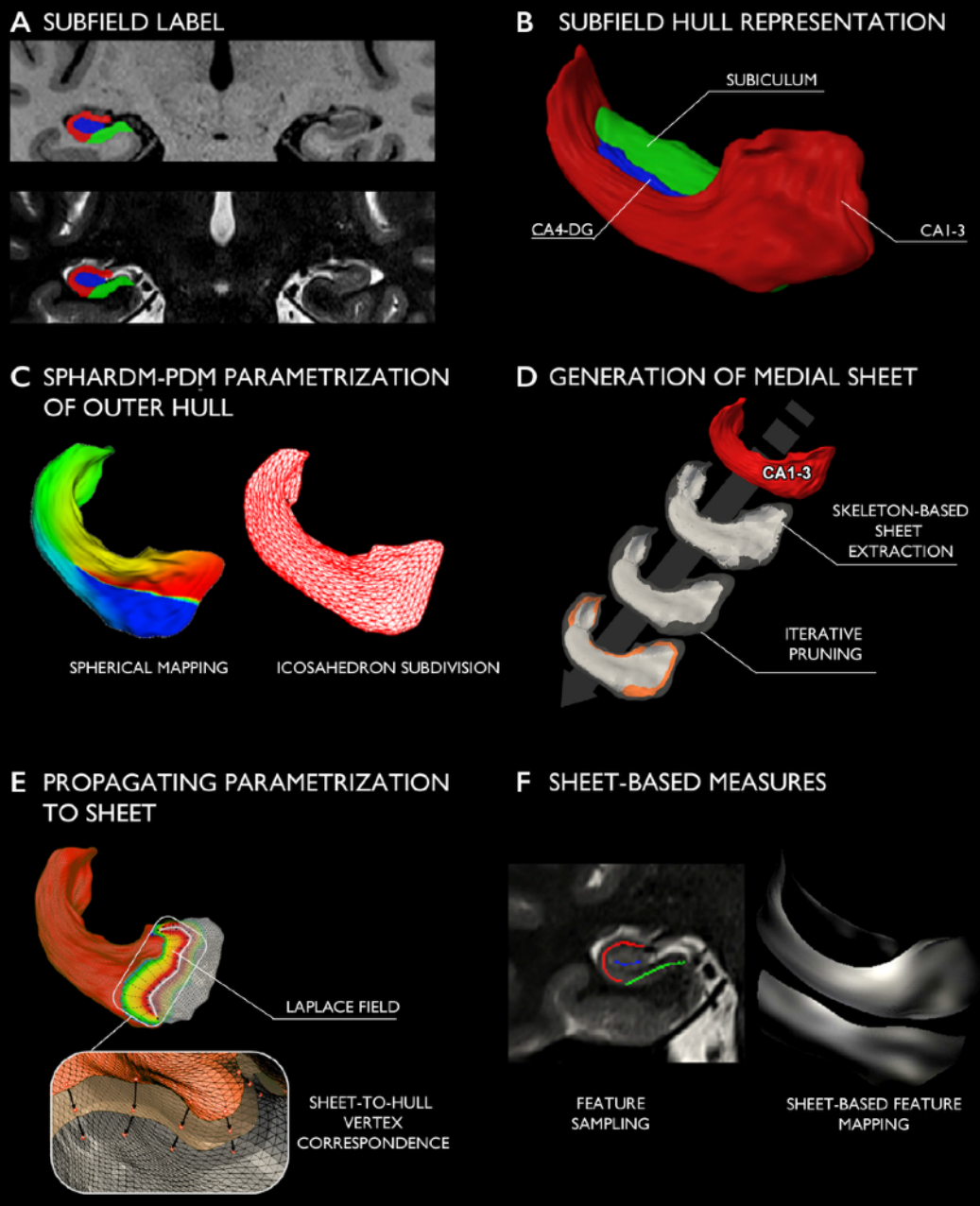
https://www.nitrc.org/projects/mni-hisub25/



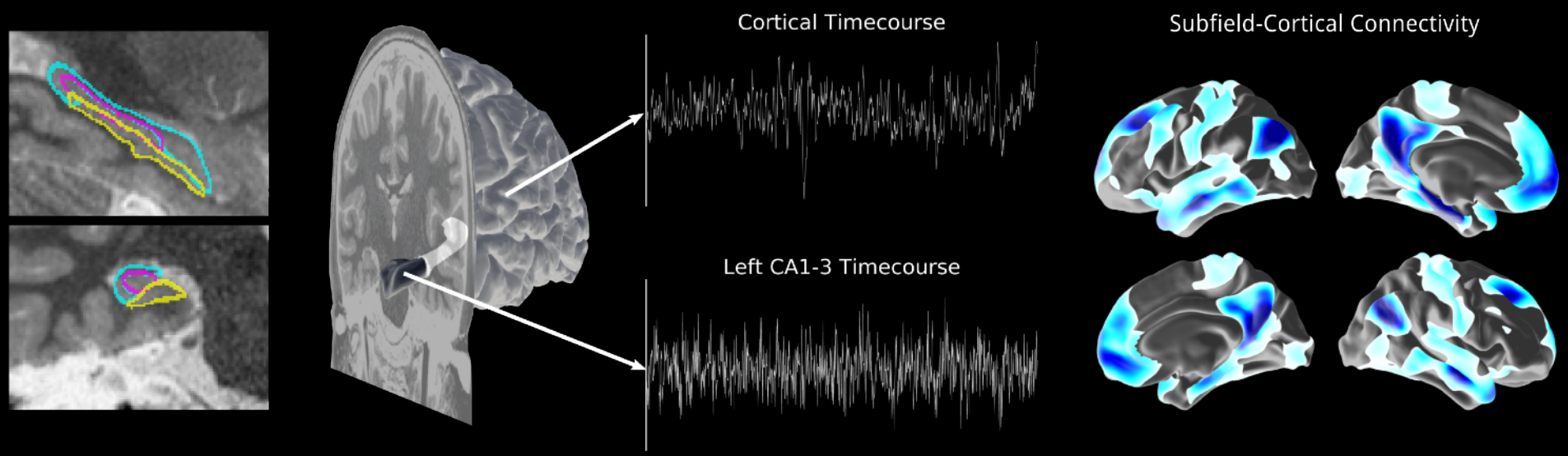


OPEN

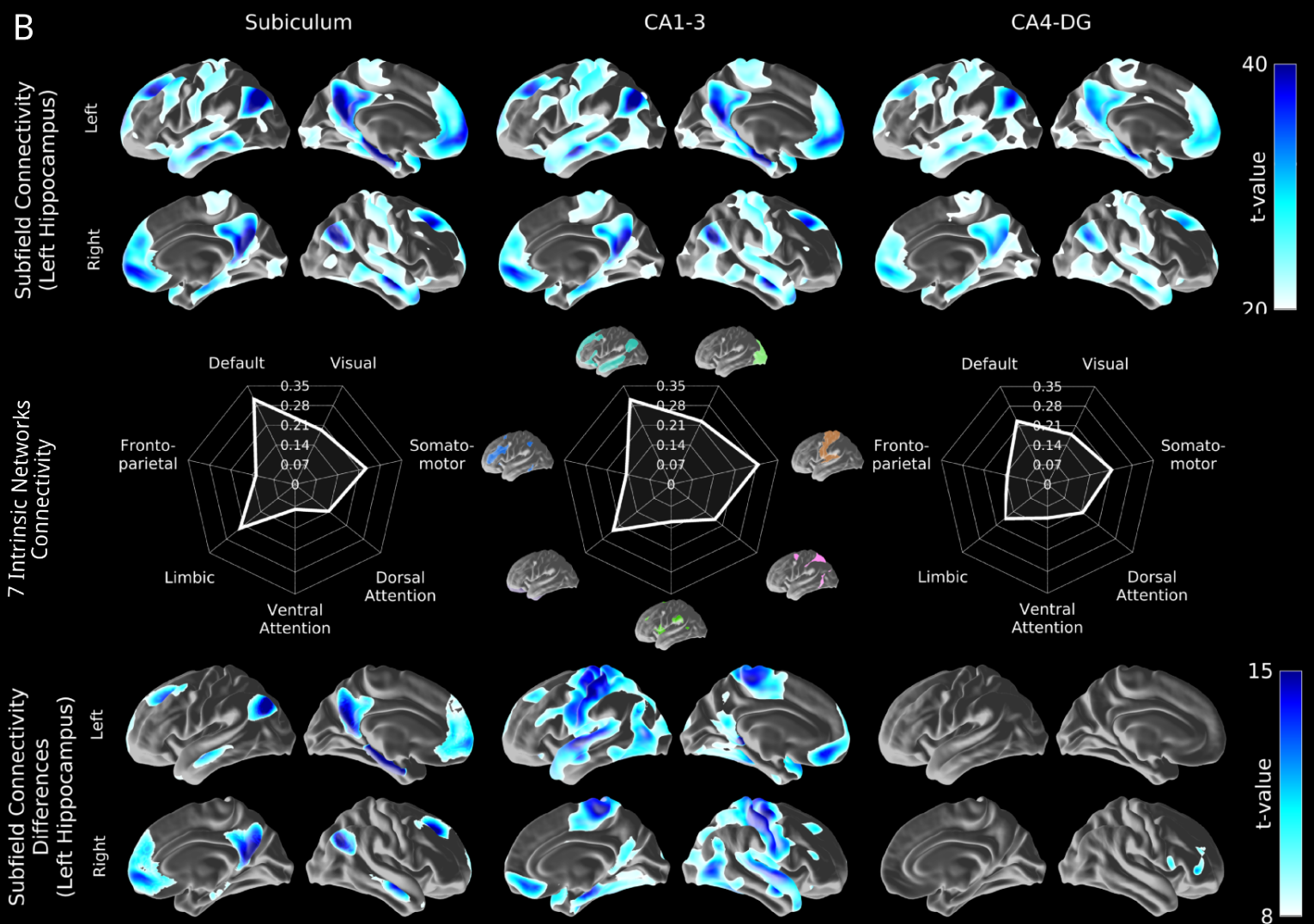
Kulaga -Yoskovitz, Bernhardt et al. (2015) Scientific Data



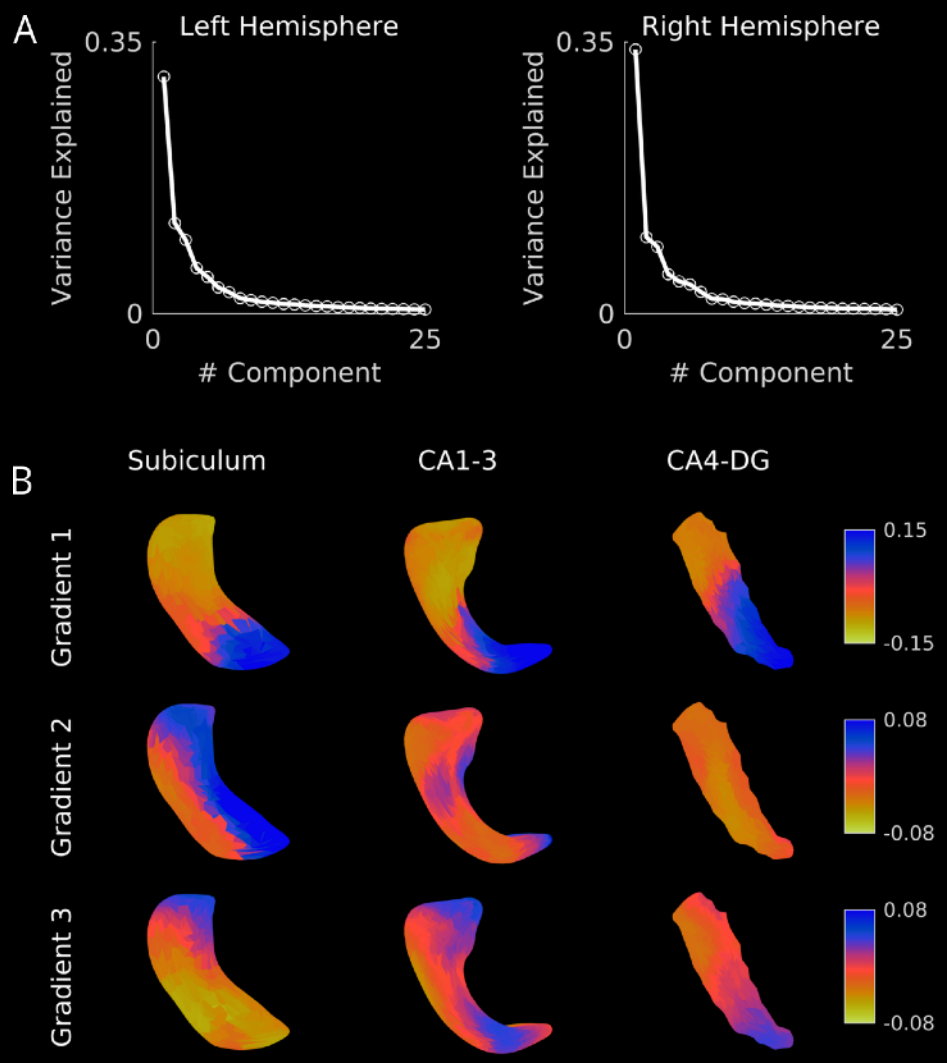
Kim, Bernhardt, et al (2015) MICCAI; Caldairou, Bernhardt, et al. (2016) MICCAI



Kim, Bernhardt, et al (2015) MICCAI; Caldairou, Bernhardt, et al. (2016) MICCAI



Vos de Wael et al (submitted)



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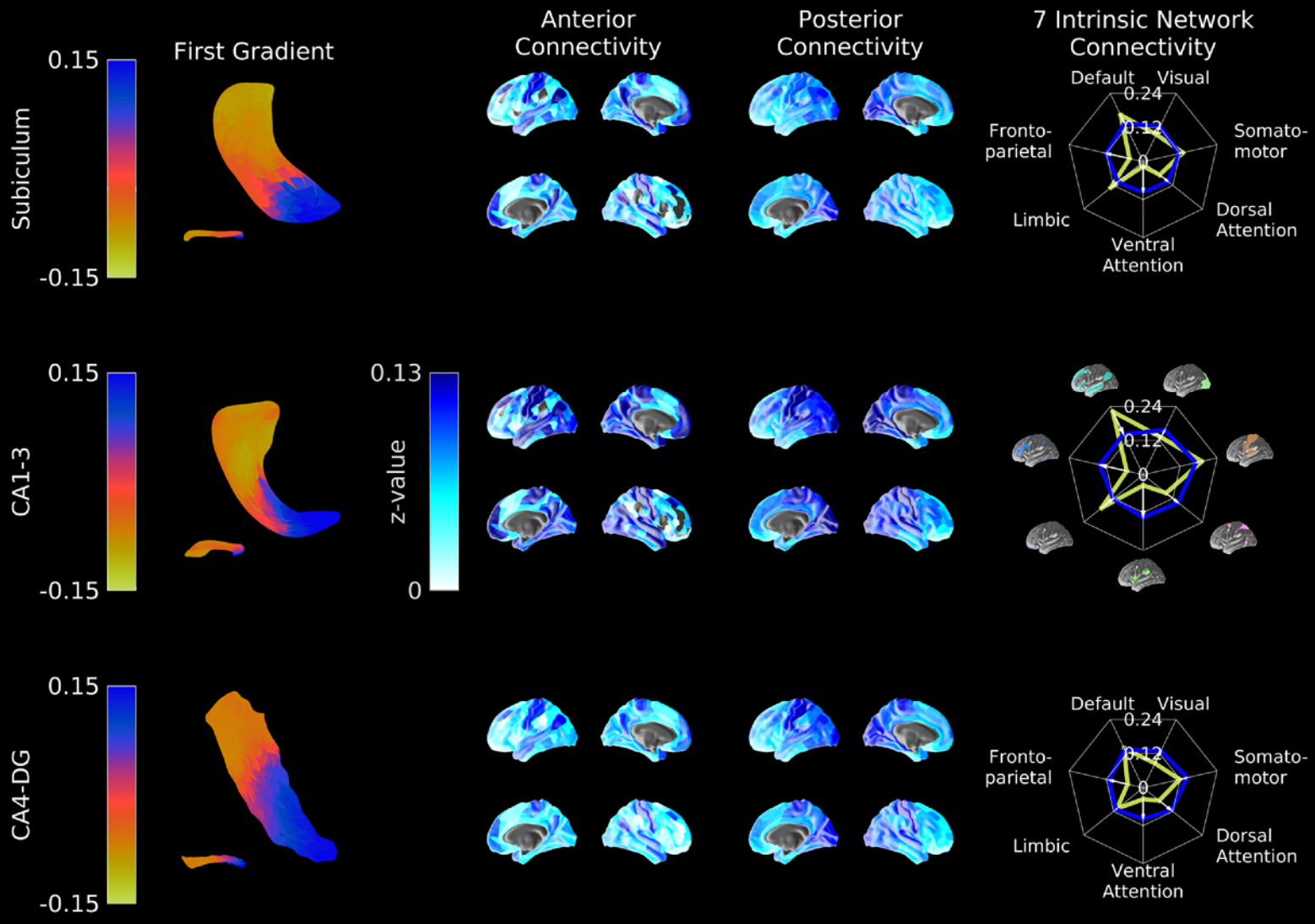

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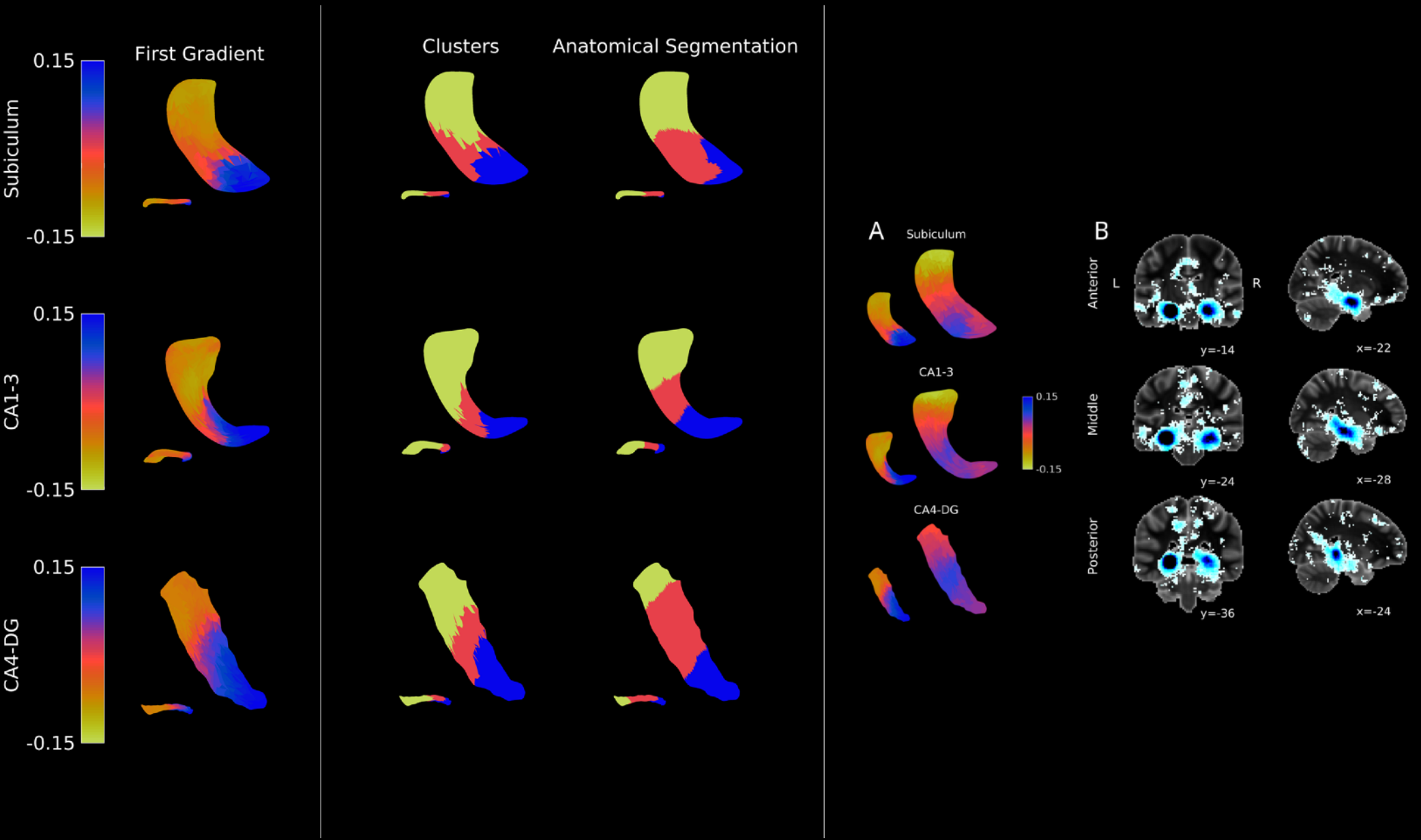

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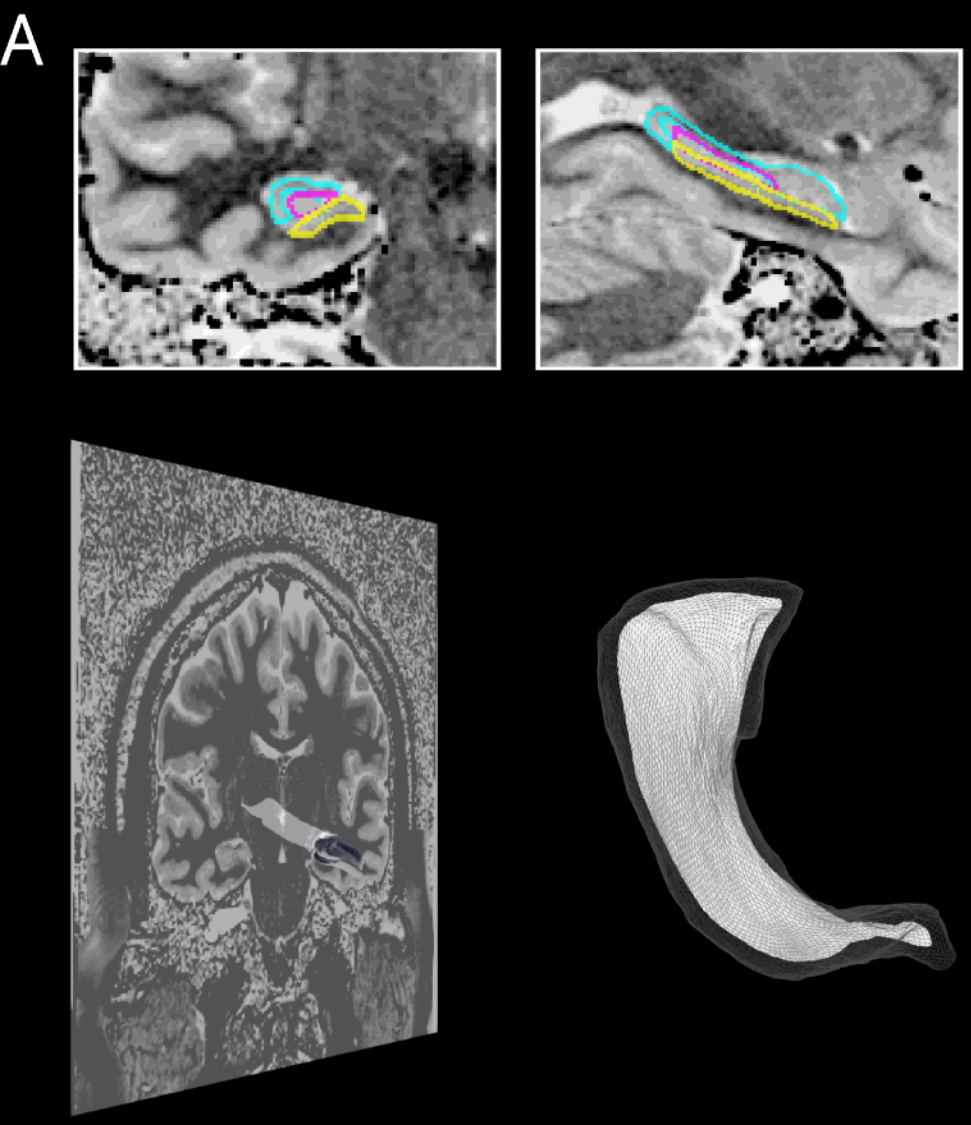
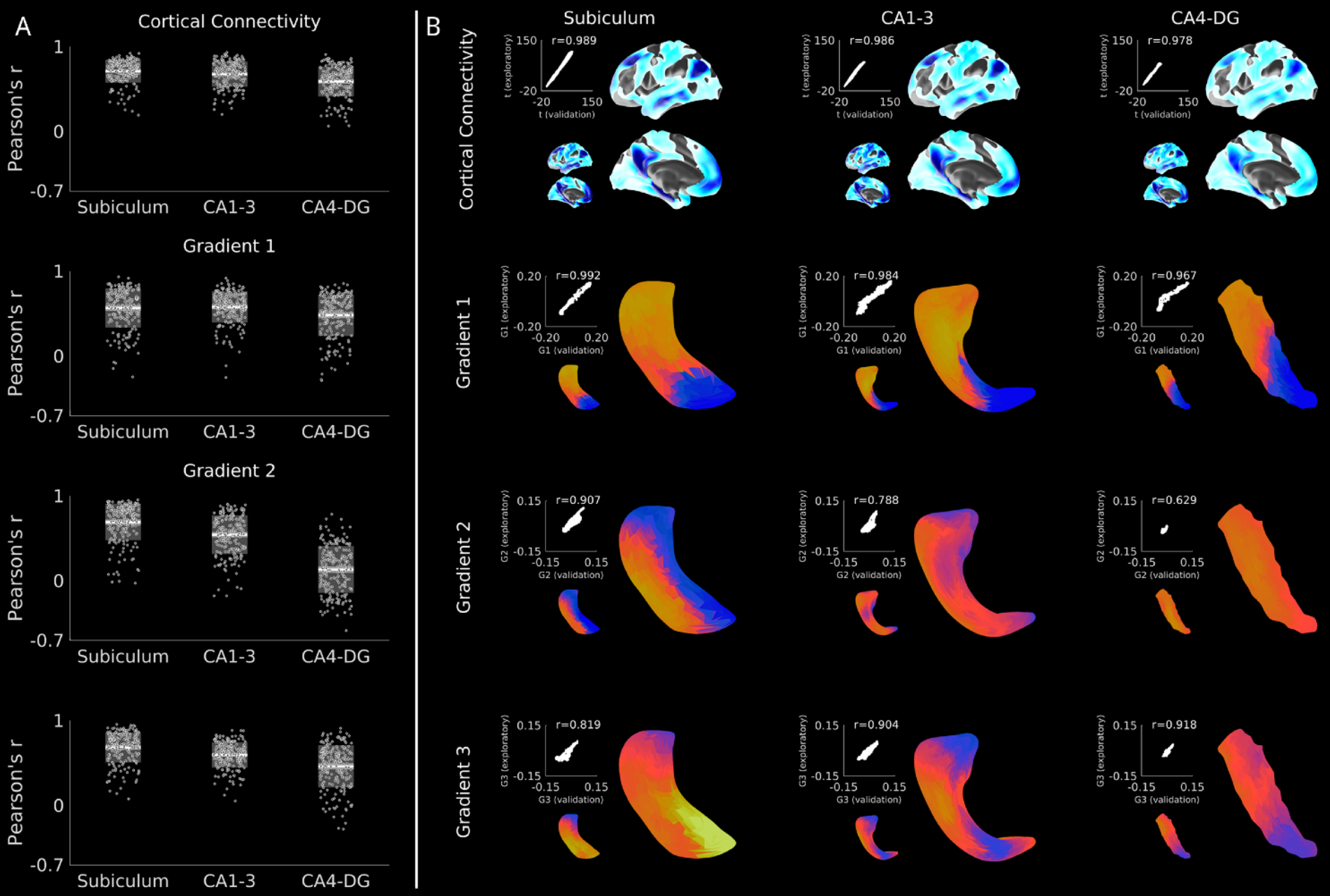


Vos de Wael et al (submitted)



Vos de Wael et al (submitted)

INTERIM SUMMARY: HIPPOCAMPUS

SURFACE-BASED ANALYTICS:
INTEGRATE SUBFIELD MARKERS OF
STRUCTURE AND CONNECTIVITY ALONG A-P EXTENT

MAP COMMON AND UNIQUE
SUBFIELD CONNECTIVITY "FINGERPRINTS"

GRADIENT BASED TECHNIQUES EVALUATE
WITHIN-SUBFIELD CHANGES IN CONNECTIVITY

G1: RELATION TO
LONG-AXIS SPECIALIZATION

G2: MEDIO-LATERAL GRADIENT
ASSOCICATED TO MICROSTRUCTE

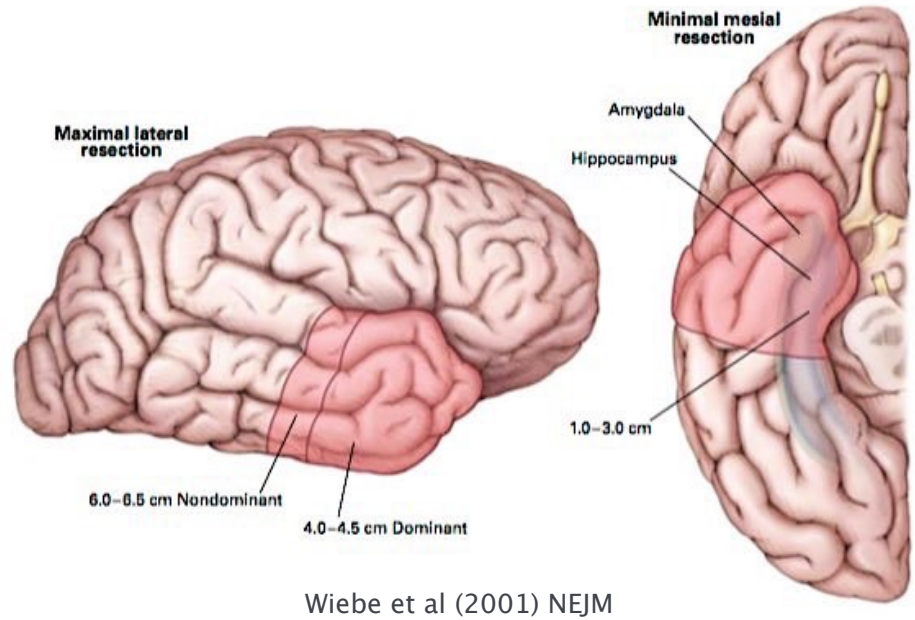
TEMPORAL LOBE EPILEPSY

ONE OF THE MOST COMMON DRUG-RESISTANT EPILEPSIES IN ADULTS

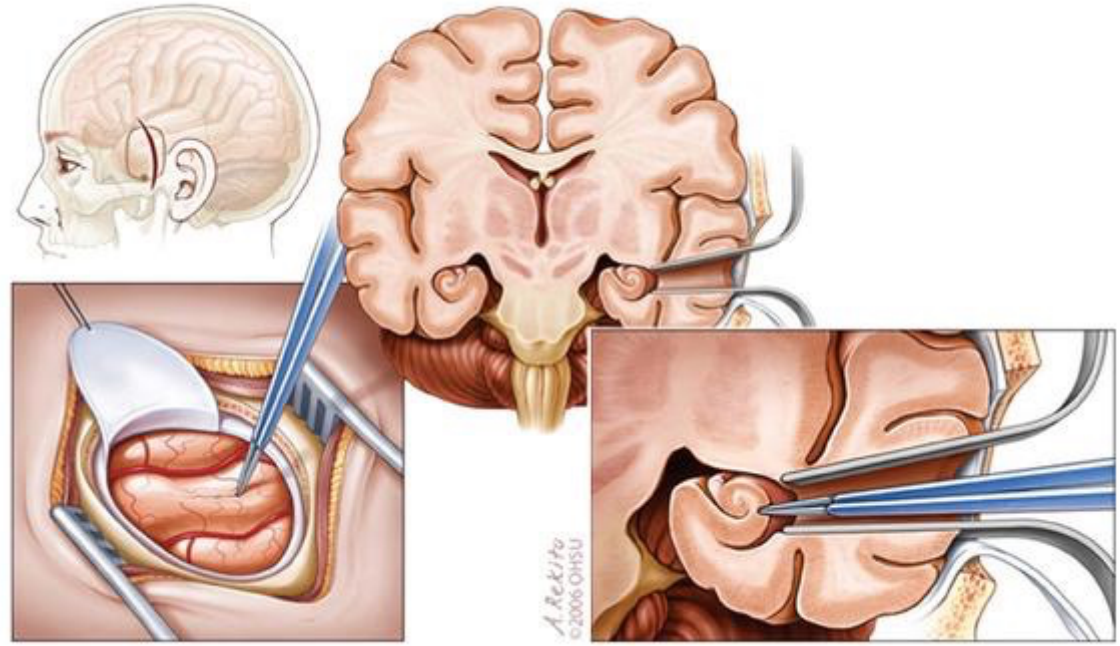
SEIZURES ARISING FROM TL

SURGERY MOST EFFECTIVE TREATMENT

ASSOCIATED WITH HIPPOCAMPAL SCLEROSIS (HS)



Wiebe et al (2001) NEJM

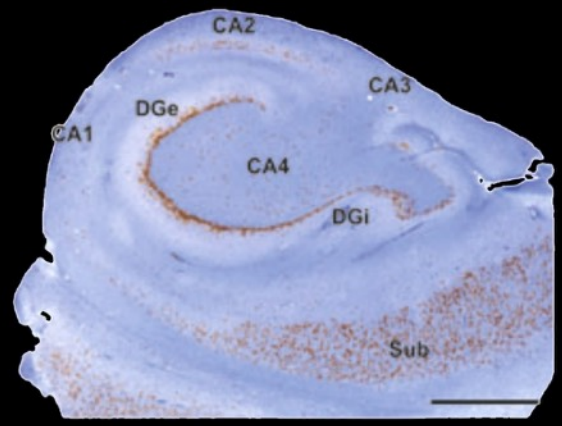


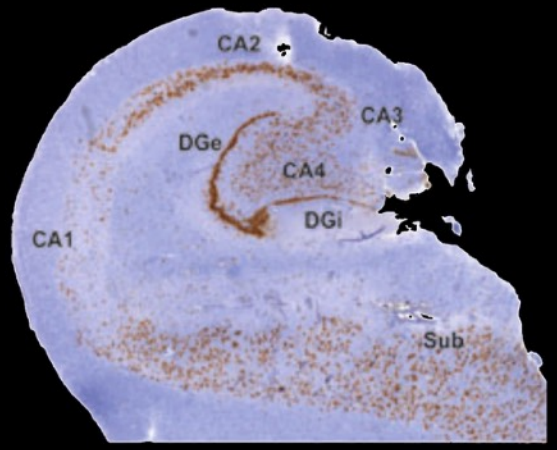
Spencer & Burchiel (2012) Epilepsy Research and Treatment

TEMPORAL LOBE EPILEPSY

HS IS THE TLE HALLMARK BUT NOT A SINGLE ENTITY

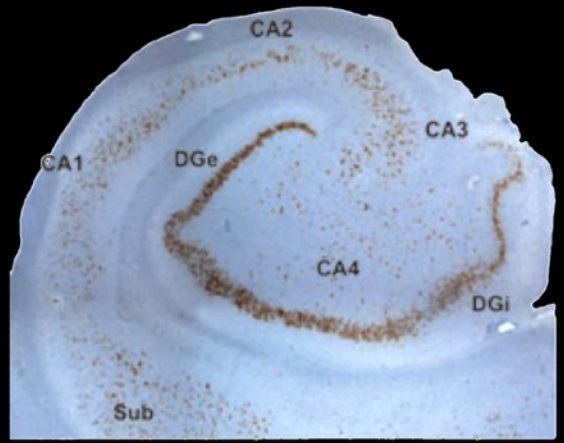
CA1+CA4
cell loss
+
gliosis

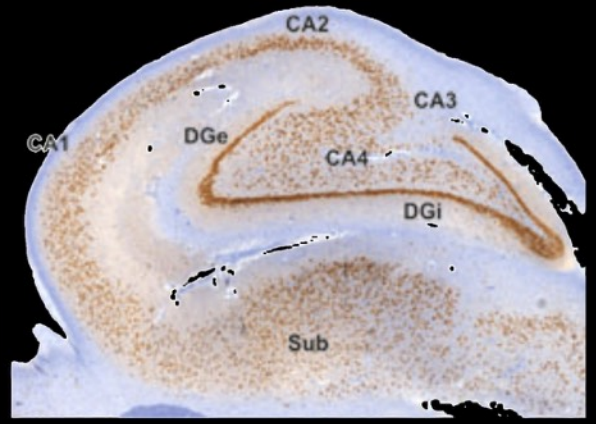




CA1
cell loss
+
gliosis

CA4
cell loss
+
gliosis

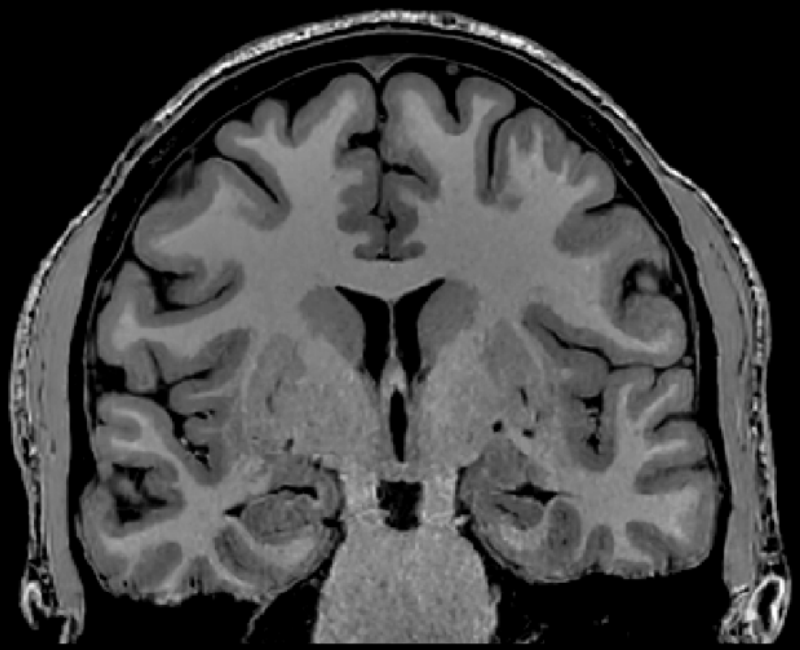




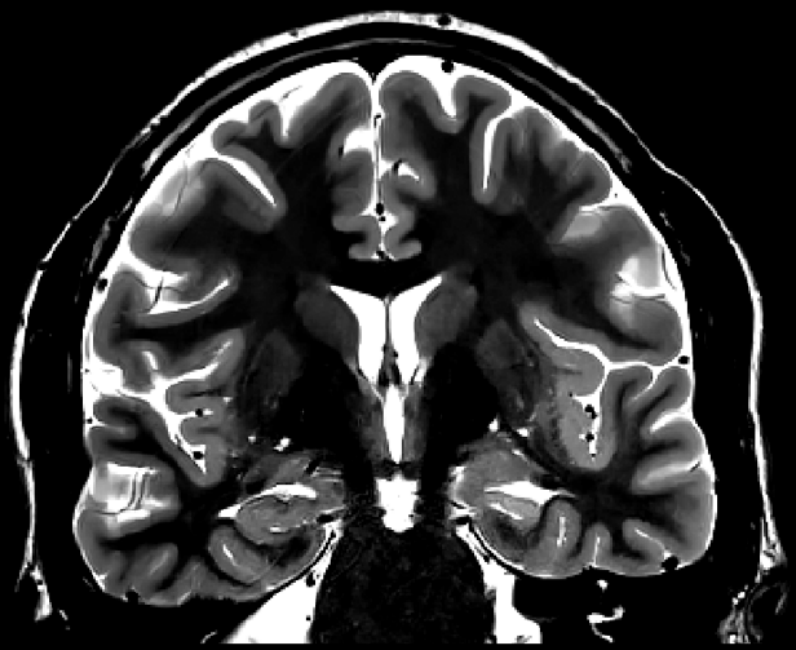
gliosis
only

Blümcke et al (2013) Epilepsia

THE CONTRIBUTIONS OF NEUROIMAGING TO TLE EVALUATION AND DIAGNOSIS OF HS



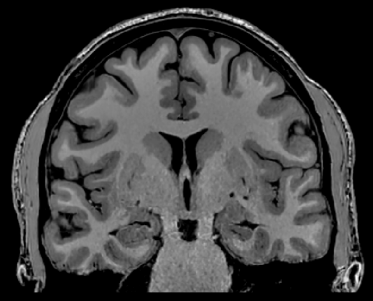
T1-weighted

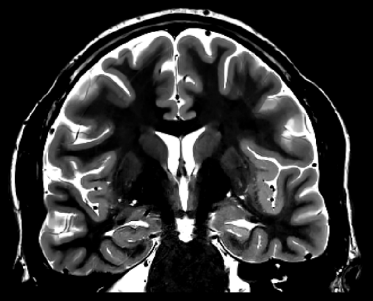


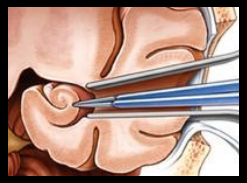
T2-weighted

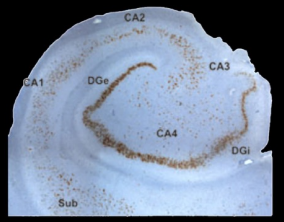
Cascino (1991) Ann Neur; Cendes (1993) Neurology; Jackson (1990) Ann Neur; Kuznieckiy (1997) Neurology; Bernasconi (2003) Brain

STUDY DESIGN







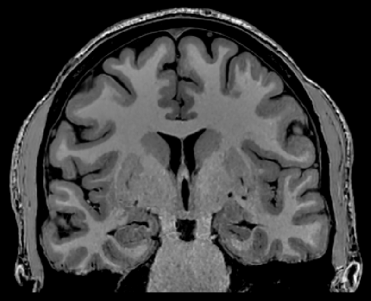


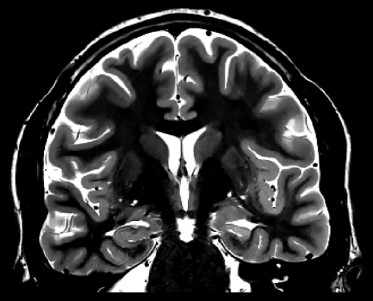
24

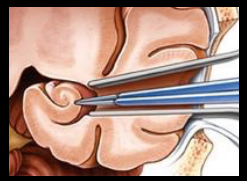
3T MRI DATA

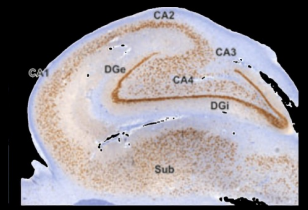
SURGERY

HS







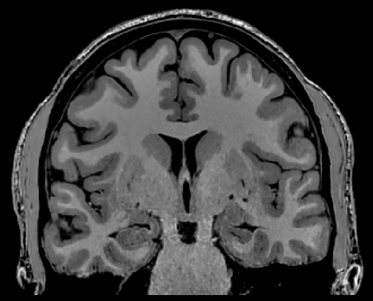


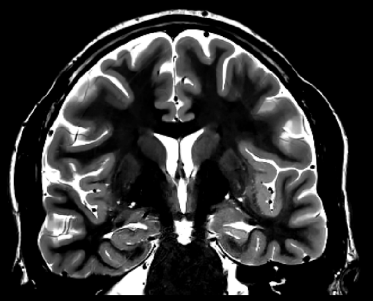
19

3T MRI DATA

SURGERY

GLIOSIS



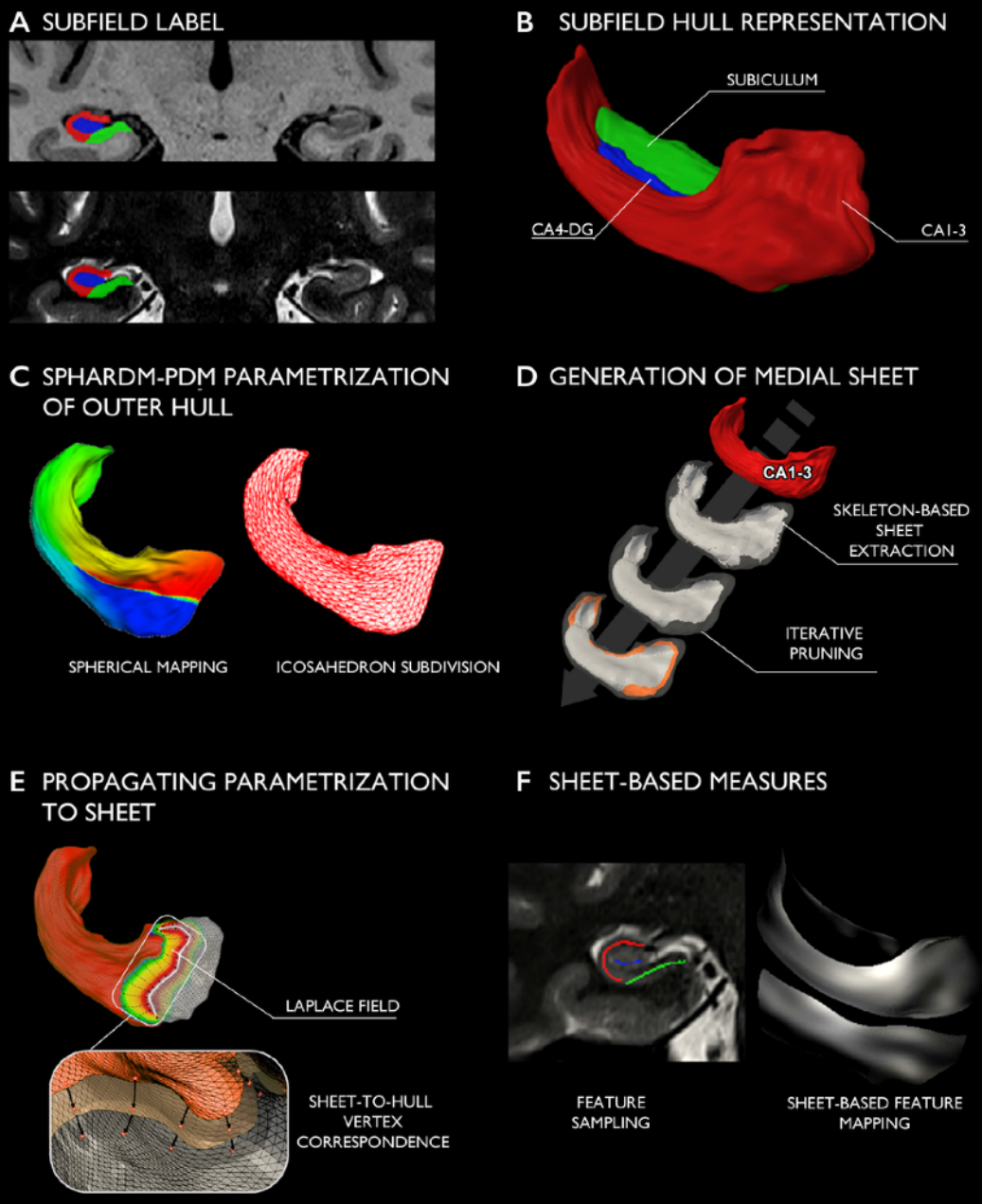


25

3T MRI DATA

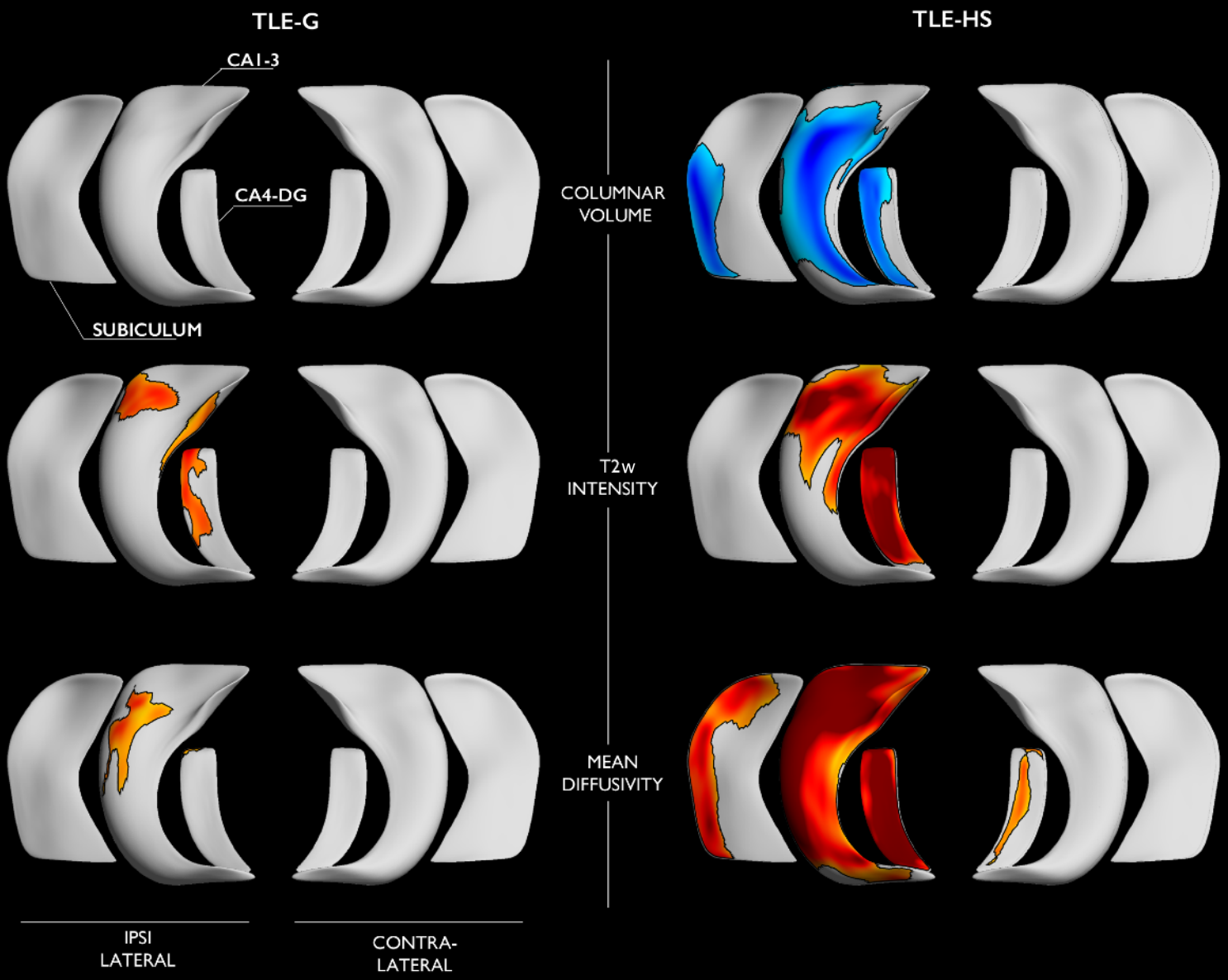
CONTROLS

IMAGE PROCESSING



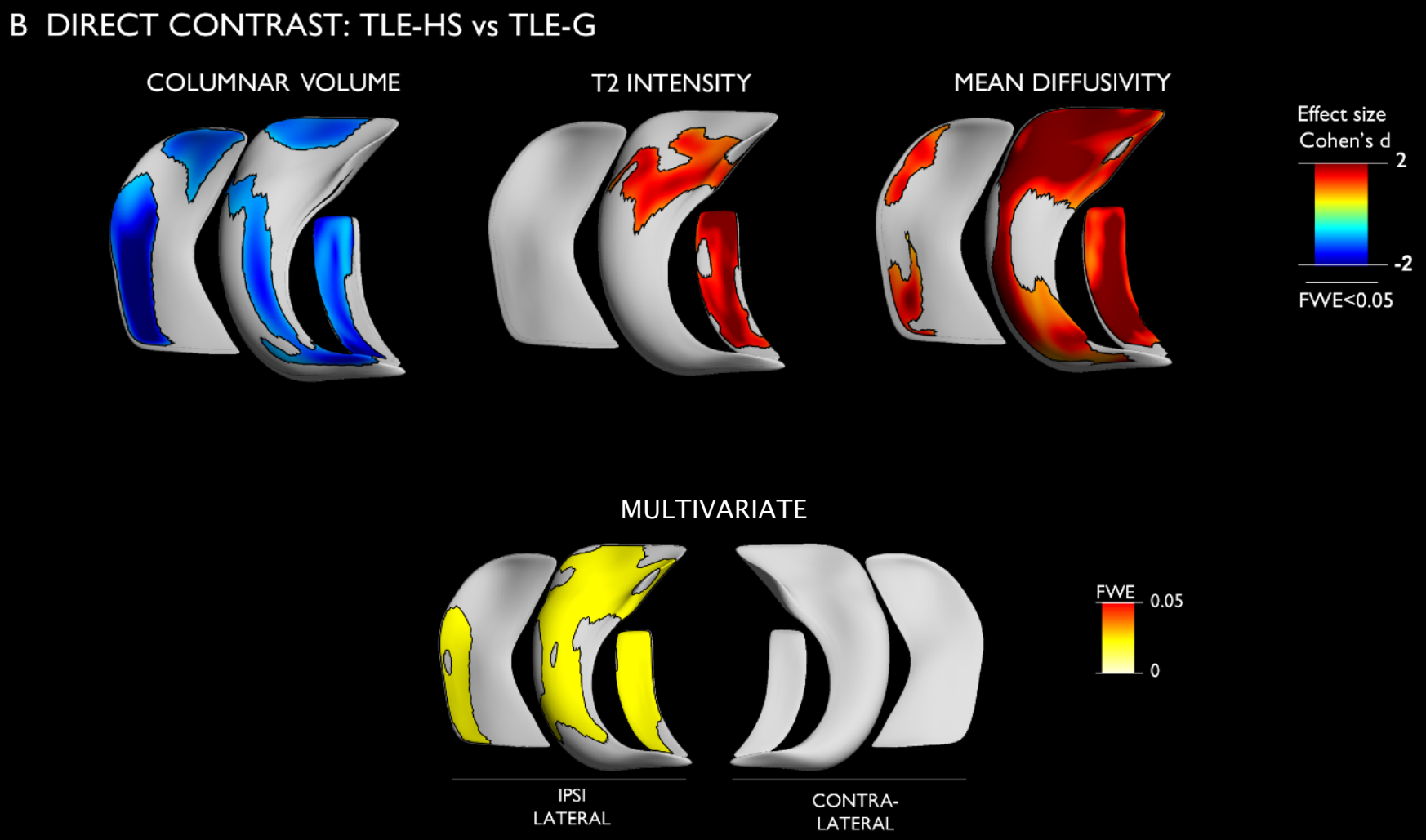
Kim et al (2015) MICCAI

FEATURE-SPECIFIC COMPARISON TO CONTROLS



Annals of Neurology, 2016

DIRECT CONTRASTS



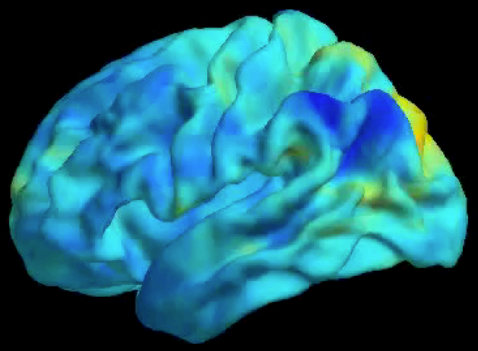
Annals of Neurology, 2016

FUNCTION

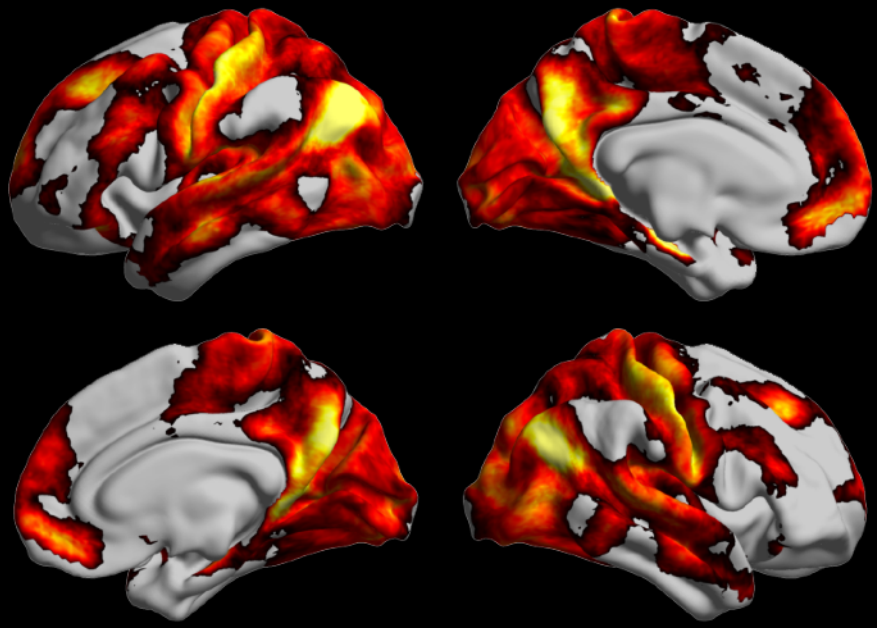
rs-FMRI ANALYSIS OF
INTRINSIC FUNCTIONAL NETWORKS

HIPPOCAMPUS HIGHLY INTEGRATED
WITH DMN

TLE-HS vs TLE-G:
DISEASE MODEL TO PROBE
STRUCTURE-FUNCTION RELATIONS

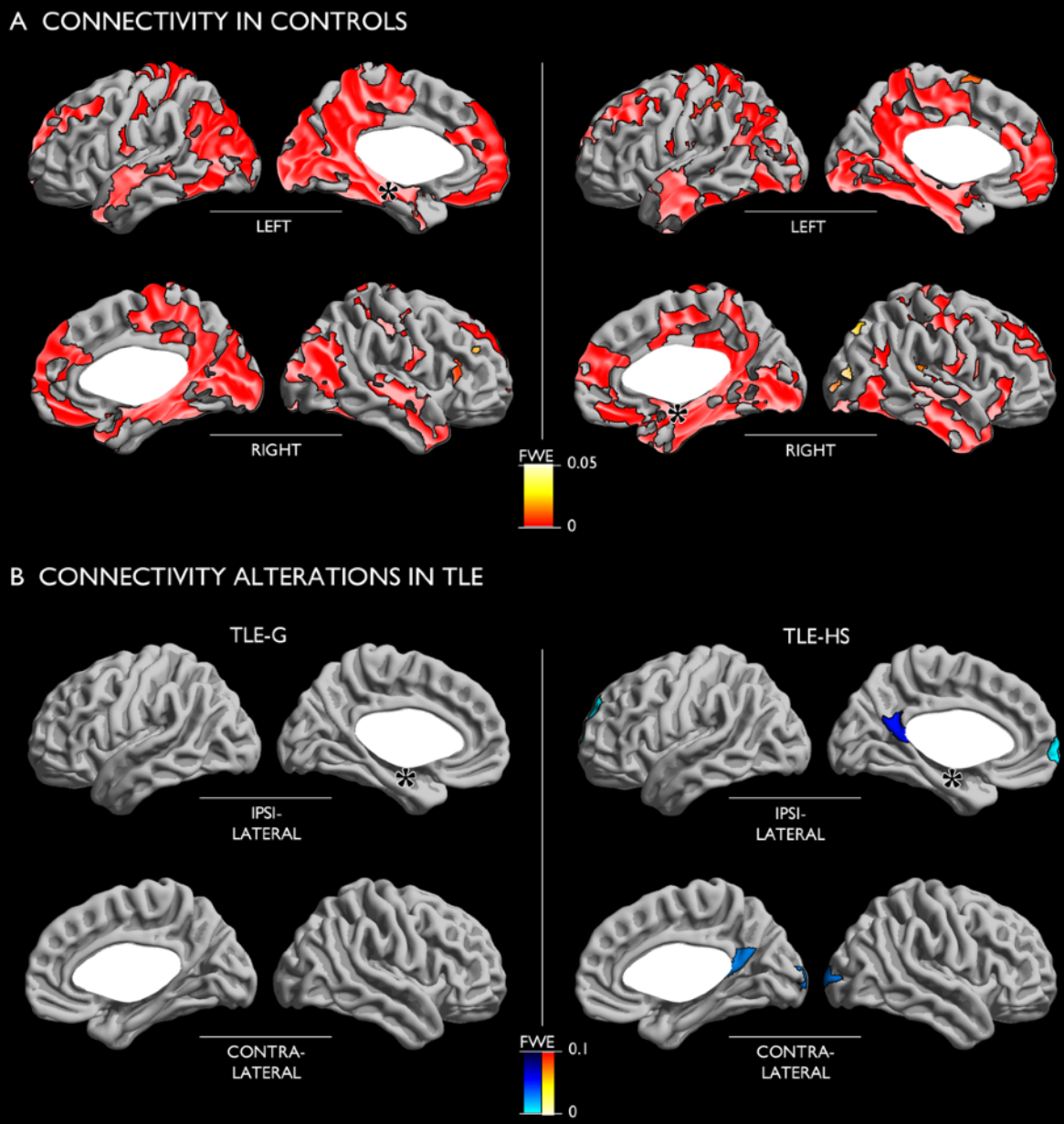


Brain at rest



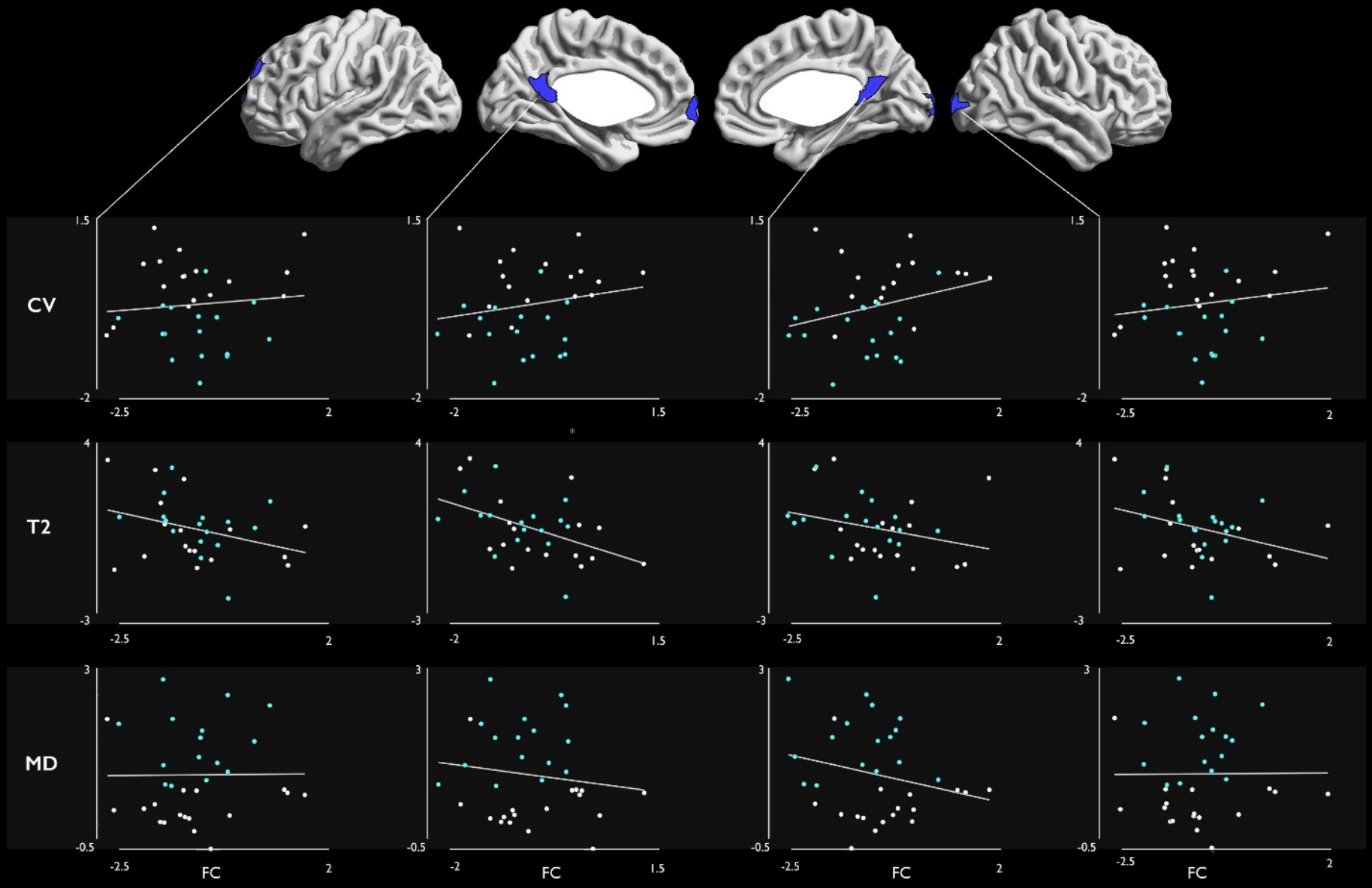
HCP hippocampal connectivity

FUNCTIONAL ANOMALIES IN TLE

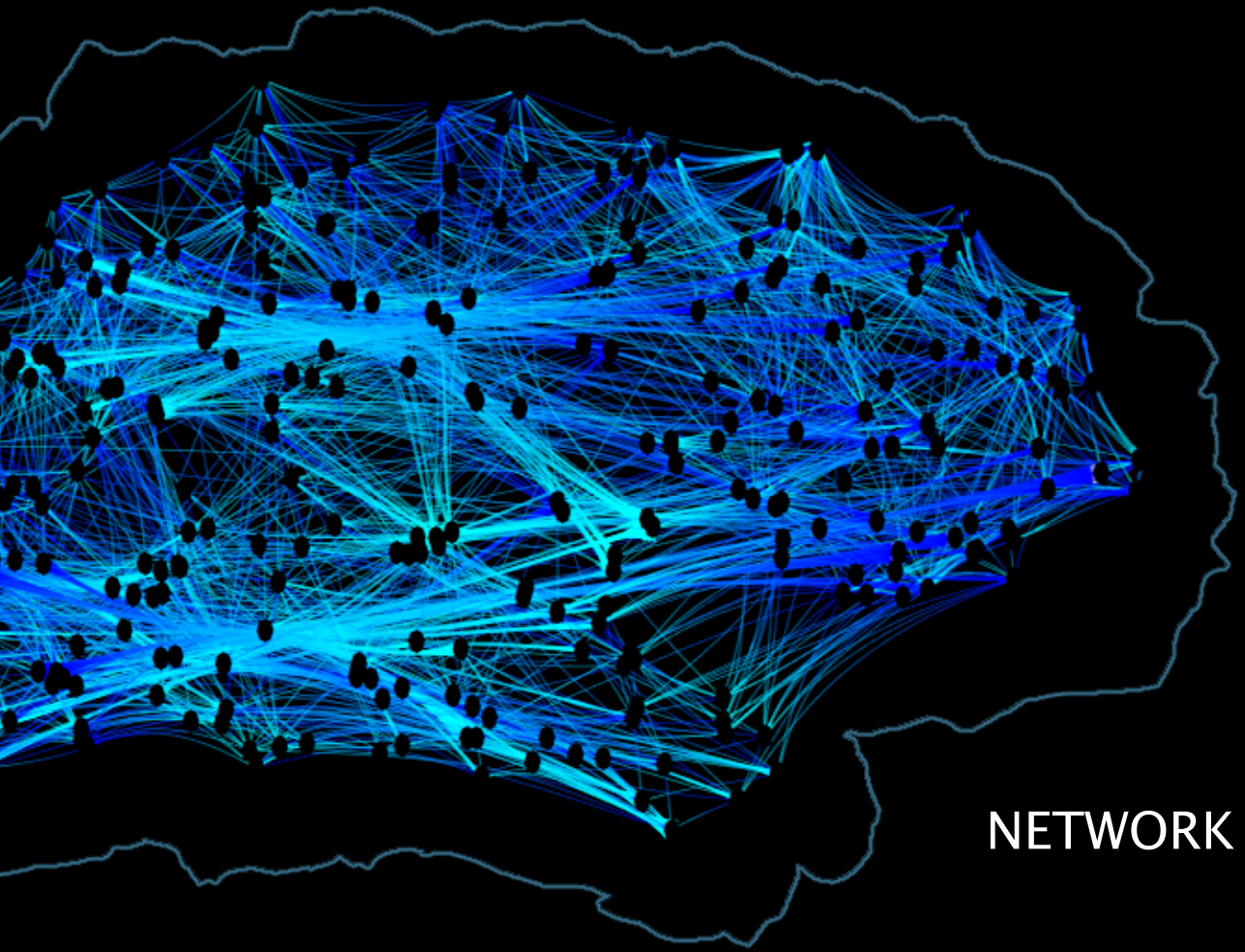


Annals of Neurology, 2016

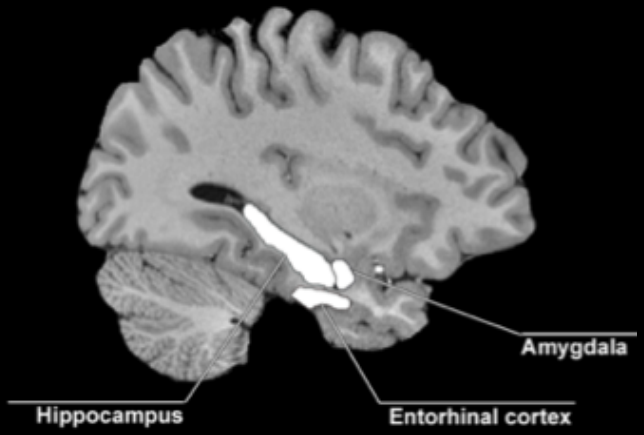
STRUCTURE–FUNCTION RELATIONSHIPS IN TLE



Annals of Neurology, 2016



NETWORK LEVEL COMPROMISE IN TLE



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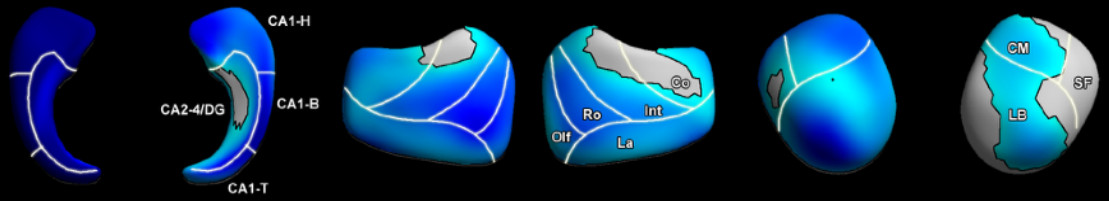
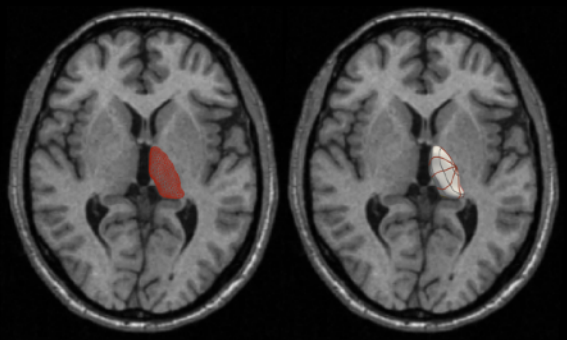
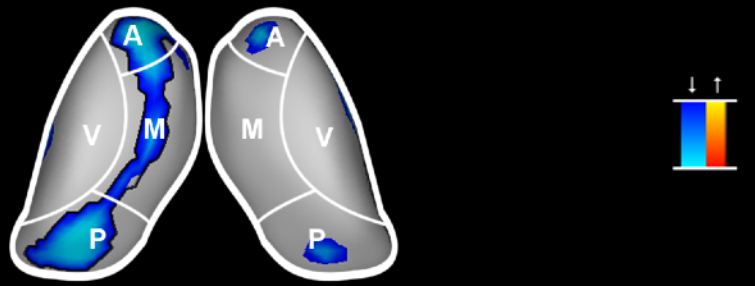


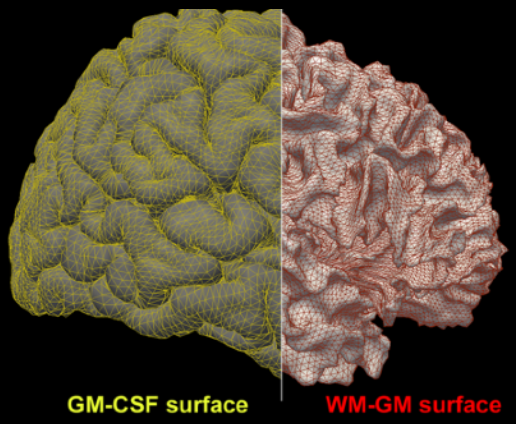
I C I C I C

Hippocampus EC Amygdala

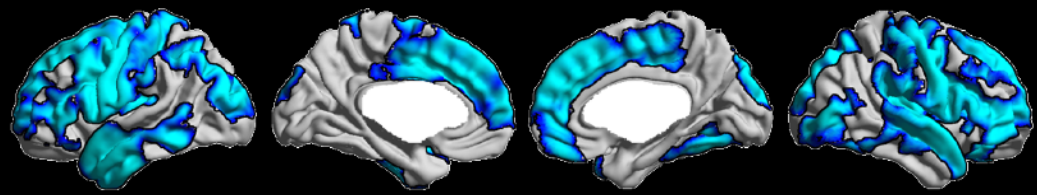


THALAMUS

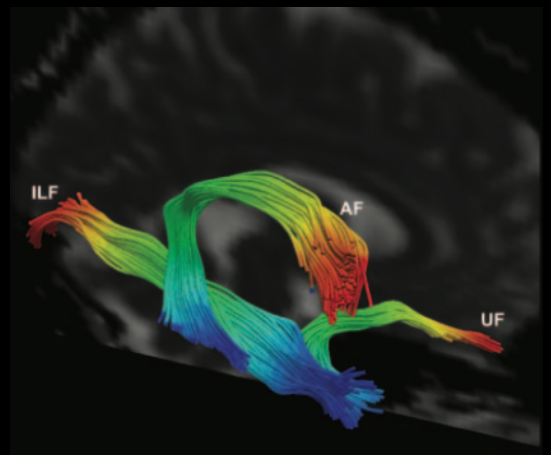




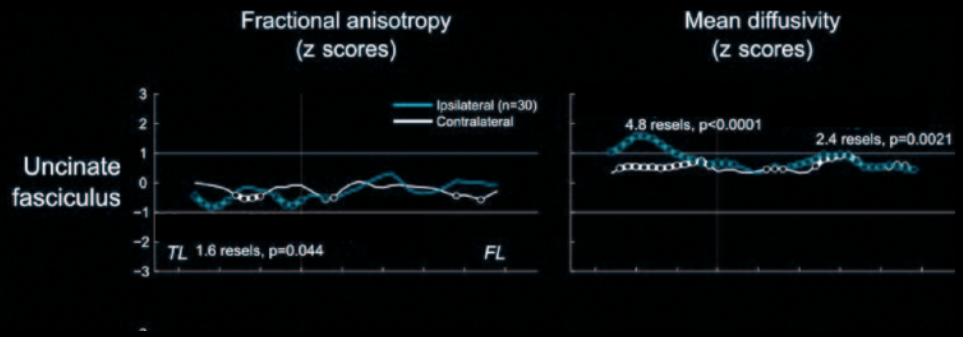
NEOCORTEX

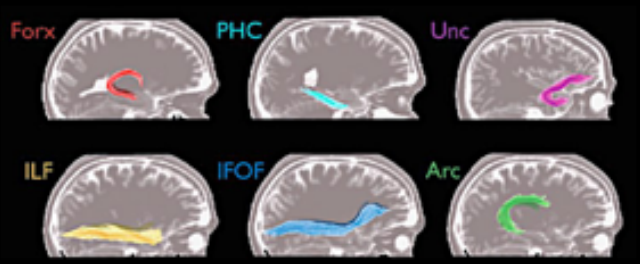


2008 NIMG, 2009/10 Neurology, 2015 Hum Brain Mapp

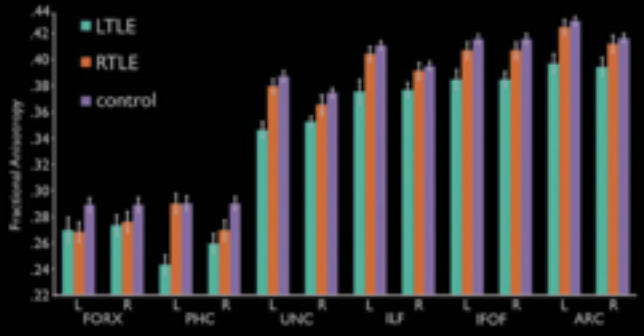


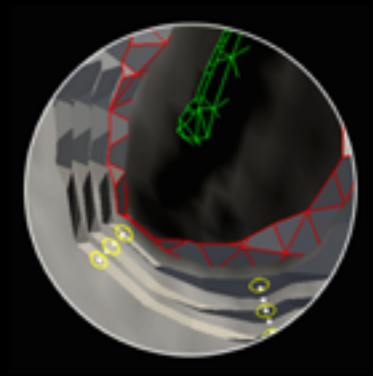
INDIVIDUAL BUNDLES



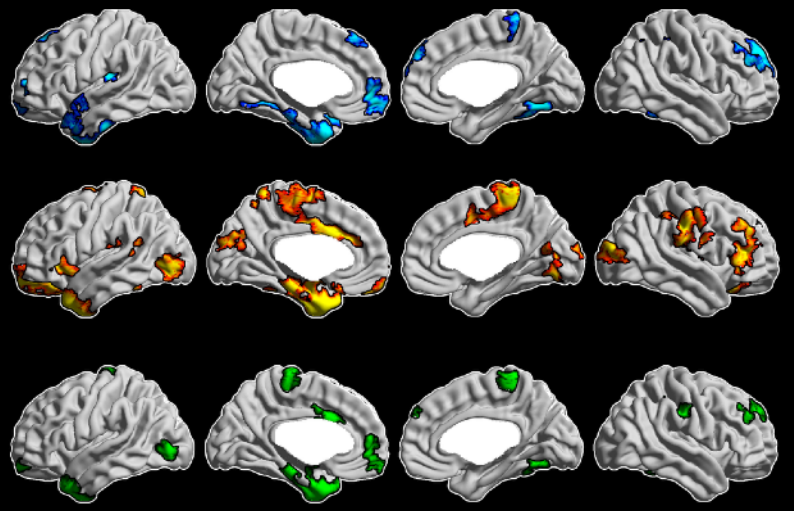


MULTIPLE TRACTS





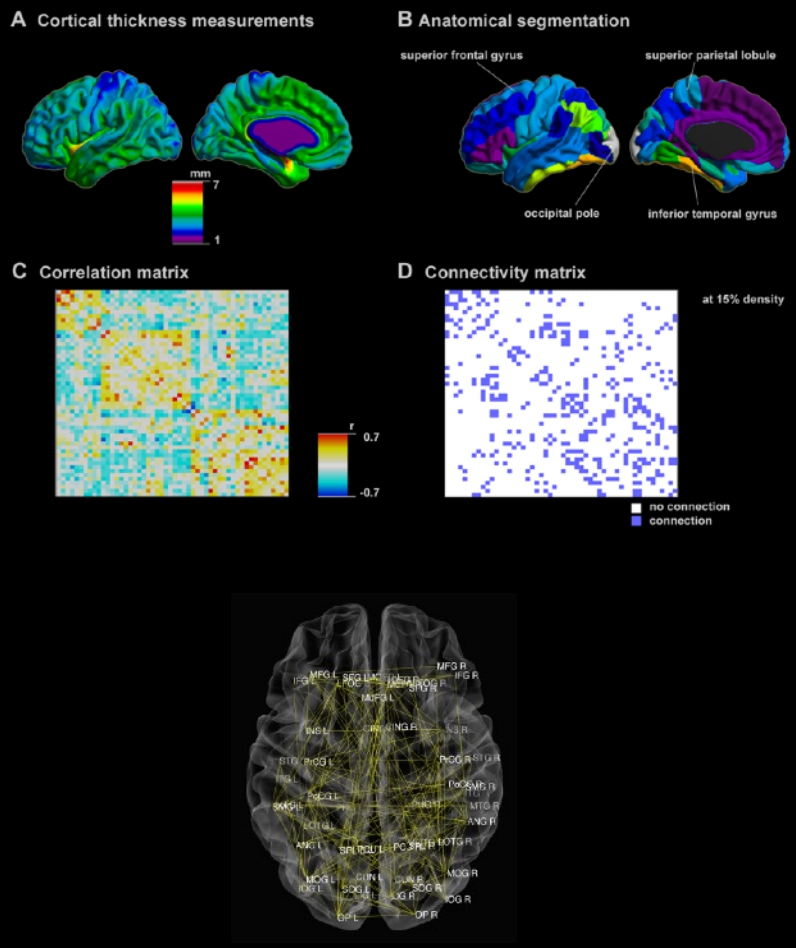
SUPERFICIAL WM



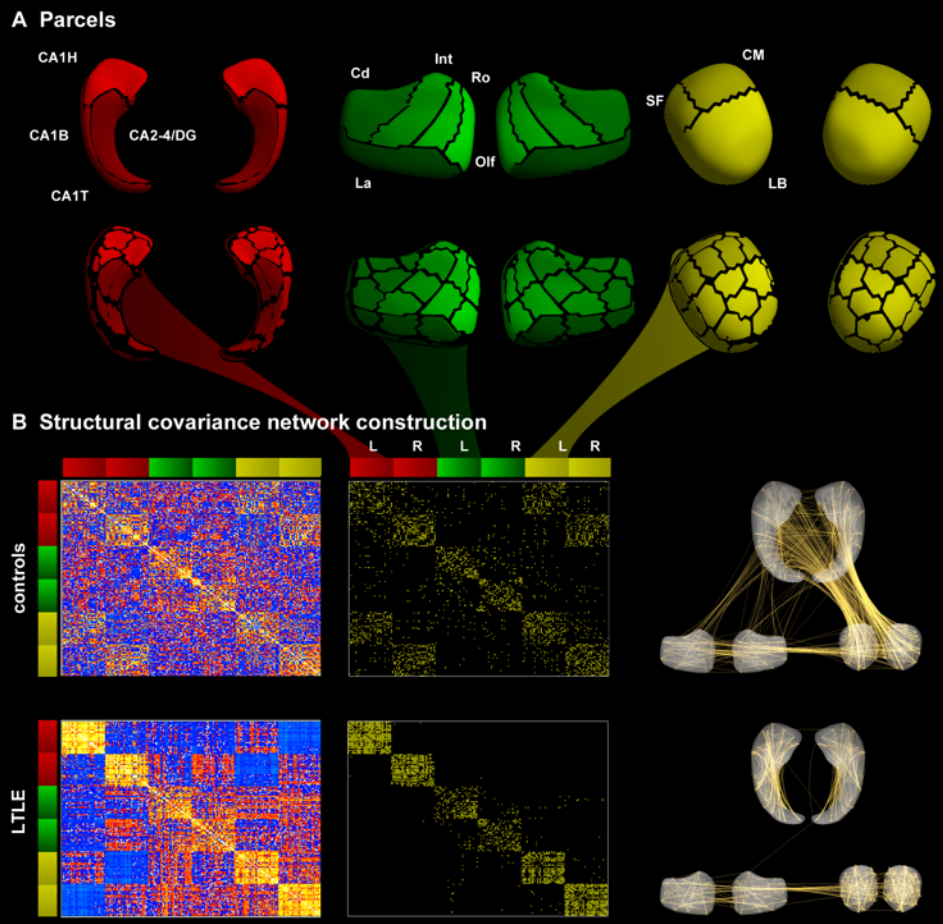
Kemmotsu (2011) Epilepsia; Concha et al. (2012) Neurology; Liu, Bernhardt et al. (2016) Brain

MACROLEVEL STRUCTURAL NETWORK GENERATION

NEOCORTEX



MESIOTEMPORAL LOBE

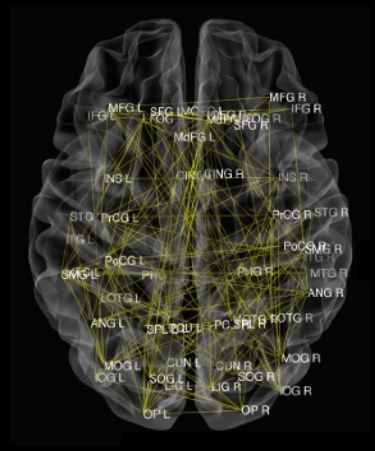


Cerebral Cortex 2011, 2016

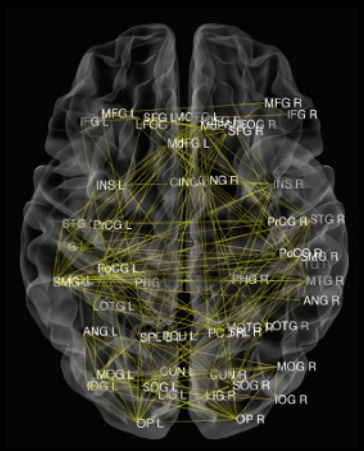
MACROLEVEL STRUCTURAL NETWORK ALTERATIONS

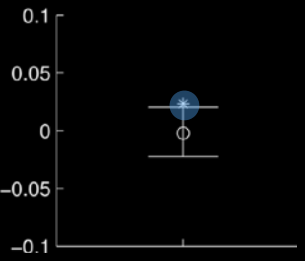
NEOCORTEX

CONTROLS

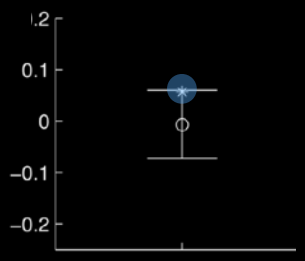


TLE





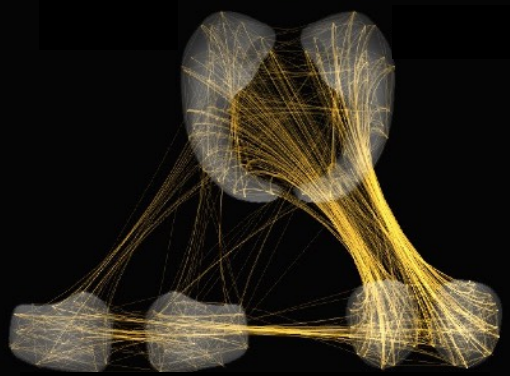
CLUSTERING



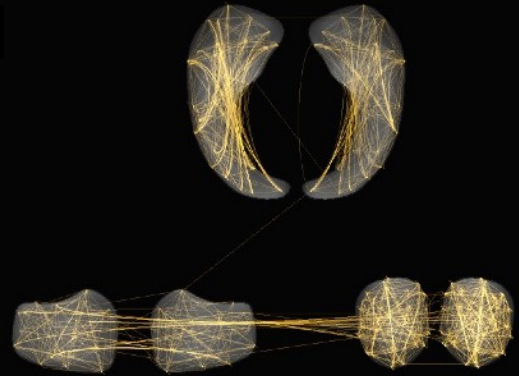
PATH LENGTH

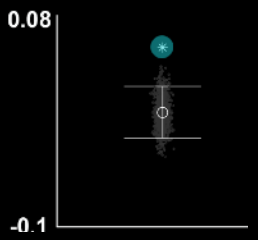
MESIOTEMPORAL LOBE

CONTROLS



TLE





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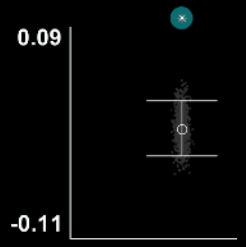
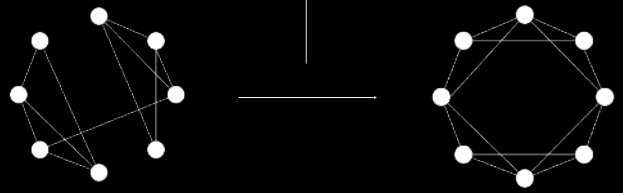
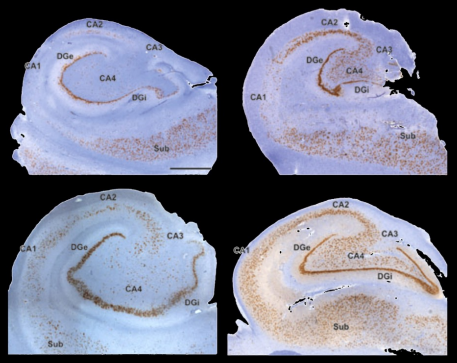


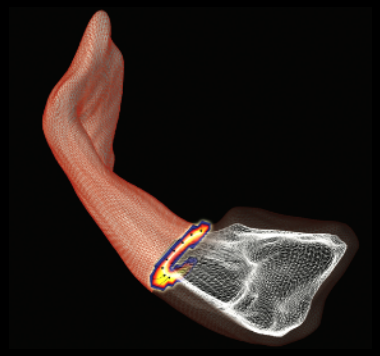
PATH LENGTH

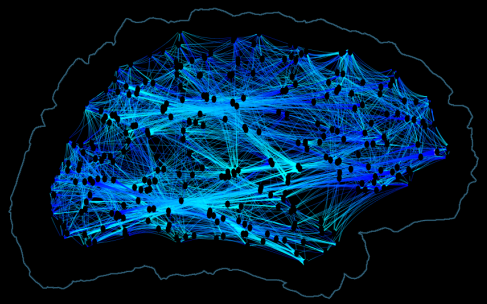


Cerebral Cortex 2011, 2016

MICRO-MACRO-INTERACTIONS

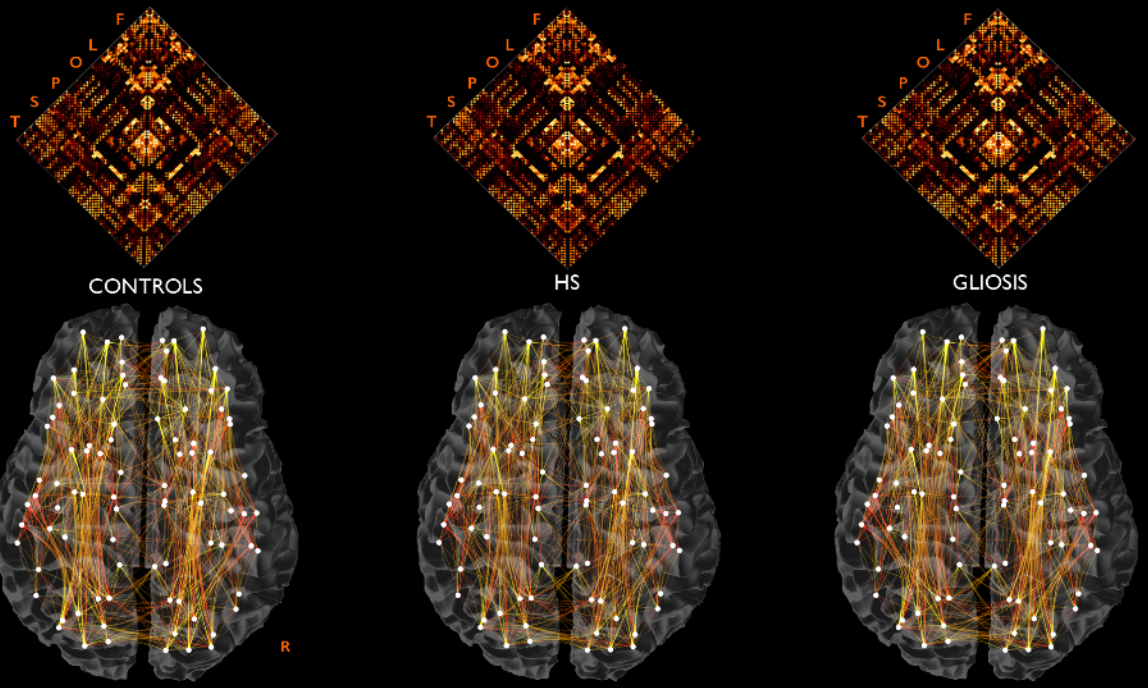




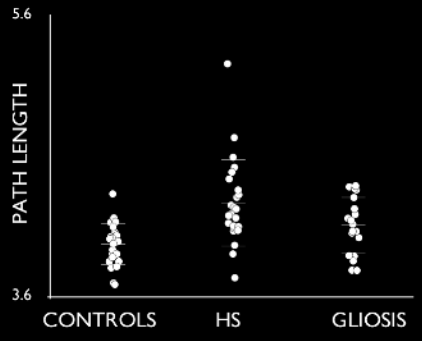


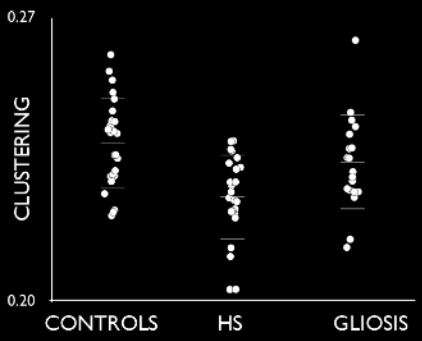
LINKING MACRO/MICROLEVEL DISRUPTIONS

A STRUCTURAL CONNECTOMES



B TOPOLOGICAL PARAMETER ANALYSIS





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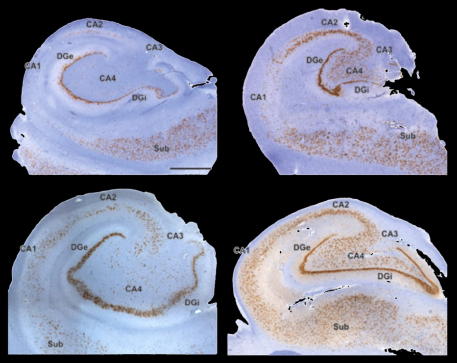
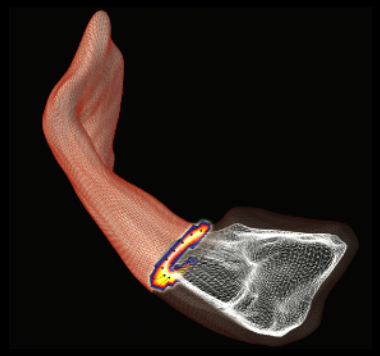
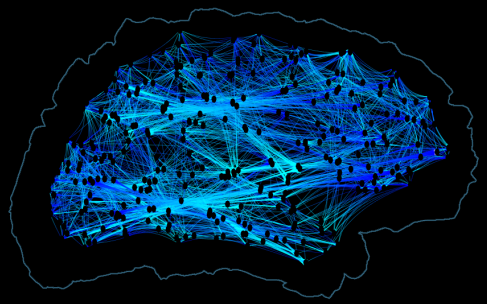
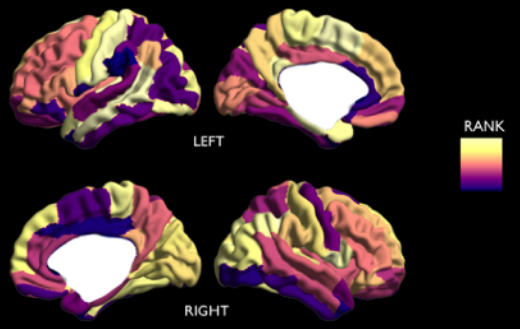




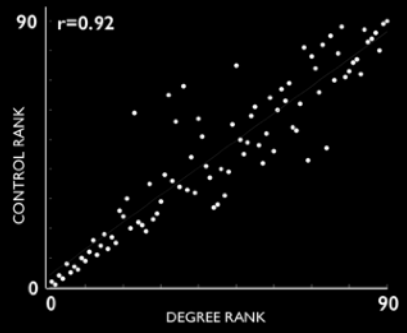


LINKING MACRO/MICROLEVEL DISRUPTIONS

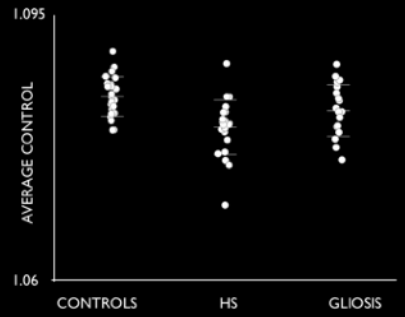
A NETWORK CONTROLLABILITY

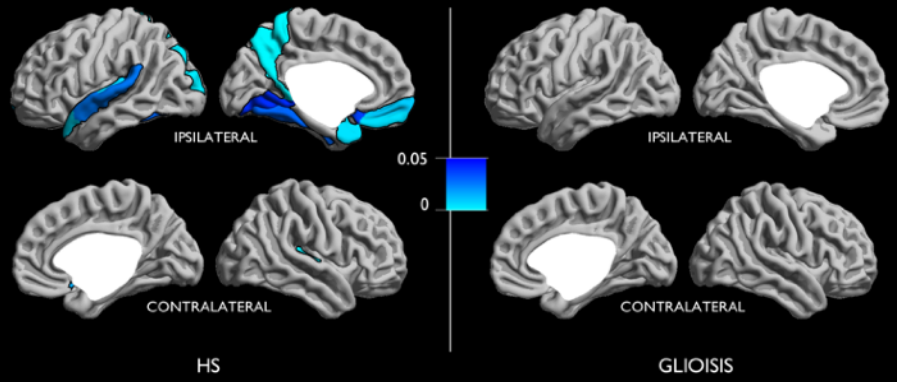


B RELATION TO CENTRALITY

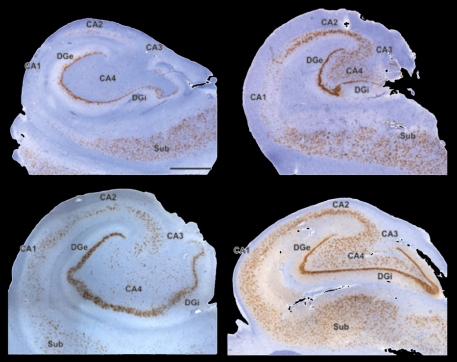


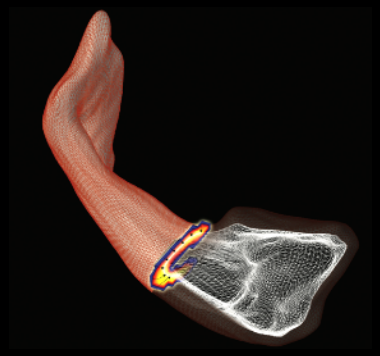
C CONTROLLABILITY ALTERATIONS IN TLE

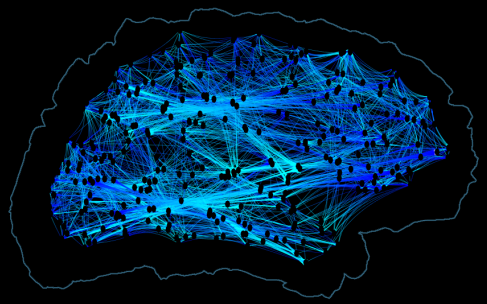




LINKING MACRO/MICROLEVEL DISRUPTIONS



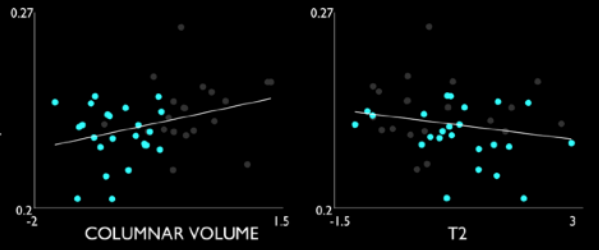


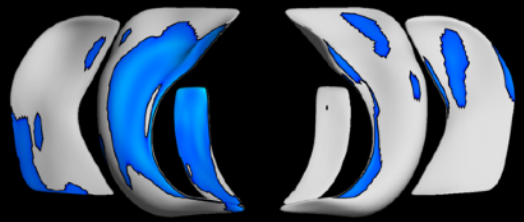


MULTIVARIATE SURFACE-WIDE

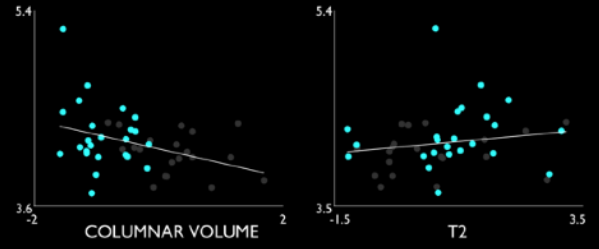
UNIVARIATE POSTHOC

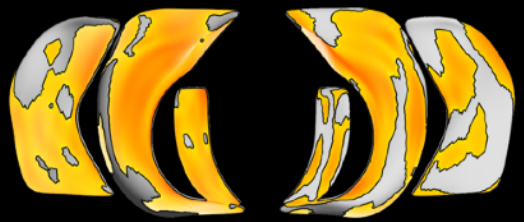
CLUSTERING COEFFICIENT



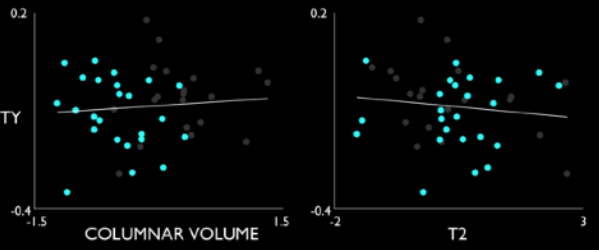


PATH LENGTH





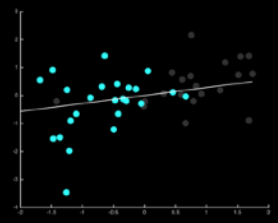
AVERAGE CONTROLABILITY



MULTIVARIATE POSTHOC

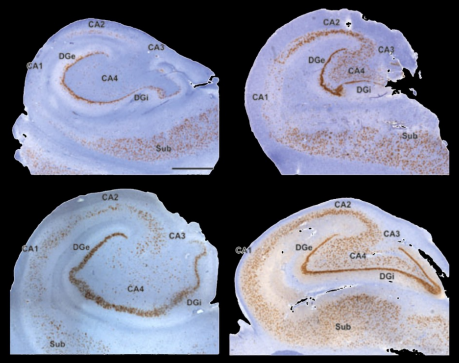
INTERSECTION

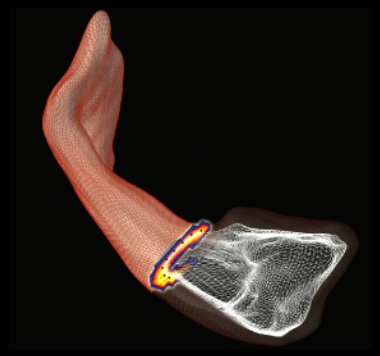
CLUSTERING & PATH LENGTH & CONTROLLABILITY

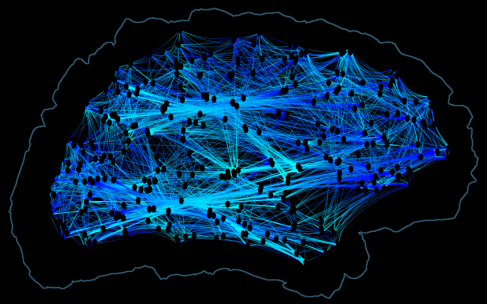


IPSILATERAL CONTRALATERAL

Submitted

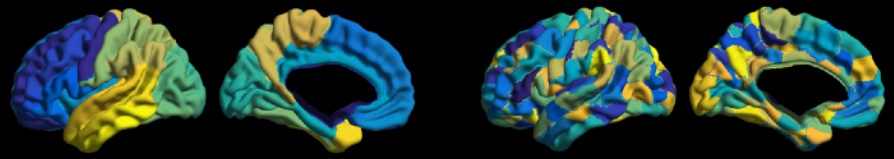




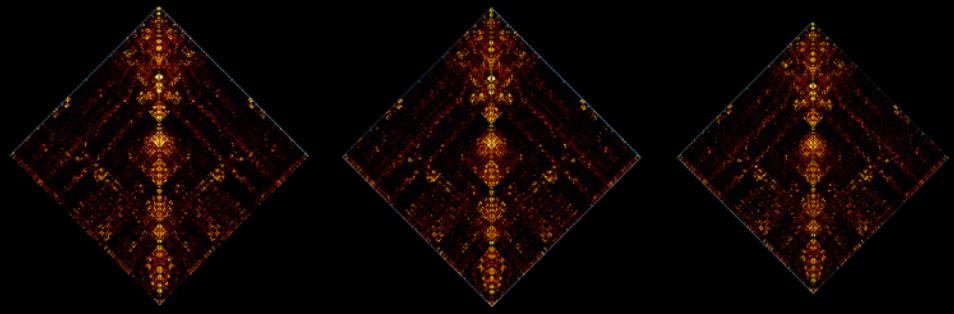


REPRODUCIBILITY AT HIGHER SPATIAL SCALE

A AAL SUBPARCELLATION

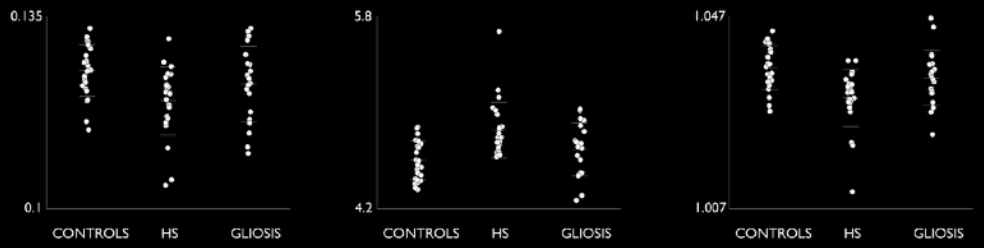


B HIGH-RESOLUTION CONNECTOMES IN CONTROLS AND TLE

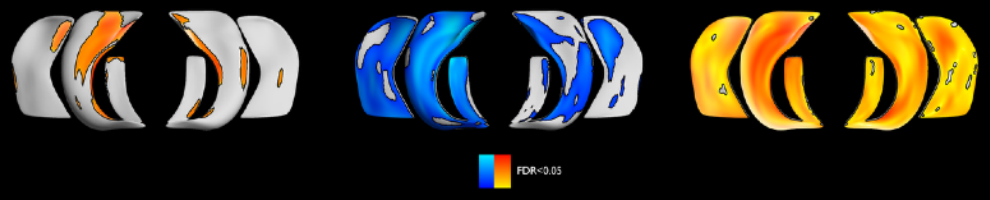


CONTROLS HS GLIOSIS

C RELATION TO TOPOLOGY AND CONTROLLABILITY



CLUSTERING PATH LENGTH CONTROLLABILITY



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INTERIM SUMMARY: EPILEPSY

MULTIPARAMETER MRI:
IN-VIVO DESCRIPTION OF HS IN TLE

WHOLE-BRAIN STUDIES INDICATE
MARCOLEVEL ANOMALIES BEYOND MTL

HS GRADES NEVERTHELESS CLOSELY
RELATE TO CONNECTOME PHENOTYPES

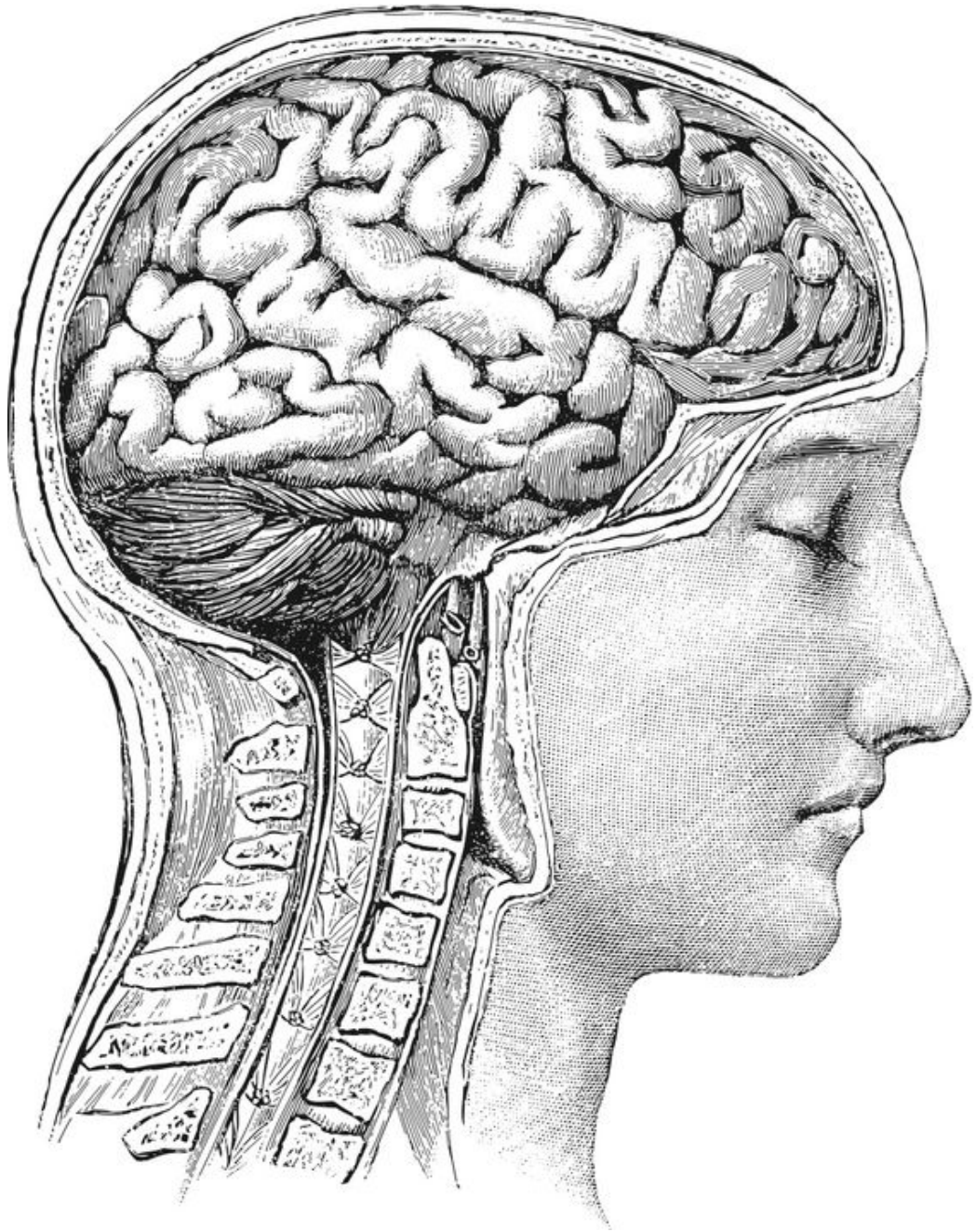
NEUROIMAGING AND CONNFCTOMICS
PROMISE TO PROVIDE PROGNOSTIC MARKERS OF
PATHOLOGY AND OUTCOMES

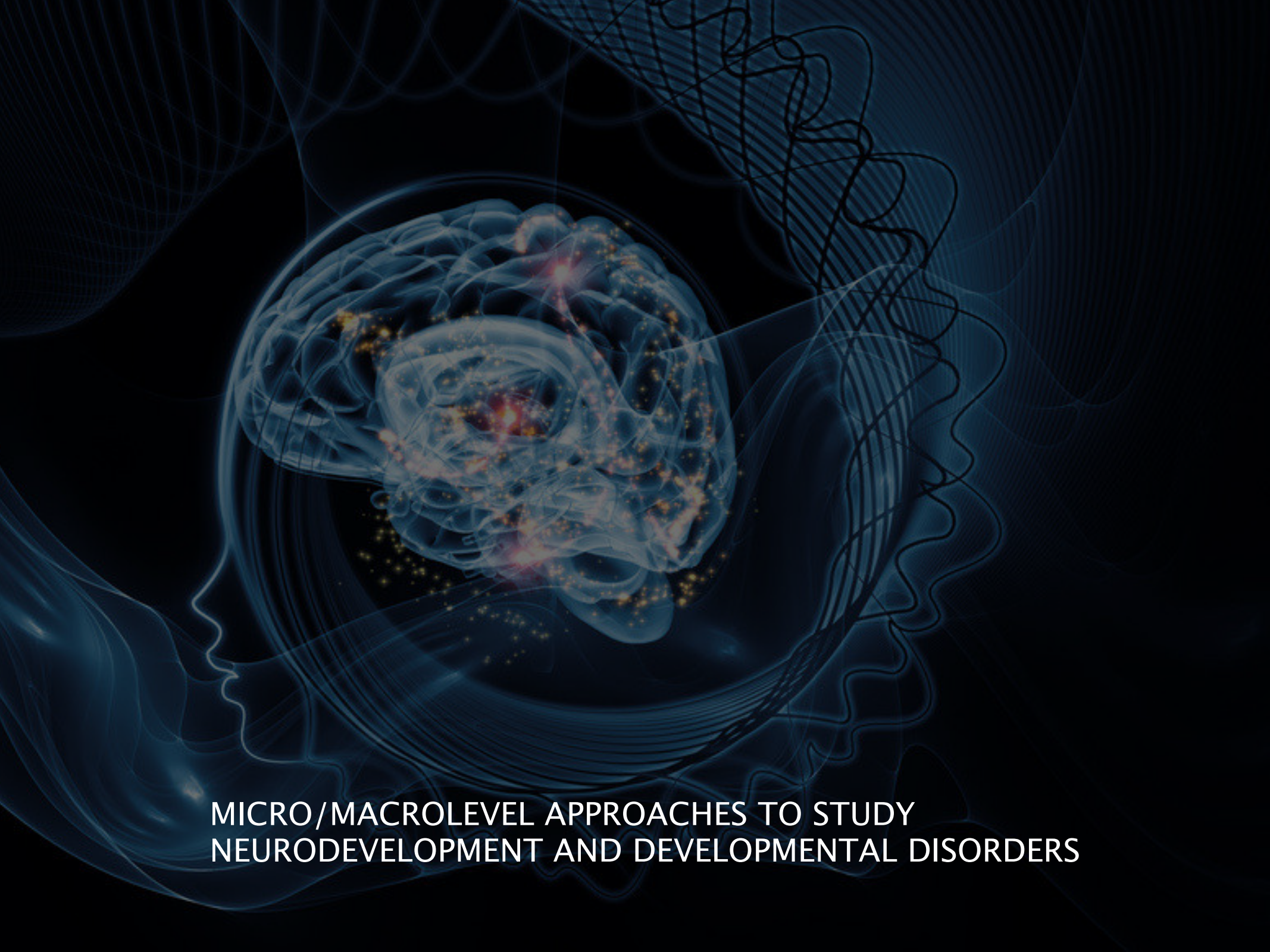
SUMMARY

MRI UNVEILS MICROSTRUCTURE AND MACROSCALE NETWORKS

STRUCTURE–FUNCTION STUDIES OF HIPPOCAMPAL NETWORK EMBEDDING

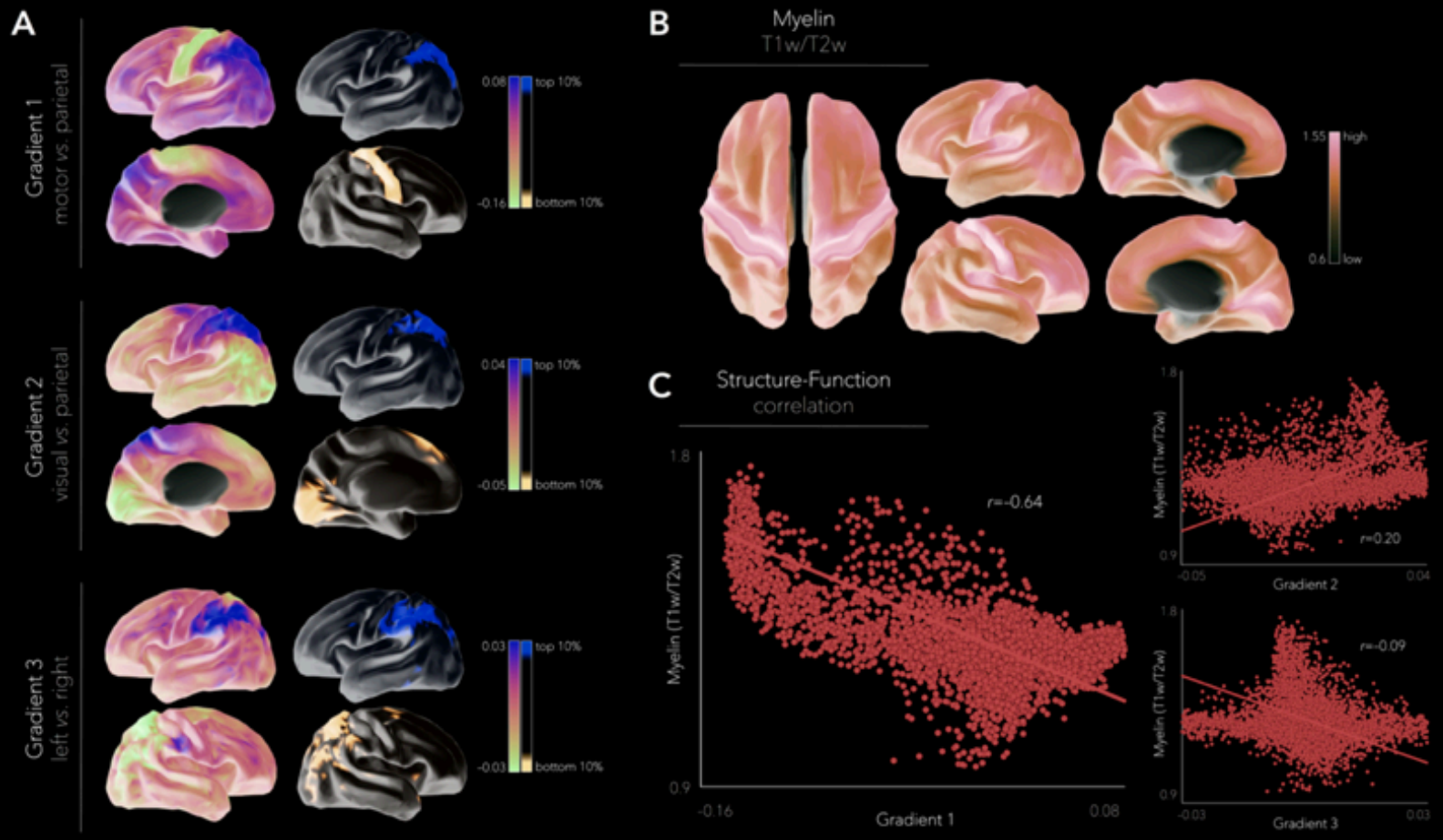
HISTOLOGY, MRI, AND CONNECTOMICS CHARACTERIZE CAUSAL IMPACT OF HIPPOCAMPAL LESIONS





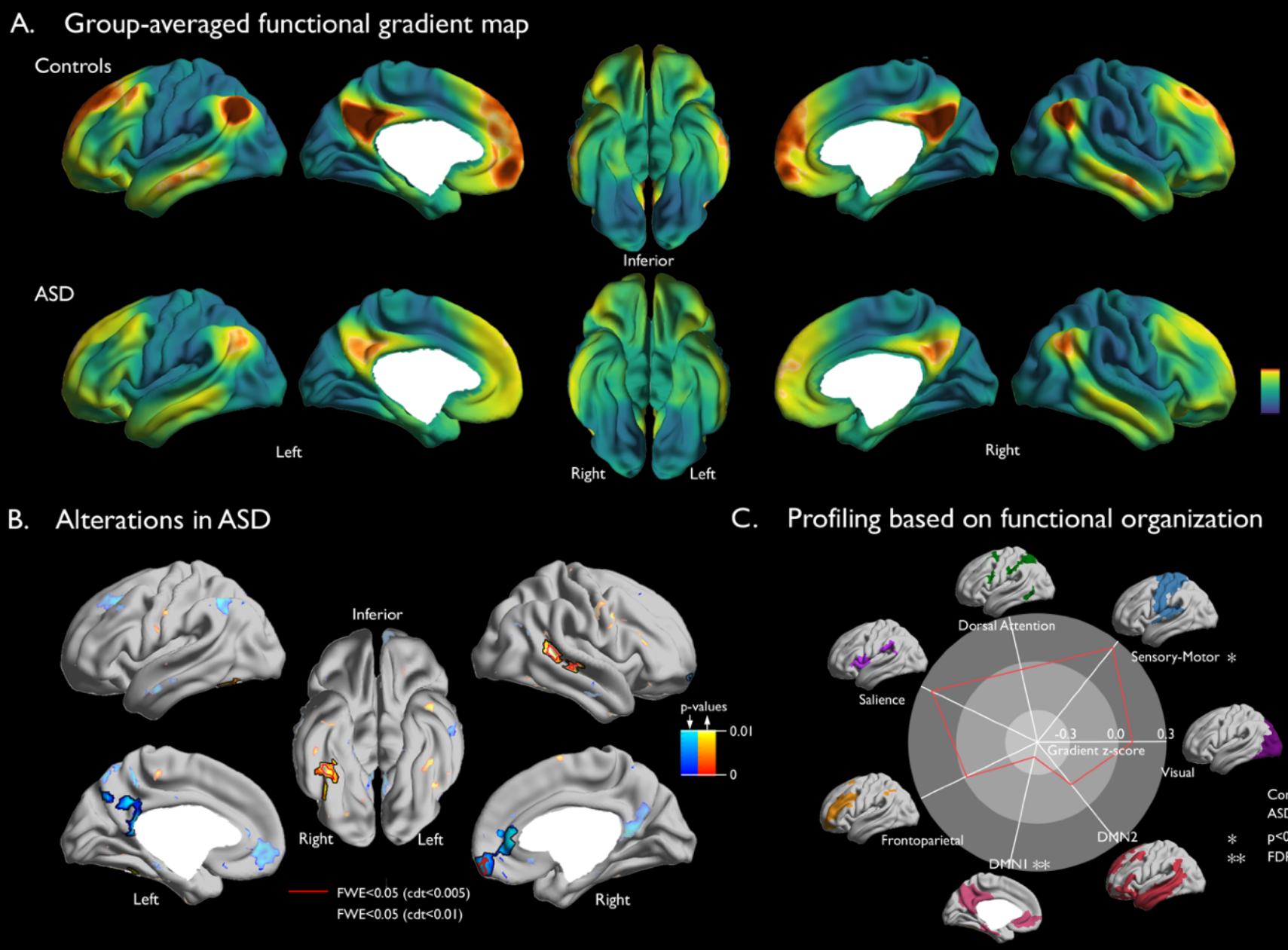
MICRO/MACROLEVEL APPROACHES TO STUDY NEURODEVELOPMENT AND DEVELOPMENTAL DISORDERS

GRADIENTS IN DEVELOPMENT



Lariviere et al (2018) OHBM

ALTERED CONNECTOME ORGANIZATION IN AUTISM



Hong et al (2018) OHBM

Neda Bernasconi

Andrea Bernasconi

Jessie Kulaga Yoskovitz

Ravnoor Gill

Benoit Caldairou

Min Liu

Jeffrey Hall

Marie Christine Guiot

Luis Concha

Raul Cruces

Reinder Vos de Wael

Sara Lariviere

Seok-Jun Hong

Shahin Tavakol

Zhengge Wang

Brian Hyung

Tabea Haas Heger

Jonathan Smallwood

Beth Jeffreys

Sofie Valk

Tania Singer

Alfred Anwander

Daniel Margulies

http://mica-mni.github.io

twitter: @BorisBernhardt

Michael Milham

Adriana DiMartino

Together We Will.

Canadian League Against Epilepsy